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Mensen voor Aarde en Ruimte, Aarde en Ruimte voor Mensen
Des hommes et des femmes pour la Terre et l'Espace, La Terre et l'Espace pour l'Homme

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Deel 1: Wetenschappelijke activiteiten

Partie 1: Activités Scientifiques

Part 1: Scientific Activities

Summary

Reference Systems and Planetology

Mission and objectives

The mission of the Operational Directorate "Reference Systems and Planetology" is to contribute to the elaboration of reference systems (terrestrial and celestial) and timescales, to integrate Belgium in the international reference frames (concerning space geodesy and time), and to obtain information on the Earth's interior, rotation, dynamics, and crustal deformation, at local, regional, and global levels. The ultimate goals are the understanding of the dynamics of the Earth's interior and surface deformation.

Additionally to the planet Earth, these objectives have been extended to the other terrestrial planets, Mars, Venus, and Mercury, and to the moons of the solar system planets.

This work closely related to the international activities and opportunities, to the activities described in the statutes of the Royal Observatory of Belgium (ROB), as well as in the strategic plan of ROB General Director.

The activities of the Operational Directorate are grouped into two general themes: (1) Space geodesy and timescales with GNSS, and (2) Rotation and internal structure of the Earth and the other terrestrial planets. In total they are divided into four different scientific projects (research and/or operational projects). The present objectives of the projects are described here below with the important milestones reached this year for each of them. A further description is also provided in the introduction of some projects.

(a) <u>GNSS (Operational and research project)</u>

The objective of the GNSS project is to integrate Belgium in international terrestrial coordinate reference systems through the integration of several continuous observing GNSS reference stations and associated services in international GNSS observation networks. The 'GNSS' project contributes actively to the European and global developments of GNSS observation networks, their products and applications since more than ten years. This has resulted in a number of responsibilities within the EUREF Permanent GNSS Network (EPN) and the International GNSS Service (IGS). The continuation of these responsibilities, and the services associated with them, is one of the main objectives of this project.

The project is also involved in the Solar Terrestrial Center of Excellence (STCE) where GNSS observations are used to monitor the Earth's ionosphere and troposphere targeting the high-end GNSS user community and scientific applications by taking advantage of the GNSS data available in the international services to which the project is contributing. In addition, as it was the case in several European Agencies simultaneously involved in the EPN data analysis and performing tropospheric research, these activities found a natural synergy and led to the involvement in the EUMETNET E-GVAP project.

The service activities described above are based on a solid dose of research that guarantees that the services are of the highest level. The research concerns the modeling, mitigation and understanding of the GNSS error sources affecting the services mentioned above. Examples are the investigation of the influence of the reference frame, the GNSS antenna calibration, the troposphere and the ionosphere on GNSS-based positioning and deformation monitoring.

At the moment, a part of the services is already based on multiple GNSS, more specifically on GPS and GLONASS (Russian equivalent of GPS) observations. With the upcoming GALILEO positioning system, the scientists involved in this project will also work on the incorporation, processing, and enhancement of GALILEO precise positioning in the research and the services they maintain.

<u>*Milestones reached this year:*</u>

(1) *The first 3-constellation (GPS, GLONASS and GALILEO) GNSS receiver was installed at ROB.*

(2) *A method to generate in near-real time 0.5°x0.5° grid TEC maps and TEC variance over Europe each 15 min. from the EPN has been developed. It will be implemented in 2011 to routinely generate such maps.*

(3) *It was shown that using GNSS data from national densification networks in addition to the EPN provides an added-value for tropospheric tomography. In the case of ionospheric tomography, the additional stations induce inhomogeneities in the GNSS signal distribution and therefore mainly densification stations located in the UK and Scandinavia (homogenizing the overall inter-station distances) will provide a real added value.*

(4) *First results of simulation tests with MIDAS (ionospheric tomography software) showed that the MIDAS algorithm tends to under-estimate the vTEC (vertical total electron content) and that fine grids lead to greater resolution of ionospheric structures but also increase likelihood of artifacts in the reconstruction. The 2°x2° grid offers the best trade-off between these problems.*

(5) *Study of the 23rd Solar cycle revealed a clear correlation between the F10.7 observed flux solar parameter and the daily mean TEC obtained from GNSS. Further modeling of the relation between F10.7 and GNSS-based TEC will provide valuable input for space weather predictions.*

(6) *44 days of GNSS data were gathered in 2010 at the Princess Elisabeth station in Antarctica and then the station was shut down due to a general power outage at the base. A new system for power distribution and communication is designed and installed at the Emile Danco shelter for operation in 2010-2011.*

(7) *20 new GNSS stations have been included in the EUREF Permanent Network (EPN) and the EPN Central Bureau web site received a total of about 2.5 million hits in 2010.*

(8) *The outdated software used at the EPN CB that generates plots of the satellite tracking of the EPN stations has been replaced with new software (developed by the GNSS team) which now also verifies the availability of the new GPS L5 signal.*

(9) *It was demonstrated that the network effect biasing position and velocity solutions obtained from regional GNSS networks is significantly reduced when homogeneously reprocessed regional solutions are used and tied to the ITRF2008.*

(10) *EUREF started reprocessing of historical GNSS data of the EPN: ROB contributed to a benchmark test followed by the reprocessing of the data of 2006. The remaining data-analysis (1996-2005) will be done in 2011.*

(11) *It was shown that differences between GNSS-based velocity solutions from different analysis centers often originate in the use of different data time spans in the different solutions raising the need for a closer link between regional and global GNSS network coordination.*

(12) *The installation of an NTRIP caster (for real time streaming of GNSS data) at ROB was completed as well as the necessary developments to download in real-time GNSS observation data and products (orbits, clocks).*

(b) <u>Time – Time Transfer (Operational And Research Project)</u>

The scientists involved in this project have the responsibilities to establish the Belgian time scale (UTC(ORB)) and to participate in international timescales by incorporating Belgium in these timescales. We maintain presently six high-quality clocks for participation in two international timescales: the International Atomic Time (TAI) and the International GNSS Service Timescale (IGST). The present requirement for the clock precision and stability is at the level of the nanosecond over one day, which can only be achieved with high-quality clocks, when located in temperature-controlled environment. Our six clocks are located in such an environment and their performances are continuously monitored by inter-comparison between themselves and also with atomic clocks of other laboratories participating to TAI or IGST. In order to perform these comparisons, as well as to transfer time at the centers where the computations for the international timescales are performed, we need methods which insure a time-transfer precision matching the required precision of the timescales. These comparisons are usually performed using code measurements of GPS satellites in common view. The scientists involved in the project work on the improvement of the time transfer by using both code and phase measurements of geodetic receivers, in order to enhance its precision and accuracy. This requires the establishment of new analysis strategies, new error modeling, and new computer codes. It also requires the installation of new equipment and the adaptation of the procedures to these new equipments. The scientists of this project also take care of the legal issues related to the legal time. An additional important part of the work is related to the quality control and maintenance of the clocks, as our involvement in the definition of international timescale impose us a quasi-perfect reliability.

Milestones reached this year:

(1) *We have upgraded the ORB software R2CGGTTS used by the time laboratories for their contribution to UTC, in order to allow the use of GLONASS and GALILEO data.*

(2) *We have quantified the effect of adding GLONASS observations to the GPS ones for time transfer solutions (clock comparison) based on the Precise Point Positioning technique (PPP, a method that performs precise position determination using a single GNSS receiver).*

(3) *We have demonstrated the possibilities offered by the future very precise Galileo E5 code for time transfer applications.*

(c) Geodesy and Geophysics of Terrestrial Planets (Research Project)

In the project on the 'geodesy and geophysics of terrestrial planets' the gravity field, the rotation and orientation variations (polar motion, precession, nutations, and librations), and the tides of the terrestrial planets and large natural satellites are investigated in order to gain insight into their interior structure and composition. Geodesy data on the gravity field and rotation of a planet can be obtained from landers or/and orbiting spacecraft. In this project, radio science data from spacecraft in orbit around Mars and Venus, such as Mars Global Surveyor (MGS), Mars Odyssey, MarsExpress (MEX), VenusExpress (VEX), and Mars Exploration Rovers (MERs) are the principal source of information. Radio science data from the upcoming BepiColombo mission to Mercury and the ExoMars/Mars-Network mission to Mars will be processed in the future. For the analysis of the data, and for simulations of future experiments, the GINS/DYNAMO numerical code is used and further developed; this code is one of only a few codes in the world that can compute accurate orbits of spacecraft from radio science data. Besides the data-analysis, the project has a strong theoretical research component, which is oriented towards the construction of detailed mineralogical models for the interior of the planets and the dynamical response of these models to both internal and external forcing. The time-variable gravitational interaction with the other planets, moons, and the Sun is particularly important for changes in the gravity field and rotation. Therefore, the orbital motion of the large bodies of our Solar System is also investigated, both theoretically and observationally.

Milestones reached this year:

(1) The core size and composition of Mars have been estimated from the latest available data on the moment of inertia and tidal amplitude as determined from spacecraft around Mars. We have shown that the core of Mars is entirely liquid and has about the same relative size as the core of the Earth but contains a larger fraction of light elements.

(2) It has been demonstrated on the basis of MEX radio science data that the volcano Ascraeus Mons has a lower surface density and an inverted density structure with respect to the neighboring volcano Olympus Mons.

(3) We have shown that Mars is more susceptible to atmospheric erosion than Venus and the Earth due to its smaller mass and atmospheric pressure, and due to the lower volatile content of the impactors on Mars.

(4) A new phase (phase B2) has started, in collaboration with OMP (Orban Microwave Products), for the Lander Radio-science experiment LaRa in order to develop and test a more representative breadboard of the instrument and to study the possibility of implementing ranging capability.

(5) We have shown that Doppler shift measurements on a direct to Earth two-way X-band radio link from an equatorial lander on Mars can be used to improve the current knowledge on the rotation rate

variations and precession/nutation after a few hundred days of operation and will allow determining information on the core.

(6) The time-variable gravity field of Mars due to the atmosphere and atmospheric angular momentum variations of Mars have been theoretically calculated by using the latest General Circulation Models of the Martian atmosphere and the results, together with re-processed HEND data from the Mars Odyssey spacecraft, have been compared to radio science data from MRO and MGS.

(7) From our recent new estimates of the low densities of Phobos and Deimos from MEX radio tracking data, we have shown that the moons either have a high interior porosity or contain a large fraction of low-density material, most likely in the form of water ice. The large porosity values suggest that re-accretion may have occurred in their early history and that the moons formed in situ instead of being captured. However, if large amounts of ice instead of porosity are responsible for the low density, the moons are more likely captured.

(8) An analytical model has been developed to show that planetary perturbations cause long-period librations of Mercury of which the largest signal can even exceed the amplitude of the principal 88 day forced libration.

(9) We have shown that by using laser altimetry cross tracks of the future BepiColombo mission to Mercury, a similar accuracy on the obliquity and libration amplitude can be obtained as from the standard method based on the comparison of the positions of selected spots at the surface of Mercury at different times on camera pictures.

(10) It has been shown that information on the size of the inner core of Mercury can be determined from rotation and gravitational data to be determined by the NASA MESSENGER spacecraft, but that for accurate results also data on the tides of Mercury must be used, for which ESA's BepiColombo mission (launch 2014) will be needed.

(11) Based on geometrical and dynamical considerations, the position of the Laplace pole of Mercury (a mean or reference plane about whose axis the instantaneous orbital plane of a satellite/moon precesses) and other quantities related to it like the orbital precession frequency have been determined.

(12) By taking into account the influence of solar insolation and tidal dissipation on the local lithospheric thickness of Mercury it has been shown that planetary contraction could have led to the observed orientation of lobate scarps, if these formed during the epoch of fast rotation preceding despinning.

(13) A tool has been developed that simulates the Doppler/Range signal of a spacecraft fully within General Relativity and alternative theories of gravity. The general relativistic effect on the Doppler signal for BepiColombo has been shown to be four orders of magnitude smaller than the Doppler signal itself, but five orders of magnitude larger than the measurement precision.

(14) The density of the atmosphere of Venus over the North Pole has been derived from VEX tracking data and has been shown to be 55% less dense than predicted by current models based on data from previous missions at low to middle latitudes.

(15) We have shown that the observed obliquity of Titan can be explained by assuming that Titan contains a subsurface ocean.

(16) Titan's polar motion has been shown to consist basically of a superposition of small diurnal wobbles and larger semi-annual and annual wobbles caused by seasonal changes in wind and pressure. The polar motion path is expected to be elliptical instead of nearly circular if Titan has a subsurface ocean.

(17) Numerical and semi-analytical tools have been developed to compute tectonic patterns on terrestrial planets due to global contraction or expansion and despinning when the lithospheric thickness depends on the latitude. The tectonic pattern predicted when the lithosphere is thinner at the equator accounts for the location and orientation of the equatorial ridge on Iapetus, a moon of Saturn.

(18) A general geometrical method has been developed for the calculation of the tide-generating potential of any Solar System body. Accurate spectral representations of the tide-generating potentials have been obtained in this way for the Galilean satellites.

(19) It has been shown that libration observations of the Galilean moons can be used to estimate the thickness of the outer solid layer above the molten core of Io or above a putative sub-surface ocean in the case of Europa, Ganymede, and Callisto. For the latter satellites, the libration is insensitive to the possible existence of a liquid core.

(20) It has been shown that orbital perturbations due to the Sun and other planets and satellites lead to long-period librations for the icy Galilean satellites with amplitudes as large as or even larger than the amplitude of the main libration at orbital period for the Keplerian problem.

(21) A scientific book on asteroseismology "Linear Isentropic Oscillations of Stars. Theoretical Foundations" by P. Smeyers and T. Van Hoolst has been completed in 2010 and has been published by Springer-Verlag in December.

(d) Earth Rotation (Research Project)

The objectives of the project 'Earth rotation' are to better understand and model the Earth rotation and orientation variations, and to study physical properties of the Earth's interior and the interaction between the solid Earth and the geophysical fluids. The work is based on theoretical developments as well as on the analysis of data from Earth rotation monitoring and general circulation models of the atmosphere, ocean, and hydrosphere. The scientists involved in this project work on the improvement of Very Long Baseline Interferometry (VLBI) and GNSS observations and of the determination of geophysical parameters from these data, as well as of analytical and numerical Earth rotation models. They study the angular momentum budget of the complex system composed of the solid Earth, the core, the atmosphere, the ocean, the cryosphere, and the hydrosphere at all timescales. This allows them to better understand the dynamics of all the components of the Earth rotation, as Length-of-day variation (LOD), polar motion (PM), and precession/nutation, as well as to improve their knowledge and understanding of the system, from the external fluid layers to the Earth deep interior.

Milestones reached this year:

(1) We have combined VLBI and GPS observations and achieved a better accuracy and a better consistency in the resulting nutation series.

(2) We have computed the topographic torque at the core-mantle boundary and its effects on nutations, and we have shown that some harmonics of the topography are enhanced due to the coupling of the nutation forcing and the topography itself.

(3) We have computed the electromagnetic torque at the core-mantle boundary and its effects on nutations, and we have shown that the numerical more-complete approach used provide results slightly different with respect to the analytical approach.

A. GNSS positioning and Time

A.1. GNSS

A.1.1. Objectives

The GNSS project aims at using GNSS (Global Navigation Satellite Systems, like GPS, GLONASS and GALILEO) observations to

- integrate Belgium in international terrestrial reference frames;
- improve our knowledge of deformations of the Belgian and European Earth's crust;
- improve our knowledge of the spatial and temporal variations in the Earth's atmosphere (troposphere and ionosphere) with emphasis on the European region;
- improve our knowledge of the relation between reference frames and the accuracy of the applications mentioned above, as well as time transfer.

In order to reach these objectives, project members maintain a network of continuous observing GNSS stations, perform research to understand, model, and mitigate the error sources, and play a leading role in related international scientific services (see Kaderplan – Plan-Cadre of the Royal Observatory of Belgium, March 2006, par. 4.1.1 and 4.4.1).

A.1.2. Progress and results

A.1.2.1. GNSS Observation Network and its Integration in International Observation Networks

- We operate 12 continuously tracking GNSS stations. Four of them are integrated in international GNSS observation network: the station BRUS (located at ROB) is integrated in the network of the International GNSS Service (IGS, http://www.igs.org) and the stations BRUS, DOUR (Dourbes), DENT (Dentergem), and WARE (Waremme) are integrated in the EUREF Permanent Network (http://epncb.oma.be/ see Section *GNSS Services*).
- In order to facilitate the transition of the ROB network from a GPS-only network to a network tracking in addition to GPS also the GLONASS and Galileo satellite constellations, the following major actions were taken in 2010:
    - Installation of two new multi-GNSS receivers (PolaRx3 Septentrio) in Uccle; they were configured to track GPS, Glonass and GIOVE-A and B satellites of the European Galileo system. More multi-constellation receivers will be added in the coming year(s), eventually resulting in capturing multi constellation data in all ROB GNSS stations.
    - Evaluation of most commercially available multi-GNSS reference station antennas based on data sheets as well as with antenna measurements of our own antennas in the anechoic chambers of the university of Leuven and Bonn.
    - Reconfiguration of the currently deployed GPS receivers to no longer track Space Based Augmentation System (SBAS) signals and track satellites marked as unhealthy.
    - Replacement of all old separate computers used for controlling the GPS receivers at our site in Uccle with a single low power one (actually two: a main and a backup) in order to reduce the power generated in the GNSS room. This measure should reduce the stress on the air conditioning system shared with the atomic clock room.
- Due to the fact that our primary station BRUS will soon be destroyed (construction works done by the "Regie der Gebouwen"), the secondary station BRUX has been prepared for integration in the IGS: a new supporting structure for the antenna has been designed in order to shield the new multi-GNSS antenna from all reflections of the dome the antenna sits on. For that purpose, the team studied multipath suppression techniques at GNSS reference stations.
- Research on the implementation of correlators in GPS receivers has been performed. This will be of much value when performing research on Software Defined Radio (SDR) GNSS receivers.

A.1.2.2. GNSS at Princess Elisabeth base in Antarctica

- GNSS team members assisted the crew in Antarctica for the installation and maintenance of the GPS equipment at the polar station in Antarctica (2009-2010 and 2010-2011 missions) at the Princess Elisabeth base.
- A box with communication and power distribution, common to all teams using the E. Danco shelter has been designed and built by the GNSS team
- The analysis of the data available from the ELIS GPS station (4 days in 2009 and 44 days in 2010) showed that the position of the station is estimated at the millimetre level with repeatability estimated to 1.8, 2.1, and 3.6 mm on East, North, and Up-components.

A.1.2.3. EUREF

EUREF is the IAG Subcommission responsible for defining, maintaining, providing access to, and promoting the usage of the European Terrestrial Reference System (ETRS89) and European Vertical Reference System (EVRS), both recommended by the EU for all geo-referencing in Europe. A key instrument in maintaining and providing access to the ETRS89 is the EUREF Permanent GNSS Network (EPN). The EPN consists of the following components: a network coordinator responsible for the EPN Central Bureau, Data Centres, Analysis Centers and permanently observing GNSS tracking stations. Members of the GNSS team are heavily involved in the EUREF activities: they manage one of the EPN data centers, analysis centers and they are in charge of the daily management of the EPN through the EPN Central Bureau which is hosted at ROB. In addition to its routine activities, in 2010:

- The EPN CB included 20 new stations in the EPN (see Figure 1) bringing the total number of EPN station to 245. Also an additional 10% of the EPN stations started tracking GLONAS satellites in addition to GPS, bringing the total to 58% (see Figure 2).
- The outdated software used at the EPN CB that generates plots of the satellites tracking of the EPN stations has been replaced with new software (developed by the GNSS team) which now also verifies the availability of the new GPS L5 signal.
- The EPN CB web server and software/script server have been migrated to one new server involving the update of several of the programs.
- The ROB contribution to the EPN benchmark reprocessing showed excellent agreement of the ROB solution with the results of other analysis centers. In addition, the reprocessing for 2006 was also delivered to EUREF.
- We performed a study aiming at determining the impact of the new IGS08 GNSS receiver antenna calibrations on the estimated GNSS station coordinates. It was demonstrated that coordinate differences, obtained by using on one hand the old IGS05 calibration model and on the other hand the IGS08 model, can reach up to 4 mm in the horizontal and 8 mm in the vertical. The new EUREF approach for future maintenance of the ETRS89 is partly based on these results.

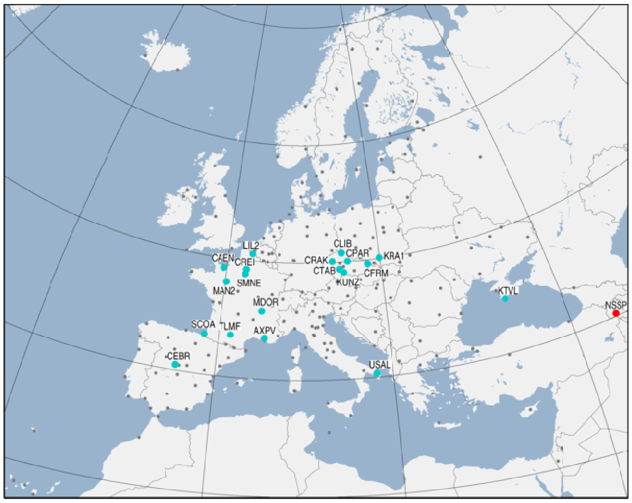

Figure 1: **Changes in the EPN in 2010 (blue: stations added to the network, in red: decommissioned stations)**

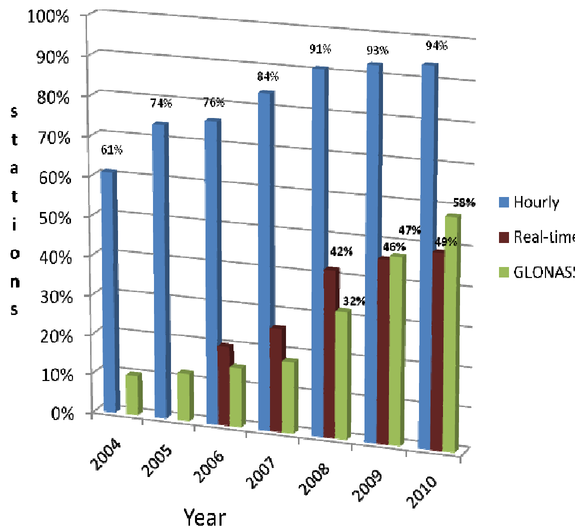

Figure 2: Evolution of the % of EPN stations providing hourly, real-time or GPS+GLONASS data

In addition, in 2010, team members contributed to:

- the validation of several new ETRS89 densification campaigns,
- the real-time analysis project, by installing and maintaining a broadcaster for real-time GNSS data from the EPN.

A.1.2.4. Improvement of the knowledge of deformations of the Earth's crust

- The team extended the investigation of the influence of the network effect within regional GNSS networks. In 2010, the ITRF2008 and new homogeneously reprocessed regional (and global) solutions were tested. The agreement (RMS of position/velocity differences) of these new solutions with the ITRF2008 improved with a factor three compared to the previous study (using ITRF2005 and old solutions). Consequently, also the error caused by the network effect was reduced. It can nevertheless still reach 1 mm/yr in the vertical and 0.5 mm/yr in the horizontal. Despite the improvement seen on the estimated positions and velocities when using the reprocessed ITRF2008, it was also shown that the use of the new improved reference solution did not impact the residual position time series which are still significantly affected by the network effect: in regional network analysis the amplitude of the annual and semi-annual signals are underestimated in all components of the station time series (27% resp. 15% reduction of the annual resp. semi-annual signal in the height component). In addition, also the phase of the annual and semi-annual signals is altered.
- The team heavily contributed to the activities of the IAG Working Group on "Regional Dense Velocity Fields" (see http://epncb.oma.be/IAG). With the goal to generate a high-quality position/velocity solution for a core network of GNSS stations, several newly reprocessed global and regional cumulative position and velocity solutions (containing about 400 densification sites of the ITRF2008) were submitted to ROB in the summer of 2010. The GNSS team tested all solutions and concluded that the 3D-RMS of the agreement of the new solutions with the ITRF2008 (after outlier rejection) varies between 0.6 and 1.1 mm/yr; it is extremely good for some solutions, while others still require more iterations to reach the required level of agreement. We identified already a part of these disagreements which often originate in the use of different data time spans within the ITRF2008 and the submitted solution. Some cases were also identified where the residual position time series from the ITRF2008 significantly underperformed compared to the time series from a regional solution. This raised the need for more interaction between the regional reference frame

Subcommissions and the IGS and/or the ITRF product center in order to prevent from facing a similar situation in the next release of the ITRF. The problem has already been discussed with the EUREF Technical Working Group, the IGS Analysis Coordinator, the IGS Reference Frame coordinator and the IERS Service Center for Reference Frames.

- In an attempt to improve the coordinate on one hand the GNSS contribution to the FP7 project EPOS (European Plate Observing System) and on the other hand the European contribution to the IAG WG on Regional Dense Velocity Fields', a COST action 'Towards a European GNSS Observatory' was prepared and submitted. It was not selected, but a new upgraded version will be resubmitted.

A.1.2.5. Ionosphere

- A method to generate in near-real time 0.5°x0.5° grid TEC maps and TEC variance (see Figure 3) over Europe each 15 min. from the EPN data has been developed and will be implemented in 2011 to routinely generate such maps. Different parameters, data input, and interpolation methods have been tested. The results showed that the most adapted interpolation for such a product is the spline interpolation. The resulting TEC maps were compared with Global Ionospheric Maps (GIMs) and showed good agreement with a mean differences lower than 1 TECU, except during stormy days when GIMs seem to underperform. The development of the maps also comprised the development of a tool able to smooth GNSS data.
- The GNSS team developed together with the planetology team a tool to estimate TEC gradients during 45 minutes close to the Goldstone complex (California, US) targeting radio science applications. The TEC varies from 3 to 10 TECU depending on the solar cycle phase and the season during the year.
- In support of the evaluation of tomographic applications, the team investigated the GNSS signal distribution that sounds the Earth's atmosphere over Europe when using:
  a) GLONASS and simulated Galileo data in addition to GPS,
  b) dense GNSS networks (in Belgium, France, Germany, Sweden and UK) in addition to the EUREF Permanent Network (EPN).

  It has been shown that:
    - In the case of the troposphere, the use of dense GNSS tracking networks insures a coverage of 73% compared to 14% in the case of EPN only. The use of multi-GNSS data increases the GNSS signal distribution by a factor of 2.
    - In the case of the ionosphere, the use of dense GNSS networks allows reducing the number of empty voxels by 17% and improves the coverage especially in the north. But, this densification induces inhomogeneities in the GNSS signal distribution and therefore mainly densification stations located in the UK and Scandinavia (homogenizing the overall inter-station distances) will provide a real added value. The use of multi-GNSS data improves the GNSS signal coverage along the day by a factor of 2.

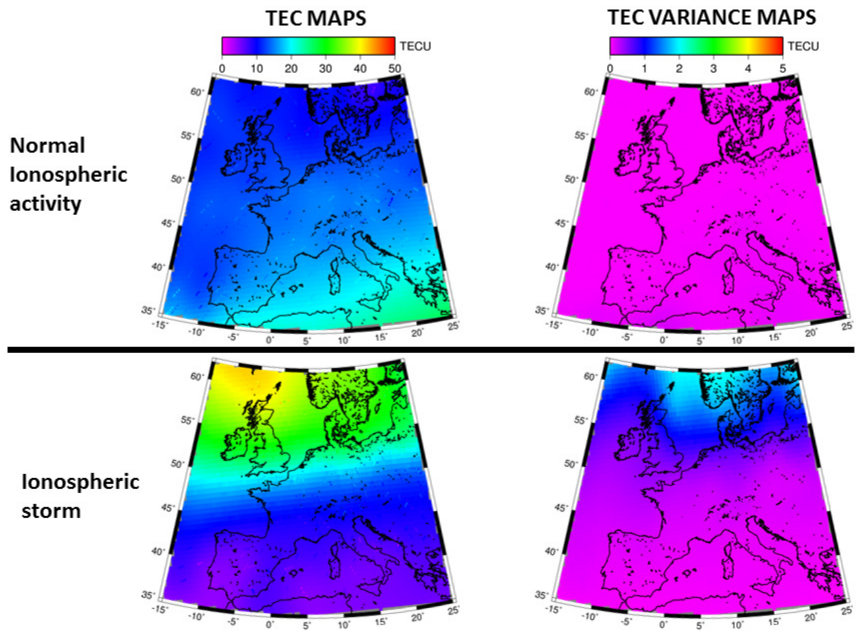

Figure 3: 0.5°x0.5° TEC maps over Europe (left) and its variance (right) in TECU estimated over 15 minutes in a near-real time approach, for: a normal ionospheric activity (top , DOY 303 2003, 12:30-12:45 UT) and during an ionospheric storm (DOY 303 2003 , 22:30-22:45).

- The team investigated the presence of small variations in the ionosphere during the 2010 August storm period (in response to a CME impact). For that purpose the TEC variation along the GPS signal paths between the EPN ground stations (more than 240 sites) and the GPS satellites were examined. Disturbances for this geomagnetic storm present amplitude of 3 to more than 7 TECU and an apparent periodicity of 30 minutes and are related to ionospheric events detected from MIDAS reconstructions.
- The team investigated capability of the ionospheric imaging algorithm, MIDAS 2.0, to detect small structures in the ionosphere. The process two-step plasma instability process seen by MIDAS on the day-night terminator gradient of the F-layer ionosphere above Europe on 30th October 2003 which was initially interpreted as a primary Gradient Drift Instability with subsequent secondary Kelvin-Helmholtz waves, was most likely artifactual due to the small grid resolution that was used to run MIDAS. The team therefore begun investigating the optimal spatial resolution of the MIDAS imaging when using the large amount of GNSS data available in Europe. For that purpose simulated GNSS data were used as input (obtained by the ASiF software, also developed by the team). First results showed that the MIDAS algorithm tends to under-estimate the vTEC (vertical total electron content) and that fine grids lead to greater resolution of ionospheric structures but also increase likelihood of artifacts in the reconstruction. The 2°x2° grid offers the best trade-off between these problems. Final conclusions will be ready for 2011.
- Collaboration with the University of Reading (UR) on development of a polar-cap patch identification and tracking algorithm has been pursued. A first adaption of the "feature-tracking" algorithm from UR (extensively applied to meteorological storm studies) to the problem of tracking polar-cap patches has proved feasible; however some optimisation to remove "false-positive" identifications is yet to be completed.
- The team continued to investigate the correlation between the solar activity and the daily mean TEC discretized each 10° of latitude. The best correlation is found for the F10.7 observed flux, when TEC

is expressed in geomagnetic coordinates. Moreover, the maximum correlation (R=0.94) is close to S30° latitude during winter while the minimum (R=0.74) occurs during summer period close to the South Pole. Finally the correlation is larger during the phases of Solar transition activity (R=0.71±0.09) and decreases during maximum (R=0.49±0.05) and minimum (R=0.32±0.19) phases with a complete de-correlation at N50° during Solar minimum.

A.1.2.6. Troposphere

- E. Pottiaux has finished to write his Ph.D. dissertation "Sounding the Earth's Atmospheric Water Vapour Using Signals Emitted by Global Navigation Satellite Systems" and obtained successfully his degree of Doctor in Sciences.
- The team contributed to the development and to the daily maintenance of the ROB near real-time "EUMETNET EIG GNSS water VApour Program" (E-GVAP) II analysis center. It was also demonstrated that all requirements for GNSS-meteorology are achieved by the ROB E-GVAP service.
- The team continued to investigate the added value of the use of Belgian dense GNSS network to improve the knowledge of spatial and temporal variations of the atmosphere. The Belgian dense network was used to monitor the location, movement and variability of small-scale atmospheric water vapour structures. The results showed that the densification is mandatory to sense the small-scale structures and to provide valuable information for weather forecasting and nowcasting applications.

A.1.2.7. Study of the added-value of Galileo

- The GNSS team participated to the FP7 project SX5 (Scientific Service Support based on GALILEO E5 Receivers) which aims at developing a software application for precise positioning based on an E5 GALILEO receiver primarily targeting scientific users and at exploiting the benefits derived by the use of the GALILEO E5 signals with respect to services to the scientific community. The role of ROB in the consortium is to use its expertise in GNSS positioning and deformation monitoring to evaluate the scientific potential of the GALILEO E5 receivers. Within that frame the SX5 requirement document for the position, position changes, and time transfer has been written.

A.1.3. Perspective for next years

- Continue the maintenance and modernization (GLONASS and Galileo) of the ROB network of permanent GNSS stations, e.g. upgrade the entire GNSS network (all ROB stations) to a multi-constellation system, implement a web based interface to easily monitor and manage the ROB GNSS network, implement and install the newly designed antenna supporting structure for the site of BRUX, continue research on GNSS antennas and on suppression of reflection and other multipath problems at GNSS reference stations.
- Integrate the new GNSS station BRUX in the IGS and EUREF networks.
- Continue scientific research on GNSS engineering. The aim is to build a GNSS receiver on an FPGA (Field-programmable Gate Array is an integrated circuit designed to be configured by the customer or designer after manufacturing) in house, to have a fully configurable flexible platform suited for research on signal processing, positioning algorithms, receiver calibration, or even GNSS array antennas.
- Continue to maintain, extend, and improve the EUREF service center (management of the EPN Central Bureau, EPN Data Centre, EPN real-time broadcaster and EPN Analysis Centre), e.g. continue the development of new software to perform data quality check of all new GNSS signals.
- Continue the efforts to generate a dense velocity fields based on GNSS observations in the frame of the IAG working group on regional dense velocity fields.
- Continue to acquire, manage and distribute scientific knowledge within the frame of GNSS: study of error sources, improvement of the precision and reliability of the positioning, improvement of the knowledge of spatial and temporal variations of the atmosphere, and improvement of the knowledge

of crustal deformations. Special emphasis will be put on the new satellite signals such as GPS L5 and the upcoming Galileo signals.

- Continue to contribute to GIANT project at Belgian Antarctic Base, e.g. by analyzing the data for several applications, designing and implementing a new GNSS box for use at the polar station in Antarctica.
- Generate routinely TEC maps over Europe based on EPN station data.
- Continue to investigate the correlation between the solar activity and the ionospheric TEC in collaboration with solar physics department of ROB.
- Continue to monitor the European troposphere by developing and maintaining the ROB E-GVAP II service.
- Start a complete revision of the ROB E-GVAP II service to adhere to the next generation of user requirements and to new types of products and applications.
- Continue to exploit of the Belgian dense GNSS network to improve the knowledge of spatial and temporal variations of the atmosphere.
- Start a collaboration with the RMI concerning the ROB E-GVAP activities.
- Start a collaboration with the RMI concerning the possible use of GNSS observation for climate applications.
- Continue the collaboration with RMI and BISA within the STCE Water Vapour and Climate System working group concerning the water vapour observation techniques inter-comparisons.

A.1.4. Personnel involved

Scientific staff:	W. Aerts (SW1, research engineer, STCE, 50%)
	Q. Baire (SW1, software development in support of EPN CB, ionospheric, positioning and timing applications, STCE/FP7 SX5)
	N. Bergeot (SW1, PhD researcher on ionosphere, STCE)
	R. Burston (SW1, PhD researcher on ionosphere, STCE)
	C. Bruyninx (SW2, head of GNSS team, statutory)
	J.-M. Chevalier (SW1, researcher on ionosphere, STCE)
	F. Roosbeek (SW2, head of ICT team, statutory, 5%)
	J. Legrand (SW1, PhD researcher on ground deformations, stagiair-statutair)
	E. Pottiaux (SW1, PhD researcher on troposphere, STCE)
Technical staff:	D. Mesmaker (ICT Expert GNSS, statutory)
	A. Moyaert (ICT Expert GNSS, statutory)

A.1.5. Partnerships

List of international partners or collaborators having actively contributed to the project in the last year

- Z. Altamimi, LAREG/IGN, France
- A. Caporali, University of Padua, Italy
- M. Craymer, NRCAN, Canada
- J. Dawson, Geoscience Australia, Australia
- S. de Haan, Koninklijk Nederlands Meteorologisch Instituut (KNMI), The Netherlands
- M. Dunseath Terao, University of Rennes 1
- R. Fernandes, University of Lisbon, Portugal
- S. Ficher, R. Khachikyan, IGS Central Bureau, Jet Propulsion Laboratory (JPL), NASA, US
- M. Guichard, Data center SONEL and TIGA (IGS), Université de La Rochelle, France
- H. Habrich, J. Ihde, J. Söhne, Bundesamt für Kartographie und Geodäsie (BKG), Germany
- K. Hodges, University of Reading, UK
- J. Jones, Met. Office, U.K.

- A. Kenyeres, FÖMI Satellite Observatory, Hungary
- R. King, Massachusetts Institute of Technology (MIT),US
- J. Griffiths, NOAA/NGS, USA
- D. Lavallée, Technical University of Delft (TUD), Netherlands
- C. Mitchell, University of Bath, Department of Electronic and Electrical Engineering
- L. Sanchez, Deutsches Geodätisches Forschungsinstitut (DGFI), Germany
- A. Santamaria-Gomez, IGN, Spain and LAREG/IGN, France
- P. Spencer, University of Bath, Department of Electronic and Electrical Engineering
- G. Stangl, Austrian Academy of Sciences, Austria
- N. Romero, ESOC, Darmstadt, Germany
- H. Vedel, Danish Meteorological Institute (DMI), Denmark
- G. Weber, Bundesamt für Kartographie und Geodäsie (BKG), Germany
- G. Wöppelmann, Scientific responsible of SONEL, Université de La Rochelle, France
- P. Zeimetz, Universität Bonn, Germany

List of national partners or collaborators having actively contributed to the project in the last year

- P. Voet, Nationaal Geografisch Instituut (NGI)
- Prof. G. Vandenbosch, ESAT-TELEMIC, K.U.Leuven, antenna measurements
- P. De Kimpe, Royal Military Academy (RMA), Brussels
- P. Termonia, Royal Meteorological Institute (RMI), Belgium
- R. van Malderen, Royal Meteorological Institute (RMI), Belgium
- J. Nemeghaire, Royal Meteorological Institute (RMI), Belgium
- H. De Backer, Royal Meteorological Institute (RMI), Belgium
- C. Hermans, Institut d'Aeronomie Spatiale (IAS), Belgium

Grants/Projects used for this research/service

- FP7-project SX5
- Solar Terrestrial Center of Excellence

A.1.6. Scientific outreach

Meeting presentations

(1) Burston R., Hodges K., Astin I., Bergeot N., Chevalier J.-M., and Bruyninx C.
Combining Ionospheric Imaging with Feature Tracking to Automate Identification and Tracking of Polar-cap Plasma Patches
Space Weather Workshop 2010, 27-30/04/2010, Boulder, US

(2) Bruyninx C., Altamimi Z., Becker M., Craymer M., Combrinck L., Combrink A., Dawson J., Dietrich R., Fernandes R., Govind R., Herring T., Kenyeres A., King R., Kreemer C., Lavallée D., Legrand J., Santamariá Gómez A., Sánchez L., Shen Z., Sella G., and Wöppelmann G.
IAG Working Group on Regional Dense Velocity Fields: First Results and Steps Ahead
EGU General Assembly 2010, May 02-07, 2010, Vienna, Austria (Geophysical Research Abstracts, Vol. 12, EGU2010-10794)

(3) Chevalier J.-M., Bruyninx C., Legrand J., Bergeot N., and Burston R.
Assessing the added-value of dense GNSS networks and multi-GNSS observations for tomographic applications
EGU, May 2010, Vienna, Austria (Geophysical Research Abstracts, Vol. 12, EGU2010-10538)

(4) Kudryashova M., Lambert S., Dehant V., and Bruyninx C.
Determination of nutation offsets by combining VLBI/GPS-produced normal equations
EGU General Assembly 2010, May 02-07, 2010, Vienna, Austria

(5) Legrand J., Bruyninx C., Bergeot N., Santamaría-Gómez A., Bouin M.N., Wöppelmann G. and Altamimi Z.
Station Position Time Series Obtained from Regional and Global GNSS Network Analysis
EGU, May 2010, Vienna, Austria (Geophysical Research Abstracts, Vol. 12, EGU2010-9321)

(6) Habrich H., Altiner Y., Bruyninx C., Ihde J., Mervart L., Söhne W., and Weber G.
Development of the EUREF GNSS services and reference networks
United Nations/Moldova/United States of America Workshop on the Applications of Global Navigation Satellite Systems, May 17-21 2010, Chisinau, Moldova

(7) Bergeot N., Bruyninx C., Aerts W., Lombardi D., Camelbeeck T., Van Camp M., Legrand J., and Moyaert A.
Installation of a GPS station at the Princess Elisabeth base to monitor crustal motions due to ice mass variations
Belgian IPY Symposium, 26 May 2010, Brussels, Belgium

(8) Aerts W., Baire Q., Bergeot N., Bruyninx C., Burston R., Chevalier J.-M., Defraigne P., Legrand J., Pottiaux E., and Roosbeek F.
EUREF Annual Report
Symposium of the IAG Subcommission for Europe (EUREF), May-June 2010, Gävle, Sweden

(9) Bruyninx C.
Activities and Initiatives of the EUREF Technical Working Group
Symposium of the IAG Subcommission for Europe (EUREF), June 02-04 2010, Gävle, Sweden

(10) Bruyninx C., Baire Q., Legrand J. and Aerts W.
The EPN Infrastructure: Status, Monitoring and Plans
Symposium of the IAG Subcommission for Europe (EUREF), May-June 2010, Gävle, Sweden

(11) Chevalier J.-M., Bruyninx C., Legrand J., Bergeot N., and Burston, R.
Sounding the Atmosphere: Improvement of the Ray Geometry Using Dense European GNSS Networks and Multi-GNSS Signals
Symposium of the IAG Subcommission for Europe (EUREF), May-June 2010, Gävle, Sweden

(12) Söhne W., Iocovone D., Aerts W., Bruyninx C., Pacione R., and Weber G.
EPN Regional Broadcasters for Real-time GNSS Data Dissemination
EUREF Symposium 2010, June 2-4 2010, Gävle, Sweden

(13) Legrand J., Bruyninx C., Bergeot N., Santamaría-Gómez A., Bouin M.N., Wöppelmann G., and Altamimi Z.
EPN vs. Global Network Analysis: Influence on GNSS Positions, Velocities and Residual Position Time Series
Symposium of the IAG Subcommission for Europe (EUREF), May-June 2010, Gävle, Sweden

(14) Burston R., Bergeot N., Bruyninx C., and Chevalier J.-M.
A Two-stage Mid-latitude Instability Process: Gradient-drift and Kelvin-Helmholtz Waves?
Beacon Satellite Symposium 2010, 07-11 June 2010, Barcelona, Spain

(15) Chevalier J.-M., Bruyninx C., Legrand J., Bergeot N., and Burston R.
Impact of Dense GNSS Networks and Multi-GNSS on Trans-ionospheric Ray Path Distribution for Tomographic Applications
Beacon Satellite Symposium 2010, 07-11 June 2010, Barcelona, Spain

(16) Lombardi D., Bergeot N., Bruyninx C.,Camelbeeck T., Francis O., Rapagnani G., Van Camp M., and van Dam T.
Installation and preliminary data analysis of a permanent geodetic and seismic station at the new Belgian Princess Elisabeth Station in East Antarctica

International Polar Year Oslo Science Conference, 8-12 June 2010, Oslo, Norway

(17) Bruyninx C., Baire Q., Legrand J., and Pottiaux E.
Efforts Towards an Improved Long-term Monitoring of the EUREF Permanent Network
IGS Analysis Workshop and Vertical Rates Symposium 2010, June 2010, Newcastle, UK

(18) Bruyninx C., Habrich H., Kenyeres A., Söhne W., Stangl G., and Völksen C.
The EUREF Permanent Network and its GNSS-based Services and Products as a European Standard
IGS Analysis Workshop and Vertical Rates Symposium, June 28 - July 02, 2010, Newcastle, UK

(19) Pottiaux E., and Bruyninx C.
National Report of Belgium (ROB) to the E-GVAP II Joint Expert Team Meeting 2010
E-GVAP II Joint Expert Teams meeting 2010, 23-24 September 2010, Oslo, Norway

(20) Bruyninx C., Altamimi Z., Becker M., Craymer M., Combrinck L., Dawson J., Dietrich R., Fernandes R., Herring T., Kenyeres A., King R., Kreemer C., Lavallée D., Legrand J., Sánchez L., Sella G., Shen Z., Santamaría-Gómez A., and Wöppelmann G.
IAG SC1.3 Working Group on Regional Dense Velocity Fields: First Results and Steps Ahead
IAG Commission 1 Symposium 2010 Reference Frames for Applications in Geosciences (REFAG2010), October 04-08, 2010, Paris, France

(21) Bruyninx C., Altamimi Z., Brockmann E., Caporali A., Dousa J., Fernandes R., Habrich H., Hornik H., Ihde J., Kenyeres A., Lidberg M., Mäkinen J., Poutanen M., Sacher M., Söhne W., Stangl G., Torres J., and Völksen C.
EUREF and its Contribution to the European Geodetic Infrastructure
IAG Commission 1 Symposium 2010 Reference Frames for Applications in Geosciences (REFAG2010), October 04-08, 2010, Paris, France

(22) Legrand J., Bruyninx C., Bergeot N., Santamaría-Gómez A., Bouin M.N., Wöppelmann G., and Altamimi Z.
Limitations of Regional GNSS Networks for Geophysical and Geodynamical Studies
IAG Commission 1 Symposium 2010 Reference Frames for Applications in Geosciences (REFAG2010), October 04-08, 2010, Paris, France

(23) Bergeot N., Burston R., Legrand J., Chevalier J.-M., Bruyninx C., Defraigne P., Baire Q., and Pottiaux E.
TEC Variations and Ionospheric Disturbances over Europe during the August 2010 Storm Event.
Seventh European Space Weather Week, 15-19 November 2010, Brugge, Belgium

(24) Pottiaux E., Bruyninx C., and Defraigne P.
Sounding the Earth's Atmospheric Water Vapour Using Signals Emitted by Global Navigation Satellite Systems
METEOCLIM Symposium 2010, November 5, 2010, Uccle, Belgium

(25) Bruyninx C., Baire Q., Legrand J., Aerts W., and Pottiaux E.
Modernization of the EPN tracking network and introduction of IRTF2008/IGS08
EPN LAC Workshop 2010, November 18-19, 2010, Warsaw, Poland

(26) Pottiaux E., Aerts W., Baire Q., Bergeot N., Bruyninx C., Burston R., Chevalier J.-M., Defraigne P., and Legrand, J.
EPN-related Activities and Research at ROB (LAC)
EPN LAC Workshop 2010, November 18-19, 2010, Warsaw, Poland

(27) Bruyninx C.
Maintenance of the ETRS89 using EUREF's Permanent GNSS Service

International Symposium, on GNSS, Space-Based and Ground-Based Augmentation Systems and Applications, November 29-30, 2010, Brussels, Belgium

(28) Aerts W., Bruyninx C., and Defraigne P.
Bandwidth and Sample Frequency Effects in GPS Receiver Correlator
NAVITEC 2010, December 8-10, 2010, Noordwijk, Nederland

(29) Bergeot N., Legrand J., Burston R., Bruyninx C., Defraigne P., Chevalier J.-M., Clette F., Marque C., and Lefevre, L.
Correlation between solar activity and Earth's ionospheric electron content during the 23rd solar cycle
AGU Fall Meeting 2010, December 2010, San Francisco, USA

(30) Chevalier J.-M., Benoit, L. Bergeot N., Bruyninx C., Legrand J., Burston R., Defraigne P., Pottiaux E., and Baire Q.
Near Real Time GPS-Based Ionospheric Models: Application to Belgium
AGU Fall Meeting 2010, December 2010, San Francisco, USA

(31) Pottiaux E.
Sounding the Earth's Atmospheric Water Vapour Using Signals Emitted by Global Navigation Satellite Systems
Ph.D. private defense, Université Catholique de Louvain (UCL), Louvain-La-Neuve, Belgium

Wikis and Websites

- EUREF Permanent Network Central Bureau Information System: http://epncb.oma.be/
- IAG SC1.3-WG1 on "Regional Dense Velocity Fields": http://epncb.oma.be/IAGWG
- IGS Networked Transport of RTCM (Radio Technical Commission for Maritime Services) via Internet Protocol (Ntrip) monitoring: http://igs.oma.be/real_time/
- GNSS web site http://www.gnss.be/
- EPN Reprocessing web page http://129.187.165.2/wiki_epnrepro/index.php/Main_Page

Brochures

- Flyer on EUREF Permanent Network

A.1.7. Missions

Assemblies, symposia:

W. Aerts: Galileo Application Days, Seminar on Remote Data Acquisition, Automation 2010, RF Technology Day, AGIV Trefdag, Navitec 2010

Q. Baire: Symposium of the IAG Subcommission for Europe (EUREF), IGS Workshop, Vertical Rates Symposium

N. Bergeot: Space Weather Workshop, Belgian IPY Symposium Programme, Beacon Satellites Symposium, Seventh European Space Weather Week, AGU Fall Meeting

C. Bruyninx: Symposium of the IAG Subcommission for Europe (EUREF), IGS Workshop, Vertical Rates Symposium, IAG Commission 1 Symposium 2010 Reference Frames for Applications in Geosciences (REFAG2010), EUREF Local Analysis Centers Workshop, International Symposium on GNSS

R. Burston; Space Weather Week, Beacon Satellite Symposium, Institute of Navigation GNSS Technical Meeting

J.-M. Chevalier: EGU General Assembly, Beacon Satellite Symposium, AGU Fall Meeting

J. Legrand: EGU General Assembly, Symposium of the IAG Subcommission for Europe (EUREF), IGS Analysis Workshop and Vertical Rates Symposium, IAG Commission 1 Symposium 2010 Reference Frames for Applications in Geosciences (REFAG2010), EPN LAC Workshop

E. Pottiaux: IGS Analysis Workshop and Vertical Rates Symposium, METEOCLIM 2010 Symposium, EPN Local Analysis Centre Workshop

Commissions, working groups (days):

W. Aerts (June 3, October 14)
N. Bergeot (April 26, June 3)
C. Bruyninx (March 8-9, May 31, April 21, June 1, June 28, October 5 , October 8, October 26, November 22-23)
J.-M. Chevalier (June 3)
J. Legrand (February 10-12, March 17-19, May 3, May 31, June 28, October 5)
E. Pottiaux (June 3, September 23-24)

Research visits (days):

W. Aerts (April 26, August 23-24)
N. Bergeot (February 25, September 13)
J. Legrand (February 25, October 11)
E. Pottiaux (June 3, September 23-23)

Field missions (days):

W. Aerts (December 22)
N. Bergeot (September 14)

A.2. TIME – TIME TRANSFER

Using the same data from GNSS stations, the research is dedicated to an optimal exploitation of GNSS data for geophysics, geodesy, atmospheric studies and time transfer.

A.2.1. Objectives

- To maintain high-quality clocks for participation in the international timescales (mainly TAI and IGS), and for the realization of a local high-quality timescale UTC(ORB) close to UTC;
- To maintain the official Belgian time called UTC(ORB) within one hundred of nanosecond of UTC;
- To define a legal Belgian time;
- To provide UTC(ORB) to Belgian users via NTP;
- To provide to the time community up-to-date software able to generate the GNSS time transfer results in the CGGTTS (Common GPS GLONASS Time Transfer Standard) format from dual-frequency geodetic receivers connected to atomic clocks. The software is named R2CGGTTS (RINEX to CGGTTS); it was developed and is maintained by Pascale Defraigne at the ROB: this software is since 10 years used by the BIPM for the realization of TAI; it will also be used by the Galileo navigation system for the steering of Galileo System time based on a set of atomic clocks located in Europe (as expressed in Galileo Time Service Provider Interface Control Document);
- To answer to the users concerning their possible questions/problems about that software;
- To develop and improve the GNSS time transfer strategies and to test them.

A.2.2. Progress and results

A.2.2.1. Time scale generation

- *Monitoring of UTC(ORB):*
  The bias between UTC(ORB) and UTC suffered from some clock problems during 2010 reducing the stability, but the requirement of UTC(ORB)-UTC<100 ns was verified during the whole year.
- *Legal aspects of UTC(ORB) in Belgium*:

We continued the procedure to get UTC(ORB), or equivalent realizations of UTC, as legal time for Belgium.

- *Time scale algorithm*:
  We developed a clock ensemble algorithm for the monitoring and steering of UTC(ORB) in order to be independent of the other laboratories. The conclusion was that with the current stabilities of the ROB's cesium clocks, the algorithm does not provide the prediction of UTC-UTC(ORB) with a sufficient precision. The use of the algorithm will be again investigated when the new Caesium clocks will be installed in 2011.

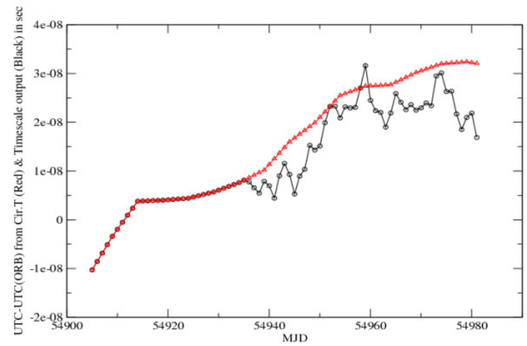

Figure 4: Predicted UTC-UTC(ORB) with time scale algorithm for next 45 days (in black) and corresponding true UTC-UTC(ORB) from Circular T by BIPM (in red).

- *Time Laboratory*:
  - We managed the clock signals needed for GNSS receivers BRUS, ZTBR, PLB1, PLB2.
  - We operated the maintenance of the H-maser, with reparation of several failures. Pascale Defraigne managed the H-maser problems: the H-maser used for UTC(ORB) lost its PLL several times, consuming a lot of time to reset it each time; it finally stopped delivering a 5MHz frequency. P. Defraigne changed the signal generating UTC(ORB) when the maser CH1-75 stopped to work in November 2010 from the H-maser to our youngest cesium clock up to the repair of the H-Maser (foreseen for 2011).
  - We participated in the BIPM Pilot Project TAIPPP: using the Precise Point Positioning (PPP) for GPS time transfer used in the context of the computation of TAI.
  - We prepared the new design of the Time lab in collaboration with Wim Aerts.
  - We prepared the Public market for the purchase of 3 new cesium clocks HP-5071A.
  - Cesium clock nr 4 stopped to work in October 2010.
  - We have fine-tuned the controls of the air conditioning in the GPS room, reducing the temperature variations with a factor of ten. Besides, a 'free cooling' strategy, using outside air instead of a cooling engine was implemented and tested.

- *Project*:
  In collaboration with Microsystèmes, France, we contributed to the proposal for Design and development of a robust on-board Frequency Reference Subsystem, ref EGEP-ID32. The objective was the design assembly and tests of a robust on-board reference system for the Galileo satellites, based on the intercomparison of the on-board atomic clocks. The proposal was unfortunately not selected finally.

- *Steering of Galileo System Time*:
  We studied the optimum steering strategies for the GST (Galileo System Time), and prepared a document about the architecture and operations for the Galileo Time Service Provider (part of a white book).

A.2.2.2. R2CGGTTS software follow-up

- *Help for the Precise Time Facility of the Galileo navigation system*:
  We provided the needed support to the Galileo PTF for the installation and well-functioning of the R2CGGTTS software. PTF is the time laboratory where the Galileo System Time is generated.

- *Upgrade for GLONASS data*:

We adapted, in collaboration with Aurélie Harmegnies (BIPM), the software in order to include the possibility to use also GLONASS observations in GNSS time transfer. As the computation procedure is based on broadcast orbits, and as the GLONASS orbits are given as positions and velocities each hour, the program performs numerical integration of orbits for the GLONASS satellites while still modeling the GPS satellite motions using keplerian orbits. Furthermore, the differences between the reference systems for GLONASS and GPS were introduced in order to be able to combine the observations made on both systems; the inter-frequency biases of the GLONASS data must still be corrected for, as they increase the noise of the results.

- *Upgrade for new RINEX 3.0 format*:
  We developed a new version (V4.3_R3) of the R2CGGTTS software in order to adapt the software to the new RINEX format (RINEX 3.0) dedicated to common GPS-GLONASS-GALILEO observations.

- *Upgrade for Galileo data*:
  We introduced in the software the possibility to use Galileo data; first tests were performed with the signals from the two experimental satellites GioveA and GioveB signals in order to study the capabilities of Galileo for time and frequency transfer; this study was performed in collaboration with Alexandre Moudrak, from ESTEC.

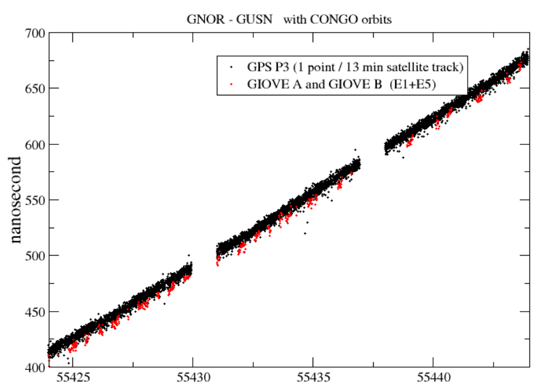

Figure 5: Time transfer between GNOR (ESTEC, the Netherlands) and GUSN (USNO) obtained via common view from CGGTTS results.

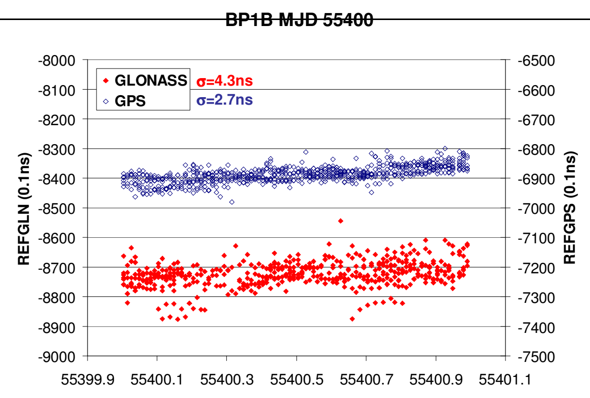

Figure 6: Comparison between the CGGTTS results obtained with either GLONASS satellites or GPS satellites after correction for precise satellite positions and clocks. The ESOC post-processed satellite orbits and clocks are used in both cases

A.2.2.3. High precision GNSS time transfer

- *Combination of GPS and GLONASS data in Precise Point Positioning (PPP):*
  We developed the combination of data from GPS and from GLONASS in a global PPP analysis. That combination was possible now thanks to the IGS center ESA which now provides combined products for satellite orbits and clocks, in which both GLONASS and GPS clocks are given with respect to the same reference. The results have shown that it is important to determine the inter-frequency hardware delays of the GLONASS satellites as these can include some multipath effects which vary with time. A second important result was that the use of GLONASS satellites in the solution does not modify the GPS-only solution, except for short data batches where the additional GLONASS code data helps in the determination of the ambiguities, and hence improves the solution.

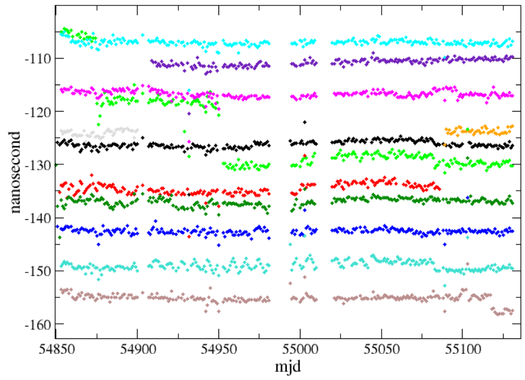

Figure 7: Values of the inter-frequency hardware delays computed with Atomium for the link ONSA-WTZR (two GNSS stations) during 6 months. Some periodic variations appear for some frequencies, probably due to multipath.

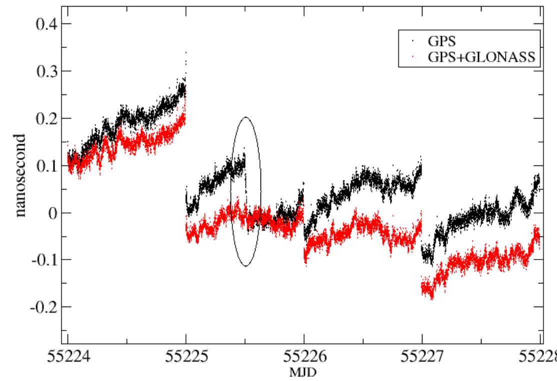

Figure 8: Differences between the Atomium PPP solution and the IGS solution for the time link ONSA-WTZR, with GPS data only or with GPS+GLONASS data, showing the improvement thanks to the GLONASS data when there is a tracking interruption as in WTZR during the MJD 55225

- *Combination of GPS and TWSTFT data*:
  We finalized the computation of the combined GPS+Two-Way (TW) solution for time transfer, focussing on the long-term variations of the differences between the TW and GPS results; we also finalized a publication.

- *Impact of antenna setup on time transfer solutions*:
  In order to understand the possibilities for multipath suppression at GNSS reference stations, we computed time transfer solutions for different configurations of the GNSS station BRUX, and looked at correlation between the results and the presence or not of absorbing material; no significant correlation could be found between the presence of absorbing material and the day-boundary discontinuities in the clock solutions, but a shift in the antenna position due to the absorbing material was shown. This shift is however not explained by the calibrations performed with or without absorbing material. This should be further studied.

- *Use of the precise E5 code from Galileo*:
  We investigated the possibilities of the precise E5AltBOC code of the future Galileo constellation for time transfer accuracy. This code should be used without any combination with another code signal in order to avoid an increase of the noise level. The idea proposed here is to use the Code-plus-Phase (CPC) ionosphere-free combination. This combination will have the noise/multipath of the E5AltBOC code, and no ionosphere delay; however it is ambiguous as the measurements are

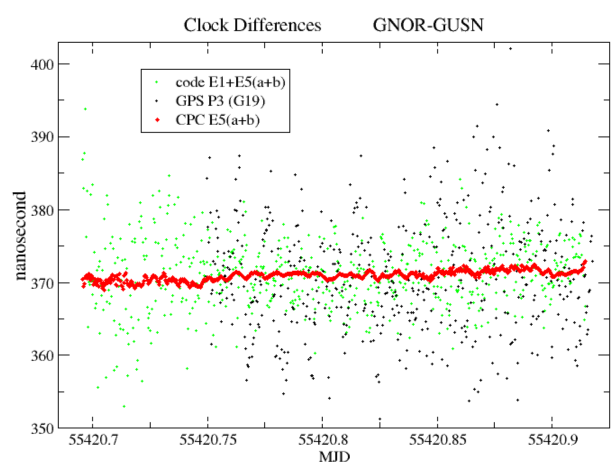

Figure 9: Comparison between the clock solutions obtained with either dual-frequency ionosphere-free combination of pseudoranges, or the CPC combination.

performed with the carrier phase only. So, the next step of this research will be to solve for the ambiguity.

- *Impact of receiver setup on time transfer solutions*:
  We finalized, in collaboration with G. Petit (BIPM) and P. Uhrich (LNE-SYRTE) the study of the optimal GNSS receiver setup for timing applications.

- *Contribution to the SX5 FP7 project*:
  We have participated to the SX5 FP7 project. In this frame, she provided an analysis of the user requirements for the GNSS time transfer community.

A.2.3. Perspective for next years

- Total renewal of the time lab, in order to increase the reliability of the UTC(ORB) and its delivery to users via NTP (Network Time Protocol);
- new Cesium clocks with higher short term stability than the present ones;
- replacement of the frequency-dividers by HROG: High-Resolution phase and frequency Offset Generator;
- Repair of the H-maser by replacing the quartz oscillator;
- Setup of a new time scale algorithm using these high-performance clocks for the steering of UTC(ORB);
- The frequency of UTC(ORB) will be redefined as output of the HROG rather than the output of the MASER as done presently;
- Finalizing the Belgian legal aspects of UTC;
- Upgrading the website of the time laboratory;
- Introduce the "real-time" IGS orbits and clock products for the monitoring of UTC(ORB) in real time;
- Continuing the study of using the Galileo E5 signal for accurate Time transfer;
- Improving the orbit determination in the Atomium software; presently, the orbits are determined by interpolation between the IGS points; The project is to fit a piece-wise keplerian orbit in order to avoid the problems in the beginning and end of the day;
- Fixing the ambiguities to their integer values within the Atomium software. Presently the ambiguities are determined as floating quantities; Using the integer products provided by the CNES/CLS analysis center of the IGS, it is possible to better constrain the ambiguities to their integer value, and hence improving the position, clock and atmosphere solutions obtained in PPP with Atomium;
- Add the recent results concerning GNSS time and frequency transfer on the website;
- R2CGGTTS: finalize the version using both GPS and GLONASS data.

A.2.4. Personnel involved

Scientific staff: P. Defraigne (Project leader), W. Aerts, Q. Baire, C. Bruyninx, S. Sharma

Technical staff: E. Driegelinck

A.2.5. Partnerships

List of international partners or collaborators having actively contributed to the project in the last year

- Dr Pierre Uhrich, Laboratoire Temps-Fréquence, LNE-SYRTE, Observatoire de Paris.
- Dr Andreas Bauch, PTB, Germany.
- Dr Patrizia Tavella, Istituto Nazionale di Ricerca Metrologica, Italy.
- Dr Jerome Delporte, CNES, France
- Alexander Moudrak, ESTEC (The Netherland)
- Aurélie Harmegnies, Bureau International des Poids et Mesures, France.

- Gérard Petit, Bureau International des Poids et Mesures, France
- Mari Carmen Martinez, University of Alicante, Spain.

Grants/Projects used for this research/service

- Solar Terrestrial Center of Excellence
- EU funding for the travels related to the meeting of the Galileo FOC Timing Working Group
- Belspo grant for Outside Europe Post-Docs.

Visitors:

- Sharma Suman, Nov. 2009-June 2010.
- Aurélie Harmegnies (BIPM): July 27-30, 2010
- Martinez-Belda Mari Carmen: March 28-April 23, September 6-30, October 19-December 21, 2010
- Eric Dierkx, VSL (Time Laboratoy of The Netherland), March 10, 2010
- Jean-Claude Pouytes, Microsystèmes, September 24, 2010

A.2.6. Scientific outreach

Meeting presentations

(1) S. Sharma, P. Defraigne,
New Time Scale at the Royal Observatory of Belgium,
EFTF, Noordwijk, April 12-16, 2010.

(2) P. Defraigne,
Galileo Time Service Provider, Architecture and Operations,
Meeting of the Galileo Timing Interface Working Group, Torino, November 11-12, 2010.

(3) P. Defraigne, M.C. Martinez, A. Mudrak, S. Binda,
Galileo Common View: format, processing and tests with GIOV",
PTTI, Washington, November 2010

(4) P. Defraigne, Q. Baire, A. Harmegnies,
Time and frequency transfer combining GLONASS and GPS data
PTTI, Washington, November 2010

(5) P. Defraigne, G. Petit, P. Uhrich, W. Aerts,
Requirements on GNSS receivers from the perspective of timing applications
EFTF, Noordwijk, April 2010

(6) P. Defraigne,
GNSS receivers for timing applications,
International Committee on GNSS, Turin, October 2010, invited

(7) P. Defraigne, M.C. Martinez, A. Mudrak, S. Binda,
Galileo Common View: format, processing and tests with GIOVE
PTTI, Washington, November 2010

(8) P. Defraigne, Q. Baire, A. Harmegnies,
Time and frequency transfer combining GLONASS and GPS data
PTTI, Washington, November 2010

Wikis and Websites

- www.gnss.be

Brochures

- ORB part of the BIPM Annual report

A.2.7. Missions

Assemblies, symposia:

- April 12-16: EFTF, Noordwijk, The Netherlands, (P. Defraigne, W. Aerts)
- June 27-July 2, IGS workshop, Newcastle, UK, (P. Defraigne, Q. Baire, C. Bruyninx)
- October 17-20: International Committee on GNSS, Turin, Italy, (P. Defraigne)
- November 15-19: PTTI meeting, Washington, US. (P. Defraigne)

Commissions, working groups (days):

- June 3: STCE Meeting, Uccle, (P. Defraigne, Q. Baire, W. Aerts, C. Bruyninx)
- February 9: Meeting Galileo, Brussels, (P. Defraigne)
- June 24: WG on GNSS (region wallonnne), Liège, (P. Defraigne)
- July 16: Kick-Off meeting of the Galileo FOC (Full Operational Capability) Timing Working Group, Brussels, (P. Defraigne)
- November 11-12: 1st progress meeting of the Galileo FOC Timing Working Group, Turin. (P. Defraigne)

B. Earth and Planetary Sciences

B.1. Planets and Moons of the Solar System

B.1.1. Objectives

Although it is generally accepted that the interior of the four terrestrial planets is similar to that of the Earth, even basic questions on the global interior structure and composition of Mercury, Venus, and Mars remain unanswered. The Earth's interior structure has been successfully investigated through the analysis of the propagation of seismic waves in the Earth's solid and liquid internal layers. For lack of seismometers on the other planets – though they are planned for Mars and some seismic data on the Moon has been obtained by the Apollo missions – planetary geodesy is one of the primary means for probing the interior structure of planets. At ROB, Section 1 is involved in studies of the gravity field and rotation of terrestrial planets and large natural satellites.

The gravity field of planetary bodies can best be studied through the precise monitoring of the trajectory of passing or orbiting spacecraft. Because the gravity field of a planet is determined by the planet's mass distribution, spatial and temporal variations in the gravity field can be used to determine physical properties of the interior and atmosphere of the planet. Since the beginning of the space age, the large-scale structure of the gravity field of planets and moons has been successfully used to determine the moment of inertia, which is a measure of the radial density distribution and an important constraint on the interior structure. More recent efforts use tides, which can also be observed through their time-variable effect on the gravity field, to obtain more accurate information on the deep interior, in particular on global fluid layers such as a liquid iron core in terrestrial planets and an internal subsurface ocean in icy satellites.

Constraints on planetary interiors can also be obtained from rotation variations. Three broad classes of rotation variations are usually considered: rotation rate variations, orientation changes with respect to inertial space (precession and nutation), and orientation changes with respect to the rotation axis (polar motion). They are due to both internal (angular momentum changes between solid and liquid layers) and external (gravitational torques) causes. By studying rotational variations of a terrestrial planet, more can be learnt about the excitation processes. Moreover, as the rotational response depends on the planet's structure and composition, also insight into the planetary interior can be obtained. This is particularly so for the rotational variations due to well-known external gravitational causes, such as for example for the nutations of Mars and the librations of Mercury.

The geophysical interest of these studies is to improve our knowledge of the interior, surface, atmosphere, and dynamics of rocky planets and large natural satellites. For that purpose, the relations of rotation variations, gravity field, and tidal variations with interior and atmosphere properties and orbital motion characteristics are investigated. These studies rely on theoretical developments as well as on analyses of radio tracking data of spacecraft flying by, in orbit around, or landed on these planets or satellites. Scientists of Operational Direction 1 are involved in several ESA solar system missions (Mars Express, Venus Express, BepiColombo) at Co-I level, actively participate with ESA in preparations for new and upcoming missions (e.g. EJSM-Laplace), and lead the development of a coherent X-band transponder and antenna for use in a future Mars mission. We also develop theories and strategies for the future exploitation of space data.

B.1.2. Progress and results

B.1.2.1. Development of future missions

- Preparations for a radio-science experiment LaRa (Lander Radioscience) to be implemented on a future planetary lander have continued. LaRa has been designed to transpond an X-band signal transmitted from the Earth ground stations back to the Earth (see Figure 10). The relative radial velocity between the lander and the Earth is inferred from Doppler effects measured at the Earth ground stations and will be used to determine accurately the surface displacement of the lander, yielding information on the rotation and tides of the planet. In 2010, a new phase (phase B2) started in collaboration with OMP (Orban Microwave Products) to develop and test a more representative breadboard of the instrument and to study the possibility of implementing ranging capability. Reviews for design, manufacturing readiness, and testing readiness were completed.

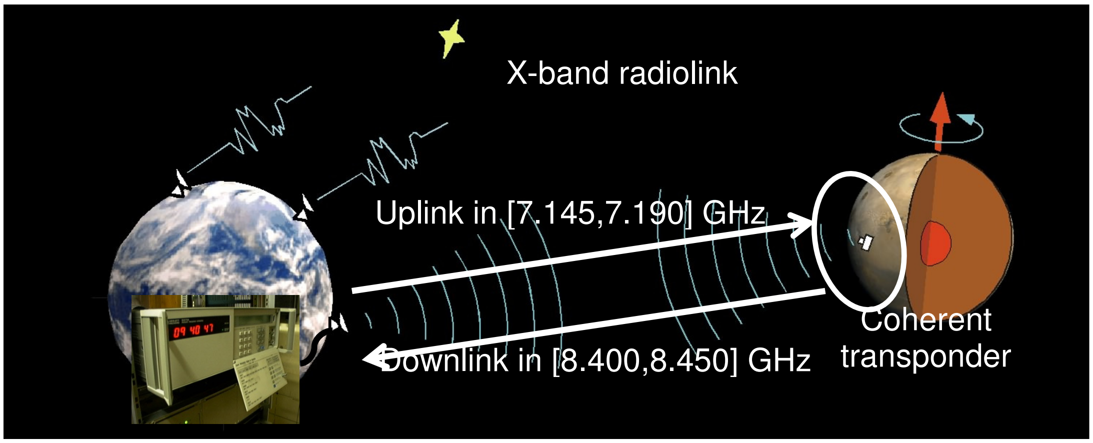

Figure 10: Representation of the radio link between the Earth and Mars with LaRa

- Within the Cosmic Vision program of ESA, we are involved at the Joint Science Definition Team (JSDT) level in the preparations of the ESA-NASA EJSM-Laplace mission to the Jupiter system. In 2010, the preparations focused on finalizing the main documents presenting the science case for EJSM-Laplace, which will be used for the down-selection of the current three ESA L-class mission candidates [43].

B.1.2.2. Mars: radio tracking data processing

- The ROB Mars data base consists of radio tracking data of several space missions and their associated ancillary data (such as wheel off-loading events and the attitudes of the spacecraft bus, the solar panels, and the steerable antenna). About 350 BASH and FORTRAN codes have been developed over time to manage and process the data. Mars Express (MEX), Venus Express (VEX), Mars Odyssey (M01), and Mars Reconnaissance orbiter (MRO) processing are at an operational level at ROB. Mars Global Surveyor (MGS) processing is mainly done by CNES at the Observatoire Midi-Pyrénées but also partially at the Royal Observatory of Belgium. In 2010, efforts went particularly to updating, upgrading, and debugging the existing software. Additionally, Mars Exploration Rovers (MER) Doppler data have been collected and new software tools have been developed for data processing.

➢ The perturbing effect of the Sun on radio tracking data has been studied in order to explain a periodic error in the range data of MGS, MO1 and MEX, which has been detected in our group from the precise orbit determination of these spacecraft. We have shown that the time delays can be explained by propagation through the solar corona and interplanetary plasma for a steady state spherically symmetric model of the associated electron density. However, since we have shown last year that due to the non-spherically symmetric and time-dependent structure of the solar corona and solar wind, more complicated models must be used when the radio wave passes close to the Sun (i.e. at solar elongation lower than 10°), it remains to be determined how the low elongation range errors can be explained (see Figure 11).

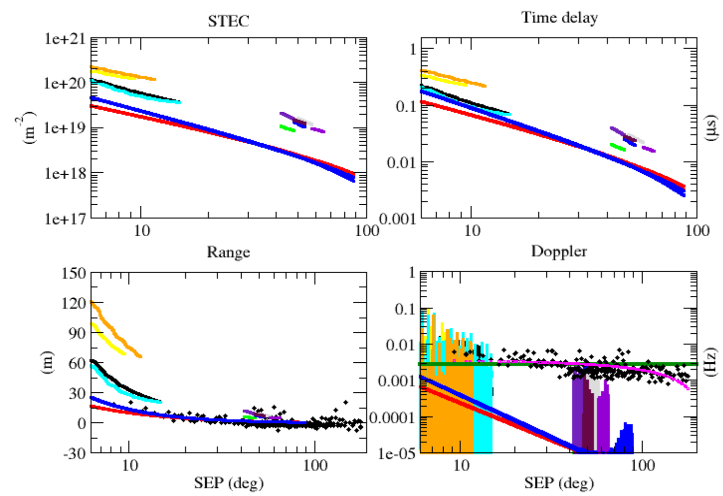

Figure 11: Time Delay, Range and Doppler induced by Slant Total Electron Content from steady-state radial models (red and blue solid lines) and 3D models (others colored lines). Black dots are range biases and Doppler residuals from MEX data.

B.1.2.3. Mars: LaRa

➢ Numerical simulations have been performed to assess the accuracy on the orientation and rotation variation parameters of Mars by using a direct to Earth two-way Doppler X-band radio link from an equatorial lander. Improvements with respect to the current knowledge are expected for the rotation rate variation and precession/nutation after a few hundred days of operation. Moreover, the expected improvements in nutation are expected to be sufficiently good to allow determining information on the core. However, polar motion cannot be observed [25].
➢ An error assessment has been made of the phase and frequency tracking measurements for a system consisting of a distant transponder and a ground station on Earth interacting through microwave links ([28], [34]).
➢ A radio signal is delayed when it propagates through the neutral atmosphere of Mars. We have shown that the effect of the atmosphere on the range and Doppler shift data of a radio link between a lander and an orbiter or the Earth is above the instrument noise and has to be corrected for if the elevation angle of the spacecraft or the Earth in the lander/rover sky is below 4˚ in S-band, below 14˚ in X-band, and below 35˚ in K-band.
➢ A tool has been developed to estimate the effect of the variability of the Earth's ionosphere on radio-tracking data as a function of the time of measurement and the orientation of the antenna.

B.1.2.4. Mars: interior structure, rotation and tides

➢ The core size and composition of Mars have been estimated from the latest available data on the moment of inertia and tidal amplitude of Mars. In order to obtain robust estimates, we have not assumed a specific mantle mineralogy in our models of the interior structure of Mars but instead considered all conceivable mineralogical compositions with mineral iron concentration between 5% and 40%. At the 1σ confidence level, the core size is expected to be in the interval [1716, 1850] km and the weight fraction of sulfur in the core is between 13 and 18 wt% (Figure 12). For the cold and hot mantle temperature end-members considered, the high sulfur estimate implies that the core of Mars is entirely liquid and contains no solid inner part, in contrast to the Earth. A publication on these results on the interior of Mars has been written and has been submitted for publication.

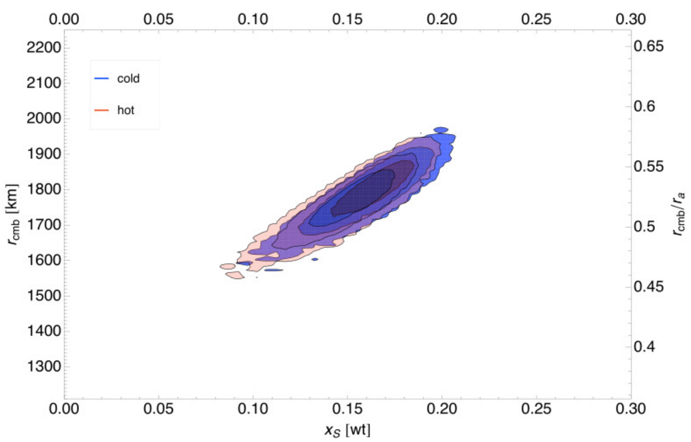

Figure 12: Inferred joint probability densities for core sulfur weight fraction/ core size (x_S, r_{icb}) from measured planet mass, average moment of inertia, and Love number k_2. The blue/red surfaces represent the results obtained from the cold/hot mantle temperature end-members. The contours are the 0.997, 0.95, and 0.683 probability domains.

- A general geometrical method has been further developed for the calculation of the tide-generating potential of any Solar System body. The main advantage is that any realistic orbit configuration can be dealt with as easily as for a simple orbital configuration. Accurate spectral representations of the tide-generating potentials have been obtained in this way for the Galilean satellites [46].
- In collaboration with colleagues from Nantes University, a paper has been written on the deep interior of Mars, Venus, and the Earth.
- A numerical code for mantle convection has been installed and initial calculations have been made to study the thermal evolution of Mars.
- Published data about the high pressure melting temperature and high pressure and high temperature elastic properties of solid fcc-Fe and liquid Fe – the iron phases that are stable in the core of Mercury and Mars – have been used to fit the parameters of an empirical formulation of the Gibbs free energy for both phases. From the resulting Gibbs energies the melting temperature and elastic properties at high pressure and temperature can be calculated in a consistent way.

B.1.2.5. Mars: crust and lithosphere

- The investigation of the structure of the Martian crust and lithosphere is conducted by performing Doppler shift measurements of the velocity variations during the pericenter passage of the Mars Express spacecraft in its orbit around Mars. Because of its low altitude at pericenter, MEX can determine short-wavelength gravity perturbations (below a size of 400 km), which are mainly due to minor density variations (a few hundred kg/m^3) of surface and near-surface features and give information about the elastic thickness of the lithosphere. It has been demonstrated on the basis of MEX data that the volcano Ascraeus Mons has a lower surface density than the neighboring volcano Olympus Mons. This observation shows the inadequacy of the traditional loading model used to fit gravity observations and a new model has been implemented, in which the loading density can change with altitude. The new loading model better fits the observations than the classical models and reveals that Ascraeus Mons has an inverted density structure with respect to Olympus Mons.

B.1.2.6. Mars: atmosphere and polar caps

- In collaboration with E. Javaux (ULg) a review paper on the habitability of Mars has been published [13].

- By using the latest General Circulation Models (GCM) of the Martian atmosphere developed at the Laboratoire de Météorologie Dynamique de Paris (LMD) and at NASA AMES, the time-variable gravity field of Mars due to the atmosphere and atmospheric angular momentum variations of Mars have been theoretically calculated. The results, together with re-processed HEND data (Gamma Ray Spectroscopy) from the Mars Odyssey spacecraft, were compared to radio science data from MRO and MGS. The results have been published in a peer review journal.
- A review paper on the comparison of angular momentum variations of Mars, Venus, and the Earth has been written and is now in press in a peer review journal.
- Meteorite impacts cause atmospheric erosion but also deliver material and volatiles to the planet. A semi-analytical model to study the effect of meteorite impacts on the atmospheric evolution of Mars has been developed over the last few years. We have shown that planetary mass and atmospheric pressure have the most important effect on the evolution of the atmospheric mass. In 2010, the model has been improved by implementing a more accurate impact history. With respect to Venus and the Earth, we have shown that Mars is more susceptible to atmospheric erosion due to its smaller mass and atmospheric pressure, and due to the lower volatile content of the impactors on Mars (Figure 13). A peer review article on these results has been written and is in press (see also [37]).

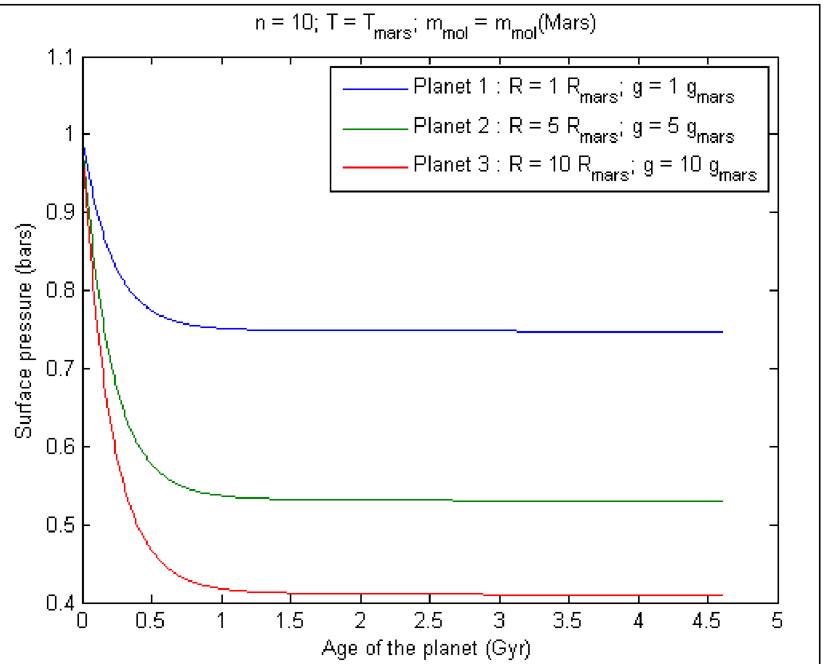

Figure 13: Surface pressure evolution of 3 hypothetical planets, which differ by their planet mass. Planet temperature T and molar mass m_{mol} are set equal to the present Mars conditions. The mean radius R and surface gravity g are set equal to one, five, and ten times the mean Martian radius R_{Mars} and the Martian gravity g_{Mars} for planet 1, planet 2, and planet 3, respectively. The initial atmospheric pressure is set to 1bar.

B.1.2.7. Mars: moons

- Our recent new estimates of the low densities of 1.876 +/- 0.02 g/cm^3 and 1.48 +/- 0.22 g/cm^3 for Phobos and Deimos from MEX radio tracking data show that the moons either have a high interior porosity or contain a large fraction of low-density material, most likely in the form of water ice ([2], [35]). For example, a porosity range between 25-45% and 33-63% would be required to account for the bulk density of Phobos and Deimos, respectively. The large porosity values suggest that re-accretion may have occurred in their early history and that the moons formed in situ instead of being captured. However, if large amounts of ice instead of porosity are responsible for the low density, the moons are more likely captured.
- On 3 March 2010, Mars Express flew closest ever to Phobos, reaching a distance of only 77 km from the moon's surface. Radio tracking data collected during this event have been used to determine for the first time characteristics of the gravitational field of Phobos related to its non-spherical shape (in particular the C_{20} coefficient of the gravitational field). Due to the large error on the estimate,

interpretations in terms of the mass distribution inside Phobos are not yet possible, but it has been shown that the error can be reduced substantially if radio tracking data can be obtained for flyby distances of less than 60 km, which ESA is now planning to do in the extended phase (2010-2012) of the MEX mission.

- By discretizing the volume of Phobos into cubes of equal volume and with density either of water ice, or of rocks with or without porosity, interior models of Phobos have been constructed that satisfy the mass of Phobos. We have shown last year that Phobos is unlikely to have a homogenous internal mass distribution since the resulting forced libration amplitude deviates significantly from the observed forced libration amplitude. Models with an interior mass distribution in large clusters of equal density, however, can fit the observed libration amplitude of Phobos, if the rock density is larger than 2100 kg/m^3. This suggests that Phobos is not composed of light carbonaceous meteoritic material as thought on the basis of the similarity of the spectral properties of its surface with those of several carbonaceous asteroids ([41], [42],).
- In view of Russian Phobos-Grunt mission to Phobos foreseen for launch in October 2012, the expected precision on the libration of Phobos has been estimated from Doppler and star tracker simulated data. We have shown that with both types of measurements, a relative accuracy could be reached of a few percent, more than an order of magnitude better than the current accuracy on the libration of Phobos.

B.1.2.8. Mercury

- Planetary perturbations lead to long-term variations in the rotation rate of Mercury with typical periods of the order of several years. An analytical formulation for the amplitudes and phases of these forced long-period longitudinal librations has been developed. Due to the proximity of the periods to the free libration period of about 12 years the forced liberations are resonantly enhanced to values above one arcsecond. In particular, the free libration period can be very close to the Jupiter induced forced libration period of 11.86 year and can result in large libration amplitude at that period, even exceeding the 35 arcsec amplitude of the principal 88 day forced libration. It has also been shown that the unknown amount of internal dissipation in Mercury is likely to affect measurably only the phase of the 11.86 year libration. This study has been published in Icarus [76] (see also [62]).
- The rotation of Mercury can be determined by comparing the positions of selected spots at the surface of Mercury at different times on camera pictures. Over the last few years, a package of simulation and estimation tools, including complex measurement and dynamic force models, has been developed to investigate the feasibility and precision level of the experiment under realistic conditions. This study is in press in Planetary and Space Science and formed the basis of the PhD thesis of G. Pfyffer, defended and awarded on February 25, 2010 [66]. This year, a study was undertaken to assess whether the results can be optimized by using altimeter data in addition to camera data. An advantage of laser altimetry data is that they do not depend on the solar incidence angle on the surface or on the presence of target features and do not require a complex image correlation process. Using the same approach as for the image-based method it has been shown that a similar accuracy on the parameters of interest (librations and obliquity) can be obtained using laser altimetry cross tracks only (see Figure 14). The combination of both laser altimetry and images in one single parameter estimation process is ongoing.

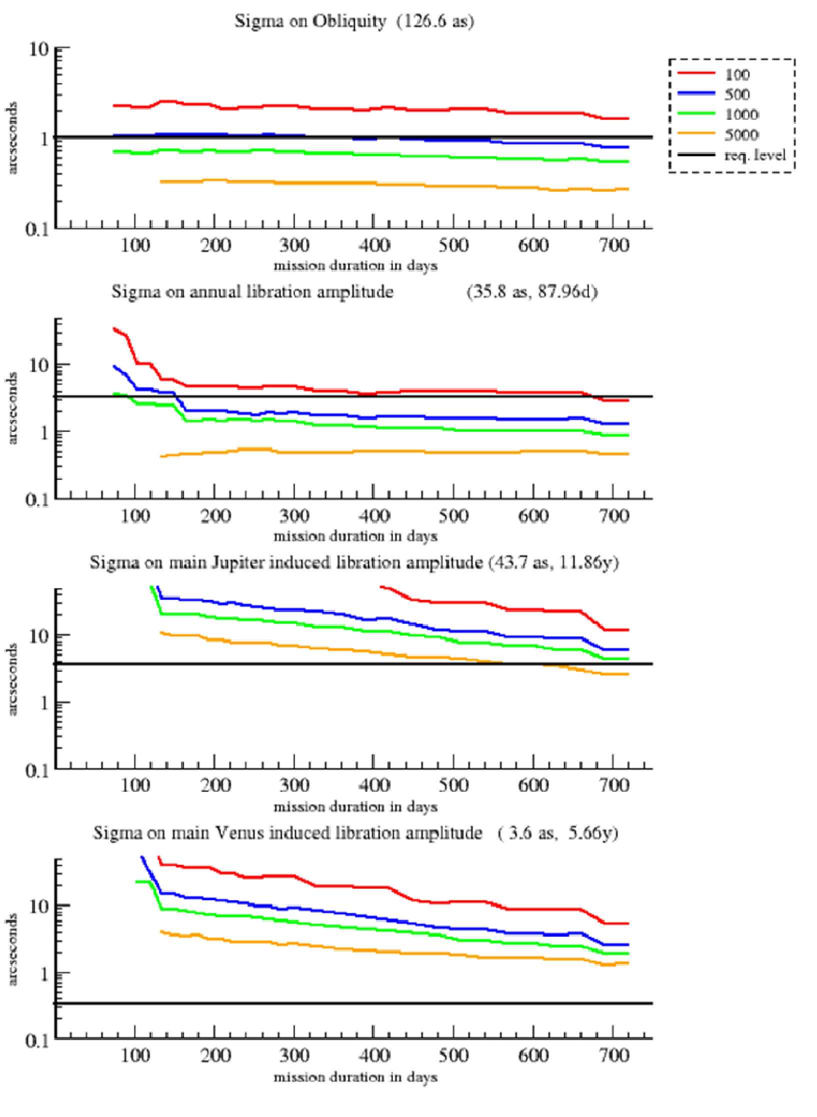

Figure 14: Formal errors on the obliquity, annual libration amplitude, Jupiter induced libration amplitude and Venus induced libration amplitude (from top to bottom) as a function of mission duration, for a nominal mission. Each colored line represents a different number of crossovers considered. The thick black line represents the minimum mission requirement.

- Mercury is probably the only other terrestrial planet of the solar system that like the Earth has a solid inner core in the otherwise liquid iron core. Several methods to prove the existence of an inner core and to determine its size are investigated. First, it has been shown that information on the size of the inner core can be determined from rotation and gravitational data, which will be available after orbit insertion of the NASA MESSENGER spacecraft around Mercury in 2011. However, the uncertainty on the inner core size is expected to be of the order of several hundred kilometers. A significant improvement of the results can be obtained by also using data on the tides of Mercury, for which ESA's BepiColombo mission (launch 2014) will be needed. Alternative methods are also investigated, in particular the possibility to study the inner core from its direct gravitational interaction on the libration of the mantle and from a translation mode of the inner core. With all these methods, information on the inner core can only be obtained if the radius of the inner core is at least several hundred kilometers.

- An important objective of ground-based observations and future space mission is to determine an accurate value for the obliquity of Mercury because this provides a constraint on the polar moment of inertia of the planet and therefore on its internal structure. In order to be able to interpret the equilibrium obliquity of Mercury, the position of the Laplace plane (a mean or reference plane about whose axis the instantaneous orbital plane of a satellite/moon precesses) has to be known accurately. Based on geometrical and dynamical considerations, the position of the Laplace pole and other quantities related to it like the orbital precession frequency have been determined. The method has also been extended to the Laplace plane of natural satellites.
- Tectonic patterns on terrestrial planets due to thermal contraction and despinning have been studied. For thin elastic shells, it has been shown that despinning tectonic patterns depend only on the ratio of two Love numbers (l_2/h_2), which has a fixed value in thin shell theories. This result is important for the prediction of the type of faulting in the equatorial region. A new numerical method (besides the previously developed semi-analytical method) has been developed to compute stresses in a thin elastic shell with axisymmetric thickness variation. The results with applications to the icy moon Iapetus and Mercury have been published in Icarus [9]. It has for example been shown that the tectonic pattern predicted when the lithosphere is thinner at the equator accounts for the location and orientation of the equatorial ridge on Iapetus.

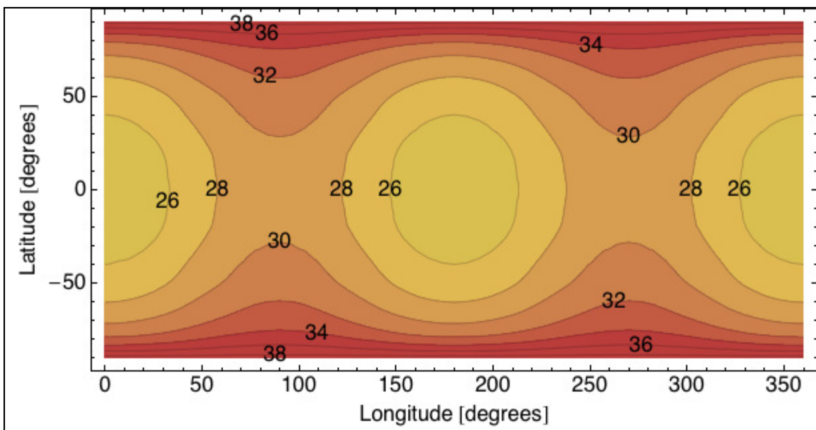

Figure 15: Effect of solar insolation on the lithospheric thickness (in km) for a uniform basal heat flux.
Mercury is in resonance 3:2

- The influence of solar insolation and tidal dissipation on the local lithospheric thickness of Mercury has been calculated in order to study the effect of a heterogeneous lithospheric thickness on the orientation of lobate scarps on Mercury (Figure 15).
- It has been shown that planetary contraction could have led to the observed orientation of lobate scarps, if these formed during the epoch of fast rotation preceding despinning [4].
- Tidal heating in Mercury has been calculated for various models of the interior of Mercury in order to assess whether it can contribute importantly to the thermal evolution of Mercury (Figure 16). It has been shown that although tidal heating is currently not important, it might have contributed substantially to the thermal state, orbital evolution, and surface tectonic patterns in an early state of fast rotation [39].
- In order to characterize the linear and non-linear responses of a fluid cavity undergoing forced longitudinal libration a numerical code has been installed on the clusters of the ROB (collaboration with R. Laguerre (UCL), J. Noir (ETH Switzerland), and M. Lebars (IRPE France)). The ultimate goal of the study is to build a model of viscous dissipation and angular momentum variations in planetary cores and subsurface oceans undergoing forced longitudinal libration.

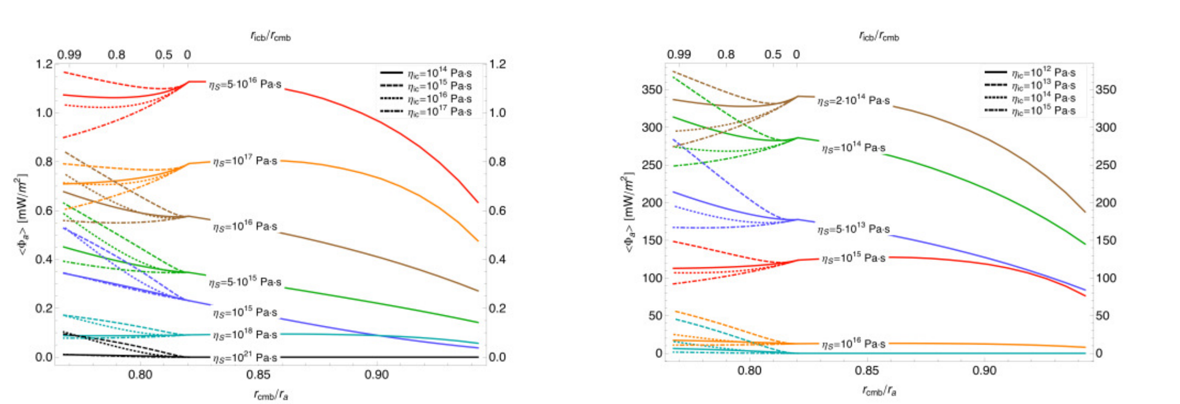

Figure 16: Surface heat flow due to tidal dissipation as a function of core size for the tidal potential of the present 3:2 resonance configuration (left) and for an early rapidly rotating configuration (right). r_{icb}, r_{cmb}, η_s, and η_{ic} are the inner core radius, the core radius, the mantle viscosity, and the inner core viscosity.

- A tool has been developed that simulates the Doppler/Range signal of a spacecraft within General Relativity: planetary motion, spacecraft motion, and the Doppler/Range signals are computed from the space-time metric in the World Function formalism developed at the Observatory of Paris. The general relativistic effect on the Doppler signal for BepiColombo has been shown to be 4 orders of magnitude smaller than the Doppler signal itself, but 5 times larger than the measurement precision (see Figure 17). Alternative theories of gravitation, such as scalar-tensor theories in which the gravitation is not only modeled by a tensor field (the metric) but also by a scalar field, have been considered for future characterization of their effects on Doppler and range signals ([34], [35], [20]).

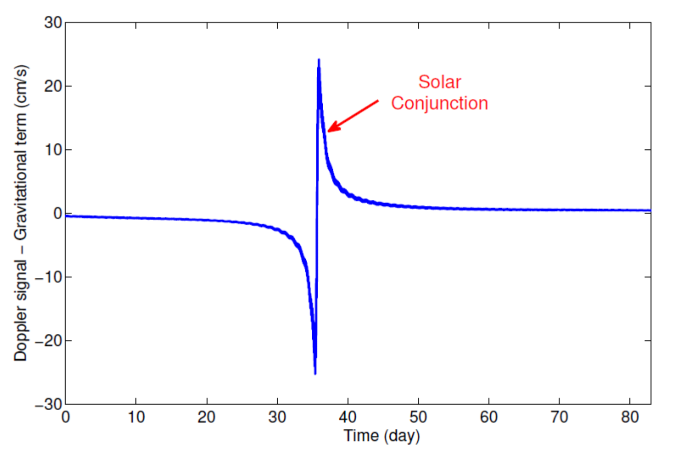

Figure 17: Relativistic correction on the frequency shift simulated for the BepiColombo mission during 88 days. The jump corresponds to a solar conjunction.

- The very high accuracy in range and Doppler measurements of future missions such as BepiColombo make it possible to test general relativity and alternative theories of gravity. Software has been developed to compare the range and Doppler shift in different theories of gravity. Several of these alternative theories are being studied. For the Parameterized Post-Newtonian theories (PPN), the effects of a change in the PPN parameter β on the range and Doppler shift of the MGS spacecraft have been estimated and it has been shown that a change of 10^{-4} with respect to the value of 1 in general relativity produces a signal in range and Doppler at the limit of detectability.

B.1.2.9. Earth

- We have previously shown that the temperature and mineralogy of the lower mantle of the Earth can be reliably estimated from seismological and electromagnetic data. The model is currently being refined by using additional seismological data, increasing the amount of minerals considered, and taking into account spin transitions in minerals, which have recently been shown to have an important influence on the thermo-elastic properties of the deep mantle.

B.1.2.10. Venus

- On 22-28 February and 10-16 April 2010, the Venus Express (VEX) spacecraft flew through the thermosphere of Venus above the North Pole at an altitude of about 180 km, and even reached altitudes as low as 165 km on 23-25 October 2010. The density of the atmosphere of Venus over the North Pole has been derived from VEX tracking data during these and previous campaigns and has been shown to be 55% less dense than predicted by current models based on data from previous missions at low to middle latitudes.

B.1.2.11. Natural satellites

- Several lines of evidence suggest that large icy satellites have a subsurface ocean beneath an ice shell, and may have a liquid iron core. A model developed to calculated librations for synchronously rotating satellites with up to two internal global liquid layers has been applied to the four Galilean satellites of Jupiter. It has been shown that observations of the ice shell librations by future missions to the Jupiter satellite system can prove the existence of a subsurface ocean and can constrain the thickness of the ice shell. The results of this study have been published in Icarus [3].
- In collaboration with an international team of planetary scientists, two review articles have been published on the dynamics and evolution of icy satellites in Space Science Reviews ([36], [75]).
- In collaboration with colleagues from France and the US, a study has been published on the librational response of Enceladus, a moon of Saturn [67].
- Previous studies, in which the icy moons are considered to behave as rigid bodies, have shown that the equilibrium obliquities of the Galilean satellites and Titan are small and well below 1 degree. However, the theoretically predicted obliquity value for an entirely solid Titan, the only icy moon for which the obliquity has been measured, is about 2.5 times smaller than the observed value. By using a similar description as used for the librations to include the effect of a subsurface ocean, expressions for the obliquity of Titan have been determined and theoretical obliquity values have been obtained in agreement with the observed value, suggesting that Titan has a subsurface ocean (see Figure 18). The results are in press in Geophys. Res. Lett. An application of the same method to Europa has shown that the obliquity of Europa would allow constraining the ice shell thickness.
- The forced librations of a satellite rotating synchronously with its orbital motion have a dominant signal at the orbital period if the

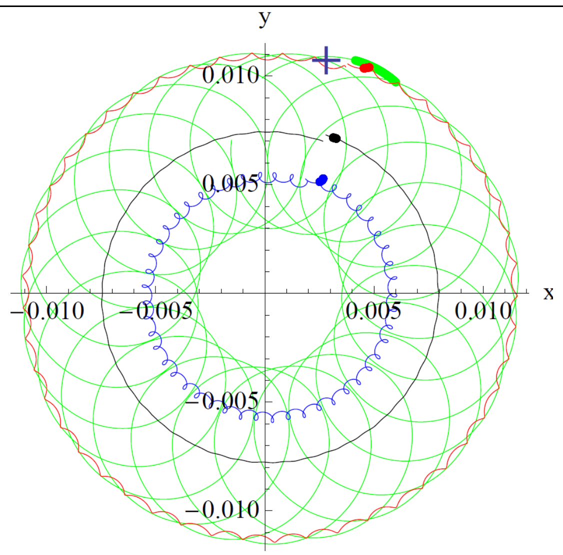

Figure 18: Projection of the orbit normal (blue) and of the rotation axis on the Laplace plane (black for the solid case, red and green for two different internal structure models of Titan with an internal ocean) over the period of the main precession, beginning at J2000 (thin curves) and over the observation period of Stiles et al. 2008 (thick curves). The "+" marker is the projection of the rotation axis measured by Stiles et al. 2008. The obliquity of the internal structure models with an ocean is closer to the observation than in the solid case. (Unit of the graph is radian.)

orbit is considered to be Keplerian. In a collaboration with N. Rambaux (IMCCE, Paris), it has been shown that orbital perturbations due to the Sun and other planets and satellites lead to longer-period librations for the icy Galilean satellites with amplitudes as large as or even larger than the amplitude of the main libration at orbital period for the Keplerian problem. This study has been submitted to Astronomy and Astrophysics, where it is in press.

- The polar motion of Titan forced by its atmosphere has been studied in collaboration with T. Tokano (Köln, Germany). A new method has been developed to calculate polar motion for the strongly triaxial Titan. Based on Tokano's general circulation model of Titan's atmosphere, it has been shown that Titan's polar motion basically consists of a superposition of small diurnal wobbles and larger semi-annual and annual wobbles caused by seasonal changes in wind and pressure. Polar motion has an amplitude of a few meters, but if there is a decoupling subsurface ocean underneath the crust, the wobble amplitude could be larger by an order of magnitude. Moreover, the polar motion path is then expected to be elliptical instead of nearly circular. A paper is in press in Journal of Geophysical Research.
- A method, initially developed by Smith (1974) and Wahr (1981), to calculate deformation and rotation variations of a biaxial, rotating, hydrostatically pre-stressed planet has been generalized to triaxial, synchronously rotating, hydrostatically pre-stressed satellites. By using expansions on a basis of generalized spherical harmonics, the governing partial differential equations of continuum mechanics lead to an infinite system of ordinary differential equations, which has been truncated for computational purposes.
- In collaboration with V. Lainey (IMCCE), a study has been started of the astrometry data of the Saturnian system in order to better constrain the interior structure, dissipation, and orbital evolution of moons of Saturn. A paper on astrometric reduction of photographic plates using the ROB digitizer for improving the dynamics of the Jovian system has been submitted and is now in press.
- As part of a study to investigate the precision of future radio science experiments in determining the tides and gravitational field of the Galilean moons of Jupiter, the effects of the gravity field of Europa on the distance between a spacecraft in orbit around the satellite and the Earth and on the Doppler signal have been modeled. Because of the proximity of the Galilean satellites to the massive planet Jupiter, also the direct gravitational effect of Jupiter on the spacecraft has been included in the model. In order to obtain an accurate analytical solution for the orbital variations of the spacecraft, the classical Kaula method for solving the Lagrange equations has been modified.
- The effect of Jupiter on the Doppler effect on a radio signal between a spacecraft in orbit around Europa and the Earth has been shown to be about 4 times larger than the effects of the non-spherical gravity field, rotation, and tides of Europa. All individual geophysical parameters of Europa have a significant effect above the expected noise level of future spacecraft missions on the Doppler signal, strongly suggesting that the geophysical parameters can all be determined with a radio-science experiment. The effect of the geophysical parameters is largest for a mid or low altitude, edge-on spacecraft orbit with finite eccentricity. A preliminary inversion by means of the least square method has been investigated in order to assess the precision that can be reached for noised Doppler data.
- In collaboration with UCL, we have continued to investigate the effect of a subsurface ocean on the rotation and external gravity field of Europa using a finite element method to solve the governing equations.

B.1.2.12. Atomic-scale modeling of the core of terrestrial planets

- Collaboration has been started with UGent to perform first-principles quantum mechanical calculations of material property data for the core at the high core pressures and temperatures of Mercury and Mars. The results are expected to be essential for a correct interpretation of spacecraft geodesy data in terms of the interior structure of Mars and Mercury and will advance our understanding of the formation and evolution of these planets. Software for ab initio calculations has been installed. The equation of state of fcc-Al at high pressure and zero temperature has been calculated and the phonon spectrum of fcc- Al has been determined. From the phonon spectra and from the zero temperature equation of state the thermoelastic properties of fcc-Al can be calculated at high pressure and temperature.

B.1.2.13. Miscellanea

- A scientific book on asteroseismology "Linear Isentropic Oscillations of Stars. Theoretical Foundations" by P. Smeyers and T. Van Hoolst has been completed in 2010 and has been published by Springer-Verlag in December [1].
- In collaboration with colleagues from Paris, a study has been made of the rotational motion of the dwarf planet Ceres in the main asteroid belt.

B.1.3. Perspective for next years

In the next few years, the current research projects will be continued but also extended in both applications and methodologies. Tracking data to four spacecraft in orbit around Mars (MarsExpress, MGS, ODY, and MRO) will be analyzed in order to constrain (1) the interior structure and mineralogy of Mars, (2) properties of the crust and lithosphere at selected targets, (3) the CO_2 condensation and sublimation cycle of the atmosphere and polar caps, and (4) the mass and gravity field of the Martian moons Phobos and Deimos. Additional radio tracking data to the American Viking landers, Mars Pathfinder and MER rovers (Mars Exploration Rovers) will be taken into account. The use of altimeter data at ground track crossings for the determination of rotation variations of Mars and other planets and satellites will also be further studied. In order to improve the interpretation of the radio tracking data to orbiting spacecraft, the effects of relativistic corrections on the radio tracking data will be estimated. In the same effort, alternative theories of gravity will be studied.

Analysis of VenusExpress radio science (VeRa) data will be continued to estimate the density of the upper atmosphere of Venus from the atmosphere drag on the VenusExpress spacecraft.

Models of the interior structure of terrestrial planets and large natural satellites will further be developed and refined. Besides using the most recent laboratory data on planetary materials, the feasibility to calculate thermo-elastic and melting properties of core material of terrestrial planets at high pressure and temperature from quantum mechanical atomic physics will be assessed. Our modeling of planetary bodies will also be extended to bodies of smaller size, such as the Martian moon Phobos.

Theoretical and simulation studies to constrain the interior structure of terrestrial planets and large and intermediate-size rocky and icy natural satellites by rotational, tidal, gravitational, and orbital data will be continued. Besides analytical methods for the response of a fluid internal layer to gravitational forcing, the use of numerical methods will also be studied. In view of the upcoming Mercury missions, the librations of Mercury will be modeled in more detail. Strategies and numerical tools will be developed to determine the interior of Mercury and satellites from measurements of the obliquity, libration, and tides. Also the surface tectonics of Mercury will be investigated, as well as that of icy satellites.

The studies of the changes in the atmosphere of Solar System bodies like Mars, Venus, and Titan, both on short (seasonal) and long time scales will be continued, and their effects on the rotation and gravity field of the planet will further be evaluated. The model of the evolution of the Martian atmosphere will further be developed. The scientific and technical preparations for the radio science experiment LaRa of the ExoMars lander will be continued and participation in the development of new missions to the planets and satellites will be persuaded. This includes link budget studies of the radio links and modeling of the noise of the signal at the propagation effects and instrumental level.

An FP7 project will begin on the digitalization of plates and the re-analysis of spacecraft data in order to better determine the ephemerides of the moons of the solar system (Galilean moons and moons around Saturn, Uranus and Mars).

In 2011, we also expect that 5 team members will obtain their Ph.D.: R.-M. Baland, L.B.S. Pham, S. Le Maistre, A. Rivoldini, A. Trinh.

B.1.4. Personnel involved

Scientific staff: R.-M. Baland, M. Beuthe, V. Dehant, A. Hees, Ö. Karatekin, R. Laguerre, S. Le Maistre, M. Mitrovic, C. Nkono, G. Pfyffer, L.B.S. Pham, P. Rosenblatt, A. Rivoldini, A. Trinh, T. Van Hoolst, M. Yseboodt

Technical staff: L. Van Camp

B.1.5. Partnerships

List of international partners or collaborators having actively contributed to the project in the last year

- J.-E. Arlot, IMCCE, Paris, France
- G. Balmino, OMP, Toulouse, France
- J.-P. Barriot, Univ. Polynésie Française, Tahiti
- S. Bruinsma, CNES/GRGS, Toulouse, France
- J. Castillo, JPL, USA
- G. Choblet, University of Nantes, France
- F. Deleflie, Observatoire de la Côte d'Azur, Grasse, France
- A. Fienga, Institut de Mécanique Céleste et de Calcul des Ephémérides (IMCCE) / Observatoire de Besançon, Besançon, France
- W. Folkner, JPL, USA
- F. Forget, Laboratoire de Météorologie Dynamique, Paris, France
- B. Häusler, Universität der Bundeswehr Institut für Raumfahrttechnik, Munich, Germany
- J.L. Issler, CNES, Toulouse
- M. T. Jaekel, Laboratoire de Physique Théorique, Ecole Normale Supérieure, France
- A. Konopliv, JPL, USA
- V. Lainey, IMCCE, Paris, France
- B. Lamine, Laboratoire Kastler Brossel, France
- H. Lammer, Space Research Institute, Austria
- M. Lebars, IRPE, France
- S. Lebonnois, Laboratoire de Météorologie Dynamique, Paris, France
- C. Le Poncin-Lafitte, SYRTE, Observatoire de Paris, France
- P. MacNeice, Goddard Space Flight Center, Greenbelt, Maryland, USA
- J.-L. Margot, Cornell University, Ithaca NY, USA
- J.-C. Marty, OMP, Toulouse, France
- M. Menvielle, CETP, Paris, France
- A. Mocquet, University of Nantes, France
- I. Mueller-Wodarg, Imperial college of London, London, UK
- J. Noir, UCLA, USA
- J. Oberst, DLR, Berlin, Germany
- M. Pätzold, University of Cologne, Germany
- S. Peale, University of California, Santa Barbara, USA
- N. Rambaux, IMCCE, Paris, France
- S. Reynaud, Laboratoire Kastler Brossel, France
- S. Rosat, Institut de Physique du Globe de Strasbourg, Strasbourg, France
- T. Tokano, University of Cologne, Germany
- P. Vacher, University of Nantes, France
- O. Verhoeven, LPG, University of Nantes, France
- P. Vernazza, ESA/ESTEC, Noordwijk, The Netherlands
- K. Willner, Technische Universität Berlin, Germany
- P. Wolf, SYRTE, Observatoire de Paris, France

- C. Yoder, JPL, USA
- A. Zakharov, Space Research Institute (IKI), Moscow, Russia
- The MEX MaRS team, the VEX VeRa team, the BC MORE team, the BC BELA team, the NEXT SDT team, the MEMO team, and the LaRa team.

List of national partners or collaborators having actively contributed to the project in the last year

- V. Debaille, ULB
- E. Deleersnijder, UCL
- A. Füzfa. naXys, FUNDP
- E. Javaux, ULg
- A. Lemaître, FUNDP
- B. Noyelles, FUNDP
- D. Orban, B. Slade, and S. Burger, OMP (Lara Belgium Consortium)
- S. Paris, VKI
- E. Callut, V. Descamps, J.P. Halain, A. Orban, E. Renotte and L. Rossi (CSL) (Lara Belgium Consortium)
- C. Craeye and D. Vanhoenacker, TELE, UCL
- R. Meys, LIST/Dispositifs de Télécommunications, ULB
- J.-P. De Cuyper, L. Winter, and A. Zhukov, ROB

Grants/Projects used for this research/service

- PRODEX Contract: C90319, LaRa
- PRODEX: Contract: C90365, Planet Interior
- BELSPO, Action 1: Contract nr. MO/33/020, "Study of the internal structure of terrestrial planets by stochastic inversion of geophysical data"
- BELSPO, Supplementary Researcher: G. Pfyffer
- FRIA: PhD, R.M. Baland (2007-2011)
- FNRS Aspirant: A. Hees (2008-2012), L.B.S. Pham (2007-2011) and A. Trinh (2007-2011)
- FNRS/FRFC 2009-2012: 10000 €, "Rotation and internal structure of the terrestrial planets"

B.1.6. Scientific outreach

Meeting presentations

(1) Gowen R. and more than 10 authors, including Dehant V.
An update on micro-penetrators for in-situ sub-surface investigations of Ganymede and Europa
3rd EJSM workshop, ESTEC, Noordwijk, The Netherlands, 18-20 January 2010

(2) Van Hoolst T., and Bunce E.
Report and recommendations of the Jupiter system working group of EJSM
EJSM Joint Science Definition Team meeting, Monrovia, 27-29 January 2010

(3) Pfyffer G.
Libration and obliquity of Mercury from the BepiColombo radio science and camera experiments
8th BepiColombo MPO Science Working Group (SWG) , ESTEC, the Netherlands, 10 March 2010

(4) Rosenblatt P., Rivoldini A., Le Maistre S., Marty J.-C., and Dehant V.
Preliminary analysis of close flyby of Phobos by MEX on March 3rd 2010
MaRS Team Meeting, Bonn, Germany, 18-19 March 2010

(5) Rosenblatt P., Nkono C., Dehant V., and Bird M.
Quantification of plasma effects on radio signals for future high-precision geodetic experiments (LaRa)
MaRS Team Meeting, Bonn, Germany, 18-19 March 2010

(6) Rosenblatt P., Le Maistre S., Dehant V., Bruinsma S., Müller-Wodarg I. and the VExADE team
Analysis of VEX tracking data for VExADE campaign 3
VeRa Team Meeting, Bonn, Germany, 18-19 March 2010

(7) Rambaux, N., Castillo-Rogez, J. C., Williams, J.G., Karatekin Ö.
Librational Response of Enceladus to Its Interior Structure.
Lunar and Planetary Institute Science Conference, 1-5 March 2010

(8) Dehant V.
Internal structure
Mars Advance School/Workshop in Les Houches, Ecole de Physique des Houches, France, 28 March-2 April 2010

(9) Rivoldini A., Rosenblatt P., Le Maistre S., Dehant V., and Marty J.C.
Modeling of the interior structure of Phobos
ISSI workshop: "Phobos and Deimos: After Mars Express and before Phobos-Grunt", Bern, Zwitzerland, 29 March - 1 April 2010

(10) Rosenblatt P., Andert T., Pätzold M., Dehant V., Le Maistre S., Marty J.C.
About the origin of Phobos
ISSI workshop: "Phobos and Deimos: After Mars Express and before Phobos-Grunt", Bern, Zwitzerland, 29 March - 1 April 2010

(11) Rosenblatt P., Le Maistre S., Marty J.C., Dehant V.
Precise Orbit Determination of Mars Express: Application to the determination of the mass of the Martian moons
ISSI workshop: "Phobos and Deimos: After Mars Express and before Phobos-Grunt", Bern, Zwitzerland, 29 March - 1 April 2010

(12) Lainey, V., Karatekin Ö, Desmars, J., Charnoz, S.
Saturnian Tidal Dissipation from Astrometric Observations
Bulletin of the American Astronomical Society 41, 936, April 2010

(13) Karatekin Ö., Comblen R., Toubeau J., Deleersnijder E., Van Hoolst T., and Dehant V.
Tidal response of Europa's subsurface ocean
EGU General Assembly, Vienna, Austria, 2-7 May 2010

(14) Le Maistre S., Karatekin Ö., Rosenblatt P., and Dehant V.
Seasonal variations in the rotation of Mars
EGU General Assembly, Session PS 2.2, Vienna, Austria, 2-7 May 2010

(15) Pham L.B.S., Karatekin Ö., and Dehant V.
Effect of an intense meteorite bombardment period on the atmospheric evolution of Mars
EGU General Assembly, Session PS 2.2, Vienna, Austria, 2-7 May 2010

(16) Karatekin Ö., Lebonnois S.
Atmospheric angular momentum variations of Venus
EGU General Assembly, Vienna, Austria, 2-7 May 2010

(17) Karatekin Ö., Laguerre R., and Noir J.
Numerical study of librationally driven Flow in planetary interiors
EGU General Assembly, Vienna, Austria, 2-7 May 2010

(18) Trinh A. and Dehant V.
Towards an open-source tool dedicated to the representation of gravitational interaction with neighbouring celestial bodies in planetary

EGU General Assembly, Session PS2.0 on `Open Session on Terrestrial Planets´, Vienna, Austria, 2-7 May 2010

(19) Lange C., Richter L., Ho T.M, Kroemer O., Sohl F., and Karatekin Ö.
The 'Geosaucer' and beyond - 'The Future of Small Long-Lived Landing Systems for Titan'.
EGU General Assembly, Vienna, Austria, 2-7 May 2010

(20) Beuthe M.
Iapetus' ridge, the remnant of a global contraction event
FNRS Contact Group, Brussels (Planetarium), 25 May 2010

(21) Pfyffer G.
Libration and obliquity of Mercury from the BepiColombo radio science and camera experiments
FNRS Contact Group, Brussels (Planetarium), 25 May 2010

(22) Rosenblatt P., Rivoldini A., Le Maistre S., Marty J.C., and Dehant V.
Preliminary analysis of Mars Express radio-tracking data at Phobos very close flyby (acquired on March 3rd 2010)
Journée GINS, Toulouse, France, 3 June 2010

(23) Beuthe M., Le Maistre S., Rosenblatt P., Dehant V., Häusler B., and Pätzold M.
MEX-MaRS: Gravity on Target
30th MarsExpress Science Working Team, Kiruna, Sweden, 7-10 June 2010

(24) Rosenblatt P., Rivoldini A., Le Maistre S., Marty J.C., Dehant V., Pätzold M., Andert T.P., and Häusler B.
Phobos' interior and gravity field from Mars Express radio-tracking data at close flyby (closest approach at 77 km)
Mars Express 30th Science Working Team meeting, Kiruna, Sweden, 7-10 June 2010

(25) Rosenblatt P., Le Maistre S., Dehant V., Bruinsma S., Müller-Wodarg I., and the VExADE team
Estimation of Venus' atmospheric density using Venus Express tracking data Venus Atmospheric Drag meeting
ESOC, Darmstadt, Germany, 11 June 2010

(26) Karatekin Ö., Paris S., and Adam O.
Multiple Pressure measurements on a planetary atmospheric vehicle for attitude and density determination.
7th International Planetary Probe Workshop, Barcelona, 14-18 June 2010

(27) Grasset O., Blanc M., Bunce E., Clark K., Coustenis A., Dougherty M., Erd C., Greeley R., Lebreton J.-P., Pappalardo R., Prockter L., Senske D., Titov D., and the Joint Science Definition Team (including Van Hoolst T.), 2010
The Europa Jupiter System Mission: A pathfinder for future landings in the Jupiter system
7th International Planetary Probe, Barcelona, 14-18 June 2010

(28) Hees A., Wolf P., Le Poncin-Lafitte C., Füzfa A., and Dehant V.
Range And Doppler simulations in GR and in alternative theories of gravity
GPhyS Colloquium, 'Gravitation and Fundamental Physics in Space', in memory of Philippe Tourrenc, Paris, France, 22-24 June 2010

(29) Pfyffer G.
Libration and obliquity of Mercury from the BepiColombo radio science and camera experiments
BepiColombo Geodesy and Geophysics WG, Berlin, Germany, 1-2 July 2010

(30) Rivoldini A., Van Hoolst T., and Dehant V.
Expected Results on the Outer and Inner Core from the BepiColombo mission

BepiColombo Geodesy and Geophysics WG, Berlin, Germany, 1-2 July 2010

(31) Yseboodt M.
Long-period forced librations in longitude of Mercury
BepiColombo Geodesy and Geophysics WG, Berlin, Germany, 1-2 July, 2010

(32) Noir J. Calkens M., Laguerre R, and Karatekin Ö.
Dynamical response of internal fluid layer to librations
SEDI, Santa Barbara, California, July 18-23, 2010

(33) Rosenblatt P., Bruinsma S., Mueller-Wodarg I., and Häusler B.
Probing Venus' polar upper atmosphere in situ: Preliminary results of the Venus Express Atmospheric Drag Experiment (VeXADE)
COSPAR 38th scientific meeting, Bremen, Germany, July 18-25, 2010

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COSPAR 38th scientific meeting, Bremen, Germany, July 18-25, 2010

(35) Rosenblatt P., Rivoldini A., Le Maistre S., Marty J.C., Dehant V., Pätzold M., Andert T.P., and Häusler B.
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(37) Dehant V.
MarsGeO, Mars Geophysical Observatories
EPSC2010, Rome, Italy, 19-24 September 2010

(38) Dehant V., Oberst J., and Nadalini R.
Geodesy on the Moon
EPSC2010, Rome, Italy, 19-24 September 2010

(39) Pätzold M., Andert T., Rosenblatt P., Dehant V., Marty J.-C., and Le Maistre S.
The mass of Phobos from the Mars Express close flybys
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(40) Beuthe M., Rivoldini A., and Dehant V.
Influence of solar insolation and tidal dissipation on the global tectonics of Mercury
EPSC2010, Rome, Italy, 19-24 September 2010

(41) Rosenblatt P., Andert T., Pätzold M., Dehant V., Marty J.-C., and Le Maistre S.
Revisiting Phobos' origin issue from the Mars Express Radio-Science experiment data
EPSC2010, Rome, Italy, 19-24 September 2010

(42) Le Maistre S., Folkner W.M., Rosenblatt P., Rivoldini A., Dehant V., and Marty J.-C.
Mars rotation and orientation angles from direct to Earth Doppler measurements of the stationary SPIRIT rover
EPSC2010, Rome, Italy, 19-24 September 2010

(43) Rivoldini A., Beuthe M., and Van Hoolst T.
Past and present tidal dissipation in Mercury
EPSC2010, Rome, Italy, 19-24 September 2010

(44) Senske D., and the EJSM SDT team (including T. Van Hoolst)
Europa Jupiter System Mission Jovian Tour Science
EPSC2010, Rome, Italy, 19-24 September 2010

(45) Pham L.B.S., Karatekin Ö., and Dehant V.
Effect of an meteorites and asteroids bombardments on the atmospheric evolution of Mars
EPSC2010, Rome, Italy, 19-24 September 2010

(46) Lammer H., Karatekin Ö., Morschhauser A., Grott M., H. Gröller, Lichtenegger H.I.M., Terada N., Kulikov Yu. N., Shematovich V.I., Dehant V. and D. Breuer
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EPSC2010, Rome, Italy, 19-24 September 2010

(47) Rosenblatt P., Rivoldini A., and Dehant V.
Inhomegeneous mass distribution inside Phobos
EPSC2010, Rome, Italy, 19-24 September 2010

(48) Vernazza P., Cipriani F., Dukes C., Fulvio D., Howard K.T., Witasse O., Brunetto R., Strazzulla G., Binzel R.P., Bland P.A., Baragiola R., Rosenblatt P.
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(49) Rambaux, N., Castillo-Rogez, J. C., Williams, J.G., Karatekin Ö.
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(50) Hees A., Wolf P., Le Poncin-Laffite C., and Dehant V.
Relativistic effects in the Bepicolombo mission
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(51) Lainey, V., Karatekin Ö, Desmars, J., Charnoz, S.
Saturnian Tidal Dissipation from Astrometric Observations.
EPSC2010, Rome, Italy, 19-24 September 2010

(52) Yseboodt M., Dehant V., Baland R.M., Trinh A., Le Maistre S., Rosenblatt P., and Marty J.-C.
Future geodesy missions using triangular radio links between landers, orbiters, and the Earth
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(53) Yseboodt M. and Dehant V.
Long-period forced librations in longitude of Mercury
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(54) Baland R.M., Yseboodt M., Van Hoolst T., and Dehant V.
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(55) Trinh A., Dehant V., and Van Hoolst T.
Spectral representation of the gravitational and magnetic fields of neighbouring celestial bodies in planetary sciences
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(56) Karatekin Ö., Pham L.B.S., and Dehant V.
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10th European Workshop on Astrobiology (EANA'10), Pushchino, Moscow Region, Russia, 6-8 September 2010

(57) Lammer H, Karatekin Ö, Morschhauser A., Grott M., Lichtenegger H.I.M., Groller H, Kulikov, Breuer D.
Outgassing and Loss of the Martian atmosphere during the Noachian epoch.
10th European Workshop on Astrobiology (EANA'10), Pushchino, Moscow Region, Russia, 6-8 September 2010

(58) Van Hoolst T.
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Libration Workshop, ETH, Zürich, Switzerland, 30 September – 1 October 2010

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Flow field driven by librations: Numerical studies.
Libration Workshop, ETH, Zürich, Switzerland, 30 September – 1 October 2010

(60) Rambaux N., Van Hoolst T., and Karatekin O.
Librational response of Europa, Ganymede, and Callisto
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(61) Rosenblatt P., Rivoldini A., Le Maistre S., and Dehant V.
The internal structure and the origin of Phobos
The first Moscow Solar System Symposium (1M-S^3) Mars system studies, Moscow, Russia, 11-15 October 2010

(62) Rosenblatt P., Rivoldini A., Le Maistre S., and Dehant V.
The internal structure and the origin of Phobos
MaRS meeting, Boston, USA, 1st November 2010

(63) Rosenblatt P., Bruinsma S., Müller-Wodarg I., Häusler B., Svedhem H., and Marty J.C.
First ever in situ observations of Venus' polar upper atmosphere density using the tracking data of the Venus Express Atmospheric Drag Experiment (VExADE)
VeRa meeting, Boston, USA, 2 November 2010

(64) Pham L.B.S., Karatekin Ö., and Dehant V.
L'effet des impacts de comètes et d'astéroïdes sur l'évolution atmosphérique de Mars, Vénus et de la Terre
Paris, Orsay, France, Atelier « Evolutions primitives de Vénus et de la Terre », Laboratoire IDES, Université Paris-Sud, 16 November 2010

(65) Hees A., Wolf P., Le Poncin-Laffite C., Füzfa A., and Dehant V.
Relativistic effects in space mission
Journées GRAM 2010, 'Gravitation, References, Astronomie, Metrologie', Rome, Nice, 29-30 November 2010

(66) Karatekin Ö.
ROB Mars Science for NOMAD
NOMAD SWT, December 2010

(67) Baland R.-M., Van Hoolst T., Yseboodt M, and Karatekin Ö.
Titan's obliquity: an evidence for a subsurface ocean?
LAL Workshop, Dynamics of planetary satellites and rings, Lilles, France, 15 December 2010

(68) Yseboodt M.
Laplace plane and equilibrium obliquity: Application to Mercury and to natural satellites
LAL Workshop, Dynamics of planetary satellites and rings, Lilles, France, 15 December 2010

(69) Dehant V., Breuer D., Grott M., Spohn T., Lognonné Ph., Read P., Vennerstroem S., Banerdt B., and the MarsTwin team

MarsTwin: an M-mission to Mars with two geophysical laboratories
AGU Fall Meeting, San Francisco, USA, 13-17 December 2010

(70) Pfyffer G., Van Hoolst T., and Dehant V.
Librations and obliquity of Mercury from the BepiColombo laser altimetry, radio science and camera experiments
AGU Fall Meeting, San Francisco, USA, 13-17 December 2010

(71) Karatekin Ö., Comblen R. , Deleersnijder E., and Dehant V.
Tidal response of Europa's subsurface Ocean
AGU Fall Meeting, San Francisco, USA, 13-17 December 2010

Seminars

(1) Baland R.-M.
The obliquity of Europa and Titan
ROB, 15 January 2010

(2) Van Hoolst T.
A planetary geodesy approach to investigate global internal liquid layers in planets and satellites
Invited seminar at the Institute of Astronomy, K.U.Leuven, 22 January 2010

(3) Van Hoolst T.
Global internal liquid layers in planets and satellites
Invited departemental seminar, Department of Physics and Astronomy, K.U.Leuven, 24 February 2010

(4) Dehant V.
What can we learn about Mars' interior from radioscience?
Invited seminar, Technical University of Delft, Delft, The Netherlands, 26 February 2010

(5) Dehant V.
What can we learn about Mars' interior from radioscience?
Invited seminary at ESTEC, Noordwijk, The Netherlands, 18 June 2010.

(6) Van Hoolst T.
Planetary sciences at ROB
Seminar at the annual meeting of the operational direction 'Reference Systems and Planetology', 22 June 2010

(7) Dehant V.
Habitability of the red planet Mars
Conference at the SCKCEN, Mol, 26 November 2010

Wikis and Websites

- Web sites for LaRa ftp drop documents
- Web sites for PRODEX PlanetInterior ftp drop documents
- Web sites for ESPACE ftp drop documents
- Web site of OD 1

Brochures

- Flyer on the work done at ROB and IASB concerning Mars (prepared for the Exhibition ‘Destination Mars’
- Press map entitled ‘Study of the moons of Mars, Phobos and Deimos, at the Royal Observatory of Belgium under the Mars Express Mission’, in English, French and Dutch, 10 pages each
- Update of the Press maps on LaRa and MarsExpress

B.1.7. Missions

Assemblies, symposia:

R.-M. Baland (European Planetary Science Congress, Rings and satellites Workshop)
M. Beuthe (FNRS contact group meeting, European Planetary Science Congress)
V. Dehant (Mars Workshop, EGU, Munk Workshop, Journées Systèmes de Référence, Workshop, European Planetary Science Congress, AGU)
A. Hees (Workshop on Relativistic Positioning Systems: from a paradigm shift to practical applications, GPhys workshop, GPhys Colloquium, European Planetary Science Congress, Journées 2010 de l'Action Spécifique "Gravitation, Références, Astronomie, Métrologie)
Ö. Karatekin (Alliance workshop, EGU, IPPW, EANA, European Planetary Science Congress, Libration Workshop, Atelier "Evolutions primitives de Vénus et de la Terre", AGU)
S. Le Maistre (Journées Systèmes de Référence, European Planetary Science Congress)
G. Pfyffer (BepiColombo Science Working Group, FNRS Contact Group, BepiColombo Geodesy/Geophysics Workshop, AGU)
L.B.S. Pham (EGU, European Planetary Science Congress, Atelier "Evolutions primitives de Vénus et de la Terre")
A. Rivoldini (BepiColombo Geodesy/Geophysics Workshop, European Planetary Science Congress)
P. Rosenblatt (COSPAR, European Planetary Science Congress, 1st Solar System Symposium)
T. Van Hoolst (EJSM Science Meeting, FNRS contact group meeting, ISSI workshop: "Phobos and Deimos. After Mars Express and before Phobos-Grunt", BepiColombo Geodesy/Geophysics Workshop, European Planetary Science Congress, Libration Workshop, 'New Views on Earth Interior', Rings and satellites Workshop)
M. Yseboodt (BepiColombo Geodesy/Geophysics Workshop, European Planetary Science Congress, 'New Views on Earth Interior', Rings and satellites Workshop)

Commissions, working groups (days):
M. Beuthe (3 days)
V. Dehant (25 days)
S. Le Maistre (2 days)
P. Rosenblatt (11 days)
T. Van Hoolst (9 days)

Research visits (days):
V. Dehant (4 days)
A. Hees (40 days)
Ö. Karatekin (13 days)
M. Mitrovic (1 day)
P. Rosenblatt (7 days)
A. Rivoldini (1 day)
T. Van Hoolst (6 day)
M. Yseboodt (3 days)

Field missions (days):
V. Dehant (6 days)

B.2. Earth Rotation

B.2.1. Objectives

Long-term objectives: to understand and model the Earth rotation and orientation variations, i.e., length-of-day, precession, nutations, librations, and polar motion; to understand the associated physics of the Earth's interior and the interaction between the 'solid' Earth and the geophysical fluids.

B.2.2. Progress and results

B.2.2.1. Book on 'Precession, Nutation, and Wobble of the Earth'

- V. Dehant has done many efforts for finalizing her book on 'Precession, Nutations, and Wobbles of the Earth'. The book should be submitted in summer 2011.

B.2.2.2. VLBI and GNSS

- The present Earth nutation model is based on adjustments of geophysical parameters on Very Long Baseline Interferometry (VLBI) observations. In order to improve the model it is thus necessary to improve the parameter determination from observation by combining VLBI and GNSS (Global Navigation Satellite System) data. The main objective of this work is to develop and implement a strategy of normal equation (Neq) combination derived from GPS/VLBI observation processing and aimed to produce a consistent time series of nutation offsets. Such a time series expected to be more consistent (w.r.t. reference frames) and more accurate than nutation offsets estimated from VLBI data only. The so-obtained new nutation series can be used to determine the geophysical parameters involving Earth interior properties, which will then allow to better understand the internal structure of the Earth. In 2010, the work on the combination between GNSS and VLBI has advanced and a strategy has been found for the combination of VLBI and GNSS and for the processing these data in order to obtain a better accuracy and a better consistency of the nutation series. Furthermore, the GNSS determination of Earth orientation parameters. At present, the procedure is implemented and a comparison of the obtained results with IERS C04 time series has been performed. The comparison shows rather good agreement between ROB combined estimation for polar motion and the values from IERS C04. For UT1-UTC and nutation offsets the correspondence is worse. There are mainly two reasons for this: (1) in the procedure of "propagating" the functional values starting from VLBI estimations, further estimations of UT1-UTC and nutation offsets are drifting away due to systematic errors in orbits modeling, and (2) nutation values given by IERS C04 are interpolated values and thus do not suit very well for comparison purposes. Due to the latter reason, it's necessary to compare ROB results with the results of an independent combination procedure (for example, a combination campaign of Paris Observatory).

B.2.2.3. Topographic coupling at the CMB and nutations

- Nutations are influenced by the deep interior of the Earth and in particular by phenomena happening at the core-mantle boundary (CMB); V. Dehant, in collaboration with Marta Folgueira, has computed the pressure torque on the topography at the core-mantle boundary. This torque can be decomposed into three parts: (1) the constant part of the torque at equilibrium (without additional mantle and core rotations; this part is not interesting in the context), (2) the torque due to the inertial rotation pressure (related to the non-Poincare part of the fluid on the topography, and (3) the torque due to the inertial rotation pressure on the topography related to the Poincare part of the fluid. The two last parts of the total torque involve the coefficients of the development of the topography in harmonics. Only these two last parts are of importance when computing the effects of a perturbing potential and related additional rotations for the core and the mantle.
- The philosophy of the computation follows Wu and Wahr (1997, GJI 128, 18) and consist in introducing a scalar function in the Navier-Stokes equation and in separating it into two equations of which the solutions can be computed analytically. With the choice for one of the velocity field to be the Poincare fluid, both parts of the velocity field are incompressible. The boundary conditions at the CMB are imposed on the total velocity and yield thus an additional important relation involving the analytical expressions of the velocity fields and the topography coefficients. This allows solving for the velocity field coefficients in terms of the topography coefficients.
- V. Dehant and M. Folgueira have found that there are particular topography coefficients that are enhanced due to the cross-coupling between different spherical harmonics. This is very important as

the total torque is thus shown to be dependent on the geometry and on particular amplitudes of the topography. This was previously shown with an example in Wu and Wahr, but here they show that this is not an artifact from the choice of the topography but rather a general fact.

- Other coupling mechanisms at the core-mantle boundary have been examined in collaboration with Laurence Koot [38] and with Chengli Huang.

B.2.2.4. GNSS standard for applications

- In collaboration with Jean-Luc Issler, a New Worldwide Multimodal SBAS Standard compatible with all the existing and planned regional GNSS systems (and their evolutions) in the world, like IRNSS, QZSS, PCW, BEIDOU-1, WAAS, EGNOS, SDCM, GAGAN, MSAS. The proposed worldwide multimodal U-SBAS standard carries additional channels (signals and messages) to cover the non-aeronautical specific Safety-of-Life (SoL) services, and also High Precision Positioning Services (HPPS), Position Velocity Time (PVT), authentication services, safety services, scientific application services, High Precision Timing Services (HPTS), etc. U-SBAS is designed to be fully interoperable with the current SBAS standards and to allow significant performance and service improvements in operational, scientific and/or security areas. It becomes indeed imperative to guarantee for all GNSS users the compatibility, interoperability and interchangeability between all these systems. The goal is to ensure that the user's multi-mode receiver can choose and mix signals from different GNSS and SBAS systems to achieve more availability, accuracy, and robustness. Attaining that objective will require agreements on frequency plans and signal designs, as well as other details including means to ensure interoperability of system times and geodetic reference systems.

B.2.3. Perspective for next years

- M. Kudryashova, V. Dehant, and C. Bruyninx will finish and publish the nutation evaluation from combined VLBI data and GNSS data. This work will be done in the frame of an Action 1 project.
- M. Folgueira and V. Dehant will finish and publish the evaluation of the topographic coupling mechanism at the core-mantle boundary.
- L. Koot, back from her Post-Doc position in Canada, will work on the electromagnetic and viscous coupling mechanisms at the core interfaces.
- V. Dehant, in collaboration with P.M. Mathews, shall finish her book on "Precession, nutation, and wobble of the Earth". This book will be published by Cambridge University Press.

B.2.4. Partnerships

List of international collaborators having actively contributed to the project in the last year

- Sébastien Lambert, Christian Bizouard, and Nicola Capitaine (Observatoire de Paris),
- Jean-Luc Issler (CNES, Toulouse),
- Marta Folgueira (Madrid University, Spain),
- Sonny P.M. Mathews (Madras University),
- Olivier de Viron (Institut de Physique du Globe de Paris).

Grant(s)/Project(s) used for this research/service

- Belspo Action 1 M0/33/023 Determination and modeling of nutation from VLBI (Very Long Baseline Interferometry) and GNSS (Global Navigation Satellite System) observations, PIs: V. Dehant and C. Bruyninx, staff: Maria Kudryashova.

Visitors:

- Nicole Capitaine (SYRTE, Paris), 24-25 March, Lemaître Prize,
- Christian Bizouard (SYRTE, Paris), 22-25 June, work on excitation of polar motion by earthquakes
- Olivier de Viron (IPGP), 9 July, work on angular momentum,

- Folgueira Marta, Universidad Complutense de Madrid, 5-10 November, Effect of CMB topography on nutations

B.2.5. Scientific outreach

Meeting presentations

(1) Kudryashova M., Lambert S., Dehant V., and Bruyninx C.
Nutation offsets obtained by combining VLBI/GPS-produced normal equations
EGU General Assembly, Vienna, Austria, 2-7 May 2010.

(2) Dehant V.
Geophysics controlling Earth's rotation
Crafoord symposium in geosciences, organized by the Royal Swedish academy of Sciences, Stockholm, Sweden, 10 May 2010.

(3) Dehant V., Oberst J., and Nadalini R.
Geodesy instrument package on the Moon for improving our knowledge of the Moon and the realization of Reference Frames
Journées Systèmes de Référence spatio-temporels, Paris, 20-21 September 2010.

(4) Kudryashova M., Lambert S., Dehant V., and Bruyninx C.
Determination of nutation offsets by combining VLBI/GPS-produced normal equations
Journées Systèmes de Référence spatio-temporels, Paris, France, 20-22 Sept., 2010 (poster).

(5) Issler J.-L., Tawk Y., Jovanovic A., Botteron C., Farine P-A., Landry R.Jr., Sahmoudi M., and Dehant V.
U-SBAS (Universal SBAS): A New Worldwide Multimodal SBAS Standard
ION GNSS 2010 conference, session `GNSS Space Based Augmentation Systems (SBAS)´, Portland, Oregon, 21-24 September 2010.

(6) Botteron C., Issler J.-L., Tawk Y., Jovanovic A., Farine P.-A., Landry R.Jr., Sahmoudi M., Dehant V., Caporali A., and Reboul S.
Universal-SBAS: A complete worldwide mutimodal standard
Fifth meeting of the International Committee on GNSS IGC-5 meeting, Turin, Italy, 18-22 October, 2010.

(7) Issler J.-L., Tawk Y., Jovanovic A., Botteron C., Farine P.-A., Landry R.Jr., Sahmoudi M., and Dehant V.
U-SBAS (Universal SBAS): A New Worldwide Multimodal SBAS Standard
Navitec workshop, 'Navitec 2010 and European Workshop on GNSS Signals and Signal Processing', ESTEC, The Netherlands, 8-10 December 2010.

B.2.6. Missions

Assemblies, symposia, conferences:

- EGU, Vienna, Austria, 3-7 May
- Munk Workshop, Stockholm, Sweden, 9-10 May
- Journées Systèmes de référence spatio-temporels, Paris, France, 20-21 September
- REFAG, Paris, France, 7 October
- AGU, San Francisco, USA, 12-18 December

Commissions, working groups:

- CNBA, Brussels, 19 January, 25 May
- Lemaître Prize, UCL, Louvain-la-Neuve, 24-25 March

- ESAC, Frascatti, Italy, 10-12 May
- CPS of CNES, Toulouse, France, 8-11 June, 30 November
- Galileo WG, Redu, 24 June
- Working group on combination, Munich, Germany, 9-10 December

Thesis:

- Defense PhD Thesis of L. Seoane, Paris, 25 January
- Defense PhD Thesis of E. Pottiaux, Louvain-la-Neuve, 23 April, 7 June
- Defense PhD Thesis of Zhu Ping, Louvain-la-Neuve, 28 May

Seismology - gravimetry

Introduction

The scientific activities of the Operational Directorate seismology-gravimetry are mainly related to the study of the seismic activity and their consequences in northwest continental intraplate Europe and to the understanding of its causes.

In order to support our scientific research and expertise and to provide pertinent information to the public and the authorities, we develop different operational projects with the purpose of:

- Monitoring the seismic activity in Belgium and surrounding regions by analysing the data from the Belgian seismic and accelerometric stations, developing and maintaining these networks;
- Developing the ways to provide fast and reliable information to the authorities and the public when an earthquake is felt or occurred in Belgium;
- Providing our measured seismic phases for worldwide seismic events and waveform data from specific well-calibrated stations to the seismological international centers (EMSC, ORFEUS, IRIS and ISC);
- Providing the scientists in other institutions, the public, the administration and the private companies in Belgium with a scientific and technical expertise in earthquake seismology.

Other scientific activities of the section are devoted to conduct and analyse gravity measurements at the Earth surface and also to analyse data from space experiments, mainly GRACE. Gravity measurements supply information on geographical structural heterogeneities in the underground and on geodynamical processes and their time evolution. An important part of this scientific work is devoted to evaluate crustal deformation using its imprint on the gravity signal. For this purpose, the section is in charge of the scientific and technical follow-up of the superconducting gravimeter installed in the Membach station, of an absolute gravimeter and several field relative gravimeters.

The Directorate has also the responsibility of the GIANT and LISSA projects that provide scientific analysis of the permanent seismic and geodetic measurements, and annual absolute gravity measurements that have been undertaken at the « Princess Elisabeth » base in Antarctica.

We undertook in 2010 investigations in volcano-seismology with the purpose improving the monitoring of two volcanoes in Indonesia.

C. Seismology, seismic hazards and risks, and earthquake monitoring

C.1. Project « Seismology, seismic hazards and risks »

C.1.1. Objectives

Seismic activity in Western Europe

The Royal Observatory of Belgium is conducting different research activities on the seismic activity in western Europe.The data collected by the Belgian seismic network allow us to evaluate precisely the location, the magnitude and the focal mechanism of present earthquakes in western Europe. The earthquakes recorded by this modern network, progressively implanted since 1985, form a list of events covering a very short time period compared to the duration of the mechanical processes generating large earthquakes on active faults. Thus, to have a correct image of the seismic activity, it is necessary to enlarge our information as far as possible in time and hence to investigate historical documents to retrieve earthquakes of the past. The known earthquake history of Western Europe north of the Alps begins around 750 A.D. Until the XIVth century, the scarce historical sources allow the elaboration of a list of the strongest earthquakes, but few can be reliably assessed in terms of magnitude and location. Since the middle of the XIVth century, the number of different sources (chronicles, annotations, diaries, parish registers, account registers, etc.) has increased significantly. These give more details on local effects and allow more reliable estimation of damage and felt areas of the earthquakes. It is possible to determine their probable epicentral area and also to estimate their magnitude by comparison with recent earthquakes for which the magnitude was instrumentally determined.

Paleoseismology and active faults in continental intraplate regions

As most large earthquakes provoke visible surface deformation, it is possible to retrieve the traces of past large earthquakes by their fingerprint in the morphology and the geologic records. This is the objective of paleoseismology. In continental intraplate Europe, active faults remain largely unidentified and the potential for large earthquakes unknown. To evaluate this potential, the problems to solve are different from those encountered in seismically active zones. Identifying active faults is a difficult problem mainly because their morphological expression is often not clear due to the low level of deformation, the climatic regime and the strong anthropic activity. On the other hand, the interpretation of deformations and their dating are very complex due to the long duration of the seismic cycle which produces overlap between tectonic and climatic events.

Seismic hazards and risks

To provide the decision makers (engineers, urban planners…) with usable information to prevent the worst consequences of future earthquakes, scientists introduced the concept of seismic hazard of a region or a site. It defines the characteristics of the strong ground motions to consider in the design of buildings, taking into account their lifetime and their societal importance (private houses, public administrations, hospitals, schools, power plants…).
Adequate preventive action requires studying the vulnerability of the buildings. It defines their sensitivity to the strong ground motions caused by earthquakes. The vulnerability concept includes the importance of the buildings in terms of costs, but also in terms of unsubstantial value or threat to human lives. The seismic risk, linked to the impact on buildings, defines the damage costs of a future earthquake in a given construction. The stakes concern also the impact in terms of human lives, number of injuries, economical costs due to the activity interruption or perturbation, social costs of homeless,…

During the recent years, we developed methodologies to evaluate local seismic hazard in Belgium, basically by introducing site effects evaluation by the combination of experimental techniques with 1-D numerical modeling. In cooperation with the Department of Architecture of the Polytechnic Faculty of Mons, we began also vulnerability and seismic risk studies.

LISSA

The section will also install in 2010 a seismic broadband station in the « Princess Elisabeth » Belgian base in Antarctica. That station will allow to monitor the seismic activity in Antarctica, in the framework of international seismological cooperation, and to study the properties of the lithosphere at proximity of the base.

Volcano-sismology in Indonesia

In cooperation with the “Département des Sciences de la Terre et de l’Environnement” of the Brussels University (ULB), we undertook a study to discriminate the seismic precursors for phreatic and magmatic eruptions on two volcanoes in Indonesia.

The first one is the “Kawah Ijen”, which is a plinian stratovolcano. This volcano is located in the eastern part of Java Island. It represents one of the most dangerous volcanos among the 69 active in Indonesia. It hosts a crater lake which is the largest acidic lake in the world. Many people live and work (exploiting the sulfur inside the crater) around the volcano. Kawah Ijen is frequently active. If this Crater Lake would be drained off the crater, it would be a human and economical disaster.

The second volcano is the “Papandayan”, which is also a stratovolcano (7°32′ S, 107°73′ E, 2665 masl) located in West Java, Indonesia, approximately 160 km southeast of the capital Jakarta and 20 km southwest of nearest district Garut.

The project concerns also the improvement of the monitoring capabilities of the activity of those two volcanoes.

C.1.2. Progress and results

C.1.2.1. Seismic activity in northwest Europe

Seismic activity by instrumental measurements

(1) The seismic activity in Ardenne since 1985 has been relocated using modern relative location techniques in order to improve the earthquake locations and study their spatial distribution throughout the Ardenne. The structural importance of the Hockai Fault Zone (HFZ) has been evidenced. This zone is supposed to be responsible for the 18 September 1692 "Verviers" earthquake and its estimated magnitude 6 ¼ makes it the largest historical earthquake northwest of the Alps (Alexandre, 2008). The HFZ is a NNW-SSE trending zone that limits two zones. The zone at the West of the HFZ knows earthquakes down to about 25 km, the zone at the East towards the Eifel knows events down to 20 km while the HFZ itself is characterized by shallower events, down to 9 km maximum. Southeast of the HFZ, earthquakes under Manderfeld occur at very large depths, to about 29 km deep. We refute the hypothesis that the Midi Fault now absorbs most of the current deformation of the region. We show that the seismic activity does not concentrate on the Midi Fault and that it is even crossed by active structures, from the surface down to 10 km deep for example in the region of Charleroi, or that the activity concentrates under the fault in the vicinity of Rötgen in Germany.

(2) We continued the study of the earthquake sequence that strucked the Brabant province since July 2008 and lasted up to 2010. A methodology allowing automatic analysis of the whole set of recordings from the mobile seismic stations installed in the region of Court-Saint-Etienne since August 2008 has been developed and helped to identify the very small earthquakes of the sequence that have not been identified by the Belgian seismic permanent stations. We also conducted preliminary tests on automatic cross-correlation of the seismic traces to determine more precise phase relative arrival time measurements that will allow us to obtain more precise earthquake relative locations.

ROB earthquake catalogue

(1) The study undertaken in 2009 concerning the earthquakes that occurred in Western Europe from 1900 to 1940 has been continued. For this purpose, we continue to collect all the available information from European seismic stations with the purpose of better evaluate the earthquake magnitude and location. We also introduced intensity data for the events that have been felt during this period. Therefore, all the earthquakes reported in the ROB catalogue will be referenced with the original information that proved their occurrence, location and magnitude.

(2) Since 1985, the ROB earthquake catalogue is progressively purged of the fake earthquakes which came from the traditional worthless compilations of historical seismicity. On the other hand, several earthquakes unknown until now were added in the list, many dates were corrected, new epicentral areas were suggested and new epicentral intensities were estimated.

Historical earthquakes

(1) The improvement of the general earthquake catalogue of the ROB was made possible by the improvement of our documentary basis. During the year 2010, several research missions were carried out in different libraries or archives, with the aim of finding new data on the effects of past earthquakes, either in old manuscripts or in old printed books. The gathered reading notes or photocopies were classified in the documentary catalogue of the seismology, according to the rules of historical criticism. Only texts coming from original sources (or second-hand sources coming from lost original sources) were retained in our basis documentation. On the other hand a part of the material already gathered during the previous years, particularly in the period 1985-1997, was reclassified during the year 2010.

(2) The study on the major earthquake of 23 February 1828 is now carried out, as far as the synthesis of the gathered documentary material is concerned; this paper will be submitted to an international journal. Concerning the other earthquakes occurred in the Belgian area during the 19th century, a special attention was paid to the events which were also felt in the Netherlands: thanks to the collaboration with the KNMI (Bernard Dost), Dutch documents (mainly from newspapers) were exchanged for Belgian documents concerning these cross-border earthquakes. The material from Belgian newspapers and other written sources of the 19th century was systematically gathered. Moreover a specific study was initiated about an other shock in the year 1828, occurred on December 3 (epicentre in Aachen area), whose the effects in Belgium were until now underestimated (possible mix-up in some sources with the event of February 23).

(3) In the frame of the EC FP7- SHARE project, various scientific institutes, one of whom the R.O.B., are elaborating a new Consensus European Earthquake Catalogue (CEEC), from the year 1000 A.D. The name of the documentary electronic basis of this catalogue is "AHEAD" (Archive of Historical Earthquake Data). We have been involved in this project for our expertise in the methodological problems raised by the use of medieval sources to study the long-term seismic activity in Europe.

C.1.2.2. Paleoseismology and active faults in intraplate continental regions

Database of seismogenic sources in Western and central Europe

In the frame of the EC project SHARE (“Seismic Hazard Harmonization in Europe”), ROB participates in Task 2 (“European database of active faults and seismogenic sources”) of WP3 (“Earthquake sources and activity rates)”. In this task, ROB coordinates the collection of regional data for Central and Western Europe. In 2010, we carried out the collection of regional data and preparation for entry in the database.

The Roer Valley graben

In the framework of the SHARE project, we have devised a seismic-source model for the RVRS, consisting of composite (i.e., unsegmented) seismic sources. We distinguish 15 seismic sources based on major stepovers, bifurcations, intersections, gaps, and important changes in strike, dip direction or slip rate. In our concept, each composite seismic source may encompass one or more segments, but it is unlikely that a segment would extend across more than one source. The sources are further subdivided into one or more informal fault sections, each with an associated surface trace. For each source, we describe the limits and the composing fault sections, and present the geological arguments for them. We have compiled all relevant data concerning the seismic-source parameters required for the database, putting lower and upper bounds on strike, dip, rake, slip rate, and seismogenic depth, and an upper bound on earthquake magnitude (Mmax). The total length of all seismic sources is ~600 km. The longest sources are the Peelrand fault and the Viersen fault, which are ~105 km long. The Erft/Swist fault (~55 km) is thought to correspond to the longest possible length of fault that could rupture in one earthquake. Slip rates are below 0.1 mm/yr. The fastest slipping fault is the Peelrand fault.

This source model provides a solid and fully documented basis for more detailed, fault-based seismic hazard assessment, and diverse modeling exercises, e.g. concerning seismic activity, crustal deformation, stress transfer and fault interaction. It also serves as a guide for further paleoseismic studies, showing where more studies are needed to better determine seismogenic parameters. A manuscript describing the model is prepared, to be submitted early 2011.

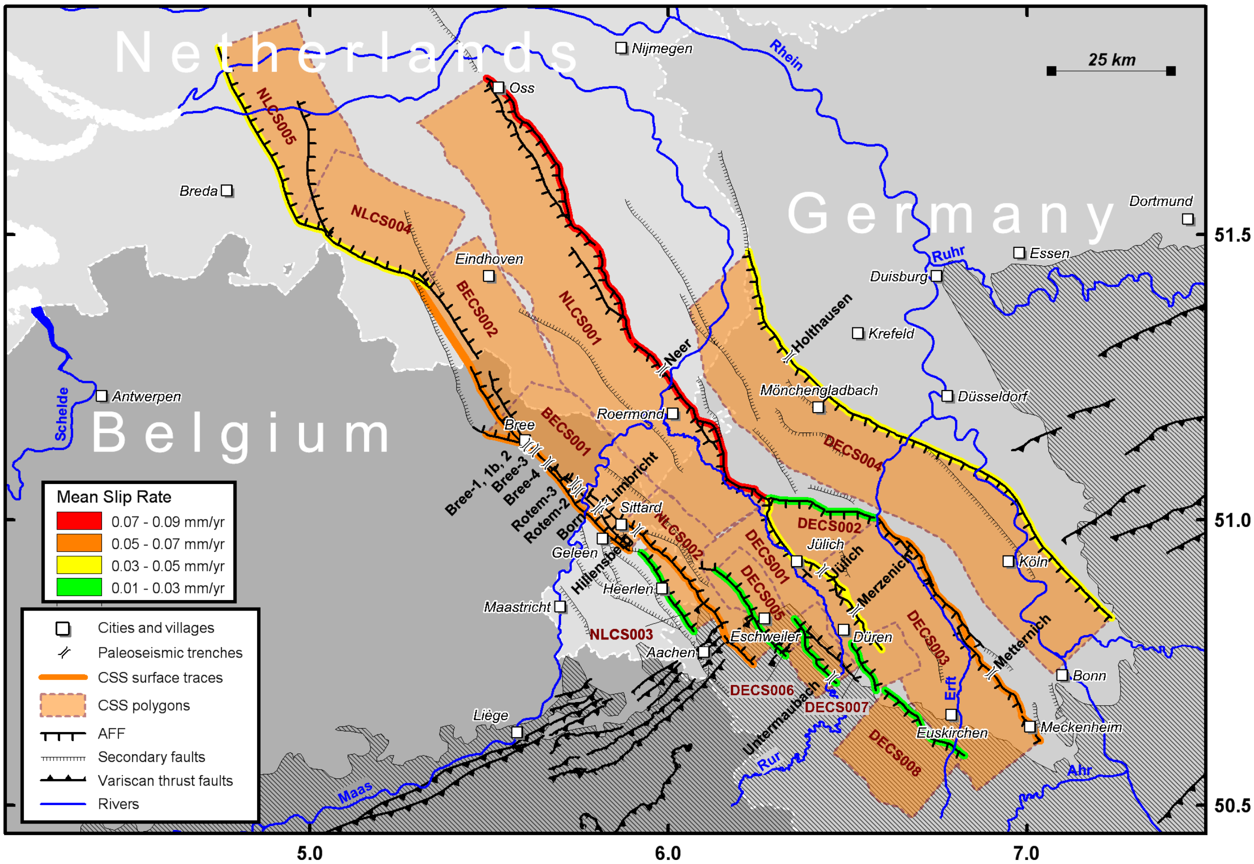

Figure 19: Model of seismic sources in the Roer Valley Rift System. The surface traces are colored according to their slip rate.

<u>The Hockay fault zone</u>

We demonstrated the important role of the Hockai Fault Zone (HFZ) in the structural and thus seismotectonic framework of the region. This zone is also supposed to be the source region of the 1692 M 6 ¼ "Verviers" earthquake. Although it currently knows a moderate seismic activity, no faults are clearly visible and followable, unlike faults in the Roer Valley Graben for example. The search for faults in the field is thus very important to try to identify and characterize them. We first summarized about 15 years of individual geophysical research conducted in the region and we then continued the prospection started in 2008 in the vicinity of Hockai to identify faults on field. We then combined the analysis of the new large dataset of about 10 km of electrical resistivity tomography profiles, 125 gravimetric and 168 H/V ambient noise measurements acquired on a WSW-ENE profile crossing the HFZ on the Vecquée Crest. This work allowed us to identify structures linked either with the stratigraphy or with supposed faults. At least 3 zones show sufficient evidences of a fault structure and to determine its orientation. This was the first large scale geophysical profile to be done in this region. The structures could all be linked with a seismic swarm that occured in 1989-1990 just south of the Vecquée Crest.

The Artois faults and their prolongation in the Strait of Dover

(1) In April 2010, we conducted a geophysical survey in the English Channel on board R/V Belgica, and in cooperation with the Renard Centre of Marine Geology (RCMG) of the University of Gent. The marine survey covered an area of ~150 km² off the coast of Sangatte, and its objective was to look for evidence of recent activity of the Sangatte fault, such as displacement of young sediments or tectonic seafloor morphology. The Sangatte fault may have been the source of the large historical earthquake in the English Channel in 1580, with an estimated magnitude of M_S=6.0. We deployed the onboard multibeam echosounder to obtain an image of the seafloor morphology, and RCMG's single-channel seismic reflection equipment to obtain an image of subsurface layers down to a depth of 50 to 75 m. The multibeam and seismic-reflection data from the English Channel should be interpreted, and linked with our onshore observations in 2011.

(2) We continued the investigation in the vicinity of Vimy, close to Arras in the North of France. We acquired new data on the supposed surface trace of the Marqueffle fault in order to map and characterize it. We identified some interesting variation of the material present at relatively shallow depths, from cretaceous to clay and loessy terrains.

C.1.2.3. Seismic hazards and risks

Probabilistic seismic-hazard assessment for the near-surface facility for low- and intermediate-level radioactive waste in Dessel, Belgium

The study for the National Institute for Radioactive Waste and Fissile Materials (NIRAS/ONDRAF) concerns an analysis of the design seismic loading of the facility that will be constructed in Dessel for the storage of category-A radioactive waste. This study started in 2008, and consists of two main parts: (1) probabilistic seismic-hazard assessment (PSHA) to determine the bedrock response spectrum, and (2) modeling the seismic transfer function of the sediment cover at the site. The bedrock response spectrum and the transfer function are then convolved to obtain the surface response spectrum, which is used by engineers to design the structure; this part of the study is carried out by Tractebel. Most of the PSHA analysis was conducted in the past two years, although we continued to work on the final report. In 2010, we concentrated our efforts on the determination of the transfer function. In a first step, we conducted linear elastic modeling using information (layer thickness and shear-wave velocity) from two nearby boreholes, and using the program Transfer1D developed by our former colleague Philippe Rosset. To take into account uncertainties on layer parameters, a Monte Carlo approach was used with 100 simulations, and the 84^{th} percentile of the magnitudes of the transfer function was calculated. Because the next step of the analysis requires the full complex form of the transfer function, we reconstructed the corresponding phase using the Hilbert transform, which assumes that the system is minimum phase. We compared our results with two other modeling programs (EERA and Strata), and we also ran an equivalent-linear analysis, which takes into account nonlinear behavior of soils under cyclic loading conditions.

Evaluation of spectral acceleration during the 1983 Liège earthquake based on the existing data on the damages

We constrained a first estimation of the geographical distribution of damage and spectral accelerations at local (St. Nicolas, Liège and Flemalle districts) and regional scales for the 1983 Liège Earthquake using HAZUS fragility curves for unreinforced masonry. We compare them with the spectral accelerations expected for those locations according to the classical attenuation laws used to assess seismic hazard in Western Europe.

C.1.2.4. LISSA

The main progress of the project in 2010 relies on the installation of various instruments at the PE base during the expedition BELARE 2009-2010. These instruments are installed near or within the scientific shelter at approximately 350 m north of the PE base (Figure 2).

We installed a borehole seismometer 10 m away from the shelter in a 13 cm wide, 13 m deep hole drilled by IPF in the granite rock the year before. The borehole seismometer was then successfully installed on February 22 after an inconclusive (due to problems of seismometer itself) first tentative on February 17. As for every permanent seismic station worldwide, an official station code was given. It is ELIB.

Figure 20: Location of the PE base and the northern scientific shelter and equipments

Until March 31, the GPS and seismometer instruments performed normally with the exception of March 10 and the period of March 22 to 26 for which the GPS and seismometer instruments were off probably because of power outage at the PE base. From March 31 and until the December 8, the PE base and all the equipments were off due to a power outage of the whole electrical system. This implies more than 8 month of data gap as well as a long-term power cut-off of the instruments, which could have been damaging for the instrument electronics. The instruments being off for 8 month, we discussed a procedure with International Polar Fundation (responsible for the Princess Elisabeth base working) describing the most appropriate way to turn the instruments back on when the first team will be back in November 2010. On December 2010, the power of our instruments was turned on again and all instruments started again without any damage. Since then the instruments are properly running and data are collected every day via the satellite connection.

Despite the large data gaps, the seismometer ELIB succeeded to record major global teleseismic earthquakes. Most of them are aftershocks from the great Mw=8.8 Chile earthquake, which was one of the first recorded events at the station. The closest earthquakes are located near the South Sandwhich islands region (South Atlantic, 2500 km away from ELIB) while the farthest are located near Kamshatka (North Pacific, 18000 km away from ELIB) and represent near anti-podal event that will be used to analyse seismic core phases.

C.1.2.5. Volcano-sismology in Indonesia

Continuous monitoringof the Kawah Ijen volcano

Three broadband seismometers, temperature/leveling divers and a meterological station have been installed since May 2010 on the Kawah Ijen volcano (Figure 3). Internet connection has been installed in Kawah Ijen observatory in order to download data from Belgium.

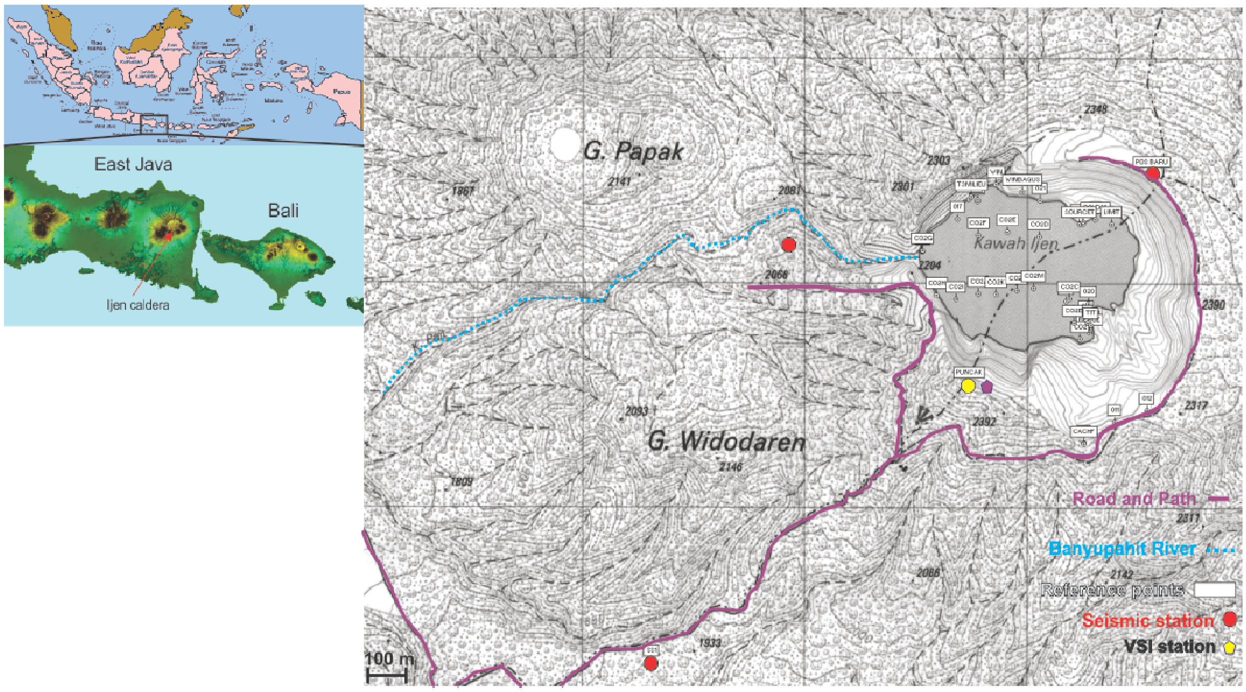

Figure 21:general geographical context and localization of seismic stations

Our analysis of the first 6 months of recording allows inferring an interesting correlation between seismic amplitude (in 1-8 Hz band) and lake temperature. Crater lake temperature fluctuations reflect the subsurface volcanic activity. Therefore, the continuous amplitude calculation in 1-8 Hz seismic band could be of valuable tool in a perspective of monitoring as it is easily achieved even with short period telemetered seismometers located 2-3 km far from the active crater. The use of an anemometer and a rain gauge further improves the discrimination between volcanic and environmental processes.

Non continuous monitoring

A degassing and bathymetric map of Kawah Ijen crater lake has been defined by echosounding the lake. It portrays that mainly the centre part of the lake floor is degassing. CO_2 measurements revealed an extremely important concentration of this specie in surface waters. A similar survey has been realized on a less acidic volcanic lake (Taal volcano, Philippines). Apart from providing the first degassing map of that lake to the local authorities, it gave us a better understanding of CO_2 behavior. Due to its insolubility in magma, this gas could be a new interesting parameter to monitor a volcano.

A H/V seismic survey was carried out during three weeks in October 2010. This constitutes a Master Thesis aimed to better constrain site effects and refine the velocity model of Kawah Ijen volcano. The study of anthropogenic activity on seismic data acquisition has also been focused through the use of ratiograms.

C.1.3. Perspective for next years

In 2011, the different projects will be continued, part of them in the framework of the FP7-EC project SHARE and the project for NIRAS/ONDRAF.

C.1.4. Personnel involved

Scientific staff:
P. Alexandre (responsible of the historical seismicity studies)
T. Camelbeeck (responsible of the section)
C. Caudron (PhD, action 2: contract WI/33/J02)
F. Collin (responsible contacts with the public)
D. Garcia Moreno (active faults studies, replacement contract)
E. Knuts (historical seismicity, "supplementary researcher" contract)
D. Kusters (seismicity variability)
T. Lecocq (Phd, FRIA FC 76908)
D. Lombardi (LISSA and GIANT, Science Policy contract)
D. Syahbana (Phd, ULB financial support)
K. Vanneste (active faults and main researcher NIRAS project)
K. Verbeeck (seismic investigation for NIRAS, CCHO: 2007-4177/00/00)

C.1.5. Partnerships

List of international partners or collaborators having actively contributed to the project in the last year

- Klaus Hinzen, University of Cologne (Germany)
- Bernard Dost, Netherlands Meteorological Institute (The Netherlands)
- Seth Stein, Northwestern University (U.S.A.)
- Roger Musson, British Geological Survey (United Kingdom)
- Michel Sébrier et Françoise Bergerat, University Pierre and Marie Curie (Paris)
- Jean-Pierre Colbeaux, Scientific council of the regional parks of the North of France
- David Beaumont, Oona Scotti, Hervé Jomard, Marc Cushing and Stéphane Baize, Institut de Radio-protection et de Sûreté Nucléaire (France)
- Olivier Francis, Tonie van Dam and Gilbert Klein (University of Luxemburg)
- Marlena Yaneva and Alexander Radulov, Geological Institute, Bulgarian Academy of Sciences
- Olivier Bellier (CEREGE, Aix-en-Provence)
- Massimiliano Stucchi and Paola Albini, Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Milano.
- Jérôme Lambert, Bureau de Recherches Géologiques et Minières, Orléans.
- Gottfried Grünthal, GeoForschungsZentrum, Potsdam.
- Jochen Wöessner, Nicolas Deichmann and Iris Marschall, Swiss Seismological Service / ETH. Zurich, Switzerland.
- Denis Jongmans (LGIT, Grenoble)
- Dr. Kurt Decker, Department for Geodynamics and Sedimentology, Viena University, Austria.
- Dr. Thierry Winter, BRGM, Natural Risk Service, France
- Gianluca Valensise and Roberto Basili (INGV Roma)

List of national partners or collaborators having actively contributed to the project in the last year

- A. Plumier and Hervé Degée, Liège University, ARGENCO
- A. Sabbe, Faculté Polytechnique de Mons, Architecture dept
- Alain Cerise (Military direction of the Brabant province)
- Johan Berte, Alain Hubert and Nighat Amin Johnson (IPF)
- Alain Bernard (Université Libre de Bruxelles)
- Jozef Van Dyck, K.U.Leuven, Departement Burgerlijke Bouwkunde
- Geert Degrande and Mattias Schevenels, K.U.Leuven, Departement Burgerlijke Bouwkunde
- Prof. Wim Haegeman, Universiteit Gent, Vakgroep Civiele Techniek
- Michiel Dusar and Walter De Vos, Belgische Geologische Dienst, KBIN
- Sara Vandycke, Université de Mons

- Laurent Wouters and Wim Cool, NIRAS/ONDRAF
- Alain Van Cottem and Richir Thomas, Tractebel
- Marc De Batist; Wim Versteeg, Rindert Janssens and Mathias Baeye, University of Gent
- Claude de Moreau de Gerbehaye and M. Baptiste, Archives Générales du Royaume / Rijksarchief.
- Christian Dury, Archivist, Archives de l'Évêché de Liège.

Grants/Projects used for this research/service

- BELSPO grant EA/33/2A
- Grant nr. 226967 from EC-Research Framework Programme FP7, SHARE
- Contract CCHO: 2007-4177/00/00 with NIRAS/ONDRAF
- Grant FRIA FC 76908
- Grant Action 2 contract WI/33/J02

Visitors:

- Alain Sabbe (Mons University), on 22 July 2010
- Dr. Roberto Basili, Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Sismologia e Tettonofisica (Italy). 19th - 22th January 2010. SHARE Workshop plus two-day-training on the software applications to create the European database.
- Dr. Gianluca Valensise, Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Sismologia e Tettonofisica (Italy). SHARE Workshop, 19th - 20th January 2010.
- Dr. Vanja Kastelic, Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Sismologia e Tettonofisica (Italy). SHARE Workshop, 19th - 22th January 2010.
- Prof. Dr. Jochen Wöessner, Swiss Seismological Service / ETHZ. SHARE Workshop, 19th - 20th January 2010.
- Dr. Kurt Decker, Department for Geodynamics and Sedimentology, University of Viena (Austria). SHARE Workshop, 19th - 20th January 2010.
- Prof. Dr. Michel Sebrier, Institut des Sciences de la Terre de Paris (France). SHARE Workshop, 19th - 20th January 2010.
- Dr. Stephane Baize, Institut de Radioprotection et de Sûreté Nucléaire (France). SHARE Workshop, 19th - 20th January 2010.
- Dr. Femke Goutbeek, Koninklijk Nederlands Meteorologisch Instituut (The Netherlands). SHARE Workshop, 19th - 20th January 2010.
- Prof. Dr. Klaus Hinzen, Universität zu köln (Germany). SHARE Workshop, 19th - 20th January 2010.
- Lenhardt Wolfgang, Department of Geophysics, Central Institute for Meteorology and Geodynamics (Austria). SHARE Workshop, 19th - 20th January 2010.
- Dr. Alexander Radulov, Geological Institute, Bulgarian Academy of Sciences (Bulgaria). SHARE Workshop, 19th - 20th January 2010.
- Dr. Marlena Yaneva, Geological Institute, Bulgarian Academy of Sciences (Bulgaria). SHARE Workshop, 19th - 20th January 2010.

C.1.6. Scientific outreach

Meeting presentations

(1) Pierre Alexandre
Les mandements épiscopaux liégeois comme source de l'histoire du climat et des séismes.
Colloque "Les mandements des princes-évêques de Liège", Liège, May 28, 2010.

(2) Thierry Camelbeeck, Thomas Lecocq, Kris Vanneste, Koen Verbeeck, Michel Van Camp
The seismic activity near Brussels since July 2008
ESC 32nd General Assy, Montpellier, France (September 2010)

(3) Thierry Camelbeeck, Elisabeth Knuts, Alain Sabbe, Pierre Alexandre

The Earthquake of February 23, 1828 in Central Belgium: New Historical Data and Damages in the Architectural Inheritance.
European Seismological Commission, 32nd General Assembly, Montpellier, September 6-10, 2010.

(4) García Moreno, D., Camelbeeck, T., Vanneste, K. & Verbeeck, K.
Preliminary work in the framework of SHARE on the seismogenic sources in Western and Central Europe.
SHARE WP3.2 Western and Central Europe meeting – Royal Observatory of Belgium, 19 and 20 January 2010.

(5) García Moreno, D., Camelbeeck, T., Vanneste, K. & Verbeeck, K.
Progress and preliminary results of the database of composite seismogenic sources for Western and Central Europe.
March 16th -17th, 2010 Workshop for the Work Package 3 (WP3) of the project SHARE. University of Athens, Greece.

(6) Basili R., Garcia Moreno D., Kastelic V., Nemser E., Petricca P., Sboras S. & Valensise G.
Developing seismogenic source models based on geologic fault data in the Euro-Mediterranean area: SHARE mission accomplished?
32nd General Assembly of the European Seismological Commission (ESC), 6 – 10 September 2010, Montpellier.

(7) Vanneste, K., Verbeeck, K., García Moreno, D. & Camelbeeck, T.
A database of seismic sources for the Roer Valley Rift system.
32nd General Assembly of the European Seismological Commission (ESC), 6 – 10 September 2010, Montpellier.

(8) Thomas Lecocq, Thierry Camelbeeck, Klaus-G. Hinzen, Bernad Dost
Earthquake relocation in intraplate context
ESC 32nd General Assy, Montpellier, France (September 2010)

(9) Thomas Lecocq, Corentin Caudron
The Future of Relocation Tools
AGU Fall Meeting, San Francisco, USA (December 2010)

(10) Lombardi D., Aerts, W. Bergeot N., Bruyninx C., Camelbeeck T., Francis O., Klein G., Rapagnani G., Van Camp M. and Van Dam T
Installation and preliminary data analysis of a permanent geodetic and seismic station at the new Belgian Princess Elisabeth base in East-Antarctica.
Belgium Antarctic Symposium, Brussels, May 2010

(11) Lombardi D., Aerts, W. Bergeot N., Bruyninx C., Camelbeeck T., Francis O., Klein G., Rapagnani G., Van Camp M. and Van Dam T.
A permanent geodetic and seismic station at the new Belgian Princess Elisabeth base in East-Antarctica: installation and preliminary data analysis
International Polar Year conference, Oslo, June 2010

(12) Michel Van Camp, Olivier de Viron, Thomas Lecocq, Klaus-G. Hinzen, Yves Quinif, Simon D. Williams, Thierry Camelbeeck
Tectonic, Climatic and Anthropogenic Vertical Land Movement in Western Europe by Repeated Absolute Gravity Measurements
AGU Fall Meeting, San Francisco, USA (December 2010)

(13) Kris Vanneste
Recent coseismic deformation recorded in near-surface sediments along active faults: Some examples from paleoseismic trenching in Belgium

Conference « Tectonics and Structural Geology in Belgium », Paleis der Academieën, Brussels, 14 May 2010

(14) Kris Vanneste, Koen Verbeeck, David Garcia Moreno & Thierry Camelbeeck
A database of seismic sources for the Roer Valley Rift System
European Seismological Commission 32nd General Assembly, Montpellier, France, 6-10 September 2010

(15) Koen Verbeeck, Kris Vanneste, Thierry Camelbeeck, Toon Petermans, Laurent Wouters, Alain Van Cotthem, Thomas Richir.
Experimental vs. Theoretical baserock to surface transfer functions at Dessel, Belgium.
European Seismological Commission 32nd General Assembly, September 6-10, Montpellier, France (2010), (Poster presentation).

Seminars

(1) Lombardi D.
Présentation de la mission de terrain GIANT-LISSA 2009-2010 à la nouvelle station Antarctique Princess Elisabeth
Royal Observatory of Belgium, Brussels, April 2010

(2) Lombardi D.
Geodetic and seismological research at the Princess Elisabeth base, Queen Maud Land, Antarctica, GIANT-LISSA Field Report 2009-2010
University of Luxembourg, Luxembourg, April 2010

(3) Lombardi D.
Geodetic and seismological research initiative at the new Princess Elisabeth base, Queen Maud Land, Antarctica
IPGP, Paris, April 2010

(4) Lombardi D.
Geodetic and seismological research at the Princess Elisabeth base, Queen Maud Land, Antarctica
IPGS, Strasbourg, May 2010

(5) Lombardi D.
The LISSA project: seismological research at the Princess Elisabeth base, East-Antarctica, during the BELARE expedition 2009-2010
ETH, Zurich, July 2010

(6) García Moreno, D.
Progress and preliminary results of the database of composite seismogenic sources for Western and Central Europe.
March 18th, 2010 at the Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Sismologia e Tettonofisica, Rome, Italy.

(7) Kris Vanneste, Koen Verbeeck & Thierry Camelbeeck
Active faults in the Roer Valley Graben: Towards a segment model
SHARE Workshop, Royal Observatory of Belgium, Brussels, 19-20 January 2010

C.1.7. Missions

Assemblies, symposia:

T. Camelbeeck

- BESEIG-meeting in Liège on 26 January 2010
- Meeting of the Rhine-Maas Seismology group in Bensberg on 23 March 2010
- BELQUA workshop in Brussels on 2 March 2010

- European Union of Geosciences in Vienna from 4 to 5 may 2010
- BESEIG-meeting at the ROB on 10 May 2010
- Meeting “Géorisques” in Liège on 8 June 2010
- SHARE-project meeting and general assembly in Roma, 14-16 June 2010
- European Seismological Commission General Assembly in Montpellier, 5-10 September 2010
- BESEIG-meeting in UCL (Louvain-la-Neuve) on 19 October 2010

D. Garcia Moreno

- SHARE WP3.2 Western and Central Europe meeting – Royal Observatory of Belgium, 19 and 20 January 2010.
- March 16th -17th, 2010 Workshop for the Work Package 3 (WP3) of the project SHARE. University of Athens, Greece.
- Submarine Paleoseismology: The Off-shore Search of Large Holocene Earthquakes. Universitätszentrum Obergurgl, Obergurgl, Austria 11-16 September 2010

T. Lecocq

- ESC 32nd General Assy, Montpellier, France (September 2010) : 1 week
- AGU Fall Meeting, San Francisco, USA (December 2010) : 1 week
- Rhine-Meuse-Seismologists Meeting : 1 day

D. Lombardi

- Belgium Antarctic Symposium, Brussels, May 2010
- International Polar Year conference, Oslo, June 2010

K. Vanneste

- SHARE Workshop, Royal Observatory of Belgium, Brussels, 19-20 January 2010
- Conference « Tectonics and Structural Geology in Belgium », Paleis der Academieën, Brussels, 14 May 2010
- European Seismological Commission 32nd General Assembly, Montpellier, France, 6-10 September 2010

Koen Verbeeck

- SHARE Workshop, Royal Observatory of Belgium, Brussels, 19-20 January
- European Seismological Commission, General Assembly, Montpellier, France, 6-9 September

Commissions, working groups (days):	T. Camelbeeck (18 days) K. Vanneste (6 days) K. Verbeeck (8 days)
Research visits (days):	T. Camelbeeck (1 day) D. Garcia Moreno (3 days) K. Verbeeck (2 days)
Field missions (days):	P. Alexandre (25 days) T. Camelbeeck (1 day) E. Knuts (66 days) D. Garcia Moreno (10 days) T. Lecocq (13 days) D. Lombardi (60 days) K. Vanneste (7 days) K. Verbeeck (14 days)

C.2. Seismic monitoring

C.2.1. Objectives

We installed, maintain and analyse the data from the seismic and accelerometric Belgian networks.

C.2.1.1. The Belgian seismic monitoring network

The Belgian seismic network, with 24 permanent stations, is mainly dedicated to the monitoring and the scientific study of the seismic activity in Belgium. The ROB is managing 3 stations in Grand-Duchy of Luxemburg (in cooperation with the European Center for Geodynamics and Seismology) and one station in The Netherlands (in cooperation with the Netherlands Meteorological Institute). Earthquakes worldwide with magnitude greater than 4.5 – 5.0 are recorded by the Belgian seismic network. The measurements on these recordings are sent in routine to the International Centres (EMSC and ISC) where the data from the stations worldwide are analyzed to furnish a global catalogue of earthquakes and phase arrival time models. We provide also real-time seismic signals from some Belgian stations to the ORFEUS and IRIS centres.

C.2.1.2. The Belgian accelerometric network

The accelerometric network was installed to complement the seismic network by furnishing reliable data when strong ground motions saturate traditional seismometers. It is an important tool for the professionals in the field of earthquake engineering and engineering seismology.

C.2.1.3. The earthquake database of the Royal Observatory of Belgium – web site

In 2002, an impulse was given to develop a seismological database as a tool to monitor the well-functioning of the Belgian seismic stations and of their quality control, to facilitate the search of information on the seismic activity in Belgium and northwest Europe and to control the seismic phase measurements realized routinely for the earthquakes recorded by the Belgian seismic network and their sending to the international centres. The database is developed on our intranet, but part of the information is accessible on our web site. Another objective is to develop a web site containing up to date information on earthquake seismology, on the seismic activity in northwest Europe and on the scientific activities of the section seismology.

C.2.1.4. The superconducting and spring relative, and the absolute FG5 gravimeters

The section maintains and analyses the data from the AG absolute gravimeter FG5 and the SG superconducting gravimeter in Membach and by conducting gravimetric measurements with spring gravimeters.

Since 1997 the SG of Membach participates in the Global Geodynamics Project SG data base and since 2005, in the IRIS seismic data base to promote SGs among seismologists.

C.2.2. Progress and results

C.2.2.1. The Belgian seismic monitoring network

<u>The modernization of the permanent seismic station</u>

- In <u>Uccle</u>, a new borehole seismometer was installed late February. Unfortunately the seismometer was damaged by a lightning mid-July. In <u>Dessel</u>, mid-June, the borehole seismometer was pulled off the borehole and sent back to factory for repair. The horizontal component had broken. It was installed back in the borehole mid-October. In <u>Couthuin</u> and <u>Bracquegnies</u>, the 16-bit stations were replaced with 24-bit stations. As no wired internet connection is possible in those locations, the possibility to have a wireless internet connection is under investigation and will probably be deployed in 2011. In <u>Oostende</u>, beginning of the year, a new seismometer was installed in the borehole.In <u>Maredsous</u>, the 16-bit station with removable hard-drive was replaced with a 24-bit station and connected to internet. A new station was started in Court-Saint-Etiennne. The station is composed of a broadband seismometer and is connected to internet in order to get the data remotely. In the following stations, the computer was replaced after brokerage: Rochefort, Membach, Gesves.

- Some stations have no wired access to internet. We investigated the possibility to connect those stations through UMTS/3G network. We tried a system that was not satisfactory. In 2011 we will continue to investigate for a suitable system.
- The development of a SeedLink plugin for our 24-bit own made acquisition system started. The purpose is to have all the stations streaming their records directly to the SeisComP3 server and thus minimise the delay between the creation of the data by the stations and the analysis of this data by SeisComP3.
- New products were studied in order to improve existing stations or keep pace with technology advances: Symmetric Research USB-based 24-bit digitizer; Meinberg USB-based DCF77 radio clock device; Devolo Power Line Communications (PLC) device; Geotech Instruments borehole seismometer for possible installation in Opitter station.

Seismic alert system

During 2010, we continued the research and developpement of the B-FEARS alert system and its link with SeisComP3. We organized a workshop dedicated in sharing experience among SeisComP3 users. Since March 2010, the Royal Observatory of Belgium and the Seismology Section of the University of Cologne (Germany) share the same macroseismic inquiry. Pratically, visitors clicking the link "Haben Sie ein Erdbeben gespürt" on the Bensberg website land on the ROB website. Each formular is thus inserted inside the same database. Moreover, the visitors coming through this link are also taken into account in the detection procedure. Once a new earthquake has been implemented in the database, the macroseismic inquiry is automatically opened; maps are drawn every 5 minutes, and then sent to the ROB and the BNS websites.

Mobile seismic stations

The development of a mobile station based on a 24 bit digitizer has ended up and finally all the old mobile stations were migrated to the new system. A dedicated workstation was installed and we wrote a set of software tools for easily transferring the data from the removable media to the data server. Operating manuals were written in the Wiki for the operators in charge of transferring the data.

C.2.2.2. The Belgian accelerometric network

The network is working correctly and checked thoroughly at the ORB once a week (Mol is checked twice a week). Due to construction works in the “pavillon” the UCCA accelerometer was moved from the pavillon to the “Grand-Mères” (old clocks) basement, early in January 2010. The BREA accelerometer was moved to the municipal library of Bree in 2010.

C.2.2.3. The earthquake database of the ROB – web site

- An efficient method to keep tracks and share information about the modification brought to the equipments and the measuring sites has been implemented through the introduction of such information in the section wiki. The wiki was set up in 2008 and it has thoroughly been used this year to store all kind of information about the new internet-connected stations. As the wiki is only readable by registered persons, the information get not disclosed to unwanted persons. It is expected to give a course to the technical staff about the usage of the wiki and the kind of information that need to be filled in.
- This year has seen the achievement of a long-time-ago started duty: the transfer of several software from out-of-warranty servers to newly purchased one. To achieve this goal, the rewriting of the softwares related to the remote retrieval of the seismic data has been completed and early 2009 the software has been installed on an old server (seissrv1). Then, late 2009, this server has been replaced by a brand new one (seissrv4). All the softwares have been migrated from the old to the new machine

i.e our current data storage and automatic data processing server. In the same wave, our old application server (poseidon) has been replaced by a new one (seissrv3) and all the softwares migrated to the new machine.

C.2.2.4. The superconducting and spring relative, and the absolute FG5 gravimeters

Membach

A new barometer was installed on December 22, given the observed drift of the existing one (0.55 hPa/year i.e. 8.3 hPa since the installation of the superconducting gravimeter in August 1995) and the numerous grounding problems diagnozed during fall 2008. The old barometer will be declared obsolete in 2011, after comparing it with the new one.

Metrology

Transfer function of the superconducting gravimeter

The transfer function of the SG C021 was compared to two other SGs in Pecny (Czech Republik) and Walferdange (Luxembourg). The phase responses of the SGs show difference up to 10% for the DC values.

Comparison of gravimeters: Field work

O. Francis (U Luxembourg) compared his FG5#216 to our FG5#202 at the Membach station on 2010-11-16, before leaving for Antarctica. Spring gravimeters were tested at the Membach station in February 2010.

Comparison of gravimeters: Data processing

With O. de Viron (IPGP) and O. Francis (U. Luxembourg) we have studied both from the mathematical point of view and from the synthetic cases what should be a good method to compare absolute gravimeters.

Geophysics

The CG5 gravimeter was used for geophysical prospecting across the Vecquée fault (supporting research project of Thomas Lecocq) and to measure the vertical gravity gradient in Saint-Amand-les-Eaux.

C.2.3. Perspective for next years

C.2.3.1. The Belgian seismic monitoring network

Since the dismounting of the stations in Wibrin, Meuville and Robertville during the last ten years, there is a lack of seismic stations to monitor the seismic activity in the southeastern part of Belgium. We intend to install 4 to 5 mobile stations in this region during a few months and after to definitively keep two or three of the equipped sites to install new permanent seismic stations.

C.2.3.2. The Belgian accelerometric network

We intend to open more easily the data from the network and also to discuss the possibility to cooperate more closely with the French accelerometric network (RAP).

C.2.3.3. The earthquake database of the seismology ROB – web site

We intend to develop more deeply the static part of our web site by introducing sections on basic seismology for the public and more detailed information on our scientific activities.

The data base will be completed by the results on the earthquakes that occurred from 1800 to 1950.

C.2.3.4. The superconducting and spring relative, and the absolute FG5 gravimeters

- As the absolute determination of the gravity is essential in geophysics and metrology, new intercomparison campaigns will take place (in Walferdange: regional intercomparison campaign in November 2011).

- The data acquisition system developed by the section of Seismology is now compatible with Seedlink. We plan to test it on the SG-C021, in order to compare the results with the Q330 data logger.
- We will make a comprehensive comparison of the old and new barometer at Membach.
- Continue to develop Tsoft and provide information on Earth tides to the public.

C.2.4. Personnel involved

Scientific staff:
T. Camelbeeck (project leader)
F. Collin
T. Lecocq (Phd, FRIA FC 76908)
D. Lombardi (LISSA and GIANT, Science Policy contract)
K. Vanneste
M. Van Camp (responsible of the accelerometric network)

Technical staff:
B. Bukasa (seismic stations maintenance)
S. Castelein (accelerometric stations maintenance and AG-measurements)
F. Devos (web development and database configuration)
E. Driegelinck (teleseismic events measurement)
M. Hendrickx (Membach station monitoring, SG-routine analysis and information to the public)
H. Martin (management of the server network of the section seismology)
G. Rapagnani (seismic stations and associated data management and alert system development)
W. Vandeputte (teleseismic events measurement)
L. Vandercoilden (daily routine monitoring and information to the public)

C.2.5. Partnerships

List of international partners or collaborators having actively contributed to the project in the last year

- Güralp Systems Ltd, Reading, UK
- Kinemetrics, USA
- Symmetric Research, USA
- GWR instruments, USA
- Dr T. Ahern, R. Benson (IRIS, USA)
- Dr. J. Steim (Quanterra, USA)
- Dr. R. Sleeman (ORFEUS-KNMI, the Netherlands)
- Dr. H. Wilmes and Dr. H. Wziontek (Bundesampt für Kartographie und Geodäsie, Germany)
- Prof. O. Francis (U. Luxembourg (GD Luxembourg))
- Dr. J. Gottsmann (U. Bristol, UK)
- Dr. Philippe Richard and Dr Henri Bauman (METAS, Switzerland)
- Dr. S. Williams (Proudman Oceanographic Laboratory, UK)

List of national partners collaborators having actively contributed to the project in the last year

- Wim Minnebo, Earth Explorer

C.2.6. Scientific outreach

Meeting presentations

(1) Lecocq, T., Rapagnani, G., Martin, H., Devos, F., Hendrickx, M., Van Camp, M. Vanneste, K., and Camelbeeck, T.

B-FEARS-Belgian Felt Earthquake Alert and Report System
ESC 2010 General Assembly, Montpellier, 6-10 September 2010.

(2) Collin, F., Vanneste, K., Van Camp, M., Verbeeck, K., Rapagnani, G., Martin, H., Devos, F., Bukasa, B., Lecocq, T., and Camelbeeck, T.
The National Belgian Monitoring Seismic network
ESC 2010 General Assembly (Poster), Montpellier, 6-10 September 2010.

C.2.7. Missions

Field missions (days): G. Rapagnani (9 days)
S. Castelein (16 days)
M. Van Camp (3 days)
F. Collin (13 days)
H. Martin (20 days)
M. Hendrickx (6 days)
B. Frederick (3 days)

D. Gravimetry and present-day deformation of the lithosphere

D.1. Deformations of the lithosphere in northwest Europe caused by climatic loading and tectonic strains

D.1.1. Objectives

In northwest Europe, to explain the apparent contradictions between the present day deformations measured by geodetic techniques and those inferred from the study of the seismic activity, in-situ strains, the geologic and geomorphic quaternary investigations, it is paramount to investigate the relative contributions of the tectonic forces and of the climatic loading (e.g. glacial isostatic adjustment (GIA)).

Our goals are:

1. To perform repeated absolute gravity (AG) measurements along a profile in the Ardenne and Germany. AG is an essential technique when investigating vertical motions: in terms of accuracy, the role of AG is becoming critical, as a geodetic technique independent of the International Terrestrial Reference Frame (ITRF). Although much work has been undertaken to improve the precision of vertical crustal motions from CGPS, the absolute accuracy of these is currently still limited by the accuracy of the ITRF, which is~2 $mmyr^{-1}$ in the vertical. This limitation stems from difficulties in the accurate determination of the geocentre of the ITRF and its long-term motion with respect to the centre of mass of the Earth system. Using the AG measurements should allow us to correct for a bias affecting vertical station velocities estimated by current GPS results. This is paramount to ensure reliable long-term measurements of vertical land movements;
2. To better understand the relationship between present-day deformations and the observed ones in the karst morphology in the Walloon caves. For that purpose strain measurements in the Rochefort cave are essential to understand the local deformation rates and to relate them with the regional scale;
3. To model and correct the hydrological effects on geodetic and geophysics measurements.

D.1.2. Progress and results

D.1.2.1.Absolute gravity measurements

<u>Repeated absolute gravity measurements in Belgium, Germany and France</u>

Repeated absolute gravity (AG) measurements have been performed in Oostende (Belgian coastline) and at 8 stations along a southwest-northeast profile across the Belgian Ardennes and the Roer Valley Graben (Germany), in order to estimate the tectonic deformations in the area.

After 8-15 years (depending on the station), all stations but Jülich show that the gravity rates of change must belong to the [-3.1, 8.1] $nm/s^2/yr$ interval. At all stations but Jülich, the results agree, within the error bars, with the subsidence predicted by the Glacial Isostatic Adjustment. At 4 stations in the profile (Bensberg, Monschau, Membach and Sprimont) and in Oostende, the gravity rates of change do not significantly differ from zero. Significant increases lying in the 0.2-8.1 $nm/s^2/yr$ interval are found in the three southernmost stations Manhay, Werpin and Sohier. For Jülich see section “Hydrogeodesy”.

After correcting for the GIA effect, the inferred gravity rates and consequently the vertical land movements, reduce to zero within the uncertainty level at all stations except Jülich and Sohier.

The velocities as a function of longitude and latitude may indicate a possible shoulder uplift in response to rifting in the Roer Graben, but the possible gravity rates of change, ranging [-3.5, 7.6] $nm/s^2/yr$ (2σ), are still not precise enough to support this hypothesis. Anthropogenic uplift or volcanism may also bias the results in Monschau, Membach and Bensberg, masking the GIA effect, but this cannot be resolved at this time. By measuring for some one more decade we should be able to separate contributions from these different sources and to resolve the GIA effect.

These results are currently being published.

Concurrently, in the framework of collaboration with the "Parc Naturel Régional Scarpe-Escaut", repeated AG measurements were undertaken in 2009.

Characterizing long time scale hydrological effects on gravity for improved distinction of tectonic signals

The influence of the hydrological effects on repeated gravity measurements has been investigated, based on the time series of 18 superconducting gravimeters and on predictions inferred from the Land Dynamics (LaD) world-Gascoyne land water-energy balances model. Presently, the global hydrologic models are not precise enough to fulfill the geodetic requirements and are not efficient to separate the hydrology from tectonic motion in the land-based gravity time series. However, although the LaD model predictions and the gravity observations present significant differences in the time domain, it is shown that they have similar amplitudes in the frequency domain in most of the cases. The time series of the Global Geodynamics Project (GGP) make it possible to investigate phenomena of a few years in the best case. Given the similarity between the power spectral densities (PSDs) of the LaD model predictions and the SG measurements when taken at the same epoch, it makes sense to use the LaD model to study the spectral behavior of the hydrological effects down to the decadal time scale, which is not yet possible with land-based measurements. We showed that the PSDs of the hydrological effects flattens at low frequency and is characterized by a generalized Gauss-Markov structure. With such a noise, the time necessary to measure a gravity rate of change of 1 $nm/s^2/a$, at the one sigma level, should not extend any longer than 17 years at the locations where the hydrological effects play a major role. These results have been published.

D.1.2.2.Rochefort geophysical laboratory:

In cooperation with Sara Vandycke (UMons) and Yves Quinif (UMons), we continue analysing and interpreting more than ten years of extensometric measurements on the fault in the Rochefort cave. These measurements at the fault "Fontaine-Bagdad", which presents the most significant displacement in the karstic morphology of the order of 0.3 m, evidences continuous relative movements of 0.04 mm/year and 0.01 mm/year respectively in the fault dip direction and in the strike direction. They suggest that the geological displacement could have been continuous. Hence, if this is the case, the total displacement could have occurred since the end of the last glacial period. The microtectonic analysis from the recent striated faults suggests that the maximal principal horizontal stress direction is oriented N030°E. It is similar to the post last glacial period compressive stress resulting from the Glacial Isostatic Adjustment in this part of Europe, but it is perpendicular to the direction derived in Western Europe from earthquake fault plane solutions. We provide evidence that the fault movements cannot be caused by gravity due to the surface topography or to the vacuum in the cave. We propose the hypothesis that these fault slips are an expression of the deformation of the lithosphere due to the compressive strain acting since the end of the last Glacial period in the peripheral bulge of the flexure resulting from the unloading of the large ice sheet in Fennoscandia.

D.1.3. Perspective for next years

D.1.3.1.Repeated AG measurements:

The repeated AG measurements in Oostende and St-Amand-les-Eaux are a long-term project. We plan to continue the profile once a year; within the 10 next years, we should be able to constrain any possible long-term trend with accuracy better than 1 $nm/s^2/yr$ ($\Leftrightarrow$ 0.5 mm/yr).

Intraplate deformations linked to active tectonic structures such as the Roer Valley Graben or to the GIA around the peripheral bulge remain close to or below the accuracy of current geodetic techniques. Identifying them is further complicated by anthropogenic effects in the vicinity of the Roer Valley Graben. In the future, other investigations such that InSAR, PSInSAR and densifying CGPS stations, aligned with the ongoing AG measurements, should provide a clearer picture of the anthropogenic influences, and further allow the investigation of latitude dependence of GIA and/or the influence of the rifting in the Roer Graben.

Together with the IPGP, we also plan to use climate models in order to simulate the influence of possible climate changes on the long term gravity measurements.

D.1.4. Partnership

List of international partners without grant

AG measurements in Jülich and Bensberg:

- Prof. K.-G. Hinzen (U. of Cologne)
- Dr E. Pomplun, Dr. E. Kümmerle and M. Möllmann-Coers (Forschungszentrum Jülich)
- Dr Juliet Biggs, U. Bristol

AG/SG measurements:

- Prof. O. Francis (U. Luxembourg)

COST, Glacial Isostatic adjustment, repeated AG measurements.

- Dr S.D.P. Williams (Proudman Oceanographic Laboratory, UK)
- Dr. M. King (U. Newcastle)
- Dr. J. Mäkinen, Finnish Geodetic institute

Hydrological effects on gravity measurements:

- Dr. J. Mäkinen, Finnish Geodetic institute
- Dr O. de Viron (IPGP, Paris)
- Dr L. Métivier (IGN France)
- Prof. B. Meurers (U. Vienna)
- Dr W. Zürn, Dr. T. Forbrigger, Dr. R. Widmer (BFO, U. Karlsruhe, U. Stuttgart)
- Prof. J. Chery, Prof. R. Bayer, Prof. H. Jourde (U. Montpellier)

List of national partners without grant

Hydrological effects on gravity measurements:

- Prof. M. Vanclooster & P. Defourny (UCL)
- Prof. V. Hallet (FNDP, Namur)
- Prof. Y. Quinif, Dr O. Kaufmann (FPMS Mons)
- Dr P. Meus (DGRNE, Division de l'Eau, MET)
- Ir Luc Funken NNN
- Ir J. Verstraeten (Afdeling Waterwegen Kust, Oostende)

D.1.5. Scientific outreach

Meeting presentations

(1) Van Camp, M., de Viron, O., Lecocq, T., Hinzen, K.G., Quinif, Y., Williams, S.D., Camelbeeck, T.
Tectonic, Climatic and Anthropogenic Vertical Land Movements in Western Europe by Repeated Absolute Gravity Measurements
AGU Fall meeting (Poster), San Francisco, USA, December 13-17, 2010.

(2) Van Camp, M., de Viron, O., Lecocq, T., Hinzen, K.-G., Quinif, Y., Williams, S., Camelbeeck, T.
Tectonic, Climatic and Anthropogenic effect in Western Europe by Repeated Absolute Gravity Measurements
IGCP 565 Workshop 3: Separating Hydrological and Tectonic Signals in Geodetic Observations, Reno, Nevada, October 11-13, 2010.

D.1.6. Missions

Assemblies, symposia, conferences:

M. Van Camp

- EGU assembly, Vienna, AT, 3-5 May 2010.
- IGCP Reno, USA, 11-13 October 2010.
- AGU Fall meeting, San Francisco, USA, 12-18 December 2010.

Commissions, working groups (days):	M. Van Camp (3 days)
	T. Camelbeeck (2 days)
Research visits (days):	T. Camelbeeck (1 day)
Field missions (days):	M. Van Camp (34 days)
	B. Frederick (3 days)
	M. Hendrickx (6 days)
	S. Castelein (28 days)

D.2. GIANT: Geodesy for Ice in ANTarctica

D.2.1. Objectives

The U. Luxemburg and the ROB propose an experiment to utilize contemporary geodetic techniques to provide information on the ice mass balance of the Antarctic Ice sheet, in the vicinity of the Princess Elizabeth station. This experiment will provide information that can be used to convert the satellite altimetric data into mass balance information.

The huge mass of glaciers deforms the Earth's crust. This is the case of the Antarctic continent, which is deforming slowly due to large amounts of ice melting at the end of the last ice age, 10.000 years ago. On the other hand, there is a faster deformation caused by variations of current glaciers, caused by global warming. To separate these two components of the deformation, it is necessary to combine measurements of surface deformation from GPS data with measurements of gravity variations using an absolute gravimeter. This is the aim of the GIANT project (Geodesy for Ice in Antarctica), lead by the ROB and the University of Luxembourg. From the 2011 austral summer, the ROB will proceed to an annual gravitymeasurement campaign, in collaboration with the University of Luxembourg.

D.2.2. Progress and results

A first absolute gravity mission is in preparation. It should take place from December 2010 to end of January 2011. It will be conducted by the University of Luxemburg.

D.2.3. Perspective for next years

The first gravimetric measurements will be done at the PES by our colleagues of the Luwemburg University.

D.2.4. Partnerships

List of international collaborators without grant

- Prof. O. Francis, Dr T. van Dam (U. of Luxembourg).

List of national collaborators

- Mr. A. Hubert, Ir. J. Berte (International Polar Fundation).

D.2.5. Scientific outreach

Meeting presentations

(1) Bergeot, N., Bruyninx, C., Aerts, W., Lombardi, D., Camelbeeck, T., Van Camp, M., Legrand, J., and Moyaert, A.
Installation of a GPS station at the Princess Elisabeth base to monitor crustal motions due to ice mass variations
Belgian IPY Symposium, Palace of the Academies, Brussels, May 26, 2010.

D.3. Space geodesy and hydrology

D.3.1. Objectives

Modeling continental hydrology is a key issue in the geosciences for the coming years as the distribution of the water mass is the main source of uncertainty in many questions of geodesy and climatology, and because the water availability is a crucial problem with societal implication. The major difficulty is to constrain the hydrology models with relevant data, which implies the need to gather data in remote areas, with a fair sampling both in time and in space.

Our objective is to investigate existing hydrological models and to compare them with land-based measurements and the observations of the Gravity Recovery and Climate Experiments (GRACE) satellite, which has now been orbiting the Earth for about 7 years, monitoring the Earth gravity field and its space and time variations. This is done both on a world-wide scale and on specific case studies.

This is a first step toward improvement of the hydrological models. Thi is essential if one wants to use GRACE to investigate geodynamical phenomena, which are presently masked by the hydrological effects.

D.3.2. Progress and results

D.3.2.1.Membach:

We were the first to establish a reliable model to correct hydrological effects on SG measurements. This model is based on comprehensive local hydrogeological investigations (Van Camp et al., JGR, 2006). To improve the model, we started repeated electric tomography profiles in June 2010. Permanent monitoring of changes in soil properties is of increasing interest in many engineering applications such as management of groundwater contamination, landslide and sinkhole risks prevention, detection of saline water intrusion, as well as comprehension of charge and discharge processes of subsurface aquifer.

To assess the efficiency of electrical resistivity in monitoring charge and discharge processes of subsurface aquifer, and to better model the hydrological effects on the gravity measurements, an automated permanent geoelectrical acquisition system was installed in June 2010 to monitor subsurface resistivity variations. The aim of this experiment is to better understand charge and discharge processes of the subsurface aquifer, which are expected to be mainly due to rainfall variations. Resistivity measurements are automatically taken twice a day at fixed hours.

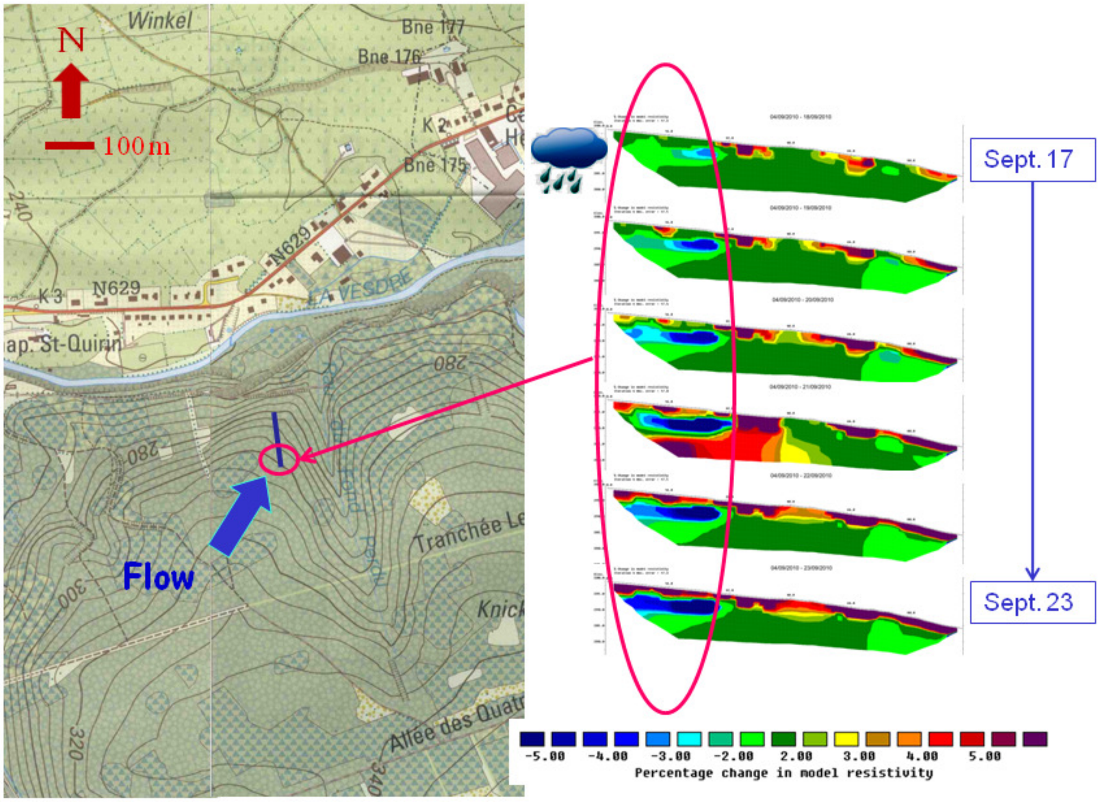

Figure 22: Relative variation in the resistivity observed above the Membach station after a rainfall. A decrease appears during the days following the rainfall, probably due to near-surface hillside flow. The blue line represents the profile above the Membach station.

The preliminary results evidence changes in resistivity after rainfall. These changes depend among other on the saturation degree and on the slope. An example is given on Figure 4.

With a better knowledge of the spatial and temporal changes in the soil water content, this permanent profile will allow us to improve our hydrological model, which is paramount for investigating slow tectonic deformation. This experiment is also a case study for the geophysicists performing repeated electric tomography measurements.

D.3.2.2.Jülich

In the northern part of the AG profile, the Jülich station, in the Roer Graben, is influenced by anthropogenic effects: water withdrawal for mining purposes induces subsidence, causing an increase in gravity belonging to the [33.0, 46.1] nm/s²/yr interval. Combining this residual gravity rate of change with the vertical velocity provided by repeated leveling, indicates an increase in density, caused by compaction processes.

D.3.3. Perspective for next years

- Membach: We will interpret the results from the repeated electric tomography profile: data has to be corrected for temperature bias, then, interpreted in the light of the gravity and soil moisture measurements, as well as of local hydrological models.

- Jülich: we would like to combine our AG data with other geodetic techniques, e.g. PSInSAR or GPS measurements. This should allow us to better understand compaction processes in the aquifer and aquitards, which is paramount for monitoring areas affected by subduction (e.g. New Orleans).
- BFO: we are invited to perform new AG measurements in 2011. The measurements will take place at the existing measurement point behind the air lock as well as on the new location beyond the air lock, close to the newly installed SG.

D.3.4. Partnership

List of international partners without grant

- M. Diament, O. de Viron (IPGP-Paris)
- J.-F. Crétaux (CNES-Toulouse)
- A. Güntner (GFZ Potsdam)
- A. Sun (CNWRA, Texas)
- M. Rodell (NASA Goddard Flight Centrum)

List of national partners without grant

- Prof. M. Vanclooster (UCL).

D.3.5. Scientific outreach

Meeting presentations

(1) Deceuster, J., Kaufmann, O., Van Camp, M., and Lecocq, T.
Automated permanent resistivity monitoring of charge and discharge processes of subsurface aquifer at the Membach station, Belgium
AGU Fall meeting, San Francisco, USA, December 13-17, 2010.

Seminars

(1) Van Camp, M.
Hydrology and land-based gravimetry
GFZ Potsdam, October 28, 2010.

D.3.6. Missions

Research visits (days): M. Van Camp (4 weeks at IPG Paris)
Field missions (days): M. Van Camp (2 days)

D.4. Volcano Deformation and Temporal Gravity Change

D.4.1. Objectives

On volcanoes, ground-surface displacement (GSD) rates detectable with modern geodetic techniques are of special interest, because they are often interpreted as indicators of magma intrusion into the shallow crust, a major cause of volcanic unrest. Nevertheless, in many cases, observed surface displacements display a multifaceted pattern, implying that the magma plumbing system has a complex geometry. Additionally, available models cannot distinguish between an aqueous, low-density, low-viscosity fluid and a dense and viscous magma. The interplay between multiphase (magma - aqueous fluids - gas) flow dynamics and crustal mechanics in active volcanoes is poorly understood. Such inherent limitations hamper the ability to obtain reliable insight on processes associated with volcano deformation and thus, to provide an insightful hazard assessment.

D.4.1.1. Gravity

Continuous, high-precision microgravity measurements may discriminate between magma intrusion and hydrothermal injection at shallow depths, because the density of magma differs by a factor of 3 or more from the density of superheated vapor or gas. Combining microgravity and other geodetic data with quantitative dynamic models should provide insight into the nature of the fluid inducing deformation.

D.4.2. Progress and results

We performed tidal analysis of the time series recorded at Montserrat (Souffrière Hills volcano) by Jo Gottsmann. The results are being published.

Jo Gottsmann installed 2 spring gravimeters (one CG5, one Burris) at the Membach station for one month in February 2010. They were compared to the SG-C021 and the CG5 belonging to the Observatory. This allowed testing the calibration factor and sensitivity to air pressure variations, but also qualifying the drift and the ability of these instruments to monitor long term gravity changes.

D.4.3. Perspective for next years

We are still in close contact with Jo Gottssmann, and share our experience in terms of gravity and other environmental measurements (in collaboration with Corentin Caudron and Alain Bernard).

D.4.4. Partnership

List of international partners without grant

- Dr Jo Gottsman (U. Bristol);
- Dr Nicolas Fournier (Wairakei Research Centre, New Zealand).

D.4.5. Scientific outreach

Meeting presentations

(1) Gottsmann, J., Van Camp, M., and Fournier, N.
Monitoring and observations of active volcanoes using in-situ and remote sensing techniques
EGU meeting, Vienna, Austria, May 2-7, 2010.

Astronomy and Astrophysics

E. Asteroids

E.1. RUSTICCA

The Royal Observatory of Belgium has a long tradition of excellent astrometry of asteroids and comets. In the last years, worldwide asteroid astrometry got a new impetus thanks to several developments. First, there was the extension of the asteroid population with new groups, such as the Transneptunian objects. More influence came from the awareness that asteroids may pose a threat to civilisation if one would collide with the Earth. The Royal Observatory of Belgium continues to provide excellent astrometry of asteroids thanks to the RUSTICCA project, and participates when possible in international projects.

E.1.1. Objectives

The Project "RUSTICCA", standing for "Revalorising the Ukkel Schmidt Telescope by Installing a CCD Camera", started in 1993 and consists in the installation of a CCD camera on the Ukkel Schmidt Telescope and modernising the telescope. The main objective of this camera is to continue the long-lasting tradition of excellent astrometric observations of minor planets performed at Ukkel, but also other types of observations have been performed: photometry of cataclysmic variables (discontinued since people interested in this subject have left the Observatory), photometry of the mutual phenomena of the satellites of Jupiter, observations of possible occultations of stars by minor planets, photometry of mutual phenomena of an asteroid and its satellite, and we tried to observe mutual phenomena of the satellites of Saturn and Uranus.

E.1.2. Progress and results

E.1.2.1. Observations in 2010

In 2010 observations have been performed on 21 nights by 4 observers. They include Peter De Cat (8 nights, 406 frames), Eric Elst (1 night, 30 frames), Thierry Pauwels (12 nights, 317 frames), Emmanuel Thienpont (3 nights, 73 frames).

These observations concerned:

- Astrometry of minor planets: 18 nights covering 40 fields by 734 images, producing 622 astrometric positions. Out of these, 1 field with 13 images (without position) of objects of the Near-Earth Objects confirmation page. Observers: Peter De Cat, Eric Elst, Thierry Pauwels and Emmanuel Thienpont. The positions have been published in the MPSs.
- Occultations of stars by minor planets, the so-called Planoccult phenomena: 3 events attempted on 2 nights, with 19 images and films, producing 3 light curves. Observers: Thierry Pauwels and Emmanuel Thienpont. All three events turned out to be negative, meaning that Ukkel was not in the shadow path of the asteroid. The results of negative events are also published if the same event was observed to be positive somewhere else in the world.
- 2 nights without results because of technical problems.

The three nights of Emmanuel Thienpont were together with Thierry Pauwels as initiation to the observation procedure.

Together they produced 753 images and films.

E.1.2.2. Other activities

Apart from the observations themselves, a lot of work was routinely put in the preparation of the observations (setting up the list of objects to observe in the coming night, many times just in case the weather might clear up), the reductions of the observations (running the automatic processes, searching asteroids, measuring them and identifying them), and finally computing ephemerides for newly found objects. Most observations are checked (and sometimes partially or totally reduced) by two team members, and some team members did the reductions of observations by other team members.

The status of each of the RUSTICCA-objects was constantly kept up to date, to find out which objects were in needed of observations and when.

The maintenance of the telescope also took a lot of attention. See the technical report in the individual report of Thierry Pauwels.

Concerning the software Thierry Pauwels had to adapt the procedures to retrieve data from the Minor Planet Center to their new website, we improved the software for treating the Planoccult observations, and we made a script to save web cam weather images for feedback on the decisions of whether or not to observe.

All raw data was further archived on CD-ROM, along with the necessary documentation to interpret the observations in the future, adding another 15 CD-ROMs to the archive, containing 727 images and films.

For new observers Thierry Pauwels started to make an English version of the reduction manual, describing the software to treat the observations of astrometric observations of asteroids. Such a manual existed already, but was in French and outdated. This manual could not be completed due to lack of time.

There were negotiations about a compensation scheme for observations in the week-end, which led to a proposal, which was subsequently refused. There were also negotiations about the conditions to have Emmanuel Thienpont being included in the team of observers. These negotiations did not come to an agreement yet.

E.1.2.3. Summary of the results obtained since 1996

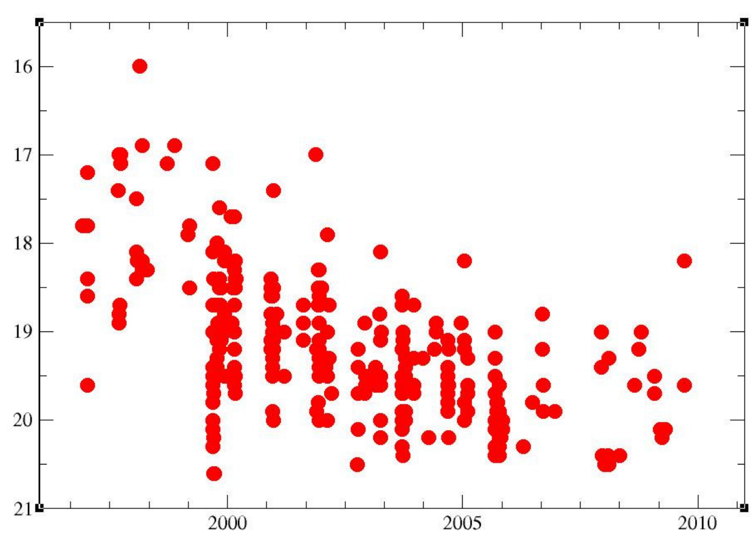

Figure 23: Preliminary designation of minor planets discoveries attributed to RUSTICCA. In abscissa the date of discovery and in ordinate the magnitude at the time of discovery.

From 1996 to 2010 a total of 23 661 astrometric positions of minor planets and 73 astrometric positions of comets have been published in the Minor Planet Circulars. The number of only 672 published positions in 2010 is very low compared to the previous years. There are several reasons for this. Traditionally the most productive months are September and December. However, due to the late aluminisation of the mirror, which was in turn caused by the installation of a new articulated lift in September, no observations were possible in September, and the last two months of the year suffered from an exceptionally high number of cloudy nights. Apart from a few very occasional volunteers, there were only 2 staff members available for the permanence at the telescope, and thus it is inevitable that some clear nights were lost.

Excluding the Daily Orbit Updates, 293 positions of minor planets (NEOs) and comets have been published in the Minor Planet Electronic Circulars.

The total number of preliminary designations of minor planets attributed to observations of the RUSTICCA project amounts to 310. 2010 was the first year since the start of the project without any preliminary designation being assigned to Ukkel. This is partly due to the low number of observations, but even more to the effect of potential discoveries getting exhausted, and we may anticipate that with the current set-up in the future only a few more preliminary designations will be assigned to Ukkel. Within a few years one may expect that no more unknown asteroids will exist in the magnitude range observable by the RUSTICCA project.

Figure 23shows for each assigned preliminary designation in abscissa the date of discovery and in ordinate the magnitude at the time of discovery. Dots are lying inside a triangle. The lower limit corresponds to the limit magnitude of the telescope and lies around 20.5. On the other side, the upper limit is clearly diagonal (apart from three outliers, objects that had escaped detection for longer than normal). It represents the magnitude of the brightest object that can still be discovered. In 1996 there were still undiscovered asteroids of magnitude 16.5, nowadays the brightest undiscovered asteroids are fainter than magnitude 19. A brute extrapolation of this plot would put the last discovery from Ukkel with the current means around 2015, about one year later than we extrapolated in our 2007 report.

51 of the minor planets with preliminary designation assigned to Ukkel are currently multiple opposition objects, and 143 have been permanently numbered, with the discovery assigned to a RUSTICCA observation. The discoverers with the number of discovered minor planets are: Henri Boffin (8 minor planets), Peter De Cat (5 minor planets), Eric Elst (10 minor planets), Eric Elst and Henri Debehogne (13 minor planets), Eric Elst and Sergei Ipatov (4 minor planets), Eric Elst and Dirk Taeymans (1 minor planet), Thierry Pauwels (95 minor planets), Thierry Pauwels and Henri Boffin (1 minor planet), Thierry Pauwels and Peter De Cat (2 minor planets), Thierry Pauwels and Sergei Ipatov (3 minor planets), Thierry Pauwels and Anthony Jonckheere (1 minor planet).

A total of 43 light curves of cataclysmic variables could be established (1999-2003), 25 light curves of mutual phenomena of the Galilean satellites of Jupiter (1997, 2003 and 2009), and 9 light curves of mutual phenomena of an asteroid and its satellite (2006-2008).

The team observed 67 potential occultations of stars by minor planets in the period 2003-2010. 16 of these gave no results due to clouds, 2 others because the target star turned out to be too faint, and 2 phenomena failed because of technical problems. 43 other phenomena gave a negative result, meaning that we could deduce from the observations that the shadow of the minor planet missed Ukkel. 2 phenomena in 2005, 1 in 2008 and 1 in 2009 gave a positive occultation, where precise timings of the beginning and end of the occultation could be derived. Given the uncertainty in the predictions of the occultation paths, 4 positive occultations out of 67 attempted is a good result.

The archive now consists of 405 CD-ROMs with a total of 28 827 images and films.

E.1.3. Perspective for next years

Astrometric observations of minor planets are still expected to be useful for a few years, though the number of preliminary designations (and discoveries) assigned to Ukkel in the future is expected to be very low. At the current rate of world-wide observations, this could be for another 3 or 4 years. However, big survey programmes are planned for the near future, which could accelerate the rate of discoveries of faint objects. At the moment when all objects in the reach of the telescope will be well-known or routinely observed elsewhere, new observation programmes will have to be defined. An interesting programme may be the mutual phenomena of asteroids and their satellites, of which a few have already been observed in 2006-2008. Mutual phenomena of the satellites of Jupiter happen every 5-6 years, the last season having been 2009, and we plan to continue to observe these. Also occultations of stars by minor planets will continue to be observed.

E.1.4. Personnel involved

Scientific staff:	Thierry Pauwels (observer and reductions)
	Peter De Cat (observer and reductions)
Technical staff:	Emmanuel Thienpont (observer)
	Marc De Knijf and team (maintenance of telescope)

E.1.5. Partnerships

List of international partners or collaborators having actively contributed to the project in the last year

- Minor Planet Center, Cambridge, MA, USA for the identification and publication of asteroid positions.
- EAON (European Asteroidal Occultation Network) for the preparation and reduction of PLANOCCULT observations.

List of national partners or collaborators having actively contributed to the project in the last year

- Eric W. Elst

Visitors:

- Short visits: 1

F. Asteroseismology

The overall objective of asteroseismology is to probe the internal structure of pulsating stars, and therefore of stars. To this aim, we observe and study the light and the spectral variations of main-sequence pulsating stars of spectral type B-A-F over a time-scale of several seasons or years. We furthermore aim at investigating the interactions that may arise between stellar pulsations and various other phenomena such as multiplicity, chemical composition and magnetic fields. The team members are strongly involved in the analysis and exploitation of data from space missions being distributed at a high rate, while additionally dealing with projects of ground-based follow-up.

A few highlights:

- The first analysis of the spectroscopic data of HR 8799, a planet-hosting pulsating γ Dor star, suggests that there is a misalignment of more than 20 deg between the stellar rotational inclination and the planetary orbital axis.
- The analyses of the out-of-primary-eclipse data of the eclipsing Algol systems Y Cam and CT Her lead to the first detection ever of as many as eight independent pulsational frequencies for this subclass of pulsators.

F.1. Asteroseismology (including binary or multiple stars)

F.1.1. Objectives

Specific attention is given to the study of B-A-F pulsating components of binary or multiple systems of stars with the goals to improve knowledge of pulsation physics through constraints on the physical parameters of the variable component derived from the binary or multiple nature of the system, as well as to study the interaction between pulsation and binarity. Since more than 50% of all stars are expected to be binaries, understanding the effects of binarity on the pulsation characteristics is a matter of prime importance. We presently focus unto those binaries which are promising targets for the application of spectral disentangling.

F.1.2. Progress and results

F.1.2.1. Main-sequence O-B stars (SPB=slowly pulsating B star; βCep = β Cephei star)

P. De Cat was invited to talk about “Asteroseismic observations of OB stars” during the IAU Symposium 272 “Active OB stars: structure, evolution, mass loss and critical limits”. The recent asteroseismic results of SPB stars, β Cep stars, Be stars and B-type supergiants were highlighted and discussed. Thanks to new longitudinal field measurements for four β Cep and two SPB stars, the rotation period could be determined and the magnetic geometry could be constrained for ξ^1 CMa, 15 CMa, α Pyx and 33 Eri. A dipole fit provided a satisfactory fit to the data and among the very few presently known magnetic β Cep stars, ξ^1 CMa and α Pyx possess the largest magnetic fields with a dipole strength of several kG [42]. We tried to start a systematic search for magnetic fields in γ Dor stars too, but our proposal was rejected [42].

F.1.2.2. Rotation and pulsation in main-sequence gravity mode pulsators

We aim to investigate and improve mode identification procedures, specifically with regard to main-sequence g-mode pulsators. We also want to study eventual correlation(s) between the amplitude and/or type of the excited modes and the projected rotational velocity of the pulsating star by obtaining at least one high-resolution spectrum for as many as possible SPB and γ Dor stars (“classification”) and by organising dedicated multisite campaigns for a few of them (“multisite observations”). The detection of such a relationship may allow theoreticians to revise their pulsation theories and make successful asteroseismology able to be achieved with less detailed knowledge of stellar pulsation modes.

- Application for a 2-year extention of the project (awaiting decision) [36]
- Continuation of data gathering of the high-resolution spectra needed for the characterization (determination of v.sini, Teff, log g, abundances; detection of binarity; detection of line-profile variations) of the SPB and γ Dor stars. In 2010 we obtained 99 spectra (including 11 SPB and 11 γ Dor stars for which we didn't have any data yet), bringing the total to 1126 high-resolution spectra for 160 objects. We have now stopped these observations. The analysis of the spectra is on-going and the results will be published in a series of papers.
- HR 8799 is a γ Dor star for which four orbiting objects are found by direct imaging. A large-scale spectroscopic multi-site campaign was organised in the fall of 2009 to complement the 6 weeks of white-light photometry obtained by the satellite MOST. The first analysis of the spectroscopic data suggests that there is a misalignment of more than 20 deg between the stellar rotational inclination an the planetary orbital axis (work in progress).
- We continued to reduce the spectra, combine the data obtained during multi-site campaigns, optimize the software, and performed the first analysis for a few stars: the γ Dor stars HD 40745 and HD 189631 [28], the γ Dor stars HD 12901 and HD 135825 (Brunsden et al., in preparation) and the SPB stars HD 25558 and HD 21071 (Wright et al., in preparation).
- Three weeks of continuous white-light photometry would be gathered with the satellite MOST for the SPB star HD 25558 from 1 to 21 November (proposal submitted in 2009). This star was already observed by us during a one-season spectroscopic multi-site campaign in 2008, but the resulting time series is insufficient for an in-depth asteroseismic modelling (Wright et al., in preparation). We managed to organised a complementary multi-disciplinary, multi-site campaign including:
    - high-resolution spectroscopy from 8 observatories: HERCULES@MJUO/1.0-m (35 dedicated nights), GAOES@GAO/1.5-m (11 shared nights), COUDE@XING/2.16-m (3 dedicated nights), GIRAFFE@SAAO/1.9-m (14 dedicated nights), HERMES@ENO/1.2-m (50 hours of pooled observations), RA@McD/2.1-m (15 nights; observations on 9 nights), 2mAST@FO/2-m (42 shared nights), 9682M@DAO/1.2-m (10 dedicated nights)
    - multi-colour photometry from 2 observatories: MP@SAAO/0.5-m (14 dedicated nights) and FCCT@FO/0.75-m (9 dedicated nights).
    - spectropolarimetry from 2 observatories: NARVAL@PdM/2-m (9 shared nights), ESPADONS@CFHT/3.6-m (12 shared nights).

  Many observing proposals were thus submitted [29][44][45][45][96] and our negotiations resulted in several new collaborations. The data gathering is still on-going. The detection of a weak magnetic field announced by Hubrig et al. (2009, AN 330, 317) has now been confirmed (Neiner, private communication). From a first look at the newly obtained spectra, we suspect that HD 25558 is a long-period double-lined binary with at least one pulsating component. If true, this will complicate the forthcoming analysis of the data considerably (work in progress).

F.1.2.3. Candidate binary systems among pulsating A/F-type stars

The region in the H-R diagram where the main sequence intersects the Cepheid Instability Strip is of great astrophysical interest as it hosts A- and F-type stars which are affected by a rich variety of physical processes ongoing in their interiors: this includes processes such as pulsation, (radiative) diffusion, convection, (differential) rotation and magnetism. Main-sequence A-type stars are among the best candidates to study this complex interplay. We explored a sample of suspected A/F-type binaries in a systematic way and searched for pulsation(s), for non-standard chemical composition or for possible hidden component(s). Thus, we detected the atypical Delta Scuti star HD 68725 = HIP 40361. Our spectroscopic follow-up shows that the pulsating component belongs to a binary system, the orbital period of which is not (yet) well-determined. Additional spectra were acquired with the HERMES high-resolution spectrograph during 2009-2010 which need to be analysed with those of an international spectroscopic campaign (including Bulgarian, Mexican and Spanish partners and US and Chinese sites). Complementary photometric light curves have been obtained with the HOACS instrumentation during the previous winter. This study is on-going.

F.1.2.4. The oscillating eclipsing binary systems (oEA stars) Y Cam, YY Boo, CT Her and Hip 7666

Y Cam. Y Cam belongs to the class of oscillating Algol-type binary systems (named oEA stars), of which only a handful members are presently known. These stars represent important case studies as we do not yet understand their evolutionary stage. They allow to study pulsations in semi-detached binaries where the process of mass accretion is (still) on-going. We present the results of a detailed photometric analysis based on a three-continent multisite photometric campaign carried out mainly during the Northern winter 2002-2003. The results indicate a semi-detached system with the secondary filling its Roche lobe. No significant contribution from a third body is found. The residuals from the computed binary solution were next used to investigate the pulsational content of the primary component. The frequency analysis of the out-of-primary-eclipse data leads to a set of eight significant and independent pulsational peaks in a well-defined region of the frequency spectrum. We performed a preliminary mode identification for most of the frequencies on the basis of the collected multicolour photometry, the observed frequency spacings and the mode visibility in eclipsing binaries [69].

YY Boo (cf. project HOACS). The semi-detached eclipsing binary YY Boo is found to contain a rapidly pulsating delta Scuti type component with an amplitude of 0.1 mag in B. A rough binary model based on BV photometry is used to disentangle the variations due to pulsation and geometric effects [30].

CT Her. CT Her is another member of the subclass of oscillating Algol-type binary systems. We reported the results of an extensive analysis based on a five-year, multisite photometric campaign carried out in the years 2004-2008. The primary component is a multiperiodic Delta Scuti-type pulsator with a main pulsation period of only 27 min. We performed a modelling using the code PHOEBE and detected up to 8 significant pulsation frequencies in the frequency range between 45-53 c/d in the B-residual data.

HIP 7666 (cf. project HOACS).

CCD observations of 25 high-amplitude Delta Scuti stars (HADS) allowed to derive 218 maxima from their light curves [86]. Three new proposals for high-resolution HERMES spectra for known and newly detected oEA stars were submitted and granted in the context of the HERMES Consortium [29][70][73].

F.1.3. Perspective for next year(s)

In order to derive fundamental stellar parameters and abundances for our main targets of the sample of A-F type, an automated procedure based on the simultaneous application of a simplex minimization procedure and the code SYNSPEC was developed. This procedure will be applied to the high-resolution spectra collected with the new spectrograph SOPHIE equipping the 1.93-m telescope of the Observatoire de Haute-Provence (OHP, France). Our next detailed studies will concern the oEA stars HIP 7666 and IU Per for which a vast amount of data has been collected. A vast set of photometric B- and V-data for IU Per was assembled during 2006-2008 and continued in 2010. This data set will be modelled and frequency-analysed. The increased time resolution will allow us to improve the frequency-analysis significantly compared that of the latest publication (with a time resolution of only 12 days).

The many collaborations and the large quantity of data obtained during the multisite campaigns of the project on rotation and pulsation of main-sequence gravity-mode pulsators will keep us on-going for some time to come. In addition to the data acquisition and interpretation, we also contacted Dr. R. Townsend who is developing the next generation of spectroscopic mode identification software. We will thus be in a prime position to test the improvements made with this software by examining how our results differ using the new method of Dr. Townsend compared to the Fourier Parameter Fit (FPF) approach used so far.

F.1.4. Personnel

Scientific staff: P. De Cat, Y. Frémat, P. Lampens, D. Wright.

Technical staff: E. Thienpont (since May, 1st)

F.1.5. Partnerships

List of international partners without grant

- M. Cunha, Centro de Astrofisica da Universidade do Porto, Portugal
- Z. Kraicheva, D. Dimitrov, Institute of Astronomy, Bulgarian Academy of Sciences, Sofia, Bulgaria
- S. Kleidis, Zagori Observatory, Athens, Greece
- D. Kurtz, University of Central Lancashire, Preston, UK
- D. E. Mkrtichian, Sejong University, Seoul, Korea
- P. G. Niarchos, A. Liakos, Ch. Vamvatira-Nakou, University of Athens, Greece
- C. W. Robertson, SETEC Observatory, USA
- E. Rodríguez, M.J. López-González, Instituto de Astrofísica de Andalucía, Granada, Spain
- A. Strigachev, Institute of Astronomy of the Academy of Sciences, Sofia, Bulgaria
- J. Vidal-Saínz, J.M. Gómez-Forellad, Grup d'Estudis Astronomics (GEA), Barcelona, Spain
- Group of K. Pollard (University of Canterbury, Christchurch, New Zealand): local correspondents and observers with HERCULES@MJUO/1.0-m, gDor stars, participation in all phases of the data reduction and analysis
- J. Telting (Nordic Optical Telescope, Santa Cruz de La Palma, Spain): local correspondent and observer with FIES@ENO/2.6-m for the Roque de los Muchachos Observatory (La Palma), pixel-to-pixel method, analysis of spectroscopic data
- S. Yang (University of Victoria, Victoria, Canada): local correspondent and observer with 9682M@DAO/1.2-m, pulsating stars
- H. Lehmann (Thüringer Landessternwarte Tautenburg, Germany): local correspondent and observer with CES@TAUT/2.0-m, Algol systems with pulsating components
- Group of J.N. Fu (Beijing Normal University, Beijing, China): local correspondent for Xinglong observatory, photometry of stars in open clusters
- E. Kambe (Beijing Normal University, Beijing, China): local correspondent and observer with HIDES@OAO/1.88-m, pulsations of hot stars
- E. Poretti (INAF-Osservatorio Astronomico di Brera, Merate, Italy): correspondent for observations with FEROS@ESO/2.2-m and HARPS@ESO/3.6-m, dSct stars
- R.J. Dukes (College of Charleston, South Carolina, USA): correspondent and observer with the Four-College Consortium Automatic Photoelectric Telescope in Arizona, photometry of variable stars
- R. Townsend (University of Wisconsin-Madison, Wisconsin, USA): effects of rotation, calculation of synthetic line profiles
- S. Hubrig (European Southern Observatory, Chile): derivation and interpretation of magnetic fields from spectropolarimetric observations
- O. Hashimoto (Gunma Astronomical Observatory, Japan) & S. Honda (Kwasan Observatory, Kyoto University, Japan): correspondent and observer with GAOES@GAO/1.5-m
- C. Neiner (GEPI, Observatoire de Paris, Paris, France) & MiMeS consortium: derivation and interpretation of magnetic fields from spectropolarimetric observations
- A.-N. Chené (Universidad de Concepción, Conceptión, Chile; Universidad de Valparaíso, Valparaíso, Chile) et al.: campaign on the γDor star HR8799
- Group of C. Engelbrecht (University of Johannesburg, Johannesburg, South Africa): observations at SAAO
- B. Constanheira (Institut für Astronomie, Vienna, Austria): observations with RA2@McD/2.1-m
- M. Williamson, F. C. Fekel, G. W. Henry & M. W. Muterspaugh (Tennessee State University, Nashville, USA): local correspondents and observers with 2mAST@FO/2.0-m

List of national partners without grant

- Group of C. Aerts (Katholieke Universiteit Leuven): observers for HERMES@ENO/1.2-m, analysis of B-type main-sequence pulsators, modeID techniques including the moment and the FPF methods
- Group of M.-A. Dupret/A. Noels, Université de Liège (specialised in asteroseismic modeling)

- P. Van Cauteren, Beersel Hills Observatory, Belgium
- P. Wils, VVS, Belgium

Grants used for this research

- Belgo-Bulgarian bilateral project "Photometric and Spectroscopic Follow-up Studies of Binary Systems of Special Interest" (grant nr. BL/33/011ext)
- Action-1 "Pulsation, chemical composition and multiplicity in main-sequence A- and F-type stars" of the Federal Science Policy (grant nr. MO/33/018)
- Action-1 “Rotation and pulsation in main-sequence gravity mode pulsators” of the Federal Science Policy (grant nr. MO/33/021)
- Grant nrs. G.0178.02 and G.0332.06 from the Fund for Scientific Research (FWO) – Flanders (Belgium)

Visitors

- E. J. Brunsden, University of Canterbury (Christchurch, New Zealand), 07/06/2010-02/07/2010, Towards asteroseismology for main-sequence g-mode pulsators: the case studies of the gamma Doradus stars HD 12901 and HD 135825
- A.-N. Chené, Universidad de Concepción (Conceptión, Chile) & Universidad de Valparaíso (Valparaíso, Chile), 26/07/2010-30/07/2010, Multi-site campaign of the gamma Doradus star HR 8799: aging the first direct-imaged planetary system by asteroseismology
- K. Pollard, University of Canterbury (Christchurch, New Zealand), 14/06/2010 - 21/06/2010, Towards asteroseismology for main-sequence g-mode pulsators: the case study of the gamma Doradus star HD 182640
- Y. Yang (Beijing Normal University, Beijing, China), 08/11/2010-07/12/2010, Towards asteroseismology for main-sequence g-mode pulsators: data from the 2.16-m telescope of the Xinglong observatory (China)
- F. Maisonneuve (University of Canterbury, Christchurch, New Zealand), 06/12/2010-22/12/2010, Reduction of spectroscopic data obtained for HD 25558 with COUDE@XING/2.16-m and HERCULES@MJUO/1.0-m

F.1.6. Missions

Assemblies, symposia

- P. De Cat: IAU Symp. 272 “Active OB stars: structure, evolution, mass loss and critical limits”, 19-23/07/2010, Paris, France
- P. De Cat: Big Science with Small Telescopes, Oct. 19-22, Jena-Dornburg, Germany

Research visits

- P. De Cat: 18/11-03/12/2010: University of Texas, Austin, Texas, USA (1-day research visit, 19/11/2010) + McDonald Observatory, Mt. Locke, Texas, USA (9 nights of spectroscopic observations with RA2@McD/2.1-m; 22/11-30/11/2010)
- P. De Cat: 16 1-day missions, Inst. voor Sterrenkunde, KU Leuven, Leuven, Belgium
- P. De Cat : 1 1-day mission, Inst. d’Astrophysique et de Géophysique, Université de Liège, Belgium
- D. Wright: University of Canterbury, New Zealand, 18th January – 9th March
- D. Wright: 6 1-day missions, Inst. voor Sterrenkunde, KU Leuven, Leuven, Belgium
- D. Wright : 2 1-day missions, Inst. d’Astrophysique et de Géophysique, Université de Liège, Belgium

Field missions

- P. Lampens : Jan. - Dec. 2010, Differential CCD photometry of selected Delta Scuti variable stars, Beersel Hills Observatory, Belgium, 0.4m telescope + SBIG CCD camera (9 nights, co-observer: P. Van Cauteren)

F.1.7. Scientific outreach

Meeting presentations

(1) De Cat P., Gutiérrez-Soto J., Degroote P., Simon-Díaz S., Uytterhoeven K.
Asteroseismologic observations of OB stars
Invited review presented during the IAU Symposium 272 “Active OB stars: structure, evolution, mass loss and critical limits”, 19-23/07/2010, Paris, France

(2) De Cat P.
Asteroseismic results using multi-site campaigns
Invited review presented during the conference "Big Science with Small Telescopes: The role of 2 - 4m Telescopes in the Era of the Large and Extremely Large Telescopes", 19-22/10/2010, Dornburg castle, Germany

(3) Chené A.-N., Wright D., De Cat P., Marois C., MOST team
In-depth asteroseismic analysis of HR8799
Poster presented during the conference "Big Science with Small Telescopes: The role of 2 - 4m Telescopes in the Era of the Large and Extremely Large Telescopes", 19-22/10/2010, Dornburg castle, Germany

(4) Wright D.J., De Cat P., Kambe E., Lehman H., Yang S., Dukes R., Pollard K.R, Cottrell P.L., Brunsden E.J., Maisonneuve F., Engelbrecht C., Ulusoy C., Hashimoto O. and the Mercator telescope observers
Detailed spectroscopic studies of gravity mode pulsations: The case study of the Slowly Pulsating B star HD 25558
Poster presented during the conference "Big Science with Small Telescopes: The role of 2 - 4m Telescopes in the Era of the Large and Extremely Large Telescopes", 19-22/10/2010, Dornburg castle, Germany

(5) Wright, D.
Reduction of HERCULES data using MATLAB
Physics and Astronomy, University of Canterbury, New Zealand

(6) Wright, D.
Results for spectroscopic multisite campaigns on several γ Doradus and Slowly Pulsating B stars
Royal Observatory of Belgium, Brussels, Belgium

(7) Wright, D.
Preliminary results from the multisite campaign on HR 8799
University of Liège, Liège, Belgium

F.2. Asteroseismology from space

We are actively involved in the asteroseismic space missions MOST (Canada), CoRoT (CNES-CNRS-ESA-Brazil) and KEPLER (NASA). CoRoT (launched in December 2006) probes the inner structure of the stars, as well as detects many extrasolar planets, by observing the periodic micro-eclipses occurring when these bodies transit in front of their parent star. Due to the high photometric performances and the long observing runs covering five months without interruption, the experiment is a pioneer mission in both domains. KEPLER (launched in March 2009) observes fixed fields and continuously monitors over 100.000 stars for at least 4 years, with a slow cadence,and additionally 512 stars with a rapid cadence. The mission is designed to search for extra-solar planetary systems using the transit technique, particularly Earth-like planets in the habital zone. Both missions provide a huge amount of extremely high-quality data useful for refined asteroseismic studies.

F.2.1. Objectives

Lots of very accurate light curves from the exoplanetary and asteroseismic CoRoT fields are available via the thematic teams. The launch of the KEPLER mission occurred in March 2009. We contributed to the selection of interesting asteroseismic targets from the KEPLER Input Catalogue (KIC) and the KEPLER Asteroseismology Scientific Consortium (KASC) database.

F.2.2. Progress and results

F.2.2.1. Contributions to the KEPLER mission

- Representation and management of the Kepler Asteroseismic Science Consortium working group 6 "Slowly pulsating B stars" (KASC#6):
  - Target selection (every three months: in 2010 quarters Q5, Q6, Q7 and Q8)
  - Working group chair meetings (every three months: 1/2-day teleconference meetings)
  - SOC member of the third Kepler Asteroseismology Workshop "Kepler Asteroseismology in Action", 14-18/06/2010, Aarhus, Denmark
  - Coördination and contributions to papers (cf. below).
- The stellar parameters of a subsample of 16 B-type main-sequence Kepler targets were derived based on observations with CES@TAUT/2.0-m.
- The first view on the variability in B-stars based on the analysis of Kepler data obtained in quarters Q0-Q4 was reported.
- Preparing and/or giving input to 17 observation proposals for and 2 poster presentations about ground-based observations of Kepler targets [39][40][37][43][29][75]0[102][77][81][103][107][104][29][102][106][107][81][56][79]. Especially the preparation of the proposal for observations with the Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST) was a large time investment [37]. With LAMOST it is possible to obtain low to medium resolution spectra of up to 4000 targets with a single exposure. Hence, it is the only instrument in the northern hemisphere capable of providing spectra needed to classify nearly all of the more than 6000 objects observed within the Kepler Asteroseismic Science Consortium (KASC) in a homogeneous way within one observation season. Hence, hundreds of astronomers worldwide will profit from these observations. Our proposal was approved for observations in 2011. Spectroscopic observations resulting from proposal [40] were included in the study of HD 181068: a red giant in a triply-eclipsing compact hierarchical triple system for which evidence of tidally-induced oscillations driven by the orbital motion of the close pair is found. The spectra obtained at the McDonald observatory for the δ Scuti star KIC 7548479 were used to determined the stellar parameters of this object. It is the first δ Scuti star showing clear evidence for the simultaneous presence of p-mode oscillations excited by the opacity mechanism and stochastically driven solar-like oscillations. The spectra obtained for Am star KIC 11445913 were used to determine the radial velocities, suggesting that it is a single-lined spectroscopic binary. P. De Cat applied for "Krediet aan navorsers" (2011) to finance future observations missions for ground-based observations of Kepler targets, but the proposal was rejected [36].

F.2.2.2. Contributions to the CoRoT mission

- *The interacting binary AU Mon = HD 50846.*
  AU Mon is a rare, strongly interacting semi-detached binary system consisting of a Be and a G-type component. AU Mon shows emission lines typical similar to those observed in Be stars. Analyses of resolution échelle spectra led to the determination of improved and consistent fundamental stellar properties of both components of this system. We derived new, accurate ephemerides for both the orbital motion and the long-term, overall brightness variation of this strongly interacting (Be + G) semi-detached binary with a mass ratio of 0.17 ± 0.03. The long-term variation must be due to attenuation of the total light by some variable circumbinary material. From this, we obtained improved

stellar masses, radii, luminosities as well as effective temperatures. We reported the discovery of rapid light changes visible in the high-quality residual light curves which are probably due to irregularities in the (circum)stellar gas distribution, rather than being caused by stellar pulsations. We further show that the observed lines of the B-type primary may not be of photospheric origin [16].

- The results for another Be star observed by CoRoT (ID 102761769) have also been published [20] .
- Input was given concerning two proposals for follow-up ground-based observations [77].

F.2.2.3. Eclipsing binaries with pulsations with CoRoT and Kepler

Various telescope time applications have been submitted to monitor bright Kepler and/or CoRoT targets in radial velocity with the aim to obtain the complementary data needed for a full exploitation of the light curves from space. We contributed to several applications with the HERMES spectrograph (cf. interdepartemental report) as well as to a few other applications through the Kepler-WG9 collaboration (e.g. WHT and NOT, La Palma, Spain).

F.2.3. Perspective for next years

The CoRoT and KEPLER missions will continue to produce a huge data-flow of highly precise data, thus allowing to remain actively involved with analysis, modelling and interpretation of current and future satellite asteroseismic data. The HERMES spectra obtained for several binary systems observed by the KEPLER satellite will be analysed next year.

F.2.4. Personnel

Scientific staff: P. De Cat, Y. Frémat, P. Lampens

F.2.5. Partnerships

List of international partners without grant

- C. Maceroni, INAF - Osservatorio Astronomico di Roma, Monte Porzio Catone, Italy
- D. E. Mkrtichian, Sejong University, Seoul, Korea
- A. Prša, Villanova University, Villanova, PA/USA
- P. Harmanec, Astronomical Institute of the Charles University, Czech Republic
- CoRoT B star working group (Chair: C. Aerts)
- CoRoT γ Dor stars working group (Chair: P. Mathias)
- CoRoT O star working group (Chair: C. Aerts)
- Kepler Asteroseismic Science Consortium (KASC; Chair: J. Christensen-Dalsgaard)
- KASC Working group #3 “β Cephei stars” (Chair: G. Handler)
- KASC Working group #6 “slowly pulsating B stars” (Chair: P. De Cat)
- KASC Working group #9 “pulsations in eclipsing binaries” (Chair: C. Aerts)
- KASC Working group #10 “γ Doradus stars” (Chair: J. Gouzik)

List of national partners without grant

- Group of C. Aerts, Inst. voor Sterrenkunde, KULeuven, Leuven, Belgium
- Belgian Group of Asteroseismology (BAG) led by C. Aerts & A. Noels

F.2.6. Missions

Assemblies, symposia, conferences

- P. De Cat: 3rd Kepler Asteroseismology Workshop “Kepler Asteroseismology in Action”, 14-18/06/2010, Aarhus, Denmark

Commissions, working groups

- P. De Cat: Contact group meeting, 25/05/2010, Planetarium, Brussels, Belgium
- P. De Cat, P. Lampens: Great in Belgium, 17/05/2010, ULB, Belgium
- P. De Cat, P. Lampens: Great kick-off meeting WG03 (Binary and multiple systems), 17-18/05/2010, ULB, Belgium
- P. De Cat: Great variable star working group meeting, 06/09/2010, KUL, Belgium

Research visits

- P. De Cat: 21/06-01/07/2010: McDonald Observatory, Mt. Locke, Texas, USA (7 nights of spectroscopic observations with RA2@McD/2.1-m; 22/06-28/06/2010)

F.2.7. Scientific outreach

Meeting presentations

(1) De Cat P., Briquet M., Bruntt H., Catanzaro G., Corbally C.J., Frandsen C., Frasca A., Fu J.N., Gray R.O., Gutiérrez-Soto J., Kiss L., Kurtz D.W., Marconi M., Molenda-Żakowicz, Niemczura E., Østensen R., Ripepi V., Smalley B., Southworth J., Szabó R., Telting J., Uytterhoeven K., Van Winckel H.
Characterization of KASC targets with the Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST)
Poster presented during the third Kepler Asteroseismology Workshop “Kepler Asteroseismology in Action”, 14-18/06/2010, Aarhus, Denmark

(2) Briquet M., Bruntt H., De Cat P., Gutiérriez-Soto J., Handler G., Marconi M., Molenda-Zakowics J., Niemczura E., Papícs P., Szabó R., Uytterhoeven K.
Characterization of Kepler main-sequence pulsators with HERMES
Talk presented by P. De Cat during the HERMES consortium days, 04/10/2010-05/10/2010, Leuven, Belgium

G. Stellar Characterization

G.1. Objectives

Stellar characterization is a must have while identifying pulsation modes or understanding the properties of stars. It is the very first step towards a better understanding of stellar physics. For example, effective temperatures of early-type supergiants are important to test stellar atmosphere as well as internal structure models of massive and intermediate mass galactic and extra-galactic stars at different evolutionary phases. These effective temperature values are however discrepant depending on the method used to determine them. The objectives are therefore to obtain a new calibration of the effective temperature for these stars as a function of observational quantities that are highly sensitive to the ionization balance in the photosphere and its gas pressure, but independent of the insterstellar extinction. Characterization is also applied in all other projects e.g. for describing the components of stellar systems (cf. "Binaries") or for determining the main properties of pulsating stars (cf. "Asteroseismology").

Highlight:

- Massive Be stars can be the progenitors of Long Gamma Ray Bursts.

G.2. Progress and results

Previous parameter determinations (i.e. mainly average stellar masses and angular speeds on the ZAMS) obtained for a large sample of SMC Be stars have been used to test the hypothesis that Be stars may be the progenitors of long gamma ray bursts (LGRBs). By comparing these parameters to predictions made for the LGRB progenitors (Figure 24) and by comparing the expected rate of yearly galactic LGRB rate to the observations, we proposed the most massive Be stars as LGRB progenitors [51].

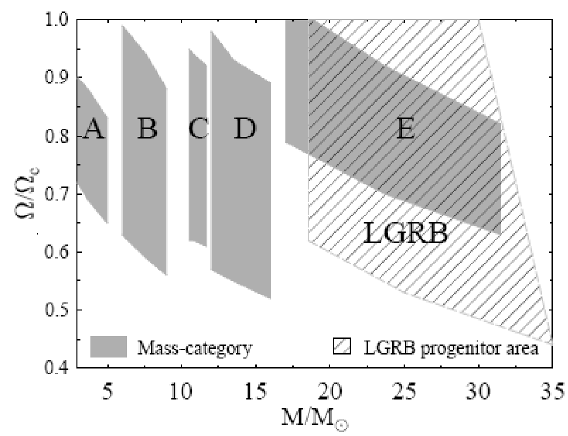

Figure 24: Be star masses and angular speeds are compared to the values expected for LGRB progenitors.

G.3. Perspective for next years

In the coming years, we will continue to apply stellar characterization and spectral synthesis to the study of the angular momentum evolution of massive fast rotators and Be stars.

G.4. Partnerships

List of international collaborators having actively contributed to the project in the last year

- Martayan, C., ESO, Chile
- Zorec, J., Institut d'Astrophysique de Paris

Visitors

- Zorec, J., Institut d'Astrophysique de Paris, 11.-14.01.2010, Differential rotation in A and B type stars, and angular momentum evolution of Be stars.
- Zorec, J., Institut d'Astrophysique de Paris, 06.12.2010-10.12.2010, Differential rotation in A and B type stars, and angular momentum evolution of Be stars.

H. Instrumentation

The design of new instrumentation is the mandatory path to a better comprehension of the universe and the stars. Through their development, we take a part to a work that generally profits to the whole scientific community while ensuring us a good knowledge of the instrument and of its possibilities.

Highlight:

- The Hermes data reduction pipeline is working and already provides good results.

H.1. The spectrograph HERMES

H.1.1. Objectives

HERMES is the acronym for High Efficiency and Resolution Mercator Echelle Spectrograph. The project consists in designing, constructing, and integrating the spectrograph at the Mercator telescope through a collaboration between the ROB and the KULeuven, the ULB, the Thüringer Landessternwarte Tautenburg, Germany, as well as the Geneva Observatory, Switzerland (cf. the interdepartemental report for our contributions).

H.1.2. Progress and results

Three proposals for high-resolution spectroscopic observations were submitted, two of which are in collaboration with the partner-institutes. Various of these telescope applications were submitted to monitor bright KEPLER and/or CoRoT targets in order to obtain the complementary data needed for a good exploitation of the light curves. Spectroscopic observations with the HERMES spectrograph attached at the Mercator telescope were acquired during 2 campaigns on site. First user tests with the new HERMES reduction pipeline were performed using some of the recently collected spectra.

H.1.3. Partnerships

List of national partners without grant

- H. Van Winckel et al., Instituut voor Sterrenkunde, KULeuven, Leuven
- A. Jorissen et al., Université Libre de Bruxelles

Visitors

- A. Tkachenko, Thüringer Landessternwarte Tautenburg, Tautenburg, Germany: April 26-30 (1 week)

H.1.4. Missions

Assemblies, symposia, conferences

- P. De Cat, Y. Frémat, P. Lampens, K. Torres, D. Wright: HERMES workshop, 04/10/2010-05/10/2010, Leuven, Belgium
- Y. Frémat: KU Leuven, Leuven – 25.01.2010, HERMES Telescope Allocation Committee meeting

Field missions

- P. Lampens : Feb. 18 - 28, Observations with the spectrograph HERMES mounted at the Mercator telescope, Observatory Roque de los Muchachos, La Palma (Spain), framework of the HERMES Consortium
- P. Lampens : Aug. 12 - 22, Observations with the spectrograph HERMES mounted at the Mercator telescope, Observatory Roque de los Muchachos, La Palma (Spain), framework of the HERMES Consortium

H.2. The "Humain Observatory for Astrophysics of Coeval Stars" (HOACS)

H.2.1. Objectives

The radio-astronomical station of Humain which is a part of the Royal Observatory of Belgium, is still a privileged site in Belgium with respect to location and environmental light pollution. It is therefore a proper site for the construction of a small optical observatory. The aim is to operate a small and well-equipped observatory which will be dedicated to a few specific observational programmes. The project "HOACS" was launched with the goal to perform photometric observations of (intrinsic as well as extrinsic) variable stars under sky conditions which are better than those in the region of Brussels, in support of the ongoing astronomical research projects of the Observatory.

H.2.2. Progress and results

After installation of the two 0.40-cm telescopes and of the computer network in 2009, the observatory entered its full operation modus in 2010. Observations were performed with the telescopes and their instruments on a routine basis [48]. Campaigns for specific targets were held as part of our international multisite campaigns. In total, we secured about 7000 CCD images and more than 100 hours of photometric data using two filters. Our first-priority targets in 2010 were: BS Uma [86] (cf. Figure 25), YY Boo [30], HIP 7666, IU Per as well as several other high-amplitude Delta Scuti stars [86] (cf. "Asteroseismology of binary or multiple stars"). HIP 7666 was discovered to be variable by the Hipparcos mission and is a known oEA star since 2005. We are performing a multi-year photometric monitoring of this target since Dec. 2008. Another follow-up campaign of HIP 7666 was held during Autumn 2010. The 0.4-m telescope (HULC1) had a stability problem which was solved after its complete dismounting in October. This was followed by an optical realignment. Consequently, we now have a stable guiding and sharper images.

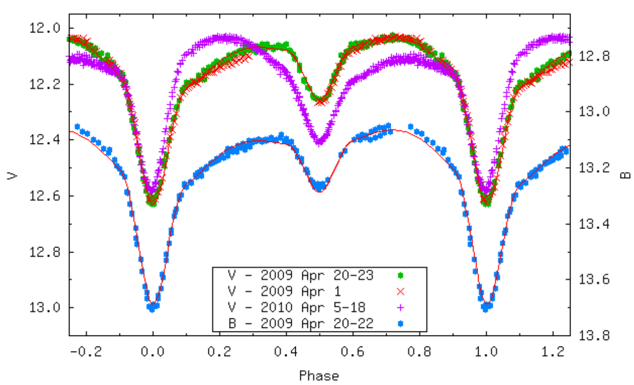

Figure 25: Variable light curves of the binary BS Uma during the years 2009 and 2010 (see two upper V light curves).

H.2.3. Perspective for next years

The observations at the Humain observatory will be continued during the next years in the context of the projects related to "Binaries and Multiple Stars" and "Asteroseismology".

H.2.4. Personnel involved

Scientific staff

- P. Lampens (project coördinator)

Technical staff

- Ir. V. Rogge (Security) helps to deal with the maintenance works under the control of the Walloon Administration of Buildings (Province of Luxemburg).
- Dhr. Janssens (technical expert) helps with logistical support.
- E. Thienpont (ICT expert, since May, 1st)

Volunteer

- P. Van Cauteren (observer)

H.2.5. Missions

Commissions, working groups, visitors

- Visit to LHOIST company, 23/04/10 (morning)
- Visit by LHOIST to the Humain station, 23/04/10 (afternoon)
- Visit with E. Thienpont (ICT) to the Humain station, 19/05/10
- Meeting with Electrabel delegation at the Humain station, 02/06/10
- Meeting with Ir. A. Mathijs for resolving the stability problem of the Minimount, 03/10/10
- Meeting of the Working Group LHOIST-ROB, BELSPO, Brussel, 25/10/10

Field missions

- P. Lampens : Jan - Dec. 2010, Differential CCD photometry of selected Delta Scuti and eclipsing variable stars, Humain Optical Observatory for Astrophysics of Coeval Stars (HOACS), Humain, Belgium, 2 x 0.4m telescopes equipped with SBIG CCD camera's (co-observer: P. Van Cauteren)(the observations in Oct. abruptly stopped due to repair of the heating system): 27 nights in total

I. Stellar winds and circumstellar structures

The research topic "stellar winds and circumstellar material" splits in several poles of interest: the strong radiatively driven winds from the most massive, short-lived stars, the mass-loss mechanism of the Asymptotic Giant Branch (AGB) stars and the strong winds in late evolutionary stages of intermediate-mass stars that give rise to planetary nebulae.

Multi-wavelength studies of the winds of massive stars show that they are structured and contain shocked gas; if this is not taken into account, predicted mass loss rates may be significantly in error and valuable indicators of stellar duplicity may be overlooked. The project I.1 concentrates on the understanding of the stellar winds in hot stars by confronting observations and theory (using hydrodynamic and radiative transfer modelling). The study of AGB stars (project I.2) stars is manifold, but concentrates on the understanding of the mass-loss mechanism, the derivation of mass-loss rates and the relation to fundamental stellar parameters, and the global evolution of stars on the AGB as a function of time, metallicity, mass, etc.

The mass loss in the final steps of evolution of initial intermediate mass stars is a complex process with repercussions on the internal evolution of the star itself. The complex interplay among various physical processes is not yet understood, but the structure of the circumstellar material must clearly reflect the history of the mass loss events. The project I.3 "Post-AGB stars and Planetary Nebulae" uses a multitude of observing techniques and a radiative transfer code developed by one of its members to gain insight in the late evolution stages of these stars.

I.1. Hot stars

I.1.1. Objectives

Hot stars have radiatively driven stellar winds. Considerable observational evidence exists that these winds are not smooth, but structured. In binary stars, the collision of both winds results in a highly structured colliding-wind region. This project tries to elucidate the nature of structure in the wind of both single and binary stars, by studying these stars observationally (at various wavelengths) and theoretically (by constructing models for the hydrodynamics and radiative transfer).

I.1.2. Progress and results

I.1.2.1. Non-thermal radio emitters

R. Blomme and D. Volpi continued the work on non-thermal radio emission in colliding-wind binaries. In such a system, the colliding stellar winds create a pair of very strong radiative shocks. At the shocks the electrons are accelerated up to relativistic speeds and spiral around the magnetic field lines thus emitting radio synchrotron radiation. This synchrotron emission was thought to be completely absorbed due to the free-free absorption of the stellar winds especially in the case of short-period binaries.

D. Volpi upgraded the theoretical model used previously and obtained a more realistic time evolution of the radio synchrotron emissivity from electrons along the wind post-shock streamlines. The model was applied to two binary systems: Cyg OB2 No. 8A and No. 9.

Cyg OB2 No. 8A. The simulated synchrotron emissivity seems to originate close to the shock where the greatest part of the non-thermal radiation is present. Even if the area where the synchrotron emission is present is not wide, the total flux is not negligible due to the extended three-dimensional volume around the shock. The model predicts phase-locked radio variability which is consistent with the observations, even if the phase of the flux maximum and minimum do not quite agree. Results were published in [11].

Cyg OB2 No. 9 (Figure 26). A preliminary 6 cm light curve from our modelling shows variability in the radio flux linked to the orbital period that is the fingerprint of non-thermal radiation. Compared to the observations by Van Loo et al. (2008), the theoretical fluxes are much too high and the maximum occurs too early. These preliminary results have been presented at conferences.

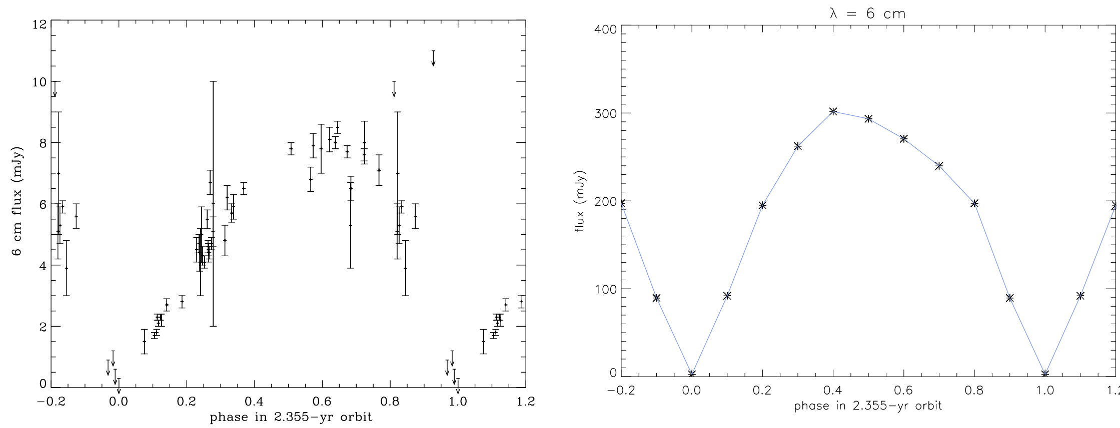

Figure 26: Cyg OB2 No. 9. On the left: the observed VLA radio fluxes at 6 cm from Van Loo et al. (2008, A&A, 483, 585). On the right: 6 cm model light curve

In order to improve the match between observations and the simulated results, R. Blomme ran hydrodynamical simulations of the Cyg OB2 No. 9 system. These simulations were done using the publicly available code ATHENA. The components of the Cyg OB2 No. 9 binary system were followed in their eccentric orbit and the hydrodynamical properties of the colliding-wind region were determined. D. Volpi is adapting the synchrotron emission code to take the hydrodynamical model as input. The programme will then calculate the transfer of this synchrotron emission through the free-free absorption processes occurring in the two stellar winds. Preliminary results were presented at a conference.

On the observational side, J. Vandekerckhove continued the reduction of radio data for another colliding-wind binary, 9 Sgr. These data will soon enable us to estimate a binary period of this system, thereby providing important information that – so far – has not been detected in the spectroscopic data. Additional radio observations are also being planned: a proposal led by R. Blomme has been awarded observing time on the EVLA (Expanded Very Large Array) to follow Cyg OB2 No. 9 during its periastron passage in 2011.

Optical spectra of non-thermal radio emitters were also acquired. HD 167971 was observed with the FEROS instrument on the 2.2-m telescope at ESO in Chile (PI: C. Nitschelm). The Hermes instrument on the Mercator telescope was also used to acquire a few spectra of the non-thermal radio emitters 9 Sgr, HD 168112 and HD 167971. Preliminary results (presented at (5)) clearly show radial velocity changes in HD 168112, strongly suggesting this star to be a binary.

Time was also invested in long-term planning of large-scale surveys at radio-wavelengths, using the updated and new instruments that are currently being developed. The ambitious project "MeerGAL: A MeerKAT high frequency Galactic Plane Survey" on the future MeerKAT instrument was awarded 3,300 hrs (PI: Mark Thompson, R. Blomme is one of the CoIs). R. Blomme also gave an invited review on radio observations of massive stars at the 39th Liège International Colloquium.

I.1.2.2. Stellar photosphere and wind structure

A. Lobel further developed the Wind3D code for parallel 3-D radiative transfer computations of large-scale wind structures in massive hot stars. A new input wind model parameterization module was implemented and has been extensively tested for detailed modeling of Discrete Absorption Components (DACs) and Rotational Modulations (RMs) observed in dynamic spectra of massive hot stars. The results have been presented at an international conference as well as in the popular science literature. To investigate the physical nature of RMs the publicly available Zeus3D code has been used. Preliminary results show that RMs are caused by periodic enhancements of the radiatively-driven outflow at the inner wind boundary due to pressure-density wave action at the rotating stellar surface. A main journal paper applying this to HD 64760 is in preparation.

D. Volpi participated in the service observations for the Hermes consortium, a collaboration between KULeuven, the Université Libre de Bruxelles and the Royal Observatory of Belgium with contributions from the Observatory de Genève and the Thüringer Landessternwarte Tautenburg). Hermes is an echelle spectrograph installed at the Mercator telescope on La Palma. D. Volpi collected new spectra of the hot stars HD 203064, HD 209975, and HD 214680 as well as spectra of hypergiants and Luminous Blue Variables (LBVs). The obtained data will be used to study the large-scale structure in the hot star winds and its connection with the photosphere.

Two Mercator-HERMES proposals by A. Lobel for 5-year spectroscopic monitoring observations of eight Luminous Blue Variables (LBVs) and 10 cool hypergiants have been accepted. A. Lobel is also part of an international collaboration that observed MWC 314, and found it to be a new LBV binary. They observe large changes of radial velocity in S II absorption lines over only ~5 days in Sep 2009 (see Figure 27). The result has very recently been confirmed with similar large radial velocity changes observed with HERMES over ~8 days in Oct. 2010. First results of both HERMES monitoring campaigns have been presented at national and international meetings (10).

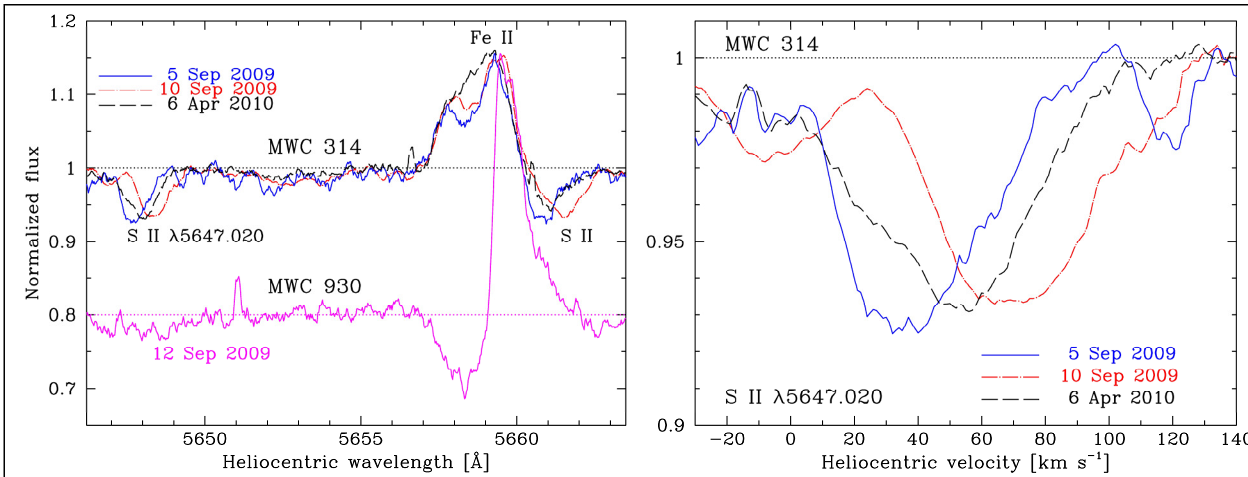

Figure 27: Large radial velocity changes of ~33 km s^{-1} observed in S II absorption lines (right-hand panel) of MWC 314 over 5 days with Mercator-HERMES reveal its LBV binary nature. The radial velocity of optical emission lines (i.e., of Fe II in the left-hand panel) are however invariable, signaling a stable circumstellar or circumbinary (disc) envelope. The spectrum of LBV candidate MWC 930 reveals many strong optical P Cygni profiles in Sep 2009 (*magenta curve*), signalling wind properties of a massive hot star (adapted from).

A. Lobel joined a new international working group for medium-resolution spectroscopic monitoring of the bright hypergiants Eta Car and Rho Cas by amateur astronomers. The observing programs of the working group are coordinated by E. Thienpont (ROB), and currently involve contributions of observers in Australia, Germany, and France. First results show that good quality optical spectra can be observed for both stars. Periodic changes of photospheric lines are monitored in Rho Cas, while a remarkable transient absorption feature was observed in Eta Car over a period of less than one month.

I.1.2.3. Gaia science exploitation

In preparation for the scientific exploitation of future Gaia data (specifically in the context of massive stars), various activities were undertaken. As co-facilitator of the GREAT (Gaia Research for European

Astronomy Training) Working Group on Massive Stars, R. Blomme organized the writing of a White Paper. This paper concentrates on the additional observations that are required in order to exploit the full potential of the Gaia data. The Working Group on Massive Stars joined the Working Group on Open Clusters and Young Associations to introduce a Letter of Intent for the ESO Public Surveys Call. The proposed survey is titled "Open Star Clusters: the path from molecular clouds to the MW disc population" (PI: Sofia Randich, Arcetri, Italy). CoIs include R. Blomme and Y. Frémat.

A. Lobel is co-facilitator of the Gaia GREAT Working Group on Stellar Atmospheres. He obtained funding by the European Science Foundation (ESF) and the Research Foundation – Flanders (FWO) for organizing an international 2-day workshop on "Stellar Atmospheres in the Gaia Era: Quantitative Spectroscopy and Comparative Spectrum Modelling", to be held on 23-24 June 2011 at the Vrije Universiteit Brussel (VUB) in collaboration with J. P. De Grève and W. van Rensbergen of VUB.

I.1.2.4. Other

An observing project with the ESO instruments X-Shooter, NACO and AMBER (PI: C. Martayan; CoIs include R. Blomme, Y. Frémat, A. Lobel) has been used to study, amongst others, the Pistol star. This star is the analogue of the more famous eta Car, which is a Luminous Blue Variable (LBV). These stars show large eruptions leading to substantial mass loss and considerable nebulosity around the star. The new observations obtained here show the Pistol star to be a binary, making the analogy with the eta Car binary even stronger. This discovery is highly important for the possible physical mechanisms that lead to large mass ejections in these LBVs. Preliminary results were presented at conferences and an A&A Letter (first author: C. Martayan) is in preparation. Further observations are also planned (PI: C. Martayan, CoIs include R. Blomme, Y. Frémat, A. Lobel).

In collaboration with P. Young and U. Feldman, A. Lobel investigated the symbiotic nova RR Tel. High-resolution spectra observed with STIS-HST and ESO-UVES have been utilized for accurate measurements of the reference wavelengths of many forbidden and intercombination emission transitions. The wavelengths are used to determine new energy levels. An investigation of the emission line profiles reveals that the RR Tel nebula consists of at least two components at different velocities. The components have different densities, and a simple model of the lines' emission demonstrates that most of the lines principally arise from the high density component. A major research paper has been submitted to the ApJ.

For the interpretation of the data from the Pistol Star, as well as data from other early-type stars, R. Blomme has in previous years calculated a number of theoretical spectra, using the publicly available CMFGEN code. During 2010 a job-student (Benjamin Laevens) used these models and developed software that allows an easy comparison to the observed spectra.

I.1.3. Perspective for next years

R. Blomme will interpret the reduced 9 Sgr radio data. In collaboration with D. Volpi, this system will be modelled. D. Volpi will continue to develop the synchrotron emission code. This updated code will be applied to Cyg OB2 No. 9 and to other O-type binary systems. The space of the model parameters will be better investigated in order to understand the physics at the base of the data. The emission from early-type stars will be studied in other bands, such as X-rays.

R. Blomme will also reduce and interpret the optical spectra of HD 167971, in collaboration with H. Hensberge. As data come in from the e-MERLIN COBRaS project, R. Blomme and J. Vandekerckhove will start reducing them. R. Blomme will continue the construction of a grid of CMFGEN models and will compare the output to the observations. Planning for the future exploitation of Gaia data will also continue, and will receive a greater emphasis in the coming years.

Research on multi-D radiative transfer modeling and quantitative spectroscopy by A. Lobel of hot star wind structures will continue utilizing the high-performance computing facilities of the ROB. Future research on hot stars will focus on determining the detailed physics properties of large-scale wind structures such as rotational modulations observed in HD 64760, based in part on the new parameterized input modeling method with the Wind3D code. The development of the code with international collaborators will continue for performing multi-D RT calculations of LBVs based on our long-term HERMES monitoring programs.

I.1.4. Personnel involved

Scientific staff:	R. Blomme (ROB)
	A. Lobel (ESA Prodex Gaia contract C90290)
	D. Volpi (Action 1 contract, MO/33/024)
Technical staff:	J. Vandekerckhove (ROB)

I.1.5. Partnerships

List of international partners or collaborators having actively contributed to the project in the last year

- ***J. Drew, University of Hertfordshire, UK.*** Co-facilitator Workgroup Massive Stars in GREAT Consortium.
- ***C. Nitschelm, Universidad Católica del Norte, Chile.*** Spectroscopic observations of non-thermal radio emitter HD 167971.
- ***R. K. Prinja, University College London, UK.*** PI of COBRaS, the e-MERLIN Legacy project to observe Cyg OB2.
- ***S. Randich, INAF-Osservatorio di Arcetri, Italy.*** PI of ESO Public Survey proposal.
- ***M. Thompson, University of Hertfordshire, UK.*** PI of MeerGal, the Meerkat Legacy proposal to observe, among others, massive radio-emitting stars.
- ***J. Groh, MPIA-Bonn, Germany.*** Research collaboration program on radiative transfer modeling of LBV binaries monitored with Mercator-HERMES.
- ***C. Martayan, European Southern Observatory, Chile.*** Research collaboration program on spectroscopic and imaging observations of the Pistol Star with ESO instruments.
- ***P. Young, U. Feldman, Naval Research Laboratory, G. Mason Univ., Fairfax, VA, USA.*** Research collaboration program on the analysis of high-resolution HST and ESO-UVES spectra of RR Tel.
- ***I. Kolka,Tartu Obs., Estonia; C. Soubiran, Univ. Bordeaux, France.*** Research collaboration on properties of prominent emission lines in Be stars.
- ***J.A. Toalá Sanz, University of Mexico UNAM, Mexico.*** Research collaboration program on the development of the Wind3D radiative transfer code with application to massive hot stars.

List of national partners or collaborators having actively contributed to the project in the last year

- ***C. Aerts, KULeuven.*** CoRoT data of O-type stars.
- ***M. De Becker, M. Godart, E. Gosset, L. Mahy, T. Morel, Y. Nazé, G. Rauw, Université de Liège.*** Non-thermal radio emitters, CoRoT data of O-type stars and ESO Public Survey collaboration.
- ***P. Royer, KU Leuven.*** Research collaboration program for the development of the HHighRepect database based on a survey observing program with Mercator-HERMES.
- ***N. Gorlova, KU Leuven.*** Research collaboration program for modeling and monitoring of LBVs with Mercator-HERMES.
- ***J.-P. De Grève, W. van Rensbergen, VU Brussel.*** GREAT-ESF workshop on Stellar Atmospheres coordination meetings at VUB.

Grants/Projects used for this research/service

- Action 1 project MO/33/024 (Colliding winds in O-type binaries) from BELSPO
- ESA Prodex Gaia contract C90290
- FWO-project G.0332.06 "Observationele bepaling van nauwkeurige interne en circumstellaire structuurmodellen van sterren", Promotor: Prof. Dr. Conny Aerts, partners: K.U.Leuven, UGent, V.U.Brussel, ROB (J. Cuypers).

Visitors:

- Short visits: 2

I.1.6. Scientific outreach

Meeting presentations

(1) Blomme, R.
Radio observations of massive stars
39th Liège Int. Astrophys. Coll. "The multi-wavelength view of hot, massive stars", Liège, invited review

(2) Blomme, R.
Massive Stars
Workshop "Ground-based observations and theoretical analysis for the Gaia Science on Open Clusters and Young Associations", Catania, Italy, contributed paper

(3) Blomme, R.
Massive Stars GREAT working group
Meeting "GREAT in Belgium", ULB, Brussels, contributed paper

(4) Blomme, R.
WGB5 Massive stars
GREAT Plenary Meeting 3, ESTEC Noordwijk, The Netherlands, contributed talk

(5) Blomme, R.
Stellar winds of massive stars
HERMES meeting, Leuven, contributed paper

(6) Lobel, A.
GREAT-ESF in Belgium: Stellar Atmospheres
Gaia Workshop, ULB, Brussels, Belgium, invited talk

(7) Lobel, A., Heiter, U.
GREAT-ESF: Stellar Atmospheres
GREAT Plenary Meeting 3, ESTEC Noordwijk, The Netherlands, contributed talk

(8) Lobel, A., Toalá, J.A., Blomme, R.
3-D Radiative Transfer Modeling of Structured Winds in Massive Hot Stars with Wind3D
39th Liège Int. Astrophys. Coll. "The multi-wavelength view of hot, massive stars", Liège, contributed talk

(9) Lobel, A., Groh, J.H., Torres, K., Gorlova N.
Long-term Spectroscopic Monitoring of LBVs and LBV Candidates
IAU Symposium 272, "Active OB Stars: Structure, Evolution, Mass Loss, and Critical Limits", Paris, France, poster paper

(10) Lobel, A., Groh, J.H., Torres, K, Gorlova, N.
Long-term Spectroscopic Monitoring of Luminous Blue Variables and Hypergiants
Mercator-HERMES Consortium meeting, KU Leuven, Belgium, contributed talk

(11) Martayan, C., Blomme, R., …, Frémat, Y., Lobel, A., …
X-shooter, NACO, and AMBER observations of the LBV Pistol Star
39th Liège Int. Astrophys. Coll. "The multi-wavelength view of hot, massive stars", Liège, poster paper

(12) Martayan, C., Blomme, R., …, Frémat, Y., Lobel, A., …

High-angular Resolution Observations of the Pistol Star
IAU 272, "Active OB Stars: Structure, Evolution, Mass Loss, and Critical Limits", Paris, France, poster paper

(13) Volpi, D., Blomme, R., De Becker, M., Rauw, G.
Non-thermal radio emission from colliding-wind binaries: modelling Cyg OB2 No. 8A and No. 9
IAU Symposium 272 "Active OB stars: structure, evolution, mass loss and critical limits", Paris, France, poster paper

Wikis and Websites

- R. Blomme is responsible for contents of the website of "Hot Star Group" of the ROB (webmaster = J. Vandekerckhove) http://www.astro.oma.be/HOTSTAR/index.html
- R. Blomme is co-facilitator of the GREAT (Gaia Research for European Astronomy Training) Working Group on Massive Stars. He organized and contributed to the White Paper, available on the Great Wiki site: http://cam08.ast.cam.ac.uk/GreatWiki/WG5MassiveStars
- A. Lobel is responsible for the website for the GREAT workshop "Stellar Atmospheres in the Gaia Era: Quantitative Spectroscopy and Comparative Spectrum Modelling" http://great-esf.oma.be

I.1.7. Missions

Assemblies, symposia:

R. Blomme (ELSA Conference "Gaia: at the frontiers of astrometry", Paris)

R. Blomme, A. Lobel, D. Volpi (39th Liège Int. Astrophys. Coll. "The multi-wavelength view of hot, massive stars")

A. Lobel, D. Volpi (IAU Symposium 272, Active OB stars: structure, evolution, mass loss and critical limits, Paris)

Commissions, working groups (days):	R. Blomme (8 days) J. Cuypers (2 days) A. Lobel (11 days) D. Volpi (1 day)
Research visits (days):	R. Blomme (3 days)
Field missions (days):	D. Volpi (11 days)

I.2. AGB stars

Essentially all stars with an initial mass between 1 and 8 solar mass will pass through the Asymptotic Giant Branch (AGB) phase at the end of their life before becoming Planetary Nebulae and White Dwarfs. Mass loss is one of the main characteristics of AGB stars. Because of the nucleosynthesis that takes place in the interior and the dredge-up of this material to the surface, AGB stars, together with possibly Supernova, dominate the return of gas from stars to the interstellar medium (ISM) from which new generations of stars are born. The central stars are cool (T_{eff} < 3000 K) and dust usually forms close to the star, and in this way, AGB stars are also very important contributors to the dust content in the ISM.

I.2.1. Objectives

The study of AGB stars is manifold, but concentrates on the understanding of the mass-loss mechanism, the derivation of mass-loss rates and the relation to fundamental stellar parameters, and the global evolution of stars on the AGB as a function of time, metallicity, mass, etc. The studies encompass sometimes individual stars or samples of stars, both in our Galaxy and in the Local Group, and sometimes more theoretical population studies to put the AGB phase in the broader context of stellar evolution.

I.2.2. Progress and results

I.2.2.1. The Herschel Guaranteed Time (GT) Key Programme (KP) MESS (Mass-loss of Evolved StarS)

The Royal Observatory is leading the Herschel Guaranteed Time Key Project "MESS" (Mass loss of Evolved StarS, GTKP MESS) which brings together an international consortium of astrophysicists. This project will observe a wide variety of evolved stellar objects in spectroscopic and photometric mode in the far-IR using both the PACS and SPIRE instruments on board the Herschel satellite. The main aims of this project are three-fold: (1) to study the time-dependence of the mass loss process, via a search for shells and multiple shells around a wide range of evolved objects, in order to quantify the total amount of mass lost at the various evolutionary stages of low to high-mass stars, (2) to study the dust and gas chemistry as a function of progenitor mass, and (3) to study the properties and asymmetries of a representative sample of low- and intermediate- (i.e. AGB, post-AGB, PN) as well as high-mass (i.e. RSG, WR, LBV) post main sequence objects, and supernovae.
M. Groenewegen is the principal investigator of this GTKP, thanks to the GT awarded to Belgium because of its 20% share and co-PI ship (Prof. Waelkens, KUL) in the development of the PACS instrument (K.U. Leuven+CSL+IMEC). The programme aims at observing about 100 AGB, post-AGB, PNe, WR, LBV, SN stars with the PACS bolometer and SPIRE instrument at particular wavelengths between 110 and 500 micron in the far infrared and about 40 objects with the PACS spectrometerbeween 60 and 120 micron and the SPIRE-FTS instrument between 200 and 500 micron.
Herschel was successfully launched May 14, 2009, and after the commissioning of the telescope and instruments, and the so-called Science Demonstration Phase (SDP), entered the Routine Phase (RP) at the turn of 2009-2010, and this will last until the end of the mission (nominally 3 years).

M. Groenewegen also helped in preparing the observations for this Science Demonstration Phase (SDP), and, when these data became available in September he worked on the data reduction.

A PRODEX proposal, led by Waelkens, and involving all institutes with a stake in GTKPs using Belgian time, was approved. P. van Hoof started working on this project on 1 May 2009 and is involved in the analysis and modelling of the post-AGB and PN data. He is also responsible for the maintenance of the dedicated data reduction server at the ROB ("hipesrv"). P. van Hoof started by collecting and reducing complementary satellite data from IRAS, ISO, Spitzer, and other observatories. He then produced flux estimates for the PNe in the MESS programme necessary for defining the observing templates with Herschel PACS. He also added several new commands to the photoionization code Cloudy (see section K.1) needed for modelling the Herschel data. The coding is now complete and the commands will be part of the upcoming Cloudy release.

During the year several consortium meetings took place. The imaging and spectroscopic AOR's needed several updates and refinements to the latest findings and instructions.

Most of the other work performed in 2010 was geared towards the preparation of publications for the A&A special issue on Herschel that was published in July. M. Groenewegen contributed significantly to the papers by Ladjal et al. ([44]) which presents the discovery of a bow-shock associated with the well-known carbon star CW Leo, and an analysis of the observed SPIRE and PACS fluxes. He also contributed to the article by Kerschbaum et al. ([43]) which present PACS observations of carbon stars that have detached shells, thought to be associated with a very large mass-loss rate event of short duration in the past due to a thermal pulse. The paper presents one new discovery of such stars, and the PACS observations of two stars known to possess shells from earlier CO data, but where spatially resolved observations of the thermally emitting dust are now presented for the first time. The paper presents the 1-dimensional intensity profiles and fits to this data based on radiative transfer modelling, M. Groenewegen contributed in a minor way to the paper by Cernicharo et al. ([13]), who presented the first detection of HCl in CW Leo, to the paper by Decin et al. ([17]), who presented data of SiO and SiS molecules around the same star, to the paper by Wesson et al. ([86]), who presented SPIRE spectra of the carbon-rich objects AFGL 2688, AFGL 618 and NGC 7027, and to the paper by Royer et al. ([73]), who presented PACS and SPIRE spectroscopy on the well-known supergiant VY CMa.

A highlight in the latter half of 2010 was the publication of the very first paper published in Nature based on Herschel data by Decin et al. ([16]). A few years ago a water line was discovered in the spectrum of CW Leo. In a carbon star, the abundance of water is expected to be extremely low (all oxygen is bound in CO, and only carbon-containing molecules should exist). At the time this was interpreted as possibly due to the infall on the central star of "icy bodies", and this result (itself a Nature paper) drew a lot of attention at the time. The interpretation was based however on a single water line. Decin et al. now present data on dozens of water lines detected with the PACS and SPIRE spectrometers. Using appropriate modelling the theory of the infall of comets (and other theories that have been put forward) can all be disproved, mainly because it is shows that the excitation temperature of the water is very high, implying that the water is formed quite close to the star. The new hypothesis that is put forward is that the circumstellar material around CW Leo is clumpy, and that interstellar UV photons can deeply penetrate triggering chemical reactions that allow the water to be formed. The publication of the paper was accompanied by a press release that was picked up by many media both in Belgium and internationally (VRT news, Metro, BBC World, amongst others).

On behalf of the consortium, M. Groenewegen prepared and submitted a paper describing the MESS program (target selection, observing strategy, reduction strategy, photometry of AGB stars observed up to October 2010).

I.2.2.2. VISTA-VMC

M. Groenewegen is co-investigator of one of the six *public surveys* (PS) selected by ESO to be carried out in the first few years of operation of the VISTA (Visible and Infrared Survey Telescope for Astronomy) telescope, called VMC (VISTA Magellanic Cloud, P.I. Maria-Rosa Cioni) survey. M. Groenewegen will lead the effort in the field of AGB stars. The commissioning of the telescope was carried out in the winter of 2009/2010 and is now in full operation.

An Action 1 project was approved in 2009 and M. Gullieuszik started as a postdoctoral researcher on March 1, 2010. M. Gullieuszik worked on part of the data that was taken in the first observing season 2009/10. The data reduction and generation of source catalogues with magnitudes and source positions is done by a dedicated centre (CASU, which reduces the data for all 6 PS) in the UK. As could be expected at the start of such a huge effort, there were many versions of the data products released in rapid succession reflecting the ramp up of the "learning curve". Although this led to some delays in the analysis (as some steps had to be repeated several times using the latest catalogues each time), M. Gullieuszik could develop and test the software on our side. The main aim of the program is to 1) correlate the new VISTA (Y,J,K) magnitudes with other available data in the literature, mainly optical data, and mid-IR data from the publically available SAGE survey in order to construct spectral energy distributions (SEDs), 2) Select the AGB stars from this catalogue, 3) fit the SEDs with the radiative transfer (RT) model provided by M. Groenewegen (see I.2.2.3), and derive mass-loss rate and luminosity. Steps 1 and 3 are now implemented for a simple selection of the AGB stars.

Ultimately, when data for the entire Magellanic Clouds (MCs) are available, it would be possible to determine the mass return to the ISM based on all AGB stars, but also compare in detail (that is, spatially resolved) the properties of AGB stars over the MCs, and with the underlying main-sequence population. The latter step is in collaboration with Leo Girardi in Padua who leads the VMC effort there.

M. Gullieuszik and M. Groenewegen attended the VMC consortium meeting where a status report was presented.

I.2.2.3. Spitzer data of evolved stars in the Magellanic Clouds

M. Groenewegen continued to work on the analysis of AGB stars and RSGs (Red Super Giants) in the Small and Large Magellanic Clouds for which Spitzer IRS spectra are available. Collaborator Greg Sloan provided spectra reduced in a uniform way of programs that have become publically available. The total database currently stands at 340 objects (compared to 200 that M. Groenewegen and co-workers analysed in a 2009 paper).

In preparation of the final analysis, several upgrades have been implemented to the tools used previously. Firstly, new model atmospheres have now become publically available for both oxygen-rich objects (the MARCS models) and C-rich objects. Secondly, the correlation of the objects with other data (-bases) in the literature has been improved and updated (e.g. with new Akari data), so that better and more complete SEDs are available besides the Spitzer IRS spectra.

More importantly though, M. Groenewegen has worked on including the publically available radiative transfer code DUSTY as a subroutine in a minimisation program. In the 2009 paper, the same technique was used but with M. Groenewegen's old RT code. However, DUSTY offers more flexibility. The new MoD ("More of DUSTY") code will be used not only for this work, but also by M. Gullieuszik for the analysis of the VISTA data (see I.2.2.2), and by M. Groenewegen in future work on the analysis of Herschel data. Especially for the latter the new code offers enhanced possibilities as it allows fitting not only broad-band magnitudes (SEDs) and spectra, but also visibility curves, and intensity profiles that come out of the Herschel imaging.

I.2.2.4. Other

M. Groenewegen was involved and contributed to several other projects that were described in the 2009 Annual Report and that led to a publication in 2010:

- The work by Ladjal et al. ([46]) on Apex LABOCA data of several AGB stars.
- The work of Uttenthaler et al. ([79]) on Spitzer IRAC and MIPS observations of several fields in the direction of the Galactic Bulge.
- M. Groenewegen's contribution at the IAU General Assembly ([20]).

I.2.3. Perspective for next years

Data from the MESS GTKP will continue to be taken in 2011. In conjunction with the MESS partners in Belgium and in the other partner countries the scientific analysis will continue with several papers already in preparation, including analysis of Planetary Nebulae and AGB stars performed at the ROB within the PRODEX program.

New VISTA-VMC data will be taken in every winter for the coming four years. The initial period where changes in data reduction and catalogue generation (performed in the UK and not under our control) were quite rapid has probably ended, we should enter a phase were consolidated results can be obtained. Most of the software to analyse the data is now in place and several publications are expected in 2011.

In the course of 2011 additional spectra will become available from Spitzer IRS programs that are currently still embargoed, and a final analysis of late-type stars in the Magellanic Clouds will be undertaken.

I.2.4. Personnel involved

Scientific staff:	M. Groenewegen (ROB)
	G. Van de Steene (ROB)
	P. van Hoof (Grant nr. C90371 from PRODEX)
	M. Gulieszik (Action 1 project MO/33/026)

I.2.5. Partnerships

List of international collaborators having actively contributed to the project in the last year

- Greg Sloan, Cornell University
- Leo Girardi, Padua University
- Maria-Rosa Cioni, ESO and Univ. of Hertfordshire

- Franz Kerschbaum, University of Vienna

List of national partners collaborators having actively contributed to the project in the last year PACS Team in Leuven

- Alain Jorissen, Sophie van Eck (ULB)

Grant(s)/Project(s) used for this research/service

- Grant nr. C90371 from PRODEX
- Action 1 project MO/33/026

I.2.6. Scientific outreach

Meeting presentations

(1) Groenewegen, M.A.T.
MESS – Mass loss of Evolved Stars, initial results
Oral presentation at : "ESLAB 2010, Herschels First Results Symposium"

(2) Groenewegen, M.A.T
MESS – Mass loss of Evolved Stars, first results
Invited presentation at: COSPAR 2010

(3) Groenewegen, M.A.T.
MESS – Mass loss of Evolved Stars, an overview
Invited presentation at: "Why Galaxies care about AGB stars II"

(4) M. Gullieuszik, M.A.T. Groenewegen and the VMC team
The AGB stellar population in the Magellanic system: first results from the VMC survey
Why galaxies care about AGB stars II, Vienna, August 2010

Seminars

(1) Gullieuszik, M.
Asymptotic giant branch stars. Theoretical models and observational constraints.
Royal Observatory of Belgium

Wikis and Websites

- https://forge.roe.ac.uk/twiki/bin/view/VMC/WebHome -not public-
- http://star.herts.ac.uk/~mcioni/vmc/ VMC survey homepage

I.2.7. Missions

Assemblies, symposia, conferences:

M. Groenewegen:
- The origin and fate of the Sun, ESO-Garching, 2-5 March 2010
- ESLAB 2010, Herschels First Results Symposium, Noordwijk, 4-7 May 2010
- VMC consortium meeting, Padua, 28-29 June. 2010
- COSPAR 2010, Bremen, 19-23 July 2010
- Why Galaxies care about AGB stars II, Vienna, 16-20 August 2010
- GREAT workshop on comparative modelling of stellar spectra, Vienna, 23-24 August 2010
- Observing with ALMA – Early Science, Grenoble, 30/11-1/12 2010
- VMC Consortium meeting, Padua, 28-29 June 2010

M. Gullieuszik:
- Why Galaxies care about AGB stars II, Vienna, 16-20 August 2010

Commissions, working groups:
- M .Groenewegen (9)
- M. Gullieuszik (2)

Research visits:
- M. Groenewegen (14)
- M. Gullieuszik (1)

Field missions:
- M. Groenewegen, Observing trip, La Silla, Chile, 23-28 September 2010

I.3. Post-AGB stars and Planetary Nebulae

I.3.1. Objectives

In this research topic the final stages of evolution of intermediate mass stars is studied, i.e. the evolution from the Asymptotic Giant Branch (AGB) through the planetary nebula phases. This evolution is still poorly understood mainly because of a complex interplay among various physical processes between the central star and its circumstellar nebula (created through mass loss, which also influences the internal evolution of the central star). Hence these objects provide excellent laboratories of astrophysical processes.

I.3.2. Progress and results

I.3.2.1. The Herschel Guaranteed Time (GT) Key Programme (KP) MESS (Mass-loss of Evolved StarS) and the planetary nebula NGC6720 (Ring Nebula)

The Herschel satellite and the Herschel Guaranteed Time (GT) Key Programme (KP) MESS (Mass-loss of Evolved StarS) were described in section I.2.2.1.

PACS and SPIRE images have been obtained for NGC 6720 (the Ring Nebula) in SDP time. The images have been prepared for presentation during the “Initial results workshop” in Madrid in December 2009. NGC6720 is an evolved planetary nebula with a central star that is currently on the cooling track, due to which the outer parts of the nebula are recombining. There is a striking resemblance between the dust distribution and the H_2 emission, which appears to be observational evidence that H_2 has been formed on grain surfaces. The physical conditions of the dust were determined and it was investigated whether the H_2 could have been formed since the central star underwent a strong drop in luminosity about 1000 to 2000 years ago. These results were presented in the first results letter “Molecular hydrogen in NGC 6720: formation on dust grains” [82]. After the SDP phase more data were obtained and first results were presented. Lot of time was spent in writing the script for the map making with *photproject*, and finally giving up upon. A new script was written and several tests performed with the new mapmaking program *Scanamorphos*. The PACS maps for all the data obtained with the PACS and SPIRE instruments on board the Herschel Telescope. Some scripts were adapted to reduce the scan maps and parallel PACS/SPIRE maps up to level 1. *Scanamorphos* deals much better with the sometimes large extent and high dynamic range present in our objects. The remaining problems were discussed and the maps were remade when different versions and improvements became available.

The maps are ready to be analysed. The overview article has been accepted for publication [57]. A follow up Hermes Open Time-1 proposal was prepared in July 2010, but unfortunately not accepted.

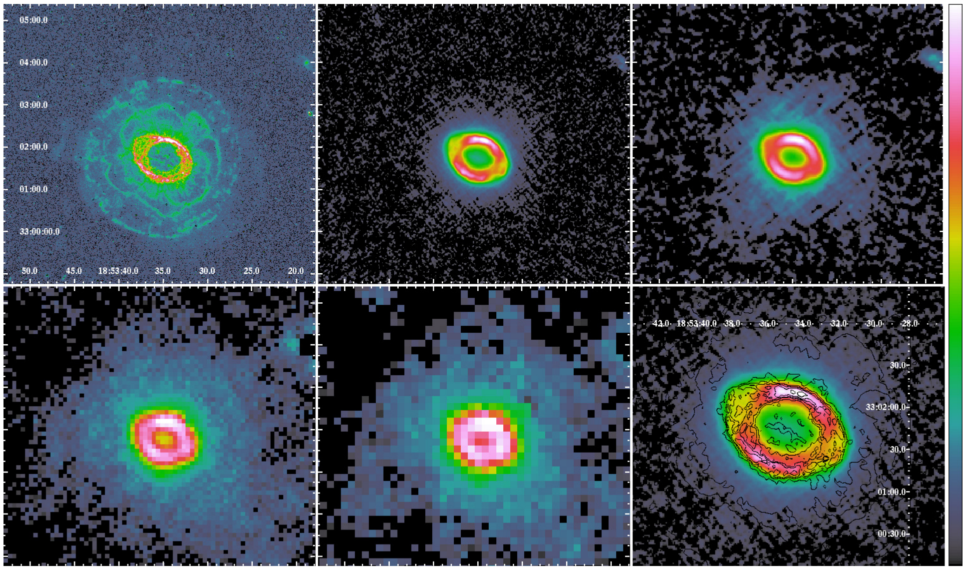

Figure 28: NGC 6720 in five photometric bands. Top row from left to right: H2 2.12 m, PACS 70 µm, PACS 160 µm. Bottom row from left to right: SPIRE 250 µm, SPIRE 350 µm, and an overlay of the Calar Alto H2 contours on the PACS 70 µm image. The H2 image is not flux calibrated. The maps have standard orientation (N to the top, E to the left).

I.3.2.2. Evolved objects in binaries: the evolution and binary connection

The Hermes spectrograph in combination with the Mercator telescope is a unique tool to study binary evolutionary channels and large program focuses on the wide variety of distinct (suspected or proven) classes of binary stars with evolved components. By combining high S/N single observations with low S/N time series, we aim at quantifying orbital and chemical characteristics of every distinct subgroup. The suspected orbital periods range from days (sdB stars, planetary nebulae) to years (post-AGB stars, Ba stars, J-type silicate stars etc.) so the sampling rate is tuned to the expected behaviour. The ultimate goal of this long program is to connect the zoo of different objects, into a sound evolutionary picture which accounts for the chemical peculiarities and the dynamical constraints set by orbital distribution and binarity rates. Checking of the data and preparation of the observations chewed up a lot of time before the data became available at the Observatory in September 2010. Since then scripts have been written to make logs and plots, which facilitates the former significantly. Once the new pipeline becomes available and the data are rereduced, the analysis will make progress.

I.3.2.3. A Statistical Sample of Planetary Nebulae in the Galactic Bulge: Measuring Masses and Mass-Loss Rates

In collaboration with R. Sahai from JPL G. Van de Steene proposed to exploit Herschel's unprecedented sensitivity to obtain 100-500 micron photometry for a statistical, flux-limited (in the IRAS 60 micron band) sample of Galactic bulge planetary nebulae (GBPNe), using PACS and SPIRE. The Galactic Bulge volume, offers a unique, nearby environment where a statistical population of PNe, all at roughly the same well-established distance, can be studied in order to understand these objects, test theoretical models for their formation and evolution, and address the mystery of the constancy of the PN luminosity function (an important cosmological distance indicator). Much of the mass ejected during the preceding AGB phase is expected to lie outside the ionised shells in these objects, and can only be detected via the thermal emission from cold dust. Herschel provides us the only platform to measure the mass budgets of a statistical sample of GBPNe, and thus help us address one of the longest standing astrophysical problems: the relationship between the birth mass of solar mass stars and the mass left at the end when they die. PNe are an important contributor to the total mass return to the ISM for the old Bulge population, and the proposed observations will allow us to infer the PN contribution to the total rate of mass loss in the Bulge, a crucial input to evolutionary models. The robust constraints to the progenitor masses of PNe from our study will allow elemental enrichments to be determined as a function of initial stellar mass, providing key information for models of AGB nucleosynthesis. Besides constructive comments, G. Van de Steene prepared ALL imaging AOR´s in time. The proposal was awarded 25h of priority-2 time.

I.3.2.4. FP7 proposal entitled: The Herschel Space Observatory: New challenges for the Study of Evolved Stars

The central idea of this project is a comprehensive analysis and interpretation of HIFI and PACS & SPIRE data collected for evolved stars. In synergy ground based observations will be obtained in order to enable extensive modelling of the photospheric and circumstellar chemistry. The main scientific aim of such analysis is to gain deeper insight into the mass-loss process of evolved stars of low and intermediate mass (1–8 $M_{\odot}$). The mass loss rates as well as reasons for departure from spherical symmetry among ejected envelopes are among the main unsolved problems of stellar astrophysics. This collaborative endeavour aims at a much better understanding in the chemical and physical fate of solar like stars.

I.3.2.5. The shaping of planetary nebulae: the structure of the inner regions with ESO's Very Large Telescope Interferometer.

Planetary nebulae (PNe) form in the late stages of the life of sunlike stars when the outer layers of gas, which have been expelled during the asymptotic giant branch (AGB) phase, glow with energy from the central star producing beautiful objects. Many post-AGB stars have extremely complex and varied morphologies, but the mechanisms, which produce such a wide variety of shapes and features, are still not well understood. The presence of a binary central star, stellar winds, and magnetic fields may all play a role. High resolution, state-of-the-art instruments are needed to peek inside the inner regions of these objects where the processes responsible for the shaping originate. ESO’s Very Large Telescope Interferometer with the MIDI and AMBER instruments was used to study the inner regions of the post-AGB star HD101584 and PN Hen2-90. They both show a fast bipolar outflow and seem to contain a binary central star and a disk. The VLTI observations resolve the inner regions and allow us to model in detail the geometry and chemistry of their compact disks. The determination of the different components of these systems, their physical properties, and their influence on commonly observed properties in their optical spectra, could teach us much about the physics of other (fainter) post-AGB stars.

Setup and preparation of this Action 1 project was submitted to the Scientific Council in 2010 but not forwarded, although it was considered as a good proposal from a scientific point of view. An observing proposal to continue the study of Hen2-90 with the VLT interferometer was accepted and granted time to be observed when the object is visible during P87 in 2011.

I.3.2.6. Sakurai's Object

When intermediate mass stars reach the final stages of their evolution, they experience thermal pulses. These are semi-periodic helium shell flashes that occur mostly at the tip of the AGB. It is theorized that about 25% of all objects will experience one additional (very) late thermal pulse (VLTP) after they have left the AGB. Despite this high percentage, this process is only very rarely observed. The discovery of Sakurai's star in 1996 provided the first opportunity in modern times to observe a very late thermal pulse. This object has baffled the scientific community with its very fast evolution. To reproduce this evolution we have proposed a new theoretical model which suppresses convective mixing under the influence of flash burning. A strong prediction of this model is that the star will evolve back to a temperature of 80,000K within 10 years. In an international collaboration we are monitoring this evolution. We have obtained new optical spectra (FORS2, VISIR on the VLT) in 2010 and a new proposal for VLT FORS2 and

VISIR observations in 2011 has been accepted. The reduction of the VLT data is underway. In van Hoof et al. (2007) we proposed that the marked increase in radio flux that we observed in 2006 and 2007 is due to an increase in temperature of the central star, now starting to photoionize carbon. The new data will be used to test that proposal and deepen our understanding of this process. P. van Hoof was PI on a proposal of an international team of experts to obtain PACS and SPIRE spectra of all known VLTP objects with Herschel during OT1. Unfortunately this proposal was not awarded any time.

I.3.3. Perspective for next years

G. Van de Steene will continue to work on Herschel PAC data of the MESS program and publish the results. She will also work on data of PNe in the galactic bulge as they will become available. New Herschel OT2 proposals will be prepared.

Hermes data will be collected and analysed. Proposals to continue the project will be prepared and submitted.

P. van Hoof will continue to work on the Herschel MESS data at least until 30 April 2011. He will be responsible for the analysis and publication of both spectroscopic and photometric data of selected post-AGB stars and PNe. He will also continue to maintain the dedicated data reduction server.

I.3.4. Personnel involved

Scientific staff: M. Groenewegen, G. Van de Steene, P. van Hoof

I.3.5. Partnerships

List of international collaborators having actively contributed to the project in the last year

- MESS consortium
- Hermes consortium on binary stars
- Mike Barlow, University College London, stellar evolution expert
- Toshiya Ueta, University of Denver, stellar evolution expert
- Vicent Peris, Valencia University, astrophotographer
- Roland Ottensamer, University of Vienna, data reduction expert
- Bruce Sibthorpe, Royal Observatory Edinburgh, data reduction expert
- Tanya Lim, Rutherford Appleton Laboratory, data reduction expert
- Mikako Matsuura, University College London, stellar evolution expert
- Albert A. Zijlstra, University of Manchester, stellar evolution expert
- Marcin Hajduk, Centrum Astronomii, Torun, radio expert
- Stefan Kimeswenger, Leopold-Franzens University Innsbruck, stellar evolution expert
- Albert A. Zijlstra, University of Manchester, stellar evolution expert
- Marcin Hajduk, Centrum Astronomii, Torun, radio expert

List of national partners collaborators having actively contributed to the project in the last year

- H. Van Winckel, IVS, K.U.Leuven, Hermes project PI
- N. Gorlova, IVS, K.U.Leuven, Hermes data analysis
- Katrina Exter, IVS, K.U.Leuven, Herschel data reduction expert
- Leen Decin, IVS, K.U.Leuven,, Molecular expert

Visitors:

- Short visits: 2 persons

Grant(s)/Project(s) used for this research/service

- Grant nr. C90371 from PRODEX

I.3.6. Scientific outreach

Meeting presentations

(1) van Hoof P.A.M., Van de Steene G.C., Groenewegen M.A.T., Exter K.
NGC 6720 - PACS
MESS Consortium meeting, Leuven (oral presentation)

(2) van Hoof P.A.M., Barlow M.J., Van de Steene G.C., Exter K.M., Groenewegen M.A.T.
Molecular hydrogen in the Ring Nebula: formation on dust grains?
MESS consortium meeting, Leuven (oral presentation)

(3) van Hoof P.A.M., Van de Steene G.C., Barlow M.J., Exter K.M., Sibthorpe B., Ueta T., Peris V., Groenewegen M.A.T., Blommaert J.A.D.L., Cohen M., De Meester W., Ferland G.J., Gear W.K., Gomez H.L., Hargrave P.C., Huygen E., Ivison R.J., Jean C., Leeks S.J., Lim T.L., Olofsson G., Polehampton E.T., Regibo S., Royer P., Swinyard B.M., Vandenbussche B., Van Winckel H., Waelkens C., Walker H.J., Wesson R.
Herschel images of NGC 6720: H2 formation on dust grains
ESLAB2010, Noordwijk (poster)

(4) van Hoof P.A.M., Exter K.M., Van de Steene G.C., Barlow M.J., Lim T., Sibthorpe B., Groenewegen M.A.T., Ueta T., Matsuura M., Blommaert J.A.D.L., Cohen M., De Meester W., Gear W.K., Gomez H.L., Hargrave P.C., Huygen E., Ivison R.J., Jean C., Leeks S.J., Olofsson G., Polehampton E.T., Regibo S., Royer P., Swinyard B.M., Vandenbussche B., Van Winckel H., Waelkens C., Wesson R.
Imaging Planetary Nebulae with Herschel-PACS and SPIRE
Asymmetrical Planetary Nebulae V, Bowness-on-Windermere (oral presentation)

(5) van Hoof P.A.M., Exter K.M., Van de Steene G.C., Barlow M.J., Lim T., Sibthorpe B., Groenewegen M.A.T., Ueta T., Matsuura M., Blommaert J.A.D.L., Cohen M., De Meester W., Gear W.K., Gomez H.L., Hargrave P.C., Huygen E., Ivison R.J., Jean C., Leeks S.J., Olofsson G., Polehampton E.T., Regibo S., Royer P., Swinyard B.M., Vandenbussche B., Van Winckel H., Waelkens C., Wesson R.
Imaging Planetary Nebulae with Herschel-PACS and SPIRE
MESS consortium meeting, Leuven (oral presentation)

(6) Exter K.M., van Hoof P.A.M., Van de Steene G.C., Decin L.
Status Update on NGC 7027
MESS consortium meeting, Leuven (oral presentation)

Wikis and Websites

- http://homepage.oma.be/gsteene: homepage
- http://www.astro.oma.be/NEWS/seminars/seminar.htm: website for ROB seminars

I.3.7. Missions

Assemblies, symposia, conferences:

- G. Van de Steene, 01 -05 March ESO – Garching (G):The Origin and Fate of the Sun: Evolution of Solar-mass Stars Observed with High Angular Resolution
- G. Van de Steene, 04 – 07 May ESTEC – Noordwijk (NL): Herschel first results symposium
- G. Van de Steene, 20 -25 June, Windermere (UK): Assymetric Planetary Nebulae 5
- P. van Hoof: Annual meeting Dutch Astronomers Club, Utrecht, The Netherlands
- P. van Hoof: RAS meeting on super-AGB stars, London, UK
- M. Groenewegen, P. van Hoof: 16 – 17 February: 1st MESS consortium meeting, Leuven

- M. Groenewegen, P. van Hoof: 17 September: PACS SDP meeting, Leuven
- M. Groenewegen, P. van Hoof: 9 – 10 November: 2nd MESS consortium meeting, Leuven
- M. Groenewegen: 14-16 December, Herschel SDP DP Workshop, ESAC, Spain
- M. Groenewegen, P. van Hoof: 17 – 18 December: Herschel SDP initial results workshop, Madrid

Commissions, working groups (days):

- G. Van de Steene (3)
- P. van Hoof (5)
- M. Groenewegen (5)

Research visits (days)

- M. Groenewegen (10)

J. Variable Stars, Binary Stars and Stars in Young Stellar Groups

In this section astrophysical research on individual stars or on small groups of stars is described. There is certainly overlap with other topics, but in the other sections the emphasis is more on the characteristics of the star(s) as being in a certain evolutionary phase or belonging to a broad class, while here characteristics of smaller classes or of individual objects are studied to gain insight in astrophysical processes or to improve applications as e.g. distance estimates.

J.1. Visual Binaries - Binaries and Multiple Stars

Stellar formation and evolution cannot be really understood without a good knowledge of the properties of binary and multiple systems, because 50 to 70% of all stars belong to such a system. Binary and multiple stars with well-characterized components are attractive targets to study different phenomena of high astrophysical relevance including their own formation and history. Astrometry helps in the full characterization of the components in a powerful way as it allows to determine the orbital motions and, derived from these, the stellar masses - a fundamental property of stars - in a straightforward manner. Wide binaries, especially if the components have different spectral types, can be used to calibrate the luminosities and temperatures of single stars and to confront evolutionary tracks and models. They represent the high angular momentum class. In contrast, close binaries offer excellent opportunities for the combination of data obtained with different techniques resulting in great progress for understanding the impact of binarity on the stellar atmospheres or close binary evolution.

A few highlights:

- The evolutionary status of the primary component of the binary system θ^2 Tau can hardly be explained by the existing models currently available for the Hyades cluster.
- The components of the eclipsing and triple system RV Crt are not located on the same isochrone, implying that mass transfer between the components may have occurred in the past.
- BS UMa is a highly active low-mass eclipsing binary.

J.1.1. Objectives

Visual binaries allow a direct calibration of the mass-luminosity relation on the lower main sequence via the study of their orbital motions. Differential magnitudes and colours are collected along with accurate relative positions with the purpose to investigate the physical status, to improve the knowledge of their orbits and to derive the associated properties such as photometrically derived mass ratios. With the aim of contributing to the understanding of the stellar structure, formation and evolution, we study double and multiple systems by applying the technique of spectra disentangling. This powerful tool allows to determine the orbital parameters and to reconstruct the individual component spectra of star systems. Its usage, in combination with other techniques (e.g. photometry and astrometry), permits an accurate determination of component fundamental properties, such as the mass and the radius.

J.1.2. Progress and results

J.1.2.1. Visual binaries: θ^2 Tau

Important progress has been made on the study of the θ^2 Tau binary system, a detached and single-lined interferometric-spectroscopic binary having a component which is not a main sequence star anymore but is still located near the TAMS. We used the method of spectra disentangling in order to determinate accurate fundamental parameters (including the light ratio), and to perform a spectral analysis of the components of this 141-day system. Both components are members of the Hyades open cluster. Notwithstanding the heavily blended lines in the observed composite spectra caused by the fast rotation of the secondary component, which previously impeded an accurate determination of the mass ratio of this system, we obtained the component spectra and an improved spectroscopic orbit. Combining both spectroscopy and long-baseline optical interferometry, we derived the orbital parallax and the component masses with unprecedented accuracy [3]. We also relied on échelle spectra obtained with the new HERMES spectrograph for this work. This study brings important clues for a correct interpretation of stellar evolution in the Hyades cluster. From hereon, the disentangled spectra of both components can be studied as if they were single stars, and shed a new light on their chemical composition.

J.1.2.2. Visual binaries: 66 Ophiuchus

66 Oph is a triple visual-spectroscopic system. The hotter component A shows strong light variability from the ultraviolet to the infrared. It is a Be star for which non radial pulsation modes have been identified in the past. At that time, however, the Be star was considered to be a single star. Recently, Masson et al. (2009) and Štefl et al. (2004), using interferometric and spectroscopic data, proved the presence of a close binary companion (orbital period of ~ 10.8 days) orbiting around a common center of mass with component A. Using (a) 34 high-resolution NARVAL échelle spectra, obtained in 2007 to 2009 at the French 2-m Bernard-Lyot telescope (Observatoire du Pic du Midi) and (b) 15 high-resolution HERMES échelle spectra, obtained at the Belgian Mercator Telescope, we confirmed the presence of the close binary pair (BA+BB) in the system. Our results reveal a circular orbit, which is in good agreement with Štefl et al. (2004). The reconstructed component spectra obtained by applying the technique of spectra disentangling permitted us to derive the projected rotational velocity (i.e. 5.3 ± 0.4 and 12 ± 2 km s−1 for components BA and BB, respectively). Note that the value obtained for component BA should be considered as an upper limit.

The program *Girfit* (Frémat et al. 2006) was modified in order to determine the stellar parameters of components BA and BB self-consistently (e.g. effective temperature, log g, projected rotational velocity, systemic velocity, as well as the individual light contributions). This enhanced procedure allows to compare the reconstructed composite spectra with a set of synthetic spectra computed for a large number of different parameter combinations. The results obtained so far reveal that 66 Oph BA is somewhat hotter (~11300 K) than component BB (~9100 K), and that the close components contribute together by about 8% to the total light of the system (LA/(LBA+LBB) ~ 11.5). We also estimated a systemic velocity of ~19 km s−1 assuming log(g) = 4 for the components BA and BB. From (a) theoretical evolutionary tracks in the main-sequence stage, (b) age and E(B-V) as determined by Floquet et al. (2002) and (c) the mass ratio, MBB/MBA determined by our spectroscopic analysis, we were able to select four possible solutions in terms of masses, log g, effective temperature, radius etc. We are in the process of determining which of these solutions is acceptable for 66 Oph BA and BB. The accurate determination of the component fundamental parameters will permit us to verify the impact of the close binary's presence on previously published conclusions regarding the light variability of component A (Floquet et al. 2002).

J.1.2.3. 0-C binaries: BL Cam

The O-C times of the extreme metal-deficient field high-amplitude SX Phe variable BL Cam have been investigated, both on the short-term and the long-term scales. A positive (161 ± 3) x 10^{-9} yr^{-1} secular relative increase in the main pulsation period of BL Cam, together with short-term (144.2 days) and long-term (~3400 days) variations, both incompatible with a scenario of stellar evolution, were detected. Interpreted as a light travel-time effect, the short-term O-C variation is indicative of a massive stellar component (0.46 to 1 $M_{\odot}$) with a short period orbit (144.2 days), within a distance of 0.7 AU from the primary. More observations are needed to confirm the long-term O-C variations: if they were also to be caused by a light travel-time effect, they could be interpreted in terms of a third component, in this case probably a brown dwarf star, orbiting in about 3400 days at a distance of 4.5 AU from the primary.

J.1.2.4. Eclipsing binaries

New photoelectric times of minima of 36 eclipsing binary systems, among which various eclipsing binaries with eccentric orbits, were also reported. BS UMa is a highly active low-mass eclipsing binary. CCD photometry shows a rapidly changing light curve.

J.1.2.5. RV Crateris

RV Crt is a triple system composed by an eclipsing binary, AB with an orbital period of 1.17 days, and a wide component C (orbital period of ~103 years). A light-time effect, discovered recently in the eclipse timings of photometric data, proves that component C physically belongs to the system. The probable presence of a 4th component, of orbital period around 14 years, is also verified. The combined spectroscopic-photometric analysis, taking into account the light time effect, led us to a revised accurate determination of the fundamental parameters (mass, radius, surface gravity (log g), effective temperature, etc.) of components A and B. Their location in the H-R diagram and confrontation with theoretical evolutionary tracks (Figure 29) shows that component A is probably in the main-sequence stage. However, the situation is more complex for component B, which presents 2 different possible scenarios and might be in (a) the pre main-sequence or (b) the post main-sequence stage.

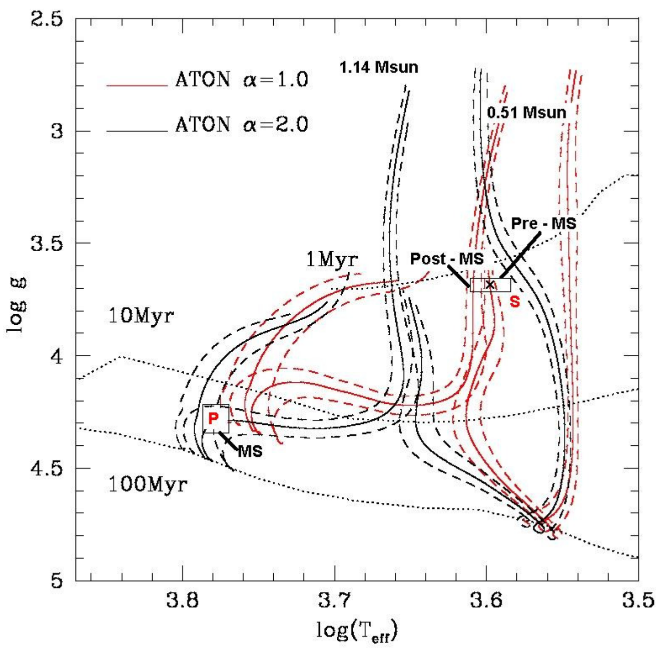

Figure 29: Location of the components of RV Crt in the H-R diagram: the curves represent evolutionary tracks for the masses of component A (P) and B (S) for two levels of convection efficiency (α) (see colours and labels).

Furthermore, we were not be able to locate both components in the same isochrone, implying that a possible mass transfer between the components occurred in the past. This scenario can be confirmed from our photometric analysis. The evolutionary states of components A and B are still debated. Other stellar evolution models, available in the literature, are being used to determine which of these scenarios apply to RV Crt. A paper containing our findings will be submitted to Astronomy & Astrophysics. Another paper describing the analysis of the reconstructed component spectra is in preparation.

J.1.3. Perspective for next years

Future work will consist using the disentangled component spectra of θ^2 Tau to perform a detailed chemical analysis, in order to determine as accurately as possible the evolutionary status of both components and to test whether or not convective overshooting is needed in the models. New systems will be identified for application of the spectra disentangling method (also based on the collection of spectra with the HERMES spectrograph mounted at the Mercator telescope). For a few highly relevant binary and multiple systems for which very high-angular resolution astrometric data would be most beneficial, we will apply for interferometric observations provided they satisfy the criteria for eligibility (ESO for the Southern and/or CHARA (US) for the Northern objects). We will furthermore continue to investigate the properties of various eclipsing binaries with particularly interesting features.

More specifically, for RV Crt:

- Study of the chemical composition of the components (collaboration with L. P. Vaz);

- Obtaining interferometric observations in attempt to detect the fourth component and to clarify the multiplicity of the system.

For θ^2 Tau:

- The reconstructed component spectra will be used in a chemical composition analysis (collaboration with S. Hekker);
- Additional HERMES observations will be planned during the critical phase of periastron passage in order to check the velocity amplitude of component B, the mass of component A and their evolutionary status.

For 66 Oph:

- Determination of the fundamental parameters of the components BA and BB;
- Check the influence of the presence of the components BA and BB on the previous conclusions regarding the light variability of component A;
- Usage of additional spectra to determine the orbit of the wide component A and its spectrum (collaboration with S. Štefl).

J.1.4. Personnel

Scientific staff: Y. Frémat, P. Lampens, K. Torres

J.1.5. Partnerships

List of international partners without grant

- H. Hensberge, Brazil (θ^2 Tau)
- Y. Lebreton, Observatoire Paris-Meudon, Laboratoire GEPI, Meudon, and Université de Rennes, Rennes - France (θ^2 Tau)
- P.G. Niarchos, Department of Astrophysics, Astronomy and Mechanics, University of Athens, Greece (eclipsing binaries)
- J.-L. Prieur, Université Sabatier, Toulouse, France (the speckle camera PISCO)
- P. Škoda, Astronomical Institute of the Academy of Sciences, Ondrejov, Czech Republic (θ^2 Tau)
- B. Ulas, Onsekiz Mart University of Canakkale, Dept. of Physics, Canakkale, Turkey (eclipsing binaries)
- L.P. Vaz et al., Federal University of Minas Gerais (UFMG), Belo Horizonte, Brazil (RV Crt)
- S. Hekker, University of Birmingham, UK (θ^2 Tau)
- M. Floquet and C. Neiner Observatoire de Paris-Meudon, Paris, France (66 Oph)
- S. Štefl, ESO, Santiago, Chile (66 Oph)

Grants used for this research

- Project "Disentangled Components of Multiple Stars as Laboratories of Stellar Evolution" (grant of supplementary researcher)

Visitors/students

- "Observations of visual double stars collected by Dr. E. Van Dessel during 1969-74", August 2010, including data quality control, digitalisation, formatting and preparation for electronic publication, (S. Rabtach)

J.1.6. Scientific outreach

Meeting presentations

(1) Lampens, P.,

Text accompanying the presentation "Démêlement des spectres d'étoiles doubles et triples. Description de la technique, application et résultats." given on Sept. 2009, Rouen (in French)
Published by the "Commission des Etoiles Doubles de la Société Astronomique de France", France

(2) Lampens, P., Torres, K., Frémat, Y., Hensberge, H.
Spectra Disentangling applied to the Hyades binary θ^2 Tauri AB
FNRS Contactgroup "Astronomie & Astrophysique" & Astronomy Day of the Royal Observatory of Belgium, May 25, Planetarium, Brussel

(3) Torres, K., Vaz, L.P.R., Hensberge, H. et al.
The triple stellar system RV Crateris: spectroscopic orbit and accurate absolute dimensions
In: 11th FNRS Contact Group "Astronomie & Astrophysique" & Astronomy Day of the Royal Observatory of Belgium, 25th May, 2010

J.1.7. Missions

Assemblies, symposia

- P. Lampens: Big Science with Small Telescopes, October 19-22, Jena-Dornburg, Germany
- P. Lampens: GREAT kick-off meeting - Gaia Binaries, May 17-18, ULB, Brussels
- P. Lampens, K. Torres: Contact group meeting, 25/05/2010, Planetarium, Brussels, Belgium

J.2. Cepheids

J.2.1. Objectives

Cepheids are considered to be among the most important distance indicators through the use of the period-luminosity relation, e.g. in the Hubble H_0-project where galaxies which contain both Cepheids and supernova are used to tight together the distance scale in the local and far-away Universe.

Nevertheless, over the last decade questions have been raised about the PL-relation: is it linear? (there may well be a break near 10 days), do slope and zero point depend on metallicity ? (There is evidence for it, but the data is partly contradicting). The study of Cepheids aims at improving our understanding of the Cepheid PL-relation.

J.2.2. Progress and results

M. Groenewegen was actively involved in the paper by Pedicelli et al. ([64]) who derived Baade-Wesselink distances to four metal-rich Cepheids (based on M. Groenewegen's 2008 paper).

Bertrand Lemasle visited one day to discuss progress on the analysis of ESO data (UVES and FLAMES, P.I. M. Groenewegen) taken in Period 82 (2006). He has determined metallicities for 4 Cepheids already (UVES), and the future analysis of the FLAMES data will add metallicities for additional 6 Cepheids in the LMC cluster NGC 1866.

Related to the aspect of the distance scale and the potential that Gaia will have in this respect, M. Groenewegen attended the kick-off meeting of the GCDS (GREAT Chemo-Dynamical Survey). This meeting was organised by the GREAT (Gaia Research for European Astronomy Training) in response to the ESO call for Public Spectroscopic Surveys made in mid-2010. Although the Gaia RVS will get spectra of 150 million objects, the resolution and wavelength coverage are not enough for many science cases. As Gaia will provide accurate distances, the idea is to obtain high-resolution spectra of 100000 Red Clump and F/G type stars throughout the Milky Way. Although the main aim is the study of Galactic evolution and stellar populations, a very interesting side project could be the metallicity dependence of various distance indicators. An independent project is SPARKS whose main aim is to determine Iron and alpha-element abundances for 30000 objects in 70 galaxies up to 25 Mpc, including Cepheids. M. Groenewegen is Co-I on two Letters-of-Intent that have finally been submitted in response to this call:

- The Gaia-ESO survey: Galactic Astrophysics via VISTA Imaging, Gaia Astrometry, and Eso SpectrOscopy (P.I. Gerry Gilmore)
- SPARKS – Stellar Population Abundances and Radial Kinematics Survey (P.I. Rolf-Peter Kudritzki)

M. Groenewegen was also involved in the paper by Pedicelli et al. ([82]) which studied the metallicity gradient in the Galaxy, by using Cepheids.

J.2.3. Perspective for next years

In the coming few years, several improvements can be made. Firstly, radial velocity data of more LMC and SMC will be published in the literature, enlarging the number of stars in these galaxies for which a BW-analysis can be done. In addition, radial velocities of galactic cepheids can be obtained using the HERMES spectrograph. The analysis of the V- and R-band surface-brightness relation will be continued.
A decision on the GAIAESO and SPARKS projects is expected to be taken in 2011. If positive, the role of M. Groenewegen within one or both of these projects will need to be detailed.

J.2.4. Personnel involved

Scientific staff: M. Groenewegen (ROB)

J.2.5. Partnerships

List of international collaborators having actively contributed to the project in the last year

- Martino Romaniello, ESO
- Giuseppe Bono, INAF-Rome
- Silvia Pedicelli, INAF-Rome
- Bertrand Lemasle, Universiteit Groningen

J.2.6. Scientific outreach

J.2.7. Missions

Assemblies, symposia, conferences:

- M. Groenewegen, Gaia GREAT chemo-dynamical survey (GCDS) kick-off Meeting, Paris, 17 April 2010
- M. Groenewegen, Gaia at the frontiers of astrometry, Sevres-Paris, 7-11 June 2010

J.3. Analysis of data from the CoRoT satellite

J.3.1. Objectives

CoRoT (Convection Rotation and planetary Transits) is a space mission led by the French Space Agency (CNES) in conjunction with ESA and other international partners. The satellite was launched on 27/12/2006. The mission has two main scientific goals: the search for Exoplanets, and Asteroseismology. Detecting planets using the occultation (or Transit) method requires the continuous monitoring of several thousands of stars, for a long period, and with high photometric precision. As an important consequence, lots of high quality light curves of variable stars are obtained.

J. Cuypers is involved in the classification of these variable stars and, as a member of the CoRoT B star and the O star working group, he contributes to the characterization of the candidate O and B variable stars. In 2010, mostly O stars were analysed in close collaboration with R. Blomme (KSB) and colleagues from Liège.

J.3.2. Progress and Results

The SRa02 of the CoRoT space mission for Asteroseismology was partly devoted to stars belonging to the Mon OB2 association. An intense monitoring was performed on Plaskett's Star (HD47129) and the unprecedented quality of the light curve allows us to shed new light on this very massive, non-eclipsing binary system. R. Blomme and J. Cuypers of the ROB were members of the team led by L. Mahy (Liège) that studied the new observations of this star in detail. J. Cuypers assisted in the detection of periodic variability which might be associated with pulsations or interactions between both components and searched for variations related to the orbital cycle which could help to constrain the inclination and the morphology of the binary system. Fourier-based prewhitening and a multiperiodic fitting procedure were applied to analyse the time series and extract the frequencies of variations. The periodogram exhibits a majority of peaks at low frequencies. Among these peaks, a list of 43 values was highlighted, including two different sets of harmonic frequencies whose fundamental peaks are located at about 0.07 and $0.82d^{-1}$. The former represents the orbital frequency of the binary system whilst the latter could probably be associated with non-radial pulsations. The study of the $0.07d^{-1}$ variation revealed the presence of a hot spot most probably situated on the primary star and facing the secondary. The investigation of this unique dataset constitutes a further step in the understanding of Plaskett's Star. These results provide a first basis for future seismic modeling. The existence of a hot region between both components renders the determination of the inclination ambiguous.

A paper was written and has been accepted for Astronomy and Astrophysics.

In collaboration with many others (including L. Mahy, E. Gosset and M. Godart [ULg]), R. Blomme, assisted by J. Cuypers, studied the CoRoT observations of three O-type stars: HD 46223, HD 46150 and HD 46966. The frequency analysis reveals a substantial number of frequencies, but none can be convincingly identified as being connected to pulsations. The semi-amplitude spectrum is dominated by red noise. This dominant red noise component in the O-type stars suggests a different origin than the pulsations seen in later-type stars. We speculate that it is related to the sub-surface convection zone found in theoretical modelling of these early-type stars. A paper on this is nearly ready to be submitted to A&A.

J.3.3. Perspective for next years

More data will become available from the CoRoT satellite in the next years. If new data of O or B stars will be released, R. Blomme and J. Cuypers will continue to analyse and interpret these data in close collaboration with the Leuven and Liège team.

J.3.4. Personnel involved

Scientific staff:	R. Blomme (ROB)
	J. Cuypers (ROB)
	P. De Cat (ROB, see report of Dep 2)

J.3.5. Partnerships

List of international collaborators having actively contributed to the project in the last year

- CoRoT B star working group (Chair: C. Aerts)
- CoRoT O star working group (Chair: C. Aerts)

List of national partners/collaborators having actively contributed to the project in the last year

- C. Aerts, P. De Groote, Institute of Astronomy, Department of Physics and Astronomy, K.U.Leuven
- M. Godart, E. Gosset, L. Mahy, T. Morel, Y. Nazé, G. Rauw, Université de Liège Institut d'Astrophysique et de Géophysique, Liège
- And the national partners included in the list of international collaborators

Grant(s)/Project(s) used for this research/service

- FWO-project G.0332.06 “Observationele bepaling van nauwkeurige interne en circumstellaire structuurmodellen van sterren”, Promotor: Prof. Dr. Conny Aerts, partners: K.U.Leuven, UGent, V.U.Brussel, ROB.

Visitors:

- Short visits : 1 person

J.3.6. Scientific outreach

Meeting presentations

- J. Cuypers: CoRoT O star working group (BAG), "Preliminary results for HD 46150", on behalf of R. Blomme, Liège, 10/5/2010

J.3.7. Missions

Assemblies, symposia, conferences:

- J. Cuypers, Seismological challenges for stellar structure, 4th HELAS International Conference, 1-5 February, 2010, Lanzarote, Spain.

Commissions, working groups:

- J. Cuypers: CoRoT O star working group meeting (Liège, 10/5/2010)

J.4. Analysis of variable star data observed by the Kepler satellite

J.4.1. Objectives

The KEPLER satellite (launched in March 2009) continuously monitors over 100 000 stars for at least 4 years, with a 30-minute cadence, and additionally 512 stars with a 1-minute cadence. The KEPLER mission is designed to search for extra-solar planetary systems, particularly Earth-like planets in the habitable zone, using the transit technique, but the stellar data obtained are also excellent for variable star detection and asteroseismic studies. Our aims are to characterize and classify preselected sets of variable stars in order to obtain information on the classes of variable stars as a whole and to identify interesting objects for further study.

J.4.2. Progress and results

J.4.2.1. Kepler observations of variability of B-stars

An analysis of the light curves of B-type stars observed by Kepler was done by a large group of astronomers including J. Cuypers and P. De Cat from ROB, and coordinated by L. Balona. This was a joint effort of the KASC working groups on ‘β Cephei stars’ and ‘Slowly Pulsating B stars’. J. Cuypers analysed 5 of these stars and commented on the results.

The analysis of in total 48 B-stars resulted in 15 pulsating stars, all of which show low frequencies characteristic of SPB stars. Seven of these stars also show a few weak, isolated high frequencies and they could be considered as SPB/β Cep hybrids. In all cases the frequency spectra seem different from what is seen from ground-based observations. It is suggested that this is because most of the low frequencies are modes of high degree which are predicted to be unstable in models of mid-B stars. There are non-pulsating stars within the β Cep and SPB instability strips. An article was composed and submitted to MNRAS.

J.4.2.2. Kepler observations of variability of AF-stars

An analysis of the light curves of A- and F-type stars observed by Kepler was done by a large group of astronomers including J. Cuypers and P. De Cat from ROB. J. Cuypers analysed a few of these stars and submitted some comments on the results. Final results or conclusions are not yet obtained, but a report and a paper is being prepared.

J.4.3. Perspective for next years

The analysis of the first data releases will continue and summarizing articles will be written. New data will be available as well, and will be analysed to see if they confirm the earlier results. Candidates for follow-up studies will be searched.

J.4.4. Personnel involved

Scientific staff: J. Cuypers (ROB)
P. De Cat (ROB)

J.4.5. Partnerships

List of international collaborators having actively contributed to the project in the last year

- KASC Working group #3 "β Cephei stars" (Chair: G. Handler)
- KASC Working group #6 "Slowly Pulsating B stars" (Chair: P. De Cat, ROB)
- KASC Working group "AF stars" (Chair: K. Uytterhoeven)

Grant(s)/Project(s) used for this research/service

- FWO-project G.0332.06 "Observationele bepaling van nauwkeurige interne en circumstellaire structuurmodellen van sterren", Promotor: Prof. Dr. Conny Aerts, partners: K.U.Leuven, UGent, V.U.Brussel, ROB.

J.4.6. Missions

Assemblies, symposia, conferences:

- J. Cuypers, Part of the 3rd Kepler Asteroseismology Workshop "Kepler Asteroseismology in Action", 14-18/06/2010, Aarhus, Denmark was followed on the internet as a teleconference.

J.5.Eclipsing binaries

J.5.1. Objectives

Eclipsing binaries can provide fundamental mass and radius determinations if combined with other observations. The detection of large quantities of eclipsing binaries with well-defined parameters is now possible thanks to large surveys from ground and from space. Large number statistics will be available soon. These results are important to study stellar populations and galactic structures and individual systems can be selected for detailed follow-up studies.

J.5.2. Progress and results

Although eclipsing binaries are variable stars, often a different treatment of the data of these stars is necessary to detect and characterise them. In the context of the Gaia mission (see next Research theme), but also as a separate item, studies on detecting and characterising eclipsing binaries were imitated.

Ideas put forward by Patrick Wils (VVS) were studied and applied to some test samples as e.g. the Hipparcos catalogue. A few students (secondary school) showed interest and will help with the analysis of some data sets. As a first example, the data of the ROTSE-project (Robotic Optical Transient Search Experiment) will be analysed. These data are available in the Northern Sky Variability Survey (NSVS) (http://skydot.lanl.gov), but have to be put in easy usable format before the analysis.

A first report and, if new eclipsing binaries were found, a list of stars will be published.

J.5.3. Perspective for next years

Methods to extract eclipsing binaries from large variability surveys will be studied further. More surveys will be analysed with the most promising methods, but the outcome will also depend on the interest of students or volunteers.

J.5.4. Personnel involved

Scientific staff: J. Cuypers (ROB)

J.5.5. Partnerships

Only students helped with this project so far (Jean Duffy, 17-30/07; Vicky De Block, 01/07 and 21/12)

J.6.Stars in Stellar Groups

J.6.1. Objectives

Hot stars, and especially spectroscopic binaries, in young stellar groups are analysed with the purpose to characterize these stellar populations. In the Sco-Cen associations and NGC 2244 a long-term goal is to measure also the internal velocity dispersion. The latter goal requires the identification of binaries, and the first one uses fundamental parameters of binaries as anchor points.

J.6.2. Progress and results

In cooperation with M. David (UA), the analysis of all-sky CCD photometry from the ASAS project and from the Hipparcos satellite with the purpose to detect in the young associations in Scorpius-Centaurus binaries in the magnitude range V=8 to 10, in this case in particular close-binaries with components with a non-spherical shape, was continued and is now in the publication-preparation stage. As a by-product, several other types of variables stars were detected, namely various pre-main sequence stars and a few pulsating stars. For 12 of the variable stars spectra at several epochs were measured for radial velocities. Six RV variables, five of them previously unknown, were detected. The orbital period of the previously known variable HD 146285 was derived (7.3 days, with some ambiguity due to the time gap between earlier and our observations).

In the framework of the EVRENA project ((1)(2)(3)(4) [3]) on Algol binaries lead by V. Bakiş, with participation of researchers from Turkey, Slovakia, Chile and Belgium (H. Hensberge), observations were planned with the HERMES spectrograph and executed by ROB observers in 2010 (V559 Cas, P. Lampens and D. Volpi), and a proposal for time on the ESO FEROS spectrograph was granted with time end of March 2011. Observations at the National Observatory in Turkey were planned and executed in cooperation with the Turkish partners. The analysis of a very massive double-lined eclipsing binary QR Serpentis with extreme mass ratio was started during a four-week work visit in Turkey. It belongs to the open cluster NGC 6611. The aim is to recover both component spectra and to determine the orbit and the fundamental stellar parameters. The analysis of LT CMa was published [3].

Observations on two very massive binaries in NGC 2244 are continued with the HERMES spectrograph. The work on the Hyades binary Θ^2 Tau and on the chemical peculiar stars in open clusters is now published. The abundance analysis of the disentangled component spectra of HD 57370A in NGC 2367 is in progress. A progress report (5) was presented in the Brazilian annual SAB meeting in September 2010.

J.6.3. Perspective for following years

The study of objects in the frame of the EVRENA project, and the projects on Sco-Cen, NGC 2244 will continue, as well as the cooperation on specific objects with Brazilian institutes.

J.6.4. Personnel involved

Scientific staff: H. Hensberge (retired)

J.6.5. Partnerships

List of international collaborators having actively contributed to the project in the last year

- C. Nitschelm UCN, Antofagasta, Chile (Sco-Cen, EVRENA)
- S. Daflon, ON, Rio de Janeiro, Brazil (abundance analysis HD57370A)
- V. Bakis, Onsekiz Mart Univ., Turkey (EVRENA project)
- E. Paunzen, Institut für Astronomie, Univ. Wien, Austria (organisation paper)

List of national partners collaborators having actively contributed to the project in the last year

- M. David, UA (Sco-Cen, analysis of ASAS data)
- E. Gosset (ULg, spectra of QR Ser)

Grant(s)/Project(s) used for this research/service

- EVRENA project grant (Turkey): financing of travel to and stay at Onsekiz Mart University in the framework of the EVRENA project
- Grant Observatorio Nacional, Rio de Janeiro: financing of travel to and stay at ON for cooperation with S. Daflon on HD57370A

J.6.6. Scientific outreach

Meeting presentations

(1) H. Hensberge
Spectra Disentangling I : Basics and Observing Strategy
Aug. 26, Canakkale, Turkey, National mini-workshop on `Composite Spectra of Binary Stars', 2010 August 26-27

(2) H. Hensberge
Spectra Disentangling II: Technical Aspects
Aug. 27, Canakkale, Turkey, National mini-workshop on `Composite Spectra of Binary Stars', 2010 August 26-27

(3) H. Hensberge, S. Daflon, S. Ilijić, D. Mello
Spectra Disentangling III : Analysis of the non-eclipsing SB2 HD 57370A, with error analysis
Aug. 27, Canakkale, Turkey, National mini-workshop on `Composite Spectra of Binary Stars', 2010 August 26-27

(4) H. Hensberge
Spectra Disentangling IV : Practicum: use of fd3 code and numerical convergence
Aug. 27, Canakkale, Turkey, National mini-workshop on `Composite Spectra of Binary Stars', 2010 August 26-27

(5) S. Daflon, H. Hensberge, D. Mello, S. Ilijić
HD57370A : analysis of the close-binary and detection of a third companion
XXXVth annual meeting Brazilian Astronomical Society (SAB), Passa Quatro, MG, Sept. 7 - 12

J.6.7. Missions

Research visits:

- H. Hensberge, May 19 - May 30 : Observatorio Nacional (ON), Rio de Janeiro, Brazil: scientific cooperation with S. Daflon (HD57370A)
- H. Hensberge, August 16 - September 10 : Onsekiz Mart Univ., Cannakale, Turkey: EVRENA project (V. Bakiş)

K. Software and Databases

To aid their own research, but also as a service to others, astrophysicists at the ROB maintain astronomically interesting tools (CLOUDY) or databases (SpectroWeb, line lists) and make those available to colleagues and the public.

K.1. The Photoionization Code Cloudy

K.1.1. Objectives

Cloudy is a code designed to model the interstellar medium in the widest possible sense. It can treat a wide range of physical conditions, ranging from gamma-ray and X-ray photoionized plasmas to photodissociation regions (PDR) and molecular clouds. As such it can model many types of objects, including (but not limited to) active galactic nuclei, star forming regions, planetary nebulae, and post-AGB stars. It was the first code that could produce a fully self-consistent model of a photo-ionized region including the PDR and molecular regions surrounding it. The code is being developed continually with the aim of improving the modelling results and to widen its scope. The code is publicly available and is widely used. Currently around 150 refereed papers per year cite the use of Cloudy.

K.1.2. Progress and results

The photoionization code Cloudy plays a crucial role in the research of P. van Hoof. He is a member of the international development team of this code. Most importantly he is the primary author of the grain model in Cloudy. Grains play an important role in many environments (including post-AGB stars and PNe) because of extinction, photoelectric heating, their influence on the charge and ionization balance of the gas, as catalysts for grain-surface chemical reactions (e.g. H_2 formation), and as seeds for freeze-out of molecules. His most important contribution to Cloudy in 2010 was the inclusion of molecular data from CDMS (http://www.astro.uni-koeln.de/cdms/catalog) and NASA JPL (http://spec.jpl.nasa.gov/ftp/pub/catalog/catdir.html). These allow the spectra of certain molecules for which no collisional data exist to be modelled in LTE. P. van Hoof advised on several group publications discussing new features of the code and its application to various astrophysical objects (refereed journal publication. P. van Hoof fixed many bugs in the code and assisted in updating the documentation of the code. He also assisted in the preparations for the upcoming C10.00 release of Cloudy which is scheduled for early 2011. A first release candidate of C10.00 was made available on 29 December 2010. He assisted in maintaining and updating the Cloudy web sites as listed below.

K.1.3. Perspective for next years

The development of Cloudy will continue for many years to come. This will first and foremost be aimed at implementing new physics and improving/updating the atomic/molecular data and physics that are already included in the code. Some effort will also be directed towards fixing deficiencies in the code and improving the documentation (either on the web or in the manual called Hazy). In the near future the efforts of P. van Hoof will be mainly aimed at finishing the improved opacity functions for polycyclic aromatic hydrocarbons (PAHs) and assisting in including the radio emissions from spinning grains in collaboration with Prof. A. Lazarian. These developments will have consequences for modelling many types of environments, including planetary nebulae and post-AGB stars.

K.1.4. Personnel involved

Scientific staff: P. van Hoof (Grant nr. C90371 from PRODEX)

K.1.5. Partnerships

List of international collaborators having actively contributed to the project in the last year

- Gary J. Ferland, University of Kentucky, USA. Lead author of the code.
- Ryan Porter, University of Kentucky, USA. Maintains H- and He-like iso-electronic sequences.
- Robin J.R. Williams, AWE, United Kingdom. Maintains molecular network and dynamics code.
- William J. Henney, UNAM, Morelia, Mexico. Maintains dynamics code.
- Gargi Shaw, Tata Institute of Fundamental Research, Mumbai, India. Maintains H_2 code.
- Alex Lazarian, University of Wisconsin, USA. Grain expert.

K.1.6. Scientific outreach

Cloudy is an open-source code and is freely available to everybody in the astrophysical community and beyond. The code is widely used and downloaded roughly 1 – 3 times per working day. Annually more than 150 refereed journal papers acknowledge use of the code.

Wikis and Websites

- http://www.nublado.org: this is the main portal for the Cloudy project in the form of a wiki. It contains instructions for downloading, installing, and running the code (aimed at the general user) and also more technical pages aimed at developers. The ticket system for maintaining problem reports is also located here. P. van Hoof helps in maintaining this website.
- http://svn.nublado.org: this is the main subversion code repository. All Cloudy developers submit their code changes here. P. van Hoof maintains this website.
- http://viewvc.nublado.org: this is a tool for interactively browsing the subversion repository, giving the public full access to the modification history of the code. It is also our main tool for creating tar balls for distributing the code. P. van Hoof maintains this website.
- http://tech.groups.yahoo.com/group/cloudy_simulations: this is a discussion forum where users can post questions about using the code or ask more general astrophysical questions. P. van Hoof is a moderator and an active contributor to this forum.
- http://groups.google.com/group/cloudy-dev: this is a forum for technical discussions about development of the code. It is mainly aimed at developers, but could also be of interest to users with in interest in the inner workings of the code. P. van Hoof is an active contributor to this forum.

K.2. The Atomic Line List

K.2.1. Objectives

The atomic line list is a web-based compilation of approximately 923,000 allowed, intercombination and forbidden atomic transitions with wavelengths in the range from 0.1 nm to 1000 µm. It is publicly available and its primary aim is to assist spectroscopists in the identification of absorption or emission lines in astrophysical or laboratory spectra. It is complete for all elements up to and including zinc. It is widely used in the astronomical and physical community and got nearly 10,000 visitors in 2010.

K.2.2. Progress and results

P. van Hoof integrated a large body of oscillator strength data from NIST (http://www.nist.gov/pml/data/asd.cfm) and Charlotte Froese Fischer (http://nlte.nist.gov/MCHF/). These data sets add oscillator strengths for many important transitions that were previously missing, most notably for intercombination and forbidden lines. These changes have been integrated in the ROB mirror of the beta version of the next release, but not yet in the US mirror.

K.2.3. Perspective for next years

The next release (v2.05) will add lines for elements gallium through krypton, update the data for many other ions, feature improved selection rules for the lines, fix several problems, and will feature many improvements to the web interface. The upgrade is nearly ready and planned for release as soon as it is validated. The latest beta version of the database contains approximately 1.58 million lines in the range from 0.06 nm to 1000 µm. Once the release is completed, P. van Hoof will start adding data for 5th and 6th row elements, most notably s-process elements.

K.2.4. Personnel involved

Scientific staff: P. van Hoof

K.2.5. Scientific outreach

Wikis and Websites

- http://www.pa.uky.edu/~peter/atomic: this is the search form for accessing the Atomic Line List. It has been created and is maintained by P. van Hoof.
- http://www.pa.uky.edu/~peter/newpage: this is the beta version of the next release. It has been created and is maintained by P. van Hoof.
- http://homepage.oma.be/pvh/newpage/: this is a mirror of the beta version of the next release created and maintained at the ROB by P. van Hoof.

K.3. The SpectroWeb Database

SpectroWeb at spectra.freeshell.org is a unique graphical web-application that permits users to interactively identify spectral lines and features in stellar spectra (including the Sun) from state-of-the-art spectral synthesis calculations, based on a free repository of up-to-date atomic and molecular line data.

K.3.1. Objectives

The SpectroWeb database is an online repository of identified spectral lines and features observed in spectral standard reference stars. It is permanently updated and improved, currently providing high-resolution spectra of seven bright (cool) stars selected as primary spectroscopic reference objects: Betelgeuse (Alpha Ori; M2 Iab), Arcturus (Alpha Boo; K1 III), Eps Eri (K2 V), The Sun (G2 V), Beta Aqr (G0 Ib), Procyon (Alpha CMi A; F5 IV-V), and Canopus (Alpha Car; F0 II). Their effective temperatures differ by about 1,000 K, ranging from 3500 K (M-type) to 7500 K (F-type). These stars offer a broad range of thermal conditions for the identification of mainly neutral and singly ionized spectral lines formed in their atmospheres. SpectroWeb offers a comprehensive interactive database of identified spectral lines that relies on detailed comparisons of observed spectra with advanced spectrum synthesis calculations. With its graphics display users can zoom in on the same wavelength regions of interest in different stars to investigate changes of line intensities, and to directly assess the reliability of the line identifications and the quality of the corresponding atomic line data. The database's graphics interface requires a modern Internet browser with an activated Java language interpreter. The object-oriented (Java “applet”) implementation, for example, permits to securely link many digital spectral atlases in a single database that is served from various world-wide-web domains using a standard interactive display.

K.3.2. Progress and Results

SpectroWeb has been further updated in 2010 (systematic database updates commenced in 2009) with corrected and validated oscillator strength values (the spectral line `log(gf)-values’) of over 1500 atomic absorption lines observed in the Sun, Procyon, Arcturus, and Eps Eri. The semi-empiric line oscillator strengths were measured with best fits to the disk-integrated KPNO-FTS spectrum of the Sun, observed between 4000 Å and 6800 Å, using state-of-the-art detailed spectral synthesis calculations. The spectra of

Procyon, Arcturus, and Eps Eri were observed with Mercator-HERMES with S/N ratios exceeding 2000. The complete optical spectra of the three optically bright spectroscopic reference stars were modelled in detail with LTE spectral synthesis calculations for absorption line-identification purposes which are also offered in SpectroWeb together with the observed HERMES spectra. We find for 483 Fe I, 85 Ni I, and 51 Si I absorption lines in the sample a systematic over-estimation of literature log(*gf*)-values with central line depths below 15 %. We employ a curve-of-growth analysis technique to test the accuracy of the new oscillator strength values and compare calculated equivalent line width values to the Moore, Minnaert, & Houtgast atlas of the Sun. The results of this research work were orally presented by A. Lobel in Aug 2010 at the 10th Int. Coll. on Atomic Spectra and Oscillator Strengths for Astrophysical and Laboratory Plasmas in Berkeley (1), and are being published in the Can. J. of Physics. These results were also orally presented by A. Lobel at the HERMES Consortium meeting at KU Leuven in Oct. 2010 (presentation (2). A large number of absorption line rest wavelengths offered in SpectroWeb have also been verified and updated (where needed) with the help of ROB summer student Mr. T. Hendrix.

K.3.3. Perspective for next years

In 2010 A. Lobel proposed to continue observations with Mercator-HERMES of various spectral standard reference stars with very large S/N ratios for the further development of the SpectroWeb database. Four additional bright reference stars were observed with HERMES in 2010. These spectra will be calibrated with the latest version of the pipeline including cosmic clipping. They will be utilized to further expand the current SpectroWeb implementation (of cool stars) by offering detailed reference spectra of every stellar spectral class. The large S/N ratio spectra are required for reliable identifications of (absorption) lines at 1% – 2% levels of the stellar continuum flux. Subsequent observations at reduced air-mass, from HERMES runs in the same epoch, will yield the cleanest co-added spectra possible for accurate continuum normalizations and line identifications in SpectroWeb. New science collaborations will be established for the on-going development of SpectroWeb in which ROB summer students will also be involved.

K.3.4. Personnel involved

Scientific staff: A. Lobel

K.3.5. Partnerships

K.3.6. Scientific outreach

Meeting presentations

(1) Lobel, A.,
Oscillator Strength Measurements of Atomic Absorption Lines from Stellar Spectra,
10th Int. Coll. on Atomic Spectra and Oscillator Strengths for Astrophysical and Laboratory Plasmas, ASOS 10, Univ. California, Berkeley, CA, USA, invited talk

(2) Lobel, A.,
SpectroWeb Database Development
Mercator-HERMES Consortium meeting, KU Leuven, Belgium, contributed talk

K.3.7. Missions

Assemblies, symposia, conferences:

- Lobel, 10th Int. Coll. on Atomic Spectra and Oscillator Strength for Astrophysical and Laboratory Plasmas, Univ. California Berkeley, CA, USA, 3-6 Aug 2010
- Lobel, Mercator-HERMES Consortium Workshop (Obs. program 20), KU Leuven, Belgium, 4 & 5 Oct 2010

L. Gaia

Gaia is a cornerstone mission of the ESA Space Program, scheduled for launch in late-2012. The satellite will repeatedly survey the whole sky to obtain positions, parallaxes and proper motions to micro-arcsecond precision for all of the 10^9 objects brighter than V = 20. Compared to the previous Hipparcos mission (see Figure 30), Gaia will achieve a substantial improvement in terms of astrometric accuracy and number of studied objects: parallax and proper-motion accuracy will be 100 times better and the number of stars is increased by a factor 10,000. It is an ambitious astrometric mission that will significantly improve our understanding of the formation and evolution of the Milky Way Galaxy.

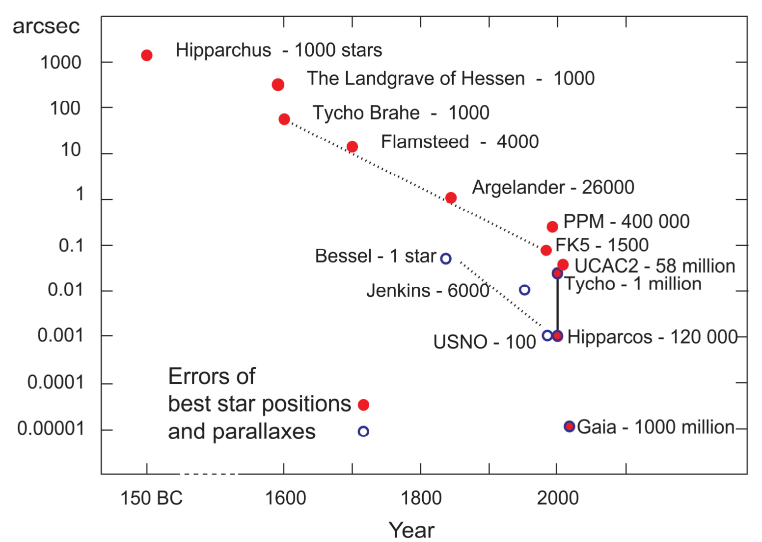

Figure 30: Evolution of the parallax and star position accuracy. Gaia is a real breakthrough that will provide parallaxes 100 times better than Hipparcos for a number of stars increased by a factor of 10,000. (Credit: ESA)

Gaia also has on-board a dispersed photometric instrument that will cover the whole optical wavelength range (330–1050 nm) and the medium resolution spectrograph (RVS or Radial Velocity Spectrograph: 847–874 nm). These instruments will enable the accurate simultaneous measurement of radial velocities (RVs), the variability characterization, as well as the determination of the astrophysical parameters (APs) down to magnitude 17 and the classification of all the targets down to magnitude 20.

The Gaia data processing represents a huge challenge due to both the sheer volume of data and the technical complexity of the processing. Such an effort has been compared to the mapping of the human genome for the impact that it will have on Galactic astrophysics. The European scientific community has been given the responsibility for all aspects of the data treatment and thus the Gaia **DPAC** (**D**ata **P**rocessing and **A**nalysis **C**onsortium) was set up in 2006. The DPAC involves more than 300 scientists in 15 countries mainly spread over 8 **C**oordination **U**nits (**CU**s). At the Royal Observatory, eight persons are involved in the DPAC and in the development of the Gaia reduction software, two of them being funded by a dedicated ESA-PRODEX program. We are contributing to the software development of four different CUs: CU4 (Object Processing), CU6 (Spectroscopic Processing), CU7 (Variability Processing), CU8 (Astrophysical Parameters).

The Gaia DPAC consortium works in six-month cycles. 2010 covers (partially) three cycles: cycles 8 (→ May 2010), 9 (June → November 2010) and 10 (December 2010 →). Cycle 10 was intended to be the last cycle, but since the launch of Gaia has been postponed, we expect 4-6 more cycles before launch.

L.1. Astrometric Reduction of Solar System Objects (CU4)

L.1.1. Objectives

T. Pauwels has been assigned the task of developing the software for DU454 (Astrometric Reduction of Solar System Objects). DU454 is one of the development units of CU4 (Object Processing) inside DPAC.

L.1.2. Progress and results

T. Pauwels committed himself to do the code development and E. Van Hemelryck (for 10% FTE) gave technical advice and produced the sequence diagrams of the software. T. Pauwels invested quite some time to continue to learn the framework for code development established by CU1 and continuously being modified by CNES.

A non-negligible time was devoted to go through the numerous documents issued by the Gaia community, describing the work of DUs that will interact with DU454 or describing the framework to use. Parallel to that T. Pauwels had to look for detailed information about software of CU1 and CU3 to use and how to use it. This was in particular the case with attitude data, Gaia ephemerides, the meaning of transitId, the global relativity model, the way data has to be formatted for the Minor Planet Center, the exact meaning of the spin axis of Gaia, the transformation between the time scales, the concept of active centring.

The software had continuously to be adapted to the changing framework. In 2010 this mainly meant adapting to new versions of the utility libraries to use: five new versions of Dpcccommon, one new version of TmTools, two new versions of GaiaTools, one new version of the data model, and one new version of Sofcommon. Other minor changes had to be applied to the software and the directory structure.

The functionality of the code expanded drastically in 2010, with lots of new features. There were three releases of the software in 2010: 8.1, 9.0 and 9.1. A lot of time was devoted to write extensive Junit tests so as to test thoroughly all code developed. Apart from that, DU454 developed some utility projects for internal use, e.g., a facility to convert between the internal binary format of the data and user readable output. All documentation was also updated and the sequence diagrams were made by E. Van Hemelryck, while T. Pauwels made the class diagrams and also produced a technical note describing the algorithm used in wp00800.

The real tests with simulated data that had been treated by all upstream processes does not really give the expected precision, but we lack information to thoroughly check how the precision can be improved.

One of the major problems we faced in 2010 was the incompatibilities between the different frameworks and libraries we have to work with, and the lack of documentation of some of the libraries, especially the use of "properties", which are not documented. Also regarding the formatting in the Minor Planet Center format a lot of decisions have to be taken and a lot of problems solved before DU454 software can continue to evolve.

L.1.3. Perspective for next years

Software developing was supposed to continue for the next one or two years, but the launch of Gaia has been postponed, and the software on which we depend has a lot of delay and bugs that show up now. This means that software development by DU454 will last longer than initially foreseen. Rather than being finalised by 2012, we still expect several years of development. Once the software will be fed with real data rather than simulated data, we will be confronted with the inevitable surprises and the code will have to be adapted accordingly.

L.1.4. Personnel involved

Scientific staff:	T. Pauwels (Coordination, science & development)
Technical staff:	E. Van Hemelryck (Java Expert, development)

L.1.5. Partnerships

List of international partners or collaborators having actively contributed to the project in the last year

- CU4 of Gaia DPAC

List of national partners or collaborators having actively contributed to the project in the last year

- D. Pourbaix, Université Libre de Bruxelles

- E. Gosset, Université de Liège

Grants/Projects used for this research/service

- PRODEX C90290, Gaia-DPAC: Binaries, Extreme Stars and Solar System Objects, D. Pourbaix (BPI, ULB), Y. Frémat (Bco-I, ROB), E. Gosset (Bco-I, Liège), T. Pauwels (Bco-I, ROB) 2007 – 2011

L.1.6. Scientific outreach

Meeting presentations

(1) Pauwels, T.
Status of DU454 Astrometric reduction
Gaia DPAC CU4 meeting #9, Genève, 26 May 2010. Contributed talk

(2) Pauwels, T.
Incompatibilities between GaiaTools and SAGA
Gaia DPCC workshop, Toulouse, 13 September 2010. Contributed talk

(3) Pauwels, T.
Status of DU454 Astrometric reduction
Gaia DPAC CU4 meeting #10, Toulouse, 16 November 2010. Contributed talk

Wikis and Websites

- Publications were published on Gaia Livelink (http://www.rssd.esa.int/llink/livelink)

L.1.7. Missions

Assemblies, symposia:

- T. Pauwels, E. Van Hemelryck (Gaia DPAC CU4 meeting #9, Observatoire de Genève, Switzerland, 26-27 May 2010)
- T. Pauwels (Gaia DPCC workshop, CNES, Toulouse, France, 13 September 2010)
- T. Pauwels (Gaia System Architecture Java10 workshop, CNES, Toulouse, France, 14-15 September 2010)
- T. Pauwels, E. Van Hemelryck (Gaia DPAC CU4 meeting #10, CNES, Toulouse, France, 16-17 November 2010)
- T. Pauwels (STS workshop, Observatoire de Paris, France, 15 December 2010)

L.2. Single transit analysis (CU6)

L.2.1. Objectives

Radial velocity measurements will be an important part of the final output catalogue of the mission. The satellite will observe the same stars several times by performing an average of 40 transits. The Single Transit Analysis (STA) top-level work package (managed by Y. Viala, Observatoire de Paris Meudon) has the responsibility to develop different techniques that will allow to measure the radial velocity of stars at each of these transits. Y. Frémat's duties in this framework are to apply Fourier transform techniques to derive the radial velocity of single stars. He is the manager of the package "Radial velocity determination by Cross Correlation in Fourier Space". R. Blomme is manager of CU6 work package GWP-S-650-10000, which implements a minimum distance method.

L.2.2. Progress and results

Nine versions of the Fouriercc software were delivered to CNES. The code is ready for scientific testing and is compliant with the current DPCC rules. Multiple peak detection, through the analysis of the cross-correlation second derivative, is now available. Problems on the error determination have been solved. This package was integrated into the SAGA framework at CNES. Y. Frémat continued the development of the noise filtering in Fourier space algorithm. Five versions were delivered. He further also performed the maintenance of the SimpleSimulator used by DU650 to produce simulations. It was modified during cycle 8 to enable the simulation of spectra belonging to spectroscopic multiple stars. The requested corresponding documentation was also delivered [48]-[52], -[120].

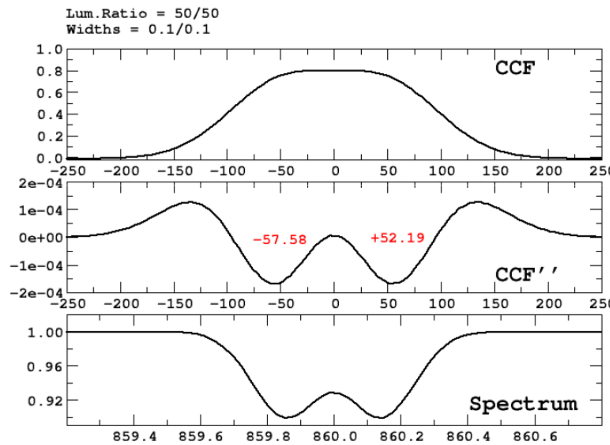

Figure 31: To detect binaries in the Cross Correlation Function (top panel), Y. Frémat implemented a technique based on the second derivative of the CCF (mid panel).

Two deliveries were made of the algorithm to determine the radial velocity by minimum distance to the CNES Data Processing Centre. This includes the code and its documentation [3]-[24]. In the second delivery, a substantial improvement was made in the way the algorithm searches for a binary signature in the observed spectrum. The STA_Combined module (developed by R. Blomme, and using modules provided by other CU6 members) was used to run a number of tests. R. Blomme wrote the analysis software for these tests. He contributed to a preliminary version of the Software Test Specifications and Software Test Report of the STA work package [120]. He also contributed to the interpretation of the tests that were done with the integrated software at CNES. Detailed reports on the results of all these activities are on the GaiaWiki pages.

L.2.3. Perspectives for next year

The next years will see continued software development and substantial testing of the code for its scientific validation. In this context, both simulated and real observations will be used.

L.2.4. Personnel involved

Scientific staff:	R. Blomme (Coordination, science & development)
	Y. Frémat (Coordination, science & development)
Technical staff:	E. Van Hemelryck (Java Expert, development)

L.2.5. Partnerships

List of international partners or collaborators having actively contributed to the project in the last year

- D. Katz, Y. Viala, C. Delle Luche, F. Arenou, Meudon, France
- N. Gerbier, A. Guerrier, A. Jean-Antoine, CNES, Toulouse, France
- K. Benson, H. Huckle, C. Parr, G. Seabroke, Mullard Space Science Laboratory, UK
- The CU6 team

List of national partners or collaborators having actively contributed to the project in the last year

- E. Gosset, Y. Damerdji, Université de Liège
- M. David, Universiteit van Antwerpen
- D. Pourbaix, Université Libre de Bruxelles

Grants/Projects used for this research/service

- PRODEX C90290, Gaia-DPAC: Binaries, Extreme Stars and Solar System Objects, D. Pourbaix (BPI, ULB), Y. Frémat (Bco-I, ROB), E. Gosset (Bco-I, Liège), T. Pauwels (Bco-I, ROB) 2007 – 2011

L.2.6. Scientific outreach

Meeting presentations

(1) Blomme, R., Delle Luche, C., Frémat, Y., Viala, Y.
STA_Combined: integration of RV modules and results
CU6 – 9th Workshop, Paris, France, contributed talk

(2) Blomme, R., Damerdji, Y., Delle Luche, C., Frémat, Y., Gosset, E., Viala, Y.
RVMdM: a new approach for multiple peaks; STA Cycle 9 tests; Proposal use of RAVE data
CU6 – Test meeting, Brussels, contributed talks

(3) Blomme, R., Damerdji, Y., Delle Luche, C., Frémat, Y., Gosset, E., Viala, Y.
STA Cycle 9 tests – Single stars; STA Cycle 9 tests – Binaries
CU6 – 10th Workshop, Bordeaux, France, contributed talks

(4) Frémat, Y.
Detection of multiple peaks
CU6 – 10th Workshop, Bordeaux, France, contributed talk

Wikis and Websites

- GaiaWiki page STA_RVMdM http://www.rssd.esa.int/wikiSI/index.php?title=CU6:_GWP-S-650:_Single_transit_analysis:_Integration:_RVMdM&instance=Gaia (restricted access)
- GaiaWiki page STA_Combined http://www.rssd.esa.int/wikiSI/index.php?title=CU6:_GWP-S-650:_Single_transit_analysis:_Integration&instance=Gaia (restricted access)
- GaiaWiki page results of various test cycles: http://www.rssd.esa.int/wikiSI/index.php?title=CU6:_GWP-S-650:_Single_transit_analysis:_STP_cycle_8, …9&instance=Gaia (restricted access)
- Publications were published on Gaia Livelink (http://www.rssd.esa.int/llink/livelink)

L.2.7. Missions

Assemblies, symposia:

- R. Blomme, Y. Frémat (Gaia – CU6 9th Workshop, Paris, France, 14-16 June 2010)
- R. Blomme (Gaia – CU6 Test meeting, MSSL, Dorking, UK, 27-28 September 2010)
- R. Blomme, Y. Frémat (Gaia – CU6 Test meeting, Brussels, 29 September 2010)
- R. Blomme, Y. Frémat (Gaia – CU6 10th Workshop + DU650 splinter meeting, Bordeaux, France, 29 November -02 December 2010)

L.3. Variability Characterization (CU7)

L.3.1. Objectives

The purpose of the Gaia Coordination Unit 7 (CU7) is to develop the processing to take care of all aspects of the variability of the Gaia data, with most emphasis on stellar objects. These activities are divided into 5 large work packages (WPs): 1) Special Variability Studies, 2) Variability Characterisation, 3) Variability Classification, 4) Specific Object Studies, and 5) Global Variability Studies. The tasks of the people involved at the Royal Observatory are the supervision of the general work package Characterization (J. Cuypers) and the concrete realization of the sub-work package Period Search (E. Van Hemelryck,

P. De Cat, J. Cuypers) while others are also active in the sub-work package Long Period Variables of the work package Specific Object Studies (M. Groenewegen). The Period Search work packages includes the coding (in Java) of that part of the variability pipeline that will deal with (possible) periodicity in the data.

L.3.2. Progress and results

Each CU7 work package undergoes a definition phase, a development phase, a verification phase, and a commissioning phase. In practice these phases overlap and an iterative process based on six-month cycles is adopted. At the beginning of every cycle new and concrete milestones are set for the software development. This way, the software requirement specifications (SRS), the software design descriptions (SDD), the software implementations, and the software tests were also during 2010 gradually improved.

J. Cuypers has been involved in the planning of the six-month cycles (through the Software Development Plan or SDP). He participated regularly to the teleconferences of CU7. He spent this year a lot of time on the statistical aspects of the detection of periodicity in very noisy date. New ideas on the application of the extremal value theory were explored. Simulations and tests were carried out, also in a more general context than the Gaia mission. It is well possible that this will be the start of a new line of research in the near future.

E. Van Hemelryck did the coding of the algorithms in Java and did many of the tests on simulated data and on data from earlier surveys.

Status and results of tests were presented at the CU7 meetings in Naples (1) and Cambridge (2).

Progress has been made in the computation of a reliable false alarm probability (i.e. the statistical probability that a period is found in data of pure noise) suitable for Gaia time series. From the first analysis of the simulations it seems possible to compute directly this false alarm probability in a similar way for several of the period search methods. Verification of this is in progress and the first implementations and tests were done by E. Van Hemelryck.

The methods and algorithms developed for the analysis of the Gaia variables were also applied to data of variable stars measured by the Hipparcos satellite. J. Cuypers assisted in the evaluation of the performance of automated classification. Because the period of the variables is one of the most important attributes, the expertise and the software developed by the ROB team was of good use. The rate of classification with the random forest methodology was remarkably good and is very promising for the Gaia implementation. A paper was written and submitted to Monthly Notices.

P. De Cat did a detailed literature search to get an up-to-date overview of the asteroseismic results of slowly pulsating B stars, beta Cephei stars and gamma Doradus stars observed by the Hipparcos satellite for the extraction of training sets for supervised classification techniques.

L.3.3. Perspective for next years

A more elaborated pipeline for the characterization of the variability will be coded and implemented. The methodology will be tested on several other surveys.

L.3.4. Personnel involved

Scientific staff:	J. Cuypers (Coordination, science & development)
	P. De Cat (Science)
	M. Groenewegen (Science)
Technical staff:	E. Van Hemelryck (Java Expert, development)

L.3.5. Partnerships

List of international partners

- Laurent Eyer, Leanne Guy, Observatoire de Genève, Switzerland

- Luis Sarro, Artificial Intelligence Department, UNED & Virtual Observatory, Spain
- Alessandro Lanzafame, Department of Physics and Astronomy, University of Catania, Italy
- All CU7 members

List of national partners

- Institute of Astronomy (Conny Aerts, Joris De Ridder, Jonas Blomme, …), Department of Physics and Astronomy, K.U.Leuven

Grants/Projects used for this research

- PRODEX C90296, Gaia-DPAC: Variability, Conny Aerts (BPI, KULeuven), Jan Cuypers (Bco-I, ROB), 2007-2009-2011. [2]
- FWO-project G.0332.06 "Observationele bepaling van nauwkeurige interne en circumstellaire structuurmodellen van sterren", Promotor: Prof. Dr. Conny Aerts, partners: K.U.Leuven, UGent, V.U.Brussel, ROB (Jan Cuypers) [1]

L.3.6. Scientific outreach

Meeting presentations

(1) Cuypers, J.
Variability Characterization
10th Gaia CU7 meeting, Naples, 18-21 May 2010. Contributed talk

(2) Cuypers, J.
Variability Characterisation issues and results
11th Gaia CU7 meeting, Cambridge, 9-12 November 2010. Contributed talk

(3) Cuypers, J.
Variability Characterization: status and future plans
11th Gaia CU7 meeting, Cambridge, 9-12 November 2010. Contributed talk

Wiki and Websites

- Inputs to the Wiki pages of CU7, mostly in preparation of meetings or as results of the splinter meetings on characterisation.
- Publications were published on Gaia Livelink (http://www.rssd.esa.int/llink/livelink)

Teleconferences

Several meetings on Gaia subjects were in the form of teleconferences (Telephone or Skype meeting with Geneva, Leuven, Madrid …):

- 19/03/2010: on general matters
- 13/04/2010; on characterisation
- 07/09/2010: on period search
- 09/09/2010: on planning of characterisation tasks
- 27/10/2010: on milestones
- 10/12/2010: on software development plan and milestones

L.3.7. Missions

Assemblies, symposia:

- J. Cuypers, E. Van Hemelryck (Gaia – CU7 10th Workshop, Naples, 18-21 May 2010)
- E. Van Hemelryck (Java Workshop, Toulouse, 14-15 September 2010)
- J. Cuypers, E. Van Hemelryck (Gaia – CU7 11th Workshop, Cambridge, 9-12 November 2010)

Research visits (days):	J. Cuypers (2 days)
Commissions, working groups (days):	J. Cuypers (Gaia GREAT meeting and Gaia GREAT meeting on double stars, ULB, 17 May 2010) J. Cuypers (Chair splinter meeting on characterisation during the CU7 meeting, Naples, 18-21 May 2010) J. Cuypers (Chair splinter meeting on characterisation during the CU7 meeting Cambridge, 9-12 November 2010)

L.4. Extended Stellar Parametrizer (ESP)

L.4.1. Objectives

The extended stellar parametrizer is one of the CU8 Top Level Work packages. Its goal is to take care of the subsample of "extreme" but important stars which may not be well treated by "standard" grids and thus by GSP-phot (Generalised Stellar Parametrizer). ESP also reconsiders combinations and specific use of the Gaia data. It is composed of 5 work packages having the responsibility to study “Cool stars”, “Ultra Cool stars”, “Anomalous Abundance Stars”, “Emission Line stars” and “Hot Stars”. Y. Frémat is manager of the ESP top level work package. He is also member of the management team of CU8 and CU8 representative for the GBOG (Ground Based Observations for Gaia). The “Hot Stars” work package is managed by R. Blomme. A. Lobel works on Emission Line Stars.

L.4.2. Progress and results

During cycle 8 and 9, all the modules were updated in order to take into account the new DM and the latest version of the DPCC libraries. The ESP algorithms have been delivered and integrated in the H1 and H2 versions of the CU8 SAGA workflow. The Hot Stars module uses a minimum distance method to fit BP/RP and RVS synthetic spectra to observations. The current version enables the determination of the effective temperature, surface gravity, and interstellar reddening. Integration tests showed that the module speed depends too much on the type of data used, and becomes too slow once RVS data is available. This is a point that we still need to improve in the coming years. The current version of the Emission Line Stars module contains tools to compute colour indexes on the RVS and the BP/RP, to detect and identify emission lines. These colour indexes are used by a classification algorithm based on a artificial neural network. All the requested documentation has been produced and delivered [56]-[59],[66]. Y. Frémat took also part to the validation of the simulated data.

Y. Frémat also collaborated on the definition of a new French multi-object spectrograph called GYES [7] aimed for the follow-up of Gaia targets at the CFH telescope, unfortunately this project was not chosen for funding by the French funding agency and the activity in this field was therefore interrupted.

A. Lobel further updated the data archive of ground-based observed spectra of various types of emission line stars (ELS). It currently offers over 1700 spectra of 12 separate ELS classes of both hot and cool stars. There is a persistent lack of observed and synthetic spectra of ELS needed for testing ESP-ELS algorithms currently under development. A Gaia Technical Note was presented at the CU8 Management Team Meeting of Feb 2010, and published online by ESA CU8 LiveLink [75]. The entire data archive has been made available online at the ROB, and has been integrated in the GaiaSimulator (GaiaSimu) by P. Sartoretti of Gaia CU2. A. Lobel started a thorough analysis of emission line properties observed with ESO-FEROS in 96 Be-stars of the data archive. Almost linear dependences of the equivalent line widths and normalized flux maxima of prominent Hα, Hβ, and Hγ emission lines are observed which will be used to discriminate Be stars from other types of abundant ELS with prominent Balmer emission lines (such as active M dwarfs or dMe) that Gaia will observe. A main journal paper describing these results is in preparation.

R. Blomme and collaborators looked at a problem raised by the C. Bailer-Jones (CU8 leader): using only the observed fluxes of stars leads to a degeneracy between effective temperature and interstellar extinction. They explored this effect in hotter stars, and found it to be substantial. Results were presented at the ELSA Conference. R. Blomme is member of the Gaia Archive Preparation (GAP) Group, on behalf of CU8. This group prepares the activities for the Coordination Unit 9 (CU9) "Catalogue Access".

L.4.3. Perspectives for next year

In the coming years, the software development will continue. The degeneracy between effective temperature and interstellar extinction will be further investigated. The possibility of extracting information about the mass-loss rate from the Hα line will be explored. Further updates of the archive of observed spectra of emission line stars for ESP-ELS will continue, also based in part on new Mercator-HERMES observations. Activities with the Gaia Archive Preparation Group will be started and possible involvement of the Royal Observatory in CU9 will be explored.

L.4.4. Personnel involved

Scientific staff:	R. Blomme (Coordination, science & development)
	Y. Frémat (Coordination, science & development)
	A. Lobel (Coordination, science & development)
Technical staff:	E. Van Hemelryck (Java Expert, development)

L.4.5. Partnerships

List of international partners or collaborators having actively contributed to the project in the last year

- C. Bailer Jones, Heidelberg and CU8 team
- A. Lanzafame, Italy
- O. Kochukov, Uppsala, Sweden
- D. Barrado, L. Saro, Spain
- S. Fernandez, A.-M. Janotto, CNES, France
- J. Zorec, IAP, France
- C. Martayan, ESO, Chile
- I. Kolka,Tartu Obs., Estonia
- C. Soubiran, Univ. Bordeaux, France

List of national partners or collaborators having actively contributed to the project in the last year

- E. Gosset, Y. Nazé, J. Poels, Université de Liège

Grants/Projects used for this research/service

- PRODEX C90290, Gaia-DPAC: Binaries, Extreme Stars and Solar System Objects, D. Pourbaix (BPI, ULB), Y. Frémat (Bco-I, ROB), E. Gosset (Bco-I, Liège), T. Pauwels (Bco-I, ROB) 2007 – 2011

L.4.6. Scientific outreach

Meeting presentations

(1) Blomme, R., Frémat, Y., Lobel, A., Martayan, C.
Emission-line stars and early-type stars with Gaia
ELSA Conference "Gaia: at the frontiers of astrometry", poster paper

(2) Frémat, Y.
Status of the RVS
Gaia CU8 classification meeting, Heidelberg, Germany, contributed talk

(3) Lobel, A.
GREAT-ESF in Belgium: Stellar Atmospheres
Gaia Workshop, ULB, Brussels, Belgium, invited talk

Wikis and Websites

- GaiaWiki page describing the validation simulations of data needed for CU8. http://www.rssd.esa.int/wikiSI/index.php?title=CU8:_Training_data:_validation_:_cycle_7_:_Emission_line_stars&instance=Gaia (restricted access)
- Publications were published on Gaia Livelink (http://www.rssd.esa.int/llink/livelink)

L.4.7. Missions

Assemblies, symposia:

- A. Lobel (Gaia Data Processing Conference, ULB, Brussels, Belgium, 21 February 2010)
- Y. Frémat, A. Lobel, E. Van Hemelryck (Gaia CU8 Classification meeting, Heidelberg, Germany, 22-25 February 2010)
- Y. Frémat, A. Lobel (Meeting "GREAT in Belgium", ULB, Brussels, 17-18 May 2010)

M. HERMES echelle spectrograph

In 2004, financial support was obtained by IvS KU Leuven (FWO and KU Leuven), ULB (FNRS) and ROB (Lotto) to build an echelle spectrograph for the Mercator telescope of the IvS at the Roque de los Muchachos Observatory on La Palma. Meanwhile, additional partners entered into the project (Thüringer Landessternwarte Tautenburg and Observatoire de Genève). The spectrograph is operational since April 2009. HERMES is the acronym for High Efficiency and Resolution Mercator Echelle Spectrograph.

M.1. Data reduction package and optics for the HERMES echelle spectrograph

M.1.1. Objectives

The Royal Observatory of Belgium has the responsability to provide the **D**ata **R**eduction and instrument control **S**oftware (**DRS**, work package WP900). The objective is to provide, in contrast to the existing pipelines, a differential data-reduction system. The WP900 working group involves personnel from the department, as well as colleagues from the other partners in the HERMES project.

The Royal Observatory of Belgium contributed with the Lotto grant to the procurement of optical components for the HERMES echelle spectrograph for the MERCATOR Telescope. For information on the layout of the instrument, see http://hermes.ster.kuleuven.ac.be.

M.1.2. Progress and results

M.1.2.1. Second and third calls for observing time

There were in 2010, two calls for observing programs. Ten proposals were submitted on the first call on 11th January (TAC meeting on 5th February 2010), 4 of these were submitted with a ROB staff as Principal Investigator (P.I.), 5 others programs were submitted in collaboration with ROB researchers. During the second call, on 3rd September 2010 (TAC meeting on 24th September 2010), 14 proposals were submitted among which 10 ROB projects (i.e. 7 with a ROB P.I.). In 2010, only 1 ROB proposal that was rejected due to technical considerations (the proposed targets were too faint to be observed in good conditions at the Mercator telescope). The ROB programs that were still running at the end of 2010 are given in Table 1.

In October 2010, a Hermes consortium meeting was organized at the Faculty Club of the KUL. Colleagues of the Astronomy and Astrophysics department presented the first scientific results they obtained with the HERMES data. The agenda of the meeting as well as their presentations can be found on the local wiki server: http://wikid23srv.oma.be/mediawiki/index.php/Hermes:consortium:meeting.

Colliding Winds in Early-Type Binaries	**R. Blomme (PI), D. Volpi**
Evolved objects in binaries: the evolutionary connection	H. Van Winckel (PI), **G. Van de Steene** et al.
Stellar atmospheres of main-sequence pulsators: characterization in terms of rotation, binarity and chemical composition	**D. Wright (PI), P. De Cat** et al.
Fundamental parameters of stars and stellar groups from studies of binary (multiple) stars	**H. Hensberge (PI)**
HERMES High Resolution Spectroscopic Database	P. Royer (PI), **A. Lobel**
Towards asteroseismology of main-sequence g-mode pulsators: a spectroscopic multi-site campaign for slowly pulsating B stars and γDoradus	**P. De Cat (PI), Y. Frémat, D. Wright** et al.

stars	
SpectroWeb: The Interactive Database of Spectral Standard Star Atlases	**A. Lobel (PI)**
Spectroscopic Monitoring Survey of Hypergiants and Luminous Blue Variables	**A. Lobel (PI)**
A Dedicated Search for LBV Binaries with Long-term Spectroscopic Monitoring	**A. Lobel (PI), K. Torres** et al.
Accurate absolute parameters for oscillating Algol-type binaries	**P. Lampens (PI), Y. Frémat, K. Torres**
Orbital and fundamental parameter determination of a sample of pulsating stars in binary systems	J. Debosscher (PI), **P. De Cat, Y. Frémat, P. Lampens, K. Torres** et al.
Characterisation of Kepler Main-Sequence pulsators with HERMES.	M. Briquet (PI), **P. Decat** et al.

Table 1: ROB observing programs running in 2010. The name of the ROB staff participating to the projects is written in boldface.

M.1.2.2. Observing runs at La Palma

In 2010, there were 3 observing runs at La Palma planned for the ROB. Two runs have been performed by P.Lampens, and one by D.Volpi. These runs are performed for the consortium and are a part of the ROB duties in the framework of the HERMES project according to the Memorendum Of Understanding (http://wikid23srv.oma.be/mediawiki/images/7/74/MOU.pdf). All consortium runs perform a pool of accepted observing programmes, but 20 percent of the time is put at the disposal of the observer. In practice, at the Astronomy and Astrophysics department, we decided to commonly use this time for our different projects.

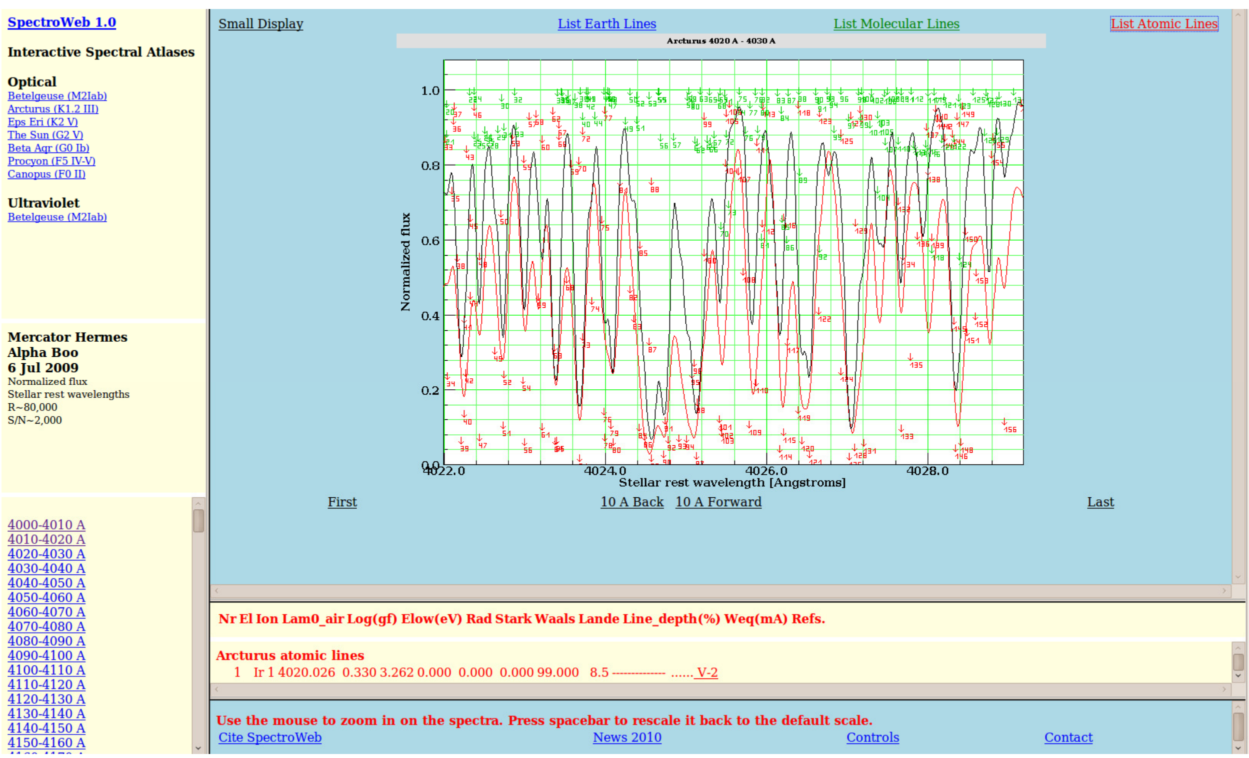

Figure 32: High quality HERMES data are now included in A.Lobel's SpectroWeb tool. The figure shows the blue part of the α Boo's spectrum (black curve) compared to theoretical predictions (red curve). To achieve the S/N ratio of 2000 several exposures have been combined.

M.1.2.3. Development of the reduction pipeline

A first paper which is describing the HERMES spectrograph as well as its first results was submitted and published. In 2010, L.Dumortier, Y.Frémat, and H.Hensberge further improved the reduction pipeline. The team developed and homogenized its working framework, and contributed in collaboration with A.Jorissen (ULB) and S.Van Eck (ULB) to the development and improvement of the modules performing the cosmic clipped data extraction and the radial velocity determination. They further modified the pipeline so that it became able to automatically merge the spectral orders and provide a 1D wavelength calibrated spectrum. In order to reduce the Hermes data taking into account the instrument evolution (e.g. configuration, temperature, and pressure changes …) the team developed several instrument models which now enables to get high quality (i.e. high signal to noise and high resolution) spectra (Figure 32).

M.1.2.4. Hermes data mirroring

All the data (raw and pipeline reduced) are available on a file server located in Leuven. In order to get a more easy and direct access to it, L.Dumortier started a daily mirroring of all the available HERMES data on the ROB local server. The available HERMES data can now be accessed directly and mounted on a remote machine (e.g. CAIPI) or locally.

M.1.3. Perspective for next years

The first phase of the pipeline development will be completed early 2011 with the 3rd pipeline release. Besides the usual software maintenance (e.g. instrument model development, …), we are planning to start the second development phase which will consist in applying some of H.Hensberge's most innovative ideas on data reduction. It is expected that the results of this second phase will be published in A&A probably in 2012. A virtual server as well as additional software will further be provided to support the Hermes data end-user.

M.1.4. Personnel involved

Scientific staff:	H. Hensberge (DRS conception, and modeling)
	Y. Frémat (ROB HERMES representative, DRS development, and modeling)
	P. Lampens (Consortium observations)
	D. Volpi (Consortium observations)
Technical staff:	L. Dumortier (ICT expert, DRS development)

M.1.5. Partnerships

List of international partners or collaborators having actively contributed to the project in the last year

- H. Hensberge, Brazil (expertise in data reduction theory)

List of national partners or collaborators having actively contributed to the project in the last year

- S. Van Eck, A. Jorissen, C. Siopis, ULB (module programming)
- H. Van Winckel, KULeuven (project manager)
- N. Gorlova, KULeuven (wavelength calibration analysis)
- G. Raskin, S. Prins, J. Perez Padilla, Mercator staff (commissioning)

Grants/Projects used for this research/service

- Financement by Lotto (2004) 'Onderdelen voor de opbouw van een hoge resolutie echelle spectrograaf voor de 1.2m MERCATOR telescoop'. H. Hensberge was promoter for ROB in the HERMES project of KULeuven – ULB – ROB

Visitors:

- Short visits: 4 persons

M.1.6. Scientific outreach

Meeting presentations

(1) Y. Frémat
Data Reduction Software status and review
Hermes Consortium Meeting, KUL, Leuven

Wikis and Websites

- Updating http://wikid23srv.oma.be/mediawiki/index.php/Hermes

M.1.7. Missions

Assemblies, symposia:	L. Dumortier (Hermes Consortium Meeting, KUL, Leuven) Y. Frémat (Hermes Consortium Meeting, KUL, Leuven)
Commissions, working groups (days):	Y. Frémat (4 days)
Field missions (days):	P. Lampens (28 days) D. Volpi (13 days)

N. Digitisation

The long-lasting activity of photographing the sky produced an important collection of astrophotographic plates. In order to keep the data accessible for modern research, they have to be digitised.

The creation and exploitation of a facility for providing digital access to the historic-scientific information contained in photographic archives. This in close collaboration with the experts in digitising astronomical plates at the US Naval Observatory in Washington DC (USNO), the experts in aerial photography at the National Geographic Institute (NGI), the documentation and photography department of the Royal Institute for Cultural Heritage (RICH) and the Geology department of the Royal Museum of Central Africa (RMCA) and AGFA-Gevaert a world-leader in photographic matters. To extend the already acquired know-how, hardware and software for digitising the information contained in the photographic images have been developed and applied taking into account the specific characteristics of the photographic image and the needs of the (foreseen) applications. It is also necessary to convert the associated metadata into a digital form in order to make the results public and directly usable for scientific research and general use through the modern techniques of the information society.

This approach has been applied to old astrometric observations in the frame of collaboration with planetary science.

In general, in addition to the astrometric observations over a long period of time one uses spacecraft observations for constraining the orbits and building the ephemerides. The advantage of the spacecraft observations is that they are very precise, while the astrometric observations are spread over a long time span. Old data are in particular very valuable for constraining the long-term motion and the dynamical orbital models.

N.1. Project "Digitisation of the heritage of the federal scientific institutes of Belspo"

N.1.1. Objectives

The federal Science Policy has recognised the importance of preserving and making available the heritage of the federal scientific institutes. The means is to digitise the collections of these institutes, and make them available via the web.

After a few pilot projects and a study of the cost of such a digitisation, the government took the principal decision to implement the basic scenario in the course of ten years, starting in 2005. By the end of 2005, the federal Science Policy (Belspo) had initiated some ten smaller scale operational projects, which would run from 2005 to 2008, but were later extended till the end of 2011. We joined project No. 7 (which we call "007") "digitisation of photographic glass plates", involving the Royal Museum of Central Africa, the Royal Institute for Cultural Heritage (RICH, interim coordinator), the Belgian Institute for Space Aeronomy and the Royal Observatory of Belgium, with the aim of digitising our astrophotographic plates on a high-resolution digitiser that should have been built in the course of the pilot project "D4A" (see reports 2002-2005), but which could not be finalised in due time because of events beyond our control. First aim of the 007 project was to make the digitiser operational, and then to start to digitise our collections.

This digitiser was built in close collaboration with the experts in digitising astronomical plates at the US Naval Observatory in Washington DC (USNO), the experts in aerial photography at the National Geographic Institute (NGI), AGFA-Gevaert (world-leader in photographic matters) and the partners of the 007 project.

As a demonstration for the capabilities of the digitiser, USNO plates have been digitised on the demand of Jean-Eudes Arlot and his team for a study of planetary satellites. Once the digitiser was finalised, mass production of digitised images of our astrophotographic glass plates could start for the partners of the 007 project.

In parallel with the building of the scanner, we started to set up a detailed catalogue with thumbnails of our plate collection and a database of the meta data.

Since these first projects were supposed to terminate by the end of 2008, Belspo has started to search actively for financing digitising projects beyond 2008. The aim is to set up a public-private partnership, starting in 2011 or 2012.

N.1.2. Progress and results

N.1.2.1. Management

The activities of Thierry Pauwels included the setting up of budgets, attending the meetings with other partners and the National Geographic Institute on January 18, October 12 and December 17, and participation to an internal meeting on October 11.

For the set-up of the public-private partnership, Thierry Pauwels acted as contact person between ROB and Belspo. This included not only the collection of astrophotographic plates, but all collections of ROB that qualify for digitisation. These collections are managed by J.-P. De Cuyper, H. Langenaken, S. Wintmolders and F. Clette. In January and February private companies got the task of setting up the call to tender. There were questionnaires to be filled in for each collection, which were filled in by the respective collection managers and gathered by Thierry Pauwels. These questionnaires were complemented by an interview on February 10. There were a lot of discussions about the outcome of these interviews and the technical fiches set up by the companies in charge of the call to tender and based on the questionnaires and the interview, and finally these fiches were not validated by ROB. Coordination of these activities were done at two meetings at Belspo, on January 2010 and June 28. Finally we got a number of questions by the companies responding on the call to tender.

As a side activity, Thierry Pauwels was asked to fill in a questionnaire by the reflection group on boosting cultural heritage on-line in Europe.

N.1.2.2. Hardware

The digitiser is based on an engineered ABL3600 air bearing XY-table from Aerotech. The mechanical subsystem includes an automatic plate holder assembly, a plate tray loader robot with plate tray magazine and turntable for photographic glass plates and film sheets and an automatic film roll transport system. These custom made devices allow a rapid exchange and loading into focus of the photographic images to be digitised without manual intervention. The optical system consists of a BCi4 12bit CMOS camera with 1280 x 1024 pixels of 7 µm x 7 µm from C-Cam Vector International mounted on a Schneider Xenoplan telecentric 1:1 objective (resolution 3630dpi). The back light illumination system uses very bright LEDs controlled by a precision DC power supply. The digitiser is installed on an isolated foundation block in a clean room. A climatisation installation delivered by Becker Reinraumtechnik regulates the clean room and adjacent archive room to a constant air temperature of 20°C ± 0.05°C and a relative air humidity of 50 % ± 1%. The archive room is equipped with three mobile double-sided archive storage units: the first one has a shelf depth of 25 cm and a storage capacity of 57 m, the second unit has a shelf depth of 30 cm and a storage capacity of 43 m and the third unit has a shelf depth of 35 cm and a storage capacity of 36 m.

Jean-Pierre De Cuyper follows-up the daily functioning of the technical installation. Together with Marc De Knijf he takes care of the maintenance and the solving of the technical problems of the digitiser, the air compressor, the vacuum pumps and the extension of the installation; and with Marc Strubbe of the climatisation installation.

Florian De Cuyper continued, under the supervision of Marc De Knijf, his master thesis in electromechanical engineering with as subject: "The putting into full-automatic production of a digitiser". He finalised his study of the mechanical and pneumatic subsystem, of the installed sensors on the digitiser and of the field bus Ethernet communication between the digitiser and the control PC. The Wago interface card was found to also posses an unused PLC functionality that could serve to monitor and secure the pneumatic sub-system. This study was then used to work out a hardware and security upgrade of the digitiser. The compressed air connection was improved and secured; the vacuum suction for film and thin glass plates was completely redesigned; the turntable was sent to DeStaCo for upgrading to have stops at 0°, 90° and 180° and a hydraulic brake was added to provide a smooth lifting of the turntable. A selection of the most appropriate distance sensors for controlling the presence of the plate tray magazine, the position of the granite base and of the plate trays in the handling system and of the extra digital and analogue input cards was made. The sensors were installed and the necessary connections to the Wago input and output cards were made. The automatic plate loader system is now secured for unattended automatic operation. The DeStaCo turntable was reinstalled after adapting the plate elevator.

Francis Renders continued with J-P De Cuyper the milling of extra plate trays and counterpressure plates out of cast MIC-6 Alu alloy plates on the Deckel milling machine in the mechanical workplace.

Uwe Laux, an optical engineer of the Thüringer Landessternwarte Tautenburg, in close collaboration with Jean-Pierre De Cuyper, continued the design of a new two-sided telecentric objective with a distortion free field of view of at least 25 mm in diameter. This will, in combination with a cooled digital camera of appropriate detector size, allow to reduce the stepping time of the XY-table by a factor of 10 and to make the digitiser an order of magnitude faster and more accurate.

In October Lars Winter visited the ROB and together with Jean-Pierre De Cuyper a hardware set-up and the software for evaluating a new type of cooled digital camera, containing a sCMOS chip, has been installed and tested.

The digitiser is designed to digitise photographic images up to 350 mm wide on glass plates, film sheets and film rolls. A counterpressure plate and a plate tray with a central opening corresponding to the actual image size are needed for loading the photographic plates, film sheets and film rolls. By the end of 2010 counterpressure plates and plate trays were available for digitising film rolls of 240 mm and 254 mm wide (with images sizes up to respectively 230 mm and 242 mm wide), film sheets of 240 mm wide (image up to 230 mm x 230 mm) and glass plates of:

- 130 mm x 180 mm and 7 inch x 5 inch (image 111 mm x 162 mm),
- 160 mm x 160 mm (image 151 mm x 151 mm),
- 165 mm x 216 mm and 6.5 inch x 8.5 inch (image 156 mm x 206 mm),
- 180 mm x 240 mm (image 171 mm x 231 mm),
- 240 mm x 240 mm (image 230 mm x 230 mm),
- 250 mm x 250 mm (image 242 mm x 242 mm),
- 300 mm x 300 mm (image 288 mm x 288 mm).
- 350 mm x 350 mm (image 343 mm x 343 mm).
- Other formats can also be loaded manually, when sandwiched between glass plates, in a tray for a larger plate format.

N.1.2.3. Software development

The distributed image capture and storage software package, for handling the huge data stream generated by the CMOS camera during the digitisation process, was further extended and improved by Georges de Decker. The variable exposure time software package was improved for digitising old aerial photographs of the fifties with large vignetting. Software was further adapted to the specific needs of the (hard) photographic images of the RICH. On some of these images large parts of the emulsion have been obscured for previous darkroom reproduction. As the 12-bit CMOS camera has a too limited dynamic range, a HDR (High Dynamic Range) capability had to be added to the software package. In order to reproduce the over- and underexposed parts of the image in an optimal way, a new method for converting the negative image into a positive one was also developed.

The climatisation installation of Becker-Reinraumtechnik uses a SAIA PLC controller for steering the climatisation as a function of a number of environmental parameters measured in real time. G. de Decker extended the software interface for reading these environmental parameters used by the SAIA controller and storing them in an Excel table. This software is used:

- to check the stability of the air temperature and relative humidity in the measuring clean room,
- to allow the adjustment of the steering parameters of the SAIA controller, and
- as an interface between the environmental parameters and the digitisation meta data table.

N.1.2.4. Digitisation

For the calibration and stability control of the digitiser, the 350 mm x 350 mm geogrid (geometric grid of chromium dots on a glass plate every 0.5 mm in the X and Y directions with diameters ranging from 50 µm to 300 µm made by BVM Maskshop in Germany) was digitised regularly. The dynamic repeatability benchmark testing showed that under stable environmental conditions the internal repeatability error in the digitised images is better than 0.08 µm. The static benchmark showed that a temperature change of 0.5°C causes a shift of 0.5 µm in the central field of view of the camera.

J.-P. De Cuyper monitors the stability of the exact mechanical table distance in the X and Y direction corresponding to the displacement of a target object of exactly 704 pixels in the row and column direction in the central field of view of the camera. This is needed to reassemble the sub-images of a digitised photograph back into one single mosaic image with minimal geometric distortion (~2 µm).

The moving dot procedure was used to calculate the distortion model parameters of the field of view error of the optical system. This model allows to convert the extracted pixel positions from the sub-images into distortion corrected metric coordinates (~0.2 µm).

On a regular basis thousands of dark and flat images were taken to generate mean dark and mean flat images for correcting the images taken by the CMOS camera.

Film rolls of 10" wide with aerial images have been digitised in close collaboration with the colleagues of the NGI and AFGA-Gevaert. From these aerial photographs mosaic images in tiled tiff format with pyramid overviews were created. For test purposes, different sets of original aerial photographic images (of Belgium (NGI) and of Katanga (CSK)) on acetate film sheets and their contact vacuum photographic copies (made in Mortsel by AGFA-Gevaert on high resolution duplication polyester film) were digitised. The NGI analysed the quality of the digital images. In both cases the digital images were found to fulfil the needed requirements for all possible photogrammetric applications. Hence, the digitisation of old (aerial) photographs can be done in an unattended automatic mode without any loss of detail by first making an analogue copy on a high-resolution duplication film roll. In case the photographic image has faded and/or the photographic film is degraded or damaged, the photographic duplication technique also improves the image quality and provides an analogue copy on polyester film that can be archived for at least a few centuries without extra costs.

In 2010 the D007 project ordered the reproduction on polyester duplication film at AGFA-Gevaert of 2000 copies on roll from the CSK. At the end of 2010 about 6565 photographic images had been digitised. Of which 1215 astrophotographic plates (USNO and Pulkovo planets plates); 4800 aerial photographic images of Katanga (CSK collection) and of Belgium (NGI collection) had been copied on film rolls and full automatically digitised; of the RICH collection 550 images had been digitised, including 150 copies of endangered originals on nitrate-cellulose film that were first copied on polyester duplication roll film.

N.1.2.5. Digital catalogue

The work on the digital catalogue and the pre-scanning of the photographic plates archived at the ROB was continued by J.-P. De Cuyper and G. de Decker. During the summer five job-students transformed standard Tyvek envelopes to sizes needed for the ROB glass plates, and transferred most of the remaining plates (mainly the 24 cm x 24 cm and 16 cm x 16 cm ones) from the old archive in the Double Astrograph building to the new climatised archive in the Telescope building, after putting them in these new envelopes.

The digital photographic plates catalogue contains meta data of 25650 direct images and spectra (mostly multiple exposures on one photographic glass plate), 13350 prescans of photographic plates and 10280 quick-looks.

N.1.3. Perspective for next years

N.1.3.1. Project funding

The running projects, including "007" have been extended with one more year, till the end of 2011. This was not foreseen, but the set-up of the public-private partnership was delayed because of the political situation. The public-private partnership may already start in 2011, but this will more probably be in 2012. At that time digitisation of our collections will be taken over by this partnership, but what the outcome of it will be, is still a complete mystery.

N.1.3.2. Hardware

The necessary counterpressure plates and plate trays will be milled at the mechanical workplace for digitising different sizes of photographic images on glass plates, film sheets and film rolls in unattended automatic mode.

The optical and mechanical design of a two-sided telecentric objective with a distortion free field of view of at least 25 mm in diameter will be finalised. A new 2K x 2.4K cooled digital camera containing a sCMOS chip will be tested. A public buying procedure will be done for the delivery of the new objective and a cooled digital camera with a field of view of 25 mm in diameter and of a computer controlled stabilised LED illumination. The upgrade of the digitiser is foreseen for end 2011 or early 2012 and will improve significantly the quality and precision of the digitised images and reduce the stepping time of the XY-table by a factor of 10, hence making the digitiser an order of magnitude faster.

N.1.3.3. Software

Further extension and development of the digitisation software for the automatic, unattended handling of the plate trays by the plate loader system, using and monitoring the newly installed security sensors. Automation of the auto-focus software with a first quick passage over the photographic image. Development of an exposure meter/optimal exposure time determination/ software for the automatic digitisation of the copies of RICH photographic images on roll film in HRD mode, with a double passage over the image. Upgrade and redevelopment of the software interface for the new cooled digital camera.

N.1.3.4. Digitisation

In 2011 the digitisation of the photographic collection of the RICH will be continued in priority, as well as of the copies of aerial and art photographs on duplication film rolls. In the framework of a FP7 EU project astrophotographic plates of the planets will also be digitised.

N.1.3.5. Digital catalogue and plate archive

The digital meta data catalogue and the plate pre-scans will be further completed and made available on Intranet by Jean-Pierre De Cuyper and Georges de Decker and some job students during the summer months. The moving of the plate archive will be completed.

N.1.4. Personnel involved

Scientific staff:	Thierry Pauwels (coordination)
	Jean-Pierre De Cuyper
Technical staff:	Georges De Decker (software engineering)

Marc De Knijf and team (technical assistance)

N.1.5. Partnerships

List of international partners or collaborators having actively contributed to the project in the last year

- Norbert Zacharias, US Naval Observatory, Washington DC, US
- Uwe Laux, Thüringer Landessternwarte Tautenburg, Germany
- Lars Winter, Hamburg, Germany

List of national partners or collaborators having actively contributed to the project in the last year

- Royal Museum of Central Africa
- Royal Institute for the study and Conservation of Belgium's Artistic Heritage
- National Geographic Institute
- AGFA-Gevaert NV, Mortsel

Grants/Projects used for this research/service

- Digitaliseringsplan van de FWI's of Belspo

Visitors:

- Short visits: 1

N.1.6. Scientific outreach

Meeting presentations

(1) E. Schmidt, J.-P. De Cuyper, L. Winter, A. Ciez, S. Ludwick
Design of a precision scanning system for digitising aero and astro photographic images
euspen International Conference, June 2010, Delft, Nederland.

(2) Jean-Pierre De Cuyper, Georges de Decker, Lars Winter and Norbert Zacharias
The Archive and Digitiser Facility at the ROB
Astronomical Data Analysis Software and Systems (ADASS XX), 07-11 November 2010, Boston, Massachusetts, USA.

Seminars

(1) Jean-Pierre De Cuyper
The Archive and Digitisation Facility at the Royal Observatory of Belgium
04 May 2010, ESO Headquarters, Garching, Deutschland.

(2) Jean-Pierre De Cuyper
The Archive and Digitisation Facility at the Royal Observatory of Belgium
03 September 2010, ROB.

(3) Jean-Pierre De Cuyper
The Archive and Digitisation Facility at the Royal Observatory of Belgium
13 December 2010, RICH.

N.1.7. Missions

Assemblies, symposia:

- Jean-Pierre De Cuyper: Astronomical Data Analysis Software and Systems (ADASS XX), 07-11 November 2010, Boston, Massachusetts, USA

Commissions, working groups:

- Thierry Pauwels (6 days).
- Jean-Pierre De Cuyper (5 days).

Research visits:

- Jean-Pierre De Cuyper (12 days).

Field missions:

- Jean-Pierre De Cuyper (16 days).

N.2. Project UDAPAC

N.2.1. Objectives

The UDAPAC project was initiated in 2000. In this project the Royal Observatory would serve as a host for the European collections of the direct (as opposed to spectra) astrophotographic plates for which the owners have no more facility, interest or know-how to keep them. In the long run, parallel with the other digitisation projects, these plates could be digitised. In parallel a group is looking for the possibility for funding of a European-wide project of digitisation of astrophotograhic plates. This could be a means to get UDAPAC funded.

N.2.2. Progress and results

In order to get a digitisation project funded, FP7 does not seem to be the right place to apply, since they fund research projects only. Therefore we concentrated on the CIP ICT PSP line, in which we found a promising call. Thierry Pauwels went to a general information day on January 14 in Brussels, and to a more targeted information day with Rainer Arlt in Luxembourg on February 4. At that latter meeting we got an interview with an officer, but it turned out that our project does not really fit in the call, since the call focuses on digitising masterpieces for a very broad target public.

Later Rainer Arlt, Elizabeth Griffin and Thierry Pauwels, manoeuvred to get an interview with someone from the reflection group on boosting cultural heritage on-line in Europe. There were contacts with Elisabeth Niggeman of the German National Library, but could not get her on a face-to-face meeting, and we finally got a restricted meeting at the Botanical Museum in Berlin with Rainer Arlt, Elizabeth Griffin, Anton Guentsch and Thierry Pauwels.

In the course of this year, Elizabeth Griffin has set up a CODATA task group, DARTG for "Data at risk task group", of which Thierry Pauwels is member.

Figure 33: View of the archive room

Concerning the archiving of European plates at ROB, negotiations are ongoing with ESO. There has been a meeting at ROB with Claus Madsen, Edwin Valentijn and Regnier Peletier on January 12. In May Jean-Pierre De Cuyper was invited by ESO to give a talk on digitisation and archiving of photographic plate collections, to visit the ESO plate archive and to discuss the moving of the ESO Schmidt plates to the ROB archive. On October 6 there was a meeting at the ESO premises in Garching-bei-München with Fernando Comeron and six other ESO staff members together with Thierry Pauwels, representing ROB, discussing the modalities of the transfer of the ESO plate collection to Ukkel. A local meeting at ROB has been held on October 11.

N.2.3. Perspective for next years

We will continue to investigate if funding sources can be identified for starting a European digitisation project. The plate vault at ROB will be prepared to accept the ESO plate collection. Transfer is already expected in the course of 2011. For digitising ESO plates *en masse* there are for the moment no funds.

N.2.4. Partnerships

List of international collaborators having actively contributed to the project in the last year

- Rainer Arlt, Astrophysikalisches Institut Potsdam.
- Ognyan Kounchev, Bulgarian Academy of Science.
- Elizabeth Griffin and the members of DARTG.
- ESO.

Visitors:

- Short visits: 4

N.2.5. Missions

Commissions, working groups:

- Thierry Pauwels (2 days).

Field missions:

- Thierry Pauwels (2 days).

N.3. Ephemerides of Solar System Moons

N.3.1. Objectives

The aim of this project, in a first step, is to determine very accurate ephemerides of the four Galilean satellites of Jupiter and of the natural satellites of Saturn from the collection of photographic plates taken by Dan Pascu at USNO over a period of more than 30 years. In collaboration with the IMCCE, Observatoire de Paris, France and the US Naval Observatory (USNO), Washington DC, US, the positions of the natural satellites and the stars on the plates are to be extracted from the digital (sub)images produced by the ROB digitiser and corrected for systematic errors caused by the distortion of the field of view during the digitisation. These corrected positions on the glass plates are then to be converted to celestial coordinates on sky by using the modern accurate UCAC2 and 3 stellar catalogues and taking into account the systematic effects (caused by the telescope, the atmosphere, etc.) at the time of the exposure. From these celestial positions very accurate orbital parameters will be calculated at different epochs as well as their evolution in time.

N.3.2. Progress and results

The work started by Vincent Robert at the ROB in 2006 was continued as part of his PhD thesis and extended. Jean-Pierre De Cuyper and Georges de Decker analysed and discussed the scientific and technical details of the extraction of the positions of the moons and the stars from the digitised images with the partners of the IMCCE and USNO. A few dozen of these plates were digitised several times with the ROB digitiser in order to optimise the geometric accuracy of the digital (sub)images and to test the software developed by G. de Decker, L. Winter and V. Robert for the construction of the fits mosaic plates images and for the extraction of the plate positions of the Galilean satellites and the stars. The obtained geometric accuracy is better than 0.1µm.

A paper on astrometric reduction of photographic plates using the ROB digitizer for improving the dynamics of the Jovian system has been submitted and is now in press.

In total 840 digitisations have been done, of which in 2010 some 515 digitisations of Galilean and Saturnian selected plates were obtained. The positions of the satellites and of the stars were extracted and corrected for systematic errors and the results are being analysed and under publication. A comparison with previous results and with those obtained with the MAMA machine was made.

N.3.3. Perspective for next years

In the frame of ESPACE, a future FP7 project, we shall work on the ephemerides of the moons of the solar system. First the plates taken by Dan Pascu with the 26" refractor at USNO in Washington DC and those from the South African Observatory will be digitised and the extracted astrometric data will be published. Also all valuable and accessible photographic plates of the moons of the solar system will be brought to ROB for digitisation and astrometric data extraction. Development of a software package (phase 1) for the localisation and the extraction of the celestial objects: stars, planets and their natural moons adapted to the different specific characteristics of the images of the satellites of Mars, Jupiter and Saturn.

In the frame of the ESPACE project the data will be used in the dynamics model code called NOE for Numerical Orbit and Ephemerides (Lainey et al. 2007, Lainey 2008) developed at IMCCE to provide new ephemeris kernels. In parallel radioscience data will be reprocessed to provide new biases residuals of spacecraft tracking data analysis with respect to a given ephemerides, and therewith new ephemerides in a mixture with the astrometric data (precessing at the normal equation level). In a second step, all data will be published in refereed journals and make accessible worldwide thanks to a proper astrometric database.

N.3.4. Partnerships

List of international partners

- Jean-Eudes Arlot, Valéry Lainey, and Vincent Robert, IMCCE, Observatoire de Paris, France
- Dan Pascu and Norbert Zacharias, US Naval Observatory, Washington DC, US
- Lars Winter, Hamburg, Germany

Visitors:

- Jean-Eudes Arlot, OBSPM, 07-09/06/2010, digitisation, project meeting
- Valéry Lainey, OBSPM, 09-10/06/2010,14/09/2010, digitisation, project meeting

- Vincent Robert, OBSPM, 07-10/06/2010,14/09/2010, digitisation, project meeting
- Chane YAO, OBSPM, 07-10/06/2010, September 2010, digitisation

N.3.5. Scientific outreach

Meeting presentations

(1) V. Robert, J.P. De Cuyper, J.E. Arlot, V. Lainey, D. Pascu
A new reduction of astrometric photographic plates using the DAMIAN digitizer
2010 Meeting of the Division on Dynamical Astronomy of the American Astronomical Society, 25-29 April 2010, Boston, Massachusetts

N.3.6. Missions

Commissions, working groups:

- 14 September 2010, project meeting, ROB
- 22 September 2010, project meeting, IMCCE, Obs de Paris, France

Research visits:

- 03 – 07 November 2010, USNO, Washington, DC, US

N.4. Ephemerides of the planets

N.4.1. Objectives

The aim is to determine very accurate ephemerides of the planets. In collaboration with the US Naval Observatory (USNO), Washington DC, US, the Southwest Research Institute, Boulder, Colorado, US and the Main Astronomical Observatory of the Russian Academy of Science in Pulkovo, St Petersburg, Russia, the positions of the planets and the stars on the plates are to be extracted from the digital (sub)images produced by the ROB digitiser and corrected for systematic errors caused by the distortion of the field of view during the digitisation. These corrected positions on the glass plates are then to be converted to celestial coordinates on sky taking into account the systematic effects at the time of the exposure. From these celestial positions very accurate orbital parameters will be calculated at different epochs as well as their evolution in time.

N.4.2. Progress and results

In total 375 digitisations have been done, of which in 2010 some 92 digitisations of selected plates from Pulkovo and Lowell were obtained. The positions of the planets and of the stars were extracted and corrected for systematic errors and the results are being analysed.

N.4.3. Perspective for next years

EPRORAD, an FP7 project for working on the improvement of the ephemerides of the planets has been introduced to the EU.

The New Horizons spacecraft is on its way to the system Pluto-Charon. We believe, in view of the near future New Horizons arrival near Pluto and Charon, that these objects are the most urgent to be digitised and will provide full visibility to ROB Digitalisation project.

We have then pushed for the digitalisation of the plates from Pluto and Charon. For New Horizons spacecraft navigation as well as for science purposes, it is necessary to obtain very precise ephemerides for these two bodies prior to reaching that distance from Earth. In order to produce ephemerides, one needs to combine all possible astrometric data.

Our future work aims thus at finding and digitising the plates as well as developing a software package for the localisation and the extraction of the celestial objects: stars and planets adapted to the different specific characteristics of the images, especially of the Pluto and Charon system.

N.4.4. Partnerships

List of international partners

- Dan Pascu and Norbert Zacharias, US Naval Observatory, Washington DC, US
- Evgenia Khrutskaya, Andrei Berezhnoy, Konstantin Grigoriev, Pulkovo Observatory, St. Petersburg, Russia
- Lars Winter, Hamburg, Germany

Visitors:

Andrei Berezhnoy, Pulkovo Observatory, 25-29 January 2010, digitisation.

Solar Physics and Space Weather

O. Solar Physics Research and Development

This theme includes all activities involving theory or data analysis (using whichever instrument) performed to directly enhance scientific understanding. It is organized in projects grouping different research areas.

O.1. Coronal Heating and Solar Wind Acceleration

O.1.1. Objectives

Solving the coronal heating problem means identifing and characterizing the several physical mechanisms that involve the transport of magnetic energy from the photosphere to the corona, its conversion and dissipation into plasma heating. During 2010 the work on this thematic has progressed both from observational and theoretical point of views.

On the energy deposition issue, the ROB activity has focused on the numerical investigation of several aspects linked to turbulence. A direct observation of the heating deposition however, is not visible, while we can have its indirect evidence through the radiation losses as a result of the plasma heating. The properties of the plasma response in terms of EUV and X-ray emission have been studied in particular in active regions, through data analysis and simulations. We have characterised loops (the building block of the corona) and the whole active regions, studying both the cooling processes and its signature in the plasma emission. The aim was to establish as many as possible observable aspects that may help modeling.

The solar group has also worked on the problem of solar wind oringin and acceleration. In particular we studied the role of turbulence.

O.1.2. Progress and results

O.1.2.1. Effect of leakage on turbulence and the line-tied approximation

Turbulence is a possible way to deposit and dissipate magnetic energy on small scales that results in plasma heating. In modeling this heating in loops, generally the the line-tying hypothesis is assumed, i.e. loop footpoints are anchored in the photosphere and leakage of the coronal power towards the photosphere is not allowed.

A.Verdini studies the accumulation of coronal magnetic field relaxing the line-tying hypothesis, In the linear regime the loop is line-tied for a short time (an Alfvén time), i.e. the coronal magnetic field increases linearly with time, but soon after the system relaxes to an equilibrium state, leading to a finite accumulation of coronal magnetic energy. A.Verdini has extended the above work (see report 2009) to the case of a turbulent regime, considering for the first time the combined effect of turbulent and leakage losses, which are sketched in Figure 1 superimposed to the contours of the compensated spectra.

The leakage time, $t_{leak}=L/V_a^{phot}$ (L=loop length, V_a^{phot}=Alfvén speed at the photosphere), is a long timescale compared to the coronal crossing time $t_{cor}=L/V_a^{cor}$, because of the strong Alfvén speed contrast existing between the corona and the photosphere ($V_a^{phot}/V_a^{cor}=\varepsilon<<1$): such timescale difference usually justifies the use of line-tied approximation in coronal simulations. In that situation the amount of energy accumulated in the corona is given by the balance between injection and dissipation (in our case study turbulent dissipation). In practice one can decrease the perpendicular injection scale in order to increase the efficiency of turbulent dissipation, making the dissipation timescale as small as needed. However, A. Verdini finds that accounting for the leakage this cannot happen, i.e. despite the leakage time is long, its influence on the dissipation timescale are not negligible. As can be seen in the turbulent dissipation timescale saturates to the minimum level given by the leakage timescale. Thus, from a dynamical point of view, the line-tied approximation is not justified as far as the dissipation mechanism is nonlinear, i.e. it depends on the amount of coronal energy, because the feedback induced by the coronal leakage is not negligible.

O.1.2.2. Identifying coronal loop cross section shape.

Magnetic coronal loops are ubiquitous in the quiet sun and active regions. However due to instrument resolution issues and lack of perspective in observations, little is known about their physical structure. Recent observations indicate they're composed of a series of small flux tubes with probably a sub-resolution cross-section.

Studies have been conducted looking at the dimensions of coronal loops. One aspect of the coronal loop that has not been studied is that of its cross section. Loops are often considered to have a circular cross section area, however recent observations have brought this into question, and and it is not clear if the cross section is circular or oblong.

Due to the unique observations made from two different directions with the STEREO telescopes, it is hoped that by observing the emission of large loop structures in different wavelengths it will be possible to identify any variation in cross section. M. J West and Andrei N Zhukov are setting up a plan of work to identify a series of individual coronal loops and analyse the difference in emission between the different observations.

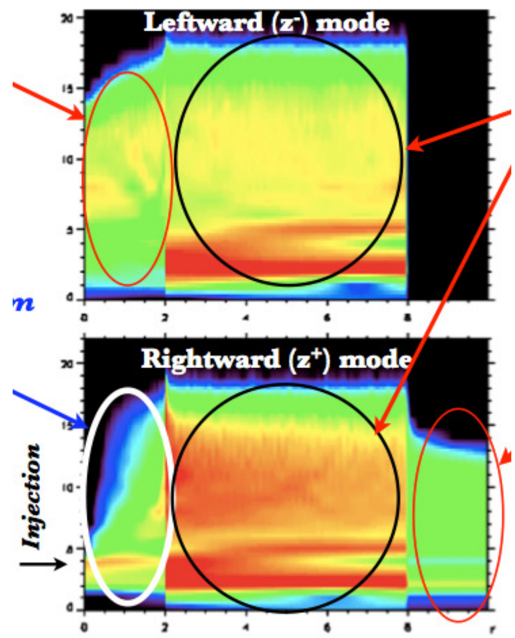

Figure 34: Contours of the compensated energy spectra ($E_k k^{5/3}$) of the two Alfvénic components. X-axis is the loop length (Mm), Y-axis is the perpendicular wavenumber mode, $\log_2(K/K_0)$. Black circles: coronal losses due to turbulence. Red Circles: coronal leakage to the photosphere. White circle: coronal injection from the photosphere.

O.1.2.3. Signatures of coronal heating in radiative loop emission.

Any complete coronal heating model of the corona needs to be able to simulate the plasma response to heating and possible observables that can benchmark the model. Impulsive coronal heating is a potentially viable heating model, where energy is dissipated through small discrete events which heat magnetic loop structures that permeate throughout the solar atmosphere. The number of flares and microflares is distributed in energy as a power law. Studies of the energy distribution of smaller events (nanoflares) rely on estimates of the amount of energy associated with observed X-ray and extreme ultraviolet (EUV) brightening.

Matthew J West has constructed an analytical cooling model to simulate the cooling of coronal loops through conduction and radiation. Previous models have only considered local cooling temperature gradients, whereas M. J West's model uses a non-local component to provide more accurate results. By setting the model to simulate random heating events, M. J West and S. Parenti are using the model to simulate the cooling of loops undergoing multiple heating events, and consequently, the ensuing cooling signature. The simulation technique was developed by S. Parenti in previous work and showed the observed coronal plasma to be cooling down; the new model improves on these results with a more accurate cooling model.

Preliminary results show that coronal loops retain their energy for longer periods, and as a consequence require less energy input, this however is not transmitted into the observed radiative signature of a cooling plasma.

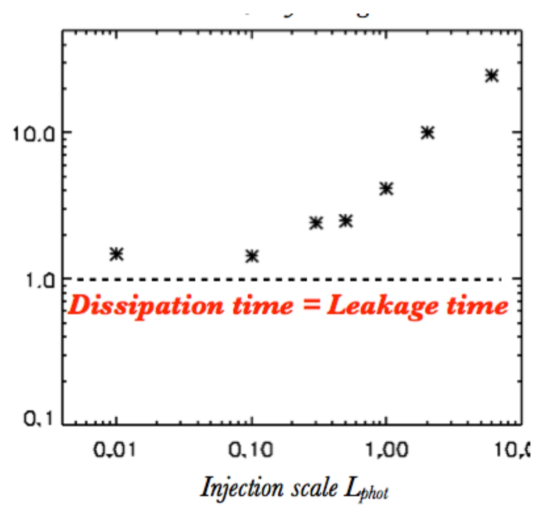

Figure 35: Dissipation time normalized to the leakage time as a function of the injection perpendicular scale (in Mm) for loops of same length and photospheric Alfvén speed (same leakage time).

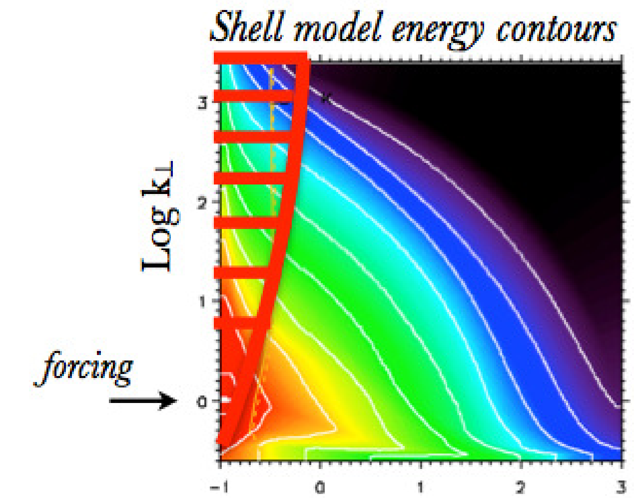

Figure 36: Contours of the time averaged energy spectrum, E(logK,□), for the Reduced MHD model. The red lines are the contours predicted by the Goldreich-Sridhar theory.

O.1.2.4.Thermal structure of active regions

The Differential Emission Measure (DEM) is a function which gives the plasma distribution in temperature along the line of sight. This can be inferred from coronal optically thin emission. For the DEM restoration procedure, related to the "solution of the spectral inverse problem", an original diagnostic method based on an iterative procedure in the frame of the probabilistic approach was used at ROB. This so-called Bayesian iterative method (BIM) is an iterative procedure based on Bayes' theorem. F. Goryaev developed this inversion technique and (in a previous project called DIMITUS), with the supervision of S. Parenti, they performed a deeper investigation of the BIM abilities in the case of both high resolution line spectra (SUMER/SOHO and SPIRIT/CORONAS-F) and broad-band imaging data (XRT/Hinode). The activity has continued in 2010 through further numerical simulations and the publication on the work (Goryaev et al., 2010).

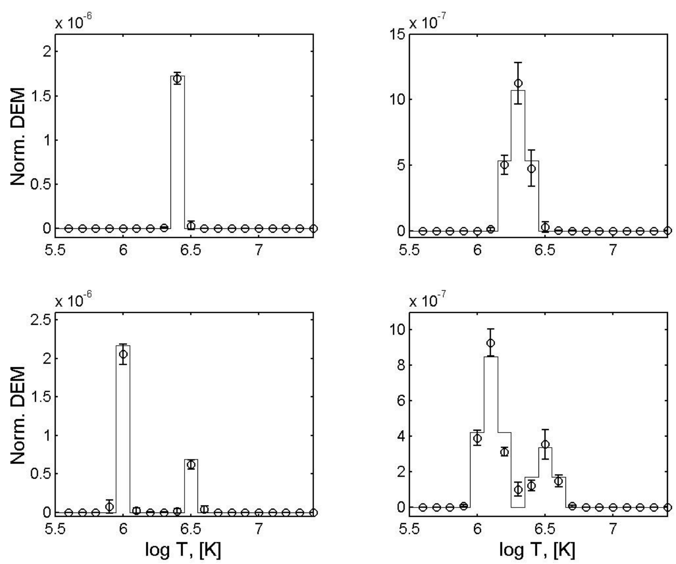

Figure 37: Test examples for AIA/SDO EUV channels: histograms - model DEMs; circles with error bars (corridor of errors) – solutions of the BIM (5% random perturbations in intesnsity flux values).

The following main results were achieved:

- BIM provides a stable solution within the framework of the probabilistic approach, satisfying the Maximum Likelihood criterion
- The confidence level for solutions is of order of uncertainties of measurements

- The absence of any restriction on the choice of temperature grid in the BIM procedure allows us to analyze its temperature resolution and to study fine structures in DEM temperature profiles
- BIM calculations for real observable data correlate with recent studies, in particular infering the existence of hot plasma in non-flaring ARs.

A new investigation on the BIM diagnostic capability for inferring the DEM has been recently started by F. Goryaev and S. Parenti. They investigate the AIA/SDO EUV narrow-band and multi-channels instrument whose data have become available in 2010. Figure 37 shows an example of forward-and-back tests on simulated data. The numerical tests and simulations show that this set of data provides reliable DEM temperature profiles in the range of temperatures logT≈5.8÷6.8.

O.1.2.5.Spicules

Spicules are latterly become a possible candidate for injecting energy into the corona and rise its temperature. In collaboration with the team of J.M. Pasachoff (Williams College), I. Dammasch concluded a work started last year aiming at characterizing spicules with SUMER data (Pasachoff et al. 2010).

O.1.2.6.Signatures of the solar wind sources in the inner corona of the Sun

The inner solar corona (1-2Rsun) plays an important role as the intermediate region where the restructuring of the solar magnetic field from closed to open configurations and the formation of the solar wind streams takes place. CORONAS-F/SPIRIT telescope-coronagraphn has revealed the existence of quasi-stationary ray-like structures extending from ARs to white-light streamers. Spectroscopic measurements (SOHO/SUMER, HINODE/EIS) have detected Doppler shifts of coronal emission lines produced by coronal outflows at the edges of ARs. F. Goryaev objective is to study a possible relationship between between the EUV coronal rays and outflows.

By studing the relationship between maps of the EUV line intensities, DEM obtained by the EIS instrument at the disk center, and stream velocities of coronal rays observed by EUV telescopes above the limb, it appears the possibility that these coronal streams may represent components of the solar wind. The work is still in progress.

O.1.2.7.Turbulent Acceleration of the solar wind

Recent observations (De Pontieu et al. 2007,Tomczyck et al. 2007) have supported the idea that the energy transported by Alfvén waves in the corona is sufficient to heat and accelerate the solar wind. On the other hand, the turbulent state of the solar wind suggests that turbulence, which is generated in the lower corona, plays a role in solar wind acceleration. A. Verdini is trying to build a two-fluid model (electrons and protons) of the solar wind, from the transition region to 1 AU, that includes Alfvén waves and Alfvénic turbulence as the driver for acceleration and heating. The two-fluid description is a necessary improvement with respect to previous models, since it allows a better comparison with observations. This is relevant for both Solar Probe+ and Solar Orbiter missions which will return the electron and proton temperatures in the inner heliosphere, where data are missing.

Adding heat conduction to the time independent code. The inclusion of the low transition region in the computational domain requires the proper treatment of this boundary, namely the inclusion of radiation and heat conduction whose balance determine the density at the lower boundary. A. Verdini is working on this aspect using, for the moment, a one fluid model an had hoc heating function that does not includes Alfvén waves and turbulence as drivers for the solar wind.

Adding Alfvén waves to the time dependent code. Parallel to the time independent code, A. Verdini is implementing the injection of Alfvén waves in a two-fluid MHD code (Grappin & Wang 2011). This code has ad hoc heating function but is faster and less tricky, as transonic solutions are automatically found once proper boundary conditions and heating are used. However, when waves are injected instability develops and the work is actually devoted to understand this behavior.

O.1.2.8. Exploring spectral anisotropy in MHD incompressible turbulence

Simulations and observations in the solar wind have shown that the energy spectrum of MHD turbulence in presence of large-scale magnetic field is anisotropic. At present there is no theory to predict the anisotropy in energy content and spectral slope at a given direction with respect to the mean filed.

The only existent theory for anisotropic turbulence (Goldreich-Sridhar), can make prediction only for the spectrum in the parallel and perpendicular direction, but not for all the inclinations. In particular, the parallel cascade is inhibited at small wavenumber, while at high enough wavenumber a "passive" cascade is produced by the imprint of the perpendicular spectrum on the parallel direction. The latter fundamental assumption is called "Critical Balance" condition as it states the equality of the eddy turnover time and the propagation time for all wavenumbers larger than the critical one. Using a reduced MHD model and full MHD simulations (Grappin & Muller 2010) A. Verdini tests if the critical balance condition is satisfied and he investigates the anisotropy in the energy spectral content and in the spectral slope.

For the test, a numerical experiment in which turbulence is produced by the nonlinear interaction of counter-propagating wave that are injected from the boundaries of a tube of uniform density and magnetic field has been set up. In this reduced MHD experiment it was seen that the critical balance condition is satisfied. It was also investigated the angular anisotropy of the spectrum and compared it to that one obtained with a full MHD calculation. As can be seen in Figure 36, the contours differ one from the other, but also from the Goldreich-Sridhar prediction.

O.1.2.9. Solar irradiance

A collaboration of I. Dammasch with U. Feldman (NRL) had lead to a paper on solar irradiance based on a study of SUMER spectra. This was submitted in 2008 and finally published in 2010.

O.1.3. Perspective for next years

O.1.3.1. Effect of leakage on turbulence and the line-tied approximation

The mechanism that leads to the timescale saturation has not completely understood yet (*Figure 34*). This could be due to a reduced injection in the corona caused by the turbulence developed in the chromosphere (cfr. the spectra in the left corona in Figure 1), or to the behavior of the scalar model used to mimic the turbulent dynamics (SHELL model, a reduced MHD description). Both issues will be investigated.

O.1.3.2. Signatures of coronal heating in radiative loop emission.

M. J West and S. Parenti will generate synthetic spectra arising from the model they are developing. For the present work they chose to synthesize the Fe xii 195 (Temperature 1.4 million K), Fe xv 284 (Temperature = 2.2 million K) spectral line intensities, which correspond to lines that are observed by the STEREO EUVI Imaging Telescope, Hinode/EIS and SDO/AIA.

O.1.3.3. Thermal structure of active regions

We plan to continue the work to test the BIM diagnostic capability of DEM on simulated SDO/AIA data. In particular we will investigate how the results of the inversion method are affected by uncertainties in the data, such as white noise and calibration.

O.1.3.4. Turbulent Acceleration of the solar wind

The plan is to have one of the two codes up and running during 2011 in order to start investigating the properties of a turbulent driven solar wind. In particular we want to understand how the repartition of the heating between proton and electron can shape the solution and how they compare to the fast solar wind (plumes and interplumes) and the slow solar wind originating at the boundaries of coronal holes.

O.1.3.5.Exploring spectral anisotropy in MHD incompressible turbulence

We expect to fully characterize the anisotropies, which originate from the combination of turbulence with propagation (in uniform, non uniform, and expanding medium). To this aim we will construct a SHELL model that is able to capture the nonlinear dynamics in the perpendicular direction and the weakened non-linear dynamics in the parallel direction. The above-mentioned studies will also be extended to situation of imbalanced turbulence, which is mostly present in the solar wind.

O.1.3.6.Flows and element abundances in transition region

I.Dammasch in co-operation with U. Feldman plan a study on transition-region redshifts .A new study on Ca abundance has been initiated.

O.1.4. Partnerships

List of international collaborators having actively contributed to the project in the last year

- Roland Grappin, LUTH, Observatoire de Meudon, France.
- Marco Velli, Dipartimento di Astronomia e Scienza dello Spazio, Univ. di Firenze, Italia Person, Institute
- Matthaeus, W. H., Bartol Research Institute, University of Delaware, Newark, Delaware 19716, USA
- Oughton, S., Department of Mathematics, University of Waikato, Hamilton, New Zeland
- A. Urnov, S. Oparin: Lebedev Physical Institute of the Russian Academy of Sciences (FIAN), Moscow, Russia.
- F. Reale: Dipartimento di Scienze Fisiche & Astronomiche, Universita di Palermo, Palermo, Italy.
- Klimchuk J. A., NASA GSFC, Code 671, Greenbelt, MD 20771, United States
- Uri Feldman, Naval Research Laboratory, USA
- Jay M. Pasachoff, Williams College, Mass., USA

Grant(s)/Project(s) used for this research/service

- PRODEX SIDC EXPLOITATION
- PRODEX SOLAR ORBITER

Visitors:

- Grappin R., LUTH Observtoire de Meudon – LPP Ecole Polytechnique, France, 12-16/07/2010, 21-24/09/2010
- Velli M., Dipartimento di Astronomia e Scienza dello Spazio, Univ. Firenze, Italy, 22/09/2010
- Alexander Urnov, Lebedev Physical Institute (FIAN, Moscow), July 2010 – SOTERIA project.
- Slemzin Vladimir, Lebedev Physical Institute (FIAN, Moscow), November 2010 – PROBA-2 Guest Investigator Program.

O.1.5. Scientific outreach

Meeting presentations

(1) Goryaev F., Parenti S., Urnov A., and Hochedez J.-F. (talk).
DEM analysis for AIA/SDO EUV channels using the probabilistic approach to the spectral inverse problem.
The 38th COSPAR Scientific Assembly 2010, Bremen, Germany, 18-25 July 2010

(2) Goryaev F., Parenti S., Urnov A., Oparin S., Hochedez J.-F., and Reale F. (talk).
DEM analysis for line spectra and broadband imaging data using a probabilistic approach to the spectral inverse problem.

The Solar Image Processing Workshop V Conference, Les Diablerets, Switzerland, 12–16 September 2010

(3) F.Goryaev, S. Parenti, A.Urnov, S. N. Oparin, J.-F. Hochedez, F. Reale (talk)
Differential Emission Measure for line spectra and broadband data from the Bayesian iterative method.
The 38th COSPAR Scientific Assembly 2010, Bremen, Germany, 18-25 July 2010.

(4) S. Parenti
Coronal loop observations
Solar Plasma Spectroscopy: Achievements and Future Challenges, 13-15 September 2010, UK

(5) Slemzin V., Urnov A., Kuzin S., Harra L., Berghmans D., and Goryaev F. (co-author of the report).
Fine structure of the solar inner corona and its relationship with coronal streams.
The 7-th European Space Weather Week (ESWW), Brugge, Belgium, 15-19 November 2010.

(6) A. Urnov, S. Kuzin, S. Bogachev, Goryaev F., B.R. Dennis, A. Reva, S. Shestov, A. Solovyev, and I. Zhitnik.
Hot coronal plasma phenomena disclosed, classified and studied in the SPIRIT experiment on CORONAS-F mission.
The 38th COSPAR Scientific Assembly 2010, Bremen, Germany, 18-25 July 2010.

(7) A. Verdini, R. Grappin, M. Velli
Coupling Photosphere and Corona: linear and turbulent regimes
02/05/2010, Poster contribution, EGU meeting, Vienna, Austria

(8) A. Verdini, R. Grappin, M. Velli
Coupling Photosphere and Corona: linear and turbulent regimes
19/07/2010, Oral contribution, COSPAR meeting, Bremen, Germany

(9) A. Verdini, R. Grappin, M. Velli
Coupling Photosphere and Corona: on "not-line-tied" loops
23/11/2010, Oral contribution, Workshop on Plasma Astrophysics, Univ. di Firenze, Firenze, Italy

(10) A. Verdini
Fully self-consistent MHD turbulence models of the solar wind (?)
30/01/2010, oral contribution, ISSI workshop "Multi-scale physics in coronal heating and solar wind acceleration - from the Sun into the inner heliosphere", Bern, Switzerland

(11) A.Verdini, M. Velli, R. Grappin, W-H. Matthaeus, S. Oughton, E. Buchlin, D. Berghmans
Alfvén waves and turbulence in the solar corona and solar wind
20-21/05/2010, poster contribution, NAC conference, Cuijk, The Netherlands

Seminars

(1) A. Verdini
Heating the solar wind and the corona: a turbulence scenario
24/11/2010, Colloquium, Univ. of Utrecht, Utrecht, The Netherlands

O.1.6. Missions

Assemblies, symposia, conferences:

- Goryaev :12–16 September 2010, the Solar Image Processing Workshop V Conference, Les Diablerets, Switzerland.
- A. Verdini, S. Parenti, F. Goryaev: 18-23/07/2010, COSPAR meeting, Bremen, Germany
- A. Verdini: 20-21/05/2010, NAC conference, Cuijk, The Netherlands

Commissions, working groups:

- A. Verdini: 20-23/11/2010, Workshop on Plasma Astrophysics, Univ. di Firenze, Firenze, Italy
- A. Verdini: 23-31/01/2010, ISSI workshop "Multi-scale physics in coronal heating and solar wind acceleration - from the Sun into the inner heliosphere", Bern, Switzerland

Research visits:

- A. Verdini: 09-19/05/2010, Dipartimento di Astronomia e Scienza dello Spazio, Univ. di Firenze, Firenze, Italy.
- A. Verdini: 27/09-10/10/2010, Dipartimento di Astronomia e Scienza dello Spazio, Univ. di Firenze, Firenze, Italy.

O.2. Physics of Solar Flares

O.2.1. Objectives

Solar flares are powerful energy release events in the solar atmosphere that are characterized by the sudden increase of electromagnetic radiation in a wide spectral range. SIDC team is active in observation and analysis of such phenomena in various wavelength ranges, and particularly in the radio (exploiting the datasets of the HUMAIN facilities), and in the SXR-EUV (using data acquired by the LYRA radiometer, which was launched in November 2009 onboard PROBA2).

O.2.2. Progress and results

O.2.2.1. Coronal shock waves associated with the slow coronal mass ejections

J. Magdalenić, C. Marqué and A. Zhukov collaborated in the study of the origin of coronal shock waves. The origin of coronal shock waves is a subject of a long-standing debate. Coronal shocks can be either flare-generated freely propagating blast waves, or CME-driven shocks. Since CMEs and flares are usually closely synchronized, it is hard to give a conclusive answer. A multi-wavelength study of large-scale coronal disturbances associated with several CME/flare events was performed. The study was focused on the events in which the flare energy release, and not the associated CME, is the most probable source of the shock wave. Therefore, events associated with rather slow CMEs were selected. To ensure minimal projection effects on the CME speed measurements, only events related to flares situated close to the solar limb were included in the study. Radio dynamic spectra and positions of radio sources were used together with LASCO and EIT observations. The kinematics of the shock wave signatures, type II radio bursts, was analyzed and compared with the flare evolution and the CME kinematics. It was found that velocities of the shock waves were significantly higher, up to one order of magnitude, than the contemporaneous CME velocities. On the other hand, shock waves were in a close temporal association with the flare energy release that was very impulsive in all events. This suggests that the impulsive increase of the pressure in the flare was the source of the shock wave.

O.2.2.2. Analyses of a Global Moreton Wave Observed on 2003 October 28

J. Magdalenić worked on the scientific publication on the global Moreton wave observed on 28 October. Work is published in the Astropysical Journal.

The particularity of the event is the global propagation of the Moreton wave and two separate wave centers. This implies that two waves were launched simultaneously. The mean velocity of the Moreton wave, tracked within different sectors of propagation direction, lies in the range of 900–1100 km/s. The perturbation profile analysis of the wave indicates amplitude growth followed by amplitude weakening and broadening of the perturbation profile. This behavior is consistent with a disturbance first driven and then evolving into a freely propagating wave. The EIT wave front was found to lie on the same kinematic curve as the Moreton wave fronts indicating that both are different signatures of the same physical process. Bipolar coronal dimmings are observed on the same opposite east-west edges of the active region as the Moreton wave ignition centers. The radio type II source, which is co-spatial with the first wave front, indicates that the wave was launched from an extended source region. These findings suggest that the Moreton wave is initiated by the coronal mass ejection expanding flanks.

O.2.2.3. Flare generated type II burst without associated coronal mass ejection on 14 November 2005

J. Magdalenić prepared the scientific publication on the radio event recorded on 14 November 2005. Work will be submitted to the Astronomy and Astrophysics.

J. Magdalenić performed a multiwavelength study of large-scale coronal disturbances associated with the flare event recorded on 14 November 2005. The coronal shock wave was associated with a GOES M3.9 flare from the NOAA AR 10822, close to the east limb (S06 E60). The shock wave signature, type II radio burst, had an unusually high starting frequency of about 800 MHz indicating that the shock was formed rather low in the corona. The coronal electron density, position of the shock wave and direction of the shock propagation were estimated using the Green Bank Solar Radio Burst Spectrometer, and the Nançay Radioheliograph observations. The soft X-ray, H alpha and RHESSI observations show that the flare was compact, very impulsive and of rather high density and temperature. All this gives indication of a strong, impulsive increase of pressure in the small flare loop. The close association of the shock wave with the impulsive energy release suggests that the impulsive increase of the pressure in the flare was the source of the shock wave. This is supported by the fact that, contrary to majority of the previously studied events, a coronal mass ejection associated with the shock wave was not observed. This case study shows that the presence of the CME is probably not a necessary condition for the shock formation.

O.2.2.4. The coronal electron density profiles derived from radio observations

J. Magdalenić performed a multiwavelength study of five radio events consisting of both, type II and type III radio bursts.

Solar radio bursts in the metric range correspond dominantly to plasma emission. Since electron plasma frequency f is linked to electron density n ($f \propto n^{1/2}$), radio bursts can provide an estimation of the coronal electron density. EUV observations show that the corona overlying active regions is not uniform. Therefore, a single density profile is not adequate to explain all types of radio bursts, possibly associated with different types of coronal structures. To be able to compare the density profiles corresponding to different coronal structures of the same active region, two types of radio emission, type II and type III bursts were analyzed. The density profiles were obtained using the Nançay Radioheliograph imaging observations and dynamic radio spectra recorded by the radiospectrographs of the Astrophysical Institute Potsdam and Humain observations (ROB). The observations of the plasma dynamics in the low corona were provided by the Extreme-ultraviolet Imaging Telescope (EIT instrument onboard SOHO). The study showed that the type III bursts were mostly associated with coronal structures having significantly larger density gradients than the generally used coronal density models. On the other hand, the coronal density models correspond rather well with the density profiles obtained from the type II bursts.

O.2.2.5. Type II burst recorded at Humain associated with the CME/flare event on 18 March

J. Magdalenić performed a multiwavelength study of large-scale coronal disturbances associated with the CME/flare event recorded on 18 March 2010. The evolution of the shock wave signatures, type II radio bursts, was analyzed using dynamic spectra recorded by Humain (ROB) and the Nancay Decameter Array together with imaging by the Nancay Radioheliograph. The study of the associated EIT wave was done using the observations of the plasma dynamics in the low and high corona provided by high time resolution PROBA 2 (SWAP and LYRA) and both STEREO spacecraft. The waves were associated with the B5.3 flare in the NOAA AR 1056 (located at N17 E47).

Observations and the model simulation of a propagation of the fast mode wave (Y.Wang) showed that it is possible that the bubble-like structure observed by SECCHI EUVI (STEREO) might not be the mass ejection but the wave.

O.2.2.6.Modeling of a reconnecting current sheet

SIDC team is also active in the research of underlying flare physics. One of the central questions about the processes that trigger and drive eruptive solar flares is what is responsible for converting stored magnetic energy to heat, radiation, and kinetic energy of ejected plasma (CMEs). It is currently widely accepted that magnetic reconnection is responsible for releasing this stored energy, but exactly how and where this process takes place is an open question.

In the previous years, D. Seaton presented a one-dimensional analytical model of a reconnecting current sheet that was developed in collaboration with T. Forbes. Nevertheless, this model was still including a number of unrealistic assumptions.

In 2010, D. Seaton & T. Forbes' studies of current sheet dynamics continued, and the one-dimensional, symmetric, steady-state model has been extended to include both time dependence and asymmetry. These two improvements give us a more comprehensive understanding of both the dynamics of reconnecting current sheets and the stability of several classes of possible solutions to the steady state equations.

In particular, the addition of time dependence to this system makes it possible to study the role of reconnection rate driving solar eruption. Previous modeling efforts by Seaton and Forbes relied on artificial assumptions about the proper choice for reconnection rate in the model. However, time-dependence allows the model to relax from any initial state to a stable, steady state. In principal, it is possible to distinguish between stable and unstable solutions, and gain insight about the true rate of reconnection during flares an eruptions.

Understanding the role reconnection plays in the dynamics of eruptive flares is especially important for constructing realistic models of such events. The reconnection rate is one of the primary determiners of the rate of energy release, and, thus, flare strength, eruption speed, and several other important properties of eruptive flares.

O.2.2.7.Flares as observed by LYRA on-board PROBA2

The XUV-EUV spectral range in the one in which solar irradiance is the most varying due to solar activity. The best-known flare monitor, GOES, is observing in that spectral range. And so does LYRA. Two of its four channels, the aluminium and zirconium channels, respectively covering the 6–20 nm range (plus contribution below 2 nm) and the 17–80 nm range (plus contribution below 5 nm), are devoted to flare detection. Over the first year of operation, they have recorded several hundreds of flares of intensity down to B1.5 in GOES scale. LYRA can therefore potentially serve as a flare monitor for space weather purposes.

In 2010, a lot of effort was spent by I. Dammasch and M. Dominique to acquire and calibrate LYRA data, and to have them accessible by the users. Among other LYRA data products, a list of flares detected by the instrument is maintained on PROBA2 website (http://proba2.sidc.be), with their main characteristics and a quicklook.

In a few cases of intense, very impulsive flares, a signature was also observed in the Lyman-alpha channel of LYRA (120–123 nm). Whether this Lyman-alpha contribution is systematic, but with a too low amplitude to be detected, or this contribution is particular to a certain type of flares is still to be determined.

It is found that flares observed in the different LYRA channels exhibit variations of their main characteristics (start, peak, and end time; shape of the flare UV and EUV flux variation). As an example, see Figure 38 in which it Lyman alpha channel clearly raises and peaks before the two EUV channels. Identically, in GOES timeseries, the flares appear to be slightly in advance wrt. LYRA EUV peak times. An analysis of this chronology has been initiated.

During the onset of strong flares, oscillations were detected in LYRA timeseries with frequencies between 0.1 and 0.01 Hz approximately (see Figure 39). Such a phenomenon has been previously reported by other instruments, in several bandpasses from HXR to radio. Its origin is still unknown, but several hypotheses exist: quasi-periodic injection of fast electrons, oscillations of the flaring loop … With its very high sampling rate, LYRA might bring a new insight on the process. We set up collaboration with T. Van Doorsselaere (KUL) to investigate it.

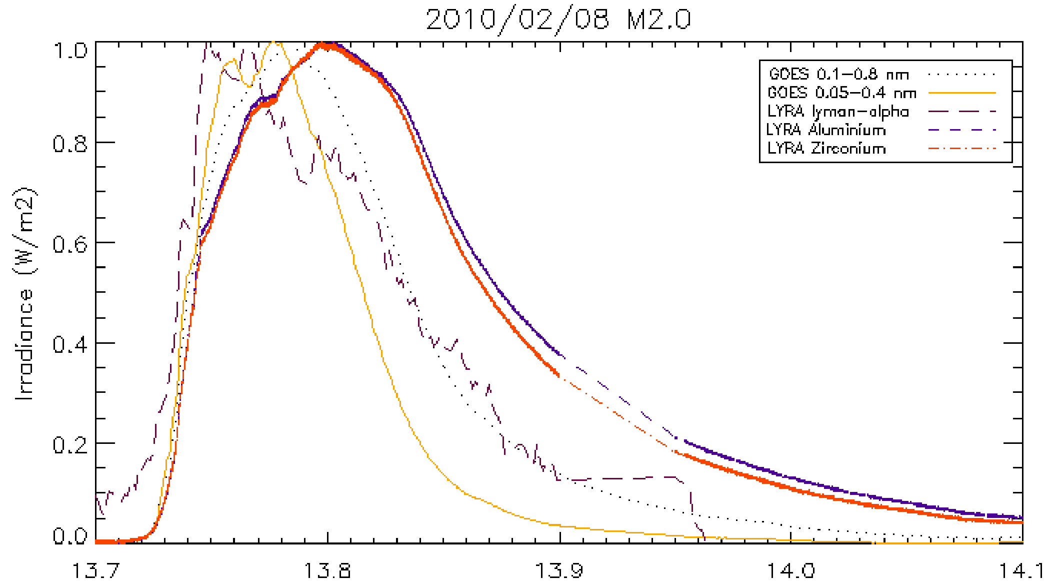

Figure 38: Flare signal in different passbands. The differences in onset and peak times are obvious.

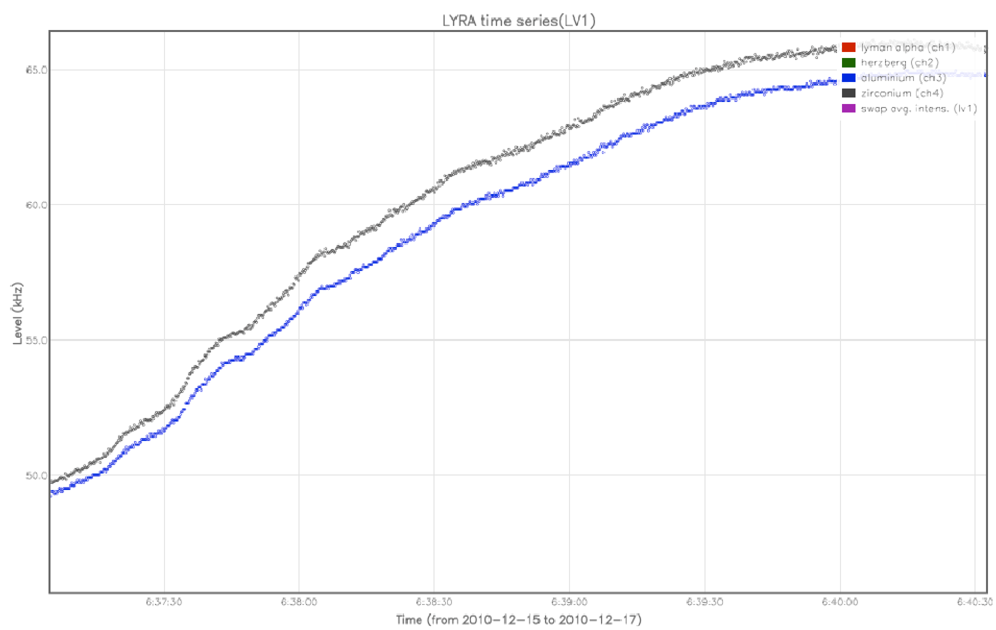

Figure 39: LYRA signals during the rise time of a flare, showing high-frequency oscillations.

O.2.3. Perspective for next years

The investigation of solar radio bursts will be continued. A particular attention will be paid to distinguishing between flare-associated and CME-associated radio bursts.

Recent papers by S. Savage[1] (2010) and K. Reeves[2] (2010) have examined the role that reconnection plays in observations and numerical models of eruptive flares. Both papers confirm that properties predicted by previous work done with Seaton's model match observations. In particular, Savage looked at the role that reconnection plays in the generation of inflowing and outflowing jets during a flare that occurred on 9 April 2008. Their observations suggest that predictions about the height of the reconnection site in the corona from previous work by Seaton and Forbes are likely correct, and it should be possible to observe this site using instruments such as XRT, SDO, and SWAP.

Savage, Reeves, Forbes, and Seaton are now engaged in a study of one such set of observations of the 3 November 2010 eruption, which was seen by both SDO and SWAP. With much new data available from both SDO and PROBA2, there should be ample opportunities for modeling and testing of predictions using solar observations in the coming years.

The analysis of flares detected by LYRA as just started in 2012 and is to be continued in the next years. To be further investigated are the quasi-periodic pulsations observed during the onsets of flares, and the inter-comparison of flare characteristics with other instruments such as GOES or EVE, that are operated at the same time as LYRA.

O.3. Physics of coronal mass ejections, Sun-heliosphere connections and space weather

O.3.1. Objectives

The focus of this research theme is investigation of the structure of CMEs, of Interplanetary CMEs (ICMEs), their relationship and link with disturbed space weather conditions at Earth, using the data from SOHO, ACE, STEREO, Hinode, PROBA-2 and SDO missions. This WP therefore addresses all stages of the CME evolution, starting from the pre-eruptive coronal configuration (streamers, active regions, prominences), continuing with CME signatures in the low corona (dimmings, EIT waves, erupting filaments), the CME structure and dynamics in three dimensions, properties and propagation of corresponding structures (ICMEs) in the interplanetary medium, and finishing with their potential geoeffectiveness.

O.3.2. Progress and results

O.3.2.1. Studies of coronal dimmings

L. Dolla and A. Zhukov made a spectroscopic investigation of solar eruptive phenomena in the low corona. It was demonstrated earlier that coronal dimmings are the most frequent extreme-ultraviolet (EUV) signature of coronal mass ejections (CMEs). However, the spectroscopic diagnostics of their plasma is difficult due to scarce observations. Fe XII (195.12 Å) line profiles observed by Hinode/EIS in a coronal dimming after an X-class flare on December 13, 2006 were analyzed. Line profile distortions were quantified with empirical coefficients (asymmetry and peakedness) that compare the fitted Gaussian to the data. It was found that the apparent line broadenings reported in previous studies are likely to be caused by inhomogeneities of flow velocities along the line of sight, or at scales smaller than the resolution scale, or by velocity fluctuations during the exposure time. The increase in the amplitude of Alfvén waves can-

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[1] See Savage, S. L. et al., 2010, *ApJ*, 722, 329
[2] See Reeves, K. K. et al. 2010, *ApJ*, 721, 1547

not alone explain the observed features, contrary to statements in the literature. A double-Gaussian fit of the line profiles shows that, both for dimmings and active region loops, one component is nearly at rest while the second component presents a larger Doppler shift than that derived from a single-Gaussian fit.

From observations of filament eruptions recorded with the Extreme-Ultraviolet Imager on *STEREO* during 2008–2009, it is evident that coronal dimmings are much more pronounced in 19.5 nm than in the lower-temperature line 17.1 nm, as viewed either on the disk or above the limb. Robbrecht et al. conclude that most of the cooler coronal plasma is not ejected but remains gravitationally bound when the loops open up. When the open flux reconnects and closes down again, the trapped plasma is initially heated to such high temperatures that it is no longer visible at Fe ix 17.1 nm.

O.3.2.2.EIT wave studies

A. Zhukov was invited to write a review paper on EIT waves, large-scale bright fronts observed propagating in the solar corona in association with CMEs. An overview of the observed properties of large-scale wave-like fronts in the solar atmosphere (Moreton waves, EIT waves and similar phenomena observed in other wavelengths) was presented in this work. The models proposed to explain these phenomena were reviewed. A particular emphasis was put on the recent EIT wave observations made by the STEREO mission. New key observational results and their implications for EIT wave models were discussed. It was concluded that no single model could account for the large variety of observed EIT wave properties. Prospects for future investigations of this complex phenomenon were outlined.

One of the first EIT wave events that were observed by STEREO/SECCHI from widely separated viewpoints was studied by A. Zhukov, L. Rodriguez and M. West. It was found that EIT wave is a bimodal phenomenon. The wave mode represents a wave-like propagating disturbance, probably a fast magnetosonic wave. The convective mode is the lateral bulk mass motion of coronal plasma due to the restructuring of the coronal magnetic field during the CME lift-off. The convective mode also allows us to explain stationary EIT wave fronts that are sometimes reported. Both modes are coupled during the EIT wave propagation in the corona. The bimodal physical nature of EIT waves may explain the inability of existing models to explain all EIT waves in the framework of a single physical mechanism.

There is strong evidence that some of EIT waves might be fast magnetosonic waves, or at least have a fast magnetosonic wave component. By making measurements of the wave speed, coronal density and temperature, it is possible to calculate the quiet Sun coronal magnetic field strength using coronal seismology. M. West and A. Zhukov investigated an EIT wave observed on February 13, 2009 by the SECCHI/EUVI instruments onboard the STEREO spacecraft that were situated in quadrature, i.e. with the angular separation of 90 degrees. The wave epicenter was observed at disk center as seen from the STEREO B satellite. The background coronal density was derived through Hinode/EIS observations of the quiet Sun, and the temperature was estimated through the narrow temperature response of EUVI bandpasses. The density, temperature and speed measurements allowed us to estimate the quiet Sun coronal magnetic field strength to be around 0.7±0.7 G.

Two advanced methods have been developed by E. Podladchikova to deal with the stereoscopic reconstruction of diffuse homogeneous objects such as EIT wave fronts and dimmings. The methods permit the 3D reconstruction of evolving complete structure of EIT waves observed by SECCHI/ EUVI telescopes. The first method deals with the reconstruction of on-disk diffusive events during the initial stage of their development when the images taken by STEREO-A and STEREO-B spacecraft are different. In this case techniques of epipolar geometry to reconstruct the 3D parameters of event are applicable.

The other method deals with the stereoscopic reconstruction of diffusive events at their latter stage when the images of STEREO A and B are similar to each other and it is impossible to match single points. A robust method to identify automatically the segments of the diffuse front in two STEREO images was used. Despite the complexity of the methods, they are both applicable for similar structures with non-distinct borders.

In general, the problem of point-matching needs a very careful elaboration. It was shown that there are always regions where stereoscopic tools cannot be applied at all for some segments of diffusive objects as the problem becomes ill-posed and solutions unstable.

E. Podladchikova reconstructed the full set of parameters of 3D EIT wave dynamics, such as the 3D spatial coordinates of the wave front crest, the inner front and outer boundaries, and the vertical and horizontal speeds. Furthermore, dimming regions, low coronal extension of CME and different parts of the wavefronts (crest and borders) were identified unumbigously. It has been rigorously demonstrated that:

- The EIT wave initiates at a certain height from the solar surface.
- The EIT wave undergoes phases of growth and declining.
- The velocity of the CME bubble border coincides with the speed of the inner front boundary.
- The borders of the wavefront coincide with the borders of the CME bubble.
- The considered EIT wave event was triggered by the lower extention of the CME bubble during the whole observation time of the event. This is an important result that gives evidence of the type of the triggered mode and solves a long-standing debate in the literature.

O.3.2.3. CME initiation in the low corona observed by SWAP and SECCHI

D. Seaton and M. Mierla led a study of a CME initiation observed on April 3, 2010 by SWAP onboard PROBA2 and SECCHI on board STEREO. A three-dimensional reconstruction of the eruption was made. It was found that the event unfolded in two parts: an initial flow of cooler material confined to a height low in the corona, followed by a flux rope eruption higher in the corona. It was concluded that mass offloading from the first part triggered a rise and, subsequently, catastrophic loss of equilibrium of the flux rope.

O.3.2.4. CMEs and their interplanetary counterparts

Classically, CMEs are observed using coronagraphs, so the coronagraphic data play a crucial role in understanding the structure and evolution of CMEs. The data from SECCHI COR1 and COR2 coronagraphs onboard STEREO can be used to reconstruct reliably the 3D structure of CMEs. Their structure, direction of propagation and speed in three dimensions remain key parameters in CME science. M. Mierla prepared a review, where the state-of-the-art techniques used to reconstruct the aforementioned parameters were analyzed, while at the same time the difficulties of stereoscopic reconstruction of optically thin plasma were highlighted. Using the same techniques, several case studies of CMEs were analyzed in detail. Four methods were applied for reconstructing CMEs: (1) forward modeling technique, (2) LCT method, (3) center of mass tracking, and (4) polarization ratio technique. It was found that every method provides an important insight on the 3D structure of CMEs, but they also display the difficulties of stereoscopic reconstruction of optically thin plasma.

Once the 3D structure and propagation direction of CMEs are calculated, they should be tested to assess the correctness of the model. L. Rodriguez led a study that compared the 3D parameters calculated using STEREO COR2 observations of CMEs at the Sun with their counterparts measured in situ in the interplanetary space (ICMEs). The study was based on a model to reconstruct the direction of propagation and angular widths of CMEs, allowing the eventual radial propagation up to 1 AU and analysis of their theoretical impact on a given spacecraft. To do so, data from the Advanced Composition Explorer (ACE) and the Wind spacecraft, located at the L1 point between the Sun and the Earth, and STEREO in situ data, were used. Then, by having the 3D geometry and direction of propagation for each CME, the CME parameters could be extrapolated to 1 AU to infer if they should have been detected in situ. The results of this analysis showed that, in general, the models and estimations done with the STEREO data to infer 3D properties of CMEs are valid.

For one of the studied CMEs, it was found that the results of the 3D reconstruction were showing unexpected values. The emission measured in the core of this CME was incompatible with the usual Thomson scattering process that dominates the white-light images used in the study. It was demonstrated that the observations could be explained by the Hα radiation. If this is also the case for other CMEs, their mass estimations may have to be revised.

The term stealth CME was introduced by Robbrecht et al. (ApJ 701, 2009) to describe slow coronal mass ejections that did not leave any obvious trace on the solar disk at the time of eruption. Their existence was long assumed, but could only be proven for a CME on June 1st 2008 using the STEREO observations from the two spacecraft, which had a separation angle of 54 degrees at the time of the eruption. In a follow up study a comprehensive analysis was performed of the evolution of the streamer blowout CME from the Sun to the STEREO-B spacecraft where it was observed as an ICME on June 6. Comparison of remote sensing with the in situ signatures is important to learn how to use remote sensing data for forecasting CME arrival and impact at Earth. The study showed that differential rotation and flux cancellation at the polarity inversion line are possible mechanisms, capable of generating the CME. A recent statistical study by Ma et al. (2010) showed that during the first half of 2009 (during solar minimum conditions) one out of three CMEs is stealth.

O.3.2.5. Physics of solar prominences and their cavities

S Parenti has started to work in a new ISSI team on a project titled "Solar Prominence Formation and Equilibrium: New Data, New Models". There are several projects and collaborations, which are planned for the next two years. In the context of this ISSI team, a new collaboration with the Institut d'Astrophysique Spatiale (Fr) and the Academy of Sciences of the Czech Republic was started. The goal of this new project is to derive DEMs in quiescent prominens and to use them to constrain a particular prominence model (the multi-stranded prominence model).

S. Parenti has analyzed SOHO/SUMER data of a prominence observed between the 7th and 8th June 2004. Line profiles of more than 50 spectral lines in the range 912-1500 Å over 50 pixel averaged data were measured. These are emitted in the temperature range $4<\log T<6.2$ allowing to cover the emission from the cooler prominence core to the hot coronal environment around it. This result was used for an inversion procedure included in the CHIANTI database do derive the DEM. The work included the selection of the most appropriate lines to be used for the inversion and the testing of different solar abundances. The final result was passed to foreign collaborators for the testing of their model.

C. Marqué and D. Seaton took part in another ISSI working group (led by S. Gibson, HAO) related to the study of prominence/filament cavities, which are often precursors of CMEs. The last meeting of this ISSI working group took place in 2010. The team worked on a sample of filament cavities observed with EUV imagers aboard the SOHO and STEREO spacecraft in order to determine their geometrical characteristics. These observations concerned one single filament during its transit on the East and West limbs of the Sun. Radio imagery was used to complement EUV, soft X-ray and white light observations of these coronal structures. Radio transfer calculations are in principle able to check that the density and temperature depletions determined by other means (e.g. EUV) are compatible with the radio observations. Radio observations were used during the transit on the disk to confirm the general morphology of the filament cavity structure.

O.3.2.6. Origin and development of dark canopies around active regions

As observed in spectral lines originating from the chromosphere, transition region, and low corona, active regions are surrounded by an extensive "circumfacular" area, which is darker than the quiet Sun. The dark areas are clearly observed in the SWAP images (17.4 nm), they should not be confused with coronal holes. In the framework of an international collaboration, E. Robbrecht examined the origin and properties of these dark moat- or canopy-like areas using Fe IX 17.1 nm images and line-of-sight magnetograms from the *Solar Dynamics Observatory*. Careful observations showed that these dark features seen in Fe IX represent chromospheric material, organized in horizontal fluxtubes connecting photospheric flux elements of opposite polarity. In emerging active regions the flux balloons outward in a dipole-like configuration. As a consequence, through reconnection with the background network, a pattern of dark fibrils is formed, diverging from the area occupied by strong plage. The diffusing fibrils gradually accumulate around large-scale polarity inversion lines. Systematic flux cancellation at the PIL results in the removal of the transverse component and the formation of proto-filaments and filaments.

O.3.3. Perspective for next years

Investigations of solar eruptive events, their interplanetary counterparts and geomagnetic consequences will be pursued further. In particular, the geoeffectiveness of limb full halo CMEs will be studied. Another important track of research is the possibility to link directly solar and interplanetary observations using STEREO data, including the information obtained by novel Heliospheric Imagers (HI) onboard STEREO. The work on prominences is planned to be pursued by trying to deduce the DEM over the single pixel data. This is a quite difficult task because of the limited signal/noise ratio of the faint prominence emission. However, once done, these results will be used for a detailed analysis of the DEM spatial variation due to the fine structuring of prominences.

O.3.4. Personnel involved

Scientific staff: L. Dolla, D. Seaton, D. Berghmans, E. Robbrecht, E. Podladchikova, L. Rodriguez, M. West, M. Mierla, S. Gissot, J. Magdalenić, C. Marqué, A. Zhukov

O.3.5. Partnerships

List of international collaborators having actively contributed to the project in the last year

ISSI working group “From the Sun to the Terrestrial Surface: Understanding the Chain” includes:
- C. Cid, Y. Cerrato, E. Saiz, University of Alcalá, Spain
- S. Dasso, C. Mandrini, Instituto de Astronomia y Fysica del Espacio, Argentina
- A. Aran, B. Sanahuja, University of Barcelona, Spain
- H. Cremades, Universidad Tecnológica Nacional/CONICET, Mendoza,
- B. Schmieder, Paris–Meudon Observatory, France
- M. Menvielle, Centre d’Etudes des Environnements Terestres et Planetaires, France
- C. Lathuillère, Laboratoire de Planétologie de Grenoble,

ISSI working group “Prominence cavities” includes:
- S.E. Gibson, HAO
- J. Hao, NAO, Chinese Academy of Sciences
- H.S. Hudson, UC Berkeley
- T.A. Kucera, GSFC
- P. McIntosh, HelioSynoptics, Inc
- K.K. Reeves, CfA
- D.J. Schmidt, U Colorado
- A.C. Sterling, MSFC
- G. de Toma, HAO
- D. Tripathi, MSSL
- D.R. Williams, MSSL

- M. Zhang, NAO, Chinese Academy of Sciences
- E. Kilpua, University of Helsinki
- I. S. Veselovsky, Skobeltsyn Institute of Nuclear Physics, Moscow State University
- S. Koutchmy, Institut d’Astrophysique de Paris, France
- J.-C. Vial, Institut d’Astrophysique Spatiale, Orsay Cedex, France
- Gunár, Stanislav and Peter Heinzel, Academy of Sciences of the Czech Republic

- N. Labrosse, University of Glasgow, UK
- Yi-Ming Wang, Naval Research Laboratory, USA
- Karin Muglach, Goddard Space Flight Center, USA
- B. Lynch, University of California, USA
- A. Vourlidas, Naval Research Laboratory, USA

O.4. Development of advanced data processing tools

O.4.1. Objectives

With the always growing data rate of EUV-XUV images taken by solar space mission, it becomes increasingly important to combine instrumental knowledge and signal theory in order to extract as much information as possible from those images.

The Solar Physics and Space Weather operational directorate at ROB has gained a large expertise in this area over the last few years. As an example of international recognition in this area, V. Delouille is leading a team at the International Space Science Institute in Bern on the 'Mining and exploiting of the NASA Solar Dynamics Observatory data in Europe'. In 2010, several computer vision techniques were improved and extended at ROB. These include feature extractions on the solar disc (of active regions (AR), coronal holes (CH), and solar eruptions), the construction of velocity and brightness variation maps between two EUV images, the 3D reconstruction of CME, and the calibration of 3D reconstruction algorithm in general. A study on fine-scale, point-like structures in solar EUV images was initiated. Finally, some statistical models were proposed to access sub-pixel information in the EUV quiet sun images.

We now describe the progress and results of these various projects.

O.4.2. Progress and results

O.4.2.1. Segmentation of coronal images

A nonparametric method for segmenting EUV solar images into active regions, coronal holes and quiet Sun (SPoCA) has been developed in the last few years. It is based on fuzzy clustering. In 2010, C. Verbeeck and B. Mampaey improved SPoCA in several respects: a stability criterion was added, the piecewise linear limb correction was replaced by a smoother variant, and morphological dilation was implemented to assemble neighboring bright AR cores into individual AR regions. An optimal set of tune-in parameters was selected for extraction of active regions on SDO-AIA images. SPoCA was also adapted to run on PROBA2/SWAP images.

Combining SPoCA's detection of AR on subsequent images allows the automatic tracking and naming of any region of interest. A graph-theoretical approach was embraced to implement the tracking scheme. Extensive tests of SPoCA were performed on long duration of AIA data.

V. Delouille is co-I on the NASA funded "Feature Finding Team", whose aim is to deliver a suite of software pipeline modules for automated feature recognition and analysis of SDO data. As such, the 6th and stable version of SPoCA is currently running at LMSAL and extracts information about AR. The resulting metadata are written into the Heliophysics Event Knowledgebase (HEK) four times a day.

O.4.2.2. International Team on 'Mining and Exploiting the NASA Solar Dynamics Observatory data in Europe' (Soldyneuro)

The second 'Soldyneuro' meeting was held on April 2010, and recent results from SPoCa were presented there. Within the framework of this group a collaboration was set up to combine the results of SPoCA's detection of individual coronal active regions to those of three other algorithms, which detect magnetic active regions and sunspots in the photosphere. On a SOHO-MDI and SOHO-EIT dataset from May-June 2003, the algorithm detection performance, positional and size accuracy were compared. A statistical correlation study was made between the physical parameters obtained by these algorithms, and time series of two selected regions of interest were followed in more detail. The results were submitted for publication.

Several other areas of collaboration were identified, amonst which: the exploitation of magnetic AR properties (as extracted from magnetogram images) to distinguish between prone-to-flare and non-flaring AR; and the study of photospheric flow and fragmentation around AR.

O.4.2.3. Detection of Solar Eruption Characteristics using NEMO

The Extreme ultraviolet Imaging Telescope (EIT) on-board SOHO spacecraft has uncovered a new class of eruptive events which are often identified as signatures of Coronal Mass Ejection (CME) initiations on solar disk. The Novel EIT wave Machine Observing (NEMO) code is an operational tool that detects automatically solar eruptions using EIT image sequences.

The NEMO version that was in operation till 1 August, 2010 consists of two main steps, namely the event detection and the eruptive dimming recognition. The event detection is based on the detection of bursts in the high order moments of the image while the eruptive dimming extraction is based on a sequence of filtering techniques applied in the pixel distributions of image sequences. In 2010, the recognition of solar eruptions linked to CMEs was made more efficient thanks to a series of updates. As a result, NEMO is now able to extract dimmings observed near the solar limb and to detect small-scale events. The NEMO catalogs now include a larger number of physical parameters associated to the dimming region

More specifically, the NEMO updates provide calculations of the surface of the dimming region, implement novel clustering technique for the dimmings and set new criteria to flag the eruptive dimming based on their complex characteristics. The surface of the dimming area is computed now directly in terms of physical variables (square kilometers) by taking rigorously into account that EIT images correspond to solar sphere projections. The clustering of dark regions is achieved through circle vicinity clustering. Furthermore, the novel methods for the eruptive dimming extraction - based on the volume metric of the dimming - increased the detection efficiency and the accuracy of the associated extracted parameters. Using a series of examples, E. Podladchikova showed that the modified version of NEMO tool presents a significantly higher temporal and spatial efficiency in the automatic detection of CME precursors. In particular, small eruptive events located near the solar limb can be detected now while major events can be detected at earlier times than before.

O.4.2.4. Velociraptor analysis of SDO/AIA images

The large amount of SDO/AIA images requires processing algorithms capable of measuring physical quantities such as apparent motions in sequences of EUV images of the solar atmosphere. The Velociraptor optical-flow algorithm is designed to estimate the apparent velocity maps in EUV images. This project aims to apply the optimized version of the Velociraptor algorithm to SDO/AIA images.

During the year 2010, S. Gissot has run the first version of the graphics processing unit (GPU) implementation of the Velociraptor algorithm. The results of the algorithm applied to SDO/AIA data were obtained and presented at SIP5 by S. Gissot (2). This work was focused on the measurement of apparent velocity maps of an erupting filament identified on August 1, 2010 as the precursor of a geo-effective halo CME, and one of the notable events observed by SDO/AIA in 2010 (see Figure 40). A one-day sequence of 1-min cadence in the 17.1 nm and 19.3 nm AIA channel was processed and both the velocity norm, angular, and intensity variation maps were estimated.

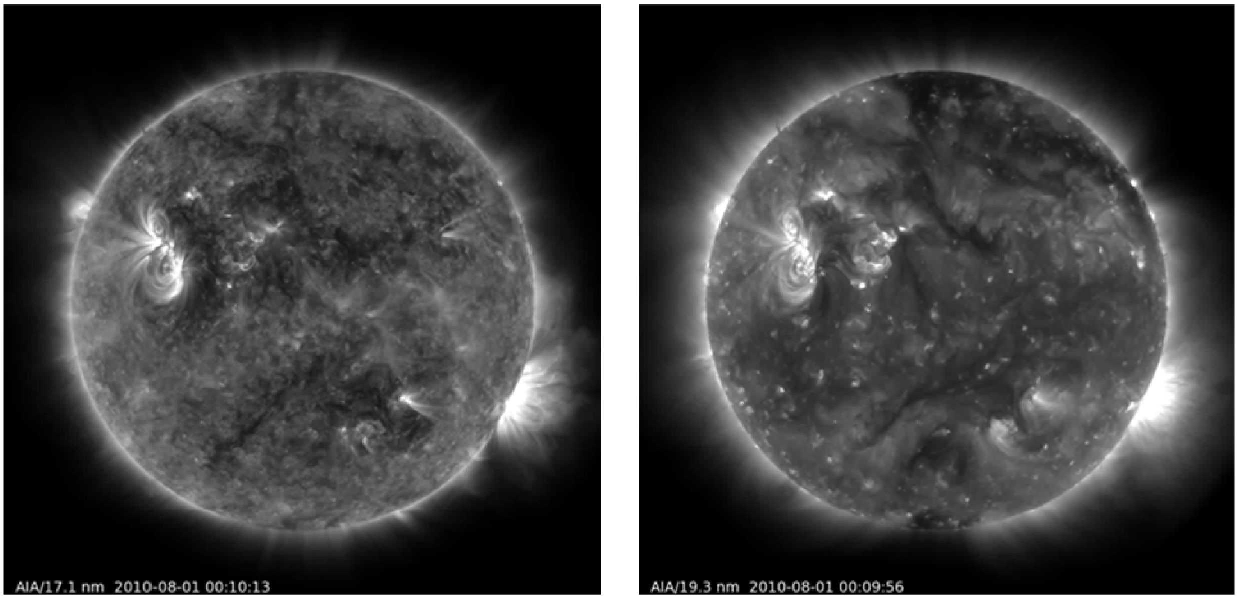

Figure 40: SDO/AIA images observed on August 1, 2010 that have been analyzed with the Velociraptor algorithm in the 17.1 nm (left) and 19.3 nm (right) channels of AIA.

At a saturation threshold value of 30 km/s for the velocity norm, the eruption is detectable (see Figure 41) and a thresholding algorithm can be applied to detect motion blobs. The same thresholding procedure can be applied on the intensity variation map, produced by the Velociraptor optical-flow algorithm.

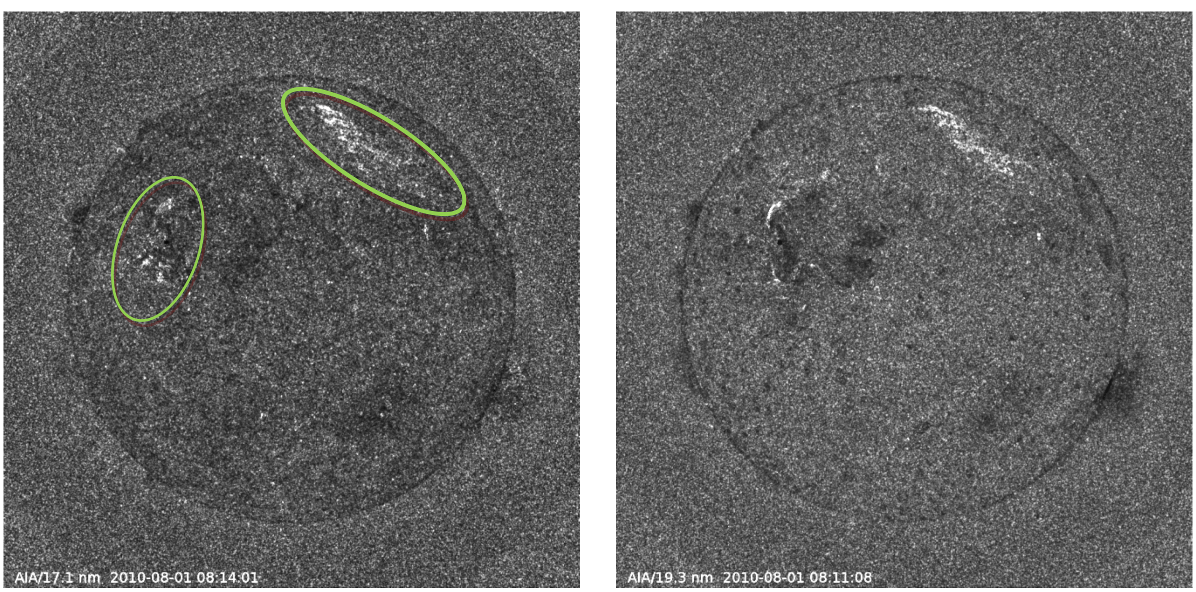

Figure 41: Extraction of an erupting filament as observed in SDO/AIA images in apparent velocity norm map (left in the 17.1 nm AIA channel, right in the 19.3 nm). Within the green contours, two zones showing high values of apparent motion norm. Fine structure can be observed in the apparent velocity field map.

O.4.2.5. CME 3D reconstruction from STEREO images

The objective is the reconstruction of CME observed in STEREO-SECCHI coronographs COR1 and 2, thus contributing to the data exploitation of the STEREO-SECCHI images.

In 2010, S. Gissot gave his support to the reconstruction algorithm of CMEs that is based on the local correlation tracking (LCT). In the LCT method, a cross-correlation is calculated between the intensity of the two stereo images along common epipolar lines. The maximum of the correlation, as a function of the relative shift along the epipolar line, is taken as evidence for a local correspondence. Samuel Gissot maintained and further developed the LCT algorithm that registers the CME bright fronts. A better adaption of the algorithm to the specific properties of the coronograph images was continued.

O.4.2.6. Calibration of STEREO 3D reconstruction algorithm

This project intends to calibrate the algorithm that has been used to reconstruct in 3D a filament eruption from STEREO-SECCHI-EUVI images (from STEREO A and B). The method is based on a stereoscopic reconstruction algorithm adapted to SECCHI-EUVI solar atmospheric images. The calibration intends to improve the confidence level at which the altitude of solar features observed in SECCHI-EUVI images can be reliably estimated.

In 2010, S. Gissot worked on a method that calibrates the 3D reconstruction method using synthetic images simulating EUVI 30.4 nm images. S. Gissot shows in [61] that the bias of the height estimation algorithm can be correctly removed from features lying at low spacecraft separation angles (between 2 and 21 degrees). From bias and variance analysis, S. Gissot showed that the height of solar features can be reliably estimated from calibration analysis at altitudes of the order of 3 Mm above photospheric surface.

O.4.2.7. Point-like structures in solar EUV images

The objective of this project is the localization and the characterization of singular pixels in solar atmospheric images in order to identify potential solar micro-event (SME).

In 2010, S. Gissot has worked on the identification of small point-like structures (PLS) visible in SoHO/EIT and SDO/AIA EUV channels. In collaboration with J.-F. Hochedez, S. Gissot implemented and developed a statistical extraction of singular pixels (PLS) that include cosmic ray hits (CRH) or SME. After defining a 5x5 neighborhood, the distribution of its 16 darkest pixels is assessed and a PLS is identified if its signal is significantly higher than the local background. This PLS extraction was applied to the whole EIT archive in order to show that there exist numerous previously disregarded solar micro-events (SME). This was presented in (3). Although in EIT images, an SME cannot be deterministically recognized on the basis of the presented singularity criterion, an excess of regular objects is seen in EIT 30.4 nm channel.

O.4.2.8. Modeling of subpixel information in EUV images

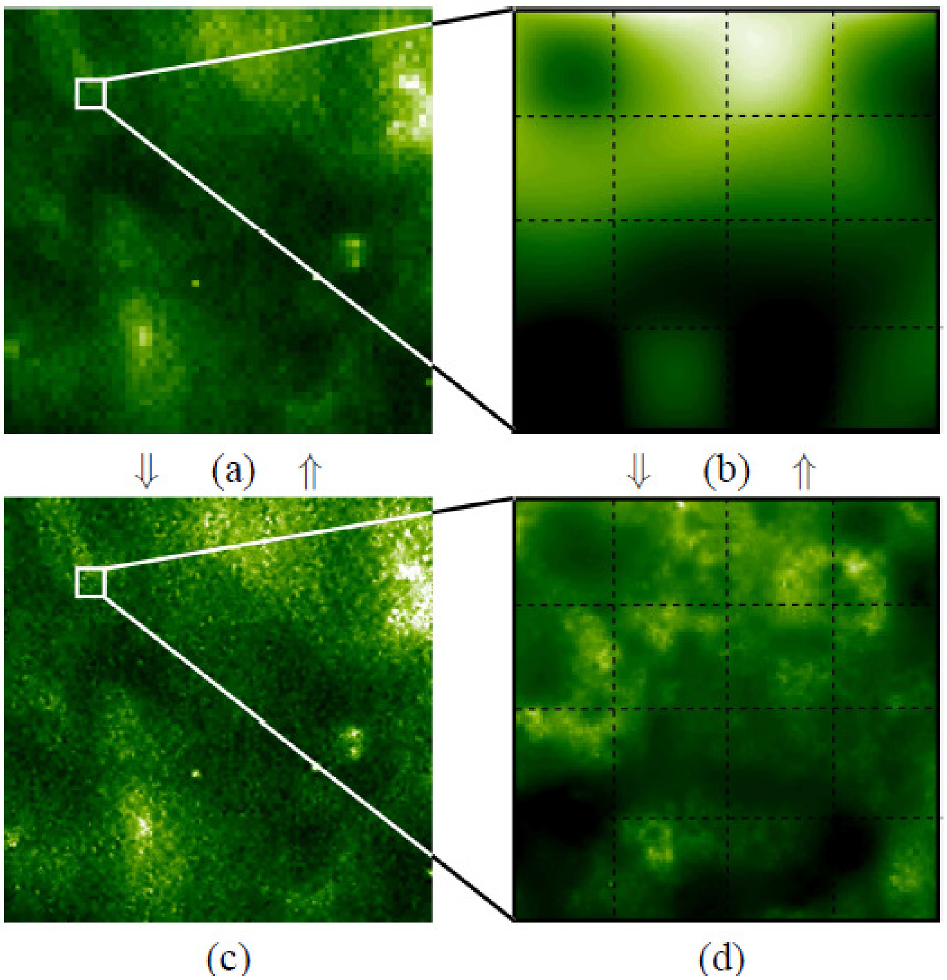

Figure 42: Illustration of the magnification procedure : (a) Initial image of size 64x64, (b) zoom in interpolated image (c) augmented image with resolution enhanced by a factor 32 (d) zoom in augmented image. The black dashes in (b) and (d) correspond to the original pixels.

V. Delouille, J.-F. Hochedez, and their collaborator have managed to analyze but also reproduce and extrapolate the stochastic behavior visible in EUV quiet Sun images. More precisely, they have produced a magnified version of quiet Sun images by inserting plausible small scales into a given observation. The plausibility stems from the statistical (scale invariance behavior preserved) and physical (light energy flux preserved) consistency with the original observation. The `virtually super-resolved' (VSR) images produced will help the physicists to calibrate and test algorithms on forthcoming higher resolution instruments (see also Section O.4.2.6). It also allows predicting histograms of future high resolution imagers. For example, VSR shows that images of the quiet corona are sufficiently smooth for the histogram to be preserved even when we observe closer to the Sun, which was not a priori guaranteed.

O.4.3. Perspective for next years

The work on segmentation of coronal images will be continued along several axes:

- 2011 will see the inclusion of our coronal holes detection module into the SDO Science Center, a suite of software pipeline modules developed by the 'Feature Finding Team'.
- C. Verbeeck will employ SPoCA to derive solar activity proxies such as Active Region areas and total intensities for several instruments including EIT, AIA and SWAP. These proxies will be included in the solar activity proxy database and web interface of the FP7 AFFECTS project.
- B. Mampaey will develop scripts to make use of the Condor software installed on the SDO compute cluster to allow SPoCA to run massively in parallel. The script will be reusable to run other software on the SDO cluster, such as Velociraptor and NEMO.

Within the ISSI Soldyneuro team, SPoCA will be applied on selected high cadence data set from SDO-AIA. Active regions properties as computed by SPoCA will be compared with their counterparts on the photospheric level.

The NEMO tool will incorporate the optimized new algorithms and will provide early warnings for CMEs precursor. New, refined, catalogs will be constructed with more accurate and more complete information about the detected solar eruptive events.

The real-time computation of all SDO/AIA images and the routine extraction of blobs of apparent motions will be implemented using the GPU-implementation of the Velociraptor algorithm. S. Gissot is currently working on the integration of this implementation in the ROB-SDO pipeline. A preliminary study must be carried out to determine the threshold on the apparent velocity norm of solar eruptive features in order to single out the solar events of interest. A second task that will be considered is the initiation of a tracking procedure using the velocity vectors yielded by the algorithm that enable to trace the apparent plasma flow fields.

The newly calibrated algorithm of 3D reconstruction of solar features will be applied to the phase of the STEREO mission during which the separation angle is low enough so that the stereoscopic reconstruction remains feasible.

The modeling of quiet sun images allows generating images which are exempts of noise, and hence it becomes possible to test quantitatively different denoising scheme on EUV images. V. Delouille will devise some denoising schemes that are tailored to the case of images exhibiting a power-law Fourier spectrum, as it is the case for quiet Sun EUV images.

O.4.4. Partnerships

List of international collaborators having actively contributed to the project in the last year

- Pierre Chainais, INRIA Lille-Nord Europe, FR
- Bernd Inhester, Max-Planck-Institut für Sonnensystemforschung, Katlenburg-Lindau, Germany
- Emilie Koenig, ISIMA, Clermont-Ferrand, France
- Pavel Leontiev, Institute of Applied System Analysis, National Polytechnic University of Ukraine (Master Student)
- Marilena Mierla, Institute of Geodynamics of the Romanian Academy, Bucharest, Romania
- Ryan Timmons, Lockheed Martin Solar and Astrophysics Laboratory, USA
- Anatoly Vuets, Institute of Applied System Analysis, National Polytechnic University of Ukraine (Master Student)

Soldyneuro ISSI team :

- Frédéric Auchère, Institut d'Astrophysique Spatiale, Orsay, FR
- Roman Brajša, University of Zagreb, Croatia
- Eric Buchlin, Institut d'Astrophysique Spatiale, Orsay, FR
- Tufan Colak, Bradford University, UK
- Thierry Dudok de Wit, U. Orléans, FR
- Alec Engell, Harvard-Smithsonian Center for Astrophysics, USA
- Peter Gallagher, Trinity College Dublin, IR
- Paul Higgins, Trinity College Dublin, IR
- Davina E. Innes, Max-Planck-Institut für Sonnensystemforschung,GE
- Matthieu Kretzschmar, LPC2E, Université d'Orléans, FR
- Nicolas Labrosse, University of Glasgow, UK
- Petrus Martens, Harvard-Smithsonian Center for Astrophysics, USA
- Rami Qahwaji, University of Bradford, UK
- Stéphane Régnier, University of Central Lancashire, UK
- Karel Schrijver, Lockheed Martin, USA

- Fraser Watson, University of Glasgow, UK

Grant(s)/Project(s) used for this research/service

- SIDC Data Exploitation PEA (BELSPO PRODEX)
- SIDC Telescience PEA (BELSPO PRODEX)
- Solar-Tererstrial Center of Excellence, WP-3
- Solar-Tererstrial Center of Excellence, RWC

O.4.5. Scientific outreach

Meeting presentations

(1) Chainais P., Koenig E., Delouille V., Hochedez J.-F.
Virtual resolution enhancement of Quiet Sun images from SOHO/EIT
Fifth Solar Image Processing Workshop, Les Diablerets, Switzerland, September 12-16, 2010, poster

(2) S. Gissot
A tool for searching eruptive events in SDO/AIA images
Solar Image Processing 5, Les Diablerets, Switzerland, 13-16 Sep 2010, contributed talk

(3) J.-F. Hochedez, S. Gissot
Point-like structures in solar ultraviolet images
ADA 6 - Sixth Conference on Astronomical Data Analysis, in honor of Albert Bijaoui, Monastir, Tunisia, 3-7 May 2010, invited talk

(4) Delouille V., Chainais, P., Koening, E.
Multifractal analysis and synthetisis of Coronal Quiet Sun images. Application to virtual resolution enhancement
Multifractal workshop, Brussels, Belgium, 9-11 June 2010, invited talk

(5) Delouille V.; Verbeeck C.; Mampaey B.; Hochedez J.-F.; Barra V.
Fast and Robust Segmentation of solar EUV images: Towards Real Time use in the age of SDO
Astronomical Data Analysis VI, May 3-7, 2010, Monastir, Tunisia, contributed talk

(6) P.C. Martens, G. Attrill, A. Davey, A. Engell, S. Farid, P. Grigis, J. Kasper, K. Korreck, S. Saar, Y. Su, P. Testa, M. Wills-Davey, P. Bernasconi, N. Raouafi, M. Georgoulis, C. Deforest, J. Peterson, T. Berghoff, V. Delouille, J. Hochedez, B. Mampaey, C. Verbeeck, J. Cirtain, S. Green, R. Timmons, A. Savcheva, R. Angryk, T. Wiegelmann, R. McAteer
Computer Vision for SDO: First Results from the SDO Feature Finding Algorithms
2010 SPD Meeting, Miami, Florida, May 23-27, 2010., invited talk

(7) Delouille V., and the 'Soldyneuro ISSI Team'
Mining and exploiting the NASA-SDO data in Europe
Fifth Solar Image Processing Workshop, Les Diablerets, Switzerland, September 12-16, 2010, poster

(8) Mampaey B. ; Delouille V. ; Verbeeck C. ; Hochedez J.-F. ; Barra V.
"Fast and Robust Segmentation of Solar EUV Images: Towards Real Time Use in the Age of SDO",
2010 SPD Meeting, Miami, Florida, May 23-27, 2010, poster

(9) Mampaey B.; Delouille V., Verbeeck C.,. Hochedez J.-F, Barra V.
Fast and Robust Segmentation of Solar EUV Images: Towards Real Time Use in the Age of SDO
CESRA 2010, La Roche en Ardenne, Belgium, June 15-19, 2010, poster

(10) Parenti S. ; Delouille V. ; Dalla S.; Bocchialini K. ; H. Ballans H.; Boyes D.; Chapman Hochedez J-F.; Mampaey B.; March M.S.; E. Soubrie E.; Walsh R., and the Soldyneuro team

Distributing and mining SDO data in Europe
COSPAR 2010, Session "New Views of the Sun with SDO (E22)", Bremen, Germany, July 18-25, 2010, sollicited Talk

(11) Verbeeck C.; Mampaey B.; Delouille V.; Hochedez J.-F.; Barra V.
SPoCA: Detection and Tracking of Active Regions in solar EUV images
Second International Space Science Institute team meeting on "Mining and exploiting the NASA Solar Dynamics Observatory data in Europe", Bern, April 28-30, 2010, contributed talk

(12) Verbeeck C.; Mampaey B.; Delouille V.; Boyes D.; Hochedez J.-F.
SPoCA: Fast and Robust Segmentation of SWAP images
PROBA2 Science Working Team Workshop, La Roche en Ardenne, Belgium, June 14-15, 2010, contributed talk

(13) Verbeeck C., Delouille V.; Mampaey B.; Hochedez J.-F.; Boyes D.; Barra V
Fast and Robust Segmentation in the SDO-AIA Era
COSPAR 2010, Session "New Views of the Sun with SDO (E22)", Bremen, Germany, July 18-25, 2010, contributed talk

(14) Verbeeck C. ; Mampaey B. ; Delouille V.; Hochedez J.-F.; Boyes D.; Barra V
Fast and Robust Segmentation and Tracking of Coronal Regions
Fifth Solar Image Processing Workshop, Les Diablerets, Switzerland, September 12-16, 2010, contributed talk

Wikis and Websites:

- Web site of the SPOCA project: http://wissdom.oma.be/web/sidcsdosoftware/SpocA/
- Website of the 'Soldyneuro' ISSI team : http://www.issibern.ch/teams/soldyneuro/
- Website of the NEMO project: http://sidc.be/nemo
- Website of the Velociraptor project: http://sidc.be/velociraptor/

O.4.6. Missions

Assemblies, symposia, conferences:

- Astronomical Data Analysis Astronomical Data Analysis VI, Monastir, Tunisia, May 3-7, 2010,
- CESRA 2010, La Roche en Ardenne, Belgium, June 15-19, 2010
- COSPAR 2010, Bremen, Germany, 19-25 July 2010
- Fifth Solar Image Processing Workshop, LesDiablerets, Switzerland, 12-16 September 2010
- Sparsity Workshop VUB, Brussels, 6-10 April 2010
- PROBA2 Science Working Team Workshop, La Roche en Ardenne, Belgium, June 14-15, 2010.
- Sparse Representation of Signals: Theory, Algorithms and Applications, UCL doctoral school, 6-7 May 2010
- 216th meeting of the American Astronomical Society/Solar Physics Division, Miami, USA, 24-28/05/2010

Commissions, working groups:

- International Space Science Institute meeting "Mining and exploiting the NASA *Solar Dynamics Observatory* data in Europe", Bern, April 28-30, 2010.
- Working group on feature detection, Institute of Plasma Physics, Prague, April 2010

O.5. Solar cycle studies

O.5.1. Objectives

The solar cycle is the most commonly known and recognized variability of the Sun's behavior. It is probably also the most documented one, but this should be seen in a conservative sense: although the solar cycle in one way or another has been recognised for many centuries, the true relevance of this has not been realized until quite recently. In this section, we highlight our efforts to document and quantify the mechanism, the diagnostics and the effects of the solar cycle.

The SoTerIA project (a European 7th Framework Program Collaborative project) Work Package 2 "Photosphere" includes as one of its objectives the study of new image-based long-term activity indices derived from solar images of the photosphere, which is clearly relevant to this section.

O.5.2. Progress and results

O.5.2.1. Study on the apparent "extended" solar cycle in coronal emission

Butterfly diagrams (latitude–time plots) of coronal emission show a zone of enhanced brightness that appears near the poles just after solar maximum and migrates toward lower latitudes; a bifurcation seems to occur at sunspot minimum, with one branch continuing to migrate equatorward with the sunspots of the new cycle and the other branch heading back to the poles. The resulting patterns have been likened to those seen in torsional oscillations and have been taken as evidence for an extended solar cycle lasting over ~17 yr. In order to clarify the nature of the overlapping bands of coronal emission, we constructed butterfly diagrams from green- line simulations covering the period 1967–2009 (see Figure 43) and from 19.5 nm and 30.4 nm observations taken with the Extreme-Ultraviolet Imaging Telescope during 1996–2009. As anticipated from earlier studies, we found that the high-latitude enhancements mark the footpoint areas of closed loops with one end rooted outside the evolving boundaries of the polar coronal holes. Rather than being a precursor of the new-cycle sunspot activity zone, the high-latitude emission forms a physically distinct, U-shaped band that curves upward again as active-region fields emerge at midlatitudes and reconnect with the receding polar-hole boundaries. Thus, the so-called extended cycle in coronal emission is a manifestation not of early new-cycle activity, but of the poleward concentration of old-cycle trailing-polarity flux by meridional flow.

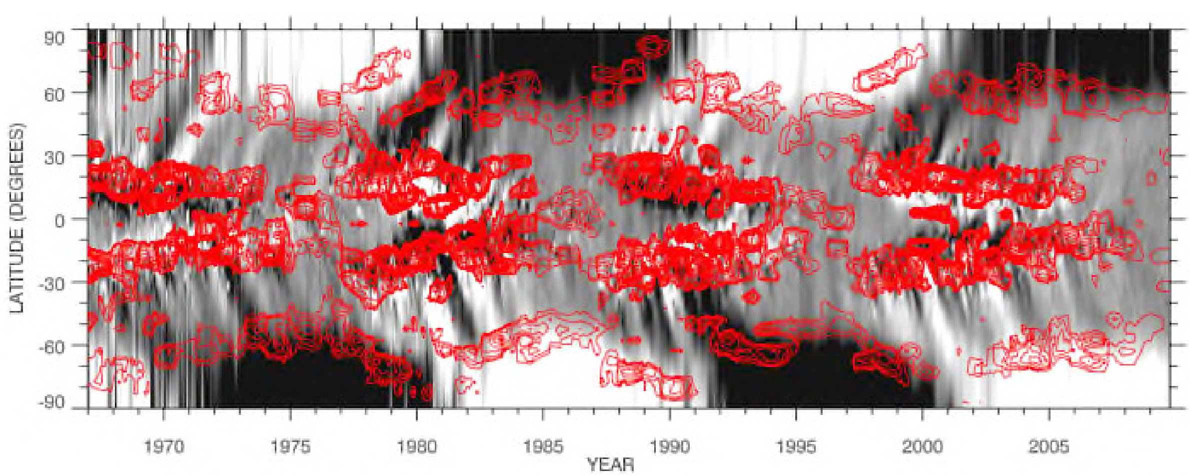

Figure 43: Contours of simulated green-line emission overlaid on a latitude-time plot of the photospheric magnetic field (saturated at +/- 4 Gauss)

O.5.2.2. Solar rotation precise measurements

In 2010, Samuel Gissot contributed to the measurement and the interpretation of the solar rotation velocity and its temporal evolution during most of the 23rd solar cycle, in the years 1998-2006. The solar differential rotation was measured by tracing small bright coronal structures (SBCS) in SOHO-EIT images. The 28.4 nm EIT channel was used and positions of more than 55 000 structures were measured applying an interactive and improved automatic method of data reduction.. The results of this analysis showed a north-south rotational asymmetry and a rigid component of the solar rotation at high latitudes. The closest representation of the observational data was achieved when all three solar differential rotation parameters are used and obtain the formula ω (b) = 14.499 (±0.006) - 2.54 (±0.06) sin2 b - 0.77 (±0.09) sin4 b (sidereal rotation velocity in deg day-1). A more differential rotation profile of SBCS than of sunspots and sunspot groups was found. The rotation velocity of SBCS is very similar to those obtained by small photospheric magnetic features. The north-south rotational asymmetry of SBCS was interpreted with a model of the relationship between solar rotation and activity.

O.5.2.3. SoTerIA

In 2010, SoTerIA entered its second year. F.Clette and L.Lefèvre developed the collaboration with the Debrecen Observatory for the exploitation of their DPD sunspot catalog in order to investigate the role of different sunspot parameters on the sunspot index determination. Final revisions and proofreading were done on the paper associated with the Space Climate Symposium of March 2009 for publication in the Journal of Atmospheric and Solar-Terrestrial Physics .

Laure Lefèvre began with the identification of existing catalogs and the assembling of the information available in the catalogs. This part is largely completed at the beginning of 2011. The first steps of this project were to merge the sunspot group lists. Those results will lead to additional scientific publications in 2011. Another interesting result to note is the discovery of a structural problem in the Debrecen data, which arises from the fact that it is very detailed, sometimes verging on “too much details”. As a unified definition of the spot is somewhat hard to find, some sorting must be done, mainly using existing parameters from the DPD catalog or other catalogs (USAF data may enable to identify non-reliable structures). Also stemming from these studies is the identification of a possible drift of the International Sunspot Number (R_i) compared to quite a number of indices.

<u>Survey of sunspots and active region Catalogs</u>

A survey was done of all the available catalogs and databases concerning photospheric parameters, as well as a survey of the available parameters, their relative importance and their relations to each other. The first step was to decide which parameters would be useful AND available for the final goal, which is the construction of new indices and proxies (see

Table 2). Then, according to the most interesting parameters, we can chose the period and the catalogs/databases best to begin the construction of a new more complete database.

A poster concerning the first steps of this analysis was presented in January 2010 at the First SOTERIA general meeting in Davos, Switzerland.

<u>Merging of the Catalogs</u>

Laure Lefèvre realized the merging of the first 2 catalogs. This encompasses the analysis of the DPD data, as well as the USAF data, comparisons of the DPD data with the international sunspot number (R_i), detection of problems in the DPD catalog but also probable problems in the R_i Numbers. Finally, it consists in developing the software needed to merge the two very different sets of data.

An *oral presentation of the first version of the catalog was made at the IAU 273 in August of 2010*. At this meeting, contact was established with R. Arlt, concerning the parameters that should be extracted from his older set of drawings. The proceedings article was subsequently submitted in October 2010. A collaboration with T. Dudok de Wit was developed for the use of this detailed catalog (ESWW7 in Brugge, November 2010).

PARAMETERS by order of importance	Units	MWILSON USAF USNO	RGO	KODAIKANAL	ROME	DEBRECEN DPD	DEBRECEN SDD	ROB
Time Coverage	Begin - end	1927-2010	1874-1982	1906-1987	1958-2000	1980-2010	1996-2008	1940-2010
Number of years		84	119	82	43	31	13	71
Date	Y,m,d,UT							
Area	P, Projected (msd) C, Corrected (msh) U, U+P	U+P, c (1981-2009)	U,U+P, p,c > 1976 no U	Up,c microhemisphere (msh)	U,U+P,p,c	U,U+P,p,c Individual Spots areas	U,U+P, p,c	
Number of spots		(1981-2009)						
Dist disk center	0 to 1							
LCM	Degrees : LCM, CMA							
Latitude	Degrees							
Longitude	Degrees							
Group's Polar Angle	degrees,position of gp relative to NP				Group's polar angle			
Position Angle	P, Bo, Lo : references		Polar angle 0 to 360			Position of pole	Position of pole	P,B,L
ID number	NOAA, or local IDs	MtWIL+ NOAA	Local < 1976		Local	NOAA	NOAA	
Morphological classification	Zurich, McIntosh, or other	USNO 1968-1971 (Waldmeier)	Local < 1976					
Image quality	1..5 Standards vary			0....10 (better)				

Table 2: Explored catalogs versus important parameters. This table is an extract of a larger table, which illustrates the availability in parameter-space and with regard to time. The black squares are missing data, and the grey squares are reconstructible data.

Analysis of the Debrecen Photoheliographic Data

Analysis of the DPD data: discussions with the Debrecen team to improve the extraction of parameters in the future. Contribution to an article by Judit Murakozy. Search for older datasets of Northern and Southern Sunspot Numbers.

Analysis of the International Sunspot Number (R_i)

Analysis of a possible drift in the R_i data. Retrieval of the data from individual stations. (November-December 2010). This work led to a meeting with the observer's team from the pilot station of the SIDC network, Locarno, at the end of January 2011. At the time of this report, the drift is still under scrutiny by Laure Lefèvre, local collaborators (L. Wauters, F. Clette) and the Locarno team.

O.5.3. Perspective for next years

- Solar cycle study on the north-south asymmetry
- We will continue the analysis of the monthly and yearly values of the parameters of solar rotation velocity, as well as the modeling of their temporal evolution.
- Continue working on suppressing the lingering discrepancies in the merging of catalogs. Laure Lefèvre also plans on carrying out a correlative analysis of the various properties. In a first approach by statistical time series analysis, but she is also considering the use of clustering methods. Indeed, it is possible to compute the Euclidean distance with multidimensional scaling, and Principal Component Analysis (PCA) can then be used to project the map on two or three principal axes depending on the levels of variance. This will enable us to pinpoint more subtle dependencies between descriptors.
- This analysis will lead to additional dynamical properties and help to separate families of parameters that share the same behavior and deduce relations between those families, which can then lead to the distinction of new categories of evolutionary profiles. After identifying inter-relations between properties, she will explore combinations of those properties that can lead to a specific scalar measure or index, at group level or for the whole Sun. Beyond the simple linear combinations of instantaneous sunspot properties, she will also take into account possible time delays as several manifestations of solar activity are notoriously lagging behind the emergence of the primary magnetic fields at the surface.

O.5.4. Partnerships

List of international collaborators having actively contributed to the project in the last year

- Yi-Ming Wang, Naval Research Laboratory
- R. Jurdana , Physics Department, University of Rijeka, Croatia
- R. Brajsa, Hvar Observatory, Faculty of Geodesy, University of Zagreb, Croatia
- H. Wöhl, Kiepenheuer-Institut für Sonnenphysik, Freiburg, Germany
- A. Hanslmeier, Institut für Physik, IGAM, Universität Graz, Austria
- Marilena Mierla, Institute of Geodynamics of the Romanian Academy, Bucharest, Romania
- Bernd Inhester, Max-Planck-Institut für Sonnensystemforschung, Katlenburg-Lindau, Germany
- Andras Ludmany, Tunde Baranyi, Judit Murakozy, Lajos Gyori, Debrecen Observatory, Hungary
- Thierry Dudok de Witt, CNRS, Orléans

Grant(s)/Project(s) used for this research/service

- Budget: Solar-Terrestrial Center of Excellence
- SOTERIA "SOlar-TERrestrial Investigations and Archives" project (EU 7th Framework Program, Nov.2008- Oct. 2011)

Visitors:

- Svalsgaard, Leif, ROB, September 14th, Calibration of Sunspot Number

O.5.5. Scientific outreach

Meeting presentations

(1) Y.-M. Wang, E. Robbrecht, N. Sheeley
The weakening of the polar magnetic fields during cycle 23
SORCE meeting, Keystone, CO, May 19-21 2010

(2) R. Jurdana-Šepić, R. Brajša, H. Wöhl, A. Hanslmeier and S. Gissot
A relationship between solar rotation and activity in the period 1998-2006
X Hvar Astrophysical Colloquium. The Active Sun 6 - 10 September 2010.

(3) Lefèvre L. Clette F (POSTER)
Exploring the SunspotCatalogs
First Soteria Meeting, DAVOS January 2010

(4) Lefèvre L., Clette F., Baranyi T., (Oral presentation)
In depth Survey of sunspot and active region Catalogs
IAU 273, Physics of Sun and Star Spots, Ventura, CA, August 2010

O.5.6. Missions

Assemblies, symposia, conferences:

- E. Robbrecht: SORCE meeting, Keystone, CO, May 19-21, 2010
- F.Clette: PICARD Gerneral Meeting, Observatoire de Paris, 8-9/3/2010
- F.Clette & L. Lefevre: Soteria General Meeting, Davos, Switzerland (18-21/1/2011)
- F.Clette & L. Lefevre: Soteria General Meeting, Debrecen, Hungary (4-8/10/2011)
- L. Lefevre: IAU 273 Symposium, Physics of Sun and Star Spots August 22-26, Ventura, CA (Oral presentation)
- L. Lefevre: ESWW7, Brugge, 15-19 November 2010

Research visits:

- Andras Ludmany, Judit Murakosy, Tunde Baranyi, Divinus Discussion, Debrecen, October 8th 2010

O.6. Physical processes and modeling: Aeronomy studies with Lyra

O.6.1. Objectives

One of the primary objectives of LYRA was the aeronomy – the study of the upper and middle Earth atmosphere. The activities related to that specific field were led in collaboration with two institutes: the BISA - Belgian Institute for Space Aeronomy (Brussels, Belgium), and the PMOD/WRC - Physikalisch-Meteorologisches Observatorium Davos/World Radiation Center (Davos, Switzerland).

PMOD wishes to use the absolute irradiance measurements performed by LYRA in two of its channels as input for one of their models that reconstructs the neutral and ionic state of the middle atmosphere in nearly real-time.

The participation of ROB to the PMOD activities is limited to the production of calibrated data, expressed in physical units, and their release in short delays.

At BISA, it is aimed at analyzing the extinction of the solar signal when absorbed by the different layers of the Earth atmosphere. This is only possible during one season every year, when the spacecraft orbit is such that PROBA2 experiences transits in the Earth shadow. From the extinction measurement, it should be possible to deduce information about the atmospheric composition.

O.6.2. Progress and results

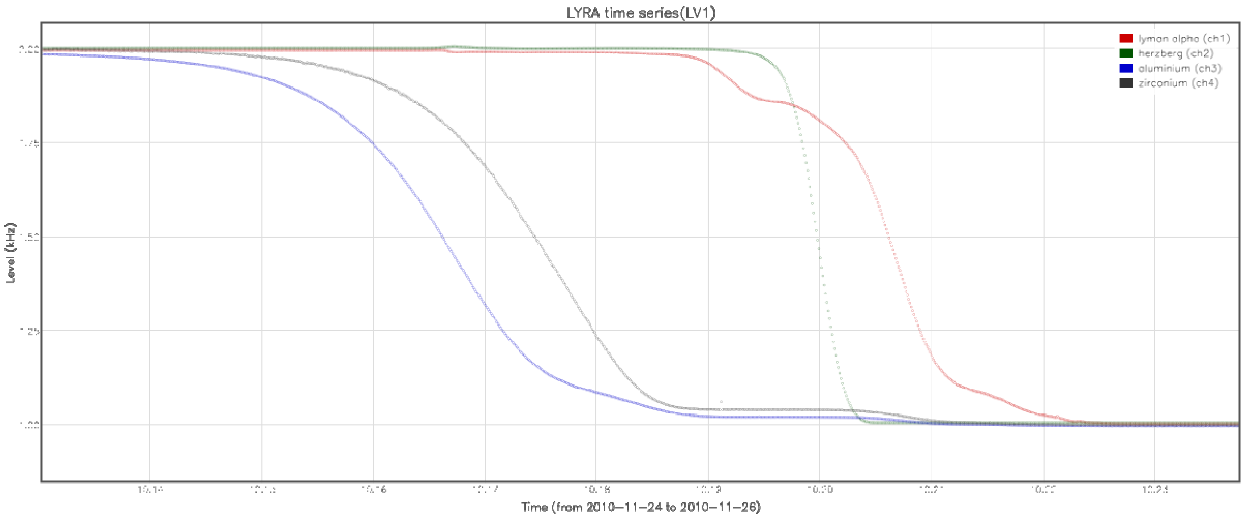

Figure 44: Occultation curves as seen by LYRA unit 3, Nov 2010

Since its launch, PROBA2 already had two eclipse seasons, in which it experiences one occultation every orbit. Although the analysis of the data acquired during both seasons is still at a starting level, their observation already led to some conclusions:

- When observing the occultation curves, we find unexpected features: the Lyman-alpha curve starts decreasing before Herzberg, as it must be, but its complete extinction happens after the one of Herzberg channel. Moreover, during the first season, we could see a bump in the Ly-alpha curve. Both these observations might be explained by an unexpected sensitivity of Lyman alpha channel to the longer wavelengths, up to the IR range. We might therefore conclude that, despite the care brought to the pre-flight calibration campaigns, the knowledge of LYRA bandpasses is still incomplete and must be further investigated.
- The profile of the curves acquired with the nominal unit (which is permanently used) has changed between the two eclipse seasons, which might indicate a spectrally dependent degradation of the unit.
- The altitude range which is scanned for each Lyra channel is summarized in Table 3, and compared to the theoretical estimations mentioned in "*The contribution of PROBA2-LYRA occultations to Earth atmosphere composition*", Dominique et al., New Horizons in Occultation Research: Studies in Atmosphere and Climate, 285-293 (2009).

Table 3: Altitude ranges scanned during occultation

Channel	Observed range of alt. (km)	Estimated range of alt. (km)
Ly-Alpha	0-150	116-189
Herzberg	50-100	45-74
Aluminium	100-450	225-320
Zirconium	100-350	154-292

O.6.3. Perspective for next years

A new investigation field has emerged from the observation of the occultation curves. They could be used to track any evolution in the spectral responsivity of LYRA channels. A collaboration on this subject was started with Gaël Cessateur from the University of Orléans as part of the PROBA2 guest investigators program and will continue next year.

The analysis of the atmospheric composition based on the occultation curves is on-going, in collaboration with the Belgian Institute for Space Aeronomy (BISA). A new collaborator recently joined this BISA team (Cédric Tétard), He will devote part of his time to this analysis.

O.6.4. Partnerships

List of international collaborators having actively contributed to the project in the last year

- T. Ergorova, PMOD-WRC (Davos, Switzerland)
- G. Cessateur, LPC2E, University of Orleans (France)

List of national partners collaborators having actively contributed to the project in the last year

- D. Gillotay, D. Fussen and F. VanHellemont, C. Tétard, Belgian Institute for Space Aeronomy

Grant(s)/Project(s) used for this research/service

- PRODEX SIDC DATA EXPLOITATION
- ESA guest investigator programme (for the visitors)

Visitors:

- G. Cessateur, LPC2E, University of Orleans (France), invited in the frame of the PROBA2 guest investigator program from 29/11 to 24/12/2010

P. Development of new solar instrumentation

Introduction:

This section covers the development of future scientific instruments and (all types of) work for the preparation of future space missions

P.1. New technologies

P.1.1. Objectives

Technology is an important driver in space science. Future missions for space astronomy and solar research require the development of critical optical components for improved UV solar observations. The selected technologies are imaging and non-imaging UV detectors, UV filters and onboard data image processing. Present technologies exhibit serious limitations in performance, technology complexity and lifetime stability. For the future space missions planned to study the Sun, new developments technologies capable of operating at high temperatures and in harsh environments are investigated. For those fields, it is not sufficient to merely watch the industry progress. It has been a successful tradition in solar terrestrial physics to trigger or to perform specific technological development. At ROB/SIDC, we have identified and developed a specific expertise in two technological disciplines: UV light detection and image processing. For both, a voluntarist way has proven beneficial in order to meet the needs with the possibilities in a timely manner.

P.1.2. Progress and results

P.1.2.1. APSOLUTE and BOLD

In 2010, Ali BenMoussa, Boris Giordanengo and Bogdan Nicula participated in the APSOLUTE teleconference and/or progress meetings at CMOSIS (Belgium). They participated in the design review meeting. The purpose of this meeting was to describe the APSOLUTE image sensor together with its functional properties and the additional goal of giving the go-ahead for tape-out of the design. For APSOLUTE, two image sensors are being developed: -1- 256x256 sensor containing 16 test pixel variants, organized in blocks of 64x64 pixels, -2- 1024x1024 sensor, containing the 'best guess pixel' variant. A calibration test plan was issued by Ali BenMoussa on 15/12/2010 (Issue2, rev1). This document provides a detailed description and methodology of all tests to be performed with a description of the measurement setups. The output of the different test campaigns are expected to allow the evaluation of the APSOLUTE sensors as well as to select a preferred pixel design with recommendation for the Flight Model (FM) detectors for EUI project onboard Solar Orbiter.

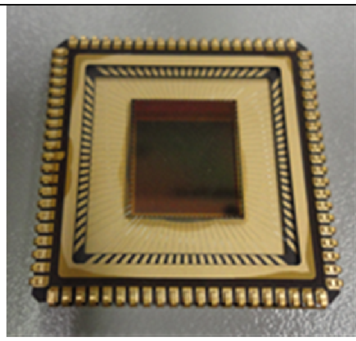

Figure 45: APSOLUTE detector

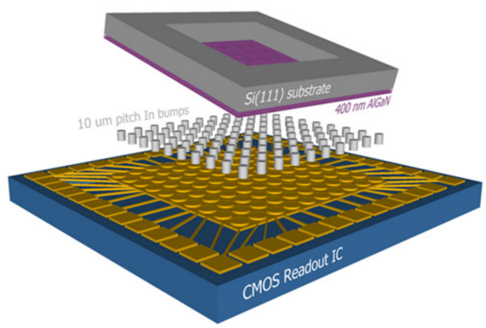

Figure 46: BOLD prototype design

In complement of the APSOLUTE project, the BOLD project was extended to 21/01/2011 (CCN3). Ali BenMoussa (as WPs Manager) and Boris Giordanengo are actively involved on the conceptual pixel design study and on the (E)UV optical testing. During 2010, the effort was focused on the technology predevelopment and on the integration of the 2D demonstrator. 2D AlGaN arrays were integrated with the CMOS ROICs (read out electronics). Two BOLD calibration campaigns were carried out in June and November 2010 at the PTB-Bessy II synchrotron. First integrations (detector flip-chip bonded to ROIC) were tested at DeMeLab (ROB) on 21/04/2010. Few cross checking of characterization results between IMEC and ROB laboratories have been performed. The two teams are in close collaboration and exchanges of samples and data are still ongoing. The results are encouraging with some part of the BOLD imager responding to the light excitation. A technical note (TN4) of the BOLD project was issued on 18/08/2010 (Issue2, rev0) by Ali BenMoussa and Boris Giordanengo. This TN described the (E)UV testing activities, a description of the samples including priority list and preliminary measurements analysis, as well as the tackling of the photoemission problem.

Boris Giordanengo started the preparation of analysis software for the detector electro-optical characterizations. Different scripts are under development such as the automation of the fixed pattern noise and the temporal noise analysis.

Figure 47: Tool used to extract the main imager characteristics (fpn, prnu, dsnu etc.)

Ali BenMoussa together with Boris Giordanengo and Bogdan Nicula followed a 2 days CMOS APS characterization training course in Barcelona (E) on November 2010 by Prof. A. Theuwissen. The course aimed to give an in-depth knowledge about the characterization solid-state imaging devices. This was done by means of hands-on measurements and evaluation of an existing camera. In this context Ali BenMoussa started to test the signal and noise performance of the EUV HAS imager sensor (spare from SWAP) in collaboration with Dr L. Duvet from ESTEC. A complete optical characterization of the HAS sensor is reported in the thesis of Eng. A. Mekaoui who performed a six months training (until May 2010) at ROB under the supervision of Ali BenMoussa.

The detector development activities (APSOLUTE and BOLD) have been presented by Ali BenMoussa during different meetings (see section Scientific Outreach). Ali BenMoussa took formal responsibility with PTB (Berlin, D) [18] and CRC (Louvain-La-Neuve, Be) for the collaboration on the detectors and multilayer UV filters tests and calibration campaigns.

P.1.2.2. UV detectors developments (single pixel)

Recent results on deep-ultraviolet solar-blind photodiodes based on high-quality AlN films grown on sapphire substrates were simulated and fabricated. cBN and diamond detectors were also reported as well as new results on LYRA photodetectors. In parallel, and in preparation for the eventual testing of the UV detectors and filters prototypes, the Detector Measurements Laboratory (DeMeLab) at ROB premises was further developed by Ali BenMoussa and reviewed by external experts (Spectra Physics) on 09/03/2010, in good accordance with the development plan for the detector prototypes.

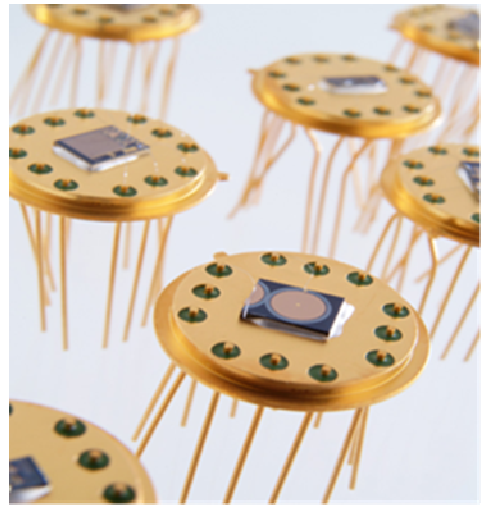

Figure 48: Single UV photodiodes (IMEC)

The LYRA radiometric model i.e. the Si-AXUV detectors' responsivity, was updated thanks to new measurements performed by Ali BenMoussa at DeMeLab facilities (see Figure 49). Ali BenMoussa has also participated to the ESIO proposal (UV flux monitor) [11] and he took formal responsibility with ETRI institute in South Korea [12] for the collaboration on the developement of future Solar UV flux monitor (LYRA successor on K-star project) [13]. The detector development activities (including LYRA) have been presented by Ali BenMoussa during different international conferences (see section Scientific Outreach).

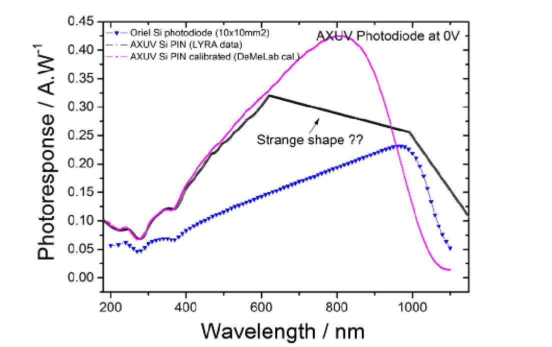

Figure 49: Response of a Si-AXUV @ DeMeLab

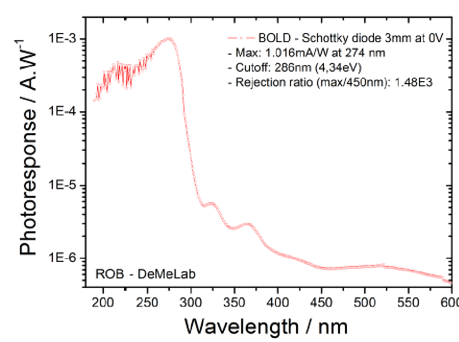

Figure 50: Response of an AlGaN diode @ DeMeLab

P.1.2.3. UV filters developments

In combination with the above, Ali BenMoussa participated in many test activities related to the multilayers UV filters characterizations. In accordance to the support activity foreseen for the specification of the UV filters onboard EUI (see section future space missions), Ali BenMoussa has coordinated and participated in the activity of filters measurements at DeMeLab and at PTB-Bessy II on Novembre 2010. A filter test and calibration plan was issued by Ali BenMoussa on 05/11/2010 (Issue1, rev0).

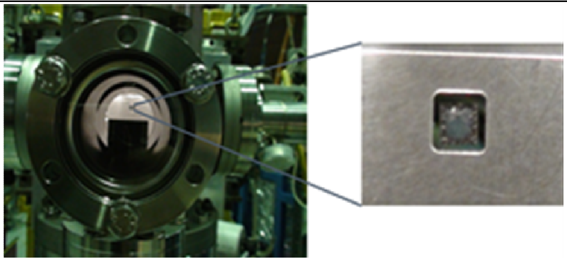

Figure 51: Filters calibration @ PTB

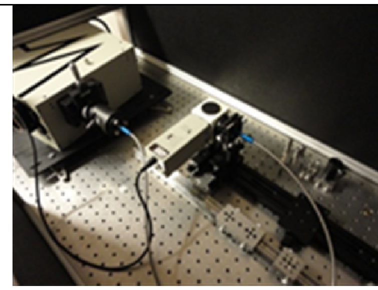

Figure 52: Filters measurement @ DeMeLab

P.1.2.4. Extreme ultraviolet Onboard Compression System (EOCS)

The Extreme ultraviolet image onboard compression system (EOCS) project aims to develop a hardware implementation of a compression system that integrates co-processing algorithms for solar EUV images. The EOCS project hardware target is an implementation into a space-qualified programmable device such as FPGA or ASIC. The EOCS compression and processing board is a technological development that can be adapted to any imager onboard spacecraft missions, in particular for the special case of EUV imagers dedicated to solar atmospheric images such as Solar Orbiter/EUI.

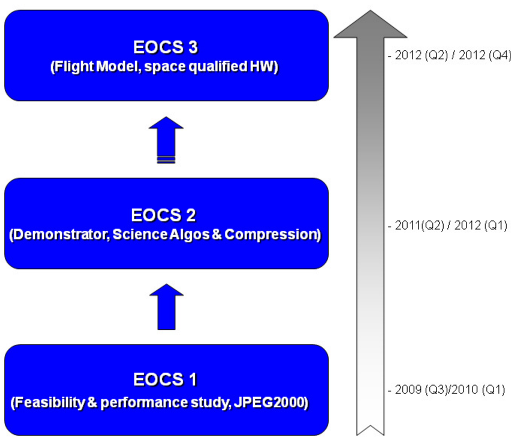

Figure 53: EOCS projects road map

The series of EOCS projects and its road map is summarized and illustrated in Figure 53. The first step of the project (EOCS1) has ended early 2010 (February 2010) and has shown the feasibility of a JPEG2000 compression IP core implemented in the Xilinx Virtex 5 reconfigurable FPGA.The objective of EOCS2 is the development of a prototype board that integrates both the compression algorithm and all other co-processing required for the processing chain of the EUI onboard electronics (calibration, image cleaning, meta-data/image summaries computation, event detection, image quality assessment, etc). EOCS3 targets the development and the procurement of a flight model for the compression and image processing system.

EOCS1, feasibility study

The goal of the EOCS1 project was to evaluate the feasibility of a compression system, in particular for the EUI instrument of Solar Orbiter; the system consists in a JPEG2000 encoder implemented in a FPGA technology, the Xilinx Virtex-5 (see Figure 54) for applications such as EUI solar atmospheric images, as illustrated in Figure 55. Adapted from a system developed by Intopix, a Belgian company specialized in high-quality image compression at very high quality, as required for digital cinema.

Figure 54: A Xilinx Virtex 5 FPGA used to implement the compression software and the co-processing algorithms.

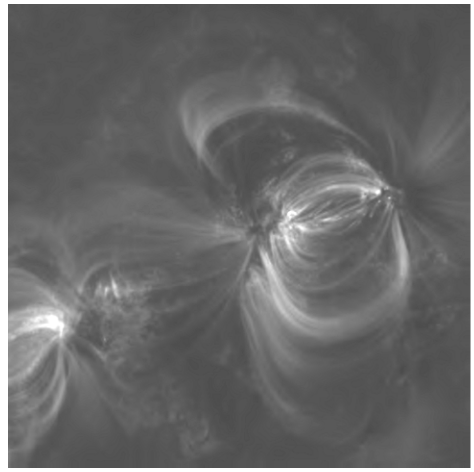

Figure 55 : SDO/AIA images, compressed at a ratio of 1000 by a JPEG2000 algorithm similar to the intoPIX IP core implemented in the Xilinx Virtex 5 FPGA.

Based on the intoPIX Pristine board and the intopix JPEG2000 IP core, the compression system integrated in the Virtex-5 FPGA was configured in order to encode 2 high-resolution image channels (2K x 2K) at a frequency of 5 Hz each, in combination with a bigger channel (4K x 4K) observing at 0.1 Hz. With a pixel depth of 12 bits, this corresponds to a total pixel rate of 44 Mega pixel per second.
An intoPIX board has been modified to enable the monitoring of the power consumption of the different voltage supplies of the FPGA and the embedded memory together with the temperature of the FPGA. The software layer controlling the board was modified to reach the different compression levels required for the tests but also to measure precisely the maximum frame rates achieved by the system. The system also supports for real-time adaptation of the compression parameters.
The following power consumption figures were obtained for the compression syste:
- 7.5 W for 2 x 5 Hz HRI and 1 x 0.1 Hz FSI
- 5.75 W for 2 x 2.5 Hz HRI and 1 x 0.1 Hz FSI
- 4.9 W for 2 x 1 Hz HRI and 1 x 0.1 Hz FSI
- 4.4 W for 2 x 0.5 Hz HRI and 1 x 0.05 Hz FSI

Max Frame Rate [Hz]	2 x 5 (HRI) + 1 x 0.1 (FSI)	2 x 2.5 (HRI) + 1 x 0.1 (FSI)	2 x 1 (HRI) + 1 x 0.1 (FSI)	2x 0.5 (HRI) + 1 x 0.05 (FSI)
DDR2 I/Os utilization	100%	50%	25%	12.5%
Projected Power [W]	7.5	5.75	4.875	4.4375

Table 4 : Description of power consumption of design A for several cadences. Using these projections, it is possible to assess precisely from actual measurements the power consumption figures of the compression system, including the FPGA, its I/Os with DDR2 external memory.

The EOCS1 study validated this system based on a Virtex5 FPGA and an external DDR2 memory compression system with the following conclusions:

- the temperature measurements of the FPGA ranges around 50°C in emulated vacuum,
- the frame rate is achieved up to FSI@0.1Hz +HRI at 5hz, (really measured),

- the test results suggest that the achieved image quality of the encoder is similar to the one provided by the JPEG 2000 reference software Kakadu,
- the projected power consumption, based on real measurements, for the complete system (compression FPGA, external memory, I/Os between FPGA and external memory), is less than 5W for HRI at 1Hz because it uses less FPGA I/Os with external memory (see Table 4).

As an outcome of the project and based on its power consumption measurements, several designs were evaluated (see Figure 56) among which one (design A, see Figure 57 for more details) was selected as the candidate for the EOCS2 project.

On February 2, 2010 was held the final review of the EOCS1 project. After having followed the project as ROB prime responsible, S. Gissot reviewed the EOCS1 final report and the deliverables, and presented these results during the EUI electronics meeting and the EUI consortium meetings. This project was satisfactorily assessed by ESA during the final review.

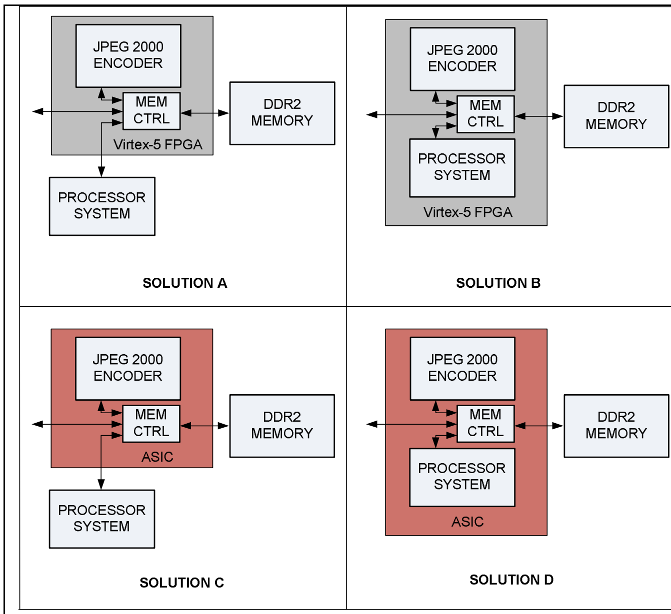

Figure 56: Possible electronics designs including the JPEG2000 compression chip, and its association with a processor system (e.g., a CPU).

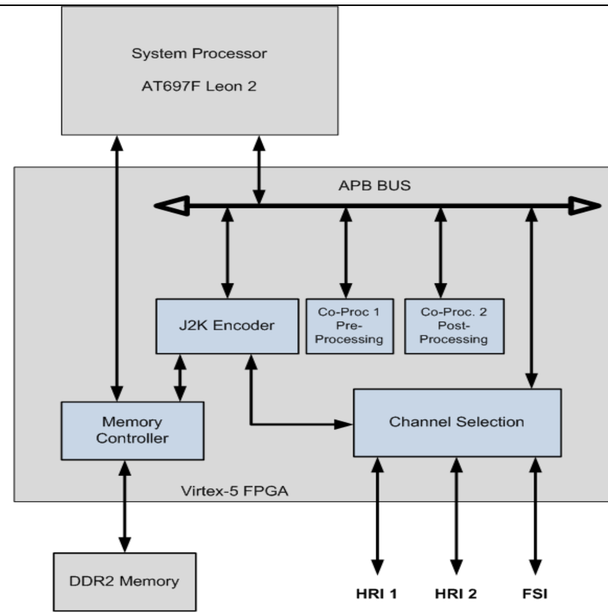

Figure 57: Design showing the Virtex 5 implementation of the JPEG2000 compression, the pre- and post-processing, as well as the link to the system processor and the DDR2 external memory.

<u>EOCS2, science algorithms implementation</u>

In 2010, the EOCS1 project led to the initiation of the EOCS project 2 (EOCS2) for which a Statement of Work was submitted to ESA in June 2010 by Ali BenMoussa and Samuel Gissot. For the EOCS2 project, an applicable document based on the compression and processing system specification was issued on 22/07/2010 by Samuel Gissot.

The goal of EOCS2 is to develop and integrate the pre- and post- processing functions with the compression function into a single design as software modules and implemented into a hardware prototype using a single FPGA component, when available, or in multiple hardware devices if needed. At the moment the Xilinx Virtex 5 FPGA is the current baseline device but this may change when during the project. The EOCS2 project will help us to demonstrate the suitability of the JPEG2000 encoder and its associated science algorithms (pre- and post-processing methods) as the baseline of the data processing system for a typical onboard system for solar atmospheric imagers such as EUI on a relatively short time-scale. To this end, its feasibility and performance potential shall be demonstrated by the development and characterization of a hardware platform demonstrator matching the technical requirements together with a preliminary design of the potential flight device. Thus, the prototype design must show the evolution path to the flight design (EOCS3).

Samuel Gissot presented the results of the EOCS1 project and EOCS2 goals at the 2nd international workshop on On-board Payload Data Compression (OBPDC 2010) conference in Toulouse on 29th October 2010 and participated to the ReSpace/MAPLD 2010 conference on programmable devices for space applications from 1-4th November 2010. The EOCS2 project has also been presented by Ali BenMoussa during the EUI compression meeting at ROB (04/10/2010) and by Samuel Gissot at the 4th EUI consortium meeting at MSSL, UK on November 29-30.

P.1.3. Perspective for next years

A last (closed) meeting of the BOLD project shall be held on 21st January 2011 at ESA (NL). The tests campaign of the APSOLUTE prototypes shall start in February 2011. A test planning was issued on 14/12/2010 (Issue1, rev3) by Ali BenMoussa. This document describes the tests activities planning for the APSOLUTE sensors (1st batch), which started in November 2010 at CMOSIS and should finish before the EUI PDR (fall 2011). This document is intended to guide the measurement campaign that will be performed in various facilities i.e. CMOSIS, DeMeLab (ROB), PTB-Bessy II (Berlin), CRC (Louvain-La-Neuve) and CSL on a relative short time scale. Measurements of multilayers UV filters and development of new solarblind detectors (AlN, cBN and diamond) are also planned in 2011. In parallel, a radiation test plan was issued by Ali BenMoussa on 15/12/2010 (Issue1, rev2). This document defines the requirements of the radiation test programs for the APS-CMOS prototypes to be tested in 2011. Following EOCS1, an EOCS2 project is in preparation. EOCS2 will implement several processing (algorithms) that will be required before and after compression. The contract should be worth 300.000 Euros and for a duration of 10 months. The EOCS2 project is expected to end in 2011, depending on the possible delay of it starting date. It should be followed by the EOCS3 project (2012) that will focus on the development and the procurement of a flight model of the EOCS processing board that will implement the compression and all co-processing algorithms. The EOCS3 hardware components will have to be space-qualified by ESA and the software codes qualified as well.

P.1.4. Personnel involved

Scientific staff:

A. BenMoussa (project leader, detector WGL; PRODEX EUI PEA, STCE)
B. Giordanengo (detector & EUI simulator development; PRODEX EUI PEA)
S. Gissot (compression expert; compression WGL, PRODEX SDE PEA)

P.1.5. Partnerships

List of international collaborators having actively contributed to the project in the last year

- A. Soltani, J.G De Jager, IEMN, F
- T. Saito, NMIJ, JP
- S. Kozumi, NIMS, JP
- H.X Jiang, Kansas State University, US
- L. Jalabert, University of Tokyo, JP
- F. Auchère, X. Zhang, IAS, F
- R. Mercier, IO, F
- U. Schuehle, L. Teriaca, MPS, D
- U. Kroth, A. Gottwald, C. Laubis, F. Scholtze, PTB, D
- L. Duvet, B. Leone, S. Gidlund, ESTEC, N

List of national partners or collaborators having actively contributed to the project in the last year

- J-P Halain, J-M Gillis, E. Callut, L. Rossi, CSL
- P. De Moor, K. Minoglou, P. Malinowshki, IMEC
- G. Berger, CRC
- B. Wolf, G. Meynants, J. Bogaerts, CMOSIS
- C. Hermans, D. Bolsee, BISA
- K. Haenen, IMO
- G. Rouvroy, F. Macé, A. Descampe, F.-O. Devaux, P. Correa, intoPIX

Grants/Projects used for this research/service

- STCE
- BOLD-GSTP
- EUI BELSPO/PRODEX

P.1.6. Scientific outreach

Meeting presentations

(1) A. BenMoussa
LYRA onboard PROBA2
SBDDXV cultuurcentrum Hasselt (Cultural Centre), Hasselt, Belgium, 22-24/02/2010

(2) M. Dominique and A. BenMoussa
Lyra new Technology and Status
PROBA-2 worshop, ESTEC NL, 22/06/2010

(3) S. Gissot, G. Rouvroy and A. BenMoussa
Preliminary design of the Extreme Ultraviolet Imager compression system on-board the Solar Orbiter mission
2nd Int. Workshop on On-Board Payload Data Compression-OBPDC, Toulouse, CNES, France, 28-29/10/2010

(4) M. Dominique, D. Berghmans, M. Kruglanski, L. Dolla, E. De Donder, A. BenMoussa and W. Schumtz
Impact of the particle environment on SWAP and LYRA data
European space weather week (ESWW7), Bruges, B, 16-20/11/2010

(5) A. BenMoussa, A. Soltani and J-C De Jaeger
Developments of wide-bandgap semiconductor photodetectors for space applications
The 37th International Symposium on Compound Semiconductors – ISCS – Kagawa, Japan, 31/05 – 04/06/ 2010

(6) A. BenMoussa
Space Weather monitoring at the Royal Observatory of Belgium – introduction to EUI
International Conference on Space Environment, Jeju, Korea, 13-15/10/2010

(7) A. BenMoussa
ROB contribution to BOLD activities
BOLD progress meeting at IMEC (B) - 05/02/2010

(8) S. Gissot
Results of EOCS1 project
EUI Electronics meeting at ROB - 25/02/2010

(9) S. Gissot
Description of the EOCS2 reference design

EUI Compression meeting at ROB - 30/03/2010

(10) A. BenMoussa
EUI Detector activities
EUI Electronics meeting at ROB - 25/02/2010

(11) A. BenMoussa
ROB contribution to UV detectors development
ROB-LPC2E meeting at ROB – 18-19/03/2010

(12) A. BenMoussa
EUI on Solar Orbiter and its detector
3rd Consortium meeting at MPS – 25-26/06/2010

(13) A. BenMoussa
Advanced technologies for solar observations
K-star meeting at ROB – 21/06/2010

(14) A. BenMoussa
Current APS implementation
EUI Electronics WG meeting at ROB - 22/11/2010

(15) A. BenMoussa
EUI onboard compression system EOCS2 project
EUI Compression WG meeting at ROB - 04/10/2010

(16) S. Gissot
Presentation of the EOCS2 project
4th EUI consortium meeting at MSSL – 29-30/11/2010

(17) S. Gissot
Presentation of EOCS2 (and 3) project,
EUI Electronics Meeting, CSL, 10/05/2010

Wikis and Websites

- BOLD website: http://bold.oma.be/
- STCE website: http://www.stce.be/
- LYRA web site: http://lyra.oma.be/

P.1.7. Missions

Assemblies, symposia:

- A. BenMoussa: SPIE Photonics Europe, CMOS APS training course, OBPDC 2010, European space weather week
- S. Gissot: OBPDC 2010, European space weather week, ReSpace/MAPLD 2010
- B. Giordanengo: CMOS APS training course
- B. Nicula: CMOS APS training course

Commissions, working groups (days):

- A. BenMoussa: IMEC,05/02/2010; ESTEC,01/03/2010, CMOSIS,02/03/2010, CMOSIS, 26/04/2010, IMEC,22/06/2010, CRC,14/07/2010, IMEC,31/08/2010, CMOSIS,15/09/2010, IMEC,29/09/2010, IMEC,05/11/2010, PTB,08-10/11/2010.
- B. Giordanengo, CMOSIS,02/03/2010, CMOSIS, 15/09/2010, PTB, 15-16/06/2010, IMEC, 22/06/2010, IMEC, 31/08/2010, IMEC, 29/09/2010, IMEC, 05/11/2010, PTB, 08-10/11/2010.
- S. Gissot : CSL, 24/06/2010.
- B. Nicula : CMOSIS, 26/04/2010, CMOSIS, 15/09/2010.

P.2. Future Space Missions

P.2.1. Objectives

Solar Orbiter is the next solar–heliospheric mission in the Cosmic Vision programme of ESA. It was also redefined as a part of a joint ESA–NASA synergetic programme that comprises ESA's Solar Orbiter and NASA's Solar Probe Plus. The Solar Orbiter mission is devoted to solar and heliospheric physics and will provide unprecedented close-up and high-latitude observations of the Sun. The solar physics group of the ROB is a Co-PI institution for the Extreme-Ultraviolet Imager (EUI) onboard Solar Orbiter, with Pierre Rochus at the Centre Spatiale de Liège (CSL) being the EUI PI.

PROBA-3 is an ESA's experimental mission devoted to the in-orbit demonstration of formation flying techniques and technologies. The mission will be implemented with a pair of small spacecraft, which together form a coronagraph. One spacecraft will carry the main optical bench and associated detectors, electronics, etc., while the second spacecraft will carry the occulter. ROB participates in the project of the coronagraph for the PROBA-3 mission, ASPIICS (Association de Satellites Pour l'Imagerie et l'Interférométrie de la Couronne Solaire), led by P. Lamy (Laboratoire d'Astrophysique de Marseille).

Figure 58: Artistic view of Solar Orbiter

P.2.2. Progress and results

P.2.2.1. Extreme Ultraviolet Imager (EUI) / Solar Orbiter

The Extreme Ultraviolet Imager (EUI) onboard Solar Orbiter consists of a suite of two high-resolution imagers (HRI) and one dual-band full Sun imager (FSI) that will provide EUV and Lyman-α images of the solar atmospheric layers above the photosphere.

For 2010, the focus of the EUI activities was on some of the technologies that condition the feasibility of the EUI instrument [3][4], namely:

- The detector prototype development activities (APSOLUTE & BOLD) and tests preparation,
- The EUI on-board data compression system (EOCS), and its associated implementation,
- The EUV multilayers filters tests and calibration,
- The Common Electronics Box (CEB) and Front End Electronics (FEE) interface definition,
- The preliminary on-board SW requirements.

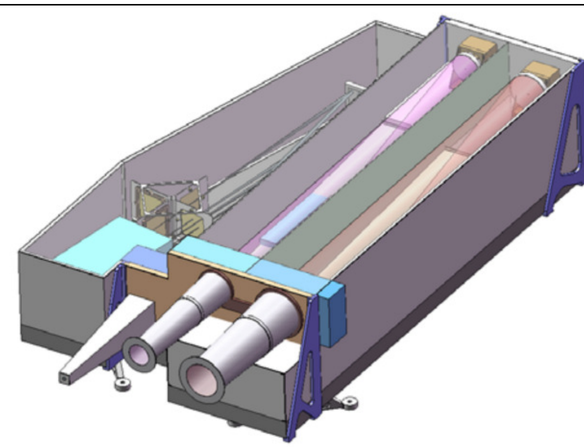

Figure 59: 3D view of the EUI optical bench (CEB not shown)

The detectors, compression and filters technological activities are detailed in the project "New technologies" since there are implemented through separate PRODEX contracts, respectively under CSL (APSOLUTE) and ROB (EOCS) management. The EUI management, technical, and scientific tasks under ROB responsibility during 2010 are listed and detailed below.

PI & ROB Project Management activities

Since January 2010, Ali BenMoussa has taken over the EUI Institute Project Management (IPM) and the EUI-PRODEX Principal Investigator at Belgian level (BPI) activities in place of Erik Pylyser who is on extended sick leave. Ali BenMoussa updated the EUI PEA proposal [3] (version 6.1 and 6.2) which takes into account the extension of the project until end of 2011. Ali BenMoussa updated also the EUI detailed work packages descriptions (version 2.0, 09/02/2010) [4]. He continued the follow-up of the agreed ROB activities [61]. He took formal responsibility with PTB (Berlin, D) and CRC (Louvain-La-Neuve, Be) for the collaboration on the detectors tests and calibration campaigns. For the list of meetings, presentations, and minutes [5][6][7][8], applicable to ROB activities and participations, see the “Scientific outreach” section.

EUI Science requirements update and Descope and Augmentation analysis

In 2010, the ROB-SIDC science team participate to the activity of the EUI Science Working Group which has been focused mainly on discussing the scientific consequences of the low counts predicted in the EUV High Resolution Imager (HRI_{EUV}) dual band configuration telescope. The results obtained from these works were implemented in a technical note (TN) issued on 28/06/2010 by Andrei Zhukov, made in collaboration with other scientific members of the EUI consortium [123]. This TN presented the limitations of the current design, proposed a descope of the dual band and the increase of the telescope aperture (from 30mm to 45mm diameter). This document was submitted to and approved by ESA. The EUI science team is investigating other subject in support of the technological development, in order to maximize the scientific return of the instrument. Susanna Parenti was active in the discussion concerning the translation of the science objectives into the instrument requirements as summarized in the Science and Instrument Requirement Document (Issue2, rev1) issued on 12/12/2010, which is a reference document for the EUI project. Andrea Verdini has studied the energy accumulation and turbulent dissipation in the corona (loops dynamics), relaxing the line-tied hypothesis, and derived scaling laws for the heating. In particular, the dissipation timescale is limited by the energy leakage down into the chromosphere. A work is in progress in which the output of the simulations are used to test and optimize automatic detection algorithms of wave motion (in Doppler images for the moment). In particular, with this application we expect to put constraints on the minimal cadence and resolution that are necessary for the wave detection.

On-board science data processing software requirements

A preliminary report of the EUI science algorithms (pre- and post-processing) was issued and delivered to the EUI consortium on 29 June 2010 by Veronique Delouille. It presents several procedure that could be included on-board EUI, their objectives and requirements. These functions include on-board calibration, pre-processing prior to compression, prioritization and image selection, triggering on particular events. This technical report has been presented by David Berghmans during the 3rd EUI consortium meeting at Katlenburg, Germany on April 28-29. A final version (Issue2, rev0) was issued on 23/06/2010 taking into account what was discussed and agreed after the 3rd EUI consortium meeting [48]. The event detection was decided to be a priority, and a prototype of event detection on SWAP images will be developed in early 2011. On-board calibration is also required because photometric accuracy can evolve and hence must be appropriately monitored. The functional requirements of the onboard data processing have been written by David Berghmans and have been edited/inserted in the EUI Science and Instrument Requirements Document (Issue2, rev2).

Compression, data prioritization and filtering, autonomy

In the context of the compression system tests, Samuel Gissot has taken on responsibility of EUI Compression Working Group (WG) Leader. Samuel Gissot has worked on the specifications of the EUI compression system, in particular in the preparation of the EUI onboard compression system projects (EOCS). In 2010, Samuel Gissot organized two EUI compression meetings at ROB.

In complement, Samuel Gissot and Ali BenMoussa are deeply involved in the EUI electronics WG since this activity strongly affects the data compression system, the detector activities and also the science algorithms development. Two EUI electronics meetings were held at ROB with the objectives to agree on the Common Electronics Box (CEB) and the Front End Electronics (FEE) needs and concepts to start specifications and preliminary design. A TN related to the science data requirement with impact on the FEE-CEB design was issued on 05/11/2010 by Ali BenMoussa in collaboration with David Berghmans, Samuel Gissot and Bogdan Nicula [14]. It provides an overview of the issue due to the current design of the FEE-CEB (e.g. impact on the image cadence, image quality and telemetry) and the sensor architecture (e.g. image artifacts that could occur due to the rolling shutter mechanism of the EUI sensor). The aim of this document is to clarify how the science data requirements could be achieved. Recommendations and possible technical options are introduced.

Mission products and operations analysis

David Berghmans and Erik Pylyser initiated analyses to identify constraints put upon the on-board operations, scientific capabilities and on-board storage capability, due to the S.O. orbits. They performed calculations needed to assess the limitations on the duration of the science programs, due to the limited on-board storage capabilities of the S.O. and EUI.

EUI operational simulator: Erik Pylyser proposed the start of the development of an EUI operational simulator, which is now under development to assess the scientific, operational and design consequences of the new and potentially upcoming constraints. As a preliminary study, based on daily averaged observational programs, the central processing unit load has been quantified by Andrea Verdini, taking into account the telemetry. The developed software can be implemented with the SPICE software in order to obtain a "local" simulator for the S.O. orbits. Since 2010, this simulator is now under the responsibility of Boris Giordanengo. Ali BenMoussa proposed to implement the EUI radiometric model allowing to simulate the signal generated by the telescopes as well as the signal to noise ratio. The different input parameters (solar spectrum, aperture diameter, filters transmission, mirrors reflectivity, quantum efficiency etc.) can be easily modified. This tool is accessible via a web interface (http://eui.sidc.be/) and will be very useful in view of the planning of EUI onboard scientific programs.

EUI observing programs: Susanna Parenti is responsible for design examples of EUI observing programs that will provide data suitable to achieve the scientific objectives of S.O. The eight programs today available were already identified the past year. The main activity in 2010 has been to refine and update their characteristics as the mission profile and the EUI project evolve. In particular, there has been changes concerning the minimum exposure times reachable (linked to the change of the HRIEUV telescope aperture) and the data compression (due to the new results from the Compression WG). These programs are detailed in an updated Table issued on 24/11/2010 which is used for scientific discussions, and it is included in the Science and Instrument Requirement Document issued on 12/12/2010 (Issue 2, rev 1).

New S.O. orbits: Due to the new orbits for the new launch scenario of S.O., Bogdan Nicula followed the European SPICE workshop in Madrid (Spain) and established contact for helping transforming the predicted orbit excel files (ESAC) into computer readable data that can be integrated into a Navigation, Attitude and Timekeeping System (NATS), useful for both the instrument analysis tool and the future EUI Data Center.

Study of the S.O. and SP Plus orbits: The possible scenarios for the S.O. launch in conjunction to the Solar Probe Plus mission has been studied by Andrea Verdini. The main objective was to identify the periods of alignment and quadrature of the two spacecrafts, as well as those of corotation with the sun. Since such periods represent special opportunities to study the sun-earth connection, specific observational programs have to be foreseen.

Ground Segment Definition and Development

In the beginning of 2010, Erik Pylyser generated a second high-level description of the EUI ground segment (EUI Data Center) interfaces with the existing ESA ground infrastructure, as well as its high-level functions and responsibilities. This text answers to the EUI instrument ground segment constraints described in the ESA provided EID-A, and was integrated in the latest version of the EID-B issued on 31/03/2010 (Issue2, rev2) [61]. Since then, this activity is on stand-by.

Communication and Public Relations

The EUI web site was updated by Andrea Verdini (style and content, update of the new EUI design, bandpasses, cadence) with an easier access to relevant information for a wide public. The web site is now accessible at http://eui.sidc.be/ . To enhance the EUI documents storage, a repository file has been developed by Boris Giordanengo with an advanced search engine. The flexible tool file repository includes also the EUI agenda for meeting planning. This tool is available at http://eui.sidc.be/file_repository/index.php.

P.2.2.2. PROBA3/ASPIICS

ASPIICS heralds the next generation of coronagraphs for solar research, exploiting formation flying to gain access to the inner corona under eclipse-like conditions (field of view from 1.04 to 3 solar radii) for long periods of time. ASPIICS will make a giant step in our knowledge of the solar corona by providing observations that will lead to the insights necessary for understanding key physical processes and for the prediction of space weather in the Sun – Earth system. L. Rodriquez, B. Nicula and A. Zhukov are Co-Investigators of PROBA-3/ASPIICS, with A. Zhukov also being the ASPIICS Science Manager. The first ASPIICS consortium meeting took place in June 2010, with discussions about technical aspects, possible descopes and their scientific impact. Two conference papers describing the ASPIICS coronagraph were published in 2010. The prospective ABCD project (ASPIICS Belgian Center of Data) that is an important contribution provided by ROB/SIDC, was still in a hiatus, due to uncertainties for the instrument and platform.

P.2.2.3. Long-term perspectives for future space missions

ROB/SIDC scientists also participate in early stages of development of other future solar missions. S. Parenti contributed to prepare the proposal for the instrument *LEMUR (Large European Module for Solar Ultraviolet Research)*, in response to the ESA call for mission of opportunity in the Cosmic Vision Programme. The instrument is proposed as contribution for the Japanese Solar-C mission. The instrument is a UV-EUV spectrometer that aims at providing high spatial resolution data (0.5”) to study the solar chromospheres-corona connection. S. Parenti was responsible for making the radiometric calculations in the selected wavebands and for a preliminary design of observing programs, and contributed to the writing of the science section of the proposal.

S. Parenti also contributed to the science section of the *Solar magnetism eXplorer (SolmeX)* proposal in response to the ESA call for M-size mission for the Cosmic Vision programme. The mission proposal aims at providing magnetic field measurements over different layers of the solar athmosphere.

S. Parenti was invited to participate to a first meeting for the MaGIX telescope. This is a stigmatic grazing-incidence X-ray Spectrograph for solar coronal observations. The instrument will be proposed for a rocket mission to NASA by the University of Alabama in Huntsville (USA). S. Parenti contributed to the scientific discussion and to the selection of wavebands.

P.2.3. Perspective for next years

Solar Orbiter is retained in the competition for ESA’s Cosmic Vision programme. The ROB/SIDC team will carry on project duties and research in consistency with ESA plans and with the EUI collaborative partnership. ESA milestones are the second and final Cosmic Vision mission selections (fall 2011) as well as the next review for EUI, the Instrument Preliminary Design Review (IPDR) which is planned to be held in the second half of 2011 (mid Oct. for EUI) and to be completed by January 2012. Upon final selection of Solar Orbiter, then from 2011 and throughout 2012-2013, the various instrument models (structural and thermal model, Engineering model, Qualification and Flight Model) will be built by the consortium and delivered to ESA. ROB's main responsibilities on the longer term lie specifically in the calibration and radiation tests of the detector models, as well as the definition, design and development of the EUI Data Centre and operational support, as requested by ESA. Solar Orbiter is planned to be launched in 2017 or 2018.

PROBA-3/ASPIICS activities will be continued as the ASPIICS selection was announced in January 2010 and the kickoff of the project is expected in 2011. Should the PROBA3 activities advance sufficiently, the ABCD project would start to concretize. The launch of PROBA-3 is expected around 2015.

Regarding other future missions, LEMUR was recommended by the ESA SSAC for selection. SOLMEX was not selected by ESA, so no further activity is planned for the moment. The MaGIXS proposal will be submitted in 2011.

P.2.4. Personnel involved

Scientific staff:
A. BenMoussa (project leader, detector WG leader; PRODEX EUI, STCE)
B. Giordanengo (website & EUI simulator development; PRODEX EUI)
A. Verdini (scientific support; PRODEX EUI)
S. Gissot (compression expert; WGL, PRODEX SDE)
D. Berghmans (Co-PI, support to operations analysis; Permanent Position)
V. Delouille (science algorithms WG Leader; PRODEX SDE)
B. Nicula (science algorithms, detectors specifications; STCE)
S. Parenti (scientific support; PRODEX SDE)
A. Zhukov (scientific support; STCE)
JF. Hochedez (scientific support until July 2010; Permanent Position)
E. Pylyser (project management until February 2010; PRODEX EUI)

P.2.5. Partnerships

List of international partners or collaborators having actively contributed to the project in the last year

- L. K. Harra, T. Kennedy, J. A. Tandy, P. Smith, MSSL, UK
- F. Auchère, X. Zhang, J-J Fourmond, E. Buchlin, T. Appourchaux, IAS, F
- R. Mercier, IO, F
- U. Schuehle, L. Teriaca, E. Marsch, S. Solanki, K. Heerlein, S. Werner, MPS, D
- Stefan Thurey, S. Gidlund, H. Schroeven, ESTEC, NL
- R. Grappin, LUTH Obs. Meudon and LPP Ecole Polytechnique, F
- M. Velli, Univ. Firenze and JPL, I
- W.H. Matthaeus, Bartol Research Institute, Univ. of Delaware, USA
- P. Chainais, Université de Clermont-Ferrand (ISIMA), F
- Emilie Koenig, ISIMA, F

List of national partners or collaborators having actively contributed to the project in the last year

- Pierre Rochus, Jean-Philippe Halain, Etienne Renotte, Jean-Marie Gillis, Eric Callut, Laurence Rossi, CSL

Grants/Projects used for this research/service

- STCE
- EUI PEA C90343 01/01/2008 - 31/12/2011 From BELSPO/PRODEX

P.2.6. Scientific outreach

Meeting presentations

(1) A. Verdini
Fully self-consistent MHD turbulence models of the solar wind
ISSI workshop "Multi-scale physics in coronal heating and solar wind acceleration - from the Sun into the inner heliosphere Bern, Switzerland, 23-31/01/2010

(2) A. Verdini, R. Grappin, M. Velli
Coupling Photosphere and Corona: linear and turbulent regimes
COSPAR meeting, Bremen, Germany, 18-23/07/2010

(3) A. Verdini, R. Grappin, M. Velli
Coupling Photosphere and Corona: on "not-line-tied" loops
Workshop on Plasma Astrophysics, Univ. di Firenze, Firenze, Italy, 20-23/11/2010

(4) A. Verdini
Heating the solar wind and the corona: a turbulence scenario
Colloquium Univ. of Utrecht, Utrecht, The Netherlands, 23-24/11/2010

(5) A.Verdini, M. Velli, R. Grappin, W-H. Matthaeus, S. Oughton, E. Buchlin, D. Berghmans
Alfvén waves and turbulence in the solar corona and solar wind
NAC conference, Cuijk, The Netherlands, 20-21/05/2010

(6) A. BenMoussa
Space Weather monitoring at the Royal Observatory of Belgium – introduction to EUI
International Conference on Space Environment, Jeju, Korea, 13-15/10/2010

(7) A. BenMoussa
EUI/Solar Orbiter updates
BOLD progress meeting at IMEC (B) - 05/02/2010

(8) A. BenMoussa
ROB EUI activities updates
EUI internal meeting at ROB – 09/02/2010

(9) A. BenMoussa
ROB EUI activities updates
EUI internal meeting at ROB – 31/03/2010

(10) A. BenMoussa
EUI ROB activities
3rd Consortium meeting at MPS – 25-26/04/2010

(11) A. BenMoussa
EUI on Solar Orbiter and its detector
3rd Consortium meeting at MPS – 25-26/04/2010

(12) S. Parenti
Science updates & high level specifications
3rd Consortium meeting at MPS – 25-26/04/2010

(13) A. Verdini
EUI web site & ftp server
3rd Consortium meeting at MPS – 25-26/04/2010

(14) S. Gissot (presented by D. Berghmans)
EUI compression system & Preliminary science algos

3rd Consortium meeting at MPS – 25-26/04/2010

(15) D. Berghmans
3 alternative strategies, Flares detection options
3rd Consortium meeting at MPS – 25-26/04/2010

(16) A. BenMoussa
3rd EUI consortium meeting – Debriefing
EUI ROB internal meeting at ROB – 05/06/2010

(17) A. BenMoussa
ROB EUI activities updates
EUI ROB internal meeting at ROB – 30/06/2010

(18) D. Berghmans
EUV-HRI needs a larger aperture
EUI interface meeting at CSL –24/06/2010

(19) S. Gissot
JPEG2000 and processing algorithm
EUI Compression WG meeting at ROB - 04/10/2010

(20) V. Delouille
EUI Science algorithm – preliminary requirements
EUI Compression WG meeting at ROB - 04/10/2010

(21) S. Parenti
Observation programs and telemetry
4th EUI consortium meeting at MSSL – 29-30/11/2010

Wikis and Websites

- EUI website: http://eui.sidc.be/
- EUI repository file: http://eui.sidc.be/file_repository/index.php
- EUI radiometric model: http://eui.oma.be/radiometric_model.

P.2.7. Missions

Assemblies, symposia:

- A. BenMoussa: Matlab Workshop, European space weather week, A
- Verdini: ISSI workshop, NAC conference, COSPAR meeting
- S. Gissot: European space weather week, ReSpace/MAPLD 2010
- B. Giordanengo: Matlab Workshop
- B. Nicula: SPICE

Commissions, working groups:

- A. BenMoussa: ESTEC, 01/03/2010, CSL, 31/03/2010, MPS, 28-29/04/2010, CSL, 10/05/2010, CSL, 24/06/2010, CRC, 14/07/2010, MSSL, 29-30/11/2010
- D. Berghmans : MPS, 24/06/2010, MSSL, 29-30/11/2010
- B. Giordanengo : MPS, 28-29/04/2010
- S. Gissot : CSL, 24/06/2010, MSSL, 29-30/11/2010
- S. Parenti : MPS, 28-29/04/2010, MSSL, 29-30/11/2010
- A. Verdini : MPS, 28-29/04/2010

Research visits:

- A. Verdini, 9-19/05/2010, 27/9-10/10/2010

Q. Solar Instrument operations, data handling and services

Q.1. USET operations, development and data production

Q.1.1. Objectives

Data collection and services

The optical USET instruments are providing visual observations since 1940 in support to the SIDC sunspot index determination, as one of the reference stations in the worldwide "sunspot" network. Since 2002, the USET also produces CCD images in support of real-time solar activity monitoring and forecasting, as well as for fundamental solar research. Those long-term observations provide a continuous characterization of the solar activity and of the sources of irradiance variations. The introduction of white-light and Hα CCD imagers, now in routine use, are also part of a wider ongoing effort to improve and better understand existing solar activity indices and to study new quantitative ground-based solar indices based on modern electronic imaging techniques. This work includes also coordinations with other similar solar facilitites in Europe and beyond.

The USET activities thus follow two base axes:

- Optical observations of the Sun and characterisation of its activity:
  - Visual observations of sunspots (drawings) in support to the international sunspot index determination
  - Digital imaging in white-light (photosphere) for synoptic observations
  - Digital imaging in the H-alpha line (chromosphere) for real-time flare patrol observations.
  - Digital imaging in the CaII-K line (chromosphere) for UV chromospheric flux indices (proxies).
  - Near-real time dissemination of those data and merging with other data sets (data portals)

- Digitization and processing of the visual sunspot observations of the Uccle station, and publication in the SIDC Bulletin of additional indices for this reference station:
  - Total, hemispheric and central zone sunspot number (raw and normalized)
  - PPSI index
  - Classification (type, sunspot count, heliographic coordinates) and history of individual sunspot groups
  - Dates of possible return of well developed sunspot groups (Zürich types E & F)
  - Digitization of past sunspot drawing collections and construction of detailed sunspot group catalogs, currently starting with the 70-year Uccle drawing collection.

Part of those activities (digitization, index studies) are currently supported by the 3-year **SoTerIA project** (SOlar-TERrestrial Investigations and Archives) ending in October 2011.

Instrument operations, maintenance and upgrade

In order to ensure the continuous operations of the USET instruments and also in order to improve and to extend the capabilities of the Uccle solar optical facilities, we develop new instruments and we upgrade existing ones by introducing new techniques at the level of optics, mechanics or image detectors. As USET telescopes work in the visible light domain, the systems can mostly be built from existing commercial components and do not require specific industrial development. Instead, the new instruments involve primarily the study and development of unique custom solutions, adapting or combining newly available technologies for the specific requirements of modern solar imaging. This work thus relies on internal ROB workshops (mechanics, electronics) and it contributed to the development of a unique internal expertise in optical instrumentation at the ROB.

The USET instrumentation objectives currently involve the following developments:

- Digital imaging system in white-light (photosphere)

- Digital imaging system in the Hα line (chromosphere)
- Digital imaging system in the CaII-K line (chromosphere)
- Telescope pointing system
- Telescope and dome automatization

Q.1.2. Progress and results

Q.1.2.1. USET management and project proposals

There was no evolution of the observing and technical team in 2010.

However, 2010 was mainly marqued by the active search for external funding, namely:

- Project proposal entitled "New sunspot proxies" for an FP7 Marie-Curie grant initiated to try keeping Laure Lefèvre after the end of the SoTerIA project (October 2011). The proposal was submitted in August 2010 (Call: FP7-PEOPLE-2010-IEF). Although it got a good rating, it was finally not selected.
- Initiation of a networking project focusing on long-term solar indices derived from historical ground-based solar observations in view of a FP7 project proposal succeeding to SoTerIA and extending the Work Package 2 achievements: F.Clette drew up a draft science rationale and contacted the entire European community of ground-absed solar researchers, exploiting his wide contact network. In spite of these efforts and the massive support of the contacted research groups, the whole concept was withdrawn following indications by EU project officers of the absence of sufficient match between this project and themes pre-defined in FP7.
- Initiation and promotion of the HaSTeNet concept: the H-alpha Solar Telescope Network project is listed as in intended call of the GSTP5 program, in segment 3 "Security for the Citizen" (Emits call Id: 10.1EEE.02; cf. http://emits.esa.int), as part of the global Space Situational Awareness (SSA) program of ESA. This Hα network was identified as a key component of the Space Weather segment of SSA. As the USET is one of the leading facilities in this field, F.Clette established a pre-consortium with 3 key partners: the Kanzelhöhe Observatory, the Observatory of Catania and the Observatory of Paris-Meudon. A draft rationale and plan was established and presented orally during the SSA session of the 7th European Space Weather Week in November 2011. Very few reactions came from the community, in particular from ESA and national delegations to ESA, in spite of the well-identified need for such a European infrastructure, the available expertise and the motivation of numerous partners, including the Uccle station.

Q.1.2.2. Instrument operations and maintenance

No major failure took place on the telescopes in 2010. The regular maintenance schedule was executed by A. Ergen and J-L Dufond under F.Clette's supervision. The telescope optics were cleaned regularly by F.Clette, who also cared for critical telescope adjustments (focusing, parallelism)

As no action was taken by the Régie des Bâtiments to do repairs, the solar dome still suffered from water leaks on rainy days. Consequently, the internal structure shows again growing signs of rusting.

On the other hand, new failures occurred in the temperature regulation of the Hα filter in May and October 2010, when it ceased to function. F.Clette and J-L Dufond in connection with the supplier diagnosed the source of the problem: a failing mechanical relay. A temporary solution was found by swapping two relays. In order to avoid the future repetition of such mechanical failures, a new temperature controller box using exclusively solid-state components was ordered from the supplier in October. It will be delivered in the spring of 2011.

Twice in July, tiny insects (acari) managed to get into the white-light CCD camera. This required the unmounting and cleaning of the cameras. Use was made of the new Demelab clean room for this operation.

Q.1.2.3. Data production and dissemination

- **Daily solar observations**: F.Clette coordinated and monitored the daily solar observations at the USET. Due to particularly bad weather conditions in November and December, the count of observing days was a bit below average. An overview of the 2010 observations is given in the tables below.

Camera	Nb. Images	Comment
Photosphere	936	White-light channel
Chromosphere	1911	H-alpha channel
Total	**2847**	

Table 5: USET CCD image statistics for 2010

Observer	Nb. duty days	Nb. days with no observations	Nb. Days with observations	Total nb. Of drawings
Boulvin	86	35	51	56
Clette	4	0	8	9
Ergen	94	28	66	68
Lemaître	90	25	65	85
Vanraes	91	35	56	60
Totals	**365**	**123**	**246**	**293**

Table 6: USET sunspot drawing statistics for 2010

- **Monthly processing of the USET sunspot drawings**: the monthly treatment of Uccle sunspot observations (sunspot group classification, execution and verification of analysis output) took place flawlessly for the whole year, indicating that the software is stable and mature. In the course of 2010, solar activity started to increase significantly after years of very quiet conditions. The resulting monthly tables are published as part of the monthly SIDC Sunspot Bulletin.

- **USET data distribution:**
  - The design of the USET web pages was further improved. In particular, a full technical instrument description was added, with an interactive user interface using new pictures of the USET and its various components. A brief history of the Uccle solar optical instruments was also included.
  - In preparation ofr the wider export of USET images to external data portals, a new logo was created by O. Lemaître combining a USET image with a drawing of the instrument.
  - As the Hα telescope is now fully operational and provides high-quality images, final arrangements were made with two global solar data portals: the Global H-alpha High-resolution Network (GHAN) managed by the New Jersey Institute of Technology and BASS2000 led by the Observatory of Paris-Meudon. The final steps were made in the preparation of the appropriate images files (format, metadata) and of the data transfer protocols.
  - As a support to SoTerIA Work Package 6, we also provided all USET images as a testing ground and initial data set for the implementation of the global data portal that is being implemented by the ROB for the entire SoTerIA project.

Q.1.2.4. Improvements to the white-light CCD telescope

The new ND4 full aperture filter ordered from the Lichtenknecker Company in December 2009 was installed in February 2010. Initial tests showed that the attenuation of the filter was lower than the specifications. After the manufacturer provided an additional ND0.9 to be placed near the focal plane, new tests proved to be satisfactory except for a weak ghost image.

As the optical performance of the 2-lens 0.94x focal reducer installed in 2009 proved to be insufficient (off-axis image degradation), a new design was done, leading to the installation of a single long-focus lens (F=4 m) with excellent results.

Thanks to the two above upgrades, the image quality was considerably improved. The image resolution is now close to the theoretical value for the telescope aperture (~1 arcsec) and only limited by the CCD pixel size and the atmospheric turbulence.

By the end of 2010, the study of the optical rail support for this telescope was started. For this design, the large size and mass of the optical assembly, compared to the other two telescopes, must be taken into account..

Q.1.2.5. Improvements to the Hα telescope

The Hα telescope continued to serve as a test bed for the installation of a common optical rail (installed in June 2009) and independent motorized controls (pointing and focusing). The experience acquired on this telescope can then be quickly transposed to the other two telescopes.

In August 2010, we proceeded with the installation of the "Z" micrometric translation stage providing motorized fine control of the focusing. In manual mode, this brought already a significant improvement on the accuracy and ease of focusing. However, except for initial benchtop tests, by lack of time and manpower, the remote commanding software could not be developed and included in the SunCap image acquisition software in 2010.

Q.1.2.6. Development of a new CaII-K CCD telescope

The first months of the year were devoted to the ordering process of the custom lenses required for the telecentric Barlow system feeding the narrow-band filter. A survey of manufacturer was carried out and three offers were obtained. The first offer made already in 2009 by Molenaar Optics was finally selected. After a final design review, the lenses were ordered in June 2010 and finally delivered in October 2010.

F.Clette also searched for and found a heat-rejection filter compatible with this application, i.e. with transmittance in the violet near 393 nm. This optical filter was also delivered in the fall of 2010.

In parallel, the electronic and mechanical design was started for the CaII-K filter enclosure and thermal regulation. The control electronics were defined and a breadboard system was tested. Mechanical drawings were prepared and the selection of appropriate materials (Invar rods, insulation) was undertaken. This work will be completed in 2011.

Q.1.2.7. Upgrade of the telescope and dome

Except for the study of the mechanical accommodation and type of rotational encoders on the USET telescope mount, not much progress could be done for the automation of the instrument.

In view of the increased automatization, webcams are required to provide a view of the inside of the dome and of the overall sky conditions. For the latter, a camera with Ethernet link and 180° wide-angle lens were selected and purchased by mid 2010. The design of a water-tight and insulated enclosure for this exterior whole-sky monitoring webcam was completed by late 2010. The construction and installation is foreseen in 2011.

Q.1.2.8. Software developments:

In 2010, most of the efforts were concentrated on the rewriting almost from scratch of an entirely new version of the SunCap camera control and image acquisition software: graphical user interface, expanded capabilities, more advanced automatic image acquisition modes, expandability of the software in view of the future inclusion of focus and pointing controls. Initial benchtop tests were made with success for the motion control of the OWIS micro-positioning stages. The interfacing is thus ready and only software development remains to be done.

A basic version of image browsing and selection software, SunGlasses, was also created. At this stage it is still missing more advanced capabilities required for working with high-cadence image sequences. Given the lack of time and the low solar activity, this key element of the planned USET data pipeline was not further developed in 2010.

In the framework of the training period, a student from the ESI (Ecole Supérieure d'Informatique de Bruxelles), Greogry Vangroeningen, developed a web-based logbook for the USET operations. This application is accessible from any PC in the ROB domain. It allows recording all events and circumstances of the USET observations (actions, observing modes, weather, observer identification). The information is saved in a database, allowing a wide range of later use for recovering specific information or statistics. The recorded information includes both manual entries by the instrument operators and automatic records of camera and telescope status including all images captured by the USET cameras, providing all metadata associated with the image archive. After a 6-month commissioning period, this application should entirely replace the paper logbook used until now.

Q.1.2.9. Digitization of the Uccle sunspot drawing collection (SoTerIA)

A major contribution to SoTerIA was started in June 2009: the global digitization en encoding of sunspot group parameters from the 70-year collection of sunspot drawings from the Uccle station (about 20000 drawings spanning 70 years). This work continued without interruption in 2010, with measurements carried out mainly by two operators (O. Lemaître and A.-M. Hernando). Drawings for the year 1957, which were still missing and almost thought to be lost, were finally recovered, thereby fully completing the drawing archive. In summer, temporary job students were hired to also continue the bulk scanning of the drawings.

By the end of 2010, about 80% of the drawings had been digitized (60 years) and about 65% of the drawings had been measured (46 years). The table below shows how the progress is distributed.

Year	0	1	2	3	4	5	6	7	8	9
1940	-	-	-	-	-	-	-	D	-	D
1950	D	-	-	-	-	D	D	D	D	D
1960	D	D	D	D	D	D	X	P	X	X
1970	X	X	X	P	X	X	P	X	X	X
1980	X	X	X	X	X	P	P	P	X	P
1990	X	X	X	X	X	P	X	X	X	X
2000	P	X	X	X	X	X	X	P	P	P
2010	X	X								

Table 7: Progress of the Uccle sunspot drawing digitization by late 2010
(D: digitized; P: partly measured; X= completed)

In order to better control any possible personal bias, the different years of the series are attributed randomly to different operators. By August 2010, we started the quality control of the measurements accumulated so far, but so far only a few years (1985-1990) could be verified. In order to streamline the quality control work, operators started building up lists of problematic groups for which the morphological classification remains ambiguous (~5% of all groups). F.Clette also started a technical document laying the base principles and methods for sunspot group tracking, in view of the implementation of a group tracking software to be applied to the catalog resulting from the Uccle drawing measurements.

Further improvements were brought to the DigiSun software by S. Vanraes, primarily to take into account actual results of the measurements (addition of new entries in the sunspot group classification grids). The software was fully documented with an updated DigiSun manual.

In the Fall of 2010, in the framework of a professional training period for ACTIRIS-Bruxelles Formation, a WEB-based application was created for providing public access to the future Uccle digitized drawing collection and associated sunspot group database. Making use of Web services, this application allows bidirectional data queries: for any selected drawing, it links to all sunspot group entries present in that observation. For any selected active region, it gives access to all drawings showing it. Images of drawings are displayed interactively, with overlay marks for each active region and coordinate grids. Due to the late discovery of a missing capability in the chosen graphical library and the short duration of the training period (October-November), the application could not be completed on time and was not operational at the end of the training period. Futher work is needed, building on the existing base delivered by this work.

Q.1.3. Perspective for next years

The priorities for 2011 will be:

- Coordination and supervision of the USET hardware and software developments.
- Coordination and participation to USET observations, data processing and data distribution.
- Instrument development (hardware):
  - Mechanical construction, installation and commissioning of the CaII-K telescope internal optics in connection with the Observatory of Rome (PSPT).
  - Construction and commissioning of the thermally-controlled enclosure of the CaII-K filter.
  - Design and construction of the motor-actuated mechanical support and focus systems for all three telescopes.
  - Completion of the solar pointer: this will involve a study phase in order to optimize the system to the actual properties of image turbulence at the Uccle site.
- Instrument development (software):
  - Development of new programs (SunGlasses) for the selection and pre-processing of high-cadence images from the 3 new camera systems.
  - Implementation of systematic procedures for the determination of the camera dark level and flat-field, which will be used in the routine observations of the new cameras.
  - Data provision to external solar portals (Global Hα Network, BASS2000)
  - Development and testing of the solar pointer control software
  - Implementation of a remote USET commanding interface allowing telescope and camera control from any workstation in the ROB through the Ethernet.
- Sunspot data digitization and long-term sunspot data exploitation in the context of the SOTERIA project:
  - Completion of the systematic digitization and encoding of the Uccle sunspot drawing collection.
  - Systematic data quality control and validation of the new Uccle sunspot catalog
  - Development of a new program for the group tracking, in replacement of the existing SOLKOP program.
- Promotion and possibly proposal of a European Hα observing network in the context of the SSA program (HaSTeNet).

Q.1.4. Partnerships

List of international collaborators having actively contributed to the project in the last year

- Manuela Temmer, Astrid Veronig, Kanzelhöhe Observatory, Austria: H-alpha instrument development. (SoTerIA project, HaSteNet project)
- Jean-Marie Malherbe, Observatoire de Paris-Meudon, France (HaSTeNet project)
- Francesca Zuccarello, Osservatorio di Catania, Italy (HaSTeNet project)

List of national partners collaborators having actively contributed to the project in the last year

- HEB-ESI (Ecole Supérieure d'Informatique): G. Vangroeningen, training period, USET software development (Feb.-June 2010)
- ACTIRIS-Bruxelles Formation: J. Nutin, training period, Web portal to the Uccle drawing database (27/9-3/12/2010)
- Job student: G. Vangroeningen, USET software development (1-15/7/2010)

Grant(s)/Project(s) used for this research/service

- SOTERIA "SOlar-TERrestrial Investigations and Archives" project (EU 7th Framework Program, Nov.2008- Oct. 2010)
- STCE: work package A.2 "Ground-based Observations"

Visitors:

- S.Federici, Institut Saint-Joseph (Charleroi), 10-12/2/2010: final year contact with a profession.
- M. Debacker, ESI, 20/4/2010: supervising professor for student training periods
- Dr. R. Molenaar, Molenaar Optics, 9/6/2010: design and manufacturing of new CaII-K optics
- Dr. H. Wang, NRL, 3/8/2010: visit of the solar telescopes
- Several groupe visits to the solar dome.

Q.1.5. Scientific outreach

Meeting presentations

(1) Clette, F., Temmer, M., Veronig, A., Zuccarello, F., Malherbe, J.-M.
HaSTeNet: a European Hα Telscope Network for SSA
7th European Space Weather Week, Brugge, Belgium, 15/11/2011 (oral presentation)

Wikis and Websites

- USET Web pages and archive (http://sidc.oma.be/USET):
    - User interface for quicklook images and database queries featuring a visual data query tool (pre-view thumbnail images) and full-rotation navigator (mosaic, movie, sliding strip).
    - Real-time web distribution of USET CCD camera images
    - Real-time web distribution of the Uccle scanned sunspot drawings

Q.1.6. Missions

Assemblies, symposia, conferences:

- F.Clette: 7th European Space Weather Week, Brugge, Belgium, 15-19/11/2011 (oral presentation)

Commissions, working groups:

- F.Clette: PhD defense, S. Mekaoui (RMI), Vrij Universiteit Brussels, 26/1/2011.

Q.2. Humain upgrades and operation

Q.2.1. Objectives

The project is part of WP2 (ground-based solar instruments) of the STCE, which has two components: optic observations with the USET telescopes in Uccle and radio observations at the Humain station, near Marche-en-Famenne. C. Marqué became in 2010 the leader of this WP. C. Marqué was hired in January 2008 as a radiophysics scientist to manage the radio aspects of this WP (development and science exploitation).

Concerning solar radio observations, the idea is to take opportunity of the existing facilities in Humain: parabola on equatorial mounts, laboratories, on-site personal, to re-develop a small set of solar dedicated radio telescopes. Compared to the past observations operated at Humain, which involved in particular the maintenance of a 48-antenna interferometer, the new observations do not deal with radio imaging but rather with the monitoring of solar activity through wide-band spectral observations (decimetric-metric band related to CMEs and flare activities) and flux measurements at selected individual frequencies (flare physics and irradiance). It involves therefore a smaller set of radiotelescopes. The scientific goals of the project fit very well with the other projects of the Solar Physics department, in particular with the Proba-2 instruments SWAP and LYRA, and the Action 1 project of J. Magdalenić. In addition, the project is aimed at supporting the SIDC space weather forecast activities as well as perpetuating the long-term solar radio observations in Belgium.

Q.2.2. Progress and results

Q.2.2.1.Spectral Observations

Callisto

Spectral observations are performed in Humain using a broadband log periodic antenna, plugged to a small Callisto spectrometer built by the ETH institute in Zürich (Switzerland). This instrument allows a monitoring of the solar activity in the frequency range 45-870 MHz (i.e. in the corona), which is in practice reduced to the band 45-387 MHz (a compromise between time accuracy and sensitivity). Callisto is both an instrument and a network. Several identical receivers are installed around the world, to provide a nearly 24-hour coverage of the solar activity in radio. The network is managed by C. Monstein (ETH).

Solar activity has been rather low since the set up of this instrument in Humain in the mid-2008. As shown in Figure 60: Number of radio burst per month recorded in Humain (blue and green bars) compared to the sunspot number (red bars), 2010 marks the real start of the new solar cycle in terms of radio burst activity. The number of bursts is increasing, roughly following the rise of the solar activity as revealed by the sunspot number. The figure shows the number of bursts per month in Humain collected by C. Monstein. Only the main bursts are listed there. Since August 2010, C. Marqué is maintaining, in parallel, a local version of the burst catalog that will be made public after cross validation. It is obvious from this figure that the local catalog contains much more bursts (mostly fainter bursts) that the one maintained by C. Monstein. In 2011, it is expected that each Callisto station around the world will maintain its own catalog. During this transition phase, objective selection criteria need to be defined. In order to create such a catalog, C. Marqué developed an IDL tool to display, manually detect and create such an event list. Figure 61 shows a screenshot of this application.

Callisto observations are being used for the space weather forecasts of the SIDC as an early warning tool of flares or CMEs: shock waves (seen as type II bursts), energy release during flares (type III bursts), or post-eruptive magnetic reconfiguration (type IV bursts). Whenever possible or needed, C. Marqué or J. Magdalenić check the daily observations regularly and provide to the forecaster on duty extra information on the radio burst which is observed. C. Marqué developed a quicklook display of the last 3 hours of observations combined with Xray light curves from the GOES satellite. This gives an easier way in associating a given radio burst and with a peculiar solar flare. Figure 62 gives an example of such a quicklook display.

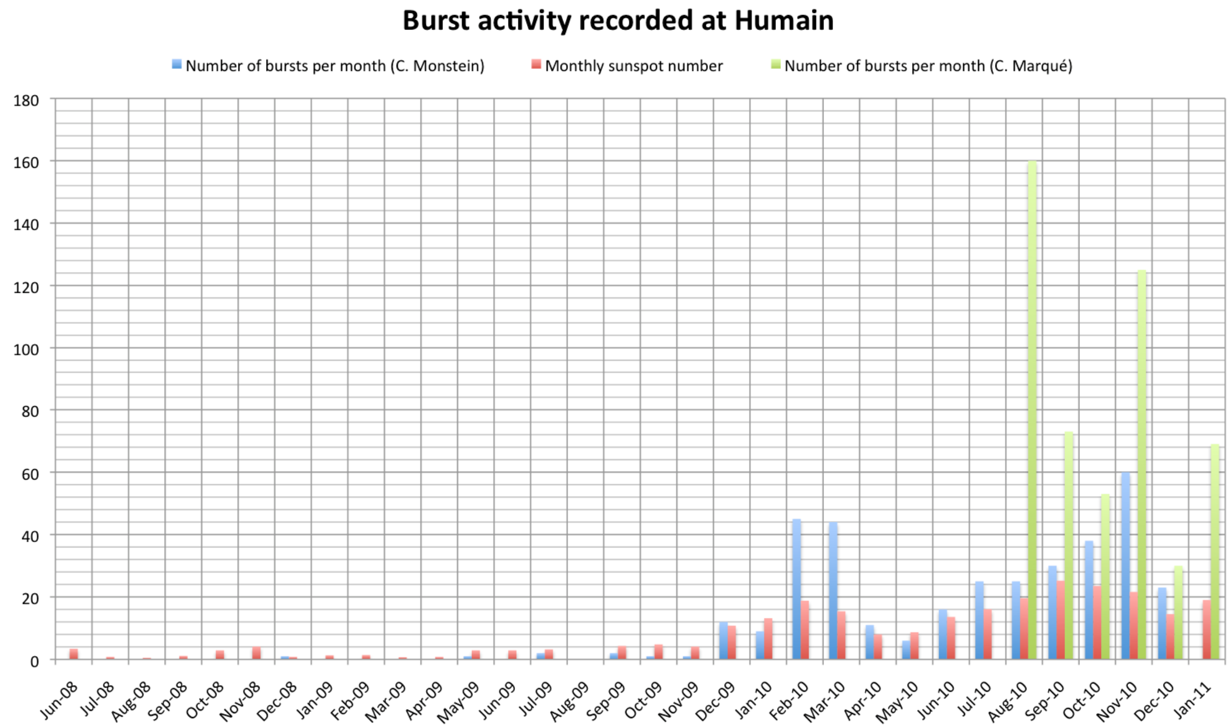

Figure 60: Number of radio burst per month recorded in Humain (blue and green bars) compared to the sunspot number (red bars)

Phoenix2

The ETH Zürich institute, which is an invaluable partner of the Humain refurbishment project since the beginning, has strongly reduced its observing and scientific activities linked to solar radio astronomy. The reason is the retirement of the chief scientist of the project, Pr. A. Benz. In this context, the ROB was contacted by ETH during the spring of 2010 to transfer some instruments from ETH to ROB. After some discussion, it was decided that ROB would receive and operate a second spectrograph, called Phoenix2 that can monitor the solar activity from the metric to the centimetric range (100 MHz – 4 GHz).

In August 2010, C. Marqué, J. –L. Dufond and J. –P. Noël went to Switzerland to discuss the technical details of this instrument and its transfer. The instrument was effectively brought to ROB in September 2010.

The instrument will be put on the same radio telescope (6-m dish) that is currently used for the Callisto observations. C. Marqué purchased a new receiving antenna, with 2 orthogonal polarizations. It will be put at the focal plane of the dish, which requires a support structure to be designed and built. J. –L. Dufond made a design proposal that has been adapted and discussed with the mechanical workshop of the Observatory. J. –P. Noël worked on a new Focal Plane Unit containing the pre-reception HF part. Its role is to produce from the two incoming linear polarizations, two circular polarizations and two redundant intensity inputs for the Phoenix2 receiver. Some HF parts required to be order in the US and had a production delay of 20 weeks.

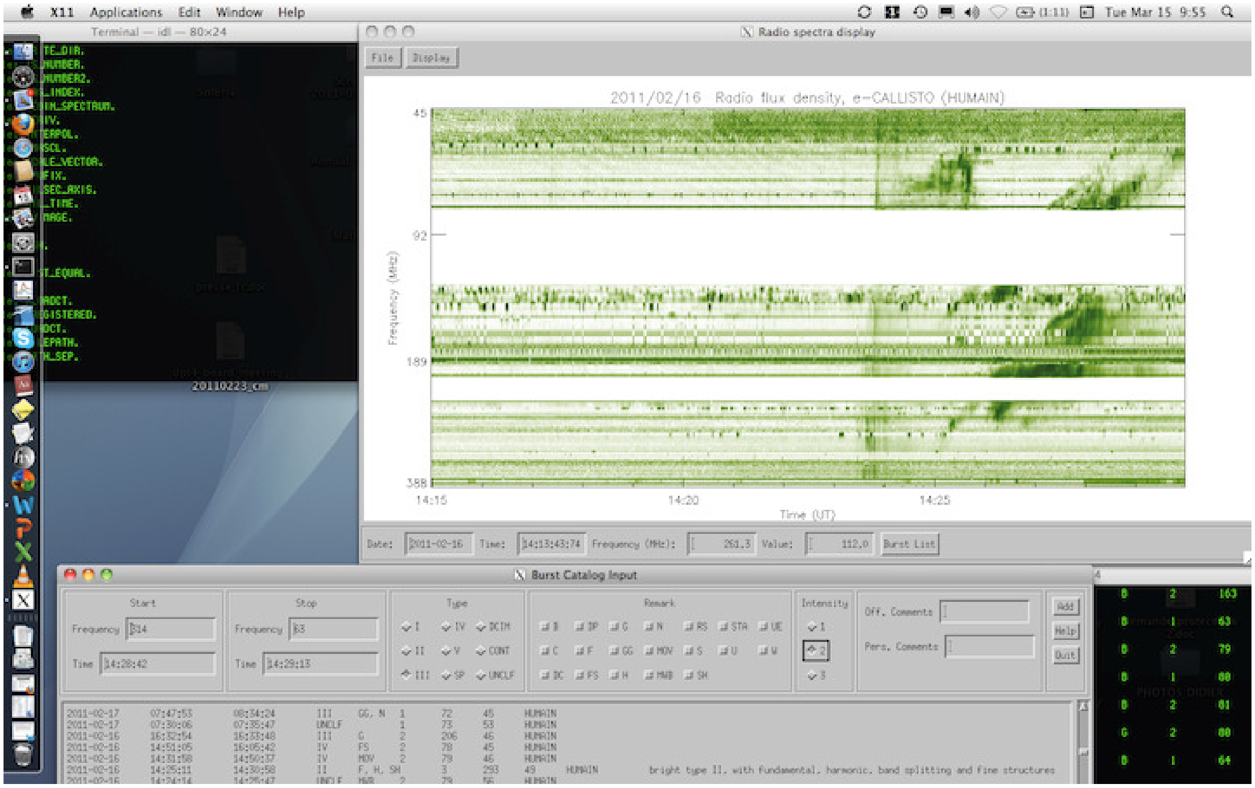

Figure 61: Screen shot of the IDL program written for the burst catalog input

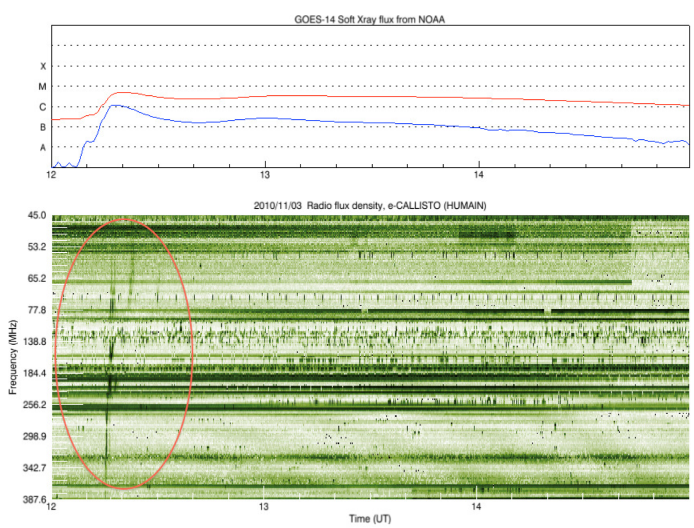

Figure 62: Quicklook view of a type II burst (red ellipse) together with the GOES light curve

Q.2.2.2. Flux-Monitoring

The flux-monitoring project is made in cooperation with Canadian colleagues from DRAO (K. Tapping) and NRCan (D. Botteler). The idea is to build a new generation of solar flux monitors in the microwave range, that would be ran on both sides of the Atlantic ocean to provide a large time coverage of the solar activity. The main frequency target is 2.8 GHz (10.7 cm of wavelength), which is very important for the space weather forecasts of SIDC. Our Canadian partners make the core design of the receiver. They received at the very end of 2010 an extra support from a university engineering team that has brought the level of details in the design to a high standard.

On the Belgian side, most efforts were put in the refurbishing of the radio telescope mount that will host the receiver. The chose telescope is one of the 48 parabolic dishes constituting the decommissioned solar interferometer of Humain, located on the North-South branch of the array, near the intersection with the EW array. In 2009, a company from Nivelle, Zimmer TMT was chosen to make the mechanical refurbishment. The antenna was dismantled in February 2010 and put back about a month later (see Figure 63).

After discussion with C. Marqué and J. –L. Dufond, the technical service of the Observatory performed some heavy work (trenches, new electric board) to bring power and network infrastructures from the entry point in the station to the refurbished antenna.

C. Marqué purchased a new parabolic dish suitable for the microwave observations at the end of 2010 and investigated some suitable receiving antenna to be put at the focus.

J. –P. Noël and J. –L. Dufond worked on the design of a new control system, including the choice of the hardware.

It was decided that the refurbishment of the next 2 antenna mounts would be done at the mechanical workshop of the Observatory. The technical service dismantled with J. –L Dufond 2 antenna on site and brought them back to the observatory in November 2010.

Figure 63: Dismantling of the antenna (left) and refurbished antenna (right) for the flux-monitoring project

Q.2.2.3. Lhoist Working group

C. Marqué participates to a working group involving the Lhoist group, and representatives of the Royal Observatory of Belgium, the Royal Meteorological Institute, the Belgium Institute for Space Aeronomy and Belspo. This working group was set up in the spring of 2010 to study the possible consequences of the extension of the Lhoist quarry near the Station of Humain. This working group meets on a regular basis and is defining procedures to assess the impact of this extension.

Q.2.2.4. CRAF activities

C. Marqué officially replaced F. Clette as Belgian representative for CRAF during the 51th CRAF Meeting that was held in Madrid in November 2010. CRAF is the Committee for Radio Astronomy Frequencies, an ESF-supported committee, which acts as the official voice of radioastronomers in regulatory international telecom meetings through its Frequency Manager. As a passive service, radio astronomy has to face increasing pressure and disturbances from other active services (telecom industries, satellite industries, unlicensed radio devices…). CRAF interacts strongly with national administrations and industries to allow a fare share of the radio spectrum that satisfies as much as possible the needs and interests of all. Two meetings are organized every year. C. Marqué attended both meetings, including one in Sweden where were discussed problems related to wind turbines development in the vicinity of radioastronomy observatories. This issue is specifically important for the radio observations in Humain, as several Belgian utility companies have announced their interest in such projects in the immediate vicinity of the Humain station.

Q.2.2.5.FP7 project Radiosun

C. Marqué was contacted by French colleagues from the Paris Observatory to answer a FP7 call (Infrastructures). A proposal, called Radiosun, lead by A. Csillaghy (Switzerland) was indeed submitted to fund a feasibility study of a multifrequency radio imager in the decimetric range in Europe. This proposal gathers several European countries: Switzerland, France, Belgium, Ireland and Italy to perform hardware studies, find potential sites, test image processing techniques, better define the science outputs and finally build a small prototype. Belgian contribution, lead by C. Marqué would consist of hosting a test baseline (pair of antenna) that would be used for the validation of the hardware and software studies. The final answer of this proposal is expected in 2011.

Q.2.3. Perspective for next years

In 2011 the following tasks will be performed.

- Callisto: The burst list will be made public on the Humain website; the main bursts (the more relevant for space weather) will be included in the monthly bulletin of the SIDC.
- Phoenix2: The support structure for the receiving antenna will be built by the mechanical workshop and installed in Humain. The focal plane unit will be fully tested at ROB before being set up. The installation of the Phoenix2 receiver in Humain is expected in the spring of 2011.
- Control of the antenna: An engineer programmer, Bram Bourgoignie, will join the team in January 2011. His first task will be to design a control software that will be used for the 6m radiotelescope (hosting Callisto and Phoenix2) and the smaller 4m dish for the flux-monitoring project. J. –L. Dufond and J. –P. Noël will finalize the control system on the hardware side.
- The new dish will need to be adapted for the existing mount and a new support structure for the horn-receiving antenna will be designed.
- It is hoped that by the end of 2011, the control system will be fully operational. On the receiver side, the front-end unit of the flux-receiving system will be assembled. Time permitting, a prototype of one channel of the receiver will be tested.
- Lhoist working group: a monitoring station will be set up to assess the impact on the radio observations of the Lhoist quarry extension. Seismologic and dust impact will also be estimated.

Q.2.4. Personnel involved

Scientific staff:	C. Marqué (project scientist, STCE)
	J. Magdalenic (advice and data exploitation through her own research project, Action 1, Belspo)
Technical staff:	J. –L. Dufond (antenna refurbishing, receiver development, maintainance, ROB, permanent staff)
	A. Ergen (until mid-2010, maintainance, ROB, permanent staff)
	J. –P. Noël (from mid-2010, antenna refurbishing, receiver development, maintainance, STCE)
	Technical service of ROB

Q.2.5. Partnerships

List of international collaborators having actively contributed to the project in the last year

- C. Monstein, ETH Zürich, Switzerland
- K. Tapping, DRAO, Canada,
- D. Botteler, NRCan, Canada

List of national partners collaborators having actively contributed to the project in the last year

Grant(s)/Project(s) used for this research/service

- STCE Work Package 2: Ground based solar monitoring

Q.2.6. Scientific outreach

Meeting presentations

(1) C. Marqué, J. –L. Dufond, A. Ergen, J. Magdalenić, J. –P. Noël
Solar radio observations in Belgium (Poster)
2010 CESRA Meeting, La Roche en Ardenne (Belgium), June 15th-19th 2010

(2) C. Marqué, in name of CRAF
Protecting the access to the radio sky: an overview of CRAF activities (Poster)
2010 CESRA Meeting, La Roche en Ardenne (Belgium), June 15th-19th 2010

(3) J. Magdalenić, C. Marqué, J. –L. Dufond, J. –P. Noël
Solar Radio Observations in Humain
Radio Science Days, ROB, Brussels (Belgium), October 14th 2010

(4) C. Marqué
Radio Spectrographic observations in Belgium
4th LOFAR Solar KSP workshop, Postdam (Germany), November 8th-9th 2010

Seminars

(1) C. Marqué
Monitoring of the solar activity with radioastronomy techniques
Belgian URSI working group, Palais des Académies, Brussels, May 25th 2010

Wikis and Websites

- Website of Humain observations: http://sidc.be/humain

Q.2.7. Missions

Assemblies, symposia, conferences:

- La Roche-en-Ardenne (Belgium): 2010 CESRA Meeting, (C. Marqué), June 13th-19th 2010
- Potsdam (Germany): 4th LOFAR KSP meeting, (C. Marqué), November 8th-9th 2010
- Bruges (Belgium): 7th ESWW, (C. Marqué), November 17th-18th 2010

Commissions, working groups:

- Göteborg (Sweden): 50th CRAF meeting, (C. Marqué), April 27th-30th 2010
- Brussels (Belgium): Belgian URSI committee, Palais des académies, (C. Marqué), May 25th 2010
- Brussels (Belgium): Lhoist-Humain working group, ROB, (C. Marqué), July 09th 2010
- Brussels (Belgium): Lhoist-Humain working group, Belspo, (C. Marqué), October 25th 2010
- Madrid (Spain): 51th CRAF meeting, (C. Marqué), November 3rd-6th 2010

Research visits:

- Zürich (Switzerland): ETH visit (Phoenix2), (J. –L. Dufond, J. –P. Noël, C. Marqué), August 09th-13th 2010

Field missions:

- Humain: Preparation of the 4m antenna to be dismantled (J. -L. Dufond, A. Ergen, C. Marqué), January 27th 2010
- Humain: Dismantling of the 4m antenna (company Zimmer Meca Tech), (C. Marqué) February 2nd 2010
- Humain: Visit of Zimmer TMC workshop (J. –L. Dufond, C. Marqué), February 18th 2010

- Humain: Visit of the station with H. Lamy (IASB) and Hungarian colleagues (VLF antenna network) (C. Marqué), March 2nd 2010
- Humain: Visit of Zimmer TMC workshop (J. –L. Dufond), March 8th 2010
- Humain: Encoder and interference checking (A. Ergen, C. Marqué), March 11th 2010
- Humain: Installation by Zimmer TMT of the repaired 4m antenna mount, (A. Ergen, C. Marqué, March 19th 2010
- Humain: Inspection of the reinstalled mount (J. -L. Dufond, J. -P. Noël, C. Marqué), April 13th 2010
- Humain/Jemelle: On site visit of the Lhoist facilities and the Humain station, (C. Marqué), April 23rd 2010
- Humain: Discussion with Zimmer TMC for post installation inspection, (J. –L. Dufond), April 29th 2010
- Humain: Encoder and interference checking, antenna inspection (with J. -L. Dufond), May 10th 2010
- Humain: Visit with Electrabel representative for the wind turbines project, (C. Marqué), June 2nd 2010
- Humain: Test of refurbished antenna motion, (J. –L. Dufond, J. –P. Noël), June 3rd 2010
- Humain: Checking of archives for motorization and mechanical parts, (J. –L. Dufond), July 19th 2010
- Humain: Work on refurbished antenna for assessing the future motorization (J. –L. Dufond), July 27 2010
- Humain: Work on 6m antenna: encoders on both axes, GPS positions of antenna (J. –L. Dufond), September 2nd 2010
- Humain: Wiring of encoders and reading of outputs; filtering of power supply of the antenna control rack (J. –L. Dufond), September 14th 2010
- Humain: Dismantling of one motor of an antenna as spare part for the 6m antenna, sorting of material available (J. –L. Dufond), October 19th 2010
- Humain: Preparation for dismantling of antenna 35 & 36 for repair at ROB (J. –L. Dufond), November 4th 2010
- Humain: Preparation for dismantling of antenna 35 & 36 for repair at ROB (J. –L. Dufond), November 17th 2010
- Humain: Replacement of a motor of the 6m antenna, inclusion of encoders in control software (J. –L. Dufond), November 23rd 2010

Q.3. Solar activity and space weather operations center

Q.3.1. Objectives

The Operations Center consists of the *World Data Centre* (WDC) for the Sunspot Index since 1981 and the *Regional Warning Centre Belgium* (RWC Belgium) of the *International Space Environment Service* (ISES) since 2000. Our core activity is the monitoring of the solar activity and space weather on time-scales that range from several years (sunspot cycle) down to hours (real-time activity monitoring). Our long-term goals are

- to remain the focal point for the international sunspot calculations;
- to continuously monitor and improve the quality of the indices and forecasts we produce
- to study the sunspot time series since its origins, its possible expansion by parallel advanced sunspot indices and its future extension by another modern non-visual index.
- to grow, together with our partners at BISA and RMI, into a European equivalent of the Space Weather Prediction Center operated by NOAA, with complementary and/or improved services;
- to play a prominent role in ESA's *Space Situational Awareness Program* (SSA);
- to improve our knowledge on the Sun-Earth connection.

To reach these objectives we have built up considerable IT infrastructure for the monitoring of solar activity, the automated detection of solar events, the logistic handling of incoming/outgoing space weather messages over the ISES network and the collection of sunspot observations from stations worldwide.

Q.3.2. Progress and results

Q.3.2.1.International Sunspot index

Throughout the year, the routine production of the International Sunspot Index was continued. This includes

- Total, hemispheric and central zone sunspot number
- Monthly provisional index
- Daily Estimated International Sunspot Index (EISN)
- Definitive sunspot index (quarterly)
- Additional indices: PPSI, sunspot areas
- Mid-term forecasts of the total sunspot number (Waldmeier and Cugnon-Denkmeier methods)

Forecast improvement

Concerning the mid-term forecast of the smoothed monthly averaged sunspot number, a new technique was implemented by T. Podladchikova to improve these forecasts. This new technique is based on a Kalman filter application. It can be applied to improve the results of any already existing forecast technique (such as those used at SIDC, or the Lincoln-McNish method used elsewhere). It was demonstrated that significant improvements (5-57%) can be established. We have implemented this technique in an automated way for a first test phase. The improved predictions are available on http://sidc.be/products/kalfil/.

This research was presented at the Seventh European Space Weather Week (15-19 November, 2010 - Brugge, Belgium) and at the Plazma Physics in Solar System (14-18 February, 2011 - Moscow, Russia).

Quality Control

F.Clette initiated the investigation of a possible drift of the sunspot index after the year 1998, suggested by discrepancies between the sunspot index and other solar indices over the declining phase of the last solar cycle. A presentation of such a study was presented by Dr. L. Svalgaard in a seminar given at the ROB in September. Subsequently, multiple exchanges took place with the observers of the pilot station of the sunspot network at Locarno in order to collect evidence of any possible trend. We also contacted K.Mursula (Univ. Oulu), the Solar Section of the AAVSO as well as Dr. A. Koeckelenbergh, former Director of the SIDC. Various data were exchanged with the Locarno team in view of a visit of that team to the ROB in early 2011.

Observers' participation

The numbers of observers using the Wolf interface http://sidc.be/WOLF/ has increased. Five observers have been registered during this year; two from United States, one from Brazil, one from Peru and one from Italy. Now 93 observers use the WOLF interface, they are located in 33 different countries, 18 countries are not in Europe (Figure 64). The countries with more than one observer are indicated in the figure.

Every first of month, we have more than 50 stations who have encoded their data. The number of stations inserting their data for the current day (typically 12:30 UT) is stable, these stations are used for the estimated index sunspot number (EISN) distributed in our space weather bulletins.

Five observers still continue to send e-mails and don't use the WOLF interface: HE40 (Helwan, Egypt), SM85 (San Miguel, Argentina), KS52 (Kislovodsk, Russia), PR203 (Prostejov, Czech Republ), CB127 (Camaguey, Cuba)

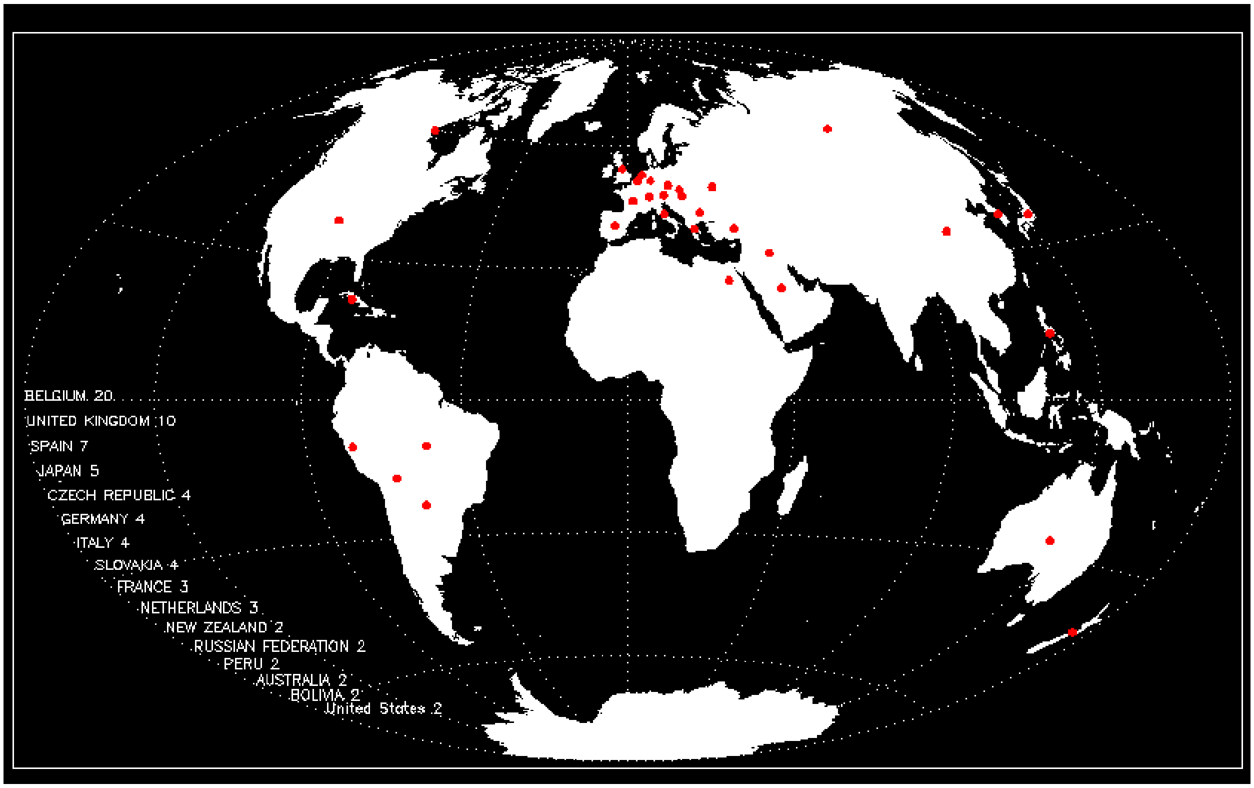

Figure 64: Localization of WDC observers

<u>Sunspot index (Ri) computation</u>

Laurence Wauters has finalized the MySQL/PHP programmation for the computation of the sunspot index using directly data from the DATA_SIDC database. In this program, a set of parameters can be chosen: the Pilot Station, the period (number of days/month/year) taken into account and the fixed final date of the period used for the computation. This programmation will permit the study of the impact of this parameters set on the Ri values.

Q.3.2.2.PreviMaster and PreviWeb Upgrade

- Eva Robbrecht took over the lead of the RWC in the summer of 2010. As a start she has organised two meetings discussing the future of the RWC and the technical details and a brainstorming session with the forecasters to receive input on their requirements for the new system. The goal of the RWC is to provide operational services and information concerning space weather. In principle any service or information produced within the STCE could be "federated" in the RWC.
- We have started preparatory work for the upgrade of the PreviMaster and PreviWeb software, which is mainly performed by Sarah Willems and Elke D'Huys. The aim of the upgrade is to modernize and improve the whole system. In 2010 we started to make an inventory of the whole system, listing all routines with their functionalities. We have started collecting requirements for the new system, which will result in a RWC requirements document. The progress and problems that emerge are discussed in weekly follow-up meetings.

Q.3.2.3.Forecaster activities

- The solar weather forecaster team in 2010 consisted of David Berghmans, Frederic Clette, Elke D'Huys, Christophe Marqué, Eva Robbrecht, Luciano Rodriguez, Petra Vanlommel and Andrei Zhukov. They each took several cycles of forecaster duty, which is organized, in weekly cycles running from Monday to Sunday. The forecaster duty includes writing a daily space weather bulletin that contains a forecast on flaring activity, geomagnetic activity and the probability for SEP events. The bulletin is issued daily at 12h30 UT. Apart from writing the bulletin, the forecaster is expected to monitor the sun during daytime, including the weekends. Whenever necessary the forecaster can issue a “presto” alert. At the end of the week the forecaster summarizes the solar and geomagnetic activity in a weekly bulletin. The SIDC issues a Monthly Bulletin at the end of each month (in PDF format) summarizing solar and geomagnetic activity and providing details on sunspot numbers.

- We have revived the weekly briefings, organized every Friday, to discuss the solar activity during the previous week. We have made a new generic email address: swforecaster@sidc.be, to make it easier to communicate with the forecaster team. This address is also communicated to some of our users. They may use it to request additional information from the forecasters. We have restructured the RWCWDC wiki and have extended the available information so that it’s ready for use again.
- Sarah Willems and Laurence Wauters performed a statistical study of the accuracy of real and forecasted data for the geomagnetic index K for day1, day2 and day3. The results of the study will be presented to the forecaster team in May 2011.

Q.3.2.4. Development of automated detection algorithms and supporting software

- FLARE DETECION: The GOES X-ray flare alert is made operational again and it has since then sent out several successful email alerts.
- CACTUS: We have created a new version of the CACTus LASCO CME catalog [D.47], using the updated CACTus algorithm. The previous version of the catalog was not extendible after 2007 and did not contain movies. The new version of the catalog is available online at http://sidc.oma.be/cactus/catalog.php. The catalog is extended automatically when new data becomes available. A number of enhanced products are also made available based on the CACTus output: monthly CME rate in graphical format (see Figure 65), ASCII and XML. This will makes it easier to share our data with people who want to use it for publications. Just like the sunspot number, also the CME rate has increased since 2009. This again shows that the CME rate is in close relationship to the sunspot number. Additionally we have seen that while the sunspot number was near 0, CME activity never receded completely. We have imported the CACTus detections in the HEK database (Helio Events Knowledge database) managed by the SDO team at LMSAL, California. Several problems remain to be resolved.

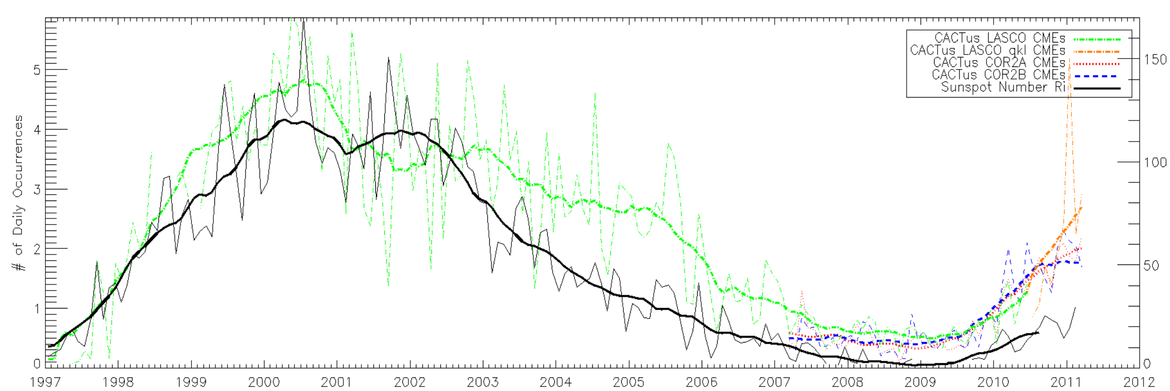

Figure 65: CACTus LASCO, SECCHI-A and SECCHI-B CME rate versus the Sunspot number.

- NEMO: In 2010, several critical updates were applied to the NEMO. The enhanced performance of NEMO includes the ability to extract limb-dimmings and the detection of small-scale events. Furthermore, the catalogues of solar eruptive events that can be constructed by NEMO may now include larger number of physical parameters associated to the dimming regions. The application on SECCHI/STEREO data encountered a series of difficulties for event detection due to the appearance characteristics in the data attributed to the new instrument and the early stages of the mission. However, application of NEMO on the high resolution SECCHI data led to the discovery of EUV Micro-Eruptions in the solar corona. The new algorithm was able to detect such small-scale eruptive events that did not present any signatures of bursts in the total EUV intensity curve or even in the derived moments of pixel distribution of the consecutive images. These algorithms underwent extensive tests with STEREO data during 2010. The production of the first eruptive events catalog for STEREO was also initiated, it is available online at http://sidc.be/nemo/catalog/. Additionally, the software was further improved with several new useful features like true dimming area computation, cluster analysis technique of dimming extraction and angular measure of intensity. A new approach was introduced: detect regions of interest out of the full disk images and check their statistical parameters. This approach improved the event discrimination and permitted the detection of smaller events as well. Remarkably, less parameters are used which makes the algorithm easier to adapt for other types of data.

- SWB: The Solar Weather Browser (SWB) is an open-source software tool that makes it easy to display and combine solar images from different observatories together with solar metadata, without the need of data processing on the users computer. For the forecast team, the SWB offers an easy tool to browse through solar data while performing the forecast and monitoring the sun.

Q.3.2.5. Space Situational Awareness Program – Precursor services

Figure 66: Screenshot of the ESA asset DB constructed in the SN-1 project.

"The overall aim of ESA's SSA Preparatory Programme is to support the European independent utilisation of and access to space for research or services, through providing timely and quality data, information, services and knowledge regarding the environment, the threats and the sustainable exploitation of the outer space surrounding our planet Earth." The projects below fit in the preparatory phase of the SSA program and are focused on the Space Weather element.

- SN-I project: The work includes activities SN-SWE-001 "analysis and evaluation of existing SWE assets" and SN-SWE-003 "Definition and detailed design of space weather services prototypes". The RWC team has participated in writing the SN-1 proposal primed by Rhea system (Louvain-La-Neuve) that was delivered to ESA on May 18 2010. After negotiation, the proposal was selected by ESA and the project officially started on Nov 1st 2010 with a duration of 1 year. The main roles for the RWC in the SN1 project are: being the solar expert service centre (ESC solar), leading the space weather assets and services review and leading the assessment of the service concepts and user feedback in an operational environment (Task 5, 2011). Figure 66 shows a snapshot of the online database that was developed within the consortium.

- SN-II proposal: The work includes activities SN-SWE-002 “Implementation design of Space Weather instruments”. The RWC team participated in the proposal writing lead by CSL. The proposal was not selected by ESA.
- CO-1 project: This project is part of the “core element”. The work includes the definition of the customer requirements for the SSA system and the definition of underlying governance and data policy. The RWC team was part of a winning proposal and it has participated in the revision of the customer requirements document.

Q.3.2.6.SODA: The Soteria Data Archive

SOTERIA is a collaborative network funded by the European commission under the Framework Programme 7 for the collection, organisation and use (via theory and simulation) of space physics data aimed at better understanding space weather. Soteria involves 16 centres in 11 European countries and is coordinated by Giovanni Lapenta of the Katholieke Universiteit Leuven (Belgium).

The work package 6 is devoted to the assimilation and the dissemination of the data archive. This means that the data’s from each partner that are part of the Soteria project will be made easily accessible through the Soteria Community and to the public.

To do so, we developed and deployed virtual observatory called SODA. SODA provides a single frontend to access the datas provided by the Soteria partners.

Its mains objectives are:

- Provide an uniform way to access data spead across different locations
- Provide a simple and user friendly way to query for data with specific properties

SODA is composed of 3 independent parts:

- *Client*: Web interface allowing the user to enter queries and displatying the results
- *Server*: Manages the available data providers and track information coming from them
- *Data providers*: Provide an interface to the local catalogs of data.

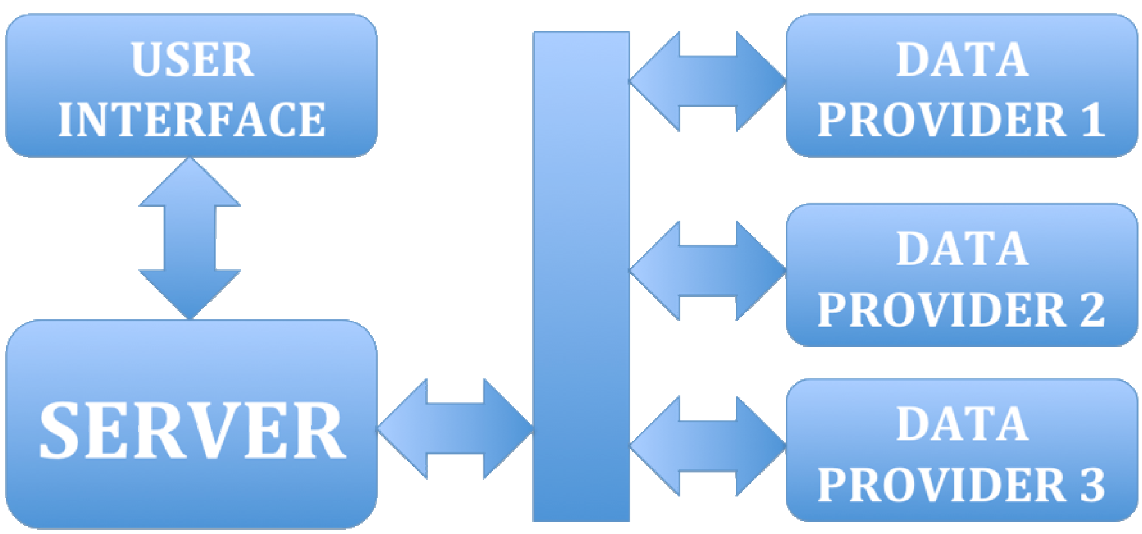

Figure 67: General structure of SoDA

Soda is running since September at the Royal Observatory of Belgium

Uset Data provider

A Data provider serving the Uset H-Alpha and White-light datasets was developped and is up and running at the observatory. It allows access to the images produced on a daily basis.

UniGraz data provider

A Data provider serving the DrawX dataset was developped and is up and running at the UniGraz institute in Austria. Benoit Callebaut made deployment and testing with the collaboration of Wolfgang Maierhofer from the UniGraz institute. It allows access to the DrawX images produced on a daily basis.

Crawling Meta Data Provider

The crawling data provider presents itself as a standard data provider but it is not linked to a specific set of data.

Instead, a user interface allows the user to register web sites or more generally network accessible resources like FTP servers to be analyzed for data files, and to build from the detected files a database of available set of datas.

This approach is necessary for institues that are not able or do not want to run a data provider at their own side.

It has the drawback of lacking of automatic update capability since it takes snapshots of the state of a remote data repository and to retrieve data files attributes present in those files only.

It has been successfully tested on the Level 0 files of the Sphinx dataset.

Installation and deployment

A server was installed and configured beginning of year 2010 in order to be able to run the the SoDA virtual observatory.

SoDA client for the Interactive Data Language

A client for IDL (Interactive Data Language) was developped. It allows running queries directly from an IDL program. It has the same level of functionality as the web interface with the added feature of directly decoding the file into IDL specific structures.

Data provider development tools

In order to make the development of Data provider by third parties, a software package was developed to generate the necessary data provider code and descriptions files interactively. The generated data provider is guaranteed to be correct, relieving the developer and the SoDA server administrator from tedious tests and debugging.

Q.3.2.7.Synergy with the FP-7projects COMESEP and AFFECTS

- The COMESEP proposal was submitted to EU in Dec 2009, which resulted in negotiations during 2010. The project has been accepted and has officially started on Feb 1st 2011 (duration: 3 years). The COMESEP project is lead by Norma Crosby (BIRA) and enables an international collaboration betwee partners from Belgium (ROB, BIRA), Austria (UNIGRAZ), Denmark (DTU), Greece (NOA), Croatia (HVAR), UK (UCLan) and non-EU participation from the USA and India. The project contains a CME and a SEP research section and an operational development section to set up an automated risk alert system for space weather. ROB is involved in searching for solar data corresponding to historical large space weather events recorded in geomagnetic indices, The CME – ICME study, the advancement of automated alerts and the set-up of the risk-alert system.
- The FP7 project AFFECTS (“Advanced Forecast For Ensuring Communications Through Space”) is a collaboration between members of the solar, geomagnetic and ionospheric scientific communities,

which started officially on March 1st 2011. It is lead by Volker Bothmer from the University of Göttingen and involves partners from Belgium (ROB), Germany (UGOE, FHG, DLR, ASTRIUM ST), Norway (UoT), and Ukraine (SRI NASU-NSAU), as well as non-EU participation from the USA. One of the main goals of the project revolves around setting up an operational chain of models to provide early warnings for space weather events (with special emphasis on those events that impact the ionosphere), operational integration into the SIDC Regional Warning Center, and subsequent quality control and feedback.

- The purpose is to integrate the results of both projects in the RWC activities in 2013-2014.

Q.3.2.8.Network activities

- The SIDC/STCE was responsible for the local organization of the *Seventh European Space Weather Week* (ESWW7), which took place in November 2010 in Bruges and the CESRA worskshop for European Radio Astronomers, which took place in June 2010 in La-Roche-en-Ardenne.
- We have visited one of the customers of the RWC to have a better mutual understanding of each other's activities.
- As consultant, F. Clette has provided guidance about key space-weather related solar observations needed for a L1 mission proposal to Bernard Boullet (CNES, Toulouse). This mini-mission proposal was finally not selected by CNES (Nov. 2010)
- Eva Robbrecht and Ronald Van der Linden have participated in the COST ES0803 workshop held in Paris (March 2010).
- Colleagues from Locarno (Switzerland), who are one of the most important contributors to the sunspot number, have visited us to discuss sunspot procedures.
- Eva Robbrecht presented the RWC activities at an internal space weather workshop in Meudon, Paris (Dec 2010).

Q.3.3. Perspective for next years

- A number of technical improvements are foreseen for the Ri calculation:
  - Migrate the last five observers who still send e-mail with sunspot data to the WOLF web interface.
  - Check the impact of the set parameters like the pilot station in on the Ri sunspot index and continue to check the impact of K factors.
  - Computation of the sunspot index before 1981 with the currently used method.
  - Try to include hemispheric computation in MySQL/PHP code.
  - Check the impact of the time of observation on the Sunspot index computation.
  - Include localisation of the sunspot group in the Wolf interface.
- We plan to finish the upgrade of the RWC and to work on the upgrade of the previweb pages according to the forecasters needs. We will organize monthly forecaster meetings during which we discuss in more detail a space weather subject to improve the quality of our predictions. We will also prepare a learning-track to train new forecasters. The RWC activities will be coordinated with our contributions to the FP-7 projects (COMESEP and AFFECTS).
- F.Clette will take over the lead of the WDS "sunspot". The investigation of the post-1998 drift of the sunspot index will be continued in collaboration with the Locarno station and also by exploiting by-products of the solar index research developed for the SoTerIA project. We will codify the methods implemented in the base software still in use nowadays. Various validation tests will be implemented on this database to fully qualify the new software (using database applications). This should result in the publication of a full description of the methods used for sunspot calculations and predictions (technical manual and scientific paper). This new software could then replace the old one, offering a higher robustness and also a more flexible use for quality control and diagnostics and for future adaptations.

- The Kalman filter technique introduced by T. Podladchikova to improve the sunspot index forecasts will be applied operationally and monitored for its performance.
- We will continue working on the SN-I project and participate in upcoming SSA proposals, our goal is to maintain the Belgian lead in space weather operations in Europe
- SIDC/STCE will be the local organizer for the 8th ESWW, which will be held in Namur, Belgium during 28/11 – 2/12 2011.
- The Soteria project ends in October 2011 and no funding is allocated for further development of SODA for the last 4 months of the project at the Royal Observatory. Fortunately, AFFECTS will re-use and enhance the actual SoDA infrastructure. SoDA will be maintained on a best effort basis unless more funding are allocated to it.In the mean time, we intend to continue to work on a few points:
    - *Integrating more datasets*: ongoing work is focused on the SphinX dataset and data from Oulu University. Integration of SWAP and LYRA datasets are also targeted. More coud be added depending on community feedback.
    - *Enhancing the web interface*: some remarks were done at the last Capacity Building Workshop and we will try to take them into account
    - *Enhancement of clients*: enhancements have to be made to the IDL client. A client with a lot more visualisation and data management functionalities could provide a big added value for the user.

Q.3.4. Partnerships

List of international collaborators having actively contributed to the project in the last year

- Dr. Norbert Jakowski and Michael Danielides, German Aerospace Center (Germany)
- Prof. Truls Lynne Hansen, Tromso Geophysical Observatory (Norway),
- Prof. Eija Tanskanen, Finnish Meteorological Institute
- Dr. Astrid Veronig, UNIGRAZ (Austria),
- Dr. Peter Beck, Austrian institute of Technology
- S. Cortesi, M. Cagnotti, Specola Solare Ticinese, Locarno (Switzerland)
- M. Bianda, R. Ramelli, IRSOL, Locarno (Switzerland)
- J. Poncy, Thales-Alenia (France)
- Wolfgang Maierhofer, Manuela Temmer, Roland Maderbacher, UniGraz (Austria)
- Dr. Tania Podladchikova, Moscow State University (Russia)
- The network of SIDC solar observers.

List of national collaborators having actively contributed to the project in the last year

- Michel Kruglanski, Norma Crosby, Erwin De Donder and Stijn Calders, BIRA
- Andre Sincennes, Simon Reid, Rhea System NV

Grant(s)/Project(s) used for this research/service

- Contract SN1 – ESA
- STCE
- SOTERIA (project n° 218816) from European Commission's Seventh Framework Programme (FP7/2007-2013)

Q.3.5. Scientific outreach

Wikis and Websites

- SN-1 asset database: http://catalogue.ssa-sn1.eu/
- RWCWDC wiki (intranet): http://sol042.oma.be:8000/RWCWDC/wiki
- Forecasting pages on the SIDC website, e.g. http://sidc.oma.be/LatestSWData/LatestSWData.php

- ESWW7 website: http://www.sidc.be/esww7/
- CESRA website: http://sidc.be/CESRA2010/index.php
- SoDA project website: http://soteria.oma.be

Q.3.6. Missions

Meeting presentations

(1) R. Van der Linden and the RWC team
Regional Warning centre Belgium
COST ES0803 workshop, Paris, March 2010

(2) Wauters L. and the WDC team
Solar sub-cycle (poster)
CESRA, 15-18 juin 2010, La Roche-en-Ardennes

(3) R.Van der Linden and the RWC/WDC team
Space Weather data and services at SIDC / RWC Belgium
COSPAR, Bremen, Germany, 15-18 July 2010

(4) R.Van der Linden and the RWC/WDC team
Annual RWC report
ISES Annula Meeting, Bremen, Germany, July 2010

(5) E. Robbrecht and the RWC team
Regional Warning centre Belgium
Space Weather workshop Meudon, Paris, 6-7 Dec 2010

(6) B. Callebaut, D. Brghmans
SoDA: The Soteria Data Archive
ESWW7, 2010-11-18, Brugge

(7) B.Callebaut, D. Berghmans
SoDA: The Soteria Data Archive
Second Soteria Annual Meeting, 2010-10-6, Debrecen

Commissions, working groups:

- COST ES0803 workshop, Paris, March 2010
- F.Clette was invited to join the COST project ES1005 "Towards a more complete assessment of the impact of solar variability on the Earth's climate" initiated by T. Dudok de Wit of the LPC2E at the Université d'Orléans. Dedicated to the study of long-term proxies relevant to the Sun-Earth and climate relations, this project was selected by the end of 2010. Its actual start is scheduled for mid-2011.
- SN-1 kick-off meeting at ROB, Nov 5, 2010
- Space Weather workshop at Meudon, Paris, Dec 6-7 2010
- Second Soteria Annual Meeting, 5-7 October 2010, Debrecen
- ESWW7, 17 – 19 November 2010, Brugge
- Soteria Summer School, 17-29 October 2010, Trieste ICTP

Q.4. PROBA2 Science Center

Q.4.1. Objectives

ROB harbours the Science Operations Center (P2SC) of the PROBA2 mission. The P2SC is a highly automated system and its operations are supported through a direct ESA contract outside the present project.

ROB also hosts the PI-teams of the SWAP and LYRA instruments. The present work package supports the PI-teams in their analysis and monitoring of the instrument behavior. This includes the routine processing and calibration data, analysis of non-nominal behavior, the preparation of special instrument campaigns and monitoring of the quality of the distributed data products.

At the same time, the direct and (near) real time delivery of the SWAP and LYRA data to the ROB also provides opportunities for fast event interpretation. ROB is in a fairly unique position in that within a few hours of a particular phenomenon in the solar corona, the full SWAP and LYRA data sets are available for analysis and discussion. The phenomena considered can be significant space weather events (major flares, CMEs, etc.) or rare events of particular interest (surges, jets, etc.).

Q.4.2. Progress and results

The progress and results of the PROBA2 Science Center is documented in full detail in the P2SC weekly reports, issues #3 till #41. Below we provide a summary of the highlights.

Q.4.2.1.Successful commissioning activities of SWAP and LYRA

PROBA2 was launched on 2 November 2009. Simple health checks of SWAP and LYRA had been performed end 2009 and the first few SWAP images had been taken mid December 2009. During the Christmas period 2009-2010, the instruments were switched off and the bulk of the SWAP and LYRA commisisioning took place in the period January 2010-March 2010.

The full SWAP and LYRA teams took part in the commissioning of their instruments that consisted of a series of well-designed campaigns to test the full functionality of the instruments and their performance in space. In general, the instruments behaved very satisfactorily. The identified non-compliances dealt mostly with the onboard software controlling the instruments and the processing of science telemetry and housekeeping in the MOC. Most of these issues have meanwhile been solved and nothing remains that would hamper full science use of the instruments.

Some noteworthy highlights were:

- Jan 4-9, 2010: LYRA door opening and first light
- Jan 14, 2010: SWAP joint campaign with the last EIT shutterless observations
- Jan 26 2010: Steering Comittee meeting PROBA2, including the ESA Project, ESA Director Courtois and MOC & SOC representatives
- March 25, 2010 Commissioning Review

This activity was closed with the SWAP and LYRA commissioning reports (each 50 pages, see below) and successful closure of the PROBA2 Commissioning Review.

Q.4.2.2.Nominal operations of PROBA2 and Solar Monitoring

The P2SC is operated since the end of the commissioning phase, in 1-week duty shifts. The weekly operator checks the health of both the LYRA and SWAP instrument, the progress of the processing pipelines and the upcoming commanding. The operator is also the coordinating person for problem solving. At the end of the week, a weekly report is written. During 2010, an operator shift was significantly more than a full time duty. Operator shifts were shared among D. Berghmans (ROB), C. Cabanas (ROB), A. De Groof (ESA), M. Dominique (ROB) and J. Zender (ESA).

Coordination between the P2SC and the technology experiments onboard PROBA2 was organized through the Science and Technology Working Group that met for the first few times in ESTEC (Feb 11 2010), Redu (May 20, 2010) or by teleconference (March 22, 2010; April 23, 2010; June 28, 2010, …).

Some highlight of the first nominal science observations with SWAP and LYRA have been:

- Jan15, 2010: an annular solar eclipse happened above Asia. The successfull prediction of the times that the Sun, the Moon, the Earth and PROBA2 were coaligned showed that orbit and ephemerides calculations (based on SPICE) are fully ready for the SWAP science mission (Figure 68, top left)

- Jan 19, 2010: SWAP observed the first M-flare of the new solar cycle (M2.3 at 13h41 UT, South East limb).Figure 68, top right panel, shows the M-flare on the NE (bottom-left) limb.
- Jul 11, 2010: total solar eclipse took place which on Earth could only be seen from the South Pacific Ocean and Easter Island. PROBA2 crossed the lunar shadow path 4 times and saw 4 lunar transits - partially covering the solar disk - between 17:20 and 22:00UT. Figure 68 (bottom left) shows 4 dips in the irradiance curves corresponding to the 4 lunar transits.
- Oct 19, 2010: Start of occultation season (Figure 68, bottom right). In every orbit there is a phase in which the spacecraft flies through the shadow of the Earth. As the occultation season progresses, these occultations becomes deeper and longer, shown by the increasing depth of the dips in the LYRA Zirconium channel (grey) and the SWAP integrated intensity (purple).

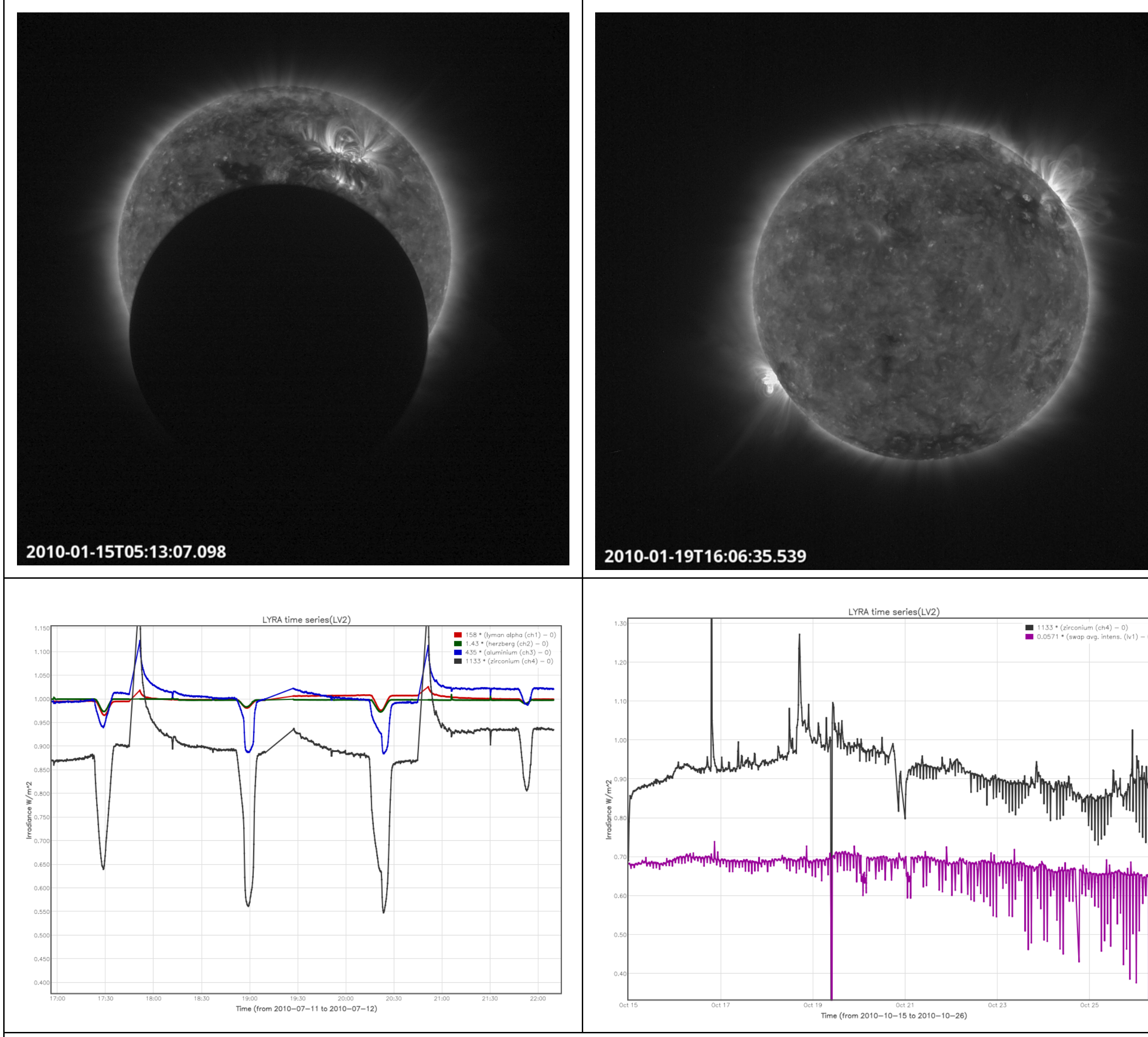

Figure 68: Some initial images and data from PROBA2/SWAP (top) and PROBA2/LYRA (bottom). See text for more information.

Q.4.2.3.Highlights completion of the P2SC infrastructure

Since the PROBA2 project did not include a "Science Operations Center", this activity is instead taken up by the SWAP and LYRA instrument teams at ROB. An IT infrastructure named PROBA2 Science Center was developed:

- to receive and store the spacecraft (science & ancillary) telemetry via the Redu ground segment
- to process this telemetry up to usable science data
- to distribute this science data, over the world wide web (www)
- to provide an interface for the instrument operator to monitor the past activity of the instruments and plan & command the future activity of the instruments.

A significant part of the P2SC was built in 2009 before the launch but all was finalized during commissioning when actually receiving nominal spacecraft telemetry. Each P2SC building block was finalized under the responsibility of a P2SC collaborator:

Full Name	**P2SC building block**	**Main developer(s)**
P2SC hardware and operating systems	Servers	Sarah Willems, Elke D'Huys
Logging, Monitoring and Activity Trigger	LMAT	Sarah Willem
User Interface	UI	Carlos Cabanas
Data Consistency and Validation Checker	DCVC	Anik De Groof
Auxiliary Data Processor	ADP	Yalim Mehmet Sarp
Position, Pointing and Time correlation	PPT	Bogdan Nicula
Data Catalog	CLOG	Bogdan Nicula
Planning Tool Interface	PTI	Carlos Cabanas
Auxiliary Data Browser	ADB	Carlos Cabanas
SWAP telemetry reformatter	SWTMR	Bogdan Nicula
SWAP engineering data generator	SWEDG	Bogdan Nicula
SWAP base science data generator	SWBSDG	Shaun Bloomfeld, Dan Seaton
LYRA telemetry reformatter	LYTMR	Marie Dominique
LYRA engineering data (LV1) generator	LYEDG	B. Giordanengo, Carlos Cabanas
LYRA base science data (LV2,3) generator	LYBSDG	Ingolf Dammasch
External web pages and archives	-	Anik De Groof
LYRA Quicklook Viewer	LY-QLV	Boris Giordanengo

Table 8: The P2SC building blocks. Documentation (requirements, design, testing, manuals) for each of these can be found on our (internal) wiki: http://sol042.oma.be:8000/Proba2SC

The full P2SC software infrastructure is stored in an online repository with version tracking (svn, see Figure 69).

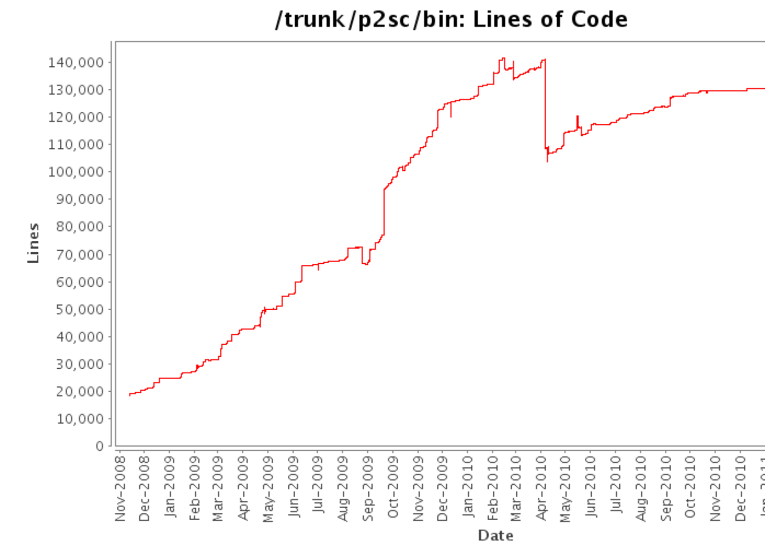

Figure 69: Number of lines of codes in all the P2SC building blocks of early SWAP and LYRA observations

Q.4.2.4. Community Building

As PI team for SWAP and LYRA we consider it essential to broaden the user base of the SWAP and LYRA data as much as possible. In this respect, we invested significant effort in welcoming a large number of visitors at P2SC and on providing a large number of PROBA2 talks at public conferences to inform the scientific community (see list of visitors and talks below).

Other highlights have been:

- Jan 26, 2010: our official "first light" press release. Besides the many journalists we were honoured to welcome Dr. D. Southwood and Dr. M. Courtois (ESA directors) and Mrs. S. Laruelle (Belgian Minister).
- May 3, 2010: SWAP & LYRA scientific data available online, Public Announcement of Guest Investigator Program.
- June 14-16, 2010 Laroche-en-Ardennes, Belgium, First PROBA2 Science Working Team
- June 22, 2010 ESTEC, PROBA2 ESTEC Workshop
- Sep, 2010: First Guest Investigators visit PROBA2 Science Center

Q.4.3. Perspective for next years

The ESA Science Programme Committee has approved on Nov 18, 2010 the extension of PROBA2 operations until the end of 2012. SWAP and LYRA data will be scientifically exploited for at least one year longer than originally planned.

This extra mission time will allow us to further:

- Study the development of the solar cycle, solar flares and CMEs
- Study the Earth aeronomy
- Improve the instrument calibration and finalize the instrument software pipelines
- Welcome visitors and share SWAP and LYRA expertise

Q.4.4. Partnerships

List of international collaborators having actively contributed to the project in the last year

- ESA: J. Zender, A. De Groof (ESTEC), E. Tilmans (Redu), L. Sanchez (ESAC)
- PMOD-WRD (Davos): W. Schmutz, A. and A. Shapiro, G. Cessateur
- TCD (Dublin): P. Gallagher, S. Bloomfield, P. Higgins
- Lebedev Institute (Moscow): V. Slemzin
- LP2CE (Orleans): Thierry Dudok de Wit
- Other SCSL members

List of national partners collaborators having actively contributed to the project in the last year

- P2SC team (ROB)

- Centre Spatial de Liege at Liege: J.P. Halain
- Center for Plasma Astrophysics (CPA) at KULeuven: Mehmet Sarp Yalim
- BIRA: Didier Fussen, Cedric Tetard
- Verhaert NV (later renamed in Qinetic Space): Dennis Gerrits and Stijn Ilsen
- Spacebel

Grant(s)/Project(s) used for this research/service

- ROB permanent staff scientist D. Berghmans contributed as SWAP PI, manager of the P2SC and project lead of the ESA contract for support of P2SC. ROB permanent staff scientist J.F. Hochedez contributed as LYRA PI up till mid June 2010, after which he took up a long-term leave outside ROB.
- The SIDC Data Exploitation project funded the contribution of M. Dominique as LYRA PI (since mid June 2010), the contributions of D. Seaton and I. Dammasch (respectively SWAP and LYRA instrument scientists) and other research contributions of L. Dolla, S. Parenti and others. The SIDC Solar Orbiter/EUI PRODEX project and the SIDC Data Exploitation project mutually complement each other: A. Ben Moussa (LYRA detector specialist) and B. Giordanengo (LYRA software) provided occasional help.
- The ESA contract for "Science Operations support and assistance for PROBA2 Science Center" (22653/09/NL/NR) funded the work done by Carlos Cabanas as well as some of the IT hardware costs and the GI-program
- The Solar Terresterial Center of Excellences funded the contribution to P2SC of B. Nicula (SWAP engineer), S. Willems and E. D'Huys (P2SC sysadmins).
- The EU FP7 project SOTERIA, complemented the space weather activities at SIDC.

Visitors:

- Alin Razvan Paraschiv and Daniela Adriana Lacatus; Observatory of Bucharest, Aug 16 2010; SWAP event catalogue
- Dinpankar Banerjee, Krishna Prasad; Bangaloore (India), Sept 6 2010; Transients and their role in heating and acceleration of the solar wind
- R. Kariyappa (Bangaloore, India), L. Dame (LATMOS, France), Sept 18 2010; Understand the solar UV & Lyman Alpha Irradiance Variability From LYRA Observations
- Yulia Shugay (Russia), Oct 5 2010; Studies of Coronal holes and solar wind velocity forecast based on SWAP data analysis
- Vladimir Slemzin, Alexander Urnov (Lebedev Russia), Louise Harra (MSSL, UK); Nov 2010; Study of the solar inner corona and search for quasi-stationary coronal streams from active regions using SWAP off-disk observations
- Gael Cessateur (Univ. Orleans, Fr); Nov 2010; Reconstruction of the Solar Variability from bandpass measurements

Q.4.5. Scientific outreach

Most of the presentations presented by the members of the PROBA2 Science Center can be downloaded from http://proba2.oma.be/Presentations

Meeting presentations

(1) Elke D'Huys and the P2SC team
The PROBA2 Science Center (Poster)
SOTERIA General Meeting, January 18-20, Davos, Switzerland

(2) M. Dominique
LYRA on-board PROBA2 - Current status and first results (Talk)
Soteria meeting, Jan 18-22 2010, Davos (Switzerland)

(3) D. Seaton & the PROBA2 Team
First Results from SWAP (Talk)
SOTERIA Annual Meeting, Davos, Switzerland, January 18–20, 2010

(4) J.F. Hochedez
LYRA early results (Talk)
First PICARD workshop, Paris, France, 8-9 March 2010

(5) A. De Groof
PROBA2: Ready for Science & Space Weather (Talk)
STEREO workshop, Dublin, Ireland, March 22, 2010

(6) A. De Groof
SWAP and LYRA onboard PROBA2, new EUV instruments (Talk)
CESRA meeting, plenary session, Jun 16, 2010, La Roche en Ardennes (Belgium)

(7) J. Magdalenic, C. Marque, A.N. Zhukov, D. Berghmans, D.B. Seaton, I. Dammasch, E. D'Huys
Type II burst recorded at Humain associated with the CME/flare event on 18 March 2010 (Talk)
CESRA meeting, plenary session, Jun 16, 2010, La Roche en Ardennes (Belgium)

(8) M. Mierla
Multispacecraft observations of 3 and 8 April 2010 Coronal Mass Ejections (Poster)
CESRA meeting, plenary session, Jun 16, 2010, La Roche en Ardennes (Belgium)

(9) D. Seaton & S. Bloomfield
SWAP Image Calibration
PROBA2 Science Working Team Meeting, La Roche en Ardennes, Belgium, June 14–16, 2010

(10) Elke D'Huys and the P2SC team
The PROBA2 Science Center
PROBA2 Science Working Team Workshop, June 14-16, La Roche-en-Ardenne, Belgium

(11) M. Dominique, J.-F. Hochedez, I. Dammasch et al.
LYRA on-board PROBA2 - Instrument overview (Talk)
CESRA/SWT meeting, Jun 14-18 2010, La Roche en Ardennes (Belgium)

(12) M. Dominique, J.-F. Hochedez et al.
LYRA on-board PROBA2 - in-orbit operations and achievements (Invited Talk)
PROBA2 workshop, Jun 22 2010, ESTEC, Noordwijk (the Netherlands)

(13) D. Berghmans and the SWAP team
SWAP 1^{st} Science Results by ROB (Invited Talk)
PROBA2 workshop, Jun 22 2010, ESTEC, Noordwijk (the Netherlands)

(14) A. De Groof and the P2SC team
PROBA2 Science Center (Invited Talk)
PROBA2 workshop, Jun 22 2010, ESTEC, Noordwijk (the Netherlands)

(15) D. Berghmans and the SWAP team
SWAP onboard PROBA2, a new EUV imager for Coronal Monitoring (Invited Talk)
AOGS, 2010, July, Hyderabad (India)

(16) D. Berghmans
Guest Investigator Program for PROBA2, SWAP and LYRA instruments (Poster)
AOGS, 2010, July 5, Hyderabad (India)

(17) D. Berghmans
Monitoring Space Weather with PROBA2 (Talk)

Presentation to ILWS annual meeting, July 16 2010, Bremen (Germany)

(18) D. Berghmans & J.F. Hochedez
Solar Observations from PROBA2: Ready for Space Weather Operations (Talk)
COSPAR 38th Scientific Assembly, July 16 2010, Bremen (Germany)

(19) J.F. Hochedez, I. Dammasch, Werner Schmutz
First Results from the LYRA solar UV radiometer (Talk)
COSPAR 38th Scientific Assembly, July 16 2010, Bremen (Germany)

(20) I. Dammasch
Solar Irradiance Observations with LYRA on PROBA2 (Talk)
Xth Astrophysical Colloquim, Sept 10 2010, Hvar (Croatia)

(21) M. Mierla, D. Seaton, D. Berghmans, G. Stenborg
3D reconstruction of the 13th April 2010 prominence eruption using SWAP and EUVI data (Talk)
Fifth Solar Image processing Workshop (SIP), Sept 12-16, 2010, Les Diablerets (Switserland)

(22) D. Berghmans
Status of SWAP and LYRA (Talk)
SOTERIA second annual meeting, Oct 10, 2010, Debrecen (Hungary)

(23) Elke D'Huys and the P2SC team
PROBA2 (Running Presentation)
Seventh European Space Weather Week, Science Fair, November 15-19, Bruges, Belgium

(24) M. Dominique, D. Berghmans, M. Kruglanski, L. Dolla, E. De Donder, A. Ben Moussa, W. Schmutz
Impact of the Particle Environment on SWAP and LYRA data
Seventh European Space Weather Week, November 15-19, Bruges, Belgium

(25) D. Seaton, M. Mierla, D. Berghmans, L. Dolla, A. Zhukov
A 3D SWAP-STEREO Reconstruction of a Mass-Loading Eruption
Seventh European Space Weather Week, November 15-19, Bruges, Belgium

(26) A. De Groof & PROBA2 Science Center Team
PROBA2/SWAP & LYRA New Instruments for Space Weather Monitoring (Running Presentation)
Seventh European Space Weather Week, November 15-19, Bruges, Belgium

(27) J. Zender, D. Vagg, M. Dominique, I. Dammasch, M. Mierla and the LYRA team
Temporal and Frequency Variations of Flares observed by LYRA onboard PROBA2
Seventh European Space Weather Week, November 15-19, Bruges, Belgium

(28) I. Dammasch, Y.S. Mehmet, D. Seaton
Solar Irradiance Variations of an Active Region observed with SWAP and LYRA (poster)
Seventh European Space Weather Week, November 15-19, Bruges, Belgium

(29) M. Mierla, L. Rodriguez, D. Berghmans, D. Besliu-Ionescu, I. Chifu, I. Dammasch, A. De Groof, C. Demetrescu, D. Crisan, V. Dobrica, S. Gissot, J.F. Hochedez, B. Inhester, J. Magdalenic, G. Maris, D. Nitoiu, D. Seaton, N. Srivastava, M. West, A. Zhukov
Multispacecraft Observations of 3 and 8 April 2010 Coronal Mass Ejections (poster)
Seventh European Space Weather Week, Session 3, November 15-19, Bruges, Belgium

Seminars

(1) D. Seaton & the PROBA2 Team
Monitoring Solar Activity with PROBA2
Space Science Seminar, University of New Hampshire, Durham, NH, USA, May 19, 2010

(2) D. Seaton & the PROBA2 Team.
Monitoring Solar Activity with PROBA2
Seminar, Harvard-Smithsonian Center for Astrophysics, Cambridge, MA, USA, May 20, 2010

(3) D. Seaton & D. Berghmans
Solar Observatories and Data Analysis Techniques
Courses, ICTP Advanced School on Space Weather, Trieste, Italy, October 19–20, 2010

(4) A. De Groof
SWAP and LYRA onboard PROBA2, new EUV instruments for coronal monitoring
Center for Plasma-Astrophysics, KULeuven (Belgium), Dec 16 2010

Wikis and Websites

- PROBA2 website: http://proba2.sidc.be/index.html/
- P2SC Operations wiki: http://p2wiki:8000/p2ops_wiki
- P2SC Science Center wiki (development): http://sol042.oma.be:8000/Proba2SC/
  LYRA Quick Look Viewer update http://proba2.sidc.be/lyra/LY-QLV/

Brochures

- “Ruimteweer waarnemen met een Belgische Satelliet”, Documentatietekst voor Leraren, E. D’Huys & P. Vanlommel, i.s.m. Vliebergh-Senciecentrum, K.U.Leuven.

Q.4.6. Missions

Assemblies, symposia, conferences:

- SOTERIA Annual Meeting, 18–20 January 2010, Davos, Switzerland
- Space Weather Workshop, 27–30 April 2010, Boulder, Colorado, USA
- CESRA & PROBA2 Science Working Team Meeting, 14–16 June 2010, La-Roche-en-Ardennes, Belgium
- PROBA2 workshop, Jun 22 2010, ESTEC, Noordwijk (the Netherlands)
- ICTP Advanced School on Space Weather Modelling and Applications, 18-29 October, 2010, Trieste, Italy
- 7th European Space Weather Week, Nov 15-19 2010, Brugge (Belgium)

Commissions, working groups:

- PROBA2 Sciene and Thecnology Operations Working Group.

Research visits:

- LYRA degradation + Herzberg jumps and noise, Aug 17-19 2010, Davos (Switzerland)

Field missions:

- Till end of March, many missions at Redu, for participating to the commissioning activities
- Missions to ESA ESTEC for MOC-SOC coordination (STOWG), 11 Febrary, 2010, Noordwijk, Netherlands.
- Missions to ESA Redu for MOC-SOC coordination (STOWG), 20 May 2010, Redu, Belgium. Till end of March, many missions at Redu, for participating to the commissioning activities

Q.5. SDO data center

Q.5.1. Objectives

The launch of the SDO (Solar Dynamics Observatory) took place in February 2010. The launch and commissioning was flawless, and this satellite has produced since May 2010 solar images at an unprecedented rate of data provision.

For all parties concerned the flow of data has presented challenges in distribution, storage, and processing. The immediate objectives of the Belgian SDO Data Centre are :

- Serve are as primary distribution node for Europe.
- Process the data in real time.
- Make the data and results available to as wide a group of users as possible.

These last two objectives have two aspects. First, the Regional Warning Center for Space Weather located at ROB requires results in minutes rather than days. Second, the volume and detail of data mean that research analysis will require both a huge increase in processing speed and development of automated assistance to data analysis.

To achieve these objective a solid hardware and software platform for handling SDO data must be provided, as described in the following section.

Q.5.2. Progress and results

The activities of the SDO data centre in 2010 can be divided as follows:

- SDO data centre in service
- Expansion of storage capacity for data
- Data networking and communication
- Data access
- Consolidation of funding for the SDO data centre

These activities benefitted from collaboration with internal and external colleagues. The team at ROB also shared both experience and software with the other data centres, and participated in the open data policy which has made the whole project possible.

Q.5.2.1.SDO Data centre in service

The SDO Data Centre, the core parts of which were installed in 2009, was put into service in February 2010. The centre, which takes data from sources in the US and acts as a source for other centres in Europe functioned as planned from day one and has operated continuously since. As foreseen from the statistics used during the design phase, some parts of the hardware have failed and been replaced ("hot swapped") or repaired, which has been done without pause in operations, due to the redundancy built-in to the system.

Figure 70 show the data centre in schematic and actual physical form respectively.

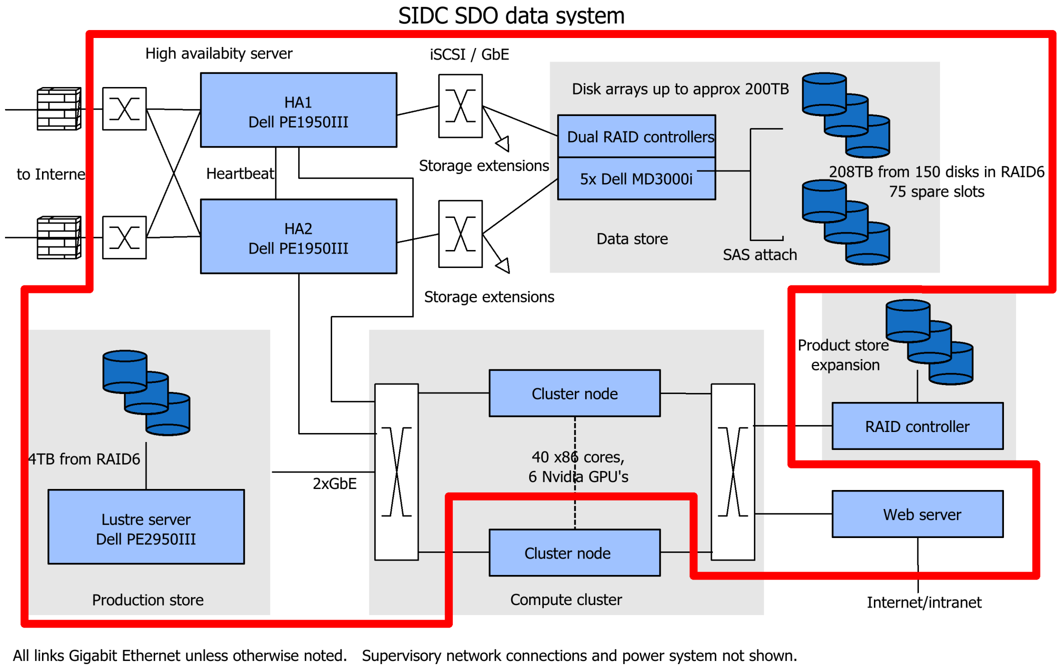

Figure 70: SDO data system at SIDC as of end 2010. A full redundancy high-availability server is connected to the internet and is connected to a data store and to cluster node.

Figure 71: ROB SDO Data centre hardware

Q.5.2.2. Expansion of storage capacity for data

The storage capacity of the SDO data centre is implemented as a rack of disks, using standardised protocols and interfaces. During 2009 sufficient space was allocated to allow additional disks to be installed. Thanks to resources made available through ROB's dotation fund, additional disks were purchased and added in 2010, bringing the storage capacity for the SDO data to 208TB of available storage, which corresponds to over six months of data. B. Mampaey configured those disks and made them available to the netDRMS. The High Availability system was also adapted to take into account the abundance of new disks.

Q.5.2.3. Data networking and communication

The data networking system is an essential part of the SDO data distribution philosophy. Indeed, the approach that was taken to prevent JSOC from being overloaded is to transmit all the data from AIA and HMI to dedicated SDO data centres using optimized network connections.

Since May 2010, ROB has become the European Hub for AIA (and part of HMI) data in the sense that it receives all data from the Centre for Astrophysics in Harvard, and it is the first element in a chain of European institutes who relay these data.

Each SDO data centre can subscribe to the series they need and fetch those data from their upward centre. In the case of ROB, the subscription mechanism to receive SDO data has been set up to receive all of AIA data as well as a part of the HMI data. The reception of temporary data started in June, and was upgraded to the reception of definitive science-grade level 1 data in September 2010 for HMI, and December 2010 for AIA.

From the start of the SIDC Telescience project, the ROB has taken the initiative in setting up a collaborative activity with the other European institutes. The third 'SDO pipeline' meeting was organized by ROB in September 2010. As a result of this series of meetings a mailing list and wiki for all the institutes active in data distribution (as opposed to the core software development) has been set up in the US, and is very active.

Q.5.2.4. Data access

The original purpose of the SDO data is to make data available to an as wide a group of users as possible. Various ways of accessing data were developed by D. Boyes in 2010: access via virtual observatory, via a filesystem, or via a website.

Data access using a virtual observatory

Working closely with Harvard Smithsonian and the VSO organisation, D. Boyes added the ROB data centre as a site to the Virtual Solar Observatory (VSO) at http://www.virtualsolar.org. The VSO allows direct selection of data, but its main application is in access via familiar instruction in the popular software suite SolarSoft, which uses the IDL package. In other words, SDO data from ROB is now available to SolarSoft users in exactly the same way as the data from previous missions.

Data access as a file system

Most computer users are familiar with the presentation of data as named files. D. Boyes therefore developed a software package which translates a query about data held in the SDO system (for example "such and such instrument plus dates plus cadence plus wavelengths") and presents the results as a quite normal directory full of files. Because of the possible large quantity of data implied, the files are not actually obtained from the archive until they are used, and then they are saved in a cache to save time on future requests.

Such a system is called a pseudo file system (PFS), and uses freely available libraries and code. During 2010 the system was only available within a data centre such as ROB, and in early 2011 it was made available anywhere on the Internet.

Data access via web site

While VSO and file system access is suitable for access to more or less known blocks of data, exploratory and "quick look" data access is probably most convenient via a traditional web page. D. Boyes therefore set up the Internet address of the web server (http://sdodata.oma.be) to also access data on the system.

Several days of recent low resolution data have been posted for access via this webpage. To avoid an avalanche of data only images every 20 minutes are taken and only the last four days shown. These data are available a few hours after the data acquisition by the satellite.

The same web server is accessed by and mediates many other data access routes, including the VSO access and PFS access, including access on the ROB intranet and compute cluster. In fact this access mostly involves very short messages such as file names, with bulk data access is by other channels. The load on the web server is thus relatively light and it brings with it the advantage of use of standard web access standards.

Q.5.2.5. Consolidation of funding for the Belgian SDO data centre

At this stage of development, a synchronisation between the storage and computing resources of the four SDO data centres in Europe would be necessary in order to substantially increase the quality of service offered to the European users. These SDO data centres are hosted at the following institutes: the Institut d'Astrophysique Spatiale (IAS, France), Max-Planck Institute for Solar System Research (MPS, Germany), Royal Observatory of Belgium (ROB, Belgium), and University of Central Lancashire (UCLan, UK).

In October 2010, the Belgian space agency delegation submitted a proposal (with V. Delouille as PI) to ESA in the frame of the "Call for Support to Nationally Led Projects", a call which also covers support to projects led by a non-member state, for which the member states contribute significantly.

The aim of this proposal was to secure, consolidate and upgrade these abovementioned Data Centres towards real collaborative operational centres in order to enable the exploitation of the full wealth of SDO data for all interested users in Europe (and beyond).

ESA support was requested in the field of

- data reception: upgrades, maintenance, tools, system administration
- data distribution: visualisation and search tools, virtual solar observatory, higher level product tools, user support
- grid computing

It thus concerned ground segment support services for existing European SDO Data Centers. This proposal was called SOLACE (Solar Dynamics Observatory Data Centres in Europe), see [49].

Although the Solar system and exploration working group (SSEWG) made a positive review of the SOLACE proposal, the Science Programme Committee (SPC) decided to reject it based on programmatic concern: according to a narrow majority of national delegations at the SPC, such a proposal would set an undesirable precedent for use of the Science Programme funding for support to data access.

Q.5.3. Perspective for next years

The data centre is now up and running. In the forthcoming years we need to consolidate its operational and developmental aspect, as well as its funding.

For the **operational** support, instructional materials, diagnostic software and training are the main current requirements.

There are subtle problem with highly reliable systems. Since problems seldom arise, technical staff are unfamiliar with them when they do. Therefore manuals which assume the user has never seen the material before have to be prepared. In addition, systems with redundancy have to be capable of self diagnosis. Operators will normally see no effect of failures of parts of the system, so have to be informed when this happens by specific messages.

In addition, the need for additional capacity in both storage and computational capacity has to be monitored. The system design allows for such addition, and actually in February 2011, 8TB of fast disk have been added to the computational and web server storage within a few hours work.

For the **development** aspect, one important part is to ensure further publicity and training material for the existing system. As an example, in early 2011, as part of the Soteria workshop held at ROB, D. Boyes was able to present examples of VSO use to the users of the SOTERIA community.

In the slightly longer term, the data centre can benefit from making use of technology developed in the context of data intensive science. The data centres at ROB and MPS have both been equipped with system software to enable what has been called ‘high throughput computing’. Well documented examples of such use will be of considerable help for solar physicist users, for whom it is to a large extend a new concept.

Along this line, a participation in a grid type structure, where the ROB is a data oriented node, is a clear direction to successful implementation of data intensive science. Facilities for this are now becoming mainstream even in consumer computing systems. The existence in Belgium of the Begrid as a part of BELNET (the national research network) makes initial steps in collaboration with individual research partners quite feasible with minimal investment.

After the rejection of the SOLACE proposal by the SPC, national initiatives are for the time being the only possible **source of funding** for the SDO data centres effort in Europe, which can have only modest ambitions as compared to what was planned in the SOLACE proposal. In Belgium, part of the activity has been taken since January 2011 by the B.USOC, in close collaboration with the ROB. It is hoped that the collaboration within the Space Pole of the three institutes will ensure the continuity of the availability of resources for the operation of the SDO data centre in Belgium after 2012.

Q.5.4. Partnerships

List of international partners or collaborators having actively contributed to the project in the last year

- Karel Schrijver, N. Hurlburt, A. Title, Lockheed Martin Solar and Astrophysics Laboratory, USA
- Piet Martens, Alisdair Davey, Ed Deluca, L. Golub, Smithsonian Astrophysics Observatory, USA
- Phil Scherrer and Rick Bogart, Stanford University SDO Joint Science Operations Centre (JSOC).
- Mike Marsh and Steven Chapman, University of Central Lancashire Centre for Astro-physics (UCLan), Preston, UK.
- Frederic Auchère and Susanna Parenti, Institut d'Astrophysique Spatiale (IAS), Université Paris Sud 11, Orsay.
- Laurent Gizon and Ray Burston, Max Planck Institute for Solar System Research (MPS/MPG), Lindau, Germany.
- Joe Hourcle, Solar Data Analysis Center, NASA and Franciso Suarez-Sola, US National Solar Observatory, NOAO, for the VSO organisation

List of national partners or collaborators having actively contributed to the project in the last year

- Fabian Roosbeek, André Somerhausen, ROB
- Arnaud Lefebvre, BIRA
- There have been valuable contributions to the functioning of the infrastructure from the staff of the KMI and BIRA

Grant(s)/Project(s) used for this research/service

- SIDC Data Exploitation PEA (BELSPO PRODEX)
- SIDC Telescience PEA (BELSPO PRODEX)

Visitors:

- Alisdair Davey, Data access through virtual solar observatory

The following visitors came for the 3rd SDO pipeline meeting on September 17, 2010:

- Igor Suarez (NOAO)
- Neal Hurlburt (LMSAL)
- Jack Ireland (GSFC)
- Keith Hughitt (GSFC)
- Rick Bogart (U. Stanford)
- Seonghwan Choi (KASI)
- Alisdair Davey (SAO)
- Frédéric Auchère (IAS, Paris)
- Susanna Parenti (IAS, Paris)
- Elie Soubrié (IAS, Paris)
- Pablo Alingery (IAS, Paris)
- Steven Chapman (UCLan)
- Silvia Dalla(UCLan)
- Stephane Regnier(UCLan)
- Hans-Peter Doerr (KIS)

Q.5.5. Scientific outreach

Meeting presentations

(1) Mampaey Benjamin
SDO data storage and transfer: Planning long-term solution
3rd SDO Pipeline Meeting, ROB, 17/09/2010

(2) Boyes, D.
Status report of SDO system at ROB
3rd SDO Pipeline Meeting, ROB, 17/09/2010

(3) Boyes D. ; Mampaey B.; Verbeeck C.; Delouille V.; Hochedez J.-F
SDO Data Access and Distribution in Europe and the ROB Data Centre)
Invited oral presentation, COSPAR 2010, Session "New Views of the Sun with SDO (E22)", Bremen, Germany, July 18-25, 2010

Seminars

(1) Boyes, D.
Stand "SDO data access" at fair
Seventh European Space Weather Week, 15-19 November, 2010 - Brugges

Wikis and Websites

- The continuing development of the project website (http://wissdom.oma.be) has had a central role in disseminating project results. It has the form of a group of wikis to which team members can contribute, but which is accessible by the general public as webpages. It also contains software repositories and issue trackers.
- The SDO data at ROB is accessed via http://sdodata.oma.be

Q.5.6. Missions

Assemblies, symposia, conferences:

- COSPAR 2010, Bremen, Germany, 19-25 July 2010
- Solar Image Processing Workshop V, LesDiablerets, Switzerland, 12-16 September 2010
- OpenGridForum/Grid2010, October 25-28, 2010, Brussels

Commissions, working groups:

- 3rd SDO pipeline meeting, Brussels, Belgium, September 17, 2010: 20 attendees in total

Q.6. Educational and public outreach projects

Q.6.1. Objectives

With the 'Educational and Public Outreach', EPO – section we want to communicate and disseminate the content of the projects of the operational directorate solar physics and space weather. The target groups are

A. The broad public,

B. Students

C. Scientists of the space weather community,

D. Governmental/Commercial entities..

The broad public is defined as the general public with no scientific background, people with a non-professional and non-scientific interest in space weather, e.g. amateur astronomers and private solar observers, local institutes, e.g. schools. We address them in their own language with a non-scientific and understandable vocabulary, explaining the jargon.

In the group 'students', we target undergraduate and PhD students. They should be addressed with a specific content. More scientific jargon and language is possible. With this group, we go further then only providing basic information. We target education in depth.

Group 'C' consists of researchers, scientists involved in instrumentation, observatories and space weather applications. We consider the scientists of our own directorate also as being a part of this group.

The fourth group gathers the people, companies and institutes who are defined as space weather end users. Satellite operators have a commercial interest in space weather applications such as space weather monitoring and forecasts. Space tourism is another stake holder: space travel companies, space port operators, insurance companies.

The EPO project is a necessary and important activity as it strengthens the raison of existence of the directorate. It's our task to point to the more value of the directorate's activities towards the whole society presented by the broad public, the scientific community, the government and commercial entities. The EPO project should raise the visibility of the directorate, raise awareness of the implications of solar activity and space weather. Several commercial entities are not yet aware of the possible impacts of space weather on their business. We see an opportunity in this lack of knowledge.

The EPO section offers also a platform for internal communication across the project boundaries.

Q.6.2. Progress and results

We describe the content and define the target group of our actions undertaking within the EPO project.

Q.6.2.1. Internal Communication Initiatives

A good internal communication defines the strength of the directorate. Good internal communication is a necessary condition for a smoothly running group. It reflects on the external communication and strengthens our position in the scientific community.

During a seminary, the presenter gives an update of the work done and the results within a project. A recent initiative is called the 'FAST meetings' and is initiated by David Berghmans. During one hour, the scientists talk about a special space weather event, an action undertaken within a project, a newly developed application or novelty within space weather that is relevant for the performance of the directorate. A fixed subject is the 'space weather briefing' in which an update of the current and forth coming space weather is given. The goal is to exchange knowledge.

Q.6.2.2. PROBA2 communication

We had a large press event on January 26, 2010 about the first achievements and images of PROBA2. The European Space Agency, ESA, the Royal Observatory of Belgium and the Solar-Terrestrial Centre of Excellence invited the press and VIPs. The ROB hosted the event. We focused on three points:

1. PROBA2 is the result of a successful European collaboration with major participation of Belgian industry,
2. The objective of the mission is to test new spacecraft and instrument technology in space,
3. The satellite is equipped with a quartet of new science instruments focusing on solar and space weather observations. For the two 'state of the art' solar telescopes SWAP and LYRA, the scientific responsibility lies in Belgium. The Czech Republic for the scientific experiments TPMU and DSLP.

We welcomed the Belgian Minister of Science, S. Laruelle, and ESA Directors Mr Courtois and Mr Southwood. After the general part, a representative of Verhaert Space illustrated the technical successes. The principal investigators of SWAP and LYRA, B. Berghmans and J-F Hochedez in collaboration with a TPMU/DSLP scientist commented on the first scientific achievements. Here, SWAP has the advantage that it visualizes the dynamic Sun. On Jan 15, 2010, SWAP witnessed an annular eclipse (see Figure 72). Beside nice images, this gives also the possibility to study the black regions (shadow of the moon) in relation with diffracted light.

Figure 72: SWAP witnesses an annular eclipse on Jan 15. The results were presented to the press.

The formal part was concluded with a Questions & Answers session and possibility for interviews (see Figure 73).

The following persons were available:

Mr Courtois,	ESA Director of Technical and Quality Management
Mr Southwood,	ESA Director of Science and Robotic Exploration
Mr Strauch,	ESA PROBA2 project manager
Mr Teston,	ESA PROBA Programme Manager
Mr Berghmans,	Principal Investigator SWAP, scientist at ROB
Mr Hochedez,	Principal Investigator LYRA, scientist at ROB
Mr Defise,	Principal Investigator SWAP, General Manager CSL
Mr Preud'homme,	Commercial Director Verhaert Space
Mr Schmutz,	Director PMOD/WRC
Ms Wagner,	Belgian Federal Science Policy
Mr Stverak,	Scientist DSLP
Mr Bloomfield	Trinity College Dublin

Media response

Both written press and television broadcasters took the opportunity to target several people. A digital press map was distributed. The media response was enormous:

1. Weerbericht één-television (BE)
2. De Standaard (BE)
3. Le Soir (BE)
4. RTE - Irish TV (IE)
5. Independant (IE)
6. Tagblatt (CH)
7. BBC (UK)
8. TV Oost (BE)
9. TV Bruxelles (BE)
10. SDA/ATS - Swiss news agency (CH)
11. Czech Radio (CZ)
12. Agence Belga - Belgian news agency (BE)
13. United Press International
14. Metrotime (BE)
15. Astronews (DE)
16. Nu (NL)
17. Skynews (Belga) (BE)

Figure 73: J.F. Hochedez is being interviewed by the visual press on Jan 26 as the Principal Investigator of LYRA.

18. Nieuws (Belga) (BE)
19. Europa Press (ES)
20. Hirado (HU)
21. National Geographic (JP)
22. Omskinform (RU)
23. RND (RU)
24. Science Daily (US)
25. Physorg.com (US)
26. Alpha Galileo (UK)

The corresponding links can be found on
http://proba2.sidc.be/index.html/gallery/breve/proba2-press-event-26-january-2010

ESA-TV made a commercial to promote the ROB contribution to the PROBA2 project. This commercial was intended for broadcasters to be picked up. Frank Deboosere, VRT, weather journal, used a part of it for his weather talk on 'één'. A broadcast like this, reaches a large part of the people in Vlaanderen.

PROBA2 scale model

The ROB-atelier built a scale model of PROBA2 that was shown at the 26 January press event. PMOD/WRC and Spacebel expressed their interest to order their own scale model. Special arrangements were taken for the request of PMOD WRC to put a replica of LYRA into scale model of PROBA2. Two other replica were made for own use. At the European Space Weather Week 7 in Brugge, PROBA2 was shown at the fair. The scale model is used to illustrate our information sessions given in the frame of PROBA2@school or seminars for the broad public.

Figure 74: We see the scale model build by the ROB in collaboration with the STCE as it was presented on the Jan 26 press event.

General conclusions

The collaboration with ESA and the international partners gave an extra boost to the prestige of the event and accordingly to the ROB and the STCE. The organization went very smooth even if the political environment was difficult. It was quite a challenge to preserve a reasonable balance between all partners and the organization. With the help of several ROB people and the governmental cell 'Event Support', the outcome was very professional.

Q.6.2.3. PROBA2@school

We collaborated with the Vliebergh-Senciecentrum (VSC). VSC is part of the 'Academisch Vormingscentrum voor Leraren' of the KULeuven. The centre offers teachers and representatives of educational studies the opportunity to follow continuing-education courses. These courses have the goal to keep up with the development in the field of academic education and scientific research. Another goal is to develop a research critical mind and to bring in new didactical insights into the daily class practice.

The PROBA2 project is called: 'Ruimteweer waarnemen met een Belgische satelliet'. The goal is to capture the attention of teachers. In a second step, we will work together with the interested teachers to develop concrete courses and exercises for students of the third grade ASO, TSO and KSO. Several applications are possible in statistics, mathematics, physics, geography.

E. D'Huys and P. Vanlommel participated in several meetings on the organization and content of the educative PROBA2@school project.

The PROBA2 introductory course for teachers was given on March 24, 2010. Teachers got a written PROBA2 bundle. The teachers were D. Berghmans, E. D'Huys and P. Vanlommel.

Several schools showed interest: Paridaens Leuven, K.A. Berchem, Sancta Maria Leuven, H. Drievuldigheidscollege Leuven, St. Lutgardinstituut Beringen, Koninklijk Atheneum Landen, Klein Seminarie Hoogstraten, Stedelijk Humaniora Bilzen.

The first actual interaction between us and school students was undertaken in November. The school of Bilzen visited the PROBA2 Science Center and the RWC Belgium.

Q.6.2.4.PROBA2@ESWW7

The PROBA2 project was present at the ESWW7 fair. The target group were scientists and commercial/governmental entities present during the European Space Weather Week.
Special attention was given to the fact that PROBA2 is 1 year in space since the launch on November 02, 2009. With the stand, the PROBA2 Science Center wanted to attract scientists to participate in the PROBA2 Guest Investigator Program. This program promotes the use of PROBA2 data. Selected investigators spend one or a few months with the Principal Investigator (PI) teams to obtain expert knowledge on the instruments LYRA and SWAP. The scientists can actively participate in the daily commanding of SWAP and LYRA. A third focus of the stand lied on the scientific outcome of the past research done with SWAP and LYRA data.

Q.6.2.5.Solar Activity and Space Weather

Despite the low solar activity, the communication about solar activity and space weather continued proactively. Contacts set during press events or in previous years lead to questions to give information sessions to groups of interested people or to write articles in more popular journals intended for the general public or for journal with a public interested in astronomy and science. This results in publications in Science Connection, Guidestar and the ESA-website and to a series of seminars given in amateur astronomer clubs.

Being active in the organization of the European Space Weather Week, gives us the opportunity to interact directly with the scientific community, with PhD-students and companies involved in commercial space weather activities. The ESWW Tutorial and Fair are successful efforts to get into contact with these target groups.

We actively participated in the International Advanced School on Space Weather Modelling and Applications held in Trieste, Italy. The science and data exploitation of PROBA2, our space weather monitoring and forecast activities were the subject of 3 half day sessions. The teachers were D. Berghmans, D. Seaton and P. Vanlommel. From the Royal Observatory, C. Cabanas, B. Callebaut, E. D'Huys, M. Dominique participated as students. The school brought in total 86 people together.

We established a good contact with an important satellite-operator, SES-Astra. A particular space weather event triggered a series of contact, e.g. company visit during which we presented our services, SES-Astra explained what the company stands for, its goals and policy. One of the actions was the creation of an emergency email alias which SES-Astra can use in case of questions or remarks. All forecasters receive this email and can respond.

Q.6.2.6. ESWW7

A highlight for the space weather community is the annual European Space Weather Week. It was the fifth time organised in Belgium by the Solar-Terrestrial Centre of Excellence and the SIDC-directorate. We welcomed 250 participants from all over the world. The ESWW is known outside the boundaries of Europe.

Figure 75: For the seventh edition of the European Space Weather Week, we developed this poster. The focus lies on the spacecraft and spacecraft environment.

Ronald Van der Linden and Petra Vanlommel are member of the Programme Committee responsible for the scientific program. The SIDC and communication cell of the STCE is responsible for the local organisation and the exploitation of the site. This year's ESWW was held in Brugge.

<u>A report</u>

Space Weather got a boost thanks to the significant investments for example by the EU FrameWork 7 and by the Space Situational Awareness (SSA) Program of ESA. The European community working in the field of space weather has a natural focus on the Space Weather part of the SSA. This ESA program supports new and existing initiatives that meet the requirements of a broad group of users of space weather applications and products. At the ESWW it became clear that SSA is an opportunity for Europe to strengthen its skills and play an important role in the space scenery.

From this increasing number of space weather programs, one could conclude that space weather is overall getting worse. It's not, but our vulnerability is increasing as our technology is getting more advanced. In these optics, the space weather effects on spacecraft and its environment are a hot issue. Post-analysis of space weather radiation events causing hazardous effects in spacecraft, seems to be a way to handle future events. It becomes more and more critical for space craft engineers to be one step ahead of the Sun. More in-depth research, modelling and forecasting can help. Data input is crucial for performing this task.

The ESWW showed again clearly and loudly that we are at the beginning of a new era, with enormous data flows coming in, e.g. from the NASA SDO mission or from dedicated space weather monitors such as PROBA2. To handle all that data we need new machinery such as virtual observatories, online quicklook viewers and automatically generated data catalogs. Space weather products and services, following naturally as the output of research and modelling activities evolve rapidly. We are progressing to more mature, worldwide, American and European application centres. But there are limitations to our space weather capabilities, including the sparsity of certain experiments, e.g. coronographs. Efforts are done, however, to assimilate data into models and implement these models into a usable platform. Bridging the gap between models and applications is an issue relevant for all physical layers, from the Sun and the corona, through the heliosphere and the magnetosphere, across the radiation belts, over the earth poles, the ionosphere, to the Earth's surface. This diversity of scales and processes is difficult to control, but several groups try.

Figure 76: A view of the poster and coffee area during ESWW7

Other side-events organized during ESWW7 contributed to a lively and dynamic conference. The space weather tutorial served as an ice-breaker and helped the people in the field to get into the subject. The keynote lecture dragged us into the world of Birkeland and aurora's. Birkeland's life teaches us the need to communicate with non-experts and to build a firm bridge between pure science and applications. The debate put the question about space exploration on the foreground: 'What is the rationale behind the decision to send humans to space?' It's in the human nature to explore, how small or grown up you are. Children's biggest fantasy are about dinosaurs and ... space, the past and the future. Further, the possibilities of a scientific market were explored during a fair: the Matroshka phantom draw our attention to the received radiation dose while traveling through space, the aurora and the Sun were visible in 3D, a huge radio receiver was mounted in the exhibition hall and the planeterrella experiment was also demonstrated. And of course, the students did their best to deliver a nice oral or poster presentation. Two nominees left home with a small but nice present in their bags.

The European Space Weather Week offers the platform to meet in a formal and informal environment, during the plenary sessions, the numerous splinters and a whole bunch of side events like the tutorial, the space weather fair, the debate-evening. Many, scientists, engineers, space weather product developers, students, national delegates, ... take this opportunity.
The ESWW is certainly an important event highlighting the directorate Solar Physics and Space Weather.

Scientific side events

- Space Weather Tutorial and quiz,
- Space Weather Fair

- Contest: The Best of…

Local Organization

- Suitable site and set up
- Creation of an esww poster
- Website: creation and instantaneous update
- Social events: welcome reception, conference dinner, beer tasting, coffee breaks, sandwich lunches
- welcome pack: booklet, USB-stick, relevant touristic material
- Promotion material: invitation for event, fair, keynote, debate
- Sponsoring
- Information desk
- Cosy corner
- Wired and wifi connection
- Daily briefings for participants
- Instantaneous display of photos on HD screen with a software-tool developed by O. Lemaître
- Photographs

Actions towards the Press and Public

- E-Invitation for the debate sent to the press, the public and amateur astronomers
- E-Invitation for the keynote lecture and the welcome reception for VIPS.
- Press conference, 30 minutes before the start of the debate.

Q.6.2.7.eHeroes

ROB is a partner in a submitted FP7 proposal '*Environment for Human Exploration and RObotic Experimentation in Space', eHEROES.* KULeuven is the main proposer. The proposal contains 4 scientific packages: Value-added data on solar sources, Solar and Space Events and their Evolution, Exploring Space in Time, Impact on Space Exploration. We are especially involved the package 'Dissemination, exploitation and management of intellectual property'. We defined the target groups, the work structures and tool, and the content for dissemination. The SIDC/STCE will take the lead in this package.

Q.6.2.8.Link with Solar-Terrestrial Centre of Excellence

The Solar-Terrestrial Centre of Excellence, STCE is a project to enforce the available knowledge on the plateau of Uccle. Communication and collaboration are one of the keywords to reach this goal. The directorate Solar Physics and Space Weather has a strong presence in the STCE.
Our scientists gave input for the overview talks given at the annual STCE meeting 2010: Research and Modeling; Applications, Services, Data storage and exploitation; Instrumentation. A. Zhukov coordinated and gave the presentation about Research and Modeling. F. Clette and C. Marqué convened the workshops 'Space Science and Weather' and 'Radio Science'.
The STCE Radio Science Day on October 14, 2010 was the follow up of the Radio Science Splinter of the STCE annual meeting. The goal was to trigger to share expertise, hardware-software between users of various radio experiments conducted on the plateau.

Q.6.2.9.2010 CESRA Meeting

CESRA is the Community of European Solar Radio Astronomers, which convenes every 3 years for a meeting discussing the last developments in the field of solar radio physics. During the 2007 CESRA meeting, C. Marqué proposed that the next CESRA meeting could be organized in Belgium. In 2009, the CESRA board granted the Observatory the task to organize the meeting after reviewing a proposal made by C. Marqué and A. Vandersyppe. The Floreal Club, a vacation center in the city of La Roche en Ardenne was chosen.

Local and Scientific Organizing Committee

The Science Organizing Committee established the scientific program of the meeting (contributed talks, invited speakers, sponsored participants etc…). It was composed of:

- H. Aurass (Potsdam)
- K. –L. Klein (Meudon)
- A. MacKinnon (Glasgow)
- V. Melnikov (Nizhnyi Novgorod)
- A. Nindos (Ioannina, co-chair with C. Marqué)
- S. Poedts (Leuven; European Solar Phys Div of EPS)
- S. Pohjolainen (Turku)

The role of the LOC was to organize all practical matters linked to the meeting: looking for sponsors, renting the venue, taking option on hotel rooms, selecting the conference diner site, organizing the social activity, organizing transportation, managing the registration of participants and abstract submissions, composing & printing booklets, managing invitation letters for visa applications, setting up of the meeting.

Meeting organization

The 2010 CESRA meeting adopted the format of previous workshops of this organization; plenary sessions in the morning where contributed and invited talks were presented, and splinter session in the afternoon where all participants could present and discuss their results. Poster sessions were scheduled the whole week. Posters were on display in the room where coffee breaks and cosy corners were installed, allowing participants to discuss.

The meeting took place from June 15th to June 19th. A welcome reception was organized in the evening of June 14th. The social activity took place in the afternoon of June 16th. The conference dinner was organized in the evening of June 17th.

Scientific program and organization

The SOC choose the general theme of the meeting to be "Energy storage and release through the solar activity cycle - models meet radio observations" and it defined five plenary and posters sessions:

- Quiet sun and plasma diagnostics of the solar atmosphere
- Pre-flare and pre-CME activity
- Particle acceleration in solar flares
- Large-scale disturbances
- Solar activity cycle

A morning session was devoted to instruments, database and reports of radio observatories.

The splinter sessions were devoted to:

- Quiet Sun
- Pre-flare & pre-CME activity
- Particle acceleration in flares
- Large-scale disturbances and shocks

Eighty-nine abstracts were submitted for presentations. The number of participants was about 105 (including participants to the Parallel Proba 2 side meeting).

Perspective for next years

Figure 77: Partial group picture of participants to the CESRA meeting

In 2011, C. Marqué will provide the final summary of the meeting (participation, finances, etc…). A Topical issue of Solar Physics will be published on the outcomes of the meeting, with C. Marqué and A. Nindos as Guest Editors.

Sponsorships

- Belspo
- STCE
- ROB
- ESA
- ESP
- Observatoire de Paris
- CESRA

Q.6.3. Perspective for next years

The internal communication needs an upgrade. Information should flow top-down and horizontal between the different projects. Efforts have been done in the past to improve the horizontal communication. We had 'Science and Coffee' meetings. The Fast Meetings are a recent effort to renew the horizontal communication. The EPO section should make an effort to support these initiatives.

It is also one of our goals to identify more member candidates in the commercial area. As a scientific group offering space weather applications, we should enlarge the group of users. Space Weather is still a new field of which the boundaries of interest are not yet discovered.

Q.6.4. Partnerships

List of international collaborators having actively contributed to the project in the last year

- PROBA2 consortium
- SOTERIA consortium
- SDO consortium

List of national partners collaborators having actively contributed to the project in the last year

- Katrien Bonte, KULeuven
- Vliebergh-Censie, lerarenopleiding KULeuven

Q.6.5. Scientific outreach

This paragraph describes the interaction of your work **with the scientific community**. Interaction with the public (including the press) must be described in the chapter 'public outreach'.

Meeting presentations

(1) P. Vanlommel
August 2010 events
SES-Astra, Betzdorf, Luxemburg, August 18, 2010

(2) D. Berghmans

Tracking Solar Activity with Online Facilities
International Advanced School on Space Weather Modelling and Applications, Trieste, Italy, 18-29 October, 2010

(3) D. Seaton
Downloading and Handling Solar Data from Satellites
International Advanced School on Space Weather Modelling and Applications, Trieste, Italy, 18-29 October, 2010

(4) P. Vanlommel
Monitoring and Predicting SpW in the Heliosphere: Operational Services - Science & Exercises
International Advanced School on Space Weather Modelling and Applications, Trieste, Italy, 18-29 October, 2010

Wikis and Websites

- Website of the CESRA conference: http://sidc.be/CESRA2010
- Website of ESWW7: http://sidc.be/ESWW7

Q.6.6. Missions

Assemblies, symposia, conferences:

- SOTERIA annual meeting, Davos, Swiss, January 18-20, 2010
- PROBA2 SWT, La Roche, Belgium, June 14-16, 2010
- CESRA, La Roche, Belgium, June 15-19, 2010
- ESWW7, Brugge, Belgium, November 15-19, 2010

Commissions, working groups:

- PC-meeting esww7, Brussels, Belgium, January 26, 2010
- PC-meeting esww7, Rome, Italy, May 27-18, 2010
- PC-meeting esww7, Brussels, Belgium, October 06-07, 2010
- PROBA2@school, Leuven, Belgium, February 23, 2010
- PROBA2@school, Leuven, Belgium, May 05, 2010

Visits to

- SES-Astra, Betzdorf, Luxembourg, August 18, 2010

Informative Visits of ROB-RWC-PROBA2 Science Center

- Studente 6de Middelbaar, February 11, 2010
- Stedelijke Humaniora Bilzen, November 23, 2010
- Lessius Hogeschool Mechelen, contactpersoon Adriaan Tirry, October 29, 2010

Informative sessions

- Studiekeuze-beroepen, Sint-Jozefs Instituut Betekom, March 08, 2010
- Workshop wetenschap KULeuven, Belgium, March 16, 2010
- Kick-off PROBA2@school, Leuven, Belgium, March 24, 2010
- Volkssterrenwacht Beisbroek, Brugge, Belgium, May 05, 2010
- Jaarvergadering VVS, werkgroep Zon, Genk, Belgium, September 18
- Werkgroep Aardrijkskunde Brabant, Heilig Hart Instituut, Leuven, Belgium, September 28
- Sint-Jozefsf College, 4de leerjaar, Aarschot, Belgium, December 13, 2010

Field missions:

- Brugge, Belgium, esww7-site
- La Roche en Ardenne: Conference dinner site selection, March 16th 2010

R. Publications

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Design, Fabrication and Physical analysis of TiN/AlN deep photodiodes
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[122] Yang X. (promotor: De Cat P.)
Towards asteroseismology for main-sequence g-mode pulsators: data from the 2.16-m telescope of the Xinglong observatory (China)
Proposal ASBL-VZW Grant 2010 Kredietaanvraag aan Navorsers (onderzoeksjaar 2011); granted

[123] A. Zhukov, B. Nicula, D. Berghmans and J-P Halain
Request for an aperture increase for the HRIEUV channel of EUI
EUI project document

S. Data sets

[D.1] Historical GNSS tracking data from EPN (since 1996)
http://www.epncb.oma.be/_dataproducts/data_access/dailyandhourly/, ftp://ftp.epncb.oma.be/epncb/obs/
Daily RINEX observation files of EPN stations, corrected for metadata errors, updated each 3 months

[D.2] EPN site log files (since 1996)
ftp://ftp.epncb.oma.be/epncb/station/log/
Machine-readable description of GNSS tracking site (e.g. equipment and co-located instrumentation), updated after each configuration change at an EPN station

[D.3] Antenna calibrations of EPN stations
ftp://epncb.oma.be/pub/station/general/epn_05.atx
Values of individual and type mean receiver antenna calibrations, used by EPN analysis centers, updated upon antenna change at EPN station

[D.4] GNSS tracking data quality checks for each EPN station (since 1996)
http://www.epncb.oma.be/_trackingnetwork/siteinfo4onestation.php?station=DENT (example for the EPN station of DENT)
Computated multipath, tracked data versus expected, number of cycle slips, etc… for each EPN station, updated daily, in graphical form

[D.5] GNSS skyplots for each EPN station (since 1996)

http://www.epncb.oma.be/_trackingnetwork/siteinfo4onestation.php?station=DENT (example for the EPN station of DENT)
Skyplots displaying satellite visibility of all EPN stations, updated monthly, in graphic al form

[D.6] Estimated positions of FLEPOS, WALCORS, GPSBru and EPN stations in ROB subnetwork (±140 stations), since 1996
ftp://epncb.oma.be/pub/product/clusters/ (public, only EPN stations)
actis.oma.be (internal use, all stations)
Rapid (daily), final (weekly) site position and reprocessed estimations by ROB analysis center in SINEX format, updated daily

[D.7] Estimated tropospheric zenith path delays of FLEPOS, WALCORS, GPSBru and EPN stations in ROB subnetwork (±140 stations), since 1996
ftp://epncb.oma.be/pub/product/clusters/
Hourly estimates, TRO SINEX format, updated weekly and submitted to EUREF

[D.8] EUREF combined weekly position and troposphere solutions (since1996)
ftp://epncb.oma.be/pub/product/combin/
Official EUREF weekly position and troposphere solutions which is a combination of the solutions provided by all EPN analysis centers, updated weekly

[D.9] EPN site classification based on precision of cumulative positions and velocities of each station (historical and present)
http://www.epncb.oma.be/_trackingnetwork/coordinates/,
ftp://epncb.oma.be/pub/station/coord/EPN/
List of Class A (with positions and velocities) and Class B (only positions) stations, updated each 15 weeks. Only Class A stations can be used by users (e.g. Mapping Agencies) when computing a densification of the ETRS89. Coordinates are available in both ITRS as ETRS89 systems.

[D.10] Official ETRS89 coordinates of EPN stations used in the different countries
http://www.epncb.oma.be/_trackingnetwork/coordinates/
Coordinate list including comparison with coordinates from [D.9]

[D.11] Plots of position time series of EPN stations (since 1996)
http://www.epncb.oma.be/_dataproducts/timeseries/
Plots of position time series for all EPN stations (4 different types), some updated daily, others updated when new solutions become available

[D.12] Rapid solutions from EPN LAC
http://www.epncb.oma.be/_dataproducts/analysiscentres/LACrapidts
Several of the EPN local analysis centers compute hourly (in near-real time) or daily (rapid) site position for EPN stations. We provide the residual position time series of these solutions. The goal is to provide a tool that allows EPN LAC to quickly inter-compare their solutions prior to the elimination of outliers.

[D.13] EUREF mail archive (since 1996)
http://www.epncb.oma.be/_newsmails/mails.php
Mails sent to the distribution lists: EUREF, EUREF analysis centers and EUREF real-time, updated upon distribution of new mail

[D.14] EPN Guidelines for Stations, Operational Centers, Data Centers and Analysis Centers
http://www.epncb.oma.be/_organisation/guidelines/index.php
Guidelines and requirements (pdf format) for routine EPN operations, updated when necessary

[D.15] Papers related to EPN

http://www.epncb.oma.be/_newsmails/papers/
On-line access to papers using GNSS data from EUREF Permanent Network, updated twice a year, or on request

[D.16] EPN Operational Center forms
ftp://epncb.oma.be/pub/center/oper
Machine-readable form describing which agency is responsible for which EPN station, includes contact information, updated upon request

[D.17] EPN Data Center descriptions
ftp://epncb.oma.be/pub/center/data
Machine-readable form describing data and products available at each of the EPN data centers, includes acces information and directory structure, and contact information, updated upon request

[D.18] EPN Analysis Center descriptions
ftp://epncb.oma.be/pub/center/analysis
Machine-readable form describing GNSS data analysis method used at each EPN analysis center, includes contact information, updated upon request

[D.19] GNSS tracking data from ROB network, including ELIS (Antarctica) (since start of operation)
http://www.epncb.oma.be/_dataproducts/data_access/dailyandhourly/,
http://www.gnss.be/_downloads/data.php, ftp://gnss.be/gnss/data/rinex/daily/ (public, only ROB EPN stations)
gnss-data, virtual server at ROB (internal use, all stations)
Daily and hourly RINEX observation files, updated hourly

[D.20] ROB site log files (since start of operation)
http://www.gnss.be/_downloads/data.php, http://www.gnss.be/ftp/station/log/ (public for EPN stations,
gnss-data, virtual server at ROB (internal use, all stations)
Machine-readable description of GNSS tracking site (e.g. equipment and co-located instrumentation), updated after each configuration change at a ROB station

[D.21] GNSS tracking data from national GNSS densification networks (Belgium: FLEPOS, WALCORS, GPSBru, Germany, France, UK) (since start of networks)
gnss-data, virtual server at ROB (internal use)
Daily RINEX observation files, updated daily

[D.22] Cumulative position/velocity solutions of GNSS core networks managed by IAG regional reference frame subcommissions
Actis, computation server at ROB (internal use)
Position/velocity solutions in SINEX format, updated upon release of new solutions

[D.23] Residual position time series of GNSS core networks managed by IAG regional reference frame subcommissions
http://iagvf.oma.be/timeseries.php (for use within IAG working group on 'Regional Dense Velocity Fields')
In graphical format, updated upon release of new solutions

[D.24] Near Real-Time (hourly) European GNSS observation database (floating windows containing last year of data, since 2002)
For internal use by the GNSS team
Hourly updated database of RINEX observation files from about 340 European GNSS stations used for the near real-time monitoring of the European atmosphere.

[D.25] Near Real-Time GNSS orbits and clocks database (2000-now)
For internal use by the GNSS team
Hourly updated database of GNSS orbit and clock products from CODE and IGS used for the rapid and near real-time monitoring of the European atmosphere.

[D.26] Precise GNSS orbits and clocks database (1995-now)
For internal use by the GNSS team
Daily updated database of precise GNSS orbit and clock products from CODE and IGS used for precise coordinate determination.

[D.27] Near Real-Time (NRT) Zenith tropospheric Path Delay (ZPD) database (2007-now)
For internal use by the GNSS team + Submitted to E-GVAP members
Hourly updated database of 15-min sampled NRT (hourly) estimations of ZPD in Bernese and COST-716 formats from about 210 European GNSS stations used for the near real-time European troposphere monitoring and for meteorology applications.

[D.28] Post-Processing Zenith tropospheric Path Delay (ZPD) database (2007-now)
For internal use by the GNSS team
Daily updated database of 1-hour sampled post-processing (daily) estimations of ZPD in Bernese and COST-716 formats from about 450 European GNSS stations used for the precise European troposphere monitoring.

[D.29] Real-Time GNSS observation database (floating windows containing last 2 weeks of data, since November 2010)
For internal use of the GNSS team
Real-time updated database of EPN observations (about 110 stations), IGS observations (about 50 stations) and real-time IGS orbits and clocks in support of the future real-time data analysis (troposphere and ionosphere monitoring)

[D.30] Clock data
ftp.bipm.fr
Clock comparisons between UTC(ORB) and our other cesium and maser clocks, sent regaularly to the BIPM and archived at the ROB for internal use.

[D.31] RUSTICCA archives
dbs029.oma.be:/home/thierry/ccd/images/
The archive contains the raw data of all images taken in the course of the RUSTICCA project at the Ukkel Schmidt Telescope. It is stored on 412 CD-ROMs, of which the last 15 were added in 2010. They contain in total 29 163 images and films. Alternatively, it is also available on an external hard disc connected to Thierry Pauwels' PC dbs029, and accessible from any computer of the oma domain through a samba mount. Images are in fits and fully self-documenting. For searching images, a file with a summary of the characteristics is available: dbs029.oma.be:/home/thierry/ccd/cdrom/list.all.

[D.32] The Interactive Database of Spectral Standard Star Atlases,
at *spectra.freeshell.org*
see section K.3

[D.33] The Atomic Line list
http://www.pa.uky.edu/~peter/atomic
see section K.2

[D.34] Uccle sunspot drawings
http://www.sidc.be/uset

Visual sunspot drawings made as part of the historical series of visual sunspot record starting in 1940 in support of the determination of the international sunspot index (daily EISN, monthly prompt index) and of long-term solar cycle studies.Data production in 2010: 293 drawings on 246 observing days.

[D.35] Digital archive of historical Uccle sunspot drawings
http://www.sidc.be/uset
70-year series of visual sunspot record starting in 1940 in support of long-term solar cycle studies and of the study of long-term trands in the international sunspot index. Data production in 2010: digitization of 30 years (~8000 drawings), measurements of 20 years (~4500 drawings).

[D.36] USET white-light CCD images of the photosphere
http://www.sidc.be/uset
Series of full-disk CCD images in broadband visible light (centered on 510nm) starting in 2002. Those images are published in near real-time on the Web in support of solar activity monitoring and forecast services and archived as FITS files for research applications. Data production in 2010: 936 synoptic images on 246 observing days.

[D.37] USET Hα CCD images of the chromosphere
http://www.sidc.be/uset
Series of full-disk CCD images in the Hα line (bandpass 0.05 nm) starting in 2003. Those images are published in near real-time on the Web (ROB, GHAN) in support of solar activity monitoring and forecast services and archived as FITS files for research applications. Data production in 2010: 1911 synoptic images on 246 observing days.

[D.38] LYRA Level 1 FITS files
http://proba2.oma.be/lyra/data/eng
Generation of the LYRA raw 'standard' time curves

[D.39] PROBA2 Science Center databases.
Databases to log, monitor and plan the PROBA2 Science Center activity.

[D.40] SWAP Level-0 FITS Files
http://proba2.oma.be/swap/level0/
Uncalibrated FITS-format files containing all SWAP/PROBA2 images received from the spacecraft. These images are also available via the SWAP Object, which is part of the SWAP/PROBA2 SSWIDL software package. Files are organized by calendar year, month, and day.

[D.41] SWAP Level-1 FITS Files
http://proba2.oma.be/swap/level1/
Prepped and calibrated FITS-format files containing only images from SWAP/PROBA2 not intended for use in calibration, obtained during earth occultation, or affected by spacecraft maneuvers. These images are corrected for dark noise, bad pixels, transient bright pixels due to radiation or particle hits to the detector, and have rotation corrected so solar north is up in each image file. These images are also available via the SWAP Object, which is part of the SWAP/PROBA2 SSWIDL software package. Files are organized by calendar year, month, and day.

[D.42] SWAP Daily Movies
http://proba2.oma.be/swap/movies/
Daily movies and running-difference movies composed of all high-quality Level-1 images obtained each day and distributed in MP4 format. These movies are currently cropped to match the EIT field of view and are organized by calendar year and month. Links are also provided to

movies containing the latest SWAP data for use in space weather forecasts and rapid analysis of recent events.

[D.43] AIA 4Kx4K full resolution images
http://sdodata.oma.be
Full resolution and full cadence images in several wavelengths of the solar atmosphere. These images take a few days to prepare from the raw data, but are the science quality data for the AIA telescopes.

[D.44] AIA 1Kx1K quicklook images
http://sdodata.oma.be
Reduced resolution images of the solar atmosphere. Alignment and calibration is not carried out to the same extent as for the full resolution images, but the data is distributed within hours of acquisition. These are served by ROB in a variety of formats including movies.

[D.45] HMI 4Kx4K full resolution magnetograms
http://sdodata.oma.be
Magnetograms computed from the HMI instruments. Like the full resolution AIA images, these take some days to compute, but are then usable in conjunction with the AIA full resolution images. It was not initially intended to carry these images, but user interest plus data compression efficiency have made it possible to carry a large subset.

[D.46] DATA_SIDC database
This database contains historical space weather data, space weather forecast, sunspot data coming from wolf interface.

[D.47] CACTus LASCO CME catalog (version 2)
http://sidc.oma.be/cactus/catalog.php
CME catalog spanning 1997 – present produced with cactus version 2.5.0

[D.48] NEMO events in EIT-SOHO data: 1997-2010
http://www.sidc.be/nemo/catalog/
Full catalog of solar eruptions detected by NEMO from EIT-SOHO data: 1997-2010The catalog contains information on the extracted events with their parameters, such as timing, diming area and movies with their dimming as well.

[D.49] NEMO-SOHO real-time events detection catalog.
http://www.sidc.be/nemo/catalog/
Catalog of NEMO-SOHO events deteted in real-time since 2006 during NEMO operational work.Past events are also accessible in the NEMO catalogue.

[D.50] Experimental catalog of small-scale eruptions detected with STEREO data.
http://www.sidc.be/nemo/whi/
Application of NEMO software to set of STEREO data(here we present only the up to present validated events)

[D.51] Humain Callisto data
http://sidc.be/humain
Radio spectrograms of the Sun, between 45 and 387 MHz, recorded automatically every day from Sunrise to Sunset. During the week, observations are made with the antenna tracking the Sun. Data are available on the mentioned website as PNG quicklook and FITS files, under an open data policy.

GENERAL SCIENTIFIC ACTIVITIES

Expertise, Audit

- C. Bruyninx: Member of the scientific Committee of “Service d’observation Institut National des Sciences de l’Univers géodesie-gravimétrie”; Reviewer for Hungarian Scientific Research Fund (OTKA); Reviewer for FNRS; Reviewer for CNES research projects.
- P. Defraigne: Member of the Scientific Committee of Laboratoire National d'Etalonnage, section Time and Frequency.
- V. Dehant: Member of “Joint Mars Architecture Review Team” of ESA and NASA; Member of “Solar System Exploration Working Group” of ESA; Member of the Science Analysis Group of Mars Exploration Program Analysis Group of NASA, NetSAG subgroup; Member of the Comité des Programmes Scientifiques of CNES ; Member of the Scientific Advisory Committee of the Helmholtz Alliance “Planetary Evolution and Life”; Member of the Scientific Committee of International Space Science Institute; Member of the Scientific Council of the Institut de Physique du Globe de Paris ;Member of “Groupe d’évaluation du Groupe de Recherches en Géodésie Spatiale ; Member of the Comité Scientifique et Technique of the Institut Géographique National de France.
- E. Pottiaux: Member of the Expert group on GNSS data processing of the EUMETNET EIG GNSS water VApor Program (E-GVAP) II.
- P. Rosenblatt: Review of the tracking data collection of the Magellan spacecraft (1991-1994) to be included in the Planetary Data System (PDS) (http://pds.nasa.gov/).
- R. Van der Linden: member of the Scientific Committee of the National Geographical Institute; Member of the science advisory team of the SN-II "Implementation Design Study of Space Weather Instruments" in the framework of the ESA SSA programme.
- T. Camelbeeck: member of the Scientific Council of the “Bureau Central Sismologique Français
- R. Blomme, jury member return-grants Belgian Science Policy, 27/5/2010;
- M. Groenewegen: External Examiner in M.Sc. thesis of Ben Tatton, University of Hertfordshire, Hatfield, 8 November 2010
- H. Hensberge: ESO, OPC subpanel D1 (Garching, Germany, Nov. 23-25)
- A. Zhukov: Member of the science advisory team of the SN-II "Implementation Design Study of Space Weather Instruments" in the framework of the ESA SSA programme.
- O. Podladchikova: Member of the FP7 evaluation comitte for the space science projects in 2010; Member of the FP7 Maria-Curie individual fellowships selection committee in 2010.
- C. Marqué: Member of working group on the extension of the Lhoist quarry near Humain

Scientific responsibilities

- P. Defraigne: responsible for the Architecture part of the ESA/EU WG on Galileo Time Service Provider.
- V. Dehant: PI of the Lander Radioscience experiment (LaRa) in the frame of the AURORA/ExoMars mission to Mars; Co-I of the Seismology experiment (SEIS) in the frame of the AURORA/ExoMars mission to Mars; Co-I of Mercury Orbiter Radio-science Experiment (MORE) in the frame of the ESA BepiColombo mission to Mercury; Co-I of BepiColombo Laser Altimeter (BeLA) in the frame of the ESA BepiColombo mission to Mercury; Co-I of the VenusExpress Radio science experiment (VeRa) in the frame of the ESA VenusExpress mission; Co-I of the MarsExpress Radio Science experiment (MaRS) in the frame of the ESA MarsExpress mission; Member of the ExoMars Science Working Team (ESWT) in the frame of the ESA MarsExpress mission; Member of the Scientific Organizing Committee of “Journées Systèmes de Références Spatio-Temporels”.
- Ö. Karatekin: Member of the Geophysics subgroup of the Galilean satellites working group in the Europa Jupiter system Mission (EJSM) study; CO-I of NOMAD instrument onboard of Martian Trace Gas Orbiter 2016.

- S. Le Maistre: Co-I of LaRa (Lander Radioscience experiment), the radioscience experiment of the ExoMars mission to Mars.
- M. Mitrovic: Co-I of LaRa (Lander Radioscience experiment), the radioscience experiment of the ExoMars mission to Mars;
- P. Rosenblatt: Co-I of LaRa (Lander Radioscience experiment), the radioscience experiment of the ExoMars mission to Mars; Co-I of the VenusExpress Radio science experiment (VeRa) in the frame of the ESA VenusExpress mission;Co-I of the MarsExpress Radio Science experiment (MaRS) in the frame of the ESA MarsExpress mission; Co-I of Phobos Grunt Radioscience experiment,
- T. Van Hoolst: Co-I of SIMBIO-SYS (Spectrometers and Imagers for MPO BepiColombo Integrated Observatory SYStem), the camera experiment of ESA's BepiColombo mission to Mercury; Co-I of MORE (Mercury Orbiter Radio-science Experiment), the radio science experiment of ESA's BepiColombo mission to Mercury; Co-I of LaRa (Lander Radioscience experiment), the radioscience experiment designed for the ExoMars mission to Mars; Member of the Joint Science Definition Team of ESA and NASA of the Europa Jupiter System Mission (EJSM), responsible for the 'Jupiter System Working group'.
- V. Delouille : Co-I of SDO Science Center/Feature Finding Team at SAO, Harvard, USA

Educational responsibilities (Lectures, students, …)

- W. Aerts: Promoter at KHLim of two MSc theses on GNSS receivers on FPGAs (end in June 2011),
- N. Bergeot: Co-promoter of internship "Contribution des Systèmes GNSS pour une Meilleure Compréhension des Déformations de la Croûte Terrestre: Application à l'Europe" of Victor Lacombe (Master on Modeling and Computational Science, University of Rennes I, France) at ROB ; Promoter of internship "Modélisation de l'ionosphère au-dessus de l'Europe à partir de données GPS" of Lionel Benoit (ENSG, Marne la Vallée, France) at ROB ; Teaching at UCL Bac 3 "PHY1312 Analyse de données GPS"; N. Bergeot: Teaching at UCL Master 1 "PHY2160 Géophysique Interne",
- C. Bruyninx: Co-promoter PhD thesis "Sounding the Earth's Atmospheric Water Vapour Using Signals Emitted by Global Navigation Satellite Systems" (E. Pottiaux, at UCL); Promoter of internship "Contribution des Systèmes GNSS pour une Meilleure Compréhension des Déformations de la Croûte Terrestre: Application à l'Europe" of Victor Lacombe (Master on Modeling and Computational Science, University of Rennes I, France) at ROB ; promoter of master thesis "Feasibility Study of Ionospheric Tomography based on GNSS Observations over Europe" of J.-M. Chevalier,
- J.M Chevalier: Co-promoter of the internship "Determining an optimal orbit for a Low Earth Orbit (LEO) satellite equipped with a GNSS receiver in order to obtain a maximum number of atmospheric occultations" of Reza Soufian (Master 1) University of Rennes 1,
- P. Defraigne: Co-promoter of Mari Carmen Martinez (Univ. Alicante) for her PhD; Promotor of Eric Pottiaux (UCL); Lecturer: Mathematical Astronomy (PHY2161), 15h, UCL,
- V. Dehant: Lecture at Université Catholique de Louvain (UCL), 7.5h, Astronomy and Geophysics ; Lecture at Université Catholique de Louvain (UCL), 22.5h, Internal Geophysics ; Lecture at Université de Nantes, 15h, Planetary Geophysics ; Lecture at Université de Liège, 2h, Planetary Habitability ; Promoter at UCL of PhD of A. Rivoldini, G. Pfyffer, S. Le Maistre, A. Trinh, L.B.S. Pham, R.M. Baland, A. Hees; Member of the jury of the PhD thesis of J. Dufey (FUNDP), L. Seoane (Observatoire de Paris), E. Pottiaux (ROB/UCL),
- Ö. Karatekin: Co-promoter of the PhD thesis of L. Pham,
- J. Legrand: Co-promoter of internship "Contribution des Systèmes GNSS pour une Meilleure Compréhension des Déformations de la Croûte Terrestre: Application à l'Europe" of Victor Lacombe (Master on Modeling and Computational Science, University of Rennes I, France) at ROB; Co-promoter of internship "Modélisation de l'ionosphère au dessus de l'Europe à partir de données GPS" of Lionel Benoit (ENSG, Marne la Vallée, France) at ROB,
- P. Rosenblatt: Lecturer at Université Catholique de Louvain (UCL), 15h, Internal Geophysics ; Co-promoter of the PhD thesis of S. Le Maistre (UCL); Member of the jury of the PhD thesis of G. Pfyffer, Université Catholique de Louvain, Louvain-La-Neuve, Belgium, 25February 2010,

- T. Van Hoolst: Lecturer of the master course “Theoretical seismology” at the Katholieke Universiteit Leuven, 26h (every two years); Lecturer of the master course “Physics of Planets” at the Katholieke Universiteit Leuven, 26h (every two years);Member of the jury of the PhD thesis of G. Pfyffer, Université Catholique de Louvain, Louvain-La-Neuve, Belgium, 25February 2010;co-promoter at the UCL of PhD students A. Rivoldini, G. Pfyffer, R.M. Baland and A. Trinh.
- M. Yseboodt: co-promoter of Rose-Marie Baland (Ph.D. student - UCL).
- P. Alexandre: Professor at the Liège University: "Géographie historique", 30 h; "Éléments de critique historique à l'usage des géographes", 30 h, member of the "jury de doctorat en Sciences" of the thesis of A. Melnik, "La gestion des risques naturels et anthropiques dans la région du lac Baïkal: une approche spatio-temporelle" (Université de Liège, February 9, 2010).
- T. Camelbeeck: lecturer at ULB (Physique du Globe et Géophysique Appliquée – 3 ECTS chacun), promoter or co-promotor of the Phd thesis of Thomas Lecocq (ULB), Corentin Caudron (ULB), Devy Syahbana (ULB) and Dimitri Kusters (ULB).
- T. Lecocq: *Electrical Resistivity Tomography*, student exercises, ULB - Responsible for the scientific control of Mehmet Cinar's intership (IT dev of our routine seismic data analyse software).
- K. Vanneste: Guest lecturer at the University of Gent, co-lecturer of the optional course “Natural Hazards” – Member of the examination committee of the Ph.D. thesis of Jasper Moernaut “Sublacustrine landslide processes and their paleoseismological significance – Revealing the recurrence rate of giant earthquakes in South-Central Chile”, University of Gent, defended 26 April 2010.
- M. Van Camp: Member of the jury of the Thesis « The effect of water storages on temporal gravity measurements and the benefits for hydrology », by N.A.B. Creutzfeldt, U. Potsdam, 29 October 2010.
- Peter De Cat: Member of the scientific committee of the PhD of Pieter Degroote
- P. Lampens: preparation and teaching of a course “Astronomie et Géophysique” at the in collaboration with Prof. V. Dehant (Part II, 7.5 hours, 2nd grade in Physics).
- P. Lampens: elaboration and organisation of a practical exercise related to double-star astronomy for students of the 3rd grade in Science (in collaboration with the titulars, Drs M.-F. Loutre and P. Defraigne) on May, 4th (2 hours).
- August, 1-31: S. Rabtach (student) worked on the preparation of an electronic publication based on observations of visual double stars made by Dr. Van Dessel at the 45-cm equatorial refractor of the Royal Observatory (1969-1974) under the guidance of P. Lampens.
- Y.Frémat: supervision of E. Van Der Beken (ULG trainee: 01-02.02.2010).
- M. Groenewegen: Co-promoter at KU Leuven of PhD student Djazia Ladjal
- V. Delouille: co-promoter at Université catholique de Louvain of Catherine Timmermans (PhD Student)
- F.Clette: Maître de Conférence, course " Le Soleil: structure, activité et impact sur l'environnement terrestre ", Université de Liège, Master "Astrophysique et Sciences Spatiales", 30h.
- A. BenMoussa: promoter at ROB of A. Mekaoui (End of Studies Project, 6 months)
- O. Podladchikova: Promoter at graduation project of third-year level student Jimmy Broche (ESI-Bruxelles); Promoter of 2 MSc thesis of 6-th year students: Pavel Leontiev and Anatoly Vuets (NTUU - Kiev).

Belgian representations at international level

- R. Van der Linden: Belgian Representative & Grantholder in the COST management committee (COST action ES0803 “Developing Space Weather Products and Service in Europe”.
- C. Bruyninx: Belgian representative in Management Committee of COSTES701 “Improved constraints on models of glacial isostatic adjustment”,
- P. Defraigne: Belgian representative for the Consultative Committee for Time and Frequency,
- V. Dehant: Belgian IAG representative at IAG Council,

- E. Pottiaux: Belgian representative of the geodesy community within the EUMETNET EIG GNSS water VApor Program (E-GVAP) II.
- T. Camelbeeck: Belgian representative at the **I**nternational **A**ssociation of **S**eismology and **P**hysics of the **E**arth **I**nterior - Belgian representative at the **I**nternational **S**eismological **C**entre
- M. Van Camp: Belgian representative at ORFEUS board of Director and in the COST management committee (COST action ES0701 "Improved Constraints on Models of Glacial Isostatic Adjustment").
- K. Vanneste: Titular member for Belgium in the European Seismological Commission (ESC) for the period 2006 – 2010.
- M. Groenewegen: Belgian representative in ESO's User Committee
- Griet Van de Steene: member of the VISA TAC committee
- F.Clette: Belgian representative to the JOSO Board (Joint Organisation for Solar Observations) since 1992.
- C. Marqué: Belgian representative in CRAF

Memberships of national scientific committees:

- R. Van der Linden: Member of the Belgian National Committee for Astronomy; Member of the Belgian National Committee for the Solar-Terrestrial Relationship
- C. Bruyninx: Vice-secretary of the Belgian National Committee for Geodesy and Geophysics; Associate Member of the National Committee for Space Research.
- P. Defraigne: Member of the CNBGG.
- V. Dehant: Member of the Belgian National Committee of Geodesy and Geophysics; Member of the Belgian National Committee of Astronomy; Member of the Belgian National Committee of Space Research;Member of the Executive Board of the Solar Terrestrial Center of Excellence,
- E. Pottiaux: Member of the STCE Water Vapour and Climate System Working Group,
- P. Rosenblatt: Member of the Belgian National Committee of Geodesy and Geophysics,
- T. Van Hoolst: Effective Member and assistant secretary of the Belgian National Committee for Astronomy (BNCA); Associate Member of the Belgian National Committee for Geodesy and Geophysics (BNCGG); Associate Member of the Belgian National Committee for Space Research,
- M. Yseboodt: Associate Member of the Belgian National Committee of Geodesy and Geophysics.
- Pierre Alexandre is member of the Contact Group of the F.N.R.S.: "Histoire de l'Environnement – Réseau Interdisciplinaire".
- T. Camelbeeck: Member of the Overseas Sciences Royal Belgian Academy - Vice-President of the Belgian Committee for Geodesy and Geophysics - Member of the BELQUA Committee
- F. Collin: Associate member of the Belgian National Committee for Geodesy and Geophysics (BNCGG).
- M. Van Camp: Associate member of the Belgian National Committee for Geodesy and Geophysics (BNCGG).
- Kris Vanneste: Member of the Belgian National Committee for Geodesy and Geophysics (BNCGG).
- Y. Frémat: HERMES Representative for the Royal Observatory of Belgium; member of the Hermes consortium and TAC (Time allocation committee) ; member of the Belgian National Committee for Astronomy
- M. Groenewegen: Member of Belgian National ESO Committee (BNEC); Coordinator of the Belgian Guaranteed Time on ESO's VLTI Sub-Array (VISA), and chairperson of the corresponding national TAC.
- F.Clette: associate member of the Belgian URSI Committee, Royal Academy of Sciences (since 2003); member of SCAS (Sous-Comité d'Astronomie Spatiale), Royal Academy of Sciences (since 1996); member of the Comité National de Recherche Spatiale, Royal Academy of Sciences (since 2003); member of the "Comité National Belge des Relations Soleil-Terre", Royal Academy of Sciences (since 2003)
- C. Marqué: Associate Member of the Belgian URSI Committee

Memberships of international scientific committees:

- R. Van der Linden: member of the Inter-Programme Coordination Team on Space Weather; member ISES Board; member of the Space Weather Working Team; member of the ESA - Space Situational Awareness Users Group; member of IAU Commission 10; member of UN-COPUOS informal working group on long-term sustainability of space travel.
- C. Bruyninx: Chairwoman of the EUREF Technical Working Group; Chairwoman of the IAG Working Group on “Regional Dense Velocity Fields” ; Chairwoman of the EPN Coordination Group; Member of the Governing Board of the International GNSS Service; Member of the Governing Board of the IAG Inter-Commission Working Group of European Geoscientists for the Establishment of Networks for Earth Science Research (WEGENER), joint with IAG Commission 3; Member of ESA Galileo Geodetic Reference Interface Working Group; Member of the IAG Inter-Commission Project IC-P1.2 on “Vertical Reference Frames”, joint with Commission 2 and IGFS; Member of the EUREF Working Group on Future Development of ETRS89; Member of the EPN Working Group on EPN Reprocessing; Member of the Working Group “European Combined Geodetic Network (ECGN)” of the EUREF Subcommission of the IAG; Member of the IGS Infrastructure Committee; Member of the IGS Working Group on “GNSS Antenna”; Member of the IGS Working Group on “Galileo/GNSS”; Member of IGS Real-Time Pilot Project Working Group; Member of Commissions 1 and 4 of IAG; Member of Commission 19 of IAU.
- P. Defraigne: Member of Organizing Committee of the IAU Commission 19 (Earth Rotation) up to August 2009; past-President of the IAU Commission 31 (Time) 2009-2012; Member of the SOC of the EFTF; Member of the Consultative Committee for Time and Frequency; Member of the Organizing Committee of the Division I “Fundamental Astronomy” of the International Astronomical Union, 2003-2009; Member of the Scientific Council Time-Frequency at the Laboratoire National d’Etalonnage (France); Member of the Galileo FOC Timing Working Group, 2010-2012, responsible for the part “Architecture et Opérations”.
- V. Dehant: Member of the Selection Committee for the Vening Meinesz Medal of the European Geophysical Union; Member of the Selection Committee for the Bowie Medal of the American Geophysical Union; Associate Member of the IERS
- Ö. Karatekin: Member of International Association of Geodesy (IAG) Commission 3 advisory board; Member of International Astronomical Union (IAU) Division III Planetary system sciences, Commission 15 on Physical Study of Comets and Minor Planets,
- J. Legrand: Member of the IAG Working Group on “Regional Dense Velocity Fields”; Member of the EPN Central Bureau; Deputy member of the Management Committee of COST ES701 “Improved constraints on models of glacial isostatic adjustment”.
- T. Van Hoolst: Head of the SBC (Special Bureau of the Core) of the IERS; Member of the Steering Committee of the Intercommission Committee on Theory (ICCT) of the International Association of Geodesy (IAG); Effective Member of IAG Subcommission 3.3 "Geophysical Fluids" of the IAG Commission 3 "Geodynamics and Earth Rotation"; Associate Member of the IERS.
- M. Van Camp: Member of the ‘Working group on Gravimetry’, Consultative Committee for Mass and Related Quantities, Bureau International des Poids et Mesures (BIPM, Sèvres, France) - Member of the Study Group 2.1.1 on Comparisons of Absolute Gravimeter SGCAG of sub-commission 2.1 (Gravity and Gravity Networks) of IAG Commission 2 (Gravity Field) - Representative of the Observatory as IRIS foreign affiliate - Member of the study group “Application of time-series analysis in geodesy” (Intercommission Committee on Theory of the IAG)
- Peter De Cat: Member of the COROT "γ Doradus stars Working Group"; Member of the COROT "B stars Working Group"; Member of the COROT "O stars Working Group"; Member of the GAIA "Hot Star Group"; Member of the GAIA-DPAC Coordination Unit 7 "Variability processing" (CU6, since 2006); Member of the HERMES consortium; Member of IAU commission 20; Member of IAU commission 26; Member of IAU commission 27; Member of the Kepler Asteroseismic Science Consortium; Member of the KASC WG #3 "β Cephei stars"; Chair of the KASC WG #6 "Slowly Pulsat-

ing B stars" and of the KASC subWG#6.3 "Ground-based follow-up observations for Slowly Pulsating B stars"; Member of the KASC WG #9 "Pulsations in eclipsing binaries"; Member of the KASC WG #10 "γ Doradus stars"; Member of the Nederlandse Astronomen Club (since 2007)

- Jean-Pierre De Cuyper: Member of the European regional FITS committee.
- Thierry Pauwels: Member of IAU Commission 7 "Celestial Mechanics & Dynamical Astronomy"; Member of IAU Commission 8 "Astrometry"; Member of IAU Commission 20 "Positions & Motions of Minor Planets, Comets & Satellites"; Member of CU4 of Gaia DPAC; DU leader of DU454 of Gaia DPAC; Member of the IAU Task Force on the Preservation and Digitization of Photographic Plates (PDPP); Member of IAU Working Group on the Astrographic Catalogue and Carte du Ciel Plates; Member of IAU Working Group "Astrometry by small ground-based telescopes"; Member of the CODATA "Data At Risk Task Group".
- Y. Frémat, P. Lampens, K. Torres: Members of the HERMES consortium
- P. Lampens: Member of IAU Commissions 26 & 27; Member of the KASC Working Group 9 "Pulsations in eclipsing binaries"; Member of the HERMES consortium; Member of the CoRoT Binary Thematic Team; Member of the European Astronomical Society (EAS)
- Y.Frémat: Members of the HERMES consortium; member of the IAU Commission 36 "Theory of Stellar Atmospheres"; member of the Data Processing and Analysis Consortium of Gaia (DPAC); member of the management team of the CU8 unit in DPAC; member of the Gaia Hot Stars Team; member of the CoRoT Be stars Team;member of the Kepler Be stars Working Group.
- R. Blomme: Member of IAU Commission 36; Member of the COROT "O stars Working Group"
- J. Cuypers: Member of IAU commissions 15, 25 and 27; Member of the GAIA-DPAC Coordination Unit 7 "Variability processing" (CU7); Member of the COROT "B stars Working Group"; Member of the COROT "O stars Working Group"; Member of the Kepler Asteroseismic Science Consortium
- M. Groenewegen: Member of IAU Commission 27; Member of Euro-VO Scientific Advisory Committee; Member of the GAIA-DPAC Coordination Unit 7 "Variability processing" (CU7)
- G. Van de Steene: Member of IAU Commission 34
- F.Clette: member of URSI Commission J (Radioastronomy); member of COSPAR (Committee on Space Research); member of IAU Commission 12 (Solar radiation and structure) and "Solar Eclipses" Working Group
- D. Seaton, Member of the American Geophysical Union; member of the American Astronomical Society & AAS Solar Physics Division; Member of ISSI Working Group on Prominence Cavities
- L. Rodriguez: Member of the ISSI international team: "From the Sun to the terrestrial surface: understanding the chain". http://www.issibern.ch/teams/terrestsurf/
- C. Marqué: Member of CRAF (Committee on Radio Astronomy Frequencies); Member of the CESRA board (Community of European Solar Radio Astronomers)

Editorial responsibilities

- R. Van der Linden: Member of the Editorial Board of the Journal of Space Weather and Space Climate
- C. Bruyninx: Member of the advisory editorial board of GPS Solutions,
- V. Dehant: Member of the IERS Conventions editorial board
- Ö. Karatekin: Associate Editor for Journal of Geophysical Research Planets; Managing-Guest-Editor for Planetary and Space Science.
- Kris Vanneste: Co-editor with L. Cucci, P.M. De Martini & E. Masana of special volume "Active tectonics in the Mediterranean and Europe: site studies and application of new methodologies" in Annals of Geophysics, to be published in 2011
- L. Rodriguez: Guest Editor for the Prospective EGU special issue "Three dimensional aspects of CMEs, their source regions and interplanetary manifestations" in press in the Journal of Atmospheric and Solar-Terrestrial Physics (JASTP).

- M. Mierla: Guest Editor for the Prospective EGU special issue “Three dimensional aspects of CMEs, their source regions and interplanetary manifestations” - Journal of Atmospheric and Solar Terrestrial Physics
- C. Marqué: Guest Editor (with A. Nindos) for a Topical Issue of Solar Physics

Meeting organization

- C. Bruyninx: Member of Scientific Committee of Symposium of the IAG Subcommission for Europe (EUREF), June 2-5, 2010, Gävle, Sweden; Chair of session “Issues in network infrastructure” at IGS Workshop, 28 June – 1 July 2010, Newcastle upon Tyne, UK; Member of Scientific Committee of WEGENER symposium, September 14-17, 2010, Istanbul, Turkey.
- P. Defraigne: Co-organizer of EFTF 2010, in Noordwijk, co-chair of group 5” Time Timekeeping, Time and Frequency Transfer, GNSS and Applications”.
- V. Dehant: Co-organizer (with Christian Muller of IASB) of COST workshop on ‘The Chemical Cosmos’, 6-8 December; Organizer of FNRS Contact Group Astrobiology, 8 December;Co-organizer (as member of the SOC) of the Journées Systèmes de Référence Spatio-temporels 2010.
- Ö. Karatekin: European Geophysical Union Program Committee Member of Planetary and Solar System Sciences group,
- T. Van Hoolst: Member of the Science Organizing Committee of the EJSM Science Meeting at Noordwijk, The Netherlands, 17-19 May.
- M. Van Camp: Co-chair of the Geodesy session “Estimating the Accuracy of Geodetic Measurements”, AGU Fall Meeting, San Francisco, December 13-17, 2010 - Member of the Geodesy Best Student Paper Committee, AGU Fall Meeting, San Francisco, December 13-17, 2010 - Co-chair and organization of the session “Separation of signals on micro to basin scales”, International Geoscience Programme (IGCP) 565 Workshop 3: Separating Hydrological and Tectonic Signals in Geodetic Observations, Reno, Nevada, October 11-13, 2010.
- T. Lecocq: Organizer of the SeisComP3 workshop in Brussels "Local/Regional tuning of SC3" - Co-Chairman of a session at AGU FM2010 : "NS - Inversion: Back to Basics" - Co-Chairman of a session at AGU FM2010 : "S – Earthquake relocations: What do They Tell Us"
- Peter De Cat: Member of the Scientific Organising Committee of the third Kepler Asteroseismology Workshop "Kepler Asteroseismology in Action", 14-18/06/2010, Aarhus, Denmark
- Y.Frémat: Co-organizer of the CU6 test meeting in Brussels (ROB) on 29.09.2010
- R. Blomme, Member of the SOC for the 39th Liège colloquium “A multi-wavelength view of Hot Massive Stars”
- M. Groenewegen: member of the Scientific Organizing Committee of the conference “Why galaxies care about AGB stars II”, Vienna, 16-20 August 2010; Preparation of the MESS videoconferences and consortium meetings.
- A. Lobel: Chair of the SOC and LOC member for GREAT-ESF Workshop “Stellar Atmospheres in the Gaia Era: Quantitative Spectroscopy and Comparative Spectrum Modelling” (on ESF & WFO-Flanders conference grant proposals 2010).
- V. Delouille: Co-organizer (member of SOC) of Solar Image Processing Workshop V, Les Diablerets, Switzerland, 2010
- V. Delouille: Leader of the Working Group on ‘Solar Disc Feature’ at the Solar Image Processing Workshop V, LesDiablerets, Switzerland, 12-16 September 2010; Co-organizer (member of LOC) of the IEEE International Conference on Image Processing (ICIP 2011), Brussels, September 2011.
- R. Van der Linden, P. Vanlommel, A. Vandersyppe and the SIDC team organised the 7th European Space Weather Week in Bruges, 15-19/11/2010.
- R. Van der Linden, Deputy Scientific Organizer of session PSW1 at the 2010 COSPAR Scientific Assembly, Bremen, Germany, July 18–25, 2010.
- D. Boyes: Leader of Working Group on ‘Emerging Informatics Infrastructure in Solar Physics’ at the Solar Image Processing Workshop V, LesDiablerets, Switzerland, 12-16 September 2010.

- A. Zhukov: Deputy Scientific Organizer of the session E22 "New views of the Sun with SDO" at the 2010 COSPAR Scientific Assembly, Bremen, Germany, July 18–25, 2010; Member of the Scientific Organizing Committee of the Fourth Solar Orbiter Workshop, Telluride, USA, March 27–31, 2011.
- S. Parenti: Main Scientific Organizer of the session *The Challenge of the Hidden Scales in Solar Dynamic Phenomena*, 38th COSPAR Scientific Assembly, Bremen, Germany, 18 - 25 July 2010.
- C. Marqué: Co-organizer of the 2010 CESRA meeting; Co-organizer of the 2010 Radio Science days
- S. Gissot : co-organizer of EUI Compression Working Group meeting, 4/10/2010, ROB

Awards/Promotions

- V. Dehant: Member of the Royal Academy of Belgium, Classe des Sciences.
- Peter De Cat was assigned as discoverer of 1 minor planet.
- Thierry Pauwels was assigned as discoverer of 8 minor planets.
- Thierry Pauwels, Anthony Jonckheere & Peter De Cat were assigned as discoverers of 1 minor planet.
- D. Seaton: Best talk by a young scientist, ESWW7, Brugge, Belgium

Varia

- P. Lampens: Co-administrator of the corporated association "*Belgian Women in Sciences*". Editor of three Newsletters (Dec. 2009, May 2010 and Dec. 2010).

Deel 2: Publieke Dienstverlenende Activiteiten

Partie 2: Activités de Service Publique

Part 2: Public Service Activities

Overview

A. PLANETARIUM

A.1. Activités

A.1.1. Visiteurs

En 2010, le Planétarium a accueilli **28.674 visiteurs**, nombre en hausse (+3.078 visiteurs / +12%) par rapport à l'année précédente qui avait cependant connu trois mois de fermeture en raison des travaux d'installation du système numérique. Le Planétarium retrouve ainsi le niveau d'affluence moyen (i.e. 28.900 visiteurs par an) observé de manière assez stable sur la période 2004-2008. Depuis l'année 2000, 290.639 personnes ont assisté à une séance payante au Planétarium de l'Observatoire royal de Belgique.

L'installation fin août d'une **nouvelle caisse et système de billetterie** équipés d'un logiciel de réservation et de gestion de base de données permettra d'obtenir dès 2011 des statistiques complètes et fiables permettant de faire des analyses plus détaillées sur, e.g., la part du public scolaire versus la part du public familial, l'impact des événements spéciaux, le succès des tickets combinés, l'équilibre entre public néerlandophone et francophone, la proportion de touristes étrangers, la répartition entre enseignants du primaire et du secondaire, l'attractivité des ateliers, les spectacles les plus appréciés, etc.

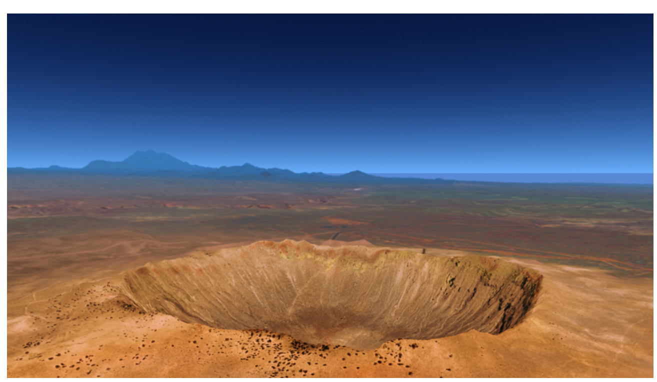
A.1.2. Spectacles

En avril a débuté la diffusion du spectacle pleine-voûte « Two small pieces of glass / L'Univers au télescope » produit par International Planetarium Society dans le cadre de l'Année Internationale de l'Astronomie.

Le 25 juin a eu lieu l'avant-première du spectacle pleine-voûte « Touching the edge of the Universe / Aux confins de l'Univers invisible » coproduit par l'ESA et l'association des planétariums allemands. Le Planétarium a pris en charge la traduction et l'enregistrement de la version néerlandophone de ce spectacle.

L'avant-première du spectacle pleine-voûte « Violent Univers / Fureurs dans l'Univers » produit par Evans & Sutherland a pour sa part été proposée le 1er décembre. Le Planétarium a pris en charge la traduction et l'enregistrement de la version francophone.

L'ancien programme « Schijn en werkelijkheid / Réel et apparent » a été complètement réécrit, programmé et mis en image pour une adaptation au système de projection numérique.



Au 31 décembre 2010, la programmation du Planétarium se composait des spectacles suivants :

- « Violent Univers / Fureurs dans l'Univers »
- « Touching the edge of the Universe / Aux confins de l'Univers invisible »
- « Two small pieces of glass / L'Univers au télescope »
- « ALMA, de zoetocht naar onze kosmische oorspong / ALMA, la quête de nos origines cosmiques »
- « Kleuterprogramma / Programme pour les tout-petits »

- « Schijn en werkelijkheid, versie 2010 / Réel et apparent, version 2010 »
- Cours d'astronomie pour écoles niveau maternelle, primaire / BaO , secondaire/ HSO et enseignement supérieur.

A.1.3. Evénements

Le Planétarium a organisé ou participé à de nombreux événements en 2010:

- une journée d'évaluation et de prospective des classes pilotes ESERO réunissant le 08 mai au Planétarium les directeurs d'école, inspecteurs et enseignants impliqués dans le projet ;
- la réunion 2010 du Groupe de Contact Astronomie et Astrophysique FNRS/ORB tenue le 25 mai au Planétarium ;
- une journée de présentation des projets de classe ESERO à la communauté enseignante le 26 mai au PASS ;
- la Nuit de l'Obscurité sur le site du Rouge-Cloître (Auderghem) le 16 octobre, en partenariat avec le Volksterrenwacht MIRA, l'Institut d'Astronomie et d'Astrophysique de l'ULB et des clubs amateurs de la région de Namur ; l'événement a permis d'accueillir plusieurs centaines de visiteurs qui ont assisté à des observations, des conférences, des concerts de musique « à la belle étoile », des contes pour enfants, des jonglages lumineux, etc. ;
- une journée d'information sur les projets de classe ESERO le 25 octobre au Planétarium.

A.1.4. Séances spéciales

Des séances spéciales de planétarium ont été organisées pour :

- les enseignants de la communauté flamande le 24 avril et le 23 octobre (journées pédagogiques) ;
- les enseignants de la communauté francophone le 16 octobre (journée pédagogique) ;
- le public familial dans le cadre des Nocturnes des Musées Bruxellois les 04 novembre et 02 décembre ;
- le grand public lors du Dag van de Wetenschap le 21 novembre au Planétarium, dans le cadre de la Vlaamse Wetenschapsweek.

A.1.5. Locations de salles

Les locaux du Planétarium ont été mis à disposition à différentes reprises dans l'année :

- réception de nouvel an du Haut-Représentant belge pour la politique spatiale le 19 janvier ;
- location par l'IFA le 29 janvier ;
- accueil du Comité de Direction de la Politique scientifique fédérale le 25 février ;
- location par la VRT (émission Goeie vrijdag) le 03 mai ;
- location pour Prosport le 22 septembre.

A.1.6. Promotion

Deux brochures scolaires (une version néerlandophone et une version francophone) ont été réalisées pour l'année scolaire 2010-2011. Ces publications s'adressent aux enseignants et décrivent au recto les programmes, les cours et les nouvelles activités pédagogiques du Planétarium, alors qu'au verso est présenté le nouveau spectacle pleine-voûte « ALMA, La quête de nos origines cosmiques ». Les dépliants/posters ont été envoyés à l'ensemble des écoles au moment de la rentrée scolaire.

Deux documents promotionnels sous forme de carte postale ont été produits pour accompagner le lancement des nouveaux spectacles Two small pieces of glass et Touching the edge of the Universe.

Une brochure grand public a été réalisée fin 2010 pour promouvoir les nouveaux horaires et le spectacle Violent Universe.

Le site Internet du Planétarium (www.planetarium.be) a été visité 107.005 fois (52.272 visiteurs différents) au cours de l'année 2010, pour un total de 682.389 pages consultées.

Un spot de promotion du Planétarium (25 secondes) a été produit en collaboration avec une firme extérieure et a été diffusé quatre semaines durant en mai dans la moitié des salles Kinepolis de Bruxelles, d'Antwerpen et de Braine-l'Alleud. Il a également été diffusé plusieurs semaines durant la même période sur les chaines de télévision du groupe RTL-TVI. Ces actions ont permis de contribuer à la notoriété accrue du Planétarium auprès du grand public.

A.1.7. Partenariats en Belgique

Au cours de l'été 2010 s'est décidé la concrétisation d'un partenariat étroit avec l'Atomium comportant plusieurs volets : (i) à l'Atomium : une exposition « Cosmos Be a star » sur l'astronomie telle que perçue par les philosophes et les artistes; (ii) entre les deux sites : l'exposition en plein air From Earth to the Universe ; (iii) au Planétarium : le lancement du spectacle Violent Universe ; (iv) le lancement d'un ticket combiné Atomium/Planétarium pour groupes et individuels.

Ce nouveau ticket combiné vient compléter ceux déjà mis en place (au niveau des visites de groupes) avec la Mini-Europe, Living Tomorrow et Technopolis.

Le Planétarium est membre des associations touristiques suivantes :

- Toeristische Attracties
- Attractions & Tourisme
- Brusselse Museumraad
- Office de Promotion du Tourisme Wallonie-Bruxelles.

A ce titre, il assiste aux différentes Assemblée générales et participe aux diverses actions promotionnelles du secteur (publication du guide et du site Internet 365.be, Nocturnes des Musées, etc.).

Le Planétarium est membre des associations de planétariums suivantes : « International Planetarium Society (IPS) », « Vereniging van Nederlandstalige Planetaria (PLANed) », « Association des Planétariums de langue Française (APLF) », « Arbeitsgemeinschaft deutschsprachiger Planetarien (ADP) » et est présent lors des différents colloques annuels.

A.1.8. Relations internationales

ESO (European Southern Observatory)

L'ESO a contracté le Planétarium pour agir en tant que représentant belge du ESO Outreach Network. Cela implique notamment la promotion des activités de l'ESO (diffusion des communiqués de presse et mise en place d'événements promotionnels) et la participation au siège de l'ESO à la réunion annuelle de coordination (ayant eu lieu les 12-13 décembre en 2010).

ESA (European Space Agency)

L'Agence Spatiale Européenne (ESA) a signé avec l'Observatoire royal de Belgique un contrat permettant au Planétarium d'établir dans ses locaux un « European Space Education Resource Office » (ESERO). Le but de ce projet pilote est de favoriser la promotion des matières et carrières scientifiques en général, et celles liées au domaine du spatial en particulier, via des contacts étroits avec le milieu éducatif. Les opérations du bureau ESERO sont menées par deux Office Managers et consistent en le suivi de projets de classes scientifiques, la création de brochures pédagogiques, l'organisation de formations pour enseignants et futurs enseignants, la tenue d'événements éducatifs liés au spatial, l'établissement de partenariats entre les autorités de l'enseignement et l'ESA, etc.

Les activités du bureau ESERO en Belgique ont été présentées les 8 et 9 mars à Noordwijk au Comité de Pilotage du Département Education de l'ESA.

Un nouvel Office Manager ESERO francophone a été recruté au cours de l'été, en remplacement du manager précédent, démissionnaire (changement de fonction).

Union Européenne (projet COMENIUS)

Le Planétarium a été partenaire du projet COMENIUS « Hands-on Universe » financé (2008-2010) par l'Union Européenne. Trois enseignants belges ont notamment été sélectionnés et envoyés dans le cadre de « Hands-on Universe » à des sessions de formation en astronomie à l'Observatoire de Haute-Provence, Cardiff et Torun.

Un nouveau dossier réunissant les mêmes partenaires européens et prolongeant les actions du premier projet a été soumis avec succès à l'Union Européenne : le kick-off meeting de « EU-HOU : Connecting classrooms to the Milky Way » a eu lieu en novembre à Paris.

IYA2009 (International Year of Astronomy)

Le Planétarium avait été choisi par le BNCA (Belgian National Committee for Astronomy) en 2007 pour agir en tant que « Special Point of Contact » auprès de l'International Astronomical Union pour la coordination et la promotion des activités réalisées en Belgique durant l'année 2009 dans le cadre de l'Année Internationale de l'Astronomie.

La participation au colloque internationale Communicating Astronomy with the Public 2010 à Cape Town en mars 2010 a permis de présenter un aperçu de l'ensemble des activités (340 au total) proposées en Belgique dans le cadre de l'Année Internationale de l'Astronomie.

A.2. Personnel

Au 31 décembre 2010, le personnel du Planétarium se composait de 17 membres :

- R. Alvarez, 1er assistant, statutaire – responsable
- V. Bastin, experte technique, contractuelle – animatrice scientifique
- G. Champagne, attaché scientifique, contractuel – création audio-visuelle
- S. Consiglio, administratief medewerker, statutaire – accueil
- D. Cornet, attaché classe 1, contractuelle – ESERO
- H. De Rycke, gedetacheerd leraar – cours
- M. Espirito, collaborateur nettoyage, contractuel – entretien
- E. Geerts, attaché klasse 1, contractuelle – ESERO
- J-C. Jacques, assistant technique, statutaire – opérateur
- A-L. Kochuyt, attaché klasse 1, statutaire – relations publiques
- A. Milis, industrieel ingenieur, statutaire – responsable technique
- O. Rezabek, ingénieur industriel, statutaire – ICT
- A. Sayer, collaborateur nettoyage, contractuelle – entretien
- V. Semeraro, administratief medewerker, contractueel – accueil
- G. Smet, technisch assistent, contractueel – animateur scientifique
- M. Sojic, enseignant sous contrat – cours
- W. Vander Putten, technisch deskundige, contractueel – infographisme

A.3. Equipement & Dotations

Dans le cadre du partenariat établi avec l'Atomium (mis en place d'un ticket combiné), le Planétarium a fait l'acquisition (sur fonds propres de l'Observatoire) d'un système audio multilingue performant, permettant aux visiteurs de se munir d'audiophones et de choisir parmi trois langues (néerlandais, français, anglais) l'écoute de la bande parlée d'un spectacle.

Cette importante acquisition, dévoilée le 1er décembre lors du lancement du spectacle Violent Universe, a été accompagnée d'un notable élargissement des horaires du Planétarium, désormais ouvert tous les samedis, les dimanches et les jours fériés pour un accueil du public 363 jours par an. Ce développement a été rendu possible par le recrutement prévu en 2011 de deux membres du personnel (accueil et technique) supplémentaires.

Nouveaux horaires

Dorénavant, le Planétarium proposera en semaine, pendant la période scolaire, en plus des leçons d'astronomie, une séance « grand public » chaque jour à 16h (séances supplémentaires à 14h et 15h les mercredis).

Les week-ends, lors des jours fériés et tous les jours durant les vacances scolaires, le public aura le choix d'assister à une séance à 11h, 12h, 14h, 15h, 16h et 17h.

Ainsi, 19 séances « grand public » sont programmées du lundi au vendredi durant la période scolaire. Ce nombre monte à 42 séances « grand public » pendant la semaine durant les périodes de vacances scolaires. L'offre élargie devrait permettre au Planétarium d'accueillir un nouveau public en 2011.

B. BIBLIOTHEQUE

B.1. Situation du personnel de la bibliothèque

Responsable scientifique : Pierre ALEXANDRE (chef de travaux).
Bibliothécaire : Sabrina WINTMOLDERS (statutaire, niveau B).
Aides-bibliothécaires :

Jean-Marie DANLOY (statutaire, niveau C).
Myriam VANDERCOILDEN (contractuelle, niveau C).
Luc VANHASSEL (statutaire BIPT, niveau D).

B.2. Activités de la bibliothèque

B.2.1. Activités générales

Pour les livres et les périodiques de l'ORB, le personnel de la Bibliothèque à assuré la centralisation des propositions d'achat, l'achat des titres sélectionnés, le catalogage de ceux-ci, le "bulletinage" des numéros de périodiques, le classement des ouvrages, l'accueil des visiteurs, le prêt aux lecteurs et le prêt inter-bibliothèques. Les mêmes services ont été effectués pour les livres et les périodiques de l'IRM, à l'exception des achats, des propositions d'achats et du "bulletinage" des périodiques, opérations directement effectuées à l'IRM.

B.2.2. Abonnements, échanges et achats

La bibliothèque a bénéficié en 2010 de 113 abonnements à des périodiques en version sur papier (56 pour l'IRM, 57 pour l'ORB) ; en outre, environ 150 publications périodiques ont été reçues soit par dons soit par échanges avec d'autres institutions. Les collections se sont enrichies par ailleurs de 43 livres acquis par achat (18 pour l'IRM, 25 pour l'ORB) et d'environ une quinzaine d'autres ouvrages reçus par dons ou par échanges.

B.2.3. Périodiques électroniques

La politique d'abonnement aux versions électroniques de certains périodiques, en sus des versions sur papier, s'est poursuivie en 2010: trente-huit abonnements ont été pris en 2010 par les deux instituts (dix-huit pour l'ORB, vingt pour l'IRM), et un abonnement commun à l'ORB, l'IRM et l'IAS pour les cinq parties du *Journal of Geophysical Research*.
Par ailleurs, l'accès au réseau électronique SwetsWise, auquel l'ORB et l'IRM sont affiliés, permet d'accéder gratuitement à la version électronique de certains périodiques pour lesquels les deux instituts ont souscrit un abonnement à la version sur papier (la version électronique pour l'année en cours étant offerte en sus par l'éditeur). Vu la politique de certains éditeurs, le nombre de ces périodiques gratuits du réseau SwetsWise a toutefois diminué en 2010 et est au stade actuel de 31 pour les trois instituts d'Uccle; grâce à SwetsWise le personnel de chaque institut, ORB, IRM ou IAS, peut avoir aussi accès (du moins pour l'année en cours) aux versions électroniques gratuites des revues dont la version papier est achetée par un des deux autres instituts.

B.2.4. Récolement général des collections

Depuis le mois d'avril 2009, un récolement général des collections de la bibliothèque a été entrepris, accompagné d'une réorganisation de l'espace disponible pour ranger ces collections. Divers ouvrages ou séries de périodiques peu ou pas consultés (livres en double, revues écrites en caractères non latins, collections devenues obsolètes) ont été transférées de la bibliothèque vers des locaux de réserve ou éliminées, ce qui a permis de faire face à l'extension annuelle des périodiques courants.

A l'occasion de ce récolement, le catalogue des ouvrages de la bibliothèque, ainsi que le fichier des prêts aux lecteurs, ont été clarifiés ou corrigés en conséquence.
Le transfert des collections conservées après récolement vers leurs nouveaux emplacements dans les rayonnages s'est effectué pour l'essentiel pendant les mois de juillet et d'août, avec l'aide d'étudiants rémunérés.
A l'occasion de l'informatisation progressive du catalogue de la bibliothèque, des ouvrages enregistrés séparément ont été regroupés dans les rayonnages avec les autres livres des collections dont ils faisaient partie.

B.2.5. Reliure des collections

Un grand nombre de périodiques ont été reliés en 2010, avec l'aide des étudiants engagés pendant les mois d'été: 519 pour l'O.R.B., 192 pour l'I.R.M.

B.2.6. Informatisation de la bibliothèque

Pour rappel, l'informatisation de la bibliothèque au moyen du système de gestion VUBIS comporte trois opérations distinctes :

- Catalogage des données bibliographiques (en ce compris les mots-clefs) relatives aux titres de périodiques, aux collections de livres et aux livres (ceux-ci étant soit enregistrés isolément soit reliés à une collection de livres).
- “Bulletinage” des périodiques, soit des numéros de l'année en cours, soit des tomes entiers après reliure.
- Attribution aux divers volumes (livres ou périodiques) de numéros de "codes-barres" permettant le prêt informatisé.

En 2010, les activités d'informatisation de la Bibliothèque ont été les suivantes :

- Catalogage et “bulletinage” systématique, avec attribution de “codes-barres”, de tous les livres et numéros de périodiques acquis en 2010 (opération effectuée depuis l'année 1996).
- Relevé systématique, en vue de leur informatisation future, des dates de clôture des collections de périodiques qui ont cessé de paraître (jusqu'ici, seules les dates de départ de ces collections avaient été relevées).
- Vérification et correction de données bibliographiques encodées avant 1996 au moyen d'un autre système de gestion informatique, et attribution de “codes-barres”, pour les livres entrés à la bibliothèque entre 1951 et 1996.
- En janvier 2010, le nouveau logiciel V-smart a été installé à la bibliothèque de l'O.R.B.-I.RM., permettant une meilleure gestion des collections et un accès direct au catalogue pour le personnel des institutions.

Dans l'accomplissement de ces travaux, la Bibliothèque a bénéficié de l'aide de Mme Christine ROBERTI, pour le bulletinage des numéros de périodiques de l'année 2010 acquis par l'IRM.

Par ailleurs, un arrêté ministériel du Service Public Fédéral de Programmation Politique Scientifique a confié aux Etablissements scientifiques fédéraux la charge de réaliser des "catalogues informatisés des bibliothèques des Etablissements scientifiques fédéraux", s'inscrivant dans le cadre de la mise en œuvre du "Plan de digitalisation du patrimoine culturel et scientifique des Etablissements scientifiques fédéraux relevant du Ministre de la Politique scientifique". Ce projet qui avait permis l'engagement, pendant l'année 2008, d'un agent contractuel ayant encodé quelque 10.200 fiches catalographiques représentant l'ensemble des livres acquis par la bibliothèque entre 1900 et 1938, n'a pas été financièrement prolongé en 2009 et en 2010.

En février 2010, la bibliothèque a participé à l'élaboration d'un nouveau projet de digitalisation du patrimoine des Etablissements scientifiques de l'État, projet géré par l'organisme MICT-IBBT; la suite donnée à ce projet n'est pas connue à ce jour.

Il reste donc à accomplir les opérations suivantes, en ce qui concerne l'informatisation de la bibliothèque: d'une part effectuer l'encodage des données relatives aux livres parus avant 1900, ainsi que ceux acquis entre 1938 et 1951; et d'autre part terminer l'encodage d'une partie des données relatives au détail des collections de périodiques antérieurs à 1996, une opération qui est déjà effectuée à quelque 75% du total. Il reste également à vérifier et à corriger une partie des données relatives aux livres acquis de 1951 à 1995, qui avaient d'abord été catalogués, au moyen d'un autre système de gestion que VUBIS, par des personnes extérieures au personnel de la bibliothèque.

B.3. Missions et Formations

B.3.1. Missions

- 12 février 2010: Participation de Sabrina Wintmolders à une réunion du groupe de travail sur la description de fonction des bibliothécaires, à la Bibliothèque Royale.
- 8 juin 2010: Participation de Sabrina Wintmolders à une réunion du "Forum des bibliothèques des Services Publics Fédéraux et des Établissements Scientifiques Fédéraux".

B.3.2. Formations

- Au mois de février, Sabrina Wintmolders, Jean-Marie Danloy, Myriam Vandercoilden et Luc Vanhassel ont suivi une formation sur le fonctionnement de V-Smart

C. SERVICE DES RENSEIGNEMENTS – DIENST INLICHTINGEN – Information service

C.1. Activities

The activities related to the information services consist of several tasks: answering questions and inquiries from public and press, assisting in all kind of outreach activities, giving general information on ORB and on astronomy and related subjects, advising the planetarium, organize the visits to the ORB, including the organization and coordination of open doors days and related activities, all kind of assistance for exhibitions and public relations activities (press communications, press conferences etc.) and preparing of texts for printing or for the web site. Thanks to an interactive tool installed by the IT section of the ROB, hot news items, often related to press releases, can now be put fast and easily on our website (http://www.astro.oma.be/EN/hotnews/index.php).

This report describes mainly activities of the persons directly related to the information services. Activities of a few other services are included, especially if those are meant for a general public and if they were communicated in reports. If activities are directly related to research, they will be found elsewhere in this annual report.

C.2. Personnel

J. Cuypers, (Dep III, information services), 'eerst-aanwezend assistent' (45%)
Y. Coene, technical expert (Dep I, information services) till May 2010.
H. Langenaken, technical expert (Dep. III) (50%). She had this year also several other more technical and administrative tasks, including the work on the archives and storage rooms of the ROB.

In many activities other personnel was involved and many staff members of the ROB gave information to the public, some occasionally, others as a part of their daily work.

C.3. Information given to the media

C.3.1. Press Releases

- Press conference on the results of Proba 2 (26/01/2010).
- Press release on the launch of Solar Dynamics Observatory, February 9, 2010.
- Press release: Solar Dynamics Observatory First Light, April 16, 2010.
- Press conference about SDO First Light, April 22, 2010
- Press conference during esww7: Human exploration of Space: challenges, risks and benefits, Oud-Sint Jan, Brugge, November 16, 2010
- Press release: PROBA2 1 year (in Dutch, French & English), November 02, 2010, see http://www.sidc.be/PROBA2anniversary/.
- Press release: CESRA - Strategic interest of Radio Observations (in Dutch, French & English), June 11, 2010, see http://www.sidc.be/news/127/welcome.html.
- Press release: Technology-testing PROBA2 opens new eye on the Sun, January 31, 2010, see http://www.esa.int/SPECIALS/Proba/SEMYNUKOP4G_0.html,.

C.3.2. Interviews (TV, Radio)

Many interviews on different subjects were given by members of the Observatory, only a selection is given.

On astronomy, celestial phenomena and time:

- J. Cuypers: Radio Charleroi, 18/02 on asteroids (live)
- J. Cuypers: Radio Gent, 01/04, astronomy in general
- J. Cuypers: Radio Studio Brussel, 16/03, daylight saving time
- J. Cuypers: TV VTM, 30/09, An exoplanet in the habitable zone
- J. Cuypers: Radio Twizz, 16/11, on the youngest black hole
- P. Defraigne: TV RTBF, “Question à la Une”, March 2010, interview related to time,
- P. Defraigne: TV RTBF, “Sans Chichi”, October 2010, interview related to time,
- P. Defraigne: Radio RTBF, October 2010, interview related to time,
- V. Dehant: TV, Les Niouz, about the exhibition ‘Destination Mars’,
- V. Dehant: Radio Beau-Fix, about the exhibition ‘Destination Mars’,
- V. Dehant: Radio TWIZZ, about the exhibition ‘Destination Mars’,
- V. Dehant: TV Arte, 50 degré nord, about the exhibition ‘Destination Mars’,
- V. Dehant: TV La Première, “Cocktail curieux”, Ocean on Mars,
- Ö. Karatekin: TV La Première (Mars),
- P. Lampens: Radio TWIZZ 06/08/2010, about the Kepler mission
- P. Rosenblatt: ESA portal story on “Mars Express close flyby to Phobos on March 3rd 2010” and (released on the ESA website: http://www.esa.int on March 2010) on “Venus Express Atmospheric Drag Experiment” (released on the ESA website: http://www.esa.int on October 8th 2010),

On seismology and related matters:

- T. Camelbeeck: TV COM (Local TV, Brabant Walloon) 04/03/2010 about earthquake activity,
- T. Camelbeeck: Interview for “Espace et vie, Brabant wallon” about earthquake activity, 01/06/2010,
- M. Van Camp: RTBF “Au Quotidien”: Membach, 21/01/2010
- M. Van Camp: TV RTBF, RTL 03/03/2010 about earthquake activity
- M. Van Camp: TV COM, 04/03/2010, about earthquake activity
- M. Van Camp: RTBF, Niouzz 08/03/2010, about earthquake activity
- K. Verbeeck: TV VRT, Terzake, 04/01/2010 on the earthquake sequence in Court-Saint Etienne http://www.deredactie.be/permalink/1.688886
- K. Verbeeck: TV VRT, Journaal, 27/02/2010, on the earthquake in Chile.

On solar physics

- V. Delouille: Interview with Jean-Olivier Pain from the Radio Suisse Romande on the launch of Solar Dynamics Observatory, February 2, 2010
- F.Clette: 11/3/2010: Interview Sud Presse (La Capitale, ed. 12/3): information about the extended solar minimum
- F.Clette: 25/1/2010: RTBF radio: Sophie Brems, about orbital solar power stations
- F.Clette: 12/8/2010: RTBF radio: conference announcement at the occasion of the "Nuit des Etoiles" at the Euro Space Center.
- C. Verbeeck, interview about SDO launch and ROB involvement, Radio 1, "Vandaag", February 10, 2010
- C. Verbeeck, interview about SDO First Light, VTM Journal, April 22, 2010, 19h

C.3.3. Documentaries

Prof. Peché (HEB, Haute Ecole de Bruxelles) proposed a project to film some aspects of the life at the Observatory by his students. Several members of the staff of the Observatory agreed to collaborate.

C.3.4. Other information given to the media

On numerous occasions, sometimes without a ‘formal’ interview, information was given by telephone or email to the media, mostly to newspaper and magazine journalists (Le Monde, De Tijd, Het Laatste

Nieuws, Het Nieuwsblad, De Standaard, De Morgen, La Libre, Athena, EOS, Govert Schilling, Science & Vie Magazine…) but also to television and radio (VRT TV1, VTM, RTL, VRT-radio, Rtbf-radio, Studio Brussel …).

C.4. Exhibitions

C.4.1. Museum of the Natural Sciences, Destination Mars

The Exhibition "Destination Mars" held at the Museum of the Natural Sciences was supported by our scientists. A flyer on the work done at ROB and IASB concerning Mars was prepared for the Exhibition and a Press map entitled 'Study of the moons of Mars, Phobos and Deimos, at the Royal Observatory of Belgium under the Mars Express Mission', was made in English, French and Dutch, 10 pages each.

C.5. Public conferences

Also in 2010 many members of the Royal Observatory gave public conferences and seminars. Below we give a non-exhaustive list.

- **V. Dehant**: "Présentation de l'Observatoire Royal de Belgique", Réunion annuelle de l'IFA, Planetarium, Brussels, 29/01/2010,
- **R. Van der Linden**: "De Koninklijke Sterrenwacht van Belgie", Jaarlijkse samenkomst van het netwerk opleidingsverantwoordelijken OFO, Planetarium, Brussel, 29/01/2010,
- **T. Camelbeeck**: Conference on the earthquake in Haïti at "Médecins Sans Frontières", Brussels, 04/02/2010
- **V. Dehant**: "La vie sur Mars. Une planète habitable ?", Conférence organisée par le KotASTRO, Auditorium Montesquieu 02, Louvain-la-Neuve, Belgium, 17/02/ 2010,
- **V. Dehant** and P. Defraigne: "La Planète Mars", Conférence organisée par Clés pour l'Univers, Ecole Robert Dubois de l'Hopital des Enfants Reine Fabiola, Belgium, 01/03/2010,
- **M. Van Camp**: Aardbevingen (Haïti), Vrije Vlaamse Bassischool, Ukkel, 18/03/2010
- **P. Defraigne**: " La Planète Mars", Home pour enfants sourds « La Clé », 19/03/2010,
- **P. Defraigne**: "La Planète Mars", Prison de Berkendael, 23/03/2010,
- **V. Dehant**: "Mars a-t-elle été une planète habitable?", Conférence organisée par le cercle des astronomes amateurs de Liège, Liège, Belgium, 26/03/2010,
- **P. Lampens**: "Onze plaats in het heelal -Wat vertellen de sterren?", Marnixring Asse-Hoppeland, 15/04/2010, Asse
- **A. Hees**: "A la découverte de la Relativité Restreinte et Générale", Collège Cardinal Mercier, classe de 6e humanité, Braine-l'Alleud, 20/04/2010,
- **M. Van Camp**: Hydrologie et Gravimétrie, SRBA, 22/04/2010.
- **E. Pottiaux**: Ph.D. public defense on "Sounding the Earth's Atmospheric Water Vapour Using Global Navigation Satellite Systems", Université Catholique de Louvain (UCL), Louvain-La-Neuve, Belgique, 06/2010,
- **J. Cuypers**: "De zwaarste en de grootste sterren', VVS-afdeling Helios, Herselt, 22/08/2010
- **J. Cuypers**: "Images of the Universe", Nacht van de duisternis, Vorst-Laakdal, 16/10/2010
- **T. Van Hoolst**: "Over rotsplaneten en ijsmanen in ons zonnestelsel", Ghent University, 04/11/2010.
- **P. Lampens:** "Quand les amateurs servent l'Astrophysique", Kot Astro, 11/11/2010, Louvain-la-Neuve
- **D. Volpi**, K. Torres, P. Lampens, seminar "The song of the stars" at the Greenlight event for girls Science Day at the International School of Brussels-20th November 2010. The seminar explained sound waves and astereoseismology. It was completed by an experimental section.
- **J. Cuypers**: "Variabele sterren en de Kepler-satelliet ", VVS-afdeling Helios, Herselt, 21/11/2010
- **V. Dehant**: "La planète Mars est-elle habitable ? A-t-elle été habitable ?", Conférence grand-public à l'Aurore, La Hulpe, 24/11/2010,
- **F.Clette**: 29/1/2010, Société Astronomique de Liège: "Un Soleil plein d'activité ... pour bientôt ?"

- **F.Clette**: Euro Space Center, Redu, Nuit des Etoiles, 12/8/2010 : "En connexion directe avec le Soleil: de l'espace jusqu'à … nous tous"
- **F.Clette**, Cercle Astronomique de Bruxelles, 15/10/2010: "Petite climatologie illustrée du Soleil: un cycle bien peu cyclique"
- **F.Clette** & J. Dekeyser (BISA), Collège Belgique, Acédémie Royale des Sciences de Belgique, 9/12/2010: "Activité et cycle solaires: causes et conséquences, surveillance et prévision"
- **P. Vanlommel**, Oriëntatie 2de jaar, Sint-Jozefs Instituut Betekom, March 08, 2010: “Wetenschapper-fysicus”.
- **P. Vanlommel**, Workshop KULeuven, Leuven, March 16, 2010: “Ruimteweervoorspeller in 50 minuten”
- **P. Vanlommel**, PROBA2@school, Vliebergh-Sencie, Leuven, March 24, 2010: “Ruimteweer »
- **D Berghmans**, PROBA2@school, Vliebergh-Sencie, Leuven, March 24, 2010: “PROBA2 – een Belgische missie”
- **P. Vanlommel**, Volkssterrenwacht Beisbroek, Brugge, May 05, 2010: “PROBA2: een nieuwe visie op ruimteweer en de Zon”
- **P. Vanlommel**, VVS, werkgroep zon, Genk, September 18, 2010: “PROBA2: een nieuwe visie op-ruimteweer – eerste resultaten”
- **P. Vanlommel**, Werkgroep Aardrijkskunde Brabant, Leuven, September 28, 2010: “De Zon – de energetische drijver van het ruimteweer”
- **E. D’Huys**, Werkgroep Aardrijkskunde Brabant, Leuven, September 28, 2010: “PROBA2: gegevens van SWAP en LYRA”
- **A. DeGroof**, Werkgroep Aardrijkskunde Brabant, Leuven, September 28, 2010: “PROBA2: Ontwikkeling, lancering en exploitatie”
- **P. Vanlommel**, ESWW7, Brugge, Belgium, November 15, 2010: “Space Weather in 20 questions – the Quiz »
- **A. DeGroof, E. D’Huys and P. Vanlommel**, Bezoek Middelbare school Bilzen, ROB, November 23, 2010: “De Zon, Ruimteweer en PROBA2”
- **P. Vanlommel**, Sint-Jozefs College, 4de leerjaar, Aarschot, December 13, 2010: “Onze Zon en PROBA2, onze satelliet”
- **C. Marque**: lecture for Belgian radio amateurs, “solar radio astronomy in Belgium”, October 23 2010

C.6. Questions from the public

In 2010 about 590 questions by email (60%N, 35%F), 540 by telephone and 220 by letter or fax were answered by the information services directly, i.e. 1350 in total. After the very high number in 2009 (1690), we are again at the level of the previous years (1280 in 2007, 1440 in 2008). However, there are no statistics of how many extra questions were answered directly by personnel from other services without passing by the information services.

Amongst the subjects of the questions (not directly related to research activities): sunset, sunrise, equinoxes and solstitia, horizontal coordinates of sun and moon, the amount of shadow, sun dials, moonrise and moonset, moon phases, fireballs, meteors, satellite re-entries, eclipses in 2010 and other years, all sort of calendar topics (Easter dates, beginning and end of Ramadan, Maya calendar), “the end of the world in 2012”, time keeping, time zones, tides, star maps and visibility of constellations, comets now and in history, Mars, Venus and other planets in the sky, information about historical scientific instruments, the profession of astronomer, external influences (sun, planets, universe, …) on climate change, structure of the universe, on satellites and space missions, candidate meteorites, photographs and images of the Observatory, history of the observatory, planets and the moon, atmospheric halos, goniometry and positional astronomy, names of asteroids, giving and/or registering of stars names, adopting or buying stars, etc.

Questions about the sun and its influence on earth (space weather etc.); about seismology, gravimetry and GPS, about asteroids and impact of asteroids on earth were forwarded to other sections of the observatory.

Questions about weather and climate were sent to the Meteorological Institute and those about space travel and aeronomy to the Belgian Institute for Aeronomy.

A few questions from the website www.ikhebeenvraag.be, an initiative of the Royal Belgian Institute of natural sciences with the support of the 'actieplan wetenschapsinformatie en innovatie', the Flemish government, were answered in 2010 by personnel from the ROB.

C.7. Archives

Information on archives, archiving and the archives of the ROB were distributed. The website was updated (http://archief-as.oma.be/). A lot of documents and photographs were digitized.

Most of the work related to this topic has been done by H. Langenaken and she followed the appropriate courses and information sessions.

There are still a lot of printouts of the Carte du Ciel images, of which too many are left in the archives. A number of sets have been shipped to interested people abroad.

C.8. Website

- The content of web pages with the answers to frequently asked questions was regularly updated. For 2010, the pages on daylight saving time and on the Islamic calendar (Ramadan) had at least one update or revision.
- The Dutch versions of the pages on the celestial phenomena of the month were revised on a regular basis.
- Many of the web pages of the information services have about 1000 visitors per months (depending on the season). Pages on sunrise and sunset, moon phases, daylight saving time, or date of Easter … can have up to 5000 hits per month, exceptionally even up to 10000.
- J. Cuypers initiated or assisted in putting new items, as e.g. press releases or announcements on the 'Hot News' pages of the ROB. In 2010 the topics were:
    - Launch of the 'Solar Dynamics Observatory';
    - Mars Express in closest flyby of Phobos;
    - The Chile Earthquake Measured by the Belgian Seismic Station in Antarctica;
    - 'Solar Dynamics Observatory' first light CESRA 2010;
    - New Web-based Earthquake Alarm System;
    - Herschel detects water vapour in a carbon star;
    - The Martian moon Phobos may have formed by catastrophic blast;
    - The polar atmosphere of Venus is thinner than expected.
    - A new website related to the Exhibition "Destination Mars" was set up: http://www.marsdiscovery.be/
- A new website related to FP7 Project ESPACE was created.
- Update of websites: we added translations and made improvements in the websites related
    - to Mars (http://planets.oma.be/MARS/index_mars.php),
    - to Venus (http://planets.oma.be/VENUS/index_venus.php),
    - to Mercury (http://planets.oma.be/MERCURY/index_mercury.php),
    - to the Galilean and Saturnian satellites (http://planets.oma.be/ISY/index_icy_sat.php),
    - to LaRa (http://lara.oma.be/index20090316.php),
    - to the Earth Rotation (http://earthrotation.oma.be/index20090316.php).

C.9. Visits

A lot of groups and individual visitors had to be guided in the Observatory this year. The individual visitors were mainly journalists and other media related persons, amateur astronomers with a specific demand and/or students. Groups were, in general, received on the first Tuesday of the month.

Dates of guided visits (individuals and groups): 04/05, 07/05, 30/05 (2) and 01/06. Visits by the 'observers' of the Royal Meterological Institute: 18/09 (N), 25/09 (F), 02/10 (F), 09/10(N). Foreign visitors were welcomed on 31/03 and 2/4 (Italian) – 17/9 (Australian) – 20/11 (Britain). Extra information was given, e.g. to stagiaires or visiting students (10/02, 16/03 (2 Student interviews), 28/05 (photographer), 01/07, 14/05, 21/05, 25-26/10 (3 students), 21/12).

C.10. Meetings and missions

A large number of meetings, internal as well as external, were attended, mainly by J. Cuypers: in total about 20 on a very large variety of subjects related to the information services, outreach and public relations. Only very few meetings with the communication responsibles of the Federal Institutes on topics of general interest, common activities and the journal Science Connection were organised this year.

C.11. Publications and related tasks

The information services assisted in some general tasks on publications and related items:

- Translation and/or help with press texts and hot news items
- Translations, corrections and proofreading of articles for the journal Science Connection;
- Text or suggestions for texts on the Observatory,
- The computer presentations describing the history and the activities of the Observatory were updated on a regular basis and used on several occasions, but mainly as the introductory part during group visits.

C.12. Publications in popular journals

[124] Bergeot N., Bruyninx C., Aerts W., Legrand J., and Moyaert
GPS en Antarctique: Mieux comprendre la fonte de la calotte polaire à la Station Princesse Elisabeth.
GPS in Antarctica: Voor een beter begrip van het smelten van de poolkap bij het Prinses Elisabethstation.
Science Connection n°29, 17-20.

[125] Cuypers, J., Lampens, P.,
Des téléscopes toujours plus grands pour scruter l'Univers
In: Louvain, UCL Revue 185, 28-29+36

[126] Dehant V., and 26 authors (including Beuthe M., Hees, A., Karatekin O., Le Maistre S., Nkono C., Pham L.B.S., Rivoldini A., Rosenblatt P., Van Hoolst T., Yseboodt M.)
La planète Mars sous la loupe des chercheurs belges
De planeet Mars onder de loep van Belgische wetenschappers
Science Connection, 32, 4-10

[127] Lobel, A., Blomme, R. :
Spiraalgolven omheen zware blauwe sterren,
Heelal, 55(2), 40-46

[128] Vanlommel, P., D'Huys, E.
De Koninklijke Sterrenwacht van België aan boord van PROBA 2: Een blik op de toekomst.
L'Observatoire Royal à bord de PROBA2 : un regard vers le futur.
Science Connection n°29, 24-28

[129] Clette, F.
Our inconstant Sun: Solar Activity and Flares
Solar Novus Today, Electronic journal of the photovoltaïc industry, 23/9/2010

[130] Clette, F.

Particle Beams: Danger in space
Solar Novus Today, Electronic journal of the photovoltaïc industry, 19/10/2010

[131] Clette, F.
Understanding Solar Wind: Consequences on Earth
Solar Novus Today, Electronic journal of the photovoltaïc industry, 16/11/2010

[132] Clette, F.
Down to the Ground: Space weather in our daily lives
Solar Novus Today, Electronic journal of the photovoltaïc industry, 9/12/2010

[133] P. Vanlommel, translation by S. Raynal
PROBA2: Belgische wetenschappers zetten de Zon in haar blootje
Science Connection, nr 28, februari-maart 2010.

[134] E. D'Huys and P. Vanlommel
Ruimteweer waarnemen met een Belgische satelliet
Information brochure for high school teachers on PROBA2, the Sun and Space Weather, published by Vliebergh-Sencie, KULeuven, 47p, March, 2010
http://sidc.oma.be/Leerkrachten/PROBA2@school_20101001.pdf

[135] P. Vanlommel and E. D'Huys
Ruimteweer waarnemen met een Belgische satelliet
Series in Guidestar (Newsletter Astro Event Group Oostende), August 2010, p 38

http://www.digilife.be/aeg/nieuwsbrief/Guidestar08-2010.pdf

Series in Guidestar (Newsletter Astro Event Group Oostende), September 2010, p 38

http://www.digilife.be/aeg/nieuwsbrief/Guidestar09-2010.pdf

Series in Guidestar (Newsletter Astro Event Group Oostende), October 2010, p 38

http://www.digilife.be/aeg/nieuwsbrief/Guidestar10-2010.pdf

Series in Guidestar (Newsletter Astro Event Group Oostende), November 2010, p 38

http://www.digilife.be/aeg/nieuwsbrief/Guidestar11-2010.pdf

Series in Guidestar (Newsletter Astro Event Group Oostende), December 2010, p 38

http://www.digilife.be/aeg/nieuwsbrief/Guidestar12-2010.pdf

[136] P. Vanlommel and E. D'Huys
De Koninklijke Sterrenwacht aan boord van PROBA2
Guidestar (Newsletter Astro Event Group Oostende), July 2010, p 38

http://www.digilife.be/aeg/nieuwsbrief/Guidestar07-2010.pdf

D. PUBLIC OUTREACH of the SCIENTIFIC DEPARTMENTS

D.1. Scientific and technical expertise to the authorities and the industry

- N. Bergeot processed GNSS data and wrote a report for the Belgian Air Force concerning radio communication problems during the August 2010 ionospheric storm.
- K. Vanneste, K. Verbeeck and T. Camelbeeck continued to provide their expertise for ONDRAF/NIRAS.
- F.Clette: 8/9/2010: information provided on space weather risks to National Security (Sûreté Nationale)

D.2. Visits

- Several researchers of the ROB participated to DREAMDAY on 19 March 2010.
- Photo session by Peter Dekens for his artistic photographic project "Nachtwacht".
- Thierry Pauwels provided images of asteroid Pieraerts.

E. THE YEARBOOK

E.1. Objectives

Every year the Royal Observatory of Belgium publishes a Yearbook with ephemerides, the most important astronomical phenomena and their visibility in Ukkel and in Belgium.

E.2. Progress and results

In 2010 the Yearbook for 2011 was published. It was produced by Carine Bruyninx (Coordinates), Frédéric Clette (The Sun, Tables), Jan Cuypers (Calendars, Comets, Meteors), Thierry Pauwels (Title, Preamble (in collaboration with the director), Constants, Planetary and Satellite Data, Planetary Phenomena, Visibility and ephemerides of the planets, Minor planets, Eclipses, Transits, Occultations, Satellites of Jupiter, Mutual phenomena of the satellites of Jupiter), Fabian Roosbeek (The Moon, Tables). Translations were made by Rodrigo Alvarez and Thierry Pauwels. Thierry Pauwels was responsible for getting the right value for ΔT, the general coordination, the lay-out and the final editing.

E.3. Perspective for next years

Production of the paper version of the Yearbook for the coming years. No major changes are foreseen in the near future.

Deel 3: Ondersteunende Diensten

Partie 3: Services d’Appui

Part 3: Logistics

Overzicht / Sommaire

A. ADMINISTRATIE / ADMINISTRATION

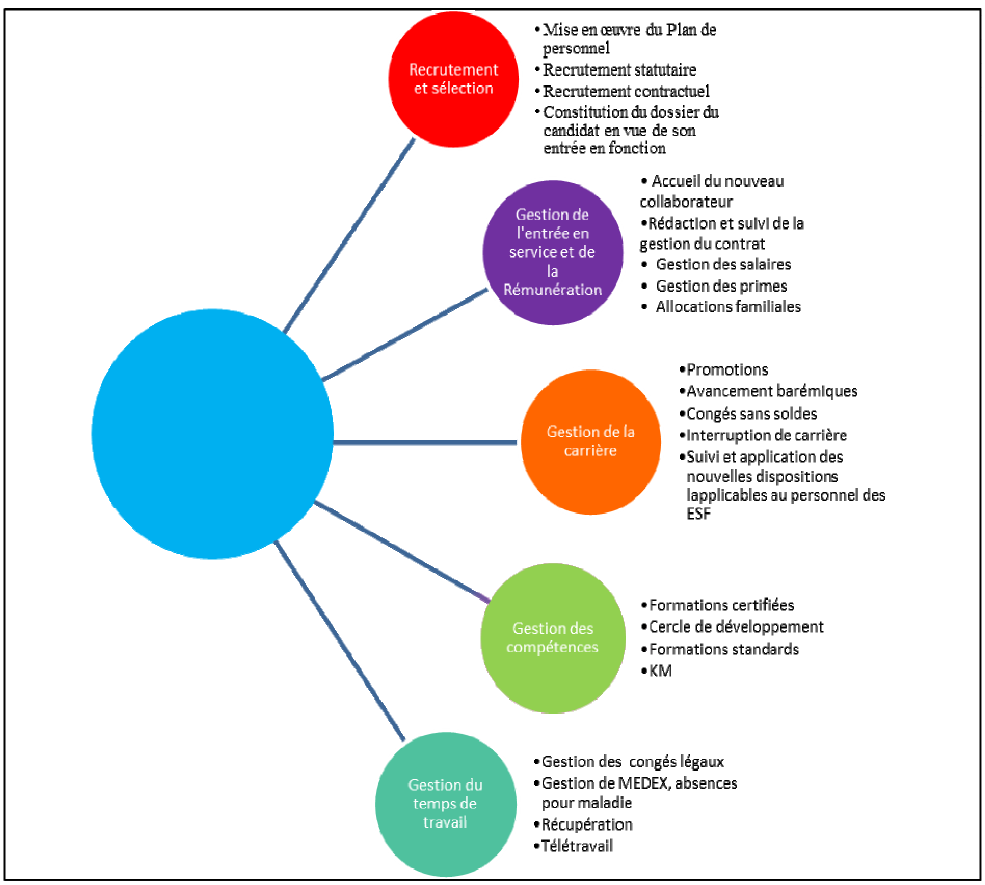
A.1. RESSOURCES HUMAINES

A.1.1. Introduction

Le service RH constitue l'une des composantes de ce qui est repris sous la dénomination plus générale de « services d'appui ». Comme le service IT, la comptabilité ou le service technique, le service RH est un service horizontal et transversal qui vient en support aux Directions opérationnelles. Il relève directement du Directeur général.

Au cours de l'année 2010, le service des ressources humaines de l'ORB a poursuivi sa mission globale de gestion de l'ensemble du personnel, statutaire et contractuel, scientifique, administratif et technique. En tant que service d'appui, le service RH a continué, en 2010, à jouer un rôle de soutien à la Direction pour la mise en œuvre de la politique menée en matière de personnel dont les grandes lignes conductrices sont recruter, accueillir, soutenir, former, développer.

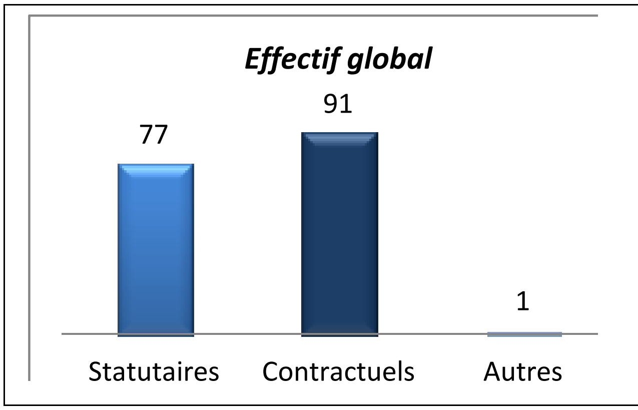
C'est dans le cadre de cette politique RH que sont mises en œuvre les missions du service RH de l'Observatoire. Elles sont au nombre de cinq et consistent entre autres dans les différentes activités que nous retrouvons ci-dessous.

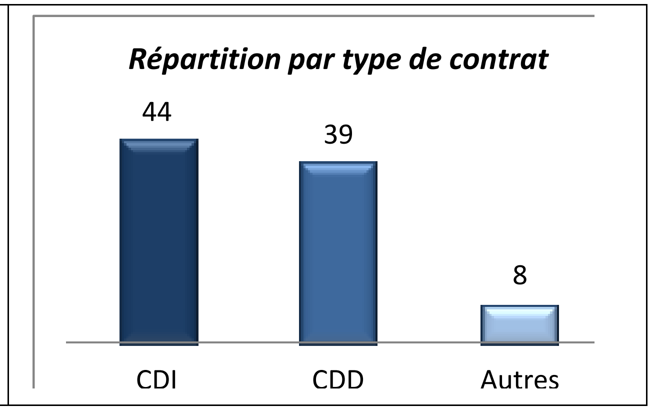


A.1.2. Situation du personnel

A.1.2.1. Effectif global

Au 31/12/2010, l'Observatoire royal de Belgique totalise un effectif global de 169 personnes dont 77 statutaires, 91 contractuels et 1 détaché de l'enseignement de la communauté néerlandophone.
L'année 2010 a connu une augmentation du nombre de statutaires puisque deux statutarisations (stage achevé dans le courant 2010) ont pu être réalisées, 1 niveau C (assistant technique) et 1 niveau B (expert technique). Ajoutons qu'un membre du personnel scientifique a, quant à lui, commencé son stage.

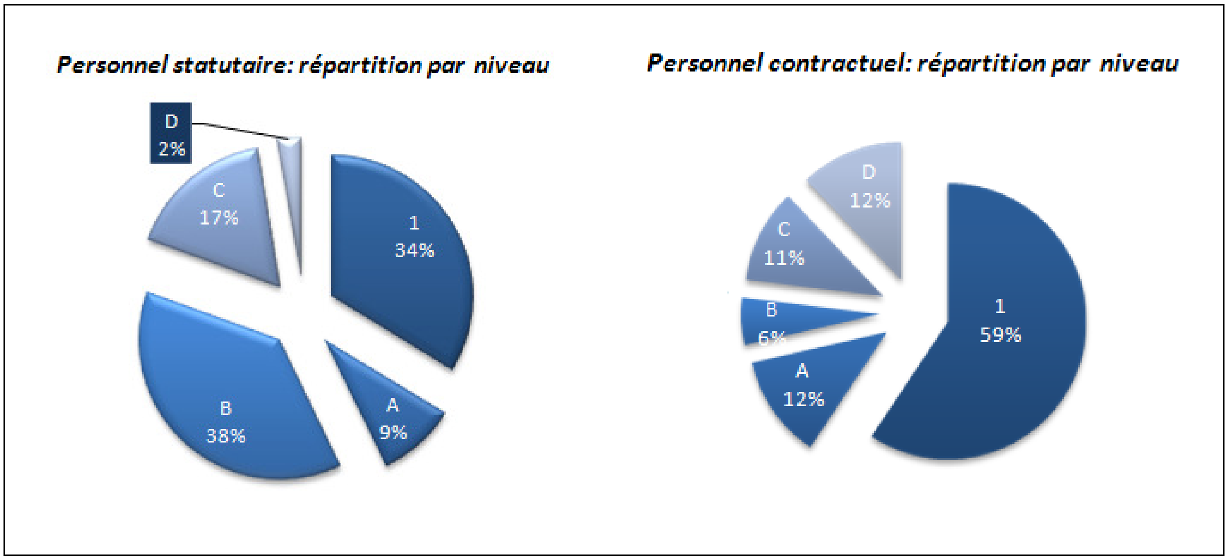




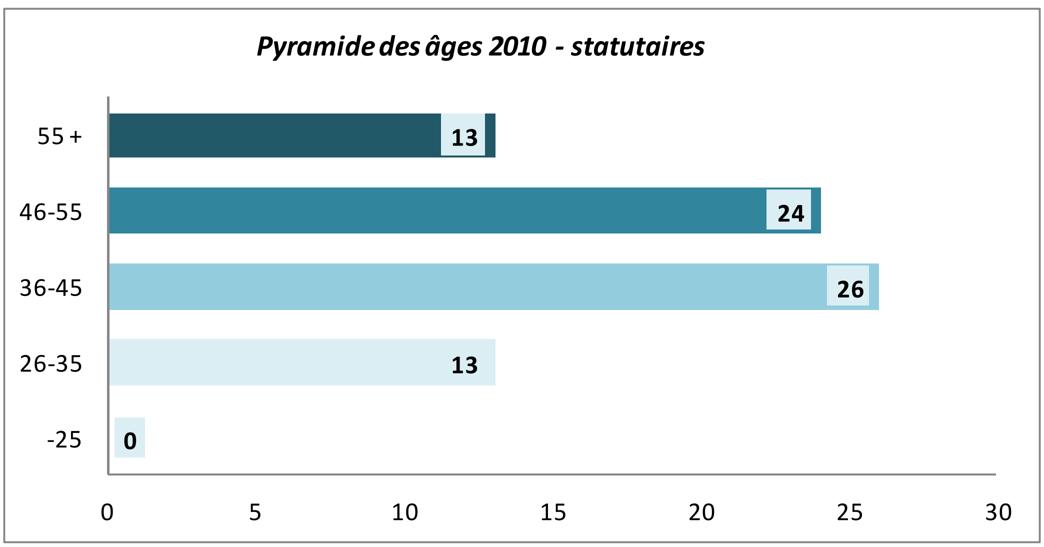
L'année 2010 connut également la publication de l'AR du 2 juin 2010, *Arrêté royal fixant les droits individuels pécuniaires des personnes engagées par contrat de travail au titre de personnel scientifique dans les établissements scientifiques fédéraux*. Cet AR s'applique au personnel scientifique engagé sous contrat de travail dans les établissements scientifiques fédéraux et prévoit le basculement de ces personnes dans la nouvelle carrière scientifique, comme ce fut le cas pour le personnel statutaire en 2009. Les anciennes échelles barémiques disparaissent au profit des nouvelles échelles SW1, SW2, SW3 et SW4. Notons que cet AR produisait ses effets, de façon rétroactive, le 1er janvier 2010.

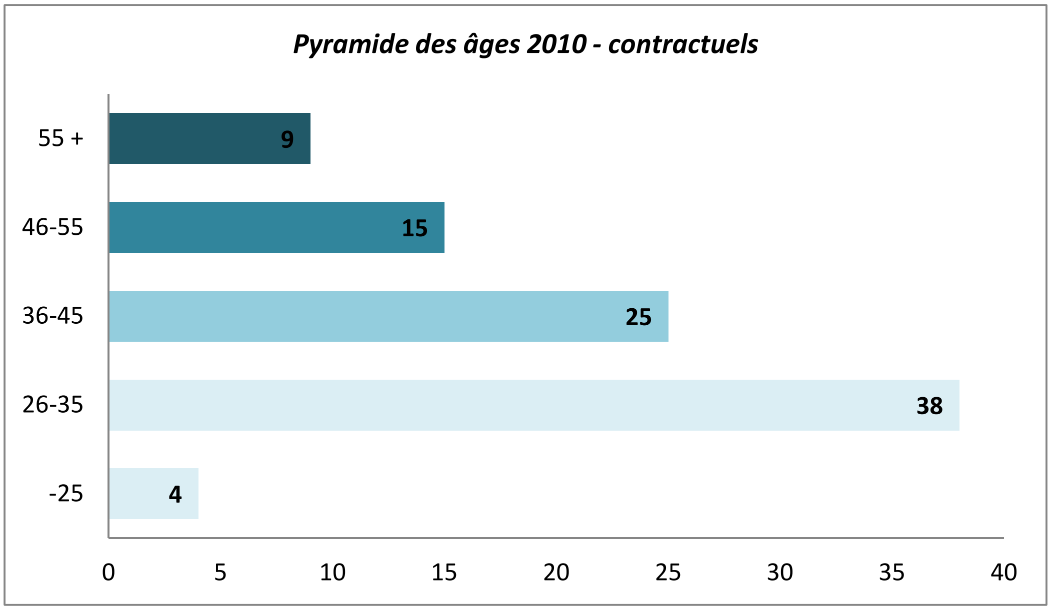
Comme chaque année, l'Observatoire a également engagé des étudiants. En 2010, l'Observatoire a engagé, du 1er juillet 2010 au 30 septembre 2010, 60 étudiants.

A.1.2.2. Répartition par niveau

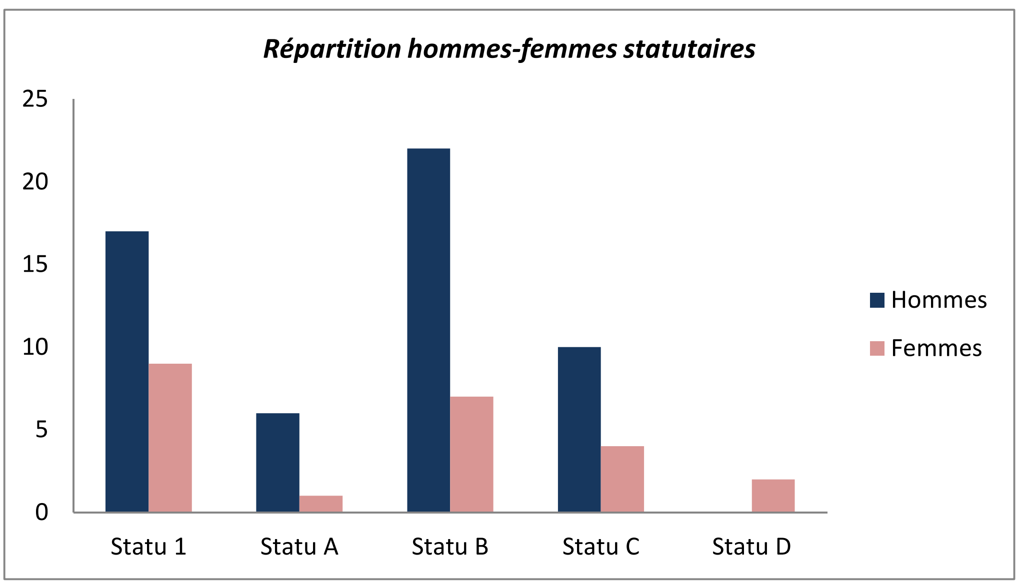


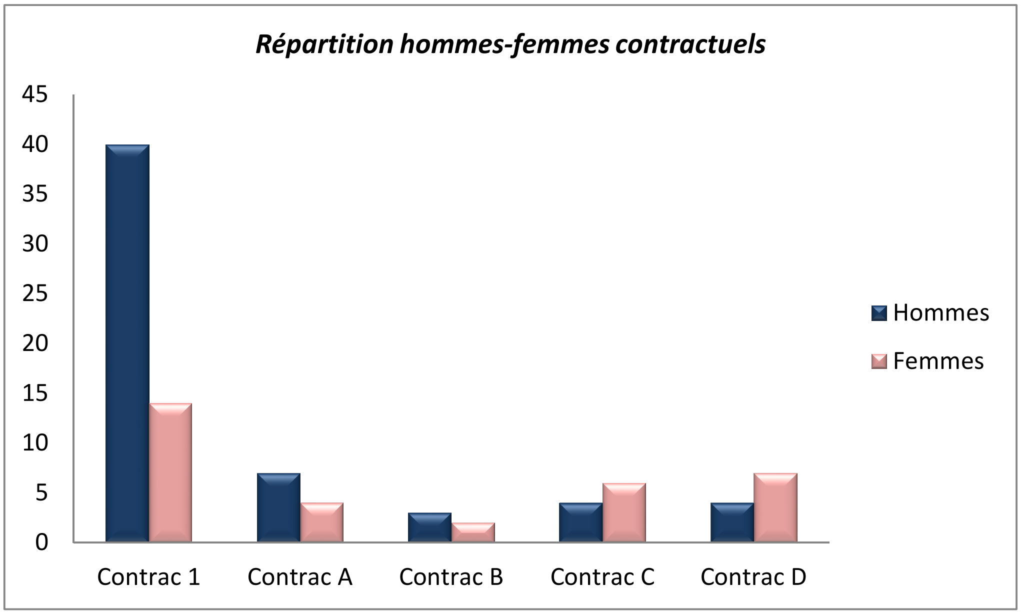
A.1.2.3. Pyramide des âges





A.1.2.4. Diversité Hommes-Femmes





A.1.3. Cercles de développement

L'année 2010 a connu la mise en œuvre des Cercles de développement. Ce concept a été développé dans l'optique de devenir un outil important et indispensable à la collaboration entre un chef fonctionnel et son collaborateur. Le Cercle doit contribuer au développement d'une meilleure communication entre le chef et l'agent.

Il s'agit de définir d'un commun accord, entre le chef et son collaborateur, des objectifs qui devront être atteints au cours du Cercle. Il s'agit également de favoriser le développement personnel et professionnel du collaborateur afin de veiller à son épanouissement et son bien-être. C'est dans ce contexte que s'inscrivent les formations auxquelles l'agent peut s'inscrire. Elles doivent lui permettre d'atteindre plus facilement ses objectifs (compétences techniques ou génériques) par l'acquisition de nouvelles compétences.

Constitué de 4 grandes étapes dont 3 obligatoires, le Cercle peut durer un ou deux ans. Notons que le Conseil de Direction de l'Observatoire a opté pour une durée de deux ans.

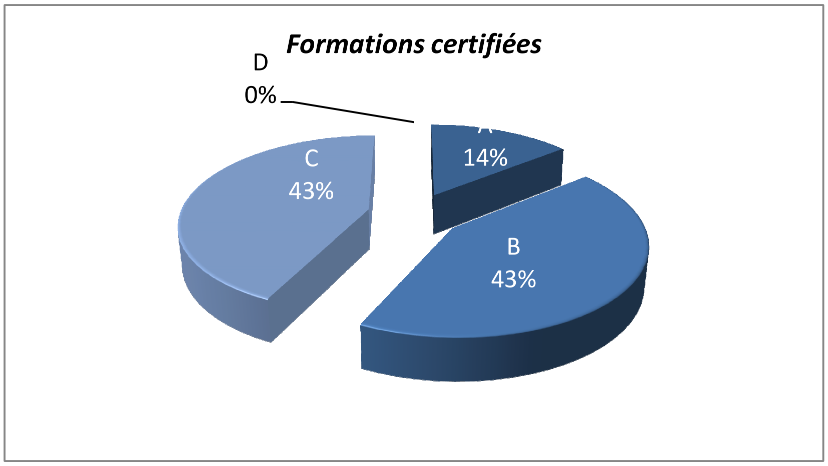
Les 4 grandes étapes du Cercle correspondent à 4 entretiens: l'entretien de fonction (accord des parties sur la description defonction), l'entretien de plannification (définition des objectifs à atteindre et des moyens à mettre en œuvre), l'entretien de fonctionnement (entretien à mi-parcours) et l'entretien d'évaluation qui clôture le Cercle.

Entamé au 1er avril 2010, la plupart des entretiens de fonction et de planification étaient réalisés fin 2010 chez la majeure partie des chefs fonctionnels.

A.1.4. Gestion des connaissances

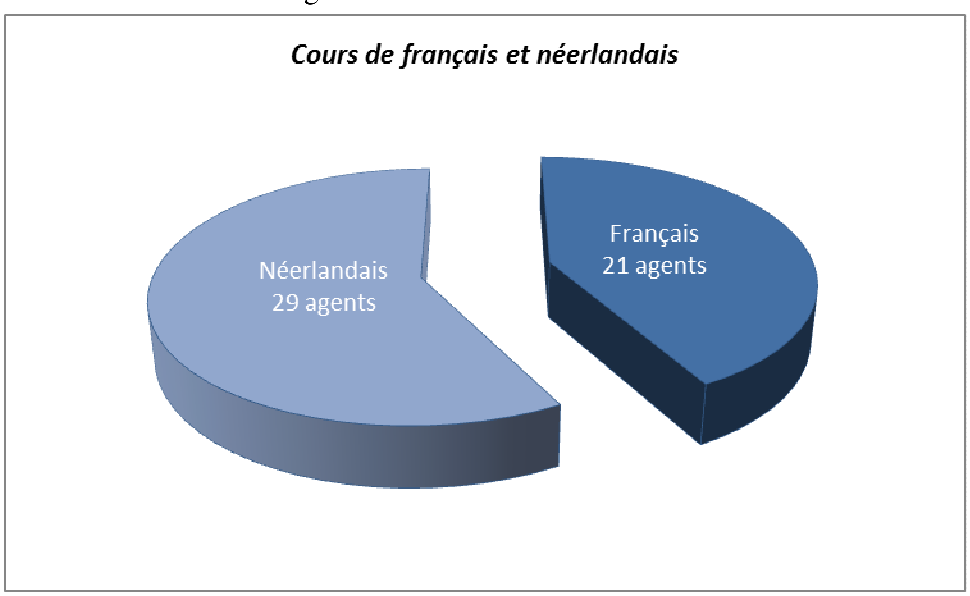
A.1.4.1. Formations standards et formations certifiées

Le personnel de l'Observatoire continue à pouvoir bénéficier de l'offre des formations standards de l'IFA, l'Institut de formation de l'administration. Ainsi, en 2010, 2 personnes ont commencé et terminé leur formation. D'autres se sont inscrites en 2010 mais n'ont pas encore été invitées. Pour la plupart, il s'agit de formations de langue ou de développement de compétences génériques.
Quant aux formations certifiées, en 2010, 7 agents ont pu passer une formation certifiée. Notons que le délai d'attente est très long, de nombreuses personnes restent donc inscrites dans les listes de participants de l'IFA mais n'ont toujours pas été convoquées.



A.1.4.2. Cours de langue

Afin de favoriser et de faciliter l'apprentissage de deux langues nationales les plus utilisées, l'Observatoire royal de Belgique organise, depuis 2009 des cours de français et de néerlandais. En 2010, ces cours ont rencontré à nouveau un très grand succès.



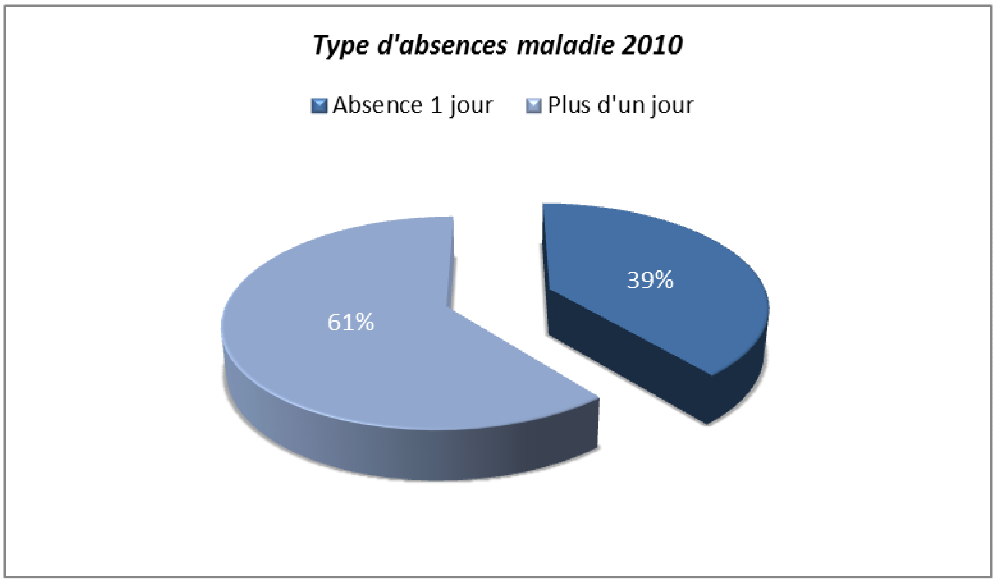
A.1.4.3. Congés de formation

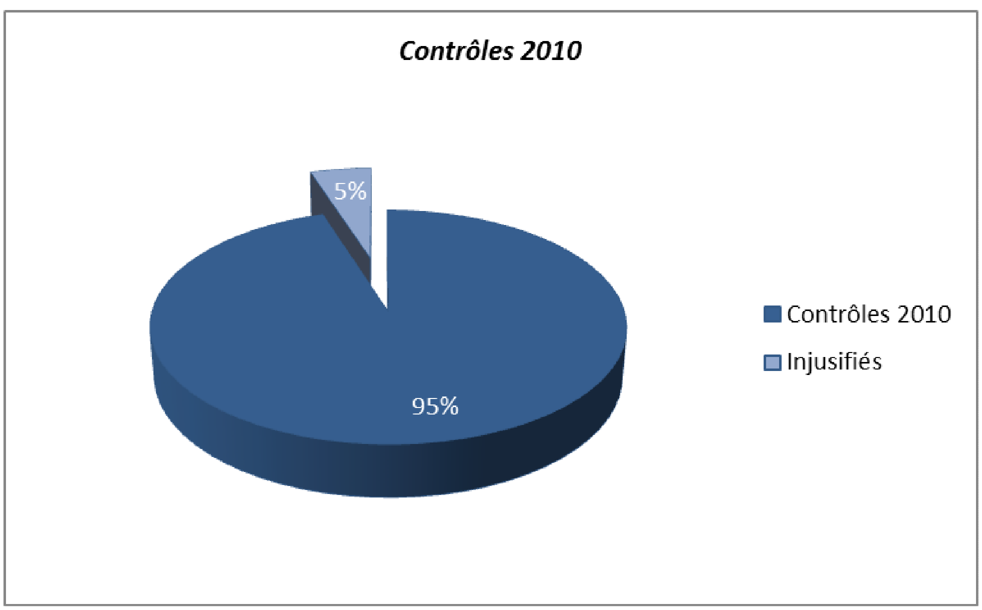
En 2010, 5 personnes ont pu bénéficier d'un congé de formation, 4 niveaux C et 1 niveau B.

A.1.5. Gestion du temps de travail

A.1.5.1. Medex

Le taux d'absentéisme de l'Observatoire s'élève à 3.29%, soit 1405 jours de maladie. Notons que le taux d'absentéisme est plus élevé chez les 50-59 ans et chez les femmes, toute tranche d'âge confondue.





Les 5% de contrôles injustifiés représentent souvent des oublis de notification de changement d'adresse.

A.1.5.2. Télétravail

Depuis sa mise en place, en 2008, le système du télétravail connaît, chaque année, un nouvel engouement. Ainsi, en 2010, 6 nouvelles demandes ont été introduites et acceptées, 5 scientifiques et 1 niveau B, ce qui représente un total de 25 agents, soit 1018 jours de télétravail. La plupart des agents n'ont pris qu'un jour de télétravail. Seules 3 personnes sur les 25 ont pris deux jours de télétravail.
Les deux jours les plus demandés sont les lundis (9 personnes) et le mercredi (8 personnes). Le jour le moins prisé est le mardi.

A.1.6. Enquête de satisfaction

A l'instar de l'IRM qui en est déjà à sa deuxième édition, l'Observatoire a souhaité réaliser, auprès de son personnel, une enquête de satisfaction. Réalisée par la société McMe, spécialisée en la matière, l'enquête anonyme a été lancée le 15 juin 2010 et s'est clôturée le 20 juillet 2010. Les résultats ont été analysés au mois d'août et ont pu être communiqués au personnel et aux chefs de services dans le courant des mois de septembre et octobre. Il est apparu que parmi les 175 collaborateurs interrogés, 122 ont complété le formulaire d'enquête, soit un taux de participation de 70%, ce qui, pour une première, est un très bon taux de réponse.

Les thèmes abordés étaient les suivants : tâche, qualité de vie professionnelle, développement personnel, collègues et chefs, stress, éléments économiques et financiers, climat.

Notons que le taux de satisfaction est, d'une manière générale, relativement élevé. Les points d'attention semblent être la communication, le développement personnel et les aspects économiques notamment les salaires et les perspectives de promotion chez les contractuels.

Il ressort de l'enquête que 86% des interrogés souhaitent l'être à nouveau.

A.1.7. Management du changement et modernisation

Le service RH se doit de rester continuellement à l'écoute des attentes de ses clients. Aussi, doit-il être un service dynamique et à l'éveil des constantes évolutions du monde des ressources humaines. Afin de rester performant et efficient, le service RH a, depuis quelques années déjà, décidé d'organiser un séminaire résidentiel une à deux fois par an afin de redéfinir, de façon régulière, ses objectifs et d'analyser en profondeur les mécanismes et les fondements de son mode de fonctionnement. Le service essaie également d'être le plus présent possible aux différents événements RH non seulement pour rester informé des nouvelles techniques RH mais également afin d'assurer une plus grande visibilité de ses activités.

A.1.7.1. Séminaire résidentiel

Le service RH a donc poursuivi, cette année, sa politique de changement. Amorcée en douceur en 2007, elle a connu, en 2010, un nouvel élan suite au séminaire résidentiel organisé à Namur pendant deux jours. L'objectif de ce séminaire était de définir une nouvelle vision du service ainsi que des objectifs clairs et précis en accord avec le plan de management du Directeur général et les objectifs individuels de chacun des membres de l'équipe. De nouvelles actions ont ainsi pu être définies et devraient pouvoir être réalisées dans le courant 2011.

A.1.7.2. Interaction réseaux RH

L'équipe RH de l'Observatoire essaie aussi, autant que possible, d'être présente dans les différents réseaux RH afin de développer et d'entretenir ses contacts. Etre ainsi présente dans les milieux professionnels des ressources humaines assure au service RH de l'Observatoire une source indiscutable d'inspiration et d'ouverture intellectuelle indispensable à une bonne gestion du changement et à l'évolution connue en 2010 par le service dans son mode de fonctionnement.
Au cours de l'année 2010, le service RH a ainsi pu assister à de nombreux séminaires et workshops organisés en matière de ressources humaines, tant par des orateurs du secteur public que privé.

Les membres du service ont ainsi notamment assisté aux réunions mensuelles du réseau RH du SPP Politique scientifique, aux réunions du réseau « Apprendre et développer » de l'IFA, l'Institut de Formation de l'administration fédérale, aux réunions du réseau « OC « (tenues dans le cadre des Cercles de développement), aux workshops et aux journées d'études organisés par les réseaux HRPublic et RH Tribune.

A.1.8. Activités entre services d'appui

En 2010, certains des projets et des objectifs définis au cours du séminaire de Namur qu'il tenait à cœur au service RH de mettre en œuvre ont pu être développés grâce à la collaboration née entre le service RH et l'un ou plusieurs autres services d'appui. Citons notamment la nouvelle brochure d'accueil, le nouveau site Intranet et la procédure d'accueil et de départ des collaborateurs.

A.1.9. Personeelslijst / Liste du Personnel

Algemeen directeur: Van der Linden Ronald

A.1.9.1. Vastbenoemd personeel / Personnel statutaire

Wetenschappelijk personeel / Personnel scientifique

Name/Nom	Functie/Fonction
Alexandre Pierre	Premier assistant
Alvarez Rodrigo	Premier assistant
Berghmans David	Werkleider
Blomme Ronny	Eerstaanwezend assistent
Bruyninx Carine	Eerstaanwezend assistent
Camelbeeck Thierry	Chef de travaux
Clette Frédéric	Premier assistant
Collin Fabienne	Premier assistant
Cuypers Jan	Eerstaanwezend assistent
De Cat Peter	Eerstaanwezend assistent
Defraigne Pascale	Premier assistant
Dehant Véronique	Chef de travaux
Frémat Yves	Assistant
Groenewegen Martin	Eerstaanwezend assistent
Hochedez Jean-François	Premier assistant
Lampens Patricia	Eerstaanwezend werkleider
Legrand Juliette	Assistant-stagiaire
Pauwels Thierry	Werkleider
Robbrecht Eva	Assistant
Roosbeek Fabian	Premier assistant
Van Camp Michel	Chef de travaux
Van De Steene Griet	Eerstaanwezend assistent
Van Hoolst Tim	Werkleider
Van Ruymbeke Michel	Premier assistant
Vanneste Kris	Eerstaanwezend assistent
Yseboodt Marie	Assistant

Technisch en administratief personeel / Personnel technique et administratif

Name/Nom	Functie/Fonction
Jans Thimoty	Attaché A1
Kochuyt Anne-Lize	Attaché A1

Rezabek Oleg	Attaché A1
Rogge Vincent	Attaché A1
De Knijf Marc	Attaché A2
Dufond Jean-Luc	Attaché A2
Milis Andre	Attaché A2
Asselberghs Somnina	Technisch deskundige
Boulvin Olivier	Expert technique
Bukasa Baudouin	Expert technique
Castelein Stefaan	Technisch deskundige
Coene Yves	Expert technique
Driegelinck Eddy	Expert technique
Dumortier Louis	Expert ICT
Duval David	Expert technique
Ergen Aydin	Expert technique
Frederick Bert	Expert technique
Hendrickx Marc	Expert technique
Herreman David	Expert ICT
Langenaken Hilde	Technisch deskundige
Martin Henri	Expert technique
Mesmaker Dominique	Expert technique
Moyaert Ann	ICT deskundige
Renders Francis	Technisch deskundige
Somerhausen André	Expert ICT
Strubbe Marc	Technisch deskundige
Van Camp Lydia	Technisch deskundige
Van Damme Daniel	Technisch deskundige
Van De Putte William	Technisch deskundige
Van Der Gucht Ignace	Technisch deskundige
Vandekerckhove Joan	Technisch deskundige
Vandercoilden Leslie	Expert technique
Vanraes Stéphane	ICT deskundige
Vermeiren Katinka	ICT deskundige
Van de Meersche Olivier	Expert Financier
Wintmolders Sabrina	Administratief deskundige
Barthélémy Julie	Chef technicien de la recherche
Brebant Christian	Assistant administratif
Bruyninckx Martine	Administratief assistent
Danloy Jean-Marie	Assistant administratif
Depasse Béatrice	Assistant administratif
De Wachter Rudi	Technisch assistent
Jacques Jean-Claude	Assistant technique
Janssens Paul	Assistant technique
Laurent Robert	Technisch assistent
Lemaitre Olivier	Assistant technique
Mortier Carine	Administratief assistent
Van Den Brande Theophilis	Technisch assistent
Vanden Elshout Ronny	Assistant technique
Verbeeren Anja	Administratief assistent
Consiglio Sylvia	Administratief medewerker
De Ridder Christiane	Administratief medewerker

A.1.9.2. Personeel met externe beurzen / Personnel sur bourses externes

Name/Nom	Functie/Fonction
Baland Rose-Marie	Boursier FRIA
Hees Aurélien	Boursier FRIA
Lecocq Thomas	Boursier FRIA
Pham Le Binh San	Boursier FNRS
Trinh Antony	Boursier FNRS
Sharma Suman	Boursier Non-EU

A.1.9.3. Contractueel personeel beheerd door de POD Wetenschapsbeleid / Personnel contractual géré par le SPP Politique Scientifique

Name/Nom	Functie/Fonction
Bizerimana Philippe	Collaborateur technique
De Vos Frédéric	Expert ICT
De Dobbeleer Rudy	Technisch assistant
Lobel Alex	Werkleider
Lubkowski Noël	Collaborateur technique
Motte Philippe	Collaborateur technique
Mouling Ilse	Administratief assistent
Noel Jean-Philippe	Expert technique
Rapagnani Giovanni	Attaché A1
Sayer Amina	Collaborateur technique
Semeraro Vanessa	Administratief assistant
Thienpont Emmanuel	ICT deskundige
Vandersyppe Anne	Administratief expert
Verbeeck Koen	Attaché

A.1.9.4. Contractueel personeel / Personnel contractuel

Wetenschappelijk personeel / Personnel scientifique

Naam/Nom	Functie/Fonction	Contract
Aerts Wim	Assistent	STCE
Baire Quentin	Assistant	Chercheur supp
Benmoussa Ali	Premier assistant	PRODEX
Bergeot Nicolas	Assistant	STCE
Beuthe Mikael	Assistant	PRODEX
Burston Robert	Assistant	STCE
Boyes John David	Assistant	PRODEX
Cabanas Carlos	Assistant	ESA
Callebaut Benoît	Assistant	SOTERIA
Caudron Corentin	Assistant-stagiair	Actie 2
Champagne Georges	Assistant	Dotation
Chevalier Jean-Marie	Assistant-stagiair	STCE
Dammasch Ingolf	Assistant	PRODEX
De Cuyper Jean-Pierre	Eerstaanwezend assistent	Digitalisation
Delouille Véronique	Premier assistant	PRODEX
D'Huys Elke	Assistent-stagiaire	STCE
Dolla Laurent	Assistant	STCE
Dominique Marie	Assistant	PRODEX
Garcia Moreno David	Assistant	UE_SHARE

Giordanengo Boris	Premier assistant	PRODEX
Gissot Samuel	Assistant	PRODEX
Goryaev Farid	Assistant	PRODEX
Gullieuszik Marco	Assistant	Action 1
Joukov Andrei	Premier assistant	STCE
Karatekin Ozgur	Assistant	PRODEX
Knuts Elisabeth	Assistant	Cherch. Supp.
Kudryashova Maria	Assistant	Action 1
Kusters Dimitri	Assistant-stagiair	HAZARDS
Laguerre Raphaël	Assistant	PRODEX
Lecocq Thomas	Assistant	HAZARDS
LeMaistre Sébastien	Assistant	PRODEX
Lefevre Laure	Assistant	SOTERIA
Lisnichenko Pavlo	Assistant-stagiair	STCE
Lobel Alex	Eerstaanwezend assistent	3 GAIA
Lombardini Denis	Assistant	Antartique
Magdalenic Jasmina	Assistant	Action 1
Marqué Christophe	Assistant	STCE
Mierla Marilena	Assistant	PRODEX
Mitrovic Michel	Assistant	PRODEX
Nicula Bogdan	Assistant	STCE
Nkono Collin	Assistant	PRODEX
Parenti Suzanna	Premier assistant	PRODEX
Pfyffer Gregor	Assistant	PRODEX
Podladchikova Olena	Premier assistant	STCE
Pottiaux Eric	Assistant	STCE
Pylyser Eric	Assistant	PRODEX
Rivoldini Attilio	Assistant	PRODEX
Robbrecht Eva	Assistant	STCE
Rodriguez Luciano	Assistant	PRODEX
Rosenblatt Pascal	Premier assistant	PRODEX
Seaton Daniel	Assistant	PRODEX
Torres Kelly	Assisstant	CHERSUPP
Van Hoof Peter	Assistent	PRODEX
Vanlommel Petra (80%)	Eerstaanwezend assistent	STCE
Verbeeck Francis	Assistent	PRODEX
Verbeeck Koen (50%)	Assistant	HAZARDS.
Verdini Andrea	Assistant	PRODEX
Volpi Delia	Assistant	Actie 1
Vranjes Jovo	Assistant	STCE
Wauters Laurence (80%)	Premier assistant	STCE
West Matthew	Assistant	PRODEX
Wright Duncan	Assistent	Action 1
Zhu Ping	Assistant	Action 2

Technisch en administratief personeel / personnel technique et administratif

Naam/Nom	Functie/Fonction	Contract
Mostaert Régis	Attaché A1	Dotation
Van Elder Sophie (60%)	Attaché A1	STCE
Wellens Véronique	Attaché A1	Dotation
Geerts Ellen	Attaché A1	ESERO

Pieront Anne	Attaché A1	ESERO
Cornet Denis	Attaché A1	ESERO
De Decker Georges	Attaché A2	Digitalisation
Willems Sarah	Attaché A2	STCE
Mampaey Benjamin	Attaché A2	PRODEX
Van Hemelryck Eric	Attaché A2	PRODEX
Vander Putten Wim	Expert ICT	Dotatie
Cinar Mehmet	Expert ICT	Hazards
Bastin Véronique	Expert technique	Dotation
Noel Jean-Philippe	Expert technique	STCE
Vandercoilden Myriam	Assistant administratif	Dotation Pole
Hernando Ana Maria	Assistant administratif	STCE
Smet Gert	Technisch assistent	Dotatie
Feldberg Liesbeth	Assistant administratif	Dotatie
Trocmet Cécile	Assistant administratif	Dotation
Wijns Erik	Technisch medewerker	Dotatie
Vandeperre Arnold	Technisch assistent	Dotatie
Espirito Santo Soares Marco (50%)	Collaborateur technique	Dotation
El Amrani Malika	Collaborateur technique	Dotation
Gonzales Sanchez Bénédicte (50%)	Collaborateur technique	Dotation
Herman Viviane (20%)	Collaborateur technique	Dotation
Ipuz Mendez Adriana (50%)	Collaborateur technique	Dotation
Reghif Harraz Mohammed (50%)	Collaboratuer technique	Dotation
Sayer Amina (50%)	Collaborateur technique	Dotation
Trindade Josefina	Collaborateur technique	Dotation
Vermeylen Jacqueline	Collaborateur technique	Dotation
Pol Suy Ancelmo	technisch medewerker	Dotatie

A.1.9.5. Gedetacheerd personeel / Personnel détaché

Naam/Nom	Functie/Fonction	Contract
Vanhassel Luc	Adjunct technicus	BIPT
De Rijcke Hendrick	Leraar	Onderwijs Vlaamse Gemeenschap

A.2. FINANCIELE DIENST / SERVICE FINANCIERE

A.2.1. Situation générale

Les moyens de fonctionnement de l’Observatoire sont présentés selon leur origine.

A.2.1.1. Enveloppe du personnel

L’enveloppe du personnel est utilisée en gros pour les salaires du personnel statutaire. L’enveloppe disponible en 2010 était de l’ordre de 4,7 millions d’euros.

A.2.1.2. Moyens propres de l’ORB

L’ORB répartit les revenus propres de l’administration en quatre postes différents :

- La dotation qui doit financer le fonctionnement et l'équipement de base de l'institution
- Les services aux tiers
- Les projets et les programmes de recherche financés par l'état belge
- Les projets et les programmes de recherche financés par des tiers

En 2010 les dépenses sur les moyens propres étaient divisées comme suit :

	ORB Dotation	ORB Services	Projets BELSPO	Projets Externes	Total
Personnel	508 787 €	128 139 €	1 526 532 €	1 551 360 €	3 714 819 €
Fonctionnement Subsistance	417 814 €	232 758 €	283 515 €	355 235 €	1 289 116 €
Fonctionnement Spécifique	14 197 €	30 061 €	28 540 €	48 965.50 €	121 765 €
Equipement Subsistance	55 278 €	126 197 €	93 731 €	62 429.77 €	337 637 €
Equipement Spécifique	36 650 €	99 634 €	227 711 €	3334 €	367 330 €
Bibliothèque	122 329 €	137 €	483 €	962 €	123 912 €
Total	1 154 849 €	616 928 €	2 160 515 €	2 022 288 €	5 954 582 €

A.2.2. Betrokken personeel / Personnel concerné

Olivier Van De Meersche	Boekhouder
Sonia Asselberghs	Adviseur & interne controle
Barthélémy Julie	Collaborateur service comptabilité
Mouling Ilse	Medewerker dienst boekhouding
Vanden Elshout Ronny	Collaborateur service comptabilité

B. TECHNISCHE DIENST / SERVICE TECHNIQUE

B.1. Uitgevoerde werken:

B.1.1. Elektronica en elektriciteit

- Onderhoud en herstelling van instrumenten (telescopen, digitalisatie, uurbureau, seismologie)
- Ontwerp en implementatie van een algoritme voor het berekenen van de sterrentijd. Realisatie van een prototype met verschillende tijdssynchronisatie en tijdsverdelingsmogelijkheden.
- Ontwerp en realisatie van een druppelladersysteem voor UPS-batterijen.
- Ontwerp en realisatie van een tijdsgesynchroniseerde minuten-pulsgever.
- Ontwerp en realisatie van hardware voor de conversie van de energie- en waterteller meetgegevens naar een RS485/Modbus verbinding.
- Herstellen van elektrische defecten en indien nodig vervangen van verouderde bekabeling en verlichting.
- Installatie van:
  - Verdeelbord telescoop 45cm
  - Verlichting in lokalen 37, 38, 39, 40, 41
  - Verlichting hoogspanningscabine, stookplaats, telefooncentrale.
  - Verlichting in oud uurbureau (lokalen 55C tot 55I)
  - Verlichting en stopcontacten onder atelier (lokaal 49A)
  - Verdeelbord voor atelier mechanica
  - Verdeelbord voor Station Humain.
- Laten uitvoeren van de verplichte jaarlijkse controle van de hoogspanningscabines

B.1.2. Verwarming KMI, KSB en BIRA, airco’s en sanitair:

- Het onderhoud van de gehele verwarmingsinfrastructuur (inclusief planetarium en Humain)
- Afleveren van de nodige attesten om te voldoen aan de geldende wetgeving.
- Voor project digitalisatie:
  - ➢ Onderhoud ontvochtiger, reinigen filters, vervangen thermometers
  - ➢ Aanpassing warmwatercircuit en opnieuw isoleren
- Het onderhoud van de airco’s
  - ➢ Airco uurbureel: demontage ventilo-convector bureel 55C
  - ➢ Grondig reinigen ventilo-convectoren tijdens plaatsing extra buitenunit
- Humain: opvolgen vervanging ketels CV
  - ➢ Plaatsen nieuwe aanzuigleiding stookolie tussen ondergrondse tank en brander
  - ➢ Plaatsen van overvulbeveiliging en 3-wegkraan op ondergrondse tanks om conform te zijn met de wetgeving.
- Bijhouden van de verbruiken van stookolie, gas en water.

B.1.3. Werkplaats mechanica

- Constructie van onderdelen voor instrumenten o.a.:
  - ➢ ALU laden en aandrukplaten voor digitalisatie van fotoplaten
  - ➢ Regelbare onderbouw voor lens zonnecamera
  - ➢ Lenshouder voor zonnecamera
  - ➢ Prototype pendule voor de constante van Newton
  - ➢ Prototype voor bepaling van windrichting en Azimuth op de marslander
- Maken van 2 maquettes van Proba 2
- Kleine herstellingswerken aan de gebouwen.

B.1.4. Telefooncentrale

B.1.4.1. Ukkel (KMI, KSB en BIRA)

- Beheer en programmatie van vaste en mobiele telefonie
- Kostencontrole.
- Maandelijkse kostenberekening voor KMI, KSB en BIRA.
- Bekabelen van telefoonaansluitingen.
- Up to date houden database Omnivista en programmatie van koppelingen tussen de telefooncentrale en Omnivista
- Herstellen en/of vervangen slecht functionerende telefoontoestellen

B.1.4.2. Planetarium:

- Beheer en programmatie.
- Aanpassingen.

B.1.5. Gebouwen

- Paviljoen seismologie: lassen van verstevigingen op de metalen dakstructuur in afwachting van de renovatie
- Planetarium:
  - o Afbraak van toog in cafetaria, oude badkamer; installatie van een refter.
  - o Inrichten van een douchelokaal.

B.1.6. Regie

- De renoveringwerken van het paviljoen seismologie zijn gestart op 3 augustus (uitvoeringstermijn:180 werkdagen).
- De kickoff meeting betreffende de beveiliging van het plateau heeft plaatsgevonden op 17 december. Voorziene startdatum 17 jan 2011 (uitvoeringstermijn: 300 werkdagen)
- De werken betreffende branddetectie zijn begonnen op 3 november.

B.1.7. Waarnemingsstations voor GPS, Seismologie en Humain

- **Opitter**: reparatie draadloze communicatie voor dataoverdracht.
- **Oostende**: Terug plaatsen van seismometer in boorgat
- **Antarctica**: Maken van sturingskast voor monitoring GPS en Seismometer
- **Membach**:
  - 2 He-vullingen;
  - Aanbrengen van een coating op de vloer om stofvrij metingen te kunnen uitvoeren met de absolute gravimeter
  - Vervaardigen van inox pinnen en haken + plaatsen ervan voor de elektrische tomografie
- **Court-Saint-Etienne**: installatie van een seismometer.
- **Humain**:
  - demontage van de oude sturingskast telescopen en plaatsen van een nieuw verdeelbord om de nieuwe in dienst te nemen telescopen te voeden.
  - Installatie van een glasvezelnetwerk.
  - Demontage van 2 bewegingsmechanismes van de telescopen om groot onderhoud te kunnen uitvoeren in de werkplaats in Ukkel

B.1.8. Energie en milieu

- Ontwerp en programmatie van software voor de digitalisatie en archivatie (grafieken/tabellen) van de energie- en waterteller gegevens van KSB en KMI.

B.1.9. Website: fase.oma.be

- Verder uitbouwen en up-tot-date houden van een interne website voor de technische dienst en voor de IDPB.

C. DIENST PREVENTIE EN VEILIGHEID / SERVICE SECURITE ET PREVENTION

Avant-propos :

Ce service a pour mission de veiller au bien-être des travailleurs sur le lieu de travail sur base d'une politique de prévention de l'employeur en collaboration avec la ligne hiérarchique, le comité de prévention, ...

Le bien-être au travail comprend différents domaines :

- la sécurité du travail (incendie, les contrôles légaux, ...)
- la surveillance médicale
- la charge psychosociale
- l'ergonomie
- l'hygiène au travail
- l'embellissement des lieux de travail
- ...

Le service de prévention est également soutenu dans ses tâches par des services externes compétents dans des domaines spécifiques.

Tâches accomplies en 2010:

- Les contrôles légaux suivants ont été réalisés soit par le SIPP soit par un organisme agréé:

- échelle, boîte de secours, éclairage de secours, machine-outil, défibrillateur, ...
- équipement de protection individuelle (harnais de sécurité, ...)
- installation technique (cabine haute tension, appareil de levage, ...)
- installation incendie (porte coupe-feu, extincteur, dévidoir et centrale incendie)

- Les travaux suivants ont été réalisés en collaboration avec le service technique:

- remplacement et amélioration de l'éclairage dans certains bureaux (1er étage, ancien bureau de l'heure, ...)
- remplacement d'anciens tableaux électriques (local cage de Faraday, atelier mécanique, labo bas, ...) et élimination des remarques contenues dans le rapport du contrôle légal de l'installation basse tension
- aménagement d'un réfectoire et d'un local douche au Planétarium
- petits travaux de sécurisation dans les bâtiments et sur le site

- Les missions suivantes ont été réalisées en collaboration avec notre service externe IDEWE :

- surveillance médicale du personnel soumis et des nouveaux collaborateurs
- visite annuelle de nos bâtiments
- visite du conseiller psychologue dans le cadre de la charge psychosociale
- demande d'information

- Dans le domaine de l'ergonomie, certaines petites améliorations ont été apportées :

- remplacement de quelques anciennes chaises de bureau
- remplacement de quelques bureaux non conformes
- remplacement d'anciens stores

- Au niveau de la sécurité incendie, les points suivants ont été réalisés :

- exercice d'évacuation annuel à l'Observatoire et au Planétarium
- mini-exercices avec l'équipe de première intervention et avec le portier

- Des visites internes de sécurité dans les bâtiments ont été entreprises régulièrement afin de localiser les éventuels problèmes et d'y remédier pour garantir la sécurité du personnel

- Les formations suivantes ont été réalisées :

- recyclage annuel pour le conseiller en prévention et participation à différentes séances d'information dans le domaine du bien-être (chantier temporaire et mobile, analyse des risques, ...)
- recyclage pour l'équipe de première intervention
- recyclage annuel pour les secouristes
- recyclage pour le personnel formé à la haute tension

- Le site intranet, le tableau d'information et la documentation du SIPP ont été régulièrement mis à jour

- Le SIPP a accompli les tâches administratives suivantes :

- rédaction du rapport annuel et des rapports trimestriels
- mise à jour de la liste nominative des risques
- rédaction des listes sécurité de l'Observatoire, du Planétarium et de la station de Humain
- mise à jour des registres de sécurité
- mise à jour du plan interne de sécurité de l'Observatoire et du Planétarium
- rédaction des déclarations d'accident de travail et suivi
- suivi des assurances contractées par l'Observatoire
- rédaction des documents nécessaires dans le cadre des conventions de stage et suivi
- réponse aux questions des membres du personnel en matière de bien-être
- mise à jour de la liste des travaux à réaliser dans le cadre de la sécurité transmise à la Régie des bâtiments
- aval de certains achats de matériels
- participation aux réunions du CCB et du groupe safety/security de la politique scientifique
- recherche d'information en matière de bien-être

- Le SIPP a établi certaines procédures de sécurité :

  - local print, 1ers soins, stage étudiant, haute tension, broyeur, nettoyage des vitres, ...

- La Régie des bâtiments a réalisé les travaux suivants dans le cadre de la sécurité et qui ont été suivis par le SIPP :

  - remplacement de l'ancienne plateforme du télescope Schmidt
  - commencement des travaux d'installation d'une détection incendie généralisée
  - placement de quelques portes coupe-feu

- Divers :

- suivi dans la gestion des produits dangereux
- suivi dans le maintien du stock des petits équipements de protection individuelle (gants, masque, ...)
- suivi dans la gestion de l'élimination des déchets spécifiques (TL, produits dangereux, ...)
- suivi des remarques transmises par le personnel dans le cadre de la sécurité.

D. ICT SERVICES

D.1. Description and Objectives

The computing facilities and the network of the Observatory as well as of the Planetarium are managed by the IT department. For users at the Observatory, the IT staff provides a logistic support for the installation and maintenance of intensive compute machines as well as users PCs. The team also maintains the global computing infrastructure consisting of amongst others the email services, application servers, printing facilities, database servers, network infrastructure, etc…

As a public service, the IT team provides access to the web site www.astro.oma.be. They also supply access to the services provided by the different scientific work groups (NTP time server from the Time Lab, Seismic charts, GPS data, Space weather, ..). The IT Department also takes part in developments related to scientific projects with international partners.

More precisely, the IT department projects are detailed as follow:

- **Backbone Infrastructure**: the objective is to maintain the backbone infrastructure operational, safe and at top performance, 24 hours a day. Our backbone infrastructure relies upon three main components, namely: the network, the servers and finally the storage.
- **Web Programming**: the objective is to develop and maintain the web site of the ROB as well as to develop user friendly web interfaces for different projects.
- **Common Resources**: The objective is to manage common resources such as file servers, HPC servers, FTP service, mail, NIS, DNS, DHCP, etc…. This project includes also the management of FAQ for users and a knowledge database for the sysadmin.
- **Users Management:** The objective is to provide help and support to the users of the Observatory. This includes the helpdesk, the setup and management of desktop PC, the management of generic application servers and the management of the IT material for users.
- **Purchases**: All the IT purchases are done by the IT department. This includes all the procedure, from defining the user or group needs to the installation of the chosen material. This include also the purchase of IT consumables (printer cartridges, printer toners, data storage media, etc …).

D.2. Progress and results

D.2.1. Backbone Infrastructure

D.2.1.1. NETWORK

- **Monitoring:** Monitoring and early warning allows us to have faster response times in case of a network shortage; to achieve this result we have setup a monitoring server with a customized application. This machine checks regularly the health of the network. In case of problem, actions are taken, and the system administrators are notified by email or by SMS.
- **Cabled Network:** We have implemented a solution to be able to separate the network into a private and a public network, based on a MAC address authentication, somewhat similar to the Wireless system; this system is only implemented on a very small number of network outlets.
- **Wireless network:** The new captive portal system has been implemented and tested

D.2.1.2. SERVERS

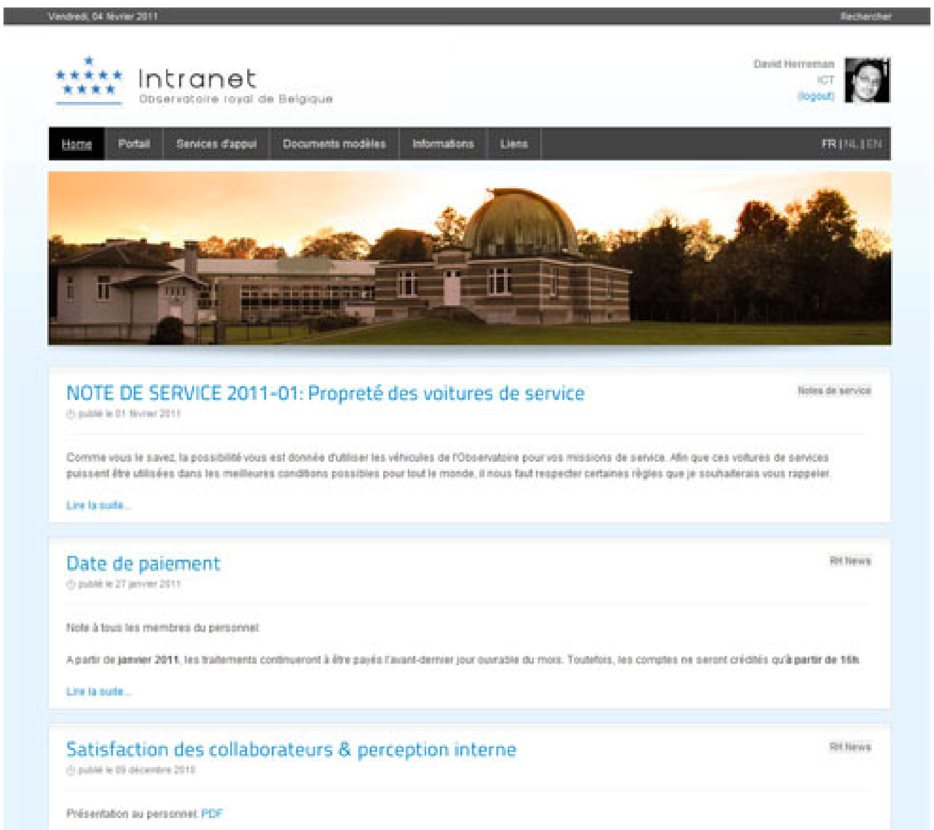
The VMWare infrastructure has been switched from the Classical ESX to the new ESXi type of servers. A large number of virtual servers have also been replaced by newer versions of their operating system, mainly Windows 2003 Servers have been replaced by Windows 2008R2 servers, and Linux Ubuntu 8.04 have been replaced by Long term support version 10.04.

D.2.1.3. STORAGE

The year 2010 has been mainly dedicated to the new local file server. A study of the different options has been carried out, contacting various companies, deploying demo units, and so on. A system was selected and purchased, then followed a long period of setting up and testing the device. In fine, the system will be modified to better fit our needs, and will be deployed early 2011.

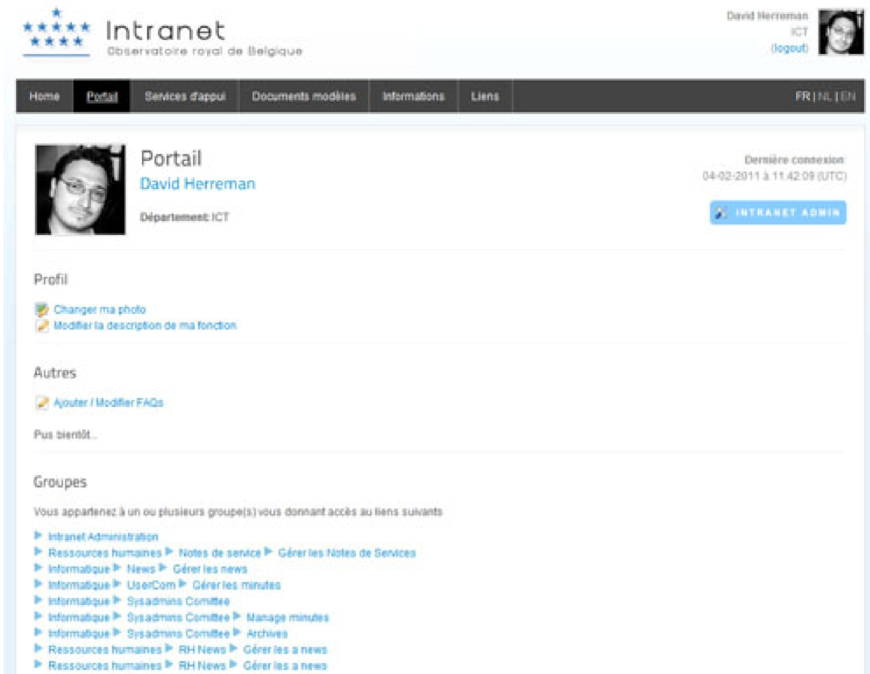
D.2.2. Web Programming

- **Intranet:** The intranet web site has been completely redone. It's based on a selfmade new CMS using technologies like Adobe Flex and PHP/MySql. The design has been redone using the "BluePrint CSS framework". The goal was to have a clean interface, clear and easy to understand for the user.

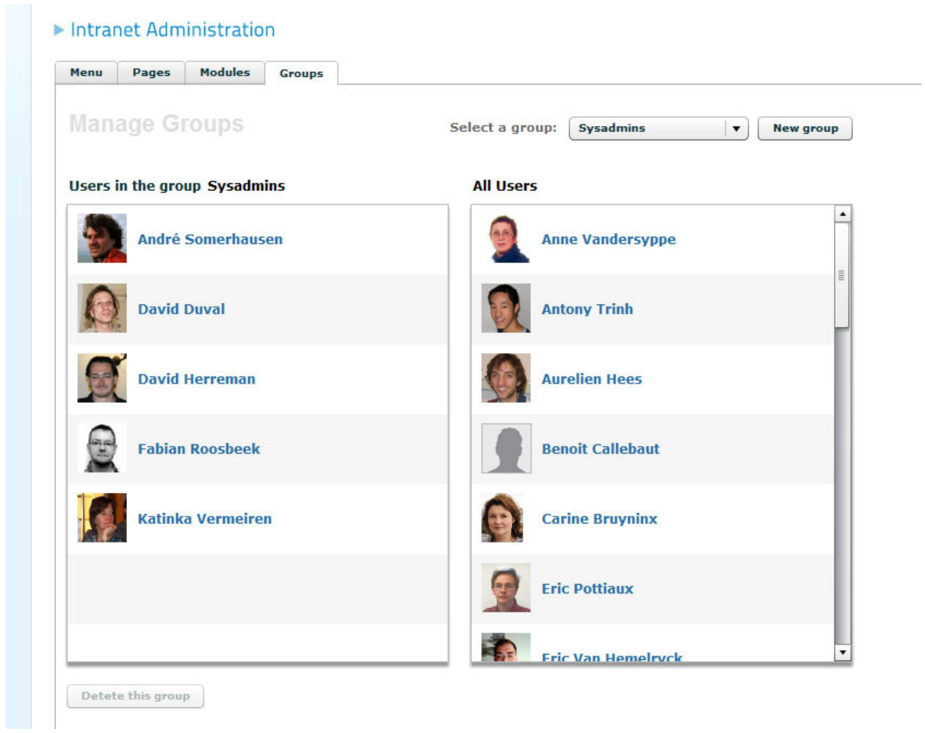


The new intranet can manage many languages: French, Dutch and English are implemented.

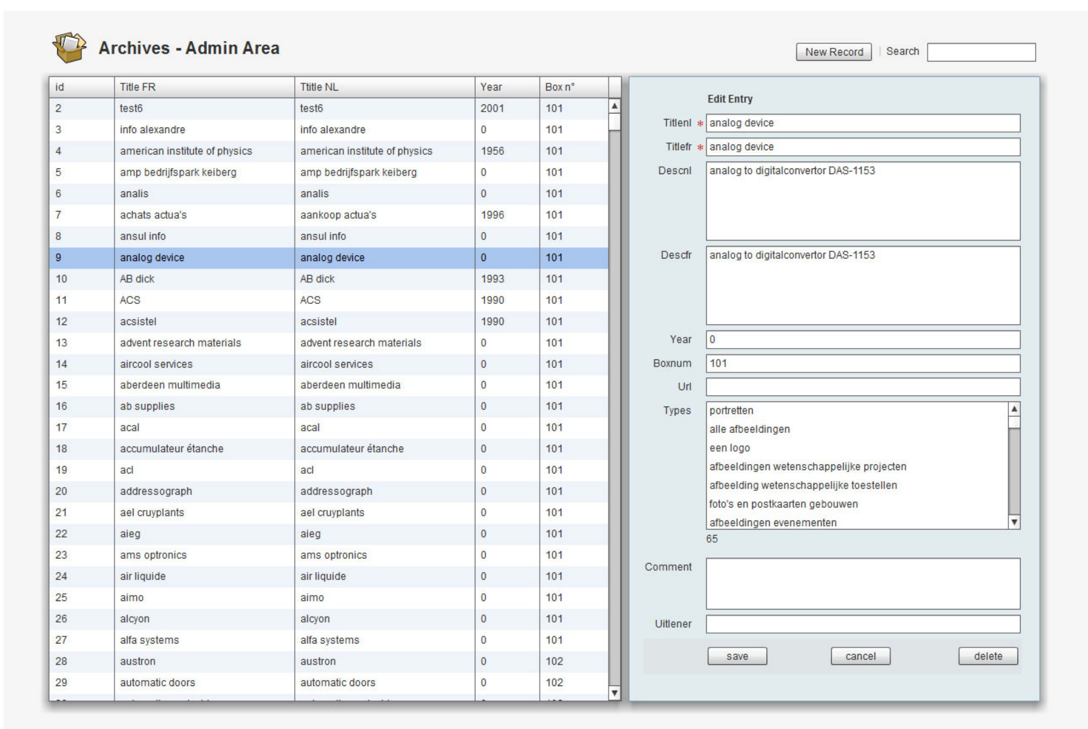
Users can now use their central username and password to authenticate into the intranet. Once authenticated, the user has access to a portal where he can change his photo, function description and more.



Group management has been added. The administrators can create and manage groups. For ex., a group "notes de service" has been created and accessible by the HR (Human Resource) service.



- **Archives:** An Adobe Flex application has been created to manage all the archives (pdf files / photographs) of the Observatory. All entries are saved in a SQL database.



D.2.3. Common Resources

- **Central DNS – NIS SERVER – ACCOUNT policy**. An LDAP server has been installed for the 3 institutes. 1 master and 3 slaves are now available. This LDAP server is the future replacement of the NIS.
- **MAIL – MAILSERVERS – Postmaster:** A new smtp server based on "Dovecot" has been implemented at the ROB: smtp-as.oma.be. This has sped up considerably the access to the mails. The two other institutes have now adopted the same system.
- A new antivirus software barracuda has been installed centrally. With the new LDAP server in place, each user will be given the possibility to check himself their rejected mails and deliver them if needed. In the near future we will investigate the possibility to implement a mail server with authentication, so that mail sent from outside the observatory can be sent via our mail server.
- **FAQS – Welcome:** We try to enhance the faqs on technet and intranet to redirect users to that info. New users are given the link to the new "Welcome new user", which gives an overview of the ICT at the ROB, such as the available servers, rules etc...
- **KNOWLEDGE base for internal use:** A knowledge base for use at the ICT department is regularly completed with specific technical information.
- **Parallel Compute Servers:** The replacement of PLATO AND ZENO has been postponed.
- **Printers:** We are in the process of renewing all the departmental printers by new models, with better performance, cheaper and more ecological.

D.2.4. Users Management

D.2.4.1. HELPDESK

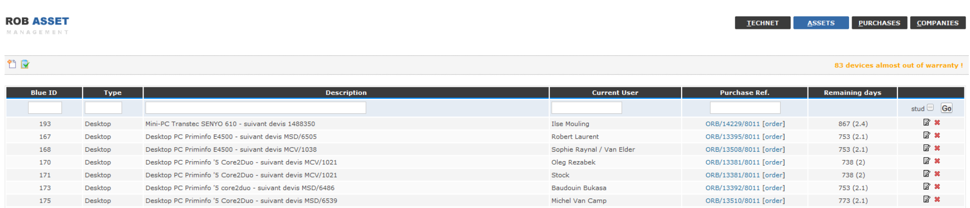
In 2010, continuous support for users has been provided via the helpdesk

D.2.4.2. DESKTOP PC

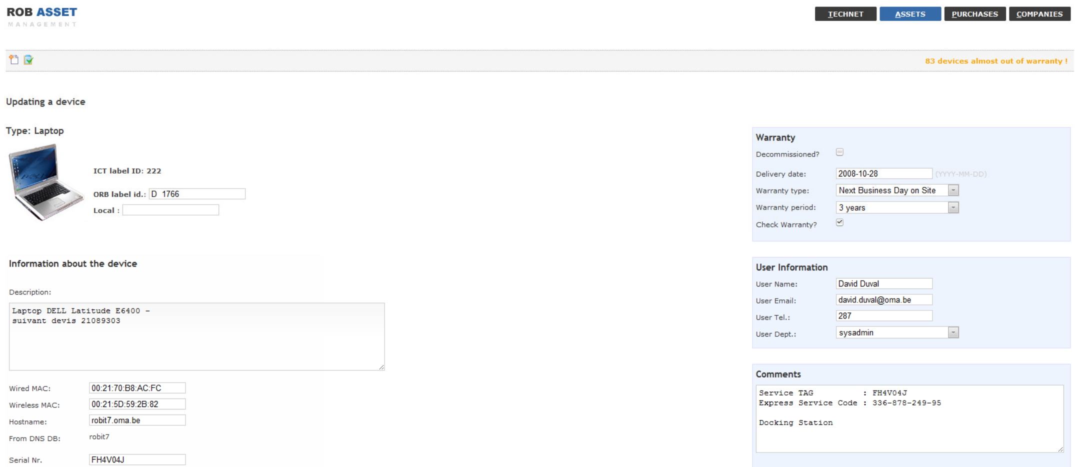
We have installed and configured several new desktop PC and laptops as well as refurbished PC and laptops with either Ubuntu (Linux) or Windows XP/Vista/7. We also install & maintain many kinds of software on these PC.

D.2.4.3. ASSETS

We maintain a database with the IT material currently in use. This database allow us to know exactly what IT material is used by all the users

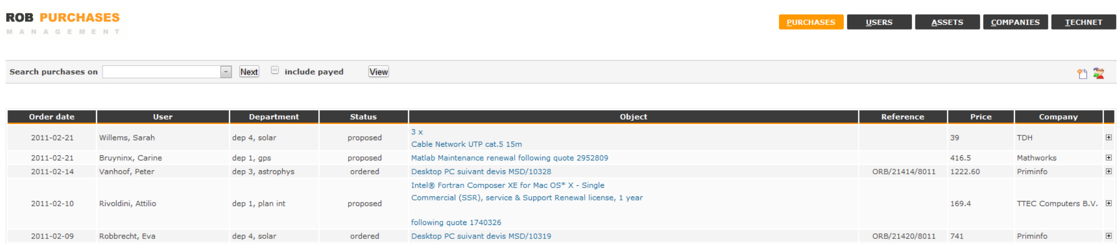


Blue ID	Type	Description	Current User	Purchase Ref.	Remaining days
193	Desktop	Mini-PC Transtec SENYO 610 - suivant devis 1488350	Ilse Mouling	ORB/14229/8011 [order]	867 (2.4)
167	Desktop	Desktop PC Priminfo E4500 - suivant devis MSD/6505	Robert Laurent	ORB/13395/8011 [order]	753 (2.1)
168	Desktop	Desktop PC Priminfo E4500 - suivant devis MCV/1038	Sophie Raynal / Van Elder	ORB/13508/8011 [order]	753 (2.1)
170	Desktop	Desktop PC Priminfo '5 Core2Duo - suivant devis MCV/1021	Oleg Rezabek	ORB/13381/8011 [order]	738 (2)
171	Desktop	Desktop PC Priminfo '5 Core2Duo - suivant devis MCV/1021	Stock	ORB/13381/8011 [order]	738 (2)
173	Desktop	Desktop PC Priminfo '5 core2duo - suivant devis MSD/6486	Baudouin Bukasa	ORB/13392/8011 [order]	753 (2.1)
175	Desktop	Desktop PC Priminfo '5 Core2Duo - suivant devis MSD/6539	Michel Van Camp	ORB/13510/8011 [order]	773 (2.1)



D.2.5. Purchases

In 2010, we have done all the IT purchases for the Observatory. Like for the assets, we maintain a database with all the purchases



D.3. Perspective for next years

- **Network**: The year 2011 will see the generalisation of the secure copper network system, providing a more secure environment on the point of view of devices physically connected to our network. An audit of the networked devices will be conducted in 2011.
- **Servers**: In 2011, the switch to the new versions will be completed, mainly for the Linux operating systems. Virtual Desktop Infrastructure will be investigated. Old ESX servers will be replaced by new ones.
- **Storage**: The first part of the year will be mainly dedicated to implementing the final solution for the local fileserver. A study of the off-site backup solutions will be carried out.
- **Intranet**: Other modules will be made for the Intranet. A first module will enable a user to create a purchase proposal and submit it to his supervisor who will use this same module to accept or reject the proposal. If accepted, the proposal will be transferred to the director and accounting, always via this same module.
- **LDAP**: A new web application will be created for the three institutes in order to manage the LDAP directory. The Intranet will be linked to the new LDAP directory.
- **Web site**: We foreseen to redo the web site of the Observatory (www.astro.oma.be) with modern tools and language.
- **FS Space**: Some investments will have to be done to continue assuring the good functioning of these fileservers, as they tend to be fully charged.

- **Parallel compute servers:** In 2011, we will start the investigation on the necessity of the replacement of PLATO and ZENO. As some users at the ROB might have other needs then the actual queuing system, we will try to find out their specific needs, to ensure that all users will benefit of the available calculating capacity.
- **HPOC Servers:** The two HPC servers alka and caipi will be replaced by a new powerful server.
- **Mail**: In 2011 we will investigate the possibility to implement a mail server with authentication, so that mail sent from outside the observatory can be sent via our mailserver.
- **VPN & SSL:** We will investigate the implementation of a SSL / VPN secure connection for access to the ROB from outside.

D.4. Personnel involved

- David Duval
- David Herreman
- Fabian Roosbeek
- André Somerhausen
- Katinka Vermeiren