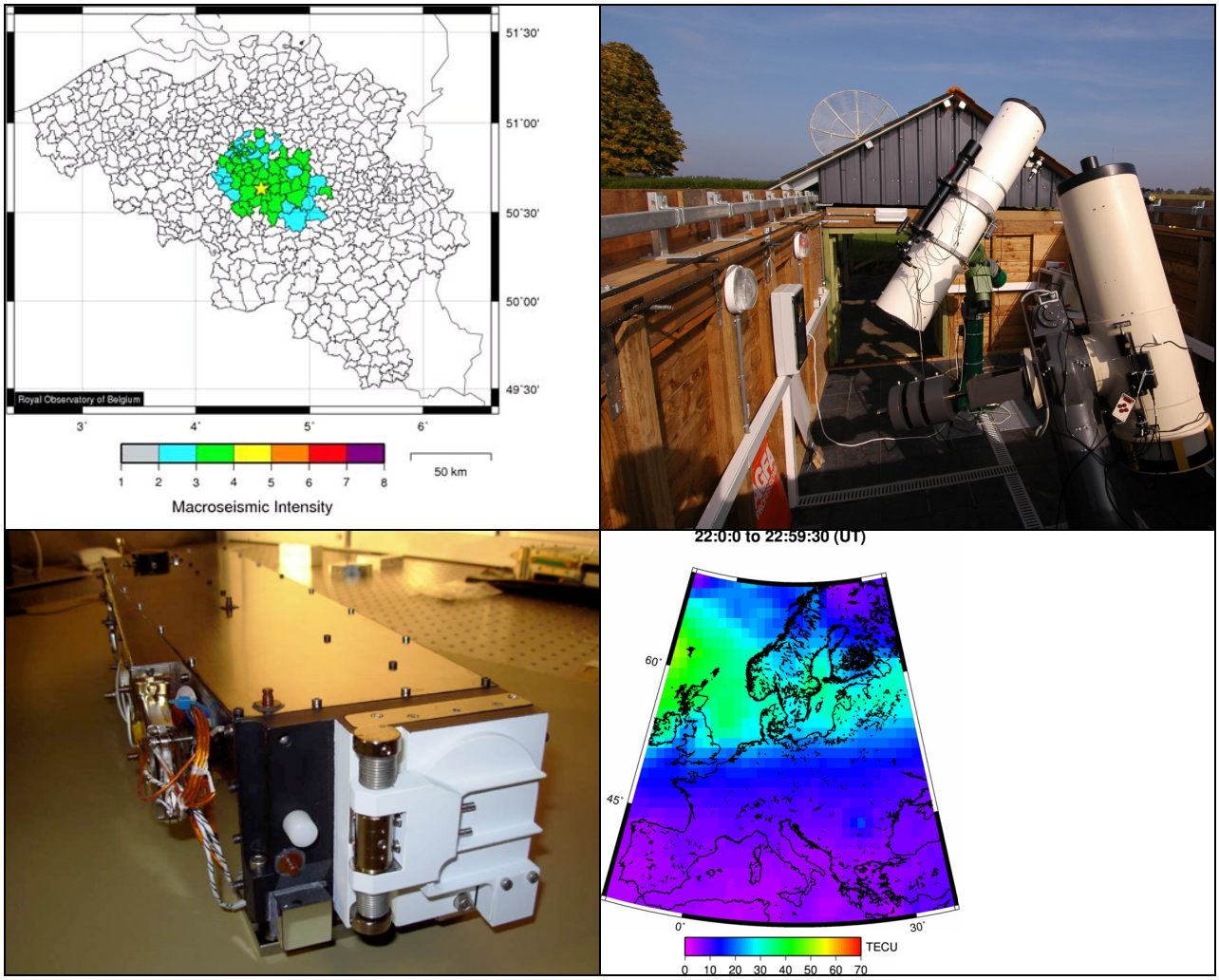
Koninklijke Sterrenwacht van België

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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Deel 1: Wetenschappelijke activiteiten

Partie 1: Activités Scientifiques

Part 1: Scientific Activities

Summary

Abbreviations

AAM	Atmospheric Angular Momentum
AGU	American Geophysical Union
AM	Angular Momentum
AMD	Angular Momentum Desaturation
AOGS	Asia Oceania Geosciences Society
BC	BepiColombo
BdL	Bureau des Longitudes
BELA	BEpicolombo Laser Altimetry experiment
BELSPO	BELgian Science POlicy
BERNESE	GNSS analysis software developed at University of Bern
BIPM	Bureau International des Poids et Mesures
CATREF	Combination and Analysis of Terrestrial REference Frames
CB	Central Bureau
CCM2	Call for Earth Explorer Core Mission (2d Call)
CCTF	Comité Consultatif pour le Temps et les Fréquences
CETP	Centre d'Etude des Environnements Terrestre et Planétaires
CGGTTS	Common GPS and GNSS Time Transfer Standards
CMB	Core-Mantle Boundary
CNBA	Comité National Belge d'Astronomie
CNBGG	Comité National Belge de Géodésie et Géophysique
CNES	Centre National d'Etude Spatiale
Co-I	Co-Investigator
COST	European CO-operation in the field of Scientific and Technological research
CSL	Centre Spatial de Liège
DGPS	Differential GPS
DLR	Deutsche zentrum für Luft- und Raumfahrt
DSN	Deep Space Network
DYNAMO	DYNAMique des Orbites
EFTF	European Frequency and Time Forum
EGNOS	European Geostationary Navigation Overlay Service
EGU	European Geophysical Union
E-GVAP	EUMETNET GPS Water Vapor Program
ENIC	Ecole Nouvelle d'Ingénieurs en Communication
ENSG	Ecole Nationale de Sciences Géographiques
EOP	Earth Orientation Parameters
EPN	EUREF Permanent GNSS Network
EPN CB	EUREF Permanent GNSS Network Central Bureau
ESA	European Space Agency
ESAC	Earth Science Advisory Committee
ESOC	European Space Operations Centre
ESTAG	Exploration, Science and Technology Advisory Group
ESTEC	European Space Research and Technology Centre
ESWW	European Space Weather Week
ETRF	European Terrestrial Reference Frame
ETRS89	European Terrestrial Reference System
EU	European Union
EUMETNET	European Network of Meteorological Services

EUREF	EUropean REference Frame
EUROPLANET	EUROpean PLAnetary NETwork
FCN	Free Core Nutation
FICN	Free Inner Core Nutation
FNRS	Fonds National de la Recherche Scientifique
FRFC	Fonds de la Recherche Fondamentale Collective
FRIA	Fonds pour la formation à la Recherche dans l'Industrie et dans l'Agriculture
FUNDP	Facultés Universitaires Notre-Dame de la Paix
GALILEO	European global satellite navigation system
GCM	General Circulation Model
GEP	Geophysical and Environmental Package
GEMS	Geophysical/Environmental Monitoring and Sounding
GEPID	GEP Interface Document
GGOS	Global Geodetic Observing System
GGSP	Galileo Geodetic Service Provider
GGTO	Galileo to GPS Time Offset
GIANT	Geodesy for Ice in Antarctica
GINS	Géodésie par Intégrations Numériques Simultanées
GLONASS	GLObal NAvigation Satellite System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GRGS	Groupe de Recherche de Géodésie Spatiale
GSFC	Goddard Space Flight Center
GTRF	Galileo Terrestrial Reference Frame
HCS	Haut Conseil Scientifique
HQ	Head Quarter
HEND	High Energy Neutron Detector
IAG	International Association of Geodesy
IAU	International Astronomical Union
ICD	Interface Control Document
ICRF	International Celestial Reference Frame
ICRS	International Celestial Reference System
IERS	International Earth Rotation and Reference Systems Service
IGN	Institut Géographique National
IGS	International GNSS Service
IGST	International GNSS Service Timescale
IGS05	IGS Realization of the ITRF2005
IIP	Instrument Information Package
IMCCE	Institut de Mécanique Céleste et de Calculs des Ephémérides
INSU	Institut National des Sciences de l'Univers
IPGP	Institut de Physique de Globe de Paris
ISSI	International Space Science Institute
ITRF2005	International Terrestrial Reference Frame (latest realization)
ITRS	International Terrestrial Reference System
IUGG	International Union of Geodesy and Geophysics
IVS	International VLBI Service
JPL	Jet Propulsion Laboratory
JSR	Journées Système de Référence
LaRa	Lander Radioscience experiment
LAREG	LAboratoire de REcherche en Géodésie

LMD	Laboratoire de Météorologie Dynamique
LOD	Length-Of-Day
LPG	Laboratoire de Planétologie et Géodynamique
MAGE	MArs Geophysics European network
µas	microarcsecond
MaRS	MarsExpress Radio Science experiment
MEMO	Mars Escape and Magnetic Orbiter
MER	Mars Exploration Rover
MEX	MarsExpress
MGS	Mars Global Surveyor
MHB	Mathews Herring and Buffett nutation model adopted by the IAU
MINT	Mars INTerior
MOLA	Mars Orbiter Laser Altimeter
MOP	Mars Orientation Parameters
MORE	Mercury Orbiter Radioscience Experiment
MoU	Memorandum of Understanding
MPO	Mercury Planetary Orbiter
MRA	Mutual Recognition Agreement
NCAR	National Center for Atmospheric Research
NCEP	National Center for Environmental Prediction
NGI	National Geographic Institute
NNO	New Norcia ESA ground station
NOE	Numerical Orbit and Ephemerides
NTP	Network Time Protocol
OC	Organizing Committee
ODF	Orbit Data Files
ODY	Mars Odyssey
OMP	Observatoire Midi-Pyrénées/Orban Microwave Products
PDR	Preliminary Design Review
PI	Principal Investigator
PPP	Precise Point Positioning
PRODEX	PROgramme for the Development of scientific EXperiments
PTB	Physikalisch-Technische Bundesanstalt
PTTI	Precise Time and Time Interval
RISE	Rotation and Interior Structure Experiment
RMA	Royal Military Academy
ROB	Royal Observatory of Belgium
RSDI	Radar Speckle Displacement Interferometry
RTK	Real Time Kinematic
S/C	Spacecraft
SIMBIO-SYS	Spectrometers and Imagers for MPO Bepicolombo Integrated Observatory SYStem
SF2A	Société Française d'Astronomie et d'Astrophysique
SLIM	Second-generation Louvain-la-neuve Ice-ocean Model
SOC	Scientific Organizing Committee
SONYR	Spin-Orbit N-bodY Relativistic model
SOWG	Science and Operation WG
STCE	Solar and Terrestrial Center of Excellence
STD	Science Definition Team
SW	Space Weather

SWG	Science WG
TAI	International Atomic Time
TEC	Total Electron Content
TID	Travelling Ionospheric Disturbance
TNF	Tracking and Navigation Files
TWSTFT	Two-Way Satellite Time and Frequency Transfer
UCL	Université Catholique de Louvain
UCLA	University of California Los Angeles
ULB	Université Libre de Bruxelles
ULg	Université de Liège
USNO	US Naval Observatory
UTC	Universal Time Coordinate
UTC(ORB)	UTC of Royal Observatory of Belgium
VeRa	VenusExpress Radioscience experiment
VEX	VenusExpress
VLBI	Very Long Baseline Interferometry
VUB	Vrije Universiteit Brussel
WEGENER	Working group of European Geoscientists for the Establishment of Networks for Earth-science Research
WG	Working Group
WOL	Wheel Off-Loading
ZTD	Zenith Total Delay

DEPARTMENT I: Reference Systems and Geodynamics

SECTION 1: Time, Earth Rotation and Space Geodesy

Introduction:

Mission and objectives

The mission of the Section 1 "Time, Earth Rotation, and Space Geodesy" is to contribute to the elaboration of reference systems (terrestrial and celestial) and timescales, theoretically as well as observationally, to integrate Belgium in the international reference frames (concerning space geodesy and time), and to obtain information on the Earth's interior, rotation, dynamics, and crustal deformation, at local, regional, and global levels. The ultimate goals are the understanding of the dynamics of the Earth's interior and surface deformation.

Additionally to the planet Earth, these objectives have been extended to the other terrestrial planets, Mars, Venus, and Mercury, and to the moons of the solar system planets. Section 1 is involved in planetary missions presently flying or included in a long-term vision.

The work of Section 1 is closely related to the international activities and opportunities, to the activities described in the statute of the Royal Observatory of Belgium (ROB), as well as in the strategic plan of ROB General Director.

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

(a) Project 1 'TIME – TIME TRANSFER' (Operational and research project)

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 six high-quality 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, when located in temperature-controlled environment. The ROB six clocks are located in such an environment and their performances are continuously monitored by inter-comparison between themselves and also with atomic clocks of other laboratories participating to TAI or IGST. 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. These 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.

<u>Milestones reached this year:</u> *(1) The tool "Atomium" dedicated to time transfer at the picosecond level and based on the GPS Precise Point Positioning (PPP) approach has been further developed with incorporating better data cleaning, allowing data analysis from any station, not necessarily driven by an atomic clock. (2) The second and third order ionospheric effects on the GPS time transfer solutions (clock*

comparisons) have been quantified and corrections for these effects have been added in the Atomium software. (3) The combined least square analysis of GPS and Two-Way data developed in 2007 has been generalized in order to get a combined time transfer solution for short and long baselines.

(b) Project 2 'GNSS' (Operational and research project)

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

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

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

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

Milestones reached this year:

(1) A first complete reprocessing of the EPN data has been performed and a long-term solution (positions and velocities) was computed.

(2) 22 new GNSS stations were integrated in the EPN tracking network and the EPN Central Bureau web site received a total of 2.7 million hits in 2008.

(3) It was demonstrated that regional GNSS estimations obtained in a network mode can be biased at the cm level (positions) or at the mm/yr level (velocities) depending on the size of the GNSS network and on the way it is tied to the conventional reference frame. This effect has a significant influence on the geodynamic interpretations, e.g. rotation pole estimation, vertical velocity interpretation.

(4) The TEC (Total Electron Content) maps estimated using the EPN GPS data with a 1°/1° grid over Europe agree at the 1-2 TECU level with other maps and, thanks to their high resolution in time and space, allow to evidence small structures in the ionosphere.

(5) The "EUMETNET GPS water Vapor Program" analysis center was restarted to provide meteorological institutes with GNSS-based tropospheric Zenith Path Delays for assimilation in the operational numerical weather models. It was also shown that dense GNSS networks allow detecting of small mesoscale atmospheric water vapor structures.

(6) The benefit of using meteorological observations available through the EUREF-EUMETNET collaboration for validating and improving GNSS analysis strategies for precise geodesy was demonstrated.

(7) The scientists of Section 1 organized the EUREF Symposium in collaboration with NGI and RMA; in total 132 scientists from 28 countries met at this symposium.

(c) Project 3 'EARTH ROTATION' (Research project)

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

Milestones reached this year: Milestones reached this year: (1) an analytical method to compute the topographic coupling at the core-mantle boundary has been established and its effects on nutations have been estimated; (2) in the analysis of Very Long Baseline Interferometry (VLBI) data, the contamination of the analysis strategy to Earth Orientation Parameters (EOP) determination has been studied and shown to be at a couple of tens of microarcsecond on the nutation amplitudes and at the level of a few tenths of day (100 days) on the FCN (FICN respectively); FCN and FICN stand for Free Core Nutation and Free Inner Core Nutation respectively; (3) An analysis of VLBI data in time domain using a Bayesian approach has been performed and the boundaries within which the geophysical parameters may be expected to change have been estimated; in particular, the extends to which the inner core and outer core parameters may vary have been estimated, which showed that, in particular for the inner core parameters, the error on the adopted parameter values, were underestimated; (4) The FCN free mode and its time variable amplitude have also been estimated from VLBI data using the same Bayesian approach.

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

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

Milestones reached this year: (1) The Lander Radio-science experiment, LaRa, has performed the Phase A and B studies of the instrument and prepared for the PDR (Preliminary Design Review); at ROB the scientist concentrated on the follow-up of the partners, the design was demonstrated to be very satisfactory by modeling of the radiosignal and computing the noise on the measurements, and simulations were performed to demonstrate the LaRa feasibility; (2) Global strain maps of Mars have been produced from altimetry data based on a model for tectonics on a one-plate planet with a

heterogeneous lithosphere; (3) It has been demonstrated that altimeter data at ground track crossing points can be used to detect the nutations of Mars and the libration amplitude and obliquity of Mercury; (4) From an analysis of eight years of MGS/Odyssey tracking data, the tidal gravitational signal of Mars, characterized by the Love number k2 has been determined to be about 0.12, which implies that the core of Mars is liquid; (5) 9 and 6 years of Doppler and range tracking data of the Mars Global Surveyor (MGS) and Mars Odyssey (ODY) spacecraft, respectively, have been analyzed in addition to the MEX tracking data in order to improve the determination of the low-degree gravity field coefficients induced by the seasonal changes in the atmosphere and ice caps; (6) From the accurate MEX orbits around Mars, the mass of the two Martian moons has been improved; (7) Meteorite impacts on Mars have been studied in the frame of the understanding of the evolution of the Martian atmosphere and shown not being able to explain alone the possible existence of a denser atmosphere on the early Mars; (8) Possible mantle and crust mineralogies of Mercury have been determined for published geochemical models for Mercury; (9) State-of-the-art interior structure models of Mercury have been calculated and the sensitivity of future geodetic observations of the rotation and tides of Mercury to key parameters of the interior (such as core size and composition) has been determined; (10) The forced librations in longitude of Mercury due to the planetary perturbations have been expressed using an analytical formulation involving directly Mercury's moments of inertia; the use of this formulation has allowed to show that planetary perturbations could lead to large forced librations in longitude due to a resonance with Mercury's free libration; (11) Observation strategies have been developed for the determination of Mercury's libration from camera images; (12) 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; (13) The recently observed rotation variations of Saturn's moon Titan have been studied and interpreted in terms of important non-hydrostatic effects in Titan; (14) 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 thermal equilibrium.

Links between the different projects of Section 1

The four projects within Section 1 all fit in the themes (1) GNSS positioning and Time and (2) Rotation and internal structure of the Earth and the other planets. They have multiple mutual links. The project 'Time and Time-transfer' uses in Brussels the same GPS receivers as the 'GNSS' project; the interaction with the GNSS project concerns choice, installation, and optimum use of the receivers, as well as data analysis strategies. Another link between these two projects is the STCE project itself (Solar and Terrestrial Center of Excellence) aiming at a better understanding of Space Weather (variations in the Sun-Earth environment, mainly originating from solar activity) and its effects on Earth and in particular on GPS, GNSS, and time transfer. This topic is deeply addressed by the projects 'GNSS' and 'Time and Time-transfer'. The Earth rotation variations and Earth orientation changes, studied by the scientists of the project 'Earth Rotation', are deduced from global measurements of Very Long Baseline Interferometry (VLBI), Satellite and Lunar Laser Ranging (SLR and LLR), and also GPS and GLONASS data, to which the GNSS project contributes; an Action 1 on this topic has been initiated in 2008. The project 'Geodesy and Geophysics of other planets' extends the geodesy research performed in the project 'Earth rotation' to the rocky planets and satellites of our solar system. As such, the methodologies are common between these two projects. Moreover, the limited amount of planetary data is a strong stimulus for developing methods utilizing synergies between different experiments. Such methods have also been applied to Earth with unprecedented results.

A. GNSS Positioning and Time

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

A.1. Time and Time transfer

A.1.1. Objectives

- To maintain high-quality clocks for participation in the international timescales (mainly TAI and IGS), and for the realization of a local high-quality timescale UTC(ORB) close to UTC;
- To maintain the official Belgian time called UTC(ORB) within one hundred of nanosecond of UTC;
- To define a legal Belgian time and to include ORB in the international Mutual Recognition Agreement (MRA);
- To provide UTC(ORB) to Belgian users via 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

1) Monitoring of UTC(ORB)

- A new procedure based on Atomium **for near-real time monitoring of UTC(ORB)** has been developed. The solution UTC(ORB)-UTC(k) is computed for 3 different UTC(k)'s with ultra-rapid IGS orbits, and updated each hour. All three links are updated each hour on ROB private web site.
- The bias between UTC(ORB) and UTC remained lower than 50 ns during 2008 (See Figure 1).
- Research for a renewal of the time lab in order to improve its reliability has been started.

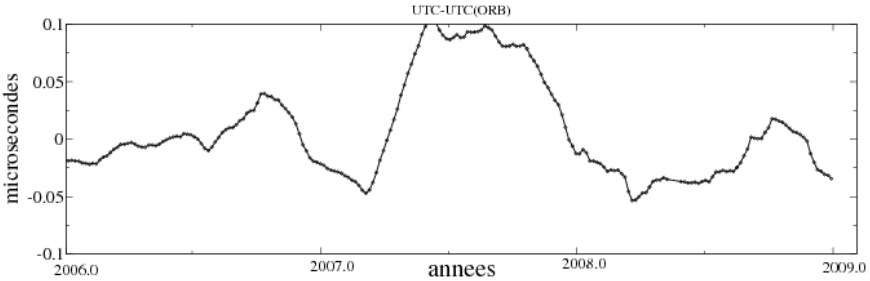

Figure 1: UTC(ORB) compared to the true UTC during the 3 last years

2) Legal aspects of UTC(ORB) in Belgium

- The procedure to get UTC(ORB), or equivalent realizations of UTC, as legal time for Belgium has been continued.
- The negotiations with the Metrology Service for collaboration in the frame of the Mutual Recognition Agreements (MRA) has been continued in order to become national laboratory maintaining the Belgian metrological unit for time, i.e. the second.

3) New version of the software R2CGGTTS for time laboratories

- A new version (V4.3) of the software R2CGGTTS (getting the CGGTTS[1] files using geodetic receivers, and the ionospheric free code P3) used by the BIPM[2] (project TAIP3: using GPS links based on R2CGGTTS for the realization of TAI) has been developed in order (1) to include the possibility to use receivers measuring C/A code rather than the P1 code, (2) to add one standard multi-channel

[1] Format compiled by the Common GPS and GNSS Time Transfer Standards (CGGTTS). CCTF stands for Consultative Committee for Time and Frequency.

[2] Bureau International des Poids et Mesures

track of 13 minutes when possible at the end of the day, and (3) to detect and disregard bad satellite orbits.

4) Time Laboratory

- Management of the clock signals needed for GNSS receivers BRUS, ZTBR, PLB1, PLB2, changing the driving frequency when necessary;
- Improvement of the web interface for the monitoring of all clocks in the lab, and realized a detailed description of the time lab structure and operational mode.
- Management of the 2 H-maser failures; one H-maser was repaired by the Kvarz Company and one by the scientists of Section 1.
- Participation to the BIPM Pilot Project TAI PPP.
- A mouss system on the antenna of the BRUX station has been set up in order to reduce the near field effects, and therefore the day boundary jumps in the clock solutions obtained with this station; however the results showed no spectacular improvement in the clock solutions and a considerable change in the phase center of the antenna. The previous setup was therefore reinstalled.

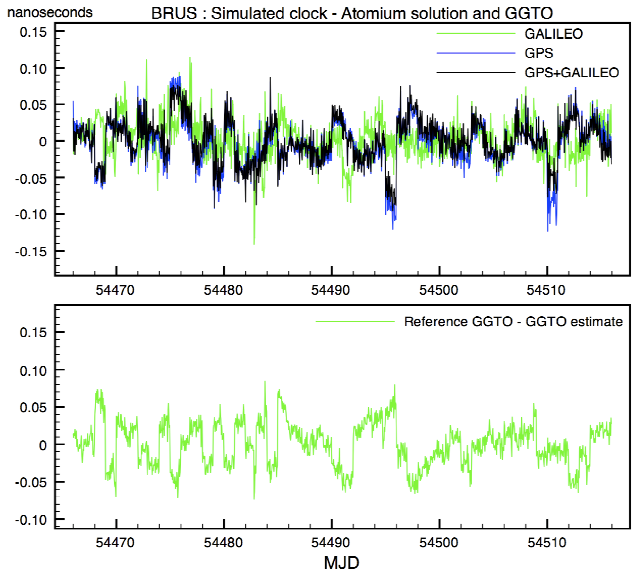

Figure 2: Difference between the simulated clock (without noise) and the Atomium solutions based on the simulated data for different GNSS constellations. Solution of the PPP analysis obtained using only GPS simulated observations (in blue), only GALILEO observations (in black). The lower graph shows the results of the restitution of the Galileo to GPS Time Offset (GGTO) in the least-square adjustment for the combined solution.

A.1.2.2. Research Activities

1) Time and frequency transfer with Atomium

- The tool "Atomium" dedicated to time transfer and positioning in the Precise Point Positioning mode has been improved in order to be able to use it for any receiver, connected or not connected to stable atomic clocks. The new algorithm is based on a given combination (named L6) of the raw data, which improves the visibility of cycle slips and outliers; its efficiency has been demonstrated (see [56]).
- The "phase-only" method based on the continuity of the ambiguities at the day boundaries has been finalized. This method has been shown to be limited at the level of some nanosecond due to the need of an integration procedure, producing random walk due to the white noise in the carrier phases. (see [56])

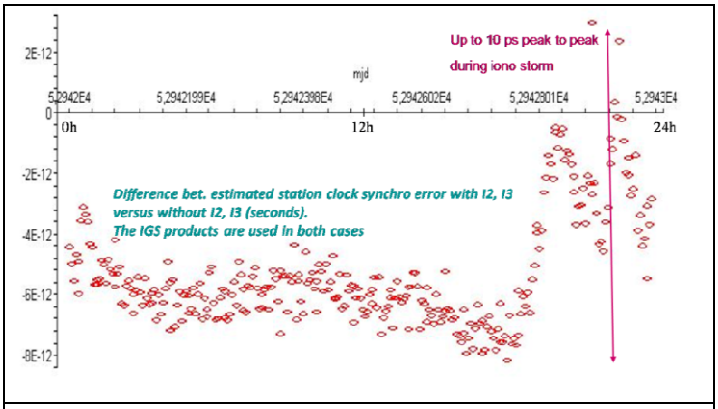

Figure 3: Effect of taking higher-order ionosphere effects, or not, into account in the L3P3 GPS measurements for the Brussels-Onsala link, on the ionosphere-stormy day 30th October 2007. The difference is taken between two ATOMIUM estimated station clock solutions, both using IGS products.

2) Using GLONASS and GALILEO for PPP

- The study of the impact of adding GLONASS on time transfer has been finished; [13]
- The simulation Software ASiF (Atomium Simulation Facility) which simulates code and phase observations for the GPS and GALILEO constellations has been developed.
- A PPP time transfer analysis combining simulated GPS and GALILEO observations and orbits has been performed. The least-square adjustment was therefore adapted in order to estimate the delay between the GPS system time and the GALILEO system time.
-

3) Ionospheric effect on Time and Frequency Transfer

- The second and third order ionospheric perturbations on GPS signals have been computed and quantified and their influence on time transfer has been estimated; and this correction has been included in the new version of the Atomium software.

4) Combination of GPS and TWSTFT data

- A combined GPS+Two-Way solution for time transfer has been computed; the method has been improved for long baselines by introducing intermediary GPS stations and working in a network approach. (see [22],[61])

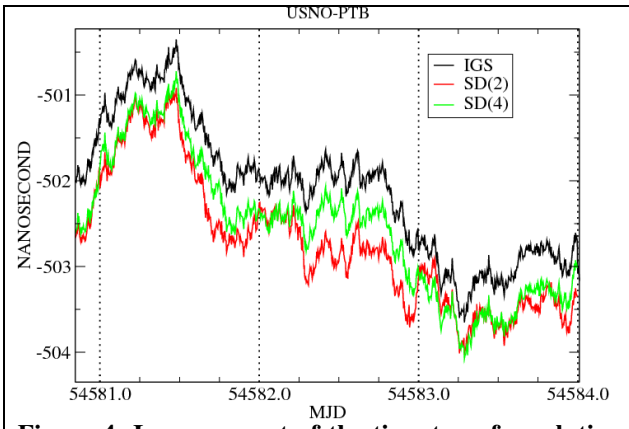

Figure 4: Improvement of the time transfer solution in common view when using intermediary stations (green curve) rather than using only the two remote stations (red curve); the black curve is the IGS solution used as reference.

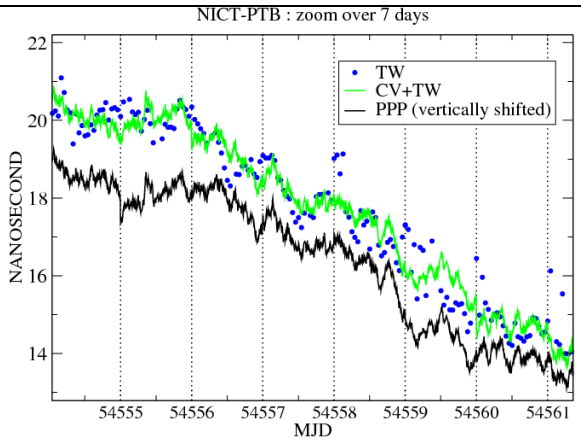

Figure 5: Combined GPS+TW solution (green curve) for a long baseline (Tokyo-Frankfurt)

A.1.3. Perspective for next years

- To develop a clock ensemble algorithm for the monitoring of UTC(ORB) in order to be able to be independent of the other laboratories.

- To introduce the resolution of integer ambiguities in Atomium in order to improve the solution.
- To study the optimal way to treat the troposphere within Atomium.
- To finalize the correction of 2nd and 3rd order ionosphere effects on time transfer for long baselines.
- To investigate the effects of high order ionosphere corrections in orbits for Time and Frequency transfer.
- To setup a time station (i.e. GNSS receiver driven by an atomic clock) observing 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 J.-M. Sleewaegen, Septentrio, Leuven.
- To improve the clock solutions obtained with Atomium.
- Total review of the time lab, and renew of a part of the instruments in order to increase the reliability of the UTC(ORB) and its delivery to users via NTP.
- Finalizing the Belgian legal aspects of UTC.
- Repair of the maser and determination of the procedure to put this maser as second candidate to generate UTC(ORB).
- In collaboration with the LaRa (Lander Radioscience) team, examine the possibility to assess the Allan Variance (stability and sensitivity) of the ExoMars LaRa instrument for the mission to Mars, using the timelab stable clocks.

A.1.4. Personnel involved

Scientific staff
- P. Defraigne, ORB;
- Q. Baire, BELSPO Suppl. Researcher (January-September), STCE (October-December)
- C. Bruyninx, ORB.
- S. Pireaux, STCE

Technical staff:
- E. Driegelinck, ORB
- F. Coutereel, STCE

A.1.5. Partnerships

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

- Dr N. Demidov, Kvarz, Russia
- Dr P. Uhrich, Laboratoire Temps-Fréquence, LNE-SYRTE, Observatoire de Paris
- Dr G. Petit, Bureau International des Poids et Mesures, Paris.
- Dr Z. Jiang, Bureau International des Poids et Mesures, Paris.

Grants/Projects used for this research/service

- STCE
- Belspo, supplementary researcher, 2007-2008.

Visitors:

- Mari Carmen Martinez, July 3 to August 3, ASBL
- Mari Carmen Martinez, October 1 to December 15, Spanish grant.

A.1.6. Scientific outreach

Meeting presentations

[1] **Defraigne P.**, M.C. Martinez
Combination of TWSTFT and GPS data for Time Transfer
Oral Presentation, 28th EFTF, Toulouse, April 2008

[2] **Baire Q., Defraigne P.**
Combining GPS and GLONASS for Time and Frequency Transfer
Poster Presentation, 28th EFTF, Toulouse, April 2008

[3] **Defraigne P., C. Bruyninx, Legrand J.**
Continuous frequency transfer using GPS carrier-phases
Poster Presentation , 28th EFTF, Toulouse, April 2008

[4] **Legrand J., Baire Q., Bergeot N., Bruyninx C., Defraigne P., Pireaux S., Pottiaux E.**
Current activities and research at ROB LAC
EUREF Analysis Workshop, October 2008, Frankfurt am Main, Germany

[5] **Pireaux S., Defraigne P., Bergeot N., Baire Q., Bruyninx C.**
Ionosphere perturbations in GPS time and frequency transfer
Poster Presentation, Session 2: Global Navigation Satellite Systems: Science, user needs and applications, ESWW 2008 (5th European Space Weather Week), 17th -21st November 2008, Brussels, Belgium

[6] **Pireaux S., Defraigne P., Bergeot N., Baire Q., Bruyninx C.**
Ionosphere perturbations in GPS time and frequency transfer
Oral Presentation, Session 10: Time and Frequency transfer, PTTI 2008 (Precise Time and Time Interval Systems and Applications Meeting), 1st -4th December 2008, Reston, Virginia, USA

[7] **Defraigne P.**, M.C. Martinez, Z. Jiang
Time transfer from combined analysis of GPS and TWSTFT data
Oral Presentation**,** PTTI 2008 (Precise Time and Time Interval Systems and Applications Meeting), 1st -4th December 2008, Reston, Virginia, USA

[8] **Bergeot N., Bruyninx C., Pireaux S., Defraigne P., Legrand J., Pottiaux E.**
Detection of ionospheric scintillations and impact on GPS kinematic positioning
Poster Presentation, Section ``Geodesy", Session ``Synergy between GNSS/GPS Observation Systems and Climate, Meteorological, and Ionospheric Applications", AGU Fall meeting, 15-19th December 2008, San-Francisco, USA; G41A-0619

[9] **Pireaux S.,**
Proper time versus TCB used for time delay interferometry in the LISA mission
Poster presentation, Atelier: Gravitation et Références pour des Applications en Astronomie et en PHysique (GRAAPH), Les Journées SF2A, 30th June-4th July 2008, Paris, France, http://www.sf2a.asso.fr/, GRAAPH 141

[10] **Pireaux S.**
Relativistic orbit determination with the RMI (Relativistic Motion Integrator) software for the LISA mission
Poster presentation, Atelier: Gravitation et Références pour des Applications en Astronomie et en PHysique (GRAAPH), Les Journées SF2A, 30th June-4th July 2008, Paris, France, http://www.sf2a.asso.fr/, GRAAPH 143

[11] **Pireaux S.,**
Time Delay Interferometry and Time Scales in the LISA mission
Oral Presentation, "E5b Session: Time scale, EFTF 2008 (22nd European Frequency and Time Forum)", 23rd -25th April 2008, Toulouse, France, Toulouse Space Show'08 DVD, E5b04 - 010

Seminars

[12] **Pireaux S.**
Géodésie spatiale, mécanique céleste et tests de la relativité générale
ASTR, Université Catholique de Louvain, Louvain la Neuve, 30th June 2008

Wikis and Websites

- Development of http://www.astro.oma.be/IAU/COM31/
- Contributions to http://www.astro.oma.be/D1/section1/

A.1.7. Missions

Assemblies, symposia: -European Frequency and Time Forum
-Precise Time and Time Interval meeting
-EUREF Symposium
-5th European Space Weather Week

Commissions, working groups (days):
FNRS commission "Astrophysics, Geophysics and Climatology", February 25, 2008.

Research visits (days): Observatoire de Paris, visit of the Time Laboratory, October 23, 2008.

A.2. GNSS positioning

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 understand, model, and mitigate 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 2008, several of ROB permanently observing GNSS stations started to stream real-time data.

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

Contribution to the preparation of the technical design of the GNSS receivers and antennas (one from ROB and one from the University of Luxembourg) that will be installed at the Princess Elisabeth I station in Antarctica has been performed in collaboration with the Royal Military Academy (A. Muls and P. De Kimpe).

A.2.2.3. EUREF Permanent Network

The daily management of the European Permanent GNSS network (EPN) is performed; EPN is a European network of continuous observing GNSS reference stations serving multi-disciplinary applications and covering 38 European countries. In that frame, the EPN CB web site is maintained and continuously updated (http://epncb.oma.be/). In 2008, the site received a total of about 2.7 million hits. Moreover,

- 22 new GNSS stations were added in the EPN, while 7 EPN stations were decommissioned, bringing the total of EPN stations to 217.
- 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).
- Contributions to the generation of the official EUREF densification of the ITRF2005 have been performed (collaboration with A. Kenyeres).
- Daily coordinates of a network of 65 GPS stations in and around Belgium have been computed. 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 spatial reference systems (ETRS89 and ITRS).
- Investigations on the usage of the Atomium software for monitoring the EPN site coordinates have been started.
- More details on these topics can be found in communications [6], [10], [11], [14], [22], [24], [27], [28], and [30] and papers [1], [13], [15], [66], [67], [69], [70], [71], [72], and [73].

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

- The influence of the reference frame definition on GNSS-based positions and velocities has been studied, demonstrating that regional GNSS solutions can show coordinate biases (up to the cm-level) with respect to each other because of the way the solution is tied to the conventional reference frame. These errors clearly exceed the noise level. Regional velocity fields show systematic effects with respect to the global velocity field with differences reaching up to 1.3 mm/yr in the horizontal and 2.9 mm/yr in the vertical depending on the geographical extend of network and the set of regional reference stations. Consequently the limitation of regional networks to reconstruct absolute velocity fields has been evidenced; when geodynamics requires the highest precisions for the GNSS-based velocities, a global reference frame definition should be applied or at least a special care has to be applied to the reference frame definition (collaboration with Z. Altamimi, G. Woppelmann, M.N. Bouin, R. Dach); see communications [1], [8], [15], [26], and [35] and papers [80] and [90].

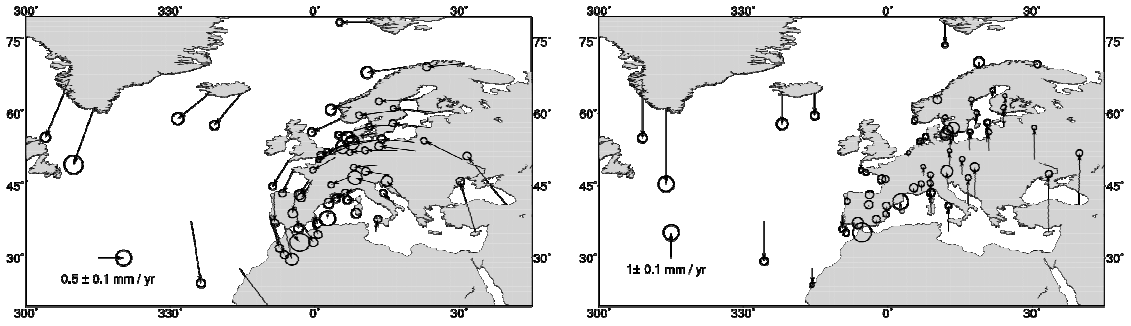

Figure 6: Difference between global and regional velocity fields (mm/yr). Left: horizontal differences, Right: vertical differences. Error ellipses are at the 99% confidence level.

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.

- A first complete re-processing of all the GNSS data gathered within the EPN (EUREF Permanent Network) was performed estimating daily positions of the EPN stations from 1996 up to now. For a significant number of the stations, the data-span has been increased compared to the "original" EPN

(collaboration with A. Kenyeres). As can be seen in Figure 7, thanks to a consistent modeling during the whole considered period, this reprocessing has allowed to considerably improve the quality of the site positions, velocities and residuals time series (see communications [7], [17], and [28] and paper [77]).

- A re-processing of recent and historical data (covering 12 years) from GPS stations in and around Belgium was performed. In this reprocessing, all FLEPOS and WALCORS sites are now included. The analysis of the resulting velocity field is under progress in collaboration with the seismology section; see communication [25].
- GNSS-based velocity solutions from all over the world have been gathered to densify the latest realization of the ITRS (International Terrestrial Reference System) and to provide regional dense velocity information in a common global reference frame. A call for participation has been launched end of 2008 and up to now velocity solutions for more than 5000 sites have been proposed to the Working Group (collaboration with the team of the IAG Working Group on "Regional Dense Velocity Fields", e.g. D. Lavallée); see communications [9], [13], [23], and [34] and paper [68].

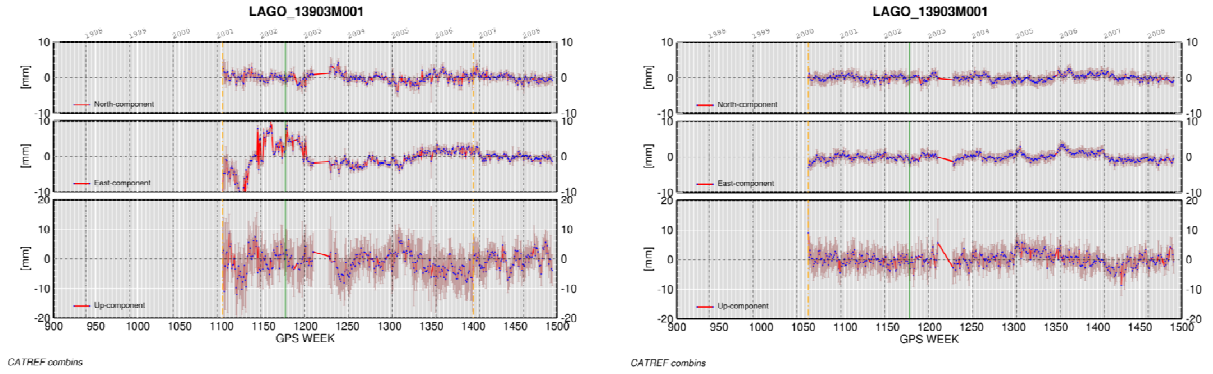

Figure 7: Comparison between original EPN time series on the left and reprocessed time series on the right for the station Lagos in the south of Portugal.

- The influence of the GPS antenna calibration type (relative or absolute) on the computed stations positions has been studied; this study demonstrated that no universal value for the difference between the coordinates obtained with absolute and relative calibrations can be found as this difference depends on the geometry of the processed network and the reference frame definition (collaboration with O. Khoda); see communication [18] and papers [78] and [79].
- A study of the influence of phase multipath on GPS positioning using the EPN data has been performed; this study demonstrated that an empiric correction of phase multipath can improve GPS ambiguity resolution (collaboration with A. Mazzoni and H. van der Marel); see communication [19].
- The geodynamic interpretation of GPS data from the Vanuatu subduction zone and Clipperton Island has been finalized. A long-term convergence rate of 54 mm/yr between the Australian plate and the Vanuatu Arc has been estimated from horizontal and vertical GPS velocity fields (see paper [48]) and new geodynamic constraints were obtained in the case of the Clipperton Island (see paper [73]) 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 E-GVAP project aims at using improved estimation techniques to provide meteorological agencies with GNSS-based troposphere Zenith Path Delays for assimilation in their operational numerical weather prediction models. The ROB E-GVAP analysis center was re-established, (see communications [2], [4], [16], [28], [20], [29] and paper [81] - collaboration H. Vedel).
- The influence of the reference frame definition, the GNSS antenna calibration and the ocean tide loading models on the modelling of the tropospheric delay error source has been studied, notably to

improve the strategy used for E-GVAP, (see communications [2], [20] and paper [81] - collaboration E. Brockmann, W. Söhne).

- The incorporation of GLONASS observations, its near real-time and post-processing treatment and its influence on the modelling and mitigation of the tropospheric delay error source has been studied (see communications [2], [16], [28], [20], [29] and paper [81]).
- A Memorandum of Understanding between EUREF and EUMETNET has been established and the benefit of this memorandum for EUREF has been demonstrated (see communications [16] and paper [81] - collaboration E. Brockmann, W. Söhne).
- The use of observations from dense GNSS networks has been demonstrated to allow monitoring the structure, movement and variability of fine mesoscale atmospheric water vapor structures, providing valuable information for Numerical Weather Prediction and nowcasting applications (see communications [4], [21] and paper [84] - collaboration S. de Haan).

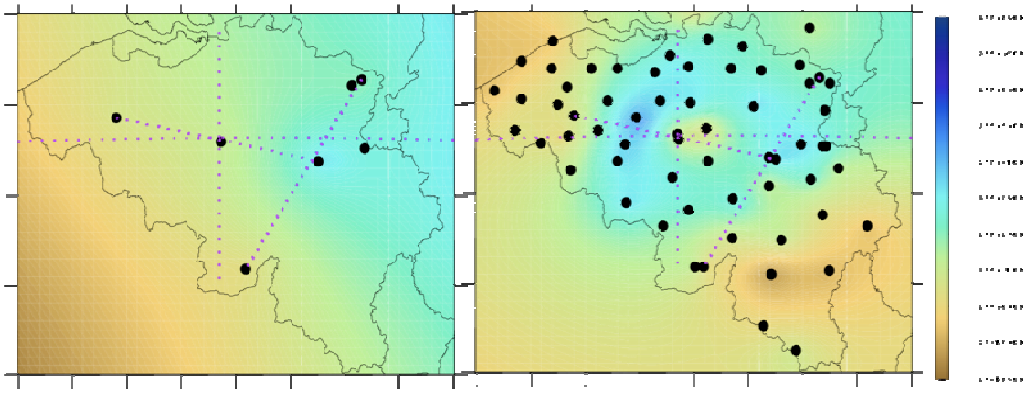

Figure 8: Tropospheric delay field reconstructed without (left) and with (right) the Belgian dense network

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

- The best way of estimating the Total Electron Content (TEC) over Europe using the EUREF Permanent Network (EPN) GPS data has been investigated. For that purpose, in a first step, the Bernese software has been used, but finally self-made software to estimate TEC maps has been developed (in collaboration with S. Jin).
- The estimation of TEC (Total Electron Content) maps based on the EPN GPS data has been started; this demonstrated that the density of the EPN allows to estimate hourly V (vertical) TEC and its RMS on a 1°/1° grid over Europe (see Figure 9). Thanks to their high resolution in time and space, these maps allow to better monitor small structures in the ionosphere than the standard global ionospheric maps.
- The TEC maps estimated with ROB software have been demonstrated to agree with CODE Global Ionospheric Map (GIM) products at 0.1±1 TECU during normal ionospheric activity and 1.2±2.8 TECU during the geomagnetic storm period.

More details are available in communications [12], [32], and [36] and papers C.3.2 and [66].

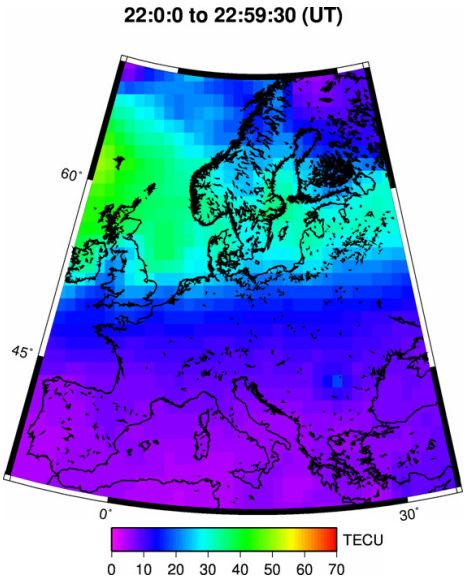

Figure 9: 1°/1° hourly TEC map over Europe from EPN GPS data between 22:00 and 23:00, day 303 of 2003 (Halloween geomagnetic storm)

A.2.3. Perspective for next years

- Continue to maintain and modernize (GLONASS and GALILEO) the ROB network of permanent GNSS stations
- 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 improve the reprocessing of historical GNSS data, the filtering of station coordinates and the estimation of site velocities of the entire EPN

A.2.4. Personnel involved

Scientific staff:	Q. Baire (MSc. researcher, STCE) N. Bergeot (post-doc researcher, STCE) C. Bruyninx (SW2/first assistant, ROB) O. Khoda (post-doc researcher, BELSPO fellowship for non-EU post-doc researchers) J. Legrand (post-doc researcher, BELSPO Action 1 MO/33/19) E. Pottiaux (MSc. researcher, STCE)
Technical staff:	F. Coutereel (engineer, STCE) A. Moyaert (ICT, ROB) D. Mesmaker (technical manager, ROB)

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, Brazil
- R. Dach, Astronomical institute, University of Bern, Bern, Switzerland
- S. de Haan, Koninklijk Nederlands Meteorologisch Instituut, Holland
- M. Diament, Institut de Physique du Globe de Paris, France
- S. Jin, Korea Astronomy and Space Science Institute, South Korea
- A. Kenyeres, FÖMI Satellite Observatory, Hungary
- O. Khoda, Main Astronomical Observatory of the National Academy of Sciences of Ukraine
- D. Lavallée, TU Delft, Netherlands
- A. Peltier, Institut de Physique du Globe de Paris, France
- W. Söhne, Bundesamt für Kartographie und Geodäsie, Germany

- H. van der Marel, TU Delft, Netherlands
- H.Vedel, Danish Meteorological Institute, Denmark
- G. Weber, Bundesamt für Kartographie und Geodäsie, Germany
- G. Wöppelmann, Université la Rochelle, France

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

- A. Simsky, Septentrio
- P. Voet, Nationaal Geografisch Instituut (NGI)
- A. Muls, P. De Kimpe, Royal Military Academy (RMA)

Grants/Projects used for this research/service

- Grant nr. MO/33/019 from BELSPO
- Post-doctorial fellowship for non EU researchers from BELSPO
- Solar-Terrestrial Center of Excellence (STCE)

Visitors:

- A. Mazzoni, University of Rome, February 1 – April 25
- S. Jin, Korea Astronomy and Space Science Institute, South Korea, June 28 – July 18

A.2.6. Scientific outreach

Meeting presentations

[1] Legrand J., Bruyninx C., Pottiaux E.
Sensibility of the Reference Frame Definition in a Regional Network
EGU General Assembly 2008, April 14-18, 2008, Vienna, Austria

[2] **Pottiaux E**.
The Belgian contribution to the EUMETNET GPS water vapor program (E-GVAP): recent developments and applications
EGU General Assembly 2008, April 14-18, 2008, Vienna, Austria

[3] **Defraigne P., Bruyninx C., Legrand J.**
Continuous Frequency Transfer Using GPS Carrier-Phases
22nd European Frequency and Time Forum (EFTF), April 23-28, 2008, Toulouse, France

[4] **Pottiaux E.**
The Belgian contribution to E-GVAP: current status and developments
E-GVAP joint expert team meeting, May 6-7, 2008, Potsdam, Germany

[5] **Pottiaux E.**
The Belgian Active Geodetic Network
E-GVAP joint expert team meeting, May 6-7, 2008, Potsdam, Germany

[6] **Bruyninx C., Legrand J., Roosbeek F.**
GNSS Network Management Procedures: Application to the EPN
IGS Analysis Centers Workshop, June 2-6, 2008, Miami, US

[7] Kenyeres A., **Legrand J., Bruyninx C.,** Habrich H., Figurski M.
Regional Re-analysis: Expectations and experiences within the EPN
IGS Analysis Centers Workshop, June 2-6, 2008, Miami, US

[8] Legrand L., Bruyninx C.
Reference Frame Definition in a Regional GNSS Network: Global or Regional?
IGS Analysis Centers Workshop, June 2-6, 2008, Miami, US

[9] **Bruyninx C.,** Z. Altamimi, M. Becker, M. Craymer, L. Crombrinck, A. Crombrink, R. Fernandes, R. Govind, A. Kenyeres, B. King, C. Kreemer, D. Lavallée, **Legrand J.**, L. Sanchez, G. Sella
IAG Working Group "Regional Dense Velocity Fields": Objectives and Future Plans
IGS Analysis Centers Workshop, June 2-6, 2008, Miami, US

[10] Weber G., **Bruyninx C.**
Monitoring of the Real-time IGS NTRIP Interfaces
IGS Analysis Centers Workshop, June 2-6, 2008, Miami, US

[11] **Bruyninx C.**
Activities of the EUREF Technical Working Group
EUREF Symposium, June 18-21, Brussels, Belgium

[12] **Bergeot N., Bruyninx C., Pottiaux E., Pireaux S., Defraigne P., Legrand J.**
Detection of Abnormal Ionospheric Activity from the EPN and Impact on Kinematic GPS Positioning
EUREF Symposium, June 18-21, Brussels, Belgium

[13] **Bruyninx C.,** Z. Altamimi, M. Becker, M. Craymer, L. Crombrinck, A. Crombrink, R. Fernandes, R. Govind, A. Kenyeres, B. King, C. Kreemer, D. Lavallée, **Legrand J.,** L. Sanchez, G. Sella
Objectives and Challenges of the IAG Working Group "Regional Dense Velocity Fields"
EUREF Symposium, June 18-21, Brussels, Belgium

[14] **Bruyninx C., Legrand J., Roosbeek F.**
Status and Performance of the EUREF Permanent Tracking Network
EUREF Symposium, June 18-21, Brussels, Belgium

[15] **Legrand J., Bruyninx C.**
EPN Reference Frame Alignment: Consistency of the Station Positions
EUREF Symposium, June 18-21, Brussels, Belgium

[16] **Pottiaux E**., Brockman E., Schöne W., **Bruyninx C.**
The EUREF - EUMETNET Collaboration: First Experiences and Potential Benefits
EUREF Symposium, June 18-21, Brussels, Belgium

[17] Kenyeres A., **Legrand J**., Figurski M., **Bruyninx C.,** Kaminski P., Habrich H.
Homogenous Reprocessing of the EPN: First Experiences and Comparisons
EUREF Symposium, June 18-21, Brussels, Belgium

[18] Khoda O., **Bruyninx C.**
Influence of changing GPS Antenna Calibrations on (EPN) Station Coordinates
EUREF Symposium, June 18-21, Brussels, Belgium

[19] Mazzoni A., **Bruyninx C.**, Van der Marel H.
Phase Multipath analysis for permanent GNSS stations: Sites characterization and use of multipath maps in Bernese 5.0 data processing
EUREF Symposium, June 18-21, Brussels, Belgium

[20] **Pottiaux E.**
GNSS near real-time zenith path delay estimations at ROB: methodology and quality monitoring
EUREF Symposium, June 18-21, Brussels, Belgium

[21] **Pottiaux E.**
Detecting Small-scale Tropospheric Phenomena Using GNSS Observations from Dense National Networks
EUREF Symposium, June 18-21, Brussels, Belgium

[22] **Bruyninx C.**
The EUREF Permanent Network: Design and Objectives
ASG-EUPOS Conference, June 24, 2008, Warsaw, Poland

[23] **Bruyninx C**., Altamimi Z., Becker M., Craymer M., Combrinck L., Combrink A., Fernandes R., Govind R., Herring T., Kenyeres A., King B., Kreemer C., Lavallée D., **Legrand J**., Moore M., Sánchez L., Sella G., Woppelmann G.
Towards the Provision of Regional Dense Velocity Fields in a Global Reference Frame
WEGENER General Assembly, September 15-18, 2008, Darmstadt, Germany

[24] Ihde J., **Bruyninx C.**, Habrich H., Kenyeres A., Poutanen M., Sacher M.
EUREF's Reference Networks EPN, UELN, and ECGN – Basis for Tectonic Monitoring and Investigations in Europe
WEGENER General Assembly, September 15-18, 2008, Darmstadt, Germany

[25] **Camelbeeck T., Bruyninx C**., Vanneste K., **Alexandre P., Legrand J., Bergeot N., Van Camp M.**
Crustal Deformation in Stable Continental Europe: A comparison of Seismicity, Geodetic and Geologic Information
WEGENER General Assembly, September 15-18, 2008, Darmstadt, Germany

[26] **Legrand J., Bergeot N., Bruyninx C**., Woppelmann G., Bouin M.-N., Altamimi Z.
Impact of the Reference Frame Definition on Geodynamic Interpretations
WEGENER General Assembly, September 15-18, 2008, Darmstadt, Germany

[27] **Bruyninx C., Legrand J., Roosbeek F.**
EPN Coordination Status and Plans
EUREF Local Analysis Centers Workshop, October 22-23, 2008, Frankfurt, Germany

[28] **Legrand J., Baire Q., Bergeot N., Bruyninx C., Defraigne P., Pireaux S., Pottiaux E.**
Current activities and research at ROB LAC
EUREF Local Analysis Centers Workshop, October 22-23, 2008, Frankfurt, Germany

[29] **Pottiaux E.**
The Belgian Contribution to E-GVAP: current status and developments
E-GVAP joint expert team meeting, 7 November 2008, Copenhagen, Denmark

[30] Ihde J., **Bruyninx C**., Habrich H., Kenyeres A., Poutanen M.
Development of EUREF's GNSS Reference Network EPN
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AGU Fall Meeting, 15-19 December 2008, San Francisco, US

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[36] **Bergeot N., Bruyninx C., Pottiaux E., Pireaux S., Defraigne P., Legrand J.**
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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://www.epncb.oma.be/EUREF2008/, EUREF 2008 symposium
- http://www.gps.oma.be/, GNSS project
- 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:	N. Bergeot (EUREF, WEGENER, ESWW, AGU) C. Bruyninx (IGS AC workshop, EUREF, ASG-EUPOS, EUREF LAC workshop, AGU) J. Legrand (IGN Research Days, IGS workshop, EUREF, EUREF LAC workshop, AGU) E. Pottiaux (IGN Research Days, EGU, EUREF)
Commissions, working groups (days):	N. Bergeot (1) C. Bruyninx (15) J. Legrand (5) E. Pottiaux (9)
Research visits (days):	N. Bergeot (8 days) J. Legrand (6 days) E. Pottiaux (5 days)
Field missions (days):	N. Bergeot (7 days)

B. Earth and planet rotation and interior

The scientists of Section 1 are dealing with the understanding and modelling of 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.2) and a second project to the other terrestrial objects of the solar system (see paragraph B.1).

B.1. Planets

Introduction

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

The gravity field of planetary bodies can best be studied through the precise monitoring of the trajectory of passing or orbiting spacecraft. Because the gravity field of a planet is determined by the planet's internal mass distribution, spatial and temporal variations in the gravity field can be used to determine physical properties 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. The moment of inertia is considered as one of the major constraints on the interior structure of planets and large moons. More recent efforts use tides, which can also be observed through their time-variable effect on the gravity field, to obtain 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. This kind of research is inspired by Lord Kelvin's study of the Earth's deep interior by means of solid body tides in the 19th century.

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 libration of Mercury.

The geophysical interest of these studies is to improve our knowledge of the interior, 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 have been investigated. These studies rely on theoretical developments as well as on analyses of radio tracking data of spacecrafts in orbit around or landed on these planets or satellites.

B.1.1. Objectives

ESA's MarsExpress mission to Mars has started its science phase in January 2004, and the scientists of Section 1 are involved in its radio-science experiment MaRS (at Co-I level). Their main objectives are to determine accurate gravity maps of selected areas on Mars for a better understanding of properties of the crust and lithosphere and to obtain the time-variable part of the low-degree gravity field for studies of Mars' interior.

BepiColombo is an ESA mission to Mercury scheduled for launch in 2014. Section 1 is involved at Co-I level in the radio science, the altimeter, and the camera teams. The radio-science experiment will measure Doppler shifts of radio links between the Earth and the lower of two Mercury orbiters (MPO) of the BepiColombo project. From the three experiments, the rotation variations (called librations) and gravity field of Mercury will be determined. The results will be used to determine the interior structure and dynamics of the innermost planet of our solar system. A point of main interest is the determination of the physical state (liquid or solid) and size of Mercury's core, which will have large implications for our knowledge of the formation and evolution of terrestrial planets. On a longer time scale, the scientists of

Section 1 participate in studies for a future mission to the Galilean satellites and have started extending similar studies as for Mercury to large satellites of the Solar System.

For the interpretation of gravity and rotation data in terms of interior properties, models of the interior structure and composition of terrestrial planets and large moons are an essential requirement. A major objective therefore is the development of interior structure models of terrestrial planets. For that purpose, recent data on material properties at high pressure and temperature have been used.

Preparations for the radio-science experiment LaRa (PI: V. Dehant) of the future ExoMars mission to Mars have been continued. In particular, an X-band transponder and antenna have been developed (presently, the experiment is at the Technological Readiness Level 5) in collaboration with the Belgian company OMP and with CSL.

B.1.2. Progress and results

B.1.2.1. Preparation of future missions

- The lander platform of the ExoMars mission will house a radio-science experiment called LaRa (Lander Radio-science). LaRa 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 Martian lander and the Earth is inferred from Doppler effects measured at the Earth ground stations and will be used to determine accurately the rotation of Mars. The fifth release of the LaRa breadboard has been successfully delivered in the third quarter of 2008 (see representation of the BB in Figure 10). This last release of the X-band transponder has been optimized for weight, physical dimensions and performances. The LaRa transponder release 5 is able to acquire a signal at 7162 MHz (carrier frequency of the signal emitted by the ground station) and perfectly track a signal with a Doppler rate simulating the real Doppler shift between Mars and the Earth. The current design has also confirmed that LaRa can keep a permanent coherency between the uplink and downlink signals with a transponder ratio of 880/749 (according to X-band turnaround ratio value specified at the ground station).The coherency is essential to assure an accurate two-way Doppler measurement.

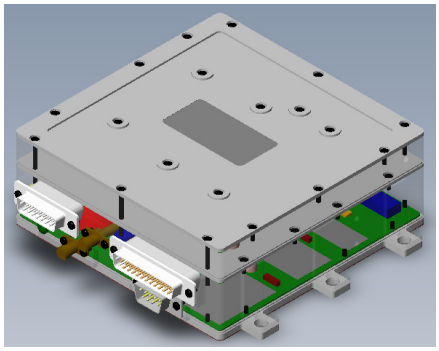

Figure 10: LaRa transponder.

- Mathematical models describing the behavior of the transponder in the presence of the noise (thermal effects) and an end-to-end MatLab simulator for a two-way Doppler measurement process which consists of an X-band transponder (LaRa instrument) and a ground station (DSN/ESA) that interact through the radio links have been developed in order to assess the key performances of LaRa.
- Follow-up of the industry building LaRa (i.e. OMP), preparation and updating of ESA documents, preparation of the pre-PDR in November 2008, and discussions and meetings with ESA, with the industry, with PRODEX, and with the LaRa team. Figure 11 shows the transponder of LaRa and the two antennas, as well as the link with the platform power generator and computer unit. Figure 12 is a schematic of the LaRa experiment, showing the ground stations using an atomic clock, an uplink in X-band, a coherent transponder, and a downlink in X-band (see papers [52] and [75] and reports [106][107][108][109][119][110][112][113][114][115][116][117] [118][119][121] and [110]).

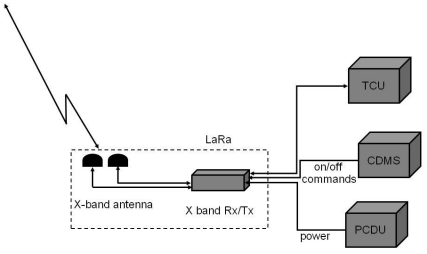

Figure 11: Representation of LaRa and its interfaces with the platform.

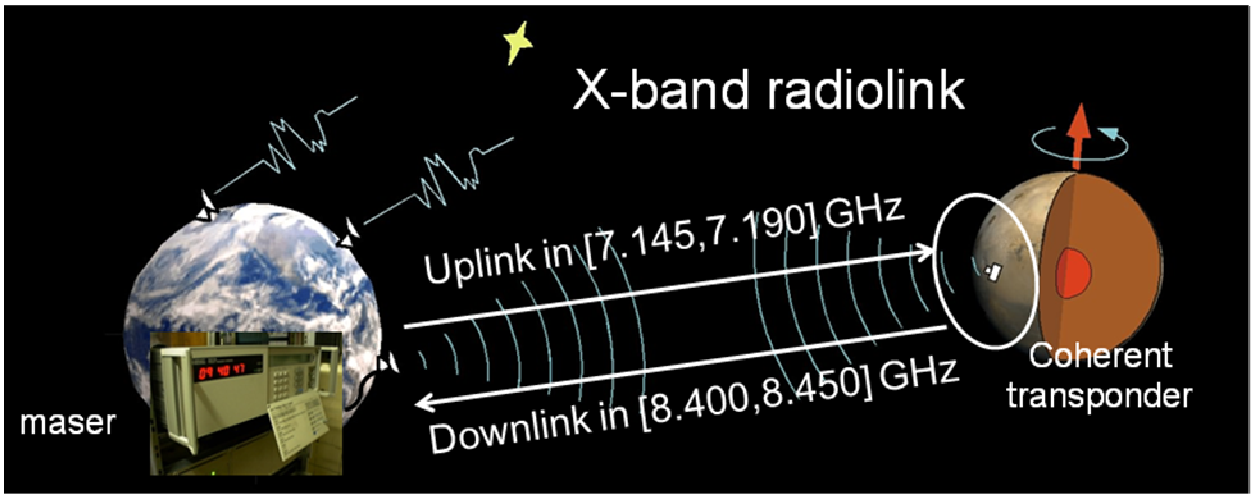

Figure 12: Representation of the Radiolink between the Earth and Mars in the frame of LaRa.

- A paper on the results of a geophysical experiment (collaboration with V. Pletser) in order to simulate the Martian environmental context has been published ([59],[60]).
- Within the Cosmic Vision and AURORA programs of ESA, contributions to proposals for an orbiter (MEMO) and landers (Mars-NET) to Mars and to a mission to the Galilean moons of Jupiter (LAPLACE) have been performed. Several papers ([50], [54], [55]), extended abstracts and papers in proceedings ([28], [15], [75], [92], [93]) have been published.

B.1.2.2. Mars: MEX data processing

- ROB Mars data base consists of radio tracking data of several space missions and their associated ancillary data. About 350 shell and FORTRAN codes have been developed over time to manage and process them. In 2008, efforts went particularly to enhancing the flexibility of the codes for processing new mission data.
- At present all MEX tracking data until July 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 such as the determination of the attitude of the bus, solar panels, and the steerable antenna, and the computation of the residual accelerations induced by the wheel off-loadings (WOL) or angular momentum desaturations (AMD).
- Accurate orbits of MEX have been determined by using the Doppler and range tracking data performed by the MEX radioscience experiment (MaRS) during 2004 to 2008 (see paper [10]). The average precision is about 20 meters, which is 2 to 3 times better than the precision of the orbits provided by the navigation team of ESOC (European Space Operation Center). The orbits have been made available to the scientific community.

B.1.2.3. Mars: LaRa

- Development and implementation of GINS software routines for analyzing radio links between a lander on Mars and the Earth and simulations of the LaRa experiment have been performed (see papers [52] and [75]).
- Study of the precision that can be obtained on the orientation of Mars as a function of the Doppler noise level, the duration of the tracking period, and the lander position error.
- With the same codes developed, the processing the direct-to-Earth data from the Mars Pathfinder and Viking lander missions have been started.

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

- A study has been finished on the determination of the gravity field and tides of Mars from MGS and ODYSSEY tracking data ([56]). 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. This value indicates that Mars has a liquid core. The discrepancy between these results suggests that the Love number cannot be accurately determined yet because of its small effect on the spacecraft dynamics.
- Interior structure models of Mars have been updated to incorporate the most recent data on thermo-elastic properties of liquid metal alloys and their melting properties. By using a coherent thermodynamic description for the liquid part of the core an empirical melting law for iron-sulfur systems has been derived. Moreover, the range of mantle mineralogies has been largely extended. A publication on these state-of-the-art interior models is in preparation.
- By means of the theoretical models for the interior structure of Mars, the tidal amplitude has been shown to imply the core size to be in the range 1479-1753 km and the core sulfur concentration to be between 6-18 wt%.
- For the state-of-the-art interior models, forced rotation variations have been calculated. The new interior models have been shown to lead to larger nutation amplitudes than did previous basic interior models, which had a smaller core. These theoretical predictions will allow better interpreting geodesy experiments like LaRa in terms of the interior structure of Mars.
- A study has been published on the use of the MOLA altimeter onboard the MGS spacecraft to determine Mars' rotation variations [8]. 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 communication [11]). See Figure 13.

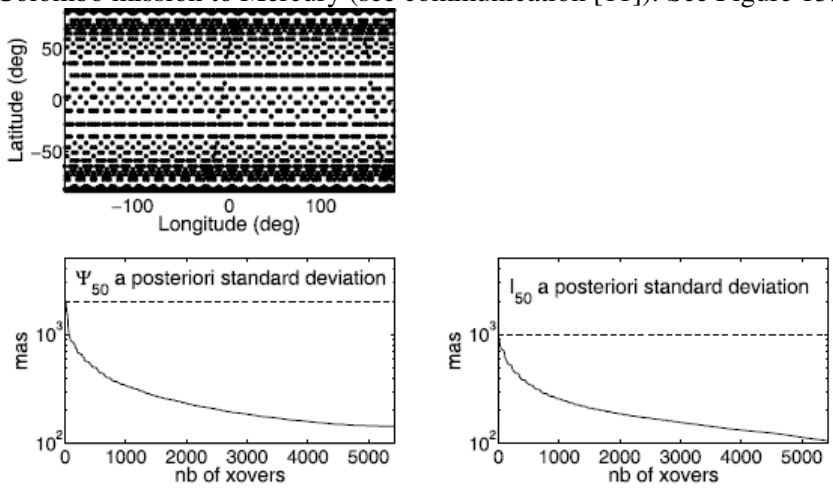

Figure 13: Nutations can be obtained with a 10% precision level from Mars Orientation Parameters (MOP) inversion. The figure presents the a posteriori deviation for the main nutations as a function of the number of cross-over points used in the inversion

- A general analytical method has been developed for the calculation of the tide-generating potential of any Solar System body. Tables of approximate tide-generating potentials and planetary torques have been produced for the major Solar System bodies.

B.1.2.5. Mars: crust and lithosphere

- The investigation of the internal structure of the Martian crust and lithosphere is conducted by performing gravity observations during the pericenter passage of the MarsExpress spacecraft in its orbit around Mars. In 2008, there were only three new passes of low signal-to-noise ratio above the Tharsis area, which is the focus of the work on Mars. Possible sources of noise have been reanalyzed is has been shown that some antennas give on average better results.
- A code (based on paper [1]) has been developed for the modeling of tectonics on one-plate planets having a heterogeneous lithosphere. The code is very flexible, allowing flexural support, isostasic support (i.e. no deflection), and support by crust thickness variations or by mantle density perturbations (for example a plume under Tharsis). In order to test the results of the model, global strain maps (see Figure 14) have been produced from the latest catalog of Martian faults generated with MOLA data. Various scenarios have been tried in order to improve the modeling of Martian tectonics. A small lithospheric thickness has been shown to be possible on Mars in the Noachian epoch if the surface density is higher in the Tharsis areas and in mascon basins.

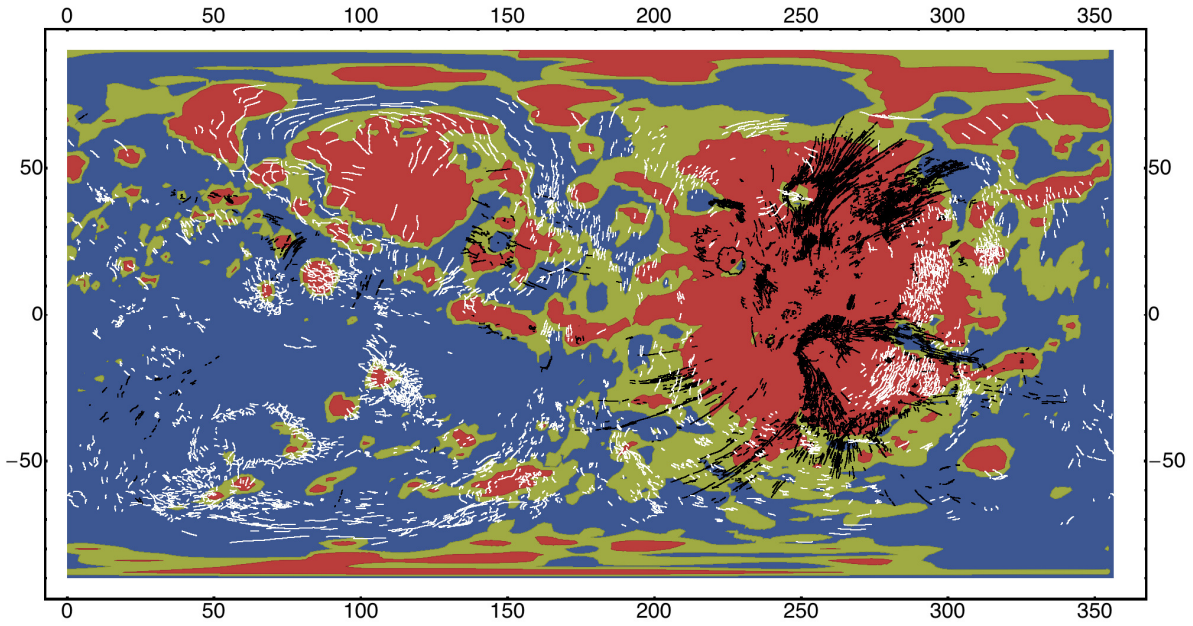

Figure 14: Predicted fault style on Mars for the model with variable density in the Noachian epoch. Regions with predicted normal, strike-slip and thrust faults are colored in blue, green and red, respectively. Observed normal faults are drawn in black whereas observed thrust faults are drawn in white (observed strike-slip faults are not shown).

B.1.2.6. Mars: atmosphere and polar caps

- In a semi-analytical approach, the effect of impacts on the atmospheric evolution of Mars has been studied. Meteorite impacts cause atmospheric erosion but also deliver material and volatiles to the planet. Meteorite impacts have been shown to be not able to explain alone the possible existence of a denser atmosphere on the early Mars (see paper [58]). For different models the atmospheric pressure can even increase with the meteorite impacts (see Figure 15).

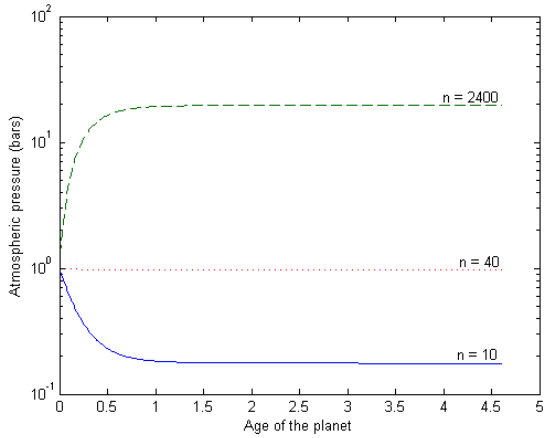

Figure 15: Evolution of the surface pressure *P* on Mars (bars) as a function of time *t* in billions of years (Gyr), assuming an initial surface pressure P(*t* = 4.6 Gyr) = 1 bar The calculations are made for the tangent plane model, with different values of *n*, the ratio of the critical mass to the tangent mass.

- A paper has been published on the effect of the internal structure of Mars on seasonal surface deformations due to loading (see paper [7]).
- Participation in a review paper on the habitability of Mars in collaboration with E. Javaux (ULg) (see paper [95]).
- In a continuing study of the time-variable gravity field of Mars, 9 and 6 years of Doppler and range tracking data of the Mars Global Surveyor (MGS) and Mars Odyssey (ODY) spacecraft, respectively, have been analyzed in addition to the MEX tracking data in order to improve the determination of the low-degree gravity field (see paper [56]). These gravity variations are geophysically interesting because they are linked with the CO_2 sublimation and condensation cycle of Mars' atmosphere. If the MEX orbit were to be as precisely known as the orbits of the American spacecraft, its tracking data would allow improving the current estimates of the time-variable gravity field.

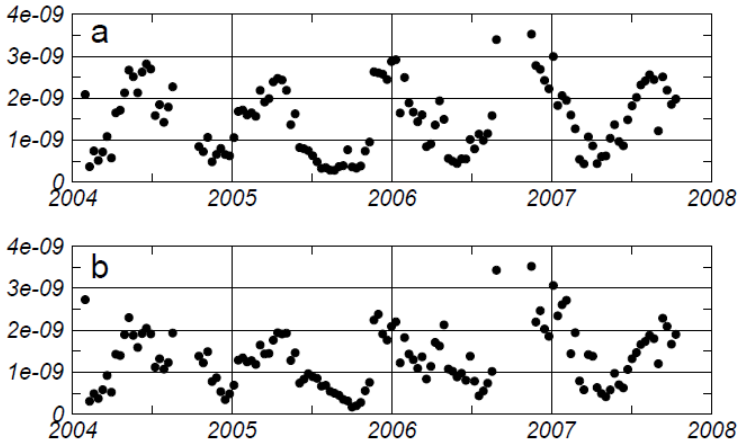

Figure 16: Formal uncertainty of time series for (a) C_{20} and (b) C_{30} harmonics coefficients of the gravity field from MEX tracking data.

- The variations in the seasonal and long-term (over the last 500 kyr) CO_2 and H_20 surface loadings have been calculated by using a Martian General Circulation Model (GCM) and the long-term insolation variations. These data were used to investigate the effect of the Martian interior on surface deformation and rotation variations of Mars. Only surface displacements can be used to infer estimates of the mantle viscosity of Mars with the present observational precision (see paper [94]).

B.1.2.7. Mars: moons

- From the accurate MEX orbits around Mars, the mass of the two Martian moons has been improved (see paper [10]). 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 radioscience data during the close flyby of Phobos in July 2008 were also used to determine the mass of Phobos. The resulting low densities of both moons (see Figure 17) are thought to be due to porosity in their interiors, and suggest that re-accretion may have occurred in their early history.

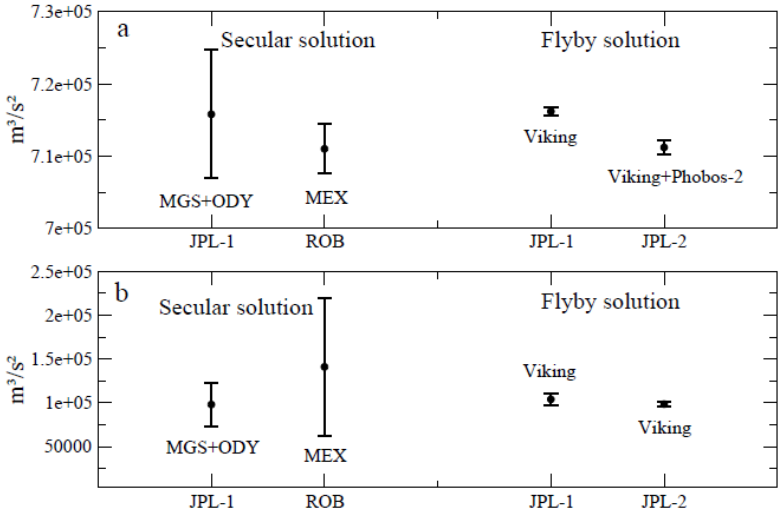

Figure 17: Solutions for Phobos (a) and Deimos (b) GMs. JPL-1 are from Konopliv et al. (2006), JPL-2 from Jacobson (2008) and ROB values.

- The accurate MEX orbits determined at ROB have been used in the processing of Phobos' astrometric observations taken by the SRC (Super Resolution Camera) onboard MEX in order to improve the ephemerides of Phobos (see paper [10]).

B.1.2.8. Mercury

- Possible mantle and crust mineralogies of Mercury have been determined for published geochemical models for Mercury. In a paper in press in Planetary and Space Science [63], 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.

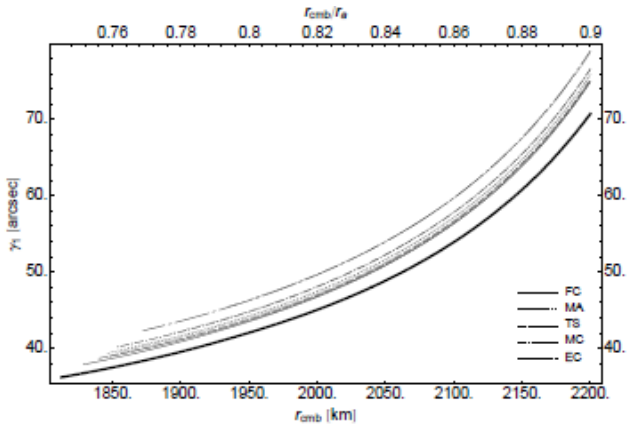

Figure 18: 88-day libration amplitude as a function as a function of core size for hot (gray) and cold (black) models. Crust density is 2900kg=m^3 except for the results for the cold FC model, which are also shown for the crust density of 3300kg=m^3 (thick black)

- State-of-the-art interior structure models of Mercury have been calculated. The models are based on the mass and radius of Mercury and on assumptions on the core composition and mantle mineralogy, and incorporate the most recent data on thermoelastic properties of liquid metal alloys and their melting properties. Moreover, the sensitivity of future geodetic observations of the rotation and tides of Mercury to key parameters of the interior (such as core size and composition) has been studied. This study will serve to specify required observational precisions for the BepiColombo mission to Mercury and to determine the interior structure of Mercury when rotation and tide results become available (see paper [61]).
- Planetary perturbations lead to long-term rotation variations, or forced librations in longitude, with typical periods of the order of several years. Results of the numerical integration have shown that five waves are above the arcsecond level, the accuracy level of the libration observations (see paper [57]).
- 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 a very large libration amplitude at that period (see paper [57]). Figure 19 shows the amplification of different forced libration as a function of the value of the moments of inertia (of $(B-A)/C_m$).

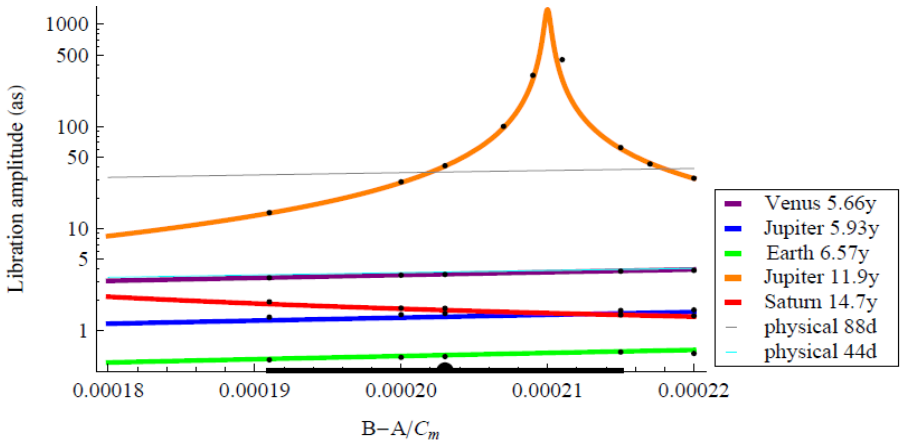

Figure 19: Amplitude (in arcsecond) of the forced librations due to the planets as a function of the $(B - A)/C_m$ ratio for Mercury. The large black dot represents the nominal value for this ratio and the black line is the 1 sigma uncertainty around this value from Margot et al. (2007). The 88-day and 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.

- A feasibility study has been initiated to estimate the inner core size of Mercury from upcoming spacecraft data on the planetary moment of inertia, the moment of inertia of the silicate shell, the tidal surface deformation, and the tidal external potential variations.
- 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 (one example is shown in Figure 20). 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 (see communication [78]).

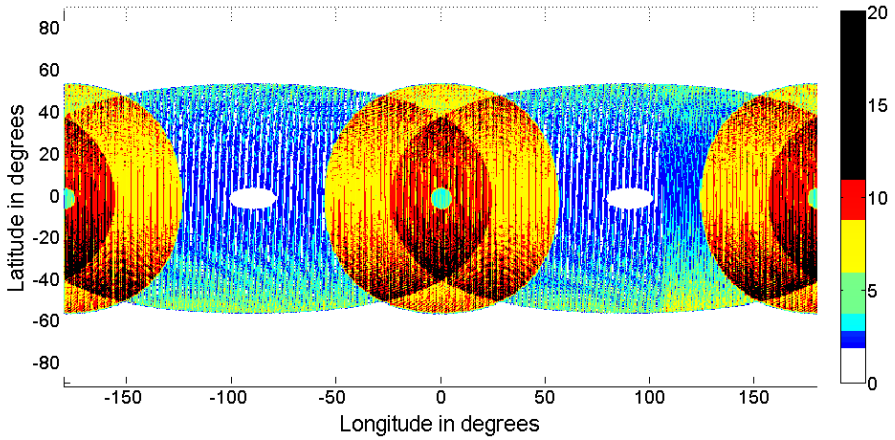

Figure 20: Possible camera measurements of the Hermean surface for the nominal BC orbit, with no cut-off in altitude but accounting for illumination conditions

- Relativistic corrections on the motion of the BepiColombo and Mars-NEXT spacecraft have been calculated by assuming that the central planet is spherically symmetric and non-rotating and neglecting the gravitational effect of other Solar System bodies. After 5 revolution periods of the spacecraft, the difference between the relativistic and Newtonian theories is of the order of a centimeter.

B.1.2.9. 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 [64]).

B.1.2.10. 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 communications [29], [58]).
- Information on the upper atmosphere of Venus can be obtained from the atmospheric drag on the VenusExpress (VEX) spacecraft passing through the atmosphere. An atmospheric drag experiment started on August 2008 and an initial analysis of the radio-tracking data of VEX to determine the atmospheric drag has been performed.

B.1.2.11. Natural satellites

- Several lines of evidence suggest that large icy satellites have a subsurface ocean beneath an icy shell. The Galilean moon Europa is thought to have a thin icy shell, but its thickness is not well constrained. A new method has been developed to determine the thickness of the icy shell by means of libration observations (see paper [12]).
- In collaboration with American and French colleagues, a review paper [49] on the rotation of Europa has been written.
- 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. Internal gravitational and pressure coupling between the ice shell and the interior beneath a putative ocean have been shown to likely diminish any differential rotation between shell and interior and leads to rotation variations of the shell about a factor 5 smaller than observed. This result has been published in Geophysical Research Letters [4].

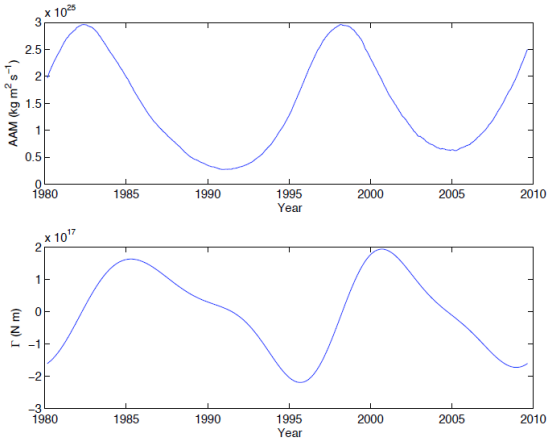

Figure 21: Seasonal variations of the atmospheric angular momentum and the atmospheric torque on Titan.

- The gravitational forcing by Saturn, due to misalignment of the long axis of Titan with the line joining the mass centers of Titan and Saturn has been shown to further reduce the rotation variations with respect to those for a spherical Titan by an order of magnitude. Moreover, this theoretical study indi-

cates that Saturn's torque causes the rotation to be slower than synchronous in contrast to the Cassini observations. Those large differences with the observations suggest that non-hydrostatic effects in Titan are important (see paper [61]).

- The model developed for the rotation variations induced by the atmosphere of Titan has been adapted for the study of short-periodic rotation variations forced by Saturn. Preliminary results for those librations have been obtained and applications to other icy satellites have been initiated (see communication [68]).
- Previous studies, in which the icy moons are considered to behave as rigid bodies, have shown that the equilibrium obliquities of Europa and Titan are small and well below 1 degree. When the satellites are supposed to have a subsurface ocean, the equilibrium obliquity has been demonstrated to be the same as in the rigid case. Therefore, the obliquity doesn't depend on the 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.
- 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 thermal equilibrium. A paper describing these results is accepted for publication in Nature [53].

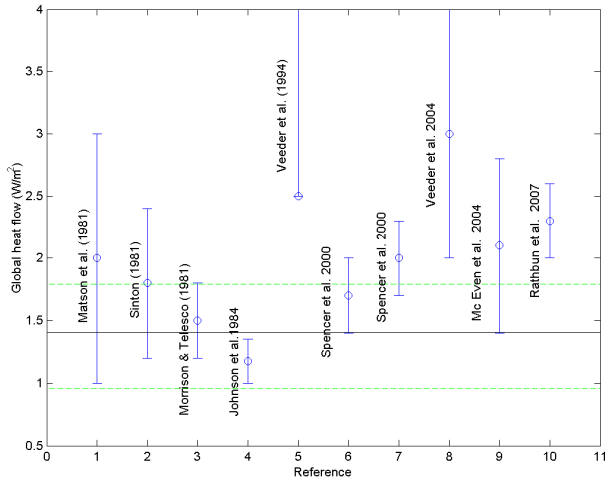

Figure 22: The surface heat flow of Io determined by the present study (2.24 ± 0.45 W.m^{-2} shown by the horizontal lines) is in good agreement with the results of remote observations of Io's thermal emission, suggesting that Io is close to thermal equilibrium.

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 will be taken into account. Together with simulations for LaRa, these data will allow assessing the precision of the LaRa experiment. In view of future radio-science experiments, the expected improvements when radio tracking data to both a lander and an orbiter are available will also be quantified. The model using altimeter data at ground track crossings for the determination of rotation variations of Mars will be extended. 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 started to (1) estimate the density of the upper atmosphere of Venus from the atmosphere drag on the VenusExpress spacecraft, (2) measure the time-variable gravity field and constrain its deep interior structure, and (3) obtain new constraints on the loading density and lithospheric elastic thickness. Lithospheric stress and strain fields will be modeled and compared with observed tectonic features on Venus and Mercury.
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. This synergistic approach to probe the interior of terrestrial planets by joint geodetic, seismic, and electromagnetic means will also be further pursued and will be applied to the Earth, Mars, and the Moon.
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.
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 of 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:
R.-M. Baland (FRIA)
M. Beuthe (PRODEX)
V. Dehant (ROB)
A. Hees (FNRS)
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S. Le Maistre (PRODEX)
M. Mitrovic (PRODEX)
G. Pfyffer (FRIA, Action 1)
L.B.S. Pham (FNRS)
P. Rosenblatt (PRODEX)
A. Rivoldini (PRODEX)
A. Trinh (FNRS)
T. Van Hoolst (ROB)
O. Verhoeven (Action 1)
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Technical staff:
L. Van Camp (ROB) (4/5)
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B.1.5. Partnership

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

- J.-E. Arlot, IMCCE, Paris, France
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- J. Aurnou, UCLA, USA
- G. Balmino, OMP, Toulouse, France

- J.-P. Barriot, Univ. Polinésie Française, Tahiti
- L. Bergamin, Advanced Concepts Team, ESA
- D. Breuer, DLR, Berlin, Germany
- J.-C. Marty, OMP, Toulouse, France
- B. Bills, NASA GSFC, USA
- G. Choblet, University of Nantes, France
- F. Deleflie, Observatoire de la Côte d'Azur, Grasse, France
- P. Delva, Advanced Concepts Team, ESA
- O. de Viron, IPGP, France
- W. Folkner, JPL, USA
- F. Forget, Laboratoire de Météorologie Dynamique, Paris, France
- B. Häusler, Universität der Bundeswehr Institut für Raumfahrttechnik, Munich, Germany
- H. Hussmann, DLR, Berlin, Germany
- D. Izzo, Advanced Concepts Team, ESA
- A. Konopliv, JPL, USA
- V. Lainey, IMCCE, Paris, France
- Lammer H., Space Research Institute, Austria
- B. Langlais, LPG, University of Nantes, France
- S. Lebonnois, Laboratoire de Météorologie Dynamique, Paris, France
- J.-C. Marty, OMP, Toulouse, France
- M. Menvielle, CETP, Paris, France
- A. Milani, Univ. Pisa, Italy
- A. Mocquet, University of Nantes, France
- J. Noir, UCLA, USA
- J. Oberst, DLR, Berlin, Germany
- M. Pätzold, University of Cologne, Germany
- N. Rambaux, IMCCE, Paris, France
- V. Robert, IMCCE, Paris, France
- S. Rosat, Institut de Physique du Globe de Strasbourg, Strasbourg, France
- F. Sohl, DLR, Berlin, Germany
- T. Spohn, DLR, Berlin, Germany
- P. Tarits, Université de Brest, France
- S. Tellmann, University of Cologne, Germany
- W. Thuillot, IMCCE, Paris, France
- T. Tokano, Universität zu Köln, Cologne, Germany
- P. Vacher, University of Nantes, France
- O. Verhoeven, LPG, University of Nantes, France
- A. Vienne, IMCCE, Paris, France
- 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

- G. Degrez, ULB
- E. Deleersnijder, UCL
- R. Laguerre, ULB
- A. Lemaître, FUNDP
- E. Javaux, ULg
- 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)

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 8: Contract: C90182 (1114100 € for 2005-2008), 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 2008: 12000 €, "Networking in the frame of internal structure of the terrestrial planets"
- EuroPlaNet: EU, Coordination Action, Call: FP6-2202-Infra structures-1, 001637, Contract: 001637

Visitors:

- Antoine Mocquet, Nantes University, France, 11 February – 8 March, FNRS/FRFC
- Short visits: 17 persons

B.1.6. Scientific outreach

Meeting presentations

[1] Dehant V.
Geodesy with multiple lander radioscience
NEXT Science Payload Definition Team Meeting, ESTEC, ESA, Noordwijk, the Netherlands, 10-11 January 2008

[2] **Dehant V.**
Gravity from Orbiter
Mars-NEXT Science Definition Team meeting, ESA ESTEC, Noordwijk, the Netherlands, 10-11 January 2008

[3] Langlais B., **Dehant V.**
MAGNETometer on the Orbiter
NEXT Science Payload Definition Team Meeting, ESTEC, ESA, Noordwijk, the Netherlands, 10-11 January 2008

[4] Langlais B., **Dehant V.**
Why do we need accurate, low-altitude three-component measurements of the magnetic field on Mars?
NEXT Science Payload Definition Team Meeting, ESTEC, ESA, Noordwijk, the Netherlands, 10-11 January 2008

[5] Vennerstroem S., Menvielle M., **Dehant V.**
Magnetometer network experiment
NEXT Science Payload Definition Team Meeting, ESTEC, ESA, Noordwijk, the Netherlands, 10-11 January 2008

[6] **Dehant V**.
Radioscience onboard landers and orbiters
AURORA-NEXT Science Definition Team (SDT), ESTEC, ESA, Noordwijk, the Netherlands, 10-11 January 2008

[7] **Dehant V**.
Lander Interior and Geodesy Payload
AURORA-NEXT Science Definition Team (SDT), ESTEC, ESA, Noordwijk, the Netherlands, 31 January-1st February 2008

[8] **Dehant V.**, Orban D., Renotte E., **Mitrovic M**., and the LaRa Team (including **Van Hoolst T., Rosenblatt P.**)
The LaRa experiment, requirements and interfaces
TAS-I interface meeting, Thales Alenia Space, Roma, Italy, 3-4 March 2008

[9] Chicarro A., Breuer D., Chassefière E., **Dehant V.,** Fisackerly R., Grady M., Pinet P., Rossi A., Santovincenzo A.
Mars-NEXT mission
Lunar and Planetary Science XXXIX, League City, Texas, abstract 1656, March 10-14, 2008

[10] **Pham L.B.S**.
Does impact erosion set the limit to the size and mass of habitable planets – Mars as an example
Workshop ISSI, Bern, Switzerland, 17-19 March 2008

[11] **Trinh A., Dehant V.**
Tides and Altimetry
BeLA Science Team Meeting, Granada, Spain, 30 March-2 April 2008

[12] Verhoeven O., Mocquet A., Vacher P., **Rivoldini A**., Menvielle M., Arrial P.-A., Choblet G., Tarits P., **Dehant V**., **Van Hoolst T**.
Nouvelles contraintes sur la température et la composition du manteau inférieur fournies par une inversion jointe de données séismiques et électromagnétiques
Séminaire, Laboratoire de Planétologie et Géodynamique, Université de Nantes, 4 avril 2008

[13] **Dehant V.**
The LaRa experiment
ExoMars Science Working Team (ESWT), ESTEC, Noordwijk, the Netherlands, 7-9 April 2008

[14] **Le Maistre S., Dehant V**., **Beuthe M.**
Gravity on target, tracking and global gravity, Phobos mass determination
MarsExpress Radio Science team, Cologne, Germany, 10 April 2008

[15] **Rosenblatt P., Beuthe M., Le Maistre S., Dehant V**.
Gravity on target, tracking and global gravity, Phobos mass determination
MarsExpress Radio Science team, Cologne, Germany, 10 April 2008

[16] **Rosenblatt P., Beuthe M., Le Maistre S., Dehant V.**
Gravity status and the drag experiment
VenusExpress Radio Science team, Cologne, Germany, 11 April 2008

[17] **Rivoldini A., Van Hoolst T., Verhoeven O**.
The Interior Structure of Mercury
EGU 2008, General Assembly, Vienna, Austria, 14-18 April 2008

[18] Chicarro A., Breuer D., Chassefière E., **Dehant V.,** Fisackerly R., Grady M., Pinet P., Rossi A., Santovincenzo A.
Mars-NEXT – a future step in the European exploration of Mars
EGU 2008 General Assembly, Vienna, Austria, 14-18 April 2008

[19] **Dehant V.,** Folkner W., Orban D., Renotte E., **Le Maistre S., Mitrovic M.,** Chicarro A., and the LaRa Team (including **Van Hoolst T.** and **Rosenblatt P.**)
The geodesy experiment LaRa (Lander Radioscience, onboard ExoMars) and future radioscience experiments
EGU 2008 General Assembly, Vienna, Austria, 14-18 April 2008

[20] **Pham L. B. S., Karatekin Ö., Dehant V**.
Effect of Impacts on the Atmospheric Evolution of Mars
EGU General Assembly 2008, Vienna, Austria, 14-18 April 2008

[21] **Rosenblatt P., Le Maistre S.,** Marty J.C., **Dehant V.**
Numerical simulations of a geodetic orbital experiment for future mission to Mars
EGU 2008 General Assembly, poster, Vienna, Austria, 14-18 April 2008

[22] **Le Maistre S., Rosenblatt P.,** Marty J.C**., Dehant V., Karatekin Ö., Rivoldini A.**

Improvement of Mars orientation and rotation model from the LaRa experiment onboard ExoMars
EGU 2008 General Assembly, poster, Vienna, Austria, 14-18 April 2008

[23] Blanc, M. and the LAPLACE consortium (including **Dehant V**. and **Van Hoolst T**.)
LAPLACE: a mission to Europa and the Jupiter System for ESA's Cosmic Vision Programme
EGU 2008, General Assembly, Vienna, 14-18 April 2008

[24] Chicarro A., Breuer D., Chassefière E., **Dehant V.,** Fisackerly R., Grady M., Pinet P., Rossi A., Santovincenzo A.
Mars-NEXT – A future step in the European exploration of Mars
Mars Water Cycle Workshop, Paris, France, 21-23 April 2008

[25] **Dehant V.**
The geodesy experiment using radioscience within ExoMars and Mars-NEXT
Mars-NEXT 4th Science Definition Team meeting, ESA HQ, Paris, France, 24-25 April 2008

[26] **Dehant V.**
Clarifications on Radio Science links
Mars-NEXT 4th Science Definition Team meeting, ESA HQ, Paris, France, 24-25 April 2008

[27] Holmes D.P., Thompson T., Simpson R., Tyler L., **Dehant V., Rosenblatt P.,** Häusler B., Pätzold M., Goltz G.
The challenges and opportunities for international cooperative radio science; experience with the MarsExpress and VenusExpress Missions
SpaceOps 2008 Conference on 'Protecting the Earth, Exploring the Universe', Heidelberg, Germany, 12-16 May 2008

[28] Chicarro A., Breuer D., Chassefière E., **Dehant V**., Fisackerly R., Grady M., Pinet P., Rossi A., Santovincenzo A.
Mars-NEXT mission- A future step in the European exploration of Mars
International Conference for the 200th anniversary of Astronomy in Kharkiv, The Solar System Bodies: from Optics to Geology, Astronomical Institute of Kharkiv V.N. Karazin National University, Kharkiv, Ukraine, 26-29 May 2008

[29] **Karatekin Ö., Van Hoolst T., Dehant V.**
Effects of the Atmospheric Dynamics on the Rotations of Mars and Venus
5th Annual Meeting of AOGS, Asia Oceania Geosciences Society (AOGS), Busan, Korea, 16-20 June 2008

[30] Lainey V., Arlot J.-E., **Karatekin Ö., Van Hoolst T**.
Observed tidal dissipation in the Jovian System
AOGS, Busan, Korea, 16-20 June 2008

[31] Lainey V., Arlot J.-E., Desmars J., **Karatekin Ö.,** Noyelles B., Rambaux N., Renner S., Vienne A.
First steps toward an accurate quantification of the Saturnian tidal dissipation
AOGS, Busan 16-20 June 2008

[32] Deleflie F., Rossi A., Portmann C., Guzzo M., Métris G., Hauteserres D., Messignac B., **Rosenblatt P.**
Long-term stability of trajectories of the space debris population, perturbed by gravitational effects
COSPAR meeting, Montreal, Canada, July 13-20, 2008

[33] Chicarro A., Breuer D., Chassefière E., **Dehant V.,** Fisackerly R., Grady M., Pinet P., Rossi A., Santovincenzo A.
Mars-NEXT mission – A future step in the European exploration of Mars
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[34] Chicarro A., Breuer D., Chassefière E., **Dehant V.,** Fisackerly R., Grady M., Pinet P., Rossi A., Santovincenzo A.
Mars-NEXT mission – A future step in the European exploration of Mars
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[35] Asmar S., Iess L., **Dehant V**., Milani A., Tortora P.
Planned BepiColombo Radio Science Investigation
37th COSPAR Scientific Assembly, Montréal, Canada, 13-20 July 2008

[36] Banerdt W.B., Jones M.A., Herrell L., Miyake R., Kondos S., Timmerman P., Albert D., Chui T., Davis P., **Dehant V**., Johnson C.L., Khurana K., Lognonné P., Manga M., Moldwin M., Morgan P., Nakamura Y., Neal C., Oberst J., Paik H.-J., Russell C., Schubert G., Smrekar S., Spohn T., Wieczorek M.
Concept Study for an Autonomous Lunar Geophysical Experiment Package (ALGEP)
NLSI Lunar Science Conference, NASA Ames Research Center, Moffett Field, California, LPI Contribution No. 1415, abstract no. 2108, 20-23 July 2008

[37] **Dehant V.**
LaRa versus enhanced LaRa
Mars-NEXT 5th Science Definition Team meeting, ESA ESTEC, Noordwijk, the Netherlands, 23-24 July 2008

[38] **Verhoeven O.,** Mocquet A., Vacher P., **Rivoldini A.,** Menvielle M., Arrial P-A., Choblet G., Tarits P., **Dehant V.**, **Van Hoolst T.**
Constraints on thermal state and composition of the Earth's lower mantle from electromagnetic impedances and seismic data
SEDI meeting, Kunming, China, 27-31 July 2008

[39] **Dehant V.**
La Terre et les planètes telluriques : leurs composantes, leurs mesures
Cours d'été du GRGS, Forcalquier, France, 1st September 2008

[40] **Rosenblatt P., Le Maistre S., Dehant V.**
VEX tracking data for VEXADE (VEX Atmospheric Drag Experiment)
VeRa Team Meeting, Brussels, 15-16 September 2008

[41] **Rosenblatt P., Le Maistre S., Dehant V.**
Determination of Phobos GM from MEX-Phobos flyby of July 17th 2008
MaRS Team Meeting, Brussels, 15-16 September 2008

[42] **Rosenblatt P., Le Maistre S., Dehant V.**
Determination of Phobos GM from MEX-secular orbit changes
MaRS Team Meeting, Brussels, 15-16 September 2008

[43] **Rosenblatt P., Beuthe M., Le Maistre S., Dehant V.**
Gravity on target and time variation gravity with MEX
MaRS Team Meeting, Brussels, 15-16 September 2008

[44] **Rosenblatt P., Marty J.C., Balmino G., Le Maistre S., Dehant V.**
Determination of Mars gravity field from MGS and Odyssey
MaRS Team Meeting, Brussels, 15-16 September 2008

[45] **Dehant V., Le Maistre S., Mitrovic M., Rosenblatt P.,** Chicarro A., Fisackerly R., and the LaRa team and the SDT of Mars-NEXT
Rotation and internal dynamics from future geodesy experiment
European Planetary Science Congress 2008, Munster, Germany, 21-24 September 2008

[46] Breuer D., Chicarro A., Chassefière E., **Dehant V.,** Fisackerly R., Grady M., Pinet P., Rossi A., Santovincenzo A.
Study of habitability from Mars-NEXT
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[47] Chicarro A., Breuer D., Chassefière E., **Dehant V.,** Fisackerly R., Grady M., Pinet P., Rossi A., Santovincenzo A.
Mars-NEXT mission – A future step in the European exploration of Mars
European Planetary Science Congress 2008, Munster, Germany, 21-24 September 2008

[48] **Rivoldini A., Van Hoolst T., Verhoeven O.**
Improvements on the interior structure of Mercury expected from geodesy measurements
European Planetary Science Congress 2008, Munster, Germany, 21-24 September 2008

[49] **Van Hoolst T., Karatekin Ö.**
The influence of internal gravitational coupling and ice viscosity on Titan's length-of-day variations
European Planetary Science Congress 2008, Munster, Germany, 21-24 September 2008

[50] **Dehant V.**, Folkner W., Chicarro A., and the LaRa team and the SDT of Mars-NEXT
Rotation and internal dynamics from future geodesy experiment
Journées Systèmes de Référence Spatio-temporels, Dresden, Germany, 21-23 September 2008

[51] **Dehant V.**, and the LaRa team
Lander Radioscience/LaRa Project background and summary of science objectives
Pre-Preliminary Design Review Meeting, CSL & OMP, 23-24 September 2008

[52] **Dehant V.**, and the LaRa team
Lander Radioscience/LaRa Operations
Pre-Preliminary Design Review Meeting, CSL & OMP, 23-24September 2008

[53] **Dehant V.**, and the LaRa team
Lander Radioscience/LaRa Requirements
Pre-Preliminary Design Review Meeting, CSL & OMP, 23-24 September 2008

[54] **Mitrovic M., Dehant V.**
Modeling LaRa radio signal
Pre-Preliminary Design Review Meeting, CSL & OMP, 23-24 September 2008

[55] **Le Maistre, Dehant V.**
LaRa experiment simulations
Pre-Preliminary Design Review Meeting, CSL & OMP, 23-24 September 2008

[56] **Dehant V.**, and the LaRa team
Lander Radioscience/LaRa AOB: Importance of the radio links lander-orbiter and orbiter-Earth for science
Pre-Preliminary Design Review Meeting, CSL & OMP, 23-24 September 2008

[57] **Yseboodt M., Dehant V., Van Hoolst T**.
Librations of Mercury due to planetary perturbations
DPS meeting, Division for Planetary Sciences of the American Astronomical Society, Ithaca, NY, USA, 10-15 October 2008

[58] **Karatekin Ö., Dehant V.,** Lebonnois S.
Length of day variations of Venus
DPS meeting, Division for Planetary Sciences of the American Astronomical Society, Ithaca, NY, USA, 10-15 October 2008

[59] **Dehant V.**

Partie 4: L'intérieur de la Terre et la géodynamique globale; 4.4. Les autres planètes du système solaire
Lecture organized by IFA, Brussels, 20 October 2008

[60] **Dehant V.**, Rosat S., Trinh A., Pfyffer G.
Mercury rotation variations from altimetry crossover data
BeLA Science Team Meeting, Roma, Italy, 20-22 October 2008

[61] **Dehant V.** Pfyffer G.
Mercury rotation variations from camera data and perspectives
BeLA Science Team Meeting, Roma, Italy, 20-22 October 2008

[62] **Van Hoolst T., Rivoldini A., Verhoeven O**.
Expected improvements on Mercury's interior structure from BepiColombo geodesy experiments
BepiColombo Geodesy and Geophysics Working Group Meeting, Rome, 20-22 October 2008

[63] **Dehant V.**
Partie 5: Les Sciences de la Terre et de l'Espace et la Société; 5.4. Les Risques Naturels ; (5) Les catastrophes cosmiques
Lecture organized by IFA, Brussels, 27 October 2008

[64] **Dehant V.**
Partie 5: Les Sciences de la Terre et de l'Espace et la Société; 5.5. La vie dans l'univers
Lecture organized by IFA, Brussels, 27 October 2008

[65] Chicarro A., Breuer D., Chassefière E., **Dehant V**., Fisackerly R., Grady M., Pinet P., Rossi A., Santovincenzo A.
Mars-NEXT mission
Business meeting in the archeological geology Division Meeting, Geological Society of America, 27 October 2008

[66] Chicarro A., Breuer D., Chassefière E., **Dehant V**., Fisackerly R., Grady M., Pinet P., Rossi A., an Santovincenzo A.
Mars-NEXT mission; science context
European Mars Exploration Conference, ESTEC, 16 November 2008

[67] **Pham L.B.S., Karatekin Ö., Dehant** V., Lammer, H.
Effect of Impacts on the Atmospheric Evolution of Mars
ESLAB 2008, Cosmic Cataclysms and Life, Frascati, Italy, 10-14 November 2008

[68] **Van Hoolst, T**.
Libration and rotation of large icy satellites
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[69] **Le Binh San Pham, Karatekin Ö., Dehant V**., Lammer H.
Effects of impacts on the atmospheric evolution of Mars
Groupe de Contact 'Astrobiologie' du FNRS-FRS, Planetarium, Brussels, 20 November 2008

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MarsExpress Radio Science team, Stanford, USA, 11 December 2008

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MarsExpress Radio Science team, Stanford, USA, 11 December 2008

[72] **Rosenblatt P., Le Maistre S.,** Bruinsma S., **Dehant V.**
Status of the drag experiment

VenusExpress Radio Science team, Stanford, USA, 11 December 2008

[73] Chicarro A., Breuer D., Chassefière E., **Dehant V**., Fisackerly R., Grady M., Pinet P., Rossi A., Santovincenzo A.
Mars-NEXT a future step in the European exploration of Mars
Royal Society Annual Meeting, 12 December 2008

[74] **Dehant V., Le Maistre S., Mitrovic M., Rosenblatt P., Rivoldini A.,** Folkner W., Orban D., Renotte E., and the LaRa team
Rotation and internal dynamics of Mars from the LaRa experiment in ExoMars
AGU Fall Meeting, Session: P14: Landed Measurements on Mars: Ground Truth for Orbital Data, San Francisco, USA, 15-19 December 2008

[75] **Rosenblatt P., Le Maistre S.,** Marty J.C., **Dehant V.,** Pätzold M., **Van Hoolst T.**
Improvement of the mass determination of both Martian moons using MEX, MGS, ODY and MRO tracking data
AGU Fall Meeting, Session: P14: Landed Measurements on Mars: Ground Truth for Orbital Data, San Francisco, USA, 15-19 December 2008

[76] **Beuthe M., Dehant V**.
Martian tectonics on a spatially heterogeneous lithosphere
AGU Fall Meeting, San Francisco, USA, 15-19 December 2008

[77] **Van Hoolst T., Karatekin Ö**, Rambaux N.
The Influence of Internal and External Torques on Titan's Length-of-day Variations
AGU Fall Meeting, San Francisco, USA, 15-19 December 2008

[78] **Pfyffer G., Van Hoolst T.**, **Dehant V**.
Libration and obliquity of Mercury from the BepiColombo radio science and camera experiments
AGU Fall Meeting, San Francisco, USA, 15-19 December 2008

Seminars

[79] **Karatekin Ö**.
Dynamic stability of space capsules at low speeds
VKI Lecture series on Experimental determination of dynamic stability parameters, von Karman Institute for fluid dynamics, Rhode-St-Genèse, 18-22 February 2008

[80] **Dehant V**.
A la découverte de la Planète Mars
Conférence-séminaire pour l'Université Catholique de Louvain, Unité ASTR, Louvain-la-Neuve, 15 February 2008

[81] **Dehant V**.
Habitabilité des planètes et lunes telluriques
Conférence-séminaire à l'Université de Liège, Liège, 6 March 2008

[82] **Verhoeven O**., Mocquet A., Vacher P., **Rivoldini A**., Menvielle M., Arrial P-A., Choblet G., Tarits P., **Dehant V., Van Hoolst T**.
Nouvelles contraintes sur la température et la composition du manteau inférieur fournies par une inversion jointe de données séismiques et électromagnétiques
Laboratoire de Planétologie et Géodynamique, Université de Nantes, 4 April 2008

[83] **Rosenblatt P**.
Accurate spacecraft orbit to determine tides, rotation and gravity field of planets
Observatoire de la Côte d'Azur, Grasse, France, 15 May 2008

[84] **Karatekin Ö**.
Planetary atmospheres: Atmospheric angular momentum variations of Mars and Venus

Annual meeting of section 1, Royal Observatory of Belgium, June 2008

[85] **Baland R.-M.**, Lanotte A., Salmon S.
La recherche de planètes habitables dans les systèmes binaires
Course of Astrobiologie (Geol0263-1, Javaux Emmanuelle, ULg), 6 June 2008

[86] **Baland R.-M.**
Résonance spin-orbite: Etat de Cassini d'Europe
Course of Dynamique Céleste et Résonances (SMAT M127, Lemaître Anne, FUNDP), 30 June 2008

[87] **Beuthe M**.
Martian tectonics on a spatially heterogeneous lithosphere
Internal team seminar, Royal Observatory of Belgium, Brussels, 28 October 2008

[88] **Trinh A**.
Representations of the rotation group SO(3) and the spectral analysis of tide-generating potentials
Internal team seminar, Royal Observatory of Belgium, Brussels, 28 October 2008

[89] **Rosenblatt P**.
Accurate spacecraft orbit to determine tides, rotation and gravity field of planets
Institut de Mécanique Céleste et de Calcul des Ephémérides (IMCCE) / SYRTE / Observatoire de Paris, Paris, France, 17 November 2008

[90] **Hees A**.
Vibrating system in General Relativity: toward new test in General Relativity?
ESA/ESTEC, Noordwijk, the Netherlands, 26 November 2008

[91] **Yseboodt M.**
Mercury's rotation: the motion of the spin axis in space, the librations
Internal team seminar, Royal Observatory of Belgium, Brussels, 4 December 2008

Wikis and Websites

- Updating of the MarsExpress SPICE kernel orbits with the accurate orbits produced at ROB (see paper [10]) (ftp://ssols01.esac.esa.int/pub/data/SPICE/MEX/kernels/spk/)

B.1.7. Missions

Assemblies, symposia:

M. Beuthe (AGU fall meeting)
V. Dehant (EGU General Assembly, European Planetary Science Congress 2008, Summer School Forcalquier, AGU fall meeting)
Ö. Karatekin (AOGS, American Astronomical Society DPS meeting, ESLAB Symposium: Cosmic Cataclysms and Life)
S. Le Maistre (EGU General Assembly)
G. Pfyffer (Scientific Writing School for Young Astronomers, AGU Fall meeting)
L.B.S. Pham (EGU General Assembly, ESLAB Symposium: Cosmic Cataclysms and Life, ISSI workshop)
A. Rivoldini (EGU General Assembly, European Planetary Science Congress 2008)
P. Rosenblatt (EGU General Assembly, AGU fall meeting)
A. Trinh (2nd F.R.S.-FNRS 'Astrobiology' contact group workshop)
T. Van Hoolst (EGU General Assembly, European Planetary Science Congress 2008, Workshop on Moons of the outer

	Solar System: exchange processes involving the interiors, AGU fall meeting) M. Yseboodt (American Astronomical Society DPS meeting)
Commissions, working groups (days):	M. Beuthe (2 days) V. Dehant (41 days) S. Le Maistre (4 days) P. Rosenblatt (7 days) T. Van Hoolst (6 days)
Research visits (days):	V. Dehant (17 days) Ö. Karatekin (7 days) P. Rosenblatt (17 days) A. Trinh (12 days) T. Van Hoolst (1 day) O.Verhoeven (26 days) M. Yseboodt (1 day)

B.2. Earth rotation and interior

B.2.1. Objectives

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

B.2.2. Progress and results

B.2.2.1. Analysis of VLBI data

- Very Long Baseline Interferometry (VLBI) measures differential arrival time of radio signals from distant radio sources (e.g., quasars) on antennas located quite uniformly on the continents. Although very distant, these radio sources are not point-like and are not observed on a regular basis. The observations are precise but the precision depend on the stability of the sources observed and the noise on the observations. This behaviour/precision changes with time. In this context, L. Koot has developed a new inversion strategy of the VLBI observations relying on the following two main aspects: (1) the Earth interior parameters are estimated directly from the nutation data time series; this has allowed to use all the available information of the data time series and to take into account the time variable error on the data; (2) the observations are inverted using a probabilistic (Bayesian) inversion method as it does not require the model to be linear and easily allows for the incorporation of model uncertainties. The results obtained by applying this inversion procedure to the most recent VLBI observations have been published this year (see [5] and [31]).

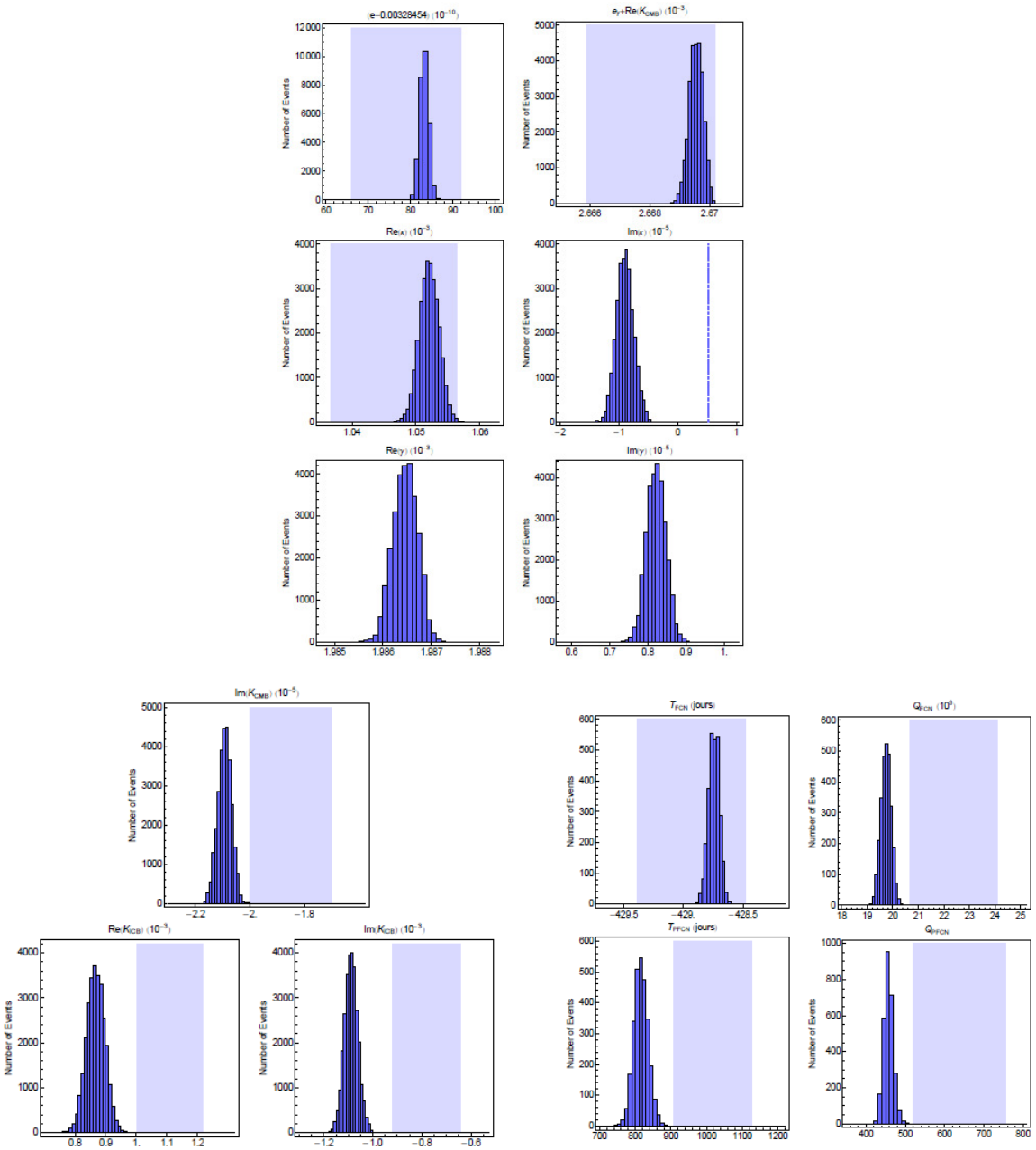

Figure 23: Marginal of the probability density for the dynamical ellipticity, the compliances, the coupling constants, and the quality factors of the FCN and the FICN; the colored rectangular zones indicate the 3σ domain of the estimation performed by Mathews et al (2002) for comparison.

- VLBI data have also been used by L. Koot for estimating the FCN free amplitude (most probably excited by the atmosphere).

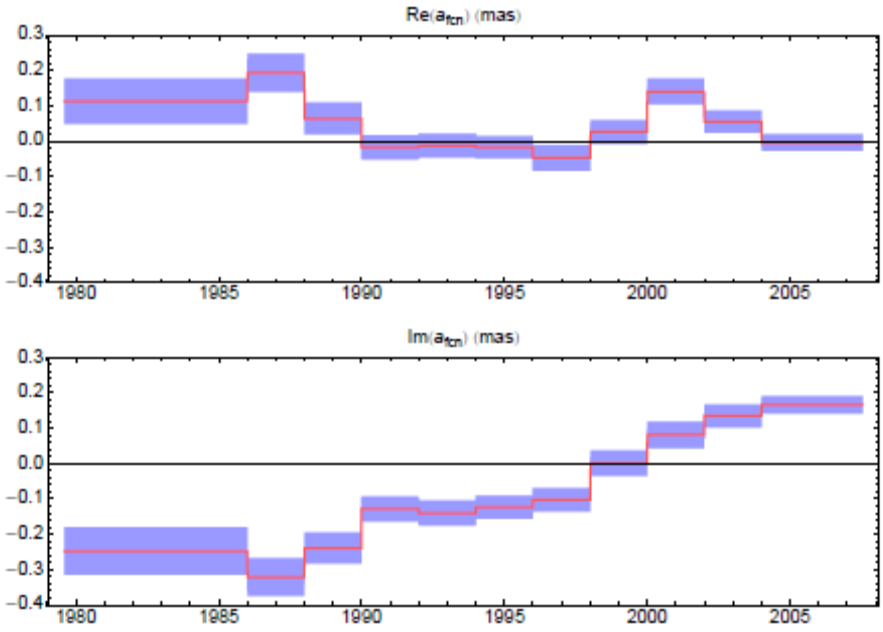

Figure 24: Amplitude of the free FCN as a function of time; real part and imaginary part; the red curve represents the estimated mean and the colored zone indicates the 3σ domain.

- VLBI data are used to determine the precession and nutation of the Earth (Earth orientation in space). These nutations are very sensitive to the interior of the Earth in particular to the liquid core and its coupling mechanisms with the inner core and the mantle. V. Dehant has worked on these coupling mechanisms considering a topographic coupling in collaboration with Marta Folgueira (Spain). First results have been presented and published (see [28]).
- VLBI data and the contamination of the stability of the radio sources used in the determination of the nutations have been evaluated (see [5] and [28]).
- The celestial frame instabilities have been studied from VLBI data and the impact on geophysical studies has been assessed in collaboration with S. Lambert and A.M. Gontier from the Observatoire de Paris. A paper has been published on that subject [5].
- After the work of Rothacher et al. (1999) it is expected that using GNSS observations in addition to VLBI observations can improve our knowledge about nutation in the short-period domain (nutation terms with periods up to 25-30 days). There are two ways of combination of different technique observations: (1) at the "product" level when one combines nutation offsets derived from VLBI observations with nutation rates derived from GNSS observations; (2) at the normal equation level when matrices of normal equations should be combined with subsequent re-estimation of interested parameters. The methods of the combination at the "product" level being developed rather well, M. Kudryashova has concentrated on the second method expected to provide more consistent results. She has developed the first steps to perform combinations at the level of normal equations.

B.2.2.2. Report as President of Commission 19 from IAU or of Commission 3 of IAG

- Several reports have been done in the frame of the duty of V. Dehant as President of Commission 19 of the IAU [19][31] and [24].
- Several reports have been done in the frame of the duty of V. Dehant as President of Commission 3 of the IAG [42][47] [24] and [28].

B.2.2.3. Theory of nutation

- A review of the new results on nutations obtained at the ROB has been presented at the Journées Systèmes de Référence and published in the proceedings (see [13]).

- A new nutation model has been published in the literature by another group. But the model has been judged to be inexact while residuals are close to the observation. V. Dehant, in collaboration with P.M. Mathews (India), N. Capitaine (France), P. Wallace (UK) and S. Lambert (France). Two papers have been published (see [2] and [20]).
- V. Dehant and M. Folgueira have also computed the contributions of the tidal Poisson terms in the theory of nutation of a non-rigid Earth. A paper has been published (see [26]).
- A. Trinh has begin the study of including triaxiality in the computation of the Earth (and other terrestrial planets) deformation, rotation, and orientation.

B.2.3. Perspective for next years

- M. Kudryashova, V. Dehant and C. Bruyninx will evaluate nutation from combined VLBI data and GNSS data. This work will be done in the frame of an Action 1 project.
- M. Folgueira and V. Dehant will evaluate the topographic coupling mechanism at the core-mantle boundary.
- V. Dehant, in collaboration with P.M. Mathews shall finish their book on "Precession, nutation, and wobble of the Earth".
- The procedure of nutation rates estimation will be checked (by comparison with previous results of M. Kudryashova obtained during her work in the Institute of Geodesy and Geophysics (Vienna)) and revisited in order to produce SINEX output.
- SINEX files from GNSS observations will be collected at ROB; VLBI SINEX files will be collected in Paris Observatory.
- A strategy of combination of VLBI/GNSS SINEX files will be developed (M. Kudryashova, C. Bruyninx, and V. Dehant).
- Study of the couplings between the mantle and the core and between the outer and inner cores from VLBI observations and obtaining of constraints on the physical properties of the core-mantle and inner core boundaries.

B.2.4. Personnel involved

Scientific staff:	V. Dehant (project leader, ROB permanent)
	L. Koot (Aspirant FNRS)
	M. Kudryashova (on Action 1 – Belspo - M0/33/023)
Technical staff:	L. Van Camp (ROB permanent)
	R. Laurent (ROB permanent)

B.2.5. Partnerships

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

- Olivier de Viron and Marianne Greff-Lefftz (IPGP, France)
- Nicole Capitaine and Sébastien Lambert, Observatoire de Paris
- Marta Folgueira, Madrid University, Spain
- Sonny P.M. Mathews, Madras University

Grants/Projects used for this research/service

- Action 1 – Belspo - M0/33/023 "Determination and modeling of nutation from VLBI (Very Long Baseline Interferometry) and GNSS (Global Navigation Satellite System) observations"
- BELSPO-Action 1, 1-MO/33/013, Interaction planète-couches fluides : Effet sur la rotation planétaire, S. Lambert
- 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
- FNRS Aspirant, L. Koot

- EU, Descartes Prize 2003, M. Folgueira

Visitors:

- Prof Shu and Sun Heping, Huhan, China, 8-11 September

B.2.6. Scientific outreach

Meeting presentations

[1] Capitaine N., Mathews P.M., **Dehant V.**, Wallace P., Lambert S.
Comparisons of precession-nutation models
Fifth IVS General Meeting, Session on 'Interpretation of VLBI Results in Geodesy, Astrometry and Geophysics', St Petersburg, 3-6 March 2008

[2] Capitaine N., Mathews P.M., **Dehant V.,** Wallace P., Lambert S.
Comparisons of precession-nutation models
Fifth IVS General Meeting, Session on 'Interpretation of VLBI Results in Geodesy, Astrometry and Geophysics', St Petersburg, March 2008

[3] **Dehant V.,** Capitaine N., Mathews P.M., Wallace P., Lambert S.
Comparisons of precession-nutation models and models of the Earth's interior
EGU 2008 General Assembly, Vienna, Austria, 14-18 April 2008

[4] **Koot L., Rivoldini A.,** de Viron O., **Dehant V.**
Using VLBI measurements of nutation to estimate Earth internal structure parameters
EGU 2008 General Assembly, Vienna, Austria, 14-18 April 2008

[5] **Dehant V.**
Partie 1: La Terre dans l'espace et les systèmes de référence ; 1.1. La Terre dans le système solaire
Lecture organized by IFA, Brussels, 29 September 2008

[6] **Dehant V.**
Partie 1: La Terre dans l'espace et les systèmes de référence ; 1.2. La Rotation de la Terre.
Lecture organized by IFA, Brussels, 29 September 2008

[7] **Dehant V.**
Partie 1: La Terre dans l'espace et les systèmes de référence ; 1.3. Les référentiels astronomiques, géographiques et géodésiques
Lecture organized by IFA, Brussels, 29 September 2008

Seminars

[8] **Kudryashova M.**
Estimation of the nutation parameters from GNSS observations
ROB Section 1 seminary, 8 December 2008

[9] **Koot L.**
What can be learned about the Earth internal structure from the nutation data?
University of Leeds, School of Earth and Environment, Leeds, United Kingdom

Wikis and Websites

- Updating of SBC website (http://sbc.oma.be)
- Updating of the private Section 1 website

B.2.7. Missions

Assemblies, symposia: V. Dehant (EGU Vienna, Austria, 13-18 April)
L. Koot (EGU Vienna, Austria, 13-18 April)
V. Dehant (EUREF, Brussels, 18 June)

V. Dehant (AGU San Francisco, USA, 14-21 December)
L. Koot (Ecole de Physique des Houches, 13-17 October)

Research visits (days): V. Dehant (Observatoire de Paris, 1 day, October 31st)
L. Koot (Institut de Physique du Globe de Paris, 11-14 February)

C. Publications

C.1. Publications with peer review

[1] **Beuthe M.**
Thin elastic shells with variable thickness for lithospheric flexure of one-plate planets
Geophysical Journal International, 172(2), 817-841 (2008), DOI: 10.1111/j.1365-246X.2007.03671.x

[2] Capitaine N., Mathews P.M., **Dehant V.,** Wallace P., Lambert S.
On the IAU 2000/2006 precession-nutation and comparison with other models and VLBI observations
Celest. Mech. Dyn. Astr., DOI: 10.1007/s10569-008-9179-9

[3] **Defraigne P.,** Guyennon N., **Bruyninx C**.
GPS Time and Frequency Transfer: PPP and Phase-only Analysis
International Journal of Navigation and Observation, DOI: 10.1155/2008/175468

[4] **Karatekin Ö., Van Hoolst T**., Tokano T.
Effect of internal gravitational coupling on Titan's non-synchronous rotation
Geophys. Res. Letters, 35, L16202, DOI: 10.1029/2008GL034744

[5] **Koot L., Rivoldini A.,** de Viron O., **Dehant V.**
Estimation of Earth interior parameters from a Bayesian inversion of VLBI nutation time series
J. Geophys. Res., 113(B8), CiteID B08414, DOI: 10.1029/2007JB005409

[6] Lambert S.B., **Dehant V.**, Gontier A.-M.
Celestial frame instability in VLBI analysis and its impact on geophysics
Astron. Astrophys., 481(2), pp. 535-541, DOI: 10.1051/0004-6361:20078489

[7] Métivier L., **Karatekin Ö., Dehant V**.
The effect of the internal structure of Mars on its seasonal loading deformations
Icarus, 194(2), pp. 476-486, DOI: 10.1016/j.icarus.2007.12.001

[8] Petiteau A., Auger G., Halloin H., Jeannin O., **Pireaux S.,** Plagnol E., Regimbau T., Vinet J-Y.
LISACode: A scientific simulator of LISA
Physical Review D, 77023002, 2008

[9] **Rosat S., Rosenblatt P., Trinh A., Dehant V.**
Mars and Mercury rotation variations from altimetry crossover data: Feasibility study
J. Geophys. Res., 113(E12), CiteID E12014, DOI: 10.1029/2008JE003233

[10] **Rosenblatt P**., Lainey V., **Le Maistre S**., Marty J.C., **Dehant V**., Pätzold M., **Van Hoolst T**., Häusler B.
Accurate MarsExpress orbit to improve the determination of the mass and ephemeris of the Martian moons
Planet. Sp. Sci. 56/7, pp. 1043-1053, DOI: 10.1016/j.pss.2008.02.004

[11] Torres J.A., Z. Altamimi, C. Boucher, E. Brockmann, **C. Bruyninx**, A. Caporali, W. Gurtner, H. Habrich, H. Hornik, J. Ihde, A. Kenyeres, J. Mäkinen, H. v d Marel, H. Seeger, J. Simek, G. Stangl, G. Weber
Status of the Europeean Reference Frame (EUREF)

"Observing our Changing Earth", IAG Symposia Series, Vol. 133, pp. 47-56, DOI: 10.1007/978-3-540-85426-5

[12] **Van Hoolst T**., Rambaux N., **Karatekin Ö., Dehant V., Rivoldini A**.
The librations, shape, and icy shell of Europa
Icarus 195/1, pp. 386-399, DOI: 10.1016/j.icarus.2007.12.011

C.2. Publications without peer review

[13] **Baire Q., Defraigne P.**
Combining GPS and GLONASS for Time and Frequency Transfer
Proceedings of the 28th EFTF, 2008 (CD-rom)

[14] Bavier M., **Bruyninx C.,** Lejeune S., Moins M., **Pottiaux E., Roosbeek F.**, Voet P., Warnant R.
National report of Belgium
Mitteilungen des BKG, Band 40, EUREF Publication No. 16, Ed. BKG, Frankfurt am Main, pp. 214-215

[15] Breuer D., Chicarro A., Chassefière E., **Dehant V.**, Fisackerly R., Grady M., Pinet P., Rossi A., Santovincenzo A.
Study of habitability from Mars-NEXT
Extended abstract (2p), European Planetary Science Congress 2008, Munster, Germany, 21-24 September 2008, EPSC Abstracts Vol. 3, EPSC2008-A-00346

[16] **Bruyninx C.**
GPS and GLONASS Data Analysis using Stations from the EUREF Permanent Network
Mitteilungen des BKG, Band 40, EUREF Publication No. 16, Ed. BKG, Frankfurt am Main, pp. 377-383

[17] **Bruyninx C., Roosbeek F**.
The EUREF Permanent Network: Recent Achievements
Mitteilungen des BKG, Band 40, EUREF Publication No. 16, Ed. BKG, Frankfurt am Main, pp. 105-112

[18] Brzezinski A., Ma C., **Dehant V., Defraigne P**., Dickey J.O., Huang C.-L., Souchay J., Vondrák J., Charlot P., Richter B., Schuh H.
Commission 19: Rotation of the Earth, Triennial report 2006-2009
Proceedings of the International Astronomical Union , Volume 4, Transactions T27A, December 2008, pp 37-49, DOI: 10.1017/S1743921308025271

[19] Capitaine N., Andrei A.H., Calabretta M.R., **Dehant V.**, Fukushima T., Guinot B.R., Hohenkerk C.Y., Kaplan G.H., Klioner S.A., Kovalevsky J., Kumkova I.I., Ma C., McCarthy D.D., Seidelmann P.K., Wallace P.T.
Division 1 WG Nomenclature for fundamental astronomy
In: Proc. IAU, 3, Transactions T26B, pp.74-78, DOI: 10.1017/S1743921308023685, Cambridge University Press.

[20] Capitaine N., Mathews P.M., **Dehant V.**, Wallace P., Lambert S.
Comparisons of precession-nutation models
In: Proc. Fifth IVS General Meeting, Session on 'Interpretation of VLBI Results in Geodesy, Astrometry and Geophysics', St Petersburg, March 2008, Eds. A. Finkelstein and D. Behrend, Russian Science Series, pp. 221–230

[21] **Defraigne P., Bruyninx C., Legrand J**.
Continuous Frequency Transfer Using GPS Carrier-Phases
Proc. EFTF 2008 (on CD)

[22] **Defraigne P.,** Martinez M.C.

Combination of TWSTFT and GPS data for Time Transfer
Proceedings of the 28th EFTF, 2008 (CD-rom)

[23] **Defraigne P**., Manchester R.N., Matsakis D., Hosokawa M., Leschiutta S., Petit G., Zao-Cheng Z.
Commission 31: Time, Triennial report 2006-2009
Proceedings of the International Astronomical Union , Volume 4, Transactions T27A, December 2008, pp 50-54 , DOI: 10.1017/S1743921308025283

[24] **Dehant V.**
Report of Commission 3 on Earth Rotation and Geodynamics
Geodesist's Handbook, J. Geodesy, 78(9-12), Part Commission reports, Commission 3, pp. 765-773; or IAG Travaux, publication on the web, Part Commission reports, Commission 3, 17 p.

[25] **Dehant V.,** Brzezinski A.
Commission 19: Rotation of the Earth
In: Proc. IAU, 3, Transactions T26B, DOI: 10.1017/S17439213080236, Cambridge University Press

[26] **Dehant V.**, Folgueira M., Rambaux N., Lambert S.B.
Contributions of tidal Poisson terms in the theory of the nutation of a nonrigid Earth
In: IUGG proceedings Perugia, Italy, 'Observing our Changing Earth', pp. 455-462, DOI: 10.1007/978-3-540-85426-5

[27] **Dehant V.**, Lambert S.B., Rambaux N., Folgueira M., **Koot L.**
Recent advances in modeling precession-nutation
In: Proc. Journées Systèmes de Références Spatio-temporels, Paris, France, September 2007, Ed. N. Capitaine, pp. 82-87.

[28] **Dehant V., Le Maistre S., Mitrovic M., Rosenblatt P.,** Chicarro A., Fisackerly R., and the LaRa team and the SDT of Mars-NEXT
Rotation and internal dynamics from future geodesy experiment
Extended abstract (2p), European Planetary Science Congress 2008, Munster, Germany, 21-24 September 2008, EPSC Abstracts Vol. 3, EPSC2008-A-00162

[29] Drewes H., **Dehant V.**, Lambert S.
Inconsistencies in geodetic concepts, models and analyses at the 0.1 ppb level
Position paper, in: Proceedings of the GGOS workshop, Munich, Germany, October 2006

[30] Folgueira M., **Dehant V.**
Estimation of the topographic torque at the core-mantle boundary on the nutation
In: Proc. Journées Systèmes de Références Spatio-temporels, Paris, France, September 2007, Ed. N. Capitaine, pp. 115-116.

[31] Fukushima T., Vondrak J., Capitaine N., Krasinsky G.A., Milani A., Platais I., **Dehant V.**, Matsakis D.N.
Division 1 fundamental astronomy
In: Proc. IAU, 3, Transactions T26B, pp.71-73, DOI: 10.1017/S1743921308023673, Cambridge University Press

[32] Holmes D.P., Simpson R., Tyler G.L., Pätzold M., **Dehant V., Rosenblatt P.,** Häusler B., Goltz G., Kahan D., Valencia J., Thompson T.
The challenges and opportunities for international cooperative radio science; experience with the MarsExpress and VenusExpress missions
Space Obs. 2008 Conference, AIAA 2008-3556, on CD

[33] **Karatekin Ö**.
Dynamic stability of space capsules at low speeds
VKI Lecture series Monograph 2008-02 on "Experimental determination of dynamic stability parameters", ISBN 978-2-930389-81-8

[34] **Koot L., Rivoldini A.,** de Viron O., **Dehant V.**
Estimation of Earth interior parameters from a Bayesian inversion of nutation time series
In: Proc. Journées Systèmes de Référence spatio-temporels 2007, Paris, France, September 2007, Ed. N. Capitaine, pp. 91-94.

[35] **Kudryashova M.**, Snajdrova K., Weber R., Heinkelmann R., Schuh H.
Combination of Nutation Time Series Derived from VLBI and GNSS
IVS 2008 General Meeting Proceedings, eds. A. Finkelstein and D. Behrend, 2008, pp. 240-246

[36] Lambert S.B., **Dehant V.**, Gontier A.-M.
Earth's interior with VLBI… and the Celestial Reference Frame?
In: Proc. Journées Systèmes de Références Spatio-temporels, Paris, France, September 2007, Ed. N. Capitaine, pp. 103-106.

[37] Moins M., **Bruyninx C**.
Relative Positioning in Europe: Influence of the GPS+Galileo Satellite Geometry
Mitteilungen des BKG, Band 40, EUREF Publication No. 16, Ed. BKG, Frankfurt am Main, pp. 335-342

[38] **Pireaux S.**
Proper time versus TCB used for time delay interferometry in the LISA mission
Proceedings of the Atelier: Gravitation et Références pour des Applications en Astronomie et en PHysique (GRAAPH), Les Journées SF2A, 30th June-4th July 2008, Paris, France, http://www.sf2a.asso.fr/, GRAAPH 141.

[39] **Pireaux S.**
Relativistic orbit determination with the RMI (Relativistic Motion Integrator) software for the LISA mission
Proceedings of the Workshop: Gravitation et Références pour des Applications en Astronomie et en PHysique (GRAAPH), Les Journées SF2A, 30th June-4th July 2008, Paris, France, http://www.sf2a.asso.fr/, GRAAPH 143.

[40] **Pireaux S.**
Time Delay Interferometry and Time Scales in the LISA mission,
Proceedings of the EFTF 2008 (22nd European Frequency and Time Forum)", 23rd -25th April 2008, Toulouse, France, Toulouse Space Show'08 DVD, E5b04 - 010.

[41] **Pireaux S., Defraigne P., Bergeot N., Bruyninx C.**
Influence of Ionospheric Perturbations in GPS Time and Frequency Transfer
Proceedings of the PTTI 2008 (Precise Time and Time Interval Systems and Applications Meeting), 1st-4th December 2008, Reston, Virginia, USA (CD-rom)

[42] Rambaux N., **Karatekin Ö., Van Hoolst T**.
Europa's librations and ice shell thickness
In: Proc. of the Société Française d'Astronomie et d'Astrophysique (SF2A), Grenoble, France, 2-7 July 2007

[43] Rummel R., Beutler G., **Dehant V.**, Gross R., Ilk K.H., Plag H.-P., Poli P., Rothacher M., Stein S., Thomas R., Woodworth P.L., Zerbini S., Zlotnicki V.
Understanding a dynamic planet: Earth science requirements for gravimetry
In: The Global Geodetic Observing System: Meeting the requirements of a global society on a changing planet in 2020, the Reference Document GGOS-2020, May 2007, pp. 54-61; December 2008, pp. 89-134

[44] **Van Hoolst T**.
GGFC Special Bureau for the Core

IERS Annual Report 2006, Eds. W.R. Dick and B. Richter, Verlag des Bundesamts für Kartographie und Geodäsie, Frankfurt am Main, p. 104-105

[45] **Van Hoolst T., Karatekin Ö**.
The influence of internal gravitational coupling and ice viscosity on Titan's length-of-day variations
In: European Planetary Science Congress 2008, 2 pages

[46] Vondrák J., McCarthy D.D., Fukushima T., Brzezinski A., Burns J.A., **Defraigne P.**, Evans D.W., Kaplan G.H., Klioner S.A., Knežević Z., Kumkova I.I., Ma C., Manchester R.N., Petit G.
Division I: Fundamental Astronomy, Triennial report 2006-2009
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DEPARTMENT 1: Reference systems and geodynamics

SECTIONS 2-3: Gravimetry & Seismology

Introduction:

The scientific activities of the section seismology-gravimetry are related to the study of the seismic activity and its 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, the section develops 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.

The section is hosting since 2007 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 of the section are devoted to conduct and analyse gravity measurements at the Earth surface and also to analyse data from space experiments, mainly GRACE. Gravity measurements supply information on geographical structural heterogeneities in the underground and on geodynamical processes and their time evolution. An important part of this scientific work is devoted to evaluate crustal deformation using its imprint on the gravity signal. For this purpose, the section is in charge of the scientific and technical follow-up of the superconducting gravimeter installed in the Membach station, of an absolute gravimeter and several field relative gravimeters.

The section has also the responsibility of the GIANT and LISSA projects that provide scientific analysis of the permanent seismic and geodetic measurements, and annual absolute gravity measurements that will be done at the « Princess Elisabeth » base in Antarctica.

D. Seismology, seismic hazards and risks, earthquake monitoring

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

D.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 dif-

ferent sources (chronicles, annotations, 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.

Understanding the irregularity of the seismic cycle: a case study in Turkey

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.

D.1.2. Progress and results

D.1.2.1.Seismic activity in northwest Europe

The seismic sequence in central Belgium

During 2008, the earthquake activity in Belgium was characterized by the beginning of a seismic sequence some 25 km to the south-east of Brussels (region of Court-Saint-Etienne), that is always running in April 2009 with more than 150 recorded earthquakes. The first earthquake occurred on July 12, 2008 and was of 2.2 M_L magnitude. The strongest earthquake occurred on July 13 at 13h45m. It was of magnitude 3.2 and was felt up to the region north of the city of Brussels (Figure 25). At the beginning of the sequence, we installed two mobile seismic stations in Ottignies and Grand-Leez on July 16 and five other ones at the beginning of August. These stations recorded earthquakes that are not recorded by the stations of the Belgian permanent seismic network and provide data that will allow conducting a very detailed study of the sequence.

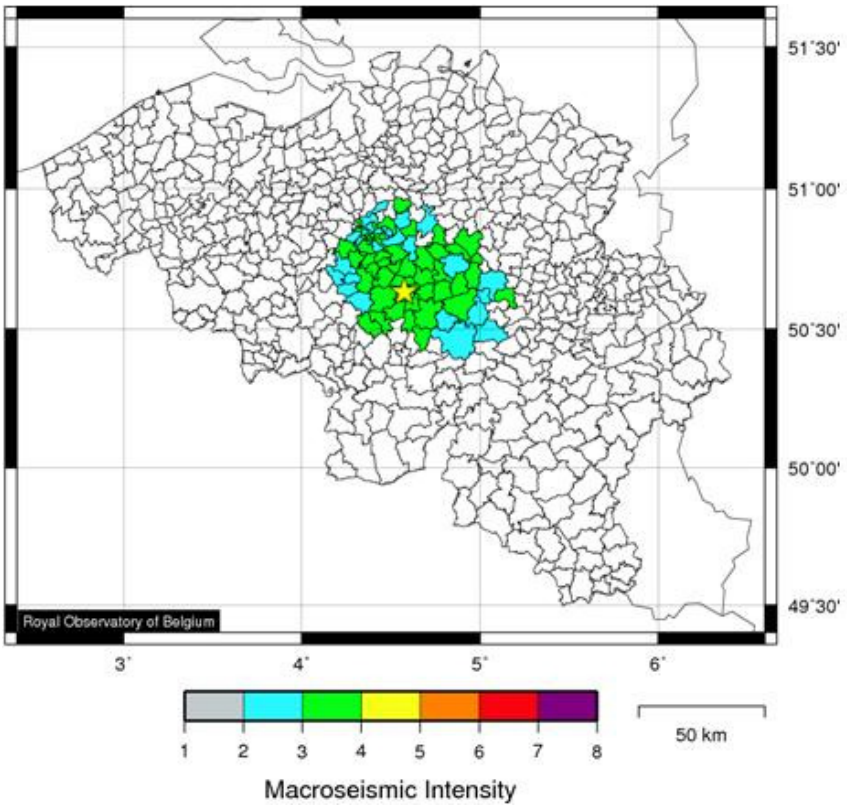


Figure 25: Macro-seismic map of the July 13, 2008 in Court-Saint-Etienne (from the on line questionnaire "Did you feel it?")

Compilation study "Seismicity of Flanders" for the Flemish Government

The section seismology-gravimetry coordinates a compilation study "Seismicity in Flanders" for the Department "Leefmilieu, Natuur en Energie" of the Flemish Government. It consists of two main tasks:

- Study of seismic hazard, including time-independent factors (geologic conditions, soil stability, ...) and time-dependent factors (earthquake probabilities), which should lead to the drafting of a seismic hazard map;
- Study of the earthquake history of Flanders and surrounding areas, and its situation in the current tectonic context.

In this project, we work 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 Royal Observatory of Belgium is involved in 5 different work packages:

- WP3: Seismic hazard map of Flanders at bedrock level (in cooperation with KULeuven);
- WP5: Seismic catalogue of Flanders and its surroundings;
- WP6: Seismotectonic zoning 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.

Researches on historical earthquakes

In the year 2008, our knowledge of the major earthquake that occurred on 23 February 1828 in the central part of Belgium has highly grown, following investigations in Archives and Libraries to find new data in written sources. It is of great interest in the history of seismology because it was the object of various scientific studies contemporary of the event, one of them even resulting in one of the first published macroseismic map worldwide. Despite this fact, very few recent investigations have been conducted about this event. To improve its knowledge, we synthesized and critically assessed the information provided by those scientific studies and by other written sources of the Low Countries, mainly old newspapers, annotations, letters as well as administrative documents from municipalities and parishes. So it is possible to obtain a better picture of the damage in the epicentral area and of the perceptibility area of the tremor. The amount of severe damage to many houses and other buildings in some localities suggests that the maximal observed intensity is at least VII in the EMS-98 scale. The farthest cities where the shaking was noticed are Commercy in Lorraine southward (~ 250 km from the earthquake center), Soest in Westphalia eastward, Ijbergen in the Netherlands northward and Dunkerque in French Flanders westward. The epicenter is located near the city of Hannut, in the northwestern part of the Province of Liège. A new macroseismic map of this earthquake will be soon established from this material.

A part of the historical material gathered and critically assessed since 1985 has already been inserted in the earthquake database of the Royal Observatory of Belgium. In the year 2008, the presentation of the historical sources in this database has been reorganized, with the aim to better emphasize the critical work already accomplished. The historical part of the ROB database has been divided in two sections: 1) Earthquakes occurred in Belgium and neighbouring areas from the known origins. 2) Earthquakes occurred in Europe from 350 A.D. to 1526 A.D. In addition, let us remind that the database has been designed to automatically generate a future publication of the texts concerning the long-term seismicity of the studied regions.

Structure of the crust in Belgium and surrounding regions

We finalized the analysis and interpretation of the Moho-depth estimation in Belgium using arrival times of PMP phases recorded by the stations of the Belgian seismic network. Underneath the Belgian onshore part of the Brabant Massif, it is 31 ± 2 km. This result is the first time that such an evaluation has been done. Our result is comparable to the values obtained offshore by seismic reflection profiles.
More to the east, the Moho-depth has been evaluated by combining the analysis of PMP and SMS seismic phases. We obtained the similar values around 31 km from the Campine region to the western part of the Roer Graben and the northern part of the Ardennes. With the recordings of SMS phases reflected underneath the Eifel region, a value of 28 km has been obtained. This thinning of the crust is in agreement with the presence of the Eifel plume and with the results obtained by German scientists using receiver function analysis. At the southeast of Grand-Duchy of Luxemburg, two seismic reflection phases are observed on the seismograms. The first can be interpreted as resulting of the presence of a reflector at depths ranging from 15 to 24 km. We interpreted the second reflection as the current Moho interface. Those new data allow improving the current maps of Moho-depth in Europe.

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

Are the faults limiting the Artois Plateau and the Flanders plain active?

We are continuing the investigation on the faults limiting the Artois Plateau to the Flanders plain with the purpose of evidencing their recent geological activity. We are collecting available information on the prolongation of these faults across the Channel and we conducted three days field work to conduct subsurface geophysics along the Marqueffles fault between the locality of Vimy and the Scarpe valley.
In parallel, we conducted also a specific investigation in the archives of the North of France to better evaluate the epicentral area and the magnitude of the 2 September 1896 earthquake that struck this region.

Active faults and past large earthquakes in the Upper Thracian Depression, Bulgaria

Following the geophysical survey in 2007 and exploratory trenches by our Bulgarian colleagues, we excavated two new trenches across Popovitsa fault at the site of Taterevo in September/October. The two trenches were situated close to each other, but in different depositional environments. The largest trench (trench 3) was located on an alluvial fan; the other trench (trench 4) was smaller, and located adjacent to a small channel. We found evidence for at least three surface-rupturing earthquakes, including the 1928 earthquake. In trench 3, the combined vertical offset of the two most recent earthquakes is c. 0.75 m (offset of base of black soil unit in Figure 26). It is hard to distinguish these two events in trench 3, but correlation with trench 4 suggests that the 0.75 m offset is the result of two different large earthquakes, the most recent of which was the 1928 earthquake. Further down in the stratigraphy of trench 3, an additional vertical offset of c. 1.0 m is evidenced. The deformation associated with this offset is distributed over a broad graben-like fault zone in front of the main fault. It is not yet clear, however, if this offset is the result of one faulting event, or more than one, because erosion has occurred in the downthrown block. We did not find any macroscopic organic matter in the trenches that could be used for radiocarbon dating. Instead we collected sediment samples for dating with optically stimulated luminescence (OSL). Some samples have been sent to the lab for dating, and we are currently waiting for the results.

We completed also our magnetic data in the Upper Thracian Depression by conducting measurements at 139 new sites. The field work was conducted between 18 May and 1 June. The data where checked daily and the final reduction of the data has been carried out in Sofia directly after the field work. There are now 250 magnetic measurements covering the whole zone of interest, corresponding to an area of 3150 km². Their interpretation in parallel with the gravity data should help in the structural analysis of the Thracian depression.

Figure 26: Overview of the west wall of Tatarevo trench 3. The fault is situated in the middle of the trench, and clearly displaces the uppermost black soil unit

D.1.2.3. Understanding the irregularity of the seismic cycle: a case study in Turkey

Trenches across the North Anatolian Fault System

For the first trench site excavated during summer 2006 along the 1943 earthquake rupture, the team obtained a reliable record of six major earthquakes in the last 3000 years. The earthquake chronology is tightly constrained by radiocarbon dating of multiple components of the sample charcoal, and our results indicate an average inter-event time of 385 ± 166 yrs. Finally, we also developed a new promising technique mapping the magnetic susceptibility, directly measured on trench walls. It was used to access sediment provenance independently of the trench log and helped identifying sediments related to earthquakes. The second trench site was excavated during summer 2007 across the Kelkit fault segment that ruptured in 1939. The team obtained a record of seven major earthquakes over 4000 years. The earthquake chronology is not very well constrained by radiocarbon dating because we have multiple reworking and contamination. However the results are particularly interesting when compared with other paleoseismic trenches further east on other fault segments that also ruptured in 1939. We show that the 1939 earthquake (see Figure 27) was not typical. The latter means that M>7 earthquakes that occurred before the 1939 earthquake had a much shorter earthquake rupture length.

During summer 2008, the team studied two additional trench sites (e.g. Elmacik and Gunulan sites) respectively west and east of the previous sites, in order to get a more complete picture of the earthquake history of the segments that ruptured in 1943 and 1939. The western Elmacik trench contains a well dated but relict reliable record of seven earthquakes that occurred after 1000 AD.

The easternmost Gunulan site shows a record of up to 6 events but very poorly dated. The team did not found enough charcoal in the trench to get reliable dating, probably because of the very arid climate in that region.

Lake Studies along the North Anatolian Fault

We have nearly achieved all the sedimentological analysis on long and short cores from six lakes (Yenicaga L., Ladik L., Borabay L., Gollukoy L., Zinav L., Asacipetecik L.) along the North Anatolian Fault, which consist mainly in analysis of water content, organic matter content, mineralogy, isotopes; geophysical analysis using a Geotek core scanner, geochemical analysis using an ITRAX core scanner. Those analyses were necessary in order to constrain the sedimentological signature of earthquakes in the different lakes. To get a reliable paleoseismological record from the long-core analysis, we need to date organic matter produced outside the lake. So the team is planning to extract pollens and micro-charcoal from the cores. We have also achieved the dating of all short cores using 210Pb and 137Cs, and the first characterization of the 20^{th} century earthquake sequence along the North Anatolian Fault in lakes. We have also been focusing more closely on understanding the detailed sedimentological processes related to the M>7 1943 earthquakes in Lake Ladik along the North Anatolian Fault by analyzing the physical, mineralogical and geochemical properties of the sediments through the core, and obtaining a more accurate age model than previously obtained.

Lake Hazar Studies

On the East Anatolian Fault, the team has focused on the Lake Hazar, which is a 20 km long, 5 km wide and 210 m deep active pull-apart basin. The lake, its sediments and its fault related structure have never been studied before (no reliable bathymetric maps, no geophysical survey, no limnological survey in the deep part of the lake, no coring), even if it is a major active structure capable of producing earthquakes of magnitude greater than 7 and is located within 100 km of at least three dams on the Euphrates-Tigris river system. Two known historical earthquakes of magnitude 6.7 and greater than 7.1 occurred in that area in 1874 and 1875, but possible associated fault ruptures are unknown.

The Seismic campaign done during 2007 reveals that a continuous strike-slip fault cross the lake linking the two faults located in the northeast and southwest ends of the lake. Consequently, the team obtained a better understanding of the seismic cycle at this location of the fault, and particularly of the occurrence of the 1874, M=7.1, and the 1875, M=6.7, earthquakes in that area.

The long cores taken during summer 2007 have been analyzed using X-ray core scanner in Bordeaux and Geotek core scanner in Rhodes Island U.; radiocarbon dating show that we have a sedimentary record of about 4000 years with clear indication of earthquakes. The team will thus be able to constrain the long term earthquake recurrence on the East Anatolian Fault and compare it with the North Anatolian record we obtained, one of the main goal of the project.

Geomorphological Study

We were also able to constrain cumulated earthquake slip displacements in the central part of the North Anatolian Fault using offset geomorphological markers. In summer 2008, we focus on the central part of the North Anatolian Fault affected by the 280 km long 1943 earthquake rupture in an area located near Kamil where the fault forms a small pull-apart exploited by the Kizilirmak River to cross the fault and reach the Black Sea. Geomorphological data and radiocarbon dating shows that in that area the North Anatolian Fault does not exhibit characteristic slip. Indeed new offset measurements linked to 1943 earthquake confirm the small 1 to 2 m dextral slip associated with this earthquake. However larger offset geomorphological markers, which age were constrained using radiocarbon dating, indicate that slip during the previous 1668 and 1050 earthquakes were very large reaching 8 to 10 m. The result of this research will be described in a paper to be submitted before September 2009.

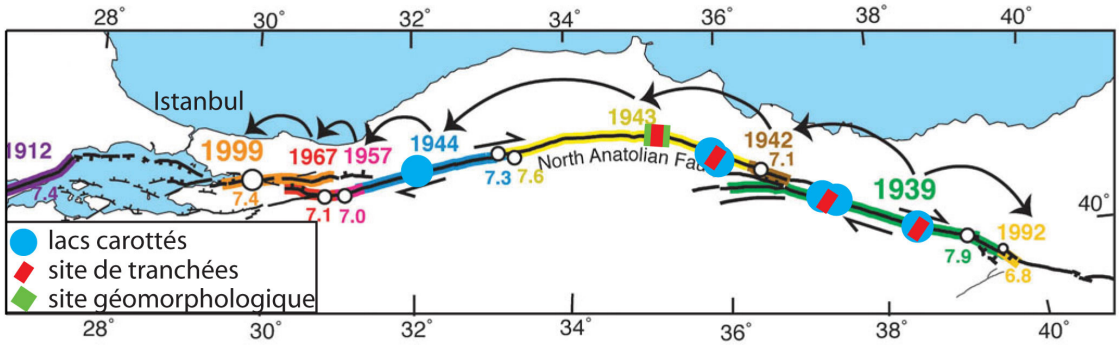


Figure 27: Sites studied along the North Anatolian Fault with respect to the westward propagating ruptures that occurred along the fault during the 20th century

D.1.2.4.Seismic hazards and risks

Eurocode 8

In the frame of the revision of the Belgian national annex to the European norm ENV 1998, the Belgian committee for Eurocode 8 asked the Royal Observatory of Belgium to draft a seismic zoning map with a finer gradation than the map used in the earlier version of the annex. This earlier map was based on a probabilistic seismic hazard analysis (PSHA) by Leynaud et al. (2000), but because the data and input files behind the analysis had not been preserved, we decided to re-implement these calculations using more recent PSHA software. Due to a number of uncertainties in the original publication, we were not able to reproduce the earlier results exactly, but our results are quite similar. The upshot is that we now know all the parameters that have been used, and can thus easily carry out new calculations if a parameter needs to be changed. Based on these new calculations, we prepared a new zoning map in which zones are defined based on the 0.02 g contours of peak ground acceleration (PGA) corresponding to a return period of 475 years (as opposed to 0.05 g contours in the older version). In each zone, the PGA is assumed to be constant. The resulting map is shown in Figure 28.

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 the frame of this study, a new source-zone model was defined, the seismotectonic model, and described in detail. In comparison to the PSHA analysis for the compilation study "Seismicity of Flanders", calculations were carried out for only one site, but taking into account a larger number of uncertainties. We constructed a logic tree, with different branches for source-zone model (seismotectonic model and two-zone model), ground-motion model (attenuation laws of Ambraseys et al., 1996, and Berge-Thierry et al., 2003), maximum magnitude (evaluated Mmax +0, +0.25, and +0.5), and seismicity model. For the last level of the logic tree, we explored the uncertainties related to the magnitudes determined in the seismic catalog, as well as uncertainties related to calculation of the frequency-magnitude relation for individual zones. To that end, we set out an innovative approach involving Monte-Carlo sampling of the b values (slope of the frequency-magnitude relation) for each zone, but adding the constraint that the summed activity of all zones should fall within the two-sigma bounds of the activity calculated for the entire catalog. Thus, we obtained 200 compatible seismicity models, resulting in 2400 end branches in the logic tree. For each of these end branches, we calculated exceedance rates for PGA as well as for spectral acceleration, using the freely available seismic-hazard program CRISIS. The result for PGA is shown in Figure 28. For a return period of 8574 years, equivalent to 4% probability of exceedance in 350 years (the total duration of the operational phase and the monitoring phase after clo-

sure of the facility), the median and 84th percentile of the calculated PGA amount to 0.203 g and 0.224 g, respectively. By slicing the logic tree in different ways, a sensitivity analysis can be made for all the choices that have been made.

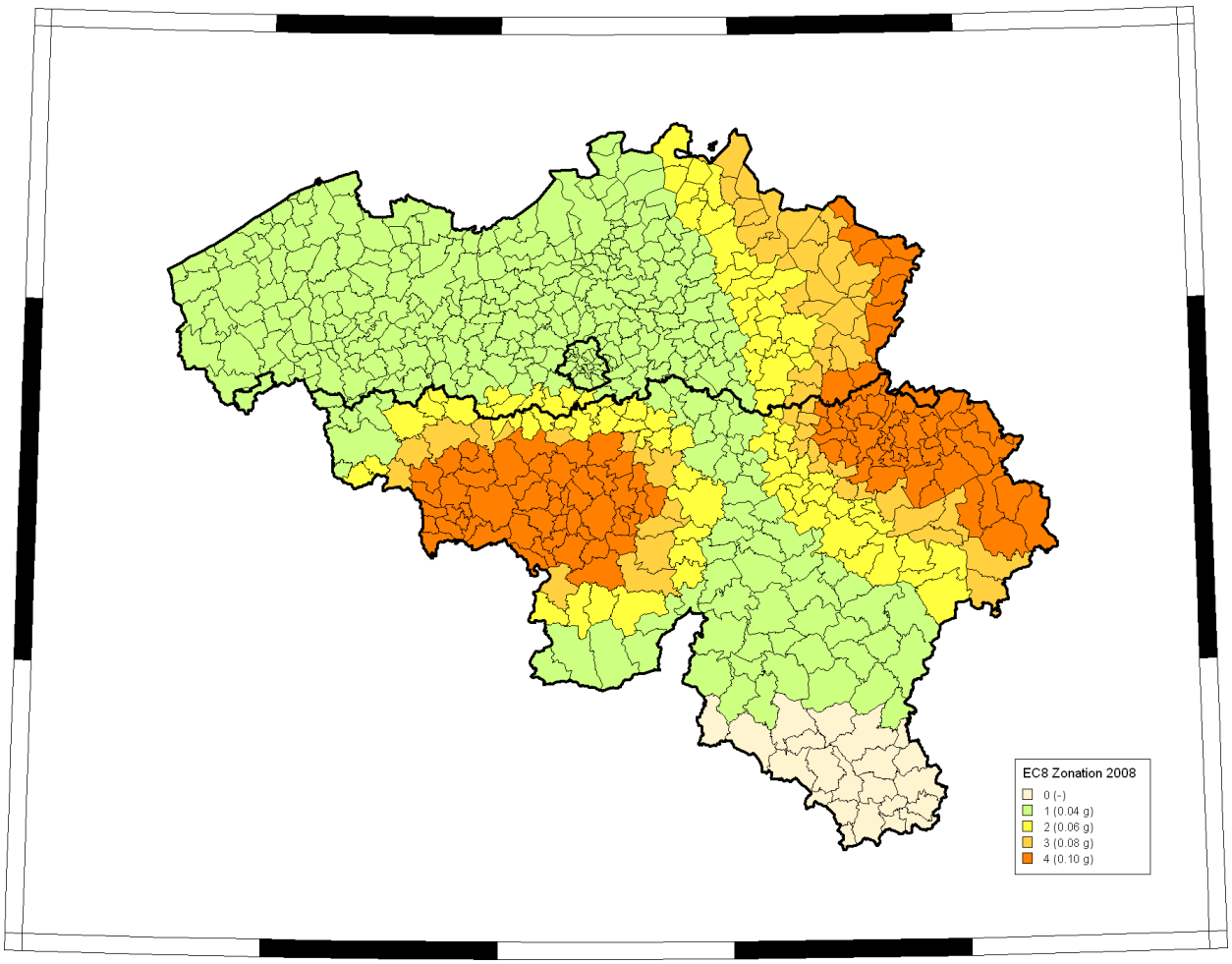


Figure 28: Seismic zoning map for Belgium according to the revised Belgian national annex to ENV 1998.

D.1.2.5.LISSA

We conducted seismic measurements in Uccle to evaluate the characteristics of the seismic noise generated by the pumps to be installed by the Royal Meteorological Institute and U. Gent to monitor air pollution in the Princess Elisabeth Antarctic base. These devices induce vibrations that may lower the performances of the broadband seismometer to be installed by the Royal Observatory of Belgium (ROB) and of the LaCoste gravimeter to be installed by U. Luxembourg.

From 2008-02-27 to 2008-03-06, 3 compressors provided by the RMI and U. Gent were tested in Uccle and Membach. Given the terrible influence of the compressors observed on the seismometers, the IPF decided to build two separate shelters, one being dedicated to geodetic and seismological experiments, far away from the other shelter dedicated to climate research.

The shelter is especially dedicated to offer scientists a low noise laboratory. As far as we know, apart from the SANAE station operated by South Africa, the Princess Elizabeth station will be the only one in Antarctica located inland *and* on the bedrock.

D.1.3. Perspective for next years

The section seismology-gravimetry will participate to the FP7-EC project SHARE (2009-2012) with the responsibility with GFZ-Potsdam (Germany) of the earthquakes and active faults datasets in central and Western Europe.

The seismic sequence south of Brussels will be investigated in detail with the purpose of delineating the active structure(s) generating those earthquakes and of determining their focal mechanisms.

A synthesis of the seismic activity that occurred in our regions since 1985 will be finalise, including a relocation of the whole dataset, the determination of fault-plane solutions using body waves waveform and a homogeneous determination of the magnitude.

It is intended to begin the development of a local magnitude scale based on the measurements of maximal S wave ground displacement on the horizontal components and to establish a relationship with seismic moment.

The compilation study "Seismicity of Flanders" will end in March 2009. We are in the process of writing the final report, which is intended to be a reference in Dutch for earthquakes in Flanders (and in Belgium in general).

Concerning the historical seismicity of the Belgian area, a part of the important documentation gathered from 1985 has not yet been fully exploited, that's to say it should subject these documents to the rules of historical criticism, publish the original texts and insert the reliable data in the databank of the ROB. New investigations in archives and libraries to look for documents on past seismicity are necessary to complete the already gathered documentation on the past seismicity of our regions; several of the major earthquakes need new studies of their area perceptibility and their effects and damage on the buildings of the concerned area. Particularly the poorly known earthquake of 4 April 1640 will be the subject of some investigations: it is possible that its epicenter, until now located in Rhineland, should be located in fact in Eastern Belgium or even in the Grand Duchy of Luxembourg.

The PSHA study for the nuclear waste disposal facility at Dessel will also be finalised in 2009. Most of the calculations have been carried out, but need to be analysed further. We will carry out a sensitivity analysis, to evaluate the impact of the different choices that have been made, and a disaggregation, to evaluate which earthquake magnitudes at which distances contribute most to the seismic hazard at Dessel.

The local seismic tomography study of Belgium and the surrounding regions will be finalising.

We will analyse the geophysical data from the Marqueffles fault in northern France. Based on the results, we will decide how to continue our investigation of the region. We will conclude interpretation of the Tatarevo trenches in Bulgaria. We will carry out a study of published trenching results on the North Anatolian fault, in order to resolve the spatiotemporal pattern of rupturing.

A broad-band seismic station will be installed during the period November 2009 - February 2010 at the Princess Elisabeth base in Antarctica.

D.1.4. Personnel involved

Scientific staff:

P. Alexandre (responsible of the historical seismicity studies)
U. Avsar (PhD, MEXT-CT-2005-025617)
X. Boës (Postdoc, MEXT-CT-2005-025617)
T. Camelbeeck (responsible of the section)
M. Everaerts (magnetic measurements in Bulgaria)
A. Ferrari (coordinator Marie Curie project, MEXT-CT-2005-025617)
J. Fraser (Phd, MEXT-CT-2005-025617)
D. Garcia Moreno (active faults studies, replacement contract)
D. Kusman (historical seismicity, CCHO: 2007-4177/00/00)
E. Knuts (historical seismicity, "supplementary researcher" contract)
T. Lecocq (Phd, FRIA FC 76908)
E. Sichien (Phd, IWT-43205)

K. Vanneste (coordinator of the compilation study "Seismicity of Flanders")
K. Verbeeck (seismic investigation for NIRAS, CCHO: 2007-4177/00/00)

D.1.5. Partnerships

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

- Seth Stein, Northwestern University (U.S.A.)
- Klaus Hinzen, University of Cologne (Germany)
- Bernard Dost, Netherlands Meteorological Institute (The Netherlands)
- 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

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
- Jozef Van Dyck, KULeuven, 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)
- Laurence Nuttin, Universite Libre de Bruxelles

Grants/Projects used for this research/service

- Project VLA07-4.2 by the Flemish Government
- Contract CCHO: 2007-4177/00/00 with NIRAS/ONDRAF
- Bilateral project with Bulgaria
- 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 IWT-43205

Visitors:

- Stefan Shanov, Alexander Radulov and Marlena Yaneva, Geological Institute of the Bulgarian Academy of Sciences,11-16 September 2008, bilateral cooperation.
- Vlamynck Nele, Gent University, 15 days (July 2008), MEXT-CT-2005-025617

- Caudijzer Alexandre, Gent University, 15 days (July 2008), MEXT-CT-2005-025617
- Drab Laureen, Ecole Normale Supérieure (Paris), 15 days (August 2008), MEXT-CT-2005-025617
- Maricq Nathalie, ULB, 15 days (August 2008), MEXT-CT-2005-025617
- Short visits: 21 persons

D.1.6. Scientific outreach

Meeting presentations

[1] **Kris Vanneste**, **Koen Verbeeck**, Florias Mees & Dimitri Vandenberghe
New paleoseismic evidence for prehistoric surface rupturing in the intraplate Lower Rhine graben area
Tectonic Studies Group Annual Meeting, 8-10 January 2008, La Roche-en-Ardenne, Belgium

[2] **Kris Vanneste**, **Koen Verbeeck**, **Thierry Camelbeeck**
A decade of paleoseismic research in the Roer Valley graben
Seismic risk – Earthquakes in North-Western Europe, 11-12 September 2008, Liège, Belgium

[3] **Koen Verbeeck, Kris Vanneste, Thierry Camelbeeck, Toon Petermans,** Sara Vandycke, Jean-Pièrre Colbeaux, Christophe Tesnière, Michel Sébrier & Françoise Bergerat
Active tectonics in Northern France
Tectonic Studies Group Annual Meeting, 8-10 January 2008, La Roche-en-Ardenne, Belgium

[4] **Hubert-Ferrari A.** , J. Suppe 2008.
Surface effects of active folding, illustrated with examples from the TianShan intracontinental mountain belt (China).
Tectonic Studies Group annual meeting, 8-10 Jan, La Roche-en-Ardenne, Belgium.

[5] **Hubert-Ferrari A**., **D. Garcia**, J. Moernaut, M. Van Daele, E. Damci, N. Cagatay, M. De Batist, 2008.
The Hazar pull-apart along the East Anatolian Fault: Structure and active deformation.
Tectonic Studies Group annual meeting, 8-10 Jan, La Roche-en-Ardenne, Belgium.

[6] **Avsar, U.**, **Boes, X**., **Hubert-Ferrari, A**., Fagel, N., Schmidt, S. 2008.
Kuzey Anadolu Fayı Üzerinde Yer Alan Sığ Göllerde Tarihsel Depremlerin Sedimantolojik İzlerinin Araştırılması.
Active Tectonics Research Group 12nd Workshop, Duzce/Turkey.

[7] **Boes, X.**, Moran, B., Roger, K., Avsar, U., Moernaut, J., King, J., Cagatay, N., **Hubert-Ferrari, A.** 2008.
Radionuclide profiles and recent earthquakes history of Lake Hazar Pull-apart basin (East Anatolian Fault, Turkey).
European Geosciences Union General Assembly 13-18 April 2008 Poster Presentation, Geophysical Research Abstracts, 10, 11204.

[8] **Avsar, U.**, **Boes, X**., **Hubert-Ferrari, A**., Fagel, N., King, J. 2008.
Traces of the last earthquake sequence (1939-1944) along NAF from lacustrine sediments.
European Geosciences Union General Assembly 13-18 April 2008 Poster Presentation, Geophysical Research Abstracts, 10, 05406.

[9] **Fraser, J**., Pigati, J., **Hubert-Ferrari, A.**, **Vanneste, K**., **Avsar, U**., Altinok, S. 2008.
A 3000 year chronology of North Anatolian Fault ruptures, utilizing magnetic susceptibility trench logging, near Lake Ladik, Turkey.
European Geosciences Union General Assembly 2008 Poster Presentation 13-18 April 2008, Vienna, Austria, Geophysical Research Abstracts, 10, 00069.

[10] **Garcia Moreno D.** , **Hubert-Ferrari A.**, Moernaut J., Van Daele M., Damci E., De Batist M. 2008.
The Hazar pull-apart along the east Anatolian fault: Structure and active deformation.

European Geosciences Union General Assembly 13-18 April 2008. Vienna, Austria, Geophysical Research Abstracts, 10, 01808.

[11] **Avsar, U.**, **Boes, X**., **Hubert-Ferrari, A**., Fagel, N., Schmidt, S., 2008.
Sedimentological traces of the last earthquake sequence (1939-1944) along the NAF on recent lake sediments.
International Conference and 106th annual meeting of the Deutsche Gesellschaft für Geowissenschaften (DGG) and 98th annual meeting of the Geologische Vereinigung e.V. (GV), Aachen/Germany. September 29th - October 2nd, 2008.

[12] **Boes, X.**, Jasper, M., Avsar, U., Namik, C., **Hubert-Ferrari, A**., 2008.
Lake Hazar: a potential high-resolution 150 ka record of climate and tectonic interactions in Anatolia.
Eos Trans. AGU 89 (53), Fall Meet. Suppl., Abstract PP11B-1391.

[13] **Fraser, J**., **Hubert-Ferrari, A**., **Vanneste, K**., **Avsar, U**., Altinok, S. 2008.
Defining Additional Stratigraphy in Paleosismic Trenches by 2D Logging of Magnetic Susceptibility. A Paleoseismic Investigation Near Lake Ladik, North Anatolian Fault, Turkey.
Eos Trans. AGU 89 (53), Fall Meet. Suppl., Abstract T21B-1942.

[14] **Avsar, U**., **Boes, X.**, **Hubert-Ferrari, A**., Fagel, N., Schmidt, S., 2008.
Sedimentological Fingerprints of Recent Earthquakes in Lake Sediments: A Case Study on the North Anatolian Fault (NAF), Turkey.
Eos Trans. AGU 89 (53), Fall Meet. Suppl., Abstract T21A-1919.

[15] **Garcia Moreno, D**.; **Hubert-Ferrari, A.**; Moernaut, J.; Fraser, J.; Van Daele, M.; Damci., E and M. De Batist. 2008.
Structure and evolution of a main segment boundary along the East Anatolian Fault, Turkey.
27th ECGS Workshop: Seismicity Patterns in the Euro-Med Region. 17-19 November of 2008.

[16] **Hubert-Ferrari, A**., **J. Fraser**, **X. Böes**, **U. Avsar**, **K. Vanneste** et E. Altunel, 2008.
Seismic patterns of the Anatolian fault system (Turkey).
27th ECGS Workshop: Seismicity Patterns in the Euro-Med Region. 17-19 November of 2008. Présentation oral invité.

[17] Lecocq, Th., Van Camp, M., Vanneste, K. and Camelbeeck, T.
The seismic sequency since July 2008 in central Belgium
Seismicity Patterns in the Euro-Med Region, 27th ECGS Workshop, Luxembourg, November 17-19, 2008.

[18] **Thierry Camelbeeck, Koen Verbeeck, Kris Vanneste, Toon Petermans,** Sara Vandycke, Jean-Pièrre Colbeaux, Christophe Tesnière, Michel Sébrier & Françoise Bergerat
Active tectonics in Northern France
Visit of the responsibles of the Parc Régional Scarpe-Escaut, 24 October 2008, ROB

Seminars

[19] **Kris Vanneste**, **Thierry Camelbeeck** & Jozef Van Dyck
Reimplementation of Leynaud et al. (2000) PSHA calculation for Belgium with CRISIS and SeisHaz
BeSeiG meeting, Mons, 21/03/2008

[20] **Kris Vanneste** & **Thierry Camelbeeck**
Probabilistic seismic-hazard assessment for surface storage of low- to medium-level radioactive waste at the nuclear site in Mol-Dessel: Preliminary Results
Meeting with Federaal Agentschap voor Nucleaire Controle (FANC), Studiecentrum voor Kernenergie, Mol, 14/11/2008

[21] **A. Hubert-Ferrari**

Les chevauchements actifs du TianShan (région de Kuche): Structure, évolution temporelle et déformation induite en surface
Départmental Seminar of the University of Cergy-Pontoise, Jan 2008.

[22] **Koen Verbeeck, Kris Vanneste**, **Thierry Camelbeeck,** Michiel Dusar & Noël Vandenberghe
Seismotectonic zones for probabilistic seismic hazard assessment in Belgium
Meeting with Federaal Agentschap voor Nucleaire Controle (FANC), Studiecentrum voor Kernenergie, Mol, 14/11/2008

Seminars

[23] **Avsar**, U., 2008.
Lake sediment records: A new way to obtain extensive chronology of earthquakes.
Offenses Diplomaden und Doktoraden Seminar SS 2008, Aachen/Germany.

Wikis and Websites

- A. Hubert-Ferrari: Updating of website
  http://seismologie.oma.be/CYCLE/SeismicCycleSite/Introduction.html

D.1.7. Missions

Assemblies, symposia:

K. Vanneste (Tectonic Studies Group Annual Meeting)
K. Vanneste (International BESEIG-workshop)
K. Verbeeck (Tectonic Studies Group Annual Meeting)
K. Verbeeck (International BESEIG-workshop)
A. Hubert-Ferrari (EUROSEIS-Workshop in Luxemburg)
A. Hubert-Ferrari (38th TSG Annual General Meeting)
T. Camelbeeck (International BESEIG-workshop)
T. Camelbeeck (EUROSEIS-Workshop in Luxemburg)
T. Camelbeeck (Meeting of the APS and AFPS in Manosque)
T. Camelbeeck (BELQUA annual meeting in Brussels)
M. Everaerts (GEGEO 2008 IAG conference)
T. Lecocq (DGATLP (Région Wallonne) : Meeting on "Mouvements du sol : Chutes de blocs et de parois"
T. Lecocq (International BESEIG-workshop)
T. Lecocq (EUROSEIS-Workshop in Luxemburg)
D. Garcia Moreno (Tectonic Studies Group annual meeting)
D. Garcia Moreno (EGU General Assembly)
D. Garcia Moreno (EUROSEIS-Workshop in Luxemburg)
U. Avsar (EGU General Assembly)
U. Avsar (DGG and GV coupled meeting)
U. Avsar (Active Tectonic Researcg Group workshop)
U. Avsar (AGU Fall Meeting)
J. Fraser (EGU General Assembly)
J. Fraser (AGU Fall meeting)

Commissions, working groups (days):

K. Vanneste (3 days)
K. Verbeeck (3 days)
M. Van Camp (7 days)
T. Camelbeeck (16 days)
T. Lecocq (3 days)

Research visits (days):

A. Hubert-Ferrari (18 days)
T. Camelbeeck (3 days)

D. Garcia Moreno (60 days)
U. Avsar (4 days)
Name (dates or number of days)

Field missions (days):

K. Vanneste (28 days)
K. Verbeeck (26 days)
T. Camelbeeck (5 days)
M. Everaerts (13 days)
T. Lecocq (9 days)
A. Hubert-Ferrari (42 days)
D. Garcia Moreno (30 days)
U. Avsar (68 days)
J. Fraser (92 days)

D.2. Project « Seismic monitoring »

D.2.1. Objectives

The section of seismology installed, is maintaining and analysing the data from the seismic and accelerometric Belgian networks.

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”.

The 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.

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.

The superconducting and spring relative gravimeters and the absolute FG5 gravimeter

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 2004, we are conducting gravity and magnetic measurements in the Upper Thracian Depression in Bulgaria to investigate the upper crustal structure of this region where two large earthquakes occurred in 1928. This study is done in parallel with our investigation on the active faults that generated these two events.

A convention has been signed in 2006 with the Walloon Region to include the sites of the WALCORS GPS network in the Belgian Gravimetric Base Network BLGBN98. The WALCORS network includes 23 GPS stations. The interest for the Walloon Region is that, in case of anomalous behavior of the GPS antennas, it will be possible, by repeated gravity measurements, to check if this behavior is associated with gravity changes and thus corresponds most probably with real vertical displacements of the antenna.

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.

D.2.2. Progress and results

D.2.2.1.The Belgian seismic monitoring network

Seismic alert system

Concerning our plan for an automatic system for the detection and localization of seismic events, we have attended the annual meeting of the SeisComP users (Barcelona) where the SeisComP3 software has finally been delivered to the participants after 2 years of development. We have tested SeisComP3 by providing it with several sequences of the Ottignies/Louvain-la-Neuve events that occurred this year. The results are quiet convincing for local events of magnitude greater than 2. It is then planned to set it up for analyzing our data continuously. The purpose would be to fine tune its configuration and see how it behaves on the long run.

Rochefort seismic station

A major upgrade of the Rochefort station (installing a Q330 datalogger, a local UTP network, a fibre optic cable between the cave and the surface) was made during the spring 2008 (this also benefit all other geodetic and hydrologic experiments performed in the cave). It allows us to send the seismic data to the international centres ORFEUS and IRIS.

Mol and Dessel seismic stations

On each of the Mol and Dessel sites, one borehole and one surface seismometers have been installed. An internet connection between each station and the Observatory has been set up for data retrieval. This installation is part of a project with the Belgian Agency for Radioactive Waste and Enriched Fissile materials (ONDRAF/NIRAS).

Borehole seismometer in Oostende

In March 2008, a borehole was drilled down to bedrock at the scientific education centre “Earth Explorer” in Oostende. Drilling was funded by the Flemish Government, and the Belgian Geological Survey assisted in the operations, while NIRAS/ONDRAF funded downhole geophysical measurements. ROB is responsible for installing a seismometer in this borehole, but as this seismometer was ordered only after drilling, the borehole remains empty to this day, unfortunately.

Mobile seismic stations in the Walloon Brabant

A seismic sequence started on 12 July 2008 some 20 km to the southeast of Brussels. 2 days after the first event, we installed two temporary broadband seismic stations (Güralp CMG-3ESPCD) to densify our network near the epicentral area. The sequence continued in August and we decided to install five more stations to even better monitor the activity. These stations were always working at the end of the year.

D.2.2.2.The accelerometric network

The network is working correctly and checked thoroughly at the ORB once a week (Mol is checked twice a week). All the stations have been visited for maintenance, except the BREA, KINA, MASA, MONA, STNA and STWA ones.

The analog phone connection with accelerometer of Mol (“MOLA”) is malfunctioning. Numerous tests were performed during the summer-fall 2008, but without success. The problem was solved in January 2009.

The stations of La Louvière (LLVA), Uccle/Kriekenput (KKPA) and Uccle/ORB (UCCA) successfully recorded the Court-Saint-Etienne M=3.2 earthquake. This earthquake, felt up to Brussels, was too small to trigger the other accelerometers.

We took profit of the M=3.2 event to test the calibration of the Uccle seismic station, as well as of the 6 newly bought Güralp broadband stations that were in test in July, by comparing them with the accelerometric data.

D.2.2.3.The earthquake database of the Royal Observatory of Belgium – web site

A new web-server dedicated to the section of seismology has been installed and configured. This server also replaces the old database server definitely broken this year. New backup procedures have been set up for the website and the database. These procedures need to be tested and improved.
A new organization of the seismic data has been thought and implemented on the data servers. Also, some information not recorded in the database have been identified and stored in the wiki. Moreover, a way to safely centralize and record passwords for the ADSL accounts and modem has been implemented.
During the 2008 seismic sequence south of Brussels, we noticed that when the population felt an earthquake, they rushed to the Royal Observatory website to find information and also to spontaneously fill in the "Did you feel it?" web inquiries. This rush was even so important that our servers could not manage and answer all requests without long delays. We created a website monitoring tool in order to alert us when an unusual number of connections were made to the seismology homepage. The monitoring tool switched to an alert and report system with the implementation on the SMS server at the ROB. The system, now called "**B-FEARS**" for **Belgian Felt Earthquake Alert and Report System**, has detected more than 40 earthquakes since 12 July 2008. Its core is based on the ratio of the short term average on the long term average of visits to the website. When an alert is triggered, the system checks the database for already filled-in forms and reports by email and SMS. The system also loads all latest available files from the real-time (ADSL) stations and sends out a PNG with the traces of the 10 most recent files (2 minutes each, 20 minutes in total).
When people fill in a "Did you feel it?" form, they must fill in a zip code but they are also invited to provide a postal address. Very often (more than 90% of the cases) people do provide it. Using Google to georeference this address automatically, we are able to pin a form to a neighborhood or even to a house. This gives us the ability to more precisely analyze the intensity distribution around an epicenter.

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

In Membach, an old acquisition system for the supra-conducting gravimeter data has been replaced by a new one developed this year. The UPS system got broken and repaired by the seller. We have then developed a system to automatically bypass the UPS in case of failure of this one. The whole new system (UPS + bypass) has been installed this year.

In 2008 the last measurement campaign of the WALCORS-project has been achieved between 7 April and 9 May. In total 25 days of survey including extra connections where carried out by ROB. Finally each of the 23 GPS stations of the WALCORS network is included in 8 gravity connections. This allowed to obtain that the adjusted gravity values are known to better than 10µgal. A systematic seasonal effect has been detected and that at least four GPS station recorded variation exceeding 15 µGal and should be followed more closely to analyze their origin.

D.2.3. Perspective for next years

To be able to generate an alert for local earthquakes using the seiscomp3 software, many permanent seismic stations will be equipped with an internet connection. This will allow continuous data flow to be recorded at the central station of Uccle.

The accelerometers must be visited on regular basis for maintenance and/or repair. Beginning 2009 the BREA, KINA, MASA, MONA, STNA, STWA and THEA stations will be visited for maintenance. We may also connect the MOLA station or other ones on internet. Tests will be undertaken for that purpose.

We will develop the scripts that allow recovering from the International Seismic Center data-base the seismic phase measurements from the Belgian seismic stations that have been provided to this center between 1960 and 1985. They will be included in our database.

D.2.4. Personnel involved

Scientific staff:
T. Camelbeeck (Responsible of the section)
M. Everaerts (responsible of the WALCORS-project)
T. Lecocq (Phd, FRIA FC 76908)
M. Van Camp (supervise the working of the accelerometric network)
K. Vanneste

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

D.2.5. 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, Torild van Eck and Reinout Sleeman, Netherlands Meteorological Institute (The Netherlands)
- Winfried Hanka, Andres Heinloo, Joachim Saul, GFZ Potsdam (Germany)
- Goddey Stéphanie, Remy Bossu and Gilles Mazet-Roux, EMSC (France)
- Jan Becker and Bernd Weber, GEMPA (Germany)
- Valentino Lauciani, Matteo Quintiliani and Salvatore Mazza, INGV (Roma)
- Fabian Euchner, ETH Zürich
- Thomas Blake, Dublin Institute for Advanced Studies (Ireland)
- Claudio Satriano, Università degli Studi di Napoli

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

- Wim Minnebo, Earth Explorer

Visitors:

- Short visits: 5 persons

Grants/Projects used for this research/service

- convention between the ROB and the MET (Walloon region) « CONVENTION DE PRESTATIONS DE SERVICES »

D.2.6. Scientific outreach

Meeting presentations

[1] Van Camp, M., Camelbeeck, T., Petermans, T., Castelein, S.
The accelerometric network in Belgium, Accelerometric data exchange and archiving workshop (NERIES) (poster)

Grenoble, France, March 10-11, 2008.

[2] **Everaerts M**
Poster seasonal gravity campaign carried out on permanent GPS stations in Walloon region (Belgium)
Poster GGE0 2008 IAG conference (international association of geodesy) in Chania Crete (Grece) 23-27 June 2008

[3] Barbier F, **Everaerts M**, Yans J
Oral presentation Apport de la radiometrire aeroportée U, Th K, pour la cartographie des roches altérées en region
Colloque geologica belgica Namur 17/10/2008

Seminars

[4] **Kris Vanneste**
Installatie Boorgatseismometer Oostende
Press Conference, Earth Explorer, Oostende, 21/03/2008

Wikis and Websites

- The seismology section website is described as a part of the operational project
- Frédéric Devos: installation and configuration of the section seismology wiki
- The different part of the section seismology wiki are:
  - Seismic Routine (Kris Vanneste & Thomas Lecocq)
  - IT (Kris Vanneste, Giovanni Rapagnani, Henri Martin & Thomas Lecocq)
  - Paleoseismology Field Procedures (Kris Vanneste & Koen Verbeeck)
  - Geophysical Equipment (Kris Vanneste, Koen Verbeeck, Thomas Lecocq, David Garcia Moreno)
  - Seismology Website (Frederic Devos, Kris Vanneste)
  - Contact List (Thomas Lecocq & Leslie Vandercoilden)
  - Administration (Henri Martin)

D.2.7. Missions

Assemblies, symposia:	M. Van Camp (Accelerometric data exchange and archiving) M. Van Camp (Evaluation du mouvement sismique lors des forts séismes) T. Camelbeeck (ORFEUS annual coordination workshop in Barcelona) G. Rapagnani (ORFEUS annual coordination workshop in Barcelona)
Commissions, working groups (days):	M. Van Camp (3 days)
Research visits (days):	M. Everaerts (9 days)
Field missions (days):	B. Bukasa (25 days), T. Camelbeeck (1 day) S. Castelein (13 days) M. Everaerts (32 days) T. Lecocq (8 days) H. Martin (16 days) G. Rapagnani (17 days) M. Van Camp (4 days) M. De Knijf (2 days) P. Birezimana (3 days) B. Frederick (3 days)

E. Gravimetry

E.1. Project « Gravimetry and geodynamics »

E.1.1. Objectives

Geodynamics of intraplate continental Europe

Studying earthquake recurrence in space and time in continental intraplate regions is difficult because present earthquake activity does not reflect necessarily the potential long-term activity and foreseeing future earthquake activity cannot be based on the available short earthquake record only.

Therefore, to investigate the relative contributions of the tectonic forces and of the climatic and sedimentary loadings and to characterize the long term seismic activity in northwest Europe, we are investigating the strain released by the known seismic activity, that observed in the recent geological record and the present deformation measured by geodetic techniques.

Different investigations are related to these objectives:

1. To interpret the present-day deformations by including the WALCORS and FLEPOS GPS networks in the European network, in collaboration with Section 1 of ROB;
2. To perform absolute gravity measurements along a profile in the Ardennes and Germany. Comparison of these measurements with the GPS data will allow us to determine a stable reference, which is paramount to ensure reliable long-term measurements;
3. 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;
4. To model and correct the hydrological effects on geodetic and geophysics measurements.

These investigations are favoured by the development of geophysical instrumentation for the Rochefort laboratory, but also for the monitoring of the water levels in Uccle and for the Lanzarote Geodynamical Laboratories of Cuerva de los Verdes, Jameos del Agua and Timanfaya. In parallel, we are developing mathematical tools to detect very weak signals in the time series from these instruments.

Metrology

Gravimetry is a domain strongly related to metrology because g enters in the determination of standards derived from the kilogram (electrical intensity, pressure, force) and is to play an essential role in the new realization of the kilogram. g is also a key value to determine the geoid, the dynamic surface of the Earth.

The Royal Observatory of Belgium possesses an absolute gravimeter and as such participated to the “key comparisons” of AGs at the “Bureau International des Poids et Mesure” in Paris. Independently of these official comparisons in Paris, our absolute gravimeter participates in numerous intercomparison campaigns and in calibrating and controlling relative gravimeters.

Since Cavendish first measured Newton's Gravitational constant 200 years ago, "Big G" remains one of the most elusive constants in physics. As an alternative to the classical torsion balance experiments, we are developing at the ROB a static vertical pendulum in feed-back loop control to determine G.

Gravimetry and hydrology

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.

If one wants to use land or space-based gravity data to better observe geodynamic processes, hydrological effects must be corrected. Doing this, we will also have the opportunity to improve hydrological models.

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 6 years, monitoring the Earth gravity field and its space and time variations.

GIANT

The University of Luxemburg and the ROB proposed 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 Belgian base in Antarctica. This experiment will provide information which can be used to convert the satellite altimetric data into mass balance information.

We proposed a program to install two continuously operating GPS stations at a bedrock site (which is quite exceptional in inland Antarctica) at the proposed Belgian Antarctic Observatory. In order to derive reliable surface deformations, the GPS data will be analyzed in a dedicated manner taking into account the location of the BAB and the extreme ionospheric conditions. In addition, the proposed GPS observations will be supported with annual observations of absolute gravity at the Belgian base itself.

E.1.2. Progress and results

E.1.2.1. Geodynamics of intraplate continental Europe

Absolute gravity measurements

To better assess the present-day crustal deformations, absolute gravity 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 Ardennes 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 $+2.4\pm1.8$ nm/s²/yr is observed (average of the rates at all stations but Jülich). This is equivalent to a subsidence rate of -1.2 ± 0.9 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.

Our study indicates that, even in difficult conditions like Jülich and Ostend, AG measurements repeated once a year can resolve vertical land movements at the mm level, which is appropriate to monitor GIA effects, present-day ice mass changes, deformations at plate boundaries or subsidence in river deltas, provided the instruments are carefully maintained. The seasonal variations do not influence the trend significantly if campaigns are repeated during the same season, but can provide insights into ongoing hydrological processes. This study also confirms the need to measure for decades, using accurate and stable geodetic techniques like AG, for investigating slow deformation processes in intraplate context.

We are also participating in the COST action "Improved constraints on models of glacial isostatic adjustment" (Action ES0701). The goal is to place improved constraints on models of GIA through the development of state-of-the-art surface velocity measurements. This Action addresses the current uncertainty in polar ice mass contributions to present-day global sea level rise by producing more accurate models of GIA and then apply them to produce new, more accurate, ice mass change signals from the Gravity Recovery and Climate Experiment (GRACE) satellite mission (2002-present).

Figure 29 shows the variations with respect to the averaged gravity value and the error bars include the experimental standard deviation of the mean and the instrumental set-up noise. For legibility the error bars are not given in Membach but are similar to e.g. the Monschau ones.

Analysis of very weak signals (VWS) in seismic, climatic and tidal observations

During the past year, we validated the stacking method to the analysis of very weak geophysical signals. We showed on one year Lanzarote tide gauge records with minute sampling rate that a stacking-spectrum (SSP) approach gives better amplitude and phase determination than Fourier Transform.

At the same time, we begun to apply continuous wavelets transform (CWT) and wavelet denoising (WD) to improve the analysis of tidal gauge and superconducting gravimeter records.

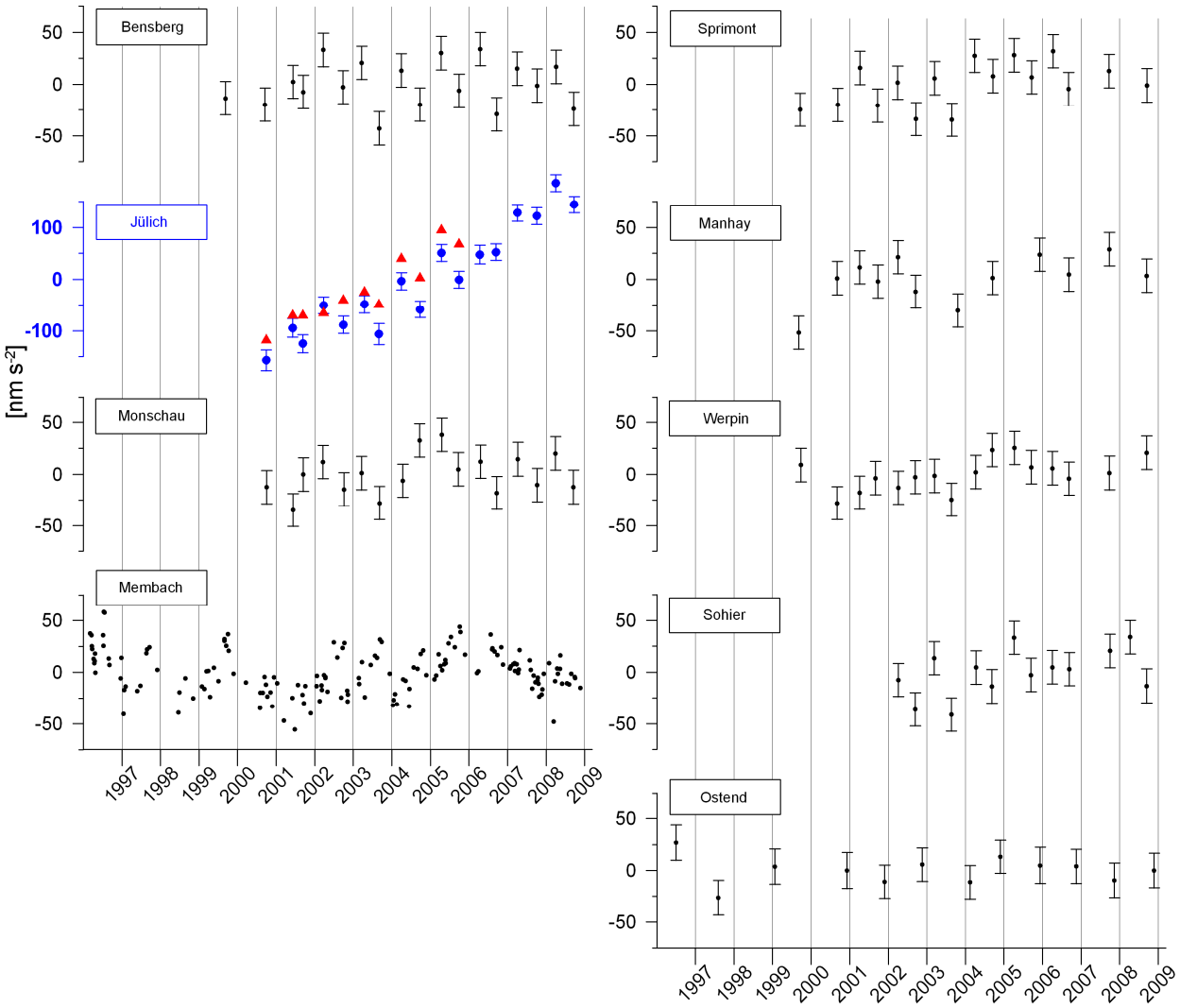


Figure 29: Absolute gravity values at different stations. In Jülich, the triangles represent the data after correcting for the hydrological effects of the unconfined aquifer, considering 22% porosity. In Jülich, gravity increases due to man-induced subsidence.

E.1.2.2. Gravimetry and hydrology

The level of the Victoria Lake is analyzed using space gravity and altimetry data, together with the output of the large-scale land dynamics (LaD) water model. The good agreement between the space gravity and altimetry proves the robustness of the results. Comparing these geodetic observations with the LaD land water model allows one to better estimate the relative contribution of the precipitation, evaporation and run-off. It favors a slight increase in the evaporation with respect to that predicted by the LaD model, which allows explaining most of the low frequency time variable Victoria Lake water level. Similarly, the runoff has to be lowered by a factor 5, which is explained by the storage effect of the lake. With these slight adaptations, this study evidences the consistence of the LaD model with the satellite geodetic observations for multiannual signals, and shows that the 2002-2005 decrease in the lake water level is due to an increased evaporation, accompanied by a repeated deficit in the rainfall.

This work, based on a case study, clearly shows the ability of space gravity and altimetry techniques to investigate multiannual processes in water basin at the regional scale. Moreover, for the first time, this also evidences the possibility to assimilate space geodesy data into land water models. This is paramount to improve global hydrology models, those resulting in one way or another from local and regional investigation.

In Membach:

- We were the first to establish a reliable model to correct hydrological effects on SG measurements. This model is based on comprehensive local hydrogeological investigations (Van Camp et al., JGR, 2006). For the first time we had also the opportunity to apply our hydrological model to improve the signal from a storm surge in the North Sea, which caused ocean loading deformations on the northwest European shelf. This event was generated by winds over the northern North Sea and the surge travelled southwards as a Kelvin wave along the east coast of the UK, taking about 9 hours to travel, with increasing amplitude, from Scotland to the Thames estuary and then to Belgium, the Netherlands and Germany. British colleagues have now evidenced this phenomenon on European GPS time series.
- To have a better idea on the spatial pattern of the hydrological effects above the Membach station, an electric tomography profile was performed on July 18 with O. Kaufmann (FPMS). We will repeat this profile at winter time, in February 2009, when the ground is saturated.

In Rochefort:

In karst aquifers, the void spaces consist of caves and conduits, smaller fissures, and a porous matrix. From a drainage point of view, they are structured in two types of subsystems: the drains with low retention capacity and high permeability, and the annex systems with high capacity but weak connectivity to the drain. The degree of interconnection or the permeability of the different subsystems can vary over several orders of magnitude. Because of the heterogeneity of such aquifers, it is not possible to know the spatial distribution of the different subsystems. When the system is flooded, the rise of the water table depends on the characteristics of the subsystems. The drains are distinguished from the annex subsystems by very short residence time of water. This dynamic is essentially nonlinear and does not permit reliable predictions.

The main inputs of the Rochefort cave are swallow holes of the Lomme River. The river is canalized; however, in strong flood conditions, the water spills over the dyke and sinks into the Nou Maulin swallow hole, connecting suddenly the cave network. This induces very fast rises of the water table in the caves, causing fast gravitational effects that can be investigated using precise gravimetric methods. The absolute gravimeter FG5-202 was installed on the ground surface above the cave during the winters 2005-2006 and 2006-2007. After solving numerous technical problems (dust, temperature stability, power cuts) that affected the 2006 and 2007 investigations, to better investigate flow dynamics and the role of the epikarst, new gravity measurements were performed during the winter 2008. An automatic rain gauge was installed during the spring 2008.

E.1.2.3. GIANT

We participated in different meeting with the Belgian Science Policy and the International Polar Foundation (IPF) to design the laboratory where the geophysical measurements will take place. This laboratory should be build during the austral summer 2008-2009.

E.1.3. Perspective for next years

- Membach: we will repeat during the winter 2008-2009 the electrical tomography profile that was performed in July 2008, in order to better understand the spatial pattern of the ground water content in the unsaturated zone above the station. The feasibility to install a permanent electrical tomography system will be investigated. We would also like to establish a comprehensive hydrological model of the micro basin around the Membach station.

- Rochefort: The 10 years of extensometric measurements will be analyzed at the light of the geodynamic context of northwestern Europe. The AG time series will be compared with the data from the strain meters and environmental sensors, in particular to investigate the elastic behavior of the bedrock during floods.
- Jülich: we would like to combine our AG data with other geodetic techniques, e.g. PSInSAR or GPS measurements. This should allow us to better understand compaction processes, which is paramount for monitoring areas affected by subduction (e.g. New Orleans). Promising contacts have been taken with Juliet Biggs, U. Miami, who is proficient in InSAR technique and is willing to investigate the subsidence at Jülich.
- We are continuing the investigation of long-term hydrological effects on repeated AG measurements. A paper is in preparation "Hydrology and Noise Affecting Land-Based Gravity Measurements", by Van Camp M., Métivier, L., de Viron, O., Meurers, B. and Williams S.D.P., to be submitted to J. Geophys. Res. This investigation will also be discussed at the COST meeting organized at the ROB on March 16-17 (hydrological effects on AG measurements).
- BFO: we are invited to perform new AG measurements in February 2009. When the planned SG is installed, we will foster our collaboration on the hydrological effects on gravity 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).
- GIANT: If the construction works are on schedule at the Princess Elisabeth Antarctic base, GPS measurements will start in February 2009. It is hoped to start gravity and seismic measurements in late 2009 or early 2010. Two continuously operating GPS stations will be installed by Dr. N. Bergeot in February 2009.

E.1.4. Personnel involved

Scientific staff:	Z Ping (Phd thesis, action 2) M. Van Camp (responsible of the research in gravimetry) M. Van Ruymbeke (responsible of the "laboratory of geophysics") T. Camelbeeck
Scientific staff:	S. Castelein M. Hendrickx J.-P Noel G. Rapagnani

E.1.5. Partnerships

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

- Prof. K.-G. Hinzen (U. of Cologne);
- Dr E. Pomplun, Dr. E. Kümmerle and M. Möllmann-Coers (Forschungszentrum Jülich);
- Dr Juliet Biggs, U. Miami;
- Prof. O. Francis, Dr T. van Dam (U. of Luxembourg);
- Dr S.D.P. Williams (Proudman Oceanographic Laboratory, UK);
- Dr. M. King, Dr Nigel Penna (U. of Newcastle);
- Dr. J. Mäkinen, Finnish Geodetic institute;
- M. Diament, O. de Viron (IPGP-Paris)
- J.-F. Crétaux (CNES-Toulouse)
- Dr. G. Appleby, Mrs V. Smith (NERC Space Geodesy Facility, Herstmonceux, UK);
- Dr. J. Mäkinen, Finnish Geodetic institute;
- Dr L. Métivier (IGN France);

- Prof. B. Meurers (U. of Vienna);
- Dr L. Timmen, O. Gitlein (U. Hanover);
- Dr M. Poland, Dr W. Thatcher, Dr M. Dzurisin, Dr S. Hurwitz and the staff of the USGS Volcano Hazards Program;
- Dr Jo Gottsman (U. Bristol);
- Prof. Glyn Williams-Jones (Simon Fraser U.).
- Dr T. Ahern, R. Benson (IRIS, USA);
- Dr. J. Steim (Quanterra, USA);
- Dr. R. Sleeman (ORFEUS-KNMI, the Netherlands);
- Dr. Herbert Wilmes (Bundesampt für Kartographie und Geodäsie, Germany).
- Kinemetrics, USA;
- Micro-g-LaCoste, USA;
- Symmetric Research, USA.
- Bureau International des Poids et Mesures, France;
- Dr. Philippe Richard and Dr Henri Bauman (METAS, Switzerland);
- Dr. S. Williams (Proudman Oceanographic Laboratory, UK);
- Dr. G. Appleby (NERC Space Geodesy Facility, Herstmonceux, UK).
- Dr W. Zürn, Dr. T. Forbrigger, Dr. R. Widmer (BFO, U. Karlsruhe, U. Stuttgart).
- V.Y. Timofeev, Institute of Petroleum Geology and Geophysics SB RAS, Novosibirsk
- Dimitar Dimitrov Central Laboratory of Geodesy Bulgarian Academy of Science
- Pascal Sailac EOST Strasbourg
- P Keating Geological Survey of Canada
- Junxian Chen Tongji University
- R. Barzaghi – Director, International Geoid Service, Polytecnico Milano Person, Institute
- H Duquenne Lareg IGN France
- H. Denker – Institut fur Erdmessung, Univ. Hannover
- S. Bonvalot – Director, Bureau Gravimetrique International, CNES, Toulouse

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

- Prof. M. Vanclooster & P. Defourny (UCL);
- Prof. V. Hallet (FNDP, Namur);
- Prof. Y. Quinif, Dr O. Kaufman (FPMS Mons);
- Dr P. Meus (DGRNE, Division de l'Eau, MET);
- Mr. A. Hubert, J. Berte (International Polar Fundation).
- Dr. A. Mangold (IRM), for the test of the pumps.
- Ir J. Verstraeten (Afdeling Waterwegen Kust, Oostende);
- P. Lambot, Claude Verteneuil (Belgian National Geographic Institute)
- Dr. A Demoulin (Université de Liège)
- Dr. Johan Yans (Fondation Universitaire Notre Dame de la Paix à Namur)

Visitors:

- Short visits: 10 persons

E.1.6. Scientific outreach

Meeting presentations

[1] Van Camp, M.
The Absolute Gravimeter: A tool to investigate volcanic areas
2008 Volcano Deformation and Gravity Workshop (Invited talk), Vancouver, WA, USA, May 13-16, 2008.

[2] Diament, M., **Van Camp, M**, and de Viron, O.
Investigating ETS using the GRACE time variable gravity data, AGU Fall meeting (Poster)

San Francisco, USA, December 15-19, 2008.

[3] de Viron, O., Panet, I., Diament, M., **Van Camp, M.**
Observing Earth dynamics using GRACE
14th General Assembly of WEGENER (Invited talk), Darmstadt, Germany, September 15-18, 2008.

[4] **Van Camp, M.**, Metivier, L., de Viron, O., Williams, S.D.P., Meurers, B.
Hydrology and Noise Affecting Land-Based Gravity Measurements
AGU Fall meeting (Poster), San Francisco, USA, December 15-19, 2008.

[5] **Van Camp, M.**, Métivier, L., Williams, S.D.P., Vanclooster, M., Dassargues, A., et de Viron, O.
De l'influence des phénomènes hydrologiques sur les mesures gravimétriques
Colloque de l'Annee Internationale de la Planete Terre, L'eau dans tous ses Etats, visions spatiales (Poster), UNESCO, Paris, November 17-19, 2008.

[6] Camelbeeck, T., Bruyninx, C., Vanneste, K., Alexandre, P., Legrand, J., Bergeot, N., Van Camp, M.
Crustal deformation in stable continental Europe: a comparison of seismicity, geodetic and geologic information
14th General Assembly of WEGENER, Darmstadt, Germany, September 15-18, 2008.

[7] Lecocq, T., Van Camp, M., Alexandre, P., Camelbeeck, T.
Identifying Active Structures in a Low Deformation Intraplate Context: Investigations in Eastern Belgium
31st General Assembly of the European Seismological Commission ESC 2008, Hersonissos, Crete, Greece, September 7-12, 2008.

[8] Camelbeeck, T., Vanneste, K., Van Camp, M.
The seismic activity in stable continental Europe
Seismic Risk 2008 - Earthquakes in North-Western Europe, Liège, Belgique, September 11-12, 2008.

[9] Steim, J., **Van Camp, M.,** Rivera, L.
Connecting a Quanterra Data Logger Q330 on the GWR C021 Superconducting Gravimeter for low frequency seismology
AGU Fall meeting (Poster), San Francisco, USA, December 15-19, 2008.

[10] **Van Camp, M.**, Steim, J. , Rivera, L., Rapagnani, G.
Connecting a Quanterra Data logger Q330 on the GWR C021 Superconducting Gravimeter
31st General Assembly of the European Seismological Commission ESC 2008 (Poster), Hersonissos, Crete, Greece, September 7-12, 2008.

[11] Francis, O., Kipfstuhl, L., Westkott, M., **Van Camp, M.**
Accurate transfer function determination of the superconducting gravimeter OSG-CT40 in Walferdange (Luxembourg)
New Challenges in Earth's Dynamics ETS 2008 (Poster), Jena, Germany, September 1-5, 2008.

[12] Francis, O., van Dam, T., Germak, A., M. Amalvict, R. Bayer, M. Bilker-Koivula, M. Calvo, G.-C. D'Agostino, T. Dell'Acqua, A. Engfeldt, R. Faccia, R. Falk, O. Gitlein, Fernandez, J. Gjevestad, J. Hinderer, Jones, J. Kostelecky, N. Le Moigne, B. Luck, J. Mäkinen D. Mclaughlin, T. Olszak, P. Olsson, A. Pachuta, V. Palinkas, B. Pettersen, R. Pujol, I. Prutkin, D. Quagliotti, R. Reudink, C. Rothleitner, D. Ruess, C. Shen, V. Smith, S. Svitlov, L. Timmen, C. Ulrich, **M. Van Camp**, J. Walo, L. Wang, H. Wilmes, L. Xing
Results of the European Comparison of Absolute Gravimeters in Walferdange (Luxembourg) of November 2007
IAG International Symposium Gravity, Geoid and Earth Observation 2008, Chania, Greece, 23-27 June 2008.

[13] Zhu P., Van Ruymbeke M.
Detecting Earth's Free Oscillations from Lanzarote tide gauge stations using wavelets

"Wavelets and Applications", Louvain-la-Neuve, 5 May 2008.

[14] Zhu P., Van Ruymbeke M.
Detecting Earth's Free Oscillations from Lanzarote tide gauge stations after Sumatra-Andaman earthquake by wavelets
Earth Tide Symposium 2008: New Challenges in Earth Dynamics, 1-5, Sep, 2008, Jena, Germany

[15] **Zhu P., Van Ruymbeke M.,** Cadicheanu N. and Naslin S.
A stacking method and its applications
Earth Tide Symposium 2008: New Challenges in Earth Dynamics, 1-5, Sep, 2008, Jena, Germany

[16] Zhu P.,Cadicheanu N., Van Ruymbeke M.
Tidal triggering earthquakes: a case study at Vrancea Seismic zones
Earth Tide Symposium 2008: New Challenges in Earth Dynamics, 1-5, Sep, 2008, Jena, Germany

[17] Zhu P.
Base tones of Earth's Free Oscillations recorded by Superconducting Gravimeters
Earth Tide Symposium 2008: New Challenges in Earth Dynamics, 1-5, Sep, 2008, Jena, Germany

E.1.7. Missions

Assemblies, symposia:	M. Van Camp (ESC General Assembly) M. Van Camp (WEGENER) M. Van Camp (Colloque Année Internationale de la Planète Terre) M. Van Camp (AGU Fall meeting) M. Van Camp (Polar Sciences Belgian Committee) M. Van Ruymbeke (Earth Tide Symposium) Z. Ping (Matlab Conference, Leuven) Z. Ping (Earth Tide Symposium)
Commissions, working groups (days):	M. Van Camp (3 days)
Research visits (days):	M. Van Camp (5 days)
Field missions (days):	M. Hendrickx (9 days) M. Van Camp (42 days) M. Everaerts (46 days) S. Castelein (26 days) G. Rapagnani (2 days) Z. Ping (21 days) M. Van Ruymbeke (36 days) J.-P. Noël (9 days)

F. Publications

F.1. Publications with peer review

[1] Pierre Alexandre, David Kusman, Toon Petermans, Thierry Camelbeeck
The 18 September 1692 earthquake in the Belgian Ardenne and its aftershocks
Modern Approaches in Solid Earth Sciences - Historical Seismology: interdisciplinary studies of past and recent earthquakes 209-230.

[2] **Ducarme B.**, Timofeev V. Y., **Everaerts M**., Gornov P. Y., Parovishnii V. A., **Van Ruymbeke M.**
A Trans Siberian tidal gravity profile (TSP) for the validation of tidal gravity loading corrections
Journal of Geodynamics, Volume 45, 2-3, March 2008 Pages 73-82

[3] **Van Camp, M.**, Steim, J., Rapagnani, G., and Rivera, L.

Connecting a Quanterra Datalogger Q330 on the GWR C021 Superconducting Gravimeter
Seismological Research Letters 79 (6), 778-789, 2008.

[4] Wang, B., **P. Zhu**, Y. Chen, F. Niu, and B. Wang
Continuous subsurface velocity measurement with coda wave interferometry
Journal of Geophysical Research, 113, B12313, doi: 10.1029/2007JB005023

[5] N. Cadicheanu, **Zhu P.**, **Van Ruymbeke M.**
Spatial and temporal variations of the correlation coefficient between M2 and S2 earth tides components and earthquake occurrences for the intermediate depth seismic activity zones
Acta Geod. Geoph. Hung., 43 (2-3), 131-144, doi: 10.1556/AGeod.43.2008.2-3.3

F.2. Publications without peer review

[6] Dimitar Dimitrov, Ivan Georgiev, Jean-Claude Ruegg, **Thierry Camelbeeck**, Emil Botev
Surface co- and post-seismic deformations in the Chirpan-Plovdiv earthquakes region by geodetic data
Geodesy - Bulgarian Academy of Sciences, 19, 76-83.

[7] **Thierry Camelbeeck**, Hervé Degée, Hughes Wilquin, Alain Sabbe, Anne-Marie Barszez
Seismic risk in Belgium for ordinary buildings: methodological aspects and study cases
Seismic risk - Earthquakes in North-Western Europe, éditions de l'Université de Liège. Scientific editors: Thierry Camelbeeck, Hervé Degée, Geert Degrande and Alain Sabbe 281-292.

[8] Alain Sabbe, **Thierry Camelbeeck**, Anne-Marie Barszez
Moderate seismic activity and architectural heritage: methodological aspects and application in Wallonia
Seismic risk - Earthquakes in North-Western Europe, éditions de l'Université de Liège. Scientific editors: Thierry Camelbeeck, Hervé Degée, Geert Degrande and Alain Sabbe 191-200.

[9] **Thierry Camelbeeck**, **Pierre Alexandre**, **David Kusman**
Les séismes en Belgique et leurs effets sur le bâti, le patrimoine architectural et l'environnement
Proceedings of the Conference "Valuation and prevention of seismic risk in Walloon Region", Editeur responsable Danielle Sarlet, DGATLP, Namur D/2008/5322/34, 97-109.

[10] **Philippe Rosset**, **Toon Petermans**, **Thierry Camelbeeck**
L'aléa sismique local en Belgique
Proceedings of the Conference "Valuation and prevention of seismic risk in Walloon Region", Editeur responsable Danielle Sarlet, DGATLP, Namur D/2008/5322/34, 17-31.

[11] **Lecocq Thomas**, **Toon Petermans**, **Pierre Alexandre**, **Thierry Camelbeeck**
Earthquake relocation in the Ardenne (Belgium): identification of active structures in intraplate context
Seismic risk - Earthquakes in North-Western Europe, éditions de l'Université de Liège. Scientific editors: Thierry Camelbeeck, Hervé Degée, Geert Degrande and Alain Sabbe 15-24

[12] Dimitrov D, Mihailov E, **Everaerts M**, Stroyanov L.
Results from the new gravimetric measurement in the region of the earthquake in April 1928 (Chirpan-Plovdiv)
Bulgarian Academy of sciences geodesy n°19, 66-74.

[13] **Kris Vanneste**, **Koen Verbeeck**, **Thierry Camelbeeck**
A decade of paleoseismic research in the Roer Valley graben
Seismic risk - Earthquakes in North-Western Europe, éditions de l'Université de Liège. Scientific editors: Thierry Camelbeeck, Hervé Degée, Geert Degrande and Alain Sabbe, pp.57-64

[14] Dominique Similox-Tohon, Max Fernandez-Alonso, **Kris Vanneste**, Marc Waelkens, Philippe Muchez, Manuel Sintubin

An integrated neotectonic study of the Çanakli basin (SW Turkey): remote sensing, surface geology and near-surface geophysics
In: Sagalassos VI. Geo- and bio-archaeology at Sagalassos and in its territory (edited by Degryse, P. & Waelkens, M.). Leuven University Press, Leuven, pp.131-153

[15] Dominique Similox-Tohon, Max Fernandez-Alonso, **Kris Vanneste**, Marc Waelkens, Philippe Muchez, Manuel Sintubin
Identifying active normal faults in the Burdur-Isparta region (SW Turkey): remote sensing, surface geology and near-surface geophysics
In: Sagalassos VI. Geo- and bio-archaeology at Sagalassos and in its territory (edited by Degryse, P. & Waelkens, M.). Leuven University Press, Leuven, pp.75-130

[16] **Thierry Camelbeeck**, **Kris Vanneste**, **Michel Van Camp**
The seismic activity in stable continental Europe
Seismic risk - Earthquakes in North-Western Europe, éditions de l'Université de Liège. Scientific editors: Thierry Camelbeeck, Hervé Degée, Geert Degrande and Alain Sabbe, pp.25-32

[17] **J. Fraser,** J. Pigati, **A. Hubert-Ferrari**, **K. Vanneste**, **U. Avsar**, S. Altinok
A 3000 year chronology of North Anatolian Fault ruptures, utilizing magnetic susceptibility trench logging, near Lake Ladik, Turkey.
Geophysical Research Abstracts, EGU, Vol10, 2008

[18] **Boes X**., Moran B., Roger K., **Avsar U.**, Moernaut J., King J., Cagatay N., **Hubert-Ferrari A.** 2008.
Radionuclide profiles and recent earthquakes history of Lake Hazar Pull-apart basin (East Anatolian Fault, Turkey).
European Geosciences Union General Assembly 2008, Geophysical Research Abstracts, 10, 11204.

[19] **Avsar U., Boes X., Hubert-Ferrari A.**, Fagel N., King J. 2008.
Traces of the last earthquake sequence (1939-1944) along NAF from lacustrine sediments.
European Geosciences Union General Assembly 2008, Geophysical Research Abstracts, 10, 05406.

[20] **Garcia Moreno D., Hubert-Ferrari A.,** Moernaut J., Van Daele M., Damci E., De Batist M. 2008.
The Hazar pull-apart along the east Anatolian fault: Structure and active deformation.
European Geosciences Union General Assembly 2008, Geophysical Research Abstracts, 10, 01808.

[21] **Boes X.**, Jasper M., **Avsar U.,** Namik C., **Hubert-Ferrari A.,** 2008.
Lake Hazar: a potential high-resolution 150 ka record of climate and tectonic interactions in Anatolia.
Eos Trans. AGU 89 (53), Fall Meet. Suppl., Abstract PP11B-1391.

[22] **Fraser J., Hubert-Ferrari A.**, **Vanneste K., Avsar U.,** Altinok S. 2008.
Defining Additional Stratigraphy in Paleosismic Trenches by 2D Logging of Magnetic Susceptibility. A Paleoseismic Investigation Near Lake Ladik, North Anatolian Fault, Turkey.
Eos Trans. AGU 89 (53), Fall Meet. Suppl., Abstract T21B-1942.

[23] **Avsar U., Boes X., Hubert-Ferrari A.,** Fagel N., Schmidt S., 2008.
Sedimentological Fingerprints of Recent Earthquakes in Lake Sediments: A Case Study on the North Anatolian Fault (NAF), Turkey.
Eos Trans. AGU 89 (53), Fall Meet. Suppl., Abstract T21A-1919.

F.3. Publications in press, submitted

[24] **J. Fraser,** J. Pigati, **A. Hubert-Ferrari**, **K. Vanneste**, **U. Avsar**, S. Altinok
A 3000-year record of ground-rupturing earthquakes along the central North Anatolian Fault near Lake Ladik, Turkey. [submitted]
Re-submitted to: Bulletin of the seismological sociatey of America

[25] **D. Garcia Moreno, A. Hubert-Ferrari**, J. Moernaut, M. Van Daele, E. Damci and M. De Batist (2008).
The Hazar pull-apart along the East Anatolian Fault: Structure and active deformation.
Geophysical Research Abstracts, 10.

[26] **Hubert-Ferrari A.,** J. Van Der Woerd, G. King, R. Armijo, I. Villa. 2009.
Long-term evolution of the North Anatolian fault (Turkey),
In press in: Special Publication of the Geological Society of London : Geodynamics of Collision and Collapse at the Africa-Arabia-Eurasia Subduction Zone, Editor R. Govers.

[27] Wang X. , J. Suppe, S. Guan, **A. Hubert-Ferrari**, R. Gonzalez-Mieres, J. Chengzao. 2009.
Cenozoic Structure and Tectonic Evolution of the Kuqa Foldbelt, southern Tianshan, China,
In press in: American Association of Petroleum Geologists Special Publication.

[28] **Boës X**., Moran B., King J., N. Cagatay, **Hubert Ferrari A.** 2009.
Large earthquakes cycles in lake sediments along the East Anatolian Fault, Turkey.
Submitted to: Journal of Paleolimnology.

[29] **Garcia Moreno D., A. Hubert-Ferrari**, J. Moernaut, **J. Fraser, X. Boes**, M. Van Daele, M. De Batist, E. Damci, N. Cagatay.
Structure of the central part of the East Anatolian Fault zone, eastern Turkey.
Submitted to the Proceeding of the 27th European Center for Geodynamics and seismology Workshop.

[30] **D. Garcia Moreno, A. Hubert-Ferrari,** J. Moernaut, **X. Boes**,**J. Fraser,** M. Van Daele, **U. Avsar**, E. Damci, N. Cagatay, M. De Batist, 2008
Structure and evolution of Hazar Basin, situated on the central part of the East Anatolian Fault, Eastern Turkey
Submitted to Basin Research.

[31] Francis, O., van Dam, T., Germak, A., M. Amalvict, R. Bayer, M. Bilker-Koivula, M. Calvo, G.-C. D'Agostino, T. Dell'Acqua, A. Engfeldt, R. Faccia, R. Falk, O. Gitlein, Fernandez, J. Gjevestad, J. Hinderer, Jones, J. Kostelecky, N. Le Moigne, B. Luck, J. Mäkinen D. Mclaughlin, T. Olszak, P. Olsson, A. Pachuta, V. Palinkas, B. Pettersen, R. Pujol, I. Prutkin, D. Quagliotti, R. Reudink, C. Rothleitner, D. Ruess, C. Shen, V. Smith, S. Svitlov, L. Timmen, C. Ulrich, **M. Van Camp**, J. Walo, L. Wang, H. Wilmes, L. Xing
Results of the European Comparison of Absolute Gravimeters in Walferdange (Luxembourg) of November 2007
IAG International Symposium on Gravity, Geoid and Earth Observation 2008, Crete, June 2008 (in press).

[32] Vitushkin, L., Jiang, Z., Robertsson, L., Becker, M., Francis, O., Germak, A., D'Agostino, G., Palinkas, V., Amalvict, M., Bayer, R, Bilker-Koivula, M., Desogus, S., Faller, J., Falk, R., Hinderer, J., Gagnon, C., Jakob, T., Kalish, E., Kostelecky, J., Lee, C., Liard, J., Lokshyn, Y., Luck, B., Mäkinen, J., Mizushima, S., Le Moigne, N., Nalivaev, V., Origlia, C., Pujol, E.R., Richard, P., Ruess, D., Schmerge, D., Stus, Y., Svitlov, S., Thies, S., Ullrich, C., **Van Camp, M.**, Vitushkin, A., Wilmes, H., 2008
Results of the Seventh International Comparison of Absolute Gravimeters ICAG-2005 at the Bureau International des Poids et Mesures, Sèvres
International Symposium on Gravity, Geoid and Earth Observation 2008 (in press).

[33] **Zhu P., Van Ruymbeke M.,** N. Cadicheanu
A stacking method and its application to Lanzarote tide gauge records
Submitted to Journal of Geodynamics

F.4. Thesis, internal reports

[34] Baumann, H, Francis, O., and **Van Camp, M.**
Absolute Gravimeter Intercomparison
Euramet Project #1093, Federal Office of Metrology METAS, Switzerland, 2008 (accepted).

[35] **Everaerts M**. Ducarme B
Calibration Gravimetrique du reseau Walcors
For The " Ministére wallon de l'équipement et des transport- Direction de la topographie de la cartographie DTC" submitted on the 15/12/2008

[36] **Van Camp, M.**
Test of the calibration and of the high and low frequency behavior of the broadband stations EBN/HRK/MEM/RCH/UCCBs/UCCBh
Internal report, July 29, 2008.

[37] **Van Camp, M.**
Testing the influence of the compressors on the seismometers
internal report on the vibration caused by the pumps to be installed by the Royal Meteorological Institute (RMI) and U. Gent to monitor air pollution at the Princess Elisabeth station, March 2008.

DEPARTMENT 2: Astrometry

SECTION 4: Astrometry of Solar System bodies

Introduction

The Royal Observatory of Belgium has a long tradition in 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 civilization 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".

Recently the section got involved, together with other sections of the Royal Observatory, in the data reduction of the astrometric satellite Gaia, in the Coordination Unit dealing with solar system objects. The activities within this project are described in a separate chapter.

The long-lasting activity of photographing the sky in the department produced an important collection of astrophotographic plates, most of them under the management of the section. In order to keep the data accessible for modern research, they have to be digitized. Since several years digitization projects have been started at the Royal Observatory. These activities are described in the Theme "Digitization".

Finally the section is responsible for producing the Yearbook of the Royal Observatory.

Some members of the section are also active in projects which are not directly related to the nominal activities of the section, such as asteroseismology. These activities are described in the reports of the sections in which these activities best fit.

G. Asteroids

G.1. Project "RUSTICCA"

G.1.1. Objectives

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

G.1.2. Progress and results

G.1.2.1. Observations in 2008

In 2008 observations have been performed on 50 nights by 7 observers. They include P. De Cat (14 nights, 1053 frames), R. Desmet (1 night, 39 frames), E. Elst (13 nights, 246 frames), A. Jonckheere (1 night, 52 frames), T. Pauwels (29 nights, 1125 frames), K. Puttemans (1 night, 108 frames) and P. Vingerhoets (7 nights, 239 frames).

These observations concerned:

- Astrometry of minor planets: 42 nights (1 of which failed to produce anything due to technical problems) covering 138 fields by 2120 images, producing 1840 astrometric positions. Out of these, 6 fields with 88 images produced 36 positions of objects of the Near-Earth Objects confirmation page. Observers: P. De Cat, R. Desmet, E. Elst, A. Jonckheere, T. Pauwels, K. Puttemans and P. Vingerhoets. The positions have been published in the MPSs and MPECs ([2], [3], [6], [7], [8], [9], [10], [11], [12], [13], [14], [15]).
- Occultations of stars by minor planets, the so-called Planoccult phenomena: 15 events attempted on 14 nights, with 92 images and films, producing 11 light curves. Observers: P. De Cat, T. Pauwels, P. Vingerhoets. There was again 1 positive event, 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 ([4], [5]). The remaining 4 events gave no usable results due to too bad weather conditions.
- Mutual phenomena (eclipses and occultations) of an asteroid and its satellite: 1 event attempted on 1 night, with 114 images, producing 1 light curve. Observers: T. Pauwels, P. Vingerhoets.
- Mutual phenomena (eclipses and occultations) of satellites of Saturn, the so-called PHEURA phenomena: 1 night attempting 1 phenomenon. The observations were done in very difficult conditions, and no attempt has yet been made to reduce the data obtained. Observers: P. De Cat, T. Pauwels, P. Vingerhoets.

Together they produced 2331 images and films.

G.1.2.2. Other activities

Apart from the observations themselves, a lot of work was put routinely in the preparation of the observations (setting up the list of objects to observe in the coming night, many times just in case the weather might clear up), the reductions of the observations (running the automatic processes, searching asteroids, measuring them and identifying them), and finally computing ephemerides for newly found objects.

One of the asteroids found at Ukkel reached the NEO Confirmation Page, meaning it was suspected to be an NEO (near-Earth asteroid), but finally turned out not to be interesting enough to issue an MPEC (Minor Planet Electronic Circular) for it.

In the reduction software a new module was added allowing an easier and better co-adding of images, and an html-page was written for easier checking of the weather forecast.

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

All raw data has been archived on CD-ROM, along with the necessary documentation to interpret the observations in the future, adding another 42 CD-ROMs to the archive, containing 2181 images and films. Since the oldest CD-ROMs of the archive are now more than 10 years old, it was time to make additional copies. A job student, Walid Rabtach, has been put on the task in July, and copied almost the complete archive to an external hard disk and to a set of 46 DVDs. Only few CD-ROMs gave problems to read.

Since the team of observers is too small to exploit all clear nights, we are looking for volunteers. These would include people who have already observed under supervision, but who could then observe independently. A convention for volunteers has been set up, we updated the observer's manual and we started setting up a manual for the reduction software.

There was a possibility to buy a CCD camera that could be used to make an all-sky camera, allowing to have a better view of the quality of the sky in real time. However, the price of the camera was too high, and the project was put on hold.

G.1.2.3. Summary of the results obtained since 1996

From 1996 to 2008 a total of 22 451 astrometric positions of minor planets and 73 astrometric positions of comets have been published in the Minor Planet Circulars. The number of 1740 published positions in 2008 ([2], [3], [6], [7], [8], [9], [10], [11], [12], [13], [14], [15]) is again rather low compared to the top years 2003-2005, but still slightly better than 2007. This can partly be explained by the weather, but also

partly by a lack of staff. Apart from a few volunteers, there were only 1.5 staff members available for the permanence at the telescope, and thus it is inevitable that some clear nights were lost.

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

The total number of preliminary designations of minor planets attributed to observations of the RUSTICCA project amounts to 302. With 8 new designations attributed in 2008, the situation is somewhat better than in 2007, but the effect of potential discoveries getting exhausted is clearly discernible.

2008 saw the attribution of the 100th discovered asteroid by the RUSTICCA project. 173 of the minor planets with preliminary designation attributed to Ukkel are currently multiple opposition objects, and 110 have been permanently numbered, with the discovery attributed to a RUSTICCA observation. The discoverers with the number of discovered minor planets are: H. Boffin (7 minor planets), P. De Cat (4 minor planets), E. Elst (7 minor planets), E. Elst and H. Debehogne (11 minor planet), E. Elst and S. Ipatov (4 minor planets), E. Elst and D. Taeymans (1 minor planet), T. Pauwels (71 minor planet), T. Pauwels and H. Boffin (1 minor planet), T. Pauwels and P. De Cat (2 minor planets), T. Pauwels and S. Ipatov (2 minor planets).

A total of 43 light curves of cataclysmic variables could be established (1999-2003), 19 light curves of mutual phenomena of the Galilean satellites of Jupiter (1997 and 2003, [20]), and 9 light curves of mutual phenomena of an asteroid and its satellite (2006--2008).

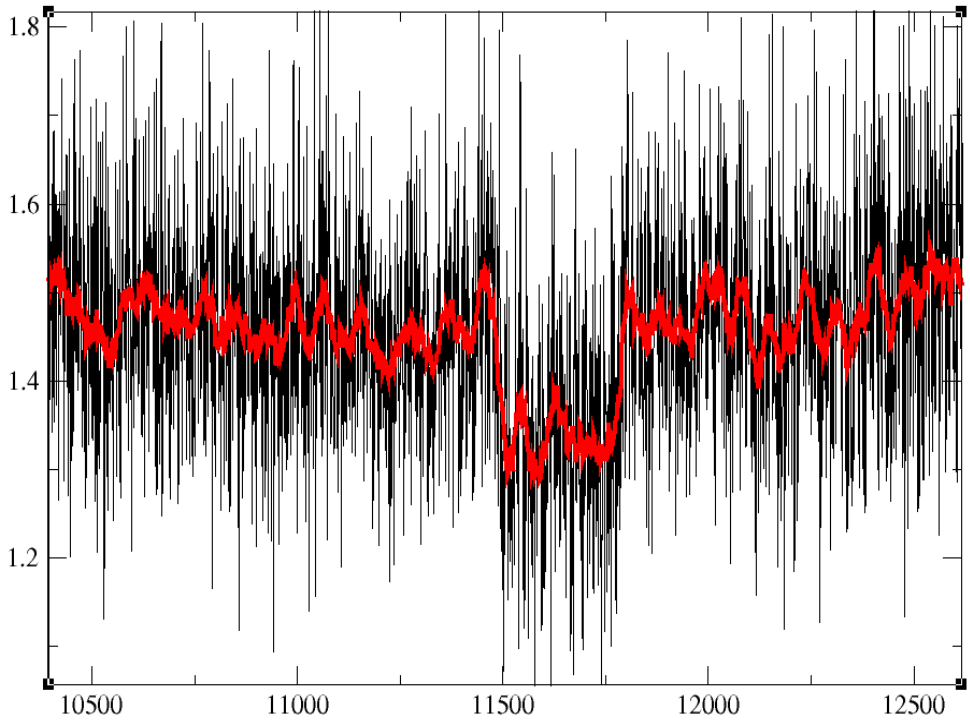


Figure 30: Detail of the light curve of the Metis occultation as observed from Ukkel

The team observed 58 potential occultations of stars by minor planets in the period 2003-2008. 15 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. 36 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 and 1 in 2008 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, 3 positive occultations out of 58 attempted is a good result.

The archive now consists of 378 CD-ROMs with a total of 27 474 images and films.

G.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 10 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. In 2009, there is again a season of mutual phenomena of the satellites of Jupiter, which we plan to observe. At present there are some volunteers that will join the team of observers. This way we hope to be slightly more efficient in utilizing the clear nights in the coming years.

G.1.4. Personnel involved

Scientific staff:

- T. Pauwels (observer and reductions, dotation)
- P. De Cat (observer and reductions, dotation)

Technical staff:

- W. Rabtach (copying archive, job student)
- M. De Knijf and team (maintenance of telescope, dotation)

G.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 and PHEURA 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: 3

H. Digitization

H.1. Project "Digitization of the heritage of the federal scientific institutes of Belspo"

H.1.1. Objectives

The federal Science Policy has recognized the importance of preserving and making available the heritage of the federal scientific institutes. The means is to digitize the collections of these institutes, and make them available via the web.

After a study of the cost of such a digitization, the government took the principal decision to implement the basic scenario in the course of ten years, starting in 2005. By the end of 2005, the federal Science Policy (Belspo) had initiated some ten smaller scale operational projects, which would run from 2005 to 2008. We joined project No. 7 (which we call "007") "digitization of photographic glass plates", involving the Royal Museum of Central Africa, the Royal Institute for the study and Conservation of Belgium's Artistic Heritage (interim coordinator), the Belgian Institute for Space Aeronomy and the Royal Observatory of Belgium, with the aim of digitizing our astrophotographic plates on a high-resolution digitizer that should have been built in the course of the "D4A" project (see reports 2002-2005), but which could not be finalized in due time because of events beyond our control. First aim of the 007 project is to make the digitizer operational, and then to start to digitize our collections. In parallel we want to set up a detailed catalogue with thumbnails of our plate collection. Once the digitizer is finalized, mass production of digitized images of our astrophotographic glass plates should start.

Since these first projects were supposed to terminate by the end of 2008, Belspo has started to search actively for financing digitizing projects beyond 2008. Two committees are supporting this activity. The aim is to set up a public-private partnership.

H.1.2. Progress and results

H.1.2.1.Management

In order to investigate the possibility of a public-private partnership, Belspo set up two working groups: "call to tender" and "juridical aspects". T. Pauwels is member of the former one to represent the Observatory. R. Van der Linden is member of the latter one.

H.1.2.2.Hardware

A 2D-digitiser facility of high geometric and radiometric resolution and precision designed and ordered under the D4A pilot-project, was started up, tested and put into production. J.-P. De Cuyper is the project scientist of the digitizer facility and directing official in charge of the follow-up of the warranty and maintenance of the air bearing XY-table with add-ons delivered by Aerotech and the temperature and humidity control system of the clean room and the adjacent plate archive room delivered by Becker Reinraumtechnik.

The digitizer is based on an engineered ABL3600 air bearing XY-table from Aerotech. The mechanical subsystem includes an automatic plate holder assembly, a plate tray exchange robot with plate tray magazine and turntable for photographic glass plates and film sheets and an automatic film roll transport system. These custom made devices allow a rapid change and loading into focus of the photographs to be digitized without manual intervention. The optical system consists of a BCi4 12bit CMOS camera from C-Cam Vector International mounted on a Schneider Xenoplan telecentric 1:1 objective. The back light illumination system uses very bright LEDs (lifetime min. 50000h), controlled by a precision power supply. The digitizer is installed on an isolated foundation block in a clean room. A acclimatization installation delivered by Becker Reinraumtechnik regulates the clean room and adjacent archive room to a constant air temperature of 18°C +/- 0.1°C and a relative air humidity of 50% +/- 1%.

J.-P. De Cuyper follows-up the daily functioning of the technical installation. Together with M. De Knijf he takes care of the maintenance and the solving of the technical problems of the digitizer, the air compressor, the vacuum pumps and the extension of the power and data cabling; and with M. Strubbe of the acclimatization installation. In order to stabilize the return air temperature M. De Knijf and B. Frederik constructed and installed an air evacuation conduct on the hot air outlet of the cooling unit of the air compressor, while M. Strubbe together with a job student started the thermal isolation of the return air conduct.

With Becker Reinraumtechnik a maintenance contract was subscribed and by the end of August the first maintenance was done. Early September the airflow regulator in the by-pass air conduct broke, causing a complete blocking of the bypass airflow and fluctuations of the clean room temperature of more than 0.8°C. In the second half of December Becker finally send us an adapted airflow regulator of larger di-

ameter and the conic connection parts. The technical service of the ROB immediately started the preparatory works for the replacement of the broken airflow regulator and at the same time for the repositioning of the smoke protection valve behind the bypass air conduct.

Early 2008, J.-P. De Cuyper and L. Winter installed a new CMOS BCi4 production camera, with DC power supply over the USB cable. A special mechanical alignment device was constructed by F. Renders for accurately aligning the pixel rows and columns of the digital camera with the axes of the XY-table. The automatic film roll transport system was fully tested and put into production for the full automatic digitization of (aerial) photographs on film rolls, by J.-P. De Cuyper and G. De Decker.

J.-P. De Cuyper and Uwe Laux, an optical engineer of the Thüringer Landessternwarte Tautenburg, tested different types of light diffusing materials in combination with a new light finger containing the LEDs. Mid 2008 the 350 mm x 350 mm full size diffuser plate in the base of the play tray holder was removed. The LEDs were placed in a light finger with a small diffuser on top of it. The light finger is mounted as high as possible beneath the plate tray holder on a cooling unit in the opening of the granite table. With this setup is the flat field is unique and no longer depends on the position of the XY-table as it was before. The intensity fall off to the corners is less than 3%.

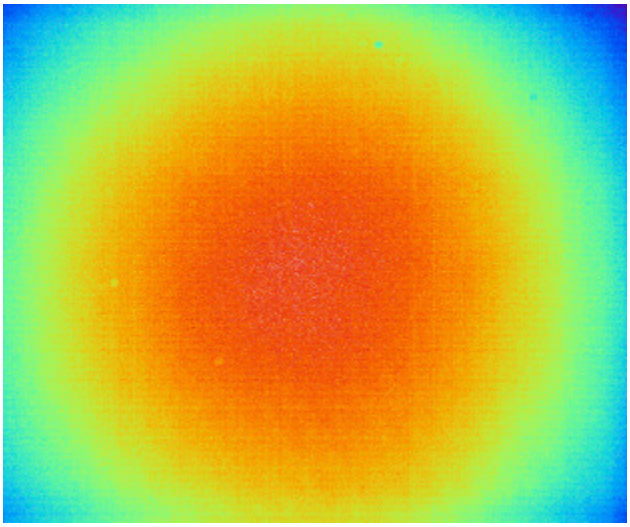


Figure 31: Flat field, direct image of the lightfinger

J.-P. De Cuyper and L. Winter continued design and construction of a new illumination control unit and the testing of the usability of different microprocessors. This new concept is necessary in order to be able to adapt the illumination in less than 10 ms without compromising the 16-bit stability and precision of the light intensity. In collaboration with I. Van der Gucht and D. Van Damme, they continued the design and construction of a high precision computer regulated DC power supply needed for the illumination control system.

After aligning the digital camera with the axes of the XY-table, the moving dot procedure was used to determine the distortion model of the field of view error. The "distortion free" field of view of the Schneider Xenoplan 1:1 two-sided telecentric objective was found to be less than 7 mm in diameter. This limits the size of the subimages for recomposing the overall mosaic images of the (aerial) photographs to 5 mm x 5 mm.

J.-P. De Cuyper and Uwe Laux continued the design of a new two-sided telecentric objective with a distortion free field of view diameter of at least 25 mm. This will allow to reduce the stepping time of the XY-table by a factor of 10 and to make the DAMIAN digitizer an order of magnitude faster.

For the calibration and stability control of the digitizer, the 350 mm x 350 mm geogrid (geometric grid of chromium dots on a glass plate every 0.5 mm in the X and Y directions with diameters ranging from 50 µm to 300 µm made by BVM Maskshop in Germany) was digitized nearly daily. The static and dynamic repeatability benchmark testing showed that under stable environmental conditions the internal repeatabil-

ity error in the digitized images is below 0.08 µm. A temperature change of 0.5°C was found to cause a shift of 0.5 µm in the central field of view of the camera.

The moving dot procedure was used to determine the distortion model of the field of view error of the optical system. This model allows the mapping of the extracted pixel positions into metric plate coordinates.

On a regular basis thousands of dark and flat images were taken to generate mean dark and mean flat images for correcting the images taken by the CMOS camera.

The DAMIAN digitizer can digitize photographic images up to 350 mm 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 2008 counter pressure plates and plate trays were available for digitizing 1 size of film rolls, 1 size of film sheets and 5 sizes of glass plates.

H.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 digitization process, was further extended and improved by G. De Decker, in order to overcome the severe security problems and firewall restrictions encountered after the switch over from Windows 2000 to Windows XP. He also extended the software for converting the raw format subimages into pmi, tiff and fits format, to generate mosaic images in tiff and fits format and to create pyramid overviews in tiff format. A variable exposure time software package was developed for digitizing (aerial) images in full dynamic range and to generate from these subimages a mosaic image reconverted to a constant (mean) exposure time.

The acclimatization installation of Becker-Reinraumtechnik uses a SAIA IC controller for steering the acclimatization as a function of a number of environmental parameters measured in real time. G. De Decker extended the software interface for reading these environmental parameters used by the SAIA controller and storing them in an Excel table. This software is used:

- To check the stability of the air temperature and relative humidity in the measuring clean room.
- To allow the adjustment of the steering parameters of the Saia controller.
- As an interface between the environmental parameters and the digitization metadata table. At the time of capture of a digital subimage, the values of the environmental clean room parameters (temperature, relative humidity, overpressure, etc.) are recorded in the metadata table and written to the header of the corresponding subimage file.

For the DT80000 digital temperature sensor G. De Decker developed a software interface allowing a real time reading of the voltage and converting it into a calibrated temperature in °C. Together with the data of the relative humidity sensor, this gives an independent and calibrated control measurement for cross checking the values measured and used by the SAIA controller.

L. Winter optimized and tested the moving dot software for the alignment of the BCi4 camera with the axes of the XY-table and the software for calculating a correct distortion model of the field of view error of the camera.

In October J.-P. De Cuyper determined the exact mechanical table distance in the X and Y direction corresponding to the displacement of a target of exactly 704 pixels in the row and column direction in the central field of view of the camera. G. De Decker adjusted the step and stare motion control software of the XY-table to be able to adapt the XY-table stepping to the actual size of the 704 x 704 subimages. This makes it possible to reassemble these subimages of a digitized (aerial) photograph back into one single mosaic image with minimal geometric distortion.

H.1.2.4.Digitization

Several film rolls with aerial images of the NGI have been digitized in close collaboration with the colleagues of the NGI and AFGA-Gevaert. From these film rolls 303 mosaic images in tiled tiff format with pyramid overviews were created. For test purposes, different sets of original aerial photographic images on film sheet and their contact vacuum photographic copies (made in Mortsel by AGFA-Gevaert) were

digitized in different ways. The NGI analyzed the quality of the digital images. In both cases the digital images were found to fulfill the needed requirements for photogrammetric applications.

H.1.2.5.Digital catalogue

The work on the digital catalogue and the pre-scanning of the photographic plates archived at the ROB was continued by J.-P. De Cuyper, G. De Decker, G. Peeters and D. Duval and during the summer by 4 jobstudents. For the prescanning the AFGA DuoScan HiD A4 flatbed scanner at the ROB was used for the smaller plates and the AGFA XY-15 Plus A3+ graphical flatbed scanner at the NGI for the larger ones and for scanning the paper maps of the CdC Atlas. At the end of 2008 the digital photographic plates catalogue contained metadata of 25 239 direct images and spectra (mostly multiple exposures on one photographic glass plate), 12 582 prescans of photographic plates and 6278 quick-looks.

H.1.3. Perspective for next years

The digitizer should be further fine tuned with an automatic plate loader, a better illumination and a telecentric objective with a larger distortion-free field, and the software will be further enhanced. The digital catalogue will be supplemented with the still missing pre-scans, will be put in the format of a relational data base, and will be made available on internet. Routine high-precision digitization of our collection should start on the scanning time allocated to the ROB.

The financing of the project "007" was foreseen till the end of 2008, but will be extended till the end of 2009 using the money left over. To extend the project beyond 2009, two options are foreseen. On the one hand a public-private partnership could be established by Belspo. On the other hand, in the coming years the UDAPAC project is supposed to start (see project UDAPAC). Since it will use the same facilities, we expect that there will be some interaction between the digitization of our collections and UDAPAC.

H.1.4. Personnel involved

Scientific staff:

- R. Van der Linden (coordination, dotation)
- T. Pauwels (coordination, dotation)
- J.-P. De Cuyper (management, Belspo project)
- L. Winter (expertise, Belspo project)

Technical staff:

- G. De Decker (software engineering, Belspo project)
- G. Peeters (data input, dotation)
- D. Duval (data input, dotation)
- M. De Knijf and team (technical assistance, dotation)
- B. Frederik (technical assistance, dotation)
- M. Strubbe (technical assistance, dotation)
- F. Renders (technical assistance, dotation)
- I. Van der Gucht (technical assistance, dotation)
- D. Van Damme (technical assistance, dotation)
- Géraldine de Decker (job student, data input, dotation)
- Florian De Cuyper (job student, data input, dotation)
- Frederik De Cuyper (job student, data input, dotation)
- Hugo de Decker (job student, data input, dotation)

H.1.5. Partnerships

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

- Norbert Zacharias & Gary Wieder, US Naval Observatory, Washington DC, US

- Uwe Laux, Thüringer Landessternwarte Tautenburg, Germany

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

- Royal Museum of Central Africa
- Royal Institute for the study and Conservation of Belgium's Artistic Heritage
- National Geographic Institute
- AGFA-Gevaert NV, Mortsel

Grants/Projects used for this research/service

- Digitaliseringsplan van de FWI's of Belspo

Visitors:

- Uwe Laux, Thüringer Landessternwarte Tautenburg (TLS), 18-22/02/2008 and 14-18/07/2008
- Short visits: 18.

H.1.6. Scientific outreach

Meeting presentations

[1] **De Cuyper J.-P**., Winter L., **De Decker G**., Zacharias N., Pascu D., Arlot J.-E., Robert V., Lainey V.
New Astrometric reduction of the USNO Photographic plates of Planetary Satellites
1 - 5 November 2008, Québec, Canada, ADASS XVIII conference.

Seminars

[2] **De Cuyper J.-P**., Laux U.
Proposal of the Optical Improvements for multiplying the production capacity of the DAMIAN digitiser with a factor of ten
16 July 2008, Brussel, NGI

[3] **De Cuyper J.-P., De Decker G.**
Digitalisatie van orignelen en fotografische reproducties van oude foto's met een vervagend beeld en/of een gedegradeerde en beschadigde drager
27 August 2008, Brussel, NGI

[4] **De Cuyper J.-P., De Decker G.**
Digitalisatie van oude luchtfoto's met de DAMIAN digitalisatiefaciliteit
13 October 2008, Brussel, NGI

[5] **De Cuyper J.-P.,**
Digitisation of old astrometric plates with the DAMIAN digitiser
7 November 2008, US Naval Observatory, Washington, DC, USA

H.1.7. Missions

Assemblies, symposia:

- J.-P. De Cuyper (ADASS XVIII conference)

Commissions, working groups:

- T. Pauwels (2 days).

Research visits:

- J.-P. De Cuyper (12 days)

Field missions:

H.2. Project UDAPAC

H.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 digitization projects, these plates could be digitized. Until now no concrete action has been undertaken. In 2005 there were some discussions on the opportunity to start the raising of funds for UDAPAC. However, some people had the feeling that it would be better to wait till the Damian digitizer would be operational and could have demonstrated its utility, so that applications for funding would be stronger.

H.2.2. Progress and results

There were no real activities in 2008, since it is felt that it is too early to start the operational phase of UDAPAC. First, the Damian digitizer should demonstrate its scientific capabilities.

H.2.3. Perspective for next years

In the next years, once the archives room and the digitizer have been realized in the 007 project, routine operations in UDAPAC should start. Before that a funding source must be searched.

H.2.4. Partnerships

Visitors:

- Short visits: 1

I. Publications

I.1. Publications with peer review

I.1.1. Publications with peer review

[1] Zacharias N., **Winter L.,** Holdenried E. R.**, De Cuyper J.-P.**, Wyco G. L., Wieder G.
The StarScan plate measuring machine: overview and calibrations
PASP, 120, 644 (astro-ph 0806.0256).

[2] **De Cat P**., et al.
18 positions of minor planets
Minor Planet Electronic Circulars 2008-C89, 2008-C90.

[3] **Pauwels T**., et al.
4 positions of minor planets
Minor Planet Electronic Circulars 2008-J42.

[4] D. Herald, et al. (125 authors, including **Pauwels, T.**)
Geocentric Occultation Observations
MPC 63586.

[5] D. Herald, et al. (54 authors, including **De Cat, P., Pauwels, T., Vingerhoets, P.**)
Geocentric Occultation Observations
MPC 64436.

[6] **Elst E.**
350 positions of asteroids
MPS 239302, 239313, 239348, 239419, 239513, 239825, 239854, 239894, 239908, 240013, 240049, 240064, 240083, 240146, 240189, 240224, 240238, 240244, 240318, 240371, 240448, 240505,

240525, 240536, 240574, 247154, 247329, 248953, 249781, 249842, 249849, 249882, 250155, 250180, 250189, 250247, 252633, 255156, 255205, 255206, 255217, 255233, 255244, 255374, 255468, 255476, 255534, 255632, 255637, 255954, 256514, 256805, 256808, 256925, 256930, 257241, 257737, 257743, 257744, 257939, 257953, 258050, 258235, 258273, 258304, 258383, 258689, 258827, 259005, 259026, 260228, 260429, 260432, 260434, 260461, 261730.

[7] **Elst E.**, Debehogne H.
4 positions of asteroids
MPS 237617.

[8] **Elst E.**, Desmet R.
84 positions of asteroids
MPS 248922, 248965, 249033, 249104, 249117, 249194, 249200, 249216, 249220, 249309, 249311, 249327, 249429, 249597, 249613, 249645, 249692.

[9] **De Cat P.**
612 positions of asteroids
MPS 235283, 235747, 235748, 235761, 235779, 235793, 235794, 235936, 235960, 235996, 236015, 236037, 236214, 236215, 236419, 236522, 236542, 236696, 236807, 236864, 237069, 237138, 237356, 237394, 237461, 237467, 237484, 237523, 237586, 237695, 237753, 237790, 237924, 238248, 238344, 238388, 238422, 238423, 238434, 238615, 238768, 238878, 238879, 238907, 239417, 244653, 244807, 245234, 245259, 245358, 245368, 245428, 245440, 245444, 245477, 245478, 245501, 245504, 245515, 245629, 245683, 245722, 245818, 245885, 245936, 245937, 246019, 246181, 246258, 246285, 246310, 246319, 246325, 246456, 246467, 246496, 246532, 246572, 246580, 246616, 249033, 249094, 249104, 249449, 249736, 249758, 250599, 250610, 251433, 255290, 255415, 255721, 255749, 255761, 255762, 255792, 255795, 255922, 255954, 255980, 255981, 256166, 256241, 256242, 256252, 256302, 256346, 256350, 256391, 256406, 256410, 260487, 260527, 260720, 260750, 260766, 260768, 260774, 260776, 260781, 260799, 260910, 261103, 261200.

[10] **De Cat P.,** Puttemans K.
61 positions of asteroids
MPS 237461, 237484, 237606, 237748, 237751, 237754, 238054, 238434, 238655, 238745, 238859, 238982, 239326, 239651.

[11] **Pauwels, T.**
591 positions of minor planets
MPS 232547, 232604, 232676, 232678, 232742, 232829, 232855, 232903, 233049, 233060, 233146, 233197, 233217, 233334, 233471, 233476, 234124, 234236, 234440, 234671, 234737, 235017, 237408, 237461, 237484, 237586, 237629, 237660, 237695, 237698, 237701, 237702, 237748, 237749, 237751, 237753, 237754, 237787, 237952, 238054, 238200, 238248, 238254, 238344, 238434, 238514, 238519, 238745, 238859, 238899, 238947, 239112, 239371, 239449, 239645, 239651, 239791, 239900, 240061, 240862, 242049, 242267, 242380, 242498, 242618, 244114, 248995, 249109, 249826, 249842, 249849, 249882, 250272, 250391, 250483, 250594, 251407, 252681, 253518, 255723, 258235, 259037, 260475, 260492, 260510, 260526, 260556, 260586, 260720, 260750, 260755, 260766, 260768, 260929, 260945, 261039, 261095, 261103, 261129, 261171, 261200, 261211, 261285, 261419, 261510, 261650, 261877, 261901, 262263, 262523, 262941, 266694, 266772, 268831, 269135, 269287.

[12] **Pauwels, T., Jonckheere, A., De Cat, P.**
14 positions of minor planets
MPS 236419, 236602, 236696.

[13] **Pauwels, T.,** Boffin, H.
4 positions of minor planets
MPS 250402.

[14] **Pauwels, T., De Cat, P.**
10 positions of minor planets
MPS 233486, 249850.

[15] **Pauwels, T., Vingerhoets, P.**
3 positions of minor planets
MPS 251998.

Notes:

- There is some debate about whether the MPCs are considered as reviewed or not. B. Marsden (former director) insisted on the fact that the MPCs are a "refereed journal" (though the refereeing process is almost entirely automated nowadays).
- We have grouped positions according to the author list. ADS groups them per month, irrespective of authors. This way the count of publications is totally different (basically one per month). For an objective count, one should count positions rather than publications.

I.2. Publications without peer review

[16] Bucciarelli, B, et al. (26 authors including **De Cuyper, J.-P., Pauwels, T.**, van Dessel, E.)
Division I / Commission 8 / Working Group Astrographic Catalogue and Carte du Ciel Plates
Transactions IAU, Volume 3, Issue 26B (2007), Karel van der Hucht, ed., p. 95-97.

[17] Thuillot, W., et al. (26 authors including **Pauwels, T.**)
Division I / Commission 25 / Working Group Astrometry by small ground-based telescopes triennial report 2006-2009
Transactions IAU, Volume XXVIIA, Reports on Astronomy 2006-2009, K. van der Hucht, ed., p. 63-67.

[18] **Pauwels, T., Vingerhoets, P., Cuypers, J.**
A problem with the reduction of the observations of the PHEMU97 and PHEMU03 events with the Ukkel Schmidt Telescope
Proceedings of the workshop "Mutual events of the Uranian satellites in 2007-2008 and further observations in network", J.-E. Arlot, N. Emelianov, W. Thuillot, eds., 2008, 29-32.

[19] **Pauwels, T., De Cat, P., Vingerhoets, P.**
The possibility to observe PHEURA events with the Ukkel Schmidt Telescope
Proceedings of the workshop "Mutual events of the Uranian satellites in 2007-2008 and further observations in network", J.-E. Arlot, N. Emelianov, W. Thuillot, eds., 2008, 25-28.

I.3. Publications in press, submitted

[20] Arlot J.-E., et al. (119 authors including Cuypers, J., Lampens, P., Pauwels, T., Vingerhoets, P.)
The PHEMU03 catalogue of observations of mutual phenomena of the Galilean satellites of Jupiter
Submitted to A&A.

[21] **De Cuyper J.-P., Winter L., De Decker G., Zacharias N., Pascu D., Arlot J.-E., Robert V., Lainey V.**
New Astrometric Reduction of the USNO Photographic Plates of Planetary Satellites
ASP Conference Series, Vol. XXX, 2009, Eds. D.A. Bohlender, D. Durand and P. Dowler, 4 p.

I.4. Reports, thesis, etc

[22] **Pauwels, T., Bruyninx, C., Clette, F., Cuypers, J., Roosbeek, F., Sauval, J.**
Annuaire de l'Observatoire royal de Belgique -- Jaarboek van de Koninklijke Sterrenwacht van België 2009
Drukkerij EPO, ISSN 0373-4900.

DEPARTMENT 2: Astrometry and Dynamics of Celestial Bodies

SECTION 5: Astrometry and Dynamics of Stellar Systems

Introduction:

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

J. 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 different phenomena of high astrophysical relevance including their own formation and history. Astrometry helps in the full characterization of the components in a powerful way as it allows determining the orbital motions and, derived from these, the stellar masses - a fundamental property of stars - in a straightforward manner. **Wide binaries**, especially if the components have different spectral types, are used to calibrate the luminosities and temperatures of single stars and to confront evolutionary tracks and models. They represent the high angular momentum class. In contrast, **close binaries** offer excellent opportunities for the combination of data obtained with different techniques resulting in great progress for understanding the impact of binarity on the stellar atmospheres or close binary evolution.

J.1.Project "Visual Binaries - Binaries and Multiple Stars"

J.1.1. Objectives

Visual binaries allow a direct calibration of the mass-luminosity relation on the lower main sequence via the study of their orbital motions. Differential magnitudes and colours are collected along with accurate relative positions with the purpose to investigate the physical status, to improve the knowledge of their orbits and to derive the associated properties such as photometrically derived mass ratios. Binary and multiple stars (particularly eclipsing binaries) are an important source of precise fundamental stellar parameters and hence provide empirical constraints on stellar evolution.

J.1.2. Progress and results

Visual binaries: θ² Tau, RV Crt and V831 Cen

In the context of the spectroscopic analyses of particularly interesting binaries and multiple stars such as the spectroscopic triple system DG Leo [14] and the Hyades binary θ² Tau [23], attending the workshop concerning all aspects of the code KOREL - a Fourier method for disentangling composite spectra - was very useful. This work is done with the help of Dr. K. Torres who has been hired to work on spectra disentangling and its application. 44 high-resolution ELODIE spectra and 70 additional spectra of lower signal-to-noise, provided by Dr. G. Torres (USA), were used in the analysis of θ² Tau. Thanks to the procedure adapted to the complexity of the case by K. Torres, new solutions for the orbital parameters and the mass ratio were obtained using the direct measurements of the secondary's radial velocities for the first time. Applying both KOREL and FD3 spectra disentangling codes, the disentangling of the components of this member of the Hyades open cluster will enable us to complete a full study of the binary system.

This study will have important implications for a correct interpretation of stellar evolution in the open cluster.

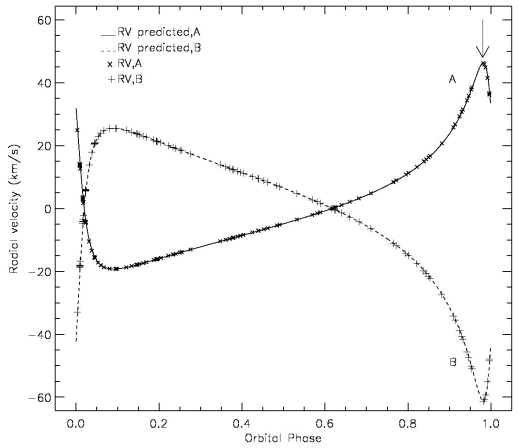


Figure 32: The distribution of radial velocity measurements as a function of orbital phase for the close binary system θ2 Tau is shown in the left panel. It is obvious from this plot that we still can improve our solution by adding new observations

The same spectra disentangling techniques were applied to RV Crateris, an eclipsing close binary suspected to be in a wider triple system. The combination of light-curve analysis with the disentangling techniques permitted to obtain the component spectra and to accurately measure the orbital parameters. A light-time effect was furthermore discovered in the (photometric) eclipse timings, proving that the wide component is gravitationally bound to the system (with a probable orbital period of 70 yrs).

For V831 Cen, a visual orbit with an orbital period of ~27 yrs has been computed from 30-40 astrometric data, considering different weights according to the source and the type of the measurements. However, no solution was found that is fully compatible with the light curve model proposed by Bakis and Hensberge. A modification of the code VBSB2 used to compute the orbit is needed for further progress.

Eclipsing binaries: RW Cr and VZ Leo

Using the programme PHOEBE based on the Wilson-Devinney method, we derived new geometric and photometric elements from the RI light curves of two Algol-type eclipsing binary systems: RW CrB and VZ Leo. Both systems form a semi-detached binary where the secondary component fills its Roche lobe whereas the primary component is well inside. In the case of RW CrB, the asymmetry in the light curve was explained by a spot model. For VZ Leo, it is the first published light-curve solution. The orbital period changes of both systems were studied indicating period decreases, which could be explained by non-conservation of the angular momentum. Since both primary stars are candidates for δ Scuti pulsations, we performed a time-series analysis of the residual I-data. However, no evidence of any short-periodic light variation was found. Finally, we compared these two systems with similar binary systems [7].

New photoelectric times of minima of 45 eclipsing binary systems, among which various eclipsing binaries with eccentric orbits, were also reported [8].

J.1.3. Perspective for next years

Future work will consist in deriving accurate component masses of the Hyades binary system θ² Tau by application of the codes KOREL and/or FD3 and by simultaneous fitting of the radial velocities and the interferometric data. We will next use the disentangled component spectra to perform a detailed chemical analysis, in order to determine as accurately as possible the physical properties and the evolutionary status of the components, and to test whether or not convective overshooting is needed in the models. For a few systems of high astrophysical interest for which we would need very high-angular resolution astrometric data, we will apply for interferometric observations provided the objects satisfy the criteria for eligibility (ESO for the Southern and/or CHARA/US for the Northern hemisphere). We will continue to observe and study various eclipsing binaries having special or particularly interesting properties.

J.1.4. Personnel

Scientific staff:

- Y. Frémat (staff researcher)
- P. Lampens (project coordinator)
- K. Torres (contractual researcher since 01/11/08)
- H. Hensberge (senior researcher, Dept. 3)

Technical staff:

- D. Duval (technical expert, until 30/06/08)
- K. Lefever (ICT expert, since 01/07/08)

J.1.5. Partnerships

List of international partners without grant

- P.G. Niarchos & collaborators, Department of Astrophysics, Astronomy and Mechanics, University of Athens, Greece (eclipsing binaries)
- P. Škoda, Astronomical Institute of the Academy of Sciences, Ondrejov, Czech Republic (θ^2 Tau)
- G. Torres, Harvard-Smithsonian Center for Astrophysics, Cambridge, MA (θ^2 Tau)
- B. Ulaş, Onsekiz Mart University of Canakkale, Dept. of Physics, Canakkale, Turkey (eclipsing binaries)

Grants used for this research

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

Visitors

- K. Torres, Fed. Univ. of Minas Gerais, Brazil: 2 days (project with Drs. Y. Frémat and H. Hensberge)

J.1.6. Scientific outreach

J.1.6.1. Meeting contributions

[23] Lampens, P., Frémat, Y., De Cat, P., Hensberge, H.,
Spectral disentangling and combined orbital solution for the Hyades binary θ^2 Tau (poster)
Summer school on KOREL organised by Prof. P. Hadrava, 15-19 Sep, Ondrejov, Czech Republic

J.1.7. Missions

Research visits

- Ondrejov Observatory, Czech Republic, Sep 15-19: school on spectra disentangling with KOREL

K. 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 aim at investigating the interactions that may arise between stellar pulsations and various other phenomena such as multiplicity, chemical composition and magnetic fields.

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

K.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, understanding the effects of binarity on the pulsation characteristics is a matter of prime importance. We focus our efforts unto those systems which are promising targets for the application of the technique of spectral disentangling.

K.1.2. Progress and results

K.1.2.1. Main-sequence A-F stars (γ Dor = γ Doradus star; δ Sct = δ Scuti star)

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 hosts stars which 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 are exploring 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) [1]. An IDL procedure based on the simultaneous application of a simplex minimization procedure and the code SYNSPEC has been developed in order to derive in a semi-automatic way the fundamental stellar parameters and the chemical abundances [23]. The new procedure was tested on synthetic spectra as well as on real spectra (Vega). It will be applied to all the collected spectra including the ones recently acquired with the spectrograph SOPHIE during three nights at the Observatoire de Haute-Provence (OHP, France).

The spectroscopic binary HD 68725 = HIP 40361

For the atypical and newly detected δ Sct star **HD 68725**, a binary of this sample, another large campaign has been organized in continuation of the 2007-run which was unsuccessful due to the weather mostly. Photometric data were collected in 2005-2006 (Belgium, Greece) as well as in the winter of 2007-2008 (Belgium, Greece, Kansas/US). The 2008-2009 winter campaign now also includes Mexican and Spanish observatories. The light curves indicate a multiperiodic behaviour. Possible pulsation frequencies are 8.5, 8.8 and 9.2 c/d. The long-term monitoring of the radial velocities is being performed at the National Astrophysical Observatory, Rozhen, by the Bulgarian partners while, also here, the collaboration has been extended to help covering the full orbital period with high-resolution spectra (including Mexican, Spanish, US and Chinese sites). The radial velocity shows variability at two different time scales: a) at a scale of ~1 month due to the binarity and b) at a scale of several hours due to the presence of pulsations. Two proposals requesting additional data for special targets of the already investigated A/F-star sample were written: one [38] was intended to obtain the orbital parameters of the new binary and one [39] was for the monitoring of the line profile variations due to pulsations detected in the high-resolution spectra. Both applications were however rejected (submitted to OHP, France).

The oscillating eclipsing binary systems CT Her and IU Per

We reported the latest results of a long-term, multi-site campaign carried out on the Algol-type eclipsing binary system **CT Her**, the primary component of which is a δ Sct-type pulsator with a main pulsation period of only 27 min. CT Her belongs to the new class of oscillating Algol-type binary systems. We performed a modelling of the light curves in two passbands using PHOEBE and detected up to 7 significant pulsation frequencies in the frequency range between 45-53 c/d in the B-residual data (independent of the adopted solution for the binary model). The remaining standard deviation of the ca. 7500 B-residuals spread over 4 years is 5.0 mmag [2][3]. A paper on CT Her is in preparation. We are currently focusing our attention unto **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 be analyzed next year in the framework of a PhD thesis conducted at the University of Athens. The time resolution we will have, will allow to improve the frequency-analysis significantly compared that of the most recent paper (with a 12-days time resolution). An application for photometric observations with the Aristarchos telescope (Greece) in order to collect time-

series photometry of the oEA star AO Ser was submitted [58]. This application was granted, but could not be carried out for some specific technical reason.

Mass determination in binary systems with pulsating components

The combination of spectroscopic and interferometric data enables an accurate, model-independent mass determination of multiple stars. Therefore, we are partners in a project of stellar mass determination for 2 SPB and 11 γ Dor stars which belong to double-lined spectroscopic binary systems [52]. Coupled proposals were accepted by ESO [33][45] and will be submitted to CHARA (VEGA, US). The observations will be performed in 2009. Moreover, 8 confirmed/candidate γ Dor stars will be considered within the scope of a large spectroscopic programme using HARPS (ESO, La Silla) [35].

K.1.2.2. Main-sequence O-B stars (SPB = slowly pulsating B-type star; β Cep = β Cephei star)

Influence of rotation and magnetism on the mode selection, mixing of elements, and evolution

- We organized and performed a spectroscopic multi-site campaign for the bright β Cep star **ε Cen**. The observational material consists of 1207 spectra obtained with HERCULES (MJUO), 146 spectra obtained with GIRAFFE (SAAO) and 903 spectra obtained with CORALIE (ESO, La Silla). The spectra are currently being reduced. Their analysis will start in the near future.
- **θ Car** is a peculiar B0.2V star with enhanced nitrogen and carbon deficiency and a known binary system. The observed chemical peculiarities are attributed to a past episode of mass transfer between the two components. Using 69 CORALIE spectra allowed us to significantly improve the orbital parameters. No unstable modes were found with periods of the order of several minutes [4]**.**
- **β Cru** is a bright southern β Cep star in a binary system with an orbital period of ~5 yrs. We applied for guaranteed time with the interferometer AMBER [32][44]. Unfortunately, the secondary component was not resolved by the interferometric observations till now. Depending on the observations of 2009, we will decide to stop or to continue requesting time in order to cover the full orbital period.
- We collaborate in a systematic **survey of magnetic fields** in SPBs and β Ceps: at least one magnetic field measurement was obtained for all the confirmed southern SPBs. Where possible, the projected rotational velocity and the fundamental parameters (effective temperature T_{eff}, surface gravity log g, mass M, radius R and luminosity L) were determined [2]. Although a proposal for FORS1+UVES time (UT2/ESO) was rejected [47], we will again apply for additional observations.

K.1.2.3. Main-sequence gravity mode pulsators

Characterization of gravity modes

- The gravity modes observed in the **SPB** and **γDor** stars are not fully characterized (yet). Indeed, current spectroscopic methods of mode identification have still not been shown to be usable for the growing number of observed g-modes. In order to improve this situation, 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. Pollard [5][6]. International collaborations to assist with the data acquisition have been sought, involving a total of 18 instruments at 12 observatories spread over the globe. Many proposals for telescope time have been submitted. The aims include three aspects: 1) identification and classification of suspected SPB and γ Dors; 2) multi-site campaigns for the pulsation mode identification of selected SPB and γ Dors; and 3) investigating and improving current mode identification methods with respect to g-modes specifically. The observations for the identification and classification part are nearly complete. Many suspected SPB or γ Dor stars were observed at the OHP [36]. Additional spectra have been obtained in Japan (HIDES/OAO), in Chile (FEROS/ESO) and are still being taken at La Palma (FIES). At least one high-resolution, high signal-to-noise (S/N) spectrum is now available for 50 objects. These spectra are currently being reduced.

- Multi-site campaigns have been organized for 4 γ Dor and 2 SPB stars ([31][37][41][42][43][51][54][55][56][57]) resulting in more than 300 spectra for several targets and ~150 high-resolution, high-S/N spectra for the others. For many stars, the main spectroscopic and photometric periods coincide. Moreover, HD147787 is a double-lined binary with an orbital period of ~40 days and we suspect that both components are pulsating (Fig. 2). The spectra are being reduced and will be analyzed together with those of 2007. Some observations were done in spectropolarimetric mode to check if our targets exhibit a weak magnetic field. Data reduction has started. We also planned multi-site campaigns for 7 new targets in 2009. The total allocated time is 22 nights at 3 observatories.

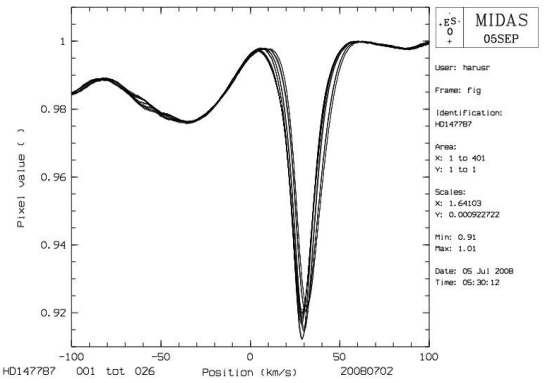


Figure 33: Cross-correlation profiles of HD 144787 with HARPS (ESO/La Silla) observed on 2/7/2008

K.1.3. Perspective for next year(s)

We will carry out a detailed chemical abundance analysis for the A-/F-type stars of the sample for which high-resolution, high S/N spectra have already been acquired. The next step in the study of CT Her will consist in incorporating the data collected at the epoch of the primary minimum in order to uniquely determine the binary parameters. We plan photometric-spectroscopic analyses of selected oEA stars. The data sets on IU Per will be modelled and frequency-analysed in the framework of a PhD thesis to be conducted at the University of Athens. As a follow-up on previously obtained OHP spectra, new high-resolution spectra of the suspected pulsating Ap star HD 98088 will be requested in collaboration with Drs. M. Cunha and D. Kurtz. 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 relating to the limits and strength of the Coriolis force's effect on g-mode pulsation are expected in the next years. It is also our intention to include simultaneous photometric and spectroscopic observations and to search for magnetic fields in SPB and γ Dor stars.

K.1.4. Personnel

Scientific staff:

- P. De Cat (staff researcher)
- Y. Frémat (staff researcher)
- S. Hekker (contractual scientist, Action-1)
- P. Lampens (project coordinator)
- D. Wright (contractual scientist, Action-1, since 01/05/08)
- In collaboration with: J. Cuypers (senior researcher, Dept. 3)

Technical staff:

- D. Duval (technical expert, until 30/06/08)
- K. Lefever (ICT expert, since 01/07/08)

K.1.5. Partnerships

List of international partners without grant

- M. Cunha, Centro de Astrofisica da Universidade do Porto, Portugal: theory of Ap-stars
- S. Fauvaud, GEOS, Angoulème, France: data analysis
- Z. Kraicheva, D. Dimitrov, Institute of Astronomy, Bulgarian Academy of Sciences, Sofia, Bulgaria

- S. Kleidis, Zagori Observatory, Athens, Greece: private observatory
- 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
- 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, observations + data reduction
- C. Nitschelm, Universidad Catolica del Norte, Antofagasta, Chile: local correspondent + observations
- J. Telting, Nordic Optical Telescope, Santa Cruz de La Palma, Spain: local correspondent, observations + data reduction/analysis
- P. Mathias, Observatoire de Côte d'Azur, Nice, France: local correspondent + data reduction/analysis
- H. Lehmann, Thüringer Landessternwarte Tautenburg, Tautenburg, Germany: local correspondent, observations + data reduction
- J.N. Fu, Beijing Normal University, Beijing, China: local correspondent for Xinglong observatory
- E. Kambe, Okayama Astrophysical Observatory, Okayama, Japan: local correspondent, observations + data reduction
- K. Pollard et al., University of Canterbury, Christchurch, New Zealand: local correspondent, observations + data reduction/analysis + help coordination observations in the Southern hemisphere
- S. Hubrig et al., European Southern Observatory, Chile: magnetic fields (spectropolarimetry)
- E. Poretti et al., INAF-Osservatorio Astronomico di Brera, Merate, Italy: ESO large programme on ground-based observations for CoRoT targets
- K. Uytterhoeven, Service d'Astrophysique, Saclay, France: data analysis

List of national partners without grant

- C. Aerts et al., Katholieke Universiteit Leuven: data analysis (BAG)
- A. Noels et al., Université de Liège: asteroseismic modelling (BAG)
- P. Van Cauteren, Beersel Hills Observatory, Belgium: private observatory
- P. Wils, VVS, Belgium: data analysis

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 at OHP, France)

Visitors

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

K.1.6. Missions

Assemblies, symposia, conferences, workshops

- De Cat: 11/04/2008: Contact Group Meeting, Brussels, Belgium
- De Cat, Frémat, Wright: 04-06/06/2008: FAMIAS workshop, Leuven, Belgium

- De Cat, Lampens, Wright: 23-27/06/2008: HELAS-N5 workshop on Interpretation of Asteroseismic Data, Wroclaw, Poland

Research visits

- De Cat: 11 x 1-day visits, Inst. voor Sterrenkunde, K.U.Leuven
- Wright: 9 x 1-day visits, Inst. voor Sterrenkunde, K.U.Leuven, collaboration with W. Zima (FAMIas)

Field missions

- De Cat: 11-23/05/2008: South African Astronomical Observatory, Sutherland, South Africa (5 nights of spectroscopic observations with GIRAFFE@SAAO/1.9-m; 14-18/05/2008)
- De Cat: 28/06-11/07/2008: European Southern Observatory, La Silla, Chile (7 nights of spectroscopic observations with HARPS@ESO/3.6-m)
- De Cat: 05-18/10/2008: Beijing + Xinglong Observatory, China (4 nights of spectroscopic observations with COUDE@XING/2.16-m)
- De Cat: 08-21/12/2008: McDonald Observatory, Mt. Locke, Texas, USA (8 nights of spectroscopic observations with RA2@McD/2.1-m)
- Frémat & Hekker :10-14/08/2008, OHP, France, spectroscopic campaign with the SOPHIE spectrograph on the 1.93-m telescope
- Lampens & Van Cauteren: Jan - Dec. 2008, CCD photometry of selected δ Scuti variable stars, Beersel Hills Observatory, Belgium, 0.4m telescope + SBIG CCD (16 nights)
- Wright: 06-13/12/2008: Beijing + Xinglong Observatory, China (3 nights, COUDE@XING/2.16-m)
- Wright: 26-29/12/2008: OHP, France (3 nights, SOPHIE@1.93-m)

K.1.7. Scientific outreach

Meeting contributions

[1] **Hekker, S., Frémat, Y., Lampens, P., De Cat, P.**
Pulsation, chemical composition and multiplicity in main-sequence A-and F-type stars
Oral presentation made at the Belgian National Contact group meeting

[2] **Hekker, S., Frémat, Y., Lampens, P., De Cat, P.**
Pulsation, chemical composition and multiplicity in main-sequence A-and F-type stars
Poster presentation at the HELAS-N5 Conference, Wroclaw, Poland

[3] **Hekker, S., Frémat, Y., Lampens, P., De Cat, P.**
Pulsation, chemical composition and multiplicity in main-sequence A-and F-type stars
Oral presentation made at the JENAM-2008, Vienna, Austria

[4] **P. Lampens, A. Strigachev, S.-L. Kim, E. Rodríguez, M.J. López-González, J. Vidal-Saínz, D.** Mkrtichian, D. Litvinenko, P. Van Cauteren, P. Wils, J.M. Gómez-Forellad
Frequency analysis of the δ Scuti-type pulsations in the semi-detached eclipsing binary CT Her
Poster presented at the HELAS-N5 Conference, Wroclaw, Poland

[5] Pollard K. R., Wright D. J., Zima W., Cottrell P. L., **De Cat, P.**
High-resolution spectroscopy and mode identification in non-radially pulsating stars
Talk during the HELAS-N5 Conference, Wrocław, Poland

[6] **Wright D.J.**, **De Cat P.**, Pollard K.R., Zima W.
Rotation and pulsation in g-mode main sequence pulsators
Poster during the HELAS-N5 Conference, Wrocław, Poland

Seminars

[7] **De Cat, P.**
Observational asteroseismology of SPB stars
Beijing Normal University, Beijing, China on 07/10/2008

[8] **Lampens, P.**
Collaboration entre astronomes, professionnels et amateurs: pourquoi et dans quel but?
SRBA, Brussel, 16/02/2008

[9] **Lampens, P**.
Over asteroseismologie, eclipsen en nauwe dubbelsterren
VVS-General meeting, Genk, 26/04/2008

[10] **Wright, D.**
Non-radial pulsation mode identification in γDor stars
Beijing Normal University, Beijing, China on 08/12/2008

K.2. Stellar characterization

K.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.

Another example of the importance of **characterization** is the metallicity of the star, Z, which may lead to observed differences: e.g. B-type stars have less-efficient stellar winds at low metallicity (in the Large and the Small Magellanic Clouds: LMC: Z=0.006; SMC: Z=0.002) than at high metallicity (Milky Way: Z=0.020). Thus, B-type stars keep more angular momentum and rotate faster at low metallicity than at high metallicity. Consequently, one can expect to find more Be stars at low than at high metallicity.

K.2.2. Progress and results

K.2.2.1. OB supergiants

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 [30].

K.2.2.2. Metallicity and pulsations

Theory does not predict pulsations in B-type stars at low metallicity (SMC) due to the lack of metallic elements. It is relevant to verify this prediction from an observational point-of-view. Using the sample of B and Be stars observed in the SMC by Martayan et al. (2007a) with the VLT-GIRAFFE, we cross-matched the coordinates of these stars with the light curves in the MACHO database. First short-term multiperiodic Be stars in the SMC were found by Martayan et al. (2007b). This study was refined and extended to B stars and we found ~30 Be stars, which exhibit 2, 3 or 4 short-term periods and 9 B stars with 1 or 2 short-term periods (Diago et al. 2008). We also found that the instability domain is shifted towards higher temperatures in the SMC than in the MW; it seems that fast rotation favours the pulsations. This last point is confirmed by a recent theoretical study. All our results imply that there is a need for new opacities. Note that these mono or multi-periodic B and Be stars are not binaries, for the binaries in this sample (Martayan et al. 2008).

K.2.2.3. Nature of emission line stars

To test the scenario of evolution/frequency of Be stars proposed by Martayan et al. (2007a) in function of the mass, metallicity, and rotational velocity of the star; it is important to observe young open clusters, to find the emission line stars (ELS) and to determine their nature: classical Be stars or pre-main sequence stars (PMS). For that, we used our observations with the VLT-GIRAFFE and the WFI in slitless spectroscopic mode in NGC6611 and M16. NGC6611 was previously known to host a lot of Be stars. However, our study show that there is only a small number of true ELS, the other fake Be stars are in fact B stars with nebular emission lines. We also show that the majority of the ELS are in fact PMS stars. The classical Be stars found in this sample confirm the evolutionary status scenario in the Milky Way (Martayan et al. 2008).

K.2.2.4. WFI-Hα survey

Using the Wide Field Imager in slitless spectroscopic mode, we observed the SMC/LMC in order to find the ELS in Hα. We obtained 8 million spectra in open clusters and in the SMC/LMC fields. By cross-correlation with photometric catalogues, we were able to classify the stars. Preliminary results as well as the codes developed for analysing the data were presented at the ESO 2007-colloquium about instrumentation. Full results about the emission-line stars and normal stars observed in SMC open clusters can be found in Martayan et al. (2009). We show that there are 3 to 5 times more Be stars in the SMC than in the MW, this enhancement is probably due to low metallicity effects.

K.2.3. Perspective for next years

K.2.3.1. OB supergiants

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.

K.2.3.2. Metallicity and pulsations

This study is currently extended to the intermediate metallicity galaxy the LMC for B and Be stars in the sample of Martayan et al. (2006). The comparison between existing models for pulsating stars at the metallicity of the LMC and observations will provide interesting results. With the identified B, Be stars from the WFI study (Martayan et al. 2009) in SMC open clusters, the cross-matching with light curves and a search for periodicity will be done.

K.2.3.3.*Nature of emission line stars*

This study is currently extended to stars observed in other open clusters in the MW, and a proposal for observing ELS with the VLT-FLAMES in young open clusters in the SMC will be introduced in order to test the scenario of evolution/appearance of Be stars at different metallicities.

K.2.3.4. WFI-Hα survey

This study is currently in exploitation and a first article about the number of Be stars in SMC is submitted. The field of the SMC will be treated as well as the LMC. The results will be compared with the MW but also with the results in SMC open clusters.

K.2.3.5. Chemical abundances and effects of fast rotation

While at low metallicity, the stars rotate faster than at high metallicity, it is expected that the fast rotation effects on the surface chemical abundances are more developed than in the MW. However, preliminary results from Hunter et al. (2008) in the LMC seem to show that there are no effects of the lower metallicity and of the rotation on the surface abundances. These results were however obtained with limited signal to noise ratios spectra and with medium/low resolution and on targets with intermediate metallicity and slow rotators. To better quantify and test the effects of the low-metallicity and fast rotation on the surface chemical abundances, we shall use the new VLT-X-Shooter spectrograph (currently commissioned) in the GTO of the GEPI by observing B and Be stars in the SMC. The very large wavelength coverage (300-2500nm) and efficiency of X-Shooter will allow to obtain high resolution spectra (20000) with high signal to noise ratios (>300) and to better constrain the freedom parameters of this study (veiling, inclination angle, etc).

K.2.3.6. Study of LBV and early O stars in the MW and Magellanic Clouds

With the new VLT-X-Shooter spectrograph (currently commissioned) in the GTO (08/2009 till 12/2011) of the GEPI, we will observe Galactic LBV stars and extreme early O stars, which seem to have a discrepant behaviour regarding the stellar physics. In particular, we expect to obtain the full spectrum from the UV to IR for the LBV like Pistol star and to precise their nature, mass, etc, and to solve the origin of the discrepancy for the others O stars.

K.2.3.7. Scientific preparation of the E-ELT multi-object spectrograph EVE-OPTIMOS

C. Martayan is a member of the scientific team of the multi-object spectrograph EVE-OPTIMOS for the European Extremely Large Telescope. He is in charge of the massive stars for the scientific case definition of the stellar aspects for this MOS. First simulations were done for early-type stars in galaxies beyond the Local Group; reports were prepared for the scientific justification as well as for the instrument requirements and design. This work will be pursued in the next years.

K.2.4. Personnel

Scientific staff

- Y. Frémat (staff researcher)
- C. Martayan (contractual researcher, Gaia-PRODEX)

K.2.5. Scientific outreach

Meeting presentations

[1] **Frémat, Y., Martayan, C**., Zorec, J., Floquet, M., Hubert, A.-M., Neiner, C.
On the evolutionary status of Be stars and Gaia prospects

Poster presented in Baltimore (USA), IAU Symposium 258 on The Ages of Stars.

[2] **C. Martayan**, D. Baade, J. Fabregat
The WFI Hα spectroscopic survey of the Magellanic Cloud: Be stars in SMC open clusters
IAUS 256, Keele, United Kingdom (27/07-02/08/2008), talk

[3] **C. Martayan**, J. Zorec, Y. Frémat
ZAMS rotational velocities of Be/Oe stars and LGRBs progenitors in the Magellanic Clouds
IAUS 256, Keele, United Kingdom (27/07-02/08/2008), poster

[4] **C. Martayan**, P. Diago, J. Guttiérez-Soto, J. Fabregat, A.-M. Hubert, M. Floquet, C. Neiner, M. Mekkas
Variability of B and Be stars in the LMC/SMC: binaries and pulsations
IAUS 256, Keele, United Kingdom (27/07-02/08/2008), poster

[5] **C. Martayan,** D. Baade, J. Fabregat
The WFI Halpha spectroscopic survey
SF2A 2008, Paris, France (July 2008), poster

[6] **C. Martayan,** Y. Frémat, R. Blomme, A. Jonckheere, C. Delle-Luche, P. Sartoretti, D. Katz, Y. Viala, A.-M. Hubert, M. Floquet, C. Neiner
Radial velocities, dynamics of stars and nebulosities with GAIA and VLT-GIRAFFE
Galactic & Stellar Dynamics in the era of high resolution surveys, Strasbourg 03/2008, France, poster+short oral presentation

Seminars

[7] **C. Martayan**
Invited seminar at the Southampton University, UK, 15/10/2008

[8] **C. Martayan**
Invited seminar at the Liège Astrophysics department, Belgium, 02/10/2008

[9] **C. Martayan**
Invited seminar at the Royal Observatory of Belgium, 11/03/2008

[10] **C. Martayan**
Invited seminar at the Geneva Observatory, Switzerland, 26/02/2008

[11] **C. Martayan**
Seminar at the LESIA-Observatoire de Paris, France, 31/01/2008

[12] **C. Martayan**
Seminar at the Institut d'Astrophysique Spatiale d'Orsay, France, 29/01/2008

K.2.6. Missions

Assemblies, symposia

- Frémat: Baltimore, IAU Symp. 258 "Ages Of Stars". August 11-17, 2008. Poster presentation and symposium discussions.
- Martayan: IAU Symp. 256, Keele, United Kingdom (July 2008), partially funded by the ROB
- Martayan: Galactic & Stellar Dynamics in the era of high resolution surveys, Strasbourg 03/2008, France, partially funded by the ROB

Commissions, working groups:

- Martayan: E-ELT, EVE-OPTIMOS science team

Research visits:

- Martayan: 18/12/2008 Paris, France, 1st meeting about the E-ELT/EVE-OPTIMOS MOS

K.2.7. 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)
- D. Baade, ESO Garching, GERMANY
- J. Fabregat, Observatori Astronomic, Universidad de Valencia, SPAIN
- C. Neiner et al., GEPI-Observatoire de Paris-Meudon, France
- G. Meynet, A. Maeder, Observatoire de Genève, Switzerland
- J. Zorec, Institut d'Astrophysique de Paris, France
- F. Royer et al., GEPI-Observatoire de Paris-Meudon, France

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

K.3.1. Objectives

We are involved in the space missions **CoRoT** (CNES-CNRS-ESA-Brazil) and **KEPLER** (NASA). CoRoT (launched in Dec. 2006) will probe the inner structure of the stars, as well as detect many 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 covering five months without interruption, 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 were distributed by the leaders of the thematic teams (TT) during 2008. KEPLER (launch in 2009) will observe fixed fields and continuously monitor 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.

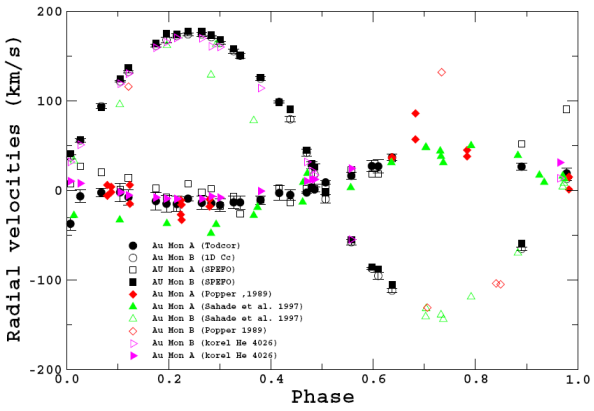


Figure 34: In black, the radial velocities derived for the primary and secondary components of the semi-detached binary AU Mon are plotted. These radial velocities are derived with a procedure especially adapted by Y. Frémat for this study. They are expected to be more accurate than the other determinations (plotted in colour).

K.3.2. Progress and results

Contributions to the CoRoT mission

We participate to the CoRoT Thematic Teams on the Be, Binary and Variable Stars and are thus involved in the analysis of Be stars, of eclipsing binary systems, as well as of different types of variable stars.

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

C. Martayan analysed the light curve of one Be star using Fourier decomposition. The preliminary analysis provides more than 30 frequencies, including harmonics and composite frequencies. He participated to the analysis of several more light curves and ground-based spectra of Be stars. Y. Frémat's task is to study the available spectroscopic data and to interpret the spectra in terms of stellar parameters. One of the emission-line stars, AU Mon, is also a semi-detached eclipsing binary and a huge effort was made to interpret the satellite data in combination with the ground-based spectroscopy (Fig. 3). AU Mon is a strongly interacting semi-detached binary system consisting of a Be and a G-type component. P. Lampens modelled the CoRoT light curves together with all available past photometric data sets using the modelling tool PHOEBE (v.0.31a). High-resolution spectra were analysed as well in order to derive a radial velocity (RV) curve for the component not affected by the phenomenon of mass accretion. A consistent solution which fits very well all the light curves as well as the RV curve of the mass-losing star was derived. Improved stellar masses, radii, luminosities as well as effective temperatures were obtained. A paper on AU Mon has been submitted [24].

K.3.2.2. B-type stars

P. De Cat performed a period analysis of the B-stars observed in the exofield to select SPB and β Cep star prototypes for supervised classification [25]. Respectively 20 and 19 candidate β Cep and SPB stars were allocated to the ROB. A period analysis of the data on 19 candidate SPB stars was performed. A few targets turned out to be either binaries, spotted stars or Be stars. A photometric mode identification for the 3 modes observed in the ground-based data of the only β Cep star observed in a seismofield so far, i.e. HD180642, was also done. Preliminary results point towards degree l = 0, 3 and 0/3 for the modes with frequencies 5.48694, 0.30818 and 7.36673 c/d, respectively.

K.3.2.3. γDor stars

P. De Cat contributed to the classification of the light curves of 26 potential γ Dor stars by doing a frequency analysis: 7 objects were classified as probable γDor (or SPB) stars, 7 objects as candidate γ Dor/δ Sct (or SPB/β Cep) hybrids, 5 as candidate spotted stars (with/without pulsations), 3 objects as binaries (with/without pulsating component), 1 object as a spotted star showing an eclipse, 1 object as a constant star, and 2 unclassified. He also produced a semi-automatic version of his method. In this way, up to 45 significant frequencies were found. From the stars observed in the exofield during the various runs, 32 were classified as 1^{st}-priority γ Dor star candidates and 1060 are $2^{nd}/3^{rd}$-priority γDor star candidates. The analysis of the 1^{st}-priority targets has started. The future observations using world-class instruments [34][46] will be crucial for the final classification.

K.3.2.4. O-type stars

The CoRoT data allocated to the ROB team are not yet available.

K.3.2.5. Eclipsing binaries

The Binary Team coordinates the analyses of CoRoT light curves of any eclipsing binary identified as such by the CoRoT Variability Classifier tool. A significant number of the observed binaries show evidence of rapid pulsations on top of the eclipses or ellipsoidal variations. We have selected 10 cases likely with early-type components and are presently analyzing their light curves in order to derive the orbital periods and the main pulsation characteristics. This work is in progress. Future interpretations will have to rely on new spectroscopy to be gathered for the most promising systems.

Contributions to the Kepler mission

A list of potential Kepler targets, i.e. known variable stars of spectral type A/F was provided to the group leaders. Two proposals with targets for the Kepler Asteroseismic Investigation concerning δ Scuti stars and eclipsing binaries with pulsating components were submitted to the KASC in collaboration with the BAG [48]. P. De Cat was involved in the preparation of 2 more proposals [49][50]. Four letters of intent

(LoI) were written in which specific tasks related to the analysis and the organization of working groups were precisely defined. The structure will be decided early 2009. The launch of this NASA-mission is expected to happen in March 2009.

K.3.3. Perspective for next years

K.3.3.1. CoRoT

The analysis of CoRoT Be stars will provide statistics on the frequencies, information on the internal structure, as well as on the bursts observed in the light curves with beating phenomenon of non-radial modes of pulsations. Currently, VLT-FLAMES observations for CoRoT variable stars are being performed for their spectral classification. The first run at ESO is on-going and a second run will be requested. The CoRoT light curves and ground-based data for various other targets will soon be made available. Their interpretation will require a rapid treatment and interpretation similar to the analyses performed in 2008. First results will be presented during the 1st International CoRoT Conference (2009).

K.3.3.2. Kepler

Concerning KEPLER, we plan to gather complementary information from the literature and/or perform complementary ground-based observations needed to study interesting KEPLER asteroseismic targets. However, the full task organization will be decided early 2009.

K.3.4. Personnel

Scientific staff:

- P. De Cat (staff researcher)
- Y. Frémat (staff researcher)
- P. Lampens (senior researcher)

Technical staff:

- D. Duval (technical expert, until 30/06/08)
- K. Lefever (ICT expert, since 01/07/08)

K.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. Prša, Villanova University, Villanova, PA/USA
- P. Harmanec, Astronomical Institute of the Charles University, Czech Republic
- C. Neiner, Observatoire de Paris-Meudon and the CoRoT Be Team
- CoRoT γDor stars working group (Chair: P. Mathias)
- Kepler Asteroseismic Science Consortium (Chair: J. Christensen-Dalsgaard)

List of national partners without grant

- CoRoT O/B star working group, C. Aerts (Chairperson) et al., Inst. voor Sterrenkunde, KULeuven

K.3.6. Scientific outreach

Meeting presentations

[1] **P. De Cat** and the ROB and K.U.Leuven teams
Analysis of γDor lightcurvess provided by the CVC
Talk during CoRoT γDor stars working group meeting (Nice, France; 3-days 26-28/05/2008)

[2] Desmet, M., **Lampens, P.**, **Frémat, Y.**, Harmanec, P., Janot Pacheco, E., Briquet M., Aerts, C.
Status of eclipsing binary AU Mon
Oral presentation made by M.Desmet at CoRoT B-star meeting Liège, 17 December 2008

[3] Desmet, M., **Frémat, Y.**, **Lampens, P.**, Harmanec, P., Janot Pacheco, E., Briquet M., Aerts, C.
Status of eclipsing binary AU Mon
Oral presentation made by M.Desmet during the CoRoT B-star meeting at IVS KULeuven, 18 November 2008

[4] Desmet, M., **Frémat, Y.**, Briquet, M., Degroote, P.
Eclipsing Binary HD50846
Oral presentation made by M.Desmet during the CoRoT meeting at IVS, 20 February 2008

[5] **Frémat, Y., Lampens, P.**
HD50846: First results with KOREL
Oral presentation made by Y.Frémat during a meeting at IVS KULeuven, March 21, 2008

[6] **Frémat, Y.**, Harmanec, P.
HD50846: Spectroscopic analysis
Oral presentation made by Y.Frémat during a meeting at IVS KULeuven, December 17, 2008

[7] Desmet , M. **Frémat, Y.**, **Lampens, P.**, Harmanec, P., Aerts, C. et al.
New analysis of the highly evolved, semi-detached massive binary AU Mon based on CoRoT's first observations
First International CoRoT Symposium, Paris, 2-5 Feb 2009 (poster)

[8] **Lampens, P.** et al.,
First CoRoT results on new pulsators in eclipsing binaries
First International CoRoT Symposium, Paris, 2-5 Feb 2009 (poster)

K.3.7. Missions

Assemblies, symposia

- De Cat, Lampens: Kepler Asteroseismology Science Consortium, June 10-11, Aarhus, Denmark (video-audition)

Commissions, working groups

- De Cat: 1 CoRoT γDor stars working group meeting (Nice, France; 26-28/05/2008)
- De Cat, Frémat: 3 CoRoT B-star working group meetings (Leuven:21/03/2008,15/09/2008; Liège:18/11/2008)
- Frémat: 2 CoRoT O star working group meetings (Leuven: 16/09/2008; Liège:18/11/2008)
- Frémat, Lampens: 1 CoRoT meeting on B-type stars, 17/12/2008, Inst. voor Sterrenkunde, Leuven

Research visits

- For all, discussions were held at the Inst. voor Sterrenkunde, K.U.Leuven: 21/03/2008, meeting with the COROT Be stars team; 8 and 22/10/2008, meeting with M.Desmet, P. Harmanec and C.Aerts for the interpretation of AU Mon's results.
- Martayan: 28/01-01/02/2008, Meudon, France, 1st meeting about first CoRoT light curves
- Martayan: 14-15/07/2008, Meudon, France, preparation of VLT-observations for CoRoT variable stars

Visitor

- T. Semaan, GEPI-Observatoire de Paris-Meudon, 9-13/02/2009, VLT-FLAMES spectra for classification of COROT variable stars

L. Instrumentation

The design of new instrumentation is the mandatory path to a better knowledge of the universe and its content. By participating to such developments, we contribute to a project which generally profits to a vast scientific community while ensuring us a profound knowledge of the new instrument and its possibilities.

L.1. The spectrograph HERMES

L.1.1. Objectives

HERMES is the acronym for High Efficiency and Resolution Mercator Echelle Spectrograph. The project consists in designing, constructing, and integrating the spectrograph at the Mercator telescope through a collaboration between the ROB and the K.U.Leuven, the ULB, the Thüringer Landessternwarte Tautenburg, Germany, as well as the Geneva Observatory, Switzerland (cf. report of Dept. 3).

L.1.2. Progress and results

Y.Frémat, in collaboration with L. Dumortier, took an active part to the development of the spectrograph's reduction pipeline in Python. He developed several modules allowing the measurement and modeling of the order positions and the determination of the spectral line positions in spectra made with the wavelength calibration lamp. P. Lampens, with the help of D. Duval, contributed to produce a catalogue of bright reference stars needed for calibration purposes of the new spectrograph.

L.1.3. Perspective for next years

The instrument commissioning will take place during the first months of 2009, and an important involvement will be required to adapt the pipeline to the first data obtained with the spectrograph. Scientific exploitation is planned for April 2009.

L.1.4. Partnerships

List of national partners without grant

- J. De Ridder, H. Van Winckel, Inst. voor Sterrenkunde, K.U.Leuven
- A. Jorissen, S. Van Eck, Université Libre de Bruxelles
- As well as the entire HERMES Consortium

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

- LOTSPECTRO

L.1.5. Scientific outreach

Meeting presentations

[1] **Frémat, Y., Blomme, R., Cuypers, J., De Cat, P., Groenewegen, M., Hekker, S., Hensberge, H., Lampens, P., Lobel, A., Martayan, C., Van Hoof, P., Van de Steene, G., Torres, K., Wright, D**.
ROB science with HERMES
Oral presentation at the K.U.Leuven Hermes Science Meeting 20/11/2009

L.1.6. Missions

Meetings

- Frémat, Lampens, Torres: 20/11/2008. Science Meeting of the HERMES Consortium, Leuven

L.2. Humain Observatory for Astrophysics of Coeval Stars (HOACS)

L.2.1. Objectives

The radio-astronomical station of Humain, which is a part of the Royal Observatory of Belgium, is still a privileged site in Belgium with respect to location and environmental light pollution. It is therefore 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.

L.2.2. Progress and results

The construction of the building which should protect the telescopes and the instruments was almost though not entirely finished in May. The ROB took on its budget and responsibility to finish the floor and to replace the entire roof mechanism with motor. A juridical procedure is currently still blocking the finalization of the access path to the building. Nevertheless, things have progressed fast since then: the Minimount equipped with telescope was put into position on May, 22nd; the mount and optical adjustments as well as the installation of the exterior/interior PCs, the proper software and parts of the network were done in the summer. At the end of August, a first test run was obtained. The illustration below shows the status of the observatory after installation of the two 0.40-cm telescopes in October (Fig. 4). In November, the entire network was operating well, including telescope control and image acquisition from the control room. Observations were performed with the telescopes and their instruments during the second half of the year. The project HOACS is now ready and operational.

An intensive campaign for two specific targets was held at the end of the year as part of our multisite campaigns. In total, we secured 5200 CCD images and 86 hours of photometric data using two filters. Our first-priority targets were: IU Per, HD 68725 as well as several high-amplitude δ Scuti stars (cf. "Asteroseismology of binary or multiple stars"). A first and unexpected result is the detection that HD 68725 also shows eclipses.

At the same time, the new ICT expert got introduced to the image analysis and data reduction procedures that are applied to obtain the differential photometric data and derived light curves. This training consisted in a theoretical part (with the general course in astronomy/astrophysics for non-scientists) as well as a practical part (manipulation of the commercial software package Mira-AP for aperture photometry and newly made programmes in FORTRAN). Unfortunately, at the end of the year, the new ICT expert resigned from his position at the ROB.

Figure 35: Status of the small optical observatory at the Humain radio-astronomy site of the Royal Observatory of Belgium (Oct. 2008)

L.2.3. Perspective for next years

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

L.2.4. Personnel involved

Scientific staff

- P. Lampens (project coordinator)

Technical staff

- K. Lefever (ICT expert, since 01/07/08)
- Ir. V. Rogge (ROB Security) helps to deal with the construction under the control of the Walloon Administration of Buildings (Province of Luxemburg)
- Dhr. Janssens (technical expert, Dept. 4) helps with logistical support.

Volunteer

- P. Van Cauteren (free-lance observer)

L.2.5. Visitors:

- Representants of the LHOIST company, ROB, 27/10/08

M. Publications

M.1. Publications with peer review

[1] **Hekker, S., Frémat, Y., Lampens, P., De Cat, P.** (2008)
Pulsations, chemical composition and multiplicity in main sequence A- and F-type stars
CoAst 157, 317

[2] **Lampens, P.**, Strigachev, A., Kim, S.-L., Rodríguez, E., López-González, M. J., Vidal-Saínz, J., Mkrtichian, D., Litvinenko, D., Van Cauteren, P., Wils, P., Gómez Forellad, J. M. (2008)
A three-year photometric study of the oscillating Algol-type binary CT Her

CoAst 153, 54

[3] **Lampens, P.**, Strigachev, A., Kim, S.-L., Rodriguez, E., Lopez-Gonzales, M. J., Vidal-Sainz, J., Mkrtichian, D., Litvinenko, D., Van Cauteren, P., Wils, P. (2008)
Frequency analysis of the δ Scuti type pulsations in the semi-detached eclipsing binary CT Her
CoAst 157, 328

[4] Hubrig S., Briquet M., Morel T., Schöller M., González J. F., **De Cat P.**
New insights into the nature of the peculiar star θ Carinae
A&A 488 (2008), 287-296

[5] Pollard K. R., Wright D. J., Zima W., Cottrell P. L., **De Cat, P.**
High-resolution spectroscopy and mode identification in non-radially pulsating stars
Communications in Asteroseismology 157 (2008), 118-123

[6] **Wright D.J.**, **De Cat P.**, Pollard K.R., Zima W.
Rotation and pulsation in g-mode main sequence pulsators
Communications in Asteroseismology 157 (2008), 383-384

[7] Ulaş, B., Niarchos, P.G., **Lampens, P.**, Liakos, A. (2009)
The Algol-type eclipsing binaries RW CrB and VZ Leo: new RI photometric study and search for pulsations
ApSS 319, 55

[8] Borkovits, T., Van Cauteren, P., **Lampens, P.**, Dufoer, S., Kleidis, S., Van Leenhove, M., Csizmadia, S., Regaly, Zs., Patkos, L., Klagyivik, P., Biro, I. B., Hegedüs, T., Kiss, Z. T. (2008)
New and Archive Times of Minima of Eclipsing Binary Systems
IBVS, 5835, 1

[9] Diago, P. D.; Gutiérrez-Soto, J.; Fabregat, J.; **Martayan, C.**
Pulsating B and Be stars in the Small Magellanic Cloud
2008, A&A, 480, 179

[10] Michel, E., Baglin, A., Weiss, W. W. et al. (incl. **Frémat, Y.**,…., **Martayan, C**., …)
First asteroseismic results from CoRoT
2008, Communications in Asteroseismology, 156, 73-87

[11] **Martayan, C.**, Floquet, M., Hubert, A. M., Neiner, C., **Frémat, Y.**, Baade, D., Fabregat, J.
Early-type objects in NGC 6611, the Eagle Nebula
2008, A&A, 489, 459-480

[12] Kanaan, S., Meilland, A., Stee, P., Zorec, J., Domiciano de Souza, A., **Frémat, Y.**, Briot, D.
Disk and wind evolution of Achernar: the breaking of the fellowship
2008, A&A, 486, 785-798

[13] **Martayan, C.**, **Frémat, Y.**, **Blomme, R.**, **Jonckheere, A.**, Delle-Luche, C., Sartoretti, P., Katz, D., Viala, Y., Floquet, M., Hubert, A.-M., Neiner, C.
Radial velocities, dynamics of stars and nebulosities with GAIA and VLT-GIRAFFE
2008, Astronomische Nachrichten, 329, 1033

M.2. Publications without peer review

[14] **Lampens, P., Frémat, Y., Hensberge, H**., Tamazian, V., Docobo, J. A., Balega, Y. (2008)
DG Leo: A Triple System with a Surprising Variety of Physical Phenomena
In: Multiple Stars Across the H-R Diagram, ESO Astrophysics Symposia, Springer-Verlag Berlin Heidelberg, 2008, 59

[15] Sordo, R., Vallenari, A., Bouret, J. C., Brott, I., Edvardsson, B., **Frémat, Y.**, Heber, U., Josselin, E., Kochukhov, O., Korn, A., Lanzafame, A., Martins, F., Schweitzer, A., Thevenin, F., Zorec, J.

New high resolution synthetic stellar libraries for the Gaia Mission
2008, Memorie della Societa` Astronomica Italiana, 10

[16] **Martayan, C.**, **Frémat, Y.**, **Blomme, R.**, **Jonckheere, A.**, Borges, M., de Batz, B., Leroy, B., Sordo, R., Bouret, J.-C., Martins, F., Zorec, J., Neiner, C., Nazé, Y., Alecian, E., Floquet, M., Hubert, A.-M., Briot, D., Miroshnichenko, A., Kolka, I., Stee, P., Lanz, T., Meynet, G.
The Gaia satellite: a tool for Emission Line Stars, Hot Stars
2008, Proceedings of the SF2A meeting, SF2A-2008, 499

[17] Gutiérrez-Soto, J., Neiner, C., Hubert, A.-M., Floquet, M., Huat, A.-L., Diago, P. D., Fabregat, J., Leroy, B., de Batz, B., Andrade, L., Emilio, M., Facanha, W., **Frémat, Y.**, Janot-Pacheco, E., **Martayan, M.**, Suso, J., Garrido, R.
First results on Be stars with CoRoT
2008, Proceedings of the SF2A meeting, SF2A-2008, 475

[18] Viala, Y. P., **Blomme, R.**, Damerdji, Y., Delle Luche, C., **Frémat, Y.**, Gosset, E., **Jonckheere, A.**, Katz, D., **Martayan, C.**, Morel, T., Poels, J., Royer, F.
Radial velocities with the Gaia RVS spectrometer
2008, Proceedings of the SF2A meeting, SF2A-2008, 51

[19] Soubiran, C., Allende Prieto, C., Altmann, M., Bragaglia, A., Clementini, G., **Frémat, Y.**, Heiter, U., Joliet, E., Pancino, E., Sartoretti, P., Smart, R., Thuillot, W.
Ground-Based Observations for Gaia (GBOG)
2008, Proceedings of the SF2A meeting, SF2A-2008, 35

[20] **Frémat, Y.**, Zorec, J., **Martayan, C.**, Lanz, T.
CNO abundance determination in massive fast rotating stars
2008, Revista Mexicana de Astronomia y Astrofisica Conference Series, 33, 53

[21] Cidale, L. S., Torres, A., Arias, M. L., Zorec, J., **Frémat, Y.**, Vallverdu, R. E., Granada, A.
Fundamental Parameters, spectrophotometric variability of He-strong stars
2008, Revista Mexicana de Astronomia y Astrofisica Conference Series, 33, 51

[22] Bouret, J.-C., Lanz, T., **Frémat, Y.**, Martins, F., Lefever, K., **Blomme, R.**, **Martayan, C.**, Neiner, C., Quinet, P., Zorec, J.
The spectra of massive stars with Gaia
2008, Revista Mexicana de Astronomia y Astrofisica, 33, 50

M.3. Publications in press, submitted

[23] **Hekker, S., Frémat, Y., Lampens, P., De Cat, P.**,
Abundance determination for A- and F-type main-sequence stars: A semi-automatic procedure
MNRAS (2009), in press

[24] Desmet, M., **Frémat, Y.,** Baudin, F., Harmanec, P., **Lampens, P.** and 12 co-authors,
Combined modelling of the interacting eclipsing binary AU Mon based on CoRoT and ground-based photometry and high-resolution spectroscopy
A&A (2009), submitted

[25] Degroote P., Miglio A., Debosscher J., Montalbán J., **Cuypers J.**, Briquet M., **De Cat P.**, Thoul A., Morel T., Niemczura E., Balaguer-Núñez L., Maceroni C., Ribas I., Noels A., Aerts C.
Space observations of B stars with CoRoT
Communications in Asteroseismology (2009), in press

[26] Hubrig S., Briquet M., **De Cat P.**, Schöller M., Morel T., Ilyin I.
New magnetic field measurements of β Cephei stars and Slowly Pulsating B stars
Astronomische Nachrichten (2009), accepted

[2] Yakut K., Zima W., Kalomeni B., Van Winckel H., Waelkens C., De Cat P., Bauwens E., Vučković M., Saesen S., Le Guillou L., Parmaksizoğlu M., Uluç K., Khamitov I., Raskin G., Aerts C.
Close binary stars in the solar-age galactic open cluster M67
A&A (2009), submitted

[27] Desmet M., Briquet M., Thoul A., Zima Z., **De Cat P.**, Handler G., Ilyin I., Krzesinski J., Lehmann H., Masuda S., Mathias P., Mkrtichian D.E., Telting J.,Uytterhoeven K., Yang S.L.S., Aerts C.
An asteroseismic study of the β Cephei star 12 Lacertae: multisite spectroscopic observations, mode identification and seismic modeling
MNRAS (2009), submitted

[28] T. Böhm, W. Zima, C. Catala, E. Alecian, K. Pollard, and **D. Wright**.
Discovery of non-radial pulsations in the spectroscopic binary Herbig Ae star RS Cha
A& A (in press)

[29] **Martayan, C.**, Zorec, J., **Frémat, Y.**
ZAMS rotational velocities of Be/Oe stars, LGRBs progenitors in the Magellanic Clouds
Proceedings of the IAU Symposium 256, in press

[30] Zorec, J., Cidale, L., Arias, M.L., **Frémat, Y.**, Muratore, M.F., Torres, A.F., **Martayan, C.**
Fundamental Parameters of B Supergiants from the BCD System. I. Calibration of the (λ, D) parameters into Teff
Submitted to A&A

M.4. Reports

[31] **De Cat P.**, **Wright D.J.**, Pollard K.R., Cottrell P.L., Zima W., **Frémat Y.**
Towards asteroseismology of main-sequence g-mode pulsators: a spectroscopic multi-site campaign for the gamma Doradus stars HD40745, HD48501, and HD55892
European Southern Observatory (Chile) time application for HARPS at the 3.6-m telescope in 10/2008-03/2009; 7 nights requested, 0 nights allocated

[32] Desmet M., Aerts C., Acke B., **De Cat P.**, **Cuypers J.**, Briquet M., Mathias P., Bonneau D.
High-precision mass determination of the components of the binary star beta Crucis
European Southern Observatory (Chile) time application for guaranteed time for AMBER/VLTI in 10/2008-03/2009; 3 hours requested, 3 hours allocated

[33] Mathias P., Bonneau D., Jankov S., Chadid M., Aerts C., **De Cat P.**
Mass determination of the SPB star HD140873
European Southern Observatory (Chile) time application for guaranteed time for AMBER/VLTI in 10/2008-03/2009; 0.25 nights requested, 2.4 hours allocated

[34] Neiner C., Debosscher J., Sarro S., Hubert A.-M., Martayan C., Huat A.-L., **Frémat Y.**, Degroote P., Briquet M., **De Cat P.**, et al.
Spectroscopic characterization of new CoRoT Variable Stars discovered in the exoplanet fields of the mission
European Southern Observatory (Chile) time application for GIRAFFE/UVES at the 8-m UT2/VLT telescope in 10/2008-03/2009; 29.1 hours requested, 29.1 hours allocated (service mode)

[35] Poretti E., Baglin A., Catala C., Michel E., Rainer M., Uytterhoeven K., Aerts C., Amado P., Briquet M., Carrier F., **De Cat P.**, Desmet M., Floquet M., **Frémat Y.**, et al.
Continuing the ground-based observations of the CoRoT asteroseismic targets
European Southern Observatory (Chile) time application for HARPS at the 3.6-m telescope in 10/2008-09/2010; 45 nights requested, 45 nights allocated (large programme)

[36] **De Cat P.**, **Wright D.J.**, Mathias P., Telting J., Briquet M., Yakut K., Jankov S.
Classification and rotation of main-sequence g-mode pulsators

Observatoire de Haute Provence (France) time application for SOPHIE at the 1.93-m telescope in 09/2008-02/2009; 3 nights requested; 3 nights allocated (26-28/12/2008, all nights with OPTICON support)

[37] **Wright D.J.**, **De Cat P.**, Mathias P., Telting J.H., Zima W., Briquet M., **Frémat Y.**
Towards asteroseismology of main-sequence g-mode pulsators: a spectroscopic multi-site campaign for HD 21071, HD 25558 and HD 218396
Observatoire de Haute Provence (France) time application for SOPHIE at the 1.93-m telescope in 09/2008-02/2009; 7 nights requested, 0 nights allocated

[38] **Hekker S.**, **Frémat Y.**, **Lampens P.**, **De Cat P.**
Pulsations, chemical composition and multiplicity in A- and F main sequence stars: orbital parameters for HD68725
Observatoire de Haute Provence (France) time application for SOPHIE at the 1.93-m telescope in 09/2008-02/2009; 0.3 nights requested; 0 nights allocated

[39] **Hekker S.**, **Frémat Y.**, **Lampens P.**, **De Cat P.**
Pulsations, chemical composition and multiplicity in A- and F main sequence stars: special cases
Observatoire de Haute Provence (France) time application for SOPHIE at the 1.93-m telescope in 09/2008-02/2009; 6 nights requested; 0 nights allocated

[40] **De Cat P.**, **Wright D.J.**, Telting J., Mathias P., Briquet M., Yakut K., Jankov S.
Classification and rotation of main-sequence g-mode pulsators
Roque de los Muchachos Observatory (Canary Islands) time application for FIES at the 2.4-m telescope in 10/2008-03/2009; 6x0.5 nights requested; 0 nights allocated

[41] **Wright D.J., De Cat P.**, Telting J.H., Mathias P., Zima W., Briquet M., **Frémat Y.**, Dukes R.
Towards asteroseismology of main-sequence g-mode pulsators
Roque de los Muchachos Observatory (Canary Islands) time application for FIES at the 2.4-m telescope in 10/2008-03/2009; 7 nights requested; 0 nights allocated

[42] **De Cat P.**, Mktrichian D., **Wright D.J.**, Mathias P., Zima W., Briquet M., **Frémat Y.**
Magnetic fields and asteroseismology of main-sequence g-mode pulsators: a spectroscopic multi-site campaign for the slowly pulsating B stars HD 21071 and HD 25558, and the gamma Doradus star HD 218396
Bohyunsan Optical Astronomical Observatory (South Korea) time application for BOES at the 1.8-m telescope in 08/2008-12/2008; 7 nights requested, 4 nights allocated (05-08/12/2008)

[43] Nitschelm C., **De Cat P.**, **Wright D.J.**, Pollard K.R., Maisonneuve F., Zima W., **Frémat Y.**
Towards asteroseismology of main-sequence g-mode pulsators: a spectroscopic multi-site campaign for gamma Doradus stars
European Southern Observatory (Chile) time application for FEROS at the 2.2-m telescope in 04/2009-09/2009; 2x4 nights requested, 0 nights allocated

[44] Desmet M., Aerts C., Acke B., **De Cat P.**, **Cuypers J.**, Briquet M., Mathias P., Bonneau D.
High-precision mass determination of the components of the binary star beta Crucis
European Southern Observatory (Chile) time application for guaranteed time for AMBER/VLTI in 04/2009-09/2009; 3 hours requested, 3 hours allocated

[45] Mathias P., Bonneau D., Jankov S., Chadid M., Aerts C., **De Cat P.**
Mass determination of the SPB star HD140873
European Southern Observatory (Chile) time application for guaranteed time for AMBER/VLTI in 04/2009-09/2009; 2.4 hours requested, 2.4 hours allocated

[46] Neiner C., Debosscher J., Sarro S., Hubert A.-M., Martayan C., Huat A.-L., **Frémat Y.**, Degroote P., Briquet M., **De Cat P.**, et al.

Spectroscopic characterization of new CoRoT Variable Stars discovered in the exoplanet fields of the mission
European Southern Observatory (Chile) time application for GIRAFFE/UVES at the UT2/VLT telescope in 04/2008-09/2009; 26.3 hours requested, 26.3 hours allocated (service mode)

[47] Hubrig S., Langer N., Nazé Y., Przybilla N., Morel T., Scholler M., Walborn N., Briquet M., **De Cat P.**, et al.
A systematic survey of magnetic fields in massive stars
European Southern Observatory (Chile) time application for FORS2 at the UT1/VLT telescope and for UVES at the UT2/VLT telescope in 04/2008-09/2010; 16 nights and 40 hours requested, 0 nights and 0 hours allocated

[48] **Lampens P.**, et al. (including **P. De Cat**)
Beta Cephei stars, SPB, delta Scuti stars, Doradus stars in EB's
http://astro.phys.au.dk/KASC/proposals/P16.htm

[49] Aerts C., De Ridder J., et al. (including **P. De Cat**)
Asteroseismology of Gamma Doradus stars with Kepler
http://astro.phys.au.dk/KASC/proposals/P17.htm

[50] Aerts C., De Ridder J., et al. (including **P. De Cat**)
Slowly Pulsating B stars
http://astro.phys.au.dk/KASC/proposals/P19.htm

[51] **Wright D.J.**, **De Cat P.**, Maisonneuve F., Pollard K.R., Mathias P., Telting J.H., Zima W., Briquet M., **Frémat Y.**, Dukes R.
Towards asteroseismology of main-sequence g-mode pulsators: a spectroscopic multi-site campaign
Observatoire de Haute Provence (France) time application for SOPHIE at the 1.93-m telescope in 03/2008-08/2009; 6 nights requested, 6 nights allocated (10-15/07/2009, 3 nights with OPTICON support)

[52] Mathias P., **De Cat P.**, Bonneau D., Bouabid M.-P., Mounard D., Aerts C., Thoul A.
Mass determination of SB2 pulsating stars
Observatoire de Haute Provence (France) time application for SOPHIE at the 1.93-m telescope in 03/2009-08/2009; 5 nights requested; 5 nights allocated (service mode)

[53] **De Cat P.**, **Wright D.J.**, Telting J., Mathias P., Briquet M., Yakut K., Jankov S.
Classification and rotation of main-sequence g-mode pulsators
Roque de los Muchachos Observatory (Canary Islands) time application for FIES at the 2.4-m telescope in 04/2009-09/2009; 6x6 hours requested; 0 hours allocated

[54] **Wright D.J.**, **De Cat P.**, Telting J.H., Mathias P., Zima W., Briquet M., **Frémat Y.**, Dukes R., Pollard K., Maisonneuve F.
Towards asteroseismology of main-sequence g-mode pulsators
Roque de los Muchachos Observatory (Canary Islands) time application for FIES at the 2.4-m telescope in 04/2009-09/2009; 6 nights requested; 0 nights allocated

[55] **De Cat P.**, **Wright D.J.**, Pollard K.R., Telting J.H., Mathias P., Zima W., Briquet M., **Frémat Y.**
Towards asteroseismology of main-sequence g-mode pulsators: spectroscopic multi-site campaigns for slowly pulsating B stars and gamma Doradus stars
McDonald Observatory (Texas, USA) time application for the RA2/CE combination at the 82-inch telescope in 12/2008-03/2009; 8 nights requested; 8 nights allocated (11-18/12/2009)

[56] **Wright D.J.**, **De Cat P.**, Kambe E., Pollard K.R., Telting J.H., Mathias P., Zima W., Briquet M., **Frémat Y.**
Towards asteroseismology of main-sequence g-mode pulsators: spectroscopic multi-site campaigns for slowly pulsating B stars and gamma Doradus stars

Okayama Astrophysical Observatory Kurashiki (Japan) time application for HIDES at the 1.88-m telescope in 01/2009-06/2009; 12 nights requested; 6 half nights (10-15/01/2009) and 6 full nights (06-11/03/2009) allocated

[57] **De Cat P.**, **Wright D.J.**, Briquet M., Dukes R., **Frémat Y.**, Fu J.N., Kambe E., Lehmann H., Maisonneuve F., Mathias P., Mkrtichian D., Nitschelm C., Pollard P., Telting J.H., Yang S., Zima W.
Towards asteroseismology of main-sequence g-mode pulsators
Xinglong Observatory (China) time application for the high-resolution spectrograph at the 2.16-m telescope in 2009; 16 nights requested; 10 nights allocated (11-16/04/2009 and 30/10-02/11/09)

[58] Niarchos, P., **Lampens, P.**, Vamvatira-Nakou, V., Liakos, A., Manimanis, V.,
Time-series photometry of AO Ser, an Algol-type eclipsing binary with a pulsating component
Application for Aristarchos telescope time at Helmos Observatory (4 nights)

DEPARTMENT 3: Astrophysics

SECTIONS 6 & 7: Astrophysics of galactic and extragalactic objects & Physics of stellar atmospheres

Introduction:

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.

The research of Department 3 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.

The main research topics are "stellar winds and circumstellar structures" with hot stars and evolved evolutionary stellar phases as main subjects, and 'variable stars' and 'binary stars' where the aims are to obtain fundamental stellar parameters and, ultimately, 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. The department is also involved in the operational interdepartemental project to provide in an 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 (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 projects rely heavily on external grants and personnel on temporary contracts. There exist strong connections with research projects of Department 2.

Some highlights of astrophysical research in 2008:

- Large-scale structures in stellar winds of massive stars (Corotating Interaction Regions) – press-release N.1.2.1 and section **Error! Reference source not found.**)
- Hubble Space Telescope snapshot survey results published in Astrophysical Journal (section N.3.2.6)
- Frequencies and amplitudes of 20 known and 1 newly discovered γ Doradus stars were derived from the Mercator telescope survey data (sO.1)
- An analysis of distance estimates and the metallicity effect on the PL-relation for a sample of about 60 galactic Cepheids was published (section O.2)

N. 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 N.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 N.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 N.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.

N.1. Hot stars

N.1.1. Objectives

Hot stars have radiatively driven stellar winds. Considerable observational evidence exists that these winds are not smooth, but structured. This project tries to elucidate the nature of this structure, by studying these stars both observationally (at various wavelengths) and theoretically (by constructing models for the hydrodynamics and radiative transfer).

N.1.2. Progress and results

N.1.2.1. Large-scale structure in stellar winds

A. Lobel and R. Blomme modelled the large-scale structure (so-called Co-rotating Interaction Regions) in the winds of hot stars. This work has been published in the Astrophysical Journal [2], presented at conferences [16][17][19][20][30], and made available to the larger public through a press release. The research paper provided new evidence that the Discrete Absorption Components seen in ultraviolet spectral lines are in fact large-scale spiraling density- and velocity-structures in the equatorial wind. These wind structures can be traced back to faint rotating hotspots at the stellar surface. The bright spots do not co-rotate with the stellar surface, but lag five times behind the rapidly rotating surface.

We also continue modelling another effect seen in some of the spectra of hot stars, the so-called “rotational modulations”. A. Lobel submitted a conference talk paper [33] which proposes that the rotational modulations result from mechanical wave action producing a regular pattern of almost linear (somewhat “spoke-like”) regions around the star due to stellar pulsations at the fast-rotating wind base of HD 64760. R. Blomme experimented with the Zeus hydrodynamics code to see if we could create such spoke-like structure in the wind. Preliminary modelling shows that a pattern of almost linear large-scale wind structures can develop and are sustained in the line-driven winds of hot stars. Further numerical testing (for code stability and accuracy) is required to establish whether or not these remarkable wind structures are physically real.

N.1.2.2. COBRaS project

R. Blomme collaborated in preparing a Legacy Project for the e-MERLIN radio telescope (based in the UK). The proposed project, named COBRaS (Cyg OB2 Radio Survey), was awarded nearly 300 hrs of observing time. The project is a large international collaboration led by R. Prinja and consists of 32 Co-Is (including R. Blomme and J. Vandekerckhove). The project aims to deliver the most detailed radio census for the most massive OB association in the northern hemisphere. We intend to make a mosaic of the core region of the Cyg OB2 association, consisting of 42 pointings at 6 cm and 7 pointings at 20 cm.

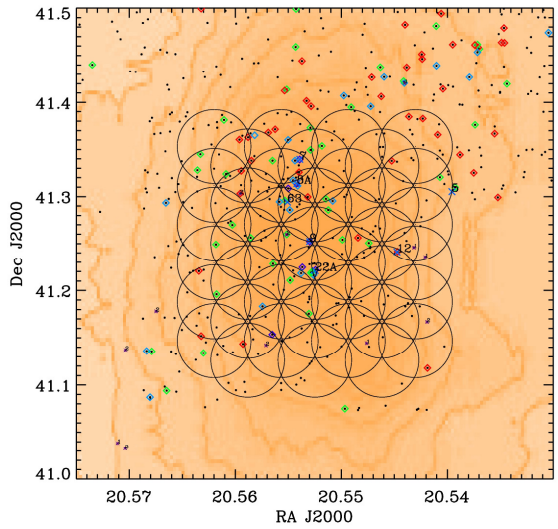


Figure 36: The proposed mosaic of the Cyg OB2 core region at 6 cm.

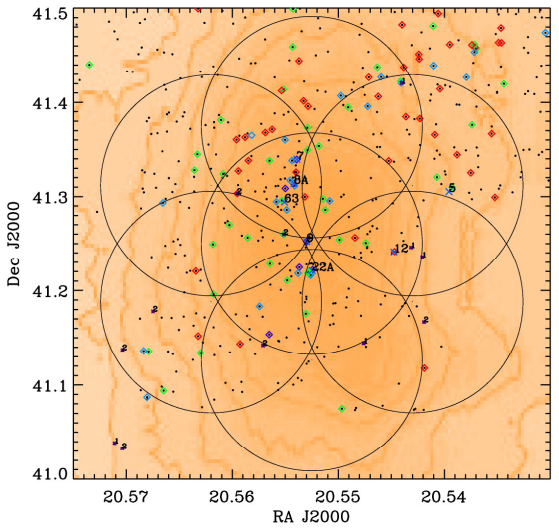


Figure 37: The same as Figure 36, but at 20 cm.

N.1.2.3. Non-thermal radio emitters

The O5If star Cyg OB2 No. 9 is one of the best-known non-thermal radio emitters. Our previous work had already suggested that these stars are binaries, where the non-thermal radio emission is due to the collision between the two winds of the binary components. The radio archive data show that the fluxes clearly follow a 2.35-yr period, which indicates that Cyg OB2 No. 9 must be a binary [3]. R. Blomme and J. Vandekerckhove also finished the reduction of the radio data for another non-thermal radio emitter (Cyg OB2 No. 8A) and we are currently modelling the radio fluxes, in collaboration with M. De Becker and G. Rauw, who provided X-ray data [18][29][31][32]. For another non-thermal radio-emitter, R. Blomme and H. Hensberge obtained a series of optical spectra with the FEROS instrument (PI: E. Unda-Sanzana, observer: C. Nitschelm). We successfully applied for follow-up observations to be performed in 2009. The combined dataset will provide information that is essential to start modelling the non-thermal radio emission of this system.

N.1.2.4. Grid of stellar atmosphere models

In preparation of a study of thermal radio emission from a number of hot stars, R. Blomme started constructing 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 will become available from the COROT satellite as well as the XSHOOTER project. R. Blomme will lead the reduction of the COROT data for one O-type star (in collaboration with C. Aerts and others) and he collaborates with C. Martayan in proposing objects for the guaranteed time on the XSHOOTER project.

N.1.3. Perspective for next years

R. Blomme and A. Lobel will apply the Zeus hydrodynamics code and the Wind3D radiative transfer code to a large number of stars and more spectral lines in order to continue modelling large-scale struc-

ture in the stellar wind. Further research of A. Lobel will primarily focus on determining the physical properties of rotational modulations in hot star winds, based in part on parameterized input models for Wind3D. A research summer student (J. A. Toalá Sanz, UNAM, Mexico) will also be involved in July 2009 for the development of the new model parameterization method and its application to IUE observations of HD 64760, and a number of key hot stars.

The reduction of existing and new radio data on thermal and non-thermal radio emitters will continue. R. Blomme will also reduce the optical spectra of HD 167971. Publications on radio data of Cyg OB2 No. 8A and 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. With the aid of a collaborator paid on an Action 1 project, R. Blomme will model the non-thermal radio emission of colliding-wind binaries. For the thermal emitters, R. Blomme will continue the construction of a grid of models and will compare the output to the observations.

N.1.4. Personnel involved

Scientific staff: R. Blomme (ROB)
A. Lobel (ROB contract 10/07/2008 – 09/04/2009)
Technical staff: J. Vandekerckhove (ROB)

N.1.5. Partnerships

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

- R. K. Prinja, University College London, UK
- S. Van Loo, University of Leeds, UK
- S. M. Dougherty, DRAO, Canada
- E. Unda-Sanzana, C. Nitschelm, Universidad Católica del Norte, Chile

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

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

Grants/Projects used for this research/service

- ROB funding

N.1.6. Scientific outreach

Meeting presentations

[1] R. Blomme
Non-Radial Pulsations and Large-Scale Structure in Stellar Winds
38th Liège International Astrophysical Colloquium "Evolution and Pulsation of Massive Stars on the Main Sequence and Close to it", Liège, Belgium, invited talk

[2] **R. Blomme, H. Hensberge**
NGC 2244 Spectroscopy
COROT meeting, Liège, Belgium

[3] **R. Blomme**
The Colliding Winds of Cyg OB2 No. 8A
"Hot And Cool: Bridging Gaps in Massive Star Evolution", Pasadena, CA, USA, poster presentation

[4] N. Gorlova, V. Kovtyukh, **A. Lobel**, G. Rieke
Spectroscopic Update on the Moon Star

Poster Presentation, 5th Spitzer Research Conference, "New Light on Young Stars: Spitzer's View of Circumstellar Disks", Pasadena, CA, USA

[5] **A. Lobel**
3-D Radiative Transfer Modelling of Massive-star UV Wind Line Variability
38th Liège International Astrophysical Colloquium, "Evolution and Pulsation of Massive Stars on the Main Sequence and Close to it", Liège, Belgium, contributed talk

[6] **A. Lobel**
Radiative Transfer Modeling the Winds and Circumstellar Environments of Hot and Cool Massive Stars
"Hot And Cool: Bridging Gaps in Massive Star Evolution", Pasadena, CA, USA, contributed talk

Seminars

[7] **A. Lobel**
Radiative Transfer Modeling of the Winds of Massive Stars
Oral Presentation, Florida Theoretical Astrophysics Seminars, 17 Nov. 2008, Bryant Conf. Room, Univ. of Florida at Gainesville, FL, USA

Wikis and Websites

- R. Blomme is responsible for contents of the website of "Hot Star Group" of the ROB (webmaster = J. Vandekerckhove) http://www.astro.oma.be/HOTSTAR/index.html
- R. Blomme made the website on "Co-rotating Interaction Regions" (part of website of "Hot Star Group") http://www.astro.oma.be/HOTSTAR/CIR/CIR.html

N.1.7. Missions

Assemblies, symposia:

- R. Blomme (ESO Instrument Development meeting)
- R. Blomme (Australia's Bid to Host the Square Kilometre Array Radio Telescope)
- R. Blomme (Contact Group)
- R. Blomme, A. Lobel (Evolution and Pulsation of Massive Stars on the Main Sequence and Close to it)
- R. Blomme (Belspo meeting on ESA plans)
- R. Blomme, A. Lobel (Hot And Cool: Bridging Gaps in Massive Star Evolution)

Research visits (days):

- R. Blomme (6 days)
- A. Lobel (3 days)

N.2. AGB stars

N.2.1. Objectives

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 Nebule 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.

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.

N.2.2. Progress and results

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

M.Groenewegen worked this year mostly in adapting his existing dust radiative transfer code to be able to include it as a subroutine in a newly written minimization code. Previously model runs were compared 'by eye' to observed spectral energy distributions but this clearly has limitations. In the new code, luminosity, mass-loss rate and the temperature at the inner dust radius are determined via a Levenberg-Marquardt minimization routine. The code was developed and tested on the High Performance Computer (HPC) of the Pool Space. First results have been obtained on 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 are publically available. 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 newly developed code, testing different grain types and spectral atmospheres. The initial set of computations has been performed and a first analysis is underway.

N.2.2.2. 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. The VMC consortium had their first science meeting in Hatfield (Univ. of Hertfortshire) to discuss the status and organize the science preparation. M. Groenewegen will lead the effort in the field of AGB stars, and gave a presentation. The commissioning of the telescope will be carried out in the winter of 2008/2009.

N.2.2.3. MESS

Mess (Mass loss of Evolved StarS) is a Herschel Guaranteed Time (GT) Key Program (KP) which is led by Belgium with M. Groenewegen as the principal investigator. It involves the Hermes partners KUL, ULB, and ROB, as well as ULg and international partners. The GT has been 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 MESS program will observe about 100 AGB, post-AGB, PN, WR, LBV, SN stars with the PACS bolometer at 110 and 170 micron (and partly with SPIRE at 250, 350, and 500 micron), and about 40 objects with the PACS spectrometer between 60-120 micron (and a few with SPIRE-FTS between 200 and 500 micron). The aim is a better understanding of the mass loss process

(time dependence and asymmetries) and dust formation. M. Groenewegen visited the Herschel Key Project Coordination and Science Exploitation workshop in ESTEC, Noordwijk, 1-2 July 2008 and the Herschel pre-launch data processing workshop at ESAC, 4-5 December 2008 in order to keep the team informed, and be prepared for the launch. The preparations continued for this space mission which will be launched in 2009, with observations starting later next year.

N.2.3. Perspective for next years

The analysis of the SEDs of AGB stars and RSGs in the MCs will be finished in 2009. By that time additional spectra will become available from Spitzer IRS programs that are currently ongoing. By 2010 a final analysis 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 this will require a substantial effort in analysis. The source catalogues will need to be cross-correlated with other photometric catalogues in order to build the SEDs which then will need to be fitted. As VMC will likely take 4-5 years to complete this will also be an effort of longer duration.

Herschel will be launched in 2009 and first data will become available in the last quarter from the Science Demonstration Phase. Herschel will fly for about 3.5 years, and the data from the MESS GTKP will be taken over the first 2 years.

N.2.4. Personnel involved

Scientific staff: M. Groenewegen

N.2.5. Partnerships

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

- Prof. Franz Kerschbaum, Institut fuer Astronomie der Universitaet Wien
- Greg Sloan, Cornell University
- Igor Soszynski, Warsaw University
- M.-R. Cioni, University of Hertfortshire

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

- Prof. Christoffel Waelkens, K.U. Leuven

N.2.6. Scientific outreach

Meeting presentations

[1] Groenewegen M.A.T.
AGB stars and the VMC survey
VMC consortium meeting, Hatfield

Seminars

[2] **Groenewegen M.A.T.**
Why Galaxies care about AGB stars
Vienna

[3] **Groenewegen M.A.T.**
From AGB stars to Cepheids: some projects I am involved in
Royal Observatory of Belgium

N.2.7. Missions

Assemblies, symposia, conferences:

- M. Groenewegen: IAU Symposium 256, The Magellanic system, Keele (UK)
- M. Groenewegen: Herschel Key Project Coordination and Science Exploitation workshop, ESTEC (NL)
- M. Groenewegen: Herschel data processing workshop, ESAC (SPA)
- M. Groenewegen: Multi-wavelength astronomy and the Virtual Observatory, ESAC (SPA)

Commissions, working groups:

- M. Groenewegen (6 days)

Research visits:

- M. Groenewegen (29 days)

N.3. Post-AGB stars and Planetary Nebulae

N.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.

N.3.2. Progress and results

N.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 a new theoretical model which suppresses convective mixing under the influence of flash burning was proposed. 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. This evolution is monitored in an international collaboration. Progress reports of this campaign were presented in [23], [24], [25], [38], and [39]. New radio observations (e-Merlin) and optical spectra (FORS1/2, VISIR on the VLT) were obtained in 2008 and a new proposal for VLT FORS2 and VISIR observations in 2009 has been accepted. The reduction of the e-Merlin data has been completed. The reduction of the VLT data is underway. In van Hoof et al. (2007) it is proposed that the marked increase in radio flux 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.

N.3.2.2. CK Vul

CK Vul was discovered in 1670 and was long thought to be a nova. Modern observations made this classification very unlikely and one of the proposed theories is that this is one of a handful of known post-VLTP objects. Based on radio data and optical (Hα+[N II]) images an in-depth analysis of the nebula surrounding this object was performed. By comparing the image obtained in 2004 with a similar image from 1991, the expansion of the nebula was clearly determined. By studying the rate of expansion it was found that the nebula originated in the 1670 explosion. For the first time a very faint and large (70 arcsec) bipolar emission nebula which also is centered on the 1670 explosion was detected. Furthermore a very compact radio source which coincides with the center of expansion of the nebula was discovered. It has no

optical counterpart. It is claimed that this is the central star which had not previously been detected. The radio emission is consistent with free-free emission, and we believe this to originate from a circumstellar or circumbinary disk. These results were presented at a meeting in [22].

N.3.2.3. Morphology and kinematics of the bipolar post-AGB star IRAS 16594-4656

The spectrum of IRAS 16594-4656 shows shock excited H_2 emission and collisionally excited emission lines such as [O I], [C I], and [Fe II]. The goal is to determine the location of the H_2 and [Fe II] shock emission, to determine the shock velocities, and constrain the physical properties in the shock. High resolution spectra of the H_2 1-0 S(1), H_2 2-1 S(1), [Fe II], and Paβ emission lines were obtained with the near infrared spectrograph Phoenix on Gemini South. A high resolution UVES spectrum was obtained via the collaboration with M. Reyniers (KULeuven). The position-velocity diagrams of H_2 1-0 S(1), H_2 2-1 S(1), and [Fe II] show that this emission is spatially extended. The collisionally excited [O I] and [C I] optical emission lines have a similar double peaked profile compared to the extracted H_2 profile and appear to be produced in the same shock. They all indicate an expansion velocity of ~8 km/s and the presence of a neutral, very high density region with n_e around 3 x 10^6 to 5 x10^7 cm^{-3}. The [Fe II] emission however is single peaked. It has a Gaussian FWHM of 30 km/s and a total width of 62 km/s at 1% of the peak. The Paβ profile is even wider with a Gaussian FWHM of 48 km/s and a total width of 75 km/s at 1% of the peak. The H_2 emission is excited in a slow 5 to 20 km/s shock into dense material at the edge of the lobes, caused by the interaction of the AGB ejecta and the post-AGB wind. The 3D representation made by A. Ginsburg of the H_2 data shows a hollow structure with less H_2 emission in the equatorial region. The [Fe II] emission is not present in the lobes, but originates close to the central star in fast shocks in the post-AGB wind or in a disk. The Paβ emission also appears to originate close to the star. These results have been published in [4] and presented at a meeting in [40].

N.3.2.4. NGC 7027

NGC 7027 is the brightest planetary nebula at radio wavelengths. Its spectral energy distribution is a classical case of free-free emission: optically thick below 2GHz, optically thin above 5 GHz, and the turnover range in between. The well-understood radio SED and the bright, compact nebula makes NGC 7027 a valuable calibrator at a wide range of frequencies. It also allowed tying together the high frequency calibrators (planets) and the low frequency ones (radio galaxies). Data from a 25-year monitoring program with the VLA shows a clear evolution in the radio flux: an increase of the optically thick flux and the decrease of the optically thin flux. The former is the result of the expansion of the nebula leading to an increase of the $\tau = ⅔$ radius, while the latter is the result of the evolution of the central star. Using the rate of flux increase at optically thick frequencies an expansion distance of 980±100 pc was derived. By comparing the decline in flux at optically thin frequencies with theoretical models by Blöcker we could determine the mass of the central star to be 0.65±0.01 $M_{\odot}$. Based on this analysis we could also determine that the central star is heating up at a rate of 155 K/yr, while the luminosity is decreasing at a rate of 0.07 %/yr. These results were presented in paper [8].

N.3.2.5. IRAS12316-6401 – a new symbiotic Mira?

We discovered IRAS12316-6401 in our search for obscured PNe from the IRAS catalogue. The evolutionary status of this object is still under debate. From IRAS and MSX photometry it is clear it has an extended circumstellar envelope containing cool dust, which is typical for PNe. However, the high-resolution optical emission line spectrum obtained with EMMI shows very broad emission lines with velocities up to at least 600 km/s. This is not normally observed in regular PNe, but is typical for symbiotic binaries. The emission line spectrum shows high excitation lines from [Fe VII] and possibly also [Fe VI], which is also unusual for PNe since iron is strongly depleted into refractory grains. The broad emission lines must therefore be formed in gas where grains never were formed, or where they have been fully destroyed. The information in the spectroscopic image suggests that this system is driving a powerful jet which is aimed almost directly at us. This jet is ionized by a hot white dwarf. It seems very plausible that a binary companion is feeding the material for the jet. However, to date no direct evidence for the exis-

tence of such a companion exists. No stellar continuum has been detected in the spectrum, possibly due to extinction by dust. The evidence we have gathered so far is pointing toward the fact that this is an extended symbiotic Mira, but the proof is not yet conclusive. If this is confirmed by future observations, IRAS12316-6401 would only be the 9th object in the elusive class which may be important to better understand the formation of bipolar PNe. These results were presented at meetings in [41].

N.3.2.6. HST snapshot survey of post-AGB stars and proto-planetary nebulae

Within this international collaboration the results from a Hubble Space Telescope (HST) snapshot survey of post-AGB objects are shown. The aim of the survey is to complement existing HST images of PPN and to connect various types of nebulosities with physical and chemical properties of their central stars. Nebulosities are detected in 15 of 33 sources. Images and photometric and geometric measurements are presented. For sources with nebulosities we see a morphological bifurcation into two groups, DUPLEX and SOLE, as previous studies have found. We find further support to the previous results suggesting that this dichotomy is caused by a difference in optical thickness of the dust shell. The remaining 18 sources are classified as stellar post-AGB objects, because our observations indicate a lack of nebulosity. We show that some stellar sources may in fact be DUPLEX or SOLE based on their infrared colors. The cause of the differences among the groups is investigated. We discuss some evidence suggesting that high progenitor-mass AGB stars tend to become DUPLEX post-AGB objects. Intermediate progenitor-mass AGB stars tend to be SOLE post-AGB objects. Most of the stellar sources probably have low mass progenitors and do not seem to develop nebulosities during the post-AGB phase and therefore do not become planetary nebulae. The article was published [5].

N.3.2.7. The disk in the binary post-AGB star HD10158

G. Van de Steene and P. Van Hoof used the VLTI with MIDI and AMBER to investigate the dust in the disk of the hot post-AGB star HD101584. This object shows many properties which are typical of other hot post-AGB stars, but who are too faint to be observed with VISA. Many of these properties are attributed to a putative disk formed because of an elusive binary companion. With AMBER we will determine the inner rim of the disk. With MIDI the angular diameter of the circumbinary disk and the spatial distribution of the chemical dust components will be determined. The MIDI+AMBER combination will provide an accurate determination of the composition and temperature distribution in the disk of HD101584. The goal is to obtain information about the disks in the inner regions of hot post-AGB stars which are very similar to HD101584. The 2-week observing run was prepared using P2PP and the data was collected at the end of May in visitor mode.

N.3.2.8. The disk in the planetary nebula Hen 2-90

Jets operating during the late AGB and/or early post-AGB evolution appear to play a fundamental role in the shaping of planetary nebulae. The driving agents for two-sided jets are generally thought to be embedded in accretion disks. However, these equatorial disks have not been observed up to now. The planetary nebula Hen 2-90 shows an active knotty jet, and it is reported to have an accretion disk. It was observed with ISO is bright in the mid-infrared, and was observed with MIDI on the VLTI. The MIA-EWS package was installed. All the data have been fully reduced in several ways. Expert advice was solicited to help to resolve problematic issues with the data. The problems are not fully resolved yet and need to be further looked into with expert advice.

N.3.3. Perspective for next years

P. van Hoof and G. Van de Steene will prepare for and work on Herschel-PACS data of post-AGB stars and planetary nebulae that are gathered in the MESS guaranteed time program. They will be working on the reduction and interpretation of the data and will also continue to monitor the spectral evolution of Sakurai's object. To this end optical spectra (using FORS and VISIR on the VLT) and radio observations will be obtained on a yearly basis. These data will be analyzed and modeled using the photoionization

code Cloudy to derive the evolution of the central star temperature as a function of time. These data will be used to test the new theory proposed by Falk Herwig.

In support of both lines of research, P. van Hoof will continue to develop the modeling code Cloudy, as well as his web-based Atomic Line List as needed (see sections N.4N.5). Working on the data obtained with the Hermes telescope on La Palma in the framework of the joined project to monitor the variability of bright post-AGB stars and central stars of planetary nebula will continue. The reduction of the VLTI data obtained with MIDI and AMBER is scheduled as well.

N.3.4. Personnel involved

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

N.3.5. Partnerships

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

- Toshiya Ueta, University of Denver, USA
- T. Ueta, Dept. of Astronomy and Astrophysics University of Denver, USA
- A. Ginsburg, Dept. of Astronomy and Astrophysics University of Denver, USA
- N. Siódmiak, Space Telescope Science Institute, USA
- M. Meixner, Space Telescope Science Institute, USA
- Sugerman, Goucher College, USA
- R. Szczerba, N. Copernicus Astronomical Center, Poland
- Albert A. Zijlstra, University of Manchester
- Marcin Hajduk, Centrum Astronomii, Torun
- Nye Evans, School of Chemistry and Physics, Keele
- Steward P.S. Eyres, Centre for Astrophysics, Preston
- Stefan Kimeswenger, Institut fuer Astrophysik, Innsbruck
- Falk Herwig, School of Chemistry and Physics, Keele
- Rick A. Perley, NRAO, Socorro

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

- Maarten Reyniers, K.U. Leuven
- Hans Van Winckel, K.U.Leuven
- Prof. Christoffel Waelkens, K.U. Leuven

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

- Belspo – Action 1, MO/33/017 (Jan. 1 – June 30)

N.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

N.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
- P. Van Hoof: FRNS Contact Group Meeting, Planetarium, Brussels

Field missions:

- P. Van Hoof (11 days)

Commissions, working groups:
- G. Van de Steene (2 days)

N.4. The Photoionization Code Cloudy

N.4.1. 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 120 papers per year cite the use of Cloudy.

N.4.2. Progress and results

The photoionization code Cloudy plays a crucial role in the research of P. van Hoof. He is a member of the international development team of this code. Most importantly he is the primary author of the grain model in Cloudy. Grains play an important role in many environments (including post-AGB stars and PNe) because of extinction, photoelectric heating, their influence on the charge and ionization balance of the gas, as catalysts for grain-surface chemical reactions (e.g. H_2 formation), and as seeds for freeze-out of molecules. His main contributions to Cloudy in 2008 were a major upgrade of the dielectronic recombination treatment of ions and a complete rewrite of the electron temperature and density solvers. The former resulted in improved models of planetary nebulae and other objects which are irradiated by high-energy photons. The latter resulted in improved stability of the code and more accurate modeling results, especially in molecular regions. These developments will be part of the upcoming release in 2009. P. van Hoof advised on several group publications discussing new features of the code and its application to various astrophysical objects (refereed journal publications [6], [7], [9], [35], [36], [37], and meeting presentation [21]). 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 release of the bug-fix roll-up c07.02.02 in July 2008, as well as the new general release c08.00 of the code in August 2008. Furthermore he assisted in the preparations for the upcoming c09.00 release of Cloudy which is scheduled for April of 2009. He assisted in maintaining and updating the Cloudy web sites as listed below.

N.4.3. 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 physics that is 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 next year the efforts of P. van Hoof will be mainly aimed at finishing the improved opacity functions for polycyclic aromatic hydrocarbons (PAHs). This development will have consequences for modeling many types of environments, including planetary nebulae and post-AGB stars.

N.4.4. Personnel involved

- P. Van Hoof (Belspo – Action 1, MO/33/017, Jan. 1 – June 30)
- P. Van Hoof (NSF grant AST 0607028, Sep. 1 – Dec. 31)

N.4.5. Partnerships

List of international partners without grant

- Gary J. Ferland, University of Kentucky, USA. Main 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.
- Joe C. Weingartner, George Mason University, Fairfax, USA. Grain expert.
- Nick P. Abel, University of Cincinnatti, USA. Maintains molecular network.
- Gargi Shaw, Tata Institute of Fundamental Research, Mumbai, India. Maintains H2 code.

Grant/Projects used for this research/service

- Belspo – Action 1, MO/33/017 (Jan. 1 – June 30)
- NSF grant AST 0607028 (Sep. 1 – Dec. 31)

N.4.6. 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 100 refereed journal papers acknowledge use of the code.

Wikis and Websites

- http://www.nublado.org: this is the main portal for the Cloudy project. It contains links to all the other websites. P. van Hoof helps in maintaining this website.
- http://wiki.nublado.org: this is the wiki for the Cloudy project. 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.

N.4.7. Missions

Assemblies, symposia, conferences:

P. Van Hoof: Cloudy development summit, Imperial College, London, UK
P. Van Hoof: Cloudy development summit, Institute of Astronomy, Cambridge, UK

N.5. The Atomic Line List

N.5.1. Objectives

The atomic line list is a web-based compilation of approximately 923,000 allowed, intercombination and forbidden atomic transitions with wavelengths in the range from 0.1 nm to 1000 μm. It is publicly available and its primary aim is to assist spectroscopists in the identification of absorption or emission lines in

astrophysical or laboratory spectra. It is complete for all elements up to and including zinc. It is widely used in the astronomical and physical community and got nearly 10,000 visitors in 2008.

N.5.2. Progress and results

Due to lack of time, no progress has been achieved in 2008.

N.5.3. Perspective for next years

The next release (v2.05) will add lines for elements gallium through krypton, update the data for several 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 5^{th} and 6^{th} row elements, most notably s-process elements.

N.5.4. Personnel involved

Scientific staff: P. Van Hoof

N.5.5. 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.

O. Variable Stars

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

O.1.1. Objectives

Research on variables stars leads to a better knowledge of stellar structure and evolution. In order to achieve this goal, observation and detection of the variability of the stars and a precise analysis of the observed periodicities is necessary. The emphasis of the research carried out here, is on detection of multiple periods in pulsating variable stars in general and on B-type and γ Doradus stars in particular.

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. However, mode identificiation is not simple for these stars since the spectrum of g modes is very dense and only a few modes seem to have large amplitudes to be well observed from the ground. Therefore, observables as photometric amplitude ratios and line profile variations are extremely useful to identify the modes. By observing light variations in different passbands the identification of the degree ℓ of the pulsation mode becomes possible. A selected group of γ Dor stars and some 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.

O.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 went on. Classical methods of period analysis and new methods developed by J. Cuypers were further applied to these data in search for periodicities. A sample of 21 variable stars (about one third of the known members) of the γ Doradus class was identified and analysed. The La Palma data were combined by J. Cuypers with the Hipparcos data and with data from literature. This resulted in an extremely reliable and precise set of frequencies for these stars. Amplitudes for mode identification could be derived in the seven colours of the Geneva photometric system. These amplitudes, in particular the ratios with reference to the highest amplitude, will be used for the asteroseismological mode identification of these stars as initiated by A. Miglio and colleagues from Liège and Leuven.

This work has been done in collaboration with Peter De Cat (Dep. 2) and collaborators of the Institute of Astronomy. A paper for A&A has been prepared.

O.1.3. Perspective for next years

J. Cuypers will contribute to the initiated seismological study of the analysed γ Doradus stars.The variable A and F stars observed by the Mercator telescope but not (yet) classified as confirmed γ Doradus variables, will be analysed separately.

O.1.4. Personnel involved

Scientific staff: J. Cuypers, P. De Cat (Dep. 2)

O.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.

O.1.6. Scientific outreach

Meeting presentations

[1] **J. Cuypers**,
Analysis of MERCATOR data: γ Doradus stars
BAG Meeting, Leuven, 17/12/2008

O.1.7. Missions

Commissions, working groups:
BAG meeting (Leuven, 17/12/2008)
Research visits:
J. Cuypers (6)

O.2. Cepheids

O.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.

O.2.2. Progress and results

M.Groenewegen published an analysis of distance estimates and the metallicity effect on the PL-relation for a sample of about 60 galactic Cepheids ([13]). The distance estimates are 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 this study, Groenewegen collected all galactic Cepheids for which sufficient optical V-band, infrared K-band and radial velocity data was available. The analysis of the radial velocity and light curves results in the distance (and mean radius of the star), and therefore the absolute magnitude.A period-luminosity relation is fitted, and then the residual can be plotted against metallicity which is available in the literature for most cases. No statistically significant effect is found, but this is in part due to the limited range in metallicity spanned by the Galactic Cepheids.
In a different work ([12]), Romaniello et al. determined the abundances in a sample of 32 Galactic, 22 LMC, and 14 SMC Cepheids. M Groenewegen was the P.I. of the original ESO time request (Period 66) and involved in the data taking and finalisation of the manuscript. Some of the abundances were already used in paper [13].
In observing runs in November (M.Groenewegen) and December 2008 (collaborator Pedicelli) spectra for additional MC Cepheids were obtained and now an abundance study can be carried out.

O.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 that will become operational in 2009.

O.2.4. Personnel involved

Scientific staff: M. Groenewegen

O.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

O.2.6. Missions

Field missions:
M. Groenewegen (6 days)

O.3. Analysis of data from the CoRoT satellite

O.3.1. Objectives

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

J. Cuypers is involved in the classification of these variable stars and, as a member of the CoRoT B star and the O star working group, he will contribute to the characterization of the candidate O and B variable stars.

O.3.2. Progress and Results

O.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 was done in collaboration with Jonas Debosscher (KULeuven) and Luis Sarro (Madrid). J. Cuypers gave input on characteristics of variable stars in general and on periods and period search methods in particular. This information has been implemented in the tools developed for the classification of the variable stars of large surveys, as e.g. the OGLE data (The Optical Gravitational Lensing Experiment (OGLE) project is a long term project with the main goal of searching for the dark matter with microlensing phenomena) and the variables detected by the satellite CoRoT. Now the classification methods are also being adapted for the satellite Gaia (see further).

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, are the first results of this classification were summarized in an article, submitted to Astronomy and Astrophysics [44].

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

The CoRoT classification team has sent to the ROB a set of 39 candidate variable B-stars (19 candidate SPB and 20 β Cep stars) observed in the exofield during IRa01 (initial run, anti-center direction, 55 days).

J. Cuypers and P. De Cat did a first period analysis and results were reported to the B BAG team and to Pieter De Groote, Ph. D. student at the KULeuven, who did a large part of the pre-processing and the further analysis. An automated data analysis tools which include algorithms for jump correction, light curve detrending, frequency detection, frequency combination search and frequency and period spacing search was developed. Besides numerous new classical slowly pulsating B stars, evidence for a new class of low-amplitude B-type pulsators with a very broad range of frequencies was found, as well as several slowly pulsating B stars with residual excess power at frequencies typically factor three above their expected g-mode frequencies. J. Cuypers found that many of the β Cephei candidates are probably eclipsing or ellipsoidal variables. First results were reported at a BAG meeting [1] and at the 38th Liège International Astrophysical Colloquium [2].

A meeting was attended to discuss the possibilities of analysing O stars observed by CoRoT. Collaboration with R. Blomme is foreseen, but in 2008 no data of O stars were available yet.

O.3.3. Perspective for next years

A huge amount of data will be available from the CoRoT satellite in 2009. J. Cuypers will continue to analyse and interpret the data, mostly of candidate B type variables, in close collaboration with P. De Cat (ROB) and the Leuven and Liège team. When data for O stars will be available, J. Cuypers will collaborate with R. Blomme (ROB) for the period analysis.

O.3.4. Personnel involved

Scientific staff: J. Cuypers, R. Blomme

O.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)
- And those included in the list of international collaborators

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

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

O.3.6. Scientific outreach

Meeting presentations

[1] J. Cuypers,
CoRoT: β Cephei and SPB candidates
BAG Meeting, Luik, 12/03/2008

[2] P. De Groote, C. Aerts, **J. Cuypers** et al.,

Space Observations of Corot O and B Stars
38th Liège International Astrophysical Colloquium: Evolution and Pulsation of Massive Stars on the Main Sequence and Close to it, Liège, July 7-11 2008

Wikis and Websites

- Gaia Wiki pages of CU7 on Variability Characterisation and related matters.

O.3.7. Missions

Assemblies, symposia, conferences:

- J. Cuypers: 38th Liège International Astrophysical Colloquium: Evolution and Pulsation of Massive Stars on the Main Sequence and Close to it, Liège, July 7-11 2008

Commissions, working groups:

- J. Cuypers (18/01, 20/02, 12/03)
- J. Cuypers (18/11)

O.4. Research project: Kepler

KEPLER (launched in March 2009) will continuously monitor 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 habital zone, using the transit technique, but the stellar data obtained are also excellent for asteroseismic studies.

J. Cuypers followed the second Kepler Asteroseismic Science Consortium (KASC) Workshop (Åhrus, Denmark; 09-12/06/2008) online. He submitted 2 electronic letters of intent in which he proposes to be a member of the working groups for SPB and γ Doradus stars.

P. Binary stars

P.1. Binary Stars in young stellar groups

P.1.1. 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.

P.1.2. Progress and results

The investigations on the numerical aspects of the spectrum disentangling method, in cooperation with S. Ilijić and K.B.V. Torres resulted in a refereed paper [10], in further discussions on open issues, a detailed investigations on convergence in on-going studies of particular stars (V831 Cen, θ^2 Tau) and in an update of the fd3 software by S.I.

Concerning specific star studies, emphasis was on V831 Cen belonging to the Scorpius-Centaurus association Lower Centaurus-Crux. The analysis is primarily based on spectra obtained by V. Bakiş on Mount John, New Zealand. The detection of a light-time effect in the analysis of photometry since 1950 shows the system consists of three stars [26]. After a careful removal of instrumental effects in his spectra, the strongest spectral features of this third star, due to Mg I, were disentangled from the observed spectra. They correspond to absorptions less than three per cent deep in the composite spectra (to be published in 2009).

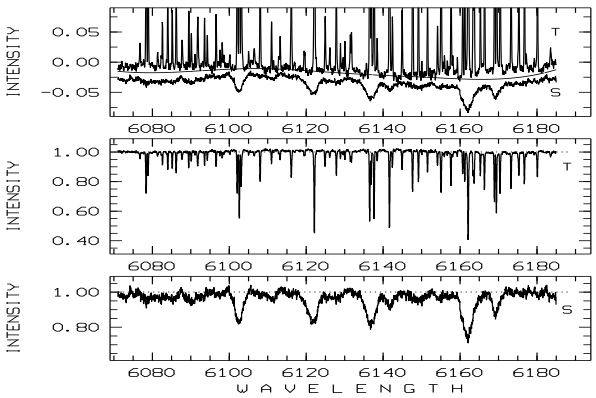


Figure 38. : Recovering component spectra with unbiased low-frequency Fourier components

More information on multiple stars in Sco-Cen was collected in common high resolution spectroscopic observing programs with UA and UCN executed at SAAO, South Africa and ESO, Chile by C. Nitschelm and by analysis of All-Sky Automated Survey (ASAS, http://www.astrouw.edu.pl/asas) photometry in cooperation with M. David. The purpose of the latter is to detect variable stars and in particular close binary stars with ellipsoidal components (stars fainter than visual magnitude 7.5). Several variable stars, among which at least two ellipsoidal binary stars, were identified. The spectra of these binary stars can now be obtained and studied efficiently.

The project on the young star cluster NGC 2244 was revived with the successful application for photometry at CTIO, Chile (observing run in January 2009) and the visit of Gh. Deridder to re-investigate the Walraven photometry for the cluster. Carefully reduced spectra taken earlier with the CASPEC spectrograph (ESO) were put at the disposal of colleagues at ULg and KULeuven in October, in preparation of their analysis of COROT satellite data for O-type objects in this star cluster.

In addition to the study of binary stars in these stellar groups, cooperations on the analysis of two triple systems deserve to be mentioned: HD 167971, consisting of three O-type components with interacting winds (main investigator R. Blomme, see his report) for which C. Nitschelm will also perform a second observing run in mid-2009 to complete the coverage of the orbital phases; and HD 208905, another massive, B-type obvious triple system (spectra obtained by S. Daflon and P. Koubsky). At ROB, a significant part of the data was cleaned from instrumental effects which prevented a meaningful analysis (some wavelength ranges require further attention).

P.1.3. Perspective for next years

The analysis of V831 Cen will be continued, for presentation at the Binary Star meeting in Brno. During an 8-week visit at UCN, April-May 2009, the photometry in NGC 2244, meanwhile obtained at CTIO, will be reduced and first results derived. Extensive work visits at ON, Rio de Janeiro and UFMG, Belo Horizonte are foreseen to participate in the analysis of HD 208905 with S. Daflon and HD 156208 and RV Crt with L.P. Vaz. The work on ASAS data with M. David will be concluded.

Further observations on NGC 2244 and the most northern subgroup of Sco-Cen will profit from the availability of the HERMES spectrograph (see Interdepartemental report on HERMES).

P.1.4. Personnel involved

Scientific staff: H. Hensberge, R. Blomme

P.1.5. Partnerships

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

- L.P. Vaz, K.B.V. Torres, UFMG, Belo Horizonte, Brazil (promoter, PhD student) : RV Crt & spectra disentangling (joint analysis)
- V. Bakış, Onsekiz Mart University, Çanakkale, Turkey: η Muscae, V831 Centaurus (observer spectra, joint analysis)
- K. Pavlovski, University of Zagreb, Croatia: NGC2244 (discussions)
- S. Ilijić, University of Zagreb, Croatia: numerical codes & theory of spectra disentangling (discussions and update of his software)
- P. Koubsky, Ondrejov Astronomical Observatory, Czechia & S. Daflon, ON, Rio de Janeiro, Brazil: HD208905 (joint research during visit P.K., work on spectra taken by S.D.)
- C. Nitschelm, UCN, Antofagasta, Chile: Scorpius-Centaurus and HD 167971 (observations at ESO and SAAO)
- Gh. Deridder, Toronto, Canada (free researcher): NGC 2244 (calibration photometry)

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

- M. David, UA: Scorpius-Centaurus (joint analysis of ASAS data)
- R. Blomme, ROB: HD 167971 (common observing project)
- G. Rauw, Ulg: NGC 2244 - 114 (exchange of data)
- P. Lampens, ROB: V831 Cen (astrometric aspects)

Visitors:

- P. Koubsky, Ondrejov Astronomical Observatory, 26/02 until 06/03, cooperation on HD 208905
- V. Bakış, Onsekiz Mart University, Çanakkale, 01/07 until 30/07, cooperation on V831 Cen and η Mus
- Gh. Deridder, Toronto (free researcher), 01/07 until 28/07, cooperation on NGC 2244

P.1.6. Scientific outreach

Seminars:

[1] Hensberge H.:
Modern analysis techniques for spectroscopic binaries, Çanakkale, Turkey, Nov. 5
Modern analysis techniques for spectroscopic binaries
University Onsekiz Mart, Canakkale, Turkey, Nov. 5

P.1.7. Missions

Research visits:
H. Hensberge (15 days)

Q. Distance scale in the local universe

Q.1. Mean absolute magnitudes of Red Clump stars

Q.1.1. Objectives

To obtain accurate distances to objects in the Universe is extremely difficult in most cases. Nevertheless this is a quantity of crucial importance in deriving luminosities and other stellar properties. By studying different distance indicators it should be possible to calibrate out various possible systematic effects that are inherent to any single distance indicator, and to establish an accurate distance scale ladder.

Q.1.2. Progress and results

In [11], M.Groenewegen published the analysis of the mean absolute magnitude in the I- and K-band of Red Clump (RC) stars. This analysis is based on the catalog of revised Hipparcos parallaxes that became available in 2007. In addition, a numerical model was build to simulate the selection of RC stars from

various catalogs in order to control and correct for selection biases. The result was that the absolute I-magnitude of -0.22 was found to be in agreement with previous results, but the absolute K-magnitude of -1.54 is significantly fainter than previously assumed, because of a selection bias.

Q.1.3. Perspective for next years

Using the recent publication of the revised Hipparcos parallaxes other distance indicators could be investigated as well.

Q.1.4. Personnel involved

Scientific staff: M. Groenewegen

Q.1.5. Partnerships

- Maurizio Salaris, University of Liverpool

R. Atomic Data for Spectral Standard Stars

R.1. 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.

R.1.1. 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 (Figure 39). The

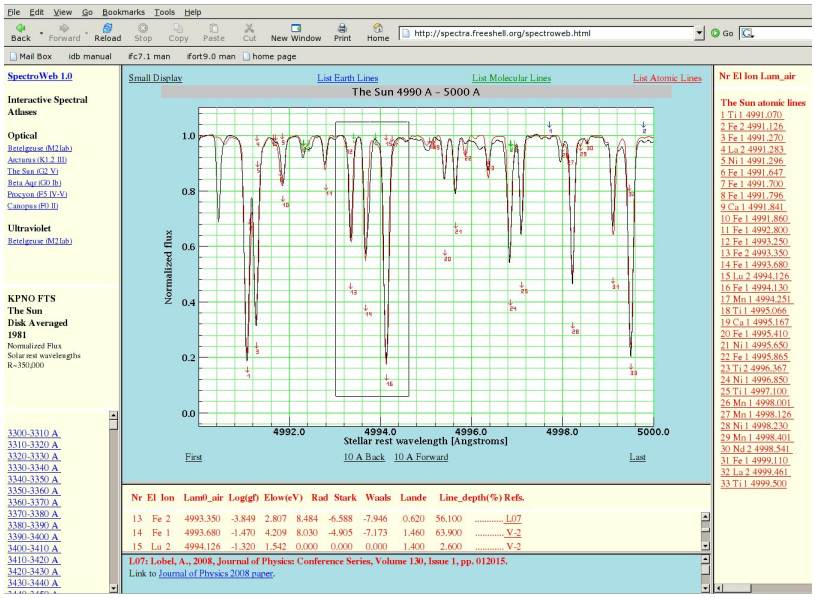


Figure 39. The SpectroWeb database at http://spectra.freeshell.org showing 10 Å of the solar spectrum with atomic line identifications (right-hand sub frame) and atomic line data & literature references (lower sub-frames).

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.

R.1.2. Progress and Results

A. Lobel updated the SpectroWeb database with 1178 oscillator strength values of atomic absorption lines observed in the optical spectrum of the Sun and Procyon [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. A subset of 660 line oscillator strengths has been validated with synthetic spectrum calculations of Procyon observed with ESO-UVES between 4700 Å, and 6800 Å. The new log(*gf*)-values in SpectroWeb are improved over the values offered in the online Vienna Atomic Line Database (VALD-2). He finds for neutral iron-group elements, such as Fe I, Ni I, Cr I, and Ti I, a statistically significant over-estimation of the VALD log(*gf*)-values for weak absorption lines with normalized central line depths below 15%. For abundant lighter elements (e.g., Mg I and Ca I) this trend is statistically not significantly detectable, with the exception of Si I for which the log(*gf*)-values of 60 weak and medium-strong lines are substantially decreased to best fit the observed spectra. The newly measured log(*gf*)-values are available in the SpectroWeb database which interactively displays the observed and computed stellar spectra, together with corresponding atomic line data.

R.1.3. 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 ~ 2^m to 5^m 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.

R.1.4. Personnel involved

Scientific staff: A. Lobel

R.1.5. Scientific outreach

Websites

- ***Lobel A.,*** SpectroWeb: The Interactive Database of Spectral Standard Star Atlases, at spectra.freeshell.org; 2008 regular on-line updates of spectral atomic data & references.

S. Solar Spectroscopy

S.1. Solar Abundances and relevant Spectroscopic Data

S.1.1. Objectives

The determination of accurate abundances in the solar photosphere (adopting the best spectroscopic data and the most representative solar models) remains very important in solar and stellar physics.

S.1.2. Progress and results

A full revision of the solar abundance of a large number of elements has been carried out. Special attention has been paid to the selection of our atomic lines (i.e. unblended solar lines with very accurate transition probabilities). This new determination has been based on new intensity measurements from the best solar spectra adopting the most representative 1D and 3D solar models.

A solar-calibrated atomic and molecular data bank in the infrared is in progress and will include about 110.000 lines in the spectral region from 250 to 10.000 cm^{-1} [lambda 1.000 – 40.000 nm]. It enables to reproduce rather well the observed solar spectrum and should also be useful for the calculation of synthetic spectra of cool (solar-type) stars. This data bank will be available on the ROB website. Part of this data bank (about 70.000 lines from 600 to 5.600 cm^{-1}) is complete and is available on simple request.

S.1.3. Perspective for next years

Two main works in 2009: several papers about the chemical composition of the Sun, based on our review for ARAA (in collaboration with N. Grevesse, M. Asplund, P. Scott and others) and the completion of the IR spectroscopic data base.

S.1.4. Personnel involved

Scientific: J. Sauval (retired)

S.1.5. Partnerships

List of international partners without grant

- Martin Asplund, Max Planck Institut für Astrophysik, Garching
- Pat Scott, Department of Physics, Stockholm University

List of national partners without grant

- Nicolas Grevesse, Institut d'astrophysique, Université de Liège

T. Publications

T.1. Publications with peer review

[1] **Lobel, A.**
SpectroWeb: Oscillator Strength Measurements of Atomic Absorption Lines in the Sun and Procyon
Journal of Physics: Conference Series, Vol. 130, Issue 1, pp. 012015

[2] **Lobel, A., Blomme, R.**
Modeling Ultraviolet Wind Line Variability in Massive Hot Stars
ApJ, 678, 408

[3] Van Loo, S., **Blomme, R.**, Dougherty, S. M., Runacres, M. C.
Non-thermal radio emission from O-type stars. III. Is Cygnus OB2 No. 9 a wind-colliding binary?
A&A, 483, 585

[4] **Van de Steene G.C**., Ueta T., **van Hoof P.A.M**., Reyniers M., Ginsburg A.G.
Kinematics and H_2 morphology of the multipolar post-AGB star IRAS 16594-4656
A&A, 480, 775

[5] Siodmiak, N., Meixner, M., Ueta, T., Sugerman, B. E. K., **Van de Steene, G.C.**, Szczerba, R.
HST snapshot survey of post-AGB objects
2008, ApJ, 677,382

[6] Shaw G., Ferland G.J., Srianand R., Abel N.P., **van Hoof P.A.M**., Stancil P.C.
On the enhanced cosmic ray ionization rate in the diffuse cloud towards ζ Persei
ApJ, 675, 405

[7] Ferland G.J., Fabian A.C., Hatch N.A., Johnstone R.M., Porter R.L., **van Hoof P.A.M**., Williams R.J.R.
The origin of molecular hydrogen emission in cooling-flow filaments
MNRAS, 386, L72

[8] Zijlstra A.A., **van Hoof P.A.M**., Perley R.
The evolution of NGC 7027 at radio frequencies: a new determination of the distance and core mass
ApJ, 681, 1296

[9] Abel N.P., **van Hoof P.A.M.,** Shaw G., Ferland G.J., Elwert T.
Sensitivity of PDR Calculations to Microphysical Details
ApJ, 686, 1125

[10] **Hensberge H.,** Ilijić S., Torres K.B. V.
On the separation of component spectra in binary and higher-multiplicity stellar systems: bias progression and spurious patterns
A&A 482, 103-122

[11] **Groenewegen M.A.T.**
The red clump absolute magnitude based on revised Hipparcos parallaxes
A&A 488, 935-941

[12] Romaniello M., Primas F., Mottini M., Pedicelli S., Lemasle B., Bono G., Francois P., **Groenewegen M.A.T**., Laney C.D.
The influence of chemical composition on the properties of Cepheid stars. II-The iron content
A&A 488, 731-747

[13] **Groenewegen M.A.T.**
Baade-Wesselink distances and the effect of metallicity in classical Cepheids

A&A 488, 25-35

[14] Scott P., Asplund M., Grevesse N., **Sauval A.J.**
On the solar Nickel and oxygen abundances
ApJ. 691, L119-L122, 2009

T.2. Publications without peer review

[15] **Blomme, R.**
Radio observations of mass loss in OB stars
Proceedings of "Mass loss from stars and the evolution of stellar clusters", Eds. A. de Koter, L. Smith, R. Waters, ASPC 388, 145

[16] **Blomme, R.**
Corotating Interaction Regions and clumping
Proceedings workshop "Clumping in Hot Star Winds", Eds. W.-R. Hamann, A. Feldmeier, L. Oskinova, Potsdam: Univ.-Verl., ISBN 978-3-940793-33-1, 151

[17] **Blomme, R., Lobel, A.**
Modelling ultraviolet wind line variability in massive hot stars
IAU Symposium 250, "Massive stars as cosmic engines", Eds. F. Bresolin, P.A. Crowther, J. Puls, Cambridge University Press, 525

[18] De Becker, M., Rauw, G., Pittard, J.M., **Blomme, R.**, Romero, G.E., Sana, H., Stevens. I.R.
The investigation of particle acceleration in colliding-wind massive binaries with SIMBOL-X
Proceedings workshop "Simbol-X: the hard X-ray universe in focus", Memorie della Societa Astronomica Italiana, 79, 242

[19] **Lobel, A**.
Modelling DACs in UV Lines of Massive Hot Stars
Proceedings "Clumping in Hot Star Winds", Eds. W.-R. Hamann, A. Feldmeier, L. Oskinova, Potsdam: Univ.-Verlag, ISBN 978-3-940793-33-1, 81

[20] **Lobel, A., Blomme, R.**
Three Dimensional Radiative Transfer in Winds of Massive Stars: Wind3D
UV Astronomy: Stars from Birth to Death. Proceedings of the Joint Discussion n.4 during the IAU General Assembly of 2006, Eds. Ana I. Gómez de Castro, Martin A. Barstow, 119

[21] **van Hoof P.A.M.**, Abel N.P., Williams R.J.R., Porter R.L., Ferland G.J.
Modeling X-ray ionization of grains with Cloudy
Proceedings of the Far-Infrared 2007 workshop, ed. Kramer C., EAS Publication Series, Vol. 31, p. 213

[22] Hajduk M., Zijlstra A.A., **van Hoof P.A.M.,** Lopéz J.A., Drew J.E., Evans A., Eyres S.P.S., Gesicki K., Greimel R., Kerber F., Kimeswenger S., Richer M.G.
On the evolved nature of CK Vul
Proceedings of the Hydrogen Deficient Stars conference, eds. Werner K., Rauch T., ASP Conference Series, Vol. 391, p. 151

[23] Hajduk M., Gesicki K., **van Hoof P.A.M.**, Lopéz J.A., Zijlstra A.A.
Studying the old planetary nebula of V4334 Sgr
Proceedings of the Hydrogen Deficient Stars conference, eds. Werner K., Rauch T., ASP Conference Series, Vol. 391, p. 163

[24] Kimeswenger S., Zijlstra A.A., **van Hoof P.A.M.,** Hajduk M., Herwig F., Lechner M.F.M., Eyres S.P.S., **Van de Steene G.C.**
Morphologies of the nebulae around "born again" central stars of planetary nebulae

Proceedings of the Hydrogen Deficient Stars conference, eds. Werner K., Rauch T., ASP Conference Series, Vol. 391, p. 177

[25] **van Hoof P.A.M.,** Hajduk M., Zijlstra A.A., Herwig F., **Van de Steene G.C.,** Kimeswenger S., Evans A.
Recent observations of V4334 Sgr and V605 Aql
Proceedings of the Hydrogen Deficient Stars conference, eds. Werner K., Rauch T., ASP Conference Series, Vol. 391, p. 155

[26] Bakış V., Demircan O., **Hensberge H**., Bakış H.
Scorpius-Centaurus oymağındaki çift ve çoklu sistemlerin özellikleri örnek çalışma: η Muscae ve V831 Centaurus
In: Proceedings 16th national astronomy meeting, held in Çanakkale, Turkey, 8 – 12 September 2008

[27] Milone E.F., Young A.T., Bauwens E., ..., **Hensberge H**., ... (30 authors)
Division IX / Commission 25: Working Group Infrared Astronomy
Transactions IAU, Vol. 4, issue 27A, Reports on Astronomy 2006-2009, 313 - 315 (ed. K. van der Hucht, Cambridge: Cambridge University Press

[28] **Pauwels, T.,** Vingerhoets, P., **Cuypers, J.,**
A problem with the reduction of the observations of the PHEMU97 and PHEMU03 events with the Ukkel SchmidtTelescope,
Proceedings of the workshop "Mutual events of the Uranian satellites in 2007-2008 and further observations in network", J.-E. Arlot, N. Emelianov, W. Thuillot, eds., 2008, 29-32.

T.3. Publications in press, submitted

[29] **Blomme, R.**, Van Loo, S., De Becker, M., Rauw, G., Dougherty, S.M., Runacres, M.C.
Non-thermal radio emission from the colliding winds of O-star binaries
Proceedings of "Massive Stars: Fundamental Parameters and Circumstellar Interactions", Eds. P. Benaglia, G. Bosch and C.E. Cappa, in press

[30] **Blomme, R.**
Non-radial Pulsations and Large-Scale Structure in Stellar Winds
Proceedings of the 38th Liège International Astrophysical Colloquium, Comm. in Asteroseismology, in press

[31] **Blomme, R.**
The colliding winds of Cyg OB2 No. 8A
Proceedings of "Hot and Cool: Bridging Gaps in Massive Star Evolution", Eds. C. Leitherer, Ph.D. Bennett, P.W. Morris and Th. van Loon, ASP Conf. Ser., in press

[32] De Becker, M., **Blomme, R.**, Micela, G., Pittard, J.M., Rauw, G., Romero, G.E., Sana, H., Stevens, I.R.
Non-thermal processes in colliding-wind massive binaries: the contribution of Simbol-X to a multi-wavelength investigation
Proceedings of "Simbol-X: focussing on the hard X-ray universe", in press

[33] **Lobel A.**
3-D Radiative Transfer Modelling of Massive-Star UV Wind Line Variability
Proceedings of the 38th Liège International Astrophysical Colloquium, Comm. in Asteroseismology, submitted

[34] **Lobel A.**
Radiative Transfer Modeling the Winds and Circumstellar Environments of Hot and Cool Massive Stars

Proceedings of "Hot and Cool: Bridging Gaps in Massive Star Evolution", Eds. C. Leitherer, Ph.D. Bennett, P.W. Morris and Th. van Loon, ASP Conf. Ser., submitted

[35] Ferland G.J., Fabian A.C., Hatch N.A., Johnstone R.M., Porter R.L., **van Hoof P.A.M.,** Williams R.J.R.
Collisional heating as the origin of filament emission in galaxy clusters
MNRAS, in press

[36] Abel N.P., Dudley C., Fischer J., Satyapal S., **van Hoof P.A.M.**
Dust-bounded ULIRGs? Model predictions for infrared spectroscopic surveys
ApJ, submitted

[37] Shaw G., Ferland G.J., Henney W.J., Stancil P.C., Abel N.P., Pellegrini E.W., Baldwin J.A., **van Hoof P.A.M.**, Heathcote S.
Rotationally warm molecular hydrogen in the Orion bar
ApJ, submitted

[38] Kimeswenger S., Zijlstra A.A., **van Hoof P.A.M.,** Hajduk M., Lechner M.F.M., **Van de Steene G.C.,** Gesicki K.
Symmetry and asymmetry in "born again" planetary nebulae
Proceedings of the Asymmetric Planetary Nebulae IV conference, eds. Corradi R.L.M., Manchado A., Soker N., in press

[39] **van Hoof P.A.M.,** Hajduk M., Zijlstra A.A., Herwig F., Evans A., **Van de Steene G.C.,** Kimeswenger S., Kerber F., Eyres S.P.S.
Recent observations of Sakurai's object
Proceedings of the Asymmetric Planetary Nebulae IV conference, eds. Corradi R.L.M., Manchado A., Soker N., in press

[40] **Van de Steene G.C.,** Ueta T., **van Hoof P.A.M.,** Reyniers M., Ginsburg A.G.
Morphology and kinematics of the bipolar post-AGB star IRAS 16594-4656
Proceedings of the Asymmetric Planetary Nebulae IV conference, eds. Corradi R.L.M., Manchado A., Soker N., in press

[41] **van Hoof P.A.M., Van de Steene G.C.**
IRAS12316-6401: A New Symbiotic Mira
Proceedings of the Asymmetric Planetary Nebulae IV conference, eds. Corradi R.L.M., Manchado A., Soker N., in press

[42] Degroote, P., Bodewits, D., **Cuypers, J**., Waelkens, C.
The rotation and coma profiles of comet C/2004 Q2 (Machholz)
Astron. Astrophys., in press

[43] Degroote P., Miglio A., Debosscher J., Montalbán J., **Cuypers J.**, Briquet M., **De Cat P.**, Thoul A., Morel T., Niemczura E., Balaguer-Núñez L., Maceroni C., Ribas I., Noels A., Aerts C.
Space observations of B stars with CoRoT
Communications in Asteroseismology, in press

[44] Debosscher, J., Sarro, L.M., ..., **Cuypers, J.,** et al.,
Automated Supervised Classification of Variable stars in the CoRoT Exoplanet programme: method and application to the first four fields
Astron. Astrophys., submitted

[45] J.-E. Arlot, et al. (119 authors including **Cuypers, J., Lampens, P., Pauwels, T.**, Vingerhoets, P.)
The PHEMU03 catalogue of observations of the mutual phenomena of the Galilean satellites of Jupiter
Astron. Astrophys., submitted

[46] Asplund M., Grevesse N., **Sauval A.J.,** Scott P.
The chemical composition of the Sun
Annual Review Astronomy Astrophysics Vol. 47 (submitted)

T.4. Thesis, Reports, etc

[47] **Cuypers, J.,**
Tijdrekening en Kalenders, Chronologie et Calendriers,
In: Jaarboek 2009, Koninklijke Sterrenwacht van België, 16-41

[48] **Cuypers, J**., **Sauval, J**.
Kometen, Comètes
In: Jaarboek 2009, Koninklijke Sterrenwacht van België, 152-185

[49] **Sauval, J., Cuypers, J.,**
Essaims de météores/ Meteoorzwermen
In: Jaarboek 2009, Koninklijke Sterrenwacht van België, 186-189

DEPARTMENT 4: Solar Physics (SIDC)

SECTION 8 & 9: Structure and Dynamics of the Solar Atmosphere

U. Solar atmosphere, heliosphere and space weather research

U.1. Physical processes and modeling

U.1.1. Objectives

The activities in this section concern the investigation of physical processes occurring in different environments, from the Sun surface all the way up to the Heliosphere, both in the active and quiet Sun.

They can be roughly divided in the following subtopics (in square parenthesis the persons involved):

1) Coronal Modeling: global models of the solar corona, a turbulent solar corona

In order to characterize the corona two lines of investigation have been pursued. The first one, led by C. Marqué, exploits PFSS extrapolations to obtain the coronal magnetic field configurations. After loading the corona with plasma, synthetic images of the quiescent corona can be produced, which, through the comparison with observations provide a semi-empirical electron density and (proton) temperature model. The second one, led by E. Podladchikova, aims at characterizing the coronal properties as if they were completely determined by the turbulent dynamics, specifically by the kinematic dynamo that may shape the large scale magnetic field.

2) The Coronal Heating problem in magnetically closed regions (loop structure and dynamics)

Two main objectives can be identified in this second subtopic. First, the determination of the temperature structure of Active Regions. This is achieved through the combination of data analysis (Hinode/EIS and SOHO/EIT) and of forward modeling of coronal loops. In particular the signature of turbulence in the Li-like emission line and EUV radiation is sought. The second objective concerns the study of the dynamics of a single loop, taking into account the stratification of the solar atmosphere and the influence of the photospheric boundary conditions, in order to derive the amount of accumulatd energy in the corona (and the corresponding timescale), i.e. the energy reservoir eventually released in explosive events. Also in this case, we focus on the turbulence, which is the only process included in the mode that is responsible for the energy release in the corona.

3) Reconnection processes and dynamics in current sheets

The main objective here is to determine the dynamics and the properties of a reconnecting (or not) current sheet, in order to identify observables that, from the one hand, can constraint the theoretical model and, from the other hand, can define specific targets for observations at small scales.

4) The solar wind, from coronal holes to the Heliosphere

We are interested in understanding the physics that drives the acceleration of the fast solar wind and the heating of the corona (in coronal holes) and in the subsequent evolution of the solar wind in the heliosphere. Concerning the latter we aim at estimating the plasma properties of the interplanetary environment.

U.1.2. Progress and results

1) An important progress was made on this project. It was possible so far to find solutions that might fit the morphology or the EUV flux, but usually not both, and in particular not at different wavelengths. The previous model had up to 8 free parameters to adjust, which now have been reduced to 6 parameters (two, related to coronal hole values, are now imposed). Also, a different strategy has been used to find optimal solutions: to explore the whole parameter space in a systematic way, with a coarse step, and once all solutions are calculated, to try different fitting functions or approaches to select the “best” solution. The results are very encouraging since the EUV irradiance in the 195 Å and 284 Å bands are well matched.

Concerning the other topic, we studied the influence of α-effect on the coronal heating experimental signature properties, in particular on the energy dissipation and on the observational characteristics of the magnetic field. Using developed previously coronal heating code we created the artificial solar corona as if it is formed by α-effect.

2) Parenti & Young 2008 investigated the condition under which turbulence signatures can be identified in the radiative emissions of a Li isoelectronic sequence and in the measure of EUV radiation from narrow (Hinode/EIS) and wide band instruments (SOHO/EIT). The main results is that Li-like lines are not suitable to diagnose small-scale coronal heating, while, when comparing intensity distribution from narrow and wide band instruments, particular caution must be taken, since the intensity distribution of the main line in the wide band instrument is contaminated by the secondary spectral lines. A new collaboration with the University of Cambridge is devoted to build SOHO/CDS spectral line intensity distributions in AR over different temperatures. The aim is to compare the results with the numerical simulation findings of Parenti et al. 2006 and Parenti & Young 2008. The work is in progress. The study on a single loop dynamics has shown that the boundary conditions at the photospheric level enormously influence the level and time scale for the energy accumulation in the coronal magnetic field. As a consequence, both the occurrence and intensity of energy release events changes dramatically depending if the loop is line tied (footpoint fixed in the photosphere) or not (footpoint moves subject to coronal dynamics). This is found to be the case also in presence of a (weak) turbulent dissipation, acting mainly in the corona.

3) We have developed a one-dimensional analytical model of a reconnecting current sheet based on work by B. Somov & V. Titov. This model extends the Somov & Titov framework to include the effects of thermal conduction and realistic CME/Flare magnetic field configurations on the reconnecting current sheet. This model makes several specific predictions about the properties of current sheets that agree with numerical simulations by several authors. It also allows us to study how reconnection affects the larger dynamics of solar eruptions and make several specific improvements to the analytic CME model of Reeves & Forbes and Lin & Forbes

4) Concerning the acceleration of the fast solar wind two main achievements have been reached. First it has been demonstrated that reflection of low-frequency Alfvén waves launched from Sun is able to trigger a turbulent cascade. Second, using a simplified version of this reflection driven turbulence and exploiting a 1-D solar wind model, a detailed study of the parameter space that influence the solar wind properties has been carried out. The plasma properties in the interplanetary environment are sought through a detailed study of the shock interaction with planets. The STEREO-twin spacecraft launched by the end of 2006 by NASA has the sequence of 6 (per satellite) imagers that were able to follow visually a shock wave propagating from the solar disk up to the interaction stage with the solar system planets. At this stage the image calibration is good enough to start the scientific analysis of the different stages of shock wave propagation throughout the solar system. This preliminary study is the first attempt to make the interpretation of observed phenomena and to identify the types of the observed waves.

U.1.3. Perspective for next years

1) C. Marqué will submit these results to a refereed journal in 2009, in a paper focused on irradiance and comparison with imaging instruments. The resulting density and temperature distributions will be used for assessing the magnetosonic speed distribution in the corona for a set of selected eruptive events involving CMEs and type II radio bursts (Action 1 project with J. Magdalenic).

2) The work in progress just described will be concluded. An ISSI working group dedicated to AR structure and properties will end its activity with the last meeting in January 2009. A new submission of proposal is under discussion. We expect to publish it in a short letter, in the early months of 2009, the work on the loop dynamics and boundary conditions. On the other hand, the numerical work will be extended to study the parameter space dependence. In addition, some particular simulation setups will be selected to study the turbulent spectra and dissipation.

3) This model makes several predictions about the properties of the current sheet where reconnection happens during eruptive flares that could potentially be observed by SWAP, thanks to its extensive capac-

ity to observe off-limb. One possible line of future research is to use SWAP as a platform for observations in support of our model. We plan also to improve the current model accounting for a quadrupolar configuration of the magnetic field, which may prove to more realistically model flares.

4) We plan to extend the numerical simulations on turbulence and the solar wind model down to the chromosphere, in order to account for the formation of a transition region and for its effect on the development of turbulence. We also expect to derive a better analytical approximation for the reflection driven turbulent heating with the aim of including it in more complex solar wind models.

U.1.4. Personnel involved

Scientific staff: Christophe Marqué
J. Magdalenic
Elena Podladchikova
Andrea Verdini
Dan Seaton
Susanna Parenti
Ronald Van der Linden

U.1.5. Partnerships

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

- M. Kretzschmar, LPCE, University of Orléans, France
- P. Young, Naval Research Laboratory, USA
- H. Mason, Department of Applied Mathematics and Theoretical Physics, UK
- Velli M., Dipartimento di Astronomia e Scienza dello Spazio, Univ. Di Firenze, Italia
- Roland Grappin, LUTH, Observatoire du Meudon, France.
- Terry Forbes, University of New Hampshire
- Kathy Reeves, Harvard-Smithsonian Center for Astrophysics
- Serge Koutchmy, IAP, France
- Velli M., Dipartimento di Astronomia e Scienza dello Spazio, Univ. Di Firenze, Italia
- Buchlin E., IAS, Orasy, 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

Grants/Projects used for this research/service

- Subcontract SVT-7702 from SAO in support of NASA Grant NNM07AA02C
- ROB/PRODEX
- STCE

Visitors:

- B. Vrsnak, Nov. 24th 2008

U.1.6. Scientific outreach

Meeting presentations

[1] **J. Magdalenic, C. Marqué, A. N. Zhukov, B**. Vrsnak
A multiwavelength study of the origin of coronal shock waves: flares or CMEs?
IXth Hvar Astrophysical Colloquium, Sept. 22 - 26 2008, Hvar, Croatia

[2] **J. Magdalenic, C. Marqué, A. N. Zhukov,** B. Vrsnak
On the origin of coronal shock waves associated with limb events (Poster)

12th European Solar Physics Meeting, Sept. 08-12 2008, Freiburg, Germany

[3] **J. Magdalenic, C. Marqué, A. N. Zhukov**, B. Vrsnak
On the origin of coronal shock waves associated with limb events (Poster)
5th European Space Weather Week, Nov. 17-21, Brussels, Belgium

[4] **Susanna Parenti**
Heating and dynamics of coronal loops
ESPM-12, Freiburg 8-12 September 2008

[5] **Susanna Parenti,** Peter Young
EUV signatures of small scale heating in loops
Solar Activity during the Onset of Cycle 24, Napa 8-12 December 2008

[6] **D. Seaton** & T. Forbes
An Analytic Model for Reconnection Dynamics in an Eruptive Flare Model Poster
Fifth European Space Weather Week, Brussels, Belgium

[7] **Verdini A**., Velli M., Buchlin E.
Alfvénic turbulence and the acceleration of the fast solar wind
12th European Solar Physics Meeting, Freiburg, Germany, 8-12 Sept 2008

[8] **Podladchikova O**., Koutchmy, S.
First Optical Observations Of Shock Waves Interaction With The Solar System Planets. The Preliminary Analysis (Solicited speaker)
Isradynamics - Dynamical Processes in Space Plasmas. 11-19 May, 2008, Dead Sea, Israel

[9] **Podladchikova O**.
New Diagnostics Techniques of Space(Invited Lecturer)
3rd Open Summer School-Seminar"Achievements and Applications of Contemporary Informatics, Mathematics and Physics - **Neuromodelling**" (AACIMP-2008), 11-21 August 2008, Kiev, Ukraine

[10] **Podladchikova O**.
Cellular Automata to describe turbulent plasma processes (Invited Lecturer)
3rd Open Summer School-Seminar"Achievements and Applications of Contemporary Informatics, Mathematics and Physics - **Space Research**" (AACIMP-2008), 11-21 August 2008, Kiev, Ukraine

[11] **Podladchikova O.**
EUV Micro-Eruptions by SECCH -.Discovery and Diganostic.
7th SECCHI Consortium Meeting, 13-19, March, Meudon, Paris,

[12] **Podladchikova O.,** Krasnoselskikh, V.
Turbulent Kinematic Dynamo Driver of Coronal Hetaing
37 COSPAR Scientific Assemby, 13-12, July, Monréal, Canada,

[13] **Podladchikova O**.,
EUV coronal wave recognition for SECCHI/STEREO:Problems and Achievments.
37 COSPAR Scientific Assemby, 13-12, July, Monréal, Canada,

[14] **Podladchikova O.**
EUV Micro-Waves in the Solar Corona,
AGU, American Geophysical Union, Fall Meeting 2008, 15- 19 December, 2008, San-Francisco, USA

[15] **Podladchikova O., Nicula, B., Willems, S., Berghmans, D**
NEMO: Detection of CMEs without Coronographs in Real Time at SIDC.
Fifth European Space Weather Week, 17-21 November, 2008, Brussels, Belgium

Websites

- *The role of spectroscopy and imaging data in understanding coronal heating*. ISSI web page://www.issibern.ch/teams/Spectdata/ [SPA]

U.1.7. Missions

Assemblies, symposia:

- Parenti (COSPAR, Montreal 13-20 Juliet 2008)
- Parenti (ESPM-12, Freiburg 8-12 September 2008)
- Parenti (Solar Activity during the Onset of Cycle 24, Napa 8-12 December 2008)
- Seaton (November 17-21, Brussels, Belgium; Fifth European Space Weather Week)
- Verdini (Division of Plasma Physiscs Meeting, Dallas, Texas, USA, 19-21/11/08)
- Verdini (12th European Solar Physics Meeting, Freiburg, Germany, 8-12 Sept 2008)
- Podladchikova (Isradynamics - Dynamical Processes in Space Plasmas. 11-19 May 2008 Israel)
- Podladchikova (3rd Open Summer School-Seminar "Achievements and Applications of Contemporary Informatics, Mathematics and Physics - Space Research" (AACIMP-2008), 11-21/08/08, Kiev, Ukraine)
- Podladchikova (7th SECCHI Consortium Meeting, 13-19, March, Meudon, Paris)
- Podladchikova (37 COSPAR Scientific Assemby, 13-12, July, Monréal, Canada)
- Podladchikova (AGU Fall Meeting 2008, 15- 19 December, 2008, San-Francisco, USA)

Commissions, working groups (days): Verdini (6 days)

Research visits (days): Verdini (20 days)

U.2. Investigations of the solar atmosphere from spectroscopic diagnostics

U.2.1. Objectives

Spectroscopic observations are highly suited to lead to further insight in the solar atmosphere. They provide diagnostics on plasma velocities and are important for studies of various solar phenomena, like coronal heating, solar wind acceleration, and eruptions. Data from the SOHO-SUMER and HINODE-EIS VUV spectrometers build the foundation of international co-operations involving scientists from ROB.

U.2.2. Progress and results

I. E. Dammasch continued the collaboration with several groups (MPS, Williams, NRL), which led to publications on Doppler shifts in active region loops **[7]** and the properties of the coronal line Ne VIII **[25]** as observed with SUMER. Investigations of chromospheric dynamics (spicules) and emission measure vs. temperature slope were presented at conferences, and publications were prepared. L. Dolla started working on Hinode-EIS data to investigate transient coronal dimmings which appear after coronal mass ejections. S. Parenti and J.-F. Hochedez submitted a successful proposal to BELSPO on DEM inversion methods **[91]** in collaboration with A. Urnov of the solar physics group at LPI, Moscow. S. Parenti extended the investigations on physical parameters of prominences with a group at IAS, leading to the publication of a spectral atlas based on SUMER data **[19]**. Instabilities of prominences can cause CMEs, thus being relevant for space weather.

U.2.3. Perspective for next years

I. E. Dammasch plans further collaboration concerning the exploitation of SUMER data, e.g. on the subject of redshifts in transition-region lines. L. Dolla will study literature as well as the characteristics and existing datasets of the EIS instrument. First results are expected in 2009. J.-F. Hochedez expects an effective collaboration beginning with the visit of F. Goryaev at ROB in 2009. S. Parenti will lead observa-

tion programs for SOHO and Hinode in order to study prominences. She and D. Seaton will also contribute to an ISSI working group on the same subject. The goals are to complete a comprehensive study of the properties of coronal prominence cavities using existing observations, new ones, and modeling. The reasons that these cavities form and the physical parameters that govern their behavior remains an unsolved problem in astrophysics. Because many cavities erupt, an understanding of cavity dynamics may provide a window into the genesis of coronal mass ejections as well.

U.2.4. Personnel involved

Scientific staff: I. E. Dammasch (scientist, SIDC Exploitation PEA)
L. Dolla (scientist, STCE)
J.-F. Hochedez (scientist, ROB permanent)
S. Parenti (scientist, SIDC Exploitation PEA)

U.2.5. Partnerships

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

- T. Berger, Lockheed Martin Solar and Astrophysics Laboratory, USA
- Werner Curdt, Max-Planck Institute for Solar System Research, Germany
- Bhola N. Dwivedi, Banaras Hindu University, India
- Uri Feldman, Naval Research Laboratory, USA
- Alexander Urnov and Farid Goryaev, Lebedev Physical Institute/FIAN, Russia
- Donald M. Hassler, Southwest Reseach Institute, USA
- N. Labrosse, University of Glasgow, UK
- Enrico Landi, Naval Research Laboratory, USA
- Jay M. Pasachoff, Williams College, USA
- Alphonse C. Sterling, NASA, USA, and JAXA, Japan
- Evan D. Tingle, Wesleyan University, USA
- Klaus Wilhelm, Max-Planck Institute for Solar System Research, Germany
- ISSI Working Group on Coronal Prominence Cavities
- J.-C. Vial, Institut d'Astrophysique Spatiale, France

Grants/Projects used for this research/service

- PRODEX (SIDC Data Exploitation PEA)
- STCE
- BELSPO non-EU post doctoral fellowship

U.2.6. Scientific outreach

Meeting presentations

[1] U. Feldman, G. A. Doschek, J. F. Seely, E. Landi, **I. E. Dammasch**
A proposed new method for the determination of the solar irradiance at EUV wavelength range (Poster)
37th COSPAR Scientific Assembly

[2] **S. Parenti**
Quiescent prominence investigation in the EUV-UV range
Solar Activity during the Onset of Cycle 24, Napa 8-12 December 2008

Wikis and Websites

- http://www.issibern.ch/teams/coronalprom/index.html

U.2.7. Missions

Assemblies, symposia:	L. Dolla (Fifth European Space Weather Week) S. Parenti (First SMESE Workshop) S. Parenti (Solar Activity during the Onset of Cycle 24)
Commissions, working groups (days):	S. Parenti (3 days)

U.3. Investigations of the solar atmosphere from disc images or time series

U.3.1. Objectives

With SOHO-EIT, TRACE, STEREO-EUVI, Hinode-XRT, and soon SDO-AIA and PROBA2-SWAP, XUV-EUV images are quenching solar physicists, but they still present challenges. How to handle their inherent limitations in e.g. spatial or spectral resolution? How to reconstruct the third spatial dimension? How to carry quantitative studies and interface them with models? The preferred approach at SIDC is to combine instrumental knowledge and signal theory in order to estimate physical quantities, such as height, temperature or speed. Those can then be investigated, in combination or not with models, in order to understand solar phenomena: coronal heating, differential rotation, eruption initiation, EIT waves, etc.

U.3.2. Progress and results

U.3.2.1.Sub-pixel analysis

Telescopes will never resolve the solar scenes at their physical scales, and imaging data are interdependently limited by their spatial resolution, cadence, and signal-to-noise ratio (SNR). In **[9]**, solar rotation induces a displacement of less than 1 pixel between consecutive EUV images. Statistical moments over short enough time windows disclose sub-pixel solar structures and provide insights about their temporal variability.

It is important to assess whether solar radiance and telescope parameters (cadence, effective area) offer sufficient SNR. In **[10]**, P. Chainais, V. Delouille, and J-F Hochedez evidence scale-invariance in Quiet Sun (QS) images observed by SOHO-EIT, and emulate, via stochastic processes, increased angular resolution and closer observing distance to the Sun. The QS, being irregular, exhibits a better SNR than a uniform source would. The multifractal spectrum permits to quantitavely estimate this gain. The algorithm also extrapolates *real* QS images up to any better resolution, maintaining their multifractal spectrum and their histogram. This enables indefinite (virtual) zooming into a given QS image.

U.3.2.2.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), filament channels, flares, etc. This firstly allows determining automatically the location of the source of the fast solar wind (CH). Secondly, it enables solar cycle studies about AR, QS, and CH properties. Thirdly, it permits to focus heavy post-processing on e.g. AR only. Fourthly, it helps reconstructing the solar UV spectrum. This approach paves the way to bridging observations between image data and scalar time series from photometers. V. Barra, V. Delouille and J.-F. Hochedez have developed the Spatial Possibilistic Clustering Algorithm (SPOCA), which is multi-channel, unsupervised, and spatially-constrained (**[1] [2] [2] [46] [47]**). It manages the arbitrariness stemming from the various noises and from the imprecision in the definition and borders of the above regions. In [1] and **[46]**, the latest version of SPoCA is applied to the SoHO-EIT archive (January 1997 till May 2005, viz. almost a 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*.

U.3.2.3. Velociraptor: motion and brightness variation, 3D reconstruction from STEREO images

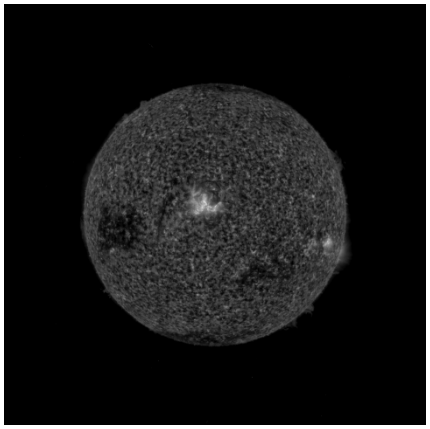


Figure 40: Original solar image as observed by STEREO-SECCHI-EUVI

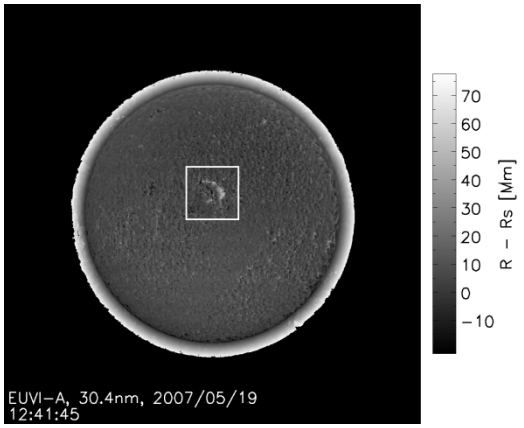


Figure 41: The associated stereoscopic reconstruction. The grey value represents the height above solar surface.

Movies of the solar corona in EUV passbands exhibit dynamical patterns of magnetically structured plasma. In previous years, S. Gissot and J-F Hochedez have developed a multiscale optical-flow algorithm (VELOCIRAPTOR). In **[12]**, they explore and analyze with it the oscillation of coronal loops. The motion field of each image pair is estimated, features are tracked to form trajectories, which are then analyzed by a Morlet wavelet to provide e.g. the local oscillation period.

STEREO-SECCHI-EUVI provides the first EUV images enabling 3D reconstruction of solar coronal structures. **[13]** presents a stereoscopic reconstruction method based on Velociraptor. We select pairs of images taken in the 30.4 nm passband of both EUVI, and apply a rigid transform to the EUVI-B image to set it in the frame of reference of EUVI-A. The optical flow provides a dense map of displacements from which we reconstruct height using our stereoscopy reconstruction formula.

The above figures are from **[13]**, where we demonstrate the possibility of estimating the altitude of coronal objects in NASA STEREO data by way of our VELOCIRAPTOR optical flow algorithm. The detected feature is a filament that is moreover proven to rise. Although such events can be very geo-effective, they remain essentially invisible without our processing.

In 2008, it was established that the Velociraptor algorithm could be sped up significantly if it was rewritten in a more performance-friendly language such as C. This study motivated the effort towards a re-implementation in C on graphics processing unit (GPU).

U.3.2.4. Exploitation of STEREO – SECCHI data to study the origin of CMEs

In order to obtain the 3D structure of active regions (ARs), a technique that allows an automatic matching of pixels in both images was developed **[65]**. The method is known as local correlation tracking (LCT). It matches the points in the first image with the corresponding ones in the second image by means of correlation analysis. This information is then used to triangulate the 3D coordinates of each pixel. By applying this method, the 3D structure of active regions could be retrieved. In particular, the extraction of coronal loop heights, observed nearly simultaneously in the 171, 195 and 284 Å passbands can be carried out. It was found, and demonstrated, that some loops that look co-spatial in the 171 Å and 195 Å images have in fact different heights and thus occupy different volumes. This result has important implications for multi-wavelength studies of coronal loops, especially for calculations using the filter-ratio techniques.

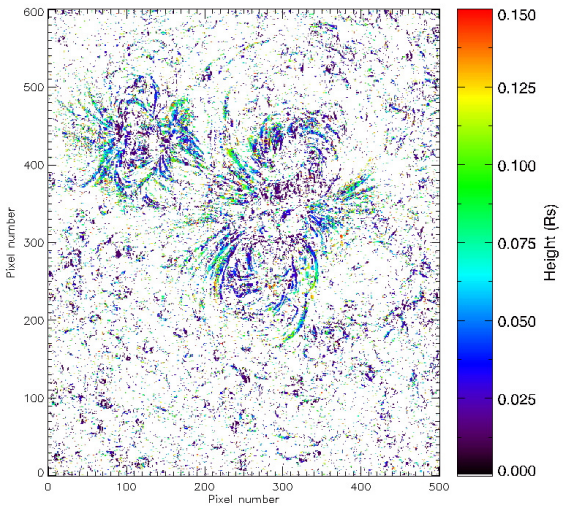


Figure 42: 3D configuration of the NOAA active regions 0953 (close to the centre of the image) and 0954 (in the top left corner of the image) as observed in the 171 Å pass band of SECCHI-EUVI, on 2 May 2007 at 01:01:30 UT. The colour shows the height above the so solar surface in solar radii.

U.3.2.5. EIT waves

EIT waves are known to be linked to the origin of CMEs. There are currently two main interpretations. The first one describes them as a fast mode magnetosonic waves propagating freely in the corona. The second does not consider them as a true MHD waves but instead, it invokes several possibilities linked to the magnetic field opening/restructuring during coronal mass ejection (CME) evolution in the low corona. In **[7]**, important observational evidence is given in supports of the latter explanation. **[8]** compares quantitatively the above alternative interpretations of EIT waves. Independent 3D MHD codes perform dimensionless numerical simulations of a slowly rotating magnetic bipole. They generate a twisted magnetic flux tube that expands quickly. We analyse the origin, the development, and the EUV observability of the narrow electric current sheets that appear in the simulations, and confront them with SOHO-EIT observations (EIT waves of 7 April and 12 May 1997). The timing, orientation, and location of the observed patches are remarkably well reproduced, and we conjecture that propagating EIT waves can be the observational signature of Joule heating in electric current shells that separate expanding flux tubes from their surrounding fields. We also propose that the bright edges of halo CMEs correspond to plasma compression in current shells.

U.3.2.6. Thermal structure of active regions: signature of nanoflares and temperature diagnostics

Reale, Parenti et al. 2007 showed the AR diagnostic possibilities of the HINODE-XRT multi-band instrument. During 2008, S. Parenti has further worked, in collaboration with the University of Palermo, on a non-flaring AR in order to better establish its thermal components. The nanoflares picture for AR coronal heating requires the presence of small part of the plasma at very high temperature (>5 MK). The work in progress on XRT data seems to show such a component. The analysis of the thermal evolution of a post-flare AR is also in progress. The aim is to decide upon the maximum detectable temperature, and how a flare can affect the whole AR temperature.

U.3.2.7. Study of solar rotation

In **[31]**, SOHO-EIT solar images at 28.4 nm are used to visually identify coronal bright points (CBPs) as tracers of the solar rotation. Their velocity is determined for October and November 1999 and the resulting parameters are discussed. In **[32]**, EIT images are used to analyze the proper motion, velocity distributions, lifetimes, and diffusion coefficient of CBPs. The results obtained by our interactive method for three tracer subtypes (point-like structures, small loops, and small active regions) of coronal bright points for the period 4 June 1998 to 22 May 1999 are presented and compared. Distributions of lifetime, meridional velocities, residual azimuthal velocities and velocities of proper motions are presented for the three tracer subtypes. The correlation between the absolute velocity of proper motion and lifetime is investigated.

U.3.2.8.Shutterless program

In the context of monitoring the solar activity ROB is leading a high cadence EIT/SOHO observational program which runs every three months. This program generally runs in coordination with other instruments on board SOHO and TRACE. New missions STEREO and Hinode often participate too.

U.3.3. Perspective for next years

Both Spoca and Velociraptor will be applied to SDO-AIA data. However, Spoca pertains to our collaboration with the SDO science center at SAO, Harvard, while Velociraptor needs to be further specified and significantly accelerated by way of graphics card programming and will run at ROB in the WisSDOm center. In parallel, the EIT and STEREO exploitation of Velociraptor will address long term behavior of the solar differential rotation and 3D reconstructions. In 2008, the research agreement between Cécile Delannée and SIDC was renewed and will contribute to the study of EIT waves. Concerning the observation of AR, there is the plan for extending the analysis to spectrometer data to validate the results found. The Hvar collaboration on solar rotation will be continued. Concerning the filament cavities, the project collaborators are currently designing an observation program using existing spacecraft and ground-based observatories. However, there is currently no instrument that can provide observations of cavities in the EUV that overlaps with what is visible in coronagraphs in white light because of the size of the occulting disk required to produce good coronagraphic images. Because of its field-of-view, SWAP is the first instrument that may provide coverage of these extended features in the EUV. Thus observations with SWAP, once launched, may provide the first opportunity for simultaneous observations of prominence cavities in both EUV and white light. Thus it is likely that we will want to design a SWAP observational program to coincide with observations with other instruments.

An article on the 3D reconstruction of loops and active regions was submitted **[65]**, with examples of reconstruction presented for several active regions. It is planned to analyze more active regions and use the derived geometry for investigations of physical processes in active region loops. The STEREO mission has entered its extended phase, with the separation angle between the spacecraft now exceeding 90°. While this angle is well beyond the limit for doing successful on disc stereoscopic studies, other kind of interesting research topics can be foreseen.

The Shutterless program will be carried out throughout 2009.

U.3.4. Personnel involved

Scientific staff:
J.-F. Hochedez (Lead, scientist, ROB permanent)
S. Gissot (Co-lead, scientist, SIDC data exploitation PEA)
V. Delouille (Co-lead, scientist, SIDC data exploitation PEA)
D. Seaton (scientist, SIDC data exploitation PEA)
L. Rodriguez (scientist, SIDC data exploitation PEA)
M. West (scientist, SIDC data exploitation PEA)
A. Zhukov (scientist, STCE)
M. Mierla (scientist, grant)
F. Clette (scientist, ROB permanent)

U.3.5. Partnerships

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

- Vincent Barra, Pierre Chainais, Emilie Koenig, Clément Rey, Université B. Pascal Clermont II, F
- Roman Brajsa, Hvar Observatory, University of Zagreb, Zagreb, Croatia
- Hubertus Wöhl, Kiepenheuer-Institut für Sonnenphysik, Freiburg, Germany
- Fabio Reale, University of Palermo-INAF, IT
- Jim A. Klimchuk, NASA Goddard Space Flight Center, USA
- Sarah Gibson, High Altitude Observatory, Working Group Leader
- Bernd Inhester, Max-Planck-Institute for Solar System Research

- STEREO – SECCHI consortium

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

- Jean-Pierre Antoine, UCL, Louvain-La-Neuve.

Grants/Projects used for this research/service

- ROB
- PRODEX (SIDC Data Exploitation PEA)
- CoSSMIC Tournesol project
- ROB/STCE

Visitors:

- Boris Filippov, Izmiran, 20 March 2008, altitude of erupting filements/prominences
- Emilie Koenig, Université Clermont II, 29 May-25 June 2008, synthèse de texture sur la sphère
- Bernd Inhester, Max-Planck Institute für Sonnensystemforschung, 7-10 July and 11-12 Dec. 2008
- Jack Ireland, GSFC NASA, 19 Sep. 2008, solar image processing
- Cécile Delannée, 3 Dec 2008, EIT waves

U.3.6. Scientific outreach

Meeting presentations

[1] Barra, V.; Delouille, V.; Kretzschmar, M.; Hochedez, J.-F.; Gissot S.
Fast and robust segmentation of solar EUV images: algorithm and results for solar cycle 23 (poster)
Image Processing Workshop IV - Algorithm comparison and effective implementation. October 26 - 30, 2008, Baltimore Inner Harbor, Baltimore, MD, USA

[2] Barra, V.; **Delouille, V.; Hochedez, J.-F. ; Krijger, J. M.**
'SPoCA', a Spatial Possibilistic Clustering algorithm for EUV images (poster)
SDO HMI / EVE / AIA Science Teams Meeting, Nappa Valley, CA, 25-28 March 2008,

[3] **Gissot, J.-F. Hochedez, J.M. Krijger**
Velociraptor, a motion estimation algorithm analyzing the dynamics in EUV movies of the solar atmosphere (poster)
SDO science mtg, 25-28 March 2008, Napa Valley, Ca, USA

[4] **Gissot S.**
Tracking of EUV Solar Features (Invited speaker)
Solar Image Processing Workshop IV - Algorithm comparison and effective implementation. October 26 - 30, 2008, Baltimore Inner Harbor, Baltimore, MD, USA

[5] **Rodriguez L., Zhukov A. N., Gissot S.**
Automatic extraction of stereoscopic information from STEREO - EUVI images
37th COSPAR Scientific Assembly, Montreal, Canada, July 2008

[6] **Rodriguez L., Zhukov A. N., Gissot S., Mierla M., Marqué C.**
Stereoscopy with EUVI data
STEREO/SECCHI Consortium Meeting, Paris, April 2008

[7] **Mierla M.**, Inhester B., **Marqué C., Rodriguez L., Gissot S., Zhukov A.N, Berghmans D**, Davila J
3D reconstruction of Coronal Mass Ejections using SECCHI-COR Data
5th European Space Weather Week, Brussels, Belgium, November 2008

[8] **Zhukov A. N., Rodriguez L.**, de Patoul J.
STEREO/SECCHI Observations of the EIT Wave on December 8, 2007: Evidence against the Freely Propagating Wave Hypothesisof the EIT Wave Origin
STEREO/SECCHI Consortium Meeting, Paris, April 2008

[9] **Rodriguez L., Zhukov A., Gissot S., Mierla M., Marqué C.**
Stereoscopy with EUVI Data
STEREO/SECCHI Consortium Meeting, April 23, 2008, Meudon, France

[10] **Rodriguez L., Zhukov A., Gissot S.**
Automatic extraction of stereoscopic information from STEREO – EUVI images
COSPAR General Assembly, July 14–19, Montreal, Canada (poster presentation)

Wikis and Websites

- http://sidc.be/velociraptor/
- http://www.sidc.be/EIT/High-cadence : Official web site of the "EIT Shutterless" program

U.3.7. Missions

Assemblies, symposia:
- COSPAR, Montreal 13-20 Jul. 2008

U.4. Coronagraphic, radio and in-situ investigations in the heliosphere

U.4.1. Objectives

The intrinsic dynamic nature of the Sun has its most visible expression in the form of eruptive events. Their study is of high relevance for the SIDC, and has a two-fold interest. The first interest is related to space weather in the near-Earth environment, which is driven by the Sun and most directly by the solar wind and the transient solar events carried along with it. The second interest, related to the first, relies on the importance of understanding the fundamental science leading to the origin and development of solar transients. Among them, one can mention coronal mass ejections (CMEs), flares, coronal shock waves, coronal dimmings and EIT waves as 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 phenomena closely linked with CMEs. It is observed as a sudden localized decrease of EUV intensity and is interpreted as a loss of mass in the low solar corona during 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) offered 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.

U.4.2. Progress and results

U.4.2.1.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. 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 coronal mass ejection (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 by A. Zhukov and L. Rodriguez. 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 con-

trary, such a behavior is possible e.g. for erupting prominences. It is concluded that this event provides observational evidence that even EIT waves with a symmetric front can be produced by a magnetic field restructuring during the CME eruption.

Another case study, an EIT wave on November 6, 2006, was investigated by C. Delannée, C. Marqué and A. Zhukov. The wave was observed in EUV, soft X-rays, and Hα, conjointly with a CME and a flare. The wave front propagated on the disc and above the limb. The observations in the three bandpasses show bright fronts that are co-spatial when observed at the same time, suggesting that the same wave is observed in different bandpasses. At most locations, the wave front is not observable in Hα, but just in the EUV and in soft X-rays. Several parts of the wave front remain at locations they first appeared for several minutes in soft X-ray to one hour in the EUV. The northern footprint of the CME related to this wave can be followed down to the limb. It corresponds to the last location of the wave on the limb that remains stationary for one hour. The coronal magnetic field extrapolation reveals that the stationary brightenings on the disc are lying at separatrix surfaces (where the magnetic field connectivity changes abruptly) and that the northern footpoint of the CME is at the edge of the northern coronal hole. This event shows that coronal waves are related to CMEs and, in particular, to the magnetic field large-scale topologies [52].

In collaboration with G. Attrill (MSSL, UK), A. Zhukov investigated the problem of the link of coronal dimmings and the magnetic connection of CMEs with the Sun. It is generally accepted that a special type of coronal dimmings (transient coronal holes, TCHs) corresponds to the magnetic footpoints of CMEs that remain rooted in the Sun as the CME expands out into the interplanetary space. However, observations demonstrate that dimmings may disappear whilst the magnetic connectivity is maintained. Three CME-related dimming events were analyzed; the morphology of the dimmings and their recovery was studied. Dimmings observed in SOHO/EIT data have a deep central core (TCHs) and a more shallow extended dimming area. It was found that the dimmings recover not only by shrinking of their outer boundaries but also by internal brightenings. It was demonstrated that the model of interchange reconnections between "open" magnetic field and small coronal loops is a strong candidate for the mechanism facilitating the recovery of the dimmings. This process disperses the concentration of "open" magnetic field (forming the dimming) out into the surrounding quiet Sun, thus recovering the intensity of the dimmings whilst still maintaining the magnetic connectivity to the Sun [1].

The LASCO coronagraphs and the EIT coronal imager onboard SOHO have systematically observed coronal mass ejections throughout solar cycle 23. Many thousands of events have been witnessed in variable coronal configurations from solar minimum to solar maximum and back. For the first time in history, data is now available to statistically study this evolution of CME characteristics along a full solar cycle. However, such long-term studies require extracting CMEs using a fixed definition of the criteria that the candidate event should fulfill in order to be classified as CME. Computer programs like "CACTus" (Computer Aided CME Tracking) and "NEMO" (Novel EIT wave Machine Observing) were developed that scan systematically the many thousands of images and produce consistent event lists.

NEMO is the first software package elaborated by O. Podladchikova at the SIDC for the CME detection without coronagraphs. Solar disk imaging telescopes (like SOHO/EIT and STEREO/SECCHI/EUVI) provide us with a lot of unquantified signatures of CMEs already at the very early stage of their development. NEMO went through extensive tests of application, stabilization and validation. The main result of the NEMO software is the identification and classification of on-disk CME mathematical quantities. In 2008 NEMO on-disk detection of CMEs became fully automatic with the 195 Å EIT data of the solar corona. NEMO runs twice a day and provides both the automatic detection and the extraction of the CME on-disk parameters in real-time. NEMO application to the SECCHI/EUVI data encountered a series of complications, mainly due to the early stage of the mission with unstable flow of uncalibrated data. However, NEMO application on high-resolution SECCHI data nevertheless led to the new results. Namely, small-scale events with a morphology similar to large-scale coronal mass ejections accompanied by coronal waves and dimmings were studied on the base of the SECCHI data. The higher temporal and spatial resolution of EUVI allowed us to detect and analyze micro-events with the technique of dimming and coronal wave extraction, to resolve their fine structure and to prove unambiguously their identity to coronal EUV large-scale waves discovered by the SOHO mission. These micro-events differ from those on a

large scale by having smaller geometrical sizes, a shorter lifetime, and the reduced intensity of coronal waves and dimmings. SECCHI small-scale coronal waves are seen to develop from microflaring sites up to a distance of 40,000 km in a wide angular sector of the quiet Sun during 20 min. The total intensity and area of the small-scale dimmings are two orders of magnitude smaller than for large-scale events. The speed of small-scale coronal waves is around 19 km/s, which is an order of magnitude smaller the than slow magnetosonic wave speed in corresponding layers of the solar corona.

U.4.2.2. Coronal mass ejections (CMEs)

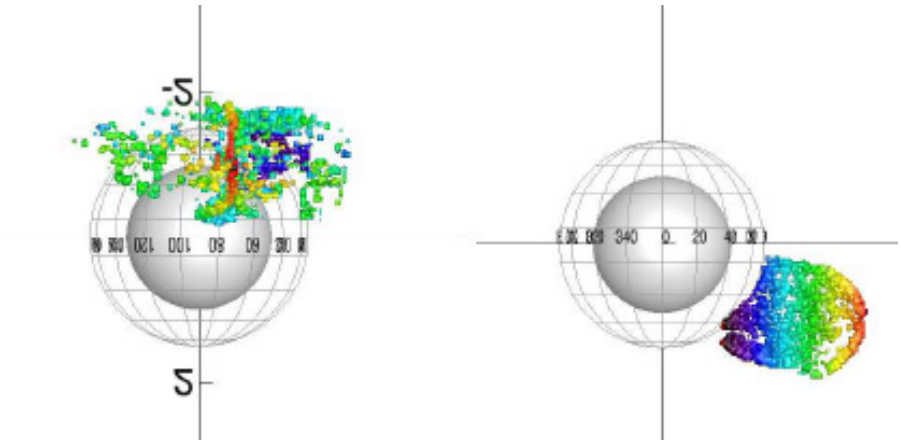


Figure 43: A 3D reconstruction of the CME observed by STEREO/SECCHI COR1 on 31 August 2007. The reconstruction was performed by the local correlation tracking/tie-point method. Colors represent the distance along the Y-axis (blue meaning closer to the Sun center). The left panel shows the CME seen approximately head-on (X and Z axes in the image plane, Z downwards and X towards right), while the right panel displays the CME seen edge-on (Y and Z axes in the image plane, Z upwards and Y towards right).

CACTus runs in an operational way and its realtime output is available at http://sidc.be/cactus. A statistical analysis of a CME list produced by CACTus that covers a full solar cycle was performed. This has allowed pointing out important differences existing between CME statistics produced by human inspection on the one hand and by computer codes such as CACTus and others on the other hand. These differences bring new insights on what CMEs are and on their relevance to the heliospheric climate.

From the LASCO images, it is not possible to infer the true direction of propagation of a CME. The new data from the Solar TErrestrial RElations Observatory (STEREO), which was launched in October 2006, provided us with the first-ever stereoscopic images of the Sun's atmosphere. The stereoscopic images obtained from the Sun Earth Connection Coronal and Heliospheric Investigation (SECCHI) onboard STEREO can help us to determine the location of the CME in 3D space and to derive their true direction of propagation.

M. Mierla applied the stereoscopic triangulation to localize blobs of plasma that can be distinguished in a CME. For three CME events the projected speeds were derived as observed by both STEREO spacecraft, and their true speeds were evaluated. A similar method was applied to the reconstruction of a leading edge of a partial halo CME, thus proving to be a useful tool for space weather forecasting.

M. Mierla led the follow-up study on the 3D structure of CMEs. Four methods were applied for reconstructing the CMEs: forward modeling, local correlation tracking (LCT) with tie-pointing, the apparent center of mass tracking and the polarization ratio technique. These reconstruction methods were applied to the observations of three structured CMEs observed by STEREO (Figure 43). A comparison of the results obtained from the application of the four reconstruction algorithms was presented and discussed. At the same time, the study brought to light some difficulties linked to the stereoscopic reconstruction of optically thin plasma.

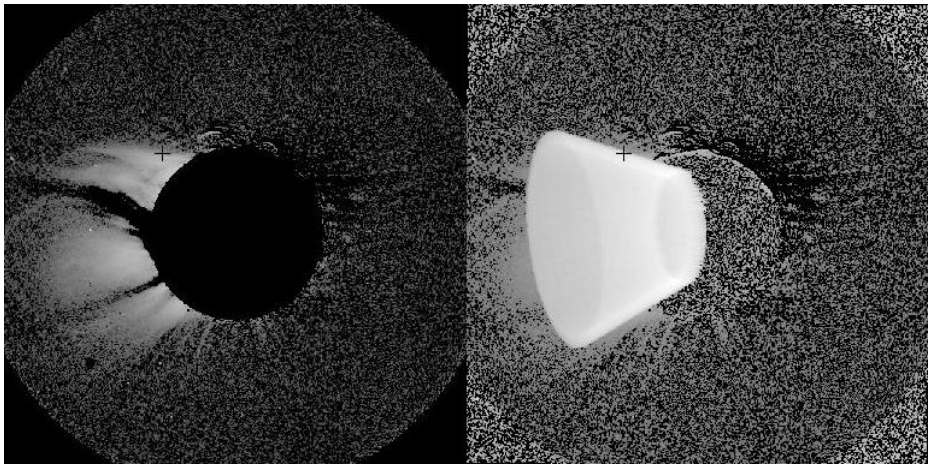


Figure 44: STEREO COR1 coronagraph image of a CME (left), and the same CME with an overlayed model (right).

Another track in the 3D reconstruction of CMEs was pursued by M. West and A. Zhukov. The goal is to derive precise values of electron density in CMEs using forward modeling. A CME event on March 25, 2008 with a classical three-part structure was chosen and the cone model was employed to fit the lateral parts of the CME (Figure 44). Synthetic images as taken by both STEREO spacecraft are generated. The intensities of structures in real and synthetic images are compared. The coronal electron density is calculated through an iterative procedure.

U.4.2.3.Interplanetary disturbances

L. Rodriguez and A. Zhukov participated in the investigation of Sun – Earth connections partially funded by International Space Science Institute (ISSI, Bern, Switzerland) in the framework of the working group "The Stages of Sun – Earth Connection". Several ICMEs observed at different locations of the heliosphere were alanyzed by L. Rodriguez and A. Zhukov, in an attempt to establish the link between different aspects of this phenomenon, starting with information on the origins of the magnetic clouds at the Sun and following by the analysis of in situ observations at 1AU and at Ulysses. The candidate source regions were identified in SOHO/EIT and SOHO/MDI observations. Hints on the internal magnetic field configuration of associated CMEs are obtained from LASCO C2 images. In the interplanetary space, magnetic field and plasma data from ACE and Ulysses, as well as information on the plasma composition were analyzed and the results compared between both spacecraft in order to understand how the ICME (Interplanetary CME) structures interact and develop in their cruise from the Sun to 5 AU. An attempt was made to find solar features that show a relationship with the type of ICME seen later (i.e. cloud or non-cloud ICME). Estimates of global magnitudes (magnetic fluxes and helicity) were obtained from magnetic field models applied to the data on magnetic clouds.

L. Rodriguez and A. Zhukov participated in the joint analysis (made by the ISSI team) of solar and interplanetary sources of the severe magnetic storm on May 15, 2005. 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.

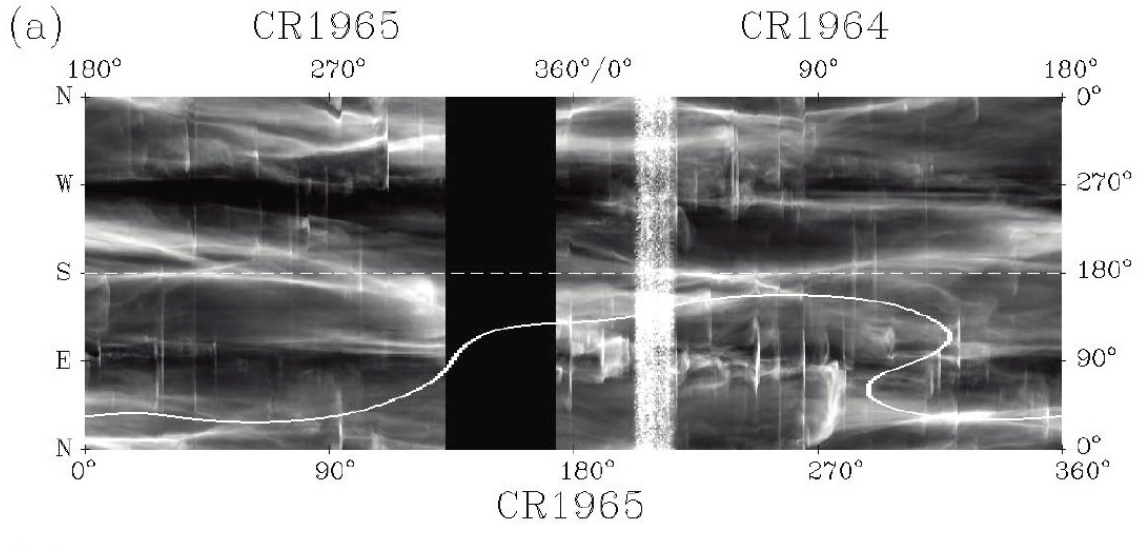


Figure 45: Carrington map of the solar corona at 3 solar radii as observed by the SOHO/LASCO C2 coronagraph, displaying the complete Carrington rotation (CR) 1965 at the east limb. Bright horizontal (vertical) structures represent coronal streamers (CMEs). White dashed line indicates the south pole, and white solid line shows the position of the neutral line as given by the potential field source surface (PFSS) model. Black vertical band represents a LASCO data gap. The bright irregular vertical stripe is the solar energetic particle event. Carrington longitudes are given for respective Carrington rotations on the horizontal axes, and position angles are shown on the right vertical axis. It is clear that the PFSS neutral line can account only for a few streamers.

Another track of research pursued by L. Rodriguez and A. Zhukov in collaboration with the ISSI team is the analysis of frontside full halo CMEs with non-typical geomagnetic response. 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 for each case. 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 farther away from disk center, while the other two CMEs originated closer to the central meridian but had weaker geomagnetic response. 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. On the contrary, the geomagnetic response of the terrestrial magnetosphere can be explained successfully using plasma and magnetic field in situ measurements from the L1 point.

M. Mierla participated in a study of a halo CME on August 25, 2001 that arrived at Earth and produced a geomagnetic storm. Using data from SOHO, Ulysses, ACE and WIND, the CME characteristics and its impact on the Earth were computed. An advanced method was applied to estimate the true radial speed of the CME. The calculated arrival time agreed well with obsrvations by ACE and WIND.

U.4.2.4.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 most of the CMEs originate from inside the streamer belt of the solar corona. A study of the three-dimensional structure of the streamer belt was performed by A. Zhukov, in collaboration with

the Laboratoire d'Astrophysique de Marseille (LAM). A model developed at LAM permits to simulate the quasi-stationary configuration of the streamer belt starting from the National Solar Observatory photospheric magnetograms and using the potential field source surface model. The synoptic maps of the streamer belt obtained with the SOHO/LASCO C2 coronagraph and the simulated synoptic maps constructed from the model of the warped plasma sheet have been compared (Figure 45). The epoch of solar cycle maximum was now addressed and the origin of polar streamers was investigated. A key conjecture is that polar streamers are "classical" streamers (loops with the current sheet above them) associated with polar crown photospheric neutral line. The position of the current sheet was found comparing the position of streamers, loops observed by EIT and of neutral lines of the photospheric magnetic field. To determine the position of the neutral lines, the synoptic maps produced by HelioSynoptics (Dr. P. McIntosh) were used. The method turned out to work surprisingly well and the positions of polar streamers were successfully reproduced. Such a description permits us to determine correctly the polarity of the heliospheric magnetic field during Ulysses polar pass in 2000 (work in collaboration with L. Rodriguez) – a feature that has up to now escaped theoretical interpretation. The conclusion of the work is that during the solar cycle maximum the streamer belt has a configuration drastically different from that given by the PFSS model [26].

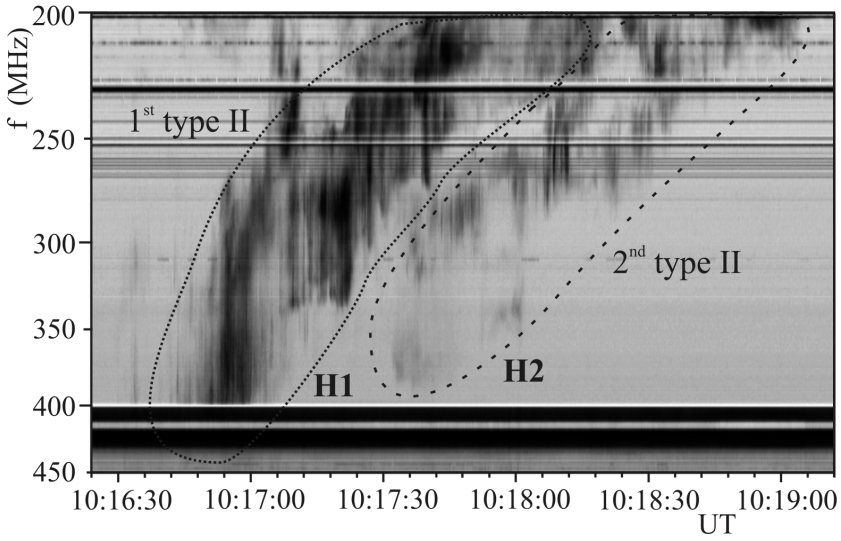


Figure 46: Dynamic radio spectrum (intensity in the range of frequencies versus time) recorded by Astrophysical Institute Potsdam on January 21, 2005. Enhanced radio emission (black patches) in two harmonic lanes (H1 and H2) of a multiple type II burst is clearly visible.

U.4.2.5.Radio-spectral diagnostics of solar radio bursts

J. Magdalenić, C. Marqué and A. Zhukov studied the origin of coronal shock waves, which is a subject of a long-standing debate. Coronal shocks can be either flare-generated freely propagating blast waves, or CME-driven shocks. Since CMEs and flares are usually closely synchronized, it is hard to give a conclusive answer. A multi-wavelength study of coronal shocks associated with several CME/flare events was performed. To avoid the influence of projection effects, only events associated with flares located at the limb or close to the limb were considered. The kinematics and evolution of shock wave signatures – metric type II radio bursts (see an example in Figure 46) – were analyzed and compared with the CME evolution and kinematics during the onset and early stage of the CME. The plane-of-the-sky position of the type II burst source (obtained from Nançay radioheliograph observations) was examined, relative to the leading edge of the CME. Additionally, in two events the type II band-split was used to determine the magnetic field and the Alfvén velocity. The shock velocity and the shock height estimations derived from type II radio bursts strongly depend on the chosen coronal density model [15]. This procedure is not applicable for events closer than 75° to the central meridian, but in the case of limb events the influence of projection effects is rather small. This gives an opportunity to derive an appropriate density model along the propagation path of the shock wave using positions of type II radio sources. The obtained shock velocities are significantly higher that the CME velocities, with differences as large as one order of magni-

tude. The observational results were compared with the theoretical model that considers the shock wave formation in front of a CME (3D piston scenario). The results showed that the shock waves were probably not driven by these slow CMEs, but rather initiated by the accompanying flares.

U.4.3. Perspective for next years

The investigations of solar eruptive events, their low corona and interplanetary counterparts together with their geomagnetic consequences will be continued in the framework of the STCE project (WP ROB A.4). STEREO data will be used extensively and more work will be done related to multi-spacecraft study of CMEs and ICMEs. For instance, looking at a CME remotely by one of the STEREO spacecraft and sampling the CME plasma in situ by the instruments mounted on the second spacecraft will provide important insights on the CME evolution and internal structure. The investigations of coronal shock waves using radio observations will be further pursued, together with the forward modeling of several selected events.

L. Rodriguez and A. Zhukov will participate in another series of ISSI workshops with the same team (new project title: "From the Sun to the Terrestrial Surface: Understanding the Chain"). The focus will now shift from studies of single events to the analysis of many events with larger amounts of data, with the goal to find possible physical explanations leading to improvement of our understanding of CMEs and of the very important issue of geo-effective event forecasting.

The scientific exploitation of CACTus will be continued. D. Berghmans will give an invited talk the Space Climate Symposium 3 (March 2009, Finland). Bram Bourgougnie (student in computer sciences, UGent) will further optimise the CACTus algorithm and systematically test alternative implementations. It is planned to provide user-friendly interface for real-time CME detection by NEMO. NEMO catalog on the base of full SOHO/EIT data is planned to be developed and compared with the CACTus catalog. The events extracted by NEMO will be provided as overlays in the Solar Weather Browser. The NEMO algorithm will be applied to the upcoming SWAP and SDO data. The study of micro-eruptions observed by STEREO/SECCHI will be pursued further.

U.4.4. Personnel involved

Scientific staff:

D. Berghmans (CME studies with CACTus; ROB permanent staff member)
C. Delannée (EIT wave observations and analysis)
S. Gissot (LCT expertise; SIDC Data Exploiatation)
J. Magdalenić (coronal shock wave and radio data analysis; Action 1)
C. Marqué (radio data analysis; Action 1 until April 1, 2008, STCE since April 1, 2008)
M. Mierla (3D reconstruction of CMEs; BELSPO postdoctoral fellowship)
O. Podladchikova (coronal dynamics studies with NEMO; SIDC Data Exploitation until April 1, 2008, STCE since April 1, 2008)
L. Rodriguez (coronal and interplanetary data analysis; SIDC Data Exploitation)
M. West (3D forward modeling of CMEs, SIDC Data Exploitation)
A. Zhukov (STEREO WP leader of the SIDC Data Exploitation project and Solar Atmosphere Studies WP leader for the STCE project; SIDC Data Exploitation until October 1, 2008, STCE since October 1, 2008)

U.4.5. Partnerships

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

- G. Attrill, Mullard Space Science Laboratory, University College of London, UK
- P. Lamy, A. Llebaria, F. Saez, Laboratoire d'Astrophysique de Marseille, France
- S. Koutchmy, Institut d'Astrophysique de Paris, France
- G. Stenborg, NASA Goddard Space Flight Center, USA

- B. J. Thompson, NASA Goddard Space Flight Center, USA
- E. Huttunen, University of Helsinki
- B. Vršnak, Faculty of Geodesy, Zagreb University, Croatia
- H. Aurass, G. Mann, Astrophysicalische Institut Potsdam, Germany
- A. Veronig, N. Muhr, Institute of Physics, Graz, Austria
- I. Chifu, C. Dumitrache, A. Oncica, A. S. Popescu, Astronomical Institute of the Romanian Academy, Bucharest, Romania
- STEREO/SECCHI consortium
- B. Inhester, Max-Planck Institute for Solar System Research, K.-Lindau, Germany
- N. Srivastava, Udaipur Solar Observatory, Udaipur, India
- J. Davila, Goddard Space Flight Center, USA
- E. Robbrecht, Naval Research Laboratory, US
- ISSI working groups "The Stages of Sun – Earth Connection" and "From the Sun to the Terrestrial Surface: Understanding the Chain" include: C. Cid, Y. Cerrato, E. Saiz, University of Alcala, Spain, S. Dasso, C. Mandrini, Instituto de Astronomia y Fysica del Espacio, Argentina, A. Aran, B. Sanahuja, University of Barcelona, Spain, H. Cremades, Universidad Tecnológica Nacional/CONICET, Mendoza, Argentina, B. Schmieder, Paris – Meudon Observatory, France, M. Menvielle, Centre d'Etudes des Environnements Terestres et Planetaires, France

Grants/Projects used for this research/service

- PRODEX contract "SIDC Data Exploitation"
- STCE
- Action 1 project "Global waves and shocks in the corona: origin, nature, inverse & forward modeling"
- BELSPO postdoctoral fellowship in the framework of cooperation with non-EU researchers
- International teams program, ISSI, working group "The Stages of Sun – Earth Connection" (team leader: C. Cid, University of Alcala, Spain)

Visitors:

- B. Inhester, MPS, Germany, 7 June – 10 June 2008
- N. Srivastava, USO, India, 3–16 November 2008
- B. Vršnak, Hvar Observatory, Faculty of Geodesy, Zagreb University, Croatia, November 23–25, 2008
- B. Inhester, MPS, Germany, 11-12 December 2008
- Bram Bourgoignie, student UGent, 1 day per week

U.4.6. Scientific outreach

Meeting presentations

[1] Mierla M., Davila J., Thompson W., Inhester B., Srivastava N., Kramar M., St. Cyr O.C., Stenborg G., Howard R.A.
Estimating the CMEs Propagation Direction by Using SECCHI-COR1 Data
STEREO Workshop, Paris, France, 20–24 April 2008 (oral presentation)

[2] **Mierla M.**, Inhester B., **Marqué C., Rodriguez L., Gissot S., Zhukov A., Berghmans D.,** Davila J.
3D Reconstruction of CMEs Using SECCHI-COR Data
Fifth European Space Weather Week, Brussels, Belgium; 17–21 November 2008 (poster presentation)

[3] **Mierla M.**, Schwenn R.
On the Slow Solar Wind
4th El Leoncito Solar Physics School : "RECENT PROGRESS IN SOLAR PHYSICS"; San Juan – San Luis, Argentina, 24–29 November 2008 (oral presentation)

[4] **Berghmans D.**, Robbrecht E., **Van der Linden R.**
Computer Aided CME Tracking
Fifth European Space Weather Week, Brussels, Belgium, 17–21 November 2008 (invited talk)

[5] Robbrecht E., **Krijger M., Berghmans D., Nicula B.**
Automatic detection of CMEs in STEREO/COR2 data
EGU General Assembly, April 2008, Vienna, Austria (poster presentation)

[6] Robbrecht E., Vourlidas A., Stenborg G., **Berghmans D., Krijger M., Nicula B.**, Howard R.
Building the SECCHI CME List
AGU 2008 Joint Assembly, Eos Trans. AGU, 89(23), Jt. Assem. Suppl., Abstract SP23B-03 (oral presentation)

[7] Robbrecht E., Vourlidas A., **Berghmans D., Nicula B.**, Howard R.
Building the SECCHI CME List
SECCHI Team Meeting, Meudon Observatory, April 23–24, 2008 (oral presentation)

[8] **Zhukov A. N., Rodriguez L.,** de Patoul J.
STEREO/SECCHI Observations of the EIT Wave on December 8, 2007: Evidence against the Freely Propagating Wave Hypothesis of the EIT Wave Origin
STEREO/SECCHI Consortium meeting, April 23, 2008, Meudon, France (oral presentation)

[9] **Zhukov A. N.**
EIT Waves and EUV Dimmings
Third Workshop for Young Researchers on Coronal Mass Ejections and Related Phenomena, May 30, 2008, Meudon, France (invited talk)

[10] **Zhukov A. N.**, Veselovsky I. S.
Global Coronal Mass Ejections
COSPAR General Assembly, July 14, 2008, Montreal, Canada (oral presentation)

[11] **Zhukov A. N.**
Global Coronal Mass Ejections
Third International Symposium on KuaFu Project, September 15, 2008, Kunming, China (invited talk)

[12] **Magdalenić J, Marqué C., Zhukov A. N.,** Vršnak B.
On the Origin of Coronal Shock Waves Associated with Limb Events
12th European Solar Physics Meeting, September 8–12, 2008, Freiburg, Germany (poster presentation)

[13] **Magdalenić J, Marqué C., Zhukov A. N.,** Vršnak B.
A Multiwavelength Study of the Origin of Coronal Shock Waves: Flares or CMEs?
IXth Hvar Astrophysical Colloquium, September 23, 2008, Hvar, Croatia (oral presentation)

[14] **Magdalenić J, Marqué C., Zhukov A. N.,** Vršnak B.
On the Origin of Coronal Shock Waves Associated with Limb Events
Fifth European Space Weather Week, November 17–21, 2008, Brussels, Belgium (poster presentation)

[15] **Mierla M.,** Inhester B., **Marqué C., Rodriguez L., Gissot S., Zhukov A.N., Berghmans D.,** Davila J.
3D Reconstruction of Coronal Mass Ejections Using SECCHI-COR Data
Fifth European Space Weather Week, November 17–21, 2008, Brussels, Belgium (poster presentation)

[16] **Podladchikova O.**
EUV Micro-Eruptions by SECCHI – Discovery and Diganostic

7th SECCHI Consortium Meeting, 13–19 March 2008, Meudon, Paris (oral presentation)

[17] **Podladchikova O.**
EUV Coronal Wave Recognition for SECCHI/STEREO: Problems and Achievements
37th COSPAR Scientific Assemby, 13–18 July 2008, Montréal, Canada

[18] **Podladchikova O.**
EUV Micro-Waves in the Solar Corona
AGU Fall Meeting 2008, 15–19 December 2008, San-Francisco, USA

[19] **Podladchikova O., Nicula B., Willems S., Berghmans D.**
NEMO: Detection of CMEs without Coronagraphs in Real Time at SIDC
Fifth European Space Weather Week, 17–21 November 2008, Brussels, Belgium (poster presentation)

Seminars

[20] **Mierla M.**
Structures in the Solar Corona: Dynamics and 3D Reconstruction
Royal Observatory of Belgium, 14 February 2008

[21] **Mierla M.**
3D Reconstruction of Coronal Mass Ejections Using SECCHI-COR Data
Royal Observatory of Belgium, 25 September 2008

[22] **Mierla M.**
On the 3D Reconstruction of Coronal Mass Ejections
MPS, Germany, 30 October 2008

[23] **West M. J.**, Cargill P., Bradshaw S.
An Assessment of Heat Conduction Models in Loop Cooling
Royal Observatory of Belgium, 9 September 2008

[24] **Zhukov A. N.**
Solar Coronal Mass Ejection Observations in the EUV
Skobeltsyn Institute of Nuclear Physics, Moscow State University, June 25, 2008, Moscow, Russia

Wikis and Websites

- SOHO/EIT dimming catalog (by M. J. West and B. J. Thompson): http://solweb.oma.be/users/mwest/DimmingWork/Dimming.html
- CACTUS CME catalog: http://sidc.be/cactus
- NEMO catalog of on-disk CME counterparts: http://sidc.be/nemo

U.4.7. Missions

Assemblies, symposia:

M. Mierla, O. Podladchikova, L. Rodriguez, A. Zhukov (STEREO/SECCHI Consortium Meeting, April 20–24, Meudon, France)
L. Rodriguez, A. Zhukov (Third Workshop for Young Researchers on Coronal Mass Ejections and Related Phenomena, May 28–30, Meudon, France)
O. Podladchikova, L. Rodriguez, A. Zhukov (COSPAR General Assembly, July 13–21, Montreal, Canada)
J. Magdalenić (12^{th} European Solar Physics Meeting, September 8–12, Freiburg, Germany)
A. Zhukov (Third International Symposium on KuaFu Project, September 13–20, Kunming, China)

	J. Magdalenić (IXth Hvar Astrophysical Colloquium, September 22–26, Hvar, Croatia) M. West (The Royal Astronomical Society Meeting, October 10, London, UK) M. West (SECCHI consortium meeting, October 22 – 24, NRL, Washington DC, USA) D. Berghmans, M. Mierla, J. Magdalenić, O. Podladchikova, L. Rodriguez, M. West, A. Zhukov (Fifth European Space Weather Week, November 17–21, Brussels, Belgium) O. Podladchikova (AGU Fall Meeting, 15–19 December, San-Francisco, USA)
Commissions, working groups:	L. Rodriguez, A. Zhukov (4 days)
Research visits (days):	M. Mierla (3 days) A. Zhukov (6 days) J. Magdalenić (10 days) J. Magdalenić (7 days)

V. Solar Instrumentation

V.1. Design and construction of radiotelescopes in the HUMAIN station

V.1.1. Objectives

The design and construction of new radiotelescopes for the Humain station is carried out in the framework of a modernization and redeployment project submitted in 2004 (HUMSolAR). This instrumental development effort has now become part of Work Package 2 of the Solar-Terrestrial Center of Excellence (STCE) and proceeds in the context of international collaborations. It involves an expertise in HF (high frequency techniques) as well as special laboratory equipment for testing and calibration. The following sytems are now under development:

- Solar radio flux monitors at multiple discrete frequencies: this includes absolute flux measurements at 600 MHz, and future extension to other frequencies, including 2,8Ghz (10.7 cm flux).
- Radio spectrographs covering the 30MHz-3GHz frequency range (CALLISTO)
- Remote operation of the radiotelescopes from Uccle: antenna control, data acquisition modes.
- Near-real time transmission and processing of the Humain data in support to the SIDC solar flare monitoring.

V.1.2. Progress and results

The newly recruited radioastronomer, Christophe Marqué (Jan. 2008), allowed to start the actual redeployment of solar radio instruments at the Humain station in the context of the Solar-terrestrial Center of Excellence (STCE).

Figure 47: the new 50-1300 MHz log-periodic antenna mounted on the outer ring of a refurbished 6m parabola.

V.1.2.1. CALLISTO spectrograph

In 2008, the collaboration with the ETH Zürich radioastronomy group flourished further and led to the actual rebirth of radioastronomy in the Humain station.

- CALLISTO receivers: A log-periodic antenna covering the range 50-1300MHz was mounted in parallel with the modernized 6m parabolic antenna (Fig. 4). The pointing electronics that had been damaged during a thunderstorm in 2007 was repaired. New HF cabling was installed between the antenna and the laboratory. In May 2008, C. Monstein, Chief Engineer at the ETH Zürich, came to Humain and brought a first CALLISTO receiver. This receiver, which covers the 45-870 MHz frequency range, was installed and tested. From May to mid-November, the receiver was set up to monitor its whole frequency range. This revealed a degradation of radio interferences (RFI) only above 500 MHz compared to the spectrum monitoring campaign of 2006, as well as significant intermodulation due to the FM band (87-108 MHz; Fig. 5). Since November, the receiver has been programmed to monitor only the very lower part of the spectrum (92-45 MHz) in order to avoid strong man-made emissions, before a filtering strategy is developed. In November, at the occasion of the CRAF meeting, C. Monstein brought a second CALLISTO receiver that will be used for tests and RFI monitoring and should finally be converted to operate at higher frequencies (> 1GHz).
- Data transmission and remote control: A portable control PC was purchased. It runs the standard receiver control software and it was configured to transmit the acquired data to the ROB in real time via the ADSL connection (downloads every 15 minutes). A new version of the antenna pointing software was developed in view of the remote operation of the antenna from Brussels. This work will be completed in 2009.

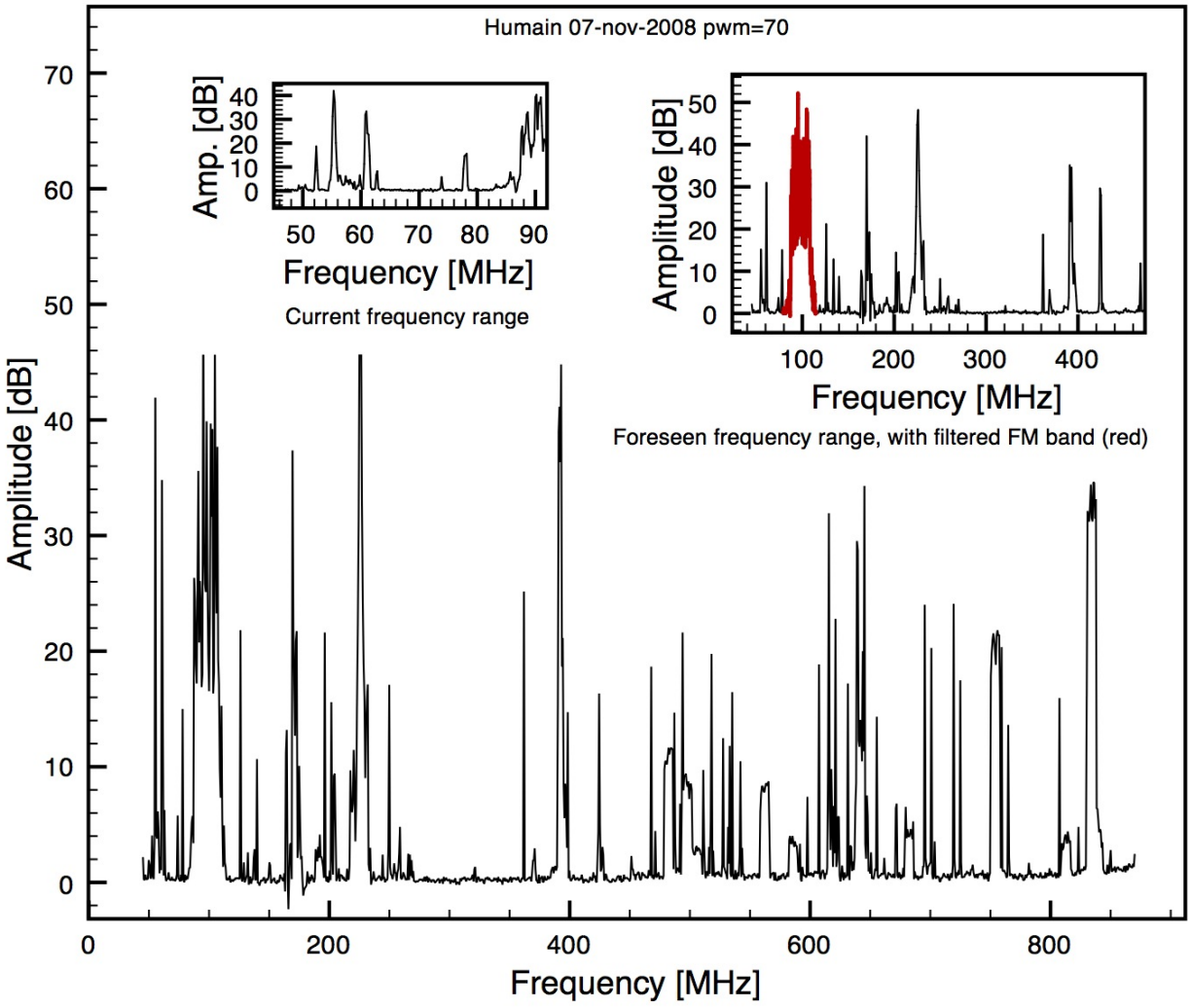


Figure 48: Measured spectrum at Humain between 45 and 870 MHz with the foreseen future spectral range (top right) and the current one (top left)

V.1.2.2. Next-generation solar flux monitors (NGSFM)

In 2008, an actual collaboration was initiated with Dr. K.Tapping (Dominion Radio Astronomy Observatory, Penticton Canada) and Dr. D. Boteler (Geological survey of Canada, Ottawa) for the joint development and construction of new absolute solar radio flux monitors. This project is benefiting from the 60-year scientific heritage of the 10.7cm reference solar flux measured in Penticton. It involves the design of new receivers based on state-of-the-art HF components but also on the extension of the frequency coverage by measuring 6 frequencies in parallel, including the historical 2.8GHz flux, in order to better characterize the slowly varying component (S component). Another goal is to implement a 24h/day coverage thanks to a worldwide network of at least 3 stations. The principles of this collaboration were established during two personal meetings with K. Tapping and D. Boteler, at the occasion of the COSPAR General Assembly (C. Marqué, Montréal, July 2008) and of a visit to the Geological Survey (F. Clette, Ottawa, 21-22/8/2008).

The terms of this collaboration would attribute the design work to the DRAO, while the construction and testing of the final receivers would be carried out by the ROB. The Geological survey would provide some funding as well as the antenna to be used in Penticton. The observing network would include 3 stations (Canada, Belgium, Japan), with one unit installed at the Humain station. For the Humain instrument,

it will be necessary to refurbish and adapt an existing antenna or purchase a new dish and mounting. A preliminary study of the options was carried out late in 2008 and will continue in 2009.

Exchanges of technical information continued in the fall of 2008, but the construction of a first prototype will only start in 2009, as the funding expected by the Canadian collaborators was not allocated before Jan. 2009.

V.1.3. Perspective for next years

The main tasks for 2009 will be:

- Recruiting of new staff (technician, ICT) in the framework of the STCE.
- CALLISTO spectrographs:
  - Optimization of the first receiver by reducing intermodulation effects associated with strong radio transmitters (mainly the FM band) and by minimizing internal interferences due to the local electronic devices and PCs by the installation of RF notch filters.
  - Preparation of a second receiver operating at higher frequencies, which will first allow making a survey of RFI in the high frequency range 1-3 GHz.
  - Implementation of a remote control system allowing unattended operation of the radiotelescope directly from Brussels. This also involves the installation of a GPS-based clock for providing an accurate time reference.
- Absolute solar flux monitors: in 2009, the development and testing of the new-generation solar flux monitors should make its actual start, once the Canadian team will secure its funding:
  - The first step will involve the construction and testing of a mono-frequency prototype designed by K. Tapping (DRAO). Probably late in 2009, the design of the base receiver could be finalized and all necessary components should then be identified and purchased. Then, it will be possible to start the overall hardware design and construction of the entire receiver unit (circuits, cabling, enclosure).
  - In parallel, for the Humain implementation, the selection of an antenna and mount will be continued, followed by the installation and cabling of the new or refurbished antenna. This work will involve the manufacturing of a new parabolic dish as well as the laying of new power and signal cables. Different bilateral collaborations will be pursued in this context, probably implying a few short stays at other observatories (Ottawa/Penticton, Zürich, Bologna).
- Radiofrequency laboratory: in view of the abundant development, testing and maintenance work, the selection and purchase of HF laboratory equipment will be pursued (spectrum analyzer, frequency generators, programmable receivers, filters, etc.).

V.1.4. Personnel involved

Scientific staff:	F.Clette (Global mangement, ROB permanent staff)
	C. Marqué (Lead scientist, radioastronomer, STCE)
Technical staff:	J-L. Dufond (Engineer technician, electronics, ROB permament staff)
	A. Ergen (Technician, electronics, ROB permanent staff)
	P. Janssens (Local intendant/gardener, ROB permanent staff)

V.1.5. Partnerships

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

- Dr Arnold Benz & Eng. Christian Monstein, Eidgenössische Technische Hochschule (ETH), Zürich, Switzerland.
- Dr Kenneth Tapping, Dominion Radio Astrophysical Observatory, Penticton (Ottawa), Canada.
- Dr. David Boteler, Geological Survey of Canada, Ottawa, Canada
- Dr Roberto Ambrosini, Instituto de Radioastronomia, Bologna, Italia

Grants/Projects used for this research/service

- STCE: work package 2 “Ground-based Observations”

Visitors:

- Short visits:
  - CALLISTO installation, 27-29/5/2008: 1 visitor
  - Associated scientists: 3 visitors

V.1.6. Scientific outreach

Meeting presentations

[1] F. Clette, C. Marqué
New solar radiotelescopes in Belgium
URSI Forum, 30/5/2008 (oral)

[2] **F. Clette, C. Marqué,** C. Monstein, **J.-L. Dufond, A. Ergen**
New solar radiotelescopes in Belgium
URSI General Assembly, 10-16/8/2008 (poster)

V.1.7. Missions

Commissions, working groups:
- F.Clette: URSI Forum, 30/5/2008, Brussels, Palace of Academies (Oral presentation)
- F.Clette: Belgian URSI Committee meeting, Palace of Academies, 16/12/2008

Research visits:
- C. Marqué: Paris Observatory, Meudon, March 13th 2008.
- F.Clette: Geological Survey of Canada (D. Boteler, Ottawa), 20-21/8/2008.

Field missions:
- J-L. Dufond, A. Ergen: Humain station: 18 days.
- C. Marqué: Humain station, 6 days
- F. Clette: Humain station: 2 days.

V.2. Improvements of ROB solar telescopes (USET)

V.2.1. Objectives

In order to ensure the continuous operations of the USET instruments (Uccle Solar Equatorial Table) 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

V.2.2. Progress and results

V.2.2.1. Ttelescope replacements and upgrades

- Hα telescope: in January 2008, a new camera (QImaging RETIGA 4000R) was coupled with the new H-alpha optics, providing a 2-time increase in image resolution as well as more advanced controls. Replacing the old telescope (Lyot filter and DALSA 1Kx1K camera), this new H-alpha imaging system has been in routine operation since then (see images in figs. 1 & 2). As the ROB mechanical workshop was not operational in 2008, this new telescope is still mounted on a provisional platform built with basic means. Other solutions were investigated in view of the construction of a definitive platform in 2009.

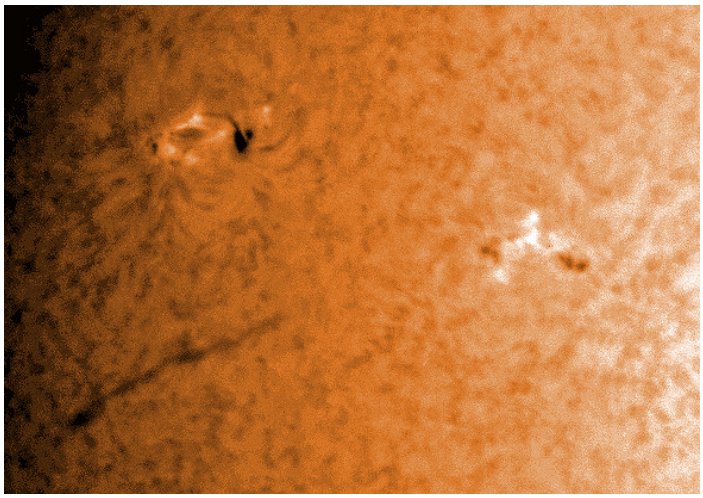


Figure 49: Close-up view of two small active regions and a filament extracted from a whole-disk Hα image produced with the new USET Hα telescope and QImaging Retiga 4000R camera (25/3/2008)

- White-Light telescope: On June 25, 2008, a new camera identical to the Hα camera was installed on the white-light telescope. It also provides a doubling of the image resolution. In 2008, the image scale was not yet optimized for the larger CCD sensor dimensions. A new custom-made focal reducer should be designed and built in 2009. Stilll, the camera, mounted on the existing optics, delivered already excellent images in daily operation.
- CaII-K telescope: By the lack of manpower, almost no progress was made in 2008 in the preparation of the new CaII-K telescope. Still, in December 2008, the telescope that will feed the system was selected and purchased: namely, an apochromatic refractor (Williams Optics) with a 132mm aperture.

V.2.2.2. Cameras and image acquisition

- Imagers: two of 3 new QImaging cameras purchased on the LOTTO budget were tested and put in operation (cf. above): this revealed a problem of internally trapped dust particles in the camera light path. One of the cameas was returned to the manufacturer in February 2008 but this did not solve the problem. Thus led to the conclusion that in the future, we will have to do the cleaning ourselves using internal facilities at the ROB or the neigbouring institutes (cf. Deme-Lab, A. Ben Moussa).
- Data transmission: in February 2008, Firewire repeaters were tested successfully and installed, allowing the extension of the connexion over 15 meters from the new CCD cameras in the dome to the acquisition PC installed in the control room downstairs. This solution is now operational and has been replicated for the two other cameras.
- CCD software development: an entirely new camera control and image acquisition software, SUNCAP, was developed and implemented over the first half of 2008. This software features access to all control parameters of the new cameras but also special automated imaging modes allowing the sequential acquisition of synoptic images and of high-cadence images triggered by solar flares. Due to the very low solar activity, the flare capture capability could not be tested yet. The program is also built to accommodate future extensions like the remote control of the telescope focus and pointing.

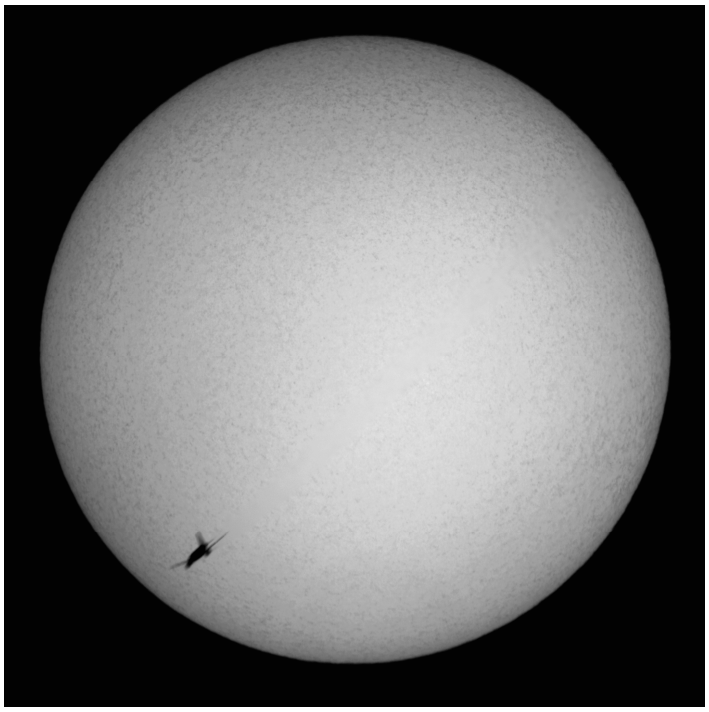


Figure 50: Sample whole disk Hα image of a very quiet Sun with a fleeting intruder captured with the new USET Hα telescope and camera. Thanks to the interline CCD sensor, the camera exposure is controlled electronically without any mechanical shutter, allowing continuous high-cadence imaging.

V.2.2.3. Telescope pointing and automatization

- Independent motorized telescope pointing and focusing: in October and November 2008, an extensive study and selection of high-precision linear translation stages was carried out. Those mechanical elements form the last part needed for the new solar CCD imaging system of the USET. Those translation stages will allow accurate independent centering of the images on the 3 telescopes as well as the motorized focusing. The system will be remote-controlled in order to integrate it with the image acquisition software and hardware located in the USET control room. One of the key capabilities of this mechanical setup will be to acquire easily and routinely controlled shifted image sequences necessary to extract the evolving camera flat-field correction, leading to photometrically calibrated images. Three sets of OWIS stages were finally selected and ordered on the corresponding LOTTO budget (closed at the end of 2008). Those devices were chosen for the combination of good load capacity and an industrial-type environmental dust shielding. The delivery will take place in early 2009.

- Design and construction of a solar autoguider (Fig. 3): in 2008, this development effort continued mainly as part of the 3-month training work of a graduate student in informatics (Pierre Charlier, ESI, Feb.-May 2008). This training work consisted in designing and building a microcontroller system that would form the basis of the closed-loop pointing system (fed by the pointer optics qualified in 2007) and would also allow remote control of the USET telescope and dome. The system was also developed in view of the remote control of radio antennas at the Humain station. However, despite an extension of the work of P. Charlier through a 1-month student-job position in July 2008, the system was not completed and proven. Due to the shortcomings of this student work, no real progress was finally achieved in 2008 and a new design study be started in 2009 on new bases.

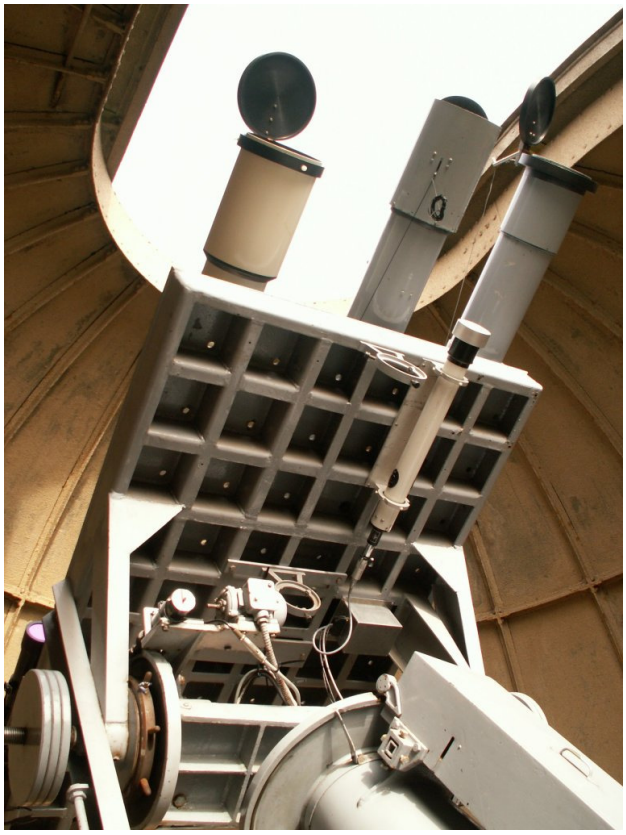


Figure 51: View of the underside of the Equatorial Table, showing the small pointer telescope with the sensor unit (4-quadrant photodiode) and electronic box.

V.2.3. Perspective for next years

The priorities for 2009 will be:

- Hardware development:
  - Design and construction of an optimized focal reducer for the white-light telescope.
  - Design and construction of the CaII-K telescope and optics in connection with the Observatory of Rome (PSPT).
  - Design and construction of the motor-actuated mechanical support and focus systems for the new telescopes.
  - Completion of the solar autoguider: this will involve a study phase in order to optimize the system to the actual properties of image turbulence at the Uccle site.
- Software development:
  - 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.

V.2.4. Personnel involved

Scientific staff: F. Clette (Lead scientist, instrument design & development, permanent ROB staff)

Technical staff: J-L. Dufond (Engineer-technician: electronics, permament ROB staff)
S. Vanraes (ICT, programmer, observer, permanent ROB staff)
A. Ergen (Technician: electronics, permanent ROB staff)
O. Boulvin (Operator-observer; permanent ROB staff)
O. Lemaître (Operator-observer, permanent ROB staff)

V.2.5. Partnerships

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

- M. Bianda, IRSOL-Specola Solare Ticinense, Switzerland

Grants/Projects used for this research/service

- LOTTO equipment grant (attributed in November 2006)

V.3. SWAP

V.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). After launch on the PROBA2 satellite, the Royal Observatory of Belgium will be the principal investigator institute for the exploitation of the data.

V.3.2. Progress and results

In this pre-launch phase, the SWAP data reduction effort is focussed on improving our instrument understanding and on setting up a pre-flight calibration reference. Both aspects progressed well in 2008.

V.3.2.1. Instrument understanding

Analysis of image sequences taken by the SWAP detector & electronics revealed that one of the detector read-out modes (Destructive Read Out) exhibits an image lag effect. This effect is well-known for APS detectors and is in essence a defect. However, since the second read-out mode (Non-destructive read out) is not affected, no science potential is lost [6].

V.3.2.2. Calibration

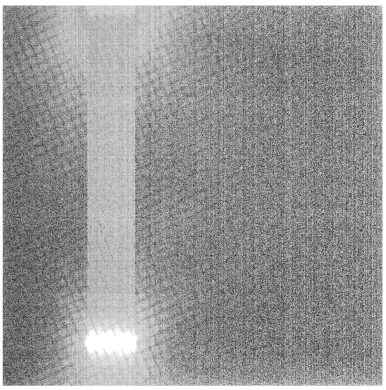


Figure 52: The image lag effect.

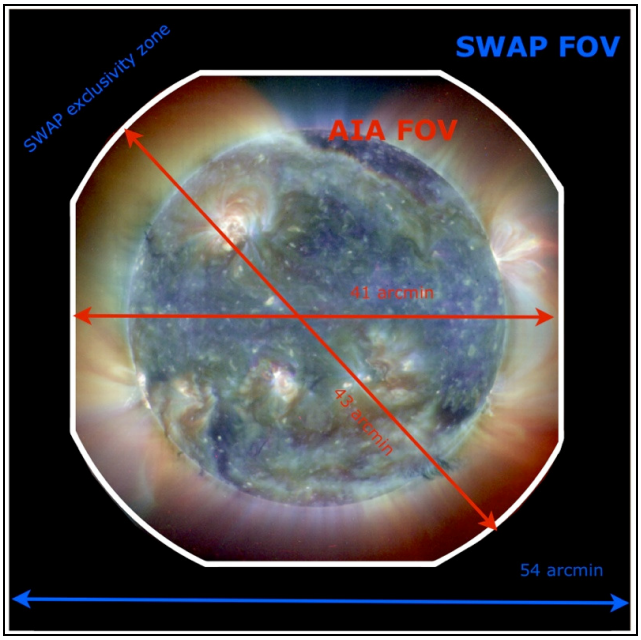


Figure 53: Comparison SWAP versus AIA

Following the breaking of the SWAP front-filter, a new calibration campaign was executed at the PTB facilities of the BESSY synchrotron in Berlin (20080702-20080704). A first round-table discussion meeting (July 17), together with CSL confirmed the data taken to be adequate and of good quality. The data reduction is currently ongoing in collaboration with the SWAP Dublin team and joint meetings are regularly scheduled (20081020 and 21, next meeting 20080126). The end goal of this effort is a pre-flight calibration paper which was foreseen for 2008-Q4 but is now expected for 2009-Q2.

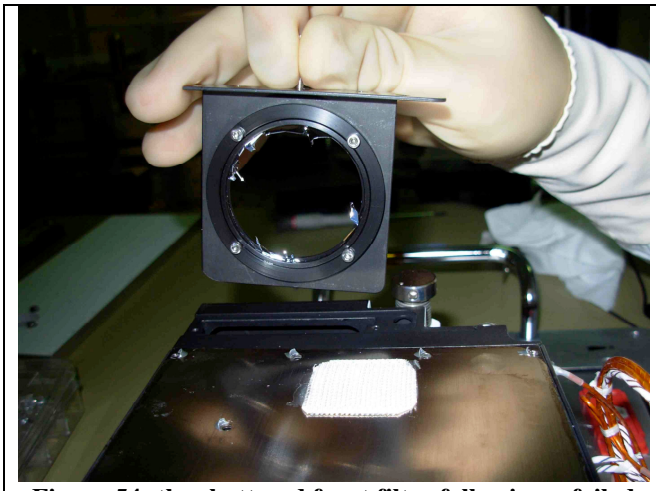


Figure 54: the shattered front filter following a failed vibration test.

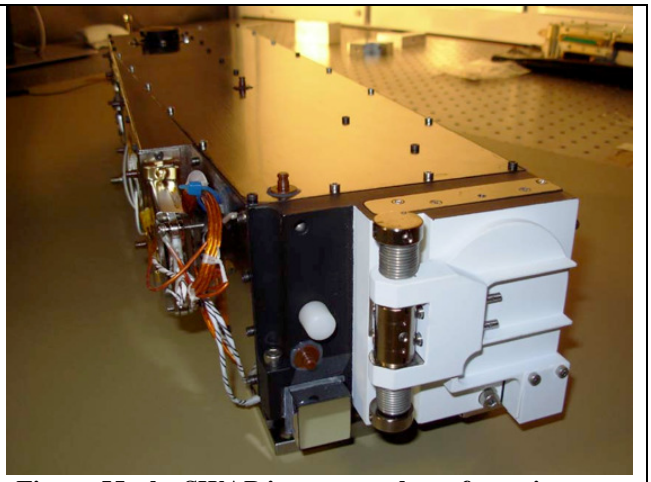


Figure 55: the SWAP instrument box after reintegration.

V.3.3. Perspective for next years

At the time of this writing, the PROBA2 launch is foreseen for July 16 2009, with regular SWAP operations starting 5 weeks later.

A poster presentation on SWAP is foreseen for the Space Climate Symposium 3 (March 2009, Finland).

The SWAP pre-flight calibration paper is advancing well and foreseen to be submitted in 2009 to an international, refereed journal.

V.3.4. Partnerships

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

- The partners of the SCSL team (see http://proba2.sidc.be/SCSL/)

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

- Centre Spatial de Liege at ULiege
- Center for Plasma Astrophysics (CPA) at KULeuven
- Verhaert NV
- Spacebel

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

- PRODEX grant "SIDC Data exploitation"
- "Nationally Led Mission" project

Visitors:

- Shaun Bloomfield & Claire Raftery, Trinity College Dublin, October 20-21.
- Joe Zender (ESA), regular visitor (several days per week).

V.3.5. Scientific outreach

Meeting presentations

[1] D. Berghmans and the SWAP team
SWAP, yet another EUV imager
SDO science Team Meetings, March 25-28, San Francisco, US.

[2] A. De Groof, D. Berghmans, B. Nicula and J.P. Halain, J.M Defise, T. Thibert and U. Schuehle

SWAP, a Belgian solar EUV imager onboard PROBA2
Talk at 9th FNRS contact group meeting, April 11, Brussels.

[3] A. De Groof, D. Berghmans, J.M Defise, B. Nicula, U. Schuehle
SWAP Onboard PROBA2: An Innovative EUV Imager Designed for Space Weather
Poster at 12th European Solar Physics Meeting, 8-12 September 2008, Freiburg, Germany.

[4] D. Seaton and SWAP team
SWAP
Talk presented at the PROBA2 splinter session of the ESWW5 conference, Nov 2008, Brussels, Belgium.

Seminars

[5] **D. Berghmans**
SWAP towards improved space weather monitoring
Defense for promotion to "Geaggregeerde Werkleider" (now "Werkleider / W3"), January 22, ROB.

Wikis and Websites

- http://swap.sidc.be/
- http://proba2.sidc.be/SCSL/
- wikipedia

V.3.6. Missions

Assemblies, symposia:

- March 24-30; San Francisco, US. Poster presentation on SWAP. Discussions on coordination with SDO/AIA.
- April 28- May 2; Boulder, US. Invited talk on PROBA2.
- November 17-21, Brussels, Belgium; Fifth European Space Weather Week.

Commissions, working groups:

- June 10-12; Prague, Czech Republic. Presentation on SWAP & PROBA2 for the ILWS working group.

Research visits:

- February 28-29; Dublin, Ireland. Coordination with the SWAP team lead by P. Gallagher at Trinity College Dublin.
- October 22; Leuven, Belgium. Coordination with CPA about SWAP participation and temporary replacement of Anik De Groof.

Field missions:

- July 2-5; Berlin, Germany. Final (re-) calibration of SWAP at the PTB facilities at the BESSY synchrotron.

V.4. LYRA

V.4.1. Objectives

LYRA is a solar X-ray and UV radiometer that will embark in late 2009 on the ESA PROBA2 mission. Its purpose is to monitor the solar UV 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 degradation properties of optical filters. It was built by a Belgian–Swiss–German consortium with additional international collaborations (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 institute, our objective is to make LYRA a success in every respect. In 2008, this mainly meant the preparation of its future scientific exploitation and flight operations.

V.4.2. Progress and results

V.4.2.1. Preparation to scientific exploitation

The knowledge of solar extreme and far ultraviolet irradiance variations is essential for the physics and chemistry of the Earth middle and upper atmosphere. For a long time, this knowledge was derived from empirical models based on proxies of the solar activity. However, the accurate modeling and the prediction of the Earth atmosphere necessitate improving the precision of the irradiance and its variations below 200 nm. LYRA will provide 6-hourly solar irradiance at Lyman-alpha (121.6 nm) and in the Herzberg continuum (~200-220 nm wavelength range). Egorova et al **[11]** have developed a statistical tool for the reconstruction of the solar spectrum from LYRA measurements. It uses linear regression based on two LYRA channels. The accuracy of the reconstructed irradiance has been evaluated against data from SUSIM and SOLSTICE on UARS. Kretzschmar et al **[14]** 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 subset of the spectrum while controlling the accuracy.

The heliosynchronous orbit of PROBA2 will generate 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 **[48]** consider the possibility to retrieve 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.

V.4.2.2. Preparation to data reduction and operations

In 2008, the testing of the LYRA onboard SW was finished as part of the SVT5 series of campaigns. LYRA related SVT5 **[80] [81]** telecons were held on 6, 23, 29 January, 28 March and 13 May 2008. Other preparations to the LYRA operations were carried out during meetings on 15 April, 27 August and 9 September. It was concluded on 6 February that LYRA will have difficulties to run with a 10 or 20 ms cadence. This is contrary to the expectations and due to the PROBA2 onboard SW. On 1 April, it was observed with relief that LYRA filters looked fine despite the accident that caused the destruction of the SWAP filter. J.F. Hochedez met with J. Zender on 30 January to agree on the scope and delivery of the following documents:

- First light Procedure (LFLP) **[77]**
- LYRA User Manual (LUM) **[78]**
- LYRA operations preparation (LOP) **[79]**
- LYRA Data Management Plan (LDMP) **[83]**

During 2008, the LYRA team defined the levels of LYRA products (FITS headers, etc.), and reviewed the calibration analysis led by I. Dammasch. Future scientific analysis of LYRA data requires indeed an in-depth understanding of the instrument response, its filters, sensors, etc.

- **[73]** is about the results of the latest BESSY measurement campaign, suggested changes due to new flatfield simulations, suggested changes due to Davos measurements concerning the long-wavelength extension of the responsivity curves, and, consequently, an update of these curves used for the recalculation of the radiometric model.
- **[74]** is about the algorithms to calculate the solar signal in absolute physical units from its corresponding LYRA channel output, using another new set of solar sample spectra from instruments already in space.

- **[75]** is about estimating the expected variation of LYRA channel outputs and related solar values, comparing the radiometric model's predictions during the preparation phase, and defining the boundaries of test data, algorithms, and warning flags for the calibration software.

Results from this report were also used for a poster presentation at ESWW5 **[2]**.

V.4.2.3. LYRA family

The LYRA development triggered the participation of J-F Hochedez in the Dynamiccs ESA Cosmic Vision proposal **[23]**, as partner to the SUITE ANR proposal (02/2008) **[82]**, and in the CAMUS CNES proposal **[55]**. The PICARD PREMOS calibration paper **[66]** was submitted in 11/2008.

V.4.3. Perspective for next years

The preparation of LYRA scientific exploitation will go on until the November 2009 launch. A research visit was setup in November 2008 for M. Kretzschmar to visit SIDC in early 2009. The preparation to data reduction and operations will intensify, including the conversion of the calibration analysis into P2SC software (EDG and BSDG).

V.4.4. Personnel involved

Scientific staff: J.-F. Hochedez (LYRA PI, ROB permanent scientist)
M. Dominique (LYRA scientist, SIDC data exploitation PEA)
B. Giordanengo (LYRA scientist, Solar Orbiter PEA)
I. E. Dammasch (LYRA scientist, SIDC data exploitation PEA)
A. Benmoussa (LYRA scientist, Solar Orbiter PEA)

V.4.5. Partnerships

List of international partners or 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
- J. Zender, ESA, Noordwijk, NL

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

- CSL, Liège
- Verhaert, Kruibeke
- Spacebel

Grants/Projects used for this research/service

- SIDC Data Exploitation PEA (Prodex)

Visitors:

- J. Zender, ESA, 30 January 2008

V.4.6. Scientific outreach

Meeting presentations

[1] **Dominique**, Dudok de Wit, **Hochedez**, and the LYRA team
LYRA expected performance and scientific perspectives (talk)
European Space Weather Week 5, 17-21 November 2008, Brussels, Belgium

[2] **I. E. Dammasch, M. Dominique, B. Giordanengo, A. BenMoussa, J.-F. Hochedez**
Upcoming LYRA Science Data Products (poster)
European Space Weather Week 5, 17-21 November 2008, Brussels, Belgium

Wikis and Websites

- http://lyra.sidc.be/
- LYRA in wikipedia
- http://solwww.oma.be/users/dammasch/reports.html

V.4.7. Missions

Assemblies, symposia:	Dominique (ESWW5) Dammasch (ESWW5)
Commissions, working groups (days):	Hochedez (2) Dammasch (2)
Field missions (days):	Dominique (2)

V.5. Solar space technologies

V.5.1. Objectives

Building upon their heritage, collaborations, and knowledge of both the needs and opportunities, members of the SIDC initiate and contribute to the development of critical optical components for improved UV solar observations. The selected technologies are currently imaging and non-imaging wide bandgap UV detectors and porous diffractive filters. In 2006-2009, the purpose of the BOLD project (Blind to Optical Light Detectors) is to demonstrate the feasibility of wide-bandgap nitride-based detectors for EUV/VUV imaging in space. A GSTP project has been set up by BELSPO and ESA, involving IMEC, ROB, and CRHEA (F). Its goal is the manufacturing and testing of an AlGaN hybridized 2D APS of 512x512 format and 10µm pixel pitch. It will be characterized from the EUV to the visible ranges. Porous filters are highly complementary to BOLD sensors; and are also investigated at SIDC.

V.5.2. Progress and results

V.5.2.1. UV detectors and BOLD

Wide bandgap semiconducting materials can serve UV detection. They promise solarblindness and enhanced robustness against the known degradation by UV and energetic particles irradiations. In 2008, interesting results were published by Benmoussa et al concerning aluminium nitride AlN **[3]**, diamond C* **[4]**, by Soltani et al for boron nitride BN **[22]**, and by Malinowski et al for AlGaN **[36]** in the frame of the BOLD project. We unfortunately had to take note of the destruction the LYRA MSM device that had been refurbished as 'MSM24r'. The BOLD GSTP project carried out a pre-CDR review on 22 May and went successfully through its CDR review on 1 December 2008. It was additionally prolongated until June 2009 via a CCN in August 2008.

JF Hochedez is co-author of the ISSI book 'Photons in Space', edited by M. Huber **[60]**. B. Giordanengo gave an invited talk at the "detector for astrophysics" workshop.

V.5.2.2. Porous filters

After several years of work, the article on the characterization of track membranes acting as diffractive porous filters was submitted (and accepted) **[54]**. But before that, in January, April, and November 2008, we carried out indepth final review and corrections to the manuscript. We therein describe the fabrication and performance of diffractive filters designed for space-based x-ray and EUV solar observations. 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 500nm, enabling their transmittance to short wavelengths only. The spectral transmittance of various diffractive filters with different pore parameters was measured from the soft x-ray to the near IR range (namely, in 1–1100 nm).

V.5.2.3. DEMELAB

The Detector Measurment Laboratory (DeMeLab) of STCE-SIDC was agreed and initiated in 2008 as a main element of STCE WP-A5. Dedicated meetings were held on 26 September and 26 November 2008.

Figure 56: Photograph of DeMelab (electrical bench) facility

Technology is an important driver in space science. Fore 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 SIDC, 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 the 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.

We just started to design and assemble an electrical bench. The electrical characteristics (Femto Amp range) were measured on diamond photodetectors. Two optical characterization benches (from EUV and NUV to VIS) are under study.

V.5.3. Perspective for next years

The Demelab objectives for the next few years are:

- Exploration and support to the development of "smart camera" features: Noise lowering via multiple non-destructive readout (NDR) mode, cosmic ray hits on-the-fly removal, SNR increase via multiple adaptive resets, high dynamic range etc.,
- Design and implementation of an archival system for test data and metadata,
- Design and implementation of a library of analysis software for detector optoelectrical, characterization. Relationships with image compression and its implementation,
- Support to the other STCE partners (electro-optical characterization & analysis) e.g. Testing of USET cameras.

A BOLD calibration campaign is planned in 2009 at the PTB-Bessy II synchrotron. It will assess the performance of the first 2D array demonstrators in the EUV-VUV range. The APSOLUTE project for Backside CMOS will start in 2009.

V.5.4. Personnel involved

Scientific staff: J.-F. Hochedez (ROB permanent scientist)
A. BenMoussa (scientist, DeMeLab, BOLD, Solar Orbiter PEA)
B. Giordanengo (BOLD, Solar Orbiter PEA)
M. Dominique (Porous Filters, SIDC Exploitation PEA)

V.5.5. Partnerships

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

- J.-Y. Duboz, CRHEA, Valbonne, France

- A. Soltani, Institut d'Electronique de Microélectronique et de Nanotechnologie, Lille, France
- A. Mitrofanov, LPI/FIAN, Moscow, Russia
- P. Apel, Joint Institute for Nuclear Research (Dubna, Russia)
- Dr T. Saito, NMIJ : National metrology Insitute 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)
- Udo Schuehle, Max Planck Insitute (Lindau, Germany)
- M. Richter and F. Scholtze, PTB (Berlin, Germany)
- L. Duvet, ESTEC, NL

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

- Dr C. Hermans, D. Bolsee, Belgian Institute for Space Aeronomy
- Dr K. Haenen, Dr V. Mortet, IMO, Diepenbeek
- Pawel E. Malinowski, Kyriaki Minoglou, Piet de Moor, C. Van Hoof, J. Roggen, IMEC, Leuven

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

- BOLD ESA-GSTP
- ROB STCE
- PRODEX (SIDC Data Exploitation and EUI PEA)

V.5.6. Scientific outreach

Meeting presentations

[1] **A. BenMoussa** (Invited speaker)
Recent developments on wide bandgap based UV sensors.
Diamond 2008, 19th European conference, 7-11 September Stiges, Spain,

[2] **Pylyser, Hochedez**
S.O.-EUI Status Update December 2008 (talk)
BOLD CDR, 1 December 2008, IMEC Leuven

[3] **Giordanengo, Benmoussa, Hochedez,** Soltani, de Moor, Minoglou, Malinowski, Duboz, Chong, Zou, Zhang, Lee, Dahal, Li, Lin, Jiang
Recent ROB debelopments on Wide bandgap UV sensors (talk)
CNES workshop in Nice "détecteurs pour l'astrophysique", 17-20 November 2008, Nice, F

[4] **A. BenMoussa, B. Nicula, B. Giordanengo, M. Dominique, D. Berghmans, J.-F. Hochedez**
Development of Advanced Technologies for Solar Observations (talk)
STCE KOM, March 2008

Wikis and Websites

- http://bold.sidc.be

V.5.7. Missions

Assemblies, symposia: B. Giordanengo (CNES workshop "détecteurs astrophysique")

A. BenMoussa (Diamond 2008)

Commissions, working groups (days): J.-F. Hochedez (2)
A. BenMoussa (9)
B. Giordanengo (2)

V.6. Solar Orbiter and EUI

V.6.1. Objectives

Solar Orbiter (S.O.) is going to be the major solar and heliophysics ESA space mission after SOHO. It is planned for launch in 2017. Thanks to several attributes of its orbit, it will offer unique new observations. Its highly eccentic orbit with perihelion at 0.22AU will eventually be elevated out of the ecliptic plane up to 30 degrees. From those exclusive vantage points its payload of remote sensing and in-situ instruments will take advantage of proximity, high resolution and co-rotation to return data detailing previously unexplored regions of the Sun in unprecedented detail. SIDC has developed special interest for EUI, the suite of UV telescopes, in line with our heritage and expertise.

V.6.2. Progress and results

V.6.2.1. EUI proposal and interactions with the Consortium and ESA

In the first half of January 2008, the Solar Orbiter EUI proposal was finalized. The EUI team at SIDC wrote several sections and discussed the comments of the Red Team. As PI, J-F Hochedez wrote the management and financial plans, cover letter, and submitted the proposal on 15 January. [84]. On 1 February, the Belgian EUI KOM was held at CSL. During the rest of 2008, the main issue has been the mass budget descope, later requested formally by ESA on 2 July. It led to a dual band 2 HRI +1 FSI configuration, of which the mass was re-estimated. All solutions have been thoroughly compared to each others on 25 August at CSL. An important EUI meeting occurred at ESA HQ on 24 October when the PI updated ESA with the EUI consortium status and defended the selected instrument configuration. This meeting was successful. Another meeting occurred at CSL on 11 December to finalize the feasibility of the demanding mass budget descope.

All along 2008, the communication with the Consortium partners has been insured via monthly telecons (29 May, 27 Aug, 28 Aug, 24 Sep, 20 Oct, 23 Oct, 26 Nov, and 17 Dec) and emails. An internal ROB EUI PR meeting occurred on 17/4. The SIDC team prepared an EUI web site, but following an ESA request, it could not be released until the official EUI selection.

V.6.2.2. Detectors for EUI

One of the main Belgian contributions to EUI is its imaging detectors. We received a project offer from E2V in January 2008. A meeting occurred on 27/2 to refine the detectors specification. A Detector WG (DWG) telecom occurred on 18/3 as well as an IMEC-ROB-CSL meeting on 19/3. A dedicated meeting was held at BELSPO on 17/9. Contacts with the CMOSIS Company happened in the autumn. A draft SOW was sent to ESA on 7/10. A CMOSIS-ROB-CSL telecom occurred on 10/10 and an ESA-ROB-CSL telecom on 28 November. A meeting was held at CMOSIS on 15 December. It was decided that CSL would be prime for the detector pre-development.

V.6.2.3. Compression for EUI

One main Belgian contribution to EUI is its image compression system (EOCS). JF Hochedez, S. Gissot and V. Delouille visited the IntoPIX Company on 10/4. After much communication, we wrote a draft SOW on 24/9 and setup more intense collaboration with MSSL on that subject on 2/11. New versions of the SOW for the 'EOCS1' project were proposed to PRODEX on 20/11 and on 10/12.

V.6.2.4. Miscellaneous

J-F Hochedez was invited to be a member of the SLIM radiometer onboard Solar Orbiter, and a co-I of the GIHRI proposal submitted to NASA in SMEX FOSO (PI L. Golub). GIHRI was to be integrated as part of EUI. Their common mass budget consolidation was made from March to June when the EUI PI sent the outcome to the ESA S.O. project manager. On 1 Septembre, the launch of Solar Orbiter was decided to be postponed till 2017. A third Solar Orbiter workshop (SO3) has been suggested in October 2008.

V.6.3. Perspective for next years

A first ESA review (ISRR) is expected in 2009, followed by IPDR in 2010.

The development activities concerning detectors (APSOLUTE) and compression (EOCS1) are needed to start in 2009 in order to meet the TRL5 requirement.

V.6.4. Personnel involved

Scientific staff: J.-F. Hochedez (Principal Investigator, ROB permanent)
E. Pylyser (Local Project Manager, Solar Orbiter PEA)
A. Verdini (scientist, Solar Orbiter PEA)
B. Giordanengo (detectors, Solar Orbiter PEA)
A. BenMoussa (detectors, Solar Orbiter PEA)
S. Gissot (algorithms, SIDC Exploitation PEA)
V. Delouille (algorithms, SIDC Exploitation PEA)
S. Parenti (scientist, SIDC Exploitation PEA)

V.6.5. Partnerships

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

- Richard Marsden, Philippe Kletzkine, Danielle Renton, M. Coradini, ESA
- Leon Golub, Ed DeLuca, and the SAO GIHRI team members
- Udo Schühle, Luca Teriaca, Werner Curdt, Sami Solanki, Eckart Marsch, and the MPS EUI team members, Max-Planck Institute für Sonnensystemforschung, Germany
- Louise Harra, Sarah Matthews, Lidia Van Driel, and the MSSL EUI team members, Mullard Space Sciences Laboratory, University College of London, UK
- Thierry Appourchaux, Frédéric Auchère, Jean-Claude Vial, and the IAS EUI team members, Institut d'Astrophysique Spatiale, France
- Institut d'Optique (France)

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

- Pierre Rochus, Jean-Marc Defise, Jean-Philippe Halain, and EUI team members, CSL, Liège
- François-Olivier Devaux, Antonin Descampe, Université catholique de Louvain & IntoPIX, LLN
- L. Hermans, J. Bogaerts, T. Baeyens, CMOSIS, Antwerpen

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

- PRODEX (EUI PEA and SIDC Data Exploitation PEA)
- ROB-STCE

Visitors:

V.6.6. Scientific outreach

Meeting presentations

[1] Hochedez, J.-F.
Imaging detectors for S.O. EUI
BELSPO meeting on EUI detectors, 17 September 2008

[2] **Hochedez, J.-F.** and the EUI consortium
S.O.-EUI : January - October 2008
ESA EUI meeting at ESA HQ, 24 October 2008

Wikis and Websites

- http://eui.sidc.be

V.6.7. Missions

Assemblies, symposia:	J.-F. Hochedez (SMESE workshop, SOC member) E. Pylyser (SMESE workshop) E. Pylyser (Astrophysics and Astronomy Day, Brussels) E. Pylyser (8th European Mars Convention 8, Antwerp) E. Pylyser (12th European Solar Physics Meeting, Freiburg) E. Pylyser (5th European Space Weather Week, Brussels)
Commissions, working groups (days):	J.-F. Hochedez (3)
Research visits (days):	J.-F. Hochedez (7) E. Pylyser (6) A. BenMoussa (3) A. Verdini (1)

W. Instrument operations, data handling and services

W.1. Solar optical observations (Uccle Solar Equatorial Table)

W.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 main axes:

- 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)

W.1.2. Progress and results

W.1.2.1. USET staff

There was no evolution of the observing and technical team in 2008. In December 2008, Olivier Boulvin was selected for the permanent position left vacant by G.Evrard, after many years with contractual status.

W.1.2.2. Solar optical observations and operational duties

- 2008 statistics for the visual sunspot observations:
  - The number of observing days in 2008 was again lower than on the previous year, though only slightly (-4 days: 67% duty cycle). The number of drawings was significantly lower than in 2007 due to the large number of spotless days (one single drawing per day).

- All observations were done by only 6 "core" observers, i.e. much less than on previous years. This marks the return to a normal observing team, following the recruiting of two vacant positions late in 2007. Occasional voluntary observers are no more needed to ensure the continuity of the observing service, which also helps to improve the consistency of the observations.

Observer	Nb. duty days	Nb. days with no observations	Nb. days with observations	1 drawing	2 drawings	Total nb. Of drawings
Berghmans	3	1	2	2	0	2
Boulvin	86.5	29.5	57	41	21	83
Clette	2	0	2	2	0	2
Ergen	77	20	57	50	7	64
Lemaître	109	39	70	59	11	81
Vanraes	87.5	29.5	58	51	7	65
Total	**365**	**119**	**246**	**205**	**46**	**297**

- 2008 statistics for the CCD observations:
  - Less white-light images were produced in 2008 than in 2007, due to the absence of any sunspots during extended periods of time.
  - For the Hα channel, we switched from the old telescope (1Kx1K images, Lyot filter) to the new telescope (2Kx2K images, Fabry-Pérot monochromator) in January 2008.
  - For the white-light channel, we switched from the old 1Kx1K camera to the new 2Kx2K camera in June 2008.

Camera	Nb. Days	Nb. Images
Photosphere	246	785
Chromosphere	246	1054
Total	**246**	**1849**

- Telescope operation and maintenance:
  - Equipement failures: the new H-alpha filter suffered from random malfunctions by mid-2008. The control electronics were finally replaced under warranty by October 2008 with almost no impact on the continuity of the observations. Since then, the filter operated flawlessly.

- Regular maintenance: this work involved again lubrication, optical cleaning and regular refocusing of the telescopes. As no action was taken by the Régie des Bâtiments to do repairs, the solar dome still suffered from water leaks on rainy days.

W.1.2.3. Data processing and distribution

- Sunspot drawings:
  - Real-time quicklook drawings: the Uccle sunspot drawings were scanned immediately after the observations, included in near-real time in the "Latest Solar Data" web page of the SIDC, together with drawings from the Catania, Locarno and Crimea observatories and also in the USET Web pages and archive.
  - The monthly processing of Uccle sunspot observations (Uccle sunspot indices, sunspot group classification, quality control) took place flawlessly except for a software malfunction in October 2008 caused by three successive spotless Carrington rotations, an exceptional circumstance (July, August and September 2008). The resulting Uccle sunpot indices and sunspot group evolution data are published in the monthly SIDC "Sunspot bulletin" (page 4).
- CCD images: CCD images from the different telescopes are transferred automatically to a dedicated archive. The base FITS files are converted into PNG image files after reformatting to a constant intensity scale and constant scale (disk centered). In 2008, the IDL conversion software was upgraded to accept different image formats, following the introduction of the new CCD cameras. Those images are displayed as quicklook images on the USET front Web page and are used as preview thumbnail images for the archive query tool (Fig. 6).

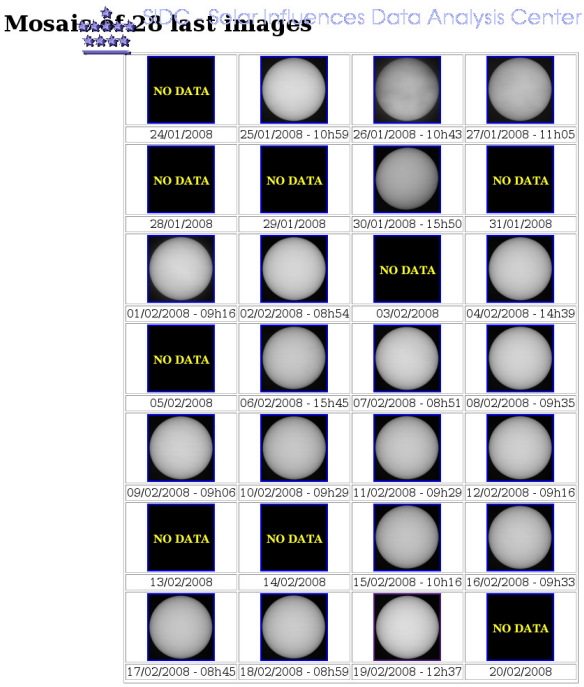


Figure 57: One of the graphical user interfaces of the USET Web site giving direct access to quicklook images acquired over the last solar rotation. It also gives a direct overview of the days with and without observations in Uccle.

- USET web site: beyond the normal daily maintenance of the pages and the monitoring of the data flow, there was no significant development of the USET web pages. No significant disruption occurred in the course of 2008 although data were not refreshed for a few hours or days on several occasions. The USET data interface still lacks visibility as the USET page is still located in a secondary subsection of the main SIDC page.

W.1.2.4. 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). It was officially accepted by June 2008 with Nov. 1st, 2008 as the starting date. In 2008, we actively took part in the SOTERIA kick-off meeting that was organized during the 5th ESWW. F. Clette presented a talk outlining the ROB contribution to WP2. Our SOTERIA participation includes three main work items:

- 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 items are relevant to this section. Namely:

- Global digitization:
  - Digitizing software: the existing DIGISUN program, already used routinely for the current drawing digitization and encoding, was rewritten and improved: better user interface and flexibility in the output format of data files. This work also forms the first step of the development of a new version of this application that will be adapted to the bulk digitization of drawing collections. This application should be adaptable to other drawings collections in the SOTERIA context and beyond.
  - Data exploitation and active region database: this mainly involves the development of a new program for the group tracking, in replacement of the existing SOLKOP program, the last but major software piece still used for the monthly processing of the Uccle drawings. This requires an extensive study in order to document it and recover the base algorithms that it contains and that were applied over the last 25 years to generate the published Uccle tables. In 2008. an initial draft document was prepared outlining the logic and algorithm of new group-tracking software that should succeed to SOLKOP
  - Common standard: As the output of the above sunspot encoding should be compatible with other sunspot databases generated by SOTERIA Work Package 2 (photosphere), in December 2008, F.Clette prepared an extensive list of all possible sunspot and sunspot group descriptors. This template list was submitted to the WP2 consortium in order to constitute a reference document and a common format that can address the needs of all WP2 members and will facilitate the exploration of new solar activity indices.
- Routine production of photospheric and chromospheric image:
  - This work is already in progress and well advanced in the framework of an expiring LOTTO budget (see above). In order to address the needs of SOTERIA and in particular Work Package 6, special efforts will be done at the level of data distribution (archive, database and WEB access).

In parallel with the SOTERIA context, preliminary contacts were established with the solar team of the Astronomical Institute in Tatranska Lomnica (J. Ribak) and with the Specola Solare Ticinense (M. Bianda, S. Cortesi) in order to prepare a coordinated digitization of other drawing collections, covering complemntary time intervals next to the Uccle drawings.

W.1.3. Perspective for next years

The future priorities will be:

- Continuation of the USET observations, data processing and data distribution.
- Commissioning and exploitation of a new CaII-K telescope.
- Software development:
  - Development of new programs for the selection and pre-processing of high-cadence images from the 3 new camera systems.
  - Implementation of systematic procedures for the determination of the camera dark level and flat-field, which will be used in the routine observations of the new cameras.
  - Upgrade and reorganization of the USET web pages (with O. Lemaître).
- Long-term sunspot data exploitation in the context of the SOTERIA project:

- Software development: Development of a new application for sunspot drawing digitization adapted to the bulk digitization of drawing collections.
- 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.
- Development of a new program for the group tracking, in replacement of the existing SOLKOP program.
- Study of new image-based activity indices derived from solar images of the photosphere (CCD, photographic): initial data sets (USET, SOHO/MDI).

W.1.4. Personnel involved

Scientific staff: F. Clette (Lead scientist, instrument design & development, permanent ROB staff)

Technical staff: J-L. Dufond (Engineer-technician: electronics, permament ROB staff)
S. Vanraes (ICT, programmer, observer, permanent ROB staff)
A. Ergen (Technician: electronics, permanent ROB staff)
O. Boulvin (Operator-observer; permanent ROB staff)
O. Lemaître (Operator-observer, permanent ROB staff)

W.1.5. Partnerships

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

- M. Bianda, IRSOL-Specola Solare Ticinense, Switzerland

Grants/Projects used for this research/service

- SOTERIA "SOlar-TERrestrial Investigations and Archives" project (EU 7th Framework Program, Nov.2008- Oct. 2010)

W.1.6. Scientific outreach

Meeting presentations

[1] F. Clette
SOTERIA WP2 Photosphere: ROB contribution
SOTERIA kick-off meeting, Work Package 2 session, 17-21/11/2008 (5th ESW Week, Royal Library, Brussels).

Wikis and Websites

- Development of a new USET Web data access page featuring visual data query tool (preview thumbnail images) and a whole-rotation navigator (mosaic, movie, sliding strip). Via an SQL database, it gives access to the whole USET archive of CCD images as well as the scans of USET drawings. (URL: www.sidc.be/USET)

W.1.7. Missions

Commissions, working groups:

- SOTERIA kick-off meeting, 17-21/11/2008 (5th European Space Weather Week, Brussels).

W.2.Solar radioelectric observations at the Humain station

W.2.1. Objectives

The radiotelescopes at the Humain station provide radioelectric observations of the Sun for the monitoring and study of solar flares and coronal mass ejections (CMEs) and the long-term recording of the absolute solar radio flux in the upper-chromosphere and low corona for the production of long-term solar ac-

tivity indices and irradiance proxies. The ongoing modernization of this facility will bring the following capabilities:

- The integrated absolute radio flux at 600 MHz, and future extension to other frequencies, including 2,8Ghz (10.7 cm flux). This work builds on the expertise of the SIDC regarding long-term solar reference indices.
- Radio spectrograms of radio bursts in the 30MHz-3GHz range (CALLISTO), for flare and CME monitoring and diagnostics.
- Near-real time transmission and processing of the Humain data in support to the SIDC solar flare monitoring.

The new radio observations will also be complementary with the SWAP and LYRA data from the PROBA2 mission and will provide base solar data supporting the STCE activities.

W.2.2. Progress and results

W.2.2.1. Radioastronomy team

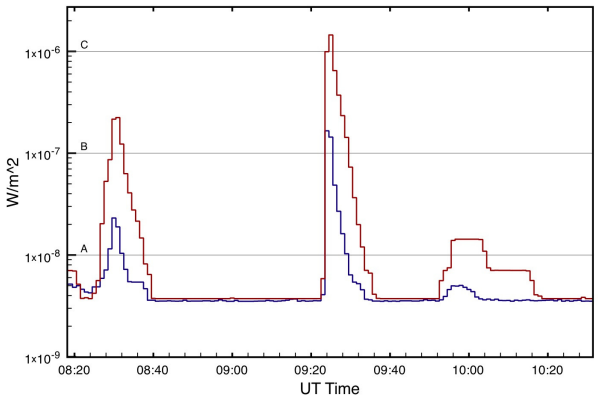
The newly recruited radioastronomer, Christophe Marqué (Jan. 2008), allowed to start the actual redeployment of solar radio instruments at the Humain station in the context of the Solar-terrestrial Center of Excellence (STCE). He could also take over a number of tasks associated with radio instruments that were previously relying entirely on F.Clette, as unique scientist. This year, F.Clette thus assumed mainly the overall management, the coordination with external collaborators and all actions relative to the protection of the radio spectrum.

W.2.2.2. Instrument operations and maintenance

Most of the efforts are now concentrated into the construction of an entirely new set of instruments that will progressively be put in operation over the next 3 years. In the current timeline, radio flux measurements will start to be produced only in 2010 or 2011.

On the other hand, the first CALLISTO spectrograph was commissioned in May 2008. The current configuration uses a log-periodic antenna mounted in parallel with one of the 6m-parabola. From May to mid-November, the receiver was set up to monitor its whole frequency range (45-870 MHz) in order to establish the sources of artificial interferences (RFI; see section on instrumentation).

Since November, the receiver has been used in routine operation using only the lower part of the spectrum (45-82 MHz) until proper filters are installed for the range 100-500MHz in 2009. Due to the very low solar activity, it is only by Dec. 11, 2008 that a first minor radio burst occurred. This was a weak event but it was detected by the Humain radiotelescope as well as by two other CALLISTO stations, confirming that the receiver works properly with sufficient sensitivity (Fig. 7).



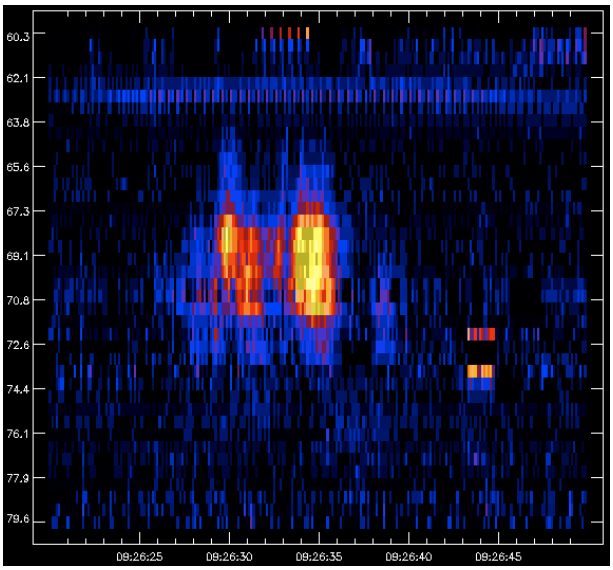


Figure 58: C-class flare of Dec. 11th 2008 (top) associated with the first radio burst (right) observed in Humain with the Callisto receiver

W.2.2.3. Data processing and distribution

- Data transmission and remote control: a new portable PC was purchased for CALLISTO receiver control and spectrum acquisition. It runs the standard receiver control software and has been configured to transmit the acquired data to the ROB in real time via the ADSL connection (downloads every 15 minutes).
- CALLISTO website: by November 2008, a dedicated Web page was implemented. It displays graphically the Humain radio spectra in near real time. In addition, the ETH Zürich downloads data from all CALLISTO receivers around the world (including Humain) when there is a solar event and makes them available on a dedicated website named DIRAC (http://pandora.ethz.ch:8080/frontend/). Following a request from the ETH, we agreed to take over this central data-dsitribution website in the course of 2009.

W.2.2.4. Preservation of the site quality and protection of the radioelectric spectrum

- CRAF (Committee on Radio Astronomy Frequencies, ESF): in 2008, we took an increasingly active role in this organization. C. Marqué attended the 46th CRAF Council meeting (Thessaloniki, Greece, 17-18/4/2008). A proposal to host the next CRAF meeting at the ROB was accepted. The 47th CRAF meeting thus took place at the ROB on Nov. 12-14, 2008. During this meeting, a visit to the Humain station was organized on Nov.13 for all radioastronomers attending the meeting. The visit was highly appreciated by the 20 participants. Taking advantage of the location in Brussels, a special round table was organized at the end of the meeting to allow direct discussions with EU officials: Frank Greco (Deputy Head of the Radio Spectrum Unit, EC), Ari Sorsaniemi (Radio Spectrum Unit, EC), Alain van Gaever (Policy Development and regulatory Framework, EC), E. Righi (Scientific Project Officer EC and in particular of RadioNet), Mats Gyllenberg (new ESF-PESC Chair). Two representatives of the BIPT, M. Vandroogenbroek and G. De Laet , also attended this meeting.
- BIPT (Belgian Institute for Post and Telecommunication):
  - We continued to answer to frequency allocation requests from the IBPT
  - We invited BIPT representatives to the 47th CRAF meeting and to the associated visit of the Humain site (cf. above), in order to inform them better about our present and future activities and increase their awareness of specific needs of radioastronomy.
- Lhoist Industries: New negotiations took place with the local and General Directors of the Lhoist company concerning the future extension of the quarry located near the Humain station.

- URSI (Union Radio Scientifique Internationale): as member of the URSI Commission J (radio-astronomy), F.Clette continued to act as URSI representative to the FAGS Council, which emphasizes the current connection between solar radioastronomy and operational space-weather services. He participated to the Belgian URSI Committee, in particular with an oral presentation of the new radioastronomy projects at the Humain station during the joint Belgian-Dutch URSI forum in May 2008.

W.2.2.5. LOFAR

During the URSI General Assembly, we were approached by colleagues from the LOFAR project (ASTRON, Netherlands) about possible collaborations oriented towards solar physics (metric radio bursts). This led to a first informal meeting at the ROB on Nov. 21, 2008 with two LOFAR representatives. Delegations of the Dourbes station (RMI) and of the ROB-GNSS Group were also present at this meeting. Now major perspective emerged from the conclusions, in part because no substantial budget is available on the Belgian side.

W.2.3. Perspective for next years

The main tasks for 2009 will be:

- Continuation of the redeployment work of new radiotelescopes and recruiting of new staff (technician, ICT).
- CALLISTO:
  - Implementation of a remote control system allowing unattended operation of the radiotelescope directly from Brussels. This also involves the installation of a GPS-based clock for providing an accurate time reference.
  - Improvement of the RFI rejection (HF filters) and extension of the measured frequency range to 500MHz.
- Absolute solar flux monitors: in 2009, the development and testing of the new-generation solar flux monitors should make its actual start, once the Canadian team will secure its funding:
- Radio protection of the Humain site (CRAF, BIPT, etc.)

W.2.4. Personnel involved

Scientific staff:	F.Clette (Global mangement, ROB permanent staff)
	C. Marqué (Lead scientist, radioastronomer, STCE)
Technical staff:	J-L. Dufond (Engineer technician, electronics, ROB permament staff)
	A. Ergen (Technician, electronics, ROB permanent staff)
	Janssens, Paul (Local intendant/gardener, ROB permanent staff)

W.2.5. Partnerships

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

- Dr Arnold Benz & Eng. Christian Monstein, Eidgenössische Technische Hochschule (ETH), Zürich, Switzerland.
- Dr Kenneth Tapping, Dominion Radio Astrophysical Observatory, Penticton (Ottawa), Canada.
- Dr. David Boteler, Geological Survey of Canada, Ottawa, Canada
- Dr Roberto Ambrosini, Instituto de Radioastronomia, Bologna, Italia

Grants/Projects used for this research/service

- STCE: work package 2 “Ground-based Observations”

Visitors:

- Short visits:
  - CRAF Council meeting , 12-14/11/2008: 25 visitors

- LOFAR meeting, 21/11/2008: 2 visitors
- Associated scientists: 3 visitors

W.2.6. Scientific outreach

Meeting presentations

[1] C. Marqué, F. Clette, J.-L. Dufond, A. Ergen
New developments of solar radio observations in Belgium)
European Space Weather Week 5, Brussels, Belgium, 17-21/11/2008 (poster)

Seminars

[2] **F.Clette**
Four centuries of sunspot index: from Wolf to the SIDC
Geological Survey of Canada (D. Boteler, Ottawa), 20-21/8/2008.

Wikis and Websites

- Website to access near-real time Humain observations as well as past archived data (quick-look and FITS files). C. Marqué was helped by L. Wauters and O. Lemaître. URL: http://sidc.be/humain

W.2.7. Missions

Assemblies, symposia:
- C. Marqué: Meeting SMESE, Paris, March 10-12 2008
- C. Marqué: COSPAR General Assembly, Montreal, July 13-20 2008
- F.Clette: URSI General Assembly, Chicago, USA, 10-16/8/2008.

Commissions, working groups:
- C. Marqué: 46th CRAF Council Meeting, Thessaloniki, April 17-18 2008
- F. Clette: 47th CRAF Council Meeting, ROB, Brussels, 12-14/11/2008 (Meeting organizer).
- F.Clette: Belgian URSI Committee meeting, Palace of Academies, 16/12/2008

W.3.Space weather Regional Warning Center

W.3.1. 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.

W.3.2. Progress and results

W.3.2.1. Internal Management

The RWC activities are now supported by the STCE ROB WP1.
Communication acts on two levels: internal and external. Good Internal communication is one of the necessities to perform well. A website, regular meetings, email contact, (in)formal live contacts, ... can contribute to a good internal communication. The RWC-performance is being guided by the RWCWDC-wiki (http://sol042.oma.be:8000:RWCWDC), regular internal meetings and a more general SIDC consultation meeting [18] open for the whole departement. With open communication in mind, the departement 4 days were organized. The RWC was presented as an operational service [12], [13], [14], [15], [16], [17].

W.3.2.2. External Management

The RWC Belgium was represented on several meetings and reunions relevant for the space weather business. R. Van der Linden introduced Space Weather as representative of the International Space Environment Service (ISES) at a UN-COPUOS meeting [1]. UN-COPUOS is the UN Committee for the Peaceful Use of Outer Space. These meetings are important for the visibility of the RWC broader then only the space weather community.
The RWC Belgium is also an important player in the ISES and FAGS structure ([2], [3], [4], [5], [7], [107]), in the present COST activities [9] and the general Space Weather community [10],[11].
Being present at international level is one of the key issues to get involved in future projects like the European Space Situational Awareness program.

W.3.2.3. Routine operations

For the RWC activities, a continuous data stream from ground-based spacecraft instruments has to be analysed and interpreted. The daily routine of RWC activities include 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. This results in publications [106] and [107].

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.

W.3.2.4. New Developments

The **Solar Weather Browser** (SWB) is a 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. A renewed effort was done on the server side of the SWB. The daily maintenance of the tool became again a priority. This included also the restorage of the downloaded Hα images from the Kanzelhohe Observatory and the preparation for inclusion of our own USET Hα and white-light data.

The **CACTus** software was developed originally to run on LASCO coronograph images. The software is also applicable on images obtained from the Sun Earth Connection Coronal and Heliospheric Investigation (SECCHI) aboard the Solar TErrestrial RElations Observatory (STEREO) Ahead and Behind. STEREO is a fleet of two identical spacecrafts. We have now the ability to watch coronal mass ejections from 3 points of view: STEREO Behind, SOHO and STEREO Ahead. Given the seperation angle in 2008 between the two satellites, COR1 and COR2 from the SECCHI-package give us the possibility to provide a

more precise estimate of the speed of an earthward directed CME. Combining remote and in situ data of the three spacecrafts, we are able follow in some cases a CME on its path through space.

We illustrate this with an example in Figure 59 and Figure 60. On Apr 26, 2008, a prominence eruption took place. The event was associated with a B3.8 flare peaking at 14:08 UT. A CME was detected in the LASCO-images. CACTus detected a partial halo CME in the LASCO-images. A solar surface EUV-wave, a 'solar tsunami' combined with a coronal dimming was clearly visible in the SOHO/EIT and STEREO/EUVI images. “NEMO” (Novel EIT wave Machine Observing) scans systematically the many thousands of images searching for EUV-waves as a proof of a CME. A structure preliminarily identified as an interplanetary shock was detected by ACE on Apr 30 around 15:00 UT. It marked the arrival of an interplanetary disturbance associated with a partial halo CME on Apr 26. The interplanetary CME (ICME) itself seemed to have missed the earth, and only the plasma shock wave was detected. The interplanetary magnetic field went down to -8 nT in the aftermath of the shock. Disturbed geomagnetic conditions (K=5 reported by IZMIRAN and NOAA and K=4 by Dourbes) were registered. The complete STEREO/SECCHI instrument suite detected the CME: EUVI, COR1-2 and HI1-2. HI-2 onboard STEREO Ahead had a nice side-way view on the cloud traveling through space and pictured the moment the erupted prominence reached earth. In situ solar wind data made clear that one leg of the cloud passed STEREO Behind on Apr 29, the shock passed ACE on Apr 30, while STEREO Ahead measured only a minor change in the solar wind parameters early on Apr 30.

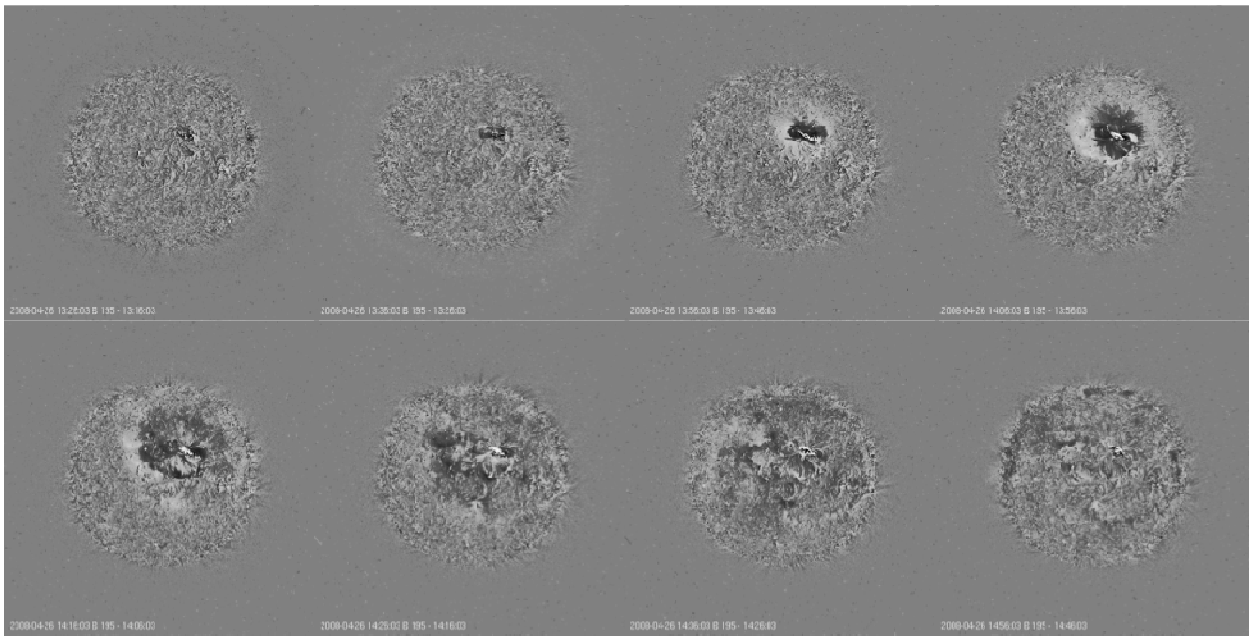


Figure 59: ***This is a sequence of difference images from the EUVI telescope aboard of the STEREO Behind. By taking the difference of two succeeding images, the changing's become visible. A solar tsunami or EUV-wave is visible. The tsunami runs over the solar disk. An EUV-wave is a signature of a CME.***

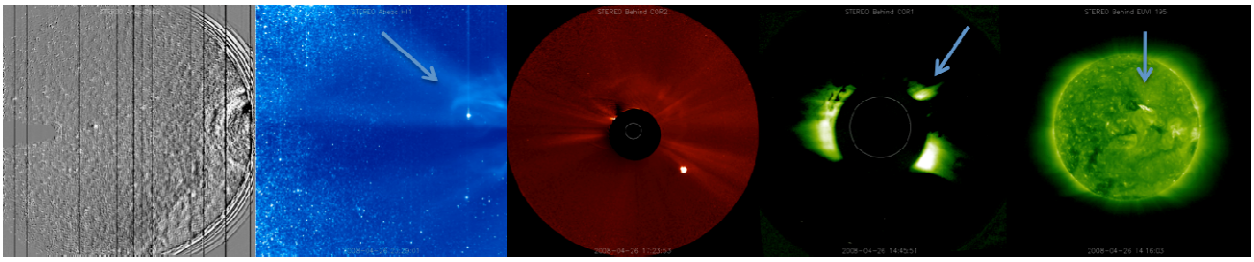


Figure 60: ***The eruption and the plasma cloud was seen by the complte SECCHI set of telescopes. From right to left: EUVI, COR1, COR2, HI1 and HI2. The first three images mentioned are taken by STEREO B. The last two images are taken by STEREO A and give a side view of the plasma cloud. On HI1 and HI2, the Earth on the left***

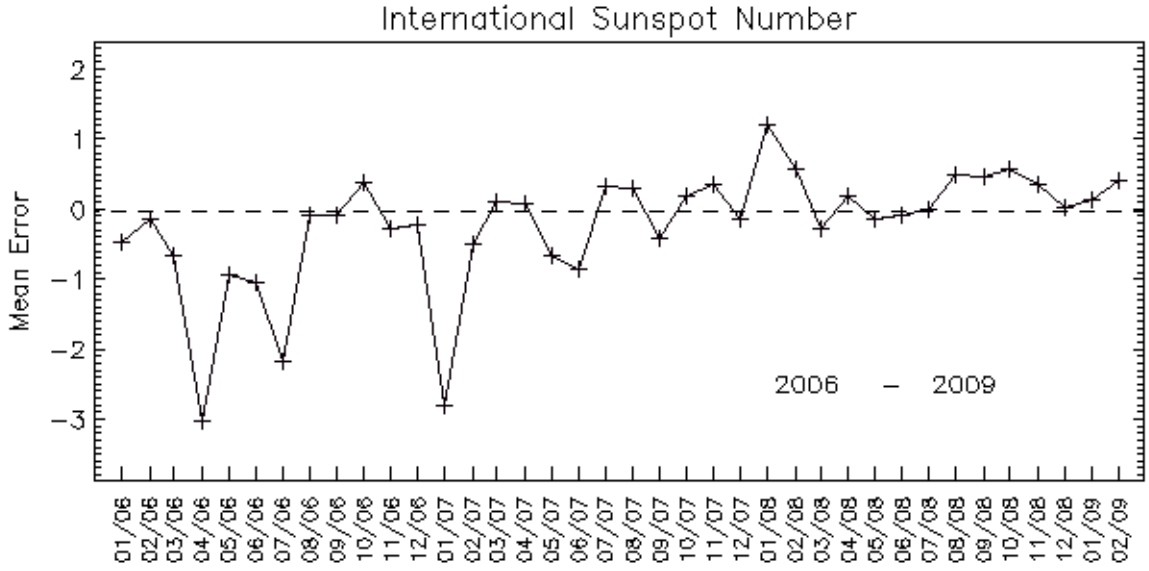
side of the image is behind the occulter. In EUVI, we see the post flare loops. The cloud passed COR1 and COR2 in which is appears as a halo CME, i.e. directed to the observer

NEMO (Novel EIT wave Machine Observing), a new software package for detection of EIT waves forms one block of the Space Weather software package together with CACTus (the CME detector which works with coronograph data). NEMO consists of a series of high level image processing techniques especially developed to extract eruptive features from the EUV solar disk. This technique is based on the general statistical properties and underlying physics of eruptive on-disk events. Such events are tell-tale signs of coronal mass ejections that are not always seen by coronographs.

NEMO runs automatically on a daily basis. The real time results are made available online: http://sidc.be/nemo. If the CME is associated with a flare, the profile of the X-ray flux curve gives an indication of the fact that an eruptive plasma event occurred. The type of radio outburst is another way to identify CMEs. NEMO gives also a clear indication of the strength of the event. NEMO runs on EIT and STEREO data.

All **monthly reports** from 1981 **are archived** in a digital form and available online in pdf-format. From 1981, when the SIDC as Sunspot Index Data Center was founded, up to the end of 2000, the bulletin reported the Provisional International and hemispheric daily sunspot numbers: daily, monthly and the summary of the ursigrams. From Jan 2001 onwards, the report was extended with the section 'Monthly Summary of Solar and Geomagnetic Activity'.

The evaluation of the **Estimated International Sunspot Number** (EISN) is updated. The EISN is a solar activity index calculated on a daily basis. This solar activity index is sent within the ursigrams. The sunspot counts that are inserted by the observer before 12:30 UT in the Wolf database are used as input. The monthly mean error and monthly mean square error are made internally available through previweb. We compare the EISN with the daily Provisional International Sunspot Number (PISN) in Figure 61.



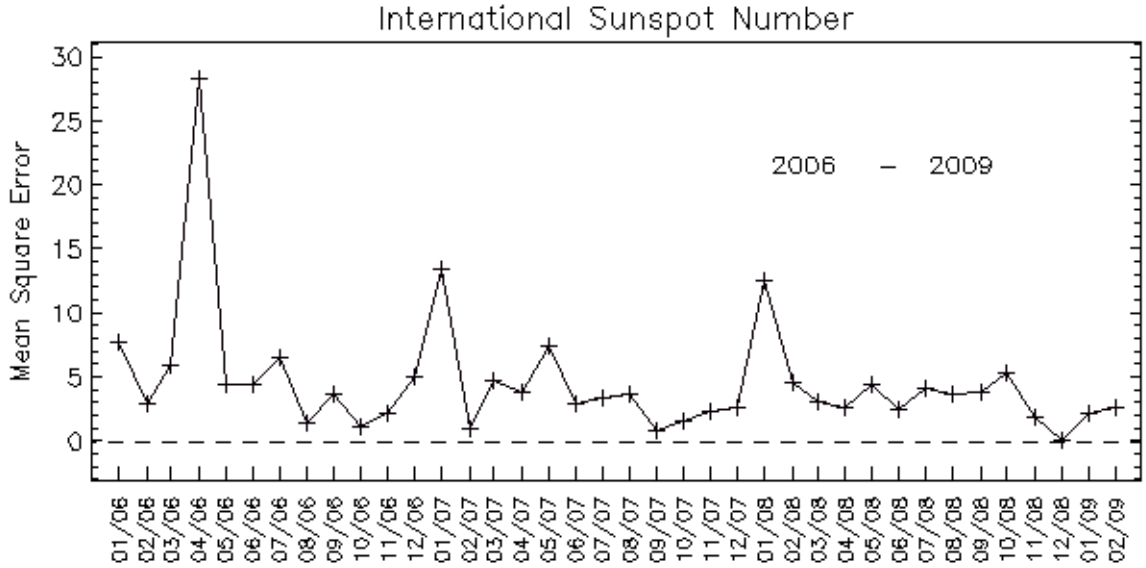


Figure 61: The monthly mean error and monthly mean square error of the Estimated International Sunspot Number is shown from Jan 2006 up to the present. The mean error is calculated as the mean of (PISN – EISN). Values below zero indicate that the EISN underestimates the International Sunspot Index. The mean square error makes it easy to compare individual months: during Jan 2008, the EISN gave an almost perfect estimate of the PISN.

W.3.2.5. Organisation of Meetings, Events and Public Outreach

The RWC concerns the involvement of the scientific space weather community, commercial and amateur organizations and the general public. Special attention is given to the users. This human aspect triggers the necessicity of *space weather education* and awareness of society. In view of this, the RWC pays special attention to publicity and promotion of space weather and related activities. Our **website** is the ultimate window to the space weather community and the public on which for example on a regular basis 'News Items' are posted.

E. Podladchikova got the internationally recognized Zeldovich medal during the COSPAR conference in Canada. The medal is conferred for excellence and achievements. D. Berghmans and his colleagues in the EIT-consortium were nominated for the prestigious European Descartes prizes for the unique and excelling contributions to solar physics and space research.

Contrary to the level of solar activity, 2008 was filled with excitement about the absence of sunspots, the duration of the solar minimum, the observational differences between pores and sunspots, the treatment of the International Sunspot Index. Wrong interpretations of the International Sunspot Index about the calculation and about the content of the index itself, led to speculative remarks and unscientific statements. We tried to clarify those issues on amateur websites dedicated to sunspots. We published the text 'The sunspot number clarified'. Questions from Belgian observers were addressed during an oral presentation. We started with a gathering of a solar dictionary. The goal is also to have a scientific publication. When observers, scientists or simply interested people need information about sunspots, this publication can serve as a unique reference.

The planetarium@Heizel is creating a Space Weather Show. Scientists of the SIDC were members of the panel that had to correct the scientific content of the scenario. The scenarist found his inspiration from the daily routine work done at our Regional Warning Center. There have been several iterations on the script.

A series of educative information sessions was given to local amateur astronomers about Space Weather, as well as publications in popular science magazines. Besides the general public, the communication with the scientific community is also a goal. School for PhD-students, scientists in general are an easy platform [6].

Several scientists are involved in the project: 'www.ikhebenvraag.be'. This is an initiative of the Royal Belgian Institute of natural sciences with the support of the 'actieplan wetenschapsinformatie en innova-

tie', the Flemish goverment. Space Weather Scientists answer questions related to the topic of solar physics: space, Sun, space weather.

W.3.2.6. The fifth European Space Weather Week

The fifth edition of the European Space Weather Week took place in Brussels, Nov 17-21, 2008. The Space Weather week brings together the different space weather actors in Europe: scientists, commercial entities and end-users. The keywords of this year: the ESA Space Situational Awareness action, GNSS, offshore drilling, magnetic surveying and geomagnetism, space weather models, data-tools-services, solar weather. The logo is presented in Figure 62.

Figure 62: The logo of the European Space Weather Week, designed by W. Vander Putte@planetarium, Heizel. It shows the Earth in the grip of the Sun. The logo is easy to interpret and the trading brand of the esww.

Besides the large number of participants (222), the success of the conference was reflected by the numerous splinters (10) and side meetings (8). The European Space Weather Week offered a convenient platform to discuss past and future collaborations. Also some special events were organized. The Space Weather Tutorial 'Space Weather: ingredients, effects' together with the review in the form of a quiz, focused on students and people new to the space weather community, see [8]. More than 60 people welcomed the new concept. The Space Weather Fair turned into a vivid workshop showing hands-on tools and concrete user-friendly space weather products. This year keynote lecture was 'A European Weathering Space in a Week in Dec 2006', given by the ESA astronaut Dr Christer Fuglesang who could interest 150 people talking about his close encounter with the SPEs of Dec 2006: a space weather expert at first hand. The contest 'the best of' was won by H. Bochnicek in the category posters and by A. Veronig in the category oral presentations. Both are young female scientists who presented their work in a clear, understandable way attracting people's attention. The press release attracted the attention of the press and resulted in several written publications in newspapers and a live radio interview.
The STCE and the SIDC are the local organizers of the esww5. The STCE manifests itself as a strong Belgian player in the international space weather community.

W.3.2.7. Scientific outreach: SIDC@esww5fair

During the fifth European Space Weather, 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 lively stand. On a daily basis, the space weather was broadcasted. Visitors could browse through solar data with the Solar Weather Browser while explanation was given by one of the forecasters. A radio antenna was installed measuring real-time the radio waves in the local environment. This was a reference to the ROB radio station in Humain, Belgium.

W.3.3. Perspective for next years

W.3.3.1. The sixth European Space Weather Week

The ESWW6 will be held on Nov 16-22, 2009 at the Royal Observatory of Belgium. R.A.M. Van der Linden and P. Vanlommel are members of the program committee. New ideas are brought in such that the space weather week becomes innovative. The new idea this time is to organize a debate 'solar influences on climate'. This for sure will attract the attention of a community much broader then the space weather oriented one.

A renewed website is online: http://www.sidc.be/esww6.

W.3.3.2. The MySQL database

A **MySQL database** contains information related to different aspects of the RWC. The database links products and users, keeps track of the daily forecast and measurements like flares, 10cm flux, and geomagnetic disturbances described by the A- and K-index. During 2009, further steps will be taken to incorporate more strongly the daily RWC processes on different levels: the public website, the private website used for the forecast, this is Previweb, and PreviMaster.

W.3.3.3. Nemo

The nemo outcome will be presented in a user-friendly form straightforward to interpret. A possibility is an automatic email alert in case of a detected EUV-wave with references to the data. This would be useful in the first place, for the forecaster on duty. The on disk info can help to distinguish between false and true CACTus-alerts.

W.3.4. Personnel involved

Scientific staff:	D. Berghmans
	R. Van der Linden
	F. Clette
	C. Marqué
	L. Rodriguez
	P. Vanlommel
	L. Wauters
	A. Zhukov
Technical staff:	O. Boulvin
	S. Willems

The daily duty cycle of forecasting and monitoring activities were shared by D. Berghmans, F. Clette, C. Marqué, L. Rodriguez, P. Vanlommel, R. Van der Linden, A. Zhukov.

W.3.5. Partnerships

List of international partners Person, Institute

- 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 724 community

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

- ROB Planetarium
- RMIB and BISA

Visitors:

- David Boteler, ISES, 27/02/2008.
- Scenarist Planetarium Space Weather show, 04/03/2008.
- M. Vandenhove, THALES, 03/09/2008.
- Nilson Sant'Anna, RWC Brazil, 24-25/11/2008

W.3.6. Scientific outreach

Meeting presentations

[1] R. Van der Linden

Space Weather: an international affair – and beyond
UN-COPUOS, February 08, Paris, France

[2] R. Van der Linden
Annual report FAGS service: the SIDC
FAGS annual meeting, April 24, Paris, France

[3] R. Van der Linden
Annual RWC report
ISES annual meeting, July 10-11, Ottawa, Canada

[4] R. Van der Linden
UNCOPUOS activity report
ISES annual meeting, July 10-11, Ottawa, Canada

[5] R. Van der Linden
RWC Belgium@Solar Influences Data Analysis Center
COSPAR, July 13-20, Montreal, Canada

[6] D. Berghmans
Sun-Earth System: Space Weather
Lecture at the STFC Summer school « Intro to Solar & Solar-Terresterial Physics », Septembre 16, Sheffield, UK.

[7] R. Van der Linden
The Belgian Solar-Terrestrial Center of Excellence: Building Space Weather Capacity in Europe
IAASS3, October 21- 23, Rome, Italy

[8] P. Vanlommel
How to become a space weather specialist in 60 minutes
ESWW5, November 16-20, Brussels, Belgium.

[9] R. Van der Linden
COST ESO803 WG2: Space Weather Products and Services
COST ESO803 Kick-off meeting, November 16-17, Brussels, Belgium.

[10] R. Van der Linden
The SIDC at the Solar-Terrestrial Center of Excellence
ESWW5, November 16-20, Brussels, Belgium.

[11] R. Van der Linden
European Resources for Space Weather Applications: An Overview of Existing and Planned Data, Tools and Services.
ESWW5, November 16-20, Brussels, Belgium.

Seminars

[12] P. Vanlommel
External services based on data: Products and User-profile
Dep 4 Days, Februari 21, Brussels, Belgium.

[13] P. Vanlommel
Scientific-Educational Public Outreach/Inreach
Dep 4 Days, Februari 21, Brussels, Belgium.

[14] S. Willems
Server structure at the SIDC
Dep 4 Days, Februari 20-21, Brussels, Belgium.

[15] L. Wauters

Database management at the RWCWDC
Dep 4 Days, Februari 20-21, Brussels, Belgium.

[16] F. Clette
Sunspots: internal, historical and future aspects
Dep 4 Days, Februari 21, Brussels, Belgium.

[17] C. Marqué
The RWC: daily forecast
Dep 4 Days, Februari 20-21, Brussels, Belgium.

[18] R. Van der Linden
The future of Space Weather at SIDC
Internal SIDC team consultation, December 18, Brussels, Belgium.

Wikis and Websites

- Internal development wiki: http://sol042.oma.be:8000:RWCWDC
- Internal development wiki: http://pb2sc.oma.be:8000/ESWW/
- http://www.sidc.be/esww5
- http://www.sidc.be/esww6
- http://www.sidc.be/

W.3.7. Missions

Assemblies, symposia:	Fifth European Space Weather Week, Brussels, Belgium COSPAR, Montreal, Canada ISES annual meeting, Ottawa Canada FAGS annual meeting, Paris, France IAASS3, Rome, Italy UN-COPUOS, Paris, France UN-COPUOS, Glasgow, UK
Commissions, working groups (days):	Space Weather Working Team (Jun 04, Nov 19)

W.4.PROBA2 Science Center

W.4.1. 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 launch has been confirmed with a launch window between July and September 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 above). 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

W.4.2. Progress and results

W.4.2.1. System Validation Tests

As foreseen, we focussed in the first few months of 2008 on the analysis of PROBA2 SVT test data. Numerous issues (bugs & misunderstandings) were discovered ([72]) and treated in subsequent runs of the SVT tests. At the present time we believe all issues have been adequately processed but final confirmation is pending due to repetitive postponement of a hopefully last SVT run (currently scheduled mid January 2009).

W.4.2.2. Improved organisation

In the course of 2008, the developments of the SWAP and LYRA teams for P2SC were brought together in a 2-month iterative development process under 1 P2SC responsible (D. Berghmans). Weekly progress meetings are organised and minuted. All project documentation is live updated at the P2SC internal wiki and stable releases are published on the SIDC documentation facility.

The P2SC development was further strengthened during the summer through the "Nationally Led Missions" program with technical support of ESA staff (J. Zender) and by the funding of the P2SC hardware. A status review on P2SC (20081013, ESTEC) was successfully passed and confirmed this set-up to be adequate.

In addition the following technical management tools have been installed:

- An internal wiki (Trac system) is operational and in full use as the basis for editing requirements, specifications, test results and meeting notes. The released documents are an extraction of this wiki.etc.
- A document management repository (Nuxeo system) is operational in full use as the reference for all released documents. The system is accessible at http://dac.oma.be:8080/nuxeo/dav/default/proba2/workspaces/p2sc-tree/
- A software repository (svn system) is operational and in full use as the reference storage of all developed p2sc software. The operational p2sc software will be a checkout of this repository.

W.4.2.3. Cycle 0: hardware installation & prototypes

The P2SC hardware was ordered in June, delivered in August and installed in September. It concerns two redundant servers, a mass storage device (RAID) and redundant optical fibre and switches for in total nearly 33k, ordered through the "National Led Missions Budget" at ESTEC.

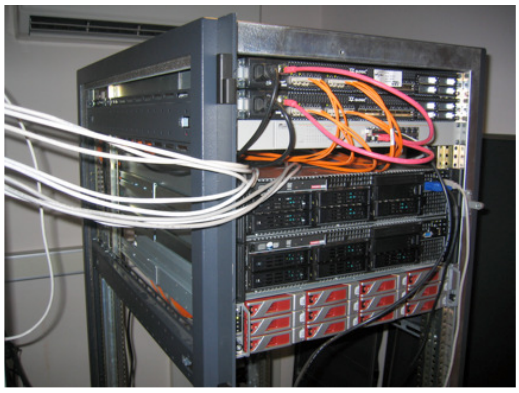


Figure 63: The P2SC hardware, installed in September 2008.

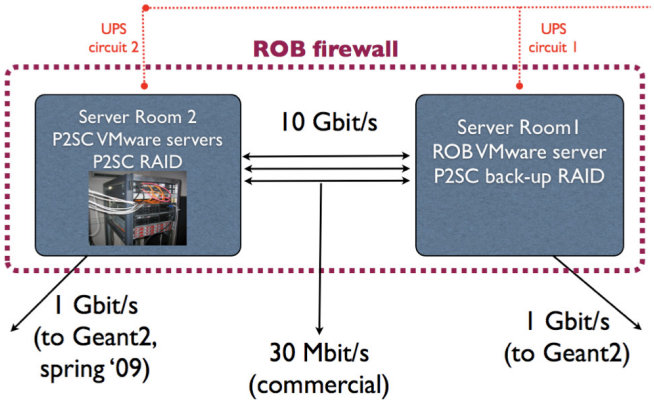


Figure 64: The P2SC as integrated in the ROB environment.

The following steps were undertaken:

- The P2SC servers, FC cabling and switches, and the mass storage device (RAID) arrived late August 2008. One device (a FC switch) was dead on arrival. It was send back to the supplier and repaired under warranty. All hardware is now functioning.
- The physical installation took place in September 2008.
- The installation of base operating systems, the virtualization layer, the operating systems of the virtual servers and the organization of the directory structure was finalized by end November 2008.
- All foreseen tests were passed successfully, except 1 test (HWTest4, MOC/SOC interface) which could not be closed formally as the IP addresses of the communicating computers cannot be frozen yet.
- A few requirements have not been tested formally (although they were implemented). This will be corrected for in cycle 2.
- The P2SC hardware is in use since late November 2008 to test the tools described below.

Following discussions with the ROB system administrators, we opted for a VMware system that runs 6 virtual servers on the 2 hardware machines. Each of the virtual servers corresponds to the various building blocks of the P2SC.

Meanwhile, prototypes of most required software tools have been developed off-line. Priority was given to those software tools that were required for the System Validation Tests such as the Planning Tool Interface and the Ancillary Data Browser.

W.4.2.4. Cycle 1: development of base infrastructure Telemetry Reformatters

Cycle 1started with the P2SC status review and formally ended at the end of December 2008. The goal was to have all software tools up and running on the P2SC servers, that directly interact with the Redu data up and running. This required also some base infrastructure on the P2SC servers to be ready (directory organization, error reporting, activity triggering). Most of this work was indeed completed but insufficient time remained available for testing and documentation. These aspects are now finalized in the first two weeks of January 2009.

The P2SC tools that were approaching completeness at the end of 2008 were:

- The Ancillary Data Processor (ADP) was finished largely by early December 2008. Yalim Mehmet took over the finalization of ADP, integration with LMAT and testing and documentation since then. ADP tests have been mostly successful; remaining issues include fine-tuning of certain requirements and subsequent delta developments. These should be completely finished early February.
- The SWAP Telemetry Reformatter (SWTMR) requirement and specifications where finished early November. The SWTMR is in an advanced state (since Dec 2007). The SWTMR was tested to compile on the P2SC servers. The current activity is to finish up the SWTMR interfaces with LMAT and to produce the formal test report.
- The LYRA Telemetry Reformatter (LYTMR) requirement and specifications where finished early November and the LYTMR is now in a finalized state. The formal testing is however delayed given the complexity of producing test data sets and delay of LMAT. The LYTMR is working well on 'good' input data. Testing with non-compliant data is postponed till early 2009.
- The Data Consistency and Validation Checker (DCVC) requirements and design were frozen mid-November. The framework of the DCVC program was finished by mid-December. Individual consistency checks are now being implemented for both SWAP and LYRA data.
- The SWAP engineer data generator (SWEDG) depends on the output of the SWTMR and the ADP and was therefore originally scheduled for cycle 2. Nevertheless, its development was advanced as much as possible to allow freezing the interface (engineering FITS files) with the developers at TCD Dublin.

W.4.3. Perspective for next years

The P2SC development is peaking towards the PROBA2 launch expected July 16 2009 when all P2SC components of the PROBA2 Science Center (P2SC) need to be completed. The following milestones are foreseen:

- Cycle 1: October 13 2008 – January 16 2009

  Main Objective: to have a core P2SC system working that can handle in a semi-automated way the SVT data.
- Cycle 2: January 19 2009 – March 20 2009

  Main objective: to have a P2SC system working that is ready for use in an End-to-End test with Redu
- Cycle 3: March 23 2009 – May 22 2009

  Main objective: to have a P2SC system working with all planning tools in place and which includes production of at least the basic science products (engineering FITS files)
- Cycle 4: May 25 2009 - July 24 2009

  Main objective: to have a P2SC system working that is ready for commissioning, including the full science pipelines.
- Cycle 5: Jul 27 2009 - Sept 25 2009

  Main objective: to have a P2SC system that is handling real instrument and spacecraft data.
- Cycle 6: Sept 28 2009 - Nov 27 2009

  Main objective: to have a fully operational P2SC system delivering science products to the external science community

W.4.4. Partnerships

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

- The partners of the SCSL team (see http://proba2.sidc.be/SCSL/)

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

- Centre Spatial de Liege at ULiege
- Center for Plasma Astrophysics (CPA) at KULeuven
- Verhaert NV
- Spacebel

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

The P2SC is a group effort, led by D. Berghmans, with support from the LYRA and the SWAP instruments teams. Important contributions are acknowledged from the following, institutes, funding sources and people:

- ROB permanent staff: D. Berghmans, J.F. Hochedez
- ROB STCE funding: E. D'Huys, B. Nicula, S. Willems,
- ROB, PRODEX: I. Dammasch, D. Dominique, B. Giordanengo, D. Seaton, A. Stanger
- KULeuven, PRODEX: A. De Groof, Y. Mehmet
- TCD, PRODEX: S. Bloomfield, C.H. Lin, C. Raftery, P. Higgins
- ESA D/SRE: J. Zender

Visitors:

- J. Zender, ESA D/SRE, two days per week, since mid 2008
- Y. Mehmet, KULeuven-PRODEX, five days per week since Dec 1 2008
- A. De Groof, KULeuven-PRODEX, one day per week up till end Nov 2008

W.4.5. Scientific outreach

Meeting presentations

[1] D. Berghmans
The potential of PROBA2 as a European space weather satellite
Invited talk at Space Weather Workshop, April 29-May 2, Boulder, Colorado US.

[2] **D. Berghmans**
2008 Update ILWS at Belgium (including PROBA2 report)
Belgian contribution to the ILWS working group meeting, Prague, Czech Republic.

[3] **D. Berghmans**
Science Consortium for SWAP and LYRA
Final Presentation of the ISSI international Team, presented at the PROBA2 splinter session of the ESWW5 conference, Brussels, Belgium.

Seminars

[4] **D. Berghmans** on behalf of **the SWAP and LYRA teams**
The PROBA2 Science Center
Presentation at the P2SC Status Review, October 13 2008, ESTEC, Nederland.

Wikis and Websites

- Internal P2SC development wiki: http://sol042.oma.be:8000/Proba2SC
- Internal P2SC document server: http://dac.oma.be:8080/nuxeo/dav/default/proba2/workspaces/
- External P2SC website (placeholder at the moment): http://proba2.sidc.be/

W.4.6. Missions

Assemblies, symposia:
- Fifth European Space Weather Week, November 17-21, Brussels, Belgium.

Commissions, working groups:
- Octobre 13-14, ESTEC, Nederland. P2SC Status Review.

Research visits:
- February 28-29; Dublin, Ireland. Coordination with the SWAP team lead by P. Gallagher at Trinity College Dublin
- November 5, Leuven, Belgium. P2SC development coordination.

Field missions:
- November 25, Redu ESA Ground station, Belgium. Discussion meeting on interfacing P2SC and Redu.

W.5.SDO data center

W.5.1. 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 Array (AIA). Data rates produced by EVE are by several orders of magnitude smaller than HMI and AIA. The latter produce both 4kx4k images. Each of the four telescopes within AIA will deliver an image every 5 seconds (10 bandpasses). HMI products compress heavily, and as a result, its

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 SIDC SDO data centre is meant as a platform to produce rapid solar weather reports, to further distribute SDO data for European needs, and to provide SDO-based byproducts computed at SIDC.

W.5.2. Progress and results

W.5.2.1. Data Management platform

The data management platform was designed by David Boyes as data storage and computing installation centre, equipped with arrays of computers and storage, high capacity networking, environmental management and multiple levels of software resources, see Figure 65. The aim is to have a data server which can run for a minimum of five years with annual downtime measured in minutes. High availability database servers and some storage was delivered and tested in 2008; moreover the data network connectivity of the ROB site has been upgraded in speed, and now allows for a safety factor.

W.5.2.2. Reception and redistribution of SDO data

Situated in Stanford, JSOC is responsible for the basic preparation of the science data, and is deeply involved in the HMI instrument, where as LMSAL is the PI institute for AIA. JSOC had at the start of 2008 gone a long way towards implementing a database system for transferring the data. B. Mampaey and D. Boyes successfully installed and tested this system (called JSOC suite) on our cluster.

Around May and June 2008, the chance to obtain the full AIA data stream appeared very low due to difficulties in term of outward bandpass faced by JSOC. It is now agreed that SIDC will receive the data from the Smithsonian Astrophysical Observatory (SAO), who directly receives it from the JSOC in Stanford.
Several options will be made available to the users for acquiring the data:

- High volume data feeds from the database, by special arrangement.
- Using the computing resource on what will appear to them simply as a vast library of standard format astronomy data files.
- Accessing the data and computing resource via a web interface.

W.5.2.3. Scientific applications

The implementation of two existing SIDC applications for the database and compute cluster is underway. These are Velociraptor and SPoCA, which were advertised at the SDO Science Team meeting in 03/2008. Velociraptor produces velocity field as well as brightness variation maps. Initially the application was developed in IDL, and would take up to one hour to process two EIT images. By rewriting the code in C, T. Berghoff managed to speed up the algorithm by a factor of 80. Ways of increasing further the speed, in particular through hardware acceleration, are being investigated. This is necessary in order to process the huge increase in data volumes which the SDO mission will generate, even with the computing capacity being installed.
J-F Hochedez and V. Delouille joined on 12/6 the NASA SDO Science center proposal led by P. Martens at SAO. The Harvard SAO proposal was submitted on 1/8 **[37]**, and declared successful on 30/9. Collaboration telecons occurred on 23/10 and 24/11. The agreement is to deliver Spoca to the SAO SDO center, while tailoring Velociraptor at SIDC into a fast and AIA-dedicated tool named 'Raptor'.

W.5.2.4. Project communication

Effective communication is an integral part of the project at several levels. This has been planned from the start to cover public information, scientific collaboration access, and application development by teams.

To this end a web server based system has been designed and configured. This provides:

- A public entry point for the project.

- A wiki and template based system to allow project staff to rapidly post publications in a uniform style.
- An issue recording and tracking system for system and application development.
- A software repository with version control.
- Access based on personal identification depending on project role.
- Modular design allowing for adding functions.
- Access via web browser or client program over the internet.

This system is running on an intranet server while the ROB IT department decides how it can be opened to the public in a secure manner.

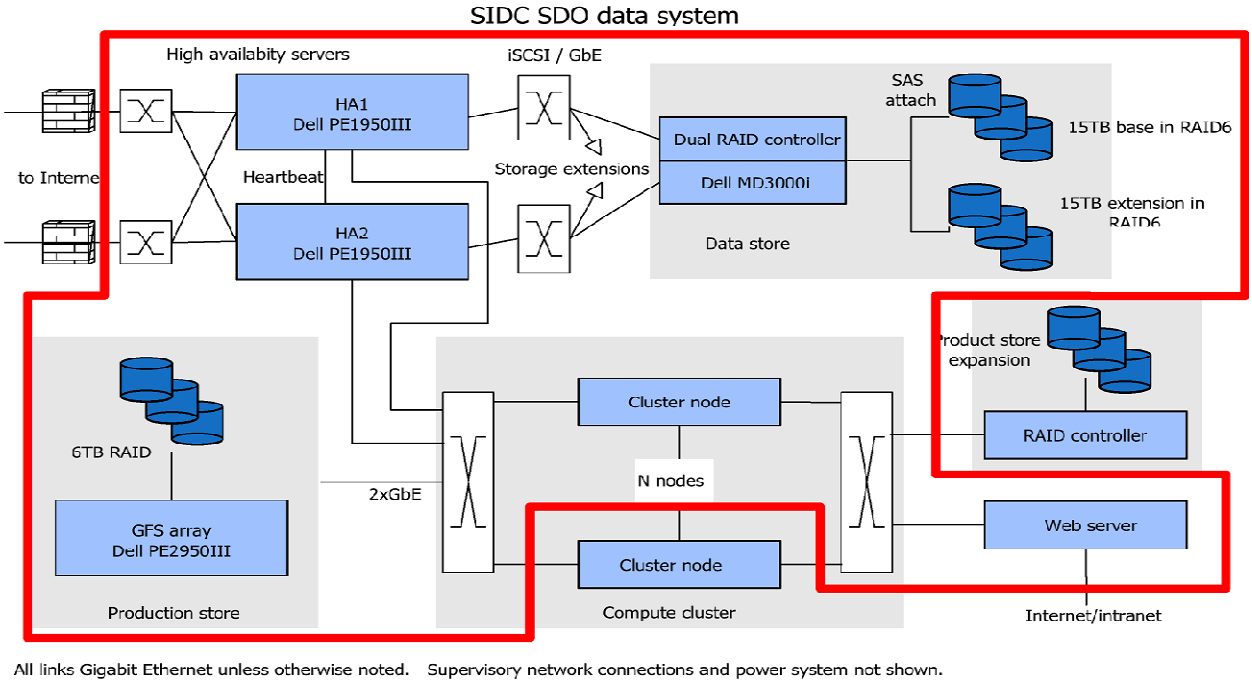


Figure 65: SDO data system at ROB/SIDC

W.5.3. Perspective for next years

In 2009, in a challenging context, it will be agreed that SIDC becomes the redistribution site for Europe of all AIA data, viz. any AIA data distributed in Europe will transit through WisSDOm. ROB will redistribute all the data to University of central Lancashire (UCLan). The expected SDO launch date is February 2010.

W.5.3.1. Operational SDO data center

The immediate task is to get the data into operation so that data can be received, redistributed, and processed locally. This will involve:

- Getting the data system online, that is installing and testing the JSOC database systems and testing the system reliability
- Testing the whole data transfer protocol, from SAO onwards, up to UCLan
- Implementing parts of Figure 65 which are outside the red line, and installing applications on them.
- Training and preparing instructions for operator intervention in the computer centre.

W.5.3.2. 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.

W.5.3.3. Scientific applications

SPoCA will be adapted to analyse AIA images, taking into account the additional wavelengths brought by AIA compared to EIT. 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 will be exploited at ROB/SIDC. The SDO data center at ROB may also welcome other scientific applications that require intensive access to SDO data.

W.5.4. Personnel involved

Scientific staff:	M. Krijger (BPI SDIC/Telescience from January-August 2008, statutaire)
	V. Delouille (BPI SIDC/Telescience from September 2008 on, PRODEX SDE)
	D. Boyes (IT responsible, PRODEX SIDC/Telescience)
	S. Gissot (Algorithmics, PRODEX SDE)
	J.-F. Hochedez (Algorithmics, statutaire)
Technical staff:	B. Mampaey (IT resources, PRODEX SIDC/Telescience)
	T. Berghoff (IT resources, PRODEX SIDC/Telescience)

W.5.5. Partnerships

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

- Karel Schrijver, N. Hurlburt, A. Title, Lockheed Martin Solar and Astrophysics Laboratory, USA
- Phil Scherrer, Stanford University, and Hansen Experimental Physics Laboratory, USA
- Piet Martens, Alisdair Davey, Ed Deluca, L. Golub, Smithsonian Astrophysics Observatory, USA

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

- Fabian Roosbeek, André Somerhausen, ROB
- Arnaud Lefebvre, BIRA

Grants/Projects used for this research/service

- SIDC Telescience PEA (Prodex)
- SIDC Data Exploitation PEA (Prodex)

Visitors:

- Jack Ireland, GSFC NASA, 19 Sep. 2008, solar image processing

W.5.6. Scientific outreach

Meeting presentations

[1] Barra, V.; Delouille, V.; Kretzschmar, M.; Hochedez, J.-F.; Gissot S.
Fast and robust segmentation of solar EUV images: algorithm and results for solar cycle 23 (poster)
Solar Image Processing Workshop IV - Algorithm comparison and effective implementation. October 26 - 30, 2008, Baltimore Inner Harbor, Baltimore, MD, USA

[2] Barra, V.; **Delouille, V.; Hochedez, J.-F. ; Krijger, J. M.**
'SPoCA', a Spatial Possibilistic Clustering algorithm for EUV images (poster)
SDO Science Teams Meeting, 25-28 March 2008, Nappa Valley, CA, USA

[3] **S. Gissot, J.-F. Hochedez, J.M. Krijger**
Velociraptor, a motion estimation algorithm analyzing the dynamics in EUV movies of the solar atmosphere (poster)
SDO Science Teams Meeting, 25-28 March 2008, Nappa Valley, CA, USA

[4] **D. Berghmans and the SWAP team**

SWAP, yet another EUV imager launched soon (poster)
SDO Science Teams Meeting, 25-28 March 2008, Nappa Valley, CA, USA

Wikis and Websites

- http://wissdom.oma.be/

W.5.7. Missions

Assemblies, symposia: SDO Science Teams Meeting, Nappa Valley (2 people)
Solar Image Processing Workshop IV (5 people)
5th European Space Weather Week

X. Publications

X.1. Publications with peer review

[1] Attrill, G. D. R.; van Driel-Gesztelyi, L.; Démoulin, P.; **Zhukov, A. N.;** Steed, K.; Harra, L. K.; Mandrini, C. H.; Linker, J.
The Recovery of CME-Related Dimmings and the ICME's Enduring Magnetic Connection to the Sun
Solar Physics 252, 349–372, (2008)

[2] Barra, V.; **Delouille, V.; Hochedez, J.-F.**
Segmentation of extreme ultraviolet solar images via multichannel fuzzy clustering
Advances in Space Research, 42, p. 917-925, (2008)

[3] **BenMoussa, A.; Hochedez, J. F.**; Dahal, R.; Li, J.; Lin, J. Y.; Jiang, H. X.; Soltani, A.; de Jaeger, J.-C.; Kroth, U.; Richter, M.
Characterization of AlN metal-semiconductor-metal diodes in the spectral range of 44-360 nm: Photoemission assessments
Applied Physics Letters, Volume 92, Issue 2, id. 022108 (2008)

[4] **BenMoussa, A.**; Soltani, A.; Haenen, K.; Kroth, U.; Mortet, V.; Barkad, H. A.; Bolsee, D.; Hermans, C.; Richter, M.; DeJaeger, J. C.; **Hochedez, J. F.**
New developments on diamond photodetector for VUV solar observations
Semiconductor Science and Technology, Volume 23, Issue 3, p. 035026 (2008)

[5] P.K. Browning, C. Gerrard, A.W. Hood, R. Kevis, **R.A.M. Van der Linden**
Heating the corona by nano°ares: simulations of energy release triggered by a kink instability
Astronomy and Astrophysics 485, 837-848 (2008).

[6] De Groof, A.; **Berghmans, D.; Nicula, B.;** Halain, J.-P.; Defise, J.-M.; Thibert, T.; Schuehle, U.
CMOS-APS detectors for solar physics; Lessons learned during the SWAP pre-flight calibrations
Solar Physics, 249, p.147-163, (2008)

[7] **Dammasch, I. E.;** Curdt, W.; Dwivedi, B. N.; **Parenti, S.**
The redshifted footpoints of coronal loops
Annales Geophysicae 26, 2955-2959, (2008)

[8] **Delannée, C.;** Török, T.; Aulanier, G.; **Hochedez, J.-F.**
A New Model for Propagating Parts of EIT Waves: A Current Shell in a CME
Solar Physics, Volume 247, Issue 1, p. 123-150, (2008)

[9] **Delouille, V.;** Chainais, P.; **Hochedez, J.-F.**
Spatial and Temporal Noise in Solar EUV Observations
Solar Physics, Volume 248, p. 441-455, (2008)

[10] **Delouille, V.;** Chainais, P.; **Hochedez, J.-F.**
Quantifying and containing the curse of high resolution coronal imaging

Annales Geophysicae, 26, p. 3169-3184, (2008)

[11] Egorova, T.; Rozanov, E.; **Hochedez, J.-F.**; Schmutz, W.
Reconstruction of the solar spectral UV irradiance for nowcasting of the middle atmosphere state on the basis of LYRA measurements
Atmospheric Chemistry and Physics, Volume 8, Issue 11, p. 2965-2973, (2008)

[12] **Gissot, S.; Hochedez, J.-F.**
Oscillation analysis using optical flow: Application to an EUV movie of the solar corona
Statistical Methodology, 5, p. 340-349, (2008)

[13] **Gissot, S. F.; Hochedez, J.-F.;** Chainais, P., Antoine, J.-P.
3D Reconstruction from SECCHI-EUVI Images Using an Optical-Flow Algorithm: Method Description and Observation of an Erupting Filament
Solar Physics, Volume 252, p. 397-408, (2008)

[14] Kretzschmar, M.; Dudok de Wit, T.; Lilensten, J.; **Hochedez, J.-F.**; Aboudarham, J.; Amblard, P.-O.; Auchère, F.; Moussaoui, S.
Solar EUV/FUV irradiance variations: analysis and observational strategy
Acta Geophysica, Published online (2008)

[15] **Magdalenić, J.**, Vršnak, B., Pohjolainen, S., Temmer, M., Aurass, H., Lehtinen, N. J
A Flare-Generated Shock during a Coronal Mass Ejection on 24 December 1996
Solar Physics, 253, 305-317, (2008)

[16] **Mierla, M**., Davila, J., Thompson, W., Inhester, B., Srivastava, N., Kramar, M., StCyr, O.C., Stenborg, G., Howard, R.A.
A Quick Method for Estimating the Propagation Direction of Coronal Mass Ejections using STEREO-COR1 Images
Solar Physics, 252, 385, (2008)

[17] **Nicula, B.; Marqué, C.; Berghmans, D.**
Visualization of distribututed solar data and metadata with the Solar Weather Browser
Solar Physics, 248, p. 225-232, (2008)

[18] **Parenti, S.**; Young, P. R.
On the ultraviolet signatures of small scale heating in coronal loops
Astronomy and Astrophysics, 492, 857, (2008)

[19] **Parenti, S.**, Vial, J.-C., Lemaire, P.
Solar prominence properties derived from the UV-EUV SUMER spectral atlas
Advances in Space Research, 41, 144, (2008)

[20] **Rodriguez, L.;** Krupp, N.; Woch, J.; Fraenz, M.
Elemental abundances of energetic particles within magnetic clouds detected by Ulysses
The Astrophysical Journal, 673, 621-628, (2008)

[21] **Rodriguez, L.; Zhukov, A. N.;** Dasso, S.; Mandrini, C. H.; Cremades, H.; Cid, C.; Cerrato, Y.; Saiz, E.; Aran, A.; Menvielle, M.; Poedts, S.; Schmieder B.
Magnetic Clouds seen at different locations in the Heliosphere
Annales Geophysicae 26, 213-229, (2008)

[22] Soltani, A.; Barkad, H. A.; Mattalah, M.; Benbakhti, B.; de Jaeger, J.-C.; Chong, Y. M.; Zou, Y. S.; Zhang, W. J.; Lee, S. T.; **Benmoussa, A.; Giordanengo, B.; Hochedez, J.-F.**
193 nm deep-ultraviolet solar-blind cubic boron nitride based photodetectors
Applied Physics Letters, Volume 92, Issue 5, id. 053501 (2008)

[23] Turck-Chièze, S.; Lamy, P.; Carr, C.; Carton, P. H.; Chevalier, A.; Dandouras, I.; Defise, J.-M.; Dewitte, S.; Dudok de Wit, T.; Halain, J.-P.; Hasan, S.; **Hochedez, J.-F.;** Horbury, T.; Levacher, P; Meissonier, M.; Murphy, N.; Rochus, P.; Ruzmaikin, A.; Schmutz, W.; Thuillier, G.; Vivès, S.
The DynaMICCS perspective
Experimental Astronomy, Published online, (2008)

[24] **Verdini, A.;** Velli, M.; Buchlin, E.
Reflection Driven MHD Turbulence in the Solar Atmosphere and Wind
Earth, Moon, and Planets, Springer Netherlands, DOI 10.1007/s11038-008-9250-2

[25] Wilhelm, K.; Curdt, W.; **Dammasch, I. E.;** Hassler, D. M.
Comment on 'Energy levels and spectral lines of Ne VIII'
European Physical Journal, D 47, 325, (2008)

[26] **Zhukov, A. N.;** Saez, F.; Lamy, P.; Llebaria, A.; Stenborg, G.
The Origin of Polar Streamers in the Solar Corona
The Astrophysical Journal 680, 1532–1541, (2008)

X.2. Publications without peer review

[27] Buchlin, E.; **Verdini, A.;** Cargill, P. J.; Velli, M.
Turbulence in anisotropic heliospheric plasmas
SF2A-2008, editor: Charbonnel C., Combes F. and Samadi R.

[28] **Clette, F.**
New prospects for solar radioastronomy in Belgium
CRAF Newsletter, N° 17, European Science Foundation, 3/2008

[29] **Clette, F.**
Uccle-USET sunspot numbers, sunspot group table, list of possible return of large sunspot groups
SIDC sunspot bulletin (12 monthly issues)

[30] **Berghmans, D. ; BenMoussa, A. ;** De Groof, A.
The PROBA2 satellite on the hunt for solar eruptions
Physicalia Mag. 30, 2, 61-70, (2008)

[31] Brajša, R.; Mulec, M.; Hanslmeier, A.; Wöhl, H.; Ruždjak, V.; **Hochedez, J.-F.**
Coronal Bright Points as Tracers for Solar Rotation in October-November 1999
Central European Astrophysical Bulletin, Vol. 32, p. 117-124, (2008)

[32] Brajša, R.; Wöhl, H.; Vršnak, B.; Ruždjak, V.; Clette, F.; **Hochedez, J.-F.;** Verbanac, G.; Skokić, I.; Hanslmeier, A.
Proper Motions of Coronal Bright Points
Central European Astrophysical Bulletin, Vol. 32, p. 165-190, (2008)

[33] Chifu, I.; Oncica, A.; **Mierla, M.**; Munoz, G.; Dumitrache, C.
Investigation of the halo (I)CME from August 25, 2001
RoAJ, v. 18, p. 101, (2008)

[34] **Clette, F.; Berghmans, D.; Vanlommel, P.; Van der Linden**, **R.A.M.;** Koeckelenbergh, A.; Wauters, L.
Du Nombre de Wolf a l'indice international des taches solaires: 25 ans de SIDC (1ère partie)
Ciel & Terre, 124, 3, pp.66—75

[35] **Clette, F.; Berghmans, D.; Vanlommel, P.; Van der Linden**, **R.A.M.;** Koeckelenbergh, A.; Wauters, L.
Du Nombre de Wolf a l'indice international des taches solaires: 25 ans de SIDC (2ème partie)
Ciel & Terre 124, 4, 98-109, (2008)

[36] Malinowski, P. E.; John, J.; Lorenz, A.; Aparicio Alonso, P.; Germain, M.; Derluyn, J.; Cheng, K.; Borghs, G.; Mertens, R.; Duboz, J.-Y.; Semond, F.; **Hochedez, J.-F.; BenMoussa, A.**
AlGaN photodetectors for applications in the extreme ultraviolet (EUV) wavelength range
Optical Sensors 2008. Edited by Berghmans, Francis; Mignani, Anna Grazia; Cutolo, Antonello; Meyrueis, Patrick P.; Pearsall, Thomas P. Proceedings of the SPIE, Volume 7003, p. 70030N-70030N-8 (2008)

[37] Martens, Petrus; Kasper; Davey; Korreck; Wills-Davey; Attrill; Grigis; Saar; Engell; Savcheva; Bernasconi; Raouafi; Cirtain; Angryk; Banda; DeForest; **Hochedez; Delouille;** de Moortel; Georgoulis; Wiegelmann
SDO Science Center
Proposal to NASA Heliophysics (2008)

[38] **Parenti, S.**
Heating and Dynamics of Loops and Flares
ESPM-12, 2.78, (2008)

[39] **Parenti, S.,** Reale F., Reeves, K.K.
Fine Thermal Structure of a Flare Observed with Hinode/XRT
ASP Conference Series, Vol. 397, 182, (2008)

[40] Popescu, A.S.; **Mierla, M.**
Mass estimates and wave propagation for the eruptive event of 8th of January 2002
In "Exploring the Solar System and the Univers", AIP Conf. Proc. 1043, Eds, V.Mioc, C.Dumitrache, N.A.Popescu, 309-313, (2008)

[41] Reale F., **Parenti, S.,** Reeves, K.K. et al.
Hinode/XRT Diagnostics of Loop Thermal Structure
ASP Conference Series, Vol. 397, 50, (2008)

[42] **Robbrecht, E.; Hochedez, J.-F.**; Fleck, B.; Gurman, J.; Forsyth, R.
Preface: SOHO 20 - Transient events on the Sun and in the heliosphere
Annales Geophysicae, Volume 26, Issue 10, p. 2953-2953, (2008)

[43] **Verdini, A.;** Velli, M.; Buchlin, E.
Alfvénic Turbulence and the Acceleration of the Fast Solar Wind
12th European Solar Physics Meeting, Freiburg, Germany, held September, 8-12, online at http://espm.kis.uni-freiburg.de, p.3.69, (2008)

[44] **WDC-Sunspot team**
Provisional sunspot numbers, Monthly solar indices, Monthly Summary of Solar and Geomagnetic activity
SIDC sunspot bulletin (12 monthly issues)

[45] **WDC-Sunspot team**
Definitive sunpot numbers
SIDC-News (4 quarterly issues)

X.3. Publications submitted, accepted, or in press

[46] Barra, V.; **Delouille, V.; Kretzschmar, M.; Hochedez, J.-F.**
Fast and robust segmentation of solar EUV images: algorithm and results for solar cycle 23
Astronomy and Astrophysics, in press

[47] Barra, V.; **Delouille, V.; Hochedez, J.-F.**
Segmentation, Tracking and Characterization of Solar Features from EIT Solar Corona Images
[Barra SCIA Segmentation Tracking and Characterization of Solar Features from EIT Solar Corona Images 20081210.pdf]

16th Scandinavian Conference on Image Analysis, in Oslo June 15-18, 2009, Proc. In Lecture Notes in Computer Science, accepted

[48] Barkad, H. A.; Soltani, A.; Rousseau, M.; Benbakhti, B.; De Jaeger, J.-C.; **BenMoussa, A.; Hochedez, J.-F.;** Monroy, E.
Modelling, Fabrication and Measurement of AlN based Photodetectors.
Diamond and Related Materials, in press, (2009)

[49] **BenMoussa, A.;** Soltani, A.; Schühle, U.; Haenen, K.; Chong, Y. M.; Zhang, W. J.; Dahal, R.; Jiang, H. X.; Bolsée, D.; Hermans, C.; Richter, M.; Kroth, U.; **Giordanengo, B.;** Barkad, H. A.; Mortet, V.; De Jaeger, J. C.; Scholze, F.; **Hochedez**, **J.-F.**
Recent developments on wide bandgap based UV sensors
Diamond and Related Materials, 18, 860-864 (2009)

[50] **BenMoussa, A.; Dammash, I. E.; Dominique, M.; Giordanengo, B.; Hochedez, J.-F.;** Schühle, U.; Theissen, A.; Koller, S.; Schmutz, W.; Gillotay, D.; Stockman, Y.; Defise, J-M.; Kretzschmar, M.
Pre-Flight Calibration of LYRA, the Solar VUV radiometer on board PROBA2
Astronomy and Astrophysics, accepted (2009)

[51] Dasso, S.; Mandrini, C. H.; Schmieder, B.; Cremades, H.; Cid, C.; Cerrato, Y.; Saiz, E.; Demoulin, P.; **Zhukov, A. N**.; **Rodriguez, L.;** Aran, A.; Menvielle, M.; Poedts, S.
Linking two consecutive non-merging magnetic clouds with their solar sources
Journal of Geophysical Research, in press, (2008)

[52] **Delannée, C.; Marqué, C.; Zhukov, A. N.;** Biesecker D.
A Coronal Wave as CME Footprint
Submitted to Solar Physics, (2008)

[53] **Dominique**, **M.;** Gillotay, D.; Fussen, D.; Vanhellemont, F.; **Hochedez**, **J.-F.;** W. Schmutz
The contribution of PROBA2-LYRA occultations to Earth atmosphere composition analysis
Proc. for the 3rd meeting on Occultations for Probing Atmosphere and Climate, accepted

[54] **Dominique**, **M.;** Mitrofanov, A. V.; **Hochedez**, **J.-F.;** Apel, P.; Schühle, U.; Pudonin, F. A.; Orelovich, O. L.; Zuev, S.Yu.; Bolsee, D; Hermans, C.; **BenMoussa, A.**
Track membranes with open pores used as diffractive filters for space-based X-ray and EUV solar observations
Applied Optics, 48, 5, p.834-841 (2009)

[55] Dudok de Wit, Kretzschmar, Auchère, **Hochedez**, Lilensten
CAMUS : Capteur Multicanal pour la mesure de l'irradiance UV Solaire
Proposal to CNES, 15 Apr. 2009

[56] Fazakerley A. N., Lahiff D. A., Rozum I., Kataria D., Bacai H., Annekallu C. and **West M J.**
Cluster-PEACE In-Flight Calibration Status
15th CAA Workshop Publications

[57] Feldman, U.; **Dammasch, I. E.;** Landi, E.
On the emission measure of the solar lower transition region (2x10^4 – 2x10^5 K)
Astrophysical Journal, in press

[58] Feldman, U.: Brown, C. M.; Seely, J. F.; **Dammasch, I. E.;** Landi, E.; Doschek, G. A.; Colgan, J.; Abdallah, J.; Fontes, C. J.; Sherrill, M. E.
A new approach for deriving the solar irradiance from non-flaring solar upper atmosphere plasma at 2x10^4 < T < 2x10^7 K
Submitted to Journal of Geophysical Research

[59] Giordanengo, B.; BenMoussa, A.; Hochedez, J.-F.; Soltani, A.; de Moor, P.; Minoglou, K.; Malinowski, P.; Duboz, J.-Y.; Chong, Y. M.; Zou, Y. S.; Zhang, W. J.; Lee, S. T.; Dahal, R.; Li, J.; Lin, J. Y. ; Jiang, H. X.
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EAS Publications Series, 37, 199, (2009)

[60] **Hochedez, J.-F.**; Schühle, U.
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Photons in Space, ISSI book, Bern (to appear in 2009)

[61] **Mierla, M**.; Inhester, B.; **Marqué, C.; Rodriguez, L.; Gissot, S.; Zhukov, A. N.; Berghmans, D**.; Davila, J.
On 3D reconstruction of Coronal Mass Ejections: I. Method description and application to SECCHI-COR Data
Solar Physics 259, 123, (2009)

[62] Muhr, N. Vršnak, B., Temmer, M., Veronig, A. M.., **Magdalenić, J.**
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Submitted to Astronomy and Astrophysics, (2008)

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ApJ 691, 1222-1234, (2009)

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Three Frontside Full Halo CMEs with a non-typical geomagnetic response
Submitted to Space Weather Journal, (2008)

[65] **Rodriguez L., Zhukov A. N., Gissot S., Mierla M.**
Three-dimensional reconstruction of active regions
Solar Physics 256, 41, (2009)

[66] Schmutz, Werner; Fehlmann, André; Hülsen, Gregor; Meindl, Peter; Winkler, Rainer; Thuillier, Gérard; Blattner, Peter; Buisson, François; Egorova, Tatiana; Finsterle, Wolfgang; Fox, Nigel; Gröbner, Julian; **Hochedez, Jean-François**; Koller, Silvio; Meftah, Mustapha; Meisonnier, Mireille; Nyeki, Stephan; Pfiffner, Daniel; Roth, Hansjörg; Rozanov, Eugene; Spescha, Marcel; Wehrli, Christoph; Werner, Lutz; Wyss, Jules U.
The PREMOS/PICARD instrument calibration
Metrologia, Volume 46, Issue 4, pp. S202-S206 (2009)

[67] Srivastava, N.; Inhester, B.; **Mierla, M.;** Podlipnik, B.
3D reconstruction of the leading edge of the May 20, 2007 partial halo CME
Solar Physics 259 (STEREO special issue), 213, (2009)

[68] **Zhukov, A. N.; Rodriguez, L.;** de Patoul, J.
STEREO/SECCHI Observations of the EIT Wave on December 8, 2007: Evidence against the Freely Propagating Wave Hypothesis of the EIT Wave Origin
Submitted to Solar Physics, (2008)

X.4. Reports, thesis, etc

[69] **BenMoussa, A.; Hochedez, J-F.;** and DWG contribution
EUI detectors specifications V3 to 4.0 (3 docs)
Technical Report

[70] **BenMoussa, A.; Hochedez, J-F.;** and DWG contribution
Detectors-Tests-Calibration-Plan-I1-R0-20080307 to I1R2 (3 docs)

Technical Report

[71] **Berghmans, D.; Dominique, M.; Hochedez, J.-F.**
PROBA2 Science Center, Technical Description
Internal report, P2SC-ROB-PL-2

[72] **Clette, F.**
Report on the CRAF visit to the Humain station
Summary report of the 47th CRAF Meeting, 11/2008 (report)

[73] **Dammasch, I .E.**
LYRA Responsivity: Update
http://solwww.oma.be/users/dammasch/IED_20080115_LYRA_Responsivity_Update.pdf
LYRA project document

[74] **Dammasch, I .E.**
LYRA Calibration Methods: New Spectra
http://solwww.oma.be/users/dammasch/IED_20080718_Calibration_Methods.pdf
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[75] **Dammasch, I .E.**
LYRA Output: Expected Variations
http://solwww.oma.be/users/dammasch/IED_20080801_LYRA_Expected_Variations.pdf
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[76] De Groof, A.; **Nicula, B.; Stanger, A.; Berghmans, D.**
Analysis report of SWAP data and associated housekeeping and ancillary data during the PROBA2 System Validation Test 5
Internal report, SWAP-ROB-RP-1-V1_0-2008Jan16_SVT5Report

[77] **Dominique, Hochedez**
LYRA first light procedure – version 2.0 – 04/02/08
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[78] **Dominique, Dammasch, Hochedez**
LYRA User Manual – version 2.1
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[79] **Dominique, Hochedez**
LYRA Operations preparation – version 1.0 – 18/03/08 [ROB-LOP-V1R0-20080318.pdf]
LYRA project document

[80] **Dominique, M.**
System Validation Test, Report on LYRA activities [ROB-SVT5Report-V0R0-20080121]
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[81] **Dominique, M.**
On-board software evaluation report [ROB_LYRA_OBSWevaluation_V1R0_20080628.pdf]
LYRA project document

[82] Dudok de Wit et al
SUITE : Solar UV irradiance and impact on the terrestrial environment
Proposal to ANR, 28 Feb. 2008

[83] **Giordanengo, B.; Hochedez, J.-F.; Dominique, M.; Dammasch, I. E.**
LYRA Data Management Plan – version 1.2 and 2.2
LYRA project document (2 docs)

[84] Halain, J.-P.; **BenMoussa, A.; Hochedez, J.-F.;** et al.

Adaptation of APS detectors to the Solar Orbiter EUI requirements
Statement of Work, 8 October 2008

[85] **Hochedez, J.-F.,** et al
EUI proposal
Submitted to ESA on January 15, 2008, in response to the ESA AO for S.O. scientific payload

[86] **Hochedez, Pylyser**
EUI Nomenclature Definitions, version 1.0, 08/10/08
EUI project document

[87] **Hochedez, J.-F.**
SIDC 2007 [SIDC-ROB-RP-001-D4_annrep2007-JFH-V1.0-20081130.doc]
Annual report for ROB

[88] **Hochedez, J.-F.**
Filenaming and other nomenclatures at ROB-SIDC
[SIDC-ROB-SP-001-V1_1-20080912-JFH-FilenamingAndOtherNomenclatures.pdf]
SIDC management document

[89] **Hochedez, Pylyser**
Proposal to PRODEX – EUI PEA – version 5.9 – 04/11/08
[EUI BelspoA2 Prodex9 2008_2010 V5.9_AllChAcptd_Final 20081104 JFH_EHP]
PRODEX proposal for the EUI PEA

[90] **Hochedez J.-F., et al**
Proposal to PRODEX – SDE PEA – version 5.4 – 20/10/2008
[SidcDataExpl BelspoA2 Prodex9 2008_2010 V5.3_AllChangesAccepted 20081020 ROB_KUL]
PRODEX proposal for the SIDC Data Exploitation PEA

[91] **Parenti,** Urnov**, Hochedez**
DIMITUS – DEM Inversion Method for Imaging Telescopes for the Ultraviolet Sun
[SIDC-ROB-PRO-BelspoNonEuPostdocs_Dimitus_FaridGoryaev-VFinal-20080213-JFH_SPA]
Proposal to BELSPO for Non-EU Research fellowships, 13 Feb 2008

[92] **Pylyser, Hochedez**
EUI Monthly Progress Reports (March, June, July, September, October, November, December 2008)
EUI project document (7 docs)

[93] **Pylyser, Hochedez**
MoT of the EUI teleconference held on 04/01/08, 08/01/08, 09/01/08(AM & PM)
EUI project document (4 docs)

[94] **Pylyser, Hochedez**
MoM of the EUI meeting on Detector Specifications held on 27/02/08
EUI project document

[95] **Pylyser, Hochedez,** Halain
MoT of telecon with CMOSIS held on 10/10/08 – version 1.3 – 15/10/08
EUI project document

[96] **Pylyser, Hochedez,** Halain
MoM of meeting with IMEC, CSL, and ROB held on 14/10/08 version 1.1 – 16/10/08
EUI project document

[97] **Pylyser**
MoT on EOCS with intoPIX (1), held on 08/09/08 and 10/09/08
EUI project document (2 docs)

[98] **Pylyser**
Statement of Work for intoPIX: 'Technical Assistance in the specification of the EUI On-board Compression System – EOCS1', version 1.4, 10/12/08
EUI project document

[99] **Pylyser**
EUI Products (WP outputs, documentation, PA/QA) @ ROB: version 1.1, 02/06/08
EUI project document

[100] **Pylyser**
EUI On-board Software Concept: version Draft, 03/07/08
EUI project document

[101] **Pylyser, Gissot**
EOCS Test Requirements Specifications, version 0.4, 07/12/08
EUI project document

[102] **SIDC-RWC team**
Daily URSIGRAM, PRESTO and alert bulletins (365 daily bulletins)

[103] **SIDC-RWC team**
Weekly and monthly solar and geomagnetic activity summaries (52 weekly bulletins)

[104] **Vanraes, Hochedez**
An express user guide to the Nuxeo-based SIDC Document Archive Center (DAC)
SIDC management document

[105] Zender, J.; **Hochedez, J.-F.; Berghmans, D.**
PROBA2 Science Centre, Overview, Concept and implementation
Internal report, P2SC-ROB-PL-1

[106] **Van der Linden, R.; Vanlommel, P.; and the SIDC-team,**
SIDC Monthly Bulletin of Solar and Geomagnetic Activity, 12 issues
The Sunspot Bulletin

[107] **Van der Linden, R.A.M.; and the SIDC team**.
Annual report 2008 to the International Space Environment Service.
ISES Annual Report

[108] **Van der Linden, R.A.M.; and the SIDC team.**
Annual report 2008 to the International Space Environment Service.
FAGS Annual Report

[109] **The SIDC team**
Outgoing messages from RWC Belgium: e.g. 365 daily ursigrams, 52 weekly bulletins, 4 quarterly bulletins, 12 Monthly Ri Reports, 12 Monthly Ri_hemispheric Reports, all-quiet-alerts, presto alerts, halo CME alerts, GOES X-ray flare detection alert, reduced GPS accuracy alert, advance alert: enhanced geomagnetic activity warning.
E-mail distribution. The alerts are sent when needed, the other bulletins are sent on a regular basis.

Numerous other, more specific, project reports (in particular on EUI, LYRA, SWAP, and P2SC) are available at our internal document server.

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 du CNES;
- V. Dehant: Chair of ESAC Evaluation Panel for 'Biomass, CoReH2O and FLEX';
- V. Dehant: Member of "Earth Science Advisory Committee (ESAC)" of ESA;
- V. Dehant: Member of "Exploration, Science and Technology Advisory Group (ESTAG)" of ESA;
- V. Dehant: 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;
- V. Dehant: President of the Panel 'Earth Science' for the evaluation of the Descartes Research Prize;
- V. Dehant: Member of the Scientific Advisory Committee of the Helmholtz Alliance "Planetary Evolution and Life";
- V. Dehant: Member of "Groupe d'évaluation du GRGS";
- V. Dehant: Member of the High Scientific Committee of the Observatoire de Paris;
- T. Camelbeeck: Member of the scientific committee of "Evaluation of pelitic rocks" (ONDRAF/NIRAS) – meeting in Brussels on 10 June
- A. Hubert-Ferrari: Referee for National Sciences Foundation- Tectonic Section, Israelian Science Foundation, European Sciences Foundation
- Y. Frémat: Referee for a proposal submitted to the Czech Science Foundation (GACR)
- M.Groenewegen: evaluator of a South-African National Research Foundation proposal
- R. Van der Linden is member of the Scientific Committee of the Belgian National Geographical Institute
- R. Van der Linden was elected Grantholder and WG2 Chairperson of COST ES0803 "Developing Space Weather Products and Services in Europe".

Meeting organization

- C. Bruyninx: Co-organizer of EUREF Technical Working Group meeting, June 17, 2008 Brussels, Belgium;
- C. Bruyninx: Co-organizer of EUREF symposium, June 18-21, 2008, Brussels, Belgium;
- C. Bruyninx: Organizer of PLEGG meeting, July 8-9, 2008, Brussels, Belgium;
- C. Bruyninx: Co-organizer of WEGENER General Assembly, July 8-9, 2008, Brussels, Belgium;
- C. Bruyninx: Organizer of PLEGG wrap-up meeting, September 2-3, 2008, Brussels, Belgium;
- P. Defraigne: Co-organizer of EFTF 2008, in Toulouse, Chair of Group 5 "Time Timekeeping, Time and Frequency Transfer, GNSS and Applications";
- P. Defraigne: Preparation as a chair of the JD 6 "Time and Astronomy" at the IAU GA in Rio, August 2009.
- A. Hubert-Ferrari : conveners at EGU General Assembly 2009 of the CL35 session: Assessment of climate events in lake sediments: deciphering climate, tectonic or anthropic influence
- T. Camelbeeck: Co-organizer of the colloquium "Seismic risk. Earthquakes in North-Western Europe", Liège, 11 and 12 September 2008 and co-organizer of the EUROSEIS workshop of the ECGS in Luxemburg, 17-19 November 2008.
- M. Van Camp: Chair of the G03 session "Extracting Signals in Geodetic Measurements", AGU Fall Meeting, San Francisco, December 15-19, 2008.
- Y. Frémat, A. Jonckheere, C. Martayan and R. Blomme participated to the organization of the 6th CU8 meeting, held at ROB on November 24-26, 2008.
- M. Groenewegen: Member of the STOC of the workshop ``multi-wavelength astronomy and the VO", held at ESAC, Spain, December 1-3, 2008
- R. Van der Linden: PC Member and LOC Chair for 5th European Space Weather Week, organized by the Royal Observatory of Belgium in Brussels on 17-21 November 2008.

- Petra Vanlommel: PC Member and local organizer for 5th European Space Weather Week, organized by the Royal Observatory of Belgium in Brussels on 17-21 November 2008.
- J.-F. Hochedez: SOC member of the SMESE workshop

Educational responsibilities (Lectures)

- 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);
- A. Trinh: Teaching Assistant, Université Catholique de Louvain, PHY1261 "Astronomie et Géophysique", 7.5 h ;
- 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: Professor at the Liège University: "Géographie historique", 30 h; "Éléments de critique historique à l'usage des géographes", 30 h.
- T. Camelbeeck: lecturer at ULB (Physique du Globe et Géophysique Appliquée – 30 h) and at UCL (Géophysique interne – 20 h) – 3 hours lecture at the Faculté Polytechnique de Mons on "the earthquake strong ground motions", on 29 February 2008.
- M. Everaerts: Guest lecturer at the Liège University of the course "Gravimetrie, Magnetisme et leurs applications géologique – field gravimetric training (2 days) for the Universities of Gent and Brussels
- A. Hubert-Ferrari: Lecturer at the ENS (Paris).
- Lecocq, T. *Geophysical methods on field,* travaux pratiques pour étudiants de l'ULB, 2008-03-18/20 - *Geophysical methods on field,* travaux pratiques pour étudiants de l'ULB, 2008-10-28/30
- K. Vanneste: Guest lecturer at the University of Gent, co-lecturer of the optional course "Natural Hazards".
- M. Van Ruymbeke: Lecturer at the UCL, " Méthode expérimentale en physique" (15h) - Professor for Lanzarote projects belonging the Casa de los Volcanes (20h).

Educational responsibilities (students)

- P. Defraigne: co-promoter of PhD of M.C. Martinez (Univ. Alicante) – Member of the Jury of PhD Thesis and "Rapporteur", student Loic Duchayne, Observatoire de Paris, 23 October 2008
- 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
- S. Pireaux: co-promoter of PhD of A. Hees
- P. Rosenblatt: co-promoter of PhD of S. Le Maistre
- T. Van Hoolst: co-promoter of PhD students R.M. Baland, A. Rivoldini, and A. Trinh
- T. Camelbeeck: co-promoter at Strasbourg University of the PhD-thesis of Valérie Calbini – co-promoter at ULB of the PhD-thesis of Jeffrey Frazer – co-promoter at ULB of the PhD-thesis of Thomas Lecocq – co-promoter at Gent University of the PhD-thesis of Els Sichien – Responsible of the training of Elodie Tytgat : « Analyses sismiques au sein d'un observatoire sismologique », Rapport de stage de 1ère année de l'Ecole et Observatoire des Sciences de la Terre Université Louis Pasteur Strasbourg I – stage of Marina Moussel from the Liège University (7 and 8 February 2008).
- M. Everaerts: co-promotor of the Phd-thesis of F. Barbier at the FUNDP Namur.
- A. Hubert-Ferrari: co-promoter at U. of Ghent of David Garcia (master) and Ulas Avsar (PhD thesis), co-promoter at ULB of Jeff Fraser (PhD thesis), co-promoter at ENS and U. d'Orsay of Laureen Drab (PhD thesis)
- M. Van Camp : Participation in the 1 month training at the ROB of Elodie Tytgat : « Analyses sismiques au sein d'un observatoire sismologique », Rapport de stage de 1ère année de l'Ecole et Observatoire des Sciences de la Terre Université Louis Pasteur Strasbourg I.

- K. Vanneste: Member of the Ph.D. jury of Athanas Macheyeki "Fault segmentation, paleostress and paleoseismic investigation in the Dodoma area: Implications for seismic hazard evaluation", Univeristy of Gent
- M. Van Ruymbeke: PhD: promoter: 2 (Naslin & ZhuPing), co-promoter: 1(Cadicheanu)
- P. Lampens: European referee for the PhD thesis presented by Dr. O. Creevey at the University La Laguna, Tenerife, Islas Canarias on the subject "Astrosismologia y Sistemas Binarios: la relación entre la dependencia de los parámetros estelares y los errores observacionales"
- P. Lampens: Co-promotor of PhD thesis of Miss Ch. Vamvatira-Nakou, University of Athens, Greece
- R. Blomme was member of the PhD thesis jury of Antoine Guerrier "Calibration des données spectroscopiques de la mission Gaia", Meudon, France, 09/01/2008
- R. Blomme was member of the PhD thesis jury of Natacha Linder "A multi-wavelength study of interactions in O+O binary systems", Liège, 15/12/2008
- J. Cuypers: Member of the advisory board, (external) reviewer of the Ph.D. thesis, "The Hunt for Quasi-periodicities with Wavelet and Camera" by Claire Blackman, University of Cape Town
- M.Groenewegen: Co-promoter at KU Leuven of PhD. student Djazia Ladjal
- Hensberge H.: co-promoter and jury member of PhD thesis of K.B.V. Torres at UFMG, Belo Horizonte, Brazil
- Hensberge H.: jury member Ph. D. thesis C. Papadaki, Vrije Universiteit Brussel, October 2008
- E. Robbrecht: supervision of Bram Bourgoignie, master student Computer Sciences at the University of Ghent.
- J.-F. Hochedez: Co-promoteur of the PhD thesis of S. Gissot

Belgian representations at international level

- P. Defraigne: Belgian representative for the Consultative Committee for Time and Frequency.
- C. Bruyninx: Belgian Representative in the COST Management Committee of COST ES0701 "Improved constraints on models of glacial isostatic adjustment";
- 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 - Belgian representative at ORFEUS
- M. Everaerts: Belgian representative of the working group for the calculation of a new European Geoid.
- M. Van Camp: Belgian representative in the COST management committee (COST action ES0701 "Improved Constraints on Models of Glacial Isostatic Adjustment").
- K. Vanneste: Titular member for Belgium in the European Seismological Commission (ESC) for the period 2006 – 2010.
- G. Van de Steene: Belgian representative in ESO User's Committee
- R. Van der Linden: Belgian Representative in the COST management committee (COST action ES0803 "Developing Space Weather Products and Service in Europe".

Memberships of national scientific committees:

- P. Defraigne: FNRS commission "Astrophysics, Geophysics and Climatology";
- C. Bruyninx: Vice-secretary of the Belgian Committee for Geodesy and Geophysics - Associate member of the National Comittee for Space Research;
- V. Dehant: Member of the Belgian National Committee of Geodesy and Geophysics (+IAG representative) - Member of the Belgian National Committee of Space Research - Member 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 (BNCGG) - T. Van Hoolst: Associate member of the Belgian National Committee for Space Research.
- T. Camelbeeck: Member of the Overseas Sciences Royal Belgian Academy - member of the Belgian Committee for Geodesy and Geophysics - member of the BELQUA Committee

- M. Everaerts: Associate member of the Belgian National Committee for Geodesy and Geophysics (BNCGG).
- M. Van Camp: Associated Member of the Comité National Belge de Géodésie et de Géophysique - Member of BeSeiG.
- K. Vanneste: Member of the Belgian National Committee for Geodesy and Geophysics.
- P. De Cat: Member of WEGA (since 1992) - Member of the Vereniging voor Sterrenkunde (since 1993) - Member of the HERMES Consortium
- Y. Frémat: ROB representative for the HERMES Consortium
- P. Lampens: Member of the HERMES Consortium - ROB representative in the Belgian national ESO Committee (BNEC) - Administrator of the corporated association "*Belgian Women in Sciences"*
- G. Van de Steene: member of Belgian National ESO Committee - member of VISA time allocation committee
- 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

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 - Head of Central Bureau of the EPN - Head of EPN Analysis Center - Head of EPN Data Center - Associate Member of the International GNSS Service (IGS) - Member of the EPN Special Project "Time Series Monitoring" - Member of WEGENER (Working group of European Geoscientists for the Establishment of Networks for Earth-science Research) Governing Board - Member of the Working Group "European Combined Geodetic Network (ECGN)" of the EUREF sub-commission of the IAG - Member of the Inter-Commission Project IC-P1.2 on "Vertical Reference Frames" of the IAG - 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 IGS Working Group on GNSS - Member of Commission 1, 3 and 4 of the IAG - Member of Commissions 31 of the IAU - Member of Commissions 19 of the IAU
- P. Defraigne: Member of OC of the IAU commission 19 (Earth Rotation) - President of the IAU commission 31 (Time) - 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 - Member of Commissions 31 of the IAU - Member of Commissions 19 of the IAU - Member of Commission 3 of the IAG
- V. Dehant: Member (as Past-President) of the Executive Committee of Commission 3 "Geodynamics and Earth Rotation" of IAG (International Association of Geodesy) - Member (as Past-President) of the Executive Committee of Commission 19 "Earth Rotation" of IAU (International Astronomical Union) - 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 Commissions 31 of the IAU - Member of Commissions 19 of the IAU- Member of Commission 3 of the IAG
- J. Legrand: Member of the IAG Working Group on "Regional Dense Velocity Fields" - Deputy member of the Management Committee of COST ES0701 "Improved constraints on models of glacial isostatic adjustment" - Member of the EPN Central Bureau;
- E. Pottiaux: National delegate within E-GVAP and member of the GNSS processing expert team;
- S. Pireaux: Member of the International Society on General Relativity and Gravitation research group - Member of the French LISA-FRANCE group (http://www.apc.univ-paris7.fr/LISA-France/) developing LISACode;

- F. Roosbeek: Member of the EPN Central Bureau - Member of Commission 1 and Commission 4 of the IAG - Member of Commissions 19 of the IAU - Member of Commission 3 of the IAG
- 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 - Member of Commissions 19 of the IAU - Member of Commission 3 of the IAG
- Ö. Karatekin: 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 - Member of the AGU, IAG, GGP - Member of the study group "Application of time-series analysis in geodesy" (Intercommission Committee on Theory of the IAG).
- A. Hubert-Ferrari: Member of European Geosciences Union
- T. Lecocq: member of European Geosciences Union and American Geophysical Society
- P. De Cat: Member of IAU commission 27 - 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 Nederlandse Astronomen Club;
- T. Pauwels: member of IAU Commission 7 "Celestial Mechanics & Dynamical Astronomy" - member of IAU Commission 8 "Astrometry" - member of IAU Commission 20 "Positions & Motions of Minor Planets, Comets & Satellites" - member of CU4 of Gaia DPAC - DU leader of DU454 of Gaia DPAC - member of IAU Task Force on the Preservation and Digitization of Photographic Plates (PDPP) - T. Pauwels: member of IAU Working Group on the Astrographic Catalogue and Carte du Ciel Plates - member of IAU Working Group "Astrometry by small ground-based telescopes"
- S. Hekker: Member of the Kepler Asteroseismic Science Consortium
- P. Lampens: Member of the Kepler Asteroseismic Science Consortium
- Y. Frémat: member of the IAU. Division IV 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 - Member of IAU Commissions 26 and 27
- R. Blomme: member of IAU Commission 36 "Theory of Stellar Atmospheres" - Member of the COROT "O stars Working Group"
- Herman Hensberge: Member of IAU Commission 25 "Stellar Photometry and Polarimetry"
- J. Cuypers: Member of IAU commission 27 - Member of the COROT "B stars Working Group" - Member of the COROT "O stars Working Group" - Member of the GAIA-DPAC Coordination Unit 7 "Variability processing" (CU7) - Member of the Kepler Asteroseismic Science Consortium
- 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
- D. Berghmans: member of the ESA Solar System Working Group (SSWG) - member of the Space Weather Working Team – Belgian representative in the Working Group of International Living with a Star - member of IAU Commission 10
- P. Vanlommel: member of the Space Weather Working Team
- F. Clette: member of IAU Commission 12
- Dan Seaton: member of the American Geophysical Union – member of the American Astronomical Society & Solar Physics Division, the Sigma Xi
- J.-F Hochedez: member of IAU Commission 10

Editorial responsibilities

- C. Bruyninx: Editor for Special EUREF Issue of the Bulletin of Geodesy and Geomatics;
- C. Bruyninx: Member of the advisory editorial board of GPS Solutions.
- P. Lampens: "Stars and the Milky Way" in Dutch and in French (with help for some translation by R. Alvarez), basic course in astronomy/astrophysics for technical experts in the context of an OFO/IFA certified formation, Part 2, 96 pages of text and figures. Full-day course taught on Oct, 7th. Contributions to conceptual and practical organization, preparation, teaching and evaluation.
- P. Lampens: supervision of "L'évolution stellaire et l'héliophysique", Glossaire terminologique anglais-français-néerlandais, mémoire de fin d'études de l'Université de Mons-Hainaut, Ecole d'Interprètes Internationaux, présenté avec succès par Melle Sophie Deprit (2007-2008).
- E. Robbrecht and J.-F. Hochedez: Guest Editors of the Special Issue of Annales Geophysicae: "SOHO20 - Transient events on the Sun and in the heliosphere"
- Dan Seaton is author & team member for the production of a book about the use of inquiry to improve science instruction in secondary education. This book is the final product of the Leitzel Center for Science, Mathematics, & Engineering Education at the University of New Hampshire's Partnerships for Research Opportunities to Benefit Education (PROBE) program. (Participation in PROBE, through a National Science Foundation GK-12 Fellowship, supported two of my five years in graduate school. More information at: http://leitzelcenter.unh.edu/probe/index.html)

Journal Refereeing

- C. Bruyninx: Referee for GPS Solutions - Referee for Bulletin of Geodesy and Geomatics
- Ö. Karatekin: Referee for Advances in Geosciences - Referee for a book chapter on Europa
- T. Van Hoolst: referee for Celestial Mechanics and Dynamical Astronomy, Geophysical Journal International, Journal of Geophysical Research
- A. Hubert-Ferrari: Referee for Journal of Geophysical Research, Geophysical Journal International, Tectonophysics, Turkish Journal of Earth Sciences, Earth and Planetary Sciences Letters. Geological Society of London, Geology, Quaternary Journal of Sciences, Geological Society of America
- M. Van Camp: Geophys. J. Int. (1x); Hydrogeology J. (1x); J. Geophys. Res. (2x); Metrologia (2x); Measurement Science and Technology (1x); J. Geodesy (1x); J. Geodyn. (1x).
- P. Lampens: Referee for A&A (1 paper) and for Communications in Asteroseismology (3 papers)
- G. Van de Steene: referee for Astrophysical Journal
- M. Groenewegen: Referee for MNRAS, Astronomical Journal (2x)
- J. Cuypers: Referee for Communications in Asteroseismology
- H. Hensberge: Referee for MNRAS and Astrophysical Journal

Awards

- V. Dehant: "Membre Correspondant" du BdL (Bureau des Longitudes);
- Arrigo P., Allouis E., Barraclough S., Carusi A., **Dehant V.,** Kemble S., **Karatekin Ö.,** Paetzold M., Parkinson R., Perkinson M.-C., Perozzi E., Povoleri A., Sembely X., Trenkel C., Watt M., Wolters S.: Bronze Medal (third place, 5000€ donated to the Annual Scholarship Programme of the International Space University (ISU)) for Apophis Mission Design from the Planetary Society;
- E. Pottiaux: Best student poster award, EUREF 2008 symposium.
- H. Boffin: assigned as discoverer of 1 minor planet.
- H. Debehogne, E. Elst: assigned as discoverers of 3 minor planets.
- E. Elst: assigned as discoverer of 60 minor planets.
- E. Elst, H. Debehogne: assigned as discoverers of 4 minor planets.
- T. Pauwels: assigned as discoverer of 11 minor planets.
- T. Pauwels, P. De Cat: assigned as discoverers of 1 minor planet.
- D. Berghmans led a proposal "A new view on the Sun with the Extreme ultraviolet Imaging Telescope" that was nominated for the 2007 Descartes Prize for Transnational Collaborative Research.
- E. Podladchikova received the Zeldovich Medal at the COSPAR 2008 GA.

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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 2008, le Planétarium a accueilli **29.213 visiteurs** hors événements spéciaux, chiffre en légère augmentation (+625 visiteurs / +2.2%) par rapport à l'année précédente.

La part du **public scolaire** (21.038 élèves) s'élève à 72% du nombre total de visiteurs. Le public familial (mercredis après-midi, dimanches, congés scolaires) atteint le nombre de 8.175 visiteurs (28%).

La répartition entre public néerlandophone (14.083 visiteurs / 49.2%) et public francophone (15.130 visiteurs / 51.8 %) reste **équilibrée**.

La fréquentation des **ateliers** (workshops) permettant aux élèves d'effectuer des activités pédagogiques en supplément du cours a sensiblement diminué : seuls 2.869 élèves (-26.8%) y ont participé au cours de l'année 2008. Ceci est dû au fait que les ateliers qui étaient les années passées proposés aux premières années des classes primaires sont progressivement remplacés par des activités plus adaptées à cette tranche d'âge.

A.1.2. Formations

Des journées **Portes Ouvertes** ont été organisées pour les enseignants et leur famille les 26 janvier (journée francophone) et 26 avril (journée néerlandophone), en partenariat avec le bureau ESERO.

Une **journée de formation** aux projets scientifiques a été proposée aux directeurs d'écoles participant au projet pilote « Espace et enseignement » le 16 septembre dans l'auditoire du Planétarium, en partenariat avec le bureau ESERO.

A.1.3. Evénements

Le Planétarium a participé aux événements suivants :

- la **Nuit des Chercheurs 2008** : des activités spéciales (liaison de vidéo-conférence en direct entre le public présent au Planétarium et les chercheurs de l'ORB situés aux Grottes de Lorette, exposition, planétarium gonflable) ont été organisées le 20 septembre en partenariat avec la Section de Sismologie, l'asbl Grottes de Lorette et la Faculté Polytechnique de Mons ;
- la **Nuit Blanche 2008** : des concerts de musique électronique ont eu lieu dans la grande salle du Planétarium la nuit du 4 octobre ;
- la journée « **L'Espace, j'en rêve** » à l'Euro Space Center (animation d'un planétarium gonflable) ;
- **Wetenschapsfeest** à Mechelen les 17-19 octobre (animation d'un planétarium gonflable).

A.1.4. Séances spéciales

Des séances spéciales de planétarium ont été organisées pour :

- le grand public dans le cadre du *Erfgoeddag* le 13 avril ;

- les visiteurs de l'Expo-Sciences les 8-10 mai ;
- les participants au *Family Day OMRON* le 14 septembre ;
- les participants au *Family Day "BruXPO 58-08"* le 28 septembre ;
- le grand public dans le cadre des *Nocturnes des Musées Bruxellois* les 16 octobre et 13 novembre ;
- les participants au *"Bijt in Brussel-dag"* le 27 novembre.

A.1.5. Locations de salles

Les locaux du Planétarium ont été mis à disposition à différentes reprises dans l'année :

- réception de nouvel-an du Haut-Représentant belge pour la politique spatiale le 22 janvier ;
- colloque du *Belgian National ESO Committee* (BNEC) le 22 février ;
- réunion du *Groupe de Contact Astronomie FNRS/ORB* le 11 avril ;
- colloque de présentation de la *mission spatiale PLATO* le 5 mai ;
- location par *De Vlaams Energieagentschap* le 19 juin ;
- location par le *Service Public Fédéral P&O* le 23 juin ;
- location par la *Royal Netherlands Academy of Arts and Sciences* le 26 juin ;
- location par *Adhesia* le 29 août ;
- location par l'asbl *Prosport* le 5 septembre ;
- location par *De Koninklijke Belgische Ruitersportfederatie* le 30 septembre;
- location par *La Poste* le 22 octobre ;
- location par *Unilever* le 21 novembre.

A.1.6. Site web et brochures

Deux **dépliants/posters** (une version néerlandophone et une version francophone) ont été réalisés en 2008. 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 la constellation d'Orion (dans le cadre de l'Année Internationale de l'Astronomie) ; les dépliants/posters ont été envoyés à l'ensemble des écoles au moment de la rentrée scolaire.

Fin 2008 a été préparée la **brochure destinée au grand public** : elle présente les différents programmes et contient diverses informations pratiques ; elle couvre l'année 2009.

Le **site Internet** du Planétarium a été totalement remanié et bénéficie maintenant d'une présentation visuelle moderne et attractive : www.planetarium.be.

A.1.7. Partenariats

Les collaborations avec la **Mini-Europe** et **Living Tomorrow** (Vilvoorde) sous forme de tickets combinés pour les groupes se sont poursuivies avec succès.

Le Planétarium a été l'un des participants des différentes réunions organisées par le « **Forum Espace & Enseignement** ». Ce Forum, soutenu par le Fonds Prince Philippe, est destiné à promouvoir les carrières scientifiques auprès des acteurs de l'enseignement belge.

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.1.8. Personnel

Au 31 décembre 2008, le personnel du Planétarium se composait de **16 membres** :

- R. Alvarez, 1er assistant, statutaire - responsable
- V. Bastin, experte technique, contractuelle – animatrice scientifique
- G. Champagne, attaché scientifique, contractuel - R&D
- S. Consiglio, administratief medewerker, contractueel – accueil
- H. De Rycke, gedetacheerd leraar – cours
- D . De Winter, administratief deskundige, contractueel – accueil
- 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. Milis, industrieel ingenieur, statutaire - responsable technique
- O. Rezabek, ingénieur industriel, statutaire - ICT
- R. Mostaert, enseignant sous contrat - cours
- A. Sayer, collaborateur nettoyage, contractuelle - entretien
- 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 (d'une durée totale de deux années) 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, notamment mais pas exclusivement, le milieu éducatif.

Après les phases de recrutement, d'étude et de définition de stratégie, a débuté en novembre 2007 la **phase opérationnelle** qui a vu la réalisation de plusieurs projets en 2008: projets de classes-pilotes, création de fiches pédagogiques, organisation de portes ouvertes, participation à des salons, etc.

Cette phase opérationnelle a pris fin le 30 octobre 2008, lors de la remise du « *Consolidated evaluation and associated final report* » à l'ESA. Ce document marque le terme des deux ans du projet pilote. Fort du succès obtenu par les deux Office Managers ESERO (B. Froidure, T. Goethals), l'ESA a tout de suite entamé des négociations avec l'Observatoire afin de poursuivre le projet ESERO au Planétarium pour une nouvelle période de deux ans.

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 « ***Special Point of Contact*** » auprès de *l'International Astronomical Union* pour la coordination et la promotion des activités à planifier et réaliser 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 a été mis en place ; ce Comité s'est réuni à cinq reprises en 2007 (5 mars, 19 mai, 15 septembre, 3 novembre, 4 décembre).

Plusieurs **projets d'activités** (pièces de théâtre sur Galilée, olympiade d'astronomie, édition spéciale de timbre, etc.) ont été définis au cours de ces réunions.

A.4. Exposition ESA

Grâce à un financement spécifique de l'ESA, le Planétarium a lancé un appel d'offre pour la réalisation dans le hall d'une **exposition interactive** présentant au grand public les activités et missions de l'ESA.

La conception de cette exposition a été confiée à la firme Hüttinger (Allemagne), qui en a effectué la réalisation et l'installation en décembre.

A.5. Equipement & Dotations

Au cours de l'année 2007 a été menée à bien toute la procédure de sélection relative à deux appels d'offre d'achat (subsides obtenus auprès du Lotto pour l'achat d'équipement scientifique) diffusés dans le cadre de deux procédures négociées sans publicité. Le **système de contrôle, serveur média et projecteurs vidéos haute-technologie** acquis dans le cadre de ces appels d'offre ont été installés en février 2008. Ils permettent de projeter deux fenêtres vidéo sur le dôme de manière symétrique, et donc de pouvoir utiliser la totalité de la capacité de la salle.

Le Planétarium a bénéficié d'un subside accordé dans le cadre de la **Dotation spécifique 2008** pour financer plusieurs activités liées à l'Année Internationale de l'Astronomie (achat de spectacle de planétarium, communication, exposition).

Il a également obtenu **deux subsides spécifiques** accordés par la Ministre de la Politique scientifique pour promouvoir les activités de l'Année Internationale de l'Astronomie d'une part, et pour participer au financement du projet de planétarium numérique d'autre part.

C'est également pour ce dernier projet que le Planétarium s'est vu attribué un financement d'achat d'équipements scientifiques par la **Loterie Nationale** et d'un sponsoring par la **Banque Nationale de Belgique**.

En partenariat avec plusieurs acteurs de l'année Internationale de l'astronomie, un **projet EWI** a été proposé (sans succès) à la Région Flamande.

Le Planétarium est partenaire d'un projet international COMENIUS intitulé « Hands-On-Universe » déposé auprès de l'Union Européenne à l'automne 2008. L'évaluation est attendue pour début 2009.

B. BIBLIOTHEQUE

B.1. Situation du personnel de la bibliothèque commune à l'ORB et à l'IRM

Responsable scientifique : Pierre ALEXANDRE (Chef de travaux).

Personnel de la bibliothèque :

- Jean-Marie DANLOY (Technicien de la recherche, statutaire).
- Myriam VANDERCOILDEN (Technicienne de la recherche, contractuelle).
- Ana Maria HERNANDO (Technicienne de la recherche, contractuelle), du 18 février au 14 décembre 2008.
- Luc VANHASSEL (Adjunct-Technicus der vorsing, statutair BIPT).

Recrutement : Suite à un recrutement organisé par le SELOR, en date du 2 décembre 2008, le jury a sélectionné, pour un poste de bibliothécaire-documentaliste de niveau B (statutaire), la candidature de Mme Sabrina WINTMOLDERS; elle entrera en fonction en 2009.

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 2008 de 154 abonnements à des périodiques en version sur papier (74 pour l'IRM, 80 pour l'ORB) ; en outre, environ 160 publications périodiques ont été reçues soit par dons soit par échanges avec d'autres institutions. Les collections se sont enrichies par ailleurs de 45 livres acquis par achat (15 pour l'IRM, 30 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 2008: trente-sept abonnements ont été pris en 2008 par les deux instituts (dix-huit pour l'ORB, dix-neuf 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). Le nombre de ces périodiques gratuits du réseau SwetsWise a fortement augmenté en 2008 et est au stade actuel de 78 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 instituts.

B.2.4. Classement des collections

Diverses collections de périodiques peu ou pas consultés (collections 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.

Par ailleurs, le récolement général des collections de livres antérieurs au XXe siècle a été poursuivi. A l'occasion de l'informatisation progressive de la bibliothèque, des ouvrages enregistrés séparément ont été rattachés aux grandes collections dont ils faisaient éventuellement partie. La reliure de 139 volumes de périodiques a également été effectuée.

B.2.5. Informatisation de la bibliothèque

Pour rappel, l'informatisation de la bibliothèque de l'ORB – IRM 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 2008, les activités d'informatisation de la Bibliothèque, en dehors de celles financées spécifiquement par le SPFP Politique Scientifique (voir plus bas), ont été les suivantes :

- Catalogage et "bulletinage" systématique, avec attribution de "codes-barres", de tous les livres et numéros de périodiques acquis en 2008 (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 2008 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 travail s'est déroulé du 1er novembre 2005 au 31 décembre 2008. L'arrêté a attribué une somme totale de 19.078 Euro pour les deux institutions (ORB et IRM). Cette somme a permis l'engagement, du 18 février au 14 décembre 2008, d'un agent contractuel, Mme Ana Maria HERNANDO, qui a été chargée d'encoder les données des livres et brochures antérieures à la date de 1951. Mme Hernando a encodé pendant ladite période quelque 10.200 fiches catalographiques, représentant l'ensemble des livres acquis par la bibliothèque entre 1900 et 1938.

Il reste 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. 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.

C. INLICHTINGEN – INFORMATION

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.

C.2. Information given to the media

C.2.1. Press Releases

- Hottest Stars in Delicate Embrace by Spiral Arms (A. Lobel and R. Blomme) http://www.astro.oma.be/HOTSTAR/press/pressen08.html
- On the mass of Phobos (P. Rosenblatt and colleagues) http://www.esa.int/esaCP/SEMB82TG7MF_index_0.html
- Belgian solar physicists win prizes (E. Podlachikova, D. Berghmans and colleagues) http://www.astro.oma.be/common/pdf/Press_be_en.pdf
- On the recent Earthquakes in Belgium (12-14/06, 8-9/08 and 13/09/2008) http://seismologie.oma.be (T. Camelbeeck, K. Vanneste, M. Van Camp, K. Verbeeck, T. Lecocq, and colleagues)
- On the leap second (P. Defraigne and colleagues) http://www.astro.oma.be/EN/hotnews/leap_secEN.pdf

C.2.2. Interviews

Many interviews were given by members of the Observatory, including:

- Radio Scorpio (08/01 on space debris etc.)
- RTL-TVI, (January, on the leap year)
- RTBf Radio (29/01, on asteroids)
- RTL "Tout s'explique" (07/02 on earthquake activity)
- TELEPRO (20/02, on earthquake activity in Belgium)
- Focus-WTV (21/03, concerning the borehole seismometer in Oostende)
- RTL-TVI (12/05, about the Sichuan earthquake)
- RTL "Tout s'explique" (14/05 on tides)
- RTBf News (22/05 about earthquakes and the experiments in the Rochefort cave)
- Radio Suisse Romande (04/06, about Sun-Earth relations)
- Grenz-Echo (29/07, on the work performed at the Membach station)
- RTBf Radio (31/07, on solar eclipses)
- VRT-Radio 2 (31/07, on solar eclipses, 2 times)
- RTBf Au Quotidien (26/08 on astronomy)
- ID (05/09, interview by Bérangère Cornez for article "voyage en géodésie"
- RTBf Radio (02/10, on asteroids)
- RTBF, Au Quotidien (29/10 on Daylight Saving Time)
- RTBf radio (18/11 on European Space Weather Week)
- VRT-Radio 1 (18/12 on the leap second)
- RTBF (29/12 on the leap second)
- FM Brussel (29/12, on the leap second)
- RTL-TVI (31/12 on the leap second)
- In addition, members of the seismology section gave numerous interviews concerning the sequence of earthquakes in Brabant wallon.

- Radio Donna, during the kick-off of the website www.ikhebeenvraag.be

C.2.3. Information given to the media

On numerous occasions information (without interview) was given by telephone or email to the media, mostly to newspaper and magazine journalists (De Tijd, Het Laatste Nieuws, Het Nieuwsblad, De Standaard, De Morgen, La Libre, Athena …) but also to television and radio (VRT TV1, VTM, RTL, VRT-radio, Rtbf-radio …).

C.2.4. Assistance with TV and film recordings:

In a few cases assistance was given to TV and film recordings on the site in Uccle, e.g.:

- RTBf, 26/02, on Quetelet;
- RTBf, RTL & TV-Brussel, 01/08, on the solar eclipse;
- TV show "G-Pi-G", preparation of a seismic station for an experiment
- Film: Sterrenkunde in Vlaanderen

C.3. Public conferences

Also in 2008 many members of the Royal Observatory gave popular public conferences:
Some examples:

- "A la découverte de la Planète Mars", Conférence pour l'Université des Ainés, Woluwé-Saint-Lambert, 15/01/08 (V. Dehant)
- "The satellite CoRoT", VVS-afdeling Helios, Ramsel-Herselt, 20/01/08 (J. Cuypers)
- "Space Weather: an international affaire and beyond", Utrecht, the Netherlands, 16/02/08 (P. Van Lommel, T. Krijger)
- "Collaboration entre astronomes, professionnels et amateurs: pourquoi et dans quel but?", SRBA, Ukkel, 16/02/08 (P. Lampens)
- "La terre ne tourne pas en 24 heures", Printemps des sciences, Louvain-la-Neuve, 11/03/08 (P. Defraigne)
- "Les tremblements de terre", invited by the association La Maison des Sciences de la Vie et de la Terre, Faculté Polytechnique de Mons, 13/03/08 (T. Camelbeeck)
- "De sterren", Sterrenkijkdagen, Westerlo, 15/03/08 (J. Cuypers)
- "Late stadia van ster-evolutie", Part 5 of a 6-part course "Actuele Onderwerpen in de Sterrenkunde", Volkssterrenwacht Beisbroek, 19/03/08 (G. Van de Steene)
- "Soleil et Terre: en liaison directe avec une étoile », Société Royale Belge d'Astronomie, Brussel, 19/04/08 (F. Clette)
- "Over asteroseismologie, eclipsen en nauwe dubbelsterren", VVS-General meeting, Genk, 26/04/08 (P.Lampens)
- "La recherche sur les planètes telluriques et sur Mars en particulier", 3 Conferences organized by the Euro Space Center, Redu, 01/10/2008 (V. Dehant)
- "De Aarde in de ban van de Zon", Urania, Hove, 07/10/08 (P. Van Lommel)
- "Mars Resarch at the Royal Observatory", Mars Society Meeting, Antwerp, 18/10/08 (J. Cuypers)
- "De Zon in het vizier", Urania, Hove, 21/10/08 (P. Van Lommel)
- "Alles wat je wilde weten over het zonnevlekkengetal (maar nooit durfde vragen) ", Annual reunion VVS-werkgroep Zon, Mira, Grimbergen, 08/11/08 (P. Van Lommel)
- "Het project RUSTICCA", Mira, Grimbergen, 03/12/08 (T. Pauwels)
- "PROBA2 satellite: pre-launch briefing", Urania, Hove, 16/12/08 (D. Berghmans)

C.4. Questions from the public

In 2008 about 510 questions by email, 640 by telephone and 290 by letter or fax were answered by the information services directly. This is an increase from 1280 in 2007 to 1440 for 2008. I.e. about 10% more, but, apart from some extra letters (90), there is no clear explanation for this increase.

Amongst the subjects of the questions (where not directly related to research activities): sunset, sunrise, equinoxes and solstitia, horizontal coordinates of sun and moon, the amount of shadow, sun dials, moon rise and set, moon phases, fireballs, meteors, satellite re-entries, eclipses in 2008 and other years, all sort of calendar topics (Easter dates, beginning and end of Ramadan), 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, distances in the universe, structure of the universe, on satellites and space missions, candidate meteorites, photographs and images of the Observatory, history of the observatory, evolution of the solar system, the planets and the moon, atmospheric halos, goniometry and positional astronomy, giving and/or registering of stars names, adopting or buying stars, on the Large Hadron Collider of CERN, black holes, etc.

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.

Questions about weather and climate were sent to the Meteorological Institute and those about space travel and aeronomy to the Belgian Institute for Aeronomy.

The ROB participated to 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 goverment.

C.5. Digital photographs, illustrations and movies

- More (digital) photographs of all aspects of the ROB were processed. Pictures of the instruments of the museum, of some of the buildings and the domes and of the meridian line of the main entrance were made. Old pictures and/or text were scanned and archived. A few were sent out for a variety of purposes, including for foreign journals or seminars abroad.
- The work on the digital photo archive continued.
- New animation movies on scientific subjects were made.

C.6. Website

- The content of web pages with the answers to frequently asked questions was regularly updated. For 2008, the pages on summer time, tides 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.
- Items for the Hot News website of the Observatory were prepared in three languages and sent to the webmaster (e.g. on the mass of Phobos, on Stars with mass loss in spirals and on the leap second).

C.7. Visits

A large number of groups and individual visitors were given a tour of 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.
Dates of guided visits (individuals and groups): 04/02, 06/02, 13/02, 21/02, 07/03 (Scicom), 13/03 (Dream Day), 18/03 (VUB), 19/03, 27/03, 30/05, 08/09, 11/09, 03/10, 24/10, 03/11, 19/11.
In a few cases extra information was given, e.g. to stagiaires or visiting students (e.g. on 13/03, 18/03, 8-10/4, 16-18/12).

C.8. Meetings and missions

Only a 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 few of those

meetings took place at the Cabinet of Minister of Science Mrs. Laruelle (17/03, 28/05, 06/06, 29/09). The subjects were the communication of the federal institutes and the creation of an electronic newsletter.

In 2008 the meetings on the International Year of Astronomy 2009 continued. J. Cuypers attended the meetings on 05/03, 19/05, 15/09, 03/11, 04/12 (Planetarium) and 16/12 (Technopolis). J. Cuypers did new suggestions for possible activities and dates of star gazing nights in 2009. He presented also the project to prepare an edition of Space Connection on Astronomy in Belgium (see further).

J. Cuypers attended the meeting "Kennismakers" at the Heizel (Brussels) at the occasion of the 80th anniversary of the FWO (23/10/2008).

A first preparatory meeting on the open doors of October 2009 took place.

C.9. Publications and related tasks

- Translations, corrections and proofreading of articles for the journal Science Connection;
- Translation and/or help with press texts (e.g. on Phobos, on Stars with mass loss in spirals and on the leap second);
- Some suggestions for texts on the Observatory in Belspo publications were made;
- The audiovisual presentations describing the history and activities of the Observatory were updated on a regular basis and used on several occasions, mainly as the introductory part during group visits.
- J. Cuypers took the responsibility to prepare a special issue of Space Connection (part of Science Connection) on Astronomy in Belgium. This issue has to appear at the occasion of the International Year of Astronomy 2009. Therefore he had to contact all astronomical research institutes and amateur astronomy associations in Belgium and ask for a short description of there activities and some illustrations. These texted had to be adapted and edited to a homogeneous format. A selection of images of celestial objects was made by J. Cuypers to illustrate this issue as well. All remaining translations (French to Dutch and Dutch to French) were done by J. Cuypers with some aid by Y. Coene. At the end of 2008 a manuscript of 24 pages in both languages was ready.

C.10. Publications in popular journals

[110] **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 (2008).

[111] **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 (2ème partie)
Ciel & Terre 124, 4, 98-109 (2008).

[112] **Pauwels, T**.
Henri Debehogne overleden
Heelal 53 (2008), nr. 2, 65-65.

[113] **Pauwels, T.**
2008 TC_3 de eerste asteroïde waarvan de inslag op Aarde voorspeld is
Heelal 53 (2008), nr. 12, 409-411.

[114] **P. Vanlommel**
Het weer in de ruimte
Zenit, 5, 223-226

[115] **P. Vanlommel, M. Mierla, L. Rodriguez, A.N. Zhukov, D. Berghmans, R.A.M. Van der Linden, S. Gissot, O. Podladchikova, E. Robbrecht**
STEREO: een dubbele dosis Zon
Heelal, 53, 396-408

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 2007 the Yearbook for 2008 was published. It was produced by C. Bruyninx (Coordinates), F. Clette (The Sun, Tables), J. Cuypers (Calendars, Comets, Meteors), T. Pauwels (Title, Preamble, Constants, Planetary and Satellite Data, Planetary Phenomena, Visibility and ephemerides of the planets, Minor planets, Eclipses, Transits, Occultations, Satellites of Jupiter), F. Roosbeek (The Moon, Tables) and J. Sauval (Comets, Meteors), with the technical assistance of G. Evrard and D. Mesmaker. The preparation (choosing the value of Delta_t to apply) was done by T. Pauwels. Translations were made by R. Alvarez and T. Pauwels. The general coordination, lay-out, final editing and contact with the publisher was done by T. Pauwels.

In 2007 the Yearbook had to be adapted to the demotion of Pluto to dwarf planet.

The chapter "Coordinates" was also rewritten to be adapted to the extensive use of GPS nowadays. The revised version includes the coordinates of our IGS permanent GPS station and the coordinates of the Schmidt telescope. For that purpose the coordinates of the Schmidt telescope have been computed from GPS measurements.

T. Pauwels programmed the computation of the PHEMU phenomena (mutual eclipses and occultations of the Galilean Satellites), with the intention of including them in the Yearbook 2008. However, there are no such events visible from Ukkel in 2008, so they will appear for the first time in the Yearbook 2009.

F. Clette finalised the process of completely rewriting the totally outdated software to compute the chapters related to the Sun and the Tables. This was done in collaboration with T. Pauwels, in order to make advantageous use of existing software.

D.1.3. Perspective for next years

In 2009 we shall introduce a new chapter with mutual phenomena of the satellites of Jupiter.

D.1.4. Publications

Pauwels, T., Bruyninx, C., Clette, F., Cuypers, J., Roosbeek, F., Sauval, J.
Annuaire de l'Observatoire royal de Belgique - Jaarboek van de Koninklijke Sterrenwacht van België 2008

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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	Werkleider	
	Geaggregeerd werkleider (vanaf 01/02/2008)	
Blomme Ronny	Werkleider	
Bruyninx Carine	Werkleider	
Camelbeeck Thierry	Chef de section f.f.	
Clette Frédéric	Chef de travaux	
Collin Fabienne	Chef de travaux	80 %
Cuypers Jan	Werkleider	
De Cat Peter	Werkleider	
Defraigne Pascale	Chef de travaux	80 %
Dehant Véronique	Chef de section	
Frémat Yves	Assistant	
Groenewegen Martin	Werkleider (vanaf 01/02/2008)	
Hensberge Herman	Departementshoofd d.d.	
Hochedez Jean-François	Chef de travaux	
Krijger Johannes Matthys	Assistent (tot 01/10/2008)	
Lampens Patricia	Departementshoofd	
Pauwels Thierry	Afdelingshoofd	
Roosbeek Fabian	Chef de travaux	
Van Camp Michel	Chef de travaux	
	Chef de travaux – aggregée (à partir du 01/04/2008)	
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
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

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 (à partir du 01/04/2008)	
Langenaken Hilde	Technisch deskundige	
Martin Henri	Expert technique	80%
Mesmaker Dominique	Expert technique	
Moyaert Ann	ICT deskundige	80%
Peeters Georges	Technisch deskundige (tot 01/11/2008)	80%
Peeters Roger	Technisch deskundige (tot 01/05/2008)	
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	
Verbeemen Christiane	Expert technique (jusqu'au 01/04/2008)	50%
Vermeiren Katinka	ICT deskundige	80%
Van de Meersche Olivier	Expert Financier (à partir du 01/06/2008)	
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
Koot Laurence	Boursier FNRS
Lecocq Thomas	Boursier FRIA
Pfyffer Gregor	Boursier FRIA

Pham Le Binh San	Boursier FNRS
Sichien Els	Beursstudent IWT
Trinh Antony	Boursier FNRS
Khoda Oleg	Boursier Non-EU (jusqu'au 01/03/2008)
Mierla Marilena	Boursier Non-EU (à partir du 01/02/2008)

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	
Lefever Koen	Expert ICT	
De Vos Frédéric	Expert ICT	
De Winter Davy	Technisch deskundige	
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 (à partir du 09/07/2008)	
Lobel Alex	Werkleider (vanaf 10/07/2008)	

A.1.1.4. Contractueel personeel / Personnel contractuel

Wetenschappelijk personeel / Personnel scientifique

Naam/Nom	Functie/Fonction	Contract
Avşar Ulaş	Attaché	EU Marie Curie
Baire Quentin	Attaché	Chercheur supp
Benmoussa Ali	Chef de travaux	PRODEX
Bergeot Nicolas	Assistant	STCE
Berghoff Tobias	Attaché (à partir du 01/10/2008)	PRODEX
Beuthe Mikael	Assistant	PRODEX
Boës Xavier	Attaché	EU Marie Curie
Boyes John David	Assistant	PRODEX
Champagne Georges	Attaché	Service contract / Cherch. Sppl.
Coutereel Frank	Attaché (tot 01/12/2008)	STCE
Dabrowski Bartosz	Assistant (vanaf 01/10/2008)	PRODEX
Dammasch Ingolf	Attaché	PRODEX
De Cuyper Jean-Pierre	Werkleider	DIGITALISATION
Delouille Véronique	Assistant	PRODEX
	Chef de travaux (vanaf 01/11/2008)	PRODEX
D'Huys Elke	Attaché (vanaf 16/10/2008)	STCE
Dolla Laurent	Assistant (à partir du 01/10/2008)	STCE
Dominique Marie (50%)	Assistant	PRODEX
Everaerts Michel	Chef de travaux	Action 1
Fraser Jeffrey	Attaché	EU Marie Curie
Garcia Moreno David	Attaché (jusqu'au 08/07/2008)	EU Marie Curie
Giordanengo Boris	Assistant	PRODEX
Gissot Samuel	Assistant	PRODEX

Hees Aurélien	Assistant (du 01/09/2008 au 1/11/2008)	LARA
Hekker Saskia	Assistent	Action 2
Hubert-Ferrari Aurelia	Chef de département	EU Marie Curie
Joukov Andrei	Assistant	PRODEX
	Chef de travaux (à partir du 01/10/2008)	STCE
Karatekin Ozgur	Assistant	PRODEX
Knuts Elisabeth	Attaché (à partir du 01/11/2008)	CHERCH SUPP.
Kudryashova Maria	Assistant (à partir du 01/12/2008)	Action 1
Kusman David Pierre	Assistant (à partir du 01/07/2008)	HAZARD
LeMaistre Sébastien	Attaché	PRODEX
Legrand Juliette	Assistant	Action 1
Magdalenic Jasmina	Assistant (à partir du 01/04/2008)	Action 1
Mampaey Benjamin	Attaché (à partir du 01/10/2008)	PRODEX
Marqué Christophe	Assistant	STCE
Martayan Christophe	Assistant	PRODEX
Mitrovic Michel	Assistant	PRODEX
Nicula Bogdan	Assistant	PRODEX
	Assistant (vanaf 01/10/2008)	STCE
Parenti Suzanna	Assistant	PRODEX
	Chef de travaux (vanaf 01/10/2008)	PRODEX
Petermans Toon	Attaché (tot 01/03/2008)	HAZARDS
Pireaux Sophie	Assistant	STCE
Pfyffer Gregor	Attaché (à partir du 01/10/2008)	Action 1
Podladchikova Olena	Chef de travaux	PRODEX
	Chef de travaux (vanaf 01/04/2008)	STCE
Pottiaux Eric	Attaché	PRODEX
	Attaché (à partir du 01/11/2008)	STCE
Pylyser Eric	Assistant	PRODEX
Rivoldini Attilio	Attaché	PRODEX
Robbrecht Eva	Assistent (tot 01/03/2008)	PRODEX
Rodriguez Luciano	Assistant	PRODEX
Rosenblatt Pascal	Assistant	PRODEX
Seaton Daniel	Assistant (vanaf 16/07/2008)	PRODEX
Stanger Andrew	Attaché	PRODEX
Torres Kelly (80%)	Assistant	CHERCH. SUPP
Van Hoof Peter	Assistent (tot 30/06/2008)	Actie 1
Vanlommel Petra (80%)	Werkleider	STCE
Verbeeck Koen	Attaché	BIJKOM. OND.
Verdini Andrea	Assistant	PRODEX
Verhoeven Olivier	Assistant (jusqu'au 01/10/2008)	Action 1
Wauters Laurence (80%)	Assistant	PRODEX
	Chef de travaux (vanaf 01/10/2008)	STCE
West Matthew	Assistant (à partir du 16/07/2008)	PRODEX
Wright Duncan	Assistent (vanaf 01/05/2008)	Action 1
Zhu Ping	Attaché	Action 2

Technisch en administratief personeel / personnel technique et administratif

Naam/Nom	Functie/Fonction	Contract

Goethals Thomas	Attaché A1	ESERO
Jonckheere Anthony	Adviseur A3 (jusqu'au 01/07/2008)	PRODEX
Mostaert Régis	Attaché A1	Dotation
Van Elder Sophie (60%)	Attaché A1	STCE
Wellens Véronique	Attaché A1	Dotation
De Decker Georges	Attaché A2	Digitalisation
Willems Sarah	Attaché A2	PRODEX
	Attaché A2 (à partir du 01/10/2008)	STCE
Herreman David	Expert ICT (jusqu'au 01/04/2008)	Dotation
Vander Putten Wim	Expert ICT	Dotatie
Bastin Véronique	Expert technique	Dotation
Vandercoilden Myriam	Assistant administratif	Dotation Pole
Hernando Ana Maria	Assistant administratif (à p. du 16/02/08)	Digitalisation
Smet Gert	Technisch assistent	Dotatie
Trocmet Cécile	Assistant administratif	Dotation
Wijns Erik	Technisch medewerker	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%)	Collaboratuer 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
Ducarme Bernard	Chercheur qualifié	FNRS
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 2008 était de l'ordre de 4.6 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 2008 les dépenses sur les moyens propres étaient divisées comme suit :

	ORB Dotation	ORB Services	Projets BELSPO	Projets Externes	Total
Charges 2008					
Personnel	487 025.84 €	58 115,00 €	1 020 235.89 €	1 584 751.38 €	3 150 128.11 €
Fonctionnements Subsistances	371 770.17 €	159 844.94 €	131 729.97 €	346 349.71 €	1 009 694.79 €
Fonctionnements Spécifiques	14 710.66 €	22 931.70 €	30 605.22 €	86 227.88 €	154 475.46 €
Equipements Subsistance	55 703.14 €	59 403.25 €	57 277.99 €	61 477.84 €	233 862.22 €
Equipements Spécifiques	18 396.40 €	131 156.24 €	292 196.51€	3 981.30 €	445 730.45 €
Bibliothèque	164 370.91 €	137.32 €	0.00 €	225.26 €	164 733.49 €
Total	1 111 977.12 €	431 588.45 €	1 532 045.58 €	2 083 013.37 €	5 158 624.52 €

A.2.2. Betrokken personeel / Personnel concerné

Asselberghs Somnina	Boekhouder
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
El Amrani Malika	Nettoyage
Gonzales Sanchez Bénédicte	Nettoyage
Herman Viviane	Nettoyage (Humain)
Ipuz Mendez Adriana	Nettoyage (Planetarium)
Sayer Amina	Nettoyage (Planetarium)
Vermeylen Jacqueline	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.
- Laten uitvoeren van de verplichte jaarlijkse controle van de hoogspanningscabines

C.1.2. Informatica

- Netwerkbekabeling :
- Installatie van extra netwerkaansluitingen op verschillende plaatsen.
- Stroomvoorziening :
- Installatie van een tweede UPS van 30KVA voor de 2 serverlokalen + het uurbureel.

C.1.3. Verwarming (KMI, KSB en BIRA), airco's en sanitair:

- Het onderhoud en de herstellingen van de gehele verwarmingsinfrastructuur
- Het onderhoud van de airco's
- Vervangen defect sanitair Planetarium
- Aanpassen luchtkanalen van airco digitalisatie + isolatie

C.1.4. Werkplaats mechanica

- Constructie van kleine onderdelen voor instrumenten.
- Kleine herstellingswerken aan de gebouwen.

C.1.5. Telefooncentrale

C.1.5.1. Ukkel (KMI, KSB en BIRA)

- Beheer en programmatie van vaste en mobiele telefonie
- Kostencontrole.
- Maandelijkse kostenberekening voor KMI, KSB en BIRA.
- Kableren van telefoonaansluitingen .
- Up to date houden database Omnivista en programmatie van koppelingen tussen de telefooncentrale en Omnivista

C.1.5.2. Planetarium :

- Beheer en programmatie.
- Aanpassingen.

C.1.6. Gebouwen

- Herinrichten van verschillende lokalen om extra burelen te verkrijgen. Dit omvat schilderen, plaatsen van nieuwe verlichting, elektriciteit, data en telefonie
- Inrichten van een picknickruimte en ontmoetingsruimte

C.1.7. Regie

- Opstellen van een meerjarenplan om het de toestand van de oude gebouwen te stabiliseren en te verbeteren alsook om aan de noden van de toekomst te voldoen. Volgende werken zijn prioriteit:

- Beveiliging van het plateau en de gebouwen.
- Brandbeveiliging en veiligheidsverlichting
- Restauratie van daken en koepels
- Vervangen van oude elektrische installaties

- De start van de werken aan de portiersloge en het paviljoen seismologie waren gepland maar zijn jammer genoeg nog niet begonnen

C.1.8. Waarnemingsstations voor GPS en Seismologie

- Rochefort: installatie van glasvezelnetwerk.
- Humain: automatisatie dak van waarnemingsgebouw, plaatsen van telescopen, afwerken netwerk en elektriciteit
- Membach: plaatsen van UPS, plaatsen glasvezel voor GPS-antenne, 2 He-vullingen

C.1.9. Energie en milieu

- Plaatsen van automatische verlichting in de toiletten van het hoofdgebouw.
- Gescheiden ophaling van brick
- Aanvraag gedaan voor een energie-audit.

C.1.10. Website: fase.oma.be

- Opstarten van een interne website voor de technische dienst en voor de IDPB.

C.1.11. Veiligheid en gezondheid

- Différentes demandes ont été introduites 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: cahier des charges réalisé
  → renforcement du compartimentage RF
  → installation de dévidoirs supplémentaires: travaux réalisés
  → installation de sorties de secours conformes …

- *dans les bâtiments du Planétarium :*

  → Une lettre a été envoyée à la Régie des bâtiments afin qu'il réponde à nos demandes urgentes en matière de sécurité incendie.

- Les plans interne d'urgence de l'Observatoire et du Planétarium ont été finalisés et envoyés au service du gouverneur de Bruxelles et à IBGE. Le service de prévention des pompiers de Bruxelles a également réalisé le plan d'intervention du site.
- Le personnel du Planétarium a suivi une formation d'une journée relative l'évacuation. Deux membres supplémentaires du Planétarium ont été formés au secourisme d'entreprise.
- Les exercices d'évacuation à l'Observatoire et au Planétarium ont été réalisés conformément au RGPT.
- Plusieurs visites internes de sécurité ont été réalisées
- Notre médecin du travail a procédé aux examens annuels des personnes soumises et à la visite annuelle dans nos bâtiments.
- La liste des risques de notre personnel a été mise à jour.
- Les produits dangereux ont été centralisés. Chaque produit a également sa fiche de sécurité. Les déchets sont évacués par une firme spécialisée.

- Une sécurité électrique a été ajoutée sur les machines de l'atelier mécanique.
- Les contrôles annuels légaux (extincteurs, harnais, …) ont été réalisés.
- Un dossier a été constitué pour le remplacement des anciens éclairages. Quelque uns de ces éclairages ont déjà été remplacés.
- Une demande a été introduite auprès de la Régie des bâtiments pour remplacer la plateforme du télescope Schmidt.
- Mise en conformité de notre station située à Humain (incendie, équipement de travail, …)
- Les plans d'actions 2009 ont été réalisés.
- Divers problèmes minimes de sécurité ont été traités

C.2. Personeelsbestand

- De heer Roger Peeters werd gepensioneerd.
- De heer Bert Frederick is begonnen op 1/1/08
- Mevrouw Hilde Langenaken werkt deeltijds voor de technische dienst (administratie,telefoon,briefwisseling,database)

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 amongst others the email services, application servers, printing facilities, database servers, network infrastructure, etc…

As a public service, the IT team provides access to the web site www.astro.oma.be. They also supply access to the services provided by the different scientific work groups (NTP time server from the Time Lab, Seismic charts, GPS data, Space weather, ..). The IT Department also takes part in developments related to scientific projects with international partners.

More precisely, the IT department's activities can be grouped as follows:

- **Network and Security**: the objective is to maintain the network infrastructure operational, safe and at top performance, 24 hours a day.
- **Servers and user PCs**: The objective is to install and maintain powerful compute servers, servers providing global computing infrastructure (i.e. email services, application servers, printing facilities, database servers, login server, ...) and desktop user PCs
- **User Support**: The objective is to provide help and support to the users of the Observatory.
- **AMABEL Infrastructure**: AMABEL is a join project between three institutes: ROB, RMI and BIRA. The AMABEL project finances common resources such as file servers and compute servers.
- **Purchases**: All the IT purchases are done by the IT department. This includes all the procedure, from defining the user or group needs to the installation of the chosen material. This include also the purchase of IT consumables (printer cartridges, printer toners, data storage media, etc …).

D.2. Progress and results

D.2.1. Network and Security

D.2.1.1.NETWORK INFRASTRUCTURE

- The three server rooms ("Central téléphonique" (CT), "Mire Nord" (MN) and "Bureau de l'heure" (BH)) are connected with an extremely reliable and fast network. Fibers have been installed between the three locations, thus defining a network triangle which is the backbone of our network. In 2008, the connection between the CT and the two other locations has been upgraded to 10 Gbps and the CT core switch has been doubled in order to provide redundancy.
- In 2008, the Wifi network has been improved in two manners:
  1. The antenna cables have been replaced as they were not good quality, and there was considerable signal loss due to the length of the cables.
  2. There are now two SSID: The first one, "rob-private", which is accessible by all internal ROB laptop. Identification is based on the MAC address of the laptop and the second one, "rob-public", which is accessible by external visitors for a limited time with restricted rights. Identification is based on a captive portal with login and password.

D.2.1.2.SECURITY & MONITORING

Different kind of security tests are regularly made at different network levels. Modifications are made keeping the objectives in mind.

D.2.2. Servers and users PC

D.2.2.1.VIRTUAL SERVERs INFRASTRUCTURE

- Our infrastructure is based on a pool of central servers, these are virtual servers running on Vmware environment spread out in three different physical locations, with high availability storage.
- We have installed three ESX Vmware servers, located in three different server rooms, with Virtual Infrastrure 3 (VI3) for the management.
- Virtual machine disk (vmdk) storage: as the performance of a virtual server depends greatly on the quality of its disk, the storage where the files are located is of the utmost importance. We have setup different architectures and tested each of them carefully (iSCSI, Fiber-Channel, NFS) and selected the most appropriate: NFS.
- Virtual machine management: Working with virtual machines is a completely different approach to computing than managing physical servers. With virtual machines, the choice of memory, hard disk, number of CPUs is not fixed due to the hardware configuration, but is nearly dynamically allocatable. The installation and tuning are complicated and very critical for the performance and reliability of the system. Furthermore, since we have several servers, the High Availability (HA) and the Distributed Resource Scheduler (DRS) have to be installed and configured. During a two-day-training, different aspects of the vmware configuration, some fine tuning, and last some best practices were implemented on the VI3 infrastructure of the Observatory.

D.2.2.2.Backup Server

An effort has been done in providing secure and reliable disk space for the users to be able to backup. We have installed a new system with a large iSCSI device (3.2 TB) that is also transferred to off-site location, partially to the planetarium. Different levels of snapshots are also foreseen.

D.2.2.3.Windows Server

We provide a centralized Windows server for all of our Linux users. This allows them to run MS software from time to time (mainly for Powerpoint presentations and Word articles).

D.2.2.4. Interactive Compute Server (KAOS4)

KAOS 4 is a high performance compute server for heavy scientific tasks. We do regular maintenance of this server in order to keep it at a high level of performance.

D.2.2.5. Departmental Servers

We provide continuous maintenance of departmental servers.

D.2.2.6. SMS Server

This system is used, for example, in the time lab of the observatory: if the temperature (which must be as stable as possible for the sanity of the atomic clocks) reaches a certain level, a SMS is send to the GSM of the scientific in charge as well as to the electronic lab.

D.2.2.7. Services Server

Helios, which was our login and general services server, has been split in two servers: helios as the login server and sphinx for the services.

D.2.2.8. ROB Internet & Intranet Web Servers

- Updates are regularly done on the web server concerning the intranet and the ROB website.
- A new webmail application has been installed on the server. A stable version has been released in December 2008 and is actually tested by the system administrators and some users. If this new application satisfied us, it will replace the old one (based on SquirrelMail).

D.2.2.9. NTP Server (joint project with the Time Lab of the ROB)

Two NTP servers (ntp1.oma.be & ntp2.oma.be) are reliable time synchronization sources to allow anybody to synchronize on UTC(ORB) and by extension to UTC. All servers and PCs of the 3 institutes (ROB, RMI, BISA), as well as a huge number of external anonymous clients, use these time sources.

D.2.2.10. Installation & Maintenance of User PC

- We install & configure either Ubuntu (Linux) or Windows XP/Vista on the user desktop PCs. We also install & maintain many kind of auxiliary software on these PCs.
- All our desktop PCs have a 5 years warranty NBD on site and our laptop a 3 years warranty NBD on site as well as an accidental cover damage warranty. This allows us to guarantee the functioning of these systems with a one day delay in case of failure.
- A new ICT collaborator is now fully devoted to these tasks. He is responsible of the complete PC configuration procedure: delivery, encoding valuable information in databases, installation of OS and software, delivery to the user and RMA tasks.

D.2.2.11. Public PC

A public PC is available in the printer room. This allows visitors (or users without personal PC) to have access to internet, to scan and print documents or to read/write DVD.

D.2.3. User Support

D.2.3.1. HelpDesk

- We provide to the users a direct support in the form of a helpdesk. In practice, anybody can send an email to helpdesk@oma.be and a sysadmin will help the user.
- In 2008, continuous support for users has been provided, including installation of machines and configuration as well as some guidance in the development of departmental projects.

D.2.3.2. Technet

- Technet is the equivalent of intranet but for IT specific topics. Here we provide news about major changes to our computer infrastructure, FAQs, extensive information about our hardware infrastructure including statistics & graphs about our server resources and the status of the different services.
- A new web application has been created for a better management of our assets (Pc desktop, laptops, screens, …) by the system administrators. This database contain information such as warranty type/period, the description of the material, the ICT label ID and the ORB label ID, serial number… This application is linked with the application for managing the ROB purchases.
- For the printers' management, the web application for managing the ROB printers/toners has been improved with the AJAX technology. A 3D chart has been created to see the total page usage for all ROB printers. The information used to generate this graph comes directly from the printers by using SNMP (Simple Network Management Protocol). Another chart has been created in order to have a historic of the page usage for each printer. This graph makes the difference between color and b&w prints. With this new chart, we have also the possibility to compare the page usage for max. three printers, with always the possibility to select a time period.
- For the Wifi network, a new web form has been created for adding new MAC addresses in our Radius server. Furthermore, we can now see all online users connected to the ROB private wireless network in a table updated every five seconds. The system administrators can now see the status of all our wireless access points on one page.
- A new knowledge base system has been installed in order to give the possibility to the ROB system administrators to centralize informations in one place (private section). Concerning the public FAQ, a new system has been installed using Wordpress (Blog tool and publishing platform). This new system makes the management of the frequently asked questions easier and gives also the possibility to the users to add comments.
- An IP Request form has been created on technet enabling the ROB users to make a request for a new IP address.
- A backup server form has been created which enables a user to automatically create a new account on the backup server within two clicks.
- An ftp server form has been created for ROB/RMI user wanting a new account on the FTP server (omaftp).

D.2.3.3. USERCOM

The USERCOM is a working group of user's representatives and system administrators. The aim is, on the one hand, to learn about the user's wishes, and the other hand, to share IT knowledge. We have participated to 5 USERCOM meeting in 2008.

D.2.3.4. General Services

- We print posters on the 42" plotter for the users
- We participate to the recycling process for products like cardboard boxes, toners, old computers, …

D.2.3.5. General Infrastructure

- We provide a laptop that can be used in any room for videoconferencing.
- We provide all the necessary infrastructure to allow users to work from home (teleworking).

D.2.4. Amabel Infrastructure

- The three institutes of the Space Pole share a common part of the IT infrastructure. Certain services are centralized such as the mail facilities, the large file servers, the central compute server and several other secondary servers. We participate in the maintenance of the central machines (file server, mail server, and compute server).

- Internet lines have been upgraded. The physical capacity of the main and backup lines is now 1 Gbit and our internet provider (Belnet) gives us on top of that: 100 Mbits for the non-commercial network and 30 Mbits for the commercial one.
- The planetarium is now directly connected to the ROB with a 100 Mbits dedicated line.
- The idea of installing a common Active Directory structure for the 3 institutes has been postponed.
- A new NIS master server (hardware) has been installed. Old users are being removed according to our new policies.
- A work-around has been installed for the bug in the anti-virus software on the main mail servers. New anti-virus software will be installed in the near future.
- The file server is shared between the 3 institutes. It is used for common disk space like the incoming mails and for offering easy sharable disk space for the users of the 3 institutes.
- The different logs are verified regularly, so that in case of problems we can act as necessary.
- Two common non-interactive compute servers are available for the 3 institutes. They allow users to submit heavy computation with a queuing system. They are intended to be used mainly for batch processes. In that context several different queues are defined with different specifications. The queuing system being used is PBS Pro
- Plato is now operational. Zeno has not yet been updated as some programs still have to be upgraded to the newer OS. New FAQs will have to be added to technet to inform users about this new compute server.
- A common FTP server is available for the 3 institutes. This allows anybody to share files with the outside world. This system is administrated by the ROB system administrators.

D.2.5. PURCHASES & RMA

- The IT staff is in charge of the IT purchases & RMA. This includes the definition of the user needs, contacting different resellers, making the buying proposal and checking the received material.
- We maintain a stock of small IT materials available to the users (CD, DVD, …)
- The IT department is responsible of the IT consumables (printer cartridges, printer toners, data storage media, etc …). We are in charge of the purchase of these consumables.

D.3. Perspective for next years

- VIRTUAL SERVER INFRASTRUCTURE:
  - As the final option selected is NFS from the central NetApp fileserver, some tuning might still have to be performed to get the last drops of power from the file server. Tests on restoring a previous snapshot will be carried out also in the beginning of 2009.
  - Some more tuning and tests will be done, amongst other to evaluate the possibility of replacing expensive departmental servers by virtual machines, possibly even using virtualization on blade servers. Work will be done in the first part of 2009 on the monitoring of the vmware infrastructure in order to detect and solve as soon possible any problem.
- NETWORK INFRASTRUCTURE:
  1. The distribution switches will be upgraded and the connection from the desktop PC to the network will be improved.
  2. The idea would be to actively monitor the core switches in order to have a better overview of the traffic in the three network room. A complete documentation will also be created, probably using web technologies to allow a more dynamic system with real-time status.
  3. We plan to add two or three supplementary access points to the Wifi network, and possibly replacing some of the existing access points by more powerful (more simultaneous users) ones.

- TECHNET:
    1. We will write a lot of new FAQ for the users based on the new WordPress system.
    2. We have now useful applications on technet to manage the purchases, assets, printers, toners and users. Each application has their own database. What we should do next years is to link all these databases in order to make a global and complete system with a new and unique front-end.
- INTRANET: New Intranet using SPIP cms.
- BACKUP: A new GUI interface will be setup for the backup of the desktop PC.
- PUBLIC INFORMATION: A new server will be installed for the Information department.
- FILE SERVER: Installation of the new fileservers of the FS_SPACE project
- KAOS SERVER: Two new high performance servers will be setup newt year to replace KAOS4.

D.4. Personnel involved

- David Duval
- David Herreman
- Fabian Roosbeek
- André Somerhausen
- Katinka Vermeiren

Inhoudstafel / Table de matières