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 jaarverslag 2006 van de Koninklijke Sterrenwacht van België (KSB) dat u hier wordt voorgesteld, biedt u een overzicht van de wetenschappelijke activiteiten van onderzoek en dienstverlening van mijn instelling. Net zoals vorig jaar hebben we ervoor gekozen om de werking van de KSB uitgebreid te beschrijven, zodat dit tevens kan dienen als presentatie van onze instelling naar het publiek en de wetenschappelijke wereld. Dat het werk van de Sterrenwacht van hoogstaand internationaal niveau is blijkt niet alleen uit de omvang van dit rapport en de vele erin vermelde wetenschappelijke publicaties. In de loop van 2006 werd tevens een studie uitgevoerd onder leiding van Prof. Capron waaruit zeer duidelijk bleek dat de KSB internationaal tot de topinstellingen qua wetenschappelijk onderzoek kan gerekend worden. Ook het succesgehalte bij het binnenhalen van onderzoeksprojecten en -opdrachten toont dit aan.

Dit jaarverslag beschrijft het eerste volledige kalenderjaar dat de KSB geleid werd door een Algemeen Directeur in een mandaatfunctie. Het is bijgevolg ook een jaar geweest dat er binnen de instelling heel wat kleine en minder kleine veranderingen gebeurd zijn, maar ook een jaar waarin veel nieuw enthousiasme gevonden is om nieuwe wegen in te slaan voor de toekomst. Ook de omgeving waarin de Sterrenwacht werkt ondergaat nog grote veranderingen, en dit zal ook in de toekomst nog het geval zijn. Ik prijs me gelukkig dat ik bij al deze veranderingen steeds mag rekenen op gemotiveerd en dynamisch personeel dat de opduikende kinderziektes er met de glimlach bijneemt.

Net als vorig jaar richten we dit jaarverslag ook grotendeels naar een internationaal publiek, en werd daarom het wetenschappelijk verslag in het Engels opgesteld, om op die manier te kunnen dienen als voorstelling van onze instelling t.o.v. de volledige buitenwereld.

Het verslag is opgesteld in drie delen. In het eerste deel vindt u een omstandig verslag van de wetenschappelijke activiteiten. U vindt er o.a. het bewijs dat we dankzij ruimtegeodesie met indrukwekkende precisie de beweging van de rotatie-as kunnen opvolgen en er zelfs de invloed van atmosferische omstandigheden in terugvinden (p. 33, onderwerp van een perscommuniqué), indicaties hoe we dankzij gravimetrische metingen kunnen aantonen dat de aardkorst in België een neerwaartse beweging heeft in de grootteorde van een millimeter per jaar (p. 74), en hoe de KSB reeds volop actief is met de voorbereiding van de ESA *Cornerstone* missie GAIA (p. 129, 147, 150 …) en het ambitieuze Solar Orbiter (p. 215).

Het tweede deel omvat de publieke dienstverlening, en tenslotte komen in het derde onderdeel de ondersteunende diensten aan bod.

Ik hoop uw nieuwsgierigheid gewekt te hebben om in de volgende bladzijden de Koninklijke Sterrenwacht van België te (her)ontdekken en beter te leren kennen. U zal er een onderzoeksinstelling aantreffen met een overvloed aan projecten en nieuw perspectieven; een instelling die zich weet aan te passen aan een nieuwe wereld en die weet rekening te houden met de eisen en mogelijkheden van een samenleving in permanente evolutie.

Ik wens u een aangename lectuur.

AVANT-PROPOS

Le rapport annuel 2006 de l'Observatoire royal de Belgique (ORB) qui vous est présenté ici vous offre un aperçu des activités de recherche et de service de mon établissement. Tout comme l'année précédente, nous avons choisi de vous offrir une vision assez détaillée des travaux réalisés par l'Observatoire. Ainsi, ce rapport, pourra-t-il faire découvrir notre institution tant au grand public qu'à la communauté scientifique. Le très haut niveau international du travail de l'Observatoire ne ressort pas seulement de l'ampleur de ce rapport mais aussi et surtout par les nombreuses publications scientifiques citées. Dans le courant de l'année 2006, une étude fut réalisée sous l'égide du Professeur Capron. Il en ressort très clairement que l'Observatoire peut être compté parmi les instituts de pointe en matière de recherche scientifique, tout comme le démontre notamment le taux élevé d'acceptation des projets introduits et des missions de recherche menées.

Ce rapport annuel est aussi le premier de l'Observatoire dirigé durant une année complète par un Directeur général sous mandat. Ce fut une année de multiples changements pour l'institution. Ce fut aussi une année au cours de laquelle l'enthousiasme n'a pas manqué pour avancer ensemble vers un nouvel avenir. Le contexte dans lequel l'Observatoire évolue subit encore de grands bouleversements et ce sera encore le cas dans les années à venir. Je m'estime donc heureux d'avoir pu compter sur un personnel motivé et dynamique qui s'adapte, avec le sourire, à ce nouvel environnement.

Tout comme l'année passée, ce rapport est aussi, en grande partie, destiné à la communauté internationale. C'est d'ailleurs pour cette raison que la partie scientifique de ce rapport fut rédigée en anglais et peut, ainsi, servir de carte de visite pour un public étranger.

Le rapport annuel 2006 est composé de trois parties. Vous pourrez lire, dans la première partie, un rapport circonstancié des activités scientifiques. Vous trouverez entre autres la preuve que, grâce à la géodésie spatiale, nous pouvons suivre avec une impressionnante précision le mouvement de l'axe de rotation de la Terre et même y retrouver l'influence des conditions atmosphériques (p. 33, sujet d'un communiqué de presse), la façon dont, grâce aux mesures gravimétriques, nous pouvons démontrer que la croûte terrestre en Belgique a un mouvement descendant de l'ordre de grandeur d'un millimètre par an (p.74), ou encore comment l'Observatoire participe activement à la préparation de la *Cornerstone mission* GAIA de l'ESA , (p. 129, 147, 150, …) et à l'ambitieux projet *Solar Orbiter* (p. 215).

Les deuxième et troisième parties couvrent respectivement le service public et les services d'appui.

J'espère vous avoir donné l'envie de découvrir et de mieux connaître, au fil des pages, un institut riche en projets et en perspectives nouvelles, un institut qui a su s'adapter à un monde nouveau et faire face aux défis et aux exigences d'une société en perpétuelle évolution.

C'est avec grand plaisir que je vous souhaite une très agréable lecture.

Deel 1: Wetenschappelijke activiteiten

Partie 1: Activités Scientifiques

Part 1: Scientific Activities

Summary

List of abbreviations

AAM	Atmospheric Angular Momentum
AGU	American Geophysical Union
AGW	Atmospheric Gravity Wave
BC	BepiColombo
BELA	BEpicolombo Laser Altimetry experiment
BELSPO	BELgian Science Policy
BIPM	Bureau International des Poids et Mesures
CB	Central Bureau
CCM2	Call for Earth Explorer Core Mission (2d Call)
CCTF	Comité Consultatif pour le Temps et les Fréquences
CETP	Centre d'Etude des Environnements Terrestre et Planétaires
CGGTTS	CCTF Group on GNSS Time Transfer Standards
CIP	Celestial Intermediate Pole
CMB	Core-Mantle Boundary
CNBGG	Comité National Belge de Géodésie et Géophysique
CNES	Centre National d'Etude Spatiale
COMU	COMUnication Department of UCL
Co-I	Co-Investigator
COST	european CO-operation in the field of Scientific and Technological research
CW	Chandler Wobble
DGPS	Differential GPS
DLR	Deutsche zentrum für Luft- und Raumfahrt
DSN	Deep Space Network
DYNAMO	DYNAMique des Orbites
EGNOS	European Geostationary Navigation Overlay Service
EGU	European Geophysical Union
E-GVAP	EUMETNET GPS Water Vapor Program
ENIC	Ecole Nouvelle d'Ingénieurs en Communication
ENSG	Ecole Nationale de Sciences Géographiques
EPN	EUREF Permanent GPS Network
ESA	European Space Agency
ESOC	European Space Operations Centre
ESTEC	European Space Research and Technology Centre
ETRF	European Terrestrial Reference Frame
ETRS	European Terrestrial Reference System
EUREF	EUropean REference Frame
EUROPLANET	EUROpean PLAnetary NETwork
FCN	Free Core Nutation
FICN	Free Inner Core Nutation
FNRS	Fonds National de la Recherche Scientifique
FRIA	Fonds pour la formation à la Recherche dans l'Industrie et dans l'Agriculture
FUNDP	Facultés Universitaires Notre-Dame de la Paix
GEP	Geophysical and Environmental Package
GEPID	GEP Interface Document

GINS	Géodésie par Intégrations Numériques Simultanées
GEMS	Geophysical/Environmental Monitoring and Sounding
GLONASS	Russian GLObal NAvigation Satellite System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GRGS	Groupe de Recherche de Géodésie Spatiale
GSFC	Goddard Space Flight Center
HCS	Haut Conseil Scientifique
HEND	High Energy Neutron Detector
IAG	International Association of Geodesy
IAU	International Astronomical Union
ICD	Interface Control Document
ICRF	International Celestial Reference Frame
ICRS	International Celestial Reference System
ICW	Inner Core Wobble
IERS	International Earth Rotation and Reference Systems Service
IGN	Institut Géographique National
IGS	International GNSS Service
IIP	Instrument Information Package
IMCCE	Institut de Mécanique Céleste et de Calculs des Ephémérides
IPGP	Institut de Physique de Globe de Paris
ISSI	International Space Science Institute
ITRF	International Terrestrial Reference Frame
ITRS	International Terrestrial Reference System
IUGG	International Union of Geodesy and Geophysics
IVS	International VLBI Service
JPL	Jet Propulsion Laboratory
JSR	Journées Système de Référence
LaRa	Lander Radioscience experiment
LAREG	LAboratoire de REcherche en Géodésie
LMD	Laboratoire de Météorologie Dynamique
LOD	Length-Of-Day
LPG	Laboratoire de Planétologie et Géodynamique
MAGE	MArs Geophysics European network
MaRS	Mars express Radio Science experiment
MEMO	Mars Escape and Magnetic Orbiter
MEX	Mars Express
MGS	Mars Global Surveyor
MINT	Mars INTerior
MOLA	Mars Orbiter Laser Altimeter
MORE	Mercury Orbiter Radioscience Experiment
MoU	Memorandum of Understanding
MPO	Mercury Planetary Orbiter
MRA	Mutual Recognition Agreement
NNO	New Norcia ESA ground station
NOE	Numerical Orbit and Ephemerides
NTP	Network Time Protocol
ODF	Orbit Data Files

ODY	Mars Odyssey
OMP	Observatoire Midi-Pyrénées/Orban Microwave Products
PI	Principal Investigator
PNP	Programme National de Planétologie
PPP	Precise Point Positioning
PRODEX	PROgramme for the Development of scientific EXperiments
PST	Project Scientist Team
PTB	Physikalisch-Technische Bundesanstalt
RENAG	REseau NAtional Géodesique
RISE	Rotation and Interior Structure Experiment
RSDI	Radar Speckle Displacement Interferometry
RTK	Real Time Kinematic
ROB	Royal Observatory of Belgium
S/C	Spacecraft
SIMBIO-SYS	Spectrometers and Imagers for MPO Bepicolombo Integrated Observatory SYStem
SF2A	Société Française d'Astronomie et d'Astrophysique
SLIM	Second-generation Louvain-la-neuve Ice-ocean Model
SLR	Satellite Laser Ranging
SONYR	Spin-Orbit N-bodY Relativistic model
SOWG	Science and Operation WG
SYRTE	Systèmes de Référence Temps-Espace
SWG	Science WG
TAI	International Atomic Time
TEC	Total Electron Content
TID	Travelling Ionospheric Distubance
TNF	Tracking and Navigation Files
TWSTFT	Two-Way Satellite Time and Frequency Transfer
UCL	Université Catholique de Louvain
UCLA	University of California Los Angeles
ULB	Université Libre de Bruxelles
ULg	Université de Liège
USNO	US Naval Observatory
UTC	Universal Time Coordinate
UTC(ORB)	UTC of Royal Observatory of Belgium
VeRa	Venus Express Radioscience experiment
VEX	Venus Express
VLBI	Very Long Baseline Interferometry
WG	Working Group
ZTD	Zenith Total Delay

DEPARTMENT 1: Reference Systems and Geodynamics

SECTION 1: Time, Earth Rotation, and Space Geodesy

Introduction

Mission and objectives

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

Additionally to the planet Earth, these objectives have been extended to the other terrestrial planets, Mars, Venus, and Mercury, and to the large moons of the solar system planets. These missions are included in a long-term vision, closely related to the international activities and opportunities, and to the activities described in the statutes of the Royal Observatory of Belgium (ROB) as well as in the strategic plan of our Director.

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 they 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 2006 for each of them. A further description is also provided in the introduction of some projects.

(a) Project 1 'TIME – TIME TRANSFER' (Operational & 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 GNSS 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) We have developed the calibration procedure of the GPS/EGNOS receivers PolaRx2 (Septentrio) for time applications; (2) We have developed the tool "Atomium" dedicated to time transfer at the picosecond level for GPS and extended the tool developed for GPS*

time and frequency transfer to GLONASS; (3) we have explained the origin of the day-bounday discontinuity problems in the combined pseudorange/carrier phase time transfer computations.

(b) Project 2 'GNSS-BASED GEODESY AND GEODYNAMICS' (Operational & 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 item, 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 (194 permanent stations), its data flow, data quality control, and data analysis. 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 the GALILEO precise positioning system.

<u>Milestones reached this year:</u> *(1) 2006 sees the installation of two new GPS stations: one in Jalhay and another one in Uccle which is serving as a full backup for the Brussels IGS station; (2) multi-GNSS data processing (GPS and GLONASS) was set up and is now running routinely as part of our contribution to EUREF; (3) the first real-time GNSS data streams are becoming available within the EUREF Permanent Network.*

(c) Project 3 'EFFECT OF THE EARTH ATMOSPHERE IN SPACE GEODESY' (Operational & 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 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 Department of Solar Physics, 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) Using ionosonde measurements, we have studied the ionospheric "physical conditions" which prevail when Traveling Ionospheric Disturbances (TIDs) are observed and we have better understood the physical origin of TIDs, which are due to interactions between the neutral atmosphere and the ionosphere; (2) we have demonstrated that severe geomagnetic storms and large amplitude/short wavelength (about 10 km) TIDs can lead to positioning errors larger than one meter even on short baselines (a few km); (3) We have reduced the latency of our RTK products which assess Space Weather effects on the RTK positioning technique: this product is now available within 15 minutes on our GPS-Space Weather web site; (4) we have demonstrated that GPS and Galileo triple frequency data improve the precision of the reconstructed TEC by more than an order of magnitude; (5) we have showed that Total Zenith Delays reconstructed using GPS data do not allow to detect small-scale structures in water vapour in a reliable way due to the fact that they are computed on 15-20 minute periods, which smoothes out short-term and small-scale effects; other "test quantities" have to be found in the future.*

(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 very long baseline interferometry (VLBI) observations as well as of analytical and numerical Earth rotation models. They study the angular momentum budget of the complex system composed of the solid Earth, the core, the atmosphere, the ocean, the cryosphere, and the hydrosphere at all timescales. This allows them to better understand the dynamics of all the components of the Earth rotation, as length-of-day variation (LOD), polar motion (PM), and precession/nutation, as well as to improve their knowledge and understanding of the system, from the external fluid layers to the Earth deep interior.

Milestones reached this year: *(1) in our theoretical work, we have demonstrated that the contributions on the long-periodic nutations of Poisson terms in the tidal potential are small but significant at the microarcsecond level and that the liquid core has an important contribution in that effect; (2) we have studied the electromagnetic coupling at the core-mantle boundary and its effects on the tides and nutation within a numerical integration approach and shown the order of magnitude of these effects; (3) we have shown that the atmosphere could globally excite the Free Core Nutation (FCN) but the atmospheric data (in the current state-of-the-art) could not reproduce the exact time variability of the observed FCN amplitude; we have nevertheless estimated the time variable amplitude of the FCN from VLBI data and our model has been proposed for the IERS conventions; (4) from the observational point of view, precise VLBI-only EOP and reference frames determination is routinely done in collaboration with the Paris Observatory IVS Analysis Center; (5) on the data interpretation field, we have shown that taking GPS-based determinations of the VLBI station positions could improve the determination of VLBI-only Earth rotation parameters; (6) we have analyzed polar motion when the two large oscillations, the Chandler and the annual wobbles,* *interfered destructively (every 6.4 years), slowing down the pole motion (from November 2005 till February 2006); we have explained the small centimeter level loops by atmospheric and oceanic contributions; this paper has been press released; (7) using a Bayesian approach we have estimated from the analysis of VLBI data in the time domain the boundaries within which the geophysical parameters may be expected to change, and in particular, to which extent the inner core parameters and precession may vary.*

(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.

<u>Milestones reached this year:</u> *(1) The analysis of Mars Express radio science data has allowed us to show that 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; (2) The combination of other spacecraft data (MGS and Odyssey) has allowed us to obtain the time variation of the gravity field and the Love number k_2 indicating that Mars has a large liquid core; (3) The use of MOLA altimeter data at ground track crossing points from the MGS spacecraft has been studied to determine Mars' rotation variations and we have demonstrated that this method could lead to a better estimate of the rotation rate variations of Mars and to the first direct observation of nutations of Mars; (4) the use of spacecraft and astrometric data of Phobos and Deimos has allowed us to obtain ephemerides for the two moons of Mars; (5) Based on our models for the interior of Mars, ranges of core sizes, effective mantle viscosities, and crust mean densities and thicknesses have been calculated in agreement with the latest estimates of the moment of inertia factor, mean density, Love number k_2, and global tidal dissipation; our results show that a perovskite layer, similar to the Earth's lower mantle, could be possible; (6) The effect of inertial coupling between mantle and core on Mercury's libration has been studied with the SONYR model with appropriate treatment for the initial conditions; we have shown that the joint analysis of expected data of space missions to Mercury on tidal displacements, tidal gravitational variations, librations and obliquity can strongly constrain the core size and composition of Mercury and that the concentration of light elements (S) in the core can be estimated with a precision of a few percent and the outer core radius with a precision of some tens of kilometers; (7) we have shown that the tidal gravitational Love number k_2 of Titan, to be measured by the Cassini spacecraft, is essentially unaffected by the atmospheric tides; (8) we have shown that it is possible to determine the thickness of the icy shell of the icy satellites by means of librations (rotation variations); (7) the tidal dissipation in Io has been determined from astrometric observation and used for interior modeling.*

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. 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 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.

A. Science Theme "Time and Time Transfer"

A.1. Operational and Research project "Time and Time Transfer"

A.1.1. Objectives

- To maintain high-quality clocks for participation in the international timescales (mainly TAI and IGS), and for the realization of a local high-quality timescale UTC(ORB) close to UTC;
- To develop strategies and tools for GNSS time transfer in order to improve the precision of remote clock comparisons, and perform high-performance analyses of the data gathered at ROB;
- To maintain the official Belgian time called UTC(ORB) within one hundredth of a nanosecond of TAI;
- To define a legal Belgian time and to include ROB 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).

A.1.2.1. Service

- During the year 2006, 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 accuracy. The plot for each clock is now available in near-real time on private web-pages as well as the comparison between our realization of UTC and the true UTC, as presented in the picture here below;

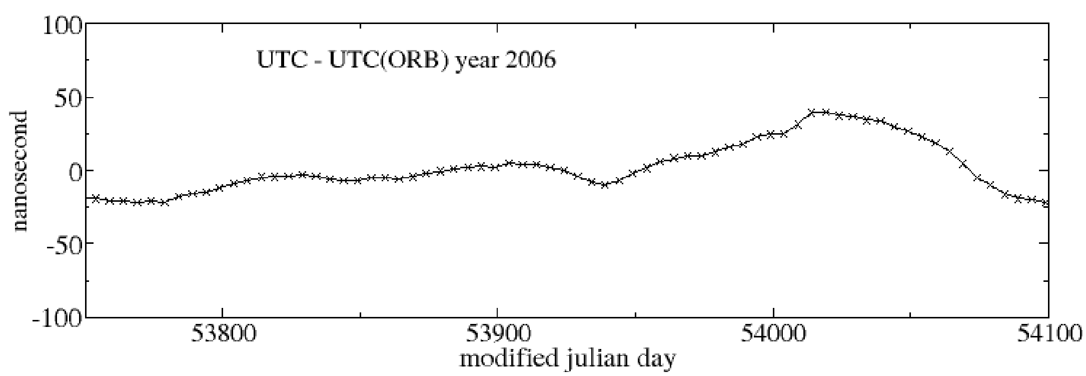

Figure 1: Difference between UTC and UTC(ROB) throughout the year 2006

- The new H-maser CH1-75A installed in December 2005 was monitored during 2006. This clock encountered two main problems (frequency divider, and synthesizer fault) during the year, demanding the intervention of the manufacturer.
- We have performed the management of the clock signals needed for GNSS receivers BRUS, ZTBR, PLB2 and BRUX.
- The NTP server is now fully operational for the diffusion of UTC(ORB) via internet; there are presently more than 40.000 hits per day on each of the servers.

- We have continued the procedure to get UTC(ORB), or equivalent realizations of UTC, as legal time for Belgium.
- We have negotiated with the Metrology Service for collaboration in the frame of the Mutual Recognition Agreements (MRA).
- We have participated in the calibration campaign of the Ashtech Z-XII3T receivers and Septentrio receivers for time applications, organized by the BIPM and aiming at obtaining the hardware time delay of the clock, the needed periphery, and the associated cables.
- We have installed a new antenna cable (with small sensitivity to temperature variations) for the ZTBR receiver.
- We have improved the time counting acquisition software in order to include new devices in the time laboratory.

A.1.2.2. Results

- We modernized the software R2CGGTTS (getting the CGGTTS[1] files using geodetic receivers, and the ionospheric free code P3) used by the BIPM in order to allow its use for the Novatel receivers which do not collect P1 code but rather C/A and P2 code.
- We have finalized the study of the calibration of GPS/EGNOS[2] receivers PolaRx2 (Septentrio) for time applications, and the definition of the procedure to calibrate all the PolaRx2 in the time labs.
- We have developed the tool "Atomium" dedicated to time transfer only, in the Precise Point Positioning mode (PPP)[3]. The first results were presented at the BIPM; we succeeded to reach the few hundred Picosecond precision level.
- We have studied the pseudorange multipath and noise and their implication discontinuities in time and frequency transfer solutions. Result: the geometrical multipath cannot explain the day-boundary jumps. Temperature explains a part of them, but another effect must be found to explain the rapid pseudorange variations in some stations.
- We have studied the Kalman filtering in GPS carrier-phase and code analysis for time transfer (in collaboration with L. Tollet, student UCL).
- We have extended the tool developed for GPS time and frequency transfer to GLONASS.
- We have started the development of a new analysis of GPS carrier phases in order to get a continuous solution for the clocks.

A.1.3. Perspective for next years

- To continue the development of the GPS time and frequency transfer analysis tool "Atomium"; to perform comparisons between the different techniques and different software.
- To investigate the impact of adding GALILEO and enhanced GPS on time transfer.
- To continue the investigation of the impact of adding GLONASS on time transfer.
- To continue the procedure to propose UTC(ORB) as basis for legal time in Belgium.

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

[2] The European Geostationary Navigation Overlay Service (EGNOS) is a satellite based augmentation system under development by ESA, the European Commission, and EUROCONTROL. It is intended to supplement the GPS, GLONASS, and GALILEO (when it becomes operational) systems by reporting on the reliability and accuracy of the signals.

[3] Precise Point Positioning (PPP) is a method that performs precise position determination as well as receiver clock solution using a single GPS receiver. This positioning approach arose from the advent of widely available precise GPS orbit and clock data products and has accuracy at the centimetre level.

- Depending on the Metrology Service requirements, to prepare the Quality Criteria for the Time laboratory (norm ISO17025 for calibration certification), necessary for the key comparisons of the MRA.
- To continue the development of the tool for continuous frequency transfer based on phase-only analysis.
- To continue the investigations of the effect of multipath on GPS time and frequency transfer.
- In collaboration with the BIPM, to study the effect of combining the results of GPS phase-only analysis and two-way (TWSTFT) links in the TAI computation.
- 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 (2% of time), Quentin Baire (100 % since October 2006)

Technical staff: Eddy Driegelinck

A.1.5. Partnerships

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)
Septentrio (J.-M. Sleewaegen)

Grants/Projects used for this research/service
Quentin Baire got a “supplementary researcher” contract from BELSPO.

Visitors: 3

A.1.6. Publications

A.1.6.1. Publications with peer system

None

A.1.6.2. Publications without peer system

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

[2] **Defraigne P.** and **Bruyninx C.,** 2005
Testing the capabilities of GPS receivers for time transfer
In: Proc. PTTI 2005, Vancouver, août 2005 (CD-ROM)

A.1.6.3. Publications in press, accepted or submitted

[3] **Bruyninx C., Carpentier G.,** and **Defraigne P.**
Analysis of the Coordinate Differences caused by Different Methods to align the Combined EUREF Solution to the ITRF
In: Proc. EUREF Symposium, Vienna, May 2005, in press.

[4] **Defraigne P., Bruyninx C.**
Multipath mitigation in GPS-based time and frequency transfer
In: Proc. EFTF 2006, March 2006 (CD-rom), in press.

[5] **Roosbeek F., Defraigne P.**
Long Term Study of the H-Maser Clocks at the Royal Observatory of Belgium
In: Proc. EFTF 2006, March 2006 (CD-rom), in press.

[6] Petit G., **Defraigne P.**, Warrington B., Uhrich P.
Calibration of dual frequency GPS receivers for TAI
In: Proc. EFTF 2006, March 2006 (CD-rom), in press.

[7] **Defraigne P., Bruyninx C**.
On the impact of multipath in GPS-based time and frequency transfer
In: Proc. IGS Workshop, May 2006, Darmstadt, Germany, in press.

[8] **Defraigne P., Bruyninx C**.
On the link between GPS pseudorange noise and day-boundary discontinuities in geodetic time transfer solutions
Accepted for publication in GPS solutions.

A.1.6.4. Reports, thesis, etc

[9] **Defraigne P.**
CCTF 2006: Report of the Royal Observatory of Belgium
Report presented in the frame of the 17th session of the CCTF (Comité Consultatif du Temps et des Fréquences), Paris, September 2006.

A.1.7. Scientific outreach

Meeting presentations

[1] **Defraigne P., Guyennon N.**
Transfert de temps par GNSS
Observatoire de Paris, 16 janvier 2006

[2] **Defraigne P., Bruyninx C.**
Multipath mitigation in GPS-based time and frequency transfer
EFTF 2006, Braunschweig, April 2006.

[3] **Bruyninx C., Defraigne P.**
On the effect of code multipath mitigation in GPS-based time and frequency transfer
EGU 2006, Vienna, April 2006

[4] **Roosbeek F., Defraigne P.**
Long Term Study of the H-Maser Clocks at the Royal Observatory of Belgium,
EFTF 2006,Braunschweig, April 2006.

[5] Petit G**., Defraigne P.,** Warrington B., Uhrich P.
Calibration of dual frequency GPS receivers for TAI,
EFTF 2006, Braunschweig, April 2006.

[6] **Defraigne P., Bruyninx C**.
On the impact of multipath in GPS-based time and frequency transfer,
IGS Workshop, May 2006, Darmstadt, Germany

[7] **Defraigne P., Guyennon N**.
Atomium, a new tool for time and frequency transfer
Meeting of the working group on TAI, Paris, September 2006.

Editorial responsibilities
P. Defraigne: Referee for IEEE Transaction on Instrumentation and Measurement

P. Defraigne: Referee for Metrologia

A.1.8. Missions

Research missions (assemblies, symposia, workshops, etc): 4
Operational meetings (commissions, working groups): 3
Field missions: 0

B. Science Theme "Space Geodesy with GNSS"

B.1. Operational & research project "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 (reference frame maintenance, troposphere and ionosphere monitoring and deformation monitoring);
- to use these GNSS observations to integrate Belgium in international terrestrial reference frames;
- to determine deformations of the Earth's crust;
- to improve the long-term accuracy of GNSS-based positioning.

B.1.2. Progress and results

B.1.2.1. GNSS Observation Network (operational activities)

Continuation of

- Daily maintenance of the ROB network of permanent GPS stations (Figure 2)
- Integration of the ROB GPS data in international observation networks (IGS/EUREF)
- Distribution of the ROB GPS data to the user community (surveyors, scientists, other ROB projects) using the Internet

Installation of new

- Pilar and GPS station in Brussels to serve as a full backup of the BRUS IGS station (BRUX)
- GPS station at Jalhay (JALH), near Membach for comparison with gravity measurements (collaboration seismology section)

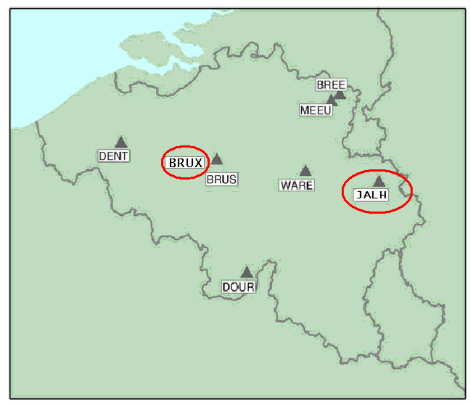

Figure 2: Permanent GPS stations operated by the project. Stations with a red circle have been installed in 2006.

B.1.2.2. EUREF Permanent Network (service activities)

<u>EPN Central Bureau</u>

- Daily management of the European permanent GNSS network of over 190 stations, distributed over more than 30 countries.
- Liaison between EPN station operators and analysis centres, providing the necessary station configuration metadata (type of receiver, antenna, absolute antenna calibrations, antenna height,…) and ensuring the datasets meet the requirements of the analysis (including daily checks of the GPS data flow and GPS data quality).
- Maintenance and (at least) daily updates of the EPN CB web site (http://epncb.oma.be/):
    - our web documents have been converted from HTML to XHTML and CSS in order to respect the W3C standard;
    - the PHP language has been implemented in all new and existing web pages;
    - in 2006, the website received more than 3 million hits, an increase of 40% with respect to 2005.

- More than 50 new programs were written to improve the functioning of the EPN CB and to support new web pages. Most striking new web pages include fully interactive maps, new direct data download capabilities, and interactive forms.
- The software developed for monitoring the quality of the RINEX data from the EPN and latency of the hourly RINEX data files at the EPN data centres has been completely rewritten in order to run in a more efficient way.
- In 2006:
  - 11 new GNSS stations were integrated in the EPN network;
  - A new procedure for monitoring real-time GNSS data streams was developed and it is presently in its validation phase;
  - The GPS data quality checks were partly extended to include GLONASS data quality checks;
  - Elaboration and distribution of new station operation guidelines including guidelines for stations streaming real-time data and a new policy for the inclusion of new antenna/radome pairs within the EPN;
  - Creation and maintenance of a new (password protected) data base containing individual absolute calibrations from the EPN stations;
  - Design of a new data flow for the International GNNS Service.

<u>EPN Data Analysis Centre</u>

- Computation of daily the coordinates of a network of 65 GPS stations in and around Belgium. These coordinate solutions are a service that the ROB delivers to EUREF; the coordinates are submitted weekly to EUREF and they contribute to the maintenance of the European and international spatial reference systems (ETRS89 and ITRS).
- In 2006:
  - a new ocean loading model was introduced;
  - the modelling of the troposphere was ameliorated by introducing the estimation of tropospheric gradients;
  - GLONASS observations were added;
  - relative receiver and satellite antenna calibrations were replaced by absolute calibrations.

B.1.2.3. Determination of deformations of the Earth's crust and improvement of long-term GNSS-based positioning (research activities)

Deformations of the Earth's crust are determined by computing regularly the positioning of permanent GPS stations and then by combining these positions together to obtain their time evolution, and, if possible, their linear velocities. In 2006 we demonstrated that the EPN time series do not behave as white noise but as a combination of white noise and the Flicker noise model (Figure 3). By applying this new noise model, more reliable estimates of the precision of the estimated velocities (

Figure 4) were obtained (see publication **[24]** and communications **[12], [14], [17], [19]**).

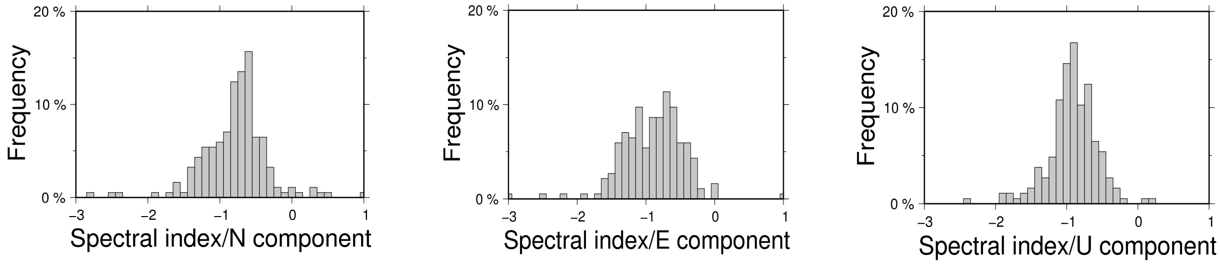

Figure 3: Histograms of the distribution of the spectral indices for the North, East and Up coordinate components. The 'extreme' values (k < -2) come from short time series (< 1 year).

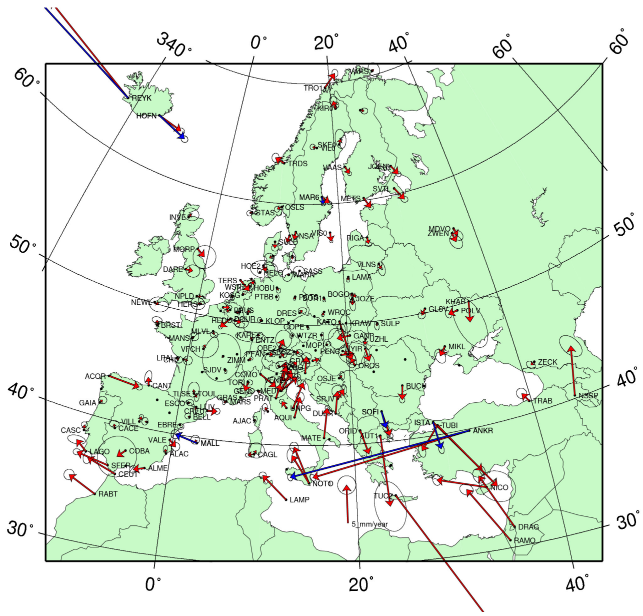

Figure 4: Estimated EPN residual velocities with respect to the Eurasian tectonic plate. Some sites have double velocity estimations, because following an event (equipment change, earthquake) the station showed different characteristics.

- Continued to investigate the gain of adding the GALILEO constellation to the GPS constellation in terms of formal errors for all the parameters to be estimated (collaboration with S. Daghay – VUB) (see publications **[18], [19]** and communications **[10], [18]**). In 2006, the models were extended to take into account the effect of the troposphere and ionosphere on the formal errors.
- Started the development of a GPS/GALILEO pseudo-range data simulator together with the necessary analysis programs for computing positions based on the simulated data.
- Investigated the gain of adding GLONASS observations to the positions presently obtained with GPS only (see publications **[1], [10], [11]** and communications **[3], [6], [9]**).
- Finished a re-processing of historical data of the ROB and EPN permanent GPS stations in and around Belgium using the most recent modeling schemes used by the Bernese 5.0 software. Based on these results the velocities of our geophysical stations located at Bree and Meeuwen have been obtained (collaboration seismology section).

B.1.3. Perspective for next years

- Continue the maintenance of the ROB GPS network, the EPN service activities (EPN Central Bureau, EPN Data Centre, EPN Analysis Centre). In 2007, part of the software supporting the management of the EPN CB will have to be completely reviewed/restructured/rewritten as the software is presently the product of ten years of continuous developments in different programming languages. In addition, the further development of the real-time GNSS data streams and their monitoring will also get special attention.

- Upgrade the ROB GPS network with new GNSS receivers. This will imply a complete reorganization of the data flow acquisition chain.
- Continue to improve the GPS data modeling and the estimation of site velocities.
- Perform near-real time (and later real-time) positioning while taking special care of the modeling of the tropospheric error.
- Investigate the possibility to use the ROB and EUREF networks for improved monitoring of the troposphere and ionosphere.
- Perform again a re-processing of the ROB and EPN permanent GNSS stations in and around Belgium. In this reprocessing, tropospheric gradients will be estimated, absolute antenna phase centres will be applied and GLONASS observations will be processed in addition to GPS. If available, re-computed satellite orbits will also be used.

B.1.4. Personnel involved

Scientific staff: C. Bruyninx (Project Leader), F. Roosbeek, P. Defraigne, M. Moins, G. Carpentier (from Jan 1 to Jan 31 2006).

Technical staff: D. Mesmaker, A. Moyaert, R. Laurent

B.1.5. Partnerships

List of international partners without grant

- Kenyeres, FOMI Satellite Observatory, Hungary
- Volksen, Bayerische Kommission fuer die Internationale Erdmessung (BEK), Germany
- G. Stangl, Institute of Space Research, Austria
- H. Habrich, G. Weber, D. Dettmerung, W. Sohne, Bundesamt für Kartographie und Geodäsie (BKG), Germany
- Z. Altamimi, IGN/LAREG, France
- H. Van der Marel, TU Delft, Netherlands

List of national partners without grant

- S. Daghay, VUB

Grants/Projects used for this research/service

- BELSPO Action 1, MO/33/12, "Study of the impact of using combined GALILEO and modernized GPS measurements for high accuracy positioning and timing applications", Jan. 2005 – March 2007, M. Moins

Visitors: 6

B.1.6. Publications

B.1.6.1. Publications with peer review

[1] **Bruyninx C.** (only on-line version, paper version to come in 2007)
Comparing GPS-only with GPS+GLONASS Positioning in a Regional Permanent GNSS Network
GPS Solutions, DOI: 10.1007/s10291-006-0041-9

[2] Timofeev Y., Ardyukov D.G., Calais E., Duchkov A.D., Zapreeva E.A., Kazantsev S.A., **Roosbeek F., Bruyninx C.**, 2006
Displacement Fields and Models of Current Motion in Gorny Altai
Russian Geology and Geophysics, Vol. 47, No. 8, pp. 923-937

B.1.6.2. Publications without peer review

[3] **Bruyninx C., Carpentier G., Roosbeek F.**
Day-to-day Monitoring of the EPN
Mitteilungen des BKG, Band 35, EUREF Publication No. 14, Ed. BKG, Frankfurt am Main, pp. 37-44

[4] **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
Mitteilungen des BKG, Band 35, EUREF Publication No. 14, Ed. BKG, Frankfurt am Main, pp. 204-207

[5] **Bruyninx C.,** A. Kenyeres
EPN On-line resources in support of geodynamical applications
Proc. Wegener 2006 "Geodesy of the Mediteranean", 4-7 Sept. 2006, Nice, France (on CD-rom)

[6] **Carpentier G., Bruyninx C., Roosbeek F.**
Quality and Latency of the Data within the EUREF Permanent Network
Mitteilungen des BKG, Band 35, EUREF Publication No. 14, Ed. BKG, Frankfurt am Main, pp. 348-356

[7] 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
Mitteilungen des BKG, Band 35, EUREF Publication No. 14, Ed. BKG, Frankfurt am Main, pp. 49-58

B.1.6.3. Publications in press, submitted

[8] **Bavier M., Bruyninx C., Lejeune S., Moins M., Pottiaux E., Roosbeek F.,** Voet P., **Warnant R.**
National report of Belgium
Proc. EUREF symposium, June 2006, Riga

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

[10] **Bruyninx C.**
Introducing GLONASS in the EUREF Permanent Network: First Results
Proc. IGS Workshop, May 2006, Darmstadt, Germany

[11] **Bruyninx C.**
GPS and GLONASS Data Analysis using Stations from the EUREF Permanent Network
Proc. EUREF symposium, June 2006, Riga

[12] **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

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

[14] **Bruyninx C.**, Stangl G., Weber G.
Network Operations and Data Flow within the EPN
IGS annual report 2003-2004

[15] **Bruyninx C., Roosbeek F.**
The EUREF Permanent Network: Recent Achievements
Proc. EUREF symposium, June 2006, Riga

[16] 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

[17] Daghay S., **Moins M., Bruyninx C.**, Rolain Y., **Roosbeek F**., Steenhaut O.
A Comparison between GPS-only and GPS+GALILEO Positioning: The Effect of the Changed Constellation
Proc. HUT-ICCE'06, Oct. 10-11, 2006, Hanoi, Vietnam

[18] **Moins M., Bruyninx C.**
Relative Positioning in Europe: Influence of the GPS+GALILEO Satellite Geometry
Proc. EUREF symposium, June 2006, Riga

[19] Moore A., **Bruyninx C.**, Noll C., Scharber M.
IGS Network and Data Center Position Paper
Proc. IGS Workshop, May 2006, Darmstadt, Germany

[20] Noll C., Moore A., **Bruyninx C.**, Scharber M.
IGS Data Flow – Today and Proposal for the Future
Proc. IGS Workshop, May 2006, Darmstadt, Germany

[21] Weber R., **Bruyninx C.**
The GNSS Working Group of the IGS – Challenges of the GNSS Modernization Programs
Proc. IGS Workshop, May 2006, Darmstadt, Germany

[22] **Bruyninx C**., Altamimi Z., Boucher C., Brockmann E., Caporali A., Gurtner W., Habrich H., Hornik H., Ihde J., Kenyeres A., Mäkinen J., Stangl G., van der Marel H., Simek J., Söhne W., Torres J.A., Weber R.
The European Reference Frame: Maintenance and Products
Submitted to IAG Proceedings

[23] **Bruyninx C., Carpentier G., Roosbeek F.**
The EUREF Permanent Network: Monitoring and On-line Resources
Submitted to IAG Proceedings, Oct. 2006

[24] Kenyeres A., **Bruyninx C.**
Noise and Periodic Terms in the EPN Time Series
Submitted to IAG Proceedings

B.1.6.4. Reports, thesis, etc

B.1.7. Scientific outreach

Meeting presentations

[1] **Bruyninx C**., H. Habrich and W. Söhne

Objectives and Status of EUREF
GAGOS Workshop, Feb. 13-14, 2006, Munich, Germany

[2] **Bruyninx C**.
EPN Status and Reliability
EUREF Local Analysis Centers Workshop, March 15-16, 2006, Padua, Italy

[3] **Bruyninx C**.
First experiences with GPS+GLONASS data analysis in a regional network of GPS and GPS+GLONASS receivers
EGU 2006 General Assembly, April 2-7, 2006, Vienna, Austria

[4] A. Moore, **Bruyninx C.,** C. Noll, M. Scharber
IGS Network and Data Center Position Paper
IGS Workshop, May 8-12, 2006, Darmstadt, Germany

[5] C. Noll, A. Moore, **Bruyninx C.**, M. Scharber
IGS Data Flow – Today and Proposal for the Future
IGS Workshop, May 8-12, 2006, Darmstadt, Germany

[6] **Bruyninx C**.
Introducing GLONASS in the EUREF Permanent Network: First Results
IGS Workshop, May 8-12, 2006, Darmstadt, Germany

[7] R. Weber, **Bruyninx C.**
The GNSS Working Group of the IGS – Challenges of the GNSS Modernization Programs
IGS Workshop, May 8-12, 2006, Darmstadt, Germany

[8] **Bruyninx C**., **Roosbeek F**.
The EUREF Permanent Network: Recent Achievements
EUREF Symposium, June 13-17, 2006, Riga, Latvia

[9] **Bruyninx C**.
GPS and GLONASS Data Analysis using Stations from the EUREF Permanent Network
EUREF Symposium, June 13-17, 2006, Riga, Latvia

[10] **Moins M**., **Bruyninx C**.
Relative Positioning in Europe: Influence of the GPS+GALILEO Satellite Geometry
EUREF Symposium, June 13-17, 2006, Riga, Latvia

[11] **Bavier M., Bruyninx C., Lejeune S., Moins M., Pottiaux E., Roosbeek F.,** Voet P., **Warnant R.**
National report of Belgium
EUREF Symposium, June 13-17, 2006, Riga, Latvia

[12] **Bruyninx C.,** Kenyeres A.
Contribution of the EUREF Permanent Network to Crustal Deformation Monitoring
ALPS GPSQUAKENET Workshop, June 26-27, 2006, Brussels

[13] R. Weber, **Bruyninx C.**
The EUREF Permanent Network (EPN) and its applications
AFREF Workshop, July 9-13 2006, Cape Town, South Africa

[14] **Bruyninx C.,** Kenyeres A.
EPN On-line resources in support of geodynamical applications
XIII Assembly of the WEGENER project, Sept. 4-7, 2006, Nice, France

[15] **Bruyninx C**.

The European Reference Frame – Maintenance and Related Products
INTERGEO, GREF, FIG, Oct. 9-13, 2006, Munich, Germany

[16] **Bruyninx C., Carpentier G., Roosbeek F**.
The EUREF Permanent Network: Monitoring and On-line Resources
INTERGEO, GREF, FIG, Oct. 9-13, 2006, Munich, Germany

[17] Kenyeres A., **Bruyninx C.**
Analysis of the Noise and Periodic Terms in the EPN Coordinate Time Series
INTERGEO, GREF, FIG, Oct. 9-13, 2006, Munich, Germany

[18] Daghay S., **Moins M., Bruyninx C.,** Rolain Y., **Roosbeek F.,** Steenhaut O.
A Comparison between GPS-only and GPS+GALILEO Positioning: The Effect of the Changed Constellation
HUT-ICCE'06, Oct. 10-11, 2006, Hanoi, Vietnam

[19] Kenyeres A., **Bruyninx C.**
Seasonal Terms in the EPN Coordinates Time Series: Artifact or real Signal?
AGU Fall Meeting 2004, December 11-15, 2006, San Francisco, US

Websites

- Complete review of *the AGU geodesy section website (*http://www.agu.org/sections/geodesy/)
- The EPN CB website http://epncb.oma.be/ has been improved: new web pages have been added and existing web pages have been revisited be fully dynamical to reduce future manual updates (in collaboration with D. Mesmaker, A. Moyaert). In 2006, the website received a total of 3.161.210 hits which is an increase of 40% with respect to 2005.

Brochures

- Update of EPN flyer

B.1.8. Missions

Assemblies, symposia (number):	C. Bruyninx (7) F. Roosbeek (2)
Commissions, working groups (days):	C. Bruyninx (7)
Field missions (days):	A. Moyaert (3) R. Laurent (3)

B.2. Research & operational project: "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" that 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 2006, the following tasks have been performed:

B.2.2.1. Space Weather and ionosphere

- ***Ionosphere activity monitoring***: Traveling Ionospheric Disturbances (TIDs), 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 can strongly degrade GNSS accuracy. Therefore, we have started a detailed study of these phenomena mainly based on GNSS and ionosonde measurements. On the one hand, GNSS measurements have been used to analyze the different characteristics of TIDs in space and time (amplitude, wavelength, period, frequency of occurrence depending on season, local time, solar activity …). On the other hand, we are studying the ionospheric "physical conditions" which prevail when TIDs are detected based on ionosonde measurements which allow to have a better understanding of the physical origin of TIDs, most of which being produced by severe thunderstorm cell complexes (the plasma signatures of Atmospheric Gravity Waves (AGWs)).

- ***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 Real Time Kinematic (RTK) surveying technique. Using this software, we have demonstrated that severe geomagnetic storms and large amplitude/short wavelength (about 10 km) TIDs can lead to positioning errors larger than one meter even on short baselines (a few km). This study is based on the GPS data collected in the "Active Geodetic Network", which is a dense network of about 60 permanent GPS stations installed on the Belgian territory.

- ***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 ionospheric activity effects on GNSS applications through a web-based interface. New features have been added to this web service: daily, weekly and monthly bulletins of our RTK product have been added to the usual daily weekly and monthly bulletins sent via email by the SIDC. In addition, the use of the "Active Geodetic Network" data, which are available in "true" real time, has allowed us to improve the latency of our RTK products which are now available within 15 minutes (instead of 75 minutes) after the observations. A more "user friendly" user interface has also been implemented.

- ***Development of modernized GPS and GALILEO simulation and data processing software:*** we have developed 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. This method has been validated successfully based on simulated GPS and GALILEO triple frequency data. First results show that this new technique should improve the precision of the reconstructed TEC by more than an order of magnitude. It will be validated on real GALILEO (GIOVE A) data in the near future.

B.2.2.2. Water vapour and troposphere

- ***Assessment of the neutral atmosphere effect on GNSS accuracy***: It is well-established that the presence of small-scale structures in the ionosphere can degrade high accuracy real-time GNSS positioning techniques at the meter level but, at the present time, we have not much information about the effects of small-scale structures in water vapour (due to thunderstorms, heavy rain falls, …) on these positioning techniques. Therefore, we started a study on this topic based on the data from the Active Geodetic Network. First results indicate that Zenith Total Delays (ZTD) reconstructed using GPS data do not allow to detect small-scale structures in water vapour in a reliable way: indeed, GPS ZTD are usually computed on 15-20 minute periods; for this reason, short-term and small-scale effects are smoothed out. Other "test quantities" have to be found in the future.

B.2.3. Perspective for next years

The team related to this project has left the ROB on 31/12/2006 and is moving to Section 8 "Ionospheric Profiles" of the Royal Meteorological Institute of Belgium. The activities of this part of the section will be taken over by new personnel during 2007.

B.2.4. Personnel involved

Scientific staff: M. Bavier, S. Lejeune, E. Pottiaux, J. Spits, R. Warnant (project leader)

Technical staff: E. Driegelinck

B.2.5. Partnerships

List of international partners without grant

- Prof. I. Kutiev, Dr. B. Andonov, Dr. P. Marinov, Geophysical Institute of the Bulgarian Academy of Sciences
- Prof. A. Dodson, Dr. M. Aquino, University of Nottingham, IESSG.

List of national partners without grant

- Dr. J.-C. Jodogne, Dr. J. Rasson, Royal Meteorological Institute of Belgium.
- Prof. R. Billen, University of Liège, Department of Geometrology and Geomatics.

Grants/Projects used for this research/service

- Belspo-Action 2 (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".
- Belspo-Chercheurs supplémentaires (01/10/2004-30/09/2006) "Effets atmosphériques en géodésie spatiale"

- 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”.
- Prodex-ESA SIDC Space Weather Pilot Project
- Prodex-SIDC Telescience (01/01/2005-31/12/2006)
- COST 296: “Mitigation of Ionospheric Effects in Radio Systems”
- COST 724: “Developing the basis for monitoring, modeling and predicting Space Weather”

B.2.6. Publications

B.2.6.1. Publications with peer review

[1] **Warnant R.**
L’effet de l’atmosphère terrestre sur les GNSS: une perturbation ou un signal géophysique ?
Bul. Soc. Geog. Liège, 47, pp. 19-23.

B.2.6.2. Publications without peer review

[2] **Lejeune S., Warnant R.**
Near real time assessment of the ionosphere effect on high accuracy GNSS applications which require ambiguity resolution
Proceedings of the 2nd COST296 Workshop (on CD-Rom), Rennes, 3-7 October 2006.

[3] **Spits J., Warnant R.**
Real Time TEC monitoring using triple frequency GNSS data: a three step approach
Proceedings of the 2nd COST 296 Workshop (on CD-Rom), Rennes, France, 3-7.10.2006

[4] **Warnant R., Lejeune S.**
Characterisation of ionospheric small-scale structures over mid-latitudes in Europe.
Proceedings of the International Civil Aviation Organization meeting, Montreal, Canada, October 2006.

B.2.6.3. Publications in press, submitted

[5] **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., in press.

[6] **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., in press.

[7] **Warnant R., Lejeune S., Bavier M.**
Space Weather influence on satellite based navigation and precise positioning
In: Space Weather - Research towards Applications in Europe, Astrophysics and Space Science Library series, Vol. 344, Ed. J. Lilensten, Springer, in press.

[8] **Lejeune S., Warnant R.**
A novel method for the quantitative assessment of the ionosphere effect on high accuracy GNSS applications which require ambiguity resolution
J. Atmospheric and Solar-Terrestrial Physics, in press.

B.2.7. Scientific outreach

Meeting presentations

[1] **Bavier M., R. Warnant R., Lejeune S.**
Detecting and forecasting ionospheric irregularities using a cross-correlation method applied to the Belgian dense GNSS network.
Presented at the European Geosciences Union General Assembly 2006, Vienna, Austria, April 02-07 2006.

[2] **Bavier M., Warnant R.**
Detection and characterization of ionospheric irregularities using the Belgian dense GNSS network
Presented at the COST296 2nd Workshop, Rennes, 3-7 October 2006.

[3] **Bavier M., Warnant R., Lejeune S.**, Andonov B., Kutiev I.
Development of customer-oriented space weather related services for real-time GPS applications.
Presented at the 3rd European Space Weather Week, 13-17 November 2006, Brussels, Belgium.

[4] **Lejeune S., Warnant R.**
Near real time assessment of the Space Weather effect on navigation based on the DGNSS technique.
Presented at the 3rd European Space Weather Week, 13-17 November 2006, Brussels, Belgium.

[5] **Lejeune S., Warnant R.**
Near real time assessment of the Space Weather effect on high accuracy GNSS applications which require ambiguity resolution
Presented at the 3rd European Space Weather Week, 13-17 November 2006, Brussels, Belgium.

[6] **Spits J., Warnant R.**
Real Time TEC monitoring using triple frequency GNSS data: a three step approach
Presented at the 2nd COST 296 Workshop, 3-7 October 2006, Rennes, France.

[7] **Spits J., Warnant R.**
Real Time TEC monitoring using triple frequency GNSS data: a three step approach
Presented at the 3rd European Space Weather Week, 13-17 November 2006, Brussels, Belgium

[8] **Warnant R.**, Kutiev I., Jodogne J.-C., **Pottiaux E.**
GALOCAD: GALileo LOcal Component for nowcasting and forecasting Atmospheric Disturbances.
Presented at the 1st GALILEO Joint Undertaking Workshop for Small and Medium Enterprises, Brussels, April 5-6 2006.

Websites

- GPS Space Weather services (http://www.gpsatm.oma.be) in collaboration with the SIDC and with the Royal Meteorological Institute.

B.2.8. Missions

Assemblies, symposia (12):

M. Bavier (3)
S. Lejeune (3)
E. Pottiaux (1)
J. Spits (3)
R. Warnant (2)

C. Science Theme "Rotation and internal structure of the Earth and the other planets"

The research aims at better understanding the rotation of the Earth and of the other terrestrial planets or satellites, their interior, and the relation between their rotation and interior.

C.1. Research project "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

C.1.2.1. High order terms in the non-rigid Earth's rotation

The effects of the tidal force on the dynamic shape of the Earth has been computed as this was a contribution missing in the nutation model IAU 2000A [4] (in collaboration with Prof. P.M. Mathews) (IAU stands for International Astronomical Union). Complementary, other second order effects in the nutation theories, related to the contribution of the Poisson's terms of the external gravitational potential, have been investigated. This work demonstrated that the contributions on the long-periodic nutations are small but significant at the microarcsecond level and that the liquid core has an important contribution in that effect [13] (in collaboration with Dr. M. Folgueira).

Estimation of Earth interior parameters from nutation observations (in collaboration with O. de Viron (IPGP, France)); we have studied how well the parameters can be retrieved from the different nutation series and we have compared with the IAU adopted nutation model.

C.1.2.2. Geophysical excitation of the Earth's Free Core Nutation

The Earth's retrograde Free Core Nutation (RFCN), a free mode associated with the rotation of the liquid core inside the visco-elastic mantle, is a broad-band processes of which the nominal frequency and quality factor depend on geophysical parameters (e.g. core flattening, elasticity, magnetic couplings at the core-mantle interface and inner core boundary). At this frequency, the external excitation (e.g., atmosphere, oceans) is only noise. Our study aims (i) at developing the formulae linking the excitation power within a frequency band around the nominal frequency to the observed power, and (ii) at applying these formulae to real data (global circulation models for atmosphere and oceans) compared against the RFCN observed through VLBI, in order to check the global magnitude of the contribution and its time variability. It has been shown that the atmosphere could globally excite the RFCN but, due to strong inconsistencies between the atmospheric models, the atmospheric data (in the current state of the art) could not reproduce for any time variability of the observed RFCN amplitude [5] (also paper in preparation).

C.1.2.3. Observational strategy in very long baseline interferometry

VLBI remains the most powerful technique to observe the Earth's orientation variations. Its long term stability is currently better than any other space geodetic technique. However, VLBI suffers from poor constraints on the terrestrial frame, due to a small number of observing stations (~40 strong stations). As a result, spurious biases and drifts can show up in short term EOP series. We have investigated whether taking GPS-based determinations of the VLBI station positions (through the IGS solutions and recent local ties) could improve the determination of Earth rotation parameters (polar motion and UT1). The results showed that this combination decreases the biases and naturally improves VLBI-only EOP determinations, not by a huge factor but significantly (paper in preparation).

C.1.2.4. Towards the second realization of the ICRF

The International Celestial Reference Frame (ICRF) is a corner stone for reliable VLBI analysis, and especially for deriving the nutation offsets (i.e. residuals between the observation and a theory). The accumulation of VLBI delays and new analysis strategies allow the initial ICRF (created in 1998) to be redefined. This mission needs a large amount of analyses. The creation of a working group on the Second Realization of the ICRF, chaired by Dr. Chopo Ma (NASA/GSFC), has been decided at the IAU 26th General Assembly (Prague, August 2006). ROB is member of this WG with the task to compute time series of radio center positions for all radio sources observed during geodetic VLBI sessions (around 700 radio sources), using a precise strategy to free these positions from reference frame effects.

C.1.2.5. VLBI analysis

Precise VLBI-only EOP and reference frames determination is routinely done in collaboration with the Paris Observatory IVS Analysis Center (http://ivsopar.obspm.fr/). VLBI time delays as received from the correlators from observation campaigns are treated with the Calc/Solve software (NASA/GSFC). Nutation estimates with respect to the IAU 2000A model are presented in Figure 5. These residuals can be compared with those presented in Figure 7, which presents the IERS EOP C 04 reference series.

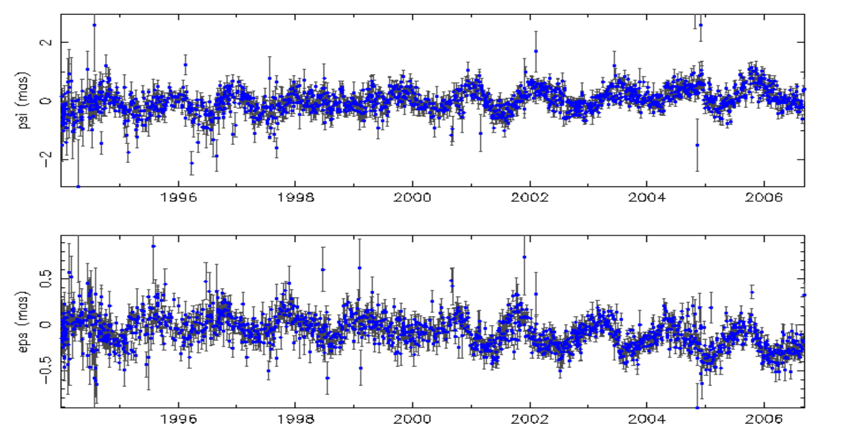

Figure 5: Nutation residuals (in milli-arcseconds) as a function of time (in year) computed at ROB.

C.1.2.6. Excitation of the rapid polar motion

The terrestrial motion of the Earth's rotation pole shows mainly two large oscillations: the Chandler and the annual wobbles driven by mass redistributions in surface geophysical fluids. These contributions interfere destructively every 6.4 years, slowing down the pole motion at that period of time. This is the case for the recent period from November 2005 till February 2006. Due to the high precision of Earth orientation data of these days and for the first time in the history of polar motion observation, very small structures of the motion are observed. We compared the observed polar motion (IERS EOP C 04 data) with the contribution of atmosphere (NCEP/NCAR Reanalysis) and oceans (JPL ECCO-2) predicted from global atmospheric and oceanic analyses and models. We clearly see that centimeter level polar motion displacements during the 2005-2006 winter season (see Figure 6) are almost fully explained by major pressure events on the continents and on the ocean, especially a depression over Northern Europe in-phase with similar events over North America [2].

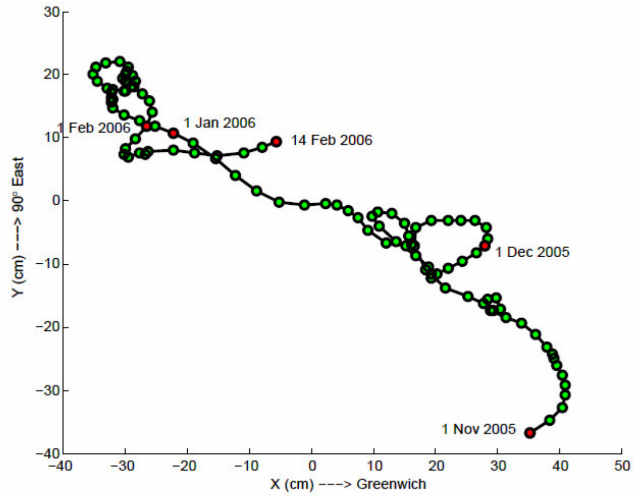

Figure 6: Polar motion from November 2005 till February 2006. The red dots indicate some dates during the wander of the pole.

C.1.2.7. Observed FCN free mode

We have estimated the FCN free mode amplitude from the IERS EOP C 04 nutation series. The adoption of our model by the IERS (International Earth Rotation and Reference Frames service) is being discussed. Figure 7 presents the nutation residuals in milli-arcseconds (mas) between the VLBI observation and the IAU adopted model. We have superimposed the estimated FCN free mode amplitude as a function of time (in year).

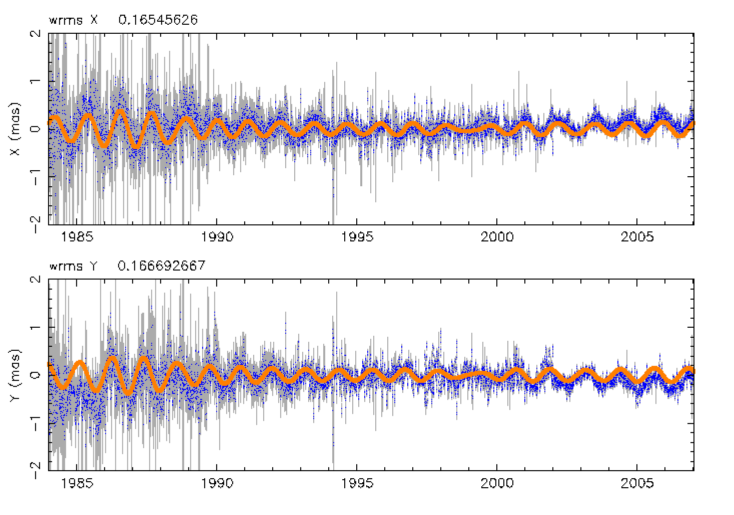

Figure 7: In blue, the nutation residuals (in milli-arcseconds) between the VLBI observation and the IAU adopted model; in orange, the estimated FCN free mode amplitude as a function of time (in year).

C.1.2.8. Geophysical fluid effects

We have examined the angular momentum series of the atmosphere and we have characterized their internal noise. We have then created a combined series starting from all the atmospheric angular momentum series available using the noise (varying as a function of the series and of time) [1].

C.1.2.9. Non Rotating Origin

We have examined carefully and explained the concept of the Non-Rotating Origin (NRO) to the scientific community. We have prepared a paper and several 3D representations of the coordinate transformation involving the NRO (in collaboration with O. de Viron (IPGP, France) and N. Capitaine (Observatoire de Paris, France)). We have presented this (invited talk) at IAU and we have put the paper and the animations on the web (http://www.astro.oma.be/D1/DIDAC/originenontournante.php).

C.1.2.10. Nutation modeling in the time domain

Second order/non-linear effects on nutation have been studied by using a numerical integration of a simple non-linear Earth rotation model. The inertial and visco-magnetic couplings have been introduced in the numerical model in order to obtain a more complete response of the Earth to the forcing including the planetary interactions. The model considers cross product coupling. We have obtained nutation amplitudes in the time domain for the solid Earth and the core. The nutations of the whole Earth from this numerical integration method have been compared with the precise analytical solutions. A paper is in preparation.

We have studied the atmospheric excitation of nutation in the time domain in order to incorporate this effect in the nutation modeling. We have determined the geophyisical parameters for nutation modeling jointly with the atmospheric excitation. This estimation of the parameters is sensitive to the accounting or not of the atmosphere. We have also considered in addition the precession and obliquity rate estimations as well. We considered a priori distribution of the parameters, which allows us to better determine the error bars on the nutation parameters. The numerical results obtained for the geophysical parameters are close to those obtained by Mathews et al. 2002 which validates our method. The errors bars that we have obtained as well can now be considered as realistic. We have seen in our results that two of the parameters considered (one related to the inner core and one related to precession) are not well determined. A paper is in preparation.

C.1.2.11. Electromagnetic coupling at the CMB and core flow; effects on nutation

Study of the electromagnetic coupling at the core-mantle boundary and its effects on the tides and nutation within a numerical integration approach (in collaboration 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 (Huang et al. 2007). In the frame of core flow study, the effect of the Poincaré motion and more general core motions on the rotation of planets has been continued (collaboration with O. de Viron, IPGP).

C.1.2.12. Book 'Precession, nutation, and wobble of the Earth' and review papers

Advance in the preparation of the final version of the book on 'Precession, Nutation, and Wobble of the Earth' (in collaboration with Sonny Mathews).
We have prepared (invited) two contributions for the proceedings of the IAG and for the set of geophysical paper contribution to a "treatise" [3], [12].

C.1.2.13. Special Bureau for the Core

We are hosting the website of the Special Bureau for the Core of the IERS. This website provides information and data on the core, which is updated according to the new references and the advances of the studies of the core.

C.1.3. Perspective for next years

In addition to or in the frame of the continuation of the above mentioned studies, we consider the following particular additional objectives for next year:

C.1.3.1. Celestial frame issues

The computation of radio source coordinates time series (see C.1.2.4 above) will allow one to determine which ones are suitable to define a stable (non rotating) reference frame. We actually plan for finding about 250-300 radio sources. This will be achieved through (i) a selection scheme based on the statistical analysis of the time series, and (ii) comparison with other indices of astrometric suitability. Note that the IAU WG on the Second Realization of the ICRF is asked to bring the new ICRF by 2009 (IAU 27th General Assembly).

C.1.3.2. High accuracy VLBI

A clear quantification of the effects of the VLBI analysis strategy on the determination of geophysical parameters has never been done (although several works already investigated in this direction). Because it is relevant for both VLBI and geosciences, I foresee to conduct such a work by (i) producing VLBI series with the possibility to play with the various options (models, constraints) and (ii) estimating Earth's interior parameters from the output series. Conclusions of this work should give crucial information for the best analysis strategy to adopt for coming years as well as information on the ability of VLBI to explore the Earth deep interior.

C.1.3.3. Precession and long period nutation determination

The long period nutation and the precession are influenced by the second order terms mentioned above. The determination of the geophysical parameters is thus contaminated by these contributions. We plan to study new VLBI residuals that account for these effects. We shall also consider the effects of temporal changes in the moment of inertia and we shall evaluate the order of magnitude of these effects with the aim of improving nutation residual.

C.1.3.4. Cylindrical geometries inside the core and effects on length-of-day

We plan to evaluate the viscosity between the cylinders involved in the torsional oscillation of the core in order to obtain possible angular moment contributions and identify the effects on decadal length-of-day variations. A new core-mantle coupling based on cylindrical model will be developed and introduced in SONYR model (acronym of Spin-Orbit N-bodY Relativistic model), a numerical approach to integrate the spin-orbit N-body problem. This coupling is particularly interesting to represent the impact of the core on the proper rotation namely the Earth's length-of-day variations at decadal timescale.

C.1.3.5. Polar motion

We shall investigate the polar motion (mainly the Chandler wobble) through a non-linear model taking into account the spin-orbit and geophysical fluid interactions. To perform this task, we will use the SONYR model extended to the geophysical fluid interactions modeled by angular momentum series of atmosphere and ocean. In order to get rid of the initial conditions of the numerical integration method, we shall introduce dissipation in the mantle. This will allow us to really get a Chandler wobble resonance comparable with observations.

C.1.3.6. Nutations over geological timescales

We shall study the Earth rotational normal mode called the Free Core Nutation (FCN) generated by the presence of a flattened liquid core inside the Earth. Particularly, some resonance between the FCN and an annual forcing period in space could arise over a long period of time and lead to important geophysical and geological events for the Earth (e.g. Greff-Lefftz and Legros, 1999). The resonance will arise from a change in the annual period and in the FCN period when specific values of the Earth rotation speed and of the core oblateness are used. The objective is to identify and explain these behaviors by investigating the prograde and retrograde nutations during such events. The physical explanation of the core flattening changes is related to mantle convection: the lateral heterogeneities in the mantle induce internal loading on the CMB and deform it. We shall therefore also intend to examine the impact of different mantle convection models, the associated changes in the core flattening, and their impact on Earth rotation. Particularly, during the history of the Earth, the tectonic plates move at the surface of the Earth and the associated subducting slabs can reach the CMB and change the core flattening, which in turn influence the rotation of the Earth. Further work in that frame will be related with the presence of an inner core.

C.1.3.7. Nutations and librations of a tri-axial planet

A numerical method to calculate rotation variations of a planet with a bi-axial ellipsoidal form will be extended to include tri-axial planets. This method will serve to determine a more accurate theoretical nutation series for the Earth and to study accurately the librations of Mercury and the large synchronously-rotating natural satellites (a new PhD thesis by Antony Trinh will start on that subject).

C.1.4. Personnel involved

Scientific staff: V. Dehant (Project Leader), S. Lambert, L. Koot, T. Van Hoolst. N. Rambaux

C.1.5. Partnerships

List of international partners without grant

- Eng. C. Barache, Drs. S. Bouquillon, C. Bizouard, N. Capitaine, A.-M. Gontier, M. Feissel-Vernier, and J. Souchay, Paris Observatory, France
- Dr. C. Le Poncin-Lafitte, Lohrmann Observatory Technical University of Dresden, Germany
- Dr. K. Le Bail, Institut Géographique National, Champs-sur-Marne, France
- Prof. P.M. Mathews, Department of Theoretical Physics, Univ. of Madras, India
- Dr. M. Folgueira-Lopez, Universidad Complutense de Mardrid, Spain
- Dr. O. de Viron, Institut de Physique du Globe de Paris (IPGP), Paris, France

Grants/Projects used for this research/service

- Belspo-Action 1 project
- Bilateral cooperation between China and Belgium
- EU Descartes Nutation Prize 2003

Visitors:

- Marta Folgueira, University of Madrid, Spain, 2x one month, Descartes Nutation Prize;
- Chengli Huang, Shanghai, China, 3 months, Bilateral cooperation China-Belgium;
- Laurent Métivier, IPGP, Paris, France, three months, Descartes Nutation Prize.
- Short visits: 1

C.1.6. Publications

C.1.6.1. Publications with peer review

[1] **Koot L.**, de Viron O., **Dehant V.**
Atmospheric angular momentum time-series: characterization of their internal noise and creation of a combined series
J. Geodesy, 79, pp. 663-674, ISSN: 0949-7714, DOI: 10.1007/s00190-005-0019-3.

[2] **Lambert S.**, Bizouard C., **Dehant V**.
Rapid variations in polar motion during the 2005-2006 winter season
Geophys. Res. Letters, 33, L03303, DOI: 10.1029/2006GL026422.

[3] **Dehant V., 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, Chapter 124, pp. 887-894.

[4] **Lambert S.B.** and Mathews, P.M.
Second-order torque on the tidal redistribution and the Earth's rotation
Astr. Astrophys., 453, pp. 363-369.

[5] **Lambert S.B.**
Atmospheric excitation of the Earth's free core nutation (Research Note),
Astr. Astrophys., 457, pp. 717-720.

C.1.6.2. Publications without peer review

[6] 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., and Wallace P.
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, pp. 143-146.

[7] **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, pp. 165-172.

[8] **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, pp. 187-188.

[9] **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, on CD rom, 6 p.

[10] **Lambert S.B.** and Gontier A.-M.
A comparison of R1 and R4 IVS networks
In: D. Behrend and K.D. Baver (Eds), International VLBI Service for Geodesy and Astrometry (IVS) 2006 General Meeting Proceedings, NASA/CP-2006-214140, pp. 264-268.

[11] **Lambert S.B.**
Baseline and site repeatability in the IVS rapid network
In: D. Behrend and K.D. Baver (Eds), International VLBI Service for Geodesy and Astrometry (IVS) 2006 General Meeting Proceedings, NASA/CP-2006-214140, pp. 296-299.

C.1.6.3. Publications with peer review in press, accepted or submitted

[12] **Dehant V**. and Mathews M.P.
Earth Rotation Variations
in: Treatise of Geophysics, invited paper, Elsevier Publ., eds. T. Herring and J. Schubert, accepted for publication.

[13] Folgueira M., **Dehant V., Lambert S.B., Rambaux N.**
Impact of tidal Poisson terms to non-rigid Earth rotation

Astron. Astrophys., under revision.

[14] Le Poncin-Lafitte C. and **Lambert S.B.**
Numerical study of relativistic frequency shift for cold-atom clock experiments in space
Class. Quantum Grav., in press.

[15] Souchay J., Lambert S.B., and Le Poncin-Lafitte C.
A comparative study of rigid Earth, non rigid Earth nutation theories and observational data
Astron. Astrophys., accepted for publication.

C.1.6.4. Publications without peer review in press, accepted or submitted

[16] **Dehant V.**
Report of Commission 3 on Earth Rotation and Geodynamics
In: Proc. 3rd KAGI21international symposium on 'Active Geosphere Investigation', IAG Travaux, J. Geodesy, Part Commission reports, Commission 3, 1-16, in press.

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Report of Commission 19 on Earth Rotation and Reference System
IAU Transactions, in press.

[18] Capitaine C., 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., Wallace P.
Report of Division I Working Group on 'Nomenclature for Fundamental Astronomy' (NFA)
IAU Transactions, in press.

[19] **Dehant V.,** de Viron O., Capitaine N.
The 3D representation of the new transformation from the terrestrial to the celestial system
In: Proc. JD 16, Invited Paper IAU General Assembly, Prague, 14-25 August, 2006, Highlights of Astronomy, Volume 14, in press.

[20] **Dehant V.,** Brzezinski A., Capitaine N., Defraigne P., Dickey J., Fukushima T., Gambis D., Hefty J., Huang C., Ma C., Malkin Z., Poma A., Ray J., Richter B., Ron C., Sidorenkov N., Soffel M., Souchay J., Vondrak J., Wilson C.
Commission 19: Rotation of the Earth: report of business meeting
In: Proc. JD 16, Invited Paper IAU General Assembly, Prague, 14-25 August, 2006, Highlights of Astronomy, Volume 14, in press.

[21] Huang C.-L., **Dehant V.,** Liao X.-H., de Viron O., **van Hoolst T**.
Does The Magnetic Field In The Fluid Core Contribute A Lot To Earth Nutation?
In: Proc. JD 16, Invited Paper IAU General Assembly, Prague, 14-25 August, 2006, Highlights of Astronomy, Volume 14, in press.

[22] **Lambert S.B.,** Bizouard C., **Dehant V.**
The winter dance of the Earth's pole
In: Proc. SF2A 2006, eds. D. Barret et al., extended abstract, in press.

[23] Barache C., Berio P., Bizouard C., Bouquillon S., Collilieux X., Coulot D., Deleflie F., Exertier P., Feraudy D., Gontier A.-M., **Lambert S.B.**, Vanderschueren Y.
A first step for the French Geodetic VO
In: Proc. SF2A 2006, eds. D. Barret et al., extended abstract, in press.

[24] **Lambert S.B.**
The Earth's nutation: observational and geophysical issues
In: Proc. SF2A 2006, eds. D. Barret et al., extended abstract, in press.

[25] Gontier A.-M., **Lambert S.B.**, Barache C.
The IVS team at the Paris Observatory: how are we doing?
In: Proc. SF2A 2006, eds. D. Barret et al., extended abstract, in press.

[26] **Lambert S.B.**, Bizouard C., **Dehant V.**
The winter dance of the Earth's pole
In: Proc. SF2A 2006, eds. D. Barret et al., extended abstract, in press.

[27] **Lambert S.B.**, Le Poncin-Lafitte C., Bouquillon S.
Radio-optical realizations of celestial reference frames,
In: Proc. SF2A 2006, eds. D. Barret et al., extended abstract, in press.

[28] Le Poncin-Lafitte C. and **Lambert S.B**.
Testing the relativity with ACES,
In: Proc. SF2A 2006, eds. D. Barret et al., extended abstract, in press.

C.1.6.5. Reports, thesis, etc

[29] Ducrocq C.
Etude du couplage visqueux entre le Manteau et le Noyau
Rapport de stage; student Engineer of ENSG, France; Promotor: Ö. Karetekin; Official responsible: V. Dehant;

C.1.7. Scientific outreach

Meeting presentations

[1] **Dehant V.**
Origine du magnétisme terrestre et étude du noyau de la Terre et des autres planètes telluriques
Conference at 'Connaissance et vie d'aujourd'hui' Mol, February 20, 2006.

[2] **Dehant V.**
Nutation de la Terre dans l'espace; Prix Descartes 2003
Journée de présentation du Prix Hook, Nice, France, April 28, 2006, invited.

[3] **Dehant V.** and **Van Hoolst T.**
Planetary rotation and habitability
Presented at the national group of contact Astrobiology, Brussels, June 13, 2006.

[4] **Lambert S.B.,** Bizouard C., **Dehant V**.
Rapid polar motion excited by surface geophysical fluids
Presented at the 'Société Française d'Astronomie et d'Astrophysique (SF2A)', Paris, France, June 26-30, 2006.

[5] **Dehant V.,** de Viron O., Capitaine N.
The 3D representation of the new transformation from the terrestrial to the celestial system
Invited talk, JD16 on 'Nomenclature, Precession and new models in Fundamental Astronomy; Applications and scientific contribution to astronomy', IAU 26th General Assembly, Prague, Czech Republic, August 14-25, 2006.

[6] **Dehant V.**
Brief report on the IAU Commission 19 activities
Business Meeting of Commission 19, IAU 26th General Assembly, Prague, Czech Republic, August 14-25, 2006.

[7] **Dehant V.**
Business: new members, new associated, new OC, terms of reference

Business Meeting of Commission 19, IAU 26th General Assembly, Prague, Czech Republic, August 14-25, 2006.

[8] **Dehant V.** and the Descartes Fellows
Summary of what has been done in the frame of the Descartes Prize
Science Meeting of Commission 19, IAU 26th General Assembly, Prague, Czech Republic, August 14-25, 2006.

[9] Huang C.-L., **Dehant V.,** Liao X.-H., de Viron O., **van Hoolst T**.
Does the magnetic field in the fluid core contribute a lot to Earth nutation?
Invited talk, JD16 on 'Nomenclature, Precession and new models in Fundamental Astronomy; Applications and scientific contribution to astronomy', IAU 26th General Assembly, Prague, Czech Republic, August 14-25, 2006.

[10] **Koot L., Rivoldini A**., de Viron O., **Dehant V.**
Estimation of Earth interior parameters from nutation data in the time domain
Poster, Science Meeting of Commission 19, IAU 26th General Assembly, Prague, Czech Republic, August 14-25, 2006.

[11] Drewes H**., Dehant V., Lambert S**., Wahr J.M.
Inconsistencies in geodetic concepts, models and analyses at the 0.1 ppb level
GGOS workshop, Munich, Germany, October 8-9, 2006.

[12] **Lambert S.B**
Rapid polar motion during the 2005-2006 winter season
AGU 2006 Fall Meeting, San Francisco, California, invited talk.

[13] **Lambert S.B.**, Barache C., Gontier A.-M., Bizouard C., Becker O.
OV-SYRTE: Etat au 1er décembre 2006
OV-France, Réunion du Groupe de Travail VO-Paris, Paris, France

[14] Gontier A.-M., Barache C., Bizouard C., **Lambert S.B.**, Becker O.
Projet pilote de l'OP/SYRTE, OV-France
Réunion du Groupe de Travail Géodésie, Grasse, France

[15] **Lambert S.B.**
Recent issues in observation and theory of nutation
IAU 2006 General Assembly, Commission 19 Business Meeting, Prague, Czech Republic, invited talk.

[16] Le Poncin-Lafitte C. and **Lambert S.B.**
Relativistic theory for time delay and frequency shift; Application to the ACES mission
11th Marcel Grossmann Meeting, Berlin, Germany

[17] Barache C., Berio P., Bizouard C., Bouquillon S., Collilieux X., Coulot D., Deleflie F., Exertier P., Feraudy D., Gontier A.-M., **Lambert S.B.**, Vanderschueren Y.
A first step for the French Geodetic VO
Semaine de l'Astrophysique Française - Journées SF2A 2006, Paris, France

[18] **Lambert S.B.**
The Earth's nutation: recent observational and geophysical issues
Semaine de l'Astrophysique Française - Journées SF2A 2006, Paris, France

[19] Gontier A.-M., **Lambert S.B.**, Barache C.
The IVS team at the Paris Observatory: how are we doing?
Semaine de l'Astrophysique Française - Journées SF2A 2006, Paris, France

[20] **Lambert S.B.**, Bizouard C., **Dehant V.**

Rapid polar motion excited by surface geophysical fluids
Semaine de l'Astrophysique Française - Journées SF2A 2006, Paris, France

[21] **Lambert S.B.**, Le Poncin-Lafitte C., Bouquillon S.
Radio-optical realizations of celestial reference frames
Semaine de l'Astrophysique Française - Journées SF2A 2006

[22] Le Poncin-Lafitte C. and **Lambert S.B.**
Testing the relativity with ACES
Semaine de l'Astrophysique Française - Journées SF2A 2006, Paris, France

[23] Bougeard M.L. and **Lambert S.B.**
Sensitivity analysis in application to Earth orientation SSA modeling
EGU 2006 General Assembly, Vienna, Austria

[24] **Lambert S.B.** and Gontier A.-M.
A comparison of R1 and R4 IVS networks
IVS 2006 General Meeting, Concepción, Chile

[25] **Lambert S.B.**
Baseline and site repeatability in the IVS rapid network
IVS 2006 General Meeting, Concepción, Chile

Editorial responsibilities

- V. Dehant: Referee for JGR, PEPI, GRL, and for the above proceedings;
- T. Van Hoolst: Referee for JGR, Treatise on Geophysics
- S. Lambert: Referee for GRL, Acta Geodetica et Geomaterialia.

C.1.8. Missions

Assemblies, symposia (number):	V. Dehant (2)
	S. Lambert (3)
	L. Koot (1)
Commissions, working groups (days):	V. Dehant (3 days)
	S. Lambert (several days)

C.2. Research project: "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 and large natural satellites.

The gravity field of planetary bodies can best be studied through the precise monitoring of the trajectory of passing or orbiting spacecrafts. Because the gravity field of a planet is determined by the planet's internal mass distribution, spatial and temporal variations in the gravity field can be used to determine physical properties of the planet. Since the beginning of the space age, the large-scale structure of the gravity field of planets and moons has been successfully used to determine the moment of inertia, which is a measure of the radial density distribution. The moment of inertia is considered as one of the major constraints on the interior structure of planets and large moons. 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 large natural satellites. For that purpose, we investigate the relation of rotation variations, gravity field, and tidal variations 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.

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 (MPO) of the BepiColombo project. From the three experiments, the rotation variations (called librations) and gravity field of Mercury will be determined. The results will be used to determine the interior structure and dynamics of the innermost planet of our solar system. A point of main interest is the determination of the physical state (liquid or solid) and the size of Mercury's core, which have large implications on the formation and evolution of terrestrial planets. In 2006, we have focused on theoretical studies of the rotation, interior and gravitational field of Mercury, and have performed numerical simulations of the mission. We also extended theses studies to large satellites of the Solar System.

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

We continued negotiations and preparations for a Mars mission including a geophysical package on a lander and submitted as PI a radio science experiment (LaRa) for the ExoMars lander to ESA. A contract with a Belgian company for the study of an X-band transponder and antenna has been signed.

C.2.2. Progress and results

C.2.2.1. General results

- IIP, ICD, and GEPID documents have been prepared and sent to ESA for selection of the radio science experiment LaRa on the ExoMars lander to be launched in 2013. These documents define the scientific objectives of the experiment, the instrument, and its interfaces with the payload platform.
- In the frame of the Scout mission AO, we have participated in the preparation of a proposal for a radio science experiment called RISE (Rotation and Interior Structure Experiment) on the Geophysical/Environmental Monitoring and Sounding (GEMS) mission.
- Radio science documents have been written for three missions: an AURORA orbiter to Mars, the MEMO orbiter that will be proposed to the ESA Cosmic Vision, and the mission ARCHIMEDES proposed by the Mars Society.
- Participation to a proposal for a Jupiter-Europa mission for ESA's Cosmic Vision.
- An extended invited review paper on the rotation of the terrestrial planets has been written for the Elsevier reference work 'Treatise on Geophysics'. The paper is accepted and will be published in 2007.

C.2.2.2. 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) estimates of 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 allows obtaining the orbit of the spacecraft, the global gravity field, and its time variations.
- A database 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 database has been written.
- We have developed interfaces to transform Mars Express and Odyssey 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. GINS software has also been adapted to take into account ancillary spacecraft data, such as the orientation of the S/C and its components, epoch and magnitude of the desaturation maneuvers, and navigation orbits.
- Accurate MEX orbits have been determined with a precision of about 45 meters, better than the ESOC navigation error of about 200 meters.
- Observed Doppler shifts are now routinely transformed into 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.

- Numerical codes have been written to determine spacecraft orbits around a planet from a given planetary gravity field and gravity variations based on Kaula's analytical developments. This study is used to better understand the current data and to prepare future missions.
- The use of MOLA altimeter data from the MGS spacecraft has been studied to determine Mars' rotation variations. In particular, altimeter data at ground track crossing points can be used to improve the S/C orbit. In a simulation study, we demonstrated that this method could lead to a better estimate of the rotation rate variations of Mars and to the first direct observation of nutations of Mars.

C.2.2.3. Mars: gravity field, 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 (lower than the previous American missions Mars Global Surveyor and Odyssey), 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. The programs for the analysis of MEX data are now thoroughly tested and MEX data for local gravity have been successfully compared with the Martian global gravity field and published in Geophysical Research Letters.
- Three series of gravity pericenter passes above Tharsis and Olympus, with about 10 useful passes per series, have been analyzed. Because of large variations in data quality among passes, it is not yet possible to give constraints on the crustal and lithospheric structure under Olympus Mons and in the Tharsis area. Further observations are expected in 2007, and we should then be able to derive geophysical constraints.
- New tools have been developed to include variations in the local elastic thickness of the lithosphere in gravity investigations of the lithospheric structure of telluric planets. Equations for the deflection of a spherical thin shell of variable thickness have been derived, and a numerical method of solution of the non-linear system of equations of the fourth order on the sphere has been developed. First results show that the exact solution can deviate significantly from the approximate deflection obtained by patching solutions with constant elastic thickness.

C.2.2.4. Mars: interior structure

- Our numerical code for the interior structure of terrestrial planets has been extended to include a solid inner core, non-elastic properties of the solid parts, and the computation of the complex electromagnetic impedance of the mantle from its thermal structure and composition.
- Based on our models for the interior of Mars, ranges of core sizes, effective mantle viscosities, and crust mean densities and thicknesses have been calculated in agreement with the latest estimates of the moment of inertia factor, mean density, Love number k_2, and global tidal dissipation. The results show that the geodetic data imply a liquid core, a hot mantle, and a core size of about (1700±50) km. A perovskite layer, similar to the Earth's lower mantle, could be possible (Van Thienen et al. 2006).
- From an analysis of seven years of MGS/Odyssey tracking data, we have obtained a degree-two Love number $k_2 = 0.145 \pm 0.003$. This value indicates that Mars has a large liquid core.
- We have investigated the impact of mantle superplumes on the tidal deformations of the Earth and showed that the presence of such large heterogeneities in the mantle significantly perturb the body tides. An application to the effect of Tharsis on the tides of Mars has been initiated.

C.2.2.5. Mars: atmosphere and polar caps

- A paper demonstrating the small atmospheric excitation of the Inner Core Wobble (ICW) of Mars has been published in Astronomy and Astrophysics.
- A study on the possibility to use observations of the length-of-day (LOD) of Mars as a tool to study the core of Mars has been published in Advances in Space Research.
- A paper on the seasonal changes in the polar cap masses and the mean atmospheric pressure variations estimated from recent determinations of the low-degree zonal gravity coefficients of Mars, from CO_2 thickness observations of the High Energy Neutron Detector (HEND) onboard Mars Odyssey, and from general circulation models of the atmosphere has been published in Journal of Geophysical Research.
- Surface displacements due to atmospheric loading have been calculated for a visco-elastic response of the interior. The same approach has been used to study the effect of climate changes on the rotation of Mars on the last 500,000 years. Extreme changes are required for the effect to be observable on a few years time with the present observational precision.
- We have studied the effect of the evolution of the magnetic field of Mars on atmospheric escape and the possibility for liquid water to exist at the surface throughout the history of Mars. A basic climate model based on an energy balance computation has been developed, which takes into account the changing insulation of the Sun. A paper is now in press in a special issue of Space Science Reviews on Mars' habitability.
- In our effort to obtain precise gravity data, we have determined the low-degree seasonal variations of the gravity field from an analysis of seven years of MGS/Odyssey tracking data. These variations are geophysically interesting because they are linked with the CO_2 sublimation and condensation cycle of Mars' atmosphere. The results on the even and odd zonal coefficients are in good agreement with previous studies using a smaller data set and independent data from General Circulation models of the Martian atmosphere and the High Energy Neutron Detector (HEND) instrument on-board Mars Odyssey.
- By including MEX radio science data in the analysis of the low-degree time-variable gravity field of Mars, simulation studies have shown that the solutions for the degree-two and degree-three coefficients of the gravity field can be improved by lowering the contributions of the higher-degree coefficients. However, the errors on the orbit from our analysis with GINS are still too large, most likely due to the non-continuous tracking of MEX (contrary to MGS and ODY), the lack of solar panel orientation information, and possibly erroneous information on desaturation maneuvers. We note that the non-gravitational forces on MEX induce accelerations larger or comparable to the acceleration expected from the time-variable part of gravity.

C.2.2.6. Mars: moons

- A study in which new accurate ephemerides of the Martian moons Phobos and Deimos have been determined (accuracy below 1 km) has been accepted for publication in Astronomy and Astrophysics. These ephemerides have been introduced in GINS to determine the mass of Phobos from radio-tracking data during close encounters of MEX with Phobos. For the close encounter of June 2006 (closest distance of about 450 km), the signal-to-noise ratio was too low to improve Phobos' mass.
- We participated in a study on the origin of the Martian moons with M. Efroimsky (USNO, USA) and P. Gurfil (Technion, Israel). We addressed the low inclination and eccentricity of the Martian moons and demonstrated that the Martian precession and nutation can not significantly decrease the inclination and eccentricity over a billion years. The results are published in Celestial Mechanics and Dynamical astronomy.

C.2.2.7. Mercury: interior structure and libration

- An invited review paper on the interior structure, rotation, and tides of Mercury has been written. We have shown that the joint analysis of expected data of space missions to Mercury on tidal displacements, tidal gravitational variations, librations and obliquity can strongly constrain the core size and composition of Mercury. It may be expected that the concentration of light elements (S) in the core can be estimated with a precision of a few percent and the outer core radius with a precision of some tens of kilometers. These results would have important implications for the formation and evolution of Mercury.
- Interior structure models of Mercury have been developed based on the mass and radius of Mercury and by assuming plausible core compositions and mantle mineralogies. The sensitivity of future geodetic observations of the rotation and tides of Mercury to key parameters of the interior (such as core size and composition) has been studied. This study will serve to specify required observational precisions for the BepiColombo mission to Mercury and to determine the interior structure of Mercury when rotation and tide results become available.
- 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. 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 (in collaboration with Namur, A. Lemaitre, S. D'hoedt).
- In collaboration with S. Peale (UCLA Santa Barbara) and J.-L. Margot (Cornell University), we have shown that planetary perturbations lead to forced librations in longitude with periods on the order of several years and a maximum total amplitude of about 30 arcseconds. We further showed that the measurement of the 88-day libration amplitude for the purposes of determining Mercury's core properties is not compromised by the additional librations, because of the latter's small amplitude and long period.
- For length-of-day (LOD) 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 extended this study 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. The influence of this core dynamics on the librations is found to be well below the observational precision of ground-based RSDI and upcoming space missions to Mercury.

C.2.2.8. Mercury: geodesy experiment simulations

- Repeated photographic measurements of selected target positions on the surface of Mercury are central to the BepiColombo strategy to determine the obliquity and libration in longitude of Mercury. We simulated these measurements in order to estimate the expected libration accuracy as a function of the number of measurements, the number of different targets and their locations on the surface of the planet, and the spacecraft initial conditions. The analysis has been extended to include data from several surface regions on Mercury, to improve the surface illumination model, and to allow for more parameters to be estimated. Observation strategies (timing and position of surface positions to be measured) are developed as a function of spacecraft orbit initial conditions that will optimize the scientific results. The numerical code has been extended to allow similar analyses of other solar system bodies, and first results for the libration of the Galilean satellite Europa have been obtained.

C.2.2.9. 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, but these data do not uniquely determine the mantle mineralogy since they can not precisely discriminate between temperature and composition effects. We have studied the additional use of electromagnetic data to separate temperature and composition. Our results prove that a mantle of pyrolitic composition and associated with an adiabatic temperature is compatible with the whole set of seismic and electromagnetic data that we have considered. The results have been submitted to Journal of Geophysical Research.
- The surface magnetic impedance data have been inverted to estimate the electrical conductivity of the mantle and the thickness of the individual conducting layers. In a more extended inversion, the temperature and the composition of the lower mantle has been inferred from a radial profile of the acoustic wave velocity and data on the mantle density and surface impedance.

C.2.2.10. Natural satellites

- Seismic measurements on the Moon recorded in the seventies by the Apollo missions have been reanalyzed to prepare a future inversion of first arrival times of seismic waves. A selection procedure has been developed to reject arrival times of secondary waves that were erroneously interpreted as first arrival times.
- It has been shown that the core size of the Moon could be determined with a precision of 50km from the polar moments of inertia and the tides if the mantle mineralogy is known.
- A preliminary inversion of Apollo electromagnetic data has been made by using the most recent measurements of the conductivities of the minerals to constrain the temperature and mineralogy of the Moon.
- 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.
- Several lines of evidence suggest that large icy satellites have subsurface ocean beneath an icy shell. The Galilean moon Europa is thought to have a thin icy shell, but its thickness is not well constrained. We have studied a new method to determine the thickness of the icy shell by means of librations (rotation variations). By assuming that the main coupling between the icy shell, the ocean, and the solid interior is the gravitational coupling between the two solid layers, we have shown that the libration amplitude differs by about 10% between models with a thin and thick shell.
- A study showing that the tidal gravitational Love number k_2 of Titan, to be measured by the Cassini spacecraft, is essentially unaffected by the atmospheric tides has been published in Icarus.
- The effect of ice rheology and a possible subsurface ocean on the tides and tidal dissipation of icy satellites has been studied.
- A synthetic representation of our ephemerides of the Galilean moons has been published in Astronomy and Astrophysics.
- Io's orbital acceleration has been determined with the numerical model NOE of the orbital evolution of natural satellites developed at ROB and an extensive set of observations. The resulting tidal dissipation is in agreement with that determined from internal models of Io. A similar study on Europa has been initiated.

- In collaboration with J. Arlot and W. Thuillot (IMCCE, France), a new dynamical model of the Uranian satellites has been published in Astronomy and Astrophysics. This study prepares for the interpretation of the observations over the next three years of the mutual occultations and eclipses of the Uranian satellites, an event which happens every 42 years.
- In collaboration with UCL (Toubeau, Deleersnijder, Remacle), we have studied the effect of dynamic tides in the subsurface ocean of Europa on the total tidal signal.
- By means of a new generation scanning machine, we have started a new analysis of photographic plates of the satellite systems of Mars, Jupiter, and Saturn to obtain an improved data set. These results are expected to lead to better estimates of the tidal dissipation in these systems.

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, MGS and ODY tracking data will be further analyzed in order to constrain (1) the interior structure and mineralogy of Mars, (2) properties of the crust and lithosphere at selected targets, and (3) the CO_2 condensation and sublimation cycle of the atmosphere and polar caps. Additional radio tracking data to the American MER rovers will be taken into account. Moreover, MOLA altimeter data at ground track crossings will be interpreted in terms of rotation variations of Mars. A similar study for simulated data will be performed for Mercury. Analysis of Venus Express radio science (VeRa) data will be started. 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. Our synergetic approach to probe the interior of terrestrial planets by joint geodetic, seismic, and electromagnetic means will also be further pursued and will be applied to the Earth, Mars, and the Moon. In view of the upcoming Mercury missions, the 3:2 resonance and libration of Mercury will be modeled in more detail. Strategies and numerical tools will be developed to determine the interior of Mercury from obliquity and libration measurements. Further attention will be devoted to changes in the atmosphere of Mars and Venus, both on short (seasonal) and long time scales, and to their effects on planetary rotation. Our studies on the interior structure, rotation and tides of terrestrial planets will be extended to the large and intermediate-size rocky and icy natural satellites of the Solar System. We will further develop our Martian climate model in order to asses the habitability of Mars and to understand the atmosphere evolution of Mars. We will continue the negotiations and scientific preparations for the radio-science experiment LaRa to be included on the ExoMars lander, and will participate to the development of new missions to the planets and satellites.

C.2.4. Personnel involved

Scientific staff: M. Beuthe, V. Dehant, J. Duron, Ö. Karatekin, V. Lainey, S. Le Maistre, L. Métivier, G. Pfyffer, P. Rosenblatt, N. Rambaux, A. Rivoldini, V. Robert, T. Van Hoolst (project leader), O. Verhoeven, M. Yseboodt.

Technical staff: S. Raynal, L. Van Camp

C.2.5. Partnerships

List of international partners without grant

- J.P. Barriot, J.C. Marty, G. Balmino (Observatoire Midi Pyrénées, France)
- M. Paetzold (PI MaRS), T. Andert (University of Cologne, Germany)
- A. Mocquet, P. Vacher, C. Sotin, G. Choblet, G. Tobie (University of Nantes, France)
- M. Menvielle (CETP, France)
- O. de Viron, M. Greff-Lefftz, M. Wieczorek, D. Mimoun, P. Lognonné (IPGP, France)
- J.E. Arlot, V. Lainey, V. Robert, A. Vienne, L. Duriez, W. Thuillot (IMCCE, France)

- P. Tarits (Institut Universitaire Européen de la Mer de Plouzane, France)
- E. Bois, F. Deleflie (Observatoire de la Côte d'Azur, France)
- D. Breuer, J. Oberst, F. Sohl, T. Spohn, K. Willner (DLR, Berlin, Germany)
- B. Häusler (Universität der Bundeswehr Institut für Raumfahrttechnik Munich, Germany)
- B. Folkner, S. Asmar, A. Konopliv (JPL, USA)
- G. Neumann (GSFC, USA)
- J. Bell, J. Margot (Cornell Univ., USA)
- S. Peale (UCLA Santa Barbara, USA)
- F. Forget (LMD, France)
- T. Dowling (University of Louisville, USA)
- M. Efroimsky, D. Pascu (USNO, USA)
- P. Gurfil (Technion, Israel Institute of Technology, Israel)
- MEX MaRS team, VEX VeRa team, BC MORE team, BC BELA team, BC SIMBIO-SYS, and the LaRa team

List of national partners without grant

- A. Lemaître, J. Henrard, S. D'Hoedt (Facultés Universitaires de Notre-Dame de la paix, FUNDP)
- E. Deleersnijder, J.F. Remacle, J. Toubeau (UCL)
- E. Javaux (ULg)
- D. Orban, S. Burger (OMP)
- G. Degrez, Y. Detandt (ULB)

Grants/Projects used for this research

- PRODEX8 Project Planet Interior
- MAGE (Mars Geophysical European Network, EU)
- Tournesol project: `Synergie pour la modélisation de l'intérieur des planètes telluriques, basée sur des données séismiques, géodésiques et des sondages électromagnétiques'.
- PNP (France): 'Etude de couplages rotation/noyau des planètes telluriques'.
- EUROPLANET (EU).
- Action 2: J. Duron, A. Rivoldini.
- FNRS: postdoc grant O. Verhoeven, postdoc grant M. Yseboodt.
- FRIA: PhD grant for G. Pfyffer.
- ESA postdoc: N. Rambaux (until 31/3/2006).

Visitors: *about 30*

C.2.6. Publications

C.2.6.1. Publications with peer review

[1] **Beuthe, M., Rosenblatt, P., Dehant, V.,** Barriot, J.-P., Pätzold, M., Häusler, B., **Karatekin, Ö., Le Maistre, S., Van Hoolst, T.**
Assessment of the Martian gravity field at short wavelength with Mars Express
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Acta Astronautica, Vol. 59, pp. 517-523, DOI: 10.1016/j.actaastro.2006.04.006.

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Planet. Space Sci., 54(13-14), pp. 1315-1335, DOI: 10.1026/j.pss.2006.04.032

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[28] Vacher, P., **Verhoeven, O.**
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Planetary and Space Science.

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Astronomy and Astrophysics

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Celestial Mechanics and Dynamical Astronomy

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Astronomy and Astrophysics

[40] Barriot, J.P., **Dehant, V., Yseboodt, M., Duron, J**.
Monitoring Mars Length-of-Day variations from a high altitude circular equatorial orbit
Celestial Mechanics and Dynamical Astronomy

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Etude des couplages rotation-noyau des planètes telluriques
In: Proc. Programme National de Planétologie de l'INSU, 11-13 September 2006, Nancy, France, extended abstract

[48] Rambaux, N., **Van Hoolst, T., Dehant, V.,** Bois, E.,
An accurate theory of Mercury's rotation and centrifugal librations

In: Proc. Programme National de Planétologie de l'INSU, 11-13 September 2006, Nancy, France, extended abstract

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MEMO: Mars Escape and Magnetic Orbiter
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Integrating the motion of satelletites in a consistent relativistic framework: the SCRMI prototype software
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C.2.6.5. Reports, thesis, AO replies, etc

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Response to Cosmic Vision Call, first draft, 51 pages

[53] **Karatekin, Ö., Rosenblatt, P., Dehant, V., Van Hoolst, T.**
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13 pages

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Experiment proposed to the NASA Announcement of Opportunity-Mars Scout 2006 and Mission of Opportunity NNH06ZDA002O, 4 pages

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C.2.7. Scientific outreach

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Geophysical constraints on the internal structure of Mars
MAGE Workshop on 'Mars Dialogue', DLR Berlin, February 8-9, 2006

[2] **Lainey V**.
New exploration of the Martian system by mean of the Martian moon dynamics
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[3] **Karatekin Ö., Van Hoolst T., Dehant V**.
Martian global scale CO_2 exchange from orbital tracking data
Second workshop on 'Mars atmosphere modelling and observations', Granada, February 27 - March 3, 2006

[4] **Dehant V**.
Géodésie de la planète Mars et propriété de l'intérieur de Mars
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[8] **Rivoldini A., Lainey V., Verhoeven O.,** Mocquet A**., Van Hoolst T**.
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Accurate MEX Orbit Calculations from MaRS Radio-Tracking Data: New Constraints on Mars' Time-Variable Gravity Field from a Joint Inversion of MGS and MEX Data
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Mercury libration determination and the link with the interior of the planet
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[11] **Guyennon N., Karatekin Ö., Van Hoolst T.**
Ice rheology and the tidal response of Titan
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Radioscience on orbiter in the frame of the ExoMars program

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Signature of core-mantle coupling on the librations of Mercury
EGU Meeting, Vienna, Austria, April 3-7, 2006

[14] **Métivier L.,** Greff-Lefftz M., Diament M.
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Mars Express Radioscience team meeting, Stanford, USA, 5-6 October, 2006

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Editorial responsibilities

- V. Dehant: referee for JGR
- Ö. Karatekin: referee for JGR and Aerospace Science and Technology
- V. Lainey: referee for Astronomy and Astrophysics
- T. Van Hoolst: referee for JGR, Astronomy and Astrophysics, and Treatise on Geophysics
- O. Verhoeven: referee for JGR

Expertise, Audit

- CCM2 expert board meeting, ESTEC, Noordwijk, The Netherlands: 26-27 /2
- Meeting MoU CNES-ROB, Paris, 18/10

C.2.8. Missions

Assemblies, symposia (number): 33

Commissions, working groups (days): 116

Research visits (days): 86

SECTION 2: Seismology

Introduction:

In the most seismically active regions of the world, earthquake prevention can be based on the experience of recent destructive earthquakes and on seismic hazard assessed by a multidisciplinary methodology combining earthquake seismology, geodesy and earthquake geology. Within many regions at the interior of lithospheric plates, it is more difficult to evaluate the risks associated with the earthquake occurrence, simply because very destructive earthquakes have not been experienced recently and the known seismic activity is not necessarily representative of the future seismic activity due to its limited period of observation.

Nevertheless, during the last decade, authorities in countries like the United States, Canada or France began to take into consideration that earthquake risks can be high in these regions of low seismic activity when they are densely populated and (or) highly industrialized. The recent damaging earthquakes of Liège (Belgium on November 8, 1983 – M_S=4.7) and Roermond (The Netherlands on April 13, 1992 – M_S=5.4) provide examples of the high vulnerability of northwest Europe in the case of small or moderate earthquakes.

Thus, we focus the activities of the section seismology on the necessity to develop methodologies to better understand the seismic activity and the potential for large earthquakes in this part of intraplate Europe but also to evaluate correctly our vulnerability to such earthquakes, which is essential to adopt adequate prevention measures.

The main activities of the section seismology are:

- Monitoring the seismic activity in Belgium and surrounding regions by analysing the data from the Belgian seismic and accelerometric stations, developing and maintaining these networks;
- Developing the ways to provide fast and reliable information to the authorities and the public when an earthquake is felt in Belgium;
- Providing our measured seismic phases for worldwide seismic events and waveform data from specific well-calibrated stations to the international seismological centres;
- Conducting scientific research on earthquake seismology and geology and on 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 is also in charge of the scientific and technical follow-up of the superconducting gravimeter installed in the Membach station and of the ROB absolute gravimeter.

A. Science Theme "Seismic Activity - Methodologies and Regional Studies"

To characterize the seismic activity in a region, it is necessary to collect and analyse reliable information on the active seismogenic zones and faults, and their respective earthquake activity.

The data collected by the Belgian seismic network allow us to evaluate precisely the location, the magnitude and the focal mechanism of present earthquakes in northwest Europe. That information is reliable to identify some active regions, to define locally the deformation associated with earthquake activity, and to provide important data on the propagation of seismic waves at the local and regional scales. The earthquakes recorded by this modern network, progressively implanted since 1985, form a list of events covering a very short time period compared to the duration of the mechanical processes generating large earthquakes on active faults. Thus, to have a correct image of the seismic activity, it is necessary to enlarge our information as far as possible in time and hence to investigate historical documents to retrieve earthquakes of the past. The known earthquake history of our regions begins around 700 AD. Until the XIVth century, the rare historical sources allow the establishment of a list of the strongest earthquakes, but few can be reliably assessed in terms of magnitude and location. Since the XIVth century, the number of different sources (chronicles, annotations, parish registers, account registers,…) has increased significantly. These give more details on local effects and allow more reliable estimation of damage and felt areas of the earthquakes. It is possible to determine their probable epicentral area and also to estimate their magnitude by comparison with recent earthquakes for which the magnitude was instrumentally determined (project: seismicity in northwest Europe).

As most large earthquakes provoke visible surface deformation, it is possible to retrieve the traces of past large earthquakes by their fingerprint in the morphology and the geologic records. This is the objective of paleoseismology. In continental intraplate Europe, active faults remain largely unidentified and the potential for large earthquakes unknown. To evaluate this potential, the problems to solve are different from those encountered in seismically active zones. Identifying active faults is a difficult problem mainly because their morphological expression is often not clear due to the low level of deformation, the climatic regime and the strong anthropic activity. On the other hand, the interpretation of deformations and their dating are very complex due to the long duration of the seismic cycle which produces overlap between tectonic and climatic events. In the framework of the European projects PALEOSIS (1998-2000) and SAFE (2001-2004) and some Belgian research projects, we proposed and developed new approaches in paleoseismology to study active normal faults in intraplate context. The experience of our team is now used in different other projects elsewhere in the world (project: paleoseismology and active faults).

A.1. Project "Seismicity of Northwest Europe"

A.1.1. Objectives

The main objectives of the project are to conduct seismotectonic analysis of the seismic activity in northwest Europe and to provide a reliable catalogue of earthquakes in Belgium and the surrounding regions. As instrumental earthquake data are available only since ~1900, they are not sufficient to obtain a realistic picture of the long-term seismic activity in northwestern Europe. Historical seismicity studies are thus essential to complement instrumental studies.

We investigate also the structure of the lithosphere which is important in the understanding of the seismic activity, but also to provide reliable crustal models for earthquake location.

A.1.2. Progress and results

A.1.2.1. Instrumental seismicity

In 2006, we began a careful examination of the waveforms from the Belgian seismic stations for the period 1995-2005 to retrieve local earthquakes which could have escaped our attention due to the lack of a good procedure during this period. During this year, we covered the period 2002-2005.

In October 2006, we began a new project devoted to a detailed analysis of the seismicity and the seismotectonics of the Ardennes-Eifel region. This study, supported by a doctoral FRIA financial support, will include a synthesis of the present knowledge and a complete study of the earthquakes recorded since 1985. The analysis of the spatial distribution of hypocenters combined with fault plane solutions will indicate active zones where geological, geomorphological and geophysical investigations could be done to evidence possibly active faults, and to study their potential long-term activity

A.1.2.2. Structure of the crust

Presently, the scientific research to improve our knowledge of the structure of the crust in Belgium is conducted in the framework of an IWT-Vlaanderen financial support for a PhD-thesis. The second year of the project was devoted, as was the first year, to evaluate the Moho depth underneath Belgium and the surrounding regions. An important effort has been done first to select from our database well-recorded and located artificial explosions in the southern North Sea and induced earthquakes generated by the mining activity in the Saar basin in Germany.

This research provided already an important result, namely the first real evaluation of the crustal thickness in the Brabant Massif, which is around 31 km in the region of Gent. The study suggested also that the Moho depth in the Ardennes, which is around 32 km near the Variscan front, seems to increase to the southwest to a depth of 34 km.

A.1.2.3. Historical seismicity

During 2006, we collected new data from original sources concerning the past earthquakes in Northwest Europe, more particularly about the seismic events of 1640 (epicenter in Eastern Belgium?), 1692 (epicenter in the Belgian Ardennes), 1755-1762 (epicenters in the Lower Rhine Embayment) and 1828 (epicenter in Hesbaye area). Based on these data, the macroseismic maps of these earthquakes have been improved.

According to newly discovered historical records, new hypotheses are suggested about the epicenter of the 1640 event: maybe this epicenter was not in the Aachen area, but in Eastern Belgium (province of Liège or province of Luxemburg). Other new documents gathered about the major earthquake of 1692, 18 September, led to a new discussion on the perceptibility area of this event.

In the framework of a study, undertaken in cooperation with the Faculté Polytechnique de Mons, on the churches damaged during the 1828 earthquakes, original information has been collected on the earthquake effects in villages of Hesbaye that confirmed the importance of the destructions in that region.

We also continued 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.

A.1.3. Perspective for next years

A.1.3.1. Instrumental seismicity

A strong effort will be done to elaborate a complete and homogeneous catalogue for the period 1985-2007, starting from the installation of the first stations of the modern Belgian seismic network. In the framework of the FRIA financial support FC76908, a detailed investigation of the earthquakes that occurred in the Ardennes-Eifel region during the period 1985-2007 will be done.

A.1.3.2. Structure of the crust

A synthesis of the investigation on the Moho depth in Belgium will be done with the purpose of preparing a publication. The part of the project devoted to the crustal structure by a local seismic tomography over Belgium will be undertaken by testing the different computer programs that will be used on synthetic data, and by collecting the available data that have the required quality.

A.1.3.3. Historical seismicity

The investigation of the 1828 earthquake will be continued by a specific search of information in the archives for the Hesbaye region. The specific research on the damages in the churches of this region will be continued in cooperation with the Faculté Polytechnique of Mons.

The earthquake catalogue will be improved by incorporating the magnitude values evaluated for historical earthquakes for which sufficient information is available.

A.1.4. Personnel involved

Scientific staff: Alexandre Pierre (leader of the historical seismicity studies), Camelbeeck Thierry (coordinator of the whole project and routine seismic monitoring), Collin Fabienne (routine seismic monitoring), Foriers Edouard (search of local earthquakes data from 2002 to 2005), Lecocq Thomas (FRIA-FC76908), Petermans Toon (involved in the source parameters evaluation for the historical earthquakes), Sichien Els (IWT-43205, study on the crustal structure), Van Camp Michel (routine seismic monitoring), Vanneste Kris (routine seismic monitoring)

Technical staff: Castelein Stefaan, Martin Henri, Vandeputte William

A.1.5. Partnerships

List of international partners without grant

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

Grants/Projects used for this research/service

- Ph. D. grant n° 43205 of the Institute for the Promotion of Innovation through Science and Technology in Flanders (IWT-Vlaanderen).
- Ph. D. grant n°FC76908 of the Fonds de la Recherche pour l'Industrie et l'Agriculture (FRIA)

A.2. Project "Paleoseismology and active faults"

A.2.1. Objectives

The research project "Paleoseismology and active faults" aims to develop and apply methodologies to identify active faults and to search for evidence of paleoearthquakes in the geologic record. These studies use a multidisciplinary approach combining investigations of the ground morphology, subsurface geophysical and geological investigations. For this purpose, the section seismology possesses a geodetic total station, the material to study aerial photos and the instruments to conduct resistivity, induced-polarisation and ground-penetrating radar measurements, and also the equipment to realize up to 6 m deep hand-borings.

These investigations extend our knowledge of the seismic cycle of active faults in intracontinental contexts but also plate boundaries, and thus contribute to a better assessment of seismic hazard. Investigations are focused on Belgium and neighboring areas, but also on other regions of the world, Bulgaria, Tanzania, Turkey and China.

Currently, most of the research activities are framed 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).
- 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. 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. The project is seeking to obtain a most extensive chronology of past events along both the North and the East Anatolian Faults. For that purpose, we use 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.
- We are also participating to two other projects on active structures in Turkey and China. We study the long-term evolution of a major strike-slip fault, the North Anatolian Fault by focusing on the Karliova triple junction area, where the eastern extremity of the North Anatolian Fault joins the East Anatolian Fault.

  By studying the active Yakeng and Quilitak anticlines of the southern Tianshan thrust belt of western China, we take advantage of an unusual coincidence of excellent subsurface data and well-preserved geomorphic expression to present evidence for a variety of little-recognized but probably widespread active-tectonic phenomena.

A.2.2. Progress and results

A.2.2.1. "Fault activity in NW Europe and its relationship to seismic activity"

The year 2006 was mostly devoted to the analysis and publication of the paleoseismic results acquired during previous years on the Geleen fault, an active border fault of the Roer Valley graben. We studied the part of this fault that traverses the Belgian Maas River valley. Because surface sediments in this area are relatively young (max. 15000 years), the geomorphic expression of the slowly slipping Geleen fault is subdued compared to the Bree fault scarp further north. Only in a few places a fault scarp, less than 1 m high, can be identified. Combined geophysical and geomorphic reconnaissance in the area indicated that the surface trace of the Geleen fault is quite different from the straight line that is indicated on the existing geological and geomorphic maps. We found evidence of a broad northward bend, offset by a stepover from the Bree fault scarp. It is presently unknown whether this stepover represents a segment boundary, and thus whether the Geleen fault can rupture in two separate, 10-to-15-km long segments, or in a single, 26-km-long segment. According to empirical relationships, the maximal earthquake that can be produced by this fault would be M 6.5 ± 0.3 or M 6.7 ± 0.3, respectively. We excavated two paleoseismic trenches across the southern part of the Geleen fault, one in 2002 and the other in 2005. The data from these trenches are complementary and in good agreement. The 2002 trench records only the most recent large earthquake, the age of which is constrained between ca 3,000 years BP and ca 1,000 years BP by radiocarbon dating and an archeological finding. OSL dating of the oldest sediments indicate that the penultimate faulting event is older than 12,900 ± 3,800 years BP. In the 2005 trench, we found evidence of two paleo-earthquakes, the most recent one corresponding with the event found in the 2002 trench, and an older event. Optically stimulated luminescence (OSL) and radiocarbon dating constrain the age of the first event between 2,400 and 3,700 years BP, and the second event between 14,700 and 18,900 years BP. In both trenches, we paid particular attention to the identification of the event horizon and the colluvium derived from degradation of a fault scarp. This is not straightforward due to soil development, which has obliterated most stratification down to 1 m depth. In the 2005 trench we could vaguely discern a horizon that we interpreted as the ground surface at the time of the last event, covered by structureless sediment thought to represent colluvium. In the 2002 trench we observed a horizon truncating fault splays on one wall and coinciding with a prehistorical, man-made stone pavement on the other wall. To corroborate our field interpretation, we took undisturbed samples from several levels in the trench and analyzed thin sections using a microscope. These thin sections confirmed the presence of an in-situ soil below the supposed event horizon, and of colluvial sediment above, thus supporting our hypothesis. In both trenches, we also found microscopic and macroscopic evidence of soft-sediment deformation below the event horizon, which we attribute to co-seismic liquefaction. In the 2002 trench, we observed a gravel dike, and in the 2005 trench we observed a series of sand dikes extending up to the event horizon. These features are unambiguous evidence for the co-seismic nature of faulting. Although the dating uncertainties are relatively high, it is hard to achieve better precision given the limited stratigraphic resolution. The paleoearthquakes identified in the two trenches in the Maas River valley seem to correlate with the two youngest events found on the Bree fault scarp. Unfortunately, the dating uncertainties do not allow asserting that these events are the same, but the good correlation suggests that this could indeed be the case, which would mean that the 26-km-long Geleen fault defines a single seismic source.

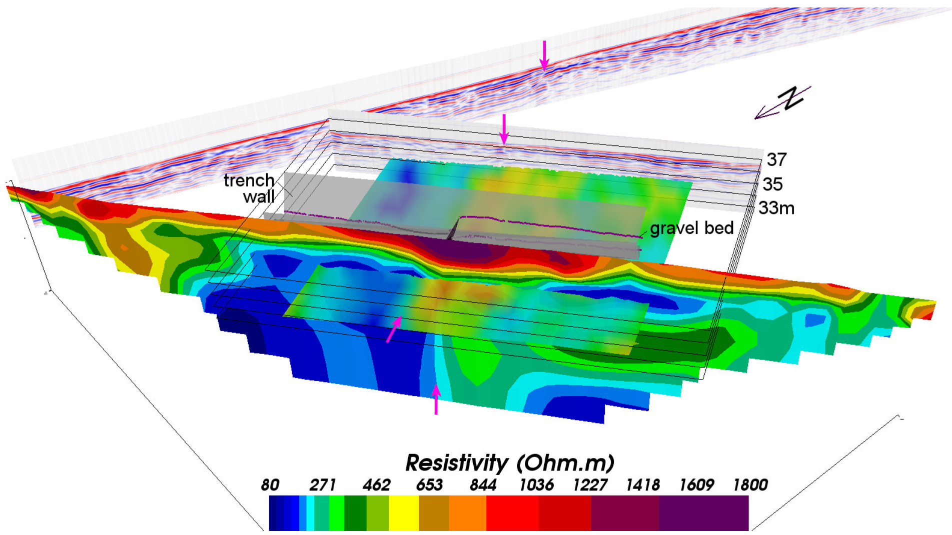


Figure 8: Combined 3-D view of the different geophysical and trenching data at site Rotem 2005. The strong resistivity contrast in the horizontal plane connects a vertical resistivity contrast on the tomography profile in the foreground, with anomalies on the GPR profiles in the back (pink arrows). This anomaly marks the exact position of a normal fault throwing near-surface layers and soils 1 m down to the north-east in the trench.

We also re-examined a study by the University of Amsterdam of a paleoseismic trench on the same Geleen fault in the Netherlands. According to this study, fault displacements at the surface are not caused by large earthquakes, but are the result of delayed-response, post-seismic relaxation creep following only moderate earthquakes not rupturing the Earth's surface. Based on the data presented in this study, and on our own observations, we prove the main paleoseismic argument for this mode of faulting to be wrong. We can explain the observations in a simple and consistent way by applying the basic principles of paleoseismology. We thus obtain an alternative, event-driven faulting history which is remarkably similar to the record of surface-rupturing earthquakes that we obtained further north on the Bree fault scarp. We have started writing a manuscript on these findings.

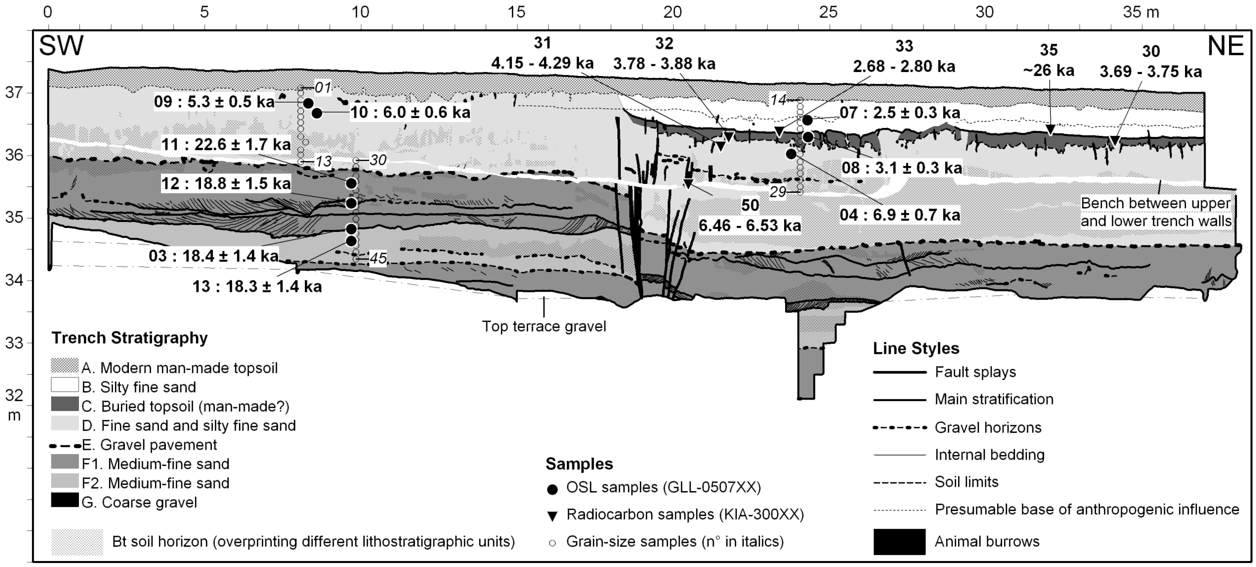


Figure 9: Simplified drawing of the sedimentary succession exposed on the northwestern wall of the 2005 trench near Rotem. The location and age of the radiocarbon and OSL samples is indicated. All ages are expressed as ka before AD 2005.

We also carried out a first reconnaissance survey in the Boulonnais-Artois region in northern France, a region with active faults where the large (M=6) historical earthquake of 1580 took place. We visited the faults for which we have the most indications that they are capable of producing large earthquakes: the Sangatte Fault and the Marqueffles Fault.

Along the Sangatte fault we first visited the outcrop of the falaise between Sangatte and Cap Blanc Nez (Figure 10). The contact between Cretaceous and Pleistocene sediments in the cliff between could be interpreted as either a fault or a paleo-cliff. If it is a paleo-cliff, it could be controlled by a fault, but since cliffs erode rapidly, the controlling fault would be expected to lie seaward (in this case northeastward) of the cliff. The geologic map of Marquise shows just north of Sangatte, at about 2 km from the paleofalaise outcrop, a drop in the isobaths of the top of the Gault Clay Formation (± 99.6 Myr.) from -60 m to the SSW to -180 m to the NNE over a distance of 1 km. The direction of this structure is WNW-ESE. Above this anomaly the outcrop zone of the Lower and Middle Turonian is narrow, indicating steeply inclined layering. SSW of this structure ridges of chalk are shown to outcrop on the beach (possibly indicating recent uplift) and not on the other side. This structure also correlates better with an anomaly on the Bouger gravity map and probably also with the faults interpreted from confidential offshore borehole data by J.-P. Colbeaux (Lille University).

This structure may be a fault that has been drawn on the map as a flexure due to lack of data between boreholes on either side. Unfortunately for us the topography is rather flat above this structure but the sediments and the surface are also young (Flandrien supérieur, Assise de Dunkerque: Holocene-Historic) and possibly there has been no movement since this deposition. This structure on the geologic map is a good candidate for an active fault.

A further 50 km southeast, we visited several sites along the Marqueffles fault. At Marqueffles, this fault has a high (± 70 m) topographic scarp which is probably an old back eroded scarp of the cumulative movements since Cretaceous. The possibly active fault is situated about 700 m toward the northeast in a valley parallel to the fault, if the geologic map is correct. This is a complex site and due to the configuration of the valley it will be difficult to find evidence for active faulting here. At the Souchez River Valley, the orientation of the Marqueffles fault changes from N117E° west to N133E° east of this valley and from a more back-eroded scarp west to a less back-eroded scarp east. The southwestern termination of the

Marqueffles, between Farbus and Fampoux where the topographical scarp is less than 30 m high, looks like a good site for further investigation. The morphology indicates that the termination of the fault consists of two 3 km long right stepping en-echelon faults with stepovers of about 1 km. There was certainly possibility to find sites suitable for geophysical prospecting and possibly trenching. The Marqueffles fault ends against the linear system of valleys which we also interpret as a fault probably dextral strike-slip with reverse or normal (down to the north) component because of the presence of Loess deposits on the scarp as indicated by the geologic map, the reduced scarp height and the open landscape. Arguments for activity of the fault are the proximity to the Biache Saint Vaast site (Colbeaux et al., 1981) and the 02/09/1896, intensity VII earthquake in the region of Arras & Douai (Scarpe valley) and the fresh aspect of the scarp.

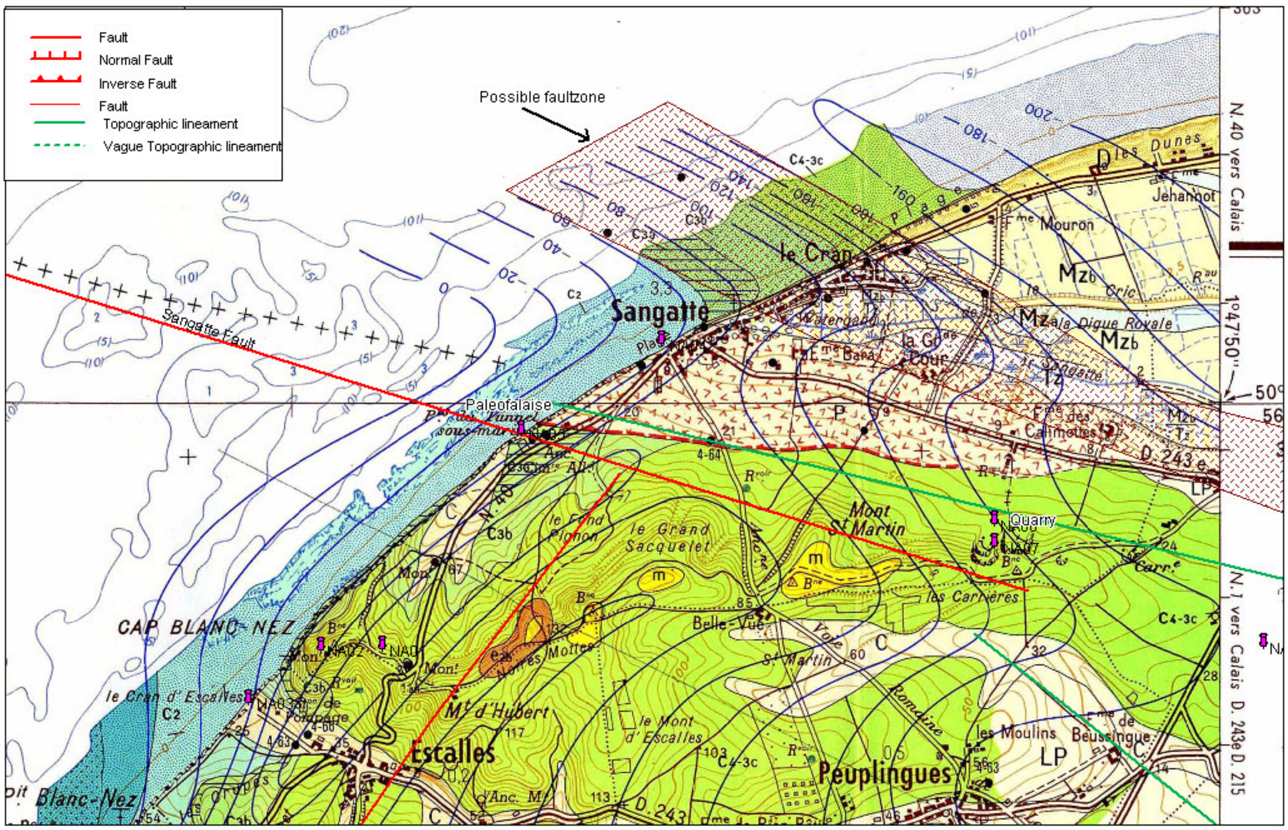


Figure 10: excursion stops (small arrows in violet-colour) around Sangatte indicated on the geologic map of Marquise (BRGM, 2005).

A.2.2.2. "Active faults and past large earthquakes in the Upper Thracian Depression"

The bilateral project with the Bulgarian Academy of Sciences was stalled in 2006, but will be resumed in 2007. We analyzed the data obtained during the geophysical survey in 2005, and described the results in a report. Our final conclusions are not much different from the preliminary conclusions already presented in our annual report of 2005, and will not be repeated here.

In December 2006, we visited our Bulgarian colleagues in Sofia, in order to discuss our contrasting views concerning the interpretation of the paleoseismic trenches near Popovitsa and Kopanite, and to plan the field work to be carried out in 2007.

A.2.2.3. "Understanding the irregularity of seismic cycles: a case study in Turkey"

During the first year of the project, we have been able to select four different key sites, located near lakes that are suitable for paleoseismological trenching studies. Three key sites, Destek, Resadiye and Golova, are located on the North Anatolian Fault System and near lakes Ladik-Boraboy, Zinav-Gollukoy, and Asagitepecik. The last key site is located near lake Hazar on the East Anatolian Fault. We plan to open paleoseismological trenches on each site, and combine these data with sedimentary cores from the nearby lakes in order to set up an extensive database of the chronology of earthquakes over the last 2000 years. The analysis of a first trench opened at Destek (on the eastern part of the central segment of the North Anatolian Fault) during the summer of 2006 has revealed six major earthquakes that can be accurately dated. We have applied, for the first time, direct geophysical measurement of physical properties (magnetic susceptibility measurement) on trench exposures. Finally we have developed collaboration with Dr. J. Pigati, US Geological Survey, Arizona for a more accurate dating of the different sedimentary layers in the trench using gastropods. In that way we may greatly extend the chronology of earthquakes in that area.

We have also taken short gravity cores from seven lakes. We are running a range of analyses (geochemical with an X-ray core scanner, geophysical with a Geotek core scanner, bulk mineralogy, grain size, organic matter, clay mineralogy, …) on these cores in order to characterize the signature in the sediments of the most recent large earthquake that occurred at the sites under study. This signature will then be used to identify the other major past earthquakes of the last few thousand years on long (3-6 meters) cores. We plan to take long cores during the summer of 2007. We are also accurately dating a short core in each lake combining radionuclide data (137Cesium and 210Lead) in collaboration with Rhode Island University.

A.2.2.4. "Evolution of a major strike-slip fault"

The deformation of a volcano that remarkably sits across the North Anatolian Fault eastern termination in Turkey, together with previous studies, put strong constraints on the long-term evolution the fault. We argue that after a first phase of 10 Ma, characterized by a maximum slip rate of about 3 mm/yr, and during which most of the trace was established, the slip rate jumped to 20 mm/yr in on average over the last 2.5 Ma, without substantial increase of the fault length. The transition correlates with a change in the geometry at the junction with the East Anatolian Fault that makes the extrusion process more efficient.

A.2.2.5. "Deformation of the TianShan Mountain Range (China)"

We explore the kinematic mechanisms of active large-scale folding, based on analysis of two adjacent major anticlines in Tianshan (Central Asia) that share an acceleration of shortening rate leading to topographic emergence and folded geomorphic surfaces. Their folding mechanisms are fundamentally different. Yakeng anticline is a gentle pure-shear detachment fold with 1200 m of shortening and a well-constrained history of growth. In contrast, Quilitak anticline is a complex fault-bend fold characterized by discontinuities in uplift rate across active axial surfaces. Quilitak southern topographic front is marked by ~600-700 m high triangular facets that result from active folding of a pediment across an active axial surface. Sections logged across the active ~115 m wide hinge zone show that recent strata provide a bed-by-bed record of fold-scarp growth, which kinematics can be constrained using a finite-width kink-band migration model.

A.2.3. Perspective for next years

In 2007, it is our intention to continue publishing the paleoseismic results obtained during the previous years in the Belgian Maas River valley. We are preparing a manuscript concerning the paleoseismic re-interpretation of a trench across the Geleen fault in the Netherlands, published earlier by the University of Amsterdam. We also want to write a more general paper summarizing all paleoseismic results from the two trenches near Rotem, and building on the more specific papers submitted for publication in 2006.

We also expect to carry out new field work: geomorphic and geophysical site investigations on the Marqueffles and Sangatte faults in the Boulonnais-Artois region in France, and if possible on the Heerlerheide fault in the Roer Valley graben. In the frame of the bilateral project with the Bulgarian Academy of Sciences, we will finalize the interpretation of the Popovitsa and Kopanite trenches and start publishing the results. As the project is resumed in 2007, a new paleoseismic trench will be investigated, either on the Popovitsa fault, or on the eastern extension of Chirpan fault.

The Marie Curie Excellence Team is seeking to obtain a most extensive chronology of past events along both the North and the East Anatolian Faults. In 2007 for the second year of the project, we will:
(1) excavate and conduct paleoseismic investigations in 2-3 trenches at a site at Resadiye selected in 2006 across the studied fault. This will be combined with geomorphic mapping, subsurface geophysics, and geophysical measurements directly on trench walls;
(2) take (3–6 meters) long sedimentary cores from six different lakes selected in 2006. During the same field campaign, we will also acquire high-resolution seismic reflection profiles in each lake to select the best coring sites and to model site response to earthquakes.

A.2.4. Personnel involved

Scientific staff: Vanneste Kris (scientific responsible project "paleoseismology and active faults), Verbeeck Koen, Camelbeeck Thierry (manager project MO/33/011), Hubert-Ferrari Aurélia (project leader EC-Marie Curie Project MEXT-CT-2005-02), Boës Xavier, Fraser Jeffrey, Avsar Ulas

A.2.5. Partnerships

List of international partners without grant

- Geological Institute, Bulgarian Academy of Sciences
- Erhan Altunel, Hatice Kutluk, Eskisehir Osmangazi University, Turkey
- Naime Arslan, Eskisehir Osmangazi University, Turkey
- Moran Bradley, University of Rhode Island, Narragansett, USA
- Namik Cagatay, Istanbul Technical University
- Emin Demirbag, Istanbul Technical University
- James Dolan, U. Southern California, USA
- Neyran Soylu Elif, Samsum Ondokuz Mayis University, Turkey
- Chip Heil, University of Rhode Island, Narragansett, USA
- King John, University of Rhode Island, Narragansett, USA
- Jarg Pettinga, University of Canterbury, New Zealand
- Jeff Pigati, USGS Arizona, USA
- Andy Nicol, Institute of Geological and Nuclear Sciences, New Zealand
- Rolando Armijo, Institut de Physique du Globe de Paris, France
- Geoff. King, Institut de Physique du Globe de Paris, France
- Jérome Van Der Woerd, Institut de Physique du Globe de Strasbourg, France
- Igor Villa, U. of Bern, Switzerland
- John Suppe, Princeton University
- Jean-Pierre Colbeaux (University of Lille and Scientific Council of Natural Parks in the North – Starit of Dover region.
- Michel Sébrier and Françoise Bergerat (University Pierre and Marie Curie, Paris)

List of national partners without grant

- Dr. Dimitri Vandenberghe, Luminescene Laboratory, University of Gent
- Dr. Florias Mees, Laboratory of Mineralogy and Petrology, University of Gent

- Prof. Etienne Paulissen, Physical and Regional Geography Research Group, Katholieke Universiteit Leuven
- Nathalie Fagel, University of Liège
- Prof. Marc de Batist, Ghent University
- Nadine Matielli, ULB
- Prof. Philippe Claeys, VUB
- Prof. Yves Quinif and Sara Vandycke (Faculté Polytechnique de Mons)

Grants/Projects used for this research/service

- Belspo-Action 1 "Fault activity in NW Europe and its relationship to seismic activity" contract MO/33/011
- Marie Curie Excellence Grant (MEXT-CT-2005-02)

B. Science Theme "Present-Day Deformation of the Lithosphere"

The present surface ground movements provide an instantaneous picture of the long-term geodynamical processes inside and at the surface of the Earth. They are a key to understand the possible relationship with the present and recent earthquake activity and the tectonic processes at the geological scale.

In northwest Europe, Quaternary tectonic deformation is identified in the morphology and the geologic record in the subsiding Lower Rhine Embayment and the uplifted Rhenish Massif. Vertical relative movements of 0.05 to 0.1 mm/yr have been identified across the border faults of the Roer Graben. The incision of rivers in the Ardenne and the Eifel mountains, interpreted as a Pleistocene regional uplift, is evaluated to be of the same order of magnitude.

Investigations during the last decades on the glacial isostatic adjustment (GIA) show also the importance of this phenomenon in present-day vertical movements. GIA models predict that Belgium and western Germany are on the subsiding peripheral bulge of the GIA ranging from 55° N to 43°N, at rates up to 2 mm/yr. Thus, evaluating the different components of the present-day vertical movements is important to model their relative impact in terms of rates and wavelengths. Quantifying the GIA appears as fundamental to define a stable reference with the purpose of evaluating other geodynamic movements which should be an order of magnitude less important, even if their wavelength is far shorter, and to monitor changes in mean sea level.

For these reasons, we laid out a profile of absolute gravity (AG) sites across the Belgian Ardenne and the Lower Rhine Embayment, which is repeated biannually since 1999 (project: Evaluation of crustal movements by absolute gravity measurements). 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, we are studying their influence on our measurements at specific sites (project: Hydrological effects in gravity). 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 since 1997. This experiment provides valuable information on superficial crustal deformation in the Belgian Ardenne (project: Rochefort geophysical laboratory).

The slow crustal deformations are also monitored using continuous GPS in Bree and Meeuwen across the western border fault zone of the Roer Graben.

B.1. Project "Evaluation of crustal movements by absolute gravity measurements"

B.1.1. Objectives

To better constrain the present-day crustal deformations, absolute gravity (AG) measurements using the FG5-202 gravimeter have been conducted along a profile twice a year since September 1999. This 140 km long profile includes 8 stations across the Belgian Ardenne and the Roer Graben. The bi-annual rate was chosen to detect problematic stations as fast as possible, to correct for seasonal effects and to improve the signal to noise ratio on the data. During measurement of 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. We also perform AG measurements in Ostend yearly. The Belgian AG data should help constrain vertical deformation in the Ardenne and glacial isostatic adjustment (GIA) models.

Continuous GPS measurements were interrupted in 2003 in Membach; a new station is operational in Jalhay since 2006.

B.1.2. Progress and results

Our analysis of repeated absolute gravity (AG) measurements in Belgium and Germany shows that at all stations except Jülich, there is no detectable gravity variation higher than 2.1 nm s^{-2}, in the best case, and 9.6 nm s^{-2} in the worst case, at the 95% confidence level. This is equivalent to vertical movements of 1.1 and 4.8 mm/yr respectively. Although not yet significant, the observed rates do not contradict the subsidence predicted by glacial isostatic adjustment models (Figure 11) and provide an upper limit on the possible uplift of the Ardennes.

In Jülich, a rate of gravity change of 36.7 nm s^{-2}/year equivalent to 18.4 mm/yr of vertical movement is due to anthropogenic subsidence. These measurements complement other geodetic measurements around the browncoal mining region. This will allow us to get an insight into mass redistribution phenomena related to gradual surface subsidence. The Jülich experience demonstrates that anthropogenic subsidence can reduce or eliminate the possibility of monitoring tectonic deformation in the Graben.

In Ostend, the AG measurements agree with tide gauge data and mean sealevel measurements but disagree with the continuous GPS. In Membach, differences in the rates observed since 1996 and 1999 indicate that long-term environmental effects may influence the inferred trend. This study indicates that, even in difficult conditions, AG measurements repeated once a year can resolve vertical land movements at the scale of a few mm after 5 years.

The observed vertical land movement (VLM), as a function of latitude, is shown in Figure 11 and compared with the GPS observations of Nocquet *et al.* (2005). Although not yet significant, the trends observed along the profile are mostly positive and agree with GIA models. This also provides an upper constraint on the possible uplift of the Ardenne.

Our investigations demonstrate that absolute gravimetry is an appropriate tool to monitor GIA effects, present-day ice mass changes, deformations at plate boundaries or subsidence in river deltas, provided the instruments are carefully maintained. The seasonal variations do not influence the trend significantly if campaigns are repeated during the same season, but can provide insights into ongoing hydrological processes. In Membach, differences in the rates observed since 1996 and 1999 indicate that long term environmental effects may influence the inferred trend. Thus, it will be necessary to observe over longer periods before interpreting the GPS and AG data in terms of tectonic rates of deformation and hence produce convincing arguments in favor of one (or more) of the hypotheses concerning the origin of the crustal movement: are the present deformations linked to active faults in the Ardenne and/or bordering the Roer Graben, to the possible Eifel Plume (Ritter *et al.*, 2001; 2006), or to the Fennoscandian GIA?

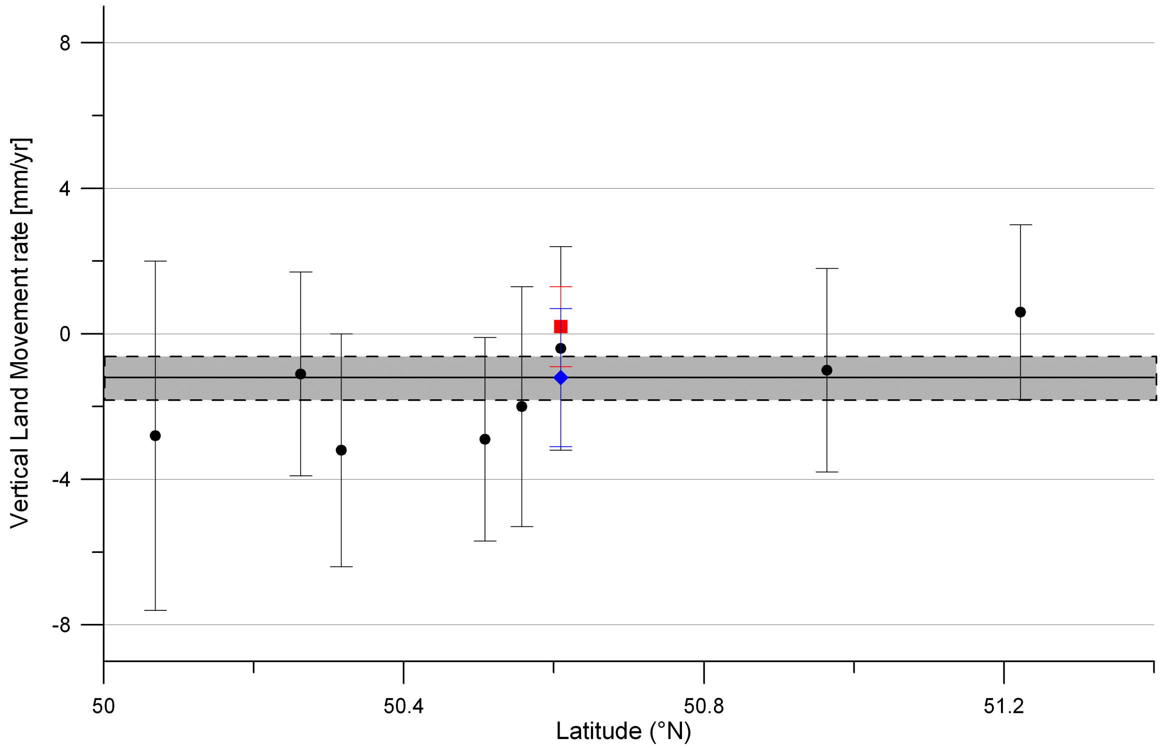


Figure 11: Vertical velocities as a function of latitude, observed by the repeated Absolute Gravity measurements at all stations except Jülich, assuming a gradient of -2 nm/s²/mm. For Membach, the velocity is based on all the measurements since 1996 (red square), since 1999 (blue diamond) and on the 2 AG measurements/yr performed since 1999 (black circle). The GIA subsidence rate of 1.2 ± 0.6 mm/yr (Nocquet et al., 2005) is given by the black and the dashed lines (for the error bars at the 2σ level).

B.1.3. Perspective for next years

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

Considering that Belgium is influenced by the Glacial Isostatic Adjustment, The ROB has proposed to the Nordic Geodetic Commission (NKG) to take its AG measurements in Belgium into account to constrain the deformations along the post glacial rebound (PGR) peripheral bulge. In this framework the new NEOgLID (North European Observations of gravity for Land and Ice Deformation, Van Camp & Strykowski, 2006) project aims at putting together the AG campaigns undertaken in north-western Europe. This should include our time series but also, for example, the AG values observed in the United Kingdom at three stations since 1995 and in Fennoscandia at about 30 stations since 2003. This project has received a warm welcome and as a consequence, during the latest General Meeting of the Nordic Geodetic Commission (Copenhagen 2006-06-02, http://www.nkg.fi/RESOLU_06_sess_fin.pdf (resolution #1)) it was officially decided *to encourage cooperation with groups making repeated AG measurements not only in the uplift area, but also in the peripheral area*.

In collaboration with J.-P. Boy (Ecole et Observatoire des Sciences de la Terre, Strasbourg) and S.D.P. Williams (Proudman Oceanographic Laboratory), we plan to further investigate the gravitational influence of the storm surges in the North Sea on the deformation of the continental plateau. Using the data from the superconducting gravimeter of Membach we participated in a first investigation published in Fratepietro et al., GRL, 2006.

B.1.4. Personnel involved

Scientific staff: Van Camp Michel (project leader), Camelbeeck Thierry

Technical staff: Hendrickx Marc, Castelein Stefaan

B.1.5. Partnership

- Prof. H.-G. Scherneck (Onsala Space Observatory), Dr. G. Strykowski (The Danish National Space Center), and the Working Group for Geodynamics of the Nordic Geodetic Commission;
- Laboratoire de Géodésie et Géomatique, Le Mans : Dr. J. Nicolas;
- Géosciences Azur, Sophia Antipolis : Dr J.-M. Nocquet;
- Université de Luxembourg : Prof. O. Francis, Dr T. van Dam ;
- Proudman Oceanographic Laboratory : Dr. S.D.P. Williams, Prof. T. Baker;
- Dr L. Timmen, O. Gitlein (University of Hannover);
- Dr M. Amalvict, J.-P. Boy, J. Hinderer (EOST, Strasbourg);
- Dr O. de Viron (IPGP, Paris).

B.2. Project “Hydrological Effects on Gravity”

B.2.1. Objectives

This project aims at a better understanding of ground-water variation effects on gravity measurements performed at the Membach, Jülich and Rochefort stations.

B.2.2. Progress and results

In Membach:

We have continued investigating the hydrological processes and their influence on gravity at the underground Membach station, where absolute (AG) and superconducting (SG) gravity measurements have been performed since 1996. We confirmed the ability of our model to correct seasonal variations and to study the interannual variability (Figure 12).

We also collaborate with Bruno Meurers (University of Vienna) to investigate gravitational influences of short variations due to barometric changes. A rainfall admittance model was applied on the Vienna and Membach (SG) data. We demonstrated the possibility to improve the signal to noise ratio of gravity time series by correcting for local hydrological effects. Short-term atmospheric events associated with heavy rain induce step-like gravity signals that deteriorate the frequency spectrum. Based on 4D modeling constrained by high temporal resolution rain gauge data, rainfall admittances for Vienna and Membach were calculated. This allowed routine correction for Newtonian rain water effects, which reduces the standard deviation of residuals after tidal parameter adjustment by 10%. It also improved the correction of steps of instrumental origin when they coincide with step-like water mass signals. For long-period constituents and proper interpretation of long-term gravity changes hydrogeological investigations like those by Van Camp et al. (JGR, 2006) should be performed, because discharge processes like run-off, infiltration and evapotranspiration must be controlled by hydrogeological measurements.

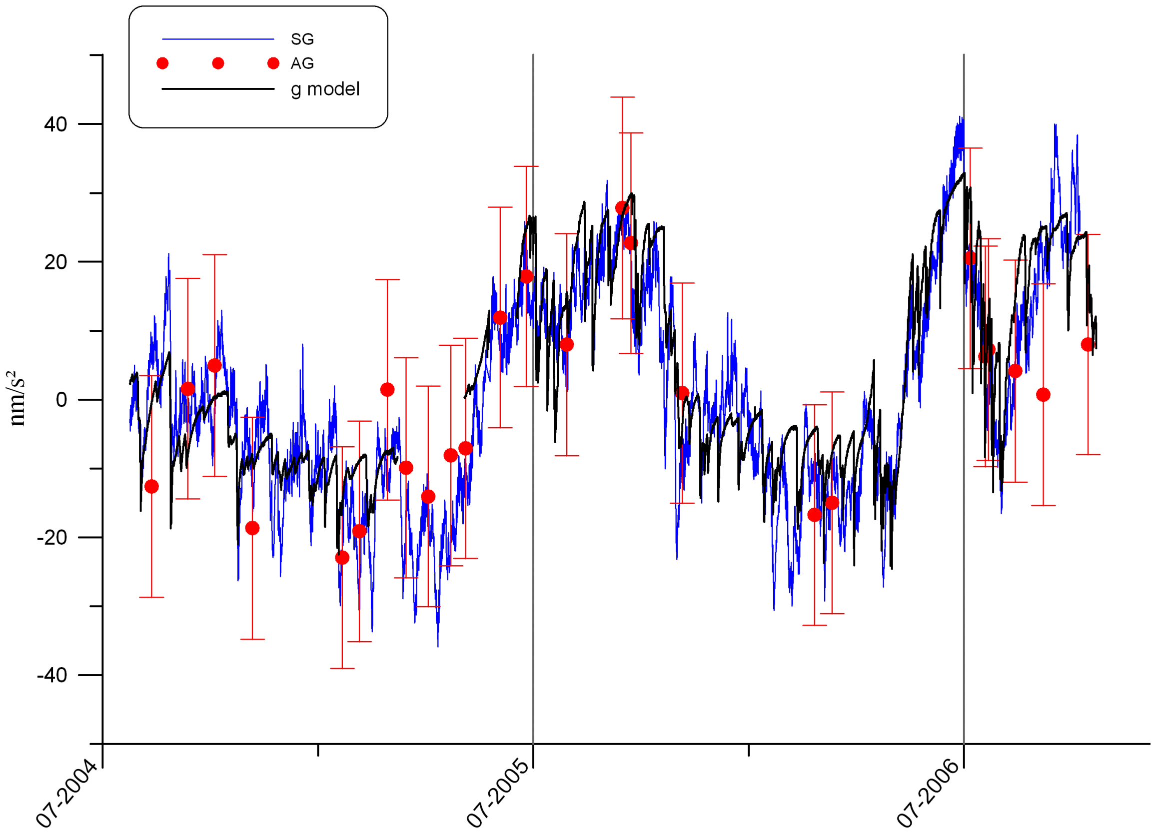


Figure 12: Observed and modelled gravity variations at the Membach station. Model is based on water content provided by the soil moisture probes installed above the station.

In Jülich:

At the Jülich site the seasonal variations are mostly caused by changes in the shallow unconfined aquifer. We took the data from wells recording around the station, modelled the gravity effect, and evaluated the porosity that best reduces the seasonal variations. We found a porosity of 22%. The seasonal variations, as well as a step-like function in fall 2003, are smoothed out.

In Rochefort:

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

The main inputs of the Rochefort cave are swallow holes of the Lomme River. The river is canalized and the karst system is partly disconnected from the hydraulic system. However, in strong flood conditions, the water spills over the dyke and sinks into the most important swallow hole, the Nou Maulin, connecting to the cave network. Therefore, the man-made canalization prevents progressive recharge of the karst conduits, suddenly filled up during flash floods. This induces very fast rises of the water table in the caves, causing fast gravitational effects that can be investigated using precise gravimetric methods. The absolute gravimeter FG5-202 was installed on the ground surface above the cave, from 20 December 2005 to 20 March 2006. On 15 February and 8 March, the Lomme River spilled over its dyke and sank into the Nou Maulin. Meanwhile, gravity increased by 50 and 90 nm s^{-2} in February and March, respectively. A first conclusion is that during these sudden floods, the pores and fine fissures were poorly connected with the enlarged fractures, cave, and conduits. This moderate gravity variation suggests either a weaker porosity or that only filling of the cave and conduits was responsible for the observed gravitational effect.

B.2.3. Perspective for next years

- In Membach: the model illustrated in Figure 11 is especially good at removing long-term variations. We must continue the efforts undertaken with B. Meurers and M. Vanclooster to better understand the short-term variations, which are season-dependant. On the other hand, we were the first to provide SG time series reliably corrected based on comprehensive local hydrogeological investigations. Remaining variations are partly due to atmospheric influences that are not completely removed using the 1D model. Using the corrected time series we have undertaken collaboration with the University of Hannover to apply and test 3D atmospheric models on the corrected Membach time series. We also collaborate with the EOST (Strasbourg). Such a work has already been done at other locations but the improvement was partly masked by the uncorrected hydrological effects, which should not be the case in Membach anymore.
- In Rochefort: to investigate recharge and discharge processes as a function of the degree of saturation in the karst, monitoring the outlet of the whole system (spring of Eprave), and performing geophysical investigation, are being considered to assess the dynamics. In particular, the influence of soil moisture variation in the unsaturated epikarst, as well as the vertical heterogeneity of the saturated zone, also is questionable. After solving numerous technical problems that affected the 2006 investigations, to better investigate flow dynamics, new gravity measurements will be performed during the winter 2007. This study also benefit from measurements of environmental probes and extensometers installed in the cave to monitor deformations induced by tectonics and hydrology.

B.2.4. Personnel involved

Scientific staff: Van Camp Michel

B.2.5. Partnerships

- Dr. L. Timmen and O. Gitlein (University of Hannover)
- Prof. F. Boulvain, Prof. A. Dassargues (ULg/KUL)
- Prof. M. Vanclooster (UCL)
- Prof. B. Meurers (University of Vienna)
- Dr T. van Dam (ECGS, Luxemburg)
- Prof. Y. Quinif, Dr O. Kaufman (FPMS Mons)
- 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)
- EOST, Strasbourg: Dr M. Amalvict, Dr J.-P. Boy, Dr J. Hinderer and Dr P. Gegout
- BGI, France: Prof. R. Biancale.

B.3. Project “Rochefort Geophysical Laboratory”

B.3.1. Objectives

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. The project aims to monitor the present tectonic activity in the cave by the development and the maintenance of a geophysical laboratory since 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..

B.3.2. Progress and results

The instruments installed in the Rochefort laboratory have been maintained and continued to work efficiently.

A preliminary analyses of the two extensometers installed in January 1998 across the Fontaine-Bagdad fault suggests that extensometer 1 indicate a continuous relative slip rate of 0.02 – 0.03 mm/yr, whereas extensometer 2 do not show any significative movement (Figure 13).

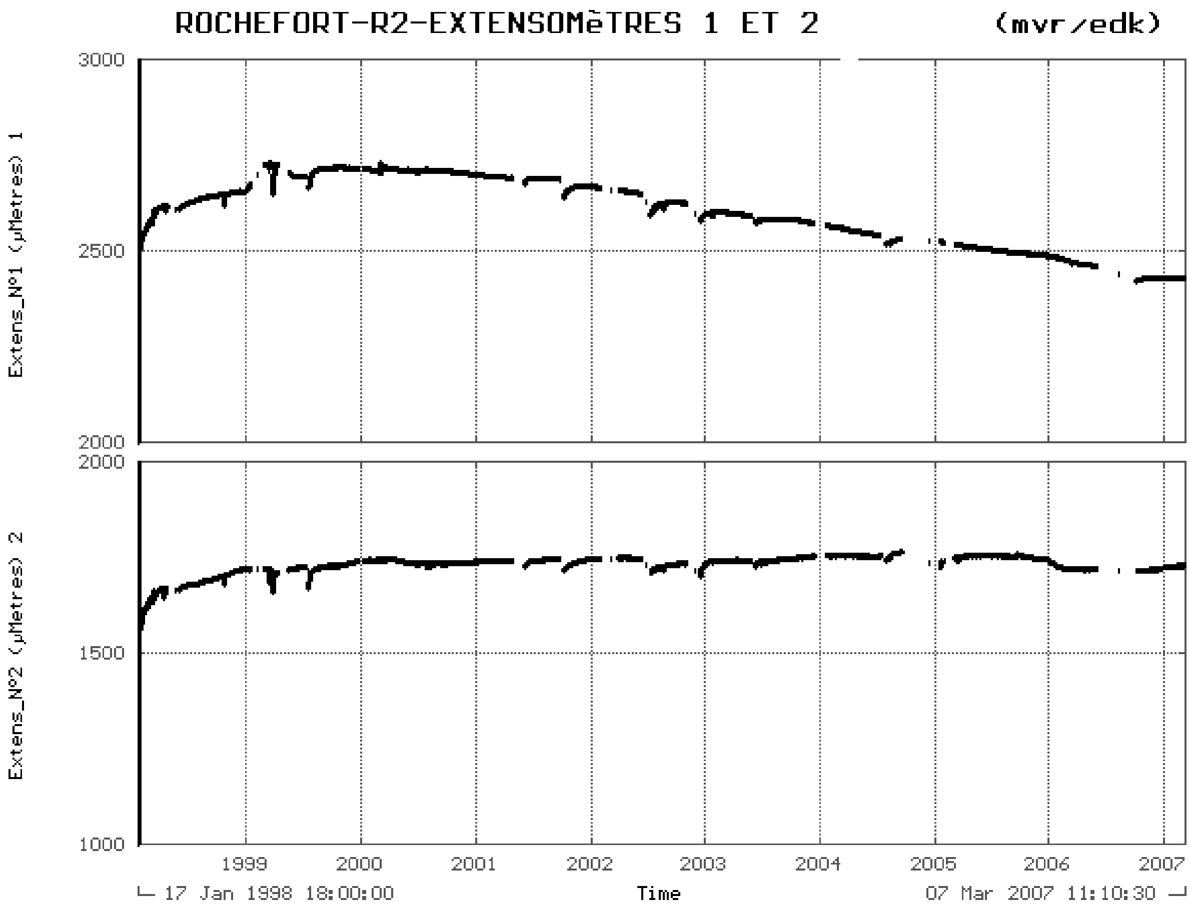


Figure 13: Measurements of the extensometers 1 and 2 across the Fontaine-Bagdad fault in the Rochefort cave.

We began also an analysis of the water table level influence on the elastic deformation measured by the extensometers in the cave with the purpose of furnishing information on the mechanical behaviour of the subsurface rocks in karstic regions and establishing the possible relationship with the long-term slip on the different faults identified in the Rchefort cave.

B.3.3. Perspective for next years

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

A synthesis and the interpretation of the measurements collected since 1998 in the caves will be realized

B.3.4. Personnel involved

Scientific staff: Camelbeeck Thierry, Van Ruymbeke Michel

Technical staff: de Kerkhove Eric

B.3.5. Partnerships

- Prof. Yves Quinif (Faculté Polytechnique de Mons)

C. Science Theme “Seismic Hazards and Risks”

To provide the decision makers (engineers, urban planners,…) with usable information to prevent the worst consequences of future earthquakes, scientists introduced the concept of seismic hazard of a region or a site. It defines the characteristics of the strong ground motions to consider in the design of buildings, taking into account their lifetime and their societal importance (private house, public administration, hospital, school, power plant,…).

Adequate preventive action requires studying the vulnerability of the buildings. It defines their sensitivity to the strong ground motions caused by eartrhquakes. The vulnerability concept includes the importance of the buildings in terms of costs, but also in terms of unsubstantial value or threat to human lives. The seismic risk, linked to the impact on buildings, defines the damage costs of a future earthquake in a given construction. The stakes concern also the impact in terms of human lives, number of injuries, economical costs due to the activity interruption or perturbation, social costs of homeless,…

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

C.1. Project “Site Effects”

C.1.1. Objectives

Many studies demonstrate that the seismic response of a site is largely dependent on the local geological conditions. The purpose of this project is to develop and integrate different methodologies, which allow estimating site effects from ambient noise records and numerical simulation. It aims to develop techniques to be specifically used in urban areas. By integrating the procedures into databases, it will improve strongly the seismic hazard studies conducted at the ROB and the expertise of the ROB for the increasing external requests in the field of seismic hazard assessment.

C.1.2. Progress and results

This year, we have further elaborated the methodologies to constrain site effects and we have applied these methodologies to the Brussels-Capital Region. We conducted ambient noise measurements at 161 sites in the region of Brussels to better constrain the resonance frequency of the subsoil. The resonance frequency is highly dependent on the thickness of the unconsolidated sediments and varies from more than 1.5 Hz in the south of Brussels, where the Paleozoic rock is almost outcropping in the Senne Valley, to 1.0 - 1.5 Hz in the centre of Brussels along the Senne Valley, to less than 1.0 Hz at the more elevated areas and the north of Brussels (Figure 14). For the processing of the ambient noise data, we created a stand-alone program in python language with a user-friendly interface, which replaced the older Matlab version.

The 1-D numerical simulations using the transfer functions of the unconsolidated subsoil, provide us reliable amplitude values for the resonance frequencies and their harmonics. These calculations were done every 100 meter for an area of 22 km² (multi-layer model) and every 200 meter for an area of 224 km² (1-layer model). If the parameters for the modeling are well-known (i.e. the geologic model with isohypse values, shear wave velocities, damping and density), the resolution of the resonance frequencies after interpolation is better than these obtained from the ambient noise measurements. For calculating the shear wave velocity for each unconsolidated layer separately, which were not available for the area of Brussels, we developped a new formula based on the measurements of vertical effective stress and cone pressures of CPT’s (Cone Penetration Test), which are abundant in Brussels. Damping values were calculated by using the spectral slope method applied on data recorded at the Uccle seismic station by a surface and a borehole seismometer. Until now, for three local or regional seismic events powerful enough, we determined a quality factor Q around 9.

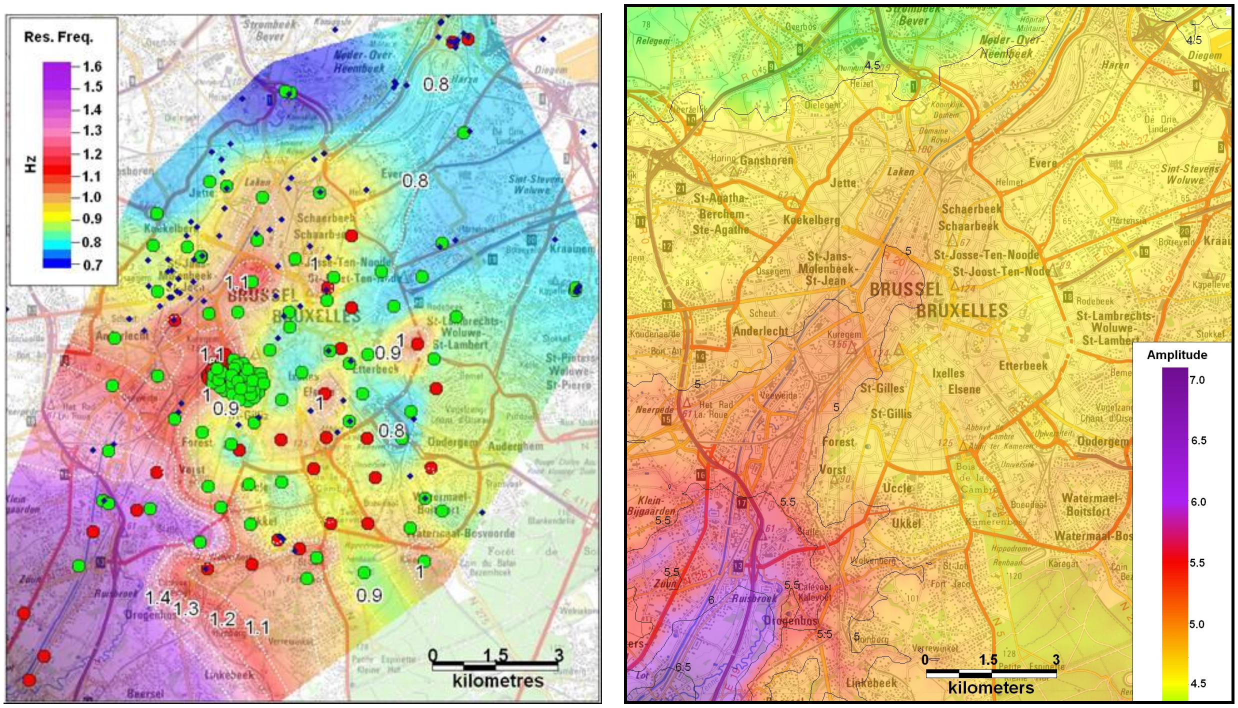


Figure 14 Left: Interpolation of the resonance frequency of the ambient noise measurements in the Brussels-Capital Area. The green dots represent the measurements where the quality was good, while the red dots indicate a medium quality. Right: Interpolation of the amplitude values of the first mode of the calculated transfer functions for the 1-layer model.

In order to improve the handling and processing of the parameters for thousands of gridpoints, we made different databases in Excel and programmed several macros to automatically import and further calculate the necessary parameters and export it again to text files. For the 1-D numerical simulation, two models were used, a 1-layer model, which considers the unconsolidated sediments as one layer above the hard rock, and a multi-layer, which accounts for every geological layer above the hard rock and varies in the Brussels area from 4 to 11 layers. The two models give similar results, concerning the resonance frequency, but regarding the amplitude values, the multi-layer model gives slightly higher values. In general, the peak amplitude for the resonance frequency varies between 4.5 and 6.5 with higher amplitudes associated with higher resonance frequencies (see Figure 14). If the spectral characteristics of the earthquake signal and the 1D-transfer functions of the subsoil are in good agreement, we can expect important site effects.

A similar study was also conducted for a smaller area in and around the city of Ath. This area was interesting for site effect evaluation because during the 1938 Oudenaarde earthquake (M = 5.0) only one specific part of the city has suffered more damage (collapse of chimneys). Preliminary results alleged that the resonance frequency of the damaged houses and the first peak of the transfer function of the subsoil in that area, are in the same order, giving rise to greater site effects.

Finally, a new database in Excel of all the geological boreholes of Flanders with lithological description was created by importing data from the public internet database of the Databank Ondergrond Vlaanderen (DOV). Therefore, a procedure has been designed a to extract the geologic information from PDF files into a Excel database. This database is very useful for future seismic hazard studies including the site-effects in Flanders.

C.1.3. Perspective for next years

In 2006, we improved also the software, running in a Matlab environment, for the numerical simulations in order that the resulting transfer functions are adapted to execute in 2007 some realistic seismic scenarios for the region of Brussels. This will allow us to better constrain the seismic hazard at a local scale by convoluting the calculated transfer functions of the subsoil with synthetic earthquake signals. These signals will be precisely modelled to realistic earthquake scenarios. First, we can model signals by taking into account the expected Peak Ground Acceleration (PGA) on bedrock, which is calculated for Brussels considering the Eurocode 8 code. Secondly, we can also simulate signals considering the earthquake sources and magnitudes of some historical earthquakes, which caused damage in the Brussels area. Thirdly, to have an idea of the worst-case scenarios, we can model signals considering the maximum credible earthquakes in some different seismic zones in and around Belgium. The used methodologies and the experience of this research project can be used for future seismic hazard studies in Belgium.

C.1.4. Personnel involved

Scientific staff: Camelbeeck Thierry, Petermans Toon, Vanneste Kris

Technical staff: Bukasa Baudouin, Castelein Stefaan

C.1.5. Partnerships

Grants/Projects used for this research/service

- Belspo-Action 1 "Seismic hazard – strong ground motions: evaluation of site effects and local seismic hazard in Belgium": M0/33/016

C.2. Project "Seismic Hazards and Risks

C.2.1. Objectives

This project concerns the development of methodologies to evaluate seismic hazard, the vulnerability of existing buildings and the seismic risks in Belgium. The part of the project devoted to vulnerability and seismic risks is done in cooperation with the Department of Architecture of the Polytechnic Faculty of Mons.

C.2.2. Progress and results

We began to investigate methodologies to evaluate seismic risks in Belgium. The available information to assess the vulnerability of existing buildings are the archives of the Royal Observatory of Belgium on the known earthquakes that struck our regions and the files concerning the 1983 Liège earthquake in the archives of the Calamity Funds.

Based on specific searches in these archives, we undertook three specific studies.

C.2.2.1. "Damage evaluation and site effects in the city of Ath during the 1938 earthquake"

The first was dedicated to compare the predicted and the real damage level in the city of Ath during the 11 June 1938 earthquake, and to evaluate their possible relationship with the local geological conditions. At the time of the earthquake, the head of police of the city reported precisely the addresses of the damaged houses and their kind of damage. Thus, it has been possible to map them precisely. Ath is a little city with a small historical center. It is crossed by the river "La Dendre", which is now channeled. It was about 16 km far from the epicenter of the 1938 earthquake. An intensity of VI is assessed according to the Europan Macroseismic scale (EMS-98). For the assessment of the vulnerability, a probabilistic method for rapid diagnosis has been proposed, based on an **i**ndex of **v**ulnerability including 11 parameters of major influence for building resistance (structural system, configuration of front elevation …). These parameters have been adapted from the Italian expertise to the Belgian buildings. Even if some changes to the houses have been made since 1938, we used photographs as a visual support for the vulnerability assessment. When there were uncertainties, we used ranges of vulnerability indexes instead of precise values. Globally, the vulnerability index of the damaged houses is medium and homogeneously distributed. The predicted damage rate is based on the evaluated vulnerability index and the intensity of the earthquake in Ath. The "real" damage rate is calculated according to the prices of the construction market in 2005. The reconstruction costs and the transposition of actual prices to prices in 1938 are based on the index of the Belgian Association of Experts. These evaluations indicate that the real damages are less important than the modelled ones. These differences can be explained in different ways and are probably due to a combination of these explanations (lack of information in the report of the police captain, problem related to the use of intensity…). This observation points also to the need of a better calibration of the method to evaluate vulnerability and the need to develop specific vulnerability curves for the Belgian buildings.

The damage map shows a concentration of damages in the north-west of the historical center. We investigated the possibility that this is caused by the local geological conditions. Thus, we measured the soil resonance frequency in the city by the H/V method. The first results point out that the corner frequencies of the soil in the historical centre and in the damaged areas are different. In the centre, the frequency is about 2 Hz while in the damaged areas, it is about 4 Hz, which should be close to the resonance frequency of 2 to 3 stories buildings typical in Ath.

C.2.2.2. "Repair costs in Hainaut of the 1938 and 1949 earthquakes"

Our second study is a first attempt to evaluate the current repair costs induced by earthquakes in Belgium. We investigated the costs in the Hainaut province of the 11 June 1938 (M=5.0) and 3 April 1949 Havré (M=4.5) earthquakes using a synthesis of the available data in the archives of the Royal Observatory of Belgium. These data include the official macroseismic inquiries by the Royal Observatory of Belgium, letters of victims and scientific reports at the time of the earthquakes by the Royal Observatory. The costs refer to material damages and do not include for instance economic or human life losses. Moreover the evaluation is based on identified cases and do not represent the whole cost. So the costs mentioned are really an underestimation. The repair costs have been assessed for each kind of damage. Unit prices have been applied for each task necessary for a particular repair, according to the « bordereau de prix unitaires » published by ASPEN (architects and engineers office). The quantities have been determined for a common room of the beginning of the 20th century (L.450 x l.350 x h.280 cm). The global costs for repairs in the Hainaut rise to € 3.740.000 for the 1938 earthquake and to 3.590.000 € for the 1949 earthquake. These costs can be appropriated on all the damages houses (the exact number is not known). For an earthquake similar to that of 1938, the repair costs for one building are around € 2100. For an earthquake similar to the 1949 earthquake, the repair costs for one building are around € 2560. We have to remember that these are minimal amounts: the information we have is incomplete and the stakes (number of buildings, …) are greater today than in the past.

DAMAGES IN HAINAUT	UNIT COST OF REPAIRS (2005)		CASES IDENTIFIED IN 1938	Total costs (2005) for the damages of 1938		CASES IDENTIFIED IN 1949	Total costs (2005) for the damages of 1949
DAMAGED CHIMNEYS (TOTAL)	1.820 €		1789	3.255.980 €		1405	2.557.100 €
DAMAGED ROOFS	620 €		200	124.000 €		46	28.520 €
CASE OF FALLING BRICKS	100 €		60	6.000 €		108	10.800 €
DAMAGED CELLING	390 €		128	49.920 €		512	199.680 €
FISSURED WALLS	1.570 €		168	263.760 €		496	778.720 €

FALLING WALLS	520 €	5	2.600 €	0	- €
OTHERS (breaking of small objects not included)		147		96	
Breaking glasses (veranda,…)	330 €	106	34.980 €	55	18.150 €
		Total	**3.737.240 €**	**Total**	**3.592.970 €**

Table 1: Synthesis of the damages mentioned in the macroseismic surveys and assessment of repair costs in the Hainaut province for the 1938 and 1949 earthquakes.

C.2.2.3. "Relationship between repair costs and damage grade in EMS-98 macroseismic scale"

The third investigation is an attempt to establish a relationship between the repair costs and the damage grade according to the EMS-98 macroseismic scale. The study of about 50 files of the Calamity Fund concerning houses damaged during the 1983 Liège earthquake give us already some information on this relationship. For a damage grade of 2, repair costs vary between € 270 and € 2800, so an average of € 1960. For a damage grade of 3, repair costs vary between € 1820 and € 12800, so an average of € 5950. All these costs, even if they are approximations, show the importance to identify the architectural and engineering factors aggravating the vulnerability of constructions and to react as a consequence. We start to constitute a database based on the folders of the Calamity Fund archives for the 1983 earthquake. Until now, around 80 files were saved. The aim of this investigation is to establish a statistical relationship between the costs related to the damage grade to the different types of buildings in Belgium.

The folders are also very instructive on the way to manage a post seismic expertise.

C.2.3. Perspective for next years

In 2007, investigations concerning the damages to churches caused by the Hesbaye 1828 earthquake will be undertaken in the framework of the master-thesis of a student of the Faculté Polytechnique de Mons. We intend also to develop different methodologies to evaluate seismic hazard.

C.2.4. Personnel involved

Scientific staff: Barszez Anne-Marie, Camelbeeck Thierry, Petermans Toon

Technical staff: Bukasa Baudouin

C.2.5. Partnerships

Grants/Projects used for this research/service

- Belspo-Action 1 "Seismic hazard – strong ground motions: evaluation of site effects and local seismic hazard in Belgium": M0/33/016

D. Operational Projects Supporting 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.

D.1. Project "Seismic and Accelerometric Networks – Gravity Measurements"

D.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, and since 2005, in the IRIS data base.
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 recent objective is to provide also real-time seismic signals from some Belgian stations to the ORFEUS and IRIS centres.

D.1.2. Progress and results

D.1.2.1. "Seismic network"

Due to the good working of our automatic procedures, we were able in 2006 for the first time to assume a careful supervision of the seismic network state with the purpose of detecting as fast as possible the failures and organizing the necessary repairs.

We finished the installation of our new acquisition systems in the stations of Clavier (CLA) and La Chartreuse (LCH), where the arranging works at the station have been finished in May. A new mobile station has also been installed in Maredsous (MRD). To be able to study the influence of site effects in Uccle, we also installed a broad-band station at the ground surface with instrumental characteristics similar to the ones of the seismometer in the borehole. We closed the Heyd station (HEY) near Durbuy. The Quanterra system equipping the Membach station was sent back to the factory for repairing, implying unfortunately that the recordings of the broad-band station were interrupted for a large part of the year.

The broad-band seismometer from PMD-Eentec Company has been installed in the Opitter borehole. It appeared immediately that it was not working properly. Thus, we recovered and opened it. It was filled with water. After contacting the PMD-Eentec company, we sent it back to the company. They admitted their responsibility in the problem and promised us to repair the instrument as soon as possible. We hope to recover it in 2007.

We summarize the working status of the stations of the network for each month of the year 2006 in Table 2. The green cells correspond to periods for which data are available, the red cells to periods where the stations are out of order and the orange cells inform of some failures in the station during this period. In each cell, the number of files retrieved in the station is given. Blue cells at the end of the year 2006 indicate that all the data are not yet recovered.

Table 2: Working status of the stations of the Belgian seismic network in 2006

	J-06	F-06	M-06	A-06	M-06	J-06	J-06	A-06	S-06	O-06	N-06	D-06
BOU	738	765	1337	1082	1006	922	826	821	820	820	829	456
BRQ	747	816	1346	1083	1013	922	1011	826	998	1355	273	
CLA	Before new installation				245	875	823	749	795	821	810	456
CTH	387	726	1343	1083	1013	924	1011	826	997	623		
DOU	710	740	1288	1026	965	908	822	801	799	821	804	456
EBN	721	739	1294	1036	968	906	823	802	799	822	808	456
GES	428	549	1335	1082	787	921	827	656	818	819	829	456
HEY	740	767	1338	1082	214							
HRK	742	767	1338	1082	1011	923	827	816	819	822	829	456
KLB	736	766	1337	1081	1010	920	891	820	819	811	829	456
LCH	Before installation				374	922	825	821	820	821	829	456
LES	455	301	0	0	0	0	0	12	989	1354	763	457
MEMB	44	0	0	0	0	0	0	0	0	0	0	0
MEMS	712	738	1279	1036	567	631	719	419	782	821	809	450
MRD	Before new installation							302	998	1165	847	
RCH	723	989	1217	1075	1044	1155	1191	553	1056	1008	1052	593
ROB	739	763	1338	1081	1010	922	826	820	820	353	828	456
RQR	739	764	1337	1082	1011	923	824	821	513	701	828	456
SKQ	739	763	1336	1082	1011	919	825	800	815	821	828	456
SNF	713	737	1288	981	968	909	808	750	800	821	808	456
STI	559	755	1341	1072	1009	922	827	821	811	821	828	456
UCCS	Before installation						611	692	687	675	700	381
UCCH	587	617	1056	873	843	800	793	696	685	671	701	375
VIA	737	764	1187	1081	1007	920	1005	813	817	768	379	442
WLF	713	737	1284	1035	967	906	1005	804	800	821	809	455
ZEV	744	765	1335	1081	1011	923	828	821	820	821	826	456

We observed in 2006 a lowering of the number of archived data files, 218104 files for 26 seismic stations, compared to 277845 files for 23 stations in 2005. This is explained by a better identification of the files corresponding to real seismic events

The evolution of this annual number of data files and the global computer storage necessary to store them is provided on Figure 15.

The continuous increase of data files since the beginning of the installation of digital stations in 1985 stopped in 2003. This corresponds to the establishment of a good methodology to keep most of the data corresponding to real seismic events. The needed computer storage continues to increase because we keep more data for the strongest teleseismic events (3 hours of recordings for earthquakes with magnitude greater than 7.0).

Our present application server POSEIDON, working since 2002, is not sufficient for our present needs: (a) continuous increase with time of the requested computer storage (Figure 15); (b) increase of the number of users and (c) strengthen computation independence in case of crisis (earthquake). Thus, it will be necessary to replace this application server in 2007.

Since January 1, 2006 the newly developed daily procedure allowed us to also determine source parameters for earthquakes in Belgium and surrounding regions with a delay not exceeding three days and make them accessible directly on our web site. This improvement allowed also the possibility to transmit alert messages to the Euro-Mediterranean Seismological Center (EMSC-CSEM) for earthquakes with magnitude greater than 2.0 in our regions.

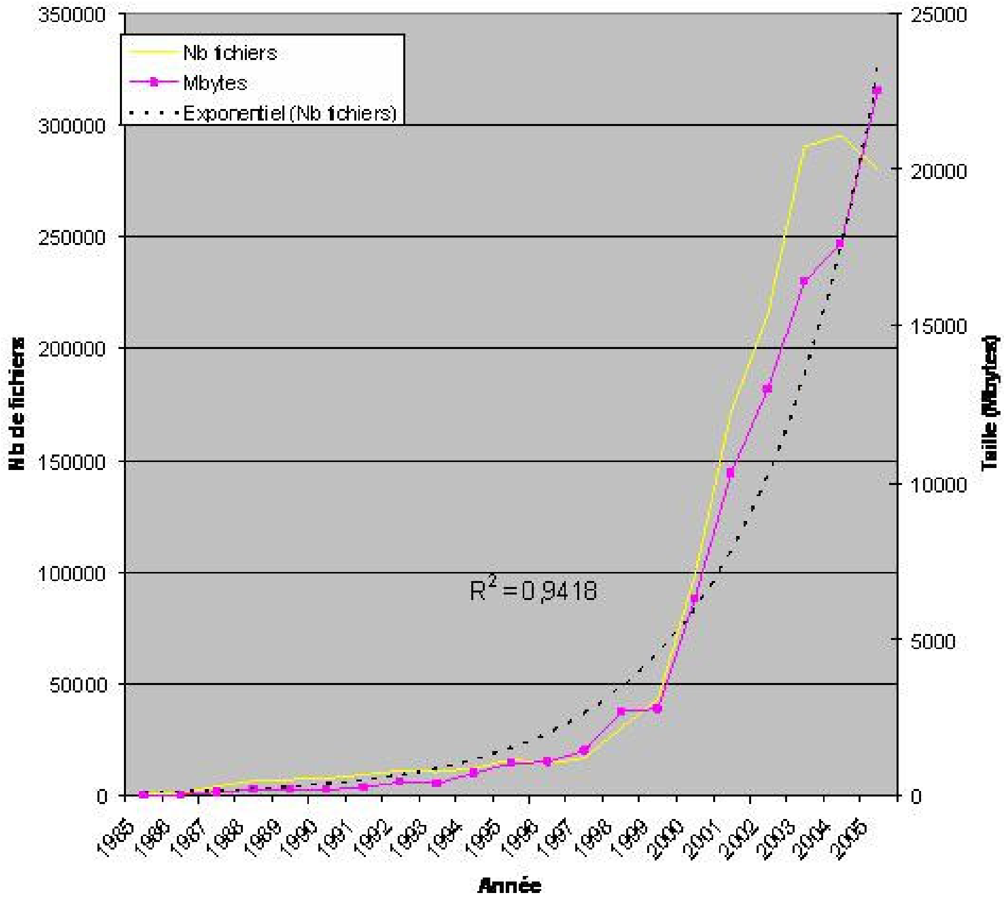


Figure 15: Evolution of the annual number of archived data files and the corresponding computer storage from 1985 to 2005.

D.1.2.2. "Accelerometric network"

The network is working perfectly and checked thoroughly at the ROB once a week (Mol station is checked twice a week). Two additional accelerometers were installed in Ans and Sart-Tilman (replacing old-fashioned Sig instruments).

Unfortunately, the instrument in Sart-Tilman was not working properly. Previously, this accelerometer (ETNA3616) was already sent to the supplier (Kinemetrics) for repairing. After strong discussions, we finally obtained a free standard exchange of the instrument.

In 2006, the batteries of all the stations have been replaced.

D.1.2.3. "Gravity measurements"

Membach station:

Using 9 years of joint and episodic absolute gravity measurements, we investigated in detail the instrumental drift of the superconducting gravimeter in Membach, Belgium. The superconducting gravimeter GWR-C021 time series, similar to other SGs, shows a downward instrumental drift of a few 10 nm/s²/year. Based on a statistical analysis of the difference [SG-AG], we showed that the best drift model of the follows an exponential law. Improper step correction, the thermal levellers used to compensate tilts and room or electronics temperature variations are unlikely to induce the observed drift. Rather, magnetic variations, gas adsorption on the levitating sphere, or helium gas pressure variations around it are most probably the combined causes of the drift. In practice, either linear or exponential drift models are equivalent as long as the record duration does not exceed 10 years. For very long records (longer than 10 years), we demonstrated that the instrumental drift of the SG GWR-C021 is better modeled using an exponential. Otherwise, there is a risk that the mismodeling of the instrumental drift will leave signal that could be wrongly interpreted as a geophysical trend. In addition, the exponential model allows us to more accurately estimate the magnitude of the error due to AG setup noise. This complements the Van Camp et al (JGR 2005) investigations. This study emphasized that the SG instrumental drift can be removed with high precision, provided regular AG measurements are performed. These results were published in Van Camp & Francis, J. Geod., 2006.

Metrology:

The FG5-202 was compared to the Luxemburg FG5-216 on 16-20 January 2006.

Contacts have been carried on with the Service de la Métrologie in order to designate the Observatory as responsible for gravity in Belgium.

Data exchange

We have continued collaboration with IRIS and the GFZ Potsdam to implement SG data on the IRIS database. Careful test of the Q330 datalogger connected to the SG-C021 evidenced a calibration default. Kinemetrics has accepted a free standard exchange.

We also collaborate with the Bureau Gravimetric International (BGI) concerning archiving AG data.

D.1.3. Perspective for next years

D.1.3.1. "Seismic network"

In 2007, we will finalize the project to install a borehole seismic station in Oostende in the "Earth Explorer" site.
In Opitter, a seismometer will be installed at the ground surface to put the station in operation as soon as possible. This seismometer will be replaced by a borehole instrument when it will be available.
We will finalize the works in Membach by installing a reliable uninterruptible power supply to ensure availability of data in case of earthquakes.

D.1.3.2. "Accelerometric network"

The accelerometers must be visited on regular basis for maintenance and/or repair. The Sart-Tilman accelerometric station should be operating again during spring 2007.

D.1.3.3. "Gravity measurements"

Tests could be performed to investigate the actual cause of the SG drift. However, the time required for such an experiment is so long that repeating such an experiment is impracticable. As longer and longer time series of joint AG and SG observations are analyzed, it is hoped that we will be able to determine with absolute certainty whether the long-term drift behaviour of the SG is exponential or linear in character.

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 stations.

We will continue discussions with the Service de la Métrologie 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".

Together with J. Steim we will continue investigating the efficiency of the Q330 datalogger on the S.G., and together with IRIS and GFZ Potsdam, working on the implementation of SG data on the IRIS database.

D.1.4. Personnel involved

Scientific staff: Collin Fabienne, Camelbeeck Thierry, Van Camp Michel

Technical staff: Bukasa Baudouin, Castelein Stefan, De Vos Frédéric, Martin Henri, Rapagnani Giovanni, Vandeputte William

D.1.5. Partnerships

- Prof. Klaus Hinzen (seismic network of the Cologne University)
- Dr. Bernard Dost (Netherlands Seismic network)
- Prof. Michel Granet (French national seismic network)
- Euro-Mediterranean Seismological Centre
- ORFEUS data Center
- Dr Tim Ahern, R. Benson (IRIS, USA)
- B. Ritscheld (GFZ Potsdam)
- Dr. J. Steim (Quanterra, USA)
- Kinemetrics, USA
- Micro-g-LaCoste, USA
- GWR instruments, USA
- Afdeling Waterwegen Kust, Ostende: Ir J. Verstraeten
- Université de Luxembourg (GD Luxembourg) : Prof. O. Francis.
- Bureau International des Poids et Mesures, France
- METAS, Switzerland: Dr. Philippe Richard
- Proudman Oceanographic Laboratory, UK: Dr. S. Williams
- SPF Economie, Division Métrologie.
- BGI, France: Prof. R. Biancale.

D.2. Project "Seismological Database and Website"

D.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 web site. Another objective is to develop a web site containing up to date information on earthquake seismology, on the seismic activity in northwest Europe and on the scientific activities of the section seismology.

D.2.2. Progress and results

In 2006, a strong effort have been made to provide more information in quasi real-time on our web site. Presently, the signals of four seismic stations are on line: Uccle, Membach, Sart-Tilman and Dourbes. This gave the opportunity to the personnel of the section to control at home the seismic activity level and to confirm the occurrence of an earthquake to the Centre de Crise and the media faster than previously.

Since January 2006, we supplied information concerning earthquakes in our regions with a delay not exceeding three days (during the week-ends). We are now able to provide alerts in due time to the Euro-Mediterranean Seismological Center for earthquakes with magnitude greater than 2.0.

An important step is also the integration of our earthquake locations and their uncertainties in maps generated by Google Map.

The press archives of the section seismology concerning the earthquakes of 11 June 1938 and 8 November 1983 have been classified, introduced in the historical database and controlled. This work has been done partially by students engaged temporarily during the summer holidays.

D.2.3. Perspective for next years

In 2007, we will focus the development of the web-site on two aspects: (1) we will develop the software to provide on the real-time seismograms information on the strong earthquakes in the world and in Belgium; (2) an effort will be made to provide more information on our scientific research.

The work of introducing and controlling the data in our historical database will be continued.

D.2.4. Personnel involved

Scientific staff: Camelbeeck Thierry, Collin Fabienne, Vanneste Kris

Technical staff: De Vos Frédéric, Martin Henri, Rapagnani Giovanni

E. Publication List

E.1.1.1. Publications with peer review

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

[2] Similox-Tohon D., Sintubin M., Muchez P., Verhaert G., **Vanneste K.**, Fernandez, M., Vandycke S., Vanhaverbeke H., & Waelkens, M.
The identification of an active fault by a multidisciplinary study at the archaeological site of Sagalassos (SW Turkey)
Tectonophysics, 420 (3-4), p. 371-387

[3] **Van Camp, M.**, Meus P., Quinif Y., Kaufmann O., **van Ruymbeke M.**, Vandiepenbeeck M. and **Camelbeeck T.**
Karst water system investigated by absolute gravimetry
EOS trans. AGU, 87 (30), p298, 2006.

[4] **Van Camp, M.**, M. Vanclooster, O. Crommen, **T. Petermans**, **K. Verbeeck**, B. Meurers, T. van Dam and A. Dassargues
Hydrogeological investigations at the Membach station, Belgium and application to correct long periodic gravity variations,
Journal of Geophysical Research, **111**, B10403, doi.10.1029/2006JB004405, 13pp, 2006.

[5] **Van Camp, M.** and Francis, O.,
Is the instrumental drift of superconducting gravimeters a linear or exponential function of time?,
Journal of Geodesy, doi.10.1007/s00190-006-0110-4, 8pp, 2006.

[6] F. Fratepietro, T. F. Baker, S. D. P. Williams and **Van Camp, M.**,
Ocean loading deformations caused by storm surges on the north-west European shelf,
Geophysical Reseach Letters, **33**, L06317, doi:10.1029/2005GL025475, 4pp 2006.

[7] Nicolas, J., Nocquet, J.-M., **Van Camp, M.**, van Dam, T., 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,
Geophysical Journal International, **167(3)**, 1127-1137, doi:10.1111/j.1365-246X.2006.03205.x, 2006.

E.1.1.2. Publications without peer review

[8] **Alexandre P.,** Demarée G**.**
Climat, séismes et comètes de 1739 à 1762: les chronogrammes d'Egidius Mercier, curé d'Erembodegem.
Ciel et Terre, t. 122, 2006, pp. 98-104.

[9] **Alexandre P.**
Critical Review of the book of R. Gläser, Klimageschichte Mitteleuropas. 1000 Jahre Wetter, Klima, Katastrophen (Darmstadt, 2001).
Revue Belge de Philologie et d'Histoire, t. 84, 2006, pp. 483-484.

[10] Radulov A., **Vanneste K.**, **Verbeeck K.**, Yaneva M., **Petermans T.**, **Camelbeeck T.** & Shanov S.

Paleoearthquake correlation in three trenches along Orizovo – Chirpan active fault segment
Proceedings of the National Conference "Geosciences 2006", Sofia, 2006, Bulgarian Geophysical Society & Bulgarian Geological Society, p. 71-73

[11] Vandenberghe D., **Vanneste K.**, **Verbeeck K.**, Paulissen E., Buylaert J.-P., De Corte F. & Van den haute P.
Late Weichselian and Holocene earthquake events along the Geleen fault in NE Belgium: OSL and 14C age constraints
Proceedings of the Netherlands Centre for Luminescence Dating Symposium, Utrecht, 2006, Series Volume 4, p. 10-11

[12] **Van Camp, M.,** 2006.
The Membach station,
Cahiers du Centre Européen de Géodynamique et de Séismologie, Luxembourg, **26**, pp31-32, ed. by O. Francis and T. van Dam.

[13] **Petermans T.,** Devleeschouwer X., Pouriel F., **Rosset P.**
Mapping the local seismic hazard in the urban area of Brussels, Belgium
In: Proceedings of the 10th IAEG Congress, Nottingham, United Kingdom, 6-10 September 2006, Theme Paper 4 – 424, 12pp

E.1.1.3. Publications in press, submitted

[14] **Vanneste K.**, **Verbeeck K.** & **Petermans T.**
Imaging a low-sliprate, active normal fault in 3D using shallow geophysical methods: the Geleen fault in the Belgian Maas River valley
Submitted to Geophysics

[15] **Vanneste K.**, Mees F. & **Verbeeck K.**
Application of thin-section analysis to identify paleoearthquakes on the "slow", active Geleen fault, Roer Valley graben
Submitted to Tectonophysics Special Issue "Earthquake Geology: methods and applications"

[16] Vandenberghe D**.**, **Vanneste K.**, **Verbeeck K.**, Paulissen E., Buylaert J.-P., De Corte F. & Van den haute P.
Late Weichselian and Holocene earthquake events along the Geleen fault in NE Belgium: OSL age constraints
Submitted to Quaternary International Special Issue "Application of luminescence dating to Quaternary environmental change and tectonic movements"

[17] **Van Camp M.**, Williams S.D.P., Hinzen K.-G. and **Camelbeeck T.**,
Vertical land movements constrained by absolute gravity measurements
submitted to Geophys. J. Int., 2007.

[18] **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.), in press, 2007.

[19] **Camelbeeck, T., Alexandre, P.,** Kusman, D.
Les séismes en Belgique et leurs effets sur le bâti, le patrimoine architectural et l'environnement.
Evaluation et prévention du risque séismique en Wallonie. Numéro spécial d'Aménagement et Urbanisme, revue éditée par la DGTALP du Ministère de la Région Wallonne.

[20] **Alexandre P**., Kusman D., **Petermans T., Camelbeeck T.**
The 18 September 1692 Earthquake in the Northern Part of the Belgian Ardenne – A Review of the Available Historical Data.
Special Volume: Modern Approaches in Historical Seismology: Interdisciplinary studies of past and recent earthquakes, "J. Vogt in-memoriam", Springer-Verlag.

[21] Meurers, B., **Van Camp, M**., and **Petermans, T.**
Correcting gravity time series using rain fall modeling at the Vienna and Membach stations and application to Earth tide analysis,
J. Geod., in press, 2007.

[22] **Hubert-Ferrari A.**, J. Van Der Woerd, G. King, R. Armijo, I. Villa
Long-term evolution of the North Anatolian fault (Turkey)
submitted to Earth and Planetary Sciences Letters.

[23] **Hubert-Ferrari A**., J. Suppe and R. Gonzalez-Mieres
Mechanisms of active folding of the landscape (Southern Tianshan, China)
accepted, to be published in Journal of Geophysical Research

[24] Fagel N., **Boës X**., Loutre M.F.
Climate oscillations evidenced by spectral analysis of Southern Chilean lacustrine sediments: the assessment of ENSO over the last 600 years.
Journal of Paleolimnology, in press.

[25] Sterken M., Verleyen E., Sabbe K., Terryn G. Charlet F., Bertrand S., **Boës X**., Fagel N., De Batist M., Vyverman W.
Late Quaternary climatic changes in Southern Chile, as recorded in a diatom sequence of Lago Puyehue (40°40'S).
Journal of Paleolimnology, in press.

[26] **Boës X**., and Fagel N.
Timing of Late Glacial and Younger Dryas-like event in Southern Chile varved sediments.
Journal of Paleolimnology, in press.

[27] **Boës X**., Sterken M, and Fagel N.
Relationships between South Chilean varved lake sediments, precipitation and ENSO: the last 600 calendar years (Lago Puyehue)
Journal of Paleolimnology, in press.

[28] Fagel N., **Boës X**.
High Resolution clay mineral record in Lake Baikal sediments : the Holocene and Late Glacial transition.
Paleo 3, in press.

[29] De Vleeschouwer, Van Vliët-Lanoé B., Fagel N., Richter T., **Boës X.**
High resolution petrography on resin impregnated Holocene peat columns containing tephras. Principle, applications and perspectives.
Quaternary International, Special issue on Tephrostratigraphy, in press.

E.1.1.4. Reports, thesis, etc

[30] **Vanneste K**. & **Verbeeck K.**
Scientific Report Bulgaria Mission 2005
Report of geophysical reconnaissance survey, carried out in 2005 in the frame of the bilateral project "Active faults and past large earthquakes in the Upper Thracian Depression" (BL/33/B09), 26 pages

[31] **Verbeeck K**. & **Vanneste K.**
Artois field trip 200609
Report of reconnaissance survey in the Boulonnais-Artois region, 7 pages

[32] **Van Camp M.** and Strykowski G.
"NEOgLID" North European Observations of gravity for Land and Ice Deformation
Proposal of scientific cooperation for the Nordic Geodetic Commision, March 2006, 2pp.

[33] **Van Camp, M.**
Report on the OECD Global Science Forum
Workshop on Earthquake Science and its Contribution to Society, 1-2 June 2006, Potsdam, Germany, 7pp.

[34] **Petermans T. and Camelbeeck T.**
Evaluation of site-effects and local seismic hazard in Belgium
Second year report Contract M0/33/016

[35] **Sichien Els, Henriet J.-P., Camelbeeck T.**
Een studie van de structuur van de Belgische korst door locale seismische tomografie.
Aanvraagdossier 2de termijn.

F. Scientific Outreach

Meeting presentations

[1] **Vanneste K**. **Verbeeck K.**, **Camelbeeck T.**, **Petermans T.**, et al.
Paleoseismic investigation of active faults in the Belgian Maas valley
ROB internal communication, Ukkel, 16 May 2006 (Oral presentation by K. Vanneste)

[2] Vandenberghe D., **Vanneste K.**, **Verbeeck K.**, Paulissen E., Buylaert J.-P., De Corte F. & Van den haute P.
Optical dating of aeolian and fluvio-aeolian sands affected by active faulting in the Belgian Maas valley
UK Luminescence and ESR Dating Research Meeting, Liverpool, September 2006 (Poster presentation by D. Vandenberghe)

[3] Vandenberghe D., **Vanneste K.**, **Verbeeck K.**, Paulissen E., Buylaert J.-P., De Corte F. & Van den haute P.
Late Weichselian and Holocene earthquake events along the Geleen fault in NE Belgium: OSL and ^{14}C age constraints
Netherlands Centre for Luminescence Dating Symposium "Luminescence dating - applications and research", Utrecht, October 2006 (Oral presentation by D. Vandenberghe)

[4] Vanclooster, M., A. Dassargues, O. Crommen, T. van Dam, **Van Camp, M.**
Hydrogeological investigations at the Membach station, Belgium and application to correct long periodic gravity variations
AGU Fall meeting, San Francisco, USA, December 11-15, 2006.

[5] Quinif, Y., P. Meus, **M. Van Camp**, O. Kaufmann, **M. van Ruymbeke**, M. Vandiepenbeeck, **T. Camelbeeck**
Karst Water System Investigated by Absolute Gravimetry, AGU Fall meeting
San Francisco, USA, December 11-15, 2006.

[6] **Van Camp M.**, S.D.P. Williams, K.-G. Hinzen, **T. Camelbeeck**
Intraplate Deformations Measured using an Absolute Gravimeter Across the Ardenne and the Roer Graben (North-western Europe)

AGU Fall meeting (poster), San Francisco, USA, December 11-15, 2006.

[7] J. Nicolas, J.-M. Nocquet, **M. Van Camp**, T. Van Dam, J.-P. Boy, J. Hinderer, P. Gegout, E. Calais, and M. Amalvict
Seasonal effect on Laser, GPS, and Absolute Gravity vertical positioning at the OCA geodetic station Grasse, France
XIII Assembly of Wegener, Nice, France, 4-7 September 2006.

[8] **Van Camp M.**, S.D.P. Williams, and **Camelbeeck, T.**
Tectonic deformations inferred from absolute gravity measurements in Belgium and across the Roer Graben
XIII Assembly of Wegener, Nice, France, 4-7 September 2006.

[9] **Petermans T., Rosset P., Foriers E., Camelbeeck T**.
Evaluation and mapping of local site effects and seismic hazard: case study in Brussels region
Presentation at the "2nd Geologica Belgica meeting", Liège on 7 September 2006

[10] **Rosset P., Petermans T., Camelbeeck T.**
L'aléa sismique local en Belgique
Presentation at the « Colloque evaluation et prevention du risque sismique en Wallonie », Namur on 16-17 October 2006. Proceedings in press

[11] **Petermans T.**, Devleeschouwer X., Pouriel F., **Rosset P.**
Mapping the local seismic hazard in urban area of Brussels
Poster presentation at the "10th IAEG Congress", Nottingham, United Kingdom on 6-10 September 2006

[12] **Van Camp M.**, Vanclooster M., Dassargues A., Crommen O., **Petermans T.**, **Verbeeck K.**, Meurers B., van Dam T.
Hydrology and gravity at the Membach station, Belgium
Geologica Belgica Meeting, 2nd Belgian geological congress, Liège, Belgium, 7-8 September 2006.

[13] **Van Camp M.,** and **Camelbeeck, T.**
Repeated absolute gravity measurements across the Roer Graben to infer tectonic deformation
Nordic Geodetic Commission General Assembly (poster), Copenhagen, Denmark, May 29-June 2, 2006

[14] B. Meurers, and **Van Camp, M.**
Long and short term hydrological effects on gravity in Vienna
Workshop on Analysis of Data from Superconducting Gravimeters and Deformation Observations regarding Geodynamic Signals and Environmental Influences, Jena, March 27 - 31, 2006.

[15] T.F. Baker, F. Fratepietro, S.D.P. Williams, and **Van Camp, M.**
Gravity variations and displacements caused by storm surge loading on the north-west European shelf
Workshop on Analysis of Data from Superconducting Gravimeters and Deformation Observations regarding Geodynamic Signals and Environmental Influences, Jena, March 27 - 31, 2006.

[16] **Van Camp, M.**, and **Camelbeeck, T.**
Tectonic deformations inferred from absolute gravity measurements in Belgium and across the Roer Graben
27th meeting of the Working Group for Geodynamics, Nordic Geodetic Commission, As, Norway, March 14-15, 2006.

[17] J. Suppe, R. Gonzalez-Mieres, and **A. Hubert-Ferrari**
Extracting high resolution records of deformation from well-imaged sections

Geological Society of America Meeting, Oct. 2006.

[18] **Hubert-Ferrari A.**
Surface effects of an actively growing blind fault-bend fold: Examples from the TianShan.
University of Munich, Geophysics Department, May 2006. Invited seminar.

[19] **Boës X**, Loutre M.F., De Batist M., Fagel N.
Inter-hemispheric Comparison of Mid-latitude Lacustrine Archives and High-latitude Ice Cores over the Younger Dryas and the Little Ice Age
European Geosciences Union General Assembly 2006. Vienna, Austria, 2-7 April 2006. Invited lecture.

[20] Fagel N., **Boës X**., Mackay A.
Holocene and Eemian clay records in Lake Baikal: weathering condition recovery during inter-glacials
European Geosciences Union General Assembly 2006.Vienna, Austria, 2-7 April 2006.

[21] Loutre M.F., **Boës X.,** Fagel N., De Batist M.
Climate control of varve thickness in Chilean lacustrine sediments during the last centuries: ENSO oscillations and solar activity
European Geosciences Union General Assembly 2006.Vienna, Austria, 2-7 April 2006

[22] **Boës X.**, Loutre M.F., De Batist M., Fagel N.
Inter-hemispheric Comparison of Mid-latitude Lacustrine Archives and High-latitude Ice Cores over the Younger Dryas and the Little Ice Age
European Geosciences Union General Assembly 2006. Vienna, Austria, 2-7 April 2006

[23] **Boës X**., Sterken M., Loutre M.F, De Batist M., Urrutia R., Fagel N.
Age modeling by layer counting of laminated lake sediments generated by seasonal winds in South America
Second Carlsberg Dating Conference organized by the Copenhagen Ice Core Dating group (NGRIP). Copenhagen, Danemark, 15-17 November 2006

[24] **Boës X**., Hubert Ferrari A., Fagel N.
Assessment of climatic and seismic cycles in southern Chile from high resolution XRF and magnetic susceptibility measurements of historic lake sediments
American Geophysical Union, AGU Fall meting, San Francisco, USA, 11-15 December 2006

[25] **Sichien E**., Henriet J.-P., **Camelbeeck T.**
Estimating crustal thickness in Belgium using Moho-reflected waves
Poster presentation at the 1st ECEES congress, Geneva, Switzerland on 3-8 september 2006

[26] **Verbeeck K., Petermans T.,** Delvaux D., Kervyn F., Macheyeki, A. and Temu E.B.
Electrical tomography on the Kanda Fault in Tanzania
Informal meeting for the Rukwa project at RMCA, Tervuren on 27/11/2006

Editorial responsibilities

- Camelbeeck Thierry: Referee for Geophysical Journal International, Tectonophysics and Natural Hazards
- Hubert-Ferrari Aurélia: Referee for National Science Foundation, Journal of Geophysisical Research, Geophysical Journal International, Geology, Turkish Journal of Earth Sciences, Tectonophysics and Earth and planetary Sciences Letters
- Van Camp Michel: Referee for Geophysical Research Letters (2); Geophysical Journal International (1); Proceedings of the International Symposium of The International Gravity Field Service (2)

Meeting organization

- Camelbeeck Thierry and Anne-Marie Barszez: Co-organizer of the colloquium "Risque sismique en Région wallonne", Namur, 16 et 17 octobre 2006.
- Van Camp Michel: co-chairing the Session #2, WEGENER Conference, Nice, September 4-7, 2006.
- Van Camp Michel: co-chairing and co-organizing the Session G2 "Enhanced Geophysics by Combinations of Independent Geodetic Measurements", AGU Fall Meeting, San Francisco, December 11-15, 2006.

Assemblies, symposia (number):

Boës Xavier (14 days)
Camelbeeck Thierry (8 days)
Petermans Toon (8 days)
Sichien Els (5 days)
Van Camp Michel (8 days)
Verbeeck Koen (2 days)

Commissions, working groups (days):

Petermans Toon (4 days)
Camelbeeck Thierry (18 days)
Van Camp Michel (7 days)
Vanneste Kris (2 days)

Research visits (days):

Avsar Ulas (5 days)
Boës Xavier (6 days)
Camelbeeck Thierry (11 days)
Ferrari-Hubert Aurélia (12 days)
Fraser Jeffrey (5 days)
Van Camp Michel (4 days)
Vanneste Kris (6 days)
Verbeeck Koen (5 days)

Field missions (days):

Alexandre Pierre (7 days)
Avsar Ulas (77 days)
Boës Xavier (62 days)
Camelbeeck Thierry (12 days)
Ferrari-Hubert Aurélia (24 days)
Fraser Jeffrey (77 days)
Petermans Toon (6 days)
Van Camp Michel (75 days)
Vanneste Kris (11 days)
Verbeeck Koen (3 days)

SECTION 3: Gravimetry and Earth Tides

Introduction

Geophysics becomes one of the applied sciences concerned at maximum with the future of humanity. Climatic changes, aquifers monitoring, seismic risks in very crowded area's, civil protection, education in geosciences and the definition of the space and time references justify that research on the gravitational field of the Earth in its static and dynamic aspects remain a priority in an institute like ROB. Also, the evolution of space techniques in this field requires precise ground based monitoring to constrain the gravitational and earth tide models.

A. Science Theme "Gravimetry"

Research in gravimetry 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. Project "Gravity Field Monitoring in Belgium"

A.1.1. Objectives

A convention has been signed in 2006 with the Walloon Region to include the sites of the WALCORS GPS network in the Belgian Gravimetric Base Network BLGBN98.

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.

Several campaigns, performed in spring and in autumn, are scheduled to include the WALCORS points in BLGBN98 and detect eventual seasonal variations. The convention concerns 4 campaigns from September 2006 to April 2008. Reiteration of the network is planned after 5 years.

A.1.2. Progress and results

We finished in 2006 a first campaign. The WALCORS network includes 23 GPS stations, most equipped with special concrete pillars providing good conditions for gravity measurements. The scale of the network is constrained by 6 reference stations: 3 absolute gravity stations and 3 stations taken from BLGBN98. The network was subdivided in 10 loops of 6 stations, so that each station was visited at least twice with two LCR gravimeters. These instruments have a resolution better than 1µgal ($10nms^{-2}$ or $10^{-9}g$). Each station is thus included in 8 gravity connections with neighboring stations. It is thus possible to detect and eliminate anomalous connections. Finally the RMS error on one gravity connection is 15µgal and the adjusted gravity values are known to better than 10µgal. The difference between the nominal and adjusted values at the reference points is lower than 3µgal, so that the network is very well constrained.

A.1.3. Perspective for next years

Two campaigns are scheduled in 2007 and one in 2008. The organization of the campaigns will be very similar to 2006 campaign. First results on the seasonal variability are expected in the middle of this year and overall stability assessment at the end of the convention.

A.1.4. Personnel involved

Scientific staff : Bernard Ducarme, Michel Everaerts

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

Grants used for this research

- CONVENTION DE PRESTATIONS DE SERVICES concernant la calibration gravimétrique du réseau Walcors, passée entre la Région Wallonne et l'Observatoire Royal de Belgique (ORB)

A.1.6. Publications

A.1.6.1. Publications with peer system

None

A.1.6.2. Publications without peer system

None

A.1.6.3. Publications in press, accepted or submitted

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

A.1.7. Missions

Commissions, working groups (days):	B. Ducarme (2) M. Everaerts (11) R. Verbeiren (2)
Field missions (days):	B. Ducarme (4) M. Everaerts (8)

A.2. Project "Gravity Field Monitoring Abroad"

A.2.1. Objectives

In the frame of the long term relationship between the Instituto de Astronomía y Geodesia (CSIC-UCM) and the ROB some gravity measurements have been done in the Graciosa Island situated north of Lanzarote. This island was poorly known in term of its gravimetric anomaly repartition. The aim is to establish a detailed gravity Bouguer map of the area.

A.2.2. Progress and results

The gravity campaign has been carried out in November 2006. The final reduction of the data has been carried out in December.

A.2.3. Perspective for next years

The collaboration with the Spanish partner will be continued. We plan to interpret the observed data with techniques developed at the observatory. This will help to understand the tectonic setting of the Island. The long term perspective is to compute the geoid of the Canary Islands.

A.2.4. Personnel involved

Scientific staff: Michel Everaerts, Michel van Ruymbeke

A.2.5. Partnerships

List of international partners

- Prof. Ricardo Viera from Instituto de Astronomía y Geodesia (CSIC-UCM)IAG

A.2.6. Publications

A.2.6.1. Publications with peer system

None

A.2.6.2. Publications without peer system

None

A.2.6.3. Publications in press, accepted or submitted

None

A.2.7. Missions

Field missions (days): M. Everaerts (7)

A.3. Project "Potential Field Interpretation Techniques"

A.3.1. Objectives

Since many years at the ROB techniques for the interpretation of gravimetric and magnetic potential fields are developed. They are applied to understand the structure of the crust in Belgium and other territories. This year it was planned to do a systematic study of the Brabant massif with the wavelet analysis software implanted and tested in 2005 in the frame of the action 1 project entitled: 'Gravimetric and magnetic Potential field analysis for a better understanding of the structure of the crust in Belgium'.

A.3.2. Progress and results

The objective to analyze the gravimetric and magnetic data on the Brabant massif on profile with the wavelet software implemented in 2005 and compare the result obtained in previous study done with FFT techniques have been achieved. The results have been presented in two international congresses: the International Association for Geodesy (IAG) meeting in Istanbul, Turkey and the International Association for Mathematical Geology (IAMG) meeting in Liege, Belgium.

Software called "Get-worm" from P. Keating from the Geological Survey of Canada, allowing to analyze the tectonic context in 3D from girded data, has been implemented. Some preliminary tests have been done successfully. This will allow us to study faults behavior at depth.

Software called "Rodin", developed at the IPGP, has also been implemented. One of the ways to investigate the depth of bodies is to use the Euler deconvolution technique. But one of the main disadvantages of this method is that the classical Euler deconvolution mixes good and poor solutions. The Rodin software has the enormous advantage to select the reliable solution. This method will be used as a back-up for the other methods

Since 2004 gravimetric measurements have been carried out in Bulgaria. Two destructive earthquakes M = 6.8 and M = 7.0 (Karnik V., 1969) occurred on April 14 and April 18, 1928 near the city of Plovdiv in south Bulgaria. These earthquakes are among the most important that occurred in Europe in the 20th century. The aim was to understand the tectonic setting of the graben. In total 170 points have been measured in a zone of 3150 km². The graben area was well delimited using Bouguer anomaly map. To give more constraints to our interpretation, magnetic measurements have also been carried out in 2005 roughly along a N-S profile. In total 200 km have been measured. Some preliminary results have been presented in the EUG meeting in Vienna.

A.3.3. Perspective for next years

- Continuation on of the work of interpretation of potential field data with emphasis on the Ardennes
- Continuation of the work with our Bulgarian partners
- Publishing the results in scientific journals and presentation in international congress.

A.3.4. Personnel involved

Scientific staff: Michel Everaerts

A.3.5. Partnerships

List of international partners

- Dr Pascal Saillac, EOST Strasbourg
- Dr P Keating, Geological Survey of Canada
- Dr Dimitar Dimitrov, Bulgarian Academy of Sciences

Grants/Projects used for this research/service

- Action 1 project 'Gravimetric and magnetic Potential field analysis for a better understanding of the structure of the crust in Belgium'.

A.3.6. Publications

A.3.6.1. Publications with peer system

None

A.3.6.2. Publications without peer system

None

A.3.6.3. Publications in press, accepted or submitted

None

A.3.7. Scientific outreach

Meeting presentations

[1] **Everaerts M.**, D. Dimitrov, Il. Cholakov, **Th. Camelbeeck**
Gravity and magnetic measurements in the area of Chirpan - Plovdiv 1928 Earthquakes (Bulgaria)
Poster, European Union of Geosciences GA, 3-7 April 2006, Vienna

[2] **Everaerts M.**

Wavelet analysis of Belgian gravimetric networks to recover geometrical characteristics of sources
Oral Presentation, IAG meeting, Istanbul 28/08 – 01/09/2006

[3] **Everaerts M**.
Wavelet analysis on the Brabant massif anomalies
Poster, IAMG meeting 3-8 September, Liege, Belgium

Editorial responsibilities

- M. Everaerts: reviewed 1 paper for Geophysics (gravimetry), 1 paper for African Journal of Geo-sciences (geodesy), 2 papers for IAG proceeding of Istanbul (gravimetry, geodesy)

A.3.8. Missions

Assemblies, symposia (number): M. Everaerts (3)

B. Science Theme “Earth Tides”

Earth tidal research is performed in a widely international context, as the Royal Observatory of Belgium (ROB) is sheltering the International Centre for Earth Tides (ICET), which in turn is responsible of the data base of the Global Geodynamics Project (GGP), a network of more than 20 stations equipped with superconducting gravimeters. These instruments are characterized by a very high sensitivity (10^{-11}g) and a very low instrumental drift, a few parts in 10^{-9}g, and provide new possibilities in tidal gravity studies. Many foreign scientists are thus collaborating with us not only in the framework of GGP but also for studies related to tidal phenomena in general.

B.1. Project “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 we use principally the global network of superconducting gravimeters (SG), known as Global Geodynamics Project (GGP).

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

B.1.2. Progress and results

We prepared actively the Workshop on “Analysis of Data from Superconducting Gravimeters and of Deformation Observations regarding Geodynamic Signals and Environmental Influences”, Jena, March 27-31 2006, and presented 5 communications. Two communications ([1], [2]) presented a comparison of different tidal prediction programs. The main conclusion is that the different codes agree within 0.01% of the tidal range. However the models of the Earth response to the tidal forces disagree at the 0.1% level and the modeling of the ocean tides indirect effects is only precise at the 0.2% level in general. Two communications ([3], [4]) presented a comparison of the two main tidal analysis programs, ETERNA and VAV. It was found that the ETERNA error estimation can be biased in some anomalous conditions. For what concerns the error estimation for the Long Period (LP) waves no program is really correct. We confirmed the interest of global pressure corrections for LP waves determination in SG records. Finally we improved the determination of the gravimetric effect of the ocean Pole tide. Introducing a “self consistent” ocean Pole tide, we have been able to compute a phase difference between the gravimetric effect and the polar motion [5]. An additional communication, presented by S. Panepinto, concerned the application of wavelet filtering to the processing of tidal signals. These communications have been published in the Proceedings of the meeting ([3], [4], [5], [6], [7] and [9]).

During the stay of S. Panepinto we analyzed the tidal gravity results obtained on the Etna and Stromboli volcanoes and prepared a poster for the AGU fall meeting [6].

We helped Hu X.G. to finalize two papers on the application of wavelet filtering to the analysis of LP tides and polar motion effects in SG records [10, 11].

We finalized a paper [12] summarizing the results obtained during the project “Earth Tidal Observations in Siberia” sponsored by the S&T bilateral cooperation agreement between Belgium and Russia (convention BL/33/R09). Preliminary results have already been published [8].

We performed a compilation of the results of 16 high quality tidal gravity stations located around a profile crossing Europe from Brussels to Vienna. The core of this group is formed by 7 GGP stations equipped with modern CT and CD superconducting gravimeters. The advantage of this region compared with the rest of the world is that the ocean tides loading effects are very low and homogeneous in the diurnal band and that we have a concentration of excellent stations. The standard deviation on the tidal parameters of one station, after correction of the ocean loading, is only 0.8%. The calibration is thus homogeneous. The error on the mean is thus close to 0.02%, while the difference between models is close to 0.1%. In such conditions it should be possible to discriminate the different models describing the elastic response of the Earth to tidal forces and to refine our knowledge of the core resonance parameters.

B.1.3. Perspective for next years

In 2007 we shall attend two important meetings: the "First Asia Workshop on superconducting gravimetry" and the XXIV General Assembly of IUGG. We shall prepare different communications.

We shall finalize our study of the European tidal gravity stations along the profile Brussels-Vienna. The evaluation of the core resonance on this data set will be performed by S. Rosat. Much work has already been done to determine the eigenfrequency and quality factor of the diurnal rotational FCN (Free Core Nutation) mode with a non-linear least-squares inversion method (often based on the Levenberg-Maquardt optimization algorithm) using the international GGP (Global Geodynamics Project) network of superconducting gravimeters (SGs); however the non-linear least squares methods lead to under-estimated or even sometimes negative Q-value for the FCN quality factor. Florsch and Hinderer have proposed a Bayesian inversion method to estimate the FCN parameters. A comparative study of the Bayesian and the non-linear least squares approaches of the FCN in SG time-series is in progress.

In collaboration with A.P. Venedikov we shall study the localization and estimation of jumps and other perturbations in the tidal records. This topic is very important for the preprocessing of tidal data. We shall also investigate very long ocean tides series.

In collaboration with Zhou J.C. we prepare a report on the detection of M4 ocean tide loading inside the GGP network.

In the framework of the Working Group "Precise Tidal Predictions" of the Earth Tides Subcommission (IAG), we shall continue the evaluation of the tidal software.

Recently the FCN period has been identified in the residues of the nutation series by Vondrak et al. (2005), but with a period drifting from 435 days and 460 days, while the observed resonance effect is stable. In collaboration with Hu X. G. and V.Dehant we shall try to identify by wavelet filtering the corresponding peak in the diurnal tidal spectrum somewhere between K_1 and ψ_1.

B.1.4. Personnel involved

Scientific staff: Bernard Ducarme, Michel Everaerts, Séverine Rosat

Technical staff: Leslie Vandercoilden

B.1.5. Partnerships

List of international partners without grant

- Prof. A.P. Venedikov, Institute of Geophysics, Bulgarian Academy of Sciences
- Dr. V.Y. Timofeev, Trofimuk Institute of Petroleum Geology and Geophysics SB RAS, Novosibirsk
- Dr. H.P. Sun, Dr. X.G. Hu, Mr. Chen X.D., Mr.Zhou J. C. Institute of Geodesy and Geophysics, Chinese Academy of Sciences, Wuhan
- Dr. F. Greco, Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Catania
- Mr. S. Panepinto, Dipartimento di Chimica e Fisica della Tierra, Universita di Palermo

Grants/Projects used for this research/service

- S&T bilateral cooperation agreement between Belgium and Russia (convention BL/33/R09)

Visitors

- Stefano Panepinto, Dipartimento di Chimica e Fisica della Tierra, Universita di Palermo, 6 months (February-July)
- Zhou Jiang. Cun, Institute of Geodesy and Geophysics, Chinese Academy of Sciences, Wuhan, 6 weeks (November 2-December 19)
- Filippo Greco, Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Catania, 1 week in May

B.1.6. Publications

B.1.6.1. Publications with peer review

[1] **Ducarme B.**, Sun H.-P., XU J.-Q.
Determination of the free core nutation period from tidal gravity observations of the GGP super-con-ducting gravimeter network
Journal of Geodesy, 2006, DOI:10.1007/s00190-006-0098-9

[2] **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 50 years tide gauge record at Cananéia (SP-Brazil) with the VAV tidal analysis program
Dynamic Planet, Cairns, Australia, 22-26 August, 2005. Springer, IAG Symposia, 2006, 130, 453-460

B.1.6.2. Publications without peer review

[3] **Ducarme B.**,
Comparison of some tidal prediction programs and accuracy assessment of tidal gravity prediction
Bull. Inf. Marées Terrestres, 2006, 141, 11175-11184

[4] **Ducarme B.**, XI Qinwen
A problem with the Venus terms in ETERNA software
Bull. Inf. Marées Terrestres, 2006, 141, 11185-11188

[5] **Ducarme B., Vandercoilden L.**, Venedikov A. P.
Estimation of the precision by the tidal analysis programs ETERNA and VAV
Bull. Inf. Marées Terrestres, 2006, 141, 11189-11200

[6] **Ducarme B.**, Neumeyer J., **Vandercoilden L.**, Venedikov A. P.
The analysis of Long Period tides by ETERNA and VAV program with or without 3D pressure correction
Bull. Inf. Marées Terrestres, 2006, 141, 11201-11210

[7] Panepinto S., Greco F., Luzio D., **Ducarme B.**
An overview of wavelet multi-resolution decomposition compared with traditional frequency domain filtering for continuous gravity data denoising
Bull. Inf. Marées Terrestres, 2006, 141, 11213-11223

[8] Timofeev V. Y., Gornov P. Y., Shevchienko B. F., Ardyukov D. G., **Ducarme B., Everaerts M.**, Perestoronin A.N.
Geodynamic study of Sikhote-Alin zone by GPS and Tidal gravity methods (in Russian)
Proc. Symp. "Tectonic, deep structure and minerageny of East Asia", January 24-26 2006, Khabarovsk, Institute of Tectonics and Geophysics, Far East Branch RAS (ISBN 5-7442-1406-2), 70-73.

[9] Chen X. D., **Ducarme B.**, Sun H. P.
Influence of the equilibrium ocean pole tide on the gravity field

Bull. Inf. Marées Terrestres, 2007, 143, 11443-11450

B.1.6.3. Publications in press, submitted

[10] Hu X.-G., Liu L.T., **Ducarme B.**, Hsu H.T., Sun H.P.
Wavelet filter analysis of local atmospheric pressure effects in the long-period tidal bands
Physics Earth Planet. Int., in press

[11] Hu X. G., Liu L. T., **Ducarme B.**, Xu H. J., Sun H. P.
Estimation of the pole tide gravimetric factor at the chandler period through Wavelet filtering
Geoph. J. Int; in press

[12] **Ducarme B.**, Timofeev V. Y., **Everaerts M.**, Gornov P. Y., Parovishnii V. A., **van Ruymbeke M.**
A Trans Siberian tidal gravity profile (TSP) for the validation of tidal gravity loading corrections
Submitted to J. of Geodynamics

B.1.7. Scientific outreach

Meeting presentations

[1] **Ducarme B.**
Comparison of some tidal prediction programs and accuracy assessment of tidal gravity prediction
Workshop on Analysis of Data from Superconducting Gravimeters and of Deformation Observations regarding Geodynamic Signals and Environmental Influences, Jena, March 27-31 2006

[2] **Ducarme B.**, XI Qinwen
A problem with the Venus terms in ETERNA software
Workshop on Analysis of Data from Superconducting Gravimeters and of Deformation Observations regarding Geodynamic Signals and Environmental Influences, Jena, March 27-31 2006

[3] **Ducarme B.**, Vandercoilden L., Venedikov A. P.
Estimation of the precision by the tidal analysis programs ETERNA and VAV
Workshop on Analysis of Data from Superconducting Gravimeters and of Deformation Observations regarding Geodynamic Signals and Environmental Influences, Jena, March 27-31 2006

[4] **Ducarme B.**, Neumeyer J., Vandercoilden L., Venedikov A. P.
The analysis of Long Period tides by ETERNA and VAV program with or without 3D pressure correction
Workshop on Analysis of Data from Superconducting Gravimeters and of Deformation Observations regarding Geodynamic Signals and Environmental Influences, Jena, March 27-31 2006

[5] Chen X. D., **Ducarme B.**, Sun H. P.
Influence of the equilibrium ocean pole tide on the gravity field
Workshop on Analysis of Data from Superconducting Gravimeters and of Deformation Observations regarding Geodynamic Signals and Environmental Influences, Jena, March 27-31 2006

[6] Panepinto S., Greco P., **van Ruymbeke M.**, **Ducarme B.**, Luzio D.
Tidal gravity observations at Mt. Etna and Stromboli: results concerning the modeled and observed tidal factors
Poster, AGU Fall meeting

[7] Timofeev V. Y., Ardyukov D.G., Gornov P.Y, **Ducarme B., Everaerts M.**, Parovishnii V.A., Frid M.
GPS and Tidal Method for Geodynamic Study in Siberia and in Far East of Russia.

The 6-th Workshop of Asia-Pacific Space Geodynamics Program, October 16-18, 2006, ICC Jeju, KOREA

Editorial responsibilities

- **B. Ducarme**: Referee for Journal of Geodesy, Geophysical Journal International, Journal of Geodynamics

B.1.8. Missions

Assemblies, symposia (number):	B. Ducarme (1)
Commissions, working groups (days):	B. Ducarme (4)

B.2. Project "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 database 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 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 2006 we edited the CD-ROM's ETGGP#8 [1] and ETGGP#8a [2] with the data from July 2004 till June 2005.

The "Bulletin d'Information des Marées Terrestres" (BIM) n° 141 and 142 were 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. BIM 143 is already posted on the ICET WEB site.

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 is still a great success as some 20 CD-ROMS with ETERNA software were requested from ICET in 2006.

The ICET WEB site (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 a decimal classification;

- 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 directly or on request from ICET;
- ocean tides loading computations and the predicted tidal gravity parameters for all the tidal gravity stations.

ICET has been contacted by the Department of Technical support (Topographic Service) of the European Nuclear Research Center (CERN) in connection with the installation the Large Hadron Collider (LHC). The persons in charge have to monitor on line the tilt of the ground. As a first step our expertise is required to determine the most appropriate tidal parameters from theoretical models as well as from clinometric measurements. In a second step we should provide software for the real time prediction of the tidal tilts.

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 database, the data processing, the training of young scientists and the welcome of visiting scientists. ICET will also provide his expertise upon request.

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

As B. Ducarme, ICET Director, is retiring at the beginning of 2008, it will be necessary to prepare in 2007 the transfer of the Service.

B.2.4. Personnel involved

Scientific staff: Bernard Ducarme

Technical staff: Leslie Vandercoilden

B.2.5. Partnerships

List of international partners without grant

- D. Crossley, J. Hinderer: Global Geodynamics Project (GGP)
- B. Rittschel: GeoForschungsZentrum Potsdam (D)
- J. Bogusz: Varsaw University of Technology, Institute of Geodesy and Geodetic Astronomy
- J. Boerez: Topographic Service,Technical Support Department, European Center for Nuclear Research (CERN)

Grants used for this research

- Federation of Astronomical and Geophysical Services (FAGS)

Visitors

- Stefano Panepinto, Dipartimento di Chimica e Fisica della Tierra, Universita di Palermo, 6 months (February-July)
- Zhou Jiang. Cun, Institute of Geodesy and Geophysics, Chinese Academy of Sciences, Wuhan, 6 weeks (November 2-December 19)

B.2.6. Publications

B.2.6.1. Publications with peer system

None

B.2.6.2. Publications without peer system

[1] **Ducarme B.**, **Vandercoilden L.**
Global Geodynamics Project: CD-ROM ETGGP #8
International Centre for Earth Tides

[2] **Ducarme B**., **Vandercoilden L.**
Global Geodynamics Project: CD-ROM ETGGP #8A
International Centre for Earth Tides

B.2.7. Scientific outreach

Websites

- **B. Ducarme, L. Vandercoilden**: Website of the International Centre for Earth Tides

C. Science Theme "Geophysical Instrumentation (EDAS project)"

C.1. Project "The EDAS Concept"

C.1.1. Objectives

The expertise of the ROB in term of instrumental gravimetry is unique by the variety of domains concerned. Since the beginning of tidal gravity profiles managed worldwide, we have overcome a lot of metrological problems related to the setting and calibration procedure, environmental induction, standardization of the maintenance, data treatment, etc. Our collaboration with scientists abroad could help to reinforce past expertise with the aim to keep a so long tradition initiated mainly by P. Melchior. Evolution of space techniques requires ground based monitoring to constrain models.

EDAS (European Data Acquisition for Scientists) 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 is developed to be more friendly user and accessible. This work is performed in conjunction with various projects that include the management of risks induced by tectonic, volcanic or seismic processes.

The implementation of the EDAS concept continues to be developed at the ROB which disposes of a laboratory and a series of metrological workstations necessary for the development of prototypes. Various instruments are installed at different locations to qualify systematically different approaches.

Sensors so developed at the ROB have proved to be capable of detecting e.g. 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, we have compared the signature for the different parameters on S1, S2, M1 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.

C.1.2. Progress and results

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

C.1.3. Perspective for next years

The EDAS concept tries to furnish software and hardware including didactic tools adapted to scientists without specific background. The main objective for 2007 consists to complete existing systems to reach more effective user autonomy. Some high tech projects are in priority, under investigation:

- The two way sensor adapted to very high precision bolometer in the few hertz frequency band designed for the solar monitoring satellite "PICARD".

- With the collaboration of Ramon Ortiz (MNCN, Madrid) we continue to solve difficulties existing in the seismic monitoring of volcanoes by adapting the prototype of data logger (picoDAS) for the seismic field stations.
- We continue to develop EDAS applications for the sea level monitoring in Algeria
- Recent observation recorded in Rochefort cave by stain meters suggest to continue to complete actual series of EDAS probes with new series of sensors.

A priority for all these projects requires that we continue to develop a new low-power data logging systems named DigitROB, which will be used with batteries supply only. This new generation of digitizer will simplify human intervention and consequently be more adaptable to different geophysics and geodynamics monitoring system.

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 can 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 continuously carried out. A new version of HiCum method will be tested using the different type of data bank. We will promote the study based on the promising results obtained before.

In 2007, special attention will be paid to the presentation of the EDAS concept to the scientific community. We will participate to the EGU meeting in Vienna with a series of oral presentations and posters covering various aspects of our researches.

C.1.4. Personnel involved

Scientific staff: Michel van Ruymbeke (Laboratory manager). Michel Everaerts (geological interpretation of analysis results), Thierry Camelbeeck, Zhu Ping, Nicoleta Cadicheanu

Technical staff: Francis Renders (builds the mechanical parts of EDAS products), Ir S. Naslin (design of a gravitational balance), J.Ph.Noël (in charge of the EDAS new electronics development), E. de Kerchove (volunteer, manages the EDAS database), G. Tuts (volunteer, manages the database dedicated to the Lanzarote projects and participates in the training of students in learning EDAS and software MGR), Fr.-X. Kremer (volunteer, manages administration and archives), M.-Fr. Seny (volunteer, reading and correcting the scientific papers), Robert DuBois (volunteer, participates to the students training and end-works)

C.1.5. Partnerships

List of international partners without grant

- Wuhan Institute of Seismology a branch institute of the China Earthquakes Administration (previously China Seismology Bureau)
- INCT (Institute National de Cartographie et Télédétection) of Algeria
- Prof. Dorel Zugravescu, Academy of Sciences of Romania
- Dr Olivier Francis, Luxemburg university
- Dr Fr. Beauducel, Dir Obs.Guadeloupe – IPGP (Fr)
- Mr. S. Panepinto, Dipartimento di Chimica e Fisica della Tierra, Universita di Palermo

List of national partners without grant

- Dr Steven Dewitte, Royal Meteorological Institute of Belgium

C.1.6. Publications

C.1.6.1. Publications with peer system

None

C.1.6.2. Publications without peer system

[1] **M. van Ruymbeke**, J. Rasson et **G. Tuts**
La thermométrie géophysique à l'ORB de 1970 à nos jours
Bulletin des sciences géographiques N°18 INCT Algérie pp 2-12

[2] Sun Shao-an, Xiang Ai-min, **Zhu Ping**
Gravity change and its mechanism after the first water impoundment in Three Gorges Project
ACTA SEISMOLOGICA, SINICA , Vol.19 No.5(522-529), Sep, 2006.

C.1.6.3. Publications in press, accepted or submitted

[3] **Zhu Ping, van Ruymbeke M.**, Howard, R. & Li Hui
Tidal and non-tidal influences on seismic activity in China
Journal of Geodesy and Geodynamics (Wuhan 430071, China), Vol.25 N°2, 2005 (in press)

[4] **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

C.1.7. Outreach

Meeting presentations

[1] Baoshan Wang, **Ping Zhu**, Yong Chen, Fenglin Niu, Bin Wang
Continuous in-situ measurement of stress-induced travel time variation with coda interferometry
American Geophysics Union, Fall Meeting, San Francisco, American, 11-15, December, 2006.

C.2. Project "EDAS Monitoring"

The EDAS concept is applied in monitoring of several geophysical processes. A large database contains the records of series of sensors generally dedicated to the observation in a multi parameters approach. The high dynamics of EDAS systems allows detecting very weak signals in well protected environment.

C.2.1. Objectives

The main sites are:

- Uccle with a borehole aquifers monitoring and gravimetric and climatic sensors
- Rochefort in a karstic environment crossed by an active fault
- Lanzarote where a volcanic monitoring is active since 1990
- Gravimeter with EDAS-MVR feed-back maintenance

C.2.2. Progress and results

C.2.2.1. Uccle aquifer

The borehole is equipped with 3 sensors for aquifer monitoring, a gravimeter, 1-micro-barometer and a rain-meter. The data of each sensor are recorded in physical units (Figure 16). Over ten years the water level of level C rose about 60 cm and level B of about 20 cm. Components like pressure, temperature and lux-meter are also monitored since November 1998. An electronic rain-meter is online with Boreholes recorder.

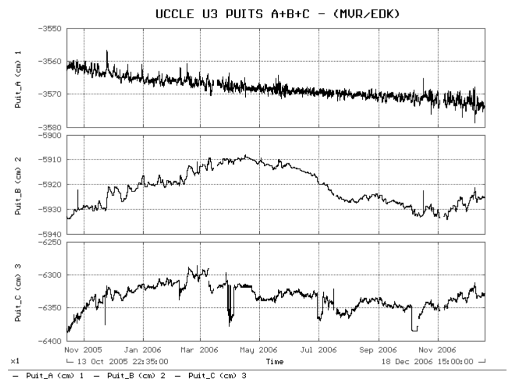


Figure 16: U3 Boreholes PA+PB+PC

C.2.2.2. Rochefort Cave

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 the detection of variation of stress, 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. A series of systems have been set-up to monitor and to test the principles involved where a multi-parameter approach is required for the study of geophysical phenomena. Tidal gravity signal treatment could meet some geodynamics purposes. Seismic aspects are considered from the various monitoring tools. The instrumentation adapted to this work includes extensometers, drop meters, atmospheric pressure, and temperature and light intensity sensors. All of which have been developed at the ROB. A 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).

All data from Rochefort laboratories are registered from 1997 to 2006 in the EDAS database. They furnish opportunities to collaborate with some scientists.

On 2005 March 18, we had an event with heavy rains increasing dramatically the Lomme river level (Figure 17, left).We observed the ground deformation with quartz stain meters N°5 and N°6. Specific analysis at this moment seems to demonstrate a correlation between rain falls and opening just above Lomme, of the fracture where our stain meters are located. Another event occured on January 2007 (Figure 17, right), featuring a great break-up followed by original conditions recovering. Amplitudes are respectively of 6 µm with quartz stain meter N°3 and 1.3 µm with N° 4.

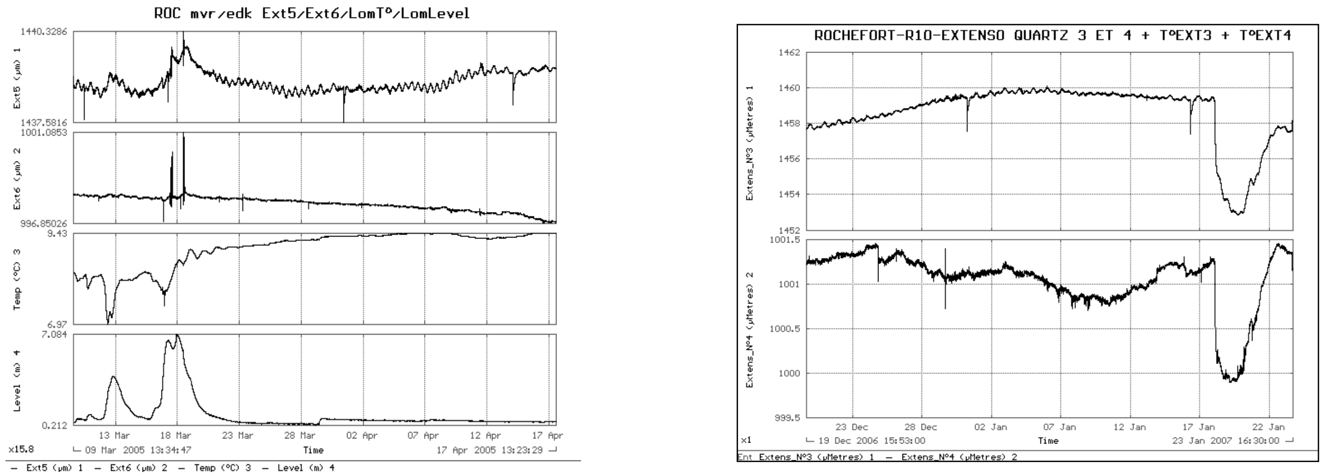


Figure 17: Stainmeters Ext 5&6 with Lomme level (left) and Quartz stain meters Ext5&6 (right)

C.2.2.3. Lanzarote volcanic area

In Lanzarote, we have three observational sites equipped with 42 instruments and 12 EDAS recorders: Cueva de los Verdes (10), Jameos del Agua (12) and Timanfaya (20). A database with series of more than ten years records is completed. This is done in collaboration with Prof Ricardo Vieira (Instituto de Astronomía y Geodesia (CSIC-UCM) and with Prof Ramon Ortiz (Depart.de Volcanologia, Museo Nacional de Ciencias Naturales, Madrid), with the effective support of Casa de los Volcanes belonging the Cabildo Insular of Lanzarote

We contribute heavily to the XIX Curso de Volcanología y Geofísica Volcánica organized on June 1-10, 2006 in the Canaries Archipelago by DEPARTAMENTO DE VOLCANOLOGÍA MUSEO NACIONAL DE CIENCIAS NATURALES (CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS (C.S.I.C.)), with the support of the "Cabildo de Lanzarote. Lectures and practical exercises with EDAS material were given about monitoring ground deformation techniques with the help of, J.Ph. Noël.

C.2.2.4. EDAS Gravimeter feed-back with MVR technology

The Maximum Voltage Retroaction electronics designed at ROB are 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 2006, we modify the two gravimeters in Spain. LC&R 487, 336 & 1006 of ROB were opened for a maintenance check. Dr Michel Everaerts collaborated to the application of these techniques.

In the ROB gravimetric caves, the maintenance of the LaCoste & Romberg gravimeters of the ROB and other institutes.is assumed and we record their signals for control and adjustment.

C.2.3. Perspective for next years

C.2.3.1. Uccle aquifer

The maintenance, collection of records and data treatment of this instrumentation will be kept active. The interest from geologist for aquifer monitoring and very long series of records of this borehole justifies keeping the project in activity as long as necessary.

C.2.3.2. Rochefort Cave

Rochefort lies 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 energy transfer function. If a link between ground deformation and water flow can be established, then water flow monitoring could be a useful tool in the prediction of catastrophic events. More data are suitable to confirm this and the further development of water flow monitoring equipment is probably required. Recent observations of relationship between gravity field variations and strain meters signatures justify improving and completing the network of ground deformation devices in the cave of Rochefort. This includes the use and development of novel sensors and data treatment systems using past expertise of the Royal Observatory of Belgium (ROB).

C.2.3.3. Lanzarote volcanic area

The systematic treatment of all the different signals which started in 2004 continues to be under validation with ready to use information needed for geophysical modeling. Multi parameters approach of sea-level monitoring is covering with dedicated sensors, the domains of geodesic references, tidal monitoring and tsunami questions.

Geneviève Tuts, engaged since 2005, will collect with the help of Eric de Kerchove all original data in the different formats used since 1980, and put them in a in an homogeneous set of files.

Next step will be to control all the calibration procedures by a systematic treatment of the maintenance archives.

C.2.3.4. EDAS Gravimeter feed-back with MVR technology

We plan to improve electrostatic feed-back loop of gravimeters by the introduction of micro-processor based control. It will allow introducing more flexibility in the feed-back to a low damped instrument.

C.2.4. Personnel involved

Scientific staff: M. van Ruymbeke (project leader), Th. Camelbeeck, M. Van Camp, Zhu Ping

Technical staff: Eric de Kerchove, Jean-Philippe Noël

C.2.5. Partnerships

List of national partners without grant

- Prof. Verheyden Sophie, De Geest Peter, Dept. of Geology, Vrije Universiteit Brussel
- Prof.Yves Quinif & Prof. Jean Pierre Tsibangu, Faculté Polytechnique de Mons
- Mr. Philippe Meus, technical manager MET

List of international partners without grant

- Dr Dominique GENTY, Univ. Paris-Sud, Lab.d'Hydrologie et de Géochimie Isotopique, Orsay
- Prof. Ricardo Vieira Dias, Univ. Computense Madrid, Casa de los Volcanes, Lanzarote (Spain)

C.2.6. Publications

C.2.6.1. Publications with peer review

None

C.2.6.2. Publications without peer review

[1] **M. van Ruymbeke**, Liu 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, pp134-140, published in 2006

C.2.6.3. Reports, thesis, etc

[2] **M. van Ruymbeke**, J.P. Barriot
Micro-gravimetric methods: static and dynamic aspects
Publication of a CDROM with material introduced during the Summer School of IAG/BGI/ICET, organized by the BGI and ROB between October 23-28, 2005 in the "Casa de los Volcanes" at Lanzarote

C.2.7. Missions

Field missions: Michel van Ruymbeke (12)
Michel Everaerts (11)
Eric de Kerckhove (7)
Jean Philippe Noël (11)

C.3. Project "Gravitational Balance"

C.3.1. Objectives

We aim to use our metrological expertise (EDAS) and our Earth tide instrumentation knowhow to design a new kind of gravitational balance dedicated to the measurement of the universal constant of gravitation G.

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

C.3.2. Progress and results

- Our experiment is based on a vertical pendulum (see Figure 19) with a second pendulum mass above the axis of rotation in order to increase the mechanical sensitivity of the pendulum. Taking into consideration that the earth's gravitational field provides the main contribution to the restoring torque of the pendulum, the mechanical restoring torque coming from the suspension with bias such as inelastic effects can then be lowered and adjusted with a very high accuracy (depending on the second mass position). This geometry provides only one degree of freedom of movement and a low sensitivity to micro seismic acceleration.
- This low degree of freedom of movement of the beam allows us to use interferometric sensors to monitor the beam's position.
- We use a specific mass geometry which minimizes 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.

The second mode minimizes the work of the suspension and its inelastic effects.
These electrostatic forces can be precisely related to fundamentals physical units.

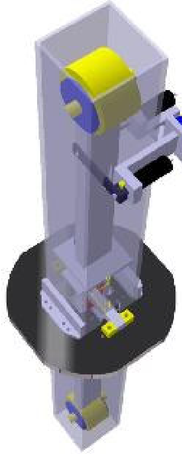
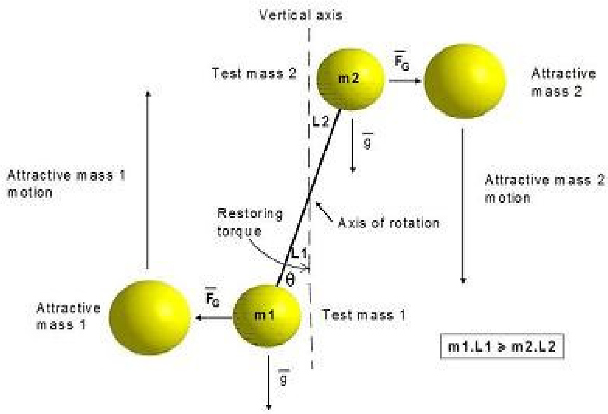
	

Figure 18: Sketch of our Astatic vertical pendulum	**Figure 19: Schematic principle of our Astatic vertical pendulum**	**Figure 20: Picture of the gravitational balance in underground laboratory**

Installation of a new balance in underground laboratory

- Construction of a new balance with a flexure joint instead of a knife edge for the axis of rotation (see Figure 18 and Figure 20).
- Installation July 2006 of the new balance with a new attractive mass motion system in the "Walferdange Underground Laboratory for Geodynamics" for low noise and long term study (see Figure 20).
- Study of electrostatic force calibration procedure.

Numerical simulation

In parallel with our balance experiments, we continue to improve the numerical model of our gravitational balance. We have been able to compare real and virtual signals, which allows to:

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

Feed-back regulator

The previous push pull regulator is replaced by a numerical PID feed-back regulator equipped with a microprocessor in order to keep the beam of the balance in the same position, using electrostatic forces. The high Q factor of our apparatus makes it necessary to develop specific methods (normalized polynomials method with adjustable damping coefficient) to determine the PID's parameters. This new regulator provides a very good signal to noise ratio and no drift of the zero.

Remote control

We are programming the remote control software (see Figure 21) and gravitational balance's microprocessor in order to monitor our experiment from the internet. Full control of the balance is then possible (monitoring, data logger, calibration process, application of forces, actuators control, feed-back coefficient…). It is also possible to upload new software on the balance's microprocessor (change of feed-back algorithm…).

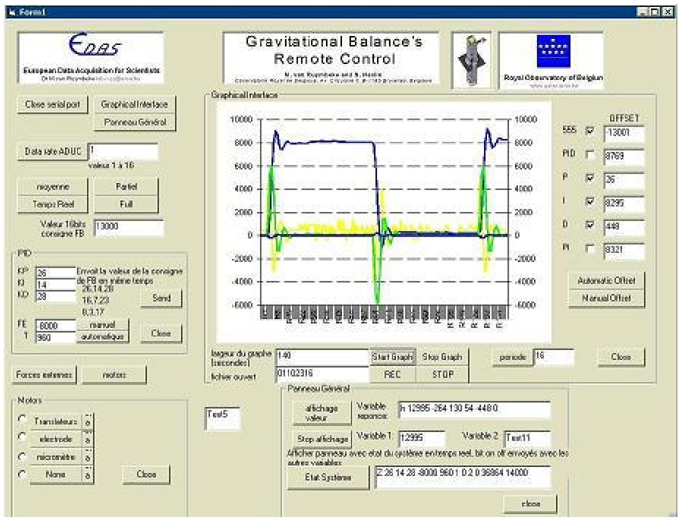


Figure 21: Remote control interface

C.3.3. Perspective for next years

- Presentation of a PhD in engineering sciences on this topic at the "Université Catholique de Louvain" (UCL).
- Design of a new electronic interface for our electrostatic sensor to monitor the beam position with a lower time response and a higher resolution in order to increase the feed-back gain.
- Study and design of a small interferometer sensor (to replace our electrostatic sensor) for very low time response and high resolution.
- Optimisation of the numerical PID regulation algorithm.
- Use of a monocristal flexure strip for the axis of rotation of the balance to lower the inelastic effect of the suspension.
- Design of customized software to compute the electrostatic force acting between any geometry of conductive materials at different electrical potentials.
- Analyse of the results and determination of the metrological limits of this specific approach for a second generation prototype.

C.3.4. Personnel involved

Scientific staff: Michel van Ruymbeke, (Project manager) Sébastien Naslin (design and validation)

Technical staff: Francis Renders (preparation the mechanical equipment for the laboratory)

C.3.5. Publications

C.3.5.1. Publications with peer review

None

C.3.5.2. Publications without peer review

None

C.3.5.3. Reports, thesis, etc

None

C.3.6. Scientific outreach

Meeting presentations

[1] **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.3.7. Missions

Assemblies, symposia (number):	S. Naslin (1)
Field missions (days):	S. Naslin (30)

C.4. Project "Inertial Platform"

C.4.1. Objectives

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 Intercomparison 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.4.2. Progress and results

In 2006, we integrated our inertial platform in the Gravilux project (GDL) and moved this original device in the Underground Laboratory of Walferdange (Gr.-D. of Luxembourg), being a very suitable place for this experiment. We tried to control the scale factor of the gravimetric tidal phenomena with the comparison of signals obtained simultaneously with a superconducting gravimeter and a LCR gravimeter calibrated with the platform. It could become an effective alternative to the super conducting gravimeter calibration obtained by comparison with absolute gravimeter.

C.4.3. Perspective for next years

We will operate with electronic control acting weekly on the step motor moving the platform. So the calibration sequence becomes systematic with a perfect repeatability. It allows with an adequate data treatment to determine the scale factor of gravimetric tides in Walferdange. We could compare the results of this method with the absolute gravimetric inter-comparison method applied for the superconducting gravimeter signals

C.4.4. Personnel involved

Scientific staff: Michel van Ruymbeke

Technical staff: Francis Renders, Jean-Philippe Noël

C.4.5. Partnerships

List of international partners without grant

- Dr Olivier Francis, Luxemburg university

C.4.6. Publications

C.4.6.1. Publications with peer review

None

C.4.6.2. Publications without peer review

None

C.4.6.3. 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
pp14

C.4.7. Missions

Field missions (days): M. van Ruymbeke (8)

C.5. Project "Bolometric Oscillation Sensor (BOS)"

C.5.1. Objectives

A Bolometric Oscillation Sensor (BOS) is projected to be installed on the Picard satellite dedicated to the observation of very small variations of the solar radiation. The research & development of this sensor requires a large part of our expertise. The main deliverable of this project consists to monitor helioseismology in a spectrum between 20 seconds and more than one month.

C.5.2. Progress and results

The simulation of the sensor is operated in vacuum conditions. Control of radiant sources by pre-programmed micro processor interfaces with synchronized detection allows reaching very high dynamics on very weak signals. We use a ground based laboratory equipment to simulate measurement in the space conditions.

C.5.3. Perspective for next years

After the research and development period, we plan to elaborate in accordance with other participants, the various steps of qualification needed to reach the acceptance by authors of the project. Thermal, vibrational, electrical & mechanical tests will be conducted before the final assembling process.

C.5.4. Personnel involved

Scientific staff: Michel van Ruymbeke (Project manager)

Technical staff: Jean-Philippe Noël, D. Lopez, D. Bizoza

C.5.5. Partnerships

List of national partners

- Royal Meteorological Institute

C.5.6. Publications

C.5.6.1. Publications with peer review

None

C.5.6.2. Publications without peer review

None

C.5.6.3. Reports, thesis, etc

[1] **Michel van Ruymbeke**, Jean Rasson et **Geneviève Tuts**
La thermométrie géophysique à l'ORB de 1970 à nos jours
Ciel&Terre, Vol 122, pp 47-55

[2] Fr. van Ruymbeke
Mise au point d'un capteur embarqué sur satellite destiné à mesurer les variations du flux radiatif solaire
Mémoire FSA UCL 2005-2006, 111 pp

[3] Didier Bizoza
Banc d'essai pour l'étude d'un capteur de variation du rayonement solaire embarqué sur le satellite Picard
Travail de Fin d'Etudes Ingénieur industriel ECAM 2005-2006

C.5.7. Missions

Field missions (days): M. van Ruymbeke (1)

DEPARTMENT 2: Astrometry and Dynamics of Celestial Bodies

SECTION 4: Astrometry and Dynamics of Solar System Bodies

Introduction:

The Royal Observatory of Belgium has a long tradition in excellent astrometry of asteroids and comets. In the last years, worldwide asteroid astrometry got a new impetus thanks to several developments. First, there was the extension of the asteroid population with new groups, such as the Transneptunian objects. More influence came from the 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. Recently the section got involved in the data reduction of the astrometric satellite GAIA, in the Coordination Unit dealing with solar system objects.

D. Science Theme "Asteroids"

D.1. Operational project "RUSTICCA"

D.1.1. Objectives

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

D.1.2. Progress and results

D.1.2.1. Observations in 2006

In 2006 observations have been performed on 44 nights (including 1 day-time session) by 5 observers. They include H. Debehogne (7 nights, 210 frames), P. De Cat (15 nights, 371 frames), E. Elst (7 nights, 210 frames), T. Pauwels (29 nights, 1319 frames) and P. Vingerhoets (9 nights, 53 frames).
These observations concerned:

- Astrometry of minor planets (35 nights, 114 fields with 1371 frames, producing 1808 astrometric positions, including 8 fields with 98 frames, producing 16 positions of objects of the Near-Earth Objects confirmation page), observers: H. Debehogne, P. De Cat, E. Elst, T. Pauwels.
- Occultations of stars by minor planets (10 events attempted on 9 nights with 56 frames, producing 5 light curves); observers: P. De Cat, T. Pauwels, P. Vingerhoets.
- Mutual phenomena (eclipses and occultations) of an asteroid and its satellite (3 events attempted on 3 nights, with 328 frames, producing 3 light curves), observer: T. Pauwels.
- 2 sessions to test the possibility to observe occultations by minor planets (2 nights, 15 frames); observers: P. De Cat, T. Pauwels, P. Vingerhoets.
- 1 session to test the possibilties to observe mutual phenomena of the satellites of Uranus (1 night, 21 frames); observers: P. De Cat, T. Pauwels, P. Vingerhoets.
- 1 session to test the linearity of our CCD frame in the low illumination regime (1 night, 59 frames); observer: T. Pauwels.

➢ 1 day-time session testing the camera (P. De Cat, T. Pauwels).

Together they produced 1850 frames.

D.1.2.2. Other activities

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

In 1997 and 2003 we observed the mutual phenomena of the Galilean Satellites of Jupiter, the so-called PHEMUs. There were some problems in the reduction of our data, and we had some discussions about this with J.-E. Arlot (IMCCE, Paris). We also discussed the possibility of observing mutual phenomena of the satellites of Uranus in 2007, the PHEURA phenomena. These satellites are a lot fainter and require a different approach. We did some test observations and analysed them.

We discovered an important non-linearity in the response of our CCD camera in the low illumination regime. We did some test observations to have a rough quantification of the non-linearity. Observations of the PHEMU phenomena will have to be re-reduced.

The maintenance of the telescope also took a lot of attention. See the technical report.

To further automate the reduction of the observations, we continued to improve the software for reduction of the astrometric observations. This included the use of fast Fourier transforms in the shift of the PSFs, and the possibility to routinely co-add frames in the reduction pipeline.

Finally, all raw data has been archived on CD-ROM, along with the necessary documentation to interpret the observations in the future, adding another 29 CD-ROMs to the archive, containing 1730 images and films.

D.1.2.3. Summary of the results obtained since 1996

From 1996 to 2006 a total of 18 016 positions of minor planets and 66 positions of comets have been published in the Minor Planet Circulars.

At the end of 2006 the RUSTICCA project had already 40 % more positions published than the overall production from Ukkel in the photographic era (1920-1995). Still, after the very productive year 2005, 2006, with only slightly more than 2000 published positions, can be considered as a calm year. Main reason was the weather. Figure 22 shows the number of published positions per year (abscissa shows the year of observations; some positions observed in 2006 are not yet published). Observations in the photographic era are in blue, those of the RUSTICCA project in red. Although not all positions observed in 2006 have already been published, the dip in number of published positions is prominent. Purely based on subjective impression, it seems that the number of clear nights per year in Ukkel is

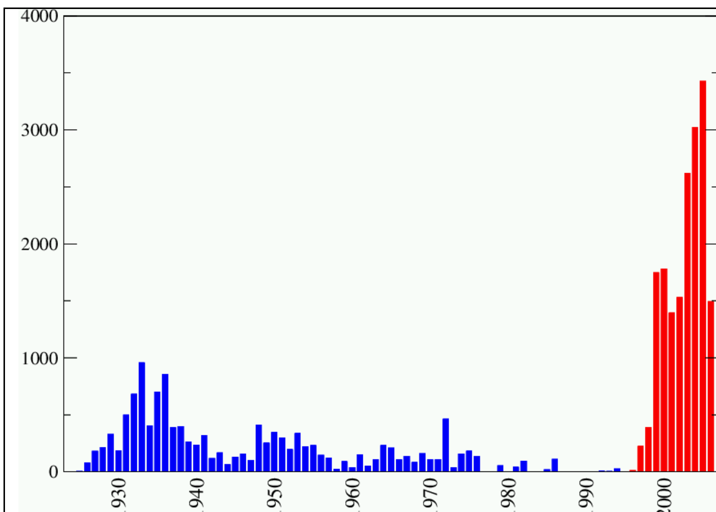


Figure 22: Number of published positions from observations in Ukkel. Blue: photographic era; red: RUSTICCA.

going down. We would not be surprised if this is linked to the global warming. After the period 1998-2002 with abnormally bad weather, 2006 was again a year with too few clear nights.

Excluding the Daily Orbit Updates, 246 positions of minor planets (NEOs) and comets have been published in the Minor Planet Electronic Circulars.

The total number of preliminary designations of minor planets attributed to observations of the RUSTICCA project amounts to 289. Again 2006 has been a calm year in this respect with only 11 new preliminary designations, compared to an average of 36 per year in the period 1999-2005. 162 of these minor planets are currently multiple opposition objects, and 80 have been permanently numbered, with the discovery attributed to a RUSTICCA observation. The discoverers with the number of discovered minor planets are: H. Boffin (6 minor planets), P. De Cat (1 minor planet), E. Elst (5 minor planets), E. Elst and H. Debehogne (5 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 (55 minor planets), T. Pauwels and H. Boffin (1 minor planet), T. Pauwels and S. Ipatov (2 minor planet).

A total of 43 light curves of cataclysmic variables could be established (1999-2003), 19 light curves of mutual phenomena of the Galilean satellites of Jupiter (1997 and 2003), and 3 light curves of mutual phenomena of an asteroid and its satellite.

The team tried to observe 33 occultations of stars by minor planets in the period 2003-2006. 11 of these gave no results due to clouds, 2 others because the target star turned out to be too faint, and 2 phenomena failed because of technical problems. 16 other phenomena gave a negative result, meaning that we could deduce from the observations that the shadow of the minor planet missed Ukkel. 2 phenomena, both in 2005, gave a positive occultation, where precise timings of the beginning and end of the occultation could be derived. Given the uncertainty in the predictions of the occultation paths, 2 positive occultations out of 33 attempted is a very high score.

The archive now consists of 309 CD-ROMs with a total of 22 704 images.

D.1.3. Perspective for next years

The linkage of the dome to the position of the telescope should be accomplished in the next years. Astrometric observations of minor planets are still expected to be useful for a few years. 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. In 2007, there is a season of interesting mutual phenomena of the satellites of Uranus, which we plan to observe. In 2008, there is a season of mutual phenomena of the satellites of Jupiter, which we plan to observe.

D.1.4. Personnel involved

Scientific staff: T. Pauwels (observer), P. De Cat (observer)

D.1.5. Partnerships

List of international partners without grant

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

List of national partners without grant

- Eric W. Elst

- Henri Debehogne
- Pierre Vingerhoets

Grants/Projects used for this research/service

- Lotto grant for the purchase of the camera.

Visitors:

- Short visits: 3

D.1.6. Publications

D.1.6.1. Publications with peer review

[1] **De Cat P.**, et al,
7 positions of minor planets
MPEC 2006-H06.

[2] **De Cat P.**,
534 positions of minor planets
MPS 161 568, 161 575, 161 632, 161 649, 161 684, 161 765, 161 773, 161 791, 161 796, 161 825, 161 932, 161 999, 162 236, 162 253, 162 360, 162 381, 162 383, 162 397, 162 405, 162 537, 162 550, 162 556, 162 626, 162 749, 167 054, 168 028, 168 096, 168 764, 168 786, 168 806, 168 821, 169 091, 169 175, 169 201, 169 205, 169 207, 169 216, 169 231, 169 307, 169 322, 169 455, 169 503, 169 616, 169 622, 169 674, 169 702, 169 934, 170 529, 170 893, 178 199, 180 980, 182 641, 182 727, 182 730, 182 780, 182 813, 182 838, 182 848, 182 957, 182 975, 182 998, 183 045, 183 050, 183 106, 183 192, 183 328, 183 410, 183 424, 183 442, 183 472, 183 655, 183 663, 183 669, 183 712, 183 766, 183 796, 184 083, 184 243, 190 286, 190 324, 190 395, 190 447, 190 487, 190 547, 190 560, 190 649, 190 859, 190 860, 190 861, 190 909, 191 088, 191 201, 191 242.

[3] **Elst, E., Debehogne, H**.
449 positions of minor planets
MPS 159 028, 160 679, 160 764, 160 798, 160 831, 160 841, 161 009, 161 242, 161 300, 161 317, 161 320, 161 330, 161 345, 161 556, 161 575, 161 684, 161 703, 161 708, 161 732, 161 805, 161 927, 162 253, 162 381, 162 405, 162 537, 162 550, 162 556, 162 560, 162 637, 162 835, 163 864, 174 695, 174 747, 174 776, 174 789, 174 816, 174 828, 174 864, 174 890, 174 994, 175 040, 176 068, 179 038, 179 062, 179 074, 179 077, 179 136, 179 202, 179 259, 179 278, 179 335, 179 442, 179 484, 179 595, 179 608, 179 637, 179 730, 179 787, 179 814, 179 898, 180 072, 180 082, 180 203, 180 707, 180 715, 180 750, 180 756, 180 786, 180 801, 180 820, 180 823, 180 845, 180 911, 180 920, 180 936, 181 041, 181 067, 181 177, 181 259, 181 548, 181 557, 181 633, 181 730, 181 752, 181 830, 181 906, 182 048, 182 071, 182 132, 185 563.

[4] **Elst, E.**, Ipatov, S.
22 positions of minor planets
MPS 177 093, 178 425, 178 447, 178 629.

[5] **Pauwels, T**., et al,
9 positions of comets
MPEC 2006-S26, 2006-S38.

[6] **Pauwels, T**.
798 positions of minor planets
MPS 158 962, 159 078, 161 046, 161 773, 162 749, 162 887, 163 812, 164 902, 164 974, 164 982, 165 268, 165 269, 165 414, 165 568, 165 605, 165 654, 165 688, 165 783, 165 805, 167 103,

167 169, 167 196, 168 845, 169 201, 169 231, 169 558, 169 617, 170 781, 170 856, 170 873, 170 893, 170 906, 170 971, 171 914, 172 026, 172 035, 172 149, 172 150, 172 845, 173 545, 173 577, 173 592, 173 751, 174 456, 174 683, 174 687, 174 706, 174 803, 174 828, 174 864, 174 955, 175 130, 175 131, 175 480, 178 165, 178 283, 178 286, 178 381, 178 447, 178 495, 178 498, 178 590, 178 654, 178 680, 178 684, 178 703, 178 711, 178 725, 178 803, 178 834, 178 884, 178 908, 178 911, 178 922, 178 935, 179 029, 179 038, 179 062, 179 074, 179 077, 179 104, 179 112, 179 117, 179 163, 179 202, 179 205, 179 229, 179 259, 179 275, 179 278, 179 280, 179 335, 179 442, 179 480, 179 577, 179 592, 179 595, 179 608, 179 637, 179 648, 179 708, 179 730, 179 778, 179 898, 179 899, 179 977, 180 000, 180 072, 180 082, 180 163, 180 311, 181 129, 181 358, 182 462, 182 657, 182 838, 183 106, 183 107, 183 220, 183 298, 183 406, 183 472, 183 546, 183 777, 187 126, 188 446, 188 498, 188 552, 188 654, 188 754, 189 915, 190 284, 190 286, 190 287, 190 289, 190 310, 190 324, 190 447, 190 487, 190 547, 190 560, 190 561, 190 833, 190 859, 190 860, 190 861, 190 958, 191 088, 191 201, 191 300, 191 494, 191 634.

[7] **Pauwels, T.**,
9 positions of comets
MPC 57772, 57773.

[8] **Pauwels, T.**, Boffin H.
6 positions of minor planets
MPS 172 845, 182 462.

[9] **Pauwels, T., De Cat, P**.
3 positions of minor planets
MPS 190 547.

[10] **Pauwels, T.**, Ipatov, S.
9 positions of minor planets
MPS 162 887, 167 196.

D.1.6.2. Publications without peer review

None

D.1.6.3. Publications in press, submitted

[11] **Pauwels, T., Vingerhoets, P., Cuypers, J.**,
A problem with the reduction of the observations of the PHEMU97 and PHEMU03 events with the Ukkel Schmidt Telescope
Submitted to *Planetary and Space Science*.

[12] **Pauwels, T., De Cat, P., Vingerhoets, P.**,
The possibility to observe PHEURA events with the Ukkel Schmidt Telescope
Submitted to *Planetary and Space Science*.

D.1.7. Scientific outreach

Meeting presentations

[1] **Pauwels, T., Vingerhoets, P., Cuypers, J.**,
Observations of the PHEMU97 and PHEMU03 events with the Ukkel Schmidt Telescope
Poster presented at "Mutual events of the Uranian satellites in 2007-2008 and further observations in network", Paris, France, November 15-18, 2006.

[2] **Pauwels, T., De Cat, P., Vingerhoets, P.**,
The possibility to observe PHEURA events with the Ukkel Schmidt Telescop,

Poster presented at "Mutual events of the Uranian satellites in 2007-2008 and further observations in network", Paris, France, November 15-18, 2006.

D.1.8. Missions

Assemblies, symposia: T. Pauwels (1), P. De Cat (1)

D.2. Operational Project "Gaia Data Reduction"

D.2.1. Objectives

The satellite GAIA, scheduled to be launched in 2011, will make a complete census of the sky up to magnitude 20. With unprecedented accuracy in position (and hence in proper motion and parallax) and photometry, GAIA will make a real 3D map of our galaxy. Several departments of the Observatory are interested in its data. In our section we are interested in the asteroids that will also be present on the GAIA images. At this time, the DPAC (Data Processing and Analysis Consortium) has been established, with the aim to develop the software for the data reduction of GAIA. DPAC is organised in CUs (Coordination Units). CU4, dealing with object processing, consists of three parts: extended objects, non-single stars, and solar system objects. In the next five years or so we shall concentrate in developing the software in the framework of CU4.

D.2.2. Progress and results

The application sent last year to the Science Policy for PRODEX funding, was sent too early. In the course of the year we sent to Belspo our desiderata for funding, as was asked by Belspo to interested participants. In November, when the Announcement of Opportunity was released, Belspo set up a strategy for what to be funded, and we made a new application for PRODEX funding, according to the guidelines set up by Belspo, and with a broader cooperation on Belgian level. There were internal meetings at the level of the Observatory on November 8 and December 21 to coordinate the writing of the proposals, and a meeting on the Belgian level at the Belspo premises on December 18.

At the international level, CU4 started its activities and there were two meetings of the Coordination Unit. This is expected to be systematic in the future, since the work of the DPAC is organised in six-month cycles, each ending at the end of May or November. Meetings are organised by the end of each cycle to review the work done in the current cycle, and plan the work for the next cycle.

Our task has been defined to work in the GWP M-454-00000 "Astrometric reduction", under the supervision of the WP manager, Jean-Eudes Arlot (IMCCE, Paris). There have been two visits of J.-E. Arlot and V. Lainey (March 20 and December 7) to discuss the work to be done.

Concrete programming will be done in Java. In June a course on Java and the specificities of GAIA has been organised in Toulouse, France. Two staff members of the section attended that course. Since our WP will get only very limited PRODEX funding for a computer scientist, we will have to do much of the programming ourselves.

D.2.3. Perspective for next years

The development of the algorithms will take place in 6-months cycles, named after the 10 highest mountains on Earth. The general principle is "to deliver simple and soon, rather than complex and late". Each GWP work package will therefore have to deliver, very rapidly prototype software with reduced functionality or performances. These will then be improved in successive development cycles or iterations. Our work package has been selected as one of the five of CU4 that have to deliver the first version of the Java code at the end of Cycle 2 (May 2007).

D.2.4. Partnerships

List of international partners without grant

- Jean-Eudes Arlot and team, IMCCE, Paris, France
- CU4 of GAIA DPAC

List of national partners without grant

- Université Libre de Bruxelles (Dimitri Pourbaix)
- Université de Liège (Eric Gosset)

Visitors: 2 short visits

D.2.5. Publications

D.2.5.1. Publications with peer review

None

D.2.5.2. Publications without peer review

None

D.2.5.3. Reports, thesis, etc

[1] Pourbaix, D., **Pauwels, T., De Cat, P., Fremat, Y., Blomme, R**., Gosset, E.
PRODEX Programme Project Proposal "Binaries, Extreme Stars and Solar System Objects"

D.2.6. Missions

Commissions, working groups (days):	P. De Cat (3), T. Pauwels (7)
Research visits (days):	P. De Cat (5), T. Pauwels (5)

E. Science Theme "Digitisation"

E.1. Operational Project 007 of the "Digitisation of the heritage of the Federal Scientific Institutes of BELSPO"

E.1.1. Objectives

The Belgian federal government has recognised the importance of preserving and making available the heritage of the scientific institutes. The means is to digitise the collections of these institutes, and put them on the web. A study by the Bureau van Dijk in 2003 revealed that to implement the basic scenario 150 million euros would be needed. Full digitisation (excluding low priority collections) would cost 500 millions. By the end of 2005, the Federal Science Policy Office initiated some ten smaller scale operational projects. The Royal Observatory of Belgium joined project No. 7 (henceforth called "007") "digitisation of photographic glass plates", involving the the Royal Museum of Central Africa (coordinator), the Royal Institute for the Study and Conservation of Belgium's Artistic Heritage, the Belgian Institute for Space Aeronomy and the Royal Observatory of Belgium, with the aim of digitising our astrophotographic plates on a high-resolution digitiser that should have been built in the course of the "D4A" project (see reports 2002-2005), but that could not be finalised in due time because of events beyond our control. First aim of the 007 project is to make the digitiser operational. In parallel we want to set up a detailed catalogue with thumbnails of our plate collection.

E.1.2. Progress and results

Most of the operations at the ROB in this project were performed by J.-P. De Cuyper, G. Dedecker and L. Winter. T. Pauwels primarily represented the Observatory in the "*Vast Bureau"*, the instance doing the daily management of the project.

A lot of effort was put into refining the budget and writing the technical annex to the Ministerial Decree, including the scientific description of the project. There were meetings of the Vast Bureau on February 7, May 2, and September 13. Internal meetings were held in the ROB on January 17, and March 15.

A special problem is that the allocated budget covers the cost of digitisation itself, but not the cost of storing the digitised images, nor distribution of them. In the search for possible sponsors or partners for storage and distribution of the data, there were meetings with potential private partners on February 20, March 15, May 9 and October 12.

E.1.3. Perspective for next years

In the course of 2007 the digitiser should be installed. Routine digitisation of our collection should start on the scanning time allocated to the ROB. The financing of the project is already foreseen till the end of 2008. There is good hope to have the project extended in some way. In the coming years the UDAPAC project is supposed to start. Since it will use the same facilities, we expect that there will be some interaction between 007 and UDAPAC.

E.1.4. Personnel involved

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

Technical staff: G. de Decker

E.1.5. Publications

E.1.5.1. Publications with peer review

None

E.1.5.2. Publications without peer review

[1] **Pauwels, T**
A Tool for Identifying Astronomical Plates
in Virtual Observatory, Plate Content Digitization, Archive Mining, Image Sequence Processing (M. Tsvetkov, V. Golev, F. Murtagh, R. Molina, eds.), 2006, p. 275-284.

E.1.5.3. Reports, thesis, etc.

[2] Fernandez, M., Buelinckx, E., **Pauwels, T**., Muller, C
Digitaliseringsplan van de FWI's en de KBF 2005-2008,
Bijlage I aan het Ministerele Besluit DI/00/07, technische specificaties

E.1.6. Missions

Commissions, working groups: 3 days

E.2. Project "DAMIAN - Digital Access to Metric Images Archives Network"

The aim of this project is to set up the facility for giving digital access to the historic-scientific information contained in photographic archives. The goal is to acquire the necessary know-how, hardware and software to digitise the information contained in the photographic images, as well as the associated meta-data, to offer the results to the public and to make them directly usable for scientific research through the modern techniques of the information society.

E.2.1. Progress and results

The construction of a 2D digitiser facility of high geometric and radiometric resolution and precision, started under the D4A pilot-project (2002-2005), was continued. The DAMIAN digitiser will be housed in a temperature and humidity stabilised clean room with adjacent archive room. The Ministry of Public Works (Regie) is still busy with the necessary renovations of the Telescope building that will house the facility. The works are now thought to be finalized by spring 2007. The climatisation is partly installed (air conducts, air treatment machine and chiller) since December 2004. The completion of the installation depends on the progress of the renovation works, but is foreseen in March 2007. Rails for the mobile archive racks were installed.

The digitiser is based on an ABL3600 air bearing XY-table with an automatic film roll transport and plate holder system, a plate stack/exchanger/loader system with a turntable and removable plate-tray magazine. Aerotech is finishing the production of the machine. The delivery is foreseen by mid 2007.

Work on the design of the digitizer continued. This included 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. A high precision computer regulated DC power supply needed for the illumination system was designed and built. The BCi4 CMOS camera with its new software driver of Vector International was tested. A geometric and radiometric benchmark for the digitiser was worked out in detail as well as the first version of the data reduction software needed to analyse the test results. G. de Decker developed a first software version for a distributed image capture and storage, in order to be able to handle the huge data stream generated by the CMOS camera during the digitisation process.

HAM1, an old Mann Comparator, was installed for use as a set-up for testing the CMOS camera and the illumination system. Unfortunately, due to dust contamination, the XY-table of the HAM1 could not be moved anymore. A complete cleaning of all moving parts needs to be done. A damage claim was sent to the contractor who caused the damage.

The National Geographical Institute (NGI) bought a 35cmx35cm geometric grid, consisting of black circular chrome dots on a blank glass plate, needed for the delivery benchmarks and the calibration of the digitiser. In collaboration with the NGI and AGFA-Gevaert test film rolls were produced for the development and testing of the filmroll transport system.

In collaboration with the Thüringer Landesternwarte Tautenburg, the design of a new panchromatic telecentric objective was continued.

The development of a digital, ODBC compliant, relational database describing the astrophotographic plate archive was continued. The database is accessible on the intranet..

The input lists of observational metadata were extended for introduction into the database and the spectroscopic plate metadata included. The metadata of the spectra taken in different resolutions with the 1.52m ESO telescope at La Silla were started. The prescanning at 250 dpi of the 16 cm plates was continued with the HiD scanner at the ROB and of the 30 cm and 24cm plates with the XY15 scanner at the NGI. Metadata concerning about 1500 spectra were encoded and some 2000 plates were prescanned.

E.2.2. Perspective for next years

The construction of the climatised clean room and of the XY-table will be realised. The acceptance testing of the Aerotech equipment in Pittsburgh is foreseen by mid 2007. After the delivery and acceptance in Ukkel the digitiser will be finished and made functional. The development of the diffuse illumination system will be extended using the latest very bright LEDs. A purpose build modular power supply and an air-cooled BCi4 CMOS camera will be installed. The necessary hardware and software for the digitisation and the data storage, handling and extraction will 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.

In the coming year the work on the digital plate catalogue will be continued. A webserver, containing the metadata database will be set up.

E.2.3. Personnel involved

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

Technical staff G. Dedecker, Ignace Van der Hucht, Marc De Knijf, Roger Peeters, Francis Renders, Georges Peeters, David Duval

E.2.4. Partnerships

List of national and international partners

National Geographic Institute (NGI), Dir. Joost Vanommeslaeghe, Dir. Herman Prils.
AGFA-Gevaert, Mortsel, Aerial Photography & Engineering Devision.
United States Naval Observatory, Washington DC, Dr. Norbert Zacharias, Dr. Dan Pascu.
Thüringer Landessternwarte Tautenburg, Dipl. Ing. Uwe Laux.

Grants used for this research

Lotto grant

Visitors (give only the total number): 12

E.2.5. Publications

E.2.5.1. Publications with peer review

None

E.2.5.2. Publications without peer review

None

E.2.5.3. Reports, thesis, etc

[1] **De Cuyper, J.-P**. and Winter L.
The D4A Digitiser
in Astronomical Data Analysis Software and Systems - ADASS XIV (eds. P. L. Shopbell, M. C. Britton and R. Ebert), ASP Conf. Series, V 347, pp 651-654..

[2] **De Cuyper, J.-P.** and 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, V 351, pp 587-590.

E.2.6. Missions

Research Missions: 1

Operational Missions: 60

E.3. Operational Project UDAPAC

E.3.1. Objectives

The UDAPAC project was initiated in 2000. In this project the Royal Observatory would serve as a host for the collections of the direct astrophotographic plates for which the owners have no more facility, interest or know-how to keep them. In the long run, parallel with the other digitisation projects, these plates could be digitised. In 2005 there were some discussions on the opportunity to start raising funds for UDAPAC. However, some people had the feeling that it would be better to wait till the D4A digitiser would be operational and could have demonstrated its utility, so that applications for funding would be stronger.

E.3.2. Progress and results

In the course of the year the director has sent a letter, co-signed by Dr. E. Griffin, to potential partners to inquire for their interest in joining the project. On November 24, there has been a meeting with Elizabeth Griffin (the driving force behind the project) to discuss how to proceed.

E.3.3. Perspective for next years

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

E.3.4. Partnerships

List of international partners without grant

- Elizabeth Griffin

SECTION 5: Astrometry and Dynamics of Stellar Systems

Introduction

Our aims are to study the properties of binaries and multiple stars, both wide and close pairs, and to exploit the fundamental data these objects provide in order to improve the understanding of binary formation and evolution (cf. Theme "Binaries") on the one hand, as well as the impact of binarity on the stellar atmospheres (cf. Theme "Asteroseismology") on the other hand.

A. Science Theme "Binaries"

Binary and multiple stars with well-characterized components are attractive targets to study a number of different phenomena of high astrophysical relevance including their own formation and history. Astrometry helps in the full characterization of the components in a powerful way as it allows to determine the orbital motions and, derived from these, the stellar masses - a fundamental property of stars - in a straightforward manner. **Wide binaries**, especially if the components have different spectral types, can be used to calibrate the luminosities and temperatures of single stars and to confront evolutionary tracks and models. They represent the high angular momentum class 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 for close binary evolution (incl. mass exchange).or for understanding the impact of binarity on the stellar atmospheres (e.g. tidal deformation, rotation, chemical composition, stellar pulsation or activity).

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 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. One of our aims is to investigate a volume-limited sample of visual binary and multiple stars in the Solar neighbourhood.

A.1.2. Progress and results

We analyzed all the observations of visual double and multiple stars performed at two Bulgarian observatories during various campaigns in the period 1998-2004 (in the framework of "*Astrometric, Photometric and Spectroscopic Follow-up of Binary Systems*"). Accurate relative astrometry and differential multi-colour (BVRI) photometry are provided for the components of a large sample of Hipparcos double and multiple stars and/or from the Gliese Catalogue of Nearby Stars. Many of these systems are nearby binaries which are part of the revised sample of the Solar neighbourhood. Recent data were acquired for 71 visual systems of which 6 are orbital binaries, 27 are nearby and 30 are multiple systems. In three cases, the systems remained unresolved. 23 new components were detected and measured. Two new visual double stars of intermediate separation were found. The estimated accuracies in position angle and angular separation are 0.04° and 0.01" respectively, while those in differential photometry are of the order of 0.01-0.02 mag. These data were compared to the data from the Hipparcos Catalogue or from the "*Catalogue des Composantes d'Etoiles Doubles et Multiples"* in order to assess the nature of the association of 55 systems. New basic binary properties were derived for 20 bound systems. Component colours and masses were provided for 2 orbital binaries **[6].**

Accurate component properties compared to suitably chosen theoretical isochrones allow to obtain information on the object's age and evolutionary status and to discriminate among various possible models of stellar evolution. In the light of obtaining accurate fundamental data for binary and multiple stars with interesting properties, we selected the bright binary system θ² Tau for a detailed study because both components are among the more massive stars of the Hyades located in the turnoff region of its colour-magnitude diagram and because the evolutionary status of the components is still under debate. New high-resolution time-series spectra obtained in service mode at the Observatoire de Haute-Provence (OHP) during a full orbital period (2005-2006) were combined with archive spectra from the ELODIE database as well as with an older time-series of spectra provided by G. Torres. To disentangle the component spectra, we applied the code KOREL developed by P. Hadrava (Ondrejov, Czech Rep.) based on the application of an efficient Fourier disentangling technique. We applied the code VCURVE (based on the Lehmann-Filhés method) to the component radial velocities. These results turned out to be in good agreement with those from other codes. Using our improved radial velocities for both components in combination with existing long-baseline optical interferometric data from VLBI, we determined a new orbit solution (Figure 23 and Figure 24) to derive the fundamental properties of both components to a high accuracy. We significantly improved the knowledge of the orbital parameters and associated fundamental properties. In particular, we obtained a very accurate dynamical parallax which should allow to address the question of convective core overshooting in the internal layers of stars from the Hyades cluster**.** The component masses and luminosities thus derived are found to be compatible with current stellar evolution models adopting the Hyades metallicity **[1][3].**

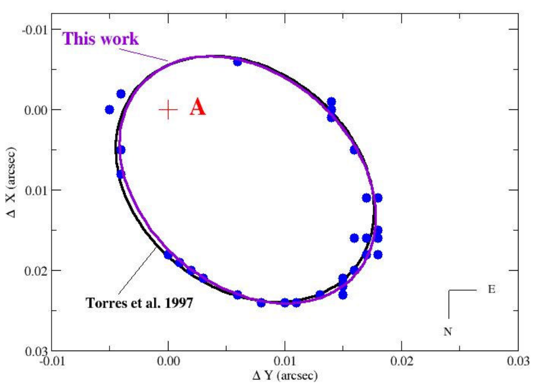


Figure 23: Astrometric orbit solution (θ² Tau)

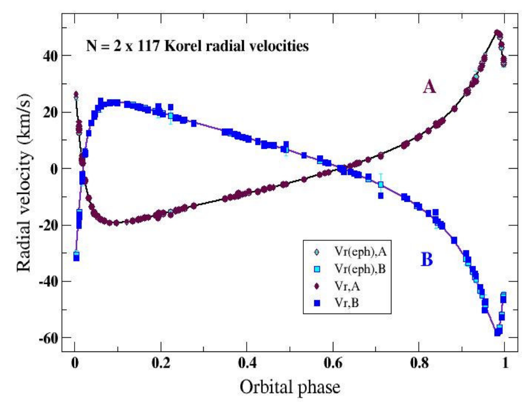


Figure 24: Spectroscopic orbit solution (θ² Tau)

We derived new relative astrometric data and near-infrared (J,H,K) colours for the components of nearby main-sequence binaries with component masses around one solar mass or less, but which do not fit well the empirical mass-luminosity relation. We described and summarized the results for a sample of nearby F-G and K binaries which have accurate parallaxes from the Hipparcos mission. This work is based on observations collected with the ESO 3.6m telescope at La Silla, equipped with the ADONIS Adaptive Optics instrument. Improving the observational data on main-sequence wide binaries is important in order to confront with the data more recently 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).

An improved ephemeris was obtained for the contact binary RZ UMi based on new times of minima and its system parameters were derived using the code Wilson-Devinney **[5].** New times of minima of various eclipsing binary systems with eccentric orbits were also reported **[2].**

A.1.3. Perspective for next years

The acquisition of component colours for nearby visual binaries and their exploitation will be continued. Future work will consist in using the disentangled component spectra to perform a detailed chemical analysis of θ^2 Tau, to determine as accurately as possible the physical properties and evolutionary status and to test whether or not convective overshooting is needed in the models. Speckle-interferometric programmes for the monitoring of close visual binaries lacking essential astrometric data will be developed, e.g. in the context of the PISCO-collaboration. For some systems of high astrophysical relevance and for which we would need very high-quality data, we intend to apply for interferometric observations (e.g. ESO for the Southern and CHARA (US) for the Northern objects).

A.1.4. Personnel involved

Scientific staff: Y. Frémat, P. Lampens (project coordinator)

Technical staff: D. Duval

A.1.5. Partnerships

List of international partners without grant

- R. Argyle, Cambridge, UK
- J.L. Prieur, Toulouse, France
- M. Scardia, Brera, Italy
- P. Škoda, Astronomical Institute of the Academy of Sciences, Ondřejov, Czech Republic
- A. Strigachev, Institute of Astronomy of the Academy of Sciences, Sofia, Bulgaria
- G. Torres, Harvard-Smithsonian Center for Astrophysics, Cambridge, MA

Grants/Projects used for this research

- Bilateral project "Astrometric, Photometric and Spectroscopic Follow-up of Binary Systems" (Ref. BL/33/011)
- Action-1 "Pulsation, chemical composition and multiplicity in main-sequence A- and F-type stars" of the Federal Science Policy (MO/33/018)
- "Modern Aspects of Theoretical and Observational Astrophysics", Federal Science Policy (IAP P5/36)
- OPTICON Transnational Access Programme, European Community
- Project G.0178.02 of the Fund for Scientific Research (FWO) - Flanders (Belgium)

Visitors:

- A. Strigachev, Institute of Astronomy, Sofia, Bulgaria: 3 weeks

A.1.6. Publications

A.1.6.1. Publications with peer review

[1] **Lampens, P., Frémat, Y., De Cat, P., Hensberge, H**.
Towards accurate component properties of the Hyades binary θ^2 Tau
Communications in Asteroseismology 148, Austrian Academy of Sciences Press (Vienna), 65

A.1.6.2. Publications without peer review

[2] Biro, I. B., Borkovits, T., Csizmadia, S., Hegedus, T., Klagyivik, P., Kiss, Z., Kovacs, T., **Lampens, P.** and 4 co-authors
New Times of Minima of Eclipsing Binary Systems and of Maxima of SXPHE Type Stars
Information Bulletin on Variable Stars, 5684, 1

[3] **Lampens, P., Frémat, Y., De Cat, P., Hensberge, H.**
Spectral disentangling and combined orbital solution for the Hyades binary θ^2 Tau

In: Proceedings of IAU Symposium 240 "*Binary Stars as Critical Tools & Tests in Contemporary Astrophysics*", eds. W. I. Hartkopf, P. Harmanec and E. F. Guinan, 22-25 August 2006, Prague, Czech Republic, 125

[4] Surdej, J., Absil, O., Bartczak, P., Borra, E., Chisogne, J.-P.,..., **Lampens, P.,** & 19 co-authors
The 4m international liquid mirror telescope (ILMT)
Proceedings of SPIE, Ground-based and Airborne Telescopes, ed. Stepp, L. M., Vol. 6267, 626704

[5] Van Cauteren, P., **Lampens, P.,** Wils, P.
Photometric elements and stellar parameters for the contact binary RZ UMi
Peremennye Zvezdy, Vol.26, No. 2

A.1.6.3. Publications in press, submitted

[6] **Lampens, P.,** Strigachev, A., **Duval, D.**
Multicolour CCD Measurements of Visual Double and Multiple Stars III
A&A, in press (2007)

[7] Biro, I.B., Borkovits, T., Hegedus, T., Kiss, Z.T., Kovacs, T., **Lampens, P.,** Regaly, Z., Robertson, C.W., Van Cauteren, P.
New Times of Minima of Eclipsing Binary Systems
IBVS, submitted (2007)

A.1.6.4. Reports

[8] **Lampens, P.**
Final report of *Project* 'Catalogue Integration and Image Processing of the ROB Wide-Field Plate Archives' (a Belgian-Bulgarian bilateral cooperation) (Ref. BL/33/B10), for BELSPO

[9] **Lampens, P.**
Final report of *Project* 'Astrometric, Photometric and Spectroscopic Follow-Up of Binaries' (a Belgian-Bulgarian bilateral cooperation) (Ref. BL/33/B11), for BELSPO

[10] **Lampens, P.,** Z. Kraicheva
Project '*Photometric and spectroscopic follow-up studies of binary systems of special interest'* presented in the framework of a new *Belgian-Bulgarian* bilateral cooperation, for BELSPO

A.1.7. Scientific outreach

Meeting presentations

[1] **Lampens, P, Frémat, Y., De Cat, P, Hensberge, H**.
Spectral disentangling and combined orbit analysis of the Hyades binary θ^2 Tau
Business Meeting, Comm. 26 "Double and Multiple Stars", XXVIth IAU General Assembly, 16-25 August 2006, Prague, Czech Republic

A.1.8. Missions

Assemblies, symposia:

- P. Lampens (2 meetings, 14 days)

Field missions:

- P. Lampens: National Astrophysical Observatory (NAO), Rozhen, Bulgaria (5 days)

B. Science Theme "Asteroseismology"

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

B.1. Research Project "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 star systems 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 of prime importance. We currently focus our efforts unto those binaries which are promising targets for the application of spectral disentangling.

B.1.2. Progress and results

B.1.2.1. Main-sequence O-B stars

The analysis of 7-colour Geneva photometric data of 64 variable O-B stars which are (candidate) β Cephei stars (β Ceps), Slowly Pulsating B stars (SPBs), or Maia stars revealed 21 pulsating variables (of which 7 are new pulsators, including 2 hybrid β Cep/SPBs), 6 non-pulsating variables (binaries or spotted stars), and 1 (photometrically) constant star. All the Maia candidates were reclassified. We performed mode identification for the 61 detected frequencies of these pulsating variables for the first time: the most probable value for the degree l is 0, 1, 2, and 4 for 1, 31, 9, and 5 modes, respectively. The calculations with the nonadiabatic pulsation code MAD for the equilibrium models with masses between 2 and 15 $M_\odot$ of *Grid 2* are now complete for both p and g-modes with $l \leq 4$ and eigenfrequencies between 0.25 and 25 c/d **[6][36]**.

For 6 multiperiodic SPBs, mode identification is still ongoing. The comparison between the photometric mode identifications based on the calculations of *Grids 1 and 2* revealed no significant differences. The moment method was applied to the observed line profile variations **[20][38]**. The spectroscopic data of the β Cep star 12 Lac obtained during a multi-site campaign revealed 7 independent frequencies and one combination frequency. One mode was identified as radial and one as a sectoral mode **[22][40]**.

One of the many open questions about SPBs, and B-type stars in general, is the presence of magnetic fields. Magnetic fields of a few 100 Gauss were detected in several B-type pulsators based on FORS1 observations **[4]**. A variable magnetic field was clearly detected for HD 55522 and HD 105382, the presence of a magnetic field is suggested for HD 138769, but no such evidence was found in HD 131120 **[5]**. A comparative study between well-studied B-type pulsators and well-studied Bp stars with known periods and magnetic field strengths revealed that: 1) Bp stars are significantly younger than SPBs, 2) longitudinal magnetic fields in SPBs are weaker than those of Bp stars, suggesting that the magnetic field strength is an important factor for B-type stars to become chemically peculiar, and 3) the strongest magnetic fields appear in very young Bp stars, indicating a decay in stellar magnetic fields at advanced ages **[21][25][39]**. We determined the stellar parameters $T_{\rm eff}$, log g, M, R, log L and age using the stellar models of *Grid 2*. We also accurately determined the projected rotational velocity of the SPBs and performed a frequency analysis for the Bp stars with enough data. We showed that a non-linear pulsation model cannot be excluded for e.g. the Bp star HD175362 **[19][37]**. We plan to continue our investigation of magnetic fields in B-type stars **[30][33]**.

B.1.2.2. Main-sequence A-F stars

The region in the H-R diagram where the main sequence interferes with the classical Cepheid Instability Strip (CIS), is of great interest as it hosts A- and F-type stars which are affected by a rich variety of physical processes ongoing in their interiors. This region (the lower end of the CIS) contains a mix of stellar groups showing different atmospheric chemical compositions and behaviours against pulsation and against multiplicity. To study the interplay of these different phenomena and their impact on the occurrence of pulsation, we observed a sample of early to late A-type main sequence stars selected from the catalogue of Grenier et al. (1999). These authors noticed that 32 % of the HIPPARCOS targets have variable radial velocities and assumed that this variability is caused by binarity or multiplicity. However, we suspect that several of these stars are non-radial pulsators showing line profile variations instead of being multiple systems. Combining high-resolution spectroscopy and CCD differential photometry, we therefore explored and reinterpreted the radial velocity variability of several poorly known HIPPARCOS targets located in the lower region of the CIS **[17][26]**. In this way, we discovered two new δ Scuti pulsating stars, one of which is a possible member of a binary system while the other one shows rapidly changing light curves indicative of the presence of multiple pulsation frequencies (this is the case of HIP 113790). Additional observations were obtained at the OHP during the NEON summer school **[8].** Three stars showed line-profile variations in their ELODIE spectra.We further uncovered five new binary or multiple systems (one SB1, three SB2 and one triple system). Using appropriate Fourier techniques, we performed preliminary frequency analyses of a large data set for the multiperiodic variable star HIP 113790. These data were collected in two filters (B, V) during a multi-site campaign held in 2005 using various small instruments across Europe (Belgium & Greece) **[26]**.We also compiled lists of the bona-fide and candidate δ Scuti and γ Doradus stars in order to select the most interesting targets for follow-up observations.

In the same framework, we started a detailed analysis of the spectrum and the spectroscopic variability of the binary and δ Scuti star θ^2 Tau. This target is special because the binary is one of the brightest members of the Hyades cluster. New high-resolution time-series spectra obtained in service mode during a full orbital period (OHP) were combined with archive spectra from the ELODIE database as well as with an older time-series of spectra provided by G. Torres. We applied the code KOREL (Hadrava 1999) to disentangle the component spectra. We succeeded in separating the spectra of the components and in measuring the radial velocities of the much weaker secondary component for the very first time **[16]** (see also Theme “Binaries” for more results).

High-resolution ELODIE spectra were also acquired for the suspected roAp binary system HD 98088. The spectra were reduced and a preliminary analysis was carried out. We suspect the presence of short-period δ Scuti-type variations in the secondary component. This preliminary result needs to be confirmed by an in-depth analysis based on the technique of spectral disentangling for this complex binary system.

We participated to the photometric multisite campaign of RR Lyr, covering more than 10 Blazhko cycles and allowing to perform a detailed analysis of the pulsations and of the Blazhko phenomenon. The light variations were fitted with the main (radial) frequency, its harmonics and the triplet frequencies.There is sufficient evidence that the Blazhko period became notably shorter than the known value of 40.8 days, whereas the main pulsation period remained roughly the same **[9].**

We contributed to a global search for pulsating, mass-accreting components in Algol-type eclipsing binaries (oEA) by observing systems with A0-F2 spectral type primaries: the results were negative. A status report was presented **[10].** We furthermore participated to the multisite campaigns of the SX Phe star BL Cam **[27]** as well as of the oscillating eclipsing binary Y Cam **[28]**.

In collaboration with Dr. Pollard et al., we started setting up multi-site campaigns for (candidate) γ Doradus stars, including binaries, with the aim to obtain high-resolution, high S/N spectra at three Southern observatories (ESO, La Silla, Chile; SAAO, Sutherland, South-Africa; MJUO, Mt. John, New Zealand).

The ESO-proposals were rejected **[29][31]** but the SAAO-proposal was successful (10 nights)**[32]**. A simultaneous campaign will be scheduled at MJUO.

During the recent years, asteroseismic studies of "hot stars" progressed a lot. Hence, the potential of seismology of β Cep, SPB, δ Scuti and γ Doradus stars is excellent **[13][26]**.

B.1.3. Perspective for next years

We will contribute to the classification effort of main-sequence variable stars by gathering high-resolution spectra for candidate pulsating stars, binaries and spotted stars, partly resulting from the Hipparcos space mission and/or from the analysis of multi-colour photometric data obtained with the Mercator telescope. We will organize multi-site campaigns for g-mode main-sequence pulsators (SPB and γ Doradus stars) and analyse the newly acquired data. We will pursue the analysis of the Hyades binary θ^2 Tau in order to improve the accuracy of the radial velocities for the secondary component and to derive the components' chemical composition. A major effort will be dedicated to the study of HD 98088. Due to the high complexity of the composite spectra, we will have to adapt our procedures and proceed - if feasible with the recently obtained spectra - to disentangle the component contributions with the aim to determine accurate fundamental parameters. We will furthermore interpret multi-site data sets of other pulsating stars in binary or multiple systems (such as the oEAs HIP 7666 and CT Her).

B.1.4. Personnel involved

Scientific staff: P. De Cat, Y. Frémat, P. Lampens, J. Cuypers, H. Hensberge

B.1.5. Partnerships

List of international partners without grant

- P.L. Cottrell, K.R. Pollard, D.J. Wright, University of Canterbury, Christchurch, New Zealand
- M. Cunha, Centro de Astrofisica da Universidade do Porto, Portugal
- S. Hubrig, ESO, Chile
- D. Kurtz, University of Central Lancashire, Preston, UK
- P. Škoda, Astronomical Institute of the Academy of Sciences, Ondřejov, Czech Republic
- G. Torres, Harvard-Smithsonian Center for Astrophysics, Cambridge, MA

List of national partners without grant

- C. Aerts et al., Katholieke Universiteit van Leuven (KULeuven), Leuven, Belgium

Grants/Projects used for this research

- Action-1 "Pulsation, chemical composition and multiplicity in main-sequence A- and F-type stars" of the Federal Science Policy (MO/33/018)
- "Modern Aspects of Theoretical and Observational Astrophysics", Federal Science Policy(IAP P5/36)
- OPTICON Transnational Access Programme, European Community
- FNRS: travel and accommodation to OHP
- Project G.0178.02 of the Fund for Scientific Research (FWO) - Flanders (Belgium)

Visitors:

- E. Atanasova, (PhD student), Institute of Astronomy, Sofia, Bulgaria: 3 weeks
- D.J. Wright, (PhD student), University of Canterbury, Christchurch, New Zealand: 1 week

B.1.6. Publications

B.1.6.1. Publications with peer review

[1] 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 Persei
A&A 446 (2006), 583-589

[2] **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
A&A 449 (2006), 281-292

[3] 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
A&A 449 (2006), 305-311

[4] Hubrig S., Briquet M., Schöller M., **De Cat P.**, Mathys G., Aerts, C.
Discovery of magnetic fields in the β Cephei star ξ^1 CMa and in several slowly pulsating B stars
Monthly Notices of the Royal Astronomical Society 369 (2006), L61-L65

[5] Briquet M., Hubrig S., Schöller M., **De Cat P.**
Discovery of magnetic fields in three He variable Bp stars with He and Si spots
Astronomische Nachrichten 328 (2007), 41-45

[6] **De Cat P.**, Briquet M., Aerts C., Goossens K., Saesen S., **Cuypers J.**, Yakut K., Scuflaire S., Dupret M.-A., Uytterhoeven K., Van Winckel H., Raskin G., Davignon G., Le Guillou L., Van Malderen R., Reyniers M., Acke B., De Meester W., Vanautgaerden J., Vandenbussche B., Verhoelst T., Waelkens C., Deroo P., Reyniers K., Ausseloos M., Broeders E., Daszyńska-Daskiewicz J., Debosscher J., De Ruyter S., Lefever K., Decin G., Kolenberg K., Mazumdar A., Van Kerckhoven C., De Ridder J., Drummond R., Barban C., Vanhollebeke E., Maas T., Decin L.
Long term photometric monitoring with the Mercator telescope: Frequencies and mode identification of variable O-B stars
A&A 463 (2007), 243-249

[7] Groenewegen M.A.T., Decin L., Salaris M., **De Cat P.**
The Pleiades eclipsing binary HD 23642 revisited
A&A 463 (2007), 579-588

[8] **Frémat, Y**., Antonova, A., Damerdji, Y., Hansen, C.J., Lederer, M.T., Tüysüz, M., **Lampens, P.,** Van Cauteren, P.
Spectroscopy of HIP 113790 at the 5th OHP NEON summer school
Commun. in Asteroseismology 148, Austrian Academy of Sciences Press (Vienna), 77

[9] Kolenberg, K., Smith, H.A., Gazeas, K.D., Elmaslı, A., Breger, M., Guggenberger, E., Van Cauteren, P., **Lampens, P.,** Reegen, P., Niarchos, P., Albayrak, B., Selam, S.O., Özavcı, I., Aksu, O.
The Blazhko effect of RR Lyrae in 2003-2004
A&A 459, 577

[10] Mkrtichian, D., Kim, S.-L., Kusakin, A. V., Rovithis-Livaniou, E., Rovithis, P. **Lampens, P.,** Van Cauteren, P., Shobbrook, R. R., Rodriguez, E., Gamarova, A., Olson, E. C., Kang, Y. W.
A Search for Pulsating, Mass-Accreting Components in Algol-Type Eclipsing Binaries
Astrophysics and Space Science 304, 169

[11] Robertson, C.W., Van Cauteren, P.,**Lampens, P.,** García-Melendo, E., Groenendaels, R., **Fox, J**., Wils, P.

New frequency analyses of the multiperiodic δ Scuti variables CR Lyn and GG UMa
Commun. in Asteroseismology 148, Austrian Academy of Sciences Press (Vienna), 71

B.1.6.2. Publications without peer review

[12] **De Cat P.**, Briquet M., Aerts C., Goossens K., Saesen S., **Cuypers J.**, Yakut K., Scuflaire R., Dupret M.-A.
Analysis of MERCATOR data - Part I: variable B stars
Communications in Asteroseismology 147 (2006), 48-51

[13] **Cuypers J.**, Goossens K., Schoenaers C., **De Cat P.**, Aerts C.
Analysis of MERCATOR data - Part II: variable A & F stars
Communications in Asteroseismology 147 (2006), 52-55

[14] **Freyhammer L. M.**, **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.
Memorie della Societa Astronomica Italiana 77 (2006), 334

[15] **De Cat P.**, Goossens K., Bouckaert F., Eyer L., **Cuypers J.**, De Ridder J., Aerts C., Dupret M.-A., Grigahcène A. and many observers
Observational results for northern and southern (candidate) γ Doradus stars
Memorie della Societa Astronomica Italiana 77 (2006), 313

[16] **De Cat P.**
A new era of asteroseismology: hot stars
in "Highlights of Recent Progress in the Seismology of the Sun and Sun-Like Stars", 26th General Assembly of the IAU, Joint Discussion 17 (2006), #19

[17] **Frémat, Y., Lampens, P.,** Alecian, E., Balona, L., Catala, C., Goupil, M.-J., Torres, G., Škoda, P.
Spectral separation of two pulsating non-single stars
Memorie della Societa Astronomica Italiana, 77, 521

[18] **Frémat, Y., Lampens, P.,** Van Cauteren, P., Robertson, C. W.
Analysis of main-sequence A-type stars showing radial velocity variability
Memorie della Societa Astronomica Italiana, 77, 174

[19] **Lampens, P.**
Intrinsic Variability in Multiple Systems and Clusters: Open Questions (invited review)
ASP Conference Series, 349, 153, Proceed. *Astrophysics of Variable Stars*, Pecs, Hungary, 5-10 September 2005, Sterken, C. and Aerts, C. (eds), San Francisco

B.1.6.3. Publications in press, submitted

[20] **De Cat P.**
Observational asteroseismology of SPB stars
Communications in Asteroseismology 148 (2007), in press (8 pages)

[21] Zima W., **De Cat P.**, Aerts C.
Mode identification of multi-periodic Slowly Pulsating B-stars: results and problems
Communications in Asteroseismology 148 (2007), in press (2 pages)

[22] Briquet M., Hubrig S., **De Cat P.**, Aerts C., North P., Schöller M.
A comparative study of B-type pulsators and non-pulsating chemically peculiar Bp stars
Communications in Asteroseismology 148 (2007), in press (2 pages)

[23] Desmet M., Briquet M., **De Cat P.**, Aerts C., Handler G., Krzesinski J., Lehmann H., Masuda S., Mathias P., Mkrtichian D.E., Telting J., Uytterhoeven K., Yang S.L.S.

A spectroscopic study of the β Cephei star 12 (DD) Lacertae
Communications in Asteroseismology 148 (2007), in press (2 pages)

[24] Saesen S., Briquet M., **Cuypers J.**, **De Cat P.**, Goossens K.
Asteroseismology of the β Cephei star KP Per
Communications in Asteroseismology 148 (2007), in press (2 pages)

[25] Saesen S., Briquet M., **Cuypers J.**, **De Cat P.**, Goossens K., Aerts C.
Asteroseismology of the β Cephei star KP Per
A&A, submitted

[26] Briquet M., Hubrig S., **De Cat P.**, Aerts C., North P., Schöller M.
On the co-existence of chemically peculiar Bp stars, slowly pulsating B stars and constant B stars in the same part of the H-R diagram
A&A, submitted

[27] **Frémat, Y., Lampens P.** et al.
Search for pulsation among suspected A-type binaries: the multiperiodic δ Scuti star HD 217860
A&A, submitted

[28] E. Rodríguez, S. Fauvaud, J.A. Farrell, A.-Y. Zhou, J.P. Sareyan, M.J. López-González, G. Klingenberg, M.Wolf, A. Rolland, P. López de Coca, P. Van Cauteren, **P. Lampens** & 19 co-authors (2006)
Asteroseismology of the extreme metal-deficient field high-amplitude SX Phe variable BL Ca
Proceedings of the Vienna Workshop on the Future of Asteroseismology, 20- 22 September, University of Vienna, Austria (poster)

[29] E. Rodríguez, J.M. García, V. Costa, P. Van Cauteren, **P. Lampens**, E.C. Olson, P.J. Amado, M.J. López-González, A. Rolland, P. López de Coca, V. Turcu, S.L. Kim, A.-Y. Zhou, M.A. Wood, E. Hintz, A. Pop, D. Moldovan, P.B. Etzel, D.J. Lee, G. Handler, D.E. Mkrtichian (2006)
δ Sct stars in eclipsing binaries: the case of Y Cam
Proceedings of the Vienna Workshop on the Future of Asteroseismology, 20- 22 September, University of Vienna, Austria (poster)

B.1.6.4. Reports, thesis, proposals, etc.

[30] **De Cat P.**, Pollard K.R., Wright D.J., Cottrell P.L., Aerts C.
Towards asteroseismology of γ Doradus stars: a spectroscopic multi-site campaign for HD 34025, HD 40745, HD 55892, and HD 65526
ESO telescope time application for FEROS observations (Run ID 078.D-0195; rejected)

[31] Briquet M., Hubrig S., **De Cat P.**, Schöller M., Aerts C.
The role of magnetic fields in pulsating B-type stars
ESO telescope time application for FORS1 observations (Run ID 078.D-0140; granted 2 nights)

[32] **De Cat P.**, Pollard K.R., Wright D.J., Cottrell P.L., Zima W., **Frémat Y.**, **Lampens P.**, Aerts C.
Asteroseismology of γ Doradus stars: a spectroscopic multi-site campaign for HD 147787, HD 167858, and HD 189631
ESO telescope time application for FEROS observations (Run ID 079.D-0238; rejected)

[33] Wright D.J., **De Cat P.**, **Frémat Y.**, Laney D., Cottrell P.L., Pollard K.R.
Towards asteroseismology of γ Doradus stars: a spectroscopic multi-site campaign for HD 147787, HD 167858, and HD 189631
SAAO telescope time application for GIRAFFE observations (granted 10 nights)

[34] Briquet M., Hubrig S., **De Cat P.**, Schöller M., Aerts C.
The evolution of magnetic fields in B-type stars

ESO telescope time application for FORS1 observations (Run ID 079.D-0241; granted 2 nights)

[35] **Lampens, P.**
Final report of Project 'Variable Components in Binary or Multiple Systems' (Ref. MO/33/007), document for Federal Science Policy

B.1.7. Scientific outreach

Meeting presentations

[1] **De Cat P.**
A new era of asteroseismology: hot stars
Invited talk presented during Joint Discussion 17 of the 26th General Assembly of the IAU (Prague, Czech Republic, August 14-25, 2006)

[2] **De Cat P.**, **Cuypers J.**,and the MERCATOR observers and team
Long term monitoring with the MERCATOR telescope
Contributed talk presented during the Science meeting of Division V of the 26th General Assembly of the IAU (Prague, Czech Republic, August 14-25, 2006)

[3] **De Cat P.**
Observational asteroseismology of SPB stars
Invited talk presented during the Vienna workshop of the Future of Asteroseismology (Vienna, Austria, September 20-22, 2006)

[4] Zima W., **De Cat P.**, Aerts C.
Mode identification of multi-periodic Slowly Pulsating B-stars: results and problems
Poster presented during the Vienna workshop of the Future of Asteroseismology (Vienna, Austria, September 20-22, 2006)

[5] Briquet M., Hubrig S., **De Cat P.**, Aerts C., North P., Schöller M.
A comparative study of B-type pulsators and non-pulsating chemically peculiar Bp stars
Poster presented during the Vienna workshop of the Future of Asteroseismology (Vienna, Austria, September 20-22, 2006)

[6] Desmet M., Briquet M., **De Cat P.**, Aerts C., Handler G., Krzesinski J., Lehmann H., Masuda S., Mathias P., Mkrtichian D.E., Telting J., Uytterhoeven K., Yang S.L.S.
A spectroscopic study of the β Cephei star 12 (DD) Lacertae
Poster presented during the Vienna workshop of the Future of Asteroseismology (Vienna, Austria, September 20-22, 2006)

[7] Saesen S., Briquet M., **Cuypers J.**, **De Cat P.**, Goossens K.
Asteroseismology of the β Cephei star KP Per
Poster presented during the Vienna workshop of the Future of Asteroseismology (Vienna, Austria, September 20-22, 2006)

[8] **Lampens, P**.,
CCD photometry with small- to medium-sized telescopes for up-to-date astrophysical research
Hoher List Colloquium 2006, Hoher List Observatory, Daun, Germany

Editorial responsibilities

- P. Lampens: Referee for Commun. in Asteroseismology, Austrian Academy of Sciences

B.1.8. Missions

Assemblies, symposia:

- P. De Cat (1)
- P. Lampens (2 meetings, 11 days)

Field missions:

- Y. Frémat: Observatoire de Haute-Provence, 1.93-m telescope + ELODIE, Interpretation of variability hints for a sample of HIPPARCOS targets located in the lower Cepheid instability strip (5 nights)
- Y. Frémat & P. Lampens: Observatoire de Haute-Provence, 1.93-m telescope + ELODIE *High-resolution spectroscopic observations of the short-period binary HD 98088*. PI: M.Cunha. (6 nights)
- P. Lampens: *Differential CCD observations of selected δ Scuti variable stars*, Beersel Hills Observatory, 0.4-m telescope + CCD (23 nights, in collaboration with P. Van Cauteren)
- P. Lampens: *Differential photometric observations of eclipsing binaries*, Hoher List Observatory, 1-m telescope + CCD (7 nights)

B.2. Project "Asteroseismology from Space"

B.2.1. Objectives

We are currently involved in the (future) space missions MOST, COROT, and GAIA. These missions (will) provide a huge amount of extremely high-quality data useful for refined asteroseismic studies. Asteroseismology is a major science driver of MOST and COROT. GAIA (launch in 2011) will provide positional and radial velocity measurements with the accuracies needed to produce a stereoscopic and kinematic census of about one billion stars in our Galaxy. Such data will allow to characterize the various stellar populations of our Galaxy. To be well-prepared for the analysis of the unprecedented huge data-flows, it is worthwhile to invest already now a large amount of time in the preparatory aspects of these missions.

B.2.2. Progress and results

B.2.2.1. The MOST and COROT missions

Since the beginning of the COROT mission preparation, an ambitious programme of ground-based observations **[14]** was set-up to provide support to the interpretation of the future data on Be stars. These data allowed to estimate the location of the candidate targets in the H-R diagram **[2]** and to study the effects of fast rotation. Be stars are main-sequence massive stars surrounded by an equatorial disk or flattened envelope that show emission in their spectra. The true origin of the Be phenomenon is still a matter of debate. Rapid, non-critical rotation in combination with one or more other physical processes is believed to provoke matter ejection and, consequently, the formation of the circumstellar equatorial disk. Since Be stars occupy the same hydrodynamically instable region in the H-R diagram as the pulsating β Cep and SPB stars, one of these additional phenomena is presently suspected to be related to the beating of different pulsation modes. This was, however, only confirmed for the Be star μ Cen. With the COROT observations that will soon be available, we hope to identify more cases and to improve the understanding of the origin of these stars.

We analyzed the long-term line profile variations of NW Ser (a Be star targeted during the short runs of the COROT mission) in detail and estimated improved stellar parameters (including the inclination angle of the star) by comparing high resolution data to synthetic spectra computed accounting for the effects of gravitational darkening **[6].** Two frequencies were detected in the line profile variations and confirmed by photometric observations. Additional data collected in 2006 will be combined with the new COROT-data.

Pulsation and rotation are two stellar phenomena that are or may be related to metallicity. In this context, we are pursuing our systematic study of large stellar samples in the Galaxy and in the Magellanic Clouds **[3][4]**. Our latest contribution concerned the Small Magellanic Cloud B and Be stars, where the effect of metallicity on the rotation rates is significant **[12].**

B.2.2.2. The GAIA space mission

2006 was mainly devoted to the distribution of the workload packages amongst the coordination unit (CU) members. P. De Cat is a member of CU6 (“Spectroscopic processing”), CU7 (“Variability processing”) and of the GAIA Hot Star Team (GHOST) (as well as of CU4, see the report of Sect. 4).. He is responsible for the Work Packages “DU-711-02000: Period search”, “DU-712-01000: Extractor”, and “S-660-05000: Assess sources spectroscopic stability/variability”. Y. Frémat is a member of CU6 (“Spectroscopic processing”) and CU8 (“Atmospheric Parameters”). To stay tuned about the activities and the progress of the respective CUs and of GHOST, various meetings were attended **[17]** (see below).

B.2.3. Perspective for next years

The first COROT-data of Be stars will be delivered in the summer of 2007 (e.g. HD 50820 as well as other Be stars of the exoplanetary fields of view). COROT will continue these observations during 2008. We will contribute to the modelling and the interpretation of the pulsation characteristics.

The development of the algorithms for the GAIA mission will take place in 6-months cycles, named after the 10 highest mountains on Earth. The general principle is “to deliver simple and soon, rather than complex and late”. Each GWP work package will therefore have to deliver, very rapidly (one of) the first cycle(s), prototype software with reduced functionality or performances. These will then be improved in successive development cycles or iterations.

B.2.4. Personnel involved

Scientific staff: P. De Cat, Y. Frémat

B.2.5. Partnerships

List of international partners without grant

- L. Eyer, P. Dubath, Observatoire de Genève, Genève, Suisse
- M. Floquet, A.-H. Hubert, C. Martayan, C.Neiner, Observatoire de Paris-Meudon, France
- J. Zorec, Institut d’Astrophysique de Paris, France
- J. Fabregat, J. Gutiérrez-Soto, University of Valencia, Spain

List of national partners without grant

- C. Aerts et al., J. Debosscher, T. Morel, KULeuven, Leuven, Belgium

Grants/Projects used for this research

- Action-1 "Pulsation, chemical composition and multiplicity in main-sequence A- and F-type stars" of the Federal Science Policy (MO/33/018)
- "Modern Aspects of Theoretical and Observational Astrophysics", Federal Science Policy(IAP P5/36)

Visitors:

- C. Martayan, Observatoire de Paris-Meudon, France (5 days)
- J. Zorec, Institut d’Astrophysique de Paris, France (3 days)

B.2.6. Publications

B.2.6.1. Publications with peer review

[1] 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 (B5 II/III) from MOST Space-based Photometry
The Astrophysical Journal 642 (2006), L165-L168

[2] **Frémat, Y**., Neiner, C., Hubert, A.-M., Floquet, M., Zorec, J., Janot-Pacheco, E., Renan de Medeiros, J.
Fundamental parameters of Be stars located in the seismology fields of COROT
A&A, 451, 1053

[3] 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
A&A, 445, 931

[4] 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
A&A, 452, 27

B.2.6.2. Publications without peer review

[5] 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
ASP Conf. Ser. 349, 249

[6] Arias, M. L., Zorec, J., **Frémat, Y.**
Circumstellar rings, flat and flaring discs
Saporo astro-ph/0601069

[7] Cidale, L.S., Torres, A.F., Arias, M.L., Zorec, J., **Frémat, Y**., Vallverdu, R.E.
Fundamental parameters and spectrophotometric variability of He-abnormal stars
to appear in Rev. Mex. A&A

[8] **Frémat, Y**., Zorec, J., Martayan, C., Lanz, T.
CNO abundance determination in massive fast rotating stars
to appear in Rev. Mex. A&A

[9] Levenhagen, R. S., Leister, N. V., Zorec, J., **Frémat, Y.**
Metallicity vs. Be phenomenon relation in the solar neighborhood
Saporo astro-ph/0601071

[10] Martayan, C., Hubert, A.-M., Floquet, M., Neiner, C., **Frémat, Y.,** Zorec, J.
Effects of metallicity, star formation conditions and evolution of B & Be stars
Saporo astro-ph/0602149

[11] Zorec, J., **Frémat, Y.,** Domiciano De Souza, A.
Differential rotation in early type stars
Saporo astro-ph/0601068

B.2.6.3. Publications in press, submitted

[12] 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. II: Small Magellanic Cloud, field of NGC 330
accepted in A&A: astro-ph/0609677

[13] Cidale, L., Arias, M.L., Torres, A.F., Zorec, J., **Frémat, Y.,** Cruzado, A.
Fundamental parameters of He-Weak and He-Strong stars
accepted in A&A

B.2.6.4. Reports, thesis, books etc

[14] Catala, C., … **Frémat, Y**., …
The ground-based observations in preparation and support of the seismology programme
The CoRoT Mission – Pre-Launch Status, ESA SP-1306, 329

[15] **De Cat P.**
Minutes of the 2nd GHOST meeting
http://www.ster.kuleuven.ac.be/~coralie/GHOST2_minutes.txt

B.2.7. Scientific outreach

Meeting presentations

[1] Cidale, L.S., Torres, A.F., Arias, M.L., Zorec, J., **Frémat, Y**., Vallverdu, R.E.
Fundamental parameters and spectrophotometric variability of He-abnormal stars
Poster presentation at the “Massive Stars: Fundamental Parameters and Circumstellar Interactions” colloquium

[2] Debosscher J., Aerts C., Vandenbussche B., Sarro L.M., **Cuypers J.**, **De Cat P.**, Eyer L.
Automated Supervised Classification of Variable Stars
Talk presented during the 2nd GHOST meeting (Marseille, France, Nov. 13-14, 2006), Nov. 14, 2006

[3] **Frémat, Y.,** Zorec, J., Martayan, C., Lanz, T.
CNO abundance determination in massive fast rotating stars
Poster presentation at the “Massive Stars: Fundamental Parameters and Circumstellar Interactions” colloquium

B.2.8. Missions

Assemblies, symposia, workshops:

- P. De Cat (5)
- Y. Frémat (2)

Research visits:

- Y. Frémat (1 week)

C. Science Theme "The Gaia Mission: Characterization of Extreme Stars"

GAIA (launch foreseen in 2011) is one of ESA's cornerstones space missions for the next ten years. It will provide positional and radial velocity measurements with the accuracies needed to produce a stereoscopic and kinematic census of about one billion stars in our Galaxy. In addition to the astrometric information, it will also provide spectrophotometric and spectroscopic data. The huge data processing effort will lead to the classification of the objects and, in the case of stars, to the determination of their basic astrophysical properties. The latter issue will be tackled by CU8 "Astrophysical Parameters" using, in particular, two algorithms, named GSP[4]-Phot and GSP-Spec, which will mainly consist in comparing observations to theoretical models.

C.1. Project "Characterization of Extreme Stars and Stellar Radial Velocity Measurement"

C.1.1. Objectives

Though the general GAIA data processing will be sufficient for most of the observed stars, some categories of "extreme-stars" will require a more elaborated treatment due to the lack of appropriate models and the complexity of the physical phenomena at play. The "Extended Stellar Parametrizer" (ESP) top level workpackage will therefore propose and test alternatives for the analysis of a subset of such stars to provide a better estimate of their astrophysical parameters or/and additional parameters suitable to their specific type. Five Specific Source Units (SSUs) are contributing to the ESP: Hot Stars, Cool Stars, Ultra Cool Dwarf Stars, Abundance Anomalous Stars and Emission Line Stars. The SSUs will study, develop and test algorithms for the estimate of *extended* stellar parameters. Some will also provide the training data (computed and observed) and models required for the testing and calibration of the ESP algorithms as well as of GSP-spec and GSP-phot softwares. We will take part: 1) in the integration of the ESP algorithms; 2) in the modelling of hot and emission line stars (e.g. Be stars); and 3) in the analysis of Ground Based Observations for GAIA (GBOG). Synthetic spectra and astrophysical parameters will further be used as input by CU6 to measure radial and projected rotation velocities by cross-correlation techniques.

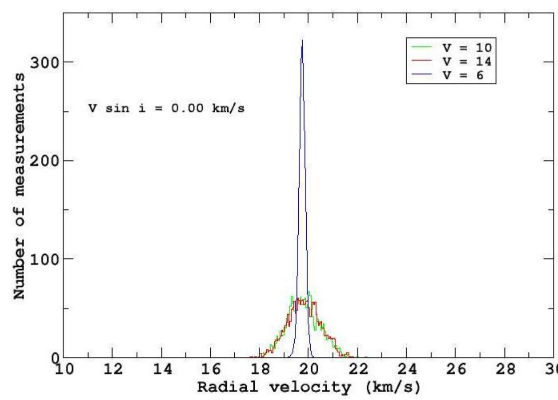


Figure 25: Distribution of the results provided by a Montecarlo simulation of the automated radial velocity measurement by cross-correlation in Fourier space of 3 samples of 1000 spectra with different magnitudes

C.1.2. Progress and results

A first grid of synthetic spectra for O- and B-type stars was delivered to the Data Processing Consortium (DPAC) **[1].** In order to determine the availability and accuracy of the existing atomic data in the wavelength range covered by the RVS spectrometer that will be on-board the satellite, we took advantage of this first delivery to compare systematically existing observations with our theoretical spectra. A good agreement was generally obtained, but we noticed that, in several cases, the strength of the neutral helium lines detected between 8450 and 8750 Å were too strong with respect to the observations. To automatically derive the radial velocities of the stars that will be observed by GAIA, we

[4] GSP: Generalised Stellar Parametrizers.

developed an algorithm based on a cross-correlation technique in Fourier Space. Preliminary tests were performed using a FORTRAN prototype (Figure 25).

C.1.3. Perspective for next years

In 2007, the development of the ESP algorithms will start and the delivery of synthetic spectra for massive stars will be continued. To meet the standards specified by the DPAC, we will develop our radial velocity measurement algorithm in *JAVA*.

C.1.4. Personnel involved

Scientific staff: Y. Frémat, R. Blomme

C.1.5. Partnerships

List of international partners without grant

- M. Floquet, A.-H. Hubert, C. Martayan, C.Neiner, Observatoire de Paris-Meudon, France
- J. Zorec, Institut d'Astrophysique de Paris, France
- J.-C. Bouret, LAM, Marseille, France

List of national partners without grant

- K. Lefever, KULeuven

Grants/Projects used for this research

- PNPS (France): GHOST and GBOG meetings in Marseille (travel and accommodation)
- SSPAIV: 1st and 2nd CU8 meetings (travel and accommodation)

Visitors:

- C. Martayan, Observatoire de Paris-Meudon, France (1 week)
- J. Zorec, Institut d'Astrophysique de Paris, France (3 days)

C.1.6. Publications

C.1.6.1. Publications with peer review

None

C.1.6.2. Publications without peer review

[1] Bouret, J.-C., Lanz, T., **Frémat, Y**., Martins, F., Lefever, K., Blomme, R., Martayan, C., Neiner, C., Quinet, P., Zorec, J.
The spectra of massive stars with Gaia
To appear in Rev. Mex. A&A

C.1.7. Scientific outreach

Meeting presentations

[1] 1st GHOST meeting, ROB, Brussels (Belgium)
Contribution of the ROB to the GHOST

[2] 1st CU8 meeting, Observatoire de la Côte d'Azur, Nice (France)
The Extended Stellar Parametrizer

[3] 1st GBOG meeting, Observatoire de Paris (France)
Ground based observations for the ESP

[4] Modeling GHOST meeting, LAM, Marseille (France)
Algorithms for CU8

[5] 2nd GHOST meeting, LAM, Marseille (France)
Choice of hot and emission line stars for GBOG

[6] 2nd CU6 meeting, ROB, Brussels (Belgium)
RV measurement by cross-correlation in Fourier Space

[7] 2nd CU8 meeting, MPIA, Heidelberg (Germany)
The Extended Stellar Parametrizer (cycle 2)

Websites

- Y. Frémat: Creation of a Gaia web page: http://www.astro.oma.be/gaia/

C.1.8. Missions

Assemblies, symposia:

- Y. Frémat (3)

D. Science Theme “Optisch Station voor Stellair Onderzoek te Humain”

D.1. Project “Humain Observatory for Astrophysics of Coeval Stars” (HOACS)

D.1.1. Objectives

Het radio-astronomisch station van Humain, dat deel uitmaakt van de Koninklijke Sterrenwacht, is nog steeds een geprivilegieerde site in België voor wat betreft ligging en lichtvervuiling en is daarom geschikt voor de oprichting van een optische sterrenwacht. De bedoeling is om op deze site een kleine maar professioneel uitgeruste sterrenwacht uit te bouwen die doelgericht gebruikt kan worden voor een aantal specifieke waarnemingsprogramma’s. Het project “HOACS” werd opgestart met de bedoeling om waarnemingen van (intrinsieke zowel als extrinsieke) veranderlijke sterren in betere omstandigheden dan in de regio Brussel te kunnen voortzetten, dit ter ondersteuning van bestaande onderzoeksprogramma’s.

D.1.2. Progress and results

Tijdens de zomer van 2005 werd het dossier met het voorstel voor de bouw van een kleine sterrenwacht voor optische instrumenten op de site van het radio-astronomische station te Humain bij de Waalse Regie der Gebouwen ingediend. Een eerste bijeenkomst werd gehouden te Humain op 11/08/2005 met alle betrokken partijen, o.a. de vertegenwoordiger van de Waalse Regie (provincie Luxemburg). Het dossier van de aankoop van een tweedehands Rademakers Minimount werd opgesteld.op 28/09/2005 Inbegrepen in dit voorstel is een 40cm f/15 Cassegrain/Nasmyth telescoop die verbouwd zal worden tot een f/3.75 Newton telescoop.In september 2005 werden de technische schema’s opgesteld (met aangepaste correcties in 2006). Na het afwijzen van de eerste aanvraag, werd het dossier opnieuw ingediend bij de Regie der Gebouwen tijdens de zomer van 2006. Deze aanvraag werd toegekend (aan de firma L. Alexandre, Saint-Hubert) in september 2006. Een tweede bijeenkomst werd gehouden op 26/09/2006 te Humain met alle (vernieuwde) betrokken partijen. Kort nadien volgde een onderhoud met Dhr. L. Alexandre (algemene bouwaannemer) in de regio Brussel (waar een gelijkaardige en operationele sterrenwacht als voorbeeld te zien is) en werd een uitgebreide specificatielijst voor de Regie uitgewerkt. De onderstaande illustraties geven een beeld weer van de aanvang van de werken: (okt. 2006, zie foto 1) en een stand van zaken (feb. 2007, zie foto 2).

Foto 1: Stand op 11/11/06

Foto 2: Stand op 04/02/07

D.1.3. Perspective for next years

Tot onze doelstellingen voor het volgend jaar behoren het opstellen van de instrumenten (HULC1 en HULC2) en van de waarnemingsprocedure evenals het opstarten van de waarnemingen op de site van Humain. Meer bepaald komen de volgende waarnemingsprogramma's in aanmerking:

- waarnemingen van pulserende veranderlijken van het type δ Scuti, SX Phe of γ Dor, al dan niet in binaire of meervoudige systemen;
- zoektocht naar pulserende componenten van eclipserende dubbelsterren van het type Algol (dubbelsterren waar mass-transfer nog volop bezig is), genaamd 'oscillating EA's';
- waarnemingen van eclipserende dubbelsterren met korte omloopsperiodes en excentrische banen;
- geselekteerde RR Lyrae sterren met het Blazhko fenomeen.

D.1.4. Personnel involved

Scientific staff: P. Lampens (projectleider)

Technical staff: V. Rogge, P. Janssens

DEPARTMENT 3: Astrophysics

SECTION 6: Astrophysics of Galactic and Extragalactic Objects

SECTION 7: Physics of Stellar Atmospheres

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 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 (B.1, B.2), a cooperation that develops further with the involvement in the aforementioned echelle spectrograph and in the preparations for the GAIA mission.

A. Science Theme "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. Project "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

Structure consisting of co-rotating interaction regions (CIRs) was studied using the Zeus hydrodynamical code. These CIRs are thought to be able to explain the discrete absorption components (DACs) seen in the ultraviolet spectral lines. We used the Zeus code to make hydrodynamical models in order to test this hypothesis quantitatively. A typical example of the output from the Zeus code is shown in Figure 26. The colour scale shows the density enhancement (compared to a smooth wind). Three CIRs are visible (the “spiral arms”); these density enhancements are responsible for the DACs seen in certain line profiles.

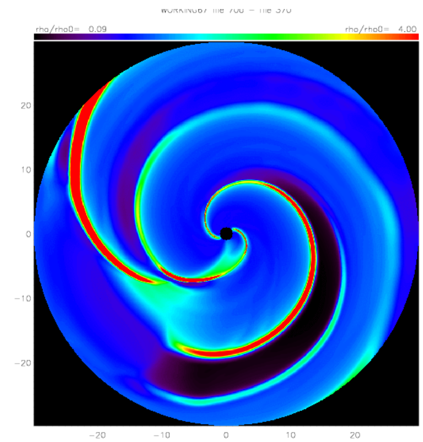


Figure 26: Hydrodynamical simulation of co-rotating interaction regions in the equatorial plane of a hot-star wind.

To calculate the spectral line profiles resulting from this hydrodynamical input, we used the radiative transfer code (Wind3D) specifically developed for this purpose. This code solves the 3-dimensional radiative transfer problem with an arbitrary 3-dimensional velocity field and incorporates the important effects of non-local thermodynamic equilibrium.The FORTRAN code (~4500 lines) has been developed for high-performance computers with parallel processing. Wind3D currently runs on the 64-bit 56 CPU compute server of the Space Pole. The code has been carefully load balanced for utilizing the OpenMP programming strategy, and shows excellent scaling properties for parallel processing.

The theoretical spectral line calculations are compared to the dynamic spectrum of the Si IV doublet lines of the early B-type Ib supergiant HD 64760 (see Figure 27 & Figure 28). The calculations with Wind3D enable us to infer the detailed physical and geometric properties of the CIRs from the DACs observed in the Si IV line profiles. The DACs are recognized as rather narrow absorption features observed to appear around ~1 day and ~11 days, drifting towards shorter wavelengths (Figure 27). We find that the observed time evolution of the DACs is well reproduced by our models (Figure 28). Very preliminary results of this work were presented in **[11]**.

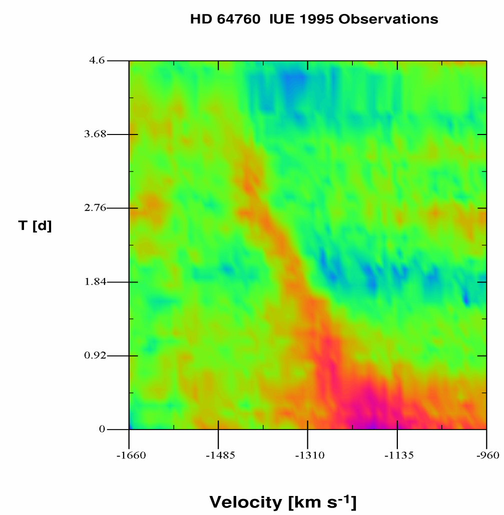
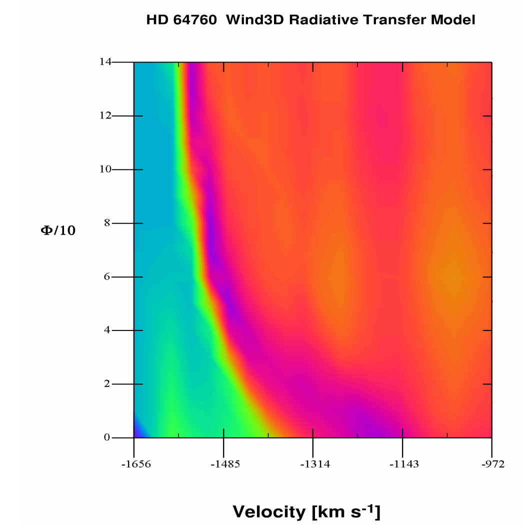
	

Figure 27: The dynamic spectrum of the Si IV ultraviolet line observed in a hot star reveals a DAC. The DAC displaces toward larger velocities over time (upward) due to rotating structures in the stellar wind.	**Figure 28: Theoretical model of a DAC computed with 3D line transport of radiation in a hydrodynamic model of the stellar wind. The width of the DAC decreases over time because the wind velocity dispersion decreases with distance from the star.**

On the observational side, we continued our work on non-thermal radio emitters. HD 167971 is a triple system and 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. Our own data from the Very Large Array (VLA) and the Australia Telescope Compact Array (ATCA) were supplemented by archive material from the VLA. The analysis of this dataset shows that we do not detect the inner colliding-wind region, but we do detect the collision region between the binary and the third star. A paper on this research is in press **[9]**. For another non-thermal radio emitter, the binary Cyg OB2 No. 8A, we collaborated in research (led by colleagues from the Université de Liège) on the X-ray observations. A paper on this research was published **[1]**.

The work on non-thermal radio emitters was continued by reducing the large amount of data available for Cyg OB 2 No. 9 (with the help of Joan Vandekerckhove). Preliminary reductions show that there is a 2.35-year period in the radio data. This strongly suggests that this seemingly single star is actually a binary. Synchrotron emission from the colliding-wind region explains the non-thermal radio emission. Summaries of the work on non-thermal emitters were presented in **[7, 8].**

For stars with thermal radio emission, we obtained ATCA observations of three B supergiants. These data have been reduced. Detailed models for the atmosphere and stellar wind still need to be made in order to interpret the data. In preparation for a legacy proposal on the e-MERLIN radio telescope (PI: R.K. Prinja, University College London), we compiled lists of possible interesting targets. A summary of the work on stars with thermal radio emission was presented in **[6, 7].**

An observing proposal on the Japanese infrared satellite Akari was also accepted. This proposal will look at six hot stars, attempting to find evidence of clumping in their stellar winds at distances of a few stellar radii above the stellar surface. The long-wavelength infrared continuum observations possible with Akari are ideally suited to cover this region of the wind.

Work was also started on the preparation of the Gaia mission. We are involved in work packages which will measure radial and rotational velocities by a minimum distance method. A small part of this work is presented in **[12]**. We are also involved in CU8 (Astrophysical Parameters), where we will collaborate on providing model spectra of hot stars for the determination of astrophysical parameters (in collaboration with Y. Frémat). As part of that effort, we started working with the stellar wind and atmosphere code CMFGEN. This code will also be useful in calculating models for which we obtained the ATCA data.

A.1.3. Perspective for next years

We will continue to refine the application of the Zeus hydrodynamics code and apply it to specific stars. After completing the implementation phase of Wind3D, the code will be further fine-tuned to achieve highest possible computational performance. Important new and quantitative results about the physical conditions of co-rotating interaction regions and clumped structures in winds of massive hot stars will therefore be obtained in the course of 2007. Next the new research results will be thoroughly compared with the existing scientific literature.

The reduction of existing and new radio data on thermal and non-thermal radio emitters will continue. Publications on Cyg OB2 No. 9 and No. 8A have a high priority. For the thermal emitters, CMGEN models will be constructed. Work will also continue on the Gaia mission, where a first version of a code to determine radial and rotational velocities will be implemented.

A.1.4. Personnel involved

Scientific staff: R. Blomme, A. Lobel

Technical staff: J. Vandekerckhove

A.1.5. Partnerships

List of international partners without grant

- Y. Viala, C. Delle Luche, D. Katz, Observatoire de Paris-Meudon, France
- R. K. Prinja, University College London, UK
- S. Van Loo, University of Leeds, UK
- S. M. Dougherty, Dominion Radio Astrophysical Observatory, Canada
- S. P. Owocki, University of Delaware, USA

List of national partners without grant

- G. Rauw, M. De Becker, E. Gosset, Université de Liège

Grants/Projects used for this research/service

- Belgian Science Policy Office: return mandate 2005-2007
- IUAP project P5/36
- FWO Grant (J. Cuypers)

Visitors: 1

A.1.6. Publications

A.1.6.1. Publications with peer review

[1] 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, 371, 1280 - 1040

[2] Gorlova N., **Lobel A.**, Burgasser A. J., Rieke G. H., Ilyin I., & Stauffer J. R.
On the CO Near-Infrared Band and the Line-splitting Phenomenon in the Yellow Hypergiant Rho Cassiopeiae

The Astrophysical Journal, Vol. 651, Issue 2, pp. 1130-1150.

[3] Gorlova N., & **Lobel A.**
UKIRT Spectra Unravel Mysteries of the Extreme Hypergiant Rho Cassiopeiae
United Kingdom Infrared Telescope Newsletter - Issue 19, Autumn 2006.

[4] Van Loo, S., Runacres, M. C., **Blomme, R.**
Can single O stars produce non-thermal radio emission?
Astron. Astrophys., 452, 1011 - 1019

A.1.6.2. Publications without peer review

[5] **Lobel A**., Avrett E. H., & Aufdenberg, J. P.
Semi-empiric Radiative Transfer Modeling of FUSE Stellar Spectra
in "Astrophysics in the Far Ultraviolet: Five Years of Discovery with FUSE", ASP Conference Series, Vol. 348, Proceedings of the Conferenc held 2-6 Aug., 2004 in Victoria, B.C., Canada. Edited by G. Sonneborn, H. Moos, and B-G Andersson, p. 171

A.1.6.3. Publications in press, submitted

[6] **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*

[7] **Blomme, R**.
Radio observations of mass loss in OB stars
Proceedings of “Mass loss from stars and the evolution of stellar clusters”, Eds. A. de Koter, L. Smith and R. Waters, *in press*

[8] **Blomme, R.**, Van Loo, S., De Becker, M., Rauw, G., Dougherty, S.M., Runacres, M.C.
Non-thermal radio emission from the colliding winds of O-star binaries
Proceedings of “Massive Stars: Fundamental Parameters and Circumstellar Interactions”, Eds. P. Benaglia, G. Bosch, & C.E. Cappa, *in press*

[9] **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., *in press*

[10] **Lobel, A**.
SpectroWeb: An Interactive Graphical Database of Digital Stellar Spectral Atlases
in "The Ultraviolet Universe: Stars from Birth to Death", 26th meeting of the International Astronomical Union, Joint Discussion 4, 16-17 Aug. 2006, Prague, Czech Republic, JD04, No. 22, Publications of the University of Madrid, in press

[11] **Lobel, A**., & **Blomme, R**., 2006,
Three Dimensional Radiative Transfer in Winds of Massive Stars: Wind3D
in "The Ultraviolet Universe: Stars from Birth to Death", 26th meeting of the International Astronomical Union, Joint Discussion 4, 16-17 August 2006, Prague, Czech Republic, JD04, No. 24, Publications of the University of Madrid, in press.

A.1.6.4. Reports, thesis, etc

[12] Sartoretti, P., Katz, D., **Blomme, R.**, Crifo, F., Delle Luche, C., **Frémat, Y**., Gosset, E., Jasniewicz, G., Viala, Y.
Simulation requirements for spectroscopic processing for cycle 2
Gaia report no. GAIA-C6-SP-OPM-PS-002-1

A.1.7. Scientific outreach

Meeting presentations

[1] **Blomme, R.**
Radio observations of mass loss in OB stars
Conference "Massive Stars: Fundamental Parameters and Circumstellar Interactions", poster presentation

[2] **Blomme, R., Lobel, A.**
Radial and rotational velocity determination by minimum distance method
2nd CU6 workshop, Brussels, contributed talk

[3] **Blomme, R**., Van Loo, De Becker, M., Rauw, G., Dougherty , S. M., Runacres, M.C.
Non-thermal Radio Emission from the Colliding Winds of O-star Binaries
Workshop "Massive Stars: Fundamental Parameters and Circumstellar Interactions", Carilo, Argentina, poster presentation

[4] **Lobel, A.**
SpectroWeb: An Interactive Graphical Database of Digital Stellar Spectral Atlases
Poster display JD4-22 at 26th meeting of the International Astronomical Union, Joint Discussion 4, 16-17 August 2006, Prague, Czech Republic.

[5] **Lobel, A**., **Blomme, R.**
Three Dimensional Radiative Transfer in Winds of Massive Stars: Wind3D
Poster display JD4-24 at 26th meeting of the International Astronomical Union, Joint Discussion 4, 16-17 August 2006, Prague, Czech Republic.

Editorial responsibilities

- R. Blomme: Referee for Bulletin de la Soc. Roy. des Sci. de Liège (1 manuscript), Astronomy & Astrophysics (1 manuscript), Astrophyical Journal (1 manuscript)
- A. Lobel: Referee for The Astrophysical Journal (2 manuscripts), The Astronomical Journal (1 manuscript), Publications of the Astronomical Society of Japan (1 manuscript)

Expertise, Audit

- R. Blomme: Referee for VLA/VLBA proposals (Very Large Array/Very Long Baseline Array)
- R. Blomme: Review of an FNRS application "Chargé de recherches"

Websites

- R. Blomme: Contents website of "Hot Star Group" of the Observatory (webmaster = Joan Vandekerckhove)
- A. Lobel: SpectroWeb: An Interactive Graphical Database of Digital Stellar Spectral Atlases at spectra.freeshell.org

A.1.8. Missions

Assemblies, symposia (number):	Blomme R.	(3)
	Lobel A.	(3)
Commissions, working groups (days):	Blomme R.	(4)
	Lobel A.	(5)
Research visits (days):	Blomme R.	(9)
Field missions (days):	Blomme R.	(10)

A.2. Project "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 earlier mass loss, which also influences the evolution of the central star). Hence, these objects provide excellent laboratories of astrophysical processes.

A.2.2. Progress and results

A.2.2.1. Sakurai's Object

When intermediate mass stars reach the final stages of their evolution, they experience thermal pulses. These are semi-periodic helium shell flashes that occur mostly at the tip of the AGB. It is theorized that about 25% of all objects will experience one additional (very) late thermal pulse (VLTP) 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. A strong prediction of this model is that the star will evolve back to a temperature of 80,000K within the next 5 to 10 years. In an international collaboration we are monitoring this evolution. A progress report of this campaign was presented in [2]. We have obtained new radio observations (VLA) and optical spectra (FORS1/2 on the VLT) in 2006. This year the reduction of the VLA and optical data from 2005 and 2006 has been completed. Exciting new insights resulted from these observations. The radio flux shows a marked increase between 2005 and 2006, while the optical data of 2005 and 2006 show a steady decline in flux as well as excitation level compared to the 2001 spectrum. Taken at face value these results seem contradictory. Our interpretation is that in the optical we see the spectrum of a shock which occurred between 1999 and 2001 and which is currently dissipating. The radio flux observed in 2004 and 2005 probably also originated in that shock. The marked increase in radio flux in 2006 is ascribed to an increase in temperature of the central star, now starting to photoionize carbon. The central star temperature must be lower than hitherto thought. A paper describing the new observations is currently in preparation.

A.2.2.2. CK Vul

CK Vul suddenly brightened in 1670 and was long thought to be a nova. Modern observations made this classification very unlikely and currently the most promising theory is that this star is one of a handful of known post-VLTP objects. As such it will help us better understand what Sakurai's object will look like in a few centuries time and thus better constrain models for Sakurai's object. Based on radio data and optical (Hα+[N II]) images we performed an in-depth analysis of the nebula surrounding this object. We detected for the first time a very faint and large (70 arcsec) bipolar emission nebula. By comparing our image obtained in 2004 with a similar image from 1991, we could clearly determine that the inner parts of the nebula are expanding (the outer parts were not covered by the 1991 image). By studying the rate of expansion we found that the nebula originated in the 1670 explosion. Furthermore we discovered a very compact radio source which coincides with the center of the nebular expansion. This radio source has no optical counterpart. We believe that the radio emission originates in the vicinity of the central star which has not been detected so far. The radio emission is consistent with free-free emission, and we believe this emission to originate in a circumstellar or circumbinary disk. These results were discussed in [6] and [7].

A.2.2.3. Abundance Analysis of post-AGB Stars

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 are continuing the collaboration with Van Winckel and Reyniers at the KU 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 2006 we have finalized the analysis of the Geneva photometry we obtained for both objects. We also collected photometry from various sources in the literature. We have produced the final fit of these data in order to determine the luminosity of both objects, as well as the extinction. The abundance analysis of both stars is also complete and a paper describing the work is currently nearing completion.

A.2.2.4. Modeling UVES spectra of post-AGB stars

In 2006 we also started modeling UVES spectra of four emission line post-AGB stars. We obtained funds to hire Darko Jevremovic who started working in September at the ROB. His task is to produce non-LTE wind-blanketed stellar atmosphere models using the Phoenix code that match the observed spectra. For this purpose, he built a small grid of NLTE models with a temperature range from 10000 to 12000 K and different characteristics of the stellar wind (terminal velocity, wind beta, mass-loss ratio). For this preliminary grid we treated H, He, Ca, Mg, and Na in NLTE. Our first results show fair agreement with the observed spectra. Differences, which occur in some spectral lines, are due to uncertainties in abundances (which we intend to address by varying the abundance of the elements), as well as the need to treat more elements in NLTE (which is dependent on available computer resources).

A.2.2.5. The morphology and kinematics of IRAS 16594-4656 in the near infrared

The near-infrared spectrum of IRAS 16594-4656 shows strong shock excited H_2 and [Fe II] emission lines. The goal of the project is to determine the location of the H_2 and [Fe II] shock emission in this multipolar post-AGB star and to determine the shock velocities. In addition to our own high resolution near infrared spectra, new high resolution spectra of H_2 1-0 S(1), obtained with the phoenix instrument, were retrieved from the archive and all data were re-reduced in the same manner and re-analyzed to clarify the morphology and kinematics of the object. We confirmed that not only the H_2 emission, but also the [Fe II] emission are extended. These lines don't usually coexist in the same region. Indeed the H_2 emission originates at the edge of the lobes, while the [Fe II] emission originates close to the central star. The Paβ emission appears to originate close to the central star as well, but the seeing conditions were a lot worse and it remained unresolved. We made a representation of the bipolar morphology at the derived angle of orientation. It has become clear that the morphology of IRAS 16594-4656 is more complicated than the prototypical bipolar nebulae. We do see multiple kinematical components in this multipolar nebula. The results have been written up for publication and will be submitted soon.

A.2.2.6. HST Snapshot survey of post-AGB objects and proto-planetary nebulae

Within an international collaboration we did a Hubble Space Telescope (HST) snapshot survey of post-AGB objects. The project has as aim to complement existing HST images of PPN and to connect various types of nebulosities with physical and chemical properties of their central stars. We presented the results in a paper submitted to ApJ [10]. Nebulosities are detected in 13 of 31 sources. Images and photometric and geometric measurements are presented. The remaining 18 sources are classified as stellar post-AGB objects. Most of the stellar sources probably have low mass progenitors and may not become PNe.

A.2.2.7. NGC 7027

NGC 7027 is the brightest planetary nebula at radio wavelengths. Its spectral energy distribution is a classical case of free-free emission: optically thick below 2GHz, optically thin above 5 GHz, and the turn-over range in between. The well-understood radio SED and the bright, compact nebula makes NGC 7027 a valuable calibrator at a wide range of frequencies. It also allows us to tie together the high frequency calibrators (planets) and the low frequency ones (radio galaxies). We have data from a 25-year monitoring program with the VLA showing a clear evolution in the radio flux: an increase of the optically thick flux and a decrease of the optically thin flux. The former is the result of the expansion of the nebula lowering the optical depth, while the latter is the result of the evolution of the central star. Using these data we derived independent values for the distance and for the stellar mass. The latter is the first such determination for a PN. First results were presented in [4]. A paper describing this work is currently in preparation.

A.2.2.8. IRAS12316-640: a new symbiotic Mira?

We discovered IRAS12316-6401 in our search for obscured PNe from the IRAS catalogue. The evolutionary status of this object is still under debate (see [5]). From IRAS and MSX photometry it is clear it has an extended circumstellar envelope containing cool dust, which is typical for PNe. However, the high-resolution optical emission line spectrum obtained with EMMI shows very broad emission lines with velocities up to at least 600 km/s. This is not normally observed in regular PNe, but is typical for symbiotic binaries. The emission line spectrum shows high excitation lines from [Fe VII] and possibly also [Fe VI], which is also unusual for PNe since iron is strongly depleted into refractory grains. The broad emission lines must therefore be formed in gas where grains never were formed, or where they have been fully destroyed. The information in the spectroscopic image suggests that this system is driving a powerful jet which is aimed almost directly at us. This jet is ionized by a hot white dwarf. It seems very plausible that a binary companion is feeding the material for the jet. However, to date no direct evidence for the existence of such a companion exists. No stellar continuum has been detected in the spectrum, possibly due to extinction by dust. The evidence we have gathered so far is pointing toward the fact that this is an extended symbiotic Mira, but the proof is not yet conclusive. If this is confirmed by future observations, IRAS12316-6401 would only be the 9th object in the elusive class which may be important to better understand the formation of bipolar PNe.

A.2.2.9. Distance determination to NGC 55 from the planetary nebula luminosity function

In article [2], we analysed [O III], Hα, and continuum images of the Sculptor Group Spiral Galaxy. We identified 21 new planetary nebula candidates. We constructed the [O III]λ5007 planetary nebula luminosity function (PNLF) and determined a most likely distance of 2.3 ± 0.35 Mpc. The distance to NGC 55 is a bit larger than previously determined distances, which means that the Sculptor Group is a bit further away from the Local Group than previously thought. The PNLF distance to NGC 55 is comparable to the PNLF distance to NGC 300, adding support to the suggestion that these galaxies form a bound pair. There doesn't seem to be a shortage of planetary nebula candidates in this metal poor galaxy.

The results of the referee's requests, together with his comments, were incorporated in the article.

A.2.3. Perspective for next years

During the evolution towards 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.

A.2.4. Personnel involved

Scientific staff: G.C. Van de Steene, P.A.M. Van Hoof, D. Jevremovic

A.2.5. Partnerships

List of international partners without grant

Sakurai
- Albert A. Zijlstra, University of Manchester
- Marcin Hajduk, Centrum Astronomii, Torun
- Don Pollacco, Queen's University Belfast
- Nye Evans, School of Chemistry and Physics, Keele
- Steward P.S. Eyres, Centre for Astrophysics, Preston
- Florian Kerber, ESO, Garching
- Stefan Kimeswenger, Institut für Astrophysik, Innsbruck
- Jorge Lopéz, UNAM, Ensenada
- Mikako Matsuura, National Astronomical Observatory of Japan
- Myfanwe Bryce, Jodrell Bank Observatory, Manchester
- Krzysztof Gesicki, Centrum Astronomii, Torun

IRAS 16594-4656
- T. Ueta, Dept. of Astronomy and Astrophysics University of Denver, USA

HST snapshot survey
- T. Ueta, Dept. of Astronomy and Astrophysics University of Denver, USA
- N. Siódmiak, Space Telescope Science Institute, USA
- M. Meixner, Space Telescope Science Institute, USA
- Sugerman, Goucher College, USA
- R. Szczerba, N. Copernicus Astronomical Center, Poland

NGC 7027
- Albert A. Zijlstra, University of Manchester
- Rick A. Perley, NRAO, Socorro

Galactic Center PNe
- Panos Boumis, National Observatory of Athens
- Stavros Akras, National Observatory of Athens

NGC 55
- George H. Jacoby, WIYN, USA
- Robin Ciardullo, Pennsylvania State University, USA

List of national partners without grant

- Hans Van Winckel, K.U. Leuven
- Maarten Reyniers, K.U. Leuven
- Herwig Dejonghe, University of Gent
- Christophe Praet, University of Gent

Grants/Projects used for this research/service

- Belspo-IAP
- Belspo-Action 1

A.2.6. Publications

A.2.6.1. Publications with peer review

[1] 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, 369, 875

[2] **Van de Steene, G. C.**, Jacoby, G.H., Praet, C., Ciardullo, R., Dejonghe, H.,
Distance determination to NGC55 from the planetary nebula luminosity function
A&A, 455, 891

[3] Nava, Aida; Casebeer, Darrin; Henry, Richard B.C.; **Jevremovic, Darko**
On the Determination of N and O Abundances in Low-Metallicity Systems
ApJ 2006, 645, 1076

A.2.6.2. Publications without peer review

[4] **van Hoof P.A.M.**, Bryce M., Evans A., Eyres S.P.S., Hajduk M., Herwig F., Kerber F., Kimeswenger S., Lopéz J.A., Matsuura M., Pollacco D.L., **Van de Steene G.C.**, Zijlstra A.A.
The Real-Time Evolution of Sakurai's Object and other (V)LTP objects
IAU symp. 234 `Planetary Nebulae in our Galaxy and Beyond', p. 75

[5] Boumis P., Akras S., **van Hoof P.A.M., Van de Steene G.C.**, Papamastorakis J., Lopéz J.A.
New Planetary Nebulae towards the Galactic Bulge
IAU symp. 234 `Planetary Nebulae in our Galaxy and Beyond', p. 373

[6] Perley R.A., Zijlstra A., **van Hoof P.**
The Radio Evolution of NGC7027
Proceedings of the 209th AAS meeting, #92.02, BAAS, Vol. 38

[7] **Van de Steene, G.C.**, Jacoby, G.H., Praet, C., Ciardullo, R., Dejonghe, H.
The PNLF distance to the Sculptor Group Galaxy NGC 55
'Planetary Nebulae beyond the Milky Way', ESO Astrophysics Symposia, Springer, p. 91

[8] Chaboyer, Brian C.; Dotter, A.; Baron E.; Ferguson, J.; **Jevremovic**, D.; Sarajedini, A
The HST/ACS Survey of Galactic Globular Clusters: New Stellar Evolution Tracks, Isochrones and Luminosity Functions
2007 AAS/AAPT Joint Meeting, American Astronomical Society Meeting 209, #100.10

[9] Dotter, Aaron L.; Chaboyer, B.; Baron, E.; Ferguson, J. W.; **Jevremovic,D**.; Lee,H.; Worthey,G.
Self-Consistent Stellar Evolution Models with Updated Physics and Variable Abundances
2007 AAS/AAPT Joint Meeting, American Astronomical Society Meeting 209, #40.03

A.2.6.3. Publications in press, submitted

[10] **van Hoof P.A.M., Van de Steene G.C.**
IRAS12316-6401: A New Symbiotic Mira?
Proceedings of the workshop on `evolution and chemistry of symbiotic stars, binary post-AGB stars and related objects', in press

[11] Hajduk M., Zijlstra A.A., Evans A., Kerber F., **van Hoof P.A.M.**, Pollacco D.L., Eyres S.P.S., Kimeswenger S., Gesicki K.
Nova 1670 Vul
Proceedings of the workshop `Why Galaxies Care About AGB Stars', in press

[12] Hajduk M., Zijlstra A.A., **van Hoof P.A.M.**, Lopéz J.A., Drew J.E., Evans A., Eyres S.P.S., Gesicki K., Greimel R., Kerber F., Kimeswenger S., Richer M.

The enigma of CK Vul: the central star and nebula of the oldest nova
MNRAS, submitted

[13] N. Siodmiak, M,. Meixner, T. Ueta, B. Sugerman, **G.C. Van de Steene**, R. Szczerba
HST snapshot survey of post-AGB objects and proto-planetary nebulae
Submitted to Astrophysical Journal

[14] Aaron Dotter, Brian Chaboyer, **Darko Jevremovic**, Eddie Baron, Jason Ferguson,
An ACS Galactic Globular Cluster Survey: Stellar Evolution Tracks, Isochrones, Luminosity Functions and Synthetic Horizontal Branch Models,
ApJ submitted

[15] Aaron Dotter, Brian Chaboyer, Jason Ferguson, Lee, Hyun-chul; Worthey, Guy , **Darko Jevremovic**, Eddie Baron
Stellar Population Models and individual Element Abundances I: Sensitivity of stellar Evoulution Paramaeters
ApJ submited

A.2.7. Scientific outreach

Meeting presentations

[1] **van Hoof P.A.M.**, Bryce M., Evans A., Eyres S.P.S., Hajduk M., Herwig F., Kerber F., Kimeswenger S., Lopéz J.A., Matsuura M., Pollacco D.L., **Van de Steene G.C.**, Zijlstra A.A.
The Real-Time Evolution of Sakurai's Object and other (V)LTP objects
Invited contributed talk at IAU symp. 234 `Planetary Nebulae in our Galaxy and Beyond'

[2] **van Hoof P.A.M.**, Bryce M., Evans A., Eyres S.P.S., Hajduk M., Herwig F., Kerber F., Kimeswenger S., Lopéz J.A., Matsuura M., Pollacco D.L., **Van de Steene G.C.**, Zijlstra A.A.
The Real-Time Evolution of Sakurai's Object and other (V)LTP objects
Oral presentation at the FRNS Contact Group Meeting

[3] van Hoof P.A.M., Van de Steene G.C.
IRAS12316-6401: A New Symbiotic Mira?
Poster presentation at the workshop on `evolution and chemistry of symbiotic stars, binary post-AGB stars and related objects'

Editorial responsabilities

- G.C. Van de Steene: referee for ApJ

Expertise, Audit

- G. C. Van de Steene: Representative of KSB in Herschell PACS mission of the K.U.Leuven for post-AGB stars and Planetary Nebulae

A.2.8. Missions

Assemblies, symposia (number): Van de Steene G.C. (1)
Van Hoof P.A.M. (3)

A.3. Project "The Photoionization Code Cloudy"

A.3.1. Objectives

Cloudy is a code designed to model the interstellar medium in the widest possible sense. It can treat a wide range of physical conditions, ranging from gamma-ray and X-ray photoionized plasmas to photodissociation regions (PDR) and molecular clouds. As such it can model many types of objects, including (but not limited to) active galactic nuclei, star forming regions, planetary nebulae, and post-AGB stars. It was the first code that could produce a fully self-consistent model of a photo-ionized region including the PDR and molecular regions surrounding it. The code is being developed continually with the aim of improving the modeling results and to widen its scope. The code is publicly available and is widely used. Currently more than 100 papers per year cite the use of Cloudy.

A.3.2. Progress and results

The photoionization code Cloudy plays a crucial role in the research of van Hoof. He is a member of the international development team of this code. Most importantly he is the primary author of the grain model in Cloudy. Grains play an important role in many environments (including post-AGB stars and PNe) because of extinction, photoelectric heating, their influence on the charge and ionization balance of the gas, as catalysts for chemical reactions (e.g. H_2 formation), and as seeds for freeze-out of molecules. It is therefore important to keep the grain model in Cloudy up-to-date. To this end van Hoof continued his work on implementing the new X-ray treatment of grains as well as improved opacity functions for polycyclic aromatic hydrocarbons (PAHs), both of which are important for modeling PNe and post-AGB stars. Furthermore, van Hoof finished including new stellar atmosphere grids in Cloudy (e.g., grids from Rauch, Lanz & Hubeny, Castelli, and Kurucz) which will be part of the upcoming release. These will enable more accurate modeling of PNe as well as other objects. One of the new Rauch grids models hydrogen-deficient PG1159 stars, which will be essential for modeling (V)LTP objects like Sakurai's object. Van Hoof advised on several group publications discussing new features in the code and its application to various astrophysical objects (refs [2]-[5] below). Van Hoof fixed several bugs in the code and assisted in updating the documentation of the parts of the code that he is responsible for. He also assisted in the release of version c06.02 of the code in February 2006 as well as three bug-fix roll-ups later on in the year. Furthermore he assisted in the preparations for the upcoming release of Cloudy which is scheduled for February of 2007. He assisted in installing, maintaining and updating the Cloudy web sites as listed in section A.2.6. Van Hoof also started preparations for organizing the Cloudy Development Summit to be held in 2007 at the ROB. This workshop will bring Cloudy developers together to discuss future development of the code.

A.3.3. Perspective for next years

The development of Cloudy will continue for many years to come. This will first and foremost be aimed at implementing new physics and improving/updating the physics that is already included in the code. Some effort will also be directed towards fixing deficiencies in the code and improving the documentation (either on the web or in the manual called Hazy). In the next year the efforts of van Hoof will be mainly aimed at finishing the new X-ray treatment of grains and implementing improved opacity functions for polycyclic aromatic hydrocarbons (PAHs). These developments will have consequences for modeling many types of environments, including planetary nebulae and post-AGB stars.

A.3.4. Partnerships

List of international partners without grant

- Gary J. Ferland, University of Kentucky
- Ryan Porter, University of Kentucky
- Robin J.R. Williams, AWE, United Kingdom
- William J Henney, UNAM, Morelia
- Joe C. Weingartner, George Mason University, Fairfax
- Nick P. Abel, University of Cincinnatti
- Gargi Shaw, University of Kentucky

Grants/Projects used for this research/service

- Belspo-IAP
- Belspo-Action 1

A.3.5. Publications

A.3.5.1. Publications with peer review

None

A.3.5.2. Publications without peer review

[1] 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
JQSRT, 99, 712

[2] Abel N.P., Ferland G.J., Shaw G., **van Hoof P.A.M.**
Self-consistent Modeling of Ulirgs
Proceedings of the 208th AAS meeting, #49.21, BAAS, Vol. 38

A.3.5.3. Publications in press, submitted

[3] Shaw G., Ferland G.J., Srianand R., Abel N.P., **van Hoof P.A.M.**
On the enhanced cosmic ray ionization rate in the diffuse cloud towards ζ Persei
ApJ, submitted

[4] Röllig M., Abel N.P., Bell T., Bensch F., Black J., Ferland G.J., Jonkheid B., Kamp I., Kaufman M.J., Le Bourlot J., Le Petit F., Meijerink R., Morata Chirivella O., Ossenkopf V., Roueff E., Shaw G., Spaans M., Sternberg A., Stutzki J., Thi W.-F., van Dishoeck E.F., **van Hoof P.A.M.**, Viti S., Wolfire M.G.
A PDR-code comparison study
A&A, in press

[5] Abel N.P., **van Hoof P.A.M.**, Shaw G., Elwert T., Ferland G.J.
Sensitivity of PDR Calculations to Microphysical Detail
ApJ, submitted

A.3.6. Scientific outreach

Editorial responsibilities

- P.A.M. van Hoof: Referee for MNRAS.

Scientific Software

- Cloudy is an open-source code and is distributed under a BSD-style license. It can be freely obtained from http://www.nublado.org

Websites

- Assisted in answering user questions on the discussion forum: http://tech.groups.yahoo.com/group/cloudy_simulations
- Assisted in maintaining the Subversion repository for the photoionization code Cloudy: https://cloud9.pa.uky.edu/svn/cloudy

- Maintained the ViewVC repository browser for Cloudy: https://cloud9.pa.uky.edu/cgi-bin/view.cgi
- Assisted in setting up the Cloudy Wiki: https://cloud9.pa.uky.edu/trac/cloudy

A.4. Project "The Atomic Line List"

A.3.1. Objectives

The atomic line list is a web-based compilation of approximately 1.1 million allowed, intercombination and forbidden atomic transitions with wavelengths in the range from 0.06 nm to 1000 µm. It is publicly available and its primary aim is to assist spectroscopists in the identification of absorption or emission lines in astrophysical or laboratory spectra. It is complete for all elements up to and including zinc. It is widely used in the astronomical and physical community and beyond and serves more than 10,000 users per year.

A.3.2. Perspective for next years

The upgrade to v2.05 which will include lines for elements gallium through krypton, update the data for several other ions, fix several problems, and will feature many improvements to the web interface is nearly ready and planned for release in 2007. Once that is completed, van Hoof will start adding data for 5th and 6th row elements, most notably s-process elements.

A.3.3. Scientific outreach

Websites

- Maintainance of the Atomic Line List: http://www.pa.uky.edu/~peter/atomic

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

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

B.1.2. Progress and results

The general project variable stars and asteroseismology includes several subtopics. All are included in this description. Also the scientific activities related to the preparation of the satellite Gaia are listed here, since they were in 2006 still of general interest.

Earlier developed methods to improve the detection of periods in variable stars were tested further and applied to a large number of data sets of variable stars. The algorithms were adapted to the (new) future needs: a few data sets with a huge number of observations per star, as will be the case for the satellite CoRoT (launched end 2006, see further) or a huge number of data sets with only few observations per star as for the satellite Gaia (launch foreseen for 2011).

A comparative study of different methods of period analysis was initiated. The whole dataset of epoch photometry available from the Hipparcos satellite was re-analysed. Preliminary results on the known periodic variables were reported at the Gaia CU7 meeting in Leuven in November. All methods tested recovered between 70 and 90% of the periods as given in the Hipparcos catalogue. The Lomb-Scargle method seems the most efficient but a few further tests are necessary. A report and a publication are in preparation. First estimate of the number of flops for a specific method of period analysis were reported to the Gaia CU7.

To Jonas Debosscher (Instituut voor Sterrenkunde, KULeuven, further IVS) and Luis Sarro (Madrid), input was given on characteristics of variable stars in general and on periods and period search methods in particular. This information has been implemented in the tools developed for the classification of the variable stars that will be detected by the satellite CoRoT. CoRoT (Convection Rotation and planetary Transits) is a space mission led by the French Space Agency (CNES) in conjunction with ESA and other international partners. The primary objective of CoRoT will be to search for extrasolar planets. Over its planned 2½ year mission it will observe perpendicular to its orbital plane, meaning there will be no Earth occultations, allowing 150 days of continuous observation. The probe will monitor the brightness of stars, watching for the slight dimming that happens in regular intervals when planets transit their primary sun. Since CoRoT can detect very small luminosity variations a lot of variable stars will be detected and these have to be classified. The classification methods will in the future be adapted for the satellite Gaia.

The in-depth analysis of the observations of the Mercator telescope operated by the IVS went on. Our new methods and classical methods of period analysis were further applied to these data in search for variable stars and periodicities. This work has been done in collaboration with Peter De Cat (Dep. II) and collaborators of the IVS. With Sophie Saesen of IVS a detailed investigation of the multiperiodic β Cephei star KP Per was performed. The alias problems of the frequency analysis were partly solved combining old photometry from literature with the new data. The three already known frequencies in this star were confirmed and amplitudes in the 7 colours of the Geneva Photometric System could be derived. These amplitudes were used in an asteroseismological study to identify two dipole modes in the star. Inspection of the stellar models that reproduce the observed frequency spectrum constraints the mass of this star between 10 and 13 $M_\odot$, the radius between 7 and 9.5 $R_\odot$ and the age between 12 and 17 Megayears. Posters on the results of this research were presented at the Nederlandse Astronomenconferentie (Ameland) and at the Vienna Workshop on Asteroseismology. A paper was submitted to Astronomy and Astrophysics.

The study of the γ Doradus stars photometrically observed with the Mercator telescope and SAAO (South Africa) in the frame of an earlier international collaboration continued. The data were combined with earlier observations by the satellite Hipparcos or by ground-based observatories in order to improve the accuracy of the periods, phases and amplitudes. Since this was not in all cases consistent yet, further analysis is necessary. The spectroscopic study of the southern γ Doradus stars was published.

Methods to detect multiple periods were applied to observations of radial velocity and light variations of two binary post-AGB stars. The binary motion was easily detected and at least one other periodicity was found. More variation seems presented but it is unclear whether this is a manifestation of a changing period or a sign of multiple periodicities.

The spectroscopic study of the pulsation modes in the β Cep-type primary component of the binary HD92024 [6] was continued. The software code from the IvS of the KULeuven was adaped (1) to deal with the specific need to check selected modes, and (2) to use a modified least-squares criterion. Time-dependent line-profile computations are now performed to discern between the remaining candidate-modes.

In cooperation with H. Sana (ESO) high-resolution spectra were obtained of the O9.5III+B1-2III-IV binary HD152219, a suspected non-radial pulsator. For the project on the binary θ^2 Tau [4], with a δ Sct-type component, see project A.1 of department 2.

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.

The analysis of the observations of γ Doradus stars will go on.

The first data on variable stars observed with the satellite CoRoT will be analysed and the methods of classification of light curves of variable stars will be tested.

The preparatory work for the ESA-satellite GAIA (launch in 2011) in the context of variable star detection, period search and classifications will become a, if not the, main topic in the years to come.

Period analyses of stars of different type will be continued and methods will be evaluated and adapted in view of the new or expected data. Attempts will be made to optimize the algorithms to analyze huge amounts of stars simultaneously.

The spectroscopic analysis of binaries with pulsating-star components will be continued.

B.1.4. Personnel involved

Scientific staff: J. Cuypers, H. Hensberge, P. De Cat, P. Lampens, Y. Frémat

B.1.5. Partnerships

List of international partners without grant

- Laurent Eyer, Observatoire de Genève, Switzerland
- Luis Sarro, Artificial Intelligence Department, UNED & Virtual Observatory, Spain
- Integral Science Data Centre, Geneva, Switzerland
- CU7 of Gaia DPAC
- L. Freyhammer, UCLAN, U.K.
- H. Sana, ESO, Chile

List of national partners with/ without grant

- Institute of Astronomy, Department of Physics and Astronomy, K.U.Leuven
- C. Sterken, VUB

Grants/Projects used for this research/service

- FWO-project G.0178.02 “Observationele studie van sterren en stersystemen”, Promotor: Prof. Dr. Conny Aerts, partners: K.U.Leuven, UGent, V.U.Brussel, KSB
- FWO-project G.0332.06 “Observationele bepaling van nauwkeurige interne en circumstellaire structuurmodellen van sterren”, Promotor: Prof. Dr. Conny Aerts, partners: K.U.Leuven, UGent, V.U.Brussel, KSB
- Inter-University Attraction Pool, IAP Project P5/36 of ULg-KULeuven-VUB-ROB (2002-2006): Modern aspects of theoretical and observational (ground-based and space born) astrophysics

Visitors:

- L. Freyhammer, UCLAN, 06/07-20/07, IAP P5/36

B.1.6. Publications

B.1.6.1. Publications with peer review

[1] **Cuypers, J.,** Goossens, K., Schoenaers, C, **De Cat, P**., C. Aerts, C.,
Analysis of Mercator data Part II: variable A & F stars,
Communications in Asteroseismology, vol. 147, 52-55

[2] **De Cat, P.,** Eyer, L., **Cuypers, J.**, Aerts, C., Vandenbussche, B., Uytterhoeven, K., Reyniers, M., Kolenberg, K., Groenewegen, M., Raskin G., Maas, T., Jankov, S.,
A spectroscopic study of southern (candidate) γ Doradus stars. I. Time series analysis,
Astron. Astrophys., 449, 281-292

[3] **De Cat P.,** Briquet, M., C. Aerts, C., Goossens, K., Saesen, S., **Cuypers, J.,** Yakut, K., Scuflaire, R., Dupret, M.-A.,
Analysis of Mercator data Part I: variable B stars,
Communications in Asteroseismology, vol. 147, 48-51

[4] **Lampens P., Frémat Y., De Cat P., Hensberge H.**
Towards accurate component properties of the Hyades binary θ^2 Tau
Communications in asteroseismology 148, 65

B.1.6.2. Publications without peer review

[5] **De Cat, P**., Goosssens, K., Bouckaert, F., Eyer, L., **Cuypers, J.,** De Ridder, J., Aerts, C., Dupret, M.-A., Grigahcène, A.,
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

[6] Freyhammer L.M., **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
MmSAI Vol. 77, 334

B.1.6.3. Publications in press, submitted

[7] **De Cat, P.,** …, **Cuypers, J.**, … (40 authors),
Long term photometric monitoring with the Mercator telescope - Frequencies and mode identification of variable O-B stars,
Astron. Astrophys., in press

[8] Saesen, S., Briquet, M, **Cuypers, J., De Cat, P.,** Goossens, K.
Asteroseismology of the β Cephei star KP Per,
Communications in Asteroseismology, vol. 149, in press

[9] Saesen, S., Briquet, M, **Cuypers, J., De Cat, P.,** Goossens, K., Aerts, C.,
Asteroseismology of the β Cephei star KP Per,
Astron. Astrophys. Submitted

[10] **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: 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.1.6.4. Reports, thesis, etc

[11] Waelkens, … **Cuypers, J.,** …et al.,
Text for the IAP Proposal: Stars: seismology, evolution, composition and environment

[12] Aerts, …, **Cuypers, J., De Cat, P.,** et al.,
Text for the Prodex proposal: Gaia-DPAC: Variability

[13] **Cuypers, J., De Cat, P.,**
Text on the feasibility of observing variable stars with the telescope of the (public-amateur) observatory Altair (Zoutleeuw)

B.1.7. Scientific outreach

Meeting presentations

[1] **Cuypers, J**.,
Presentation of the Work Packages related to Variability Characterization and Period Search
Genève, 2nd Gaia CU7 meeting, Genève, 03-04/04/06

[2] **Cuypers, J.,**
A review of the photometry of γ Doradus stars
Liége, BAG meeting on γ Doradus stars, 05/05/06

[3] Saesen, S., Briquet, M, **Cuypers, J., De Cat, P.,** Goossens, K**.**
Asteroseismology of the β Cephei star KP Per
Poster presented by Sophie Saesen at the Nederlandse Astronomenconferentie, Ameland, 10-12/05/06

[4] Saesen, S., Briquet, M, **Cuypers, J., De Cat, P.,** Goossens, K**.**
Asteroseismology of the β Cephei star KP Per,
Poster presented by Sophie Saesen at the Workshop on the Future of Asteroseismology, Vienna, 20-22/09/06

[5] **Cuypers, J.,**
Presentation of the Work Packages related to Variability Characterization with preliminary results on the analysis of the Hipparcos variables with different period search methods
Leuven, 3rd Gaia CU7 meeting, Leuven, 09-10/11/06

[6] Debosscher, J., Sarro, L., Aerts, C., **Cuypers, J**., et al,
Classification of Variable Stars
Leuven, 3rd Gaia CU7 meeting, Leuven, 09-10/11/06

[7] **Hensberge, H**.
Disentangling the component spectra of binaries and triple systems
UCLAN, Institute of Astronomy Lectures, 21/11/06

Editorial responsibilities

- **Cuypers, J.,** Referee for Monthly Notices of the Royal Astronomical Society

Websites

- A minor update of the general webpage of Department III

B.1.8. Missions

Assemblies, symposia (number):	Cuypers J. (7)
Commissions, working groups (days):	Cuypers J. (2)
Research visits (days):	Cuypers J. (32)
	Hensberge H. (8)

B.2. Project "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

In 2006, a detailed analysis was made of the methods to separate the spectra of multiple systems [2]. Analytical solutions for simple, few-pixel spectra were computed in order to understand in detail the singular value decomposition (SVD) technique and the computing schemes used in different codes. We point out specific limitations of different codes and argue that in Fourier domain the mode-zero equation should be solved when one of the relative light ratios in a multiple system is time-dependent, and that SVD should be used also in Fourier-domain. Singular sets of equations lead always to spurious patterns when using velocity-domain techniques, but in Fourier domain only in case of interference with the number of bins over the studied wavelength range when the SVD technique is applied. Component spectra resulting from different techniques are very similar, except (possibly) for their low-frequency behaviour in case of biased input spectra. The computing time for spectral disentangling in velocity space was optimized by a piecewise definition of the wavelength domain, depending on the size of the largest Doppler shifts.

As far as observations and their analysis is concerned, progress was made on a number of multiple systems: RV Crateris, RW Lacertae, HD 123335, HR 6412. It was shown that the F8-type third component of RV Crt (which dominates the spectrum) belongs physically to the system. This follows from the detection of a light-time effect, based on the mean orbital period of the late-F + late-G close binary, in a study of 89 years of eclipse timings, the comparison of detailed modern photometry over 15 years, and of the spectroscopic eclipse timing derived from the study of the subtle change in the line depths of the third component during the primary eclipse.

On spectra of RW Lac obtained by G. Torres (USA) spectra disentangling was applied to very low signal-to-noise spectra and the late-type components of the close binary were separated. This is the first case wherein we experiment with low signal-to-noise data, and we conclude that the technique works satisfactorily at s/n = 20. While the main purpose is to check the assumption of the authors that both stars have low metallicity, the spectra allowed us to detect the very faint third companion suspected from the author's analysis of the light curve of the eclipsing close binary. We await mid-eclipse spectra to attempt the separation of the spectra of the 3 components, and to avoid external assumptions necessary to normalize the intrinsic spectra of the close binary components.

The interpretation of the photometry of HD 123335 (V883 Cen) was finished and the paper (also including the results on ηMus) is presently circulating between the many authors. V883 Cen shows one eclipse in a one-month eccentric orbit, and its ultra-sharp lined magnetic B-type component shows intrinsic micro-variability related to the changing aspect of its surface during the two-month rotation period. One of the three comparison stars, the 5th magnitude late-B subgiant HD118978, was detected to be a photometric micro-variable and belongs presumably to the class of slowly-pulsating B-type stars.

The lacking mid-eclipse spectrum of HR 6412 was obtained by C. Nitschelm at SAAO in South-Africa in an observing run wherein the binary search among the fainter members of Sco-Cen was continued. Unfortunately, the scan of the eclipses of this 38-day period binary at the Mercator telescope did not work out. The data reduction of the specific subsample of fourty candidate wider binaries in Sco-Cen, selected earlier in cooperation with Pourbaix (ULB) using Hipparcos astrometry, reached the final phases (application of the rectification procedures)

B.2.3. Perspective for next years

- 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.
- Detailed analyses on specific binary systems. Priority in 2007 goes to the analysis of RV Crt (paper on absolute dimensions of components) and RW Lac (depending on the access to mid-eclipse spectra). Start the spectroscopic analyses of HD123335 and η Mus. Finalize the paper on AC Vel (time scheme depending on collaboration with Univ. Zagreb and NBIfAPG). Complete the data set for the A-type binary HR6412, observing missing parts of eclipses.

B.2.4. Personnel involved

Scientific staff: H. Hensberge, C. Nitschelm, K.B.V. Torres

B.2.5. Partnerships

List of international partners without grant

- L.P. Vaz and collaborators, Universidade Federal de Minas Gerais, Belo Horizonte, Brazil
- K. Pavlovski, S. Ilijić, University of Zagreb, Croatia
- J.V. Clausen, E.H. Olsen, NBIfAPG, Copenhagen, Denmark
- L. Freyhammer, UCLAN, Preston, UK
- G. Torres, Harvard-Smithsonian center for Astrophysics, Cambridge, Massachussets, USA
- H. Sana, ESO, Chile
- S. Daflon, Observatorio Nacional, Rio de Janeiro, Brazil
- N. Przybilla, F. Nieva, Remeis Sternwarte, Univ. Bamberg, Germany

List of national partners without grant

- M; David, C. Nitschelm, University of Antwerp

Grants/Projects used for this research/service

- Inter-University Attraction Pool, IAP Project P5/36 of ULg-KULeuven-VUB-ROB (2002-2006): Modern aspects of theoretical and observational (ground-based and space born) astrophysics
- CNPq – Conselho Nacional de Desenvolvimento e Pesquisa, Brazilian agency

Visitors:

- L. Freyhammer, UCLAN, 06/07-20/07, IAP P5/36

B.2.6. Publications

B.2.6.1. Publications with peer review

None

B.2.6.2. Publications without peer review

None

B.2.6.3. Publications in press, submitted

[1] **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

[2] **Hensberge H.,** Pavlovski, K.
Modern analysis techniques for spectroscopic binaries
In: IAU Symposium 240 `Modern Binaries' (eds.W.I. Hartkopf, E. Guinan, P. Harmanec), PASP Conf. Ser., in press

[3] **Torres K.B.V.,** Vaz L.P.R., **Hensberge H.**
Comparison of different spectral disentangling techniques applied to a triple system
In: IAU Symposium 240 `Modern Binaries' (eds. W.I. Hartkopf, E. Guinan, P. Harmanec), poster contributions, PASP Conf. Ser., in press

B.2.7. Scientific outreach

Meeting presentations

[1] **Hensberge H.**
Spectral disentangling of triple systems: RV Crt and DG Leo
Astronomy Lectures, Universidade Federal de Minas Gerais, Belo Horizonte, Brazil, 02/2006

[2] **Hensberge H.**
Spectral disentangling applied to triple systems
Astronomy Lectures, Remeis Sternwarte, Univ. Bamberg, 05/2006

[3] **Hensberge H.,** Pavlovski, K.
Modern analysis techniques for spectroscopic binaries
IAU Symposium 240 `Modern Binaries', Prague, Czechia (General Assembly IAU), 08/2006

[4] **Torres K.B.V.,** Vaz L.P.R., **Hensberge H.**
Comparison of different spectral disentangling techniques applied to a triple system
Poster, IAU Symposium 240 `Modern Binaries', Prague, Czechia (General Assembly IAU), 08/2006

Editorial responsibilities

- H. Hensberge: referee for Astronomy and Astrophysics

B.2.8. Missions

Assemblies, symposia (number):	Hensberge H. (2)
	Torres K.B.V. (1)
Research visits (days):	Hensberge H. (57)
	Torres K.B.V. (9)

C. Science Theme “Cataclysmic stellar events”

The project discussed here was introduced by H. Boffin before his leave to the E. S. O. headquarters in Garching. It aims at the study of the accretion disk and its structure in cataclysmic variables, and is observationally oriented. Only one researcher on a temporary contract remained till end of September 2006, and this research theme will not be continued in our department.

C.1.1. Objectives

Cataclysmic variable stars (CVs) are close binary systems in which a low-mass star, filling its Roche lobe, transfers mass to its white-dwarf (WD) companion. The matter does not fall directly onto the WD but forms an accretion disk (AD) instead. Even though ADs are among the most common structures that exist, one of the great unknowns is the source of viscosity, responsible for the angular momentum transfer in the disc and thus for the accretion. CVs play a crucial role in the understanding of several physical phenomena and in particular the study of the ADs and therefore the underlying viscosity sources.

This project is devoted to the observational study of non-magnetic, dwarf nova (DN) and nova-like (NL) CVs, through photometry and spectroscopy. Whenever possible, the spectroscopic data are complemented with indirect imaging techniques like Doppler tomography.

C.1.2. Progress and results

In 2006, part of the photometric campaign conducted during the past four years has resulted in a paper, entitled ``Photometric study of selected cataclysmic variables", published by A&A [1]. We present time-resolved photometry of five poorly known CVs, V1193 Ori, LQ Peg, LD 317, V795 Her & MCT 2347-3144. The observations were made using four 1-m class telescopes (SAAO, Hoher List Observatory, Kryoneri Observatory and Skinakas Observatory), for a total of more than 250h of observations. A short summary follows in the next paragraphs.

For the first time we confirm the 3.97h orbital period of V1193 Ori photometrically and attribute it to the irradiation of the companion star. An asset to this explanation is the fact that the only spectroscopic study performed so far draws the same conclusion from the Ha emission line profile variations throughout the orbit. We find evidence for a QPO around 20min and confirm the high amplitude flickering. "Red noise", characterized by the power law index gamma, 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 in log-log scale. However it was found to differ between two runs, one in 2002 and another in 2003. Interestingly the decrease in the mean system brightness was followed by a decrease in the flickering amplitude and gamma.

For LQ Peg, we have been able to detect, for the first time, a clear photometric modulation of 2.99h, possibly a superhump period. Previous photometric studies have not revealed this signal and this could be attributed to the fact that the system lies at its normal high state and is neither fading nor brightening, in contrast to previous studies. Taking into account that the modulation has come up during the system's high state, that no modulation had been found in the previous years when it was observed in states other than its high one and that it has a rather large amplitude with a triangular-like form, it could represent a positive or a negative superhump. 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, we also extracted WHT spectra 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. Although the spectroscopic data are not adequate, some possible explanations such as a disc wind, a very low inclination and emission-line components produced by the irradiating side of the secondary are discussed.

LD 317 showed no periodic signal, but very strong flickering activity was always present. Combining the facts that it is already proposed to be a NL CV, that in our observations it has appeared to fade by one magnitude in 50 days and it appears in an even lower state in 2005, we conclude that it should belong to the VY Scl subtype. In this respect we must have caught the system 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 our runs was insufficient in revealing 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 when we observed it in January 2005. Moreover, the apparent fading episode, in contrast to V1193 Ori, has been followed by an increase in the flickering amplitude and gamma.

All resulting light curves of V795 Her reveal that the 2.8h modulation is present and of high amplitude. The previously reported QPO near 20 min is confirmed, as well as its resolution into two components. The frequency of the modulation, the amplitude and the phase did not prove stable. The different values we found agreed with different previously reported values. The modulation is by now strongly and broadly believed to be a superhump and superhumps are known for such instabilities. We therefore favor 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 20 days.

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 of the flickering. Possible QPOs have been detected near 30 and 60 min. The remaining photometric data of a few CVs, belonging to the same campaign, have been reduced. Their analysis is in progress and a paper in preparation.

However, in 2006 the main work has been the analysis of spectroscopic data. The unique high- resolution and large wavelength coverage echelle spectra, which we have in our possession, provide us with several emission lines whose simultaneous study allows us to probe in detail the structure of the AD and the contribution of the secondary phase. We have two datasets containing 5 targets in total. They were collected in 1999 at the NTT with EMMI and in 2001 at the VLT with UVES by H.M.J. Boffin.

The NTT dataset incorporates 4 CVs: IP Peg, AT Ara, UU Aqr & V2051 Oph. Its reduction is now complete, as well as the associated Doppler maps, and the final analysis is in progress. Preliminary results of the IP Peg spectra, containing the phase folded spectra accompanied by preliminary Doppler maps, were presented by Papadaki et al., 2005 (ASPC, 330, 373 (2005)). IP Peg is the first cataclysmic variable to show evidence of spiral arms in its accretion disc (Steeghs et al, MNRAS, 290, 28 (1997)) and therefore constitutes an excellent laboratory in order to study the accretion disc evolution and outburst mechanisms. The rest of the systems, V2051 Oph especially, are poorly studied as far as spectroscopy is concerned and no Doppler tomography has ever been applied. The UVES dataset of the system OY Car was reduced and is currently analysed.

C.1.3. Perspective for next years

None.

C.1.4. Personnel involved

Scientific staff: C. Papadaki, J. Cuypers

C.1.5. Partnerships

List of international partners without grant

- H.M.J. Boffin, ESO-Garching
- V. Stanishev, Physics Department, Stockholm University, Sweden
- D. Steeghs, Harvard-Smithsonian Center for Astrophysics, Cambridge, USA
- P. Boumis, Institute of Astronomy & Astrophysics, National Observatory of Athens, Greece

List of national partners without grant

- C. Sterken, VUB

Grants/Projects used for this research/service

- Actie 2

C.1.6. Publications

C.1.6.1. Publications with peer review

[1] **C. Papadaki**, H.M.J. Boffin, C. Sterken, V. Stanishev, **J. Cuypers**, P. Boumis, S. Akras & J. Alikakos
Photometric study of selected cataclysmic variables
A&A, 456, 599 (2006)

C.1.7. Missions

Assemblies, symposia (number): Papadaki C. (1)
Research visits (days): Papadaki C. (33)

D. Science Theme “Solar Spectroscopy”

D.1. Project “Solar Abundances and Relevant Spectroscopic Data”

D.1.1. Objectives

The determination of accurate abundances in the solar photosphere (adopting the best spectroscopic data and the most representative solar models) remains very important in solar and stellar physics.

D.1.2. Progress and results

Accurate solar isotopic ratios ($^{12}C/^{13}C$ and $^{16}O/^{18}O$) have been derived from solar infrared CO-lines [1]. A new determination of the solar N abundance has been based on atomic (N I) and molecular (NH and CN) lines [4].

The solar-calibrated atomic and molecular data bank in the IR is in process of completion. It has been successfully adopted for disentangling the pure solar part and that of the earth’s atmosphere from observed solar spectra between 700 and 5000 cm^{-1} [2].

D.1.3. Perspective for next years

Two main works: the spectroscopic data base (which should be available on the web around end 2007) and the review paper on solar abundances for ARAA (with N. Grevesse and M. Asplund).

D.1.4. Publications

D.1.4.1. Publications with peer review

[1] Scott P.C., Asplund M., **Sauval A.J.**
Line formation in solar granulation. VII. CO lines and the solar C and O isotopic abundances
Astron. Astrophys. 456, pp. 657-688

[2] 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. Quantitative Spectroscopy Radiative Transfer 102, pp. 450-463

D.1.4.2. Publications in press, submitted

[3] Grevesse N., Asplund M., **Sauval A.J.**
The solar chemical composition
In: Symposium on the Composition of Matter, eds G. Gloeckler, B. Mason & R. von Steiger, Space Sciences Series of ISSI, Springer 12 pp. (review) in press

[4] Asplund M., Grevesse, **Sauval A.J., Blomme R.**
Line formation in solar granulation. VIII. N I, NH and CN lines and the solar photospheric N abundance
Astron. Astrophys. (to be submitted)

[5] Grevesse N., Asplund M., **Sauval A.J.**
Solar abundances
Annual Review Astronomy Astrophysics Vol. 46 (invited review) in preparation

D.1.5. Scientific outreach

Websites

- Updating the Contact group *Astronomie & Astrophysique* (ROB) website

DEPARTMENT 4: Solar Physics

SECTION 8: Structure and Dynamics of the Solar Atmosphere

SECTION 9: Solar Activity

The Department for Solar Physics of the Royal Observatory of Belgium (department 4) is known in the scientific community as the "Solar Influences Data analysis Center' (SIDC) and will be referered to as such in the remainder of this report. The department is officially divided in two sections: Structure and Dynamics of the Solar Atmopshere (section 8) and Solar Activity (section 9). This historic division is however no more of relevance and omitted in what follows.

Introduction: SIDC Highlights in 2006

At the end of 2006, the SIDC consisted of about 21 'researchers & project experts' and 7 'support & technical staff'. In many cases the distinction is hard to make, except that on the first category the self-imposed minimal OPPY target applies (one paper per person per year). This apparent status quo with 2005 hides significant changes on the personnel level. In the course of 2006 we welcomed no less than 8 new colleagues who brought in significant new talent at the SIDC. Ingolf Dammasch (Jan 7), Boris Giordanengo (Oct 16), Matthieu Kretzschmar (Feb 1) reinforced the LYRA team. Christophe Marqué (Jan 7) started on the Solar Drivers of Space Weather project, Eric Pottiaux (Nov 1) on the Telescience Project. Susanna Parenti started on Feb 16 in the Supplementary Researcher program. Alexander Baranovski joined us for 6 months (May-Oct) to work on the solar cycle forecast. Last but not least, Anne Vandersyppe joined the SIDC on April 18 to become later in the year the new group secretary. On top of that, the SIDC also hosted a number of research trainees and summer job students.

A number of people left the SIDC during 2006: Thanasssis Katsiyannis (Jan 31) left for a permanent job in Greece, Ingo Baumann (June 20) turned to the Swiss insurance sector, Maria Madjarska and Armin Theissen (March 31) left for the Max Planck institute in Lindau, Dany Lafont left on Aug 31. Arille Vigneron retired at the end of April after a long career at the SIDC as World Data Center operator.

It was also a busy year for several projects. On October 25, the STEREO twin spacecrafts were finally launched. The LYRA instrument was calibrated. The SIDC became a co-I institute for the AIA instrument suite on SDO, and took the leadership of the Solar Orbiter EUI consortium. Ronald Van der Linden was appointed as member of the NASA/ISES Solar Cycle prediction panel.

The European Space Weather community assembled from Nov 13 to Nov 17 for the 3rd European Space Weather Week, organized for the first time in Brussels by the SIDC in the buildings of the Royal Library.

At the end of 2005 a plan to create a Solar Teresterial Center of Excellence (STCE) was submitted. The STCE would regroup all solar-terrestrial research of the 3 space pool institutes in Ukkle in one consistent framework. Significant new funding would help to lift the STCE to a European reference center. On the Council of Ministers of March 22, 2006, this plan was accepted with the full requested budget. Later in the year this commitment was confirmed, but the Minister for the Budget requested an additional document demonstrating the benefits for Belgium (and potential return) of the STCE. This additional document was delivered at the end of 2006. In 2007 the STCE will be ready to be implemented.

On July 12th 2006, the ROB jury for recruitment and promotion assembled to select two new permanent scientists for the SIDC. Out of 25 applications, Jean-François Hochedez and Thijs Krijger were selected. Thijs Krijger will join the SIDC in Aug 2007. Meanwhile three procedures are running at SELOR for replacing the recently retired technical staff.

In any case, continued growth for the SIDC can be expected in the coming years. 2007 looks indeed promising with the advent of the SOHO20 conference organized by SIDC in Ghent. More than 120 scientists of international origin are expected. Later in the year (November), the fourth edition of the European Space Weather Week will happen for the second time in Brussels. Next, in 2008, the SDO data will start flowing in quantity, with the promise of shifting paradigms in solar physics. Also in 2008, will occur the selection of Solar Orbiter proposals, to which SIDC intends to contribute in a significant way.

A. Science Theme "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 Science Theme "Space Weather").

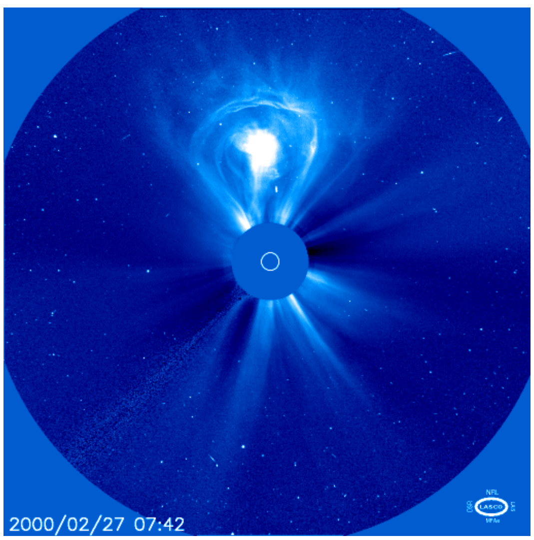
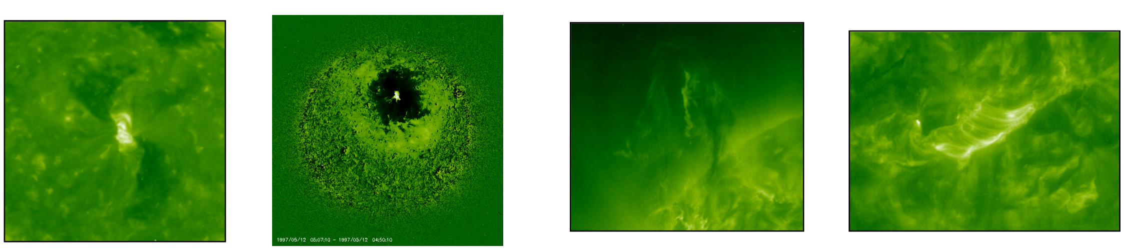


Figure 29: The "lightbulb" Coronal Mass Ejection (CME) showing the three classical parts of a CME: leading edge, void, and core. (SOHO/LASCO)

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.

Studies have shown that a number of phenomena observed with EIT are precursors (counterparts) to the CMEs seen by coronagraphs (see Figure 30). 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 30: Different on-disc signatures of CMEs observed by EIT onboard SOHO.

At the ROB, we are interested in 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 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:

[1] *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?

[2] *understanding the internal structure of CMEs*. What is the structure of an ICME (interplanetary CME)? What is its 3D magnetic configuration? How can it be deduced from the CME observations?

[3] *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 'Preparation to Future Missions' research theme). 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.

The ROB is also principal investigator in the PROBA2 mission. PROBA2 is an ESA technology demonstration mission that is scheduled for launch in May 2008. Besides the demonstration of state-of-the-art technology, PROBA2 has also a scientific payload consisting of the Lyman alpha radiometer (LYRA, see 'Variable Corona' 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. Project "STEREO/SECCHI"

A.1.1. Objectives

STEREO is a NASA space mission (successfully launched on October 25, 2006) consisting of two identical spacecraft that 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 has built the SECCHI instrument suite for the STEREO spacecraft. In 2006, the role of the SIDC was 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 STEREO spacecraft were launched in October 2006, but the commissioning phase was finished at the end of January 2007, and only then the routine scientific data flow started. In 2006 the SECCHI team at the ROB concentrated on 1) the development of software tools for the SECCHI data processing; 2) the development of stereoscopic visualization of SECCHI images and movies; 3) CME studies on the base of EIT and LASCO images combined with in situ data.

A.1.2.1. 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 (NEMO) 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. The development of the SWB is supported within, and used by, various SIDC projects. A description of the new features and developments in 2006 is available in the project description "Solar Drivers of Space Weather" within the present document.

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 and (2) clustering detections into CMEs **[1]**.

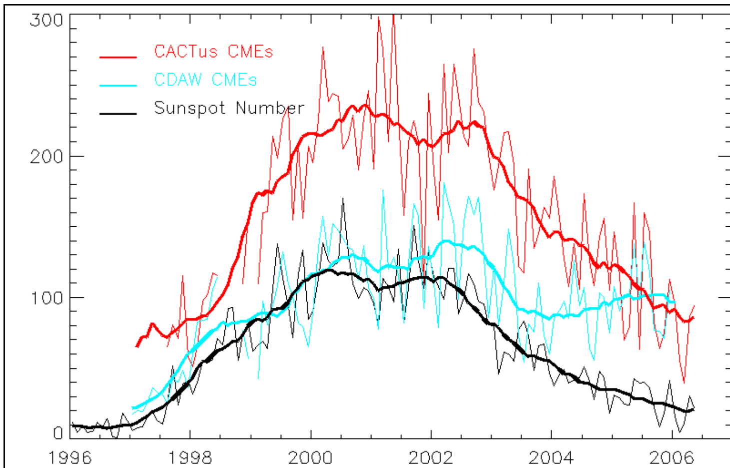


Figure 31: The monthly and monthly smoothed CME rates for cycle 23 from September 1997 trough June 2006, extracted from the CACTus (red) and the CDAW (blue) CME catalog. As a reference we have overplotted the monthly and monthly smoothed sunspot number (black) produced at SIDC – Royal Observatory of Belgium.

In 2006 the CACTus software was rewritten in SolarSoftWare (SSW). The existing CACTus CME catalog was extended and the results are made available via http://www.sidc.be/cactus. The catalog now runs from September 1997 to June 2006 and covers thus a major part of solar cycle 23. The CACTus CME database was exploited and a rigorous statistical analysis was performed on the whole catalog. The evolution of the CME characteristics over the solar cycle was studied and compared with similar results obtained by manual detection. It was shown that automated detection of CMEs is possible, but besides that important new statistical results were obtained **[8]** that will be converted into a publication in 2007. Significant differences were observed in the CME parameters deduced from the CACTus CME catalog as compared to the manually assembled CME catalog [see Figure 31]. These are not just a consequence of differently measuring the CME parameters, but mainly due to the inclusion of many small events which are discarded by the human observer. This has led to a discussion on the definition of the CME phenomenon. It indicates that automated detection not only serves for operational use but also challenges our current scientific understanding **[2, 8]**.

CACTus will make an important contribution to the Solar Event Database (SED). SED will collect the output of all our automated and perhaps manual detections in one database and will serve this information in one consistent format to internal and external users using IDL or SQL, to the Solar Weather Browser, to the daily forecaster and to science investigations. Solar image processing is expected to facilitate the treatment of large data sets used for observational analysis on event basis or via a statistical approach. Huge amounts of data will be available thanks to the technical advancements. However, a profusion of data needs intelligent meta-data, to help separating `the wheat from the chaff'. An important part of it can be provided by automated algorithms like CACTus, pre-digesting the data. In a first step the CACTus output was translated into XML format and the usefulness of different meta-information was discussed.

The CACTus performance in real-time was evaluated, focusing on the halo email-alerts. Whenever a CME larger than a critical threshold is detected an email is sent to registered users. During 2006, 6 correct halo-alerts and 6 false alerts were sent out. Due to solar minimum, the real amount of halo coronal mass ejections is much less than previous year. This of course badly influences the miss/hit rate, since the amount of false alerts remains stable. The false alerts are mainly due to corrupt images or bad data acquisition. This is a typical problem for quick-look data. A possible way to avoid this in the future might be to introduce a module which recognizes false CME detections afterwards.

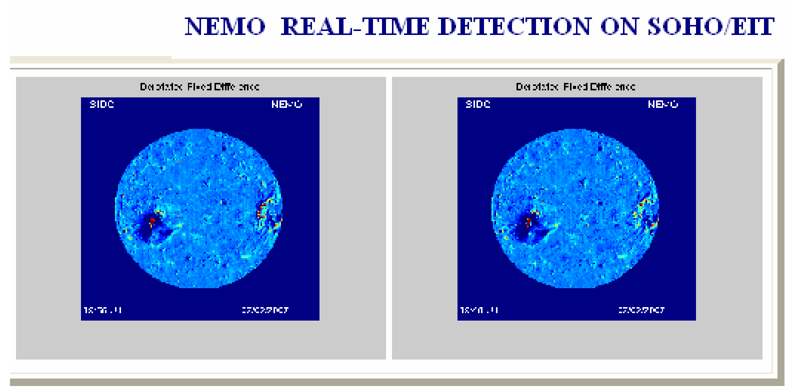


Figure 32: NEMO real-time detection on SOHO/EIT data, see http://sidc.be/nemo

The *EIT wave and dimming detector (NEMO, Novel EIT wave Machine Observer)* aims at detecting the occurrence of Earth-directed CMEs in their earliest stages as EIT waves and coronal dimmings in the extreme-ultraviolet (EUV) observations of the solar disc **[3, 7]**. The developments in 2006 were mainly devoted to the code implementation and fine-tuning, that included 19 subroutines in its deliverable stage. To recognize such object as EIT waves, large-scale explosions in the coronal plasma, standard schemes of pattern recognition used for solid objects could not be used. Therefore, the technique development and testing had to be preceded by a study and classification of events using existing databases starting as early as 1997, the date of the discovery of EIT waves. A dedicated website has been realized: http://sidc.be/nemo [Figure 32].

The final code consists of the 3 main packages: 'Detection', 'Extraction' and 'Validation'. For the detection package additional programs have been developed such as construction of base difference EUV disk images with differential rotation compensation (in the spherical coordinate system), package distinguishing eruptive dimmings from the general family of dimmings, package distinguishing CME on-disk signature and ‘blast waves’, package for EIT wave and eruptive dimming extraction from the noise. NEMO has successfully passed tests and comparison to existing 'hand-made' catalogs, and currently works at the SIDC, making detections in real time using SOHO/EIT quicklook data. A scan of the whole SOHO/EIT catalog has found several new interesting events. Finally, NEMO has been delivered to the Naval Research Laboratory and analysis of early STEREO events shows interesting possibilities for future analysis. UNIX and WINDOWS versions have been released.

Velociraptor is based on an advanced optical flow method that simultaneously estimates 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 Corona*”.

A.1.2.2. Stereoscopic visualization of SECCHI images and movies

In order to display the observations provided by SECCHI in a stereoscopic frame, special hardware and software are required. A stereoscopic image presents the left and right eyes of the viewer with different perspective viewpoints. From these two slightly different views, the eye-brain synthesizes an image with stereoscopic depth. 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. A study of the available hardware in the market was done, in order to asses which option provides the most advantages for stereoscopic displaying of images. The hardware was then acquired and it is being tested and used successfully. The base software for processing the images and creating stereoscopic movies was obtained through collaboration with the STEREO team at the Max-Planck Institute for Solar System Research in Katlenburg-Lindau, Germany. A user friendly IDL interface was then developed in order to allow a straightforward way to create stereoscopic movies. All the software and hardware was tested using images from the SOHO spacecraft, since STEREO data available since December 2006 have several calibration and diverse technical problems which are currently being solved.

A.1.2.3. Study of CMEs using in-situ and remote-sensing data

A key objective of the STEREO mission is the phenomenon of CMEs. The CME initiation process in the low corona can be observed in EUV and in white light by SECCHI, and the interplanetary counterparts of CMEs can be detected in situ by STEREO, ACE and Ulysses.

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 and merge data from several spacecraft. Currently we are using data from ACE, Ulysses and SOHO **[4]** and in the near future STEREO data will be incorporated. 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 from SOHO or STEREO/SECCHI can be used in order to correlate characteristics seen during eruption with those measured in-situ **[4]**.

A magnetic cloud (MC) is a special kind of ICME in which the magnetic field vector presents a smooth rotation, the plasma temperature is low and the magnetic field intensity is high with a low variance. It is believed that they are the interplanetary manifestation of a flux rope expelled from the Sun. Thus, 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 the global structure of magnetic clouds.

Charge states of heavy ions have been used to infer the freezing-in temperatures (a proxy for the electron temperature) in the source region of ICMEs. MCs show increased freezing-in temperatures with respect to non-cloud ICMEs and surrounding solar wind. By combining these data with a flux rope magnetic field model, it is shown that zones of increased freezing-in temperatures are confined to the flux rope region **[6]**.

At higher energies, the elemental composition of energetic particles (~1 MeV per nucleon) was studied in relation to MCs. Statistically, using a dataset of 40 MCs, we found that the relative abundances of the particles inside magnetic clouds are consistent with those found for gradual solar energetic particle events (SEPs), which correspond to particles accelerated at shocks driven by CMEs. However, there are isolated cases in which flare particles are detected, they represent a signature of impulsive solar energetic particle acceleration. In this respect, we have investigated one MC observed by Ulysses in 2001 for which there are imprints of flare acceleration seen in the composition of the energetic particles, and as well in the charge state distributions of solar wind ions **[5]**.

An important factor for the CME development is the pre-eruption configuration of the coronal magnetic field. It is well-known that most 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'Astronomie de Marseille (LAM, France). 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. In 2006 the epoch of solar cycle maximum was addressed. The origin of polar streamers was investigated. A key conjecture is that polar streamers are "classical" streamers (loops with the current sheet above them) associated with polar crown photospheric neutral line. The position of the current sheet was found comparing the position of streamers, loops observed by EIT and of neutral lines of the photospheric magnetic field. To determine the position of the neutral lines, the synoptic maps produced by HelioSynoptics (Dr. P. McIntosh) were used. The method turned out to work surprisingly well and the positions of polar streamers were successfully described. Such a description permits us to determine correctly the polarity of the heliospheric magnetic field during Ulysses polar pass in 2000 – a feature that has up to now escaped theoretical description. The conclusion of the work is that during the solar cycle maximum the streamer belt has a configuration drastically different from the one given by the potential field source surface model. A paper describing these results is now in the final stages of its preparation.

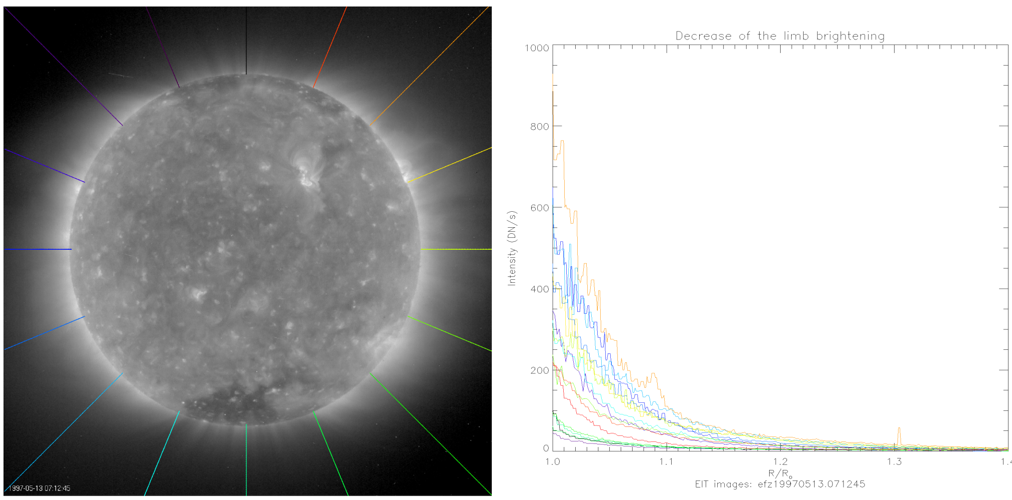


Figure 33: EIT image taken in the 195Å bandpass (left panel) with colored lines corresponding to specific position angles, and the decrease of the limb brightness for each angle (right panel).

A study of the solar corona pressure scale height as observed by EIT was launched. Starting from basic physical principles, the theoretical law of the limb brightening decrease in the isothermal corona was found. EIT images in all four bandpasses (averaged over four images per day to avoid the influence of fast intensity changes) were then taken and the profiles of radial decrease of the coronal brightness have been extracted from different position angles around the Sun [Figure 33]. The profiles are fitted with isothermal curves using the “Robust non-linear least squares curves fitting”and their properties are being investigated. Fitting errors have been estimated. The work on coronal pressure scale height is currently in progress.

A.1.3. Perspective for next years

The development of the software products will be continued. The outsourcing process of the Solar Weather Browser will go on with the addition of the SECCHI instruments at the Naval Research Laboratory (Washington, DC). New routines will be written to take into account STEREO specificities: multiple points of view, large field of view, pointing information, etc. Hinode/XRT data will also be included and specific programs for the SWAP instrument will be prepared. New maintenance mechanisms of the image database will be created in order to manage the SOHO data archive and to update when necessary the already existing files.

The CACTus software will be further adapted in such a way that it can process new coronagraphic images from SECCHI. In a first step the software will digest the images from the two satellites independently. This will be done when the first regular data becomes available. Scientific analysis of the SECCHI data using NEMO and CACTus will be started. There is also a series of requests for the NEMO code, such as from NOAA SEC (for the EIT wave daily list), from the pattern recognition groups at MSSL and IAP.

NEMO will also be adapted for the SWAP data. A list of past events interesting for scientific analysis will be produced and the real-time detection will be continued. Scientific collaborations using NEMO will be pursued, making the package freely accessible for the solar physics community, so that scientific analysis, event cataloguing and adaptation for new satellites can be continued separately by different groups.

An automated system which can deliver near real time stereoscopic movies from SECCHI data will be developed. Since our current stereoscopic equipment is only suitable for 1-person viewing, more practical (and cheaper) alternatives will be sought for providing visualization in front of a wider audience. For this purpose, the use of passive stereo systems, which do not require special electronic systems, is envisaged. Parallel to the visualization efforts, one of the main focuses will be to develop 3D reconstruction tools in order to obtain 3D representations using the images provided by SECCHI. The data obtained by SECCHI and the in-situ packages onboard STEREO will complement the previous studies on the base of SOHO, ACE and Ulysses data, contributing to a better understanding of the physics of CMEs.

The investigation of the streamer belt will be continued. The model will be applied to the SECCHI data taking into account multiple points of view. The understanding of the quiet corona magnetic configuration will allow us to get an insight into the 3D structure of CMEs, using the observations of low corona CME counterparts (e.g. coronal dimmings). Investigation of the variation of the coronal pressure scale height with the solar cycle will be performed with a goal to get an insight into the change of the coronal structure on a long temporal scale.

A.1.4. Personnel involved

Scientific staff: A. Zhukov (project leader, streamer and CME studies), J. de Patoul (coronal pressure height scale), O. Podladchikova (NEMO, EIT wave studies), E. Robbrecht (CACTus, CME studies), L. Rodriguez (3D reconstructions, CME studies), G. Lawrence, C. Marqué, B. Nicula, S. Gissot, J.-F. Hochedez, D. Berghmans, R. Van der Linden.

A.1.5. Partnerships

List of national and international partners without grant

- The ROB-SECCHI team is a member of the international SECCHI consortium which is led by the Naval Research Laboratory (NRL, Washington DC). More information can be found on http://projects.nrl.navy.mil/secchi/organizations.html
- Solar Physics group at the Department of Applied Maths, University of Cambridge, U.K.
- Angelos Vourlidas and Russel Howard, Naval Research Laboratory, USA
- Marco Russel Velli, Jet Propulsion Laboratory, USA
- Paulette Liewer, Jet Propulsion Laboratory, USA
- Barbara Thompson, NASA Goddard Space Flight Center, USA
- Douglas Biesecker, NOAA SEC, USA
- Valery Nakariakov, University of Warwick, UK
- Louise Harra, Gemma Attrill and Tibor Török, Mullard Space Science Laboratory, UK
- Vasyl Yurchishin, Big Bear Solar Observatory, USA
- Vladimir Krasnosselkikh and Thierry Dudok de Wit, LPCE/CNRS – Université d'Orleans, France
- Nicole Vilmer and Monique Pick, Paris-Meudon Observatory, France
- P. Lamy, A. Llebaria, F. Saez, Laboratoire d'Astrophysique de Marseille, France
- S. Koutchmy, Institut d'Astrophysique de Paris, France
- G. Stenborg, NASA Goddard Space Flight Center, USA

Grants/Projects used for this research/service

- ESA/PRODEX8 Contract C90188 "STEREO/SECCHI Preparation to Exploitation and Exploitation".

- Tournesol, international French – Belgian collaboration between ROB, LPCE/CNRS – Université d'Orleans and Paris Meudon Observatory (France).
- CGRI project (ICARUS) between the University of Florence and ROB led by Jean-François Hochedez and Marco Velli.
- ESA/PRODEX Contract C90192 "SIDC Telescience".

Visitors: 9 short visits

A.1.6. Publications

A.1.6.1. Publications with peer review

[1] **Robbrecht, E.** & **Berghmans, D.**
A broad perspective on automated CME tracking: Towards Higher level Space Weather Forecasting
Solar Eruptions and Energetic Particles, ed. N. Gopalswamy, R. Mewaldt, and J. Torsti, Geophysical Monograph 165, p (2006)

[2] **Robbrecht, E., Berghmans, D., Van der Linden R.A.M.**
Objective CME detection over the Solar Cycle: a first attempt
Advances in Space Research, Volume 38, Issue 3, p. 475-479 (2006)

[3] V.N. Podladchikov, N. Naroditskaya, **O. Podladchikova**
Adaptive filtering in the presence of constraints on estimated parameters
Problems of Informatics & Control, 3, pp.23-37 (2006)

A.1.6.2. Publications without peer review

[4] **Rodriguez, L.**, **Zhukov, A. N.**, Woch, J., Krupp, N., von Steiger, R., Forsyth, R.
In-situ and remote observations of CMEs
IAU Symposium Proceedings of the International Astronomical Union 233, ed. by V. Bothmer and A. Hady. Cambridge: Cambridge University Press (2006)

A.1.6.3. Publications in press, submitted

[5] **Rodriguez, L.**, Krupp, N., Woch, J., Fraenz, M.
Elemental abundances of energetic particles within magnetic clouds detected by Ulysses
Submitted to Astrophysical Journal (2006)

[6] **Rodriguez, L.**, Woch, J., Krupp, N., Cid, C.
Freezing-in temperature profiles in ICMEs
Submitted to Astrophysical Journal (2006)

[7] **O. Podladchikova**, **D. Berghmans**
Quantitative study of EIT waves dynamic characteristics. II. Structural changes in the solar active regions during the interaction with EIT waves fronts
A&A, accepted (2006)

A.1.6.4. Reports, thesis, etc

[8] **Robbrecht, E.**
New Techniques for the Characterisation of Dynamical Phenomena in Solar Coronal Images
PhD Thesis, submitted on Dec 24 at the KULeuven (2006)

A.1.7. Scientific outreach

Meeting presentations

[1] Robbrecht, E., Berghmans, D., Van der Linden R.A.M.
LASCO CME-catalog for 1997-2004 based on automated detection (Poster)
SOHO-17: Ten Years of SOHO and Beyon, May 2006, Sicily

[2] **Robbrecht, E., Berghmans, D., Van der Linden R.A.M**.
A complete LASCO CME-catalog based on automated detection (Presentation)
36th COSPAR Assembly, Beijing, China

[3] **Rodriguez, L.**, **Zhukov, A. N.**, Woch, J., Krupp, N., von Steiger, R., Forsyth, R.
In-situ and remote observations of CMEs
IAU Symposium 233, Solar Activity and its Magnetic Origin, Cairo, Egypt, April 2006.

[4] **Rodriguez, L.**, **Zhukov, A. N.**, Woch, J., Krupp, N., von Steiger, R., Forsyth, R.
Multi-spacecraft study of CMEs
SOHO-17: 10 Years of SOHO and Beyond, Sicily, Italy, May 2006.

[5] **Rodriguez, L.**, **Zhukov, A. N.**
Estudio de eyecciones coronales de masa vistas en distintos puntos de la heliósfera
1st meeting of Argentinean Researchers in Heliospheric Sciences, Buenos Aires, Argentina, September 2006.

[6] **A. N. Zhukov**
Observations of CME signatures in EUV (invited talk)
HMI/AIA Science meeting, February 13 – 17, 2006, Monterey, USA

[7] **A. N. Zhukov**
EUV observations of the Sun for the CME and space weather research (invited talk)
IAU Symposium 233, March 31 – April 4, Cairo, Egypt

[8] **A. N. Zhukov**
SOHO/EIT observations of CMEs (poster)
SOHO-17 Conference "Ten Years of SOHO and Beyond", May 7 – 12, Giardini Naxos, Italy

[9] **A. N. Zhukov,** F. Saez, P. Lamy, A. Llebaria, S. Koutchmy, G. Stenborg, **G. Lawrence**
Large-Scale Structure of the solar corona observed by SOHO (poster)
SOHO-17 Conference "Ten Years of SOHO and Beyond", May 7 – 12, Giardini Naxos, Italy

[10] **O. Podladchikova, D. Berghmans**
Solar Blast waves properties by the EIT wave Detector
Invited Talk, 'Dynamic Processes in Space Plasma', Izrael, Dead Sea

[11] **O. Podladchikova, D. Berghmans**
Interaction of EIT waves with Active Regions on The Sun
Invited Talk, 'Annual week of French meeting of Astrophysical division, Programme National Soleil-Terre' part' " Paris-France.

[12] **O. Podladchikova**, **D. Berghmans**
NEMO: EIT wave Detector for SECHHI/STEREO
Solar Image Processing Workshop, Dublin, Ireland

[13] **O. Podladchikova, D. Berghmans** ,
Invited Lecture, 45 min part of 3h lecture *'Global Solar Wave Properties'*
International Astrophysical School, Trieste, Italy

[14] **O. Podladchikova, D. Berghmans**, V.Krasnosselkikh, V.Yurchishin, V.Nakariakov

Invited Lecture, 1h of 4h lecture *'Quantitative properties of EIT waves, comparision with Moreton waves and "autowaves:" properties.'*
International School 'Advances of Modern Sciences', Polytechnic Superior School, Kiev, Ukraine

[15] **O. Podladchikova, D. Berghmans**,
On disk-Eruption Measure Tool
Space Weather Week, Brussels, Belgium

[16] **O. Podladchikova, D. Berghmans**, V.Krasnoselkikh,V.Nakariakov
Rotation of EIT waves
Hawai Observatory- ROB joint seminar, Brussels, Belgium

[17] **O. Podladchikova, D. Berghmans**,
On disk-Eruption Measure Tool- principals
First Tournesol Meeting, Brussels, Belgium

[18] **O. Podladchikova, D. Berghmans** ,
EIT wave Detector
Second Tournesol Meeting, Paris – Meudon Observatory, France

[19] **O. Podladchikova,** V.Krasnoselkikh, **D. Berghmans**, T. D. de Wit, N.Vilmer
Slow and fast blast waves in the solar condition: MHD simulations
1h Seminar at Orleans University Physical Department

[20] **O. Podladchikova, D. Berghmans**
Quantitative studies of EIT waves and their classification for the further detection
Seminar at LPCE/CNRS – Nancay Observatory

[21] **O. Podladchikova, D. Berghmans** ,
Detection of EIT waves and dimmings from EUV solar disk data
Joint meeting between SDO leading scientists C. Shrijver, Alan Title, and David Berghmans and J-F. Hochedez, Brussels, Belgium

[22] **F. Clette, O. Podladchikova,**
NEMO: an EIT waves and dimming detector for EUV imagers
April 25-28, 2006, Space Weather Week in Boulder, Colorado, USA

Editorial responsibilities

- E. Robbrecht: referee for Journal of Advances in Space Research
- O. Podladchikova: Referee for A&A, Planetary and Space Science, Journal of Solar-Terrestrial Physics
- A. Zhukov: Referee for A&A, Sun and Geophysics

Expertise, Audit

- O. Podladchikova: member of PHD defence council in Orleans University
- O. Podladchikova: member of permanent scientific council of PHD defences on solar physics in Polytechnic Superior School, Ukraine

Meeting organization

- L. Rodriguez: Co-organizer of the 1st meeting of Argentinean Researchers in Heliospheric Sciences

Websites

- Website of NEMO http://sidc.be/nemo, creation and maintenance

A.1.8. Missions

Assemblies, symposia (15):	Robbrecht E. (2)
	Rodriguez L. (3)
	Podladchikova O. (7)
	Zhukov A. (3)
Commissions, working groups (3 days):	Rodriguez L. (1 day)
	Zhukov A. (2 days)
Research visits (17 days):	Rodriguez L. (5 days)
	Podladchikova O. (7 days)
	Zhukov A. (5 days)

A.2. Project "Sun Watcher Using APS and Image Processing (SWAP)"

A.2.1. Objectives

SWAP is a solar extreme ultraviolet (EUV) imager designed for scientific studies of space weather events in the solar corona and for daily monitoring of the solar corona. The instrument is built under the project management of the Centre Spatial de Liège (CSL). After launch on the PROBA2 satellite (May 2008), the Royal Observatory of Belgium will be the principal investigator institute for the exploitation of the data. By then, SWAP will be the only instrument providing an EUV view on the solar corona from the Earth perspective at an appriopriate image cadence; also, it will take data in the previously under-exploited 17.5nm passband thus providing complementary data to the existing space weather monitoring fleet.

A.2.2. Progress and results

In 2006 the PROBA2 mission was adopted by the ESA Science Directorate as a Nationally Led Mission. The principal consequences of this development were: earmarking an additional sum of nearly 2.5M€ to support PROBA2 operations and data handling, and a commitment from ESA to optimize ground station coverage and therefore increase telemetry (TM) from the satellite. SWAP will be the main beneficiary of this additional TM since, as the only imaging instrument onboard, it will require the greater part of the available download bandwidth. Good progress has been made on the issue of the ground station(s) with several potential sites identified; the investigation continues as to whether the optimal solution within the available budget will involve just one additional station, or a smaller amount of time each from several.

During the course of the year the last stages of assembling the flight model were undertaken; this was not entirely straightforward since, like in 2005, there were issues surrounding the suitability of the candidate detectors and coatings, but following a thorough investigation the best flight model candidate was identified and extensive testing with the breadboard electronics indicated that it was acceptable for integration. A higher-than-expected noise level in the proximity electronics was solved by adding a capacitor, and a short circuit was discovered and repaired. An irregularity over noise levels in the two image capture modes, and an associated problem with memory reset, were discovered, and work is continuing to solve them. Thermal and vibration testing had both been passed, though a modified filter arrangement and additional small baffles were required to achieve vibration compliance. While the technical work in all cases was performed by CSL, the ROB SWAP team played a full role in analyzing the data and diagnosing the problem. As of the end of the year the instrument housing, optics and focal plane assembly had passed all ESA QC steps and had been fully integrated at CSL; the instrument was awaiting shipment to ESA-ESTEC to integrate the flight electronics, then shipment to PTB-BESSY, Berlin, for full photometric testing and calibration.

Work continued all year on the onboard software in collaboration with Spacebel, the contractor with responsibility for the onboard software (OBSW). In many cases key specifications needed to be clarified and/or updated, and in some instances this required new algorithms. These were developed at ROB by the SWAP team, then implementation and validation performed along with Spacebel. On a related note, some of the onboard image compression and recoding routines developed for SWAP's EUV solar images were incorporated into the OBSW for the EUVI instrument in the SECCHI suite onboard NASA's twin STEREO satellites. STEREO was launched in October 2006 with first light in December 2006, and the performance of the ROB algorithms is being evaluated.

In April 2006 all groups involved in SWAP met at the BELSPO offices, Brussels, to discuss progress and requirements for the PROBA2 ground segment, to be based at Redu, Belgium but with additional facilities at the PROBA2 Science Centre at the SIDC, Brussels, for which the ROB SWAP team has responsibility. Following the meeting the ROB team commenced work on both the science planning/instrument commanding interfaces and protocols, and also the data acquisition/reformatting and archiving/distribution frameworks. A Wiki site was developed at ROB to expedite the development of all aspects of the PROBA2 Science Centre (P2SC), which will include the ground segment and all aspects of data management and distribution. The format and syntax of the commanding have been finalised, a commanding interface designed and written, and a reference document for the SWAP Instrument Operations Sheet (IOS) written. The development of the logical checking systems for the commanding has progressed to a fairly advanced stage while the development of the data archive is underway. The content and format of the data files in binary FITS format has been finalized and reference documents for the FITS header structures of both the Raw and Science data have been written. At the same time as the P2SC was being developed internally, the Science Consortium for SWAP and LYRA (SCSL) was being formed internationally, to make best use of the expertise available within the science community. Development of the data analysis software and SWAP Analysis Manual are underway in collaboration with KU Leuven and Trinity College, Dublin; these collaborations will ensure the optimal return of important scientific results and space weather products and services made possible by a SWAP data stream provided for analysis in as close to real-time as possible. In 2006, two meetings of the SCSL were held, both at ISSI, Bern, and were well-attended and successful meetings with representatives from a number of institutes. PROBA2 in general and SWAP in particular were presented at a variety of international conferences around the year, and benefited from increased exposure as a result of inclusion in the ILWS and IHY programmes.

A.2.3. Perspective for next years

With SWAP scheduled for launch in May 2008 the coming months will ensure the success of the mission. The strategy for optimizing the downlinked TM, via one or more additional ground stations will be finalized, and the ground segment completed. The procurement of hardware and selection and optimization of systems for the PROBA2 Science Centre will take place early in 2007 and a fully redundant commanding/reformatting/archiving/serving setup implemented. The ROB SWAP team will participate fully in the calibration campaign scheduled at PTB-BESSY for late Feb. 2007, both on site and remotely, and the results of the campaign will be incorporated into the analysis software. The SWAP data analysis software and Analysis Manual will be written, and will be available for immediate use after launch and commissioning. A paper outlining the instrument's design, performance and operational capabilities will be written and submitted for publication in the peer-reviewed literature. At least two further meetings of the SCSL are foreseen for 2007, where priority will be given to analyzing the data from the calibtation campaign, and clarifying issues related to the ground segment and User Manual.

A.2.4. Personnel involved

Scientific staff: D. Berghmans (project lead, science PI of SWAP), B. Nicula (software engineer), G. Lawrence (space weather scientist), C. Marqué, J.-F. Hochedez.

A.2.5. Partnerships

List of national and international partners

- Centre Spatial de Liege at ULiege
- Center for Plasma Astrophysics (CPA) at KULeuven
- Verhaert NV
- Spacebel
- The partners of the SCSL team (see http://proba2.sidc.be/SCSL/)

Grants/Projects used for this research/service

- PRODEX contract "C90193- SWAP Preparation to Exploitation"
- ESA-ISSI contract 19260/05/NL/JA/na – Preparation of the exploitation of SWAP and LYRA on PROBA2
- ESA/PRODEX Contract C90192 "SIDC Telescience".

Visitors:

- The SWAP project requires intensive collaborations with the Belgian partners (see above). We estimate that 10 visits for meetings occurred over the year.

A.2.6. Publications

A.2.6.1. Publications with peer review

[1] **Berghmans, D.; Hochedez, J. F**.; Defise, J. M.; Lecat, J. H.; **Nicula, B**.; Slemzin, V.; **Lawrence, G**.; Katsyiannis, A. C.; **der Linden, R. Van; Zhukov, A.; Clette, F**.; Rochus, P.; Mazy, E.; Thibert, T.; Nicolosi, P.; Pelizzo, M.-G.; Schühle, U.
SWAP onboard PROBA 2, a new EUV imager for solar monitoring
Advances in Space Research, Volume 38, Issue 8, p. 1807-1811

A.2.6.2. Publications without peer review

[2] 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
RECENT ADVANCES IN ASTRONOMY AND ASTROPHYSICS: 7th International Conference of the Hellenic Astronomical Society. AIP Conference Proceedings, Volume 848, pp. 847-855 (2006)

A.2.7. Missions

Assemblies, symposia:

- 09-13/01/2006: First IHY European Assembly, Paris, France.
- 10-14/04/2006: 2006 UK Solar Physics Meeting, Aberystwyth, UK.
- 13-17/06/2006: 3rd European Space Weather Week, Brussels, Belgium.
- 11-15/12/2006: AGU Fall Meeting '06, San Francisco, CA, USA.

Commissions, working groups:

- 10-11/01/2006: 120th ESA-SSWG Assembly, Paris, France.
- 19/04/2006: PROBA2 Ground Segment meeting, BELSPO, Brussels, Belgium.
- 20-22/06/2006: First Science Consortium for SWAP and LYRA (SCSL), ISSI, Bern, Switzerland
- 29/11-01/12/2006: 2nd SCSL Meeting, ISSI, Bern, Switzerland.

A.3. Project "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 (original PI: R. Van der Linden, currently managed by D. Beghmans), BISA, VKI and K.U. Leuven. 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

A.3.2.1. Solar Weather Browser development

The Solar Weather Browser has two components: an open source client available for Unix, Mac OS and Windows, developed by B.Nicula, which displays preprocessed solar images and additional informations as overlays, and a server which actually processes all the data and creates outputs compatible with the client. The project started a couple of years ago with D. Berghmans, A. Katsiyannis and I. Baumann. In 2006, C. Marqué took over the maintenance and development of the server part of this project: developing IDL programs and UNIX scripts to fetch the original data and upload the outputs on the web server, and more generally, to maintain the consistency of the database.

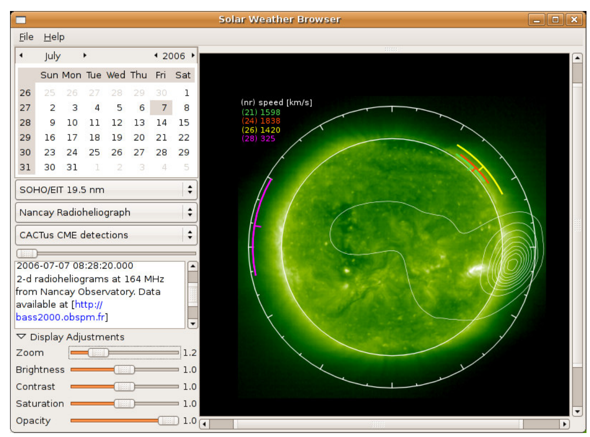


Figure 34: The Solar Weather Browser showing Nançay Radioheliograph data plotted over an EIT spectroheliogram

As part of the "normal" maintenance, the following actions were taken:

- New instruments were added to the server (see Figure 34)
- Extension of overlays output to use more systematically SVG (Scalable Vector Graphics) for a better rendering
- New generic routines were developed to speed up the data processing

In addition to these modifications, a new server architecture was developed in order to facilitate the outsourcing of the server to remote locations. The idea is that instruments providing large amounts of data should serve their quick-look data locally via a SWB server. The new server was set up locally at ROB in October 2006, and was outsourced to the Paris Observatory (Meudon) in December 2006 to hold Nançay Radioheliograph data. Tests are currently under way in Paris before the server will be public.

Finally, a version control system, based on the open source software *Subversion* was set up to structure the maintenance and future developments of the server and to provide a backup solution. A documentation describing the server architecture was started as a page on a local wiki server and should be extended as new features are added.

A.3.2.2. Electron density & temperature distribution modeling

The knowledge of the electron density & temperature distribution in the corona is important both for data analysis and theoretical modeling. Christophe Marqué is working on a full Sun forward modeling of these quantities based on potential field extrapolations, and scaling laws. CM had started this project before coming to ROB for the modeling of the coronal radio emission **[4]**, and during the past year, CM has worked on extending this application to the modeling of the EUV corona as seen by the SoHO/EIT instrument, with colleagues from ROB and KULeuven. A Potential Field Source Surface extrapolation is used to build a realistic electron density and temperature distribution in the corona. The density is modulated from one field line to the other using scaling laws. An example is shown in Figure 35, where one iso-density surface (orange) is displayed together with the extrapolated field lines. The grid illustrates the geometry of the model (spherical modeling). Synthetic EUV images are then computed by ray tracing, taking into account coronal emission processes and radiative transfer constraints, and they are compared to real observations. An example of a synthetic EUV image is shown in Figure 36. A forward modeling approach is used to determine the best electron density and temperature distribution compatible with the data. Practical issues can show up in such a work: the fitness criterion in the forward modeling has to take into account both the morphological structures and the intensity of the synthetic image when compared to the observations; a given model should be compared to different images taken at different temperatures on the same day; and finally, computing time is a limiting factor. First results of this work were presented at the 3rd SIP Workshop in Dublin in September 2006.

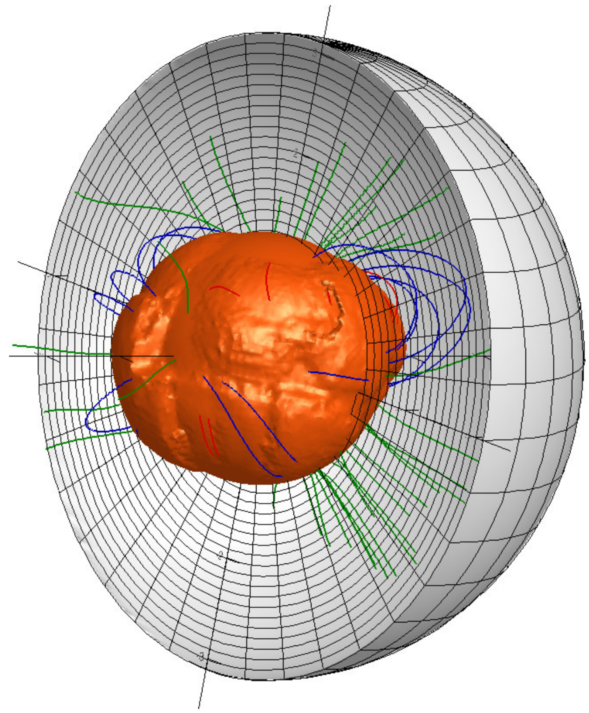


Figure 35: : Electronic iso-density surface

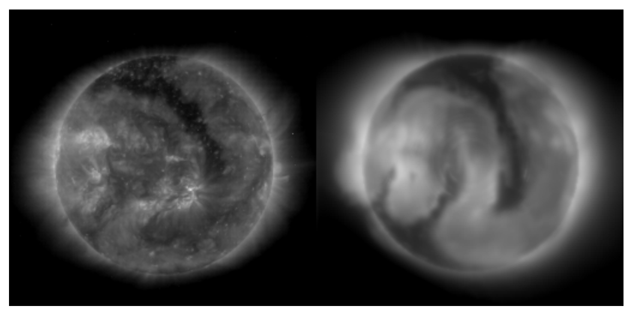


Figure 36: Comparison of a SOHO/EIT image (left) with a synthetic EUV image at the same wavelength (right)

A.3.3. Perspectives for next years

A.3.3.1. Solar Weather Browser development

The outsourcing process will go on with the addition of the SECCHI/STEREO instruments at the Naval Research Laboratory (Washington, DC). New routines will be written to take into account STEREO specificities: multiple points of view, large field of view, pointing informations, etc... Hinode/XRT data will also be included and specific programs for the SWAP instrument will be prepared.

New maintenance mechanisms of the image database will be created in order to manage the SOHO data archive and to update when necessary the already existing files.

A.3.3.2. Electron density & temperature distribution modeling

It is foreseen to submit a publication on the EUV modeling.

Practical applications of this work will be discussed with colleagues from KULeuven-CPA, to use this modeling as an input/constraint for MHD models. Possible extensions to white light forward modeling will also be tested.

A.3.3.3. CME studies

C. Marqué will extend his work on the propagation of CMEs and their relationship with Solar Energetic Particle events (SEPs). These studies were finalized in 2006 with three refereed publications **[1], [2], [3]**. Collaborations are already in place in particular on CME and SEP events relationship (K.-L. Klein). A collaboration with S. Gibson (HAO) is expected on Filament cavity-CME Study (through an IHY proposal).

A.3.4. Personnel involved

Scientific staff: C. Marqué (scientific project lead), S. Willems, D. Berghmans (administrative project lead)

A.3.5. Partnerships

List of national partners

- Centre for Plasma Astrophysics, Catholic University, Leuven, Belgium
- Belgian Institute for Space Aeronomy, Brussels, Belgium
- Von Karman Institute, Sint Genesius Rode, Belgium

List of international partners without grant

- Observatoire de Paris, Meudon (CME work, and Solar Weather Browser)
- Naval Research Laboratory, Washington DC (CME work, and Solar Weather Browser)

Grants/Projects used for this research/service

- ESA/PRODEX Contract C90204 "Solar Drivers of space weather".
- ESA/PRODEX Contract C90192 "SIDC Telescience".

Visitors:

- Anne Bouteille, Monique Pick & Renaud Romagnan (Paris Observatory), September 2006: definition with David Berghmans, Bogdan Nicula and C. Marqué of a collaboration to include Nançay Radioheliograph data in the Solar Weather Browser.
- Karl-Ludwig Klein (Paris Observatory), December 2006: discussion and collaboration in analysis of SEP events and CME observations.

A.3.6. Publications

A.3.6.1. Publications with peer review

[1] M. Pick, T. G. Forbes, G. Mann, H. V. Cane, J. Chen, A. Ciaravella, H. Cremades, R. A. Howard, H. S. Hudson, A. Klassen, K.-L. Klein, M. A. Lee, J. A. Linker, D. Maia, Z. Mikic, J. C. Raymond, M. J. Reiner, G. M. Simnett, N. Srivastava, D. Tripathi, R. Vainio, A. Vourlidas, J. Zhang, T. Zurbuchen, N. R. Sheeley, **C. Marqué**.
Multi-Wavelength Observations of CMEs and Associated Phenomena
Space Science Reviews, Volume 123, Issue 1-3, pp. 341-382, 2006

[2] **C. Marqué**, A. Posner, K.-L. Klein
Solar Energetic Particles and Radio-silent Fast Coronal Mass Ejections

The Astrophysical Journal, Volume 642, Issue 2, pp. 1222-1235, 2006

[3] J. Chen, **C. Marqué**, A. Vourlidas, J. Krall, P. W. Schuck
The Flux-Rope Scaling of the Acceleration of Coronal Mass Ejections and Eruptive Prominences
The Astrophysical Journal, Volume 649, Issue 1, pp. 452-463, 2006

A.3.6.2. Publications in press, submitted

[4] **C. Marqué**, Y.-M. Wang, P. Reiser, A. F. Thernisien
Modeling of the metric radio emission of the quiet solar corona using potential field extrapolations
Submitted to the Astrophysical Journal

A.3.7. Scientific Outreach

Meeting presentations

[1] **C. Marqué**, A. Posner & K.-L. Klein (talk given by Arik Posner)
Solar Energetic Particles and Radio-Silent Fast Coronal Mass Ejections
AGU Joint Assembly, Baltimore, May 2006

[2] **C. Marqué**, M. Kretzschmar, S. Poedts & D. Berghmans
Forward modeling of the 3D electron density and temperature distribution using EIT images
3rd SIP Workshop, Dublin, Sept. 2006

[3] B. Nicula, **C. Marqué** & D. Berghmans
The Solar Weather Browser
3rd SIP Workshop, Dublin, Sept. 2006

[4] B. Nicula, **C. Marqué** & D. Berghmans
The Solar Weather Browser
3rd Space Weather Week, Brussels, Nov. 2006

A.3.8. Missions

Assemblies, symposia:

- 3rd SIP workshop Dublin.
- 3rd Space Weather Week.

Commissions, working groups:

- Science Consortium for SWAP and LYRA: two consortium meetings so far in Bern at ISSI institute, in June and November 2006. I have presented a draft of the science planning during the first months of the mission.

Research visits:

- Visit to Paris-Meudon Observatory to develop remote site for the Solar Weather Browser server, in order to include radio data from the Nançay Radioheliograph.

B. Science Theme "The Variable Corona"

The solar atmosphere is variable and structured over a wide range of temporal and spatial scales respectively. Its faster/smaller phenomena are not resolved in the observations of contemporary instruments, but reconnection of the magnetic field is conjectured to control the physics of the magnetic corona. The instability and the complexity resulting from the generated cascades of events manifest themselves in an outstanding variety of phenomena: loops, flares, Coronal Mass Ejections (CMEs), etc. While CMEs are treated separately in the preceding part, studies on loops and flares are reported in the first section of the present research topic. A couple of relevant algorithmic tools (B2X and Velociraptor) and the UV radiometer LYRA are also reported thereafter. In the second section below, we address the Quiet Sun and Solar Cycle investigations, which are more remotely related to the coronal magnetic field and its reconnection, restructuring, and reorganisation.

SOHO-EIT will often be referred to in the following. This 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-Is at the ROB have undertaken numerous research studies.

B.1. Project "The Flaring and Nanoflaring Magnetic Corona"

B.1.1. Objectives

Describing flares and the mechanisms of coronal heating pose a number of fundamental questions. Today, neither theory nor direct observations could yet build a comprehensive and consistent paradigm. Reduced MHD models and self-organized criticality bring together the physics involved over a wide range of scales. They can therefore reproduce some statistical features of solar flares, and offer insights to Parker's nanoflares concept. In the second approach reported below, a physical forward model of magnetic loops provides observables to be confronted with EUV observations. Eventually, we aim at testing the parameters supposed to control loop heating by nanoflares. At the other end of the energy range, powerful flare events were discovered to be occasionally associated with EIT and Moreton waves. The process underlying EIT and Moreton waves are still under discussion. The "topological" approach for EIT waves that is presented hereafter is complementary with, and should be fed by new methods of data analysis such as Velociraptor. Movies of the solar atmosphere reveal movements (e.g. loop oscillations) and variations in brightness (e.g. flares, dimmings). Velociraptor estimates them both simultaneously via an advanced optical flow scheme applied on EUV image couples. As to the B2X project, its objectives are to detect all possible flares in EIT data, on the disc or at the limb (B2X is fed by single EIT images), to produce an EUV flare catalog (starting times, duration, coordinates), and to exploit scientifically the resulting database. LYRA is a solar XUV to VUV radiometer that will embark in 2008 on the PROBA2 ESA mission, next to SWAP. Its objective is to monitor the solar irradiance in 4 passbands relevant to Solar Physics, Space Weather, and Aeronomy. At SIDC, we focus on the benefits that LYRA will bring to flare physics. But LYRA also demonstrates the interest of new solar-blind diamond detectors and the degradation properties of UV filters, and both technologies are relevant to the Solar Orbiter mission.

B.1.2. Progress and results

B.1.2.1. Coronal heating

- Since 1997, O. Podladchikova is developing a reduced MHD code with elements of kinetic physics to reproduce the flaring behavior at larger spatio-temporal scales. In 2006, she has introduced in the code particle acceleration mechanisms: singular reconnection, ion-acoustic kinetic instability, and modified Buneman instability occurring during flares (See Podladchikova and Lefebvre, 2007)
- S. Parenti studies active region coronal loop plasma subject to small scale impulsive ("nanoflare") heating. Parenti et al (ApJ 2006) simulate the plasma response to heating of a multi-strands loop. As output, it provides the electron density (N) and temperature (T) temporal evolutions in each strand. This information is used to build a synthetic EUV loop spectrum that could itself serve as input to an instrument model. They have also studied the statistical behavior of the EUV radiative emission as function of the elementary strand dimension and heating energy input. Temperatures in the 1.3-8 MK range were investigated. The main result is the possible recovering of statistical properties of the assumed heating, but only when the diagnostic is performed with high temperature lines, that is, if the considered line forms while thermal conduction is the dominant cooling process in the loop.
- A. Eudes has explored successfully a sophisticated method ("CLAW", for Coronal Loop Automated Wanderer) that traces loops autonomously.

B.1.2.2. A topological approach to EIT waves

On May 2, 1998, a halo CME was observed related to an X class flare, an EIT wave, a Moreton wave, radio emission sources, and dimmings. C. Delannée has studied this event to clarify the relationship between all these structures. Delannée et al (2007) have co-aligned multi-wavelength observations and the online potential field source surface (pfss) package. The observed EIT and Moreton waves present some brightenings that remain at the same location, and we have related the connectivity of the coronal potential magnetic field to them. The areas where the magnetic field lines have drastic jumps of connectivity are cospatial to the stationary brightenings of the waves. We conclude that the EIT and Moreton waves may be due to Joule heating resulting from the generation of electric currents in the neighboring area of the drastic jumps of magnetic connectivity, while the magnetic field lines are opening during a CME. The ICARUS proposal was succesfully submitted to CGRI.

B.1.2.3. Movement and brightness variation in solar EUV image sequences

A multiscale optical-flow algorithm (Velociraptor/Movatrac) derived from a gradient-based technique (Lucas Kanade) estimates local motion and brightness variations from solar EUV image couples (Gissot and Hochedez, A&A 2007). In 2006, our algorithm was made symmetric. It computes the exact opposite estimates if the two images are swapped. This minimizes the flow when the successive local image patterns do not match, e.g. in case of temporal aliasing or cosmic ray hit artifacts. Velociraptor was also improved to regularize aperture effects, typically along coronal loops. We could thereby demonstrate a new differential rotation measurement and the identification of coronal events as Brightness Variation or velocity field outliers.

B.1.2.4. Statistical flare studies (B2X)

- B2X is based on the analysis of continuous wavelets spectra (Hochedez et al 2001, Delouille et al 2005). In 2006, J. Depatoul mainly focused on algorithmics and B2X has been improved with respect to (a) limb correction via filtering out its discontinuity, (b) implementation and assessment of a fast discrete wavelet transform version, and (c) concurrent exploitation of histogram skewness. B2X was also modified in view of database production. The B2X concepts were evaluated in the perspective of the onboard flare detector of PROBA2-SWAP.

- O. Podladchikova also analysed the spatio-temporal properties of flares, and shown that 23% are mutually triggered via induced waves, namely acoustic surface f-modes and/or flare induced sunquakes.

B.1.2.5. LYRA

LYRA has been built by a Belgian–Swiss–German consortium with additional international collaborations (Japan, USA, Russia, France). J.-F. Hochedez (ROB) is its Principal Investigator, Y. Stockman (CSL) its Project Manager, and Werner Schmutz (PMOD-WRC) its Lead Co-I.

In 2006, the LYRA consortium held 5 teleconferences; the LYRA/SWAP SIDC team met 8 times. Additionally, two SCSL meetings (science advisory committee for SWAP and LYRA) occurred at ISSI, Bern in the Spring and in the Fall. In January, the radiometric model was run at ROB to prepare the test made in Davos in February with direct sunlight. Early 2006, LYRA and SWAP were presented to the SSWG of ESA and proposed as a main element of PROBA2 in the "Nationally led mission" framework. In February, the MSM24 LYRA sensor was reprocessed by Ali BenMoussa and his collaborations to try to overcome the shortcomings of the earlier lithographic design. In March, M. Kretzschmar drafted the definition of the LYRA data products. LYRA was recalibrated at PTB, and the XN Ly-a filters were measured in the BISA UV laboratory. In April, a document, written by M. Kretzschmar and J.-F. Hochedez, proposed to extend the scope and capabilities of PREMOS-SOVAP towards White Light Flares (WLF). In July, J.-F. Hochedez presented 2 talks related to LYRA and its science at the COSPAR general assembly. A LYRA consortium meeting occurred in Ocrtober at PMOD, Davos. A draft of the LYRA user manual (LUM, written by M. Dominique) was ready in November. Along 2006, a few BISA-ROB LYRA meetings have happened on the aeronomical work of M. Dominique.

B.1.3. Perspective for next years

As a backbone of solar physics research, coronal heating studies will surely be pursued. Yet, their exact focus will depend on the orientations taken by the international community, following especially the results of HINODE and STEREO-EUVI. At the same time, SIDC will be preparing the high resolution imager of Solar Orbiter, and the investigations should therefore aim at making explicit what can be hoped from such instruments. Can there be a predictable link between maps of photospheric magnetic fields and coronal observations? Is the solution to coronal heating to be found in high temperature, high resolution image sequences? Concerning EIT wave research, it will benefit mostly from observations from EUVI, SWAP, and SDO-AIA. But these events are rare, and the latter two missions remain to be successfully launched. As to B2X, its major perspective, once optimized and stabilized is in advanced statistical exploitation of the foreseen database from EIT, and soon from AIA. An action 2 for Catherine Timmermans has been deposited to go deeper in this direction. Finally, we look forward to a successful commissioning of LYRA in late 2008. Some significant effort remains to happen for the ground segment to be ready for its operations, but the launch date was recently postponed again. It is now baselined for November 2008.

B.1.4. Personnel involved

Scientific staff: A. BenMoussa (LYRA detector development and testing), I. Dammasch (LYRA calibration analysis, LYRA PEA), V. Delouille (B2X and LYRA statistical investigation), J. de Patoul (B2X development), M. Dominique (Aeronomy and LYRA operational SW preparation), Samuel Gissot (Optical Flow studies), J.-F. Hochedez (Team leader), M. Kretschmar (Flare studies), S. Parenti (coronal heating), O. Podladchikova (coronal heating)

B.1.5. Partnerships

List of international partners without grant

- Alan Title, Karel Schijver, LMSAL, Palo Alto, California, USA (B2X)
- Marco Velli, U. Firenze, Italy and JPL/NASA, USA. (ICARUS-Tournesol CGRI proposal)

- Angelos Vourlidas, Jim Klimchuk, Enrico Landi, Naval Research Laboratory, Washington DC, USA
- Giancarlo Noci, University of Florence, IT
- Guillaume Aulanier, Nicole Vilmer, LESIA, Meudon, France. (EIT waves)
- SCSL, the Science Committee of SWAP and LYRA, a team of ~20 members representing the interest of the international community for the 2 instruments, see http://proba2.sidc.be/SCSL/
- Werner Schmutz, Silvio Kohler, Tanja Egorova, Hansjörg Roth, Eugene Rozanov, Christoph Wehrli, PMOD, Davos, CH (LYRA co-Is)
- Hilde Schroeven-Deceuninck, PRODEX office, ESA, NL
- Udo Kroth, Christian Laubis, Matthias Richter, Franck Scholze, PTB, BESSY, Berlin, Germany
- B. Inhester, MPS, Lindau-Katlenburg
- Udo Schühle, MPS, Lindau, Germany
- V. Krasnosselskikh, LPCE, France
- Bertrand Lefebvre, Imperial College, UK
- Peter Young, Rutherford Appleton Laboratory, UK

List of national partners without grant

- Daniele Carati, Université Libre de Bruxelles (ICARUS-Tournesol CGRI proposal)
- Yvan Stockman, JP Halain, JM Defise, CSL, Liège
- Ken Haenen, IMO/IMOMEC, Diepenbeck
- Didier Gillotay, Didier Fussen, Filip Vanhellemont, BISA, Ukkel
- Stefaan Poedts, Christian Maes, Bidzina Shgelashvili, KUL

Grants/Projects used for this research/service

- Supplementary Researcher Program (S. Parenti)
- SIDC EXPLOITATION PEA
- STEREO PEA
- LYRA PEA
- SWAP PEA
- EOARD (US airforce) FA8655-05-M-4021

Visitors: 9 short visits

B.1.6. Publications

See the dedicated section below

B.1.7. Scientific outreach

Meeting presentations

[1] **J.-F. Hochedez, E. Robbrecht, O. Podladchikova, A. Zhukov, D. Berghmans**
Coronal seismology, AIA/HMI and image processing (talk on 14/02, Web slides on 27/02)
Invited oral presentation, HMI/AIA Science Teams Meeting, Monterey, Ca, USA, 13-17 February 2006

[2] **Hochedez J.-F., Gissot S**.
Solar dynamics in EUV images sifted by Optical Flow
Contributed oral presentation (10 May 2006), 10 Years of SOHO and Beyond, 7-12 May 2006, Giardini Naxos, Sicily

[3] **O. Podladchikova**
SOC state as universal state of plasma
Invited Seminar, KUL, 18 May 2006

[4] **O. Podladchikova**, B. Lefebvre
Coronal Heating Models
Invited Lecture, Cairo, Egypt

[5] A. Eudes**, J.-F. Hochedez, V. Delouille, S. Parenti**
CLAW: Automated loop extraction
Oral presentation, ROB LMSAL meeting on AIA, ROB, 12-13 June 2006

[6] **Hochedez** et al
LYRA status
Oral presentation, SCSL1, 20 June 2006

[7] **Zhukov A.N., Berghmans D., Hochedez J.-F.**
SWAP and LYRA Instruments onboard PROBA-2 Microsatellite
UNIVERSAT-2006, University Satellites and Space Science, The First International Symposium on Space Education, June 26 -30, 2006, Lomonosov Moscow State University, Russia

[8] Y. Stockman, **J.-F. Hochedez**, W. Schmutz, **A. BenMoussa**, J.-M. Defise, F. Denis, M. D'Olieslaeger, **M. Dominique**, K. Haenen, J.-P Halain, S. Koller, S. Koizumi,V. Mortet, P. Rochus, U. Schühle, A. Soltani, **A. Theissen**
LYRA, solar UV radiometer on the technology demonstration platform PROBA2
Poster presentation, ICSO 2006 Proceedings, Sixth International Conference on Space Optics 27 - 30 June 2006 ESTEC, Noordwijk, The Netherlands

[9] **Hochedez, Berghmans**, Defise and the LYRA and SWAP teams
LYRA and SWAP on board PROBA2 heralding future solar UV observations
Solicited oral presentation (17 July 2006), 36th COSPAR Scientific Assembly. Held 16 - 23 July 2006, in Beijing, China, p.3272

[10] **Judith de Patoul, Véronique Delouille, Jean-François Hochedez**
B2X: automated flare detection for building an EUV flare catalog
Poster presentation, Solar Image Processing workshop III, Dublin Ireland, 6-8 September 2006

[11] **Hochedez J.-F., Gissot S**.
Solar Image Processing at the Royal Observatory of Belgium
Invited oral presentation, ADA IV, Astronomical Data Analysis, 18-20 September 2006, Marseille, France

[12] **Hochedez** and the LYRA team
LYRA and PREMOS
Sollicited oral presentation, PICARD meeting in Paris, 25 October 2006

[13] **Judith de Patoul**, **Véronique Delouille, Jean-François Hochedez**
Automatic flare detection for compiling an EUV flare catalog
Poster presentation, 3rd European Space Weather week, Brussels, Belgium, 13-17 November 2006

[14] **Véronique Delouille, Jean-François Hochedez, Judith de Patoul**, Vincent Barra
Automatic flare detection and tracking of active regions in EUV images
Oral presentation, 3rd European Space Weather week, Brussels, Belgium, 13-17 November 2006

[15] C. Delannée**,** T. Török, G. Aulanier, **J.-F. Hochedez**
An expanding current shell model for propagating EIT waves
Poster presentation, 3rd European Space Weather week, Brussels, Belgium, 13-17 November 2006

[16] **Kretzschmar, M.**
LYRA data level definition

Science Consortium for SWAP and LYRA, second meeting, Bern, November 29-December 1st, 2006

[17] **Gissot S., Hochedez J.-F**.
Multiscale optical flow algorithm probing the dynamics of EUV images
Invited oral presentation (by S. Gissot), FNRS Contact Group "Wavelets and applications", ROB, 7 December 2006

Expertise, Audit

- JF Hochedez: project proposal report "Physical processes in the atmospheres of the Sun and the stars" for a foreign government

Educational responsibilities (Seminars, students, …)

- O.Podladchikova: Member of PhD defence jury in Orleans University
- M. Kretzschmar: Promoter of two students for their course of consulting statistics at Université Catholique de Louvain-la-neuve.

Websites

- http://sidc.be/velociraptor
- http://sidc.be/B2X/
- http://lyra.sidc.be

B.1.8. Missions

Assemblies, symposia (number):	JF Hochedez (6: AIA, S17, Ada4, Esww3, Cospar, IssiSt)
	Judith de Patoul (2 : Dublin, ESWW3)
	Susanna Parenti (2 : SOHO17, ESWW3)
	M. Kretzschmar (2 : SOHO17, ESWW3)
Commissions, working groups (days):	J-.F. Hochedez (8 days: SCSL1, SCSL2, PICARD)
	Ingolf Dammasch (3 days: SCSL2)
	Marie Dominique (4 days: SCSL1, BELSPO)
	M. Kretzschmar (10 days: SCSL1, SCSL2, L'Aquila)
	Véronique Delouille (2 days : COST/ISSI)
Research visits (days):	J-.F. Hochedez (2 days: Davos)
	Ingolf Dammasch (2 days: Davos)
	Marie Dominique (2 days: Davos)
	M. Kretzschmar (5 days: Davos+ Solar Irradiance WS x3)
	Ali BenMoussa (7 days: Davos, IMOx2, IEMN x 3)
	Samuel Gissot (3 days: Meudon, LPCE)
	Véronique Delouille (2 days: Meudon)
	Judith de Patoul (2 days : Meudon)
	Susanna Parenti (7 days: SAO, NRL)
Field missions (days):	J-.F. Hochedez (1 day: PTB)
	Ali BenMoussa (3 days: PTB)
	Marie Dominique (1 day: Comsol)

B.2. Project "Quiet Sun and Long Term Studies"

B.2.1. Objectives

Three "regions" are traditionally identified in EUV solar images: Coronal Holes, Quiet Sun and Active Regions. The study of the variability of the solar corona and the tracking of its regions are of great importance in astrophysics, Space Weather and Space Climate. In the first project below, we automatically label the ondisc areas (and later also off-limb) into such a partition. Our approach will bridge spatially resolved observations from imaging telescopes at one hand, and time series from radiometers at the other hand. Time series resulting form the segmentation of EUV coronal images might provide irreplaceable information when reconstructing the solar spectrum.

Fractal analysis aims at characterizing images via all order statistics. Such analysis is applied to EIT subframes displaying only EUV Quiet Sun. It provides an advanced description of the observed phenomena, eventually leading to inferences on unresolved structures. It also permits to generate synthetic textures that are very similar to the natural QS, but controllable in their dynamics. These can serve at their turn to calibrate other image processing techniques (such as Velociraptor), or to validate physical forward models, and the radiometric design of high resolution telescopes.

The future space mission needs to be prepared not only in hardware. The flux of data products and their associated archives will programmatically become so huge that present data analysis ways will soon be outdated. Within solar physics, the SDO mission is currently the most representative of this trend. SIDC has been invited by LMSAL, the PI institute for SDO-AIA and SDO-HMI to participate significantly to the design and development of the Heliophysics Knowledge Base (HPKB), an advance system meant to cope with the above challenge via new data processing and a database methodology.

B.2.2. Progress and results

B.2.2.1. Solar EUV image segmentation (Spoca)

V. Delouille, V. Barra (ISIMA, Université de Clermont-Ferrand II), and JF Hochedez are developing a multi-channel unsupervised spatially-constrained fuzzy clustering algorithm (SPoCA for "Spatial Possibilistic Clustering Algorithm") that automatically segments EUV solar images into Coronal Holes, Quiet Sun and Active Regions. Fuzzy logic allows managing the various noises present in the images and, more importantly, the imprecision in the very definition of the above regions. SPoCA is fast and automatic. It has been applied to SoHO-EIT images taken from January 1997 till May 2005, i.e. along almost a full solar cycle. Special care was taken to insure stability of the segmentation along the data set. Results in terms of areas and intensity estimations are consistent with previous knowledge. But, the method reveals the rotational and –interestingly- the 1.3-year periodicities in the extracted time series across solar cycle 23.

B.2.2.2. Fractal analysis for solar EUV images

Together with Pierre Chainais (ISIMA, Université de Clermont-Ferrand II), V. Delouille and JF Hochedez have carried out a multifractal analysis of EIT 19.5 nm images. Our data set is selected so as to contain only Quiet Sun images from 1997. We first verified that these images exhibit both non-Gaussian intensity distribution and scale invariance for a certain spatial frequency range. We then make a wavelet based multifractal analysis of those images. We compute their structure function, and derive their singularity spectrum. Finally, we propose to model these images by using a family of stochastic processes, namely the infinitely divisible cascades, that reproduces a similar multi-fractal spectrum.

In April-May 2006, CoSSMIC ('Couronne Solaire, Segmentation et Modélisation d'Images par des Cascades'), a Tournesol proposal was prepared and submitted to CGRI in collaboration with TELE/UCL/LLN. It has been accepted in January 2007.

B.2.2.3. The Heliophysics Knowledge Base (HPKB)

JF Hochedez participated to the AIA/HMI team meeting in Monterey, Ca, USA to present the SIDC ambitions in term of Solar Image Processing for AIA. A meeting was subsequently held at ROB on 12-13 June 2006 with Alan Title and Karel Schrijver, PI and lead coIs of AIA and HMI. Several team meetings were held in the previous weeks (19 and 23 May, 6 and 9 June) to prepare extensively the ideas SIDC wanted to defend and the needed presentations on B2X, CLAW, NEMO, SWB, etc. In the second half of the year, we held a number of teleconferences between SIDC and LMSAL to better define the solution that will be implemented. It essentially consists in identifying required tools (such as SPoCA, B2X or NEMO) and standardizing their interface with the so-called HPKB, via an XML nomenclature.

B.2.3. Perspective for next years

SPoCA is now exploitable, and we already noticed in its first publication (submitted to ASR in November 2006), a number of interesting transient oscillations in the integrated intensities and areas of the coronal regions. This needs to be further studied. Additionally, image segmentations can be seen as a useful preprocessing step for many other studies, which require knowing whether an event occurred in e.g.an Active Region or not. It is for example the case for the B2X flare detector.

After a few years of ripening, the fractal analysis appears to be ready for a first publication in 2007. New developments will address the physical significance of infinitely divisible cascades, and more practically, will explicit the entangled relationships between contrast, scales, photon Poisson noise, and other noise sources. This leads to considerable perspectives in term of the methodology for imaging dynamical extended objects.

A HPKB workshop is coorganized by SIDC and LMSAL at ROB in June 2007. Participants from all involved institutes will join, review the concepts, and give a first try at the new science it will allow.

B.2.4. Personnel involved

Scientific staff: D. Bergmans (HPKB), V. Delouille (Mathematics), A. Eudes (Super-resolution), J.-F. Hochedez (Project leader), M. Kretzschmar (Spectroscopic and time series analysis)

B.2.5. Partnerships

List of international partners without grant

- Thierry Dudok de Wit, LPCE, Orléans, France
- Vincent Barra, Pierre Chainais, ISIMA, Université de Clermont-Ferrand, France

List of national partners without grant

- Jean-Pierre Antoine, Samira Biskri, FYMA, UCL, LLN
- Benoît Macq, Laurent Jacques, TELE, UCL, LLN

Grants/Projects used for this research/service

- LYRA PEA, SIDCEXPLOITATION PEA

Visitors:

- Alexandre Eudes, 1 April -18 September 2006
- Laurent Demanet, 25 September 2006
- Albert Bijaoui, during the FNRS ROB meeting, 7 December 2006
- Vincent Barra, ISIMA, Université de Clermont-Ferrand, France, 26-28 June 2006

B.2.6. Publications

See the dedicated section below

B.2.7. Scientific outreach

Meeting presentations

[1] **J.-F. Hochedez, V. Delouille, S. Gissot, E. Robbrecht, B. Nicula, O. Podladchikova, J. de Patoul, D. Berghmans**
Solar Image Processing at SIDC - Royal Observatory of Belgium
Poster presentation, HMI/AIA Science Teams Meeting, Monterey, Ca, USA, 13-17 February 2006

[2] **Véronique Delouille,** Vincent Barra, Pierre Chainais, **Samuel Gissot, Jean-François Hochedez**
Statistical signal processing of solar corona images
Poster presentation, IAP Workshop V, Institut de Statistique, UCL, Louvain-la-Neuve, Belgique, 30 March 2006

[3] **Kretzschmar, M.**
A statistical analysis of solar EUV irradiance time series including flares
Contributed poster presentation SOHO 17: 10 Years of SOHO and Beyond, 7-12 May 2006, Giardini Naxos, Sicily

[4] **J.-F. Hochedez**
Introduction of SIP at SIDC
Oral presentation, 12 June, ROB AIA Science Meeting, ROB, 12-13 June 2006

[5] **Kretzschmar, M.**
Combining SWAP and LYRA observations
Science Consortium for SWAP and LYRA, first meeting, Bern, June 20-22, 2006

[6] **Matthieu Kretzschmar, Jean-François Hochedez, Véronique Delouille**, Vincent Barra, Thierry Dudok de Wit
Synergies between solar UV radiometry and imaging
Solicited oral presentation (21 July 2006), 36th COSPAR Scientific Assembly. Held 16 - 23 July 2006, in Beijing, China, p.3278

[7] **V. Delouille**, A. Eudes, **J.-F. Hochedez**
Enhanced resolution of EUV images
Oral presentation (Delouille), Solar Image Processing workshop III, Dublin, Ireland, 5-8 September 2006

[8] **Kretzschmar, M.** and Dudok de Wit, T.
Introduction to solar spectrum reconstruction from LYRA measurements
Science Consortium for SWAP and LYRA, second meeting, Bern, November 29-December 1st, 2006

[9] **V. Delouille**, A. Eudes, **J.-F. Hochedez**
Enhanced resolution of EUV images in solar physics
Oral presentation (Delouille), FNRS contact group meeting on 'Wavelet and its applications', ROB, 7 December 2006

B.2.8. Missions

Assemblies, symposia (number):	J.-F. Hochedez (1: FNRS) V. Delouille (1: FNRS)
Research visits (days):	V. Delouille (5: ISIMA)

B.3. Publications

B.3.1.1. Publications with peer review

[1] **A. BenMoussa, J.F. Hochedez,** U. Schuehle, W. Schmutz, K. Haenen, Y. Stockman, A. Soltani, F. Scholze, U. Kroth, V. Mortet, **A. Theissen,** C. Laubis, M. Richter, S. Koller, J.M. Defise
Diamond detectors for LYRA, the Solar VUV radiometer on board PROBA2
Diam. Relat. Mater., 15, pp.802-806 (2006)

[2] **J.F. Hochedez,** W. Schmutz, Y. Stockman, U. Schuehle, **A. BenMoussa,** S. Koller, K. Haenen, **D. Berghmans,** J.M. Defise, J.P. Halain, **A. Theissen, V. Delouille,** V.A. Slemzin, D. Gillotay, D. Fussen, **M. Dominique,** F. Vanhellemont, D. McMullin, **M. Kretzschmar,** A.V. Mitrofanov, **B. Nicula, L. Wauters,** H. Roth, E. Rozanov, I. Ruedi, C. Wehrli, A. Soltani, H. Amano, **R.A.M. Van der Linden, A.N. Zhukov, F. Clette,** S. Koizumi, V. Mortet, Z. Remes, R. Petersen, M. Nesladek, M. D'Olieslaeger, J. Roggen, P. Rochus
LYRA: a Solar UV radiometer on Proba2
Advances in Space Research, 37 Issue 2, pp. 303-312

[3] **M. Kretzschmar**, Jean Lilensten, Jean Aboudarham
Retrieving the Whole Solar EUV Flux from 6 Irradiance Line Measurements
Advances in Space Research, 37(2), pp.341-346, 2006

[4] **M. Kretzschmar**, G. Consolini
Complexity in the Earth's magnetotail plasma sheet
Advances in Space Research, 37, pp.552–558, 2006

[5] G. Consolini, P. de Michelis, **M. Kretzschmar**
A Thermodynamic Approach to the Magnetospheric Complexity: The Role of Fluctuations
Space Science Reviews, 122, pp.293–299, 2006

[6] **Madjarska,** M. S.; Doyle, J. G.; **Hochedez, J.-F.; Theissen, A.**
Macrospicules and blinkers as seen in Shutterless EIT 304 Å
Astronomy and Astrophysics, Volume 452, Issue 2, June III 2006, pp.L11-L14

[7] **Parenti,** S.; Buchlin, E.; Cargill, P. J.; Galtier, S.; Vial, J.-C.
Modeling the Radiative Signatures of Turbulent Heating in Coronal Loops
The Astrophysical Journal, Volume 651, Issue 2, pp. 1219-1228., 2006

[8] **O. Podladchikova**, B. Lefebvre
Lattice models for solar flares and coronal heating
Review in the book "Solar Activity and its Magnetic Origin", ed. V. Botmer, Cambridge: Cambridge University Press, pp.481—488

B.3.1.2. Publications without peer review

[9] Y. Stockman, **J.-F. Hochedez**, W. Schmutz, **A. BenMoussa**, J.-M. Defise, F. Denis, M. D'Olieslaeger, **M. Dominique**, K. Haenen, J.-P Halain, S. Koller, S. Koizumi,V. Mortet, P. Rochus, U. Schühle, A. Soltani, **A. Theissen**
LYRA, solar UV radiometer on the technology demonstration platform PROBA2
ICSO 2006 Proceedings, Sixth International Conference on Space Optics 27 - 30 June 2006 ESTEC, Noordwijk, The Netherlands

[10] **Parenti, S.,** Buchlin E., Cargill P.J., Galtier S., Vial, J.-C.
Looking for signature of coronal heating in the radiative emission of a coronal loop

SOHO-17. 10 Years of SOHO and Beyond, Proceedings of the conference held 7-12 May, 2006 at Giardini Naxos, Sicily, Italy. Edited by H. Lacoste and L. Ouwehand. ESA SP-617. European Space Agency, 2006. Published on CDROM, p.104.1

B.3.1.3. Publications in press, submitted

[11] Delannée, C.**; Hochedez, J.-F.;** Aulanier, G.
Stationary parts of an EIT and Moreton wave: a topological model
Astronomy and Astrophysics, Volume 465, Issue 2, April II 2007, pp.603-612

[12] V.Barra, **V. Delouille, J.-F. Hochedez**
Segmentation of EUV Solar Images via multi-channel unsupervised fuzzy clustering
Submitted to Advanced in Space Research on 9 November 2006

[13] V.Barra, **V. Delouille, J.-F. Hochedez**
Segmentation of Extreme Ultraviolet Solar Images using a Multispectral Data Fusion Process
Submitted to proceedings of the IEEE International Conference on Fuzzy Systems (2007)

[14] **Gissot, S. F.; Hochedez, J.-F**.
Multiscale optical flow probing of dynamics in solar EUV images. Algorithm, calibration, and first results
Astronomy and Astrophysics, Volume 464, Issue 3, March IV 2007, pp.1107-1118 (submitted on 5 May 2006)

[15] **Gissot, S. F.; Hochedez, J.-F**.
A symmetric optical-flow algorithm with aperture regularization: Application to EUV movies of the solar corona
Statistical Methodology (Refereed Proceedings of ADAIV, submitted, STAMET-D-07-00054)

[16] Jean Lilensten, T. Dudok de Wit, P.O. Amblard, Jean Aboudarham, F. Auchere, **M. Kretzschmar**
How to choose an observed set of solar lines for aeronomy driven applications
Submitted to Annales Geophysicae, 2006

[17] T. Dudok de Wit, **M. Kretzschmar**, Jean Aboudarham, P.O. Amblard, F. Auchere, Jean Lilensten
Which solar EUV proxies are best for reconstructing the solar EUV irradiance?
Accepted for publication in Advances in Space Research

[18] **Parenti, S.,** Young, P.R.
Investigating the small-scale coronal heating with Li-like lines
Proceeding for the 2nd Solar Orbiter Workshop, in press

B.3.1.4. Reports, thesis, etc

[19] **Hochedez, J.-F**., **Gissot, S. F.**
MoVaTrac: A Multiscale Optical Flow Algorithm Analyzing the Dynamics in Solar EUV images
Final EOARD report (EOARD_FA8655-05-M-4021-FinalReport-V1.0-20060207-ROB.pdf, 7 February 2006)

[20] A. Eudes
Rapport CLAW
Internal report (claw_rapport-20061120-AE.pdf, 20 November 2006)

[21] **S. Parenti, J.-F. Hochedez**
Supplementary Research formal Report for the February 2006 (project start) - October 2006 period

SupplRes-2006SciReport-ARHeating-V2-20061215-JFH_SP.doc, 15 December 2006

[22] **Kretzschmar, M. & Hochedez, J.-F**.
White Light Flare and Solar Irradiance Measurements
(WLF-20060426-MK_JFH.pdf, 26 April 2006)

[23] **M. Kretzschmar**
Lyra data level
Internal report

[24] **Ingolf Dammasch**
LYRA: about the relationship between telemetry, users' interests, and levels of data products
(IED_20060816_LYRA_Data.pdf)

[25] **Ingolf Dammasch**
LYRA: about a way to calculate the relative detector output as a function of pointing
(IED_20060817_LYRA_Flatfield.pdf)

[26] **Ingolf Dammasch**
LYRA: about how to calculate the expected detector output with realistic sample spectra
(IED_20060818_LYRA_Radiometric.pdf)

[27] **Ingolf Dammasch**
LYRA: about the short and long term behaviour of the various detectors
(IED_20060920_LYRA_Signal.pdf)

[28] **Ingolf Dammasch**
LYRA: about the first attempt to write IDL calibration routines for all channels separately
(IED_20061025_LYRA_Calibration.pdf)

[29] **A. BenMoussa**
Final LYRA instrument GI calibration plan (1-30nm)
Technical report 09/03/2006

[30] **A. BenMoussa**
Final LYRA instrument NI calibration plan (40-240nm)
Technical report 09/03/2006

[31] **A. BenMoussa**
Pre-Analysis report: Final calibration GI beamline (1-30nm)
Technical report 09/05/2006

[32] **A. BenMoussa**
Pre-Analysis report: Final calibration NI beamline (40-240nm)
Technical report 30/05/2006

[33] **A. BenMoussa** (ROB) and A. Soltani (IEMN)
LYRA reprocessing MSM R4-20060104.doc (4th report MSM reprocessing)
Technical report 06/01/2006

[34] **A. BenMoussa**
Reprocessing photoconductor for LYRA (5th report MSM reprocessing)
Technical report 29/05/2006

C. Science Theme "Preparation of Future Space Missions"

As we exploit the observations from past and current missions, in view of physical interpretation via data calibration and data analysis, or in view of Space Weather forecast, it is irresistible to recycle the acquired knowledge, but also the encountered hurdles, in projects and hope for next generation missions and instruments. SIDC has in this respect developed some focused expertise, especially during the development of SWAP and LYRA, but already along the SOHO period. Last year, the BOLD project for novel UV imaging detectors was finally kicked-off after many years of preparation. It is reported in the first section below. In parallel, the need and prospect for new missions, large and small, have amplified in the international scientific community, and among the space agencies. There are very interesting opportunities of medium size (SMESE, PROBA3), but Belgium and SIDC attempts to play a key role also in the largest undertakings: the ESA Solar Orbiter supported by NASA, and/or the Chinese Kuafu. Finally, 2006 has seen the emergence of projects to be sent in response to the ESA Cosmic Vision call (DynaMICCS, PHOIBOS, HIRISE, and COMPASS)

C.1. Project "BOLD"

C.1.1. Objectives

High Technology developments and the progress of science observations are deeply linked. A team like SIDC must select technologies that are both key to the future of Solar Physics and of interest to the national industry. UV optics and especially UV solarblind sensors belong to this category. BOLD, a project aiming at UV sensitive "Blind to the Opical Light Detectors" has been kicked off in June 2006 after 6 years of preparation. The next envisaged ESA mission planned to study the Sun, the Solar Orbiter, requires innovative UV / EUV detectors. Present UV / VUV / EUV detectors exhibit serious limitations in performance, technology complexity and lifetime. BOLD has been set up by ESA involving Belgian (IMEC, ROB) and French (CRHEA) partners with the goal of developing new solar-blind APS detectors (focal-plane array demonstrator) using wide band gap materials. It should demonstrate feasibility after 26 months.

The LPI cooperation on porous filters has been pursued as well. They appear as a complementary technology due to their solarblindness tunable wrt wavelength cutoff.

C.1.2. Progress and results

IMEC, ROB and CRHEA prepared the draft ESA BOLD GSTP proposal (January 2006). It was finalized in March for the technical sections, and in April for the financial section. SIDC is responsible for WP-1100 (modeling), and for WP-4200 (UV testing). The KOM meeting occurred on 18 May 2006 in ESTEC. From June to October, the main focus of the work has been on modeling, while testing at BISA and PTB received attention after November (with A. BenMoussa and B. Giordanengo). A formal progress meeting (TN1 review) occurred at CRHEA in October. Some advances were noticed, but the early developments are challenging.

Concerning porous filters, new VUV transmittance measurements were received in January. The resulting paper has been written along the year. A theoretical model is in preparation (with M. Dominique).

C.1.3. Perspective for next years

BOLD GSTP is set to last nominally till August 2008. Given the difficulties encountered, it might need to be extended. Papers are in preparation to report on the BOLD and porous filters developments.

C.1.4. Personnel involved

Scientific staff: A BenMoussa (BOLD UV measurements and modeling), B. Giordanengo (BOLD modeling and UV measurements), JF Hochedez (project management)

C.1.5. Partnerships

List of international partners without grant

- Igor Zayer, Ludovic Duvet, Didier Martin, ESA, ESTEC, Noordwijk, NL
- J.-Y. Duboz, Fabrice Semond, CRHEA, Valbonne, F
- U. Schuehle, MPS, Lindau, G
- Dr A. Soltani, Brahim Benbakhti, IEMN, Lille, France
- Dr S. Averine, Institute of Radio Engineering and Electronics, Moscow, Russia
- Dr J.L Pau, ISOM & Dpto. Ingeniería Electrónica-ETSI Telecomunicación, Madrid, Spain
- Alexander Mitrofanov, LPI, Moscow

List of national partners without grant

- Marianne Germain, Joachim John, Patrick Merken, Jean Roggen, IMEC, Leuven
- K. Haenen, IMO, Diepenbeek
- Dr D. Gillotay, D. Bolsée, BISA, Ukkle

Grants/Projects used for this research/service

- BOLD ESA GSTP, LYRA PEA, SIDC Exploitation PEA

Visitors:

- 3 short visits
- Stanislas Averine, institute, 1-18 June 2006

C.1.6. Publications

See the dedicated section below

C.1.7. Scientific outreach

Meeting presentations

[1] **A. BenMoussa, J-F Hochedez**
LYRA, PREMOS and BOLD
Invited oral presentation, Conference CCT CNES, Toulouse, 6-8 December 2006

National and international responsibilities

- JF Hochedez: initiator of the BOLD project
- A. Benmoussa: coordinator of the BOLD partners (outside the GSTP project above)

Expertise, Audit

- A BenMoussa: ANR - CEA: Nanosciences and nanotechnologies
- A BenMoussa: Industrial Research call of Piedmont Region 2006

Websites

- http://bold.oma.be

C.1.8. Missions

Assemblies, symposia (number): 2
Commissions, working groups (days): 4
Research visits (days): 7

C.2. Project "Solar Orbiter, Kuafu, and Other Future Missions"

C.2.1. Objectives

Solar Orbiter (SO) is the one major ESA solar and heliophysics mission after SOHO launched in 1995. It is planned for 2015. Thanks to several aspects of its orbit it will open truly unique possibilities for important new solar and heliospheric observations. Within SO, SIDC has developed interest for EUI, the suite of EUV telescopes, in line with its heritage and expertise. Stimulated by the will to shape a key undertaking, and encouraged by Belspo, SIDC invests a lot to involve itself in SO at the highest possible level, meaning PI-ship of the EUI.

In parallel to the development of the SO mission, an opportunity has arisen thanks to Pierre Rochus at CSL to prepare for Elate (EUV and Lyman-Alpha Telescopes, or EDI, EUV Dual Imager), and more ambitiously for the suite of all Remote Sensing payloads onboard the Chinese KUAFU A mission. SO and KUAFU are very different missions. KUAFU-A is foreseen to be located at L1 and to provide synoptic observations, contrarily to Solar Orbiter. The remote-sensing payload of KUAFU A promises a breakthrough in SpW forecasting. This is why SIDC is interested in KUAFU, in addition to SO.

SIDC keeps being solicited by preliminary opportunities for space mission and space experiments. Given the early stage of the two main endeavours (SO and Kuafu), and more importantly, given the large and complementary scientific interest of the prospects, we have followed in 2006 the developments of SMESE, ASPIICS, PHOIBOS, HIRISE, COMPASS and DYNAMICCS.

C.2.2. Progress and results

In 2006, JF Hochedez participated as SOC member to the organisation of the 2nd Solar Orbiter conference. A meeting of the proto-consortium at MSSL (Dorking, UK) in early June had set up a responsibility scheme that could not be accepted by Belgium. Namely, the IAS (Orsay, France) would have had the pre-launch PI-ship, and ROB the post-launch PI-ship. Another proto-consortium technical meeting still occurred in early July. However, triggered by the ESA call for 'letters of Intent' (LOI, due on 15 September 2006), a negociation happened in August in order to move the full PI-ship to ROB. The LOI was submitted by CSL/ROB and their partners of the proto-consortium, with JF Hochedez as intended PI. The rest of the year has consisted of a talk and paper at the SO Athens conference, and interactions with ESA on technical and industrial aspects of the LOI.

After years of fast progress in 2005 and before, 2006 has been slower for KUAFU. JF Hochedez however participated to 2 progress meetings (January in Lindau and July in Beijing), made slides on the "interest for Kuafu at SIDC" in March, and an ELATE oral presentation at the COSPAR assembly in July.

C.2.3. Perspective for next years

The AO for Solar Orbiter science payload is expected in late 2007. It will be time to finalize most decisions on the design, and to write up a full winning proposal. In the meantime, the SO mission is evolving as a result of its merging with the NASA Inner Heliospheric Sentinels. The impact on the EUI specifications may be large, and the consortium adjustments, commensurable.

Kuafu perspectives in 2007 and beyond are unknown. Information from ESA and China are missing. An interesting possibility would be to include the European payload of KUAFU in the Cosmic Vision framework, especially as a complement to the Solar Orbiter + Inner Heliosphere Sentinels (to play the role of the previously foreseen "Earth Sentinel").

SMESE is a French-Chinese mission that will possibly enter Phase B in 2007. It should embark a UV coronagraph, and IR and gamma solar instruments. ASPIICS is a new coronagraphic concept relying on formation-flying. It should give access to the unexplored region of the corona where CME and the solar wind are accelerated. It is considered as the main element for the PROBA3 mission. Finally, ESA has announced intention to trigger its Cosmic Vision process in early 2007. Among all competing proposals, we have decided to support DynaMICCS (S. Turck-Chièze), a solar core to Earth atmosphere mission, HIRISE (L. Damé), an ultra high resolution mission, PHOIBOS (M. Maksimovic) a realistic solar probe mission, and COMPASS (S. Fineschi), a mission focusing on the measurement of the atmospheric magnetic fields.

C.2.4. Personnel involved

Scientific staff: D. Bergmans (advisor on EUI and Kuafu), F. Clette (PROBA3 contact person), JF Hochedez (EUI and ELATE PI), M Kretzschmar (EUI coI), G. Lawrence (EUI coI), C. Marqué (EUI coI), S. Parenti (EUI coI), O. Podladchikova (EUI coI), Luciano Rodriguez (EUI and ELATE coI), Andrei Zhukov (EUI coI)

C.2.5. Partnerships

List of international partners without grant

- Louise Harra, Lidia Van Driel, Sarah Matthews (EUI), MSSL, UK
- Udo Schuehle, Luca Teriaca, Werner Curdt, Eckart Marsch, Sami Solanki (EUI), MPS, Lindau, G
- Thierry Appourchaux, Frédéric Auchère, M.-F. Ravet, Jean-Claude Vial, Alan Gabriel (EUI), IAS, F
- Chuanyi Tu (KUAFU), Peking University, China
- J.-C. Vial (SMESE), Institut d'Astrophysique Spatiale, Orsay, F
- Ph. Lamy (ASPIICS), Laboratoire d'Astrophysique de Marseille, Marseille, F
- Fredéric Auchère (ASPIICS), Institut d'Astrophysique Spatiale, Orsay, F
- Serge Koutchmy (ASPIICS), Institut d'Astrophysique, Paris, F
- Sylvaine Turck Chièze (DynaMICCS), CEA, Saclay
- Luc Damé (HIRISE), Service d'Aéronomie, CNRS, Verrières, F
- Milan Maksimovic, LESIA, Meudon, F
- Silvano Fineschi, Oss Torino, Italy

List of national partners without grant

- JM Defise, JP Halain, P Rochus, CSL
- Marco Velli, JPL, 15 December 2006 (guest of Lena Podladchikova)
- Ludwig Klein, 15 December 2006 (guest of Christophe Marqué)

Grants/Projects used for this research/service

- SIDCDATAEXPLOITATION, SWAP, STEREO PEAs

C.2.6. Publications

See the dedicated section below

C.2.7. Scientific outreach

Meeting presentations

[1] **J.-F. Hochedez**, T. Appourchaux, J.-M. Defise, L. K. Harra, U. Schühle, F. Auchère, W. Curdt, B. Hancock, **M. Kretzschmar, G. Lawrence**, J.-C. Leclec'h, E. Marsch, R.Mercier, **S. Parenti, E. Podladchikova**, M.-F. Ravet, P. Rochus, **L. Rodriguez**, F. Rouesnel, S. Solanki, L. Teriaca, L. Van Driel, J.-C. Vial, B. Winter, **A. Zhukov**
EUI, the ultraviolet imaging telescopes of Solar Orbiter
Oral presentation (19 October), 2nd Solar Orbiter Workshop, Athens, 16-20 October 2006

[2] **Hochedez**, Berghmans
Scientific interest for KUAFU at SIDC

Oral presentation (18 July 2006), KUAFU progress meeting, PKU, Beijing, China

[3] Rochus, **Hochedez**, Defise, Blanche, Schuehle
UV solar disc imagers of Kuafu-A
Oral presentation (19 July 2006), 36th COSPAR Scientific Assembly. Held 16 - 23 July 2006, in Beijing, China., p.3256

National and international responsibilities

- JF Hochedez, PI of the EUI consortium of Solar Orbiter
- JF Hochedez, PI of the ELATE project for KUAFU-A

Expertise, Audit

- JF Hochedez: Member of the ESA Payload Working Group (PWG) for SO (Remote sensing sub-group)
- JF Hochedez: Member of the Joint ESA NASA Science and Technology Definition Team for SO and Sentinels

Websites

- eui.oma.be and eui.sidc.be

C.2.8. Missions

Assemblies, symposia (number):	JF Hochedez (2) Susanna Parenti (3) M. Kretzschmar (3)
Commissions, working groups (days):	JF Hochedez (11) D. Bergmans, M. Kretzschmar, S. Parenti, A. Zhukov (2)
Research visits (days):	JF Hochedez (4)

C.3. Publications

C.3.1.1. Publications with peer review

[1] **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, 17 Issue 4, pp.913—917 (2006)

[2] **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, J.P Halain, Z. Remes, R. Petersen, M. D'Olieslaeger, J-M Defise
Performance of diamond detectors for VUV applications
Nuclear Instruments and Methods A 568 (2006) 398-405

[3] A. Soltani, **A. BenMoussa,** S. Touati, V. Hoël, J-C. De Jaeger, J. Laureyns, Y.Cordier, C. Marhic, M.A. Djouadi and C. Dua.
Development and analysis of low resistance ohmic contact to n-AlGaN/GaN HEMT.
Diamond and Related Materials 16 (2007) 262-266

C.3.1.2. Publications without peer review

[4] **J.-F. Hochedez**, T. Appourchaux, J.-M. Defise, L. K. Harra, U. Schühle, F. Auchère, W. Curdt, B. Hancock, **M. Kretzschmar, G. Lawrence**, J.-C. Leclec'h, E. Marsch, R.Mercier, **S. Parenti,**

E. Podladchikova, M.-F. Ravet, P. Rochus, **L. Rodriguez**, F. Rouesnel, S. Solanki, L. Teriaca, L. Van Driel, J.-C. Vial, B. Winter, **A. Zhukov**
EUI, the ultraviolet imaging telescopes of Solar Orbiter
Proceedings of the 2nd Solar Orbiter Workshop, Athens, 16-20 October 2006, ESA-SP 641 (2006)

C.3.1.3. Reports, thesis, etc

[5] C. Van Hoof, M. Germain, J. John, P. Merken, **A. BenMoussa**, **J-F Hochedez** and J-Y Duboz
BOLD: Film Transfer Sensor Array
Proposal, ref P48999-02-01, 6 April 2006

[6] **A. BenMoussa** and J-F Hochedez
BOLD: UV detector pixel concept June 2006
Technical Report: Monthly Progress Report

[7] **A. BenMoussa** and J-F Hochedez
BOLD: UV detector pixel concept July 2006
Technical Report: Monthly Progress Report

[8] **A. BenMoussa** and J-F Hochedez
BOLD: UV detector pixel concept August 2006
Technical Report: Monthly Progress Report

[9] **A. BenMoussa** and J-F Hochedez
BOLD: Critical technologies Areas and Conceptual design
Technical Note 1, 10/10/2006

D. Science Theme "Space Weather and Solar Activity Indices"

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' (SIDC) 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 37: 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* (RWC) 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. The SWENET funding for SIDC has ended but the SIDC monitoring of solar activity for SWENET is ongoing at a status-quo level. We refer to the annual report of 2005 for a detailed description.

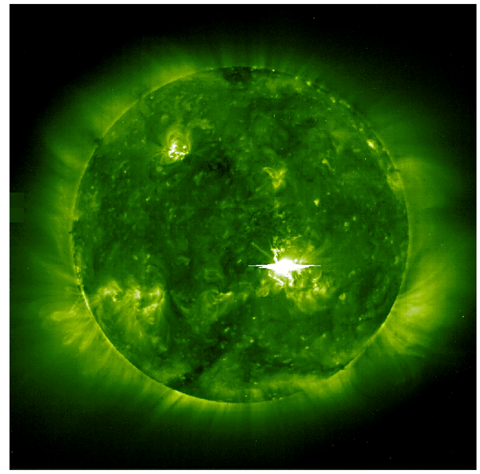


Figure 38: A bright solar flare, captured by the instrument EIT on 1998 May 2.

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. The availability of these data paves the way to base the Space Weather service provision on more firm scientific footing.

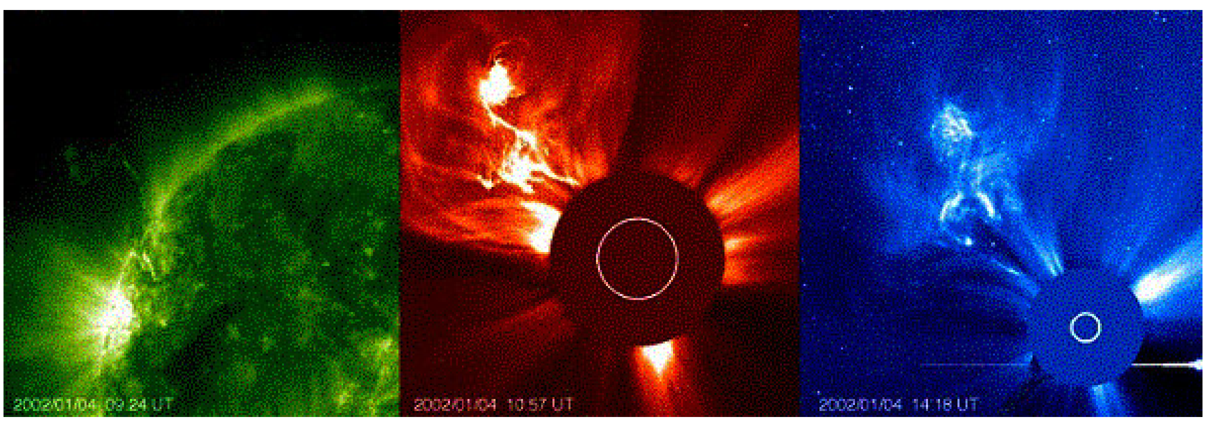


Figure 39: A solar eruption, captured by the EIT and LASCO instruments onboard the joint ESA/NASA space mission SOHO on Jan 4, 2002.

D.1. Project "The Operational Activities as RWC Belgium

D.1.1. Objectives

RWC Belgium is a permanent service center, specializing in solar monitoring and solar activity forecasting under the auspices of the ISES network. The solid base of the SIDC is the excellence of the department in solar physics research and the active participation in several space missions for solar observations. From this. we have access to a large volume of solar and heliospheric data that can collectively span operational requirements. Building on insights derived from our scientific studies, the SIDC provides expert and timely information on and assessment of solar dynamics and its likely relevance for the Earth and human technology.

D.1.2. Progress and results

The daily routines for the RWC activities consist of different steps. A continuous data stream from ground-based observatories and from spacecraft instruments has to be analysed and interpreted. One of our tasks is to simply distribute the data. The RWC acts as a hub for further distribution of solar and geophysical data, mostly in the form of ISES encoded messages. The data is also used to monitor and predict space weather. To maintain a high standard in our activities as an RWC, we make use of special software that automatically detects space weather events. This service is timely and assists the forecaster on duty in his monitoring and alerting task. Examples are CACTus, the flare detector, EIT-wave-detector (see elsewhere in this document for a description of their development in 2006). These monitoring activities result in a daily space weather forecast and an alert service. Most of the warnings are sent out automatically, some alerts need human intervention.

The monitoring, alerting and forecasting services of the RWC contain three main aspects related to the programmatic and technical level: client database management, production of data/messages and delivery of data/messages. These activities are directed on the level of the 'PreviMaster'. PreviMaster handles the solar data, the forecasts and alerts in connection with a database. The input web interface to receive the daily forecasts, the manually triggered alerts and the noticeable space weather events, e.g. powerful flares, is called PreviWeb. PreviWeb is a secured web-based interface to PreviMaster triggering the process of creating and delivering data, messages and alerts to the users, the ftp-server and the public website.

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 alert-type of messages are generated.

The daily duty cycle of forecasting and monitoring activities were shared by D. Berghmans, F. Clette, C. Marqué, G. Lawrence, P. Vanlommel, R. Van der Linden, E. Robbrecht and A. Zhukov.

Since beginning of 2006, we introduced the Estimated International Sunspot Number (EISN) as a new daily data product. This prompt sunspot index is derived from a limited subset of SIDC contributing stations that deliver their report in near real-time. This new index will help improve the day-to-day forecasts of ionospheric propagation for telecom applications, as a complement to the Provisional ISN (PISN) released monthly from a much larger observation set. A quality control of this index is automatically performed within previmaster (see Figure 40).

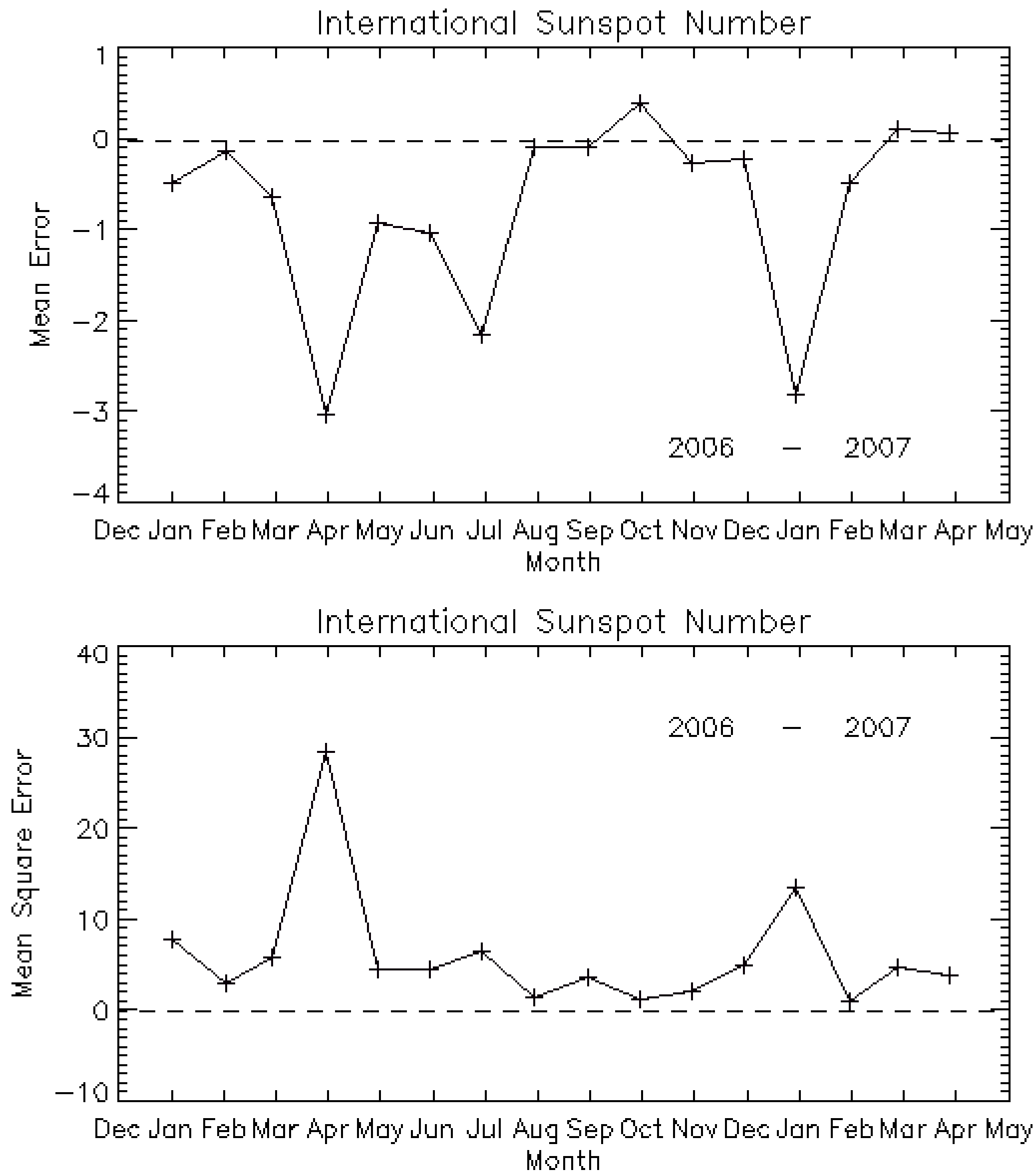


Figure 40: ***The monthly Mean Error and monthly Mean Square Error for the complete data set ranging from Jan 2006 until now. The error is defined as the difference between the PISN and the EISN.***

An often forgotten but important aspect of the RWC concerns the involvement of the scientific space weather community, commercial and amateur organizations and the general public. This human aspect triggers the necessicity of *space weather education* and awareness of society. In view of this, the RWC pays special attention to publicity and promotionn of space weather and related activities. Our website is the ultimate window to the space weather community and the public on which for example on a regular basis 'Solar Highlights' are posted. Several space weather presentations were given.

D.1.2.1.The Third European Space Weather Week

From Nov 13-17, 2006, the Third European Space Weather Week (ESWW3) was jointhly organized by the SIDC, ESA, the Space Weather Working Team (SWWT), the COST 724 and COST 296 communities. This event was built on the advances made during the first two European Space Weather Weeks held at ESA/ESTEC in 2004 and 2005. The workshop adopted the central aim of bringing together diverse communities working on all elements of space weather. Hot topics and recent advances in both scientific and applications based domains were discussed. The flow of information between new scientific results and space weather services is one of the keynotes towards the creation of a sustainable space weather activity in Europe.

The conference with 230 attendees was held at the Royal Library of Belgium (RLB). The expertise of the SIDC as a science and services center and our deep involvement in space missions like SOHO, STEREO, PROBA2 make us one of the keyrole players of space weather activities in Europe and worldwide Through the organization of this succesful ESWW3, we strengthened our position and visibility in the space weather community.

D.1.3. Perspective for following years

It is our task to continue developing products, ameliorating existing products with the requests and wishes of the scientific, technological and amateur community in our mind. At the same time, we have to keep the structure and scripts which are at the base of the RWC transparent and efficient. We act on both sides: the programmatic level which forms a platform on which the RWC can exist as a purely technical entity and the other side which is user related.

Some of the daily processes are complicated and detours on the programmatic level are made in the communication between data-bases and PreviWeb/PreviMaster. This has to be cleared out and made more transparent. For this, a well co-ordinated interaction between all human actors is needed. Early 2007, the first steps in this process were already made.

To make the operational activities of the RWC attractive to commercial entities and companies, quality control was and is a top-priority and can serve as an internal feedback tool for the forecasters. The EISN fits well in an ionospheric analysis program that will be proposed by the UK Met Office. The first contact to get involved in the EU Framework 7 proposal for integrated infrastructure initiave, 'European Ionospheric Analysis System' are made. The proposal concerns data assimilation between ionospheric observations and an ionospheric computer model.

We will finish the Space Weather Show of the planetarium, Heizel in 2007.

The Fourth European Space Weather Week
Shortly after the ESWW3, the SIDC was elected out of a list of 4 applicants to organise the Fourth European Space Weather Week (ESWW4). Our aim is to bring the organisation of the main European space weather conference on a permanent basis to Brussels, Belgium. This will establish a strong link between the SIDC and space weather sciences and applications.

The ESWW4 will be held on Nov 5-9, 2007 at the Royal Library of Belgium.

D.1.4. Personnel involved

Scientific staff: Ronald Van der Linden (project leader), D. Berghmans, F. Clette, G. Lawrence, C. Marqué, B. Nicula, L. Podladchikova, E. Robbrecht, P. Vanlommel, L. Wauters, A. Zhukov, E. Pottiaux.

Technical staff: A. Vandersyppe, O. Boulvin, S. Willems

D.1.5. 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/).
- The SWENET activities are 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. Collectively it forms part of the global European network linking up the various projects (SWENET, see http://esa-spaceweather.net/swenet/index.html).

Grants used for this activity:

ESA/PRODEX Contract C90192 "SIDC Telescience".
ESA/PRODEX Contract C90205 "SIDC Data Exploitation".
Remnants of ESA contract 16913/03/NL/LvH. (SWENET support)

D.1.6. Publications

D.1.6.1. Publications with peer review

None

D.1.6.2. Publications without peer review

[1] **Berghmans, D., Clette, F., Lawrence, G., Van der Linden, R.A.M., Vanlommel, P., Robbrecht, E., Podladchikova, O., Nicula, B., Zhukov, A., Wauters, L., Willems, S**., 2006
Solar Monitoring and Space Weather Forecasting at the SIDC
Electronic Proceedings of the IHY European General Assembly, Paris, 10-13/1/2006, http://www.lesia.obspm.fr/IHY/pages/past.html

D.1.6.3. Publications in press, submitted

None

D.1.6.4. Reports, thesis, etc

[2] **Van der Linden, R., Vanlommel P.** and the SIDC-team, SIDC Monthly Bulletin of Solar and Geomagnetic Activity, *12 issues*

[3] **R.A.M. Van der Linden and the SIDC team**. Annual report 2006 to the International Space Environment Service.

[4] **The SIDC team**
Outgoing messages from RWC Belgium, inlcuding 365 daily ursigrams, 52 weekly bulletins, 2 quarterly bulletins, 12 Monthly Ri Reports, 12 Monthly Ri_hemispheric Reports, all-quiet-alerts, presto alerts, halo CME alerts, GOES X-ray flare detection alert, reduced GPS accuracy alert, advance alert: enhanced geomagnetic activity warning. The alerts are sent when needed, the other bulletins are sent on a regular basis.

D.1.7. Scientific outreach

Meeting presentations

[1] **Berghmans, D., Clette, F., Lawrence, G., Van der Linden, R.A.M., Vanlommel, P., Robbrecht, E., Podladchikova, O., Nicula, B., Zhukov, A., Wauters, L., Willems, S**.
Solar Monitoring and Space Weather Forecasting at the SIDC
IHY European General Assembly, Paris, 10-13/1/2006 (Poster)

[2] **Vanlommel P.**
The SIDC: RWC and WDC
Departemental presentations, 23/03/2006

[3] **Clette, F., Podladchikova, O., Robbrecht, E., Vanlommel, P., Nicula, B., Baumann, I., Lawrence, G., Wauters, L., Theissen, A., Berghmans, D., Hochedez, J.-F., Van der Linden, R.**

Expanding Space Weather Services and Products at the SIDC-Brussels
US Space Weather Week, Boulder, CO, USA, 25-28/4/2006 (Poster, no proceedings)

[4] **Vanlommel, P., Zhukov, A.**
Solar Driver Modeling and Predictions
Workshop, International Advanced School on Space Weather, Trieste, Italy, 04/05/2006.

[5] **Vanlommel P., Vander Linden R., Clette F., Berghmans D**.
The Estimated International Sunspot Number
Poster presentation at the third European Space Weather Week, Brussels, Belgium, 13-17/11/2006

[6] **Lawrence, G.; Kretzschmar, M.; Berghmans, D.; Clette, F.; Hochedez, J.; Van der Linden, R.; Delouille, V.; Gissot, S.; Marqué, C.; Nicula, B.; de Patoul, J.; Podladchikova, E.; Robbrecht, E.; Vanlommel, P.; Dehant, V.**
Current and future space weather services and products from the SIDC- Brussels
Oral presentation (G. Lawrence), American Geophysical Union, Fall Meeting 2006, abstract #SA51A-04

[7] **R. Van der Linden**, H. Malcorps, N. Parmentier and the STCE team,
The Solar Terrestrial Center of Excellence: building a comprehensive space weather service in Belgium,
Poster presentation at the 3rd European Space Weather Week, Brussels, Belgium, 13-17 November 2006.

National and international responsibilities

- R. Van der Linden: Representation in ISES

Websites

- Updating the website http://sidc.be

D.1.8. Missions

Commissions, working groups (days): E. Robbrecht (2)

D.2. SIDC World Data Center for the Sunspot Index

D.2.1. Objectives

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 used 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 research in the domain of solar indices to extend the base sunspot reference.

D.2.2. Progress and results

The normal operations of the SIDC as World Data Centre for the Sunspot Index were continued in 2006. These operations include:

- Data processing:
  - Monthly determination of the provisional sunspot numbers (total and normalized hemispheric North & South counts): daily, monthly, monthly smoothed and yearly values.
  - Quarterly computation of the definitive sunspot numbers.
  - Mid-term prediction by the Waldmeier classical method and by the Combined Method (Cugnon-Denkmayr), 18 months ahead.
  - Quality control: long-term drift evaluation based on 20 selected stations and the 10cm radio flux.
- Distribution of calculated sunspot indices by e-mail and fax.
- Maintenance of the archive of yearly, monthly, monthly smoothed and daily sunspot numbers. This 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 Ak geomagnetic index).
  - 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 2006:

- A project was initiated for the long-term analysis of the sunspot time series using the mathematical approach of non-linear dynamical systems, and exploration of two new methods for predicting the future solar cycles: derivation of a chaotic mapping and of an autoregressive process allowing a prediction of the upcoming activity cycles:
  - This work could be undertaken by hiring Dr. Alexandre Baranovski on a short-term post-doc contract. A proposal for a BELSPO post-doc grant for young scientists from countries in Eastern-Europe was submitted in March 2006. As the proposal was finally not selected, the contract as well as this research initiative was terminated.

- Nevertheless, this short work period delivered some early results that were presented in a Department 4 seminar (29/6) and also at the 3rd European Space Weather Week in November 2008 (to be published in the proceedings).

- In another project a Ukrainian PhD student (T. Podladchikova) studied the characteristics of the sunspot data series to look for precursor indicators for the strength of the next solar cycle. This study resulted in a promising technique to forecast the strength of the next cycle based on an assessment of the variability in the descending phase of the previous cycle. These results were presented at the ISROSES conference (Varna, Bulgaria, September 2006) and have been submitted for publication.
- A global study was also started about the past, present and future determination of the sunspot index:
    - This new synthesis and prospective work was undertaken in response to an invitation to present an invited review at the 2nd International Symposium on Solar Climate, Sinaia, in September 2006. A first global review will be published as a refereed paper in early 2007.
    - This study implied the search for past publications, technical notes and historical documents (letters, solar drawings), back to original texts by Rudolph Wolf. Processing flowcharts describing the core principles of the sunspot index calculation used by the SIDC were also created.
    - In addition, this study allowed to identify important orientations for future work on the sunspot index, like the expansion of the total index by the backward reconstruction of hemispheric indices, a separate "per-cycle" index, the study and development of a CCD-based index for extending the historical series in the distant future, etc.
    - This work was presented as a ROB seminar (9/11/2006), highlighting the role and achievement of the SIDC WDC for the sunspot index over the last 25 years.
- The modernization of the methods for data ingestion and distribution has continued in 2006. A web interface has been developed for the submission of data to the SIDC. During 2006, most of the observers that have access to the internet have been migrated to this new interface. The interface checks the consistency of the data on the fly and forces the observers to correct the data if required. This removes one of the major time-consuming chores of the data processing when the sunspot indices are calculated from these observations. An additional benefit is that many observers now provide data on a daily basis, enabling the meaningful calculation of an Estimated International Sunspot Number (EISN) – see section of the Regional Warning Centre.
- The Director of the SIDC/WDC was invited to join the Solar Cycle 24 Prediction Panel (SC24PP) set up by NASA and SEC NOAA to assess the strength of the next solar cycle. This Panel, consisting of international experts on the evolution of the solar cycle, met for a first one-week workshop on October 2006 in Boulder (USA), followed by monthly teleconferences. The Panel will issue its findings and forecast in 2007.
- The studies undertaken by A. Baranovski and T. Podladchikova led to forecasts for the next solar cycle that were submitted to the SC24PP.

D.2.3. Perspective for next years

- Continuation of the investigations regarding the retroactive constitution of an hemispheric and cycle sunspot time series and of the study of the potential of photospheric imaging as a replacement of visual observations for the extension of the historical Ri time series.
- On the longer term, software upgrades and modernization work will be continued. This will lead to:
    - A publication of a comprehensive description and revision of the statistical method and principles used for deriving the International Sunspot Number.
    - A fully automated import and processing of observation reports.
    - Studies on the quality assessment and consistency over time of the sunspot time series.

The benefits willl be new or improved capabilities and data products, as well as increased robustness and automatisation.

D.2.4. Personnel involved

Scientific staff: R. Van der Linden (SIDC Director, science supervision, operations), F. Clette (science supervision, software and research), D.Berghmans (science supervision, observer and user management), P. Vanlommel (product development, operations, BELSPO), L. Wauters (database development), A. Baranovski (research)

Technical staff: A.Vigneron (operator, retired since May 2006), O. Boulvin (operator), A. Ergen (backup operator), G. Evrard (program maintenance)

D.2.5. Partnerships

List of international partners without grant

- Worldwide network of about 85 observing stations in 29 countries.
- ICSU Panel on World Data Centres
- ICSU Federation of Astrophysical and Geophysical Data Analysis Services (FAGS)

Grants/Projects used for this research/service

- FAGS/ICSU funding
- ESA/PRODEX Contract C90192 "SIDC Telescience".

D.2.6. Publications

D.2.6.1. Publications with peer review

None

D.2.6.2. Publications without peer review

[1] **Berghmans, D., Van der Linden, R.A.M., Vanlommel P., Clette, F., Robbrecht, E.**,
History of the Sunspot Index: 25 Years SIDC
Journal of Hist. Geophysics and Cosmical Physics vol VII, No.1 (2006)

[2] **Berghmans, D., Van der Linden, R.A.M., Vanlommel P., Clette, F., Robbrecht, E**.,
25 jaar SIDC: Geschiedenis van het zonnevlekkengetal
Heelal, 51/1, p4

[3] **The SIDC Team**
SIDC Sunspot Bulletin (12 issues).
Royal Observatory of Belgium

[4] **The SIDC Team**
SIDC News (4 issues)
Royal Observatory of Belgium

D.2.6.3. Publications in press, submitted

[5] **Clette, F., Van der Linden, R., Berghmans, D., Vanlommel, P., Robbrecht, E.,** Koeckelenbergh, A., 2007
From the Wolf Number to the International Sunspot Index: 25 years of SIDC
Adv. In Space research, in press.

[6] **Baranovski, A.L., Clette, F.,** Nollau, V., 2007
Nonlinear solar cycle forecasting: theory and perspectives
Annales Geophysicae, submitted

[7] T. Podladchikova, B. Lefevre, **R. Van der Linden**
Integral activity of the declining phase of sunspot cycle as precursor of the next cycle
PASJ, in press

D.2.7. Scientific outreach

Meeting presentations

[1] **Clette, F., Van der Linden, R., Berghmans, D., Vanlommel, P., Robbrecht, E., Koeckelenbergh, A.**
From the Wolf Numner to the International Sunspot Index: 25 years of SIDC
2nd International Symposium on Space Climate, Sinaia, Romania, 12-16/9/2006 (Invited review)

[2] **Baranovski, A.L., Clette, F.**, Nollau, V.
Nonlinear solar cycle forecasting: theory and perspectives
3rd European Space Weather Week, Brussels, 13-17/11/2006 (Poster)

[3] T. Podladchikova, B. Lefevre, **R. Van der Linden**
Integral activity of the declining phase of sunspot cycle as precursor of the next cycle
2nd International Symposium on Space Climate, Sinaia, Romania, 12-16/9/2006 (poster)

D.2.8. Missions

Assemblies, symposia:

- F.Clette: 2
- R. Van der Linden: 2

D.3. Project "Solar Optical Observations (Uccle Solar Equatorial Table)"

D.3.1. Objectives

The optical USET instruments are providing visual and CCD observations in support to the SIDC sunspot index determination, as one of the reference stations in the worldwide network. Those long-term observations provide a continuous characterization of the solar activity and of the sources of irradiance variations. The introduction of white-light and Hα CCD imagers, now in routine use, marks also an ongoing effort to improve and better understand existing solar activity indices and to study new quantitative ground-based solar indices based on modern electronic imaging techniques. The USET activities thus follow two main axes:

Optical observations of the Sun and characterisation of its activity:

- Visual observations of sunspot, digitization and exploitation of drawings
- Digital imaging in white-light (photosphere) for synoptic observations
- Digital imaging in the H-alpha line (chromosphere) for real-time flare patrol observations.

Digitization and processing of the visual sunspot observations of the Uccle station, and publication in the SIDC Bulletin of additional indices for this reference station:

- Total, hemispheric and central zone sunspot number (raw and normalized)
- PPSI index
- Classification (type, sunspot count, heliographic coordinates) and history of individual sunspot groups
- Dates of possible return of well developed sunspot groups (Zürich types E & F)

D.3.2. Progress and results

Observations and operational duties:

- 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.
- Uccle sunspot drawings were scanned immediately after the observations and 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 monthly tables of the Sunspot bulletin.
- *2006 statistics for the sunspot observations* (table below):
  - Overall, there were more observed days than in 2005 (+25 days, i.e. 10%). This may be partly due to sunnier weather conditions in summer, though December 2006 allowed very few observations.
  - The overall number of observers decreased from 15 to 8. However, the observing duties were in fact more evenly distributed, with two prime observers instead of one, each being on duty about 50% of the time. So, the change results essentially from the reduction of the number of occasional voluntary observers who cannot acquire and keep the necessary experience.

Observer	**Duty days**	**Days without observations**	**Observing days**	**1 drawing**	**2 drawings**	**Total nb. of drawings**
P.Boulvin	146	37	109	47	62	109
A.Ergen	148	33	115	71	44	115
F.Clette	27	7	20	14	6	20
L.Rodriguez	22	8	14	7	7	14
D.Berghmans	14	5	9	7	2	9
A.Zhukov	4	4	0	0	0	0
G.Lawrence	3	0	3	2	1	3
S.Gissot	1	0	1	0	1	1
Total	**365**	**94**	**271**	**148**	**123**	**271**

- *2006 statistics for the CCD observations*: the 2006 counts given below are slightly larger (~30%) than in 2005, probably partly because of the higher number of observing days.

Camera	**Nb. Images**
Photosphere	1210
Chromosphere	1216
Total	**2426**

New developments in 2006:

- **USET staff**:
  - In 2006, the USET operations were still adversely affected by the steady decrease of the human resources available. One operator retired and a calculator/programmer was absent over long periods because of health reasons. One permanent calculator position remained vacant (officially

vacant since June 2005, though effectively vacant since 2003) This lack of staff, that represents a 50% reduction of the manpower formerly dedicated to the USET, was the key parameter constraining the USET activities in 2006.

  - The reorganisation of the observations around a limited team of semi-dedicated observers, which had been introduced in 2005, was largely successful in terms of reliability and quality of observations. However, it led to an accumulation of compensations of the week-end services, given the current number of available dedicated staff. One additional dedicated USET observer would largely eliminate this unbalance (USET calculator, technician or scientist).

- **Maintenance of the CCD camera system**:
  - The system suffered only from a failure of the uninterruptible power supply (28/9/2006). This failure did not interrupt the observations but prevented the acquisition of white-light images randomly during several days in September 2006. It was traced to a lack of proper maintenance of the aging batteries.
  - The above failure led to a redefinition of the maintenance procedures. A detailed maintenance schedule was created and was implemented since October 2006. It led to a significant improvement in the regularity and consistency of maintenance work.
  - The DALSA CCD cameras continued to show aging degradation (periodic loss of synchronization on the White-light camera, dead-bits on the H-alpha camera output). By lack of time, manpower and internal capabilities for repairing camera electronics, the defects were not removed or improved in the course of 2006. All our hopes now rely in the installation of new cameras purchased on the LOTTO funding, but this will probably have to wait until late 2007 (see below)
- **New H-alpha optics**: the H-alpha system that had been selected and ordered in 2005 was delivered on 21/4/2006 after a long 8-month delivery time. The system was mounted on the equatorial table and fully tested. Those tests showed the excellent optical quality of the optics but also revealed a defect in the thermal regulation of the filter. After repeated technical interactions and negociations with the supplier, Baader Plaetarium GMBH, the filter was returned for repair by June 20. It was repaired and finally shipped back on September 18. Further tests confirmed that it is now fully functional. However, by lack of availability and manpower, no further design and construction work could be done in 2006 on the camera-filter coupling. This is postponed to the spring of 2007.
- **New camera systems (LOTTO funding):** a modernization and upgrade project for the USET instruments was prepared and submitted for LOTTO funding in February 2006. This project was selected officially by November 2006, while the funding will become available only in the course of 2007. The purpose of this project is twofold:
  - Upgrade of the old DALSA cameras (1kx1k pixels) with two new cameras with higher 2kx2k spatial resolution, which matches the optical resolution, and also providing enhanced blue sensitivity. They will be used for white-light and near-UV CaII-K line images, while the DALSA cameras (one serving as backup) will still be used on the 3rd channel (H-alpha) for some time.
  - Addition of a CaII-K photometric imaging system that will provide images of the chromosphere in a standard spectral line used to quantify stellar activity and UV variability (plages, network, flares). This system will be used to provide a CaII emission index as is done at a small number of other stations worldwide, mainly the member stations of the PSPT/RISE network. A collaboration was initiated with the Observatory of Rome (Dr. I Ermolli), which runs one of the PSPT stations, as well as contacts with the High-Altitude Observatory that created the PSPT/RISE concept and network.

  A first market survey has also been done for suppliers of appropriate digital CCD cameras and custom narrow-band filters, in order to prepare the proposal. This will have to be repeated in 2007 when it will become possible to order the equipment.

- **Design and construction of a solar pointer for the USET**: This development work was continued in 2006. The solar pointer 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 2006, the following progress was made:

- The pointer optics (mostly recuperated hardware) were assembled and mounted on the equatorial table.
- The pointer electronics were designed and a first version was built by the Dept.4 electronics laboratory, using also the ROB insfrastructure (refurbishment of the printed circuit engraving machine). It includes the 4-quadrant sensor electronics as well as the thermal regulation of the electronic box. Two sucessive versions were developed and built. The second improved version of the electronic box was assembled and ready for installation by the end of 2006.
- A provisional digitizing system was prepared in view of the optimization and commissioning of the pointer electronic settings and controls.

➢ **Other USET instrumental developments:**
  - SECTEC telescope and dome control software: production of a global organigram of the application in view of its future upgrade (solar pointer control, automatization)
  - Mechnical improvements: design and testing of a new manual opening mechanism for the telescope aperture doors, initial study of new aperture doors (improved dust protection).

➢ **New digitizing system for the solar drawings**: further development of the on-screen drawing measurement software took place in the course of a computer graduate training period, as well as a one-month student job contract in August 2006:
  - The software now includes an internal TWAIN control of the A3 document scanner, thus integrating the scanning and measurement steps into a single user interface. I also defined and implemented a new output file format that is more human-readable for quality control and also includes numerous additional quantities useful for the subsequent processing.
  - This new software has been put in normal operation since June 2006 and provides a completely new tool for the digitization of the Uccle sunspot drawings. This fexible tool also opens new research and data analysis prospects, like the backward digitization of the entire Uccle drawing archive, spanning 6 sunspot cycles, or the digitization of other drawings from other stations to produce a multi-station sunspot record with few data gaps.

➢ **Upgrade of the Uccle sunspot processing software**: this work, undertaken in 2005, aims at fixing the old unreliable software and expanding it. It will improve the quality of the produced data and simultaneously, it will open new analysis possibilities, including the exploitation of other drawing sets from other solar observing stations in Europe and beyond. In 2006, this work progessed as follows:
  - All scripts and programs have been rewritten, with the exception of the largest program dedicated to the tracking of the evolution of sunspot groups. About 50% of this undocumented software have been decoded and partly rewritten in a modern structured style.
  - The user manual was entirely updated to match the new suite of programs and scripts.
  - In this context, a detailed table for sunspot classification was created and distributed to all Dep4 scientists and observers (23/11/2006) in order to improve the consistency in the group encoding by the different observers/operators, by codifying the standard definitions, criteria and evolutionary scenarios.
  - Thanks to those updates, the monthly processing of Uccle drawings proceeded flawlessly during the 12 months of 2006, contrary to previous years. Although there is still significant work to be completed (automated elimination of past closed Carrington rotations, robustness of the group tracking method), the reliability of this analysis "pipeline" has already strongly improved.

D.3.3. Perspective for next years

➢ Continuation of the USET solar activity monitoring observations and data dissemination.

➢ Instrument development:

- Transfer of the CCD camera to the new H-alpha filter and telescope and final commissioning of the system. This may include the implementation of a software correction for dead-bits in the old H-alpha camera's, while waiting for the new LOTTO-funded cameras.
- Completion of the solar pointer: this will involve a study phase in order to optimize the system to the actual properties of image turbulence at the Uccle site.
- Design, construction and installation of new improved protective doors on all solar telescopes.
- Continuation of the redefinition and upgrade of the SECTEC telescope and dome control software.

- Installation of the new LOTTO equipment: in 2007, we will work primarily on hardware design, selection and ordering:
  - Study and selection of a new CaII-K telescope
  - Selection, purchase and initial installation of two new 2048x2048 CCD cameras.
- Trainees: over the 2006-2007 academic year, F.Clette will be again supervising one computer graduate student (ESI; Garyp Ramani) who will work on the development of a Web-based USET data access interface (data browser, interface to database, new advanced data display modes). This work will help to enhance the current limited visibility and accessibility of USET data for the international community and also provide the base concept for the SWAP/PROBA2 data distribution.
- Processing of Uccle visual observations: the emphasis will be put on the decoding and reconstruction of the remaining part of the group tracking software. This work will become vital, especially after the retirement of the main programmer at the end of January 2007. As the calculator job position will probably still be pending for some time in 2007, there is only one person (scientist) left with a knowledge of this vital processing. Given the understaffing, this prioritary work will proceed anyway at a slow pace. Once the entire software will be decoded and cleaned, it will finally open the way to comprehensive data upgrades and expansions: files and data flow redefined, additional or improved capabilities and data products, increased robustness and automatisation.

D.3.4. Personnel involved

Scientific staff: F. Clette (lead scientist, software development, instrument design, observer, data exploitation), D. Berghmans, L. Rodriguez, G. Lawrence, A.Zhukov, S.Gissot

Technical staff: J-L. Dufond (Lead technician), A. Ergen (technician, observer). O. Boulvin (primary observer, operator) S. Willems (database development), G. Evrard (program maintenance), A. Vigneron (operator, retired since Jan. 2006)

D.3.5. Partnerships

List of international partners without grant

- Dr I. Ermolli, Osservatorio Astronomico di Roma, Italy

Grants/Projects used for this research/service

- LOTTO equipment grant (attributed in November 2006)
- ESA/PRODEX Contract C90192 "SIDC Telescience".

D.3.6. Publications

- SIDC sunspot bulletin (12 monthly issues): the Uccle-USET sunspot numbers, sunspot group table, returning group list.
- Real-time web distribution of CCD camera images
- Real-time web distribution of scanned solar drawings

D.3.6.1.Publications without peer review

None

D.3.6.2.Publications without peer review

[1] **Clette, F.**
USET: the Uccle Solar Equatorial Table
Electronic Proceedings of the IHY European General Assembly, Paris, 10-13/1/2006, http://www.lesia.obspm.fr/IHY/pages/past.html

D.3.7. Scientific outreach

Meeting presentations

[1] **Clette, F.**
USET: the Uccle Solar Equatorial Table
IHY European General Assembly, Paris, 10-13/1/2006 (Poster)

Educational responsibilities

- F.Clette: promoter of student Julien Rateau (ESI, Ecole Supérieure d'Informatique, 13/2-2/6/2006)

D.3.8. Missions

Assemblies, symposia:

- F.Clette: 1

D.4. Solar radioelectric observations (Humain station)

D.4.1. Objectives

The radiotelescopes of the Humain station were installed to provide radioelectric observations of the Sun for flare monitoring and long-term recording of the solar radio flux in the upper-chromosphere and low corona. In particular, a 13-m decimetric radiometer was previously dedicated to the continuous recording of the 600MHz radio flux, which produced one of the longest existing flux series (absolute solar index, unique station worldwide). The radio observations were stopped in July 2005. In the framework of a modernization and redeployment project submitted in 2004 and still pending, new refurbished radio instruments are foreseen, offering the following new capabilities:

- Integrated absolute radio flux at 600 MHz (new state-of-the-art receiver), and future extension to other frequencies, including 2,8Ghz (10.7 cm).
- Possible future addition of radio spectrograms in the 30MHz-3GHz range (CALLISTO), for flare monitoring and diagnostics
- Near-real time transmission and processing of the Humain data in support to the SIDC solar flare monitoring.

D.4.2. Progress and results

As the radio instruments have been put out of operation since mid-2005, the radio instruments were inactive in 2006. Still, some actions took place to ensure the present and future preservation of the site and also about the definition, update and submission of proposals for future radio instruments.

- **Expansion of the HUMSOLAR concept to radio spectrography**: in January 2006, a collaboration was initiated with the Solar group of the ETH Zürich, led by Dr A.Benz. This group, which operates two radio-spectrographs since many years, has designed a compact low-cost spectrograph (CALLISTO) with the goal of replicating and installing this instrument at different stations worldwide. The

ROB Humain facility was identified as a promising partner for this project, given the existing know-how and infrastructure at the station. This allows a fast implementation and a largely automated instrument operation at a minimal cost compared to the existing hardware and facility, reducing further the streamlined budget proposed for the HUMSOLAR project. This interest was further strengthened when on-site measurements have demonstrated that the Humain station ranks as one of the best European sites regarding low electromagnetic interferences (see below). However, no financial resource or staff could be involved in the project, even to install a basic CALLISTO setup as a first expandable demonstration instrument. Therefore, despite the enthousiastic voluntary support from the ETH team, no further activity took place in 2006.

- **Survey of the background radio spectrum at the Humain station**: in the context of our potential collaboration with the ETH solar group, they sent their Lead Engineer, Christian Monstein, on their own cost for a two-day visit to the Humain station (23-24/5/2006), in order to measure the level of artificial radio interference at this location. M. Monstein brought a complete CALLISTO receiver and control PC, while we had arranged to borrow a log-periodic antenna from the IBPT technical services. The radio spectrum in the range 30-800MHz was measured in several directions along the horizon and up to the zenith. The results were published as an ETH internal report and show the high quality of the site, with a low level of interferences and the availability of several bands (30-100MHz, 250-300MHz) that are saturated by radio interferences in most of the other 50 sites surveyed previously by C.Monstein elsewhere in Europe (mainly Switzerland, Germany and Austria, see http://www.astro.phys.ethz.ch/instrument/callisto/RFSPEC2/spectrum2.htm). Those key measurements thus raised the scientific value that can be attributed to this ROB facility at a European level.
- **Inclusion in the Solar-terrestrial Center of Excellence (STCE):** an updated plan and budget estimate was established on the base of a few radiometers and 2 or 3 CALLISTO-type spectrographs tuned to different spectral bands. This plan was imbedded in the STCE project description submitted to the Ministerial Council and in the implementation plan. By this inclusion, the future prospects for solar radioastronomy at ROB are tied entirely to the approval, creation and future continuation of the multi-institute STCE structure.
- **Preservation of the site quality:**
  - Frequency allocation requests from the IBPT were processed (3/2, 15/2, 18/4, 12/5, 7/6/2006).
  - Negociations took place with the local and General Directors of the Lhoist company concerning the future long-term extension of the quarry located near the Humain station (meeting at ROB on 19/10/2006).

D.4.3. Perspective for next years

The perspectives for radioastronomy in Humain remain very uncertain. Therefore, no workplan can be drawn for 2007. If funding becomes available through the STCE budget in the course of the year, the first initiatives will be:

- Hiring a scientist dedicated to solar radio observations, an HF radio engineer and a technician to prepare and operate the radiotelescopes.
- Designing a new receiver at 600MHz to restart the calibrated flux measurements started at the Humain station more than 50 years ago and interrupted in 2005. Except for the focal array, a 6-m parabola is commissioned and available already since 2004 for this purpose.
- Installing, jointly with the ETH radio scientists, a first CALLISTO spectrograph and putting it in operation on one of the 4-m parabolas (30-800MHz decimetric band).

Most of this would probably take place in 2008 as the actual funding, if allocated, will not become available before mid-2007.

D.4.4. Personnel involved

Scientific staff: F. Clette (site preservation, scientific collaborations)

Technical staff: J-L. Dufond (support to site testing), A. Ergen (support to site testing)

D.4.5. Partnerships

List of international partners without grant

- Dr M. Messerotti, Osservatorio Astronomico di Trieste, Italy
- Dr K. Tapping, Dominion Radio Astrophysical Observatory, Penticton (Ottawa), Canada.
- Dr. A.Benz, Eng. C.Monstein, Eidgenössische Technische Hochschule (ETH), Zürich, Switzerland.

Visitors: 4 short visits

D.4.6. Publications

D.4.6.1.Reports, thesis, etc

[1] Monstein, Christian
Callisto spectrum measurement at Humain station ROB
ETH Physics, Astronomy and Electronics Work Bench Report

D.4.7. Missions

Field missions:

- F.Clette: 1 day
- J-L.Dufond: 1 day
- A.Ergen: 1 day

INTERDEPARTEMENTAL SCIENTIFIC ACTIVITIES

A. HERMES echelle spectrograph

In 2004, financial support was obtained by IvS KU Leuven (FWO and KU Leuven), ULB (FNRS) and ROB (Lotto) to build an echelle spectrograph for the Mercator telescope of the IvS at the Roque de los Muchachos Observatory on La Palma. Meanwhile, additional partners entered into the project (Thüringer Landessternwarte Tautenburg and Observatoire de Genève). The spectrograph is expected to be operational in the second half of 2008.

A.1. Data reduction package for the HERMES echelle spectrograph

A.1.1. Objectives

The Royal Observatory of Belgium has the responsability to provide in due time the data reduction and instrument control software (work package WP900). The objective is to provide, in contrast to the existing pipelines, a differential data-reduction system. The WP900 working group involves personnel from the department 2 and 3, as well as colleagues from the other partners in the HERMES project.

A.1.2. Progress and results

The work in 2006 concerned primarily the lay-out of the software package and the testing of some new principles we will introduce, in the data reduction and in the model-development software, on data from other spectrographs. 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.

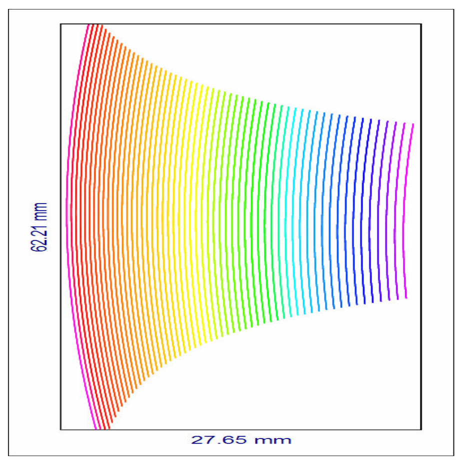


Figure 41: Echelle format of the HERMES spectrograph, projected on the CCD detector

A.1.3. Perspective for next years

An informatician was engaged and joined the project in January 2007 (Louis Dumortier). A partial involvement of M. Borges (Observatorio Nacional, Rio de Janeiro) during his one-year fellowship at ROB in 2007 is planned. A large part of the software must be available before the end of 2007. However, some parts will require input that only becomes available in the commissioning time of the instrument.

A.1.4. Personnel involved

Scientific staff: H. Hensberge, Y. Frémat, G. C. Van de Steene, P. Lampens, J.-P. De Cuyper

A.1.5. Partnerships

List of international partners without grant

- Thüringer Landessternwarte Tautenburg

List of national partners without grant

- H. Van Winckel, J. De Ridder, M. Reyniers (KULeuven)

- A. Jorissen, S. Van Eck (ULB)

Grants/Projects used for this research/service

- IAP P5/36

A.1.6. Scientific outreach

Meeting presentations

[1] **Hensberge H.**
Instrumental signatures in echelle spectra
The future of photometric, spectrophotometric and polarimetric polarization, Blankenberge, België

Meeting organization

Half-day WP900 meeting at ROB, 16/06/2006, with participation of 10 scientists from KULeuven, ULB and ROB.

A.1.7. Missions

Assemblies, symposia (number):	Hensberge H.	(1)
Commissions, working groups (days):	De Cuyper J.-P.	(1)
	Hensberge H.	(2)

A.2. Procurement of Optical Components for the HERMES Achelle Spectrograph

A.2.1. Objectives

The Royal Observatory of Belgium contributes with the Lotto grant to the procurement of optical components for the HERMES echelle spectrograph. For information on the lay-out of the instrument, see http://hermes.ster.kuleuven.ac.be.

A.2.2. Progress and results

The ROB participated in the design control of the opto-mechanical parts of the HERMES spectrograph, wrote the specifications for the buying procedure and prepared the demand to the minister for the acceptance of a negociated buying procedure without previous publication, split up in individual parcels. Companies were contacted by the HERMES consortium and negotiations lead to a second call in December,

With slightly adjusted technical specifications for a global buying.

A.2.3. Perspective for next years

Early in 2007 the buying contract will be signed. The follow-up of the buying contract will be done, including meetings at the contractor's offices.

A.2.4. Personnel involved

Scientific staff: J.-P. De Cuyper, H. Hensberge

A.2.5. Partnerships

List of international partners without grant

- U. Laux, H. Lehmann, H. Winkler (Thüringer Landessternwarte Tautenburg, Germany)
- Observatoire de Genève (Switzerland)

List of national partners without grant

- H. Van Winckel, J. De Ridder, M. Reyniers (KULeuven)
- A. Jorissen, S. Van Eck (ULB)

Grants/Projects used for this research/service

- Financement by Lotto (2004) 'Onderdelen voor de opbouw van een hoge resolutie echelle spectrograaf voor de 1.2m MERCATOR telescoop'
- IAP P5/36

Visitors: 4

A.2.6. Publications

A.2.6.1. Publications in press, submitted

[1] **De Cuyper J.-P., Hensberge H.,** Raskin, G., Van Winckel H., Lehmann, H., Winkler, J.
HERMES, a high-resolution fiber-feb spectrograph for the Mercator telescope
In: Astronomical Data Analysis Software and Systems XVI (eds. R. Shaw, F. Hill and D. Bell), ASP Conf. Ser., in press

A.2.6.2. Reports, thesis, etc

[2] **De Cuyper J.-P.**
Specifications HERMES Optical Components (in Dutch, French and English)

A.2.7. Scientific outreach

Meeting presentations

[3] **De Cuyper J.-P., Hensberge H.,** Raskin, G., Van Winckel H., Lehmann, H., Winkler, J.
HERMES, a high-resolution fiber-feb spectrograph for the Mercator telescope
XVIth ADASS Meeting, Tucson, AZ, USA (poster contribution)

A.2.8. Missions

Assemblies, symposia (number): J.-P. De Cuyper (1)
Commissions, working groups (days): J.-P. De Cuyper (8)

GENERAL SCIENTIFIC ACTIVITIES

This paragraph describes activities with a scientific and not an administrative character (appointments, etc, will be mentioned in the 'human resources' report of the ROB), related to work at the ROB, but are not directly related to any project.

Memberships of national scientific committees

- **V. Dehant** is Chairperson of the BNCGG (Belgian National Committee on Geodesy and Geophysics).
- **B. Ducarme** is secretary of the BNCGG.
- **C. Bruyninx**, **T. Camelbeeck** and **R. Verbeiren** are titular members of the BNCGG.
- **V. Dehant, T. Van Hoolst** and **R. Van der Linden** are titular members of the BNCA (Belgian National Committee on Astronomy).
- **R. Warnant** is titular member of the CNBR (Comité National Belge de Radioélectricité).
- **R. Van der Linden** is titular member of the Belgian National Committee for the Relation Sun-Earth.
- **F. Collin, P. Defraigne, M. Van Camp, T. Van Hoolst, K. Vanneste** and **R. Warnant** are associated members of the BNCGG.
- **C. Bruyninx, V. Dehant** and **R. Warnant** are associated members of the CNBRS (Comité National Belge de Recherches Spatiales).
- **Th. Camelbeeck** is associate member at the Académie Royale des Sciences d'Outre-Mer/Koninklijke Academie voor Overzeese Wetenschappen
- **Th. Camelbeeck** is chairman of the Société Royale Belge d'Astronomie, de météorologie et de physique du globe
- **Th. Camelbeeck** and **M. Van Camp** are members of BESEIG (Belgian committee of seismology and earthquake engineering)
- **Th. Camelbeeck** and **M. Van Camp** are members of Geologica Belgica.
- **P. Lampens** is ROB representant at the Belgian National ESO Committee
- **P. Lampens** is administrator of the corporated association "*Belgian Women in Sciences"*
- **G.C. Van de Steene** is member of the Belgian National ESO Committee
- **G.C. Van de Steene**: VISA Belgian Time Allocation Committee
- **P. Vanlommel**, **D. Berghmans**: members of the Belgian national committee for the International Heliospherical Year.
- **O. Podladchikova** is member of the French Astronomical Union
- **O. Podladchikova** is member of the Programme National Soleil – Terre (France)
- **O. Podladchikova** is member of Ukrainian theoretical physics union
- **S. Lambert** is associate member of IVS (International VLBI Service for Astronomy and Geodesy);
- **S. Lambert** is member of the Comité National Français de Géodésie et Géophysique (CNFGG);

Belgian representations at international level

- **V. Dehant** is President of the Comité National Belge de Géodésie et Géophysique and represents Belgium at the IUGG (International Union of Geodesy and Geophysics);
- **V. Dehant** is Belgian Reprentative in IAG (International Association of Geodesy);
- **K. Vanneste** has been appointed as titular member for Belgium in the European Seismological Commission (ESC) for the period 2006 – 2010.
- **R. Warnant** is Belgian Reprentative in COST 724 "Developing the Scientific Basis for Monitoring, Modelling and Predicting Space Weather", Management Committee member;
- **R. Warnant** is Belgian Reprentative in COST 296 "Mitigation of Ionospheric Effects on Radio Systems (MIERS)", Management Committee member;

- **P. Defraigne** is Belgian representative at the Consultative Committee for Time and Frequency, BIPM (Bureau International des Poids et Mesures).
- **Th. Camelbeeck** is Belgian representative at the International Association of Seismology and Physics of the Earth Interior,
- **M. Van Camp** is member of the 'Working group on Gravimetry', Consultative Committee for Mass and Related Quantities, Bureau International des Poids et Mesures (BIPM, Sèvres, France),
- **M. Van Camp** is representative of the ROB as IRIS foreign affiliate
- **B. Ducarme** is Director of the International Centre for Earth Tides (ICET), a service of FAGS and World Data Centre
- **R. Verbeiren** is Belgian representative EMSC
- **R. Verbeiren** is Belgian representative in the ECGS council
- **R. Verbeiren** is Belgian representative in the Board of directors of ORFEUS
- **G. C. Van de Steene**: Belgian representative in the ESO User 's Committee from 2005-2008
- **F.Clette**: Belgian representative in the CRAF (Committee for RadioAstronomy Frequencies) since 2003.
- **F.Clette**: Belgian representative to the JOSO Board (Joint Organisation for Solar Observations) since 1992.
- **D. Berghmans**: ESA Solar System Working Group, member from Jan 1 2005 till Dec 31 2007
- **R. Van der Linden** is Director of the Solar Influences Data analysis Centre (SIDC), a service of FAGS, Wold Data Centre and Regional Warning Centre of the ISES.

Memberships of international scientific committees:

- **P. De Cat, Y. Frémat, P. Lampens** are members of the HERMES consortium
- **P. De Cat** is member of the COROT "γ Doradus Working Group"
- **P. Lampens** is member of the COROT "Binaries" Thematic Group
- **F.Clette** is member of URSI Commission J (Radioastronomy)
- **F.Clette** is URSI representative to the FAGS Committee (Federation of Astronomical and Geophysical Data Analysis Services)

IAU (International Astronomical Union)

- **V. Dehant**: President of IAU Commission 19 "Earth Rotation", 2003-2006;
- **V. Dehant**: Member (as Past-President) of IAU Commission 19 "Earth Rotation" Advisory Board, 2006-present;
- **P. Defraigne**: Member of IAU Commission 19 "Earth Rotation" Advisory Board, 2003-present;
- **P. Defraigne**: Member of the Organizing Committee of Division I "Fundamental Astronomy", 2003-present;
- **V. Dehant**: Member of the Organizing Committee of Division I "Fundamental Astronomy", 2003-2006;
- **P. Defraigne**: President of IAU Commission 31 "Time", 2006-present; Vice-President, 2003-2006;
- **P. Lampens**: Member of the Organising Committee of IAU Commission 26 (Aug. 2000 →Aug. 2006)
- **T. Pauwels** is member of IAU Commission 7 "Celestial Mechanics & Dynamical Astronomy"
- **T. Pauwels** is member of IAU Commission 8 "Astrometry"
- **R. Van der Linden, D. Berghmans, J.-F. Hochedez** are members of IAU Commission 10 "Solar Activity"
- **F. Clette** is member of IAU Commission 12 "Solar Radidation and Structure"
- **J. Cuypers** is member of IAU Commission 15 "Physical Studies of Comets & Minor Planets"
- **C. Bruyninx, P. Defraigne, V. Dehant, F. Roosbeek, T. Van Hoolst**: Members of IAU Commission 19 "Earth Rotation"

- **P. De Cat, T. Pauwels** are members of IAU commission 20 "Positions & Motions of Minor Planets, Comets & Satellites"
- **H. Hensberge, J. Cuypers** are members of IAU commission 25 "Stellar Photometry & Polarimetry"
- **P. De Cat, P. Lampens** are members of IAU commission 26 "Double & Multiple Stars"
- **P. Lampens, P. De Cat, T. Van Hoolst, J. Cuypers** are members of IAU commission 27 "Variable Stars"
- **C. Bruyninx, P. Defraigne, V. Dehant** are members of IUA Commission 31 "Time"
- **Y. Frémat**, **R. Blomme** are members of IAU Commission 36 "Theory of Stellar Atmospheres"
- **H. Hensberge** is member of IAU commission 44 "Space & High Energy Astrophysics"
- **T. Pauwels**: IAU Task Force on the Preservation and Digitization of Photographic Plates (PDPP)
- **T. Pauwels**: IAU WG on the Astrographic Catalogue and Carte du Ciel Plates
- **T. Pauwels**: IAU WG "Astrometry by small ground-based telescopes"

IAG (International Association of Geodesy)

- **V. Dehant**: President of Commission 3 "Earth Rotation and Geodynamics" of IAG, 2003-present;
- **C. Bruyninx**: Network Coordinator of the EUREF Permanent GPS Network (EPN), 2003-present;
- **C. Bruyninx**: Head of Central Bureau of the EUREF Permanent GPS Network (EPN), 2003-present;
- **C. Bruyninx**: Member of the "EUREF Technical Working Group", governing board of the "sub-commission for Europe" SC1.3.a: of IAG Commision 1 "Reference Frames", 2003-present;
- **F. Roosbeek**: Member of Central Bureau of the EUREF Permanent GPS Network (EPN), 2003-present;
- **C. Bruyninx**: Member of the EPN Special Project "Time Series Monitoring", 2003-present;
- **C. Bruyninx**: Head of EPN Analysis Center: C. Bruyninx, 2003-present;
- **C. Bruyninx**: Head of EPN Data Center: C. Bruyninx, 2003-present;
- **C. Bruyninx**: Co-chair of the Inter-Commission Study Group IC-SG1.2 "Use of GNSS for Reference Frames" (joint between IAG Commision 1 "Reference Frames", Commission 4 "Positioning and Applications", and IGS International GNSS Service)), 2003-present;
- **C. Bruyninx**: Member of the IAG Inter-Commission Project 1.2 on "Vertical Reference Frames", 2003-present;
- **C. Bruyninx**: Member of the Working Group "European Combined Geodetic Network (ECGN)" of the EUREF sub-commission", 2003-present;
- **T. Van Hoolst**: Member of the IAG Commission 3 Advisory Board representing the Inter-commission on "Theory", 2003-present;
- **Ö. Karatekin**: Member of the IAG Commission 3 Advisory Board representing the Inter-commission on "Planetary Geodesy", 2003-present;
- **C. Bruyninx**: Member of the Executive Board of "Wegener", an IAG Inter-commission project, 2003-present;
- **Ö. Karatekin**: Member of steering committee of the Inter-commission on "Planetary Geodesy", 2003-present;
- **T. Van Hoolst**: Member of steering committee of the IAG Inter-commission on "Theory", 2003-present;
- **M. Van Camp** is member of the Study Group 2.1.1 on Comparisons of Absolute Gravimeter SGCAG of sub-commission 2.1 (Gravity and Gravity Networks) of IAG Commission 2 (Gravity Field)
- **C. Bruyninx, P. Defraigne, V. Dehant, Ö. Karatekin, F. Roosbeek, T. Van Hoolst**: Members of IAG Commission 3, 2003-present;
- **C. Bruyninx, F. Roosbeek**: Members of IAG Commission 1, 2003-present;
- **C. Bruyninx, F. Roosbeek**: Members of IAG Commission 4, 2003-present;
- **B. Ducarme**: member of WG "Precise Tidal Predictions", of the IAG Subcommission "Earth Tides"

EGS (European Geophysical Society)

- **O. Podladchikova**: member of the EGS

IERS (International Earth rotation and Reference systems Service)

- **T. Van Hoolst**: Head of the IERS Special Bureau for the Core
- **P. Defraigne, V. Dehant**: Members of IERS Special Bureau for the Core
- **V. Dehant**: Member of the IERS Conventions Editorial Board;
- **S. Lambert**: Member of the IERS Working Group on "Prediction";

IGS (International GNSS Service)

- **C. Bruyninx**: Associate Member of the IGS
- **C. Bruyninx**: Co-chair of the IGS Working Group on GNSS
- **P. Defraigne**: Member of the WG 'Clock Products WG' of the IGS
- **R. Warnant**: Member of the WG "Towards an IGS Combined Ionosphere Product" of the IGS

IVS (International VLBI Service)

- **S. Lambert**: Member of the WG "Second Realization of the ICRF" of IAU/IERS/IVS.

COST Action WG

- **R. Warnant**: Vice Chairman of COST 296 – Working Group 3 "Space Based Systems"
- **M. Kretzschmar, J.-F. Hochedez, V. Delouille**: Members of the WG-1 Monitoring and predicting solar activity for Space Weather of the Cost 724 action: "Developing the Scientific Basis for Monitoring, Modelling and Predicting Space Weather"

AGU (American Geophysical Union)

- **V. Dehant**: member (as Past-President) of AGU Geodesy Section Executive Committee, 2004-2006;
- **C. Bruyninx**: Secretary of the AGU Geodesy Section, 2004-2006;
- **C. Bruyninx**: member of the AGU Geodesy Section Executive Committee, 2004-2006;
- **V. Dehant**: member of the Selection Committee for the Macelwane Medal of AGU, 2004-2006;
- **V. Dehant**: member of the Selection Committee for the Bowie Medal of AGU, 2006-2008;
- **V. Dehant**: member of the Selection Committee for the Veining Meinesz Medal of EGU (European Geophysical Union), 2004-present;
- **C. Bruyninx**: member of the AGU Section and Focus Group Web Page Committee, 2004-2006;
- **O. Podladchikova**: member of the AGU

ESA

- **V. Dehant**: Co-I of MaRS (Mars Express Radio Science experiment) of Mars Express;
- **V. Dehant**: Co-I of VeRa (Venus Express Radio science experiment) of Venus Express;
- **V. Dehant**: Co-I of MORE (Mercury Orbiter Radio science experiment) of BepiColombo;
- **V. Dehant**: Co-I of BELA (BepiColombo Laser Altimeter) of BepiColombo;
- **T. Van Hoolst**: Co-I of SIMBIO-SYS (High resolution camera experiment) of BepiColombo;
- **T. Van Hoolst**: Chairman of the WG on "Jovian Satellites" within the Initiative for a Future Mission to Europa and the Jovian System;
- **V. Dehant**: Member of the WG on "Jovian Satellites" within the Initiative for a Future Mission to Europa and the Jovian System;
- **V. Dehant, T. Van Hoolst**: member of the WG on "Europa" within the Initiative for a Future Mission to Europa and the Jovian System;
- **V. Dehant**: PI of the Lander Radioscience (LaRa) experiment from GEP/ExoMars/AURORA mission, 2006-present;
- **S. Le Maistre**: Project Manager of the Lander Radioscience (LaRa) experiment from GEP/ExoMars/AURORA mission, 2006-present;
- **V. Dehant**: member of the Review Team for the Cassini-Huygens Archive;

- **V. Dehant, T. Van Hoolst, O. Verhoeven, A. Rivoldini**: member of the WG "Mars INTerior synergy";
- **R. Warnant, D. Berghmans, R. Van der Linden** are members of the ESA Space Weather Working Team;
- **P. De Cat, Y. Frémat** are members of GAIA "Hot Star Team"
- **P. De Cat, T. Pauwels**: GAIA-DPAC Coordination Unit 4 "Object processing"
- **P. De Cat, Y. Frémat**: GAIA-DPAC Coordination Unit 6 "Spectroscopic processing"
- **P. De Cat, Y. Frémat**: Coordination Unit 7 "Variability processing"
- **Y. Frémat**: GAIA-DPAC Coordination Unit 8 "Astrophysical parameters"
- **E. Robbrecht, O. Podladchikova, A. Zhukov**: Co-I of SECCHI on STEREO
- **J.-F. Hochedez**, PI of LYRA (Lyman-Alpha Radiometer) on PROBA2
- **D. Berghmans**, PI of SWAP (Sun Watcher using APS and image processing) on PROBA2
- **A. BenMoussa, I. Dammasch, M.Dominique, M. Kretzschmar**, co-I of LYRA on PROBA2
- **F. Clette, D. Berghmans, J.-F. Hochedez**, co-I of EIT on SOHO

Editorial responsibilities

- **C. Bruyninx**: Editor of GPS Solutions
- **V. Dehant**: Member of the Editorial Board of the "IERS Conventions 2000", 1998-present;
- **V. Dehant**: Editor of the Proceedings of the IAG General Assembly meeting 'Dynamic Planet', in charge of Session G3 'Earth Processes: geodynamics, tides, crustal deformation and temporal gravity changes', in collaboration with Paul Tregoning; proceedings published end 2006;
- **B. Ducarme**: Editor of "Bulletin d'Information des Marées Terrestres ;
- **E. Elst**, *Dealing with Potentially Hazardous Asteroids*, 2006, Space Science: New Research, Chapter 7, S. Maravell Editor

Educational responsibilities

- **V. Dehant**: lecturer of course 'Astronomie et Géodésie', PHYS1120, Université Catholique de Louvain, 15h (+7h30 of exercices), co-titularity with J.P. van Ypersele de Strihou;
- **V. Dehant and T. Camelbeeck** : lecturers of course 'Géophysique interne', PHYS2140, Université Catholique de Louvain, 15h (+7h30 of exercices);
- **V. Dehant, T. Camelbeeck and B. Ducarme**: lecturers of course 'Questions spéciales de Géophysique interne', PHYS3233, Université Catholique de Louvain, 8h ;
- **V. Dehant**: lecturer of course 'Géophysique interne des planètes', Université de Nantes, 15h;
- **T. Van Hoolst**: lecturer of course "Theorie van stertrillingen", Katholieke Universiteit Leuven, 26h;
- **S. Lambert**: lecturer of course 'Caractérisation spectrale et décomposition des signaux', Ecole d'été 2006 du GRGS, Forcalquier, August 2006, 2h;
- **P. Defraigne**: lecturer of course 'Astronomie Mathématique', PHYS2131, Université Catholique de Louvain, 15h (+7h30 of exercices), co-titularity with J.P. van Ypersele de Strihou and M.F. Loutre;
- **R. Warnant**: lecturer of course 'Géodésie géométrique et astronomie de position', ASTR0213, Université de Liège, 30 h;
- **R. Warnant**: lecturer of course 'Théorie des erreurs et GNSS', GEOG0615, Université de Liège, 30h;
- **O. Verhoeven**: lecturer of course 'Structure interne de Mars, Vénus et la Lune', Université de Nantes, 8h;
- **O.Verhoeven**, co-lecturer (with Antoine Mocquet) of course 'Travaux pratiques de géophysique: sismique réflexion', Université de Nantes, 2h;
- **O. Verhoeven**, co-lecturer (with Eric Beucler) of course 'Travaux pratiques de modélisation numérique', Université de Nantes, 8h.

- **M. van Ruymbeke**: Lecturer at the XIX Curso de Volcanología y Geofísica Volcánica organized on June 1-10, 2006 in the Canaries Archipelago
- **B. Ducarme**: cours d'Introduction à la Physique du Globe (PHYS1265, UCL), 20h
- **B. Ducarme**: cours de Géodésie (GEOG3110, UCL), 15h
- **M. Everaerts**: ULg, MAST0178-1, 'Gravimétrie, magnétisme et leurs applications géologiques', 15h (+15h exercises)
- **Y. Frémat**: La Rochelle – Ecole d'astrophysique du CNRS: "Outils de l'astrophysique pour une coopération professionnels/amateurs". Seminar: *Paramètres associés aux spectres stellaires* (1 week)
- **Y. Frémat**: OHP – NEON Observing School. Tutor on the AURELIE spectrograph (2 weeks)
- **F.Clette**: Maître de Conférence, course " Le Soleil: structure, activité et impact sur l'environnement terrestre ", Université de Liège, DEA "Astrophysique et Sciences Spatiales", 15h.
- **F.Clette**: Maître de stage, ESI (Ecole Supérieure d'Informatique), Julien Rateau, 13/2-2/6/2006.
- **F.Clette**: training, first contact with professional work, Charlotte Somers, ½ day, 28/3/2006.
- **O. Podladchikova**: Lecturer at the International Center of Theoretical Physics, Trieste, Italy, Title "Solar Magnetic Activity", 3h
- **O. Podladchikova**: Lecturer at Politechnical Superior School, Kiev Ukraine "Intruduction to the solar plasma", 4h
- **O. Podladchikova**: Lecture at Symposium IAU 233, "Coronal Heating simulations", 1h
- **O. Podladchikova**: 3 h lecture on solar physics at International Astrophysical School, Trieste
- **O. Podladchikova**: 4h lecture on Modern plasma physics in International Science School, Ukraine
- **O. Podladchikova**: 45 min tutorial on coronal heating at international solar physics conference, Cairo, Egypt

Expertise, Audit

- **R. Van der Linden** is member of the NASA/ISES Solar Cycle 24 Prediction Panel
- **V. Dehant**: President of the Panel 'Earth Science' for the evaluation of the Descartes Research Prize, 2005-present;
- **V. Dehant**: Member of the Review Team for the ESA Cassini-Huygens mission archive, 2004-present;
- **V. Dehant**: Member of the Review Panel for the ESA Second Call for Earth Explorer Core Mission Ideas, 2005-2006;
- **V. Dehant**: Member of "Exploration, Science and Technology Advisory Group (ESTAG)" of ESA, 2006-present;
- **V. Dehant**: Member of the FNRS commission Astronomie et Géophysique, 1996-2006;
- **P. Defraigne**: Member of the FNRS commission Astronomie et Géophysique, 2006-present;
- **V. Dehant**: Member of the High Scientific Council (HCS) of the Observatoire de Paris;
- **V. Dehant**: Member of the Scientific Council of IPGP;
- **C. Bruyninx**: Member of the Scientic Concil of RENAG (Réseau National Géodesique de France), 2006-present.
- **Y. Frémat**: Substitute board examiner of the PhD of J.Gutiérrez Soto (University of Valencia)

Seminars for scientific audience

- **Van Camp Michel**, *Apports de la gravimétrie en métrologie et en géophysique à l'Observatoire Royal de Belgique*, Observatoire de Nice, Sept. 6, 2006.
- **Van Camp Michel**, *Apports de la gravimétrie en métrologie et en géophysique*, IPGP, Paris, Feb. 6, 2006.
- **C. Marque**, Seminar, Royal Observatory of Belgium, January 2006. *Forward Modeling of the Electron Density and Temperature Distribution in the Solar Corona, Using PFSS Extrapolations and Radio Metric Observations.*

- **C. Marque**, Seminar, KULeuven-CPA, February 2006. *Forward Modeling of the Electron Density and Temperature Distribution in the Solar Corona*, Using PFSS Extrapolations and Radio Metric Observations.
- **V. Delouille**: Seminar at Institute of Statistics, UCL on ‘Multifractal analysis and motion estimation of Extreme Ultraviolet solar images’, 30 March 2006
- **Clette, F.** From the Wolf number to the International Sunpot Number: 25 years of SIDC, ROB seminar, 9/11/2006

Running or Finalized Theses

- **PhD students at ROB:** J. Duron (UCL), L. Koot (UCL), S. Le Maistre (UCL), G. Pfyffer (UCL), E. Pottiaux (UCL), A. Rivoldini (UCL), J. Fraser (ULB), Thomas Lecocq (ULB), J. Spits (ULg), S. Lejeune (ULg), U. Avsar (Ugent), E. Robbrecht (KUL)
- **PhD students outside ROB with ROB staff as co-promotor:** S. Daghay (VUB), V. Robert (Observatoire de Paris), J. Toubeau (UCL), A.-M. Barszez (FPM), Valérie Calbini (Ecole et Observatoire de Physique du Globe de Strasbourg), K.B. Torres (Universidade Federal de Minas Gerais)
- **DEA students:** G. Pfyffer
- **Master students**: Mark Cox (KULeuven), Rose-Marie Baland (UCL), Samuel Goossens (UCL), Le Binh San Pham (UCL), John Wautier (UCL), Laetitia Tollet (UCL), Antony Trinh (ULB), Thomas Lecocq (ULB), Timour Chevalier (ULB), Francois Stevens (ULB), G. Wautelet (ULg), Katrien Verheyen (KUL)
- **Trainees:** Trainee stages of few months: Quentin Bertaux (ENIG, Lilles), Sylvain Deltombe (ENIG, Lilles), Aurelien Garnier (Univ. Nantes), Pierrick Haurant (Univ. Nantes), Pierre-Yves Decavele (ENSG, Paris), Charlotte Ducrocq (ENSG, Paris), Lâmân Lelégard (ENSG, Paris), Jonathan Renault (ENSG, Paris), Thomas Rugi (ENSG, Paris), Gaétane André (COMU, UCL), Alexandre Eudes (Univsersité de Clermont-Ferrand)

Meeting organization

- **R. Van der Linden** (SOC member and LOC Chairman), **A. Vandersyppe** (LOC secretary), **P. Vanlommel** (LOC vice-chair), **D. Berghmans** (LOC), **E. Robbrecht** (LOC), **H. Langenaken** (LOC), **R. Warnant** (LOC), **V. Wellens** (LOC), **O. Boulvin** (LOC), **C. Marque** (LOC), **L. Rodriguez** (LOC): Third European Space Weather Week, 13-17 November 2006 (230 participants).
- **C. Bruyninx**: Organisation of EUREF Technical Working Group Meeting, Brussels, 2 days, March 2006;
- **V. Dehant**: Organisation of MEX/VEX Radioscience Team Meeting, Brussels, 2 days, July 2006;
- **V. Dehant**: Organization of the business meeting and scientific session of Commission 19 on ‘Earth Rotation’ at the IAU.
- Organization of the MaRS Team meeting in Brussels in July 2006
- **P. Lampens**: Member of the Scientific Organising Committee of IAU Symposium 240
- **J. Cuypers, Y. Frémat**: Co-organizer of the 1st GHOST meeting at the ROB (14.02.2006)
- **R. Blomme, J. Cuypers, Y. Frémat:** Co-organizer of the 2nd GAIA-CU6 meeting at the ROB (12.10 – 13.10.2006)
- **J. Cuypers**: 3rd Gaia CU7 meeting, K.U.Leuven, 09-10/11
- **J Sauval**: organizer of the 7th meeting of the Contact group *Astronomie and Astrophysique* (May 19) at the ROB Planetarium (as secretary)
- **D. Berghmans**: Member of SOC and Chairman of WG1, Solar Image Processing Workshop III (Dublin, September 6-8, 2006)

- **JF Hochedez**: member of the SOC of the 2nd Solar Orbiter meeting in Athens
- **D. Berghmans**: Chairman of Session 1, Third European Space Weather Week (Brussels, November 13-17, 2006)
- **D. Berghmans**: Main Organisor of "Science Consortium for SWAP and LYRA' International Team meetings at ISSI (Bern, Switserland, June 20-22 2006, Nov 29-Dec 1 2006)
- **V. Delouille**: Local Organizer for the ROB-FNRS contact group meeting on 'Wavelet and its applications' on December 7, 2006. Scientific Organizers were Christine De Mol and Jean-Pierre Antoine. The topic of the meeting was on 'Wavelet in geo- and astrophysics'. Number of attendees: 36

Awards

- **V. Dehant**: AGU Fellow
- **H. Debehogne**: assigned as discoverer of 1 minor planet
- **P. De Cat**: assigned as discoverer of 1 minor planet
- **E. Elst**: assigned as discoverer of 125 minor planets
- **E. Elst and H. Debehogne**: assigned as discoverers of 3 minor planets
- **T. Pauwels**: assigned as discoverer of 13 minor planets
- **T. Pauwels** and Sergei Ipatov: assigned as discoverers of 1 minor planet

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Overzicht / Sommaire

A. PLANETARIUM

A.1. Activités

A.1.1. Visiteurs

- En 2006, le Planétarium a accueilli 30.352 visiteurs, chiffre en légère diminution (-588 visiteurs / -1.9 %) par rapport à l'année précédente. Cette baisse est essentiellement due : (i) à la baisse de fréquentation du grand public en été en comparaison à la même période en 2005, année pendant laquelle l'exposition créée à l'occasion du 175ème anniversaire de la Belgique avait suscité beaucoup d'intérêt pendant les mois de juin, juillet et août ; (ii) à une journée spéciale consacrée en 2005 à Electrabel nous ayant permis d'accueillir 2400 visiteurs en un seul jour.
- La part du public scolaire (20.263 élèves) s'élève à 66.8 % du nombre total de visiteurs, chiffre relativement stable. Le public familial (mercredis après-midi, dimanches, congés scolaires) atteint le nombre de 10.089 (-458 personnes).
- La répartition entre public néerlandophone (16.036 visiteurs / 52.8 %) et public francophone (14.316 visiteurs / 47.2 %) est relativement équilibrée, avec une progression sensible de la part relative du public néerlandophone.

A.1.2. Expositions

- L'exposition permanente, initialement créée à l'occasion du 175ème anniversaire de la Belgique, a continué de permettre au Planétarium de jouer pleinement son rôle de vitrine du Pôle Espace.
- Dans le cadre de la mission Venus Express, à laquelle participait des équipes scientifique de l'ORB et de l'IASB, le Planétarium a accueilli dès le mois d'avril une exposition sur la planète Vénus, organisée par la « Cellule Communication» du Pôle Espace en collaboration avec les scientifiques concernés.
- Le 3 avril a été inaugurée en présence de l'Ambassadeur de Russie une exposition photographique sur le cosmonaute Youri Gagarine, dont on fêtait le 50ème anniversaire du vol ; cette exposition était visible durant deux mois.
- Une exposition photographique (portraits de scientifiques des Etablissements Scientifiques Fédéraux) installée lors de la Nuit des Chercheurs (22 septembre) a complété l'offre scénographique du Planétarium à partir du dernier trimestre.

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 & ROB Astronomy Day (19 mai) ; session d'information du Service spatial de la Politique Scientifique Fédérale (8 mars) ; journée d'information sur la biodiversité (10 mars) ; conférence de presse à l'occasion de l'approche de Vénus par la sonde Venus Express (avec notamment la présence de Mme Véronique Dehant) ; tenue du « social event » du colloque ESWW3 organisé par l'Observatoire (15 novembre).
- Des séances spéciales de planétarium ont été organisées pour : l'Association des Parents Victimes de la Route (le 17 septembre) ; les participants de l'Expo-Science (Jeunesses Scientifiques de Belgique) les 27 et 28 avril ; des organisations de cercles amateurs (VVS : séance spéciale éclipse le 25 février et assemblée générale du 22 avril, Urania : séance spéciale le 12 mars) ; la soirée de présentation du nouveau CD de Tonya (26 avril).
- Des journées de formation ont été proposées aux enseignants tant néerlandophones (niveau HSO le 25 octobre) que francophones (le 3 mars). Des enseignants ont également été conviés à une séance de présentation dans le cadre d'Educpass (27 septembre).

- Le Planétarium a également loué ses locaux à des firmes (incentives, présentations de produits, etc.) à différentes reprises (10 locations dans l'année).

A.1.4. Spectacles

- Le Planétarium n'a pas inauguré de nouveaux spectacles en 2006, mais a organisé en collaboration avec différents partenaires plusieurs événements d'importance dans la grande salle du planétaire :
- Les 21 et 22 février, des séances spéciales présentées par Frank de Winne et Sergueï Zalyoutin, cosmonaute russe commandant de la mission OdISSea, ont été proposées à de nombreux groupes scolaires dans le cadre d'Europalia Russie ; à cette occasion, le Forum Espace & Enseignement (soutenu par le Fonds Prince Philippe et Frank De Winne) a présenté ses activités à la presse, en présence de S.A.R. le Prince Philippe.
- Une soirée littéraire initiée par le CNES a été organisée au Planétarium en présence des lauréats belges du concours d'écriture de nouvelles sur le thème de l'espace (19 avril).
- L'accueil du premier Taïkonaute chinois a été effectué au Planétarium le 30 mai.
- Des activités diverses (spectacle « Space Weather », jeu de base-ball sur le thème du système solaire, stands, ateliers) ont été organisées à l'occasion de la deuxième « European Researcher's Night » financée par le département Recherche de la Commission Européenne (22 septembre).
- Le Planétarium a ouvert ses portes lors de trois (5 octobre, 9 novembre, 14 décembre) Nocturnes des Musées Bruxellois organisées par le Conseil Bruxellois des Musées.
- Des concerts de musique électronique se sont déroulés dans la grande salle du planétaire, notamment dans le cadre de la Nuit Blanche bruxelloise.

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 : 3.531 élèves y ont participé au cours de l'année 2006.

A.1.6. Brochures

- Deux dépliants/posters (une version néerlandophone et une version francophone) ont été réalisés en 2006. Ces publications s'adressent aux enseignants et décrivent au recto les programmes, les cours et les nouvelles activités pédagogiques du Planétarium, alors qu'au recto sont présentées les planètes du système solaire (cette partie poster a rencontré beaucoup de succès). Les dépliants/posters ont été envoyés à l'ensemble des écoles du Royaume au moment de la rentrée scolaire.
- Fin 2006 a été préparée la brochure destinée au grand public : elle présente les différents programmes et contient diverses informations pratiques. Elle couvre l'année 2007.
- 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 2006 : 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 collaboration avec la Mini-Europe (mise en place d'un ticket combiné pour les groupes) est reconduite ; des réunions de travail ont été poursuivies entre les acteurs du Plateau du Heysel (Planétarium, Trademart, Kinepolis, Atomium, Océade/Mini-Europe, Stade Roi Baudouin).
- Des actions de promotion des sciences envers les jeunes ont été menées avec :

    - le Conseil Bruxellois des Musées dans le cadre du projet « Tom & Charlotte » (jeu de piste à travers plusieurs musées dans Bruxelles) ;
    - l'Institut Royal des Sciences Naturelles dans le cadre du projet « Stel Je Vraag » (subsidié par la Communauté Flamande) ;
    - la VUB et le magazine MAKS dans le cadre du « Project Pi ».
- Le Planétarium a participé en 2006 à plusieurs événements extérieurs :
    - l'« Expo-Science » organisée par les Jeunesses Scientifiques de Belgique au Palais des Expositions du Heysel en avril (notamment : participation au jury de sélection) ;
    - la « Wetenschapsfeest » à Gent ayant eu lieu du 27 au 29 octobre (animation d'un planétarium gonflable) ;
    - les « Ruimtevaartdagen » organisés par VRI Ooostende du 17 au 19 novembre (animation d'un planétarium gonflable).
- 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 Franeker (Pays-Bas) et à Bruxelles. Le Planétarium a également été présent lors du colloque annuel de l'Association des Planétariums de Langue Française (APLF) ayant eu lieu à Montpellier (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.
- Lors du 55ème Salon Mondial de l'Innovation « Brussels Eureka » 2006, le 2ème Prix International de l'Organisation Mondiale de la Presse Périodique a été décerné au Planétarium « pour l'ensemble de ses activités, et plus particulièrement pour les spectacles ».

A.2. Moyens mis en oeuvre

A.2.1. Personnel

- Au 31 décembre 2006, le personnel du Planétarium se composait de 15 personnes :
    - R. Alvarez, chef de travaux, statutaire - responsable
    - V. Bastin, experte technique, contractuelle - animatrice
    - G. Champagne, attaché scientifique, contractuel - 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

- Deux appels d'offre d'achat (subsides obtenus dans le cadre de l'achat d'équipement scientifique soutenu par le Lotto) ont été rédigés et diffusés dans le cadre de deux procédures négociées sans publicité : ils concernent la livraison et l'installation d'un serveur de média et d'un système de contrôle, et la livraison et l'installation de deux projecteurs vidéo haute-technologie. La remise des offres est prévue pour février 2007.

- 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 conclu avec la firme Sylvania, fournisseur de matériel d'éclairage, a permis d'équiper le hall en luminaires divers.

A.3. Projets en cours et à venir

A.3.1. Projet ESERO

- Fin 2005, l'Agence Spatiale Européenne (ESA) avait 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.
- Le projet ESERO Belgium proposé par le Planétarium de l'Observatoire royal de Belgique a été très favorablement jugé par l'ESA. Le contrat, finalement signé le 1er octobre, permet au Planétarium de recruter deux personnes faisant fonction d'Office Manager (début des fonctions prévue en février 2007) pour mener à bien les différentes tâches liées au projet ESERO.

A.3.2. International Year of Astronomy 2009

- Le Planétarium a été choisi par le BNCA (Belgian National Committee for Astronomy) pour agir en tant que « National Node » en Belgique pour la coordination et la promotion des activités à planifier et réaliser durant l'année 2009 dans le cadre de l'Année Internationale de l'Astronomie.

B. BIBLIOTHEQUE

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 centralisation des propositions d'achat, l'achat des titres sélectionnés, le catalogage de ceux-ci, le "bulletinage" des numéros de périodiques, le classement des ouvrages, l'accueil des visiteurs, le prêt aux lecteurs et le prêt inter-bibliothèques. Les mêmes services ont été effectués pour les livres et les périodiques de l'IRM, à l'exception des achats, des propositions d'achats et du "bulletinage" des périodiques, opérations directement effectuées à l'IRM.

B.1.2. Abonnements, échanges et achats

La bibliothèque a bénéficié en 2006 de 156 abonnements à des périodiques en version sur papier (77 pour l'IRM, 79 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 52 livres acquis par achat (17 pour l'IRM, 35 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, a pris de l'extension en 2006: vingt-sept abonnements ont été pris en 2006 par les deux instituts (quinze pour l'ORB, onze pour l'IRM, et un abonnement commun à l'ORB, l'IRM et l'IAS pour les cinq parties du *Journal of Geophysical Research*).

Par ailleurs, l'accès au réseau électronique SwetsWise, auquel l'ORB et l'IRM sont affiliés, a permis d'accéder gratuitement à la version électronique de certains périodiques pour lesquels les deux instituts ont souscrit un abonnement à la version sur papier (la version électronique pour l'année en cours étant offerte en sus par l'éditeur). Au stade actuel, le nombre de ces périodiques gratuits du réseau SwetsWise est d'une quarantaine.

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 304 volumes de périodiques a été effectuée (155 pour l'ORB, 149 pour l'IRM). La collection de livres d'astronomie a été réorganisée et transférée dans de nouveaux emplacements. Par ailleurs, un récolement général des collections de livres antérieurs au XXe siècle a été entrepris.

B.1.5. Informatisation de la bibliothèque

Pour rappel, l'informatisation de la bibliothèque de l'ORB – IRM au moyen du système de gestion VUBIS comporte trois opérations distinctes :

1. 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).
2. "Bulletinage" des périodiques, soit des numéros de l'année en cours, soit des tomes entiers après reliure.

3. Attribution aux divers volumes (livres ou périodiques) de numéros de "codes-barres" permettant le prêt informatisé.

En 2006, 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 2006 (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 1951 et 1996 (le catalogage proprement dit de ces livres ayant déjà été effectué auparavant).

Dans l'accomplissement de ces travaux, la Bibliothèque a bénéficié de l'aide de Mme Christine Roberti, pour le bulletinage des numéros de périodiques de l'année 2006 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 déroule du 1er novembre 2005 au 31 décembre 2008. L'arrêté attribue une somme totale de 19.078 Euro pour les deux institutions (ORB et IRM), la somme prévue pour les années 2005 et 2006 étant de 9.502 Euro, et de 6.286 Euro pour 2007. Le projet n'est effectivement entré en vigueur qu'au cours de l'année 2006, et les sommes allouées pour les années 2005 et 2006 ont été reportées sur le budget de l'année 2007.

B.2. RECHERCHE SCIENTIFIQUE, MISSIONS ET PUBLICATIONS

B.2.1. Recherche scientifique

P. Alexandre a fourni à la section de Séismologie des données nouvelles recueillies dans les sources originales sur les tremblements de terre du passé survenus en Belgique et dans les régions voisines (Rhénanie, Luxembourg, Sud des Pays-Bas, Lorraine, Champagne, Artois et Picardie), plus particulièrement ceux qui ont eu lieu entre 1350 et 1900, période pour laquelle la documentation historique est la plus abondante dans cette zone. Les cartes macroséismiques relatives à ces événements ont ainsi pu être améliorées.

P. Alexandre a continué à insérer des données dans la banque de données informatique sur la séismicité de la Belgique de la section de Séismologie, et a poursuivi l'évaluation des anciens documents relatifs aux séismes selon les règles de la critique des sources. Pour chaque tremblement de terre a été recueilli le maximum de renseignements relatifs aux effets de la secousse sur la population et sur les différents types de bâtiments. Cette banque de données servira de base à une future publication des textes relatifs à la séismicité à long terme de l'Europe du Nord-Ouest.

C'est à nouveau le séisme majeur du 18 septembre 1692 (épicentre dans la région verviétoise) qui a fait l'objet des plus importantes recherches, et la découverte de nouveaux documents a permis de mieux cerner la zone de perceptibilité de cette secousse et d'élaborer, en collaboration avec Thierry Camelbeeck et David Kusman, une nouvelle monographie sur le sujet.

P. Alexandre a également été consulté comme "referee" pour des articles sur la séismicité historique proposés à des revues scientifiques.

Suivant en cela les recommandations qu'il a reçues du Jury de Recrutement et de Promotion de l'O.R.B. (séance du 20/9/1999), P. Alexandre a poursuivi en outre des recherches critiques de documents anciens sur les phénomènes climatiques et astronomiques du passé; en particulier, de nouvelles données sur les événements météorologiques survenus en Europe de 700 à 1000 et de 1425 à 1525 ont été rassemblées, en vue de compléter l'ouvrage déjà paru sur le climat de l'Europe occidentale de 1000 à 1425.

B.2.2. Colloques

P. Alexandre a participé au colloque de la DGATLP: "Evaluation et prévention du risque sismique en Wallonie (Namur, 16-17 octobre 2006) et y a présenté, en collaboration avec Th. Camelbeeck et D. Kusman, une communication intitulée: "*Les séismes en Belgique et leurs effets sur le bâti, le patrimoine architectural et l'environnement*".

B.2.3. Publications

[4] Alexandre P., Demarée G.
Climat, séismes et comète de 1739 à 1762: les chronogrammes d'Egidius Mercier, curé d'Erembodegem.
Ciel et Terre, t. 122, 2006, pp. 98-104.

[5] Alexandre P.
Recension critique de l'ouvrage de R. Gläser, Klimageschichte Mitteleuropas. 1000 Jahre Wetter, Klima, Katastrophen (Darmstadt, 2001).
Revue Belge de Philologie et d'Histoire, t. 84, 2006, pp. 483-484.

B.2.4. Publications sous presse, soumises à l'éditeur:

[6] Camelbeeck T., Vanneste K., Alexandre P., Verbeeck K., Petermans T., Rosset P., Everaerts M., Warnant R., 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, 2007

[7] Camelbeeck, T., Alexandre, P., Kusman, D.,
Les séismes en Belgique et leurs effets sur le bâti, le patrimoine architectural et l'environnement

[8] Alexandre P., Kusman D., Petermans T., Camelbeeck T.
The 18 September 1692 Earthquake in the Northern Part of the Belgian Ardenne – A Review of the Available Historical Data.
Special Volume: Modern Approaches in Historical Seismology: Interdisciplinary studies of past and recent earthquakes, "J. Vogt in-memoriam", Springer-Verlag.

C. INFORMATION SERVICE

C.1. Activities

The activities related to the information services consist of several tasks: answering questions and inquiries from public and press, assisting in all kind of outreach activities, giving general information on ORB and astronomy and astronomy related subjects, advising the planetarium, organize the visits to the ORB, all kind of assistance for exhibitions and public relations activities (press communications, press conferences etc.) and preparing of texts for printing or for the web site.

At this moment, only activities of the persons directly related to this service are described, and only if these activities are not directly related to their own research, because these will be found in the section on the PUBLIC OUTREACH of the SCIENTIFIC DEPARTMENTS.

C.2. Media contacts

C.2.1. Interviews

- VRT-Radio 1 (26/1, on planets)
- VTM (11/4, on Venus and Venus Express)
- Rtbf-radio (11/4, on Venus and Venus Express)
- Radio Vlaanderen Internationaal (20/7, on the exhibition of the Federal Science Policy in the Royal Palace)
- VRT-Radio 1 (21/7, on the exhibition of the Federal Science Policy in the Royal Palace)
- 4FM (6/9, on Tracking Earth's Wobbles Down to the Size of a Cell Phone)

C.2.2. Information given to the media

- VTM (15/1), RTL (23/1), La Dernière Heure (24/1) on fire balls and meteors
- Het Laatste Nieuws, De Standaard, De Morgen on different subjects (about 10 subjects in total)
- Rtbf-radio (6/9, on Tracking Earth's Wobbles Down to the Size of a Cell Phone)
- Bel-RTL (6/9, on Tracking Earth's Wobbles Down to the Size of a Cell Phone)

C.2.3. Assistance with TV and film recordings:

- Student project (13/3)
- VRT 1000 Zonnen en garnalen (1, 7-8/8)
- RTL (14/9, Telescope)
- RTBF (26/10, Pluto and the planets)
- RTBF (2/12, Quetelet)

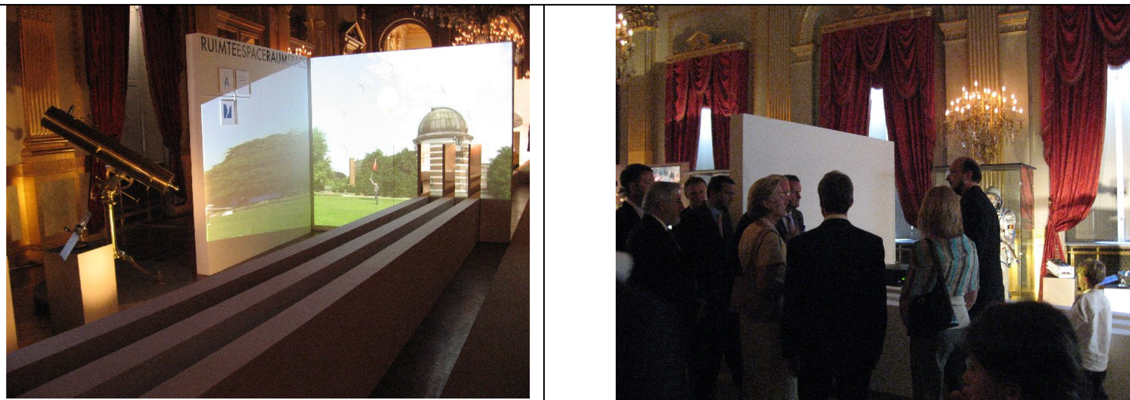

Figure 42: Pictures of the exhibition at the Royal Palace

C.3. Exhibitions

- For the exhibition on Venus and Venus Express in the Planetarium text and translations were prepared and assistance was given during the presentation of the exhibition and during the press conference on 11 April at the occasion of the injection of the spacecraft in orbit around Venus.
- The Federal Science Policy was present in the Royal Palace in the summer months (see Figure 42) with an exhibition on the Federal Institutes, including the Royal Observatory of Belgium. The telescope of Rienks of our museum was displayed at this exhibition. Text and translations for the handouts were provided.
- In 2006 the preparation of the exhibition "*Kunst en Heelal – L'Art et L'Univers*" and its related activities, including the conference by Dirk Frimout on November 30, took a lot of time. This exhibition was a collaboration between the city of Uccle, the Uccle Centre d'Art and the Royal Observatory of Belgium. The artists of the Uccle Centre d'Art showed their work inspired by Space and the Universe, the ROB presented some of the ancient scientific instruments, its history and some of its present activities. About 1000 persons visited the exhibition that took place in the Uccle Cultural Centrum from 24 November to 5 December.

Figure 43: pictures of the art exhibition "Kunst en Heelal – L'Art et L'Univers"

C.4. Public conferences

- 03/03/06 "Images of the Universe", Herselt (Sterrenkijkdagen)
- 31/10/06 "Images of the Universe", Westerlo (Halloween)

C.5. Questions from the public

In 2006 about 450 questions by email, 530 by telephone and 270 by letter or fax were answered. Amongst the subjects of the questions (not directly related to research activities): sunset, sunrise, equinoxes and solstitia, horizontal coordinates of sun and moon, the amount of shadow, moon phases, fireballs, meteors, satellite re-entries, eclipses in 2006 and other years, all sort of calendar topics, time keeping, time zones, tides, CCD astronomy, star maps and visibility of constellations over the world, comets now and in history (including Arend-Roland), Mars, Venus and other planets in the sky, information about historical scientific instruments, the profession of astronomer, external influences (sun, planets, universe, …) on climate change, distances in the universe, structure of the universe, Hubble Space Telescope and other satellites and space missions, candidate meteorites, photographs and images of the ROB, history of the ROB, old and new definitions of a planet and the case of Pluto, evolution of the solar system, the planets and the moon, atmospheric halos, visibility of objects on the moon, goniometry, crop circles, giving and/or registering of star names, buying stars or land on planets etc.

In order to supply the answers to some of the questions, programs had to be (re-)written. Subroutines created by T. Pauwels (Dep. II) were gratefully used.

Questions about the sun and its influence on earth (space weather etc.), about seismology, gravimetry and GPS, about asteroids and impact of asteroids on earth were forwarded to other sections of the ROB. Question about weather and climate were sent to the Meteorological Institute and those about space travel and aeronomy to the Belgian Institute for Aeronomy.

C.6. Digital photographs and illustrations

A large number of (digital) photographs of all aspects of the ROB were made. Pictures of the instruments of the museum, of some of the buildings and the domes and of the meridian line of the main entrance were made and sent on request. Old pictures and/or text were scanned and sent out for a variety of purposes, including for foreign journals or seminars abroad (e.g. on Euler).

The first steps to a digital photo archive were made.

C.7. Website

- The content of webpages with the answers to frequently asked questions was regularly updated. For 2006 the pages on sunrise and sunset, on moon phases and moonrise and moonset, on daylight savings time, on the calendar in general and on the Islamic calendar (Ramadan) had at least one update or revision.
- A webpage on the fireball of 15 January 2006 and on the solar eclipse of 29 March 2006 was created.
- Pages on the celestial phenomena of the month (information given by R. Dejaiffe, put on the web by H. Langenaken) were put on the web on a regular basis.

C.8. Visits

A larger than usual number of individual visitors and groups had to be guided in the ROB this year. The individual visitors were mainly journalists and other media related persons, amateur astronomers with a specific demand and/or students. Groups were, in general, received on every first Monday of the month.

In total about 50 individual visit and 12 groups were guided. In a few cases extra information was given (e.g. to stagiaires).

C.9. Meetings and missions

A large number of meetings, internal as well as external, were attended this year: in total about 20 on a very large variety of subjects. We have now regular meetings with the communication responsibles of the Federal Institutes on topics of general interest, common activities and the journal Science Connection. The regular meetings of the cell communication of the Space Pole were attended. Representatives of this cell had a meeting with the directors of the Space Pole institutes on general and common interests and collaborations.

C.10. Publications and related tasks

- Translations, corrections and proofreading of articles for the journal Science Connection e.g. translation of the interview of Ozgur Karatekin (Science Connection 13)
- Translation of press conference texts, e.g. Tracking Earth's Wobbles Down to the Size of a Cell Phone
- Texts and translations for the exhibition Venus and Venus Express (Planetarium) and translation of the press report (15 pages in the Dutch version)
- Texts and translations for the exhibition on the Federal Institutes in the Royal Palace
- Texts and translations for the exhibition Kunst en Heelal – L' Art et L'Univers
- Collaboration on the internal information brochure and documents related to safety regulations
- The computer presentations describing the history and the activities of the ROB were updated on a regular basis and used on several occasions, but mainly as the introductory part during group visits.

C.11. Personel

J. Cuypers, (Dep III), werkleider

Y. Coene, hoofdrekenaar (Dep I, gedetacheerd naar de dienst inlichtingen)

H. Langenaken, hoofdrekenaar (4/5, Dep. III). She had this year also several other more administrative tasks, including the re-organisation of the archives and storage rooms of the ROB).

In a lot of activities, including translations, other personnel of the ROB was involved.

Many other members of the ROB gave information to the public, some occasionally, others as a part of their daily work as in the sections Seismology, GPS, Solar Physics etc.

D. PUBLIC OUTREACH of the SCIENTIFIC DEPARTMENTS

D.1. Scientific and technical expertise to the authorities and the industry

- **J. Cuypers, P. De Cat**: "Zoeken naar perioden in variabele sterren: een eerste stap in de asteroseismologie", voorstel voor een educatief wetenschappelijk gericht op middelbare scholieren ingediend voor de verdere uitbouw van de nieuwe sterrenwacht Altair te Zoutleeuw

D.2. Information given to the public

- **J. van Marcke de Lummen**: Realization of didactic movies;
- **T. Pauwels** searched possible identifications of an "object" observed by Maarten Van Leenhove.
- **T. Pauwels** checked the moon on Van Eyck's Adoration of the Lamb.
- **T. Pauwels** computed ephemerides of asteroid (5522) De Rop.
- **T. Pauwels** gave advice on the typical Zeiss mounting of telescopes for Beatrix Alscher.
- **T. Pauwels** gave information about asteroid (99942) Apophys for Jasper Ostyn, student journalist.
- **P. De Cat** gave a 1-day introduction to student Marc Bauduin: about the observations of asteroids (a.m.) and asteroseismic research (p.m.)
- **P. Vanlommel**, 23, 27 Oct 2006: workshop 'Maak je eigen ruimteweerbericht', wetenschapsweek, KULeuven, in collaboration with the Center for Plasma Astrophysics.
- **P. Vanlommel**, internet publication of 11 *Solar Highlights* with general information and promotion of Space Weather.

D.3. Information given to the media

- The **SIDC** issued a press release on 17/10, at the occasion of the STEREO launch.
- **P. De Cat** was interviewed by Francis Meeus of MIRA about the definition of a planet and his own research at the Royal Observatory of Belgium.
- **T. Pauwels** gave information about comet info Schwassman-Wachman 3 to Caroline De Clercq (De Tijd).
- **E. Robbrecht** : Article for weekly French magazine « Le Nouvel Observateur », written by Michel de Pracontal, published in November 2006.
- **F. Clette**: interviewed by Mr. Paulis, "Construction", magazine of the Belgian construction sector, (10/10/2006).
- **S. Lambert**: several interviews at the radio and television following the AGU press release about a scientific paper on Earth polar motion.
- **Ö. Karatekin**: interview with the magazine "Science Connection" for "La nuit des chercheurs".
- **Ö. Karatekin**: interview with RTBF TV in the framework of "La nuit des chercheurs".
- **Ö. Karatekin**: interview with RTBF radio in the framework of "La nuit des chercheurs".
- **M. Van Camp**: interviews by RTL Radio (Grand duché de Luxembourg) 2006-01-18; VRT radio 2006-05-27; RTL-TVI 2006-07-17; RTBF (Enregistrement à Membach pour l'émission "Au Quotidien") 2006-09-04.
- **R. Van der Linden**: radio interview with Mitch Battros, producer of Earth Changes TV, California, USA, January 09.
- **A. Zhukov**: Radio interview with Mitch Battros, producer of Earth Changes TV, California, USA, January 26.

Press interviews related to space missions

- The launch of the satellite CoRoT, for "De Tijd", 27/12/06: interview of **J. Cuypers**.
- VEX Orbit Insertion event (press conference; press map realization); interviews of **V. Dehant**.

- Following several events and discoveries about the planet Mars (water on Mars), **V. Dehant** had several interviews at the radio and television.
- Participation in the live emission on RTL TVi to answer questions on space exploration and Venus Express (**Ö. Karatekin**).
- **F. Clette** was interviewed concerning the STEREO mission on 25/10/2006 (RTBF TV & radio), 25/10/2006 (Sud Presse) and 26/10/2006 (RTL-TVI)

Press interviews related to winter time

- ZDF (Deutsche television): diffusion 26/10, 16.00; interview of **P. Defraigne**
- RTBF: diffusion 26/10, 18.55 (« AU QUOTIDIEN »); interview of **P. Defraigne**
- RTBF: diffusion 28/10, 19.30 (« JT »); interview of **P. Defraigne**
- Brussel FM: interview of **R. Van der Linden**

D.4. Publications in popular journals

[1] O. Podladchikova
The life on Mars (in Russian)
Journal "Elle", Russian edition in Kiev, to appear in March 2007

[2] **Berghmans, D., Van der Linden, R.A.M., Vanlommel, P., Clette, F., Robbrecht, E**.
25 jaar SIDC: geschiedenis van het zonnevlekkengetal
Heelal, Vol. 51, No 1, 4-13

D.5. Public conferences

- **D. Berghmans**, 07 Oct 2006: public presentation at the Annual Meeting of 'VVS Werkgroep Zon', *Geschiedenis van het zonnevlekkengetal*, Europlanetarium, Genk
- **R. Blomme**: *Radio Astronomy*, amateur astronomers group Helios, June 18
- **F. Clette**: invitation to the European "Fête des Sciences" event in France: two public lectures about the solar activity, solar instrumentation and helioseismology for students and the general public (L'Isle sur la Sorgues, Avignon, France, 11-14/10/2006).
- **J. Cuypers**: *Het diagram van hertzsprung-Russell*, VVS afdeling helios, Hasselt, November 18
- **V. Dehant:** Origine du magnétisme terrestre et étude du noyau de la Terre et des autres planètes telluriques. presentation at 'Connaissance et vie d'aujourd'hui' Mol, February 20, 2006
- **C. Marque**: "Question du Jour"-RTBF La Première: radio interview on November 2nd 2006
- **E. Robbrecht**: 12 March 2006: presentation for teachers for public outreach in Volkssterrenwacht Beisbroek (Brugge).
- **J. Sauval**: *Comets,* Printemps des sciences, Louvain-la-Neuve, March 18
- **M. Van Camp:** *Les séismes de Sumatra*, SRBA, Bruxelles, 9 février 2006.
- **M. Van Camp:** *La séismologie en Belgique*, Ladies Circle Belgium de Braine-l'Alleud, 15 février 2006.
- **M. Van Camp**: Séminaire de Géophysique de la SRBA, Nov. 18, 2006
- **P. Vanlommel**, 22 April 2006: presentation '*België: een land waar de zon nooit ondergaat en het ruimteweer altijd goed is'*, VVS annual meeting, Planetarium Heizel
- **P. Vanlommel**, 09 June 2006: presentation '*Belgen in de ruimte'*, service flats 'Het molenhof', Leuven.
- **P. Vanlommel**, 10 June 2006: presentation '*Het SIDC: link tussen de Zon en West-Europa'*, amateur astronomers from the Netherlands, ROB.
- **P. Vanlommel** and **A. Zhukov**, 22 September 2006: Live show: '*Het ruimteweerbericht'*, Researcher's night, Planetarium Heizel.
- **P. Vanlommel**, 23, 27 Oct 2006: workshop 'Maak *je eigen ruimteweerbericht*', wetenschapsweek, KULeuven, in collaboration with the Center for Plasma Astrophysics.

- **P. Vanlommel**, 26 Oct 2006: presentation '*De zon-aarde connectie*', amateur astronomers, wetenschapsweek, Pollare, Ninove.

D.6. Exhibitions

- **T. Pauwels** produced a poster about asteroid (14539) Clocke Roeland for display in the belfry in Gent.

D.7. Visits

- Visits to the Schmidt Telescope: February 24: Katya Antonossova; June 12: 3 groups; July 5: Sven Van Loo and a British colleague; September 29: Amateur astronomers from Leiden.
- Group visits to the Solar Physics Departement and USET dome: 7/3, 19/4, 8/5, 12/6 and 4/12/2006.
- François Stevens (ULB) : Membach + Observatory, 27-30/03/2006
- Dr. Ludger Timmen and Dr. Olga Gitlein (University of Hannover) visited the Membach station and the Observatory on Dec. 19-20, 2006.
- Group "Baladecouverte" (Paul De Backer) visited the Seismology on Sunday 3/12/2006.

D.8. Web sites

- Realization of websites on Venus
- Realization of websites on the terrestrial planets
- Website of the third European Space Weather Week: http://sidc.be/esww3

E. “The Yearbook”

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 2006 the Yearbook for 2007 was published. It was produced by F. Clette (The Sun, Tables), J. Cuypers (Calendars, Comets, Meteors), T. Pauwels (Title, Preamble in collaboration with the director, Constants, Planetary and Satellite Data, Planetary Phenomena, Visibility and ephemerides of the planets, Minor planets, Eclipses, Transits, Occultations, Satellites of Jupiter), F. Roosbeek (The Moon, Tables) and J. Sauval (Comets, Meteors), with the technical assistance of G. Evrard. Translations were made by R. Alvarez and T. Pauwels. The final editing was done by T. Pauwels. There were no major changes compared to 2006.

F. Clette started to modernise the programmes computing the data for the chapter “Sun”, for which there are still a lot of completely outdated programmes that have to be re-written. T. Pauwels programmed the phenomena of the satellites of Jupiter, so that starting from the Yearbook 2007, they are the result of own computations. There were some discussions about these phenomena with J.-E. Arlot and V. Lainey. The computation of the phenomena now uses the theory of V. Lainey. Not all problems are yet solved. T. Pauwels started to programme the mutual phenomena of the satellites of Jupiter, with the Yearbook 2008 in mind. He debugged one of his programmes for computing eclipses.

A start has been made with the production of the Yearbook 2008, by deciding on the appropriate value to use for ΔT.

E.1.3. Perspective for next years

In 2008 we hope to introduce a new chapter with mutual phenomena of the satellites of Jupiter.

E.1.4. Partnerships

List of international partners without grant

- J.-E. Arlot, IMCCE, Paris
- V. Lainey, IMCCE, Paris
- JPL for the use of DE405

E.1.5. Publications

E.1.5.1. Reports, thesis, etc

[3] **Clette, J. Cuypers, T. Pauwels, F. Roosbeek, J. Sauval**
Annuaire de l’Observatoire royal de Belgique—Jaarboek van de Koninklijke Sterrenwacht van België 2006.

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A. ADMINISTRATIE / ADMINISTRATION

A.1. HUMAN RESOURCES

A.1.1. Personeel / Personnel

Algemeen directeur: Van der Linden Ronald

A.1.1.1. Vastbenoemd personeel / Personnel statutaire

Wetenschappelijk personeel / Personnel scientifique

Name/Nom	Functie/Fonction
Alexandre Pierre	Chef de travaux
Alvarez Rodrigo	Chef de travaux
Berghmans David	Departementshoofd a.i.
Blomme Ronny	Werkleider
Bruyninx Carine	Werkleider
Camelbeeck Thierry	Chef de section ff.
Clette Frédéric	Chef de travaux
Collin Fabienne	Chef de travaux
Cuypers Jan	Werkleider
De Cat Peter	Assistent (tot 01/10/2006) / werkleider
Defraigne Pascale	Chef de travaux
Dehant Véronique	Chef de section
Dejaiffe René	Chef de travaux
Hensberge Herman	Departementshoofd a.i.
Lampens Patricia	Departementshoofd
Pauwels Thierry	Afdelingshoofd
Roosbeek Fabian	Chef de travaux
Van Camp Michel	Chef de travaux
Van De Steene Griet	Werkleider
Van Hoolst Tim	Werkleider
Van Ruymbeke Michel	Chef de travaux
Vanneste Kris	Werkleider
Verbeiren Roland	Departementshoofd
Warnant René	Chef de travaux

Technisch en administratief personeel / Personnel technique et administratif

Name/Nom	Functie/Fonction
Vander Putten Eric	Adviseur
Baute Kristof	Attaché A1 (tot 1/3/2006)
De Knijf Marc	Attaché A1
Kochuyt Anne-Lize	Attaché A1
Milis Andre	Attaché A2
Dufond Jean-Luc	Attaché A2
Rezabek Oleg	Attaché A1
Rogge Vincent	Attaché A1
Asselberghs Somnina	Technisch deskundige
Bukasa Baudouin	Expert technique

Castelein Stefaan	Technisch deskundige
Coene Yves	Expert technique
De Smedt Alma	Expert technique
Driegelinck Eddy	Expert technique
Duval David	Expert technique
Ergen Aydin	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
Rondeaux Christian	Collaborateur technique (jusqu'au 01/04/2006)
Vigneron Arille	Collaborateur technique (jusqu'au 01/05/2006)

A.1.1.2. Personeel met externe beurzen / Personnel sur bourses externes

Name/Nom	Functie/Fonction
Koot Laurence	Boursier FNRS
Lecocq Thomas	Boursier FRIA (à partir du 01/10/2006)
Lejeune Sandrine	Boursier FRIA (jusqu'au 30/09/2006)
Pfyffer Gregor	Boursier FRIA
Sichien Els	Beursstudent IWT
Verhoeven Olivier	Boursier FNRS (jusqu'au 30/09/2006)
Yseboodt Marie	Boursier FNRS (à partir du 01/10/2006)

A.1.1.3. Contractueel personeel beheerd door de POD Wetenschapsbeleid / Personnel contractual géré par le SPP Politique Scientifique

Name/Nom	Functie/Fonction
Bizerimana Philippe	Collaborateur technique
Boulvin Olivier	Expert technique
Consiglio Sylvia	Administratief medewerker
De Ridder Christiane	Klerk
De Vos Frédéric	Expert ICT
De Winter Davy	Technisch deskundige
Lubkowski Noël	Adjoint technicien
Motte Philippe	Collaborateur technique
Mouling Ilse	Administratief assistent
Rapagnani Giovanni	Attaché A1
Sayer Amina	Collaborateur technique (à partir du 01/12/2006)
Vandersyppe Anne	Administratief expert
Vanlommel Petra	Assistent
Winter Lars	Assistant (16/10/2006 - 31/12/2006)

A.1.1.4. Contractueel personeel / Personnel contractuel

Wetenschappelijk personeel / Personnel scientifique

Naam/Nom	Functie/Fonction	Contract
Baranovski Alexander	Assistant (16/05/2006 - 01/11/2006)	PRODEX
Baumann Ingo	Assistent (tot 15/07/2006)	PRODEX
Benmoussa Ali	Assistant (jusqu'au 31/08/2006)	PRODEX
Beuthe Mikael	Assistant	PRODEX
De Cuyper Jean-Pierre	Werkleider	DIGITALISATION
Delouille Véronique	Assistant	PRODEX
Dominique Marie	Assistant	PRODEX
Everaerts Michel	Chef de travaux	Action 1
Frémat Yves	Assistant	Action 1
Giordanenco Boris	Assistant (à partir du 16/10/2006)	PRODEX
Gissot Samuel	Assistant	PRODEX
Hagedoorn Jan	Assistent (jusqu'au 28/02/2006)	PRODEX
Hochedez Jean-François	Chef de travaux	PRODEX
Hubert-Ferrari Aurelia	Chef de département	EU - Marie Curie
Jevremovic Darko	Assistant (jusqu'au 31/12/2006)	IUAP
Joukov Andrei	Assistant	PRODEX
Karatekin Ozgur	Assistant	PRODEX
Katsiyannis Athanassios	Assistant (jusqu'au 28/02/2006)	PRODEX
Kretschmar Matthieu	Assistant (à partir du 01/02/2006)	PRODEX
Lainey Valéry	Assistant (jusqu'au 01/09/2006)	EU/PRODEX
Lambert Sébastien	Assistant	PRODEX
Lawrence Gareth	Assistent	PRODEX
Lejeune Sandrine	Attaché (à partir du 01/10/2006)	PRODEX
Lobel Alex	Werkleider	Terugkeermandaat
	Chef de travaux (à partir du 01/09/2006)	PRODEX
Madjarska Maria	Assistent (jusqu'au 31/03/2006)	Actie 3
Marque Christophe	Assistant (à partir du 01/07/2006)	PRODEX

Parenti Suzanna	Assistant (à partir de 16/02/2006)	Chercheur supp
Podladchikova Olena	Assistant	PRODEX
Rosenblatt Pascal	Assistant	PRODEX
Rosat Séverine	Assistant (à partir du 01/08/2006)	PRODEX
Rodriguez Luciano	Assistant	PRODEX
Theissen Armin	Assistent (jusqu'au 31/03/2006)	PRODEX
Van Hoof Peter	Assistent	IUAP / Actie 1
Verhoeven Olivier	Assistant (à partir du 01/10/2006)	PRODEX
Wauters Laurence	Assistant	PRODEX
Baire Quentin	Attaché (à partir du 01/10/2006)	Chercheur supp
Bavier Michael	Attaché	Action 3 /PRODEX
Boës Xavier	Attaché (à partir du 15/02/2006)	EU Marie Curie
Carpentier Georges	Attaché (jusqu'au 31/01/2006)	Action 1
Champagne Georges	Attaché	Service contract
de Patoul Judith	Attaché (à partir du 01/04/2006)	PRODEX
Dammash Ingolf	Attaché (à partir du 01/07/2006)	PRODEX
Fraser Jeffrey	Attaché (à partir de 16/04/2006)	EU Marie Curie
Foriers Edouard	Attaché (jusqu'au 30/04/2006)	Action 1
Duron Julien	Attaché	Action 2
Guyennon Nicolas	Attaché (jusqu'au 30/09/2006)	Cherch. Suppl
LeMaistre Sébastien	Attaché	PRODEX
Moins Michael	Attaché	Action 1
Nicula Bogdan	Attaché	PRODEX
Papadaki Christina	Attaché (jusqu'au 30/09/2006)	Action 2
Petermans Toon	Attaché	Actie 1
Pottiaux Eric	Attaché	Action 3/ PRODEX
Rivoldini Attilio	Attaché	Action 1
Robbrecht Eva	Attaché	PRODEX
Spits Justine	Attaché	Action 2
Verbeeck Koen	Attaché	Actie 1
Barszez Anne-Marie	Attaché (jusqu'au 30/09/2006)	Action 1 / Service

Technisch en administratief personeel / personnel technique et administratif

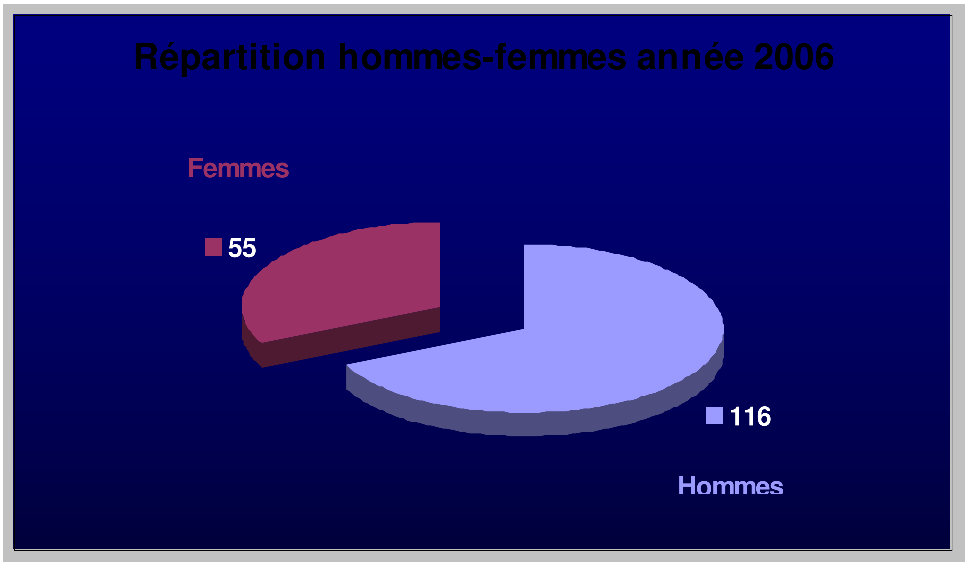
Naam/Nom	Functie/Fonction	Contract
Lafont Daniele	Attaché A1 (jusqu'au 01/09/2006)	PRODEX
Mostaert Régis	Attaché A1	Dotation
Naslin Sébastien	Attaché A1	Mécénat
Van Elder Sophie	Attaché A1	PRODEX
Wellens Véronique	Attaché A1	Dotation
De Decker Georges	Attaché A2 (à partir du 01/01/2006)	Digitalisation
Willems Sarah	Attaché A2	PRODEX
Herreman David	Expert ICT	Dotation
Bastin Véronique	Expert technique	Dotation
Vander Putten Wim	Technisch expert	Dotatie
Vandercoilden Myriam	Assistant administratif	Dotation Pole
Smet Gert	Technisch assistent	Dotatie
Wijns Erik	Technisch medewerker	Dotatie
El Amrani Malika	Collaborateur technique	Dotation
Gonzales Sanchez Bénédicte	Collaborateur technique	Dotation
Herman Viviane	Collaborateur technique	Dotation

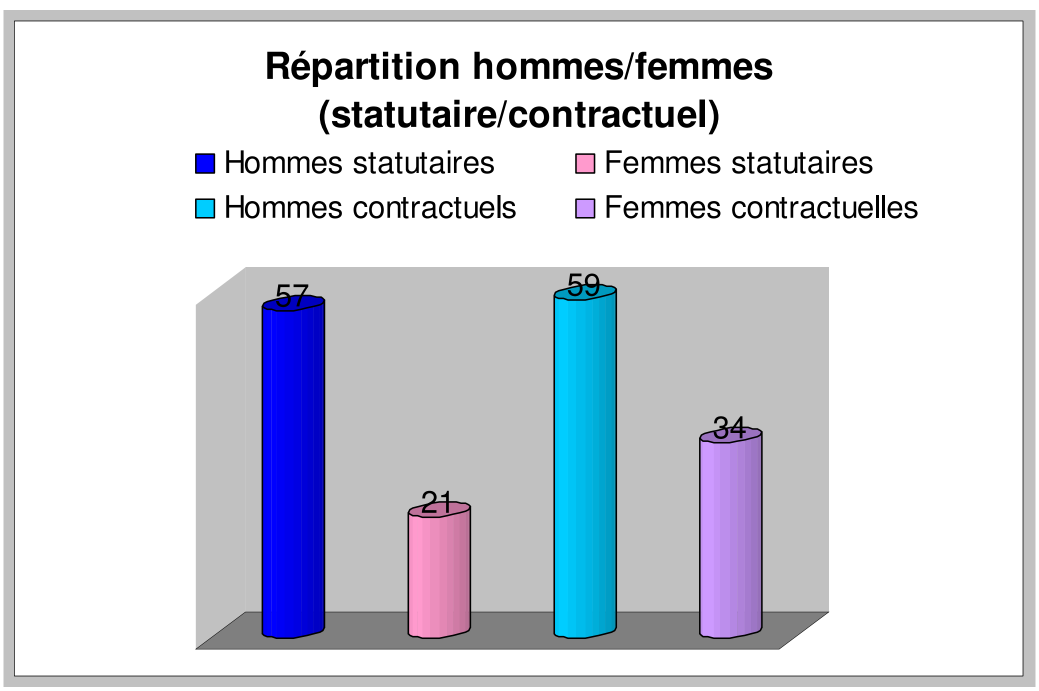
Ipuz Mendez Adriana	Collaborateur technique	Dotation
Sayer Amina	Collaborateur technique	Dotation
Vermeylen Jacqueline	Collaborateur technique	Dotation

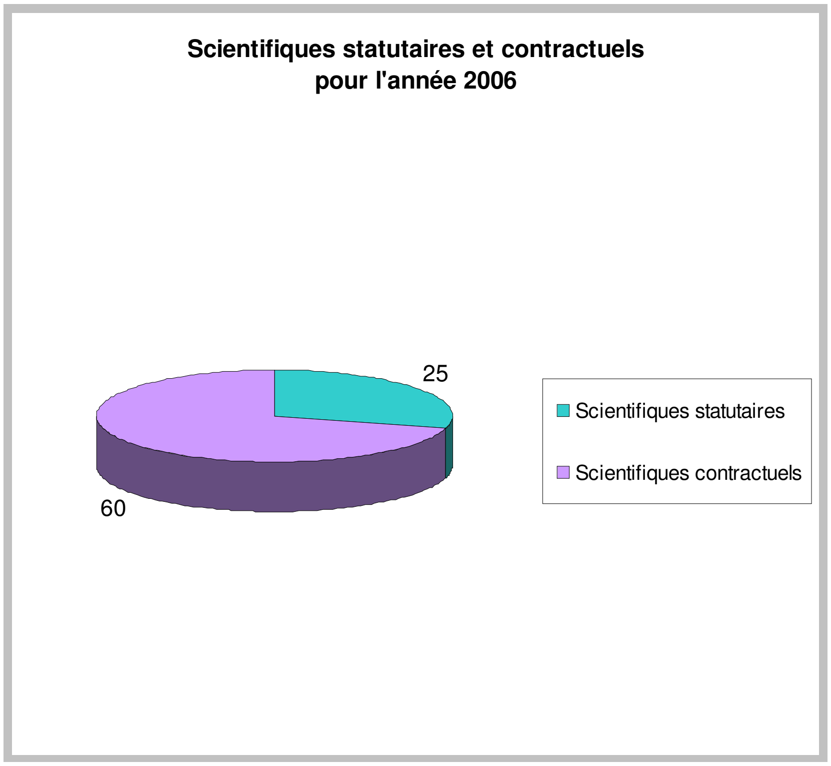
A.1.1.5. Gedetacheerd personeel / Personnel détaché

Naam/Nom	Functie/Fonction	Contract
Ducarme Bernard	Chercheur qualifié	FNRS
Vanhassel Luc	Adjunct technicus	BIPT
Van Schandevyl Pascale	Lerares	Secundair onderwijs

A.1.2. Statistieken / Statistiques



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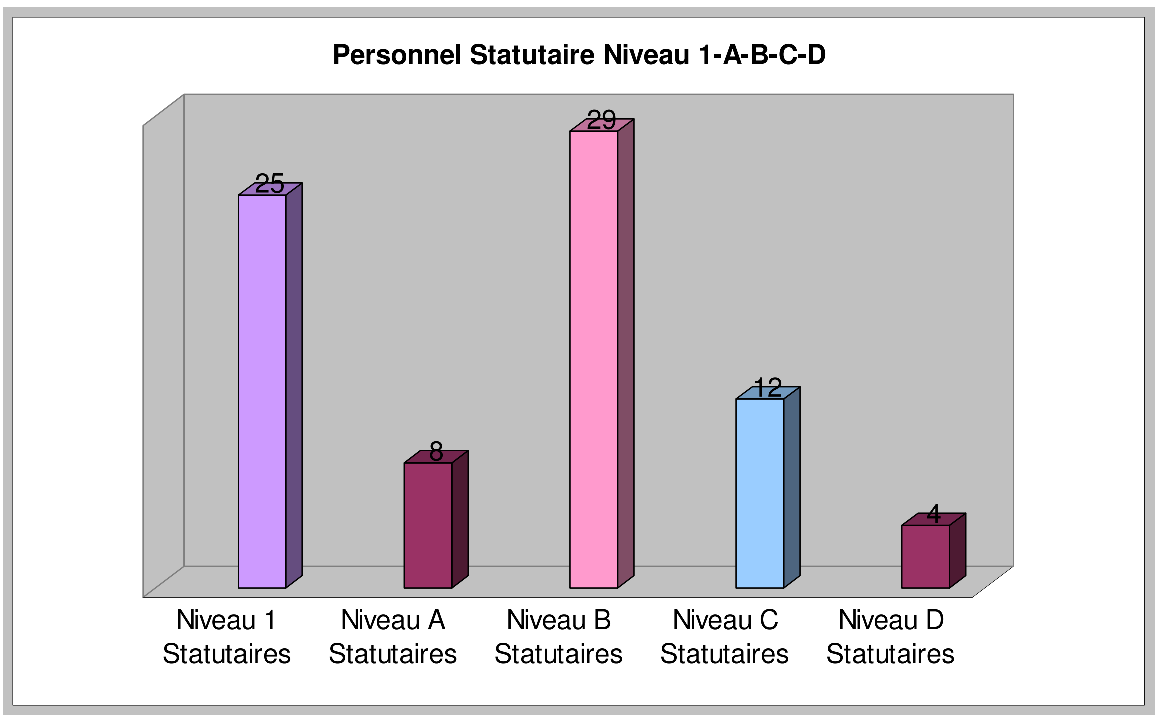
Scientifiques contractuels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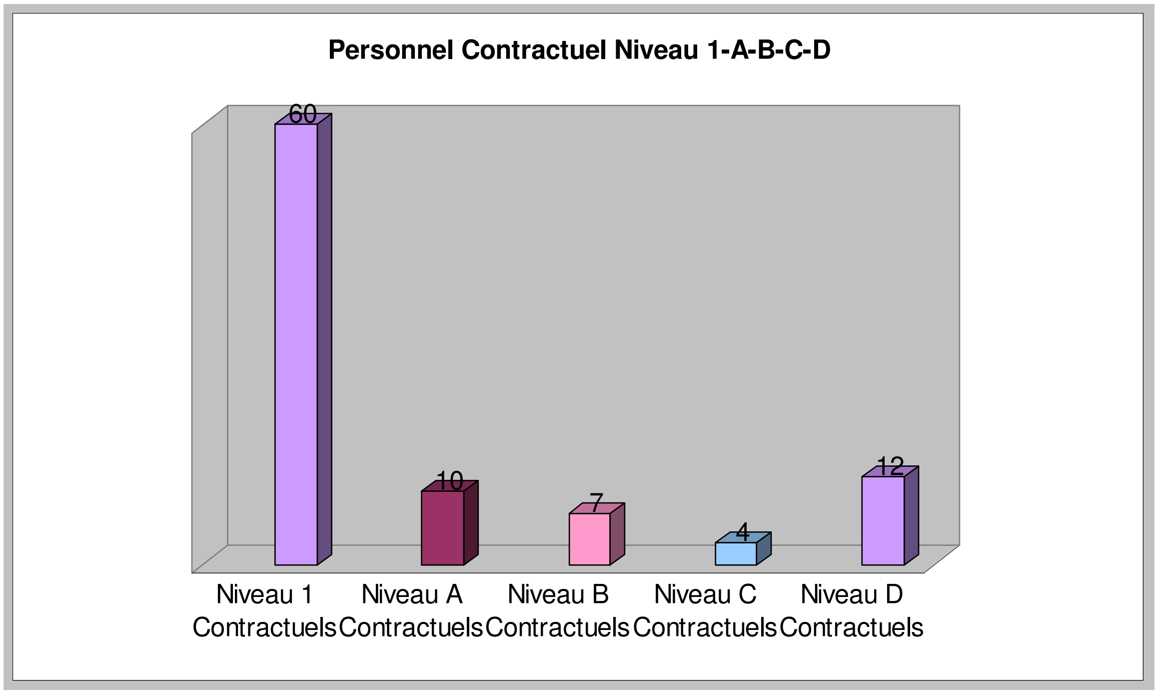


A.1.3. Betrokken personeel / Personnel concerné

Wellens Véronique	Assistante du Directeur /Resources humaines
De Ridder Christiane	Directiesecretariaat
Mortier Carine	Personeelsbeheer/Directiesecretariaat
Verbeemen Christiane	Resources humaines/Sécretariat de Direction

A.2. FINANCIELE DIENST / SERVICE FINANCIERE

A.2.1. Financiële middelen

De middelen van de KSB worden besproken naargelang hun oorsprong.

A.2.1.1. Personeelsenveloppe

De personeelsenveloppe wordt rechtstreeks beheerd door de POD Wetenschapsbeleid en wordt voornamelijk gebruikt om het statutair personeel te betalen. De theoretisch beschikbare enveloppe bedroeg in 2006 ongeveer 4.5 miljoen euro, waarvan echter slechts 4.2 miljoen euro effectief benut werd (het verschil is te wijten aan vertraging in de aanwervingsprocedures.

A.2.1.2. Eigen middelen van de KSB.

De KSB heeft inkomsten in eigen beheer vanuit vier verschillende kanalen:

- o De dotatie die de werking en basisuitrusting van de instelling moet financieren
- o Diensten aan derden
- o Projecten of onderzoeksprogramma's gefinancierd door de Belgische Staat
- o Projecten of onderzoeksprogramma's gefinancierd door derden

In 2006 waren de uitgaven op eigen middelen als volgt verdeeld:

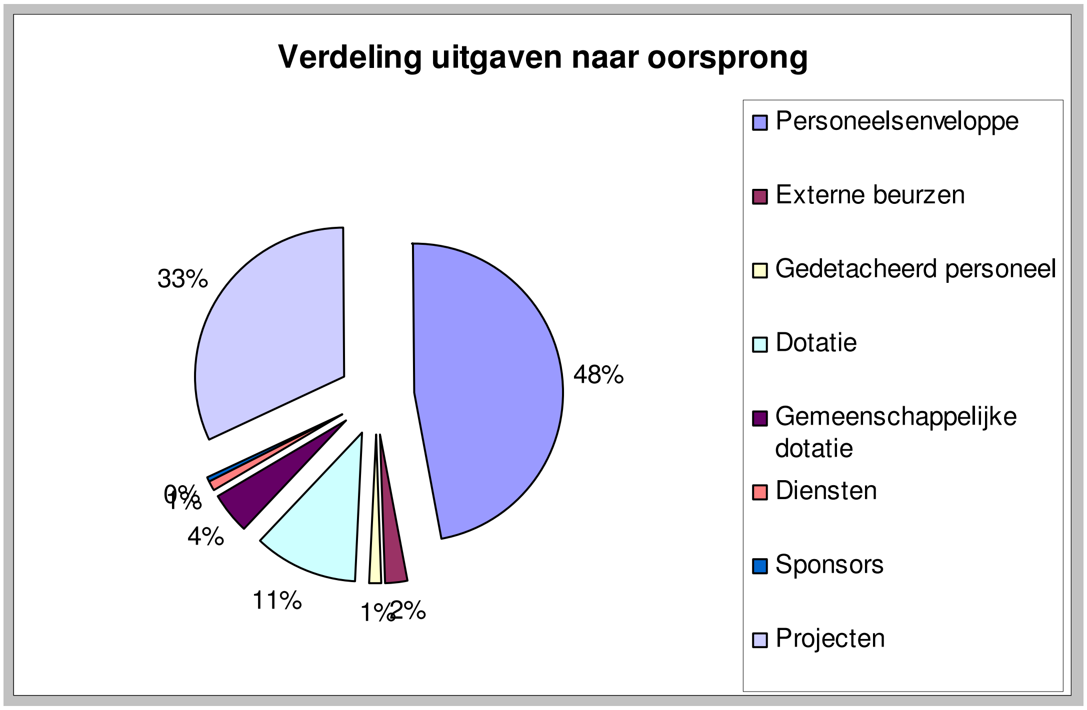
	ROB Dotatie	ROB Diensten	BELSPO Projecten	Externe Projecten	Totaal
Uitgaven 2006					
Personeel	361 000,00 €	45 022,10 €	828 053,63 €	1 449 224,10 €	2 683 299,83 €
Gewone werking	398 507,87 €	32 285,15 €	50 766,84 €	251 198,91 €	732 758,77 €
Specifieke werking	18 587,29 €	5 208,50 €	14 771,53 €	101 535,02 €	140 102,34 €
Gewone uitrusting	49 236,11 €	5 484,93 €	16 440,60 €	54 929,74 €	126 091,38 €
Specifieke uitrusting	67 514,16 €	0,00 €	18 364,68 €	21 299,06 €	107 177,90 €
Bibliotheek	111 718,95 €	0,00 €	0,00 €	770,12 €	112 489,07 €
Totaal	**1 006 564,38 €**	**88 000,68 €**	**928 397,28 €**	**1 878 956,95 €**	**3 901 919,29 €**

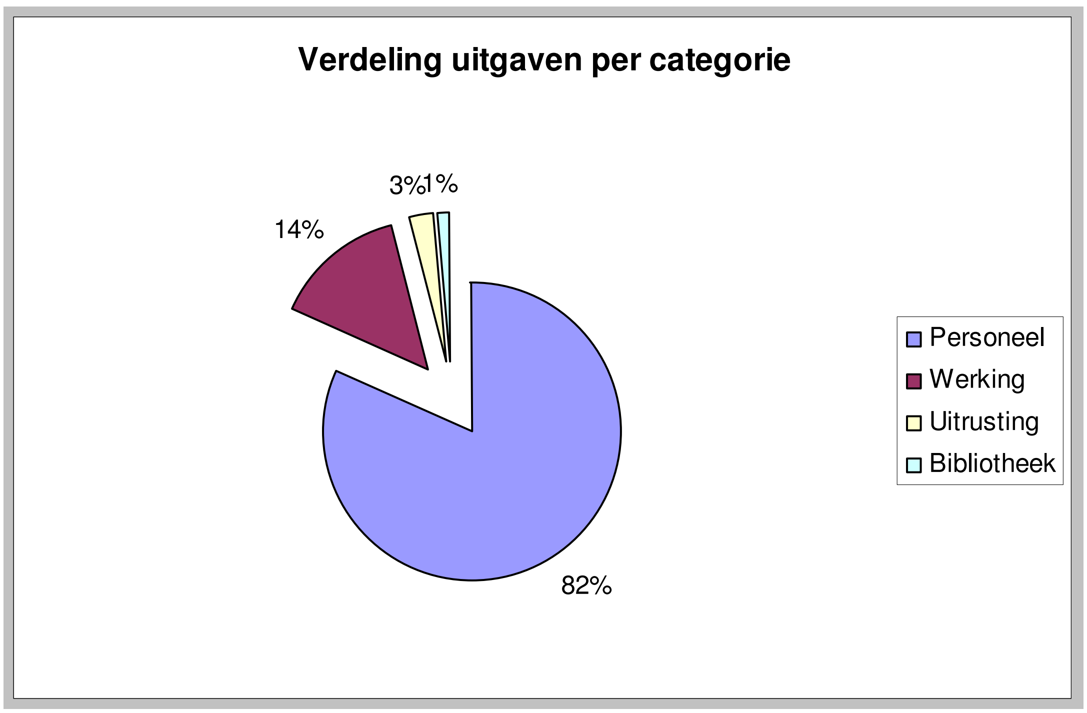
A.2.1.3. Andere middelen

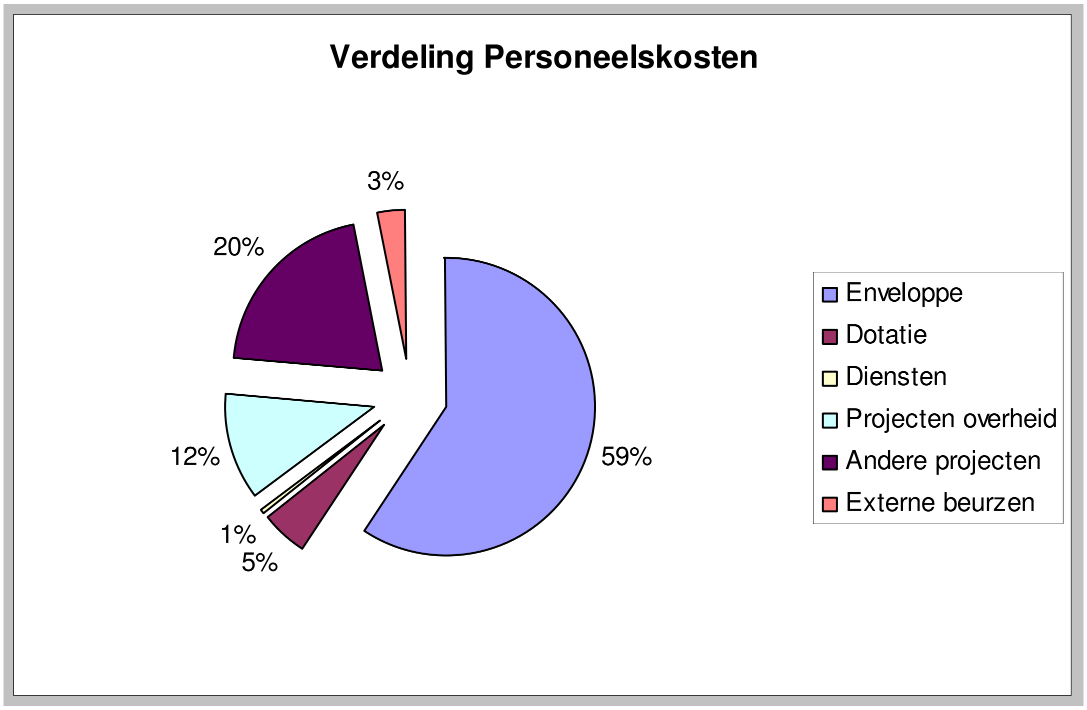
De KSB wordt tevens gesteund door andere middelen, die sterk kunnen varieren van jaar tot jaar en moeilijk kunnen worden uitgedrukt in exacte bedragen:

- o Het gemeenschappelijk budget van de "Pool Ruimte", dat gebruikt wordt om de gemeenschappelijke infrastructuur van de drie instellingen op de site in Ukkel te bekostigen.
- o Het onderhoud van de gebouwen door de "Regie der Gebouwen".
- o Beurzen van FNRS, FWO, IWT, FRIA, etc, die voornamelijk gebruikt worden om doctoraatsstudenten en onafhankelijke onderzoekers te financieren.
- o De lonen van het gedetacheerd personeel.
- o De gewaardeerde medewerking van vrijwilligers en gepensioneerde medewerkers.

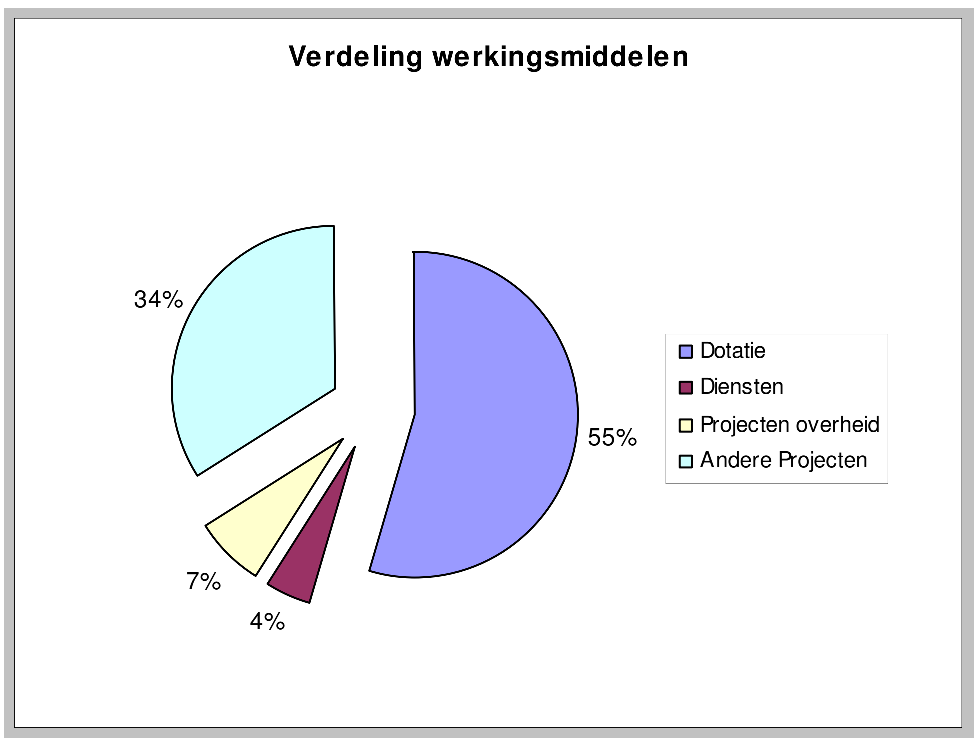
A.2.2. Statistieken / Statistiques



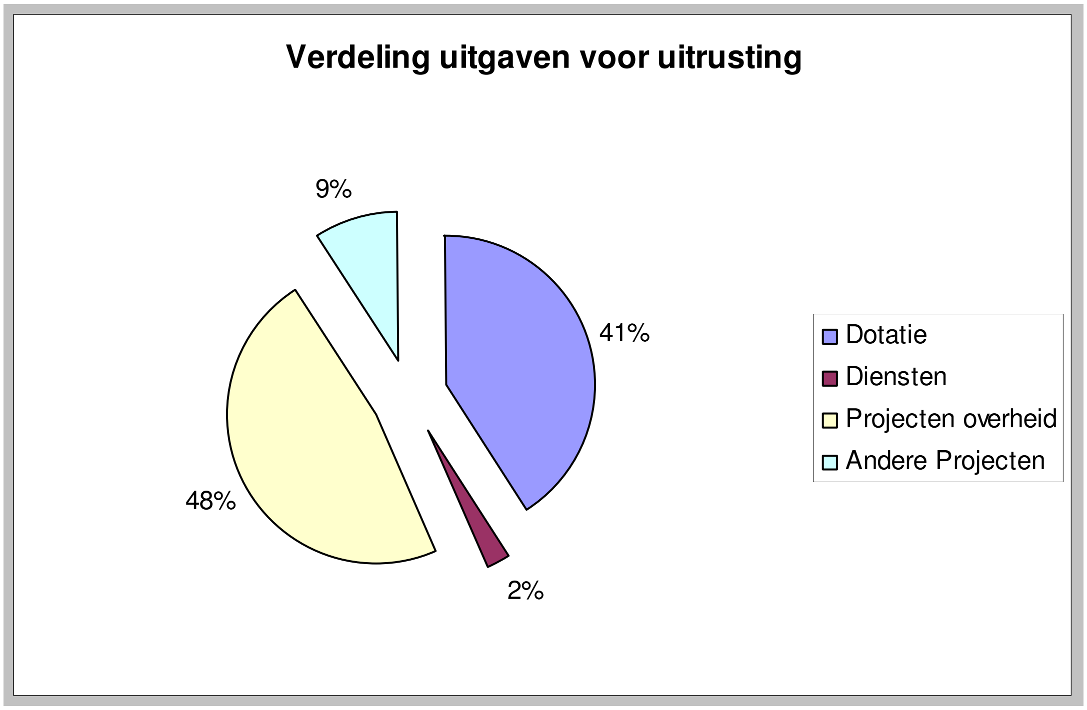




Verdeling Personeelskosten
3%
20%
12%
1%
5%
59%
Enveloppe
Dotatie
Diensten
Projecten overheid
Andere projecten
Externe beurzen



Verdeling werkingsmiddelen
34%
7%
4%
55%
Dotatie
Diensten
Projecten overheid
Andere Projecten



A.2.3. Betrokken personeel / Personnel concerné

Asselberghs Somnina	Boekhouder
Barthélémy Julie	Collaborateur service comptabilité
Mouling Ilse	Medewerker dienst boekhouding
Vanden Elshout Ronny	Collaborateur service comptabilité

B. ALGEMEEN BEHEER / GESTION GENERALE

B.1.1. Betrokken personeel / Personnel concerné

Asselberghs Somnina	Algemeen Beheerder
Christian Brebant	Téléfoniste
Béatrice Depasse	Téléfoniste
Martine Bruyninx	Onthaal
De Wachter Rudi	Tuinman
Van Den Brande Theophilis	Tuinman
Wijns Erik	Tuinman
El Amrani Malika	Nettoyage
Gonzales Sanchez Bénédicte	Nettoyage
Herman Viviane	Nettoyage (Humain)
Ipuz Mendez Adriana	Nettoyage (Planetarium)
Sayer Amina	Nettoyage (Planetarium)
Vermeylen Jacqueline	Nettoyage

C. TECHNISCHE DIENST / SERVICE TECHNIQUE

C.1.1. Betrokken personeel / Personnel concerné

Vander Putten Eric	Diensthoofd
De Knijf Marc	Ing electromechanica
Rogge Vincent	Preventieadviseur
Peeters Roger	Mechanica
Renders Francis	Mechanica
Strubbe Marc	Verwarming
Van Damme Daniel	Electronica
Van Der Gucht Ignace	Informatica
Mues Christian	Electricité
Bizerimana Philippe	Ouvrier
Philippe Motte	Chauffeur

D. IT SERVICES

D.1. Description and Objectives

The computing facilities and the network of the Observatory as well as of the Planetarium are managed by the IT department.

For researchers at the Observatory, the IT staff installs and maintains intensive compute machines such as clusters, number crunchers, compute servers, etc ..., as well as user's PCs. They provide also a logistic support on these machines.

The team also maintains the global computing infrastructure consisting of 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 cannot 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 sections could be detailed as follows:

- **Network and Security**: the objective is to maintain the network infrastructure operational, safe and at top performance, 24 hours a day.
- **Servers and user PCs**: The objective is to install and maintain powerful compute servers, servers providing global computing infrastructure (i.e. email services, application servers, printing facilities, database servers, login server, ...) and desktop user PCs.
- **Helpdesk**: 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**: All the IT purchases are 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. This include also the purchase of IT consumables (printer cartridges, printer toners, data storage media, etc …).

D.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.
- Different kind of security tests are regularly made at different network levels. Modifications are made keeping the objectives in mind.
- BASE (a NIDS) works properly. The topology of the network is available via a web interface (through Nagios) which will help to solve network problems quicker if needed.
- Wireless network is fully functional. There are two separated networks: the private one, accessible only by the ROB users which have provided us their MAC address, and the public part, accessible only in the meridian room, for any visitor. 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 has access only to limited resources (shortly, it provides an internet access to the outside world but not to our infrastructure). Since the implementation of the private wireless network, nearly 80 users take advantage of it.

BACKUP SERVER:

- In 2006, a new backup system has been installed in order 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, 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 as possible redundancy each one. 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 takes snap shots on Ultrium tapes which are transferred off-site (Planetarium). We give the possibility to everybody to have an automatic backup on this 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).

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).

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 2006, 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).

KAOS:

- KAOS is a set of 4 high performance compute servers for heavy scientific tasks, shared by the 3 institutes (RMI, BISA and ROB). This year, a fourth compute machine has been added to the existing pool. The machines have been transferred from BISA to ROB and are now managed by the ROB sysadmins. A fifth one will be bought in 2007.

TECHNET:

- Technet is the equivalent of intranet but for IT specific topics. One can 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.

- This year, a new server was installed and we have used the SNMP protocol for implementing an alert and monitoring system which allows 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 …

DEPARTMENTAL SERVERS:

- Continuous maintenance of departmental servers, including a completely new system of two servers for the GPS Space Weather service.

SERVICED & USER 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.
- A new Linux distribution is installed on the user desktop PCs: Ubuntu. This distribution is more "user friendly" and desktop oriented than our previous distribution (Gentoo). This will allow any user to manage himself his computer, without any deep IT knowledge (similar to the management of a Windows OS). Gentoo is still used for our servers and for the high compute servers.
- New anti-virus software is installed systematically on each new Windows PC: NOD32.

SMS SERVER:

- In 2006, we have installed a new 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, an SMS is sent to the GSM of the scientific in charge as well as to the electronic lab.

LOGIN & SERVICES SERVER (HELIOS):

- Continuous maintenance of Helios, the login server of the Observatory (the only server available from outside) as well as the server which run some central services: DNS, NIS, DHCP, WINS,…

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.
- After investigation of the market and the publication of the specifications, a decision has been made on the company that will deliver the new file servers (in 2007). This has been accepted and the installation will start in the near future.

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. Zeno is intended to be used mainly for batch processes. In that context several different queues are defined with different specifications. The queuing system being used is PBS Pro
- User courses have been given in 2006.

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 (Demilitarized 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 ftp-users 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.

PRINTERS:

- 12 new departmental printers have been purchased and installed, including one at the planetarium. They replace all the small individual printers.
- The print server has been stopped and any user can now print directly on any of these departmental printers.

LIBRARY:

- Most of the users of the library have been given a thin client and are no longer working from their local PC. They use telnet to access the database. The System used is VUBIS.
- Vubis needs an upgrade to be able to recognize the new standard ISBN number (now 13 characters).

WEB SERVER AND ROB WEB SITE:

- The ROB web site has been completely redone by Georges Champagne.

PUBLIC PC:

- Two new public PCs have been purchased. The first one is Linux based, the second one is Windows based. They will be available in the printer room in the beginning of 2007. This allows visitors (or users without personal PC) to have access to internet, to scan and print documents or to read/write DVD or tapes.

SOFTWARE:

- The IT department is responsible of buying and installing the software.

HARDWARE MAINTENANCE:

- The IT department is responsible for the IT hardware maintenance.

NTP SERVER (JOINT PROJECT WITH THE TIME LAB OF THE ROB):

- In order to improve the reliability and lower the charge of our NTP server (`ntp1.oma.be`, Elproma model), we have bought a second unit from another manufacturer (`ntp2.oma.be`, Meinberg). This second unit is now installed, configured, monitored and fully operational. These NTP servers are reliable time synchronization sources to allow anybody to synchronize on UTC(ORB) and by extension to UTC. All the servers and PCs of the 3 institutes (ROB, RMI, BISA), as well as a huge number of external anonymous clients use these time sources.

SUPPLIES:

- 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.

PURCHASES:

- The IT staff is in charge of the IT purchases. This includes the definition of the user needs, contacting different resellers, making the purchase proposal and checking the received material.

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 7 USERCOM meetings in 2006.

D.3. Perspectives for next years

- NETWORK & SECURITY: For improving the security, we want to associate a MAC address to each network plug.
- TECHNET: We want to setup a new database for easy monitoring of the log of our servers. We will also develop a similar system for monitoring the state of the Linux/windows serviced PCs.
- 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 provide information on the intranet without the need of an intervention from the IT staff.
- Setup of a VMWare infrastructure. That infrastructure will allow us to improve the reliability of our IT services with less physical servers.
- We want to upgrade the network to a gigabit backbone. Our internet connection will be upgraded following the new SCIENCEMAN network.
- Providing a safe work environment by a better control and setup of our firewalls and DMZ.
- VOIP will be investigated
- installation of the new fileserver of the FS_SPACE project

D.4. Personnel involved

Georges Champagne	Webmaster (for a few months only)
David Herreman	System Administrator
Oleg Rezabek	System Administrator
Fabian Roosbeek	IT Coordinator
André Somerhausen	System Administrator
Katinka Vermeiren	System Administrator

Inhoudstafel / Table de matières