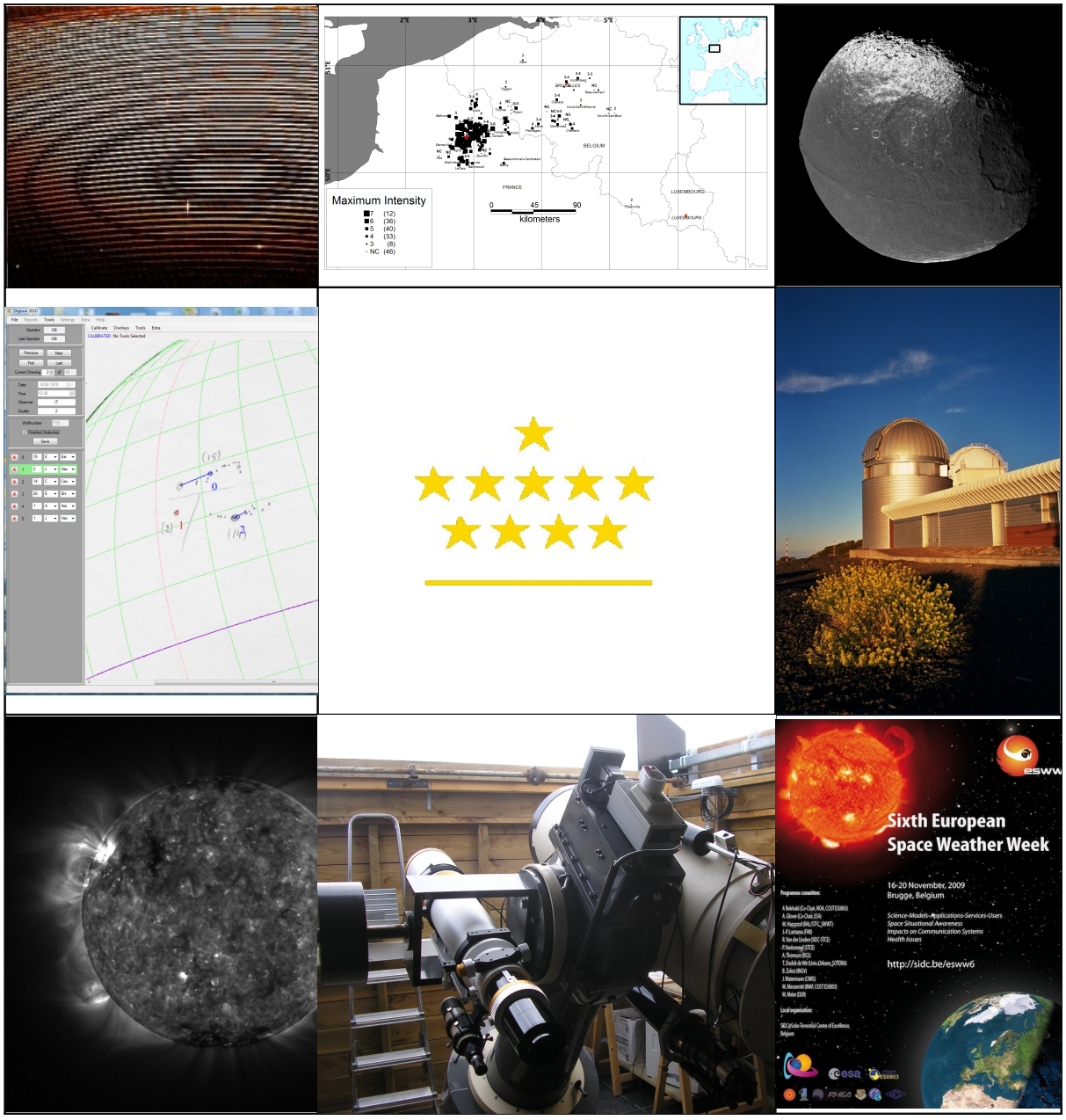
Koninklijke Sterrenwacht van België
Observatoire royal de Belgique
Royal Observatory of Belgium

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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Beste lezer,

Ik heb het genoegen u hierbij het jaarverslag 2009 van de Koninklijke Sterrenwacht van België (KSB) voor te stellen. Zoals ondertussen traditie is geworden, wordt het verslag in drie aparte delen voorgesteld, namelijk een onderdeel gewijd aan de wetenschappelijke activiteiten, een tweede deel dat de publieke dienstverlening omvat en tenslotte een onderdeel waarin de ondersteunende diensten zich voorstellen.

De kernactiviteiten van de KSB situeren zich in het wetenschappelijk onderzoek, en het hoeft dan ook niet te verbazen dat dit veruit het grootste deel van het verslag uitmaakt. Aangezien we dit verslag ook gebruiken om onze activiteiten voor te stellen aan onze collega's, die voornamelijk in het buitenland te vinden zijn, opteren we er tevens voor dit deel van het verslag in het Engels op te stellen.

Een belangrijke nieuwigheid is dat we bij het opstellen van dit verslag de ordening volgen van de nieuwe structuur van de Sterrenwacht, bestaande uit vier operationele directies, zoals vastgelegd in het Ministerieel Besluit van 22 februari 2010. Binnen elke operationele directie worden de activiteiten onderverdeeld in een aantal wetenschappelijke thema's, hetgeen uiteraard niet uitsluit dat er een aantal overlappende onderdelen zijn tussen thema's en directies. De indrukwekkende lijst van publicaties wordt gebundeld in een apart hoofdstuk achteraan deel 1 van het verslag.

Cher lecteur,

J'ai le plaisir de vous présenter le rapport annuel 2009 de l'Observatoire royal de Belgique (ORB). Comme le veut désormais la tradition, le rapport est séparé en trois parties distinctes. La première est consacrée aux activités scientifiques, la deuxième contient les activités de service public et la troisième présente les services d'appui.

Les activités principales de l'ORB sont intimement liées à la recherche scientifique, il ne faut donc pas s'étonner de voir que celle-ci constitue de loin la plus grande partie du rapport. Nous utilisons également ce rapport afin de présenter nos activités à nos collègues qui, pour la plupart, se trouvent à l'étranger. Aussi, avons-nous choisi de rédiger cette partie en anglais.

La grande nouveauté de ce rapport est que, lors de sa rédaction, nous avons suivi la nouvelle structure de l'Observatoire, constituée de quatre directions opérationnelles, comme l'établit l'Arrêté ministériel du 22 février 2010. Au sein de chaque direction opérationnelle, les activités sont divisées en thèmes scientifiques ; ce qui n'exclut pas qu'il puisse il y avoir certains chevauchements entre les thèmes et les directions opérationnelles. La liste impressionnante des publications est reprise dans un chapitre annexe situé après la première partie du rapport.

Het is moeilijk de hoofdpunten van onze activiteiten aan te duiden zonder oneer aan te doen aan de activiteiten die hier niet apart vermeld worden, maar wij raden u alvast een bijzondere lectuur aan van onze deelname aan het pilootproject voor *Precise Point Positioning* TAIPPP (blz. 13), de installatie van onze GNSS apparatuur op de Poolbasis Prinses Elisabeth (blz. 18), de opvolging van de reeks aardbevingen in de buurt van Court-St.-Etienne (blz. 59) en de aanvang van vulkanische monitoring in Indonesië (blz. 57). Opmerkelijk zijn ook de nieuwe opportuniteiten voor astronomische waarnemingen, zoals de gegevens van de satellieten CoRoT en Kepler (blz. 98), Herschell (gelanceerd op 14 mei, blz. 112), de eerste waarnemingscampagnes met de spectrafraaf Hermes (blz 138), of nog de gegevens van de nieuwe satellite 'made in Belgium', PROBA2 (blz 200). In de nabije toekomst kijken we ook uit naar de lancering van de satellieten GAIA (blz. 129) en SDO (blz. 203).

Wat de publieksgerichte activiteiten betreft vermelden we de zeer succesvolle opendeurdagen (blz 273) en de grote stap voorwaarts voor het Planetarium op de Heizel: de installatie van een full-dome projectiesysteem (blz. 264).

Uit deze en alle andere bijdragen aan dit jaarverslag is duidelijk dat dit andermaal een productief jaar was voor het wetenschappelijk onderzoek aan de Koninklijke Sterrenwacht van België.

Ik wens u een aangename lectuur!

Ronald Van der Linden

Algemeen Directeur

Il est difficile de souligner les principaux points de nos activités sans dévaloriser les activités qui ne sont pas citées ici, mais nous vous invitons à porter une attention toute particulière à la lecture de notre participation au projet pilote de positionnement précis TAIPPP (p. 13), à l'installation de notre appareillage GNSS à la Station polaire Princesse-Elisabeth (p. 18), au suivi de la série de tremblements de terre survenus dans la région de Court-St.-Etienne (p. 59) et au début de la surveillance de l'activité volcanique en Indonésie (p. 57). Soulignons également les nouvelles opportunités d'observations astronomiques, comme les données des satellites CoRoT et Kepler (p. 98), Herschel (lancé le 14 mai, p. 112), les premières campagnes d'observation menées à l'aide du spectrographe Hermes (p. 138), ou encore les données du nouveau satellite "made in Belgium", PROBA2 (p. 200). Dans un avenir proche, nous guetterons aussi le lancement des satellites GAIA (p. 129) et SDO (p. 203).

Quant aux activités destinées au public, nous citerons les journées portes ouvertes qui furent une grande réussite (p. 273) et l'avancée réalisée par le Planétarium du Heysel : l'installation d'un système de projection "full dome" (p. 264).

Au vu de ce rapport annuel, il apparaît clairement que cette année fut une nouvelle année productive pour la recherche scientifique à l'Observatoire royal de Belgique.

Je vous souhaite une agréable lecture !

Ronald Van der Linden

Directeur général

Deel 1: Wetenschappelijke activiteiten

Partie 1: Activités Scientifiques

Part 1: Scientific Activities

Summary

REFERENCE SYSTEMS AND PLANETOLOGY

Mission and objectives

The mission of this Operational Directorate is to contribute to the elaboration of (terrestrial and celestial) reference systems and timescales, to integrate Belgium in international reference frames, 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.

The activities 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. The present objectives of these projects are described below with the important milestones reached this year for each of them.

(a) Project 1 'TIME – TIME TRANSFER'

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. Presently five high-quality atomic clocks are participating 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 located in a temperature-controlled environment. ROB's five clocks are located in such an environment and their performances are continuously monitored by inter-comparison between themselves and 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, new methods have been developed insuring a time-transfer precision that matches the required precision of the timescales. The clock comparisons are usually performed using code measurements of GPS satellites in common view. The scientists involved in the project mainly 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 ROB involvement in the definition of international timescale impose us a quasi perfect reliability.

Milestones reached this year:

(1) We have participated to the BIPM Pilot Project TAIPPP, i.e. providing data for using Precise Point Positioning (PPP, a method that performs precise position determination using a single GPS receiver and from the advent of widely available precise GPS orbit and clock data products) for the computation of the TAI.

(2) We have prepared a subroutine for the second order ionospheric corrections to be provided with the IERS conventions (collaboration with Hernandez-Pajares).

(3) We have demonstrated that the second order effects cannot be correctly computed during extreme events such as an ionospheric storm due to the high variability of the magnetic field at that time (second-order ionospheric corrections use a value of the geomagnetic field at the Ionospheric Piercing Point (IPP) of each GPS signal).

(b) Project 2 'GNSS'

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. In addition, as was the case in several other groups simultaneously involved in EPN data analysis and 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 crustal deformation.

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

Milestones reached this year:

(1) GPS equipment has been installed during a 12-day period at the Princess Elisabeth Antarctic base; first tests showed that its position can be obtained with a precision of a few mm.

(2) 9 new GNSS stations were integrated in the EPN tracking network and the EPN Central Bureau web site received a total of 2.5 million hits in 2009.

(3) It was demonstrated that the errors caused by the reference frame definition on high-precision GNSS-based station positions and velocities obtained from a regional network analysis exceed the noise level. In addition, we demonstrated that in such a regional network the amplitude of the annual and semi-annual signals in all components is underestimated (27% (resp. 15%) reduction of the annual (resp. semi-annual) signal in the height component). Consequently, the geophysical interpretation of the seasonal signals observed using a regional network is challenging.

(4) A step-wise approach has been developed in order to get rid of the reference frame bias in GNSS-based position and velocity solutions obtained from a local or regional network analysis.

(5) GNSS-based velocity solutions from all over the world have been gathered and analyzed in order to densify the latest realization of the ITRS (International Terrestrial Reference System) and provide regional dense velocity information in a common global reference frame. Preliminary comparisons between different velocity solutions show an RMS agreement between 0.3 mm/yr and 0.5 mm/yr resp. for the horizontal and vertical velocities.

(6)The comparison of the intensity of the ionospheric activity and the error on GPS-based kinematic positions during the 2003 Halloween ionospheric storm (Oct. 30th, 2003) demonstrated a degradation of the position repeatability obtained with GPS. It was shown that during this period the kinematic position repeatabilities were mainly affected for stations in Northern Europe with outliers reaching 12 cm in the horizontal components, and 26 cm in the vertical component.

(7) The validation of the in-house developed GNSS software Atomium for precise point positioning on the data from the EPN demonstrated mean weekly repeatabilities of 3.1 mm for the north, 1.9 mm for the east and 5.7 mm for the up components.

(8) The GNSS signal ray concentration traversing the Earth's ionosphere above Europe was studied using a tomographic approach dividing the ionosphere in voxels. It was shown that GPS signals from the EPN traverse 85% of voxels while GPS+GLONASS+Galileo signals will traverse 94% of the voxels. This demonstrates the added value of using navigation signals from multiple satellite constellations to perform ionospheric imaging.

(9) 45 new GNSS sites were added to the E-GVAP service at ROB providing meteorological agencies with GNSS-based tropospheric zenith path delays for assimilation in the Numerical Weather Prediction models bringing the total number of routinely analyzed GNSS stations to 210.

(10) The comparison of the tropospheric zenith path delays estimated in near-real time using GPS observations with Water Vapour Radiometer data showed the excellent accuracy of the ROB tropospheric delays, with a bias of solely -1.6 mm.

(c) Project 3 'EARTH ROTATION'

The objectives of the project 'Earth rotation' are to better understand and model Earth rotation and orientation variations, and to study physical properties of the Earth's interior. 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 and to improve their knowledge and understanding of the system, from the external fluid layers to the Earth deep interior.

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

(1) We have developed a strategy for combining VLBI and GPS observations in order to achieve a better accuracy and a better consistency in the resulting nutation series.

(2) We have compared the semi-analytical precession-nutation models and shown that there are no significant discrepancies between them, except for an empirical model that has to be disregarded.

(3) Using a Bayesian approach, we have estimated certain outer core and inner core parameters from an analysis of different VLBI nutation data; the differences with respect to the adopted model arise from non-linearity effects, usage of all the available data, and the longer time series.

(d) Project 4 'GEODESY AND GEOPHYSICS OF TERRESTRIAL PLANETS'

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. Geodetic 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.

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

(1) The Lander Radio-science experiment LaRa for the next mission opportunity to Mars in the ESA AURORA program has successfully passed the PDR (Preliminary Design Review) with Technology Readiness Level TRL # 5. With the help of the US co-PI of LaRa, a SALMON (Stand Alone Mission of Opportunity Notice) proposal has been submitted to and approved by NASA for supporting access to the DSN (Deep Space Network) 70 m antennas.

(2) 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 liquid and has about the same relative size as the core of the Earth but contains a larger fraction of light elements.

(3) For the state-of-the-art interior models of Mars, forced rotation variations have been calculated. We have shown that if Mars has a core size larger than 1750 km, the ter-annual nutation is expected to be amplified by the resonance with the Free Core Nutation (FCN), a rotational normal mode of Mars, which increases the probability to observe this resonance.

(4) We have shown that meteorite impacts alone cannot explain the possible existence of a denser atmosphere on the early Mars.

(5) It has been shown that the variations of the odd and even gravity harmonics due to the Martian atmosphere dynamics perturb the orbits of the Mars Global Surveyor and Mars Odyssey spacecraft at a level of up to 70 cm and 10 cm, respectively. As the MGS/ODY orbits have an average precision of 1.5 meters, only for the odd harmonics can seasonal variations be retrieved from MGS/ODY tracking data.

(6) From radioscience data during flybys of MEX near Phobos, the mass estimation of the Martian moon Phobos has been improved.

(7) By discretizing the volume of Phobos into cubes of equal volume and with densities either of water ice, or of rocks with or without porosity, interior models of Phobos have been constructed that satisfy the observed mass of Phobos. It has been shown that it is unlikely for Phobos to have a homogenous internal mass distribution since the resulting forced libration amplitude deviates significantly from the measured forced libration amplitude.

(8) An analytical model has been developed to show that several forced librations of Mercury with periods longer than the orbital period can have large amplitudes due to a resonance with Mercury's free libration.

(9) State-of-the-art interior structure models of Mercury have been calculated and the sensitivity of future geodesy observations of the rotation and tides of Mercury to the core size, inner core size, and composition has been determined.

(10) An extensive study has been performed to investigate the expected precision on the obliquity and libration amplitude from the comparison of the positions of selected spots at the surface of Mercury at different times on camera pictures of the future BepiColombo mission.

(11) The atmosphere-induced variations in the gravity field and the rotation of Venus have been calculated. The density of the atmosphere of Venus over its North Pole has been determined.

(12) From an extensive set of astrometric observations, the rate of tidal energy dissipation in Io is determined to be in close agreement with the observed heat flux, suggesting that Io is close to a thermal steady state. This study has been published in Nature.

(13) A tool has 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.

(14) 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.

A. Reference Systems

A.1. Time and Time Transfer

A.1.1. Objectives

The Time and Time Transfer project has the following objectives:

- to maintain high-quality clocks for participation in the international timescales (mainly International Atomic Time (TAI) and the International GNSS Service Timescale (IGST)), 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 provide UTC(ORB) to Belgian users via Network Time Protocol (NTP);
- to develop and improve the GNSS time transfer strategies and to test them.

A.1.2. Progress and results

A.1.2.1. Service Activities

- Monitoring of UTC(ORB): the bias between UTC(ORB) and UTC remained very stable and lower than 50 ns during 2009
- Legal aspects of UTC(ORB) in Belgium: continuation of the procedure to get UTC(ORB) recognized as legal time for Belgium.
- Time Laboratory:
  - Management of the clock signals needed for GNSS receivers BRUS, ZTBR, PLB1, PLB2;
  - Participation to the BIPM Pilot Project TAIPPP;
  - Preparation of the new design of the Time laboratory.

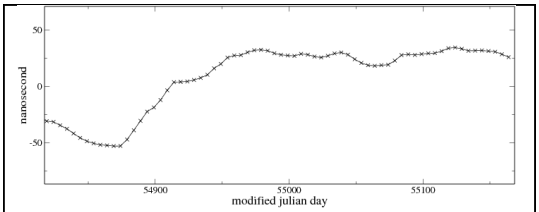


Figure 1: UTC(ORB) compared to UTC during the year 2009.

A.1.2.2. Research Activities in Time and Frequency Transfer with Atomium

- Study of the requirements for GNSS receivers for timing applications:
  GNSS receivers for timing applications should be able to transfer time with an accuracy of 1 ns or better, and to compare remote frequency standards without degradation of their frequency due to the receiver architecture. It comes out of this study that it is essential that the receiver functions be described in detail by the manufacturer. This information must contain a correct definition of the physical point corresponding to the internal reference clock inside the receiver, i.e. the physical point where the GNSS measurements are made. The information should also contain all the relations between this physical point and the input/output signals, and between this physical point and the point to which the measurements are reported (if not the same). The receivers should also provide the measurements using the standard geodetic Receiver Independent Exchange Format (RINEX) format, and if delivering the Common GPS and GNSS Time Transfer Standards (CGGTTS) files; the manufacturers should follow the future updates of this format. The timing community also will take advantage of multi-system receivers, but only if these receivers use the same internal reference for the measurements of all the systems and if the inter-frequency biases can be precisely determined.
- Improvement of the tropospheric modeling in Atomium to improve Time Transfer solutions:
  An improvement of the tropospheric parameter estimation strategy in Atomium reduced the differences between the Atomium and the IGS clock solutions, with a factor up to 10. The new strategy estimates the wet part of the troposphere (the so-called Zenith Wet Delay (ZWD)) with a 15-minute sampling rate (rather than 2 hour previously) and uses relative constraints of 1mm/15 min between successive estimations. The improvement is illustrated in Figure 2, which presents the clock solutions (shown as the differences with respect to the IGS combined solution) and the tropospheric path delays obtained with the two

strategies. The Figure also shows the solutions obtained when the troposphere is not estimated but fixed to the ROB or IGS products in the least square analysis.

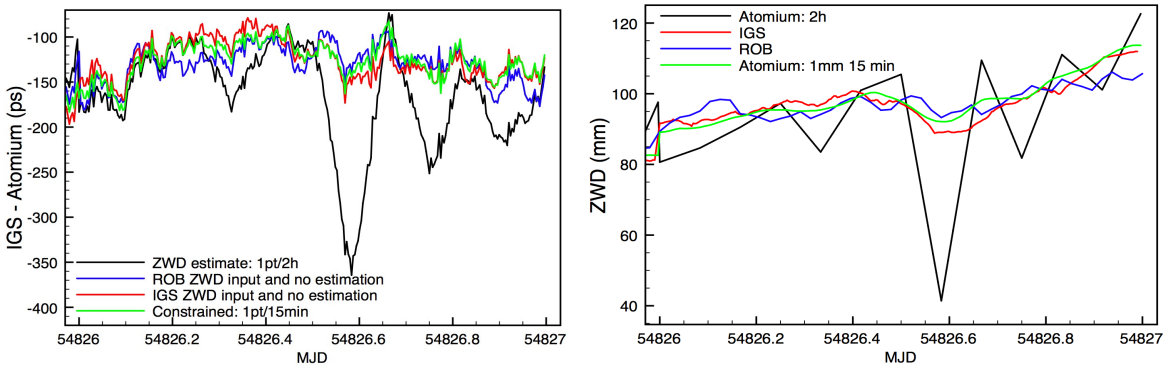


Figure 2: Left: differences between IGS and Atomium clock solutions for TLSE receiver (in Toulouse) during 1 day for different strategies of Zenith Wet Delay (ZWD) estimations and for a ZWD fixed to the ROB or IGS products. Right: ZWD computed from different strategies and software: ROB ZWD (blue) from the Bernese software, IGS combined ZWD (red), Atomium estimated ZWD without constraints (black) and with constraints (green).

- Combination of Single Differences of GPS and GLONASS data for Time and Frequency Transfer:
  We have developed a Multi-GNSS analysis for Time and Frequency transfer using the single differences of observables. This limits the distance between the receivers to about 2000 km. The results show that an increased number of satellites in common-view is a necessary but not sufficient condition to improve time and frequency transfer over long baselines, due to the need to estimate additional parameters, such as hardware delays for GLONASS code measurements and ambiguities for carrier phase measurements. The lack of correction for antenna phase center variation for GLONASS and the lower accuracy of the IGS GLONASS orbit files are also a limitation. The information added in the analysis is not modeled with the same quality. The improvement of such products and the future Galileo signal should allow improving our single difference solution in the next years.

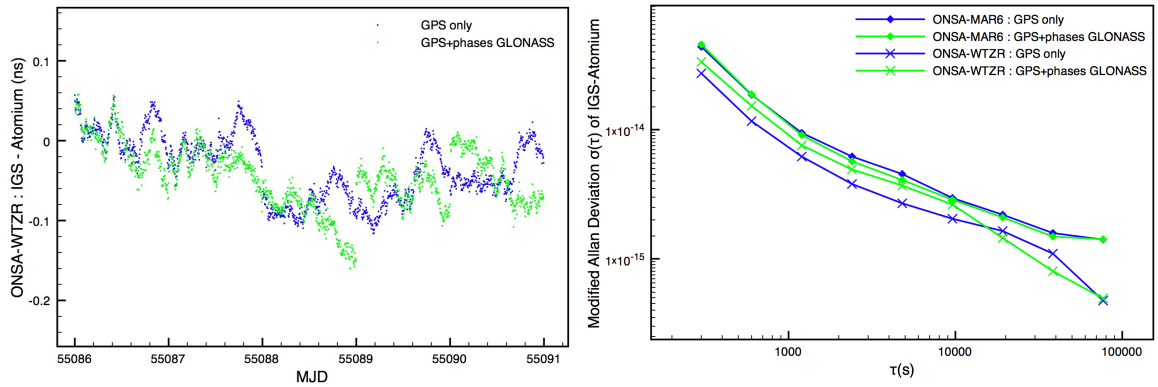


Figure 3: Left: Difference between IGS solution and Atomium solution for the link ONSA-WTZR using GPS only (in blue) and GPS+phases GLONASS (in green) measurements. Right: Modified Allan Deviation of the difference between IGS and Atomium solution for the two links using GPS (in blue) and GPS+phases GLONASS (in green).

- Influence of second and third order ionospheric perturbation on GPS time transfer:

The present requirement for the clocks participating to the generation of TAI, on which legal times are based, is at the level of the nanosecond over one day. The comparison of these clocks is done using GPS Time and Frequency Transfer (TFT). The Atomium software has been developed at ROB to investigate the improvement of time transfer by using high-end GPS receivers. It aims at performing time transfer at the picosecond (ps) level and it is based on the GPS Precise Point Positioning (PPP) and Common View (CV) approaches. Similarly to high-end GPS receiver positioning, Atomium uses the ionosphere-free combination of GPS dual-frequency measurements to remove first-order ionospheric effects from the computations. In 2008, we

computed and quantified the second and third-order ionospheric perturbations on the GPS signals and their influence on time transfer, and included this correction in the new version of the Atomium software. In 2009, STCE scientists showed that on very-long (intercontinental) baselines, second-order ionospheric delays can cause an effect up to about 10 ps in the relative clock solution, or even more for days with higher diurnal variations of the TEC (Total Electron Content). Figure 4 illustrates the effect of taking or not taking second-order ionospheric delays into account in the GPS TFT for an intercontinental link. It shows both the effect of the differential local noon maximum in the TEC and the ionospheric-storm effect. Of course, this ionospheric second-order effect on TFT is not visible for nearby stations (European links) where the local noon is synchronous, as it is the differential ionospheric effect between stations that matters in the TFT solution.

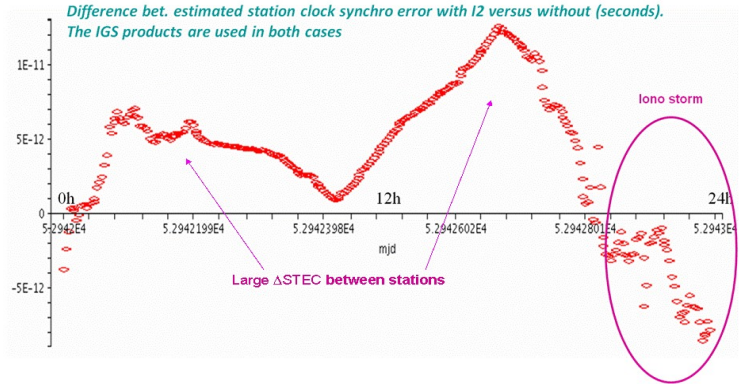


Figure 4: Effect of taking or not-taking second-order ionospheric delays into account in the GPS time and frequency transfer for the intercontinental baseline Brussels (BRUS)-Canada (NRC1) link, on the ionosphere-stormy day 30th October 2003. This effect is shown as the difference between the Atomium clock solutions estimated with and without the second-order ionospheric corrections.

- Second-order ionospheric effects during a storm:
  Second-order ionospheric corrections use a value of the geomagnetic field at the Ionospheric Piercing Point (IPP) of each GPS signal. Since no real measurements are available at each IPP, Atomium uses the International Geomagnetic field Reference (IGR) model to compute those values. However, the comparison of measurements of the magnetic field with the model during a geomagnetic storm demonstrates that the IGR model does not reproduce the rapid variations (in orientation and magnitude) of the geomagnetic field. The model might miss a factor 100 enhancement. As a consequence, we know that second-order ionospheric effects during a storm cannot be well quantified. For example, the estimation based on the IGR model shows that the 2nd order effect during the storm reaches up to the order of 10 picoseconds. However, in practice, it might reach up to the order of the nanosecond. But aside geomagnetic storm events, the IGR model can be trusted to estimate the impact of the second-order ionospheric effect on TFT, so that the magnitude of the effect of the differential local noon maximum in STEC can be trusted.

A.1.2.3. Research Activities in Time and frequency transfer for IERS Conventions

- In the frame of time and frequency transfer we have prepared a subroutine for the second-order ionospheric corrections to be provided with the IERS conventions.

A.1.2.4. Research Activities in Combination of GPS and TWSTFT data

- The method combining TFT by GPS and Two-Way Satellite Time and Frequency Transfer (TWSTFT) was validated on different time links illustrating different baseline lengths and different magnitudes of noise in the two-way (TW) data. The method was shown successful for all of them: the combined solution perfectly fitted the TW data, with an average difference between the combined solution and the TW solution less than 0.01 ps for all the links tested and with a standard deviation which falls down to 132 ps for the OP-NIST link with a particularly small noise level. In addition, it was shown that the approach developed at ROB was able to remove the large day-boundary discontinuities which are sometimes present in the GPS-only time transfer solutions, either due to GPS hardware delay changes, or due to the coloured signature of the noise of GPS codes. It was however shown that a very high noise level in the TW data used can introduce new discontinuities in the combined solution, with a magnitude up to the nanosecond level as for instance for the noisy link IT-PTB. Nevertheless, the combined solution computed for a less-noisy TW link OP-NIST has day-boundary jumps all smaller than 200 ps. The closure of

the combined solution was tested on the triangle CH-OP-ROA. Its standard deviation shows an improvement by more than a factor 5 with respect to the TW closure. It is however slightly more noisy than the GPS-only closure, due to the link-based nature of the combined-solution closure. Finally, for typical TW links with a precision of 0.5 ns, the combined solutions keep the 1 ns accuracy of the TW data, reach the 10^{-15} frequency stability at the one day averaging time, solve for the large day-boundary discontinuities existing in some geodetic clock solutions, and present day-boundary discontinuities with a standard deviation of 100 to 250 ps, i.e. of a level similar to the discontinuities of the geodetic solutions for the GPS stations having the best performances.

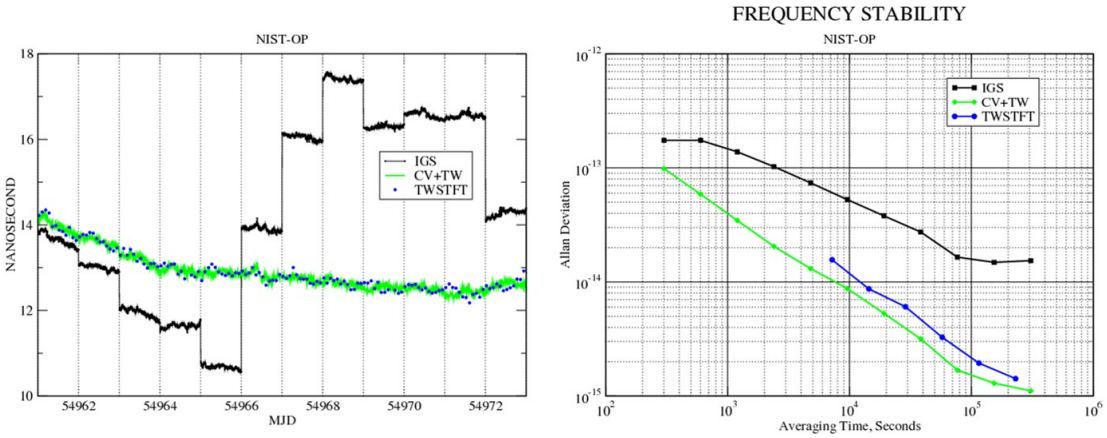


Figure 5: Comparisons between the combined GPS+TW (noted CV+TW in the figures), the TW data and the GPS-only solutions (noted IGS in the figures) for the time link NIST-OP (left); frequency stability analysis of the data analyzed (right). A linear drift was removed to all curves on the left plot ($y=-6.36\ 10^{5} + 11.70\ x$) so as to improve the visibility.

A.1.2.5. Research Activities in Time scale algorithm

- First developments for a clock ensemble algorithm for the monitoring and tuning of UTC(ORB) in order to be able to be independent of the other laboratories.

A.1.3. Perspective for next years

- Total renewal of the time laboratory in order to increase the reliability of the UTC(ORB) and its delivery to users via NTP;
- Finalizing the Belgian legal aspects of UTC;
- Elaboration of the procedure to put the second maser as secondary candidate to generate UTC(ORB);
- To continue the development of a clock ensemble algorithm for the monitoring of UTC(ORB) in order to be able to be independent of the other laboratories;
- To test the signals of GioveA and GioveB (Experimental satellites for Galileo) in order to study the capabilities of Galileo for time and frequency transfer; this will be done in collaboration with A. Moudrak, ESA;
- To develop a new version of the software R2CGGTTS (RINEX to Common GPS and GNSS Time Transfer Standards) that allows to include GLONASS observations;
- To test the possibilities for time and frequency transfer offered by the 3rd GPS frequency L5.

A.1.4. Personnel Involved

Scientific staff: P. Defraigne, W. Aerts, Q. Baire

Technical staff: E. Driegelinck

A.1.5. Partnerships

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

- Dr P. Uhrich, Laboratoire Temps-Fréquence, LNE-SYRTE, Observatoire de Paris
- Dr G. Petit, Bureau International des Poids et Mesures, Paris.
- Mari Carmen Martinez (Univ. of Alicante, Spain)
- Suman Sharma (National Physical Laboratory of India, Delhi)
- Dr Hernandez-Pajares (University of Catalonia UPC (gAGE/UPC), Spain).
- François Lahaye (Geodetic Survey Division, Natural Resources Canada (NRCan), Ottawa, Canada)

A.1.6. Scientific outreach

Meeting Presentations

[1] Defraigne P.
Precise GNSS time and frequency transfer,
EFTF-IFCS, Besançon, invited Tutorial (2h), April 2009.

[2] Pireaux S., Defraigne P., Wauters L., Bergeot N., Baire Q., Bruyninx C.
Higher order ionosphere perturbations in GPS time and frequency transfer,
EFTF-IFCS, Besançon, Oral presentation, April 2009.

[3] Baire Q., Defraigne P., Pottiaux E.,
Influence of Troposphere in PPP Time Transfer,
EFTF-IFCS, Besançon, poster, April 2009.

[4] Martinez-Belda M.C., Defraigne P.
Combination of GPS and TWSTFT data for time and frequency transfer,
EFTF-IFCS, Besançon, poster, April 2009.

[5] Baire Q., Bruyninx C., Defraigne P. Legrand J.,
Precise Point Positioning with ATOMIUM using IGS Orbit and Clock Products: First Results,
EUREF symposium, Florence, poster, May 2009.

[6] Defraigne P.
GNSS time and frequency transfer at the highest precision level: review on the laboratory equipment,
Meeting of the WG on TAI, Paris, invited talk, June 2009.

[7] Defraigne P.
Ionospheric perturbations in Time transfer,
2nd Int. Colloquium - Scientific and Fundamental Aspects of the Galileo Prog., invited talk, October 2009.

[8] Defraigne P., Petit G., Uhrich P.
Requirements on GNSS receivers from the perspective of timing applications,
2nd Int. Colloquium - Scientific and Fundamental Aspects of the Galileo Prog., October 2009.

[9] Baire Q., Defraigne P., Aerts W.
Combining Single Differences of GPS and GLONASS data for Time and Frequency Transfer,
2nd Int. Colloquium - Scientific and Fundamental Aspects of the Galileo Prog., October 2009.

Wikis and Websites

- Providing an updated version of ATOMIUM software with ionosphere corrections and STEC estimation to be added to ROB intranet for the iono-GPS team in the framework of the STCE.
- Providing material and text for the following web pages of the GNSS team (http://www.gnss.be/): tutorial/, science@rob/atmosphere/ionosphere and science@rob/ATOMIUM.

A.1.7. Missions

Assemblies, symposia:	W. Aerts (EFTF) P. Defraigne (EFTF, IAU, Galileo Symp., ESSW) Q. Baire (EFTF, Galileo Symp) S. Pireaux (EFTF, IAU Symp. 261)
Commissions, working groups (days):	W. Aerts (1) P. Defraigne (6)

A.2. GNSS

A.2.1. 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) over the European region, with emphasis on Belgium;
- improve our knowledge of the relation between reference frames and the accuracy of the applications mentioned above, as well as time transfer.

To reach these objectives, project members maintain a network of continuous observing GNSS stations, perform research to model, mitigate and understand the error sources, and play a leading role in related international scientific services (see Kaderplan van de Koninklijke Sterrenwacht van België, March 2006, par. 4.1.1 en 4.4.1).

A.2.2. Progress and results

A.2.2.1. Integration of Belgium in International Reference Frames

- The maintenance of the ROB network of permanent GPS stations has been continued. The ROB GPS data are integrated in international observation networks (IGS/EUREF) and distributed to the user community (surveyors, scientists, other ROB projects) over the Internet. In 2009,
  - The station in Waremme (WARE) started to stream real-time data, see communication A.2.6.
  - To reduce down time and facilitate data processing, a number of measures were taken. These include replacing the computer controlling the receiver at Jalhay, continually synchronizing all stations with our own Coordinated Universal Time (UTC) implementation over Network Time Protocol (NTP), and installing a fall back technique to restore internet communication in case of a Domain Name Service (DNS) failure.
  - In order to transform the GPS network managed by ROB into a GNSS network (that uses, besides the GPS signals, the signals from other constellations such as Galileo and GLONASS), two new GNSS receivers (Leica GRX1200+ and Septentrio PolaRx3) have been evaluated. A preliminary study was started to prepare the station of BRUX for 3 constellation reception (GPS, GLONASS, Galileo) with a main focus on the antenna and its related problems of multi path propagation.
- We are heavily involved in the maintenance and development of the European Reference Frame used for cartographic as well as scientific applications, see communications A.2.6, A.2.6 and A.2.6, and publications R.1, R.1 and A.2.6.

A.2.2.2. GNSS at the Princess Elisabeth base in Antarctica

- The installation of two GNSS receivers at the Princess Elisabeth station in Antarctica (ELIS station from ROB and ULUX station from the University of Luxembourg) was prepared in collaboration with A. Muls and P. De Kimpe from the Royal Military Academy and the seismology section of ROB.

- The GNSS receivers (ELIS and ULUX) and antennas at the Princess Elisabeth (PE) base in Antarctica from 10th to 22th February 2009.
- Four days of continuous data acquired during the mission in 2009 were used
    - To estimate the precision on the position we can obtain in this region (1.9, 3.2 and 4.2 mm on East, North and Vertical components).
    - To estimate the Zenith Total Delay (ZTD) time-series from ELIS and ULUX (3 mm mean differences).
    - To estimate the hourly TEC above the PE base (differences of 1.5±0.9 TECU with the CODE IGS analysis center TEC maps).
- The preparation of the 2010 mission at the PE base has been started in collaboration with A. Muls and P. de Kimpe (Royal Military Academy), P. Voet (National Geographic Institute), G. Klein and O. Francis (Luxembourg University) and the seismology section of ROB. The central computer of the system designed and built by the Royal Military Academy (RMA) was programmed. The functionality added included an interface for remotely rebooting the scientific equipment at the station and logging temperature at the site.
- For more details, see communications A.2.6, A.2.6 and A.2.6.

A.2.2.3. EUREF Permanent Network

We perform the daily management of the European Permanent GNSS network (EPN), a European network of continuous observing GNSS reference stations serving multi-disciplinary applications and covering 38 European countries. This work involves the elaboration and implementation of strategic choices for the network taking into account evolving technology (e.g. new satellite signals) and user needs (e.g. real-time data streams), see Figure 7, communications A.2.6, A.2.6, A.2.6, A.2.6 and A.2.6 and papers R.1, R.2, R.2, R.3, R.3, R.3, and R.3.

In 2009,

- 9 new stations have been included in the EPN bringing the total number of EPN station to 226 (see Figure 6).
- Several new codes and shell scripts were written to further develop the routine checks on the EPN data e.g. to improve the reliability of the real-time, hourly and daily data in the EPN (collaboration with G. Weber).
- We installed an NTRIP caster to relay the EPN streams from the main EPN NTRIP caster at Bundesamt für Kartographie und Geodäsie (BKG), Germany. This way, ROB guarantees load sharing with the main EPN broadcaster and overall communication traffic reduction.
- The EPN has started to switch from a GPS-only to a GPS/GLONASS tracking network and that it is also making its first steps to prepare the observation of Galileo satellites. Almost half of the GNSS receivers track now GLONASS satellites in addition to GPS. Furthermore, over the last year, almost 90% of the new antennas introduced in the EPN have GPS/GLONASS or GPS/GLONASS/Galileo tracking capabilities.
- We computed daily coordinates of a network of 65 GPS stations in and around Belgium. These coordinate solutions are a service that the ROB delivers to EUREF; the coordinates are submitted daily and weekly to EUREF and they contribute to the maintenance of the European and international terrestrial reference systems (ETRS89 and ITRS).
- We started investigating the usage of the Atomium software and Precise Point Positioning for monitoring the EPN site coordinates. Weekly position repeatabilities of 3.1 mm for the north, 1.9 mm for the east and 5.7 mm for the up components have been obtained.

The daily management also includes the maintenance and continuous updating of the EPN Central Bureau (CB) web site (http://epncb.oma.be/) in response of evolving user needs (see Figure 8 for access statistics).

In 2009,

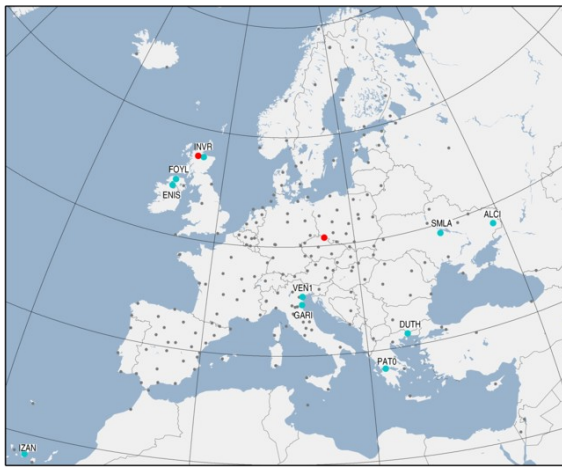
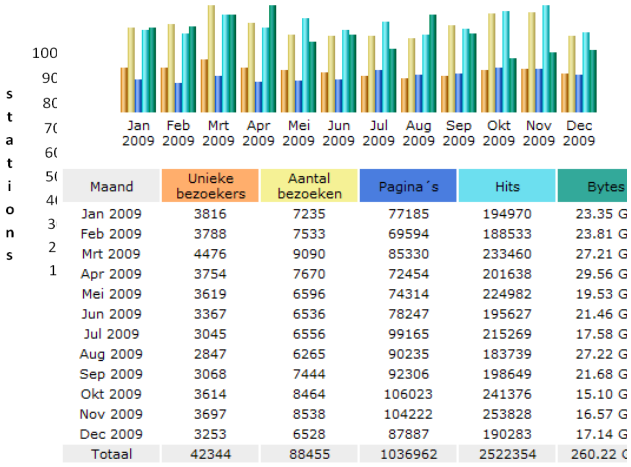


Figure 6: Changes in the EPN in 2009 (blue: stations added to the network, in red: decommissioned stations)



Maand	Unieke bezoekers	Aantal bezoeken	Pagina´s	Hits	Bytes
Jan 2009	3816	7235	77185	194970	23.35 G
Feb 2009	3788	7533	69594	188533	23.81 G
Mrt 2009	4476	9090	85330	233460	27.21 G
Apr 2009	3754	7670	72454	201638	29.56 G
Mei 2009	3619	6596	74314	224982	19.53 G
Jun 2009	3367	6536	78247	195627	21.46 G
Jul 2009	3045	6556	99165	215269	17.58 G
Aug 2009	2847	6265	90235	183739	27.22 G
Sep 2009	3068	7444	92306	198649	21.68 G
Okt 2009	3614	8464	106023	241376	15.10 G
Nov 2009	3697	8538	104222	253828	16.57 G
Dec 2009	3253	6528	87887	190283	17.14 G
Totaal	42344	88455	1036962	2522354	260.22 G

Figure 8: Statistics of EPN CB web site for the year 2009

Figure 7: Evolution of the % of EPN stations providing hourly, real-time or GPS+GLONASS data

- A new on-line site log validation and submission tool was opened to the public.
- The monitoring of the quality of the solutions provided by the different EPN analysis centers has been improved. For that purpose dynamic web pages have been designed which provide on-line the evolution of the agreement of the solutions of each analysis center with respect to the combined EUREF solutions (in terms of positioning and determination of tropospheric zenith path delays).
- A new on-line coordinate transformation utility has been developed and opened to the public.
- The monitoring of the latency of the real-time observation streams has been improved and the associated web pages have been updated.

A.2.2.4. Study of the influence of the reference frame on GNSS-based positioning and velocity determination

- The sensitivity of the reference frame definition on the station positions and velocities and residual position time series obtained from a regional GNSS network analysis has been studied (collaboration with Z. Altamimi, G. Wöppelmann, M.N. Bouin, and A. Santamaria), see communications A.2.6, A.2.6 and A.2.6 and papers R.1, R.3, R.3 and R.3. It was first demonstrated that the errors induced on station positions and velocities due to the reference frame definition exceed the noise level.

  Then, it was shown that the regional network analysis underestimates the amplitude of the annual and semi-annual signals in all components (27% (resp. 15%) reduction of the annual (resp. semi-annual) signal in the height component) (Figure 9). In addition, the phase of the annual and semi-annual signals is altered, e.g. while in a global network the predominant phase of the annual signal is 180°, this is not the case anymore in a

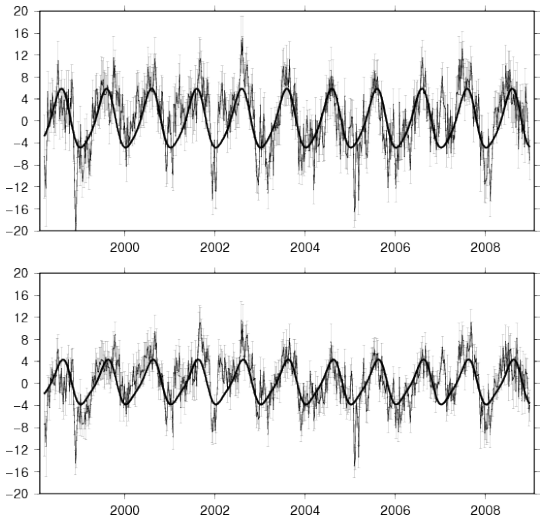


Figure 9: Residual time series of GLSV: Up component. Top: global, bottom: regional.

regional network. Consequently, the geophysical interpretation of the seasonal signals observed using a regional network is challenging.

Finally, a step-wise approach has been developed in order to get rid of the reference frame bias in GNSS-based position and velocity solutions obtained from a local or regional network analysis (see next paragraph).

A.2.2.5. Improvement of the knowledge of deformations of the Earth's crust

Deformations of the Earth's crust are determined by computing regularly the positions of permanent GNSS stations and then by combining these positions together to obtain their time evolution, including their linear velocities. As such, the study of the error sources (e.g. reference frames) that influence the accuracy of GNSS-based positioning contribute to improving our knowledge of site motions.

- The step-wise approach developed to mitigate the reference frame error on local and regional position and velocity estimates obtained from a local or regional GNSS network has been applied to estimate ground deformations in Belgium using the data from the dense Belgian GPS network (more than 60 continuously observing GPS stations). We focused on the zone from 0° to 10° longitude and 47° to 55° latitude and showed that the RMS of the residual velocities (obtained after removing the rigid motion of the European plate) in this area is 0.4 mm/yr. This confirms the level of rigidity found by other authors. This work was done in collaboration with the seismology section of the ROB. See communications A.2.6 and A.2.6.
- We coordinated the activities of the IAG SC1.3 WG1 on "Regional Dense Velocity Fields (see http://epncb.oma.be/IAG). GNSS-based velocity solutions from all over the world were gathered and analyzed in order to densify the latest realization of the ITRS (International Terrestrial Reference System) and provide regional dense velocity information in a common global reference frame. Preliminary comparisons between different velocity solutions show an RMS agreement between 0.3 mm/yr and 0.5 mm/yr resp. for the horizontal and vertical velocities.
- We finalized the geodynamic interpretation based on GPS data of the Vanuatu subduction zone and Clipperton Island (see communication A.2.6 and paper R.1 and R.1) in collaboration with M. Diament, M-N. Bouin, V. Ballu, S. Calmant and A. Peltier).

A.2.2.6. Improvement of the knowledge of the spatial and temporal variations in the Earth's troposphere

The EUMETNET EIG GPS water VApor Program II" (E-GVAP II) project aims at using GNSS-based tropospheric Zenith Path Delays for assimilation in their operational Numerical Weather Prediction (NWP) models. The GNSS group is operating one of the E-GVAP II GPS analysis centers which deliver in near real-time tropospheric Zenith Path Delays to meteorological agencies. In 2009,

- We continued to develop and ensure the daily maintenance of the ROB E-GVAP II GPS analysis center; see communications A.2.6 and A.2.6, and papers R.1 and R.1. About 45 new GNSS sites were progressively added to the network, bringing the total number of stations included in the service to 210. We also demonstrated that all GNSS-meteorology requirements are achieved by the ROB E-GVAP analysis centre.

  A quality analysis of our E-GVAP II analysis center was performed with respect to the different requirements (latency, precision, accuracy, etc…). Based on the radiosonde and numerical weather prediction data it was shown that 99% of the near real-time (NRT) tropospheric ZPD estimates delivered by ROB within E-GVAP II have an accuracy better than the threshold requested by E-GVAP for NWP applications. In addition, the comparison of the tropospheric zenith path delays (estimated in near-real time by our analysis center) with Water Vapour Radiometer data showed the excellent accuracy of the ROB tropospheric delays, with a bias of solely -1.6 mm.
- We continued the exploitation of the Belgian dense network to monitor the structure, movement and variability of small-scale atmospheric water vapor structures, providing valuable information for Numerical Weather Prediction and nowcasting applications; communications A.2.6 and paper R.1.

A.2.2.7. Improvement of the knowledge of the spatial and temporal variations in the Earth's ionosphere

- The intensity of the ionospheric activity during the 2003 Halloween ionospheric storm (Oct. 30th, 2003) was compared with the error on GPS-based kinematic positions in order to quantify the degradation of the position repeatability. It was shown that during this period the kinematic position repeatabilities were mainly affected for stations in Northern Europe with outliers reaching 12 cm in the horizontal components, and 26 cm in the vertical component; see communications A.2.6 and A.2.6 and papers R.3, R.3 and R.3.
- We investigated the added value of multi-GNSS (GPS, GLONASS and simulated Galileo data) observations (compared to GPS-only) and dense national tracking networks (in addition to the EPN) for imaging the ionosphere. The study was made using a tomographic approach where the Earth's atmosphere is divided into voxels and investigated the GNSS signal ray concentration in each voxel. It was shown that GPS signals from the EPN traverse 85% of voxels while GPS+GLONASS+Galileo signals will traverse 94% of the voxels (see Figure 10 and Figure 11). This demonstrates the added value of using navigation signals from multiple satellite constellations to perform ionospheric imaging. See paper R.4.

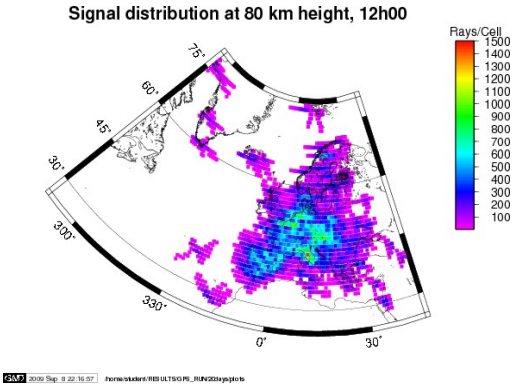


Figure 10: GPS signal distribution with EPN

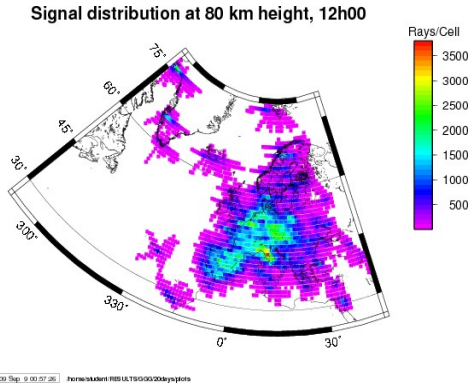


Figure 11:GPS, GLONASS and Galileo signal distribution with EPN

- We started investigating the possibility of detecting small structures in the ionosphere by assimilating the data from the EPN as well as dense national GNSS networks located in Belgium, France, UK and Germany. A previously unreported two-step plasma instability process occurring on the day-night terminator gradient of the F-layer ionosphere above Europe on 30th October 2003 was discovered. The process was interpreted as a primary Gradient Drift Instability with subsequent secondary Kelvin-Helmholtz waves.

A.2.2.8. Long term correlation between the solar activity and ionosphere electron content

- We investigated the correlation between the solar activity and the TEC in the ionosphere. A correlation close to 0.8 has been found between the daily Sunspot number from the Solar Influences Data Analysis Centre catalogue (SIDC) and the daily mean global TEC (from the CODE GIM product) during the last Solar Cycle.

A.2.2.9. Study of the perspectives with GALILEO

We evaluated the mutual relation between the GALILEO (and other GNSS) system and the science community. As there will be more stations, more satellites, a better precision, and a better consistency, the scientists will be able to do more precise science and applications, e.g. realization of terrestrial reference frames, Earth rotation and geodetic parameters, tropospheric delays, ionospheric parameters, and clock parameters; see communication A.2.6.

A.2.2.10. Contribution to the Worldwide Multimodal SBAS Standard

Several studies have been done or have been started in order to extend the current aeronautical Space Based Augmentation System (SBAS). In collaboration with Jean-Luc Issler from CNES, and other colleagues from Switzerland and Canada, we have studied the SBAS message transmitted by geostationary satellites using a classical modulation scheme in order to extend it to worldwide multimodal Universal-SBAS (U-SBAS) standard to be used in all the regions of the world, by all the civil aviations of the world, by all other types of non-aeronautical Safety of Life (SoL) users, and, in addition, by non-SoL users of any countries. We have proposed that the new worldwide multimodal U-SBAS standard could carry additional channels (signals and messages) to cover all these applications. Multimodal SBAS systems compatible with the suggested worldwide standard could serve in addition the scientific community, providing accurate time and time transfer, and reference frame and deformation monitoring. See communication A.2.6

A.2.3. Perspective for next years

- Continue to maintain and modernize (GLONASS and GALILEO) the ROB network of permanent GNSS stations: improve performance and ease of maintenance of the network, upgrade the receivers and antennas, as well as the station controlling equipment and the data transfer routines and procedures, and rework the antenna supporting structure of BRUX to minimize (or ideally eliminate) multipath propagation and errors.
- Continue to maintain, extend and improve the EUREF service center (management of the EPN Central Bureau, EPN Data Centre, and EPN Analysis Centre).
- Continue to develop and maintain the E-GVAP service.
- Continue to acquire, manage and distribute scientific knowledge within the frame of GNSS: study of error sources (e.g. reference frame), 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.
- Continue to contribute to GIANT project at Belgian Antarctic Base.
- Continue to monitor the European ionosphere concentrating on the improvement of the software, and automation of the generation of TEC maps.
- Use the GNSS data from the Belgian dense network to improve the knowledge of spatial and temporal variations of the troposphere/ionosphere and to obtain a dense velocity field suitable for geophysical interpretation (collaboration with seismology section of ROB).
- Continue to investigate the correlation between the solar activity and the ionospheric TEC in collaboration with solar physics department of ROB (collaboration with solar department of ROB).
- Continue to improve the reprocessing of historical GNSS data, the filtering of station coordinates and the estimation of site velocities of the entire EPN.
- Continue to investigate the GNSS ray distribution traversing the ionosphere as well as the troposphere using different GNSS networks, different temporal and spatial resolutions and focusing on present-day data.
- Investigate the capability of the leading ionospheric imaging software (MIDAS, University of Bath) to detect small-scale structures in the ionosphere.
- Develop a tomographic program capable of adapting to the inhomogeneous GNSS ray distribution using adaptive cells instead of regular ones resulting in a tomographic image with improved temporal and spatial resolution.
- Use GPS-based monitoring of the troposphere to develop software to compute slant tropospheric delays from GPS observations to be used afterwards in a tropospheric imaging algorithm.
- Evaluate of the long-term stability of GPS-based tropospheric delays in order to assess the capability of GPS-derived water vapour to contribute to climate monitoring.
- We will continue to study the added-value of GLONASS and Galileo signals for several scientific applications. Special emphasis will be put on the new satellite signals such as GPS L5 and the upcoming Galileo signals.

A.2.4. Personnel involved

Scientific staff: W. Aerts, Q. Baire, N. Bergeot, R. Burston, C. Bruyninx, J.-M. Chevalier, J. Legrand, E. Pottiaux

Technical staff: A. Moyaert, D. Mesmaker

A.2.5. Partnerships

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

- Z. Altamimi, IGN/LAREG, France
- V. Ballu, Institut de Physique du Globe de Paris, France
- L. Bastos, University of Porto, Portugal
- M.N. Bouin, CNRM / Centre de Météo Marine, Brest, France
- E. Brockmann, Swisstopo, Switzerland
- S. Calmant, Institut de Recherche pour le Développement, Brésil
- A. Caporali, University of Padua, Italy
- M. Craymer, NRCAN, Canada
- R. Dach, Astronomical institute, University of Bern, Bern, Switzerland
- M. Dunseath-Terao, Physics Institute of Rennes (IPR), University of Rennes 1, France S. de Haan, Koninklijk Nederlands Meteorologisch Instituut, Holland
- M. Diament, Institut de Physique du Globe de Paris, France
- S. Ficher, R. Khachikyan, IGS Central Bureau, Jet Propulsion Laboratory (JPL), NASA, US
- R. Fernandes, University of Lisbon, Portugal
- K. Gallagher, Geosciences Rennes, University of Rennes 1, France
- H. Habrich, J. Ihde, J. Söhne, G. Weber, Bundesamt für Kartographie und Geodäsie (BKG), Germany
- J.-L. Issler, CNES, Toulouse, France
- O. Khoda, Main Astronomical Observatory of the National Academy of Sciences of Ukraine
- A. Kenyeres, FÖMI Satellite Observatory, Hungary
- R. King, Massachusetts Institute of Technology (MIT),US
- R. Jr. Landry and M. Sahmoudi, ÉTS, Montreal, Canada
- D. Lavallée, TU Delft, Netherlands
- A. Peltier, Institut de Physique du Globe de Paris, France
- A. Santamaria, IGN, Spain and LAREG/IGN, France
- N. Smith, Department of Electronic and Electrical Engineering University, Bath, UK
- G. Stangl, Austrian Academy of Sciences, Austria
- Y. Tawk, A. Jovanovic, C. Botteron, and P-A. Farine, EPFL, Neuchâtel, Switzerland H.Vedel, Danish Meteorological Institute, Denmark
- G. Wöppelmann, Université la Rochelle, France

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

- P. Voet, Nationaal Geografisch Instituut (NGI)
- W. Van Heule, B. Dierickx, Agentschap voor Geografische Information Vlaanderen (AGIV)
- A. Muls, P. De Kimpe, Royal Military Academy (RMA)
- Cem Ozam Ama, Von Karman Institute (VKI)

Grants/Projects used for this research/service

- Grant nr. MO/33/019 from BELSPO
- Solar-Terrestrial Center of Excellence (STCE)

Visitors

- R. Burston, University of Bath, Sept 7- Sept. 11, 2009.

A.2.6. Scientific outreach

Meeting presentations

[1] Bergeot N., Bruyninx C., Pireaux S., Defraigne P., Legrand J., Baire Q., Pottiaux E.
Vertical Total Electron Content Maps Over Europe from EUREF Permanent Network GPS Data
Data EGU General Assembly 2009, April 19-24, 2009, Vienna, Austria (Geophysical Research Abstracts, Vol. 11, Abstract EGU2009-5654)

[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., Sánchez L., Shen Z., Sella G., Wöppelmann G.
Progress of IAG SC1.3 Working Group in Providing a Dense Global Velocity based on GNSS Observations
EGU General Assembly 2009, April 19-24, 2009, Vienna, Austria (Geophysical Research Abstracts, Vol. 11, Abstract EGU2009-4253)

[3] Bruyninx, J. Legrand, N. Bergeot, E. Pottiaux
EPN Status, Monitoring and Network Management at the Central Bureau
EGU General Assembly 2009, April 19-24, 2009, Vienna, Austria (Geophysical Research Abstracts, Vol. 11, Abstract EGU2009-10088)

[4] Camelbeeck T., Bruyninx C., Vanneste K., Legrand J., Bergeot N., Alexandre P., Williams S.D.P., Van Camp M.
Crustal Deformation in Stable Continental Europe: a Comparison of Seismicity, Geodetic and Geologic Information
EGU, April 2009, Vienna, Austria (Geophysical Research Abstracts, Vol. 11, Abstract EGU2009-3938)

[5] Legrand J., Bergeot N., Bruyninx C., Wöppelmann G., Bouin M.N., Altamimi Z.
Reliability of Regional and Global GNSS Network Solutions Expressed in the Global Reference Frame
EGU General Assembly 2009, April 19-24, 2009, Vienna, Austria (Geophysical Research Abstracts, Vol. 11, Abstract EGU2009-5238)

[6] Pottiaux E., de Haan S., Legrand J., Bruyninx C.
Dense GNSS Networks to Access Fine Structures in the Troposphere
EGU General Assembly 2009, April 19-24, 2009, Vienna, Austria (Geophysical Research Abstracts, Vol. 11, Abstract EGU2009-4453)

[7] Camelbeeck T., Bruyninx C., Vanneste K., Van Camp M.
Lithospheric Deformation in Northwest Europe: A Comparison of Seismicity, Geodetic and Geologic Information
AGU 2009 Joint Assembly, 24-27 May 2009, Toronto, Canada

[8] Baire Q., Bergeot N., Bruyninx C., Defraigne P., Legrand J., Pottiaux E., Roosbeek F., Voet P.
National Report of Belgium
EUREF 2009 Symposium, 27-30 May 2009, Florence, Italy

[9] Baire Q., Bruyninx C., Defraigne P., Legrand J.
Precise Point Positioning with Atomium using IGS Orbit and Clock Products: First Results
EUREF 2009 Symposium, 27-30 May 2009, Florence, Italy

[10] Bergeot N., Bruyninx C., Pireaux S., Defraigne P., Legrand J., Baire Q., Pottiaux E.
Using the EUREF Permanent Network to Monitor the Ionosphere
EUREF 2009 Symposium, 27-30 May 2009, Florence, Italy

[11] Bruyninx C.
Main Activities and New Initiatives of the EUREF Technical Working Group
EUREF 2009 Symposium, 27-30 May 2009, Florence, Italy

[12] Bruyninx C., Altamimi Z., Caporali A., Kenyeres A., Lidberg M., Stangl G., Torres J.A.
Guidelines for EUREF Densifications
EUREF 2009 Symposium, 27-30 May 2009, Florence, Italy

[13] 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., Sánchez L., Shen Z., Sella G., Woppelmann G.
Progress of the IAG SC1.3 Working Group in Providing a Dense Global Velocity Field Based on GNSS Observations
EUREF 2009 Symposium, 27-30 May 2009, Florence, Italy

[14] Bruyninx C., Legrand J., Roosbeek F.
EPN Status and Network Management
EUREF 2009 Symposium, 27-30 May 2009, Florence, Italy

[15] Legrand J., Bruyninx C., Bergeot N.
Results and Comparisons of a Local and a Regional Reprocessed GNSS Network
EUREF 2009 Symposium, 27-30 May 2009, Florence, Italy

[16] Lidberg M., Bruyninx C., Altamimi Z., Biagi L., Boucher C., Caporali A., Fernandes R., Häkli P., Ihde J., Legrand J., Torres J.A.
EUREF WG on the Development of the ETRS89: Objectives and First Steps
EUREF 2009 Symposium, 27-30 May 2009, Florence, Italy

[17] 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., Sánchez L., Santamaria-Gomez A., Sella G., Shen Z., Woppelmann G.
A Dense Global Velocity Field based on GNSS Observations: Preliminary Results
IAG General Assembly 2009, Aug. 31-Sept.24 2009, Buenos Aires, Argentina

[18] Bruyninx C., Habrich H., Kenyeres A., Söhne W., Stangl G., Völksen C.
Enhancement of the EUREF Permanent Network Services and Products
IAG General Assembly 2009, Aug. 31-Sept.24 2009, Buenos Aires, Argentina

[19] Legrand J., Bergeot N., Bruyninx C., Woppelmann G., Santamaria-Gomez A., Bouin M.-N., Altamimi Z.
Comparison of Regional and Global GNSS Position and Velocity Solutions
IAG General Assembly 2009, Aug. 31-Sept.24 2009, Buenos Aires, Argentina

[20] Bruyninx C., Bergeot N., Legrand J., Pottiaux E.
Moving the EPN from a GPS-only to Multi-GNSS Network: Challenges and Pitfalls
2nd International Colloquium - Scientific and Fundamental Aspects of the Galileo Programme, COSPAR Colloquium, Oct. 14-16 2009, Padua, Italy

[21] Dehant V.
Mutual relation between the GALILEO system (and other GNSS) and the science community,
Invited Speaker, Inaugural Session, 2nd International Colloquium - Scientific and Fundamental Aspects of the Galileo Programme, COSPAR Colloquium, Oct. 14-16 2009, Padua, Italy

[22] Lombardi D., Camelbeeck Th., Rapagnani G., Van Camp M., Bergeot N., Bruyninx C., Francis O., van Dam T.
Geodetic and seismological research initiatives at the new Princess Elisabeth station, Queen Maud Land, East Antarctica
95th Journées Luxembourgeoises de Géodynamique, Nov. 9-11, 2009, Echternach, G.-d. Luxembourg

[23] Pottiaux E.
E-GVAP II Analysis Centre Report: Royal Observatory of Belgium
E-GVAP II Joint Expert Team Meeting - November 2009, 16/11/2009, De Bilt, The Netherlands

[24] Ihde J., Bruyninx C., Söhne W., Weber G.
Evolution of the EPN Resources towards real-time GNSS
International Symposium on Global Navigation Satellite Systems, Space-Based and Ground-Based Augmentation Systems and Applications, Nov. 30- Dec. 2 2009, Berlin, Germany

[25] Lombardi D., Camelbeeck T., Rapagnani G., Van Camp M., Bergeot N., Bruyninx C., Francis O., van Dam T.
Geodetic and Seismological Research at the new Princess Elisabeth Station, Queen Maud Land, East Antarctica
AGU 2009 Fall meeting, Dec 14-18 2009, San Francisco (AGU Abstract C43A-0495)

[26] Ballu V., Bouin M.-N., Bonnefond P., Calmant S., Peltier A., Crawford W.C., Pelletier B., Bergeot N., Diament M.
Using seafloor pressure gauges and satellite altimetry data to constrain deformation models in a partially locked subduction zone, Central Vanuatu
Eos Trans. AGU, 90(52), Fall Meet. Suppl., Abstract G33B-0644, San Francisco, USA, 2009.

[27] Lombardi D., Camelbeeck T., Rapagnani G., Van Camp M., Bergeot N., Bruyninx C., Francis O., van Dam T.
Geodetic and seismological research initiatives at the new Princess Elisabeth station, Queen Maud Land, East Antarctica,
JLG 95th, Nov. 9-11, 2009 Luxembourg

[28] Issler J.-L., Tawk Y., Jovanovic A., Botteron C., Farine P-A., Landry R.Jr., Sahmoudi M., Dehant V.
Contribution to the Worldwide Multimodal SBAS Standard
Fourth European Workshop on GNSS signals and signal processing, GNSS signals 2009, Co-organized by CNES, ESA, DLR, and UniBW, 10-11 December 2009, German Aerospace Center (DLR), Oberpfaffenhofen, Germany

Wikis and Websites

- http://www.epncb.oma.be/, EUREF Permanent Network Central Bureau
- http://www.epncb.oma.be/IAG/, IAG Working Group on "Regional Dense Velocity Fields"
- http://igs.oma.be/real_time/, IGS Real-Time Pilot Project, Network Monitoring of the Ntrip Interface
- http://en.wikipedia.org/wiki/Regional_Reference_Frame_Sub-Commission_for_Europe, in collaboration with A. Simsky
- http://en.wikipedia.org/wiki/EUREF_Permanent_Network, in collaboration with A. Simsky.

Brochures

- Flyer of the EUREF Permanent Network, also available through http://epncb.oma.be/epnflyer.pdf

A.2.7. Missions

Assemblies, symposia:	W. Aerts (RF technology, QB50 WS, GNSS signals and signal processing) N. Bergeot (EUREF, EGU, ESWW) C. Bruyninx (EGU, EUREF, IAG, Galileo Symp) J. Legrand (EGU, EUREF, Galileo Symp.)
Commissions, working groups (days):	W. Aerts (1) N. Bergeot (1) C. Bruyninx (14) J. Legrand (6) E. Pottiaux (1)
Research visits (days):	W. Aerts (1) N. Bergeot (3 days)

	J. Legrand (6 days) E. Pottiaux (1 day)
Field missions (days):	W. Aerts (3 days) N. Bergeot (21 days)

B. Planetary Science

We try to understand and model the rotation changes and orientation variations i.e. length-of-day, precession, nutations, librations, and polar motion of these objects of the solar system in relation with the physics of their interior and the interaction between the solid planet and the geophysical fluids (internal ocean, liquid core, atmosphere…).

The rotation of the Earth being examined with high precision, one project is completely dedicated to the Earth (see paragraph B.1) and a second project to the other terrestrial objects of the solar system (see paragraph B.2).

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, we study 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. We 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), 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

A.1.1.1. Preparation of future missions

- Preparations for a radio science experiment LaRa (Lander Radioscience) to be implemented on a future planetary lander have continued. LaRa (see Figure 12 for a block diagram and Figure 13 for a LaRa schematic) has been designed to transpond an X-band signal transmitted from the Earth ground stations back to the Earth. 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 2009, the LaRa tasks included the follow-up of the industry building LaRa (i.e. OMP for Orban Microwave Products), the preparation or update of ESA documents, the preparation of the PDR (Preliminary Design Review), and discussions and meetings with ESA, the industry, PRODEX, and with the LaRa team (see reports R.4, R.4, R.4). LaRa now has a Technology Readiness Level 5 (TRL # 5). The other instruments of ExoMars have a mean TRL # 4.7. See the list of ESA reports/deliveries (Paragraph R.4). A scientific paper has been published concerning the feasibility of the LaRa experiment on Mars R.1 and concerning the results of a network mission R.1, R.2, R.3, R.3, and R.3.

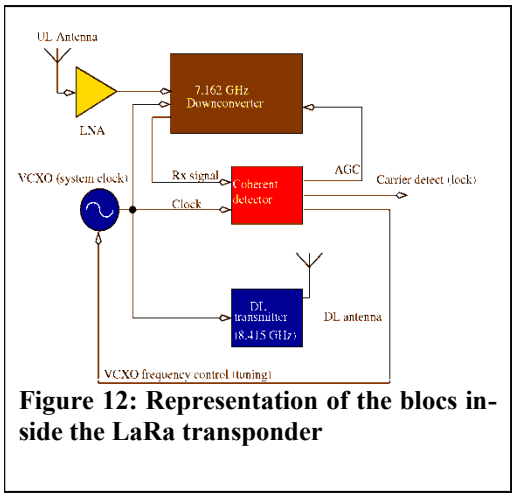


Figure 12: Representation of the blocs inside the LaRa transponder

- With the help of the US co-PI of LaRa, a SALMON (Stand Alone Mission of Opportunity Notice) proposal has been submitted to and approved by NASA for supporting access to the DSN (Deep Space Network) 70 meter antennas (see NASA press release at http://www.nasa.gov/home/hqnews/2009/may/HQ_C09_020_NASA_Salmon_Awards.html).

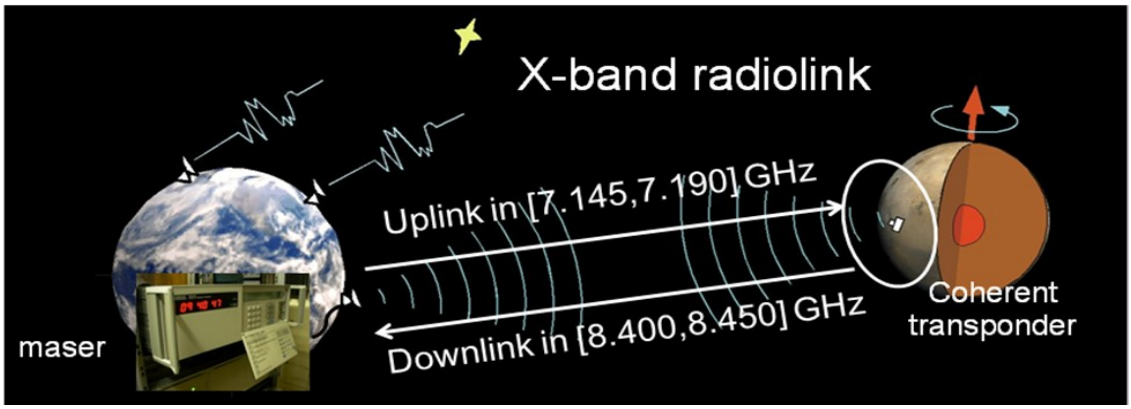


Figure 13: Representation of the radio link between the Earth and Mars in the frame of LaRa.

- Within the Cosmic Vision program of ESA, we are involved in the preparations of the ESA-NASA Europa Jupiter System Mission (EJSM) at Joint Science Definition Team (JSDT) level (see e.g. paper R.1).

A.1.1.2. 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 attitude of the spacecraft bus, the solar panels, and the steerable antenna). About 350 shell and FORTRAN codes have been developed over time to manage and process the data. In 2009, efforts went particularly to updating, upgrading, and debugging the existing software.

- At present all MEX tracking data until October 2008 have been collected, archived, processed, and analyzed using the GINS/DYNAMO orbitography codes (implemented by the French space agency (CNES) and further developed at Royal Observatory of Belgium (ROB) for planetary geodesy applications), which allows obtaining the orbit of the spacecraft, the global gravity field of Mars, and its time variations. These analyses also include the processing of ancillary data.
- The perturbing effect of the Sun on radio tracking data has been studied. It has been shown that due to the non-spherically symmetric and time-dependent structure of the solar corona and solar wind simple models to estimate the plasma effect on the radio propagation based on spherically symmetric distribution of electrons should not be used when the radio wave passes close to the Sun (i.e. at solar elongation lower than 10°).

A.1.1.3. Mars: LaRa

- The precision that can be obtained on the orientation of Mars has been studied with GINS for three different radio science link experiments involving a lander or a rover on the Martian surface: (1) a direct to Earth radio link in X-band, (2) an X-band radio link through an orbiter, and (3) a UHF radio link to an orbiter together with an orbiter-Earth link in X-band. The second case results in the most precise determination of the orientation of Mars if the orbit can be determined accurately.
- Different ranging measurement techniques (sequential ranging and pseudo noise range codes) have been studied, which would allow accurate range measurements with a standard deviation of 1 m or less. In this study, we have used different mathematical models for the signal and analyzed the two-way ranging performance in the presence of noise as well as the algorithms used to resolve the phase ambiguity. A set of MatLab scripts has been developed, which generates different structures of the ranging signal, computes the uplink and downlink spectrum and implements algorithms to solve phase ambiguity.

A.1.1.4. Mars: interior structure, rotation and tides

- A study has been published on the determination of the gravity field and tides of Mars from MGS and ODYSSEY tracking data (R.1). The k_2 Love number, representing the reaction of Mars to the tidal forcing by the Sun, has been shown to be between 0.11 to 0.13, which is lower than recent American estimates of about 0.15. Both values indicate that Mars has a liquid core but the ROB value corresponds to a smaller core than the US value. The discrepancy between those results suggests that the Love number cannot be accurately determined yet because of its small effect on the spacecraft dynamics. Inclusion of MEX tracking data does not improve the estimate of the k_2 Love number, since the orbital perturbation due to k_2 are smaller than the perturbations due to the time-variable degree-2 zonal harmonics.
- 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 specific mantle mineralogies 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%. 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 such as for the Earth. A publication on these new results on the interior of Mars is in preparation and will be submitted in the beginning of 2010.

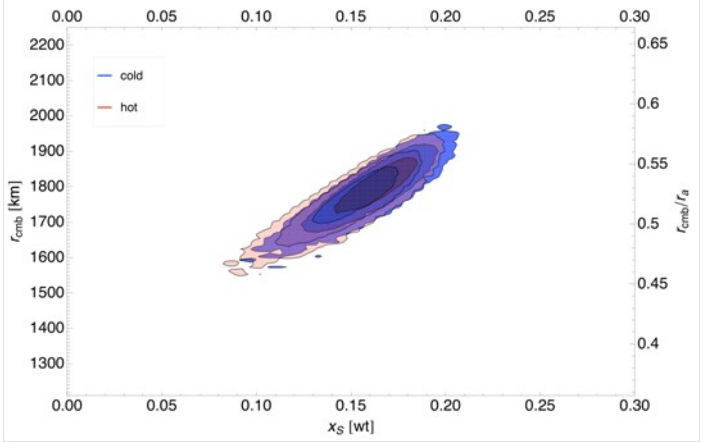


Figure 14: Inferred joint probability densities for core sulfur weight fraction / core size (x_S, r_{icb}) from measured planet mass, average moment of inertia, and Love number k_2. The blue/red surfaces represent the results obtained from the cold/hot mantle temperature end-members. The contours are the 0.997, 0.95, and 0.683 probability domains.

- For the state-of-the-art interior models of Mars,

forced rotation variations have been calculated. If Mars has a core size larger than 1750 km, the ter-annual nutation is expected to be amplified by a resonance with the Free Core Nutation (FCN), a rotational normal mode of Mars. These theoretical predictions will allow better interpreting geodesy experiments like LaRa in terms of the interior structure of Mars.

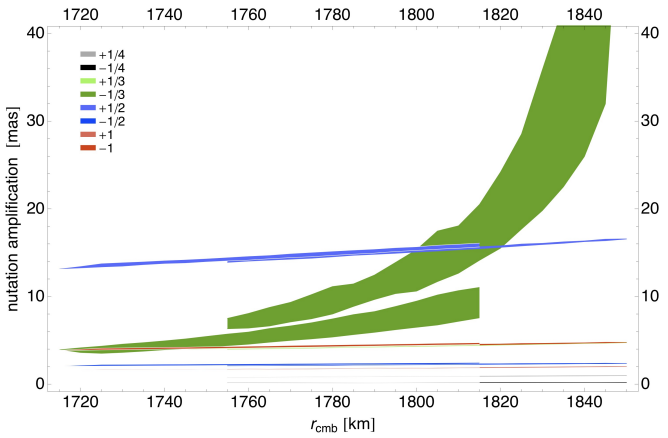


Figure 15: Expected nutation amplification for a set of mantle mineralogy models that agree with the latest estimates of the average moment of inertia and Love number k2 (Konopliv et al. 2010). The different colors correspond to the frequencies of the principal contributing solid nutation

- A study has been published on the use of the MOLA altimeter onboard the MGS spacecraft to determine Mars' rotation variations R.1. It has been shown that altimeter data at ground track crossing points can be used to detect the nutations of Mars. Information on the Martian core, which is contained in the nutations, is difficult to retrieve because the core contribution to nutations is at the level of the accuracy of the method. Simulations also demonstrate that the observational determination of the libration amplitude and obliquity of Mercury can be improved by using the BELA laser altimeter of the BepiColombo mission to Mercury. See Figure 16.

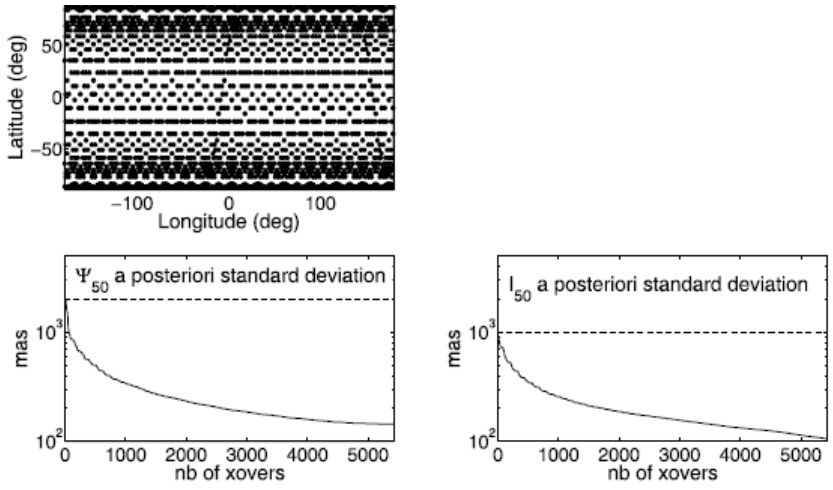


Figure 16: Nutations can be obtained with a10% precision level from Mars Orientation Parameters (MOP) inversion. The figure presents the a posteriori deviation for the main nutations as a function of the number of crossover points used in the inversion; *mas* stands for milliarcsecond.

- A general analytical method has been further developed for the calculation of the tide-generating potential of any Solar System body.
- 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.

A.1.1.5. *Mars: crust and lithosphere*

- The investigation of the structure of the Martian crust and lithosphere is conducted by performing gravity observations during the pericenter passage of the Mars Express spacecraft in its orbit around Mars. In

2009, there were four new passes above the Tharsis area, which is the focus of this investigation, but they did not significantly change previous results on the crustal density and elastic thickness of the lithosphere since their signal-to-noise ratios are not outstanding. In order to complement MEX data, a new analysis of the global gravity field of Mars has been undertaken with two different localizing techniques, namely spherical windowing and ellipsoidal projection. MEX data and the global gravity field lead to convergent conclusions: the local density is high at Olympus Mons and rather low at Ascraeus Mons. These results are being written up for publication.

A.1.1.6. Mars: atmosphere and polar caps

- Nine and six years of Doppler and range tracking data of the Mars Global Surveyor (MGS) and Mars Odyssey (ODY) spacecraft, respectively, have been analyzed in order to improve the determination of the variable low-degree gravity field (see paper R.1). These gravity variations are of geophysical interest because they are linked with the CO_2 sublimation and condensation cycle of the atmosphere of Mars. It has been shown that the variations of the odd and even gravity harmonics perturb the MGS and ODY orbit at a level of up to 70 cm and 10 cm, respectively. As the MGS/ODY orbits have an average precision of 1.5 meters, only for the odd harmonics can seasonal variations be retrieved from MGS/ODY tracking data.
- Tracking data of the Mars Reconnaissance Orbiter (MRO) have also been used, in collaboration with J.C. Marty, to find a new solution for the variation of the odd harmonics.
- By using the latest General Circulation Models (GCM) developed at the Laboratoire de Météorologie Dynamique de Paris (LMD) and at NASA AMES, the low-degree time-variable gravity coefficients 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. A peer review article on the subject has been submitted with colleagues from JPL and MIT R.3.
- A semi-analytical model to study the effect of meteorite impacts on the atmospheric evolution of Mars has been developed. Meteorite impacts cause atmospheric erosion but also deliver material and volatiles to the planet. It has been shown that meteorite impacts cannot explain a possible dense atmosphere for the early Mars at the end of the Noachian period. The results have been published in Astrobiology (see paper R.1). The model has been refined by including the effects of a critical impactor velocity, below which we consider that no atmospheric erosion occurs, and of the impact obliquity (see). From a comparison with Venus and the Earth, we have shown that, in our model, Mars is more susceptible to atmospheric erosion due to its smaller radius and planet mass.

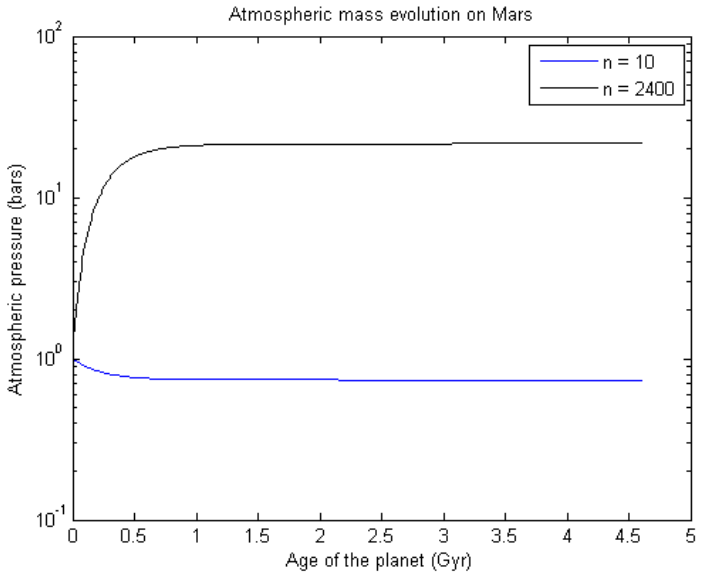


Figure 17: Evolution of the surface pressure P on Mars as a function of time t, assuming an initial surface pressure: P(t= 0) = 1 bar. The calculations are made for the tangent plane model, with different values of the model parameter n. Calculations are made following an exponential decaying impact flux.

- In collaboration with E. Javaux (ULg) a review paper on the habitability of Mars has been written (see paper R.3).

A.1.1.7. Mars: moons

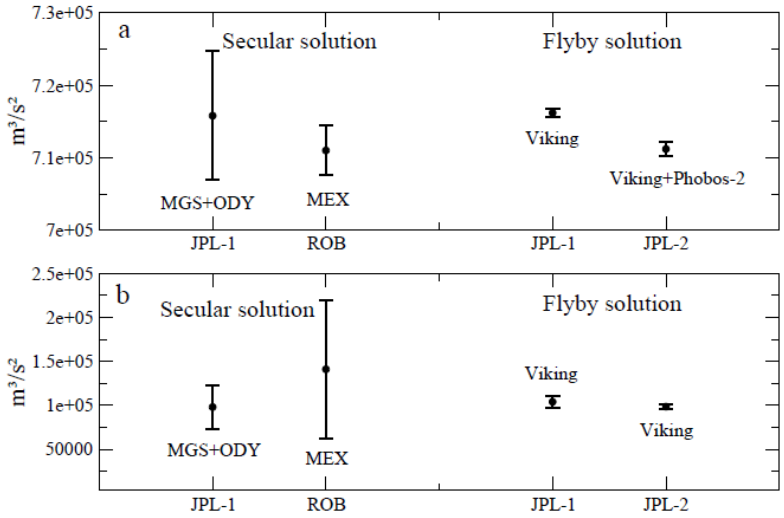


Figure 18: Solutions for Phobos (a) and Deimos (b) GMs. JPL-1 are from Konopliv et al. (2006), JPL-2 from Jacobson (2008) and ROB values.

- Accurate MEX orbits around Mars have been determined and used to derive the mass of the two Martian moons via their long-term effects on these orbits. MEX is well-suited for these kinds of studies since it can pass closer to the moons than the other spacecraft currently in orbit around Mars on account of its far more elliptical orbit. MEX radio science data during the close flyby of Phobos (closest distance of 273 km) in July 2008 were also used to determine the mass of Phobos. Both methods yielded the same mass estimate for Phobos, although the flyby result is more precise and currently the best mass estimate with a 1-σ relative error of 0.1%. The mass estimate of Deimos is not very accurate (error of 50%) because of the larger distance to MEX and the smaller mass of Deimos. The resulting low densities of both moons (see and Error: Reference source not found) are thought to be due to low-density material and/or porosity in their interiors, and suggest that re-accretion may have occurred in their early history.

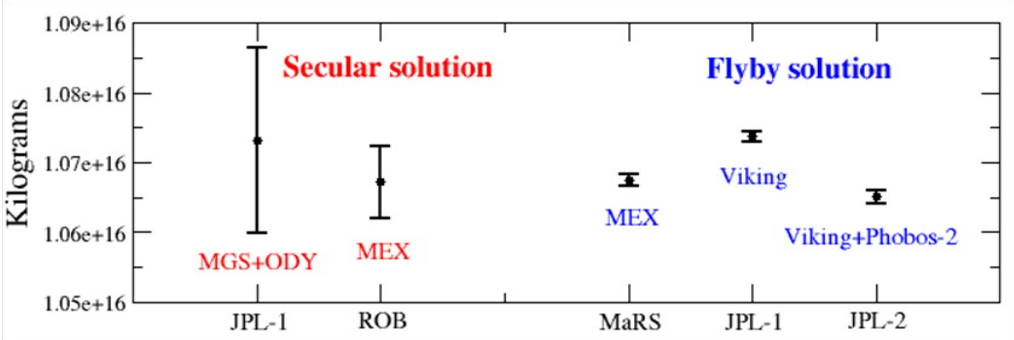


Figure 19: ROB solutions (denoted ROB and MaRS in the figure) for the Phobos mass compared with other published values.

- 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. It has been shown that it is unlikely for Phobos to have a homogenous internal mass distribution since the resulting forced libration amplitude deviates significantly from the measured forced libration amplitude. Preliminary results show that an interior mass distribution in large clusters of equal density agrees with the measured mass, centre of mass, and forced libration amplitude of Phobos (see Figure 21).

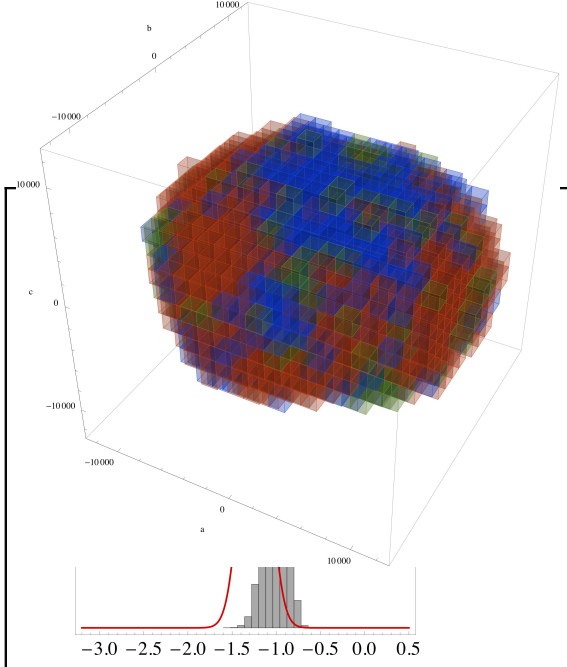


Figure 20: Inferred posterior probability density (gray histogram) of Phobos' forced libration amplitude for a homogeneous interior model. The red curve is the probability density function of the measured forced libration.

Figure 21: Mass, centre of mass, and forced libration amplitude compatible realization for the interior mass distribution inside Phobos for a model allowing for 3 different density units: silicate (3.10 g/cm^3, red), porous silicate (1.350 g/cm^3, green), or water ice (0.940 g/cm^3, blue).

- In collaboration with V. Lainey (Paris), the accurate MEX orbits determined at ROB have been used in the processing of Phobos' astrometric observations taken by the SRC (Super Resolution Camera) on-board MEX in order to improve the ephemerides of Phobos.

A.1.1.8. Mercury

- Possible mantle and crust mineralogies of Mercury have been determined for published geochemical models for Mercury. In a paper in Planetary and Space Science R.1, it has been shown that future measurements with the magnetometers onboard the MESSENGER and BepiColombo missions to Mercury will help differentiating between the models and will shed light on Mercury's formation.
- A study R.1 has been published on state-of-the-art interior structure models of Mercury and the sensitivity of future geodesy observations of the rotation and tides of Mercury to key parameters of the interior such as core size and composition. In a follow-up study, it has been shown that the size of the inner core can also 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.
- Planetary perturbations lead to long-term rotation variations, or forced librations in longitude, with typical periods of the order of several years. These librations have been determined by numerical integration of two differential equations: one for the motion of the mantle and the other for the core. Initial conditions are chosen in order to minimize the amplitude of the free libration at the initial time. The orbital elements are given by ephemerides. The long-term forced librations are a combination of many periods, but only five waves are above the arcsecond level, the accuracy level of the libration observations. These librations result from the perturbations of Venus (period of 5.66 years), Jupiter (5.96 and 11.86 y), the Earth (6.57 y) and Saturn (14.7 y). The results of this study in collaboration with Stan Peale and Jean-Luc Margot have been published in Icarus (see paper R.1).

- An analytical formulation for the amplitudes and phases of the long period librations has been developed. The proximity of the five periods to the resonance with the free libration, with a period of about 12 years, explains why these perturbations are above the arcsecond level. In particular, the free libration period can be very close to the Jupiter forcing period with a period of 11.86 year and can result in large libration amplitude at that period. Figure 22shows the amplification of different forced librations as a function of the value of the moments of inertia (see paper R.3).

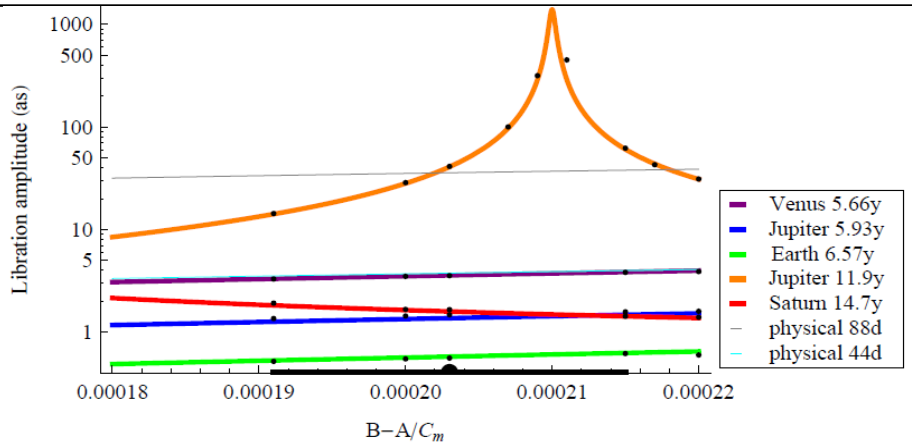


Figure 22: Amplitude (in arcsecond) of the forced librations due to the planets as a function of the (B − A)/Cm ratio for Mercury. The large black dot represents the nominal value for this ratio and the black line is the 1 sigma uncertainty around this value from Margot et al. (2007). The 88-day and 44-day physical librations have also been plotted using thin lines. A logarithmic scale is used. The small dots are the results of the numerical integration.

- An extensive study has been performed to investigate the expected precision on the obliquity and libration amplitude by using the camera experiment of the future BepiColombo mission to Mercury. 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. The effect of the different BepiColombo orbit scenarios on the spatial distribution and frequency of repeatedly observed surface targets has been studied. It has also been shown that camera observations of higher latitudes are most favorable for the determination of the obliquity and equatorial spots are best for estimating the libration. Both the obliquity and the annual libration amplitude are well solved for, in almost all circumstances reaching accuracy levels of around 1 arcsecond (lower than the mission requirement) in formal error after less than the nominal mission duration of 360 days and for data sets limited to 25 targets only. The main Jupiter and Venus induced libration amplitudes are best estimated for longer mission durations because of their long periods (see Figure 23). This study formed the basis of the PhD thesis of G. Pfyffer, submitted in 2009 (degree awarded on February 25, 2010).

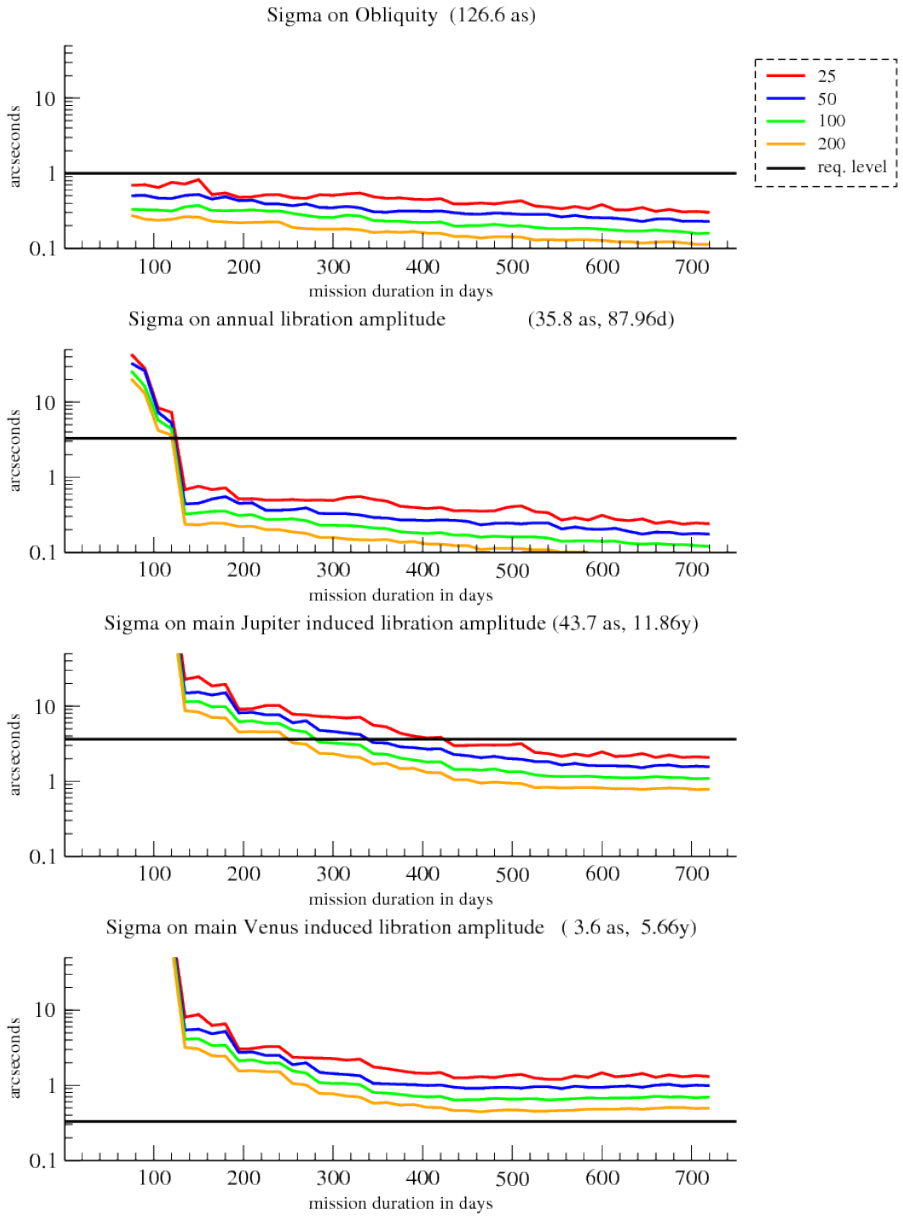


Figure 23: From top to bottom the formal error on the four parameters we solve for as a function of the mission duration. Each plot contains four lines representing each a different number of targets used to obtain the solution. The black curve represents the error level required for a successful experiment. The red, blue, green and orange curves represent 25, 50, 200 and 200 targets used respectively.

- A new project devoted to the characterization of the linear and non-linear responses of a fluid cavity undergoing forced longitudinal libration has been initiated in collaboration with R. Laguerre and J. Noir from UCLA. 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.
- Software to integrate the relativistic equations of motion has been developed. This new approach has the benefit of being relativistically consistent and safer than adding relativistic corrections to a computation in a Newtonian framework. Relativistic corrections due to the central body on the orbit of BepiColombo have been quantified.
- A tool has been developed that simulates the Doppler/Range signal of a spacecraft fully within General Relativity: planetary motion, spacecraft motion, and the Doppler/Range signals are computed from the metric (and its first derivative). First results for the Doppler/Range signals have been obtained for the BepiColombo mission. As an example, represents the relativistic correction on the frequency shift (Dop-

pler measurements), which is 4 orders of magnitude smaller than the Doppler signal itself. 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.

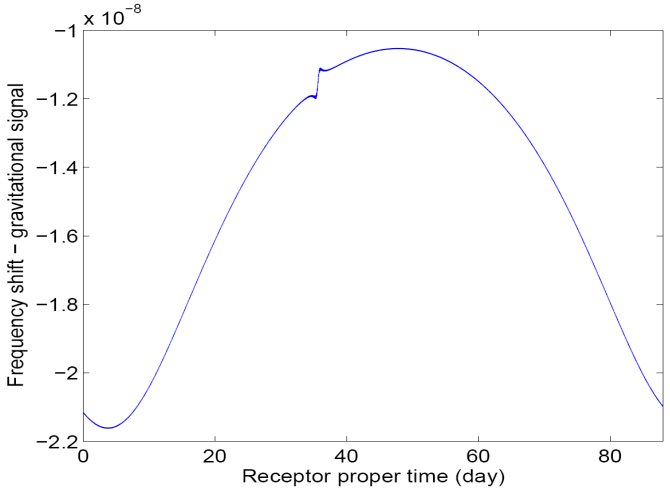


Figure 24: Relativistic correction on the frequency shift simulated for the BepiColombo mission. The small jump is the signal of the solar conjunction.

A.1.1.9. Earth

- The temperature and mineralogy of the lower mantle of the Earth has been estimated from seismological data on density and acoustic wave velocities and from electromagnetic data on the apparent resistivity. The temperature in the uppermost lower mantle (i.e. down to a depth of 1300 km) is shown to be about 2200 K and to increase along a superadiabatic gradient of 0.4 K/km between a depth of 1300 km and 2000 km. The results also indicate that the perovskite content of the lower mantle decreases linearly with depth and that the iron content is almost constant with depth (see paper R.1).

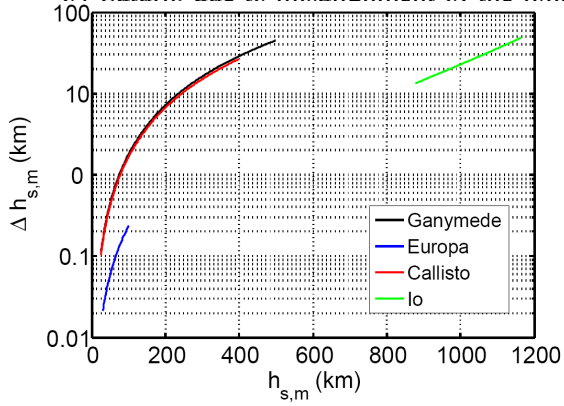
A.1.1.10. Venus

- By using a General Circulation Model (GCM) developed at the Laboratoire de Météorologie Dynamique de Paris, the atmosphere-induced variations in the gravity field and the rotation of Venus have been calculated (see paper R.3).
- A study has been started together with S. Lebonnois from LMD to extract temperature and density profiles of the Venus atmosphere from different preliminary GCM solutions, in order to make comparisons with the data from VeRa and SOIR instruments onboard the VEX spacecraft. This study is also in collaboration with colleagues from BIRA/IASB.
- Information on the density of the upper atmosphere of Venus can be obtained from the atmospheric drag on the VenusExpress (VEX) spacecraft passing through the atmosphere. VEX tracking data during the October 2009 drag experiment campaign have been analyzed to estimate the drag and density. The density of the atmosphere of Venus over the North Pole of the planet (where atmospheric density had never been measured before) derived from the campaign is in accordance with a new model of the upper atmosphere developed by I. Mueller-Woddarg.
- VEX radio science and accelerometer data have been used to study the gravity field of Venus. However, it is not possible to gain new information unless the altitude of VEX is lowered.

A.1.1.11. Natural satellites

- From an extensive set of astrometric observations, it has been shown that Io is slowly moving in towards Jupiter and that Europa and Ganymede are moving away from the planet. The rate of tidal energy dissipation in Io is determined to be in close agreement with the observed heat flux, suggesting that Io is close to a thermal steady state. The study also shows that Io, Europa and Ganymede are moving out of exact Laplace resonance, in which Europa's orbital period is twice that of Io, and half that of Ganymede. Dissipation in Jupiter is estimated at the higher end of previous estimates. The paper describing these results appeared in Nature R.1.
- An international team of planetary scientists has recently used Cassini radar observations to show that Titan's spin is slightly faster than the mean orbital motion. Angular momentum (AM) exchange between

Titan and its atmosphere is the most likely cause of the observed non-synchronous rotation. The Cassini scientists suggested that this non-synchronous rotation implies that Titan has an ocean beneath an ice shell, which would rotate independently from the interior. We have shown that the gravitational forcing by Saturn, due to misalignment of the long axis of Titan with the line joining the mass centers of Titan



pressure coupling between the ice shell and the interior be-
ential rotation between shell and interior and lead to rotation
aller than observed. Moreover, this theoretical study indicates
e slower than synchronous in contrast to the Cassini observa-
ervations suggest that non-hydrostatic effects in Titan are im-

colleagues, a review paper R.1 on the rotation of Europa has

onic patterns on terrestrial planets due to changes in the plan-
mption of a homogeneous lithosphere. As a first step, semi-
r the surface stresses due to global contraction (or expansion)
kness 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 (see Figure 25, and paper R.3). The ridge has also been modeled by assuming that it resulted from elastic buckling on a lithosphere with variable thickness. The buckling profile is very similar to what is observed but the mechanism requires an unphysically large critical stress.

- Several lines of evidence suggest that large icy satellites have a subsurface ocean beneath an ice shell. A previously developed method to determine the thickness of the ice shell by means of librations (rotation variations) has been extended to also include the effect of a liquid core on the librations. The method has been applied to the four Galilean satellites of Jupiter. For Io, it has been shown that the presence of a liquid core increases the libration of the mantle by a few percent with respect to an entirely solid Io. For Europa, Ganymede, and Callisto, the presence of a water ocean close to the surface increases by at least an order of magnitude the libration amplitude of the ice shell libration with respect to an entirely solid satellite. The shell libration depends essentially on the shell thickness, and the possible presence of a liquid core inside Europa and Ganymede has no noticeable influence on the shell libration (see Figure 26). A paper is in press in Icarus R.3.

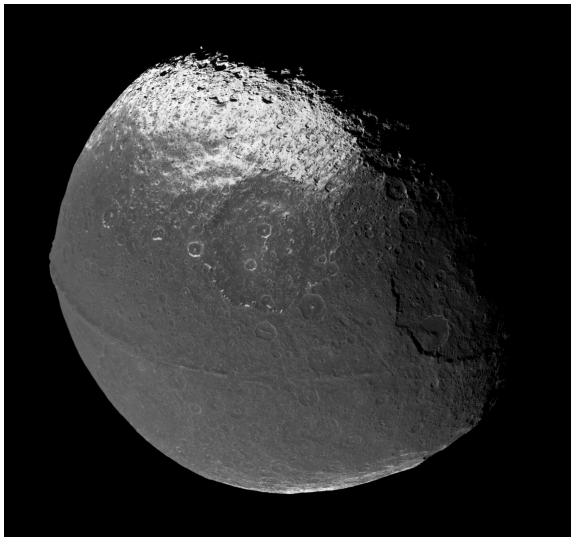


Figure 25: Equatorial ridge on Iapetus, a moon of Saturn. The ridge was discovered on 31 December 2004 by the probe Cassini. It runs along the equator spanning more than half the circumference and reaches a height of 18 km. This structure is without equivalent in the

Figure 26: Errors on the estimated surface layer thickness (h_s if the surface layer is an icy shell, h_m if it's a silicate mantle) for an observational error of 1 m on the equatorial libration amplitude.

solar system and its formation has up to now remained a mystery.	

- A tool is being developed to allow precise modeling of the rotation variations of triaxial planets and satellites. In 2009, the governing equations as derived in Smith (*Geophys. J. R. Astr. Soc.*, 1974, 37, 491-526) for biaxial planets have been extended to arbitrarily-shaped planets. To this end, the fundamental equations of continuum mechanics have been linearized around the spherically-symmetric reference equilibrium configuration. In the well-known case of a spherically-symmetric, non-rotating, elastic, isotropic (SNREI) planet, the infinite system of ordinary differential equations decouples to finite subsystems. In the general case, however, the system cannot be decoupled and must be truncated before solving for rotation variations.
- In collaboration with an international team, two review articles have been written on the dynamics and evolution of icy satellites, which are now in press in Space Science Reviews (R.3, R.3).
- 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. In the rigid case, the obliquity depends mainly on the polar moment of inertia C. By using a similar description as used for the librations, expressions for the obliquity of Titan and Europa have been determined. The observed value of 0.3° for the obliquity of Titan implies a normalized polar moment of inertia close to 0.335, about equal to the recently determined observational value by the Cassini radio science team. Measurements of the obliquity of Europa would allow constraining the ice shell thickness.
- 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. The degree-two gravity coefficients and the tides have the largest effect on the Doppler signal. Other effects like libration and obliquity have a smaller influence although it is still larger than the expected noise on the Doppler signal. In principle all these effects could therefore be measured by radio science experiments.
- Studies on the atmospheric forcing of rotation variations of Titan in collaboration with T. Tokano from Köln University and the use of a numerical ocean dynamics code for application to subsurface oceans of icy satellites have been continued.

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. Together with simulations for LaRa, these data will allow assessing the precision of the LaRa experiment. The use of altimeter data at ground track crossings for the determination of rotation variations of Mars 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 spacecraft orbital motion will be estimated.
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.

B.1.4. Personnel involved

Scientific staff: T. Van Hoolst, 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, M. Yseboodt.

Technical staff: L. Van Camp, R. Laurent

B.1.5. Partnerships

List of international 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. Polinésie Française, Tahiti
- L. Bergamin, Advanced Concepts Team, ESA
- B. Bills, NASA GSFC, USA
- 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
- W. Folkner, JPL, USA
- F. Forget, Laboratoire de Météorologie Dynamique, Paris, France
- B. Häusler, Universität der Bundeswehr Institut für Raumfahrttechnik, Munich, Germany
- A. Konopliv, JPL, USA
- V. Lainey, IMCCE, Paris, France
- H. Lammer, Space Research Institute, Austria
- S. Lebonnois, Laboratoire de Météorologie Dynamique, 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
- V. Robert, IMCCE, Paris, France
- S. Rosat, Institut de Physique du Globe de Strasbourg, Strasbourg, France
- P. Tarits, Université de Brest, France

- S. Tellmann, University of Cologne, Germany
- T. Tokano, University of Cologne, Germany
- P. Vacher, University of Nantes, France
- O. Verhoeven, LPG, University of Nantes, France
- K. Willner, Technische Universität Berlin, Germany
- P. Wolf, SYRTE, Observatoire de Paris, France, co-promoter of A. Hees
- C. Yoder, JPL, USA
- 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 collaborators having actively contributed to the project in the last year

- E. Deleersnijder, UCL
- A. Füzfa. GAMASCO, FUNDP
- E. Javaux, ULg
- A. Lemaître, FUNDP
- B. Noyelles, FUNDP
- D. Orban, B. Slade, and S. Burger, OMP (Lara Belgium Consortium)
- 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 and L. Winter, ROB (digitalization project).

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

- BELSPO-Action 1: Contract nr. MO/33/020, "Study of the internal structure of terrestrial planets by stochastic inversion of geophysical data", BELSPO (Action 1)
- PRODEX 9: Contract: C90319 (402 929 € for 2009-2010), LaRa
- PRODEX 9: Contract: C90365 (1 143 036 € for 2009-2011, contract signed until 2010), Planet Interior
- FRIA: PhD, G. Pfyffer (2004-2008) and 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"
- EuroPlaNet: EU, Coordination Action, Call: FP6-2202-Infra structures-1, 001637, Contract: 001637

Visitors:

- Short visits: 21 persons

B.1.6. Scientific outreach

Meeting presentations

[1] Chicarro A., Breuer D., Chassefière E., Dehant V., Fisackerly R., Grady M., Pinet P., Rossi A., and Santovincenzo A.
The Mars-NEXT mission: science and technical aspects
MarsExpress Science Working Team and Mars-NEXT Science Definition Team join meeting, ESA/ESTEC, 15 January

[2] Rosenblatt P., Andert T.P.,Pätzold M., Dehant V.,Häusler B., Le Maistre S., Marty J.C., Van Hoolst T.
Rubble pile Phobos: Hints for its origin.
MarsExpress Science Working Team, ESA/ESTEC, 15-16 January

[3] Gowen R. and more than 10 authors, including Dehant V. and Karatekin Ö.
Penetrators for Europa
Europa Lander Workshop, Moscow, Russia, 9-13 February

[4] Verhoeven, O., Mocquet A., Vacher P., Rivoldini A., Menvielle M., Arrial P-A., Choblet G., Tarits P., Dehant V., Van Hoolst T.
New constraints on thermal state and composition of the Earth's lower mantle from joint inversion of electromagnetic impedances and seismic data
Meeting of the Mineral Physics Group, in association with the British Geophysical Association, on 'New Views on Earth Interior', London, United Kingdom, 12-13 February

[5] Dehant V.
LaRa science team organization and work breakdown
PDR co-location meeting, CSL, Liege, Belgium, 17-19 February

[6] Dehant V.
LaRa experiment PDR: Welcome and Introduction
PDR co-location meeting, CSL, Liege, Belgium, 17-19 February

[7] Dehant V.
LaRa science team organization and work breakdown
PDR co-location meeting, CSL, Liege, Belgium, 17-19 February

[8] Dehant V.
LaRa science overview
PDR co-location meeting, CSL, Liege, Belgium, 17-19 February

[9] Dehant V.
LaRa operation planning
PDR co-location meeting, CSL, Liege, Belgium, 17-19 February

[10] Dehant V.
LaRa day/night operations
PDR co-location meeting, CSL, Liege, Belgium, 17-19 February

[11] Dehant V., Gurvits L., Pogrebenko S.
Space and planetary science in the context of IVS
IVS Board meeting, Bordeaux, France, 23 March

[12] Rosenblatt P., Le Maistre S., Dehant V., Marty J.C.
Porosity estimate into Phobos and Deimos: hints for their origin
MaRS team meeting, Cologne, Germany, 16-17 April

[13] Rosenblatt P., Le Maistre S., Marty J.C., Dehant V.
Mars' seasonal gravity changes using MEX, MGS, and ODY tracking data
MaRS team meeting, Cologne, Germany, 16-17 April

[14] Rosenblatt P., Beuthe M., Le Maistre S., Dehant V., Marty J.C.
Status on VEX gravity on target
VeRa team meeting, Cologne, Germany, 16-17 April

[15] Rosenblatt P., Le Maistre S., Dehant V., Bruinsma S., Mueller-Wodarg I.
Analysis of the VEX tracking data for VExADE (VEX Atmospheric Drag Experiment): Preliminary results
VeRa team meeting, Cologne, Germany, 16-17 April

[16] Dehant V.
Rotation and internal dynamics of terrestrial planets
EGU 2009 General Assembly, Vienna, Austria, 19-24 April

[17] Dehant V.
Interior of Mars and its orientation in space
EGU 2009 General Assembly, Vienna, Austria, 19 – 24 April

[18] Yseboodt M.
Mercury's forced librations in longitude
EGU 2009 General Assembly, Vienna, Austria, 19 – 24 April

[19] Rivoldini A., Van Hoolst T., Dehant V., Verhoeven O., Mocquet A.
Insight into the interior structure of Mars from forced nutations
EGU 2009 General Assembly, Vienna, Austria, 19-24 April

[20] A. Hees, L. Bergamin, P. Delva
Vibrating systems in Schwarzschild spacetime: towards a new test of General Relativity?
IAU symposium 261: Relativity in Fundamental Astronomy: Dynamics, References Frames and Data Analysis, Virginia Beach, 27 April – 1 May

[21] A. Hees, S. Pireaux
A Relativistic Motion Integrator: Numerical Accuracy and Illustration with BepiColombo and Mars-NEXT
IAU symposium 261: Relativity in Fundamental Astronomy: Dynamics, References Frames and Data Analysis, Virginia Beach, 27 April – 1 May

[22] Rosenblatt P., Dehant V.
The mysterious origin of the Martian moons: Phobos and Deimos. Recent progress from the Mars Express mission
Meeting of the FNRS contact group Astronomie et Astrophysique, ROB planetarium, Brussels, Belgium, 6 May

[23] Rivoldini A., Van Hoolst T., Dehant V., Verhoeven O., Mocquet A.
Insight into the interior structure of Mars from forced nutations
ESLAB 2009, International Conference on Comparative Planetology Venus-Earth-Mars, ESTEC, Noordwijk, The Netherlands, 11-15 May

[24] Dehant V., Karatekin Ö., de Viron O., Lambert S., Van Hoolst T.
Atmospheric Angular Momentum variations of Earth, Mars and Venus
ESLAB 2009, International Conference on Comparative Planetology Venus-Earth-Mars, ESTEC, Noordwijk, The Netherlands, 11-15 May

[25] Pham L.B.S., Ö. Karatekin, Dehant V.
Effects of asteroid and comet impacts on the Atmospheric evolution of Earth, Mars and Venus
ESLAB 2009, International Conference on Comparative Planetology Venus-Earth-Mars, ESTEC - Noordwijk, The Netherlands, 11-15 May

[26] Rosenblatt P., Dehant V., Marty J.C., Le Maistre S., Van Hoolst T.
Information on the interior of Mars, the Earth and Venus from orbiters around these terrestrial planets
ESLAB 2009, International Conference on Comparative Planetology Venus-Earth-Mars, ESTEC - Noordwijk, The Netherlands, 11-15 May

[27] Dehant V., Mitrovic M., Le Maistre S., Yseboodt M., Rosenblatt P., Van Hoolst T., Chicarro A.
Future radioscience missions with landers and orbiters on Mars
ESLAB 2009, International Conference on Comparative Planetology Venus-Earth-Mars, ESTEC - Noordwijk, The Netherlands, 11-15 May

[28] Rosenblatt P., Mocquet A., Dehant V.
Assessing the structure of planetary interiors from satellite and ground-based geophysical data: A comparative study
ESLAB 2009, International Conference on Comparative Planetology Venus-Earth-Mars, ESTEC - Noordwijk, The Netherlands, 11-15 May

[29] Kennedy T., Gowen R. and more than 10 authors, including Dehant V. and Karatekin Ö.

In-situ Penetrators for Ganymede and Europa
Noordwijkerhout, 11 June

[30] Rosenblatt P., Le Maistre S., Dehant V., Bruinsma S., Mueller-Woddard I. (VExADE team)
Analysis of the VEX tracking data for VExADE (VEX Atmospheric Drag Experiment): Preliminary results
Journée GINS - DYNAMO 2009, Toulouse, Observatoire Midi-Pyrénées, France, 16 June

[31] Le Maistre S.
Simulation d'une expérience de radio science avec un lien Doppler direct entre Mars et la Terre
Journée GINS - DYNAMO 2009, Toulouse, Observatoire Midi-Pyrénées, France, 16 June

[32] Gowen R. and more than 10 authors, including Dehant V. and Karatekin Ö.
Looking for Astrobiological Signatures with Penetrators on Europa
European Science Foundation Exploratory Workshop (ESFEW) on `Biosignatures on exoplanets´, Mulhouse, France, 23-25 June

[33] Dehant V.
Radioscience with a rover and an orbiter
ExoMars Science Working Team (ESWT2), ESTEC, The Netherlands, 1-2 July

[34] Gowen R. and more than 10 authors, including Dehant V. and Karatekin Ö.
An update on micro-penetrators for in-situ sub-surface investigations of Europa
NASA Europa Jupiter System Mission (EJSM) workshop, Applied Physics Laboratory, Laurel, MD, US, 15-17 July

[35] P. Delva**,** L. Bergamin, A. Hees
The motion of vibrating system in general relativity
Marcel Grossmann Meeting 12, Paris, 17 July

[36] Rosenblatt P., Dehant V., Le Maistre S., Marty J.C.
Porosity estimate into Phobos: Hints for its origin?
MarsExpress Radioscience Team meeting, Port Townsend, WA, USA, August 27

[37] Rosenblatt P., Le Maistre S., Dehant V., Bruinsma S., Mueller-Wodarg I
A short summary on the analysis of the VEX tracking data for VExADE (VEX Atmospheric Drag Experiment)
VenusExpress Radioscience Team meeting, Port Townsend, WA, USA, August 28

[38] Pfyffer G., Van Hoolst T., Dehant V.
Libration and obliquity of Mercury from the BepiColombo radio science and camera experiments
European Planetary Science Congress, Potsdam, 13-18 September

[39] Lainey V., Van Hoolst T.
Jovian tidal dissipation from inner satellite dynamics
European Planetary Science Congress, Potsdam, 13-18 September

[40] Yseboodt M., Van Hoolst T., Dehant V.
Mercury's interior from forced librations
European Planetary Science Congress, Potsdam, 13-18 September

[41] Grasset O. and the Joint Science Definition Team including Van Hoolst T.
The Jupiter Ganymede Orbiter as part of the ESA/NASA Europa Jupiter System Mission (EJSM)
European Planetary Science Congress, Potsdam, 13-18 September

[42] Gowen R., Smith A., Ambrosi R., Prieto Ballesteros O., Barber S., Barnes D., Bowyer A., Braithwaite C., Bridges J., Brown P., Church P., Collinson G., Coates A., Collins G., Crawford I., Dehant V., Dougherty M., Fielding J., Chela-Flores J., Fortes D., Fraser G., Gao Yang, Grande M., Griffiths A., Grindrod P., Gurvits L., Hagermann A., Van Hoolst T., Hopf T., Hussmann H., Jaumann R., Jones A.,

Jones G., Joy K., Karatekin Ö., Kargl G., Macagnano A., Mukherjee A., Muller P., Palomba E., Phipps A., Pike T., Proud B., Pullen D., Raulin F., Richter L., Ryden K., Sheridan S., Sims M., Sohl F., Snape J., Stevens P., Sykes J., Tong V., Stevenson T., Wells N., Wilson L., Wright I., Zarnecki J.
In-situ Science on the surfaces of Ganymede and Europa with Penetrators
European Planetary Science Congress, Potsdam, 13-18 September

[43] Van Hoolst T., Baland R.-M., Karatekin Ö., Rambaux N.
Forced libration in longitude of the Galilean satellites
European Planetary Science Congress, Potsdam, 13-18 September

[44] Baland R.-M., Yseboodt M., Van Hoolst T., Dehant V.
Influence of the internal structure of Europa on the Doppler signal of an orbiter
European Planetary Science Congress, Potsdam, 13-18 September

[45] Iess L. and the RSI team including Dehant V. and Van Hoolst T.
A high performance Ka-band transponder for EJSM/Laplace Radio Science Instrument
European Planetary Science Congress, Potsdam, 13-18 September

[46] Lange C., Ho T.-M., Karatekin Ö., Krömer O., Richter L., Sohl F.
An Instrumented Montgolfière Heat Shield for Titan Geophysics – The 'Geosaucer'
European Planetary Science Congress, Potsdam, 13-18 September

[47] Le Maistre S., Rosenblatt P., Dehant V., Marty J.C.
Study of the rotation of Mars through radioscience between lander/rover and the Earth
European Planetary Science Congress, Potsdam, 13-18 September

[48] Dehant V., Mitrovic M., Chicarro A.
Future radioscience missions with landers and orbiters to Mars; a study of the error budget
European Planetary Science Congress, Potsdam, 13-18 September

[49] Van Hoolst T., Bunce E.
Report and recommendations of the Jupiter system working group of EJSM
EJSM Joint Science Definition Team meeting, Potsdam, 18-19 September

[50] Yseboodt M., Margot J. L., Peale S. J.
Model of Mercury's Forced Librations in Longitude
41st annual meeting of the Division for Planetary Sciences of the American Astronomical Society, Fajardo, Puerto Rico, USA, 4-9 October

[51] Karatekin Ö., Lainey V., Van Hoolst T., Arlot J.
Orbital accelerations of Galilean satellites and the evolution of the Laplace resonance
41st annual meeting of the Division for Planetary Sciences of the American Astronomical Society, Fajardo, Puerto Rico, USA, 4-9 October

[52] Lainey V., Arlot J., Karatekin Ö., and Van Hoolst T.
Strong tidal dissipation in Io and Jupiter from astrometric observations
41st annual meeting of the Division for Planetary Sciences of the American Astronomical Society, Fajardo, Puerto Rico, USA, 4-9 October

[53] Rosenblatt P., Rivoldini A., Dehant V.
The interior structure of Phobos
50th Vernadsky-Brown Symposium, Moscow, Russia, 12-15 October

[54] Dehant V., Breuer D., Spohn T., Chicarro A.
Geophysics and Habitability of Mars
9th European Workshop on Astrobiology EANA'09 (European Astrobiology Network Association, EANA), Royal Library of Brussels, Brussels, Belgium, 12-14 October

[55] Pham L.B.S., Karatekin Ö., Dehant V.

Effects of asteroid and comet impacts on the atmospheric evolution of Earth, Mars and Venus
9th European Workshop on Astrobiology EANA'09 (European Astrobiology Network Association, EANA), Royal Library of Brussels, Brussels, Belgium, 12-14 October

[56] Dehant V., and the ROB team (Baland R.M., Beuthe M., Karatekin Ö, Le Maistre S., Mitrovic M., Pham L.B.S., Pfyffer G., Rivoldini A., Rosenblatt P., Trinh A., Van Hoolst T., and Yseboodt M.)
Effects of asteroid and comet impacts on the atmospheric evolution of Earth, Mars and Venus
9th European Workshop on Astrobiology EANA'09 (European Astrobiology Network Association, EANA), Royal Library of Brussels, Brussels, Belgium, 12-14 October

[57] A. Hees, L. Bergamin, P. Delva
Vibrating systems in Schwarzschild spacetime
Colloque GPHYS: Gravitation and Fundamental Physics in Space, Les Houches, 21 October

[58] Dehant V., Baland R.M., Beuthe M., Karatekin Ö, Le Maistre S., Mitrovic M., Pham L.B.S., Pfyffer G., Rivoldini A., Rosenblatt P., Trinh A., Van Hoolst T., Yseboodt M.
Report on the work on MEX, LaRa, VEX, BepiColombo, relativity, and icy satellites
Réunion de coopération de géodésie planétaire ORB-GRGS, Observatoire de Paris, France, 28 October

[59] Rosenblatt P., Le Maistre S., Marty J.C., Lainey V., Dehant V.
Results from Mars Express using GINS
Réunion de coopération de géodésie planétaire ORB-GRGS, Observatoire de Paris, Paris, France, 28 October

[60] Rosenblatt P., Le Maistre S., Dehant V., Bruinsma S., Mueller-Wodarg I. (VExADE team)
Results from Venus Express using GINS
Réunion de coopération de géodésie planétaire ORB-GRGS, Observatoire de Paris, Paris, France, 28 October

[61] Rosenblatt P., Rivoldini A., Le Maistre S., Dehant V., Marty J.C.
The interior structure of Phobos
MaRS team meeting, Brussels, Belgium, 9 November

[62] Beuthe M., Le Maistre S., Rosenblatt P., and Dehant V.
MEX-MaRS: Gravity on Target
MaRS team meeting, Brussels, Belgium, 9 November

[63] Rosenblatt P., Le Maistre S., Dehant V., Bruinsma S., Mueller-Wodarg I. (VExADE team)
VEX drag experiment (VExADE) results from drag-1 and drag-2 campaigns
VeRa team meeting, Brussels, Belgium, 10 November

[64] Rosenblatt P., Beuthe M., Le Maistre S., Dehant V., Marty J.C.
Status on VEX gravity from VExADE campaign#2
VeRa team meeting, Brussels, Belgium, 10 November

[65] Hees A.
Testing General Relativity with space missions
Belgian Cosmology and Big Bang Group meeting, Louvain-La-Neuve, 17 December

[66] Van Hoolst T., Baland R.M., Rambaux, N., Karatekin, Ö.
Librations and interior structure of the Galilean satellites
AGU Fall Meeting, San Francisco, USA, 14-18 December

[67] Van Hoolst T.
The influence of liquid internal layers on the rotation variations of terrestrial planets and icy satellites
AGU Fall Meeting, San Francisco, USA, 14-18 December

[68] Rivoldini A., Van Hoolst T., Verhoeven O.

Mercury's inner core: A strategy for estimating its size from MESSENGER and future BepiColombo geodesy data
AGU Fall Meeting, San Francisco, USA, 14-18 December

[69] Mitrovic M., Dehant V.
Error budget on radioscience transponder on Mars for future mission
AGU Fall Meeting, San Francisco, USA, 14-18 December

[70] Nkono C., Rosenblatt P., Dehant V., Le Maistre S.
Solar Corona and plasma effects on Radio Frequency waves
AGU Fall Meeting, San Francisco, USA, 14-18 December

[71] Le Maistre S., Rosenblatt P., Dehant V., Marty J.C.
Simulations of Mars rotation radioscience observation and retrieval for a rover/lander on Mars
AGU Fall Meeting, San Francisco, USA, 14-18 December

[72] Dehant V., Yseboodt M., Le Maistre S., Rosenblatt P., Mitrovic M., Orban D., Rivoldini A., Marty J.C., Van Hoolst T.
Rotation and interior of Mars from radioscience
AGU Fall Meeting, San Francisco, USA, 14-18 December

[73] Rosenblatt P., Marty J.C., Le Maistre S., Dehant V., Karatekin Ö.
Assessing the precision on the determination of the CO2 seasonal mass budget from time-variable gravity observations
AGU Fall Meeting, San Francisco, USA, 14-18 December

[74] Karatekin, Ö., Laguerre R., Noir J., Dehant, V.
Numerical study of librationally driven flow in planetary interiors
AGU Fall Meeting, San Francisco, USA, 14-18 December

[75] Beuthe M.
East-west faulting and buckling from the contraction of a lithosphere thinner at the equator, with applications to Mercury and Iapetus
AGU Fall Meeting, San Francisco, USA, 14-18 December

[76] Koot L., Rivoldini A., de Viron O., Dehant V., Dumberry M.
Constraints on the couplings at the core-mantle and inner core boundaries inferred from nutation observations
AGU Fall Meeting, San Francisco, USA, 14-18 December

Seminars

[77] Rosenblatt P.
The mysterious origin of the Martian moons: Phobos and Deimos. Recent results from the Mars Express mission
Séminaire ASTR-GEOG UCL, Université catholique de Louvain, Louvain-la-Neuve, Belgium, 6 April

[78] Rosenblatt P.
L'intérêt des développements analytiques pour la determination du champ de gravité martien.
Séminaire du Centre de Compétences Techniques du CNES, Toulouse, France, 4 June

[79] Widemann T. and Dehant V.
Les phases de Vénus; la rotation de Venus
Journée scientifique 2009 du Bureau des longitudes, 'Du Système Solaire à la voie lactée: la quête galiléenne', Paris, France, 17 June

[80] Van Hoolst T.
Basic physical characteristics of planets
Royal Observatory of Belgium, 25 June

[81] Pham, L.B.S
Epreuve de confirmation; « Habitabilité et évolution climatique de Mars »
Louvain-la-Neuve, 23 September

Lectures

[82] Dehant V.
Mars Interior: Structure and Activity
Advanced Summer School, Jiaxing, Zhejiang Province, China, organized by NAOC and ESA, July 20-24, 2009.

[83] Dehant V.
Mars Geodesy and Rotation
Advanced Summer School, Jiaxing, Zhejiang Province, China, organized by NAOC and ESA, July 20-24, 2009.

[84] Dehant V.
MEX Data Utilization: Interior, Gravity and Geodesy data
Advanced Summer School, Jiaxing, Zhejiang Province, China, organized by NAOC and ESA, July 20-24, 2009.

[85] Dehant V.
Subsurface sounding
Advanced Summer School, Jiaxing, Zhejiang Province, China, organized by NAOC and ESA, July 20-24, 2009.

[86] Dehant V.
Instrumentation on Landers and Rovers
Advanced Summer School, Jiaxing, Zhejiang Province, China, organized by NAOC and ESA, July 20-24, 2009.

Wikis and Websites

- Updating of the MarsExpress SPICE kernel orbits with the accurate orbits produced at ROB (see ftp://ssols01.esac.esa.int/pub/data/SPICE/MEX/kernels/spk/)

B.1.7. Missions

Assemblies, symposia:
- R.-M. Baland (European Planetary Science Congress)
- M. Beuthe (AGU fall meeting)
- V. Dehant (EGU General Assembly, FNRS Astronomy Contact Group, ESLAB, European Planetary Science Congress, EANA, GNSS ESA Symposium, AGU fall meeting)
- A. Hees (IAU Symposium 261, Colloque GPHYS: Gravitation and Fundamental Physics in Space, Belgian Cosmology and Big Bang Group meeting)
- Ö. Karatekin (Workshop on Water, Alliance workshop Berlin, DPS meeting, EANA, AGU fall meeting)
- S. Le Maistre (AGU fall meeting)
- G. Pfyffer (European Planetary Science Congress)
- L.B.S. Pham (Workshop on Water, EANA)
- A. Rivoldini ('New Views on Earth Interior', AGU fall meeting)
- P. Rosenblatt (ESLAB ESTEC, 50th Brown-Vernadsky micro-symposium, AGU fall meeting)
- T. Van Hoolst ('New Views on Earth Interior', Workshop 'En route to Jupiter and Saturn', European Planetary Science Congress, AGU fall meeting)
- M. Yseboodt (EGU General Assembly, European Planetary Science Congress, DPS meeting)

Commissions, working groups (days): M. Beuthe (2 days)
V. Dehant (33 days)
Ö. Karatekin (2 days)

S. Le Maistre (2 days)
P. Rosenblatt (9 days)
T. Van Hoolst (12 days)

Research visits (days): V. Dehant (22 days)
A. Hees (8 days)
Ö. Karatekin (8 days)
M. Mitrovic (5 days)
P. Rosenblatt (17 days)
T. Van Hoolst (1 day)
M. Yseboodt (1 day)

B.2. Earth Rotation

B.2.1. Objectives

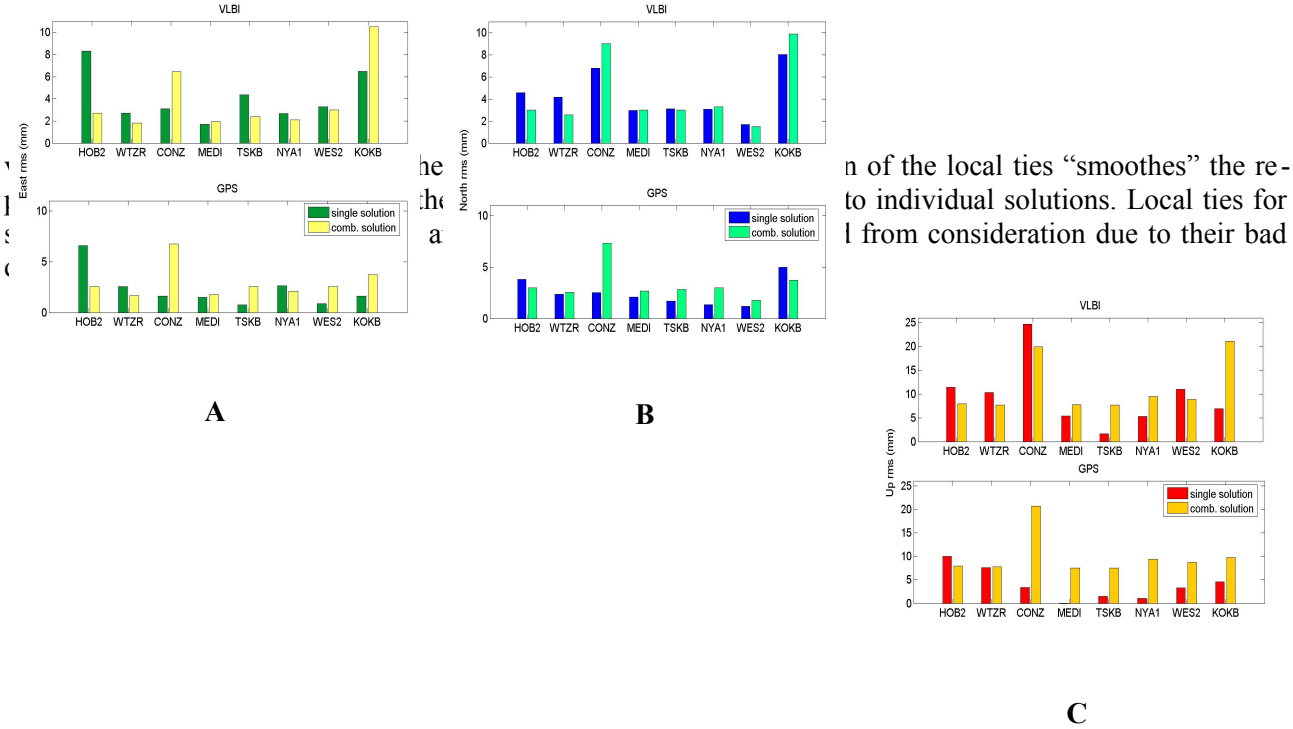
Long-term objectives: to understand and model the Earth rotation and orientation variations, i.e., length-of-day, precession, nutations, and polar motion; to understand the associated physics of the Earth's interior and the interaction between the 'solid' Earth and the geophysical fluids.

B.2.2. Progress and results

B.2.2.1. VLBI and GNSS data for Earth Rotation determination

The current nutation model adopted by the IERS is based on the analytical formulation given by Mathews et al. (1991) with numerical values for the geophysical parameters estimated from the Very Long Baseline Interferometry (VLBI) observational nutation series. Nevertheless, VLBI observations show discrepancies with the theory of the order 0.2 mas R.1 R.1. In order to improve the model, we refine the observational series and improve the parameter determination from observations in the Action 1 project on "Determination and modeling of nutation from VLBI (Very Long Baseline Interferometry) and GNSS (Global Navigation Satellite System) observations". It is expected that using GPS observations in addition to VLBI observations can improve nutation series in the short-period domain (nutation terms with periods up to 25-30 days). A strategy has been developed for the combination of VLBI and GPS observations in order to achieve better accuracy and better consistency in the resulting nutation series, which consists in combining information at the level of the so-called normal equations (written form of the equations associated a least squares method) instead of at the level of the data series or parameter series. The strategy consists of the following steps: (1) accumulation of VLBI-derived SINEX files (special file format for keeping normal equations and other necessary information) transformed into Bernese internal format of normal equations; (2) change in the GPS-data processing scheme in such a way that estimated parameters would have the same interval of validity and reference epochs as those from VLBI normal equations; (3) realization of a re-weighting procedure for normal equations produced by processing of different geodetic techniques (according to Thaller, 2008); (4) implementation of so-called ties vectors (in order to connect VLBI/GPS observational networks we need to introduce the vectors connecting the reference points of co-located sites of both techniques); (5) implementation of the equations connecting UT1-UTC and nutation angles with their first time derivatives (due to the different capabilities of VLBI/GPS in determining the Earth orientation parameters: VLBI has direct access to the angle of Earth rotation as well as to nutation angles, whereas GPS is sensitive only to the first time derivatives of those angles); and (6) data handling of spurious signals of the techniques R.3.

During the year 2009 the items (1)-(4) have been implemented into the Bernese software. The re-weighting factor derived for a test time series is in a good agreement with re-weighting factors obtained in other studies for VLBI/GPS combination. The implementation of local ties also helps to improve the stability of the terrestrial reference frame (i.e. improves repeatability of station coordinates). One of the outputs of the system is the site position series as a function of time. This position Figure 27 shows site coordinate repeatabilities, i.e. the weighted root mean square of the site position around the mean value, of the combined test solution



A **B** **C**

Figure 27: Repeatability of site coordinates in east (A), north (B) and up (C) directions. Different colors indicate repeatabilities for single technique and combined solution (see legends). All local ties have been taken into account in the combined solution, regardless of their quality.

B.2.2.2. Nutation models

We have contributed to a paper discussing the fundamental aspects of the semi-analytical precession-nutation models that were adopted by IAU Resolutions in 2000 and 2006. It has been shown that there are no significant discrepancies between the models of Mathews et al. (2002, J. Geophys. Res. 107:B4, ETG 3-1–3-26), Capitaine et al. (2003, Astron Astrophys 412:567–586), and other semi-analytical solutions based on the INPOP06 numerical integration (Fienga et al., Astron Astrophys 477:315–327, 2008). The currently observed VLBI residuals can most likely be explained by a combination of linear and 18.6-year corrections (the residuals are shown in Figure 28); although a longer time span of observations is required before the true character of the effect can be determined. It is suggested that the divergence of the predictions from the ERA-2005 theory (Krasinsky, Celest Mech. Dyn. Astr. 96:169–217, 2006) from recent VLBI results is due to the empirical nature of the ERA model R.1.

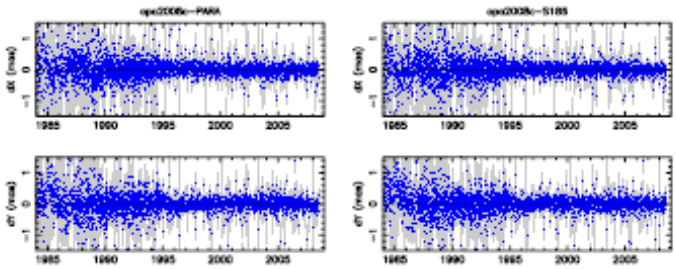


Figure 28: d*X* and d*Y* residuals of the IAU 2006 precession plus IAU 2000A nutation with respect to OPA VLBI time series after the Free Core Nutation has been removed. The original residuals have been corrected for a parabola (*left*) and a linear term plus an 18.6-year periodic term (*right*). (All the fits are weighted).

The book by Dehant and Mathews (who has been nominated 'Astronome Correspondant' of ROB) is almost finished and should be published in 2010. It is entitled "Precession, Nutation and Wobble of the Earth."

B.2.2.3. Earth interior modeling from VLBI nutation observation

In order to improve the nutation model, we have developed a new method to estimate the geophysical parameters from the nutation observations besides our efforts to improve the nutation observations themselves by combining VLBI and GNSS data. The new inversion procedure for the nutation data is characterized by the following aspects: (1) the use of the nutation data directly in the time domain, rather than in the frequency domain as it was done before, in order to avoid any loss of information and to take directly into account the time variable quality of the data, and (2) the use of a Bayesian inversion method, which allows for an inver-

sion of highly non-linear models (which is the case for the nutation model). The inversion procedure was applied to several VLBI nutation data sets, obtained from different VLBI analysis centers, in order to determine how the differences between these data series affect the estimated parameters. A joint inversion of several data sets was also performed. The new inversion method provides new estimations of the geophysical parameters which, in turn, bring new information on the Earth's interior structure and, in particular, on the coupling mechanisms at the core-mantle and inner core boundaries. In and , we present the results for the coupling constants (real and imaginary parts) at the inner core boundary (ICB) and at the core-mantle boundary (CMB) using the recent VLBI series. In order to compare our results with those of Mathews et al. (2002), the latter results are also shown. We notice that, for each parameter, the confidence interval is almost symmetric with respect to the mean and has a half-width almost equal to three standard deviations. Whatever the data set used, our results on the coupling parameters are in disagreement with those obtained by Mathews et al. (2002). The differences arise from three different causes: (1) we use a non-linear inversion method, which is more adapted to the highly non-linear dependence of the nutation model on the coupling constants, (2) we use all the available data, not only the main periodic terms, and (3) the data used by Mathews et al. (2002) were from 1979 to the end of 1999 whereas we use data from 1979 to 2009.3, so that we have 10 additional years of high quality data.

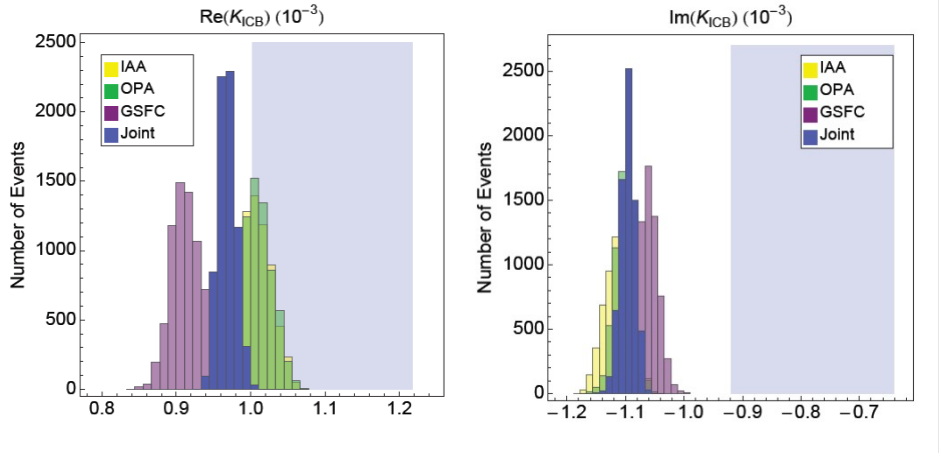


Figure 29: Marginal posterior probability densities for the real and imaginary parts of the ICB coupling constant for different nutation data sets (GSFC, OPA, and IAA), the joint inversion of the three data sets (COMB) and the GSFC data truncated to the period 1990-2009.3 (GSFC1). The blue boxes show the 3σ domains obtained by Mathews et al. (2002).

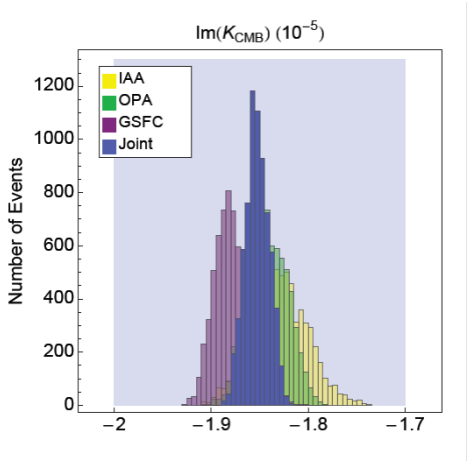


Figure 30: Marginal posterior probability densities for the imaginary part of the CMB coupling constant for different nutation data sets (GSFC, OPA, and IAA), the joint inversion of the three data sets (COMB) and the GSFC data truncated to the period 1990-2009.3 (GSFC1). The blue boxes show the 3 domains obtained by Mathews et al. (2002).

A paper on this Bayesian approach and on the results concerning the determination of some interior parameters from the nutation from VLBI data has been submitted to Journal of Geophysical Research R.3.

In collaboration with Marta Folgueira we have established a semi-analytical approach to compute the topographic torque at the core-mantle boundary inside the Earth and its contributions to the Earth nutations and rotational normal modes (to the Free Core Nutation). The method has been further developed this year by incorporating developments up to degree 4 in the topography expansion.

B.2.2.4. Special Bureau for the Core (SBC)

The Special Bureau for the Core (SBC) contacts and website are maintained within ROB. The SBC is part of the Global Geophysical Fluids Center (GGFC) of the International Earth Rotation and Reference Systems Service (IERS).

B.2.3. Perspective for next years

- M. Kudryashova, V. Dehant and C. Bruyninx will finish the nutation evaluation from combined VLBI data and GNSS data (steps (5)-(6) above). This work will be done in the frame of an Action 1 project.
- M. Folgueira and V. Dehant will continue the evaluation of the topographic coupling mechanism at the core-mantle boundary.
- 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.

B.2.4. Personnel involved

Scientific staff: V. Dehant, C. Bruyninx, L. Koot, M. Kudryashova, T. Van Hoolst

Technical staff: L. Van Camp

B.2.5. Partnerships

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

- Nicole Capitaine and Sébastien Lambert, Observatoire de Paris
- Marta Folgueira, Madrid University, Spain
- Sonny P.M. Mathews, Madras University
- Olivier de Viron, Université Paris VII/Institut de Physique du Globe de Paris

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

Grants/Projects used for this research/service

- BELSPO-Action 1, 1- M0/33/023 Determination and modeling of nutation from VLBI (Very Long Baseline Interferometry) and GNSS (Global Navigation Satellite System) observations, M. Kudryashova and L. Koot
- FNRS Aspirant, L. Koot
- EU, Descartes Prize 2003, M. Folgueira

Visitors:

- M. Folgueira, Univ. Madrid

B.2.6. Scientific outreach

Meeting presentations

[1] Dehant V.
Mutual relation between the GALILEO system (and other GNSS) and the science community
Invited Speaker, Inaugural Session, 2nd International Colloquium on `Scientific and Fundamental Aspects of the Galileo Programme', COSPAR Colloquium, University of Padova, Padua, Italy, 14-16 October, 2009.

[2] Kudryashova M., Weber R.
Contribution of the additional GNSS constellations to the nutation rates estimation: analysis of correlations
EGU General Assembly 2009, Vienna, Austria, April 19-24 2009.

[3] Kudryashova M., Lambert S., Dehant V., and Bruyninx C.
Combination of nutation rates/offsets derived from GNSS/VLBI observations on the level of normal equations at Royal Observatory of Belgium: first results
IAG General Assembly 2009, Buenos Aires, Argentina, August 2009.

[4] Kudryashova M., Lambert S., Dehant V., and Bruyninx C.
Study of local ties implementation into nutation combination project
IERS Workshop on 'EOP Combination and Prediction', Warsaw, Poland, October 19-21, 2009.

[5] Kudryashova M., Lambert S., Dehant V., and Bruyninx C.
Strategy of combination of GPS/VLBI-derived nutation parameters at the normal equation level
Session G04: 'Results of the Reprocessing of Space Geodetic Observations', AGU Fall Meeting, San Francisco, USA, December 14-18, 2009.

[6] Koot L.
Nutations and the Earth interior
Invited, World University Network for Geomagnetism - Workshop 1, School of Earth and Environment, University of Leeds, Leeds, UK, June 2009.

[7] Koot L., Rivoldini A., de Viron O., Dehant V., and Dumberry M.
Constraints on the couplings at the core-mantle and inner core boundaries inferred from nutation observations
Invited, AGU Fall Meeting, San Francisco, USA, December 14-18, 2009.

Seminars

[8] Koot L.
Etude de la structure interne de la Terre à partir des observations de la précession et des nutations
Invited, Institut de Physique du Globe de Paris, Paris, France, April 2009.

B.2.7. Missions

Assemblies, symposia:

- V. Dehant (EGU, Vienna, Austria, 19-24 April, GNSS ESA Symp., Padova, Italy, 14-16 Oct., AGU San Francisco, USA, 14-18 December)
- L. Koot (World University Network for Geomagnetism-Workshop 1, UK, June)
- M. Kudryashova (EGU, Vienna, Austria, 19-24 April, IERS Combination Workshop, Warsaw, Poland, 19-21 Oct.), IAG 2009, Buenos Aires, Argentine, 31 Aug.-4 Sep.

Research visits (days): V. Dehant (Univ. Madrid, 10-14 July, 4 days)
M. Kudryashova (Paris Observatory, Paris, France, 7 Jan.)

SEISMOLOGY AND GRAVIMETRY

Introduction:

The scientific activities in seismology & gravimetry are 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 its scientific research, its scientific 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.

ROB hosted from 2007 to 2010 a Marie Curie Excellence project which is seeking to obtain a most extensive chronology of past events along both the North and the East Anatolian Faults.

Other scientific activities are to conduct and analyse gravity measurements at the Earth surface and 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 GIANT and LISSA projects 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, earthquake monitoring

C.1. Seismology, seismic hazards and risks

C.1.1. Objectives

Seismic activity in northwest Europe

The Royal Observatory of Belgium is conducting different research activities on the seismic activity in northwest 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 northwest 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 our regions begins around 700 AD. Until the XIVth century, the rare historical sources allow the establishment of a list of the strongest earthquakes, but few can be reliably assessed in terms of magnitude and location. Since the XIVth century, the number of different sources (chronicles, an-

notations, parish registers, account registers…) 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. Our team developed an expertise in this domain, which is now used in different other projects elsewhere in the world. One of these studies is the EC Marie Curie Excellence project which is seeking to obtain a most extensive chronology of past events along both the North and the East Anatolian Faults. For that purpose, the involved team used a diverse array of complementary techniques, including trenching across the fault combined with subsurface geophysics, dating of displaced geomorphic features and drilling of lake sediments along the fault trace. The objective of the project is to get an extensive chronology of past earthquakes along the Anatolia Fault system in Turkey.

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 in-

side 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

Compilation study "Seismicity of Flanders" issued by the Flemish Government

In 2009, the project VLA07-4.2, a compilation study concerning the seismicity in Flanders, was finalized, and a final report was written. In this project, ROB was the main contractor, but we worked together with three other partners, which are technically subcontractors: the Belgian Geological Survey, the Department Civil Engineering of the University of Leuven, and the Laboratory for Soil Mechanics of the University of Gent. The project was coordinated by Kris Vanneste.

The Royal Observatory of Belgium is involved in 5 different work packages:

- WP3: Seismic hazard map of Flanders at bedrock level (in cooperation with K.U.Leuven);
- WP5: Seismic catalogue of Flanders and its surroundings;
- WP6: Seismotectonic zonation of Flanders and its surroundings;
- WP7: Description of the most important earthquakes that have affected Flanders;
- WP8: Evaluation of the financial impact of the earthquake of 11 June 1938 in Flanders.

The final report was delivered to the Flemish Government on 6 May 2009. The report was accepted, except for the contribution to WP1 (Mapping of Eurocode 8 ground types in Flanders) by the Belgian Geological Survey. After modification of this part, the final report was resubmitted on 25 September 2009, and accepted. The report provides the current state of the art concerning knowledge on seismicity in Flanders, from different perspectives (seismology, geology, and engineering).

ROB earthquake catalogue

The 7th-framework EC-project SHARE begun in June 2009. The ROB section seismology has to contribute to the European Earthquake Database, which is the task 3.1 of the project. In this framework, we undertook a complete study of the earthquakes that occurred in Western Europe from 1900 to 1940. For this purpose, all the available information from European seismic stations has been collected with the purpose of better evaluate the earthquake magnitude. We also begun to complete our database with 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. Hence, we were able to provide to GFZ-Potsdam (responsible in the SHARE project of the European earthquake catalogue from 1900) the last version of our catalogue for earthquakes since 1900. We contributed also to a new Consensus European Earthquake Catalogue (CEEC) for the period before 1900. The name of the documentary electronic basis of this catalogue is "AHEAD" (Archive of Historical Earthquake Data). From the beginning of the year 2009, we were involved in this project as an expert of the methodological problems raised by the use of medieval sources to study the long-term seismic hazard. We stated these problems at the Thessaloniki SHARE Workshop and we began to improve the medieval part of the catalogue AHEAD from the month of September 2009. This improvement notably consists in giving an opinion concerning the critical value of the material already published about various medieval earthquakes.

Since 1985, the ROB earthquake catalogue for Western Europe 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. In the frame of this report, it is not pos-

sible to cite in greater detail all the improvements brought in this catalogue during the year 2009. A new table of earthquakes reflects the state-of-the-art in this domain at the end of the year 2009 and will be presented on the website of the seismology of the R.O.B. during the year 2010.

Historical earthquakes

In the year 2009, the earthquakes occurred in the Belgian area during the XIXth century were particularly studied and revised. The elaboration of a monography concerning the major event of 23 Februar 1828 (cf. 2008 report) was pursued by some new investigations in newspapers contemporary with the facts and by a new reappraisal of the data contained in the old inquiries of P.N.C. Egen and J.J. Nöggerath. On the other hand a new study about the poorly known Valley of the Scarpe earthquake of 2 September 1896 (figure 1) was carried out and was agreed for publication in the year 2010. New material gathered in old newspapers has allowed drawing a new macroseismic map of this telluric shock. Moreover, we have looked for and have found new data concerning the effects in Belgium of the major earthquakes of 6 April 1843 (epicentre in Dutch Noordbrabant) and 29 July 1846 (epicentre in St. Goar area on the Rhine).

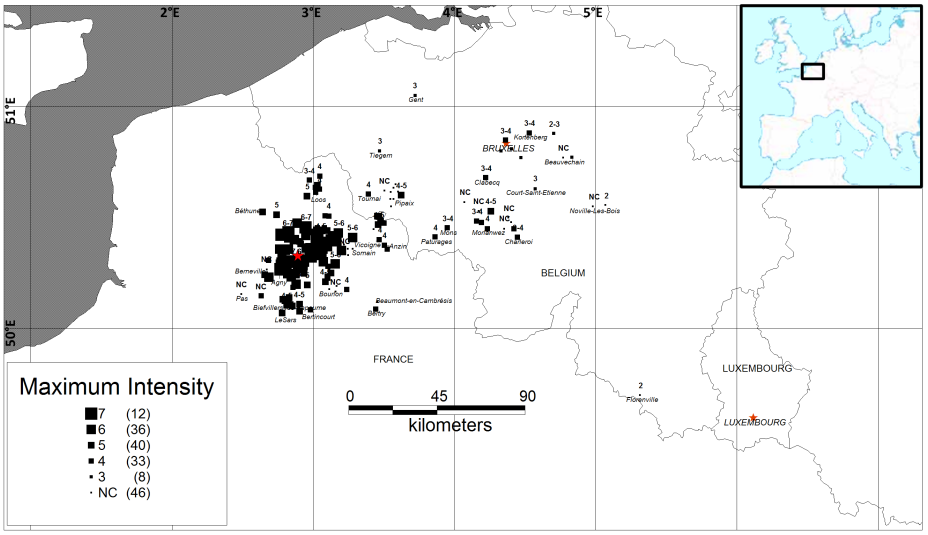


Figure 31: Macroseismic map of the M = 4.6 September 2, 1896 earthquake in the Arras region (North of France)

Present seismic activity

- A seismic sequence started on 12 July 2008 some 20 km to the southeast of Brussels. The activity did continue in 2009 with 131 earthquakes, among which 35 were felt. There was a peak in March, with 80 earthquakes. We regularly recomputed the complete analysis of the data in terms of location, relocation and fault plane solution determination.The COMPLOC relocation of the sequence shows a fault extending SE-NW on maximum 1.5 kilometers and with a NE dip of about 70 degrees (Figure 2). This orientation is in very good agreement with the fault plane solution indentified by the analysis of P, SV and SH data for the strongest events.
- In cooperation with the Faculté Polytechnique of Mons, we begun an investigation of the relationship between the seismic activity in the Hainaut zone and the activity in the coal mines.
- We improved the analysis program to measure P, SV and SH polarities and amplitudes. This data gives more information on the radiation pattern at the source that allows better constraining of the focal mechanism. Tools originally written by Thierry Camelbeeck (PhD Thesis, 1993) in FORTRAN have been transformed from standalone executable program to a PYTHON module callable from any script or program written in PYTHON. The advantage of this methodology is that it makes the comparison of focal mechanisms determined with different input parameters a lot easier. We have then build a small script to offer the choice between catalogue location and relocation, selection of amplitudes or just polarizations;

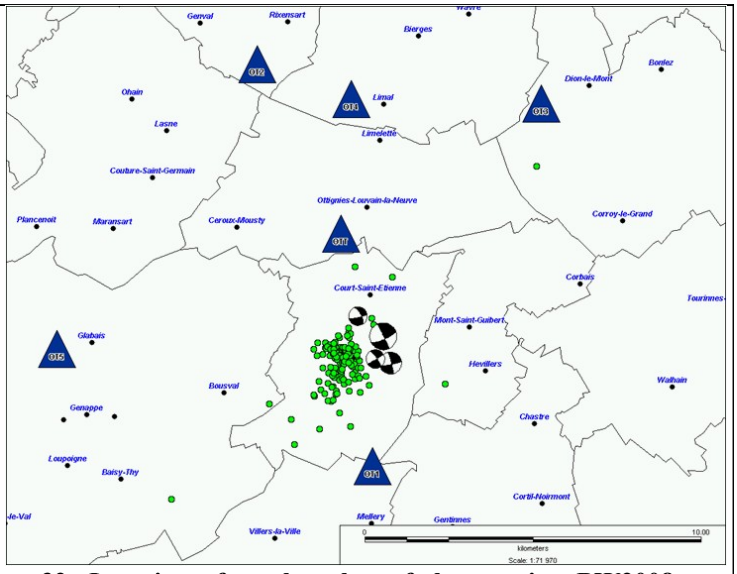


Figure 32: Location of earthquakes of the ongoing BW2008 sequence (green circles), focal mechanisms determined and temporary stations deployed in the region.

to manually set the depth of an event, etc.

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

Database of seismogenic sources in Western and central Europe

As an active partner of the FP7-EC project SHARE, the Royal Observatory of Belgium is in charge of the identification and classification of potential seismogenic sources in Western and Central Europe, including Austria, Germany, The Netherlands, Belgium, G.-D. Luxemburg, France and Switzerland.In 2009, we conducted the following investigations:

1. Seeking and storing all the available literature about active faults and potential seismogenic sources in Western and Central Europe.

2. Creating a database and a general map with all the possible seismogenic sources capable of rupturing in earthquakes of moment magnitude greater than 5.5.

3. Make a preliminary characterization of the potential seismogenic sources identified following the guidelines proposed by the DISS Working Group at the *Istituto Nationale di Geofisica e Vulcanologia* (Roma, Italy). See http://diss.rm.ingv.it/diss/

The Roer Valley graben

We conducted a small geophysical survey on the narrow strip between two submerged gravel pits just north of the surface trace of the Geleen fault. The survey was issued by the VMW (Vlaamse Maatschappij voor Watervoorziening), with the objective to determine the thickness of the in situ gravel and of its cover, and the composition of the hydraulic plug in between both pits. The survey was also of scientific interest, as it enabled us to acquire a long profile across the Feldbiss fault, which is inferred to run about halfway the area, parallel to the Geleen fault. We applied both electric resistivity tomography (ERT) and ground-penetrating radar. Particularly the ERT profiles yielded a clear image of the subsurface down to ~40 m depth. The profile across the Feldbiss fault did not show convincing evidence of faulting. However, it did reveal broad warping of the gravel top, which we interpret as folding. Folding was already observed before at larger depth on high-resolution seismic-reflection profiles, and indicates that the Feldbiss fault terminates in this area, its activity being transferred to the Geleen fault. Our new data show that this deformation is ongoing, and affects sediments of Holocene age.

The Hockay fault zone

We conducted a large scale geophysical field survey in the Hautes-Fagnes area during August 2009. During this survey, 18 electrical resistivity tomographies were acquired following a West-East progression, for a total of about 5 km. These overlapping profiles create a virtual 5 km profile crossing the Hockai Fault Zone almost perpendicularly ().

Figure 33: Oblique view on the geophysical profiles crossing the Hockai Fault Zone - August 2009 surveys

During the autumn of 2009, we reproduced the 5 km profile with other geophysical methods. H/V (ambient noise measurement, useful to know the depth of the first impedance contrasts), hand auger (useful to know near surface changes in ground composition and depth of the water table), and 4 more electrical resistivity tomographies. The information acquired will be analysed together to try to limit the number of freedom parameters. The first look at these profiles suggests that important resistivity contrasts visible on the resistivity tomographies are also visible on the H/V measurements. The depth of the water table is also, in some cases, very well correlated to the tomographies.

The Artois faults

We have conducted two days of geophysical survey and reconnaissance in the vicinity of Vimy (North of France), along a newly built highway. This road is crossing tangeant to the scarp. We have done two electrical resistivity tomographies close to the bottom of the profile, where the road comes out of the trench. The two profiles were acquired using different protocols on the same place, allowing for a comparison of the two.

The new data are well correlable with the data acquired in 2008. They confirm the existence of a strong resistivity contrast at the bottom of the scarp, possibly related to a fault. The activity of this fault, on the other hand, is not yet demonstrated. The Southern termination of the fault is unclear, maybe because the fault is changing to a bend.

Central North Anatolian fault in Turkey

The Marie Curie Excellence Grant project « Seismic Cycle » leaded by Aurélia Ferrari ended in September 2009. It focused on establishing the seismic history over several thousand of years of a main strike-slip fault system in Turkey to get deeper insights in the fault seismic behavior. The targeted North Anatolian plate-boundary was particularly suitable because of the type of faulting, its rapid deformation rate (up to 24 mm/yr), its relative structural simplicity and its particularly simple seismic behavior characterized by cascading sequences of M>7 earthquakes. The team used a diverse array of complementary field techniques involving trenching across the fault combined with subsurface geophysics, dating of displaced geomorphic features and coring of lake sediments during three main field campaigns (summers 2006, 2007, 2008). During the project we worked on four different paleoseismological sites and on six lakes covering the different fault segments.

The different paleoseismological trenches contained records of ground-rupturing earthquakes of 3000-year record in the Destek Trench (eight earthquakes), 3000-year in the Gunulan Trench (six earthquakes), of 4000-year in Resadiye Trench (eight earthquakes), a relict record of seven earthquakes between 600 AD and 2000 BC in Elmacik site. The data obtained from this project was combined with all paleoseismic studies published on the North Anatolian Fault to build a database of paleo-earthquakes (figure 4). The database was analyzed to answer some essentials questions about recurrence behavior of large earthquakes and to critically test variability in recurrence intervals. The statistical methods used show that (1) the western, central and eastern sections of the NAF have different recurrence intervals that we interpreted to be caused by changes in the fault-normal stress, and that (2) the 20th century earthquake sequence that migrated along the NAF is not typical of this fault, but may only occur around every 1200 years.

The use of lake sediments to track past earthquakes is a new approach that provides a continuous sediment record that lacks in most of the commonly used paleoseismic trenches. Continuous recording allows sediments disturbed by earthquakes to be dated, theoretically, with much greater accuracy than the layers disrupted by faulting in trenches, yielding great improvement in the chronology of past earthquakes.

In five shallow lakes along the North Anatolian Fault, the sedimentological study of short 1 m gravity cores allowed us to characterize the signature of the last sequence M> 7 of earthquake that occurred during the 20th century. The characteristics of the last earthquake sequence were used to identify earthquake disturbed sedimentary layers or seismites in 3 to 5 m long cores. The seismites were correlated to known historical earthquakes or events identified in nearby paleoseismological trenches by extrapolating the sedimentation rate obtained from the study of short cores. However in some cases, an independent reliable chronology of the lacustrine sequence could not be obtained using radiocarbon dating, because of gas emission along the fault. The study of the large Hazar Lake on the East Anatolian Fault encompassed a seismic survey and a coring survey. The seismic survey revealed that a continuous fault crosses the lake linking the two faults located in the northeast and southwest ends of the lake, and allowed a better understanding of the seismic cycle on this fault segment. The 5 m long cores collected in the Hazar Lake contained a sedimentary record of about 4000 years with clear indication of earthquakes. The Hazar Lake is a 200m deep lake very different from the 5 to 20 m deep shallow lakes along the North Anatolian Fault, and a reliable radiocarbon age model was achieved. So the long-term earthquake recurrence of the East Anatolian Fault has been constrained and compared it with the obtained record on the North Anatolian Fault.

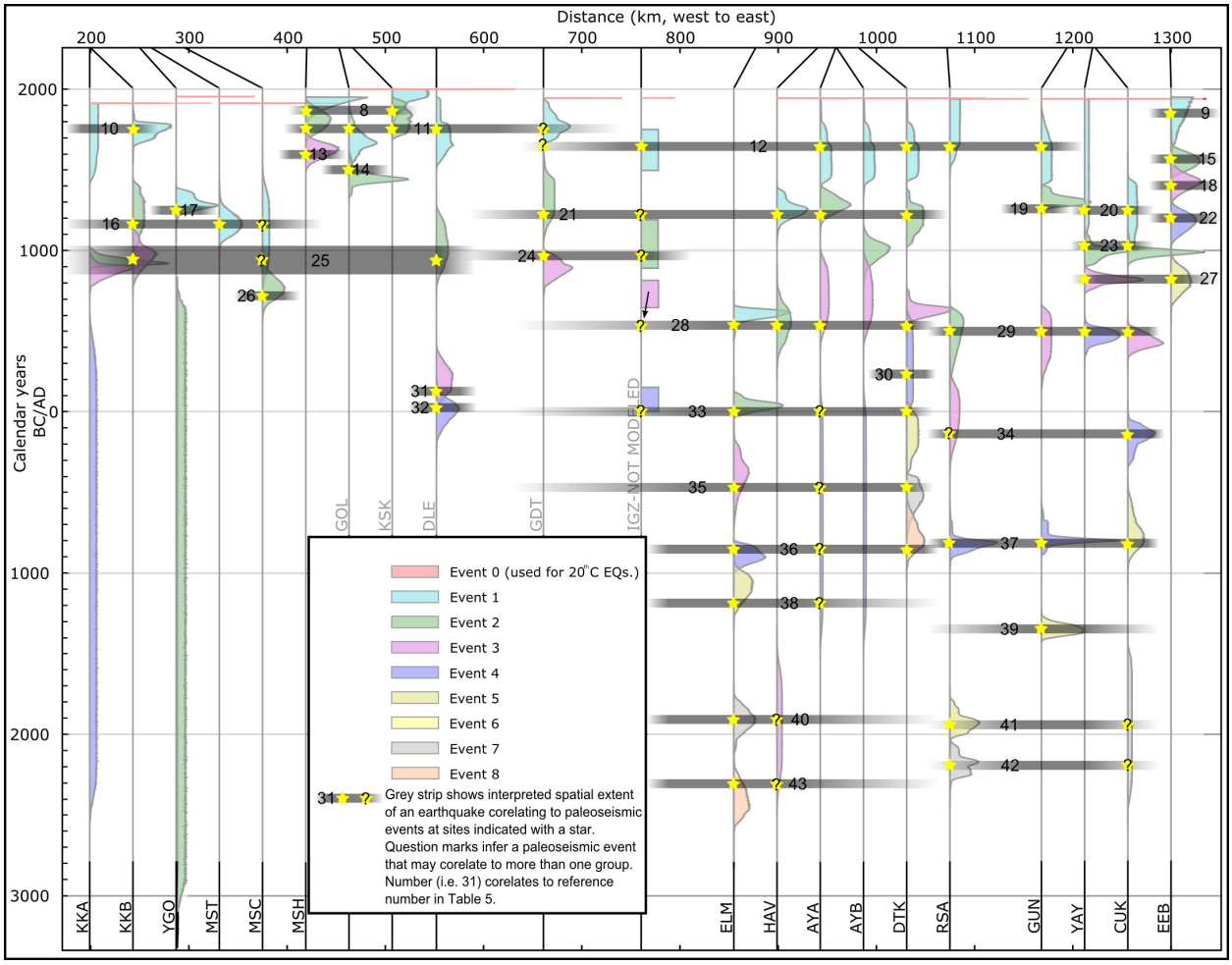


Figure 34: Graph showing paleoearthquake probability versus time (vertical axis) for different sites on the North Anatolian fault, plotted according to west-to-east distance along the fault

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

In a study for the National Institute for Radioactive Waste and Fissile Materials (NIRAS/ONDRAF), we are carrying out an in-depth probabilistic seismic hazard analysis for the near-surface disposal facility for category-A radioactive waste in Dessel. In 2009, we continued the calculations on the logic tree with 2400 scenarios, paying attention in particular to the combination of epistemic uncertainties (related to our lack of knowledge which model in the logic tree is true) and aleatory uncertainties (related to unpredictable outcomes of nature). The calculations show that the 84th percentile (P84) of the bedrock response spectrum may actually be lower than the mean value for long return periods. This is due to the lognormal nature of the uncertainty on the ground-motion model, which dominates the aleatory uncertainty. We therefore recommend taking into account the maximum of (mean, P84) of the response spectrum rather than just the P84.

In a first part of the project, we had calculated theoretical site transfer function based on measured and estimated sediment properties from boreholes at the Dessel site. To validate these theoretic calculations, we began to evaluate experimentally the site transfer function with measurements from real earthquakes recorded at 4 seismometers which where specially installed for this experiment. Two seismometers where installed at the surface, one in Mol = MOLS, another in Dessel = DSLS and two underground, one in a borehole at 680 m depth at Dessel = DSLB in cretaceous chalk and another in an underground laboratory/tunnel at 168 m depth at Mol = MOLT in Rupelian Boom clay. For all the significant local, regional and not too distant teleseismic

earthquakes we determined the spectrum of the S-wave signal on the transverse component. For the spectral range where the amplitude of this spectrum is significantly higher than that of the noise, we calculated the spectral ratios of surface station divided by underground station. We averaged the results from the different earthquake events. The result of the DSLS/DSLB spectral ratio is considered as the transfer function from bedrock to surface, or the site response spectrum. At higher frequencies the transfer function has to be corrected for the effect of the noise generated at the surface and attenuated in the underground with a factor dependent on the average quality factor of the sediments which we determined to be 24.5, the total depth = 702 m, the average S-wave velocity = 618 m/s and the frequency.

PERWEX exercice

On 13 March 2009, we participated to the "PERWEX" exercice, organized by the authorities of the Brabant waloon to test the capacity of the different emergency services to be operational. The exercice was based on an "earthquake" that destroyed a building in the city of Perwez. The ROB contributed in a way similar to what is normally done in the case of a real earthquake.

Traces of earthquakes in the architectural heritage

In cooperation with the FPMons, we continue our investigations in the village of Soiron to evaluate the damage caused by the 18 September 1692 earthquake.

C.1.2.4. LISSA

We prepared the instruments and the technical procedures in preparation of installing a seismic station at the "Princess Elisabeth" Belgian base in Antarctica. We have conducted casing modifications of the borehole seismometer, protecting boxes building, testing of the device physical installation in a test borehole and testing of the software part of the equipment. The measuring system is expected to be installed in Antarctica in early 2010.

C.1.2.5. Volcano-sismology in Indonesia

A Guralp acquisition system has been configured at the ROB and was installed in November 2009 to monitor the tremors and earthquakes associated to the volcanic activity of the Papandayan volcano in Indonesia.

Three Nanometrics seismic stations - running on solar panels - have been purchased and tested at the Royal Observatory. It is foreseen to install these equipments on the Iljen volcano (Indonesia) in 2010.

C.1.3. Perspective for next years

In 2010, the different projects will be continued, mainly in the framework of the FP7-EC project SHARE and the project for NIRAS/ONDRAF. We will also participate to the definition of the educational support to the implementation of the Eurocode-8 in the framework of BESEIG.

C.1.4. Personnel involved

Scientific staff: P. Alexandre, U. Avsar, T. Camelbeeck, C. Caudron, A. Ferrari, J. Fraser, D. Garcia Moreno, D. Kusman, E. Knuts, T. Lecocq, D. Lombardi, E. Sichien, D. Syahbana, K. Vanneste, K. Verbeeck

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, Sylvette Bonnefoy, Céline Gélis and Stéphane Baize, Institut de Radioprotection et de Sûreté Nucléaire (France)
- Marlena Yaneva and Alexander Radulov, Geological Institute, Bulgarian Academy of Sciences
- Michel Cremer; Jacques Gireaudeau; Phillippe Martinez; Sabine Schmidt, EPOC, Université Bordeaux, France
- John King; Chip Heil ; Bradley Moran ; Roger Kelly, University of Rhode Island, USA
- Erhan Altunnel; Sevgi Altinok, Eskishir Osmagazi University, Turkey
- Namik Cagatay; Emre Damci, Istanbul Technical University, Turkey
- Jeff Pigatti, USGS Arizona, USA
- Laureen Drab, Ecole Normale Supérieure, Paris
- 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, Swiss Seismological Service / ETH. Zurich, Switzerland.
- Denis Jongmans (LGIT, Grenoble)
- Gianluca Valensise and Roberto Basili (INGV Roma)
- Jean-Pierre Colbeaux, Scientific council of the regional parks of the North of France

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)
- 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
- Dr. Griet Verhaert, Departement Leefmilieu, Natuur en Energie, Vlaams Gewest
- Michiel Dusar and Walter De Vos, Belgische Geologische Dienst, KBIN
- Sara Vandycke, Faculté Polytechnique de Mons
- Laurent Wouters and Wim Cool, NIRAS/ONDRAF
- Alain Van Cottem and Richir Tomas, Tractebel
- Nathalie Fagel; Meriam El Mouhabi, University of Liege
- Marc De Batist; Jasper Moernaut; Maarten Van Daele, University of Gent
- F. Baptiste, Archives Générales du Royaume (Bruxelles)
- Claude de Moreau de Gerbehaye and M. Baptiste, Archives Générales du Royaume / Rijksarchief.
- Christian Dury, Archivist, Archives de l'Évêché de Liège.
- Sara Vandycke, Faculté Polytechnique de Mons

Grants/Projects used for this research/service

- Project SHARE
- Project VLA07-4.2 by the Flemish Government
- Contract CCHO: 2007-4177/00/00 with NIRAS/ONDRAF
- EC Marie Curie Excellence Grant, MEXT-CT-2005-025617. “Understanding the irregularity of seismic cycles: a case study in Turkey”
- Grant FRIA FC 76908
- Grant Action 2

C.1.6. Scientific outreach

Meeting presentations

[1] T. Camelbeeck, T. Lecocq, K.-G. Hinzen and B. Dost

Earthquake relocation in intraplate context
AGU meeting, San Francisco, December 2009

[2] Alexandre P.
Some methodological remarks on the use of medieval sources in historical seismicity research
Joint series na4, share Task 3.1, ESC Workshop "The Making of the European-Mediterranean Earthquake Catalogue", Thessaloniki, Greece, October 12-14 2009.

[3] T. Camelbeeck, P.Alexandre, K.Vanneste and A. Sabbe
The seismic activity and the associated risks in Northwest Europe
International meeting Provence 2009, Aix-en-Provence, 5-8 July 2009.

[4] Jeff Fraser, Kris Vanneste & Aurelia Hubert-Ferrari
Behavior of the North Anatolian fault, Turkey, insights from an integrated paleoseismic dataset
AGU Fall Meeting, San Francisco, 14-18 December 2009

[5] Lecocq, T., Lombardi, D., Van Camp, M., Vanneste, K., Verbeeck, K., and Camelbeeck, T.
The earthquake activity in Central Belgium since July 2008
95th Journées Luxembourgeoises de Géodynamique, Echternacht, Grand duché de Luxembourg, November 9-11, 2009.

[6] Lecocq, T. and Vanneste, K.
How is the ERI affected by the removal of the data related to one electrode?
AGU meeting, San Francisco, December 2009

[7] T. Lecocq, D. Lombardi, M. Van Camp, T. Camelbeeck
The seismic activity in central Belgium since July 2008
3rd International Conference Geologica Belgica, Ghent, 14-15 September 2009.

[8] Michel Van Camp, Thomas Lecocq, Kris Vanneste, Giovanni Rapagnani, Henri Martin, Frédéric De Vos, Baudouin Bukasa, Marc Hendrickx, Fabienne Collin, Thierry Camelbeeck
The Belgian National Seismic Monitoring Network
ORFEUS workshop, Erice, 2-8 May 2009

[9] Michel Van Camp, Thomas Lecocq, Kris Vanneste, Giovanni Rapagnani, Henri Martin, Frédéric De Vos, Baudouin Bukasa, Marc Hendrickx, Fabienne Collin, Thierry Camelbeeck
The Belgian National Seismic Monitoring Network
European Geosciences Union, General Assembly 2009, Wien, Austria, April 19-24, 2009.

[10] Kris Vanneste & Jozef Van Dyck
Probabilistic seismic-hazard assessment in Belgium
Third International Conference Geologica Belgia, Gent, 14-15 September 2009

[11] Koen Verbeeck, Kris Vanneste, Thierry Camelbeeck, M. Dusar, W. De Vos & N. Vandenberghe
Seismotectonic zonation of Belgium
Third International Conference Geologica Belgia, Gent, 14-15 September 2009

Seminars

[12] Thomas Lecocq & Koen Verbeeck
Results of the geophysical campaign in Northern France
Meeting with partners of the Artois project, ROB, 6 October 2009

[13] Koen Verbeeck & Thomas Lecocq
Results of the geophysical campaign in Northern France
Meeting with partners of the Artois project, Saint Amand les Eaux, 18 February 2009

[14] Kris Vanneste
PSHA Studies at the Royal Observatory of Belgium
Rhine-Meuse Seismologists (RMS) meeting, De Bilt, 26 March 2009

[15] Kris Vanneste & VLA07-4.2 Working Group
Compilation Study concerning Seismicity in Flanders
BeSeiG meeting, Mons, 3 September 2009

[16] Kris Vanneste, Koen Verbeeck & Thierry Camelbeeck
ROB Source-zone Models
SHARE Project workshop "Seismic source zones in Central and Western Europe", Geoforschunszentrum, Potsdam, 2-3 December 2009

C.1.7. Missions

Assemblies, symposia:

P. Alexandre

- Thessaloniki, October 12-14, 2009. Joint NERIES NA4, SHARE Task 3.1, ESC Workshop "The Making of the European-Mediterranean Earthquake Catalogue".

T. Camelbeeck

- Meeting of the Rhine-Maas Seismology group in De Bilt (The Netherlands) on 26 March 2009
- Global Earthquake Model meeting in Münich from 8 to 10 June 2009
- SHARE-project initial meeting and general assembly in Zürich from 14 to 16 June 2009
- "Provence 2009" meeting in Aix-en-Provence from 5 to 8 July 2009
- BESEIG-meeting in Mons on 3 September 2009
- SHARE meeting in Roma from 13 to 16 September 2009
- Meeting of the Rhine-Maas Seismology group at the ROB on 8 October 2009
- Task 3.1 of SHARE project meeting in Thessaloniki from 11 to 14 October 2009
- Journées Luxembourgeoises de Géodynamique in Echternach from 10 to 11 November 2009

D. Garcia Moreno

- Third International Conference Geologica Belgica "Challenges for the Planet: Earth Science's perspective". Ghent, 14-15 September 2009

T. Lecocq

- ORFEUS Workshop "Rapid determination of earthquake source parameters", Erice – Sicily – 2 to 8 May 2009
- AGU Joint Assembly, Toronto, 24 to 27 May 2009
- Geologica Belgica General Assembly, 15 september 2009
- 95th JLG, Echternach – Luxemburg, 10 to 11 November 2009
- AGU Fall Meeting, San Francisco – USA, 10 to 22 December 2009

K. Vanneste

- 14-18/12/2009: American Geophysical Union Fall Meeting 2009, San Francisco
- 14-15/09/2009: Third International Conference Geologica Belgica "Challenges for the Planet: Earth Science's Perspective", Gent, Belgium

Koen Verbeeck

- 14-15/09/2009: Third International Conference Geologica Belgica "Challenges for the Planet: Earth Science's Perspective", Gent, Belgium

Commissions, working groups (days):	T. Camelbeeck (3 days) T. Lecocq (2 days) K. Vanneste (2 days) K. Verbeeck (2 days) M. Van Camp (4 days)
Research visits (days):	T. Camelbeeck (10 days) D. Garcia Moreno (5 days)
Field missions (days):	P. Alexandre (18 days) T. Camelbeeck (7 days) E. Knuts (44 days)

D. Garcia Moreno (5 days)
T. Lecocq (30 days)
K. Vanneste (4 days)
K. Verbeeck (9 days)

C.2. Seismic monitoring

C.2.1. Objectives

The section of seismology installed, is maintaining and analysing 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. In November 2006 the IRIS Board of Directors authorized admission of the Royal Observatory of Belgium as "Foreign affiliate".

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

The modernization of the permanent seismic station

- The modernisation of our seismic measuring infrastructure has gone on. This year has seen the installation of ADSL line in 8 more seismic stations (Bressoux, Clavier, Bougnies, Ronquières, Opitter,

Gesves, Zevekote, and Walferdange). In Mellery (temporary station) and Seneffe, the old 16 bits acquisition equipments have been replaced by 24 bits measuring systems.

- Improvements in our home-made 24 bits permanent acquisition equipment have given the equipment a greater autonomy in case of communication brokerage. For instance, a three months telecommunication brokerage with the Opitter station as led to a loss of only 5 days of data where the old system would have had to 2 months of dataloss.
- This year has also seen lot of equipment brokerage: hard-disk failure in Kalborn, Uninterrupted Power Supply failure in Dessel, computer failure in Zevekote and Gesves, power supplies fired by lightnings in Bougnies, seismometer failure in Seneffe, optical-to-ethernet converter fired by lightnings in Rochefort, ADSL line cables rusting in Eben-Emael, power supply failure in Mellery, accidental deactivation of the power grid in Ronquières, definitive suppression of the ISDN line in Robert-Ville, unexpected shutdown of the computers in Gesves and Opitter.

Seismic alert system

- During the year, we improved the configuration of SeisComP3, the automatic detection & location software. The results we obtain now are very satisfactory, with the detection of events of magnitude greater than 1.6 in and around Belgium. As we were pionnier in the usage of this software, we have been providing information on the configuration and usage of the software to the Geoazur seismological lab (FR) and the ETH Zurich (Switzerland).
- In combination with B-FEARS, the alert based on the visitor flow on the ROB website, the alert system is now giving detailed information about an earthquake within 2 to 4 minutes after an earthquake.
- We improved the alert procedure applicable whenever an earthquake is felt in or around Belgium. This procedure includes very simple steps, mainly based on a web interface that has been reorganized to be more intuitive and accessible from outside the ROB.

Mobile seismic stations

The development of our home-made 24 bits mobile acquisition equipment has gone on with the testing and validation of the storage system that will be used for the production systems to be built in 2010. In December, the final prototype has been installed in Grand-Leez.

Installation of a borehole seismometer at Oostende

On 16 and 17 April 2009, the long-awaited broad-band seismometer was installed in the 300-m-deep borehole at the scientific education centre "Earth Explorer" in Oostende. The installation was performed by the manufacturer Güralp, together with technicians of the ROB. Installation was successful, but unfortunately, the seismometer stopped working after two weeks, probably due to water leakage. Repair has been postponed several times by Güralp, rendering the seismometer inoperational for the remainder of the year.

"Le Chesnois" seismic station

During the ongoing seismic sequence in Walloon Brabant, we have had contacts with the provincial authorities and the "Commandement provincial du Brabant Wallon", the provincial antennae of the Army. We decided to enter a form to install a new permanent seismic station in Walloon Brabant, on the telecom military site of "Le Chenoy".

Open-door exhibition

A measuring station has been built to display the seismic traces to the visitors hosted at the Royal Observatory of Belgium during the one week-end open door.

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). The BREA and UCCA accelerometer were removed due to construction works in Bree

and Uccle. The UCCA instrument moved from the historical "pavillon" to the "cave profonde" (temporary solution, will come back to the pavillon when the works are terminated). The BREA accelerometer will be installed in the municipal library of Bree in 2010.

- Research has been conducted on the possibility to connect the accelerometers to the internet through ADSL line. A serial-to-ethernet device has successfully been tested. However, an upgrade of the software used for the retrieval of the data is needed and the cost of this upgrade is too high compared to the cost benefit of switching to ADSL line.

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

The new Scintrex CG5 spring gravimeter, delivered in August 2009, was tested at the Membach station during one month in November 2009. The quality of the calibration factor and the stability of the instrument fulfill our expectations.

Metrology

For the first time, the International Comparison of Absolute Gravimeters (ICAG) was a metrological key comparison (KC), the results of which will be officially recognized under the terms of the CIPM MRA (International Committee of Weights and measures, Mutual Recognition Arrangement, www.bipm.org/en/convention/mra). This constitutes an important progress in gravimetry applications. As the official Service for Scientific Metrology (SPF économie) is not willing to design the ROB for metrology in gravimetry (in spite of our numerous efforts), we did not participate in the ICAG at the BIPM, Sèvres, in September 2009.

C.2.3. Perspective for next years

C.2.3.1. The Belgian seismic monitoring network

The borehole seismometer in Oostende will be repaired early 2010.

C.2.3.2. The Belgian accelerometric network network

All the accelerometric stations will be visited for control in 2010.

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

New seismological analysis software is developed with the purpose of improving the daily routine work and the scientific analysis of the data from the Belgian seismic stations.

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 Membach or at other stations).
- The CG5 gravimeter will participate in the test of the instruments of the U. Bristol, and then we shall use them for geophysical prospecting across the Vecquée fault.
- A new barometer should be installed, given the observed drift of the existing one (0.55 hPa/year i.e. 7.7 hPa since the installation of the superconducting gravimeter in August 1995) and the numerous grounding problems 70iagnosed during fall 2008.
- Continue to develop Tsoft and provide information on Earth tides to the public.

C.2.4. Personnel involved

Scientific staff:	T. Camelbeeck, F. Collin, T. Lecocq, D. Lombardi, K. Vanneste, M. Van Camp
Technical staff:	B. Bukasa, S. Castelein, F. Devos, E. Driegelinck, M. Hendrickx, H. Martin, G. Rapagnani, W. Vandeputte, L. Vandercoilden

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] Steim, J., **Van Camp, M**., Rapagnani, G., Rivera, L.
Connecting a Quanterra Data Logger Q330 on the GWR C021 Superconducting Gravimeter
Quanterra/Antelope User Group Meeting in Marrakech, Morocco, March 2009

C.2.7. Missions

Field missions (days):

G. Rapagnani (29 days)

S. Castelein (8 days)
K. Vanneste (2 days)
H. Martin (20 days)
M. Hendrickx (4 days)
B. Frederick (4 days)
P. Bizerimana (1 day)
R. De Dobbeleer (3 day)

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

- To better assess the present-day crustal deformations, repeated AG measurements using the FG5-202 gravimeter have been conducted along a profile twice a year since September 1999. This 140 km long profile includes 8 stations across the Belgian Ardenne and the Roer Graben. During the profile, the FG5-202 calibration is controlled at the Membach reference station. AG measurements have also been performed in Ostend yearly since 1997. Presently an average gravity rate of change of $+1.2\pm1.4$ nm/s²/yr is observed (average of the rates at all stations but Jülich). This is equivalent to a subsidence rate of -0.6 ± 0.7 mm/yr (1 nm/s² ⇔ 0.5 mm). This already provides an upper limit on the possible uplift of the Ardennes and agrees with the subsidence predicted by GIA models. This is paramount to evaluate the future impact of sea level rise. This study confirms the need to measure for decades, using accurate and stable geodetic techniques like AG, for investigating slow deformation processes in intraplate context.
- To monitor the stability of the Black Forest Observatory (Germany), where a superconducting gravimeter was installed during the fall 2009, we were invited again to perform absolute gravity measurements in February and November. Due to the instrument malfunction the November campaign was postponed to the spring 2010.

- ***COST action ES0701***: Like every geodetic measurement, gravity sums up different phenomena; isolating one particular signal is a major problem. In particular, after correcting tidal and atmospheric effects, the signature of hydrological phenomena dominates the gravity signal and is much larger than the tectonic effects. Presently, the precision of the hydrological models is not sufficient to meet the needs of geodesy, both at the local and global levels: based on these models, it is not possible to correct the gravity data in order to evidence geodynamic phenomena. Such a correction will only be possible by improving the hydrological models, which will also allow us to better understand the water cycle dynamics. A COST meeting has been organized at the ROB in cooperation with Jaakko Mäkinen (Finnish Geodetic Institute) on March 16 and 17: "Workshop on hydrological and other local effects in gravity measurements" (25 participants).
- ***Characterizing long time scale hydrological effects on gravity for improved distinction of tectonic signals:*** The influence of the hydrological noise 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. It is shown that the power spectral densities (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/s²/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.

D.1.2.2. Superconducting gravimeter at the Membach station:

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 have a better idea on the spatial patern of the hydrological effects above the Membach station, an electric tomography profile was performed in July 2008 with O. Kaufmann (FPMS). We repeated this profile at winter time, in Februari 2009, when the ground was saturated.

Our first conclusions are:

1. The resistivity generaly increases at winter time in the root zone (1st meter below the surface) and decreases underneath. This maybe due to the percolation rate (after rainfall, water percolates very quickly) and/or to the roots influencing the water content;
2. The slope seems to influence the results;
3. The electrodes could not be installed exactly at the same position, which certainly influences the measurements: some differences between the July and February measurements may be due to changes in the location of the electrodes.

D.1.2.3. Rochefort geophysical laboratory:

During the winter 2008-2009, there were no flash floods of the caves, and although some consistent rainfalls occurred when the Absolute Gravimeter was measuring, no noticeable effects were observed. This indicates that the epikarst does not store a large amount of water.

D.1.3. Perspective for next years

D.1.3.1. Repeated AG measurements:

The AG profile is a long-term project. We plan to continue the profile once a year; after 14-20 years, we should be able to constrain any possible long-term trend with accuracy better than 1 nm/s²/yr (⇔ 0.5 mm/yr).

D.1.3.2. Storm surge effects at the Membach station

In collaboration with S.D.P. Williams (POL), N. Teferle (U. Nottingham) and N. Penna (U. Newcastle) we are working on the November 2007 storm surge in the North Sea, using the GPS and gravimetric observations. We plan to run the model back to 1995 in order to compare it with the whole SG andf AG time series available at the Membach station.

D.1.3.3. Hydrological investigations:

- Membach: we will install a permanent electrical tomography system will be investigated in order to better understand the spatial pattern of the ground water content in the unsaturated zone above the station. This will contribute to establish a comprehensive hydrological model of the micro basin around the Membach station.
- Jülich: we would like to combine our AG data with other geodetic techniques, e.g. PSInSAR or GPS measurements. Promising contacts have been taken with Juliet Biggs, U. Bristol, who is proficient in In-SAR technique and is willing to investigate the subsidence at Jülich.
- BFO: we are invited to perform new AG measurements in 2010, when the FG5 gravimeter is repaired. 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.
- Rochefort: Combining the SG measurements with the AG and the CG5 instruments, as well as with electric tomography methods, will allow us to perform new investigation on the horizontal and vertical water storage variation in a karst formation.

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

Measurements in Ostend :

- Ir J. Verstraeten (Afdeling Waterwegen Kust, Oostende)

D.1.5. Scientific outreach

Meeting presentations

[1] Van Camp, M., Métivier, L., de Viron, O., Williams, S.D.P., and Meurer, B
Hydrology and Noise Affecting Land-Based Gravity Measurements
Workshop on Monitoring North American Geoid Change (Poster), Boulder, CO, USA, October 21-23, 2009

[2] Crossley, D., Van Camp, M., Friederich, J., and Liard, J., (panellists)
Role of terrestrial gravity measurements in monitoring the geoid
Workshop on Monitoring North American Geoid Change, Boulder, CO, USA, October 21-23, 2009

[3] T. Camelbeeck, Bruyninx, C., Vanneste, K., Van Camp, M., Lecocq, T.
Lithospheric deformation in Northwest Europe: a comparison of seismicity, geodetic and geologic information
3rd International Conference Geologica Belgica, Ghent, 14-15 September 2009.

[4] Van Camp, M., Williams, S.D.P., Hinzen, K.-G., Camelbeeck, T
Vertical Land Movements Constrained by Absolute Gravity Measurements
Joint AGU Spring meeting, Toronto, Canada, May 24-27, 2009

[5] T. Camelbeeck, Bruyninx, C., Vanneste, K., Legrand, J., Bergeot, N., Van Camp, M.
Lithospheric deformation in Northwest Europe: a comparison of seismicity, geodetic and geologic information
Joint AGU Spring meeting, Toronto, Canada, May 24-27, 2009

[6] T. Camelbeeck, Bruyninx, C., Vanneste, K., Legrand, J., Bergeot, N., Alexandre, P., Williams, S.D.P., Van Camp, M.
Crustal Deformation in Stable Continental Europe: a Comparison of Seismicity, Geodetic and Geologic Information
EGU meeting, Vienna, Austria, April 20-24, 2009

[7] Van Camp, M., Métivier, L., de Viron, O., Meurers, B., Williams, S.D.P.
Hydrology and noise affecting land-based gravity measurements
COST ES0701 Workshop on hydrological and other local effects in gravity measurements, Brussels, March 16-17, 2009.

D.1.6. Missions

Assemblies, symposia, conferences:

M. Van Camp

- EGU assembly, Vienna, AT, 20-24 April 2009.
- NGS 2009 Workshop on Monitoring North American Geoid Change, Boulder, 21-23 October 2009.
- AGU Fall meeting, San Francisco, USA, 13-18 December 2009.

Commissions, working groups (days): M. Van Camp (3 days)

Field missions (days): M. Van Camp (34 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 Eliza-

beth 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

We participated in different meeting with the Belgian Science Policy and the International Polar Funcation (IPF).

D.2.3. Perspective for next years

CGPS will start in February 2010. It is hoped to start gravity measurements in 2011.

We expect to be able to extract useful information on the mass balance of the region (an area of 500 km) within 7 years.

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] D. Lombardi, T., Camelbeeck, T., Rapagnani, G., Van Camp, M., Bergeot, N., Bruyninx, C., Francis, O., and van Dam, T.
Geodetic and Seismological Research at the new Princess Elisabeth Station, Queen Maud Land, East Antarctica,
AGU Fall meeting (Poster), San Francisco, USA, December 14-18, 2009.

[2] Lombardi, D., Camelbeeck, T., Rapagnani, G., Van Camp, M., Bergeot, N., Bruyninx, C., Francis, O., and Van Dam, T.
Geodetic and seismological research initiatives at the new Princess Elisabeth station, Queen Maud Land, East Antarctica
95th Journées Luxembourgeoises de Géodynamique (Poster), Echternacht, Grand Duchy of Luxemburg, November 9-11, 2009.

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. Assessing the precision of large scale water storage estimates at the Earth surface

We have investigated the quality of the estimation of the large scale water storage at interannual timescale by comparing the estimation by independent techniques in a set of different places. We used GRACE space gravity data, altimetry deduced water level from the Hydroweb database, and three state of the art hydrology models (LaD, GLDAS and WGHM). Each dataset represents very precisely in its own way the water distribution at the land surface, but none provides a realistic independent estimation for its data precision.

D.3.2.2. Investigating inter annual land water dynamics at the regional scale using GRACE data

Presently the GRACE measurements are still noisy and uncertainties remain about the calibration and validation of the data. In spite of this, GRACE is quite appropriate for investigating hydrological phenomena at the regional scale.

Based on case studies where other data are available (hydrological models, land-based data and altimetric measurements), we gather new information on the precision of GRACE and show how this information can be used to learn about hydrological phenomena on the interannual time scale. In particular, as case studies, we investigated in details the Lake Victoria (Africa) and we are currently investigating the Death Valley zone (California-Nevada, USA) and the Edwards-Trinity aquifer (Texas, USA).

D.3.3. Perspective for next years

The spatial patern of the efficiency of the hydrological models will be further investigated, as well as their efficiency to remove the hydrological effects, which mask geodynamical signal, e.g. GIA or subduction zones. Part of this work should be performed at the IPGP.

We are now collaborating with Alexander Sun (hydrologist at the Center for Nuclear Waste Regulatory Analyses CNWRA, Texas) in order to compare GRACE time series with land based measurements.

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] Van Camp, M., de Viron, O.
Investigating inter annual land water dynamics at the regional scale using GRACE data
AGU Fall meeting (Poster), San Francisco, USA, December 14-18, 2009.

[2] de Viron, O., Van Camp, M., Diament, M. and Crétaux, J.-F.
How well can we estimate large scale water storage at the Earth surface?
AGU Fall meeting (Poster) San Francisco, USA, December 14-18, 2009.

[3] de Viron, O., Van Camp, M., Crétaux, J.-F., Diament, M.
Space geodesy to improve the hydrology modeling at the global/regional scales
Joint AGU Spring meeting, Toronto, Canada, May 24-27, 2009

[4] Van Camp, M., de Viron, O., Crétaux, J.-F., Diament, M.
Space geodesy to understand the recent fall in the Lake Victoria
EGU meeting (Poster), Vienna, Austria, April 20-24, 2009

Seminars

[5] Van Camp, M.
Hydrologie et Gravimétrie
IPGP, Paris, November 10, 2009.

[6] de Viron, O., Panet, I., Diament, M., Mikhailov, V., Van Camp M.
Que peuvent nous apprendre les variations temporelles du champ de pesanteur sur la dynamique de la Terre ?
Seminar at Géoscience Azur, University of Sofia Antipolis, February 12, 2009

D.3.6. Missions

Assemblies, symposia, conferences:

- AGU Fall meeting, San Francisco, USA, 15-19 December 2009.
- EGU assembly, Vienna, AT, 20-24 April 2009.

Research visits:

- IPGP, Paris, as invited professor (20 July – 20 August 2009).

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 multi-faceted 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

The ongoing eruption of the Soufrière Hills volcano, Montserrat provides an unprecedented opportunity to study complex processes at an active andesitic arc volcano. There is for example evidence from geodetic measurements that volcanic activity follows a cyclic pattern. The cycles occur on several time scales including a short-term scale of tens of minutes to several hours, a meso-scale (6-7 weeks) and a scale of several

years. These are thought to reflect processes in the conduit and/or in the magma chamber. Geodetic signals on a small island such as Montserrat are prone to be affected by tidal perturbations. While generic models for Solid Earth and ocean loading tides may be employed to predict tidal variations, residual gravimetric records indicate a shortfall of global model predictions in various areas on Earth. On Montserrat, for example, a pronounced pattern of residual local tidal perturbation is apparent, which remains unaccounted for by generic predictions. Using tidal observations from continuous gravimetric records performed by J. Gottsmann (U. Bristol) on Montserrat, we have provided a new precision tidal model for Montserrat, which allowed analysing the residual gravity variations associated with subsurface density changes. Due to the lack of hydrological measurements it is presently not possible to prove assumed coupling between aquifers and volcanic/magmatic activity.

D.4.3. Perspective for next years

Jo Gottsmann will install 2 spring gravimeters at the Membach station for one month in February 2010. This will allow testing the calibration factor and sensitivity to air pressure variations, but also qualifying the ability of these instruments to monitor long term gravity changes, before sending them to Bolivia.

D.4.4. Partnership

List of international partners without grant

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

ASTRONOMY & ASTROPHYSICS

Introduction

Astronomy and astrophysics is one of the core activities of the Royal Observatory of Belgium. This scientific discipline covers a wide range of subjects at ROB, ranging from objects in our own solar system to the remotest galaxies, covering both observational and theoretical studies.

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 to international projects. The activities within this project are described in the project "RUSTICCA".

The long-lasting activity of photographing the sky produced important collections of astrophotographic plates. These historical plates contain data of immense value, but in order to keep the data accessible for modern research, they have to be digitised. Since several years digitisation projects have been started at the Royal Observatory. These activities are described in the Theme "Digitisation".

Stars are essential building blocks of the galaxies and as such of the Universe. Understanding their structure and evolution is the major challenge of astrophysics. Since stars evolve, process chemical elements and recycle part of the material in the galaxy, their structure and evolution are linked to the characteristics and the evolution of the Galaxy and the Universe as a whole. The stellar interiors are laboratories to study and understand all kinds of physical and chemical processes.

Our research concerns several topics of stellar astrophysics. Part of the projects have the aim to understand better the structure of the stars and/or their circumstellar environment, while others search for more insight in the very different stages of the stellar evolution. Therefore, young as well as evolved objects are studied. Characteristics of groups of stars as a whole are also derived, e.g. in order to establish a more accurate distance scale ladder for the local universe.

In the field of stellar physics and stellar evolution we study physical processes that occur in the atmospheres of early- to mid-type main-sequence stars. Characterization of the selected objects is very often an unavoidable first step. Among the different atmospheric processes, we focus on stellar pulsation, stellar rotation and the influence of an environment with varying metallicity for B(e)-type stars as well as on multiplicity, stellar pulsation and chemical composition of B(e)/A/F-type stars. Since a vast majority of stars pertains to a double or a multiple stellar system, we also perform very detailed investigations of such systems, ranging from visually resolved (wide) pairs to (very) close binaries, and using as much as possible a variety of observational techniques.

Other research topics are “stellar winds and circumstellar structures” with hot stars and evolved stellar phases as main subjects, and ‘variable stars, binary stars and stars in young stellar groups’ where the aims are to obtain fundamental stellar parameters and information on the interior structure of the stars.

Many of the projects emphasize participation in observational astronomy and analysis techniques, mostly in a national or international context. ROB is also involved in the echelle spectrograph (HERMES) at the Mercator telescope (La Palma, Spain) and in the reduction software development for the satellite Gaia. Data from other astronomical satellites (Herschel, CoRoT, Kepler …) are or will be studied as well. 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 the public.

Some highlights of astrophysical research at the ROB in 2009

- Non-thermal radio emitting hot stars – models have been developed to explain the non-thermal emission of Cyg OB2 No. 8A (Section J.1.2.1).
- In a publication in Science R.1 a team of astronomers, including a member of the ROB, demonstrated that significant dust production occurs even in galaxies with low metallicity (Section J.2.2.4).

- The Herschel satellite was launched in May 2009. The Herschel Guaranteed Time Key Project "MESS" (Mass loss of Evolved StarS) started and during the Science Demonstration Phase images of the Ring Nebula NGC6720 were obtained. These images were reduced and presented (Section J.4)

E. Asteroids

E.1. RUSTICCA

E.1.1. Objectives

The Project "RUSTICCA" (Revalorising the Ukkel Schmidt Telescope by Installing a CCD Camera), started in 1993 and consisted in the installation of a CCD camera on the Ukkel Schmidt Telescope and modernising the telescope. The main objective 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, 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

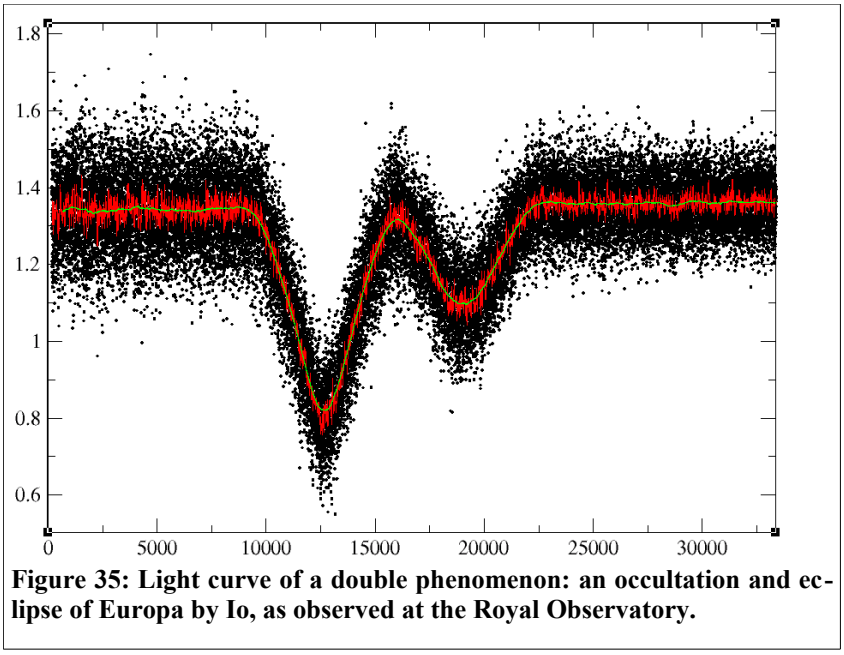


Figure 35: Light curve of a double phenomenon: an occultation and eclipse of Europa by Io, as observed at the Royal Observatory.

E.1.2.1. Observations in 2009

In 2009 observations have been performed on 38 nights by 5 observers. They include P. De Cat (9 nights, 347 frames), R. Desmet (1 night, 31 frames), E. Elst (11 nights, 272 frames), T. Pauwels (23 nights, 633 frames), P. Vingerhoets (7 nights, 58 frames).

These observations concerned:

- Astrometry of minor planets: 30 nights covering 98 fields by 1156 images, producing 1615 astrometric positions. Out of these, 1 field with 19 images (without position) of objects of the Near-Earth Objects confirmation page. Observers: P. De Cat, R. Desmet, E. Elst, T. Pauwels and P. Vingerhoets. The positions have been published in the MPSs (R.1, R.1, R.1, R.1, R.1, R.1, R.1, R.1).
- Occultations of stars by minor planets, the so-called Planoccult phenomena: 6 events attempted on 6 nights, with 36 images and films, producing 5 light curves. Observers: P. De Cat, T. Pauwels, P. Vingerhoets. There was again 1 positive event (the 4th since the start of this kind of observations), with Ukkel being in the occultation path, the other ones being negative. However, the results of negative events are also published if the same event was observed to be positive somewhere else in the world. The remaining events gave no usable results due to too bad weather conditions (R.1, R.1, R.1, R.1).
- Mutual phenomena (eclipses and occultations) of satellites of Jupiter, the so-called PHEMU phenomena: 7 nights covering 9 phenomena, producing 6 light curves (in a few cases more than one phenomenon is observed in a single light curve). Observers: P. De Cat, T. Pauwels, P. Vingerhoets.

Together they produced 1232 images and films.

E.1.2.2. Summary of the results obtained since 1996

From 1996 to 2009 a total of 22 990 astrometric positions of minor planets and 73 astrometric positions of comets have been published in the Minor Planet Circulars. The number of 1828 published positions in 2009 (R.1, R.1, R.1, R.1, R.1, R.1, R.1, R.1) is again rather low compared to the top years 2003-2005, but still slightly better than 2007.

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. With 7 new designations attributed in 2009, the situation is somewhat better than in 2007, but the effect of potential discoveries getting exhausted is clearly discernible.

60 of the minor planets with preliminary designation attributed to Ukkel are currently multiple opposition objects, and 131 have been permanently numbered, with the discovery attributed to a RUSTICCA observation. The discoverers with the number of discovered minor planets are: H. Boffin (8 minor planets), P. De Cat (5 minor planets), E. Elst (8 minor planets), E. Elst and H. Debehogne (12 minor planets), E. Elst and S. Ipatov (4 minor planets), E. Elst and D. Taeymans (1 minor planet), T. Pauwels (87 minor planets), T. Pauwels and H. Boffin (1 minor planet), T. Pauwels and P. De Cat (2 minor planets), T. Pauwels and S. Ipatov (3 minor planets).

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) (R.1), and 9 light curves of mutual phenomena of an asteroid and its satellite (2006--2008).

The team observed 64 potential occultations of stars by minor planets in the period 2003-2009. 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. 40 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 64 attempted is a good result.

The archive now consists of 390 CD-ROMs with a total of 28 436 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. At the current rate of world-wide observations, this could be for another 5+ 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. At present there are some volunteers that will join the team of observers. This way we hope to be slightly more efficient in exploiting the clear nights in the coming years.

E.1.4. Personnel involved

Scientific staff: T. Pauwels, P. De Cat

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.

- IMCCE, Paris, for the reduction of PHEMU observations.

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

- Eric W. Elst
- Pierre Vingerhoets

Grants/Projects used for this research/service

- Lotto grant for the purchase of the camera.

Visitors:

- Short visits: 1

F. Digitisation

F.1. Digitisation of the heritage of the federal scientific institutes

F.1.1. Objectives

The Federal Science Policy Office 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.

By the end of 2005, ten operational projects were launched, which were funded initailly from 2005 to 2008, but were later extended till the end of 2010. We joined project DI07 "digitisation of photographic glass plates", involving the Royal Museum of Central Africa, the Royal Institute for the study and Conservation of Belgium's Artistic Heritage and the Royal Observatory of Belgium, with the aim of digitising our astrophotographic plates on a high-resolution digitiser built in the course of the "D4A" project.

F.1.2. Progress and results

A 2D-digitiser facility of high geometric and radiometric accuracy and repeatability designed and ordered under the D4A pilot-project, was used in the framework of the federal digitisation effort under contract DI07 to digitise aerial photographs of the RMCA/NGI and the photographs of buildings and art objects of the RICH.

In collaboration with the Institût de Mécanique Céleste et de Calcul des Ephémerides of the Paris Observatory (IMCCE) and USNO, plates of the Galilean satellites were digitised and reduced.

F.1.2.1. Management

The project management activities included attending the meetings with other partners on March 20 and August 28, participation to internal discussions on February 4, June 16, and meeting with the IMCCE team on February 11 and December 8.

F.1.2.2. Hardware

In January a broken air volume regulator in the by-pass air-conduct was replaced and the fire protection valve in the inlet air-conduct repositioned, thus terminating the thermal isolation of the return air-conduct. During the yearly maintenance of the climatisation installation early July, the cause of a temperature instability problem was finally found to be due to the disfunction of the external air volume meter caused by fine dust. An extra filter was installed to prevent future problems. The communication interface of the SAIA PLC was upgraded with an internet connection and an extra static air-volume valve was placed at the entrance of the clean room. The clean room temperature setting was changed from 18°C to 20°C. The SAIA firmware was tuned up, resulting in an improved temperature stability of ± 0.05°C (± 0.1°C before).

In May Axos delivered and installed 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.

From Curtis a total of 15000 standard Tyvek (non-woven high density polyethylene from Dupond) envelopes in three different formats were bought. During the summer five students first transformed the envelopes to the sizes needed for the ROB glass plates, and then transferred about 8000 plates (mostly 30 cm and 24 cm ones) to the new archive after putting them in these new envelopes.

New clean-room curtain strips were bought to replace the old smelling ones hanging around the outflow laminator.

In July a study was made of the mechanical and pneumatic subsystem and the installed sensors of the digitiser and of the fieldbus ethernet communication between the digitiser and the control PC. The compressed air

connection on the digitiser was improved and secured; the vacuum suction for film and thin glass plates was extended and improved, the turntable was send to DeStaCo for upgrading to have stops at 0°, 90° and 180° and a hydraulic brake was installed to provide a smooth lifting of the turntable. Distance sensors were ordered to control the presence of the plate wagon, the position of the granite base and of the plate trays in the handling system as well as some extra digital and analogue input cards.

After the installation of a refurbished Deckel milling machine in the mechanical workplace, the milling of extra plate trays and counter pressure plates was initiated out of cast MIC-6 Alu alloy plates.

The DAMIAN digitiser can digitise photographic images up to 350mm wide on glass plates, film sheets and film rolls. A cast aluminium counter pressure plate and plate trays with a central opening corresponding to the actual image size are needed. By the end of 2009 counter pressure plates and plate trays were available for digitising film rolls of 240mm and 254mm wide (with images sizes up to respectively 230mm and 240mm wide), film sheets of 240mm wide (image up to 230mm x 230mm) and glass plates of:

350mm x 350mm (image 342mm x 342mm),

250mm x 250mm (image 240mm x 240mm),

240mm x 240mm (image 230mm x 230mm),

240mm x 180mm (image 230mm x 170mm),

160mm x 160mm (image 150mm x 150mm),

180mm x 130mm (image 160mm x 110mm).

F.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. The variable exposure time software package was improved for digitising old aerial photographs of the fifties with large vignetting. This 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 developed.

F.1.2.4. Digitisation

For the calibration and stability control of the digitiser, the 350mm x 350mm geogrid (geometric grid of chromium dots on a glass plate every 0.5mm in the X and Y directions with diameters ranging from 50µm to 300µm 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 below 0.08 µm. The static benchmark showed that a temperature change of 0.5°C causes a shift of 0.5µm in the central field of view of the camera.

Film rolls (9.5" and 10" wide) with aerial images have been digitised in close collaboration with the colleagues of the NGI and AFGA-Gevaert. From these film rolls 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 sheet 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 photogrammetric applications. Hence, the digitisation of old (aerial) photographs can be done full automatically without any loss of detail by first making an analogue copy on a high-resolution duplication film roll. In case the photographic image faded and/or the photographic film is degraded or damaged, the photographic duplication technique restores the image quality and provides an analogue copy on polyester film that can be archived for at least a century without extra costs.

The NGI ordered in 2009 the coping on polyester duplication film at AGFA-Gevaert of 457 Belgian and 423 CSK images from the fifties. The D007 project ordered another 1000 copies on roll of the CSK. These film rolls are digitised with the DAMIAN digitiser.

F.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. During the summer students moved the larger plates of the archive in the Double Astrograph building to the new climatised archive in the Telescope building after putting the plates in the new Tyvek envelopes. The digital photographic plates catalogue contains metadata of 25239 direct images and spectra (mostly multiple exposures on one photographic glass plate), 12582 prescans of photographic plates and 6278 quick-looks.

F.1.3. Perspective for next years

Routine digitisation of several collections should continue. Starting in 2011 a much more ambitious digitisation plan of the collections of the federal scientific institutes through a public-private partnership should start.

F.1.4. Personnel involved

Scientific staff: T. Pauwels, J.-P. De Cuyper, L. Winter

Technical staff: G. Dedecker

F.1.5. Partnerships

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

F.2. UDAPAC

F.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.

F.2.2. Progress and results

A number of Observatories have been contacted, but only a few responded. Negotiations are on-going with ESO and Leiden.

There has been an initiative by the Bulgarian Academy of Science (Milcho Tsvetkov and Ognyan Kounchev) in collaboration with the Astrophysikalisches Institut Potsdam (Rainer Arlt) to investigate whether European money could be granted to a digitisation project of European astrophotographic plates. A meeting with a number of astrophotographic plate collection holders was held in Potsdam, where everyone presented his/her collection and the on-going digitisation projects. At the end of the meeting Thierry Pauwels and Rainer Arlt were given the task to investigate the possibility to submit a European FP7 proposal. As to the Royal Observatory, UDAPAC could then be integrated in such an FP7 proposal. These investigations started by the end of the year, and there were contacts with the FP7 National Contact Point in Brussels.

F.2.3. Perspective for next years

The possibility to start an FP7 project for UDAPAC will be investigated further.

F.2.4. Personnel involved

Scientific staff: T. Pauwels

F.2.5. Partnerships

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

- Rainer Arlt, Astrophysikalisches Institut Potsdam.
- Ognyan Kounchev, Bulgarian Academy of Science.

Visitors:

- Short visits: 1

F.2.6. Scientific outreach

Meeting presentations

[1] Thierry Pauwels, Jean-Pierre De Cuyper
Digitisation at the Royal Observatory of Belgium
Presented at the digitisation meeting in Potsdam, November 20.

F.2.7. Missions

Commissions, working groups:

- T. Pauwels (2 days)

Field missions:

- T. Pauwels (1 day)

G. Binaries

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 various 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 their derived properties such as stellar masses - a most fundamental property of stars - in a straightforward way. Wide binaries are very useful to calibrate the fundamental properties of single stars and to confront evolutionary models with observations, especially if the components are in different evolutionary stages. They represent the high angular momentum class. In contrast, closer binaries offer excellent opportunities for addressing issues of relations between various phenomena in part due to the proximity effects, resulting in good progress for understanding the impact of multiplicity on the stellar atmospheres or for a better comprehension of close binary evolution.

G.1. Binaries and Multiple Stars

G.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. Binary and multiple stars (such as for example eclipsing binaries) are an important source of precise fundamental stellar parameters and hence provide empirical constraints on stellar evolution.

G.1.2. Progress and results

In 2009, we applied the spectra disentangling technique to determine accurate fundamental parameters and the spectra of the components of three stellar systems, with the aim to answer (still) open questions related to the evolutionary stage of their individual components.

G.1.2.1. Spectroscopic-visual binaries: Theta² Tau, RV Crt and 66 Oph

We used the method of spectra disentangling in order to determine accurate fundamental parameters and properties of the components of the interferometric-spectroscopic binary **Theta² Tau**. Notwithstanding the heavily blended lines in the observed composite spectra (caused by the fast rotation of the components), we obtained two component spectra and the component's radial velocities. The final orbital solution was derived including 13 new high-resolution spectra obtained with the spectrograph HERMES (cf. A.1.7) using the spectra disentangling code FDBinary. These spectra were reduced using the HERMES pipeline. Combining spectroscopy with long-baseline optical interferometry, we derived the orbital parallax and the component masses with unprecedented accuracy. The component spectra allowed a revised determination of the atmospheric stellar properties (Teff_A,B and v_A,B.sin i). They suggest a need for enhanced metallicity (as expected for members of the Hyades cluster). Such very accurate parameters are essential to distinguish between the various theoretical evolutionary tracks proposed for the Hyades cluster considering that its metallicity is well-constrained (e.g. de Bruijne et al. 2001; Perryman et al. 1998). The mass derived for the primary is however much higher than the value assumed until now R.2R.3. This may have important implications for the current understanding of stellar evolution in this nearby open cluster.

The same disentangling technique was also applied to **RV Crt**, an eclipsing close binary (with Porb=1.17 days) orbiting around a third wide component (with Porb~103 years). The combination of the light-curve analysis with the method of spectra disentangling permitted us to disentangle the spectra of the components as well as to determine the orbital parameters. A light-time effect in the eclipse timings was discovered in the photometric data, proving that the third component belongs physically to the system. A pattern also observed in the most recent residuals (over 14 years) and amplitude of ~0.01 days in light-time suggests the presence

of a newly detected, 4th, component. It seems however to be too faint at visual wavelengths to leave a detectable trace in the spectra.

66 Oph was considered in the last decade as a single Be star showing strong variability from UV to IR wavelengths. The presence of a close binary companion was first spectroscopically detected by Stefl & Hadrava (2003). Forty-nine high-resolution échelle spectra, obtained with the spectropolarimeter NARVAL (taken by the French team at the 2-m telescope, Observatoire du Pic du Midi, France,) and the spectrograph HERMES (cf. A.1.7) were used in the analysis. The disentangling code FDBinary was applied in a single spectral interval (444.262 - 449.851 nm). The preliminary results revealed a circular orbit with Porb = 10.77 days. The RV semi-amplitudes of the close binary are 49.23 and 79.49 km/s for components BA and BB, respectively. The new orbital parameters are in very good agreement with those determined by Stefl & Hadrava (2003).

G.1.2.2. O-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 (161 ± 3) x 10^{-9} /yr secular 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 (0.46-1 Msol) 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 (≥ 0.03 Msol), orbiting in about 3400 days at a distance of 4.5 AU from the primary R.3.

G.1.2.3. Eclipsing binaries: RW Cr and VZ Leo

Using the programme PHOEBE based on the Wilson-Devinney method (Prša and Zwitter 2005), we derived new geometric and photometric elements from the RI light curves of the Algol-type eclipsing binary systems **RW CrB** and **VZ Leo**. The geometry of both systems is that of a semi-detached binary where the secondary component fills its Roche lobe while the primary component is well inside. The orbital period changes of both systems were studied resulting in period decreases, which can be explained by non-conservation of the angular momentum. Finally, we compared the two systems with similar binary systems R.1.

G.1.3. Perspective for next years

Future work will consist in using the disentangled component spectra of the binary system Theta² Tau to perform a detailed chemical analysis, in order to determine as accurately as possible the chemical composition and the evolutionary status of both components. This will allow to test whether or not convective overshooting is needed in the models. A new study was started on 66 Oph, a multiple system that contains one Be star. Additional spectra will be considered in order to determine the orbit of the wide component of 66 Oph as well as its spectrum. The combined spectroscopic-photometric analysis of RV Crt will be redone taking into account the new orbital period as well as the light-time effect. The physical parameters, evolutionary state and chemical composition of the components will be determined in collaboration with the Brazilian team. New systems (some of which are being observed with HERMES) will be identified for application of the spectra disentangling method. Interferometric observations will also be requested in an attempt to clarify the multiplicity of the RV Crt system.

For a few other binary and multiple systems, we will apply for very high-angular resolution interferometric observations provided these targets satisfy the criteria for eligibility (ESO, Chile, for the Southern and/or CHARA (US) for the Northern objects). We will continue to observe and study various eclipsing binaries having very special or particularly interesting properties.

G.1.4. Personnel

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

G.1.5. Partnerships

List of international partners without grant

- J.V. Clausen, E.H. Olsen, NBIfAPG, Copenhagen, Denmark
- S. Fauvaud, GEOS, Angoulème, France: data analysis
- M. Floquet, C. Neiner from Observatoire de Paris-Meudon, Paris, France
- S. Ilijic, University of Zagreb, Croatia
- P.G. Niarchos et al., Dep. of Astrophysics, Astronomy and Mechanics, University of Athens, Greece
- E. Rodríguez et al., Instituto de Astrofísica de Andalucía, Granada, Spain: data analysis
- P. Škoda, Astronomical Institute of the Academy of Sciences, Ondrejov, Czech republic
- S. Stefl, ESO, Santiago, Chile
- G. Torres, Harvard-Smithsonian Center for Astrophysics, Cambridge, MA
- B. Ulas, Onsekiz Mart University, Dept. of Physics, Canakkale, Turkey
- L.P. Vaz et al., Federal University of Minas Gerais (UFMG), Belo Horizonte, Brazil

Grants used for this research

- Project "Disentangled Components of Multiple Stars as Laboratories of Stellar Evolution" (Grant of supplementary researcher – 2nd year)

G.1.6. Scientific outreach

Meeting contributions

[1] Lampens, P., Torres, K.B.V., Frémat, Y., Hensberge, H.
Démêlement des spectres d'étoiles doubles et triples. Technique, application et résultats
Meeting of the "Commission des Etoiles Doubles de la Société Astronomique de France (SAF)", Sept. 12, Rouen, France

[2] Lampens, P., Torres, K.B.V., Frémat, Y., Hensberge, H.
Towards Accurate Component Properties of the Hyades Binary Theta² Tau
In: Los Alamos Conference on Stellar Pulsation: Challenges for Theory and Observation, Santa Fe, New Mexico

[3] Torres, K.B.V., Lampens, P., Frémat, Y., Hensberge, H.
The Hyades binary Theta² Tauri: a new spectroscopic orbit and orbital parallax
In: Binaries - Key to Comprehension of the Universe, June 8-12, Brno, Czech republic

G.1.7. Missions

Assemblies, symposia, conferences:

- Los Alamos Conference on Stellar Pulsation: Challenges for Theory and Observation, May 31 - June 5, Santa Fe, New Mexico
- 08-12/06: Binaries - Key to Comprehension of the Universe, Brno, Czech republic

Field missions

- K. Torres: 10-19/03: Participation in the commissioning of the new HERMES spectrograph.
- P. Lampens: April 30 - May 08, Observations performed with HERMES at the Mercator telescope, Observatory Roque de los Muchachos, La Palma (Spain)
- K. Torres: 04-14/09: Observations performed with HERMES at the Mercator telescope, Observatory Roque de los Muchachos, La Palma (Spain)

Research visits:

- 03/12: Observatoire de Paris-Meudon: cooperation with M. Floquet and C. Neiner (Y. Frémat, K. Torres)

H. Asteroseismology

The overall objective of asteroseismology is to probe the internal structure of (pulsating) stars. To this aim, we observe and study the light and spectral variations of pulsating stars of spectral type B-A-F over a time-scale of several seasons and/or years. We also investigate the interactions that may arise between stellar pulsations and various other phenomena such as multiplicity, chemical composition and magnetic fields.

H.1. Asteroseismology of single, binary or multiple stars

H.1.1. Objectives

Special attention is given to the study of B-A-F **pulsating components of binary or multiple 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 and to study the interaction between pulsation and binarity. Since more than 50% of all stars are expected to be binaries, understand-ing the effects of binarity on the pulsation characteristics is a matter of prime importance. We focus our efforts unto systems which are promising targets for the application of the technique of spectral disentangling.

H.1.2. Progress and results

H.1.2.1. Candidate binary systems among A/F-type stars

The region in the H-R diagram where the main sequence interferes with the Cepheid Instability Strip (CIS) hosts stars that are affected by a rich variety of physical processes ongoing in their interiors (including pulsation, diffusion, convection and magnetism). Main-sequence A/F-type stars are the best candidates to study this complex interplay.

We explored a large sample of suspected A/F-type binaries using both high-resolution spectroscopy and differential CCD photometry in order to search for pulsations, for (non-standard) chemical composition or for possible hidden component(s). The project aims at exploring, and reinterpreting where needed, the radial velocity variability of poorly known HIPPARCOS targets located at the lower end of the CIS. A few extremely interesting cases have been added independently (e.g. Theta² Tau). In this sample, we also detected the new and atypical Delta Scuti star **HIP 40361** (HD 68725). Our spectroscopic follow-up showed that the pulsating component belongs to a binary system, the orbital period of which is of the order of one month but its value is not yet accurately known. Additional spectra were collected through an international spectroscopic campaign (including Bulgarian, Mexican and Spanish partners and US and Chinese sites, see annual report of 2008). The star was also proposed as a target for high-resolution spectra to be collected with HERMES during the year. Additional photometric light curves were obtained with the HOACS instrumentation during wintertime (for a description, see below). A tiny eclipse was observed, but bad weather impeded us to confirm this feature. We also applied for additional high-resolution spectra with HERMES@ENO/1.2-m for other specific candidates, but were however not granted time by the Telescope Allocation Committee R.4.

In order to derive fundamental stellar parameters and chemical abundances for our targets, an automated IDL procedure has been developed. The new procedure was tested on synthetic spectra and first results were obtained for the star Vega R.1. The influence of fast rotation on the determination of chemical abundances was also evaluated. This procedure will be applied to the spectra acquired with the new spectrograph SOPHIE equipping the 1.93-m telescope at the Observatoire de Haute-Provence (France) in order to derive the chemical abundances for several A/F-type stars of our sample.

H.1.2.2. The oscillating eclipsing binary systems CT Her and Y Cam

CT Her belongs to the new class of oscillating Algol-type binary systems, of which only a handful members are presently known. These stars represent important case studies as we do not yet understand their evolutionary stage. Furthermore, they allow to study pulsations in semi-detached binaries where mass accretion is (still) on-going.

We reported the results of an extensive analysis based on a five-year, multisite photometric campaign carried out in the years 2004-2008 R.3, based on a modelling of the light curves using the code PHOEBE (Prša & Zwitter 2005). The primary component of this eclipsing binary system is a Delta Scuti-type pulsator with a main pulsation period of only 27 min. For this pulsating component, we detected up to 7 significant pulsation frequencies, all in the frequency range between 45-53 c/d, in the residual data.

We are currently preparing another study of a similar target which is **IU Per**. Photometric data were collected during 2006 (Greece), 2007 (Krete) and continued in autumn 2008 (Belgium and Greece). Complete light curves were acquired using two filters (Johnson B and V). This vast data set will soon be analysed. The time resolution we will have, will allow to improve the frequency-analysis significantly compared that of the latest publication (which only has a 12-days time resolution).

A new study to which we contributed with both data (more than 100 hours of observations) and extensive suggestions concerns one of the first detected oEA stars, namely **Y Cam** (with orbital period 3.3057 days). Y Cam was extensively observed during a multi-site campaign held in the winter of 2002-2003. The frequency-analysis of the out-of-eclipse data reveals a set of eight independent frequencies, many of which are new, in a restricted frequency range. This is the largest set of excited modes discovered so far for an oEA star. A proposal for additional high-resolution HERMES spectra for two other known oEA stars, **RZ Cas** and **TW Dra**, was submitted and granted R.4.

H.1.2.3. High-amplitude Delta Scuti pulsators (HADS)

The evolution of the periods of HADS is not well understood. Stellar evolution predicts increasing periods (Breger & Pamyathnik 1998) but also decreasing periods are observed. Furthermore, it is not clear whether these period changes are monotonous or abrupt. It is therefore important to monitor the changes in the periods of these pulsating stars. We collected 271 maxima of 19 HADS. Our list also includes 8 newly discovered HADS R.1.

H.1.2.4. Main-sequence O-B stars (SPB = slowly pulsating B star; Beta Cep = Beta Cephei star)

The results of our search for magnetic fields in **SPBs** and **Beta Ceps** have been published R.1R.2R.2R.2R.3. We applied for additional time with FORS2@ESO/UT2 to be able to study the magnetic fields of upper main-sequence stars and were partly successful R.4R.4R.4.

Beta Cru is a bright southern Beta Cep star. It is a binary with an orbital period of about 5 years. Unfortunately, the secondary component was not resolved by the interferometric observations (made in April 2009). Thus, we stopped applying for more telescope time.

H.1.2.5. Rotation and pulsation in main-sequence gravity mode pulsators

The gravity modes observed in the **SPB** and **gDor** stars are not (yet) fully characterized. Indeed, current spectroscopic methods of mode identification have still not been shown to be applicable for the growing number of observed g-modes. In order to improve these procedures specifically with respect to g-mode pulsators, and to investigate whether any correlation exists between the amplitude and/or type of the excited modes and the projected rotational velocity, a significant number of such pulsators is being studied in collaboration with Dr. K. Pollard (New-Zealand). Major achievements concern: a) the coordination of multi-site campaigns, b) the collation of the data and c) the reduction, analysis and presentation of the first results.

The investigation of current methods of mode identification have identified the Fourier parameter fit (FPF) method as the most appropriate method for the analysis of g-mode pulsations, though some problems have been encountered with this method. The difficulties lie in the fact that, unlike their p-mode counterparts, the g-mode pulsations result in an asymmetric mean line profile, also the amplitude of variation appears shifted by a few km/s relative to the mean line profile. The current implementation of synthetic line profile software able to function with the FPF method (FAMIAS software) is unable to reproduce these observed phenomena. New synthetic line profile software is being developed by R. Townsend at the University of Wisconsin-Madison which will be tested on our data sets to see if it can explain the findings. If it is able to improve the mode identification then the new code will be adapted to function with the FPF method.

Thanks to our collaborators, additional spectra for the identification, classification and vsini determination of SPB and gDor stars were gathered at 4 observatories. At least one high-resolution, high-signal-to-noise ratio spectrum is now available for ~120 objects. Preliminary results have been presented in Santa Fe, New Mexico (H.3.6).

Spectroscopic multi-site campaigns for a selection of SPB and gDor stars with a sufficient spread in v.sin(i) are organized to allow a full characterization of their main pulsation modes. We focussed on 2 SPB and 4 gDor stars. For each star, the resulting 270-400 high-resolution spectra have been reduced and the line-profile analysis is ongoing. The profile variations are evident and consistent with variations expected for low-degree g-modes. The main achievements can be summarised as follows:

- The gDor star HD 189631 was observed in the summer with HARPS@ESO/3.6-m (E. Poretti et al.) resulting in 49 additional high-resolution spectra. F. Maisonneuve started the analysis of this data set and presented some preliminary results R.2.
- For HD 147787, a double-lined spectroscopic binary and gDor star, we derived a new eccentric orbit (Porb = 39.880(2) days; Figure 36) and the v.sini of both components (7(2) and 33(2) km/s for primary and secondary component, respectively) R.2. The primary component is clearly multiperiodic, and the line-profile variations are dominated by the main frequency known from photometry (0.6897(8) c/d). For the secondary component, there is no firm evidence for pulsations. The results based on all the available spectra will be presented in a forthcoming paper.
- The gDor star HD 218396 was recently found to have 3 small orbital companions from direct imaging and hence gained a lot of scientific interest (Marois et al., 2008, Science 322, 1348). In collaboration with other groups, we organized an intensified spectroscopic campaign, centered around the space-based white-light photometry obtained with the satellite MOST from 15/08 to 01/10, to derive the age of the system which would allow determination of whether these physically bound objects are truly planets or actually brown dwarfs. HD 218396 has been observed during dedicated runs R.4R.4R.4R.4R.4 and was re-introduced as one of the targets for our runs described below. The analysis of our HD 218396 data will be published soon.
- In 2009, we initiated the observations of 2 SPB and 7 gDor stars for one observation season. Several observation proposals were submitted R.4R.4R.4R.4R.4R.4 and additional observation time was obtained thanks to our collaborators. So far, 150-400 spectra were obtained for each star and the data are being prepared for analysis. The first results for the gDor star HD 40745, solely based on the HERCULES@MJUO/1.0-m data, were already presented R.2R.3 and the analysis of the full data set is progressing well. We also started the analysis of the data of the gDor stars HD 12901, HD 65526 and HD 135825.
- We started an intensified campaign for the SPB stars HD 25558 and HD 28114 (already observed in 2008 and 2009, respectively). We already applied for ground-based high-resolution spectroscopy R.4 and space-based white-light photometry with the satellite MOST R.4R.4R.4 and aim to complement these observations with multi-colour photometry (for an independent determination of the degree *l* of the modes) and spectropolarimetry (for a detailed study of the weak magnetic field).

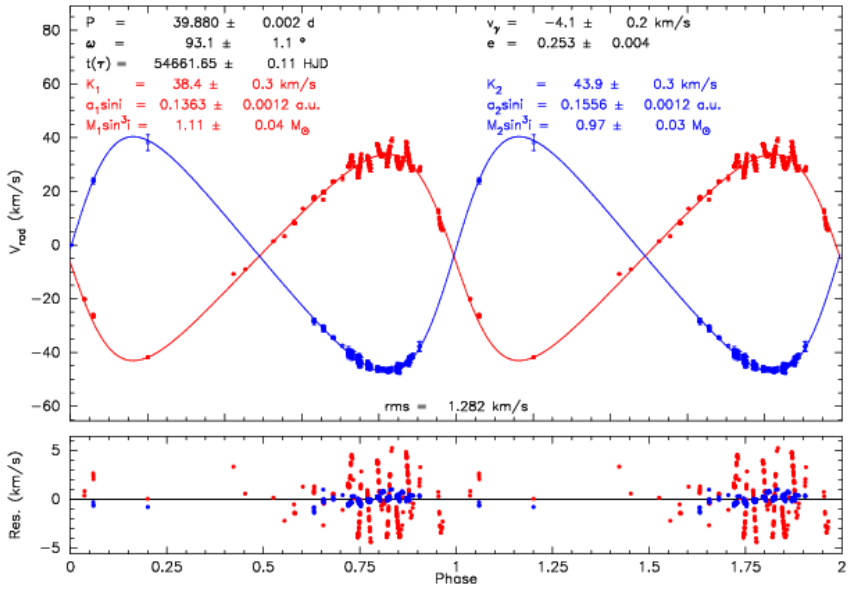


Figure 36: Top: Orbital solution based on the HARPS@ESO/3.6-m and HERCULES@MJUO/1.2-m data of 2008 in combination with the CORALIE@ESO/1.2-m data. Red symbols refer to the primary component and blue ones to the secondary component. Bottom: Residual velocities after subtraction of the orbit.

H.1.3. Perspective for next years

A detailed chemical abundance analysis for the A-/F-type stars of the sample for which high-resolution, high S/N spectra have been acquired, will be carried out. We plan photometric-spectroscopic analyses of selected oEA stars, e.g. IU Per. We will consider improvements to currently available spectroscopic methods of mode identification concerning the g-mode pulsators. We expect that the biggest simplification is the neglection of the Coriolis force. Results concerning the impact of the Coriolis force on g-mode pulsation are expected in the coming years. It is also our intention to include simultaneous photometric and spectroscopic observations and to search for magnetic fields in SPB and gDor stars. We will continue to develop the various aspects involving the coordination and acquisition of observations, the data reduction and interpretation, simulations and the improvement of the analysis methods.

H.1.4. Personnel

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

H.1.5. Partnerships

List of international partners without grant

- M. Cunha, Centro de Astrofisica da Universidade do Porto, Portugal: theory of Ap-stars
- S. Kleidis, Zagori Observatory, Athens, Greece: private observatory
- Z. Kraicheva, D. Dimitrov, Institute of Astronomy, Bulgarian Academy of Sciences, Sofia, Bulgaria
- D. Kurtz, University of Central Lancashire, Preston, UK: interpretation of Ap-stars
- D. E. Mkrtichian, Sejong University, Seoul, Korea: local correspondent, observations+ data reduction + interpretation of magnetic fields (spectropolarimetry)
- P. G. Niarchos et al., University of Athens, Greece: observations and analysis
- C. W. Robertson, SETEC Observatory, USA: private observatory
- E. Rodríguez et al., Instituto de Astrofísica de Andalucía, Granada, Spain: observations and analysis
- A. Strigachev, Institute of Astronomy of the Academy of Sciences, Sofia, Bulgaria: observations
- J. Vidal-Saínz, J.M. Gómez-Forellad, Grup d'Estudis Astronomics (GEA), Barcelona, Spain: private observatories

- S. Yang, University of Victoria, Victoria, Canada: local correspondent and observer for the Dominion Astronomical Observatory + contributes to the data reduction
- C. Nitschelm, Universidad Catolica del Norte, Antofagasta, Chile: local correspondent and potential observer for observations in Chile
- J. Telting, Nordic Optical Telescope, Santa Cruz de La Palma, Spain: local correspondent and observer for the Roque de los Muchachos Observatory (2.4-m NOT) + contributes to the data reduction and analysis
- P. Mathias, Observatoire de Côte d'Azur, Nice, France: local correspondent for the Observatoire de Haute Provence + contributes to the data reduction and analysis
- H. Lehmann, Thüringer Landessternwarte Tautenburg, Tautenburg, Germany: local correspondent and observer for the Karl Schwarzchild Observatory + contributes to the data reductions
- J.N. Fu, Beijing Normal University, Beijing, China: local correspondent for Xinglong observatory
- D. Mkrtichian, Sejong University, Seoul, Korea: local correspondent and observer for the Bohyunsan Optical Astronomical Observatory + contributes to the data reduction + derives and interpretes magnetic fields from spectropolarimetric observations
- E. Kambe, Okayama Astrophysical Observatory, Okayama, Japan: local corresponent and observer for the Okayama Astrophysical Observatory + contributes to the data reduction
- K. Pollard et al.,University of Canterbury, Christchurch, New Zealand: local correspondents and observers for the Mount John University Observatory + contribute to the data reduction and analysis + help coordination observations in the southern hemisphere
- S. Hubrig et al., European Southern Observatory, Chile: derives and interpretes magnetic fields from spectropolarimetric observations
- E. Poretti et al., INAF-Osservatorio Astronomico di Brera, Merate, Italy: coordinator of ESO large program on ground-based observations for CoRoT targets
- K. Uytterhoeven, Service d'Astrophysique, Saclay, France: contributes to the data analysis

List of national partners without grant

- C. Aerts et al., KU Leuven: contribute to the data analysis
- A. Noels et al., Université de Liège: experts in asteroseismic modelling
- P. Van Cauteren, Beersel Hills Observatory (BHO), Belgium: private observatory
- P. Wils, VVS, Belgium: data analysis

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

- Grant nr. MO/33/021 funded for 2 years: 01/05/2008-30/06/2009 by the Federal Science Policy
- Grant nrs. G.0178.02 and G.0332.06 from the Fund for Scientific Research – Flanders (FWO)

Visitors:

- F. Maisonneuve, University of Canterbury (Christchurch, New Zealand), 19/07-19/08, Towards asteroseismology for main-sequence g-mode pulsators: the case study of the gDor star HD 40745 (ASBL-grant)
- E. J. Brunsden, University of Canterbury (Christchurch, New Zealand), 09/11-09/12, Towards asteroseismology for main-sequence g-mode pulsators: training in data-analysis techniques and software packages (ASBL-grant)

H.1.6. Scientific outreach

Meeting presentations

[1] Wright D.J., De Cat P., Telting J.H., Kambe E., Pollard K.R., Maisonneuve F., Kilmartin P.M.
Rotation and pulsation in g-mode main sequence pulsators (talk)
Meeting on "Stellar Pulsation: Challenges for Theory and Observation" (Santa Fe, New Mexico, US)

[2] De Cat P., Wright D.J., Pollard K.R., Maisonneuve F., Kilmartin P.M., Lehmann H., Yang S., Kambe E., Saesen S., Carrier F., Mkrtichian D., Mantegazza L., Rainer M., E. Poretti E., Laney D., Fu J.N.

Towards asteroseismology of main-sequence g-mode pulsators: spectroscopic multi-site campaigns for slowly pulsating B stars and gamma Doradus stars (poster)
Meeting on "Stellar Pulsation: Challenges for Theory and Observation" (Santa Fe, New Mexico, US)

[3] De Cat P., Wright D.J., Pollard K.R., Maisonneuve F., Kilmartin P.M., Laney D.
Is HD147787 a double-lined binary with two pulsating components? Preliminary results from a spectroscopic multi-site campaign (poster)
Meeting on "Stellar Pulsation: Challenges for Theory and Observation" (Santa Fe, New Mexico, US)

[4] Pollard K.R., Maisonneuve F., Cottrell P.L., Kilmartin P.M., Wright D.J., De Cat P.
Spectroscopic mode-identification of gamma Doradus stars (poster)
Meeting on "Stellar Pulsation: Challenges for Theory and Observation" (Santa Fe, New Mexico, US)

Seminars

[5] De Cat P.
Rotation and pulsation in main-sequence gravity mode pulsators: first results
Beijing Normal University, Beijing, China on 09/04/2009

[6] Wright D.
Mode identification of non-radially pulsating gamma Doradus and slowly pulsating B type stars
Seminar Royal Observatory of Belgium, Brussel, Belgium on 30/04/2009

[7] Wright D.
The analysis of spectroscopic line profile variations in gamma Doradus and SPB type variables
University of Liège, Belgium on 01/10/2009

[8] Wright D.
The analysis of spectroscopic line profile variations in gamma Doradus and SPB type variables
Beijing Normal University, Beijing, China on 04/11/2009

[9] Wright D.
Spectroscopic reduction of data from the Coudé spectrograph at Xinglong observatory
Beijing Normal University, Beijing, China on 03-04/11/2009

H.1.7. Missions

Assemblies, symposia, conferences:

- 31/05-05/06/2009: International Conference Stellar Pulsation: Challenges for Theory and Observation (Santa Fe, New Mexico, USA)(3 pers)
- 06/05/2009: Contact Group Meeting, Brussels, Belgium

Field missions

- 06-13/03/2009: Observatorio del Roque de los Muchachos (La Palma) 6 nights of spectroscopic observations with HERMES@LAP/1.2-m (Wright)
- 08-18/04/2009: Beijing + Xinglong Observatory, China (6 nights of spectroscopic observations with COUDE@XING/2.16-m; 11-16/04/2009)(De Cat)
- 05/06-17/06/2009: McDonald Observatory, Mt. Locke, Texas, USA (7 nights of spectroscopic observations with RA2@McD/2.1-m; 08-14/06/2009)(De Cat)
- 10-16/06/2009: Observatoire de Haute-Provence (OHP), France (3 nights of spectroscopic observations with SOPHIE@OHP/1.93-m; 10-16/06/2009)(Wright)
- 23/09-07/10/2009: McDonald Observatory, Mt. Locke, Texas, USA (10 nights of spectroscopic observations with RA2@McD/2.1-m; 25/09-04/10/2009)(De Cat)
- 28/10-07/11/2009: Beijing + Xinglong Observatory, China (3 nights of spectroscopic observations with COUDE@XING/2.16-m; 30/10-3/11/2009)(Wright)
- Jan - Dec. 2009: Differential CCD photometry of selected Delta Scuti variable stars, Beersel Hills Observatory, Belgium, 0.4-m telescope + SBIG CCD camera (14 nights, Lampens & Van Cauteren)

Research visits:

- De Cat: 17 1-day visits to the Inst. voor Sterrenkunde, K.U.Leuven
- Frémat & Lampens: several 1-day visits to the Inst. voor Sterrenkunde, K.U.Leuven (in relation with the study of AU Mon, discussion of a HERMES proposal for new observations and the PhD defense of M. Desmet)
- Wright: 8 1-day visits, Inst. voor Sterrenkunde, K.U.Leuven, collaboration with W. Zima (FAMIas)

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

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

Visitors

- Dr. A. Strigachev, Institute of Astronomy, Sofia, Bulgaria: 4.5 weeks

H.2. Stellar characterization

H.2.1. Objectives

Characterization is the first step towards a better understanding of stellar physics and a must have when identifying pulsation modes or understanding their properties. 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. The objectives are to obtain a new calibration of the effective temperature for these stars as a function of observational quantities which are highly sensitive to the ionization balance in the photosphere and its gas pressure, but independent of the interstellar extinction.

H.2.2. Progress and results

A new and homogeneous calibration of the Balmer discontinuity was obtained for OB supergiants and the impact of this classification on the current calibration obtained for dwarfs and giants was examined. The expected average error of our effective temperature determinations is the same for all spectral types and luminosity classes. For OB supergiants, our results agree within 2000 K with other determinations found in the literature R.1. Carbon, nitrogen and oxygen chemical abundances are also interesting parameters in the context of fast rotating OB stars. For this project, high-resolution and high signal-to-noise ratio spectra for several interesting targets were acquired at the OHP with the aim to study their variation with age and rotational speed.

H.2.3. Perspective for next years

Since the stellar spectra needed by our procedure are of low resolution, it can be used to study stars and stellar systems like open clusters, associations or stars in galaxies observed with multi-object spectrographs and/or spectro-imaging devices. In the meantime, CNO abundances for the targets observed at OHP will be derived and analyzed in the context of his study of fast rotation effects in fast rotating intermediate mass stars.

H.2.4. Personnel

Scientific staff: Y. Frémat

H.2.5. Partnerships

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

- M.L. Arias, L. Cidale, Facultad de Ciencias Astronomicas y Geofisicas (Argentina)
- C. Martayan, ESO, Chile
- F. Royer et al., GEPI-Observatoire de Paris-Meudon, France
- J. Zorec, Institut d'Astrophysique de Paris, France

Visitors:

- J. Zorec, Institut d'Astrophysique de Paris (France), 12-15 January

H.3. Asteroseismology from space missions: CoRoT, Kepler

H.3.1. Objectives

We participate in the scientific exploitation of the space missions **CoRoT** (CNES-CNRS-ESA-Brazil) and **KEPLER** (NASA). CoRoT (launch in Dec. 2006) probes the inner structure of the stars and detects extra-solar 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, the experiment is a pioneer mission. CoRoT is monitoring stars in the Eyes of CoRoT (i.e. selected fields located in the directions towards the galactic center and anti-center) during about 30 days (short runs) or 150 days (long runs). Many high-accuracy light curves from the exoplanetary and asteroseismic CoRoT fields have been collected. KEPLER (launched in March 2009) observes fixed fields and monitors over 100.000 stars for at least 4 years with a slow cadence, as well as 512 stars with a rapid cadence. This mission is designed to search for extra-solar planetary systems using the transit technique, particularly Earth-like planets in the habitable zone.

H.3.2. Progress and results

Contributions to the CoRoT mission

We are involved in the analyses of CoRoT Be stars, eclipsing binary systems, as well as of different types of variable stars. Various ground-based follow-up observations for different types of CoRoT stars are ongoing R.4R.4R.4.

H.3.2.1. Be-type stars and the interacting binary AU Mon

The CoRoT data for several Be stars were made available to the Be thematic team. Our role is mainly to study and analyze the spectroscopic data available for these targets and to interpret the spectra in terms of stellar parameters and physical description. Most of the work done on these stars was made in collaboration with the Observatoire de Paris-Meudon. One of the studied emission line stars concerns AU Mon, a member of a semi-detached binary system, and a huge effort, which also implied the team at KUL, was made to interpret the CoRoT data combined to ground-based spectroscopy (Fig. 2). In 2009, several papers were submitted and accepted for publication R.1R.1R.1R.1R.1R.1R.2R.2.

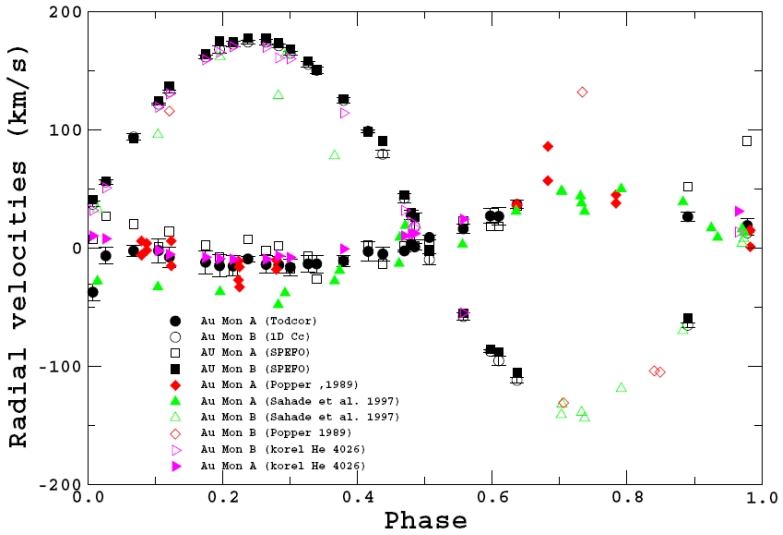


Fig. 37: The radial velocities derived for the primary and secondary components of the semi-detached binary AU Mon are represented by black symbols. The latter are based on a procedure especially made by Y. Frémat. These radial velocities are thought to be more accurate than other determinations (see coloured symbols).

H.3.2.2. B-type stars

We finished the photometric mode identification of HD 180642. An unambiguous determination of the degree l was possible for two modes: $l = 0$ for 5.48694 c/d and $l = 3$ for 0.30818 c/d. For the mode with frequency 7.36673 c/d, both $l = 0$ or 3 are consistent with the observations R.1R.2. Furthermore, one of us (P. De Cat) is responsible for the analysis of two B-stars observed in the seismo-fields:

- HD 48752 (B9V) is an eclipsing binary for which a clear primary eclips and two candidate secondary eclipses are observed in the CoRoT data. Unfortunately, one of the candidates for secondary eclips shows a severe jump, which hampers the analysis.
- HD 172046 (B8) shows variations dominated by a period of ~4 days and several periodicities with shorter periods. The origin of the observed variations is still unclear: pulsations, binarity and/or spots? The19 high-resolution spectra that have been taken recently with HERMES@ENO/1.2-m should make it possible to decide.

H.3.2.3. gDor stars

We continued with the frequency analysis of candidate gamma Doradus stars observed in the exoplanet field of CoRoT. Some of the individual programs that were used in 2008 for a "manual" frequency analy-sis were combined into one code that allows an "automatic" frequency analysis. This code was applied to 32 first priority gDor stars. We did some experiments to check the sensitivity of the results on the definition of the noise level and on the allowed range of frequencies. A poster was presented and we plan a refereed paper based on the results of all the collaborators R.2.

H.3.2.4. O-type stars

A few half-day meetings were organized dedicated to the analyses of the O stars observed by CoRoT.

H.3.2.5. Eclipsing binaries

A significant number of binaries observed by CoRoT show evidence of rapid pulsations on top of the eclipses or ellipsoidal variations. We have selected 10 cases likely with early-type components and have investigated their light curves in order to derive the orbital periods and the main pulsation characteristics. First results have been presented during the 1st International CoRoT Conference (cf. B3.6 H.3.6H.3.6). We also sub-

mitted requests for new spectroscopy concerning the most promising systems in order to be able to correctly interpret the detected pulsations.

Contributions to the Kepler mission

In 2009, the Kepler Asteroseismic Science Consortion (KASC) was structured into different working groups. P. De Cat is a member of the working groups KASC-3" Beta Cephei stars", KASC-6 "Slowly pulsating B stars", KASC-9 "Pulsations in eclipsing binaries" and KASC-10 "gDor stars". He is the chairperson of KASC-6 and its subgroup 6.3 "Ground-based follow-up observations". P. Lampens is a member of the working group KASC-9 "Pulsations in eclipsing binaries". P. De Cat's activities focused on:

- representation and management of KASC-6. All potential members were contacted and asked to fill a questionnaire inquiring about their plans and interests. The activities are driven through a Google Discussion Group named "Kepler SPB Working Group". We did a first quick analysis of the already released KEPLER data (initial run, 1st quarter, 2nd quarter) for SPB stars needed for the target selection for 5th quarter. A refereed paper describing to introduce the Kepler Asteroseismic Program and its first results was prepared by all the KASC working group chairs R.3.
- the organisation of ground-based observations by: making a large overview table with the stellar parameters and available data both in photometry and spectroscopy for the targets of all KASC WGs (and subsets for each KASC WG separately). These tables are supposed to be kept up-to-date by the chairs of the KASC subWGs responsible for ground-based observations to allow an efficient preparation of joint observation proposals;
- contributing to the preparation of observation proposals including targets of KASC-6 R.4R.4R.4R.4R.4;
- investigating the possibility to apply for time with the LAMOST (Large Sky Area Multi-Object Fiber Spectroscopic Telescope), which is a new Chinese 4-m telescope at the Xinglong observatory with 4000 optical fibers to take low to medium resolution spectra. It would be possible to use this instrument to gather the spectroscopic data for all KASC targets needed to correctly classify the stars.

H.3.3. Perspective for next years

Both the CoRoT and KEPLER missions are producing a huge data-flow of ultra-precise data, and we will remain heavily involved in the analyses of new and already existing satellite data for several years to come. New ground-based observations will be made available as well. Their interpretation will require a decent treatment and careful interpretation similar to the analyses done in 2009. The results will be reported during dedicated CoRoT conferences and KEPLER meetings.

H.3.4. Personnel

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

H.3.5. Partnerships

List of international partners without grant

- C. Maceroni et al., INAF - Osservatorio Astronomico di Roma, Monte Porzio Catone, Italy
- D. E. Mkrtichian, Sejong University, Seoul, Korea
- A. Prsa, Villanova University, Villanova, PA/USA
- P. Harmanec, Astronomical Institute of the Charles University, Czech Republic
- C. Neiner, T. Semaan, Observatoire de Paris-Meudon and the CoRoT Be Team
- CoRoT gDor stars working group (Chair: P. Mathias)
- Kepler Asteroseismic Science Consortium (KASC, Chair: J. Christensen-Dalsgaard)
- KASC Working group 3 "Beta Cephei stars" (Chair: G. Handler)
- KASC Working group 10 "Gamma Doradus stars" (Chair: J. Gouzik)

List of national partners without grant

- CoRoT O/B star working groups, C. Aerts & M. Desmet, Inst. voor Sterrenkunde, K.U.Leuven

- KASC Working Group 6 "Slowly pulsating B stars" (Chair: P. De Cat)
- KASC Working Group 9 "Pulsations in eclipsing binaries" (Chair: C. Aerts)

Visitors:

- T. Semaan, Observatoire de Paris Meudon (France), 9-13 February

H.3.6. Scientific outreach

Meeting presentations

[1] Desmet , M., **Frémat, Y.,** Baudin, F., Harmanec, P.**, Lampens, P.** and 12 co-authors,et al.,
New analysis of the highly evolved, semi-detached massive binary AU Mon based on CoRoT's first observations (poster)
First International CoRoT Symposium, Paris

[2] **Lampens, P.**, Maceroni, C., Aerts, C., De Bosscher, J., Degroote, P. and 4 co-authors,
First CoRoT results on new pulsators in eclipsing binaries (poster)
First International CoRoT Symposium, Paris

[3] Mathias P., Chapellier E., Bouabid M., Rodriguez E., Poretti E., Paparó M., Hareter M., **De Cat P.**, Eyer L.
Gamma Doradus stars in the COROT exoplanets fields: first inspection (poster)
International Conference "Stellar Pulsation: Challenges for Theory and Observation" (Santa Fe, New Mexico)

[4] Briquet M., Uytterhoeven K., Morel T., Aerts C., **De Cat P.,** Mathias P., Lefever K., Miglio A., Poretti E., Martín-Ruiz S., Paparó M., Rainer M., Carrier F., Gutiérrez-Soto J., Valtier J. C., Benkó J. M., Bognár Zs., Niemczura E., Amado P. J., Suárez J. C., Moya A., Rodríguez-López C., Garrido, R.
An asteroseismic study of the Beta Cephei CoRoT main target HD 180642: results from the ground-based campaign (poster)
International Conference "Stellar Pulsation: Challenges for Theory and Observation" (Santa Fe, New Mexico)

H.3.7. Missions

Assemblies, symposia, conferences:

- 1st international CoRoT symposium (Paris, 02-05/02/2009)(2 pers)

Field missions:

- La Silla, ESO, Chile, 2 - 6 August 2009. EFOSC observations on NTT (Frémat)

Commissions, working groups:

- CoRoT B star working group meeting (Leuven: 13/07/2009)(De Cat)
- CoRoT O star working group meetings (Leuven: 25/05/2009 & 13/07/2009)(De Cat)

Research visits:

- 8 1-day visits to the Inst. voor Sterrenkunde, K.U.Leuven (De Cat)

I. Instrumentation

The development of new instrumentation is the mandatory path to a better understanding of the universe and its content. By participating to such an undertaking, we contribute to something which profits to a larger scientific community, while ensuring ourselves a profound knowledge of the instrument and its capabilities.

I.1. Project "Humain Optical Observatory for Astrophysics of Coeval Stars" (HOACS)

I.1.1. 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 an adequate site for the construction of a small optical observatory. The aim is to operate a small but well-equipped observatory which will be dedicated to a few specific observational programmes. The project named HOACS was launched with the goal to perform photometric observations of (intrinsic as well as extrinsic) variable stars under sky conditions which are far better than those in the region of Brussels, in support of the ongoing astronomical research projects of the observatory.

I.1.2. Progress and results

Since Nov. 2008, the small optical observatory is fully operational with two telescopes in use. In February, a new focuser with temperature control was mounted in the Newton focus of the Humain light collector 1 (which also implied a change in position of the mirror M1) (Fig. 3). Observations were regularly performed with both telescopes and their instruments during 2009. A complementary system for taking flat-field calibration images was also put into place (using an EF flatfield foil). In total, we secured over 10.000 CCD images and 138 hours of photometric data in three filters (B, V and clear).

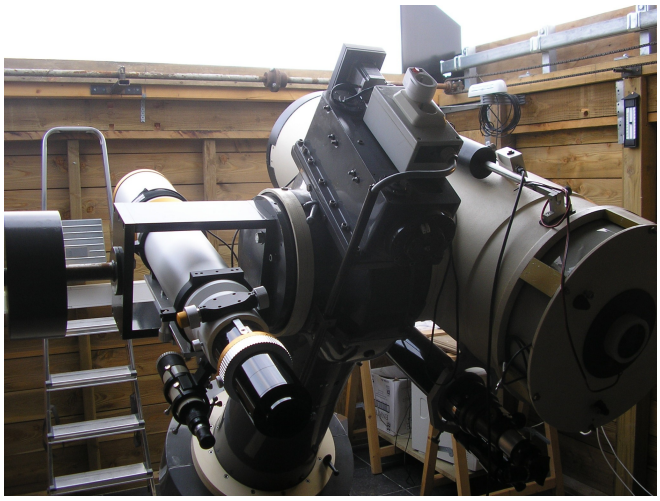


Figure 38: The Humain light collector 1 (HULC1) at the radio-astronomy site of the Royal Observatory of Belgium (March 2009).

Our first-priority targets were: the pulsating Delta Scuti star HD 68725 (22 hours), the oEA star HIP 7666 as well as five high-amplitude Delta Scuti stars (cf. B.1.2.1). In addition, individual eclipses of several eclipsing binaries were observed R.1 (including two low-mass binaries (24 + 32 hours) in a collaboration with Dr. J. Southworth) and we monitored the light curves of 3 targets of our sample of suspected A/F-type binaries. The observations were performed with the help of P. Van Cauteren, who also did the data reduction.

I.1.3. 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".

I.1.4. Personnel involved

Scientific staff: P. Lampens

Technical staff: V. Rogge, P. Janssens

Volunteers: P. Van Cauteren

Visitors

> Mr. A. Matthijs, provider of the Mini-Mount with its 0.4-m telescope (HULC1) (15/02)

> Dr. A. Strigachev, Institute of Astronomy, Sofia, Bulgaria (22/03)

> Representants of the LHOIST company (29/10)

I.1.5. Missions

Field missions

> Jan - Dec. 2009: Differential CCD photometry of selected Delta Scuti and eclipsing variable stars, Humain, Belgium, 2 x 0.4-m telescopes equipped with SBIG CCD camera's (15 nights, Lampens & Van Cauteren)

J. Stellar winds and circumstellar structures

The theme around stellar winds and circumstellar material splits in several poles of interest (other themes are also discussed further on in the report): 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 J.1 concentrates on the understanding of the structure by confronting observations and theory (using hydrodynamic and radiative transfer modelling).

The study of AGB stars (project J.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 J.3 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.

J.1. Hot stars

J.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 single and binary stars, by studying these stars both observationally (at various wavelengths) and theoretically (by constructing models for the hydrodynamics and radiative transfer).

J.1.2. Progress and results

J.1.2.1. Non-thermal radio emitters

R. Blomme, M. De Becker, and G. Rauw obtained data from the binary star Cyg OB2 No. 8A with the Very Large Array (VLA) radio interferometer, and found the signature of non-thermal radio emission. This binary consists of an O6If primary and an O5.5III(f) secondary. Each of these stars has a strong, radiatively-driven stellar wind. Where the two winds collide, shocks are formed and around these shocks electrons are accelerated to relativistic speeds due to the Fermi acceleration mechanism. These electrons then spiral around magnetic field lines and thus emit synchrotron radiation, which we detect at radio wavelengths.

The VLA data show that the radio flux is locked to the orbital phase. This is actually quite unexpected, as it was assumed that in this relatively short-period binary all synchrotron emission would be absorbed by the free-free absorption of the stellar winds. To better understand this, we therefore needed to develop more detailed models.

D. Volpi in collaboration with R. Blomme developed the code to obtain a more realistic time evolution of the radio synchrotron emissivity from electrons along the wind post-shock streamlines. The code calculates the non-thermal three-dimensional total flux around the shock area taking into account the different orbital phases of the secondary with respect to the primary and the inclination angle with respect to the observer. The simulated synchrotron emissivity originates close to the shock (Figure 39)

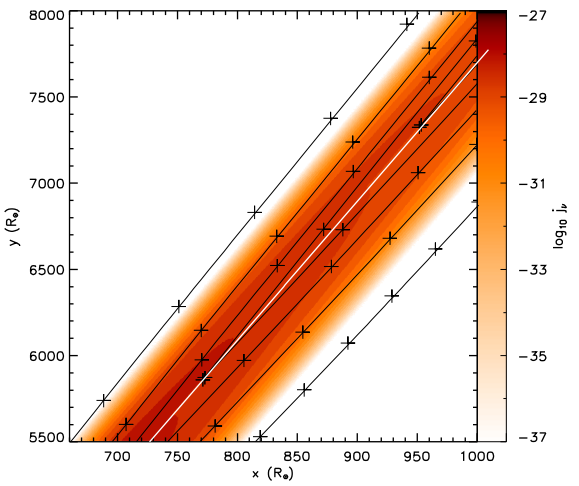


Figure 39: The simulated radio synchrotron emissivity from Cyg OB2 No. 8A. The non-thermal radiation appears concentrated close to the shock between the two stellar winds.

These models can indeed explain the orbit-locked flux variability, but problems remain in reproducing the observed times of minimum and maximum flux, as well as the spectral index (i.e. the relation between the fluxes at different wavelengths). Preliminary results were presented at workshops J.1.6R.3R.3 and presentation have now been submitted to A&A R.3.

In collaboration with J. Vandekerckhove, the reduction of radio data for another non-thermal radio emitter (9 Sgr) was continued. For three other radio non-thermal emitters, optical data were obtained with the HERMES spectrograph, and for one of them with the ESO FEROS instrument (PI and observer: C. Nitschelm, Co-I: H. Hensberge).

J.1.2.2. Structure in single-star winds

A. Lobel and J. Toalá Sanz further developed the Wind3D code for parallel processing of a new type of input models that can adequately parameterize large-scale wind structures in hot stars. These parameterized 3D models offer crucial advantages for high-performance radiative transfer computations over ab-initio hydrodynamic input models. The acceleration of the input model calculations permits us to investigate and model a much broader range of physical 3-D wind conditions with Wind3D. Results have been presented at the IAU General Assembly (presentation J.1.6). We compare the results to an accurate hydrodynamic model for DACs in HD 64760 (Figure 40), and apply the new parameterization method to best fit the detailed DAC evolution observed in another massive hot star HD 164402.

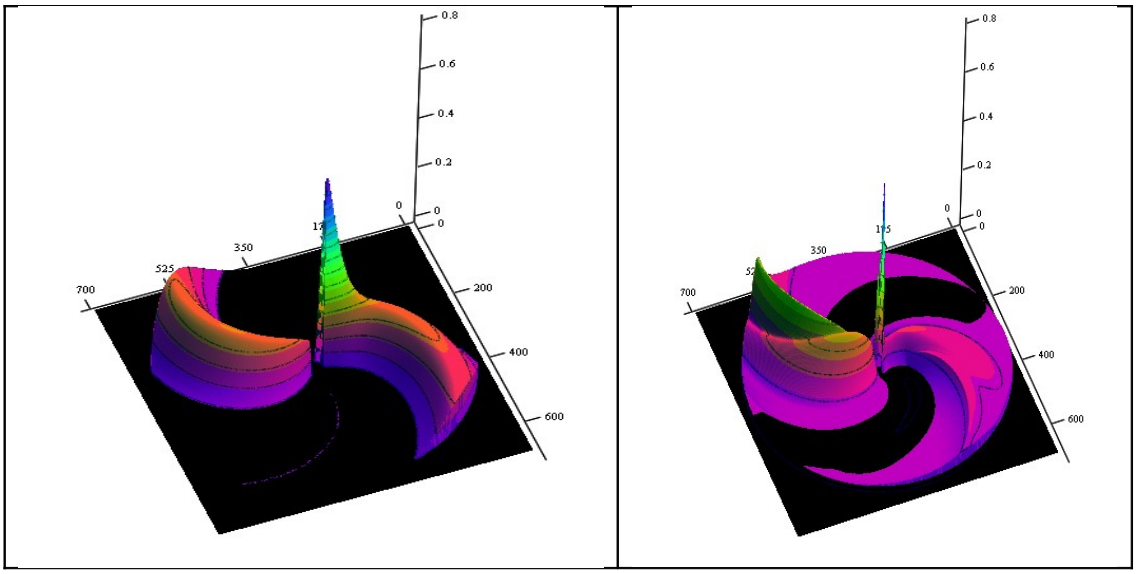


Figure 40. The left-hand panel shows the wind density structure of a parameterized model with two Co-rotating Interaction Regions extending over 30 R* from the surface in the plane of the equator. The param-eterized model is computed with the Wind3D code and best fits the hydrodynamic wind density structure of HD 64760 of Lobel & Blomme (2008), shown in the right-hand panel

The new method also adequately parameterizes the density-structure of input models for equatorial wind regions ("Rotational Modulation Regions" or RMRs) that cause Rotational Modulations in HD 64760. Rota-

tional Modulations are caused by a very regular pattern of radial density enhancements, almost linearly shaped across the equatorial wind (see presentation J.1.6). Parameterized modeling of Rotational Modulations reveals that nearly linearly shaped (rather "spoke-like") wind regions co-exist with more curved CIRs in the equatorial plane of this fast-rotating B-supergiant. This work also had a broader impact in the popular science literature (with publications in "Le Journal des Ingénieurs" and "Heelal").

R. Blomme and A. Lobel used the HERMES spectrograph to study three early-type stars, looking for variations in their stellar wind and photosphere. A preliminary reduction of the data reveals that two of these stars do indeed show variability in their Hα spectral line (which is due to variability in the stellar wind). Another HERMES proposal by A. Lobel for 5-year spectroscopic monitoring observations of eight Luminous Blue Variables was also accepted. Several of the target stars were observed in the course of 2009. A collaboration program was started for radiative transfer modeling of LBV spectra with J. Groh of MPIA-Bonn (Germany), K. Torres of ROB, and N. Gorlova of KUL-IVS, leading to a new long-term HERMES observing proposal for detecting and modeling LBV binaries (accepted Feb 2010). In Nov 2009 we also obtained new observations with XShooter, the new high-efficiency spectrograph of the VLT. It is used in a collaboration program with C. Martayan (ESO, Chile) for observing and modeling spectra of the Pistol Star, one of the most luminous (hot) stars known in the Galaxy.

In a large international collaboration program with C. de Jager and H. Nieuwenhuijzen (SRON Utrecht, The Netherlands), involving among others I. Kolka (Tartu Obs., Estonia), A. Maeder, and G. Meynet (Obs. de Genève, Switzerland), we study the time history of A-type hypergiant HR 8752 over a period of 32 years (1973 – 2005) using high-resolution spectra. We find that Teff gradually increased over this period from below 5,000 K to presently exceeding 8,000 K. The spectroscopic observations suggest that the star went through a number of successive gas shell ejections. After the ejected shells dissipate in space the star's hotter and more compact photosphere becomes visible.

In preparation of a study of thermal radio emission from a number of hot stars, R. Blomme continued the construction of a grid of models for their atmosphere and stellar wind, using the publicly available CMFGEN code. Such a grid of models will also be useful to interpret data that we obtained with XSHOOTER instrument (PI of the proposal: C. Martayan), HERMES and FEROS.

J.1.3. Perspective for next years

The reduction of existing and new radio data on thermal and non-thermal radio emitters will continue. R. Blomme will also reduce and interpret the optical spectra of HD 167971, in collaboration with H. Hensberge. Publications on the radio data of 9 Sgr and the optical data of HD 167971 have a high priority. Work on the e-MERLIN COBRaS project will continue and R. Blomme and J. Vandekerckhove will start reducing the data as they come in.

R. Blomme and D. Volpi will continue to model the non-thermal radio emission of colliding-wind binaries. They will explore the possibility to create a hydrodynamical model and will also model X-ray emission. For the thermal emitters, R. Blomme will continue the construction of a grid of models and will compare the output to the observations.

Research on multi-D radiative transfer modeling of hot star wind structures will be continued utilizing the high-performance computing facilities available at the ROB. Future research on hot stars will focus on determining the physical properties of large-scale wind structures (CIRs and RMRs) in massive stars other than HD 64760, based in part on the new parameterized input modeling method we introduced in 2009. The development of the Wind3D code with international collaborators will continue for performing multi-D radiative transfer calculations of LBVs based on our long-term HERMES monitoring programs.

J.1.4. Personnel involved

Scientific staff: R. Blomme, A. Lobel, D. Volpi

Technical staff: J. Vandekerckhove

J.1.5. Partnerships

- R. K. Prinja, University College London, UK
- E. Unda-Sanzana, C. Nitschelm, Universidad Católica del Norte, Chile
- J. Groh, MPIA-Bonn, Germany
- C. de Jager, H. Nieuwenhuijzen, SRON, The Netherlands
- A. Maeder, G. Meynet, Observatoire de Genève, Switzerland
- I. Kolka, Tartu Observatory, Estonia
- J. Toalá Sanz, University of Mexico UNAM, Mexico

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

- M. De Becker, G. Rauw, Université de Liège
- C. Aerts, KULeuven

Grants/Projects used for this research/service

- ROB contract A. Lobel, July 2008 – mid April 2009
- Action 1 project MO/33/024 (Colliding winds in O-type binaries)
- ROB funding

Visitors:

- I. Kolka, Tartu Obs., Estonia. From 16 to 20 Feb 2009. Research collaboration on modeling spectroscopic observations of the 2002 outburst of V838 Mon, discussion Cyg OB2 No. 12 and LBVs in general.
- J. Toalá Sanz, Univ. of Mexico. From 5 to 31 July 2009. Summer student research project on parameterized modeling of large-scale wind structures in massive hot stars with the Wind3D code.

J.1.6. Scientific outreach

Meeting presentations

[1] Blomme, R.
Non-Thermal Radio Emission from Colliding-Wind Binaries
Workshop "High Energy Phenomena in Massive Stars", Jaén, Spain, contributed talk

[2] Lobel, A., Blomme, R.
Radiative Transfer Modelling of Rotational Modulations in B Supergiant HD 64760
IAU XXVII General Assembly, Rio de Janeiro, Brazil, Joint Discussion 13, poster

[3] Lobel, A., Toalá, J. A.
Parametrized Structured Wind Modeling of Massive Hot Stars with Wind3D
IAU XXVII General Assembly, Rio de Janeiro, Brazil, Joint Discussion 13, poster

Seminars

[4] Volpi, D.
Nebulae blown by pulsar winds
Royal Observatory of Belgium, 03/12/2009

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

J.1.7. Missions

Assemblies, symposia:

R. Blomme (High Energy Phenomena in Massive Stars, Jaén, Spain)
A. Lobel (International Astronomical Union, XXVIIth General Assembly, Rio de Janeiro, Brazil.)

Research visits (days): R. Blomme (3)

J.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. In the cool circumstellar shells dust usually forms, and in this way, AGB stars are also very important contributors to the dust content in the ISM.

J.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.

J.2.2. Progress and results

J.2.2.1. Spitzer data of evolved stars in the Magellanic Clouds

M.Groenewegen finished the work started in 2008 on analysing a sample of 200 evolved stars in the Small and Large Magellanic Clouds for which have Spitzer IRS spectra available. This sample contains all AGB and RSGs (Red Super Giants) for which these spectra were publically available end-2008. The spectra were reduced in a uniform way by collaborator Greg Sloan. The spectra are supplemented with all available optical, near- and mid-infrared broad band data. In addition, pulsation periods are derived from published light curves, but also from new OGLE-III data, made available by collaborator Igor Soszynski. Then, the SED (spectral energy distributions) are fitted with the radiative transfer code modified and extended in 2008, testing different grain types and spectral atmospheres. The results are published in R.1. They confirm earlier work in that the mass-loss rate does not seem to depend on metallicity of the parent galaxy. The observed distribution of mass-loss rate and luminosities are compared to theoretical models that have two different prescriptions of the mass-loss process, that by Vassiliadis & Wood (1993) and Reimers' law. The Vassiliadis & Wood models overall give the best results. One star with a pulsation period of 1749 days and a bolometric magnitude of -8.0 is found: These properties make it the best observational candidate for a super-AGB star.

J.2.2.2. NIR spectroscopy of AGB stars in nearby Galaxies

M.Groenewegen, together with collaborators Lancon and Marescaux, published the results of a study on NIR spectroscopy of 2MASS selected AGB stars candidates in R.1. J- and H-band spectra of 36 objects in the Local Group galaxies Fornax, NGC 6822 and Sculptor were obtained with ISAAC. The stars have been selected from 2MASS colours and magnitudes. In Fornax twelf new C-stars were identified, and one in Sculptor. Ten new oxygen-rich stars were identified in Fornax, and 5 in NGC 6822. For some of the reddest C-stars (J-K >2) a very strong absorption feature at 1.53 micron is identified. These stars are probably all Mira variables.

J.2.2.3. VISTA-VMC

M.Groenewegen is involved in 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) survey. M.Groenewegen will lead the effort in the field of AGB stars.The commissioning of the telescope will be carried out in the winter of 2009/2010.

An Action 1 project was written and submitted (involving J.Cuypers as well) and approved. A job advertisement was put out, and a very suitable candidate accepted the offer. He will start his 2 years postdoc position in March 2010.

J.2.2.4. Other related research

M.Groenewegen was involved and contributed to several other projects that led to a publication in 2009.

Most importantly, may be, the work by Sloan et al. (R.1) published in Science. It demonstrated for the fist time that significant dust production occurs even in galaxies with low metallicity. This paper was mentioned in the media: e.g. in the Flemish weekly KNACK.

The results obtained by M.Groenewegen in R.1 were used by Matsuura et al. (R.1), who studied the gas and dust budget of the Large Magellanic Clouds.

Lagadec et al. (R.1) studied carbon stars in the Sagitarius Dwarf Galaxy and found molecularfeatures that are equally strong than in Galactic C-stars. This was unexpected as one traditionally assumes this galaxy to be metal-poor. The conclusion of the paper is that the ISM in Sagitarius must have been strongly enriched.

The work by Vanhollebeke et al. (R.1) involved a modeling of the structure of the Galactic Bulge using the TRILEGAL code, and by comparing observed number counts and colours of OGLE and 2MASS observations to model predictions. The main parameters derived are: distance Sun-Galactic Centre,R0 = 8.7±0.5 kpc, the major axis ratios of the bar $1:\eta:\zeta = 1:0.68\pm0.1:0.31\pm0.05$, and the angle between the Sun-centre line and the bar $\varphi = 15\pm13$ degrees.

In Van Winckel et al. (R.1), M.Groenewegen had a minor contribution by providing some observations

J.2.3. Perspective for next years

In the course of 2010 additional spectra will become available from Spitzer IRS programs that are currently ongoing, and a final analysis of late-type stars in the Magellanic Clouds can be undertaken. A refinement that also will be made on that timescale is to replace the relatively simple model atmospheres for M- and C-stars by highly sophisticated MARCS model atmospheres.

The first VISTA-VMC data will become available in 2010 and will require a substantial effort in analysis. The majority of the work will be done by the postdoc starting on the Action 1 project in March 2010.

J.2.4. Personnel involved

Scientific staff: M. Groenewegen

J.2.5. Partnerships

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

- Greg Sloan, Cornell University
- Ariane Lancon, Strasbourg University
- Igor Soszynski, Warsaw University
- Mikako Matsuura, UCL

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

- Grant nr. C90371 from PRODEX

J.2.6. Scientific outreach

Meeting presentations

[1] Groenewegen, M.A.T.
Mass loss of AGB stars and RSGs in the Magellanic Clouds
Oral presentation at: ``Intermediate Mass Stars and Massive Stars. A workshop around causes and consequences of different evolutionary paths''

[2] Groenewegen ,M.A.T
The predicted spectral properties of AGB stars
Oral presentation at: workshop "The Giant Branches"

[3] Groenewegen, M.A.T.
Long Period Variables as tracers of Galactic Structure
Invited presentation at: IAU Special Session 8, Rio de Janeiro

[4] Groenewegen, M.A.T.
MESS: Mass loss of Evolved Stars
Oral presentation at: ``Herschel SDP Initial Results Workshop'', Madrid

Seminars

[5] Groenewegen, M.A.T.
The life cycle of dust in AGB stars
Observatory in Vienna

[6] Groenewegen, M.A.T.
Mass loss of AGB stars and RSGs in the Magellanic Clouds
Uppsala University

J.2.7. Missions

Assemblies, symposia, conferences:

M. Groenewegen:
- Intermediate Mass Stars and Massive Stars. A workshop around causes and consequences of different evolutionary paths, Strasbourg, 9-11 Feb 2009
- The Giant Branches, Leiden Lorentz center, 11-15 May 2009
- IAU SpS 8, Rio de Janeiro, 11-14 Aug. 2009
- The Milky Way and the Local Group - Now and in the Gaia Era, Heidelberg, 31/8-4/9 2009
- Mega-SAGE # 2 & HERITAGE Meeting #1, CEA Saclay, Sept 7 - 11, 2009
- Herschel SDP DP Workshop, ESAC, Spain, 14-16 Dec. 2009
- Herschel SDP Initial Results Workshop, Madrid, Spain, 17-18 Dec 2009

Commissions, working groups:
- M .Groenewegen (5)

Research visits:
- M. Groenewegen (10)

J.3. Post-AGB stars and Planetary Nebulae

J.3.1. Objectives

In this project the final stages of evolution of intermediate mass stars, i.e. the evolution from the asymptotic giant branch (AGB) through the planetary nebula phases are studied. 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 for astrophysical processes.

J.3.2. Progress and results

J.3.2.1. 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 the next 5 to 10 years. In an international collaboration we are monitoring this evolution. We have obtained new optical spectra (FORS2, VISIR on the VLT) in 2009 and a new proposal for VLT FORS2 and VISIR observations in 2010 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.

J.3.2.2. Evolved objects in binaries: the evolutionary connection

The Hermes spectrograph in combination with the Mercator telescope is a unique tool to study binary evolutionary channels. This 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. Within this project Griet Van de Steene is responsible for the data of the sample post-AGB stars.

She has selected the sample on specific criteria, searched the literature for information, defined the exposure times, collected (archived) data, retrieved and reduced data obtained, etc

J.3.2.3. 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 responsable for the shaping originate. We have used ESO's Very Large Telescope Interferometer with the MIDI and AMBER instruments 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.

J.3.3. Perspective for next years

The projects described above are ongoing and will be continued. Data of Herschel (see section J.4) and Hermes are coming in, will be processed, analysed, and first results will be presented at conferences.

J.3.4. Personnel involved

Scientific staff: G. Van de Steene, P. Van Hoof

J.3.5. Partnerships

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

- Toshiya Ueta, University of Denver, USA
- MESS consortium

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

- H. Van Winckel, IVS, K.U.Leuven
- A. Jorissen, ULB
- S. Van Eck, ULB
- T. Masseron, ULB
- T. Dermine, ULB
- N. Gorlova, KULeuven IVS
- R. Oestensen, KULeuven IVS
- K. Exter, KULeuven IVS

Visitors:

- Toshiya Ueta, University of Denver, 20 October 2009

J.3.6. Scientific outreach

Wikis and Websites

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

J.3.7. Missions

Assemblies, symposia, conferences:

- P. Van Hoof: Annual meeting Dutch Astronomers Club, Utrecht, The Netherlands
- P. Van Hoof: RAS meeting on super-AGB stars, London, UK

Field missions:

- P. Van Hoof (11 days)

Commissions, working groups:

- G. Van de Steene (2 days)
- P. Van Hoof (2 days)

J.4. The Herschel Guaranteed Time (GT) Key Programme (KP) MESS (Mass-loss of Evolved StarS)

J.4.1. Objectives

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 percent 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.

J.4.2. Progress and results

Herschel was successfully launched May 14, 2009. It then took 3 months to reach the L2 Lagrange point, followed a 2 month performance verification phase in which the satellite was tested and calibrated. After that the science demonstration phase (SDP) started in which a selection of targets from various key programmes were observed.

PACS and SPIRE images of the "Ring Nebula" NGC6720 were obtained during the SDP (see Figure 41). A first reduction of the data was done. The images have been prepared for presentation during the "Initial results workshop" in Madrid in December 2009. A progress report was presented at the 2nd MESS consortium meeting in Leuven (presentation J.4.5).

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 GT KPs using Belgian time, was approved. P. van Hoof started working on this project on 1 May 2009 and is involved in the analysis and modeling 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 L.1) that are needed for modeling 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.

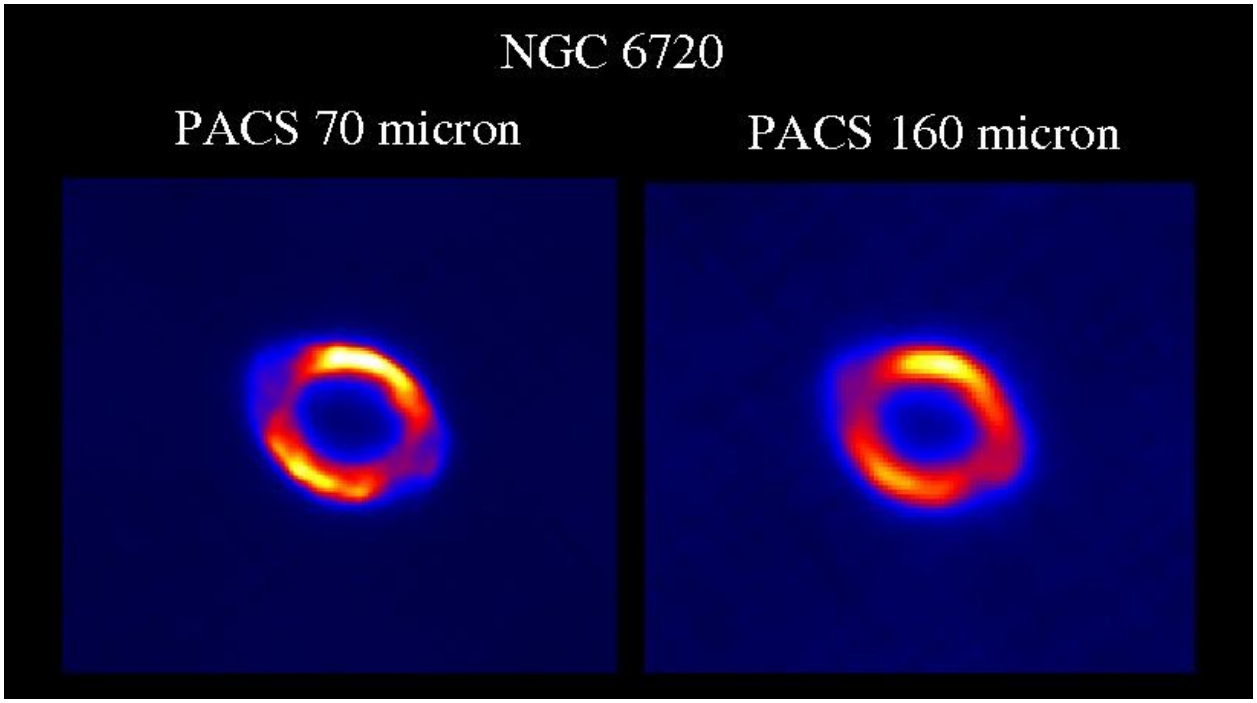


Figure 41. PACS images of the Ring Nebula NGC6720

J.4.3. Perspective for next years

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.

J.4.4. Partnerships

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

- Albert A. Zijlstra, University of Manchester, stellar evolution expert
- Marcin Hajduk, Centrum Astronomii, Torun, radio expert
- MESS consortium

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

- Katrina Exter, Katholieke Universiteit Leuven, Herschel data reduction expert

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

- PRODEX grant no. C90371 (1 May – 31 December)

J.4.5. Scientific outreach

Meeting presentations

[1] van Hoof P.A.M., Van de Steene G.C., Groenewegen M.A.T., Exter K.
NGC 6720 - PACS
2nd MESS Consortium meeting, Leuven

J.4.6. Missions

Assemblies, symposia, conferences:

- 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)

- M. Groenewegen (5)
- P. van Hoof (5)

Research visits (days)

- R. Groenewegen (10)

K. 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.

K.1. γ Doradus stars observed with the Mercator telescope

Research on variables stars leads to a better knowledge of stellar structure and evolution. Astero-seismology in particular, refers to the study of the internal structure of pulsating stars through the interpretation of their frequency spectra. In order to achieve this goal, observation and detection of the variability of the stars, a first characterisation and a precise analysis of the observed periodicities is necessary. The emphasis of the research carried out here, is on detection of periodic variability in pulsating variable stars in general, and γ Doradus stars in particular.

The general project variable stars and asteroseismology includes several subtopics, but all are not listed separately. There is also some overlap with the Gaia project described elsewhere.

K.1.1. Objectives

The class of γ Doradus stars has now over 60 members. These stars have spectral types late A or F, luminosity class IV or V and exhibit periodicity in the light variations with periods in the range 0.3 to 3 days. There is no doubt that the cause of the variations is pulsation. The modes are high-order gravity modes (g modes), excited by a flux blocking mechanism at the base of the convective envelope of the stars. Because the g modes probe the deep stellar interior the γ Dor stars are excellent targets for asteroseismology. A selected group of γ Dor stars and some extra candidates were observed with the Mercator telescope in order to find and/or confirm the periodicities in the light variations and to derive reliable amplitude ratios in different pass bands. Observational data from other telescopes and instruments will be used to study the physical parameters of this class of variable stars.

K.1.2. Progress and results

The in-depth analysis of the observations in the seven colours of the Geneva photometric system obtained by the Mercator telescope operated at La Palma by the Institute of Astronomy of the KULeuven was finished. The data were combined with observations from other telescopes. A paper with frequencies and amplitudes in the photometric pass bands of the Geneva photometric system was finalised and published in A&A R.1. The asteroseismological mode identification has started by A. Miglio and colleagues from Liège and Leuven, but no results are available yet.

A study of the physical parameters of γ Dor stars based on photometric data was initiated. A programme to calculate temperature and log g for these stars was made by job student Tom Hendrix in august 2009.

K.1.3. Perspective for next years

J. Cuypers will contribute to the initiated seismological study of the analysed γ Doradus stars and the general studies on this group of variables. The variable A and F stars observed by the Mercator telescope but not (yet) classified as confirmed γ Doradus variables, will be analysed separately. γ Doradus stars observed with space telescopes as CoRoT and Kepler will be selected for further study.

K.1.4. Personnel involved

Scientific staff: J. Cuypers

K.1.5. Partnerships

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

- Prof. Dr. C. Aerts, Instituut voor Sterrenkunde, K.U.Leuven
- Observers at the La Palma Telescope, present or former members of the Instituut voor Sterrenkunde, K.U.Leuven (co-authors of the paper)

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.

K.1.6. Missions

Assemblies, symposia, conferences:

- J. Cuypers: First CoRoT International Symposium, CNES/Helas III/Observatoire de Paris, Paris, 02-05/01/2009

Research visits:

- J. Cuypers (2)

K.2. Cepheids

K.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 H0-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 zeropoint depend on metallicity? (There is evidence for it, but it is partly contradicting). The study of Cepheids aims at improving our understanding of the Cepheid PL-relation.

K.2.2. Progress and results

M.Groenewegen started to work on an extension of the work published in 2008 where he derived distance estimates for a sample of about 60 galactic Cepheids. The distances were based on the so-called Baade-Wesselink (BW-) method, where variations in radial velocity are transformed to variations in absolute radius, and linked to variations in angular diameter, derived from variations in colours using so-called surface-brightness-relations. In that study, Groenewegen collected all galactic Cepheids for which sufficient optical V-band, infrared K-band and radial velocity data was available.

Although the sample was certainly not small, no significant metallicity effect on the PL-relation was found. The effect is certainly not very large, but a larger sample is needed to reduce the errorbar. When a surface-brightness-relation in V- and R-band is used, the sample of Galactic stars with available photometry and metallicities can be much enlarged. In 2009, M.Groenewegen has collected all relevant data from the literature. The analysis will be completed in 2010.

M.Groenewegen was also involved in the paper by Pedicelli et al. (R.1) which studied the metallicity gradient in the Galaxy, by using Cepheids.

K.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.

K.2.4. Personnel involved

Scientific staff: M. Groenewegen

K.2.5. Partnerships

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

- Martino Romaniello, ESO
- Giuseppe Boni, INAF-Rome
- Silvia Pedicelli, INAF-Rome

K.3. Analysis of data from the CoRoT satellite

K.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.

K.3.2. Progress and Results

K.3.2.1. Classification of variable stars

A large fraction of the stars observed by CoRoT are variable stars, most of them previously unknown. These variable stars had to be identified and classified. The work on automatic classification of variable stars in collaboration with Jonas Debosscher (KULeuven) and Luis Sarro (Madrid) is now finished. This information has been implemented in the tools developed for the classification of the variable stars of large surveys and the variables detected by the satellite CoRoT. Now the classification methods are also being adapted for the satellite Gaia (see also the report on the Gaia satellite).

A pipeline for fast supervised classification of light curves delivered by the CoRoT Exoplanet CCDs has been developed and the classification results obtained for the first four measured fields, which represent one-year in-orbit operation, were summarized in an article, published in Astronomy and Astrophysics R.1.

K.3.2.2. Analysis of CoRoT variable B an O stars

The CoRoT classification team has sent in 2008 to the ROB a set of candidate variable B-stars observed in the exofield during IRa01 (initial run, anti-centre direction, 55 days), but these data were in 2009 merged with all the data from candidate variable B-stars. J. Cuypers and P. De Cat collaborated in the finalisation and the summary of the results. A paper appeared in the special issue of Astronomy and Astrophysics on CoRoT R.1

R. Blomme also leads the reduction of the CoRoT data for the O-type star HD46510 (in collaboration with J. Cuypers and collegues from Leuven and Liège). Preliminary results on the temporal behaviour of the variations were reported at meetings of the BAG group on O (and B) stars. Other O stars observed by CoRoT were analysed as well and compared with this object. No similarities were found, making HD 46150 a difficult but intriguing object for further study.

K.3.3. Perspective for next years

More data will become available from the CoRoT satellite in the next years. J. Cuypers will continue to analyse and interpret data, mostly of candidate B type variables, in close collaboration with P. De Cat (ROB) and the Leuven and Liège team. R. Blomme and J. Cuypers will further collaborate on the analysis of observations of O stars by CoRoT.

K.3.4. Personnel involved

Scientific staff: J. Cuypers, R. Blomme

K.3.5. Partnerships

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

- Luis Sarro, Artificial Intelligence Department, UNED & Virtual Observatory, Spain
- 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

- Institute of Astronomy (Conny Aerts, Jonas DeBosscher and others), Department of Physics and Astronomy, K.U.Leuven
- Institut d'Astrophysique et de Géophysique, Liège (Andrea Miglio)
- CoRoT B star working group (Chair: C. Aerts)
- CoRoT O star working group (Chair: C. Aerts)

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.

K.3.6. Scientific outreach

Meeting presentations

[1] Blomme, R., Cuypers, J.
HD 46150, O5V ((f))
CoRoT meeting, ROB, contributed talk

[2] Blomme, R., Cuypers, J.
HD 46150, O5V ((f))
CoRoT meeting, KULeuven, contributed talk

[3] Blomme, R., Cuypers, J.
HD 46150, O5V ((f))
CoRoT meeting, Liége, contributed talk

K.3.7. Missions

Assemblies, symposia, conferences:

- J. Cuypers: First CoRoT International Symposium, CNES/Helas III/Observatoire de Paris, Paris, 02-05/01/2009

Commissions, working groups:

- R. Blomme (2)
- J. Cuypers: (5)

K.4. Analysis of data from the Kepler satellite

K.4.1. Objectives

KEPLER (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.

K.4.2. Progress and results

J. Cuypers did a "first look analysis" on the data for candidate SPB and γ Doradus stars.

K.4.3. Perspective for next years

As soon as more data will become available, J. Cuypers will participate in the analysis of B variables and γ Doradus stars.

K.4.4. Personnel involved

Scientific staff: J. Cuypers

K.5. The chemically peculiar star HD 158450

K.5.1. Objectives

The research summarized here deals with very temporary projects on chemically peculiar stars from previous international cooperations.

K.5.2. Progress and results

The chemically peculiar star HD 158450, belonging to the recently detected sparse stellar group Mamajek 2, was found to have a very large magnetic field (> 10 kG) by N. Drake and collaborators. The spectroscopy revealed an enigma, presenting time-invariable magnetic line splitting while polarimetry revealed a strongly time-variable longitudinal field component. As a consequence of discussions with N. Drake during the visit at ON, Rio de Janeiro, H. Hensberge analysed photometry from the all-sky ASAS project and from the Hipparcos satellite. In combination with the constraints set by the longitudinal field variability, he derived the rotation period of 8.5 days and showed that the 4 spectra on which line splitting measurements were performed covered less than 10% of the rotation cycle, explaining the lack of variability. High-resolution spectroscopy can now be planned efficiently.

As a result of a long-standing cooperation with the University of Vienna (in particular with H.M. Maitzen), a paper on rotation periods of chemical peculiar stars in open clusters was submitted for publication R.3.

K.5.3. Perspective for next years

Participation in a paper on the rotation-induced variability of HD 158450.

K.5.4. Personnel involved

Scientific staff: H. Hensberge

K.5.5. Partnerships

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

- N. Drake, Observatorio Nacional Rio de Janeiro, Brazil and Sobolev Astronomical Institute, St. Petersburg State University, Russia (magnetic field HD 158450)
- E. Paunzen, Institut für Astronomie, Univ. Wien, Austria (organisation paper)

K.6. Binary Stars in young stellar groups

K.6.1. Objectives

Binaries are an important source of precise fundamental stellar parameters and hence provide empirical constraints on stellar evolution. In stellar groups, they provide anchor points for the interpretation of the whole

stellar population. Main goals: characterize the binary population in young stellar groups (Sco-Cen, NGC 2244) and perform a detailed analysis of the most interesting close binaries (mostly, but not exclusively, in these groups) using the novel spectral disentangling technique.

K.6.2. Progress and results

This subsection summarizes the progress made applying the spectra disentangling technique on five specific multiple sysems of diverse character and collecting observations on two more such systems.

During the mission of H. Hensberge at UFMG, progress was made in analysing the young multiple star RV Crt, consisting of a late-F + late-G/early-K close binary with a sharp-lined late-F wide component and, as revealed now, a spectroscopically yet undetected fourth star. At least the cooler close-binary component is not yet on the main-sequence.

Based on photographic plates from the start of the twentieth century on, on photo-electric photometry later-on photometry and on the newest CCD photometry (ASAS), a preliminary wide, very eccentric 104-yr orbit between the dominant star in the observed spectra and the close-binary components was derived. The modern data suggest strongly the presence of a fourth star revolving around the close binary in roughly 14 years. This allowed H. Hensberge and L.P. Vaz to update the close-binary ephemeris and the final close orbit is now obtained with higher accuracy. Two papers, one dealing with the orbits, and an accompanying one presenting the observed spectra and the derived component spectra, and dealing in more detail with technical aspects, progressed well. There is a large potential to improve the wide orbit, depending on access to the plates and a measuring machine to obtain high-precision photographic photometry.

In cooperation with R. Blomme (PI) and C. Nitschelm (observer), spectra of the multiple O-type star HD 167971 at lacking orbital phases were obtained with the FEROS spectrograph at ESO. The data set is now sufficiently complete for a spectra disentangling analysis, planned in 2010. For the integration of this analysis with the (ellipsoidal, grazing eclipse) light variations, a cooperation with L.P. Vaz at UFMG, who integrated the Wilson-Devinney code with the spectra disentangling code, was initiated.

During the mission of H. Hensberge at the Observatorio Nacional (ON) in Rio de Janeiro, progress was made in the analyis of two early-type binaries and one chemical peculiar magnetic star (see section K.5 for the latter). High-resolution spectra of the early-B multiple star HD 57370A, the brightest member of the open cluster NGC 2367, obtained, reduced and normalised by the group of S. Daflon were analysed. H. Hensberge derived the 6-day orbital period and showed that there is a third component in the system with an orbital period of the order of one year (varying system velocity of the close binary in different observing runs). The third component is not (yet) detected in the spectra. Disentangled component spectra and close-binary orbital parameters were derived. A detailed abundance analysis by S. Daflon is revealing the relative light contributions of the components, and H. Hensberge is using the jackknife statistical technique to estimate uncertainties on the orbital parameters and the component spectra. It will be the first time that uncertainty estimates are obtained on Fourier-disentangled spectra.

The second project with ON concerns the spectroscopically triple system HD 208905 in the Cep OB2 stellar association, which includes also reserachers from Ondrejov Observatory (Czechia) leaded by P. Koubsky. A particular difficulty in the analysis is that many wavelength regions were covered with few spectra, only the set of Ondrejov in a small wavelength region covering the very eccentric orbit satisfactorily. A first analysis by H. Hensberge shows that the component spectra in other wavelength regions can still be recovered once the orbital parameters are fixed by the Ondrejov set. Further progress awaits the definitive analysis from the Czechian colleagues.

The analysis of the spectra of the Hyades binary θ^2 Tau is finished R.3. It consists of two late-A type components. For the first time the velocity amplitude of the secondary (which constrains the mass of the primary) was revealed. The light ratio of the close binary components was fixed from astrometry and spectroscopy. H. Hensberge contributed to the spectra disentangling analysis that was performed mainly by Kelly Torres. Spectra obtained recently with the HERMES spectrograph were added to the existing data set. The draft of the publication is in a final stage. More details can be found in the report of ROB collaborators Kelly Torres, Patricia Lampens and Yves Frémat.

With V. Bakis, the analysis of the triple system V831 Cen was continued. H. Hensberge investigated additional spectral regions applying the spectra disentangling method. V. Bakis obtained in Turkey finances for an international cooperation in the framework of the EVRENA project on Algol binaries, with participation of researchers from Turkey, Slovakia, Chile and Belgium (H. Hensberge), using observing infrastructure in both hemispheres. Observing time on the HERMES spectrograph was used to obtain spectra at critical orbital phases for the system V559 Cas in an observing run performed by K.B. Torres.

Finally, an invited review on spectra disentangling was prepared by H. Hensberge and K. Pavlovski R.3 and presented by the latter in an international meeting on binary stars in Brno.

K.6.3. Perspective for next years

The study of the specific multiple systems mentioned in this report, and not yet finished, will be continued, with priority on RV Crt (2 papers almost finished), HD57370A and HD 167971 (start of disentangling analysis planned in mid-2010). . The cooperation with the research group of V. Bakis in the framework of his international project on Algols will be expanded during a one-month visit at Canakkale, Turkey, in the summer of 2010.

K.6.4. Personnel involved

Scientific staff: H. Hensberge, R. Blomme

K.6.5. Partnerships

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

- L. P Vaz, UFMG, Belo Horizonte, Brazil (analysis wide orbit and RV Crt)
- S. Daflon, Observatorio Nacional, Rio de Janeiro, Brazil (participation in analysis HD 57370A and new observations; analysis work on HD 208975)
- C. Nitschelm UCN, Antofagasta, Chile (observer HD 167971)
- V. Bakis, Onsekiz Mart University, Canakkale, Turkey (participation in analysis V831 Cen, financement Evrena project on Algol binaries)
- K. Pavlovski, Univ. of Zagreb, Croatia (review on spectra disentangling)

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

- K. B. V. Torres, ROB (spectra RV Crt, analysis θ^2 Tau)
- P. Lampens, Y. Fremat (analysis θ^2 Tau)
- R. Blomme (preparation observations HD 167971)

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

- Grant nr.680.026/2006-1 from Conselho Nacional de Pesquisa (CNPq), Brazil (local expenses mission at ON)

K.6.6. Scientific outreach

Meeting presentations

[1] Pavlovski K., Hensberge, H.
Reconstruction and Analysis of Component Spectra of Binary and Multiple Stars (invited review)
Brno, Czech Republic, Int. Conf. "Binaries - Key to Comprehension of the Universe", June 8-12

Seminars

[2] Hensberge H.
Modern analysis techniques for spectroscopic binaries, with emphasis on collaborations with ON
Observatorio Nacional, Rio de Janeiro, October 6, 2009

[3] Hensberge, H.

Modern analysis techniques for spectroscopic double stars
Universidad Catolica del Norte, Antofagasta, Chile, May 20, 2009

K.6.7. Missions

Research visits:

- August 18 - October 8 : Observatorio Nacional, Rio de Janeiro, Brazil: scientific cooperation with S. Daflon and cooperators
- October 20 - December 21 : Universidad Federal Minas Gerais, Belo Horizonte, Brazil: scientific co-operation with L. P. Vaz

K.7. Young Stellar Groups: Scorpius-Centaurus and NGC 2244

K.7.1. Objectives

Hot stars in the young stellar groups Sco-Cen and NGC 2244 are analyzed spectroscopically with the purpose to characterize these stellar populations in general and, as a long-term goal, to measure the internal velocity dispersion in the Sco-Cen association and the open cluster NGC 2244. The latter goal requires the identification of binaries, and the first one uses fundamental parameters of binaries as anchor points.

K.7.2. Progress and results

During the mission of H. Hensberge at UCN in Antofagasta, the photometry made at CTIO (Cerro Tololo Inter-American Observatories) by C. Nitschelm and students, with the purpose to study variable stars in the very young open star cluster NGC 2244, was reduced up to the point of extracting the fluxes. Special attention is paid to a close-binary with a very short apsidal-motion period of the order of 30 years, modulating the eclipsing light-curve strongly, and to a strongly magnetic star. One student was instructed in the methods used to analyse the quality of the electronic detector, with read-out over 4 ports. One quarter of the detector was found to behave erratically in many pixels, probably due to the read-out system. Another student made her research work for the end of the undergaduate studies performing a critical analysis of all astrometry available for NGC 2244. It became clear that a global analysis of all plate material, with the method developed by a Colombian group can improve significantly the impact of the astrometry on the conclusions about the membership of tens of stars with presently conflicting indications. This work also profited from cooperation with Gh. Deridder (Toronto, Canada). Both studies were defended in December 2009. In addition, H. Hensberge participated in a short observing mission at the Cerro Armazones Observatory of the Universidad Catolica del Norte to evaluate the usefulness of the BESO (Bochum) echelle spectrograph.

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 a final stage. As a by-product, several other types of variables stars were detected, namely various pre-main sequence stars and a few pulsating stars.

K.7.3. Perspective for following years

The CTIO photometry obtained in NGC 2244 will deliver light curves of variable star. Depending on manpower, the existing astrometry for NGC 2244 will be re-analysed in detail. The results on light variables in Sco-Cen will be published.

K.7.4. Personnel involved

Scientific staff: H. Hensberge

K.7.5. Partnerships

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

- C. Nitschelm UCN, Antofagasta, Chile (observer CTIO ccd photometry)

- F. Pozo Nuñez, UCN, Antofagasta, Chile, (study ccd detector used at CTIO)
- A. Barr Dominguez, UCN, Antofagasta, Chile (study of astrometry NGC 2244)
- Gh. Deridder, free researcher, Toronto, Canada (analysis Walraven photometry and astrometry NGC 2244)

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

- M. David, UA (Sco-Cen, analysis of ASAS data)

K.7.6. Missions

Research visits:

- March 29 - May 27 : Universidad Catolica del Norte, Antofagasta, Chile: scientific cooperation with C. Nitschelm; accompanying undergraduate thesis work of two students; evaluation of spectrograph at Hexapod telescope of Bochum University at Cerro Armazones observatory of UCN

L. Astrophysical 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.

L.1. The Photoionization Code Cloudy

L.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 photo-dissociation 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 modeling 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.

L.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. H2 formation), and as seeds for freeze-out of molecules. His most important contribution to Cloudy in 2009 was that the code has been parallelized and is now able to run large grids or optimization runs on distributed memory clusters using MPI. The run_parallel.pl script for running the test suite has also been rewritten completely so that it too can run on distributed clusters. P. van Hoof furthermore added partial support for Li & Draine (2001) PAH opacities, added several new commands for optimizing models of PNe, added a treatment for continuum pumping of [N I] lines, updated the atomic data for [Fe XVII], added support for 2-D Starburst99 and 1-D / 2-D PopStar population synthesis grids, and added support for merged Tlusty O & B star stellar atmosphere grids. All these developments will be part of the upcoming release in 2010. P. van Hoof advised on several group publications discussing new features of the code and its application to various astrophysical objects (refereed journal publications R.1 R.1R.1). P. van Hoof fixed several bugs in the code and assisted in updating the documentation of the parts of the code that he is responsible for. He also assisted in the preparations for the upcoming c10.00 release of Cloudy which is scheduled for the first half of 2010. He assisted in maintaining and updating the Cloudy web sites as listed below. P. van Hoof organized the 4th Cloudy development summit which was held at the ROB on 3 – 7 August. This meeting brought together the core developers of Cloudy in order to discuss future development of the code and prepare the new main journal article describing the c10 release.

L.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 modeling many types of environments, including planetary nebulae and post-AGB stars.

L.1.4. Personnel involved

Scientific staff: P. van Hoof

L.1.5. Partnerships

List of international partners without grant

- 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 H2 code.

Grant/Projects used for this research/service

- NSF grant AST 0607028 (1 January – 30 April)

L.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 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.

L.2. The Atomic Line List

L.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 just over 10,000 visitors in 2009.

L.2.2. Progress and results

P. van Hoof undertook a comprehensive upgrade of the code for calculating the energy levels of hydrogenic ions. The new code is based on the theory in Section IV of Mohr, Taylor & Newell, Rev. Mod. Phys., 80, 633 (2008).

L.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 1.41 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.

L.2.4. Personnel involved

Scientific staff: P. van Hoof

L.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.

L.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.

L.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 six bright (cool) stars selected as primary spectroscopic reference objects: Betelgeuse (Alpha Ori; M2 Iab), Arcturus (Alpha Boo; K1 III), 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 1000 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 (L.3.5). 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.

L.3.2. Progress and Results

SpectroWeb has been extensively updated in 2009 with corrected oscillator strength values of over one thousand atomic absorption lines in the Sun, Procyon, Arcturus, and Eps Eri [1]. The updated 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 Arcturus and Eps Eri were observed with Mercator-HERMES at La Palma with S/N ratios exceeding 1,200. The HERMES spectra of both stars have been re-calibrated by Dr. Lobel with the first version of the calibration pipeline. The complete optical spectra of both stars were modeled in detail with LTE spectral synthesis calculations for absorption line-identification purposes. The HERMES spectra meet all quality requirements and have been incorporated in SpectroWeb (the Arcturus spectrum from the ESO-UVES archive was hence

retired.) We await further refinements of the HERMES calibration pipeline especially for cosmic-ray removal, shifted spectral order image correction, and absolute wavelength calibration accuracy assessment.

L.3.3. Perspective for next years

In 2009 A. Lobel will propose Mercator-HERMES observations of ten spectral standard reference stars with large spectral resolution and very high S/N ratios of ~1000 - 2000 for the further development and release of the SpectroWeb database. The HERMES spectra will permit him to 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. He will propose to observe the ten bright standard stars with V ~ 2m to 5m over the next five years. Subsequent observations at reduced air-mass, preferably from observing 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 future SpectroWeb development and ROB summer students will be involved.

L.3.4. Personnel involved

Scientific staff: A. Lobel

L.3.5. Scientific outreach

Observing proposals

- A. Lobel: 2 proposals

Websites - Online Maintained Database

[1] Lobel, A.,
The Interactive Database of Spectral Standard Star Atlases, at spectra.freeshell.org,
2009 - Regular online updates of spectral atomic data and references.

M. Gaia data reduction

Gaia is a cornerstone mission of the ESA Space Program, scheduled for launch in late 2012. The satellite is aimed to repeatedly survey the whole sky to obtain positions, parallaxes and proper motions to μas precision for all of the 10^9 objects brighter than V = 20. Compared to the previous Hipparcos mission (Figure 42), 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 10000. It is therefore considered as an ambitious astrometric mission that will significantly improve our understanding of the formation and evolution of the Milky Way Galaxy.

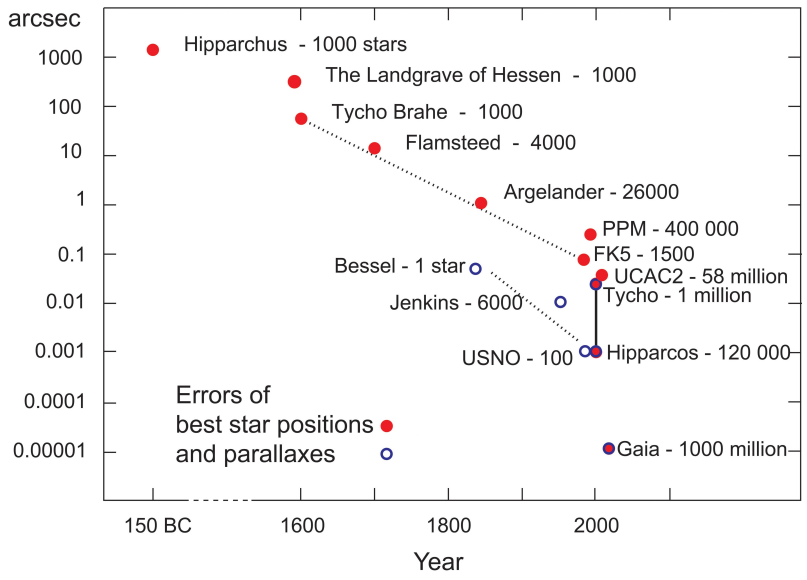


Figure 42: Evolution of the parallax and star position accuracy. Gaia is a real breakthrough that will provide parallaxes 100 times better than Hipparcos for a number of stars increased by a factor of 10000. (Credit: ESA)

The main weakness of the HIPPARCOS satellite was not to have any instrument dedicated to radial velocity determination and object/stellar classification. The strength of Gaia follows from the onboard 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, we are 8 persons to be involved in the DPAC and in the development of the Gaia reduction software, 2 of us being funded by a dedicated 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).

In March 2009, we received the visit of the representatives of the Prodex Office (March 16) which is financing our involvement in Gaia, while in July we hired our new Java Expert (E. Van Hemelryck) who is involved in the different CUs at the level of 10% on CU4 (see M.1), 50% on CU7 (see M.2.7), and 40% on CU6 and CU8 (see M.2 and M.4). The software development made for Gaia takes place in 6-months development cycles, each cycle aiming to improve the previous software deliveries. The present report describes the work carried out during cycles 6 and 7, and beginning of cycle 8.

M.1. Astrometric Reduction of Small Solar System Objects (CU4)

M.1.1. Objectives

T. Pauwels has been assigned the task of developing the software for DU454 (Astrometric Reduction of Solar System Objects). **DU**454 is one of the **D**evelopment **U**nits of CU4 of the Gaia DPAC. This task will take approximately four years.

M.1.2. Progress and results

T. Pauwels committed himself to do the code development, rather than having it done by the Java programmer. Therefore, he invested some time to continue to learn the framework for code development established by CU1 and continuously being modified by CNES. In particular, in 2009 the façade architecture was introduced.

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.

Changes in the I/O item list were only minimal in 2009, mainly adding some new items on the request of other DUs. In 2009 the data model architecture in the software was replaced by the façade architecture. Two processing chains were defined: the short-term processing, running daily with limited facilities as soon as new data arrives for science alerts; and the long-term processing, running once per cycle and producing the full precision output. Both chains were façadised. At the end of the year a new Nexus repository of libraries became available, and the software was adapted to use these libraries. Input/output, which was previously in ASCII, was migrated to the internal gbin format.

The functionalities of the code increased dramatically during the course of 2009: a new class to format the output in the format required by the Minor Planet Center, a new class to compute data at the transit level, rather than at the CCD level, implementation of the Gaia ephemerides, computation of the aberration, special tools classes for low level tasks, classes for handling covariance matrices. The code was continuously improved for better matching of the recommendations and to make it more robust. With each new piece of code the corresponding Junit tests were written. The code was continuously adapted to the evolving framework of DPAC.

A few additional utilities have been written, such as a dedicated tool to transform the native gbin format to ASCII and vice versa.

In 2009 the **SRS** document (**S**oftware **R**equirement **S**pecification) and the **SDD** document R.4 (**S**oftware **D**esign **D**escription) continued to evolve. The SRS is at version 6.2 R.4 (with version 8.0 having started), the SDD at version D.5. There were several releases of the software: 5.0, 6.0, 7.1 and 8.0, each with its corresponding **SRN** (**S**oftware **R**elease **N**ote) R.4R.4R.4R.4, and with an extensive code review by CNES in the course of August.

M.1.3. Perspective for next years

Software developing is supposed to continue for the next two or three years. For example, other functionalities still need to be included and are now in the stage of research: implementation of the real Gaia attitude, relativistic effects, photocentric shift. In parallel, the corresponding documents will be produced and adapted to the evolving software. This will be done in 10 six-month cycles, of which the first seven cycles already ended. By 2012, the final software should be ready. After that the software will be fed with real data rather than simulated data, with the inevitable surprises and the necessary adaptation of the code.

M.1.4. Personnel involved

Scientific staff: T. Pauwels
Technical staff: E. Van Hemelryck

M.1.5. Partnerships

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

- Jean-Eudes Arlot, Valery Lainey and Vincent Robert, IMCCE, Paris, France
- 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 C90296, 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. R.4R.4

M.1.6. Scientific outreach

Meeting presentations

[1] Pauwels T.
DU454 status
Presented at Gaia DPAC CU4 meeting #7, Torino, May 28.

M.1.7. Missions

Commissions, working groups: T. Pauwels (10 days)
E. Van Hemelryck (2 days)

M.2. Single transit analysis (CU6)

M.2.1. Objectives

Radial and rotational velocity measurements will be an important part of the final output catalog of the mission. The **S**ingle **T**ransit **A**nalysis (**STA**) development unit (DU650: managed by Y.Viala, Paris-Meudon) has the responsibility to develop different techniques that will allow to measure the radial and rotational velocity. The team's objectives and duties in DU650 are to implement a minimum distance method (called STA_RVMDM) and to implement Fourier transform (called STA_Fouriercc) techniques to derive the radial velocity and rotational velocity of single lined stars. R. Blomme and Y. Frémat are managers of their own Work Package.

M.2.2. Progress and results

R. Blomme and Y. Frémat continued the improvement and development of their algorithms (STA_RVMDM and STA_Fouriercc, respectively), and two software deliveries were made to the CNES Data Processing Centre. This includes the code and its documentation R.4R.4R.4R.4Error: Reference source not foundR.4R.4R.4 R.4R.4. Furthermore, R. Blomme continued the development of a linkage module called STA_Combined, using other modules provided by Y. Frémat, D. Katz, Y. Viala, C. Delle Luche, C. Parr and H. Huckle. Both the minimum distance software and linkage module were adapted to a major revision of the data model. R. Blomme used STA_Combined to run many of the formal tests that are part of the Single Transit Analysis Test Campaign R.4 and he summarized the results on the GaiaWiki pages. Y. Frémat continued the development of a JAVA package called SimpleSimulator that is used to simulate, adopting a simplified instrument model, the RVS wavelength range. Compared to the more complex CU2 simulations, these data present the advantage that one can isolate specific instrument effects in order check their impact on the RV determinations. Both codes, STA_Combined and SimpleSimulator, are used to test the software

developed within DU650. Our work on radial velocities was presented as a poster at the IAU Symposium M.4.6.

M.2.3. Perspective for next years

The code will be extended to determine multiple peaks in the cross-correlation function, which indicate the presence of a binary. Tests for the scientific validation of the code will continue.

M.2.4. Personnel involved

Scientific staff: R. Blomme, Y. Frémat
Technical staff: E. Van Hemelryck

M.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
- A. Guerrier, A. Jean-Antoine, CNES, Toulouse, France
- C. Parr, H. Huckle, Mullard Space Science Laboratory, UK

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

- E. Gosset, Y. Damerdji, Université de Liège

Grants/Projects used for this research/service

- PRODEX C90296, 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. R.4R.4

M.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 – 7th Workshop, Potsdam, Germany, contributed talk

[2] Blomme, R., Delle Luche, C., Frémat, Y., Viala, Y.
STA_Combined: integration of RV modules and results
CU6 – 8th Workshop, Nice, France, contributed talk

Wikis and Websites

- GaiaWiki page STA_Combined http://www.rssd.esa.int/wikiSI/index.php?title=CU6:_GWP-S-650:_Single_transit_analysis:_Integration (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_6, …7, …8 (restricted access)

M.2.7. Missions

Commissions, working groups: R. Blomme (6 days)
Y. Frémat (6 days)

Research visits (days): R. Blomme (1 day)
Y. Frémat (1 days)

M.3. Variability Characterization (CU7)

M.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 **W**ork **P**ackages (**WP**s): 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 Observatory are the supervision of the general work package Characterization (J. Cuypers) and the concrete realization of the sub workpackage Period Search (J. Cuypers, E. Van Hemelryck, P. De Cat). The latter includes the coding (in Java) of that part of the variability pipeline that will deal with (possible) periodicity in the data. M. Groenewegen is partly involved in the Specific Object Studies of Long Period Variables.

M.3.2. Progress and results

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 2009 gradually improved.

J. Cuypers have 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.

E. Van Hemelryck joined the team as Java expert only in August 2009 and started with learning the general Gaia structure and the tools necessary for the CU7 software development. For this purpose he visited the CU7 team in Geneva and he attended a Gaia-Java workshop in Tenerife. As a by-product of his learning process he could pinpoint and eliminate some of the double coding in the period search software.

In order to improve the efficiency and the performance of the period search module new tests on synthetic data were performed. The full interpretation of the outcome of these tests took a lot of time. First results were presented at the CU7 meeting in Vienna and the next part at the Geneva meeting. Parts were included in the Software Test Reports (STR). R.4R.4

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 contribution of the ROB to the work package Specific Object Studies: Long Period Variables was mainly in the definition of the Software Requirements and in the description of these in the corresponding SRS document R.4.
The Variability Characterisation SRS document R.4 was updated. Other documents were created, updated and uploaded to Gaia Livelink R.4R.4 (http://www.rssd.esa.int/llink/livelink).

M.3.3. Perspective for next years

The pipeline for the characterization of the variability will be finalized, coded, implemented and tested. The immediate goal is to have a full period search strategy implemented and tested on simulated Gaia data (our own synthetic data and/or data provided by the Gaia data simulation unit).

M.3.4. Personnel involved

Scientific staff: J. Cuypers, P. De Cat, M. Groenewegen
Technical staff: E. Van Hemelryck

M.3.5. Partnerships

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

- 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 Vienna, Italy
- Thomas Lebzelter, Denise Lorentz, Institute of Astronomy, Vienna University, Wien, Austria
- All CU7 members

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

- C. Aerts, J. De Ridder, J. Blomme, …, Institute of Astronomy, Department of Physics and Astrono-my, K.U.Leuven
- A. Jorissen, Institut d'Astronomie et d'Astrophysique, ULB

Grants/Projects used for this research/service

- PRODEX C90296, Gaia-DPAC: Variability, Conny Aerts (BPI, KULeuven), J. Cuypers (Bco-I, ROB), 2007-2009 R.4R.4
- 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

M.3.6. Scientific outreach

Meeting presentations

[1] Cuypers, J.,
Variability Characterization:
8th Gaia CU7 meeting, Vienna, 5-7/5/2009

[2] Cuypers, J.,
Variability Characterization: status and plans
9th Gaia CU7 meeting, Geneva, 12-14/11/2009

Wikis and Websites

- Inputs to the Wiki pages of CU7, mostly in preparation of meetings or as results of the splinter meetings on characterisation.

Teleconferences

Several meetings on Gaia subjects were in the form of teleconferences (Telephone or Skype meeting with Geneva, Leuven, Madrid, Catania…):

- 19/01/09: on general matters
- 28/01/09: on characterisation
- 17/02/09: period analysis and modelling
- 04/03/09: on the TST document
- 01/04/09: on characterisation
- 09/06/09: on general matters
- 28/10/09: on modelling and documents
- 29/10/09: general matters CU7

M.3.7. Missions

Commissions, working groups:	J. Cuypers (10 days) M. Groenewegen (5 days) E. Van Hemelryck (7 days)
Research visits (days):	E. Van Hemelryck (3 days)

M.4. Extended Stellar Parametrizer (CU8)

M.4.1. Objectives

The **E**xtended **S**tellar **P**arametrizer (**ESP**) 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 (**G**eneralised **S**tellar **P**arametrizer). 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". The latter workpackage is managed by R.Blomme, the four former are led by teams from Italy, Spain, Sweden, and Chile. 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).

M.4.2. Progress and results

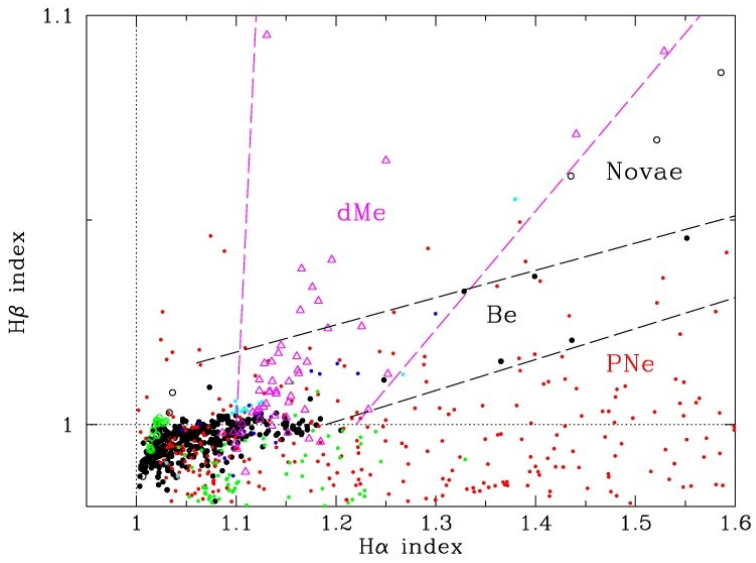


Figure 43: Diagram of H□ and H□ emission line indexes computed with Gaia Bp/Rp spectra from GOG. dMe stars (magenta triangles), Novae (open symbols), Be stars (solid black dots), and PNe (red dots) are separated over different portions of the diagram between the dashed lines.

R. Blomme and collaborators wrote a technical report on how Gaia data of Wolf-Rayet stars should be treated R.4. He also participated in the validation of simulated data and delivered a grid of Wolf-Rayet synthetic spectra. He is the contact person for the Observatory in the **GREAT** (**G**aia **R**esearch for **E**uropean **A**stronomy **T**raining) ESF proposal. He is also co-facilitator of the workpackage "Massive Stars" in the GREAT consortium.

Since mid-April, A. Lobel is replacing C. Martayan who left the observatory in March. He conducted a search for ground-based observations in all existing databases and for all classes of Emission Line stars and started a thorough study of the data he collected. Applying the **GOG** (**G**aia **O**bject **G**enerator) he is performing a critical study of what can actually be done with Gaia data to identify various types of Emission Line Stars and is preparing a technical report M.4.6M.4.6R.4 of how the data mining procedures for these ground-based observations can be utilized to train the Extended Stellar Parametrizer Algorithms currently under development. A. Lobel is also co-facilitator of the workpage "Stellar Atmospheres" in the GREAT consortium.

The team delivered an updated version of the ESP algorithm, as well as the corresponding documentation R.4R.4, to CNES in April and October 2009. These versions of the code were taking into account the comments made by CNES and the existing algorithms were improved in order to enable the identification and classification of Emission Lines Stars. Y.Frémat took part to the monthly teleconferences of the CU8 management team. He contributed to the simulated data validation, and, as a member of the management team of CU8, he reviewed several technical reports. As CU8 representative in the **GBOG** (**G**round**B**ased **O**bservations for **G**aia), he further participated to the preparation of observing proposals. In this framework, our team

contributed to a successful ESO proposal on EFOSC2 at the NTT. This observing run was completed in August 2009 by Y.Frémat.

Other documents were created, updated and uploaded to Gaia Livelink R.4R.4R.4R.4. Our work within CU6 and CU8 was presented in a poster at the IAU Symposium and a paper proceeding was published presenting previous synthetic spectra grid computations (see year report 2008 R.4).

M.4.3. Perspective for next years

Software will be delivered that determines the stellar parameters of hot stars, based on a grid of template spectra. The possibility of extracting information about the mass-loss rate from the Hα line will be explored. Techniques to recognize and classify Wolf-Rayet stars, and Emission Line Stars in general, will be developed and implemented. Collaborations with the GREAT consortium will be set up.

M.4.4. Personnel involved

Scientific staff: R. Blomme, Y. Frémat, A. Lobel
Technical staff: E. Van Hemelryck

M.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
- E. Gosset, Y. Nazé, J. Poels, Université de Liège
- B. de Batz, B. Leroy, C. Neiner, M. Floquet, A.-H. Hubert, Observatoire Paris/Meudon, France
- GHOST team
- S.Chastel, A.-M.Janotto, CNES, France

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

- E. Gosset, Y. Damerdji, Université de Liège

Grants/Projects used for this research/service

- PRODEX C90296, 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.
- ROB budget for A. Lobel (IAU Special Session 10, XXVIIth General Assembly, Rio de Janeiro, Brazil, 3 – 14 Aug 2009)

Visitors:

- A. Lanzafame, University of Catania (Italy), 14-17 April, PRODEX C90296
- I. Kolka, Tartu Observatory (Estonia), 16-20 February

M.4.6. Scientific outreach

Meeting presentations

[1] Blomme, R.
The Royal Observatory of Belgium and Gaia
GREAT Kick-off meeting, Cambridge, UK, contributed talk

[2] Blomme, R.
COBRaS: The Cyg OB2 Radio Survey
The First Workshop on Gaia Science on Open Clusters and Young Associations, Padova, Italy

[3] Blomme, R., Frémat, Y., Lobel, A., Martayan, C., Y. Nazé

Massive Stars and Emission-Line Stars with Gaia
"The Milky Way and the Local Group -Now and in the Gaia Era", Heidelberg, Germany, poster presentation

[4] Frémat, Y.,
Low Resolution Observations for ESP
6th GBOG meeting. Invited speaker. Nice, 17 – 18 November 2009.

[5] Frémat, Y.,
Report on the 5th GBOG meeting at Uppsala
7th CU8 meeting. Invited speaker. Toulouse, 8 – 10 June 2009

[6] Lobel, A., Liu, Y., Frémat, Y., Bailer-Jones, C.A.L., Blomme, R., …, Martayan, C., …
Hot Stars survey with the GAIA space mission
IAU XXVII General Assembly, Rio de Janeiro, Brazil, Special Session 10 "Next Generation Large Astronomical Facilities", poster paper

[7] Lobel, A.
Data Mining and Processing of Ground-based Observations for ESP-ELS in CU8,
6th GBOG meeting. Invited speaker, 18 November 2009, Observatoire de Nice, France.

[8] Martayan, C., Frémat, Y., Blomme, R., …
Emission Line Stars in the Milky Way with the GAIA space mission
IAU XXVII General Assembly, Rio de Janeiro, Brazil, Special Session 8 "The Galactic Plane - in Depth and Across the Spectrum", poster paper

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_6_:_Emission_line_stars&instance=Gaia (restricted access)
- Contribution to GaiaWiki page on Hot Stars:
  http://www.rssd.esa.int/wikiSI/index.php?title=CU8:_GWP-S-835-10000:_Hot_Stars&instance=Gaia (restricted access)
- Description of the provided Wolf-Rayet synthetic spectra grid:
  http://www.rssd.esa.int/wikiSI/index.php?title=CU8:_Spectral_libraries:_general&instance=Gaia (restricted access)

M.4.7. Missions

Assemblies, symposia:	A. Lobel (IAU Special Session 10, XXVIIth General Assembly, Rio de Janeiro, Brazil, 3 – 14 Aug 2009)
Commissions, working groups:	R. Blomme (13 days) Y. Frémat (11 days) A. Lobel (10 days)

N. 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.

N.1. Data reduction package and optics for the HERMES echelle spectrograph

N.1.1. Objectives

The Royal Observatory of Belgium has the responsability to provide in due time 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 2 and 3, as well as colleagues from the other partners in the HERMES project.

The Royal Observatory of Belgium contributes 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.

N.1.2. Progress and results

From January to March, took place the final commissioning of the HERMES spectrograph with the participation of H. Hensberge and L. Dumortier (Sect. N.1.2.2), while the first official science operation of the instrument started in April (Sect. N.1.2.3). Observations at HERMES are planned in 10-day shifts executed by each of the partners in proportion to their financial and man-power contribution to the development of the instrument (Sect. N.1.2.3). At each shift, a mix of the accepted observing programmes (Sect. N.1.2.1) of all partners is executed. In addition there is some reserved time (20%) in the shift over which the observer (or his institute, conform the partner's decision) can dispose freely and, as it is done at the ROB, make an intern call for targets.

N.1.2.1. First call for observing time

The first call for observing proposals has been emitted in January 2009 among all members of the consortium. As HERMES representative, Y. Frémat took part to the HERMES OPC (Observing Programmes Committee) on March 25 which allocated the observing time. Among the 17 submitted programs, 9 had a ROB PI and 3 had a ROB co-PI. And from these 12 proposals (Table 1), 11 received observing time on HERMES.

Colliding Winds in Early-Type Binaries	R. Blomme
The Connection between the Stellar Wind and the Photosphere in Early-Type Stars	R. Blomme, A. Lobel
Baade-Wesselink distances to (binary) Cepheids and the period-luminosity-metallicity relation	M.A.T. Groenewegen
Target of Opportunity observations of MESSy objects	M.A.T. Groenewegen
Spectroscopic monitoring of oEA stars	H. Lehmann, P. Lampens et al.
Evolved objects in binaries: the evolutionary connection	H. Van Winckel, G. Van de Steene et al.
Stellar atmospheres of main-sequence pulsators: characterization in terms of rotation, binarity and chemical composition	D. Wright et al.
Fundamental parameters of stars and stellar groups from studies of binary (multiple) stars	H. Hensberge et al.

HERMES High Resolution Spectroscopic Database	P. Royer, A. Lobel
Towards asteroseismology of main-sequence g-mode pulsators: a spectroscopic multi-site campaign for slowly pulsating B stars and γDoradus stars	P. De Cat et al.
SpectroWeb: The Interactive Database of Spectral Standard Star Atlases	A. Lobel
Spectroscopic Monitoring Survey of Hypergiants and Luminous Blue Variables	A. Lobel

Table 1: Submitted ROB proposals after the first call.

N.1.2.2. Instrument commissioning

During an extensive mission at the headquarters of the Mercator telescope in Santa Cruz de La Palma, H. Hensberge participated in the final commissioning phase of the spectrograph and the data reduction pipeline. He analysed calibration images in order to characterise the technical and science detectors and to fine-tune the spectrograph and the software. During the 1-week stay of L. Dumortier at La Palma, they further used the calibration images (Figure 42) to make the first tests of the DRS modules with real HERMES data (i.e. until that moment the development and testing was performed on toy and FEROS data).

Figure 44: Distribution of the 55 spectral orders on the CCD (picture taken during the HERMES commissioning)

N.1.2.3. First observing runs

As member of the HERMES consortium, and besides its implication in the optics and the software development, the ROB also has the duty to perform observing runs at the MERCATOR (Figure 46) in La Palma. In 2009, 4 of these observing shifts were therefore successfully completed by D. Wright (06.03.2009 - 12.03.2009), K. Torres (13.03.2009 - 17.03.2009 & 04.09.2009 - 14.09.2009), and P. Lampens (28.04.2009 - 11.05.2009).

See also the local wiki page:

http://wikid23srv/mediawiki/index.php/HERMES

N.1.2.4. First release of the reduction pipeline

In absence of the full characterisation of the instrument, partly due to a delayed availability of the science detector, the developed differential pipeline was adapted to operate initially in an absolute mode.

From April on, efforts to improve the data reduction pipeline in several aspects continued, including improvements on the algorithm to detect radiation events (lead by S. Van Eck), and to obtain a more precise wavelength calibration (H. Hensberge, Y. Frémat, N. Gorlova). Y. Frémat & L. Dumortier contributed to the automatisation and user-friendliness of the process, and H. Van Winckel monitored the instrument parameters and the whole scheduling and observing process. On 27 July, a scientifically usable version of the pipeline was ready so that Y. Frémat and H. Van Winckel could make the very first release of the reduction pipeline. To make the use of the pipeline easier for all users, Y. Frémat prepared the version of the DRS cookbook available with the July release. From August on, the first science results were available and ready for study (see Figure 45).

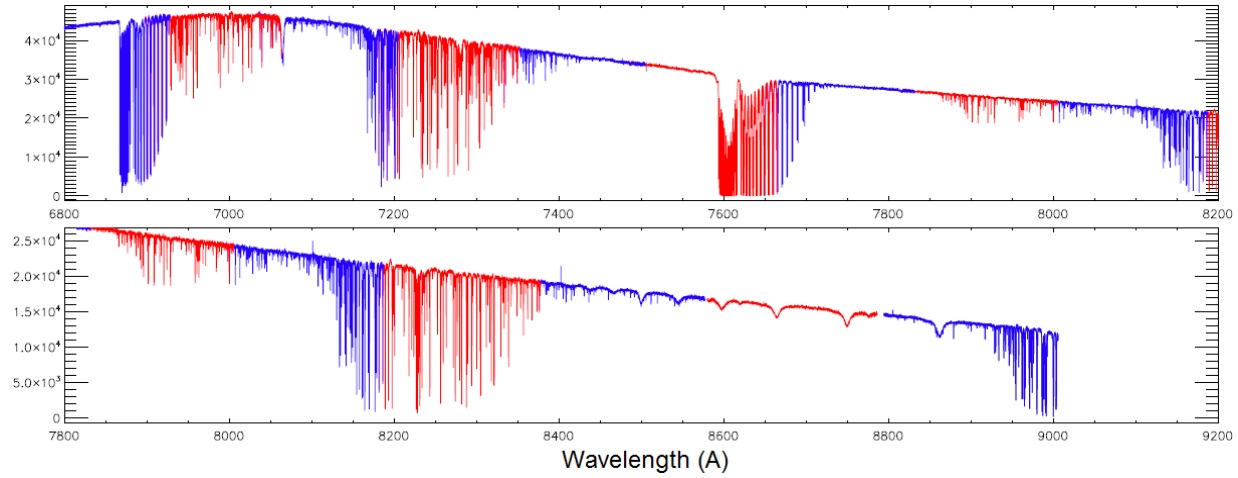


Figure 45: Resulting reduced data obtained using the pipeline version released on July 24, 2009. It shows the perfect overlap and coincidence of consecutive HERMES orders. (Reduced data obtained by R.Blomme using the pipeline)

N.1.2.5. GUI development and radial velocity determination

From the July delivery on, the pipeline continued to evolve. L. Dumortier improved the scripts, homogenized the existing python modules as well as the DRS cookbook, and started the development of several **G**raphical **U**ser **I**nterfaces (**GUI**s). He collaborated with A. Jorissen in order to construct a module that allows the automatic determination of radial velocities by cross-correlation of the HERMES data with several templates.

N.1.2.6. Problems with the Science CCD

As pointed out, since April 2009, the spectrograph is in operation for the HERMES consortium. The innovative coating on the science detector turned out to minimise very efficiently the fringing effects at the red wavelengths. Furthermore, this detector has exceptionally good cosmetic qualities. Unfortunately, in autumn the science detector was damaged and observations are since then obtained with the technical detector. By adapting the DRS pipeline and thanks to the fact that the engineering CCD was of good quality, we managed to considerably reduce the impact of such a failure on the science results.

Figure 46: Picture of the Mercator building taken by P. Lampens during the (28.04.2009 – 11.05.2009) ROB observing run.

N.1.3. Perspective for next years

With the retirement of H. Hensberge at the end of 2009, Y. Frémat will direct the project in its executional stage. During the next years, the development of the pipeline will continue. The modules for order rebinning and merging will be included in the DRS, and some GUIs have to be improved or developed. The wavelength calibration will be improved in order to provide accuracies of the order of a few m/s. While the DRS is already working well in its "absolute reduction" configuration, it still needs to be adapted in order to be able to process the data using a relative reduction approach based on the a-priori knowledge of the instrument model. These innovative developments proposed by H. Hensberge will be pursued with his help and hopefully published in a technical paper. To resolve the CCD issue (see N.1.2.6), we are planning to contribute in the acquisition of a new Science CCD.

N.1.4. Personnel involved

Scientific staff: H. Hensberge, Y. Frémat, P. Lampens, K. Torres, G. C. van de Steene, D. Wright

Technical staff: L. Dumortier

N.1.5. Partnerships

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 is promoter for ROB in the HERMES project of KULeuven – ULB – ROB

Visitors:

- Short visits: 3 persons

N.1.6. Scientific outreach

Wikis and Websites

- Installation and update of a local wiki server for the HERMES project (which is now also used for other projects): http://wikid23srv/mediawiki/index.php/HERMES

N.1.7. Missions

Field missions (days): H. Hensberge (49d)
L. Dumortier (8d)

Solar Physics and Space Weather

O. Fundamental Research into Solar Atmosphere, Heliosphere, and Space Weather

O.1. Coronal Modeling: Loop dynamics

Models based on magnetic extrapolations from magnetograms, the concept of quasi-separatrix layers and squashing factors are able to determine, in a given magnetic configuration, the locations where strong currents will form following a displacement of a field line due to photospheric footpoint motions. This information is crucial in order to use observations in identifying the sites where dissipative events, magnetic reconnection and flares can occur. However, these models are essentially static and cannot predict any time scale for the energy accumulation phase during which the magnetic field intensity increases, loading the loop system for the successive release phase. Usually the accumulation phase is studied under the line-tying hypothesis, i.e. loop footpoints are anchored in the photosphere and the displacement of one of them leads to an infinite increase (linearly in time) of the transverse coronal magnetic field. Recently Grappin et al. (2009) have studied such an accumulation phase in the opposite limit, which is considering the loop as a mean to transmit the momentum applied at one footpoint towards the other one. In the linear case, this process is regulated by the reflection of Alfvén waves at the transition region boundaries, and, for a zero-frequency displacement of one footpoint they found that the loop is line-tied for a short time (an Alfvén time) and soon after relaxes to an equilibrium state (the relaxation is due to the leakage of waves from the corona to the photosphere), leading to a finite accumulation of energy.

We are currently extending the above work to the case of non-zero-frequency displacement (for which the line-tying hypothesis is recovered at high frequencies) and to a nonlinear dissipative regime. In the latter, the transmission of energy and the system relaxation compete with the energy dissipation, defining the level of magnetic energy available for the successive release and the characteristic time scale for its accumulation.

O.1.1. Progress and results

The analytical treatment developed last year has been refined to include different turbulent closures (Kolmogorv, isotropic Iroshnikov-Kraicnan, and anisotropic Iroshnikov-Kraichnan types) that have been compared to the numerical results. The comparison is carried out exploring the parameter space with numerical simulations (i.e. length of the loop, Alfvén speed contrast, turbulent correlation length scale), and shows that the analytical approximations are valid and rather robust. Some of the results have been presented at the Solar Wind 12 conference, and are published in a dedicated volume of AIP.

O.1.1.1. Summary of the main results

- The comparison between the numerical and analytical treatment allows deriving some scaling laws for the level of the magnetic energy accumulated in the corona. Three parameters showed to be the control quantities of the system (provided that the chromosphere is the same for loop of different lengths): the Alfvén speed contrast ($\varepsilon=V_a^{photosphere}/V_a^{corona}<<1$), the loop length in the corona (L_c), which can be related to ε by a loop model (e.g. a hydrostatic model), and the perpendicular turbulent correlation length scale ($L_\perp$) or equivalently the initial shear between loop footpoints. Numerical simulations show that the leakage is dominant at short timescale, when the magnetic energy begins to accumulate (the leakage of wave power from the corona toward the photosphere is responsible for the relaxation of the footpoint shear as in the linear case). This leads to a decrease of the nonlinear time scale that soon becomes comparable and smaller than the Alfvén time scale. The system enters into a phase for which injection is balanced by dissipation (and no more by leakage) and the magnetic filed saturates to a level that is proportional to $\varepsilon^{-2/3}$. Figure 47 and Figure 48 respectively show the time evolution of the magnetic field in the corona for different choices of ε and the prediction of the analytic calculations for the corresponding footpoint shear. The agreement is quite good, at least for small Alfvén speed contrast.

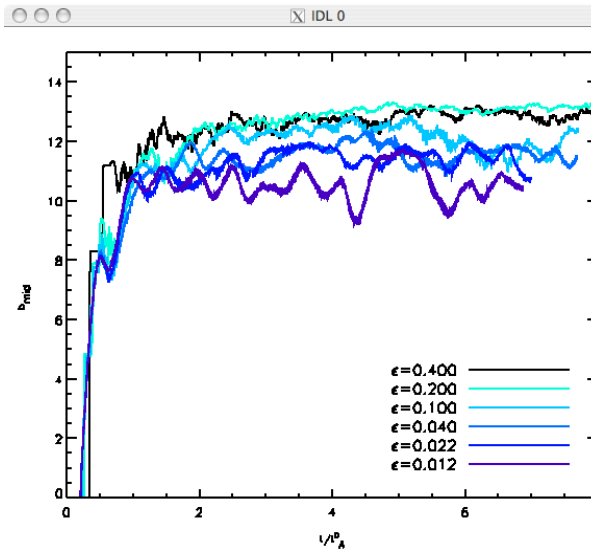


Figure 47: Coronal magnetic field intensity as a function of time (normalized to the characteristic time scale $t_A^0=L_c/V_a^0$) for loops of with different Alfvén speed contrast in presence of nonlinear turbulent dissipation and steady injection.

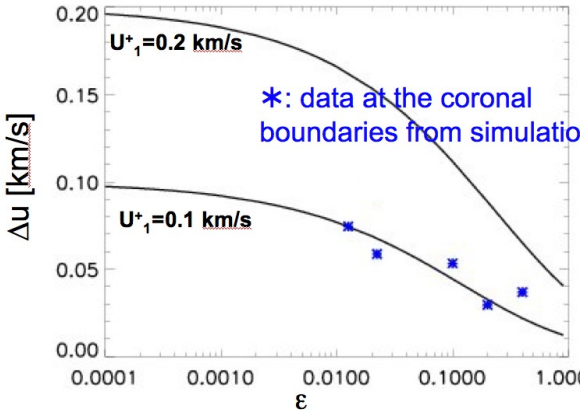


Figure 48 Footpoint shear as a function of the Alfvén speed contrast between the chromosphere and the corona. The blue symbols represent the values obtained from the simulations, while the lines are the analytical prediction obtained with different initial footpoint shear.

O.1.2. Perspective for next years

The whole work (linear and nonlinear analysis, including last year's results) will be sent to a refereed journal for publication. The research activity is ended and we are currently writing the manuscript for submission. Future developments of this workshall involve two important aspects: first, we expect to constrain some of the loop parameters (photospheric density, loop length, photospheric magnetic field intensity) by a semi-empirical model of the solar corona; secondly, we will analyze magnetograms in order derive the magnetic field distributions at the photosphere and any eventual correlation scale in time and space (a consequence of the footpoint coupling), thus constraining the injection of energy into loops and defining the applicability of non-line-tied conditions for solar loops of different length.

O.1.3. Partnerships

- Roland Grappin, LUTH, Observatoire du Meudon, France (contributed directly to the simulation data analysis)
- Marco Velli, Dipartimento di Astronomia e Scienza dello Spazio, Univ. Di Firenze, Italia (contribute to the turbulent characterization of different regimes encountered in the simulations).

O.1.4. Scientific outreach

Meeting presentations

[1] Verdini A., Grappin R., Velli M.
Coupling Photosphere and Corona, linear and turbulent regimes
Poster at Solar Wind 12, St. Malo, France, 21-26 June 2009

O.1.5. Missions

Assemblies, symposia, conferences:

- Coronal Loop Workshop, Firenze, Italy, 30 June – 3 July 2009
- Solar Wind 12, St. Malo, France, 21-26 June 2009

Research visits:

- Observatoire du Meudon, 26-28/01/09; 6-7/08/09; 21-23/12/09

O.2. Turbulent Acceleration of the fast solar wind

Recent observations of Alfvén waves in the chromosphere (De Pontieu et al. 2007) and in the corona (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 its acceleration. More generally it is though that such a turbulent state originates from nonlinear interactions close to the sun (below 15 solar radii) and during its evolution it is modified by several processes occurring in the solar wind (such as parametric decay of Alfvén waves, shear interactions between fast and slow streams, wave propagation in an expanding medium) which power the cascade at different spatial scales. An attempt to include turbulence in a consistent model has been made by Cranmer et al. (2007), but it is not clear if the dominant heating mechanism is compressive or turbulent.

With this work we study the formation of a turbulent spectrum by nonlinear interactions of Alfvén waves launched from the Sun, in the sub-Alfvénic corona, where the wind is accelerated and we implement a consistent 1D solar wind model in which turbulence and compressive phenomena (shocks) are added step by step, in order to understand the separate contribution of each mechanism.

O.2.1. Progress and results

The following investigation has been performed with codes already developed for by A. Verdini (partially in collaboration with E. Buchlin) and now running at ROB.

We had problems in adding heat conduction in the 1D solar wind code, collaborators (especially S. Oughton) are developing a time dependent code that is able to treat heat conduction and radiative losses including a transition region. On the other hand the code developed to study turbulent generation and evolution has been used to investigate the dependence of the turbulent heating on the injected spectrum (total energy, frequency and perpendicular wavenumber spectrum). The inclusion of a transition region is still problematic, mainly because of the large computational time required to treat the chromosphere and the corona at the same time. Apart from the numerical issue, we are currently trying to model the resulting turbulent heating in order to easily include it in the 1D solar wind model and to have a zero-order estimate of the properties of the resulting solar wind solutions.

The main results are summarized in the following, and rely on the analysis of several simulations.

- We showed that reflected waves consist of a classical component, propagating backward, and an anomalous component that follows the outward-propagating characteristic. The resulting nonlinear interaction of the outward propagating waves with the latter component is more efficient than the classical scenario of nonlinear interactions occurring only among counter-propagating waves, since there is no "Alfvén effect". Despite the propagation of waves limit the formation of turbulent cascade, we showed, for the first time, that for reasonable wave amplitudes a turbulent cascade develops in few solar radii from the coronal base (these results are published in an ApJ letter). The resulting turbulent heating depends on the injected spectrum at the coronal base (Figure 49): the strongest dependence is found in the perpendicular wavenumber spectrum, that influences the peak of the turbulent dissipation (at about 2 solar radii); on the other hand the frequency spectrum of the injected power mainly influences the extent of the turbulent heating in the acceleration region (between 3 and 6 solar radii).
- We studied the properties of a turbulent driven solar wind, varying some of the parameters that determine the large scale structure of open flux tubes in which the wind flows, the turbulent energy, and the supplementary heating due to type II spicules (the results are published in a letter in ApJ, 2010). We showed that when solar-like parameters are considered the turbulent heating can account for several wind properties, as well as for those of small scale turbulent fluctuations.

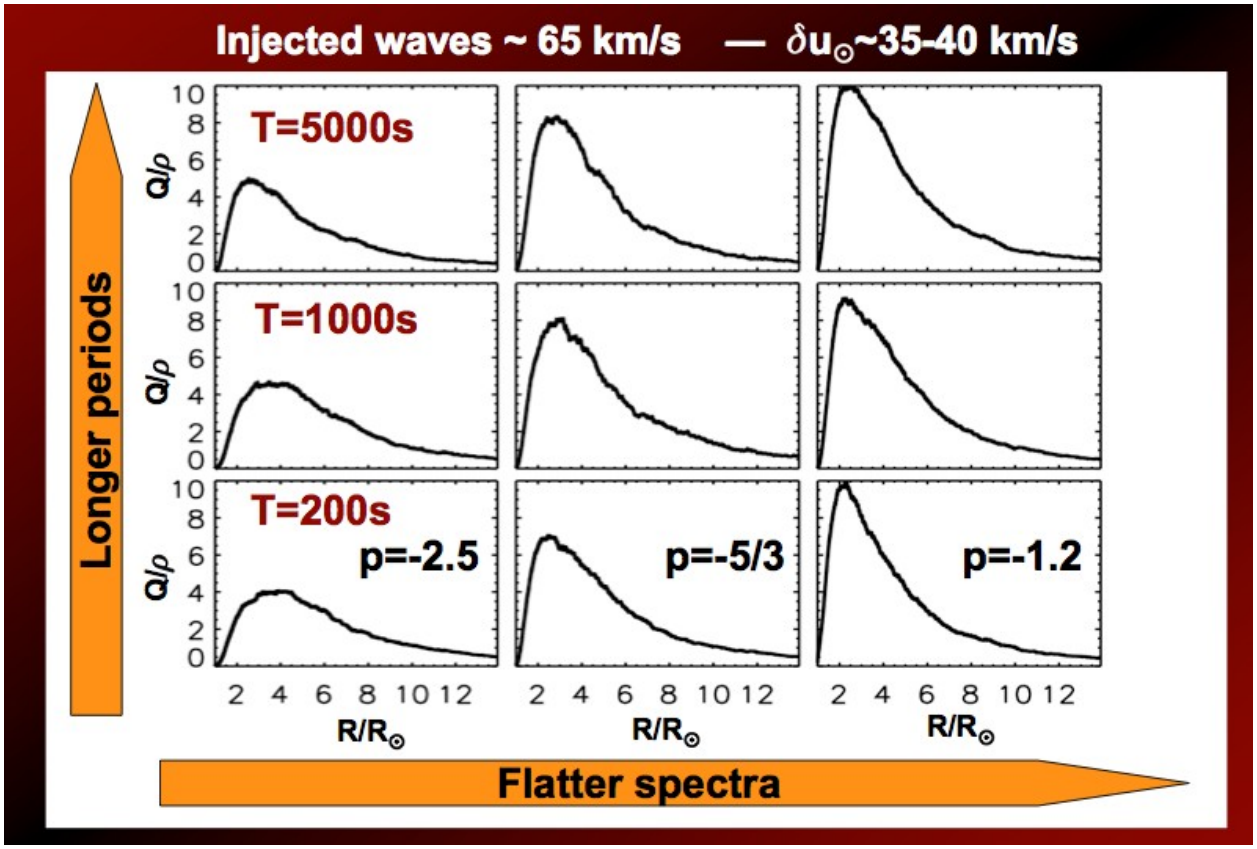


Figure 49 Total heating per unit mass (in normalized units) as a function distance for different injected spectra in which the periodicity and time auto-correlation of the driving (T) or the spectral slope (p) of the perpendicular wavenumber spectrum are varied.

O.2.2. Perspective for next years

A time-dependent code, including the transition region, will be developed by S. Oughton. At the same time the 1D code of R. Grappin will be used to characterize the solution when different phenomenologies (for the turbulent heating rate) are considered. The turbulence code will be used to refine such phenomenologies, which, at present time, seem to be not very appropriate for turbulence in the solar wind (because of the im-balance between outward and inward propagating waves).

O.2.3. Partnerships

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

- Velli M., Dipartimento di Astronomia e Scienza dello Spazio, Univ. Di Firenze, Italia
- Buchlin E., IAS, Orasy, France
- Grappin R., LUTH, Observtoire de Meudon, France
- Matthaeus, W. H., Bartol Research Institute, University of Delaware, Newark, Delaware 19716, USA
- Oughton, S., Department of Mathematics, University of Waikato, Hamilton, New Zeland
- Dmitruk, P., Instituto de Astronomía y Física del Espacio (CONICET-UBA) and Departamento de Física (FCEN-UBA), Buenos Aires, Argentina

O.2.4. Scientific outreach

Meeting presentations

[1] Verdini A., Velli M., Matthaeus W.H., Oughton S., Dmitruk P.
On a self-consisten turbulent heated solar wind

Presentation at BUKS Workshop 2009, Leuven, Belgium, 6-8 Mar. 2009

[2] Verdini A., Velli M., Matthaeus W.H., Oughton S., Dmitruk P.
On a self-consisten turbulent heated solar wind
Poster at Solar Wind 12, St. Malo, France, 21-26 June 2009

[3] Verdini A., Velli M., Buchlin E.
Turbulence in the sub-Alfvénic solar wind driven by reflection of low-frequency Alfvén waves
Poster at Solar Wind 12, St. Malo, France, 21-26 June 2009

[4] Verdini A., Velli M., Buchlin E.
Turbulence in the sub-Alfvénic solar wind driven by reflection of low-frequency Alfvén waves
Presentation (invited) at Agu Fall meeting, St. Francisco, USA, 14-18 Dec. 2009

O.2.5. Missions

Assemblies, symposia, conferences:

- BUKS Workshop 2009, Leuven, Belgium, 6-8 Mar. 2009
- Solar Wind 12, St. Malo, France, 21-26 June 2009
- Agu Fall meeting, St. Francisco, USA, 14-18 Dec. 2009

Research visits:

- Dipartimento di Astronomia e Scienza dello Spazio, Univ. di Firenze, 1-9/03/2009; 26/06-7/07 2009; 2-6/11/2009; 12-13/11/2009

O.3. Signatures of Coronal Heating

O.3.1. Objectives

Images of the solar corona are often made through emission lines with narrow temperature ranges, such as those made by the Extreme UltraViolet Imagers (EUVI) on the STEREO space craft. Such images show us all structures radiating at a particular temperature. However, it is not clear if the structures have a constant temperature, or are cooling through the temperature range from an initially higher temperature. The inner corona is largely composed of loop structures, and to determine their overall temperature from our images, numerical models of the heating and cooling of loops are required. Three-dimensional (3D) magnetohydrodynamics (MHD) models of multistranded loops are desirable to generate synthetic emission spectra, which can be used to study the statistical properties of loop radiative signatures, and help understand observations.

O.3.2. Progress and results

O.3.2.1. Signatures of coronal heating in radiative loop emission.

The coronal heating problem is concerned with identifying the energy dissipation process(es) that lead to multi-million degree coronal temperatures. Any complete 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. In this model, energy is dissipated through small discrete events heating 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.

M. J. West has constructed an analytical cooling model R.1 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 will use the model to simulate the cooling of loops undergoing multiple heating events, and consequently, the ensuing cooling signature. The simulation tech-

nique 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.

The initial results show that coronal loops retain their energy for longer periods, and as a consequence require less energy input.

O.3.3. Perspective for next years

The next step is to generate synthetic spectra arising from the model. For the present work we chose to synthesize the Fe XII 195 (temperature 1.4 million K) and Fe XV 284 (temperature = 2.2 million K) spectral line intensities, which correspond to lines that are observed by the STEREO EUVI Imaging Telescope.

O.3.4. Partnerships

List of national partners collaborators having actively contributed to the project in the last year 'Style Bold Italic')

- Parenti S, IAS Centre universitaire d'Orsay, Bât 120 – 121, 91405 Orsay France.

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

- PRODEX Contract "SIDC Data Exploration"

O.3.5. Scientific outreach

Meeting presentations

[1] West. M.J., Cargill. P.J., Bradshaw. S. J.
An Assessment of Heat Conduction Models in Loop Cooling (Talk)
Solar Coronal loops workshop IV, Astronomy and Space Science Department, University of Florence, Largo E. Fermi 2, Firenze, Italy.

Wikis and Websites

- Maintained related web page: http://solweb.oma.be/users/mwest/conduc/conduction.html

O.3.6. Missions

Assemblies, symposia, conferences:

- Solar Coronal loops workshop IV, Astronomy and Space Science Department, University of Florence, Largo E. Fermi 2, Firenze, Italy.

O.4. DEM Inversion Method for Imaging Telescopes for the Ultraviolet Sun (DIMITUS)

O.4.1. Objectives

Spectroscopic observations provide experimental material used for diagnostics of the physical properties of hot plasmas. Knowledge on the plasma temperature content is important for studies on various solar mechanisms, such as coronal heating, explosive and eruptive phenomena. To this aim, we have applied a method used for inverse problems, which are widely used in astrophysics for deriving information about the physical characteristics of plasma sources from their extreme ultraviolet (EUV) and X-ray emission.

The most general quantity which can be derived from optically thin experimental XUV spectra and broadband imaging data is the Differential Emission Measure (DEM) distribution which gives the amount of emitting material. Reconstruction of the DEM function is a rather difficult task because of the ill-posed nature of the spectral inverse problem. For this reason the availability of reliable diagnostic methods to analyze the observational data is important. Already with a full high-resolution line spectrum the spectral inverse problem is known to be an ill-posed one. The situation is even worse when we are dealing with data from spectral broad bands, and/or when there is a small amount of spectral lines or wide-band channels. This project aims

in particular at developing and verifying an inverse problem approach for the DEM analysis able to overcome these limitations.

O.4.2. Progress and results

Developped in the frame of the DIMITUS project, the Bayesian Iterative Method (BIM) is an effective tool for determining the thermal structure of emitting plasma. It is here successfully used for the DEM analysis of both line spectra and broadband imaging data. The BIM calculations correlate with recent studies confirming the existence of hot plasma in solar ARs.

O.4.2.1. Probabilistic approach to the spectral inverse problem and the BIM

There are actually many diagnostic techniques used for the DEM analysis from calibrated spectroscopic data and formulated in terms of the Fredholm integral equation of the first kind relative to the volume or column DEM distribution. In this project a probabilistic approach based on another mathematical formalization of the spectral inverse problem is applied. The probabilistic approach uses the language of the probability theory and mathematical statistics (distribution functions, hypothesis, confidence level etc.). In this approach, which deals with relative emission fluxes and normalized functions as probability distributions of random variables, an iterative procedure deduced analytically by means of Bayes' theorem (BIM) is used for the DEM reconstruction. In contrast to the standard formalization of the inverse problem, the problem formalized in the probabilistic approach is not 'ill-posed', in particular as a consequence no regularization procedure is needed. The BIM occurred already to be fruitful in solving a series of problems such as the image restoration, the signal recovery of noisy data, the deconvolution of initial X-ray spectra, the DEM temperature analysis of X-ray spectra from tokamak plasma and EUV solar spectra.

O.4.2.2. Numerical tests, model simulations and applications to observable data

Working on the project DIMITUS, Dr. F. Goryaev tested and validated the BIM. To demonstrate abilities and robustness of the BIM algorithm, in the first phase of his studies he performed a lot of tests and numerical simulations. It was established that the BIM provides very good results when analyzing high resolution line spectral data, even for a limited number of lines. The case of XRT broadband channels was also tested and it was shown that the BIM is able to infer plasma temperature structures in the case of broadband spectral data with a good confidence level. The BIM was tested using all nine XRT filters as well as the restricted case of using five filters only. It was shown that all temperature components of the plasma are well identified, in the case of both single temperature and wider multi-thermal distributions. Some limitations of the BIM results revealed for XRT data are due to the relative shape of the XRT response functions of the different filters and their large temperature widths.

In the second phase, Dr. F. Goryaev has applied the BIM to a number of real observational data which were previously analyzed with other DEM diagnostic techniques: SUMER/SOHO (Landi&Feldman 2008), SPIRIT/CORONAS-F (Shestov et al. 2010), and XRT/Hinode (Reale et al. 2009) data. The BIM confirms previous important SUMER results, showing very good quantitative agreement at $\log T \sim 6.5$, while displaying a slight shift for the two lower temperature maxima and ~30–50% difference in the DEM values for the coolest peak (Figure 1). For the SPIRIT data Dr. F. Goryaev revised and qualitatively confirmed AR DEM results including the inference on the presence of hot coronal plasma in the considered ARs at temperatures ≈9-15 MK with emission measure (EM) comparable to EM at ≈2-4 MK (Figure 2). Some quantitative differences were analyzed and explained. In the case of XRT broadband data the BIM solutions provided an evidence of the presence of hot plasma at temperatures ≈4-6 MK with EM up to ~30% as compared to that at ≈2-4 MK in a non-flaring AR on 2006 November 12.

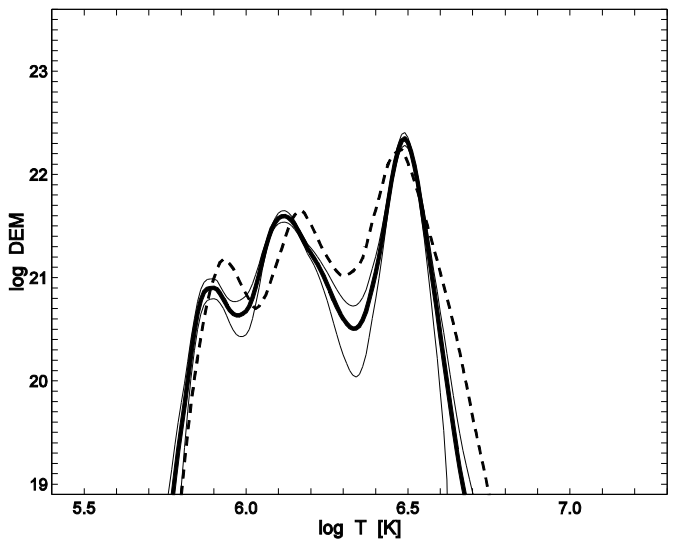


Figure 50. Results of the DEM analysis for the SUMER/SOHO line spectrum. The heavy solid line is the optimal median curve; the thin solid lines are the limits of confidence level for the DEM solution; the heavy dashed line is the curve by Landi&Feldman (2008). Three different temperature regimes can be recognized.

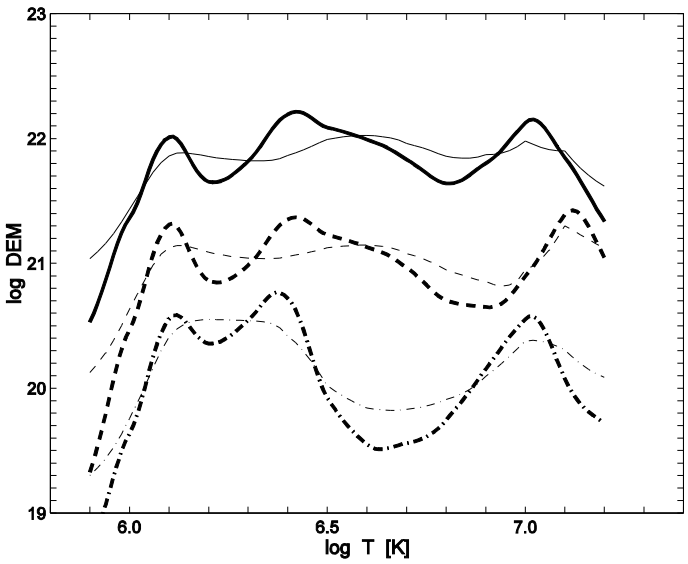


Figure 51 DEM temperature profiles reconstructed with the BIM (thick curves) for the three SPIRIT/CORONAS-F line spectra ARs and the comparison with the corresponding results (thin curves) of Shestov et al. (2010) (thin curves). The DEM is in arbitrary units. Again here, three different temperature regimes can be recognized, including a hot component around 10 MK, that could not be observed in SUMER spectra, which do not contain hot lines.

O.4.3. Perspective for next years

Very few works exist where the DEM was derived in active regions using Hinode/XRT data. For instance, Schmelz et al. (2009) used the standard xrt_dem_iterative2.pro procedure from the Solarsoft base to reconstruct AR DEM distributions. It would be interesting to compare these results with the BIM calculations. Dr. F. Goryaev is planning to make this study in a close future using different XRT data. The future work may also be related to the investigation of data from wavelength bands of intermediate width, e.g. such as STEREO/SECCHI and EIT/SOHO EUV channels, and also the new SDO/ AIA data. In the case of high resolution line spectra at present there are EIS/Hinode and SDO-EVE data. Dr. F. Goryaev is also planning to analyze them. Additionally, Dr. F. Goryaev has the intention of extending the DEM analysis to the bivariate inverse problem, i.e. in temperature but also in density of plasma.

O.4.4. Partnerships

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

- A. Urnov, S. Oparin: Lebedev Physics Institute of the Russian Academy of Sciences, Moscow, Russia.
- F. Reale: Dipartimento di Scienze Fisiche & Astronomiche, Universita di Palermo, Palermo, Italy.

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

- Non-EU post doctoral fellowship "DIMITUS" (BELSPO), 01 March – 31 December 2009.

Visitors:

- Alexander Urnov, Lebedev Physics Institute (FIAN, Moscow), July 2009, DIMITUS project.

O.4.5. Scientific outreach

Meeting presentations

[1] Goryaev F., Parenti S., Hochedez J.-F., Shestov S., Kuzin S., Urnov A., Ulyuanov A., Bogachev S., and Reale F.
Hot plasma investigation in Active Regions with SPIRIT and Hinode data.
Solar Coronal Loops Workshop IV, Florence, Italy, 30 June – 3 July 2009.

[2] Urnov A., Shestov S., Bogachev S., Goryaev F., Zhitnik I., and Kuzin S.
Space-time Dynamics of Hot Coronal Plasma Structures studied in the SPIRIT experiment.
International coronal workshop "The Sun: from active to quiet", Moscow, Russia, 19-23 October 2009.

[3] Goryaev F., Parenti S., Urnov A., Oparin S., Hochedez J.-F., and Reale F.
Differential Emission Measure analysis using a probabilistic approach to the XRT data.
The 3rd Hinode Science Meeting, Tokyo, Japan, 1-4 December 2009.

O.4.6. Missions

Assemblies, symposia, conferences:

- 30 June – 3 July 2009, Solar Coronal Loops Workshop IV, Florence, Italy.
- 19-23 October 2009, International coronal workshop "The Sun: from active to quiet", Moscow, Russia.

O.5. Investigations of the solar atmosphere from spectroscopic diagnostics

O.5.1. Objectives

Spectroscopic observations lead to further insights about the solar atmosphere. They provide diagnostics on the temperatures, densities, and thermal / non-thermal velocities of the plasma. Such investigations are key to understanding solar mechanisms like coronal heating, solar wind acceleration, or eruptions. Data from the SOHO-SUMER, HINODE-EIS, CORONAS-SPIRIT spectrometers, and even also from imagers, are spectroscopically analysed by SIDC scientists in order to explain larger scale solar observations on the basis of the micro-physics.

O.5.2. Progress and results

O.5.2.1. Temperature diagnostics using line spectrometers or broadband imagers

The Bayesian Iterative Method (BIM) and the DIMITUS project

Developed in the frame of the 'DIMITUS' grant, the Bayesian Iterative Method (BIM) enables estimating the Differential Emission Measure (DEM) using line spectra and, strikingly, broadband imaging data.

Inverse problems techniques allow deriving physical characteristics of optically thin plasma sources from their extreme ultraviolet or X-ray spectra. The BIM relies on a probabilistic Bayesian framework for solving the spectral inverse problem and reconstructing DEM distributions. To demonstrate its performance, we have carried out numerical tests, establishing the robustness and usefulness of BIM. We then applied it to solar active regions (ARs) that had been analyzed in previous papers. We confirm earlier SOHO-SUMER results, showing very good quantitative agreement at log T ~ 6.5, while displaying a slight shift for the two lower temperature maxima. With the CORONAS/F-SPIRIT data, we confirmed the controversial presence of hot plasma in ARs at temperatures 9–15 MK. With HINODE-XRT, BIM provides evidence for 30% more hot plasma at 4–6 MK than in 2–4 MK in a non-flaring AR.

Signature of nanoflares

If AR are heated via one of the nanoflare scenarios, very hot plasma (5 MK and more) should then be observed. Reale, Parenti et al (2007) first showed the diagnostic capability of the HINODE-XRT multi-band X-ray telescope. Their technique can be compared to the recent BIM developments, mentioned above. Still in collaboration with the University of Palermo and SAO, S. Parenti has further exploited XRT and TRACE observations of non-flaring AR **R.1** and post-flaring AR **R.3**, evidencing high temperatures. The aims are now

to estimate the maximum detectable temperature, and to study the influence of a flare on the whole AR temperature.

The ISSI group led by S. Parenti (The role of spectroscopic and imaging data in understanding coronal heating) held its last meeting in January 2009. The work of the group ended with an interesting report (available at the ISSI website).

O.5.2.2. Temperature and Alfvén wave amplitude above polar holes

While pointing at a coronal hole using the SOHO-SUMER spectrometer, L. Dolla observed transition region and coronal lines. He interpreted the line profiles in terms of temperature and Alfvén wave velocity.

One of the theories explaining the heating of the corona and the acceleration of the fast solar wind that comes from coronal holes relies on the dissipation of Alfvén waves. One mechanism for it is the ion-cyclotron resonance of the high frequency part of the spectrum, after a turbulent cascade. This process should produce a preferential heating of ions having low charge-to-mass ratios. To estimate the ion temperature, one can use the line width, which is broadened by the thermal Doppler Effect, but also by any velocity field in the line of sight. Such a velocity field can be produced by Alfvén waves, but the observer has only one observable and two unknown quantities. In a previous work, Dolla & Solomon (2008) had proposed a method to separate these two contributions, by using the gradient of the off-limb line widths. They applied it to data obtained from SUMER. In **R.1**, they extended this work by including a recently identified Fe VIII line at 1442.56 Å and confirmed the preferential heating of low charge-to-mass ions. They also used more recent atomic data for the density diagnostic necessary to derive the Alfvén wave amplitude, and corrected their formula. This led to an increase of the estimated amplitude, but it is still lower than what is needed in numerical models to heat the corona and to accelerate the fast solar wind.

O.5.2.3. Line distortion and inhomogeneities of flow in coronal dimmings

Below CMEs, coronal dimmings usually appear as regions of temporary lowered intensity in coronal lines, close to the erupting active region. The fainter emission is interpreted as a temporary density deficit. L. Dolla and A. Zhukov made a study of the distortion exhibited by the profiles of on-disc coronal lines inside dimmings, using HINODE-EIS.

Spectroscopic studies show that coronal dimmings are associated with large outflows lasting several hours. Using EIS, observations reveal that strong outflows occurring in low intensity regions are also associated with larger line widths than in the surrounding area. Some authors have suggested that these wide profiles may be due to turbulence or to the addition of several components having different intrinsic velocities; some others interpreted the broadening as due to the growth of Alfvén wave amplitude in those magnetically open and rarefied regions.

Dolla & Zhukov **R.3** analysed Fe XII 195.12 Å line profiles observed by EIS in a coronal dimming after an X-class flare on 13 December 2006. They noted that a lot of the profiles in the dimming appear distorted and they designed empirical coefficients to quantify this via a comparison with a fitted Gaussian. They also concluded that the flows in the dimming are inhomogeneous, with a component at rest and another that is strongly Doppler-shifted. These features cannot be explained only by the increase of the Alfvén wave amplitude in the dimming area.

O.5.2.4. Others

The evolution of prominences can lead to their instabilities and eventual eruptions. A project aims at extending the results in Parenti et al. 2005 and Parenti & Vial 2007 in deriving prominence physical parameters. A particular interest is also given to the analysis and modelisation of the H and He lines. The JOP 207/HOP 82 observation program led by S. Parenti, in collaboration with IAS (F), and the University of Glasgow (UK), was run once in 2009. The objective of the program is to study quiescent and eruptive prominences. The program is again in the SOHO/Hinode calendar for 2010. Another observation program, HOP 73, led by T. Berger with S. Parenti responsible for SUMER, ran without success. In the context of an ISSI project, S. Parenti has contributed to the writing of a review on the physics of prominences **R.3.**

The collaboration of I. E. Dammasch with U. Feldman and colleagues at NRL was continued in 2009. It resulted in an investigation based on SUMER data, about transition-region redshifts in various solar regions. The straightforward relationship between the magnitude of redshift and radiance was demonstrated for quiet Sun regions, whereas in coronal holes and active regions these characteristics become more complicated. First results were presented as a poster **O.5.6** at SOHO22. A paper will be submitted. Results of another SUMER study on emission measure submitted in 2008 were published in 2009 **R.1**. Another study on solar irradiance submitted in 2008 is still only in print **R.3**.

O.5.3. Perspective for next years

F. Goryaev plans to study more XRT data, but his future work will mainly relate to the investigation of data from multilayer pass bands such as STEREO-SECCHI, SOHO-EIT, and especially the new SDO-AIA data. Concerning high resolution line spectra, HINODE-EIS and SDO-EVE call for a BIM analysis too. Additionally, F. Goryaev intends to extend his DEM analysis to the bivariate inverse problem of recovering temperature but also density.

A research proposal (SOLIDA) has been submitted **R.4**. One of its goals enables cross-analysis between instruments of different kinds (e.g. imagers and spectrometers). Like DIMITUS, SOLIDA relies on DEM inversion techniques, but the approach of the latter consists in reducing the dimensionality.

The study of ion-cyclotron resonance and Alfvén wave amplitude will be extended by analysing Hinode-EIS observations above polar coronal holes, closer to the limb and on wider areas (full raster scans instead of a fixed slit position).

The spatial configuration of the flows in the dimming deserve further investigation, and in particular, the spatial interpretation of the double component of the fitted profiles. Differential Emission Measure determination in coronal dimming is planned.

O.5.4. Personnel involved

Scientific staff: I. E. Dammasch, L. Dolla, F. Goryaev, J.-F. Hochedez, S. Parenti, F. Verbeeck, A. Zhukov

O.5.5. Partnerships

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

- J. Solomon, S. Parenti, J.-C. Vial, Institut d'Astrophysique Spatiale (IAS), Orsay, France
- A. Urnov, S. Oparin, Lebedev Physics Institute of the Russian Academy of Sciences (FIAN), Moscow, Russia.
- F. Reale, Dipartimento di Scienze Fisiche & Astronomiche, Universita di Palermo, Palermo, Italy
- N. Labrosse, University of Glasgow, UK
- T. Berger, Lockheed Martin Solar and Astrophysics Laboratory (LMSAL), USA
- G. Doschek, U. Feldman, E. Landi, Naval Research Laboratory, USA

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

- DIMITUS, BELSPO non-EU post doctoral fellowship, 1 March - 31 December 2009
- PRODEX SDE (BELSPO/PRODEX SIDC Data Exploitation PEA)
- STCE (Solar–Terrestrial Center of Excellence)

Visitors:

- Alexander Urnov, Lebedev Physics Institute (FIAN, Moscow), July 2009, DIMITUS.

O.5.6. Scientific outreach

Meeting presentations

[1] I. E. Dammasch, U. Feldman

Transition Region Redshifts in Quiet Sun, Coronal Hole, and Active Region (Poster)
STEREO 3 – SOHO 22, Bournemouth, UK, April 2009

[2] Dolla, L., Solomon, J.
Solar off-limb line widths: Alfvén waves, ion-cyclotron waves, and preferential heating (Talk)
STEREO 3 – SOHO 22, Bournemouth, UK, April 2009

[3] Dolla, L., Solomon, J.
Solar off-limb line widths: Alfvén waves, ion-cyclotron waves, and preferential heating (Poster)
Solar Wind 12, Saint Malo, France, 21-26 June 2009

[4] Goryaev, F.; Parenti, S.; Hochedez, J.-F.; Shestov, S.; Kuzin, S.; Urnov, A.; Ulyuanov, A.; Bogachev, S.; Reale, F.
Hot plasma investigation in Active Regions with SPIRIT and Hinode data (Talk)
Solar Coronal Loops workshop IV, Florence, Italy, 30 June - 3 July 2009

[5] Goryaev, F.; Parenti, S.; Urnov, A.; Oparin, S.; Hochedez, J.-F.; Reale, F.
Differential Emission Measure analysis using a probabilistic approach to the XRT data
3rd Hinode Science Meeting, Tokyo, Japan, 1-4 December 2009

[6] S. Parenti, F. Reale, K.K. Reeves
Post flare evolution of AR 10923 from Hinode/XRT
Coronal loop Workshop, Florence, July 2009

[7] Urnov A., Shestov S., Bogachev S., Goryaev F., Zhitnik I., and Kuzin S.
Space-time Dynamics of Hot Coronal Plasma Structures studied in the SPIRIT experiment
International coronal workshop "The Sun: from active to quiet", Moscow, Russia, 19-23 October 2009

Seminars

[8] Dolla, L.
Solar Off-Limb Line Widths: Alfvén Waves, Ion-Cyclotron Waves, and Preferential Heating
Royal Observatory of Belgium (ROB), 15th January 2009

Wikis and Websites

- Website for ISSI team at Bern : http://www.issibern.ch/teams/soldyneuro/

O.5.7. Missions

Assemblies, symposia:
Dammasch (SOHO22, Bournemouth)
Dolla (BUKS 2009, Leuven)
Dolla (3rd Solar Orbiter Workshop, Sorrento)
Goryaev (Solar Coronal Loops Workshop IV, Florence)
Goryaev (The Sun: from active to quiet, Moscow)
Parenti (Solar Coronal Loops Workshop IV, Florence)

O.6. Investigations of the solar atmosphere from disc images or time series

O.6.1. Objectives

With SOHO-EIT, TRACE, STEREO-EUVI, HINODE-XRT, and soon SDO-AIA and PROBA2-SWAP, XUV-EUV images are drenching solar physics, but they still present challenges. How to handle their inherent limitations e.g. in terms of spatial, temporal, and spectral resolution? How to reconstruct the third spatial dimension? How to carry out quantitative studies and how to interface them with physical numerical models? The prefered approach at SIDC is to combine instrumental knowledge and signal theory in order to estimate physical quantities, such as height, temperature, or speed, which can then be investigated physically.

O.6.2. Progress and results

O.6.2.1. Sub-pixel analysis

Telescopes will never resolve the solar scenes at their physical scales, and imaging data are limited by their spatial resolution, cadence, and signal-to-noise ratio (SNR) in an interdependent way. Therefore the pixels of current and future EUV imagers always contain "spatial noise", namely aliasing, because their value is the average of an irregular solar signal having subpixel scales and sub-integration time variability. In this project, we aim at accessing sub-sample information by analysing the signal in the pixels, and by simulating solar EUV images using stochastic processes.

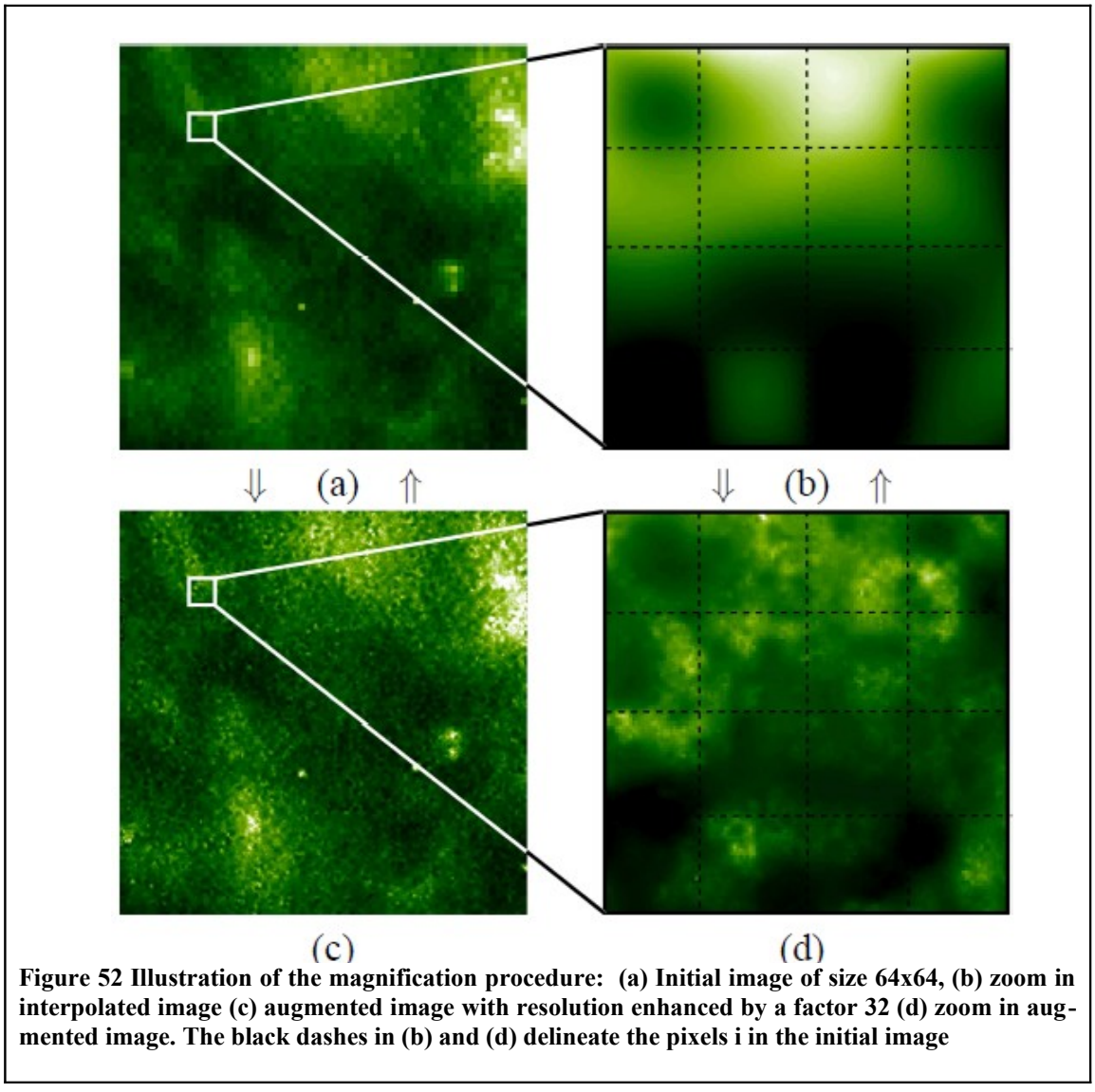


Figure 52 Illustration of the magnification procedure: (a) Initial image of size 64x64, (b) zoom in interpolated image (c) augmented image with resolution enhanced by a factor 32 (d) zoom in augmented image. The black dashes in (b) and (d) delineate the pixels i in the initial image

In **O.6.6**, **R.1** & **R.3** we developed a magnification procedure that preserves the multifractal spectrum and the visual aspect of the initial Quiet Sun (QS) image. As in previous work, we used the family of Compound Poisson Cascades (CPC) to extrapolate scale invariant properties. The idea is to perform an augmentation of information by locally adding small scale details within the initial pixel. This extrapolation yields a potentially infinite number of magnified versions of an image. It allows for large magnification factors (virtually infinite) and is physically conservative: viz. zooming out, back to the initial resolution gives the initial image

again. It is hence possible to quantitatively predict statistical and visual properties of QS images taken by future high resolution imagers such as SO-HRI.

In early 2009, J-F Hochedez noticed that the signal energy observed at high frequencies (at -or near- the pixel scale level) appeared larger than what spectral aliasing should normally produce under the assumption of pure self-similarity. The discrepancy must therefore arise from either the Sun or from another noise source that is not the above-discussed aliasing. We have verified on our synthetic data that the Poisson shot noise does generate a pattern that is consistent with this observation. A preliminary -though innovative- Poisson denoising has thereafter been performed by P. Chainais. The challenge is to denoise -thereby lowering the signal energy at high frequency-, while not making a smoothness hypothesis since we are working on multifractal images that are irregular everywhere.

O.6.2.2.SPOCA: Coronal image segmentation

This project develops methods for segmenting solar EUV images into meaningful regions such as Coronal Holes (CH), Quiet Sun (QS), Active Regions (AR), and later, filament channels and flares. Coronal segmentation allows determining automatically the location of the source of the fast solar wind (CH). Secondly, it enables solar cycle studies of AR, QS, and CH properties. Thirdly, it permits to focus heavy post-processings. Fourthly, it helps reconstructing the solar UV spectrum, which paves the way to bridging observations between image data and scalar time series from photometers. Since 2005, we have developed the Spatial Possibilistic Clustering Algorithm (SPOCA), which is a multi-channel, unsupervised, and spatially-constrained fuzzy clustering algorithm (R.1, R.1). The latest version of SPOCA was applied to the SoHO-EIT archive (a quasi-full solar cycle). Time series of the areas, mean and integrated intensities reveal that the average brightness of all regions -including CH and QS- exhibit variability *in phase* with the cycle.

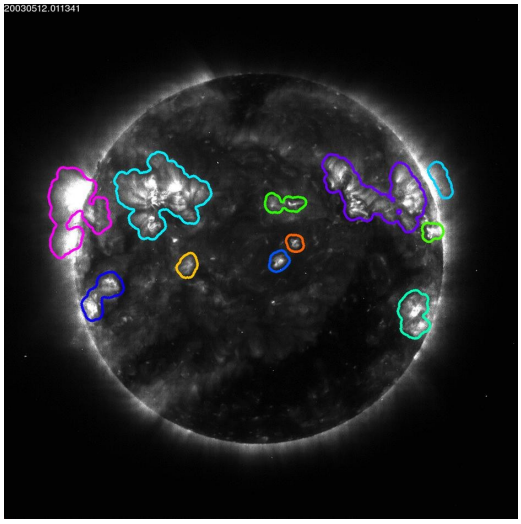


Figure 53 Segmentation using SPoCA on an EIT image from 12 May 2003. The different AR are identified and their tracking over time can be represented in movies of segmented images

In 2009, SPOCA was further developed. The limb correction was improved. The code was made robust against cosmic ray hits (CRH). The numerical stability was tested and improved. The temporal stability was investigated and found to be excellent on datasets representing QS conditions as well as datasets featuring AR belts at solar maximum. A tracking algorithm was implemented delivering beautiful movies. It is to be noted that currently SPOCA extracts either AR or CH out of the QS background, but not yet both simultaneously. A lower size limit was adopted to distinguish BP from AR. A list of SPOCA output parameters was formulated for inclusion in the HEK and the SDO pipeline.

The Royal Observatory of Belgium is co-investigator on the SDO Science Center **R.3** that is responsible for a suite of software pipeline modules doing automated feature recognition and analysis of the SDO data. The SIDC commitment to the SDO-SC is the insertion of SPOCA in the real-time SDO-AIA pipeline. SPOCA results were presented at the ISSI Soldyneuro meeting ('Mining and exploiting SDO data in Europe') **R.4**. Other SDO feature recognition algorithms are contributed by this international team and collaboration is initiated around three axes: correspondence of photospheric structures with their coronal counterparts, study of Bright Point versus Active Region populations, investigations comparing AIA with EVE measurements in view of a validation of the calibration for AIA. SPOCA will support all three axes.

As alternatives to the present SPOCA algorithm two parametric segmentation methods were tested. One is based on the fit of a Gaussian mixture model to EUV intensities. The other uses recursive dyadic partitioning (RDP) to cluster regions. Boundaries of regions are smoother with the second approach.

O.6.2.3. Raptor/Velociraptor: motion and brightness variation tracking

Movies of the solar corona in extreme ultraviolet (EUV) passbands exhibit the complex patterns of plasma dynamics structured by the magnetic field surrounding the solar surface. Since 2001, the development of the Velociraptor algorithm, which is able to extract motion (apparent velocity) and brightness variation from a set of only two successive images was developed. Velociraptor has many different applications including dimming studies, coronal seismology, solar rotation R.3, stereoscopy, and many more. It has been applied on SOHO-EIT, TRACE, STEREO-EUVI, and SDO-AIA data.

In collaboration with ISIMA, S. Gissot worked in 2009 on the Velociraptor calibration using synthetic solar images for more precise stereoscopy. Its Space Weather usage requires a high throughput and low-latency implementation in order to exploit the SDO-AIA datastream. After a C implementation of the Velociraptor algorithm in late 2008, T. Berghoff wrote in 2009 a CUDA GPU implementation. For AIA 4kx4k images, a speed of 13.5 second was achieved, when running on a top-of-the-line GPU. In comparison, the C implementation needs 5.5 minutes per image and the original IDL code would take about 8 hours. This new code called 'Raptor' runs hence 2000 times faster than the original IDL code. T. Berghoff additionally investigated and prototyped data visualization approaches based on encoding velocity and brightness variation either in 2D color maps or representing them in 3D images.

O.6.2.4. Exploitation of STEREO – SECCHI data to study the origin of CMEs

Solar disc observations provide key information regarding the initiation of space weather related phenomena (e.g. CMEs, flares, EIT waves). In this context, the early STEREO SECCHI-EUVI mission was unprecedentedly designed to assess the 3D structure of active regions (AR), so as to estimate e.g. their non-potentiality. To this aim, a local correlation tracking (LCT) technique was developed to allow automatic matching of pixels in both STEREO images **R.1**. A stereoscopic reconstruction then provides the 3D coordinates, in particular the altitude. In 2009, this technique has been further calibrated using synthesis images (texture generated in OpenGL) thanks to an international collaboration involving P. Chainais and E. Koenig from ISIMA. Coronal loop heights could be measured nearly simultaneously in the 171, 195 and 284 Å passbands. It was found that some loops look co-spatial in the 171 Å and 195 Å images while they actually have different heights and occupy different volumes. This result has important implications for multi-wavelength studies of coronal loops, especially for calculations using the filter-ratio techniques.

O.6.2.5. EIT waves

EIT waves are typically observed as moving fronts of increased coronal EUV emission in on-disk EUV observations, such as those made by STEREO SECCHI-EUVI observations. EIT waves exhibit characteristics of fast magnetohydrodynamics (MHD) waves which refract and reflect in relation to magnetic structures. Using velocity measurements made with EUVI observations and density estimates, we can use the wave motion to infer coronal characteristics, such as the coronal magnetic field.

Two methods of density estimation were used. Firstly, using HINODE EIS spectrometer measurements to estimate the density directly, and secondly using a computational model of a Coronal Mass Ejection (CME, the wave's counterpart) to produce synthetic brightness images. Using SECCHI-COR1 (coronagraph) imaging data from both STEREO spacecraft offers the unique opportunity to observe CMEs from two perspectives. By constructing a three dimensional density model to better constrain CME observations, it is possible to produce accurate density estimates. Extrapolating these density estimates down from the coronagraph images to on-disk features allows to estimate densities of EIT wave fronts. Using this technique it has been possible to estimate the inner corona magnetic field strength using a method of 'wave seismology'.

O.6.2.6. The 'Shutterless' program

The scientific aim of the EIT high-cadence synoptic program is to monitor long-term changes in the small scale dynamics of all kinds of solar structures (Active Regions, Quiet Sun, Coronal Holes, etc.), using high-cadence sequences made by EIT.

In 2009, the shutterless campaigns were planned on Jan 16, Apr. 1, and July 2.

O.6.3. Perspective for next years

O.6.3.1. Sub-pixel analysis

A dedicated method for Poisson denoising solar EUV images will be developed. Its preprocessing benefits to the performance of compression schemes will be assessed.

O.6.3.2. SPOCA: coronal image segmentation

In 2010, SPOCA will be inserted in the SDO-SC pipeline. It will populate the Heliophysics Events Knowledgebase (HEK) with tracked AR events. As part of the Soldyneuro ISSI research, SPOCA will provide statistical information for coronal regions, to be correlated with their photospheric counterparts. The identification of filament channels remains to be properly achieved. Indeed, when seen in coronal EUV passbands, filament channels are often erroneously classified as Coronal Holes by SPOCA. Using all AIA channels, and especially the ones sampling the Transition Region and the hot corona, should provide a solution to the above problem. Finally, SPOCA should be adapted to process the outputs of reconstructed DEM maps.

O.6.3.3. Raptor/Velociraptor: motion and brightness variation tracking

Several new exploitations of Velociraptor are foreseen: evolution of the long-term solar rotation oscillations, EIT waves and transient CH investigations, etc. In the future, we will use the precise calibration made on synthetic data to compute systematic reconstructions of prominences from 30.4 nm SECCHI-EUVI images in the period when stereoscopic reconstruction was possible. The spatio-temporal wavelet transform is a very promising tool that requires an efficient implementation to be fully effective and performant. This will be attempted in 2010.

As the RAPTOR algorithm runs on a special hardware platform, it is important to make the system as convenient as possible. We envision a system comprising a back-end running a compute server and multiple front-ends. The back-end would need access to the data archives, so that requests of solar data can be made without forcing the user to providing the actual data. The most important front-end would be IDL integration, offering a simple single function call for the users. Another useful front-end will be the web-interface or integration with SWB, which would include adding the corresponding visualization options.

O.6.3.4. Exploitation of STEREO – SECCHI data to study the origin of CMEs

The separation of the two STEREO spacecraft is too large at present for continuing the described 3D LCT reconstructions, but further analysis of the data from 2007 is envisaged. Eventually new methods can be used to treat the more recent data.

O.6.3.5. EIT waves

We intend to improve the estimates of the coronal field, by accurately modeling the wave. Modelling MHD waves in the solar atmosphere with 3-dimensional MHD models is an inherently complex task, requiring time consuming and complicated codes. However it has been shown that MHD waves can be modelled with reasonable accuracy using a short-wavelength WKB approximation. Such a model maps wave fronts along ray paths that are refracted off of non-uniform coronal features and is capable of reproducing many of the physical properties of these phenomena. By modeling the wave we will be able to infer the coronal field to some higher degree of accuracy.

O.6.3.6. Flare and short-term irradiance studies

Theoretical properties of the distance based upon Unbalanced Haar wavelet will be studied. The method will be applied on time series featuring a situation before a flare and after a flare, in order to try and discriminate those situations. The method is generic enough to be applied to various other situations, such as the comparison of observed and reconstructed solar spectra.

O.6.3.7. The 'Shutterless' program

In 2010, SOHO will enter the 'Bogart' stage of the mission. The Shutterless campaign will have to be stopped but a solar cycle of Shutterless data awaits analysis.

O.6.4. Personnel involved

Scientific staff: T. Berghoff, V. Delouille, S. Gissot, J.-F. Hochedez, B. Mampaey, C. Marqué, L. Rodriguez, F. Verbeeck, M. West, A. Zhukov

O.6.5. Partnerships

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

- Vincent Barra, Pierre Chainais, Emilie Koenig, Université Blaise Pascal Clermont II, F
- Petrus Martens, Harvard-Smithsonian Center for Astrophysics, USA, PI of SDO science center
- Roman Brajsa, Hvar Observatory, University of Zagreb, Zagreb, Croatia
- Hubertus Wöhl, Kiepenheuer-Institut für Sonnenphysik, Freiburg, Germany
- Marilena Mierla, Institute of Geodynamics of the Romanian Academy, Romania
- Fabio Reale, University of Palermo-INAF, IT
- K.K. Reeves, SAO, USA
- Jim A. Klimchuk, NASA Goddard Space Flight Center, USA
- Bernd Inhester, Max-Planck-Institute for Solar System Research, Germany
- Sarah Gibson, High Altitude Observatory, Working Group Leader
- The STEREO – SECCHI consortium
- The ISSI "Soldyneuro" international team (see names on website)

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

- Catherine Timmermans, Rainer von Sachs, Marc Feuerstein, Institut de Statistique, UCL
- Jean-Pierre Antoine, Michel Crucifix, UCL, Louvain-La-Neuve

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

- PRODEX SDE (BELSPO/PRODEX SIDC Data Exploitation PEA)
- PRODEX TLS (BELSPO/PRODEX SIDC Telescience PEA)
- STCE (Solar–Terrestrial Center of Excellence)
- CoSSMIC Tournesol project

Visitors:

- Farzad Kamalabadi, Illinois University, USA, 2009-06-11, solar image processing
- Roman Brajsa, Hvar Observatory, University of Zagreb, Croatia, 2009 Sept. 2-4, Solar cycle
- Josef Koller, 2009-09-07, Los Alamos National Laboratory, USA, data assimilation
- Eric Kolaczyk, Boston University, USA, 2009-10-07, Poisson denoising
- Marilena Mierla, Institute of Geodynamics of the Romanian Academy, 24 May – 6 June and 17 – 24 October 2009, Work on 3D reconstruction techniques using STEREO data. Publication under joint affiliation.

O.6.6. Scientific outreach

Meeting presentations

[1] Berghmans, D. ; Seaton, D. ; Clette, F. ; Hochedez, J.-F.
EUV imaging of the solar corona (invited talk)
"Solar Wind Symposium" held at the STCE on June 18, 2009, Brussels

[2] D. Boyes, B. Mampaey, T. Berghoff, C. Verbeeck, V. Delouille, J.-F. Hochedez
SDO Data Centre at ROB and the WisSDOm 'Web Incessant Screening SDO Manipulation' Project (poster)

6th European Space Weather Week, Brugge, Belgium, November 16-20, 2009

[3] Gissot, Samuel
Probing the dynamics in sequences of solar atmospheric images: algorithms and results (PhD private defence)
Défense privée, Université catholique de Louvain, FYMA-Département de physique, Louvain-La-Neuve, Belgium, 23 June 2009

[4] Gissot, Samuel
Probing the dynamics in sequences of solar atmospheric images: algorithms and results (PhD public defence)
Défense publique, Université catholique de Louvain, FYMA-Département de physique, Louvain-La-Neuve, Belgium, 03 September 2009

[5] Hochedez, J.-F.
Solar coronal imaging tomorrow… and in the years after tomorrow - Solar observation in IYA - 2009 (Invited lecture)
Belgian Physical Society meeting, 1 April 2009, Hasselt

[6] Hochedez, J.-F.
Solar Physics (invited series of lectures)
Novicosmo 2009 Summer School, Highlights in Astrophysics, 20-30 Sept. 2009, Rabac, Croatia

[7] Koenig, E. ; Chainais, P. ; Delouille, V. ; Hochedez, J.-F.
Amélioration virtuelle de la résolution d'images du Soleil par augmentation d'information invariante d'échelle (contributed talk)
XXIIe colloque GRETSI, Dijon (FRA), 8-11 septembre 2009

[8] Rodriguez, L.
Three-dimensional reconstruction of active regions (invited talk)
STEREO-3 / SOHO-22 Workshop, Bournemouth, England, April 27 – May 1, 2009.

[9] Rodriguez L., Zhukov A. N., Gissot S., Mierla M.
Three-dimensional reconstruction of active regions (poster)
European Geosciences Union (EGU) General Assembly 2009, Vienna, Austria, 19 – 24 April 2009.

[10] C. Timmermans, V. Delouille, R. von Sachs
Comparaison et classification de séries temporelles via leur développement en ondelettes de Haar asymétriques (poster)
Rencontres de la société francophone de classification Grenoble, Septembre 2009

[11] C. Verbeeck, V. Barra, B. Mampaey, T. Berghoff, V. Delouille, J.-F. Hochedez
Segmentation of solar EUV images - fuzzy clustering on multichannel data (talk)
International Space Science Institute meeting «Mining and exploiting the NASA Solar Dynamics Observatory data in Europe», Bern, October 19-21, 2009.

[12] C. Verbeeck, B. Mampaey, T. Berghoff, V. Delouille, J.-F. Hochedez, V. Barra
Fast and robust segmentation of solar EUV images: towards operational use in the age of SDO (poster)
6th European Space Weather Week, Brugge, Belgium, November 16-20, 2009

Wikis and Websites

- http://sidc.be/velociraptor/ (Gissot webmaster)
- http://www.issibern.ch/teams/soldyneuro: Website for the Soldyneuro ISSI team
- http://www.sidc.be/EIT/High-cadence: Official web site of the "Shutterless" program

O.6.7. Missions

Assemblies, symposia: J.-F. Hochedez (Belgian Physicl Society meeting, Hasselt)
J.-F. Hochedez (Novicosmo summer school, Rabac, HR)
F. Verbeeck (ESWW6, Bruges, B)
F. Verbeeck (Ondelettes et Sciences du Vivant, Gembloux, B)
L. Rodriguez (EGU General Assembly, Vienna, A)
L. Rodriguez (STEREO-3/SOHO-22, Bournemouth, UK)

Commissions, working groups (days):
V. Delouille (ISSI Soldyneuro, 3 days)
J.-F. Hochedez (ISSI Soldyneuro, 3 days)
J.-F. Hochedez (S. Gissot PhD defence, 2 x ½ day)
F. Verbeeck (ISSI Soldyneuro, 3 days)
S. Parenti (ISSI coronal heating, 3 days)

Research visits (days):
J.-F. Hochedez (ISIMA, 2 days)
S. Gissot (ISIMA, 3 days)

O.7. Coronagraphic, radio, and in-situ investigations in the heliosphere

O.7.1. Objectives

The intrinsic dynamic nature of the Sun has its most visible expression in the form of eruptive events. Their study and has a two-fold interest. The first is related to space weather in the near-Earth environment, which is driven by the Sun and most directly by the solar wind and transient solar events carried along with it. The second interest relies on the importance of understanding the fundamental science leading to the origin and development of solar transients. Among them, we can name coronal mass ejections (CMEs), corotating interaction regions (CIRs), flares and EIT waves as the important manifestations of the ever-changing solar atmosphere.

CMEs are the most important form of solar activity in terms of space weather affecting the near-Earth environment. CMEs are huge eruptions of plasma and magnetic fields from the Sun that may arrive to the Earth in 1 to 5 days. An important number of questions regarding their origin, internal structure and dynamics remain still unanswered. Coronal dimming is a phenomenon closely linked with CMEs. It is observed as a sudden localized decrease of EUV intensity and is interptreted as a loss of mass in the low solar corona due to a CME. An important number of spacecraft providing remote-sensing solar observations (SOHO, TRACE, STEREO, Hinode) and in-situ data (ACE, Wind, SOHO, STEREO) offers great opportunities for the investigation of solar eruptive events and their influences on space weather. SIDC research aims at studying a link between different aspects of solar eruptive phenomena, starting with the origins of CMEs at the Sun and following by their cruise through the heliosphere.

O.7.2. Progress and results

O.7.2.1. EIT waves and dimmings

The physical nature of EIT waves, large-scale bright fronts propagating in the solar corona in association with CMEs, is an important research topic at the SIDC. It still remains a subject of a continuing debate in the solar research community. Two main ways of interpreting this phenomenon have been suggested. One of them describes an EIT wave as a fast-mode magnetosonic wave freely propagating in the corona. The other interpretation does not consider an EIT wave a true magnetohydrodynamic wave but instead invokes several possibilities linked to the magnetic field restructuring during the CME evolution in the low corona. An EIT wave observed by the SECCHI/EUVI telescopes onboard the STEREO spacecraft on December 8, 2007 was investigated. The wave front had a nearly symmetric shape and exhibited a peculiar velocity profile: after an initial short propagation at a speed around 100 km/s, it nearly stopped for about 30 minutes and then was re-

accelerated up to speeds of more than 200 km/s. It is difficult to envisage such a velocity change for a freely propagating coronal wave. On the contrary, such a behavior is possible e.g. for erupting prominences. It was concluded that this event provides observational evidence that even EIT waves with a symmetric front can be produced by the magnetic field restructuring during the CME eruption R.1.

One of the first EIT wave events that were observed by STEREO/SECCHI from widely separated viewpoints was studied by A. Zhukov, M. West and L. Rodriguez. It was found that this 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.

Several thousands of EIT wave and dimming events were observed by SOHO/EIT in variable coronal configurations from solar minimum to solar maximum and back. The data is now available to study the evolution of EIT wave and dimming characteristics statistically along a full solar cycle. Following a previous study in collaboration with partners at NASA GSFC, M. West constructed a coronal dimming catalogue. Using 97 EIT wave events as primers for dimming events, a significant database of coronal dimmings observed with SOHO/EIT was created. The catalogue includes magnitude, intensity, and duration of dimmings and their relation to several other prominent solar phenomena such as flares and CMEs. The catalogue is now complete and can be used to obtain statistics of dimming events, which can subsequently be used with data from the STEREO mission to help understanding depths and intensities of dimmings that are observed from multiple vantage points.

Comprehensive long-term studies require extracting EIT waves using a fixed definition of the criteria that a candidate event should fulfill in order to be classified as an EIT wave. “NEMO” software (Novel EIT wave Machine Observing) was developed to scan systematically the many thousands of EIT images and produce a consistent event list. NEMO is the first software package elaborated for EIT wave and dimming detection. The main objectives are to present the first systematic catalogue of EIT waves produced by NEMO tool to space weather and science community, as well as the construction of a high-quality user-friendly website containing events detected in real time.

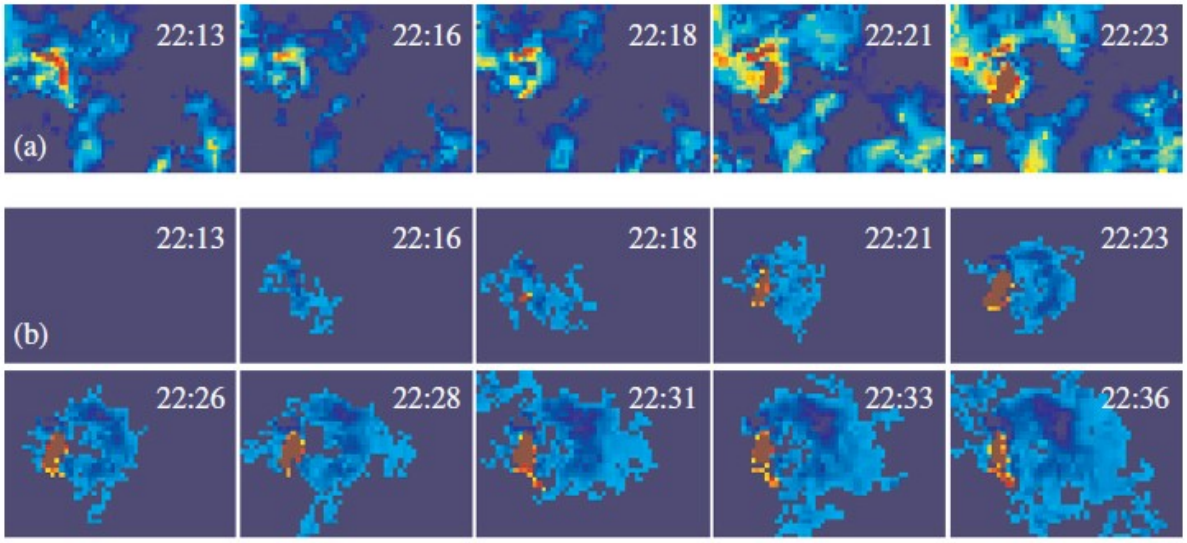


Figure 54: A micro-eruption in the solar corona observed by SECCHI/EUVI onboard STEREO A on October 17, 2007. (a) Non-differenced images. (b) Difference images.

In 2009, the structure of the basic algorithm was optimized. The algorithm criteria were modified to work with STEREO/SECCHI data within the period of the Whole Heliospheric Interval (WHI). The current version of the NEMO code consists of several parts. Detection and extraction blocks are written in MatLab and image preprocessing uses Interactive Data Language (IDL). The code was now completely rewritten in IDL (for a better performance with huge data sets), and its results are compatible with those obtained using the previous version. Further improvements include extraction of additional event parameters after detection and significant modification of the clustering algorithm. A catalogue was created to represent the most interesting and/or large-scale events observed simultaneously by SOHO and STEREO. All available EIT images taken in the 195 Å bandpass were scanned and a catalogue of EIT waves and other solar on-disk eruptions was created. Several very nice events suitable for a scientific analysis were found. An in-depth investigation of most typical detection mistakes indicated several weaknesses of the algorithm, and most of them were corrected.

Using high spatio-temporal resolution of SECCHI/EUVI data, we detected small-scale eruptive events tentatively referred to as “mini-CMEs”, as they exhibit morphologies similar to large-scale CMEs (Figure 54). A mini-CME differs from its large-scale counterparts by having a smaller geometrical size, a shorter lifetime, and reduced intensity of coronal wave and dimmings. The small-scale coronal wave develops from micro-flaring sites and propagates up to a distance of 40000 km in a wide angular sector of the quiet Sun over 20 minutes. The area of the small-scale dimming is two orders of magnitude smaller than for large-scale events. The average speed of the small-scale coronal wave is 14 km/s. The observations give a strong indication that small-scale EUV coronal waves associated with micro-eruptions propagate in the form of slow-mode MHD waves almost perpendicular to the background magnetic field R.3.

O.7.2.2. Coronal mass ejections (CMEs)

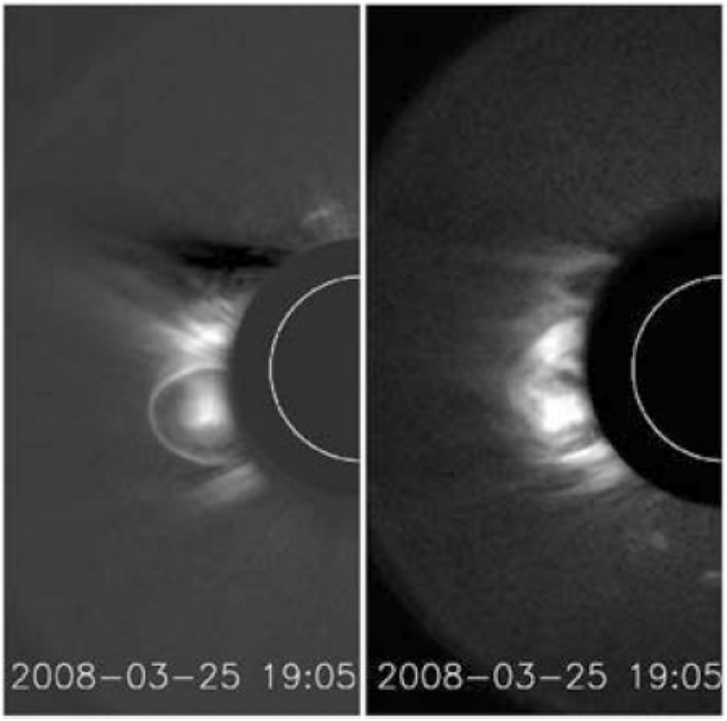


Figure 55: A CME on March 25, 2008 observed simultaneously by SECCHI/COR1 onboard STEREO B (left panel) and STEREO A (right panel). The visible solar disc is represented by the white circle, while the larger dark disc shows the coronagraph occulter. A difference in the CME appearance as seen from two viewpoints separated by 47º is clearly visible.

The data from SECCHI/COR1 and SECCHI/COR2 coronagraphs onboard STEREO provide us with the unique opportunity to reconstruct the 3D structure of CMEs and their true propagation direction. In collaboration with foreign partners, D. Berghmans, S. Gissot, C. Marqué, L. Rodriguez, M. West and A. Zhukov participated in two studies of the 3D structure of CMEs. Four reconstruction methods were applied to the observations of three structured CMEs: forward modeling, local correlation tracking (LCT) with tie-pointing, the apparent center of mass tracking and the polarization ratio technique. A comparison of results obtained from the application of the four reconstruction algorithms was presented and discussed. A review of existing techniques for 3D reconstruction of CMEs was prepared in collaboration with a large number of international partners R.3. These efforts are helpful to understand the 3D structure of CMEs, while at the same time they highlight difficulties of stereoscopic reconstruction of structures in optically thin plasma.

Another track in the 3D reconstruction of CMEs was to derive precise values of electron density in CMEs using forward modeling. STEREO SECCHI/COR1 data were used to calculate the density in CME structures by fitting a computational model to an observation of a CME. The model produces a synthetic brightness image that is matched with the observed CME brightness, thus providing more accurate density estimates than those that can be obtained using single-viewpoint SOHO/LASCO observations.

O.7.2.3. Interplanetary disturbances

We participated in the investigation of Sun – Earth connections supported by the International Space Science Institute (ISSI, Bern, Switzerland) in the framework of the working group "From the Sun to the Terrestrial Surface: Understanding the Chain". A joint analysis of solar and interplanetary sources of the severe magnetic storm on May 15, 2005 was performed. A huge interplanetary coronal mass ejection (ICME) was observed

near the Earth. The source region of the ICME exhibited a two-ribbon flare, filament eruption and a full halo CME. The sequence of events, from solar wind measurements at 1 AU and back to the Sun, was analyzed to understand the origin and evolution of this geoeffective ICME. An interpretation alternative to all previous studies of this event was proposed: the ICME is formed by two extremely close consecutive magnetic clouds (MCs) that preserve their identity during their propagation through the interplanetary medium. Observations of an interplanetary type II radio burst allow the tracking of possibly multiple structures through the inner heliosphere R.1.

Another track of research pursued by the ISSI team is the analysis of frontside full halo CMEs with non-typical geomagnetic response, a study led by L. Rodriguez. Three events that occurred in the year 2000 (close to the activity maximum of the solar cycle 23) were selected. The associated solar and heliospheric phenomena as well as their impact on the Earth's magnetosphere were investigated. Even though all three were fast full halos, the geomagnetic response was very different. After analyzing the source regions of these halo CMEs, it was found that the halo associated with the strongest geomagnetic disturbance was the one that initiated farthest away from the disk center. Therefore, these three events do not fit into the general statistical trends relating the location of the solar source and the corresponding geoeffectiveness. Possible causes of such a non-typical behavior were investigated. Non-radial direction of eruption, passage through a leg of an interplanetary flux rope and strong compression at the eastern flank of a propagating ICME during its interaction with the ambient solar wind are found to be important factors that have a direct influence on the resulting north–south interplanetary magnetic field (IMF) component and thus on the CME geoeffectiveness. Some indications that interaction of two CMEs could help in producing long-lasting southward IMF component were found. The geomagnetic response of the terrestrial magnetosphere could be explained successfully using plasma and magnetic field in situ measurements from the L1 point R.1.

Another important advantage provided by the STEREO data is the ability to combine remote-sensing observations of CMEs with in-situ measurements of their interplanetary counterparts. In collaboration with E. Kilpua (University of Helsinki, Finland) and M. Mierla (Institute of Geodynamics, Romania), we started a study that demonstrates the identification and matching of CMEs at the Sun with the corresponding ICMEs. The study is based on a forward modeling technique to reconstruct the direction of propagation and angular width of CMEs in three dimensions, thus allowing the simulation of eventual radial propagation up to 1 AU and analysis of their expected impact on a given spacecraft. So far 26 events have been analyzed, and four of them were detected both at the Sun and in situ.

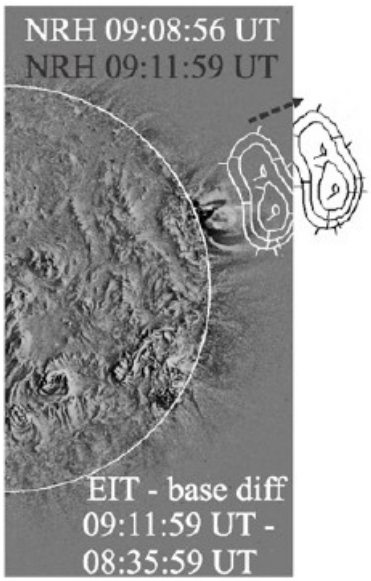


Figure 56: The propagation of the coronal shock wave (the source of the radio type II burst) during the flare/CME event on July 9, 2002. The elongated radio source (marked with white contours) of the type II burst is overlaid on the EIT image that is closest in time. The position of the radio source was corrected taking into account the time difference between the shock signatures and the EIT image and the velocity of the shock (the corrected position is denoted with black contours).

Several SIDC scientists contributed to the activities of the Work Package 3 (Chromosphere and Corona) of the EU FP7 SOTERIA project (SOlar – TERrestrial Investigations and Archives), providing contributions to the online report "Energy Release through Flares and CMEs, their Evolution and Geospace Impact Parameters for Special Events". Current state of knowledge in the field of physics of ICMEs and solar energetic particle events was reviewed. Key problems in predicting the geospace impact of solar eruptive events were discussed R.4.

O.7.2.4. Large-scale coronal structure

An important factor for CME studies is the pre-eruption configuration of the coronal magnetic field. It is well known that many CMEs originate from prominence cavities in the solar corona. C. Marqué participates in an ISSI working group "Coronal Prominence Cavities" (led by S. Gibson, HAO, USA) related to the study of prominence cavities on the base of observations in radio imagery, EUV, soft X-ray and white-light data. Radio transfer calculations are in principle able to check that the density and temperat-

ure depletions determined by other means (e.g. using the EUVdata) are compatible with the radio observations. Based on all observational data available, a geometric semi-empirical model of prominence cavities is being developed.

O.7.2.5. Radio-spectral diagnostics of solar radio bursts

The energy release during the flare/CME process leads to formation of large-amplitude coronal disturbances and shock waves. The longest-known signatures of shock waves are type II radio bursts observed in dynamic radio spectra as slowly drifting lanes of enhanced emission. We studied the origin of coronal shock waves, 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 (reported mean velocity below 500 km/s) 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 (Figure 56). 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 pressure in the flare was the source of the shock wave R.3.

In the framework of collaboration with R. Miteva (Astrophysical Institute Potsdam, Germany), parameters obtained from type II burst observations (coronal electron density, Alfvén velocity, and Alfvén Mach number) were used as an input to the theoretical model of electron acceleration at coronal shock waves. The efficiency of the theoretical model to explain the observed type II radio emission under the imposed coronal conditions was investigated.

A global Moreton wave associated with a type II burst, X17.2 flare and CME observed on October 28, 2003 was studied in collaboration with international partners R.3. The particularity of the event is the global propagation of the Moreton wave and two separate apparent wave centers. The mean velocity of the Moreton wave lies in the range of 900–1100 km/s (depending on the propagation direction). The perturbation profile analysis of the wave indicates amplitude growth followed by amplitude weakening and broadening of the perturbation profile. This behaviour 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.7.3. Perspective for next years

Investigations of solar eruptive events, their interplanetary counterparts and geomagnetic consequences will be pursued further. 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.

Investigations of solar radio bursts will be continued in the framework of the new Action 1 project ROSE (Radio Observations from the Sun to the Earth). The ROSE proposal was selected in 2009 and the work on the project will start in 2010. It will study possible continuation of shock wave propagation from the corona to the interplanetary space.

The modeling of coronal cavities will be finalized. The NEMO website will be refurbished to consolidate all available results and make it a fully operational real-time website. All STEREO/EUVI data will be scanned

and EIT waves and dimmings will be catalogued. Possibly PROBA2/SWAP and eventually SDO data can be searched for solar eruptions as well. A further modification of the NEMO algorithm will be performed to improve the quality and stability of event detection. 3D parameters and speeds of EIT waves will be ultimately included in the NEMO catalogue. The comparison of EIT wave catalogues with the catalogues of CME radio signatures is also planned.

O.7.4. Personnel involved

Scientific staff: D. Berghmans, S. Gissot, P. Lisnichenko, J. Magdalenić, C. Marqué, M. Mierla, B. Nicula, O. Podladchikova, L. Rodriguez, D. Seaton, R. Van der Linden, M. West, A. Zhukov

Technical staff: S. Willems

O.7.5. Partnerships

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

- M. Mierla, Institute of Geodynamics of the Romanian Academy, Romania
- E. Kilpua, University of Helsinki, Finland
- B. J. Thompson, NASA Goddard Space Flight Center, USA
- I. S. Veselovsky, Skobeltsyn Institute of Nuclear Physics, Moscow State University, Russia
- B. Vršnak and T. Žic, Faculty of Geodesy, Zagreb University, Croatia
- A. Veronig and N. Muhr, Institute of Physics, Austria
- R. Miteva, Astrophysical Institute Potsdam, Germany
- A. Vourlidas and R. Howard, Naval Research Laboratory, USA
- D. Webb, Air Force Research Laboratory, USA
- M. Pick, Paris–Meudon Observatory, France
- M. Velli, Jet Propulsion Laboratory, USA
- V. Krasnosselskikh, CNRS-Orleans, France
- A. Vuets and P. Leontiev, National Technical University of Ukraine, Ukraine
- STEREO/SECCHI consortium
- SOTERIA consortium

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
- H. Cremades, Universidad Tecnológica Nacional/CONICET, Mendoza, Argentina
- 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 "Coronal Prominence Cavities" includes:

- S. E. Gibson, High Altitude Observatory, USA
- J. Hao, National Astronomical Observatory, Chinese Academy of Sciences, China
- H. S. Hudson, University of California, Berkeley, USA
- T. A. Kucera, NASA Goddard Space Flight Center, USA
- P. McIntosh, HelioSynoptics, Inc., USA
- K. K. Reeves, Harvard-Smithsonian Center for Atrophysics, USA
- D. J. Schmidt, University of Colorado, USA
- A. C. Sterling, Marshall Space Flight Center, USA
- G. de Toma, High Altitude Observatory, USA
- D. Tripathi, Mullard Space Science Laboratory, UK
- D. R. Williams, Mullard Space Science Laboratory, UK

- M. Zhang, National Astronomical Observatory, Chinese Academy of Sciences, China

Grants/Projects used for this research/service

- PRODEX contract "SIDC Data Exploitation"
- Solar–Terrestrial Center of Excellence project (WP ROB A.3, WP ROB A.4)
- Action 1 project "Global Waves and Shocks in the Corona: Origin, Nature, Inverse & Forward Modeling"
- International teams program, International Space Science Institute (ISSI) at Bern, Switzerland (working groups "From the Sun to the Terrestrial Surface: Understanding the Chain" and "Coronal Prominence Cavities")
- EU FP7 project SOTERIA (SOlar – TERrestrial Investigations and Archives), WP3
- 2 grants ASBL-VZW

Visitors:

- M. Mierla, Institute of Geodynamics of the Romanian Academy, Romania, May 24 – June 6 & October 17–24
- R. Miteva, Astrophysical Institute Potsdam, Germany, May 31–June 7 & November 21–26
- L. Ofman and M. Selwa, NASA GSFC, USA, March 30–April 3
- V. Krasnosselskikh, CNRS-Orleans, France, March 30–April 3
- M. Pick, Paris–Meudon Observatory, France, October 2009
- P. Leontiev and A. Vuets, IASA, State Polytechnic University, Ukraine, November 1–30

O.7.6. Scientific outreach

Meeting presentations

[1] Marqué C.
Radio observation of filament cavities
First meeting of the ISSI working group "Solar Prominence Cavities", January 13–16, Bern, Switzerland

[2] Magdalenić J., Marqué C., Zhukov A., Veronig A., Vršnak B.
Flare-generated coronal shock without a coronal mass ejection on 14 November 2005
STEREO-3/ SOHO-22 Workshop, April 27–May 1, Bournemouth, UK

[3] West M. J., Zhukov A. N., Rodriguez L.
STEREO and SOHO observations of white light CME shock formation
STEREO-3/SOHO-22 Workshop, Bournemouth, UK, April 27–May 1

[4] O. Podladchikova
3D parameters reconstruction for diffusive objects observed with STEREO
STEREO-3/SOHO-22 Workshop, Bournemouth, UK, April 27–May 1

[5] Chifu I., Mierla M., Rodriguez L.
Statistical study of halo CMEs and their influence on the Earth magnetic field
Space Climate Symposium 3, Lapland, Finland, March 18–22

[6] Mierla M., Inhester B., Marqué C., Rodriguez L., Gissot S., Zhukov A. N., Berghmans D., Davila J.
On 3D reconstruction of coronal mass ejections using SECCHI-COR data
European Geosciences Union General Assembly 2009, Vienna, Austria, April 19–24

[7] Rodriguez L., Zhukov A. N., West M., Kilpua E., Mierla M.
Linking CMEs observed by STEREO with their interplanetary counterparts
Solar Wind 12 Conference, St. Malo, France, June 21–26

[8] Dasso S., Demoulin P., Gulisano A. M., Cremades H., Mandrini C. H., Schmieder B., Cid C., Cerrato Y., Saiz E., Rodriguez L., Zhukov A. N., Aran A., Menvielle M., Poedts S.

Expansion of magnetic clouds under different solar wind conditions
Solar Wind 12 Conference, St. Malo, France, June 21–26

[9] O. Podladchikova
Driving scales for coronal heating
Solar Wind 12 Conference, St. Malo, France, June 21–26

[10] O. Podladchikova et al.
EUV micro-eruptions
Solar Wind 12 Conference, St. Malo, France, June 21–26

[11] Lisnichenko P., Podladchikova O.
WHI: SOHO and STEREO EIT waves and eruptions as detected by NEMO
IAU XXVII General Assembly, Rio de Janeiro, Brazil, August 3–14

[12] O. Podladchikova
Introduction to solar physics
AACIMP-09 meeting, Kiev, Ukraine, August 6–15

[13] Cid C., Cerrato Y., Saiz E., Gonzalez W., Aguado J., Aran A., Cremades H., Dasso S., Lathuillère C., Mandrini C., Menvielle M., Poedts S., Rodriguez L., Sanahuja B., Schmieder B.**,** Zhukov A. N.
Solar sources related to the largest Dst variations of solar cycle 23
International Living With a Star (ILWS) conference 2009, Ubatuba, Brazil, October 4–9

[14] Cerrato Y., Saiz E., Cid C., Aguado J., Aran A., Cremades H., Dasso S., Lathuillère C., Mandrini C., Menvielle M., Poedts S., Rodriguez L., Sanahuja B., Schmieder B., Zhukov A. N.
Halo CMEs far from central meridian: why are they geoeffective?
International Living With a Star (ILWS) conference 2009, Ubatuba, Brazil, October 4–9

[15] Magdalenić J., Marqué C., Zhukov A.**,** Veronig A., Vršnak B.
Flare-generated coronal shock on 14 November 2005 (poster)
Sixth European Space Weather Week, Brugge, Belgium, November 16–20

[16] Lisnichenko P., Podladchikova O.
NEMO calibration with EIT waves and eruptive dimmings catalog for EIT/SOHO mission
Sixth European Space Weather Week, Brugge, Belgium, November 16–20

[17] Miteva R., Magdalenić J., Mann G., Önel H., Marqué C.
Electron acceleration at coronal and interplanetary shock waves (poster)
Sixth European Space Weather Week, Brugge, Belgium, November 16–20

[18] P. Leontiev, A. Vuets, V. Podladchikov, O. Podladchikova
NEMO operational development (poster)
Sixth European Space Weather Week, Brugge, Belgium, November 16–20

Seminars

[19] Zhukov A. N.
Solar coronal mass ejection observations in the EUV
Lebedev Physical Institute of the Russian Academy of Sciences, Moscow, Russia, December 29

[20] Lisnichenko P., Podladchikova O., Vuets A., Leontiev P.
NEMO operational development
Naval Research Laboratory, USA

[21] A. Vuets, P. Leontiev, P. Lisnichenko, O. Podladchikova
NEMO operational development
Royal Observatory of Belgium, November 26

Wikis and Websites

- SOHO/EIT dimming catalogue: http://solweb.oma.be/users/mwest/DimmingWork/Dimming.html
- CACTUS CME catalogue: http://sidc.be/cactus
- NEMO catalogue of on-disk CME counterparts: http://sidc.be/nemo

O.7.7. Missions

Assemblies, symposia:

- C. Marqué: first meeting of the ISSI working group "Solar Prominence Cavities", January 13–16, Bern, Switzerland; 2nd Workshop on Solar physics and space weather with LOFAR, June 24–26, Potsdam, Germany; Workshop on the future of solar radioastronomy in France, June 29–30, Meudon, France; Second meeting of the ISSI working group "Solar Prominence Cavities", November 2–4, Bern, Switzerland; Sixth European Space Weather Week, November 16–20, Bruges, Belgium
- O. Podladchikova: meeting of the ISSI working group "Shock Waves", February 2009, Bern, Switzerland; EGU General Assembly, April 19–24, Vienna, Austria; AACIMP-09 meeting, August 6–15, Kiev, Ukraine; STEREO-3/SOHO-22 Workshop, April 27–May 1, Bournemouth, UK; Wind 12 Conference, June 21–26, St. Malo, France; Sixth European Space Weather Week, November 16–20, Bruges, Belgium
- J. Magdalenić: STEREO-3/SOHO-22 Workshop, April 27–May 1, Bournemouth, UK; BUKS-2009 workshop on MHD waves and seismology of the solar atmosphere, April 6–8, Leuven, Belgium; SOTERIA WP3 meeting, June 22–23, Brussels, Belgium; 2nd Workshop on Solar physics and space weather with LOFAR, June 24–26, Potsdam, Germany; Workshop on the future of solar radioastronomy in France, June 29–30, Meudon, France; PhD thesis defence by S. Gissot, September 3, Louvain-la-Neuve, Belgium; Sixth European Space Weather Week, November 16–20, Bruges, Belgium
- L. Rodriguez: STEREO-3/SOHO-22 Workshop, April 27–May 1, Bournemouth, UK; Wind 12 Conference, June 21–26, St. Malo, France
- M. West: STEREO-3/SOHO-22 Workshop, April 27–May 1, Bournemouth, UK
- A. Zhukov: BUKS-2009 workshop on MHD waves and seismology of the solar atmosphere, April 6–8, Leuven, Belgium; SOTERIA WP3 meeting, June 22–23, Brussels, Belgium; PhD thesis defence by S. Gissot, September 3, Louvain-la-Neuve, Belgium; Event "Frank de Winne – Commander of the International Space Station", October 14, Brussels, Belgium; Sixth European Space Weather Week, November 16–20, Bruges, Belgium
- P. Lisnichenko: Sixth European Space Weather Week, November 16–20, Bruges, Belgium

Research visits (days): A. Zhukov (9 days)
J. Magdalenić (4 days)

P. Solar instrumentation

P.1. Design and construction of radiotelescopes in the HUMAIN station

P.1.1. Objectives

The project is part of WP2 (ground-based solar instruments) of the STCE, which has two components: optical observations with the USET telescopes in Uccle and radio observations at the Humain station, near Marche-en-Famenne. F. Clette is 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 advantage 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. 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.

P.1.2. Progress and results

P.1.2.1. Spectral Observations

Spectral observations performed at the Humain station rely on a Callisto receiver built by ETH Zürich. In April 2009, the mount supporting the antenna plugged to Callisto received a new control software written by A. Ergen and running under the Linux operating system. This new software is designed to receive commands both locally, from a human operator (Mr. P. Janssens) and remotely with command lines. After being installed, the next step was to make the software able to communicate with positioners in such a way that the pointing of the antenna mount can be checked for remote control or automatic procedure, which is the final goal of this work. A. Ergen designed the necessary electronic interface. The positioners and the last version of the software needs to be tested and installed on site.
Frequency converters were partly built and tested during the year (with J.-L. Dufond) to explore other frequency bands than the one initially covered by the Callisto receivers. They will permit to monitor the solar activy or the man-made interferences in the bands 1-2 GHz, and 2-3 GHz. One of the frequency converters still needs some work before being operational (stabilized Local oscillator).
For the improvement of the observations, a filter rejecting the FM band (85-110 MHz) was installed in May 2009. By preventing the strong FM band to enter the receiver, saturation and intermodulation at other frequencies could also be suppressed, leading to a significant improvement of the data quality (see Figure 57 & Figure 58).

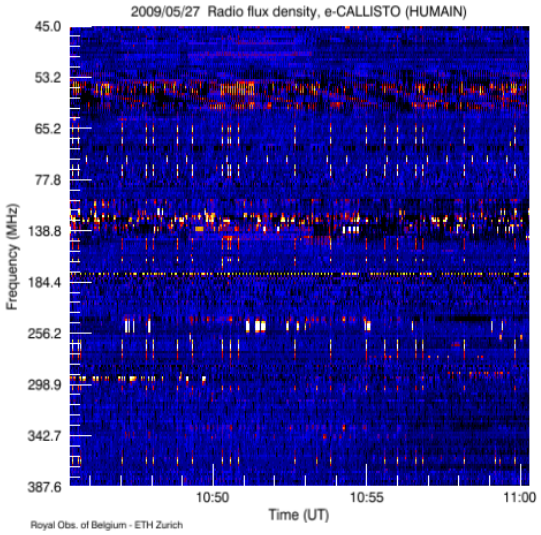


Figure 57 Typical spectrum before the filter insertion

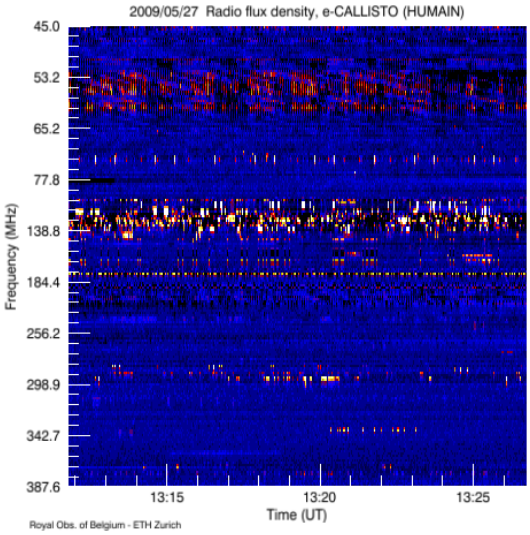


Figure 58 Typical spectrum after the filter insertion (same day)

A new frequency program was implemented in order to optimize the scientific interest of the collected data. The new observing program extends the frequency coverage from 45-92 MHz (below the FM band) to 45 to nearly 400 MHz. This program was chosen together with J. Magdalenić.

Solar activity was rather low during the year 2009: no burst was observed during the first 4 months of 2009. Between May and December, about 25 bursts were however detected, especially in December (see example in Figure 59). For most of them, they are type III bursts, related to electron beams accelerated during weak flaring events along open field lines.

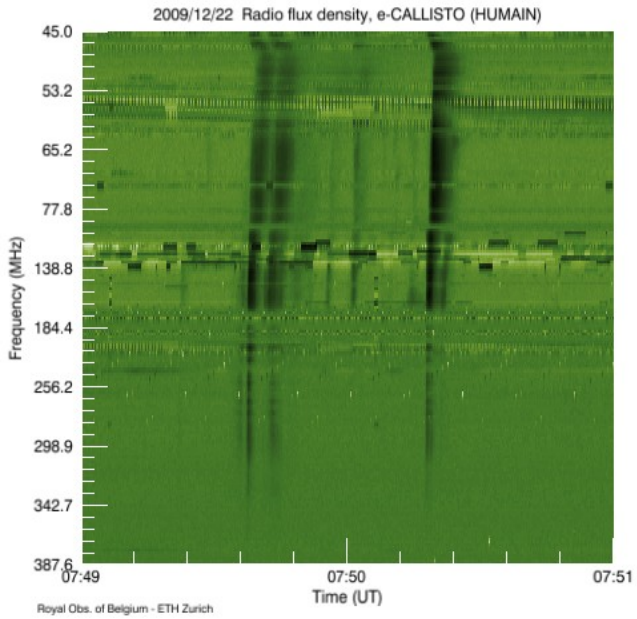


Figure 59 Group of type III bursts observed with the Callisto spectrograph in Humain on December 22nd 2009. (Reverse video: dark means bright)

P.1.2.2. Flux measurements

The project of measuring the solar flux at fixed selected frequencies is made in co-operation with Canadian colleagues from DRAO and NRCan (K. Tapping and D. Boteler). On the Belgian side, most of the work performed in 2009 consisted in the set up of laboratory infrastructures and hard-ware research (related to the antenna mount).

C. Marqué and J.-L. Dufond finalized the purchase of laboratory HF equipments, namely a signal generator and a spectrum analyzer from Agilent. The frequency cover-age allows its usage for both the spectral ob-servations (maintenance and future develop-ments) and the flux measurement project. A room was refurbished by the technical ser-vices of the Observatory to set up a small HF laboratory. C. Marqué and J.-L Dufond collected from the Royal Meteorological In-stitute a Faraday cage that will be used during the test and calibration of the future receivers.

C. Marqué performed some research related to the antenna mount that will be used on site (in Humain) for the solar flux observations. Different solutions were tested, from a complety new commercial system, to the

refurbishment of the existing hardware at the station. The latter was chosen to be the most reasonable, and in December 2009, a company was selected to perform the mechanical refurbishment of an existing 4m-parabola mount from the old solar interferometer. Due to the lack of precise documents about the performances of such mounts, pointing tests accuracy will be performed after the refurbishment.
The flux measurements are foreseen in the microwave range (above 1 GHz), and the current mesh parabolas are not suitable for precise flux measurements. C. Marqué and J.-L. Dufond investigated the possibility to reuse existing parabolic dishes from the RMI. On the other hand, C. Marqué performed several preliminary tests based on data sheets of commercial telecommunication parabolas. These studies show that such a solution could be envisioned, in terms of performances (see Figure 60). The final decision will be made once the mechanical performances of the refurbished mount will be known. Another problem is related to the wind load on a plain parabola and the mechanical stress that is transmitted to the mount. C. Marqué made preliminary estimations of this effect (see Figure 61). More precise calculation will be needed in the future.

Figure 60 Estimated "optical" performances for a commercial parabolic mirror

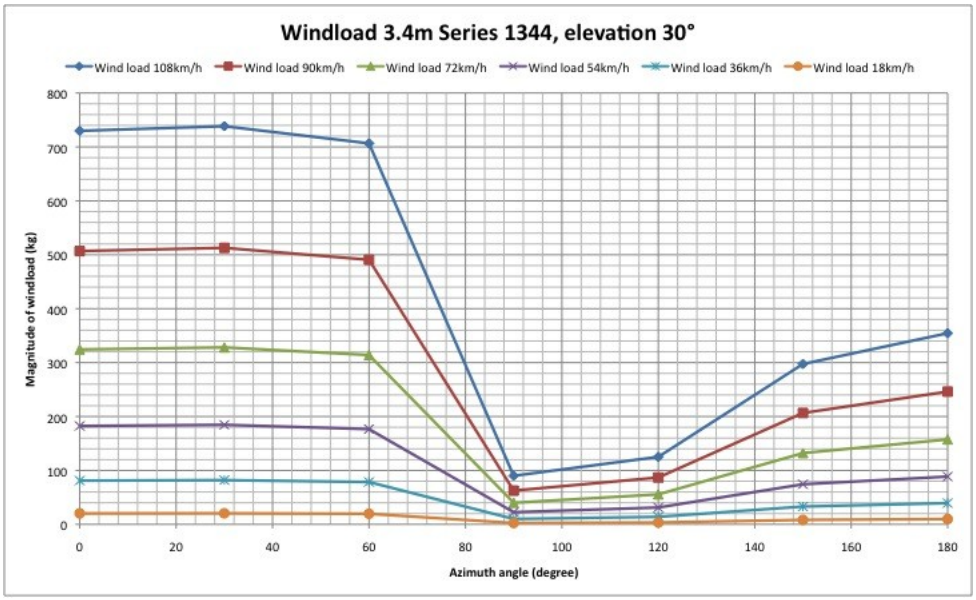


Figure 61 Estimated magnitude of the total windload on a 3.4m parabola

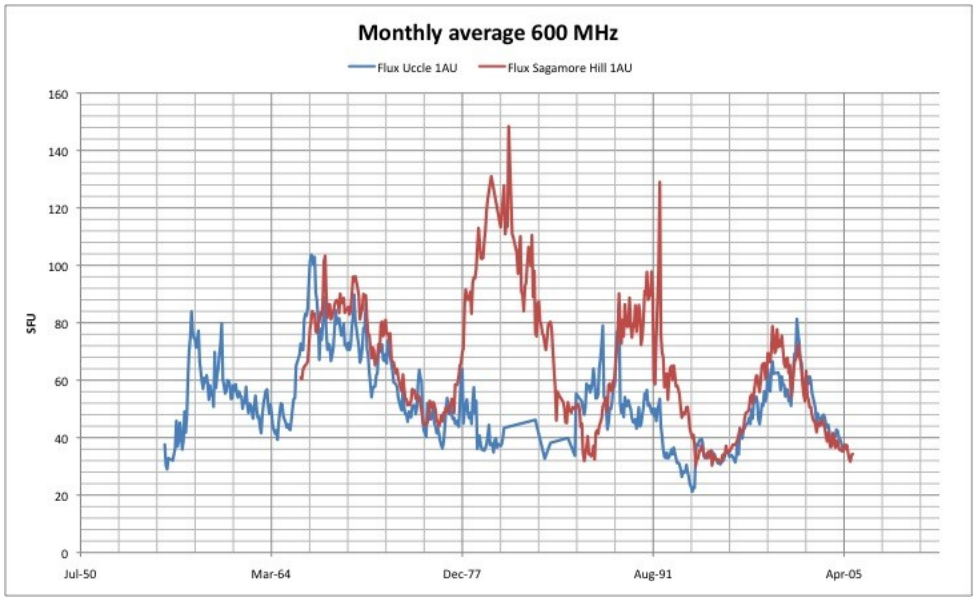
P.1.2.3. RFIs at the station

C. Marqué is involved in the monitoring of the Radio Frequency Interferences (RFI) situation on site. Broadband observations like the spectral ones currently performed at the station are very sensitive to man-made emissions. Practical decisions have been taken to reduce the level of interferences, such as filtering, selection of a new frequency program, etc…

C. Marqué replaced F. Clette during the 48th CRAF (Committee on Radio Astronomy Frequency) meeting in Paris, in May 2009. He presented a talk about the importance (both scientific and economic) of solar radio observations in the Sun-Earth relationship frame. He participated to discussions, at the observatory, dedicated to establish good relationships with nearby industry. He made a preliminary study of the possible impact of wind turbines on the radio observations, in response to projects of wind farms nearby the Humain station.

P.1.2.4. Digitization of past observations

With the help of J.-L. Dufond and two summer students (A. Hernould and N. Willems), C. Marqué initiated the digitization of past radio observations performed at the Humain station. It consists essentially of the daily flux measurement at 600 MHz, which was operated during nearly 50 years. A quick analysis reveals that the data need to be validated before being made available on the web (see Figure 62). Beyond the usual absolute calibration issues in such kind of measurements, several years are unfortunately missing (cycle 21) and others reveal technical problems (cycle 22), which seem, fortunately, to be easily solvable.



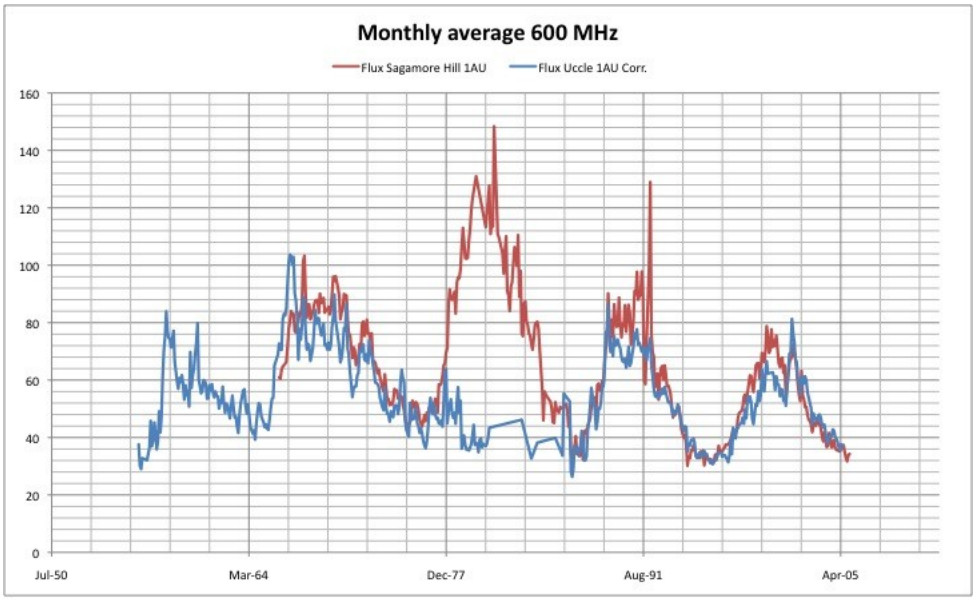


Figure 62 Digitized 600 MHz flux (monthly average) from Humain (blue) compared to the Sagamore Hill station (red). Top: uncorrected flux, bottom: preliminary corrected flux

P.1.3. Perspective for next year

P.1.3.1. Spectral Observations

Spectral observations will be developed during the year 2010, with the primary goal of extending the frequency coverage above the current upper limit of 400 MHz. The Callisto project, lead by the ETH institute in Zürich will go on. On the Belgian side, a second Callisto, which is currently used for tests in laboratory, should be set up in Humain with the frequency converters developed in Uccle, and be used for solar observations and RFI monitoring (in preparation of the flux measurement project). Discussions are ongoing to take over another spectrograph (frequencies up to 4 GHz) from the ETH institute, as solar radio observations from this institue are likely to slow down in the near future.

A project for a new spectrograph built with a French team from the Paris Observatory is also in discussions, for the frequency band below 1GHz. It should be by design, less sensitive to RFIs than the current instrument in use in Humain.

If both projects succeed, it is conceivable that by mid 2011, a full set of spectrographs will be operating in Humain, from 45 MHz to 4 GHz, providing a full coverage of the solar activity from the low to the upper corona.

C. Marqué wishes also to facilitate the usage and analysis of the current set of observations within the SIDC (a Presto alert was issued in February 2010 based on a type II burst observed in Humain). A new quicklook display of the data is already in use since the beginning of 2010. Some preliminary tests of automatic burst detection programs are currently performed and will be developed further on during the year, with the goal of providing a near real time list of solar bursts.

P.1.3.2. Flux measurements

The primary goal in 2010 for this project is to finalyze the control and pointing of the refurbished mount, choose and set up a suitable parabolic reflector, and start building the prototype of the receiver.

Pointing and tracking accuracy measurements will be made on the mount, to see if the accuracy needed for the project can be achieved. Based on the results, a final choice will be made on the parabolic mirror to be installed on the mount itself. The horn needed to collect the radio waves at the focal plane should be purchased.

The design of the whole control system, aimed to be as automatic as possible, will be established.

With the set up of a radio laboratory in Uccle, and the near completion of the design phase of the receiver by our Canadian colleagues, the building of the first prototype should start during the year 2010.

Finally, to help the current team to achieve the different tasks, the hiring of new staff members will be finalyzed, since no suitable candidates could be found in 2009.

P.1.4. Partnerships

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

- C. Monstein, ETH Zürich, Switzerland
- K. Tapping, DRAO, Canada

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

- F. Clette, ROB
- J.-L. Dufond, ROB
- A. Ergen, ROB

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

- STCE Work Package 2: Ground based solar monitoring

Visitors:

- D. Boteler, NRCan, Canada, September 3rd 2009. Discussion about antenna mount, progress of flux measurement project.

P.1.5. Scientific outreach

Meeting presentations

[1] C. Marqué, F. Clette
Solar radio astronomy and global change (talk)
48th CRAF meeting, Paris observatory, May 14th 2009

[2] C. Marqué, C. Monstein
RFI monitoring with CALLISTO (talk)
48th CRAF meeting, Paris Observatory, May 14th 2009

[3] C. Marqué, F. Clette, J.-L. Dufond, A. Ergen, J. Magdalenić, B. Dabrowski
Solar radio observations in Belgium (talk)
2nd LOFAR KSP workshop, June 24-25 2009

[4] C. Marqué, F. Clette, J.-L. Dufond, A. Ergen
Radio solar flux measurements in Belgium (Poster)
6th European Space Weather Week, Bruges, November 16th-18th 2009

Wikis and Websites

- Humain Radio data website (with the help of O. Lemaître): http://sidc.be/humain

P.1.6. Missions

Assemblies, symposia, conferences:

- Brugge: 6th European Space Weather Week, Nov. 16th-18th 2009

Commissions, working groups:

- Paris Observatory: 48th CRAF meeting, May 14th-15th 2009
- Astrophysical Postdam Institute: Solar Physics LOFAR meeting, June 24th-26th 2009
- Paris Observatory: Nançay Radioheliograph future, prospective meeting, June 29th-30th 2009

Research visits:

- University Louvain la Neuve: Meeting with Prof. C. Craeye about antenna. Feb. 23rd 2009
- ETH Zürich: Meeting with Prof. A. Benz and C. Monstein. Future of collaboration, visit of the Bleien Observatory. November 2nd 2009

Field missions: (Together with J.-L. Dufond and/or A. Ergen)

- Humain: GPS clock set up, filter tests, February 12th 2009
- Humain: New control software and PC set up (6m antenna), April 09th 2009
- Humain: Safety control for 6m antenna and control of various trenches and pipes for future cabling of antenna. May 27th 2009
- Humain: Visit due to power outage at the station (together with P. Motte). August 18th 2009
- Humain: Meeting with repair companies for antenna refurbishment. October 23rd 2009

P.2. Improvements of ROB solar telescopes (USET)

P.2.1. Objectives

In order to ensure the continuous operations of the USET instruments and also in order 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 activities 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

P.2.2. Progress and results

In 2009, most of the progress in the USET hardware development took place in the first half of the year.

P.2.2.1. Software development

No major telescope and camera software developments took place in 2009. Some improvements to the user interface and bug corrections were introduced in the SunCap image acquisition software. The existing telescope control software in BASIC language (DOS platform) was also converted to C language (LINUX platform) in preparation of the future increased automation of the USET.

P.2.2.2. New purchased equipment

- **New refractor for the planned CAII-K CCD imaging system**: an apochromatic refractor of 132mm aperture (Willimas-Optics FLT-132) ordered in 2008 was delivered early in 2009. This was the last order on the LOTTO solar instrumentation budget from 2002, closed at the end of 2008.
- **New full-aperture solar filter for the white-light CCD camera**: in order to improve the image quality on the white-light channel (recently upgraded CCD camera) a new custom-made 4-density filter was ordered from Lichtenknecker Optics in December 2009.

P.2.2.3. New equipment designed, tested and installed:

Internal development was carried out, involving equipment search and selection, mechanical design, test and commissioning. The main steps in 2009 were:

- **Mounting of the new H-alpha optics and camera on a common optical rail** (June 2006): this rail, acting as an optical bench, maintains collimation while easing the fine pointing of the telescope. It is also the first step in the planned motorization of the focusing and off-pointing of each individual solar telescope on the USET.
- **Design and commissioning of the 0.94 focal reducer for the white-light imaging system**: a final version of this reducer, installed in May 2009, provides an optimal match of the image scale with the sensor size of the new CCD cameras.
- After more than one year of flawless continuous operation of the new H-alpha telescope and filter, the old H-alpha telescope and Lyot monochromator was removed from the USET in September 2009, after more than 50 years of service (installed around 1957, first for a photographic camera system). This reconfiguration required a major rebalancing of the USET.

P.2.2.4. Optical design:

Next to the design of the 0.94 focal reducer mentioned above, a major development for 2009 was the **study of a telecentric Barlow lens system** needed to feed the narrow-band filter (2Å) of the CaII-K telescope now in preparation. The initial design was carried out in-house using an optical ray-tracing software. This design was then checked and optimized interactively by a manufacturer of custom optics, Molenaar Optics, in the context of the preparation of a quotation for the manufacturing of the multiple lenses.

Some advices on optical test setups were also provided in support to the DemeLab project.

P.2.3. Perspective for next years

The priorities for 2010 will be:

- Instrument development (hardware):
  - Ordering, installation and commissioning of the CaII-K internal relay optics in connection with the Observatory of Rome (PSPT).
  - Design and construction of the thermally-controlled enclosure of the CaII-K filter.
  - Design and construction of the motor-actuated mechanical support and focus systems for the H-alpha and white-light 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.
  - Development of new data archiving and distribution procedures.
  - 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.
  - Upgrade and reorganization of the USET web pages.

P.2.4. Personnel involved

Scientific staff: F. Clette

Technical staff: S. Vanraes, J-L. Dufond, O. Lemaître, A. Ergen

P.2.5. Partnerships

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

- Wolfgang Otruba, Manuela Temmer, Kanzelhöhe Observatory, Austria: H-alpha instrument development. (SoTerIA)

Visitors:

- Short visits: 1

P.3. SWAP

P.3.1. Objectives

SWAP is a solar extreme ultraviolet (EUV) imager designed for scientific studies of space weather events in the solar corona and for daily monitoring of the solar corona. The instrument has been built under the project management of the Centre Spatial de Liège (CSL). Since the launch of the PROBA2 satellite (Nov 2, 2009), the Royal Observatory of Belgium is the principal investigator institute for the exploitation of the data.

P.3.2. Progress and results

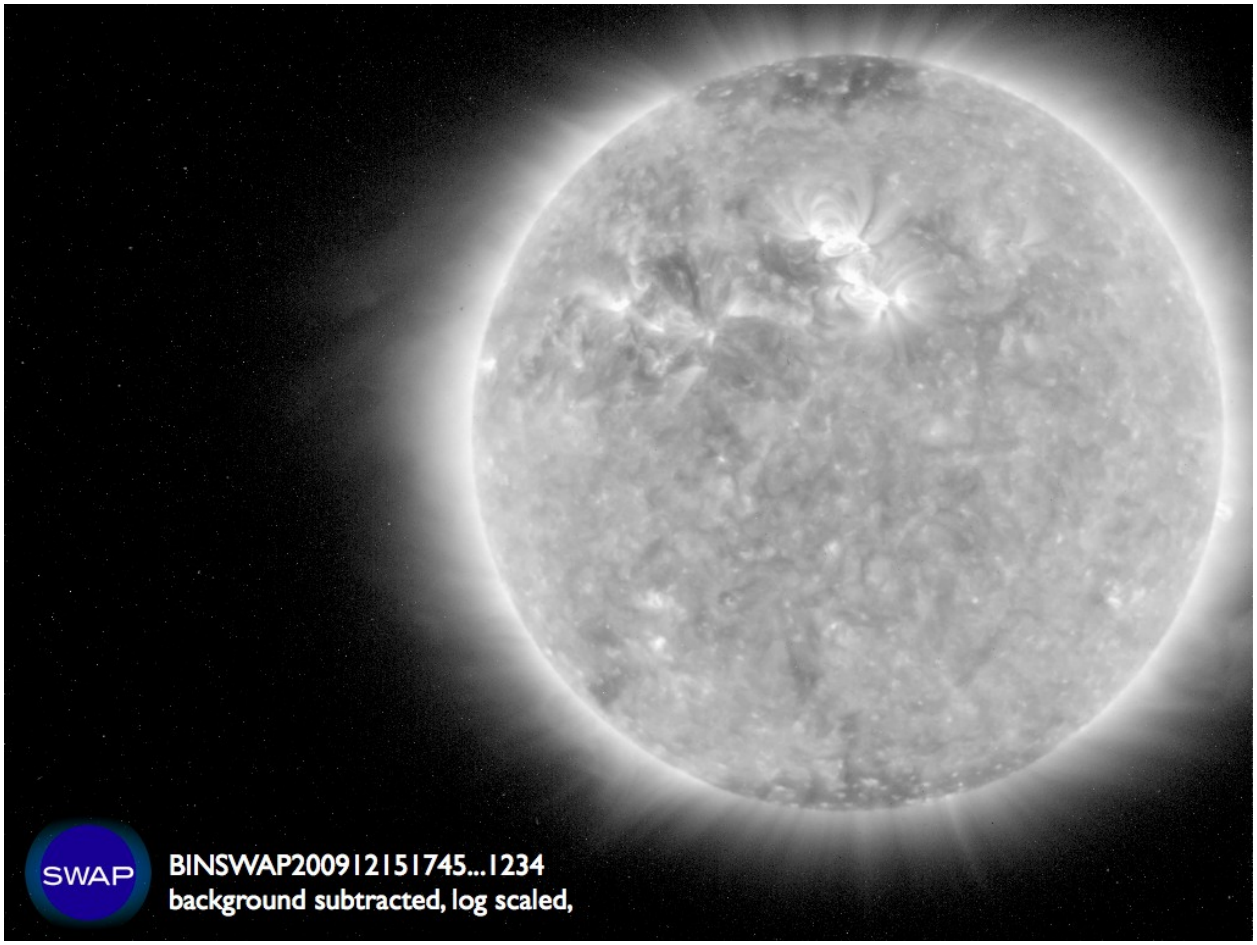


Figure 63: One of the first SWAP images, launched onboard PROBA2 (Nov 2 2009)

P.3.2.1. SWAP data reduction

The SWAP data reduction was developed as a pipeline of 3 software tools:

(1) The SWAP telemetry reformatter (SWTMR) processes incoming SWAP telemetry data from Redu (PROBA2 MOC) and stores it in internal databases and image files.

(2) The SWAP engineering data generator (SWEDG) combines the output from the SWMTR with metadata coming from Redu and with home-made metadata (e.g. attitude and positioning information). The data + metadata assembled by the SWEDG is stored as so-called engineering SWAP FITS files.

(3) The SWAP base science generator (SWBSDG) processes the engineering SWAP FITS files to science-grade SWAP FITS files.

The development and basic testing of all 3 data reductions steps (SWTMR, SWEDG and SWBSDG) was completed in 2009.

P.3.2.2. First light

On November 17 the SWAP electronics were first switched on and the housekeeping data checked. On November 20, the very first (dark) SWAP image was brought to the ground.

At this stage the SWAP door, which can open only once and never reclose, was still firmly locked. Nevertheless, we took the occasion to take 602 dark images and 278 LED images. SWAP has indeed two LEDs (LEDA and LEDB) in the focal plane assembly, which give a uniform illumination for instrument calibration.

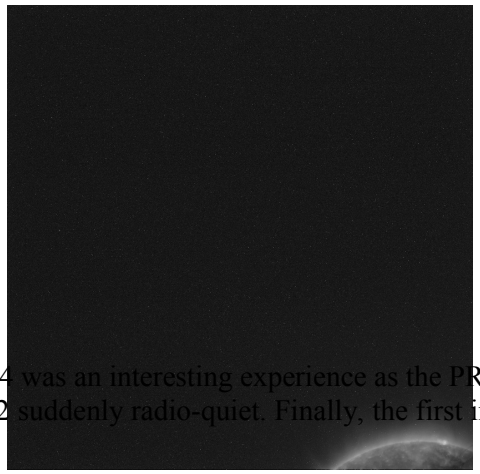


Figure 64. The first SWAP image after door opening

Finally opening the SWAP door on December 14 was an interesting experience as the PROBA2 onboard computer rebooted just before, making PROBA2 suddenly radio-quiet. Finally, the first image after door opening () showed us many things at once:

- the door was open,
- the filter was not broken,
- the solar signal strength was ok,
- the spacecraft pointing was … poor.

In the weeks afterward the pointing of the spacecraft was slowly but steadily improved (see below).

By the time of the Christmas holidays we had collected 454 images after door opening, meanwhile SWAP kept on collecting dark images (the spacecraft was not sun-pointing) while the SWAP crew dispersed to the respective Christmas trees. The data is available at http://proba2.sidc.be/swap/data/

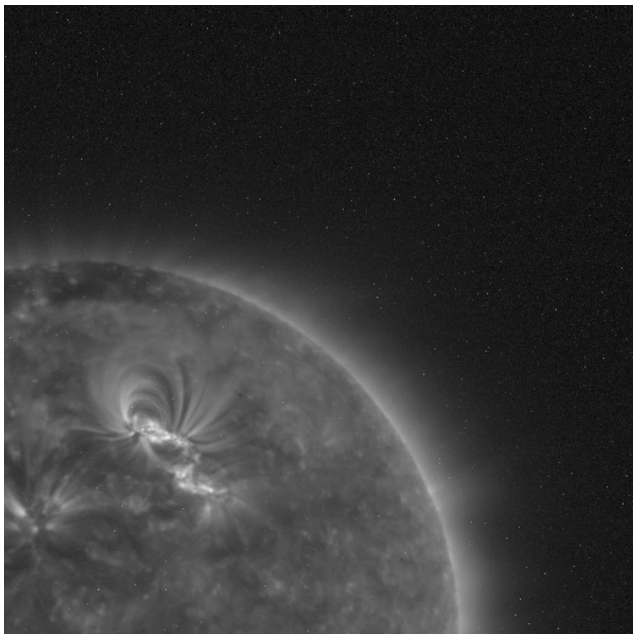


Figure 65. A subfield of a raw SWAP image.

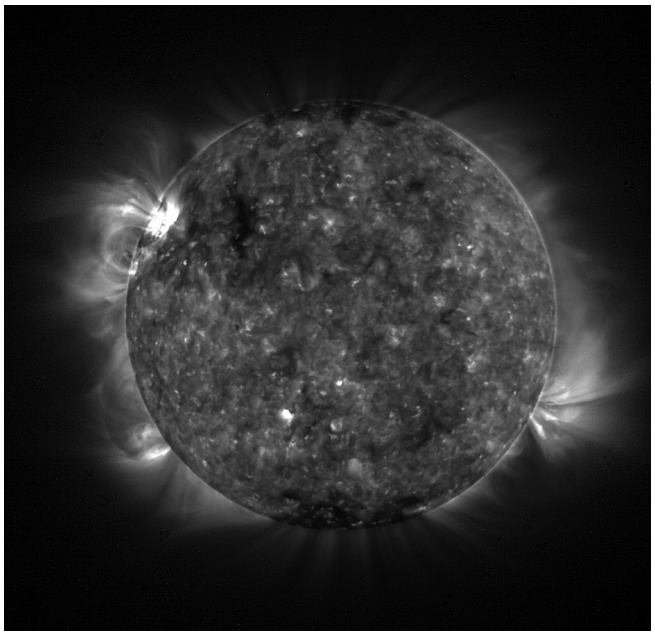


Figure 66. A processed SWAP image.

P.3.2.3. First instrument characterization

During commissioning, this work has been focused mostly on the characterization of SWAP's in-orbit detector performance, measuring dark current, mapping badly performing pixels, studying the flatness of the

detector, analyzing the first science images and using them to test our calibration schemes. This effort has produced an on-board pixel map, which is used to eliminate bad pixels from images and, therefore, improve on-board compression performance, better measurements of detector noise, and some preliminary science results.

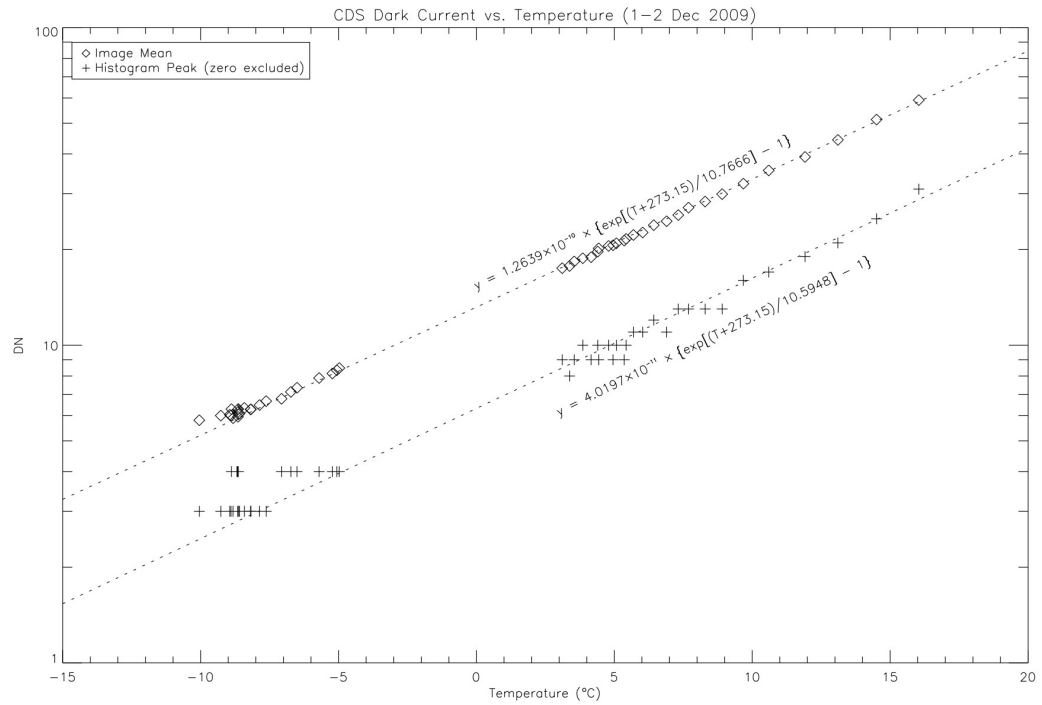


Figure 67: One example of measured SWAP in-orbit dark current.

P.3.3. Perspective for next years

The SWAP commisioning is expected to last till March 2010. After that the nominal mission is 2 years. SWAP will be operated as a space weather monitor providing regular imaging of the solar corona. We will put special emphasis on coordination with other space-based instruments, including SDO and its on-board EUV Imager, AIA, *Hinode*, TRACE, and SOHO.

A possible mission extension will be explored already towards the end of 2010.

P.3.4. Personnel involved

Scientific staff: D. Berghmans, E. D'Huys, B. Nicula, D. Seaton, A. Stanger, P. Vanlommel

Technical staff: S. Willems

P.3.5. Partnerships

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

- Peter Gallagher, Shaun Bloomfield and Claire Raftery, Trinity College Dublin, Ireland

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

- Jean-Marc Defise and Jean-Phillipe Halain at the Centre Spatial de Liege
- Stefaan Poedts and Mehmet Sarp Yalim at Center for Plasma Astrophysics (CPA) at KULeuven
- Dennis Gerrits and Stijn Ilsen at Verhaert NV
- Thomas Laroch at Spacebel
- Etienne Tilmans at the ESA Redu site

Grants/Projects used for this research/service

- SIDC Data Exploitation PRODEX C90345
- ROB/STCE personnel funding
- EU Framework 7 support (SOTERIA budget)

Visitors:

- Joe Zender, ESA, nearly every week for a few days, ESA D/SRE support to the P2SC development
- Anik De Groof, ESA, full time since summer 2009, ESA D/SRE support to the P2SC development

P.3.6. Scientific outreach

Meeting presentations

[1] Seaton, D. & the SWAP Team
Space Weather & SWAP
Space Climate Symposium, Saariselkä, Finland, March 18-21, 2009

[2] Seaton, D. & the PROBA2 Team
News from PROBA2: Intrumentation, Mission Planning, & Development
SOTERIA Workshop , Saariselkä, Finland, March 23-24, 2009

[3] D. Seaton & the PROBA2 Team
A Brief History of PROBA2
PROBA2 Launch Media Event, ROB, 2 November 2009

[4] A. De Groof, J. Zender, D. Berghmans, J.F. Hochedez, M. Dominique
PROBA2 launched.
Poster at ESWW6, Nov 16-20 2009, Brugge, Belgium

[5] I.E. Dammash, A. De Groof, J. Zender, J.F. Hochedez, D. Berghmans,
More PROBA2 Science Data Products.
Poster at ESWW6, Nov 16-20 2009, Brugge, Belgium

Wikis and Websites

- http://proba2.sidc.be/swap/data/
- http://proba2.sidc.be/index.html/swap/

P.3.7. Missions

Research visits:

- Space Climate Symposium: 18-21 March 2009, Saariselka Finnish Lapland
- SOTERIA workshop : 23-24 March 2009, Saariselka Finnish Lapland
- January 25-28, 2009: Discussion meeting with the Dublin SWAP group
- August 19-21, 2009: Discussion meeting with the Dublin SWAP group

Field missions:

- February 2, 2009: Mission to Verhaert during the System Validation Tests
- Dec 2009: Several missions to the ESA Redu site in support of the early SWAP operations.

P.4. LYRA

P.4.1. Objectives

LYRA is a solar radiometer that has embarked on 2 November 2009 on the ESA PROBA2 space mission. Its purpose is to monitor the solar ultraviolet irradiance in four passbands relevant to Solar Physics, Space Weather, and Aeronomy. LYRA also assesses the interest of new solar-blind diamond detectors and the de-

gradation properties of optical filters. It was built by a Belgian–Swiss–German consortium with additional international collaborations from Japan, USA, Russia, and France. J-F Hochedez is LYRA Principal Investigator, Y. Stockman (CSL) is its Project Manager, and W. Schmutz (PMOD) is Lead co-I in Switzerland.

As PI, the objective is to make LYRA a success in every respect. In 2009, this mainly meant the preparation of LYRA flight operations (including commissioning), data reduction, and upcoming scientific exploitation, plus actions to trigger possible successors.

P.4.2. Progress and results

P.4.2.1. Flight preparation, launch, data reduction, and early operations

The last telecon regarding SPR was held on 29/5/2009. One important LYRA issue has been the precise procedure (timing) for the doors unlocking and opening. A new version of the LYRA User Manual was released on 18/8/2009. The commissioning procedure was refined **R.4**.

PROBA2 was shipped to Russia in July, which triggered a first Press Conference at Verhaert. The mission was launched on 2 Nov. 2009. ROB organized another Press Conference at this occasion.

In the course of 2009, there were many LYRA team meetings about its data reduction pipeline. B. Giordanengo has been developing the LY-EDG, which constitutes the second stage of the LYRA pipeline at the output of the LY-TMR reformatter. I. E. Dammasch has been preparing the LY-BSDG, which converts the output of LY-EDG, expressed in digital units into Level 2 data expressed in physical units.

The first steps of LYRA commissioning (including the 'First Switch On') occurred already along November and December 2009. Preliminary analysis of the dark current and LED signals could be made. The LYRA doors will finally be opened and observations started early in January 2010.

For its radiometric calibration, simulations were performed using LYRA responses from laboratory measurements, together with sample spectra from instruments already in space. The procedures and results of the preflight calibration are demonstrated, with an emphasis on estimating channel "purities", and the planned LYRA data products are shortly explained. The instrument calibration is extensively detailed in BenMoussa et al 2009 R.1.

P.4.2.2. Preparation to scientific exploitation

The knowledge of solar extreme and far ultraviolet irradiance variations is essential for the characterization of the Earth middle and upper atmosphere. For a long time, this knowledge has been derived from empirical models based on proxies of the solar activity. However, the accurate modeling and prediction of the Earth atmosphere necessitate improving the precision on the irradiance and on its variations below 200 nm. Kretzschmar et al R.1 present a review of their previous works that led to new ways of quantitatively monitoring the solar EUV/FUV irradiance spectrum and its variability. Indeed, the high level of redundancy in the solar spectrum variability allows measuring only a small portion of the spectrum without losing too much information.

The heliosynchronous orbit of PROBA2 generates eclipse seasons. We intend to study the vertical distribution of the global extinction coefficient in the Earth atmosphere using the associated solar occultations. Dominique et al R.1 consider the possibility of retrieving the densities of thermospheric N2, O, O2 and mesospheric O2 and O3 from the extinction coefficient. A forward model of the atmosphere transmittance is presented. It incorporates the inhomogeneities of the solar emission over the solar surface to enhance the vertical resolution in the results. The chosen inversion method is tested with simulated data.

P.4.2.3. LYRA family

The LYRA development resulted in the participation of J-F Hochedez in the CAMUS proposal to CNES R.4. The PICARD PREMOS calibration R.1 and the Dynamiccs R.1 papers were accepted. The latter led to a proposal for an ISSI team R.4. In continuation of the former, the SuMo proposal was submitted Error: Reference source not found. SuMo would have been a radiometer and a sun sensor on the ESA-PROBA 3 mission, but was not selected.

P.4.3. Perspective for next years

The LYRA flight data will be exploited.

P.4.4. Personnel involved

Scientific staff: A. BenMoussa, I. E. Dammasch, M. Dominique, B. Giordanengo, J.-F. Hochedez

P.4.5. Partnerships

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

- Werner Schmutz, Silvio Koller, T. Egorova, H. Roth, E. Rozanov, C. Wehrli, PMOD, Davos, CH
- T. Dudok de Wit, M. Kretzschmar, LPC2E, Orléans, France
- Joe Zender, Anik De Groof, ESA
- The international SWAP and LYRA science consortium (SCSL, http://proba2.sidc.be/SCSL/)

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

- D. Gillotay, D. Fussen, and F. VanHellemont, Belgian Institute for Space Aeronomy
- Y. Stockman, J.-P. Halain, CSL, Liège
- Verhaert, Kruibeke

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

- PRODEX SDE (BELSPO/PRODEX SIDC Data Exploitation PEA)
- STCE (Solar–Terrestrial Center of Excellence)

Visitors:

- M. Kretzschmar, LPC2E, 12 Jan. until 9 Feb.
- Joe Zender and Anik De Groof, ESA, continuously
- Vladimir Slemzin, LPI, 29 Nov. until 2 Dec. 2009

P.4.6. Scientific outreach

Meeting presentations

[1] I. E. Dammasch, A. Ben Moussa, M. Dominique, B. Giordanengo, J.-F. Hochedez, M. Kretzschmar, J. J. Zender
LYRA Science Data Products Forthcoming (Poster)
STEREO-3 / SOHO22, Bournemouth, UK, April 27 - May 1, 2009

[2] Dudok de Wit, Aboudarham , Amblard, Auchère, Bruinsma, Hochedez, Kretzschmar, Moussaoui, Lilensten, Vieira
Reconstruction du spectre solaire UV pour la spécification de l'environnement terrestre (talk)
Atelier PNST, Ecole Polytechnique, Palaiseau, 28-30 September 2009

[3] Dammasch, I. E.; De Groof, A.; Hochedez, J.-F.; Berghmans, D.
More PROBA2 Science Data Products (poster)
Sixth European Space Weather Week, 16-20 November 2009, Brugge, Belgium

Wikis and Websites

- http://lyra.sidc.be/
- http://proba2.sidc.be/index.html/science/lyra/
- http://solwww.oma.be/users/dammasch/reports.html

P.4.7. Missions

Assemblies, symposia: I. E. Dammasch (SOHO22, Bournemouth, UK)
I. E. Dammasch (Sixth European Space Weather Week, Bruges)

J.-F. Hochedez (PROBA2 Press Conference, Kruibeke)
All LYRA team (PROBA2 Press Conference, ROB)
J.-F. Hochedez (Sixth European Space Weather Week, Bruges)

P.5. New technologies

P.5.1. UV detectors and Filters

P.5.1.1. Objectives

Future missions for space astronomy and solar research require innovative vacuum ultraviolet (VUV) photo-detectors and filters. Present UV and VUV detectors exhibit serious limitations in performance, technology complexity and lifetime stability. For the next envisaged space missions planned to study the Sun, e.g. *Solar Orbiter*, solar-blind photodetectors capable of operating at high temperatures and in harsh environments are a crucial ingredient. For these reasons, new developments of wide band gap materials photodetectors and UV filters are investigated.

P.5.1.2. Progress and results

New metal-semiconductor-metal (MSM) photodetectors based on diamond, cubic boron nitride (c-BN) and aluminium nitride (AlN) semiconductors were successfully fabricated (to). The electrical characteristics (e. g., I-V curves) and the absolute radiometric responsivities are reported and published. Dr A. BenMoussa is strongly involved in the design and the optical characterization of the reported photodetectors. He was also co-supervising the thesis of Dr H.A. Barkad Error: Reference source not found based on UV photodetectors for space applications.

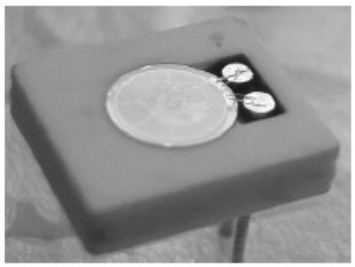


Figure 68 : Photograph of the new diamond MSM photodetector.

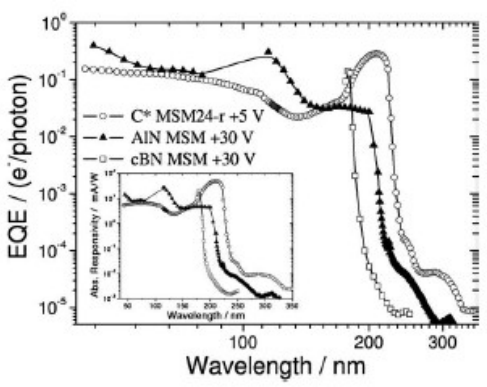


Figure 69 : External quantum efficiencies of the diamond MSM24-r photodetector, of c-BN MSM and AlN MSM photodiodes. The inset shows the corresponding absolute spectral responsivity.

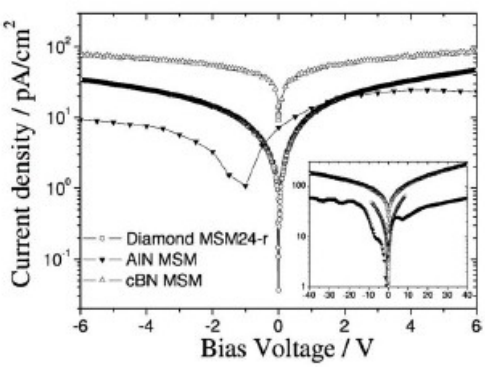


Figure 70 : Dark current density versus voltage characteristics of the diamond MSM24-r, c-BN and AlN MSM photodetectors at room temperature. The inset shows a large view of the dark current density between −40 V and +40 V.

The results of the fabrication and performance of new diffractive filters designed for space-based X-ray and EUV solar observations were published. Unlike traditional thin film filters, diffractive filters can be made to have a high resistance against the destructive mechanical and acoustic loads of a satellite launch. The filters studied are made of plastic track-etched membranes that are metal-coated on one side only. They have all-through open cylindrical pores with diameters as small as 500 nm (Figure 71 to Figure 73), limiting their transmittance to very short wavelengths. The spectral transmittance of various diffractive filters with different pore parameters was measured from the soft X-ray to the near IR range (namely, from 1–1100 nm).

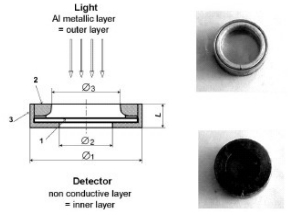


Figure 71: Schematic representation and pictures of a mounted porous filter.

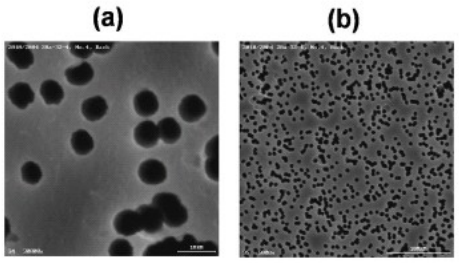


Figure 72: SEM micrographs of filters: (a), (b) "inner" surface of filter #4 at two different magnifications.

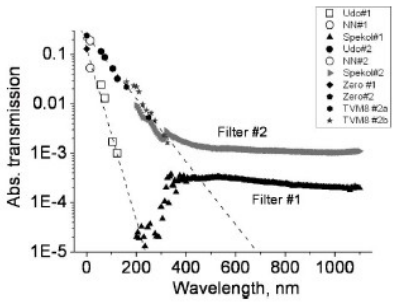


Figure 73 : Wide-band spectrum of absolute transmittance of porous filters #1 and #2.

P.5.1.3. Perspective for next years

By their nature, diamond, AlN and c-BN semiconductors are the primary choice of photosensitive materials for VUV photon detection. They present figures of merit that are several orders of magnitude higher compared to silicon semiconductors, since they provide high radiation hardness, low dark signal at room temperature, solar-blindness, and chemical as well as thermal stability. New calibration campaigns are planned for 2010 at the PTB-Bessy II synchrotron (see BOLD project). This activity will assess the performance of new design photodetectors. Other different design approaches to improve the responsivity of UV photodetectors are investigated by Dr A. BenMoussa such as size reduction towards submicron contact fingers, semi-transparent electrodes, and/or asymmetric electrodes. All these solutions can provide better detector characteristics in terms of dark current, UV/visible contrast ratio, linearity, and VUV responsivity.

A new porous filter design (with pore parameter as small as 100 nm) is under development with the collaboration of Dr L. Jalabert from Tokyo University (Fujita Laboratory). The spectral transmittance of this new filter needs to be measured in the soft X-ray range. In accordance to the support activity foreseen for the specification of the EUI filters (see EUI project), Dr. Ali BenMoussa has followed up and participated in the activity of filter development.

P.5.1.4. Partnerships

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

- Dr A. Soltani, Institut d'Electronique de Microélectronique et de Nanotechnologie (Lille, France)
- Dr T. Saito, NMIJ : National metrology Institute of Japan (Tsukuba, Japan)
- Prof Dr W. Zhang, Department of Physics and Materials Science (Hong Kong)
- Prof Dr H.X Jiang, Department of Physics (Kansas State University)
- Dr J. Morse, European Synchrotron Radiation Facility (Grenoble, France)
- A. Mitrofanov and V. Slemzin, Lebedev Physical Institute (Moscow, Russia)
- P. Apel, Joint Institute for Nuclear Research (Dubna, Russia)
- Udo Schuhle, Max Planck Insitute (Lindau, Germany)
- M. Richter and F. Scholtze, PTB (Berlin, Germany)
- Dr L. Jalabert, University of Tokyo (Japan)

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

- Dr C. Hermans, D. Bolsee, Belgian Institute for Space Aeronomy,
- Prof Dr K. Haenen, Dr V. Mortet, Dr B. BenMoussa : IMO (Hasselt)

Grants/Projects used for this research/service

- LYRA, BOLD, EUI, STCE

P.5.1.5. Scientific outreach

Seminars

[1] A. BenMoussa
Recent development of wide band gap semiconductor based UV sensors
NIMIJ/AIST, 5-9/10/2009, Tsukuba, Japan

Wikis and Websites

- See BOLD website : http://bold.oma.be/

P.5.1.6. Missions

Assemblies, symposia:
A. BenMoussa (LIMMS, Paris 10/03; CMOS Detector for high performance applications, Toulouse, CNES – F, 8-9/12/2009; RADECS09, Brugge, B, 14/09/2009; CMOS APS Advanced Course, Barcelona, Spain 28-30/10/2009

Commissions, working groups (days): A. BenMoussa (3 days)

Research visits (days): A. BenMoussa (5 days)

P.5.2. BOLD-GSTP and APSOLUTE

P.5.2.1. Objectives

The purpose of the BOLD project is to demonstrate the suitability of the nitride-based wide-bandgap imaging detectors for Solar Orbiter in order to have a solid detector baseline for its EUV telescopes. A project has been set up by ESA involving Belgian and French partners with the goal of developing new solar-blind APS detectors (focal-plane array demonstrator) using wide band gap materials where BOLD stands for "Blind to Optical Light Detectors".

In parallel to the BOLD project, a new project called APSOLUTE started beginning of October 2009 for the adaptation of existing Silicon CMOS APS detectors technology to the Solar Orbiter EUI scientific requirements. The purpose of this project is to provide a demonstrator by end of 2010 that complies as much as possible with the EUI detector specification (typically: 10µm pixel EUV sensitive, read noise ≤ 5e$^-$rms).

P.5.2.2. Progress and results

BOLD: Blind to optical Light Detectors

Initially the BOLD project started in June 2006 for a period of 26 months. The project was extended first from 30/06/2008 to 31/07/2009 (CCN1) then from 01/07/2009 to 30/04/2010 (CCN2). ROB is actively involved (as WPs Manager) on the conceptual pixel design study and on the UV optical testing. During this period the effort was focused on the technology predevelopment, e.g. design of the new mask set, as well as on the preparation of samples (256x320 arrays with 22.5 µm pitch) that were in processing for testing the flip-chip of the diode on the ROIC step. More integration samples were processed and were delivered for flip-chip (,).

APSOLUTE: APS Optimized for Low-noise and Ultraviolet Tests and Experiments

The Belgian company CMOSIS was selected by PRODEX to develop a prototype of a new CMOS APS detector, according to specifications provided by ROB and the EUI Detector Working Group (DWG). The purpose for CMOSIS is to propose several detector designs and small scale prototypes which would respond to the EUI specifications R.4R.4. In order to provide CMOSIS with the proper inputs for their design of the detector prototypes, an additional iteration occurred on the specifications for EUI detectors. The management and follow-up of the contract between CMOSIS and PRODEX was agreed to be performed by CSL. By end of September 2009, the Apsolute activity was kicked off.

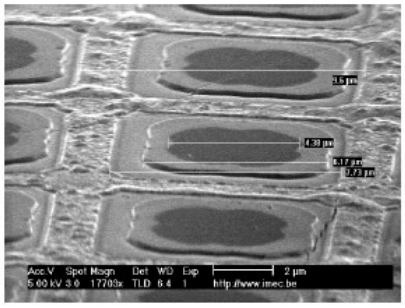


Figure 74 : Photograph of BOLD pixels in the array, 10 µm pitch with 4 µm Schottky contacts

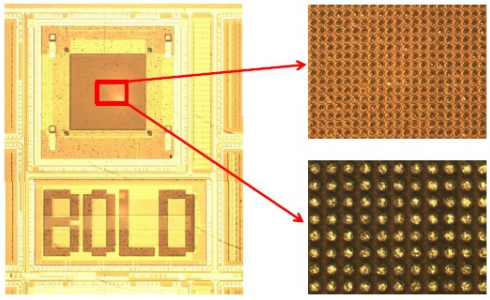


Figure 75 : BOLD CMOS ROIC

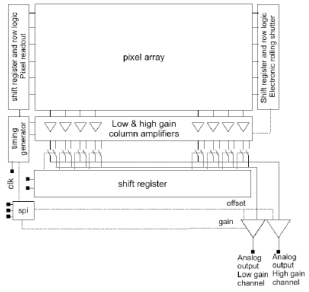


Figure 76 : Apsolute test image sensor architecture

P.5.2.3. Perspective for next years

In 2010, the processing activities will be focused on the integration of the 2D demonstrator. 2D AlGaN arrays will be integrated with the CMOS ROICs. Five integrations (detector flip-chip bonded to ROIC) should be performed.

A BOLD calibration campaign is planned for April 2010 at the PTB-Bessy II synchrotron. This activity will assess the performance of the first 2D arrays demonstrator with respect to the absolute efficiency (spectral response) in the EUV-VUV range. APSOLUTE demonstrators should be tested by end of 2010 according to the planning to allow for a best selection among the prototypes (and designs). The prime goals of the prototypes concern ultra low noise performance and maximal EUV sensitivity. Further challenges relate to the large dynamical range, small pixel pitch, advanced read-out concept(s), and radiation hardness.

P.5.2.4. Partnerships

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

- J-Y Duboz, CRHEA, France
- I. Zayer, L. Duvet, D. Martin, ESTEC, NL

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

- P. de Moor, K. Minoglou, P. Malinowski, IMEC, Leuven,
- Lou Hermans, Guy Meynants, Jan Bogaerts, Tim Baeyens, CMOSIS, Antwerp,
- J-P Halain, CSL, Liege,
- G. Berger, UCL – Cyclotron – Louvain-La-Neuve

Grants/Projects used for this research/service

- BOLD, EUI, STCE

P.5.2.5. Scientific outreach

Meeting presentations

[1] A. BenMoussa et J-P Halain
Development of EUV imagers for EUI onboard Solar Orbiter
Solar Orbiter Detector Working Meeting, ESTEC, 12/06 2009

Wikis and Websites

- BOLD website : http://bold.oma.be/

P.5.2.6. Missions

Assemblies, symposia:

A. BenMoussa (CMOS Detector for high performance applications, Toulouse, CNES –F, 8-9/12/2009 ; RADECS09, Bruges, B, 14/09/2009; CMOS APS Advanced Course, Barcelona, Spain, 28-30/10/2009)

Commissions, working groups: A. BenMoussa (4 days)

P.5.3. DEMELAB

P.5.3.1. Objectives

Technology is an important driver in space science. For some 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, we have identified and developed a specific expertise in two technological disciplines: image processing and UV light detection. For both, a voluntarist way has proven beneficial in order to meet the needs with the possibilities in a timely manner. On the UV characterization, it is worth noticing that the Uccle facilities have already been exploited by the LYRA hardware (filters and detectors) and they are again considered in the frame of BOLD and EUI projects.

The primary purpose of Demelab is to perform and interpret electro-optical measurements on imaging and non-imaging detectors of interest to solar physics including a fully automated analysis workstation in clean environment.

P.5.3.2. Progress and results

This activity started beginning of October 2009 and the working progress is described as follow: Dr A. Ben-Moussa assessed the missing Demelab equipments (mandatory or nice-to-have HW and SW) for a full opto-electrical characterization set up (Figure 79). In collaboration with Eng. A. Mekaoui, a student from ESPRIT school (Tunisia), we analyzed the two SW (cypress and python script) of the HAS set up and improved them (e.g. image processing using Matlab). The acquisitions made already contribute to a real improvement of the characterization of the HAS. It is now possible to acquire dark frame images under vacuum and/or N2 atmosphere. We started evaluating the noise performance of the HAS sensor from -5°C to +40°C using the PID temperature controller (see). Complete optical characterization (e.g. spectral response, linearity, flat field) should follow in 2010.

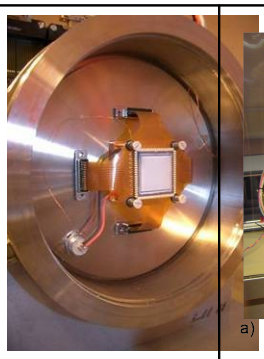


Figure 77 : Picture of the HAS (#13, spare of SWAP)

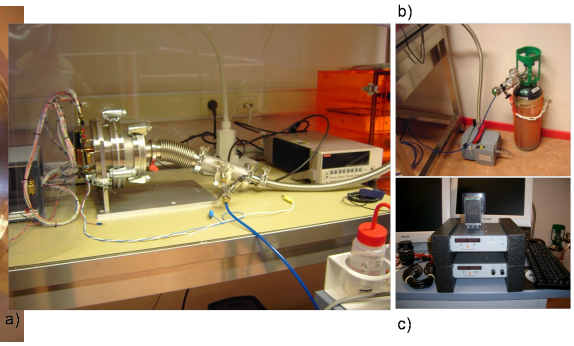


Figure 78 : a) HAS vacuum chamber connected to the vacuum and N2 lines (blue). b) MVP 040-2 vacuum pump and N2 bottle, c) 2 power supplies and PID temperature controller.

Figure 79 : Optical bench at Demelab (with Deuterium & Tungsten lamps, chopper, monochromator, integrating sphere, Θ-x-y-z translation stage,...).

In the context of the detectors developments, we continued setting up a detector laboratory (called DeMeLab), to be able to test in particular signal and noise characteristics. On 24th June 2009, Dr BenMoussa Ali sent two HAS (High Accuracy Startracker) detectors (SWAP spares #13, #14) to ESTEC/ESA. The HAS sensor flies on-board the PROBA2 SWAP instrument and it can be seen as a backup solution for EUI detector (Solar Orbiter mission). The HAS detector (see) is a technologically advanced CMOS device coated with a scintillator layer to improve sensitivity in the EUV range. It has 1024 by 1024 pixels, each pixel being 18 µm x 18 µm size. This particular type of detector is a radiation hardened, active pixel sensor (APS) see http://swap.sidc.be. The goal of this activity is to consolidate and extend ROB technological expertise of the HAS hardware and software and to improve the design of the Detector Measurements Laboratory.

P.5.3.3. Perspective for next years

A trainee (A. Mekaoui, SW engineer) started working on Demelab and on the HAS setup by mid-November 2009 for a period of 6 months. His work addresses particularly the development and experimental characterization of the HAS detectors, the design and implementation of an archival system for test data and their metadata and the design and implementation of a library of analysis software for detector electro-optical characterizations. In 2010, the HAS sensor will be characterized at ESTEC/ESA for EUV test using the Mc Pherson spectrometer. Dr A. BenMoussa will provide technical support and expertise during the detector tests. DeMeLab will also provide support during the detector characterization tests of BOLD and APSOLUTE project. Dr A. BenMoussa will analyze the results.

P.5.3.4. Partnerships

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

- Dr L. Duvet, ESTEC/ESA, NL
- Prof Dr M. Richter and Dr F. Scholtz, PTB-BESSY II, Germany (Synchrotron facilities),
- Dr A. Soltani, Institut d'Electronique de Microélectronique et de Nanotechnologie (Lille, France),

- Dr T. Saito, NMIJ : National metrology Institute of Japan (Tsukuba, Japan),
- Prof Dr W. Zhang, Department of Physics and Materials Science (Hong Kong),
- Prof Dr H.X Jiang, Department of Physics (Kansas State University),
- Dr J. Morse, European Synchrotron Radiation Facility (Grenoble, France),
- S.O.-EUI partners (IAS in F, MPS in Germany, MSSL in the UK, SAO in the USA),
- Lebedev Physical Institute, Moscow, Russia (e.g. porous filters collaboration),
- Dr L. Jalabert, University of Tokyo (Japan).

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

- Dr D. Bolsee, C. Hermans, BIRA-IASB,
- J-P Halain, CSL, Liege,
- Dr P. De Moore, Dr K. Minouglou, IMEC, Leuven,
- Pr. Dr K. Haenen, IMO, Hasselt,
- Lou Hermans, CMOSIS, Guy Meynants, Jan Bogaerts, Tim Baeyens, CMOSIS, Antwerp,

Grants/Projects used for this research/service

- STCE

Visitors:

- Short visits: 2

P.5.3.5. Scientific outreach

Wikis and Websites

- Contribution to STCE website : http://www.stce.be/

P.5.3.6. Missions

Assemblies, symposia:	A. BenMoussa (High Vacuum Technology, Leuven, 16-17/02) A. BenMoussa (Matlab seminar, 17/09) A. BenMoussa (Femlab 22/09)
Commissions, working groups (days):	A. BenMoussa (1 day)

P.6. Future Space Missions

P.6.1. Solar Orbiter/EUI

P.6.1.1. Objectives

Solar Orbiter (S.O.) is the major ESA solar (and heliophysics) mission since SOHO. It is planned for launch in 2017. Thanks to several attributes of its orbit, it will offer unique new possibilities to solar and heliospheric observations. SIDC has, with the support of BELSPO, indicated strong interest in the EUI instrument suite of UV telescopes (), in line with the SIDC heritage and expertise.

P.6.1.2. Progress and results

Until April 2009, ROB-SIDC, with J.-F. Hochedez as Principal Investigator, has led the EUI consortium (CSL (B), MSSL (UK), MPS (D), IO (F), IAS (F), and SAO (USA)) towards the formal acceptance of the instrument by ESA, end of March 2009. From April 2009 on, reorganization within the EUI consortium results in a transfer of PI-ship to P. Rochus (CSL), while each country was allocated a Co-PI.

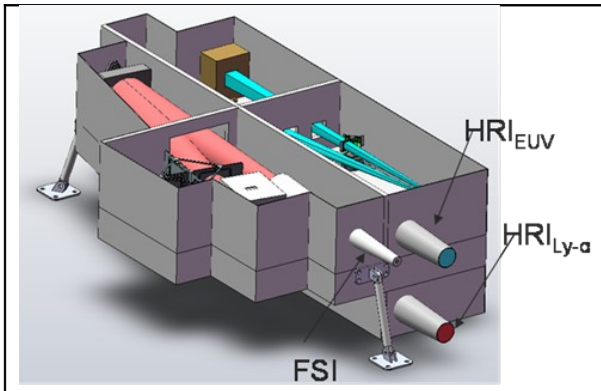


Figure 80: Schematic representation of EUI telescopes

P.6.1.3. Perspective for next years

Dr Ali Benmoussa will perform the EUI management activities in 2010. A smooth transfer from Erik Pylyser responsibilities to Ali BenMoussa will start beginning of 2010.

In Q4 of 2009, the CMOSIS contract was finally passed with PRODEX, and 2010 will see the emergence of the prototyping results of CMOSIS on the EUI detectors. As the leader of the WP EUV Calibration and WP Radiation Tests, Dr A. BenMoussa will describe the (E)UV testing activities (Electro & Optical device characterization) of the Bread Board detectors. The light source (in particular synchrotron) is already identified at this stage for the determination of the EUV sensitivity (incl. at Ly-α) of the EUI demonstrators. These activities will provide a detailed description of all performed tests (with a detailed description of the measurement set up), their results (publication) and interpretations including critical analysis of the results. These activities should start in 2010 and will assess the suitability of the EUV detectors for Solar Orbiter (identify the limitation of the detector & ROIC) and give recommendations for the 2nd batch of EUV detectors.

P.6.1.4. Partnerships

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

- Louise K. Harra, Ted Kennedy & Jason Tandy, MSSL, UK
- Thierry Appourchaux, Frédéric Auchère, J-J Fourmond, IAS, F
- Udo Schuehle, Luca Teriaca, MPS, D
- L. Duvet, D. Renton, ESTEC, NL

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

- Pierre Rochus, Jean-Philippe Halain, Etienne Renotte, JM Defise, CSL, B
- Lou Hermans, Jan Bogaerts, Guy Meynants & Tim Baeyens, CMOSIS, B

Grants/Projects used for this research/service

- PRODEX EUI PEA

P.6.1.5. Scientific outreach

Seminars

[1] A. BenMoussa, B. Nicula, B. Giordanengo, E. Pylyser, J-F. Hochedez, J-P Halain, R. Rochus, U. Schuhle, J.A. Tandy, D. Walton and F. Auchere
Development of EUV imagers for EUI onboard Solar Orbiter
3rd Solar Orbiter Workshop, Sorrento, Italy 25-29 May 2009

Wikis and Websites

- See EUI website : http://eui.sidc.be/

P.6.1.6. Missions

Assemblies, symposia:	A. BenMoussa (CMOS Detector for high performance applications, Toulouse, CNES –F, 8-9/12/2009) A. BenMoussa (RADECS09, Bruges, B, 14/09/2009) A. BenMoussa (CMOS APS Advanced Course, Barcelona – E, 28-30/10/2009)
Commissions, working groups (days):	A. BenMoussa (5 days)

Q. Instrument operations, data handling, and services

Q.1. Solar optical observations (Uccle Solar Equatorial Table)

Q.1.1. Objectives

The optical USET instruments are providing visual and CCD observations in support to the SIDC sunspot index determination, as one of the reference stations in the worldwide network. 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, marks also an 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. The USET activities thus follow two base axes and a currently ongoing 3-year project:

- Optical observations of the Sun and characterisation of its activity:
  - Visual observations of sunspot, digitization and exploitation of drawings
  - 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).
- 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)
- Participation to the **SoTerIA project** (SOLar-TERrestrial Investigations and Archives): this project proposal was submitted to the European 7th Framework Program (FP7 scheme: Collaborative project, Topic: SPA.2007.2.1.01, Space Science) in June 2007, under the Coordination of Giovanni Lapenta (KUL). The project started in November 2008 for a duration of 3 years. Our SoTerIA participation for work package 2 "Photosphere" includes three main objectives:
  - The global digitization of the Uccle collection of sunspot drawings, and possibly thereafter other drawing series.
  - The production of whole-disk CCD images in white-light, H-alpha and CaII-K to support studies of the solar cycle (WP2), of chromospheric flares and waves (WP3) and of proxies of solar spectral irradiance (WP5).
  - The study of new image-based activity indices derived from solar images of the photosphere (CCD, photographic): initial data sets (USET, SOHO/MDI).

  The first two goals are relevant to this section, while goal 3 is included in another section.

Q.1.2. Progress and results

Q.1.2.1. Maintenance of the telescope and CCD camera system operations

No major failure took place on the telescopes in 2009. The regular maintenance and optical cleaning was executed according to the plans: repairs to oil leaks in motor enclosures, new thermally isolated enclosures for the CCD cameras, etc.

Q.1.2.2. Routine USET data acquisition, processing and distribution

- **Daily solar observations**: The Sun was observed mostly by 4 observers on 263 days this year, a slight increase compared to 2008 (246 days). The duty cycle was thus equal to 72%, close to 3 days out of 4. Note also the significant increase of the number of collected images (+62% compared to 2008). This in-

crease reflects the evolution in the image acquisition modes of the new SunCap software (automatic synoptic mode), despite the low solar activity over 2009. An overview of the 2009 observations is given in the tables below.

Camera	Nb. Images	Comment
Photosphere	1025	White-light channel
Chromosphere	1967	H-alpha channel
Total	**2992**	

Table 2: USET CCD image statistics for 2009

Observer	Duty days	Days with observations	Days with no observations	1 drawing	2 drawings	Total nb. of drawings
Boulvin	85	56	29	54	2	58
Clette	11	10	1	9	1	11
Ergen	86	68	18	61	7	75
Lemaître	94	74	20	61	13	87
Vanraes	89	55	34	50	6	62
Totals	**365**	**263**	**102**	**235**	**29**	**293**

Table 3: USET sunspot drawing statistics for 2009

- **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 except for a few minor anomalies associated with the abnormally low solar activity in 2009. Again, in the first half of 2009, there were several entirely spotless solar rotations. The resulting monthly tables are published as part of the monthly SIDC Sunspot Bulletin Error: Reference source not found.
- **USET data distribution:**
  - Some improvements were introduced in our local USET web pages, improving the display of images and the navigation over the past solar Carrington rotation.
  - As we have entered routine production of the USET white-light and H-alpha synoptic images at the high 2Kx2K pixel resolution, our data can be fed to global solar data portals next to a few ground-based stations worldwide for continuous solar monitoring purposes. Therefore, by the end of 2009, contacs were established with three primary portals: the Global High-Resolution H–alpha Network (GHN, New Jersey Institute of Technology), the Virtual Solar Observatory (VSO, NASA) and BASS2000 (Observatoire de Paris-Meudon). Technical requirements for data transfers to those portals have been established and will be implemented in 2010.
  - 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 will be implemented by the ROB for the entire SoTerIA project.

Q.1.2.3. Participation to the SoTerIA project (Solar-Terrestrial Investigations and Archives)

A major contribution to SoTerIA was started in June 2009: the global digitization and encoding of sunspot group parameters from the 70-year collection of sunspot drawings from the Uccle station (about 20000 drawings spanning 70 years). Three staff members were trained for the sunspot measurement and systematic classification. After an initial census of the entire drawing archive, those operators carried out the measurements as part-time work for the rest of 2009. In summer, temporary job students were hired to support the bulk scanning of the drawings (about 20000 drawings in the collection, from 1940 to 2010).

A second A3 flatbed scanner was purchased for this work, allowing two scanning operators to work simultaneously. An entirely new and enhanced version of the **DigiSun software** was developed in early 2009. This custom-made software is optimized for bulk scanning and systematic measurements of large series of drawings. It is also designed to accept variable drawing sheet formats and layouts and includes the measurement of extended sunspot group descriptors: the McIntosh classification in addition to the classical Zürich classi-

fication and the magnetic dipole size and orientation of each active region. Since June, this DigiSun software was fully tested and is in routine use.

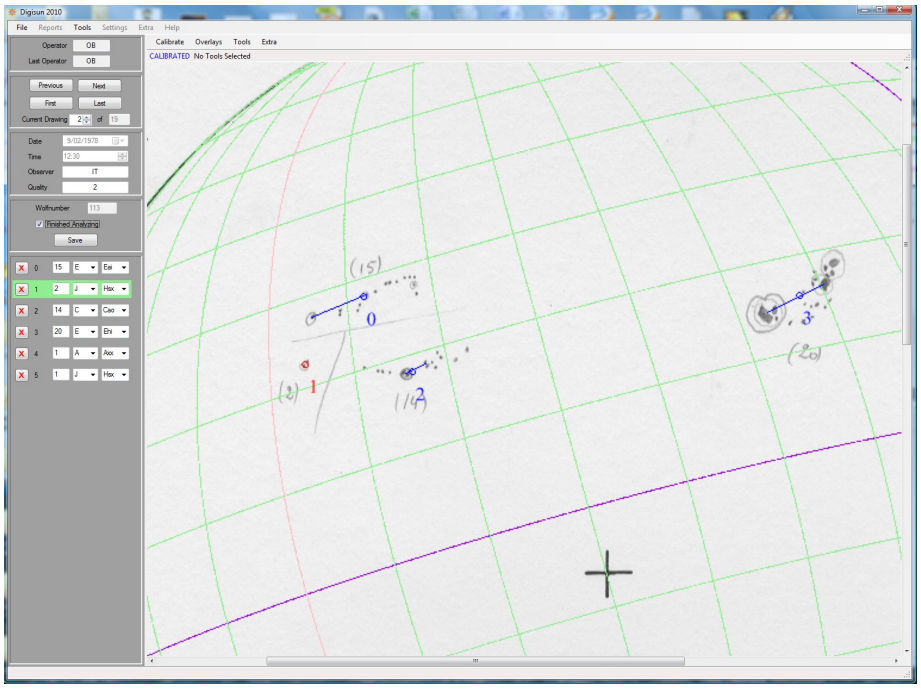


Figure 81: User display of the DigiSun application developed for the global measurement and encoding of the Uccle sunspot drawing collection. This tool includes the Zürich and McIntosh sunspot group classifications, as well as the measurement of the sunspot group heliographic coordinates (blue circles) and the magnetic dipole orientation and size (blue bars)

Q.1.3. Perspective for next years

The priorities for 2010 will be:

- Continuation of the USET observations, data processing and data distribution.
- Commissioning and exploitation of a new CaII-K telescope.
- Software development:
  - Continuation of the development of the SunGlasses software for the selection and pre-processing of high-cadence images from the new CCD 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.
  - Upgrade and reorganization of the USET web pages.
- Long-term sunspot data exploitation in the context of the SOTERIA project:
  - Systematic digitization and encoding of the Uccle sunspot drawing collection. Depending on the progress, another collection may be processed when the Uccle series will be completed.
  - Systematic data quality control and validation
  - Development of a new program for the group tracking, in replacement of the existing SOLKOP program.
  - Comparison and possible merging of this new active region catalog with the few equivalent external catalogs.

Q.1.4. Personnel involved

Scientific staff: F. Clette
Technical staff: S. Vanraes, J-L. Dufond, O. Lemaître, A. Ergen, O. Boulvin, A-M. Hernando

Q.1.5. Partnerships

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

- SOTERIA "SOlar-TERrestrial Investigations and Archives" project (EU 7th Framework Program, Nov.2008- Oct. 2010)

Visitors:

- Short visits: 5

Q.1.6. Scientific outreach

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 (preview 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.1.7. Missions

Assemblies, symposia, conferences:

- F.Clette: 6/5/2009, Belgian Astronomy & Astrophysics Contact Group (FNRS), Planetarium
- F.Clette: 16-20/11/2009, Sixth European Space Weather Week, Brugge, Belgium

Commissions, working groups:

F.Clette (1day)

Q.2. Solar Activity and Space Weather Operations Center

C.2.1. Objectives

RWC Belgium is a permanent service center specializing in solar monitoring and solar activity forecasting. It is run by the SIDC under the auspices of the ISES network. Its solid base is the solar physics research undertaken at the SIDC and our involvement in solar observations from space and ground, giving access to a large volume of solar and heliospheric data that can collectively span operational requirements. Building on insights derived from our scientific studies, the SIDC provides expert and timely information on and assessment of solar dynamics and its likely relevance for human technology.

C.2.2. Progress and results

C.2.2.1. Internal Management

The RWC-performance is being guided by the RWCWDC-wiki (http://sol042.oma.be:8000:RWCWDC) and regular internal meetings.
The RWC and the Space Weather performances were presented as part of the STCE to the committee of directors as representatives of the science institutes C.2.5.4.

C.2.1.1. External Management

RWC Belgium was represented on several meetings relevant for the space weather business.
Such presence at international level is one of the key issues to get involved in future projects like the European Space Situational Awareness program.

C.2.1.2. Routine operations

For the RWC activities, a continuous data stream from ground-based spacecraft instruments has to be analysed and interpreted. The daily routine includes different tasks:

- *Data distribution*. The RWC acts as a hub for further distribution of solar and geophysical data, mostly in the form of ISES encoded messages.
- *Monitoring solar activity and space weather*. To maintain a high standard in our activities as an RWC, we develop and use software that autonomously detects space weather events. This service is timely and assists the forecaster on duty in his monitoring and alerting task. Examples are CACTus (CME detector), B2X (flare detector), and NEMO (EIT-wave detector). These monitoring activities result in an alert service. Most of the warnings are sent out automatically in several alert-type messages, though some alerts need human intervention.
- *Forecasting solar activity and space weather*. Reports and forecasts of solar activity and space weather conditions are distributed every day (including weekends and holidays) at approximately 12:30 UT in the 'ursigram' messages. Weekly summaries are sent out in principle on Mondays, while more extensive monthly summaries of solar and geomagnetic activity are included in the Sunspot Bulletin of the SIDC. The latter also includes medium-term forecasts of the evolution of the sunspot cycle.

On the technical level, the monitoring, alerting and forecasting services of the RWC contain three main aspects: client database management, production of data/messages and delivery of data/messages. These activities are managed in a semi-autonomous way by the software package *PreviMaster*, which handles the solar data, the forecasts and alerts in conjunction with a database. The interface between the human operator and the *PreviMaster* package to receive the daily forecasts, manually triggered alerts and other subsidiary information, is a secured web-based tool called called *PreviWeb*. Continuous maintenance and upgrade of these two packages, and the SIDC website itself, is an important never-ending task.

The RWC-performance is being guided by the RWCWDC-wiki (http://sol042.oma.be:8000:RWCWDC) and regular internal planning meetings.

A description of emergency procedures were made available for all forecasters, so that every forecaster should be capable of solving failures.

C.2.1.3. Space Weather Forecasting

The quality control of the F10cm-forecast was automated by linking PreviMaster to the MySQL-database. The output needs to be made visible on previweb and the general SIDC website.

A new member for the forecast team (E. D'Huys) was welcomed at the beginning of 2009. Starting from February 2009, she actively participated in the forecasting and was the forecaster for 7 weeks during the year.

As part of the training, E. D'Huys attended the Space Climate School in Saariselkä (Finland) and participated to the annual International Space Environment Service (ISES) meeting in Boulder (25-26 April 2009). Together with the other ISES members present at the meeting, she visited the NOAA Space Weather prediction Center in Boulder as representative of the RWC (see Figure 82).

Figure 82: Visit of the ISES members to the NOAA Space Weather Prediction Center

The space weather briefings were reinitiated and take place during the weekly Science & Coffee. The forecaster on duty gives a resume of the space weather events of the past week.

C.2.1.4. Solar Weather Browser

The Solar Weather Browser (SWB) is an open-source software tool that allows easily displaying and combining solar images from different observatories together with solar metadata, without the need of data processing. For the forecast team, the SWB offers an easy tool to browse through solar data while performing the forecast and monitoring the sun. The client is readily available for Linux, Mac OS X and Windows at http://sidc.be/SWB.

The USET data starting from 2008 were reprocessed to make them available through the SWB. The codes to process the STEREO/SECCHI images were updated, in order to adapt them to a change to the data archive. Maintenance activities were carried out through the whole year.

A new e-mail address was launched (SWB@sidc.be) for users to send questions or remarks.

The Solar Weather Browser was presented in a poster at three meetings: the Space Climate Symposium in Saariselkä (Finland), the Space Weather Workshop in Boulder (Colorado) and the European Space Weather Week in Brugge (Belgium). While the SWB is already well known among the participants of the European Space Weather Week, it was quite new for the attendees of the Space Weather Workshop.

C.2.1.5. All-quiet-product

We investigated the validity and relevance of our all-quiet-alerts. We sent out a survey to all our registered users of this product. The criteria for sending an all-quiet-alert are:

1. the solar X-ray output is expected to remain below C-class level,
2. the Kp index is expected to remain below 5,
3. the high-energy proton fluxes are expected to remain below the event threshold.

It is the forecaster interpreting the space weather data, who triggers to start or end the all-quiet-alert period.
The results of the all-quiet-alert-program was presented by R. Van der Linden at the workshop 'Forecasting the All-Clear', 22-24 April, 2009, UCAR Boulder.

C.2.1.1. PROBA2 and the RWC

PROBA2 is a valuable partner of the RWC in the sense that PROBA2 is the first ESA space weather mission. PROBA2 can provide crucial and timely information about the solar conditions necessary for a good forecast performance. The relevance of PROBA2 for the space weather prediction centre was stressed on the running presentation C.2.5.4 shown during the press conference of Nov 2 highlighting the launch of PROBA2 and during the space weather fair at the esww6.
Since the commanding of the telescopes SWAP and LYRA and the exploitation of the data are done from the SIDC, we are on the first row to access the data. Special demands focusing on space weather events relevant for the forecast centre are possible.

C.2.2. Perspective for next years

C.2.2.1. Hardware infrastructure & RWC operations

A revisit to the RWC/WDC hardware infrastructure is planned with particular attention to redundancy. Two options can be considered:
(1) an architecture with virtual machine inspired on the P2SC system ,or
(2) a fully redundant system of 2 hardware servers running in parallel.
Meanwhile we await the kick-off of ESA's Space Situational Awareness program (SSA) and its associated prototype services before we take strategic decisions on the SIDC RWC/WDC.

C.2.2.2. Solar Weather Browser

Further developments on the server side of the SWB will include moving it to a dedicated server. Also improved logging to facilitate the daily monitoring of the tool and a functionality to reprocess older data, which were already envisioned last year, are still planned.

Data from the PROBA2 satellite will be included into the Solar Weather Browser. The SWB will also be an important contribution to Work Package 6 of the SOTERIA project.

C.2.2.3. The Seventh European Space Weather Week

The ESWW7 will be held on Nov 15-19, 2010 at the conference site Oud Sint-Jan in Brugge, Belgium. The SIDC/RWC is again represented in the program committee by two members. The organisation of the debate, tutorial and the keynote lecture is initiated during the kick-off meeting of Jan 26, 2010. The practical organization is again in the hands of the SIDC.

The website is online: http://www.sidc.be/esww7.

C.2.3. Personnel involved

Scientific staff: R. Van der Linden, D. Berghmans, F. Clette, E. D'Huys, C. Marqué, L. Rodriguez, P. Vanlommel, L. Wauters, A. Zhukov

Technical staff: O. Boulvin, S. Willems, A. Vandersyppe

The daily duty cycle of forecasting and monitoring activities were shared by D. Berghmans , F. Clette, E. D'Huys, C. Marqué, L. Rodriguez, P. Vanlommel, R. Van der Linden, A. Zhukov.

C.2.4. Partnerships

List of international partners

- RWC Belgium is one of the nodes in the International Space Environment Service (ISES, see http://www.ises-spaceweather.org/).
- The SIDC continues to contribute to SWENET, see http://esa-spaceweather.net/swenet/index.html.
- The COST ES0803 community

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

- ORB/KSB Planetarium
- IRM/KMI
- IASB/BIRA

Grants/Projects used for this research/service

- STCE & ROB funding
- SIDC Data Exploitation PRODEX C90345

C.2.5. Scientific outreach

C.2.5.1. The Sixth European Space Weather Week, esww6

The Sixth European Space Weather Week took place in Brugge, Belgium, from Monday 16th November to Friday 20th November 2009.

The ROB/Solar-Terrestrial Centre of Excellence (STCE) organized this meeting jointly with the ESA, the SWWT and the COST ES0803 communities. The ROB and the STCE did the local organization. We can build on our expertise of the organization we acquired during the three previous editions. This year's meeting was not in Brussels, but in Brugge.

The esww6 again adopted the central aim of bringing together diverse communities working on all elements of space weather with a strong focus on user involvement. The

keywords of the 2009 meeting were: Science-Models-Aplications-Services-Users, Space Situational Awareness, Impacts on Communication Systems, Health Issues.

Impacts on Communication Systems was the new focus of this year. Health Issues was a challenge for which we aimed for real science and no doubtful relations between medical issues and space weather.

This year's event included a second space weather fair, where users and service providers had the opportunity to interact in an informal working environment. The meeting also included a number of hands-on splinter sessions and explored community development through several dedicated business meetings.

The STCE organized the keynote lecture 'Are we alone?' by Prof. Willy Benz.

M. Hapgood, T. Dudok de Wit and P. Vanlommel took care of the debate '*Space Weather and the Earth's Climate-What are the influences & the effect of an unusually deep solar minimum.*' Dr Stuart Clark, a science journalist, was the moderator. Prof Mike Lockwood and Prof Kalevi Mursula were the panel members. Prof Henrik Svensmark could unfortunately not come at the end. The debate was open to the press, the public and the scientific community. The press was welcomed half an hour before the event.

Scientific side events

- Space Weather Tutorial and quiz, C.2.5.4
- Space Weather Fair
- Contest: The Best of

Local Organization

- Suitable site veting and set up
- Creation of an esww poster
- Website: creation and maintenance
- Social events organisation
- 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

- Press release (Eng), published on the website www.sidc.be
- E-Invitation for the debate sent to the press, the public and VIPS.
- E-Invitation for the keynote lecture and the welcome reception for VIPS.

C.2.5.2. RWC@esww6fair

During the sixth European Space Weather (Nov 16-20), a fair was organized. The fair was intended as a hands-on workshop to show products, services to the space weather community. The SIDC/RWC was present with a stand. On a daily basis, the space weather was broadcast.

C.2.5.3. RWC@le Bourget

The STCE participated as an exhibitor on the 48th International Paris Air Show – Le Bourget, which took place 15-21 June 2009. The STCE represented the involvement of Belgium in space - space weather. The RWC presented the PROBA2 scale model as a reference to the scientific instruments SWAP and LYRA. Their relevance for Space Weather was advertised in the form of a daily Space Weather Broadcast which attracted the attention of many participants. The beauty of space weather, examples of the physical measure of

radio black outs, geomagnetic disturbances, solar radiation storms and the consequences on Earth and technological system were the ingredients of a running Space Weather movie. See Error: Reference source not found.

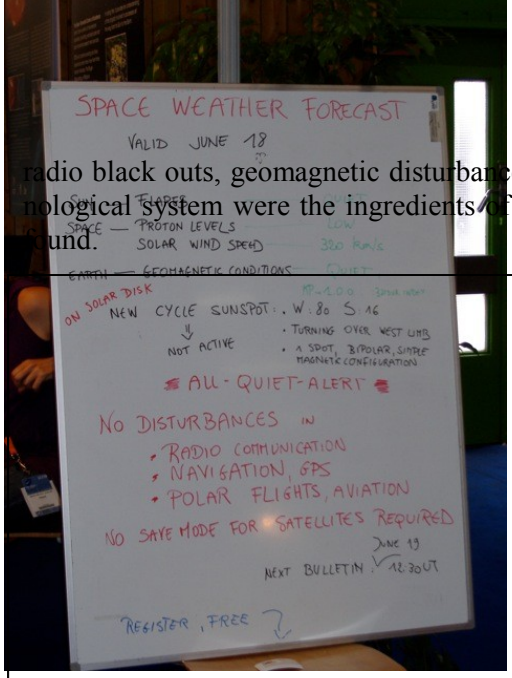


Figure 83 Visitors of the STCE-stand got extra information on the Space Weather Forecast and the implications for Space based and Earth based technological systems

C.2.5.4. Open doors Space Pole

We list the RWC activities performed during the open doors on October 03-04.

- Running presentation 'Our Dynamic Sun', P. Vanlommel
- Oral presentation 'Ruimteweer: energie-oprispingen', Dutch and French, S. Raynal, P. Vanlommel
- Oral presentation 'Le météo spatiale: les prévisions', F. Clette
- Daily written Space Weather forecast
- Running presentation: 'PROBA2: preparing for launch', D. Berghmans
- Scale model of PROBA2
- Running presentation: 'EIT', D. Berghmans
- Poster presentation: 'The Solar minimum', C. Marqué and P. Vanlommel
- Poster presentation: 'Solar Activity', P. Vanlommel

Meeting presentations

[1] R. Van der Linden
Annual RWC report
ISES annual meeting,

[2] P. Vanlommel
Space Weather Prediction Centre: SWAP-LYRA applications
Press conference: launch PROBA2, November 2

[3] R. Van der Linden, L. Wauters, P. Vanlommel
User Feedback and Performance Metrics
workshop 'Forecasting the All-Clear', Boulder, Colorado, April 22-24, 2009.

[4] R. Van der Linden, P. Vanlommel
The Solar-Terrestrial Centre of Excellence: Building Sun-Earth know-how in Belgium and beyond
Directors Committee, Brussels, Belgium, September 18, 2009

[5] D. Berghmans, E. D'Huys, D. Seaton
Space Weather tutorial 'from science to applications': quiz
ESWW6, Brussels, Belgium, November 16-20

Wikis and Websites

- Internal development wiki: http://sol042.oma.be:8000:RWCWDC
- Internal development wiki: http://pb2sc.oma.be:8000/ESWW/
- Upcoming development ideas for SWB : http://sol042.oma.be:8000/RWCWDC/wiki/SWBmainPage
- http://www.sidc.be/esww6
- http://www.sidc.be/
- http://sidc.be/private/previweb_db/
- http://sidc.be/planning/

C.2.6. Missions

Assemblies, symposia:

- SIDC Team, sixth European Space Weather Week, Nov 16-20, Bruges, Belgium
- P. Vanlommel, E. D'Huys, L. Wauters, D. Berghmans, Space Climate School & Space Climate Symposium 3, March 15-18, Saariselkä, Finland
- R. Van der Linden & E. D'Huys, All Clear Workshop, April 22-24, Boulder, Colorado
- R. Van der Linden & E. D'Huys, Space Weather Workshop, April 27-30, Boulder, Co

Commissions, working groups (days):	Space Weather Working Team, Brussels, Belgium (Nov 19) ISES meeting, Boulder, Colorado (April 25-26)
Field missions (days):	ESWW6 preparation, Brugge, Belgium (Apr 28, Oct 09) ESWW6 PC meeting (Jan 28, Feb 28-29, May 28-29) NOAA SWPC, Boulder, Colorado (April 30)
Exhibition:	Le Bourget, June 15-21, Paris, France Open Doors of the Space Pool, Oct 3-4, Brussels, Belgium

Q.3. PROBA2 Science Center

Q.3.1. Objectives

The PROBA2 mission is one of ESA's small, low-cost projects for On-Board Autonomy and part of ESA's In-Orbit Technology Demonstration Program. The spacecraft has been launched on November 2 from Plesetsk launch facility in Russia as a secondary passenger payload to the SMOS spacecraft. The PROBA2 Science Centre (P2SC) supports the operation of the two instruments for which ROB has PI-responsibility: SWAP and LYRA (see dedicated sections below). The 4 main services of the PROBA2 Science Center (P2SC) are:

- 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.

The P2SC is a group effort, led by D. Berghmans, with contributions from both the LYRA and the SWAP instruments teams.

Q.3.2. Progress and results

The P2SC hardware setup consists of two redundant physical servers powered through UPS and accessible through redundant optical fibres. Data is stored on a RAID6 mass storage device and is accessible through NFS. The two physical servers run a number of independent virtual servers corresponding to different activities of the P2SC. Also a test virtual server is foreseen to test in quarantine new upgrades of the software.

A serious performance problem was identified in the months before the launch. This performance problem was partly due to a large number of accesses to the SQL databases served over NFS. Following this problem, we reduced the number of virtual servers such that more SQL database accesses were routed locally and not over NFS. This (and other measures) solved the performance problem completely.

Figure 84: Artist impression of PROBA2 (courtesy ESA)

Following the lines agreed at the P2SC Status Review (ESA, Oct 2008), the PROBA2 Science Center was developed and tested in the course of 2009. It was ready for commissioning operations by the time of the PROBA2 launch (Nov 2 2009).

As part of the preparation to PROBA2 operations, the following repetitive activities were completed:

- participation in the PROBA2 System Validation Tests (Feb 2,3,10,11 2009, Mar 25 2009). The analysis of the data of all these different sessions is presented in the SVT report.
- regular Payload Interface Teleconference with the PROBA2 project and the Redu Mission Operation Center. Minutes of each of these are available in our online project repository.
- interface tests with the Redu Mission Operation Center and with the Villafranca ESAC final archive center
- internal P2SC coordination meetings (every few weeks)

Q.3.3. Perspective for next years

Following the end of the commissioning phase (March 2010), the P2SC will enter a routine phase. The P2SC will be operated as long as the PROBA2 mission lasts, i.e. till the end of 2011. A mission extension will be sollicited late 2010.

Q.3.4. Personnel involved

Scientific staff:	D. Berghmans, I. Dammasch, M. Dominique, B. Giordanengo, J.F. Hochedez, B. Nicula, E. D'Huys, D. Seaton, P. Vanlommel
Technical staff:	S. Willems

Q.3.5. Partnerships

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

- Peter Gallagher, Shaun Bloomfield and Paul Higgins, Trinity College Dublin, Ireland.
- G. Schwehm, ESA-ESTEC

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

- Jean-Marc Defise and Jean-Phillipe Halain at the Centre Spatial de Liege at ULiege
- Mehmet Sarp Yalim at Center for Plasma Astrophysics (CPA) at KULeuven
- Dennis Gerrits and Stijn Ilsen at Verhaert NV
- Thomas Laroch at Spacebel
- Etienne Tilmans at the ESA Redu site

Grants/Projects used for this research/service

- SIDC Data Exploitation PRODEX C90345. This preparatory activity was supported in 2009 by a number of contractuals on the present project. The activity was further supported by people hired on ROB/STCE budgets. ESA support to the PROBA2 operations was started up under the "Nationally Led Mission Program" from Oct 1 2009 onwards.
- STCE support (Bogdan Nicula, Elke D'Huys, Sarah Willems).
- SOSSIS project, ESA D/SRE support for Nationally Led Missions (Carlos Cabanas)

Visitors:

- Joe Zender, ESA, nearly every week for a few days, ESA D/SRE support to the P2SC development
- Anik De Groof, ESA, full time since summer 2009, ESA D/SRE support to the P2SC development

Q.3.6. Scientific outreach

A broad effort was done to communicate about the PROBA2-project.

Q.3.6.1. Communication to the Science Community: PROBA2@esww6fair

The PROBA2 Science Center was presented at the fair of the **esww6**. A presentation about the relevance of the PROBA2 Science Center for the Regional Warning Center was integrated in the presentation about the distribution of PROBA2 data.

Q.3.6.2. Communication to schools

We collaborated with the Vliebergh-Senciecentrum (VSC), 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 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 will be given on March 24, 2010. Teachers will get a written PROBA2 bundle. The teachers are D. Berghmans, E. D'Huys and P. Vanlommel.

meetings

- October 21, KULeuven, Belgium
- June 26, KULeuven, Belgium
- April 03, KULeuven, Belgium
- May 19, Planetarium, Brussels, Belgium

Q.3.6.3. Press worthy milestones

A kick-off meeting between Verhaert Space NV and the PROBA2 Science Center to coordinate the outreach was held on February 17. A full document was used as a reference for future actions.

June 01, 2009: press conference, the shipping

On Jun 01, a press conference concerning the shipping of the satellite to Plesetsk, was organized at Verhaert Space in Kruibeke. The organization was a common effort in which Verhaert took the lead. We produced the press release.

November 02, 2009: champagne breakfast-press event, launch

On Nov 02, the SIDC and the Solar-Terrestrial Centre of Excellence invited the press, scientist and the public to a champagne breakfast at the occasion of the launch of the satellite PROBA2 on November 2, 2009. We proudly presented our instruments SWAP and LYRA. A live link with team members worldwide was set up to receive the latest news of the launch (see Figure 85).

- In the frame 'the faces behind SWAP and LYRA', several interviews with the scientists were recorded and edited. The interviews ran on a big screen during the breakfast and were put online on the website of the PROBA2 Science Center: http://proba2.sidc.be.
- A contest 'Spot PROBA2' was set up.
- Presentations 'Data: where and how to get' – 'Space Weather Prediction Centre: SWAP-LYRA applications' ran automatically during the event.

More than 80 people attended the celebration. The press, written and TV, was present. Several amateur astronomers took the chance to come and learn more about PROBA2. We got requests from them for an article in the MIRA-journal and PROBA2-presentation at the annual meeting of the VVS.

Several interviews were done with M. Dominique, D. Berghmans and J.-F. Hochedez and appeared in the written press, on the radio and on television.

Figure 85 During the press event, a live link was set up with our colleagues in Dublin.

a

Q.3.7. Missions

Research visits:

- 2009-01-25: Discussion meeting with the Dublin SWAP group

Field missions:

- ESA VIP programme for the PROBA2 launch, Plesetsk, Russia Nov 1-3, 2009
- Various missions to Verhaert during the System Validation Tests
- Several missions to ESA Redu for MOC-SOC coordination

Q.4. SDO data center

Q.4.1. Objectives

The NASA Solar Dynamics Observatory mission (SDO) to be launched in early 2010 aims at determining how the solar magnetic field is generated, structured, and occasionally converted into violent events. SDO is designed for 5 and up to 10 years of operation. The scientific payload contains three instruments: a UV spectro-radiometer (EVE), the Helioseismic and Magnetic Imager (HMI), and the Atmospheric Imaging Assembly (AIA). Data rates produced by EVE are by several orders of magnitude smaller than HMI and AIA. Both of these produce 4k x 4k images, but HMI products compress more than AIA's. As a result the HMI archive will represent only 10% of the size of the AIA archive. Dispatching and storing the full AIA data stream represents therefore the most challenging task. The WisSDOm data centre at SIDC is meant as a platform to receive the huge SDO data stream, to further distribute SDO data for European needs, to produce rapid solar weather reports and other SDO-based science products computed locally.

Q.4.2. Progress and results

The activities within the WisSDOm data centre can broadly be divided into four sections: 1/ Operation data centre, 2/ Data networking, 3/ Scientific exploitation of data, and 4/ Communication and redistribution to the end-users.

Q.4.2.1. Operation data centre

The SDO SIDC system (WisSDOm) was designed for data transfer, storage, and computing. It is equipped with a high availability system, a compute cluster, high speed data storage and webserver nodes.

As compared to the status end of 2008, several elements have been upgraded. First, the installation of four additional compute nodes completes the initial orders made in 2008. Second, the storage capacity was upgraded from 26TB end 2008 to 52TB end 2009. Further extensions up to more than 200TB are possible with the chosen configuration. The high availability system runs a software suit known as netDRMS, written for the SDO project by the Stanford Joint Science Operations Centre (JSOC), and PostgreSQL servers.

It has been possible also to massively increase the performance of the computing resource by installing special purpose cards based on graphics processors (so called CUDA or GPU technology), which only became available at the start of 2009, see Section Q.4.2.3.

The implications for energy consumption, power and cooling requirements, as well as physical size and weight were evaluated by D. Boyes. This equipment is installed in the RMI/KMI.

In parallel with the design and installation aspects of the SDO data centre, a number of operational measures were established in 2009:

- Online documentation (done via wikis)
- Problem tracking (via ticket tracking)
- Software archiving (via subversion repositories)
- Hardware monitoring (for monitoring the condition of RAID systems, mailing disk failure notifications and running continuous tests on the ROB internal networks)
- System performance monitoring (using the 'Ganglia' software)

The SDO data centre is designed to function virtually unattended, and therefore global system monitoring measures are required. To this end data centre monitoring systems were investigated and the "Ganglia" system selected. This is an open source system, and therefore it was possible to modify it to provide monitoring of system specific requirements such as the CUDA server temperatures.

Q.4.2.2. Data networking

The data networking system is an essential part of the SDO data distribution philosophy.

In June 2009, T. Berghoff and D. Boyes wrote a set of test programs, to test both raw data transfer capacity between the US (Harvard and Stanford) and the EU Geant2 network, and stability under sustained load. The aim was to localize potential bottlenecks and to try and simplifying the rather complex protocols planned for data transfer.

These programs rapidly found an unexpected problem with standard internet transfer protocols. Using the test programs it was possible to identify and find a solution to the problem. As a follow up of these test and findings, the software team in the US has developed a set of programs specifically for SDO data transfer.

On June 9, 2009, the first meeting on the SDO pipeline in Europe was organized by the SIDC/Telescience team at ROB (see wissdom.oma.be). A second meeting was organized by the 'Institut d'Astrophysique Spatiale (IAS)' in Paris in October 2009.

Q.4.2.3. Exploitation of SDO data

Work flow management

The aim of the WisSDOm project is not only to receive and redistribute SDO data, but also to offer a platform of computing clusters where intensive algorithms can be applied on these data.

The task of managing these computation has much more subtle ramifications than at first apparent. Fortunately, a lot of work has already been done on producing generic management systems, especially for throughput systems that are used for scientific purposes. Consequently, much of the work done and software is available in the public domain.

The various management possibilities available were examined and the "Condor" system selected and installed. It is a widely used and well documented system which performs several tasks:

- Allocation of computing resources to tasks
- Scheduling of tasks
- Distribution of data and program files
- Recovery from compute node failure

These tasks are performed more or less behind the scenes. The user simply offers a program and data to the system, which takes over and transports them to the appropriate place, executes the program and delivers the result back to the user.

Data processing capacity expansion

As mentioned above, the performance of the computing resource was massively increased thanks to special purpose cards based on graphics processors (so called CUDA or GPU technology), which only became available at the start of 2009. The "Velociraptor" application, created by Samuel Gissot and of direct application to SDO images, was re-written by Tobias Berghoff for the sample hardware. This reduced the time needed for calculation from eight hours in IDL to 13 seconds. After testing, six CUDA cards were purchased and installed in the computing cluster

Scientific applications: SDO Science centre

V. Delouille and J.-F. Hochedez are co-investigator on the *SDO Science Centre*, a suite of software pipeline modules for automated feature recognition and analysis of SDO data. As such, we will deliver two modules: one detection tool for Active Regions, and one for Coronal Holes.These modules will be inserted into the SDO pipeline at Lockheed Martin Solar and Astrophysical Laboratory to run in near real time on SDO-AIA data and produce entries for the Heliophysics Events Knowledgebase (HEK).

Mining and exploitation of SDO data in Europe

V. Delouille is leader of an International team from the International Space Science Institute (ISSI) for the “Mining and Exploitation of SDO data in Europe”. The first meeting took place on 19-21 October 2009 and had 14 participants. Several algorithms for detection of solar features were presented and discussed. The majority of these algorithms will be included in the HEK in the near future. This automated processing may also help addressing scientific questions. In particular, this group studies the coronal and transition counterparts of photospheric features, and aims at combining information from all layers of the atmosphere in view of establishing models for flare prediction.

Public webserver access

The web server http://wissdom.oma.be is now publicly available. It is currently running a group of wiki's for project documentation, issue trackers and Subversion repositories.

Several levels of user access are provided. Public documents can be read by anyone, while project documentation is password protected and modification is further limited to selected users. This is mainly to prevent accidents, as backtracking is provided to recover earlier versions, so nothing is lost. Furthermore, all data is backed up daily.

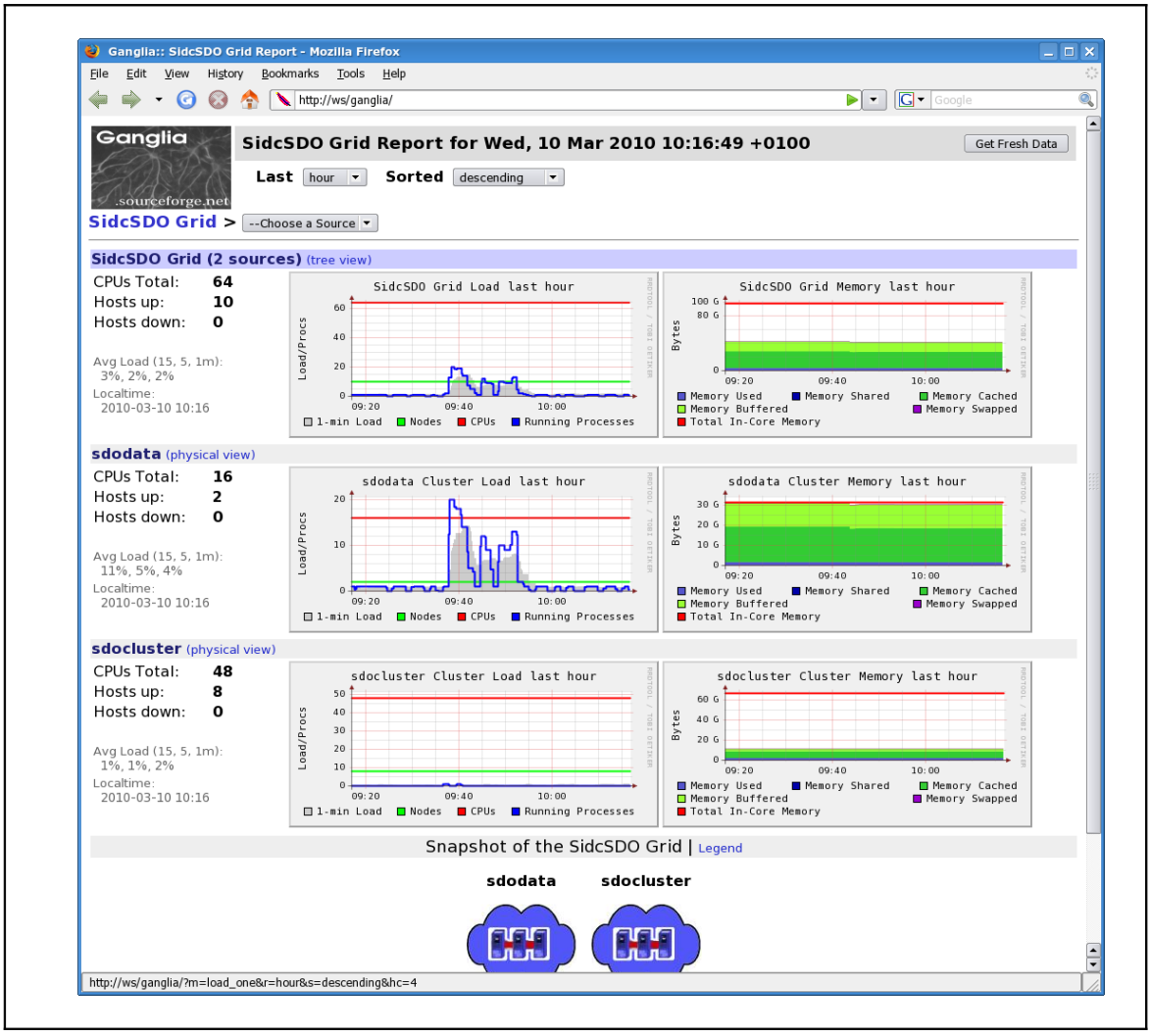


Figure 86: Data center monitor screenshot

Q.4.3. Perspective for next years

With the successful launch of SDO on 11 February 2010, the data are expected to flow end of May.
As mentioned above, all AIA data distributed in Europe will transit through ROB. The data stream will contain two types of data:

- Near real time data of AIA images with full resolution, all channels, highest possible cadence to deal with bandwidth constraint. SIDC will redistribute this data flow to European partners within our outward bandwidth capacity.
- AIA data sets properly corrected for instrumental effects, the package of which being built on request by the end-user.

We now detail the perspectives for the different areas of this project:

Q.4.3.1. Operational SDO data center

There are several areas for which effort is needed for the SDO data centre, viz.:

- Increase of storage capacity
- Possible change in storage capacity and database server capacity
- Increase of network reliability through redundancy (planned but not yet available)

- Further operator and maintenance documentation

Q.4.3.2. Data and product archiving

Experience shows the importance of ready availability from archives. Planning and implementation of archiving and distribution of SDO basic data and analysis products is therefore a priority for the immediate future.

Q.4.3.3.Redistribution of SDO data through virtual observatories

One of the priorities of the WisSDOm project is to provide access to SDO data for a large public of users. Towards this goal, web based interface for internal and external public will be implemented. Adequate visualization tools will be made available through our website. IDL access to the data will be provided internally.

ROB will become a SDO data provider for the US-based Virtual Solar Observatory (VSO). In addition, it is foreseen that SDO data will become available through the Virtual Observatory developed within the EU-funded SOTERIA project.

Q.4.3.4.Scientific applications

SPoCA will be adapted to analyse AIA images, taking into account the additional wavelengths brought by AIA compared to previous EUV telescopes. Performance enhancements will be studied. The Active Regions and Coronal Holes detection modules derived from SPoCA will be inserted into the SDO data center pipeline at SAO and at LMSAL. The outputs from SPoCA and Velociraptor (velocity and brightness variation detector) will be exploited at ROB/SIDC, where a system interface for computation intensive access will be implemented. It is envisioned that the SDO data center at ROB may welcome other scientific applications that require intensive access to SDO data, and that it may be connected to other grid computing resources for enhanced computational performance.

Q.4.4. Personnel involved

Scientific staff: V. Delouille, D. Boyes, F. Verbeeck, S. Gissot, J.-F. Hochedez, F. Roosbeeck
Technical staff: B. Mampaey, T. Berghoff, A. Somerhausen

Q.4.5. Partnerships

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

- Karel Schrijver, Neal Hurlburt, Alan Title, Lockheed Martin Solar and Astrophysics Laboratory, USA
- Phil Scherrer, Stanford University, and Hansen Experimental Physics Laboratory, USA
- Piet Martens, Alisdair Davey, Ed Deluca, Leon Golub, Justin Kasper, Smithsonian Astrophysics Observatory, USA
- Jonathan Cirtain, NASA, USA
- Bernhard Fleck, Dan Müller, ESA
- Fransisco Suarez Sola, National Optical Astronomy Observatory, USA
- IAS (Eric Buchlin, Karine Bocchialini, Elie Soubrié; Jean-Claude Vial, Susanna Parenti, Frédéric Auchère),
- TCD (Shaun Bloomfield, Paul Higgins),
- UC Lancashire (Robert Walsh, Silvia Dalla, Mike Marsh and Steven Chapman),
- MPS (Laurent Gizon, Ray Burston, Davina Innes)
- U. Glasgow (Nicolas Labrosse, Fraser Watson)
- U. Bradford (Tufan Colak, Rami Qahwaiji)

Grants/Projects used for this research/service

- SIDC Telescience PEA (Prodex)
- SIDC Data Exploitation PEA (Prodex)

Visitors:

- 2009-01-30: Borut Podlipnik and Bernd Inhester, SDO and STEREO archives in MPS, Lindau
- 2009-10-26: Alisdair Davey, WisSDOm configuration
- 2009-06-09: IAS (Eric Buchlin, Karine Bocchialini, Elie Soubrié; Jean-Claude Vial), TCD (Shaun Bloomfield), NASA (Jonathan Cirtain), SAO (Alisdair Davey, L Golub), UC Lancashire (Mike Marsch), ESA (Bernhard Fleck), MPS (Laurent Gizon), LMSAL (Karel Schrijver), First SDO in Europe meeting

Meeting presentations

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Computer Vision for the Solar Dynamics Observatory
American Astronomical Society, SPD meeting #40, #17.11; Bulletin of the American Astronomical Society, Vol. 41, p.843

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Segmentation of solar EUV images - fuzzy clustering on multichannel data
International Space Science Institute meeting «Mining and exploiting the NASA Solar Dynamics Observatory data in Europe», Bern, October 19-21, 2009

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Fast and robust segmentation of solar EUV images: towards operational use in the age of SDO
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SDO Data Centre at ROB and the WisSDOm 'Web Incessant Screening SDO Manipulation' Project
Sixth European Space Weather Week, Brugge, Belgium, November 16-20, 2009

[5] David Boyes, Véronique Delouille, Benjamin Mampaey, Tobias Berghoff, Cis Verbeeck, Jean-François Hochedez
All of the Sun all of time: distributing 1 TB/day from the Solar Dynamics Observatory satellite, 24/7 for 5+ years
BELNET Networking Conference 2009- "Connecting the dots", Le Plaza, Brussels, 26 Nov 2009

Wikis and Websites

- http://wissdom.oma.be/

Q.4.6. Missions

Assemblies, symposia, conferences:

- Sixth European Space Weather Week, 16-20 November, 2009 - Brugge, Belgium (4 people)

Commissions, working groups:

- 9 June 2009, First SDO Europe mtg, ROB, B (5 people)
- 19-21 October 2009, “Soldyneuro” ISSI team, Bern, CH (3 people)
- 23 October 2009, Second SDO Europe mtg, IAS, F (4 people)

Q.5. SOTERIA Virtual Observatory

Q.5.1. Objectives

SOTERIA is a Framework 7 project that started on Nov 1, 2008 and which is funded by the EU for 3 years. SOTERIA aims at creating a wide synergy in the fields of solar-space and geo-physics among different centers in a number of European countries to achieve a higher level of quality and accessibility for the observational data and for the models. Our goal is to help creating the basis for a deeper understanding of solar and

space processes having terrestrial impact. ROB had the responsibility over SOTERIA's Work-Package 6 that deals with the logistical, mostly IT aspects of exchange of information within and beyond the SOTERIA consortium.

Q.5.2. Progress and results

In this section we report on the results obtained in WP6 of SOTERIA: the creation of a virtual observatory infrastructure and the creation of a document repository.

Q.5.2.1. Creation of a SOTERIA document repository

Unlike other scientific communities, the space weather community did not have yet an online document repository where technical information can be hosted. With SOTERIA, and thanks to the technical help from http://www.spaceweather.eu, we have been able to complete an online document repository. We believe such an online repository can be significant help for the space weather community to aid the broad distribution of non–publishable research results such as technical reports, instrument descriptions, presentations and reference documents. The objective was to create an online reference documentation repository where the SOTERIA community, and the space weather community in general, can share documents.

The document repository is 100% completed. For a direct link to the document list, go to http://www.spaceweather.eu/en/repository/list. Note that not all documents are visible if not logged in as a user belonging to the SOTERIA group.

Q.5.2.2. Design and initial developemnt of a SOTERIA virtual observatory infrastructre

Building upon the preliminary investigation done by the SOTERIA team at the Royal Observatory, the work was divided in several steps:

1. Technical investigation of existing Virtual Observatory technologies
2. Definition of the technical Virtual Observatory design and implementation strategy
3. Design and development of a virtual observatory infrastructure for the Soteria project

The purpose of the technical investigations was to study the strong points and the weak points of existing technologies and to subsequently choose the most suited one or to develop the necessary technology.

The following technologies were investigated in more detail:

- EGSO

The "European Grid of Solar Observations" is funded by the European Commission's Fifth Framework Programme. It has good documentation and a working solar event catalog. Unfortunately it is not funded anymore since 2006.

- VSO

  American Virtual Observatory project coordinated the NASA Goddard Space Flight Center. It is a working infrastructure with around 15 data providers. It provides basic functionality of dataset sharing. Its weaknesses are an aging technology and no direct partnership with Soteria.

- KEAS - CESAR

  Virtual Observatory like system developed by the Kanzelhöhe Observatory for solar and environmental research. It is an application specifically developed for the use of that observatory. It is running but not further developed anymore.

- HELIO

  Helio is the successor of the EGSO project and is an FP7 project. It started at the same time as Soteria and isn't yet fully operational. They are developing a state-of-the-art system far beyond VSO, and that they need a user community like SOTERIA to interact with.

  The conclusion was that none of these existing technologies could be reused as is. We therefore decided to start with adapting and extending the VSO because it the only already working infrastructure, it is simple and the Observatory of Paris is already a data provider. Our target is for Soteria to become a VSO data provider. Meanwhile at ROB we are making sure that we do not depend critically on the central VSO hub, but that SOTERIA has its own central hub that can work independently from it.

On a slower timescale, we will collaborate with the HELIO project actively.
The outcome of this step is an important contribution to the WP6 VO Action Plan document and in the Wiki of the Soteria web site.

In a next step we started the software development part of this project.

The main results are:

- Reliability and Performance analysis of the VSO infrastructure.
- VSO compatible Uset Data provider service: need to be validated by the VSO team
- Enhanced VSO protocol (aka Soteria Protocol)
    - Data service implementation for Uset
    - Data service implementation for DrawX dataset from UniGraz.
- Ongoing implementation of an enhanced VSO server using the VSO and the Soteria protocols.

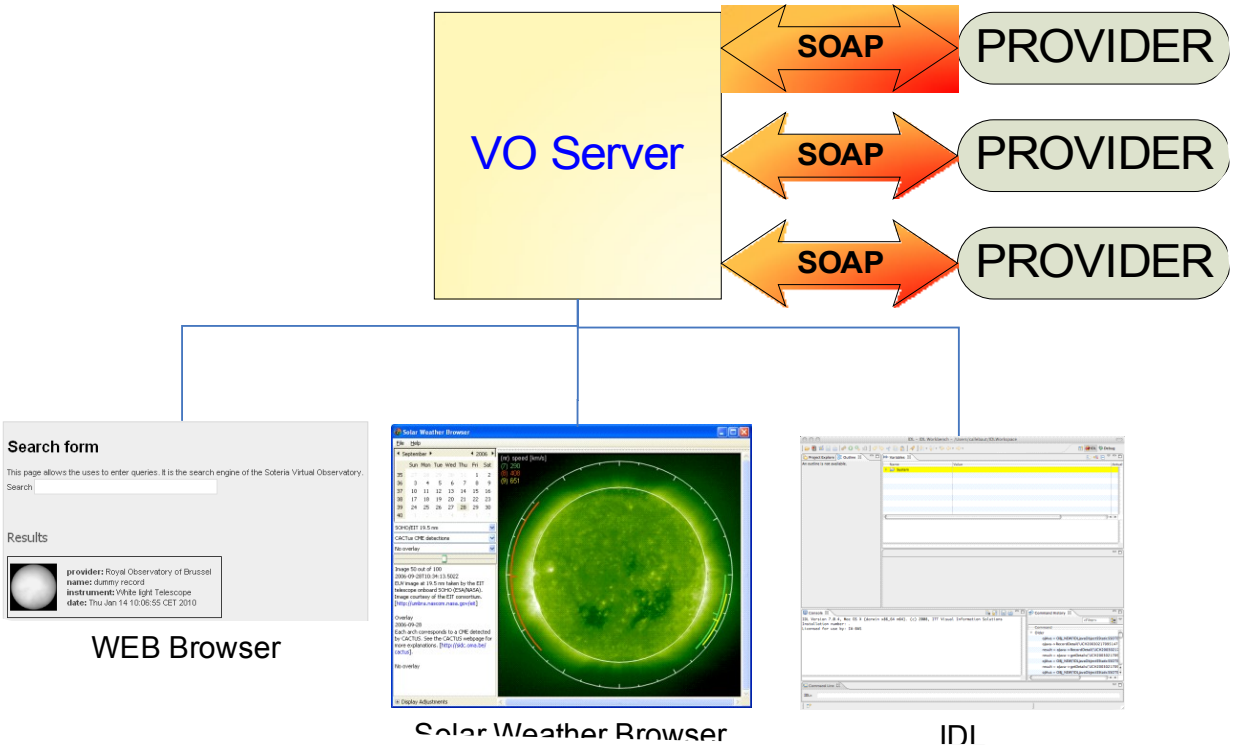

Figure 87: Soteria Virtual Observatory overview

Q.5.3. Perspective for next years

The SOTERIA project runs till the end 2011.

- We plan to have for next year an up and running implementation of a VSO compatible server with data-sets from USET and DrawX.
- We expect to become a VSO data provider.
- We expect to do operational tests with the existing HELIO web services.

Q.5.4. Personnel involved

Scientific staff: B. Callebaut, D. Berghmans, E. D'Huys

Q.5.5. Partnerships

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

- K.U. Leuven Giovanni Lapenta
- DTU Susanne Vennerstrom
- UGOE Volker Bothmer
- PMOD-WRC Werner Schmutz
- UNIGRAZ Arnold Hanslmeier
- KO András Ludmány
- MTA KFKI RMKI Karoly Kecskemety
- OBSPARIS Jean-Marie Malherbe
- NOVELTIS Vincent Germain
- SRC-PAS Janusz Sylwester
- CNRS Jean Lilensten, Thierry Dudok de Wit
- UOulu Kalevi Juhani Mursula
- HVAR Roman Brajsa
- LPI Sergey Kuzin

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

- Giovanni Lapenta (SOTERIA PI), KULeuven

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

- EU Framework 7 support (SOTERIA budget)
- STCE support (Elke D'Huys, Bogdan Nicula)

Visitors:

- Jean Abourdaham (OBSPARIS) and Wolfgang Otruba (UNIGRAZ), Jan 30 2009, SOTERIA Virtual Observatory effort
- Giovanna Lapenta (KULeuven), Volker Bothmer (U. Gottingen), Vladimir Slemin (Lebedev), etc, Jun 22-23 2009, Discussion meeting deliverables WP3

Q.5.6. Scientific outreach

Meeting presentations

[1] D. Berghmans, W.Otruba, J. Aboudarham, F. Clette, B. Nicula, B. Callebaut, E. D'Huys
Virtual Observatory Action Plan
SOTERIA workshop: 23-24 March 2009, Saariselka Finnish Lapland

[2] D. Berghmans, B. Callebaut
Virtual Observatory Action Plan
SOTERIA-HELIOS special session at ESWW6, 2009-11-18, Brugge

Websites

- http://soteria-space.eu/
- http://soteria-space.eu/wiki/index.php/Main_Page
- http://www.spaceweather.eu/en/repository

Q.5.7. Missions

Assemblies, symposia, conferences: SOTERIA workshop, 23-24 March 2009, Saariselkä, Finland

Field missions: Several meetings with S. Calders (BIRA) took place at BIRA from February- May 2009.

R. Publications

R.1. Publications with peer review

[1] Abel N.P., Dudley C., Fischer J., Satyapal S., **van Hoof P.A.M.**
Dust-Bounded Ultraluminous Infrared Galaxies: Model Predictions for Infrared Spectroscopic Surveys
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[2] Arlot, J.-E., et al., 119 authors including **Cuypers, J.**, **Pauwels, Th.**
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Astron. Astrophys. 493, 1171-1182

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Fast and robust segmentation of solar EUV images: algorithm and results for solar cycle 23
Astronomy and Astrophysics, Volume 505, Issue 1, pp.361-371

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[5] **BenMoussa, A.; Dammasch, I. E.; Hochedez, J.-F.;** Schühle, U.; Koller, S.; Stockman, Y.; Scholze, F.; Richter, M.; Kroth, U.; Laubis, C.; **Dominique, M.;** Kretzschmar, M.; Mekaoui, S.; **Gissot, S.;** Theissen, A.; **Giordanengo, B.;** Bolsee, D.; Hermans, C.; Gillotay, D.; Defise, J.-M.; Schmutz, W.
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[6] **BenMoussa, A.;** Soltani, A.; Schühle, U.; Haenen, K.; Chong, Y.M.; Zhang, W.J.; Dahal, R.; Lin, J.Y.; Jiang, H.X.; Barkad, H.A.; BenMoussa, B.; Bolsee, D.; Hermans, C.; Kroth, U.; Laubis, C.; Mortet, V.; De Jaeger, J.C.; **Giordanengo, B.;** Richter, M.; Scholz, F.; **Hochedez, J.-F.**
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Documents transmitted to ESA for the LaRa PDR.

Document Title	ExoMars reference	Delivery date	Pages
Experiment Interface Control Document	EXM-HPL-E-ICD-00005	3rd February 09	134
Design, Development and Verification plan	EXM-PL-LA-DDV-00001	27th January 09	39
Design Report	EXM-PL-LA-DR-00001	3rd February 09	69
Assembly, integration and Verification Plan	EXM-PL-LA-AVP-00001	27th January 09	65
Compliance Matrix	EXM-PL-LA-CM-00001	27th January 09	58
Verification Matrix	EXM-PL-LA-VM-00001	27th January 09	53
Ground support equipment Design Report	EXM-PL-LA-GDR-00001	27th January 09	18
mechanical DRraWings	EXM-PL-LA-DRW-00001	3rd February 09	14

Declared Components List	EXM-PL-LA-DCL-00001	27th January 09	5
Declared Materials List	EXM-PL-LA-DML-00001	27th January 09	3
Declared Processes List	EXM-PL-LA-DPL-00001	27th January 09	5
Declared Mechanical Parts List	EXM-PL-LA-DMPL-00001	27th January 09	3
Configuration item Data List	EXM-PL-LA-CDL-00001	3rd February 09	13
Planetary Protection Implementation plan	EXM-PL-LA-PPI-00001	27th January 09	30
Product Assurance Plan	EXM-PL-LA-PAP-00001	27th January 09	88
Risk Management Plan	EXM-PL-LA-RMP-00001	27th January 09	16
Cleanliness and Contamination Control Plan	EXM-PL-LA-CCP-00001	27th January 09	16
Configuration Management Plan	EXM-PL-LA-CMP-0001	27th January 09	33
FMECA (Failure Modes, Effects, and Criticality Analysis)	EXM-PL-LA-FMA-00001	27th January 09	30
FDIR (Failure/Fault Detection Isolation and Recovery)	EXM-PL-LA-FDR-00001	3rd February 09	15
RiSK assessment report	EXM-PL-LA-RSK-00001	27th January 09	30
Critical Item List	EXM-PL-LA-CIL-00001	27th January 09	34
THermal analysis Report	EXM-PL-LA-THR-0001	6th February 09	21
STRuctural mechanical analysis report	EXM-PL-LA-STR-00001	6th February 09	54
project development SCheDule (Microsoft project document)	EXM-PL-LA-SCD-0001	27th January 09	3
breadboard Thermal-vacuum test Report	EXM-PL-LA-TR-0001	27th January 09	19
STRructural THermal analyses (annexes)	STR_TH_Analyses_annexes	6th February 09	101

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Document Title	**Document reference**	**Delivery date**	**Pages**
EEE parts specifications	LaRa-OMP-SP-004	27th January 09	4
CAD models		27th January 09	O
LaRa performances specifications and verification	LARA-SP-CSL-08001	27th January 09	17
LaRa scientific requirements	LARA-RD-ROB-00001	27th January 09	16
Long lead items list	LaRa-OMP-LI-001	3rd February 09	9
Breadboard test plan	LARA-OMP-SP-001	27th January 09	28
Breadboard test procedure	LARA-PR-CSL-08001	27th January 09	27
BB Lab&Vac measurement report	LARA-OMP-RP-013	27th January 09	30
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[373] ROB (**Dehant V., Le Maistre S., Mitrovic M., Nkono C., Rosenblatt P.)**
Technical notes for the LARA project

Authors	**Document Title**	**Document reference**	**Delivery date**	**Pages**
Dehant V.	Scientific Risks Analysis	LARA-TN-ROB-00012	27th January 09	22

Nkono C., Rosenblatt P., and Dehant V.	Plasma effects on radi-osignal	LARA-TN-ROB-00014	1st October 09	21
Dehant V.	ROB Atomic Clocks Data Sheet	LARA-TN-ROB-00015	1st October 09	8
Mitrovic M. and Dehant V.	LaRa Two-Way Range Measurement	LARA-TN-ROB-00016	22d September 09	37

GENERAL SCIENTIFIC ACTIVITIES

Expertise, Audit

- C. Bruyninx: Member of the scientific committee of RENAG (Réseau National GPS), France
- V. Dehant: Member of the Comité des Programmes Scientifiques (CPS) du CNES ; Member of "Solar System Exploration Working Group (SSEWG)" of ESA; Member of "Earth Science Advisory Committee (ESAC)" of ESA; Member of "Exploration, Science and Technology Advisory Group (ESTAG)" of ESA; Member of the Mars-NEXT Science Definition Team (MarsNEXT SDT) in the frame of the Mars Sample Return (MSR) preparatory mission of the AURORA program of ESA; Member of the Science Analysis Group (SAG) of MEPAG (Mars Exploration Program Analysis Group) of NASA (National Aeronautics and Space Administration), NetSAG (Network Science Analysis Group) subgroup; Member of the Scientific Advisory Committee of the Helmholtz Alliance "Planetary Evolution and Life"; Member of "Groupe d'évaluation du GRGS" ; Member of the High Scientific Committee (Haut Comité Scientifique) of the Observatoire de Paris; Member of the Scientific Council of the Institut de Physique du Globe de Paris
- Thierry Pauwels: report about solar eclipses in the 11th century for André Berger
- R. Blomme: Jury member return-grants Belgian Science Policy, 20/5/2009
- M.Groenewegen: Referee for FWO proposals; Opponent in Ph.D. defense ceremony of Lars Mattsson, Uppsala, 29 April 2009
- A. BenMoussa: Evaluator for the 2nd call EU FP7 Strengthening Space Foundations (2009 critical components); Evaluator for the French Nano Innov 2009 program (Nanosciences and nanotechnologies).
- S. Parenti: member of the NASA Solar Research & Technology grant program scientific committee
- R. Van der Linden: member of the Scientific Committee of the National Geographical Institute;

Scientific responsibilities

- V. Dehant: Principal Investigator of the Lander Radioscience experiment (LaRa) in the frame of the AURORA/ExoMars mission to Mars; Co-Investigator of Mercury Orbiter Radio-science Experiment (MORE) in the frame of the ESA BepiColombo mission to Mercury; Co-Investigator of BepiColombo Laser Altimeter (BeLA) in the frame of the ESA BepiColombo mission to Mercury; Co-Investigator of the VenusExpress Radio science experiment (VeRa) in the frame of the ESA VenusExpress mission; Co-Investigator 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
- Ö. Karatekin: Member of the Geophysics subgroup of Galilean satellites working group in the Europa Jupiter system Mission (EJSM) study.
- S. Le Maistre: Co-Investigator of LaRa (Lander Radioscience experiment), the radioscience experiment of the ExoMars mission to Mars
- M. Mitrovic: Co-Investigator of LaRa (Lander Radioscience experiment), the radioscience experiment of the ExoMars mission to Mars
- M. Mitrovic: ROB Project Manager of LaRa (Lander Radioscience experiment), the radioscience experiment of the ExoMars mission to Mars
- P. Rosenblatt: Co-Investigator of LaRa (Lander Radioscience experiment), the radioscience experiment of the ExoMars mission to Mars; Co-Investigator of the VenusExpress Radio science experiment (VeRa) in the frame of the ESA VenusExpress mission; Co-Investigator of the MarsExpress Radio Science experiment (MaRS) in the frame of the ESA MarsExpress mission
- T. Van Hoolst: Co-Investigator of SIMBIO-SYS (Spectrometers and Imagers for MPO BepiColombo Integrated Observatory SYStem), the camera experiment of ESA's BepiColombo mission to Mercury; Co-Investigator of MORE (Mercury Orbiter Radio-science Experiment), the radio science experiment of ESA's BepiColombo mission to Mercury; Co-Investigator 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'

- J.-F. Hochedez and V. Delouille: co-I of the SDO Science Center; for "*Design and Operation of a Solar Dynamics Observatory Science Center".* Investigation is financed by NASA;
- J.-F. Hochedez: PI of the PROBA2 LYRA; co-I on PROBA2-SWAP, STEREO-SECCHI, SOHO-EIT, PICARD-PREMOS & BOS; Associate Investigator (AI) of the SDO-AIA
- D. Berghmans: PI of PROBA2-SWAP; co-I on PROBA2-LYRA, SOHO-EIT, STEREO-SECCHI.

Educational responsibilities (Lectures)

- N. Bergeot: Lecturer for UCL Bac 3 "PHY1312 Analyse de données GPS".
- P. Defraigne: lecturer at the UCL, lecture on Mathematical Astronomy (15h)
- V. Dehant: lecturer at the UCL, lecture on Astronomy and Geodesy (15h); lecture on Internal Geophysics (25h); lecturer at the Univ. Nantes on Planetary geodesy (15h)
- P. Rosenblatt: Lecturer at the Université Catholique de Louvain (UCL), lecture on Internal Geophysics (20h)
- A. Trinh: Teaching Assistant, Université Catholique de Louvain, PHY1261 "Astronomie et Géophysique" (7.5h)
- T. Van Hoolst: lecturer of the master course "Theoretical seismology" at the Katholieke Universiteit Leuven, 36h (every two years); lecturer of the master course "Physics of Planets" at the Katholieke Universiteit Leuven, 36h (every two years).
- P. Alexandre: Charge de cours à l'Université de Liège: "Géographie historique", 30 h; "Éléments de critique historique à l'usage des géographes", 30 h.
- T. Camelbeeck: lecturer at the ULB (Civil Engeneering) for the complementary master "Sollicitations cycliques et dynamiques en genie civil", 21 April 2009; lecturer at the University of Luxemburg "Introduction to seismic risk", 14 May 2009; lecturer at ULB (Physique du Globe in BAC3 et Géophysique Appliquée in Master1 – 30 h)
- T. Lecocq, *Geophysical methods on field,* travaux pratiques pour étudiants de l'ULB, 2009-10-26/28
- K. Vanneste: guest lecturer at the University of Gent, co-lecturer of the optional course "Natural Hazards"
- J.-F. Hochedez: Invited series of Solar Physics lectures, Novicosmo 2009 Summer School, Highlights in Astrophysics
- 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.

Educational responsibilities (students)

- C. Bruyninx: promoter of master thesis "Feasibility Study of Ionospheric Tomography based on GNSS Observations over Europe" of J.-M. Chevalier
- P. Defraigne: promoter of PhD of E. Pottiaux (UCL); co-promoter of PhD of M.C. Martinez (Univ. Alicante)
- V. Dehant: promoter of PhD of R.M. Baland, A. Hees, L. Koot, S. Le Maistre, G. Pfyffer, L.B.S. Pham, A. Rivoldini, and A. Trinh
- Ö. Karatekin: co-promoter of PhD of L. Pham
- J. Legrand, N. Bergeot: co- promoter of master thesis "Feasibility Study of Ionospheric Tomography based on GNSS Observations over Europe" of J.-M. Chevalier
- S. Pireaux: co-promoter of PhD of A. Hees
- P. Rosenblatt: co-promoter of PhD of S. Le Maistre; member of the jury of the PhD thesis of J. Desmars (title: "Précision d'extrapolation des éphémerides des objets du système solaire", Observatoire de Paris.
- T. Van Hoolst: co-promoter of PhD students R.M. Baland, G. Pfyffer, A. Rivoldini, and A. Trinh; member and "rapporteur" of the Jury for the PhD Thesis of Guillaume Robuchon, Université de Nantes (France).
- M. Yseboodt: co-promoter of PhD of R.M. Baland

- K. Vanneste: co-promoter of the Ph.D. thesis of Jeff Fraser "Four new paleoseismic investigations on the North Anatolian Fault, Turkey, in the context of existing data", ULB; member of the Ph.D. jury of Els Sichien "A study of the structure of the Belgian crust by Moho determination and local seismic tomography", Universiteit Gent
- M. Van Camp: Member of the jury of the Thesis «Apport de la gravimétrie et de l'inclinométrie pour la quantification du stockage et du transfert de l'eau en milieu karstique », by Thomas Jacob, U. Montpellier, 3 July 2009.
- T. Camelbeeck: rapporteur in the thesis jury of Olivier Le Roux (LGIT – Grenoble); rapporteur in the thesis jury of Stéphane Molliex (University Aix-Marseille); co-promotor of the MSc-thesis of Leslie Descamps at the Faculté Polytechnique de Mons; co-promotor of the MSc-thesis of Jean-Sébastion De Wattines at the Faculté Polytechnique de Mons; co-promoter at ULB of the PhD-thesis of Thomas Lecocq; co-promoter at Gent University of the PhD-thesis of Els Sichien
- Peter De Cat: Member of the scientific committee of the PhD of Maarten Desmet
- M.Groenewegen: Co-promoter at KU Leuven of PhD. student Djazia Ladjal.
- H. Hensberge: co-promoter at UCN, Antofagasta,Chile of lic. thesis of Francisco Pozo Nuñez: Analysis of the Tektronix camera at the 0.9-m telescope of the CTIO, for a correct data reduction with high precision using the astronomical analysis programs MIDAS and IRAF; co-promoter at UCN, Antofagasta,Chile of lic. thesis of Angie Barr Dominguez: Comparative study of the identifications of star members of the NGC 2244 open cluster
- V. Delouille: Co-promoter at Université Catholique de Louvain of C. Timmermans (PhD student); Co-promoter at Université Catholique de Louvain of M. Feuerstein (MSc student)
- J.-F. Hochedez: Co-promotor of the PhD thesis of S. Gissot
- D. Berghmans: Member of the jury for evaluation pre-doctoral year : Katrien Bonte

Belgian representations at international level

- 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 representative for the IAG (International Association of Geodesy)
- 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
- F. Collin: Belgian representative at the **E**uro**M**editerranean **S**eismological **C**entre
- K. Vanneste: titular member for Belgium in the European Seismological Commission (ESC) for the period 2006 – 2010.
- M. Van Camp: Belgian representative in the COST management committee (COST action ES0701 "Improved Constraints on Models of Glacial Isostatic Adjustment"); Belgian official representative at the ORFEUS board of directors.
- M.Groenewegen: Belgian representative in ESO's User Committee
- F.Clette: Belgian national representative in the CRAF council (Committee for RadioAstronomy Frequencies); Belgian representative to the JOSO Board (Joint Organisation for Solar Observations).
- R. Van der Linden: Belgian Representative, Grantholder and WG2 leader in the COST management committee (COST action ES0803 "Developing Space Weather Products and Service in Europe".

Memberships of national scientific committees:

- C. Bruyninx: Vice-secretary of the Belgian Committee for Geodesy and Geophysics; Associate member of the National Comity for Space Research; Member of the Executive Board of the Solar Terrestrial Center of Excellence
- P. Defraigne: Member ('membre associé') of the Belgian National Committee of Space Research
- V. Dehant: Member ('membre effectif') of the Belgian National Committee of Geodesy and Geophysics (+IAG representative); Member ('membre associé') of the Belgian National Committee of Space Research; Member ('membre effectif') of the Belgian National Committee of Astronomy;

- T. Van Hoolst: Effective Member and assistant secretary of the Belgian National Committee for Astronomy; Associate member of the Belgian National Committee for Geodesy and Geophysics; Associate member of the Belgian National Committee for Space Research
- P. Alexandre: 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; Member of BESEIG
- K. Vanneste: member of the Belgian National Committee for Geodesy and Geophysics.
- M. Van Camp : Associated Member of the Comité National Belge de Géodésie et de Géophysique ; Member of BeSeiG.
- Peter De Cat: Member of WEGA; Member of the Vereniging voor Sterrenkunde
- P. Lampens: Co-administrator of the corporate association "*Belgian Women in Sciences"*
- 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
- R. Van der Linden: Member of the Belgian National Committee for Astronomy; Member of the Belgian National Committee for the Solar-Terrestrial Relationship
- F.Clette: associate member of the Belgian URSI Committee, Royal Academy of Sciences; member of SCAS (Sous-Comité d'Astronomie Spatiale), Royal Academy of Sciences; member of the Comité National de Recherche Spatiale, Royal Academy of Sciences; member of the "Comité National Belge des Relations Soleil-Terre", Royal Academy of Sciences

Memberships of international scientific committees:

- C. Bruyninx: Chair of the EUREF Technical Working Group; Chair of the IAG Working Group on "Regional Dense Velocity Fields"; Chair of the EPN Coordination Group; 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 the Working Group "European Combined Geodetic Network (ECGN)" of the EUREF sub-commission of the IAG; Member of the EUREF Working Group on Future Development of ETRS89; Member of the EPN Working Group on Reprocessing; Member of the IAG Inter-Commission Project IC-P1.2 on "Vertical Reference Frames", joint with Commission 2 and IGFS; 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 the Management Committee of COSTES701 "Improved constraints on models of glacial isostatic adjustment"
- J. Legrand: Member of the EUREF Working Group on Future Development of ETRS89; Member of the EPN Working Group on Reprocessing; Member of the IAG Working Group on "Regional Dense Velocity Fields"; Deputy member of the Management Committee of COST ES701 "Improved constraints on models of glacial isostatic adjustment"; Member of the EPN Central Bureau
- P. Defraigne: President of the IAU commission 31 (Time); Member of OC of the IAU Commission 19 (Earth Rotation); Member of the SOC of the European Frequency and Time Forum (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; Responsible of P3 to Common GPS and GNSS Time Transfer Standards (CGGTTS) software internationally used; Member of the WG 'Clock Products WG' of the IGS
- 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; Member of "Special Bureau for the Core" (MGGF/IERS); Member of OC of the IAU Commission 19 (Earth Rotation)
- E. Pottiaux: National delegate within E-GVAP and member of the GNSS processing expert team

- 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 Sub-Commission 3.3 "Geophysical Fluids" of the IAG commission 3 "Geodynamics and Earth Rotation"; Associate Member of the IERS; Member of Commission 27 of the IAU
- C. Bruyninx, P. Defraigne, V. Dehant, F. Roosbeek, T. Van Hoolst: Members of Commissions 19 of the IAU
- C. Bruyninx, P. Defraigne, V. Dehant: Members of Commissions 31 of the IAU
- Ö. Karatekin: Member of Commission 15 of the IAU
- C. Bruyninx, J. Legrand, F. Roosbeek: Members of Commission 1 and Commission 4 of the IAG
- C. Bruyninx, P. Defraigne, V. Dehant, Ö. Karatekin, J. Legrand, F. Roosbeek, T. Van Hoolst: Member of Commission 3 of the IAG
- 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; M. Van Camp: Member of the AGU, EGU, IAG, GGP; 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"; 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 Pulsating 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
- Thierry Pauwels: IAU Commission 7 "Celestial Mechanics & Dynamical Astronomy"; IAU Commission 8 "Astrometry"; IAU Commission 20 "Positions & Motions of Minor Planets, Comets & Satellites"; CU4 of Gaia DPAC; DU leader of DU454 of Gaia DPAC; IAU Task Force on the Preservation and Digitization of Photographic Plates (PDPP); Thierry Pauwels: IAU Working Group on the Astrographic Catalogue and Carte du Ciel Plates; Thierry Pauwels: IAU Working Group "Astrometry by small ground-based telescopes".
- Y. Frémat: Member of IAU Commission 36 "Theory of Stellar Atmospheres"; Member of the Gaia Data Processing and Analysis Consortium and Gaia Hot Stars Team; Member of the CoRoT Be stars Team
- P. Lampens: Member of the CoRoT Binary Thematic Team
- R. Blomme: Member of IAU Commission 36
- J. Cuypers: Member of IAU commissions 15, 25 and 27; Member of the COROT "B stars Working Group"; Member of the Kepler Asteroseismic Science Consortium
- J. Cuypers, R. Blomme: Member of the COROT "O stars Working Group"
- H .Hensberge: Member of IAU Commission 25 and 44
- M.Groenewegen: Member of IAU Commission 27; Member of Euro-VO Scientific Advisory Committee
- G. Van de Steene: Member of IAU Commission 34
- F.Clette: URSI (Union Radio-Scientifique Internationale) representative to the FAGS Council (Federation of Astronomical and Geophysical Data Analysis Services); 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
- L. Rodriguez: Member of of an ISSI international team: 'From the Sun to the terrestrial surface: understanding the chain'

- J.-F. Hochedez: member of the 'Soldyneuro' ISSI team on 'Mining and Exploiting SDO data in Europe'
- D. Berghmans: member of the Space Weather Working Team – Belgian representative in the Working Group of International Living with a Star - member of IAU Commission 10
- R. Van der Linden: 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
- Dan Seaton: American Geophysical Union; American Astronomical Society & Solar Physics Division; Member of ISSI Working Group on Prominence Cavities
- P. Vanlommel: member of the Space Weather Working Team

Editorial responsibilities

- C. Bruyninx: Member of the advisory editorial board of GPS Solutions
- V. Dehant: Member of the IERS Conventions editorial board
- P. Defraigne: Editor of Proceedings of the Joint Discussion D6, Highlights of Astronomy, Volume 15, 2009
- L. Rodriguez: Guest Editor for the Prospective EGU special issue 'Three dimensional aspects of CMEs, their source regions and interplanetary manifestations' to be published in the Atmospheric and Solar-Terrestrial Physics Journal.
- R. Van der Linden: Guest Editor for Advances in Space Research

Meeting organization

- P. Defraigne: Co-organizer of EFTF 2009, in Besançon, co-chair of group 5 "Time Timekeeping, Time and Frequency Transfer, GNSS and Applications"
- P. Defraigne: Organizer and Chair of the JD 6 "Time and Astronomy" at the IAU GA in Rio, August 2009
- V. Dehant: Member of the Scientific Organizing Committee of "Journées Systèmes de Références Spatio-Temporels"
- P. Rosenblatt: Co-organizer of the session 'Interior and subsurface' of the international conference on comparative planetology: Venus-Earth-Mars, ESTEC, Noordwijk, The Netherlands, 11-15 May 2009
- M. Van Camp: Co-chair of the Geodesy session "Geodesy to investigate the climate system", AGU Fall Meeting, San Francisco, December 14-18, 2009.
- M. Van Camp: Member of the Geodesy Best Student Paper Committee, AGU Fall Meeting, San Francisco, December 14-18, 2009.
- M. Van Camp: COST ES0701: "Workshop on hydrological and other local effects in gravity measurements", March 16-17, 2009, Royal Observatory of Belgium.
- R. Blomme: Member of the SOC for the Liège colloquium "A multi-wavelength view of Hot Massive Stars" (2010)
- M.Groenewegen: Co-organizer of MESS 1st Consortium meeting, 16-17 February 2009, Leuven
- M.Groenewegen: Co-organizer of MESS 2nd Consortium meeting, 9-10 November 2009, Leuven
- M.Groenewegen: Co-organizer of ``The Giant Branches'' workshop, 11-15 May 2009, Leiden
- P. van Hoof: Organizer of the 4th Cloudy Development Summit held at the Royal Observatory of Belgium, 3 – 7 August.
- V. Delouille: leader of the 'Soldyneuro' ISSI team on 'Mining and Exploiting SDO data in Europe' (call 2009)
- V. Delouille: Organization of the 1st 'SDO pipeline meeting' in Europe, ROB, Brussels, 9 June 2009
- J.-F. Hochedez: SOC member of the 6th Astrophysical Data Analysis conference, May 2010
- J.-F. Hochedez: SOC member of the 3rd Solar Orbiter workshop, May 2009
- J.-F. Hochedez: SOC member of the series of NOVICOSMO astrophysical Summer Schools
- L. Rodriguez: Co-organizer of the EGU General Assembly 2009, session ST2 "On the three dimensional morphology and dynamics of coronal mass ejections"

- CESRA 2010: Preliminary work for the organization of the 2010 CESRA meeting in Belgium. (C. Marqué, A. Vandersyppe, O. Lemaître).
- ESWW6 was organised in Bruges, 16-20/09/2010 (R. Van der Linden, P. Vanlommel, A. Vandersyppe and the SIDC team).

Awards/Promotions

- V. Dehant: Professeur Extraordinaire at UCL
- T. Van Hoolst: deeltijds hoogleraar K.U.Leuven, from 1/10/09
- Henri Debehogne, Eric Elst: assigned as discoverers of 2 minor planets.
- Peter De Cat: assigned as discoverer of 1 minor planet (7 in total).
- Eric Elst: assigned as discoverer of 44 minor planets.
- Thierry Pauwels: assigned as discoverer of 16 minor planets.
- Thierry Pauwels, Sergei Ipatov: assigned as discoverers of 1 minor planet.

Table of Figures

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Deel 2: Publieke Dienstverlenende Activiteiten

Partie 2: Activités de Service Publique

Part 2: Public Service Activities

Overzicht / Sommaire

A. PLANETARIUM

A.1. Activités

A.1.1. Visiteurs

En 2009, le Planétarium a accueilli **25.596 visiteurs** hors événements spéciaux, chiffre nettement inférieur à l'année précédente (-3.617 visiteurs / -12%) du fait des trois mois de fermeture (août-octobre) qu'il a été nécessaire de planifier pour permettre le bon déroulement de travaux dans la grande salle (voir section A.4).

La part du **public scolaire** (19.658 élèves) s'élève à 77% du nombre total de visiteurs. Le **public familial** (mercredis après-midi, dimanches, congés scolaires) atteint le nombre de 5.938 visiteurs (23%). La baisse de fréquentation se répartit à la fois sur le public scolaire et le public familial. Les deux derniers mois de l'an-

née, pourtant excellents en terme d'affluence du fait de la réouverture médiatisée du dôme fin octobre, ne sont pas parvenus à compenser toute la perte subie lors des mois de fermeture qui ont précédé.

La répartition entre public néerlandophone (10.939 visiteurs / 42.7%) et public francophone (14.657 visiteurs / 57.3 %) est de manière exceptionnelle cette année **déséquilibrée** : le mois d'octobre est traditionnellement un mois très demandé par les écoles flamandes, qui pour un certain nombre ont donc dû reporter leur visite en 2010.

A.1.2. Evénements.

Le Planétarium a organisé ou participé à de nombreux événements en 2009, année internationale de l'astronomie:

- la **conférence de presse d'ouverture de l'Année Internationale de l'Astronomie** le 16 janvier, en présence de la Ministre de la Politique Scientifique ;
- un **cycle de conférence** grand-public en collaboration avec De Buren les 19 février (Gérard Bodifée), 19 mars (Govert Schilling), 16 avril (Ralph Wijers), 14 mai (Walter Van Rensbergen) et 18 juin (Christoffel Waelkens) ;
- la participation à l'**Astro-Event** à Oostende du 27 février au 1er mars ;
- des **conférences** par Patricia Lampens et Yaël Nazé le 08 mars, Journée de la Femme, dans le cadre du projet IYA2009 *She Is An Astronomer* ;
- deux **concerts de musique** dans la grande salle les 21 mars (équinoxe de printemps) et 19 décembre (ca. équinoxe d'hiver) ;
- l'organisation le 28 mars de la **Nuit de l'Obscurité** sur le site de Rouge-Cloître, en partenariat avec la Commune d'Auderghem, le Volksterrenwacht MIRA et l'ULB ;
- la présentation et la prévente de l'édition spéciale par la Poste du **timbre « Astronomie »** le 4 avril (dans le cadre du projet IYA2009 *100 Hours of Astronomy*)
- une **conférence** par Yaël Nazé le 5 avril (dans le cadre du projet IYA2009 *100 Hours of Astronomy*)
- la participation au **Ruimtevaartdagen** à Leuven du 8 au 10 mai ;
- la **conférence de presse de présentation du projet de planétarium numérique** le 11 mai, en présence de la Ministre de la Politique Scientifique ;
- les retransmissions en direct (i) du lancement de la fusée amenant **Frank de Winne** à la Station Spatiale Internationale le 27 mai, (ii) de l'arrimage le 29 mai et (iii) du retour sur Terre le 1er décembre ;
- la participation aux journées **Portes Ouvertes** de l'Observatoire les 3 et 4 octobre ;
- l'organisation par ESERO de l'**ISS Day** (connexion en direct avec Frank De Winne depuis l'ISS) à la VUB le 06 octobre ;
- **l'inauguration du nouveau système de projection numérique** le 21 octobre au matin, en présence de la Ministre de la Politique Scientifique.
- **l'avant-première du spectacle** pleine-voûte « ALMA, La quête de nos origines cosmiques », le 21 octobre au soir, en présence d'un représentant de l'ESO.

A.1.3. Séances spéciales

Des séances spéciales de planétarium ont été organisées pour :

- les visiteurs de *l'Expo-Sciences* les 13 et 14 mai ;
- le grand-public les 23 et 24 octobre, dans le cadre du projet IYA2009 *Galilean Nights* ;
- les participants d'un *Family Day* (personnel hospitalier du Nord de la France) les 24 et 25 avril ;
- le grand public dans le cadre des *Nocturnes des Musées Bruxellois* les 05 novembre et 10 décembre.

A.1.4. 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 20 janvier ;
- location par le *SPF P&O* le 28 avril ;
- réunion du *Groupe de Contact Astronomie FNRS/ORB* le 06 mai ;
- location par *BASF* le 07 mai ;

- location par *FEDIS* le 13 mai ;
- location par l'asbl *Prosport* le 04 septembre ;
- location par l'association *MIRAGE* le 29 octobre ;
- location par *VVN* le 17 novembre ;
- location par *l'Institut culturel finlandais* (concert de musique électronique) le 28 novembre ;
- mise à disposition de salle pour *Child Focus* le 03 décembre ;
- mise à disposition de salle pour *Philips* le 15 décembre ;
- location par *OTI*S le 18 décembre.

A.1.5. Site web et brochures

Deux **dépliants/posters** (une version néerlandophone et une version francophone) ont été réalisés pour l'année scolaire 2009-2010. 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.

Fin 2009 a également été préparé le **document destiné au grand public** : sous forme de carte postale, il présente le spectacle « ALMA, La quête de nos origines cosmiques ».

Le **site Internet** du Planétarium (www.planetarium.be) a été visité 32.696 fois (17.244 visiteurs différents) entre le 28 septembre 2009 (début des statistiques) et le 31 décembre 2009, pour un total de 233.770 pages consultées.

A.1.6. Partenariats

Les collaborations avec la **Mini-Europe** et **Living Tomorrow** (Vilvoorde) sous forme de tickets combinés pour les groupes se sont poursuivies avec succès. Un nouveau partenariat est né avec **Technopolis**.

Le Planétarium est membre des **associations touristiques** suivantes : « Toeristische Attracties », « Attractions & Tourisme », « Brusselse Museumraad », « Office de Promotion du Tourisme Wallonie-Bruxelles ».

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)».

A.1.7. Personnel

Au 31 décembre 2009, le personnel du Planétarium se composait de **18 membres** :

- R. Alvarez, 1er assistant, statutaire – responsable
- V. Bastin, experte technique, contractuelle – animatrice scientifique
- G. Champagne, attaché scientifique, contractuel - développement
- S. Consiglio, administratief medewerker, statutaire – accueil
- H. De Rycke, gedetacheerd leraar – cours
- E. Geerts, attaché klasse 1, contractuelle - ESERO
- A. Ipuz-Mendez, collaborateur nettoyage, contractuelle - entretien
- J-C. Jacques, assistant technique, statutaire – opérateur
- A-L. Kochuyt, attaché klasse 1, statutaire – relations publiques
- N. Lubkowski, collaborateur technicien, contractuel – technique
- A. Pieront, attaché classe 1, contractuelle – ESERO
- A. Milis, industrieel ingenieur, statutaire - responsable technique
- R. Mostaert, enseignant sous contrat – cours
- 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

- W. Vander Putten, technisch deskundige, contractueel - infographisme

A.2. Projet ESERO

Le 1er octobre 2006, 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.

Le projet initial qui a pris fin en 2008 a été prolongé en 2009 pour une nouvelle période de deux ans. Deux Office **Managers** (rôle néerlandophone et francophone) ont été sélectionnés et recrutés durant l'été, pour une prise de fonction à l'automne.

Les **opérations du bureau ESERO** consistent en le suivi de projets de classes-pilotes, la création de brochures pédagogiques, l'organisation de formations pour enseignants, la tenue d'événements éducatifs liés au spatial (ISS Day à la VUB), l'établissement de partenariats antre les autorités de l'enseignement et l'ESA, etc.

A.3. International Year of Astronomy 2009

Le Planétarium a été choisi par le BNCA (*Belgian National Committee for Astronomy*) pour agir en tant que « ***Single 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.

Un **Comité de Pilotage** regroupant des astronomes professionnels et amateurs et des acteurs du domaine de la promotion des sciences (99 inscrits sur la *mailing list*) a été mis en place. Ce Comité s'est réuni à de nombreuses reprises en 2009.

Un **site Internet** (www.sterrenkunde2009.be / www.astronomie2009.be) regroupant l'ensemble des 340 activités proposées en Belgique a été créé par le Planétarium. Plusieurs événements spéciaux (dont la conférence de presse d'inauguration) ont eu lieu en ses locaux (voir section A.1.2).

Grâce à un **subside spécifique** de la Ministre de la Politique Scientifique, il a été possible de distribuer gratuitement aux acteurs de l'IYA2009 : 1000 galileoscopes, 30.000 leaflets, 10.000 posters, 1500 flèches, 20.000 cartes du ciel, 2 télescopes (prix d'un concours de dessin) et 2000 DVDs. Il a aussi été possible de définir un partenariat publicitaire avec le groupe de presse CORELIO.

A.4. Equipement & Dotations

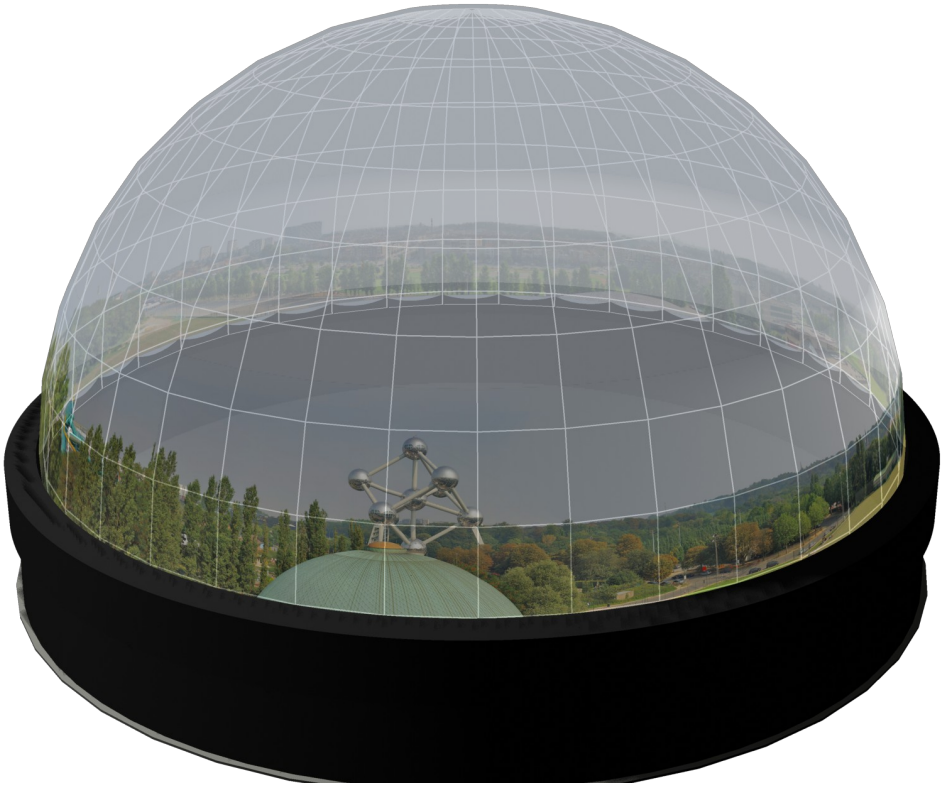
Dans le cadre de l'Année Internationale de l'Astronomie 2009, et grâce au soutien de la Ministre de la Politique scientifique fédérale, de la Loterie Nationale et de la Banque Nationale de Belgique, le Planétarium de l'Observatoire royal de Belgique a pu acquérir et installer un **système de projection numérique**. Huit projecteurs de dernière génération de la firme Barco, pilotés par un système de contrôle et de visualisation géré par la société RSA Cosmos, ont été livrés et installés dans la grande salle, ce qui a nécessité la fermeture du Planétarium d'août à octobre. Ce système de haute technologie permet de voyager en temps réel au sein de l'Univers et de projeter des spectacles pleine voûte (*full dome*) impressionnants. Il s'agit là de l'aboutissement d'un ambitieux projet nourri depuis plusieurs années déjà.

Le Planétarium a bénéficié d'un subside accordé dans le cadre de la **dotation spécifique 2009** pour financer la construction de l'exposition *From Earth to the Universe*, (de nouveau dans le cadre de l'Année Internationale de l'Astronomie). Installée lors des Portes Ouvertes de l'Observatoire en octobre, cette exposition constituée de 14 structures circulaires et de 28 panneaux illustrés a pour vocation d'être itinérante en 2010.

En partenariat avec plusieurs acteurs de l'année Internationale de l'astronomie, un **projet EWI** a été reproposé (sans succès) à la Région Flamande.

Le Planétarium est partenaire d'un projet européen COMENIUS intitulé « **Hands-On-Universe** » qui vise à former des enseignants du secondaire aux rudiments de l'astronomie. Deux enseignants belges ont pu ainsi être envoyés en France (en mai) et au Pays de Galles (en août) pour suivre des formations.

Le Planétarium a passé un contrat avec l'ESO pour agir en tant que représentant belge du **ESO Outreach Network**.



B. BIBLIOTHEQUE

B.1. Situation du personnel de la bibliothèque

Responsable scientifique : Pierre ALEXANDRE (chef de travaux).
Bibliothécaire : Sabrina WINTMOLDERS (statutaire stagiaire, niveau B).
Aides-biblothécaires :
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 interbibliothèques. 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 2009 de 144 abonnements à des périodiques en version sur papier (64 pour l'IRM, 80 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 44 livres acquis par achat (29 pour l'IRM, 15 pour l'ORB) et d'environ une cinquantaine 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 2009: trente-cinq abonnements ont été pris en 2009 par les deux instituts (dix-huit pour l'ORB, dix-sept 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 2009 et est au stade actuel de 41 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

A partir du 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 reserve 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. 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 2009, 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 2009 (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 (le catalogage proprement dit de ces livres ayant déjà été effectué auparavant).

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 2009 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 qui a 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.

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 60% 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

- 9 avril 2009: Mission de S. Wintmolders à la Bibliothèque Royale pour la préparation d'une exposition.

- 9 juin et 13 octobre 2009: Participation de S. Wintmolders à des réunions du "Forum des bibliothèques des Services Publics Fédéraux et des Établissements Scientifiques Fédéraux".
- 22 septembre 2009: Participation de S. Wintmolders à une réunion informelle d'information du projet "Open Access".

B.3.2. Formations

Du 6 au 28 juillet 2009, S. Wintmolders a suivi le "cours d'été intensif de français" dispensé par l'I.F.A./O.F.O., à raison de 12 séances de trois heures.

B.4. Étudiants rémunérés

En juillet-août 2009, la bibliothèque a bénéficié de l'aide apportée par deux étudiants rémunérés: Mlle Juliette GRIGNARD au mois de juillet et M. Joachim DOMINIQUE au mois d'août.

C. 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 astronomy and astronomy 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 item, often related to press releases, could now be put fast and easily on our website (http://www.astro.oma.be/EN/hotnews/index.php).

Amongst the highlights of this year were the activities in the frame of the International Year of Astronomy 2009, including the Open Door days at the ROB, the first results of the Belgian GPS station on Antarctica, the launch of the solar observation satellite Proba-2, and the honouring of the new Corresponding Astronomers of the ROB.

C.2. Information given to the media

C.2.1. Press Releases

- 15/01/2009: Belgian GPS Station on Antarctica
- 21/08 and 30/09/2009: Open Door Days at the Space Pole
- 22/10/2009: Proba 2 Launch
- 15/12/2009: Corresponding Astronomers of the Royal Observatory

C.2.2. 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, RTBf, Au Quotidien, on the Observatory and IYA 2009, 04/03/2009
- J. Cuypers, RTBf, on time keeping, 30/03/2009
- J. Cuypers, VRT, Eén Nieuws, on the eclipse in Shanghai, China, 22/07/2009
- P. Defraigne "Day light saving Time", RTBF, JT, 24/10/2009
- Th. Pauwels was interviewed about asteroids by RTBf for *Au quotidien*.

On seismology and related matters:

- T. Camelbeeck, Earthquake activity in Brabant (RTL-Namur) 26/02/2009
- M. Van Camp, RTBF Au Quotidien, Uccle, March 2009
- Many interviews were given after the Mw=6.3 earthquake L'Aquila, Italy on 06/04/2009. This included:
    - K. Verbeek: VRT Het journaal 7 - 06/04/09 Was de zware aardbeving voorspeld?
    - K. Verbeeck : VTM Het Nieuws – 06/04/09 13u
    - K. Verbeeck: Studio Brussel 06/04/09
    - T. Camelbeeck, RTL-TVI 07/04/2009
    - T. Camelbeeck, RTL-TVI, 26/04/2009
    - M. Van Camp, RTBF

On the Sun, on Sun-Earth relations and Proba 2:

- J.F. Hochedez, La Première (Radio): in « Planète Première » on Proba 2, 02/112009
- J.F. Hochedez, RTBF : Journal Télévisé, on Proba 2, 02/11/2009

- J.F. Hochedez, RTL-TVI: Journal Télévisé, on Proba 2, 02/11/2009
- P. Van Lommel, 'De zon is niet dood, maar een beetje lui', a news item on the VTM journal, 26/11/2009
- P. Van Lommel, 'De zon is niet dood, maar een beetje lui', a radio interview in the program 'Zet 'm op Ciska' from Studio Brussel, 26/11/2009.
- M. Dominique : La Libre Belgique (2009/10/31) : « Proba 2 veut se faire sa place au Soleil »
- M. Dominique : La Première (radio, 2009/11/02) : in the sequence « Planète Première »
- M. Dominique : RTL-TVI (2009/11/01) : JT (News)

C.2.3. Documentaries

Austrian TV Channel OktoTV: Jan Cuypers was interviewed (in English) for a documentary on Gaia in the astronomy programme 'Supernova' for the Austrian TV Channel OktoTV during the Gaia CU7 meeting in Vienna (5 May 2009). The programme was diffused 6 times in June and 6 times in August 2009. A DVD version of the programme was presented at the CU7 meeting in Geneva in November.

C.2.4. Other information given to the media

On numerous occasions information (sometimes without interview) 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, …) but also to television and radio (VRT TV1, VTM, RTL, VRT-radio, Rtbf-radio, Studio Brussel …). Some specific examples:

- Th. Pauwels provided information about comet Lulin to *Gazet van Antwerpen*.
- Th. Pauwels provided images of asteroids Vanhoeck, Tamsin and Claudedoom to the redaction of *Heelal*.

C.2.5. Assistance with TV and film recordings:

In a few cases assistance was given to TV and film recordings on the site in Uccle (16/01, on IYA, Sputnick TV; Sherlock – Ketnet TV, 16/06 – 07/08 – 11/08)

C.3. Exhibitions

C.3.1. Royal Palace, Federal Science Policy Office, 'La Science et la bande dessinée'

During the summer months (26 July- 16 September) the Belgian Science Policy Office was present in the Royal Palace (Brussels) with an exhibition on the Federal Scientific Institutes. Every entity was represented by means of a link between a scientific subject and a comic strip. For the ROB the "Schtroumpfs" were chosen. Their creator, Peyo, made in the past New Years cards for the International Centre for Earth Tides (ICET) of the ROB. The card with the Superconductive Gravimeter was used as illustration and the gravimeter itself figured there as well. In November 2009 the exhibition was also shown in the Belgian Parliament and in December 2009 in Paris under the title 'La Science et la bande dessinée' (Fondation Biermans-Lapôtre).

J. Cuypers, together with H. Langenaken and the technical services of the ROB helped in the preparation and the practical arrangements for the ORB part of this exhibition. With colleagues from the ROB texts in different languages on the ROB and on the Gravimeter were prepared.

C.3.2. Liège, Maison de la Science, 'Glasses and Telescopes'

From September 12 to December 12, 2009 an exhibit about telescopes took place in the House of Science in Liège. Some historic pieces and telescopes from the ROB were presented along the panels and experiments. J. Cuypers and H. Langenaken assisted in the prospection and the logistic handling of the ROB instruments to and from the exhibition.

C.3.3. Uccle, 'From the Earth to the Universe'

J. Cuypers assisted in the selection of the images and the texts for the panels of the exhibition 'From the Earth to the Universe', that was created at the occasion of the International Year of Astronomy 2009. He and colleagues from the Astrophysics Department made the translations (English-Dutch) for the texts on the panels. J. Cuypers assisted also during the erection of the exhibition in the week before the Open Door Day at the ROB in Uccle.

C.3.4. Brussels, Museum for Art and History

In the Brussels Museum for Art and History the exhibition room with precision instruments was renovated. About half of the instruments were given on loan from the ROB; therefore some collaboration on contents was initiated. H. Langenaken helped with the describing texts. One piece of the ROB museum was added to the exhibition: a marine chronometer by Dent.

C.4. Public conferences

Also in 2009 many members of the Royal Observatory gave public conferences and seminars

Some examples:

- **P. Alexandre**, "L'utilité de la critique historique pour l'étude des variations du climat". Conférence du Conseil de l'Éducation Permanente de l'Université Libre de Bruxelles, 05/01/2009
- **J. Cuypers** "Botsing van satellieten in de ruimte', VVS-afdeling Helios, Ramsel-Herselt, 15/02/2009
- **P. Defraigne**, "La mesure du temps : pourquoi, comment ?", Athénée Royal Crommelynck de Woluwe-Saint-Pierre, 06/03/2009
- **P. Lampens**, in the framework of the IYA2009 project "*She is an Astronomer*", Drs. Y. Nazé and **P. Lampens** co-organised a bilingual event at the Planetarium with the help of 2 women associations and the Lion's club. This attracted some 150 people, which were all very positive with the event – especially since for most of them, it was their first contact with science. **P. Lampens** gave a public talk entitled "Onze plaats in het heelal - Wat vertellen de sterren?", Planetarium, Brussels, 08/03/2009
- **T. Camelbeeck,** "Les tremblements de terre dans le Brabant Wallon" at the Provincial Palace in Wavre at the invitation of the Governor of the Province, 25/03/2009
- **J. Cuypers**, "Sterren", Nacht van de duisternis, Westerlo, 28/03/2009
- **J.F. Hochedez** , "Solar coronal imaging tomorrow… and in the years after tomorrow" (Invited lecture), Belgian Physical Society meeting, Hasselt, 01/04/2009
- **F. Clette**, "Le grand retour du Soleil: Influence, évolution et surveillance de l'activité solaire", Groupe Astronomie de Spa, Spa, 15/5/2009
- **T. Camelbeeck,** "Les tremblements de terre dans le Brabant Wallon", for the service citoyenneté of the Ottignies city, 19/05/2009
- **J. Cuypers,** "De Sterren", in the frame of IYA2009, Lagere School Zichem, 18/06/2009
- **J. Cuypers**, "De Melkweg", Summer school Astronomy, VVS, Leuven, 26/08/2009
- **V. Dehant, "**Habitability of the planets", Collège de Belgique, Royal Academy, Brussels, 01/10/2009
- **P. Lampens**, "Wat vertellen de sterren over onze plaats in het heelal?", MIRA, Grimbergen, 24/10/2009
- **J. Cuypers** "Vuurbollen en andere hemelverschijnselen", VVS-afdeling Helios, Ramsel-Herselt, 25/10/2009
- **P. Lampens**, "Onze plaats in het heelal", BIBLIONOVA library, Geleen, Nederland, 12/11/2009
- **T. Camelbeeck**, "Les tremblements de terre dans le Brabant Wallon", invited by a local association of Court-Saint-Etienne, 19/11/2009
- **T. Van Hoolst,** "Over rotsplaneten en ijsmanen in ons zonnestelsel", IYA2009 seminar series at K.U.Leuven, 01/12/2009
- **P. Defraigne**, "Histoire de la mesure du temps", Ecole du Canal, 10/12/2009.

C.5. Questions from the public

In 2009 about 540 questions by email, 830 by telephone and 320 by letter or fax were answered by the information services directly, i.e. 1690 in total. This is again a large increase compared to previous years (1280 in 2007, 1440 in 2008). But since questions on the Open Door days were not counted separately, and there were a lot of email questions on the bright fireballs of the year, the real annual increase is difficult to estimate.

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, sundials, moonrise and moonset, moon phases, fireballs (over 60 emails for two phenomena in 2009), meteors, satellite re-entries, eclipses in 2009 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 over the world, 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, black holes, etc.

In order to supply the answers to some of the questions, programs had to be (re-)written. Subroutines created by T. Pauwels (Dep. 2) were gratefully used.

Questions about the Sun and its influence on Earth (space weather etc.); about seismology, gravimetrie and GPS, about asteroids and impact of asteroids on earth were forwarded to other sections of the observatory. Often such questions arrive directly to the people concerned.

Questions about weather and climate were sent to the Meteorological Institute and those about space travel and aeronomy to the Belgian Institute for Aeronomy. Both institutes have sent us their questions on more astronomical topics.

> Only 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 2009 by personnel from the ROB.

C.6. Archives

Information on archives, archiving and the archives of the ROB were distributed. An info session was organised. New animation movies on scientific subjects were made. A policy note was formulated and circulated. A website was created (http://archief-as.oma.be/).

Most of the work related to this topic has been done by H. Langenaken and she followed the appropriate courses and information sessions.

C.7. Website

- The content of web pages with the answers to frequently asked questions was regularly updated. For 2009, 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 (information given by R. Dejaiffe, put on the web by H. Langenaken) were revised on a regular basis.
- Part of the web pages of Frequently Asked Questions was further restructured with the aid of H. Langenaken and Y. Coene.
- 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 2009 the topics were: bright meteors seen over Belgium (15/08 and 13/10/2009), Io close to thermal equilibrium, the interactive version of the yearbook of the Royal Obser-

vatory of Belgium, the Belgian GPS station on Antarctica, Proba 2, and Corresponding Astronomers of the ROB.

C.8. 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 every first Monday of the month, later this shifted to the first Tuesday of the month. Most visits were organised by H. Langenaken, while J. Cuypers was the guide for almost all cases. Assistance was given by the Solar Physics Department and the Time Laboratory.

Tours for newly arrived personnel were guided by H. Langenaken.

Dates of guided visits (individuals and groups): 02/03, 15/04, 16/04 (Icomos monuments), 08/05, 27/05, 02/06, 11/08, 27/08, 07/09, 17/11.

Foreign visitors were welcomed on 31/03 and 2/4 (Italian) – 17/9(Australian) – 20/11 (Britain).

In a few cases extra information was given, e.g. to stagiaires or visiting students (18/02, 20/03, 05/06, 18-21/08 (photographer), 04/11 (Student interviews)).

C.9. Meetings and missions

A large number of meetings on communication and related matters, internal as well as external, were attended, mainly by J. Cuypers: in total about 20 on a very large variety of subjects. 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. A meeting at the Cabinet of Minister of Science Mrs. Laruelle (19/05) was attended. The subjects were related to the communication of the federal institutes.

C.10. Publications and related tasks

- Translations, corrections and proofreading of articles for the journal Science Connection;
- Translation and/or help with press texts
- 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.
- The special issue of Space Connection on Astronomy in Belgium appeared as a part of Science Connection 25 and was also available as brochure. Thanks to the Belgian Science Policy about 20000 issues were printed and the distribution to the Belgian public started during the Open Door days of the Space Pole in October.
- Text or suggestions for texts on the Observatory, including the presentation of the ROB on the website of BRUSPACE (http://www.agoria.be/bruspace) and in Belspo publications.

C.11. Publications in popular journals

[1] **F. Clette, D. Berghmans, P. Vanlommel, R.A.M. Van der Linden,** A. Koeckelenbergh**, L. Wauters**
Du Nombre de Wolf a l'indice international des taches solaires: 25 ans de SIDC (1ère partie)
Ciel & Terre 124, 3, 66-75 (2009)

[2] **J.** Cuypers**,** et al. (34 authors),
Sterrenkunde in België,
Science Connection 25, 32p.

[3] **J. Cuypers**, et al. (34 authors),
Astronomie en Belgique,
Science Connection 25, 32p.

[4] **A. Lobel, R. Blomme**,
Bras Spiraux enveloppant des étoiles super-massives,
Le Journals des Ingenieurs no. 121 – mai 2009, p. 14-17

[5] Stijn De Jonge, **Thierry Pauwels** en Jean Meeus
Hoofdredacteurs reizen rond de Zon
Heelal, vol. 54, No. 6 (June 2009), 180-182.

C.12. Personnel

J. Cuypers, eerstaanwezend assistent

Y. Coene, technisch expert

H. Langenaken, technisch expert

Many other members of the ROB gave information to the public, some occasionally, others as a part of their daily work.

C.13. Open door days

In the weekend of 3 to 4 October (Saturday and Sunday) open doors days were held at the Observatory and the other institutes of the Space Pole. There was no overall main theme, but in the frame of the International Year of Astronomy 2009, the places in the meridian room not occupied by the museum pieces, were taken by astronomical and astrophysical presentations. The research on stellar evolution, multiple and variable stars was presented on computer screens and posters. Spectral analysis was illustrated with a small spectrometer. Information on the infrared satellite Herschel (launched in 2009) and the for 2012 foreseen "billion stars" satellite Gaia was on display. The focal plane of the Gaia satellite with the CCDs was presented on a 1:1 scale and compared to the chip of a (small) CCD camera.

Some of the ancient library books of the 16-17th century (Copernicus, Galileo, Kepler, Newton) were on display next to the collection of ancient instruments. For the occasion, the painting with the portrait of Quetelet was restored.

In the main building of the Observatory rooms were filled with posters and presentations about the research on Earth and planets. Images in 3D of the planet Mars could be seen. ROB activities on the Elisabeth base in Antarctica were presented. The seismology group paid special attention to the recent microseismicity in the centre of Belgium. An active seismometer and a gravimeter were on display. Activities of the GPS group were presented.

Outside the outdoor exhibition 'From the Earth to the Universe' of the IYA2009 was erected. It was the first time that this grand project, for which the Belgian version was initiated by our Planetarium team, was shown to the public. The team was present with some workshops on how to construct a sun motion demonstrator and other hands-on activities.

In the dome of the 45 cm Cooke-Zeiss refractor continuous explanations on the telescope were given and pictures from the Moon were on show. A special information brochure on the Cooke-Zeiss refractor with some facts on the Moon was available.

The dome of the Schmidt telescope was open as well. There was a display showing how asteroids are observed and discovered and the complete list of asteroid names. New were the special colours indicating asteroids with Belgian names, asteroids discovered from Belgium and asteroids discovered by Belgians. Eminent visitors here were Eva Palisa, grand-niece of Johann Palisa, the most successful visual discoverer of asteroids, and the grand-grand-son of the former director of the Observatory, Georges Lecointe.

The STCE and the Solar Physics department were present during the open doors in a tent with several presentations (oral and slideshows) and posters. Explanations about PROBA 2, the Sun, Space Weather and Space Weather forecasting were given. There were also guided visits to the USET telescope (Uccle Solar Equatorial Table) in the solar dome.

Since no counting was done continuously, it is difficult to estimate the total number of visitors. Indirect estimates give between 8000 and 10000 visitors, with more than 65% on Sundays. According to the results of a questionnaire done by the "Observatory of the Public" all visitors were extremely satisfied.

About 90 members of the personnel participated at different levels during one or two days. Even more helped with the general preparations, and/or the posters or exhibition stands.

The event was again a big success, and received much attention in the media. Two special press releases were sent out. A lot of journalists were contacted directly and interviews for TV, radio and newspapers were given. It was also a special item in the weather forecast by Frank Deboosere on the Flemish TV Eén.

Figure 88: The exhibition from Earth to the Universe

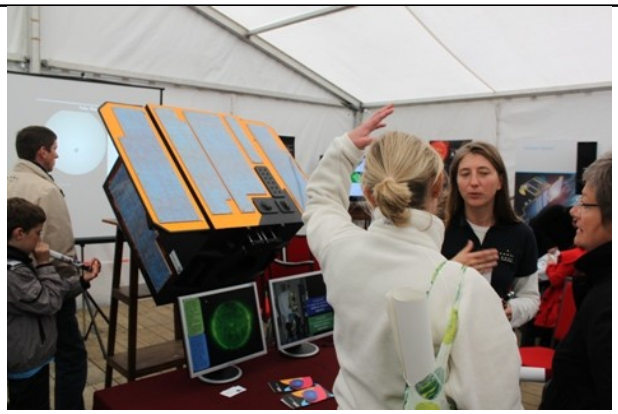


Figure 89: Space Weather forecasting explained by the STCE

Figure 90: Announcement by Frank Deboosere on TV

Figure 91: Information about astronomy in the Meridian Room

Figure 92: Eva Palisa visiting the Schmidt Telescope during the open doors.

Figure 93: Special issue of Science Connection magazine on display.

D. THE YEARBOOK

D.1.1. 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.

D.1.2. Progress and results

In 2009 the Yearbook for 2010 was published (R.4). It was produced by C. Bruyninx (Coordinates), F. Clette (The Sun, Tables), J. Cuypers (Calendars, Comets, Meteors), T. Pauwels (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), F. Roosbeek (The Moon, Tables).

T. Pauwels was responsible for getting the right value for ΔT, for the chapters "Title", "Preamble", and the general coordination and lay-out. Translations were made by R. Alvarez and T. Pauwels.

At the end of 2009 the kick-off for the Yearbook 2011 was given, with the choice of the value of ΔT, and the letter to the authors.

In 2003 Rafael Wastiels wrote a web interface for the yearbook, but this could not be released because it was not "idiot-proof". A stagiair, Rémi Reniers, was appointed to do the job. F. Clette provided the source codes for the implementation of a Web version of the Yearbook tables for the "Sun", and Fabian Roosbeek for the "Moon". No other chapters were implemented. Unfortunately, the product thus delivered was only a small subset of the capabilities that the interface of Rafael Wastiels was intended to contain, and with a very limited number of functionalities.

D.1.3. 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. HUMAN RESOURCES

A.1.1. Personeel / Personnel

Algemeen directeur: Van der Linden Ronald

A.1.1.1. Vastbenoemd personeel / Personnel statutaire

Wetenschappelijk personeel / Personnel scientifique

Name/Nom	Functie/Fonction	
Alexandre Pierre	Chef de travaux	80 %
Alvarez Rodrigo	Chef de travaux	
Berghmans David	Geaggregeerd werkleider	
Blomme Ronny	Werkleider	
Bruyninx Carine	Werkleider	
Camelbeeck Thierry	Chef de section f.f.	
Clette Frédéric	Chef de travaux	
Collin Fabienne	Chef de travaux	80 %
	Chef de travaux (depuis le 01/09/2009)	50%
Cuypers Jan	Werkleider	
De Cat Peter	Werkleider	
Defraigne Pascale	Chef de travaux	80 %
Dehant Véronique	Chef de section	
Frémat Yves	Assistant	
Groenewegen Martin	Werkleider	
Hensberge Herman	Departementshoofd d.d.	
Hochedez Jean-François	Chef de travaux	
Lampens Patricia	Departementshoofd	
Legrand Juliette	Assistant-stagiaire (depuis le 09/08/2009)	
Pauwels Thierry	Afdelingshoofd	
Roosbeek Fabian	Chef de travaux	
Van Camp Michel	Chef de travaux – aggregée	
Van De Steene Griet	Werkleider	
Van Hoolst Tim	Werkleider-geaggregeerde	
Van Ruymbeke Michel	Chef de travaux	
Vanneste Kris	Werkleider	
Yseboodt Marie	Assistant	

Technisch en administratief personeel / Personnel technique et administratif

Name/Nom	Functie/Fonction	
De Knijf Marc	Attaché A1	
	Attaché A2 (vanaf 01/10/2009)	
Kochuyt Anne-Lize	Attaché A1	
Milis Andre	Attaché A2	
Dufond Jean-Luc	Attaché A2	
Rezabek Oleg	Attaché A1	
Rogge Vincent	Attaché A1	
Asselberghs Somnina	Technisch deskundige	
Boulvin Olivier	Expert technique (à partir du 1er avril 2009)	
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	80%
Herreman David	Expert ICT	
Langenaken Hilde	Technisch deskundige	

Martin Henri	Expert technique	80%
Mesmaker Dominique	Expert technique	
Moyaert Ann	ICT deskundige	80%
Renders Francis	Technisch deskundige	
Somerhausen André	Expert ICT	
Strubbe Marc	Technisch deskundige	
Van Camp Lydia	Technisch deskundige	80%
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	80%
Van de Meersche Olivier	Expert Financier	
Wintmolders Sabrina	Administratief deskundige (vanaf 01/03/2009)	
Barthélémy Julie	Chef technicien de la recherche	50%
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	50%

A.1.1.2. Personeel met externe beurzen / Personnel sur bourses externes

Name/Nom	Functie/Fonction
Baland Rose-Marie	Boursier FRIA
Goryaev Farid	Boursier Non-Eu (à partir du 01/03/2009)
Hees Aurélien	Boursier FRIA
Koot Laurence	Boursier FNRS (jusqu'au 13/02/2009)
Lecocq Thomas	Boursier FRIA
Pham Le Binh San	Boursier FNRS
Trinh Antony	Boursier FNRS
Kusters Dimitri	Boursier FRIA
Sharma Suman	Boursier Non-Eu (à partir du 01/11/2009)

A.1.1.3. Contractueel personeel beheerd door de POD Wetenschapsbeleid / Personnel contractual géré par le SPP Politique Scientifique

Name/Nom	Functie/Fonction
Bizerimana Philippe	Collaborateur technique
Boulvin Olivier	Expert technique (jusqu'au 31 mars 2009)
Lefever Koen	Expert ICT (fin le 31/12/2008)
De Vos Frédéric	Expert ICT

De Winter Davy	Technisch deskundige (fin le 27/03/2009)	
De Dobbeleer Rudy	Technisch assistant (à partir du 1er juin 2009)	
Lubkowski Noël	Collaborateur technique	
Motte Philippe	Collaborateur technique	
Mouling Ilse	Administratief assistent	80 %
Noel Jean-Philippe	Expert technique	
Rapagnani Giovanni	Attaché A1	
Sayer Amina	Collaborateur technique	50 %
Vandersyppe Anne	Administratief expert	
Garcia Moreno David	Attaché (jusqu'au 31/08/2009)	
Lobel Alex	Werkleider (jusqu'au 09/04/2009)	
Verbeeck Koen	Attaché (vanaf 01/09/2009)	50%
Semeraro Vanessa	administratief assistent (vanaf 01/09/2009)	

A.1.1.4. Contractueel personeel / Personnel contractuel

Wetenschappelijk personeel / Personnel scientifique

Naam/Nom	Functie/Fonction	Contract
Aerts Wim	Assistent (à partir du 01/03/2009)	STCE
Avşar Ulaş	Attaché (jusqu'au 31/12/2009)	EU Marie Curie
Baire Quentin	Attaché	Chercheur supp
Benmoussa Ali	Chef de travaux	PRODEX
Bergeot Nicolas	Assistant	STCE
Berghoff Tobias	Attaché (jusqu'au 30/06/2009)	PRODEX
Beuthe Mikael	Assistant	PRODEX
Burston Robert	Attaché (depuis le 01/12/2009)	STCE
Boës Xavier	Attaché (fin le 17/04/2009)	EU Marie Curie
Boyes John David	Assistant	PRODEX
Cabanas Carlos	Attaché (du 16/02 au 30/04/2009) Assistant (à partir du 1er mai 2009)	PROBA2
Callebaut Benoît	Assistant (à partir du 01/02/2009)	SOTERIA
Caudron Corentin	Attaché (à partir du 01/10/2009)	Actie 2
Champagne Georges	Attaché	Dotation
Chevalier Jean-Marie	Attaché	STCE
Dabrowski Bartosz	Assistant (jusqu'au 30/09/2009)	PRODEX
Dammasch Ingolf	Attaché	PRODEX
De Cuyper Jean-Pierre	Werkleider	DIGITALISA-TION
Delouille Véronique	Chef de travaux	PRODEX
D'Huys Elke	Attaché	STCE
Dolla Laurent	Assistant	STCE
Dominique Marie (50%)	Assistant 100 % à compter du 16/05/2009	PRODEX
Everaerts Michel	Chef de travaux (jusqu'au 28/02/09)	Action1
Fraser Jeffrey	Attaché (jusqu'au 30/09/2009)	EU Marie Curie
Giordanengo Boris	Chef de travaux (à partir du 1 janvier 09)	PRODEX
Gissot Samuel	Assistant	PRODEX
Hekker Saskia	Assistent (jusqu'au 31/03/2009)	Action 2
Hubert-Ferrari Aurelia	Chef de département (jusqu'au 30/09/09)	EU Marie Curie
Joukov Andrei	Chef de travaux	STCE
Karatekin Ozgur	Assistant	PRODEX
Knuts Elisabeth	Attaché	CHERCH SUP
Koot Laurence	Attaché (jusqu'au 30/06/2009)	Action 1

	Assistant (du 01/07/2009 au 31/07/2009)	Action 1
Kudryashova Maria	Assistant	Action 1
Kusman David Pierre	Assistant 100 %	
	Assistant 50% (du 01/04/09 au 30/09/09)	HAZARD
Laguerre Raphaël	Assistant (du 01/06/2009 au 31/10/2009)	Dotation
LeMaistre Sébastien	Attaché	PRODEX
Legrand Juliette	Assistant (jusqu'au 05/08/2009)	Action 1
Lefevre Laure	Assistant (à partir du 01/11/2009)	SOTERIA
Lisnichenko Pavlo	Attaché (01/02/2009)	STCE
Lobel Alex	Werkleider (à partir 10/04/2009)	3 GAIA
Lombardini Denis	Assistant	Antartique
Magdalenic Jasmina	Assistant	Action 1
Marqué Christophe	Assistant	STCE
Mitrovic Michel	Assistant	PRODEX
Moreels Sandra	Attaché (du 01/09/2009 au 30/09/2009)	EU Marie Curie
Nicula Bogdan	Assistant	STCE
Nkono Collin	Assistant (jusqu'au 30/09/2009)	CHERCH SUP
Parenti Suzanna	Chef de travaux (jusqu'au 01/10/2009)	PRODEX
Pireaux Sophie	Assistant (jusqu'au 12/10/2009)	STCE
Pfyffer Gregor	Attaché	PRODEX
Podladchikova Olena	Chef de travaux	STCE
Pottiaux Eric	Attaché	STCE
Pylyser Eric	Assistant	PRODEX
Rivoldini Attilio	Attaché	PRODEX
Rodriguez Luciano	Assistant	PRODEX
Rosenblatt Pascal	Assistant	PRODEX
	Chef de travaux (à partir du 01/03/2009)	PRODEX
Sarp Mehmet Yalim	Assistant (du 01/08/2009 au 31/10/2009)	PRODEX
Seaton Daniel	Assistant	PRODEX
Sichien Els	Attaché (jusqu'au 30/10/2009)	HAZARD
Stanger Andrew	Attaché	PRODEX
Torres Kelly (80%)	Assistant 80 %	CHERCH SUP
	Assistant 100 % à partir du 1/06/2009	
Van Hoof Peter	Assistent (tot 30/06/2008)	Actie 1
Vanlommel Petra (80%)	Werkleider	STCE
Verbeeck Francis	Assistent	PRODEX
Verbeeck Koen	Attaché (50% vanaf 01/09/2009)	HAZARDS
Verdini Andrea	Assistant	PRODEX
Volpi Delia	Assistant (à partir du 01/10/2009)	Actie 1
Wauters Laurence (80%)	Chef de travaux	STCE
West Matthew	Assistant	PRODEX
Wright Duncan	Assistent	Action 1
Zhu Ping	Attaché	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 (à partir du 01/08/2009)	ESERO
Pieront Anne	Attaché A1 (à partir du 01/09/2009)	ESERO
De Decker Georges	Attaché A2	Digitalisation

Willems Sarah	Attaché A2	STCE
Mampaey Benjamin	Attaché A2	PRODEX
Berghoff Tobias	Attaché A2 (du 01/07/2009 au 30/09/2009)	PRODEX
Van Hemelryck Eric	Attaché A2 (vanaf 01/08/2009)	PRODEX
Vander Putten Wim	Expert ICT	Dotatie
Bastin Véronique	Expert technique	Dotation
Vandercoilden Myriam	Assistant administratif	Dotation Pole
Hernando Ana Maria	Assistant administratif (jusqu'au 28/02/09)	ESERO
	Assistant administratif (à partir du 1/03)	STCE
De Dobbeleer Rudy	Technisch assistant (1/03/09 t/m 31/05/09)	Modernisation
Smet Gert	Technisch assistent	Dotatie
Feldberg Liesbeth	Assistant administratif (à paritir du1/02/09)	Dotatie
Trocmet Cécile	Assistant administratif	Dotation
Wijns Erik	Technisch medewerker	Dotatie
Vandeperre Arnold	Technisch assistent (vanaf 01/02/2009)	Dotatie
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%)	Collaborateur technique	Dotation
Sayer Amina (50%)	Collaborateur technique	Dotation
Trindade Josefina	Collaborateur technique	Dotation
Vermeylen Jacqueline	Collaborateur technique	Dotation

A.1.1.5. 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 2009 était de l'ordre de 4,8 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 2009 les dépenses sur les moyens propres étaient divisées comme suit :

	ORB Dotation	ORB Services	Projets BELSPO	Projets Externes	Total
Personnel	553 726 €	104 564 €	1 340 042 €	1 609 275 €	3 607 607 €

Fonctionnement Subsistance	379 549 €	176 695 €	280 298 €	323 263 €	1 159 805 €
Fonctionnement Spécifique	12 799 €	32 567 €	102 126 €	88 814 €	236 306 €
Equipement Subsistance	32 962 €	157 353 €	133 454 €	48 783 €	372 552 €
Equipement Spécifique	18 419 €	788 523 €	161 037 €	615 €	968 594 €
Bibliothèque	60 165 €	56 €	861 €	332 €	61 414 €
Total	1 057 620 €	1 259 758 €	2 017 818 €	2 071 082 €	6 406 278 €

A.2.2. Betrokken personeel / Personnel concerné

Asselberghs Somnina	Boekhouder
Olivier Van De Meersche	Hulpboekhouder
Barthélémy Julie	Collaborateur service comptabilité
Mouling Ilse	Medewerker dienst boekhouding
Vanden Elshout Ronny	Collaborateur service comptabilité

B. ALGEMEEN BEHEER / GESTION GENERALE

B.1.1. Betrokken personeel / Personnel concerné

Asselberghs Somnina	Algemeen Beheerder
Christian Brebant	Téléfoniste
Béatrice Depasse	Téléfoniste
Martine Bruyninx	Onthaal
De Wachter Rudi	Tuinman
Van Den Brande Theophilis	Tuinman
Wijns Erik	Tuinman
Arnold Vandeperre	Tuinman
El Amrani Malika	Nettoyage
Gonzales Sanchez Bénédicte	Nettoyage
Herman Viviane	Nettoyage (Humain)
Ipuz Mendez Adriana	Nettoyage (Planetarium)
Sayer Amina	Nettoyage (Planetarium)
Vermeylen Jacqueline	Nettoyage
Reghif Harraz Mohammed	Nettoyage
Trindade Josefina	Nettoyage

C. TECHNISCHE DIENST / SERVICE TECHNIQUE

C.1. Uitgevoerde werken:

C.1.1. Elektronica en elektriciteit

- Onderhoud en herstelling van instrumenten
- Herstellen van elektrische defecten en indien nodig vervangen van verouderde bekabeling en verlichting.
- Voor volgende lokalen/gangen heeft de Regie het materiaal aangekocht en wij de installatie gedaan :
    - Gang naar bibliotheek
    - Gang naar KMI
    - Stookplaats

- 5 burelen
- Laten uitvoeren van de verplichte jaarlijkse controle van de hoogspanningscabines
- Vernieuwen van elektrisch bord 'kooi van Faraday'

C.1.2. Verwarming (KMI, KSB en BIRA), airco's en sanitair:

- Het onderhoud van de gehele verwarmingsinfrastructuur
- Afleveren van de nodige attesten om te voldoen aan de geldende wetgeving.
- Vervangen mengkranen van gebouw G
- Het onderhoud van de airco's
- Verplaatsen brandkleppen en extra filters bij de airco 'digitalisatieproject'
- Indienen van een dossier voor de plaatsing van een 2de buitenunit airco uurbureel om de bedrijfszekerheid te verhogen

C.1.3. Werkplaats mechanica

- Constructie van kleine onderdelen voor instrumenten.
- Overname van een CNC-freesmachine van het BIRA om de nodige platen te fabriceren voor het digitalisatieproject
- Opruimen en herinrichten laslokaal
- Maken van een maquette van Proba 2
- Kleine herstellingswerken aan de gebouwen.

C.1.4. Telefooncentrale

C.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

C.1.4.2. Planetarium:

- Beheer en programmatie.
- Aanpassingen.

C.1.4.3. Stations seismologie en GPS:

- Alle stations van de seismologie en GPS zijn overgeschakeld van ISDN naar ADSL
- Proefopstelling gemaakt voor de installatie van de seismometer in Antartica.

C.1.5. Gebouwen

- Paviljoen seismologie: verwijderen van de oude elektrische installatie, sanitair, binnenmuren en plafond als voorbereiding op de renovatiewerken. Plaatsen van een 'tijdelijk' hutje waarin we de controle-apparatuur voor de seismometers geplaatst hebben.
- Lokaal 'kooi van Faraday': afschieten oude bepleistering van de muren en deze nadien behandelen tegen vocht. Installatie van de kooi zelf en voorzien van de nodige aansluitingen voor elektriciteit, data en telefoon.
- Planetarium: afbraak van de oude desk en sokkel in de koepelzaal. Plaatsen van een nieuwe sokkel en een voorlopige desk met de apparatuur van het digitaal projectiesysteem. Plaatsen van de elektrische voedingen voor de projectoren.

C.1.6. Regie

- Helpen bij het opstellen van het lastenboek voor het paviljoen seismologie en de toegangscontrole. Jammer genoeg is men nog aan geen enkel van de geplande 'grotere' werken begonnen.

C.1.7. Waarnemingsstations voor GPS en Seismologie

- **Bree**: gieten van een nieuwe betonnen sokkel voor accelerometer. Plaatsen van GPS-antenne, nieuwe zekering voor elektriciteit en telefoonlijn.
- **Zevenkote**: Demontage cabine, opnieuw gieten van betonnen sokkel, reparatie van cabine en terugplaatsen ervan.
- **Humain**: geholpen bij de verhuis van de radio-telescoop Würzburg Riese. Gedeeltelijk vervangen van de elektrische leidingen in 'labo haut'
- **Membach**: 2 He-vullingen

C.1.8. Energie en milieu

- Er is een energie-audit uitgevoerd door de firma 3E. De resultaten zijn doorgespeeld aan de Regie der Gebouwen.

C.1.9. Website: fase.oma.be

- Verder uitbouwen en up-to-date houden van een interne website voor de technische dienst en voor de IDPB.

C.1.10. Diversen

- Voorbereidingen opendeurdagen (leegmaken en herinrichten lokalen, inrichten tenten, aanbrengen van de nodige veiligheidsvoorzieningen)
- Maken van een pedagogische opstelling voor demonstratie aardbevingen
- Openlucht-tentoonstelling: mee demonteren, opslaan en verhuizen

C.1.11. Veiligheid en gezondheid

C.1.11.1. Securité

- Différentes demandes ont été relancées auprès de la Régie des bâtiments afin de répondre aux obligations légales en matière d'incendie:
  - *dans les bâtiments de l'Observatoire* :
    → installation d'un système d'alarme et de détection incendie et d'un éclairage de sécurité suffisant : attribution du marché réalisée. Début des travaux en 2010
    → renforcement du compartimentage RF : mise à jour de la liste
    → installation de sorties de secours conformes : à ce jour, une seule porte a été placée
    → pose d'un film solaire aux fenêtres du bâtiment de la séismologie
    → mise en conformité des anciennes toilettes
    → remplacement de l'ancienne plateforme du télescope Zeiss : attribution du marché réalisée. Travaux prévus en 2010
    → Petits travaux divers en matière de sécurité (réparation carrelage, …)

  - *dans les bâtiments du Planétarium :*
    → Un projet de rénovation du bâtiment est prévu. Dans l'attente de ce projet, diverses demandes existantes ont été relancées (remplacement lino usé, rénovation parafoudre, …)

- Les exercices d'évacuation à l'Observatoire et au Planétarium ont été réalisés conformément au RGPT. Des mini-exercices avec l'équipe de première intervention et le portier ont été réalisés afin de maintenir l'automatisme nécessaire en cas d'incident.
- L'Observatoire et le Planétarium se sont équipés d'un défibrillateur automatique.
- Formation :
  - formation EPI pour un nouveau membre de l'équipe de l'ORB
  - information AED pour une dizaine de membre du personnel de l'ORB et du Planétarium
  - formation BA4 pour 2 membres du service technique
  - recyclage annuel pour le conseiller en prévention

C.1.11.2. Santé

- Plusieurs visites internes de sécurité des bâtiments ont été réalisées afin de lister les problèmes nécessitant une intervention de la Régie et de pallier directement ceux du ressort de l'Observatoire.
- Notre médecin du travail a procédé aux examens annuels des personnes soumises et des nouveaux membres du personnel et à la visite annuelle dans nos bâtiments.
- La liste des risques de notre personnel a été mise à jour.
- Mise en place d'un espace dédié à la collecte des déchets spécialisés (TL, produits chimiques, batterie, …) afin d'améliorer leur élimination
- Une sécurité électrique a été ajoutée sur les machines de l'atelier mécanique de la physique solaire.
- Les contrôles annuels légaux (extincteurs, harnais, …) ont été réalisés. Le contrôle quinquennal de l'installation électrique a été effectué. Suite aux remarques mentionnées dans le rapport, le service technique a commencé à apporter des modifications.
- Un site intranet concernant la sécurité et la prévention a été mis en place.
- Un Business continuity planning a été mis en place concernant la grippe H1N1.
- La politique des 3 feux verts a été mise en place pour l'achat de certains matériels.
- Des chaises de bureaux, des anciens stores, … ont été remplacés suivants les remarques de l'ergonome de notre service externe.
- L'éclairage de la chaufferie et de l'atelier attenant a été modifié ainsi que pour certains bureaux. D'autres demandes de remplacement d'éclairage de bureaux ont été envoyées à la Régie.
- Via un budget de la politique scientifique, une demande a été introduite pour les travaux suivants : aménagement d'un réfectoire et d'un local douche au Planétarium et placement d'échelle d'accès aux coupoles à l'ORB -> Travaux prévus pour 2010
- Les plans d'actions 2010, le rapport annuel 2008 et autres documents administratifs ont été réalisés.
- Divers problèmes minimes de sécurité ont été traités
- 1 accident sur le lieu du travail et 6 sur le chemin du travail sont à déplorer.

C.2. Personeelsbestand

- De heer Rudi De Dobbeleer is begonnen op 1/3/09.
- De heer Arnold Vanderperre is begonnen op 1/2/09
- Selectieprocedure opgestart voor de aanwerving van een ing. Elektronica.

D. IT 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 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 and 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 could be detailed as follows:

- 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 system administrators.
- 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 PCs, the management of generic application servers and the management of the IT material for users.
- Purchases: all IT purchases are done by the IT department.

D.2. Progress and results

D.2.1. Backbone Infrastructure

D.2.1.1.NETWORK

- **Cabled Network:** Most distribution switches have been replaced in all the buildings, thus providing 1gbit link to the desktop of all users. The new infrastructure installed is also able to carry iSCSI traffic at maximum capacity (jumbo frames and filtering).
- **Wireless network:** Upgrade in ***range*** and ***speed*** by the addition of three supplementary access points, and the replacement of two older access-points. The new access-points now deliver 802.11n technology. The ***security*** and ***reliability*** has been increased by adding a virtual server for MAC authentication.
- **Server connectivity**: The different servers have been reconfigured to not only increase bandwidth but also reliability by doubling the different network links using mainly SMLT technology. This has been implemented for the main servers in the CT server room.

D.2.1.2.SERVERS

As a great effort has been devoted to the virtualization of our service servers it was deemed useful to increase the pool of physical hosts from three to five servers. Certain departments have stepped into the new virtualization project (GPS, Planetology, Seismology, Astrophysics …) Two new servers have been added to the central server pool, and the newest version of VMware has been implemented (vSphere 4).

D.2.1.3.STORAGE

An NFS solution had been selected for the VMware images, increasing access times. Two iSCSI devices have also been deployed. This should increase performance and reduce central server disk usage.

D.2.2. Web Programming

- **Web Document management:** A web application to manage and share documents between different teams has been developed for two scientific projects. It has been done with Epiware, a powerful open source alternative for Enterprise Document Management. This application gives users rights and permissions on directories and allows managing different versions of the same document.
- **Publications**: A new web application has been created with a database system for sharing the user's publications. At the present time, the database contains all the publications of the Section 1 - department 1. The aim is to extend it to the whole Observatory. This application uses IMAPS for the authentication. Users can add, delete or update authors/publications. This application is accessible at publi-as.oma.be.
- **Stock management system:** For the management of the IT materials and consumables, a web application has been created with Adobe Flex . This application allows also managing the borrowed materials (eg, external USB DVD writer). This application is linked to the new user's database (see next point).
- **Users Database and management**: A new database has been created with information on all users of the Observatory and Planetarium. Any future web applications will be linked to this new database. To easily manage the database, a new Flex web application has been created.
- **Web Server:** A simple web application has been created with Adobe Flex in order to encode in a database the up-time of our main web server on regular basis. Updates are regularly done on the web server (**intranet** and the **ROB website).**
- **ROB Assets:** A new web application has been created for the accounting in order to manage the rob assets (furniture's, scientific materials, etc...). This application is based on the application used by the IT team for managing the IT assets.

D.2.3. Common Resources

- **FILE and backup servers for FS space:** The file servers have been upgraded and the disk space has been doubled.
- **Central DNS – NIS SERVER – ACCOUNT policy**. Old users are being removed according to our policy, to which exceptions can be added if approved by the director. To be able to administer these tasks easily, a database has been created centrally.
- **MAIL – MAILSERVERS – Postmaster:** Since this year, the postmaster activities have been separated under the 3 institutes.
- **FAQS – Welcome:** We enhanced the faqs on technet to redirect users to that info. New users are given the link to the new "Welcome new user" part of the technet, 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.
- **HPC servers:** Two new HPC servers have been setup: alka (for interactive jobs) and caipi (for non-interactive jobs). These servers replace the old KAOS machines which will be decommissioned in 2010.
- **Departmental Servers:** expensive departmental servers have been replaced by virtual machines. Some of them are hosted on our central virtual infrastructure and some projects have invested into ESX servers.

D.2.4. Users Management

D.2.4.1. HELPDESK

- Since this year, we print all the posters for the users, lowering the use of paper and ink.
- Continuous support for users has been provided via the helpdesk

D.2.4.2. DESKTOP PC

We have installed and configured 20 new desktop PC, 14 new laptops and a lot of refurbished PCs and laptops with either Ubuntu (Linux) or Windows XP/Vista/7.

D.2.4.3. IT MATERIALS

We have set up a policy to get back any used IT material (PC, screen, etc…) when giving new ones. This allows us to have more refurbished PCs for students, visitors, special events, etc…

D.2.5. Purchases & RMA

- In 2009, we have done the all the IT purchases for the Observatory (more than 200 individual purchase proposals).
- We have dealt with several RMA for damaged IT material.

D.3. Perspective for next years

- **Network**: An effort will be done in the future to better monitor the network as well as to increase security on the cabled network (MAC address authentication). The captive portal system will be replaced by a more flexible system.
- **Servers**: Further consolidation of the compute power should be achieved by integrating more departmental servers. Better monitoring and some optimization will be set as objective for the following years.
- **Storage**: A local file server for the whole observatory would be a great asset; indeed, we could consolidate data and build a central system with higher performance and more flexibility for the different work groups.
- **Intranet**: The Intranet of the Observatory (intranet.oma.be) is currently based on a very old CMS (content management system) which is no longer appropriate for future needs. The intranet will be completely redone, including the design. The CMS will be made from scratch using Adobe Flex 3. With this new intranet, users will have access to some personal data via a portal. Authentication to the portal should be made via a new LDAP server (slave server). Other modules will be made and added to the new intranet: a first one will enable a user to create a purchase proposal and submit it to his project leader for agreement. Another module will enable the administration to quickly and easily create a new service note.
- **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.
- **Account policy :** There is a need for installing a LDAP server common to the 3 scientific institutes
- **Parallel compute servers:** In 2010, 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.
- **Mail**: In 2010 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.

D.4. Personnel involved

- David Duval
- David Herreman
- Fabian Roosbeek
- André Somerhausen
- Katinka Vermeiren