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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VOORWOORD

Het is me een groot genoegen u het jaarverslag 2005 van de Koninklijke Sterrenwacht van Belgie (KSB) voor te stellen, het eerste jaarverslag waarvan de redactie werd aangevat en uitgevoerd tijdens mijn mandaat als Directeur-Generaal, en tevens het eerste jaarverslag dat in zijn totaliteit met een nieuwe vormgeving en een grotere diepgang de werking van de KSB beschrijft. Het samenvallen van de twee primeurs is evenwel toeval (of misschien net niet?) want het is vooral de verdienste van R. Verbeiren, tot 1 mei waarnemend directeur van de Sterrenwacht, dat dit document in zijn huidige vorm is tot stand gekomen. Het proces dat hij reeds eerder heeft aangevat om een jaarverslag te produceren dat tevens kan dienen als presentatie van de Sterrenwacht naar de buitenwereld, begint aldus zijn vruchten af te werpen. Ongetwijfeld zal deze evolutie zich ook in de toekomst blijven verderzetten. Het is aan u, beste lezer, om deze verdere vooruitgang in de komende jaren te beoordelen.

De overgang in mei 2005 (eindelijk!) van een waarnemend directeur naar een effectief gemandateerd algemeen directeur is natuurlijk een grote stap, die de nodige aanpassingen met zich heeft meegebracht. Wat zeker het meest positieve aspect van de definitieve benoemingen is, is dat eindelijk de impasse van besluiteloosheid werd doorbroken: tot voor de ingang van de definitieve benoemingen werden immers vele beslissingen aangaande de Federale Wetenschappelijke Instellingen uitgesteld, wat de taak van een waarnemend directeur er zeker niet eenvoudiger op maakt. Ik prijs me gelukkig dat R. Verbeiren de functie van waarnemend Directeur zeer ter harte heeft genomen, en op die manier de overstap veel eenvoudiger heeft gemaakt. Nu de weg weer open is, werken wij met fris gemoed aan de nieuwe toekomst van de Sterrenwacht.

Aangezien we met de Sterrenwacht resoluut de weg van de erkenning op internationaal niveau willen blijven bewandelen, werden grote delen van dit verslag in het Engels opgesteld, om op die manier onmiddellijk te kunnen dienen als voorstelling van onze instelling t.o.v. de buitenwereld.

Het verslag is opgesteld in drie delen: in het eerste deel vindt u een omstandig verslag van de wetenschappelijke activiteiten, daarna volgt een deel i.v.m. de publieke dienstverlening, en *last but not least* komt het onderdeel waarin de ondersteunende diensten aan bod komen.

Ik wens u een aangename lezing van dit jaarverslag.

Deel 1: Wetenschappelijke activiteiten

Partie 1: Activités Scientifiques

Part 1: Scientific Activities

Summary

DEPARTMENT 1: Reference Systems and Geodynamics

SECTION 1: Time, Earth Rotation, and Space Geodesy

Introduction: Mission and objectives

The mission of 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 large moons of the solar system planets. These missions are included in a long-term vision, closely related to the international activities and opportunities, to the global missions of the Royal Observatory of Belgium (ROB) as well as in the Director's strategic plan.

The activities of Section 1 are grouped into three general themes: (1) Time and timescales, (2) Space geodesy with GNSS, and (3) Rotation and internal structure of the Earth and the other planets that are mentioned in the strategic plan of the ROB. In total there are divided into five different scientific projects (research and/or operational projects). Here we describe the present objectives of the projects and we give 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. We maintain presently five high-quality clocks for participation in two international timescales: the International Atomic Time (TAI) and the International GPS Service Timescale (IGST). We intend to participate to the future Galileo System timescale. The present requirement for the clock precision and stability is at the level of the nanosecond over one day, which can only be achieved with high-quality clocks, when located in temperature-controlled environment. Our five 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. In order to perform these comparisons, as well as to transfer time at the centers where the computations for the international timescale are performed, we need methods which insure a time-transfer precision matching the required precision of the timescales. These comparisons are usually performed using code measurements of GPS satellites in common view. The scientists involved in the project 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, and the adaptation of the procedures to new equipments. The scientists of this project also take care of the legal issues related to the legal time. An additional important part of the work is related to the quality control and maintenance of the clocks, as our involvement in the definition of international timescale impose us a quasi perfect reliability.

<u>Milestones reached this year:</u> (1) The NTP server allowing users to synchronize their own PC is now fully operational for the diffusion of UTC(ORB) via internet and (2) the Hydrogen-maser CH1-75A has been installed in December 2005 for the realization of UTC(ORB).

(b) Project 2 'GNSS-BASED GEODESY AND GEODYNAMICS' (Operational and research project)

The mission of the project 'GNSS-based geodesy and geodynamics' is to integrate Belgium in international reference frames based on GNSS (Global Navigation Satellite System) observations of a network of

permanent GPS stations, distributed over Belgium (Brussels, Dentergem, Dourbes, Waremme, Bree, and Meeuwen). The geophysical goals related to the Belgian stations are to serve for the Space Weather and tropospheric products as explained in the next paragraph, and analyze the velocities of a regional network around Brussels in order to deduce intra-plate tectonic motions. Some of the ROB stations contribute to international networks such as, the IGS (International GNSS Service, using the station at Brussels) and the EUREF (European Reference Frame) Permanent GPS Network (EPN). The Belgian reference frame, maintained by the National Geographic Institute, is based on four EPN stations of the ROB GPS network (at Brussels, Dentergem, Dourbes, and Waremme). An important objective of this project is thus to ensure the quality of the data and the reliability of the station coordinates. This implies the maintenance of existing hardware and software, but also the establishment of a strategy for renewing the hardware and software of the Belgian GPS stations, by testing new GPS receivers, as well as by developing new pieces of software allowing better (as in easier and faster) downloading protocols and data analysis.

The scientists in this project are also much involved in the EUREF network; the ROB is a data center and an analysis center and we manage the EPN Central Bureau (CB) which coordinates the EPN network (180 permanent stations) and is taking care of the data archive, data quality control, and data analysis of these stations. They also maintain a GPS data center that makes available GPS data to all user communities. This operational project is one of the most important for geodesy in Europe.

With the upcoming Galileo precise positioning system, the scientists involved in this project will work on the incorporation, treatment, and enhancement of Galileo precise positioning system.

Milestones reached this year: (1) 2005 sees the fully operational phase of the monitoring of the EUREF Permanent Network (EPN) data quality and data flow. (2) We have shown that two commonly used methods to tie the positions obtained from a regional GNSS network to the global network can result in coordinate difference of several cm.

(c) Project 3 'EFFECT OF THE EARTH ATMOSPHERE IN SPACE GEODESY' (Operational and research project)

The mission of the project is to study and to mitigate the influence of the atmosphere on space geodetic techniques which are based on radio signals, in particular, Global Navigation Satellite Systems (GNSS). Indeed, the effect of the atmosphere (neutral atmosphere and ionosphere) on radio signal propagation is the main limitation to the precision and to the reliability of GNSS applications. Therefore, the use of GNSS signals for high precision applications in geodesy and geophysics, in particular in the frame of international projects, requires a precise modeling of the atmospheric disturbances. In practice, the scientists of this team are mainly studying the influence of the neutral atmosphere water vapor and of the ionospheric plasma on GNSS signals. For this reason, the project is divided in two main components: "Space Weather and Ionosphere" and "Neutral atmosphere and water vapor".

In the frame of the ROB scientific public service mission, the project gives support to the national and international geodesist and surveyor communities by assessing in real-time (now-casting) and forecasting the error induced by the atmosphere on GPS applications through a web interface. This activity results from collaboration with the Royal Meteorological Institute and with the Belgian Institute for Space Aeronomy in the frame of an ESA Space Weather Pilot Project.

In addition, the project also contributes to several national and international multidisciplinary research programs in the field of ionosphere physics and meteorology by reconstructing information about the atmosphere (water vapor, electron concentration in the ionosphere) using GNSS measurements. In particular, we are participating to the E-GVAP (EUMETNET GPS Water Vapor Program) in the frame of which our responsibility is to reconstruct information about Water Vapor distribution; this information is used by European National Meteorological Institutes for different applications in meteorology, in particular for weather forecasts.

The study of the impact of the ionosphere and of the neutral atmosphere on GPS is presently extended to the Galileo precise positioning system.

Milestones reached this year: (1) We have demonstrated that the data collected in a dense network of GNSS stations (with station inter-distances of about 25 km) can be used to detect the presence of ionospheric and tropospheric small-scale structures which degrade the precision of GNSS real time applications. (2) We have demonstrated that small-scale structures propagating in the ionosphere (i.e. Traveling Ionospheric Disturbances) can strongly degrade the precision and the reliability of real-time GNSS applications (up to several decimeters) even on short baselines (a few km).

(d) Project 4 '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 VLBI (Very Long Baseline Interferometry) observations as well as of analytical and numerical Earth rotation models and 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 us to better understand the dynamics of all the components of the Earth rotation, as the Length-of-day variation, the polar motion, and the precession/nutation, as well as to improve our knowledge and understanding of the system, from the external fluid layers to the Earth deep interior.

Milestones reached this year: (1) Electromagnetic coupling, important at the present observational precision, has been introduced in the numerical integration that is used to compute nutations, and second-order effects on nutation have been evaluated. (2) We have demonstrated that the Free Inner Core Nutation is not excited at an observable level by the external geophysical fluids. (3) The VLBI remaining nutation residuals have been shown to be mainly due to the effects of the geometry of the VLBI networks use.

(e) Project 5 'GEODESY AND GEOPHYSICS OF TERRESTRIAL PLANETS' (Research project)

The project aims at a better understanding of 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 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 orbiting spacecrafts. In our project, radio science data from Mars Global Surveyor (MGS), Mars Odyssey, and Mars Express (MEX) are the principal source of information. Radio science data from Venus Express (orbit insertion in April 2006) and the BepiColombo mission to Mercury will be treated in the future. For the analysis of the data, and for simulations of future experiments, large and complex computer programs are used and developed, such as GINS/DYNAMO, which is one of only a few codes in the world that can compute accurate orbits of spacecrafts 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 first MEX line-of-sight accelerations on particular targets such as the Olympus Mons have been obtained from the radioscience data, and their analysis has demonstrated that MEX confirms the MGS gravity solution up to degree and order 50 and that MEX has a much higher sensitivity to gravity attractions at small scales than MGS due to its lower pericenter altitude and therefore a better signal-to-noise ratio at the same frequency noise level as MGS. (2) The potential from mixing spacecrafts with different orbits has been demonstrated for the determination of the time variable gravity field. (3) A first value of the tidal Love number k_2 representing the mass redistribution induced by the tides and felt by the spacecraft has been determined from MGS radioscience data and showed that the Martian core is liquid. (4) Ephemerides from the Martian moons Phobos and Deimos have been released

and are presently used by the spacecraft navigation teams and the scientific community. (5) A *new method (stochastic inversion) to constrain the internal structure of Mars from a joint inversion of geophysical data has been developed and simulations have shown that the temperature and composition of the Martian mantle can be obtained from the inversion of electromagnetic, geodetic, and seismic data. (6) The effect of the core on the rotational motion of Mercury has been calculated for a large number of internal structure models and it is shown that the future libration observations with BepiColombo will allow to discriminate between internal structure models and to constrain the chemical composition of Mercury*

Links between the different projects of Section 1

The five projects within Section 1 all fit in the themes (1) Time and timescales, (2) Space geodesy with GNSS, and (3) 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. In parallel, the project 'Time and Time-transfer' uses the GPS receivers, which belong to and require the scientific expertise of the GNSS project. Similarly, the project 'Effect of the Earth atmosphere in space geodesy' uses the GPS data from the Belgian permanent stations maintained by the GNSS project. On the other hand, a careful assessment and the availability of a well-adapted modeling of atmospheric effects on GNSS signals is mandatory for high precision GNSS applications in geophysics (time transfer, reference frames, deformation monitoring, …). This topic is deeply addressed by the project 'Effect of the Earth atmosphere in space geodesy' mainly in the frame of real time or near real time applications. Complementarily, the projects 'GNSS-based geodesy and geodynamics' and 'Time and Time-transfer' correct also for the atmospheric effects targeting long time stability for reference frame maintenance and high accurate time transfer. In conjunction, the project 'GNSS-based geodesy and geodynamics' is also involved in the EUREF and IGS products including those related to the atmosphere, showing the synergies between the two projects. 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 data, to which the GNSS project contributes. 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.

National and international responsibilities and prizes

Scientists of Section 1 assume many responsibilities in national and international organizations. In Belgium, we are represented in the Belgian National Committees of Astronomy, Geodesy and Geophysics, and Space Research of the Belgian Academy of Sciences, and in the FNRS Commission for Astronomy and Geophysics. Internationally, members of Section 1 act as President, Vice-President, or Secretary of several organizations and commissions, such as the Geodesy Section of the AGU (American Geophysical Union), and commissions of the IAU (International Astronomical Union) and IAG (International Association of Geodesy). We are especially strongly involved in the IERS (International Earth rotation and Reference frame Service), with presidents, chairs, and members of several bodies, such as the Special Bureau for the Core. We participate in the IGS decisions and activities as well, such as participation in the IGS Working Groups. We participate in several space missions for the investigation of the solar system planets with co-Is (Co-Investigator) on the MEX (Mars Express) radio science experiment (MaRS, which stands for Mars express Radio Science), the VEX (Venus Express) radio science experiment (VeRa, which stands for Venus express Radio science), the BepiColombo radio science experiment (MORE, which stands for Mercury Orbiter Radio science Experiment), the BepiColombo altimeter (BELA, which stands for BepiColombo Laser Altimeter), and the BepiColombo camera (SIMBIO-SYS, which stands for

Spectrometers and Imagers for MPO BepiColombo Integrated Observatory SYStem, the name for the High Resolution Camera). We represent Belgium in several COST Actions (European CO-operation in the field of Scientific and Technological Research). We are also member of the 'Comité Consultatif pour le Temps et les Fréquences' (CCTF). Section 1 members contribute as well to the organization of conferences and workshops. In 2005, we have organized several sessions in the IAG and AGU general assemblies, as well as a workshop concerning the planet Mars in the frame of the Research and Training Network (RTN) MAGE (MArs Geophysical European network). We are also often contacted by major science journals for reviewing submitted manuscripts. At special events (leap second, Galileo launch, Venus Express launch…), we have dedicates some time to journalists: the scientists of the different projects (mainly projects 1 and 3) have been involved in 14 reports at the radio and at television and the subject of 6 articles in newspapers.

A. Time and timescales

A.1. Time and Time transfer

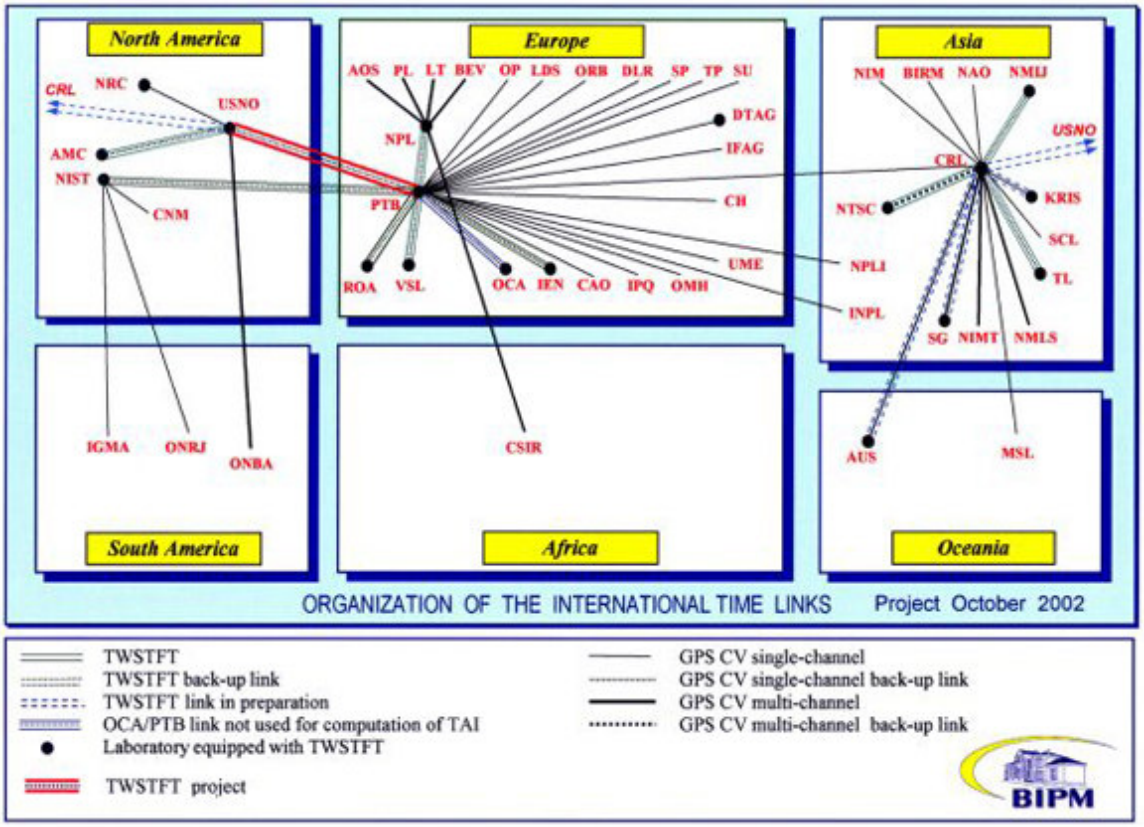


Figure 1: The time laboratory of ROB is participating in the International Atomic Time (TAI)

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 develop strategies and tools for GNSS time transfer in order to improve the precisions of remote clock comparisons, and to perform high-performance analyses of the data gathered at ROB;
- To incorporate the ROB time lab in the future GALILEO system time;
- To maintain the official Belgian time called UTC(ORB) within one hundred of nanosecond of TAI;

- To define a legal Belgian time and to include ORB in the international Mutual Recognition Agreement (MRA);
- To provide UTC to Belgian users via NTP.

A.1.2. Progress and results

The Time Laboratory of the Royal Observatory of Belgium is one of the 50 time laboratories over the world in which are distributed the 300 atomic clocks used by the BIPM (Bureau International des Poids et Mesures, Paris) for the realization of the International Atomic Time (TAI). See Figure 1.

Service

- During the year 2005, we maintained our 3 cesium atomic clocks and 2 hydrogen masers in operation and continued the near-real time monitoring of our clocks by comparison with the other laboratories' UTC(k) with a one day delay, at the nanosecond level as accuracy. The plot for each clock is now available in near-real time on private web pages;
- A new H-maser CH1-75A was installed in December 2005. During 2006, this clock should be used as source for UTC(ORB);

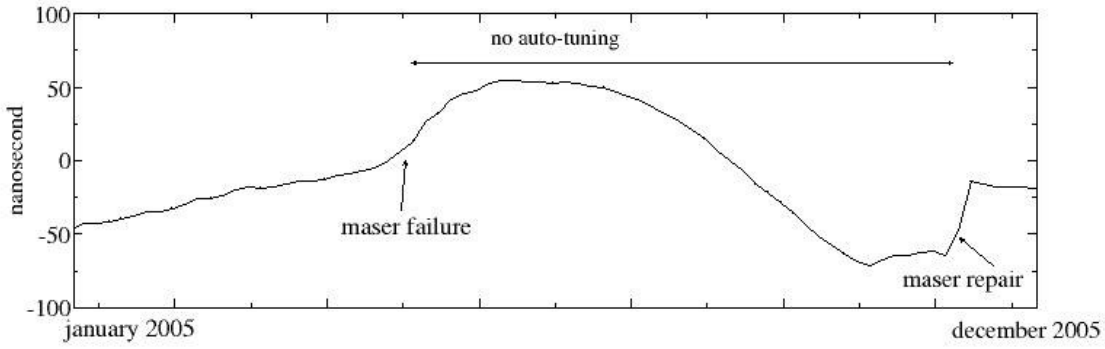


Figure 2: Precision of UTC(ORB) during 2005

- Management of the clock signals needed for GNSS receivers BRUS, ZTBR, PLB1, PLB2
- The time links using the geodetic receivers and the ionospheric free code P3, as we have developed in 2001 and 2002, are now used by the BIPM (project TAIP3) in the realization of TAI for half of the time laboratories. We modernized the software for a more general usage by all the laboratories, provided a new version (V4.0), and we contributed to its adaptation to the PolaRx2 receiver, and played the role of 'helpdesk' for all users.
- The NTP server is now fully operational for the diffusion of UTC(ORB) via internet; there are presently 2175 external users of the system.
- Continuing the procedure to get UTC(ORB), or equivalent realizations of UTC, as legal time for Belgium.
- Information of Belgium concerning the leap second of December 31.
- Negotiations with the Metrology Service for collaboration in the frame of the Mutual Recognition Agreements.

Results

- Study of the calibration of GPS/EGNOS receivers PolaRx2 (Septentrio) for time applications. Results: the receivers tested at the Observatory are well in the spec of the manufacturer, while the receiver tested at the BIPM has two outliers. The definition of the procedure to calibrate all the PolaRx2 in the time labs is in progress.
- Study of the stabilities of our atomic clocks (cesium and H-masers) at the different time scales.

- Testing the capabilities of GPS receivers for time transfer. Result: there seems to be a phase smoothing in the receiver, to be confirmed by further studies.
- First study of the use of the combined analysis of GPS carrier phase and code measurements for time transfer with a tool dedicated to time transfer only.
- Continued to investigate the optimal application of the Precise Point Positioning (PPP) and zero-difference time transfer techniques using the Bernese 5.0 software.
- Study of the history of longitude and time, in collaboration with P. Pâquet.

A.1.3. Perspective for next years

- To continue to investigate the possibilities of GPS time and frequency transfer; to perform comparisons between the different techniques and different softwares;
- To test different types of geodetic receivers to investigate the receiver-dependent signals;
- To investigate the impact of adding GALILEO and enhanced GPS on time transfer;
- To investigate the impact of adding GLONASS (GLObal NAvigation Satellite System) on time transfer;
- To continue the procedure to propose UTC(ORB) as basis for legal time in Belgium.
- Depending on the Metrology Service requirements, to prepare the Quality Criteria for the Time laboratory (norm ISO 17025 for calibration certification), necessary for the key comparisons of the MRA.
- To continue the development of a tool for time and frequency transfer based on combined analysis of codes and carrier-phase observations.
- To investigate the multipath on GPS time and frequency transfer,
- To continue the definition of calibration setup for the receiver PolaRx2 (Septentrio);
- In collaboration with the BIPM, study of the effect of using PPP (time transfer using code and carrier phase analysis) links in the TAI computation.
- To keep the NTP service at a high level of reliability and performance. This will include the installation of a second server and the configuration/setup of the redundancy system of two servers.
- Further comparison of the PPP and network zero-difference techniques.

A.1.4. Personnel involved

Scientific staff: Pascale Defraigne (***Project Leader***, 95 % of time)
Carine Bruyninx (25% of time)
Fabian Roosbeek (5% of time)
Nicolas Guyennon (100 % since November 2005)
Technical staff: Eddy Driegelinck

A.1.5. Partnerships

List of international partners without grants

- BIPM (Bureau International des Poids et Mesures: G. Petit, F. Arias)
- NRL (US Naval Research Laboratory: K. Senior)
- DLR (Institute of Communications and Navigation, German Aerospace Center: A. Moudrak)

List of national partners without grants

- Septentrio (J.-M. Sleewaegen)

Grants/Projects used for this research/service

- BELSPO "supplementary researcher" contract (Nicolas Guyennon)

Visitors: 4

A.1.6. Publications

A.1.6.1. Publications with peer system

A.1.6.2. Publications without peer system

[1] **Defraigne P., Bruyninx C.**, Moudrak A., and **Roosbeek F.**
Time and Frequency Transfer Using GNSS
In: Proc. IGS workshop (CD-rom), Bern, March 2004

[2] **Roosbeek F., Somerhausen A.**, and **Defraigne P.**
Establishment of an Internet Time Server at the Royal Observatory of Belgium
In: Proc. PTTI 2004, December 2004 (CDROM, poster02)

[3] Moudrak A., Konovaltsev A., Bauch A., **Defraigne P**., Furthner J., and Hammesfahr J.
Timing Aspects of GPS Galileo Interoperability: Challenges and Solutions
In: Proc. PTTI 2004, December 2004 (CDROM, paper30)

[4] Bauch A., Moudrak A., Hammesfahr J., **Bruyninx C., Defraigne P.**, Piriz R., and Dallat J.
Galileo Time Service Provider - the Focal Point for Galileo Timing Expertise
In: Proc. EFTF 2005, March 2005 (CD-rom), pp. 152-157

[5] Moudrak A., Konovaltsev A., Furthner J., Hammesfahr J., Bauch A., **Defraigne P.,** and Bedrich S.
Timing interoperability aspects of the GPS-Galileo offset
GPS world, vol. 16(3), pp. 24-32, March 2005

A.1.6.3. Publications in press, accepted, or submitted

[6] **Roosbeek F.** and **Defraigne P.**
Long Term Study of the H-Maser Clocks at the Royal Observatory of Belgium
In: Proc. PTTI 2005, Vancouver, August 2005 (CDROM)

[7] **Defraigne P.** and **Bruyninx C.**
Testing the capabilities of GPS receivers for time transfer
In: Proc. PTTI 2005, Vancouver, August 2005 (CDROM)

[8] **Defraigne P.** and **Bruyninx C.**
GPS time transfer: state of the art
In: Proc. JSR 2005, Varsovie, September 2005 (invited)

A.1.6.4. Reports, thesis, etc

[9] A. Janssens
L'intégration des phases des signaux GPS dans le transfert de temps
Mémoire de Licence, UCL, June 2005, Promoter: **P. Defraigne**.

A.1.7. Scientific outreach

Meeting presentations

[10] Bauch A., Moudrak A., Hammesfahr J., **Bruyninx C., Defraigne P.**, Piriz R., and Dallat J.
Galileo Time Service Provider - the Focal Point for Galileo Timing Expertise
EFTF 2005, March 2005.

[11] **Roosbeek F**. and **Defraigne P.**
Long Term Study of the H-Maser Clocks at the Royal Observatory of Belgium
PTTI 2005, Vancouver, August 2005.

[12] **Defraigne P.** and **Bruyninx C.**
Testing the capabilities of GPS receivers for time transfer
PTTI 2005, Vancouver, August 2005.

[13] **Defraigne P.** and **Bruyninx C.**
GPS time transfer: state of the art
Journées Systèmes de Référence Spatio-temporels 2005, Varsovie, September 2005 (invited).

[14] **Defraigne P.** and **Pâquet P.**
Histoire de l'Heure
Université Catholique de Louvain, February 28, 2005.

[15] **Defraigne P.** and **Pâquet P.**
Détermination des Longitudes et Histoire de l'Heure
Cercle Astronomique de Bruxelles, May 19, 2005

National and international responsibilities

- **P. Defraigne** is:
  - Member of 'Clock Products WG' of IGS since January 2003;
  - Belgian Representative at the 'Comité Consultatif des Temps et Fréquences' of the BIPM since January 2004;
  - Member of the Scientific Organizing Committee of the 'Journées Systèmes de Références Spatio-Temporels', since 2002;
  - Member of the Scientific Organizing Committee of the European Forum for Time and Frequency, since 2005.
- Commission 31 'TIME' of the IAU:
  - Vice-president from 2003 to 2006: **P. Defraigne**
  - Members: **C. Bruyninx, P. Defraigne, V. Dehant**

Educational responsibilities

- **P. Defraigne, C. Bruyninx** were advisors of the master thesis of A. Janssens (PHYS22 2004-2005, UCL)
- **P. Defraigne** was member of the PhD jury of Philippe Merck, Observatoire de Paris: « Développement d'une station terrienne de comparaisons d'horloges atomiques par liaisons micro-ondes avec un satellite de télécommunications. », December 2005.

A.1.8. Missions

Assemblies, symposia (number): P. Defraigne (2)

B. Space Geodesy with GNSS

B.1. GNSS-based geodesy and geodynamics

B.1.1. Objectives

The objectives of this project are to maintain a GNSS network in support of multi-disciplinary applications, to use GNSS observations to integrate Belgium in international terrestrial reference frames and to determine deformations of the Earth's crust by improving the long-term accuracy of GNSS-based positioning.

B.1.2. Progress and results

B.1.2.1. GNSS Observation Network

- *Daily maintenance and upgrades (software and hardware) of the ROB network of permanent GPS stations.*
- In 2005, the decision was made to install a new GPS station in Membach, collocated with a gravimeter of the ROB. The old station in Membach has been out of order since several years and had become obsolete.
- *Integration of the ROB GPS data in international observation networks (IGS/EPN).* In 2005, we started to distribute real-time data for the station of BRUS within the frame of the RTIGS network.
- Distribution of the ROB GPS data to the user community (surveyors, scientists, other ROB projects) using the Internet. In 2005, we reorganised the internal data flow at ROB.

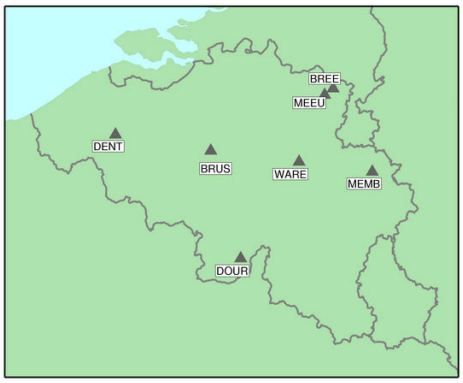


Figure 3: Network of permanent GPS stations (MEMB is being reinstalled)

- *Tests of new GPS receivers and data communication possibilities.* In 2005, the data management software of two new receivers was tested in order to verify if the receivers would respond to high data flow needs. In addition, the cost/benefit of ADSL/SDSL communications was investigated.

B.1.2.2. EPN Service: Realization of Terrestrial Reference Systems

- The project members ensure the daily management of the European Permanent GNSS Network (EPN) with over 180 stations distributed over more than 30 countries. We are the liaison between EPN station operators and analysis centres, and guarantee that the necessary station configuration metadata and the datasets meet the requirements of the analysis. Therefore our service performs daily checks of the GPS data flow and GPS data quality within the EPN. In 2005, the service integrated 25 new stations in the network.

1996 2005

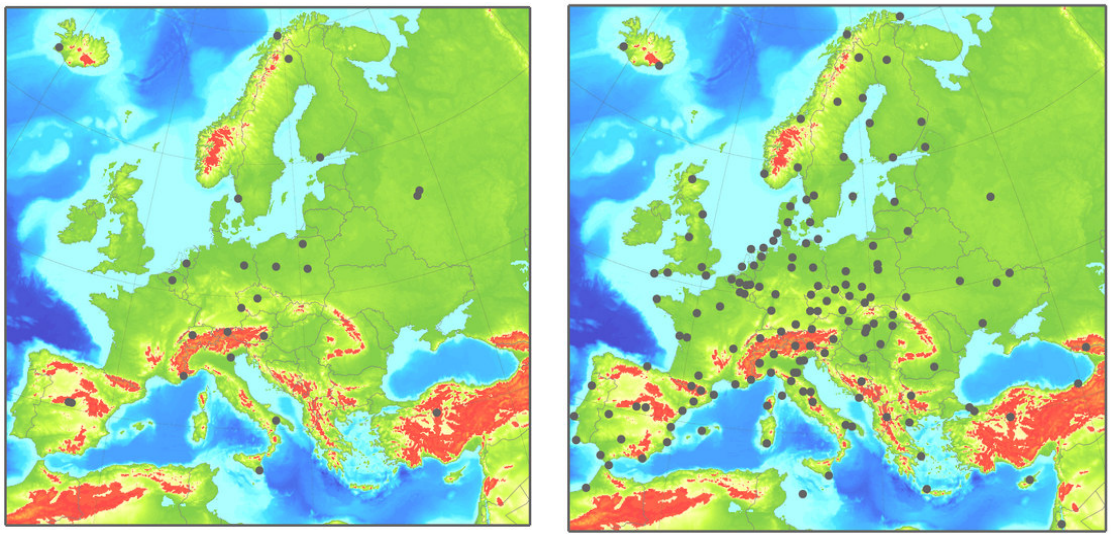


Figure 4: Stations of the European Permanent GNSS Network (EPN)

- In 2005, we demonstrated that the EPN data flow was not efficiently organised and we proposed a new organisation for the data flow, introduced new operational guidelines and implemented them

within the EPN. We also improved the reliability of the data flow monitoring and we developed alarms that automatically notify us when an EPN station shows abnormal data quality.

- As part of our service activities, we also contribute to the maintenance of the European and international spatial reference systems (ETRS89 and ITRS) by computing the daily coordinates for a network of 65 GPS stations in and around Belgium. In 2005, the software for the automated processing was fully upgraded and the Bernese 5.0 software was introduced.

B.1.2.3. Determination of deformations of the Earth's crust

Deformations of the Earth's crust are determined by computing regularly the positioning of permanent GPS stations and then combining these positions together to obtain their time evolution, and, if possible, their linear velocities.

The accuracy of the measured deformations depends on the quality of the GNSS measurements in the permanent stations, the data analysis methods used for computing the positions of the stations, and the method used to compute the coordinate time series and velocities. In 2005, progress was made on all three above-mentioned levels:

- We investigated the gain of adding the GALILEO constellation to the GPS constellation.
- We used the EPN quality check information to improve the reliability of the estimation of the EPN station velocities.
- We showed that a bug in the Bernese software degraded the quality of the combined EUREF coordinate solution.
- We showed that the coordinates of a regional GNSS network can change at the cm-level depending on how the network is tied to the global frame.
- We reprocessed the positions of the GPS stations in and around Belgium.
- We re-estimated the velocities of the permanent GPS stations in the regional network surrounding Belgium; the minimal constraint approach was used to tie the network to the ITRF2000.

B.1.3. Perspective for next years

We will continue the maintenance of the ROB GPS network and the participation to the IGS and EUREF observation networks. We plan to upgrade the ROB GPS network with new GPS receivers and install a new GPS station in Membach.

We will continue our service activities as EPN Central Bureau, EPN Data Centre, and EPN Analysis Centre. We will also continue to improve the GPS data modelling and we will compare Precise Point Positioning with Double Difference Positioning.

We will continue the reprocessing of historical GNSS data, the filtering of station coordinates, and the estimation of site velocities with both Bernese and GAMIT (GPS Analysis packages of MIT).

We will investigate the possibility to introduce GLONASS observations within the EPN and plan to start the development of GPS+Galileo positioning software.

B.1.4. Personnel involved

Scientific staff:	Carine Bruyninx (***Project Leader,*** 75%)
	Fabian Roosbeek (30%)
	Pascale Defraigne (5%)
	Georges Carpentier (action 1 MO/33/008)
	Michaël Moins (action 1 MO/33/015)
Technical staff:	Dominique Mesmaker
	Ann Moyaert
	Robert Laurent

B.1.5. Partnerships

List of international partners without grant

- Ambrus Kenyeres, FOMI Satellite Geodetic Observatory, Budapest, Hungary
- Heinz Habrich, Bundesamt für Kartographie und Geodäsie, Frankfurt, Germany
- Zuheir Altamimi, IGN, Marne-La-Vallée, France
- Günter Stangl, Institute for Space Research, Graz, Austria
- Tonie van Dam, ECGS (European Center for Geodynamics and Seismology), G.-D. Luxemburg

List of national partners without grant

- Salua Daghay, Yves Rolain, VUB, Belgium

Grants/Projects used for this research/service

- Belspo-Action 1, MO/33/008, GPSEUREF, Jan. 2002 - Jan. 2006 (G. Carpentier)
- Belspo-Action 1, MO/33/15, GPSGALILEO, Jan. 2005 – Dec. 2006 (M. Moins)

Visitors: none

B.1.6. Publications

B.1.6.1. Publications with peer review

[1] Stangl G. and **Bruyninx C.**
Recent Monitoring of Crustal Movements in the Eastern Mediterranean: The usage of GPS measurements
Nato Science Series: IV: Earth and Environmental Sciences, Vol. 61,"The Adria Microplate: GPS Geodesy, Tectonics and Hazards", Proceedings of the NATO Advanced Research Workshop on The Adria Microplate: GPS Geodesy, Active Tectonics and Hazards, Veszprem, Hungary, April 2004, Kluwer Academic Publishers, pp. 169-181

[2] Ihde J., Baker T., **Bruyninx C.**, Francis O., Amalvict M., Kenyeres A., Makinen J., Shipman S. Wilmes H.
Development of a European Combined Geodetic Network (ECGN)
Journal of Geodynamics, 40(2005), pp 450-460, doi:10.1016/j.jog.2005.0608

B.1.6.2. Publications without peer review

[3] Bruyninx C.
The EUREF Permanent Network: A multi-disciplinary GPS Network for Scientists and Surveyors
In: Proc. Earth Sciences day of the CNBGG `Geodesy and geophysics for the third millennium´, Belgian Academy of Sciences, October 13, 2005, eds. E. Arijs and B. Ducarme, pp. 135-136

[4] **Bruyninx C., Carpentier G., Roosbeek F.**
Detection and Handling of EPN Station Irregularities
Proc. IGS Workshop & Symposium "Celebrating a decade of the IGS", March 2004, Bern, Switzerland, on CD

[5] **Bruyninx C., Carpentier G., F. Roosbeek F.**
EPN Network Coordination
Proc. IGS Workshop & Symposium "Celebrating a decade of the IGS", March 2004, Bern, Switzerland, on CD

[6] **Bruyninx C.,** G. Gendt
The International GPS Service

In: IERS Annual Report 2003, Ed. Bundesamt für Kartographie und Geodäsie, Frankfurt am Main, pp. 24-27

[7] **Bruyninx C., Roosbeek F.**
Systèmes de référence terrestre et GPS
Techniques de l'ingénieur, Vol 2-205

[8] Moore A, **Bruyninx C.,** Twilley R.
IGS Network Issues
Proc. IGS Workshop & Symposium "Celebrating a decade of the IGS", March 2004, Bern, Switzerland, pp. 81-103

[9] Timofeev V., Ardukov D., Calais E., **Roosbeek F., Bruyninx C.**
On the use of Space Techniques (GPS) for Gornii Altay Crustal Movement Studies (in Russian)
Proceedings of the 2nd International Symposium "Active Geophysical Monitoring of Earth Lithosphere", Sept. 12-16, 2005, Novosibirsk, Siberian Brach of Russian Academy of Science (SB RAS), pp. 186 – 189

[10] Timofeev V., Ardukov D., Zapreeva E., Calais E., **Roosbeek F. , Bruyninx C.**
Fields and models of displacements for Chuia earthquake zone, on the south of Gornii Altay (in Russian)
Present day geodynamics and natural hazard processes in Central Asia, Part 3, Irkutsk 2005, SB RAS – Institute of Earth Crust, pp. 293-295

B.1.6.3. Publications in press, accepted, or submitted

[11] Bruyninx C.
Status of the EUREF Permanent Network
Proc. EUREF symposium, June 2005, Vienna

[12] **Bruyninx C., Carpentier G., Roosbeek F.**
Day-to-day Monitoring of the EPN
Proc. EUREF symposium, June 2004, Bratislava

[13] **Bruyninx C., Carpentier G., Defraigne P.**
Analysis of the Coordinate Differences caused by Different Methods to align the Combined EUREF Solution to the ITRF
Proc. EUREF symposium, June 2005, Vienna

[14] **Bruyninx C., Carpentier G.**, De Vidts B., Dejardin J.-P., **Everaerts M.**, Lambot P., **Lejeune S., E. Pottiaux, Roosbeek F.**, Van Huele W., Voet P., **Warnant R.**
EUREF Related Activities in Belgium
Proc. EUREF symposium, June 2004, Bratislava

[15] **Bruyninx C., Carpentier G., Lejeune S., Pottiaux E., Roosbeek F.**, Voet P., **Warnant R.**
National report of Belgium
Proc. EUREF symposium, June 2005, Vienna

[16] **Bruyninx C.**, Stangl G., Weber G.
Network Operations and Data Flow within the EPN
2003-2004 IGS Technical Reports

[17] **Carpentier G., Bruyninx C., Roosbeek F.**
Quality and Latency of the Data within the EUREF Permanent Network
Proc. EUREF symposium, June 2004, Bratislava

[18] **Daghay S., Moins M., Bruyninx C.**, Rolain Y., **Roosbeek F.**

Impact of the Combined GPS+Galileo Satellite Geometry on Positioning Precision
Proc. EUREF symposium, June 2005, Vienna

[19] Ihde J., Baker T., **Bruyninx C.**, Francis O., Amalvict M., Kenyeres A., Makinen J., Shipman S., Simek J., Wilmes H.
The implementation of the ECGN stations – Status of the 1st Call for Participation
Proc. EUREF symposium, June 2004, Bratislava

B.1.6.4. Reports, thesis, etc

B.1.7. Scientific outreach

Meeting presentations

[20] Bruyninx C.
Status of the EUREF Permanent Network
EUREF symposium, June 1-3, 2005, Vienna, Austria

[21] **Bruyninx C.**
The EUREF Permanent Network: A multi-disciplinary GPS Network for scientists and surveyors
Geodesy and geophysics for the third millenium in Belgium, 0ct. 13, 2005, Brussels, Belgium

[22] **Bruyninx C., Carpentier G., Roosbeek F.**
Analysis of the Coordinate Differences caused by Different Methods to align the Combined EUREF Solution to the ITRF
EUREF symposium, June 1-3, 2005, Vienna, Austria

[23] **Bruyninx C., Carpentier G., Lejeune S., Pottiaux E., Roosbeek F.**, Voet P., **Warnant R.**
National report of Belgium
EUREF symposium, June 1-3, 2005, Vienna, Austria

[24] **Daghay S., Moins M., Bruyninx C.**, Rolain Y., **Roosbeek F.**
Impact of the Combined GPS+Galileo Satellite Geometry on Positioning Precision
EUREF symposium, June 1-3, 2005, Vienna, Austria

[25] Kenyeres A., **Bruyninx C.**
Time series monitoring and noise analysis at the EUREF Permanent Network
Joint assembly of IAG, IAPSO and IABO, August 22-26, 2005, Cairns, Australia

[26] Timofeev V., Ardukov D., Calais E., **Roosbeek F., Bruyninx C.**
On the use of Space Techniques (GPS) for Gornii Altay Crustal Movement Studies
2nd International Symposium "Active Geophysical Monitoring of Earth Lithosphere", Sept. 12-16, 2005, Novosibirsk, Russia

National and international responsibilities

- **C. Bruyninx** is:
  - Member of the "EUREF Technical Working Group", governing board of the "sub-commission for Europe" SC1.3.a
  - Network Coordinator of the EUREF Permanent GPS Network (EPN)
  - Head of Central Bureau of the EUREF Permanent GPS Network (EPN)
  - Member of the EPN Special Project "Time Series Monitoring"
  - Head of EPN Analysis Center
  - Head of EPN Data Center
  - Co-chair of the Inter-Commission Study Group IC-SG1.2 "Use of GNSS for Reference Frames" (joint with commission 4 and IGS)
  - Member of the Inter-Commission Project 1.2 on "Vertical Reference Frames"

- Member of the Working Group "European Combined Geodetic Network (ECGN)" of the EUREF sub-commission
- Member of the Executive Board of "Wegener" inter-commission project of the IAG
- Associate Member of the International GNSS Service (IGS)
- Co-chair of the IGS Working Group on GNSS
- Observer in the European Sea Level Service (ESEAS) Technical Committee
- Member of the AM/FM GIS Belgium/Luxembourg

- **C. Bruyninx** and **F. Roosbeek** are member of Commission 1 "Reference Frames" of the IAG
- **C. Bruyninx** and **F. Roosbeek** are member of Commission 4 "Positionning and Applications" of the IAG
- **F. Roosbeek** and **G. Carpentier** are member of Central Bureau of the EUREF Permanent GPS Network (EPN)

Editorial responsibilities

- **C. Bruyninx** is member of the Advisory Editorial Board of peer reviewed journal 'GPS Solutions'

Meeting organization

- **C. Bruyninx** and **D. Mesmaker** organized the EUREF Technical Working Group Meeting, Brussels, 2 days, March 2005

Websites

- Daily updates to http://epncb.oma.be/ (±180.000 hits/month)
- Maintenance of GNSS website http://www.gps.oma.be
- Creation of new Geodesy section AGU website http://www.agu.org/section/geodesy
- EPN Brochure
- Preparation of animation and quiz for celebration of "175 anniversary of Belgium" in Planetarium

B.1.8. Missions

Assemblies, symposia (number):	C. Bruyninx (5) F. Roosbeek (1) G. Carpentier (2) M. Moins (5)
Commissions, working groups (days):	C. Bruyninx (8)
Research visits (days):	M. Moins (5)
Field missions (days):	C. Bruyninx (1) Technicians (6)

B.2. Effect of the Earth Atmosphere in Space Geodesy

B.2.1. Objectives

The goal of our project is to study and to mitigate the influence of the atmosphere on space geodetic techniques, in particular, on Global Navigation Satellite Systems (GNSS). It is divided in 2 main research topics:

- **Space Weather and ionosphere**: the goal of this project is to assess, in real-time, to forecast, a few hours in advance, and to mitigate the effect of Space Weather and of the ionosphere on GNSS applications.
- **Neutral atmosphere and Water Vapor**: the goal of the project is to analyze and to mitigate the effect of the neutral atmosphere and, in particular, of water vapor on GNSS applications.

B.2.2. Progress and results

The strategy used in our project is the following: in a first step, different techniques are developed in order to monitor all the atmospheric "parameters" which have an influence on the precision of GNSS applications. Then, the information obtained during this first step is used to understand and to mitigate the effect of the atmosphere on GNSS applications. In 2005, the following tasks have been performed:

- ***Ionosphere activity monitoring:*** We have started to process the data collected in the Belgian dense GNSS network (WALCORS and FLEPOS networks) to characterize the ionospheric small-scale (a few kilometers) activity that is the main parameter affecting high precision GNSS applications. First results show the very that Travelling Ionospheric Disturbances (TID's) which are small-scale disturbances propagating through the ionospheric plasma can induce strong gradients in the Total Electron Content (TEC) even on distances of a few kilometers. These disturbances have a very localized behavior, which emphasizes the importance of using a dense network. On the other hand, the data from the dense network have been used to understand the dynamics of TID's. The goal of this study is to forecast the occurrence of ionospheric disturbances using a-priori knowledge of their dynamics.
- ***Correlation between small-scale structures in the ionosphere and geophysical parameters:*** In collaboration with the Geophysical Institute of the Bulgarian Academy of Sciences, we are studying the geomagnetic and ionospheric (physical) conditions which are the origin of the occurrence of small-scale structures in the TEC. This study is based on geomagnetic and ionosonde measurements made at Dourbes. On the one hand, we found that geomagnetic storms are the origin of strong instabilities in the ionospheric plasma: Spread F layers, large-scale TID's … On the other hand, we also demonstrated that, even under quiet geomagnetic and ionospheric conditions, strong small-scale and medium-scale TID's are regularly observed: their physical origin is still unknown.
- ***Study of the relationship between the ionospheric activity and the positioning error:*** we have developed software allowing to assess in real-time the positioning error affecting the DGPS (Differential GPS) navigation technique and the Real Time Kinematic (RTK) surveying technique. The DGPS software is now at the end of its validation phase: we have demonstrated that this software is able to give a reliable assessment of the ionospheric error that affects DGPS applications. The RTK software is now operational on short baselines (a few km). Using this software, we have showed that strong TID's can degrade the RTK ambiguity resolution process (and the accuracy of the measured positions) even on short baselines.
- ***Development of a web-based "Space Weather" service for the users of GNSS:*** the results of the above-mentioned studies are used to provide real-time information about the atmospheric activity effects on GNSS applications through a web-based interface. New features have been added to this web service: a monthly summary of our RTK product and a longer on-line availability of all the products (all the products published since April 2004 remain on-line on our site). In 2005, the site has received more than 9 000 visits, about 100 000 pages have been browsed for a total of about 1 000 000 hits. The number of hits is very clearly correlated with Space Weather activity.
- ***Development of modernized GPS and Galileo simulation and data processing software:*** we have developed software allowing to simulate the measurements that will be made on the signals which will be emitted by Galileo and by the modernized GPS constellation (a third frequency will be added). The software has been validated by comparing simulated and real GPS measurements. In addition, we have started the development of a new technique allowing to exploit the added value of the future third frequency which will be available on modernized GPS and on Galileo for the real time reconstruction of the ionosphere Total Electron Content.
- ***Neutral atmosphere and Water Vapor:*** The neutral atmosphere introduces a delay in the propagation of GPS signals which is called Zenith Total Delay or ZTD (for propagation at the vertical of the observing station). In an atmosphere in hydrostatic equilibrium, this delay depends mainly on surface atmospheric pressure and on the Integrated Water Vapour content or IWV. On the one hand, we have continued to compute tropospheric ZTD's in near real time using a regional network of 70 GNSS stations in Europe for applications in meteorology in the frame of the EUMETNET E-GVAP project.

On the other hand, the data collected in Belgian dense GNSS network have been used in order to characterize small-scale structures in the neutral atmosphere associated with special meteorological events (thunderstorms, weather fronts …). The goal of this study is to assess the influence of such events on high precision GNSS applications.

B.2.3. Perspective for next years

The different activities carried out in 2005 will be continued. In addition, the ROB is the Coordinator of a project called GALOCAD, a European FP6 project which will be financed by the Galileo Joint Undertaking. GALOCAD stands for "Development of a Galileo Local Component for the nowcasting and forecasting of atmospheric disturbances affecting the integrity of high precision Galileo applications". This project will study whether the data collected in a dense network of GNSS stations can be exploited to set up a Galileo Local Component for the real time assessment of Galileo integrity with respect to atmospheric threats.

B.2.4. Personnel involved

Scientific staff: R. Warnant (Project Leader)
A. Barré (PRODEX)
M. Bavier (Supplementary Researcher)
S. Lejeune (PhD grant - FRIA/FNRS)
E. Pottiaux (Action 1 - 01/01/2003-28/02/2005, Action 3 – (01/03/2005-31/12/2005)
J. Spits (Action 2 – 01/10/2005-30/09/2009)
Technical staff: E. Driegelinck

B.2.5. Partnerships

List of national partners without grant

- Royal Meteorological Institute of Belgium, Department of Geophysics (Dr. J.-C. Jodogne, Dr. H. Nebdi, Dr. J. Rasson);
- University of Liège, Department of Geometrology and Geomatics (Prof. R. Arnould, Prof. R. Billen).

List of international partners without grant

- COST 296: "Mitigation of Ionospheric Effects in Radio Systems";
- E-GVAP: "Exploitation of Ground-based GPS for climate and numerical weather prediction application";
- COST 724: "Developing the basis for monitoring, modeling and predicting Space Weather";
- Geophysical Institute of the Bulgarian Academy of Sciences (Prof. I. Kutiev, Dr. B. Andonov, Dr. P. Marinov);
- University of Nottingham, IESSG (Prof. A. Dodson, Dr. M. Aquino).

Grants used for this research

- Action 1 - Belspo (01/01/2003-28/02/2005): "Development of software for the (near) real time processing of the data collected in the permanent ROB GPS network in order to participate in new geophysical applications of GPS in the international networks".
- Prodex - Belspo (01/04/2003-31/03/2005): "SIDC Space Weather Pilot Project".
- Action 3 - Belspo (01/01/2004-31/12/2005): "SIDC Space Weather Pilot Project".
- Supplementary Researchers - Belspo (01/10/2004-30/09/2006): "Atmospheric Effects in Space Geodesy".
- Prodex - Belspo (01/01/2005-31/12/2007): "SIDC Telescience".

- Ph.D. grant from FNRS/FRIA (01/10/2002-30/09/2006): "Développement d'un logiciel pour la détection, la correction et la prévision des perturbations induites par l'activité ionosphérique sur le positionnement en temps réel utilisant le Global Positioning System".
- Action 2 - Belspo (01/10/2005-30/09/2009): "Modélisation de l'effet ionosphérique affectant les systèmes de positionnement Galileo et GPS modernisé pour des applications de haute précision en géodésie et en géophysique".

Visitors: 3

B.2.6. Publications

B.2.6.1. Publications with peer review

[1] **Berghmans D., Van der Linden R., Vanlommel P., Warnant R., Zhukov A., Robbrecht E., Clette F., Podladchikova O., Nicula B., Hochedez J.-F., Wauters L., Willems S.**
Solar activity: nowcasting and forecasting at the SIDC
Ann. Geoph., Vol. 23, pp. 3115-3128.

B.2.6.2. Publications without peer review

[2] Andonov B., Kutiev I., **Warnant R.**, Nebdi H., **Bavier M.**, Rasson J.
Forecasting the Dourbes K index by using solar wind parameters
Proceedings of Beacon Satellite Symposium 2004 (on CD-ROM), 18-22 October, Trieste, Italy

[3] **Lejeune S., Warnant R., Barré A., Bavier M.**
Near real-time assessment of the ionospheric effect on navigation based on DGPS corrections
Proceedings of Beacon Satellite Symposium 2004 (on CD-ROM), 18-22 October, Trieste, Italy

[4] **Bavier M., Warnant R., Barré A., Lejeune S., Pottiaux E.**
Near real-time evaluation of the EGNOS ionospheric correction at mid-latitude
Proceedings of Beacon Satellite Symposium 2004 (on CD-ROM), 18-22 October, Trieste, Italy

[5] **Pottiaux E., Warnant R.**
Sensing the atmospheric Water Vapour and meteorological events using Tropospheric Zenith Total Delays estimated from a regional network of GPS stations
Proceedings of Beacon Satellite Symposium 2004 (on CD-ROM), 18-22 October, Trieste, Italy

[6] **Warnant R.**, Jodogne J.-C., Delobbe L., Rasson J., Grevesse J., **Pottiaux E., Bavier M., Lejeune S., Barré A., Spits J**., Nebdi H., **Van der Linden R.**
Global Navigation Satellite Systems: A new tool in atmosphere sciences
Proceedings of the Earth Science Day: "Geodesy and Geophysics for the third Millenium in Belgium", Brussels, October 13 2005, pp. 137-138, ed. by E. Arijs & B. Ducarme

[7] **Bruyninx C., Carpentier G., Lejeune S., Pottiaux E.**, **Roosbeek F.,** Voet P., Van Huele W., **Warnant R.**
EUREF Related Activities in Belgium
Proceedings of EUREF 2003 Symposium, 4-6 June 2003, Toledo, Spain, EUREF Publication No. 13, eds. J.A. Torres and H. Hornik, pp. 213-216

B.2.6.3. Publications in press, submitted

[8] **Bruyninx C., Carpentier G.**, De Vidts B., Dejardin J.-P., **Everaerts M.**, Lambot P., **Lejeune S., Pottiaux E., Roosbeek F.,** Van Huele W., Voet P., **Warnant R.**
EUREF Related Activities in Belgium
Proceedings of the EUREF 2004 Symposium, 2-4 June 2004, Bratislava, Slovakia, in press

[9] **Bruyninx C., Carpentier G., Lejeune S., Pottiaux E., Roosbeek F.**, Voet P., **Warnant R.**

National Report of Belgium
Proceedings of the EUREF 2005 Symposium, 1-3 June, Vienna, Austria, in press

[10] **Warnant R.**, Kutiev I., Marinov P., **Bavier M., Lejeune S.**
Ionospheric and geomagnetic conditions during periods of degraded GPS position accuracy: 1. Monitoring variability in TEC which degrades the accuracy of Real Time Kinematic GPS applications
Adv. Space Res., submitted

[11] **Warnant R.**, Kutiev I., Marinov P., **Bavier M., Lejeune S.**
Ionospheric and geomagnetic conditions during periods of degraded GPS position accuracy: 2. RTK events during disturbed and quiet geomagnetic conditions
Adv. Space Res., submitted

[12] Joosten P., **Lejeune S.**, Odijk D., **Warnant R.**, Kutiev I.
The effects of Travelling Ionospheric Disturbances on ambiguity resolution
Journal of Geodesy, submitted

B.2.6.4. Reports, thesis, etc

[13] **Warnant R.**
Contacts with GPS users for evaluation and improvement of the services
Technical Report of Work Package 230, Solar Influences Data Centre Space Weather Pilot Project, ESA contract 16913/03/NL/LvH

[14] **Vanlommel P., Stegen K., Warnant R., Van der Linden R.**
Final Report of the Solar Influences Data Centre Space Weather Pilot Project
Technical Report, ESA contract 16913/03/NL/LvH

[15] **Vanlommel P., Stegen K., Warnant R., Van der Linden R.**
Executive Summary of the of Solar Influences Data Centre Space Weather Pilot Project
Technical Report, ESA contract 16913/03/NL/LvH

[16] Pilonetto J.
Evaluation du modèle de correction troposphérique appliqué au système de positionnement EGNOS
Mémoire de 2ème cycle en sciences géographiques, Université de Liège

[17] Blüge T.
Influence de l'effet multi-trajets sur les mesures de pseudo-distances effectuées grâce au système GPS
Mémoire de 2ème cycle en sciences géographiques, Université de Liège

[18] **Spits J.**
Développement d'un logiciel pour la simulation de mesures de codes et de phases GPS
Mémoire de DEA en sciences géographiques, Université de Liège

B.2.7. Scientific outreach

Meeting presentations

[19] **Warnant R., Bavier M., Lejeune S., Pottiaux E.,** Andonov B., Kutiev I., **Barré A.,** Nebdi H., Rasson J., **Van der Linden R.**
Development of Space Weather related services for real-time GPS applications
Presented at the Space Environment Centre Space Weather Week, Boulder, April 5-8 2005

[20] **Warnant R., Bavier M., Lejeune S., Pottiaux E.**, Andonov B., Kutiev I., **Barré A.**, Nebdi H., Rasson J., **Van der Linden R., Roosbeek F., Bruyninx C.**

A web-based service for the real time assessment and forecast of Space Weather effects on GNSS applications
Presented at the Second European Space Weather Week, ESTEC, The Netherlands, November 14-18 2005

[21] **Warnant R.**
The SIDC GPS-Space Weather Service
Presented at the Second European Space Weather Week, ESTEC, The Netherlands, November 14-18 2005

[22] **Lejeune S., Warnant R., Barré A., Bavier M.**
Near real time assessment of the Space Weather effect on navigation based on the DGPS technique
Presented at the Second European Space Weather Week, ESTEC, The Netherlands, November 14-18 2005

[23] **Warnant R., Lejeune S., Bavier M.**
Space Weather influence on satellite based navigation and precise positioning
Invited talk, presented at the Second European Space Weather Week, ESTEC, The Netherlands, November 14-18 2005

[24] Valette J.-J., Yaya P., Prévost P.-L., Boucquaert F., Lassudrie-Duchesne P., Chouffot M., Hugentobler U., Hanuise C., Issler J.-L., Lanciaux J., **Warnant R.**
A GPS based prototype service for monitoring the ionospheric irregularities and scintillations at a global scale
Presented at the Second European Space Weather Week, ESTEC, The Netherlands, November 14-18 2005

[25] **Warnant R.**
L'effet de l'atmosphère terrestre sur les GNSS: une perturbation ou un signal géophysique ?
Présenté à la Journée d'étude « Techniques de positionnement par satellites » organisée par le Comité national belge de Cartographie et SIG, Université de Liège, 01 Octobre 2005

[26] **Lejeune S.**
Les effets ionosphériques affectant les systèmes de positionnement par satellites
Présenté à la Journée d'étude « Techniques de positionnement par satellites » organisée par le Comité national belge de Cartographie et SIG, Université de Liège, 01 Octobre 2005

National and international responsibilities

- **R. Warnant** is member of:
  - the WG "Towards an IGS Combined Ionosphere Product" of the IGS
  - the ESA Space Weather Working Team – Topical Group "Ionospheric Effects"
  - the management Committee of the COST 724 action "Developing the Scientific Basis for Monitoring, Modelling and Predicting Space Weather"
  - the management Committee of the COST 296 action "Mitigation of Ionospheric Effects on Radio Systems (MIERS)"
  - the WP 1.3 "Near Earth Space Plasma modelling and forecasting" of the COST 296 action Working Group 1 "Ionospheric monitoring and modelling"
  - the WP 3.1 "Space Plasma Effects" of the COST 296 action Working Group 3 "Space Based Systems"
  - and chairman WP 3.2 "Mitigation techniques"of the COST 296 action Working Group 3 "Space Based Systems"

Educational responsibilities

- **R. Warnant** is promoter at the UCL of the PhD of E. Pottiaux (sixth year)

- **R. Warnant** is promoter at the ULg of the PhD of S. Lejeune (third year) and J. Spits (first year)
- **R. Warnant** is/was promoter at the ULg of the master theses of J. Pilonetto (GEOM22, 2004-2005), T. Blüge (GEOM22, 2004-2005), G. Wautelet (GEOM22, 2005-2006)
- **R. Warnant** was promoter at the ULg of the DEA in sciences of J. Spits (GEOM3, 2004-2005)

Websites

Development and maintenance of a Space Weather website: http://www.gpsatm.oma.be

B.2.8. Missions

Assemblies, symposia (number):	R. Warnant (3) M. Bavier (1) S. Lejeune (2) E. Pottiaux (1)
Commissions, working groups (days):	R. Warnant (6)
Research visits (days):	S. Lejeune (1)

C. Rotation and internal structure of the Earth and the other planets

C.1. Earth Rotation

C.1.1. 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.

C.1.2. Progress and results

1. Computation of the excitation by the atmosphere of the FICN (Free Inner Core Nutation) in the Earth nutations if randomly excited (collaboration between V. Dehant, O. de Viron (IPGP, France), M. Greff-Lefftz (IPGP, Paris)); the atmospheric excitation of the FICN by a random noise has been shown to be too small in order to explain the residuals in the observed nutation series deduced from VLBI (Very Long Baseline Interferometry) data; paper published.
2. Explanation of the Non-Rotating Origin (NRO) definition (collaboration between V. Dehant, O. de Viron (IPGP, France) and N. Capitaine (Observatoire de Paris, France)); we have prepared a paper that accompanies the 3D representations of the definition of the NRO; paper about to be submitted.
3. Identification of a criterion for evaluating the quality of the Atmospheric Angular Momentum (AAM) function used to obtain the Earth rotation changes due to the atmosphere and to obtain a combined series (collaboration between V. Dehant, L. Koot and O. de Viron (IPGP, France)); we have established a strategy for combining the AAM series and characterizing the noise level of the different series; paper published.
4. Computation of a transfer function for precession and nutations expressed in terms of coordinates of the CIP (Celestial Intermediate Pole) introduced in the frame of the new IAU nomenclature and in particular when using the NRO procedure (collaboration between V. Dehant, O. de Viron (IPGP, France) and M. Folgueira (University of Madrid, Spain)); a first strategy in computing the Earth interior parameters using the X- and Y- coordinate of the pole (instead of using the classical nutation transfer function) has been set up and first tests have been performed. This work will be continued next year.

5. Development of software for the computation of tidal and nutational deformations inside the Earth using the approach of Generalized Spherical Harmonics Expansion (collaboration between V. Dehant, pre-doc students, A. Sauvigner and P. Rubishung, and O. de Viron (IPGP, France)).
6. Understanding of the fluid motion within a spherical shell in order to better model the fluid core (collaboration between V. Dehant, S. Lefèvre (pre-doc student), P. Cardin (University of Grenoble, France), D. Jault (University of Grenoble, France), M. Greff-Lefftz (IPGP, France), and O. de Viron (IPGP, France)).
7. Study of the impact of second order effect on nutation, by using a numerical integration of a simple non-linear Earth rotation model in the time domain (collaboration between V. Dehant, N. Rambaux, T. Van Hoolst, and E. Bois (Observatoire de la Côte d'Azur, Nice, France); we have obtained the nutation amplitude in the time domain for the solid Earth and the core from the numerical integration method. The nutations of the whole Earth have been compared with the precise analytical solutions; paper in preparation.
8. Study of the electromagnetic coupling at the core-mantle boundary and its effects on the tides and nutation within a numerical integration approach (collaboration between V. Dehant, with ChengLi Huang); we have computed the new equations corresponding to this case, established the new boundary conditions, and computed the Earth response in the case of the Buffett (1992, 2002) approach; paper in preparation.
9. Continuation of the development by O. de Viron of the finite difference model for computing the Earth response to the gravitational forcing. Still in development
10. Extension of the non-rigid Earth theory of nutation to the second order, considering the effects of the luni-solar potential on the dynamical shape on the Earth (i.e., zonal, tesseral and sectorial tides) (collaboration between S. Lambert and S. Mathews); paper submitted.
11. Estimation of the effect of the atmosphere, ocean, and hydrology on the Core-Mantle Boundary (Love number estimation and convolution with excitation functions); we have computed the Earth transfer function in order to obtain the influence on the Free Core Nutation (FCN) period and estimated that the effect on the FCN is too small (collaboration between V. Dehant, O. de Viron (IPGP, France)); no paper foreseen.
12. Estimation of the geodetic impact (on geocentre, Earth rotation, and gravity field) of the climate change associated at the CO_2 increase from the CMIP (Coupled Model Intercomparison Project) models (collaboration between O. de Viron (IPGP, France) and J.-P. Boy, EOST, France); work in progress.
13. Study of the atmospheric torque associated with the ENSO (El Nino Southern Oscillation) cycle (in collaboration with S.L. Marcus and J.O. Dickey (JPL)); work in progress.
14. Estimation of Earth interior parameters from nutation observations by developing a fitting procedure relying on a direct estimation of the parameters on the nutation time series. The numerical results obtained for the geophysical parameters are close to those of the IAU/IUGG adopted model obtained by Mathews et al. (2002), which validates our method. However the values we obtained are not always within their error bars (collaboration between L. Koot, V. Dehant, and O. de Viron (IPGP, France)); work in progress.
15. Identification a criterion for evaluating the quality of the Atmospheric Angular Momentum (AAM) function used to obtain the Earth rotation changes due to the atmosphere and to obtain a combined series (collaboration between L. Koot, V. Dehant, and O. de Viron (IPGP, France)); we have established a strategy for combining the AAM series and characterizing the noise level of the different series; paper published.
16. Computation of the effects of continental water (soil moisture + snow, excluding the continental cryosphere) on the Earth's rotation using the Land Dynamics Model Euphrates (LaD) monthly grid

data spanning; computation of polar motion excitation and geocenter motion (collaboration between S. Lambert and V. Dehant); work in progress.

17. Computation of geophysical excitation of the Earth's free wobbles by developing the formulae linking the excitation power within a frequency band around the wobbles nominal frequencies to the observed power, and application of these formulae to "real" data motion (collaboration between S. Lambert, V. Dehant, and L. Koot); work in progress.
18. Development of an observational strategy in very long baseline Interferometry by using networks that are the weekly 24-hour sessions R1 (on Mondays) and R4 (on Thursdays). R1 and R4 use different network geometries and we have shown that they are not consistent (work of S. Lambert); two papers will be presented at the IVS 2006 General Meeting, Concepción, Chile, January 2006.
19. A first draft of the book on 'Precession, Nutation, and Wobble of the Earth' (collaboration between V. Dehant and S. Mathews).

C.1.3. Perspective for next years

The next year we have the following perspectives:

1. To continue the test of the strategy for obtaining properties of the interior of the Earth from the celestial pole position as explained in Point 4 (collaboration between V. Dehant, O. de Viron (IPGP, France) and M. Folgueira (University of Madrid)); application of the new procedure of L. Koot in that frame; related to point 14 in the above paragraph.
2. To study the excitation process of the free wobble, in particular, by the atmosphere. The time dependence will be studied (collaboration with S. Lambert, L. Koot, and V. Dehant); this is a follow-up of Points 1 and 11.
3. To consider these atmosphere corrections in the time domain and a recent modeling of the precession rate in the nutation model in order to better evaluate the geophysical parameters that can be deduced from nutation; continuation of point 14 above (collaboration between L. Koot, V. Dehant, and O. de Viron (IPGP, Paris).
4. To work on the determination of the nutations from VLBI and, in particular, on the effects of the stability of the radio sources, accounting for the ability of the network to observe it and its magnitude (continuation of Point 17); to use the new nutation series obtained to determined the parameters as in the objective explained in Point 1 (collaboration between S. Lambert, L. Koot, and V. Dehant).
5. To continue our comparison with a more sophisticated model of the Earth between the time-domain numerical integration approach and the transfer function approach for nutation of the whole Earth and of the core (collaboration between N. Rambaux, T. Van Hoolst, V. Dehant, and E. Bois (Observatoire de la Côte d'Azur, Nice, France)), related to point 7 in the above paragraph.
6. To continue the investigation on the electromagnetic coupling at the core-mantle boundary for a case where Buffett's hypotheses are not used (collaboration between V. Dehant and ChengLi Huang), related to point 8 in the above paragraph.
7. To estimate the effect of the recent changes in the magnetic field on the length-of-day (LOD) variations in order to see if it explains the changes observed in the LOD (collaboration between V. Dehant and ChengLi Huang), related to point 8 in the above paragraph.
8. To estimate the effect of the new phase transition post-perovkite in the mantle on the FCN (collaboration between V. Dehant and P. Defraigne); this was targeted last year but never done.
9. To work on the topographic coupling at the core-mantle boundary by considering the Wu and Wahr approach and the possibility to extend it within a numerical integration procedure (collaboration between V. Dehant, T. Van Hoolst and S. Lambert).

10. To work on the topographic coupling at the core-mantle boundary by introducing it in a finite element approach (collaboration between L. Métivier and V. Dehant (Descartes Fellow visiting ROB 3 months in 2006).
11. To work on the electromagnetic coupling using the output of a geodynamo model (collaboration between V. Dehant, Weijia Kuang (GSFC, USA) and L. Métivier (Descartes Fellow visiting GSFC 6 months in 2006).
12. To work on the torsional waves in the Earth fluid core and to establish the viscosity coupling between the cylinders foreseen in this phenomena, as well as on the physical and mathematical basis of the Poincaré motion (collaboration between G. Pfyffer, V. Dehant, T. Van Hoolst, O. de Viron (IPGP, France), M. Greff-Lefftz (IPGP Paris, France)).
13. To work on the excitation of the FCN by the atmosphere, ocean, and hydrology (collaboration between S. Lambert and V. Dehant).
14. To work on the determination of the nutation from combination of GPS and VLBI with the future GALILEO (collaboration between V. Dehant, H. Schuh (Vienna Technical University, Austria) and K. Snajdrova (Descartes Fellow visiting Vienna Technical University 1 year in 2006 and 1 year ROB in 2007).
15. To finish the book on Nutation coauthored by V. Dehant and S. Mathews (Univ. Madras, India), related to point 19 in the above paragraph.

C.1.4. Personnel involved

Scientific staff: V. Dehant (Project Leader, starting in September)
L. Koot (FNRS)
O. de Viron (Action1, 8 months, Project Leader, until September)
O. Verhoeven (Action1, 1 month)
S. Lambert (Action1, 3 months)
T. Van Hoolst (ORB)

C.1.5. Partnerships

List of international partners without grant

- with Olivier de Viron (for the three last months of 2005), Laurent Métivier, and Marianne Greff-Lefftz (IPGP, France)
- with Philippe Cardin and Dominique Jault (University of Grenoble, France)
- with ChengLi Huang (Shanghai Observatory, China)
- with Marta Folgueira (University of Madrid, Spain)
- with Nicole Capitaine, Anne-Marie Gontier (Observatoire de Paris, France)
- with Weijia Kuang (GSFC, Goddard Space Flight Center, USA)
- with Harald Schuh and Kristyna Snajdrova (Vienna Technical University, Austria)
- with Zuher Altamimi and Martine Feissel-Vernier (ENSG, Paris, France)
- with Jean O. Dickey and Steve L. Marcus (Jet Propulsion Lab., USA)
- with Jean-Paul Boy (Ecole et Observatoire de Sciences de la Terre, France)
- with Richard Holme (University of Liverpool, UK)
- with Sonny P.M. Mathews (University of Madras, India)

List of national partners without grant

- with Hugues Goosse and Eric Deleersnijder (UCL)

Grants/Projects used for this research/service

- UE, Descartes Prize 2003

- Belspo China-Belgium cooperation BL/33/C18
- Belspo-Action 1-MO/33/13
- FNRS-Aspirant
- Programme National de Planétologie, France (PNP)

Visitors: 4

C.1.6. Publications

C.1.6.1. Publications with peer system

[1] **de Viron O., Koot L., Dehant V.**
Polar motion models: The torque approach
in Proc. of the Workshop on 'Forcing of polar motion in the Chandler Wobble frequency band: a contribution to understanding interannual climate variations', April 21-23 2004, Luxembourg, Cahier du Centre Européen de Géophysique et de Séismologie., Vol. 24, pp. 9-14.

[2] **Dehant V., de Viron O.,** Greff-Lefftz M.
Atmospheric and oceanic excitation of the rotation of a three-layer Earth
Astron. Astrophys., Vol. 438, pp. 1149–1161, DOI: 10.1051/0004-6361:20042210.

[3] **de Viron O.,** Schwarzbaum G., Lott F., **Dehant V.**
Diurnal and subdiurnal effects of the atmosphere on the Earth rotation and geocenter motion
J. Geophys. Res., Vol. 110, No. B11, B11404, DOI: 10.1029/2005JB003761.

[4] **Dehant V., de Viron O.,** Barriot J.-P.
Geophysical excitation of the Earth orientation parameters and its contribution to GGOS
In: Proc. 2004 IUGG General Assembly, Sapporo, Japan, J. Geodynamics, Vol. 40(4-5) Special Issue on The Global Geodetic Observing System, Edited by Hermann Drewes, Nov.-Dec. 2005, pp. 394-399.

[5] R. Holme and **de Viron O.**
Geomagnetic jerks and a high-resolution length-of-day profile for core studies
Geophys. J. Int., 160, 435-439.

C.1.6.2. Publications without peer system

[6] Dehant V., de Viron O., Van Hoolst T.
Pointcaré flow in the Earth core
In: Proc. Journées Systèmes de Référence Spatio-temporels 2004, Paris, France, September 2004, pp. 45-48.

[7] **Dehant V.**
Introduction to Kick-off meeting for the project 'Descartes-Nutation'
In: Proc. Journées Systèmes de Référence Spatio-temporels 2004, Paris, France, September 2004, pp. 61-62.

[8] Huang C., **Dehant V.**, Liao X., **de Viron O., Van Hoolst T.**
The coupling equations between the nutation and the geomagnetic field in GSH expansion,
In: Proc. Journées Systèmes de Référence Spatio-temporels 2004, Paris, France, September 2004, pp. 88-93.

[9] **Koot L., de Viron O., Dehant V.**
Atmospheric Angular Momentum of the axis of rotation of the Earth
In: Proc. Journées Systèmes de Référence Spatio-temporels 2004, Paris, France, September 2004, pp. 138-139.

[10] **Rambaux N., Van Hoolst T., Dehant V.**, Bois E.
Earth librations due to core-mantle coupling
In: Proc. Journées Systèmes de Référence Spatio-temporels 2004, Paris, France, September 2004, pp. 150-151.

[11] Capitaine N., Hohenkerk, Andrei A., Calabretta M., **Dehant V.,** Fukushima T., Guinot B., Kaplan G., Klioner S., Kovalevsky J., Kumkova I., Ma C., McCarthy D., Seidelman K., Wallace P.
Report of the IAU Division 1 WG on 'Nomenclature for Fundamental Astronomy' (NFA)
In: Proc. Journées Systèmes de Référence Spatio-temporels 2004, Paris, France, September 2004, pp. 161-165.

[12] **de Viron O**., **Dehant V.**
3D animation of the Non Rotating Origin
In: Proc. Journées Systèmes de Référence Spatio-temporels 2004, Paris, France, September 2004, pp. 166-167.

[13] Feissel-Vernier M., Ray J., Altamimi A., **Dehant V., de Viron O.**
VLBI and the Earth's rotation: Geophysical and geodetic challenges
IVS 3rd General Meeting, Ottawa, 9-12 February 2004, eds. N.R. Vandenberg and K.D. Baver, NASA/CP-2004-212255, pp. 22-31.

[14] **Dehant V., de Viron O.,** Feissel-Vernier M.
Investigation of nutation beyond the IAU2000 model
IVS 3rd General Meeting, Ottawa, 9-12 February 2004, eds. N.R. Vandenberg and K.D. Baver, NASA/CP-2004-212255, pp. 381-382.

[15] **Dehant V.**
International and national geodesy and its three pillars: (1) geometry and kinematics, (2) Earth orientation and rotation, and (3) gravity field and its variability
In: Proc. Earth Sciences day of the CNBGG `Geodesy and geophysics for the third millennium´, Belgian Academy of Sciences, October 13, 2005, eds. E. Arijs and B. Ducarme, pp. 27-35.

[16] **de Viron O., Defraigne P., Dehant V., Koot L., Van Hoolst T.**
Earth orientation and rotation
In: Proc. Earth Sciences day of the CNBGG `Geodesy and geophysics for the third millennium´, Belgian Academy of Sciences, October 13, 2005, eds. E. Arijs and B. Ducarme, pp. 123-124.

[17] **Dehant V., Francis O.**
Orbituary Baron Paul Melchior
EOS, AGU publication, Vol. 86, No. 22, 31 May 2005, p 211

[18] **Dehant V.**
Book review: 'Methods of Celestial Mechanics; Volume I: Physical, Mathematical and Numerical Principles; Volume II; Application to Planetary System, Geodynamics and Satellite Geodesy' by Gerhard Beutler (Leos Mervart and Andreas Verdun, Springer Verlag, Berlin/Heidelberg, 2005)
Celestial Mechanics and Dynamical Astronomy, DOI: 10.1007/s10569-005-0203-z, 93(1-4), pp. 373-374

[19] **Van Hoolst T.**
GGFC Special Bureau for the Core
IERS Annual Report 2003, Eds. W.R. Dick and B. Richter, Verlag des Bundesamts für Kartographie und Geodäsie, Frankfurt am Main, p. 87

C.1.6.3. Publications in press, accepted, or submitted

[20] Koot L., de Viron O., Dehant V.

Atmospheric angular momentum time-series: characterization of their internal noise and creation of a combined series
Journal of Geodesy, DOI: 10.1007/s00190-005-0019-3

[21] **Dehant V., Van Hoolst T.**
Gravity, rotation, and interior of the terrestrial planets from planetary geodesy: example of Mars
In: Proc. IAG-IAPSO-IABO General Assembly on 'Dynamic planet', Cairns, Autralia, in press.

[22] **Lambert S.B.**, Mathews, P.M.
Second-order torque on the tidal redistribution and the Earth's rotation
Astron. Astrophys., submitted.

[23] Capitaine N., Andrei A.H., Calabretta M., **Dehant V.,** Fukushima T., Guinot B., Hohenkerk C., Klioner S., Kovalevsky J., Kumkova I., Ma C., McCarthy D.D., Seidelmann P.K., and Wallace P.
Report of Division I Working Group on 'Nomenclature for Fundamental Astronomy' (NFA)
In: IAU Transactions, in press.

[24] N. Capitaine, C. Hohenkerk, A.H. Andrei, M. Calabretta, **V. Dehant**, T. Fukushima, B. Guinot, G. Kaplan, S. Klioner, J. Kovalevsky, I. Kumkova, C. Ma, D.D. Mccarthy, K. Seidelmann, P. Wallace
Latest proposals of the IAU Working Group on Nomenclature for fundamental astronomy
In: Proc. Journées Systèmes de Référence Spatio-Temporels 2005, 'Earth dynamics and reference systems: five years after the adoption of the IAU 2000 Resolutions', Warsaw, Poland, 19-21 September 2005, in press.

[25] **Dehant V.**
Next decimal for nutation modeling
In: Proc. Journées Systèmes de Référence Spatio-Temporels 2005, 'Earth dynamics and reference systems: five years after the adoption of the IAU 2000 Resolutions', Warsaw, Poland, 19-21 September 2005, in press

[26] **Koot L., De Viron O., Dehant V.**
Nutation model with Earth interior parameters adjusted on the time series data
In: Proc. Journées Systèmes de Référence Spatio-Temporels 2005, 'Earth dynamics and reference systems: five years after the adoption of the IAU 2000 Resolutions', Warsaw, Poland, 19-21 September 2005, in press

[27] **Dehant V.**
Earth rotation and orientation and perspectives for planetary geodesy
In: Proc. 3rd KAGI21international symposium on 'Active Geosphere Investigation', Wuhan, China, November 8, 2005, ed. Sun Heping, in press.

[28] **Dehant V.**
Report of Commission 3 on Earth Rotation and Geodynamics
In: IAG Travaux, J. Geodesy, in press

[29] **Dehant V.,** Capitaine N., Dickey J., Fukushima T., Gambis D., Gross R., Hefty J., Huang C., Ma C., Malkin Z., Poma A., Ray J., Richter B., Ron C., Rothacher M., Sidorenkov N., Soffel M., Vondrak J.
Report of Commission 19 on Earth Rotation and Reference System
In: IAU Transactions, in press

[30] **Dehant V.** and Mathews M.P.
Earth Rotation Variations
In: Treatise of Geophysics, invited paper, Elsevier Publ., eds. T. Herring and J. Schubert, submitted.

C.1.6.4. Reports, thesis, etc

[31] Dehant V.

Report of Commission 19 Rotation of the Earth
IAU Transactions.

[32] Capitaine, N., Andrei A.H., Calabretta M., **Dehant V.,** Fukushima T., Guinot B., Hohenkerk C., Klioner S., Kovalevsky J., Kumkova I., Ma C., McCarthy D.D., Seidelmann P.K., and Wallace P.
Report of Division I Working Group on "Nomenclature for Fundamental Astronomy" (NFA)
IAU Transactions XXVIA, 2005.

[33] Capitaine, N., Andrei A.H., Calabretta M., **Dehant V.,** Fukushima T., Guinot B., Hohenkerk C., Klioner S., Kovalevsky J., Kumkova I., Ma C., McCarthy D.D., Seidelmann P.K., and Wallace P.
NFA WG explanatory document, a) Introduction

[34] Capitaine, N., Andrei A.H., Calabretta M., **Dehant V.,** Fukushima T., Guinot B., Hohenkerk C., Klioner S., Kovalevsky J., Kumkova I., Ma C., McCarthy D.D., Seidelmann P.K., and Wallace P.
NFA WG explanatory document, b) explanation of the proposed terminology, glossary

[35] Capitaine, N., Andrei A.H., Calabretta M., **Dehant V.,** Fukushima T., Guinot B., Hohenkerk C., Klioner S., Kovalevsky J., Kumkova I., Ma C., McCarthy D.D., Seidelmann P.K., and Wallace P.
NFA WG explanatory document, b1) chart for transformation from ICRS to observed places

[36] Capitaine, N., Andrei A.H., Calabretta M., **Dehant V.,** Fukushima T., Guinot B., Hohenkerk C., Klioner S., Kovalevsky J., Kumkova I., Ma C., McCarthy D.D., Seidelmann P.K., and Wallace P.
NFA WG explanatory document, b2) summary of terms and definitions

[37] Capitaine, N., Andrei A.H., Calabretta M., **Dehant V.,** Fukushima T., Guinot B., Hohenkerk C., Klioner S., Kovalevsky J., Kumkova I., Ma C., McCarthy D.D., Seidelmann P.K., and Wallace P.
NFA WG explanatory document, b3) terminology list

C.1.7. Scientific Outreach

Meeting presentations

[38] Dickey J.O., Marcus S.L., Quinn K.J., **de Viron O**., Fukumori I., Dyurgerov M.B.
Indications of acceleration in glacier melting: recent changes in the dynamic oblateness (J2) of the Earth's gravity field
European Geoscience Union General Assembly, Vienna, Austria, April 2005.

[39] **de Viron O.,** Lott F, **Dehant V.**
The diurnal cycle in the atmosphere and its consequences on the Earth rotation and geocenter motion
Semaine de l'Astrophysique Française, Journées de la SF2A 2005, Session Astronomie Fondamentale, July 1st, 2005, Strasbourg, France.

[40] Capitaine N., Hohenkerk C., Andrei A.H, Calabretta M., **Dehant V.,** Fukushima T., Guinot B., Kaplan G., Klioner S., Kovalevsky J., Kumkova I., Ma C., Mccarthy D.D., Seidelmann K., Wallace P.,
Latest proposals of the IAU Working Group on Nomenclature for fundamental astronomy
Invited paper, Journées Systèmes de Référence Spatio-Temporels 2005, 'Earth dynamics and reference systems: five years after the adoption of the IAU 2000 Resolutions', Warsaw, Poland, 19-21 September 2005.

[41] **Dehant V.**
Next decimal for nutation modeling, Invited paper
Journées Systèmes de Référence Spatio-Temporels 2005, 'Earth dynamics and reference systems: five years after the adoption of the IAU 2000 Resolutions', Warsaw, Poland, 19-21 September 2005.

[42] **Koot L., de Viron O., Dehant V.,**
Nutation model with Earth interior parameters adjusted on the time series data

Poster, Journées Systèmes de Référence Spatio-Temporels 2005, 'Earth dynamics and reference systems: five years after the adoption of the IAU 2000 Resolutions', Warsaw, Poland, 19-21 September 2005.

[43] **Dehant V.**
International and national geodesy and its three pillars: (1) geometry and kinematics, (2) Earth orientation and rotation, and (3) gravity field and its variability
Earth Sciences day of the CNBGG (`Geodesy and geophysics for the third millennium´), Belgian Academy of Sciences, October 13, 2005.

[44] **de Viron O., Defraigne P., Dehant V., Koot L., Van Hoolst T.**
Earth orientation and rotation
Earth Sciences day of the CNBGG (`Geodesy and geophysics for the third millennium´), Belgian Academy of Sciences, October 13, 2005.

[45] **Dehant V.**
Earth rotation and orientation and perspectives for planetary geodesy
Invited talk, 3rd KAGI21international symposium on 'Active Geosphere Investigation' organized by the Institute of Geodesy and Geophysics (Chinese Academy of Sciences) and KAGI21 Office, Graduate School of Science (Kyoto University, Japan), Wuhan, China, November 8, 2005.

[46] **Dehant V.**
Earth rotation and orientation, and perspectives for planetary geodesy; application to the planet Mars, Seminar
Invited talk, Shanghai Observatory, November 11, 2005.

[47] **Koot L., de Viron O., Dehant V.**
Estimation of Earth interior parameters based on nutation time series
AGU Fall Meeting, poster, San Francisco, USA, December 5-9, 2005.

[48] Dickey J.O., Marcus S.L., Dyurgerov M.B., Quinn K.J., **de Viron O.**, Fukumori I.
Interannual-decadal changes in the Earth's dynamic oblateness: Isolation of the cryospheric contribution
AGU Fall meeting, San Francisco, USA.

[49] Johnson T.J., Kosek W., Kalarus M., **Lambert S.B.**, Wooden W.H.
Recent advancements in the determination of Earth orientation combination solutions and prediction
AGU Fall meeting, San Francisco, USA.

National and international responsibilities

- Commission 19 'EARTH ROTATION' of the IAU:
  - President: **V.Dehant**
  - Members: **C. Bruyninx, P. Defraigne, V. Dehant, F. Roosbeek, T. Van Hoolst**
- Commission 3 "Earth Rotation and Geodynamics" of the IAG
  - President: **V. Dehant**
  - Advisory Board member representing the Inter-commission on "Theory": **T. Van Hoolst**
  - Advisory Board member representing the Inter-commission on "Planetary Geodesy": **O. Karatekin**
  - Members: **C. Bruyninx, P. Defraigne, V. Dehant, Ö. Karatekin, F. Roosbeek, T. Van Hoolst**
- IERS (International Earth rotation and Reference frames Service)
  - Special Bureau for the Core: Chairman: T. Van Hoolst, members: P. Defraigne, V. Dehant
  - IERS Conventions Editorial Board: V. Dehant

Meeting organization

- **V. Dehant** was Convener at and is editor of the Proceedings of the IAG General Assembly meeting 'Dynamic Planet', Cairns, Session G3 'Earth Processes: geodynamics, tides, crustal deformation and temporal gravity changes', in August 2005.

Educational responsibilities

- **V. Dehant** is promoter and **O. de Viron** co-promoter of the PhD thesis of L. Koot (second year, UCL)
- **V. Dehant** was promoter and **O. de Viron** co-promoter of the master thesis I. Wauters (PHYS22 2004-2005, UCL)

C.1.8. Missions

Assemblies, symposia (number):	V. Dehant (6)
	L. Koot (2)
	O. de Viron (1)
	O. Verhoeven (3)
	T. Van Hoolst (1)
Commissions, working groups (days):	V. Dehant (5)
	O. de Viron (2)
Research visits (days):	V. Dehant (26)
	O. de Viron (2)
	O. Verhoeven (17)
	T. Van Hoolst (1)
Outreach missions (days):	V. Dehant (3)

C.2. Geodesy and Geophysics of terrestrial 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 using geodetic radioscience data.

The gravity field of planetary bodies can best be studied through the precise monitoring of the trajectory of passing or orbiting spacecrafts. Because the gravity field of a planet is determined by the planet's surface and 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. 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 learned 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 structure, atmosphere, and dynamics of rocky planets and natural satellites. For that purpose, we investigate the relation of rotation variations, static gravity field and its time variations (including the tidal effects) with interior and atmosphere properties and orbital motion characteristics. 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.

C.2.1. Objectives

ESA's Mars Express mission to Mars has started its science phase in January 2004, and we are involved in its radio-science experiment MaRS (at Co-I level). Our 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 and atmosphere.

BepiColombo is an ESA mission to Mercury scheduled for launch in 2013. Our group 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 of the BepiColombo project. From the three experiments, the rotation variations (librations) and gravity field of Mercury will be determined. The results will then 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 the size of Mercury's core, which have large implications on the formation and evolution of terrestrial planets. In 2005, we have focused on theoretical studies on the rotation, interior and gravitational field of Mercury, and have performed numerical simulations of the mission.

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, we use recent data on material properties at high pressure and temperature.

A further field of study is the dynamics of natural satellites over short and relatively long (tens of millions of years and more) time span. The aim is to develop highly accurate ephemerides of those bodies based on spacecraft as well as Earth-based observations. In parallel, physical parameters involved are estimated.

C.2.2. Progress and results

C.2.2.1. Mars: MEX data processing and orbit determination

- Doppler and ranging tracking data of the Mars Express (MEX) mission have been analyzed to improve: (1) the resolution of the gravity anomalies at short wavelength over targets of geophysical interest, (2) the seasonal variations of the long wavelength gravity field (the first zonal gravity coefficients J_2 to J_5, and (3) the determination of the mass and internal structure of Phobos. The analyses make heavy use of the GINS/DYNAMO orbitography programs (developed by GRGS/CNES and adapted to planetary applications at ROB), which allow obtaining the orbit of the spacecraft, the global gravity field, and its time variations. We have developed interfaces to transform Mars Express radio-tracking data into a format readable by GINS/DYNAMO. As three types of MEX radio-tracking data exist, TNF (Tracking and Navigation Files) and ODF (Orbit Data Files) from Deep Space Network antennas, and "Level02" files from New Norcia (NNO) ESA ground station, we developed several interfaces.
- Numerical programs have been developed to reduce the observed Doppler shifts to Doppler residuals by subtracting a predicted Doppler shift along the spacecraft trajectory within a gravity field of reference. Observed and predicted Doppler velocities are of the order of the spacecraft velocity, that is a

few km/s, whereas Doppler velocity residuals with respect to a gravity field of maximum harmonic degree and order 50 are of the order of 0.1 mm/s. Such an extremely precise calculation requires the use of the orbital software GINS and necessitates numerous tests regarding reference frames and reference gravity fields involved in the reduction of the observations into residuals.

- With Doppler shifts in two frequencies (X-band and S-band), the MEX radio data can be corrected for the perturbation by the ionosphere. However, a lot of data at our disposal does not contain both Doppler shifts. Therefore, we started a study of the necessity and feasibility of correcting for the ionosphere perturbations in the case of single frequency data.
- A data base for the gravity data of the MEX mission has been made, and numerical tools for updating and managing the data base have been developed. A manual for the data base has been written.

C.2.2.2. 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 Mars Express spacecraft in its orbit around Mars. Gravity perturbations reflect not only the attraction by the changing topography below the spacecraft but also the attraction by mass inhomogeneities inside the planet. Because of its low altitude at pericenter MEX (lower than the previous American mission Mars Global Surveyor (MGS)), Mars Express can determine short-wavelength gravity perturbations (below a size of 400 km), which are mainly due to minor density variations (a few hundred kg/m^3) of surface and near-surface features. This kind of information is essential to understand the mechanisms underlying the formation of crustal features, such as, e.g. the Tharsis volcanoes. For the physical interpretation of the Doppler residuals, a set of programs has been written in order to 1) filter, resample, and differentiate Doppler residuals into accelerations, 2) predict accelerations along the trajectory from both the existing spherical harmonic gravity field and from a flexure model of the lithosphere, 3) do a cross-spectral analysis of observed and predicted accelerations. Results on the quality of the global gravity field solution at short wavelength have been obtained from the best 17 MEX pericenter gravity passes above the Tharsis area. The residual acceleration measured by MEX is compared with the acceleration predicted by the global gravity field by means of a cross-spectral frequency analysis. We have shown that the global gravity field has a good resolution up to harmonic degree 73 and that peak amplitudes are not attenuated by the regularization method used in the determination of the global gravity field up to the same degree. The results are in press in Geophys. Res. Letters **[10]**.

C.2.2.3. Mars: interior structure

- A new method has been developed to constrain the internal structure and composition of Mars from an inversion of geophysical data. The code for the inversion procedure has been optimized, and various improvements have been made to the Bayesian inversion. A first paper on the mantle of Mars has been finalized and published **[1]**, see also paper **[18]**. A second paper will soon be submitted. Our results demonstrate that the seismometer, magnetometer, and radio science experiments are very complimentary for studies of the interior. In particular, we showed that the temperature and mineralogical composition of the Martian mantle can be obtained from a stochastic inversion of electromagnetic, geodetic, and seismic data. Seismometer, magnetometer, and radio science experiments are included in the Geophysical and Environmental Package (GEP), planned to fly to Mars with ESA's ExoMars mission in 2011.
- Based on our models for the interior of Mars, we have computed ranges of core sizes and crust mean densities and thicknesses in agreement with the latest estimates of the moment of inertia factor, mean density and Love number k_2. The results show that for a Martian mantle based on the SNC mineralogy, the recently published estimates of k_2 (Yoder et al. 2003) and the moment of inertia imply a hot mantle and core sizes in the range of 1650km to 1780km. On the other hand, if the core sulfur weight fraction is set at about 14wt%, as is often assumed, the mean crust thickness is chosen to be below 100km, in agreement with most crustal studies, and a Fe/Si ratio close to the chondritic 1.71 value is

taken, it follows that the core radius is about 1670km and that the mantle is hot, but such a model would barely be in agreement with Yoder's k_2 estimate.

C.2.2.4. Mars: atmosphere and polar caps

- The atmospheric excitation of the Chandler wobble (CW) and the Inner Core Wobble (ICW) has been studied. A long term simulation of Martian atmosphere that covers more than 10 Martian years has been performed, and the seasonal/inter-annual variations of the atmospheric angular momentum (AAM) have been calculated. We have shown that the random excitation of the ICW by the Martian atmosphere and icecaps is small. The results are published in Astronomy and Astrophysics **[9]**.
- A study on the possibility to use observations of the length of day of Mars as a tool to study the core of Mars has been finalized. A refereed paper is in press in Adv. Space Res. and available online since 10 May 2005 **[8]**.
- Seasonal changes in the polar cap masses and the mean atmospheric pressure have been estimated from recent determinations of the low-degree zonal gravity coefficients of Mars. The results show a good agreement with the model-dependent solutions of general circulation models of the atmosphere and with the CO_2 thickness observations of the High Energy Neutron Detector (HEND) onboard Mars Odyssey (**[12], [15]**).
- By means of simulated geodesy measurements, we have shown that the seasonal changes of the low-degree zonal gravity coefficients determined from a single orbiter contaminate each another at the level of half of the annual amplitudes of the C_{20} and C_{30} variations. These variations are geophysically interesting because they are linked with the CO_2 sublimation and condensation cycle of Mars' atmosphere. A suitable orbit has been determined that reduces the correlations between the zonal gravity coefficient estimates. An additional radio link from the Martian surface would further reduce the correlations and also improves the determination of the Length-of-Day variations **[2]**.
- In our effort to obtain precise gravity data, we have determined the low-degree seasonal variations of the gravity field from an analysis of five years of MGS tracking data. By improving on the nutation modeling, we have been able to obtain stable estimates of the C_{20} and C_{30} variations. The results are in good agreement with independent data from General Circulation models of the Martian atmosphere and the High Energy Neutron Detector (HEND) instrument on-board Mars Odyssey **[25]**.
- From the same analysis, we have obtained a degree-two Love number $k_2 = 0.098 \pm 0.001$. This value indicates that Mars has a core that is rather small and at least partially liquid. The determination of the k_2 Love number is geophysically very important, because the Love number is very sensitive to the deep interior structure, in particular to the core state and size. Other studies have given both smaller and larger values (between roughly 0.05 and 0.16), and we hope to arrive at a consensus soon.
- The MEX orbit has a much higher eccentricity (0.6) than that of MGS (0.01), and therefore a different sensitivity to the lowest-degree zonal coefficients of the gravity field. In a numerical simulation with GINS, we have shown that the J_2 to J_5 variations can be determined with a three times better precision when data from both MEX and MGS are used instead of only MGS data. To obtain a similar improvement with real data, we need to calculate the MEX orbital motion with accuracy better than that available from the navigation orbits provided by ESOC (ESA Space Operational Center). Because the non-gravitational forces on MEX induce accelerations larger or comparable to the accelerations expected from the time-variable part of gravity, we implemented these forces into our calculations with GINS. These forces include atmospheric drag, solar radiation pressure, radiation pressure related to the albedo of Mars, and also forces related to desaturations of the inertial wheels needed to control the attitude of the orbiting spacecraft. First results, based on US DSN (Deep Space Network) data only, have shown an improvement in the determination of gravity coefficients, but the increase in precision is not sufficient to improve the CO_2 mass budget. This is mainly due to the non-continuous coverage of the MEX tracking data used, but further improvement will be reached from combining DSN data with ESA NNO data.
- Recent studies of polar layered deposits, which consist mainly of water ice and dust particles, show that the time scale of the layering is linked with the variations of orbital parameter such as obliquity

and eccentricity and suggest that several climate cycles have occurred on Mars. We investigated the impact of such climate variation on the rotation of Mars. For that purpose, a computer program to calculate the viscoelastic response due to ice redistribution and the related variation of Mars' rotation has been extended. The boundary value problem (BVP) is solved in the time domain by a spectral finite-element representation, in which the angular dependence is represented by spherical harmonics and the radial dependence by finite elements. As input for the viscoelastic calculation, we developed a load model for climate cycles since 500 ka BP (500.000 years before present) with both spatial and temporal characteristics. Information about the spatial extent of the deposition area is taken from Mars images, like MOC wide-angel images of the north polar cap. The timing of the mass redistribution, or load history, is constructed from the time-variable insolation for the North Pole and mid-latitude regions.

- We calculated the change in the length of day of Mars and compared it to observed seasonal length-of-day variations for several loading histories, different source regions, and various values for the elastic thickness of the lithosphere and mantle viscosity. The maximum calculated secular change in the length of day of Mars is only 0.0004 ms/a, which is three orders of magnitude smaller than the amplitude of the seasonal length-of-day variations on Mars. For an extreme case of rapid sublimation of both the north and south polar caps, the caps must sublime by about 20 cm/a to be able to detect it in the rotation variations. As no such variations in length-of-day are observed, this cap sublimation rate can be considered as an upper bound for climate variation effects.
- A study has been initiated to deduce atmospheric densities from the re-constructed MEX orbits. For that purpose, we have installed the NASA "MARS-GRAM" code, which gives the most recent and state-of-art engineering model of the Martian atmosphere.

C.2.2.5. Mars: moons

- A precise numerical program, called NOE (Numerical Orbit and Ephemerides), that simulates the orbital evolution of natural satellites has been developed. It has been successfully used to determine accurate ephemerides of the Martian moons. The ephemerides have been fitted to all spacecraft observations available (Mariner9, Viking 1-2, Phobos 2, MOLA and MEX), as well as to Earth-based observations (from 1877 to 2003). The expected accuracy of these ephemerides is below one kilometer. An order of magnitude improvement has been obtained with respect to JPL and ESOC ephemerides that show a difference between the predicted and the observed positions of the Martian moons of 10 kilometers to 50 kilometers. We have confirmed the acceleration in Phobos' longitude, which is related to dissipation in Mars of tides raised by Phobos. Because the orbital period of Phobos is smaller than the rotation period of Mars, the tidal bulge of Mars lags behind the direction to Phobos, and the torque on it causes angular momentum to be transferred from the orbital motion of Phobos to the rotation of Mars. From the acceleration, we deduced a dissipation quality factor Q=59.41+/-0.69, assuming a Love number k_2=0.113 for Mars and GM=0.68012569 x 10^6 m^3/s^2 for the mass of Phobos.
- A FORTRAN subroutine that computes the ephemerides of the Martian moons is available and will soon be implemented in the SPICE kernel. An accurate model for the ephemerides is highly useful for mission planning (Phobos' flybys, camera pointing…).

C.2.2.6. Mercury: geodesy experiment simulations

- Simulations of the determination of the libration in longitude of Mercury from angular observables have been performed to investigate the expected precision on the libration amplitude determination. Particular attention has been devoted to the implementation in the code of the spacecraft orientation, spacecraft orbit, and target orientation with respect to the spacecraft orbiting around the planet. Besides a mean square method, we also implemented a Monte Carlo Markov Chain method to search for the libration solution. This enabled us to guarantee a correct and existing solution. In order to find

the best geometries to determine the libration, we have performed many runs of the program for different initial conditions, orbital parameters, and libration amplitude.

C.2.2.7. Mercury: libration

- The effect of inertial coupling between mantle and core on Mercury's libration has been studied with the SONYR model (acronym of Spin-Orbit N-bodY Relativistic model), which is a computer code that numerically integrates the spin-orbit N-body problem and identifies the different families of libration of the terrestrial planets, with special emphasis on Mercury's spin-orbit motion. The effect of the core on the rotational motion of Mercury has been calculated for a large number of internal structure models. It is shown that the future libration observations with BepiColombo will allow to discriminate between internal structure models and to constrain the chemical composition of Mercury (**[17], [29]**). We have set up a method to determine initial conditions in agreement with the Cassini state and studied the rotation evolution in phase space. A possible resonance between the orbital period of Jupiter and a proper libration period has been identified. We also participated in the development of a Hamiltonian theory for Mercury's rotation (**[19], [20]**, and **[21]**).
- An analytical method to calculate rotation variations in three dimensions of almost spherically symmetric terrestrial bodies with a solid mantle, a liquid outer core, and a solid inner core has been developed. The method includes both polar motion and length-of-day variations. In a first application, it has been applied at the libration of Mercury to show the effect of deformation.
- For length-of-day variations of the Earth on longer time scales than several days, the core is known to exhibit torsional oscillations in which cylindrical annuli coaxial with the rotation axis rotate as rigid bodies. We started a study to extend these studies on the Earth to the study of the libration in longitude of Mercury. In this work, both electromagnetic and viscous coupling between the cylinders and between the inner core, outer core, and mantle are considered.

C.2.2.8. Earth

- Based on a very large number of seismic observations and some geodetic measurements, accurate models of the radial density and rheology profiles of the Earth, such as the PREM model (1981), have been deduced in the past. These data, however, do not uniquely determine the mantle mineralogy since they can not precisely discriminate between temperature and composition effects. Because the knowledge of the present mantle temperature and composition can offer unique constraints on its geodynamical and thermal evolution, we study the additional use of electromagnetic data to separate temperature and composition. For the first time, we have inverted density and incompressibility modulus profiles provided by the seismic models, precise geodetic measurements of the mass and moments of inertia of the Earth, and an electrical conductivity profile. Within our modeling hypotheses, we have shown that with the PREM data and for a given electrical conductivity profile, one is able to infer the thermal state, and the mineralogical and chemical composition (in terms of iron content) for the lower mantle of the Earth. An added value is that this study on the Earth with real data is an excellent test of the inversion method planned to be used for Mars.

C.2.2.9. Natural satellites

- A paper on the ephemerides of the Galilean satellites has been finalized and published (**[3], [7]**). It has been shown that no strong dissipation inside Jupiter is required to explain the absence of a clear detection of Io's orbital acceleration.
- In collaboration with L.Iorio (Italy), we have shown that, although the ephemerides of the Galilean satellites have improved, the Lense-Thirring effect on the Galilean moons can still not be detected **[11]**.
- Collaboration with M.Efroimsky (USNO, US) and P.Gurfil (Technion, Israel) has been started on the long-term evolution of the Martian moons. Both analytical and numerical studies of the dynamics

have been performed, and their results on time scales of tens of millions of years were shown to be in very good agreement **[22]**.

- We initiated a study of the internal structure of the Moon, for which seismic measurements were recorded in the seventies by the Apollo missions. A precise knowledge of the internal structure of the Moon is important for its formation history. We plan to invert arrival times of seismic waves and magnetic field variations recorded by the Apollo stations with gravity field data provided by the Clementine and Lunar Prospector missions. This can bring new constraints on the mineralogy of the Moon, in particular on the FeO content of its mantle, a matter which is vividly discussed today. As a first step, synthetic first arrival times for the major moonquakes recorded by the Apollo stations were calculated. The comparison between synthetic and recorded arrival times constrain the seismic velocities profiles inside the Moon, which in turn constrain the lunar temperature and composition.
- The SONYR model has been extended to the spin-orbit motion of Europa (and the other Galilean satellites: Io, Ganymede, and Callisto) and a first comparison with an analytical theory has been made. We also studied the impact of core dissipation on the rotational motion of the Galilean satellites (especially Europa). In a first step, we have used a simple model with a spherical core and the viscous force is assumed to be proportional to the relative velocity between core and mantle. The major impact of the dissipation is to damp the oscillations associated with the proper frequencies resulting in librational motion independent of the initial conditions after a characteristic damping time scale.
- The effect of Titan's dense atmosphere on the degree-two gravitational Love number k_2 has been calculated. The atmospheric tides perturb the external gravitational potential of Titan in two ways. First, the atmosphere itself contributes directly to the external gravitational potential. Secondly, the variable loading of the atmosphere induces mass redistribution within Titan, which also changes the external gravitational potential. We showed that tidal Love measurements of Cassini will be essentially unaffected by the atmospheric tides unless they have at least one to two orders of magnitude larger amplitudes than predicted by present general circulation models of the atmosphere. Atmospheric effects can therefore most likely safely be neglected when studying the interior of Titan from the Love number measurements. A paper on this has been submitted **[14]**.
- Interior models of Titan and their visco-elastic responses to tidal loads have been studied in the context of the Cassini/Huygens mission. A computer model to calculate the visco-elastic response of Titan has been developed. The preliminary results were presented at the fall meeting of AGU.

C.2.3. Perspective for next years

In the next few years, our current research projects will be continued but also extended in both applications and methodologies. Mars Express tracking data will be further reduced and analyzed in order to constrain properties of the crust and lithosphere at selected targets and to obtain new estimates of the time-varying low-degree gravity coefficients and of the tidal effect on the gravitational field of Mars. Besides new Mars Express data, also radio tracking data from American Mars orbiters will be used. The gravity studies will be extended to Venus, for which the Venus Express radio science experiment is expected to obtain high-quality radio-tracking data from the end of 2006 on. We will further develop and refine our models of the interior structure of terrestrial planets and large natural satellites, with particular emphasis on the mineralogical composition and temperature. Theoretical and simulation studies to constrain the interior structure of terrestrial planets by rotational, tidal, gravitational, and orbital data will be continued and the effects of dissipation will be included. The synergetic approach to probe Mars' interior by joint geodetic, seismic, and electromagnetic means will also be further pursued and will be applied to other planets and natural satellites. In view of the upcoming Mercury missions, the libration of Mercury will be modeled in more detail. More extended models for the couplings between inner core, outer core, and mantle will be applied and developed. Strategies and numerical tools will be developed for the study of Mercury's interior from libration measurements. Further attention will be devoted to the seasonal condensation/sublimation cycle of the Martian atmosphere and polar ice caps, and to variations on long time

scales related to, e.g., obliquity variations. We will also continue the negotiations and scientific preparations for a geophysical package to be included on a Mars lander.

C.2.4. Personnel involved

Scientific staff: T. Van Hoolst (co-I SIMBIO-SYS, Project Leader)
V. Dehant (co-I MaRS, co-I VERA)
M. Beuthe (PRODEX)
R. Dejaiffe
O. de Viron (Action 1, until 1/09/2005)
J. Duron (Action 2)
J. Hagedoorn (MAGE, since 1/9/2005)
Ö. Karatekin (PRODEX)
V. Lainey (MAGE postdoc, since 1/4/04)
S. Le Maistre (PRODEX, since 15/9/2004)
G. Pfyffer (FRIA, since 1/10/2004)
N. Rambaux (ESA postdoc)
A. Rivoldini (Action 2)
P. Rosenblatt (PRODEX)
O. Verhoeven (FNRS, since 1/9/05)

Technical staff: S. Raynal (PRODEX, half-time)
L. Van Camp

C.2.5. Partnerships

List of national and international partners

- Observatoire Midi Pyrénées, France (J.P. Barriot, J.C. Marty, G. Balmino),
- University of Cologne, Germany (M. Paetzold, PI MaRS, T. Andert)
- Universität der Bundeswehr Institut für Raumfahrttechnik Munich, Germany (B. Haüsler, PI VeRa, H. Griebel, J. Selle)
- University of Nantes, France (A. Mocquet, P. Vacher, C. Sotin, G. Choblet, G. Tobie)
- CETP (Centre d'Etude des Environnements Terrestre et Planétaires), France (M. Menvielle)
- International Space Science Institute (IPGP), France (P. Lognonné, O. de Viron)
- Institut de Mécanique Céleste et de Calcul des Ephémérides (IMCCE), France (J.E. Arlot, W.Thuillot)
- Observatoire de la Côte d'Azur (E. Bois, F. Deleflie)
- Université de Lilles, France (A. Vienne, L. Duriez)
- USNO, USA (M. Efroimsky)
- Technion (Israel Institute of Technology), Israel (P. Gurfil)
- DLR, Berlin, Germany (T. Spohn, F. Sohl, J. Oberst)
- University of Bari, Italy (L.Iorio)
- Facultés Universitaires de Notre-Dame de la Paix (FUNDP), Belgium (A. Lemaître, J. Henrard, S. D'Hoedt)
- UCL (E. Deleersnijder, PI SLIM, T. Fichefet, V. Legat, J.-F. Remacle, J. Toubeau)
- COEX, a federal Center for Complexity and exobiology (http://www.exobiologie.be/aboutcentre.htm)
- Several foreign students have done a training in our group:
    - Sylvain Lefèvre, IPGP student (France), M1, title of the report: Effect of topography of the solid-liquid interface on planetary rotation: application to Earth, Mars and Europa.
    - Ariane Sauvigner: student of the Observatoire de Paris (France), M1, title of the report: Response of terrestrial planets to the gravitational forces of other stars (first part).

- Paul Rubishung: ENSG student (France), M1, title of the report: Response of terrestrial planets to the gravitational forces of other stars
- Nicolas Guyennon, student at l'Université Paul Sabatier (Toulouse, France), M2, title of the master report: Développement d'un code numérique pour la réponse viscoélastique d'un corps à un potential d'excitation
- Jordi Fontdecaba I Baig, Paris (France), DEA training (see report **[36]**)
- Quentin Bertaux: University of Lilles (France), M2, title of the report: Development of an X-band transponder.
- Sylvain Deltombe: University of Lilles (France), M2, title of the report: Development of an X-band transponder.
- Séverine Lejeune: UCL COMU, M1, title of the work: Elaboration d'un dossier de presse pour la mission spatiale Venus Express.

Grants used for this research

- PRODEX8 Project Planet Interior (1114100 € for 1/2005-12/2007, 279600 € in 2005)
- Action 2: Julien Duron 10/2003-9/2007 (159 498 €), Attilio Rivoldini 10/2002/-9/2006 (158 240 €)
- FNRS: post-doc grant O. Verhoeven (1/10/05-30/9/06)
- FRIA: PhD grant for G. Pfyffer (1/10/04-30/9/06)
- MAGE (Mars Geophysical European Network, 237 000 €) 8/03-2/06
- Tournesol project: 'Synergie pour la modélisation de l'intérieur des planètes telluriques, basée sur des données séismiques, géodésiques et des sondages électromagnétiques' 3 missions of 21 days
- PNP (France): 'Etude de couplages rotation/noyau des planètes telluriques', 5 000 €
- EUROPLANET (EUROpean PLAnetary NETwork), no fixed amount
- SLIM (UCL): one PhD student at UCL, J. Toubeau, working on an ocean model in finite element for Europa

Visitors: 29

C.2.6. Publications

C.2.6.1. Publications with peer review

[1] **Verhoeven O., Rivoldini A.,** Vacher P., Mocquet A., Choblet G., Menvielle M., **Dehant V., Van Hoolst T**., **Sleewaegen J.,** Barriot J.-P., and Lognonné P.
Interior structure of terrestrial planets. I. Modeling Mars' mantle and its electromagnetic, geodetic and seismic properties
J. Geophys. Res. (Planets), 110(E4), E04009, DOI: 10.1029/2004JE002271

[2] **Karatekin Ö., Duron J., Rosenblatt P., Dehant V., Van Hoolst T.**, and Barriot J.P.
Martian Time-Variable Gravity and its Determination; Simulated Geodesy Experiments
J. Geophys. Res. (Planets), 110(E6), E06001, DOI: 10.1029/2004JE002378

[3] **Lainey V.** and Tobie G.
New constraints on Io's and Jupiter's tidal dissipation
Icarus, Vol. 179, Issue 2, DOI: 10.1016/j.icarus.2005.07.017, pp. 485-489

C.2.6.2. Publications without peer review

[4] Noyelles B., **Lainey V.,** and Vienne A.
Observations and reduction of mutual events in the Solar System
In: Proc. IAU Colloquium No. 196, Cambridge Univcersity Press, 271-278.

[5] Piraux S., Barriot J.-P., and **Rosenblatt P**.
Relativistic modeling of the orbit of geodetic satellites equipped with accelerometers

In: Proc. Journées Systèmes de Référence Spatiaux-temporels 2004, Paris, France, pp. 238-239.

[6] Arlot J.E. and **Lainey V.**
Observation of the faint satellites of Jupiter and Saturn
In: Proc. The GAIA Symposium, ESA SP-576: The Three-Dimensional Universe with Gaia, p.279-280.

[7] Arlot J.E. and **Lainey V.**
Galilean Moons: towards an in-depth study of their internal structure, or
Satellites galiléens: vers une étude de plus en plus fine de la structure interne
Le magazine de l'Observatoire de Paris, No 1, page 14

C.2.6.3. Publications in press, accepted, and submitted

[8] **Karatekin Ö., Van Hoolst T., Tastet J., de Viron O. and Dehant V.**
The effects of seasonal mass redistribution and interior structure on Length-of-Day variations of Mars
Adv. Space Res., DOI: JASR-D-04-01301R1, in press, available online 10 May 2005

[9] **Dehant V., de Viron O., Karatekin Ö.**, and **Van Hoolst T.**
Excitation of Mars polar motion
Astron. Astrophys. 446, 345-355, DOI:10.1051/0004-6361:20053825

[10] **Beuthe M.**, Paetzold M., Haeusler B., **Rosenblatt P., Karatekin Ö., Le Maistre S., Dehant V., Van Hoolst T.**, and Barriot J.-P.
Assessment of the Martian Global Gravity Field at Short Wavelength with Mars Express
Geophys. Res. Letters, DOI:10.1029/2005GL024317, in press

[11] Iorio L. and **Lainey V.**
The Lense-Thirring effect in the Jovian system of the Galilean satellites and its measurability
Special Issue of Int. J. Mod. Phys. D on the Lense-Thirring effect, D., 'Gravitation; Astrophysics and Cosmology', Vol. 14, No. 12, 2039-2049.

[12] **Karatekin Ö., Duron J., Rosenblatt P., Van Hoolst T.,** and **Dehant V**.
Martian time-variable gravity field and its detection; Observations and simulations
Proceedings of the IAG international symposium - Gravity, Geoid and Space Missions - GGSM2004, Porto, Portugal, August 30th - September 3th 2004, International Association of Geodesy Symposia Series, ISBN: 3-540-26930-4, 129, eds. C. Jekeli, L. Bastos, J. Fernandez, in press

[13] Bois E., **Rambaux N**., Kiseleva-Eggleton L., and Pilat-Lohinger E.
Orbital stabilizing mechanisms of Earth-like exoplanets related to resonances in planetary systems
In: Evolution habitable planets, 14-16 February 2005, Bern, in press

[14] **Karatekin Ö.** and **Van Hoolst T.**
The effect of a dense atmosphere on the tidally induced potential of Titan
Icarus, submitted (minor revision)

[15] **Karatekin Ö., Van Hoolst T.**, and **Dehant V**.
Martian Global scale CO_2 exchange from time varying gravity measurements
J. Geophys. Res. (Planets), DOI: 10.1029/2005JE002591, submitted (minor revision)

[16] Barriot J.P., **Dehant V., Yseboodt M.**, and **Duron J.**
Monitoring Mars LOD variations form a high altitude circular equatorial orbit
Celest. Mech., submitted

[17] **Rambaux N., Van Hoolst T., Dehant V.**, and Bois E.
Inertial core-mantle coupling and libration of Mercury

Astronomy and Astrophysics, submitted

[18] Vacher P. and **Verhoeven O.**
Modelling the electrical conductivity of iron-rich minerals for planetary applications
Planet. Space Science, submitted

[19] D'Hoedt S., Lemaître A., and **Rambaux N.**
Mercury's Rotation: The four equilibria of the Hamiltonian model
Celestial Mechanics and Dynamical Astronomy, submitted

[20] Lemaître A., D'Hoedt S., and **Rambaux N.**
The rotation of Mercury: Hamiltonian approach for the 3:2 resonance
Celestial Mechanics and Dynamical Astronomy, submitted

[21] **Rambaux N.**
An accurate theory of the rotation of Mercury
Celestial Mechanics and Dynamical Astronomy, submitted

[22] **Lainey V.**, Gurfil P., and Efroimsky M.
Long-term evolution of orbits about a precessing oblate planet: A semianalytical and a purely numerical approach
Celestial Mechanics and Dynamical Astronomy, submitted

[23] Pireaux S., Barriot J.P., and **Rosenblatt P.**
(SC)RMI: A (s)emi-(c)lassical (r)elativistic (m)otion (i)ntegrator, to model the orbits of space probes around the Earth and other planets
In: Proc. IAC Space Generation Congress (Vancouver, Canada, 1-8th October 2004), Acta Astronautica, submitted

[24] Häusler B., Pätzold M., Tyler G.L., Simpson R.A., Bird M.K., **Dehant V.,** Barriot J.-P., Eidel W., Remus S., Selle J., Tellmann S., and Imamura T.
Radio Science Investigations by VeRa onboard the Venus Express Spacecraft
Planet. Space Sc., submitted

[25] Balmino G., **Duron J.,** Marty J.C., and **Karatekin Ö.**
Mars long wavelength gravity field time variations. A new solution from MGS tracking data
In: Proc. IAG-IAPSO-IABO General Assembly on 'Dynamic planet', Cairns, Australia, submitted

[26] **Dehant V.** and **Van Hoolst T.**
Gravity, rotation, and interior of the terrestrial planets from planetary geodesy
In: Proc. IAG-IAPSO-IABO General Assembly on 'Dynamic planet', Cairns, Australia, submitted

[27] Pireaux S., Barriot J.P., **Rosenblatt P**., and Benna M.
Integrating the motion of satellites in a consistent relativistic framework: the SCRMI prototype software
In: Proc. NASA Flight Mechanics Symposium, October 2005, submitted

[28] **Dehant V.**
Earth rotation and orientation and perspectives for planetary geodesy
In: Proc. 3rd KAGI21international symposium on 'Active Geosphere Investigation', Wuhan, China, November 8, 2005, ed. Sun Heping, in press

[29] **Rambaux N., Van Hoolst T., Dehant V.**, and Bois E.
An accurate theory of Mercury's rotation and centrifugal librations
In: Proc. SF2A 2005, eds. F. Casoli, T. Contini, J.M. Hameury, and L. Pagani, in press

[30] **Dehant V.** and **Van Hoolst T.**
Information on interior structure of the terrestrial planets from their rotation

In: Proc. Symposium 'Rotation of celestial bodies', Namur, 1-2 December 2005, in press

[31] Lognonné P., Spohn T., Breuer D., Christensen U., Igel H., **Dehant V., van Hoolst T.,** Giardini D., Primdahl F., Merayo J., Vennerstroem S., Garcia R., Wieczorek M., Sotin C., Mocquet A., Langlais B., Berthelier J.J., Menvielle M., Pais A., Pike W.T., Szarka L., and van den Berg A.
Long lived Martian geoscience observatory
In: Proc. 39th ESLAB Symposium on 'Trends in Space Science and Cosmic Vision 2020', 19-21 April, 2005, ESTEC, in press

[32] Pätzold M., Tellmann S., Andert T., Carone L., Fels M., Schaa R., Stanzel C., Audenrieth-Kersten I., Gahr A., Müller A.-L., Stracke B., Stupar D., Walter C., Häusler B., Remus S., Selle J., Griebel H., Eidel W., Asmar S., Goltz G., Kahan D., Barriot J.-P., **Dehant V., Beuthe M., Rosenblatt P., Karatekin Ö., Lainey V.,** Tyler G.L., Hinson D., Simpson R., and Twicken J.
The Observations of the Mars Express Orbiter Radio Science (MaRS) Experiment after One Year in Orbit
ESA Scientific Publication, ESA-SP-xx, yy, in press

[33] Häusler B., Pätzold M., Tyler G.L., Barriot J.-P., Bird M.K., **Dehant V.,** Hinson D., Simpson R.A., Treumann R.A., Eidel W., Mattei R., **Rosenblatt P.,** Remus S., Selle J., and Tellmann S.
Venus atmospheric, ionospheric, surface, and interplanetary radio wave propagation studies with the Venus Express Radio Science Experiment VeRa
ESA Scientific Publication, ESA-SP-xx, yy, in press

C.2.6.4. Reports, thesis, etc

[34] **Beuthe M.** and **Dehant V.**
Gravity observations over selected target areas by the Mars Express Radio Science.Experiment MaRS; Description of the observation method and rationale
Mars Express Radio Science experiment (MaRS) report to ESA for the Project Scientist Team (PST), Planet Interior report 31

[35] **Dehant V.,** Paetzold M., **Beuthe M., Van Hoolst T.,** Barriot J.P., and Haüsler B.
Gravity observations over selected target areas by the Mars Express Radio Science. Experiment MaRS
Mars Express Radio Science experiment (MaRS) report to ESA for the Project Scientist Team (PST), Planet Interior report 32

[36] Fontdecaba I., Baig, J.
Etude de la fonction de mesure de Mars Express et applications au calcul des variations temporelles du champ de gravité martien
March 2005, Planet Interior internal report 33, student report in collaboration with P. Rosenblatt

[37] **Beuthe M.**
MEX gravity passes at pericenter in 2004 and 2005
Planetary Interior Internal Report 34, December 2005

[38] **Dehant V.**
Report 'Planet Interior' for the first year of PRODEX 8

[39] **Dehant V.**
Report of activity in the frame of MAGE

[40] **Dehant V.,** Paetzold M., **Beuthe M., Van Hoolst T.,** Barriot J.P., and Haüsler B.
Gravity observations over Hellas by the Mars Express Radio Science Experiment MaRS; Simulations and rationale
Report for the MEX PST

[41] Lognonné P., Spohn T., et al., including **Dehant V.**
Preliminary study of a Long-Lived Mars Surface Package (ML2SP); feasibility and assessment study
Report for the AURORA board and ESA

[42] **Rambaux N.**
The Spin-Orbit Motion of Mercury and Core-Mantle Couplings III
3d progress report for ESA

[43] **Rambaux N.**
The Spin-Orbit Motion of Mercury and Core-Mantle Couplings IV
4th progress report for ESA

[44] Selleslags S.
De Poincarébeweging in de vloeibare kern van aardse planeten
K.U.Leuven, June 2005, Promoter: **T. Van Hoolst**.

[45] De Vrij H.
De invloed van de inwendige krachtkoppeling op de libratie van Mercurius
K.U.Leuven, September 2005, Promoter: **T. Van Hoolst**.

C.2.7. Scientific outreach

Meeting presentations

[46] Lainey V.
Ephémérides des satellites naturels, structure interne et observations
Colloque 'Astronomie et Dynamique des Systèmes Gravitationnels', Lille, France, February 5th, 2005.

[47] Bois E., **Rambaux N**., Kiseleva-Eggleton L., and Pilat-Lohinger E.
Orbital stabilizing mechanisms of Earth-like exoplanet related to resonances in planetary systems
Workshop on Evolution of habitable planets, Bern, Switzerland, 14-16 February 2005.

[48] **Lainey V.,** Andert T., **Rosenblatt P.,** Pätzold M., **Dehant V.,** and Barriot J.P.,
Mars Express and Phobos mass: a challenge for celestial mechanics, 1st Mars Express Science Conference
European Space Research and Technology Centre (ESTEC), Noordwijk, The Netherlands, 21 - 25 February 2005.

[49] Andert T., Pätzold M., **Lainey V., Rosenblatt P., Dehant V.,** and Häusler B.
Feasibility study for a precise mass determination of the moon Phobos by the radio science experiment MaRS on Mars Express
Poster, 1st Mars Express Science Conference, European Space Research and Technology Centre (ESTEC), Noordwijk, The Netherlands, 21 - 25 February 2005.

[50] **Rosenblatt P., Beuthe M.,** Pätzold M., **Dehant V.,** Barriot J.P., **Duron J.,** Marty J.C., Balmino G.
Improvement of the Martian gravity field with MEX
1st Mars Express Science Conference, European Space Research and Technology Centre (ESTEC), Noordwijk, The Netherlands, 21 - 25 February 2005.

[51] Pätzold M., Häusler B., Tyler G.L., Asmar S.W., Barriot J.P., **Dehant V.,** Hinson D.P., Simpson R.A., and the MaRS team associates
The Mars Express Orbiter Radio Science Experiment (MaRS)
1st Mars Express Science Conference, European Space Research and Technology Centre (ESTEC), Noordwijk, The Netherlands, 21 - 25 February 2005.

[52] Lognonné P., Spohn T., **Dehant V.,** Sotin C., Banerdt B., and the Mars Geoscience Observatory team

A NetResearch visit to Mars
1st Mars Express Science Conference, European Space Research and Technology Centre (ESTEC), Noordwijk, The Netherlands, 21 - 25 February 2005.

[53] Banerdt W.B., Christensen U., Crisp D., **Dehant V.,** Delory G., Lognonné P., Sotin C., and Spohn T.
A Network of geophysical observatories for Mars
36th Lunar Planetary Science Conference, Lunar Planetary Institute, League City, Texas, USA, 14-18 March 2005.

[54] **Karatekin Ö., Dehant V., de Viron O.,** and **Van Hoolst T.**
Atmospheric excitation of Mars polar motion
36th Lunar Planetary Science Conference, Lunar Planetary Institute, League City, Texas, USA, 14-18 March 2005.

[55] **Lainey V.**
Ephémérides des satellites naturels, structure interne et observations
Séminaire, Nantes, France, April 7th, 2005.

[56] Lognonné P., Spohn T., Breuer D., Christensen U., Igel H., **Dehant V., Van Hoolst T.,** Giardini D., Primdahl F., Merayo J., Vennerstroem S., Garcia R., Wieczorek M., Sotin C., Mocquet A., Langlais B., Berthelier J.J., Menvielle M., Pais A., Pike W.T., Szarka L., and van den Berg A.
Long lived Martian geoscience observatory
39th ESLAB Symposium: 'Trends in Space Science and Cosmic Vision 2020', 19-21 April, 2005.

[57] Thomas N. et al., including **Dehant V.**
A multi-disciplinary investigation of the Jovian system
39th ESLAB Symposium: 'Trends in Space Science and Cosmic Vision 2020', 19-21 April, 2005.

[58] **Rosenblatt P., Beuthe M. , Dehant V., de Viron O., Duron J., Karatekin Ö., Lainey V., Le Maistre S., Rivoldini A., Van Hoolst T.**, and Barriot J.P.
Fine details for discussion concerning the gravity analysis
Mars Express Radioscience team meeting, Munich, Germany, April 21, 2005.

[59] **Dehant V., Beuthe M. , de Viron O., Duron J., Karatekin Ö., Lainey V., Le Maistre S., Rosenblatt P., Van Hoolst T.,** and Barriot J.P.
Status concerning the gravity analysis
Mars Express Radioscience team meeting, Munich, Germany, April 22, 2005.

[60] **Karatekin Ö., Dehant V., Beuthe M., de Viron O., Le Maistre S., Rosenblatt P., Van Hoolst T.**
Status concerning the TNF/ODF Doppler data analysis
Mars Express Radioscience team meeting, Munich, Germany, April 22, 2005.

[61] Andert T., Pätzold M., **Lainey V., Rosenblatt P., Dehant V.,** and Häusler B.
Feasibility study for a precise mass determination of the moon Phobos by the radio science experiment MaRS on Mars-Express
EGU, Vienna, Austria, April 2005.

[62] Häusler B., Pätzold M., Tyler G.L., D. Simpson, S. Asmar, J.-P. Barriot, and **Dehant V.**
Radio science investigation with Venus Express
EGU, Vienna, Austria, April 2005.

[63] **Rosenblatt P.,** Marty J.C., Pätzold M., **Dehant V.,** Balmino G., **Le Maistre S., Duron J., Van Hoolst T.,** and Häusler B.
Assessment of the Mars Express orbit determination for the improvement of Mars' gravity field
EGU, Vienna, Austria, April 2005.

[64] **Rivoldini A., Verhoeven O., Van Hoolst T.,** Mocquet A., Choblet G., Menvielle M., Vacher P., and **Dehant V.**
Mars interior models
EGU, Vienna, Austria, April 2005.

[65] **Beuthe M.,** Pätzold M., **Rosenblatt P.,** Barriot J.-P., **Dehant V.,** and Häusler B.
Admittance analysis of Mars Express line-of-sight data
EGU, Vienna, Austria, April 2005.

[66] **Lainey V., Dehant V., Rosenblatt P.,** Andert T., and Pätzold M.
New ephemeris of Phobos and Mars Express close flybys
EGU, Vienna, Austria, April 2005.

[67] **Dehant V., Beuthe M. , de Viron O., Duron J., Karatekin Ö., Lainey V., Le Maistre S., Pfyffer G. , Rambaux N., Rivoldini A., Rosenblatt P., and Van Hoolst T.**
EuroPlaNet: contribution from the Royal Observatory of Belgium
EGU, Vienna, Austria, April 2005.

[68] **Dehant V., Beuthe M., de Viron O., Duron J., Karatekin Ö., Lainey V., Le Maistre S., Pfyffer G., Rambaux N., Rivoldini A., Rosenblatt P., and Van Hoolst T.**
Recent Research done at the Royal Observatory of Belgium
MAGE meeting, Vienna, Austria, April 2005.

[69] **Lainey V**.
Belgian post-doc report; work done at the Royal Observatory of Belgium
MAGE meeting, Vienna, Austria, April 2005.

[70] Thuillot W., Stavinschi M., **Lainey V**., and Colas F.
Archiving the Solar system objects of the next GAIA mission, 'Virtual observatory: Plate Content Digitization, Archive Mining and Image Sequence Processing'
Sofia, Bulgaria, 27-30 April 2005.

[71] Thuillot W., Berthier J., Vachier F., **Lainey V.,** and Arlot J.-E.
Virtual Observatory and ephemerides of the Solar objects, 'Virtual observatory: Plate Content Digitization, Archive Mining and Image Sequence Processing'
COST Action 283: 'Computational and information infrastructure in the Astronomical DataGrid', Sofia, Bulgaria, April 27-30, 2005.

[72] Häusler B., Pätzold M., Tyler G.L., Simpson R.A., Hinson D., Bird M.K., Treumann A., **Dehant V.,** Barriot J.-P., and Imamura T.
Atmosperic, ionospheric, surface, and radiowave propagation studies with Venus Express radio-science experiment VeRa
Asia Oceania Geosciences Society, Singapore, June 20-24, 2005.

[73] Pätzold M., Häusler B., Tyler G.L., Asmar S.W., Barriot J.P., **Dehant V.,** Hinson D.P., Simpson R.A., and the MaRS team associates
The Mars Express Orbiter Radio Science Experiment (MaRS)
Asia Oceania Geosciences Society, Singapore, June 20-24, 2005.

[74] **Van Hoolst T.**
Rotation and tides of Mercury
DLR, invited seminar, Berlin, Germany, 29 June 2005.

[75] **Lainey V., Rosenblatt P., Dehant V.,** Pätzold M., Andert T., and Barriot J.P.
A reexamination of Phobos density using MGS and MEX data
Semaine de l'Astrophysique Française, Journées de la SF2A 2005, July 1st, 2005, Strasbourg, France.

[76] **Rambaux N., Van Hoolst T.,** Bois E., and **Dehant V.**
An accurate theory of Mercury's rotation and its centrifugal librations
Semaine de l'Astrophysique Française, Journées de la SF2A 2005, July 1st, 2005, Strasbourg, France.

[77] **Pfyffer G., Dehant V., de Viron O., Van Hoolst T.,** and **Rambaux N.**
Mercury libration determination and the link with the interior of the planet
Joint European and National Astronomical Meeting JENAM 2005, poster, Liège, Belgium, 4 to 7 July, 2005.

[78] **Dehant V., Beuthe M., Duron J., Karatekin Ö., Lainey V., Le Maistre S., Rosenblatt P., Van Hoolst T., Barriot J.-P.,** Pätzold M., and Häusler B.
Gravity Measurements with Mars Express
Joint European and National Astronomical Meeting JENAM 2005, Workshop on Astrobiology and Solar System Exploration, poster, Liège, Belgium, 4 to 7 July, 2005.

[79] Wisemberg J., Nicolis G., Zegers I., Swings J-P., Waelkens C., Maes C., Rouvas Nicolis C., Simon P.C., **Dehant V.,** Fonteyn D., Javaux E., Surdej J., Verbeure A., **Van Hoolst T.,** Gaspard P., Muller C., and Moreau D.
Belgian Federal Centre for Complexity and Exobiology (COEX)
Joint European and National Astronomical Meeting JENAM 2005, Liège, Belgium, 4 to 7 July, 2005.

[80] **Dehant V.** and **Van Hoolst T.**
Internal Planetary Evolution and Habitability
Joint European and National Astronomical Meeting JENAM 2005, Workshop on Astrobiology and Solar System Exploration, Liège, Belgium, 4 to 7 July, 2005.

[81] **Dehant V., Beuthe M., Duron J., Karatekin Ö., Lainey V., Le Maistre S., Rosenblatt P., Van Hoolst T., Barriot J.-P.,** Pätzold M., and Häusler B.
Gravity Measurements in order to probe the interior of Mars and its moon Phobos
IAG General Assembly, Cairns, Australia, Session G5 on 'GGOS and geodesy of the planets', Conveners: C. Reigber, H.-P. Plag, F. Lemoine, J.P. Barriot, poster, 25-29 August 2005.

[82] **Karatekin Ö., Van Hoolst T., Dehant V.**
Martian Global scale CO2 change from time-varying gravity measurements
IAG General Assembly, Cairns, Australia, Session G5 on 'GGOS and geodesy of the planets', Conveners: C. Reigber, H.-P. Plag, F. Lemoine, J.P. Barriot, poster, 25-29 August 2005.

[83] **Dehant V.,** Folkner W., **Van Hoolst T.**
Gravity, rotation, and interior of the planets from planetary geodesy
IAG General Assembly, Cairns, Australia, Session G5 on 'GGOS and geodesy of the planets', Conveners: C. Reigber, H.-P. Plag, F. Lemoine, J.P. Barriot, invited talk, 25-29 August 2005.

[84] **Dehant V.,** Forget F., Lognonné P., Spohn T.
Geophysical and Environment Package
ESA Pasteur Workshop, ESTEC, Noordwijk, The Netherlands, 31 August-2 September, 2005.

[85] Arlot J.E., **Lainey V**., and Thuillot W.
Mutual events of the satellites of Uranus calculated with a new dynamical model
DPS 2005, 37th annual meeting of the Division for Planetary Sciences of the American Astronomical Society in association with the Royal Astronomical Society, Cambridge, UK, 4-9 September 2005.

[86] Efroimsky, M., **Lainey V.**, and Gurfil, P.
Long term evolution of orbits about a precessing planet: the likely history of Phobos and Deimos
DPS 2005, 37th annual meeting of the Division for Planetary Sciences of the American Astronomical Society in association with the Royal Astronomical Society, Cambridge, UK, 4-9 September 2005.

[87] **Lainey V.** and Tanga P.,

Can the mass of the Martian moons been detected by GAIA's observations?
DPS 2005, 37th annual meeting of the Division for Planetary Sciences of the American Astronomical Society in association with the Royal Astronomical Society, Cambridge, UK, 4-9 September 2005.

[88] Pascu D., Arlot J. E., **Lainey V.**, Birlan M., and Robert V.
New observations of the Natural Planetary satellites through the Natural Satellites USNO Plates Archive
DPS 2005, 37th annual meeting of the Division for Planetary Sciences of the American Astronomical Society in association with the Royal Astronomical Society, Cambridge, UK, 4-9 September 2005.

[89] **Rambaux N.**
An accurate theory of the rotation of Mercury
Celmec IV, 11-16 September 2005, Rome.

[90] Lemaître A., D'Hoedt S., and **Rambaux N.**
The 3:2 spin-orbit resonant motion of Mercury
Celmec IV, 11-16 September 2005, Rome.

[91] D'Hoedt S., Lemaître A., and **Rambaux N.**
Mercury's Rotation: The four equilibria of the Hamiltonian model
Celmec IV, 11-16 September 2005, Rome

[92] **Beuthe M., Rosenblatt P., Dehant V.,** Barriot J.-P., Pätzold M., Häusler B., **Karatekin Ö., Le Maistre S.,** and **Van Hoolst T.**
MaRSian Gravity on Targets: Data Analysis
Mars Express Radioscience team meeting, Brussels, Belgium, September 12-13 2005.

[93] **Le Maistre S., Beuthe M., Rosenblatt P.,** V. Dehant, and Pätzold M.
MaRSian Gravity field from MaRS experiment: Data status
Mars Express Radioscience team meeting, Brussels, Belgium, September 12-13, 2005.

[94] **Lainey V., Dehant V.,** and Pätzold M.
New ephemerides of the Martian Moons
Mars Express Radioscience team meeting, Brussels, Belgium, September 12-13, 2005.

[95] **Rosenblatt P., Dehant V.,** Pätzold M., Häusler B., **Duron J.,** Marty J.C., **Le Maistre S., Karatekin Ö.,** and **Van Hoolst T.**
Mars' time variable gravity field from MaRS experiment: status report
Mars Express Radioscience team meeting, Brussels, Belgium, September 12-13, 2005.

[96] **Dehant V.**
Gravity treatment of MEX data at ROB
ESOC, Darmstadt, Germany, 16 September, 2005.

[97] **Dehant V.**
Habitability of subsurface oceans on icy satellites
Annual meeting of SLIM, Louvain-la-Neuve, 29 September, 2005.

[98] **Lainey V.**
Ephémérides des satellites naturels, structure interne et observations
´séminaires LTE', Paris, France, October 3rd, 2005.

[99] **Dehant V.** and **Van Hoolst T.**
Gravity, rotation, and interior of the terrestrial planets from planetary geodesy
Presentation for the Belgian ESA Ambassador, October 5, 2005.

[100] **Pfyffer G.**

Analytical development and numerical simulations of a space based radio-science experiment measuring the Mercury libration
IPGP, Paris, France, 21-25 October 2005.

[101] **Dehant V.**
Earth rotation and orientation and perspectives for planetary geodesy
Invited talk, 3rd KAGI21international symposium on 'Active Geosphere Investigation' organized by the Institute of Geodesy and Geophysics (Chinese Academy of Sciences) and KAGI21 Office, Graduate School of Science (Kyoto University, Japan), Wuhan, China, November 8, 2005.

[102] **Rambaux N**.
Librations physiques de Mercure et couplages rotation-noyau
Séminaire des Facultés Universitaires Notre-Dame de la Paix, Namur, November 8, 2005.

[103] **Dehant V.**
Earth rotation and orientation, and perspectives for planetary geodesy; application to the planet Mars
Seminar, invited, Shanghai Observatory, November 11, 2005.

[104] **Dehant V.**
Gravity observations over selected target areas by the Mars Express Radio Science Experiment MaRS
Presentation for the MEX Project, 18 November 2005.

[105] **Dehant V.**
Interior of the terrestrial planets; time variable gravity field; tides; rotation; from planetary geodesy
MAGE workshop, November 23-25, 2005.

[106] Vacher P., **Verhoeven O., Rivoldini A.,** Mocquet A., Choblet G., Menvielle M., **Dehant V.,** and **Van Hoolst T.**
Temperature and composition of the Martian deep interior inferred from the magnetic data
MEMO workshop, Paris, November 28-30, 2005.

[107] Barriot J.-P., **Dehant V.,** and **Beuthe M.**
Navigation of the Memo Satellite and the Possible Use of Navigation Data to Improve Our Knowledge of the Gravity Field of Mars
MEMO workshop, Paris, November 28-30, 2005.

[108] **Dehant V.** and **Van Hoolst T.**
Information on interior structure of the terrestrial planets from their rotation
Symposium 'Rotation of celestial bodies', Colloquium in Honor of Professor Jacques Henrard, Namur, 1-2 December 2005.

[109] **Rambaux N.**, and Henrard, J.
The rotation of Galilean satellites, Symposium 'Rotation of Celestial Bodies'
Colloquium in Honor of Professor Jacques Henrard, Namur, 1-2 December 2005.

[110] **Lainey V., Dehant V.,** Oberst J., and Pätzold M.,
New ephemerides of the Martian moons
AGU Fall Meeting, poster, December 5-9, 2005.

[111] **Rosenblatt P., Duron J.,** Marty J.C., **Dehant V.,** Pätzold M., Häusler B., **Le Maistre S., Karatekin Ö., Van Hoolst T.,** and Balmino G.
Mars' time variable gravity field from a joint inversion of MEX and MGS radio-tracking data
AGU Fall Meeting, poster, December 5-9, 2005.

[112] **Dehant V., de Viron O., Karatekin Ö.,** and **Van Hoolst T.**

Mars polar motion at short time-scale
AGU Fall Meeting, December 5-9, 2005.

[113] Seiferlin K., Thomas N., Spohn T., Oberst J., Michaelis H., Gunderson K., Whitby J.A., and the team (including **V. Dehant**)
The BepiColombo Laser Altimeter BELA: Instrument Description
AGU Fall Meeting, poster, December 5-9, 2005.

[114] **Beuthe M., Rosenblatt P., Dehant V.,** Barriot J.-P., Pätzold M., Häusler B., **Karatekin Ö., Le Maistre S.,** and **Van Hoolst T.**
Martian Gravity Field at Short Wavelength: results from Mars Express
AGU Fall Meeting, poster, December 5-9, 2005.

[115] **Rivoldini A., Verhoeven O., Van Hoolst T.,** Mocquet A., and **Dehant V.**
Mars interior structure models from tidal measurements
AGU Fall Meeting, poster, December 5-9, 2005.

[116] **Guyennon N., Karatekin Ö.,** and **Van Hoolst T.**
Visco-Elastic Response of Titan to Tidal Loads
Poster, AGU Fall Meeting, December 5-9, 2005.

[117] **Lainey V.**
Natural satellites ephemerides and internal structure
Colloque 'USNO Thursday seminar', USNO-Washington, US, December 15, 2005.

[118] **Rambaux N., Van Hoolst T.,** Bois E., and **Dehant V.**
Rotation and interior properties of terrestrial bodies
Assemblée générale de l'Observatoire de la Cote d'Azur, Nice, France, December 15, 2005.

[119] **Rambaux N.**
La connaissance des noyaux des planètes telluriques par les couplages spin-orbite et rotation-noyau
Observatory of the Côte d'Azur (OCA), Nice (invited for the general assembly of OCA), 16 December 2005

National and international responsibilities

- **Ö. Karatekin** is member of the steering committee of the IAG Inter-Commission on "Planetary Geodesy"
- **T. Van Hoolst** is member of
  - the steering committee of the IAG Inter-Commission on "Theory"
  - IAU commission 27 "Variable Stars"
- **V. Dehant** is Co-I of:
  - MaRS (Mars Express Radio Science experiment)
  - VeRa (Venus Express Radio science experiment)
  - MORE (Mercury Orbiter Radio science experiment of BepiColombo mission)
  - BELA (BepiColombo Laser Altimeter)
- **T. Van Hoolst** is Co-I of the SYMBIO-SYS (High resolution camera experiment of BepiColombo mission)
- **V. Dehant** is member of:
  - the Working Group "Planetary Lander Initiative"
  - the Review Team for the ESA Cassini-Huygens mission archive
  - the Review Panel for the ESA Second Call for Earth Explorer Core Mission Ideas
- **V. Dehant, T. Van Hoolst, O. Verhoeven, A. Rivoldini** are member of the Working Group MINT "Mars INTerior synergy"

Meeting organization

- **V. Dehant, T. Van Hoolst**, and **S. Raynal** have organized a MAGE (Mars Geophysics European network) meeting at the Planetarium in Brussels; this meeting was a two and a half day meeting in November 2005 with lecturers and conferences on the planet Mars

Educational responsibilities

- **V. Dehant** is promoter of the PhD of G. Pfyffer (first year, UCL), J. Duron (third year, UCL), A. Rivoldini (fourth year, UCL)
- **T. Van Hoolst** is/was promoter of the master theses of H. De Vrij (Natuurkunde, K.U.Leuven, 2004-2005), S. Selleslags (Wiskunde, K.U.Leuven, 2004-2005), M. Cox (Natuurkunde, K.U.Leuven, 2005-2006)

C.2.8. Missions

Assemblies, symposia (number):	T. Van Hoolst (4) V. Dehant (7) M. Beuthe (5) Ö. Karatekin (3) V. Lainey (5) S. Le Maistre (2) G. Pfyffer (3) A. Rivoldini (4)
Commissions, working groups (days):	T. Van Hoolst (14) V. Dehant (24) M. Beuthe (2) Ö. Karatekin (7) S. Le Maistre (1)
Research visits (days):	J. Duron (365) Ö. Karatekin (7) V. Lainey (8) A. Rivoldini (18)

DEPARTMENT 1: Reference Systems and Geodynamics

SECTION 2: Seismology

Introduction

The objectives of the activities of the section seismology are:

- Monitoring the seismic activity in Belgium and surrounding regions;
- Providing our measured seismic data to the seismological international centres;
- Conducting scientific research on earthquake seismology and the seismic activity in our regions;
- 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.

Since 1999, the section assumed also the scientific and technical follow-up of the superconducting gravimeter installed in the Membach station and of the ROB absolute gravimeter.

Since 2004, we are developing a seismological database as a tool to monitor the working state of the seismic stations and 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 conducted routinely for local, regional and teleseismic earthquakes recorded by the Belgian seismic network.

The progress in this work during 2005 allowed us to provide since January 1, 2006 a follow up of the seismic activity in Belgium with a delay not exceeding three days (there is no staff presence during the week-end). Now, it is also possible to visualize on the website of the section (http://www.astro.oma.be/SEISMO/NEWSITE3/index.php?LANG=FR) in quasi-real time the seismic signals from the stations Uccle and Membach. This provides the possibility for the personnel of the section to consult at home the signals from these two stations using ADSL-connection and thus to have a faster answer than previously to the questions of the authorities concerning felt ground movements during the nights and the week-ends.

During 2005, the new data acquisition system developed by our technicians, with a 24 bits A/D converter working on a Linux PC-based system, has been installed in most of the seismic stations of the Belgian network, improving strongly the quality of the seismic signals. The data from the stations Uccle and Membach are also transmitted in quasi real time to the IRIS and ORFEUS centres, respectively in the USA and the Netherlands. Hence, it is important to note that the data from the superconducting gravimeter in Membach are the first ones in the world which are available on line to the whole scientific community.

During this year, the pressure of media concerning earthquake activity in the world and the questions from the public and private companies increased also dramatically, imposing to the personnel an important supplementary work in addition to the already important normal activity caused by the non-replacement of four permanent positions since 1996. The dramatic earthquake of December 26, 2004 in Sumatra and its main consequence, the tsunami, were the source of a continuous presence of the media at the Royal Observatory during the whole month of January 2005. On the other hand, two documentaries have been realized respectively by CICADA films (for National Geographic) and the VRT (program Over Leven) on the fundamental scientific works done by our section during the last ten years on the past large earthquakes in Northwest Europe. Thus, CICADA provided us with the financial support to excavate a trench across the Geleen fault near Rotem. These works required also a strong involvement of the scientific and technical personnel of the section.

Despite the large amount of operational tasks, the scientists of the section Seismology dedicated an important part of their work to their scientific activities. In addition to the permanent study of the seismicity in Belgium and surrounding regions, we focused in 2005 the scientific activities more specifically on three other different research fields:

1. Study of active faults in intraplate regions;
2. Evaluation of site effects on strong ground-motions and seismic hazard assessment;
3. Interpretation of gravity data to infer vertical crustal deformation.

These investigations are essential to understand the tectonic deformations and their relationships with seismic activity in intraplate regions but also to evaluate the economical and environmental consequences of future strong earthquakes in Belgium.

Since October 2005, the seismology section hosts the EC-Marie Curie Project « Understanding the irregularity of seismic cycles: A case study in Turkey » MEXT-CT-2005-02. This project proposes to establish the seismic history over several thousands of years of a main strike-slip fault system in Turkey, and more particularly investigates recurrence time of large M > 7 earthquakes. Four scientists will participate to the project under the lead of Dr. Aurélia Hubert-Ferrari.

This report contains in three different sections. The first one concerns the scientific research projects conducted by the section. The second part presents the operational projects providing the basic information for our scientific research and expertise (monitoring the seismic activity by the seismic and accelerometric stations and the development of the ROB-seismology database). The third section reports on the operational projects concerning the international data exchange as well as the information service to the authorities, the public and the media. The publication list can be found at the end of the report.

A. SCIENTIFIC RESEARCH PROJECTS

As in all the intra-plate regions worldwide, it is a challenge to provide a scientific basis to evaluate the long-term seismic activity in northwest Europe and its consequences, including the location of future large earthquakes, their magnitude, their average return period and their impact. During the last ten years, we have developed at the ROB a multidisciplinary approach to provide a scientific background for answering these questions. All the scientific projects of the section of seismology are dedicated to the development and application of this multidisciplinary approach.

Our scientific research can be classified in four different projects:

1. Paleoseismology in intra-plate regions
2. Seismicity in Northwest Europe
3. Seismic hazard evaluation and strong ground motion characterization
4. Evaluation of present-day deformation in our regions.

A.1. Paleoseismology

A.1.1. Objectives

The aim of this research project is to identify seismogenic structures, and to search for evidence of paleoearthquakes in the geologic record. Investigation is focused on Belgium and neighboring areas, but expertise is also acquired in other regions of the world (e.g. Bulgaria, Tanzania) with a similar tectonic situation. This will extend our knowledge of the seismic cycle of slowly slipping faults in the intracontinental context of our region, and thus contribute to a better assessment of seismic hazard.

Currently, most of the research activities are framing in the following sub-projects:

- The research project “Fault activity in NW Europe and its relationship to seismic activity” (Action 1 MO/33/011) aims to provide information on the long-term seismic activity and present-day tectonic deformation in the region extending from the North Sea to the Roer Valley graben (RVG). Research is carried out at three different levels: (1) compilation of all information that could be indicative of recent tectonic activity in the entire region; (2) field reconnaissance in the epicentral area of important historical earthquakes and in zones with indices of recent tectonic activity, where active faults

have not yet been identified; (3) more detailed paleoseismic investigation of the known active faults in the RVG, which was the main focus during previous projects.

- The research project "Active faults and past large earthquakes in the Upper Thracian Depression" (Bilateral project BL/33/B09) is a bilateral cooperation with the Geological Institute of the Bulgarian Academy of Sciences (B.A.S.), which started in 2003 as the follow-up of a similar bilateral project running since 2000. It has been initiated by the need for Bulgarian scientists to develop paleoseismological methodologies for the purpose of seismic hazard assessment in their country. The objective is to study the fault ruptures of the great 1928 Chirpan and Plovdiv earthquakes in the Upper Thracian Depression. The cooperation provides the Royal Observatory of Belgium with the opportunity to perform paleoseismic studies in an intraplate extensional setting comparable to the RVG in NE Belgium.
- Since October 2005, the seismic section hosts the EC-Marie Curie Project « Understanding the irregularity of seismic cycles: A case study in Turkey » MEXT-CT-2005-02. This project proposes to establish the seismic history over several thousands of years of a main strike-slip fault system in Turkey, and more particularly investigate recurrence time of large M > 7 earthquakes.
- Under the framework of the research-project M0/37/12 (Geodynamical processes, erosion and sedimentation during the last 30.000 years in the region of the Tanganyika-Rukwa-Malawi Rift, western Tanzania) headed by the Royal Museum of Central Africa, we participated to the study of the Kanda fault near the important city of Sumbawanga.

A.1.2. Progress and results

A.1.2.1. "Fault activity in NW Europe and its relationship to seismic activity"

A synthesis of our investigations on the Bree fault scarp has been prepared for a paper which will be published in the book «Intraplate seismic activity» prepared by the Geological Society of America. We present most of the scientific evidence supporting the occurrence of large earthquakes to explain the observed surface faulting on the border faults of the Roer Valley Graben.

On the other hand, most of our time was absorbed by the excavation of a new trench in the RVG, supported by Cicada Films. We first had to find a suitable trench site. On the one hand, we had to keep on the safe side to ensure the presence of an active fault, but on the other hand we also wanted to obtain new and relevant data on fault activity in the RVG. We chose a site on the Geleen fault in the village of Rotem in the Belgian Maas valley, less than 2 km away from the trench we investigated in 2002. Compared to the 2002 trench, this site is located farther away from the Holocene river valley, which increases the likelihood of encountering slightly older fluvial deposits, and thus the possibility of finding evidence for events older than the one paleoearthquake we identified in 2002. Trenching at this site would also confirm our hypothesis on the irregular trace of the Geleen fault. Finally, we hoped to discover elements at this site to determine if this portion of the fault represents a segment boundary or if it shares the same history of faulting with the Bree fault scarp further north. Before trenching, we acquired two long resistivity profiles in the vicinity of the site. Both profiles show strong displacement of the base of these gravels coinciding with the position of a subtle topographic scarp, thus leaving little doubt that this scarp is indeed the geomorphic expression of an active fault. Finally, to determine the exact position of the fault at meter-scale, we carried out a pseudo-3D geophysical survey of the site using ground-penetrating radar and resistivity mapping, a technique which we applied for the first time. In resistivity mapping, we measure resistivity in one or more planes parallel to the surface, rather than in a profile. Thus, we obtain a picture of horizontal resistivity variations at different depths, which proved to be well suited to evidence the linear structure of a fault. In August, the trench was finally opened and investigated in detail over the course of a full month. We were assisted by two Bulgarian colleagues, M. Yaneva and G. Nikolov.

The preliminary results of this trench are very promising. We found evidence for two paleoearthquakes: a relatively recent event which throws down the Holocene soil sequence by about 1 m, and an older event with a vertical offset of c. 0.4 m, predating a gravel bed that we correlate with the regionally known Be-

uningen horizon, which developed during the last glacial maximum, c. 15,000 years BP. Dating results are not available yet, but the first event most likely corresponds with the event identified in the 2002 trench, dated between 1160 AD and the Early Iron Age (c. 850 – 500 BC). This is supported by the discovery of a subtle dark horizon with organic material that we interpret as a cultivated soil (Figure 5). This soil is cut by a set of sand dikes, the best examples found to date in the RVG, terminating at its top. This is additional evidence suggesting that the top of this soil represents the event horizon. The overlying sediment corresponds with colluvium derived from a degrading fault scarp. We will try to confirm the nature of buried soil and colluvium by the study of thin slides, an uncommon approach in paleoseismology. Together with the results obtained in 2002, the new trench presents a strong case for the coseismic nature of faulting on the Geleen fault.

In the framework of Action 1 project «Fault activity in NW Europe and its relationship to seismic activity » (MO/33/011) we started also to investigate the faults of the Boulonnais-Artois in the North of France. The most severe earthquakes that affected northern France are the earthquakes of April 6, 1580 (M = 6.0) and of September 2, 1896 (M = 5.0). By comparing the macroseismic intensity data (via the BOXER software), the interpreted faults on the Bouguer anomaly map (Everaerts, 2000), the morphological fault scarps and indications for quaternary fault movements in the literature we can attribute with some uncertainty the 1580 (M = 6.0) earthquake to the Sangatte Fault and the 1896 (M = 5.0) earthquake to the Marqueffles Fault. Based on similarity and because they form the same (en-echelon) fault zone we also consider other faults in the area as capable of producing similar earthquakes as the 1580 (M = 6.0) event. Considering the length of these faults and the indications in the literature for Quaternary activity and deformation up to the surface we classify these faults as capable of producing large earthquakes with a maximal magnitude of 7.0. One of these faults will be the target of future investigation to confirm recent activity.

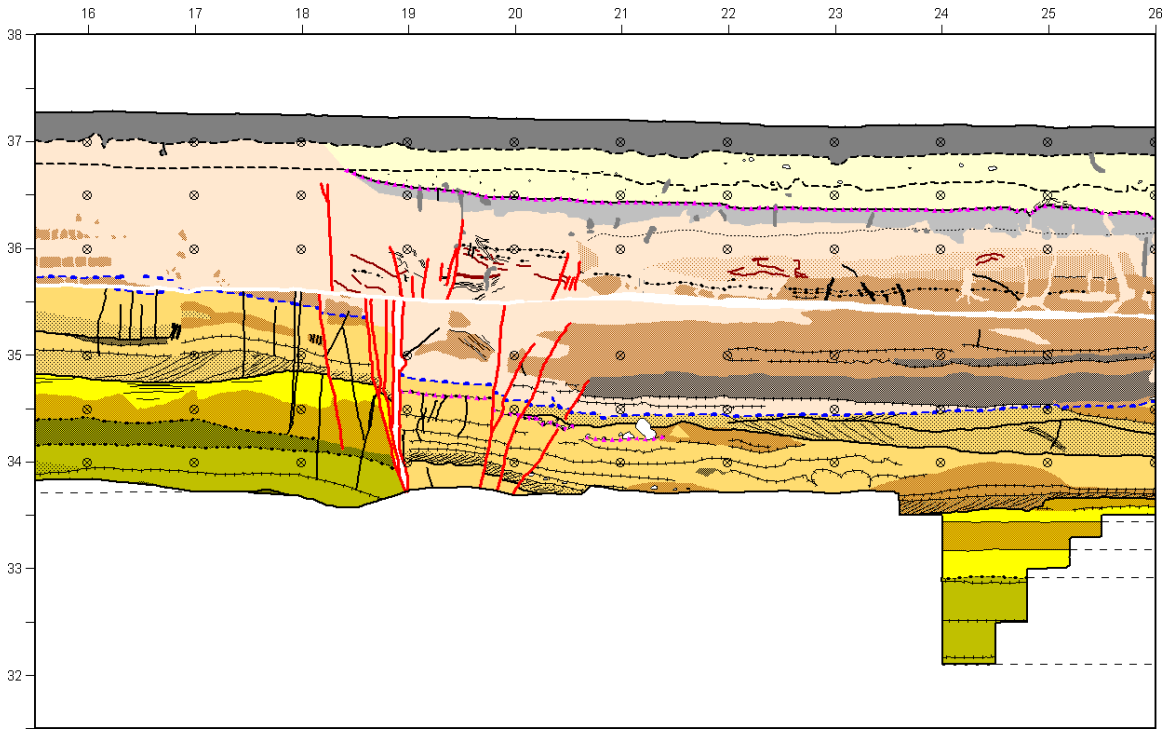


Figure 5: Detailed line drawing of fault zone on NW wall of Rotem trench. The most recent paleoearthquake has thrown down a dark horizon that we interpret as a cultivated soil (grey color)

The Geographical Information System-based-relational-database of active and capable faults that we are developing to manage, visualize and analyse the different kinds of geographical information that we are dealing with has some delay. We had to redesign the database structure to incorporate the new INQUA scale of earthquake environmental effects and to allow adding present day earthquake observations. We now still have to finalize the graphical interface and the functionality to consult and compare the data.

A.1.2.2. Active faults and past large earthquakes in the Upper Thracian Depression

We continued our analysis of the trenches excavated in previous years. Results from the trench on Chirpan fault in Cherna Gora, excavated in 2002, were published (Vanneste et al., Journal of Geophysical Research, 2006). We also worked on the interpretation of the trenches excavated in 2004 on Popovitsa fault ("Sieberg" site) and on Chirpan fault ("Kopanite"), a.o. during the visit of our Bulgarian colleagues S. Shanov and M. Yaneva in April. Preliminary results of the Sieberg trench have been published by our Bulgarian colleagues in Bulgarian journals and conferences. However, we are waiting for the results of the luminescence dating to finalize our interpretation of this trench. The radiocarbon datings of the trench at Kopanite have become available by the end of November, which should enable us to finalize our interpretation in the coming months. The 1928 earthquake and the penultimate event identified in Cherna Gora are either missing or poorly expressed in Kopanite, suggesting that the trench does not capture the complete recent faulting history.

In September and October, we conducted during two weeks new geomorphic and geophysical reconnaissance survey on the Chirpan and Popovitsa faults. We investigated 3 areas:

- The extension of Chirpan fault east of the village of Chirpan, where we recorded 7 resistivity profiles at 5 different sites over a distance of about 20 km, in order to identify this fault in the subsurface, to locate it more precisely, and to determine if it is associated with a young geomorphic scarp. Several profiles have yielded a good picture of the fault and its relation with the regional geology (Figure 6), which will help us constrain its long-term activity. As contemporary sources do not clearly indicate if this portion of the fault was activated in the 1928 earthquake or not, future trenching is needed to establish whether it belongs to the same segment as the portion west of Chirpan, which is important for determining fault dimensions and maximum magnitude;
- Along Popovitsa fault, we studied the site "Star Dere" in more detail as a possible trenching site. This site is situated 3.75 km SE of the "Sieberg" site mentioned above, on a small alluvial fan. We recorded 4 resistivity profiles, with different electrode spacings, parallel to the fan axis; in addition, we measured the topography of the site using a total station. The faulting pattern appears to be far more complex than anticipated, however, and correlation with the morphology is not straightforward. The profiles show evidence of at least 4, possibly 6, subparallel faults. Surprisingly, the main fault does not correspond with the most pronounced geomorphic anomaly; there is only slight evidence for the existence of a fault at this position. The overall faulting pattern resembles wrenching, which could imply a significant strike-slip component. The site may thus not be ideal for trenching, at least not without additional data (boreholes, GPR, …);
- The third study area is located centrally on the section of Chirpan fault between Cherna Gora and Chirpan, at the intersection with the Omourovo River. We conducted a resistivity mapping experiment at two sites, west and east of the Omourovo, in order to further improve this technique, which we applied only once before in Rotem, and to test its usefulness to image normal faults in a horizontal plane. We chose the site east of the Omourovo because our previous geophysical investigations have shown large faulting complexity, and the site west of the Omourovo because it may help resolving whether additional faults are present that were not exposed in the adjacent Kopanite trench (see discussion above). The resistivity mapping data will be studied in 2006 by ULB student T. Lecocq for his master thesis.

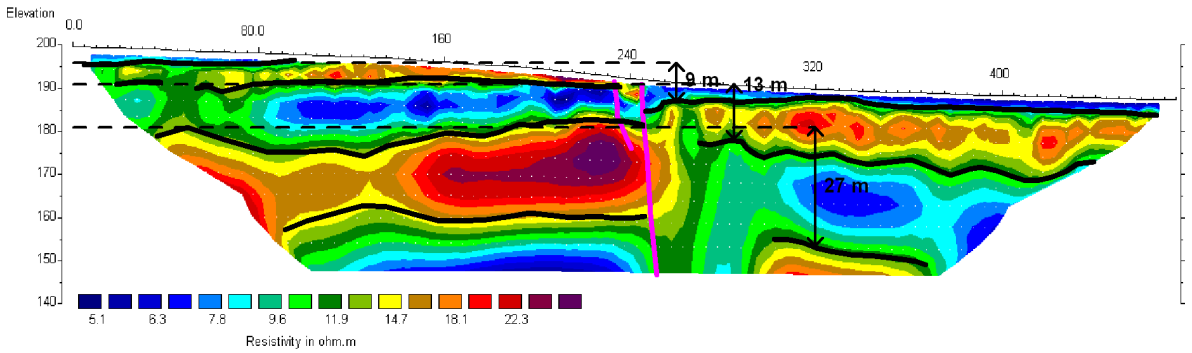


Figure 6: 2-D resistivity profile across Chirpan fault near Volovarevo, showing increasing vertical offset of stratigraphy with depth.

A.1.2.3. Active faults in Tanzania

We have participated to the investigation on the Kanda fault, located west of Lake Rukwa near the city of Sumbawanga (Tanzania) in co-operation with the Royal Museum for Central Africa (project M0/37/12). The Kanda fault, which is part of the active Tanganyika-Rukwa-Malawi rift system in the western branch of the East African Rift System, has a pronounced geomorphologic expression as a long and steep NW-SE orientated escarpment, dipping to the northeast, with topography from several meters up to 50 m and can be followed over 180 kilometer.

The geophysical material of the ROB, electric 2D tomography and Ground Penetrating Radar (GPR), was used. We conducted several electrical tomography profiles perpendicular to the fault trace to image the offset layers and differential GPS measurements to make topographical profiles and to construct a digital elevation model. In total, 13 profiles at 6 six different sites were carried out. Apart from the GPR, which did not give much information due the hard lateritic crust near the ground surface, the results of the 2D electric tomography, which were afterwards processed and interpreted at the ROB, were very satisfying and allowed us to better understand the fault geometry. One of the main achievements was the estimation of the total vertical offset at some of the sites. Together with the dating of sediments in the hanging wall, it can provide us clues of the faulting history in terms of activity and recurrence interval of the fault. Previous dating suggests a very recent activity of the fault.

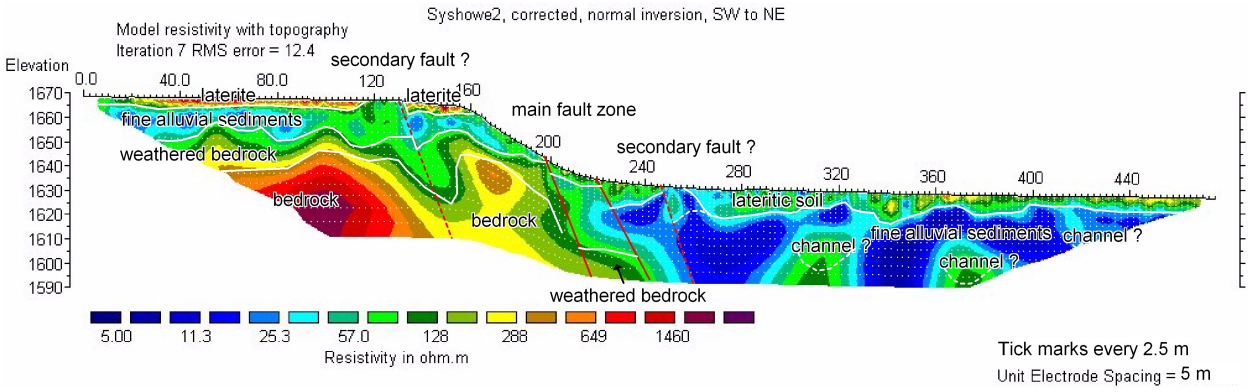


Figure 7: Electric resistivity profile of the Syshowe 2 site, Tanzania. The scarp is about 40 m high. The higher resistivity layers in the footwall represent the bedrock while the lower resistivity layers in hangingwall represent alluvial downfaulted sediments. This indicates likely a minimum of 45 meters vertical fault offset.

A.1.2.4. Understanding the irregularity of seismic cycles: A case study in Turkey

This project proposes to establish the seismic history over several thousand of years of a main strike-slip fault system in Turkey, and more particularly investigate recurrence time of large M > 7 earthquakes. The targeted North Anatolian plate-boundary is particularly suitable to characterize the physics of earthquake recurrence because of its type of faulting, its rapid deformation rate (up to 24 mm/yr), its relative structural simplicity and its particularly simple seismic behavior characterized by cascading sequences of M > 7 earthquakes.

To better understand Seismic Cycles, the Marie Curie project plans to obtain a most extensive chronology of past events along both the North Anatolian Faults, by using a diverse array of complementary techniques, involving trenching across the fault combined with subsurface geophysics, dating of displaced geomorphic features and drilling of lake sediments along the fault trace. The Section of Seismology of the Royal Observatory of Belgium was able to host this project because of its recognized international expertise in paleoseismology and subsurface geophysics applied to active faulting studies.

A.1.3. Perspective for following years

After the high demand for fieldwork in previous years, we will valorize the collected paleoseismic data, both from Belgium and from Bulgaria. The information obtained from the two trenches on the Geleen fault near Rotem in the Belgian Maas valley can be published together. However, new fieldwork has already been scheduled: one week of reconnaissance in the Artois-Boulonnais region in the north of France, two weeks in Bulgaria.

The field investigations of Marie Curie project on the North Anatolian fault in Turkey will start.

Development will be also given to the GIS-based database of active and capable faults in Belgium and surrounding regions.

A.1.4. Personnel involved

Scientific staff: Kris Vanneste (Assumed the scientific direction of the different studies conducted in the framework of the paleoseismic investigations)
Koen Verbeeck (Action 1 n° MO/33/011)
Toon Petermans (Action 1 n° MO/33/016)
Aurelia Ferrari (EC-Marie Curie Project, MEXT-CT-2005-02)

A.1.5. Partnerships

List of national and international partners

- Geological Institute of the Bulgarian Academy of Sciences – Dr. Stefan Shanov
- Geodetic laboratory of the Bulgarian Academy of Sciences – Dr. Dimitar Dimitrov
- Royal Museum for Central Africa – Dr. Damien Delvaux, Dr. François Quervyn and Philippe Tréfois (teledetection)

Grants used for this research

- Bilateral cooperation with Bulgaria (BL/33/09): from January 2003 to December 2005.
- Action 1 project «Fault activity in NW Europe and its relationship to seismic activity » (MO/33/011): from January 2003 to December 2006.
- EC-Marie Curie Project « Understanding the irregularity of seismic cycles: A case study in Turkey » MEXT-CT-2005-02.
- The field studies (geophysical investigations) in Bulgaria have been financed by the budget of the section.

Visitors: 4

A.1.6. Scientific Outreach

Meeting presentations

[1] **Vanneste K.**, Similox-Tohon D., Sintubin M. & Muchez P.
Visualizing 2D resistivity profiles in 3D at the faulted archaeological site of Sagalassos (SW Turkey). Better insights in a complex subsurface
Recent Advances in Shallow Geophysics, Environmental and Industrial Geophysics Group Meeting, British Geological Survey, Keyworth (UK), 26/05/2005, oral presentation by D. Similox-Tohon

[2] **Vanneste K., Verbeeck K., Petermans T., Camelbeeck T.**, Radulov A., Nikolov G., Yaneva M., Dimitrov D. and Shanov S.
Active fault studies in intraplate regions and the return period in intra-plate regions
Contactforum:"Geodesy and Geophysics for the third millennium in Belgium", Academy Palace, Brussel, 13/10/05, poster

[3] **Vanneste K., Verbeeck K.**, Yaneva M., Nikolov G. & **Petermans T.**
Preliminary results of a new trench across the Geleen fault in the Belgian Maas valley
Meeting of the Rhine-Maas Seismology (RMS) group, KNMI, De Bilt (NL), 03/11/2005, oral presentation

A.1.7. Missions

Assemblies, symposia (number):	Kris Vanneste (2)
	Toon Petermans (1)
Commissions, working groups (days):	Kris Vanneste (1)
Field missions (days):	Kris Vanneste (34)
	Toon Petermans (39)
	Koen Verbeeck (54)
	Thierry Camelbeeck (5)

A.2. Seismicity in northwest Europe

A.2.1. Objectives

The main objective of the project is to provide a reliable catalogue of earthquakes in Belgium and the surrounding regions and a seismotectonic analysis of the seismic activity. The knowledge of the structure of the lithosphere is important in the understanding of the seismic activity, but also to provide good earthquake location. Thus, studies on the structure of the lithosphere in north-west Europe are also included in this project

A.2.2. Progress and results

A synthesis of all the available information on the seismic activity in Belgium and surrounding regions has been prepared for the book «Intraplate seismic activity» prepared by the Geological Society of America. In the first part of this paper, we present the characteristics of the seismic activity and general geological structure of the region. After that, we discuss the reliability of previous geodetic data and the preliminary results of experiments we have conducted to evaluate present-day crustal movements. A synthesis of the seismotectonic framework of the region is also given. All the reliable fault plane solutions for earthquakes in the studied area are presented. The second part of this work discusses our recent investigations suggesting that large earthquakes are more likely than once thought and their application to assess the location of future large earthquakes. We discuss our studies on strong historical earthquakes and on the Quaternary faults in the Lower Rhine Embayment. We analyse also the scientific arguments supporting the occurrence of large earthquakes to explain the observed surface faulting on the border faults of the Roer Graben. This problem is important because it has a strong impact on long-term seismic activity as-

sessment and it is in contradiction with the theory of Ahorner concerning seismic activity in this part of Europe which was prevalent up to recently among European seismologists and geologists.

P. Alexandre supplied the Section of Seismology with new data collected from original sources concerning the past earthquakes in Northwest Europe, more particularly about the seismic events of 1382, 1449 and 1580 (tremors with epicentre in the southern North Sea and the Strait of Dover), 1395, 1504, 1640 and 1755-1762 (epicentres in the Lower Rhine Embayment), 1692 (epicentre in the Belgian Ardenne) and 1828 (epicentre in Hesbaye area). So the macroseismic maps of these earthquakes have been improved. P. Alexandre continued also to insert historical data in the earthquake database of the ROB and carried out the assessment of the ancient seismic documents according to the rules of historical criticism. So we have already for each historical earthquake a provisional catalogue of the contemporary sources at our disposal describing the effects of the shock on the population and on the different kinds of buildings. Critical data supplied and published by P. Alexandre served as a basis for a new interpretation of the major earthquake of 3 January 1117 in northern Italy and lower Germany (E. Guidoboni and A. Comastri, in *Journal of Geophysical Research*, 110, 2006, B12309).

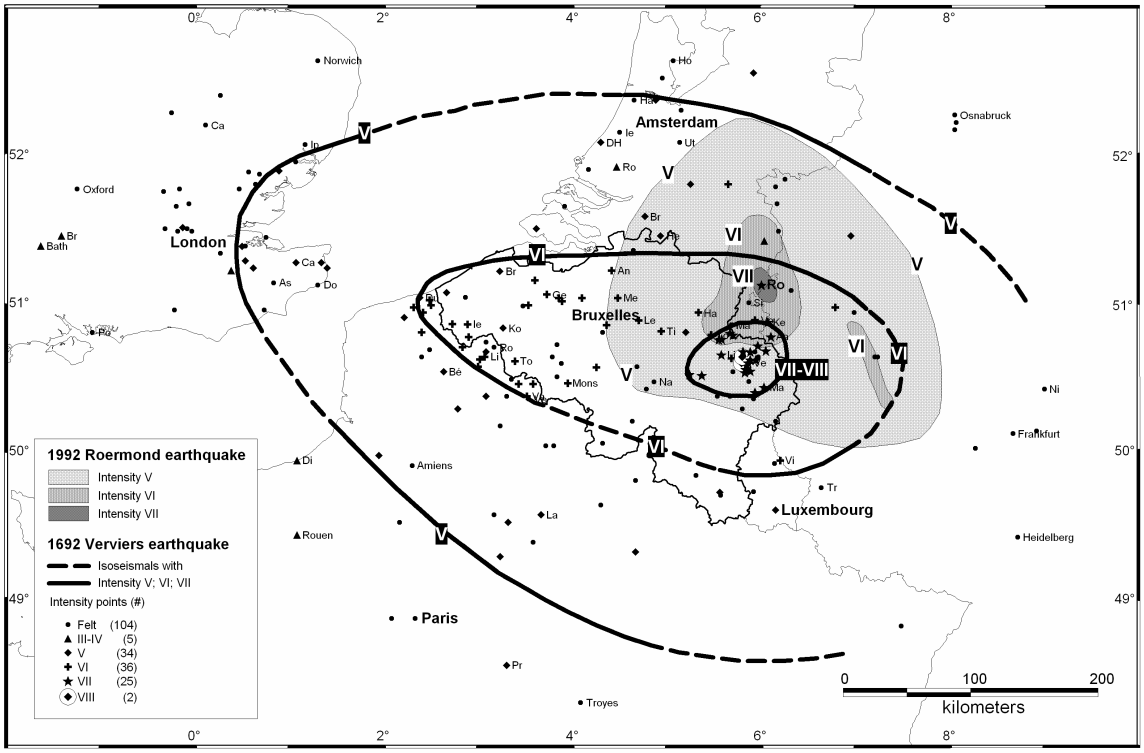


Figure 8: New comparative macroseismic maps for the earthquakes of September 18, 1692 in the region around Verviers and of April 13, 1992 at Roermond. This comparison illustrates the difference in the extension of the effects of these two earthquakes with magnitudes of respectively 6.3 (estimated from the geographical extension of the event effects) and 5.4 (determined from data of seismic stations).

A PhD student from the Ghent University, Els Sichien started her work on the structure of the crust in Belgium by relocating the earthquakes recorded by the Belgian seismological network since 1985 with the purpose of obtaining a uniform dataset. The used velocity model is the non-published one calculated by Fabienne Collin with the VELEST software. The used location program is a modified version of the HYPO-71 software developed at the ROB, including a different velocity model for P- and S-waves and a reliable analysis of the uncertainties. The second step in this project is to determine the Moho-depth and its lateral variability in Belgium. Els Sichien developed a procedure to measure the reflected PMP- and SMS-waves on the Moho, based on the comparison of real seismograms with synthetic seismograms cal-

culated by the AXITRA-program developed by O. Coutant of the University of Grenoble. To determine the spatial variability of the Moho-depth, she first divided the Belgian territory in a grid of 10 by 10 km. Over this grid, the PMP-reflection points of every couple earthquake location - seismic station are determined. For each grid cell, the seismograms, corresponding to the bounce-points in the grid cell, are stacked after the needed corrections (distance, etc.) to produce a seismic section similar to that of a seismic reflection survey.

A.2.3. Perspective for next years

A critical synthesis of the historical seismicity of northwest Europe from the 8th century onward will be continued and published by P. Alexandre. New data on the earthquakes of 1640, 1692, 1755-1762 and 1828 will be looked for, and the collected information will be inserted in the ROB database of historical seismicity.

During the second year of her project, Els Sichien will pick the PMP and SMS arrivals to calculate the Moho depth and its lateral variability in Belgium. She will start to select the data that will be used in the local velocity tomography and to test the programs that will be used. During the second term (third and fourth years) the local tomography will be realized and its results will be interpreted.

A.2.4. Personnel involved

Scientific staff: Thierry Camelbeeck (Project leader)
Pierre Alexandre (Inserts historical data in the earthquake database of the R.O.B. and carries out the assessment of the ancient seismic documents according to the rules of historical criticism)
Els Sichien (IWT grant)
Fabienne Collin

A.2.5. Partnerships

List of national and international partners

- Seismic section at the KNMI in De Bilt (The Netherlands)
- Seismic station Bensberg of the Cologne University (Germany)
- European Center for Geodynamics and Seismology and University of Luxemburg (GD Luxemburg)

Grants used for this research

- Els Sichien is funded by a Ph. D. grant of the Institute for the Promotion of Innovation through Science and Technology in Flanders (IWT-Vlaanderen)

A.2.6. Missions

Assemblies, symposia (number):	Pierre Alexandre (1)
	Thierry Camelbeeck (2)
Field missions (days):	Pierre Alexandre (12)
	Thierry Camelbeeck (1)

A.3. Seismic hazard – strong ground motions

A.3.1. Objectives

One challenge within the community of seismologists is to provide in every region of the world a realistic evaluation of the strong ground motions which will be generated by future large earthquakes. This requires a detailed modeling of the corresponding seismic source, crustal structure and local geological

characteristics (site effects). The objective of this project is to develop and apply methodologies for that purpose on the Belgian territory. Two main aspects are considered:

- Implement existing methods of seismic hazard assessment on the particular case of intraplate regions like Belgium,
- Develop methodologies to investigate site effects and implement them in a routine procedure.

A.3.2. Progress and results

P. Rosset developed procedures to assess probabilistic seismic hazard and to evaluate site effects combining experimental H/V methodology and 1-D modelling. Guidelines describing these procedures have been prepared (see also internal reports):

- *Guidelines of used and developed tools for ambient noise analysis*
- *Guidelines of used and developed tools for probabilistic seismic hazard analysis*
- *Guidelines of used and developed tools for numerical analysis in one dimension*
- *Guidelines of used and developed tools for generation of synthetics time series (preliminary version)*

These methodologies have been used to evaluate local seismic hazard in the Mons Basin (Philippe Rosset) and to study site effects in the region of Brussels (Toon Petermans). 139 ambient noise recordings were carried out and processed in the Brussels area to evaluate the resonance frequency (H/V method) of the subsoil. An area in St-Gillis was chosen to conduct a microzonation analysis, with a grid spacing of 150 m. The measurements give very reliable results with a strong negative coupling between the H/V resonance frequency and the thickness of the unconsolidated layer. In the Senne Valley, the H/V resonance frequency is around 1 to 2 Hz, while on the higher situated areas, the H/V frequency varies between 0.7 and 1 Hz.

The numerical analysis is needed to retrieve the amplitude of the ground response by calculating the transfer function of the soil. As a test of the model, the measured H/V resonance frequencies are compared with the calculated ones. Preliminary results of the numerical analysis on the same H/V sites corresponds well with the obtained H/V and are currently based on a 1-layer 1D model of the subsoil. This model is based on the linear correlation between the thicknesses of the soft-sediment with the shear wave velocity.

A good knowledge of the geotechnical parameters (shear wave velocity, damping, thickness and density of the geological layers) of the underground is important for the numerical analysis. Therefore we started a partnership with the Belgian Geological Survey, who developed the BUG program (Brussels Urban Geology), a 3D GIS-based geological model of Brussels area including the data of all CPT's (cone penetration test) and borings of Brussels. Also the online database of DOV ("Data Ondergrond Vlaanderen") was imported in our own GIS software (MapInfo 7.0) and was used for the 1-layer-1D model.

For a comparison with real seismic events, we studied all the earthquakes that struck Brussels and checked up the damage distribution. The 5.0 M_s Zulzich-Nukerke earthquake in 1938 gives the best insights in the potential damages for a moderate event. More than 1000 chimneys around Brussels were destroyed. We reread all the letters that were sent after the earthquake to the Observatory and mapped the damage distribution. Particularly the higher elevated areas seem to have suffered more and this is also mentioned in two sources of two earlier earthquakes (23 February 1828 and 2 September 1896) where the vibration was especially felt in the higher areas.

A.3.3. Perspective for next years

The interpretation of site effects in Brussels will be finalized using the numerical analysis. The data of the BUG program will be introduced in our database in order to start the calculations. Before the modeling we need to obtain reliable data for the shear wave velocity and the damping for each geological formation by making a correlation with the CPT data. We will compute the ground response for every 200 m in a grid of 10 x 10 km. In a later phase, seismic scenarios will be introduced by convoluting existing or synthetic earthquake signals with the transfer function of the soil (calculated frequency spectrum). The final

result will be the contour maps representing the resonance frequency and the amplitude of the ground response and amplification maps for different seismic scenarios.

A.3.4. Personnel involved

Scientific staff: Philippe Rosset (Supplementary researcher, Project leader, developed the instrumental and numerical tools for the study of site effects. He conducted the field measurements in the Mons Basin. He initiated the collaboration with the Geological Survey of Belgium)
Toon Petermans (Action 1 n° MO/33/016, conducted the investigations on the microzonation in Brussels)
Edouard Foriers (Action 1 n° MO/33/016)
Thierry Camelbeeck (Participated to the interpretation of the results and conducted the discussions to promote a project on seismic risk in Belgium)

A.3.5. Partnerships

List of national and international partners

- Faculté Polytechnique de Mons, Service Architecture et Urbanisme. Prof. Wilquin Hugues et Dr. Sabbe Alain
- Faculté Polytechnique de Mons, Groupe Mines et Géologie. Prof. Quinif Yves, Dr. Rorive Alain, Dr. Vandycke Sara, Ir. Kaufmann Olivier
  - Institut royal des Sciences Naturelles de Belgique, Dpt VII : Service Géologique de Belgique. Dr Xavier Devleeschouwer
- Cologne University, Department of Earthquake Geology, Allemagne. Mr. Bernd Weber
- Institute of Earthquake Engineering and Engineering Seismology, Section for Risk, Disaster Management and Strategic Planning, Skopje, RD de Macédoine. Prof. Goran Trendafilovski.
- Centre d'Etude des Risques Géologiques, Sciences de la Terre. Université de Genève, Suisse. Dr. Frischknecht Corine
  - Université McGill, Département de Génie civil et mécanique appliquée. Montréal, Québec, Canada. Prof. Luc Chouinard
  - Service Suisse de Sismologie, ETH, Zurich. Dr. Faeh Donat

Grants used for this research

projet « Chercheur supplémentaire »
projet ACTION 1 – MO/33/016 « Evaluation of site effects and local seismic hazard in Belgium »

A.3.6. Missions

Assemblies, symposia (number):	Philippe Rosset (5) Toon Petermans (1)
Field missions (days):	Philippe Rosset (10) Toon Petermans (10)

A.4. Present-day deformation

A.4.1. Objectives

Although idealized tectonic plates would be purely rigid, intraplate earthquakes reflect the important and poorly understood tectonic processes of intraplate deformation. To quantify the rigidity of North West Europe and how deviations from plate rigidity give rise to intraplate deformation and earthquakes, the section is conducting different experimentation and measurements. These measurements can provide also

valuable information on the postglacial rebound (PGR) effects in Belgium and on the present evolution of the mean sea level. The different parts of the project are described in the following.

1. To better constrain the present-day crustal deformations, absolute gravity measurements using the FG5-202 gravimeter are conducted along a profile twice a year since September 1999. This 140 km long profile includes 8 stations across the Belgian Ardenne and the Roer Graben. The bi-annual rate was chosen to detect problematic stations as fast as possible, seasonal effects and to improve SNR. During the profile, the FG5-202 calibration is controlled at the Membach reference station, where a superconducting gravimeter is continuously monitoring the gravity with a resolution of 0.1 μGal (1 μGal = 10 nm/s^2).
2. Slow crustal deformations are also monitored using GPS in Bree (Eastern Campine block) and Meeuwen (Roer Graben) since 1997 with the purpose to evidence and characterize the movements on the Feldbiss fault zone (in cooperation with ROB section 1).
3. In order to separate absolute and relative sea level trends we also perform AG measurements in Oostende yearly to monitor vertical land movements and therefore participate in the ESEAS project (European Sea Level Service).
4. Measuring crustal motion at the 1 mm/yr level still remains a challenge. Time-dependent displacements of stations are influenced by hydrological variations. To correct gravity data for these effects, their influence is being investigated at the Membach, Jülich, Vienna and CERGA (France) stations. The Membach experiment also contributes to investigate the influence of the water storage variations in small river basins on the time dependent gravity field. This work can also be essential to correct local effects that can mask regional effects such as changes in continental water storage. Local effects, indeed, could prevent the combination of satellite data (e.g. GRACE) with ground-based gravity measurements.
5. During the last decade, recent faulting activity was evidenced in different karstic networks in Belgium. In the northern part of the Rochefort cave, some walls are cut by three faults post-dating karstic events. To monitor this activity, a geophysical laboratory has progressively been installed in the cave from 1997. It includes 6 extensometers and 1 broad-band seismometer. We intend to determine if these faults are linked to tectonic structures at the crustal scale and to characterize the continuous or sudden behaviour of fault movements.

A.4.2. Progress and results

(1) At this present time, except for the station influenced by mining at Jülich, there is currently no detectable gravity rate of change larger than 1.3 μGal/yr. This is equivalent to an uplift of 6.5 mm/yr, using a deformational gradient of -0.2 μGal/mm. Other geodetic measurements were undertaken in 1997 in the Eastern Campine block and the Roer Graben. From geodetic measurements, it is still not possible to provide information concerning the characteristics of the deformation (seismic, partly aseismic or aseismic) in Campine, the Ardenne and the Roer Graben.

Contacts have been taken with the Working Group for Geodynamics of the Nordic Geodetic Commission, in order to include the Belgian AG time series in the study of the Fennoscandian postglacial rebound (PGR). The PGR models predict that Belgium is on the peripheral bulge of the PGR deformation. The peripherical bulge region of the crust is located at the edge of an ice load and goes up as the ice mass grows due to the transfer of mantle material from beneath the load to the edges. Predicted deformations at the peripheral bulge are poorly constrained by geodetic measurements. Moreover there are still significant uncertainties on the ice load, the timing of the ice history and the earth model which result in large uncertainties in the estimated rates of PGR. Therefore our AG data should help constraining models.

(4) We have investigated the hydrological processes and their influence on gravity at the underground Membach station (eastern Belgium), where absolute (AG) and superconducting (SG) gravity measurements have been performed since 1996. The gravity station was excavated in low-porosity argillaceous sandstone. Geophysical prospecting showed that the thickness of the weathered zone covering this bed-

rock can be highly variable between zero and 10 meters. To quantify the gravity effect induced by the hydrological variation above the Membach station, we used the time series from the soil moisture probes that were installed in 2004 in the shallow upper 60 cm partially saturated zone, 48 m above the SG. Using the inferred gravimetric water content, a digital elevation model and a spatial discretization of the weathered zone in rectangular prisms, the gravitational effect of the prisms on SG data was calculated and compared with the gravity effect inferred from a regional water storage model.

For the first time the influence of hydrological effects on gravity measurements has been quantified at the Membach station. The seasonal variations, as well as short decreases in gravity due to rainfall, were successfully modeled (Figure 9). The removal of the hydrological effects from the gravity signal improves our ability to monitor long-term gravity changes related to tectonics and the PGR.

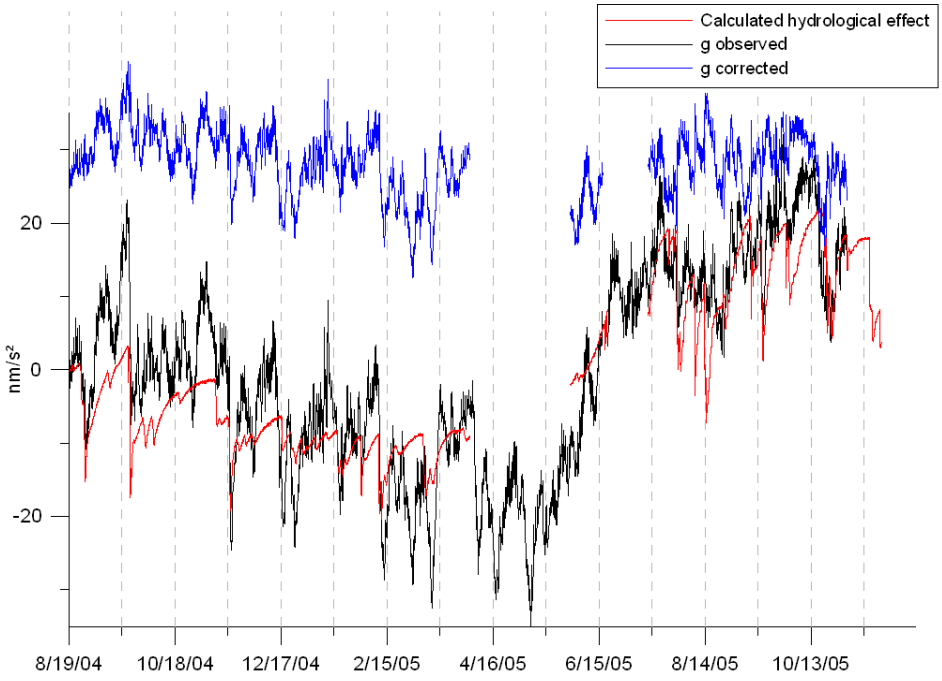


Figure 9: Gravity changes observed by the SG at the Membach station (black). The gravitational influence calculated using the soil moisture measurements is in red. Although some short variations are smoothed especially when the ground water content is high, the model is especially successful for removing the seasonal variation. In blue the SG time series after removing the modeled hydrological effect.

In 2005 a large part of the field experiments in Membach were performed by O. Crommen, in the framework of his master thesis.

We also collaborate with Bruno Meurers (University of Vienna) who investigated how far tidal analysis results can be improved when a rain fall admittance model is applied on the Vienna and Membach SG data. Step-like signals deteriorate the frequency spectrum estimates and tidal analysis. Using water load modelling constrained by high temporal resolution (1 min) rain data, we reduced by about 10 % the standard deviation of the residuals after tidal parameter adjustment in Vienna and Membach. Additionally, the rainfall admittance model is well suited to improve the correction of instrumental offsets when they coincide with step-like signals originating from rain water load. This method, however, is not suitable for long-period variations. In this case hydrogeological investigations like those performed around the Membach station must be preferred because the discharge processes have to be controlled by soil moisture and water table measurements.

(5) The instruments installed in the Rochefort laboratory have been maintained and continued to work efficiently. No specific movement has been detected on the monitored faults.

A.4.3. Perspective for next years

(1, 3) The profile is a long-term project. We plan to continue the profile twice a year up to 2009 at least; then, after 14-20 years, we should be able to constrain any possible long-term trend with accuracy better than 1 nm/s²/yr.

Measurements at the Oostende station will as usual occur on a yearly basis, and like the Ardenne profile, this is a very long-term project.

We plan to investigate the PGR effect on the Belgian AG time series.

(4) The investigations concerning hydrological effects on gravity will be continued in Membach, Jülich, Rochefort and Vienna.

(5) The long-term deformation measurements will be continued in the Rochefort cave.

A.4.4. Personnel involved

Scientific staff: Michel Van Camp (Project leader, responsible of the projects conducted with the absolute gravimeter)
Michel van Ruymbeke (Developed the extensometers, assumes their maintenance and analyses the collected data in the Rochefort cave)
Thierry Camelbeeck (Coordinates the project in the caves in relationship with the local authorities)

Technical staff: Marc Hendrickx
Stefaan Castelein
Aydin Ergen
Mr. Eric de Kerkhove (Voluntary technician, manages the data from the instruments in the Rochefort and Ramioul caves)
Mrs. R. Howard (Voluntary technician, participated in the analysis of cave data)

A.4.5. Partnerships

List of national and international partners

- Laboratoire de Géodésie et Géomatique, Le Mans : Dr. J. Nicolas
- Géosciences Azur, Sophia Antipolis : Dr J.-M. Nocquet
- ECGS/Université de Luxembourg : Prof. O. Francis, Dr T. van Dam
- Proudman Oceanographic Laboratory : Dr. S.D.P. Williams, Prof. T. Baker
- Prof. H.-G. Scherneck (Onsala Space Observatory), Dr. B. Pettersen (Norvegian University of Life Sciences) and the Working Group for Geodynamics of the Nordic Geodetic Commission.
- Dr M. Amalvict, J.-P. Boy, J. Hinderer and P. Gegout (EOST, Strasbourg)
- Dr O. de Viron (IPGP, Paris).
- Faculté Polytechnique de Mons – Prof. Yves Quinif
- ASBL Grotte de Lorette-Rochefort
- Prof. A. Dassargues (ULg/KUL)
- Prof. M. Vanclooster (UCL)
- Prof. B. Meurers (University of Vienna)
- Dr P. Meus (DGRNE, Division de l'Eau, MET)
- Prof. K.-G. Hinzen (University of Cologne)
- Dr E. Pomplun, Dr. E. Kümmerle and M. Möllmann-Coers (Forschungszentrum Jülich)

Grants used for this research

The Rochefort and the AG-profile projects were initiated with the help FRFC-NFWO projects but presently, no external financial support is available.

A.4.6. Missions

Assemblies, symposia (number):	M. Van Camp Name (14)
Commissions, working groups (days):	M. Van Camp (1)
Field missions (days):	M. Van Camp (53)
	M. Van Ruymbeke (5)
	E. de Kerkhove (5)
	M. Hendrickx (75)
	S. Castelein (27)

A.4.7. Scientific outreach

Meeting presentations

[1] **Van Camp, M.**
1. Gravimeters for seismological broadband monitoring: Earth's free oscillations
2. Introduction to the Earth tides
3. Uncertainty of absolute gravity measurements
Joint BGI/IAG/ICET Summer School on Microgravimetric methods: Static and Dynamic Aspects, Lanzarote, Canaries, Oct. 23-28, 2005.

[2] **Van Camp, M.**,
History of the Belgian seismic stations from 1898 until now
Belgian National Committee for Geodesy en Geophysics, Brussels, February 17, 2005, poster

B. OPERATIONAL PROJECTS FOR SCIENTIFIC RESEARCH AND EXPERTISE

In order to support its scientific research, its scientific expertise and to provide pertinent information to the public and the authorities, the section of seismology develops and maintains different tools. Their good working state is fundamental for the continuity of the different activities of the section.

B.1. Seismic and accelerometric networks – gravity measurements

B.1.1. Objectives

The section of seismology installed, maintained and analysed the data from the seismic and accelerometric Belgian networks and continued the long tradition of the ROB in gravity measurements by maintaining and analysing the data from the AG absolute gravimeter FG5 and the SG superconducting gravimeter in Membach. The maintenance and the optimal working of these equipments require a continuous attention from the personnel of the section. There is also a necessity to maintain the quality of the instrumentation in agreement with the world standards and to improve our capacity to exchange seismic data in real time with the international centres. In particular, the AG participates in numerous intercomparison campaigns and in calibrating and controlling relative gravimeters. Since 1997 the SG of Membach participates in the Global Geodynamics Project data base.

B.1.2. Progress and results

The accelerometric network is working correctly and checked thoroughly at the ORB once a week (Mol is checked twice a week). A new accelerometric station was installed Uccle (station Kriekenput: KKPA).

In 2005, the new data acquisition system under Linux developed at the ROB has been installed in 13 permanent stations of the Belgian seismic network. The quality of the seismic signals has been improved compared to the previous system. The working of the seismic network in 2005 is summarized in table 1, where the green cells correspond to periods for which data are available, the red cells to the period during

which the stations were out of order and the orange cells inform of some failures in the stations during this period. During this year, several stations, which did not work correctly, reworked on a permanent basis:

HEY (Heyd) – the problems linked to the Belgacom ISDN-lines have been finally solved;

ROB (Robertville) – Electrabel provided us the facilities to reinstall the station with an access to communication links;

SKQ (Steenkerque) – the station is more reliable since the change of the acquisition system;

WLF (Walferdange), KLB (Kalborn) and VIA (Vianden) – these two stations in Grand-Duchy of Luxemburg have been reinstalled properly.

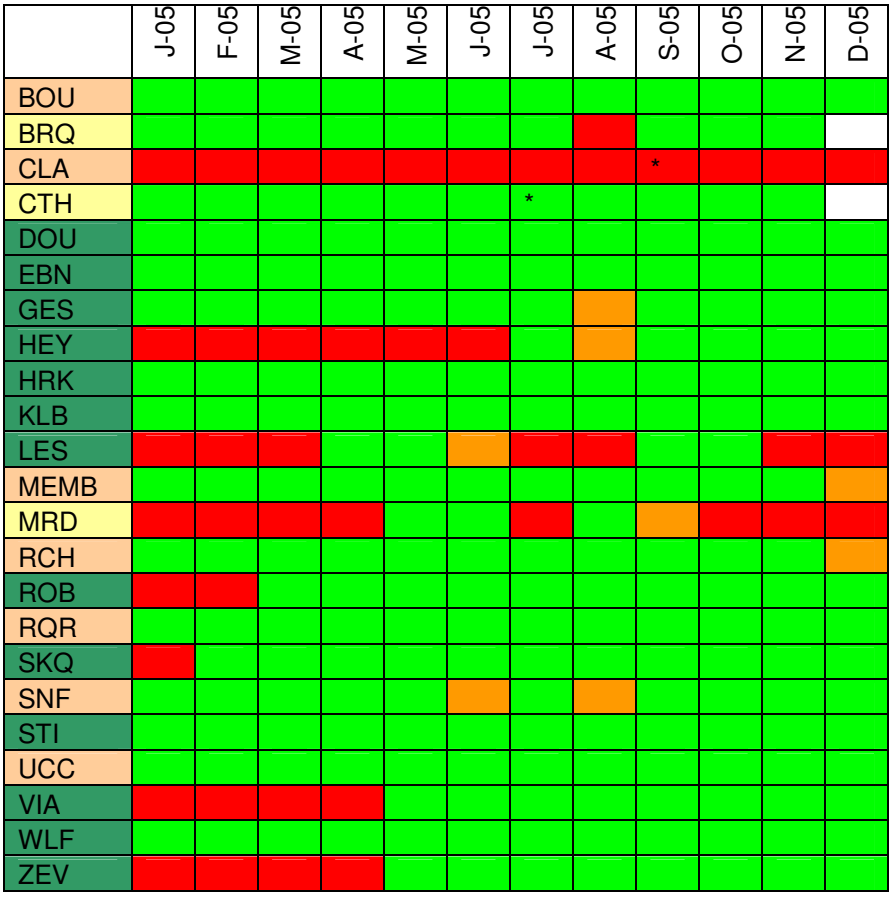


Table 1: Status of the 23 seismic stations of the Belgian network in 2005 (pink station are equipped with the previous generation of acquisition systems, yellow stations are equipped with mobile systems and dark green stations are updated Linux stations)

In 2005 many works were accomplished to improve the facilities at the Membach station:

- New data acquisition systems on the L4-3D seismometer and the C021 superconducting gravimeter;
- New environmental probes (inside and outside the station), connected to new data acquisition systems;
- A Quanterra Q330 data acquisition system was installed to send the data of the SG and of the Broadband seismometer to the IRIS and ORFEUS consortiums. Using the newly installed ADSL connection, these data are provided on-line at the Observatory and to IRIS and ORFEUS (the data can be seen live on http://www.iris.washington.edu/servlet/quackquery/budFileSelector.do?network=BE).

Providing the SG data to IRIS, necessary to provide SG data to seismologists, and downloading on-line seismic data to Brussels is a key factor in the operational project "seismic alert";

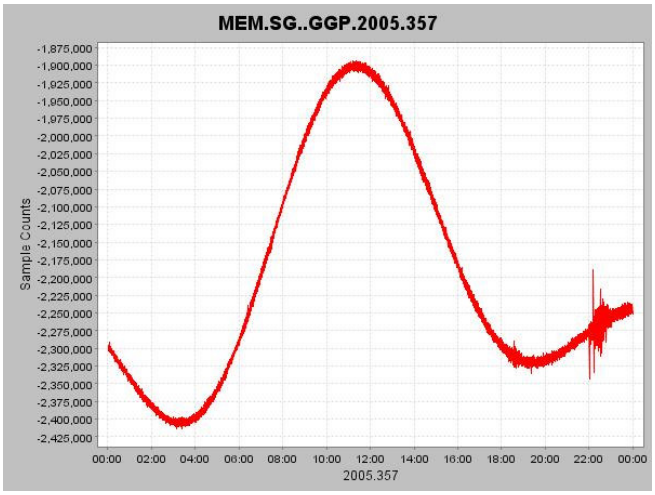


Figure 10: Example of the plot of the SG time series provided on the IRIS web page (http://www.iris.washington.edu/servlet/quackquery/budFileSelector.do?station=MEM&location=++&channel=GGP&network=SG)

- All the new systems are connected on a new UTP network;
- Upgrade of the 220 V installation (this includes a continuous monitoring this voltage).
- The transfer function of the superconducting gravimeter SG-C021 was controlled.

On request on the ECGS, the absolute gravimeter FG5-202 was compared to the Luxemburg FG5-216 in May 2005. The FG5-202 participated also in the International Comparison of Absolute Gravimeters (ICAG 2005) at the BIPM, Sèvres, France. In particular, as stated by the technical protocol of the 7th ICAG5 (decided by the Consultative Committee on Mass and Related Quantities Working Group on Gravimetry and the IAG Sub-Commission 2.1 "Gravimetry and Gravity networks" Study Group 2.1.1 on Comparison of Absolute Gravimeters), the gravimeters FG5-108 (BIPM) and FG5-202 monitored the gravity field during all the period of the absolute measurements. This allows one to apply the correction for possible changes in the gravity field.

Contacts have been taken with the Belgian Service of Metrology in order to designate officially the Royal Observatory as responsible for gravity in Belgium.

B.1.3. Perspective for next years

The accelerometers must be visited on regular basis for maintenance and/or repair. In 2006 two additional accelerometers will be installed: in Ans and Sart-Tilman (replacing old-fashioned Sig instruments).

The upgrading of the seismic network will be continued. Station CLA (Clavier) will be equipped with a new Linux system. Station MRD (Maredsous) has recurrent failures due to its temporary situation. We will study the possibility to install there a permanent station. The station of Opitter will be installed when the tests on the borehole seismometers and the whole instrumental system (including the WIFI part) will be done. The renovation works at La Chartreuse (Liège) will be conducted in 2006. After that, the seismic station will be reinstalled. In Membach, a reliable uninterruptible power supply will be installed to ensure availability of data in case of earthquakes.

As the absolute determination of the gravity is essential in geophysics and metrology, new intercomparison campaigns will take place in Luxemburg and possibly in other sites. We plan also to measure the transfer function of the SG located in Walferdange.

We will continue discussions with the Belgian Service of Metrology in order to be "designated institute" for measuring gravity. This will allow Belgium to claim a new "Calibration and Measurement Capability" in the field of "Mass and related quantities".

Finally we will continue to develop the Tsoft software and provide information to the public.

B.1.4. Personnel involved

Scientific staff: Thierry Camelbeeck (Responsible for operational problems linked to the seismic network)
Fabienne Collin (Provided an important help in this task)
Michel Van Camp (Assumes the responsibility for the accelerometric network and the absolute gravimeter FG5)

Technical staff: Giovanni Rapagnani, Baudouin Bukasa, Stefaan Castelein, and Henri Martin provided the technical expertise for the different stations (maintenance, repairing, material modifications, communication software problems...)
Marc Hendrickx (Assumed the maintenance and the analysis of the data from the superconducting gravimeter in Membach.
Marc De Knijf (ROB Technical service, maintenance of FG5)

B.1.5. Partnerships

List of national and international partners

- European Euro-mediterranean Seismological Center (Bruyères-le-Châtel, F)
- International Seismological Center (Newbury, UK)
- ORFEUS - Seismic section at the KNMI in De Bilt (The Netherlands): Dr. B. Dost and R. Sleeman
- Seismic station Bensberg of the Cologne University (Germany)
- Ecole et Observatoire des Sciences de la Terre à Strasbourg (France)
- Centre Européen de Géodynamique et de Séismologie in Walferdange (GD Luxembourg) : Prof. O. Francis.
- Bureau International des Poids et Mesures, France
- METAS, Switzerland: Dr. Philippe Richard
- IRIS (Incorporated Research Institutions for Seismology), USA: Tim Ahern and Rick Benson
- Jülich Forschungszentrum, Germany: M. Möllmann-Coers.
- Dr. J. Steim (Quanterra, USA)
- Kinemetrics, USA
- Micro-g-LaCoste, USA
- GWR instruments, USA
- Afdeling Waterwegen Kust, Oostende: Ir J. Verstraeten
- Proudman Oceanographic Laboratory, UK: Dr. S. Williams
- SPF Economie, Division Métrologie.

B.1.6. Missions

Assemblies, symposia (number): Fabienne Collin (1)

Field missions (days): Michel Van Camp (13)
Fabienne Collin (65)
Baudouin Bukasa (25)
Stefaan Castelein (24)
Giovanni Rapagnani (19)
Henri Martin (17)

B.2. Seismological database – website

B.2.1. Objectives

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 should become accessible on our website in the future. Another objective is to develop a website containing up to date information on earthquake seismology, on the seismic activity in northwest Europe and on the scientific activities of the section seismology.

B.2.2. Progress and results

Different aspects of the database have been developed in 2005:

- We develop the software allowing the daily monitoring of the working of the seismic stations, introducing simple procedures to determine the location and magnitude of earthquakes.
- Improvements have also been done concerning the introduction in the database of the daily seismic phase measurements.

The most significant improvement accomplished in 2005 is the replacement of our web pages by new ones (http://www.astro.oma.be/SEISMO/NEWSITE3/index.php?LANG=FR). These pages, written in Dutch, French and English, contain now the description of the activities of the section, a history of the seismology at the ROB and information on the Belgian seismic network. Part of the web is dynamic, including a seismological database for earthquakes in our regions and elsewhere in the world and the seismic activity in quasi real time with the visualisation of the high-frequency seismic signals from the stations Uccle and Membach.

In 2005, we also implemented quickly after their occurrence, specific web pages on the three following destructive earthquakes: 26 December 2004 and 28 March 2005 in Sumatra and 8 October in Pakistan.

B.2.3. Perspective for next years

An important objective for 2006 is to develop new software to do the different measurements on the seismograms. It will include all the facilities of the present DP-software, with a new graphical environment and it will allow the new phase measurements to be automatically implemented in the database.

Other software will be developed to automatically create readable output files from the historical seismicity database. This will allow P. Alexandre to control all the information introduced in the database.

The scientists of the section will also devote a part of their time to prepare texts on general aspects of seismology and concerning their works to be implemented in the web-site.

B.2.4. Personnel involved

Scientific staff:	Kris Vanneste (Assumed the management of the development of the website)
Technical staff:	Henri Martin (Responsible for the development of the database and the internet site)
	Frédéric De Vos (Wrote the software associated to the database and the website)
	Marc Hendrickx (Assisted in the management of the development of the website)

C. OPERATIONAL PROJECTS ON INTERNATIONAL DATA EXCHANGE AND THE SERVICE TO THE AUTHORITIES

C.1. Seismic alert

C.1.1. Objectives

When ground movements are felt by the population, it is important to quickly provide reliable information concerning their origin. The « Centre de Crise » of the FPS Home Affairs asked to receive as fast as possible (less than 1 hour after the event occurrence) confident information on the earthquakes or other events felt in Belgium. Presently, it is not possible for the ROB to realize this task during the night and the week-end. The main objective of the project is to improve this situation by realizing a seismic alert system based on the automatic detection of strong earthquakes by a real-time analysis of the seismic signals of the Belgian seismic stations.

C.1.2. Progress and results

In 2005, we prepared a proposal for the creation of an operational centre for the monitoring of the seismic activity and the evaluation of seismic risk. This proposal received the support of the Ministers of the Science Policy and of the Home Affairs. The first part of the project concerns the conditions to maintain the scientific and technical environment necessary to the well-working of the seismic network. The second part is dedicated to the minimal conditions to develop an efficient seismic alert system. Up to now, no support has been provided yet.

Independently of this proposal, we developed the procedures to monitor the seismic activity, including the relationships with our database and web pages, in a way compatible for the future development of an automatic seismic alert.

In 2004, the ROB technical service removed the old infrastructure inside the seismology house ("pavillon de séismologie") because this building is the most appropriate to install the Seismic Alert centre. A file to repair the seismology house has been introduced at the "Régie des bâtiments" but no work has been conducted in 2005.

C.1.3. Perspective for next years

Our activities will depend on the reaction coming from the SPP Science Policy and Home Affairs and the "Régie des bâtiments". An ACTION 1 proposal will be introduced in 2006 with the purpose of developing the automatic alert based on seismic signals.

C.1.4. Personnel involved

Scientific staff:	Thierry Camelbeeck managed the different parts of the project
	Michel Van Camp
	Kris Vanneste
Technical staff:	Henri Martin
	Giovanni Rapagnani (Rosetta plan)
	Marc DeKnijf (Technical service ROB)

C.1.5. Partnerships

List of national and international partners

The Crisis Center of the FPS Home Affairs

Visitors: 1

C.2. International seismic data exchange

C.2.1. Objectives

The international exchange of seismic data has a very long history at the ROB. A large part of the routine work of the section is dedicated to the measurements of arrival times, sense of motion, amplitude and period of ground-motions on the recordings by the Belgian seismic stations for the earthquakes occurring everywhere on Earth. The main objective of these measurements is to send them to the International Centres (EMSC, NEIS, ISC…) where the data from the stations worldwide are analyzed to furnish a global catalogue of earthquakes and phase arrival time models. A new objective is to provide also real-time seismic signals from some Belgian stations to the ORFEUS and IRIS centres.

C.2.2. Progress and results

In 2005, we recover all the delay accumulated on the measurements of local and nearby earthquakes. Thus, our seismic database has been completed. From January 2006, this will allow us to follow the seismic activity in Belgium and the surrounding regions with a delay not exceeding three days (after the week-ends) and to have quasi real-time information on our website. For teleseismic measurements, our delay will not exceed 6 months, which is an improvement over the previous years.

We established closer links with the Euro-Mediterranean Seismological Center for the procedures to exchange seismic measurements in routine, but also in urgency. For this cooperation, 2 stations received in an international code: BEBN for (Eben-Emael) and BCLA for (Clavier).

In 2005 much work has been done to provide a real-time exchange of seismic signals from the broadband seismometers in Uccle and Membach and the superconducting gravimeter in Membach to the ORFEUS and IRIS data centers (the data can be seen live on the IRIS web page - http://www.iris.washington.edu/servlet/quackquery/budFileSelector.do?network=BE). Providing the SG data to IRIS is a world première, necessary to provide SG data to seismologists.

The AUTODRM software has been adapted to the actual rules of data exchange between the server of the seismological section and foreign institutes

The computer program TESEO from the INGV (Rome, Italy) for the digitisation of historic seismograms has been studied and installed.

C.2.3. Perspective for next years

The routine procedures will have a delay not exceeding three and fifteen days for local and teleseismic earthquakes respectively.

The station Rochefort (RCH) will be equipped with a new system allowing real-time data transmission to the ORFEUS and IRIS centres.

C.2.4. Personnel involved

Scientific staff: Fabienne Collin assumed the responsibility for this operational project
Thierry Camelbeeck realized the daily measurements whereas Fabienne Collin measured the data which are late
Edouard Foriers conducted the measurements of local earthquakes which were late
Michel Van Camp devoted a part of his time to the technical aspects of the development of the on-line data transmission
Roland Verbeiren (software interventions)

Technical staff: William Vandeputte, Stefaan Castelein realized the daily measurements
Henri Martin, William Vandeputte, Frédéric De Vos and Giovanni Rapagnani developed the procedures.

C.2.5. Partnerships

List of national and international partners

- EMSC (Euro-mediterranean Seismological Center)
- ECGS in Walferdange (GD Luxemburg)
- KNMI in De Bilt (The Netherlands)
- Bensberg network from the Cologne University (Germany)
- IRIS
- ORFEUS

C.2.6. Missions

- **Assemblies, symposia (number):** R. Verbeiren (2)
- **Commissions:** R. Verbeiren (2)

D. Publications

D.1. Publications with peer system

[1] **Vanneste K.**, Radulov A., De Martini P., Nikolov G., **Petermans T., Verbeeck K., Camelbeeck T.**, Pantosti D., Dimitrov D. & Shanov S.
Paleoseismic investigation of the fault rupture of the 14 April 1928 Chirpan earthquake (M 6.8), southern Bulgaria
J. Geophys. Res. 111, B01303, doi:10.1029/2005JB003814 (published in 2006)

[2] Frischknecht C., **Rosset P.** and Wagner J.J.
Toward Seismic Microzonation—2-D Modeling and Ambient Seismic Noise Measurements: The Case of an Embanked, Deep Alpine Valley
Earthquake Spectra, 21, 635-651.

[3] Park, J., Song, T. R., Tromp, J., Okal, E., Stein, S., Roult, G., Clevede, E., Laske, G., Kanamori, H., Davis, P., Berger, J., Braitenberg, C., **Van Camp, M.**, Lei, X., Sun, H., Xu, H., and Rosat, S.
Long-period behavior of the 26 December 2004 Sumatra-Andaman earthquake from its excitation of Earth's free oscillations
Science, 308, 1139-1144.

[4] **Van Camp, M.,** Williams, S.D.P., and Francis, O.
Uncertainty of absolute gravity measurements
J. Geophys. Res., 110, B05406, doi:10.1029/2004JB003497, 9pp.

[5] **Van Camp, M.**, and Vauterin, P.
Tsoft: graphical and interactive software for the analysis of time series and Earth tides
Computers in Geosciences, 31(5) 631-640, 2005

[6] Francis, O., van Dam, T., Amalvict, M., Andrade de Sousa, M., Bilker, M., Billson, R., D'Agostino, G., Desogus, S., Falk, R., Germak, A., Gitlein, O., Jonhson, D., Klopping, F., Kostelecky, J., Luck, B., Mäkinen, J., McLaughlin, D., Nunez, E., Origlia, C., Palinkas, V., Richard, P., Rodriguez, E., Ruess, D., Schmerge, D., Thies, S., Timmen, L., **Van Camp, M.**, van Westrum, D. and Wilmes, H.
Results of the International Comparison of Absolute Gravimeters in Walferdange (Luxembourg) of November 2003
International Association of Geodesy Symposia Gravity, Geoid and Space Missions GGSM 2004, Vol. 129 Jekeli, Christopher; Bastos, Luisa; Fernandes, Joana (Eds.), XVI, 368 p, Springer-Verlag, pp 272-275.

D.2. Publications without peer system

[7] **Alexandre P.**, Kusman D., **Camelbeeck T.**
Le tremblement de terre du 18 septembre 1692 dans le nord de l'Ardenne (Belgique) – Impact sur le patrimoine architectural.
Actes des VIes Rencontres du Groupe APS: "Archéosismicité et Vulnérabilité. Environnement, bâti ancien et société" (Perpignan, 4-5.10.2002) (sous le direction d'A. Levret), 10 pp., CD-ROM édité par le Groupe APS, Perpignan, 2005.

[8] **Camelbeeck T.**
The seismology and physics of the Earth in the prevention of earthquakes: intraplate seismicity in NW Europe
Volume of the contact forum "Geodesy and Geophysics for the third millennium in Belgium", edited by E. Arijs & B. Ducarme

[9] Radulov A., **Vanneste K.**, **Verbeeck K.**, Shanov S., **Camelbeeck T.**, and Yaneva M.
Past seismicity of the fault activated during the April 18, 1928 earthquake according to data from a trench near Popovitsa, Southern Bulgaria
Geology and Mineral Resources, 6, 2004, pp. 13-20 (in Bulgarian)

[10] Yaneva M., Radulov A., Nikolov G., Shanov S., **Camelbeeck T.**, Nikolov N., Mitev A., Kostov K., **Vanneste K.** & **Verbeeck K.**
Geological records for paleoseismicity of Popovitsa fault in a trench near Popovitsa, Southern Bulgaria
Proceedings of the Annual Scientific Conference of the Bulgarian Geological Society, Sofia, 2004, pp. 107-109.

[11] **Vanneste K.**, **Verbeeck K., Petermans T., Camelbeeck T.,** Radulov A., Nikolov G., Yaneva M., Dimitrov D. & Shanov S.
Active fault studies in intraplate regions and the return period of large earthquakes
Abstract volume of the contact forum "Geodesy and Geophysics for the third millennium in Belgium", edited by E. Arijs & B. Ducarme, pp. 185-187.

[12] **Van Camp M., Vanneste K. & Camelbeeck T.**
The Sumatra earthquake recorded by the Belgian seismic network
Abstract volume of the contact forum "Geodesy and Geophysics for the third millennium in Belgium", edited by E. Arijs & B. Ducarme, pp. 185-187.

[13] Rosset **P., Petermans T., and Camelbeeck T.**
Evaluation of the local seismic hazard in Belgium
Abstract book of "Geodesy and Geophysics for the third millenium in Belgium", Brussels, October 13, 2 pp.

[14] **Rosset P.**, Barszez A.-M., **Camelbeeck T.,** Quinif Y., Sabbe A. and Wilquin H.
Mapping the local seismic hazard and its influence on built environment: case study in the Mons Basin (Hainaut, Belgium)
"Mobilité, Société et Environnement en cartes", Deuxième journée des géographes belges, Gent, November 9, Tome 2, SOBEG/BEVAS Ed., 305-312.

[15] **Rosset P., Petermans T.,** Devleeschouwer X., Pouriel F. and **Camelbeeck T.**
Identifying the influence of the local geology in case of earthquake for urban planning: case study in Brussels
"Mobilité, Société et Environnement en cartes", Deuxième journée des géographes belges, Gent, November 9, Tome 2, SOBEG/BEVAS Ed., 171-177.

[16] **Van Camp, M.**

Séismes géants et symphonie tellurique
Science Connection 9, 17-20, décembre 2005 + Dutch translation : Van Camp, M., 2005, Gigantische aardschokken en een symfonie van de aarde, Science Connection 9, 17-20, december 2005

D.3. Publications in press, submitted

[17] **Rosset P.** and Chouinard L., Puente A., Madriz R., Mitchell D., Adams J.
Estimation of site effect in Montreal; The influence of marine clay
submitted to the Canadian Journal of Civil Engineering, 15 pp.

[18] **Petermans T.,** Devleeschouwer X., Pouriel F. and **Rosset P.**
Mapping the local seismic hazard in the urban area of Brusssels, Belgium
Extended abstract for the International Association of Engineering Geology 2006, paper number 424.

[19] Nicolas, J., Nocquet, J.-M., **Van Camp, M.**, Boy, J.-P., Hinderer, J., Gegout, P., Calais, E., and Amalvict, M.
Seasonal effects on Laser, GPS, and Absolute Gravity vertical positioning at the OCA geodetic station, Grasse, France
Geophys. J. Int, submitted

[20] **Camelbeeck, T., Vanneste, K., Alexandre, P., Verbeeck, K., Petermans, T., Rosset, P., Everaerts, M., Warnant, R., and Van Camp, M.**
Relevance of active faulting and seismicity studies to assess long term earthquake activity in Northwest Europe
Continental Intraplate Earthquakes, Geological Society of America, S. Stein and S. Mazzotti (eds.), accepted, 2006.

[21] **Van Camp, M.** and Francis, O.
On the drift of a superconducting gravimeter, constrained by 113 absolute gravity measurements
J. Geodesy, submitted, 2006.

[22] **Van Camp**, M., Vanclooster, M., Crommen, O., **Petermans, T., Verbeeck, K.,** Meurers, B., van Dam, T., and Dassargues, A.
Local hydrological effects on the long-term gravity variation in Membach, Belgium
JGR, submitted.

[23] Fratepietro, F., Baker, T.F., Williams, S.D.P., and **Van Camp, M.**
Ocean loading deformations caused by storm surges on the north-west European shelf
GRL, accepted, 2006.

[24] Meurers, B., **Van Camp, M.** and Petermans, T.
Improvement of tidal analysis results by a priori heavy rain fall modeling
J. Geodesy, submitted.

D.4. Report, thesis, etc

[25] Crommen, O.
Etude de l'impact hydrologique sur les mesures de pesanteur réalisées à Membach, mémoire de fin d'étude ingénieur civil géologue
ULg, 2004-2005. Promoteur: A. Dassargues, co-promoteurs: **M. Van Camp**, M. Vanclooster.

[26] **Verbeeck K., Camelbeeck T.**
Fault activity in northwest Europe and its relationship to seismic activity
Report after 3 years of research for contract MO/33/011, 2004.

[27] **Verbeeck K., Petermans T.**
Geophysical Research visit Tanzania 2005

Report for the project: Geodynamical processes, erosion and sedimentation during the last 30.000 years in the region of the Tanganyika-Rukwa-Malawi Rif, western Tanzania, 2004.

[28] **Rosset P.**
Guidelines of used and developed tools for ambient noise analysis
Internal Report.

[29] **Rosset P.**
Guidelines of used and developed tools for probabilistic seismic hazard analysis
Internal Report.

[30] **Rosset P.**
Guidelines of used and developed tools for numerical analysis in one dimension
Internal Report.

[31] **Rosset P.**
Guidelines of used and developed tools for generation of synthetics time series (preliminary version)
Internal Report.

[32] **Rosset P.**
Impact d'un grand tremblement de terre régional sur la région de Bruxelles ; Influence de la géologie locale
Dossier d'information.

[33] **Rosset P.**
Besoins d'une évaluation de l'impact d'un grand tremblement de terre régional sur le Bassin de Mons
Dossier d'information.

DEPARTMENT 1: Reference Systems and Geodynamics

SECTION 3: Gravimetry and Earth Tides

Introduction

Evolution of space techniques requires urgently ground based monitoring to constrain models. Geophysics becomes one of the applied sciences concerned at maximum with the future of humanity. Climatic changes, aquifers monitoring, seismic risks on very crowded area, civil protection interfacing, education by geosciences experimental methods, definition of the space and time references justify that researches on the gravitational field of the Earth in its static and dynamic aspects, remain a priority in an institute like ROB. Tidal gravity signal treatment could meet some geodynamics purposes.

A. Gravimetry

A.1. Gravity Field Monitoring in Belgium and abroad

A.1.1. Objectives

This research theme is meant:

- To interpret the gravity and magnetic anomalies for a better understanding of the tectonic settings in specific areas,
- To monitor long term gravity changes by field observations and relate them with geophysical or geological phenomena.

A.1.2. Progress and results

M. Everaerts has written a final paper describing the work done on the geoid calculation **[6][7]**. Additionally has been collaborated with the IFE of Hannovre to calculate the new European geoïd.

In the frame of action 1 project "Analysis of gravimetric and magnetic potential fields", the following software developments have been achieved:

- In areas with a rugged topography, classical Bouguer anomaly maps are spoiled by false anomalies. To avoid that, terrain corrections must be applied so that gravity data can be interpreted correctly. To solve this problem, a terrain correction program has been implemented.
- A method based on wavelet transforms, allowing characterising the geometry of the source without a-priori hypotheses has been implemented. On a test profile encouraging results have been obtained (Figure 11).

B. Ducarme and M. Everaerts finished in 2005 the monitoring of the of a high precision gravity network in the East of Belgium in the framework of the HARD project for the GPS monitoring of ground motion in the Ardennes-Eifel massif. The goal was the determination of seasonal gravity changes that could be associated with underground water fluctuations and eventual vertical ground motion in ten GPS sites. Between 2003 and 2005 we performed five campaigns in spring or in autumn. The simultaneous use of 2 gravimeters allowed to get a precision close to 5µgal (50 nms-2). It means that gravity variations should exceed 10µgal to be detected. Such variations have been found only around Mont Rigi, where the peat-moss can store water after heavy rainfall. Interesting correlations have been found between GPS height and rainfall. A poster has been presented at the EGU meeting and a paper is submitted for publication in the proceedings **[4]**.

In 2004 a gravity network has been established in the area of Plovdiv in Bulgaria. The aim was to establish a detailed gravity Bouguer map of the area. A second gravity campaign has been carried out by M. Everaerts in spring 2005. The result of the two campaigns has been presented at the EUG in Vienna. To

have additional constraints to interpret the data, a magnetic campaign has been carried out in autumn 2005 and profile of 200 km has been measured. This will help to understand the tectonic setting of the area.

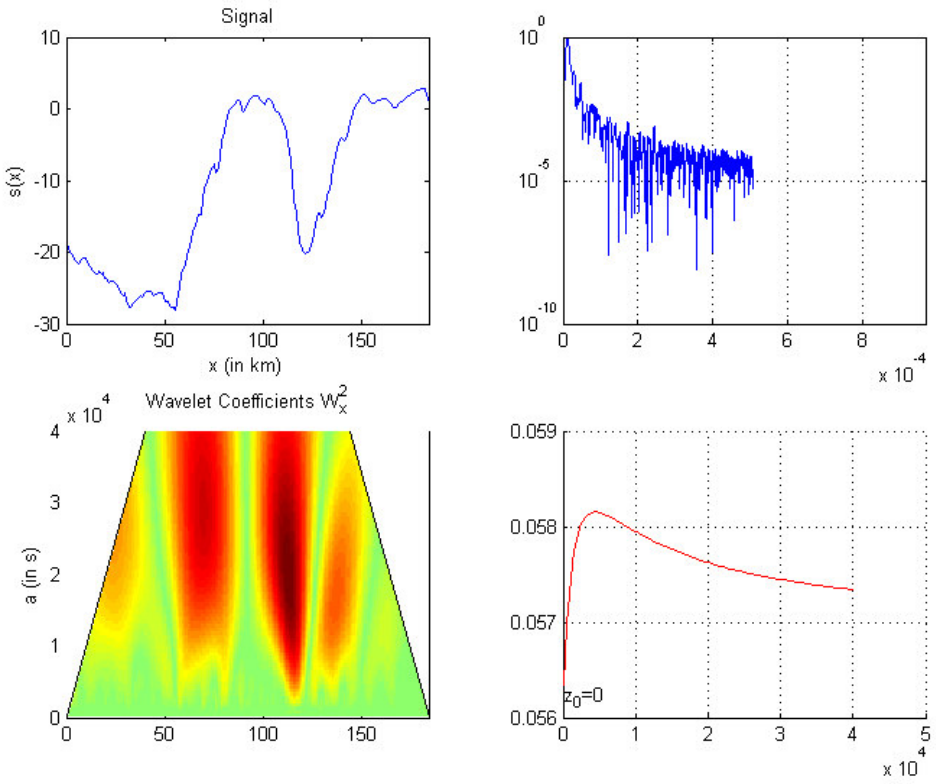


Figure 11: Gravimetric profile from the French border, south of Mons, till north of Gent
Upper left: gravimetric signal of the negative anomaly (x=km, y=mGal)
Upper right: Fourrier spectrum of the signal (x=cycle/m, y=log E (energy))
Lower left: Wavelet transform: only the maxima are significative (x=km, y=altitude)
Lower right: Uncertainty on the tested depth (x=km, y= uncertainty)

A.1.3. Perspective for next years

- The analysis of the gravity and magnetic anomalies for Belgium and the surrounding countries will be continued in collaboration with different Belgian and foreign universities and institutions. New versions (3D) of the wavelet transform software will be installed and used to arrive at a final interpretation.
- A convention will be signed in 2006 with the Walloon Region to include the sites of the WALCORS GPS network in the Belgian Gravimetric Base Network BLGBN98. The pillar supporting the antenna is adapted to gravity measurements. For Geodetic purposes this new network will insure the collocation of two complementary techniques. Moreover the integrity of these sites is guaranteed. 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.Two campaigns are scheduled in 2006 and two in 2007, in collaboration with the National Geographic Institute, to include the WALCORS points in BLGBN03 and detect eventual seasonal variations. Reiteration of the

network is planned after 5 years. This new gravity network could be connected later on to the FLEPOS and GPSBRU.

- Gravity investigations in the Plovdiv area in Bulgaria will be continued in collaboration with the Bulgarian Institute for geodesy.

A.1.4. Personnel involved

Scientific staff Michel Everaerts (Project leader)
Bernard Ducarme (FNRS Research associate)

A.1.5. Partnerships

List of national partners

- NGI (Belgian National Geographic Institute, Geodesy Department), Mr. Ph. Lambot
- ULg (University of Liège, Dept. of Physical Geography and Quaternary), Prof. A. Demoulin
- BGS (Belgian Geological Survey, departement of the KBIN), Dr Piet Laga, Dr W. De Vos
- UCL (Université de Louvain-la-Neuve), Prof D. Laduron
- ULB (Université Libre de Bruxelles), Prof A. Herbosch
- ULg (University of Liège, Departement og geology), Prof Poty
- FPMs (Facultés Polytechniques de Mons), Dr M. Hennebert
- UG (Ghent Universiteit), Prof J. Verniers
- KULeuven (Katolieke Universiteit Leuven), Prof N. Van Den Berghe, Prof M. Sintubin

List of international partners

- Ecole et Observatoire de Sciences de la Terre (EOST), Strasbourg, France
- NGI France
- Musée d'Histoire Naturelle du Grand Duché de Luxembourg »
- Bulgarian Academy of Science

Grants used for this research

Action 1 grant from FSP

A.1.6. Publications

A.1.6.1. Publications in press, submitted

[1] Minguely, Mansy, **Everaerts**, Manby, Averbuch
Apport de la modélisation géophysique pour la compréhension de la structuration du Pas de Calais
Comptes rendus Geoscience 2005 - Volume 337 - Numéro 3

[2] Duquenne H., **Everaerts M.**, Lambot Ph.,
Merging a Gravimetric Model of GPS/Levelling data: an example in Belgium
Proceedings of the IAG Symposia, 129, p 131-136, 2005

[3] Duquenne H., **Everaerts M.**, Lambot Ph.,
Gravimetrie, geoïde et nivellement par GPS en Belgique
Revues x,y,z n°105 4e trimestre 2005 p31-38

[4] Demoulin A., **Everaerts M., Ducarme B.**
Seasonal height changes Influence in GPS and gravimetric campaign data
Journal of Geodynamics, submitted

A.1.7. Scientific outreach

Meeting presentations

[5] M. Everaerts, D. Dimitrov, Th. Camelbeeck
Gravity campaign in the Chirpan - Plovdiv area south of Bulgaria
European Geoscience Union à Vienne 24-29 avril 2005, poster

[6] **M. Everaerts, B. Ducarme**, A. Demoulin
Joint analysis of GPS and Gravity seasonal variations in eastern Belgium
European Geoscience Union à Vienne 24-29 avril 2005, poster

[7] **M. Everaerts**, Ph. Lambot
Field gravity measurements and their use in Geodesy and Geophysics
Earth Sciences day of the CNBGG `Geodesy and geophysics for the third millennium´, Belgian Academy of Sciences, October 13, 2005, poster

Seminars, lectures

[8] **M. Everaerts**
Ecole francophone sur le Géoïde
Summer school IGNF, Paris, 28/06-01/07

[9] **M. Everaerts**
Summer school on micro-gravimetric techniques
Lanzarote, Canary Islands 19/10-29/10

[10] **M. Everaerts**
The sedimentary basin dynamics
Seminar/lecture in the frame of the DEA in the department of geology in Lille University, 22/11

A.1.8. Missions

Assemblies, symposia (number):	M. Everaerts (2)
Commissions, working groups (days):	M. Everaerts (1)
Field missions (days):	M. Everaerts (45)
	B. Ducarme (5)

B. Earth Tides

B.1. Global and Regional Earth Tides Studies

B.1.1. Objectives

Interpretation of global earth tides observations with emphasis on the fine spectrum of the tidal waves, the determination of the liquid core resonance effect (NDFW) in the diurnal spectrum and the detection of the effect of the polar motion on gravity. For that purpose the global network of superconducting gravimeters (SG), known as Global Geodynamics Project (GGP), is used principally.

Gravimeters, clinometers and strainmeters are also used to monitor interactions between ground deformation, tidal signals and meteorological parameters.

B.1.2. Progress and results

B.Ducarme finalized 4 papers for the “Proceedings of the 15th International Symposium on Earth Tides”, which have been published in a special issue of the Journal of Geodynamics, “Earth Tides and Geodynamics: Probing the Earth at Subseismic Frequencies”, vol. 41, 1-3, 2006.

B. Ducarme extended his study of the gravity pole tide to the influence of the ocean pole tide on gravity in collaboration with Mr. Chen from the Institute of Geodesy and Geophysics of the Chinese Academy of Sciences. Preliminary results have been included in the paper published in Journal of Geodynamics on the estimation of the pole tide gravimetric amplitude factor. New results based on a more sophisticated model of the ocean pole tide will be presented at the next GGP meeting in Jena (March 2006).

In collaboration with Prof. A. P. Venedikov (Institute of Geophysics, Bulgarian Academy of Sciences) and Mr. Daniel S. Costa (Escola Politécnica, Universidade de São Paulo, Brasil), B. Ducarme applied the program VAV04 for the analysis and prediction of ocean tides to a 50 years tide gauge records from Cananéia (Brasil).Together with a precise determination of the tidal waves derived from the tidal potential, the shallow water components and the radiation waves, they were able to extract very long period components such as the ocean pole tide or an 11 year periodicity in perfect opposition with the solar cycle represented by the "Wolf number". These very long records allowed also the determination of the mean sea level variations. The observed value 0.511□0.006 cm/year is much larger than the mean value on the Brazilian coast. Three years of GPS observations from the same site show indeed a subsidence of the ground of 0.38□0.11 cm/year. It is thus a local effect. A paper presented at Symposium G3 at the joint IAG/IAPSO meeting "Dynamic Planet" in Cairns (Australia) has been accepted for publication.

The project "Earth Tidal Observations in Siberia" sponsored by the S&T bilateral cooperation agreement between Belgium and Russia (convention BL/33/R09) came to its end. Four stations have been occupied: Novosibirsk, Talaya, Khabarovsk and Yuzno-Sakhalin. The publication of the results is in progress **[6]**.

After positive results concerning the tidal triggering obtained for the Baïkal Lake seismic data bank, we try to understand prior conclusions. Significant relationship between seismic activity and tidal modulation was detected in China and Romania data banks. The main objective consists to decrypt how local geological patterns are related to the observed tendencies. Considering promising statistical tools adapted to the huge number of events recorded with modern instruments, we confirm interests for seismic activity forecasting, to relate results with ground deformation monitoring (GPS, gravity field ...). We enlarge our collaboration on that topic with Chinese Earthquakes administration and the Romanian academy of sciences.

B.1.3. Perspective for next years

The modeling of the ocean pole tide effects on gravity will be continued for all the GGP stations with more than 5 years of observation. In collaboration with colleagues from the GeoForschungZentrum Potsdam we shall recompute the long period waves and the pole tide contribution in the GGP records using a 3D model for the atmospheric pressure correction.

We shall perform a re-analysis of the tide gauge records at Oostend using the program VAV.

B.1.4. Personnel involved

Scientific staff	Bernard Ducarme (FNRS Research associate)
	Michel van Ruymbeke
	Michel Everaerts
Technical staff	Leslie Vandercoilden

B.1.5. Partnerships

List of national and international partners

- Institute of Geodesy and Geophysics of the Chinese Academy of Sciences
- Institute of Geophysics, Bulgarian Academy of Sciences
- Escola. Politécnica, Universidade de São Paulo, Brasil

Visitors: 3

B.1.6. Publications

B.1.6.1. Publications with peer system

[1] Sun H.P., **Ducarme B.**, Xu H.T., **Vandercoilden L**., Xu J. Q., Zhou J.Q.
Adaptability of the ocean and earth tidal models based on global observations of the superconducting gravimeters
Science in China series D, 35(7):649-657.

[2] Timofeev V.Y., **van Ruymbeke M**., Woppelmann G., **Everaerts M.,** Zapreeva E.A., Gornov P.Y., **Ducarme B.**
Tidal gravity observations in Eastern Siberia and along the Atlantic coast of France
Proc. 15th Int. Symp. On Earth Tides, Journal of Geodynamics, 41, 30-38

[3] Arnoso J., Benavent M., **Ducarme B**., Montesimos F.G.
A new ocean tide loading model in the Canary Islands region
Proc. 15th Int. Symp. On Earth Tides, Journal of Geodynamics 41, 100-111

[4] **Ducarme B.**, Venedikov A.P., Arnoso J., Vieira R.
Analysis and prediction of ocean tides by the computer program VAV
Proc. 15th Int. Symp. On Earth Tides, Journal of Geodynamics 41, 119-127

[5] **Ducarme B.**, Venedikov A.P., Arnoso J., Chen X.D., Sun H.P., Vieira R.
Global analysis of the GGP superconducting gravimeters network for the estimation of the pole tide gravimetric amplitude factor
Proc. 15th Int. Symp. On Earth Tides, Journal of Geodynamics 41, 334-344

B.1.6.2. Publications without peer system

[6] Timofeev V. Y., Ardukov D. G., Gribanova E. I., **Ducarme B., van Ruymbeke M.**, Masalskii O. K.
Strain measurements of earth crust in south-western Baikal rift (in Russian)
Proceedings on the 2nd International Symposium "Active Geophysical monitoring of Earth lithosphere, 12-16 September 2005, Novosibirsk Siberian Branch of Russian Academy of Science (SB RAS), 190-195

[7] **Ducarme B., van Ruymbeke M.**, Venedikov A.P., Arnoso J., Vieira R.
Polar motion and non tidal signals in the superconducting gravimeter observations in Brussels
Bull. Inf. Marées Terrestres, 140, 11153-11171

B.1.6.3. Publications in press, submitted

[8] **Ducarme B.**, Venedikov A.P., de Mesquita A.R., De Sampaio França C.A., Costa D.S., Blitzkow D., Vieira R., Freitas S.R.C.
New analysis of a 50 years tide gauge record at Cananéia (SP-Brazil) with the VAV tidal analysis program
Accepted for publication in Journal of Geodesy

[9] El Wahabi A., **van Ruymbeke M., Ducarme B.**
Precursory signal of the 1995 eruption of Mount Etna detected by continuous gravity observations
Submitted for publication

[10] **Ducarme B.**, Sun H.-P., Xu J.-Q.
Determination of the Free Core Nutation parameters from the tidal gravity observations of the GGP superconducting gravimeters network
Submitted for publication in Journal of Geodesy

[11] Cadicheanu N., **van Ruymbeke M.**, Zugravescu D., **Everaerts M.** and Howard R.

An attempt to detect periodical tendencies in Vrancea seismic activity by the HiCum stacking method
Submitted for publication to the Academy of Sciences of Romania

[12] Zhu P., van Ruymbeke M., Howard R. & Li H.
Tidal and non-tidal influences on seismic activity in China
Journal of Geodesy and Geodynamics (Wuhan 430071, China), Vol.25 N°2, in press

B.1.7. Scientific outreach

Meeting presentations

[13] **Ducarme B.:** 1 oral presentation, 1 poster
Monitoring and Understanding a Dynamic Planet with Geodetic and Oceanographic tools,
Dynamic Planet 2005: Cairns, QLS, Australia, 22-26/08/2005

[14] **Ducarme B.:** 1 invited lecture, 1 poster
Geophysical Information about Processes in the Earth Core
2nd National Scientific Conference « Earth Inner Core" Moscow, Russia, 16-17/11/2005

B.1.8. Missions

Assemblies, symposia (number): B. Ducarme (2)

B.2. The International Center for Earth Tides (ICET)

B.2.1. Objectives

The terms of reference of the International Centre for Earth Tides (ICET) are:

- to collect all available measurements on Earth tides as World Data Centre C;
- to evaluate these data by convenient methods of analysis in order to reduce the very large amount of measurements to a limited number of parameters which should contain all the desired and needed geophysical information;
- to compare the data from different instruments and different stations distributed all over the world, evaluate their precision and accuracy from the point of view of internal errors as well as external errors;
- to build a data bank allowing immediate and easy comparison of earth tides parameters with different Earth models and other geodetic and geophysical parameters ;
- to ensure a broad diffusion of the results and information to all interested laboratories and individual scientists.

B.2.2. Progress and results

Since 1997 ICET is the scientific responsible of the "Global Geodynamics Project-Information System and Data Centre" (GGP-ISDC, http://ggp.gfz-potsdam.de/). The data owners can upload themselves the original minute sampled data. The data are carefully preprocessed at ICET using a standard procedure, to correct for tares and spikes. The data are then decimated to one hour and analyzed. The analysis results are directly communicated to the data owners. This follow up is required to detect quickly the anomalies that could affect the data. Each year CD-ROM's are edited with the raw and corrected minute data as well as the log files and the auxiliary data, when available. In 2005 B. Ducarme edited the CD-ROM's ETGGP#7 and ETGGP#7a with the data from July 2003 till June 2004.

The "Bulletin d'Information des Marées Terrestres" (BIM) n° 140 was printed in 300 copies. Some 275 copies are sent to libraries and individual scientists all over the world. It is devoted to scientific papers concerning tidal research.

ICET made an agreement with Marion Wenzel, wife of late Prof.H.G.Wenzel, who inherited the property rights on the ETERNA tidal analysis and prediction software. ICET is now allowed to distribute freely this software among the scientific community for non commercial purposes. This initiative met a great success as some 15 CD-ROMS with ETERNA software were requested from ICET in 2005.

The ICET website (http://www.astro.oma.be/ICET/) has been updated and developed. Besides general information including historical aspect and last ICET reports, it proposes to the visitors an access to:

- the general bibliography on Earth Tides from 1870-1997 either by alphabetical order of the first author or following the decimal classification introduced by Prof. P.Melchior;
- the table of content of all the BIM issues, and starting from BIM 133 an electronic version of the papers;
- various tidal analysis and preprocessing software available from different websites or on request from ICET. The VAV tidal analysis software has been recently uploaded;
- the ocean tides loading computations for all the tidal stations.

ICET welcomed in 2005:

- Mr. Daniel S. Costa (Escola. Politécnica, Universidade de São Paulo, Brasil), Prof. A.P.Venedikov (Institute of Geophysics, Bulgarian Academy of Sciences and Mr. X.D. Chen (Institute of Geodesy and Geophysics, Chinese Academy of Sciences, Wuhan).
- Mr. Costa stayed three months for training on tidal preprocessing and analysis method. He worked mainly on tidal gravity and oceanic data from Cananéia station (SP, Brasil)
- Prof. Venedikov worked six weeks at ICET (April-May) to prepare a paper on the analysis of ocean tides data at Cananéia.

ICET took part to the preparation of the summer school on "microgravimetric methods: static and dynamic aspects", which took place in Lanzarote (Canarias) from October 24 to 28, 2005.

B.2.3. Perspective for next years

ICET will continue to perform the tasks corresponding to its terms of reference, essentially by the diffusion of information and software, the scientific responsibility of the GGP data bank, the data processing, the training of young scientists and the welcome of visiting scientists.

The Centre will continue to develop its website. The content of its data bank will progressively become available on the net.

B.2.4. Personnel involved

Scientific staff Bernard Ducarme (FNRS Research associate)
Technical staff: Leslie Vandercoilden

B.2.5. Partnerships

List of national and international partners

- Global Geodynamics Project - Consortium

Visitors: one trainee and two guest scientists

B.2.6. Publications

B.2.6.1. Publications with peer system

B.2.6.2. Publications without peer system

[1] **Ducarme B.**, **Vandercoilden L.**
Global Geodynamics Project: CD-ROM ETGGP #7

International Centre for Earth Tides

[2] **Ducarme B.**, **Vandercoilden L.**
Global Geodynamics Project: CD-ROM ETGGP #7A
International Centre for Earth Tides

B.2.7. Scientific outreach

International responsibilities

- Director International Centre for Earth Tides: **B. Ducarme**

B.2.8. Missions

Commissions, working groups (days): B. Ducarme (2)

C. Geophysical Instrumentation

C.1. Gravimetric & Earth Tides Instrumentation

C.1.1. Objectives

The expertise of the ROB in terms of instrumental gravimetry and earth tides is unique by the variety of domains concerned. Since the beginning of the world tidal gravity profile, initiated by Prof. P. Melchior in 1980, a lot of metrological problems have been overcome related to the setting and calibration procedure, environmental effects, standardization of the maintenance and data treatment, etc. Special attention is paid to the problems induced by water in the ground deformation (aquifers, oceanic tides, cave water flow, rain effects on climate, etc).

C.1.2. Progress and results

The tidal station of Chizé was dismantled and the gravimeter LCR1006 transferred to ROB.

Using the original ROB inertial platform of calibration of gravimeters, M. van Ruymbeke obtained improvement in the scale factor determination. It helps to fix the real amplitude of tidal components to constrain theoretical models of tidal modulation. In 2005, a new design of the inertial platform mechanics shows a 0.1% level of confidence reached for the gravimeter scale factor. Participation to the Inter comparison Campaign of Absolute Gravimeter at the Bureau International des Poids et Mesures (BIPM) in Paris, was the occasion to control scale factor of the LaCoste&Romberg gravimeter LCR336 on absolute gravimeter network.

C.1.3. Perspective for next years

We aim to integrate our inertial platform in the Gravilux project (GDL) and move this original device in the Underground Laboratory of Walferdange (Gr.-D. of Luxembourg), being the best place for this device. By simultaneous records with a LCR gravimeter on the platform and a superconducting gravimeter, it is an effective alternative to the super conducting gravimeter network calibration, simplest than the expensive comparison with absolute gravimeter.

In addition the second prototype of gravitational balance could be evaluated by Sebastien Naslin in vsimilar conditions in Walferdange laboratory to fix real limits of the instrument developed in the EDAS laboratory.

New Maximum Voltage Retroaction electrostatic feedback control and micro-temperature sensor adapted to the LC&R gravimeters, could precise long period tidal & non-tidal parameters. New multi parameters sensors are suitable for the understanding of interactions with gravitational field.

C.1.4. Personnel involved

Scientific staff: Dr M. van Ruymbeke (Manages the laboratory)
Dr M. Everaerts (Partner for the geological interpretation of analysis results)
Technical staff: Mr. Fr. Renders

C.1.5. Partnerships

- The Maximum Voltage Retroaction electronics designed at ROB is used in many LaCoste&Romberg gravimeters. Since thirty years, we assume the installation inside gravimeters, the validation of the system and the training of the users. More than 25 LC&R from various groups of Belgium, France, Spain, Italy, Greece, Great-Britain, Finland, Algeria, Mexico, Costa-Rica, Brazil are included in the collaboration.
- In 2005, we modified the two gravimeters in charge of the monitoring of the Vesuvius & Campi flegrei (Napoli) and we solved recurrent problems of a gravimeter for the IPGParis.

C.1.6. Publications

C.1.6.1. Reports, thesis, etc

[1] **M. van Ruymbeke, S. Naslin**, M. Redmann,
Determination of the scale factor of gravimeters using inertial forces induced with a lift
Report presented at the meeting at the BIPM during the ICAG2005 meeting (Sept.19,2005)

[2] M. Redmann (TFE ISIB)
Amelioration et modernisation d'un générateur de micro-accelerations en métrologie gravimétrique (170pp)

C.1.7. Scientific outreach

Meeting presentations

[3] **M. van Ruymbeke, S. Naslin**, M. Redmann
Determination of the scale factor of gravimeters using inertial forces induced with a lift
Poster presented to the Forum organized at the Belgian Sciences Academy for the 175th anniversary of Belgium (October, 13th, 2006)

Meeting organization

- A Summer School of IAG/BGI/ICET on: "Micro-gravimetric methods: static and dynamic aspects" was organized by BGI and ROB between October 23-28, 2005 in the "Casa de los Volcanes" belonging to the Cabildo Insular of Lanzarote, Canaries Archipelago. The local committee was chaired by J.-P. Barriot and **M. van Ruymbeke**. ROB was represented by **M. van Ruymbeke, M. Van Camp and M. Everaerts** as invited Professors.

C.1.8. Missions

Assemblies, symposia (number): M. van Ruymbeke (1)
Field missions (days): M. van Ruymbeke (26)

C.2. Gravitational balance

C.2.1. Objectives

The project aims to use our metrological expertise (EDAS) and our Earth tide instrumentation know how to design a new kind of gravitational balance dedicated to "G" measurement.

As an alternative to torsion balance experiments, an astatic vertical pendulum is used. Its specific design should eliminate the main source of error in current experiments and should provide considerably different systematic uncertainties.

C.2.2. Progress and results

- An astatic vertical pendulum (Figure 12) has been developed where the earth's gravitational field provides the main contribution to the restoring force of the pendulum. The mechanical contribution of the suspension is then very low and can be adjusted with a high accuracy. This geometry provides only one degree of freedom of movement and a low sensitivity to micro seismic acceleration.
- A specific mass geometry has been used minimizing the sensitivity of the gravitational force to the test mass coordinates.
- The gravitational force induced by the change of the attractive masses position can be calibrated by two independents ways:
  - in free deflection mode using the transfer function of the gravitational balance.
  - in feed-back loop mode where electrostatic forces are applied in order to keep the test mass at same position.

These electrostatic forces can be precisely related to fundamentals physical units.

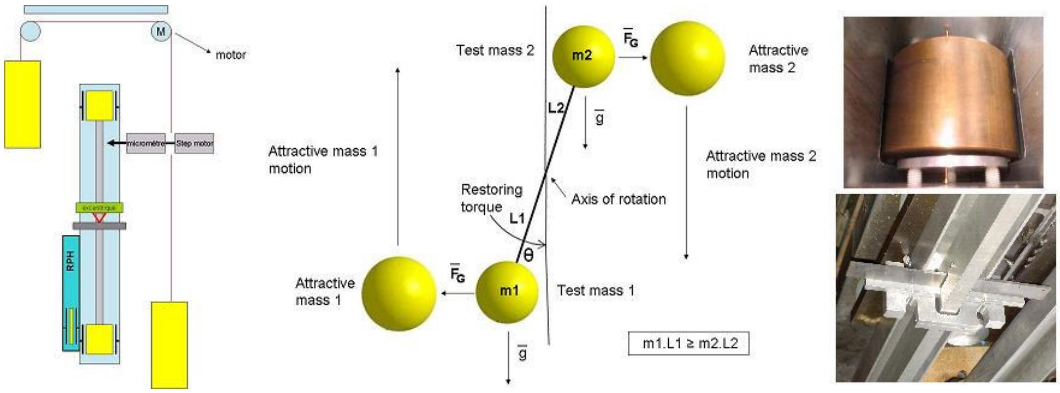


Figure 12: Schematic principle and picture of our Astatic vertical pendulum

Compare to our former horizontal pendulum, this new geometry provides a very good signal to noise ratio and already allows us to improve our calibration process at the level of 1E-8 Newton with electrostatic forces.

Numerical simulation

In parallel with our balance experiments, a virtual gravitational balance has been numerically simulated, enabling to compare real and virtual signals, which allows to:

- Validate the physical principles associated with our apparatus.
- Provide information which helps to understand the reaction of our apparatus to a variety of effects.
- Adjust the different parameters such as feed-back regulator or electrostatic damping and test different configurations before applying them to the real balance.
- Validate the procedure of data treatment.

Feed-back regulator

A theoretical study has been started to replace our previous push pull regulator by a PID regulator. The high Q factor of our apparatus involves to develop specific methods (normalized polynomials method with adjustable damping coefficient) to determine the PID's parameters. Our first numerical simulation provides very good results, close to critical damping.

Non spherical mass computation

Custom software has been designed to compute the gravitational force for any mass geometry. Additional softwares have been developed to optimize mass geometry with objective criteria.

C.2.3. Perspective for next years

- Continue to improve our calibration process on the astatic vertical pendulum and to point out the contribution of all disturbances that may affect our gravitational balance.
- Theoretical and experimental studies of flexure joints instead of knives edges for the axis of rotation.
- Continue to update our numerical model with new parameters to fit with the measured signal from our apparatus.
- Scale the weight of the errors for our method.
- Specific attention will be paid to electrostatic force calibration, frequency-dependent capacitance, feed-back regulator and electrostatic damper controlled by microprocessor.
- Start the construction of a new attractive mass lift adapted to our new balance geometry.
- Installation of the gravitational balance in an underground laboratory for low noise and long term study.
- Overview the possibility to defend a PhD on this topic.

C.2.4. Personnel involved

Scientific staff: M. van Ruymbeke, (Project initator)
Ir S. Naslin (granted by a private donator)
Technical staff: F. Renders (prepared the mechanical equipment for the laboratory)

C.2.5. Partnerships

C.2.6. Publication

[1] **M. van Ruymbeke** and **S. Naslin**
Measurement of Newton's constant using an astatic vertical pendulum
Report presented at the meeting at the BIPM during the ICAG2005 meeting (Sept.19, 2005)

C.2.7. Scientific outreach

Meeting presentations

[2] **M. van Ruymbeke and S. Naslin**
Measurement of Newton's constant using an astatic vertical pendulum
Poster presented to the Forum organized at the Belgian Sciences Academy for the 175th anniversary of Belgium (October, 13th, 2006) Communication, poster

C.2.8. Missions

Assemblies, symposia (number): S. Naslin (3)
Field missions (days): S. Naslin (4)

C.3. The EDAS project Geophysical instrumentation

C.3.1. Objectives

EDAS (Environmental Data Acquisition Systems) develops additional electronic instruments with resistive and capacitive transducers in order to provide a series of tools operating on standard supplies. In addition managing software are being developed to be more friendly user and accessible. This work is being done in conjunction with a diverse range of projects.

C.3.2. Progress and results

The implementation of the EDAS concept continues to be developed at the ROB, containing a laboratory to develop instruments, a stock room, a library, an area for meetings and seminars and of workstations.

A collaboration has been initiated with the IRM-KMI in the domain of space monitoring for the development of a bolometer in the frame of the project PICARD.

A series of experiments using EDAS are active in the boreholes of the laboratory in Brussels, complemented with climatic and gravimetric monitoring.

Of particular interest are areas where there is a risk of tectonic, volcanic or seismic movement. To this end the instruments are installed at different locations:

At Rochefort and Ramioul Caves (Belgium), a series of systems have been built to monitor and to test the principles involved where a multi-parameter approach is required for the study of geophysical phenomenon. Seismic aspects are considered from the various monitoring tools.

M. van Ruymbeke applied EDAS for instruments prototyping and geophysical monitoring purposes at the three sites of Lanzarote Geodynamical Laboratories in collaboration with Pr Ricardo Vieira (Instituto de Astronomía y Geodesia (CSIC-UCM) and with Pr Ramon Ortiz (Depart.de Volcanologia, Museo Nacional de Ciencias Naturales, Madrid), with the effective support of Casa de los Volcanes belonging the Cabildo Insular de Lanzarote A data bank with series of more than ten years records is permanently completed. A systematic treatment of all the different signals started in 2004 to prepare edition of DVD with ready to use information needed for experimentation of methods and geophysical modeling.

The MGR software developed with André Somerhausen (ROB) & François Beauducel (Observatoire volcanologique et Sismologique de Guadeloupe - Institut de Physique du Globe de Paris) is being adapted to provide a user-friendly interface and the means whereby data could be sent across the Internet to and from a remote site. A program has also been included to provide synthetic data for the validation of analysis methods like HiCum.

HiCum has been used to highlight the effect of Earth-tides and climatic oscillations on a variety of parameters. Validation of HiCum has been carried out and a paper including this and notes on the HiCum procedure has been published.

The EDAS laboratory is engaged in the preparation of material for this kind of targeted educational course including different aspects of the EDAS concept, in order to train new users in the process and to encourage the use of EDAS in an even wider range of projects. New abroad partners could be included in the management required to reach such goal.

C.3.3. Perspective for next years

The EDAS concept tries to furnish software and hardware including didactic tools adapted to scientists without technical background. The main objective for 2006 consists to complete existing systems to reach a more effective user autonomy. Some high tech projects are under investigation:

A proposition for a two way sensor adapted to very high precision bolometer in the few hertz frequency band in a solar monitoring satellite (PICARD project)

The collaboration with Ramon Ortiz (MNCN, Madrid) could solve difficulties existing in the seismic monitoring of volcanoes by adapting the last prototype of data logger (picoDAS) which will simplify dramatically the field stations

Application of this new technique is planned in Algeria for the sea level and tsunami monitoring

Recent observation recorded in Rochefort cave by stain meters suggest to complete actual series of EDAS probes with new types of sensors under development.

A priority for all these projects requires that we continue to develop new low-power data logging systems (picoDAS and femtoDAS), which will used in remote sites where long-lived systems are needed.

C.3.4. Personnel involved

Scientific staff: M. van Ruymbeke (Manages the EDAS laboratory)
S. Naslin (granted by a private donator)
Technical staff: Fr. Renders
Volunteers: Eric de Kerchove, Geneviève Tuts, Rosamund Howard, Ir Jacques Beaujean, François-Xavier Kremer, Robert Du Bois

C.3.5. Partnerships

- Wuhan Institute of Seismology (China Earthquakes Administration) to adapt EDAS to questions related to some natural disaster problems, including the three gorges dam seismic risk monitoring.
- INCT (Institut National de Cartographie et Télédétection) of Algeria, where our instruments are used to study gravimetry and ocean tides in and around Algiers. A prototype of capacitive tide gauge was installed only few hours before the Tsunami earthquake in 2003 and the records have already excited interest in the geodynamic community. The second EDAS sea level monitoring station is now active and a project to set-up a series of such stations along the 2000km of Algerian coast is prepared in join venture with ROB. A comparison of classical and our tide gauge in geodetic referencing, is published by M.Haddad in the Bulletin des Sciences Géographiques of the INCT (Algeria) October 2005 N°16 pp 12-15
- The EDAS laboratory has partnerships to support projects located in the Soqotra island (Yemen) with Peter De Geest (Dept. of Geology-Vrije Universiteit Brussel), Chize (Centre Littoral de Geophysique-Universite de La Rochelle) and at the Villars caves with Dominique Genty (Laboratoire d'Hydrologie et de Géochimie Isotopique, Université de Paris-Sud).
- We contribute to introduce ground deformation techniques to the scientists attempting to the XVIII Curso de Volcanología y Geofísica Volcánica organized on June 1-24, 2005 in the Canaries Archipelago by DEPARTAMENTO DE VOLCANOLOGÍA MUSEO NACIONAL DE CIENCIAS NATURALES (CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS (C.S.I.C.))
- Practicals with EDAS material took place", in the meeting rooms of Casa de los Volcanes located in the Jameos del Agua, with the support of the "Cabildo de Lanzarote".
- Some collaboration continues with the «Jeunesses Scientifiques de Belgique » to promote sciences to secondary-school students.

C.3.6. Publications

C.3.6.1. Reports, thesis, etc

[1] Renaud Jacqmotte (TFE ECAM)
Influence d'un champ électrostatique sur l'interface eau/air d'un clinomètre longue base de haute resolution
[2] Jean-Philippe Noël (stage /TFE INRACI)
Système d'acquisition de données EDAS
[3] Christophe Leclercq (stage /TFE INRACI)
Système d'acquisition de données EDAS
[4] Marta Redman & Martin Lefranc (stage ISIB)
Introduction à la Métrologie EDAS
[5] Martin Lefranc (TFE ISIB)
Etude préliminaire d'un capteur solaire pour le satellite Picard, Réalisation et validation d'un prototype
[6] Nicolas Chapuis (DESS ECAM)
Etude préliminaire de capteur embarqué sur satellite artificiel

C.3.7. Scientific outreach

Meeting presentations

[7] M. van Ruymbeke, Fr. Beauducel and A. Somerhausen
The European Data Acquisition for Scientists (EDAS) developed at the Royal Observatory of Belgium
Poster presented to the Forum organized at the Belgian Sciences Academy for the 175th anniversary of Belgium (October, 13th, 2005)

[8] **M. van Ruymbeke** and R. Vieira
Fifteen years of geophysical researches of the Royal Observatory of Belgium in the Laboratories of Lanzarote Island
Poster presented to the Forum organized at the Belgian Sciences Academy for the 175th anniversary of Belgium (October, 13th, 2005)

C.3.8. Missions

Field missions (days): M. van Ruymbeke (33)

C.4. Karstic caves Research

C.4.1. Objectives

This project aims to develop systems dedicated to providing a multi parameter approach for the study of changes in a cave environment and to provide a useful analysis method in the recovery of tectonic, climatic and earth-tide signatures on weak signals in a noisy environment. This includes the use and development of novel sensors and data treatment systems (MGR and HiCum software), all of which have been developed at the Royal Observatory of Belgium (ROB).

C.4.2. Progress and results

A case study in the Ramioul cave in Belgium, has demonstrated the potential of monitoring movements in a cave in order to predict rock collapse in a nearby quarry. This work indicates that caves can be good 'sensors' for stresses similar to those appearing in tectonics plates.

A laboratory dedicated to the monitoring of geophysical parameters has been set up in the karstic network of the Rochefort caves in Belgium. The instruments used for this work include; drop meters, extensometers, and atmospheric pressure, temperature and light intensity sensors. All of which have been developed at the ROB. The high precision reached by these systems has allowed us to evaluate the effects induced by environmental, seismic, tectonic variations, or other sources. Special attention has also been paid to the permanent monitoring of water-flow. Both the effects of water on other parameters and the origins of the changing flow rate have been considered.

The sensors developed at the ROB have proved to be capable of detecting modulations in air pressure, temperature and strain due to earth tides with a high degree of accuracy. The use of EDAS has provided the means for the continuous monitoring of these parameters and sufficient data for their analysis by the stacking method HiCum. Using HiCum, M. van Ruymbeke has compared the signature for the different parameters on S1, S2 and M2 periods. The experiments have demonstrated that the complement of tools developed at the ROB can be used in the monitoring of tectonic movements in caves. The results have also demonstrated that, whilst caves are a good location for detecting small changes, a multi-parameter approach is essential for the sensible interpretation of results. In addition the air temperature and rock temperature have been found to display different signals, which demonstrate the high dependency of parameters on precise location. This approach has increased our understanding of the mechanisms at work and has enabled us to make a number of tentative hypotheses.

The laboratory has also collaborated at an international level with work in the Villars caves in France and the IRD Brasilia project in Brazil.

C.4.3. Perspective for next years

Rochefort is in an area of low tectonic activity; further studies should now be carried out using these sensors at sites of greater tectonic activity in order to understand the transfer function. If a link between plate movement and water flow can be established, then water flow monitoring could be a useful tool in the prediction of catastrophic events. Our early results indicate that a connection does exist but caution must be exercised with the drop meters, as the HiCum method depends on a wealth of records for its accuracy and with only hourly records we are working at the limits of accuracy of the methodology. More data is therefore required to confirm this and the further development of water flow monitoring equipment is probably required in order to achieve this.

C.4.4. Personnel involved

Scientific staff: M. van Ruymbeke (Project leader)
Technical staff: E. de Kerchove, Mrs R.Howard, volunteers

C.4.5. Partnerships

List of national and international partners

- Prof. Verheyden Sophie, De Geest Peter, Dept. of Geology, Vrije Universiteit Brussel
- Pr Yves Quinif & Pr Jean Pierre Tsibangu, Faculté Polytechnique de Mons
- Dr Dominique Genty, Univ. Paris-Sud, Lab.d'Hydrologie et de Géochimie Isotopique, Orsay

C.4.6. Publications

C.4.6.1. Publications in press, submitted

[1] **M. van Ruymbeke**, L. Shaoming, Y. Quinif, **T. Camelbeeck**, Cai Wei Xin, J-P. Tsibangu, F. Sondag, E. de Kerchove & R. Howard
The monitoring of tectonic movements in natural caves
Proceeding of the International Conference on Continental Earthquakes, Beijing China July 12-14, 2004 (in press)

C.4.7. Scietific outreach

[2] **M. van Ruymbeke**, Liu Shaoming, Y. Quinif, **Th. Camelbeeck**, Cai Wei Xin, J.-P. Tsibangu, Fr. Beauducel, Fr. Sondag, **E. de Kerchove** and **R. Howard**
Extensometric measurements to monitor fault activity in the Rochefort cave (Belgium)
Poster presented to the Forum organized at the Belgian Sciences Academy for the 175th anniversary of Belgium (October, 13th, 2005)

C.4.8. Missions

Field missions (days): M. van Ruymbeke (26)

DEPARTMENT 2: Astrometry

SECTION 4: Astrometry of Solar System bodies

A. Asteroids

The Royal Observatory of Belgium has a long tradition in excellent astrometry of asteroids and comets. Recently, 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 realisation that asteroids may pose a threat to civilisation if one would collide with the Earth. The Royal Observatory of Belgium continues to provide excellent astrometry of asteroids thanks to the RUSTICCA project, and participates when possible to international projects.

A.1. RUSTICCA

A.1.1. Objectives

The Project "RUSTICCA", standing for "Revalorising the Ukkel Schmidt Telescope by Installing a CCD Camera", started in 1993 and consists in the installation of a CCD camera on the Ukkel Schmidt Telescope and modernising the telescope. The main objective of this camera is astrometric observations of minor planets, but also other types of observations have been performed: photometry of cataclysmic variables, photometry of the mutual phenomena of the satellites of Jupiter and observations of possible occultations of stars by minor planets.

A.1.2. Progress and results

A.1.2.1. Observations in 2005

In 2005 observations have been performed on 53 nights (including 3 day-time sessions, 1 session without results because of technical problems, and 3 sessions without results because of clouds) by 6 observers. They include H. Debehogne (9 nights), P. De Cat (18 nights), E. Elst (10 nights), C. Papadaki (1 night), T. Pauwels (34 nights) and P. Vingerhoets (9 nights). These observations concerned:

- Astrometry of minor planets (41 nights, including 1 without results because of technical problems, H. Debehogne, P. De Cat, E. Elst, T. Pauwels).
- Occultations of stars by minor planets (14 events attempted on 12 nights, out of which 3 were clouded, P. De Cat, C. Papadaki, T. Pauwels, P. Vingerhoets).
- 2 sessions to test the values on the display (P. De Cat, T. Pauwels).
- 1 session to test the possibilities to observe occultations and mutual phenomena of the satellites of Uranus (P. De Cat, T. Pauwels, P. Vingerhoets).
- 3 day-time sessions for dark frames and flat fields (T. Pauwels).

Together they produced 1625 frames.

A.1.2.2. Other activities

Apart from the observations themselves, a lot of work was put routinely in the preparation of the observations, the reductions of the observations, keeping track of the asteroids in need of observations and archiving the raw data. We should point out that often one observer reduces the observations of another observer, thus building a strong team. The maintenance of the telescope also took a lot of attention.

To further automate the reduction of the observations, we continued to improve the software written for reduction of the observations, both for astrometric observations and observations of asteroidal occultations or mutual phenomena of the satellites of Jupiter.

In a near future a change in format is planned for submission of astrometric observations of minor planets to the Minor Planet Center. A start was made to adapt the reduction software to accept and produce the new format.

A.1.2.3. Summary of the results obtained since 1996

From 1996 to 2005 a total of 15 998 positions of minor planets and 57 positions of comets have been published in the Minor Planet Circulars.

In early 2005 a milestone was reached by the RUSTICCA project, when the total number of published positions in the RUSTICCA era (since 1996) overtook the number of published positions observed from Ukkel in the photographic era (1920–1995, 12 931 published positions). From this one can deduce that the CCD camera is roughly 5000 times more efficient than the photographic plate. The left histogram in Figure 13 shows in blue the published positions in the photographic era, and in red the published positions derived with CCD. The increase in the number of published positions in 2003 can be attributed to the fact that the period 1998–2002 suffered from abnormally bad weather, but even more to the fact the P. De Cat joined the team of observers, thus effectively almost doubling the observing capacity. The quality of our submitted positions is illustrated in the right figure, where in green the positions submitted and published are shown, and in red the positions submitted but not (yet) published. The percentage of published positions has been every year well over 90%.

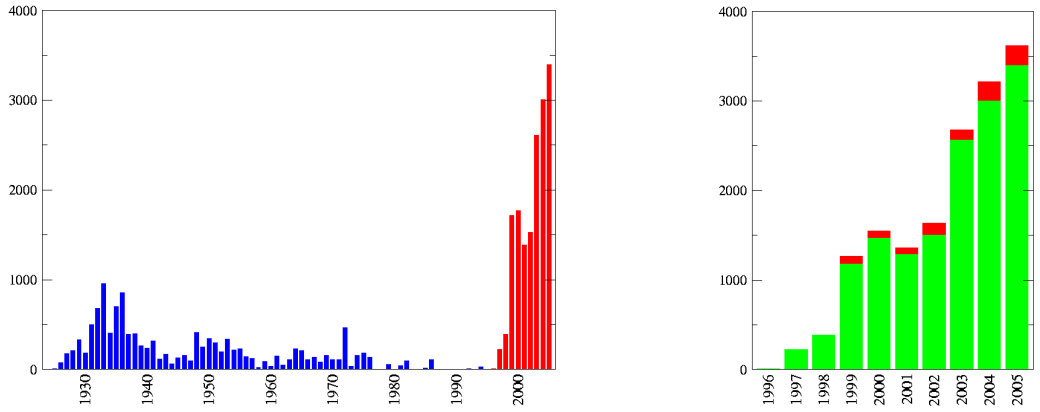


Figure 13: Number of published asteroid positions

Excluding the Daily Orbit Updates, 230 positions of minor planets (NEO's) 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 278. 140 of these minor planets are currently multiple opposition objects, and 60 have been permanently numbered, with the discovery attributed to a RUSTICCA observation. The discoverers with the number of discovered minor planets are: H. Boffin (1 minor planet), E. Elst (3 minor planets), E. Elst and H. Debehogne (6 minor planets), E. Elst and S. Ipatov (3 minor planets), E. Elst and T. Pauwels (1 minor planet), E. Elst and D. Taeymans (1 minor planet), T. Pauwels (43 minor planets), T. Pauwels and H. Boffin (1 minor planet), T. Pauwels and S. Ipatov (1 minor planet).

A total of 43 light curves of cataclysmic variables could be established (1999–2003), and 19 light curves of mutual phenomena of the Galilean satellites of Jupiter (1997 and 2003).

The team tried to observe 23 occultations of stars by minor planets in the period 2003–2005. 7 of these gave no results to due clouds, and 3 others because the target star turned out to be too faint. 11 other phenomena gave a negative result, meaning that we could deduce from the observations that the shadow of the minor planet missed Ukkel. However, 2005 saw also the first positive observation, with two phenom-

ena (the Flammario occultation on 10/11 April and the Palma occultation on 12/13 October) where precise timings of the beginning and end of the occultation could be derived. Given the uncertainty in the predictions of the occultation paths, 2 positive occultations out of 23 attempted is a very high score.

2005 saw yet another milestone for the RUSTICCA project with the discovery of 2005 CZ_{36}, not only the first NEO (Near-Earth Object) detected by the RUSTICCA project, but even a PHA (Potentially Hazardous Asteroid, of which at that time 631 out of an estimated population of 1100 were known). The discovery was possible only by a combined effort of the whole team. The first image was taken by E. Elst and H. Debehogne on 5 February, the second series by P. De Cat on 6 February. Only on 11 February, during a routine inspection of old frames T. Pauwels found that the object had an unusual speed and might have been an NEO. By a combination of bad weather and full moon no observations were possible before 27 February. At that time the uncertainty on the position of the object had increased such that 6 frames were necessary to cover the uncertainty region. The object was found back, but the Minor Planet Center did not recognise the identification. However, alerted by E. Elst of the special nature of the object, it was put on the NEO Confirmation Page of the website of the Minor Planet Center. Subsequently it was observed on 2 March from Sabino Canyon Observatory (Tucson, Arizona) and Great Shefford (UK). These observations were sufficient to link all the position, compute an orbit and deduce that the object is a PHA. The object was followed till August, but apart from possibilities under bad conditions in 2008 and 2012, the next opportunity to observe this object is only in 2015.

The archive consists of 280 CD-ROMs with a total of 20 974 images.

A.1.3. Perspective for next years

The further automation of the telescope and the linkage of the dome to the position of the telescope should be accomplished in the next years. Astrometric observations of minor planets are expected to be useful until 2007–2008. At that moment it is expected that with the limit magnitude of the telescope (20.5) most of the objects in the reach of the telescope will be well-known or routinely observed elsewhere. By that time new observation programmes will have to be defined.

A.1.4. Personnel involved

Scientific staff: T. Pauwels (Project leader)
P. De Cat
C. Papadaki (Belspo Action2 grant)
H. Debehogne (volunteer, honorary head of department of the ROB)
E. Elst (Volunteer, honorary head of department of the ROB)
P. Vingerhoets (Volunteer, amateur astronomer)

A.1.5. Partnerships

List of international partners without grant

- Data reduction and publication is performed at the Minor Planet Center, Massachusetts, USA.

Grants/Projects used for this research/service

The CCD camera and the upgrade of the telescope were financed by a LOTTO grant.

Visitors: 3

A.1.6. Publications

A.1.6.1. Publications with peer system

[1] **Pauwels T**., Vingerhoets P., **Cuypers J.**

Photometric observations of the mutual phenomena of the Galilean Satellites of Jupiter in 1997 and 2003 at the Royal Observatory of Belgium.
Astronomy and Astrophysics 437 (2005), 705–710.

[2] **De Cat P.**, et al
5 positions of comets.
MPEC 2005-G23.

[3] **Elst E., Debehogne H.**, et al
5 positions of comets.
MPEC 2005-K14.

[4] **Pauwels T.**, et al
17 positions of minor planets.
MPEC 2005-C24, 2005-E13, 2005-K61.

[5] **Boffin H.**
24 positions of minor planets.
MPS 127 781, 127 782, 127 785, 127 860, 128 209, 128 484, 128 838.

[6] **De Cat P.**
1196 positions of minor planets.
MPS 123 450, 123 596, 123 608, 123 634, 123 673, 123 674, 123 704, 123 882, 123 905, 124 600, 124 615, 124 674, 124 714, 124 731, 124 791, 124 804, 124 815, 124 817, 124 824, 124 862, 124 865, 124 917, 125 028, 125 034, 125 122, 125 192, 125 201, 125 287, 126 308, 126 331, 126 355, 126 366, 126 390, 126 392, 126 403, 126 408, 126 437, 126 439, 126 450, 126 452, 126 516, 126 535, 126 593, 126 613, 126 616, 126 623, 126 641, 126 644, 126 650, 128 942, 129 110, 129 346, 129 718, 129 743, 129 744, 129 811, 130 063, 130 775, 130 810, 130 858, 130 859, 131 474, 131 475, 131 496, 131 605, 131 654, 131 726, 131 796, 131 797, 131 944, 131 945, 131 993, 132 314, 132 334, 135 917, 141 571, 141 607, 141 793, 141 800, 141 818, 141 961, 142 046, 142 477, 142 486, 142 528, 142 561, 142 577, 142 733, 142 737, 142 990, 143 071, 143 223, 143 322, 143 394, 143 412, 143 423, 143 644, 143 857, 143 898, 143 932, 143 944, 143 969, 143 993, 144 047, 144 048, 144 072, 144 086, 144 093, 144 107, 144 108, 144 121, 144 263, 144 284, 144 332, 144 353, 144 354, 144 394, 144 395, 144 412, 144 422, 144 436, 144 451, 144 478, 144 479, 144 492, 144 493, 144 495, 144 496, 144 886, 145 057, 145 212, 145 301, 145 339, 145 347, 145 439, 145 496, 145 608, 145 669, 145 745, 147 766, 149 114, 149 136, 149 192, 149 218, 149 250, 149 312, 149 323, 149 360, 149 368, 149 369, 149 383, 149 409, 149 547, 149 549, 149 599, 149 640, 149 658, 149 688, 149 789, 149 896, 149 898, 149 899, 149 937, 149 964, 150 127, 150 194, 150 201, 150 275, 150 308, 150 336, 150 382, 150 457, 150 473, 150 555, 150 607, 150 817, 150 909, 150 910, 151 198, 151 241, 152 035, 152 274, 155 910, 156 027, 156 040, 156 050, 156 146.

[7] **De Cat P.**
5 positions of comets.
MPC 53 928.

[8] **Elst E.**
101 positions of minor planets.
MPS 123 526, 123 942, 123 958, 124 057, 124 168, 124 171, 124 183, 124 273, 124 302, 124 307, 124 325, 124 376, 124 412, 124 433, 124 446, 124 451, 124 461, 124 817, 124 824, 125 435, 138 411, 155 933.

[9] **Elst E., Debehogne H.**
427 positions of minor planets.
MPS 126 355, 126 392, 126 408, 126 412, 126 437, 126 438, 126 439, 126 450, 126 535, 126 555, 126 579, 126 594, 126 609, 126 611, 127 793, 127 860, 128 186, 128 478, 128 480, 128 482, 128

645, 132 809, 132 836, 135 073, 136 997, 139 679, 141 030, 141 169, 141 172, 141 260, 141 352, 141 497, 142 174, 142 196, 142 202, 142 209, 142 215, 142 257, 142 263, 142 264, 142 300, 142 307, 142 309, 142 355, 142 378, 142 383, 142 387, 142 402, 142 636, 142 666, 142 667, 142 756, 144 121, 144 284, 144 451, 146 427, 146 446, 146 540, 146 612, 146 687, 147 067, 147 093, 147 094, 147 180, 147 195, 147 216, 147 236, 147 285, 147 290, 147 328, 147 337, 147 405, 147 440, 147 458, 147 464, 147 475, 147 645, 147 646, 147 898, 150 642, 150 817, 150 827, 150 828, 151 106, 151 180, 151 212, 151 964, 152 344, 152 345, 154 077, 155 802, 156 027, 156 117.

[10] **Elst E., Debehogne H.**
5 positions of comets.
MPC 54 136.

[11] **Elst E.**, Ipatov S.
3 positions of minor planets.
MPS 131 775.

[12] **Pauwels T.**
1858 positions of minor planets.
MPS 123 364, 123 945, 124 072, 124 092, 124 146, 124 168, 124 183, 124 220, 124 231, 124 270, 124 378, 124 391, 124 440, 124 442, 124 451, 124 452, 124 453, 124 457, 124 473, 126 301, 126 308, 126 313, 126 323, 126 335, 126 355, 126 356, 126 366, 126 374, 126 377, 126 392, 126 401, 126 403, 126 408, 126 414, 126 417, 126 437, 126 438, 126 439, 126 452, 126 535, 126 556, 126 557, 126 565, 126 568, 126 575, 126 579, 126 587, 126 594, 126 641, 126 664, 127 128, 127 147, 127 218, 127 221, 127 222, 127 428, 127 477, 127 496, 127 594, 127 618, 127 633, 127 678, 127 736, 127 990, 129 941, 130 001, 130 033, 130 071, 130 589, 130 779, 131 787, 132 545, 133 111, 133 922, 134 078, 134 126, 134 657, 134 781, 134 836, 134 879, 134 883, 135 161, 135 209, 135 354, 135 613, 135 621, 135 624, 135 798, 135 883, 135 917, 137 087, 138 376, 138 422, 138 831, 139 364, 140 918, 140 955, 140 970, 141 014, 141 037, 141 090, 141 091, 141 133, 141 163, 141 167, 141 174, 141 176, 141 185, 141 198, 141 201, 141 204, 141 343, 141 377, 141 419, 141 431, 141 469, 141 487, 141 515, 141 571, 141 643, 141 672, 141 750, 141 767, 141 793, 141 800, 141 809, 141 815, 141 818, 141 832, 142 043, 142 202, 142 238, 142 249, 142 253, 142 256, 142 257, 142 260, 142 263, 142 264, 142 296, 142 337, 142 339, 142 355, 142 359, 142 383, 142 386, 142 387, 142 415, 142 666, 142 733, 143 218, 143 235, 143 355, 143 356, 143 374, 143 394, 143 405, 143 423, 143 430, 143 492, 143 617, 143 618, 143 639, 143 645, 143 660, 143 682, 143 764, 143 767, 143 819, 143 825, 143 852, 143 857, 143 881, 143 925, 143 941, 143 944, 143 993, 143 998, 144 072, 144 079, 144 085, 144 086, 144 093, 144 096, 144 105, 144 107, 144 108, 144 121, 144 263, 144 332, 144 353, 144 354, 144 394, 144 395, 144 412, 144 422, 144 436, 144 451, 144 453, 144 478, 144 492, 144 493, 144 495, 144 496, 144 886, 145 057, 145 123, 145 282, 145 301, 145 339, 145 347, 145 348, 145 439, 145 445, 145 579, 145 608, 145 688, 145 690, 145 746, 149 192, 149 204, 149 250, 149 328, 149 355, 149 360, 149 409, 149 524, 149 527, 149 549, 149 789, 149 896, 149 898, 149 899, 149 964, 150 127, 150 194, 150 201, 150 313, 150 473, 151 152, 151 198, 152 172, 155 355, 155 995, 156 037, 156 072, 156 146.

[13] **Pauwels T.**
8 positions of comets.
MPC 54 136.

[14] **Pauwels T., Boffin H**.
9 positions of minor planets.
MPS 130 010, 138 417.

[15] **Pauwels T., De Cat P.**
16 positions of minor planets.
MPS 127 894, 132 506, 134 927.

A.1.6.2. Publications in press

[16] **Pauwels T.**, Vingerhoets P., **Cuypers J.**
Photometric observations of the mutual phenomena of the Galilean Satellites of Jupiter in 1997 and 2003 at the Royal Observatory of Belgium.
Notes Scientifiques et Techniques de l'IMCCE S084.

A.1.7. Missions

Assemblies, symposia (number):	T. Pauwels (2)
Commissions, working groups (days):	T. Pauwels (1)
Field missions (days):	T. Pauwels (1)

DEPARTMENT 2: Astrometry and Dynamics of Celestial Bodies

SECTION 5: Astrometry and Dynamics of Star Systems

Introduction: Mission and objectives

The main objective of the section is to conduct research in the field of binaries and double and multiple stars at an internationally appreciated level. Binaries and multiple systems provide fundamental stellar data which are not easily obtained from single stars or more complex stellar associations (objective 1). This also makes them suitable stellar laboratories for addressing open questions in other astrophysical domains, for example the study of various phenomena in stellar atmospheres (objective 2).

A. Binaries

It is by now widely accepted that the vast majority of stars belongs to a **binary or a multiple system**, irrespective of spectral type. Recent surveys of high astrometric quality, both from space - up to 3000 new binaries were discovered by the Hipparcos mission [1] - and from Earth, show clear evidence that improving the resolution of the instruments generates an increasing number of new detections and that the true frequency of binaries and multiple stars is still underestimated. The origin and formation process of binary and multiple systems is presently not completely understood and may not be unique: fragmentation of a rotating collapsing cloud can simulate the formation of the wide binaries but remains problematic to explain the close ones [2]. Clues can be derived from the observed distributions of their statistical properties such as frequencies, orbital periods, true separations, orbital eccentricities, mass ratios or any other intrinsic property of the components (e.g. [3]).

Binary and multiple stars with well-characterized components are attractive targets to study a number of different phenomena of high astrophysical relevance including also 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, can be used to calibrate the luminosities and temperatures of single stars and to confront evolutionary tracks and models. They represent the high angular momentum class and should not be forgotten when it comes to understand binary properties.

On the other side of the broad spectrum in separation, close binaries offer excellent opportunities for the combination of data obtained with different techniques resulting in great progress on understanding the impact of binarity on stellar atmospheres (e.g. tidal deformation, rotation, chemical composition, stellar pulsation or activity (cf. Theme “Asteroseismology”) or for close binary evolution (including mass exchange)).

[1] Lindegren, L., 1997, ESA SP-402, 1
[2] Bodenheimer, P., Burkert, A., 2001, IAU Symp. 200, 13
[3] Eggenberger, A., Halbwachs, J.-L. et al., 2004, Rev. Mex. A. A. 21, 28

A.1. Research project “Visual Binaries and Multiple Stars”

A.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 being 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. Our goal is to investigate a volume-limited sample of visual binary and multiple stars in the solar neighbourhood.

A.1.2. Progress and results

In collaboration with Dr. Strigachev, we analyzed the data on visual double stars collected at two Bulgarian observatories during the period 1998-2004 (in the framework of the bilateral project *"Astrometric, Photometric and Spectroscopic Follow-up of Binary Systems"* with Bulgaria and with help of D. Duval). Accurate relative astrometry and differential multi-colour (BVRI) photometric data were obtained for the components of a sample of Hipparcos visual double stars, many of which are nearby binaries with parallaxes larger than 0.04" (forming part of the revised stellar sample of the Solar neighbourhood). A summary paper is in preparation.

In the framework of a study of main-sequence binaries with component masses around one solar mass or less, we derived new relative astrometric data and near-infrared (J,H,K) colours for the components of nearby binaries which do not fit well the empirical mass-luminosity relation. This work is based on observations collected with the ESO 3.6m telescope at La Silla, equipped with the ADONIS Adaptive Optics instrument. The results for a sample of nearby F-G and K binaries which have accurate parallaxes from the Hipparcos mission and which were obtained using a deconvolution method will be submitted for publication. Improving the observational data on main-sequence wide binaries is important in order to confront with the much improved data obtained on the pre-main sequence wide binaries in nearby star formation regions (e.g. Taurus-Auriga and Orion Nebula Cluster associations within 200-500 pc).

We revised the orbit determination for the triple star DG Leo (also named Kui 44 AB). Two different methods were employed to determine (a) a pure astrometric orbit and (b) a combined astrometric-spectroscopic orbit. Both orbital solutions are in excellent agreement with each other (Figs. 1 and 2) **[1]**. The accuracy of the orbital elements has been much improved thanks to the inclusion of a new speckle datum obtained at the critical orbital phase immediately past-periastron passage using the 6-m BTA telescope (red arrow in Figure 14, with the help of Dr. Balega), after a plea for follow-up high-accuracy astrometric observations **[2]**. The distance to the system has been improved with respect to the Hipparcos parallax, allowing to determine more accurately the systemic mass and to better constrain the mass of the pulsating component. This result was presented at a recent ESO workshop **[3]**. A manuscript was completed (in collaboration with Dr. Docobo et al.).

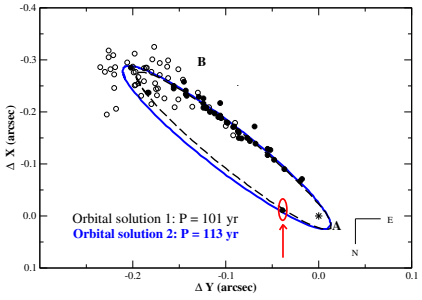


Figure 14: Astrometric data and "best" orbits

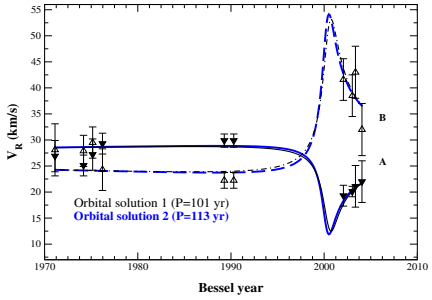


Figure 15: Spectroscopic data and "best" orbits

A.1.3. Perspective for following years

The acquisition of component colours for nearby visual binaries and their exploitation will be continued. Speckle-interferometric programmes for the monitoring of close visual binaries lacking essential astrometric data will be developed, in particular in the context of the PISCO-collaboration. The goal is to improve the accuracy on the component masses of nearby systems. The impact of performing speckle observations in young associations will be investigated (e.g. research on Sco-Cen in Dep. 3). For a few systems of very high astrophysical relevance, we plan to apply for VLTI interferometric observations (ESO).

A.1.4. Personnel involved

Scientific staff: P. Lampens (Project leader)
Y. Frémat (contractual researcher)
Technical staff: D. Duval

A.1.5. Partnerships

List of national and international collaborations

R. Argyle (Cambridge, UK)
J. Docobo et al. (Santiago de Compostela, Spain)
J.L. Prieur (Toulouse, France)
M. Scardia (Brera, Italy)
A. Strigachev (Sofia, Bulgaria)

Grants used

Bilateral project: "Astrometric, Photometric and Spectroscopic Follow-up of Binary Systems" (Ref. BL/33/011)

Visitor(s): 1

A.1.6. Publications

A.1.6.1. Publications with peer review

A.1.6.2. Publications without peer review

[1] **Lampens, P.**, Tamazian, V., Docobo, J. A., **Frémat, Y.**
New orbit for WDS 09498+2111,
IAU Commission 26 Information Circular, 156, 1

[2] **Lampens, P., Frémat, Y.**
Are these observations really necessary?
In: Proc. of Astrometry in the Age of the Next Generation of Large Telescopes, Flagstaff, AZ, 17-22 Oct. 2004, eds. K. Seidelman & A. Monet, ASP Conf. Ser. 338, 276

A.1.6.3. Publications in press, submitted

[3] **Lampens, P., Frémat, Y., Hensberge**, H., Tamazian, V., Docobo, J. A., Balega, Y.
DG Leo: a triple system with a surprising variety of physical phenomena
In: Proc. of ESO Workshop on Multiple Stars across the H-R Diagram, Garching, Germany, 12-15 July 2005, eds. S. Hubrig & A. Tokovinin

A.1.6.4. Reports, thesis

A.1.7. Scientific outreach

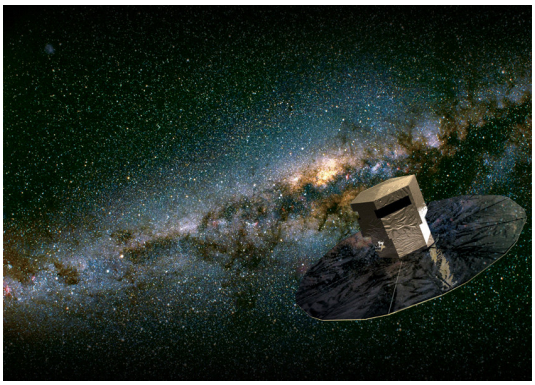
- **P. Lampens** is member of the Organising Committee of IAU Commission 26 "*Double and Multiple Stars*"

A.1.8. Missions

Assemblies, symposia (number): P. Lampens (1)

A.2. Binaries from space (missions)

A.2.1. Objectives



The objective is to contribute to the scientific preparation of the ESA cornerstone mission GAIA (launch foreseen in 2011), in particular in the framework of detection and analysis of double and multiple stars. After the PRODEX-6 project "Double stars: From HIPPARCOS to GAIA" expired (end 2004), no action of immediate follow-up was undertaken due to a shortage in staff (1 resignation) and because a broadening of the scope of contributions for the preparation of GAIA was on its way. The need for an interdepartemental GAIA project was considered and deemed opportune (see also B.2.).

A.2.2. Progress and results

After the meeting held at the quarters of Federal Science Policy (Feb. 2005), it became evident that a broadening of the scope of potential contributions for GAIA was foreseen at a national level. In the course of the year, ROB scientists from Dept. II and III committed themselves to various GAIA-defined tasks and work packages in the framework of the Coordination Units CU4 (Object Processing), CU6 (Spectroscopic Processing), CU7 (Variability Processing) and CU8 (Astrophysical Parameters). An interdepartemental GAIA project based on four topics, being of high relevance for the astronomical research of ROB scientists, was defined and structured. The outcome was a proposal for a PRODEX-8 project, made in collaboration with the group of the *Institut d'Astrophysique et de Géophysique (GAPHE)* from the *Université de Liège*, and encompassing four areas of astronomical research perfectly related to the outcome of the mission: double and multiple stars, hot stars, variable stars and solar system objects. This proposal was submitted at the end of the year **[1]**. Such a project would however require additional staff, in particular with a decent experience in informatics, as explained in the document.

A.2.3. Perspective for following years

The GAIA preparatory work will be converted into concrete tasks and precise goals and strategies. The contributions and responsibilities in this context will be developed and extended in the following years.

A.2.4. Personnel involved

Scientific staff: P. Lampens (Project leader, Dep 2)
R. Blomme (Dep 3)
J. Cuypers (Dep 3)
P. De Cat (Dep 2)
Y. Frémat (contractual researcher, Dep 2)
A. Lobel (contractual researcher, Dep 3)
T. Pauwels (Dep 2)
P. van Hoof (contractual researcher, Dep 3)

A.2.5. Partnerships

International/national collaborations

- The GAIA scientific community
- Institut d'Astrophysique et de Géophysique (GAPHE), Université de Liège (E. Gosset et al.)

Grants used: none

Visitor(s): none

A.2.6. Publications

A.2.6.1. Reports, thesis, etc

[1] Lampens P., Blomme R., Cuypers J., De Cat P., Frémat Y., Gosset E., Lobel, A., Nazé Y., Pauwels T., Rauw G., van Hoof, P.
PRODEX-8 project proposal "TOols And SofTware for GAIA" (TOAST4GAIA)

A.2.7. Scientific outreach

Meeting presentations

[2] Lampens, P.
Summary of scientific interests and potential contributions from the ROB
Belgian meeting on the GAIA space mission, 22/02/2005, OSP, Brussels

National and international responsibilities

- **P. Lampens** is member of the GAIA Coordinating Unit 4 *"Object Processing"*
- **P. De Cat** became associate member of the GAIA Hot Star Group
- **P. De Cat** and **T. Pauwels** became members of the GAIA Solar System Working Group

A.2.8. Missions

Assemblies, symposia (number):	P. Lampens (1)
Commissions, working groups (days):	P. Lampens (3)
	P. De Cat (6)
	T. Pauwels (7)

B. Asteroseismology

Introduction

The rapidly developing research domain of **asteroseismology** refers to the study of the internal structure of pulsating stars through interpretation of their frequency spectra. Stellar pulsations are presently the only way to indirectly probe the stellar interiors. Indeed, the frequency spectrum of the excited modes is a fingerprint of internal physical processes. Hence, detection of several well-identified modes forms the basis of a successful asteroseismic study. To this aim we observe and study the light and spectral variations of pulsating stars of spectral type B-A-F over a timescale of several seasons and/or years (cf. project B.1.). At least four classes of main-sequence pulsators are investigated:

- *δ Scuti (δ Sct) stars* are main-sequence or giant mid to late A-type stars pulsating in radial and non-radial acoustic *(p-)*modes with typical periods of 0.5-6 hours. Photometric amplitudes up to decimagnitudes are observed. Their modes are excited by the opacity mechanism acting on the partially ionized He II-III zone [1].
- *γ Doradus (γ Dor) stars* were first introduced as an independent class one decade ago. These are main-sequence early F-type stars located at the red edge of the δ Sct instability strip and pulsating in non-radial gravity *(g-)*modes with typical periods of 0.4-3 days. The light curves show photometric amplitudes of milli- to centimagnitudes. Although there is no consensus about the driving mechanism yet, their pulsations are driven by a flux-blocking mechanism at the base of their convective envelope [2, 3].

- *β Cephei (β Cep) stars* are early B-type stars which pulsate in both radial and non-radial (low-order) *p/g*-modes with typical periods of 2-12 hours and photometric amplitudes of milli- to centimagnitudes. Their pulsations are driven by the opacity mechanism acting on the iron group elements [4].
- *Slowly pulsating B (SPB) stars* are main-sequence mid to late B-type stars pulsating in non-radial (high-order) *g*-modes with typical periods of 0.5-5 days and photometric amplitudes of milli- to centimagnitudes. Their pulsations are also driven by the opacity mechanism acting on the iron group elements [5].
- *Be stars* are main-sequence, fast rotating massive stars that show emission in their spectra and which are surrounded by an equatorial disk or a flattened envelope. Rotation is however not enough to explain the origin of their circumstellar environment. One possible explanation is the beating of multi-periodic non-radial pulsation modes, which in fast rotators are confined at the equator.

So far, still unknown amplitude and mode selection mechanisms are operating in these various classes of main-sequence pulsators. The future space missions dedicated to asteroseismology will most probably allow to answer (at least some) remaining open questions (cf. project B.2.).

[1] Breger, M., 2000, ASP Conf. Ser. 210, 3
[2] Handler, G., 1999, MNRAS 309, 19
[3] Dupret, M.-A., Grigahcène, A., Garrido, R. et al., 2004, A&A 414, L17
[4] Dziebowski, W., Pamyatnykh, A., 1993, MNRAS 262, 204
[5] Dziembowski, W., Moskalik, P., Pamyatnykh, A,. 1993, MNRAS 265, 588

B.1. Asteroseismology of binary or multiple stars

B.1.1. Objectives

Specific 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 presently focus our efforts unto close binaries which are promising targets for application of spectral disentangling.

B.1.2. Progress and results

Photometric and spectroscopic long-term monitoring was/is being performed for a large sample of main-sequence O-B and A-F stars under the coordination of the asteroseismology group of the *Instituut voor Sterrenkunde* (KULeuven). The data collected over various years contain information with respect to the long-term pulsation behaviour of the variable O-B and A-F stars. The photometric data of 7-colour Geneva photometry, gathered with a photomultiplier attached to the 1.2-m MERCATOR telescope (2001-2004, La Palma, Spain), are analyzed using classical techniques of frequency analysis. The spectroscopic data were obtained with the CORALIE spectrograph attached to the EULER telescope (1998-2004, La Silla, Chile). In 2005, we collected spectra with the ELODIE spectrograph attached to the 1.93-m telescope (*Observatoire de Haute-Provence, France*) and with the spectropolarimeter MUSICOS attached to the 2-m telescope Bernard Lyot (*Observatoire du Pic du Midi, France*). We also rely on the complementary acquisition of CCD differential photometry obtained at BHO (*Beersel Hills Observatory, Belgium*) the year round. We contribute to a large extent to the analyses and apply various tools to identify the modes of the observed frequencies. In parallel, we are obtaining fundamental stellar parameters for a better characterization and improved understanding of the pulsation physics.

B.1.2.1. Main-sequence O-B stars

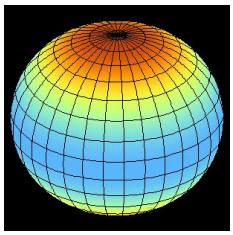


Figure 16: Colour-coded illustration of an l = 2 pulsation mode

The data of 31 variable O-B stars were submitted to a frequency-analysis, leading to (re)classification of these objects. The method of photometric mode identification was applied using 2 grids of equilibrium models and theoretical nonadiabatic eigenfrequencies. All well-identified modes have l $\leq$ 2 **[12]**. In the case of HD 92024 (β Cep and eclipsing binary in NGC 3292), two modes have l = 2 while 1 mode has l = 4 **[22]**. For HD 203664 (β Cep), the main mode has l = 2 **[16]**. Fundamental parameters were derived for a sample of 25 SPBs with measurements of the magnetic field **[23]**.

Recently, new data were collected for two early-B type close binaries in order to study the effects of tidal interaction (with the *Observatoire de Paris-Meudon*).

B.1.2.2. Main-sequence A-F stars

Using high-resolution spectroscopy and differential CCD photometry (performed at BHO), 32 A-stars located in the Cepheid instability strip were investigated. In the process of clarifying the origin of the radial velocity variability, we detected 3 δ Sct variable stars - among which 2 are new **[4, 19]** - and 8 spectroscopic binaries or multiples. Fundamental stellar parameters were derived using spectral synthesis **[21]**. One new and spectacular δ Sct star, HIP 113790, was intensively monitored from Aug to Dec (multi-site).

In-depth studies of δ Sct stars in binary or multiple systems, for example of the triple star DG Leo **[3, 6, 14]**, were made. A combined astrometric-spectroscopic orbit was derived **[24]**. New spectroscopic observations for the δ Sct star θ^2 Tau (a spectroscopic binary in the Hyades cluster) were collected **[20]**. Two oscillating eclipsing binary systems will be analysed: a) HIP 7666, a classical δ Sct star in a detached binary **[2]**, and b) CT Her, a target for which we organized a photometric campaign in 2005 (multi-site, in collaboration with BHO, Bulgaria, Spain, South-Korea (USA site) and Ukraina). A review of open questions in the field was presented at a PhD summer school **[15]**.

A full study of the binarity, variability and rotation of 37 southern candidate γ Dor stars was completed **[17, 18]**. Preliminary results of the frequency analyses for 36 northern γ Dor candidates were presented as well **[11, 18]**. Further results based on CCD observations performed at BHO consist of a photometric analysis of the RR Lyr star OV And showing a possible Blazhko effect **[5]**; the detection of new short-periodic variable stars of type δ Sct in 3 poorly studied open clusters **[9]**; and, a photometric analysis of the high-amplitude δ Sct star GSC 00144-03031 **[8]**. During the summer of 2005, two students were taught to process time-series CCD frames of a field centered on the open cluster NGC 1528 with the software PODEX (developed by T. Kallinger, University of Vienna). From the 300 or so stars analyzed, 31 stars were found to show signs of variability and a further 31 are suspected of variability.

B.1.2.3. The HERMES project

The scientists of Dep. 2 are motivated and interested to make use of the future HERMES Echelle spectrograph for both asteroseismic and binary star studies. It is expected to equip the MERCATOR telescope at La Palma, Spain, from 2008 onward. Contributions to help develop the reduction pipeline were defined (cf. the report of Dep. 3 for a description of the HERMES projec

B.1.3. Perspective for following years

The study of pulsating stars in binary or multiple systems applying the same techniques as used for the triple star DG Leo (e.g. the spectroscopic binary θ^2 Tau, the oscillating eclipsing binary HIP 7666) will be pursued. Analysis and interpretation of the acquired data for the high-priority targets as well as of new spectroscopic and photometric data for a broad sample of A- and F-type stars will enable to study the occurrence of pulsation, binarity and chemical peculiarity in the lower Cepheid instability strip (in the

framework of an Action-1 starting next year **[25]**). The work on the frequency analyses and the mode identification of β Cep and γ Dor variable stars will also be continued. There is a plan to join follow-up observations of southern γ Dor stars (in collaboration with Dr. Pollard, New-Zealand). We will apply for VLTI/VISA time for selected binary targets in order to determine the inclination i, the only missing factor to obtain accurate masses, as soon as the ESO Auxiliary Telescopes are available with the required instrumentation (see also A.1.3.).

B.1.4. Personnel involved

Scientific staff: P. De Cat (Dep 2)
Y. Frémat (contractual researcher, from Jan, 1 till Jul, 31 in the framework of Action-1 MO/33/007, from Nov, 1 in the framework of the IAP P5/36)
P. Lampens (Dep 2)
J. Cuypers and H. Hensberge (Dep. 3)

B.1.5. Partnerships

List of national and international collaborations:

- T. Arentoft, Aarhus (Denmark)
- The Belgian Asteroseismology Group (Belgium)
- Neiner, Observatoire de Paris-Meudon (France)
- E. García-Melendo & coll. (Grup d'Estudis Astronómics), Barcelona (Spain)
- R. Garrido & coll., Granada (Spain)
- P. Harmanec & coll., Prague (Czech Republic)
- K. Kolenberg & coll., Vienna Observatory (Austria)
- P. Mathias, Nice (France)
- Mkrtichian & coll., Seoul (Korea)
- P. Niarchos & coll., University of Athens, Athens (Greece)
- J. Peña & coll., UNAM, Mexico City (Mexico)
- Strigachev, Bulgarian Academy of Sciences, Sofia (Bulgaria)
- P. Van Cauteren & coll., Beersel Hills Observatory (BHO) & VVS (Belgium)
- P. Wils, VVS (Belgium)

Grants used:

- LOTTO 1999: since 2002 this grant provides for a CCD camera to equip a small telescope (Ref. 2LOTCCDEQ45)
- Action 1: project MO/33/007: "Variable Components of Binary or Multiple Stars"
- FWO-project G.0178.02: "Observational study of Stars in Stellar Systems" (cf. report of Dep. 3)
- IAP P5/36: "Modern aspects of theoretical and observational (ground-based and space-born) astrophysics"(cf. report of Dep. 3).
- OPTICON (Optical Infrared Coordination Network for Astronomy) – EU-grant to perform service observations of θ^2 Tau at OHP (2005-2006)

Visitor(s): 2

B.1.6. Publications

B.1.6.1. Publications with peer review

[1] **De Cat P.**, Briquet M., Daszyńska-Daszkiewicz J., Dupret M.-A., De Ridder J., Scuflaire R., Aerts C. *A study of bright southern slowly pulsating B stars. III. Mode identification for singly-periodic targets in spectroscopy,*
AA 432 (2005), 1013

[2] E. Escolà-Sirisi, J. Juan-Samsó, J. Vidal-Sáinz, **P. Lampens**, E. García-Melendo, J. M. Gómez-Forrellad, P. Wils
A classical δ Scuti star in the new eclipsing binary system HIP 7666,
AA 434, 1063

[3] **Frémat Y., Lampens P., Hensberge H.**
Spectral disentangling of the triple system DG Leo: orbits and chemical composition,
MNRAS 356, 545

[4] **Frémat Y., Lampens P.**, Van Cauteren P., Robertson C. W.,
New variable and multiple stars in the lower part of the Cepheid instability strip
Communications in Asteroseism. 146, 6

[5] Kolenberg K., Guggenberger E., Lenz P., Van Cauteren P., **Lampens P.**, Wils P.
OV And, a new field RRab Blazhko star?
Communications in Asteroseism. 146, 11

[6] **Lampens P., Frémat Y.**, Garrido R., Peña J., Parrao L., Van Cauteren P., **Cuypers J., De Cat P.**, Uytterhoeven K., Arentoft T., Hobart M.
A photometric study of the light variations of the triple system DG Leo,
AA 438, 201

[7] Libich J., Harmanec P., Vondrák J., Yang S., Hadrava P., Aerts C., **De Cat P.**, Koubsky P., Škoda P., Šlechta M., Uytterhoeven K., Mathias P.
The new orbital elements and properties of ε Per
AA 446 (2006), 583

[8] Poretti E., Suárez J. C., Niarchos P. G., Gazeas K. D., Manimanis V. N., Van Cauteren P., **Lampens P.**, Wils P., Alonso R., Amado P. J., Belmonte J.A., Butterworth N.D., Martignoni M., Martín-Ruiz S., Moskalik P., Robertson C.W.
The double-mode nature of the HADS star GSC 00144-03031 and the Petersen diagram of the class
AA 440, 1097

[9] Van Cauteren P., **Lampens P.**, Robertson C. W., Strigachev A.
Search for intrinsic variable stars in three open clusters: NGC 1664, NGC 6811, NGC 7209
Communications in Asteroseism. 146, 21

B.1.6.2. Publications without peer review

[10] **Cuypers J.**, Goossens K., Schoenaers C., **De Cat P.**, Aerts C., et al. (contributed talk)
Analysis of MERCATOR data Part II: variable A & F stars
In: Proceedings of JENAM 2005 Distant worlds, CoAst 147 (2006), 52

[11] **De Cat P.**, Briquet M., Aerts C., Goossens K., Saesen S., **Cuypers J.**, Yakut K., Scuflaire R., Dupret M.-A., et al. (contributed talk)
Analysis of MERCATOR data Part I: variable B stars
In: Proceedings of JENAM 2005 Distant worlds, CoAst 147 (2006), 48

[12] Gavrilović N., Jankov S., Mathias P., **De Cat P.**
Investigation of rotational velocity of ε Persei
Memorie della Societa' Astronomica Italiana Suppl. 7 (2005), 128

[13] **Lampens P., Frémat Y., Cuypers J.**, Uytterhoeven K. (invited talk)
Pulsating stars in multiple systems, 3rd Granada Workshop on Tidal Evolution and Oscillations in Binary Stars
ASP Conf. Ser. 333, eds. Claret, A., Giménez, A. & J.-P. Zahn, 149

[14] **Lampens P.** (invited review)
Intrinsic Variability in Multiple Systems and Clusters: Open Questions
PhD Conference on Astrophysics of Variable Stars, Pécs, Hungary, 5-10 Sept. 2005, ASP Conf. Series 349, eds. C. Sterken & C. Aerts, 153

B.1.6.3. Publications in press, submitted

[15] Aerts C., **De Cat P**., De Ridder J., Van Winckel H., Raskin G., Davignon G., Uytterhoeven K.,
Multiperiodicity in the large-amplitude rapidly-rotating β Cephei star HD 203664
AA 449, 281 (2006)

[16] **De Cat P.**, Eyer L., **Cuypers J.**, Aerts C., Vandenbussche B., Uytterhoeven K., Reyniers K., Kolenberg K., Groenewegen M., Raskin G., Maas T., Jankov S.
A spectroscopic study of southern (candidate) γ Doradus stars. I. Time series analysis
AA 449, 305 (2006)

[17] **De Cat P.**, Goossens K., Bouckaert K., Eyer L., **Cuypers J.**, De Ridder J., Aerts C., Dupret M.-A., Grigahcène A., et al. (contributed talk)
Observational results for northern and southern (candidate) γ Doradus stars
In: A.R. Walker & G. Bono (eds.), Proceedings of International Astrophysics Meeting Stellar pulsation and evolution, Memorie della Societa' Astronomica Italiana 76 (4 pages)

[18] **Frémat Y., Lampens P**., Van Cauteren P., Robertson C.W.
Analysis of main sequence A-type stars showing radial velocity variability
To appear in the proceedings of the meeting "Stellar pulsation and evolution" (Rome, 19-24 June 2005), Memorie della Societa' Astronomica Italiana 46/4, eds. A.R. Walker & G. Bono

[19] **Frémat Y., Lampens P.**, Alecian E., Balona L., Catala C., Goupil M.-J., Torres G., Skoda P.
Spectral disentangling of 2 pulsating multiple stars
To appear in the proceedings of the meeting "Stellar pulsation and evolution" (Rome, 19-24 June 2005), Memorie della Societa' Astronomica Italiana 46/4, eds. A.R. Walker & G. Bono

[20] **Frémat Y., Lampens P.**, Van Cauteren P., Neiner C.
HIPPARCOS targets in the lower part of the Cepheid instability strip suspected of variable radial velocity: stellar parameters and origin of the variability
Submitted to A&A

[21] **Freyhammer L., Hensberge H.**, Sterken C., **De Cat P.**, Aerts C.
The oscillation modes of the β Cephei star in HD 92024 in the open cluster NGC 3293
In: A.R. Walker & G. Bono (eds.), Proceedings of International Astrophysics Meeting Stellar pulsation and evolution, Memorie della Societa' Astronomica Italiana 76 (poster)

[22] Hubrig S., Briquet M., Schöller M., **De Cat P.**, Mathys G., Neiner C.
Detection of magnetic fields in Slowly Pulsating B stars
In: S. Stefl, S. Owocki & A. Okazaki (eds.), Proceedings of International Workshop Active OB-Stars: Laboratories for Stellar & Circumstellar Physics, ASP Conference Series (poster)

[23] **Lampens P., Frémat Y., Hensberge H.**, Tamazian V., Docobo J., Balega Y.
DG Leo: a triple system with a surprising variety of physical phenomena
In: Proc. of the ESO Workshop on Multiple Stars across the H-R Diagram, July 2005

B.1.6.4. Reports, thesis, etc

[24] **Lampens P., Frémat Y., De Cat P.**
Action-1 research proposal on Pulsation, chemical composition and multiplicity in main-sequence A- and F-type stars
Project MO/33/018, Jan. 2005

[25] **Lampens P. and colleagues from Dep. 2 and 3**
Future ground-based and space astronomy of the ROB departements 2 and 3
document for the BNCA (Nov. 2005)

B.1.7. Scientific outreach

Meeting presentations

[26] Lampens P.
DG Leo: a triple system with a surprising variety of physical phenomena
ESO Workshop on Multiple Stars across the H-R Diagram, 19/07/05

[27] **Lampens P.**
Intrinsic Variability in Multiple Systems and Clusters: Open Questions
PhD Conference on Astrophysics of Variable Stars, Pécs, Hungary, 09/04/05

[28] **De Cat P.**, Eyer L., **Cuypers J.**, Aerts C., Vandenbussche B., Uytterhoeven K., Reyniers K., Kolenberg K., Groenewegen M., Raskin G., Maas T., Jankov S.
Spectroscopic time-series of 36 southern (candidate) γ Doradus stars
Nederlandse Astronomen Conferentie 2005, Blankenberge, Belgium (poster)

National and international responsibilities

- **P. De Cat** & **P. Lampens**: members of IAU Comm. 27 (Variable Stars)
- **P. De Cat** became associate member of the COROT γ Doradus Working Group

Educational responsibilities

- **P. Lampens** assisted in the training for J. Fox and R. Martyn (reduction of CCD frames of the open cluster NGC 1528 making use of PODEX) (01/08-31/08/05). A poster was prepared for the "Open Doors" of the Pole Space.

B.1.8. Missions

Assemblies, symposia (number):	P. De Cat (5)
	P. Lampens (3)
Research visits (days):	P. De Cat (37)
	P. Lampens (1)
Field missions (days):	P. Lampens (16, 3 observational campaigns)

B.2. Asteroseismology from space (missions)

B.2.1. Objectives

We are currently involved in the (preparation of the) space missions MOST, COROT, and GAIA (see also A.2.). These missions are expected to provide a huge amount of super-quality data useful for refined asteroseismic studies. Asteroseismology is a major science objective of COROT (launch in 2006). GAIA (launch in 2011) will provide unprecedented positional and radial velocity measurements with the accuracies needed to produce a stereoscopic and kinematic census of about one billion stars in our Galaxy. Combined with multi-epoch astrophysical information, these data will allow characterizing the various stellar populations of our Galaxy.

B.2.2. Progress and results

B.2.2.1. The MOST mission

The Canadian mission MOST (launched on 30/06/2003) is performing continuous photometric observations of fields centered around well-chosen objects with a total time-span up to 60 days. We analyzed the MOST white-light photometry of HD 163830 which revealed itself as a new SPB star. 21 frequencies in the range 0.036 – 2.01 d^{-1} with amplitudes from 0.7 to 8 mmag were identified. The highest frequency (2.0039 d^{-1}) is a known artefact arising due to modulation of stray Earthshine during the satellite's Sun-synchronous dusk-down orbit. The other 20 frequencies are consistent with low-degree, high-order non-radial g-modes. Due to a lack of colour information, we were unable to perform an independent mode identification **[8]**.

B.2.2.2. The COROT and GAIA missions

The preparation of dedicated archives is a basic requirement for both missions. For COROT and GAIA, updated descriptions of the pulsation parameters of β Cep and SPB pulsators were compiled in order to define models for the supervised classification of massive stars (for the GAIA "Variable Stars Working Group", to be incorporated in CU7 and CU8). We estimated the percentage of all B-type stars belonging to these classes of pulsating stars based on current knowledge. For COROT, we participated to the GAUDI archive by determining the stellar parameters of the group of Be stars **[4, 9]**. The aim of studying Be stars with COROT is to observe the coincidence between phases of matter ejection and beating events. Unfortunately, fast rotation strongly affects the interpretation of the observed spectroscopic or photometric data. Stellar flattening generates gravitational darkening that significantly modifies the shape of the continuum and of the spectral lines **[1]**. We initiated a systematic study on large stellar samples in the Galaxy **[5]** as well as in the Magellanic Clouds **[10, 2]**. We also plan to extend this work to the study of A-type stars, thereby focusing on the spectroscopic and photometric modeling of intern and of surface differential rotation **[11]**. In 2005, we started to contribute to the automatic classification of hot and peculiar stars and the determination of stellar radial and (projected) rotation velocities in the framework of the GAIA mission, as a part of the units CU6 and CU8.

B.2.3. Perspective for following years

Studies of the effects of rotation on the photospheric chemical composition of fast rotating and intermediate mass stars will be continued and extended including also the effect of internal and of surface differential rotation. We intend to keep contributing to the COROT mission and will increase our involvement at various levels of the preparation of the GAIA mission (tasks and work packages to be defined within CU6 "Spectroscopic Processing", CU7 "Variability Processing" and CU8 "Astrophysical Parameters"). Follow-up observations of SPB and β Cep candidate variables with the aim to accurately estimate the percentage of misclassification with GAIA will be endeavoured.

B.2.4. Personnel involved

Scientific staff: P. De Cat
Y. Frémat (contractual researcher, from Jan, 1 till Jul, 31 in the framework of Action-1 MO/33/007, from Nov, 1 in the framework of the IAP P5/36)

B.2.5. Partnerships

List of national and international collaborations:

- The COROT scientific community
- The GAIA scientific community
- The Belgian Asteroseismology Group (Belgium)
- M. Floquet, A.-M. Hubert, C. Neiner, Observatoire de Paris-Meudon (France)

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

Grants used:

- Action 1: project MO/33/007: "Variable Components of Binary or Multiple Stars"
- 01.08.2005 – 31.10.2005: EARA grant (European Association for Research in Astronomy) for a stay at the Institute of Astrophysics, Paris, and the Meudon Observatory, Meudon (France) to study of the differential rotation in massive stars as a contribution to the preparation of the GAIA mission
- IAP P5/36: "Modern aspects of theoretical and observational (ground-based and space-born) astrophysics"(cf. report of Dep. 3).

Visitor(s): none

B.2.6. Publications

B.2.6.1. Publications with peer review

[1] **Frémat Y.**, Zorec J., Hubert A.-M., Floquet, M.
Effects of gravitational darkening on the determination of fundamental parameters in fast-rotating B-type stars
AA 440, 305

[2] Martayan C., Hubert A. M., Floquet M., Fabregat J., **Frémat Y.**, Neiner C., Stee P., Zorec J.
A study of the B and Be star population in the field of the LMC open cluster NGC 2004 with VLT-FLAMES
AA 445, 931

[3] Neiner C., Floquet M., Hubert A. M., **Frémat Y.,** Hirata R., Masuda S., Gies D., Buil C., Martayan C.
Rotation, pulsations and outbursts in the Be star υ Cygni (HD 202904)
AA 437, 257

[4] Solano E. , … **Frémat Y**. …
GAUDI: A Preparatory Archive for the COROT Mission
AJ 129, 547

[5] Zorec J., **Frémat Y**., Cidale L.
On the evolutionary status of Be stars. I. Field Be stars near the Sun
AA 441, 235

B.2.6.2. Publications without peer review

[6] Gutiérrez-Soto J., Fabregat J., Suso J., Suárez J. C., Moya A., Garrido R., Hubert A. M., Floquet M., Neiner C., **Frémat Y.**
Multiperiodic Pulsations in the Be Stars NW Ser and V1446 Aql
Astrophysics of Variable Stars, Pecs, Hungary, 5-10 September 2005, eds. Sterken, C. and Aerts, C. ASP Conference Series 349, 249

[7] Neiner C., Hubert A.M., **Frémat Y.**, Floquet M.
Variability of B and Be stars with GAIA
Proceedings of the Symposium "The Three-Dimensional Universe with Gaia" (ESA SP-576), 603

B.2.6.3. Publications in press, submitted

[8] Aerts C., **De Cat P.**, Kuschnig R., Matthews J.M., Guenther D.B., Moffat A.F.J., Rucinski S.M., Sasselov D., Walker G.A.H., Weiss W.W.

Discovery of the new slowly pulsating B star HD 163830 (B5II/III) from MOST spacebased photometry
Submitted to Astrophysical Journal Letters

[9] **Frémat Y.**, Neiner C., Hubert A.-M. et al.
Fundamental parameters of Be stars located in the seismology fields of COROT
AA (astro-ph/0509336)

[10] Martayan C., **Frémat Y.,** Hubert A.-M., Floquet M., Zorec J., Neiner C.
Effects of metallicity, star formation conditions and evolution in B and Be stars. I: Large Magellanic Cloud, field of NGC 2004,
AA (astro-ph/0601240)

[11] Zorec J., **Frémat Y.**, Domiciano De Souza A.
Differential rotation in early type stars
To appear in the proceedings of the Sapporo meeting on active OB stars; ASP Conference Series ; eds: S. Stefl, S. Owocki and A. Okazaki (astro-ph/0601068)

B.2.6.4. Reports, thesis, etc

[12] Korn A., Barklem P., Bigot L., **Frémat Y.**, Lanzafame A., Plez B.
Need for atomic/molecular data for GAIA astrophysical parametrization
GAIA-C8-TN-UAO-AK-001

B.2.7. Scientific outreach

Meeting presentations

[13] **Frémat Y.**
Higher members of the Paschen series in B and Be stars
April 27-29 2005, 9th GAIA RVS Workshop, Barcelona, Spain

International/national responsibilities

- **Frémat Y.** is:
  - core member of the GAIA RVS working group (now CU 6 "Spectroscopic Processing")
  - member of the GAIA HOt Stars Team (GHOST; now CU 8 "Astrophysical Parameters")

B.2.8. Missions

Assemblies, symposia (number):	Y. Frémat (1)
Commissions, working groups (days):	P. De Cat (1)
Research visits:	Y. Frémat (90)

DEPARTMENT 3: Astrophysics

SECTIONS 6 & 7

Introduction

Stars evolve, process chemical species into different ones and re-cycle part of the material in the galaxy and a new cycle of star formation. Stellar structure, stellar evolution and galaxy evolution are closely linked. Many physical processes intervene in this cycle. The research in department 3 concerns several, but evidently only a small part, of the building blocks contributing to the general picture and encompass projects giving insight in very different stages of the star's life, from young objects to very evolved ones. We have grouped them in three research themes: stellar winds and circumstellar structures playing their major role in evolved evolutionary phases; binaries and asteroseismology as tools to study fundamental stellar parameters and interior structure; and studies concentrating on cataclysmic stellar events. Many of the projects emphasize participation in observational astronomy and analysis techniques, as expected from the Observatory. The department is now also involved in an operational project that will provide in a few years an echelle spectrograph at the Mercator telescope (La Palma, Spain). Theoretical aspects are more strongly emphasized in C.1 and A.1. Several of the projects rely significantly on grants obtained in cooperation with Belgian universities and personnel on temporary contracts. There exist also strong connections with the research projects of department 2, a cooperation that will develop further with the involvement in the aforementioned echelle spectrograph and in the preparations for the GAIA mission.

A. Stellar winds and circumstellar structures

The theme around stellar winds and circumstellar material splits again in two poles of interest (other themes are discussed further on in the report): the strong radiatively driven winds from the most massive, short-lived 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 A.1 concentrates on the understanding of the hydrodynamics producing the structure by confronting theory and observations.

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 A.2 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.

A.1. Hot stars

A.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).

A.1.2. Progress and results

Previously, we had shown that the radio fluxes of the non-thermal radio emitter HD 168112 change periodically. This indicates that the star is most probably a binary. The analysis of the VLA (Very Large Array) and ATCA (Australia Telescope Compact Array) radio observations has now been published **[1]**.

The fact that HD 168112 is a binary is consistent with the theoretical work done by Sven Van Loo for his PhD thesis **[13]**. This thesis was successfully defended at the KULeuven on 29/04 (M. Runacres and R. Blomme were co-promoters) In it, he shows that the non-thermal radio data cannot be explained by a single star. M. Runacres and R. Blomme collaborated on a paper with S. Van Loo, describing this important theoretical result. The paper has been submitted for publication **[10]**.

We continued our work on the non-thermal radio emitters by studying HD 167971. This is known to be a triple system. It therefore has the interesting property of having two colliding-wind regions: one between the components of the inner binary, and one between the combined winds of the binary and the third, more distant, star. The analysis of our own VLA and ATCA data, supplemented by archive material from the VLA, shows that we do not detect the inner colliding-wind region, but we do detect the second colliding-wind region. From the variability of the radio fluxes, quantitative estimates of the orbit of the third component can be made. This research has been submitted for publication **[7]**.

For the same star, X-ray data were also studied, in work led by colleagues from the Université de Liège. The high X-ray flux confirms the existence of the colliding-wind regions. This work has been published **[2]**.

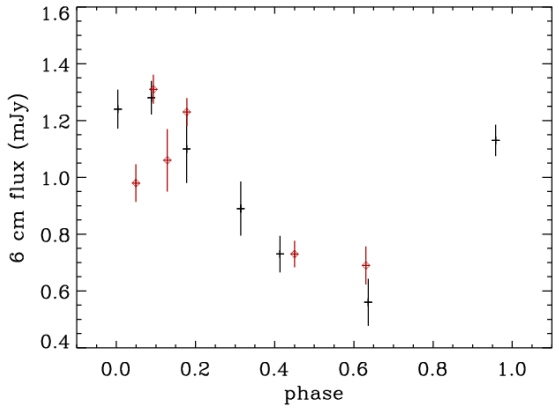


Figure 17: Radio flux variability versus orbital phase of Cyg OB2 No 8A

Continuing the work on non-thermal radio emitters, the binary Cyg OB2 No. 8A was studied. We obtained observing time at the VLA to study the variability as a function of orbital phase. The results show that the flux variability is indeed phase-locked and repeats from one orbit to the next (see Figure 17). Problems remain in explaining this highly interesting result: the stellar winds have so much free-free absorption that they should block us from seeing the colliding-wind region. In a conference paper **[5]**, we suggested that this discrepancy might be explained by assuming that the stellar winds are porous to radiation. For this star, a first version of a paper on the X-ray data was also prepared **[9]**, again led by colleagues from the Université de Liège. Work on this object will continue, both on radio and X-ray data.

We also obtained very high angular resolution images of the colliding-winds in Cyg OB2 No. 9, another non-thermal radio emitter (VLBA – Very Long Baseline Array, project led by S. Dougherty, NRC, Canada). This star was not known to be a binary, but radio archival material again shows a strong periodicity. Preliminary results are very encouraging: they show the characteristic shape of a colliding-wind region. This again supports the binary hypothesis as an explanation for non-thermal radio emission.

Work on thermal radio sources also continued. A preliminary analysis of our SEST data on ζ Pup was presented at the "Active OB stars" conference **[8]**. These data suggest variability on a ~19 hr period in the sub-millimetre observations. If confirmed, these observations would point to the importance of Corotating Interaction Regions as the explanation for structure in the stellar winds of early-type stars. A research programme was started in which A. Lobel will further explore this hypothesis using theoretical modelling. Since the start of this project (1 Dec. 2005), he commenced to implement a preliminary version of the radiative transfer code. The 3-D code is being developed in incremental steps based on an existing implementation for the calculation of flux continua in hot stars.

In view of future work on the data reduction of the GAIA mission, some preliminary work on atmospheric modelling was also done.

A.1.3. Perspective for next years

The reduction of existing and new radio data on thermal and non-thermal radio emitters will continue. With the help of a specialist in sub-millimetre observations, we will do the final reduction of the SEST data. Some previously collected and reduced data on thermal radio emitters will also be prepared for publication. For the interpretation of these data, we shall be using the CMFGEN atmosphere+wind code. This code will also be useful in our planned activities on GAIA data reduction. The Zeus hydrodynamics code will be applied to provide input to the radiative transfer code to be developed by A. Lobel. He will further implement the Adam radiative transfer scheme to compute detailed line profiles and compare them with observations. The current assumptions will be replaced by more realistic conditions of hot star winds. These combined model calculations will enable us to investigate the physical properties of time-dependent changes observed in the detailed wind profiles of hot stars.

A.1.4. Personnel involved

Scientific staff: R. Blomme (Project leader)
A. Lobel (Belspo return mandate from 01/12/2005)
M. Runacres (IAP researcher, ended 28/02/2005)
Technical staff: J. Vandekerckhove (absence for medical reasons 17/01/2005-10/02/2006)

A.1.5. Partnerships

List of national and international partners

- Université de Liège (research group G. Rauw)
- University College London, UK (research group of R.K. Prinja)
- University of Delaware, USA (research group S.P. Owocki)
- Dominion Radio Astrophysical Observatory, Canada (S. Dougherty).

Grants used for this research

- IAP project P5/36 (1 researcher)
- Belspo return mandate (1 researcher)

Visitors: 1

A.1.6. Publications

A.1.6.1. Publications with peer review

[1] **Blomme, R.**, **Van Loo S.**, De Becker M., Rauw G., **Runacres M.C.**, Setia Gunawan D.Y.A., Chapman J.M.
Non-thermal radio emission from O-type stars. I. HD 168112
Astron. Astrophys., 436, 1033 - 1040

[2] De Becker M., Rauw G., **Blomme R.**, Pittard J.M., Stevens I.R., **Runacres M.C.**
An XMM-Newton observation of the multiple system HD 167971 (O5-8V + O5-8V + (O8I)) and the young open cluster NGC 6604
Astron. Astrophys., 437, 1029 – 1046

[3] **Runacres M.C.**, Owocki S.P.
A pseudo-planar, periodic-box formalism for modelling the outer evolution of structure in spherically expanding stellar winds
Astron. Astrophys., 429, 323 – 333

[4] **Van Loo S., Runacres M.C., Blomme R.**
A layered model for non-thermal radio emission from single O stars

Astron. Astrophys., 433, 313 - 322

A.1.6.2. Publications without peer review

[5] **Blomme R.**
Observations of non-thermal radio emission in O-type stars
Proceedings of "Massive Stars and High-Energy Emission in OB Associations", JENAM 2005, Eds. G. Rauw, Y. Nazé, R. Blomme, and E. Gosset, 45 – 48

[6] **Van Loo S.**
Can single O stars produce non-thermal radio emission? Or are they binaries?
Proceedings of "Massive Stars and High-Energy Emission in OB Associations", JENAM 2005, Eds. G. Rauw, Y. Nazé, R. Blomme, and E. Gosset, 61 - 64

A.1.6.3. Publications in press, submitted

[7] **Blomme R**., De Becker M., **Runacres M.C.**, **Van Loo S.,** Setia Gunawan D.Y.A.
Non-thermal radio emission from O-type stars. II. HD 167971
Astron. Astrophys., submitted

[8] **Blomme R.**
Structure in the Winds of OB Stars: Radio and Millimetre Observations
Proceedings "Active OB stars" conference, Eds. S. Stefl, S. Owocki & A. Okazaki., ASP Conf. Proc., in press

[9] De Becker M., Rauw G. Sana H., Pollock A.M.T., Pittard J.M., **Blomme R.**, Stevens I.R., **Van Loo, S.**
XMM-Newton observations of the massive colliding wind binary and non-thermal radio emitter Cyg OB2#8A (O6If + O5.5III(f))
MNRAS, submitted

[10] **Van Loo, S., Runacres, M. C., Blomme, R.**
Can single O stars produce non-thermal radio emission?
Astron. Astrophys., submitted

[11] **Van Loo, S.**
Non-thermal radio emission from O stars: binary versus single
Proceedings of Workshop "Massive Stars in Interacting binaries"

[12] **Van Loo, S.**
Are all non-thermal radio-emitting O stars binaries?
Proceedings "Active OB stars" conference, Eds. S. Stefl, S. Owocki & A. Okazaki., ASP Conf. Proc., in press

A.1.6.4. Reports, thesis, etc

[13] **Van Loo, S.**
Non-thermal radio emission from single hot stars
PhD Thesis, KULeuven

A.1.7. Scientific outreach

Meeting organization

- **R. Blomme** was member of the LOC of the Workshop "Massive Stars and High-Energy Emission in OB Associations", part of the JENAM 2005, Liège, 4 – 8 July 2005 and co-editor of the proceedings of this workshop.

Educational responsibilities (Seminars, students, …)

- **R. Blomme** is:
  - Co-promotor of the Ph.D. thesis by S. Van Loo ("Non-thermal radio emission from single stars"; promoter: M. Goossens - KULeuven, co-promoters: R. Blomme, M. C. Runacres).
  - Jury member of the Ph. D. thesis by M. De Becker ("A multi-wavelength observational study of the non-thermal emission from O-type stars"; promoter: G. Rauw, ULg).

A.1.8. Missions

Assemblies, symposia (number):	R. Blomme (4)
Commissions, working groups (days):	R. Blomme (3)
Research visits (days):	R. Blomme (8)
	A. Lobel (1)

A.2. Post-AGB stars and Planetary Nebulae

A.2.1. Objectives

We have been studying the final stages of evolution of intermediate mass stars, i.e. the evolution from the asymptotic giant branch (AGB) through the planetary nebula phases. This evolution is still poorly understood mainly because of a complex interplay among various physical processes between the central star and its circumstellar nebula (created through mass loss, which also influences the internal evolution of the central star). Hence, these objects provide excellent laboratories of astrophysical processes.

A.2.2. Progress and results

- 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 when they are on the cooling track. Despite this high percentage, this process is only very rarely observed. The discovery of Sakurai's star in 1996 provided the first opportunity in modern times to observe a very late thermal pulse. This object has baffled the scientific community with its very fast evolution. To reproduce this evolution we have proposed a new theoretical model which suppresses convective mixing under the influence of flash burning (**[3]** and **[7]**). A strong prediction of this model is that the star will evolve back to a temperature of 80,000 K within the next 5 to 10 years. In an international collaboration we are monitoring this evolution. We have obtained new radio observations (VLA) and optical spectra (FORS1+2 on the VLT) in 2005. These observations confirm the onset of ionization in the recent ejecta. The bipolar morphology that was previously reported could not be confirmed. Both the radio and optical observations show no apparent signs of increased ionization, but a more detailed analysis is needed. We have successfully submitted an Action 1 proposal in order to continue this research. Furthermore we have submitted successful observing proposals for the VLA and VLT (FORS2) in order to continue our monitoring campaign in 2006.
- The thermal pulses that occur at the end of the AGB evolution mix chemically enriched material from the helium burning shell to the surface of the star. This process will alter the chemical composition of the stellar photosphere leading to the enrichment of certain elements. This allows us to test the theory of nuclear burning. This is specifically the case for the so-called s-process elements which are formed by slow neutron capture. The source of those neutrons is still not fully understood and accurate abundance determinations of post-AGB stars are needed to make progress. We have started a collaboration with Van Winckel and Reyniers at the K.U.Leuven to do such an analysis for two post-AGB stars that are strongly enriched in s-process elements (IRAS08281-4850 and IRAS14325-6428). The analysis is based on high-resolution optical spectra obtained with UVES on the VLT and EMMI on the NTT. During 2005 we improved upon the analysis of the EMMI spectra and we have obtained

accurate Geneva photometry with the Swiss telescope at La Silla. Infrared photometry has also been collected from the literature. These will be used to constrain the stellar temperature and luminosity. The abundance analysis of both stars is now complete and a paper describing the work is currently in preparation.

- In collaboration with P. Boumis and S. Akras from the National Observatory of Athens we are studying a sample of galactic bulge PNe. During an extended stay, we assisted Akras in creating Cloudy models for a subsample of PNe. Since then additional (blue) spectra have been obtained and new Cloudy models are being created. A paper describing the observations and the models is in preparation.
- In collaboration with T. Ueta (USA) from the NASA Ames Research Center we continued to study the shock emission in the bipolar post-AGB star IRAS 16594-4656. The near-infrared spectrum (obtained with Phoenix on Gemini-South) shows strong H_2 emission lines and some typical metastable shock excited [Fe II] lines. We continued the analysis of this spectrum. We concluded that H_2 originates at the edge of the lobes while [Fe II] comes from closer to the central star, as does Paβ. A paper describing our analysis has been significantly improved, but a gap remains in the understanding the kinematics and geometry due to orientation effects which are difficult to disentangle.

A.2.3. Perspective for next years

During the evolution toward the PN stage drastic changes are observed in the circumstellar structure and kinematics, while the star evolves towards higher temperatures and finally starts to ionize the nebula around it. We will continue to study the formation of PNe by studying several post-AGB stars and their circumstellar shells spectroscopically and via imaging in the optical and at infrared wavelengths.

The main emphasis of the research during the coming years will be twofold. One part will be monitoring the spectral evolution of Sakurai's object. Another part of the research will be modeling high resolution spectra of post-AGB stars obtained with UVES on the VLT and EMMI on the NTT with the aim of deriving the chemical composition of these stars. Both LTE and non-LTE model atmospheres will be used for this work. An effort will be made to obtain grant money to employ Dr. Darko Jevremovic at the ROB to assist in this task.

A.2.4. Personnel involved

Scientific staff: Griet C. Van de Steene
Peter A. M. van Hoof (IAP P5/36)

A.2.5. Partnerships

List of national and international partners:

- IAP P5/36 members
- National Observatory of Athens
- NASA Ames Research Center
- Sakurai's international collaboration (A.A. Zijlstra, University of Manchester, UK; M. Hajduk, Centrum Astronomii UMK, Torun, Poland; F. Herwig, Los Alamos National Laboratory, USA; F. Kerber, STECF, ESO, Garching, GermanyS. Kimeswenger, University of Innsbruck, Austria; D.L. Pollacco, Queen's University Belfast, UK; A. Evans, Keele University, UK; J.A. Lopez, UNAM, Ensenada, Mexico; M. Bryce, University of Manchester, UK; S.P.S. Eyres, University of Central Lancashire, Preston, UK; M. Matsuura, University of Manchester, UK)

Grants used for this research:

- Belspo IAP P5/36

Visitors: 2

A.2.6. Publications

A.2.6.1. Publications with peer review

[1] Jonauskas V., Keenan F.P., Kisielius R., **van Hoof P.A.M.**, Foord M.E., Heeter R.F., Rose S.J., Ferland G.J., Norrington P.H.
Relativistic analogues of nonrelativistic integrals in R-matrix calculations
J. Phys. B: At. Mol. Opt. Phys., 38, L79-85

[2] Jonauskas V., Bogdanovich P., Keenan F.P., Foord M.E., Heeter R.F., Rose S.J., Ferland G.J., Kisielius R., **van Hoof P.A.M.**, Norrington P.H.
Energy levels and transition probabilities for nitrogen-like Fe XX
A&A, 433, 745-798

[3] Hajduk M., Zijlstra A.A., Herwig F., **van Hoof P.A.M.**, Kerber F., Kimeswenger S., Pollacco D.L., Evans A., Lopez J.A., Bryce M., Eyres S.P.S., Matsuura M.
The Real-Time Stellar Evolution of Sakurai's Object
Science, 308, 231-233

[4] Shaw G., Ferland G.J., Abel N.P., Stancil P., **van Hoof P.A.M.**
Molecular Hydrogen in Star-forming Regions: Implementation of its Microphysics in Cloudy
ApJ, 624, 794-807

[5] Abel N.P., Ferland G.J., Shaw G., **van Hoof P.A.M.**
The H II Region/PDR Connection: Self-Consistent Calculations of Physical Conditions in Star-Forming Regions
ApJS, 161, 65-95

A.2.6.2. Publications without peer review

[6] **van Hoof P.A.M.**, Foord M.E., Heeter R.F., Bailey J.E., Chung H.-K., Cuneo M.E., Goldstein W.H., Jonauskas V., Keenan F.P., Kisielius R., Liedahl D.A., Ramsbottom C., Rose S.J., Springer P.T., Thoe R.S.
Modeling X-ray photoionized plasmas produced at the Sandia Z-facility
Proceedings of the 5th international conference on high energy density laboratory astrophysics, ed. Kyrala G., Ap&SS, 299, 147-153

[7] Zijlstra A.A., Hajduk M., Herwig F., **van Hoof P.**, Kerber F.
The second death of Sakurai's Object (V4334 Sgr)
Proceedings of the Planetary Nebulae as Astronomical Tools conference, AIP Conference Proceedings, Vol. 804, p. 183-186

A.2.6.3. Publications in press, submitted

[8] Zijlstra A.A., Gesicki K., Walsh J.R., Péquignot D., **van Hoof P.A.M.**, Minniti D.
The Planetary Nebula Population of the Sagittarius Dwarf Spheroidal Galaxy
MNRAS, submitted

[9] Foord M.E., Heeter R.F., Chung H.-K., **van Hoof P.A.M.**, Bailey J.E., Cuneo M.E., Liedahl D.A., Fournier K.B., Jonauskas V., Kisielius R., Ramsbottom C., Springer P.T., Keenan F.P., Rose S.J., Goldstein W.H.
Study of X-ray photoionized Fe plasma and comparisons with astrophysical modeling codes
Proceedings of the Radiative Properties of Hot Dense Matter conference, Ed. Lee R.W., JQSRT, in press (now published as JQSRT, 99, 712-729)

[10] **Van de Steene G.C.**, Jacoby G.H., Praet C., Ciardullo R., Dejonghe H.
PNLF distance determination to NGC 55

2006, eds. L. Stanghellini, J.R. Walsh, & N.D. Douglas, ESO Astrophysics symposia, Springer Verlag

[11] **Van de Steene G.C**., Jacoby G.H., Praet C., Ciardullo R., Dejonghe H.
PNLF distance determination to NGC 55,
2005, A&A submitted

A.2.7. Scientific outreach

Educational responsibilities

- **G. Van de Steene** is:
  - Promoter van Thomas Vielvoye, Onderzoekswerk in de Sterrenkunde K.U.Leuven 2005, "Spectrale classificatie van post-AGB sterren"
  - Mentor of Stavros Akras, National Observatory of Athens
- **P. van Hoof** gave a talk at the ROB and the KU Leuven on "*The Real-Time Stellar Evolution of Sakurai's Object"*

A.2.8. Missions

Assemblies, symposia (number):	G. Van de Steene (2)
	P. van Hoof (3)
Commissions, working groups (days):	G. Van de Steene (5)
Research visits (days):	G. Van de Steene (13)
	P. van Hoof (5)
Field missions (days):	G. Van de Steene (9)

B. Variable stars, asteroseismology and binaries

Research on variable stars and binaries in particular has a long history at the Observatory. In the last years, an evolution towards new observing and analysis techniques and to the modern field of asteroseismology is on-going. The growing emphasis on pulsating stars, especially in binary systems, offers opportunities for closer cooperation with various Belgian universities active in this field. Inside the Observatory, it fosters cooperation between two different departments, with a number of common publications.

The subdivision made between variable stars and asteroseismology on the one hand, and binaries and stellar groups on the other is partially artificial, since pulsating stars are not always single stars and their presence in binaries is particularly attractive (see B.1). Hence, pulsating stars in binaries are discussed in B.1 and B.2 concentrates mostly on binaries in young associations and young stellar groups. The latter are often quite massive and may have significant stellar winds. This links these binaries are also to the research described in A.1.

B.1. Variable stars and asteroseismology

B.1.1. Objectives

The research domain of asteroseismology refers to the study of the internal structure of pulsating stars through the interpretation of their frequency spectra. In order to achieve this goal, observation and detection of the variability of the stars is necessary. The accurate description of the frequency spectrum when multiperiodicity is present is the next step. The research carried out here has as objective to detect the interesting variables, with some emphasis on hot stars and on stars in clusters, to find the periodicities in the observed variations and to make that information available for asteroseismological analysis.

Because binary stars are important sources of precise stellar fundamental parameters, pulsating variables in binaries are intensively studied. One of the main study objects here is a β Cephei star in an eclipsing

binary. It is attempted through a combined spectroscopic and photometric analysis to 1) determine accurate dimensions of the binary components with data of high time resolution and 2) attempt asteroseismological analysis of the pulsating component.

Variable stars in star clusters share common ages, original composition and, to a good approximation, distance. In the case of the globular cluster ω Centauri, photometry of 1,300,000 stars is used to 1) study the cluster's chemical and evolutionary properties, 2) search for new variables of different classes, and 3) to test stellar-evolution models with known ones. In parallel, northern open clusters rich in short-period variables, such as δ Scuti stars, were searched for to facilitate dedicated future asteroseismic studies.

B.1.2. Progress and results

The project variable stars and asteroseismology includes several topics: hot stars, binaries with pulsating components, large scale surveys in the field and in clusters, period analysis methods, preparatory simulations for space missions, analysis of individual stars of different variability type, oscillation theory.... These topics are not listed separately but all are included in this description.

Earlier developed methods to improve the identification of multiple periods in variable stars were tested further and applied to a large number of data sets of variable stars. A new algorithm that makes use of the observations in all the filters of the Geneva system simultaneously has been development and will be implemented in the period search algorithms. Also data sets with unequal mean values can be handled together now.

Figure 18: The Mercator building at La Palma

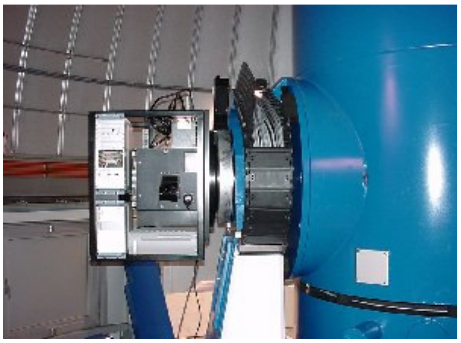


Figure 19: The Geneva photometer at the Mercator telescope

The in-depth analysis of the observations of the Mercator telescope (Figure 18) operated by the Institute of Astronomy (IVS, Instituut voor Sterrenkunde, KULeuven) has been continued. This 1.2-m telescope is located on the Roque de los Muchachos observatory on La Palma, Spain. Since 2001, it has been intensively used to observe variable B, A, and F main sequence stars and some selected other variables in the seven filters of the Geneva photometric system (Figure 19).

Our new methods and classical methods of period analysis were further applied to these data in search for variable stars and periodicities **[14]**, **[15]**. This has been done in collaboration with Peter De Cat (Dep. II) and the IVS, this year in particular with Kristof Goossens. He presented his 'Licentiaatsthesis' on this subject.

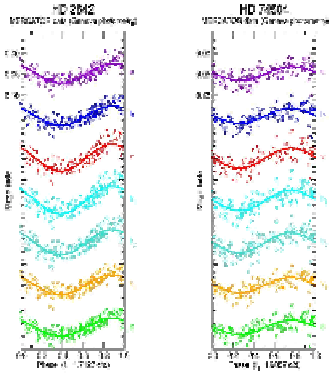


Figure 20: Light curves in the 7 filters of the Geneva system for the γ Doradus stars HD 2842 and HD 74504

The spectroscopic study of the southern γ Doradus stars was finished (see the publications by De Cat (Dep II) et al **[13]**, **[16]**). The γ Doradus stars photometrically observed with the Mercator telescope (Figure 20) were studied in more detail and a preliminary report was presented. A quality analysis of these data was done in order to assess the importance of data on nights of lower quality. These data were combined with earlier observations by the satellite Hipparcos or from other ground-based ob-

servatories in order to improve the accuracy of the periods, phases and amplitudes found. This was not in all cases successful yet.

The study of the β Cephei variable star in the eclipsing binary HD92024 was done in collaboratrion with Brussels (VUB), Croatia and Liege (ULg). The mass of observations has been collected during the last 15 years from ESO, La Silla with, in particular, 4-colour photometry from the Strömgren Automatic Telescope and high-resolution spectroscopy from the FEROS instrument (ESO 1.5m). The system has **[4]** two B1III and B7-B9V components of 15 and 3 solar masses, radii of 8.4 and 2.1 solar radii and temperatures of 25500 and 12500 K. Detailed analysis of line-profile variations in all lines in the wavelength region from H-alpha to H-epsilon indicated that about 30 lines contained significant pulsational information. An initial pulsational analysis of the 103 FEROS spectra was performed **[11]** for three oscillation frequencies known from photometry. The results were presented at a conference in Rome with the following conclusions: line-profile variations from different He and Si lines exhibit similar variations and by combining their information, the significance of the spectroscopic variability can be enhanced. Two mode identification procedures were tried and consistently indicated that the frequencies f1 and f3 are both modes of degree $\ell = 2$, while f2 is either $\ell = 4$ or $\ell = 6$. The moment method was also tried, but had little distinctive power on the current set of data and in particular for the high-degree mode of f2. These results are, however, very promising for subjecting HD 92024 to an asteroseismic analysis where, e.g., assumptions based on the known orbital inclination will constrain the parameter space considerably.

The paper on the line-profile variability of another pulsating star in a bright spectroscopic binary (κ Scorpii) appeared **[1]**.

Of a few δ Scuti stars a period analysis was performed. The analysis of the multiple star system DG Leo was completed. A detailed description of the results obtained on this system and other multiple star systems with pulsating components can be found in the report of Dep. II (**[3][9][10]**).

In collaboration with Brussels (VUB), Rome (OAR), Germany (Potsdam), Canada (DAO) and Denmark (CUAO) a photometric investigation was carried out on the globular cluster ω Centauri with the purposes of detecting and studying variables **[12]**, and to study the cluster's complex evolution history **[7][8]**. The observational basis consists of FORS observations (Chile, Paranal) obtained at high angular resolution (0.3 arcseconds), about 5000 time-series data points from the Danish 1.5 meter (optical, La Silla), the 3.5 meter NTT (near-infrared, La Silla) and observations from the ESO archive (optical/near-infrared, WFI/2.2m, HST, VLT).

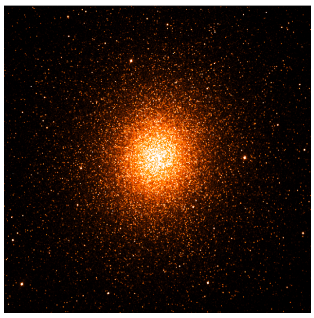


Figure 21: The globular cluster ω Centauri

An investigation of ω Centauri's reddening distribution was also performed **[6][17]** and showed foreground and internal reddening variations of up to a factor of two across the cluster, which has implications for photometric studies of the cluster's stars. The cluster's variables of the types RR Lyrae and SX Phe are being studied **[18]** in near-infrared wavelengths as well in order to establish their Period-Luminosity relations in these bands, where these relations are less affected by the cluster's intrinsic spread in metallicity and their light curves more symmetric appearances. An estimate of the cluster distance was made with these relations using 181 RR Lyrae stars to yield 5.52 ± 0.13 kpc, in nice agreement with a distance derived separately by Thompson et al. (2001) using an eclipsing binary in ω Centauri.

In the open cluster NGC 1817 one of the largest known populations of δ Scuti stars could be identified and a paper on this was accepted **[5]** by the Publications of the Astronomical Society of the Pacific. This was a result of collaboration with IfA (Denmark) and VUB (Belgium).

The paper on the high-latitude supergiant HD190390 in collaboration with Maarten Reyniers of the IVS appeared in A&A **[2]** and a poster on this subject was presented at the meeting of the Nederlandse Astronomenconferentie (NAC) in Blankenberge.

B.1.3. Perspective for next years

The analysis of the periodic variables observed by the Mercator telescope will be continued in collaboration with the IVS.

A new reduction and analysis of earlier data on γ Doradus stars observed at SAAO (South Africa) in the frame of an international collaboration will be continued. This will happen in collaboration with Laurent Eyer (Observatoire de Genève, Suisse) and Peter De Cat (ROB).

The identification of the non-radial pulsation modes in HD92024 will be performed.

Some insight will be gained in the methods of classification of light curves of variable stars observed with the satellite COROT (to be launched at the end of 2006). The preparatory work for the ESA-satellite GAIA (launch in 2011) in the context of variable star detection, period search and classifications will be resumed. This is also in collaboration with Laurent Eyer and Peter De Cat (ROB).

Period analyses of stars of different type will be continued. Attempts will be made to optimize the algorithms to analyze a huge amount of stars simultaneously.

B.1.4. Personnel involved

Scientific staff: J. Cuypers
H. Hensberge
P. De Cat (Dep 2)
L.M. Freyhammer (IAP P5/36, till end of August 2005)

B.1.5. Partnerships

List of national and international partners

- Belgian Asteroseismology Group: Instituut voor Sterrenkunde (KULeuven), Institut d'Astrophysique et de Géophysique (Ulg, Liège), Observational Astronomy Group (VUB, Brussel) and others
- Department of Physics, University of Zagreb, Croatia
- Astronomical Observatory of Rome (OAR), Italy
- Astrophysikalisches Institut Potsdam (AIP), Germany
- Department of Physics and Astronomy, Aarhus University, Denmark
- Astronomy Observatory, Niels Bohr Institute for Astronomy, Physics and Geophysics, Copenhagen University, Denmark
- Observatoire de Genève, Switzerland
- Dominion Astronomical Observatory, Canada

Grants used for this research

- IAP P5/36: "Modern aspects of theoretical and observational (ground-based and space-born) astrophysics", main promotor: J.P. Swings (Ulg); promotors: C. Waelkens (K.U.Leuven) C. Sterken (VUBrussel) and H. Hensberge (ROB).
- FWO-project G.0178.02: "Observational study of Stars in Stellar Systems", promotor: C. Aerts, K.U.Leuven; co-promotor: H. Dejonghe (UG), C. Sterken (VUB), C. Waelkens (K.U.Leuven) and J. Cuypers (ROB).

Visitors: 2

B.1.6. Publications

B.1.6.1. Publications with peer system

[1] Uytterhoeven K., Briquet M., Aerts C., Telting J.H, Harmanec P., Lefever K., **Cuypers J.**
Disentangling component spectra of κ Sco, a spectroscopic binary with a pulsating primary. II. Interpretation of the line-profile variability

Astron. Astrophys. 432, 955-967

[2] Reyniers M., **Cuypers J.**
The evolutionary status of the bright high-latitude supergiant HD190390
Astron. Astrophys. 432, 595-608

[3] **Lampens P., Frémat Y.**, Garrido R., Peña J.H., Parrao L., Van Cauteren P., **Cuypers J., De Cat P.**, Uytterhoeven K. & Hobart M.
A Photometric Study of the Light Variations of the Triple System DG Leo,
Astron. Astrophys. 438, 201-209

[4] **Freyhammer L.M., Hensberge H.**, Sterken C., Pavlovski K., Smette A. & Ilijic S.
The β Cephei variable in the eclipsing binary HD92024 I. Determination of the orbit
Astron. Astrophys. 429, 631

[5] Arentoft T., Bouzid M. Y., Sterken C., **Freyhammer L. M.**, Frandsen S.
A Dozen δ Scuti Stars in the Open Cluster NGC 1817
The Publications of the Astronomical Society of the Pacific, Volume 117, Issue 832, pp. 601

[6] Calamida A., Stetson P. B., Bono G., **Freyhammer L. M.**, Grundahl F., Hilker M., Andersen M. I., Buonanno R., Cassisi S., Corsi C. E., et al.
Reddening Distribution across the Center of the Globular Cluster ω Centauri
The Astrophysical Journal 634L, 69

[7] **Freyhammer L. M.**, Monelli M., Bono G., Cunti P., Ferraro I., Calamida A., Degl'Innocenti S., Prada Moroni P.G., Del Principe M., Piersimoni A.,et al.
On the Anomalous Red Giant Branch of the Globular Cluster ω Centauri
The Astrophysical Journal 623, 860

[8] Monelli M., Corsi C.E., Castellani V., Ferraro I., Iannicola G., Prada Moroni P.G., Bono G., Buonanno R., Calamida A., **Freyhammer L. M.**, et al.
The Discovery of More than 2000 White Dwarfs in the Globular Cluster ω Centauri
The Astrophysical Journal 621L, 117

B.1.6.2. Publications without peer system

[9] **Lampens P., Frémat Y.**, Garrido R., Peña J.H., Parrao L., Van Cauteren P., Cuypers J., **De Cat P.,** Hensberge H., Arentoft T., Mathias P. & Hobart M.
Pulsation of the δ Scuti Multiple System DG Leo
In The A-Star Puzzle, eds. J. Zverko, W. W. Weiss, J. Ziznovsky & S. J. Adelman, IAU Symp. 224, 835-839

[10] **Lampens P., Frémat Y.**, Uytterhoeven K., **Cuypers J.**
Pulsating components in multiple systems
Tidal Evolution and Oscillations in Binary Stars: Third Granada Workshop on Stellar Structure, eds. A. Claret, A. Giménez and J.-P. Zahn, ASP Conference Series, Vol. 333, 149

[11] **Freyhammer L.M., Hensberge H.**, Sterken C., **De Cat P.** and Aerts C.
The oscillation modes of the β Cephei star in HD 92024 in the open cluster NGC 3293
In "Memorie della Societá Astronomica Italiana", Vol. 76/4, eds. A.R. Walker & G. Bono

[12] Calamida A., Bono G., Buonanno R., Corsi C.E., Monelli M., Dall'Ora M., **Freyhammer L.M.**, Munteanu A.
Eclipsing binaries in the galactic globular cluster ω Centauri
AIP Conference Proceedings, Volume 797, pp. 61-67

B.1.6.3. Publications in press, submitted

[13] **De Cat P.**, Eyer L., **Cuypers J.**, Aerts C., Vandenbussche B., Uytterhoeven K., Reyniers M., Kolenberg K., Groenewegen M., Raskin G., Maas T.,
A spectroscopic study of southern (candidate) γ Doradus stars. I. Time series analysis,
Astron. Astrophys., in press

[14] **De Cat P.**, Briquet M., Aerts C., Goossens K., Saesen S., **Cuypers J.**, Yakut K., Scuflaire R., Dupret M.-A. et al.
Analysis of Mercator data Part I: variable B stars
in press and already available as Electronic Proceedings Jenam conference (Liège, 2005) http://www.astro.ulg.ac.be/RPub/Colloques/JENAM/proceedings/proceedings.html

[15] **Cuypers J.**, Goossens K., Schoenaers C, **De Cat P.**, Aerts C., et al.
Analysis of Mercator data Part II: variable A & F stars
in press and already available as Electronic Proceedings Jenam conference (Liège, 2005) http://www.astro.ulg.ac.be/RPub/Colloques/JENAM/proceedings/proceedings.htm

[16] **De Cat P.**, Goosssens K., Bouckaert F., Eyer L., **Cuypers J.**, De Ridder J., Aerts C., Dupret M.-A., Grigahcène A., et al.
Observational results for northern and southern (candidate) γ Doradus stars
Proceedings of the workshop on "Stellar Evolution and Pulsation" (Rome, 2005), Mem. S.A.It, vol.75, 282-285, in press

[17] Calamida A. Stetson P.B., Bono G., **Freyhammer L.M.**, Buonanno R., Corsi C.E., Hilker M., Grundahl F. and Monelli M.
Multiband photometry of stellar populations in ω Centauri
In "Memorie della Societá Astronomica Italiana", Vol. 76/4, eds. A.R. Walker & G. Bono.

[18] Del Principe M., Piersimoni A.M., Bono G., Storm J., Caputo F., Cassisi, **Freyhammer L.M.**, Marconi M. and Stetson P.B.
Near-Infrared Observations of RR Lyrae Variables in ω Centauri
In "Memorie della Societá Astronomica Italiana", Vol. 76/4, eds. A.R. Walker & G. Bono.

B.1.6.4. Reports, theses

[19] **J. Cuypers**
End Report FWO Project G.0178.02 (Observational Study of Stars)

[20] **J. Cuypers**
Preliminary report on the Analysis of A & F stars observed with the Mercator telescope.

B.1.7. Scientific outreach

Meeting presentations

[21] **J. Cuypers**
Analysis of Mercator data Part II: variable A & F stars
JENAM 2005 (Joint European and National Astronomy Meeting), session "Asteroseismology", Liège, 06-07/07/05

[22] **P. De Cat, J. Cuypers**
Analysis of Mercator data Part I: variable B stars
JENAM 2005, session "Asteroseismology", Liège, 06-07/07/05 (talk by Peter De Cat)

[23] **M. Reniers, J. Cuypers**
The high-latitude supergiant HD190390: bright but obscure
Nederlandse Astronomenconferentie, Blankenberge, 18-20/05/05, poster

[24] **L. Freyhammer**
Conference Stellar Pulsation and Evolution: Theory and Observations, Monte Porzio Catone, Italy, 17-25/06/2005: Three posters

National and international responsibilities

- **H. Hensberge** is promotor for ROB in IAP Project P5/36 of ULg-KULeuven-VUB-ROB: Modern aspects of theoretical and observational (ground-based and space born) astrophysics.

Educational responsibilities

- **H. Hensberge** was member of jury PhD thesis of L. Freyhammer (VUB, January 2005)
- **P. De Cat**:
  - co-supervised, in collaboration with **J. Cuypers** and C. Aerts (KUL), the master thesis "Analyse van Mercatorgegevens van variabele sterren" of Kristof Goossens (2004-2005, KUL)
  - is a member of the follow-up commission of Maarten Desmet (KUL), who started his PhD research on 01/10/2005. Since one of his first tasks is to perform the reduction of the multi-site observations of the β Cep star 12 Lacertae, he is helping him with the reduction of the spectroscopic data.
  - gave an introduction on photometric mode identification in the course of the master thesis of Sophie Saesen (K.U.Leuven).
  - was a member of the evaluation commission of the student talks presented at the PhD Conference on Astrophysics of Variable Stars (05-10/09/2005, Pécs, Hungary).

B.1.8. Missions

Assemblies, symposia (number):	J. Cuypers (3) H. Hensberge (3) L. Freyhammer (1)
Research visits:	L. Freyhammer (22)
Field missions (days):	J. Cuypers (31) H. Hensberge (10) L. Freyhammer (14)

B.2. Binaries and stellar groups

B.2.1. 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. The main goals are to (1) 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, and (2) characterize the stellar populations in selected young stellar groups in general and, as a long-term goal, to measure the internal velocity dispersion in the Sco-Cen association and the open cluster NGC 2244.

B.2.2. Progress and results

From the observational side, the search for binaries among the fainter members of Sco-Cen was continued using the echelle spectrograph GIRAFFE at SAAO (cooperation with UA). The same observing run was used to collect observations at critical orbital phases for the A-type star binary HR 6412, namely in mid-eclipse and near periastron. HR 6412 is an eclipsing binary with a long (38 days), eccentric orbit, studied in cooperation with L.P. Vaz at UFMG, Belo Horizonte. In late 2003, the cooperation extended to KU Leuven, to complete the light curve at the Mercator telescope. Two eclipses of 20 hours each need to be

covered in detail. Depending on weather conditions, full photometric and spectroscopic coverage could be obtained already in 2006.

At ESO, high-resolution spectroscopy was obtained for the second time during the eclipse of the B-type binary HD 123335, mapping a different part of the surface of the peculiar, magnetic component. This is cooperation with VUB, UA and UFMG.

The data reduction of the specific subsample of 40 candidate wider binaries in Sco-Cen, selected earlier in cooperation with Pourbaix (ULB) using Hipparcos astrometry, was performed, with the application of the final rectification procedures still lacking, partly because changes in the calibration unit require software adaptations.

Combining the spectral disentangling technique with the analysis of the eclipsing light curve, the orbit and absolute dimensions of the close binary in the hierarchical triple RV Crt were determined **[2]**. The stars appear to be pre-main sequence stars, with the lighter one being the larger one and more distant from the main sequence. The third component shows Li in its sharp-lined spectrum, as expected for a young star. Further analysis of the component spectra will be undertaken as part of the PhD thesis that K. Torres started in 2004. She will work one year at ROB starting March 2006, paid on a Brazilian fellowship.

As part of the cooperation with S. Daflon (Observatorio Nacional, Rio de Janeiro), the lacking high-resolution echelle (CASPEC) spectra of fairly sharp-lined OB stars in NGC 2244 were prepared for analysis at ON. In the same framework, help in data reduction of Brazilian FEROS echelle spectra was provided. The abundance analysis of the eclipsing binary in NGC 2244 was published **[1]**. The cooperation with KU Leuven on the search of pulsating stars in this young cluster has not yet delivered data because of bad weather conditions.

A refinement of the quantitative description of the stellar content of NGC 2244 from the data presented in the PhD of Verschueren has started in cooperation with Gh. Deridder (Toronto, Canada) but is still far from concluded. This work will profit also directly from the abundance analyses performed at ON.

B.2.3. Perspective for following years

1. Identification of binaries in the Hipparcos-selected subsample of stars in Sco-Cen. Analyse and interprete the spectroscopic data of the binary search program in Sco-Cen, and investigate the usefulness of different observing techniques (e.g. interferometry) to improve the completeness of the binary sample.
2. Detailed analyses on specific binary systems. Priority in 2006 goes to the analysis of RV Crt (paper on absolute dimensions of components) and the finalization of a the refereed paper on HD123335 and η Mus and the completion of the data set for the A-type binary HR6412.
3. A refinement of the quantitative description of the stellar content of NGC 2244. It includes the interpretation of Walraven photometry, low-resolution spectra taken at OHP and high-resolution spectra taken with various echelle spectrographs. This will take several years.

B.2.4. Personnel involved

Scientific staff: J. Cuypers
H. Hensberge
L.M. Freyhammer (IAP P5/36, till end of August 2005)

B.2.5. Partnerships

List of national and international partners

- Universiteit Antwerpen, Vrije Universiteit Brussel, KULeuven (IvS)
- Universidade Federal Minas Gerais, Belo Horizonte, Brazil
- National Observatory, Rio de Janeiro, Brazil
- University of Zagreb, Croatia

- Niels Bohr Institute for Astronomy, Physics and Geophysics, Copenhagen University, Denmark

Grants used for this research

- IAP P5/36: "Modern aspects of theoretical and observational (ground-based and space-born) astrophysics", main promotor: J.P. Swings (Ulg); promotors: C. Waelkens (K.U.Leuven), C. Sterken (VUBrussel) and H. Hensberge (ROB).

Visitors: 3

B.2.6. Publications

B.2.6.1. Publications with peer review

[1] Pavlovski K., **Hensberge H.**
Abundances from disentangled component spectra: the eclipsing binary V578 Mon
A&A 439, 309-315

B.2.6.2. Publications without peer review

B.2.6.3. Publications in press, submitted

[2] **Hensberge H.**, Vaz L.P. R., Torres K.B.V., Armond T.
Spectral disentangling applied to triple systems: RV Crt
In: Multiple Stars across the H-R Diagram, ESO Astrophysics Symposia, Proceedings of the ESO Workshop held in Garching, Germany, 12-15 July 2005, S. Hubrig, M. Petr-Gotzens and A. Tokovinin (eds.), in press

B.2.7. Missions

Field missions (days): L. Freyhammer (17)

C. Cataclysmic stellar events

The projects discussed here were introduced by H. Boffin before his leave to the E. S. O. headquarters in Garching. The theoretical project on chemical evolution of galaxies has been since redirected and emphasizes now the thermonuclear burning at the surface of accreting compact stars. The second project aims at the study of the accretion disk and its structure in cataclysmic variables, and is observationally oriented. Both projects depend on temporary contracts, of which one ended in 2005 and the other will end in 2006 and the future of this research theme at the Observatory is uncertain, despite the broad cooperation with Belgian universities.

C.1. Chemical evolution of galaxies

C.1.1. Objectives

The goal of this multidisciplinary research project is to develop computing tools that will allow the exploration of the multidimensional aspects of the propagation of a thermonuclear combustion front in degenerate stellar plasma. The ultimate goal of this endeavour is the study of the nucleosynthesis associated with different cataclysmic stellar events (SNIa, Classical Novae) as well as the development numerical methods which can contribute to the future development of multi-dimensional (3d) stellar hydrodynamics.

C.1.2. Progress and results

In a first step, we are interested in modelling supersonic reactive flows, or *detonations*, consisting of a precursor shock wave igniting combustible stellar plasma and a reaction zone immediately behind the

shock. Beyond the uni-dimensional picture, terrestrial detonation experiments clearly show that the detonation front consists of sets of incident shocks, transverse waves and Mach stems all interacting to form cellular structures wherein pockets of unburnt gas can subsist. The cellular tri-dimensional nature of detonations could play a significant role in the thermonuclear explosion of the accreted matter on a white dwarf star. The aim of our numerical study is to investigate the complex dynamics of the reaction front and the concomitant nucleosynthesis in a potentially interesting situation for the chemical evolution of galaxies.

In this context, in 2004 we developed a Riemann solver adapted to the equation of state appropriate to the stellar plasma of the explosive mixture. This module has been inserted in a 2d/3d eulerian hydrocode designed for the project. This research is conducted in collaboration with the IAA-ULB and Prof. M Palexandris (UCL). The next step, started in November 2004, was the development of the nucleosynthesis part of the code. A general operator splitting algorithm based on "Strang splitting", wherein nuclear kinetics and energy generation are considered together with the hydrodynamic calculation, was investigated. In 2005, this algorithm was put and tested on different simple cases of "thermonuclear shock tube" in which a detonation appears.With the hydrodynamics code developed since 2003, we can perform now our first bidimensional simulations incorporating a realistic stellar equation of state and a limited nuclear reactions network (an "alpha-chain" extending from ^{4}He to ^{56}Ni) for the energy generation. A slightly perturbed ZND profile is used as initial condition to produce (2d) cellular structures in the detonating stellar plasma.

Concurrently to this work of computational fluid dynamics, we worked on the preparation of a tool for computing in detail the structure of a planar detonation front according to the model of Zeldovich-Von Neuman-Doering (ZND). This program, adapted to the equation of state of the astrophysical plasma, serves to calibrate the characteristic length scales which appear in the 2d hydrodynamic simulations envisaged. In particular, it will be also used to study, by means of the most complete nuclear kinetics possible, the potential pathologies due to endothermic processes inside the reactive wave. This research is conducted in collaboration with the IAA-ULB and the Laboratoire de Combustion et de Détonique (CNRS-Poitiers-France). The effort carried out with the team of the LCD - Poitiers leads actually to the re-examination - with more extended nucleosynthetic networks and diverse initial nuclear mixtures - of results obtained by Sharpe (1999) in planar detonations and later in curved geometry (Sharpe, 2001).

C.1.3. Perspective for next years

None, because of end of temporary contract.

C.1.4. Personnel involved

Scientific staff: Y. Busegnies, Supplementary researcher (3/4) and IAP P5/36 researcher (1/4)

C.1.5. Partnerships

List of national and international partners

- Astrophysics, Université Libre Bruxelles
- Université Catholique de Louvain
- Université de Bordeaux
- Combustion laboratories in Poitiers and Marseille, France
- Dépt. d'Astrophysique du Commissariat à l'Energie Atomique, Saclay, France

Grants used for this research

- IAP project P5/36 (1/4 researcher)

Visitors: 0

C.2. Cataclysmic variables (CV)

C.2.1. Objectives

This research started in October 2002 and constitutes part of the PhD thesis of Christina Papadaki, which is conducted at the VUB under the supervision of promoter C. Sterken and co-promoter H. Boffin at the European Southern Observatory. It is mainly devoted to the better understanding of the accretion disc phenomena and the underlying viscosity sources of non-magnetic cataclysmic variables (CVs), called dwarf novae and nova-likes. This study is based on both photometric and spectroscopic data.

C.2.2. Progress and results

In 2005 two observing sessions have been performed in order to obtain additional data. Those data combined with other acquired before **[2]**. Time-resolved photometry of five poorly known CVs is presented; while for one of them data were also acquired from the ING archive. The observations were made using four 1-m class telescopes (SAAO, Hoher List Observatory, Krioneri Observatory and Skinakas Observatory), for a total of more than 250h of observations. A short summary follows in the next paragraph.

For the first time the orbital period of V1193 Ori was confirmed photometrically and the light variation with a period equal to the orbital period is attributed to the extra light of the side of the secondary that is face on with the primary, i.e. the irradiation of the companion star. Evidence was also found for a QPO around 20min and the high amplitude flickering was confirmed. “Red noise” which is assumed to be due to flickering through a shot noise-like process is present in the light curves and clearly visible from the linear part of the average power spectrum (PS) in log-log scale. In LQ Peg, a clear modulation of 2.99h, possibly a superhump period, was detected. Flickering was found to vary within a narrow interval and a candidate QPO, resolving into two components, was also detected near 30min. “Red noise” was once more present. For this object, WHT spectra were extracted from the ING archive. Both the blue and the red arm spectra show single-peaked emission lines. All lines are weak compared to continuum and show no orbital radial-velocity variations. Some possible explanations such as a disc wind, a very low inclination of the system, or emission-line components produced by the irradiating side of the secondary are suggested. LD 317 showed no periodic signal, but very strong flickering activity was always present. Combining the facts that it was already proposed to be a NL CV, that in our observations it appeared to fade by 1 mag in an interval of approximately 50d and that it appears in an even lower state in 2005, it must belong to the VY Scl subtype. In this respect the system must have been observed during two fading episodes, one in 2003 and one in 2005. Judging by its mean magnitudes the star fades by at least 2.5 mag. Unfortunately the coverage of the available runs was insufficient to reveal any rising episodes. Light curves from AAVSO observers, before our 2003 data and during autumn 2004, show that in October 2003, the system was already in a fading episode, but still brighter than when we observed it. It also seems that it started a fading episode in October 2004. At that time, it was still much brighter than in January 2005. All resulting light curves of V795 Her reveal the 2.8h modulation and its high amplitude. The previously reported QPO near 80c/d, as well as its resolution into two components could be confirmed. In our campaign, the frequency of the modulation, the amplitude and the phase did not prove stable. This has been reported before and it is inevitable since the modulation is by now strongly and broadly believed to be a superhump and superhumps are known for such instabilities. We therefore favour the disc-precessing model with the superhump period being unstable not only in period and amplitude but also in phase for time intervals longer than 20d. Last but not least, the two runs of MCT 2347-3144 show a difference in the mean magnitude of the system, which appears brighter in 2003. In 2002, the most likely period is around 6h. In 2003, no periodicity was found. This could, however, be attributed to the increase - by a factor 0.5 - of the flickering. Possible QPOs have been detected near 25 and 50c/d.

The reduction of all echelle spectroscopic data, obtained by H. Boffin in 1999 with the ESO NTT, La Silla (Chile), is now completed. These data concern 4 CVs: IP Peg, AT Ara, UU Aqr and V2051 Oph. Particular care had to be taken in the reduction process to allow for a better interorder combination of the

spectra and for their flux calibration. For one of them, IP Peg, a preliminary analysis has been presented in **[1]**. This contains the phase folded spectra accompanied by preliminary Doppler maps, constructed after applying the Doppler imaging technique to our set of spectra.

C.2.3. Perspective for next years

Concerning the spectroscopic data, the analysis on IP Peg will be completed. The same procedure will then be applied for the analysis of the remaining three CVs for which spectroscopic data are available. These unique high resolution and large wavelength coverage echelle spectra provide us with several emission lines whose simultaneous study allows us to probe in detail the structure of the accretion disc and the contribution of the secondary phase.

As far as photometric data are concerned, there are still ten CVs for which we have obtained data throughout the period of my Ph.D. However not all targets are extensively observed. Our aim is to analyse all available photometric data, which are already reduced, and organise them in one paper. It is possible that additional data will be needed if one of the remaining CVs reveals peculiarities of special interest.

C.2.4. Personnel involved

Scientific staff: C. Papadaki (Action 2 PhD grant)
J. Cuypers (limited involvement)

C.2.5. Partnerships

List of national and international partners

- National Observatory of Athens, Greece
- Physics Department, University of Crete, Greece,
- Physics Department, Stockholm University, Sweden,
- Astrophysical Institute of the Academy of Sciences, Sofia, Bulgaria,
- Harvard-Smithsonian Center for Astrophysics, Cambridge, USA

Grants used for this research

- Belspo PhD grant (Action 2)

Visitors: 1

C.2.6. Publications

C.2.6.1. Publications without peer review

[1] **Papadaki C.**, Boffin H.M.J., Steeghs D.
Simultaneous Doppler Maps of IP-Peg in outburst
ASPC, 330, 373

C.2.6.2. Publications in press, submitted

[2] **Papadaki C.**, Boffin H.M.J., Sterken C., Stanishev V., **Cuypers J.**, Boumis P., Akras S., Alikakos J.
Photometric study of selected cataclysmic variables
Astron. Astrophys., accepted

C.2.7. Missions

Research visits (days): C. Papadaki (10)
Field missions (days): C. Papadaki (27)

D. HERMES echelle spectrograph

D.1. Hardware and software development

D.1.1. Objectives

HERMES is a bench-mounted fibre-fed cross-dispersed echelle spectrograph that will be installed on the 1.2 m MERCATOR telescope located at the Roque de los Muchachos international observatory on La Palma, Spain. It is build by a consortium lead by the Instituut voor Sterrenkunde of the KU Leuven. The spectrograph is developed with the aim to serve projects requiring long-time monitoring and time-critical observations using a system of pooled observations.

D.1.2. Progress and results

The main responsibilities of the Royal Observatory in this project are, besides the participation in the general lay-out of the instrument, (a) the development of the data reduction software, and (b) the involvement in the technical aspects similar to those for which experience was gained in the D4A digitalization project.

With regard to the software definition and development, a work package was defined (WP900) and a two-day workshop was organized to explain the scientist of the consortium the intricacies of echelle data reduction, providing a basis for technical choices to be made in an early stage. Several follow-up meetings of the WP900 group were organized, and a lay-out for the data reduction package was produced. A large number of scientists from department 2 and 3 participated in the discussions, confirming the interest for this project at the Observatory. This lay-out is currently refined. The software will contain a first-look pipeline, a refined differential data reduction system that should deliver the spectra to be archived as well as quantitative indications on the limitations of the automated reduction procedure, and software routines to assist astronomers to improve the archived data, if required by their project.

With regard to the technical aspects, experts from the Thüringer Landessternwarte Tautenburg were contacted on initiative of the ROB to evaluate the optical design of the instrument. They decided to participate fully as a consortium member. Several consortium meetings were attended and special attention was given to the choice of the CCD detector financed by a FNRS grant to the ULB. A significant part of the time investment went into the design of the climatisation of the spectrograph room.

D.1.3. Perspective for next years

In 2006, the proper development of the data reduction software will start. Help by an ICT expert as well as of some scientist with limited involvement at present is envisaged. The software must be available before the end of 2007. However, some parts will require input that may only become available in the commissioning time of the instrument. The Lotto budget will be used to buy the optical elements of the spectrograph. Involvement in design and construction of mechanical parts and the climatisation system is planned.

D.1.4. Personnel involved

Scientific staff: H. Hensberge (project leader)
J.-P. De Cuyper
G. Van de Steene (limited involvement)
P. De Cat, Y. Frémat, P. Lampens (all dep. 2, limited involvement)

D.1.5. Partnerships

List of national and international partners

- IvS KULeuven, ULB
- Thüringer Landessternwarte Tautenburg
- Observatoire de Genève

Grants used for this research

- Lotto-uitrusting 2004: Onderdelen voor de opbouw van een hoge resolutie echelle spectrograaf voor de 1.2 m MERCATOR telescoop

Visitors: 3

D.1.6. Publications

Report on the lay-out of the data reduction software

D.1.7. Scientific outreach

National and international responsibilities

- H. Hensberge is promotor for ROB in the HERMES Project of KULeuven-ULB-ROB: Construction of an echelle spectrograph for use at the MERCATOR telescope. He is in charge of the work package on Data Reduction.
- H. Hensberge, P.Lampens, J. Cuypers, J.P. De Cuyper, P. De Cat, G. Van de Steene are member of the HERMES Consortium

D.1.8. Missions

Commissions, working groups (days): H. Hensberge (8)

E. Solar Spectroscopy

E.1. Solar Abundances and relevant Spectroscopic Data

E.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 both in solar and stellar physics.

The lack of consistent spectroscopic data (especially gf-values) for IR atomic lines present in the solar spectrum has led us to the creation of a solar-calibrated data base to be used for the calculation of synthetic IR spectra of cool stars.

E.1.2. Progress and results

New solar abundances have been derived from analyses of the photospheric spectrum. They result from the use of a three-dimensional (3D) hydrodynamical model of the solar atmosphere instead of classical 1D hydrostatic models (adopted during more than four decades), accounting for departures from LTE and improved atomic and molecular data. The new solar abundances for C, N and O are lower than previously recommended values and the present solar metallicity, Z, is almost a factor two lower than the earlier widely used value **[1-6]**. This new solar composition implies a decrease of the metal content in the solar convection zone and poses serious challenges, most notably for helioseismology.

My other time-consuming work is related to a *solar-calibrated spectroscopic data bank in the infrared.*

A comparison of ISO (Infrared Space Observatory) and synthetic spectra of cool stars (in collaboration with spectroscopists at the KULeuven) has clearly revealed a rather large disagreement due to the adopted atomic line data. Accurate data bases are available for most of the molecular transitions observed in IR solar and stellar spectra. On the contrary, there is a lack of accurate atomic data banks in the IR region:

gf-values are lacking or very uncertain for lots of lines. Therefore I started a new line list, first adopting spectroscopic data from existing files such as solar line lists by Geller (1992) and by Melendez & Barbuy (1999) as well as data bases by Hirata & Horaguchi (1995) and by van Hoof (1999). An empirical solar gf-value has been derived for any contributing atomic line from a line-by-line fit of observed solar (ATMOS and Mark IV - JPL) space spectra or ground-based spectra recorded at Jungfraujoch and at Kitt Peak. In a few spectral regions showing very strong atmospheric absorptions (250-625 cm^{-1}; 6700-7460 cm^{-1} and 8675-8970 cm^{-1}) the line data is rather uncertain in the absence of space spectra.

My present data base covers the spectral region from 250 to 10000 cm^{-1} (1-40 µm) and includes about 113000 lines of which 92000 molecular lines (CO, CH, CN, C_2, NH and OH), 17000 identified atomic lines and 3800 unidentified lines (they are very probably high excitation lines of the iron-peak elements, as yet not observed in the lab). For any line, we give the relevant following parameters: line wavenumber (cm^{-1}), spectroscopic designation, excitation potential (cm^{-1}), "solar" log gf-value (and also other laboratory or theoretical gf-values from other data bases), enhancement factor of the classical (Unsöld) damping constant, ...

Interim versions of this data base have already been successfully adopted for interpreting ISO spectra (2.38-12 micron) of cool stars with a nearly solar composition (see Decin et al.: A&A 364, 137, 2000 and A&A 400, 679-727, 2003) and have also been helpful to a team of geophysicists for disentangling the pure solar part and that of the earth's atmosphere from the observed solar spectrum between 700 and 5000 cm^{-1} **[7]**.

E.1.3. Perspective for next years

As an active retired astrophysicist my intention is mainly to collect as yet unpublished results obtained in collaboration with N. Grevesse (Univ. Liège), M. Asplund & P. Scott (Mt Stromlo Obs.), F. Hase (IMK Karlsruhe) et al.

My solar-scaled spectroscopic data bank should be available on the web around mid 2006 in order to support the interpretation of IR spectra of cool stars obtained from space missions (ISO, Spitzer Space Telescope …).

E.1.4. Personnel involved

Scientific staff: A.J. Sauval, retired

E.1.5. Partnerships

List of national and international partners

- Université de Liège (N. Grevesse)
- Mount Stromlo Observatory, Australia (M. Asplund, P. Scott)
- IMK Karlruhe, Germany (F. Hase)

Grants used for this research

Visitors: 1

E.1.6. Publications

E.1.6.1. Publications with peer review

[1] Asplund M., Grevesse N., **Sauval A.J.**, Allende Prieto C., **Blomme R.**
Line formation in solar granulation. VI. [CI], CI, CH and C2 lines and the photospheric C abundance
Astron. Astrophys. 431, pp. 693-705

[2] Asplund M., Grevesse N., **Sauval A.J.**, Allende Prieto C., Kiselmann D.

Line formation in solar granulation. IV. [OI], OI and OH lines and the photospheric O abundance
Astron. Astrophys. 435, pp. 339-340 (erratum)

[3] Asplund M., Grevesse N., **Sauval A.J.**
The Solar Chemical Composition
In: Cosmic Abundances as Records of Stellar Evolution and Nucleosynthesis, eds T.G. Barnes III & F.N. Bash, ASP Conf. Ser. 336, pp. 25-38 (review)

E.1.6.2. Publications without peer review

[4] Asplund M., Grevesse N., **Sauval A.J.**
The new solar abundances – Part I: the observations
In: JENAM Meeting, Liège, Communications in Asteroseismology 147, pp. 76-79

[5] Asplund M., Grevesse N., **Sauval A.J.**
The new Solar Chemical Composition
In: Element Stratification in Stars: 40 years of Atomic Diffusion, eds G. Alecian, O. Richard & S. Vauclair, EAS Publ. Ser. 17, pp. 21-32

E.1.6.3. Publications in press, submitted

[6] Scott P.C., Asplund M., Grevesse N., **Sauval A.J.**
Line formation in solar granulation. VII. CO lines and the solar C and O isotopic abundances
Astron. Astrophys. (submitted)

[7] Hase F., Demoulin P., **Sauval A.J.**, Toon G.C., Bernath P., Goldman A., Hannigan J.W., Rinsland C.
An empirical line-by-line model for the infrared solar transmittance spectrum from 700 to 5000 cm^{-1}
J. Quant. Spectrosc Rad. Transf. (submitted)

DEPARTMENT 4: Solar Physics

SECTIONS 8 & 9: Structure and Dynamics of the Solar Atmosphere & Solar Activity

Introduction: overall objectives and evolution of the Department

The year 2005 has been a very exciting year for the Department of Solar Physics. The year started with a renewal of our PRODEX projects (now PRODEX8), most of them for a period of two years (2005-2006), some of them for three years. The Solar Physics Department of the ROB thus continues to flourish, supplementing the limited Observatory dotation with a significant amount of external funding from peer-reviewed competitive tenders. At the end of 2005, the SIDC harbored 15 researchers and 6 project experts. The technical staff consisted of 5 people, including since January 1st 2005. Mr. A. Ergen. Two new contractual post-doc scientists were welcomed in the team, these are: Dr. I. Baumann and Dr. L. Rodriguez. The in-house science staff was supplemented by long-term visitors Dr. V. Slemzin, Dr. C. Marque, Mrs. J. Patoul and Mrs. K. Verheyen.

Up to 20 original science papers were published (+8 papers that are either in press or accepted for publication) during the year in internationally refereed journals. The self-imposed OPPY target (one paper per person per year) was thus successfully met in 2005 and we are close to 2 papers per active researcher. This has been an especially strong result taking into account that a lot of time & energy has not been available for publishing. Indeed, the permanent services (see below), the preparation of the SECCHI mission (launch 2006) and the PI-participation in SWAP and LYRA onboard PROBA2 (launch 2007) are requiring significant resources. New participations in future space mission after 2007 were actively searched for. Dr. J.-F. Hochedez became co-investigator on PREMOS (onboard CNES mission PICARD, launch 2008), Dr. D. Berghmans became co-investigator on AIA (onboard NASA mission SDO, launch 2008) as representative of the ROB.

In May 2005, Dr. R. Van der Linden – up till then acting department head – was nominated Director General of the Royal Observatory. After he left, Dr. D. Berghmans took up duty as acting department head of the Solar Physic Group. Dr. F. Clette remained in charge of the sub-team managing the ground-based instruments (see below). With only 2 senior scientists in permanent positions left within the group, a significant fraction of the project management was delegated to scientists in contractual positions. Dr. A. Zhukov (lead STEREO project) and especially Dr. J.-F. Hochedez (lead LYRA and EIT projects, work leader since April 2005) bring a much appreciated contribution in this respect.

Important changes also occurred in the ground-instrumentation. The solar physics activities at the radio-astronomy station in Humain were halted on July 31, 2006. Since then, the site and the remaining personnel came under direct control of the Director General. In many annual reports preceding the current one, it was pointed out that manpower was lacking to maintain both the Humain radio-astronomy station as well as the Uccle Solar Equatorial Table. At the same time, attempts to attract additional resources for the radio-astronomy station were not given a fair chance. Therefore the decision was finally taken to concentrate all manpower on the USET instruments and to abandon - at least temporary - radioastronomy in Humain while hoping for better times for radio solar physics in the future.

This drastic action has made it possible to concentrate the technical efforts on the USET instruments. Mr. J-L. Dufond and Mr. A. Ergen are now working as Lead and Assistant Instrument Technicians on the development, maintenance and operations of the USET instrument under the guidance of Dr. F. Clette. They are assisted by a contractual operator (Mr. O. Boulvin, Lead Observer) for the daily observations. Still the lack of technical staff remains problematic. One calculator position became vacant after a 2-year procedure in May 2005 (D.Carré, permanent invalidity). The procedure to have this position filled has been running since then and is now within the hands of SELOR. Two more retirements are foreseen in the coming year, putting the activities of the World Data Center for the Sunspot Index under serious pressure.

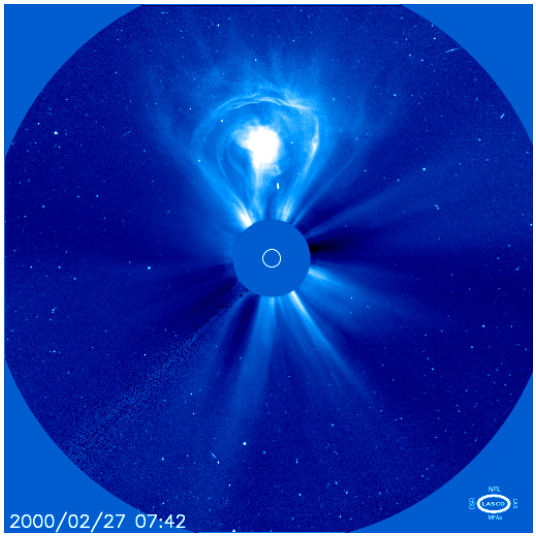
Already now the SIDC as World Data Center for the sunspot index can only survive thanks to the support of USET technical staff, post-docs and even the Director General. More stable manpower for the WDC is highly needed.

Despite this problematic situation, the daily operations of the SIDC – as a center for *scientific servicing* to the community – have been again an absolute success. Besides the production of solar observations from the USET telescopes (246 drawings and 1900 CCD images), the SIDC produced among others 365 daily ursigrams, 52 weekly bulletins, 12 Monthly Ri Reports, 12 Monthly Ri_hemispheric Reports and 79 presto alerts.

In order to remove the confusion that seems to exist over the relationship between the SIDC and the Solar Physics Department of the Royal Observatory of Belgium, it was decided to identify the name 'SIDC' with the entire scope of activities of the Solar Physics Department. In the remainder of this chapter, the term "SIDC" and the "Solar Physics Department" will be used in parallel and refer both to the full solar physics team at ROB, active in fundamental research as well as in scientific servicing. This report was edited by D. Berghmans on the basis of contributions by F. Clette, J.-F. Hochedez, R. Van der Linden and A. Zhukov.

A. CME Studies

Coronal Mass Ejections (CMEs) are probably the most spectacular phenomena observed on the Sun. A CME is a huge bubble of plasma threaded with magnetic field lines that is ejected from the Sun over the course of several hours. The Large Angle and Spectrometric Coronagraph (LASCO) on the Solar and Heliospheric Observatory (SOHO) is the first instrument that has detected CMEs routinely over a time-scale comparable with a solar cycle. At solar minimum we observe about one CME a week. Near solar maximum we observe an average of 2 to 3 CMEs per day.

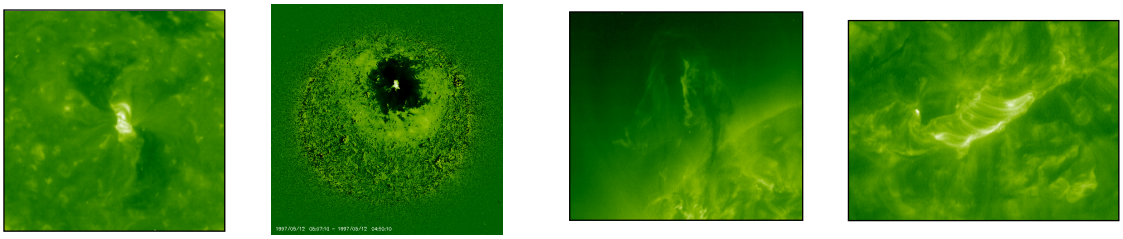


The study of CMEs is important for solar-terrestrial relations as some CMEs may be directed towards the Earth and – with a suitable magnetic field orientation – produce geomagnetic storms. They are therefore seen as the solar events causing the most hazardous space weather conditions on earth. They can trigger geomagnetic storms which e.g. affect the terrestrial communication and the reliability of power systems. (See Research Theme "Space Weather").

CMEs are mainly observed as intensity enhancements in coronagraphic white light images. However, the *origin* of CMEs cannot be traced by coronagraphs, as the occulting disc obscures a direct view of the initiation site. The Extreme-ultraviolet Imaging Telescope (EIT) onboard the Solar and Heliospheric Observatory (SOHO) with its full disc coverage is well suited for the detection of CME initiation in the solar atmosphere.

Figure 22: The "lightbulb" Coronal Mass Ejection (CME) showing the three classical parts of a CME: leading edge, void, and core. (SOHO/LASCO)

Studies have shown that a number of phenomena observed with EIT are indeed precursors to the CMEs seen by coronagraphs. These phenomena include dimmings, EIT waves, prominence eruptions and flares. None of these associated phenomena are however a necessary condition for the occurrence of a CME. Different CMEs can be generated or associated with a variable subset of this list. The observations made by EIT are used to obtain information about the still-enigmatic CME initiation mechanisms.



Dimming EIT wave Erupting prominence Post-eruption arcade

Figure 23: Different on-disc signatures of CMEs observed by EIT onboard SOHO.

At the ROB, we are interested in the understanding the complete CME process from its precursors on the solar disc, down to its effect on the Earth magnetosphere. This research theme thus naturally touches at the "Space Weather" research theme (see below) but is in contrast to the latter – which is of an applied nature – concerned with fundamental research. More specifically our fundamental questions are:

- *understanding the CME initiation process.* We want to understand which structures and events are precursors for CMEs. Based on the characteristics of the eruption source, can we determine the later evolution of the CME?
- *understanding the internal structure of CMEs*. What is the structure of an interplanetary CME? What is its 3D magnetic configuration? How can it be deduced from the observations?
- *understanding the geo-effectiveness of a CME.* What determines the ability of a CME to trigger a geomagnetic storm? Can we simulate this process? Can we estimate the time-of-arrival of a CME at the magnetosphere?

The ROB heritage as co-investigators in the LASCO & EIT instruments has given us good understanding and access to the state of the art instrumentation (see the 'Coronal heating' research theme for details on our EIT activities). The most important upcoming space mission for CME studies is the STEREO twin spacecrafts mission, with each spacecraft carrying the SECCHI remote sensing instrument package. The ROB is again co-investigator for this mission. We actively prepare the exploitation of this mission on the basis of LASCO/EIT images.

The ROB is also principal investigator in the PROBA2 mission. PROBA2 is an ESA technology demonstration mission that is scheduled for launch in September 2007. Besides the demonstration of state-of-the-art technology, PROBA2 has also a scientific payload consisting of the Lyman alpha radiometer (LYRA, see "Solar Irradiance" research theme) and the Sun Watcher using APS and image processing (SWAP). SWAP in an evolved version of EIT, especially optimized for observations of CMEs on the solar disc.

Finally, the ROB also participates in a Belgian network ("Solar Drivers of Space Weather") for numerical simulations of CMEs. The network consists of the Von Karman institute (contributing advanced numerical methods), the KULeuven/CPA (project lead and contributing expertise in MHD simulations), BISA (contributing magnetospheric know-how) and ROB. The role of ROB is to provide observational input that can be used as initial conditions for the simulations. ROB has contributed for this the CACTus software (Computer Aided CME Tracking).

In what follows, we will give a detailed overview of our activities in the 'STEREO/SECCHI' project, the 'SWAP' project and the 'Solar Drivers of Space Weather' project. All three projects are supported by ESA/PRODEX and specifically aim at studying coronal mass ejections.

A.1. STEREO/SECCHI

A.1.1. Objectives

STEREO is a NASA space mission consisting of two identical spacecraft that will observe the solar corona and heliosphere simultaneously from 2 viewpoints in the ecliptic plane. In Belgium, both the ROB and the 'Centre Spatial de Liège' (CSL) are co-investigators in the consortium that builds the SECCHI instrument suite for the STEREO spacecraft. The role of the solar physics group of the ROB is the scientific preparation of this mission. The primary goal of SECCHI (Sun Earth Connection Coronal and Heliospheric Investigation) is to advance the understanding of the 3D structure of the solar corona, especially regarding the origin of coronal mass ejections (CMEs), their evolution in the interplanetary medium, and the dynamic coupling between CMEs and the Earth environment.

A.1.2. Progress and results

The launch of the STEREO spacecraft is for July 2006. Once the commissioning phase ends and both spacecraft are inserted in their heliocentric orbit, the nominal mission will begin. The routine scientific data flow will probably start only in the first half of 2007. In the current pre-launch phase the SECCHI team at the ROB concentrates on 1) the development of software tools for SECCHI data processing; 2) CME studies on the base of EIT and LASCO images combined with in situ data.

Development of software tools

Four software tools for the automatic processing of the SECCHI data on the ground are currently being developed: the Solar Weather Browser, CACTus, EIT wave/dimming detector and Velociraptor.

The *Solar Weather Browser* is a visualization interface that was originally developed for the "SIDC ESA Space Weather Applications Pilot Project". It aims to provide the solar physics community with a powerful tool to access large amount of solar observations in a fast and efficient way. During 2005 the data from several new instruments (LASCO, SPIRIT, Catania H-alpha, etc) have been successfully added. A number of bugs in the server part of the software have been fixed and some important features have been added (for example the ability to process data from different dates). Those changes resulted in a much more reliable and useful software, better positioned to serve the needs of the solar physics community.

The *Computer Aided CME Tracking* (CACTus) software has been further developed. It is designed to automatically detect coronal mass ejections (CMEs) in coronagraphic images from LASCO onboard SOHO. The detection of a CME is done in two steps and is applied simultaneously on C2 and C3 running difference images: (1) detection of bright features moving radially outward (2) clustering detections into CMEs. CACTus is the first of its kind (Robbrecht & Berghmans, 2004, A&A) and serves now as reference for other CME detection software which is currently being developed elsewhere. During 2005 the software has been continuously maintained, running in real-time. CACTus real-time performance has been evaluated monthly, focusing on the email-alerts which it sends out (whenever a CME larger than a critical threshold is detected an email is sent to registered users). During 2005 38 correct halo CME alerts and 7 false alerts have been sent. We could fix most problems responsible for false alerting. A possible implementation of the wavelet "A trous" algorithm to enhance the contrast (without taking running differences) has been investigated. Although it turned out to be possible to use wavelet instead of running difference, the new algorithm has not been implemented. The background in the LASCO images has been studied. It contains the F-corona and streamers. Both have to be removed from the images if not using the running difference technique. The noise in the LASCO images has been studied and the cleaning routine has been adapted.

Using CACTus, objective CME catalog has been created by March 2005, spanning the LASCO archive. The current output covers data from 1997 – 2004 and is available online. CACTus will be used to analyse the images from the two pairs of STEREO coronagraphs, first with the beacon data and subsequently with the science data. CACTus catalogues will be an integral part of the SECCHI real-time space weather

monitoring effort and the results of every CACTus scan will be made available via the WWW as soon as they are available. To facilitate this, the ROB STEREO team agreed to install the current real-time version of CACTus on the local machine at the Naval Research Laboratory (NRL, SECCHI PI team) running initially on real-time data from the LASCO coronagraphs onboard SOHO but also on simulated data from two simultaneous viewpoint as will be provided by SECCHI. The installation of CACTus on the designated NRL computer will be fully operational there by Feb 2007.

The version of CACTus compatible with the SolarSoftWare (SSW) was developed and tested during 2005. Initially this version worked interactively after a user provided a set of dates for analysis; toward the end of 2005 work began on the process of developing a version of SSW-CACTus which would run in real time in batch mode, automatically scanning the real-time archive for recently-arrived images and processing them. The real-time variant of SSW-CACTus is expected to be running routinely at ROB by early 2006. The output will be monitored alongside the existing CACTus output to check for consistency and agreement, and SSW-CACTus will eventually become the default version. The transition is anticipated by mid 2006.

Additionally, its incorporation into the SECCHI analysis suite means that CACTus' input requirements will have partly shaped the nature of the SECCHI beacon mode. The CACTus performance on beacon data has been investigated as a test for SECCHI. Beacon data are highly compressed low resolution COR-2 data (covering the field of view of 2 to 15 solar radii) and will be used for space weather forecasting. The smaller field of view (in comparison to LASCO) only can cause problems for the detection of fast CMEs (faster than 1000 km/s). Since these are the most important for space weather, enough images (ideally 8 per hour) have to be acquired in the beacon mode. The lower resolution of the beacon data will influence the accuracy of the detection and the detection of very small events, but this is no problem for space weather forecasting. Efforts by the ROB STEREO team continue to ensure the optimal combination of images for CACTus' operation.

The *EIT wave and dimming detector* aims at detecting the occurrence of Earth-directed CMEs in their earliest stages as EIT waves and coronal dimmings in the EUV observations of the solar disc. The software is written in MATLAB 7 and is now in the stage of being set up. Event occurrence is detected using high order moments in base difference images. The appearance of such coherent structures as EIT waves and dimmings increases strongly the mathematical moments (variance, skewness, and kurtosis) of the spatial intensity distribution. These high order moments are zero for the normal Gaussian distribution for pure white noise that one would expect if the Sun is quiet. They can thus be used for the detection of occurrence of organized large-scale structures. The next step is to determine the location, timing, structure and dynamics of the EIT wave and the associated dimming. Final validation deals with dimming area verification. Fast increase of dimming area is found to be a robust statistically established criterion of EIT wave presence on the Sun.

Velociraptor is based on a new image-processing tool that will simultaneously estimate both motion and intensity variation from two successive EUV coronal images. It is an application of a method developed in the research theme "*The Variable Magnetic Corona"*.

In addition to the post-acquisition data processing tools, a method of 8-bit *data recoding* that will be used by the SWAP imager on PROBA2 (see Nicula et al. 2005) was presented to the SECCHI consortium. The flexibility of the method was demonstrated to the officials responsible for SECCHI onboard image processing and compression. Following extended and detailed discussions during the first half of 2005 it was agreed that the 8-bit recoding method would be included from the very beginning as part of the onboard compression options for the SECCHI instrument package. The results of the application of the method to data capturing a variety of solar events – CMEs, flares, EIT waves, dimmings – were presented. It was demonstrated that all these important signatures of solar activity were readily observed in 8-bit data and thus space weather monitoring and studies were not hindered by the reduction in bit-depth. The results of the method as applied to coronagraph data had been presented for the first time; previously the method had only been used with full-disk images of direct (as opposed to scattered) solar radiation.

In order to *display* the observations provided by SECCHI in a stereoscopic frame, special hardware and software are required. Software must perform an offset perspective projection for each eye, thus simulating what each eye would see if it were immersed in the three-dimensional virtual world that the software renderings are based on. The necessary hardware includes a workstation with a graphics card capable of providing a sync signal (to differentiate the views) and stereoscopic visualization eyewear. Currently, neither the software nor the hardware is available at ROB. Starting in late 2005, the different possibilities in order to obtain a full implementation to produce stereo images are being evaluated.

CME studies on the basis of EIT and LASCO images

A key objective of the STEREO mission is the phenomenon of Coronal Mass Ejections (CMEs). The CME initiation process in the low corona will be observed in the extreme-ultraviolet (EUV) by SECCHI, and its data can now be simulated with the SOHO/EIT data.

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 has been performed, 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 SOHO/LASCO C2 coronagraph and the simulated synoptic maps constructed from the model of the warped plasma sheet have been compared. The earlier findings have been confirmed: the streamers are associated with folds in the plasma sheet. Although the large-scale structure of the streamer belt is described reasonably well, some features, however, cannot be explained in this framework. It has been proposed that two types of large-scale structures take part in the formation of these additional features. The first one is an additional fold of the neutral line, which does not appear in the modeled source surface neutral line, but is well visible in photospheric magnetograms. The second one is a plasma sheet with a ramification in the form of a secondary short plasma sheet. It was shown that if these structures are taken into account, the observed configurations of the streamer belt can be better described. The secondary plasma sheet can be formed between two secondary current sheets connected with the main current sheet. The result suggests that the potential field source surface model is not fully adequate for the description of the fine structure of the streamer belt, even during the epoch of low solar activity.

The investigation of the streamer belt configuration during the epoch of high solar activity was started. The position of the current sheet can be found comparing the position of streamers, of loops observed by EIT and of neutral lines at the photosphere or chromosphere. Instead of the photospheric neutral line, the chromospheric neutral lines traced by filaments have been used as its configuration is smoother. To determine the position of the chromospheric neutral lines more precisely, the chromospheric synoptic maps have been acquired from P. McIntosh (HELIOSynoptics).The method turned out to work surprisingly well for the main large-scale structures associated with the polar crown filaments. The reason is that streamers during the activity maximum are more radial, as can be seen during total solar eclipses (collaboration with S. Koutchmy, Institut d'Astrophysique de Paris). Again, the streamer belt may have a configuration different from the one given by the potential field source surface model. The folds of the current sheet correspond well to the folds of the chromospheric neutral line.

An investigation of low corona counterparts of flux rope CMEs have started. It turns out that the symmetric double dimming structure is not always observed. Moreover, in some cases the dimming pattern covers a large part of the solar disc. This indicates a non-local character of the CME initiation process. Possible reasons of such a behavior are currently under investigation.

An EIT wave triggering an EUV flare has been found. By performing the timing-location inter-flare analysis, a statistically significant flare-to-flare remote triggering for whole ensemble of solar flares (with EUV, Halpha, hard X-Ray data of solar disk) has been found. Detailed studies of this issue show that perturbations created by an initial flare, propagate at characteristic velocities around 110 km/s and can trigger

a distant flare when encountering remote marginally stable pre-flare magnetic structures, resulting sometimes in series of events.

A study of the CMEs connection with their interplanetary counterparts has been started. The study of CMEs in the interplanetary medium (ICMEs) is normally hampered by the fact that the in-situ data used represents only a 1D cut through a full 3D structure. To increase the amount of information available, one has to use data from several spacecraft. Currently these are ACE, Ulysses and SOHO, in the near future STEREO data will be available. Multi-spacecraft studies are best suited to help unveil open questions regarding the internal structure of CMEs. When the source region is clearly discernable, EUV and white light data can be used in order to correlate characteristics seen during eruption with those measured in-situ. A flux rope model can be applied to those ICMEs which present a cloud structure, using data from the different satellites, in order to get a better approximation of what the global structure of magnetic clouds may look like. The techniques developed under the present project will be used for the investigation of STEREO data. Results from these studies will be combined with those obtained in the frame of the working group "The Stages of Sun-Earth Connection", one of the groups forming the "International Teams Program" supported by ISSI (Bern, Switzerland). In collaboration with Sergio Dasso (IAFE, Argentina) a study has been started in order to correlate different signatures with the boundaries of ICMEs, of special interest is to define whether the limits of an ICME as seen in magnetic field data correlate to the boundaries dictated by composition data.

A.1.3. Perspective for next years

The development of the software products will be continued. The clustering technique of CACTus will be improved. A new version of the online CME catalog, covering data from 1997 – 2005, will be created using the updated software. The SSW versions of CACTus and EIT wave/dimming detector will be finalized and tuned so that they are compatible with the SECCHI data and can be run on the data of each spacecraft separately. The conversion to SSW-CACTus will be followed by the widespread distribution of the routines via the SSW network and its implementation by other institutions. Monitoring the real-time installation of SSW-CACTus at NRL working with LASCO and simulated multi-point data will continue. This latter study will lead to a fully operational version for the dual-spacecraft SECCHI environment prior to STEREO launch.

EIT wave detection technique can be greatly improved. New criteria will be developed with the new SECCHI data of better resolution and time cadence. An online EIT wave catalog will be created, covering data from 1997 – 2005. The nature of triggering agents of sympathetic events will be investigated. LASCO images for the Solar Weather Browser will be enhanced by adopting the 8-bit recoding method already utilized for solar disk images. This will de-noise the images and make the files smaller, reducing demands on server storage, bandwidth, and user cache size.

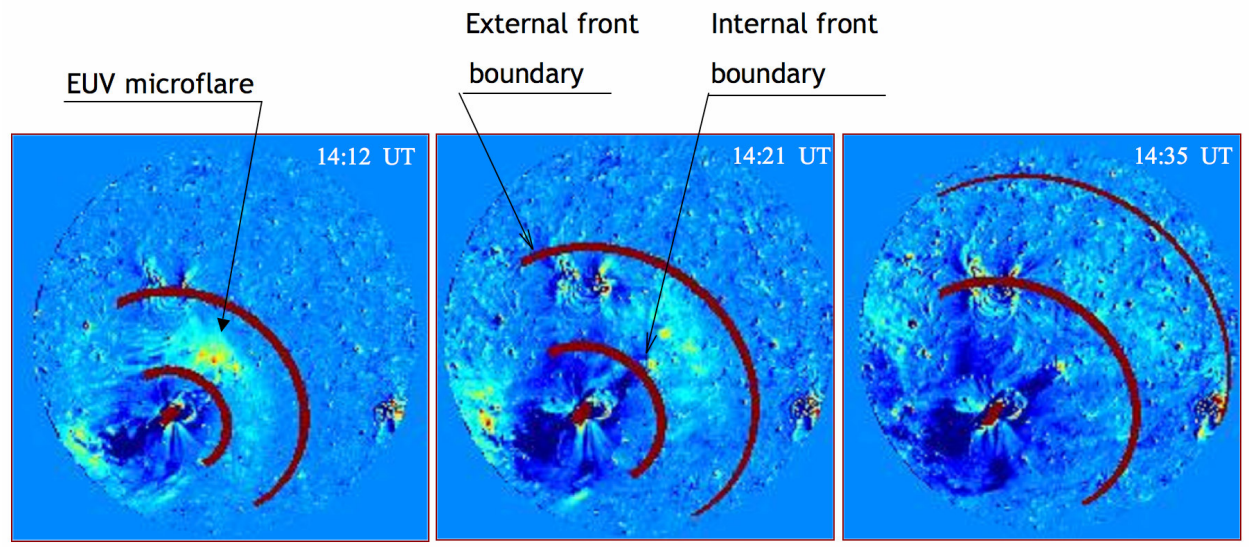


Figure 24: Detection of EIT wave of April 7, 1997

The investigation of the streamer belt will be continued. The model will be applied to several Carrington rotations during the epoch of high solar activity, taking as input the chromospheric neutral lines. The positions of streamers as observed and as given by the model will be compared. Later the model will be applied to the SECCHI data expected in the end of 2006. The study of low corona and in situ counterparts of CMEs will be continued to get an insight into the 3D structure of CMEs. The necessary tools in order to obtain stereo visualizations will be implemented.

A.1.4. Personnel involved

Scientific staff: D. Berghmans (Project leader)
A. N. Zhukov, E. Robbrecht, E. Podladchikova, L. Rodriguez (since October 1, 2005), hired on PRODEX projects
G. Lawrence, B. Nicula, S. Gissot, J.-F. Hochedez (additional contributions, hired on PRODEX projects)

A.1.5. Partnerships

List of national and international partners:

- The ROB-SECCHI team is a member of the international SECCHI consortium which is led by the Naval Research Laboratory (NRL, Washington DC)
- The complete consortium list is: Naval Research Laboratory, Max-Planck Institut fur Aeronomie, University of Kiel, Rutherford Appleton Laboratory, Mullard Space Science Laboratory, NASA Goddard Space Flight Center, University of Birmingham, Centre de Spatial Liege, Lockheed Martin Advanced Technology Center, Centre d'Astrophysique Spatiale, Institut d'Optique, USAF Space Test Program, Swales Aerospace, Hytec Incorporated, Praxis Incorporated, The Hammers Company, Boston College, Smithsonian Astrophysical Observatory, Royal Observatory of Belgium, Observatoire de Paris, Laboratoire d'Astronomie Spatiale, NASA Jet Propulsion Laboratory, Science Applications International Corporation, Stanford University, University of Michigan, Southwest Research Institute.
- More information can be found on http://projects.nrl.navy.mil/secchi/organizations.html. Collaborations with the Institut d'Astrophysique de Paris (France) and IAFE (Argentina) have also been established.

Grants used for this research:

- ESA/PRODEX Contract C90131 "SECCHI Exploitation".
- ISSI Grant for International Team "3D Reconstruction Techniques for the Stereo Mission"

Visitors: 5

A.1.6. Publications

A.1.6.1. Publications with peer review

[1] **Robbrecht E.**, **Berghmans D.**
Entering the era of automated CME recognition: a review of existing tools
Sol. Phys. 228, pp. 239-251 (2005)

[2] **Podladchikova O.**, **Berghmans D.**
Automated detection of EIT waves and dimmings
Sol. Phys. 228, 267-286 (2005)

[3] Saez F., **Zhukov A.N.**, Lamy P., Llebaria A.
On the 3-dimensional structure of the streamer belt of the solar corona
Astron. Astrophys. 442, pp. 351-358 (2005)

A.1.6.2. Publications without peer review

[4] **Podladchikova O.**, **Berghmans D.**
Interaction of EIT wave with active regions on the Sun
Solar Wind 11 - SOHO 16 Conference Proceedings, ESA SP-592, pp 535-538 (2005)

[5] **Podladchikova O.**, **Berghmans D.**
Energetic dynamics of EIT wave structure analyzed by EIT Wave Detector
Solar Wind 11 - SOHO 16 Conference Proceedings, ESA SP-592, pp.751-754 (2005)

A.1.6.3. Publications in press, submitted

[6] **Robbrecht E.**, **Berghmans D.**
A broad perspective on automated CME tracking: Towards Higher level Space Weather Forecasting
Geophys. Monograph Series, Book title: Solar Eruptions and Energetic Particles, in press (2005)

[7] Podladchikov V.N., Naroditskaya N., **Podladchikova O.**
Adaptive filtering in the presence of constraints on estimated parameters
Problems of Informatics & Control, in press

[8] **Podladchikova O.**, **Berghmans D.**
Quantitative study of EIT waves dynamic characteristics. I.Topology and energetics of EIT wave structures
Astron. Astrophys., submitted

[9] **Podladchikova O.**, **Berghmans D.**
Quantitative study of EIT waves dynamic characteristics. II. Structural changes in the solar active regions during the interaction with EIT wave fronts
Astron. Astrophys., submitted

[10] **Podladchikova O.**, Krasnoselskikh V., **Berghmans D.**, Lefebvre B., Nakariakov V., **Van der Linden R.**
Can flares trigger other flares in distant active regions?
APJL, submitted

A.1.6.4. Reports, thesis, etc

[11] **E. Robbrecht**
PhD report of work done during academic year 2004-2005

[12] Twelve monthly reports summarizing the real-time performance of our automatic CME detection software CACTus

A.1.7. Scientific outreach

Meeting presentations

[13] **E. Robbrecht**
CACTus performance on STEREO data [method, beacon data]
STEREO workshop, Hamburg, Germany, 02-04/05/05, oral presentation

[14] **E. Robbrecht**
Entering the ERA of Automated CME recognition
10th Assembly of the International Association of Geomagnetism and Aeronomy, IAGA-2005, Toulouse, France, 20-29/07/05, oral presentation

[15] **E. Robbrecht**
Automated CME tracking: real-time performance and objective CME catalog
11th European Solar Physics Meeting (SPM11): The dynamic Sun: challenges for theory and observations, Leuven, Belgium, 11-16/09/05, poster

[16] **E. Robbrecht**
Real-time CME detection [performance statistics, beacon data, website]
SECCHI science consortium meeting, Fairfax, USA, 12-14/10/05, poster

[17] **E. Robbrecht**
Automated CME tracking: real-time performance and objective CME catalog
2nd European Space Weather Week, ESTEC, The Netherlands, 14-18/11/05, poster

[18] **Podladchikova E.V.**, Krasnoselkikh V., **Van der Linden R.**, Lefebvre B.; **Berghmans D., Vanlommel P.**
Spatio Temporal flare correlations from SIDC flare catalog
24 – 29 April (2005), EGU General Assembly, Vienna, EGU05-A-10084;

[19] **Berghmans D., Podladchikova E.V**.
EIT waves and dimmings detector for SECCHI/STEREO mission
24 – 29 April (2005), EGU General Assembly, Vienna EGU05-A-10023;

[20] **O. Podladchikova, D. Berghmans**.
The algorithms of EIT waves detector
1- 4 May (2005), SEE Meeting for the NASA STEREO mission, Hamburg

[21] **Podladchikova O.**; Krasnoselkikh V., **Van der Linden R., Berghmans D.**
Waiting time distribution for flares from SIDC Catalog
12 - 17 June, Whistler Canada (2005), Solar Wind 11 / SOHO 16: From Sun to Heliosphere

[22] **O. Podladchikova, D. Berghmans**
Automatic Detection of EIT Waves and Dimmings
12 - 17 June, Whistler Canada (2005), Solar Wind 11 / SOHO 16: From Sun to Heliosphere

[23] **O. Podladchikova,** V. Krasnoselskikh, **D. Berghmans,** B. Lefebvre, V. Nakariakov, **R. Van der Linden**
Trigger of one flare by another in different active region

11 - 16 September (2005), European SPM-11: The Dynamic Sun: Challenges for Theory and Observations Leuven,

[24] Krasnoselskikh, V., **Podladchikova, O.**
The signatures of the magnetoacoustic slow wave in the "EIT wave"
11 - 16 September (2005), European SPM-11: The Dynamic Sun: Challenges for Theory and Observations, Leuven

[25] **Podladchikova O., Berghmans, D.**
Recognition of EIT waves in the EUV solar corona.
11 - 16 September (2005), European SPM-11: The Dynamic Sun: Challenges for Theory and Observations Leuven

[26] **Podladchikova O., Berghmans, D**
EIT wave detection in STEREO/SECCHI EUV data: What do we want to detect?
11-14 October, 2005 "STEREO/SECCHI Consortium Meeting", Oct. 11-14, 2005, Fairfax, USA,

Educational responsibilities

- D. Berghmans is:
  - co-promotor for the PhD of Eva Robbrecht
  - lector of the Master thesis of Katrien Verheyen

Websites

- **O. Podlachikova** is responsible for the STEREO EIT wave detector website
- **E. Robbrecht** is responsible for the STEREO document administration and website

A.1.8. Missions

Assemblies, symposia (number):	D. Berghmans (3) A. Zhukov (5) E. Robbrecht (6) E. Podladchikova (5) G. Lawrence (2)
Research visits (days):	A. Zhukov (28) G. Lawrence (4)

A.2. PROBA2/SWAP (Sun Watcher using Active Pixel system detector and image processing)

A.2.1. Objectives

SWAP is an extreme ultraviolet (EUV) solar imager launching in 2007 on ESA's PROBA2 technological platform. Using off-axis optics and EUV-enhanced active pixel sensor detector (coated APS) it will image the corona every minute, detecting phenomena (solar flares, EIT-waves) associated with CMEs. Onboard and ground-based image processing will automatically detect these phenomena and issue alerts, serving as a high performance solar monitoring tool for operational space weather forecasting.

A.2.2. Progress and results

During 2005 the ROB SWAP team continued to provide scientific and technical expertise and support to the instrument technology institute at the Centre Spatial de Liège (CSL); during the year this primarily concerned the proximity electronics, and detector/focal plane assembly. Several critical issues on the noise levels generated in the electronics have been identified and discussed with CSL. A campaign at CSL (see mission list) highlighted certain key areas as being compromised by a lack of a clear under-

standing of certain components of this system. The ROB-SWAP team provided constant input to CSL to resolve this issue and by the end of the year it was felt that the system was well understood and that the necessary steps to improve the actual flight systems had been identified, and work was in progress at CSL to implement them. A critical step during the year was the selection and characterization of the flight model detector at PTB Bessy over the course of two campaigns (see mission list). ROB participated fully in both campaigns. From the results of the first campaign it was concluded that the multi-layer coatings on both samples were below the acceptable standard for the flight model. Five further uncoated samples were ordered from FillFactory (Belgium) with the SWAP team assuming responsibility for arranging their coating by AST (UK); two of the five were coated, and were characterized during the second Bessy campaign, leading to the selection of the flight model. The data are still being analyzed and the results will be utilized during the full instrument calibration campaign scheduled immediately prior to instrument delivery in August 2006. The ROB team participated in the SWAP CDR (see mission list), the conclusions of which are partly summarized in several mission documents (see document list).

The onboard software driving the instrument and processing its images is to be developed by Spacebel (Hoeilaert), commencing 2006. Specifications and interpretation support were provided by ROB and CSL to Spacebel (see mission list below), and subsequent consultations regarding modification. A special recoding technique was developed to boost the performance of generic compression techniques (eg JPEG), which will be integral to the onboard software. Initial discussions with the PROBA2 ground segment team (Redu and Spacebel staff) regarding the interface of the SWAP science center, proved constructive. It was agreed to wait for the prime contractor selection for the PICARD CMS ground segment before progressing further, and a meeting was held with the PICARD responsible on December 16. The SWAP/LYRA science ground segment will be organised as closely in parallel with the PICARD one as possible. The EIT-wave detector and the Solar Weather Browser currently developed within the STEREO project, as well as the flare detector developed within the SIDC RWC project, are earmarked for transitioning to the SWAP project. This activity will kick-off following instrument delivery.

A proposal was submitted (and accepted) for ESA support to the 'PROBA2 Solar Operations' as a Nationally Led Mission, which would transfer post-launch control of PROBA2 from ESA's Technology Directorate to Science. One of the goals of this proposal is to obtain a second ground station, as it is long established that SWAP will suffer from a significant telemetry shortfall particularly since the approval of a modified orbit in 2005. The additional operations require additional manpower resources, which ESA has agreed to support, and ESA SPC has appointed Herman Opgenoorth to open a negotiation phase on how much ESA will contribute. Enquiries as to the availability and suitability of several resources were made by the ROB SWAP team, and also by BELSPO, and a study of the various options will be concluded in mid 2006. Regarding the modified orbit, its ramifications with regard to visible light eclipses and EUV occultations, and energetic particle impacts on overall system degradation and individual image degradation were studied, since there was initially some flexibility over the orbit altitude. The final choice of orbit parameters was made in Sept 2005.

Additionally, PROBA2 will benefit from enhanced international awareness and recognition as a result of adoption as an ESA science mission, and this is augmented by the approval of proposals to include PROBA2 in NASA's 'International Living With a Star' (ILWS) programme, and the International Heliophysical Year (IHY) framework. Also, a proposal was accepted for an international "Science Consortium for SWAP and LYRA' (SCSL) team at ISSI (Bern) in June 2006. The SCSL will assemble a team of international expertise that will assist the ROB PI teams for SWAP and LYRA to optimise the scientific return of the two instruments. This will be the first of several meetings to be held during the pre-launch/operational phase, and will result in a community-based agreement on a data analysis policy and support, amongst numerous areas. Scientific know-how is being accumulated within ROB, by both SWAP team and associated researchers, for the future scientific exploitation of SWAP data, involving literature studies and publication on EIT waves, flare statistics, CME eruptions, etc. PROBA2/SWAP was presented at several conferences (see mission list), and in the literature. In addition, the SWAP website

(http://swap.oma.be) was completely re-worked in early 2005, and will be further updated in early 2006; the website has benefited from increased visibility via the ESA, ILWS and IHY connections.

A.2.3. Perspective for following years

The following milestones are foreseen:

- Commence SWAP ground segment work package: early 2006
- Commence writing SWAP instrument paper for pre-launch peer-reviewed publication: early 2006
- Conclude study of potential additional ground station resources, mid 2006
- SWAP& LYRA ISSI meeting: June 18-23, 2006
- SWAP final calibration: beginning of August 2006
- SWAP delivery to PROBA2: Aug 23 2006
- PROBA2 launch: September 2007

A.2.4. Personnel involved

Scientific staff: David Berghmans (ROB SWAP Project Manager)
Bogdan Nicula, Gareth Lawrence, Thanassis Katsiyannis (Hired on the SWAP PRODEX grant)
Important contributions are brought by other personnel of the Department of Solar Physics such as J-F. Hochedez, F. Clette and A. Zhukov.

A.2.5. Partnership

List of national and international partners:

- Centre Spatial de Liege, Liege, Belgium
- Centre for Plasma Astrophysics, Catholic University, Leuven, Belgium
- P.N. Lebedev Institute, Moscow, Russia.
- Max Planck Institute, Lindau, Germany.
- ESTEC, Noordwijk, NL.

Grants used for this research:

- ESA/PRODEX Contract C90193 "SWAP Preparation to Exploitation".

Visitors:

- During the course of the year we have welcomed many (>10) visitors in the context of the industrial development (e.g. onboard software) of the SWAP instrument.

A.2.6. Publications

A.2.6.1. Publications with peer review

[1] **Nicula B., Berghmans B., Hochedez J.-F.**
Poisson recoding of solar images for enhanced compression
Sol Phys 2005, 228, 253-264

A.2.6.2. Publications without peer review

[2] **Katsiyannis A. C., Berghmans D., Hochedez J.-F., Nicula B., Lawrence G.**, Defise J.-M., **Ben-Moussa A., Delouille V., Dominique M.**, Lecat J.-H., Schmutz W., **Theissen A.,** Slemzin V.
SWAP: An EUV imager for solar monitoring on board of PROBA2
SPIE, 2005, 5901, 236

[3] **Katsiyannis A. C., Berghmans D., Nicula B.**, Defise J.-M., **Lawrence G.**, Lecat J.-H., **Hochedez J.-F.**, Slemzin V.
SWAP: An EUV imager for solar monitoring on board of PROBA2
ESA SP-596, p 70

[4] **Lawrence G, Berghmans D., Hochedez J.-F., BenMoussa A.**, Defise J.-M., **Delouille V., Dominique M., Katsiyannis A.**, Lecat J.-H, **Nicula B.**, Schmutz W., Slemzin V. & **Theissen A.**
Space Weather with ESA's PROBA2 mission
ESA SP-592, p.695

A.2.6.3. Publications in press, submitted

[5] **Berghmans D., Hochedez J.-F.**, Defise J.-M., Lecat J.-H., **Nicula B.**, Slemzin V., **Lawrence G., Katsyiannis A., Van der Linden R., Zhukov A., Clette F.**, Rochus P., Mazy E., Thibert T., Nicolosi P., Pelizzo M.-G., Schuhle U.
SWAP onboard PROBA-2, a new EUV imager for solar monitoring
Adv. in Space Res., 2005, in press, available online April 27, 2005

[6] **Katsiyannis A.C., Berghmans D., Nicula B.**, Defise J.-M., **Lawrence G.**, Lecat J.-H., **Hochedez J.-F.**, Slemzin V.
SWAP: An EUV imager for solar monitoring on board of PROBA2
7th HELLAS, submitted.

A.2.7. Missions

Assemblies, symposia (number):	D. Berghmans (3)
	G. Lawrence (2)
Commissions, working groups (days):	D. Berghmans (1)
Research visits (days):	D. Berghmans (11)
	G. Lawrence (8)
Field missionss (days):	B. Nicula (10)

A.3. Solar Drivers of Space Weather

A.3.1. Objectives

The "Solar Drivers of Space Weather", ESA PRODEX 8 project is a collaboration between the ROB (PI : R. Van der Linden), BISA, VKI and KULeuven. The purpose of this project is to study the physics behind the recurrent structure, heating and acceleration of the solar wind, the acceleration of energetic particles, and the formation and propagation of transients like CMEs and induced shocks from their birth in the solar corona up to their arrival at the Earth's magnetosphere. Also the background solar wind and the embedded interplanetary magnetic field (IMF) are studied as the environment through which the CMEs propagate. The past IMF can be reconstructed on the basis of the geomagnetic *aa* index. It is our aim to reconstruct the historic IMF starting from a flux transport model on the solar surface and extrapolating the so-obtained surface field into the heliosphere using potential field models.

A.3.2. Progress and results

We have finished work package WP1A which was to model the magnetic field near the Sun from magnetograph observations which can be used as magnetic boundary conditions in the global numerical solar wind simulations performed by the MHD group (S. Poedts and C. Jacobs) at the Center for Plasma Astrophysics of the K.U. Leuven. The propagation of the solar wind and CMEs is described by the three-dimensional magnetohydrodynamics (MHD) equations. The initial magnetic field in the simulations has been substituted from a simple dipole field into a more realistic potential field using the potential field source surface model. In the latter the surface magnetic field is extrapolated into the heliosphere assuming

that there are no electric currents above the photosphere and that the magnetic field becomes radial at a so-called source surface (typically set at 2.5 solar radii). This source surface field has been derived from Mt. Wilson magnetograms.

In collaboration with M. Schuessler (Max Planck Institute for Solar System Research) simulations of the historic solar surface magnetic field were made on the basis of the RGO sunspot data (available since 1874) and the monthly sunspot number (available since ~1700) using a flux transport model. The corresponding open magnetic flux is extrapolated once using a potential field model and once using a current sheet model. Doing so, we hope to be able to reproduce the historic IMF variation and thus to present a complete model of the solar large-scale magnetic field containing the solar dynamo, the redistribution of magnetic flux and the extrapolation into interplanetary space.

A.3.3. Perspective for following years

In collaboration with CPA, we foresee to build and evaluate real-time solar wind models for operational use. Later on, CME initiation models will be implemented in this near-real time solar wind model. Finally, these combined simulations will need to be integrated and evaluated as an operational CME simulation tool into the Space Weather operations of the RWC Belgium.

A.3.4. Personnel involved

Scientific staff: D. Berghmans (Project manager)
S. Willems, I. Baumann (Hired on PRODEX project)
Additional contributions by: R. Van der Linden, P. Vanlommel

A.3.5. Partnerships

List of national and international partners:

- Centre for Plasma Astrophysics, Catholic University, Leuven, Belgium
- Belgian Institute for Space Aeronomy, Brussels, Belgium
- Von Karman Institute, Sint Genesius Rode, Belgium

Grants used for this research:

- ESA/PRODEX Contract C90204 “Solar Drivers of space weather”.

Visitors:

- <5, mostly partners within the Belgian network

A.3.6. Publications

A.3.6.1. Publications with peer review

[1] **Baumann, I.**, Schmitt, D., Schüssler, M.
A necessary extension of the surface flux transport model
Astronomy & Astrophysics, vol. 446, pp.307-314 (2006)

A.3.6.2. Publications without peer review

A.3.6.3. Publications in press, submitted

[2] Cadez V.M., **Vanlommel P.**
Effects of localized horizontal flow patters on eigenfrequencies of stellar global modes
Serv. Astron. J., in press

A.3.7. Missions

Assemblies, symposia (number): Baumann (1)
Field missions (days): Baumann (1)

B. The variable magnetic Corona

The magnetic solar atmosphere is variable at all time-scales. Its faster and smaller phenomena are not resolved with the current telescopes. It is a research topic of the Solar Physics Department (alias SIDC) to bridge observation and theory and addressing at this angle the coronal heating issue. These studies are developed in the first section of the present theme. While Coronal Mass Ejections are treated as a separate theme, flares are considered in the second section dealing with the preparation of the LYRA radiometer. Finally, the last section covers the coronal variability commensurable with the solar rotation or slower.

The solar corona is a very dynamic environment and several mechanisms compete in its various areas. Magnetic energy dissipation can be due to wave dissipation 'AC' (if $t_A >> t_p$) or to continuous currents 'DC' (if $t_A << t_p$), where t_A is the characteristic transit time of Alfven waves in the loop, and t_p is the characteristic time of sub-photospheric convection. However, to explain heating by Alfven wave dissipation, these Alfven waves must be excited on a time scale shorter than the typical timescale of the corona (t_A~100s), and for example, the characteristic time of granular convection is 400-900s, i.e. too slow. By contrast to the AC mechanisms, the heating theories based on current dissipation operate even with slow driving. The energy source is then in the random agitation of the footpoints of magnetic field lines and current dissipation produces the heating. The characteristic time of resistive magnetic diffusion is $t\eta = l^2/\eta$, larger than observable scales. Normal resistivity is therefore not an efficient dissipation means. Reconnection is a much faster and more efficient processes with $\sim t_A = l/V_A$. It is the natural candidate to explain phenomena like flares, CMEs, bright points, blinkers, nanoflares observed in closed magnetic field regions. Observational studies associate nanoflares and small-scale reconnections. Constant changes in the magnetic fields dominating the corona lead to many types of instabilities in the coronal plasma and in the magnetic field itself. These instabilities manifest themselves in a variety of scales and events.

EIT will often be referred to in the following. The instrument and the role of its data are therefore briefly introduced here. EIT is the Extreme ultraviolet Imaging Telescope of the Solar Heliospheric Observatory (SoHO). It is monitoring the topology and dynamics of the solar corona and transition region in four different wavelength passbands, which correspond to temperature regimes from 60,000K up to 2,000,000K. The EIT instrument has been built by a Belgian-French-US consortium, and is operated very successfully since January 1996. In November 1998, a PRODEX Experiment arrangement was agreed between the ROB and the European Space Agency (ESA). Since then, its Co-Investigators at the ROB have undertaken numerous studies. Three fields of expertise have been selected for the EIT Science at ROB. One is the analysis of small or rapid phenomena; the second is the development of image processing tools treating automatically and systematically the observations; and the third relates EIT data to Space Weather forecasting treated as another theme.

B.1. Coronal heating

B.1.1. Objectives

All coronal heating theories entail small scales, i.e. large gradients and fast phenomena. While the scales at work are far below current observations, the path to understanding coronal physics involves nevertheless addressing intermediate scales, say one order of magnitude below current observations. Therefore, analysis of existing data is conducted in parallel with participations to the design of future missions, in particular Solar Orbiter, truly capable of a breakthrough in related knowledge.

B.1.2. Progress and results

The activity can be into five parts:

1. HiC et NUNC (**Hi**gh **C**adence to study the **N**anoscale **U**ltraviolet **N**etwork and **C**orona) was submitted as an Action 3, and which was granted during 2005. It aimed at studying transient phenomena in the solar atmosphere using the EIT Shutterless data and multi-instrument observations such as CDS, SUMER, MDI and TRACE observations.
2. The Supplementary Researcher grant (attributed to Dr Parenti) investigates the matching of theoretical magnetic loop models and observations. The idea is to define and study benchmark tests by confronting the small scale observables with the plasma response predicted by theoretical forward models. EIT, CDS and SUMER data will be used to prepare the analysis of upcoming observations by Stereo and Solar-B, and to eventually help define the S.O. payload.
3. Fractal analysis that aims at characterizing precisely the Quiet Sun and at synthesizing its texture. We have studied the statistical properties of Quiet Sun images using the multifractal spectrum, and we have synthesized images having the same multifractal spectrum as EUV solar images. Such synthesis is additionally useful for calibrating the optical flow technique (Velociraptor/Movatrac) which is developped by Samuel Gissot and Jean-Francois Hochedez.
4. The EUI-S.O. proto-consortium has met three times (Germany, France, Belgium). Note that the last event happened at the ROB, organized by Jean-Francois Hochedez (JFH). The design and the work breakdown between partners have become more precise in 2005. JFH contributed to the consortium inputs to the various PDD versions (Feb), the mass justification and breakdown issues (Feb and April). He and Armin Theissen created a Wiki interface for the EUI documents (eui.oma.be). During the year, a lot of lobbying effort toward ESA was necessary to defend the mission itself. It involved writing letters to the agencies and lately instigating a second S.O. workshop (Athens 2006, JFH is member of the Scientific Organizing Committee). SIDC and CSL have adopted a strategy for EUI, which puts emphasis on the FSI.
5. Organization of a “SOHO workshop”. Belspo approved the organization of a large “SOHO workshop”. The preparation of this event, anticipated in the Fall of 2007, started in 2005. The first focus has been the definition and the search of an appropriate location.
6. A project was submitted (and meanwhile accepted) to the ‘Ministerie van de Vlaamse Gemeenschap, Departement Onderwijs’ in response to the ‘Tournesol call 2006-2007’.The title of the project is "Schokgolven en veranderlijkheid van de UV-straling in de corona van de zon" (PI: Thierry Dudok de Wit - Univ. Orleans) and foresees travel money for several joint meetings with research groups in Orleans and Meudon.

B.1.3. Perspective for following years

The shutterless data need to be exploited before new observations surpass them. I will naturally participate to the two investigations mentioned above addressing the Quiet and the Active Sun heating. Finally, the development of the Solar Orbiter seems confirmed but vulnerable at the time this report is written. The future investment of the SIDC in it will have to depend on political decision at ESA level. In 2006, the SOC and most other elements of SOHO20 will be defined. The Tournesol project will lead to a strengthening of the collaboration with the French partners.

B.1.4. Personnel involved

Scientific staff: J.-F. Hochedez (Project leader, PRODEX)
D. Berghmans
V. Delouille, S. Gissot, O. Podladchikova A. Theissen, A.C. Katsiyannis (PRODEX)
M. Madjarska (Action 3)

B.1.5. Partnerships

List of national and international partners:

- IAS, France
- CPA, K.U.Leuven
- Observatoire de Paris, Meudon
- University of Orleans

Grants used for this research:

- ESA/PRODEX Contract C90205 "SIDC Data Exploitation".
- ESA/PRODEX Contract C90209 "LYRA preparation to Exploitation".
- BELSPO Action 3 : Hic et Nunc
- BELSPO: Grant for supplementary researcher

Visitors: 8

B.1.6. Publications

B.1.6.1. Publications with peer review

[1] I. Ugarte-Urra, J.G. Doyle, R.W. Walsh, **M.S. Madjarska**
Electron density and filling factor along a coronal loop observed with CDS/SoHO,
Astron. Astrophys. 439, 351-359 (2005)

[2] J.G. Doyle, J. Giannikakis, L.D. Xia, **M.S. Madjarska**
Line broadening of EUV lines across the solar limb: A spicule contribution?
Astron. Astrophys. 431L, 17 (2005)

[3] A. De Groof, C. Bastiaensen, D. Muller, **D. Berghmans**, S. Poedts
Detailed comparison of downflows seen both in EIT 30.4nm and Big Bear H alpha movies
Astron Astrophys, 2005, 443 (1), 319-328

[4] **Katsiyannis A. C.**, Murtagh F., Keenan F.P.
The application of a Trous filtering and Monte Carlo analysis on SECIS 2001 solar eclipse observations
SoPh, 2005, 228, pp323

[5] McAteer, J. M. A., Gallagher P. T., Brown D. S., Bloomfield D. S., Moore R., Williams D.R., Mathioudakis M., **Katsiyannis A.**, C., Keenan F. P.
Observations of Ha Intensity Oscillations on a Flare Ribbon
ApJ, 2005, 620, pp1101

B.1.6.2. Publications without peer review

[6] **Hochedez J.-F., Lawrence G., Nicula B.**
Belgian contribution to the EUI of Solar Orbiter (presentation by JFH)
1st EUI consortium meeting, Frankfurt

[7] **Madjarska, M.S.**, Doyle, J.G., **Hochedez, J.-F., Theissen, A.**
Spicules and blinkers as seen in Shutterless EIT 304 A
Proc. on "Chromospheric and Coronal magnetic Fields", ESA SP-596, p. 73

B.1.6.3. Publications in press, submitted

[8] **Madjarska, M.S.**, Doyle, J.G., **Hochedez, J.-F., Theissen, A.**
Macrospicules and blinkers as seen in EIT Shutterless 304
Astron & Astrophys, accepted

[9] D. Garcia-Alvarez, C.M. Johns-Krull, J.G. Doyle, I. Ugarte-Urra, **M.S. Madjarska**, C.J. Butler
Optical and EUV observations of solar flare kernels

Astron & Astrophys, accepted

B.1.6.4. Reports, thesis, etc

[10] **J.-F. Hochedez** and **M.S. Madjarska**
HiC et NUNC II
Action 3 proposal (failed)

[11] **J.-F. Hochedez** and **S. Parenti**
Supplementary Researcher proposal (succeeded)

[12] **J.-F. Hochedez, E. Robbrecht, D. Berghmans, D. Lafont**
Minutes of the 1st LOC meeting of 19 Sep 05
SOHO 20, in preparation

Minutes of the 2nd LOC meeting of 17&18 Nov 05
SOHO 20 in preparation

B.1.7. Missions

Assemblies, symposia (number):	M.S. Madjarska (1)
Commissions, working groups (days):	J.-F. Hochedez (5)
Research visits (days):	M.S. Madjarska (11)

B.2. UV irradiance and the PROBA2-LYRA radiometer

B.2.1. Objectives

LYRA is a solar XUV to VUV radiometer that will embark in 2007 on PROBA2. Its objective is to monitor the solar irradiance in 4 passbands relevant to Solar Physics, Space Weather, and Aeronomy. LYRA also demonstrates the interest of new solar-blind diamond detectors and the degradation properties of UV filters. It is built by a Belgian–Swiss–German consortium with additional international collaborations (Japan, USA, Russia, France). JFH (ROB) is LYRA's Principal Investigator, Y. Stockman (CSL) is Project Manager, and Werner Schmutz (PMOD) is Instrument Scientist. In 2005, an opportunity to embark LYRA "PIN" detectors on the PREMOS-PICARD mission has emerged (and materialised in 2006).

B.2.2. Progress and results

The following up of the LYRA project was carried out by JFH (PI), including participation to all meetings and teleconferences. A PROBA2 Science Management Plan was written jointly with the SWAP project. An ISSI (International Space Science Institute) proposal (SCSL) for the scientific exploitation and its international extension was submitted and selected. The SCSL contract was with ESA and ISSI was finished in December.

To materialize the opportunity of flying LYRA PIN detectors on PICARD-PREMOS, an Agreement was prepared between B and CH that is now signed by all parties. It foresees that 3 new PINs will be bought by ROB and PMOD to IMOMEC. It includes also an agreement about data rights. As a consequence of this agreement, JFH became PICARD coI.

A meeting with Dr. Koizumi in Japan was organized to discuss how one can extend PIN sensitivity into the EUV. Dr Koizumi is performing critical steps of the diamond PIN fabrication.

As to MSM detectors, there have been several important concerns in 2005 and earlier in the project that I reported into a thorough open letter to PRODEX. It resulted in a change of the LYRA manager at IMO and a decision to try and reprocess new MSMs on old substrates. This action has taken a lot of effort. It involved designing a new mask concept and writing a traceability memorandum. Nonetheless, LYRA

must still carry AXUV (Si) detectors, which is a deficiency in a sense but it does present advantages such as direct real-world comparison of competing technologies.

A LYRA radiometric model was developed by Dr Theissen and Dr Benmoussa under the guidance of Dr. Hochedez. This tool is useful to understand and predict the LYRA signal. It had to be made more complex in order to account for AXUV detectors and various filter possibilities. All project documents maintained in the LYRA document archive have been reviewed with a particular attention to the test and calibration reports written by Dr BenMoussa and German colleagues. Calibration plans have been written for all synchrotron campaigns.

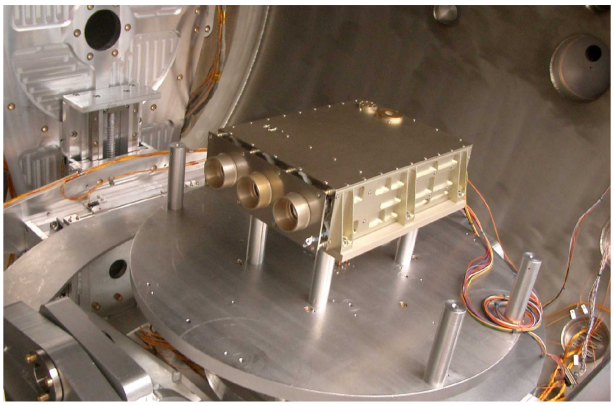


Figure 25: LYRA inside the vacuum chamber of the GI beamline (1-30nm): 11-22 July 2005.

Transmission tests of filters were performed by Dr BenMoussa and Ms Dominique of ROB and 2 colleagues of BISA at RMI and BISA. After heliostat LYRA testing in Davos, it appeared that the Zr and the Ly-alpha Si channels might sense much more contamination than foreseen. The diagnostic was discussed in length and recovery actions implemented.

Ms Dominique is in charge of the LYRA software (specifications and now follow-up). One interesting issue among others has been the pulsation of the LEDs. The future LYRA ground segment has been addressed.

Under the guidance of JFH, preparatory LYRA scientific exploitation was conducted by Dr Delouille (Denoising and flare extraction), Dr Theissen (spectral "inversion", flat field deconvolution 10/5) and Ms Dominique (Aeronomy).

B.2.3. Perspective for following years

The following milestones are foreseen:

- LYRA final calibration: March '06
- LYRA delivery to PROBA2: Spring '06
- Science Consortium for SWAP and LYRA (SCSL) ISSI meeting: June 18-23, 2006 and December 2006
- PROBA2 launch: September 2007

B.2.4. Personnel involved

Scientific staff: J.F. Hochedez (Project leader)
D. Berghmans
A. Ben Moussa, M. Dominique, V. Delouille, A. Theissen, , B. Nicula, A. Zhukov, G. Lawrence, L. Wauters (PRODEX)
R. Van der Linden

B.2.5. Partnerships

List of national and international partners:

- Centre Spatial de Liège, Belgium
- IMO/IMOMEC, Diepenbeek, Belgium
- PMOD/WRC, Davos, CH
- MPS, Lindau, Germany
- PTB, Berlin, Germany
- BISA, Uccle, Belgium
- ESA, HQ, Paris F and ESTEC, Noordwijk, NL
- NRL, Washington, USA
- NIST, MD, USA
- Amano Lab, Japan
- LPI, Moscow, Russia
- UCL, LLN

Grants used for this research:

- ESA/PRODEX Contract C90209 "LYRA preparation to Exploitation"
- ESA/PRODEX Contract C90205 "SIDC Data Exploitation"

Visitors: 4

B.2.6. Publications

B.2.6.1. Publications with peer review

[1] **A.BenMoussa, A. Theissen**, F. Scholze, **J.-F. Hochedez**, U. Schühle, W. Schmutz, K. Haenen, Y. Stockman, A. Soltani, D. McMullin, R.E. Vest, U. Kroth, C. Laubis, M. Richter, V. Mortet, **S. Gissot, V. Delouille, M. Dominique**, S. Koller, Z. Remes, R. Petersen, M. D'Olieslaeger, J.-M. Defise.
Performance of diamond detectors for VUV applications
Nuclear Instruments and Methods A (2005)

[2] **A.BenMoussa, J.-F. Hochedez**, U. Schühle, W., Schmutz, K. Haenen, Y. Stockman, A. Soltani, F. Scholze, U. Kroth, V. Mortet, **A. Theissen**, C. Laubis, M. Richter, S. Koller and J-M Defise.
Diamond detectors for LYRA, the Solar VUV radiometer on board PROBA2
Diamond and Related Materials (2005)

[3] **Hochedez J.-F.**, Schmutz W., Nesladek M. , Stockman Y., Schühle U., **BenMoussa A.**, Koller S., Haenen K., **Berghmans D.**, Defise J.-M., Halain J.-P., **Theissen A., Delouille V.**, Slemzin V., Gillotay D., Fussen D., **Dominique M.**, Vanhellemont F., McMullin D., Kretzschmar M., Mitrofanov A., **Nicula B., Wauters L.**, Roth H., Rozanov E., Rüedi I., Wehrli C., Amano H., **Van der Linden R., Zhukov A., Clette F.**, Koizumi S., Mortet V., Remes Z., Petersen R., D'Olieslaeger M., Roggen J., Rochus P.
LYRA: the Solar UV radiometer aboard the ESA Proba2
Advances in Space Research, Volume 37, Issue 2, 2006, Pages 303-312, Received 22 October 2004; revised 20 July 2005; accepted 17 October 2005. Available online 7 December 2005

B.2.6.2. Publications without peer review

B.2.6.3. Publications in press, submitted

[4] **A. BenMoussa**, U. Schühle, F. Scholze, U. Kroth, K. Haenen, T. Saito, J. Campos, S. Koizumi, C. Laubis, M. Richter, **A. Theissen** and **J.-F. Hochedez**.

Radiometric characteristics of new diamond pin-photodiodes
Measurement Science and Technology (2006), accepted, expected online April 2006

B.2.6.4. Reports, thesis, etc

[5] Fussen D., **Hochedez J.-F.**, Antoine J.-P., Fromm M., Vanhellemont F., **Dominique M.**
DAECA: Detection of Antarctic Exotropospheric Clouds and Aerosols (July)
Proposal submitted to the Research Programme "Science for a Sustainable Development" (failed)

[6] **D. Berghmans, J.-F. Hochedez** et al.
SCSL proposal to ISSI: submission 18/3, contract, 9/12
Proposal to ISSI, Bern (succeeded)

[7] **D. Berghmans, J.-F. Hochedez, Katsyiannis**
Proba2 Science Management Plan
Proba2 project document to ESA

[8] **A. Benmoussa, J.-F. Hochedez**
2 Calibration Plans: GI & NI (May)
LYRA Project document

[9] **A. Benmoussa, J.-F. Hochedez**
5 Calibration reports: 2 GI (January & July) & 3 NI (January, July and August)
LYRA Project document

[10] U. Schuehle, **J.-F. Hochedez**
ROB-MPS-PTB-CSL Letter of Agreement: 22/9
LYRA Project document

[11] **J.-F. Hochedez, A. Benmoussa**, U. Schühle, M. Stockman
MSM open letter to PRODEX (22/3)
LYRA Project document

[12] **J.-F. Hochedez** et al
LYRA detectors Traceability agreement
LYRA Project document

[13] **A. Benmoussa, J.-F. Hochedez**
MSM reprocessing – 3 reports in 2005: 11/5, 23/6, 25/11
LYRA Project document

B.2.7. Scientific outreach

Meeting presentations

[14] **G. Lawrence, D. Berghmans, J.-F. Hochedez, A. BenMoussa,** J.-M. Defise, **V. Delouille, M. Dominique, A. Katsiyannis,** J.-H. Lecat, **B. Nicula**, W. Schmutz, V. Slemzin & **A. Theissen**
Space Weather with ESA's PROBA2 mission
SOHO-16/Solar Wind 11 Conference, Whistler, BC, Canada 13-17 June 2005

[15] **J.-F. Hochedez, B. Berghmans**, J.-M. Defise, S. Poedts, A. de Groof, D. Gillotay, D. Fussen et al.
Science goals of LYRA & SWAP
Talk by JFH at the FNRS contact group meeting (2005/03/11)

[16] **V. Delouille, J.-F. Hochedez**, P. Fryzlewicz, **A. BenMoussa, M. Dominique, A. Theissen**
LYRA: The Large Yield Radiometer onboard the ESA PROBA2
EGU Meeting, Vienna, 24-25 April 2005 (presentation by VD)

Educational responsibilities

- **A. BenMoussa** was supervisor for M. SAY from Institut Superieur Industriel de Bruxelles (ISIB)

B.2.8. Missions

Assemblies, symposia (number):	J.-F. Hochedez (1) A. BenMoussa (2) M. Dominique (1) V. Delouille (4)
Commissions, working groups (days):	A. BenMoussa (10) M. Dominique (5)
Research visits (days):	J.-F. Hochedez (14) A. BenMoussa (27)
Field missions (days):	M. Dominique (2)

B.3. Solar cycle studies

B.3.1. Objectives

Since 1996, the EIT telescope on board SoHO observes the Sun in four EUV wavelengths. The analysis of coronal variability in EUV imaging data can bring unique insights on the complex solar dynamo(s). It is also a topic for Solar Terrestrial relationships through the modeling of irradiance. The image processing and statistical techniques developed for cycle studies are often useful to the solar weather forecast.

Also the LASCO coronagraphs onboard SOHO now spans a full solar cycle of information on the solar outer corona and the behaviour of CMEs. Therefore also the analysis over long-time range of LASCO data is an important objective.

B.3.2. Progress and results

Among others, multiscale methods can exploit the wealth of the large EIT archive. We have used the wavelet spectrum, and showed how it can be applied in the long-term study of the solar corona. Applied on He II EIT images, it is able to extract a characteristic scale of the network. This advanced technique is also very sensitive to flares (down to B level) in coronal EIT images.

A new paper was written with Dr Roman Brajsa and accepted. We have analyzed the centre-to-limb function and latitudinal distribution of coronal bright points, from 4 June 1998 to 22 May 1999. An indication of a two-component latitudinal distribution of coronal bright points was found. Possible implications for the interpretation of the solar differential rotation are discussed.

A new technique based on fuzzy clustering was studied to automatically segment EUV solar images into the usual quiet sun (QS), coronal holes (CH) and active regions (AR).

The package for automated detection of CMEs (CACTus) developed in the SECCHI project was successfully applied to the full archive of LASCO data.

B.3.3. Perspective for following years

The flare extractor based on the wavelet spectrum is ready to be made operational (real-time and archive reprocessing). In 2006, Movatrac and the fuzzy clustering are reaching the maturity to be run on the archive. Movatrac could detect precisely the oscillations of the differential rotation parameters. A new collaboration is being set up in order to interpret the trend discovered in the network scale.

A renewed version of CACTus will again be applied to the full archive of LASCO images.

B.3.4. Personnel involved

Scientific staff: S. Gissot, JF Hochedez (PRODEX)
D. Berghmans
G. Lawrence, V. Delouille, E. Robbrecht (PRODEX)
R. Van der Linden

B.3.5. Partnerships

List of national and international partners:

- UCL, LLN, B
- CEREMADES, Paris Dauphine, F
- NRL, Washington DC, US

Grants used for this research:

- ESA/PRODEX Contract C90192 "SIDC Telescience"
- ESA/PRODEX Contract C90205 "SIDC Data Exploitation"
- ESA/PRODEX Contract C90131 "SECCHI Exploitation"

Visitors: 3

B.3.6. Publications

B.3.6.1. Publications with peer review

[1] **V. Delouille, J. de Patoul, J.-F. Hochedez**, L. Jacques, and J.-P. Antoine
Wavelet spectrum analysis of EIT/SoHO images
Solar Physics, 228(1), pages 303-323.

[2] Brajsa R., Wöhl H., Vrsnak B., Rusdjak V., **Clette F., Hochedez J.-F.**, Verbanac G., Temmer M.
Spatial Distribution and North South Asymmetry of Coronal Bright Points from Mid-1998 to Mid-1999
Solar Physics, Volume 231, Issue 1-2, pp. 29-44

B.3.6.2. Publications without peer review

[3] V. Barra, **V. Delouille, J.-F. Hochedez**, P. Chainais
Segmentation of EIT Images Using Fuzzy Clustering: a Preliminary Study
Proceedings of the 11th European Solar Physics Meeting "The Dynamic Sun: Challenges for Theory and Observations" (ESA SP-600). 11-16 September 2005, Leuven, Belgium. Editors: D. Danesy, S. Poedts, A. De Groof and J. Andries. Published on CDROM, p.77.1

B.3.6.3. Publications in press, submitted

[4] **Robbrecht E., Berghmans D., Van der Linden R.A.M.**
Objective CME detection over the Solar Cycle: a first attempt
Advances in Space Research, in press

[5] **V. Delouille**, M. Jansen, R. von Sachs,
Second generation wavelet denoising methods for irregularly spaced data
accepted to be published in Signal Processing

B.3.7. Scientific outreach

Meeting presentations

[6] **D. Berghmans, E. Robbrecht, O. Podladchikova, S. Gissot, V. Delouille, J.-F. Hochedez**
Computational techniques for automated CME reporting (talk by David Berghmans)
HPC WISER Workshop on Computing in Space and Astrophysical Plasmas, Leuven

[7] V. Barra, **V. Delouille, J.-F. Hochedez**, P. Chainais
Segmentation of EIT Images Using Fuzzy Clustering: a Preliminary Study (Poster)
11th European Solar Physics Meeting "The Dynamic Sun: Challenges for Theory and Observations" (ESA SP-600). 11-16 September 2005, Leuven, Belgium

Educational responsibilities

- **J.F. Hochedez**:
  - is co-promotor for the PhD of Samuel Gissot
  - member of jury for 2005/03/19 of Leen Devalk, trained in 2004

B.3.8. Missions

Assemblies, symposia (number):	S. Gissot (1) J.F. Hochedez (2) V. Delouille (2)

C. Space Weather

The mission of the Royal Observatory of Belgium (ROB) is twofold: it includes both the expansion of knowledge through scientific research *and* the valorization of this knowledge through the provision of a public scientific service. These two aspects meet supremely in the emerging scientific discipline called *Space Weather*, which studies the variable environment of the earth in space and the consequences this can have for human society and technology.

Solar activity is the main driver of space weather. The Earth is orbiting within the outer atmosphere of our home star, the sun. Despite its apparent invariable, simple, spherical shape, we now know that the Sun is variable in many ways. Energetic solar phenomena such as flares and coronal mass ejections have an impact on the space environment of the Earth through different physical connections. Solar activity spans a wide range of timescales, from the secular modulation of the well-known 11-year solar activity cycle, over the 27 days of solar rotation, down to sub-second timescales during eruptions. Monitoring this solar activity and evaluating its likely consequences for the near-Earth environment thus requires both a long-term commitment as well as daily dedication to follow up the ongoing dynamics in the solar atmosphere. Only a permanent service center that specializes in solar monitoring and solar activity research and that has extensive access to solar data can span these wide requirements. The ‘Solar Influences Data analysis Center’ at the ROB performs this task within several international networks. The SIDC undertakes to provide expert and timely information on and assessment of solar dynamics and its likely relevance for the Earth environment to an extensive set of users of the service.

Figure 26: A complex, active sunspot group observed on 30 March 2001 in white light by the ground-based telescope of the SIDC

White-light observations of the solar photosphere are a simple but important way to characterize solar activity. The 11-year solar activity cycle is the most prominent source of solar variability. The existence of this cycle has been known for centuries due to observations of sunspots on the solar surface. The sunspot index is the oldest solar index measuring solar activity and is used for many studies on the cyclical behaviour of the Sun. Elsewhere in this report we describe our contribution to the long-term monitoring of this cycle.

Sunspots provide a good measure for the solar activity cycle, but certainly do not constitute its most relevant manifestation. During solar maximum, the sun generates a large number of energetic eruptions such as solar flares. Solar flares produce intense electromagnetic radiation and high-energy particles, and may be associated with global plasma expulsions from the solar corona known as Coronal Mass Ejections (CMEs). These have the potential of causing severe damage to human technology in space and on the ground and to hamper communication systems. Increased fluxes of high-energy particles, for example, are detrimental for Earth-orbiting satellites and expose airplane crews and passengers to enhanced doses of radiation. Disturbances in the solar wind interact with the Earth's magnetosphere, causing geomagnetic storms that, amongst other things, disturb GPS signals. All these effects form part of what is now commonly called 'Space Weather'. The SIDC operates a service to help users reduce the impact of space weather on activities of human interest. Since 1 Jan 2000, the SIDC has become a *Regional Warning Center* of the International Space Environment Service (ISES) and in this capacity provides short-term (3-day) forecasts of solar activity and its impact on the space environment of the Earth (see below in Project 2 for more detail).

In 2003, ESA started to set up the Space Weather European Network (SWENET) in an effort to initiate the construction of a global space weather service in Europe. This was justified by an earlier study highlighting the strong fragmentation of space weather activities in Europe. The solar physics department of the ROB successfully applied to become one of the Service Development Activities of SWENET. In the framework of this ESA-funded Space Weather Applications Pilot Project, our daily solar monitoring and forecasting activity has been extended and diversified, e.g. by developing a user-friendly interface to solar data, the Solar Weather Browser. These activities are described below in the first Project in this theme.

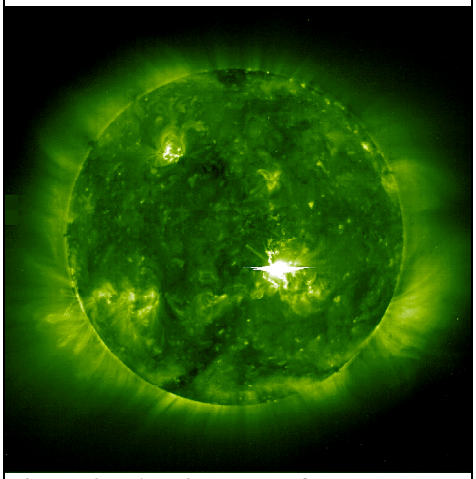


Figure 27: A bright solar flare, captured by the instrument EIT on 1998 May 2.

White-light sunspot observations help in predicting energetic solar events, but today, thanks to space missions such as e.g. SOHO, GOES and ACE, a much wider range of observations is available to characterize the solar variability on the level of radiation, particle fluxes, and plasma flows. CMEs, for example, are now routinely registered by the LASCO coronagraph (see below).

The availability of these data paves the way to base the Space Weather service provision on more firm scientific footing. Scientific studies described in the other sections of this report from part of this effort, and so does a scientific collaboration set up in the frame of the INTAS scheme (project 3).

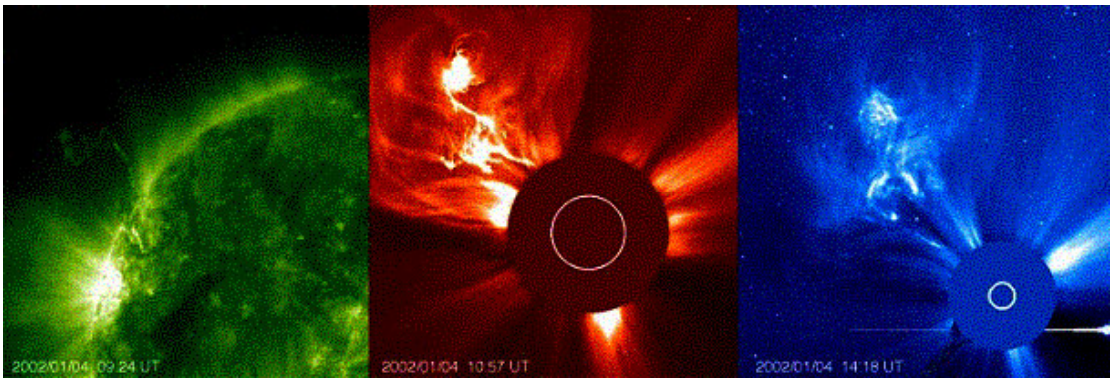


Figure 28: A solar eruption captured by the EIT and LASCO instruments onboard the joint ESA/NASA space mission SOHO on Jan. 4 2002

Of particular relevance to future Space Weather research and monitoring in our group is the upcoming PROBA2 space mission (to be launched in 2007), with the solar instruments SWAP and LYRA (described elsewhere in this document). These instruments will lead to much more detailed diagnostics of flares and related phenomena such as EIT waves. From these, we may hope to achieve a much better understanding of the initiation processes of flares and CMEs, and thus, when supplemented by adequate theoretical research and modeling, a much better predictability of solar activity as a whole.

C.1. Participation in the ESA Space Weather Applications Pilot Project

C.1.1. Objectives

In 2002, the SIDC successfully applied to become one of the Service Developments Activities (SDA) of ESA's Space Weather Applications Pilot Project. To this purpose we established collaboration between several research units within the Space Pole. The purpose is to contribute our expertise in solar observations, solar activity research and space weather monitoring to support the activities of the other groups participating to our own SDA and to the global SWENET network, and to develop tools to automatically detect solar events relevant for space weather. The funding of the project ended April 2005. The routine activities of this project were incorporated in the activities of the RWC (see below).

C.1.2. Progress and results

In 2004, we turned to the 'service and evaluation provision' phase in the Space Weather Applications Pilot Project, which we finished in the course of 2005. All major developments were completed in 2004. Minor additions and upgrades of the products developed still continued throughout the last phase of the project.

One of the deliverables under the project is the Solar Weather Browser (SWB), a first version of which was completed early in 2004, but which has since then been further improved. The SWB is a software tool developed by the Royal Observatory of Belgium for easy visualization of solar images in combination with any context information that can be overlaid on the images and that is space weather relevant. It consists of 3 developments: (1) the SWB backend server (SWB-server), (2) the SWB user interface and (3) the SWB download and user support website. The backend server collects data from a variety of sources using different protocols. After acquiring the data, the backend server pre-processes the different types of data with specialized software and makes them available on the distribution website. In this way, the user does not need detailed information on the location and accessibility of the data, nor on specialized software required. The splitting of the SWB in a user interface and a backend server has the additional advantage that new types of data can be included without the need to re-distribute the user interface. In 2005, the SWB client program was improved. Coronograph overlays were introduced and enhancements of the user interface and optimizations of the internals were implemented.

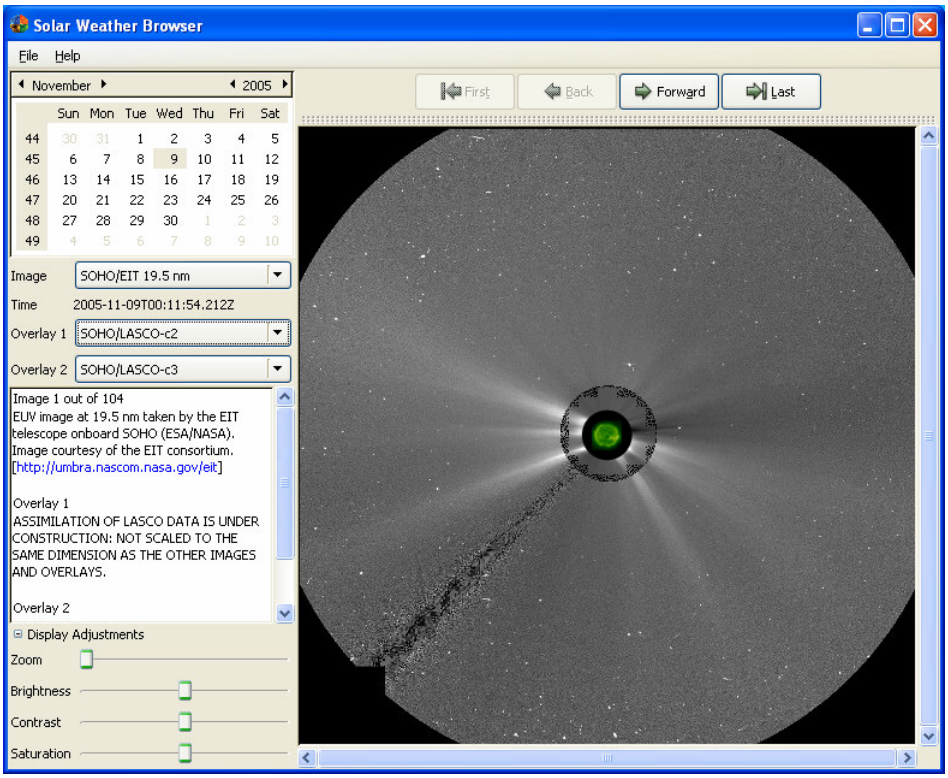


Figure 29: A screenshot of the Solar Weather Browser, here showing how it can be used to visually relate EUV solar images (from EIT) with LASCO-C2 and LASCO-C3 to have a complete field of view from the solar disk up to 32 solar radii.

The software package *CACTus* was developed for automated and objective detection of Coronal Mass Ejections (CMEs) in coronagraph images. This development took place for a large part outside of the current project, but in view of the direct relevance of fast detections of CMEs for space weather operations, we implemented this software package in a fully automated data stream to generate near-real-time alerts of significant halo CMEs. This implementation has been fully operational during the second half of the past year. A monthly evaluation of its real-time performance is included in the '*SIDC Monthly Bulletin of Solar and Geomagnetic Activity*', focusing on the email-alerts which it sends out. Whenever a CME larger than a critical threshold is detected an email is sent to registered users.

In this project, we established a close collaboration with Dr. R. Warnant and his co-workers in the GPS section of the Observatory. This group has specialized in scientific studies of the influence of ionospheric perturbations (which may be caused by space weather events) on the accuracy of GPS positioning. A *near-real-time assessment of GPS accuracy*, available through their website did already exist since 2004. In 2005, an operational model to *forecast* geomagnetic disturbances by predicting the local K-index of Dourbes has also been developed and implemented on our website. These GPS products are fully integrated in the SIDC space weather service by a fully automated alerting service when strong deterioration of GPS accuracy is observed or expected.

An evaluation of the quality of the SIDC forecasts, by comparing those with alternative methods derived from statistical studies and physics-based event estimators was done for the whole period of the project. This study will not only help us improve the future forecasting techniques, but should also lead to a better knowledge about the precise causes of short-term variability in solar indices (such as the 10cm radio flux) and about the changes in global space weather event distributions over the solar cycle. This study was handed over to the Space Weather European Network (SWENET) to be integrated in their services and

evaluation of the offered products. SWENET gathers most information from other SDA's and makes it available. Through the SWENET website (http://www.esa-spaceweather.net/swenet/index.html), one can register to receive our products.

In April 2005, the project ended. A final report, including a business plan was written. The final report includes a complete overview of the start, the achievements and evaluation of the project. The business plan concentrates on the used resources, the commercial potential of the products and services and the future plans in case of (no) extended funding. A final presentation as SDA in SWENET was given at the second European Space Weather Week in ESTEC, Nov. 2005. We supported the cost benefit analysis ordered by ESA, which will have to establish whether there is sufficient interest in space weather throughout Europe to support a continuation of this type of project in the long term. The results of this report are not available yet. The SIDC project was successful in many aspects. The positive collaboration between the three institutes of the Space Pole, ROB, RMI, and BISA led to important progress in the creation of a comprehensive space weather service. The SIDC as an RWC became more visible and up-to-date through some products specifically set up for the general public. The number of users grew drastically since the start of the project. SIDC data was used as input to other SDAs. There was a successful and satisfactory collaboration with several of them leading to the development of specific products, even after the term of the project. At the end of 2005, the Estimated International Sunspot Number (EISN) was produced on request of the users.

C.1.3. Perspective for next years

The project finished in April 2005. The services are continued for at least one year, as contractually foreseen. This is also done in the framework of the SIDC as a Regional Warning Center (RWC) of the ISES.

The forecast evaluation procedure initiated is expected to lead to further scientific studies of the relationship between solar EUV radiation and solar radio fluxes. Also, statistical studies of solar flare distributions and their variation over the solar cycle will still be performed. The event detection tools will be further developed to build event catalogues than can be correlated with solar activity indices and that will assist scientific studies of the solar origins of space weather disturbances. This will be done in the framework of other running projects, e.g. online CME catalog for STEREO/SECCHI. Furthermore, these tools will be used to assist in the management of the large volumes of solar data that is expected to become available in the coming years, e.g. for the reduction of telemetry requirements for space missions by selecting the most relevant images to downlink.

C.1.4. Personnel involved

Scientific staff: Ronald Van der Linden (Project manager)
P. Vanlommel.(ESA contract)
Additional contributions from: David Berghmans, Frederic Clette, Andrei Zhukov, Bogdan Nicula, Laurence Wauters, Sarah Willems, E. Robbrecht, Gareth Lawrence.

C.1.5. Partnerships

List of national and international partners

- This project is a collaboration between the Royal Observatory of Belgium (solar physics and GPS groups), the Royal Meteorological Institute, the Belgian Institute for Space Aeronomy, and Creaction Int.
- Our service forms part of the global European network linking up the various projects (SWENET, see http://esa-spaceweather.net/swenet/index.html).
- The Space Weather Working Team (SWWT) contributes to the coordination of European space weather projects (see http://www.estec.esa.nl/wmwww/WMA/spweather/esa_initiatives/swwt/).

Grants used for this research

- ESA contract 16913/03/NL/LvH.

Visitors:

- 2, in addition to the presence of typically 4-6 scientists from the other participating institutes at the monthly local progress meetings.

C.1.6. Publications

C.1.6.1. Publications with peer review

C.1.6.2. Publications without peer review

See publications 'RWC'

C.1.6.3. Publications in press, submitted

C.1.6.4. Reports, thesis, etc

[1] **Vanlommel P., Van der Linden R.**
Final Report: Evaluation of SIDC forecast/services, submitted to ESA
Contractual report to ESA

[2] **Vanlommel P., Van der Linden R.**, Stegen K., **Warnant R.**
Final Report, submitted to ESA
Contractual report to ESA

[3] **Vanlommel P., Van der Linden R.**
Executive Summary Report, submitted to ESA
Contractual report to ESA

[4] **Vanlommel P., Berghmans D., Van der Linden R.**
Business plan, submitted to ESA
Contractual report to ESA

[5] **Warnant R.**
Final Report: Contacts with GPS users for evaluation and improvement of the services
Contractual report to ESA

[6] **Van der Linden R.**
Final Report: Production solar message
Contractual report to ESA

[7] **Van der Linden R., the SIDC team**
Monthly progress reports to ESTEC for the ESA Space Weather Applications Pilot Project.

C.1.7. Scientific outreach

Meeting presentation

[8] **Van der Linden R., Vanlommel P., Berghmans D., Robbrecht E., Clette F., Nicula B., Zhukov A., Wauters L., Warnant R., Pottiaux E., Lejeune S., Barre A., Bavier M.**, Nebdi H., Jodogne J.-C., Rasson J., Stegen K., Heynderickx D., Roth M., De Keyser J., Kruglanski M., Henry J.-P., Marche J.P.
The SIDC Project: a comprehensive operational space weather service in Belgium
Poster presentation at the European Space Weather Week, ESTEC, Nov. 29 - Dec. 03 2004.

Poster at the Space Weather Week, Boulder, 5-8 April 2005.

[9] **Van der Linden R., Vanlommel P., Berghmans D., Robbrecht E., Clette F., Nicula B., Zhukov A., Wauters L., Warnant R., Pottiaux E., Lejeune S., Barre A., Bavier M.**, Nebdi H., Jodogne J.-C., Rasson J., Stegen K., Heynderickx D., Roth M., De Keyser J., Kruglanski M., Henry J.-P., Marche J.P.
The SIDC Project: a comprehensive operational space weather service in Belgium, final report
Poster at the European Space Weather Week, ESTEC, Noordwijk, 13-16 November 2005.

Educational responsibilities

- **E. Robbrecht** was mentor for Inneke d'Hollander, a student of the Higher Nautical School of Antwerp: "Invloed van het ruimteweer op de instrumenten aan boord"

C.1.8. Missions

Assemblies, symposia (number):	R. Van der Linden (2) P. Vanlommel (3)
Commissions, working groups (days):	R. Van der Linden (2)

C.2. Operational activities as Regional Warning Center (RWC) Belgium

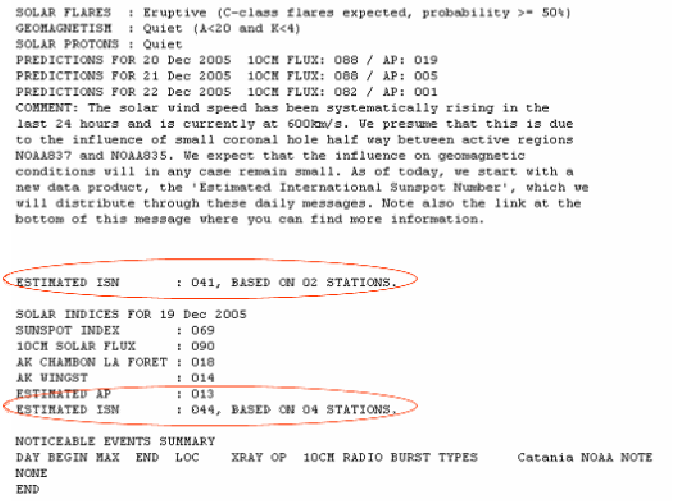
C.2.1. Objectives

RWC Belgium offers a permanent service center, specializing in solar monitoring and solar activity forecasting under the auspices of the ISES network. For this, we have access to a large volume of solar and heliospheric data that can span these wide 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 the Earth and human technology.

C.2.2. Progress and results

The main task of the SIDC as Regional Warning Center of the ISES is to perform continuous monitoring of solar and geomagnetic activity, which includes daily forecasts of several internationally recognized activity indices. The role as a RWC implies handling data flows from various sources; most of them arriving through e-mail or internet downloads. To perform these activities in an efficient way, we use the locally developed software packages 'PreviMaster' and 'PreviWeb', which are continually improved and adapted to changing data sources and user requirements. Both software packages were significantly extended during 2005 under the impulse of the joint development of user products for the ESA Space Weather Applications Pilot Project. During 2004, we have also replaced the servers that handle SIDC data, at the same time implementing tighter security constraints and a more structured network. The PreviWeb interface has been completely rewritten by linking it up to scripts populating a MySQL database. This SIDC database includes recorded data since 2001 and forecast data since March 2003. It is linked to other databases containing references to solar data and event catalogues derived from this data.

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. Besides these default distributions, several other types of messages are generated, the most important ones being the fast alerts discussed earlier like the all-quiet-alert which becomes more relevant approaching solar minimum, and the 'presto' messages, which are intended to alert our users of strong perturbations to space weather. When conditions warrant, press contacts are also established. The main method of information distribution is through the internet: the SIDC website and e-mail. The growing international interest in our service is reflected in the steady growth in the website visits and e-mail registrations.



```
SOLAR FLARES   : Eruptive (C-class flares expected, probability >= 50%)
GEOMAGNETISM   : Quiet (A<20 and K<4)
SOLAR PROTONS  : Quiet
PREDICTIONS FOR 20 Dec 2005  10CM FLUX: 088 / AP: 019
PREDICTIONS FOR 21 Dec 2005  10CM FLUX: 088 / AP: 005
PREDICTIONS FOR 22 Dec 2005  10CM FLUX: 082 / AP: 001
COMMENT: The solar wind speed has been systematically rising in the
last 24 hours and is currently at 600km/s. We presume that this is due
to the influence of small coronal hole half way between active regions
NOAA837 and NOAA835. We expect that the influence on geomagnetic
conditions will in any case remain small. As of today, we start with a
new data product, the 'Estimated International Sunspot Number', which we
will distribute through these daily messages. Note also the link at the
bottom of this message where you can find more information.

ESTIMATED ISN       : 041, BASED ON 02 STATIONS.

SOLAR INDICES FOR 19 Dec 2005
SUNSPOT INDEX       : 069
10CM SOLAR FLUX     : 090
AK CHAMBON LA FORET : 018
AK WINGST           : 014
ESTIMATED AP        : 013
ESTIMATED ISN       : 044, BASED ON 04 STATIONS.

NOTICEABLE EVENTS SUMMARY
DAY BEGIN MAX  END  LOC    XRAY OP  10CM RADIO BURST TYPES     Catania NOAA NOTE
NONE
END
```

Figure 30: The first ursigram sent which included the Estimated ISN. This was announced through the 'Solar Highlights' on Dec. 20, 2005

End 2005, we started with an electronic version of the SIDC Monthly Bulletin of Solar and Geomagnetic Activity. Typically around the 7th of the month, an email is sent to the registered users with the information where the electronic version of the bulletin can be found.

On user request, the Estimated International Sunspot Number was developed. Previweb is adapted in that sense that this EISN is now sent together with the daily ursigrams. The observations used to calculate the EISN reach us through the newly developed Wolf Interface. Observers have to give their input before 12:30UT. A statistical reliable method was developed and is run by previmaster. Typically 4 to 5 stations contribute. The 'Solar Highlights' are used to make publicity and to attract more stations.

An evaluation on the performance of the SIDC as Regional Warning Center during the September 2005 events was made. The fast alert service did well. The results were presented during the Second European Space Weather Week in ESTEC.

C.2.3. Perspective for next years

The SIDC will continue its activities as a Regional Warning Center of the ISES. However, since the ESA pilot project formally ended in March 2005, and ESA did not extend the project, activities will probably be reduced to a lower level. We will continue to strengthen our scientific research as the solid basis of our space weather forecasting activities. The SIDC activities will benefit from a strong participation of the solar physics department team in space missions such as PROBA2 and STEREO, and from a participation in international research networks.

This number of stations contributing to the EISN will steadily grow as more observers start to know the Wolf Interface and the relevance of the EISN. In April 2006, a seminar for amateur astronomers is planned. This opportunity will be used to urge them to use the available facilities. A forecast of one day ahead of the EISN will be developed and sent together with the daily ursigrams.

C.2.4. Personnel involved

Scientific staff: R. Van der Linden (Project manager)
Additional contributions from: D. Berghmans, F. Clette, G. Lawrence, E. Robbrecht, P. Vanlommel, A. Zhukov, S. Willems, L. Wauters, B. Nicula, J.-F. Hochedez, O. Boulvin, D. Lafont.

The daily duty cycle of forecasting and monitoring activities were shared by D. Berghmans (53), F. Clette (48), G. Lawrence (27), R. Van der Linden (31), E. Robbrecht (75), P. Vanlommel (85) and A. Zhukov (46).

C.2.5. Partnerships

List of national and international partners

RWC Belgium is one of the nodes in the International Space Environment Service (ISES, see http://www.ises-spaceweather.org/).

Grants used for this activity:

ESA/PRODEX Contract C90192 "SIDC Telescience".
ESA/PRODEX Contract C90205 "SIDC Data Exploitation".

Visitors: None.

C.2.6. Publications

C.2.6.1. Publications with peer review

[1] **Hochedez J.-F., Zhukov A., Robbrecht E., Van der Linden R., Berghmans D., Vanlommel P., Theissen A., Clette F.**
Solar weather monitoring
Annales Geophysicae, 23, issue 9, pp. 3149-3161, 2005.

[2] **Berghmans D., Van der Linden R., Vanlommel P., Warnant R., Zhukov A., Robbrecht E., Clette F., Podladchkova O., Nicula B., Hochedez J.-F., Wauters L., Willems S.**
Solar activity: nowcasting and forecasting at the SIDC
Annales Geophysicae, 23, issue 9, pp. 3115-3128, 2005.

C.2.6.2. Publications without peer review

C.2.6.3. Publications in press, submitted

C.2.6.4. Reports, thesis, etc

[3] **R.A.M. Van der Linden and the SIDC team**
Annual report 2005 to the International Space Environment Service.

[4] **The SIDC team**
Outgoing messages from RWC Belgium: 365 daily ursigrams, 52 weekly bulletins, 2 Monthly Bulletins of Solar and Geomagnetic Activity (since Nov. 2005), 2 quarterly bulletins, 12 Monthly Ri Reports, 12 Monthly Ri_hemispheric Reports, all-quiet-alerts, 79 presto alerts, halo CME alerts, GOES X-ray flare detection alert, reduced GPS accuracy alert, advance alert: enhanced geomagnetic activity warning. The alerts are sent when needed; the other bulletins are sent on a regular basis.

C.3. INTAS Project 03-51-6206 "Solar and interplanetary disturbances causing severe geomagnetic storms"

C.3.1. Objectives

The investigations in the framework of this project (started in 2004) are carried out in collaboration with Max-Planck-Institut für Sonnesystemforschung (Germany), Skobeltsyn Institute of Nuclear Physics (Russia), IZMIRAN (Russia) and Astronomical Institute (Czech Republic). The objective of the project is to study the strongest geoeffective disturbances in the corona and inner heliosphere that occurred during the current solar cycle.

C.3.2. Progress and results

The solar and interplanetary sources of extreme solar events of October – November 2003 and November 2004 have been identified using data from SOHO (EIT and LASCO), CORONAS-F (SPIRIT) and ACE spacecraft. A comparison of the solar atmosphere observations obtained by EIT and SPIRIT has been per-

formed. It has been demonstrated that global changes occurred in all spectral ranges of the solar electromagnetic radiation with the asymmetry in the heliologitude. This phenomenon was accompanied by more localized enhanced energy releases, manifested as CMEs and flares. The most powerful of them were observed on the side of the Sun that was brighter even without these local enhancements. These results suggest that the physical causes of solar and heliospheric phenomena in October – November 2003 are not exclusively local and do not belong only to active regions and solar atmosphere above them. The energy supply and driving forces probably have a more global nature.

During the visit of I.S. Veselovsky (Skobeltsyn Institute of Nuclear Physics) to the ROB (10-23/04/05) some space weather studies were performed. It has been shown that the temporal profile of the Dst index for extreme geomagnetic storms follows quite well the changes of the north – south component (Bz) of the interplanetary magnetic field. The quantitative description is still a challenge, but it seems now clear that the supply of free energy from inside the magnetosphere is quite weak and geomagnetic storms can be triggered only by external disturbances, i.e. perturbations in the solar wind.

C.3.3. Perspective for next years

The project is financed for three years (2004 – 2006). The investigation of solar and interplanetary sources of severe geomagnetic storms will be continued. The sources of more recent severe storms that occurred in January, May and September 2005 will be identified and these storms will be compared to other extreme events.

C.3.4. Personnel involved

Scientific staff: A. Zhukov (Project leader)
Additional contributions from: R. Van der Linden

C.3.5. Partnerships

List of national and international partners

This research project is a collaboration between 5 scientific institutes.

Grants used for this research:

INTAS grant 03-51-6206

Visitors: none.

C.3.6. Publications

C.3.6.1. Publications with peer system

[1] Veselovsky I.S., Dmitriev A.V., Zhitnik I.A., **Zhukov A.N.**, Zel'dovich M.A., Kuzin S.V., Naumkin A.A., Persiantsev I.G., Ryazanov A.Yu., Shugai Yu.S., Yakovchuk O.S., Bogachev S.V., Shestov S.V.
Global Variations and Asymmetry of the Sun during Extremely High Activity in October–November 2003
Solar System Research, Vol. 39, No. 3, 2005, pp. 169-175.

[2] Veselovsky I.S., Bothmer V., Cargill P., Dmitriev A.V. Ivanov K.G., Romashets E., **Zhukov A.N.**, Yakovchouk O.S.
Magnetic storm cessation during sustained northward IMF
Advances in Space Research 36 (2005) 2460-2464.

[3] Slemzin V.A., Kuzin S.V., Zhitnik I.A., Delaboudinière J.-P., Auchere F., **Zhukov A.N., Van der Linden R.**, Bugaenko O.I., Ignat'ev A.P., Mitrofanov A.V., Pertsov A.A., Oparin S.N., Stepanov A.I., Afanas'ev A.N.
Observations of Solar EUV Radiation with the CORONAS-F/SPIRIT and SOHO/EIT Instruments
Solar System Research, Vol. 39, No. 6, 2005, pp. 489-500.

C.3.6.2. Publications without peer system

C.3.6.3. Publications in press, submitted

C.3.6.4. Reports, thesis, etc

C.3.7. Missions

Commissions, working groups (days): A. Zhukov (6)

D. Solar activity indices

As the World Data Center for the Sunspot Index and a data analyses service of the FAGS, the SIDC is in charge of the determination, archival and mid-term prediction of the International Sunspot Number, the most fundamental solar activity index. Given its unequalled time coverage of three centuries, it is used as a reference index in innumerable studies and publications. Most other indices, introduced more recently, are calibrated on the sunspot number in order to define long-term irradiance models for backwards and forward extrapolations. Along that axis, the solar physics team has developed internally new researches in the domain of solar indices to extend the base sunspot reference.

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. The introduction of white-light and Hα CCD imagers, now in routine use, marks also an ongoing effort to improve and to better understand existing solar activity indices and to study new quantitative ground-based solar indices based on modern electronic imaging technologies.

The Humain station was previously dedicated to the continuous recording of the 600MHz radio flux, one of the few long-term indices preceding the space-era, which is provided only by this station. In the framework of a modernization and redeployment project submitted in 2004 and still awaiting a full evaluation, the Humain radio instruments could record absolute fluxes in other radio bands, including 10.7cm, and provide spectrographic diagnostics of radio bursts in near-real time to support the SIDC services. At the moment, however, radio observations in Humain have been suspended.

Finally, in preparation of the science exploitation of the PROBA2/SWAP imager, a correlative study has been initiated between SOHO/EIT and CORONAS/SPIRIT images and the 10.7 cm radio flux, in order to establish a predictive relationship between the spatially-resolved extreme UV flux and the standard 10cm radio index. The team also prepares UV irradiance variability studies based on the absolute standard fluxes from the PROBA2/LYRA radiometers now in development.

D.1. SIDC, World Data Center for the International Sunspot Index

D.1.1. Objectives

Determination of the International Sunspot Index, based on visual sunspot observations from a world wide network of observing stations. Since 1981, the SIDC maintains and makes accessible to the scientific community the sunspot archive spanning 3 centuries, i.e. the longest existing record of solar activity, previously under the responsibility of the Zurich Observatory. The SIDC also publishes, through its Sunspot Bulletin, various solar indices as well as mid-term activity forecasts.

D.1.2. Progress and results

The normal operations of the SIDC as World Data Centre for the Sunspot Index include:

Data processing:

- Determination of the provisional sunspot number (Total and normalized hemispheric North & South counts)
- Computation of the monthly, smoothed monthly and yearly means.
- Computation of the definitive sunspot number (Total & hemispheric, published quarterly) based on the entire network
- Mid-term prediction by the Waldmeier classical method and by the Combined Method, 18 month ahead.
- Quality control: long-term drift evaluation based on 20 selected stations and the 10cm radio flux.

Archive:

- Maintenance of the archive: yearly, monthly, monthly smoothed and daily sunspot numbers.
- The archive is publicly accessible through the SIDC web and FTP site (ASCII data files and plots)

Sunspot Bulletin (monthly publication):

- Provisional sunspot table and plot
- 24-month predictions of the monthly Sunspot Number
- Summary of the URSIGRAMS, with additional indices (PPSI, 600MHz flux, 2800MHz (10cm) flux, Terre Adélie cosmic ray counts, solar flare index, X-flare index, Wingst geomagnetic index Ak).
- Uccle daily provisional relative and normalized sunspot numbers derived from the digitized USET drawings.
- Table of major sunspot groups observed at Uccle and probable return of major groups derived from Uccle sunspot group classification.
- Quarterly SIDC-News issue: SIDC definitive international and Hemispheric Sunspot Numbers for 3 months.

New developments in 2005:

- The SIDC-WDC faced serious problems of understaffing in 2005, due to long term sickness absences of two staff members, a vacant position (since May; new recruitment in progress) as well as the nomination of R. Van der Linden as ROB Director. The continuity of the SIDC services was ensured thanks to the re-assignment of the remaining staff (one scientist, F. Clette and one technician, A. Ergen) and the appointment of P. Vanlommel on a replacement contract.
- This year, a special effort was dedicated to the modernization of the SIDC sunspot processing:
  - Development and preliminary testing of the "WOLF" web interface: this new tool will allow observers to enter their reports directly into an SIDC database. This interface features consistency checking and will thus speed up the data import step, by strongly reducing the workload of semi-manual error checking. It also opens new possibilities, like the calculation of a daily estimated sunspot number based on a small subset of stations.
  - Start of the rewriting and documenting of the SIDC procedures and programs: this work was suspended in December but full operating manuals were already completed. As a complete renewal of the operators team will occur over the 2006-2008 period (multiple retirements), this effort is necessary to preserve and consolidate the past experience and know-how, also as a base for future redefinitions and expansions of the WDC products and services.
  - Rationalization of the address management, of the report collection and of the bulletin distribution (paper mail, fax, e-mail). The number of addressees receiving free copies of the Sunspot Bulletin was drastically reduced, while at the same time the Bulletin is made available for free in electronic format through the website.

- Contacts were established with several new observers (mostly amateur astronomers). Indeed, a renewal of the observing network is needed to compensate for unavoidable departures, and a special attention must be devoted to non-European SIDC contributors, in continents and longitudes bands that are still sparsely covered by the SIDC network.
- At the occasion of the upcoming 25th anniversary of the SIDC's foundation, several papers were prepared or already published to retrace the history of the SIDC and the International Sunspot Index. This was done in collaboration with Dr. A. Koeckelenbergh, founder of the SIDC, who provided important first-hand information, as well as copies of original historical documents.

D.1.3. Perspective for next years

The year 2006 will bring the celebration of the 25th anniversary of the creation of the SIDC in Brussels. The automation of the sunspot index processing will be continued. Observers will be invited to report their observations through the new web interface of the SIDC. Processing scripts and programs, as well as the associated data flow, will be updated, in connection with the RWC URSIGRAM automated processing. This effort should lead to the publication of a fully up-to-date description of the method leading to the sunspot index determination: an appropriate benchmark after 25 years of SIDC activities. The recruiting of replacement staff for the multiple positions that are currently vacant or will soon become vacant will be crucial to support this major effort. We also expect to add daily estimations of the sunspot number and a short-term forecast of the sunspot index to the daily ursigrams produced by the RWC. Further migration of paper copies to electronic versions of the Sunspot Bulletin will be encouraged. In the longer term, a fundamental revision of the way the sunspot number is calculated should be foreseen.

D.1.4. Personnel involved

Scientific staff: R. Van der Linden, F. Clette (Project leaders, shared in 2005)
SIDC team: A. Vigneron, O. Boulvin, A. Ergen, L. Wauters, P. Vanlommel, G. Evrard, D. Berghmans.

D.1.5. Partnerships

List of national and international partners

- The SIDC is one of the World Data Centers in the World Data Center System (http://www.ngdc.noaa.gov/wdc/wdcmain.html)
- The SIDC is a data analysis service of the Federation of Astronomical and Geophysical Data Analysis Services (FAGS, see http://www.kms.dk/fags/index.html)

Grants used for this research:

- ESA/PRODEX Contract C90192 "SIDC Telescience".

Visitors:

6 visiting scientists, including some observers of the SIDC network.

D.1.6. Publications

D.1.6.1. Publications with peer review

D.1.6.2. Publications without peer review

[1] **The SIDC Team**
The Sunspot Bulletin (12 issues)
[2] **The SIDC Team**
SIDC News (4 issues)
[3] **Berghmans D., Van der Linden R.A.M., Vanlommel P., Clette F., Robbrecht E.**

History of the Sunspot Index: 25 years SIDC
in Proc. IAGA "Historical event and people in aeronomy, geomagnetism and solar-terrestrial Physics", Ed. W. Schröder, J. Hist. Geophysics and Cosmical Physics, Vol. VII, No.1, pp. 288-299.

D.1.6.3.Publications in press, submitted

D.1.6.4.Reports, thesis, etc

[4] **The SIDC Team**
Annual report to FAGS

D.1.7. Scientific outreach

[5] **Berghmans D., Van der Linden R.A.M., Vanlommel P., Clette F., Robbrecht E.**
History of the Sunspot Index: 25 years SIDC
IAGA, 2005, Toulouse, France, oral presentation

D.1.8. Missions

Assemblies, symposia (number): D. Berghmans (1)

D.2. The Uccle Solar Equatorial Table (USET)

D.2.1. Objectives

Optical observations of the Sun for the characterization of its activity and of sources of irradiance variations. This includes visual sunspot observations, digital imaging in white-light (photosphere) and in the H-alpha line (chromosphere) for real-time flare patrol observations. Advanced exploitation of the visual sunspot observations of the Uccle station, and publication in the SIDC Bulletin of additional indices for this reference station (hemispheric and central zone indices, PPSI, individual group evolution).

D.2.2. Progress and results

Maintenance of the CCD camera system: the cameras did not suffer from any major failure in 2005. However, the performance and reliability of the aging cameras is slowly degrading. Therefore, several actions were undertaken:

- Isolated enclosures were installed to protect the cameras from extreme temperatures, from high humidity and from dust.
- A market study was undertaken over the last 3 months of 2005 to select new CCD cameras to upgrade the existing ones (higher resolution 2048x2048 pixels, enhanced blue sensitivity, standard remote PC interface).
- The upgrade of the camera control PC was initiated. The required change in control library software induced some delays, preventing the completion of this upgrade in 2005.

Additional work on the telescopes:

- *The full 2-axis stepping-motor control of the USET mounting* was commissioned on June 15, 2005. The new motorization and control electronics improves the tracking and control of the telescope but it also opens many future possibilities for the computerization and automation of the telescope operation.
- *Initial development of a solar pointer*: Building on the new computer controlled motorization, this device will improve the accuracy of drawings and allow an accurate and controlled centering of the CCD camera system (mechanical drift correction, atmospheric image motion, controlled off-pointing for flat-field sequences). In 2005, the key components were identified and selected (objective lens,

filters and 4-quadrant sensor (sensor size and focal length matching, spectral response, sensor response time, etc.). This work will continue in 2006.

New H-alpha optics (LOTTO funding): given the limited quality (resolution and contrast) of the vintage Lyot filter on the USET, it had been decided in 2004 to replace it with a new H-alpha system. In the course of 2005, a new optical system based on a focal Fabry-Pérot monochromator was selected and ordered. The monochromator is a high-uniformity 0.5Å device (vs 0.7 Å for the current filter), with thermal control. Given the long delivery time of the filter, the new H-alpha system will be delivered only in early 2006 and enter normal operation in the second half of 2006, after installation and commissioning.

New digitizing system for the solar drawings: in 2005, the development of a new encoding and digitization software was started in the framework of the training work of a graduate student in computer sciences, Julien Moreau (ESI, 14/2-27/5/2005). Unfortunately, over his 3-month training period, the student could not complete the program. Although the essential components are finished at 80%, the software is not yet functional. Therefore, the processing of the USET drawings had still to be done manually in 2005. Fortunately, this task remained manageable thanks to the rather low solar activity. The software will be completed in the spring of 2006, with the collaboration of a new ESI graduate student, Julien Rateau.

Observations:

- Like in previous years, the CCD synoptic images were automatically transferred to a dedicated archive and the latest images were uploaded to the SIDC servers and were displayed in the "Latest Solar Data" pages, together with imagery from other observatories and spacecrafts, for worldwide access.
- This year, all Uccle sunspot drawings were scanned immediately after the observations. The scanned document (jpeg file) was 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. Sunspot group evolution data, derived from encoded drawings, were used for the Uccle tables of the Sunspot bulletin (p.4).
- The 2005 statistics for the sunspot observations are the following:
  - Number of observations: 310 (1 drawing on 182 days, 2 drawings on 64 days)
  - Number of observing days: 246 (out of 365)
  - Number of observers: 15, with mainly O. Boulvin (161 drawings/ 200 days).
- The 2005 statistics for the CCD observations are the following:
  - White-light (photosphere): 783 images over 215 days (3.6 im/day)
  - H-alpha (chromosphere): 1116 images over 222 days (5.02 im/day)

D.2.3. Perspective for next years

- Instrument development:
  - Installation of the new Hα filter and telescope (and association with the international Hα network).
  - Completion of the new digitizing and encoding software tool for solar drawings.
  - Design study and development of a solar pointer and installation of absolute encoders to ensure accurate tracking for CCD cameras.
  - Selection, purchase and installation of two new 2048x2048 CCD cameras (LOTTO funding)
  - Design and acquisition of a new CaIIK chromospheric telescope (LOTTO funding)
- Full debugging and rewriting of the USET processing software: this effort will allow writing up a structured description of the method. It will also bring improvements and an increased robustness. The know-how can later be applied to other data (digital solar images from Uccle and other sources). The recruiting of replacement staff will be crucial to support this major effort.
- Trainees: over the 2005-2006, academic year, F. Clette will be supervising one student working on the development of the USET instrument and the associated data acquisition (Julien Rateau, ESI)

D.2.4. Personnel involved

Scientific staff: F. Clette (Project manager, observations, development, testing and calibration of instruments)
Technical staff: J-L. Dufond, A. Ergen (Technical maintenance and instrument development)
Data processing: A.Vigneron, G.Evrard, O.Boulvin
Observers: A. Ben Moussa, D. Berghmans, O.Boulvin, F.Clette, M. Dominique, J-L Dufond, A.Ergen, S. Gissot, G.Lawrence, E.Podladchikova, E. Robbrecht, A. Theissen, R. Van der Linden, A. Vigneron, A. Zhukov.

D.2.5. Partnerships

Grants used for this research

- LOTTO grant
- ESA/PRODEX Contract C90192 "SIDC Telescience".

D.2.6. Publications

- SIDC sunspot bulletin (12 monthly issues): the Uccle-USET relative and normalized sunspot numbers, large sunspot group table, large returning group list.
- Real-time web distribution of more than 1900 CCD camera images.
- Real-time web distribution of 246 scanned solar drawings.

D.2.7. Missions

Assemblies, symposia (number): F. Clette (2)

D.3. The Humain radio-astronomy station

D.3.1. Objectives

Radio-electric observations of the Sun for flare monitoring and long-term recording of the solar radio in the upper-chromosphere and low corona:

- Integrated radio flux at 600 MHz.
- Near-real time transmission and processing of the Humain data, in support to the SIDC solar flare monitoring.
- Future extension to other frequencies: radiometer at 2,8Ghz (10.7cm), decimetric radio-burst spectrograph.

D.3.2. Progress and results

- *Preservation of the Humain site quality*: again this year, a continuous attention had to be devoted to the protection of the perimeter around the station and of the Humain radio frequencies against radio interferences: the Electrabel wind turbine project has been abandoned. The coordination with the CRAF was maintained at the international level (600 and 408MHz bands protection in future ITU regulations, wind turbine issue). We continued to process frequency allocation requests for the IBPT and we maintained contacts with the Lhoist industries concerning the exploitation of their quarry located in the immediate neighborhood of the station.
- Station development and projects: 2005 was a critical year for the Humain station that was never in such an extremely fragile situation because of structural reasons (quick drop of staff after years without replacement) and of the postponement of the evaluation of a modernization project submitted in 2004. The main steps were the following
  - Evaluation of the HUMSOLAR project by international radioastronomy experts: the HUMSOLAR project submitted for a BELSPO Action1 funding in April 2004 did not progress in

2005 despite repeated calls and warnings of the critical situation. Following a request of the Scientific Council in June 2004, the project was submitted to the evaluation of ten international experts (directors of radioastronomy facilities and international project PIs) who gave their reports in February 2005. All reports supported the absolute flux and real-time dissemination via the SIDC. One idea was criticized as unfeasible (flare diagnostic by a few discrete frequencies) but another solution was suggested within the same budget envelope: i.e. a full multi-frequency radio spectrograph. The HUMSOLAR project was adapted accordingly. Unfortunately, partly because of the transition phase around the change of ROB director, the evaluation of the project was stopped at the level of the Scientific Council (March 16 meeting).

- Interruption of the observations (August 2005): unfortunately, in the meantime, the new Director concluded that no more funding was available to continue paying the salary of the local electronician, M. Walkiers (contractual), which left the station with only one person to maintain the site and operate the instruments. Consequently, given the case of absolute necessity and considering the safety issues with only one remaining staff member, M. Janssens, at an isolated site, the observations had to be suspended for an undetermined duration in August 2005. In the months that followed, as this state of affairs resulted from practical impossibilities and internal ROB reactions, rather than a fully argued assessment, the whole matter was submitted by F.Clette to the President of the board of BELSPO, M. P. Mettens, who convened a meeting with the leaders of the station (F. Clette, D. Berghmans, R. Van der Linden). As a conclusion, he prompted the scientists in charge of Humain to submit a new development and routine operation plan for this facility. The submission of such a plan, as well as an audit of the site and instruments, is now planned for 2006.

Observations and instrument status at the end of 2005:

- The normal observations of the 600MHz solar flux, and also the 27khz SEA recordings, were carried out continuously from January 1st to July 31:
  - 600MHz radiometer: 210 observed days over 212 days of operation.
  - Daily plots including flare events were produced for publication on the SIDC website (http://www.sidc.oma.be/radio/).
  - The solar background flux was derived and published among reference indices in the SIDC Sunspot Bulletins (p.3, continuation of time series beginning in 1954).
- On August 1st, all antennas were stopped and since then, are no more rotated on a weekly basis to avoid internal rust buildup in the bearings. Receivers were switched off and the 600MHz parabola was placed in a horizontal position to prevent wind damage. Thus, under the coordination of M. Dufond, all working instruments were left in such a way that they can be reactivated at any time. The 6-m refurbished dish is ready to receive new receiver electronics. No irreversible damage or failure is expected during a 6 to 12-month interruption. For what concerns the data gap in the 600MHz 50-year long time series, it is unfortunate and detrimental, but as long as it remains short relative to the solar 11-year cycle duration, it does not decrease significantly the value and usefulness of the entire series. Still, all of the above indicates that a final decision for the future of radioastronomy in Humain must be obtained within 6 to 12 months, and that past delays on the evaluation must not be repeated.

D.3.3. Perspective for next years

The future orientation of the radio-astronomy activities at the Humain station will depend on the conclusions, at the level of BELSPO, concerning extra funding, on the base of a long-term science and budget plan to be submitted in early 2006. Normally, an audit should also be organized on request of the Scientific Council.

International activities:

- Study of synergies for future radio instruments in Humain in the context of the CESRA and the International Heliophysical Year.

- Possible technical collaboration with ETH Zurich for the installation of a radio spectrograph (CALLISTO project)

D.3.4. Personnel involved

Scientific staff: F. Clette (Project management, site protection)
Technical staff: J-L Dufond (management)
Technical maintenance, instrument operations:, P. Janssens (resident), S.Walkiers.
Data processing: J-L. Dufond, A. Ergen.

D.3.5. Partnerships

List of national and international partners

- Dr. K. Tapping (Dominion Radio Astronomical Observatory, Penticton, Ottawa, Canada)
- Dr. M. Messerotti (Trieste Solar Radio Observatory, Italy)

D.3.6. Publications

- Web distribution of daily 600MHz solar flux plots on the SIDC web pages (until 31/7/2005).
- Daily-averaged 600MHz background flux listed in the SIDC Sunspot Bulletins (12 issues, solar indices table, 3 p.) (until 31/7/2005).

D.3.7. Missions

Commissions, working groups (days): F. Clette (1)
Work missions (days): F. Clette (2)
Field missions (days): J.L.. Dufond (30)

INTERDEPARTEMENTAL SCIENTIFIC ACTIVITIES

A. Observational facilities

P. Lampens has explored the possibility to construct a small optical facility at Humain, visited the station on 18/08/2005 (accompanied by J.-L. Dufond, Dep. 4, and V. Rogge, Security engineer) and started a discussion with all concerned parties.

B. Digitisation

The Royal Observatory of Belgium possesses 30 000 photographic images of the sky, 1000 photographic spectra, 20 000 drawings of the sunspots, 7500 photographic images of the solar photosphere, 750 000 images of the solar chromosphere, lots of historical seismograms, and a very rich library with historical works. All these records are an invaluable scientific heritage of the past, containing still a lot of scientific information. All these are in danger, because they suffer from deterioration, and they are inaccessible to foreign researchers. Other federal scientific institutes also have enormous collections that suffer from the same problems. At the federal level it was realised that there is a need to digitise these collections, so as to preserve their scientific content, and subsequently to make them accessible to other researchers via the web.

First, POD Science Policy initiated pilot projects to develop the necessary technologies. The D4A project is such a pilot project aiming at building a high-precision scanner. It involves the Royal Observatory of Belgium, the National Geographic Institute and the Museum of Central-Africa, and a few other partners. Meanwhile, a study started, aiming at establishing the needs of the federal institutions for digitisation of their heritage.

Also on the international level, but then specifically for astronomy, there have been initiatives. The UDAPAC project was started in 2000, with the intention to gather and digitise the European astronomical direct photographic plates for which the host institute either have no interest or have no money to keep their collections themselves. This UDAPAC project is still at the level of an intention, but the D4A project should prepare the way for the UDAPAC project, by creating the necessary environment (archives) and building a scanner, that will later be useable by UDAPAC.

B.1. D4A Project - Digital Access to Aero and Astrophotographic Archives

B.1.1. Objectives

The aim of this pilot-project (FSP I2/KSB/103) is to preserve the historic-scientific information contained in the astrophotographic plate archive of the ROB and in the aerial photographic archives of the NGI and the RMCA. In collaboration with AGFA-Gevaert a world-leader in photographic matters, the goal is to acquire the necessary know-how, hardware and software to digitise the information contained in the photographic plates, as well as the associated metadata. The project set out to offer the results to the public and to make them directly usable for scientific research through the modern techniques of the information society.

B.1.2. Progress and results

The D4A project is building a 2D digitiser facility of high geometric and radiometric resolution and precision, that will be housed in a temperature and humidity stabilised clean room with adjacent archive room. The ROB is financing this with a Lotto grant that became available in March 2003 and through the ROB dotation. The Ministry of Public Works (Regie) is doing the necessary renovations of the Telescope building that will house the climatised clean room and the plate archive in its basements.

J.-P. De Cuyper is project coordinator and in charge of the purchase of an airbearing XY-table and a temperature and humidity controlled clean room for the digitiser facility. For both a negotiated purchase procedure is followed.

The digitiser is based on an ABL3600 airbearing XY-table from Aerotech, with as add-ons: an automatic film roll transport and plate holder system, a plate stack/exchanger/ loader system and a turntable. The final drawings of the film transport and the plate holder system were officially accepted. Aerotech started the production of the machine. The delivery is foreseen in spring 2006.

The climatisation is already partly installed (air conducts, air treatment machine and chiller) by Becker Reinraum Technik GmbH, allowing the finishing of the renovation works in the basements by the Regie. After several meetings, some together with Becker, the Regie agreed to also provide the warm-water exchanger for the climatisation and the needed electrical installation (380V3P transformer of 25KVA, a 6KVA UPS, etc.). J.-P. De Cuyper is responsible for the follow-up of the renovation works and worked out together with **Marc De Knijf** and **Eric Vander Putten** the technical specifications for the renovations. The rails for the mobile archive racks were purchased and installed by AXOS.

Together with Lars Winter (external consultant) the design of the digitiser is continued. Work was done on the further development of the solid state diffuse illumination system using very bright LED's (1W/5W). A total diffuse illumination was found to give an optimal reduction of the background plate noise in the digital images. In collaboration with **I. Van Der Gucht**, the design and construction of a high precision computer regulated DC power supply (needed for the illumination system) was started. The air-cooled BCi4 CMOS camera with its new software driver of Vector International was tested. A geometric and radiometric benchmark was worked out in detail as well as the first version of the data reduction software needed to analyse the results.

The HAM1, an old Mann Comparator, was shipped from USNO Washington DC to ROB and installed for use as a set-up for testing the CMOS camera and the illumination system. **R. Peeters** and **F. Renders** made the necessary metal parts needed for the set-up.

The NGI ordered a 35cmx35cm geometric grid, with black circular chrome dots on a blank glass plate, designed by J.-P. De Cuyper and Lars Winter, needed for the delivery benchmarks and the calibration of the Digitiser. In collaboration with the NGI and AGFA-Gevaert test film rolls were produced and shipped to Aerotech for the development and testing of the filmroll transport system.

Using the 24cmx24cm geometric grid of the ROB, several commercial flatbed scanners were tested in their optical resolution mode(s). In collaboration with Uwe Laux, an optical engineer of the Thüringer Landesternwarte Tautenburg, the characteristics and systematic errors of the Schneider Xenoplan 1:1 telecentric objective were studied and the design of a new panchromatic telecentric objective was started.

The development of a digital, ODBC compliant, relational database describing the astrophotographic plate archive was continued in collaboration with **G. de Decker,** the informatician of the D4A project. The database is accessible on the intranet through html Pages (using Data Access Pages and Java Scripts).

G. Peeters and **D. Duval** extended the Excel input lists of observational metadata for introduction into the database. During the summer two students started the introduction of the spectroscopic plate metadata into Excel lists. The metadata of all spectra taken in different resolutions with the 1.52m telescope at OHP were completed. Those of the spectra taken at the 1.52m ESO telescope at La Silla were started and continued by **G. Peeters**. The prescanning at 250 dpi of the 16 cm plates with the HiD scanner at the KSB was continued by **D. Duval** and of the 30 cm and 24cm plates with the XY15 scanner at the NGI by the two students.

In parallel, a bilateral cooperation with Bulgaria under the name "Catalogue Integration and Image Processing of the ROB Wide-Field Plate Archives" was pursued. This cooperation made it possible to produce digital catalogues for the Carte du Ciel and the Triplet wide-field plate archives and to integrate the metadata obtained in the context of the digitization project into the "Wide-Field Plate Data Base" maintained at Sofia (http://draco.skyarchive.org/search/). Footprints of the Carte du Ciel plates were also in-

corporated. In this way, the contents of two historical ROB plate collections are accessible by the astronomical community.

B.1.3. Perspective for next years

In the coming year, the Digitisation project will extend the digital plate catalogue. A webserver, containing the metadata database will be set up on Internet, after making a study of the available hardware and software systems in order to optimise the accessibility and the maintenance costs.

The construction of the climatised clean room and of the XY-table and the add-ons will be realised. The building the Digitiser will be finished by working out a diffuse very bright LED's based colour illumination system with purpose build modular power supply and an air-cooled BCi4 CMOS camera. The necessary hardware and software for the digitisation and the data storage, handling and extraction will further be developed and/or acquired. Depending on the type of data contained in the photographs and their type of application, different calibrated end products will be made available.

B.1.4. Personnel involved

Scientific staff:	Jean-Pierre De Cuyper (project coordinator)
	Thierry Pauwels (secretary of "Vast Bureau")
Technical staff:	Georges Peeters, David Duval
Support from:	ROB technical services
	Georges de Decker (informatician of the D4A project, employed by RMCA)

B.1.5. Partnerships

List of national and international partners

- National Geographic Institute (NGI), Dir. Joost Vanommeslaeghe, Dir. Herman Prils.
- Royal Museun of Central Africa (RMCA), Prof. Dr. Johan Lavreau, Dr. Max Fernandez.
- AGFA-Gevaert, Mortsel, Aerial Photography & Engineering Devision.
- Hamburg, Dr. Lars Winter
- United States Naval Observatory, Washington DC, Dr. Norbert Zacharias
- Thüringer Landessternwarte Tautenburg, Dipl. Ing. Uwe Laux

Grants used for this research

- Lotto grant
- FSP I2/KSB/103
- Bilateral project 'Catalogue Integration and Image Processing of the ROB Wide-Field Plate Archive', ref. BL/33/B10
- ROB budget

Visitors: 9

B.1.6. Publications

B.1.6.1. Publications with peer review

B.1.6.2. Publications without peer review

[1] **De Cuyper J.-P.**, and Winter L.
The D4A Digitiser
The PDPP Newsletter 3, pp 19-22

[2] Tsvetkova K., Tsvetkov M., Stavinschi M., Fresneau A. and **Lampens P.**,
Astrometric plate catalogues in the Wide-Field Plate Database.

Romanian Astronomical Journal 15 (2005), Suppl., Proceedings of the Scientific Session "Astrometry with Small Telescopes", Bucharest, Romania, 22-23 October 2004, eds. M. Stavinschi & V. Mioc (in the framework of the)

B.1.6.3. Publications in press, submitted

[3] **De Cuyper J.-P.**, Winter L.
The D4A Digitiser
in Astronomical Data Analysis Software and Systems - ADASS XIV (eds. P. Shopbell, M. Britten and R. Ebert), ASP Conf. Series, p 4.

[4] **De Cuyper, J.-P.**, Winter L.
The D4A Digitiser
in Astronomical Data Analysis Software and Systems - ADASS XV (eds. C. Gabriel, C. Arviset, D. Ponz and E. Solano), ASP Conf. Series, p 4

[5] **Pauwels T.**,
A tool for identifying astronomical plates
To be published in the proceedings of the conference "Virtual Observatories: Plate Content Digitization, Archive Mining and Image Sequence Processing".

B.1.6.4. Reports, thesis, etc

[6] **Lampens P.**, Tsvetkov M.
Report on bilateral project Catalogue Integration and Image Processing of the ROB Wide-Field Plate Archive (reference BL/33/B10, Dec. 2005)

B.1.7. Missions

Assemblies, symposia (number):	J.P. De Cuyper (1)
Commissions, working groups (days):	T. Pauwels (3)
Field missions (days):	J.P. De Cuyper (60)

B.2. Operational project "Digitisation of the heritage of the Federal Scientific Institutes of POD Science Policy"

B.2.1. Objectives

The federal Science Policy has recognised the importance of preserving and making available the heritage of the scientific institutes. The intention is to digitise the collections of these institutes, and put them on the web. A study by the Bureau van Dijk in 2003 to compute the cost of this revealed that to implement the basic scenario 150 million euros would be needed. Full digitisation (excluding low priority collections) would cost 500 millions. The European Investment Bank was prepared to lend 75 million euros (half of the sum needed for implementing the basic scenario), on condition to get the guarantee that digitalisation would produce enough income to reimburse the loan. To investigate the financial return of digitisation a second study was ordered at the Bureau van Dijk, "Haalbaarheidsstudie die tegemoetkomt aan de eisen van de EIB in het kader van een onderzoek naar een aanvraag voor een lening conform de beslissing van de Ministerraad van 30 april 2004". This study was initiated in 2004.

B.2.2. Progress and results

On 20 January the Bureau van Dijk presented at Belspo the final report of their study. T. Pauwels was member of the follow-up committee of this study, representing the Royal Observatory. The outcome was that the financial return of the digitisation would be able to pay back no more than 10% of the foreseen loan by the EIB. This was only true for such institutes as musea, where there are clients from a broad pub-

lic. In the case of the ROB, where the only clients are scientific institutes, there would be no financial return at all. The idea of a loan by the EIB was abandoned.

Nevertheless, with a budget straight from POD Science Policy, 10 smaller scale projects were defined and started at the end of 2005. The Royal Observatory is involved in two of these projects: project No. 1, digitisation of library catalogues, involving all the participating institutes, except the BISA (Royal Library as coordinator), with P. Alexandre as the contact person for the ROB, and project No. 7, "digitisation of photographic glass plates", involving the KMMA (coordinator), the KIK, the BISA and the Royal Observatory, with T. Pauwels as contact person for the ROB.

Although projects could start from November 2005, both projects decided not to start their operational phase before 2006. The activities in 2005 were restricted to the administrative preparation of the projects.

B.2.3. Perspective for next years

The operational phase of digitisation project No. 1 should start somewhere in 2006 or early 2007, with an encoder engaged for 9 months. The objectives are to add the bibliographic data (including key words) in the catalogue, to list available volumes of the journals and to add bar codes to the books in order to automate the lending.

The digitisation project No. 7 should start in January 2006. In a first phase the project is set up for 3 years, but should normally extend for 10 years. In that time it should be possible to digitise all our astrophotographic plates. This project is the logical and operational continuation of the pilot project D4A (see previous item). The D4A project has not completely achieved its goal. The scanner that had to be built in the D4A project, is not ready yet. Its completion will be taken over by project No. 7. The digitisation of our plates should be performed with this scanner.

B.2.4. Personnel involved

P. Alexandre, J.-P. De Cuyper, T. Pauwels (with some help by F. Clette and K. Vanneste).

B.2.5. Partnerships

- Partners of the study "van Dijk": the 10 Federal Scientific Institutions, the Filmarchief van België, the Federal Science Policy, the Bureau van Dijk.
- Partners of project No. 7: the Royal Museum of Central Africa, the Koninklijk Instituut voor het Kunstpatrimonium, the Belgian Institute for Space Aeronomy.

Visitors: 5

B.2.6. Publications

B.2.6.1. Reports, thesis, etc

[1] Moens J.
Analyse van de modaliteiten voor de realisatie van het digitaliseringsplan van de federale wetenschappelijke instellingen en het Koninklijk Belgisch Filmarchief, goedgekeurd door de federale regering op 30/4/2004, 13 December 2004
With the help of the members of the follow-up committee.

[2] Fernandez M., Buelinckx E., **Pauwels T.**, Muller C.
Project 7: Digitalisering van originele fotografische dragers (glasplaten, film negatieven en positieven)

B.2.7. Missions

Assemblies, symposia (number): T. Pauwels (1)
Commissions, working groups (days): T. Pauwels (6)

GENERAL SCIENTIFIC ACTIVITIES

Belgian representations at international level

- **V. Dehant** is Belgian representative in the IAG Council
- **G. Van de Steene** is Belgian representative in the ESO Users Committee
- **R. Verbeiren** is Belgian representative in the IASPEI (till sep 2005), ESC, EMSC, ECGS council and the Board of directors of ORFEUS

Memberships of international scientific committees

- **V. Dehant, C. Bruyninx** are IAG Fellows
- **V. Dehant** is member of:
  - the WG "Nomenclature for fundamental astronomy", IAU Division 1WG
  - the Geodesy Section Executive Committee as Past-President of the AGU Geodesy Section
  - the Selection Committee for the Macelwane Medal of the AGU
  - the Selection Committee for the Vening Meinesz Medal of the EGU
  - the Scientific Council of the IPGP (Institut de Physique du Globe de Paris)
  - the Evaluation Committee (Audit) of the UMR-CNRS 8630 'Systèmes de Référence Temps-Espace' (SYRTE) of the SYRTE (Observatoire de Paris)
  - the Evaluation Committee (Audit) of the UMR-CNRS 5562 'Dynamique terrestre et planétaire' (Toulouse)
  - the High Scientific Committee of the Observatoire de Paris
- **C. Bruyninx** is Secretary of the Geodesy Section of the AGU
- **G. Van de Steene** represents the ROB in:
  - Herschel PACS Guaranteed time working group
  - VISA Belgian Time Allocation Committee

Memberships of national scientific committees

- **C. Bruyninx, T. Camelbeeck, V. Dehant** (Vice-president), **R. Verbeiren** are titular member of the BNCGG (Belgian National Committee on Geodesy and Geophysics)
- **B. Ducarme** is secretary of the BNCGG and responsible of the website of the Committee: http://www.astro.oma.be/BNCGG/:
- **F. Collin, P. Defraigne, M. Van Camp, T. Van Hoolst, K. Vanneste, R. Warnant** are associated member of the BNCGG
- **V. Dehant, T. Van Hoolst** and **R. Van der Linden** are titular member of the BNCA (Belgian National Committee on Astronomy)
- **C. Bruyninx, P. Defraigne, V. Dehant, F. Roosbeek, T. Van Hoolst, R. Warnant** are associated member of the CNBRS (Comité National Belge de Recherches Spatiales)
- **R. Warnant** is titular member of the CNBR (Comité National Belge de Radioélectricité)
- **V. Dehant** is member of the FNRS commission « Astronomie et Géophysique »
- **T. Camelbeeck, V. Dehant, P. Lampens, R. Van der Linden** are member of the Scientific Council of the ROB
- **P. Lampens** is:
  - ROB representant at the Belgian National ESO Committee (2 meetings attended)
  - administrator of the corporated association "*Belgian Women in Sciences"* (1 meeting attended)
- **G. Van de Steene** is member of the Belgian National ESO Committee

Educational responsibilities

- **P. Alexandre**, ULg, GEOG0208-1, 'Eléments de critique historique à l'usage des géographes'
- **Th. Camelbeeck**, ULB, GEO073, 'Géophysique Appliquée', 15h

- **F. Clette,** ULg (Institut d'Astrophysique, J-C Gérard, Academic year 2004-2005) 'Le Soleil: structure, activité et impact sur l'environnement terrestre', DEA in Astrophysics and Space Science.
- **P. Defraigne**, in co-titularity with J.-P. van Ypersele de Strihou, UCL, PHYS2131, 'Astronomie sphérique et Astronomie mathématique', 8h (+ 15h exercices)
- **V. Dehant** in co-titularity with J.P. van Ypersele de Strihou, UCL, PHYS1120, 'Astronomie et Géodésie', 15h (+7h30 of exercices)
- **V. Dehant** in co-titularity with **T. Camelbeeck**, UCL, PHYS2140, 'Géophysique interne', 15h (+7h30 of exercices)
- **V. Dehant** in co-titularity with **T. Camelbeeck** and **B. Ducarme,** UCL, PHYS3233, 'Questions spéciales de Géophysique interne', 8h
- **B. Ducarme** in co-titularity with J.P. van Ypersele de Strihou, UCL, PHYS1120, 'Physique du globe', 30h
- **M. Everaerts,** ULg, MAST0178-1, 'Gravimétrie, magnétisme et leurs applications géologiques', 15h (+15h exercises)
- **T. Van Hoolst**, K.U.Leuven, 'Theorie van stertrillingen', 26 h
- **M. van Ruymbeke** in co-titularity with H. Buyse, UCL, PHYS2904, 'Physics sensors', 22.5h
- **M. van Ruymbeke** in co-titularity with A. Cornet, R. Prieels, UCL, PHYS2905, 'Laboratory of applied physics', 60h
- **R. Warnant,** ULg, ASTR0213, 'Géodésie géométrique et astronomie de position', 30 h
- **R. Warnant,** ULg, GEOG0615, 'Théorie des erreurs et GNSS', 30 h
- **R. Warnant,** in co-titularity with **B. Ducarme,** UCL, GEOG3110, 'Géodésie', 7.5 h

Running or Finalized Theses (summary)

- **PhD:** promoter: **7**, co-promoter: **7**, jury: **3**
- **DEA**: promoter: **1**
- **Master**: promoter: **11**, co-promoter: **4**
- **TFE/EW**: promoter: **1**, mentor: **7**

Meeting organization

- **D. Berghmans** was member of the LOC of the solar physics conference "SPM11: The Dynamic Sun: Challenges for Theory and Observations", Leuven, 2005/09/11-16, 224 participants. Contribution: LOC, organization of social event (Observatory visit)
- **B.Ducarme** was co-organiser of the Contactforum « Geodesy and Geophysics for the Third Millenium in Belgium » (13/10/2005) sponsored by the Academies; co-editor of the Proceedings: 2005 KVAB, D/2005/0455/16, 200pp.:
- **J. Sauval** is as secretary involved in the Organization of the 6th meeting of the FNRS Contact group *Astronomie & Astrophysique* (11/03)

Awards

- **T. Pauwels** was recognised as the discoverer of 8 additional minor planets (97576, 100604, 104020, 106825, 108087, 108953, 111819 and 118397).

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Part 2: Public Service Activities

Summary

A. PLANETARIUM

A.1. Activités

A.1.1. Visiteurs

- En 2005, le Planétarium a accueilli 30.940 visiteurs, chiffre en nette progression (+2.648 visiteurs / +9.4 %) par rapport à l'année précédente. Depuis l'année 2000 et ses 20.126 visiteurs, la progression a ainsi été de +10.814 personnes (+53.7 %).
- La part du public scolaire (20.393 élèves) s'élève à 65.9 % du nombre total de visiteurs, chiffre relativement stable. Le public familial (mercredis après-midi, dimanches, congés scolaires) atteint le nombre de 10.547 personnes, soit 34.1 % du nombre total de visiteurs.
- La répartition entre public néerlandophone (15.421 visiteurs / 49.8 %) et public francophone (15.519 visiteurs / 50.2 %) est très équilibrée.

A.1.2. Expositions

- Dans le cadre du 175ème anniversaire de la Belgique, le Planétarium a accueilli l'exposition « Entre Ciel et Terre – 175 ans d'histoire des Sciences de la Terre et de l'Univers en Belgique ». Cette exposition, dont une large partie est permanente, a été réalisée conjointement par l'Observatoire royal de Belgique, l'Institut Royal Météorologique et l'Institut d'Aéronomie Spatiale de Belgique. Elle permet au Planétarium de jouer pleinement son rôle de vitrine du Pôle Espace.
- L'exposition a été inaugurée le 13 mai 2005, et s'est prolongée (pour sa partie temporaire) jusqu'au 31 août 2005. Elle a été honorée par la visite en juin 2005 de S.A.R. le Prince Philippe, de Monsieur le Ministre Verwilghen et de Monsieur le Président Mettens.
- La visibilité de l'exposition Pôle Espace (partie permanente) durant la période allant de la mi-mai à la fin décembre peut être estimée à environ 24.000 personnes (public du Planétarium + public reçu lors d'événements spéciaux).

A.1.3. Conférences, colloques, séances spéciales

- Plusieurs réunions et colloques ont été tenus dans les locaux du Planétarium : réunion du Groupe de Contact Astrophysique FNRS, sessions d'information de la Politique Scientifique fédérale sur des matières liées à la politique spatiale.
- Des séances spéciales de planétarium ont été organisées pour : le Forum de Lutte contre la Pauvreté, les participants de l'Expo-Sciences (Jeunesses Scientifiques de Belgique) ; des cercles amateurs (CBAA, VVS) ; le Rotary Club (conférence de M. Van Ruymbeke, ORB) ; une école de professionnels de la voile.
- Des journées de formation ont été proposées aux enseignants tant néerlandophones (deux journées spéciales : BaO et HSO) que francophones (une journée regroupant les enseignants du primaire et du secondaire).
- Des cours prodigués par C. Muller (IASB) et V. Dehant (ORB, cours MAGE) à destination d'étudiants universitaires ou en post-doctorat ont eu lieu dans l'Auditorium.
- Le Planétarium a également loué ses locaux à des firmes (incentives, présentations de produits, etc.) à différentes reprises (11 locations dans l'année).

A.1.4. Spectacles

- En février a eu lieu la première projection au public du spectacle « Missie Saturnus / Mission Saturne », produit par le Planétarium de Munich et adapté en français pas l'APLF (Association des Planétariums de Langue Française) et en néerlandais par le Planétarium de Bruxelles.
- Ce spectacle, dont le thème est centré sur la planète Saturne et ses satellites (mission Cassini/Huygens) a bénéficié d'une assez bonne couverture médiatique. Il s'adresse à un public plus averti que les autres spectacles du Planétarium.
- Une présentation de ce spectacle et du travail réalisé pour son adaptation par le Planétarium de Bruxelles a été publiée dans l'édition 2006 de la revue « Planétarium » de l'APLF (*Mission Saturne : une coproduction Munich-Bruxelles*, R. Alvarez, « Planétarium », pg.19, 2006).

A.1.5. Ateliers

- La formule des ateliers (workshops) permettant aux écoles venues assister à un programme ou un cours de prolonger leur visite au Planétarium en effectuant des activités pédagogiques (fabrication d'une carte du ciel, d'un déclinateur solaire, calcul des échelles du système solaire, etc.) sous la direction des animateurs ou des enseignants détachés au Planétarium continue de connaître un succès toujours croissant : 9.084 élèves y ont participé au cours de l'année 2005, soit trois fois plus d'élèves qu'en 2004.
- Plusieurs nouveaux thèmes d'ateliers ont vu le jour, notamment grâce aux enseignements tirés lors des journées de formation suivis par nos animateurs scientifiques dans le cadre de l'European Association for Astronomy Education (EAAE).

A.1.6. Brochures

- Deux dépliants/posters (une version néerlandophone et une version francophone) ont été réalisés en 2005. Ces publications s'adressent aux enseignants et décrivent les programmes, les cours et les nou-

velles activités pédagogiques du Planétarium. Elles ont été envoyées à l'ensemble des écoles du Royaume au moment de la rentrée scolaire.

- Fin 2005 a été préparée la brochure destinée au grand public : elle présente les différents programmes et contient diverses informations pratiques. Elle couvre l'année 2006.
- Le site Internet du Planétarium est continuellement mis à jour. On peut y trouver l'actualité du moment.

A.1.7. Collaborations

- Les fructueuses collaborations avec divers organismes liés au monde de l'astronomie amateur se sont poursuivies en 2005 : avec l'Observatoire populaire Mira de Grimbergen (publication commune dans la revue Attractions & Tourisme), avec la Vereniging Voor Sterrenkunde (VVS), avec le Comité Belge des Astronomes Amateurs (CBAA).
- La formule des B-dagtrips/B-excursions organisée par la SNCB proposant aux groupes scolaires de bénéficier de tarifs avantageux sur la combinaison trajet train + visite Planétarium a été poursuivie ; la collaboration avec la Mini-Europe (mise en place d'un ticket combiné pour les groupes) est reconduite ; une action spéciale a été menée avec CERA en été ; un contrat de collaboration a été signé avec la firme Sodhexo (chèque culture) ; des réunions de travail ont été initiés entre les acteurs du Plateau du Heysel (Planétarium, Trademart, Kinepolis, Atomium, Océade/Mini-Europe, Stade Roi Baudouin).
- Le Planétarium a de nouveau ouvert avec succès ses portes le 21 juillet lors de l'opération de la Politique Scientifique fédérale « 1 euro = entrée aux musées fédéraux et autres institutions fédérales ». Il a accueilli 717 visiteurs lors des 6 séances organisées ce jour. Il a également été représenté durant les festivités organisées à l'occasion du 175ème anniversaire de la Belgique par la Politique Scientifique fédérale.
- Le Planétarium a participé en 2005 à plusieurs événements:
  - la « Space & Earth Week », organisée par la Commission Européenne et l'ESA à l'Autoworld en février (animation d'un planétarium gonflable) ;
  - les « Nationale Sterrenkijkdagen » organisé par Astro Event à Oostende en mars ;
  - l'« Expo-Sciences » organisée par les Jeunesses Scientifiques de Belgique au Palais des Expositions du Heysel en avril ;
  - l'événement scolaire « Sport J-175/25 » qui s'est déroulé en juin sur le Plateau du Heysel ;
  - le colloque « Sharing the Space » (ESA Skateholder Workshop) organisé par l'ESA à Bruxelles en juillet ;
  - la « European Researcher Night », organisée par la Commission Européenne en septembre ;
  - les « Nocturnes des Musée Bruxellois », organisées en septembre par le Conseil Bruxellois des Musées.
- Des réunions de travail de PLANed, l'association des planétariums de langue néerlandophone née sous l'impulsion du Planétarium de l'ORB, se sont déroulées à Ridderkerk et Asten (Pays-Bas). Cette association, maintenant reconnue officiellement par l'IPS (International Planetarium Society), accueille 12 membres-planétariums. Le Planétarium a également été présent lors du colloque annuel de l'Association des Planétariums de Langue Française (APLF) ayant eu lieu à St Etienne (France).
- 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 a également assisté aux réunions organisées par Bruspace (association du secteur spatial en Région Bruxelloise).

A.2. Moyens mis en oeuvre

A.2.1. Personnel

- Nouveaux collaborateurs : en 2005, le Planétarium a accueilli deux nouveaux collaborateurs => une personne chargée des Relations Publiques (poste statutaire ouvert depuis août 2003) et un expert administratif pour l'accueil (poste contractuel).
- Départ à la pension : A. Anthonissen, administratief assistent, statutaire – accueil
- Au 31 décembre 2005, le personnel du Planétarium se composait de:
  - R. Alvarez, 1er assistant, statutaire - responsable
  - V. Bastin, experte technique, contractuelle - animatrice
  - G. Champagne, attaché scientifique, contractuel (Prog. de R&D de la Région Brux.) - R&D
  - S. Consiglio, administratief medewerker, contractueel – accueil
  - 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 sous mandat – relations publiques
  - N. Lubkowski, coll. technicien, contractuel (détaché du Palais des Congrès) - technique
  - A. Milis, industrieel ingenieur, statutaire - responsable technique
  - R. Mostaert, enseignant détaché - cours
  - A. Sayer, collaborateur nettoyage, contractuelle - entretien
  - G. Smet, technisch assistent, contractueel - animateur
  - W. Vander Putten, technisch deskundige, contractueel - infographisme
  - P. Van Schandevyl, lerares – cours

A.2.2. Equipement

- Dans le cadre du 175ème anniversaire de la Belgique, le Planétarium a grandement étoffé son hall d'exposition en acquérant des panneaux (support de posters), des structures modulaires d'exposition, des bornes interactives, du matériel informatique, du matériel d'éclairage (lampes et spots directionnels), des structures tubulaires de support, des tentures.
- Le reste des frais d'équipement technique concerne les dépenses usuelles : matériel informatique, matériel de projection, lampes spéciales pour le planétaire (projecteur d'étoiles), microphones, câbles audio, etc.
- Un accord de sponsoring a été conclu avec la firme Sylvania, fournisseur de matériel d'éclairage : il sera rendu effectif en 2006.

A.3. Projets en cours et à venir

A.3.1. Planétarium numérique

- Le Planétarium poursuit, via le travail d'un Licencié en Sciences recruté fin 2002, l'étude de nouvelles méthodes numériques de représentation du ciel étoilé. Cette étude est menée conjointement avec la firme De Pinxi, dans le cadre d'un projet de Recherche & Développement financé par la Région Bruxelloise.
- La majeure partie du développement du logiciel de planétarium numérique est maintenant achevée ; l'étude doit se poursuivre avec la période de test in-situ.

A.3.2. Projet ESERO

- Fin 2005, l'Agence Spatiale Européenne (ESA) a invité le Planétarium à remettre un dossier pour l'établissement en Belgique d'un « European Space Education Resource Office » (ESERO). Le but de ce projet 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.

- Si le projet ESERO Belgium proposé par le Planétarium de l'Observatoire royal de Belgique est jugé favorablement par l'ESA, une ou deux personnes faisant fonction d'Office Manager seraient recrutées courant 2006 pour mener à bien les différentes tâches liées au projet.

B. BIBLIOTHEQUE

Introduction

B.1. Activités

B.1.1. Activités générales

Pour les livres et les périodiques de l'ORB, le personnel de la Bibliothèque à assuré la cen¬tra¬lisation 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.1.2. Abonnements, échanges et achats

La bibliothèque a bénéficié en 2005 de 161 abonnements à des périodiques (77 pour l'IRM, 84 pour l'ORB); en outre, environ 175 publications périodiques ont été reçues soit par dons soit par échanges avec d'autres institutions. Les collections se sont enrichies par ailleurs de 74 livres acquis par achat (34 pour l'IRM, 40 pour l'ORB) et d'environ une cinquantaine d'autres ouvrages reçus par dons ou par échanges.

B.1.3. Périodiques électroniques

L'abonnement aux versions électroniques de certains périodiques, en sus des versions sur papier, prend de l'extension: dix-sept abonnements ont été pris en 2005 par les deux instituts, et un abonnement commun aux cinq parties du *Journal of Geophysical Research* a été renouvelé pour l'année 2005.

Par ailleurs, le développement du réseau électronique SwetsWise, auquel l'ORB et l'IRM sont abonnés, s'est poursuivi; ce réseau consiste en l'accès gratuit à la version électronique de certains périodiques pour lesquels les deux instituts ont souscrit un abonnement à la version sur papier. Au stade actuel, le nombre de ces périodiques gratuits du réseau SwetsWise est d'une soixantaine (30 pour chaque institut).

B.1.4. Classement des collections

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 220 volumes de périodiques a été effectuée. La collection de périodiques de géophysique a été réorganisée et transférée dans de nouveaux emplacements. L'inventaire et le classement à part des ouvrages les plus anciens ont été poursuivis.

B.1.5. Informatisation de la bibliothèque

Pour rappel, l'informatisation de la bibliothèque de l'ORB – IRM au moyen du système de gestion VU-BIS 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 2005, les activités d'informatisation de la Bibliothèque ont été les suivantes:

- Catalogage et “bulletinage” systématique, avec attribution de “codes-barres”, de tous les livres et numéros de périodiques acquis en 2005 (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 des 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 1967 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 Chr. Roberti, pour le bulletinage des numéros de périodiques de l’année 2005 acquis par l’IRM.

Un arrêté ministériel du Service Public Fédéral de Programmation Politique Scientifique a confié aux Etablissements scientifiques fédéraux la charge de réaliser des "catalogues informatisés des bibliothèques des Etablissements scientifiques fédéraux", s'inscrivant dans le cadre de la mise en œuvre du "Plan de digitalisation du patrimoine culturel et scientifique des Etablissements scientifiques fédéraux relevant du Ministre de la Politique scientifique". Ce projet se déroulera du 1er novembre 2005 au 31 décembre 2008. L'arrêté attribue une somme de 3.294 Euro à l'ORB et de 765 Euro à l'IRM, mais les chiffres exacts seraient en réalité, selon un document transmis par le coordinateur du projet (Bibliothèque Royale) de 19.078 Euro pour les deux institutions, la somme prévue pour les années 2005 et 2006 étant de 9.502 Euro. Etant donné que le projet n'est effectivement entré en vigueur qu'en 2006, suite aux réunions organisées par le coordinateur du projet les 12 et 25/1/2006, les sommes allouées pour l'année 2005 ont été reportées à l'année 2006.

C. DIENST INLICHTINGEN

Inleiding

Deze dienst verzorgt een zeer groot deel van de Openbare Dienstverlening (inlichtingen aan openbare diensten, publiek en media) en is in grote mate bevolkt door leden van Dep. III, maar vele andere personeelsleden van de KSB (inclusief het planetarium) hebben aan deze dienstverlening meegewerkt.

C.1. Algemene activiteiten

E-mail vragen

Het aantal vragen via e-mail nam dit jaar voor het eerst licht af: van boven 500 tot 450 in 2005. Er is nu veel meer informatie dan vroeger te vinden op het Internet, zowel op onze eigen web site als elders, zodat een aantal concrete vragen nu direct het antwoord op Internet heeft. Een deel van de vragen bereikt onze diensten via het planetarium en KMI, enkele via het algemene adres van de Pool Ruimte en het BIRA, maar ook daar wordt nu geregeld rechtstreeks naar de webpagina's verwezen, zodat een deel van de vragen ons niet meer bereiken. Er worden ook meer rechtstreekse vragen gestuurd naar diverse diensten van de KSB (seismologie, zonnefysica, …), zodat ook hier niet alle vragen nog via de dienst inlichtingen passeren.

Telefonsiche vragen

Daarnaast werden in 2005 meer dan 600 telefonische vragen beantwoord (360 Nederlandstalig, 250+ Franstalig, 9 anderstalig), waarbij alleen rekening werd gehouden met antwoorden gegeven door de verdere expliciet vermelde personeelsleden van de KSB.

Als antwoord op hoofdzakelijk schriftelijke vragen, werden meer dan 230 brieven geschreven of faxen verstuurd.

Omwille van de activiteiten in het kader van 175 jaar België was er zeker een groter aantal telefonische oproepen, zodat het moeilijk is dit jaar enige conclusies te trekken in verband met stijgen of dalen van de aantallen.

De verstrekte inlichtingen zijn vooral tijdstippen van zonsopkomst, zonsondergang en schemering voor politie, gerecht, advocatuur of particulieren. Verder waren er vragen i.v.m. de maan, zomer- en wintertijd, de kalender: gregoriaans, Islamitisch (Ramadan), schrikkeljaren, getijden, meteoren en meteorieten, zonsverduisteringen in verleden en toekomst, Mars en sterrenkunde en astrofysica in het algemeen en waren er een aantal zeer concrete vragen naar schaduwberekeningen.

Hoofdzakelijk aan drukkers en uitgevers, maar ook aan enkele openbare diensten, zoals aan de afdeling Bos en Groen van het Ministerie van de Vlaamse Gemeenschap, en aan het KMI, werden kalenders en lijsten van hemelfenomenen voor de volgende jaren verstrekt.

Media

Aan de media (TV (Rtbf (2x), VTM, TV1, TV Brussel), radio (Radio 1, Radio 2, FM Brussel), kranten en tijdschriften (15)) werd uitgebreide informatie gegeven over diverse onderwerpen, inclusief de activiteiten in het kader van 175 jaar België (zie verder). Er was begeleiding en assistentie voor een aantal opnamen (TV, film, fotosessies) die op het domein van de sterrenwacht gebeurden.

IT-ondersteuning

Een derde (en laatste) reeks computerprogramma's i.v.m. diverse hemelfenomenen (kalender, zon, maan, kometen etc.) werd aangepast aan de nieuwe vragen en aan de nieuwe manier van opmaak van het jaarboek (Latex-versie). Hiervoor werd dankbaar gebruik gemaakt van subroutines geschreven door Th. Pauwels (Dep. II).

Computerpresentaties

De computerpresentaties die de activiteiten van de Sterrenwacht beschrijven worden continu up-to-date gehouden. Ook aan de webpagina's i.v.m. inlichtingen en algemene informatie over de Sterrenwacht wordt bijna continu gewerkt. Het onderdeel "Vragen aan de sterrenwacht" op de web site van de KSB werd regelmatig bijgewerkt. De jaarlijkse informatie die traditioneel aan drukkerijen en andere belangstellenden wordt bezorgd, is op de webpagina's van de KSB te vinden is en wordt eveneens regelmatig vervolledigd. De gegevens over de belangrijkste hemelverschijnselen die door R. Dejaiffe (Dep. I) worden bijeengezocht, worden omgezet tot een op de KSB-site beschikbare webpagina. Ook andere algemene informatie over de Sterrenwacht werd op de webpagina's geplaatst.

Web site

Per maand zijn er rond de 20000 (unieke) bezoekers van de web site van de sterrenwacht (voor zover men deze kan traceren), met pieken in oktober (48000) op het moment van de (bij ons gedeeltelijke) zonsverduistering) en de overgang naar wintertijd en maart (28000) bij de overgang naar zomertijd. Minstens 25%, vermoedelijk veel meer, van de bezoekers passeren langs een webpagina met algemene en specifieke informatie (Nederlands of Frans). De pagina's met de tabellen van zonsopgang en zonsondergang worden tussen de 1000 en 2000 keer per maand geconsulteerd. De infopagina's worden in aantal bezoekers slechts voorafgegaan door de pagina's van de seismologie en deze van het planetarium (1000 tot 1600 bezoekers per maand). Het is echter niet duidelijk in deze statistieken of de interne herziening en consultatie van deze pagina's ook in de statistieken werd opgenomen. Voor de webpagina's van de inlichtingen is dit laatste aantal zeer klein.

Rondleidingen

In 2005 ging een aantal rondleidingen en groepsbezoeken op de Sterrenwacht door (3 februari, 22 maart, 29 juni, 8 september, 14 september, 21 september, 13 oktober, 9 november, 21 november). Voor een deel was er ook assistentie van andere departementen.

Activiteiten Pool Ruimte

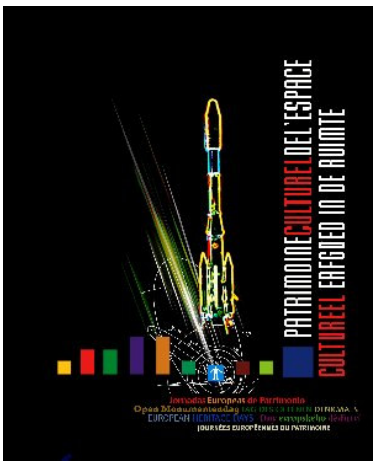
Aan talrijke vergaderingen i.v.m. activiteiten waarmee de Space Pole (KSB, KMI en BIRA) naar buiten trad, werd deelgenomen en er werd meegewerkt aan de persberichten die de KSB en het planetarium verzonden. Ook op de vergaderingen van het redactiecomité van het tijdschrift Science Connection, dat deels evolueert naar een vergadering van communicatieverantwoordelijken van de federale wetenschappelijke instellingen, was een vertegenwoordiger van de Sterrenwacht aanwezig.

Er werd advies gegeven over teksten voor diverse activiteiten, waaronder ook enkele van het planetarium. Ook vele andere teksten bestemd voor het grote publiek werden vertaald en/of aangepast.

Uitleningen

Voor de tentoonstelling De Zon, Een eeuwig mysterie, (Museum Boerhaave, Leiden) werden een aantal instrumenten van de sterrenwacht uitgeleend en werd er informatie over verstrekt tijdens het bezoek van de verantwoordelijke en in navolgende emails.

Voor de tentoonstelling Made in Belgium (Brussel) werd de draagbare meridiaankijker uit het museum en een weegschaal, gemaakt door Merlin, toebehorend aan Quetelet ter beschikking gesteld en een tekst over Quetelet werd meegestuurd (in samenwerking met de heer Van Boxmeer).



Voor het Europese project Cultural Space Heritage (Cultureel Erfgoed in de Ruimte) werd de Theodoliet van Ertel uit het museum beschreven als verre voorloper van het onderzoek op het gebied van plaatsbepaling en referentiesystemen. Voor de web site van dit project werden illustraties geleverd en een tekst (door Dr. P. Pâquet, ere-directeur van de KSB) die ook in het museum werd aangebracht, onder andere tijdens de opendeurdagen van September.

C.2. Activiteiten in het kader van 175 jaar België

Op **14 mei 2005** stelde de POD Wetenschapsbeleid zich samen met de federale instellingen voor aan het publiek tijdens een evenement op de **Kunstberg** te Brussel. Voor deze activiteit werden illustraties geleverd zowel voor het tentendorp als voor het spektakel met lichtbeelden achteraf. Op de dag zelf was er permanentie in de tent van de Koninklijke Sterrenwacht en het Planetarium en bij de randactiviteiten. In de tent van de KSB werden een aantal posters gepresenteerd (o.a. over België en Belgen in het heelal en over de onderzoeksactiviteiten van de KSB). Er werd een miniplanetarium getoond en er was informatie over de tentoonstelling 'Tussen hemel en aarde' in het planetarium.

De tentoonstelling 'Tussen hemel en aarde' ging door in het planetarium van 13 mei tot 31 augustus. Hierin werd een overzicht gegeven van de geschiedenis van KSB, KMI en BIRA en van de huidige activiteiten van deze instellingen (zie ook het verslag van de planetariumwerking hierover).

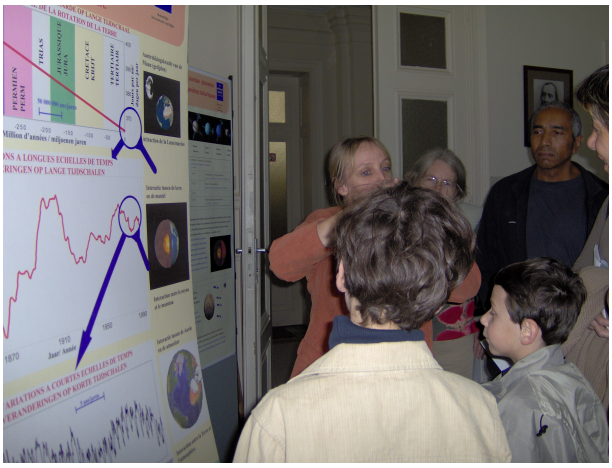
Onze bijdrage voor deze tentoonstelling was vrij groot. Allereerst was er het opzoeken en selecteren van de illustraties voor de panelen en poster. Er werden teksten verzameld en opgesteld over de geschiedenis en de huidige activiteiten van de KSB. Er werden ook specifieke programma's geschreven voor de interactieve onderdelen van de tentoonstelling. Typische oude en nieuwe instrumenten werden geselecteerd en ter plaatste opgesteld, met hulp van personeel van de KSB. Er was tijdens de duur van de tentoonstelling soms permanentie door leden van de sterrenwacht, waarbij uitleg ter plaatse werd gegeven en er werd over de tentoonstelling bericht aan de pers.

Op **21 juli** stelde de POD Wetenschapsbeleid een informatietent op in de Koningstraat ter gelegenheid van de speciale viering van de nationale feestdag in het kader van 175 jaar België. De tent mocht verschillende duizenden bezoekers verwelkomen. Er werd uitleg gegeven over de activiteiten van KSB, KMI en BIRA en over de programma's en evenementen van het planetarium.

Voor het boek "*België – België, De tien instellingen van het Federaal Wetenschapsbeleid*", o.l.v. Wim De Vos en Anne Cahen-Delhaye, werd een hoofdstuk over de geschiedenis van de Koninklijke Sterrenwacht van België geschreven en ook een deel van de vertaling gebeurde door personeel van de KSB met hulp van anderen.

C.3. Opendeurdagen

De Opendeurdagen van de Pool Ruimte te Ukkel waren een groot succes. Op 17 en 18 september (autoloze zondag te Brussel) werden ter gelegenheid van de open monumentdagen van het Brusselse gewest de poorten opengezet. Een groot deel van het centrale gebouw, de meridiaanzaal, de koepel van de zonnetelescoop en van de Carte-du-Ciel-kijker en deel van het domein kon bezocht worden.
Nagenoeg iedereen van het personeel van de KSB werkte eraan mee. Zowel voor de beschrijving van de geschiedenis van de KSB, de algemene activiteiten als de specifieke onderwerpen van de onderzoekgroepen werden panelen, posters en interactieve opstellingen ontworpen. De dienst inlichtingen werkte intens mee aan de voorbereiding, organisatie en coördinatie van het geheel en gaf ook algemene informatie aan pers en publiek. Een aantal foto's van vroeger werden geplaatst op de lokatie die zij voorstelden zodat de evolutie van de gebouwen in de tijd duidelijk was.
Hoewel een realistische schatting van het juiste aantal zeer moeilijk is, zijn er vermoedelijk om en bij de tienduizend bezoekers gepasseerd tijdens het gehele weekend. De rondleidingen met reservatie konden het aantal geïnteresseerden niet altijd verwerken.
Hieronder enkele foto's ter illustratie van het succes (foto's gemaakt door personeel van de KSB).




C.4. Personeel

J.. Cuypers, (Dep III), werkleider

Y. Coene, hoofdrekenaar (Dep I, gedetacheerd naar de dienst inlichtingen, werkt samen met J. Cuypers)

H. Langenaken, hoofdrekenaar (Dep III, gedetacheerd naar de dienst inlichtingen)

Voor een aantal activiteiten, inclusief vertalingen, kon een beroep gedaan worden op P. Defraigne (Dep. I).

Vele andere leden van de Sterrenwacht werken mee aan het verstrekken van inlichtingen, sommige occasioneel, voor anderen is dienstverlening een essentieel deel van hun opdracht, zoals bij de diensten seismologie, GPS, zonnefysica (ruimteweer) etc.

C.5. Publicaties

[3] **Cuypers J.**
Koninklijke Sterrenwacht van België
in het boek “België – België, De tien instellingen van het Federaal Wetenschapsbeleid”, o.l.v. Wim De Vos en Anne Cahen-Delhaye, 136-153.

Belgen en België in het Heelal, Les Belges et la Belgique dans l’Univers (Deel 1: Maan, Kometen en asteroïden; Deel 2: Mercurius, Venus, Mars)

Posters

Astrofysica – Astrophysique
3 posters, Dep. II and III

Geschiedenis van de Sterrenwacht
Poster

[4] **Cuypers J.**
Tijdrekening en Kalenders
in: Jaarboek 2006, Koninklijke Sterrenwacht van België, 14-39

[5] **Sauval J.**, **Cuypers J.**
Periodieke kometen/Comètes périodiques en Essaims de météores/ Meteoorzwermen
in: Jaarboek 2006, Koninklijke Sterrenwacht van België, 150-187

C.6. Zendingen

De vergaderingen in het kader van de beschreven activiteiten worden niet vermeld.

D. PUBLIC OUTREACH of the SCIENTIFIC DEPARTMENTS

D.1. Scientific and technical expertise to the authorities and the industry

- The FLUXYS Company asked us to provide them with the data from the seismic stations Steenkerque, Seneffe, Bracquegnies and Bougnies for the Ghislenghien explosion of July 2004. We provided also a one day assistance to use of TSOFT software and one day lecture about propagation of seismic and sonic waves from explosions.
- EQECAT, a private company developing hazard software for Insurance industry, asked us to organise a one day workshop to discuss different aspects of the seismic hazard assessment in Belgium.
- The value of gravity has been computed for 9 different sites in Belgium for the FINA Antwerp Olefins Company.

D.2. Information given to the public

- The scientist of the section of seismology answered on numerous questions from the public (generally by phone calls or E-mails) concerning earthquakes in Belgium or elsewhere in the world. Some of the questions are more critical because they concern potential damages due to an earthquake in Belgium and could have judicial consequences.
- **Th. Pauwels** posted various informations to the VVS (Vereniging voor Sterrenkunde)

D.3. Information given to the media

Press interviews related to Time (P. Defraigne):

- 1 radio interview concerning summer time (BEL RTL, end of March)
- 1 TV interview concerning winter time (RTBF, end of October)
- 4 TV interviews concerning leap second (RTBF, RTL-TVI, TV Brussel, VTM, end of December)
- 2 radio interviews concerning leap second (Bel RTL, Nostalgie, end of December)
- 2 paper press interviews concerning leap second (Athena, Vers l'Avenir, end of December)

Press interviews related to the launch of the first Galileo satellite and to our involvement in the GALOCAD project (R. Warnant):

- 2 live radio interviews (RTBF-La Première)
- 5 TV interviews for the News (RTL-TVI, RTBF)
- 3 interviews for newspapers (Le Soir, La Libre Belgique, La Dernière Heure)

Press interviews about planet

- 1 radio interview (RTBF) by **M. Beuthe**
- Venus Express press map (**V. Dehant** in collaboration with **Séverine Lejeune**) and contribution to web site.

Press interviews about the tsunami of December 26, 2004 (Section of seismology)

- The devastating megathrust earthquake of December 26th, 2004 in Indonesia has had an unprecedented mediatic impact. The personnel of the seismology section had to provide information on a daily basis, to welcome journalists, to go to TV studios and even to present the Membach station. Providing immediate valuable information is highly appreciated and benefits the whole Observatory, even at an international level (via ARTE and TV5, an interview was broadcasted worldwide)

Press interviews related to asteroids en comets (Th. Pauwels)

- RTBf (B. Luypaert): about the relation between tsunamis and full moon, comets and meteorites.

- Che magazine: about asteroids, wormholes …
- RTBf: Qui de nos deux, séquence ``Les coulisses de …", about the life of an astronomer.
- Sud-Presse (Yannick Hallet): about naming asteroids
- Searching images of asteroid Balduinus for the RTBf

Press interviews related to solar physics

- 2005/04/12: **J-F Hochedez**: 1-hour interview on Solar Physics at Radio Campus
- 2005/10/03: **J-F Hochedez**: short interview on eclipses at ROB by Radio Campus
- 2005/06/23: **F. Clette**: Telephone Interview from New York by Wall Street Journal (S. Power): disturbances of new anti-impact radars in automobiles on radioastronomy.

D.4. Publications in popular journals

[6] **Defraigne P**. and **Pâquet P.**
Détermination des longitudes et Histoire de l'Heure
Ciel et Terre 121(4), pp. 98-113, 2005

[7] **Roosbeek F., Defraigne P., and Somerhausen A**.
Synchroniser l'heure de son PC sur une horologe atomique de l'Observatoire Royal de Belgique
Ciel et Terre, Volume 121, n°3, May-June 2005, pp. 79-82

[8] **Roosbeek F., Defraigne P., and Somerhausen A**.
Het tijdslaboratorium van de KSB
Short text in Heelal, Volume 50, n°10, October 2005, page 352

[9] **Van Camp M.** and **de Viron O.**, 2005,
La mesure de la Terre est une des bases de son étude physique
Ciel et Terre, 121 (3), 66-78.

[10] **Vanneste K., Van Hoolst T.** & **de afdeling seismologie**
De aardbeving en tsoenami van 26 december 2004 in de Indische Oceaan – Deel 1: de aardbeving van 26 december 2004
Heelal, 50(7), pp. 216-227.

[11] **Vanneste K., Van Hoolst T.** & **de afdeling seismologie**
De aardbeving en tsoenami van 26 december 2004 in de Indische Oceaan – Deel 2: de tsoenami van 26 december 2004
Heelal, 50(8), pp. 261-269.

[12] **Clette, F**, 2005:
Pierre Cugnon: une vie au soleil
Ciel et Terre, Vol. 121, No. 1, p. 21-22

D.5. Public conferences

- **D. Berghmans**: "Het weer in de ruimte", Volksterrenwacht Urania, 2005/09/11
- **R. Blomme** gave a public conference on radio astronomy for the amateur astronomers group Wega, 7/5/2005
- **J. Cuypers** gaf in 2005 verschillende lezingen over algemene onderwerpen uit de sterrenkunde en aanverwante wetenschappen:
  - 19/03/2005 "Sterren, sterrenhopen en nevels", Herk-de-Stad (Sterrenkijkdagen)
  - 17/07/2005 "Kraters op Mars", Herselt (Helios-VVS)
  - 12/08/2005 "Sterren ", Averbode (Wereldjongerendagen)
  - 21/08/2005 & 20/11/2005 "Getijden op aarde en in het heelal", Herselt (Helios-VVS)
- **P. Defraigne**

- 'Histoire de l'Heure', Université Catholique de Louvain, 28/02/2005
- 'Détermination des Longitudes et Histoire de l'Heure', Cercle Astronomique de Bruxelles, 19/05/2005

- **V. Dehant**
  - public conference during the Descartes Prize Events in Madrid and Brussels
  - public conference in Rochefort, 14/02/2005
- **J.F. Hochedez**
  - 2005/10/20: gave a talk at the conference in honour of Delaboudinière
  - 2005/11/24: Popularization talk at Reims
- **P. Lampens**
  - **'***Pour moi, une triple svp'*, 10/02/2005, SRBA conference, KMI, Brussel
  - 'The Carte du Ciel enterprise more than 100 yr ago', 17-18/09/05, "Open Doors" of the Pole Space, many groups of 15 pers. each for 2 days (assisted by D. Duval)
- **T. Pauwels**, Popular-scientific lecture "Het project RUSTICCA", as one in a series of courses for amateur astronomers. Urania, Hove, 18/10/2005
- **E. Robbrecht** gave a presentation on
  - "Solar activity" for the Service Club Soroptimist International in Sint-Niklaas, 2005/10/27
  - "The sun and space weather" in the popular observatory MIRA in Grimbergen during the annual meeting of the solar observers' amateur club, 2005/11/11
- **M. Van Camp**:
  - 'Le séisme de Sumatra du 26 décembre 2004 et le tsunami qui s'ensuivit : et en Europe, sommes-nous à l'abri?', Les midis du Service Protestant d'Education Permanente SPEP, Ixelles, 16/02/2005, Les Midis de l'Association Nationale Administration-Université ANAU, Bruxelles, 23/03/2005
  - 'La Station Géophysique de Membach', Fifty-One club d'Eupen, 15/02/2005.
- **T. Van Hoolst**, presentation on Mars for primary schools, Planetarium, Brussels, 23/11/2005
- **K. Verbeeck**, 'De waarschijnlijkheid van zware aardbevingen in België, resultaten van 8 jaar paleoseismologisch onderzoek' at Jeugdhuis Brusselsestraat, Leuven for WEGA, 16/03/2005

D.6. Exhibitions

- **V. Dehant** organized the MAGE event in November 2005, in collaboration with **S. Raynal**. The outreach part of the MAGE event contains the following events:
  - outreach for the schools: explanation and exhibition about the planet Mars at the Planetarium;
  - Evening conferences: (a) November 23d: "Evolution Climatique de Mars." (in French), Francois Forget ; (b) November 24st: "Mars Express results.", Augustin Chicarro, Project Scientist of Mars Express.
- 3D animations concerning the tides of Mercury and the effects of the flattening of a planet on the orbit of a spacecraft around it (in collaboration with J. van Marcke de Lummen (student job), O. de Viron (IPGP, France), and T. Van Hoolst).
- **T. Pauwels** created a simulation a search for asteroids for a broad public. He wrote the software and explanatory texts to give feedback. **H. Langenaken** has set up a web interface to run the application. The simulation was displayed at the exhibition at the Planetarium. The simulation has later been sent to a school for educational purposes.
- **P. De Cat** and **Th. Pauwels** produced a new complete list of asteroid names for display in the Schmidt telescope dome, replacing the previous version.
- **J.-F. Hochedez** wrote the introduction to EIT for exhibit at the Planetarium
- **P. Vanlommel** made an update of the 'Space for you'-movie and made the poster 'De Zon' in the framework of exposition 175 jaar België

D.7. Visits

- Visit of **Lt.-Generaal Van de Put** op 09/11/2005.
- Guided tour at ROB for SPM-11-conference attendants, 14/09/2005.
- Student visits and guidance:
  - 14/02/2005: Silvine Loiseau (P. Lampens).
  - student in search of "exceptional professions" (T.Pauwels)
  - 29/4/2005: F. Clette welcomed a group visit, Liège DEA students (course of M. Arnould)
  - 22/08/2005: Jeremy and Rafe, students working at the Observatory
  - 21/11/2005: F. Clette welcomed a group visit, students of V. Dehant (UCL)
- Amateur astronomer groups
  - 03/03/2005: members of Urania
  - 17/12/2005: F. Clette welcomed an amateur astronomer group (Lead: P. Dobbelaere): preparation meeting for the March 29, 2006 total solar eclipse
- Station visits :
  - M. Van Camp guided visits to the station Membach by the BRF (13/01/2005) and the Fifty-One club of Eupen (15/12/2005)
  - 24/5/2005: F. Clette welcomed a group at Humain from UTAN (Université des Ainés), Namur

D.8. Web sites

- The section of seismology developed further the web site of the section to improve the visibility of its research, but also to make on line information on the seismic activity in Belgium and in the world available to the public

D.9. Documentaries

- The CICADA filming production finalized their project to realize a documentary for National Geographic on the possible occurrence of large earthquakes in northwest Europe. A part of the time of the personnel of the section of seismology was devoted to inform them about our scientific work and to help them in the realization of the documentary. For that purpose, CICADA provided the financial support to excavate in August 2005 a new trench across the Geleen fault near Rotem.
- In parallel, the section of seismology has been contacted by the VRT to participate to another documentary about the seismic activity in Belgium in the frame of the program "Over Leven". They realized a sequence in the Rotem trench and in the epicentral region of the 1692 Verviers earthquake. The documentary was presented at the VRT on December 25, 2005. M. Van Camp guided the visit of the VRT to the remaining of the 1692 Earthquake around Verviers on 31/08/2005.

E. "The Yearbook"

E.1. Book

E.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.

E.1.2. Progress and results

In 2005 the Yearbook for 2006 was published. It was produced by F. Clette (The Sun, Tables), J. Cuypers (Calendars, Comets, Meteors), R. Dejaiffe (Coordinates, Constants, Planetary Data, Satellite Data), T. Pauwels (Title, Preamble (in collaboration with the director), 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. Translations were made by R. Dejaiffe and T. Pauwels. The final editing, the general coordination and the lay-out was done by T. Pauwels. There were no major changes compared to 2005. F. Clette has put some effort in modernising the programmes of his chapters, and T. Pauwels searched for theories of the satellites of Jupiter in view of automating this chapter, and wrote the software to compute stellar occultations by the moon.

E.1.3. Perspective for next years

Publication of the Yearbooks 2007ff. Starting with the Yearbook 2007, we hope to compute the phenomena of the satellites of Jupiter ourselves, so that the problem of the double rounding will be solved. This will also better automate this chapter. Starting with the next "season", we hope to introduce a new chapter listing the mutual phenomena of the Galilean Satellites of Jupiter visible from Belgium.

E.1.4. Personnel involved

T. Pauwels, coordinator
F. Clette, J. Cuypers, R. Dejaiffe, F. Roosbeek, scientific staff members of the Observatory, J. Sauval, honorary head of section,
G. Evrard, technical staff member of the Observatory.

E.1.5. Publications

[13] **F. Clette, J. Cuypers, R. Dejaiffe, T. Pauwels, F. Roosbeek, J. Sauval**,
Annuaire de l'Observatoire royal de Belgique—Jaarboek van de Koninklijke Sterrenwacht van België 2006.

E.2. "Web interface for the Yearbook"

E.2.1. Objectives

The paper version of the Yearbook of the Observatory gives data for Ukkel and for some phenomena also for a selection of places in Belgium. With the possibility of the internet, it is now easy to make these computations for any place anywhere in the world. Since the programmes already exist, it is sufficient to write a web interface to achieve the stated goal. This interface has been written by R. Wastiels, a student, in 2003, but still has to be made "idiot-proof", to prevent blocking our server.

E.2.2. Progress and results

No progress was made on the web interface in 2005 due to lack of staff. A student had been foreseen to do the job, but finally did not show up.

E.2.3. Perspective for next years

In 2006 a webmaster should be enrolled. He could fine tune the existing web interface. Once a core is operational, more programmes can be added.

E.2.4. Personnel involved

T. Pauwels, head of section
A. Somerhausen, sysadmin

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Deel 3: Ondersteunende Diensten

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Summary

A. ADMINISTRATION

A.1. HUMAN RESOURCES

A.1.1. ROB Staff

Waarnemend directeur: Verbeiren Roland (tot 30/04/2005)
Algemeen directeur: Van der Linden Ronald (vanaf 01/01/2005)

A.1.1.1. Permanent staff

Scientific staff

Name	Degree
Lampens Patricia	Departementshoofd
Verbeiren Roland	Departementshoofd
Dehant Véronique	Chef de section
Pauwels Thierry	Afdelingshoofd
Camelbeeck Thierry	Chef de travaux agrégé
Alexandre Pierre	Chef de travaux
Alvarez Rodrigo	Chef de travaux
Berghmans David	Werkleider
Blomme Ronny	Werkleider
Bruyninx Carine	Werkleider
Clette Frédéric	Chef de travaux
Collin Fabienne	Chef de travaux
Cuypers Jan	Werkleider
Defraigne Pascale	Chef de travaux
Dejaiffe René	Chef de travaux
Ducarme Bernard	Chercheur qualifié FNRS
Hensberge Herman	Werkleider
Roosbeek Fabian	Chef de travaux
Van De Steene Griet	Werkleider
Van Der Linden Ronald	Werkleider
Van Hoolst Tim	Werkleider
Van Ruymbeke Michel	Chef de travaux
Vanneste Kris	Werkleider
Warnant René	Chef de travaux
De Cat Peter	Assistent (Stagiair tot 30/10, vastbenoemd vanaf 1/11)
Van Camp Michel	Assistant (Stagiair 31/7, définitif depuis 1/8)

Technical and administrative staff

Vander Putten Eric	Adviseur
Baute Kristof	Attaché A1 (stagiair vanaf 01/02/2005)
De Knijf Marc	Attaché A1
Milis Andre	Attaché A2
Dufond Jean-Luc	Attaché A2
Rezabek Oleg	Attaché A1 (stagiair depuis 01/05/2005)
Rogge Vincent	Attaché A1 (stagiair depuis 01/05/2005)
Asselberghs Somnina	Technisch deskundige
Bukasa Baudouin	Expert technique

Carre Daniel	Expert technique (retraité depuis 31/03/2005)
Castelein Stefaan	Technisch deskundige
Coene Yves	Expert technique
Driegelinck Eddy	Expert technique
Duval David	Expert technique
Hendrickx Marc	Expert technique
Kesteloot Gisèle	Expert technique
Langenaken Hilde	Technisch deskundige
Martin Henri	Expert technique
Mesmaker Dominique	Expert technique
Moyaert Ann	ICT deskundige
Olivier Jean-Pierre	Expert technique
Peeters Georges	Technisch deskundige
Peeters Roger	Technisch deskundige
Renders Francis	Technisch deskundige
Somerhausen André	Expert ICT
Strubbe Marc	Technisch deskundige
Van Camp Lydia	Technisch deskundige
Van Damme Daniel	Technisch deskundige
Van De Putte William	Technisch deskundige
Van Der Gucht Ignace	Technisch deskundige
Vandekerckhove Joan	Technisch deskundige
Vandercoilden Leslie	Expert technique
Verbeemen Christiane	Expert technique
Vermeiren Katinka	ICT deskundige
Barthélémy Julie	Chef technicien de la recherche
Brebant Christian	Assistant administratif
Bruyninckx Martine	Administratief assistent
Danloy Jean-Marie	Assistant administratif
Depasse Béatrice	Assistant administratif
De Wachter Rudi	Technisch assistent
Jacques Jean-Claude	Assistant technique
Janssens Paul	Assistant technique
Laurent Robert	Technisch assistent
Mortier Carine	Administratief assistent
Mues Christian	Assistant technique
Van Den Brande Theophilis	Technisch assistent
Vanden Elshout Ronny	Assistant technique
Anthonissen Antoinette	Technisch medewerker (gepensioneerd op 30/06/2005)
Rondeaux Christian	Collaborateur technique
Vigneron Arille	Collaborateur technique

A.1.1.2. Staff working on external grants

Sichien Els	Beursstudent IWT (vanaf 1/01/2005)
Koot Laurence	Boursier FNRS
Lejeune Sandrine	Boursier FRIA
Pfyffer Gregor	Boursier FRIA (vanaf 1/01/2005)
Rambaux Nicolas	Boursier ESA (jusqu'à 31/03/2005)

A.1.1.3. Contractuel staff managed by BELSPO

Bizerimana Philippe	Collaborateur technique
Boulvin Olivier	Expert technique
Consiglio Sylvia	Administratief medewerker
De Vos Frédéric	Expert ICT
De Winter Davy	Technisch deskundige (vanaf 19/09/2005)
Ergen Aydin	Expert technique
Mouling Ilse	Administratief assistant
Rapagnani Giovanni	Attaché A1 - Plan Rosetta

A.1.1.4. Contractual staff

Scientific staff

Name	Degree	Contract
De Cuyper Jean-Pierre	Werkleider	DIGIT
Everaerts Michel	Chef de travaux	Action 1
Hochedez Jean-François	Chef de travaux	PRODEX
Hubert-Ferrari Aurelia	Chef de département (depuis 01/10/05)	Marie Curie
Lobel Alex	Werkleider (vanaf 01/12/05)	BELSPO
Baumann Ingo	Assistent	PRODEX
Benmoussa Ali	Assistant	PRODEX
Beuthe Mikael	Assistant	PRODEX
Busegnies Yves	Assistant (tot 30/09/05)	Cherch. Suppl
De Viron Olivier	Premier assistant (tot 31/08/05)	Action 1
Delouille Véronique	Assistant	PRODEX
Dominique Marie	Assistant (depuis 01/02/05)	PRODEX
Frémat Yves	Attaché	Action 1
Gissot Samuel	Assistant	Cherch. Suppl
Hagedoorn Jan	Assistent (vanaf 01/09/2005)	PRODEX
Joukov Andrei	Assistant	PRODEX
Karatekin Ozgur	Assistant	PRODEX
Katsiyannis Athanassios	Assistant	PRODEX
Lainey Valéry	Assistant	MAGE
Lambert Sébastien	Assistant (depuis 01/10/2005)	PRODEX
Lawrence Gareth	Assistent	PRODEX
Madjarska Maria	Assistent (vanaf 01/4/2005)	Actie 3
Podladchikova Olena	Assistant	PRODEX
Rosenblatt Pascal	Assistant	PRODEX
Rodriguez Luciano	Assistant (depuis 01/10/2005)	PRODEX
Rosset Philippe	Assistant (jusqu'à 30/09/2005)	Cherch. Suppl
Runacres Marc	Assistent (tot 28/02/2005)	IUAP
Theissen Armin	Assistent	PRODEX
Van Hoof Peter	Assistent (vanaf 01/02/2005)	IUAP
Vanlommel Petra	Assistant	PRODEX
Verhoeven Olivier	Assistant (depuis 01/09/2005)	Action 1
Wauters Laurence	Assistant	PRODEX
Barré Aline	Attaché (jusqu'à 30/11/2005)	PRODEX
Bavier Michael	Attaché	Action 3
Carpentier Georges	Attaché	Action 1
Champagne Georges	Attaché	External contract
De Patoul Judith	Attaché (jusqu'à 15/01/2005)	PRODEX

Foriers Edouard	Attaché (depuis 01/11/2005)	Action 1
Duron Julien	Attaché	Action 2
Freyhammer Lars	Attaché (tot 31/08/2005)	IUAP
Guyennon Nicolas	Attaché (depuis 01/11/2005)	Cherch. Suppl
LeMaistre Sébastien	Attaché	PRODEX
Libbrecht Christophe	Attaché (jusqu'à 31/03/2005)	PRODEX
Moins Michael	Attaché	Action 1
Nicula Bogdan	Attaché	PRODEX
Papadaki Christina	Attaché	Action 2
Petermans Toon	Attaché	Actie 1
Pottiaux Eric	Attaché	Action 3
Rivoldini Attilio	Attaché	Action 1
Robbrecht Eva	Attaché	PRODEX
Spits Justine	Attaché (depuis 01/10/2005)	Action 2
Verbeeck Koen	Attaché	Actie 1

Technical and administrative staff

Lafont Daniele	Attaché A1	PRODEX
Mostaert Régis	Attaché A1	Dotation
Naslin Sébastien	Attaché A1	Mécénat
Van Elder Sophie	Attaché A1	PRODEX
Wellens Véronique	Attaché A1	Dotation
Willems Sarah	Attaché A1	PRODEX
Herreman David	Expert ICT	Dotation
Bastin Véronique	Expert technique	Dotation
Vander Putten Wim	Technisch expert	Dotatie
Vandercoilden Myriam	Assistant administratif	Dotation Pole
Walckiers Stéphane	Assistant technique (jusqu'à 31/07/2005)	PRODEX
Smet Gert	Technisch assistent	Dotatie
Wijns Erik	Technisch assistent	Dotatie
El Amrani Malika	Collaborateur technique	Dotation
Gonzales Sanchez Bénédicte	Collaborateur technique	Dotation
Herman Viviane	Collaborateur technique	Dotation
Ipuz Mendez Adriana	Collaborateur technique	Dotation
Sayer Amina	Collaborateur technique	Dotation
Vermeylen Jacqueline	Collaborateur technique	Dotation

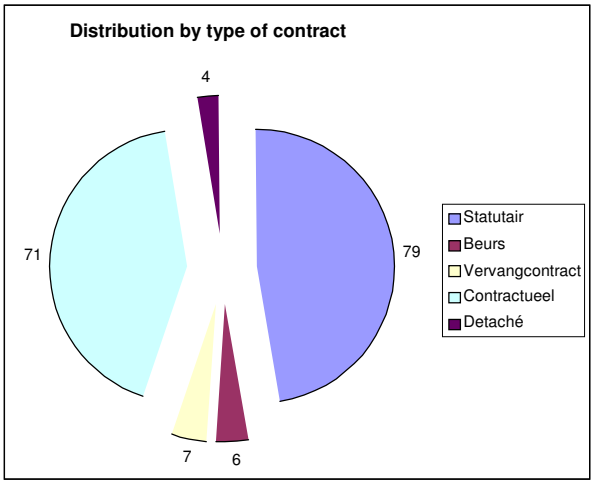
A.1.1.5. Staff detached to the Observatory

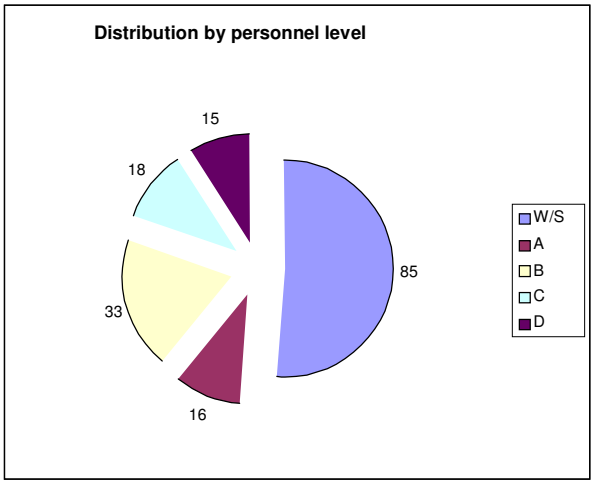
Lubkowski Noël	Adjoint technicien	Palais des Congrès
Vanhassel Luc	Adjunct technicus	BIPT
De Ridder Christiane	Klerk	Congressenpaleis
Van Schandevyl Pascale	Lerares	Secundair onderwijs

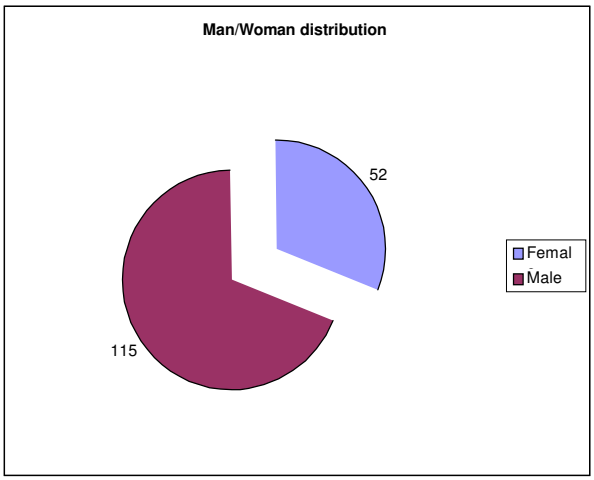
A.1.1.6. Staff detached to other organizations

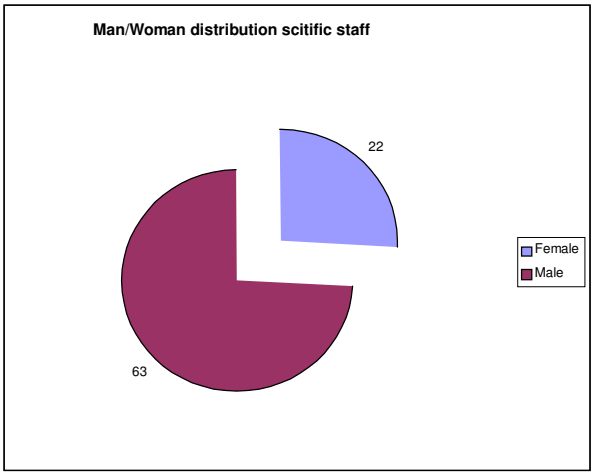
Boffin Henri	Chef de travaux (jusqu'à 31/03/2005)	Interruption de carrière
De Temmerman Marnic	Technisch assistent (tot 31/03/2005)	Loopbaanonderbreking
De Smedt Alma	Technisch deskundige	BELSPO
Knockaert Luitgarde	Technisch deskundige	BELSPO

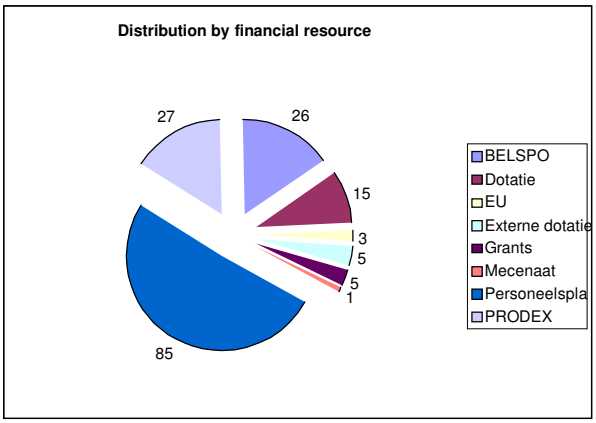
A.1.2. Statistics

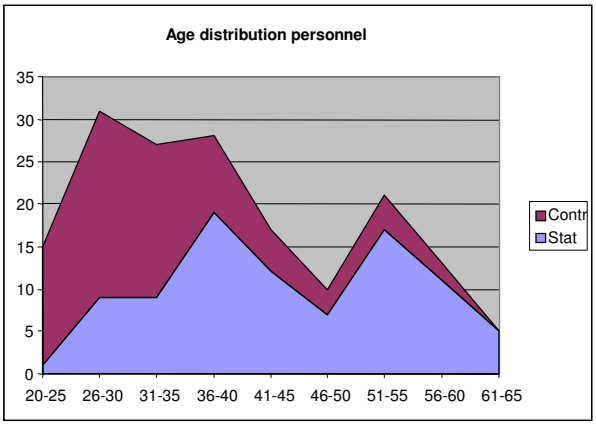












A.1.3. Personnel involved

Asselberghs Somnina	Personeelsbeheer/Algemeen Beheer
Brebant Christian	Acceuil
Bruyninckx Martine	Onthaal

Depasse Béatrice	Acceuil
De Ridder Christiane	Onthaal/Directiesecretariaat
Mortier Carine	Personeelsbeheer/Directiesecretariaat
Verbeemen Christiane	Resources humaines/Sécretariat de Direction
Wellens Véronique	Resources humaines/Sécretariat de Direction

A.2. FINANCIAL SERVICES

Introduction

A.2.1. Numbers

Financial resources are discussed depending their origin:

A.2.1.1. Belspo human resources

This resource is directly handled by Belspo and finances the permanent and replacement staff that is included in the personnel plan. The distribution by the level of personnel is estimated as follows:

Personnel Level	Amount
W/S	1.533.000 €
A	555.000 €
B	1.391.000 €
C	513.000 €
D	102.000 €
Total	**4.094.000 €**

A.2.1.2. Financial resources of the ROB.

The ROB has direct income from four different sources:

- The dotation to finance the functioning and basic equipment of the institute
- Miscellaneous services delivered by the ROB
- Projects financed by Belspo (actions, lotto, bilateral contracts, etc)
- Projects not financed by Belspo (EU, FNRS-FWO, ESA, PRODEX, etc)

	ROB Dotation	ROB Services	BELSPO Projects	External Projects	Reserve Fund	Total
Expenses 2005						
Personnel	306.378,07 €	110.702,67 €	738.677,04 €	1.026.907,30 €		2.182.665,08 €
Normal functioning	554.581,34 €	117.557,11 €	60.426,47 €	206.980,16 €		939.545,08 €
Specific functioning	49.720,87 €		10.284,11 €	37.322,07 €		97.327,05 €
Normal equipments	134.067,94 €	13.979,01 €	83.735,82 €	50.975,28 €		282.758,05 €
Specific equipments	99.735,25 €		188.015,54 €	2.199,55 €		289.950,34 €
Library	66.266,98 €		887,45 €	1.467,53 €		68.621,96 €
Tranfers			3.619,01 €	106.003,87 €		109.622,88 €
Total	**1.210.750,45 €**	**242.238,79 €**	**1.085.645,44 €**	**1.431.855,76 €**	**0,00 €**	**3.970.490,44 €**

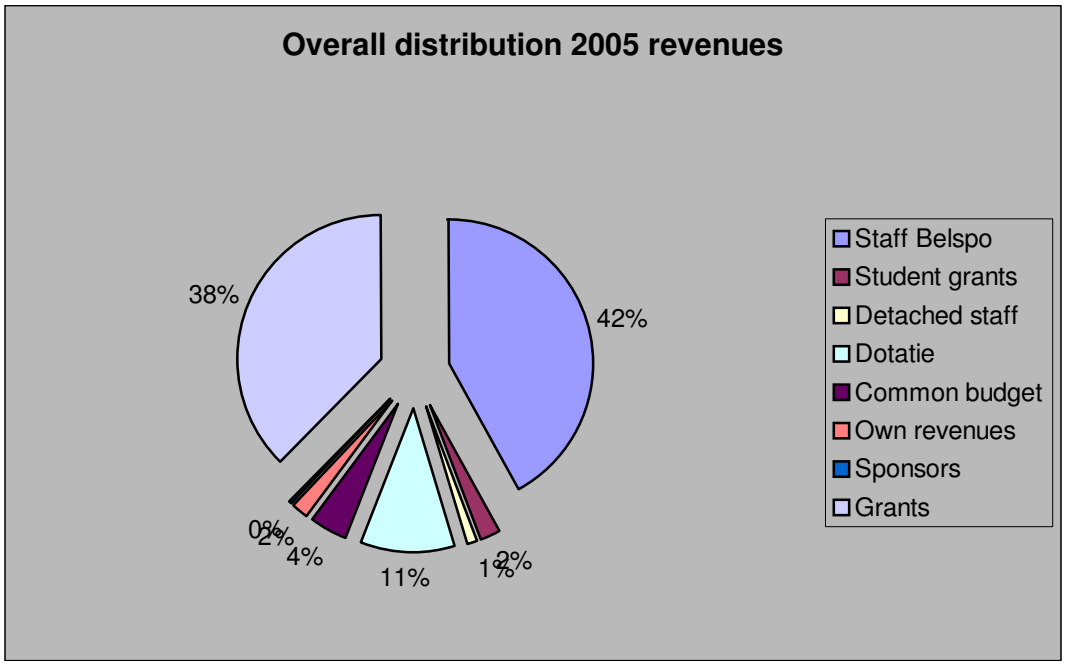
A.2.1.3. Other financial resources

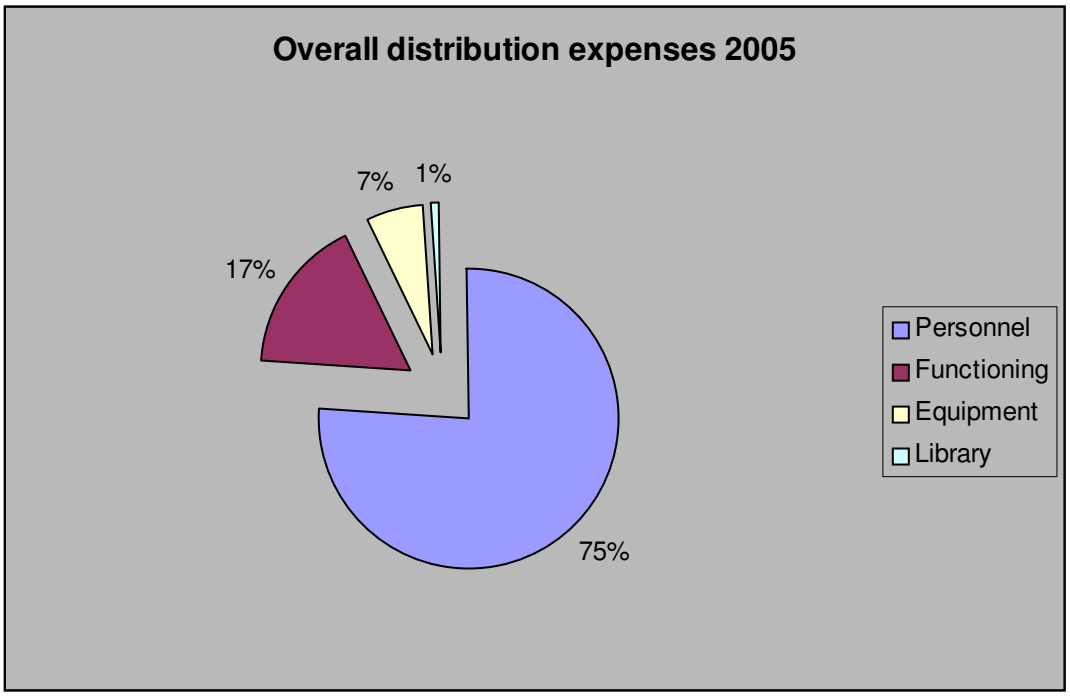
The ROB is also supported by other financial resources, which can vary considerably year by year and where it is difficult to put in exact values:

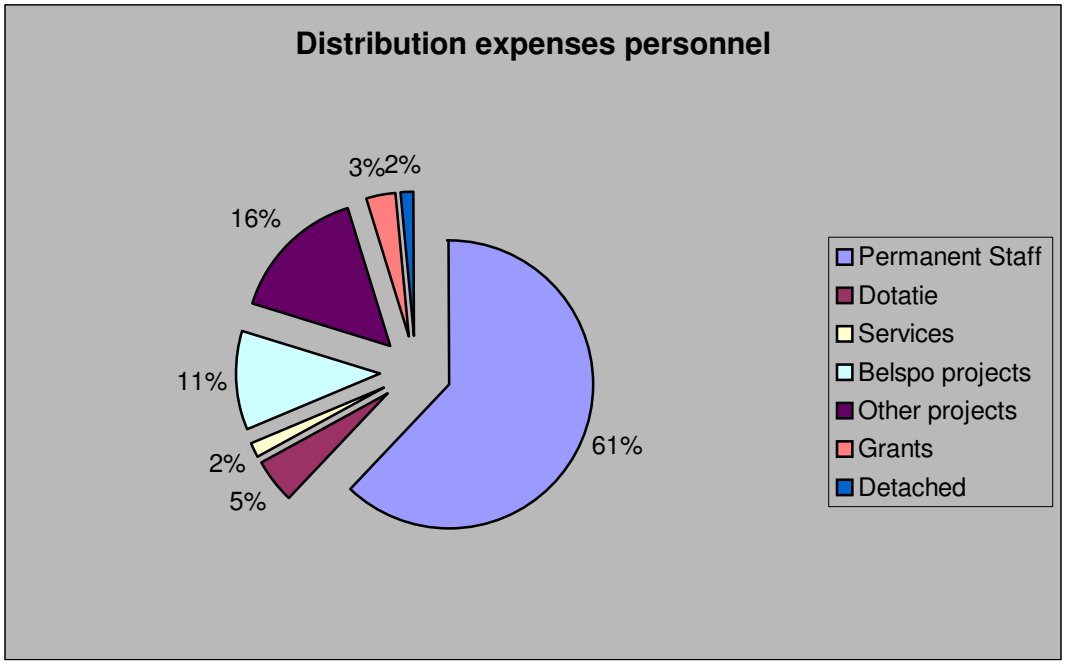
- The common budget of the "Space Pole", which finances the energy (heating, electric power), central telephone facilities and the common IT infrastructures of the "Space Pole". The part for the ROB can be estimated at 400.000 €/year.
- The maintenance and renovation of the buildings and offices of the ROB by the "Regie der Gebouwen".

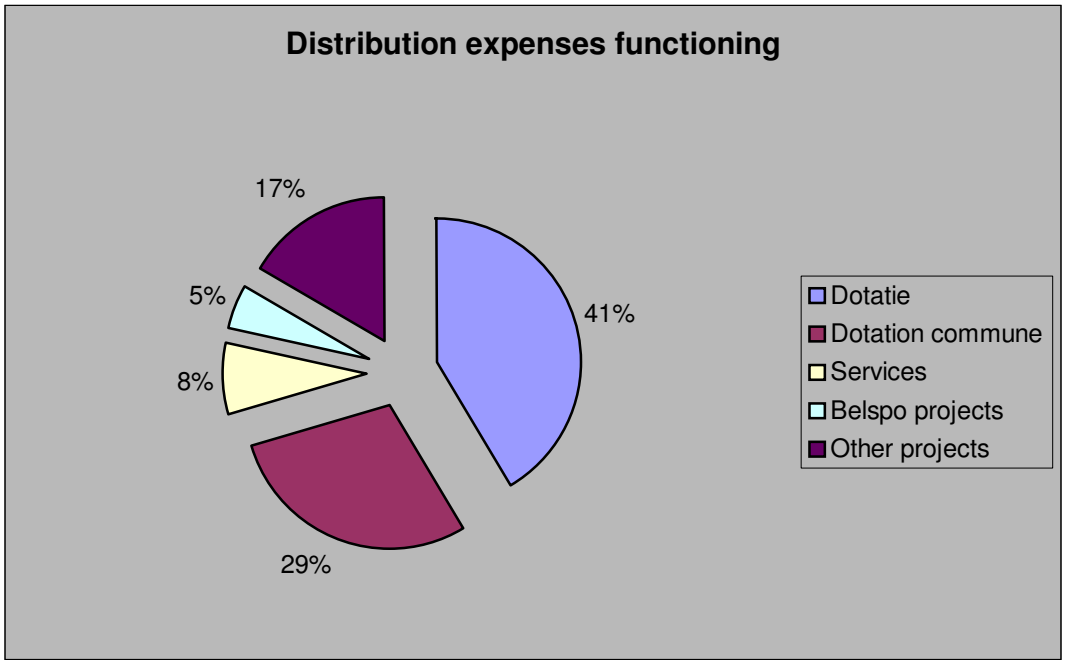
- Grants from FNRS, FWO, IWT, FRIA, etc, financing university students that are performing their PhD thesis at the ROB. In 2005 this amount can be estimated at 220.000 €
- Wages paid by different organizations for people detached to the ROB (Palais des Congrès, BIPT, Vlaams Onderwijs). In 2005 estimated at 100.000 €

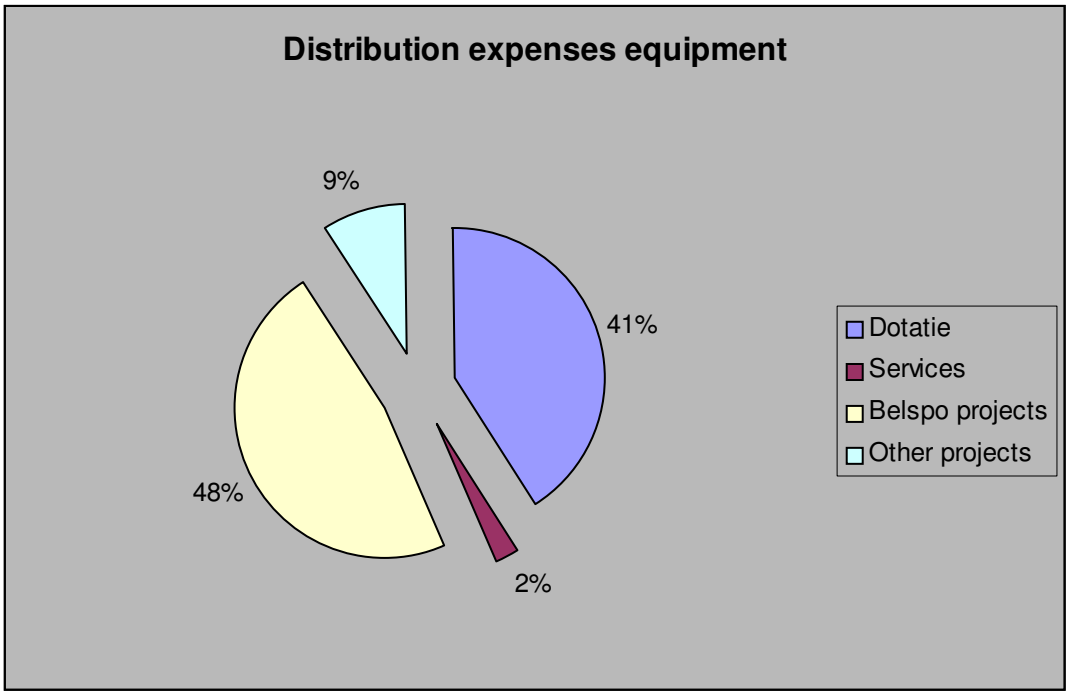
A.2.2. Statistics






Distribution expenses personnel
3%
2%
16%
11%
2%
5%
61%
Permanent Staff
Dotatie
Services
Belspo projects
Other projects
Grants
Detached


Distribution expenses functioning
17%
5%
8%
41%
29%
Dotatie
Dotation commune
Services
Belspo projects
Other projects



A.2.3. Personnel involved

Asselberghs Somnina
Barthélémy Julie
Mouling Ilse
Vanden Elshout Ronny

B. TECHNICAL SERVICES

B.1.1. Personnel involved

Vander Putten Eric	Diensthoofd
DeKnijf Marc	Ing electromechanica
Rogge Vincent	Ing veiligheid
Peeters Roger	Mechanica
Renders Francis	Mechanica
Strubbe Marc	Verwarming
Van Damme Daniel	Electronica
Van Der Gucht Ignace	Informatica
De Wachter Rudi	Tuinman
Mues Christian	Electricité
Van Den Brande Theophilis	Tuinman
Rondeaux Christian	Jardinier (Humain)
Bizerimana Philippe	Ouvrier
Ergen Aydin	Electronique
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. IT SERVICES

C.1. Description and Objectives

The computing facilities and the network of the Observatory are managed by the IT department.

For researchers at the Observatory, the IT staff provides a logistic support for the installation and maintenance of intensive compute machines such as Beowulf Clusters, number crunchers, compute servers, etc... as well as for users PCs.

The IT team also maintains the global computing infrastructure consisting of amongst others the email services, application servers, printing facilities, database servers, network infrastructure, etc…

Finally, an important task is to investigate the different options for improvements, balancing ease-of-use, reliability and performance. We can not overlook the current trends and evolution of different technologies and it is therefore important to keep our existing systems up to date.

The IT department's responsibilities can be split as follows:

- The **Network and Security**: the objective is to maintain the network infrastructure operational and at top performance, 24 hours a day.
- The **Servers**: The objective is to maintain servers providing global computing infrastructure consisting of amongst others the email services, application servers, printing facilities, database servers, login server, etc ...
- **Helpdesk & User PC**: The objective is to provide help and support to the users of the Observatory.
- **AMABEL Project**: AMABEL is a joint project between three institutes: ROB, RMI and BIRA. The AMABEL project finances common resources such as file servers and compute servers.
- **Purchase**: From 2005, all the IT purchases must be done by the IT department. This includes all the procedure, from defining the need of the user or group to the installation of the chosen material.

C.2. Progress and results

NETWORK & SECURITY:

- Some extensions to the network have been cabled and some switches have been replaced in order to provide Gigabit speeds to the desks of our users.
- Wireless network has been installed in 2005. There will be two separated networks: the private one, accessible only by the ROB users which have provided us their MAC address, and the public part, accessible for any visitor. At the present time, the private part is up and running and the public part is under development. The private network provides a complete access to our network infrastructure (access to others computers, printers, etc ..), like any computer inside the ROB, while the public part will have access only to limited resources (shortly, it provides an internet access to the outside world but not to our infrastructure)
- Weak users password tests are made and if some are found, the user is asked (with explications and help if needed) to change it
- A NIDS (Network Intrusion Detection System) has been implemented in the DMZ (DeMilitarized Zone). This implementation allows us to follow tentative intrusions on the websrv and the ftpsrv servers.

BACKUP SERVER:

- Until now, the backup facilities consist of 5 departmental servers with a few hundred of Gb of disk space and a tape backup system on each of them. Each user could have an account on one of them and is responsible of its backup. These backup systems are no more under warranty and the disk

space is no longer sufficient. In view of this situation, a complete backup system was devised, to provide data integrity in case of problems. Problems in this context can be categorized into several different types: small mishaps, such as a user who inadvertently deletes a file; larger accidents such as a computer or a server hard disk crash; and finally major disasters such as a raging fire destroying buildings, or an airplane crash on the plateau ... Our system is devised to deal with the different scenarios. We have two servers with as much redundancy as possible. The first (backup server) receives the data, the second one (tape server) is specialized in managing magnetic tapes for recovery of data online. Finally a tape device will take snap shots on Ultrium tapes which will be transferred off-site (planetarium). Most of this system is now operational. We have started installing the first users on the system. During 2006, we will give the possibility to everybody to have an automatic backup on this system.

SERVER ROOM:

- The servers of the Observatory were located in an office that had been converted into a server room, with a domestic air-conditioning system. A new server room has been installed with better equipment regarding air conditioning and power supply. The servers have been moved to the new room. The old server room has been transformed into the secondary server room, in which is located the tape server (see backup system)

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). This server has been upgraded this year to a more powerful one.

LINUX SERVER:

- In the same way as for the Windows server, we provide a centralized Linux server for all of our Windows users. This allows them to run Linux software from time to time (mainly Latex, bash scripting, programming languages).

ADMINISTRATION:

- A new application server has been installed. All members of the administration have always been working with a Microsoft environment. Up to now, they have been using individual PCs, with different versions of operating system, different versions of their applications and office products. This often caused problems of compatibility or of tracking of the correct version of the administrative documents. The other negative aspect of the previous structure was that there was nearly no backup, at least there was no systematic approach to the backup problem, hence important, even critical documents were stored on machines that were no longer under warranty, without any backup. This situation was of course unacceptable on the mid to long term. Therefore, to solve these different issues, it was decided to provide a central application server, with a standard configuration, managed by the system administrators. A dual Xeon server was purchased, and installed with Windows server 2003 operating system, standard Microsoft office suite and the accounting software (PIA client). The members of the administration staff may connect to this machine by using the Remote Desktop Protocol (RDP). Thin clients have been installed to connect to this central server. Thin Clients are small machines with no mobile parts (no hard disk and no fans) therefore they don't make any noise. No data is stored on the clients either, so it is very easy and safe for the users. Finally, the software is maintained centrally, so we can ensure that the users always have an up to date environment, with the latest security updates.

HELDESK:

- 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 2005, continuous support for users has been provided, including installation of machines and configuration.

AMABEL:

- 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). We have also participated in the tests and installation for the new compute server.

FEMTO (will be replaced by KAOS):

- Femto is a high performance compute server for heavy scientific tasks. In 2005, in order to keep this service at a high level of performance, it has been decided to join the effort of the 3 institutes (RMI, BISA and ROB) in order to buy a new high performance interactive compute server common for these institutes. This pool of servers is composed of 4 multi-processors (64 bits) high end servers, using Linux operating system.

TECHNET:

- Technet is the equivalent of intranet but for IT specific topics. One could find news about major changes to our computer infrastructure, FAQs, extensive information about our hardware infrastructure including statistic graphs about our server resources and status of the different services, a download area for Windows and Linux software and some links to interesting sites. Until recently, we were also providing a forum to the users.

YEARBOOK:

- There is a project initiated by Thierry Pauwels to make an interactive version of the yearbook of the Observatory.

SERVICED PC:

- We give the possibility to the users to administrate their PC for them. This means that all the updates and new software installations are done by the system administrators. At the present time, we administrate 34 linux PC and no Windows PC.

SMS SERVER:

- Since 2004, we have a SMS server which allows sending SMS for alert notification. 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 sent to the scientific in charge as well as to the electronic lab. A new server, with a new application, offering a lot of supplementary options has been bought in 2005. It will be installed in the beginning of 2006.

GENTOO SERVER:

- Gentoo is the linux distribution used and recommended at the Observatory. Because this distribution allows the users to use source packages over binary packages, we have setup a local Gentoo server at the observatory for fetching the sources packages of every possible Gentoo linux application. We provide also, since this year, precompiled binary packages for rapid installation of Gentoo.

LOGIN & SERVICES SERVER (HELIOS):

- At the present time, we use a common server as the login server of the Observatory (the only server available from outside) and for running some central services: DNS, NIS, DHCP, WINS…
- Some security measures have been taken, such as disallowing the root login

FILE SERVER:

- A common 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. As the extension of the contract is almost coming to an end, we will in the very near future start with the new purchase procedure. Therefore we are already investigating the market to have an idea on what possibilities are available for our needs. Our wish is to have a new file server at two different levels: limited high availability disk space and big & fast high capacity disk space.

COMPUTE SERVER (ZENO):

- A common non-interactive compute server is available for the 3 institutes. It allows users to submit heavy computation with a queuing system. A new system has been installed this year (Zeno): A Silicon Graphics (SGI), Altrix Bx2 with 56 Itanium2 processors, 112 GB RAM and 2 x 1168 local disk and linux as Operating system. An additional SGI parallel computer with 64 Itanium2 processors, 256 GB RAM and 2 x 1168 local disk will be delivered at mid contract (after 2 years). Users of the Observatory are already using the new compute server.
- Zeno is intended to be used mainly for batch processes. In that context several different queues have been defined with different specifications. The queuing system being used is PBS Pro

FTP 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. This server resides in the DMZ (De-militarized Zone) and has Gentoo linux as OS. The available user disk space has been divided in 4 main parts:
  - /dist in which user files for distribution are put. These directories are not cleaned up automatically
  - /pub in which temporary files are put. These directories are cleaned up once a month
  - /incoming in which anonymous ftpusers can put files for the user. These directories are cleaned up regularly as well.
  - /private, which is only used for certain users and is password protected.
- All the home directories have been renamed to avoid login names to be seen on the internet.
- Ftp as the user root has been disallowed.

PRINT SERVER:

- A print server is used for managing the print jobs submitted to our central printers. Until now, it was also used for managing the department printers.
- The print server has been completely changed and is now running a modern printer daemon: cups. The departmental printers have been removed, so that users themselves can intervene in case of jobs being blocked and so on. As a consequence of Cups being used in stead of lprng, printers are accessible via different protocols (ipp, http etc...)

LIBRARY:

- The staff of the library has been working up to now on very old equipment. Backups of their work were scarce; reliability of their machines was very low. With the experience acquired with the application server for the administration, we decided to install a similar system for the library staff. Also based on thin clients, for the same reasons as the administration. This has been successfully implemented.

WEB SERVER AND ROB WEB SITE:

- Regular maintenance of the web site has been done. It consists mainly in putting new announcements, job vacancies, news, etc…
- Questions to webmaster@oma.be are answered or redirected to the scientific in charge.

PUBLIC PC:

- A public PC is available in the printer room. This allows visitors (or users without personal PC) to have access to internet or to scan and print documents.

SOFTWARE:

- Since this year, the IT department is responsible of buying and installing the software.

HARDWARE MAINTENANCE:

- Since this year, the IT department is responsible for the IT hardware maintenance.

NTP SERVER (JOINT PROJECT WITH THE TIME LAB OF THE ROB):

- In 2004, we have set up an NTP server as a reliable and operational time synchronization source to allow anybody to synchronize on UTC(ORB) and by extension to UTC.
- In 2005, we have registered our server on organizations like ntp.org, we have exchanged emails with the manufacturer (Elproma) for improving the performance and the reliability of the server, we have built several web statistic tools for monitoring the server and we have answered to questions from people who want to synchronize on the ntp server. This year, a high availability cluster (HAC), composed of two servers providing NTP services to the public was also installed and configured. This system insures that we have a maximum uptime for this public service.
- At the present time, there are about 2200 clients using this service. This represents 3000 hits/hour.
- Because the NTP service has become more and more popular, we have also made a market study for buying a second NTP server. This will improve the reliability and lower the charge of our current NTP server. This new server will be delivered in the beginning of 06.

PLANETARIUM:

- Due to some problems in the connection of the Planetarium (delocalized near the Heysel) it was important to install new hardware for the connection. A new Cisco router was installed and configured. This router should be adequate for the upgrade to the connection that is foreseen in 2006.
- We have made an inventory of the stations present and working on this site.
- We have studied the possibility of replacing the belnet internet lines of the planetarium by ADSL ones. This will not be possible due the high bandwidth used.

SUPPLIES:

- From 2005, 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.
- A XLS file has been developed in order to follow the stock of the printer consumables on a web interface.

PURCHASES:

- From 2005, The IT staff has been in charge of the IT purchases. This includes the definition of the user needs, contacting different resellers, making the buying proposal and checking the received material.
- A special application has been set up in order to follow the purchases on a web interface

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 6 USERCOM meeting in 2005.

C.3. Perspective for next years

- NETWORK & SECURITY: For improving the security, we want to associate a MAC address to each network plug. We will send security recommendations to the users. For improving the network, we need to fine tune the configurations of our central switches. We will also finalize the Wifi coverage by adding the public part.
- BACKUP SERVER: At the end of 2006, we want that all the users have their backup on the central system.
- TECHNET: We will improve the FAQ and update the news more often. We will also use the SNMP protocol for implementing an alert and monitoring system which will allow us to monitor the printers (need to refill the paper tray, need to replace the cartridge/toner, …), to monitor the space disk available on servers, etc … We want also to setup a new database for easily monitoring the log of our servers. We will also develop a similar system for monitoring the state of the Linux/windows serviced PC.
- YEARBOOK: A new webmaster will be in charge of developing the interactive version of the yearbook.
- SERVICED PC: We want to collect information about each PC at the ORB in order to make a database.
- SMS SERVER: We will implement an alert system for the critical servers.
- LOGIN & SERVICES SERVER (HELIOS): WE want to separate the login facility from the other services.
- INTRANET: We want to give the possibility to the administration to administrate the intranet without the need of an intervention from the IT staff.
- A lot of our servers are coming to the end of their maintenance contract. Therefore, some of them will be replaced by new ones and extended maintenance contract will be chosen for the other ones. We will also group some services with are at the present time on different servers.
- We want to upgrade the network to a gigabit backbone
- Enhancing performance by fine tuning each machine in our server farm,
- Providing a safe work environment by a better control and setup of our firewalls and DMZ.
- Finally, we wish to get a closer participation from our users by setting up forums, possibly mailing lists

C.4. Personnel involved

David Herreman (System Administrator)
Oleg Rezabek (System Administrator)
Fabian Roosbeek (IT Coordinator)
André Somerhausen (System Administrator)
Katinka Vermeiren (System Administrator)
Kristof Baute (System Administrator)

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