Scientific Report 2004

Summary

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. This mission is included in a long-term vision, closely related to the international activity, and to the activities described in the statute of the Royal Observatory of Belgium (ROB).
The activities of Section 1 are divided into five different scientific projects (research and/or operational projects).

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

The scientists involved in this project have the responsibilities to establish the Belgian time scale UTC(ORB) and to participate in international timescales by incorporating Belgium in these timescales. We maintain presently five high-quality clocks for participation in two international timescales: the International Atomic Time (TAI) and the International GPS Service Timescale (IGST). We will 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 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 important part of the work is also related to the quality control and maintenance of the clocks, as our involvement in the definition of international timescale impose us a near perfect reliability.

(b) Project 2 'GNSS-BASED GEODESY AND GEODYNAMICS' (Operational 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 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 GPS 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 (160 permanent stations) and is taking care of the data archive, data quality control, and data analysis of these stations. They also maintain a GPS data center that makes available GPS data to all user communities. This operational project is one of the most important for geodesy in Europe.
With the upcoming Galileo precise positioning system, the scientists involved in this project will work on the incorporation, treatment, and enhancement of Galileo precise positioning system.

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

The mission of the project is to study and to mitigate the influence of the atmosphere on space geodetic techniques which are based on radio signals, in particular, Global Navigation Satellite Systems (GNSS). Indeed, the effect of the atmosphere (neutral atmosphere and ionosphere) on radio signal propagation is the main limitation to the precision and to the reliability of GNSS applications. Therefore, the use of GNSS signals for high precision applications in geodesy and geophysics, in particular in the frame of international projects, requires a precise modeling of the atmospheric disturbances. In practice, the scientists of this research team are mainly studying the influence of the neutral atmosphere water vapor and of the ionospheric plasma on GNSS. 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. In addition, the project also contributes to several national and international collaborations in the field of ionosphere physics and meteorology by reconstructing information about the atmosphere (water vapor, electron concentration in the ionosphere) using GPS measurements.
The study of the impact of the ionosphere and of the neutral atmosphere on GPS is presently extended to the Galileo precise positioning system.

(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 the interaction between the solid Earth and the geophysical fluid dynamics. The work is based on the analysis of data from Earth rotation monitoring and general circulation models of the atmosphere, ocean and hydrosphere. In addition, the observation and model of the Earth interior are used. The scientists involved in this project work on the improvement of analytical and numerical Earth rotation model and they study the angular momentum budget of the complex system composed of the solid Earth, the core, the atmosphere, the ocean, the cryosphere, and the hydrosphere at all timescales. This allows us to better understand the dynamics of all the components of the Earth rotation, as the Length-of-day variation, the polar motion, and the precession/nutation, as well as to improve our knowledge and understanding of the system, from the external fluid layers to the Earth deep interior.

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

The objectives of the project are to better understand and model the gravity field, the rotation, the orientation variations (polar motion, precession, nutations, and librations), and the tidal deformations of the terrestrial planets, and to study the interaction between the solid part of the planet and the geophysical fluid dynamics (core, atmosphere, and ocean), if they exist. Since the end of the 20th century, the study of the terrestrial planets Mars, Venus, and Mercury is again one of the central themes of astronomical and geophysical research, as shown, for example, by the recent and future space missions to these planets by all

major space agencies like NASA and ESA. Especially many missions to Mars have been launched and are scheduled, with, at present (2005), five spacecrafts (three orbiters, two landers) actively investigating the planet. In the absence of seismometers on these planets, geodesy is one of best tools to probe the planetary interior. Section 1 is involved in analyses of radio science data from Mars Global Surveyor (MGS) and Mars Express (MEX). Data from Venus Express and BepiColombo missions to Venus and Mercury will be analyzed in the future. The scientists involved in this project perform also simulations of radio science data of future space missions, in order to infer what will be the scientific return and to bring out a set of optimal observation strategies.
For the analysis of real data and for simulation of future experiments, ROB has developed computer softwares which are strategic tools for the future. In particular the GINS/DYNAMO computer software computing orbits of spacecrafts starting from radio science data is one of the few existing ones in the world.

Links between the different projects of Section 1

The five projects within Section 1 all fit in the theme 'Time, Earth Rotation, and Space Geodesy', and have multiple mutual links. The project 'Time and Time-transfer' uses the GPS receivers, which belong to and require the scientific expertise of the GNSS project. Similarly, the project 'effect of the Earth and planetary atmospheres in space geodesy' uses the GPS data from the Belgian permanent stations maintained by the GNSS project. The Earth rotation variations and Earth orientation changes, studied by the scientists of the project 'Earth Rotation', are deduced from global measurements of Very Long Baseline Interferometry (VLBI), Satellite and Lunar Laser Ranging (SLR and LLR) and also GPS data, to which the GNSS project contributes. The project 'Geodesy and Geophysics of other planets' extends the geodesy research performed in the project 'Earth rotation' to the rocky planets and satellites of our solar system. As such, the methodologies are common between these two projects.

National and international responsibilities and prizes

Scientists of Section 1 assume many responsibilities in national and international organizations. In Belgium, we are represented in the Belgian National Committees of Astronomy, Geodesy and Geophysics, and Space Research of the Belgian Academy of Sciences, and in the FNRS Commission for Astronomy and Geophysics. Internationally, members of Section 1 act as President, Vice-President, or Secretary of several organizations and commissions, such as the Geodesy Section of the AGU (American Geophysical Union), and commissions of the IAU (International Astronomical Union) and IAG (International Association of Geodesy). We are especially strongly involved in the IERS (International Earth rotation and Reference frame Service), with presidents, chairs and members of several bodies, such as the Special Bureau for the Core. We participate in the IGS decisions and activities as well, such as participation in the IGS Governing Board and in Pilot projects. We participate in several space missions for the investigation of the solar system planets with several co-Is (Co-Investigator) on MEX (Mars Express) radio science experiment (MaRS, which stands for Mars express Radio Science), VEX (Venus Express) radio science experiment (VeRa, which stands for Venus express Radio science), BepiColombo radio science experiment (MORE, which stands for Mercury Orbiter Radio science Experiment), BepiColombo altimetry experiment (BELA, which stands for BepiColombo Laser Altimeter), and BepiColombo camera experiment (SIMBIO-SYS, which stands for Spectrometers and Imagers for MPO BepiColombo Integrated Observatory SYStem, the name for the High Resolution Camera). We participate as Belgian delegate at COST (European COoperation in the field of Scientific and Technological research) actions. We participate also in the 'Comité Consultatif pour le Temps et les Fréquences' (CCTF). Section 1 members contribute as well to the organization of conferences and workshops. In 2004, we have organized several sessions in the EGU (European Geophysical Union) and AGU general assemblies. We are also often contacted by major science journals for reviewing submitted manuscripts. At special events, we are pleased to dedicate some time to journalists.

This year, one of Section 1 member has received the Lagrange Prize of the Belgian Academy of Science and Letter.

A. 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 precisions of remote clock comparisons and to perform performance analyses of the data gathered at ROB,
- To incorporate the ROB time laboratory in the future GALILEO system time,
- To maintain the official Belgian time called UTC(ORB) within one hundred of nanosecond of TAI,
- To define a legal Belgian time and to include 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 40 time laboratories over the world in which are distributed the 250 atomic clocks used by the BIPM (Bureau International des Poids et Mesures, Paris) for the realization of the International Atomic Time (TAI).

Service

- During year 2004, we have 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 internet.
- The time links using the geodetic receivers and the ionospheric free code P3, as we have developed in 2001 and 2002, are now used by the BIPM (project TAIP3) for the realization of TAI by half of the time laboratories. We have modernized the software for a more general usage by all the laboratories, and responded to all questions from users.
- Development of a NTP server for the diffusion of UTC(ORB) via internet.
- Start of the procedure to get UTC(ORB), or equivalent realizations of UTC, as legal time for Belgium.
- Calibration of the two Ashetch Z-XII3T receivers using the traveling BIPM receiver.

Results

- We have studied the impact of the setup (in particular the role of the splitters) on the time transfer results. Results: we have shown that it is impossible to calibrate the splitters with a high accuracy, so that it is better to avoid them in the setup.
- We have developed methods for computation and prediction of GPS-Galileo time offset; in collaboration with A. Moudrak (DLR). Results: we have shown that the broadcast orbits and broadcast satellites clock are sufficient, and that the last value is the best prediction.
- We have continued the tests of new types of geodetic receivers for their suitability to time transfer by common view.
- We have begun a study of the different capabilities of several time transfer computation strategies (TAIP3, Gamit, Bernese, Gipsy, IGS solution), in collaboration with Ken Senior (NRL) and Jim Ray (NGS).

A.1.3. Perspective for next years

- To continue to investigate the possibilities of GPS time and frequency transfer; comparisons between different techniques and different softwares;
- To test different types of geodetic receivers in order to investigate the receiver-dependence of the signals;
- To investigate the impact of adding GALILEO and enhanced GPS on time transfer;
- To continue the procedure to propose UTC(ORB) as basis for legal time in Belgium;
- Depending on the Metrology Service requirements, to prepare the Quality Criteria for the Time laboratory (norm iso 17025 for calibration certification), necessary for the key comparisons of the MRA;
- Depending on the result of the selection after the European 6th PC call, preparation of the Galileo Time Service Provider (GTSP) in collaboration with the other laboratories or industrial partners of the consortium;
- Development of a tool for time and frequency transfer based on the combined analysis of codes and carrier-phase observations;
- Study of Time History at the Royal Observatory of Belgium.

A.1.4. Personnel involved

Scientific staff: Pascale Defraigne (Dr., chef de travaux, ***Project Leader***)
Carine Bruyninx (Dr., werkleider)
Fabian Roosbeek (Dr., chef de travaux)
Technical staff: Eddy Driegelinck (Expert technique)

A.1.5. Partnerships

International collaboration:

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)
NGS (US National Geodetic Survey: Jim Ray)

Visitors: nihil

A.1.6. Publications

A.1.6.1. Publications with peer system

A.1.6.2. Publications without peer system

Defraigne P., C. Bruyninx, A. Moudrak, **F. Roosbeek**
Time and Frequency Transfer Using GNSS
In: Proc. IGS workshop, Bern, March 2004.

Moudrak A., **C. Bruyninx,** A. Bauch, **P. Defraigne,** A. Konovaltsev, J. Hammesfahr
Determination of GPS-Galileo Time Offset to Support System Interoperability,
In: Proc. European GNSS conference, Rotterdam, May 2004 (CD-rom).

Roosbeek F., A. Somerhausen, P. Defraigne
Establishment of an Internet Time Server at the Royal Observatory of Belgium
In: Proc. PTTI 2004, December 2004 (CD-rom).

Moudrak A., A. Konovaltsev, A. Bauch, **P. Defraigne,** J. Furthner, J. Hammesfahr
Timing Aspects of GPS Galileo Interoperability: Challenges and Solutions
In: Proc. PTTI 2004, December 2004 (CD-rom).

Defraigne P.
CCTF 2003: Report of the Royal Observatory of Belgium
Report presented in the frame of the '16ème session du comité consultatif du Temps et des Fréquences', Paris, April 2004.

A.1.6.3. Reports, thesis, etc

A.1.6.4. Communications (other than those above)

Bruyninx C., F. Roosbeek, P. Defraigne, J. Ray, K. Senior
Study of time transfer methods I, comparison of geodetic clock analysis strategies
Precise Time and Time Interval PTTI 2004 symposium, December 7-9, Washington DC, US

Defraigne P.
Testing the suitability of the receiver PolarRx2 for time and frequency transfer
TAI Working group meeting, Paris, March 2004.

A.1.7. Missions

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

B. Operational/service project 'GNSS-based geodesy and geodynamics'

B.1.1. Objectives

The mission of this project is to integrate Belgium in international terrestrial spatial reference frames. We accomplish this through (1) space geodetic observations (maintenance of a GPS observation network) (2) services (Central Bureau of the EUREF Permanent Network (EPN), EPN Data Centre, and EPN Analysis Centre), and (3) research (in order to maintain the highest quality for both the observations and services).

B.1.2. Progress and results

Observations

We maintain a network of different permanent GPS stations, distributed over Belgium (see Figure 1).

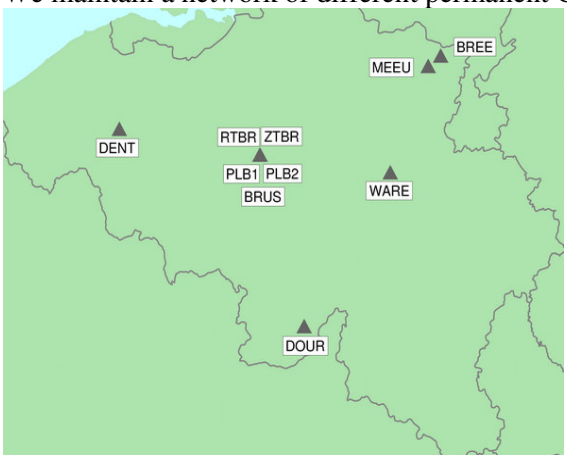


Figure 1: Network of permanent GPS stations maintained by the Project

The station in Brussels (BRUS) is integrated in the network of the International GPS Service (IGS) and four of our stations belong to the European Permanent Network (EPN) (see also Table 1for more details). As such, several analysis centres use their observations in order to contribute to the realization of European (ETRS89) and international (ITRS) terrestrial reference systems.
In addition to the existing network, one of the GPS stations at Ukkel sends its GPS data in real-time through the Internet. The station participates to the EUREF-IP (IP=Internet Protocol) project, which aims at setting up and maintaining a real-time GNSS infrastructure using the Internet.

In addition, also other projects within Section 1 of

Department 1, such as 'Atmosphere in Space Geodesy' and 'Time and Time Transfer' rely heavily on the data from the GPS stations managed by the members of this operational project.

In 2004, we have changed the data flow within our GPS network: instead of retrieving RINEX data from our GPS stations, we retrieve now the binary (native) GPS data. In this way, our data flow follows the latest guidelines of the IGS. This change necessitated the adaptation of existing computer programs and the creation of new programs for the management of the data flow.

Station	Network/Inclusion in data bases	Data Delay	Remarks
BRUS	IGS and EPN	hourly	Used also for contribution to TAI and IGS time scales
BREE	ROB	hourly	Upgrade of OS station PC to Windows XP Defect GPS ontvanger – in reparatie
DENT	EPN	hourly	Upgrade of OS station PC to Windows XP
DOUR	IGS	hourly	Upgrade of OS station PC to Windows XP
MEEU	ROB	hourly	Defect GPS ontvanger – hersteld na reparatie
PLB1	ROB	daily	Mainly used for time transfer tests
PLB2	ROB	daily	Mainly used for time transfer tests
RTBR	EUREF-IP	real-time	
WARE	EPN	hourly	Upgrade OS station PC to Windows XP
ZTBR	Backup-BRUS	hourly	

Table 1: Overview of the permanent GPS tracking stations maintained by the project.

Services

The management of the Central Bureau of the EUREF Permanent Network and the network coordination of the EPN has been continued. The EPN is the network that maintains the European Reference Frame and it is the European contribution to the international terrestrial reference frame. The EPN Central Bureau acts as liaison between station operators and analysis centres, providing necessary station configuration metadata and ensuring the datasets meet the requirements of the analysis. As EPN Central Bureau, we manage a permanent GNSS network of over 160 stations, distributed over more that 30 countries with ±100 participating agencies. In 2004, 8 new stations were integrated in the network. As EPN Central Bureau (CB) we perform permanent quality controls of the EPN data and a continuous monitoring the EPN data flow.

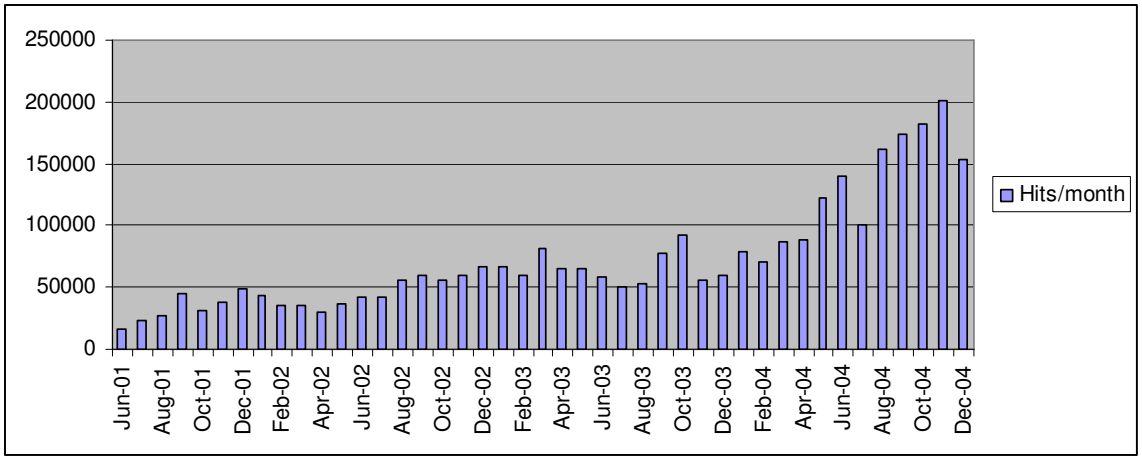


Figure 2: Number of monthly hits (from outside oma.be domain) on the web site of the EPN CB

One of the most important tasks of the EPN Central Bureau is the maintenance and continuous updating of the EPN CB web-site (see http://www.epncb.oma.be/, 2000 pages). In 2004, the number of hits has grown spectacularly (see Figure 2). The total number of hits (from machines outside the oma.be domain) over 2004 was more than 1.5 million.

As EPN Data Centre, we make the IGS and EPN data of the ROB permanent GPS stations available through the Internet.

As EPN Analysis Centre, we maintain a high precision (sub-cm positioning) GPS data analysis centre that uses the Bernese software (University of Berne, Switzerland) to analyse GPS data following international state-of-the-art procedures. Our analysis centre is engaged to compute the daily coordinates for network of 47 GPS stations. These coordinate solutions contribute to the maintenance of the European and international spatial reference systems (ETRS89 and ITRS).
We have continued to develop and maintain a comprehensive web site (http://www.gps.oma.be) which gives background information on the activities of our project (NL, FR, UK). The site has been switched from html to xhtml using css.

Research/Improvement of Products

The provision of observations and services of the highest level requires research which allows keeping the observations and services competitive.
The research of our group concentrated in 2004 on the following topics:

- Investigation of correlations between the quality of GPS data and the stability of the computed coordinates. In EPN stations such as ACOR and BZRG we were able to demonstrate that the motion of the GPS coordinates was not caused but local tectonics, but by antenna tracking problems.
- Our analysis centre has been computing daily station positions since 1996 and we have used these daily positions to determine the long-term velocities of a regional network around Belgium in order to deduce intra-plate tectonic motions. Due to the improvement of the computation techniques, a complete reprocessing of the old data since 1996 became necessary. This work was initiated in 2003 and has been continued in 2004.
- Investigation of the optimal definition of the datum used to compute coordinate time series (like the one on the EPN CB web-site). We have showed that the minimal constraint approach used in the CATREF software is a better method to compute the EPN time series. Previously, the EPN time series were computed by constraining the coordinates of a selected set of EPN stations which could cause network distortions.

In addition, we have started a study of the future GALILEO system in order to define the main working areas for the next years.

Software developments

Updates, optimisation or extensions of the following computer programs (non-exhaustive list) was done in 2004:

- Latency monitoring of the hourly data from the EPN stations: correction of bugs and creation of new graphics; the results are available on EPN CB web site;
- Shell scripts around CATREF that allow the automated creation of the 'raw EPN time series', results are available on EPN CB web site;
- EditConfig, a graphical program that controls all options of the data flow of the ROB GPS stations, was extended to allow the transfer of raw GPS data;
- GlobRIN, a program to create RINEX data from raw GPS data, has been updated to deal with observations from EGNOS satellites;
- Datachecker, a program to verify and correct RINEX headers using information from site logs, was updated;

- Station description: Update of program that creates individual station web pages; the results are available on EPN CB web site.

The following new computer programs were developed (non-exhaustive list):
- get_drinash, get_hrawash, and get_plrx: programs to retrieve daily and/or hourly Ashtech and/or Septentrio data from the remote ROB GPS stations;
- yearlycheckhourly: program to create yearly data holding files for hourly RINEX data available in the ROB data centre;
- stationlocaleffects: program to create web pages that display correlations between GPS data quality checks and the coordinate time series; the results are available on EPN CB web site;
- DataAvailability4PreviousMonth: program that computes statistics of the availability of the hourly EPN data; the results are distributed through EUREF mail.

Collaborations

Through the EPN CB activities, the project has close collaborations with about 100 agencies mainly in Europe.

B.1.3. Perspective for next years

During the upcoming years, we will continue the maintenance of our GPS network and adapt it to new international guidelines; we will continue our participation to international observation networks and will participate to IGS and EUREF projects for real-time data dissemination serving the generation of real-time products.
Due to the release of a new version of the Bernese GPS analysis software (V5.0), a complete re-computation of all GPS data from 1996 on will be necessary.
In addition, we will study all aspects of the interoperability of GPS and the upcoming Galileo system and assess the reliability and accuracy improvements of using a combined GPS/Galileo constellation with respect to GPS and GALILEO individually.
We will also continue with our EPN activities as EPN Central Bureau, EPN data center, and EPN analysis center.
We will use the new modeling possibilities of the Bernese 5.0 software to reprocess all GPS data since 1996. In order to assess the reliability of our coordinate solutions, we will compare the results from two scientific GPS software packages: GAMIT and the Bernese.
In order to assess the stability of the GPS station coordinates, we will improve the reliability of our methodology used to determine variations in the station coordinates and we will continue our study of the different methods to combine regional and global GPS solutions.

B.1.4. Personnel involved

Scientific staff:	Carine Bruyninx (Dr., werkleider, ***Project Leader***)
	Fabian Roosbeek (Dr., Chef de Travaux)
	Georges Carpentier (attaché scientifique, action 1 MO/33/008)
	Salua Daghay (wetenschappelijk attaché, half time, from Oct-Dec 2004)
	Michaël Moins (wetenschappelijk attaché, half time, from Oct-Dec 2004),
Technical staff:	Ann Moyaert (ICT expert)
	Dominique Mesmaker (expert technique)
	Robert Laurent (technisch medewerker).

B.1.5. Partnerships

Grants used for this research:

Action 1 MO/33/008 (2002-2005) – Ontwikkeling van snelle kwaliteitstesten voor het geodetische "European Reference Frame" GPS netwerk ten behoeve van nieuwe wetenschappelijke toepassingen.

Visitors: 3

B.1.6. Publications

B.1.6.1. Publications with peer system

Kenyeres A., **Bruyninx C.**
Monitoring of the EPN Coordinate Time Series for Improved Reference Frame Maintenance
GPS solutions, Vol 8, No 4, pp. 200-209.

B.1.6.2. Publications without peer system

Bruyninx C.
The EUREF Permanent Network: a multi-disciplinary network serving surveyors as well as scientists
GeoInformatics, Vol 7, pp. 32-35.

Bruyninx C., Carpentier G., Roosbeek F.
Today's EPN and its network coordination
Mitteilungen des BKG Band 33, EUREF Publication No. 13, Ed. BKG, Frankfurt am Main, pp. 38-49.

Bruyninx C., Carpentier G., Everaerts M., Lejeune S., Pottiaux E., Roosbeek F., Voet P., Van Huele W., **Warnant R.**
EUREF Related Activities in Belgium
Mitteilungen des BKG Band 33, EUREF Publication No. 13, Ed. BKG, Frankfurt am Main, pp.213-216.

Bruyninx C., Habrich H., Soehne W., Weber G., Stangl G.
The EUREF Permanent Network in 2002
2001-2002 IGS Technical Reports, ed. IGS Central Bureau, Pasadena, US, JPL publication 04-017, pp. 119-123.

Bruyninx C., Stangl G., Weber G.
Network Operations and Data Flow within the EPN
2001-2002 IGS Technical Reports, ed. IGS Central Bureau, Pasadena, US, JPL publication 04-017, pp. 275-278.

Ihde J., Baker T., **Bruyninx C.,** Francis O., Hinderer J., Kenyeres A., Makinen J., Shipman S., Simek J., Wilmes H.
Concept and Status of the ECGN Project
Mitteilungen des BKG Band 33, EUREF Publication No. 13, Ed. BKG, Frankfurt am Main, pp. 57-65.

Simsky A., Sleewagen J.-M., **Bruyninx C.**
POLARX2, A New GPS Receiver For Geodetic Applications
Mitteilungen des BKG Band 33, EUREF Publication No. 13, Ed. BKG, Frankfurt am Main, pp. 325-330.

Beuthe M., Bruyninx C., Carpentier G., Defraigne P., Dehant V., de Viron O., Duron J., Karatekin Ö., Lejeune S., Pottiaux E., Renaud F., Rivoldini A., Roosbeek F., Rosenblatt P., Van Hoolst T., Verhoeven O., Warnant R., Yseboodt M.
Space Geodesy, Report of the Royal Observatory of Belgium
COSPAR report Period 2002-2003, pp. 68-76.

B.1.6.3. Publications in press, submitted

Bruyninx C., Carpentier G., Roosbeek F.
Detection and Handling of EPN station irregularities
Proc. IGS Symposium and Workshop, March 2004, Bern, Switzerland.

Bruyninx C., Carpentier G., Roosbeek F.
EPN Network Coordination
Proc. IGS Symposium and Workshop, March 2004, Bern, Switzerland.

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

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

Bruyninx C., G. Gendt
The International GPS Service
IERS Annual Report 2003, BKG, Frankfurt am Main

Bruyninx C., Roosbeek F.
Utilisation du GPS pour accéder aux systèmes de Référence Globaux, Européens et Nationaux
Techniques de l'ingénieur

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

Ihde J., Baker T., **Bruyninx C.,** Francis O., Amalvict M., Kenyeres A., Makinen J., Shipman S. Wilmes H.
Development of a European Combined Geodetic Network (ECGN)
Proceedings of the IUGG General Assembly in Sapporo, 2003.

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

Ihde J., Baker T., **Bruyninx C**., Francis O., Amalvict M., Kenyeres A., Makinen J., Shipman S., Simek J., Wilmes H.
First Results of the Development of a European Combined Geodetic Network
Proc. GGSM 2004 Porto, September 2004.

Moore A, **Bruyninx C.**, Twilley R.
IGS Network Issues
Proc. IGS Symposium and Workshop, March 2004, Bern, Switzerland.

Stangl G. and **Bruyninx C.**
Recent Monitoring of Crustal Movements in the Eastern Mediterranean: The usage of GPS measurements
Nato Science Series, Kluwer Academic Publishers.

B.1.6.4. Reports, thesis, etc

Bruyninx C.

Hybride GPS+Galileo Plaatsbepaling
Request for 'IWT beurs'

Bruyninx C.
Study of the impact of combined Galileo and modernized GPS measurements for high accuracy positioning and timing applications
Request for 'Action 1 budget'

Bruyninx C.
Guidelines for EPN stations and Operational Centres
Endorsed by EUREF Technical Working Group.

B.1.6.5. Communications (other than those above)

Bruyninx C.
GNSS-based Geodesy and Geodynamics
RTP9.16 Navigation Workshop, December 9, 2004, London, UK.

Kenyeres A., **C. Bruyninx**
Data Quality Monitoring and Noise Analysis at the EUREF Permanent Network
AGU Fall Meeting 2004, December 13-17, 2004, San Francisco, US.

B.1.7. Missions

Research missions (assemblies, symposia, workshops, etc…): 3
Operational meetings (commissions, working groups): 5
Field missions: 10

C. Operational and research project 'Effect of the Earth and Planetary Atmospheres in Space Geodesy'

C.1.1. Objectives

Nowadays, 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 Global Navigation Satellite Systems (GNSS) applications. Therefore, the use of GNSS signals for high precision applications in geodesy and geophysics (reference frames, tectonics …), in particular in the frame of international projects, requires a precise modeling of the atmospheric disturbances. The applications which require precise results in real-time are particularly affected by these effects. The goal of our project is to study and to mitigate the influence of the atmosphere on space geodetic techniques, in particular on 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.

In the frame of the ROB scientific public service mission, the project also 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 GNSS applications through a web interface. In addition, the project also contributes to several national and international collaborations in the field of ionosphere

physics and meteorology by reconstructing information about the atmosphere (water vapor, electron concentration in the ionosphere) using GNSS measurements.

C.1.2. Progress and results

The strategy used in our project is the following: in a first step, different techniques are developed in order to monitor all the atmospheric "parameters" which have an influence on the precision of GNSS applications, in particular, the Total Electron Content (TEC) of the ionosphere and the Integrated Water Vapor content (IWV) of the neutral atmosphere; the Total Electron Content is the integral of the free electron concentration on the receiver-to-satellite path and the Integrated Water Vapor Content is the integral of the water vapor concentration on the receiver-to-satellite path. In a second step, the information obtained about the TEC and the IWV is used to understand and to mitigate the influence of the atmosphere on GNSS applications.

C.1.2.1. Space Weather and ionosphere

In 2004, the following tasks have been performed:

- ***Ionosphere activity monitoring***: the existing ionosphere activity monitoring software has been updated to deal with highly disturbed ionospheric conditions (ionospheric storms, equatorial or polar ionosphere) and to give a better characterization of the ionospheric small-scale (a few kilometers) activity which is the main parameter affecting high precision GNSS applications.
- ***Study of the relationship between the ionospheric activity and the positioning error***based on the measured ionospheric activity and Space Weather conditions, we have developed software allowing to assess in real-time the positioning error affecting the DGPS (Differential GPS) navigation technique (meter precision) and the Real Time Kinematic (RTK) surveying technique (centimeter precision). The RTK software is still under development. In addition, we have implemented procedures which monitor the reliability of the EGNOS system ionospheric correction.
- ***Forecast of the positioning error due to the ionospheric activity***: we have found a correlation between local geomagnetic activity (Dourbes K index) and GNSS positioning error (high precision applications): on the period 2000-2003, geomagnetic storms characterized by $K \geq 8$ were followed by degraded positioning conditions in 100 % of the cases. Consequently, in collaboration with the Geophysical Institute of the Bulgarian Academy of Sciences, we have implemented a model allowing to forecast (in real time) the Dourbes local geomagnetic activity index. This model enables us to forecast the occurrence of degraded positioning conditions; in particular, if the model forecasts $K \geq 8$, a warning is sent to registered users. The software has been successfully tested during the November 7-10, 2004 geomagnetic storm.
- ***Development of a web-based "Space Weather" service for the users of GNSS:*** based on the results of the above-mentioned studies, we have developed a web site which provides real-time information about the atmospheric activity effects on GNSS applications. From July to December 2004, a total of about 2000 different external hosts (outside OMA network) visited our web pages, we received 3000 visits and 25000 pages were downloaded. In addition, we observed a 119 % increase in the number of visits per month between July (398) and December (877) and a 411 % increase of the number of downloaded pages per month (9793 in December).
- ***Development of GPS and Galileo simulation software:*** we have developed a software allowing to simulate the measurements that will be made on the signals which will be emitted by the Galileo system and by the modernized GPS constellation (a third frequency will be added). The software is presently in validation phase.

C.1.2.2. Neutral atmosphere and Water Vapor

The neutral atmosphere introduces a delay in the propagation of GPS signals which is called Zenith Total Delay or ZTD (for propagation at the vertical of the observing station). In an atmosphere in hydrostatic

equilibrium, this delay depends mainly on surface atmospheric pressure and on the Integrated Water Vapour content or IWV.

In 2004, we have implemented data processing procedures allowing the near real-time computation of the tropospheric Zenith Total Delay (ZTD) using a regional network of 70 GNSS stations in Europe. On the one hand, these ZTD's are used for meteorological applications in the frame of the European fifth framework TOUGH project (Targeting the Optimal Use of GPS Humidity): the ROB is an official processing centre of this project since November 2004. On the other hand, we have started to exploit this ZTD data bank for the improvement of the GNSS tropospheric correction. As a first step, the data bank is used to assess the reliability of the EGNOS tropospheric correction.

C.1.3. Perspective for next years

The different activities carried out in 2004 will be continued. In particular, we intend to exploit the dense network of GPS permanent stations recently installed in Belgium (about 70 stations) to characterize small-scale gradients in the atmosphere (i.e. in water vapor and TEC). These gradients play a major role in the modeling of the atmospheric effects on high precision GNSS applications.

C.1.4. Personnel involved

Scientific staff:	René Warnant (Dr., chef de travaux, ***Project Leader***)
	Aline Barré (attaché scientifique, ESA/PRODEX "Space Weather")
	M. Bavier (attaché scientifique, FSP - Action 3 (from 01/01 to 30/09)
	- Supplementary Researchers (from 01/10 on).
	S. Lejeune (attaché scientifique, Ph. D. grant from FRIA/FNRS)
	E. Pottiaux (attaché scientifique, FSP - Action 1)
Technical staff:	Eddy Driegelinck (Expert technique)
Students:	T. Blüge (student ULg 2004-2005, GEOM22)
	J. Pilonetto (student ULg 2004-2005, GEOM22)
	J. Spits (student ULg 2004-2005, DEA in Geomatics)

C.1.5. Partnerships

List of national collaborations:

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

List of international collaborations:

- COST 271: "Effects of the Upper Atmosphere on Terrestrial and Earth-Space Communications"
- COST 296: "Mitigation of Ionospheric Effects in Radio Systems";
- COST 716: "Exploitation of Ground-based GPS for climate and numerical weather prediction application";
- COST 724: "Developing the basis for monitoring, modeling and predicting Space Weather".
- Fifth Framework European Project THOUGH "Targeting the Optimal Use of GPS Humidity in Meteorology"
- Geophysical Institute of the Bulgarian Academy of Sciences (Prof. Ivan Kutiev).

Grants used for the project:

- Ph. D. grants from FNRS/FRIA (2002-2006): "Développement d'un logiciel pour la détection, la correction et la prévision des perturbations induites par l'activité ionosphérique sur le positionnement en temps réel utilisant le Global Positioning System".

- ACTION 1 from Federal Science Policy (2003-2004): "Development of software for the (near) real time processing of the data collected in the permanent ROB GPS network in order to participate in new geophysical applications of GPS in the international networks".
- ESA/PRODEX (April 2003- March 2005): "SIDC Space Weather Pilot Project".
- ACTION 3 from Federal Science Policy (2004-2005): "SIDC Space Weather Pilot Project".
- Supplementary Researchers (October 2004-September 2005): "Atmospheric Effects in Space Geodesy".

Visitors: 1

C.1.6. Publications

C.1.6.1. Publications with peer system

Morel L., Witasse O., **Warnant R.**, Cerisier J.-C., Blelly P.-L., Lilensten J.
Diagnostic of the dayside ionosphere of Mars using the Total Electron Content measurement by the NEIGE/Netlander experiment
Planet. Space Science, 52, pp. 603-611, doi:10.1016/j.pss.2003.12.007.

Jodogne J.-C., Nebdi H., **Warnant R.**
Comparison of the TEC computed using the NeQuick model, the TEC deduced from GPS measurements and the IEC automatically estimated from the Digisonde data
Adv. in Radio Science, 2, pp.269-273.

C.1.6.2. Publications without peer system

Bruyninx C., Carpentier G., Everaerts M., Lejeune S., Pottiaux E., Roosbeek F., Voet P., Van Huele W., **Warnant R.**
EUREF Related Activities in Belgium
Mitteilungen des BKG Band 33, EUREF Publication No. 13, Ed. BKG, Frankfurt am Main, pp.213-216.

C.1.6.3. Publications in press, submitted

Andonov B., Kutiev I., **Warnant R.**, Nebdi H., **Bavier M.**, Rasson J.
Forecasting the Dourbes K index by using solar wind parameters
Proc. of Beacon Satellite Symposium 2004, 18-22 October, Trieste, Italy.

Lejeune S., Warnant R., Barré A., Bavier M.
Near real-time assessment of the ionospheric effect on navigation based on DGPS corrections
Proc. of Beacon Satellite Symposium 2004, 18-22 October, Trieste, Italy.

Bavier M., Warnant R., Barré A., Lejeune S., Pottiaux E.
Near real-time evaluation of the EGNOS ionospheric correction at mid-latitude
Proc. of Beacon Satellite Symposium 2004, 18-22 October, Trieste, Italy.

Pottiaux E., Warnant R.
Sensing the atmospheric Water Vapour and meteorological events using Tropospheric Zenith Total Delays estimated from a regional network of GNSS stations
Proc. of Beacon Satellite Symposium 2004, 18-22 October, Trieste, Italy.

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
Proc. of EUREF 2004 Symposium, 2-4 June, 2004, Bratislava, Slovakia.

C.1.6.4. Reports, thesis, etc

Warnant R., Lejeune S., Bavier M., Pottiaux E.
Assessment of the effect of TEC large-scale gradients on low-precision GPS applications by giving error maps depending on geographic location
Technical Report of Work Package 213, Solar Influences Data Centre Space Weather Pilot Project, ESA contract 16913/03/NL/LvH.

Nebdi H., **Warnant R., Lejeune S.**
Study of the correlation between small-scale TEC variability and geomagnetic activity
Technical Report of Work Package 222, Solar Influences Data Centre Space Weather Pilot Project, ESA contract 16913/03/NL/LvH.

Warnant R., Lejeune S., Nebdi H.
Forecasts of black and red conditions for RTK users
Technical Report of Work Package 223, Solar Influences Data Centre Space Weather Pilot Project, ESA contract 16913/03/NL/LvH.

C.1.6.5. Communications (other than those above)

Warnant R., Bavier M., Lejeune S., Pottiaux E., Andonov B., Kutiev I., **Barré A.**, Nebdi H., Rasson J., **Van der Linden R.**
Development of Space Weather related services for real time GPS applications in the frame of the SIDC Space Weather Pilot Project,
Poster presented at the first Space Weather Week, ESTEC, The Netherlands, 29/11-03/12/2004.

C.1.7. Missions

Assemblies, symposia, workshops: 8
Commissions, working groups: 0
Field missions: 1

D. Research project 'Earth rotation'

D.1.1. Objectives

To understand the Earth rotation variations, to model the effect of the geophysical fluids on Earth rotation, to model the Earth precession and nutations, to understand the associated physics of the Earth interior, to understand the budget of angular momentum of the system composed of the solid Earth, the core, the atmosphere, and the ocean in the frame of long term and short term (diurnal and subdiurnal) variations in Earth rotation.

D.1.2. Progress and results

Continuation of past projects

- Transfer function for atmospheric and oceanic effect on a three-layer Earth (+ Greff-Lefftz (IPGP, F)), paper submitted.
- Routine production of Atmospheric Angular momentum forecast for the geodetic community (+ Lucas (ECMWF)).
- Equatorial atmospheric torque associated with the ENSO cycle (+ Marcus (JPL) and Dickey (JPL)), paper in preparation.
- Geophysical excitation of geocenter motion (+ Dickey, Quinn (JPL), and Marcus), paper in preparation.
- Development of a numerical method of computation of the nutation transfer function (+ Deleersnijder (UCL)).

- Comparison of the different atmospheric angular momentum series and characterization of annual and interannual variabilities. Paper in preparation.
- Realization of a didactic animation for explaining to a broad astronomer audience the concept of non-rotating origin. Paper in preparation.
- Writing of a book on precession, nutation and wobble (VD + Mathews (Univ. Madras))

New projects

- Analysis of the UT1 forecast: comparison of the AAM forecast from the US (NCEP), UK (UKMO), Japan (JMA) and European (ECMWF) models and characterization of the UT1 predictions (+ Bizouard and Gambis (Obs. Paris)).
- Construction of a combined AAM series for an enhanced estimation of the atmospheric effect on Earth rotation and to improve the UT1 prediction. Paper in preparation.
- Production of an atmospherically corrected Length-of-day series to be used in core related studies. Analysis of this series in terms of geomagnetic jerks (+ Holme (University of Liverpool)), paper accepted for publication.
- Interpretation of the celestial motion of the Celestial Intermediate Pole in terms of Earth model parameters (+ Folguera (University of Madrid)).
- Study of the effect of a large meteoritic impact on the Earth rotation.
- Study of the Earth-atmosphere interaction for the diurnal cycle (+ Lott (Ecole Normale Supérieure)), paper in preparation.
- Investigation of the correlation between length-of-day and mean surface temperature at decadal time-scale (+ Marcus and Dickey).
- Study of the variation of the Earth dynamic ellipticity in terms of change in the hydrology and ice cover changes (+ Marcus and Dickey) .
- Estimation of the Earth internal parameters for different Earth models by inversion of the nutation data given in the frequency domain.
- Resolution of the coupled differential equations describing the nutation as a function of time for several time-dependent forcing.

D.1.3. Perspective for next years

- In collaboration with Dickey and Marcus, study of the interaction between large-scale climate oscillation and the Earth rotation.
- In collaboration with Salstein, Gambis, and Bizouard, test of the validity of Earth rotation prediction using the ECMWF atmospheric angular momentum prediction.
- In collaboration with Deleersnijder, effect of the CMB topography on the Nutation transfer function.
- Study of the core motion associated with nutation and libration, using the Wu and Wahr (1997) method.
- Generalization of the nutation transfer function estimation (STS software) to higher order.
- Development of a method for the estimation of the Earth internal parameters of a two layers Earth by inversion of the nutation data given in the time domain. Computation of the accuracy of the estimated parameters (with the Monte Carlo error propagation method) for a perfectly periodic forcing both with this time domain method and with the frequency domain method.
- Forcing of the model by oceans and atmosphere in the diurnal frequency band (Sasao and Wahr 1981) and development of a method for recovering the Earth internal parameters by inversion of the nutation data given in the time domain.
- Generalization of the Earth model to a three layer Earth.

D.1.4. Personnel involved

Scientific staff: Olivier de Viron (Dr., assistant scientifique, ***Project Leader***)

Véronique Dehant (Dr., chef de section)
Laurence Koot (attaché scientifique)
Pascale Defraigne (Dr., chef de travaux)
Tim Van Hoolst (Dr., werkleider)

D.1.5. Partnerships

International collaboration:

- Observatoire de Paris (Capitaine, Bizouard, Feissel, Gambis),
- Atmospheric and Environmental Research, Inc. (Salstein)
- Ecole Normale Supérieure (Lott)
- JPL (Dickey, Marcus, Fukumori)
- IPGP (Greff-Lefftz)
- ECMWF (Lucas)
- University of Madras (Mathews)
- University of Liverpool (Holme)
- University of Madrid (Folguera)

National collaboration:

- Université Catholique de Louvain (Deleersnijder, Goosse)

Grants used for this research

- Action 2 (O. de Viron, 2004/01/01 – 2007/12/31)

Visitors: 5

Students:

- Graduating student: Wanters, UCL

Trainee student: G. Schwarzbaum, ULB

D.1.6. Publications

D.1.6.1.Publications with peer review system

Huang C., **Dehant V.,** Liao X.
The explicit equations of infinitesimal elastic-gravitational motion in the rotating, slightly elliptical fluid outer core of the Earth
Geophys. J. Int., 157(2), pp. 831-837, DOI: 10.1111/j.1365-246X.2004.02238.x.

Marcus S.L., **de Viron O.,** Dickey J.O.
Atmospheric Contributions to Earth Nutation: Geodetic Constraints and Limitations of the Torque Approach
J. Atmos. Sci., 61 (3), 352-365, February 2004.

de Viron O., Salstein D. A., Bizouard C., Fernandez L.
Low frequency excitation of length-of-day and polar motion by the atmosphere
J. Geophys. Res. (Solid Earth), 109, 10.1029/2003JB002817, March 2004.

de Viron O., Boy J.-P., Goosse H.
Geodetics effects of the Ocean response to atmospheric forcing in an Ocean General Circulation Model
J. Geophys. Res. (Solid Earth), 10.1029/2003JB002837, March 2004.

D.1.6.2.Publications without peer review system

Chao B.F., **Dehant V.**, Gross R.S., Plag H.P., Ray R.D., Salstein D.A., van Dam T., **Van Hoolst T.**, Watkins M., Wilson C.R.

The Global Geophysical Fluids Center (GGFC) of the International Earth Rotation Service
in: Proc. IERS Workshop, Munich, Allemagne, November 2002, IERS Technical Notes, 30, Eds. B. Richter, W. Schwegmann, and W. Dick, pp. 115-120.

de Viron O., Dehant V.

Reliability of atmospheric torque for geodesy
in: Proc. IERS Workshop, Munich, Allemagne, November 2002, IERS Technical Notes, 30, Eds. B. Richter, W. Schwegmann, and W. Dick, pp. 125-126.

Van Hoolst T., Dehant V., Kuang W.

Special Bureau for the Core
in: Proc. IERS Workshop, Munich, Allemagne, November 2002, IERS Technical Notes, 30, Eds. B. Richter, W. Schwegmann, and W. Dick, pp. 168-179.

Ponsar S., **Dehant V., Van Hoolst T.**

Electromagnetic core-mantle coupling
in: Proc. IERS Workshop, Munich, Allemagne, November 2002, IERS Technical Notes, 30, Eds. B. Richter, W. Schwegmann, and W. Dick, pp. 216-219.

de Viron O., V. Dehant

La rotation de la Terre
Ciel et Terre, 120, pp. 143-148.

Van Hoolst T.

Naar de kern van de aarde
Karakter 5, 9-11, Academische stichting Leuven.

D.1.6.3.Publications in press, accepted, submitted

Dehant V., Barriot J.-P.

Geophysical nutation and polar motion models as contribution to IGGOS
in: Proc. 2004 IUGG General Assembly, Sapporo, Japan, in press.

Rambaux N., Van Hoolst T., Dehant V., Bois E.

Earth librations due to core-mantle coupling
in: Proc. Journées Systèmes de Référence Spatio-temporels 2004, Paris, France, September 2004, in press.

Capitaine N., Hohenkerk, Andrei A., Calabretta M., **Dehant V.,** Fukushima T., Guinot B., Kaplan G., Klioner S., Kovalevsky J., Kumkova I., Ma C., McCarthy D., Seidelman K., Wallace P.

Report of the IAU Division 1 WG on 'Nomenclature for Fundamental Astronomy' (NFA)
in: Proc. Journées Systèmes de Référence Spatio-temporels 2004, Paris, France, September 2004, in press.

De Viron O., Dehant V., Van Hoolst T.

Poincaré flow in the Earth core
in: Proc. Journées Systèmes de Référence Spatio-temporels 2004, Paris, France, September 2004, in press.

Koot L., de Viron O., Dehant V.

Atmopsheric Angular Momentum of the axis of rotation of the Earth
in: Proc. Journées Systèmes de Référence Spatio-temporels 2004, Paris, France, September 2004, in press.

Dehant V., de Viron O., Greff-Lefftz M.
Atmospheric and oceanic excitation of the rotation of a three-layer Earth
Astron. Astrophys., accepted under modifications.

de Viron O., Koot L., Dehant V.
Polar motion models: The torque approach
in Proc. Chandler Wobble Workshop, April 21-23, 2004, Luxembourg, Cahiers du Centre Europ. de Géodyn. et de Séism., accepted under modifications.

Holme R., **de Viron O**.
Geomagnetic jerks and a high-resolution length-of-day profile for core studies
Geophys. J. Int., Accepted for publication.

Feissel-Vernier M., Ray J., Altamimi Z., **Dehant V., de Viron O.**
VLBI and Earth Rotation: Geophysical and Geodetic Challenges; Earth Rotation Challenges
IVS 2004 GM Proceedings, in press.

Dehant V., de Viron O., Feissel-Vernier M.
Investigation of nutation beyond the IAU2000 model
IVS 2004 GM Proceedings, in press.

Huang C., **Dehant V.**
Effects on nutations of the inner core and outer core differential rotations with respect to the mantle
Phys. Earth planet. Inter., submitted.

D.1.6.4.Reports, thesis, etc

Beuthe M., Bruyninx C., Carpentier G., Defraigne P., Dehant V., de Viron O., Duron J., Karatekin Ö., Lejeune S., Pottiaux E., Renaud F., Rivoldini A., Roosbeek F., Rosenblatt P., Van Hoolst T., Verhoeven O., Warnant R., Yseboodt M.
Space Geodesy, Report of the Royal Observatory of Belgium
COSPAR report Period 2002-2003, pp. 68-76.

Dehant V.
Report of the Commission 3 of the IAG
IAG news (emails).

Dehant V.
Descartes Prize Nutation Proposal
Publication of the European Union (flyer)

Koot L.
Effets atmosphériques sur la rotation de la Terre: étude comparative des séries de moment cinétique atmosphérique
Report for the 'Diplôme d'Etudes Approfondies en Physique' at the Université Catholique de Louvain.

D.1.6.5.Publications of abstracts

de Viron O., Schwarzbaum G., Lott F., **Dehant V**,
Diurnal and semi-diurnal effect of the atmosphere on the Earth rotation and geocenter motion
Eos Trans. AGU, 85(47), Fall meet. Suppl., Abstract G43B-0807.

Gambis D., Bizouard C., **de Viron O.**,
Prediction of Universal Time (UT1) from Atmospheric Angular Momentum
Eos Trans. AGU, 85(47), Fall meet. Suppl., Abstract G43B-0809.

Dickey J.O., Marcus S.L., Quinn K.J., **de Viron O.,** Fukumori I., Dyurgerov M.B.

Recent Changes in the Dynamic Oblateness (J2) of the Earth: Contributions from the Earth's Subsystems and Their Implications
Eos Trans. AGU, 85(47), Fall meet. Suppl., Abstract G23A-05.

Koot L., de Viron O., Dehant V.,
Atmospheric Angular Momentum Time Series: Characterization of Their Internal Noise and Construction of a Combined Series
Eos Trans. AGU, 85(47), Fall meet. Suppl., Abstract G34A-06 Invited.

Bois E., **Rambaux N., Dehant V., Van Hoolst T.,**
Rotation and impact of the Earth's core on Earth's rotation
Eos Trans. AGU, 85(47), Fall meet. Suppl., Abstract G43B-0811.

D.1.6.6. Commmunications (other than those above)

de Viron O.
Earth-Atmosphere interaction at Sub-Diurnal Timescale and its Effects on Earth rotation
Invited paper, FGS workshop 2004 on 'Ringlaser Gyroscope and Earth rotation', Wettzell, Germany.

Bizouard C., **de Viron O.**, Salstein D., Gambis D.
Prediction of Universal time UT1 from atmospheric angular momentum
EGU first General Assembly, Nice, France.

Dickey J. O., Marcus S. L., **de Viron O.,** Fukumori I.
Update on recent Earth oblateness variations – Unraveling climate and post-glacial rebound effects
EGU first General Assembly, Nice, France.

de Viron O., Boy J.-P., Goosse H.
Ocean effect on the Earth rotation: the pressure forcing contribution
Solicited paper, EGU first General Assembly, Nice, France.

Dehant V., Schuh H.IAG Commission 3 on Earth rotation and Geodynamics, a frame for Earth Tides, International Symposium on Earth Tides, Ottawa, Canada, July 2004.

Dehant V., de Viron O.
3D representation of the Non-Rotating Origin
Journées Systèmes de Référence Spatio-temporels 2004, Session 3, oral, Observatoire de Paris, September 20-22, 2004.

D.1.6.7. Outreach and Website

Production of didactic animation about Earth rotation

- The non-rotating origin, in collaboration with N. Capitaine, S. Lambert, VD.
- Nutations of the Earth and VLBI (+J. Van Marcke).

Presentations for the public

- **Dehant V**. , invited conference, Nice, 3 April, 2004.
- **Dehant V.** , invited conference at the 5th Anniversary of the Descartes Prize, Brussels, 12 July, 2004.

D.1.7. Missions

- 9 missions: Assemblies, symposia, workshops
- 3 missions: Join research
- 2 missions AGU Fall meeting planning

E. Research project 'Geodesy and geophysics of other planets'

E.1.1. Objectives

The general objective of the project is to improve our knowledge of the interior structure, atmosphere, and dynamics of rocky planets and natural satellites. We thereto investigate their rotation variations, gravity field, and tidal variations, and the dependence of these quantities on 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. In 2004, we focused mainly on the terrestrial planets Mars and Mercury.

A major objective in 2004 has been the preparation of a radio-science proposal for ESA's upcoming BepiColombo mission to Mercury, called HeRS (Hermean Radio-Science experiment). After review and selection by ESA, the HeRS proposal has been highly evaluated but not selected as the precision of the other radio science project, called MORE, is better. Following ESA recommendations, we are now officially invited to join the MORE team. We are also present in the prestigious BepiColombo mission with a Co-I for the camera SIMBIO-SYS (Spectrometers and Imagers for MPO BepiColombo Integrated Observatory SYStem), and a Co-I of the BELA altimeter for BepiColombo (BepiColombo Laser Altimeter). A major aim of the BepiColombo mission is the measurement of the rotation variations and gravity field of the innermost planet of our solar system in order to determine its interior structure and dynamics. Of particular interest is the determination of the physical state (liquid or solid) and size and composition of Mercury's core, which have large implications on the formation and evolution of terrestrial planets. Data from the three instruments will be needed for that purpose. Many theoretical studies on Mercury's rotation, interior and gravitational field, and also numerical simulations of the mission have been undertaken in 2004.

ESA's Mars Express mission (MEX) has started its science phase in January 2004, and we are involved in its radio-science experiment MaRS (at Co-I level). Our main objective is to determine accurate gravity maps of selected areas on Mars for studying the properties of the crust and lithosphere, and to obtain the time-variable part of the low-degree gravity field for studies of Mars' interior. We thereto develop theoretical models and numerical codes and perform numerical simulations. Due to organizational and technical problems, only a limited number of data have been obtained in 2004, and we expect to have more data in 2005. In our effort to obtain precise gravity data, we are also involved in a European reanalysis of the seasonal variations of the gravity field of Mars from NASA's Mars Global Surveyor (MGS) spacecraft (S/C). These variations are linked with the CO_2 sublimation and condensation cycle of Mars' atmosphere. We study this cycle by using data from the MGS and Odyssey spacecrafts, and investigate possibilities to improve the determination of the time-varying gravity field by means of simulated geodesy experiments.

On the more theoretical side, we continue our studies of the interior of Mars and other planets. We use recent data on material properties at high pressure and temperature, and further develop a synergetic probabilistic approach to derive the interior of Mars by using data from a geodesy experiment, a seismic experiment, and electromagnetic sounding. Applications to other planets are foreseen.

Although the NetLander mission to Mars has been cancelled last year, which included our radio-science project for Mars (NEIGE), we continue the negotiations and preparations for a Mars mission with several landers.

E.1.2. Progress and results

Mars: interior structure

A synergetic probabilistic approach using data from a geodesy experiment, a seismic experiment, and electromagnetic sounding to derive the interior of Mars has been further developed. A first paper on this subject has been finalized. New data on the melting of iron alloys have been used to determine precise core models consisting of a solid inner core and a liquid outer core, in various evolutionary phases. For

different mantle mineralogies and temperature profiles and the measured values for the mass and moment of inertia, estimates of crust thickness, crust mean density and core size have been obtained. From comparisons with other estimates of these parameters, it follows that some combinations of mantle mineralogy and temperature profile are unlikely.

In the framework of the stochastic inversion we have investigated the procedures for the computation of standard errors on estimated values computed from Markov chains simulated by Monte Carlo methods and have studied the influence of the step size of the random walk in the configuration space, induced by the Metropolis sampler, on the convergence rate and on the correlation length of Markov chains.

Mars: crust

A new method that uses spherical wavelets has been developed for estimating the local lithospheric thickness from topography and gravity data of Mars. Our estimates for the local lithospheric and crustal parameters are on the whole in agreement with the estimates of spatio-spectral methods, both for the real and simulated data.
The gravity inversion program LOSGRA (J.-P. Barriot) has been installed at the Royal Observatory of Belgium and documented. Tests have been done with data from the Venusian probe Magellan.

Mars: atmosphere/polar caps

We have performed numerical simulations to improve the determination of the second- and third-degree zonal components of the gravity field J_2 and J_3 from radio-tracking by using the GINS software. The determination of these time-varying coefficients suffers from contamination by higher-degree terms, and leads to errors as large as 50%. We found that radio-tracking to two spacecrafts with different inclinations permits to separate the lowest-degree coefficients from the higher-degree terms, and that only a very small residual error remains in these simulations. Our numerical simulations also showed that the joint use of MGS and MEX tracking data can potentially improve the time-varying gravity field by a factor of two because the eccentricities of the orbits of these S/C are quite different (0.01 and 0.6, respectively).
In collaboration with F. Deleflie (Observatoire de la Cote d'Azur, Nice, France and FUNDP of Namur, Belgium), we have started a study (analytical and numerical) to separate the short and long periods in the S/C motion in order to reach a better resolution of the time-variable J_2 and J_3.
We have calculated the excitation of the ICW by the Martian atmosphere and have shown it to be very small, most likely below the observational detection limit.
The development of a Martian climate model in collaboration with F. Forget (LMD), B. Levrard (Observatoire de Paris) and J. Laskar from (Observatoire de Paris) is in progress. The main objective is to investigate the mutual influence of orbital dynamics, climate, and evolution of polar water ice caps.

Mars: moons

The highly eccentric orbit of MEX allows flybys over Mars' moon Phobos, offering the possibility to estimate its mass more accurately than presently known. We performed numerical simulations of such tracking data and started developing very general software dedicated to the calculation of ephemerides of natural satellites and the reduction and interpretation of the future Phobos flyby data.

Mars: orbit determination

Ancillary software and interfaces needed to process the MaRS Doppler data with GINS have been developed.
Software to estimate the separate contributions of each component of the gravity field to the S/C motion around a planet has been developed. It is based on the linear theory of gravity perturbations developed by W. Kaula.
We have collaborated with S. Pireaux and J.-P. Barriot (from CNES) in the development of new orbit determination software that integrates the S/C motion in a relativistic framework instead of a Newtonian one.

Mercury: geodesy experiment simulations

Simulations of the determination of the libration in longitude of Mercury from angular observables have been performed to investigate the expected precision on the libration amplitude determination from the pattern matching experience.

Numerical simulations of radio-tracking data have been performed to estimate the resolution of the gravity field determination in the framework of the proposal HeRS, submitted to ESA for its Mercury Polar Orbiter (MPO) of the BepiColombo mission. The simulations predict a resolution up to the degree and order 25 (or 300 km at the planetary surface). This will considerably improve the actually badly known gravity field of Mercury. The impact of solar plasma effects on the radio signal has been examined in collaboration with M. Paetzold (Köln University), and a strategy to improve the gravity field determination has been set up.

Mercury: interior structure

A large set of Mercury models with different cores has been constructed, and the sensitivity of the moments of inertia and the tides of Mercury to interior structure parameters have been calculated. It is shown that the observation of the moment of inertia and the tides, in particular the Love number , can strongly constrain the interior of Mercury. Since they have a different dependence on the core properties, the joint use of the Love number and the moments of inertia will improve the determination of the interior structure. The tidal dissipation in Mercury has been calculated and shown to be small. Its influence on the evolution of Mercury and its magnetic field is only marginal.

Mercury: libration

Inertial coupling between mantle and core has been included into the SONYR model (acronym of Spin-Orbit N-bodY Relativistic model), which is a computer code that numerically integrates the spin-orbit N-body problem and identifies the different families of libration of the terrestrial planets, with special emphasis on Mercury's spin-orbit motion. The effect of the core on the rotational motion of Mercury has been calculated for a large number of internal structure models. It has been shown that the libration observations with BepiColombo will be accurately enough to be able to discriminate between internal structure models and to constrain the chemical composition of Mercury.
We initiated an analytical method to study the librations of Mercury, in which the influence of a solid inner core and a liquid outer core are taken into account. This model extends classical Mercury's libration models, which only consider the variations in rotation rate and do not consider coupling between the mantle and the core. It is also more general than the models developed for Earth nutation since those do not include the rotation rate variations. We demonstrated the existence of a librational normal mode associated with the inner core.
A toy model with dissipation was elaborated in order to analyze and identify the impact of dissipative mechanisms on the rotation of Mercury (in collaboration with A. Lemaître and J. Henrard, FUNDP of Namur, Belgium).

Other planets/satellites

A reference paper on the ephemerides of the Galilean satellites has been finalized.
In collaboration with G. Tobie (Lunar and Planetary Laboratory, Arizona, USA), an upper bound has been deduced for the global dissipation of Io.
The SONYR model was extended to the spin-orbit motion of Europa (and the other Galilean satellites: Io, Ganymede and Callisto).
We have included the impact of Jupiter's oblateness on the SONYR model. As a consequence, we obtain consistent amplitude for the Laplace resonance between the orbital motions of Io, Ganymede, and Europa.
The proper frequencies generated by the spin-orbit resonance motion of Europa have been determined in collaboration with J. Henrard (FUNDP).

Preliminary comparison tests between analytical and numerical approaches for the spin-orbit motion of Europa were performed in collaboration with A. Lemaître and J. Henrard (FUNDP).
The effect of Titan's atmosphere on the degree two gravitational Love number k_2 has been calculated. A study of interior structure models for Titan and their visco-elastic response to forcing has been initiated.

E.1.3. Perspective for next years

Mars Express tracking data will be reduced and analyzed in order to obtain new estimates of the time-varying low-degree gravity coefficients. The numerical codes based on Kaula's theory will be extended to include the tides, and will be applied to Mars and Venus. The gravitational acceleration of the MEX S/C along the tracks dedicated to gravity passes will be modeled to constrain the properties of the crust and lithosphere. Theoretical and simulation studies to constrain the interior structure of terrestrial planets by rotational, tidal, and gravitational data will be continued. The synergic approach to probe Mars' interior by joint geodetic, seismic and electromagnetic means will also be further pursued, for example by including additional constraints, and will be applied to other planets and natural satellites. Further attention will be devoted to the seasonal condensation/sublimation cycle of the Martian atmosphere and polar ice caps, and to variations on long time scales related to, e.g., obliquity variations.
In view of the upcoming Mercury missions, the libration of Mercury will be modeled in more detail. In particular, more extended models for the couplings between inner core, outer core, and mantle will be applied and developed. Strategies and numerical tools will be developed to determine the interior of Mercury from libration measurements.

E.1.4. Personnel involved

Scientific staff: T. Van Hoolst (Dr., werkleider, ***Project Leader,*** co-I SIMBIO-SYS)
Michael Beuthe (Dr., assistant scientifique, PRODEX)
Pascale Defraigne (Dr., chef de travaux)
René Dejaiffe (Dr., chef de travaux)
V. Dehant (Dr., chef de section, co-I MaRS, co-I VeRa, Co-I MORE, Co-I BeLA)
Olivier de Viron (Dr., assistant scientifique, FSP-Action 1)
Julien Duron (attaché scientifique, FSP-Action 2)
Özgur Karatekin (Dr., assistant scientifique, PRODEX)
Valéry Lainey (Dr., assistant scientifique, MAGE postdoc since 1/4/04)
Sebastien Le Maistre (attaché scientifique, PRODEX since 15/9/2004)
Gregor Pfyffer (FRIA grant since 1/10/2004)
Nicolas Rambaux (ESA postdoc, since 1/4/2004)
Attilio Rivoldini (attaché scientifique, FSP-Action 2)
Pascal Rosenblatt (Dr., assistant scientifique, PRODEX)
Marie Yseboodt (Dr., assistant scientifique, PRODEX until 1/9/04)
Technical staff: Sophie Raynal (attaché administrative, PRODEX, half-time)
Lydia Van Camp (technisch expert)

E.1.5. Partnerships

International collaboration:

- WG MINT aiming to derive the Mars interior properties from the NEIGE, SEIS, and MagNet data,
- MaRS team (all PIs, Co-Is and Technical team of MaRS)
- VeRa team (all PIs, Co-Is and Technical team of VeRa)
- MAGE (Mars Geophysical European Network) Training Network
- SIMBIO-SYS team (all PIs and Co-Is)
- BELA team (all PIs and Co-Is)
- MORE team (PI, and some Co-Is)

- Collaborations with:
  - Observatoire Midi Pyrénées (Barriot, Vienne, Marty, Balmino)
  - University of Cologne (Paetzold (PI MaRS), Andert)
  - Universität der Bundeswehr München (Haeusler, PI VeRA)
  - University of Nantes (Mocquet, Vacher, Sotin, Choblet),
  - CETP (Menvielle),
  - IPGP (Lognonné, Greff-Lefftz)
  - Observatoire de la Côte d'Azur (Bois, Deleflie)

Grants used for this research:

- PRODEX6 (875000 euro for 2002-2004) and PRODEX7 (170200 euro for 2003-2004)
- Action 2 (Julien Duron 10/2003-9/2007, Attilio Rivoldini 10/2002/-9/2006)
- MAGE (Mars Geophysical European Network), 8/2002-8/2005
- Tournesol project: "Synergie pour la modélisation de l'intérieur des planètes telluriques, basée sur des données séismiques, géodésiques et des sondages électromagnétiques"

Visitors: 7

E.1.6. Publications

E.1.6.1. Publications with peer review system

Rosenblatt P., Marty J.C., Perosanz F., Barriot J.P., **Van Hoolst T., Dehant V.**
Numerical simulations of a Mars geodesy network experiment: Effect of orbiter angular momentum desaturation on Mars' rotation estimation
Planetary and Space Science, 52, pp. 965-975, doi:10.1016/j.pss.2004.07.017.

Duron J., Rosenblatt P., Yseboodt M., Karatekin O., Dehant V., Van Hoolst T., Barriot J.P.
Joint estimation of Martian C_{20} and rotation variations from simultaneous geodetic measurements : Numerical simulations of a Network Science Experiment
Geophys. Res. Lett., 108(E7), doi: 10.1029/2003JL082003.

Dehant V., Lognonné P., Sotin C., and the NetLander team
Network science, NetLander: a European mission to study the planet Mars
Planetary and Space Science, 52(11), pp. 977-985.

Lainey V., Arlot J.E., Vienne A.
New accurate ephemerides for the Galilean satellites of Jupiter: paper II
Astron. Astrophys., 427, pp. 371-376, doi: 10.1051/0004-6361:20041271.

Rambaux N., Bois E.
Theory of Mercury's spin-orbit motion and analysis of its main librations
Astron. Astrophys., 413, pp. 381-393, doi: 10.1051/0004-6361:20031446.

Morel L., Witasse. O, **Warnant R**., Cerisier J-C., Blelly P., and Lilensten J.
Diagnostic of the dayside ionosphere of Mars using the Total Electron Content measurement by the NEIGE/NetLander experiment
Planet. Space Sc., 52, pp. 603-611.

E.1.6.2. Publications without peer review system

Paetzold M., Neubauer F.M., Carone L., Stanzel C., Haeusler B., Remus S., Selle J., Hagl D., Hinson D.P., Simpson R.A., Tyler G.L., Asmar S.W., Axford W.I., Hagfors T., Barriot J.-P., Cerisier J.C., Imamura T., Oyama K.I., Janle P., Kischengast G., **Dehant V.**

MaRS: Mars Express orbiter radio science
Mars Express, The scientific payload, ESA Publication, SP-1240, pp. 141-164.

Vienne J., Barriot J.P., **Rosenblatt P., Yseboodt M., Duron J., Dehant V.**
Numerical simulations of the NEtlander Ionosphere and Geodesy Experiment (NEIGE): landing site position determination from Doppler tracking between an orbiter and landers,
in: Proc. International Workshop on Planetary Probe Atmospheric Entry and Descent Trajectory Analysis and Science, Lisbon, Portugal, 2003, ESA SP-544, pp. 351-355.

Karatekin O., Dehant V., Charbonnier J.-M.
Dynamic Stability of Atmospheric Entry Probes
in: Proc. International Workshop on Planetary Probe Atmospheric Entry and Descent Trajectory Analysis and Science, Lisbon, Portugal, 2003, ed. A. Wilson, ESA SP-544, pp. 101-105.

Duron J., Rosenblatt P., Karatekin O., Yseboodt M., Dehant V., J., Barriot J.P., Vienne J.
Simultaneous estimate of the Martian rotation and the C_{20} gravity coefficient variations in the frame of a network science experiment
Proceedings of the "Société Française d'Astronomie et d'Astrophysique (SF2A)", Scientific highlights 2003 (Bordeaux, France, June 16-20, 2003), Eds: F. Combes, D. Barret, T. Contini and L.Pagani, p. 59-62.

E.1.6.3. Publications of abstracts

Beuthe M., Barriot J.-P., Paetzold M., **Rosenblatt P.**
Local Gravity Fields from Mars Express residual Doppler
Eos Trans. AGU, 85(47), Fall meet. Suppl., Abstract G43A-0801

Rosenblatt P., Paetzold M., **Dehant V.,** Barriot J.P., **Duron J**., Marty J.C., Balmino G.
Improvement of the determination of the seasonal variations of Mars gravity field using both MGS and Mars Express tracking data
Eos Trans. AGU, 85(47), Fall meet. Suppl., Abstract G43A-0800

Andert T., Paetzold M., Lainey V., Rosenblatt P., Dehant V., Barriot J.P.
Mass and internal structure of Phobos from close flybys by Mars-Express
Eos Trans. AGU, 85(47), Fall meet. Suppl., Abstract G43A-0802

Rivoldini A., Verhoeven O., Van Hoolst T., Mocquet A.
Mars conformant planetary interior models
Eos Trans. AGU, 85(47), Fall meet. Suppl., Abstract G43A-0798

Dehant V., de Viron O., Legros H., **Van Hoolst T**., **Rambaux, N.**
Libration dynamics of a three-layer Mercury
Eos Trans. AGU, 85(47), Fall meet. Suppl., Abstract G43A-0791

Rambaux N., Dehant V., Van Hoolst T., Bois E.
Signature of Mercury's core on its librations
Eos Trans. AGU, 85(47), Fall meet. Suppl., Abstract G43A-0792

Van Hoolst T.
Mercury's interior structure and geodesy
Eos Trans. AGU, 85(47), Fall meet. Suppl., Abstract G43A-0790

Karatekin O., Van Hoolst T.
Tidal loading on Titan
Eos Trans. AGU, 85(47), Fall meet. Suppl., Abstract P53A-1449

E.1.6.4. Publications in press, submitted

Verhoeven O., **Rivoldini A.**, Vacher P., Mocquet A., Choblet G., Menvielle M., **Dehant V.**, **Van Hoolst T.**, Sleewaegen J., Barriot J.-P., Lognonné P.
Interior structure of terrestrial planets. I. Modelling Mars' mantle and its electromagnetic, geodetic and seismic properties
J. Geophys. Res., Planets, accepted for publication.

Karatekin O., Duron J., Rosenblatt P., Dehant V., Van Hoolst T., J.P. Barriot,
Martian Time-Variable Gravity and its Determination; Simulated Geodesy Experiments
J. Geophys. Res., Planets, accepted with modifications.

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 Astron., accepted with modifications.

Karatekin O., Van Hoolst T., Tastet J., de Viron O., Dehant V.
The effects of seasonal mass redistribution and interior structure on Length-of-Day variations of Mars
Adv. Space Res., submitted.

Dehant, V., de Viron, O., Karatekin O., Van Hoolst T.
Excitation of Mars polar motion by the seasonal CO_2 cycle
Journal of Geophysical Research (Planets), submitted.

Karatekin O., Duron J., Rosenblatt P., Dehant V.
Martian time-varying gravity field and its detection; Observations and simulations
In: Proc. IAG international symposium - Gravity, Geoid and Space Missions – GGSM2004 (Porto, Portugal, August 30– September 3, 2004), in press.

Pireaux S., Barriot J.P., **Rosenblatt P.**
(SC)RMI: A (s)emi-(c)lassical (r)elativistic (m)otion (i)ntegrator, to model the orbits of space probes around the Earth and other planet,
In: Proc. IAC Space Generation Congress (Vancouver, Canada, October1-8, 2004), in press

Pireaux S., Barriot J.P., **Rosenblatt P.**
Relativistic modeling of the orbit of geodetic satellites equipped with accelerometers
In: Proc. Journées Systèmes de Référence, Paris, France, September 20-22, 2004, in press.

Noyelles B., **Lainey V.,** Vienne A.
Observations and reduction of mutual events in the Solar System
In: Proc. IAU Colloquium No. 196, 2004, in press.

Thuillot W., Arlot J.E., Stavinschi M. Birlan M., **Lainey V.**
Ground-based astrometry at the time of the GAIA space mission
Bucharest, October 2004, in press.

Arlot J.E., **Lainey V.**, 2004,
Observation of the faint satellites of Jupiter and Saturn
In: Proc. The GAIA Symposium, in press.

Lainey V., Tobie G., 2004,
Io's secular acceleration vs. observations accuracy
In: Proc. Semaine de l'Astrophysique Française, SF2A, Paris 2004, in press.

Vienne A., Noyelles B., **Lainey V.**, 2004,
Les phénomènes mutuels dans les systèmes jovien et saturnien
In: Proc. Semaine de l'Astrophysique Française, SF2A, Paris 2004, in press.

E.1.6.5. Reports, thesis, etc

Rambaux N.
Modèle spin-orbite à N-corps: Application à l'étude comparée de la rotation des planètes telluriques
Thèse de Doctorat en Mécanique Céleste de l'Université de Toulouse

Pfyffer G.
Etude de l'intérieur de Mercure à partir de sa libration: Théorie et simulations
UCL, June 2004, Promoter: V. Dehant, Co-Promoter: M. Yseboodt

Courtens G.
Inwendige structuur van aardse planeten met een kern van ijzer en zwavel
K.U.Leuven, June 2004, Promoter: T. Van Hoolst.

Yseboodt M., Rambaux N., Rosenblatt P., Pfyffer G.,
La libration de Mercure obtenue à partir des mesures photographiques par BepiColombo
Internal ORB report

Rambaux N.
The Spin-Orbit Motion of Mercury and Core-Mantle Couplings I
1st progress report for ESA

Rambaux N.
The Spin-Orbit Motion of Mercury and Core-Mantle Couplings II
2d progress report for ESA

Dehant et al.
Report NEIGE for PRODEX
ORB, 19 pp.

Dehant et al.
MAGE report of activity
ORB, 17 pp.

Dehant V., Barriot J.P., Paetzold M., HeRS Co-Is (including **T. Van Hoolst**) and Consultants
Hermean Radio Science Experiment, HeRS, Proposal to the European Space Agency on the Mercury Planetary Orbiter (MPO) of the ESA BepiColombo mission
Science and Technical Plan, 48 pp.

Dehant V., Barriot J.P., Paetzold M., HeRS Co-Is (including **T. Van Hoolst**) and Consultants
Hermean Radio Science Experiment, HeRS, Proposal to the European Space Agency on the Mercury Planetary Orbiter (MPO) of the ESA BepiColombo mission,
Experiment Interface Document – Part B (EID-B), 25 pp.

Dehant V., Barriot J.P., Paetzold M., HeRS Co-Is (including **T. Van Hoolst**) and Consultants
Hermean Radio Science Experiment, HeRS, Proposal to the European Space Agency on the Mercury Planetary Orbiter (MPO) of the ESA BepiColombo mission
Managment Plan, 23 pp.

Dehant V., Barriot J.P., Paetzold M., HeRS Co-Is (including **T. Van Hoolst**) and Consultants
Hermean Radio Science Experiment, HeRS, Proposal to the European Space Agency on the Mercury Planetary Orbiter (MPO) of the ESA BepiColombo mission
Financial Plan, 33 pp.

Dehant V., J.P. Barriot, M. Paetzold, HeRS Co-Is (including **T. Van Hoolst**) and Consultants
Hermean Radio Science Experiment, HeRS, Proposal to the European Space Agency on the Mercury Planetary Orbiter (MPO) of the ESA BepiColombo mission
Clarification document (45 questions), 22 pp.

Dehant V., J.P. Barriot, M. Paetzold, HeRS Co-Is (including **T. Van Hoolst**) and Consultants
Hermean Radio Science Experiment, HeRS, Proposal to the European Space Agency on the Mercury Planetary Orbiter (MPO) of the ESA BepiColombo mission
Correcting the Plasma Contribution using a dual-frequency downlink, 28 pp.

Dehant V., J.P. Barriot, M. Paetzold, HeRS Co-Is (including **T. Van Hoolst**) and Consultants
Hermean Radio Science Experiment, HeRS, Proposal to the European Space Agency on the Mercury Planetary Orbiter (MPO) of the ESA BepiColombo mission
Complement to the clarification meeting, 28 pp.

Lognonné P., T. Spohn, **V. Dehant,** D. Giardini, F. Primdahl, R. Garcia, M. Wieczoreck, C. Sotin, B. Langlais, A. Mocquet, J.-J. Berthelier,
Planetary European Network of Geophysical Observatories (PENGO)
Proposition for the ESA Cosmic vision, 3 pp.

Seiferlin K. , including **V. Dehant**,
Mission to Europa
Proposition for the ESA Cosmic vision.

Lognonné P. ., including **V. Dehant**
Observatoire géoscience planétaire
Proposition for the CNES in the frame of the US mission Mars Science Laboratory, 10 pp.

Spohn T., P. Lognonne, J. Block, S. Ulamec, R. Nadalini, **V. Dehant**, N. Kömle, M. Menvielle, K. Seiferlin, J. Grygorczuk, J. Benkhoff, A. Chicarro, L. Richter, M. Hilchenbach, F. Goesmann,
Proposal For a European Lander Mission Roadmap To Explore Mars
WG report on Planetary Lander Initiative, 16 pp.

E.1.6.6. Communications (other than those that also appear in printed proceedings or printed abstracts)

Barriot J.-P., **Dehant V**.
NEIGE: a geodesy network on Mars, to study the internal structure of the planet, and the balance of volatiles
Hawaii International Conference on System Sciences, HICSS-37, Big Island, Hawaii, January 5-8, 2004.

Yseboodt M., Barriot J.-P., **Dehant V., Rosenblatt P**.
Uncertainties on Mars interior parameters deduced from orientation parameters using different radio-links: analytical simulations
35th Lunar and Planetary Science Conference, League City, Texas, USA, March 15-19, 2004.

Paetzold M., Asmar S., Barriot J.-P., **Dehant V**., Hausler B., Hinson D., Simpson R., Tyler G.
MaRs: Radio Science first results
35th Lunar and Planetary Science Conference, League City, Texas, USA, March 15-19, 2004.

Dehant V. and the ROB team
Summary of the activities at ROB
Mars Express Radio Science Team Meeting, Toulouse, France, April 22-23, 2004.

Beuthe M., Rivoldini A., Dehant V.
Martian lithospheric thickness from spherical wavelet analysis
1st EGU General Assembly, Nice, France, April 25-30, 2004, session PS1.1, abstract EGU04-A-03090.

Duron J., Karatekin O., Rosenblatt P., Dehant V., Van Hoolst T., Barriot J.P.
Estimation of Martian zonal gravity coefficients by combining different simulated geodetic measurements

1st EGU General Assembly, Nice, France, April 25-30, 2004.

Rosenblatt P., Dehant V., Paetzold M., Karatekin O., Barriot J.P., Van Hoolst T.
Numerical simulations of the estimation of Mars' gravity field variations from the MaRS experiment onboard Mars Express
1st EGU General Assembly, Nice, France, April 25-30, 2004.

Rivoldini A., Verhoeven O., Menvielle M., **Dehant V.,** Mocquet A., Vacher P., Choblet G., **Van Hoolst T**.
Planetary interior structure inferred from electromagnetic, geodetic and seismic network science
1st EGU General Assembly, Nice, France, April 25-30, 2004

Verhoeven O., Rivoldini A., Vacher P., Mocquet A., Choblet G., Menvielle M., **Dehant V.**
Geophysical models of the Martian internal structure
1st EGU General Assembly, Nice, France, April 25-30, 2004.

Van Hoolst T.
Mercury's core from tides and libration observations
1st EGU General Assembly, Nice, France, April 25-30, 2004

Yseboodt M., Pfyffer G., Rosenblatt P., Van Hoolst T., and Dehant V.
Simulations of the Mercury libration determination from angular observable
1st EGU General Assembly, Nice, France, April 25-30, 2004.

Paetzold M. and the MaRS team (including **V. Dehant**)
Mars Express Radio Science (MaRS): first results
1st EGU General Assembly, Nice, France, April 25-30, 2004.

Van Hoolst T., Dehant V., Barriot J.P.
Mars nutation and length-of-day determination
Berkeley, USA, 25-26 May, 2004.

Rambaux, N.
Mercury's spin-orbit model and its physical libration
Semaine de l'Astrophysique Française, Journées de la SF2A 2004, Paris, Session Astronomie Fondamentale, 14-18 June, 2004.

Yseboodt M., Rosenblatt P., Deleflie F., Lemoine J.M., **Duron J., Dehant V.**
Seasonal variations of Mars gravity field: Taking advantage of lumped coefficients
35th COSPAR meeting, Paris, France, 18-25 July, 2004.

Pireaux S., Barriot J.P., **Rosenblatt P.**
A semi-classical relativistic motion integrator (SCRMI), to model the orbits of space probes around the Earth and other planets
35th COSPAR meeting, Paris, France, 18-25 July, 2004.

Verhoeven O., Rivoldini A., Vacher P., Mocquet A., Choblet G., Menvielle M., **Dehant V**., **Van Hoolst T.**
Study of the Martian interior structure: expectations from network science
35th COSPAR meeting, Paris, France, 18-25 July, 2004.

Karatekin O., de Viron O., Dehant V., Defraigne P.
Global-scale surface mass redistribution and interior structure of Mars
35th COSPAR meeting, Paris, France, 18-25 July, 2004.

Banerdt B., **Dehant V**., Lognonné P., and Spohn T.
International Scientific Collaboration for a Network Mission to Mars
35th COSPAR meeting, Paris, France, 18-25 July, 2004.

Pireaux S., Barriot J.P., **Rosenblatt P.**

Integrating the motion of geodetic satellites in a coherent relativistic framework

GGSM2004, IAG International Symposium on Gravity, Geoid and Space Missions, Porto, Portugal, August 30 – September 3, 2004.

Karatekin O., Duron J., Rosenblatt P., Dehant V., Barriot J.P.

The effect of higher degree zonal gravity harmonics on Martian time-varying J_2–J_3 and consequences on seasonal CO_2 variation estimates

GGSM2004, IAG International Symposium on Gravity, Geoid and Space Missions, Porto, Portugal, August 30 – September 3, 2004.

Barriot J.-P., **Dehant V., Yseboodt M., Rosenblatt P., Duron J**.

NEIGE: A geodetic network on Mars, to study the cinematic of the planet, its internal structure, and the balance of volatiles

GGSM2004, IAG International Symposium on Gravity, Geoid and Space Missions, Porto, Portugal, August 30 – September 3, 2004.

Rivoldini A., Verhoeven O., Vacher P., Mocquet A., Choblet G., Menvielle M., **Dehant V., Van Hoolst T.**

A joint inversion method of electromagnetic, geodetic and seismological data for the study of planetary interiors

Ecole de Géophysique interne des Houches, 29 August -10 Septembre, 2004

Barriot J.-P., **Dehant V.,** Cerisier J.-C., Folkner W.

NetLander Ionospheric and Geodesic Experiment (NEIGE): goals and strategy

Journées NetLander fin de phase B, CNES, Toulouse, France, September9, 2004.

Lainey V., Rosenblatt P., Dehant V., Barriot J.P., Paetzold M., Andert T.

Phobos close encounters by Mars Express and its internal structure

Réunion des sciences de la Terre 2004, Strasbourg, France, September 20-25, 2004.

Verhoeven O., Rivoldini A., Vacher P., Mocquet A., Choblet G., Menvielle M., **Dehant V., Van Hoolst T**.

Study of the internal structure of Mars

Réunion des sciences de la Terre 2004, Strasbourg, France, Session RSTGV16 on 'Meteorites and planets', September 20-25, 2004.

Dehant V., Barriot J-P., **Van Hoolst T**.,

Geodesy with Mars lander network

Réunion des sciences de la Terre 2004, Strasbourg, France, Session RSTGV16 on 'Meteorites and planets', September 20-25, 2004.

Dehant V.,

Report of the activity within the MAGE network at ROB

MAGE Meeting 2004, Strasbourg, France, September 20-25, 2004.

Dehant V. and the ROB team

Results from simulations concerning MEX and Ephemerides of Phobos

Mars Express Radio Science Team Meeting, Stanford, USA, September 29-30, 2004.

Rambaux N.

Librations de la Terre et de Mercure causées par les couplages noyau-manteau

October 26, 2004, Namur.

Lainey V., Tobie G.

Io's Secular Acceleration vs. Observational Accuracy

American Astronomical Society, DPS meeting, Louisville, KY, USA, November 8-12, 2004.

Lainey V.

Natural satellites dynamics, internal structure and high accurate observations
USNO, Washington, December 8, 2004.

E.1.6.7. Website and outreach

26/05/04 : “La planète Venus.”, by P. Rosenblatt, Liége.
18/11/04: conference organized by the EU MAGE Training Network, Brussels, Belgium.
19/11/04: "L’eau sur Mars", by François Costard, conference organized by the EU MAGE Training Network, Brussels, Belgium.
20/11/04: public exhibition organized by the EU MAGE Training Network, Brussels, Belgium.

E.1.7. Missions

Research missions (assemblies, symposia, workshops, etc): 48
Operational meetings (commissions, working groups): 29
Field missions (observations, station maintenance, etc): 0

DEPARTMENT 1: Reference Systems and Geodynamics

SECTION 2: Seismology

Introduction

Mission and objectives

The objectives of the activities of the section seismology are:

- Monitoring the seismic activity in Belgium and surrounding regions;
- Providing our measured seismic data to the seismological international centers;
- Conducting scientific research on earthquake seismology and the seismic activity in our regions;
- Providing the scientists in other institutions, the public, the administration and the private companies in Belgium with a scientific and technical expertise in earthquake seismology.

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

Monitoring

An efficient answer to this large number of activities implies a coherent distribution of tasks and a modern management. For these reasons, we focused in 2004 a part of our works on the development of a seismological database as a tool to monitor the working state of the seismic stations and their quality control, to facilitate the search of information on the seismic activity in Belgium and northwest Europe and to control the seismic phase measurements realized routinely for local, regional and teleseismic earthquakes recorded by the Belgian seismic network.
There is also a necessity to maintain the quality of the instrumentation in agreement with the world standards. Thus, we finalized the development of a new data acquisition system with a 24 bits A/D converter which works on a Linux PC-based system. It has been tested successfully allowing a systematic change in the seismic stations during the year 2005.

Service

Our monitoring mission has two implications:

- It is necessary to have a prompt answer in case of an earthquake felt in Belgium. The crisis center of the FPS Home Affairs requires preliminary information on the events in a one hour time delay. In 2004, using the ROB own resources, we undertook developing some of the propositions presented in the note submitted to the ROB Scientific Council in 2003 (without any answer). We informed also the President of the PPS Science Policy of the different problems at the ROB related to an earthquake alert system.
- After an earthquake, the FPS Home Affairs needs the ROB expertise to define the calamitous character of the event. Different meetings have been organised to implement new rules for this definition and to clarify the ROB role in post-seismic surveys.

During this year, the pressure of media concerning earthquake activity in the world and the questions from the public and private companies increased also dramatically, imposing to the personnel an important supplementary work in addition to the already too important normal activity caused by the non-replacement of four permanent positions since 1996.

Research

Despite the large amount of operational tasks, the scientists of the section Seismology dedicated an important part of their work to their scientific activities. In addition to the permanent study of the seismicity in Belgium and surrounding regions, we focused in 2004 the scientific activities more specifically on three other different research fields:

- Study of active faults in intraplate regions;
- Evaluation of site effects on strong ground-motions;
- Interpretation of gravity data to infer vertical crustal deformation.

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

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

A. SCIENTIFIC RESEARCH PROJECTS

Compared to other regions classified as stable continental region, the seismic activity in northwest Europe appears as relatively significant. The geological structure is also far better known and understood than in many other intra-plate regions worldwide because geological investigations have been done continuously since the end of the XIXth century, mainly in relationship with mining and quarrying industries. These two independent characteristics explain why this part of Europe is to be considered as an intraplate test area to study the relationship between tectonic deformations studied in the geological record, present-day deformation measured by geodesy and earthquake activity. The importance of studying the seismic activity here is also linked to the increasing risk from earthquakes in these densely populated and highly industrialized areas. The 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) demonstrated the high vulnerability of northwest Europe in the case of small or moderate earthquakes and thus the necessity to better understand the seismic activity and the potential for large earthquakes.
As in all the intra-plate regions worldwide, it is a challenge to provide a scientific basis to evaluate the long-term seismic activity in northwest Europe and its consequences, including the location of future large earthquakes, their magnitude, their average return period and their impact. During the last ten years, we have developed at the ROB a multidisciplinary approach to provide a scientific background for answering these questions. All the scientific projects of the section of seismology are dedicated to the development and application of this multidisciplinary approach.
Thus, the scientific research conducted at the section of seismology can be classified in four different projects: 1. paleoseismology in intra-plate regions; 2. seismicity in Northwest Europe; 3. seismic hazard evaluation and strong ground motion characterization; 4. evaluation of present-day deformation in our regions.

A.1. Research Project « Paleoseismology » [1]

A.1.1. Objectives

The research project Paleoseismology is an ongoing research project of the Section Seismology, initiated in 1995. The aim of this project is to identify seismogenic structures in Belgium and neighboring areas and in other intraplate regions, and to search for evidence of paleoearthquakes in the geologic record. This will extend our knowledge of the seismic cycle of slowly slipping faults in the intracontinental context of our region, and ultimately lead to a better assessment of seismic hazard.

A.1.2. Progress and results

- In 2004, the EC-project “SAFE” (Slow Active Faults in Europe) terminated, and we presented the results of our paleoseismic investigations in the Roer Valley graben (Geleen fault and Rauw fault), and in the epicentral area of the 1692 Verviers earthquake at the final project meeting in Paris.

- We started the development of a Geographical Information System (GIS)-based database of active and capable faults in Belgium and surrounding regions. We devised a table structure to organize the different kinds of geographical information (fault traces, trenches, maps, geophysical profiles, geomorphic anomalies, earthquakes, etc). The data are created as properties linked with different types of geographical objects in the GIS-program MapInfo. We are implementing the database program in an object-oriented program written in Python, which can run alongside MapInfo and interact with it through the Windows COM protocol. The basic structure is functional, and we are now designing a graphical interface to consult and edit the data.

- In the framework of the Action 1 project «Fault activity in NW Europe and its relationship to seismic activity » (MO/33/011), we continued to collect published information on the recent tectonic activity in the area between the Roer Graben and the North Sea. The considered information includes: topographic (DEM), Tertiary geologic, Bouguer gravity anomaly, aero-magnetic, natural radiation, earthquake epicenters, leveling differences and the present-day stress field. To handle in parallel these different data, they were all introduced in the GIS-program MapInfo. We continued to investigate the epicentral area of the 18 September 1692 earthquake in the northern part of the Ardenne searching evidence of active faulting. We began also to investigate the more than 40 km long and 40 m high, linear, NNE-SSW morphological structure between Brussels and Mons. The purpose of the study is to determine if the lineament could correspond to a fault and in this case, if it is an active one.

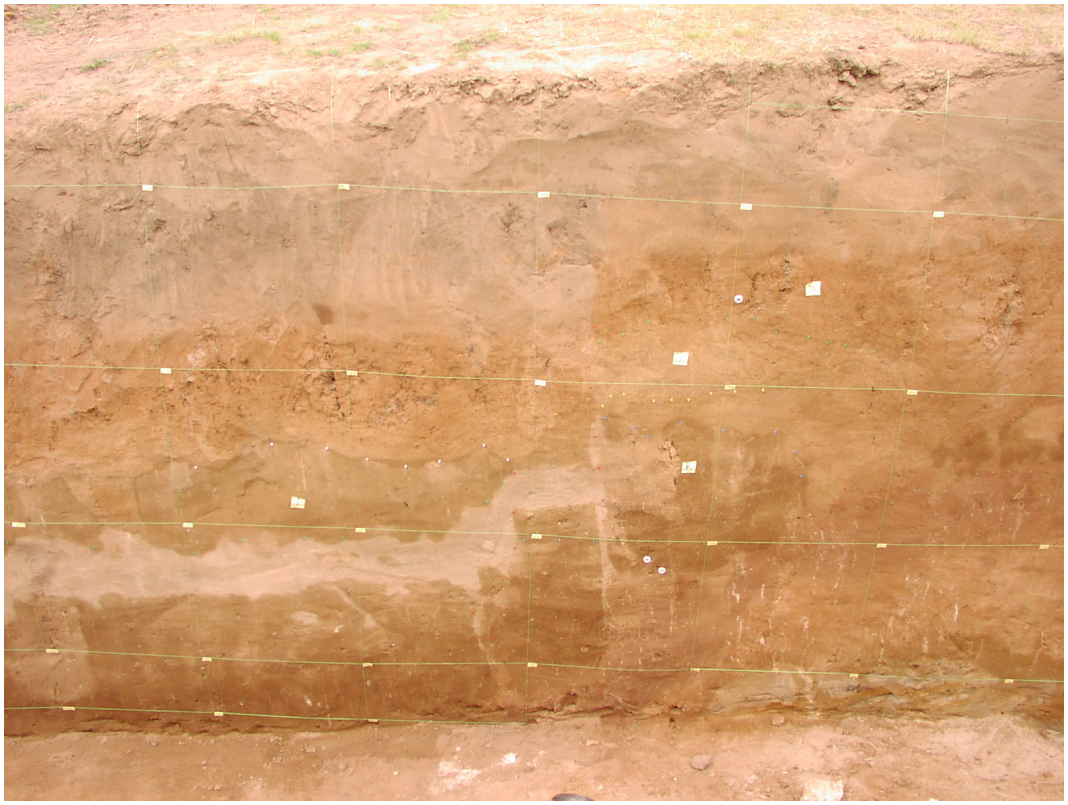


Figure 3: The trench at the Sieberg site (Popovica fault, Bulgaria) – the fault zone.

– In the framework of our bilateral project with the Bulgarian Academy of Sciences, we conducted two field surveys in Bulgaria. During the first survey in April-May we investigated a trench at a site just west of Popovitsa where we identified the Popovitsa fault on a 2-D resistivity profile we collected the year before. The trench (Figure 3, Figure 4) exposed a clear fault zone that consisted of three main fault strands, each corresponding with a separate fault movement or surface-rupturing earthquake. The most recent fault movement along the central fault strand could be correlated with the M 7.1 earthquake of April 18, 1928. The displacements evaluated from the trench for the two older events are comparable to or even slightly larger than that of the 1928 earthquake, suggesting that the older paleo-earthquakes were at least similar in size to the 1928 event. We are waiting for the dating results of this trench to evaluate the displacement rate and recurrence interval for this fault.

– During the second survey in September-October, a second trench was investigated on Chirpan fault, which ruptured in the M 6.9 earthquake of April 14, 1928. This trench was excavated in a small dry valley intersecting the main fault scarp, a few km east of the Cherna Gora trench excavated in 2002. At this site, located in younger river deposits, we expected better stratigraphic resolution and more datable material for the most recent fault movements, which would complete the results of Cherna Gora trench. We are still in the process of making the final trench log, and interpreting the trench observations. We have also prepared a manuscript with the results of the Cherna Gora trench, which is close to being completed, and will be submitted to an international journal.

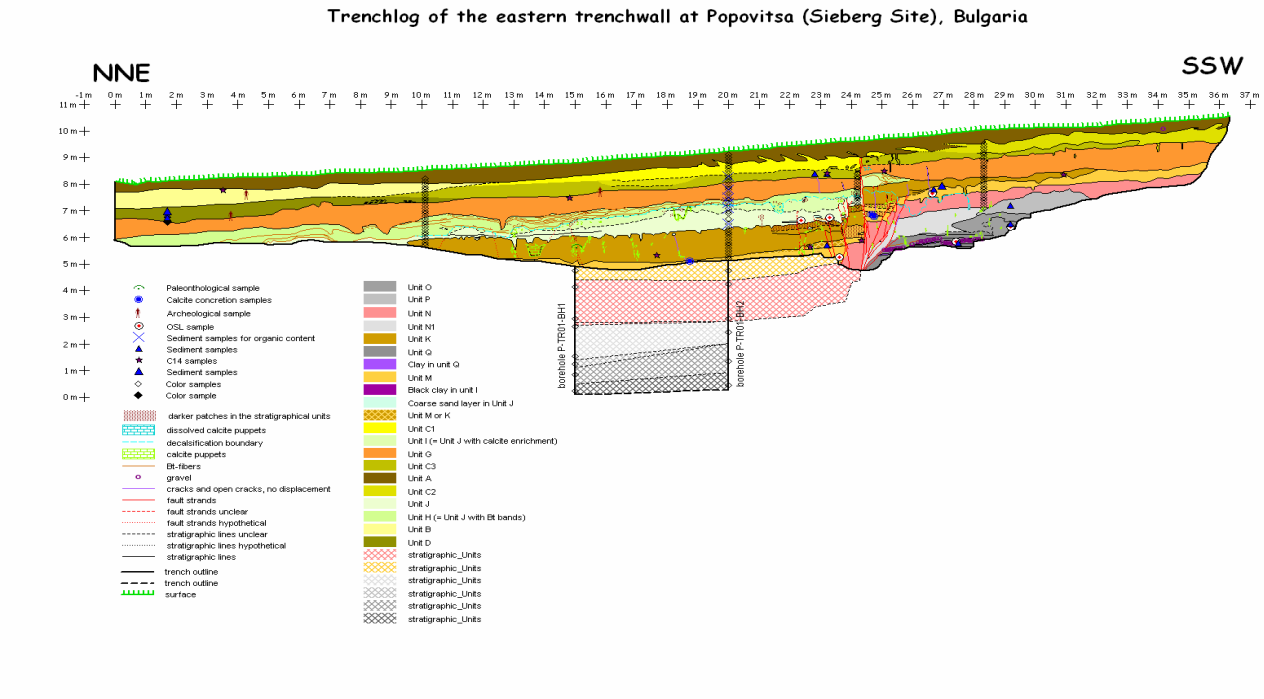


Figure 4: Geological cross-section of the trench excavated on the "Sieberg" site.

– For the third consecutive year, we conducted a 2-D resistivity survey at the archeological site of Sagalassos, SW Turkey, in cooperation with the Structural Geology and Tectonics Group of the University of Leuven. We collected three profiles perpendicular to the suspected trace of a normal fault which is thought to be responsible for the destruction and final abandonment of this ancient town. In addition,

we recorded two long profiles parallel to this structure. These profiles connect all cross-sections recorded during the surveys in 2002 and this year, and will help to get a better understanding of the complex bedrock structure at the site. Because of the large differences in length, elevation and depth of the different profiles, we needed to develop a new technique to visualize the dataset, together with a digital elevation model, in 3-D.

- In cooperation with Philippe Tréfois of the Royal Museum for Central Africa, we conducted investigations using high spectral resolution (project PRODEX casi-atm 2003: "Mapping of active faults and related changes in soils and vegetation with hyperspectral and thermal imagery, Roer graben, Belgium.") to map and quantify the variations in topography, soils and vegetation at the limit of the crustal blocks separated by the Bree fault scarp. We studied the causes of these variations in relation with the fault activity, geometry and deformational mechanism.

A.1.3. Perspective for next years

In 2004, much time has been devoted to field work and presentation of results at various meetings, leaving no time for publication. In the upcoming year, we intend to publish the results obtained during previous years. A first paper concerning our paleoseismic investigations in Bulgaria is nearly ready for submission. When the final luminescence dating become available, the results of the trench excavated on the Geleen fault in Rotem in 2002 will be published as well. We will continue our interpretation of the trenches excavated last year in Bulgaria, and conduct a geomorphic reconnaissance survey in autumn to study the eastern extension of Chirpan fault. The project at the archeological site of Sagalassos in Turkey has come to an end, but last year's results will be presented at an international meeting, and a new publication will be prepared. We hope to continue development of our GIS-based database of active and capable faults into a functional tool, so that we can start entering the available data. Finally, if time permits, we hope to carry out additional fieldwork on active faulting in either the Roer Valley Graben, the area SW of Brussels, or northern France. At the request of the Royal Museum for Middle Africa (Action 1 project MO/37/012), we will participate to the investigation on the Kanda fault, located west of Lake Rukwa, near Sumbawanga, Tanzania.

A.1.4. Personnel involved

Kris Vanneste assumed the scientific direction of the different studies conducted in the framework of this project. He was assisted in the field work and interpretation by Koen Verbeeck (ACTION 1 n° MO/33/011), Toon Petermans and Thierry Camelbeeck who is the scientific responsible for the different supporting research projects.

A.1.5. Partnerships

List of national and international partners

- University of Utrecht – Prof. Kabir Roy Chowdhoury (sub-surface geophysics)
- University of Cologne – Dr; Klaus Hinzen (archeoseismology)
- Institut géologique de l'Académie des sciences de Bulgarie – Dr. Stefan Shanov
- Laboratoire de géodésie de l'Académie des sciences de Bulgarie – Dr. Dimitar Dimitrov (geodesy)
- Université de Liège (department of geography) – Dr. Alain Demoulin (physical geography)
- Faculté Polytechnique de Mons – Prof. Yves Quinif (tectonic deformation in caves)
- Royal Museum for Central Africa – Dr. Philippe Tréfois (teledetection)
- CEREGE (Aix-en-Provence) – Dr. Lionel Siame (cosmonucleides)
- Katholiek Universiteit Leuven, department of geology – Prof Noël Vandenberghe and Manuel Sintubin.

Grants used for this research

- European « *S*low *A*ctive *F*aults in *E*urope » project (EVG1-CT-2000-00023): from February 2000 to April 2004.
- Bilateral cooperation with Bulgaria (BL/33/09): from January 2003 to December 2005.
- Action 1 project «Fault activity in NW Europe and its relationship to seismic activity » (MO/33/011): from January 2003 to December 2006.
- The field studies (trench excavation, hand borings, dating,…) in Bulgaria have been financed by the expertise budget of the section.

Visitors: 3

A.1.6. Missions

Assemblies, symposia, workshops: Kris Vanneste (14 days), Koen Verbeeck (4), Toon Petermans (2 days), Thierry Camelbeeck (5 days)
Field missions: Kris Vanneste (30 days), Toon Petermans (23 days), Koen Verbeeck (29 days), Thierry Camelbeeck (7 days)

A.2. Research project « seismicity in northwest Europe »[2]

A.2.1. Objectives

The main objective of the project is to provide a reliable catalogue of earthquakes for Belgium and the surrounding regions. Depending on the earthquake epoch, the methodologies to recover the data, to analyse them and to evaluate earthquake source parameters are different.
Since 1985, the date of installation of the modern Belgian seismic network, we collected high-quality digital data on the earthquakes that occurred in Belgium and the surrounding regions. The source parameters (location, local magnitude, fault-plane solutions) of these earthquakes are determined routinely by simple procedures but they can be improved by the elaboration of a joint dataset with our colleagues from the Netherlands and Germany.
For the earthquakes that occurred before 1985, the data consist of seismograms on paper. We continue to collect seismograms and seismic bulletins from European seismic stations with the purpose of obtaining a dataset as complete as possible. The evaluation of source parameters with these data requires more elaborate methodologies.
As earthquake instrumental data are available only since ~ 1900, historical seismicity studies are essential to complete instrumental studies. The objectives of this part of the project are twofold: 1. to collect information on the earthquakes that occurred in northwestern Europe before 1900 and implement them in the seismicity database of the ROB, and 2. to analyse these data to better constrain the source parameters (mainly epicenter and magnitude) of these historical earthquakes and to furnish information on their effects in Belgium.

A.2.2. Progress and results

In the framework of our cooperation (Rhine Maas seismology group – RMS) with our Dutch and German colleagues of De Bilt and Cologne, we established a joint dataset for the years 2000, 2001 and 2002. All the waveforms for earthquakes greater than M_L=3.0 will be included in a common CD.
We participated in the international EUROSEISMOS-project (Saving and Studying the Seismograms of the Strongest Euro-Mediterranean Earthquakes). In that frame, we recovered the original seismograms of selected earthquakes from the Uccle station (period 1904-1963) which were sent to Rome in 2003 to be scanned and digitized.
The section seismology was responsible for the EC-project SAFE working package 2 « Seismological aspects of large earthquakes ». The purpose of this research was to implement the information synthesized from historical earthquakes in methods designed to search for active faults in low deformation tectonic areas. We focused on the historical context of the 1692 September 18 earthquake that struck the north of

the Belgian Ardenne, because this event had the strongest known impact in northwest Europe (importance of the destructions, number of deaths, felt area,…). All the results of these investigations were included in our report to the European Commission. In the frame of this project, new historical documents about this 1692 earthquake were gathered and synthesized.
Similarly, new material about the earthquake of 4 April 1640, was collected and a new map of the felt area of this earthquake was drawn.
Finally, the catalogue of the seismic events that occurred in Belgium was improved by further research concerning the local effects of various historical earthquakes.

A.2.3. Perspective for next years

A critical synthesis about the historical seismicity of northwest Europe from the 8th century onward will be continued and published in a scientific popularization journal, by P. Alexandre and Th. Camelbeeck. New data on the earthquakes of 1640, 1692, 1755-1762 and 1828 will be looked for, and the collected information will be inserted in the ROB database of historical seismicity.
In the framework of an IWT-funded research project starting in 2005, Els Sichien will study crustal structures in Belgium using local seismic tomography. For that purpose, a first research will involve relocating all the local events recorded by the Belgian stations since 1985 using the same procedure.

A.2.4. Personnel involved

Pierre Alexandre continued to insert historical data in the earthquake database of the R.O.B. and carried out the assessment of the ancient seismic documents according to the rules of historical criticism. Thierry Camelbeeck assumed the scientific responsibility and Fabienne Collin is also involved in the project.

A.2.5. Partnerships

List of national and international partners

- Jean Vogt from Strasbourg
- Seismic section at the KNMI in De Bilt (The Netherlands)
- Seismic station Bensberg of the Cologne University (Germany)
- Centre Européen de Géodynamique et de Séismologie à Walferdange (GD Luxembourg)
- SGA Storia Geofisica Ambiente s.r.l. – Prof. Graziano Ferrari

Grants used for this research

This research project is only supported by the proper budget of the ROB

A.2.6. Missions

Field missions (number of days): Pierre Alexandre (15), Thierry Camelbeeck (1)

A.3. Research project « Seismic hazard – strong ground motions »[3]

A.3.1. Objectives

One challenge within the community of seismologists is to provide in every region of the world a realistic evaluation of the strong ground motions which will be generated by future large earthquakes. This requires a detailed modeling of the corresponding seismic source, crustal structure and local geological characteristics (site effects). The objective of this project is to develop and apply methodologies for that purpose on the Belgian territory. Two main aspects are considered: 1. to implement existing methods of seismic hazard assessment on the particular case of intraplate regions like Belgium; 2. to develop methodologies to investigate site effects and implement them in a routine procedure.

A.3.2. Progress and results

In 2004, a methodology has been developed to evaluate site effects using complementary field and numerical approaches. Firstly, records of ambient noise are used to calculate the predominant mode of resonance of a site (H/V method) and secondly, numerical calculations for 1D and 2D geological structures are used to confirm the obtained predominant frequency and to evaluate the amplitude of the site response. A straightforward analysis of ambient noise records is now available to cover and map rapidly an area in terms of predominant mode of resonance. The numerical analysis procedure is also running and takes into account the uncertainties on the input parameters.

The analysis of 63 sites in the Mons Basin shows the main influence of the thickness of the Quaternary and Tertiary sediments on the frequency/period of the predominant H/V polarization peak (Figure 5) but also identifies other interfaces. Digitization of the existing geo-technical maps (scale 1/10000) and integration of borings and geological data are almost completed in the Mons Basin. 1D modeling calculations are performed for the investigated sites into the Mons Basin using reference earthquakes. Preliminary results indicate that we can expect large amplification in the central part of the Basin at frequencies below 2 Hz (Figure 6).

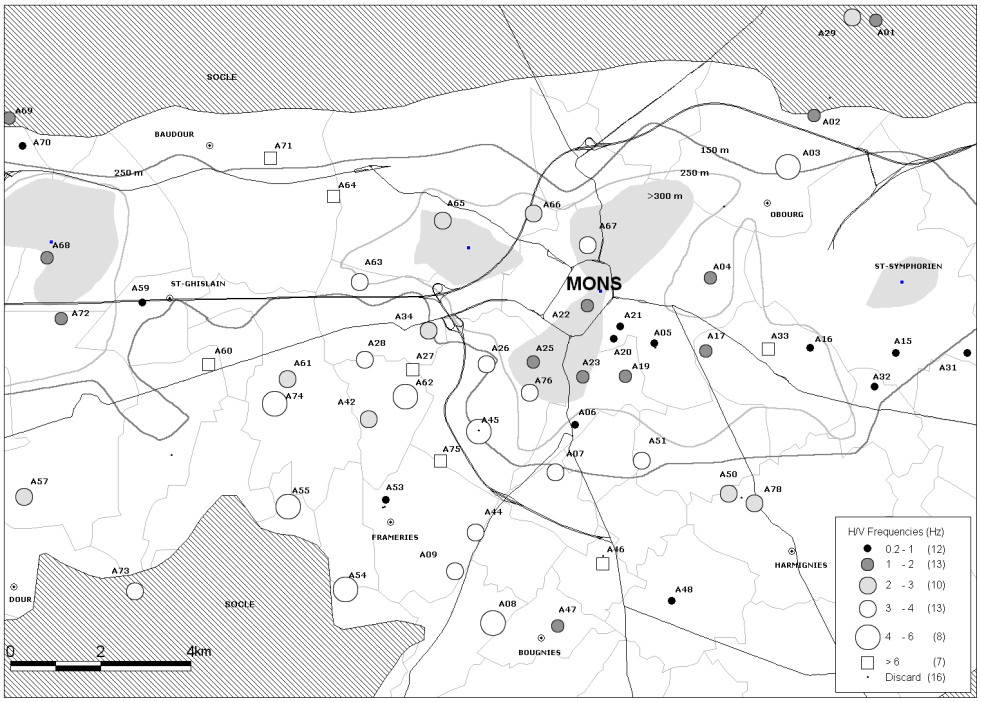


Figure 5: Sites analyzed with seismic ambient noise records. Predominant frequencies of resonance are ranked into 6 classes. Isocurves of the depth of the bedrock (150, 250 and higher than 300m) are indicated

A.3.3. Perspective for next years

The microzonation of the central part of the Mons Basin is planned for the end of 2005. Working meetings have been engaged with geologists of the Faculté Polytechnique de Mons to improve the 3D geological model we develop. A joint study of the surroundings of the old city center with colleagues of the Service Architecture et Urbanisme is also initiated to promote seismic risk analysis in this region.

A partnership with the Geological Survey of Belgium leads to delimit a pilot zone in Brussels in order to engage site effect assessment using the on-going results of the Brussels Urban Geology (BUG) project of our colleagues. First investigations in the pilot zone and the vicinity have been already kicked off.

Collaboration with European colleagues working on 2D modeling is also planned for 2005.

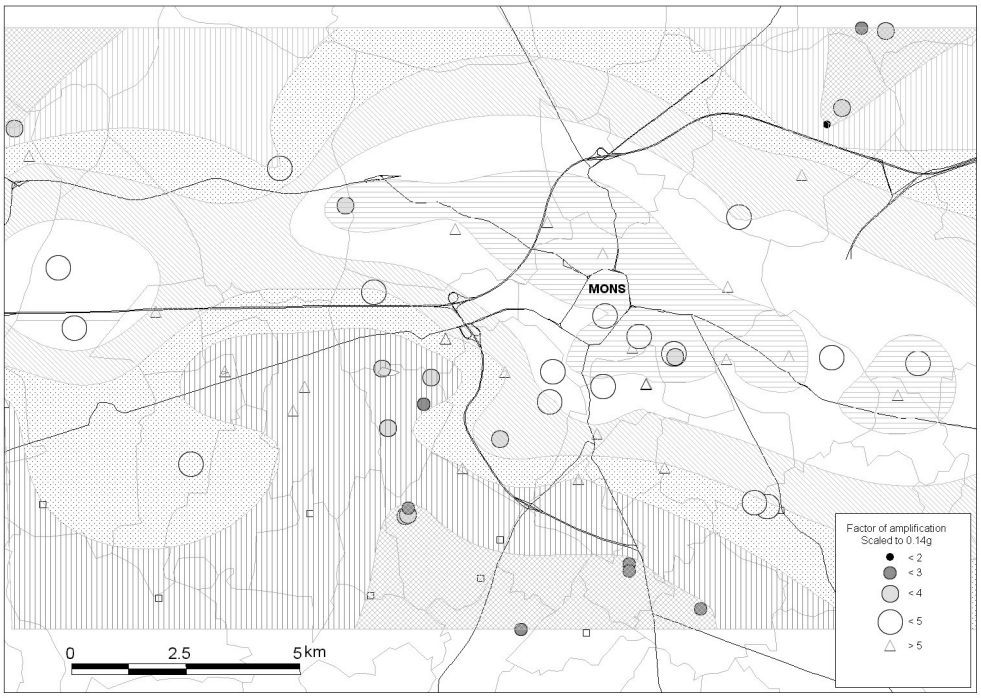


Figure 6: Relative amplification based on the calculated Peak Ground acceleration at the surface and referred to a value of 0.14g for investigated sites. Different zones are mapped in respect to their spectral response (cf Rosset and Camelbeeck, Internal report 2004)

A.3.4. Personnel involved

Philippe Rosset (chercheur supplémentaire) developed the instrumental and numerical tools for the study of site effects. He conducted the field measurements in the Mons Basin. He initiated the collaboration with the Geological Survey of Belgium. Thierry Camelbeeck participated to the interpretation of the results and conducted the discussions to promote a project on seismic risk in the Mons Basin.

A.3.5. Partnerships

List of national and international partners

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

Grants used for this research: projet « Chercheur supplémentaire »

Visitors: 5

A.3.6. Missions

Assemblies, symposia, workshops: Philippe Rosset (14 days), Thierry Camelbeeck (7 days)
Field missions: Philippe Rosset (11 days)

A.4. Research project « Present-day deformation »[4]

A.4.1. Objectives

Although idealized tectonic plates would be purely rigid, intraplate earthquakes reflect the important and poorly understood tectonic processes of intraplate deformation. To quantify the rigidity of North West Europe and how deviations from plate rigidity give rise to intraplate deformation and earthquakes, the section is conducting different experimentation and measurements. These measurements can provide also valuable information on the postglacial rebound (PGR) effects in Belgium and on the present evolution of the mean sea level. The different parts of the project are described in the following.

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

A.4.2. Progress and results

- In collaboration with the Proudman Oceanographic Laboratory, we investigated at the Membach station the structure of the noise affecting SG and AG data series, in order to identify the noise source(s) and to get a better idea of the ability of AG to monitor vertical crustal deformations. Undertaking the AG profile in 1999, the ROB pioneered a new method and at that time, there was no thorough study quantifying the abilities of AG to constrain vertical deformation. Using the Membach experience (Figure 7) and data from the Proudman Oceanographic Laboratory, we evaluated the uncertainties of repeated AG measurements. As accounting for the type of noise (red, white, …) is very important

when estimating gravity variations and their uncertainties, the gravity rate of change and the associated uncertainties as a function of the noise structure were computed. We showed that such repeated AG measurements should allow one to constrain gravity rate of change with an uncertainty of 1 nm/s^2/yr (or 0.5 mm/yr) after 14 or 24 years, depending on the noise model and the number of campaigns per year. Our study proved that long-term measurements using absolute gravimeters are appropriate for monitoring slow vertical tectonic deformation. Due to its absoluteness, an AG could theoretically go back to any undisturbed measured gravity point even after 100 years and make a measurement that is relevant. No relative geodetic techniques could compete with that. These novel results were published in Van Camp et al., 2005 and presented at the EGU, BIPM and AGU meetings. At this time, except for the station influenced by mining at Jülich, there is currently no detectable gravity rate of change larger than 1.3 µGal/yr. This is equivalent to an uplift of 6.5 mm/yr, using a deformational gradient of -0.2 µGal/mm. The Bree-Meeuwen GPS-measurements indicate already that there is no vertical (resp. horizontal) relative movement between the two sites larger than 0.5 mm/yr (resp. 0.3 mm/yr). As a conclusion, from geodetic measurements, it is still not possible to provide information concerning the characteristics of the deformation (seismic, partly or totally aseismic) in the Campine, the Ardenne and the Roer Graben.

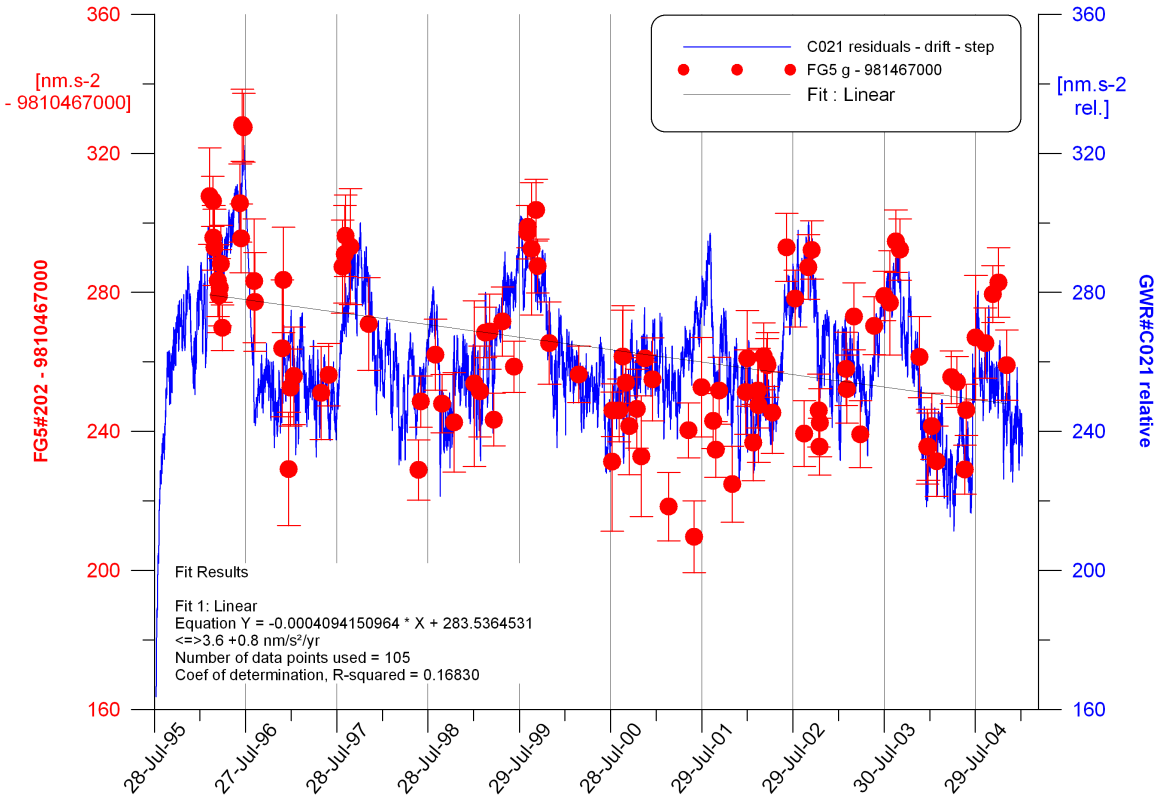


Figure 7: Absolute and superconducting gravity measurements

– To improve absolute and superconducting gravity measurements, we have undertaken studies to understand the influence of hydrology. If we look at the SG and AG time series from the underground Membach Station (Figure 7), two effects can be distinguished: one seasonal-like and a long-term geophysical trend. The seasonal effect is a 50 nm/s² term due to hydrological variations. A closer look also evidences shorter seesaw variations, related to rainfalls. So, hydrogeological prospecting has been undertaken above the Membach station to correct the gravity variations induced by the variable

mass of water stored in the soil above the gravimeters. With M. Vanclooster (UCL/GERU) and A. Dassargues (ULg/KUL), humidity probes were installed 45 m above the station in August 2004. With B. Meurers (U. Vienna) we have undertaken study of rainfall effects on data from superconducting gravimeters at the Membach and Vienna stations.

- Since October 2000, AG measurements have been performed twice a year at the Jülich Research Centre close by two opencast brown coal mines. To prevent the mines from being flooded, continuous water pumping has been carried out for 50 years, causing a subsidence of more than 1 cm/yr. Today, we observe a trend of +24±6 nm/s²/year, which can be interpreted as a subsidence of -12±3 mm/yr, comparable to the repeated levellings and GPS measurements. We are in contact with German colleagues for interpreting the data.

- Together with J. Nicolas, we summarized in 2004 the geodetic measurements (Satellite Laser Ranging SLR, GPS and AG) performed at the CERGA observatory (Grasse, France). The results were presented at the EGU, JLG and AGU meeting and a paper has been submitted. Both SLR and GPS time series show an obvious annual signal with a magnitude of 5 to 6 mm. The AG measurements also exhibit a clear annual signal of 3 µGal peak to peak. The comparison with atmospheric, ocean, and hydrological loading models indicates that the largest part of the signal can be explained by continental scale hydrological loading mainly due to soil moisture. The cumulative effects of the different loading effects can explain the 5-6 mm observed annual variation, as well as the gravity changes.

A.4.3. Perspective for next years

- The profile in the Ardenne and Oostende measurements are long-term projects. We plan to continue the profile twice a year up to 2009 at least; then, after 14-20 years, we should be able to constrain any possible long-term trend with accuracy better than 1 nm/s²/yr. Measurements at the Oostende station will as usual occur on a yearly basis.
- A new GPS station will be installed at the Membach station to better constrain crustal deformation in the Ardenne and to complete AG measurements.
- To understand the influence of hydrology:
  - Together with A. Dassargues (ULg) and M. Vanclooster (UCL) we plan to install piezometric probes in the Vesdre valley and a flux meter in a stream close to the Membach station. Then models of the ground water variation effects will be established.
  - 3-D modeling of these latter as well as meteorological effects on gravity will be performed with B. Meurers (University of Vienna).
  - Jülich: contacts are being undertaken with German colleagues in order to combine the AG time series with other geodetic and hydrological measurements performed at this station.
  - In Rochefort, to study the relationship between the hydrology and extensometric measurements, but also to determine the porosity in the karst (this will provide novel information), we will conduct two months of continuous measurements with the FG5 absolute gravimeter in parallel to water level measurements inside the cave. This project is typically devoted to long-term measurements. Thus, the maintenance of the instruments in the caves will continue in the next years.
- The CERGA project has been terminated in 2004.

A.4.4. Personnel involved

Michel Van Camp is responsible of the AG projects. He realized all the measurements done with the AG, with the help of Aydin Ergen, Marc Hendrickx and Stefaan Castelein
Michel van Ruymbeke developed the extensometers, assumes their maintenance and analyses the collected data in the Rochefort cave. Mr. Eric de Kerkhove, as voluntary technician, manages the data from the instruments in the Rochefort and Ramioul caves. Mrs. R. Howard, also as voluntary technician, par-

ticipated in the analysis of cave data. Thierry Camelbeeck coordinates the project in the caves in relationship with the local authorities.

A.4.5. Partnerships

List of national and international partners

- ULg & KUL: Prof. A. Dassargues
- UCL : Prof. M. Vanclooster
- University of Vienna : Prof. B. Meurers
- Laboratoire de Géodésie et Géomatique, Le Mans : Dr. J. Nicolas
- Géosciences Azur, Sophia Antipolis : Dr J.-M. Nocquet
- EOST, Strasbourg : Dr M. Amalvict, J.-P. Boy, J. Hinderer and P. Gegout
- ECGS/Université de Luxembourg : Prof. O. Francis
- Proudman Oceanographic Laboratory : Dr. S.D.P. Williams, Prof. T. Baker
- Faculté Polytechnique de Mons – Prof. Yves Quinif
- ASBL Grotte de Lorette-Rochefort
- CERAK

Grants used for this research

The Rochefort project has been initiated with the help of two FRFC-NFWO projects but presently, no external financial support is available.

A.4.6. Missions

Assemblies, symposia, workshops
M. Van Camp (18 days)
Commissions, working groups
Michel Van Ruymbeke (1 day), Eric de Kerkhove (1 day), Thierry Camelbeeck (1 day)
Field missions
Michel Van Camp (38 days), Michel Van Ruymbeke (6 days), Eric de Kerkhove (5 days), Aydin Ergen (15 days), Marc De Knijf (3 days), Marc Hendrickx (5 days) and Stefaan Castelein (7 days).

B. OPERATIONAL PROJECTS FOR THE SCIENTIFIC RESEARCH AND EXPERTISE

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

B.1. Operational project « Seismic and accelerometric networks – gravity measurements »[5]

B.1.1. Objectives

The section of seismology installed, maintained and analysed the data from the seismic and accelerometric 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 centers. In particular, the AG participates in numerous intercomparison campaigns

and in calibrating and controlling relative gravimeters. Since 1997 the SG of Membach participates in the Global Geodynamics Project data base.

B.1.2. Progress and results

In 2004, 3 new accelerometers were installed in Mol (2) and Marcinelle (1). The ROB owns now 16 accelerometer stations connected via a Belgacom line, and one without connection. It is now possible to measure ground motion in the epicentral zone of earthquakes with $M_S > 3.5$, such as those of the Hainaut (1965-1967), Liège (1983) and Roermond (1992). The network is checked thoroughly at the ORB once a week (Mol is checked twice a week).
We finalized the development of a new data acquisition for the seismic stations. It includes a 24 bits A/D converter (SYMRES) which works on a Linux PC-based system. It has been tested successfully allowing a systematic change in the seismic stations during the year 2005. In parallel, an experimental procedure has been developed to calibrate the L-4C and L4-3D seismometers. A part of these instruments has already been calibrated.
On request of the ECGS, the FG5-202 was compared to the Luxemburg FG5-216 in June 2004.
The calibration of the METAS (Metrology and Accreditation Switzerland) Scintrex relative gravimeter was checked and adjusted in Membach from 2003-12-17 to 2004-03-22.
Renewing and testing the new data acquisition systems of Membach has been undertaken, in collaboration with the ECGS.

B.1.3. Perspective for next years

The newly developed PC-based acquisition system will be progressively installed in the seismic stations. An experimental procedure to calibrate the LE-3D seismometers, based on the seismic noise, should be developed in 2005. The part of the database dedicated to the seismic stations will help managing the network (see operational project 7).
The accelerometers must be visited on regular basis for maintenance and/or repair. In 2005 two additional ETNA accelerometers should be installed: in Alleur and Sart-Tilman (replacing old-fashioned Sig instruments).
As the absolute determination of the gravity is essential in geophysics and metrology, new intercomparison campaigns will take place in Luxemburg and at the BIPM. In particular, together with the FG5 owned by the BIPM, the ROB FG5-202 will monitor the stability of the gravity at the BIPM during the whole comparison campaign (2005-09-05/2005-09-19).
To ensure the good working of the SG, we will finalize renewing the data acquisition system at the Membach station. In particular a Quanterra 24 bit Q330 data acquisition system will be installed; this will allow us to send easily on-line the data of the SG and of the broadband Güralp seismometer to the IRIS and ORFEUS consortiums. In particular this will make available on-line, for the first time in the world, SG data to the community of seismologists.
The SG transfer function will be checked, as already done in 1996 and 1998. We will also measure the transfer function of the SG located in Walferdange.
Finally we will continue to develop the Tsoft software and provide information to the public.

B.1.4. Personnel involved

Thierry Camelbeeck is responsible for the operational problems linked to the seismic network. Fabienne Collin provided an important help in this task. Michel Van Camp assumes the responsibility for the accelerometric network. Baudouin Bukasa, Stefaan Castelein, Giovanni Rapagnani and Henri Martin provided the technical expertise for the different stations (maintenance, repairing, material modifications, communication software problems,..).
Michel Van Camp is responsible for the FG5 absolute gravimeter. Marc Hendrickx assumed the maintenance and the analysis of the data from the superconducting gravimeter in Membach. He was helped in the maintenance by the ROB Technical service (Marc De Knijf and Aydin Ergen).

B.1.5. Partnerships

List of national and international partners

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

Grants used for this research

Normal budget of the ROB
Giovanni Rapagnani is supported by the Rosetta project

Visitors: 5

B.1.6. Missions

Assemblies, symposia, workshops
Michel Van Camp (1 day), Thierry Camelbeeck (3 days).
Commissions, working groups
Michel Van Camp (3 days), Thierry Camelbeeck (2 days)
Field missions
Michel Van Camp (12 days), Fabienne Collin (11,5 days), Thierry Camelbeeck (1 day), Kris Vanneste (4 days), Baudouin Bukasa (37 days), Stefaan Castelein (19 days), Giovanni Rapagnani (10 days) and Henri Martin (19 days). Marc De Knijf (5 days)

B.2. Operational project « seismological database – web site»[6]

B.2.1. Objectives

In 2002, an impulse has been 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 centers. The database is developed on our intranet, but part of the information should become accessible on our web site in the future. 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.

B.2.2. Progress and results

Different aspects of the database have been developed in 2004:

- We developed the software allowing to insert data, to modify and to consult the instrumental part of the database. When a new acquisition system or seismometer is calibrated, its calibration and characteristics are systematically stored in the database.

- Improvements have been introduced in the daily seismic measurement procedure. They allow to locate automatically the local and regional earthquakes and to simplify the procedures to evaluate the magnitude. We added in the procedure the possibility to evaluate M_S (based on surface waves), which allows easier comparisons with international catalogs than the presently-used m_b (based on P-waves).
- The links between the different parts of the database have been studied and their compatibility established.

B.2.3. Perspective for next years

In 2005, all the information concerning the seismic stations, since the first digital seismic stations in 1985 to now, will be implemented in the database. This will allow us to manage the daily operation of the network by using directly the database. The seismicity database will be also completed. New software to analyze seismic data will be developed under LINUX with the purpose to be used on our GAIA and POSEIDON systems.

B.2.4. Personnel involved

Henri Martin is responsible for the development of the database and the internet site. Frédéric De Vos wrote the software associated to the database. Kris Vanneste and Marc Hendrickx assumed the management of the development of the web-site.

B.2.5. Partnerships

Grants used for this research

Frédéric De Vos has been paid by the expertise budget of the section.

B.2.6. Missions

Nihil

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

C.1. Operational project « Seismic alert »[7]

C.1.1. Objectives

During the discussions with the « Centre de Crise » of the FPS Home Affairs after the Alsdorf (Germany) earthquake of 22 July 2002, it clearly appeared to the « Centre de Crise » that it was important for them to receive as fast as possible (less than 1 hour after the event occurrence) confident information on the earthquakes felt in Belgium. Presently, it is not possible for the ROB to realize this task. The objectives of the project are: 1) to study the technical and organisational procedures necessary to be able to fulfil this urgency mission; 2) to prepare a proposal to inform our Ministry of the technical and financial aspects of the mission; 3) to realize the technical and organisational dispositions of the objective #1 if the financial support is obtained for this new activity. In the negative the ROB could not be able to provide satisfactory information when an earthquake strikes, as it was awkwardly the case during the Liège event in 1983.

C.1.2. Progress and results

In 2004, the project “seismic alert” was presented to the President of the PPS Science Policy to inform him about the reality of the seismic risk in Belgium and the importance of a better seismic alert system. By our own resources, we undertook preliminary actions for the establishment of a future seismic alert.

The ROB technical service demolished the existing infrastructure inside the seismology house ("pavillon de séismologie"). All the instruments, power supply and communication links have been installed in the seismology cave to assume the continuous well-functioning of the Uccle seismic station. A file to repair the seismology house has been introduced at the "Régie des bâtiments".
With the ROB normal budget, the high-availability cluster server necessary for the alert has been acquired. It has been installed in our dwelling up to the restoration of the seismology house.
In spite of our reports, no external supports have been provided yet.

C.1.3. Perspective for next years

They will depend on the reaction coming from the SPP Science Policy and Home Affairs and the "Régie des bâtiments".

C.1.4. Personnel involved

Thierry Camelbeeck managed the different parts of the project. Henri Martin, Marc DeKnijf (Technical service), Michel Van Camp and Kris Vanneste assisted in the technical aspects.

C.1.5. Partnerships

List of national and international partners

The Crisis Center of the SPP Intérieur

Visitors: 1

C.2. Operational project « International seismic data exchange »[8]

C.2.1. Objectives

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

C.2.2. Progress and results

In 2004, we sent on a regular basis our data to the EMSC. Some of the measurement procedures have been improved.

C.2.3. Perspective for next years

Our objectives at the end of 2005 are to be able to organize (1) a daily monitoring of the seismic activity in our regions and in the world; (2) a follow-up of the routine measurement with a delay not exceeding 10-15 days and (3) to provide on-line data to IRIS and ORFEUS from the Membach, Uccle and Rochefort stations.

C.2.4. Personnel involved

Fabienne Collin assumed the responsibility for that operational project. William Vandeputte and Stefaan Castelein realized the daily measurements whereas Fabienne Collin measured the data which are late. The new procedures have been developed by Henri Martin, William Vandeputte and Frédéric De Vos.

C.2.5. Partnerships

List of national and international partners
We send our phase measurements at the EMSC (Euro-mediterranean Seismological Center). We collaborate with the ECGS in Walferdange (GD Luxemburg), KNMI in De Bilt (The Netherlands) and the Bensberg network from the Cologne University (Germany).

C.2.6. Missions

Nihil

C.3. Operational project « Information to the authorities, the public and the media – scientific expertise »[9]

C.3.1. Objectives

This operational project concerns: a) the information given to the authorities, the public and the media by the personnel of the section seismology. It concerns the seismic activity in Belgium and elsewhere in the world, and b) the scientific and technical expertise given by the scientists of the section on the different aspects of earthquake seismology and engineering.
Since 1999, we are actively participating in the activities of the scientific museum at the Rochefort cave in cooperation with the CERAK, the Rochefort administration and the Société Anonyme des Grottes de Han.

C.3.2. Progress and results

In 2004, we answered numerous questions from the public (generally by phone calls or E-mails) concerning earthquakes in Belgium or elsewhere in the world. Some of the questions are more critical because they concern potential damages due to an earthquake in Belgium and could have judicial consequences.

We had more specific queries using our scientific or technical expertise:
- NIRAS-ONDRAF asked us to install two accelerometers in Mol to monitor the underground tunnel devoted to test future nuclear waste disposal and the surface of the nuclear site. We assume twice a week the control of the well-functioning of the instruments.
- We conducted for TRACTEBEL S.A. a preliminary seismic hazard evaluation of the nuclear sites of Tihange and Doel.
- The police magistrate responsible for the inquiry on the Ghislenghien catastrophe required a report on the information about the catastrophe that can be retrieved in the data recorded by the seismic stations of SKQ, BOU and SNF.
- As during the previous years, we continued to inform the “Service des Barrages” of the Ministère de l’Equipement et des Transports each time an earthquake caused a tilt recorded in Membach by the tiltmeters of the superconducting gravimeter.
- The private society PROBABILITAS asked us to provide detailed reports on some aspects of seismic hazard assessment in Belgium (Mmax, focal depth and site effects).
- Different meetings have been organized with the FONDS DES CALAMITES to implement new rules to define the calamitous character of an earthquake and to clarify the ROB role in post-seismic surveys.

The devastating megathrust earthquake of December 26th, 2004 in Indonesia has had an unprecedented mediatic impact. The personnel of the Section had to provide information on a daily basis, to welcome journalists, to go to TV studios and even to present the Membach station. In spite of the holiday, all the demands were fulfilled (even on the morning of New Year). Providing immediate valuable information is highly appreciated and benefits the whole Observatory, even at an international level (via ARTE and TV5, an interview was broadcasted worldwide).

C.3.3. Perspective for next years

The web site of the section seismology will be modified to give a better insight of the different activities of the section, to provide basic knowledge in seismology, on the seismic activity in our regions and elsewhere in the world and on the earthquakes in Belgium. Part of the available information for the public will be a partial access to our database (developed on our intranet).

C.3.4. Personnel involved

All personnel of the section.

C.3.5. Partnerships

none

C.3.6. Missions

Answers to the public and journalists, in particular:

D. Publications

The superscripted numbers refer to the projects.

D.1.1.1.Publications with peer system

[3]Chouinard L., **Rosset P.**, Puente A., Madriz R., Mitchell D., Adams J.
Seismic hazard analysis in Montreal
Proceeding of the 13th World Conference on Earthquake Engineering Vancouver, B.C., Canada, August 1-6, 2004, Paper No. 7010, 12 pp, 2004.

[4]Francis, O., **Van Camp, M.**, van Dam T., Warnant R. and Hendrickx M.
Indication of the uplift of the Ardenne in long term gravity variations in Membach (Belgium)
Geophys. J. Int. 158, pp. 346-352, 2004.

[1]Similox-Tohon, D., **Vanneste K.**, Sintubin M., Muchez P. and Waelkens M.
Two-dimensional resistivity imaging: a tool in archaeoseismology. An example from ancient Sagalassos (Southwest Turkey)
Archaeological Prospection, 11, pp. 1-18, 2004.

[3,5]Teerlynck, H., **Van Rompaey, G.**, Nguyen, F., **Van Camp, M.**, Jongmans, D. and **Camelbeeck, T.**
Use of microtremor measurement for assessing site effects in Northern Belgium – interpretation of the observed intensity during the Ms=5.0 June 11, 1938 earthquake
J. Seismology, 8(1) pp. 41-56, 2004.

D.1.1.2.Publications without peer system

[2,3]**Alexandre, P., Kusman, D. et Camelbeeck, T.**
Le tremblement de terre du 18 septembre 1692 dans le nord de l'Ardenne (Belgique) - Impact sur le patrimoine architectural, Archéosismicité et Vulnérabilité. Environnement, bâti ancien et société
Actes des VIe Rencontres du Groupe APS, 10 pages, 2005.

[3]Benjumea B., Hunter J. H., Al yuncha Z., **Rosset P.**
Earthquake ground motion response studies; a contribution to the Ottawa Valley Landslide Project
Abstract book of the conference Geohazard, Edmonton, Canada, 2004.

[1]**Camelbeeck T., Vanneste K., Petermans T., Alexandre P., Kusman D.** and **Verbeeck K**.
Investigations conducted by the Royal Observatory of Belgium (partner 3)

Extended abstract for the final meeting of the EC-project "SAFE", Paris, 5-6 April 2004, pp. 12-15, 2004.

[1,2]**Petermans T., Camelbeeck T., Alexandre P., Kusman D., Verbeeck K., Vanneste K.** and Demoulin A,
The 1692 September 18 earthquake in the Belgian Ardennes and its geologic context
Extended abstract for the final meeting of the EC-project "SAFE", Paris, 5-6 April, 2004, pp. 50-53, 2004.

[1]Radulov, A., **Camelbeeck T.**, De Martini P., Nikolov G., Pantosti D., **Petermans T.**, Shanov S., and **Vanneste K.**
Trenching evidence for three post-glacial surface-rupturing earthquakes preceding the 1928 rupture on Chirpan fault, Southern Bulgaria
Proc. 32nd International Geological Congress, Firenze, Italy, Vol. 2, 2004, pp. 12-14, 2004.

[3]**Rosset P.**, and **Camelbeeck T.**
Influence of quaternary and tertiary deposits on the seismic response : Applications in the Brabant Massif and the Mons Basin
Abstract book of Journée d'Etudes de Geologica Belgica, Mons, 09 March 2004.

[3]**Rosset P.**, and **Camelbeeck T.**
Site response in the Mons Basin (Hainaut , Belgium)
Abstract book of the XXIX ESC conference Potsdam, Germany, 13-17 September 2004.

[3]**Rosset P.**, and Chouinard L.
Investigation of site response in Montreal (Quebec, Canada)
Abstract book of the XXIX ESC conference Potsdam, Germany, 13-17 September 2004.

[1]Similox-Tohon D., **Vanneste K.**, Sintubin M., and Muchez P.
The use of 2D resistivity imaging in active tectonics: examples from different sites in SW Turkey
Proc. 5th International Symposium on Eastern Mediterranean Geology, Thessaloniki, Greece, 2004, pp. 952-955, 2004.

[4,5,9]**Van Camp, M.**, **Camelbeeck, T.**, and Richard, P.
Le kilogramme, la constante de Planck et le soulèvement de l'Ardenne
Ciel et Terre 120 (1), pp 5-11, janvier-février 2004 (French translation and adaptation of the paper published in Physicalia 25 (3), 2003), 2004.

[5,6,9]**Van Camp, M.**, and **Camelbeeck, T.**
Histoire des stations sismiques belges : de la station « Solvay » au réseau national de surveillance sismique
Ciel et Terre 120 (6), pp 162-176, novembre-décembre 2004.

[1]**Vanneste K.**, and **Camelbeeck T.**
Study of active faults at the Royal Observatory of Belgium
Guidebook to field trip "Tectonics in Belgium", COST Action 625 meeting, Kortrijk/Gent, 8-12 December, 2004, pp. 10-13, 2004.

[1]**Vanneste K.**, Radulov A., **Camelbeeck T.**, De Martini P., Nikolov G., Pantosti D., **Petermans T.** and Shanov S.
Paleoseismological investigation of the fault rupture associated with the M 6.8 earthquake of April 14, 1928 near Chirpan, Southern Bulgaria
Proc. 5th International Symposium on Eastern Mediterranean Geology, Thessaloniki, Greece, 2004, pp. 659-662, 2004.

[1]**Vanneste K., Petermans T., Verbeeck K., Béatse H. and Camelbeeck T.**
A historic surface-rupturing earthquake on the Geleen fault, Belgian Maas Valley

Extended abstract for the final meeting of the EC-project "SAFE", Paris, 5-6 April 2004, pp. 78-81, 2004.

[1]**Vanneste K.**, Siame L., Radulov A., **Verbeeck K.**, Nikolov G., **Petermans T.**, Dimitrov D., Mitev A. and Shanov S.
Late Quaternary interaction of the Omourovo River and Chirpan fault, Southern Bulgaria, from geomorphologic and geophysical data
Proc. 32nd International Geological Congress, Firezne, Italy, Vol. 2, p. 1455, 2004.

[1]**Verbeeck K., Béatse H., Petermans T.,** Wouters L., **Vanneste K., and Camelbeeck T.**
Paleoseismologic investigation of the Rauw Fault at Mol, North Belgium
Extended abstract for the final meeting of the EC-project "SAFE", Paris, 5-6 April, 2004, pp. 82-85, 2004.

D.1.1.3.Publications in press, submitted

[3]Frischknecht C.**, Rosset P.**, and Wagner J.J.
Toward seismic microzonation : 2D modeling and ambient seismic noise measurements
The case of an alpine valley, Earthquake Spectra (accepted).

[4,5]Francis, O., van Dam, T., Amalvict, M., Andrade de Sousa, M., Bilker, M., Billson, R., D'Agostino, G., Desogus, S., Falk, R., Germak, A., Gitlein, O., Jonhson, D., Klopping, F., Kostelecky, J., Luck, B., Mäkinen, J., McLaughlin, D., Nunez, E., Origlia, C., Palinkas, V., Richard, P., Rodriguez, E., Ruess, D., Schmerge, D., Thies, S., Timmen, L., **Van Camp, M.**, van Westrum, D. and Wilmes, H.
Results of the International Comparison of Absolute Gravimeters in Walferdange (Luxembourg) of November 2003
Proceedings of the IAG International Symposium - Gravity, Geoid and Space Missions - GGSM2004, Springer-Verlag, 2005 (accepted).

[4,5]Nicolas J., Nocquet J.-M., **Van Camp M.**, Boy J.P., Hinderer J., Gegout P., Calais E., and Amalvict
M. Seasonal effect on Laser, GPS, and Absolute Gravimetry vertical positioning at the OCA geodetic station, Grasse, France
J. of Geodyn., 2005 (submitted).

[1]Radulov, A., **Vanneste K.**, **Verbeeck K.**, Shanov S., **Camelbeeck T.**, and Yaneva M.
Past seismicity of the fault activated during the April 18, 1928 earthquake according to data from a trench near Popovitsa, Southern Bulgaria
Geology and Mineral Resources, 2005 (in press).

[4,5]**Van Camp, M.,** Williams, S.D.P., and Francis, O.
Uncertainty of absolute gravity measurements
J. Geophys. Res. DOI 2004JB003497, 2005 (in press).

[5,9]**Van Camp, M.** and Vauterin, P.
Tsoft: graphical and interactive software for the analysis of time series and Earth tides
Computers in Geosciences, 2005 (in press).

D.1.1.4.Reports, thesis, etc

[9]**Camelbeeck T.**
Maximum credible earthquake in the different seismic zones of Belgium
Technical Report bought by Probabilitas, 12 pp, 2004.

[9]**Camelbeeck T.**
Focal depth and possible site effects in the different seismic zones of Belgium
Technical Report bought by Probabilitas, 12 pp., 2004.

[5,9]Defraigne, P., and **Van Camp, M.**
Description des activités du Bureau de l'Heure et du service de Gravimétrie
Report for the Belgian Metrology Service, Oct. 2004.

[2]**Petermans T., Camelbeeck T., Alexandre P., Kusman D., Verbeeck K., Vanneste K.,** Demoulin A., Nguyen F. and Jongmans D.
Seismological aspects of large earthquakes, the September 18, 1692 earthquake in the Belgian Ardennes and its geologic context
Contribution of partner#3 to WP 2, SAFE-report, Project No: EVG1-2000-00023, 43 pp., 2004.

[9]**Rosset P.**, and **Camelbeeck T.**
Seismic hazard Analysis of Tihange and Doel Sites, Probabilistic and deterministic approaches
Technical Report bought by Tractebel, 52 pp., 2004.

[3,9]**Rosset P.**, and **Camelbeeck T.**
Evaluation et réduction du risque sismique en Belgique – Effets de site dans le bassin de Mons
Internal Report, 15 pp., 2004.

[5,9]**Van Camp, M.**, and **Camelbeeck, T.**
Report on the installation of two accelerometers at the Belgian Nuclear Research Centre (SCK-CEN)
Mol, 17 pp., Oct 2004.

DEPARTMENT 1: Reference Systems and Geodynamics

SECTION 3: Gravimetry, Earth Tides

A. Gravimetry

A.1. Gravity Field Monitoring in Belgium and abroad

A.1.1. Objectives

- Study of the gravity field in connection with the geoid computation and the determination of the tectonic structures
- Monitoring of long term gravity changes by field gravity observations.

A.1.2. Progress and results

This year the new gravimetric geoid BG03 as been adapted to the leveled GPS points of the Belgian geodetic network.. This network has been established by the NGI and was completed end of 2003. This dense geodetic network consist of 4024 points. This calculation has been done in collaboration with the NGI France. This new surface is now operational and can bee used for all field campaigns to known the orthometric height on each GPS measurement.

A second research axis has been to continue to interpret the gravity and magnetic anomaly to better understand the tectonic settings for specific areas (see publications)

The Belgian Gravity Base Network has been updated and the publication on CD-ROM of its final version (BLGBN03) was finalized.

A third research axis has been to continue the HARD project. In 2003 we started the observations of a high precision gravity network in the East of Belgium in the framework of the HARD project for the GPS monitoring of ground motion in the Ardennes-Eifel massif. We want to determine which gravity changes could be associated with an eventual vertical ground motion in ten GPS sites. We performed two campaigns one in spring and one in autumn to detect seasonal effects associated with the water table variations. The simultaneous use of 2 gravimeters allows to get a precision better than 5µgal (50 nms^{-2}).

A forth research axis has been started in 2004, it consisted in establishing a gravity campaign in the area of Plovdiv in Bulgaria. The aim was to establish a gravity Bouguer map of the area. This will help us in to understand the tectonic setting of the area.

A fifth research axis was also started in 2004 it consist of establishing gravity measurement on the geodynamic polygon of Caldarusani in Romania. The final aim is to understand the geodynamic of this region. To reach this goal two Lacoste-Romberg gravimeters have been lend to the Romanian Academy of Science and a Romanian operator as been instructed to use the electronic output of those gravimeters to improve the accuracy of the measurements.

A.1.3. Perspective for next years

- Continuation of the analysis of the gravity and magnetic anomalies for Belgium and the surrounding countries
- Continuation of the collaboration with different Belgian and foreign universities and institutions. For this purpose we plan to use and develop new software based on the wavelet transform.

- In 2005 we plan to make a last campaign in April for the gravity monitoring of the 10 GPS sites of the HARD project. We also plan to include progressively the permanent GPS sites of the WALCORS network inside the BLGBN network as these sites become fundamental geodetic reference points.
- In 2005 we plan to continue to make gravity investigation in the Plovdiv area in Bulgaria and the collaboration with our Bulgarian colleagues.
- In 2005 we plan to analyze the gravity data obtained in Romania in the 2004 campaign. Nicoleta Cadichianu from the Romanian Academy of Science will visit to the observatory for this purpose.

A.1.4. Personnel involved

Michel Everaerts, Chef de travaux

A.1.5. Partnerships

List of national and international partners

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

Visitors: 1

A.1.6. Publications

A.1.6.1. Publications in press, submitted

Minguely B., Mansy J-L., **Everaerts M**., Mamby G. M., Averbusch, O
Apport de la modèlisation géophysique pour la compréhension de la structure du détroit du Pas-de-Calais données géophysique pour la comprehension de l'évolution géodynamique du Pas de Calais
in press Acad. Sci (Paris)

Duquenne H., Everaerts M**., Lambot P.**
Merging a Gravimetric Model of the Geoid with GPS/Levelling data:an Example in Belgium
IAG series proceedings, in press

A.1.6.2. Communication, Poster

Bornain S., **Everaerts M.**
The Gravimetry of the Grand-Duchy of Luxembourg analyse of the general Bouguer map of this contry and establishement of a local gravity network for a defined area stolzembourg to characterise different tectonic system
EGU Nice (25-30 avril) Poster

Duquenne H., **Everaerts M.**, Lambot P.
Merging a Gravimetric Model of the Geoid with GPS/Levelling data: an Example in Belgium
Gravity, Geoid and space Mission 2004 Porto Portugal 30/08 3/09 Presentation

Everaerts M.
An history of the Belgian Gravity and some processing on the maps
Seminar 17/03 KULeuven

A.1.7. Missions

Assemblies, symposia, workshops: 3
Commissions, working groups: 1

Field missions(days): HARD (24), Bulgaria (13), Romania (5), Lanzarote (4), Metrology (1)

B. Earth Tides

B.1. Global and Regional Earth Tides Studies

B.1.1. Objectives

Interpretation of global earth tides observations with emphasis on the fine spectrum of the tidal waves, the determination of the liquid core resonance effect (NDFW) in the diurnal spectrum and the detection of the effect of the polar motion on gravity. For that purpose 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 finalized several communications for the 15th International Symposium on Earth Tides:
With Dr. Maité Benavent from the Instituto de Astronomia y Geodesia (CSIC-UCM), Madrid we studied the design of local ocean tide model in the nearby of El Hierro (Canary Islands).
With the help of Prof. A. P. Venedikov (Institute of Geophysics, Bulgarian Academy of Sciences) we developed a new computer program VAV04 for the analysis and prediction ocean tides and compared the results of programs ETERNA and VAV. The program VAV04 was applied to the tide gauge data of Ostend;
With the help of Prof. A. P. Venedikov we performed a global analysis of the GGP superconducting gravimeters network for the estimation of the polar motion effect on gravity; In collaboration with M. van Ruymbeke and colleagues from the Institute of Geophysics (UIGGM-SBRAS) of Novosibirsk (Russia) and of the University of La Rochelle we presented the results of tidal gravity observations in eastern Siberia at Khabarovsk/Zabaikalskoe and along the atlantic coast of France at Chizé;
In collaboration with colleagues from the Institute of Geophysics (UIGGM-SBRAS) of Novosibirsk (Russia) we studied tidal water level changes in deep wells located in Eastern Siberia.
We began the modelling of the ocean pole tide effect on gravity with the help of Mr. Chen from the Institute of Geodesy and Geophysics of the Chinese Academy of Sciences.

B.1.3. Perspective for next years

The modelling of the ocean pole tide effects on gravity will be continued for all the GGP stations with more than 5 years of observation. We shall continue to refine the VAV04 program for the analysis of ocean tides.

B.1.4. Publications

B.1.4.1. Publications with peer system

Sun H.P., Xu J.Q., **Ducarme B**., 2003
Experimental earth tidal model in considering nearly diurnal free wobble of the Earth's liquid core
Chinese Science Bulletin, 48, 9, 935-940

Sun H.P., Xu J.Q., **Ducarme B.**, 2004
Detection of the translational oscillations of the Earth's solid inner core based on the international superconducting gravimeter observation
Chinese Science Bulletin, 49, 11, 1165-1176

Xu J.Q., Sun H.P., **Ducarme B.**, 2004

A global experimental model for gravity tides of the Earth
Journal of Geodynamics, 38, 293-306

Ducarme B., Venedikov A.P., Arnoso J., Vieira R., 2004
Determination of the long period tidal waves in the GGP superconducting gravity data
Journal of Geodynamics, 38, 307-324

B.1.4.2. Publications without peer system

Ducarme B., 2004
Where goes tidal research today?
Progress in Geodesy and Geodynamics, Hubei Science and Technology Press, China, 60-70

Ducarme B., Timofeev V. Y., 2004
Activité tectonique et deformation de la croûte dans la région du lac Baïkal
Geodynamics : Outline of a Domain, D. Zugravescu, C. Suteanu editors. Editura Academiei Romane

B.1.4.3. Publications in press, submitted

J. Arnoso, M .Benavent, **B. Ducarme**, F.G. Montesimos
Design of local ocean tide model in the nearby of El Hierro (Canary Islands)
Proc. 15th Int. Symp. on Earth Tides, Ottawa, August 2-6, 2004. Accepted for publication in Journal of Geodynamics

B. Ducarme, A.P. Venedikov, R. Vieira, J. Arnoso
Analysis and prediction of ocean tides by the computer program. VAV
Proc. 15th Int. Symp. on Earth Tides, Ottawa, August 2-6, 2004. Accepted for publication in Journal of Geodynamics

B. Ducarme, A.P. Venedikov, J. Arnoso, R. Vieira
Global analysis of the GGP superconducting gravimeters network for the estimation of the polar motion effect on gravity variations
Proc. 15th Int. Symp. on Earth Tides, Ottawa, August 2-6, 2004. Accepted for publication in Journal of Geodynamics

V.Yu. Timofeev, **M. van Ruymbeke**, G. Woppelmans, **M. Everaerts**, E.A. Zapreeva, P.Yu. Gornov, **B. Ducarme**
Tidal gravity observations in eastern Siberia at Khabarovsk/Zabaikalskoe and along the atlantic coast of France at Chize
Proc. 15th Int. Symp. on Earth Tides, Ottawa, August 2-6, 2004. Accepted for publication in Journal of Geodynamics

B.1.5. Missions

Assemblies, symposia, workshops: 1
Commissions, working groups
Field missions: Roumanie (8), Beijing (17)

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

B.2.1. Objectives

The terms of reference of the International Centre for Earth Tides(ICET) are :
- to collect all available measurements on Earth tides as World Data Centre C;

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

B.2.2. Progress and results

Since 1997 the ROB and ICET are responsible of the "Global Geodynamics Project-Information System and Data Centre" (GGP-ISDC, http://etggp.oma.be/). The data owners can upload themselves the original minute sampled data. The data are carefully preprocessed at ICET using a standard procedure, to correct for tares and spikes. The data are then decimated to one hour and analysed. 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 2004 we edited the CD-ROM's ETGGP#6 and ETGGP#6a with the data from July 2002 till June 2003.
The “Bulletin d’Information des Marées Terrestres”(BIM) n° 139 was printed in 300 copies. Some 275 copies are sent to libraries and individual scientists all over the world. It is devoted to scientific papers concerning tidal research..
ICET made an agreement with Marion Wenzel, wife of late Prof.H.G.Wenzel, who inherited the property rights on the ETERNA tidal analysis and prediction software. ICET is now authorised to distribute freely this software among the scientific community for non commercial purposes. This initiative met a great success as some forty CD-ROMS with ETERNA software were requested from ICET in 2003.
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 the decimal classification introduced by Prof. P.Melchior;
- the table of content of all the BIM issues, and starting from BIM 133 an electronic version of the papers;
- tidal analysis and preprocessing software available from different WEB sites or on request from ICET.

ICET welcomed in 2004, visitors and four guest scientists:
Prof. A.P.Venedikov (Institute of Geophysics, Bulgarian Academy of Sciences, Dr. Maité Benavent from the Instituto de Astronomia y Geodesia (CSIC-UCM), Madrid, Prof H.P. Sun and Mr. X.D. Chen (Institute of Geodesy and Geophysics, Chinese Academy of Sciences, Wuhan).
Prof. Venedikov worked six weeks at ICET (April-May) to finalize its tidal analysis software and extend its application to ocean tides. A first global determination of the amplitude factor of the Pole tide was obtained. As a follow up, three communications, oral or poster, have been presented at the 15th International Symposium on Earth Tides.
Mrs. Benavent stayed during three months (April-May) to work on new ocean tides models around Canarias Islands and made an oral presentation at the ET Symposium.
Mr. Chen stayed two and half month (October-December) to work on the ocean pole tide loading in connexion with pole tide gravity observations.
Prof. Sun stayed three weeks in December to finalize several papers.
Prof. Brimich came one week in October to process strainmeter data.

Prof. de Freitas paid a visit to discuss cooperation on ocean and gravity tides reduction.

B.2.3. Perspective for next years

In 2003 the maintenance of the GGP Data Centre was transferred from the ROB to the GeoForschungsZentrum Potsdam (D), but ICET will still assume the scientific responsibility by evaluating the data and preparing derived products.
ICET will continue to perform the tasks corresponding to its terms of reference, essentially by the diffusion of information and software, the scientific responsibility of the GGP data bank, the data processing, the training of young scientists and the welcome of visiting scientists.
The Centre will continue to develop its WEB site. The content of its data bank will progressively become available on the net.

B.2.4. Personnel involved

B. Ducarme, director ICET
L. Vandercoilden, technician

B.2.5. Partnerships

List of national and international partners:

GeoForschungsZentrum Potsdam (D)

Grants used for this research: IFAG

Visitors (give only the total number): 2 visitors and 4 guest scientists

B.2.6. Publications

B.2.6.1. Publications with peer system

B.2.6.2. Publications without peer system

Ducarme B., Vandercoilden L.
Global Geodynamics Project: CD-ROM ETGGP #6
International Centre for Earth Tides

Ducarme B., Vandercoilden L.
Global Geodynamics Project: CD-ROM ETGGP #6A
International Centre for Earth Tides

C. Geophysical instrumentation

C.1. The EDAS project

C.1.1. Objectives

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

C.1.2. Progress and results

The implementation of the EDAS concept continues to be developed at the ROB, containing a laboratory to develop instruments, a stock room, a library, an area for meetings and seminars and a of workstations. A series of experiments using EDAS are active in the boreholes of the laboratory in Brussels, complemented with climatic and gravimetric monitoring. Of particular interest are areas where there is a risk of tectonic, volcanic or seismic movement. To this end the instruments are installed at different locations:

- At Rochefort and Ramioul Caves (Belgium), a series of systems have been built to monitor and to test the principles involved where a multi-parameter approach is required for the study of geophysical phenomenon. Seismic aspects are considered from the various monitoring tools.
- We apply EDAS for instruments prototyping and geophysical monitoring purposes at the three sites of Lanzarote Geodynamical Laboratories in collaboration with Pr Ricardo Vieira (Instituto de Astronomía y Geodesia (CSIC-UCM) and with Pr Ramon Ortiz (Depart.de Volcanologia, Museo Nacional de Ciencias Naturales, Madrid), with the effective support of Casa de los Volcanes belonging the Cabildo Insular de Lanzarote A data bank with series of more than ten years records is permanently completed. A systematic treatment of all the different signals started in 2004 to prepare edition of DVD with ready to use information needed for experimentation of methods and geophysical modeling.

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

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

The first international “CURSO EDAS” was organized on 10-14May 2004 with the support of the ”Cabildo de Lanzarote” in the meeting rooms of Casa de los Volcanes located in the Jameos del Agua. The EDAS laboratory is so engaged in the preparation of material for this kind of targeted educational course including different aspects of the EDAS concept, in order to train new users in the process and to encourage the use of EDAS in an even wider range of projects. New abroad partners could be included in the management required to reach such goal.

C.1.3. Perspective for next years

The EDAS concept tries to furnish software and hardware including didactic tools adapted to scientists without technical background. The main objective for 2005 consists to complete existing systems to reach a more effective user autonomy. Some high tech projects are under investigation:

- A proposition for a two way sensor adapted to very high precision bolometry in the few hertz frequency band in a solar monitoring satellite (PICARD project)
- The EONS project conducted with Polar foundation requires selecting an optimizing solution to meet some specific needs
- The collaboration with Ramon Ortiz (MNCN, Madrid) could solve difficulties existing in the seismic monitoring of volcanoes by adapting the last prototype of data logger (picoDAS) which will simplify dramatically the field stations
- Application of this new technique is planned in Algeria for the sea level and tsunami monitoring
- Modernization of the EDAS site in the gulf of Corynth, installed during the Gaia CE program by the IPGP (France), is overviewed

- The elevator for gravimeter calibration, designed and built in ROB, is re-activated with some new tools which could improve the sensitivity determination of tidal gravimeter. A better than 0.1% accuracy seems to be achieved. We aim to integrate these calibrations in the Gravilux project (GDL) and move this original device in the Underground Laboratory of Walferdange (GDL), being the best place for this device. In addition the second prototype of gravitational balance could be evaluated in very similar conditions to fix real limits of the instrument developed in the EDAS laboratory by Sebastien Naslin.
- Recent observation recorded in Rochefort cave by stain meters suggest to complete actual series of EDAS probes with new types of sensors under development. (reference to the report form the seismological section)

A priority for all these projects requires that we continue to develop new low-power data logging systems (picoDAS and femtoDAS), which will used in remote sites where long-lived systems are needed.
Parallel and complementary activities dedicated to the maintenance of LaCoste&Romberg gravimeters for foreign laboratories allow collecting a part of the laboratory needed funds.

C.1.4. Personnel involved

M. van Ruymbeke, Chef de travaux, manages the EDAS laboratory.
Mr. Fr. Renders, technician of the ROB
Ir S. Naslin, engineer payed by a private donator
E. de Kerchove, Geneviève Tuts, Rosamund Howard, Ir Jacques Beaujean, François-Xavier Kremer, Robert Du Bois, Pierre Gosselain, volunteers

C.1.5. Partnerships

- Wuhan Institute of Seismology belonging the China Seismological Bureau, to adapt EDAS to some natural disaster problems.
- INCT (Institut National de Cartographie et Télédétection) of Algeria, where our instruments are used to study gravimetry and ocean tides in and around Algiers. A prototype of capacitive tide gauge was installed only few hours before the Tsunami earthquake in 2003 and the records have already excited interest in the geodynamic community. The second EDAS sea level monitoring station is now active and a project to set-up a series of such stations along the 2000km of Algerian coast is prepared in join venture with ROB.
- The EDAS laboratory has partnerships to support projects located in the Soqotra island (Yemen) with Peter De Geest (Dept. of Geology-Vrije Universiteit Brussel), Chize (Centre Littoral de Geophysique-Universite de La Rochelle) and at the Villars caves with Dominique GENTY (Laboratoire d'Hydrologie et de Géochimie Isotopique, Université de Paris-Sud).
- HiCum has been successfully used with Zhuping of the SSB-CEA (China) and Nicoletta Cadicheanu of the Romanian Academy of Sciences, on the base of results described in the paper published with Timoféev after the study of the frequency of earthquakes in and around Lake Baikal (Siberia-Russia). A paper was published on this topic

C.1.6. Publications

C.1.6.1. Publications with peer system

Liu Shaoming & **Michel van Ruymbeke**.
Search for Gravitational Absorption Effect during total solar eclipse of August 11,1999
Journal of Geodesy and Geodynamics (Wuhan 430071,China) Vol.24 N°4 pp 13-18

C.1.6.2. Publications without peer system

Timoféev V.YU., Zapreeva E.A., **van Ruymbeke, M**. &Ardukov D.G.
Tidal modulation of seismic activity Baïkal rift zone and Altay-Sayan region
Revue de l'Académie des Sciences de Novosibirsk, Russia, (in russian) pp 181-189

C.1.6.3. Publications in press, submitted

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)

Timoféev V.YU., **van Ruymbeke, M.,**Woppelmans G., Everaerts, M., Zapreeva E.A., Gornov P.Yu. & **Ducarme, B.**
Tidal Gravity Observations in the Eastern Siberia and along the Atlantic Coast of France
Proceeding of the XVth International Symposium on Earth-Tides, Canada (accepted)

C.1.6.4. Reports, thesis, etc

Vincent Tercelin de Joigny de Pamele (IRA)
Inclinomètre à niveaux hydrostatiques de haute résolution en géophysique

Nicolas Chapuis (ECAM)
Création d'un logiciel intégrant différents outils EDAS à l'ORB

Alexis de Broqueville (ISAT)
Recherche de périodicité en milieu karstique

Pierrick Demaude (INRACI)
Prototype d'acquisition de données adapté au milieu souterrain

Mimoun Yamani (INRACI)
Prototype d'acquisition de données adapté au milieu souterrain

Marta Redman (ISIB)
Stage de dévelopment EDAS

Martin Lefrancq (ISIB)
Stage de dévelopment EDAS

C.1.7. Missions

Filed missions: China (14), Lanzarote (26), Madrid (3), Paris (1), Belgium (2)

C.2. Karstic caves Research

C.2.1. Objectives

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

C.2.2. Progress and results

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

A laboratory dedicated to the monitoring of geophysical parameters has been set up in the karstic network of the Rochefort caves in Belgium. The instruments used for this work include; drop meters, extensometers, atmospheric pressure, temperature and light intensity sensors. All of which have been developed at the ROB. The high precision reached by these systems has allowed us to evaluate the effects induced by environmental, seismic, tectonic variations, or other sources. Special attention has also been paid to the permanent monitoring of water-flow. We have considered both the effects of water on other parameters and the origins of the changing flow rate.
The sensors developed at the ROB have proved to be capable of detecting modulations in air pressure, temperature and strain due to earth tides with a high degree of accuracy. The use of EDAS has provided the means for the continuous monitoring of these parameters and sufficient data for their analysis by the stacking method HiCum. Using HiCum, we have compared the signature for the different parameters on S1, S2 and M2 periods. The experiments have demonstrated that the complement of tools developed at the ROB can be used in the monitoring of tectonic movements in caves. The results have also demonstrated that, whilst caves are a good location for detecting small changes, a multi-parameter approach is essential for the sensible interpretation of results. In addition the air temperature and rock temperature have been found to display different signals, which demonstrate the high dependency of parameters on precise location. This approach has increased our understanding of the mechanisms at work and has enabled us to make a number of tentative hypotheses.
The laboratory has also collaborated at an international level with work in the Villars caves in France and the IRD Brasilia project in Brazil.

C.2.3. Perspective for next years

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

C.2.4. Personnel involved

M. van Ruymbeke, chef de travaux
E. de Kerchove, Mrs R.Howard, volunteers

C.2.5. Partnerships

national
Prof. Verheyden Sophie, De Geest Peter, Dept. of Geology, Vrije Universiteit Brussel
Pr Yves Quinif & Pr Jean Pierre Tsibangu, Faculté Polytechnique de Mons

International
Dr Francis Sondag, IRD Institut de Recherche pour le Développement, Brasilia, BRASIL
Dr Dominique GENTY, Univ. Paris-Sud, Lab.d'Hydrologie et de Géochimie Isotopique, Orsay

C.2.6. Publications

C.2.6.1. Publications with peer system

Tsibangu J-P.,**van Ruymbeke, M**.,Vandycke S.,Quinif Y. & **Camelbeek T.,** 2004
Studying underground motions in the Ramioul's cave-Belgium

Engineering geology for infrastructure planning in Europe, Proceeding Springer Verlag-Liège 2004, EURENCE, pp 614-623

C.2.6.2. Publications without peer system

C.2.6.3. Publications in press, submitted

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 (in press)

C.2.6.4. Reports, thesis, etc

C.2.7. Missions

Missions for the maintenance of Rochefort: 5 days

DEPARTMENT 2: Astrometry

SECTION 4: Astrometry of Solar System bodies

A. Research Theme "Asteroids"

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

A.1. Operational project "RUSTICCA"

A.1.1. Objectives

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

A.1.2. Progress and results

A.1.2.1. Observations in 2004

In 2004 observations have been performed on 62 nights by 7 observers. They include H. Debehogne (5 nights), P. De Cat (26 nights), E. Elst (9 nights), C. Papadaki (2 nights), T. Pauwels (32 nights), P. Vingerhoets (3 nights) and L. Winter (assisted in 1 day-time test). These observations concerned:

- Astrometry of minor planets (56 nights, H. Debehogne, P. De Cat, E. Elst, T. Pauwels).
- Occultations of stars by minor planets (4 events on 4 nights, P. De Cat, C. Papadaki, T. Pauwels en P. Vingerhoets).
- Tests of guiding errors (2 nights and 1 day-time test, P. De Cat, T. Pauwels en L. Winter).

A.1.2.2. Other activities

Apart from the observations themselves, a lot of work was put routinely in the preparation of the observations, the reductions of the observations and the reductions of the observations. We should point out that often one observer would reduce the observations of another observer, thus building a strong team. In 2004, the reductions also included the final reduction of the PHEMU03 observations (see report 2003).
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 written for reduction of the observations, both for astrometric observations and observations of occultations or mutual phenomena of the satellites of Jupiter, the software to keep track of the situation of the RUSTICCA minor planets and the software to prepare the observations.
In a near future a change in format is planned for submission of astrometric observations of minor planets to the Minor Planet Center. A start was made to adapt the reduction software to accept and produce the new format.
We also invested some time in keeping track of the status of the various RUSTICCA minor planets (minor planets with a preliminary designation assigned to an Ukkel observation) and determining which ones

need to be observed. Finally, all raw data has been archived on CD-ROM, along with the necessary documentation to interpret the observations in the future.

A.1.2.3. Summary of the results obtained since 1996

From 1996 to 2004 a total of 12 365 positions of minor planets and 39 positions of comets have been published in the Minor Planet Circulars, thus approaching the number of astrometric positions of minor planets published obtained at Ukkel in the photographic era (1920-1995). The efficiency of our CCD camera is well demonstrated by Figure 8, showing the yearly number of published positions obtained from Ukkel. In blue the positions obtained photographically, in red the positions obtained in the RUSTICCA project. There is a clear explosion of the number of published positions, in spite of the fact that the sky in Ukkel degraded enormously since the 1930s, and that rules for positions to be published are now much more severe than fifty years ago (a lot of the positions published in the 1930s would no longer qualify for publication nowadays). The sole year 2004 produced about ¼ as many positions as the whole period 1920-1995. The efficiency of a CCD camera is even more prominent in one considers that a single photographic plate covered 64 square degrees of sky, while our CCD frame covers only some 0.4 square degrees.

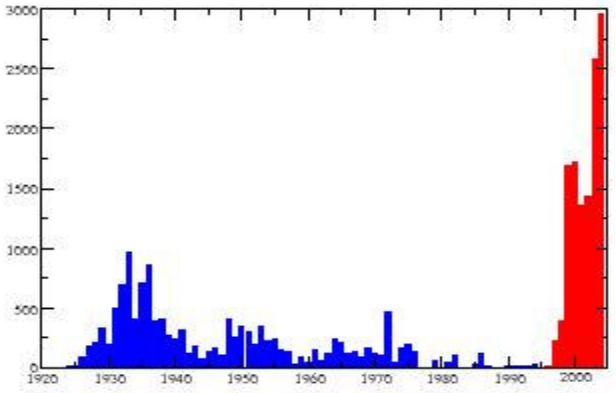


Figure 8: Number of published asteroid positions

203 positions of minor planets (NEO's) 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 238. 106 of these minor planets are currently multiple opposition objects, and 51 have been permanently numbered, with the discovery attributed to a RUSTICCA observation. The discoverers with the number of discovered minor planets are: H. Boffin (1 minor planet), E. Elst (3 minor planets), E. Elst and H. Debehogne (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 (35 minor planets), T. Pauwels and H. Boffin (1 minor planet), T. Pauwels and S. Ipatov (1 minor planet).
A total of 43 light curves of cataclysmic variables could be established, and 19 light curves of mutual phenomena of the Galilean satellites of Jupiter. The archive consists of 249 CD-ROMs with a total of 19 349 images.

A.1.3. Perspective for next years

The further automation of the telescope, and the linkage of the dome to the position of the telescope should be accomplished in the next years. Astrometric observations of minor planets are expected to be useful until 2007-2008. At that moment it is expected that with the limit magnitude of the telescope

(20.5) most of the objects in the reach of the telescope will be well-known or routinely observed elsewhere. By that time new observation programmes will have to be defined.

A.1.4. Personnel involved

H. Debehogne, volunteer, honorary chief of department of the ROB.
P. De Cat, staff member of the ROB.
E. Elst, volunteer, honorary chief of department of the ROB.
C. Papadaki, temporary member of the ROB.
T. Pauwels, chief of section of the ROB.
P. Vingerhoets, volunteer, amateur astronomer.
L. Winter, Hamburg, giving us some advice about the telescope.

A.1.5. Partnerships

List of national and international partners

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

Grants:

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

Visitors: 4.

A.1.6. Publications

A.1.6.1. Publications with peer system

De Cat P., et al.
Positions in the MPEC's: 13 minor planets
MPEC 2004-L55, 2004-R29, 2004-R33

De Cat P., et al.
Positions in the MPEC's: 15 comets
MPEC 2004-E02, 2004-F82

Pauwels T, et al.
Positions in the MPEC's: 22 minor planets
MPEC 2004-F26, 2004-R33, 2004-R42, 2004-R46

Pauwels T, et al.
Positions in the MPEC's: 8 comets
MPEC 2004-E02

Boffin H.
Positions in the MPC's: 11 minor planets
MPS 115 209, 118 434

De Cat P.
Positions in the MPC's: 1044 minor planets
MPS 100 775, 100 803, 100 824, 100 968, 101 105, 101 111, 101 148, 101 226, 101 279, 101 296, 101 297, 101 298, 101 310, 101 325, 101 366, 101 367, 101 424, 101 427, 101 467, 101 474, 101 505, 101 535, 101 604, 101 627, 101 663, 101 695, 101 719, 101 732, 101 859, 101 879, 102 141, 102 203, 102 378, 102 459, 102 492, 102 852, 102 952, 103 070, 103 078, 103 079, 103 095, 103 269, 103 314, 103 355, 103 424, 103 523, 103 589, 103 591, 103 678, 103 683, 103 684, 103 695, 103 773, 104 142, 104 160, 104 208, 104 243, 104 250, 104 361, 104 410, 104 560, 104 678, 104

753, 104 796, 106 058, 106 061, 106 086, 106 124, 106 303, 106 305, 106 367, 106 458, 106 548, 106 589, 107 266, 107 313, 107 438, 107 457, 107 813, 108 003, 108 004, 108 019, 108 198, 108 219, 108 295, 108 332, 108 391, 108 415, 108 672, 108 720, 108 808, 109 077, 109 078, 109 393, 109 806, 109 818, 110 034, 112 507, 112 564, 112 586, 112 611, 112 615, 112 634, 112 776, 112 782, 112 790, 112 801, 112 809, 112 987, 113 038, 113 075, 113 202, 113 267, 113 323, 113 586, 114 019, 121 526, 121 548, 121 580, 121 595, 121 604, 121 635, 121 672, 121 712, 121 724, 121 738, 121 739, 121 743, 121 745, 121 793, 121 844, 121 850, 121 878, 121 879, 121 994, 122 006, 122 082, 122 091, 122 151, 122 153, 122 219, 122 329, 122 331, 122 443, 122 447, 122 455, 122 459, 122 466, 122 580, 122 602, 122 603, 122 705, 122 751, 122 832, 122 869, 122 963, 122 973, 122 976, 122 992, 123 003, 123 009, 123 015, 123 112, 123 143, 123 200, 123 222, 123 224

De Cat P.

Positions in the MPC's: 15 comets

MPC 51 353, 51 355, 51 356

De Cat P., Pauwels T,

Positions in the MPC's: 39 minor planets

MPS 100 125, 100 387, 100 428, 100 454, 100 553, 100 563

Elst E.

Positions in the MPC's: 326 minor planets

MPS 97 768, 112 493, 112 502, 112 507, 112 511, 112 516, 112 535, 112 538, 112 555, 112 565, 112 576, 112 612, 112 629, 112 651, 112 654, 112 661, 112 684, 112 687, 112 689, 112 717, 112 752, 112 765, 112 813, 112 818, 112 832, 112 835, 112 860, 112 892, 112 896, 112 897, 112 902, 112 917, 112 921, 113 035, 113 054, 113 062, 113 075, 113 083, 113 091, 113 118, 113 130, 113 141, 113 169, 113 186, 113 202, 113 241, 113 267, 113 314, 113 328, 113 535, 113 642, 113 734, 113 748, 113 794, 113 972, 114 478, 114 561, 114 564, 114 565, 114 593, 114 662, 115 827, 115 860, 116 574, 116 575, 117 743, 118 598, 119 321

Elst E., Debehogne H.

Positions in the MPC's: 340 minor planets

MPS 97 876, 100 014, 100 067, 100 124, 100 204, 100 233, 100 238, 100 242, 100 244, 100 270, 100 279, 100 286, 100 387, 100 452, 100 453, 100 493, 100 556, 100 560, 100 563, 102 954, 102 960, 102 999, 103 081, 103 180, 103 183, 103 197, 103 323, 103 405, 103 407, 103 684, 103 710, 103 755, 104 016, 104 125, 104 153, 104 228, 104 357, 104 358, 104 480, 104 506, 104 512, 104 513, 104 570, 104 621, 104 705, 104 710, 104 734, 104 765, 104 779, 105 140, 105 216, 106 307, 107 617, 108 552, 108 568, 108 572, 108 591, 108 600, 108 605, 108 606, 108 618, 108 621, 108 691, 108 720, 110 747, 112 891

Elst E., Ipatov S.

Positions in the MPC's: 12 minor planets

MPS 97 875, 115 298, 120 582

Pauwels T.

Positions in the MPC's: 1246 minor planets

MPS 99 982, 100 040, 100 532, 100 656, 100 660, 100 664, 100 667, 100 703, 100 774, 100 820, 100 868, 101 226, 101 325, 101 326, 101 604, 103 819, 104 145, 104 357, 104 419, 104 420, 104 683, 104 713, 104 754, 104 970, 105 007, 105 121, 105 200, 105 212, 105 213, 105 216, 105 263, 105 400, 105 732, 105 927, 106 086, 106 303, 106 305, 106 589, 106 723, 107 439, 107 457, 107 483, 108 517, 108 614, 110 074, 110 081, 110 095, 110 126, 112 496, 112 503, 112 504, 112 507, 112 510, 112 542, 112 586, 112 607, 112 608, 112 611, 112 624, 112 634, 112 645, 112 646, 112 651, 112 661, 112 680, 112 686, 112 707, 112 722, 112 755, 112 758, 112 789, 112 790, 112 792, 112 797, 112 800, 112 809, 112 810, 112 813, 112 814, 112 831, 112 832, 112 835, 112 874, 112 892, 112 922, 112 928, 112 987, 113 003, 113 036, 113 038, 113 054, 113 075, 113 083, 113 109, 113

120, 113 161, 113 194, 113 202, 113 241, 113 245, 113 267, 113 270, 113 291, 113 314, 113 323, 113 328, 113 423, 113 586, 113 685, 114 019, 115 365, 118 316, 118 322, 118 407, 118 730, 118 882, 120 553, 120 564, 121 070, 121 173, 121 195, 121 308, 121 309, 121 362, 121 526, 121 595, 121 635, 121 667, 121 724, 121 839, 121 840, 121 844, 121 849, 121 878, 121 879, 121 947, 122 091, 122 175, 122 184, 122 219, 122 329, 122 443, 122 444, 122 447, 122 448, 122 459, 122 460, 122 494, 122 615, 122 655, 122 689, 122 751, 122 757, 122 799, 122 832, 122 871, 123 009, 123 039, 123 040, 123 076, 123 130, 123 140, 123 188, 123 190, 123 191, 123 197, 123 209, 123 211, 123 231

Pauwels T.
Positions in the MPC's: 15 comets
MPC 51 352, 53 299

Pauwels T., De Cat P.
Positions in the MPC's: 4 minor planets
MPS 96 763

Stanishev V., Kraicheva Z., **Boffin H. M. J.**, Genkov V., **Papadaki C.**, Carpano S.
Accretion Disk Evolution in DW Ursae Majoris: A Photometric Study
Astronomy & Astrophysics., 416, 1057-1067 (2004).

A.1.6.2. Publications in press, submitted

Pauwels T., Vingerhoets P., **Cuypers J**.
Photometric observations of the mutual phenomena of the Galilean Satellites of Jupiter in 1997 and 2003 at the Royal Observatory of Belgium
accepted for publication in Astronomy and Astrophysics.

A.1.7. Missions

2 field missions.

A.2. Research project "EDENS"

A.2.1. Objectives

EDENS (European DEep-sky NEO Survey) was the response of Europe and the Spaceguard Foundation on the recommendations formulated by the OECD concerning the protection of the Earth against the threat by minor planets. It aimed at conducting a more efficient search for earth-threatening minor planets up to a diameter of about 200 meter (see the report of 2003 for more details).

A.2.2. Progress and results

An FP6 application was submitted, but early 2004 we got the message that the application was not retained. As such, there have been no further activities in 2004.

Research Theme "Digitisation"

The Royal Observatory of Belgium possesses 30 000 photographic images of the sky, 1000 photographic spectra, 20 000 drawings of the sunspots, 7500 photographic images of the solar photosphere, 750 000 images of the solar chromosphere, and lots of historical seismograms. All these records are an invaluable scientific heritage of the past, containing still a lot of scientific information. All these are in danger, because they suffer from deterioration, and they are inaccessible to foreign researchers. Other federal scientific institutes also have enormous collections that suffer from the same problems. At the federal level it was realised that there is a need to digitise these collections, so as to preserve their scientific content, and subsequently to make them accessible to other researchers via the web.

First, Belspo initiated pilot projects to develop the necessary technologies. The D4A project is such a pilot project aiming at building a high-precision scanner. It involves the Royal Observatory of Belgium, the National Geographic Institute and the Museum of Central-Africa, and a few other partners. Meanwhile, a study started, aiming at establishing the needs of the federal institutions for digitisation of their heritage.
Also on the international level, but then specifically for astronomy, there have been initiatives. The UDAPAC project was started in 2000, with the intention to gather and digitise the European astronomical direct photographic plates for which the host institute either have no interest or have no money to keep their collections themselves. This UDAPAC project is still at the level of an intention, but the D4A project should prepare the way for the UDAPAC project, by creating the necessary environment (archives) and building a scanner, that will later be useable by UDAPAC.

DEPARTMENT 2: Astrometry and Dynamics of Celestial Bodies

SECTION 5: Astrometry and Dynamics of Star Systems

A. Research Theme "Binaries"

It is now widely accepted that the vast majority of stars belongs to a binary or a multiple system, irrespective of spectral type. Recent surveys of high astrometric quality, both from space - up to 3000 new binaries have been discovered by the Hipparcos mission [1] - or from the ground, show clear evidence that improving the resolution of the instruments generates an increasing number of new detections and that the true frequency of binaries and multiple stars is probably still underestimated. The origin and formation process of binary and multiple systems may not be unique and is presently not well understood. Observational clues can be derived from the distributions of their statistical properties such as frequencies, orbital periods, true separations, eccentricities, masses and mass ratios or any other intrinsic property of the components (e.g. [2]).

Binary and multiple stars with well-characterized components are attractive targets to study a number of different phenomena of high astrophysical interest including their own formation and history. Astrometry helps in the full characterization of the components in a most powerful way as it allows to determine the orbital motions and, derived from these, the stellar masses - a most fundamental property of stars - in a straightforward manner. Wide binaries, especially if they have different spectral types, can be used to calibrate the luminosities and temperatures of single stars and to confront evolutionary tracks and models.

On the other side of the broad spectrum in separation, close binaries offer excellent opportunities for the combination of data obtained with different observational techniques resulting in good progress on the impact of binarity on e.g. stellar atmospheres (tidal deformation, rotation, chemical composition, stellar pulsation and/or activity (cf. Research "Asteroseismology")) or binary evolution (with/without mass transfer).

[1] Lindegren, L., 1997, ESA SP-402, 13
[2] Eggenberger, A., Halbwachs, J.-L. et al., 2004, Rev. Mex. A. A. 21, 28

A.1. Research project "Visual Binaries and Multiple Stars"

A.1.1. Objectives

Visual binaries allow a direct calibration of the mass-luminosity relation on the lower main sequence via the study of their orbital motions. Differential magnitudes and colours must be gathered along with accurate relative positions with the purpose to investigate the physical status, to improve the orbits and to determine the associated properties such as (photometric) mass ratios. Our goal is to investigate a volume-limited sample of visual binary and multiple stars that is as complete as possible.

A.1.2. Progress and results

In the framework of the bilateral project "Astrometric, Photometric and Spectroscopic Follow-up of Binary Systems", the data on visual double stars of the observational campaigns performed at Bulgarian observatories with CCD's since 1998 were gathered and merged into one dataset. In the case of multiple observations of the same target these results were discussed case-by-case. In this way accurate relative astrometry and differential multi-colour (BVRI) photometric data were obtained for the components of many Hipparcos visual double stars, of which a large fraction is formed by nearby systems with paral-

laxes larger than 0.04" (forming part of the revised stellar sample of the Solar neighbourhood). A summary publication is in preparation. Previous results on visual double stars were published [1].

We are additionally involved in observational programmes for close visual binaries with sub-arcsecond separations making use of techniques such as Adaptive Optics (AO) or speckle interferometry in order to reach higher angular resolutions. The speckle camera (PISCO) is operational at Merate (Italy) since 2004 [3]. The aim is to derive the colours of the individual components of those binaries which do not fit well the empirical mean mass-luminosity relation, but which have accurate parallaxes (from the Hipparcos mission). Updated lists of close visual binaries in need of a monitoring with the speckle technique were sent to M. Scardia (in the context of the PISCO-collaboration) and J. Docobo. The triple star DG Leo merits follow-up observations (see Figure 9) [4]. First results of AO-observations obtained with a deconvolution method in the NIR passbands (J,H,K) were presented for a sample of nearby F-G and K orbital binaries [2]. A revised orbit was derived for the visual binary Fin 320.

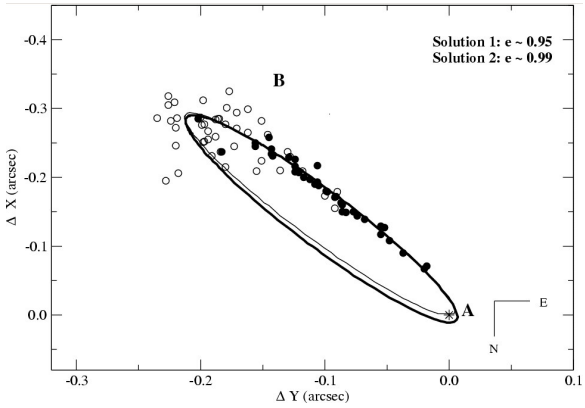


Figure 9: Observations and predicted relative visual orbits for DG Leo: the best two solutions are represented by the solid curves. The micrometric and speckle data are represented by unfilled and filled circles respectively (from [4]).

A.1.3. Perspective for next years

The acquisition of component colours for nearby visual binaries and their exploitation will be pursued. A speckle-interferometric programme for the monitoring of close visual binaries lacking essential astrometric data will be further defined, in particular in the context of the PISCO-collaboration. The goal is to improve the accuracy on the component masses of nearby systems. For a few systems of very high astrophysical interest we will additionally try to obtain long-base interferometric observations (ESO, VLTI). In the frame of a closer cooperation between existing ROB projects, the impact of speckle observations in the young association Sco-Cen will be evaluated (cf. report from Dept. III).

A.1.4. Personnel involved

P. Lampens, head of Department
D. Duval, calculator

A.1.5. Partnerships

List of national and international partners

R. Argyle (Cambridge, UK)
J. Docobo (Santiago de Compostela, Spain)
J.L. Prieur (Toulouse, France)
M. Scardia (Brera, Italy)

– A. Strigachev (Sofia, Bulgaria)

Grants used for this research

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

Visitor(s): 1

A.1.6. Publications

A.1.6.1. Publications with peer system

[1] Strigachev A., **Lampens, P.,** 2004,
Multicolour CCD measurements of nearby visual double stars. II,
A&A 422, 1023

A.1.6.2. Publications without peer system

[2] **Lampens,P.,** Prieur, J.L. & Argyle, R. 2004, (poster)
Infrared differential photometry of selected orbital binaries,
IAU 191 Coll. The environment and evolution of double and multiple stars, eds. C. Allen & C. Scarfe, Rev. Mex. de Astronomía y Astrofísica 21, 75

[3] Scardia, M., Prieur, J.-L., Koechlin, L., Aristidi, E., **Lampens,P.,** Strigachev, A., Oblak, E., Kurpinska-Winiarska, M., Ghigo, M., Mazzoleni, F. and Sala, M., 2004,
The speckle camera PISCO is now operational on the 1-meter Zeiss telescope of I.N.A.F. – Osservatorio Astronomico di Brera at Merate, Italy,
IAU Comm. 26, Information Circular No. 153, eds. J. Docobo & J. Ling

A.1.6.3. Publications in press, submitted

[4] **Lampens, P., Frémat, Y.,** 2005,
Are these observations really necessary?
In: Proc. of Astrometry in the Age of the Next Generation of Large Telescopes, Flagstaff, AZ, 17-22 Oct. 2004, eds. K. Seidelman, A. Monet, ASP Conf. Ser., in press

A.1.6.4. Reports, thesis, etc

[5] **Lampens, P.,** April '04, report for COSPAR

A.1.7. Missions

Assemblies, symposia, workshops : 1
Commissions, working groups : 0
Field missions : 1 (observational campaign)

A.2. Research project "Binaries from space (missions)"

A.2.1. Objectives

The objective is to contribute to the scientific preparation of the ESA space mission GAIA, more specifically in the framework of detection and analysis of double and multiple stars. Techniques and algorithms in the area of image processing and data reduction were developed and tested. Binary star observations from a mission as GAIA were simulated using a population synthesis code and a Galaxy model was constructed to help planning the design of the mission.

A.2.2. Progress and results

A.2.2.1. Combining GAIA "windows"

During the 5 year observational phase of GAIA, several **one-dimensional observations** ("patches") from the same object will be acquired at different epochs and different transit angles. It is scientifically very important to combine all the observations to produce a **two-dimensional image** in order to have a detailed map of the stellar surroundings. Most of the emerging objects will be physical components, but some background/foreground objects will also be found. The combination procedure will further increase the image resolution in the across scan-direction. The method previously developed for the cancelled DIVA mission was modified and improved. The image window in the astrometric field of view from which the patches are taken, is not a square but is elongated in the across scan-direction. The procedure consists of combining patches that are stretched back to 2D images when the original centroid positions of the GAIA windows are known.

The window combining method used for GAIA is a simple but very fast mapping procedure that can easily handle all realistic complexities occurring during the data reduction. The method is not intended to be a perfect image restoration technique, but the purpose is to fulfill the scientific requirement of detecting faint neighbouring sources existing in the close vicinity of the main point sources. Examples of the patch combination procedure applied to simulated GAIA observations were produced and the basic reduction procedure to detect faint companions around primary targets was illustrated [5]. We computed the ultimate detection limits that can be achieved using the method and possible complexities related to the artefacts of the combined images were discussed. A complete description of the image combination technique and its performances is published [2, 3].

A.2.2.2. Binary simulations

A preliminary analysis of visual double-star observations with GAIA was made based on a synthetic binary star catalogue extended down to the 20th magnitude [1]. However, the old Galaxy model did not include binary evolution and the results using the GSC 2.2 catalogue were not very reliable since the completeness levels of this catalogue are very difficult to evaluate. Hence, we constructed a new Galaxy model that includes an assumed 0.75 fraction of binary stars. Also, more advanced synthetic binary evolution algorithms were used to study different binary populations in detail. As a result, a new synthetic binary star catalogue was created that is complete down to the visual magnitude limit $m_v < 24$, which is the ultimate magnitude limit of the combined GAIA images. This Galaxy model is compatible with the observed stellar counts published in the literature. These results were presented at the 2004 GAIA Symposium [4].

A.2.3. Perspective for next years

The GAIA preparatory work should be continued: extensions of the GAIA imaging analysis should include the study of high-density regions and the estimation of physical parameters of the new objects detected in the combined image. Binary orbit calculations and the photometric variability of double stars during the mission should be furthermore addressed in the future developments.

The newly developed image combination and binary star analysis tools should be integrated into the GAIA Data Access and Analysis System (GDAAS) package.

A.2.4. Personnel involved

P. Nurmi, scientific collaborator and core member of the GAIA Working Groups (WG) on Imaging, on Photometry & on Double and Multiple Stars (01.01.04 – 08.10.04)

A.2.5. Partnerships

List of national and international partners

F. Arenou (Observatoire de Paris-Meudon, leader of the GAIA Double and Multiple Star Working Group)
A. Brown (Leiden University, leader of the GAIA Photometric Data Reduction Task)

Grants used for this research

ESA-PRODEX: “Double Stars: From Hipparcos to GAIA” (Ref.. 14847/00/NL/SFe(IC))

A.2.6. Publications

A.2.6.1. Publications with peer system

[1] **Nurmi, P**., 2004a,
Observational Properties of Synthetic Visual Binary Catalog
Proc. of IAU Coll. 191, Revista Mexicana de Astronomía y Astrofísica (Serie de Conferencias) Vol. 21, pp. 263-264

A.2.6.2. Publications without peer system

A.2.6.3. Publications in press, submitted

[2] **Nurmi, P.**, 2004b,
Combining GAIA windows: The method and simulations
Astrophysics and Space Science, in press

[3] **Nurmi, P.**, 2004c,
Observing faint binaries with GAIA
Symposium, Meudon, France, in press

[4] **Nurmi, P.**, 2004d,
Galaxy simulations of visual binary stars
Symposium, Meudon, France, in press

A.2.6.4. Reports, thesis, etc

[5] **Nurmi, P.**, 2004e,
Combining GAIA windows II: SNR calculations of secondary sources using different numerical binnings and samplings in AF11
GAIA technical report DMS-PN-02, 1-16

[6] **Lampens, P., Nurmi, P.**
June ’04, report for PRODEX-6

A.2.7. Missions

Assemblies, symposia, workshops: 2

Commissions, working groups: 2

B. Research Theme “Asteroseismology”

The rapidly developing research domain of **asteroseismology** refers to the study of the internal structure of pulsating stars through interpretation of their frequency spectra. Stellar pulsations are presently the only way to indirectly probe stellar interiors. Indeed, the frequency spectrum of the excited modes is a fingerprint of internal physical processes. Hence, detection of several well-identified modes forms the

basis of a successful asteroseismic study. To this aim we observe and study the light and spectral variations of pulsating stars of spectral type B-A-F over a timescale of several seasons and/or years. At least four classes of main-sequence pulsators are investigated:

- δ Scuti (δ Sct) stars are main-sequence or giant mid to late A-type stars pulsating in radial and non-radial acoustic (p-)modes with typical periods of 0.5-6 hours. Photometric amplitudes up to decimagnitudes are observed. Their modes are excited by the opacity mechanism acting on the partially ionized He II-III zone [1].

- γDoradus (γDor) stars were first introduced as an independent class one decade ago. These are main-sequence early F-type stars located at the red edge of the δ Sct instability strip and pulsating in non-radial gravity (g-)modes with typical periods of 0.4-3 days. The light curves show photometric amplitudes of milli- to centimagnitudes. Although there is no consensus about the driving mechanism yet, pulsational driving seems to occur at the basis of their convective envelope [2,3].

- β Cephei (β Cep) stars are early B-type stars which pulsate in both radial and non-radial (low-order) p/g-modes with typical periods of 2-12 hours and photometric amplitudes of milli- to centimagnitudes. Their pulsations are driven by the opacity mechanism acting on the iron group elements [4].

- Slowly pulsating B (SPB) stars are main-sequence mid to late B-type stars pulsating in non-radial (high-order) g-modes with typical periods of 0.5-5 days and photometric amplitudes of milli- to centimagnitudes. Their pulsations are also driven by the opacity mechanism acting on the iron group elements [5].

So far, unknown amplitude and mode selection mechanisms are operating in these four classes of main-sequence pulsators.

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

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 stars with the goals to improve knowledge of pulsation physics through constraints on the physical parameters of the variable component derived from the binary or multiple nature of the system and to study the interaction between pulsation and binarity. Since more than 50% of all stars are expected to be binaries, understanding the effects of binarity on the pulsation characteristics is a matter of prime importance.

B.1.2. Progress and results

We continued the in-depth study of the **triple system and δ Sct DG Leo**. After a successful spectral disentangling of the component spectra from new time-series spectra, we were able to show that all three components have similar effective temperatures, surface gravities, ages and masses but different atmospheric chemical compositions as mild metallicity was detected in only two of them [10,11,14,19]. We also reported the results of a multi-site photometric campaign performed over 3 years and demonstrated the presence of up to four pulsation frequencies in the range 10-13 c/d as well as an additional slow variation due to orbital motion in the high-quality photometric data sets [12, 20, 21, 22].

Other **δ Sct stars in binary systems** were investigated and found to be promising cases for application of the disentangling method: this concerns the Hyades cluster star θ^2 Tau, a "twin" spectroscopic binary consisting of two rapidly rotating stars of nearly identical colour and mass - both may well be δ Sct stars - and the recently detected eclipsing binary HIP 7666, one of the rare known cases of a classical δ Sct star in a detached eclipsing binary [18, 34]. In 2004 a multi-site photometric campaign was launched in four different countries (Belgium, Spain, South-Korea and Ukraina). This will enable to study the pulsations in a short-period binary in an unperturbed way (i.e. not affected by mass transfer/exchange).

We furthermore started analysing spectra of a broad sample of A-type stars located in the lowest part of the Cepheid instability strip with the aim to study the occurrence of pulsation, binarity and chemical peculiarity in this extremely complex part of the colour-magnitude diagram. A total of 32 poorly known HIPPARCOS targets were observed at the Observatoire de Haute-Provence (OHP). A large proportion of them was found to be spectroscopically variable and are presently being photometrically monitored. Five multiple systems were discovered, one of which is also showing rapid line profile variations (LPV's) indicative of non-radial pulsation(s).

More results include the non-confirmation of the presence of two tidally coupled periodicities of type **δ Sct in the eclipsing binary** WX Eridani [13], the discovery of a short-periodic pulsating component in the Algol-type binary TU Her [15, 34], and the non-confirmation of the short-period variability of V521 Cas, a wrongly classified δ Sct star in NGC 8879 [16].

In collaboration with Belgian, US and Spanish amateur- and professional astronomers, we discovered two new **δ Sct stars** among various candidate stars (Koen 2001). A physics student was trained to handle the data of GG Uma and helped with the frequency analyses during a 1-month learning experience. Multiple frequencies were detected in both cases.

The cross-correlation profiles of 37 southern **γ Dor** candidate **stars** obtained from 1998 to 2002 (ESO, Chile) revealed in half of the cases the presence of LPV's due to non-radial pulsation. Five stars have been classified as possible γ Dor stars. At least 16 stars turned out to be new binaries of which 12 are double-lined. Preliminary orbits could be determined for 10 systems. At least 5 of them are also ellipsoidal variables [30].

Time-series multi-colour photometry (Geneva) and high-resolution spectroscopy (ESO) obtained in 1996-1998 for 13 bright southern **slowly pulsating B (SPB) stars** were analysed. Mode identification was next performed based on photometric as well as spectroscopic diagnostics [29]. The spectroscopic results for 7 singly-periodic targets were published: 4 are pulsating in an l=1 sectoral mode while the analyses of the remaining stars was inconclusive [17]. No spectroscopic evidence for the existence of secondary components was found in the case of 7 binaries. An eccentric orbit with a 56.74 days period and a frequency of 7.1160 c/d were determined for the **binary and β Cep star** θ Oph.

In **close binaries**, tidal interaction between the components generates aspherically distorted stellar surfaces. In order to study such effects, two early-B type close binaries will be observed with a spectropolarimeter at the Observatoire du Pic du Midi (OPM).

B.1.3. Perspective for next years

The long-term and detailed studies of particular short-period pulsators of spectral type B-A-F (single or multiple) will be continued or completed. The datasets gathered for B-A-F type variables with the Mercator telescope (La Palma) since 2001 will be subjected to detailed frequency analyses and mode identification. In the case of DG Leo*, we will pursue the in-depth analysis of this "Rosetta stone of δ Sct pulsa-

tion" by next addressing the identification of the pulsation modes. The same will be performed for the Cep and eclipsing binary HD 92024* (*: with Dept. III). We will investigate more **pulsating stars in binary or multiple systems** by applying the same techniques (e.g. the spectroscopic binary θ2 Tau, the eclipsing binary HIP 7666 or the young binary RS Cha). Analysis and interpretation of new data of these high-priority targets as well as of a broader sample should cast new light on the link between pulsation, multiplicity, rotation and chemical composition in A-F type stars.

We plan to extend the application of the technique of **spectral disentangling** to a broader sample of double- and multiple-lined stars among various classes of short-period main-sequence pulsators and will address questions related to applicability and limitations through detailed tests with synthetic data (e.g. obtained with the PULSTAR code).

B.1.4. Personnel involved

P. De Cat, assistent
Y. Frémat, scientific collaborator replacing H. Boffin (01.01.04 –31.12.04)
P. Lampens, head of Department
J. Cuypers and H. Hensberge, senior researchers**,** Dept. III

B.1.5. Partnerships

List of national and international partners:

T. Arentoft, Aarhus (Denmark)
Various members of the Belgian Asteroseismology Group (BAG) (Belgium)
H.W. Duerbeck, C. Sterken, VUB, Brussel (Belgium)
M. Floquet, A.-M. Hubert, C. Neiner, Observatoire de Paris-Meudon (France)
E. García-Melendo & coll. (Grup d'Estudis Astronómics), Barcelona (Spain)
R. Garrido & coll., Granada (Spain)
P. Harmanec, Prague (Czech Republic)
S. Ilijic, University of Zagreb (Croatia)
P. Mathias, Nice (France)
P. Niarchos & coll., University of Athens, Athens (Greece)
J. Peña & coll., UNAM, Mexico City (Mexico) & coll.
P. Van Cauteren, Beersel Hills Observatory & VVS (Belgium)
P. Wils, VVS (Belgium)
J. Zorec, Institut d'Astrophysique de Paris (France)

Grants used for this research:

Action 1: project MO/33/007: "Variable Components of Binary or Multiple Stars"
FNRS travel grant to attend the Workshop in Dubrovnik, Croatia (Y. Frémat)
FWO-project G.0178.02: "Observational study of Stars in Stellar Systems" (cf. report from Dept. III)
IUAP P5/36: "Modern aspects of theoretical and observational (ground-based and space-born) astrophics"(cf. report from Dept. III).
OPTICON (Optical Infrared Coordination Network for Astronomy) – EU-grant to perform observations at OHP (Y. Frémat, Dec. 2004)

Visitor(s): 2

B.1.6. Publications

B.1.6.1. Publications with peer system

[1] Briquet M., Aerts C., Lüftigner T., **De Cat P.,** Piskunov N.E., Scuflaire R., 2004,

He and Si surface inhomogeneities of four Bp variable stars
A&A 413, 273

[2] Aerts C., **De Cat P.,** Handler G., Heiter U., Balona L. A., Krzesinski J., Mathias P., Lehmann H., Ilyin I., De Ridder J., Dreizler S., Bruch A., Traulsen I., Hoffmann A., James D., Romero-Colmenero E., Maas T., Groenewegen M. A. T., Telting J. H., Uytterhoeven K., Koen C., Cottrell P. L., Bentley J., Wright D. J., **Cuypers J.**, 2004,

Asteroseismology of the β Cephei star ν Eridani - II. Spectroscopic observations and pulsational frequency analysis
MNRAS 347, 463

[3] Aerts C., **Cuypers J., De Cat P.,** Dupret M.-A., De Ridder J., Eyer L., Scuflaire R., Waelkens C., 2004,

Long-term multicolour photometry and high-resolution spectroscopy of the two γ Doradus stars HD12901 and HD48501
A&A 415, 1079

[4] Mathias, P., Le Contel J.-M., Chapellier E., Jankov S., Sareyan J.-P., Poretti E., Garrido R., Rodríguez E., Arellano Ferro A., Alvarez M., Parrao L., Peña J., Eyer L., Aerts C., **De Cat P.**, Weiss W. W., Zhou A., 2004,

Multi-site, multi-technique survey of γDoradus candidates. I. Spectroscopic results for 59 stars,
A&A 417, 189

[13] Arentoft, T., **Lampens, P.,** Van Cauteren, P., Duerbeck, H.W., García-Melendo, E., Sterken, C. 2004,

On the δ Scuti component of the eclipsing binary WX Eridani,
A&A 418, 249

[14] **Frémat, Y., Lampens, P., Hensberge, H.,** 2005,

Spectral disentangling of the triple system DG Leo: orbits and chemical composition
MNRAS 356, 545

[15] **Lampens, P.,** Van Cauteren, P., Strigachev, A., Kim, S.-L., Kang, Y.B., Koo, J.-R., Mkrtichian, D.E., 2004,

Discovery of a short-periodic pulsating component in the Algol-type eclipsing binary system TU Her,
IBVS 5572, 1

[16] Van Cauteren, P., **Lampens, P.,** Pigulski, A., 2004,

Note on the short-period variability of V521 Cas in NGC 8879,
Commun. in Asteroseismology 144, 23

B.1.6.2. Publications without peer system

[5] **De Cat P.,** Daszyñska-Daszkiewicz J., Briquet M., Dupret M.-A., Scuflaire R., De Ridder J., Niemczura E., Aerts C., 2004, (invited talk)

g-mode pulsations in slowly pulsating B stars
In: D.W. Kurtz & K. Pollard (eds.), Proceedings of IAU Colloquium 193 "Variable stars in the Local Group", ASP Conference Series 310, 195

[6] **De Cat P.**, De Ridder J., Uytterhoeven K., Davignon G., Raskin G., **Cuypers J., Schoenaers C.**, Daszyñska-Daszkiewicz J., Aerts C., Van Winckel H., Ausseloos M., Broeders E., De Meester W., Vanautgaerden J., Van Malderen R., Vandenbussche B., Acke B., Decin G., Decin L., Kolenberg K., Maas T., De Ruyter S., Reyniers M., Reyniers T., Van Kerckhoven C., Waelkens C., 2004, (poster)

First results of Mercator observations of variable B stars

In: D.W. Kurtz & K. Pollard (eds.), Proceedings of IAU Colloquium 193 "Variable stars in the Local Group", ASP Conference Series 310, 238

[7] De Ridder J., **Cuypers J., De Cat P.**, Uytterhoeven K., **Schoenaers C.**, Davignon G., Raskin G., Vanautgaerden J., Broeders E., De Meester W., Van Malderen R., De Ruyter S., Vandenbussche B., Maas T., Kolenberg K., Reyniers M., Decin G., Acke B., Ausseloos M., Aerts C., Van Winckel H., Waelkens C., 2004, (poster)

First results of Mercator observations of variable A and F stars

In: D.W. Kurtz & K. Pollard (eds.), Proceedings of IAU Colloquium 193 "Variable stars in the Local Group", ASP Conference Series 310, 263

[8] Mathias, P., Chapellier E., Le Contel J.-M., Jankov S., Sareyan J.-P., Garrido R., Rodriguez E., Poretti E., Alvarez M., Arellano Ferro A., Parrao L., Peña J., Eyer L., Aerts C., **De Cat P.**, Weiss W.W., Zhou A., 2004, (poster)

γDoradus stars as Eddington targets: a spectroscopic study

In: F. Favata, S. Aigrain & A. Wilson (eds.), Proceedings of 2nd Eddington Workshop: "Stellar structure and habitable planet finding", ISBN 92-9092-848-4, 355

[9] **De Cat P.**, De Ridder J., **Hensberge H.**, Ilijic S., 2004,

Spectroscopic study of the double-lined slowly pulsating B stars HD140873 and HD123515

In: R. W. Hilditch, H. Hensberge & K. Pavlovski (eds.), Workshop on Spectroscopically and Spatially Resolving the Components of the Close Binary Stars, ASP Conf. Ser. 318, 338

[10] **Frémat, Y., Lampens, P., Hensberge, H.,** Arentoft, T., **De Cat, P**., Garrido, R., Parrao, L., Peña, J.H., Mathias, P., Van Cauteren, P., 2004, (poster)

High Resolution Spectroscopy of the Triple System 20 Leo

IAU 193 Coll. Variable Stars in the Local Group, eds. D. Kurtz & K. Pollard, ASP Conf. Ser. 310, 395

[11] **Frémat, Y., Lampens, P., Hensberge, H.,** 2004,

Spectroscopic disentangling of the triple system DG Leo,

Workshop on Spectroscopically and Spatially Resolving the Components of Close Binary Stars, eds. R.W. Hilditch, H. Hensberge & K. Pavlovski, ASP Conf. Ser. 318, 342

[12] **Lampens, P**., Garrido, R., Parrao, L., Peña, J., Arentoft, T., **Frémat, Y**., 2004, (poster)

Two-site photometry of the Delta Scuti star DG Leo. Preliminary results,

IAU 191 Coll. The environment and evolution of double and multiple stars, Mérida, México, February 3-7, eds. C. Allen & C. Scarfe, Rev. Mex. de Astronomía y Astrofísica 21, 73

B.1.6.3. Publications in press, submitted

[17] **De Cat P.,** Briquet M., Daszyñska-Daszkiewicz J., Dupret M.-A., De Ridder J., Scuflaire R., Aerts C., 2004,

A study of bright southern slowly pulsating B stars. III. Mode identification for singly-periodic targets in spectroscopy

A&A, in press

[18] Escolà-Sirisi, J. Juan-Samsó, J. Vidal-Sáinz, **P. Lampens**, E. García-Melendo, J. M. Gómez-Forrellad, P. Wils, 2004,

A classical δScuti star in the new eclipsing binary system HIP 7666,

A&A, in press

[19] **Frémat, Y., Lampens, P., Hensberge, H.**, 2004, (poster)

Chemical analysis of a spectroscopic triple system of A-stars,

In: Proc. of IAU Symp. 224, The A-Star Puzzle, July 2004, Poprad, Slovac Republic, eds. Zverko, J., Ziznovsky, J., Adelman, S., Weiss, W., in press

[20] **Lampens, P., Frémat, Y**. et al., 2004, (poster)
Pulsation of the δ Scuti multiple system DG Leo,
In: Proc. of IAU Symp. 224, The A-Star Puzzle, July 2004, Poprad, Slovac Republic, eds. Zverko, J., Ziznovsky, J., Adelman, S., Weiss, W., in press

[21] **Lampens, P**., **Frémat, Y.,** Garrido, R., Peña, J., Parrao, L., Van Cauteren, P., **Cuypers, J., De Cat, P.,** Uytterhoeven, K., Arentoft, T., Hobart, M., 2005,
A photometric study of the light variations of the δ Scuti star DG Leo
submitted to A&A

[22] **Lampens, P., Frémat, Y., Cuypers, J.,** Uytterhoeven, K., 2005, (invited talk)
Pulsating stars in multiple systems, 3rd Granada Workshop on Tidal Evolution and Oscillations in Binary Stars
ASP Conf. Ser., eds. Claret, A., Giménez, A. & J.-P. Zahn, in press

[23] Neiner C., Floquet M., Hubert A.-M., **Frémat, Y.**, Hirata, R., Gies, D., Buil, C., Martayan, C., 2005,
Rotation, pulsations and outbursts in the Be star υ Cyg (HD202904)
A&A, in press

Reports, thesis, etc

[24] **De Cat P.,** Neiner C., 2004,
 Cephei stars, http://obswww.unige.ch/~eyer/VSWG/: (BCEP)

[25] **De Cat P.**, Neiner C., 2004,
Slowly pulsating B stars, http://obswww.unige.ch/~eyer/VSWG/: (SPB)

[26] Neiner C., **De Cat P.,** 2004,
Variability of β Cephei and SPB
http://obswww.unige.ch/~eyer/VSWG/VARCHAR/bcep_spb.pdf (8 pgs)

[27] Lampens P., Frémat Y., De Cat P., 2005,
Pulsation, chemical composition and multiplicity in main-sequence A- and F-type stars
Preparation of a proposal 'Action-1'

Seminars, talks : 7

[28] **De Cat P.**, 15/05/2004
Massieve trillende hoofdreekssterren
Invited talk, annual meeting of the VVS (Variable Star Working Group), Mira, Grimbergen

[29] **De Cat P.**, Briquet M., Daszynska-Daskiewicz J, Dupret M.-A., De Ridder J., Scuflaire R., Aerts C., 22/06/2004
Mode identification for Slowly Pulsating B stars
Seminar, KSB

[30] **De Cat P.**, 15/10/2004
Binaries in a sample of southern (candidate) γDoradus stars
7th BAG meeting, KSB

[31] **Frémat Y.**, **Lampens P.**, Van Cauteren P. – May 29, 2004
Spectroscopie et analyse d'étoiles δ Scuti au sein de systèmes multiples
ARAS, Observatoire de Paris-Meudon, France

[32] **Frémat Y.**, **Lampens P.** – November 9, 2004
Etude d'étoiles variables dans des systèmes multiples: L'étoile triple DG Leo

Institut d'Astrophysique de Paris, France

[33] **Lampens P.** – 28/06/04
Future Research Perspectives
prepared for Scientific Council, KSB

[34] Lampens P., Frémat, Y. – 15/10/04
δ Scuti stars in multiple stellar systems
7th BAG meeting, KSB

B.1.7. Missions

Assemblies, symposia, workshops: 6
Commissions, working groups: 27
Field missions: 3 observational campaigns

B.2. Research Project "Asteroseismology from space"

B.2.1. Objectives

We are also involved in preparatory related aspects of the future space missions COROT & GAIA, which will provide super-quality data useful for asteroseismic studies. COROT (COnvection, Rotation and planetary Transits) has two science objectives, one of which is asteroseismology. The future European astrometric mission GAIA will provide unprecedented positional and radial velocity measurements with the accuracies needed to produce a stereoscopic and kinematic census of about one billion stars in our Galaxy. Combined with multi-epoch astrophysical information, these data will allow to characterize the various stellar populations of our Galaxy. The preparation of dedicated archives is a basic requirement for both missions.

The GAIA space mission

We are currently preparing a detailed description of the various known classes of variable stars for the GAIA Variable Star Working Group (VSWG, L. Eyer as president), in particular of β Cep [2] and of SPB stars [3] (in collaboration with C. Neiner, Leuven). An additional report was delivered [4] (cf. also http://www.ster.kuleuven.ac.be /~peter/Bstars).

The COROT space mission

Several proposals for COROT additional programmes were submitted in 2004: these concerned pulsating B-A-F type stars and detection and analysis of (a) δ Sct star(s) in a binary system and in open clusters. Feedback on these proposals was provided for on request of the project coordinator (W. Weiss, Vienna).

COROT will provide new insights on B stars with shells (Be stars) by allowing to study the coincidence between the beating of multiperiodic pulsation and the occurrence of discrete mass ejection. We contributed in gathering as much as possible information on potential targets by estimating the stellar fundamental parameters of all Be stars falling in the cones of COROT. This information is already included in the GAUDI [1]database and available on the web.

B.2.2. Perspective for next years

On the basis of a ground-based spectroscopic monitoring of some 50 SPB stars, the "misclassification rate" among such candidates will be assessed. This information is needed to provide a reliable estimation of the occurrence rates of pulsating stars among B-type stars to the GAIA-VSWG. Moreover, a model for the expected light and radial velocity curves of both β Cep and SPB variables will be developed.

As a further contribution to the COROT-mission, we plan to analyze in great detail those Be stars that will in the end be selected as secondary targets and to prepare the analysis of the future COROT data.

B.2.3. Publications

B.2.3.1. Publications with peer system

[1] Solano, E.; Catala, C.; Garrido, R.; Poretti, E.; Janot-Pacheco, E.; Gutiérrez, R.; González, R.; Mantegazza, L.; Neiner, C.; **Frémat, Y.**; Charpinet, S.; Weiss, W.; Amado, P. J.; Rainer, M.; Tsymbal, V.; Lyashko, D.; Ballereau, D.; Bouret, J. C.; Hua, T.; Katz, D.; Lignières, F.; Lüftinger, T.; Mittermayer, P.; Nesvacil, N.; Soubiran, C.; van't Veer-Menneret, C.; Goupil, M. J.; Costa, V.; Rolland, A.; Antonello, E.; Bossi, M.; Buzzoni, A.; Rodrigo, C.; Aerts, C.; Butler, C. J.; Guenther, E.; Hatzes, A. 2004
GAUDI: A Preparatory Archive for the COROT Mission
AJ, 129, 547

B.2.3.2. Reports, thesis, etc

[2] **De Cat P.**, Neiner C., 2004,
β Cephei stars
http://obswww.unige.ch/~eyer/VSWG/: (BCEP)

[3] **De Cat P.**, Neiner C., 2004,
Slowly pulsating B stars
http://obswww.unige.ch/~eyer/VSWG/: (SPB)

[4] Neiner C., **De Cat P.,** 2004,
Variability of β Cephei and SPB
http://obswww.unige.ch/~eyer/VSWG/VARCHAR/bcep_spb.pdf (8 pages)

B.2.4. Missions

Assemblies, symposia, workshops: 1
Commissions, working groups : 1
C. Miscellaneous activities
C.1. Visitors
- 15/09-28/09/04: Prof. M. Tsvetkov & Dr. K. Tsvetkova (in the framework of the bilateral project 'Catalogue Integration and Image Processing of the ROB Wide-Field Plate Archive')
C.2. Meetings
- Meeting of the senior staff on 19/02, 13/05, 11/10, 8/11, 21/12
- Meeting of the Scientific Council on 01/03, 28/06
- Meeting of the Steering Committee of "Belgian Women in Sciences" on 23/01, 19/03
- 10/11/04: Meeting on the future of the Belgian Liquid Mirror Telescope (BLMT, with H. Hensberge, T. Pauwels, J. Surdej and E. Van Dessel)
- 27-28/11/04: Interviews for recruiting a security engineer (as President)
- 17/12/04: Meeting on the future of the BLMT (with J. Surdej, J.P. Swings, E. Van Dessel)
- 23/12/04: Meeting on the budget envelope of the Federal Science Institutes, Brussel (in replacement of R. Verbeiren, director) (incl. reporting)
C.3. Reports and educational tasks
De Cat, P., co-supervisor of the master thesis Analyse van Mercatorgegevens van variabele sterren by Kristof Goossens (last-year student mathematics, KUL)
Lampens, P., Jul. '04: Report of the meeting of the Scientific Council (28/06)

C.4. Personalia

De Cat, P.
- core member of the GAIA Variable Stars Working Group (VSWG)
- active member and organiser of the monthly lectures of WEGA (amateur astronomy group
- member of the Astronomy Association of Flanders (VVS)

Lampens, P.
- member of the Organising Committee of IAU Commission 26 “Double and Multiple Stars”
- member of the ESA-GAIA Working Group “Double Stars"
- member of the ROB Scientific Council
- administrator of the association “Belgian Women in Sciences”

DEPARTMENT 3: Astrophysics

SECTIONS 6 & 7

Introduction

Stars evolve, process chemical species into different ones and re-cycle part of the material in the galaxy and a new cycle of star formation. Stellar structure, stellar evolution and galaxy evolution are closely linked. Many physical processes intervene in this cycle. The research in department 3 concerns several, but evidently only a small part, of the building blocks contributing to the general picture and encompass projects giving insight in very different stages of the star's life, from young objects to very evolved ones. We have grouped them in three research themes: stellar winds and circumstellar structures playing their major role in evolved evolutionary phases; binaries and asteroseismology as tools to study fundamental stellar parameters and interior structure; and studies concentrating on cataclysmic stellar events. Many of the projects emphasize participation in observational astronomy, and analysis techniques, as expected from the Observatory. Theoretical aspects are more strongly emphasized in C.1 and A.1. Several of the projects rely significantly on grants obtained in cooperation with Belgian universities and personnel on temporary contracts.

A. Stellar winds and circumstellar structures

The theme around stellar winds and circumstellar material splits again in two poles of interest (other themes are discussed further on in the report): the strong radiatively driven winds from the most massive, short-lived stars and the strong winds in late evolutionary stages of intermediate-mass stars that give rise to planetary nebulae. Multi-wavelength studies of the winds of massive stars show that they are structured and contain shocked gas; if this is not taken into account, predicted mass loss rates may be significantly in error and valuable indicators of stellar duplicity may be overlooked. The project A.1 concentrates on the understanding of the hydrodynamics producing the structure by confronting theory and observations.

The mass loss in the final steps of evolution of initial intermediate mass stars is a complex process with repercussions on the internal evolution of the star itself. The complex interplay among various physical processes is not yet understood, but the structure of the circumstellar material must clearly reflect the history of the mass loss events. The project A.2 uses a multitude of observing techniques and a radiative transfer code developed by one of its members to gain insight in the late evolution stages of these stars.

A.1. Hot stars

A.1.1. Objectives

Hot stars have radiatively driven stellar winds. Considerable observational evidence exists that these winds are not smooth, but structured. This project tries to elucidate the nature of this structure, by studying these stars both observationally (at various wavelengths) and theoretically (by constructing models for the hydrodynamics and radiative transfer).

A.1.2. Progress and results

In collaboration with S. P. Owocki a powerful method was developed to study the evolution of instability-generated structure in the outer winds of hot stars: the "pseudo-planar moving periodic box method", described extensively in the year report for 2003. Its main feature is the formulation of the spherical equations of hydrodynamics in a moving reference frame, by virtue of a transformation of variables resulting in equations that still describe spherical symmetry but formally resemble the planar equations. This

method allows us to follow wind structure out to distances larger than 1000 stellar radii and it does not suffer from certain numerical problems that cause artefacts in traditional models. The method also makes it possible to measure the shock speeds with sufficient precision to translate the jump velocity of a shock to a compression ratio.

For the non-thermal radio emission from single hot stars, we have previously developed a theoretical model, in terms of synchrotron radiation from relativistic electrons accelerated in wind-embedded shocks. This model has now been extended to include the effect of cooling on the relativistic particles. In the new model, the synchrotron radiation is limited to small layers behind a shock. The model has been applied to the non-thermal emitter Cyg OB2 No. 9, resulting in significant constraints on most of the model parameters.

We also studied in detail the shock structure from time-dependent hydrodynamical simulations. This information was included in the synchrotron model to obtain a more realistic description of the stellar wind. Compression ratios and velocity jumps of typical strong shocks in the periodic box model were used as a hydrodynamic input to models of non-thermal radio emission. Contrary to previous models, it is shown that the observed non-thermal radio emission cannot be ascribed to shocks in the wind, but is probably due to colliding stellar winds in a binary system, even for those stars where there is no spectroscopic indication for binarity.

Previously, G. Rauw and his group (Université de Liège) in collaboration with us, had studied the non-thermal radio emitter HD 168112. We have now finished the analysis and interpretation of the VLA and ATCA archive data on this star. The fluxes confirm that HD 168112 is a non-thermal radio emitter. The non-thermal radio emission is due to synchrotron radiation from relativistic electrons that have been Fermi accelerated in shocks. For Wolf-Rayet stars, it is well known that these shocks are due to colliding winds in a binary system. For non-thermal O stars, the situation is less clear. HD 168112 is an apparently single star. In such a case it is assumed that the shocks providing the Fermi acceleration are due to the intrinsic instability of the radiatively driven wind. Based on that hypothesis, we used the synchrotron model mentioned above to fit the observations. We found that the velocity jump of the shocks should be very high, or there should be a very large number of shocks in the wind. Neither of these is compatible with time-dependent hydrodynamical calculations of O star winds. We therefore also explored the possibility that HD 168112 could be an as-yet-undetected binary. It turns out that the fluxes do seem to repeat on a ~ 1.4 yr period (see Figure 10). The variability is explained by assuming the star to be an eccentric binary: as the colliding-wind region moves in and out of the region where free-free absorption is important, the radio fluxes vary. The radio data therefore offer proof for binarity where the optical data have failed to do so.

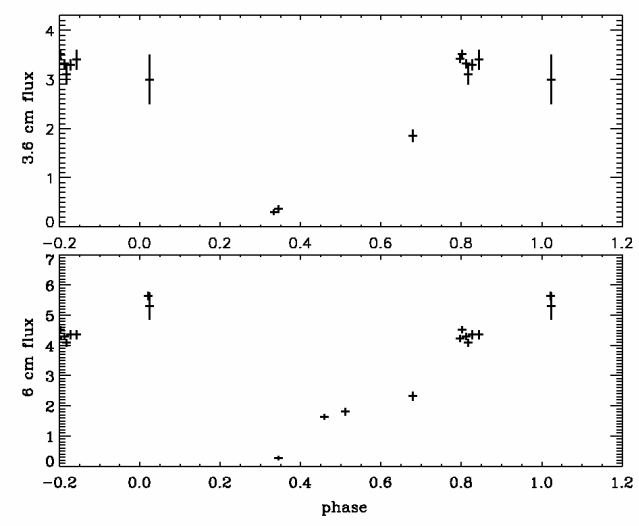


Figure 10: Fluxes of HD 168112

We continued our work on archive radio data on non-thermal emitters (HD 167971, 9 Sgr = HD 164794, stars in Cyg OB2). We reduced our VLA data and started the reduction of the VLA archive data of the thermal radio emitters HD 37128, HD 152236, HD 152408, HD 160529 and HD 190603. A preliminary

reduction of our SEST millimetre continuum observations of the O 4 I(n)f star ζ Puppis shows that there might be some variability present.

A.1.3. Perspective for next years

The reduction and interpretation of archive radio data on non-thermal and thermal hot stars will be continued. Millimetre observations already obtained at ESO will also be reduced. Further observational projects at far-infrared (Spitzer), millimetre (JCMT) and radio wavelengths (VLA, ATCA) will be introduced. On the theoretical side, a radiative transfer model will be developed to study the effect of large-scale structure (Corotating Interaction Regions) on various observational indicators. Especially the theoretical developments will be slowed down by the end of two contracts (M. Runacres, 28/02/2005; S. Van Loo, 30/09/2004). S. Van Loo will submit and defend his PhD thesis “Non-thermal emission from single hot stars" at the KULeuven in the first half of 2005.

A.1.4. Personnel involved

Dr. R. Blomme, werkleider
Dr. M. Runacres, IUAP researcher
Lic. S. Van Loo, assistant (Action 2, ended 30/09)
J. Vandekerckhove, calculator

A.1.5. Partnerships

List of national and international partners:

Université de Liège (research group G. Rauw)
University College London (research group of R.K. Prinja)
University of Delaware (research group of S.P. Owocki)

Grants used for this research:

IUAP project P5/36 (1 researcher)
PhD grant (Action 2)

Visitors: 2

A.1.6. Publications

A.1.6.1. Publications with peer system

De Becker, M., Rauw, G., **Blomme, R.**, …, **Runacres, M.C., Van Loo, S.,** Pollock, A.M.T.
A quasi-simultaneous XMM-Newton and VLA observation of the non-thermal radio emitter HD 168112
Astron. Astrophys. 420, pp. 1061-1077

Runacres M. C., Owocki, S. P.
A pseudo-planar, periodic-box formalism for modelling the outer evolution of structure in spherically expanding stellar winds
Astron. Astrophys. 429, pp. 323-333

Van Loo, S., Runacres, M.C., Blomme, R.
Non-thermal radio emission from single hot stars
Astron. Astrophys. 418, pp. 717-725

A.1.6.2. Publications without peer system

Blomme, R.
Structure in the Stellar Winds of O-type Stars
in: Proceedings of IAU Symposium 210, "Modelling of Stellar Atmospheres", (eds. N.E. Piskunov, W.W. Weiss, D.F. Gray), poster B11

Blomme, R.
Observational Effects of Corotating Interaction Regions in OB stars
in: Proceedings of IAU Symposium 215, "Stellar Rotation", (eds. A. Maeder, Ph. Eenens), pp. 47-48

A.1.6.3. Publications in press, submitted

Blomme, R., Van Loo, S., De Becker, M., Rauw, G., **Runacres, M.C.**, Setia Gunawan, D. Y. A., Chapman, J.M.
Non-thermal radio emission from O-type stars. I. HD 168112
Astron. Astrophys., submitted

Van Loo, S., Runacres, M. C., Blomme. R.
A layered model for non-thermal radio emission from single O stars
Astron. Astrophys., in press

Van Loo, S.
Non-thermal radio emission from O stars: binary versus single
Proceedings of Workshop "Massive Stars in Interacting binaries", in press

A.1.6.4. Reports, thesis, etc

A.1.7. Missions
research missions: 8

A.2. Post AGB stars and Planetary Nebulae

A.2.1. Objectives
We have been studying the final stages of evolution of intermediate initial mass stars, i.e. the evolution from the asymptotic giant branch (AGB) through the planetary nebula phases. This evolution is still poorly understood mainly because of a complex interplay among various physical processes between the central star and its circumstellar nebula (created through mass loss, which also influences the internal evolution of the central star). Hence, these objects provide excellent laboratories of astrophysical processes.

A.2.2. Progress and results
Ueta's radiative transfer code for an axisymmetric system, named 2-Dust, is used in order to understand the energetics of thermal emission within the circumstellar shells and the properties of dust grains and the central star. The 2-Dust code is upgraded so that the execution time is reduced about 50% and the radiative transfer is done following the dust temperature for each grain size and for each dust species. The latter modification is a required step to incorporate non-equilibrium heating of very small dust grains, and has been done in collaboration with R. Szczerba. The 2-Dust code was used to compute a radiative transfer model of the post-AGB star, HD 56126, contributing to a study of the object's molecular and dust shells by Meixner (STScI, USA).

Our study of the bipolar post-AGB star IRAS 16594-4656 is continued. We are now carefully analyzing the lines in the high-resolution near infrared spectra, in collaboration with P. van Hoof, to gain insight in the winds structuring this object and the shocks they produce. The near-infrared spectrum shows strong H_2 emission lines and some typical metastable shock excited lines. Based on the rotational and vibrational

excitation temperatures, as well as the ortho-to-para ratio, we concluded that H_2 is mainly collisionally excited. We obtained further high resolution near-infrared spectra of H_2 and [Fe II] with the Phoenix instrument on Gemini-South to investigate the proposed geometry and kinematics. H_2 originates at the edge of the lobes while [Fe II] comes from closer to the central star, as does Paβ. The velocities are rather low and no significant difference with slit position angle is observed. To better understand the spatial distribution of molecular hydrogen, we also reduced NICMOS data in the molecular hydrogen band from the HST archive. The images helped in understanding the spectra, but further insight into the geometry of the circumstellar shell is required. To this end the 2-Dust code was used by Mieke De Vlieger, a graduate student at the K.U. Leuven, to construct a model for the circumstellar shell.

Detecting structure developing shells would provide crucial clues to our understanding how the circumstellar shells are shaped. To investigate the critical phases of structure formation in the circumstellar shells of evolved stars, we analyzed imaging polarimetry data obtained with NICMOS polarizers on board the Hubble Space Telescope. It successfully revealed the 3-dimensional structure of the circumstellar shells of post-AGB stars (especially optically thin shells), confirming their hollow and spheroidal nature with equatorial enhancement.

Based on the success in the previous research projects new observing proposals using NACO/VLT and TIMMI2/ESO3.6 have been submitted and accepted. A total of 4 nights of observing time was obtained. Near-IR coronographic imaging polarimetry with NACO has been performed in December 2004 while mid-IR (imaging with TIMMI2 will be performed in January 2005. For the NACO observations we selected objects which are likely developing the axisymmetric structure for the first time in their mass loss history. Coronographic imaging polarimetry with NACO allows (1) high spatial resolution probing of circumstellar environment with significantly reduced PSF effects and (2) separation of dust-scattered light off the shell (polarized component) from the direct star light (unpolarized component). The observations with TIMMI2 are in collaboration with Van Winckel (K.U.Leuven). The objective is to understand how circumstellar shells of evolved stars assume the axisymmetric structure during the late AGB phase by directly probing the dust distribution via thermal mid-IR data.
Jets operating during the late AGB and/or early post-AG evolutionary phase appear to play a fundamental role in the shaping of planetary nebulae. The driving agents for two-sided jets are generally thought to be embedded in accretion disks. However, these equatorial disks have not been observed up to now. We wrote an observing proposal, meanwhile accepted, to detect such a disk for the first time and measure its extent with the VLTI. The planetary nebula Hen 2-90 shows an active knotty jet, and it is reported to have an accretion disk. It was observed with ISO, is bright in the mid-infrared, and an excellent candidate to observe with MIDI on the VLTI.

We identified 21 new, extragalactic planetary nebula candidates in the Sculptor Group spiral galaxy NGC 55, from [O III], Hα, and continuum images of the obtained with the WFI instrument at the 2.2-m telescope of ESO. The [O III] λ5007 Planetary Nebula Luminosity Function (PNLF) indicates a most likely distance of 2.30 +/- 0.35 Mpc, 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 that of NGC 300, adding support to the suggestion that these galaxies form a bound pair.

A.2.3. Perspective for next years

During the evolution toward the PN stage drastic changes are observed in the circumstellar structure and kinematics, while the star evolves towards higher temperatures and finally starts to ionize the nebula around it. We will continue to study the formation of PNe by studying several post-AGB stars and their circumstellar shells spectroscopically and via imaging in the optical and at infrared wavelengths.

With Peter van Hoof who will come to the Observatory in 2005, we will concentrate on photo-ionization modeling of planetary nebulae and spectroscopy of post-AGB stars. We will start to reduce and analyze the observational data obtained in 2005.

A.2.4. Personnel involved

Dr. G. Van de Steene, werkleider
Dr. T. Ueta, IUAP researcher (ended 30/09)

A.2.5. Partnerships

List of national and international partners:

R. Szczerba (Copernicus Astronomical Center,Torun,)
M. Meixner (STScI, USA)
K. Murakawa (Univ. of Hawaii)
P. Van Hoof (Queens Univ. Belfast)
H. Van Winckel and students (K.U.Leuven).

Grants used for this research

IUAP project P5/36 (1 researcher)

Visitors: 2

A.2.6. Publications

A.2.6.1. Publications with peer system

Jacoby G.H., **Van de Steene, G.C.**
Planetary nebulae near the galactic center: Identifications
2004, Astronomy and Astrophysics, 419, 563

Meixner, M., Zalucha, A., **Ueta, T**., Fong, D., & Justtanont, K.
The Molecular and Dust Envelope of HD 56126
2004, ApJ, 614, 371

Ueta, T., Murakawa, K., & Meixner, M.
HST/NICMOS Imaging Polarimetry of Proto-Planetary Nebulae: Probing of the Dust Shell structure via Polarized Light
2005, AJ, 129, 1625

A.2.6.2. Publications without peer system

Ueta, T.
HD 161796 (IRAS 17436+5003)
2004, in ASP Conf. Ser. 313 Asymmetric Planetary Nebula III: Winds, Structures, & the Thunderbird, eds. M. Meixner, J. Kastner, N. Soker, & B. Balick (San Francisco: ASP), 69

Ueta, T., Murakawa, K., & Meixner, M.
NICMOS Imaging Polarimetry of PPN
2004, in ASP Conf. Ser. 313 Asymmetric Planetary Nebula III: Winds, Structures, & the Thunderbird, eds. M. Meixner, J. Kastner, N. Soker, & B. Balick (San Francisco: ASP), 38

Ueta, T., & Meixner, M., in collaboration with the MIRAC team
2-Dust Layered-Shell Model of HD 1798,
2004, in ASP Conf. Ser. 309 Astrophysics of Dust 2003: A Comprehensive International Symposium on Cosmic Dust, ed. A. N. Witt, (San Francisco: ASP), 799

A.2.6.3. Publications in press, submitted

Murakawa, K., Suto, Y., Oya, S., Yates, J. A., **Ueta, T**., & Meixner, M.
High Resolution H band Imaging Polarimetry of IRC +10216: The Obscured Location of the Central Star
2005, accepted for publication in MNRAS

Ueta, T.
Imaging Polarimetry of Proto-Planetary Nebulae - Probing the History of AGB Mass Loss
2005, in Astronomical Polarimetry - Current Status and Future Directions, in press

Van de Steene G. C., Jacoby G.H., Praet C., Ciardullo R., Dejonghe H.
PNLF distance determination to NGC 55
2005, eds. L. Stanghellini, J.R. Walsh, & N.D. Douglas, ESO Astrophysics symposia, Springer Verlag

A.2.6.4. Reports, thesis, etc

Co-promotor licentiaatsthesis van Mieke De Vlieger, K.U.Leuven: Modellering van geëvolueerde sterren en hun stofschil met 2-Dust (IRAS 16594-4656)

A.2.7. Missions

Research missions: 3

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. Together, as well photometric as spectroscopic experience available at the Observatory can be combined in joint projects.

The subdivision made between asteroseismology and variable stars on the one hand and binaries on the other hand is partially artificial, since pulsating stars are not always single stars. Binaries which are selected because one or more components are pulsating are discussed in the subproject on variable stars. The combination of pulsations that potentially contain information about the interior stellar structure and duplicity that restricts the uncertainty on the stellar size and mass gives unique possibilities to improve theoretical stellar models. Another important aspect that deserves development at the Observatory is to exploit the experience in period search techniques for application in space research, where large amounts of data will become available in the future.

Research on other binaries concentrates mostly on binaries in young associations and young stellar groups, because of the additional advantage of the common group age that restricts at least one more free parameter (more characteristics may be in common between stars in the same group). Many of these stars are quite massive and may have significant stellar winds. Here is a possibility of links yet to be exploited with the project A.1.

B.1. Asteroseismology and variable stars

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.

B.1.2. Progress and results

Earlier developed methods to improve the identification of multiple periods in variable stars were tested further and applied to a large number of data sets of variable stars. In 2004 more observations of the Mercator telescope operated by the Institute of Astronomy (IVS, Instituut voor Sterrenkunde, KULeuven) became available. Since 2001, it has been intensively used to observe variable B, A, and F main sequence stars and some selected other variables as well in the seven filters of the Geneva photometric system. Our new method and classical methods of period analysis were further applied to these data in search for variable stars and periodicities. A new algorithm that makes use of the observations in all the filters of the Geneva system simultaneously is in development. This will later be implemented in the period search algorithms.

The identification of frequencies in the WIRE data of the β Cephei star κ Scorpii was completed and confronted with the final results of the spectroscopic line profile analysis of this star. K. Uytterhoeven (IVS, KULeuven) presented this study in her PhD thesis (29/09/2005) for which J. Cuypers gave advice on several topics and was member of the jury for her thesis.

A full dynamical analysis of the binary HD92024, unique in the sense that the β Cephei type primary is in an eclipsing system, has been performed in the framework of L. Freyhammer's PhD. This project is a collaboration with VUB, Univ. Zagreb and ULg . The mass of observations has been collected during the last 15 years from ESO, La Silla, with in particular 4-colour photometry from the Strömgren Automatic Telescope and high-resolution spectroscopy from the FEROS instrument (ESO 1.5m). A full dynamical analysis of the binary, with the pulsating component's temperature determined from high-dispersion spectroscopy, indicates stellar dimensions of 15 and 3 solar masses, radii of 8.4 and 2.1 solar radii and temperatures of 25500 and 12500 K for the bright B1III and faint B7-B9V components. Unfortunately, we show the secondary spectrum to be fainter than the present detection level.

Detailed analysis of line-profile variations in all lines in the wavelength region from H-alpha to H-epsilon indicated that about 30 lines contained significant pulsational information. It was demonstrated that by combining power spectra across more lines, the detection of oscillation frequencies was enhanced significantly. Collaboration with De Cat (KSB) and Aerts (KUL) was started on performing a pulsational analysis of the 103 FEROS spectra with the purpose of identifying modes of two or all three known oscillation frequencies. The fully reduced spectra are released in a data paper.

Of a few δ Scuti stars a period analysis was performed. In particular, an extensive frequency analysis on the new and revised photometric data of the multiple star system DG Leo was performed, and we collaborated in the analysis of the three-component spectra. For a more detailed description of the results obtained on this star, we refer to the report of collaborators P.Lampens and Y. Fremat (Dep.II).

With the Nordic Optical Telescope selected Northern open star clusters are searched for short-period variables of the types δ Scuti and β Cephei. In NGC 1817, we detect one of the largest known populations of δ Scuti stars. Photometry from a previously published study of NGC 7062 is about to be released in a data paper.

The new reduction and analysis of earlier data on γ Doradus stars observed at SAAO (South Africa) in the frame of an international collaboration is still going on.

The high-latitude supergiant HD190390 has been studied in detail in collaboration with M. Reyniers (IVS). Despite its brightness, the evolutionary status of this luminous F-type supergiant at high galactic latitude is not very clear, but in most papers a post-AGB (Asymptotic Giant Branch) classification is assumed. Recently new observational material has been obtained with four different instruments. An extensive abundance analysis based on high resolution, high signal-to-noise NTT+EMMI spectra and done by M. Reyniers confirmed the metal deficiency of this object together with high lithium content. A detailed variability analysis of Geneva photometry over seven years reveals beating with a period of ~3000 days. It is, however, not clear whether this beating is caused by a stable frequency triplet, or it is the consequence of small changes in the main frequency. Data obtained with the HIPPARCOS satellite and the Mercator telescope not only confirm the main period, but also support the presence of a second periodicity of 11 days, which was also found in the Geneva photometry. A conclusive evolutionary status of this object could not be given, but alternative to the UU Her (i.e. post-AGB) status, a W Vir classification is discussed. In the latter case the star is a Cepheid-like variable in an advanced evolutionary stage. It could be the first multiperiodic case ever found.

In collaboration with Brussels (VUB), Rome (OAR), Germany (Potsdam) and Denmark (CUAO) a photometric investigation is carried out on ω Centauri with the purpose of detecting and studying variables, and to study the complex evolution history of this cluster. The observational basis is FORS observations (Chile, Paranal) obtained at high angular resolution (seeing better than 0.3 arcseconds), about 5000 times series points from the Danish 1.5 meter (optical, La Silla), the 3.5 meter NTT (near-infrared, La Silla) and observations from the ESO archive (optical/near-infrared, WFI/2.2m, HST, VLT).

Due to ω Cen's uniquely large spread in chemical abundances, 3-4 separate red giant branches have been discovered in the last 6 years. One of these branches deviates strongly from the bulk of the cluster stars and the origin for the stars in this branch is particularly puzzling as they appear to be chemically and kinematically different from the rest of the cluster stars. Based on optical (VLT and HST) and NTT (near-infrared) data, we show, by comparing observations with stellar evolutionary models, that this branch and a newly discovered sub-giant branch can be described altogether as a clump of the cluster's stars positioned 500 pc beyond ω Cen. If confirmed, this supports other indications of presence of a cluster tidal tail, typical for captured dwarf galaxies. Deep HST-ACS photometry revealed the largest known population ever of white dwarfs (WDs) exceeding 2000 such objects. The sample is shown to agree with predictions based on the ratio between WDs and Horizontal Branch evolutionary lifetimes.

B.1.3. Perspective for next years

The study of the pulsations of HD92024 will be made in depth, from the spectra and from a larger set of photometry, the latter provided by Sterken, in order to eliminate alias frequencies and to identify the oscillation modes. In addition, we are investigating strategies to derive more precise masses.
The methods for period search are continuously refined and will be applied to periodic variables observed by the Mercator telescope and a larger variety of types of variables. Attempts will be made to optimize the algorithms to analyze a huge amount of stars simultaneously.
A new reduction and analysis of earlier data on γ Doradus stars observed at SAAO (South Africa) in the frame of an international collaboration will be continued, in collaboration with L. Eyer (Observatoire de Genève, Suisse) and P. De Cat (ROB).
The preparatory work for the ESA-satellite GAIA (launch in 2011) in the context of variable star detection, period search and classifications will be resumed, in collaboration with L. Eyer and P. De Cat.
Time awarded with the VLT-ISAAC instrument in 2005 will provide new, deep, NIR data of ω Cen that will allow us to constrain the spread in metallicity and cluster age(s) with accuracy better than 1 Gyr. As the photometry is being reduced and calibrated in more bands and fields, the time-series photometry will deliver many new variable and pulsating stars.

B.1.4. Personnel involved

Dr. J. Cuypers, werkleider
Dr. H. Hensberge, werkleider
Lic. L. Freyhammer, IUAP researcher

B.1.5. Partnerships

List of national and international partners:

IvS (K.U.Leuven), VUB, Ulg
Observatoire de Genève
Univ. Zagreb
OAR (Rome).

Grants used for this research:

FWO-Project G.0178.02: "Observational study of Stars in Stellar Systems" (promoter: C. Aerts, K.U.Leuven; co-promoter: H. Dejonghe (UG), C. Sterken (VUB), C. Waelkens)
IUAP project P5/36 (1 researcher)

Visitors: 1

B.1.6. Publications

B.1.6.1. Publications with peer system

Aerts, C., De Cat, P., Handler, G., Heiter, U., Balona, L. A., Krzesinski, J., Mathias, P., Lehmann, H., Ilyin, I., De Ridder, J., Dreizler, S., Bruch, A., Traulsen, I., Hoffmann, A., James, D., Romero-Colmenero, E., Maas, T., Groenewegen, M. A. T., Telting, J. H., Uytterhoeven, K., Koen, C., Cottrell, P. L., Bentley, J., Wright, D. J., **Cuypers, J.**:
Asteroseismology of the β Cephei star ν Eridani - II. Spectroscopic observations and pulsational frequency analysis,
Monthly Notices Royal Astronomical Society 347, 463 - 470

Aerts, C., **Cuypers, J., De Cat, P.**, Dupret, M.A.., De Ridder, J., Eyer, L., Scuflaire, R., Waelkens, C.:
Long-term multicolour photometry and high-resolution spectroscopy of the two γ Doradus stars HD 12901 and HD 48501,
Astron. Astrophys. 415, 1079 – 1088

Bagnulo S., **Hensberge H.,** Landstreet J.D., Szeifert T & Wade G.A.
Discovery of a huge magnetic field in the very young star NGC2244-334 in the Rosette Nebula cluster
A&A 416, 1149-1158

Frémat Y., Lampens P., Hensberge H.
Spectral disentangling of the triple system DG Leo : orbits and chemical composition
2005, MNRAS 356, 545-556

Freyhammer, L.M., **Hensberge, H**., Sterken, C., Pavlovski, K., Smette, A. & Ilijic, S.
The β Cephei variable in the eclipsing binary HD92024 I. Determination of the orbit.
Astronomy & Astrophysics 429, 631

Hensberge, H., Sterken, C., **Freyhammer, L.M**., Pavlovski, K., Ilijic, S. and Smette, A.
The β Cephei variable in the eclipsing binary HD 92024: I. Determination of the orbit
The Journal of Astronomical Data, 10, 2

B.1.6.2. Publications without peer system

Arentoft, T., **Freyhammer, L.M.**, Bouzid, M.Y., Sterken, C., Frandsen, S.
Pulsating stars in open clusters
Communications in Asteroseismology, eds. Michel Breger, 145, 67

Arentoft, T., **Freyhammer, L.M.**, Bouzid, Y., Sterken, C., Frandsen, S.
Pulsating stars in the open cluster NGC 1817
In "Variable Stars in the Local Group", ASP Conf. Series, 310, eds. D.W. Kurtz & Karen Pollard, 242

Cuypers, J., Buzasi, D., Uytterhoeven, K.:
The periods of the β Cephei star κ Scorpii as observed by WIRE, in: Variable Stars in the Local Group (eds. D. Kurtz, K. Pollard),
IAU Coll. 193, ASP Conf. Series 310, 251-254

De Cat P., De Ridder J., **Hensberge H.,** Ilijić S.
Spectroscopic study of the slowly pulsating B stars HD 140873 and HD 123515
In: Spectrocopically and spatially resolving the components of close binary stars, eds. R.W. Hilditch, H. Hensberge & K. Pavlovski, ASP Conf. Ser. 318, 338-341

De Cat, P., De Ridder, J., Uytterhoeven, K., Daszynska- Daszkiewicz, J., **Cuypers, J.**, Schoenaers, C., Ausseloos, M., Broeders, E., Vanautgaerden, J., De Meester, W., Aerts, C., Van Winckel, H., Waelkens, C., Davignon, G., Raskin, G.:
First results of Mercator observations of variable B stars in: Variable Stars in the Local Group (eds. D. Kurtz, K. Pollard),
IAU Coll. 193, ASP Conf. Series 310,238-241

De Ridder, J., **Cuypers, J., De Cat, P.**, Uytterhoeven, K., Schoenaers, C., Broeders, E., Vanautgaerden, J., De Meester, W., De Ruyter, S., Aerts, C., Van Winckel, H., Waelkens, C., Davignon, G., Raskin, G.:
First results of Mercator observations of variable A & F stars, in: Variable Stars in the Local Group (eds. D. Kurtz, K. Pollard)
IAU Coll. 193, ASP Conf. Series 310, 263-266

Frémat Y., Lampens P., Hensberge H.
Spectroscopic disentangling of the triple system DG Leo
In: Spectroscopically and spatially resolving the components of close binary stars, eds. R.W. Hilditch, H. Hensberge & K. Pavlovski, ASP Conf. Ser. 318, 342-345

Frémat Y., Lampens P., Hensberge H., Arentoft T., **De Cat P.**, Garrido R., Parrao L., Peña J.H., Mathias P., Van Cauteren P.
High resolution spectroscopy of the multiple system 20 Leo
In: IAU Coll. 193, Variable stars in the local group, ASP Conf. Ser. 310, 395

Freyhammer L.M., Hensberge H., Sterken C., Pavlovski K., Smette A., Ilijić S.
The eclipsing binary HD 92024: Getting the orbit
In: Spectrocopically and spatially resolving the components of close binary stars, eds. R.W. Hilditch, H. Hensberge & K. Pavlovski, ASP Conf. Ser. 318, 334-337

Schoenaers, C., **Cuypers, J.**
Direct detection of multiple periods in variable stars, in: Variable Stars in the Local Group (eds. D. Kurtz, K. Pollard)
IAU Coll. 193, ASP Conf. Series 310, 283-286

B.1.6.3. Publications in press, submitted

Arentoft, T., Bouzid, M.Y., Sterken, C**., Freyhammer, L.M.** and Frandsen, S.
Multimode Scuti stars in the open cluster NGC 1817
PASP, in press

Frémat Y., Lampens P., Hensberge H.
Chemical analysis of a triple system of A-type stars
In: The A Star Puzzle, eds. J. Zverko, W.W. Weiss, J. Žižnovský & S.J. Adelman, IAU Symp. 224, in press

Freyhammer, L.M., Monelli, M., Bono, G., Cunti, P., Ferraro, I., Calamida, A., Degl'Innocenti, S., Prada Moroni, P.G., Del Principe, M., Piersimoni, A., Iannicola, G., Stetson, P.B., Andersen, M.I., Buonanno, R., Castellani, V., Corsi, C.E., Dall'Ora, M., Petersen, J.O., Pulone, L., Sterken, C. and Storm, J.
On the anomalous red giant branch of the globular cluster ω Cen
ApJ, in press

Lampens, P., Frémat, Y., Garrido, R., Peña, J.H., Parrao, L., Van Cauteren, P., **Cuypers, J., De Cat, P**., **Hensberge, H**., Arentoft, T., Mathias, P. & Hobart, M.:
Pulsation of the δ Scuti Multiple System DG Leo,
Proc. IAU Symp. 224, eds. J. Zverko, W. W. Weiss, J. Ziznovsky & S. J. Adelman, in press

Lampens, P., Frémat, Y., Garrido, R., Peña, J.H., Parrao, L., Van Cauteren, P., **Cuypers, J., De Cat, P.,** Uytterhoeven, K. & Hobart, M.,
Photometric Study of the Light Variations of the Triple System DG Leo,
Astron. Astrophys, accepted

Monelli, M., Corsi, C.E., Castellani, V., Ferraro, I., Iannicola, P.G., Bono, G., Buonanno, R., Calamida, A., **Freyhammer, L.M.**, Pulone, L., and Stetson, P.B. Storm, J.
Discovery of more than two thousand white dwarfs in the globular cluster Centauri
ApJL, in press

Reyniers, M., **Cuypers, J.**:
The evolutionary status of the bright high-latitude supergiant HD190390,
Astron. Astrophys, in press

Uytterhoeven, K., Briquet, M., Aerts, C**.**, Telting, J.H, Harmanec, P., Lefever, K., **Cuypers, J.**
Disentangling component spectra of κ Sco, a spectroscopic binary with a pulsating primary. II. Interpretation of the line-profile variability,
Astron. Astrophys., in press

B.1.6.4. Reports, thesis, etc

Cuypers, J.
Report for COSPAR, April 2004

Freyhammer, L.M.
Variable stars in stellar clusters
PhD thesis,VUB, promotor C. Sterken (submitted Oct. 2004, PhD obtained Jan. 2005)

B.1.7. Missions

Research missions: 10
Operational missions: 3

B.2. Binaries

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. Main goals: characterize the binary population in young stellar groups (Sco-Cen,

NGC 2244) and perform a detailed analysis of the most interesting close binaries (mostly, but not exclusively, in these groups) using the novel spectral disentangling technique.

B.2.2. Progress and results

Binaries with components that are pulsating are discussed in project B.1; hence this report is restricted to other massive binaries and cataclysmic variables. In 2004, a large efforts was devoted to the extension of the spectroscopic data base for the associations in Sco-Cen and the study of the eclipsing binaries HD123335, RV Crt , V578 Mon and AC Vel. No progress was made on several other binaries under study (η Mus, GL Car, CPD-59 2628).

From the observational side, the search for binaries among the fainter members of Sco-Cen was continued using the echelle spectrograph GIRAFFE at SAAO during 3 weeks. A specific sub-sample of fourty candidate wider binaries, selected earlier in cooperation with Pourbaix (ULB) using Hipparcos astrometry, was observed at ESO in March (C. Nitschelm, UA) and June (H. Hensberge), and as far as brightness allowed also at SAAO. All SAAO observations were performed by C. Nitschelm (UA). The data reduction work is performed partly at UA and partly at ROB, in close cooperation.

Concerning specific eclipsing binaries, sufficient spectra of HD123335 were obtained at SAAO and ESO to obtain full coverage of the 35-day orbital cycle. The eclipse of the peculiar magnetic star in this binary was monitored simultaneously in light and spectrum on a single night at ESO (C. Sterken, VUB and cooperation with NBIfAFG Copenhagen). The period searches on HD123335 (orbital and light modulation by the rotation of the peculiar, magnetic component) were refined including the new data.

In the study of the three-component hierarchical triple RV Crt (F, G and K-type components), some twenty spectra were reduced and added to the 39 available composite spectra. Part of these are spectra from Lick observatory obtained by colleagues from UFMG, Belo Horizonte. A procedure was developed to homogenize them with the FEROS data. The analysis will be part of the PhD thesis that K. Torres started in 2004, who foresees to work one year at ROB starting in 2006, paid on a Brazilian fellowship.

A basic ingredient of modern spectroscopic studies of close binaries is the separation of the spectra of the components by the use of a disentangling method. In the framework of understanding the power of this method, it was shown that the shape of temperature-dependent line blends are well reproduced in the early-B type binary V578 Mon, and that trustworthy abundances can be derived from disentangled spectra. The limiting factor in such analysis is clearly the imperfect normalization of the observed spectra.

AC Vel is a triple-star system with a close binary consisting of two evolved B-type stars in a rather rare evolutionary stage, and a third unseen component. During a working stay in Copenhagen, the progress made by the three involved institutes (NBIfAFG Copenhagen with ROB and Univ. Zagreb) was put in a first draft version and the confrontation with stellar evolution models was planned.

B.2.3. Perspective for next years

- Finalize the data reduction of the Hipparcos-selected sub-sample of stars in Sco-Cen and finalize the observations on the stars brighter than magnitude 7.5 (one week on GIRAFFE allotted). 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. Cooperation with UA.
- Detailed analyses on specific binary systems. Finalize the first refereed paper on HD123335 and η Mus (cooperation with VUB, UA and Copenhagen). Obtain spectra of HD123335 during another eclipse, when another part of the stellar surface is visible (FEROS allotted). Finalize the paper on AC Vel (time scheme depending on collaboration with Univ. Zagreb and Copenhagen). Obtain radial ve-

locities near periastron and spectra in one of the eclipses for the A-type binary HR6412, and observe the light curve through cooperation on the Mercator telescope (cooperation with K.U.Leuven and UFMG).

This project will undoubtedly profit from the development of an echelle spectrograph on the Mercator telescope (HERMES project financed by funds obtained by K.U.Leuven, ULB and ROB).

B.2.4. Personnel involved

Dr. H. Hensberge, werkleider
Lic. L. Freyhammer, IUAP researcher

B.2.5. Partnerships

List of national and international partners:

UA (M. David, C. Nitschelm), VUB (C. Sterken) and K.U. Leuven (MERCATOR team)
UFMG Belo Horizonte (L.P. Vaz, K.B. Torres)
ON Rio de Janeiro (S. Daflon, F. Nieva)
Univ. Zagreb (K. Pavlovski, S. Ilijic)
NBIfAFG Copenhagen (E.H. Olsen, B.E. Helt, J.-V. Clausen).

Grants used for this research

IUAP project P5/36 (1 researcher)

Visitors: 1

B.2.6. Publications

B.2.6.1. Publications with peer system

B.2.6.2. Publications without peer system

Hensberge H.
Do our spectra match the requirements for a precise analysis of SB2s?
In: Spectrocopically and spatially resolving the components of close binary stars, eds. R.W. Hilditch, H. Hensberge & K. Pavlovski, ASP Conf. Ser. 318, 43-51

Hensberge H., Nitschelm C., **Freyhammer L.M.,** Bouzid M.Y., Clausen J.V., David M., Helt B.E., Olsen E.H., **Papadaki C.,** Sterken C., Vaz L.P.R.
HD 123335, an interesting eclipsing SB2 in Centaurus
In: Spectrocopically and spatially resolving the components of close binary stars, eds. R.W. Hilditch, H. Hensberge & K. Pavlovski, ASP Conf. Ser. 318, 309-311 [HH9]

Ilijić S., **Freyhammer L.M.,** Helt B.E., **Hensberge H.,** Pavlovski K., Clausen J.V.
The invisible component of the triple system AC Velorum
In: Spectrocopically and spatially resolving the components of close binary stars, eds. R.W. Hilditch, H. Hensberge & K. Pavlovski, ASP Conf. Ser. 318, 242-244 [HH10]

Ilijić S., **Hensberge H.,** Pavlovski K., **Freyhammer L.M.**
Obtaining normalised component spectra with FDBinary
In: Spectrocopically and spatially resolving the components of close binary stars, eds. R.W. Hilditch, H. Hensberge & K. Pavlovski, ASP Conf. Ser. 318, 111-113 [HH11]

Torres K.B.V., Vaz L.P.R., **Hensberge H.**
Study of the spectral disentangling code – korel – in eclipsing triple systems. Application to RV Crt

In: Spectroscopically and spatially resolving the components of close binary stars, eds. R.W. Hilditch, H. Hensberge & K. Pavlovski, ASP Conf. Ser. 318, 114-116

B.2.6.1. Publications in press, submitted

Pavlovski K., **Hensberge H.**
Abundances from disentangled component spectra: the eclipsing binary V578 Mon
A&A, submitted

B.2.6.2. Reports, thesis, etc

Ronald W. Hilditch, **Herman Hensberge** and Krešimir Pavlovski (editors)
Spectroscopically and spatially resolving the components of close binary systems
A.S.P. Conference Series, Vol. 318

B.2.7. Missions

Research: 5
Field: 1

C. Cataclysmic stellar events

The projects discussed here were introduced by H. Boffin before his leave to the E.S.O. headquarters in Garching. The theoretical project on chemical evolution of galaxies has been since redirected and emphasizes now the thermonuclear burning at the surface of accreting compact stars. The second project aims at the study of the accretion disk and its structure in cataclysmic variables, and is observationally oriented. Both projects depend on temporary contracts ending not too far in the future (autumn 2004, resp. 2005) and have consequently an uncertain future, despite the broad cooperation with different Belgian universities (ULB, UCL, VUB).

C.1. Chemical evolution of galaxies

C.1.1. Objectives

This research project was originally articulated around two main orientations: (1) the chemo-dynamic evolution of galaxies and (2) the modeling of stellar thermonuclear combustions associated with explosive astrophysical events (thermonuclear burning at the surface of accreting compact stars). Since the departure of Dr. H. Boffin, the focus was progressively reoriented - with the agreement of the other collaborators involved - towards the second axis of the project on which the emphasis was put in 2004.

C.1.2. Progress and results

The goal of this multidisciplinary research project is to develop computing tools that will allow the exploration of the multidimensional aspects of the propagation of a thermonuclear combustion front in a degenerate stellar plasma. The ultimate goal of this endeavour is the study of the nucleosynthesis associated with different cataclysmic stellar events (SNIa, Classical Novae) as well as the development numerical methods which can contribute to the future development of multi-dimensional (3d) stellar hydrodynamics. In a first step, we are interested in modelling supersonic reactive flows, or detonations, consisting of a precursor shock wave igniting a combustible stellar plasma and a reaction zone immediately behind the shock. Beyond the uni-dimensional picture, terrestrial detonation experiments clearly show that the detonation front consists of sets of incident shocks, transverse waves and Mach stems all interacting to form cellular structures wherein pockets of unburned gas can subsist. The cellular tri-dimensional nature of detonations could play a significant role in the thermonuclear explosion of the accreted matter on a white dwarf star. The aim of our numerical study is to investigate the complex dynamics of the reaction front

and the concomitant nucleosynthesis in a potentially interesting situation [see Goriely (2002)] for the chemical evolution of galaxies.

In this context, a Riemann solver adapted to the equation of state appropriate to the stellar plasma of the explosive mixture was developed (see annual report for 2003). This module has been inserted in a 2d/3d Eulerian hydro-code designed for the project. It is a second order, finite-volume method reminiscent of the original MUSCL scheme of van Leer. The first simulations of a non-reactive astrophysical shock wave propagation have been successfully achieved. This research is conducted in collaboration with IAA-ULB and Prof. M Palexandris (UCL). In November 2004, the development of the nucleosynthesis part of the code was started. A general operator splitting algorithm, wherein nuclear kinetics and energy generation are considered together with the hydrodynamic calculation, is investigated and is still in an early stage of development. Concurrently to this work of computational fluid dynamics, a tool for computing in detail the structure of a planar detonation front according to the model of Zeldovich-Von Neuman-Doering (ZND) is being prepared. This program, adapted to the equation of state of the astrophysical plasma, will serve to calibrate the characteristic length scales which will appear in the hydrodynamic simulations envisaged. It will be also used to study, by means of the most complete nuclear kinetics possible, the potential pathologies due to endothermic processes inside the reactive wave. This research is conducted in collaboration with the IAA-ULB and the Laboratoire de Combustion et de Détonique (CNRS-Poitiers-France).

In parallel, the study and implementation of the physics of thermonuclear plasmas in the Lagrangian SPH method is continued. We aim at developing adaptive non-spherical kernels for the SPH hydro-code specifically dedicated to highly compressive waves leading to the ignition of a thermonuclear detonation.

Ref : Goriely, S. et al. « He-detonation in sub-Chandrasekhar CO white dwarfs : A new insight into energetics and p-process nucleosynthesis », Astronomy&Astrophysics Letters , 383,L27-L30, 2002.

C.1.3. Perspective for next years

With the hydrodynamics code developed since 2003, we will perform our first bi-dimensional simulations incorporating a realistic stellar equation of state and a limited nuclear reactions network (an “alpha-chain” extending from ^{4}He to ^{56}Ni) for the energy generation. A slightly perturbed ZND profile will be used as initial condition to produce (2d) cellular structures in the detonating stellar plasma. The main objective of these simulations will be to estimate the robustness of the hydro-code in a situation close to the real stellar phenomenon. We can then decide on the necessity of developing approximate Riemann solvers on grounds of the capabilities and CPU time requirements of our shock-capturing algorithm. The questions coming afterward will concern the adaptive spatial meshing as well as the extension to 3D and the parallelization of our simulation tool. The effort carried out with the team of the LCD - Poitiers will lead to the re-examination - with more extended nucleosynthetic networks and diverse initial nuclear mixtures - of results obtained by Sharpe (1999) in planar detonations and later in curved geometry (Sharpe, 2001).

Ref : Sharpe, G.J. et al. « The structure of steady detonation waves in Type Ia supernovae : pathological detonations in C-O cores », M.N.R.A.S, 310,1039-1052, 1999.

Ref : Sharpe, G.J. et al. « The effect of curvature on detonation waves in Type Ia supernovae », M.N.R.A.S, 322,614-624, 2001.

C.1.4. Personnel involved

Dr. Y. Busegnies, "chercheur supplémentaire" and IUAP researcher (1/4)

C.1.5. Partnerships

List of national and international partners:

In 2003, I have taken many steps (talks, lectures, various meetings) in order to assemble a research group involving astrophysicists and experts on terrestrial combustion processes so as to tackle the study of astrophysical explosive phenomena. These efforts have led to our project being joined to the wider research project of the "Groupe de Combustion et Supernovae" under the auspices of the Centre National de la Recherche Scientifique (France). This broad collaboration also involves the Département d'Astrophysique du Commissariat à l'Energie Atomique (Saclay, France), combustion laboratories from Poitiers and Marseille, and the Département de Mathématiques Appliquées de l'Université de Bordeaux. In Belgium, I have contacted Prof. M. Papalexandris, an expert in the modelling of combustion at the Université Catholique de Louvain. Together, we have initiated a collaboration with the IAA-ULB.

Grants used for this research

IUAP project P5/36 (1/4 researcher)

Visitors: 0

C.1.6. Publications

C.1.6.1. Publications in press, submitted

Busegnies Y., Francois J., Paulus G..
SPH simulations of reactive shock tubes in an astrophysical perspective: 1d experiments
Submitted to Shock Waves, november 2004

C.1.6.2. Reports, thesis, etc

Progress report on the Belgian contribution on the project "Combustion et Supernovae thermonucléaire"
Chatelaillon France, November 2004

C.1.7. Missions

Research: 2

C.2. Cataclysmic Binaries

C.2.1. Objectives

This research is mainly devoted to the better understanding of the accretion disc phenomena and the underlying viscosity sources of non-magnetic cataclysmic variables called dwarf novae and nova-likes. Our study is based on both photometric and spectroscopic data.

C.2.2. Progress and results

The newly formed collaboration with P. Reig as well as the previously formed one with P. Boumis aims at the monitoring of some poorly known cataclysmic variables (CV). This aim is accomplished by providing us with observing time at Kryoneri and Skinakas Observatories in Greece or by monitoring targets themselves. For 2004 we have been allocated 25 nights in total.

During 2004 we have continued gathering photometric data of CVs we had already obtained data through the previous years, as well as some new CVs using different instruments in different sites. Two examples of CVs that lie in the first category are V1193 Ori and V795 Her. For V1193 Ori we have for the first time found through time-resolved photometry its previously reported spectroscopic periodicity and have continued observing it in order to confirm it and further study this system. V795 Her possesses a peculiar

2.8 hour modulation that appears and disappears through the years. In order to study this behaviour and conclude on its origin we have obtained 20 runs in total. A paper analysing our results on the previous systems among others, as well as some new targets such as LQ Peg, V751 Cyg, LD 317 and UMa7 is in progress.

Part of this year's work has also been devoted to the reduction and analysis of echelle spectroscopic data obtained by H. Boffin in 1999 with the ESO NTT, La Silla, Chile. We concentrated in particular on IP Peg. We reduced the spectra with the echelle package routines in IRAF. IP Peg is the first CV to show evidence of spiral arms in its accretion disc (Steeghs et al, 1997) and therefore constitutes an excellent laboratory in order to study the accretion disc evolution and outburst mechanisms. These unique high resolution and large wavelength coverage echelle spectra provide us with several emission lines whose simultaneous study allows us to probe in detail the structure of the accretion disc and the contribution of the secondary phase. The nine most prominent lines have been identified. The phase folded spectra accompanied by preliminary Doppler maps have been presented in a poster at "The Astrophysics of Cataclysmic Variables and related objects" conference last July at Strasbourg.

C.2.3. Perspective for next years

As far as the photometric study of CVs is concerned, our aim is to deeper analyze all the data we have obtained so far. Further photometric observations will be conducted for those targets that have been observed insufficiently. Moreover, EX Hydrae will be included in the observing list, in collaboration with C. Sterken. Two weeks of observing time have already been granted at the SAAO observatory.
As for the spectroscopic data, the work on IP Peg will continue and we will finalize the reduction and analysis of two more CVs that had been part of the same observing mission.

C.2.4. Personnel involved

Lic. C. Papadaki, researcher on PhD grant (Action 2)
Dr. J. Cuypers, werkleider (limited involvement)

C.2.5. Partnerships

List of national and international partners:

C. Sterken (VUB), H. Boffin (ESO)
P. Boumis and S. Kitsionas (National Obs. of Athens, Greece), P. Reig (Univ. of Crete, Greece)
V. Stanishev (Stockholm Univ., Sweden)
Z. Kraicheva and V. Genkov (Astrophysical Inst. of the Acad. of Sc., Sofia, Bulgaria)
D. Steeghs (Harvard-Smithsonian Center for Astrophysics, Cambridge, USA).

Grants used for this research:

4-year PhD grant

Visitors: 0

C.2.6. Publications

C.2.6.1. Publications with peer system

Stanishev V., Kraicheva Z., Boffin H.M.J., Genkov V., **Papadaki C.**, Carpano S.
Accretion Disc Evolution in DW Ursae Majoris : A photometric study
A&A, 416, 1057

C.2.6.2. Publications without peer system

Papadaki, C., Boffin, H.M.J., Cuypers, J., Stanishev, V., Kraicheva, Z., Genkov, V.:
Time resolved photometry of cataclysmic variables, in: Spectroscopically and Spatially Resolving the Components of Close Binary Stars, (eds. H. Hensberge, R.W. Hilditch, K. Pavlovski),
ASP Conf. Series, 318, 399-401

C.2.6.3. Publications in press, submitted

Papadaki C., Boffin H.M.J., Steeghs D.
Simultaneous Doppler Maps of IP-Peg in outburst
astro-ph/0409634 (ASP Conference series, in press)

C.2.7. Missions

Research: 3
Field: 8

D. Extra-galactic research

The research on extra-galactic object and gravitational lenses was introduced at the Observatory in the last decade of the 20th century by E. van Dessel, in cooperation with the group of J. Surdej at ULg, and supported by temporary contracts. These projects were set up in close connections with the links in the project for the construction of a liquid mirror telescope. After the retirement of van Dessel, it was decided in agreement with the group at ULg and the PRODEX science administration in Belgium to transfer this project to Liège, where the involved researcher is preparing his PhD. The transfer will be made at the end of March 2005.

D.1. Study of active galaxy nuclei (AGN) and galaxy clusters

D.1.1. Objectives

Our objectives are to validate and improve our current knowledge about active galaxy nuclei (AGN) and galaxy clusters.

D.1.2. Progress and results

Initially we collected the data from the XMM-LSS, SWIRE and CFHT surveys and established catalogs in X, IR and optical bands. Each catalog has been carefully examined to remove false and redundant detections, a very time-demanding but necessary investment. We also created new tools to fit spectrally and spatially the galaxy clusters, in cooperation with colleagues in Liège, Saclay and Birmingham. Soon the results of this work will be released in a database.

D.1.3. Perspective for next years

The next step is to cross - correlate the different catalogs to select AGN candidates and to study how their distribution and characteristics relate, e.g. by analyzing the distribution of AGN through galaxy clusters.

D.1.4. Personnel involved

Lic. C. Libbrecht, researcher on PRODEX contract

D.1.5. Partnerships

List of national and international partners:

ULg (research group of J. Surdej)
CEA Saclay, Univ. Birmingham

Grants used for this research:

PRODEX grant related to XMM

Visitors: 0

D.1.6. Publications

D.1.7. Missions

Research: 2
Filed: 0

DEPARTMENT 4: Solar Physics

SECTIONS 8 & 9: Structure and Dynamics of the Solar Atmosphere & Solar Activity

Introduction: overall objectives and evolution of the Department

The year 2004 has been a very busy and exciting one for the Department of Solar Physics, with the further roll-out of our participation to the preparation of the space missions STEREO and PROBA2 (instruments SWAP and LYRA), and our continued activities in research based on exploitation of EIT and other space data and ground-based solar observations. Thus, the science staff in the Department increased with the recruitment of 6 contractual scientists to contribute to the ongoing scientific studies, to assist in the construction of the two PROBA2 solar instruments and to work on the preparation of the science exploitation of PROBA2 and STEREO/SECCHI: Dr. G. Lawrence, 16/1/04 (SWAP), Miss M. Dominique, 16/1/04 (LYRA, position shared with BISA), Dr. T. Katsiyannis, 1/2/04 (Solar Drivers of Space Weather), Dr. A. Theissen, 1/3/04 (LYRA), Dr. E. Podlachikova, 1/4/04 (STEREO), Dr. V. Delouille 1/5/04 (LYRA). Towards the end of the year, applications have been prepared for the continuation of our PRODEX projects, which in the mean time have been granted. The Solar Physics Department of the ROB continues to flourish therefore, supplementing the limited Observatory dotation with a significant amount of external funding from peer-reviewed competitive tenders. The high regard of our work has been translated among other things in several invitations to team members to present invited reviews at workshops and conferences.

Regarding the permanent staff, Mr. D. Carré was again mostly on sick leave; he was absent during more than 11 months out of 12, only briefly back at work from 1/4 to 27/4/04. This continuous absence had again a very detrimental impact on the solar observing and SIDC activities, by accumulating the workload on other support staff members. This situation is aggravated by the fact that two other staff members are nearing retirement age, implying frequent absences due to ill-health and the inability to participate to the solar observations. On the other hand, a constructor of scientific instruments (Eng. technician in electronics) could finally be recruited. This position was left vacant for many years. It was opened by SELOR in 2004 following insisting requests submitted in the course of 2003. The selection process took place over several months in 2004 and led to the selection of M. Aydin Ergen, who took his position in the Department on January 1st, 2005. Together with M. Dufond, he will strongly help in the maintenance of the ground-based instruments, primarily in Uccle but also in Humain. This highly needed addition to the support staff will also increase our capability to develop new instrumentation.

In 2004, like in 2003, Pierre Cugnon was in long-term sick leave. F. Clette continued to ensure his replacement as the Head of the Department until the end of September 2004 and worked full-time for this task, despite the successful redistribution of responsibilities in the new departmental structure introduced in November 2003. In order to be able again to carry out science work and revive topics that he had abandoned since 2002, F. Clette finally decided to hand over the management of the Department to Ronald Van der Linden starting on October 1st 2004. In coming months, F. Clette will remain in charge of the sub-team managing the ground-based instruments and will work primarily on the valorization and exploitation of the Uccle solar data.

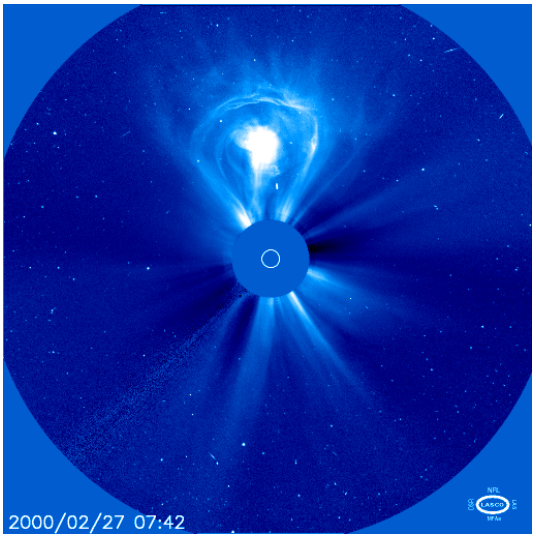
Finally, not much later, Pierre Cugnon unfortunately died following heart surgery on October 18, 2004. The funerals took place on October 22 in the presence of all the current Department staff members as well as a large community. At the ceremony, F. Clette, as the senior scientist in the Department, presented a tribute to P. Cugnon's scientific career in the name of all science colleagues of the Observatory and transmitted the numerous messages of sympathy received from foreign science colleagues and friends. In the history of the Solar Physics Department, this event concluded a transition that had started about 10

years ago, under the impulse of Pierre Cugnon, and which brought the development of new science topics, in particular space science, driven by a new generation of enthusiastic young scientists.

We have divided this report into four `Research Themes', including both the scientific and operational activities. In reality, of course, the department has a long tradition of working in close unity, so there are many areas where the separation over the research themes is not clear-cut and areas of overlap are obvious. However, there are at the same time clear distinctions in the orientation of the items that warrant their separation. We also appended to this report a brief account of our participation in `supporting activities', which includes Educational and Public Outreach and management tasks. This report was written jointly by D. Berghmans, F. Clette, J.-F. Hochedez and R. Van der Linden.

A. CME Studies

Coronal Mass Ejections (CMEs) are probably the most spectacular phenomena observed on the Sun. A CME is a huge bubble of plasma threaded with magnetic field lines that is ejected from the Sun over the course of several hours. The Large Angle and Spectrometric Coronagraph (LASCO) on the Solar and Heliospheric Observatory (SOHO) is the first instrument that has detected CMEs routinely over a timescale comparable with a solar cycle. At solar minimum we observe about one CME a week. Near solar maximum we observe an average of 2 to 3 CMEs per day.

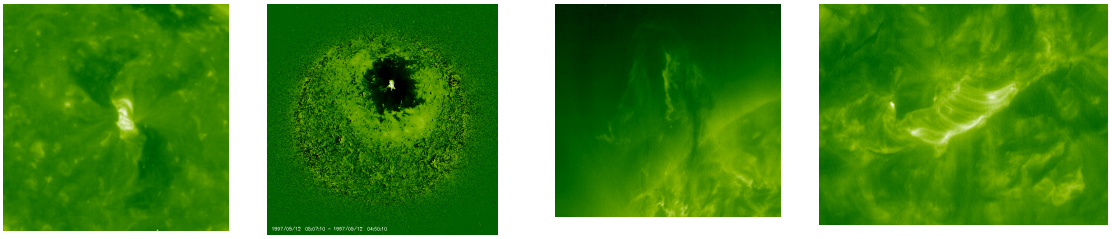


The study of CMEs is important for solar-terrestrial relations as some CMEs may be directed towards the Earth and – with a suitable magnetic field orientation – produce geomagnetic storms. They are therefore seen as the solar events causing the most hazardous space weather conditions on earth. They can trigger geomagnetic storms which e.g. affect the terrestrial communication and the reliability of power systems. (see Research Theme "Space Weather").

CMEs are mainly observed as intensity enhancements in coronagraphic white light images. However, the *origin* of CMEs cannot be traced by coronagraphs, as the occulting disc obscures a direct view of the initiation site. The Extreme-ultraviolet Imaging Telescope (EIT) onboard the Solar and Heliospheric Observatory (SOHO) with its full disc coverage is well suited for the detection of CME initiation in the solar atmosphere.

Figure 11: The "lightbulb" Coronal Mass Ejection (CME) showing the three classical parts of a CME: leading edge, void, and core. (SOHO/LASCO)

Studies have shown that a number of phenomena observed with EIT are indeed precursors to the CMEs seen by coronagraphs. These phenomena include dimmings, EIT waves, prominence eruptions and flares. None of these associated phenomena are however a necessary condition for the occurrence of a CME. Different CMEs can be generated or associated with a variable subset of this list. The observations made by EIT are used to obtain information about the still-enigmatic CME initiation mechanism.



Dimming | EIT wave | Erupting promi-nence | Post-eruption arcade

Figure 12: Different on-disc signatures of CMEs observed by EIT onboard SOHO.

At the ROB, we are interested in the understanding the complete CME process from its precursors on the solar disc, down to its effect on the Earth magnetosphere. This research theme thus naturally touches at the "Space Weather" research theme (see below) but is in contrast to the latter – which is of an applied nature – concerned with fundamental research.

More specifically our fundamental questions are:

- *understanding the CME initiation process.* We want to understand which structures and events are precursors for CMEs. Based on the characteristics of the eruption source, can we determine the later evolution of the CME?
- *understanding the internal structure of CMEs*. What is the structure of an interplanetary CME? What is its 3D magnetic configuration? How can it be deduced from the observations?
- *understanding the geo-effectiveness of a CME.* What determines the ability of a CME to trigger a geomagnetic storm? Can we simulate this process? Can we estimate the time-of-arrival of a CME at the magnetosphere?

The ROB heritage as co-investigators in the LASCO & EIT instruments has given us good understanding and access to the state of the art instrumentation (see the 'Coronal heating' research theme for details on our EIT activities). The most important upcoming space mission for CME studies is the STEREO twin spacecrafts mission, with each spacecraft carrying the SECCHI remote sensing instrument package. The ROB is again co-investigator for this mission. We actively prepare the exploitation of this mission on the basis of LASCO/EIT images.

The ROB is also principal investigator in the PROBA2 mission. PROBA2 is an ESA technology demonstration mission that is scheduled for launch in February 2007. Besides the demonstration of state-of-the-art technology, PROBA2 has also a scientific payload consisting of the Lyman alpha radiometer (LYRA, see "Solar Irradiance" research theme) and the Sun Watcher using APS and image processing (SWAP). SWAP in an evolved version of EIT, especially optimized for observations of CMEs on the solar disc.

Finally, the ROB also participates in a Belgian network ("Solar Drivers of Space Weather") for numerical simulations of CMEs. The network consists of the Von Karman institute (contributing advanced numerical methods), the KULeuven/CPA (project lead and contributing expertise in MHD simulations), BISA (contributing magnetospheric know-how) and ROB. The role of ROB is to provide observational input that can be used as initial conditions for the simulations. ROB has contributed for this the CACTus software (Computer Aided CME Tracking).

In what follows, we will give a detailed overview of our activities in the 'STEREO/SECCHI' project, the 'SWAP' project and the 'Solar Drivers of Space Weather' project. All three projects are supported by ESA/PRODEX and specifically aim at studying coronal mass ejections.

A.1. STEREO/SECCHI

A.1.1. Objectives

'STEREO' is a NASA project consisting of 2 identical spacecraft that will observe the solar corona and heliosphere simultaneously from 2 viewpoints, left and right of the Sun-Earth line. In Belgium, both the ROB and the 'Centre Spatial de Liege' (CSL) are co-investigators in the consortium that builds the STEREO/SECCHI remote sensing instrument suite for the STEREO spacecraft. The role of the solar physics group of the ROB is the scientific preparation of this mission. The primary goal of SECCHI (Sun Earth Connection Coronal and Heliospheric Investigation), a component of STEREO, is to advance the understanding of the 3D structure of the Sun's 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 expected launch data for the STEREO spacecraft is late 2006. Once the commissioning phase ends and both spacecrafts are inserted in their heliocentric orbit, the nominal mission can begin. We expect the routine scientific data flow to start only late in the first half of 2007. In the current pre-launch phase the ROB-SECCHI team concentrates on 1) CME studies on the basis of EIT and LASCO images and 2) the development of software tools.

CME studies on the basis of EIT and LASCO images

A key objective of the STEREO mission is the phenomenon of Coronal Mass Ejections (CMEs). The CME initiation process in the low corona will be observed in the extreme-ultraviolet (EUV) by SECCHI, and its data can now be simulated with the SOHO/EIT data. Of course, EIT data show the Sun from only one viewpoint, but the CME initiation can be observed from different angles taking into account its position on the solar disc. A study of CME signatures observed by EIT is performed. "CME Watch" data series (cadence of about 12 minutes) taken in four EIT bandpasses in 1999 – 2000 (during the epoch of high solar activity) have been used. While the "CME Watch"' series in the Fe XII bandpass (19.5nm) are taken routinely, the observations with similar cadence in other three bandpasses are made only occasionally.

The sources of CMEs observed by SOHO/LASCO during these periods have been identified. CME signatures observed in the low corona by EIT include: EUV dimmings, EIT waves, prominence/filament eruptions, post-eruption arcades and a variety of limb signatures. The particulars of using each EIT bandpass for the CME detection are studied. Observations in the Fe XII bandpass seem to be optimal for the CME source region identification. The Fe XV bandpass (28.4nm) is less efficient due to the lower signal-to-noise ratio. The Fe IX/X bandpass (17.1nm) is also suitable. However, significant transition region contribution to this bandpass makes the identification of CMEs on-disc more difficult. The cool He II bandpass is less convenient, although it also shows a variety of interesting events in association with CMEs, in particular erupting prominences/filaments. It is shown that EUV dimmings (often accompanied by EIT waves) are the most frequent CME signatures.

The 3D structure of EIT waves and CMEs is addressed using the observations of CME initiation close to the solar limb. These observations suggest that EIT waves can be regarded as a bimodal phenomenon. The wave mode represents a wave-like propagating disturbance. Its characteristic features are: propagation of a bright front to large distances from dimming sites; quasi-circular appearance of the wave front. The eruptive mode is a propagation of a dimming and an EIT wave as a result of consecutive opening of magnetic field lines during the CME lifting. It can be identified by noting the expansion of a dimming and appearance of another dimming ahead of a bright front. EIT waves can be readily identified in the Fe XII, Fe IX/X and Fe XV EIT bandpasses, but it is not yet clear if they can be observed in the He II bandpass.

A separate investigation (in collaboration with the Laboratoire d'Astrophysique de Marseille, LAM) concerns the 3-dimensional structure of the streamer belt. A model developed at LAM permits to simulate the quasi-stationary configuration of the streamer belt starting from the National Solar Observatory photospheric magnetograms and using the potential field source surface model. The synoptic maps of the streamer belt obtained with the SOHO/LASCO C2 coronagraph and the simulated synoptic maps constructed from the model of the warped plasma sheet have been compared. The earlier findings have been confirmed: the streamers are associated with folds in the plasma sheet. Although the large-scale structure of the streamer belt is described reasonably well, some features cannot be explained in this framework. It has been proposed that two types of large-scale structures take part in the formation of these additional features. The first one is an additional fold of the neutral line, which does not appear in the modeled source surface neutral line, but is well visible in photospheric magnetograms. The second one is a plasma sheet with a ramification in the form of a secondary short plasma sheet. It was shown that if these structures are taken into account, the observed configurations of the streamer belt can be better described. The secondary plasma sheet can be formed between two secondary current sheets connected with the main current sheet. The result suggests that the potential field source surface model is unreliable for the description of the fine structure of the streamer belt, even during the epoch of low solar activity.

A spiral-like motion of EIT waves has been discovered and radial velocity and dimming characteristics can be determined automatically. The sense of rotation is found to depend on the solar hemisphere: clockwise sense if EIT wave is in the southern hemisphere, counter-clockwise sense if it is in the northern hemisphere.

Development of software tools

A ROB-SECCHI team visited the Naval Research Laboratory (NRL) and discussed the ROB software developments. Four developments were identified as necessary: The Solar Weather Browser, CACTus, Velociraptor and the EIT wave detector.

The *Solar Weather Browser* is a visualization interface that was originally developed for the "SIDC ESA Space Weather Applications Pilot Project" (see "Space Weather" research theme).

The *Computer Aided CME Tracking* (CACTUS) software that is under development, jointly between the SIDC project and the SECCHI project, is seen as an important asset for our future contribution to the SECCHI consortium. In collaboration with G. Stenborg (NRL) we investigated the ability of the wavelet operator to enhance CME signatures in height-time diagrams from LASCO images. After applying the CACTus detection software we found that the detections showed enough similarity with the original detections to conclude that the wavelet operator might provide a useful alternative to the running difference images.

The *EIT wave detector* aims at detecting the occurrence of Earth-directed CMEs in their earliest stages as EIT waves in EUV observations of the solar disc. The EIT wave detector software tool that we are developing consists of the following steps:

1. *Event occurrence* is detected due to high order moments in running difference images. The appearance of such coherent structures as EIT waves increases strongly the mathematical moments (variance, skewness, and kurtosis) of the spatial intensity distribution. The high order moments are zero for the normal Gaussian distribution of the white noise that you would expect if there is no EIT wave. They can thus be used for the detection of organized large-scale structure occurrence. The next step is to determine the location, timing, structure and dynamics of the EIT wave and the associated dimming.

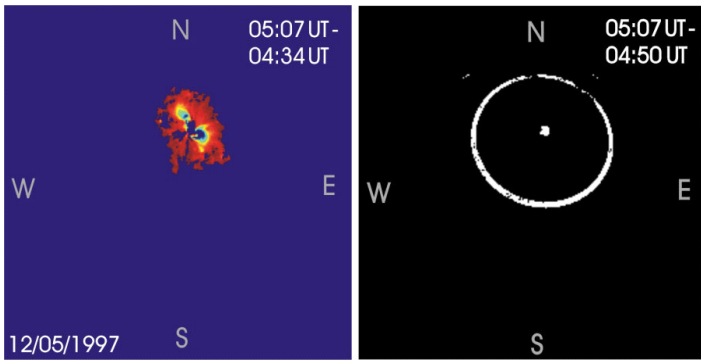


Figure 13: Result of an EIT wave detection. The picture on the left side shows an extracted dimming; on the right we show an extracted EIT wave front.

2. *Progressive build-up of dimming:* starting from the most intensive dimming, we determine the full size of the event using the assumption that the dimming is a simply connected region. On Figure 13 the left shows an example of the resulting dimming. Now, it is easy to determine the geometrical characteristics of the dimming and their evolution in time. EIT wave properties are analyzed in the polar coordinate system, where the radius vector starts at the eruption center and varies on the solar sphere projection with angle and distance defined on the sphere

3. *Ring analysis* is used to quantify the radial velocity of the EIT wave, after having applied noise filtering. The integral intensity of the rings constructed on the disc centered around the eruption center is found to represent well the global propagation of the EIT wave front (Figure 13- right). We have shown that the dimming area, the propagating front, and the eruption center regions are morphologically similar. The front velocity is also determined from this plot.

4. *Sectors analysis* or dependence of intensity on the angle in the polar coordinate system is used to quantify the angular rotation of EIT wave. Besides the radial expansion, rotation in the sense S→E→N→W is observed for this wave, forming together a spiral-like motion of the EIT wave.

Velociraptor is based on a new image-processing tool that will simultaneously estimate both motion and intensity variation from two successive EUV coronal images. It is an application of a method developed in the research theme "*The Variable Magnetic Corona"*.

A new workstation and a RAID server (mass data storage) were acquired on the project. This workstation is now the central node of the ROB-SECCHI team.

A.1.3. Perspective for next years

The PRODEX 7 funding for the ROB-SECCHI activities ended on December, 31 2004. A renewal proposal under PRODEX 8 for the activities of the ROB-SECCHI team was submitted to BELSPO and is meanwhile accepted.

The investigation of the CME source regions will be continued. A particular emphasis will be put on the correspondence of EUV dimmings observed by EIT to CME structures seen by LASCO. The investigation of the streamer belt will be continued as many plausible plasma structures are not included in the model yet. The model can be used for simulating the large-scale structure of the low corona observed during total solar eclipses (collaboration with S. Koutchmy, Institut d'Astrophysique de Paris). The interaction of CMEs with the streamer belt will also be studied.

The Solar Weather Browser is a visualization interface that was originally developed for the "SIDC ESA Space Weather Applications Pilot Project" (see "Space Weather" research theme). After the SIDC project is finalized, it will be further developed within the context of, and specifically for, the SECCHI project.

For final evaluation of the EIT wave detector it is necessary to process many more events with the developed technique, including many more complex events. When we are confident that all interesting features are well-recovered, we will use the algorithm developed for a full automated archive scan. A theoretical model for EIT waves will be constructed.

The performance of CACTus will be improved through the use of wavelet techniques and clustering methods. CACTus will be distributed as free software through the Solar Soft Library. We are finalizing an automatically generated CME catalog using CACTus, which will be published and made available to the solar community via our website.

The collaboration with the numerical modeling group under the lead of Prof. Stefaan Poedts (CPA-KULeuven) will be intensified (see also 'Solar Drivers for Space Weather Project'). At present they do a comparative study on the effect of the background wind on the CME shock evolution. We will try to merge the gap between observation and simulation using our automated software.

Several meetings are foreseen in 2005 that are important for the SECCHI activities:
the STEREO meeting (Hamburg, 1-3 May 2005)
the IAGA 2005 (Toulouse, 18-29 July 2005), 'The 10th Assembly of the International Association of Geomagnetism and Aeronomy' and present a contribution in Section GAV02 (Indices and algorithms for detecting geomagnetic and space weather events)

A.1.4. Personnel involved

Project lead: D. Berghmans
People hired on the project: A. Zhukov, E. Robbrecht (since 2004/08/01), E. Podladchikova (since 2004/04/01), S. Willems
Additional contributions from: G. Lawrence, B. Nicula, S. Gissot, J.-F. Hochedez, V. Delouille, L. Wauters.

A.1.5. Partnerships

List of national and international partners

The ROB-SECCHI team is a member of the international SECCHI consortium which is led by the Naval Research Laboratory (NRL, Washington DC). The complete consortium list is:
Naval Research Laboratory, Max-Planck Institut fur Aeronomie, University of Kiel, Rutherford Appleton Laboratory, Mullard Space Science Laboratory, NASA Goddard Space Flight Center, University of Birmingham, Centre de Spatial Liege, Lockheed Martin Advanced Technology Center, Centre d'Astrophysique Spatiale, Institut d'Optique, USAF Space Test Program, Swales Aerospace, Hytec Incorporated, Praxis Incorporated, The Hammers Company, Boston College, Smithsonian Astrophysical Observatory, Royal Observatory of Belgium, Observatoire de Paris, Laboratoire d'Astronomie Spatiale, NASA Jet Propulsion Laboratory, Science Applications International Corporation, Stanford University, University of Michigan, Southwest Research Institute. More information can be found on http://projects.nrl.navy.mil/secchi/organizations.html

Grants used for this research:

ESA/PRODEX Contract C90131 "SECCHI Exploitation".

Visitors: 1.

A.1.6. Publications

A.1.6.1. Publications with peer system

Zhukov A. N., Auchère F.
On the Nature of EIT Waves, EUV Dimmings and Their Link to CMEs
Astron. Astrophys. 427, pp. 705-716 (2004).

Zhukov A. N.
Initiation of CMEs: EIT Waves and EUV Dimmings
In: The Solar-B Mission and the Forefront of Solar Physics, ASP Conference series, Vol. 325, T. Sakurai and T. Sekii (eds.), pp. 381-388 (2004).

A.1.6.2. Publications without peer system

A.1.6.3. Publications in press, submitted

Podladchikova O., Buehner J, Nikutowsky. V.
Multiscale Magnetic Energy Release in Bright Points by Means of SVD and Principal Component Analysis
Astronomy &Astrophysics, in press.

Robbrecht, E., Berghmans, D., Van der Linden R.A.M.
Objective CME detection over the Solar Cycle: a first attempt
Advances in Space Research, in press

Robbrecht, E., Berghmans, D.
Entering the era of automated CME recognition: a review of existing tools
Solar Physics, in press

Podladchikova O., Berghmans D.
Automated detection of EIT waves and dimmings
Solar Physics, submitted.

Saez F., **Zhukov A. N.**, Llebaria A., Lamy P.
On the 3-Dimensional Structure of the Streamer Belt of the Solar Corona
Astronomy & Astrophysics, submitted.

A.1.7. Missions

Research missions (conferences and scientific visits): 13
Operational missions (commissions, working groups, consortium discussions): 5
The SECCHI project does not require field missions (observations, station maintenance).

A.2. PROBA2/SWAP

A.2.1. Objectives

SWAP is a solar EUV imager designed for scientific studies of space weather events in the solar corona and for daily monitoring of the solar corona. It specifically aims at the observations of CME signatures on the solar disc where coronagraphs are blind. The instrument is built under the project management of the Centre Spatial de Liège (CSL). After launch (Feb 2007), the Royal Observatory of Belgium will be the principal investigator institute for the exploitation of the data. At that time, SWAP may well be the only EIT replacement available to fulfill the critical mission of solar coronal monitoring

A.2.2. Progress and results

The ROB-SWAP team continued to give scientific support to the CSL-SWAP team whenever a change of the instrument design had a direct consequence on the scientific performance of the instrument. To streamline this process, we have written an instrument specification document that specifies the overarching science requirements of the SWAP mission (see below). This document is the basis for the CSL team to propagate requirements to the industrial suppliers of the SWAP subsystems.

An important contribution of the ROB-SWAP team this year was the specification of the onboard software. Two major specification documents were written, in discussion with CSL, and submitted to Verhaert, the prime contractor of PROBA2: the SWAP Data Manager and the SWAP Instrument Manager (see below). A new method was developed at ROB that boosts the compression ratio of solar images. This effort led to a scientific publication (Nicula et al, 2004) and will be used onboard the PROBA2 satellite.

In the course of the year, the ROB-SWAP team strongly supported some changes to the PROBA2/SWAP mission that were necessary for the performance of SWAP as a scientific instrument for space weather monitoring. The changes that were finally implemented are:
a new design of CMOS detector: SWAP will use the HAS CMOS detector instead of the STAR1000 detector (both from Fillfactory).
a new launch opportunity (and thus orbit): SWAP will now be launched together with the ESA SMOS satellite to a helio-synchronous dawn-dusk orbit.

Manpower support was also given to the measurement campaigns at the PTB Bessy synchrotron in Berlin were the CMOS detector and its coating are being characterized.

As future PI team, the ROB also takes up the role to inform the scientific community and the general public on the potential of the upcoming SWAP mission. A paper in a refereed journal (Berghmans et al, 2004, accepted) reviews the SWAP instrument for the scientific community. As a start of the public outreach activities, we participated to a Verhaert press-conference on PROBA2 (September 15) with a short SWAP presentation. This resulted in media-coverage on all major Belgian TV and radio channels, as well as in many newspapers.

A.2.3. Perspective for next years

A renewal proposal for the activities of the ROB-SWAP team was submitted to BELSPO and is meanwhile accepted.

The following milestones are upcoming:
- 2005/spring: follow-up of onboard software development by SPACEBEL, participation in the acceptance testing of hardware and software at CSL
- 2005/03: setting up a “Science Consortium for SWAP and LYRA”
- 2005/04: Proposal to ILWS Steering Committee for PROBA2 to become an ILWS mission
- 2005/04: Proposal to ESA/SSWG for PROBA2 to become an ESA science mission
- 2006/02/02: Instrument delivery
- 2007/Feb: launch for a two year mission duration

A.2.4. Personnel involved

Project lead: D. Berghmans
People hired on the project grant: G. Lawrence, B. Nicula
Additional contributions from: J.-F. Hochedez, T. Katsiyannis, A. Zhukov, E. Podladchikova, S. Willems, S. Gissot, V. Delouille, L. Wauters, R. Van der Linden, F. Clette

A.2.5. Partnerships

Grants used for this research:

ESA/PRODEX Contract C90117 "SWAP Preparation to Exploitation"

Visitors:

During the course the year we have welcomed many (>20) visitors in the context of the SWAP project. Besides scientific visitors (<5) this includes mostly delegations from the partners involved in the PROBA2/SWAP project (Verhaert, CSL, Spacebel,…).

A.2.6. Publications

A.2.6.1. Publications with peer system

A.2.6.2. Publications without peer system

Defise, J.-M.; **Berghmans, D.; Hochedez, J.-F.;** Lecat, J.-H.; Mazy, E.; Rochus, P. L.; Thibert, T.; Nicolosi, P.; Pelizzo, M. G.; Schuehle, U.; **Van der Linden, R.A.M.; Zhukov, A.**
SWAP: Sun watcher using APS detector on-board PROBA-2, a new EUV off-axis telescope on a technology demonstration platform
Proceedings of the SPIE, Telescopes and Instrumentation for Solar Astrophysics. Edited by Fineschi, Silvano; Gummin, Mark A., Volume 5171, pp. 143-154 (2004)

Jean-Marc Defise, Jean-Hervé Lecat, Emmanuel Mazy, Pierre Rochus, Laurence Rossi, Tanguy Thibert, **David Berghmans, Jean-François Hochedez,** Udo Schühle
SWAP: Sun watcher with a new EUV telescope on a technology demonstration platform
Proceedings of the 5th International Conference on Space Optics (ICSO 2004), 30 March - 2 April 2004, Toulouse, France. Ed.: B. Warmbein. ESA SP-554, Noordwijk, Netherlands: ESA Publications Division, ISBN 92-9092-865-4, 2004, p. 257 – 262.

A.2.6.3. Publications in press, submitted

Nicula B., Berghmans D., Hochedez J.-F.,
Poisson recoding of solar images for enhanced compression
Solar Physics, in press.

D. Berghmans, J.F. Hochedez, J.M. Defise, J.H. Lecat, **B. Nicula**, V. Slemzin, **G. Lawrence, A.C. Katsyiannis, R. Van der Linden, A. Zhukov, F. Clette**, P. Rochus, E. Mazy, T. Thibert, P. Nicolosi, M-G. Pelizzo, U. Schuhle,
SWAP onboard PROBA 2, a new EUV imager for solar monitoring
Advances in Space Research, in press.

A.2.6.4. Reports, thesis, etc

D. Berghmans, A.C. Katsiyannis, B. Nicula, J.H. Lecat, P. Franco, J.M. Defise
PROBA 2-SWAP Instrument Manager
SP-CSL/ROB-SWP-03011, Issue 3, Revision 3, 03 December, 2004

B. Nicula, D. Berghmans, J.H. Lecat, P. Franco, J.M. Defise
PROBA 2- SWAP Data Manager
SP-CSL/ROB-SWP-03011, Issue 2, Revision 2, 03 December, 2004

J.M. Defise**, D. Berghmans**, P.Rochus, J.H. Lecat,
PROBA 2- SWAP Science and Instrument System Requirements
SP-CSL/ROB-SWP-04020, Issue 2, Revision 1, 04 November, 2004

A.2.7. Missions

Research missions (assemblies, symposia, workshops, etc): 6
Operational missions (visits to PROBA2/SWAP partners): 18
Field missions (test campaigns at the PTB Bessy synchrotron): 3

A.3. Solar Drivers of Space Weather

A.3.1. Objectives

The general aim of the present project is to reveal the 'physics of the solar drivers of Space Weather', i.e. to investigate the basic physical processes of solar origin that determine Space Weather. This will contribute to the development of a science based scheme for Space Weather predictions that should be more reliable than the present 'empirical' predictions. The contribution of the ROB consists of providing observational input of CMEs and CME related events, into the simulations provided by the others teams in the consortium.

A.3.2. Progress and results

It is now established that frontside full and partial halo CMEs with source regions close to the solar disc center have the strongest chance to hit the Earth and, when containing suitable magnetic field orientation, produce geomagnetic storms. Observations of the low solar corona, in particular in the EUV, are an effective means of identifying the CME source regions. SOHO/EIT, with its continuous 24 hours per day coverage, is thus well suited to identify the sources of frontsided halo CMEs. The most frequent EUV signatures of halo CMEs are coronal dimmings. EIT waves, eruptive filaments and post-eruption arcades are also reliable signatures. The inspection of the EIT data together with photospheric magnetograms may give an idea about the ejected interplanetary flux rope magnetic field and, in particular, about the presence or absence of southward (geo-effective) field. If a source region is situated close to the solar limb, the corresponding CME also may be geo-effective, as the CME-driven shocks have large angular extent. In this case the storm can be produced by the sheath plasma behind the shock, provided it contains strong enough southward interplanetary magnetic field. It was found that EIT and LASCO are capable to identify the solar sources of the most of geomagnetic storms. In some cases, however, the identification is uncertain, so the observations by the future STEREO mission will be needed for the investigation of similar events.
A project performance report was written for PRODEX/BELSPO that reviews all the achievements of the project since its start in December 2000.

A.3.3. Perspective for next years

The current PRODEX6 project was extended through an ESA contract change notification until 2004/12/31. A new project with the same name has been submitted for financing under PRODEX 8 and has meanwhile been accepted. The method of predicting the large-scale orientation of the interplanetary magnetic field will be tested using solar and interplanetary data on more events, as currently only a small number of storms were investigated in this way. Geometrical factors determining the geo-effectiveness of halo CMEs will be also studied.
In this continuation of the project, we propose to move to a next step of implementing the techniques developed in SDSW1 into an operational environment, while at the same time keeping as driving force the ability to answer scientific questions like: how does the dynamic structure of the interplanetary magnetic field influence CME propagation; how do the properties of the erupting feature evolve in time and how does this affect the geo-effectiveness of the CME; can reliable estimates of CME propagation speed, expansion speed and other physical properties be deduced from coronagraph images; can we use magnetograph data to improve these estimates or to improve the simulation of the CME propagation? Does the chirality of an erupting prominence affect CME propagation and geo-effectiveness? Above all perhaps, there's the question to what extent the model of ideal MHD is valid in this context.

A.3.4. Personnel involved

Project lead: D. Berghmans

People hired on the project: T. Katsiyannis

Additional contributions from: A. Zhukov, G. Lawrence, E. Robbrecht, S. Willems, L. Wauters, R. Van der Linden.

A.3.5. Partnerships

List of national and international partners

The "Solar Drivers of Space Weather" project is a network of four Belgians institutions: 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.

Grant used for this research:

ESA/PRODEX contract 14711/00/NL/Sfe "Solar Drivers of Space Weather"

Visitors:

<=5, mostly partners within the Belgian network

A.3.6. Publications

A.3.6.1. Publications with peer system

Veselovsky I. S., M. I. Panasyuk, S. I. Avdyushin, G. A. Bazilevskaya, A. V. Belov, S. A. Bogachev, V. M. Bogod, A. V. Bogomolov, V. Bothmer, K. A. Boyarchuk, E. V. Vashenyuk, V. I. Vlasov, A. A. Gnezdilov, R. V. Gorgutsa, V. V. Grechnev, Yu. I. Denisov, A. V. Dmitriev, M. Dryer, Yu. I. Yermolaev, E. A. Eroshenko, G. A. Zherebtsov, I. A. Zhitnik, **A. N. Zhukov**, G. N. Zastenker, L. M. Zelenyi, M. A. Zeldovich, G. S. Ivanov-Kholodnyi, A. P. Ignat'ev, V. N. Ishkov, O. P. Kolomiytsev, I. A. Krasheninnikov, K. Kudela, B. M. Kuzhevsky, S. V. Kuzin, V. D. Kuznetsov, S. N. Kuznetsov, V. G. Kurt, L. L. Lazutin, L. N. Leshchenko, M. L. Litvak, Yu. I. Logachev, **G. Lawrence**, A. K. Markeev, V. S. Makhmutov, A. V. Mitrofanov, I. G. Mitrofanov, O. V. Morozov, I. N. Myagkova, A. A. Nusinov, S. N. Oparin, O. A. Panasenco, A. A. Pertsov, A. A. Petrukovich, A. N. Podorol'sky, E. P. Romashets, S. I. Svertilov, P. M. Svidsky, A. K. Svirzhevskaya, N. S. Svirzhevsky, V. A. Slemzin, Z. Smith, I. I. Sobel'man, D. E. Sobolev, Yu. I. Stozhkov, A. V. Suvorova, N. K. Sukhodrev, I. P. Tindo, S. Kh. Tokhchukova, V. V. Fomichev, I. V. Chashey, I. M. Chertok, V. I. Shishov, B. Yu. Yushkov, O. S. Yakovchouk, and V. G. Yanke

Solar and Heliospheric Phenomena in October–November 2003: Causes and Effects
Cosmic Research, Vol. 42, No. 5, 2004, pp. 435-488. Translated from Kosmicheskie Issledovaniya, Vol. 42, No. 5, 2004, pp. 453-508

A.3.6.2. Publications without peer system

A.3.6.3. Publications in press, submitted

Zhukov A. N.

Solar Sources of Geoeffective CMEs: a SOHO/EIT View
In: Proceedings IAU Symposium 226 "Coronal and Stellar Mass Ejections", September 13-17, 2004, Beijing, China, Cambridge University Press (in press)

Panasenco O., Veselovsky I.S., Dmitriev A.V., **Zhukov A.N.**, Yakovchouk O.S., Zhitnik I.A., Ignat'ev A.P., Kuzin S.V., Pertsov A.A., Slemzin V.A., Boldyrev S.I., Romashets E.P., Stepanov A., Bugaenco O.I., Bothmer V., Koutchmy S., Adjabshirizadeh A., Fazel Z., Sobhanian S.
Solar Origins of Intense Geomagnetic Storms in 2002 as seen by the CORONAS-F Satellite.
Advances in Space Research, 2004 (submitted).

A.3.6.4. Reports, thesis, etc

S. Poedts, J. Dekeyser, **D. Berghmans,** H. Deconinck,
Solar Drivers of Space Weather: BELSPO/PRODEX performance report

A.3.7. Missions

Research missions (visits and conferences): 3
Operational missions (commissions, working groups): 0
Field missions (observations, station maintenance): 0

B. The variable magnetic Corona

The magnetic solar atmosphere is variable at all time-scales. Its faster and smaller phenomena are not resolved with the current telescopes. It is a research topic of the Solar Physics Department (SPD) to bridge observation and theory and addressing at this angle the coronal heating issue. These studies are developed in the first section of the present theme. While Coronal Mass Ejections are treated as a separate theme, flares are considered in the second section dealing with the preparation of the LYRA radiometer. Finally, the last section covers the coronal variability commensurable with the solar rotation or slower.
The solar corona is a very dynamic environment and several mechanisms compete in its various areas. Magnetic energy dissipation can be due to wave dissipation 'AC' (if $t_A >> t_p$) or to continuous currents 'DC' (if $t_A << t_p$), where t_A is the characteristic transit time of Alfven waves in the loop, and t_p is the characteristic time of sub-photospheric convection. However, to explain heating by Alfven wave dissipation, these Alfven waves must be excited on a time scale shorter than the typical timescale of the corona (t_A~100s), and for example, the characteristic time of granular convection is 400-900s, i.e. too slow. By contrast to the AC mechanisms, the heating theories based on current dissipation operate even with slow driving. The energy source is then in the random agitation of the footpoints of magnetic field lines and current dissipation produces the heating. The characteristic time of resistive magnetic diffusion is $t\eta = l^2/\eta$, larger than observable scales. Normal resistivity is therefore not an efficient dissipation means. Reconnection is a much faster and more efficient processes with $\sim t_A = l/V_A$. It is the natural candidate to explain phenomena like flares, CMEs, bright points, blinkers, nanoflares observed in closed magnetic field regions. Observational studies associate nanoflares and small-scale reconnections. Constant changes in the magnetic fields dominating the corona lead to many types of instabilities in the coronal plasma and in the magnetic field itself. These instabilities manifest themselves in a variety of scales and events.

EIT will often be referred to in the following. The instrument and the role of its data are therefore briefly introduced here. EIT is the Extreme ultraviolet Imaging Telescope of the Solar Heliospheric Observatory (SoHO). It is monitoring the topology and dynamics of the solar corona and transition region in four different wavelength passbands, which correspond to temperature regimes from 60,000K up to 2,000,000K. The EIT instrument has been built by a Belgian-French-US consortium, and is operated very successfully since January 1996. In November 1998, a PRODEX Experiment arrangement was agreed between the ROB and the European Space Agency (ESA). Since then, its Co-Investigators at the ROB have undertaken numerous studies. Three fields of expertise have been selected for the EIT Science at ROB. One is the analysis of small or rapid phenomena; the second is the development of image processing tools treating automatically and systematically the observations; and the third relates EIT data to Space Weather forecasting treated as another theme.

B.1. Coronal Heating

B.1.1. Objectives

The Corona has a temperature much higher than the solar surface, which seems to violate the laws of thermodynamics. It remains one of the most-studied topics in solar physics. The sub-photospheric convection supplies enough magnetic energy, which AC or DC mechanisms would dissipate. We investigate both but emphasize DC schemes using mainly EIT data and models. The next observational breakthrough will come from the Solar Orbiter mission and we actively participate in its EUV imager consortium.

B.1.2. Progress and results

In 2004, Dr Van der Linden's research was oriented towards theoretical scaling laws for nanoflare heating of the solar corona. This topic was started a few years ago together with Dr. Browning. A broadened collaboration is now addressing non-linear simulations. The model relies on the 'Taylor relaxation principle', a well-known and experimentally verified theorem in plasma physics. Within the context of ideal and resistive magneto-hydrodynamics, the principle basically states that when a magnetic equilibrium is driven unstable to an ideal MHD kink instability, the plasma will resistively relax to equilibrium with the lowest energy state under the constraint of (approximate) conservation of magnetic helicity. This lowest energy state corresponds to the so-called constant-alpha linear force-free field, where all currents are co-aligned with the magnetic fields. We apply this theorem to cylindrical models of coronal loops, starting from a force-free field with a step-wise profile of the alpha parameter. This introduces two free parameters in the starting equilibrium model. By varying these free parameters a stability map is generated, and the marginal stability curve in the alpha1-alpha2 plane can be constructed. Every point on this curve then corresponds to the onset of an ideal MHD instability and for each such point we can determine how much energy is released by applying the Taylor theorem.

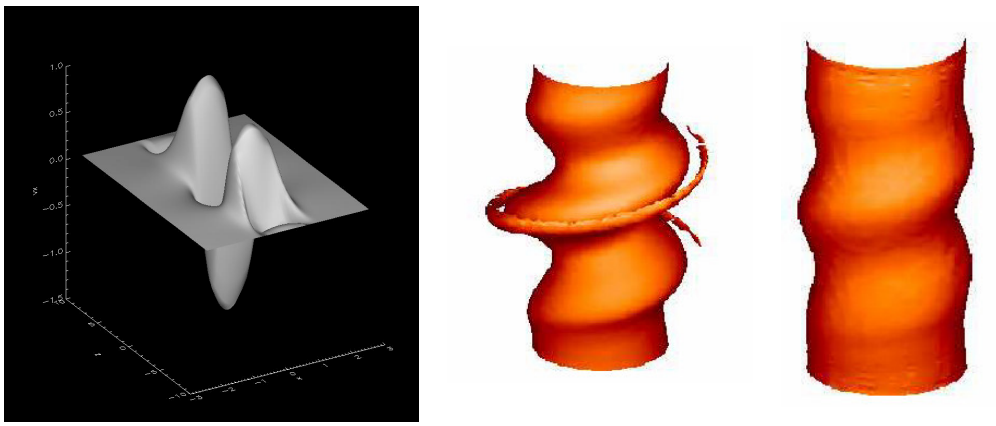


Figure 14: A comparison of the linear and nonlinear eigenfunctions in a numerical simulation of the growth of an instability. On the left, amplitude as a function of the cylindrical coordinates r and z; on the right iso-surface plots of the nonlinear functions at two different times in their evolution

Progress was made on two directions in 2004. First, in the past, we had limited the study to loops surrounded by a perfectly conducting rigid boundary. For solar corona applications this had to be modified to a free boundary condition, so we needed to calculate a new stability map for this more realistic scenario. These calculations typically require hundreds of hours of CPU time and are only feasible with a system such as the QBRICK compute server. As expected, there is a very strong effect on the stability boundary. The stable region, which used to have a complex shape and to extend to very high values of the alpha2 parameter, forms now a simple closed area for small values of alpha1-alpha2.

The second region of progress was in the addition of the non-linear simulations for a few typical cases (since these simulations are numerically very heavy, they can only be done for a few cases). Our model is precisely intended to avoid the need for such non-linear simulations and indeed, although still incomplete, the cases clearly support our earlier analysis (see Figure 14). More detailed study is however necessary.

The quest for observational evidence goes by higher spatio-temporal resolution. This is why the SPD team has initiated regular high-cadence (1-minute) sequence of observations with EIT, named shutterless campaigns (see the last section of this theme). The PROBA2-SWAP EUV telescope will operate continuously at this 1-minute rate while nominal cadence is 20' with EIT. We further intend to get involved with the AIA of the SDO NASA mission. This will offer permanent full-disc observations at 10-second cadence, in a 4k x 4k format and with unprecedented temperature coverage. Still the ultimate high-resolution observations are anticipated to come from the EUV imagers (EUI) of the ESA Solar Orbiter (S.O.) mission. Though still far from the microphysics scales, the EUI will indisputably metamorphose our view of the corona, as has always happened when resolution improved. The appearance of the corona has *not* been found self-similar until now. Dr Hochedez is a co-proposer of the mission and one of the 4 promoters of the EUI consortium. The SPD is fostering the many Belgian assets in leading the EUI definition and development. We rely on our image processing expertise and the BOLD project in complement to our Science rationale. The former will endow S.O. with the needed autonomy to point at the most interesting solar features. The second will enhance the sensitivity and robustness of the instrument that are required to properly observe small, fast and weak objects. 2004 has been a year of proto-consortium activities that has lead to an agreement in January 2005.

Flare energy releases range a large scale. In the Podladchikova et al., 1999-2004 model of coronal heating, we assume different mechanisms of small-scale driving, a wide range of driving scales, and different current instability dissipation methods that produces nanoflares. To understand the real unobservable driving processes of coronal heating, it is necessary to compare the various macroscopic physical conditions determined by the dissipated energy in the model (simulated flares) with the properties of observed flares. Waiting Time Distributions (WTD) and flare duration distributions are important criteria. Frequent flares will provide more heat. WTD gives also an indicator of flare independency. Crosby 1999 evidenced a deviation from independency (Poisson). Wheatland & Sturrock, 1998 obtained a modified Poisson law for WTD. Berghmans et al. 1998 showed power laws for the duration of transition region brightenings. Bofetta & Carbone obtained a turbulent power law WTD for long-duration events; Carbone & Lepreti obtained a good fit by a Levy distribution, assuming super-diffusive underlying processes. Buchlin et al, 2004 demonstrated that the WTD depends on the flare definition. From data analysis and simulations, Dr Podlachikova has reached the following conclusions in 2004.
a). *No dependence on definition.* A careful treatment of flare events listed in the SIDC database leads to one type of WTD whatever the flare definition (considering 1/the smallest B-class flares from all observational sources and 2/ one flare even if several are observed at the same time in different passbands).
b) *WTD of flares and CMEs are different.* The WTD distributions for flares and CMEs were treated separately, using a distinction between short-duration impulsive flares and long-duration CME-related flares. A preliminary Probability Distribution Function (PDF) reconstructed using the Pearson reconstruction method shows exponential behaviour for flares and power law behaviour for CMEs.
c) *Physical processes* providing such WTDs have been proposed. The power-law WTD can be produced fully developed turbulence with power index α in the range $-3 < \alpha < -1$. The exponential behaviour can appear when small scale fluctuations of the magnetic source are more weighted. Dissipation is always due to current instabilities.
d). It is found that *60% of the flares are mutually dependent*.

There are two ways to improve observationally on these results. One is to augment the sensitivity to flares and this will be achieved with LYRA (See next section on irradiance). The other is to perform a spatio-temporal statistical study that would e.g. address the distance between sympathetic events. Such a goal

requires a long-duration large field-of view imaging of the corona. SoHO-EIT and later PROBA2-SWAP and SDO-AIA certainly offer the necessary data, but a tool to systematically extract and characterize the flares is mandatory as well. S. Gissot is developing this tool (Velociraptor). It simultaneously detects motions, dimmings and brightenings. It is fully reported in the last section of the present theme and is also mentioned in the Coronal Mass Ejections theme since it detects their on-disc signatures.

We not only study the very existence of the hot corona in general, but also perform data analysis of intriguing observed structures. D. Berghmans with collaborators (De Groof et al 2004) have interpreted propagating disturbances along a loop. On 11 July 2001 an EIT shutterless campaign was conducted which provided 120 high-cadence (68s) 304Å images of the north eastern quarter of the Sun. The most interesting feature seen in the data is an off-limb half loop structure along which systematic intensity variations are seen, which appear to propagate from the top of the loop towards its footpoint. We have investigated the underlying cause of these propagating disturbances, i.e. whether they are caused by waves or by plasma flows. First we identify 7 blobs with the highest intensities and follow them along the loop. By means of a location-time plot, bulk velocities can be measured at several locations along the loop. The velocity curve found this way is then compared with characteristic wave speeds and with the free-fall speed in order to deduce the nature of the intensity variations. Additional information on density and temperature is derived by measuring the relative intensity enhancements and comparing the EIT 304Å sequence with Big Bear data and 171Å data (TRACE/EIT). The combination of all these constraints gives us an insight on the nature and origin of these intensity variations. The idea of slow magneto-acoustic waves is rejected, and we find several arguments supporting that these intensity variations are due to flowing/falling plasma blobs.
Finally, Dr Katsiyannis and Berghmans are exploiting the Solar Eclipse Coronal Imaging System (SECIS). Total solar eclipses provide a unique opportunity to study the solar coronal and have been popular with astronomers over the centuries. SECIS' aims at detecting high-frequency intensity oscillations in the corona. Such variations can provide physical parameters such as the *coronal* magnetic field. This emerging field is denominated coronal seismology.

B.1.3. Perspective for next years

The model of Browning & Van der Linden should be compared with the observational properties of impulsive dissipative events of the active sun and coronal holes. Magnetic sources of this model can be incorporated in the Podladchikova model. This will help the further detailed comparison with statistical properties of flares and the search of underlying mechanism of coronal heating. A new version of a reduced MHD code simulating the coronal plasma behaviour providing the dependence between flares will be created. The physical mechanisms of such dependences will be studied. WTD and Flare Duration Distribution laws will be established and published. DeGroof and Berghmans prepare new publications reporting further results on propagating disturbances. Katsiyannis intends to model the SECIS oscillations. As there are only some months left before the Solar Orbiter ESA AO, the EUI consortium has organized itself in working groups. The Hochedez leads the on-board S/W & operation WG. We are also involved in the detector, electronics, radiometry and Science WGs. As the BOLD project has just been approved, we will work to assure its success and its adequacy to the EUI needs.

B.1.4. Personnel involved

Ronald Van der Linden, Elena Podlachikova, David Berghmans, Jean-François Hochedez, Thanassis Katsiyannis, Samuel Gissot, Gareth Lawrence, Ali BenMoussa, Armin Theissen

B.1.5. Partnerships

List of national and international partners

UMIST, Manchester, UK

University of St. Andrews (Scotland, UK).
MPS, Germany
MSSL, UK
IAS, France
KULeuven
IMEC
CSL

Grants used for this research

PRODEX-STEREO (EP)
PRODEX-EIT (JFH)
PRODEX-SWAP (GL)
PRODEX-SDSW (TK)
PRODEX-LYRA (ABM, AT)
Supplementary Researcher (SG)

Visitors: 4

B.1.6. Publications

B.1.6.1. Publications with peer system

De Groof, A., **Berghmans, D.,** van Driel-Gesztelyi, L. and Poedts, S.
Intensity variations in EIT shutterless mode: Waves or flows?
Astron. Astrophys, 2004, 415, 1141

B.1.6.2. Publications without peer system

P. Browning, **R.A.M. Van der Linden**, C. Gerard, R. Kevis, A.W. Hood
Coronal heating by nanoflares: a reconnection model.
Proceedings of the SOHO 15 Workshop - Coronal Heating, 6-9 September 2004, St. Andrews, Scotland, UK (ESA SP-575). Editors: R.W. Walsh, J. Ireland, D. Danesy, B. Fleck. Paris: European Space Agency, 2004, p.210.

Schuehle, Udo H.; **Hochedez, Jean-Francois E.**; Pau, Jose Luis; Rivera, Carlos; Munoz, Elias; Alvarez, Jose; Kleider, Jean-Paul; Lemaire, Philippe; Appourchaux, Thierry; Fleck, Bernhard; Peacock, Anthony; Richter, Mathias; Kroth, Udo; Gottwald, Alexander; Castex, Marie-Claude; Deneuville, Alain; Muret, Pierre; Nesladek, Milos; Omnes, Franck; John, Joachim; Van Hoof, Chris
Development of imaging arrays for solar UV observations based on wide band gap materials
Telescopes and Instrumentation for Solar Astrophysics. Edited by Fineschi, Silvano; Gummin, Mark A. Proceedings of the SPIE, Volume 5171, pp. 231-238 (2004).

Rochus, Pierre L.; Defise, Jean-Marc; Halain, Jean-Philippe; Jamar, Claude A. J.; Mazy, Emmanuel; Rossi, Laurence; Thibert, Tanguy; **Clette, Frederic; Cugnon, Pierre; Berghmans, David; Hochedez, Jean-Francois E.;** Delaboudiniere, Jean-Pierre; Auchere, Frederic; Mercier, Raymond; Ravet, Marie-Francoise; Delmotte, Franck; Idir, Mourad; Schuehle, Udo H.; Bothmer, Volker; Fineschi, Silvano; Howard, Russell A.; Moses, John D.; Newmark, Jeffrey S.
MAGRITTE: an instrument suite for the solar atmospheric imaging assembly (AIA) aboard the Solar Dynamics Observatory
Telescopes and Instrumentation for Solar Astrophysics. Edited by Fineschi, Silvano; Gummin, Mark A. Proceedings of the SPIE, Volume 5171, pp. 53-64 (2004).

Katsiyannis, A. C.; Williams, D. R.; Murtagh, F.; McAteer, R. T. J.; Keenan, F. P.,
Initial Results from Secis Observations of the 2001 Eclipse

2004, ESA SP-575, 410

Katsiyannis, A. C.; McAteer, R. T. J.; Williams, D. R.; Gallagher, P. T.; Keenan, F. P.,
Initial Results from Secis Observations of the 2001 Eclipse
2004, ESA SP-547, 459

B.1.6.3. Publications in press, submitted

Podladchikova O., Buehner J, Nikutowsky. V.
Multiscale Magnetic Energy Release in Bright Points by Means of SVD and Principal Component Analysis
Astronomy &Astrophysics, in press.

Katsiyannis A. C., Murtagh F.,
The application of a Trous filtering and Monte Carlo analysis on SECIS 2001 solar eclipse observation
Solar Physics, submitted

B.1.6.4. Reports, thesis, etc

Podladchikova O
Reconnection Evidence in Bright Points via Principal Component Analysis
35th COSPAR Scientific Assembly 2004, Paris, France

Podladchikova O et al
Role of driving scales in a model of coronal heating
35th COSPAR Scientific Assembly 2004, Paris, France

Podladchikova O, Van der Linden R. et al.
Waiting Time Distribution from the Model of Coronal Heating and SIDC data base
Solar Image Processing II Workshop, Annapolis, Maryland, USA

B.1.7. Missions

Research missions (assemblies, symposia, workshops, etc): 4 (COSPAR/EP, SIP/EP+TK, SOHO15/TK)
Operational meetings (commissions, working groups): 2 (MPS/JFH, CSL/JFH)
Field missions (observations, station maintenance, etc): 0

B.2. UV irradiance and the PROBA2-LYRA radiometer

B.2.1. Objectives

LYRA (the LYman-alpha RAdiometer) is a solar VUV radiometer on the ESA PROBA2 mission (2007). LYRA uses diamond sensors to measure the solar irradiance in 4 channels: Herzberg, Lyman-alpha, Aluminum and Zirconium. LYRA is designed, manufactured and calibrated by a Belgian-Swiss-German consortium. Dr. Hochedez is its Principal Investigator. To prepare LYRA exploitation, we control its development, write data analysis programs to process its future time series and we expand our expertise on solar UV irradiance, particularly emphasizing high-cadence flare studies in synergy with SWAP.

B.2.2. Progress and results

ROB has to insure that the design and the development of LYRA maximize its future scientific returns. For this, we must maintain a permanent awareness of the instrument progresses, by reading and checking the documentation, by enquiring on relevant issues, and by triggering appropriate actions or studies. As Principal Investigator, Dr. Hochedez has coordinated the whole LYRA consortium (Swiss, German, US, Russian, Japanese science or technology partners, Belgian institutes and industry) with the support of the

project manager at CSL and worked on all LYRA scientific issues. Dr Benmoussa is responsible for the detector, radiometric and calibration aspects. Marie Dominique is in charge of the flight software specifications. Ms Dominique and JFH are also preparing the occultation mode with the BISA. Dr Theissen is managing the LYRA web site, and particularly its implementation of the radiometric model. Dr Theissen is also studying the inversion of LYRA data in order to reconstruct the solar UV spectrum from the 4 LYRA passbands. Dr Delouille is designing algorithms to process the LYRA time-series. She is developing advanced denoising techniques to maximize LYRA sensitivity to small flares. Second, she is giving flesh to the LYRA-SWAP synergy by relating spatial objects in images with features in time-series. The study of Gissot (Velociraptor/MoVaTrac) described in the next chapter has also relevance here in its capacity to extract flaring and micro-flaring from sequences of solar EUV movies. See the AdSR publication for more details.

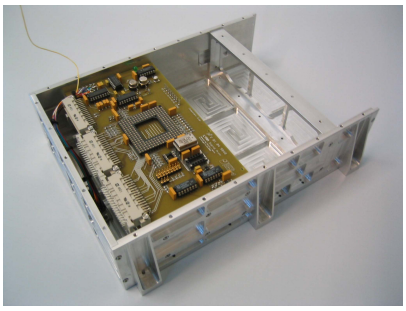


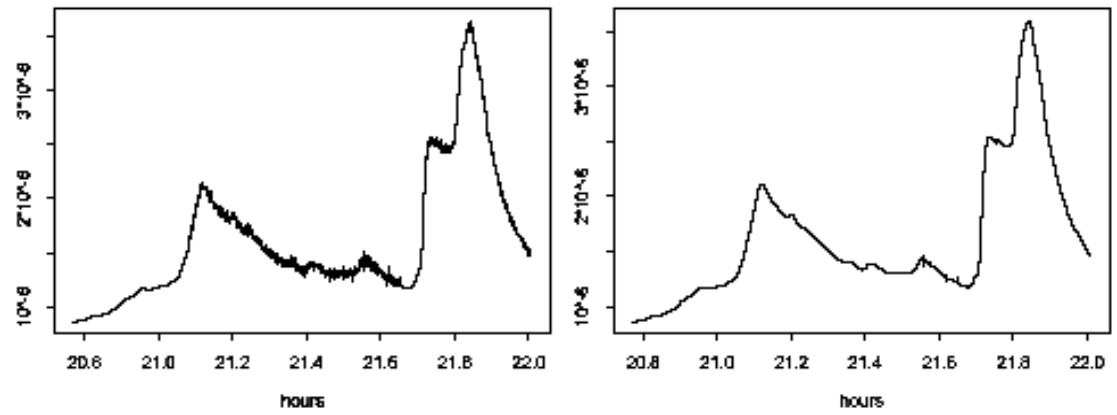
Figure 15: Exploded view of one unit (out of 3), b/ the LYRA prototype box in early 2004

B.2.3. Perspective for next years

2005 is the year of the manufacture of LYRA. The calibrated flight instrument will be delivered before the end of 2005. A lot of development work is still ahead, but at the same time we are concentrating on the ground segment and on the LYRA Science preparation. The launch is anticipated in early 2007. The operations are expected to last more than one year.

The LYRA calibration activities, which started in November 2003 and should finish in summer 2005, will pursue the following objectives: assess the instrument properties, provide understanding for feedbacks, verify the instrument's performance, publish and distribute the reports and calibration data. The results shall be found in the reports of each calibration campaign, and their analysis in the frame of LYRA will be reported in the LYRA Calibration Analysis reports. The LYRA calibration plan consists of different calibrations programs: detector campaign at PTB-BESSY and at IMOMEC, precision aperture area measurement at PMOD, UV-LED Calibration campaign at IMOMEC and Amano Lab., Filter Test/Calibration campaign at CSL, Orsay, MPS and PTB-Bessy, and Final Instrument Calibration campaign at PMOD and PTB-BESSY.

Another main concern is the impact of radiation on detection characteristics. Progress has to be made in understanding how radiation affects the optical properties of LYRA. In collaboration with SCK-CEN (Belgian Nuclear Research Center) and the University of Brussels (cyclotron of VUB), gamma dose rates (0.1Gy/h up to 50kGy/h) and charged particle beams (protons and alpha up to 40MeV) can be performed for our diamond detectors rad-hardness studies (1st test expected mid April or beginning of May 2005).



(a) (b)

Figure 16: Example of performance of the Data-Driven Haar-Fisz Transform (DDHFT): (a) wavelet estimate without variance stabilization, (b) wavelet estimate combined with DDHFT. The estimate in (b) seems almost noise-free, whereas there subsist spurious effects in the wavelet estimate (a) because it does not take into account the noise structure.

Regarding data processing, one objective in the next years is to compare different methods for extracting the flares, and to determine in each case the distribution of the flare total energy, duration, and waiting time (cf. WTD in previous section on Coronal Heating). Besides the classical approach, and the (possible made multivariate) approach based on detection of discontinuities in the signal, we will also investigate the properties of the Matching Pursuit method. Indeed, it allows decomposing a signal using an optimal basis of functions. The subsequent retrieval of peaks and their characteristics (distributions, durations, waiting times) is expected to be more precise, that is, to be less dependent on arbitrary values (such as a threshold value) than with classical approaches.
The registration of curves is a first attempt to exploit the multivariate aspect of the time series. In a second step, we aim at studying cross-correlations between the four time series using multivariate statistical tools. We also want to investigate the scaling properties of the LYRA time series. In particular it is of interest to compare the behavior of the UV irradiance at small and large time scale. Finally, we aim at analyzing in a synchronized way the UV time series of LYRA and the EUV images recorded by SWAP. In particular, a fine analysis of the high cadence time series of LYRA might reveal precursors for the flares.

B.2.4. Personnel involved

JF Hochedez, A BenMoussa, M. Dominique, V. Delouille, A. Theissen, D Berghmans, B. Nicula, A. Zhukov, G. Lawrence, L. Wauters, R. Van der Linden.

B.2.5. Partnerships

List of national and international partners

Centre Spatial de Liège, B
IMO/IMOMEC, Diepenbeek, B
PMOD/WRC, Davos, CH
MPS, Lindau, Germany
PTB, Berlin, Germany
BISA, Uccle, B
ESA HQ, Paris, F and ESTEC, Noordwijk, NL
NRL, Washington, USA
NIST, MD, USA

LPI, Moscow, Russia
Amano Lab, Japan
UCL, LLN…

Grants used for this research

PRODEX-LYRA
PRODEX-EIT

Visitors: 3

B.2.6. Publications

B.2.6.1. Publications with peer system

A. BenMoussa, U. Schuehle, K. Haenen, M. Nesladek, S. Koizumi and **J-F. Hochedez.**
PIN diamond detector development for LYRA, the Solar VUV radiometer on Board PROBA2
Physica Status Solidi (a) 201, N11, pp 2536-2541 (2004)

B.2.6.2. Publications without peer system

J.-F. Hochedez, W. K. Schmutz, M. Nesladek, Y. Stockman, U. Schühle, **A. BenMoussa**, S. Koller, **D. Berghmans**, J.P Halain, J.H. Lecat, J.M. Defise, **L. Wauters, B. Nicula**, K. Haenen, D. Gillotay, M. Kretzschmar, **S. Gissot, M. Dominique**, H. Roth, C. Wehrli, **R. Van der Linden, A. Zhukov, F. Clette,** M. D'Olieslaeger, J. Roggen, P. Rochus.
LYRA: the Lyman-alpha Radiometer on-board the ESA PROBA2
SURFACE AND BULK DEFECTS IN CVD DIAMOND FILMS (SBDD) IX& BN Workshop, February 18 - 20, 2004, Diepenbeek-Hasselt, Belgium. (http://www.imo.luc.ac.be/workshop2004/)

J.-F. Hochedez, W. K. Schmutz, M. Nesladek, S. Koller, **D. Berghmans, A. BenMoussa**, J.H. Lecat, J.M. Defise, Y. Stockman, **L. Wauters, B. Nicula**, U. Schühle, D. Gillotay, M. Kretzschmar, H. Roth, E. Rozanov, C. Wehrli, I. Ruedi, **R. Van der Linden, A. Zhukov, F. Clette**, M. d'Olieslaeger, J. Roggen, P. Rochus.
LYRA: the Solar VUV radiometer on-board PROBA II
Committee on Space Research 35th COSPAR SCIENTIFIC ASSEMBLY, Paris, France, 18-25 July 2004

P. Rochus, J.M Defise, J.H Lecat, Y. Stockman, P. Franco, J.M Gillis, E. Mazy, J.P Halain, L. Rossi, T. Thibert, **D. Berghmans, J.F Hochedez, A. BenMoussa, B. Nicula, R. Van der Linden, A. Zhukov, L. Wauters, F. Clette**, M. Nesladek, W. Schmutz, S. Koller, U. Schuehle, P. Nicolosi.
PROBA II Payload: A Belgian mini space Weather Observatory
IAC 2004 (IAA.4.11.2: Small Space Science Missions), 55th International Astronautical Congress 2004 (4-8 October), Vancouver, Canada.

B.2.6.3. Publications in press, submitted

A. BenMoussa, J.-F. Hochedez, W. K. Schmutz, U. Schühle, M. Nesladek, Y. Stockman, U. Kroth, M. Richter, Z. Remes, K. Haenen, A. Theissen, S. Koller, **M. Dominique**, J.P Halain, V. Mortet, R. Petersen, M. D'Olieslaeger.
Solarblind diamond detector for LYRA, the Solar VUV radiometer on Board PROBA II.
Experimental Astronomy (2004)

Hochedez J.-F., W. Schmutz W., Nesladek M., Stockman Y., Schühle U., **BenMoussa A**., Koller S., Haenen K., **Berghmans D**.,. Defise J.-M, Halain J.-P., **Theissen A., Delouille V**., Slemzin V., Gillotay D., Fussen D., **Dominique M**., Vanhellemont F., McMullin D., Kretszchmar M., Mitrofanov A., **Nicula B., Wauters L**., Roth H., Rozanov E., Rüedi I., Wehrli C., Amano H., **Van der Linden R.,**

Zhukov A., Clette F., Koizumi S., Mortet V., Remes Z., Petersen R., D'Olieslaeger M. , Roggen J., Rochus P.

LYRA: the Solar UV radiometer aboard the ESA Proba-2
Advances in Space Research (refereed)

Delouille V., von Sachs R.

Estimation of Nonlinear Autoregressive Models using Design-adapted Wavelets
Annals of the Institute of Mathematical Statistics, in press

Fryzlewicz P., **Delouille V.**

A data-driven Haar-Fisz transform for multiscale variance stabilization
Proceedings of the IEEE Statistical Signal Processing Workshop, submitted

Delouille V., de Patoul J., **Hochedez J.-F.,** Jacques L., Antoine J.-P.

Wavelet spectrum analysis of Solar EUV images: method and applications to network characteristic scale evolution, flare nowcasting, and extraction of Active Regions with EIT/SoHO
Solar Physics, submitted.

B.2.6.4. Reports, thesis, etc

Countless: LYRA Science Requirements, Instrument Manager, Data Manager, High-Cadence requirement, LED case, many calibration campaign reports, FM detector selection, etc. etc.

B.2.7. Missions

Research missions (assemblies, symposia, workshops, etc): 4
Operational meetings (commissions, working groups): 36
Field missions (observations, station maintenance, etc) : none

B.3. Solar cycle studies

B.3.1. Objectives

In addition to solar activity indices and UV irradiance reported elsewhere, the SPD addresses longer-term coronal variability in EUV imaging data to eventually obtain insights on the solar dynamo. Our current research is aiming at revealing long-term patterns in the differential rotation parameters. It is one of the main applications of the Movatrac described below. The second topic deals with the long-term analysis of the high-cadence Shutterless campaigns. It has been successfully proposed as the Hic et Nunc Action 3 for 2005-2006 and is detailed in the perspectives of this section.

B.3.2. Progress and results

The goal of the Movatrac/Velociraptor project is to apply motion analysis techniques to sequences of coronal images observed by the EIT (Extreme ultraviolet Imaging Telescope) instrument onboard SoHO (Solar and Heliospheric Observatory). The optical flow approach is the best candidate to analyze the subpixel motion of the coronal plasma between two successive EIT frames. Our first physical subject of interest is the solar differential rotation driving the solar corona, which can be used as a calibration step. We also study the displacements of the coronal objects at various scales (e.g. bright points, prominences, quiet-sun area and active regions).

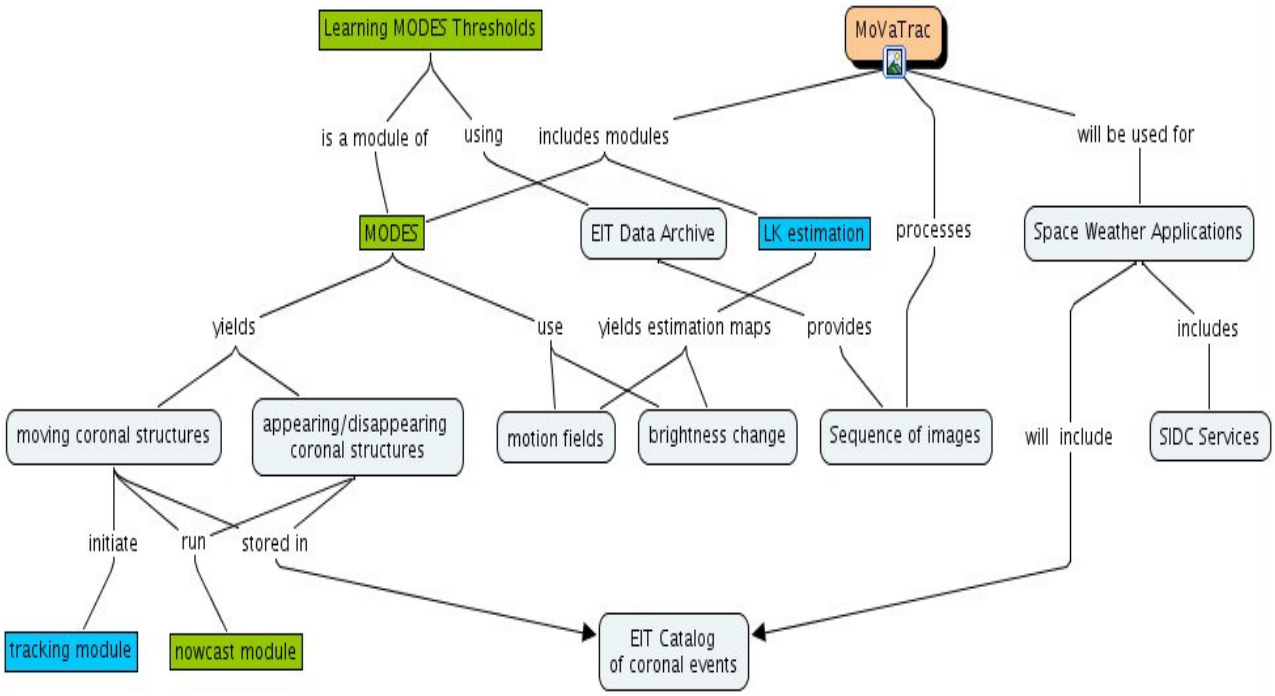


Figure 17: Concept Map describing the interactions between the different MoVaTrac entities (in gray). Blue rectangles are partly implemented modules; Green rectangles are to be developed.

We are developing a new image-processing tool that will simultaneously estimate both motion and intensity variation from two successive EUV coronal images. We identified three main reasons that make this development intricate. First, the coronal plasma is optically thin; therefore signal is integrated along the line-of-sight, and several coronal structures sometimes pile up. This is the transparency challenge. Second, EUV solar telescopes use multilayer mirrors to observe a wavelength passband, and to hence select useful emission lines and their temperature regime. Temperature changes cause coronal features to get in or out a given passband. Finally, the coronal plasma can be very unstable and swift topological reconfigurations are frequent. The current 15-minute nominal cadence of the EIT CME watch mode leads to temporal under-sampling.

Based on the classical Lucas-Kanade method, our MoVaTrac tool (Motion and intensity Variation Tracking for Space Weather applications) *simultaneously* estimates the apparent displacement field and the brightness change between two successive images. Its concept map (CMAP http://cmap.ihmc.us/) is presented in Figure 17. Already implemented modules are highlighted.

The objective of Movatrac is to easily and accurately characterize coronal activity, in particular eruptive events. The characterization includes motion tracking and detection of intensity variations between couples of successive images. Dimmings and flares will be detected in the brightness change maps. Moving objects will be extracted in the apparent velocity maps. The estimation quality is evaluated by a similarity criterion between the warped first image and the second image.

We devote a part of this project to calibration on synthetic data, in order to validate the algorithm in varied situations. We will also propose new visualization tools for the different modules of MoVaTrac.

MoVaTrac has many applications including:

Analysis of differential rotation:

By retaining only the global motion component, the solar differential rotation is studied. It provides a calibration for our method since the rotation has been the subject of several publications (e.g. Brajsa et al, 2004), but Movatrac permit to perform an effortless rotation analysis of the whole SoHO lifetime (10 years).

Detection and localization of coronal eruptive events:

We intend to describe the solar activity with a "nowcast" module, which shall extract flares, meaningful dimmings, and large sudden displacements of coronal features. To this aim, velocity and brightness variation maps will be processed in search of coherent perturbations of significant amplitudes. (See references to Velociraptor in the CME theme and the LYRA/irradiance section)

B.3.3. Perspective for next years

The information provided by the nowcast module can be stored in a database. The EIT archive will be scanned to generate the catalog of the observed events. We will build a statistical model of the solar activity based on the analysis of this EIT database. These results can then be combined with the CMEs as seen in the LASCO. The impact of the detected events on the Earth will be studied later. A key issue is here to correlate the parameters of special circumstances as seen in the EIT (at the Sun) with the geo-effectiveness of the resulting event.

MoVaTrac will be adapted to future solar EUV imagers such as SWAP and EUVI-Secchi. In particular, the objective of the VelociRaptor project is the 3D reconstruction from data of the future SECCHI set of instruments onboard STEREO.

Hic et Nunc

From the start, EIT was designed to perform two synoptic sets of observations. The basic synoptic mode acquires one image in each of the four channels every 6 hours. The CME watch mode additionally records Fe XII images at a 12 to 17 minutes cadence, of large Space Weather relevance. But the EIT camera is capable of taking images at even higher cadences, especially by taking advantage of the shutterless mode (SL, hereafter). In this mode, the shutter is kept open in order to prevent it from heating up, and to maximize the duty cycle of the integration time. Soon in the mission, Dr Clette of our team carried out episodic experiments with the SL mode, and Dr Berghmans developed a calibration technique to deconvolve the read-out contamination arising from the SL operations. But it is only during the BeER (Belgian EIT Reunion) in May 2000, that the ROB co-Investigators could convince the EIT consortium to undertake regular (quarterly) SL campaigns. They consist in running the telescope camera at a 68 sec cadence, consistently with the EIT pixel size and expected speeds at the Sun. The data are obtained either in the 30.4 nm or in the 19.5 nm bandpass (and occasionally in 17.1 nm). The 416x416 pixels field of view usually includes one quarter of the solar disk chosen to cover as many solar features as possible.

The motivation has been to build along the years a collection of synoptic high-cadence sequences. They allow studying fast events in the solar atmosphere, their statistics, and the possible trends of their properties with the 11-year solar cycle. Shortly afterwards, several other solar instruments (namely TRACE, MDI/SoHO, CDS/SoHO, and SPIRIT/CORONAS-F) proposed to join our campaigns, turning our consortium decision into a Joint Operation Program gathering all available extreme UV imagers, a spectrometer, and a magnetometer. SOHO JOP 80 and SOHO JOP 165 have also been defined by the ROB co-Is; they involve the SL mode of operations, and produced important results (Berghmans 1998, 1999, 2001, Robbrecht 2001), but they are not run on a recurrent basis. The ROB team members have coordinated all "SL campaigns", including the 18th shutterless run (end February 2005). See http://sol.oma.be/High-cadence. ROB scientists have published important results using the SL data (Robbrecht 2001, De Groof 2004); however, no one has yet addressed the original long-term motivation hitherto, and it is the aim of the Hic et Nunc (**Hi**gh **C**adence to study the **N**anoscale **U**ltraviolet **N**etwork and **C**orona) Action 3 to exploit the unique dataset we have instigated. In the frame of the present project, the work will focus on a most promising field, the multi-instrument analysis of the short-lived smallest features, the EUV Bright Points (hereafter BPs) and brightenings. These are key to all coronal heating scenarii, and much insight is anticipated from the investigation of their morphological and temporal behaviors with respect to the solar cycle.

B.3.4. Personnel involved

S. Gissot, JF Hochedez, D. Berghmans, G. Lawrence, V. Delouille

B.3.5. Partnerships

List of national and international partners

KUL (Master thesis student), B
UCL, LLN, B
CEREMADE, Paris Dauphine, F

Grants used for this research

Supplementary Researcher position
PRODEX-EIT
PRODEX-EIT_TELESCIENCE

Visitors: 1

B.3.6. Publications

B.3.6.1. Publications with peer system

Brajsa, R.; Wöhl, H.; Vrsnak, B.; Ruzdjak, V.; **Clette, F**.; **Hochedez, J.-F.;** Rosa, D.
Height correction in the measurement of solar differential rotation determined by coronal bright points
Astronomy and Astrophysics, v.414, p.707-715 (2004)

B.3.6.2. Publications without peer system

Gissot, S; Hochedez, JF
Multiscale Motion Analysis of EIT Images.
Summer School in Cargèse, 19-31/06/2004, France

Gissot S. , Hochedez J.-F.
Motion Analysis Algorithm applied to EIT Sequences (VelociRaptor).
Solar Image Processing Workshop II, November 3-5, 2004, Annapolis, Maryland, USA

B.3.6.3. Publications in press, submitted

Gissot, S; Hochedez, JF
Multiscale Motion Analysis of solar EUV image sequences
Solar Physics, in preparation

B.3.6.4. Reports, thesis, etc

Leen Devalck's master thesis (29 June '04) success
Laurent Jacques' PhD thesis (21 June '04) success
Final report for Supplementary Research position

B.3.7. Missions

Research missions (assemblies, symposia, workshops, etc): 2
Operational meetings (commissions, working groups): none
Field missions (observations, station maintenance, etc): none

C. Space Weather

The mission of the Royal Observatory of Belgium (ROB) is twofold: it includes both the expansion of knowledge through scientific research *and* the valorization of this knowledge through the provision of a public scientific service. These two aspects meet supremely in the emerging scientific discipline called

Space Weather, which studies the variable environment of the earth in space and the consequences this can have for human society and technology.

Solar activity is the main driver of space weather. The Earth is orbiting within the outer atmosphere of our home star, the sun. Despite its apparent invariable, simple, spherical shape, we now know that the Sun is variable in many ways. Energetic solar phenomena such as flares and coronal mass ejections have an impact on the space environment of the Earth through different physical connections. Solar activity spans a wide range of timescales, from the secular modulation of the well-known 11-year solar activity cycle, over the 27 days of solar rotation, down to sub-second timescales during eruptions. Monitoring this solar activity and evaluating its likely consequences for the near-Earth environment thus requires both a long-term commitment as well as daily dedication to follow up the ongoing dynamics in the solar atmosphere. Only a permanent service center that specializes in solar monitoring and solar activity research and that has extensive access to solar data can span these wide requirements. The 'Solar Influences Data analysis Center' at the ROB performs this task within several international networks. The SIDC undertakes to provide expert and timely information on and assessment of solar dynamics and its likely relevance for the Earth environment to an extensive set of users of the service.

Figure 18: A complex, active sunspot group observed on 30 March 2001 in white light by the ground-based telescope of the SIDC.

White-light observations of the solar photosphere are a simple but important way to characterize solar activity. The 11-year solar activity cycle is the most prominent source of solar variability. The existence of this cycle has been known for centuries due to observations of sunspots on the solar surface. The sunspot index is the oldest solar index measuring solar activity and is used for many studies on the cyclical behaviour of the Sun. Elsewhere in this report we describe our contribution to the long-term monitoring of this cycle.

Sunspots provide a good measure for the solar activity cycle, but certainly do not constitute its most relevant manifestation. During solar maximum, the sun generates a large number of energetic eruptions such as solar flares. Solar flares produce intense electromagnetic radiation and high-energy particles, and may be associated with global plasma expulsions from the solar corona known as Coronal Mass Ejections (CMEs). These have the potential of causing severe damage to human technology in space and on the ground and to hamper communication systems. Increased fluxes of high-energy particles, for example, are detrimental for Earth-orbiting satellites and expose airplane crews and passengers to enhanced doses of radiation. Disturbances in the solar wind interact with the Earth's magnetosphere, causing geomagnetic storms that, amongst other things, disturb GPS signals. All these effects form part of what is now commonly called 'Space Weather'. The SIDC operates a service to help users reduce the impact of space weather on activities of human interest. Since 1 Jan 2000, the SIDC has become a *Regional Warning Center* of the International Space Environment Service (ISES) and in this capacity provides short-term (3-day) forecasts of solar activity and its impact on the space environment of the Earth (see below in Project 2 for more detail).

In 2003, ESA started to set up the Space Weather European Network (SWENET) in an effort to initiate the construction of a global space weather service in Europe. This was justified by an earlier study highlighting the strong fragmentation of space weather activities in Europe. The solar physics department of the ROB successfully applied to become one of the Service Development Activities of SWENET. In the framework of this ESA-funded Space Weather Applications Pilot Project, our daily solar monitoring and forecasting activity has been extended and diversified, e.g. by developing a user-friendly interface to solar data, the Solar Weather Browser. These activities are described below in the first Project in this theme.

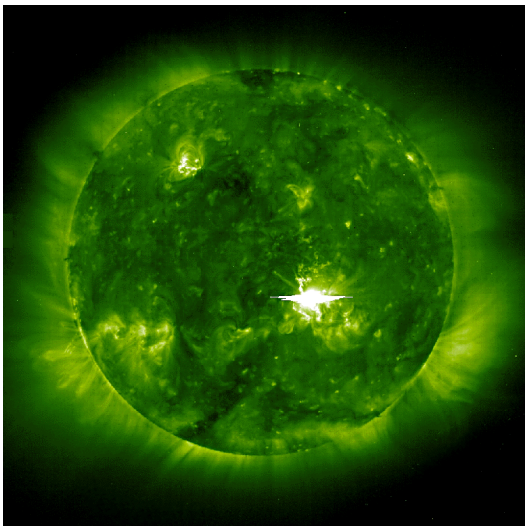


Figure 19: A bright solar flare, captured by the instrument EIT on 1998 May 2.

White-light sunspot observations help in predicting energetic solar events, but today, thanks to space missions such as e.g. SOHO, GOES and ACE, a much wider range of observations is available to characterize the solar variability on the level of radiation, particle fluxes, and plasma flows. CMEs, for example, are now routinely registered by the LASCO coronagraph (see below). The availability of these data paves the way to base the Space Weather service provision on more firm scientific footing. Scientific studies described in the other sections of this report from part of this effort, and so does a scientific collaboration set up in the frame of the INTAS scheme (project 3).

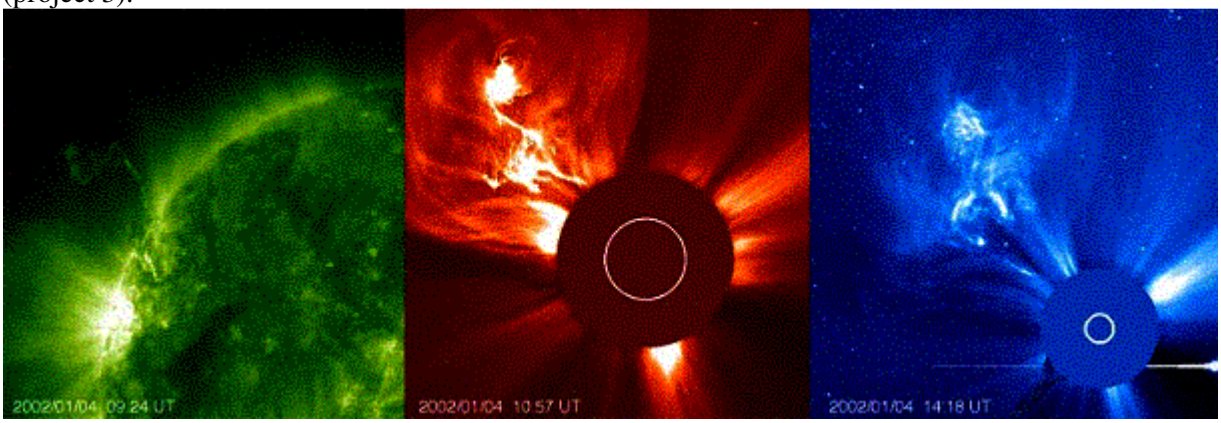


Figure 20: A solar eruption, captured by the EIT and LASCO instruments onboard the joint ESA/NASA space mission SOHO on Jan. 4 2002.

Of particular relevance to future Space Weather research and monitoring in our group is the upcoming PROBA2 space mission (to be launched in 2007), with the solar instruments SWAP and LYRA (described elsewhere in this document). These instruments will lead to much more detailed diagnostics of flares and related phenomena such as EIT waves. From these, we may hope to achieve a much better understanding of the initiation processes of flares and CMEs, and thus, when supplemented by adequate theoretical research and modeling, a much better predictability of solar activity as a whole.

C.1. Participation in the ESA Space Weather Applications Pilot Project

C.1.1. Objectives

In 2002, the SIDC successfully applied to become one of the Service Developments Activities (SDA) of ESA's Space Weather Applications Pilot Project. To this purpose we established a collaboration between several research units within the Space Pole. The purpose is to contribute our expertise in solar observations, solar activity research and space weather monitoring to support the activities of the other groups participating to our own SDA and to the global SWENET network, and to develop tools to automatically detect solar events relevant for space weather.

C.1.2. Progress and results

In April 2004, ESA's Space Weather Applications Pilot Project changed from the 'development phase' to the 'service and evaluation provision' phase. This meant that all major developments were completed early in 2004, but minor additions and upgrades of the products developed continued throughout the year.

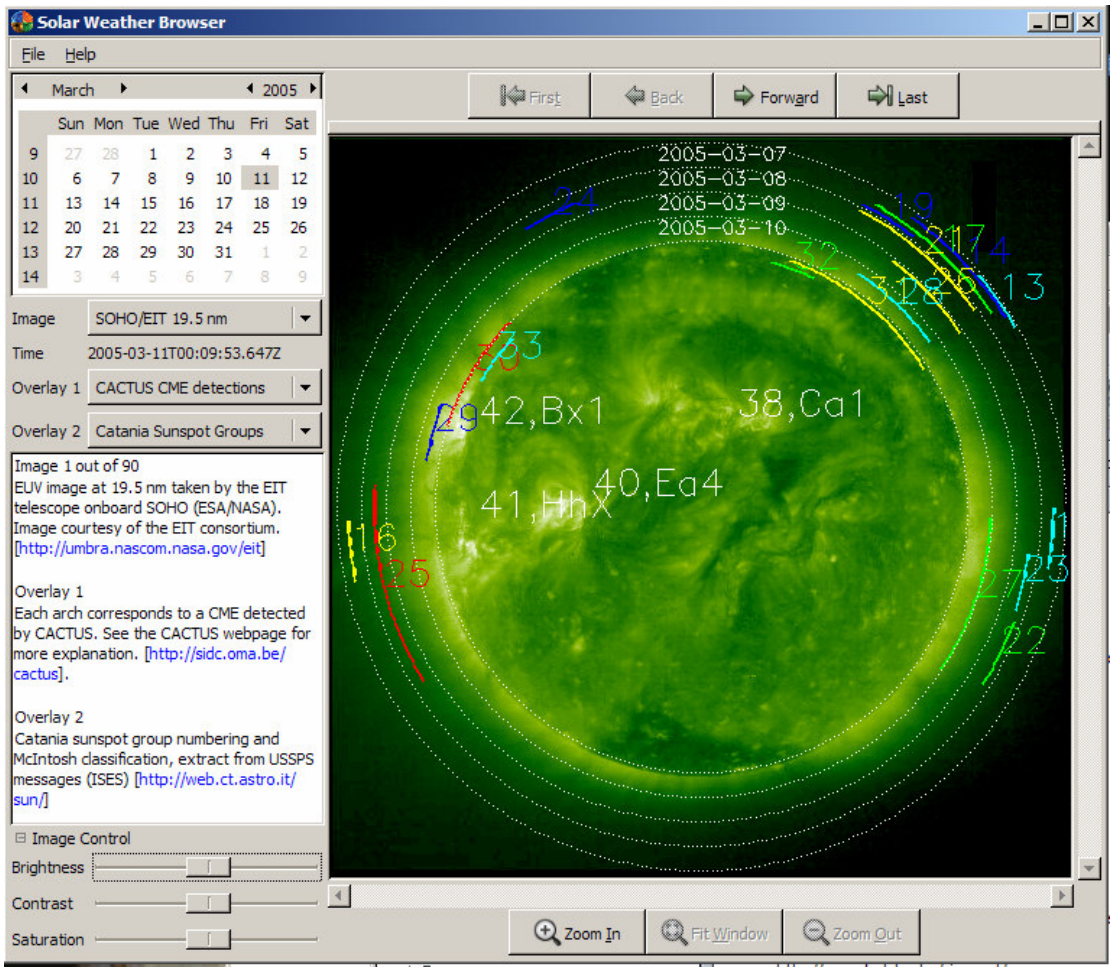


Figure 21: A screenshot of the Solar Weather Browser, here showing how it can be used to visually relate EUV solar images (from EIT) with observed sunspot group classifications (from Catania observatory) and output from feature detection algorithms (here CACTus CME detections).

One of the deliverables under the project is the Solar Weather Browser (SWB), a first version of which was completed early in 2004, but which has since then been further improved. The SWB is a software tool developed by the Royal Observatory of Belgium for easy visualisation of solar images in combination with any context information that can be overlaid on the images and that is space weather relevant

(see Fig 1). It consists of 3 developments: (1) the SWB backend server (SWB-server), (2) the SWB user interface and (3) the SWB download and user support website. The backend server collects data from a variety of sources using different protocols. After acquiring the data, the backend server pre-processes the different types of data with specialised software and makes them available on the distribution website. In this way, the user does not need detailed information on the location and accessibility of the data, nor on specialised software required to run the data. The splitting of the SWB in a user interface and a backend server has the additional advantage that new types of data can be included without the need to re-distribute the user interface.

The software package *CACTus* was developed for automated and objective detection of Coronal Mass Ejections (CMEs) in coronagraph images. This development took place for a large part outside of the current project, but in view of the direct relevance of fast detections of CMEs for space weather operations, we implemented this software package in a fully automated data stream to generate near-real-time alerts of significant halo CMEs. This implementation has been fully operational during the second half of the past year.

In this project, we established a close collaboration with Dr. R. Warnant and his co-workers in the GPS section of the Observatory. This group has specialized in scientific studies of the influence of ionospheric perturbations (which may be caused by space weather events) on the accuracy of GPS positioning. Based on these studies, they have set up a *near-real-time assessment of GPS accuracy*, available through their website. In the collaboration, we have integrated these GPS products in the SIDC space weather service, by setting up a fully automated alerting service when strong deterioration of GPS accuracy is observed or expected.

The alerts generated by CACTus and the GPS near-real-time service have been incorporated into a system of *fast alerts for space weather events***.** These fast alerts are generated in a fully automated processing chain by software that downloads relevant data, analyses the data with event detection algorithms, generates alerts for the detected events and distributes these by e-mail, through the website and (as a trial service) through SMS. During 2004, such fast alerts were added also for large solar flares and geomagnetic storm onsets.

As a final part of this project, we have started an evaluation of the quality of the SIDC forecasts, by comparing those with alternative methods derived from statistical studies and physics-based event estimators. This study will not only help us improve the future forecasting techniques, but should also lead to a better knowledge about the precise causes of short-term variability in solar indices (such as the 10cm radio flux) and about the changes in global space weather event distributions over the solar cycle.

C.1.3. Perspective for next years

The Space Weather Applications Pilot Project ends on 31 March 2005. A final report and final presentation of our activities as an SDA in SWENET will have to be prepared near that date. At the same time we will support the cost benefit analysis ordered by ESA, which will have to establish whether there is sufficient interest in space weather throughout Europe to support a continuation of this type of project in the long term.

The products developed in the course of this project will be incorporated in the ongoing activity as a Regional Warning Center of the ISES. (It is also a contractual requirement that the SDA service is continued for at least a year.) The forecast evaluation procedure initiated is expected to lead to further scientific studies of the relationship between solar EUV radiation and solar radio fluxes. Also, statistical studies of solar flare distributions and their variation over the solar cycle have been initiated.

The event detection tools will be further developed to build event catalogues than can be correlated with solar activity indices and that will assist scientific studies of the solar origins of space weather disturbances. Furthermore, these tools will be used to assist in the management of the large volumes of solar data that is expected to become available in the coming years, e.g. for the reduction of telemetry requirements for space missions by selecting the most relevant images to downlink.

C.1.4. Personnel involved

Project Manager: Ronald Van der Linden

People hired on the project grant: E Robbrecht (until 1 Aug 2004), P. Vanlommel.

Additional contributions from: David Berghmans, Frederic Clette, Andrei Zhukov, Bogdan Nicula, Laurence Wauters, Sarah Willems.

C.1.5. Partnerships

List of national and international partners

- This project is a collaboration between the Royal Observatory of Belgium (solar physics and GPS groups), the Royal Meteorological Institute, the Belgian Institute for Space Aeronomy, and Creaction Int.
- Our service forms part of the global European network linking up the various projects (SWENET, see http://esa-spaceweather.net/swenet/index.html).
- The Space Weather Working Team (SWWT) contributes to the coordination of European space weather projects (see http://www.estec.esa.nl/wmwww/WMA/spweather/esa_initiatives/swwt/).

Grants used for this research:

ESA contract 16913/03/NL/LvH.

Visitors: 2

In addition to the presence of typically 4 scientists from the other participating institutes at the monthly local progress meetings.

C.1.6. Publications

C.1.6.1. Publications with peer system

Robbrecht, E. & Berghmans, D.
Automated recognition of coronal mass ejections (CMEs) in near-real-time data
Astronomy & Astrophysics 425, 1097, 2004.

C.1.6.2. Publications without peer system

C.1.6.3. Publications in press, submitted

Robbrecht, E. & Berghmans, D.
A broad perspective on automated CME tracking (invited review)
AGU Chapman on Solar Energetic Plasmas and Particles, August, 2004, AGU Monograph, submitted

C.1.6.4. Reports, thesis, etc

Van der Linden, R.A.M; Berghmans, D.; Vanlommel, P.; Robbrecht, E.; Cugnon, P.; Clette, F.; Wauters, L.; Zhukov, A.
The expanding space weather services of the SIDC at the Royal Observatory of Belgium

Poster at the COSPAR 2004 General Assembly, Paris, 18-25 July 2004.

R. Van der Linden, D. Berghmans, E. Robbrecht, P. Vanlommel, F.Clette, B. Nicula, A. Zhukov, L. Wauters, R. Warnant, E. Pottiaux, S. Lejeune, A. Barre, M. Bavier, H. Nebdi, J.-C. Jodogne, J. Rasson, K. Stegen, D. Heynderickx, M. Roth, J. De Keyser, M. Kruglanski, J.-P. Henry, J.F. Marche
The SIDC project: a comprehensive operational space weather service in Belgium
Poster at the European Space Weather Week, ESTEC, Nov. 29 - Dec. 03 2004.

R. Warnant, M. Bavier, S. Lejeune, E. Pottiaux, B. Andonov, I. Kutiev, A. Barré, H. Nebdi, J. Rasson, **R. Van der Linden**
Development of Space Weather related services for real-time GPS applications in the frame of the SIDC Space Weather Pilot Project
Poster at the European Space Weather Week, ESTEC, Nov. 29 - Dec. 03 2004.

P. Vanlommel, R.A.M. Van der Linden, D. Berghmans, P. Cugnon, E. Robbrecht
The SIDC Space Weather Application Pilot Project: quality control of space weather forecasts
Poster at the European Space Weather Week, ESTEC, Nov. 29 - Dec. 03 2004.

R.A.M. Van der Linden and the SIDC team
Monthly progress reports to ESTEC for the ESA Space Weather Applications Pilot Project.

Berghmans D., Nicula B., Van der Linden R.
Final Report WP-412: Solar Weather Browser
Contractual report to ESA, 10 pages.

C.1.7. Missions

Research missions (visits and conferences): 3
Operational missions (commissions, working groups): 6
Field missions (observations, station maintenance): 0

C.2. Operational activities as Regional Warning Center (RWC) Belgium

C.2.1. Objectives

RWC Belgium offers a permanent service center, specializing in solar monitoring and solar activity forecasting under the auspices of the ISES network. For this, we have access to a large volume of solar and heliospheric data that can span these wide requirements. Building on insights derived from our scientific studies, the SIDC provides expert and timely information on and assessment of solar dynamics and its likely relevance for the Earth and human technology.

C.2.2. Progress and results

RWC Belgium is incorporated into the Solar Influences Data analysis Center (SIDC), which has developed into the overarching structure of a large part of the activities at the solar physics department, although most of those activities have a purely scientific justification out of their own right. The SIDC joins research, observations, data handling and data dissemination into an operational center for space weather monitoring and forecasts. To the outside world the SIDC is visible as the World Data Center for the Sunspot Index, a Regional Warning Center of the ISES and a Service Development Activity of SWENET. 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. During 2004, due to the illness and death of our valued colleague P. Cugnon, R. Van der Linden has continued to assure the project management of the SIDC, with now the official role of being its director towards the ISES, the FAGS and the World Data Center network.

The main task of the SIDC as Regional Warning Center of the ISES is to perform continuous monitoring of solar and geomagnetic activity, which includes daily forecasts of several internationally recognized activity indices. The role as a RWC implies handling data flows from various sources, most of them arriving through e-mail or internet downloads. To perform these activities in an efficient way, we use the locally developed software packages 'PreviMaster' and 'PreviWeb', which are continually improved and adapted to changing data sources and user requirements. Both software packages were significantly extended during 2004 under the impulse of the joint development of user products for the ESA Space Weather Applications Pilot Project. During 2004, we have also replaced the servers that handle SIDC data, at the same time implementing tighter security constraints and a more structured network. The PreviWeb interface has been completely rewritten by linking it up to scripts populating a MySQL database. This SIDC database includes recorded data since 2001 and forecast data since March 2003. It is linked to other databases containing references to solar data and event catalogues derived from this data.

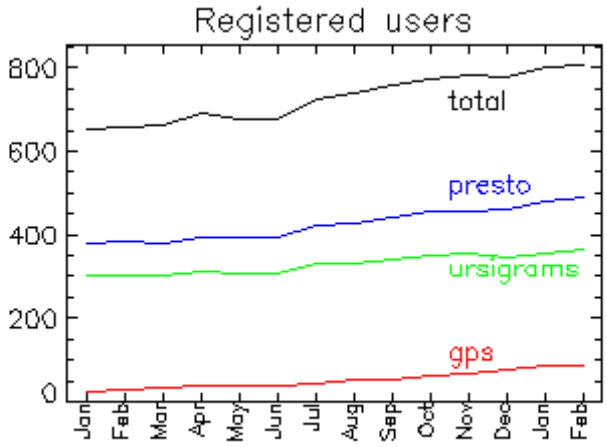


Figure 22: Registered users

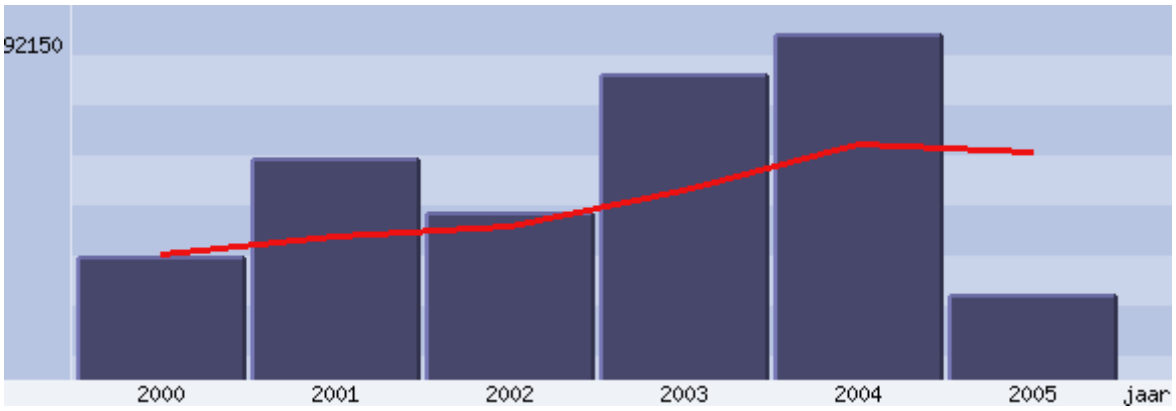


Figure 23: SIDC Web site visits

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 so-called 'ursigram' messages (originally 5 different types but reduced to 4 during 2004). Weekly summaries are sent out in principles on Mondays, while more extensive monthly summaries of solar and geomagnetic activity are included in the Sunspot Bulletin of the SIDC. Besides these default distributions, several other types of messages are generated, the most important ones being the fast alerts discussed earlier and the 'presto' messages, which are intended to alert our users of strong perturbations to space weather. When conditions warrant, press contacts are also established. The main method of information distribution is through the internet: the SIDC website and e-mail. The growing international interest in our service is reflected in the steady growth in the website visits and e-mail registrations (see Figure 23 and Figure 23).

C.2.3. Perspective for next years

The SIDC will continue its activities as a Regional Warning Center of the ISES. However, since the ESA pilot project will formally end in March 2005, and ESA currently appears to have no intention to extend the project, activities will probably be reduced to a lower level, unless other project funding is obtained. Such new opportunities may arise in the European Union framework, e.g. under GALILEO.

In the years to come, we will continue to strengthen our scientific research as the solid basis of our space weather forecasting activities. The SIDC activities will benefit from a strong participation of the solar physics department team in space missions such as PROBA 2 and STEREO, and from a participation in international research networks.

C.2.4. Personnel involved

Project leader: Ronald Van der Linden
Additional contributions from: D. Berghmans, F. Clette, E. Robbrecht, P. Vanlommel, A. Zhukov, J.-F. Hochedez, L. Wauters, S. Willems, B. Nicula, O. Boulvin, D. Lafont, G. Lawrence.

The daily duty cycle of forecasting and monitoring activities were shared by D. Berghmans (55 days), F. Clette (56), E. Robbrecht (71), R. Van der Linden (66), P. Vanlommel (72) and A. Zhukov (46).

C.2.5. Partnerships

List of national and international partners

RWC Belgium is one of the nodes in the International Space Environment Service (ISES, see http://www.ises-spaceweather.org/).

No grants were obtained for this activity.

Visitors: none.

C.2.6. Publications

C.2.6.1. Publications with peer system

C.2.6.2. Publications without peer system

Petra Vanlommel, Ronald Van der Linden, Eva Robbrecht, David Berghmans, Frederic Clette, Laurence Wauters, Andrei Zhukov, Pierre Cugnon
Een op hol geslagen zon?
Heelal 49, p. 79-86, 2004.

C.2.6.3. Publications in press, submitted

D. Berghmans, R.A.M. Van der Linden, P. Vanlommel, R. Warnant, A. Zhukov, E. Robbrecht, F. Clette, O. Podladchikova, B. Nicula, J.-F. Hochedez, L. Wauters, S. Willems
Solar activity: nowcasting and forecasting at the SIDC
Annales Geophysicae, submitted.

J.-F. Hochedez, A. Zhukov, E. Robbrecht, R. Van der Linden, D. Berghmans, P. Vanlommel, A. Theissen, F. Clette
Solar weather monitoring (invited review).
Annales Geophysicae, submitted.

C.2.6.4. Reports, thesis, etc

R.A.M. Van der Linden and the SIDC team.

Annual report 2004 to the International Space Environment Service.

The SIDC team

A total of more than 4000 outgoing messages from RWC Belgium, including 366 daily ursigrams, 52 weekly bulletins and 86 presto alerts.

C.2.7. Missions

Research missions: 0
Operational Meetings: 1
Field missions: 0

C.3. INTAS Project 03-51-6206 "Solar and interplanetary disturbances causing severe geomagnetic storms"

C.3.1. Objectives

The investigations in the framework of this project (started in 2004) are carried out in collaboration with Max-Planck-Institut für Sonnesystemforschung (Germany), Institute of Nuclear Physics (Russia), IZ-MIRAN (Russia) and the Astronomical Institute of the Academy of Sciences of the Czech Republic. The objective of the project is to study the strongest geo-effective disturbances in the corona and inner heliosphere that occurred during the current solar cycle.

C.3.2. Progress and results

The solar and interplanetary sources of extreme solar events of October – November 2003 and November 2004 have been identified using data from the SOHO (instruments EIT and LASCO) and ACE spacecraft. It has been demonstrated that global changes occurred in all spectral ranges of the solar electromagnetic radiation with strong asymmetry in the helio-longitude. This phenomenon was accompanied by more localized enhanced energy releases, manifested as CMEs and flares. The most powerful of them were observed on the side of the Sun that was brighter even without these local enhancements. These results suggest that the physical causes of solar and heliospheric phenomena in October – November 2003 are not exclusively local and do not belong only to active regions and solar atmosphere above them. The energy supply and driving forces probably have a more global nature.

C.3.3. Perspective for next years

The project is financed for three years (2004 – 2006). The investigation of solar and interplanetary sources of severe geomagnetic storms will be continued. The sources of very recent severe storms that occurred in January 2005 will be identified and these storms will be compared to other extreme events.

C.3.4. Personnel involved

Team Lead: A. Zhukov
Additional contributions from: R. Van der Linden

C.3.5. Partnerships

List of national and international partners

This research project is a collaboration between 5 scientific institutes.

Grants used for this research:

INTAS grant 03-51-6206

Visitors: none.

C.3.6. Publications

C.3.6.1. Publications with peer system

C.3.6.2. Publications without peer system

C.3.6.3. Publications in press, submitted

Veselovsky I.S., Dmitriev A.V., Zhitnik I.A., **Zhukov A.N.**, Zeldovich M.A., Kuzin S.V., Persiancev I.G., Shugay U.S., Ryazanov A.U., Yakovchouk O.S., Bogachev S.V., Shestov S.V.
Global variations of the solar output during extremely high activity in October-November 2003
Solar System Research, in press.

C.3.6.4. Reports, thesis, etc

Bothmer, V.; **Zhukov, A.N.;** Dmitriev, A.V.; Ivanov, K.G.; Panasenco, O.A.; Romashets, E.P.; Vandas, M.; **Van der Linden, R.;** Veselovsky, I.S.; Yakovchouk, O.S.
A comprehensive view of the giant Sun-Earth events in October/November 2003
Oral presentation at the EGU 2004 General Assembly, Nice, 25-30 April 2004.

Bothmer, V.; Romashets, E.; Vandas, M.; **Van der Linden, R**.; Veselovsky
Interaction of magnetic clouds in the solar wind
Poster presentation at the EGU 2004 General Assembly, Nice, 25-30 April 2004.

V. Bothmer and INTAS Team 03-51-6206
The origin of the 11- and 22-year periodicities of major geomagnetic storms
Poster presentation at IAU Symposium 226, Beijing, China, September 13-17 2004.

C.3.7. Missions

Research missions: 0
Operational Missions: 0
Field missions: 0

D. Solar activity indices

As the World Data Center for the Sunspot Index and a data analyses service of the FAGS, the SIDC is in charge of the determination, archival and mid-term prediction of the International Sunspot Number, the most fundamental solar activity index. Given its unequalled time coverage of three centuries, it is used as a reference index in innumerable studies and publications. Most other indices, introduced more recently, are calibrated on the sunspot number in order to define long-term irradiance models for backwards and forward extrapolations.

Along that axis, the solar physics team has developed internally new researches in the domain of solar indices to extend the base sunspot reference. In preparation of the science exploitation of the PROBA2/SWAP imager, a correlative study has been initiated between SOHO/EIT and CORONAS/SPIRIT images and the 10.7 cm radio flux, in order to establish a predictive relationship between the spatially-resolved extreme UV flux and the standard 10cm radio index. The team also prepares UV irradiance variability studies based on the absolute standard fluxes from the PROBA2/LYRA radiometers now in development.

The Humain station is now primarily dedicated to the continuous recording of the 600MHz radio flux, one of the few long-term indices preceding the space-era, which is provided only by this station. In a new re-development, which was the matter of a proposal in 2004, the Humain radiometric instruments may

cover other radio bands, including 10.7cm. Finally, the optical USET instruments are providing visual and CCD observations in support to the SIDC sunspot index determination, as one of the reference stations in the worldwide network. The introduction of white-light and Hα CCD imagers, now in routine use, marks also a new effort to improve and to better understand existing solar activity indices and to study new quantitative ground-based solar indices based on modern electronic imaging technologies.

D.1. SIDC, World Data Center for the International Sunspot Index

D.1.1. Objectives

Determination of the International Sunspot Index, based on visual sunspot observations from a world wide network of observing station. Since 1981, the SIDC maintains and makes accessible to the scientific community the sunspot archive spanning 3 centuries, i.e. the longest existing record of solar activity, previously under the responsibility of the Zurich Observatory. The SIDC also publishes, through its Sunspot Bulletin, various solar indices as well as mid-term activity forecasts.

D.1.2. Progress and results

The normal operations of the SIDC as World Data Centre for the Sunspot Index include:

- Data processing:
  - Determination of the provisional sunspot number (Total and normalized hemispheric North & South counts introduced in 1992)
  - Computation of the monthly, smoothed monthly and yearly means.
  - Computation of the definitive sunspot number (Total & hemispheric, published quarterly) based on the entire network (82 stations)
  - Mid-term prediction by the *Waldmeier classical method* and by the *Combined Method*, 18 month ahead.
  - Quality control: long-term drift evaluation based on 20 selected stations and the 10cm radio flux.
- Archive:
  - Maintenance of the archive: yearly, monthly, monthly smoothed and daily sunspot numbers.
  - The archive is publicly accessible through the SIDC Web and FTP site (ASCII data files and plots)
- Sunspot Bulletin (monthly publication):
  - Provisional sunspot table and plot
  - 24-month predictions of the monthly Sunspot Number
  - Summary of the URSIGRAMS, with additional indices (PPSI, 600MHz flux, 2800MHz (10cm) flux, Terre Adélie cosmic ray counts, solar flare index, X-flare index, Wingst 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.
- Individual data provision (on request)
  - We frequently get special request concerning sunspot data. The most noteworthy during 2004 were requests for a subset of the complete archive of data reports from the observers to the Data Centre (from. Prof. B. Schaefer, Louisiana State University), a request concerning minima and maxima of the solar cycle (from Prof. X. Moussas (Athens Univ.) and a request concerning data format change (from Prof. Potts, Univ. of Glasgow).

D.1.3. Perspective for next years

An increased automation of the sunspot index processing is foreseen, in connection with the data flows of the daily URSIGRAMS for the Regional Warning Center side of the SIDC activities.

D.1.4. Personnel involved

Project lead: R. Van der Linden
Additional contributions from: A. Vigneron, G. Evrard, O. Boulvin, P. Vanlommel, D. Berghmans, F. Clette.

D.1.5. Partnerships

List of national and international partners

The SIDC is one of the World Data Centers in the World Data Center System (http://www.ngdc.noaa.gov/wdc/wdcmain.html)

The SIDC is one of the data analysis services of the Federation of Astronomical and Geophysical Data Analysis Services (FAGS, see http://www.kms.dk/fags/index.html)

D.1.6. Publications

D.1.6.1.Publications with peer system

P. Vanlommel, P. Cugnon, R.A.M. Van der Linden, D. Berghmans, F. Clette
The SIDC: World Data Center for the sunspot index
Solar Physics 224, p113-120 (2004).

D.1.6.2.Publications without peer system

R. Van der Linden and the SIDC team,
The Sunspot Bulletin (12 issues).
Monthly bulletins of the SIDC containing the provisional International Sunspot Number, data obtained in Ukkel and Humain, tables of solar and geomagnetic data received and reviews of solar and geophysical activity.

R. Van der Linden and the SIDC team,
SIDC News (4 issues).
Quarterly bulletins of the SIDC for distribution of the definitive International Sunspot Number.

D.1.6.3.Publications in press, submitted

D.1.6.4.Reports, thesis, etc

R.A.M. Van der Linden and the SIDC team
Annual report 2003 to the Federation of Astrophysical and Geophysical data analysis Services.

D.1.7. Missions

Research missions: 1
Operational Missions: 0
Field missions: 0

D.2. The Uccle Solar Equatorial Table (USET)

D.2.1. Objectives

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.

D.2.2. Progress and results

- *Maintenance of the CCD camera system*: The year 2004 was marked by two severe failures that caused temporary interruptions to the routine synoptic observations started in 2002:
- The camera control PC failed on January 3rd and the observations resumed on January 23 after replacing the computer.
- The white-light camera that had been repaired in the summer of 2003 failed again completely on March 31. The camera was again in operation by September 2, after the replacement of the CCD sensor.
- *New digitizing system for the solar drawings*: a new A3 document scanner (EPSON GT-15000) was installed on January 21. While new software must still be created to measure the sunspots groups from the scanned files to continue the USET visual solar series, the drawings were already scanned daily to be published on the SIDC web site, a new capability that did not exist with the earlier digitizing system.
- Site and telescope maintenance and development:
  - Improvements to the telescopes dust protecting doors.
  - Preparation of protecting enclosures for the CCD cameras.
  - Initial tests of the new stepping-motor drive in declination.
  - Measurements of instrumental drift in view of the re-alignment of the USET mount.
  - New expanded version of the USET user manual (now in French and English).
  - Cutting of trees: the top of about 30 high trees that prevented solar observation for more than 2 hours, mainly on the East of the solar dome, was cut shorter between Nov. 29 and Dec.1, 2004.
  - A proposal of a new H-alpha filter and telescope was prepared and submitted (LOTTO funding). This new instrument should replace the old telescope currently in use and improve the degraded contrast and image resolution. A market search was conducted and several optical manufacturers were contacted in Belgium, Germany, USA and China.
- Observations:
  - Like in 2003, the CCD synoptic images were automatically transferred to a dedicated archive and the latest images were uploaded to the SIDC servers and were displayed in the "Latest Solar Data" pages, together with imagery from other observatories and spacecrafts, for worldwide access.

Camera	Nb. Days	Nb. Images	Ratio (im/day)	Comment
Photosphere	168	811	4.82	Interruption mid-April to end May
Chromosphere	171	611	3.57	Interruption between early June and August
Total		1422		

  - This year, all Uccle sunspot drawings were scanned immediately after the observations. The scanned document (jpeg file) was included in near-real time in the "Latest Solar Data" web page of the SIDC, together with drawings from Catania and Zurich. Sunspot group evolution data, derived from encoded drawings, were used for the Uccle tables of the Sunspot bulletin (p.4). The 2004 statistics are the following:
  - Number of observations: 279 (1 drawing on 237 days, 2 drawings on 21 days)
  - Number of observing days: 258 (out of 366)

- Number of observers: 12, with mainly O. Boulvin (142 drawings/ 209 days), A.Vigneron (37 drawings/ 52 days) and F. Clette (19 drawings/26 days).

D.2.3. Perspective for next years

- Commissioning of the stepper-motor drive on the declination axis of the USET.
- Completion of the new digitizing and encoding software tool for solar drawings.
- Design study and development of a solar pointer to ensure accurate tracking for CCD cameras.
- Installation of the new Hα filter and telescope (and association with the international Hα network).
- Trainees: over the 2004-2005, academic year, F. Clette will be supervising two students working on the development of the USET instrument and the associated data acquisition:
  - Julien Moreau, Ecole Supérieure d'Informatique, ESI: Upgrade of "Suncap" software and development of the new digitisation program.
  - Sammang Say, ISIB: technical engineer stagiaire, design of solar pointer electronics.

D.2.4. Personnel involved

Lead: F.Clette (observations, development, testing and calibration of instruments),
Additional contributions from: O.Boulvin (observations, data reduction), J-L Dufond (maintenance and development of instruments), A. Vigneron, A. Ben Moussa, D. Berghmans, D. Carre, M. Dominique, S. Gissot, E. Robbrecht, A. Theissen, R. Van der Linden, A. Zhukov.

D.2.5. Partnerships

D.2.6. Publications

Real-time web distribution of more than 200 CCD camera images.
Real-time web distribution of about 140 scanned solar drawings.
SIDC sunspot bulletin (12 monthly issues): the Uccle-USET relative and normalized sunspot numbers, large sunspot group table, large returning group list.

D.2.7. Missions

None.

D.3. The Humain radio-astronomy station

D.3.1. Objectives

Radio-electric observations of the Sun for flare monitoring and long-term recording of the solar radio in the upper-chromosphere and low corona:

- Integrated radio flux at 600 MHz, and future extension to other frequencies, including 2,8Ghz.
- Monitoring of "atmospherics" at 27 kHz, through the response of the Earth ionosphere to X and UV irradiance bursts associated with solar flares
- Near-real time transmission and processing of the Humain data in support to the SIDC solar flare monitoring.

D.3.2. Progress and results

- *Evolution of the work context*:
  - This year was also marked by the transfer of the buildings from the ROB to the "Régie des Bâtiments" for what concerns their maintenance.

- M. Christian Rondeaux (gardener) has been permanently on sick leave since April 2004. The gardening workload has thus been transferred to the other two staff members, putting additional strain on the already minimal team.

– *Preservation of the Humain site quality*: again this year, a continuous attention had to be devoted to the protection of the perimeter around the station and of the Humain radio frequencies against radio interferences:
  - Electrabel wind turbine project: electromagnetic field interference measurements were carried out by the IBPT at several existing wind turbine sites, an answer was sent in response to a public inquiry about the wind turbine project and in early June, a fully documented file was sent to the Ministère De la Région Wallonne, Division de l'Urbanisme, Direction d'Arlon, in response to an environmental inquiry. No further progress of this file took place in the rest of the year 2004.
  - The coordination with the CRAF (Dr. Titus Spoelstra) was maintained at the international level (600 and 408MHz bands protection in future ITU regulations, wind turbine issue)
  - Two responses were given to frequency allocation requests in the 408MHz band from the IBPT. One of them prevented the implementation of a TV broadcaster in the 408MHz band in Germany.
  - Future plans for the station and the exploitation of the quarry neighbouring the station were discussed with the managers of the Lhoist industries company.
– Station development and projects:
  - The new guiding system of the refurbished 6-m antenna has been permanently installed by mid-2004. The antenna is now ready to be fitted with a new receiver.
  - In April 2004, a project proposal for BelSpo Action1 funding was submitted to the Scientific Council of the ROB. Called "HUMSOLAR", it involves the conversion of existing radio-telescopes at the station into a multi frequency radiometer array. A LOTTO funding request was submitted simultaneously for the required equipment, primarily a high-range spectral analyzer. At the June 28 meeting, the scientific council rejected the modernization proposal, which means at least the freezing of any possible development of the station in 2004-2005. Given the importance of the possible consequence such a far-reaching decision, F. Clette required and obtained that an inquiry is done on a wider base, by seeking advice from international experts. Therefore, a new report and project description was prepared and submitted to the Director on October 1st. The Director submitted the report later in 2004 and answers are expected in the spring of 2005.
– Observations:
  - Given the absence of new means attributed to the station, only the daily 600MHz integrated flux measurements were continued systematically, still using the old 7.5m "Wurzburg" antenna:
  - Daily plots including flare events were produced for publication on the SIDC web site
  - The solar background flux was derived and published among reference indices in the SIDC Sunspot Bulletins (p.3, continuation of time series beginning in 1954).

D.3.3. Perspective for next years

The future orientation of the radio-astronomy activities at the Humain station will depend on the conclusions drawn by the ROB scientific council from the answers of international expert, following the advice request issued in 2004. In the case of a positive answer and based on the collected advices, the modernization plan would be resubmitted in a new reworked form. A negative decision of the council would unfortunately mean the termination of the solar radio-astronomy program of the ROB and of the 50 year-long 600MHz flux time series still maintained now.

D.3.4. Personnel involved

F.Clette (science management, site protection), J-L Dufond (technical management and maintenance, data processing), P. Janssens (resident technician, site maintenance, observations), C.Rondeaux (gardener), S.Walkiers (technical maintenance, observations).

D.3.5. Partnerships

Dr. K. Tapping (Dominion Radio Astronomical Observatory, Penticton, Ottawa, Canada)
Dr. M. Messerotti (Trieste Solar Radio Observatory, Italy)

D.3.6. Publications

Web distribution of daily 600MHz solar flux plots on the SIDC web pages.
Daily-averaged 600MHz background flux listed in the SIDC Sunspot Bulletins (12 issues, solar indices table, p.3).

D.3.7. Missions

Operational missions: 3
Field missions: 43

E. Activities in support to institute-wide projects and services.

Preparation of the solar chapter of the ROB yearbook:

- F. Clette and G. Evrard carried out the computation, edition and verification of the solar ephemeris tables (local circumstances for Uccle, geocentric parameters, solar rotations).
- In May and June 2004, F. Clette started reviewing the programs and the translation of the old BASIC sources to the C language (chosen for its widespread use on PC platforms). This work had to be suspended for a few months but will be continued in 2005.

Public outreach:

- Special observations were carried out at the occasion of the exceptional **Venus transit** of June 8, 2004. Thanks to favorable weather conditions and a proper preparation, the entire event was recorded successfully: a time-lapse sequence was acquired with a 4-min cadence during 5 hours, and a higher 30 sec cadence during the limb transits. All images were processed and registered before being assembled into a movie. The processed images were distributed in near-real time through a special web page of the SIDC site.
- **Group visits:**
  - 09/03/04: Group of Danish students
  - 30/04/04: Université de Liège DEA students
  - 25/11/04: staff of the Dourbes station
- **Numerous answers to requests for information (telephone, mail).**
- **Interviews:**
  - 15/01/04: F Clette was interviewed by "La Meuse-La Lanterne" for an article on the Humain station
  - 17/05/04: F Clette was interviewed by "Le Soir" newspaper, C. Du Brulle, on the PROBA2 project
  - 11/08/04: F Clette was interviewed by RTBF television (Philippe Toussaint) on the Humain radio-astronomy station.
  - 15/09/04: David Berghmans participated to a Verhaert press-conference on PROBA2 with a short SWAP presentation entitled “SWAP, monitoring our star”. This resulted in media-coverage in all major Belgian TV and radio channels, as well as in many newspapers.
  - 13/10/04: F Clette provided solar dome footage for a report about the ROB (V. Dehant, Descartes prize) to "La Libre Belgique".
  - 07/12/04: D. Berghmans and J.-F. Hochedez were interviewed by “Fedra” on the PROBA2 project

- **Public lectures:**
  - 23/01/04: P Vanlommel gave a public lecture "*Ruimteweer: de Halloween-stormen"*
  - 16/02/04: E Robbrecht gave a lecture "*De Zon en het Ruimteweer*" to 'jong KVCV (Koninklijke Vlaamse Chemische Vereniging)' linked to the University of Gent.
  - 27/03/04: R Van der Linden gave a lecture "De zon-aarde connectie" to public observatory 'Altair' (Zoutleeuw).
  - 08/04/04: E Robbrecht gave a lecture "*De Zon en het Ruimteweer*" to MARNIX ring Land van Waas, Sint-Niklaas.
  - 25/06/04: J.-F. Hochedez gave two talks to primary school children.
  - 03/07/04: D. Berghmans gave a lecture "*Zonnestormen in okt/nov 2003*" to "VVS Werkgroep Zon", Astrolab Iris, Ieper.
  - 20/09/04: F Clette gave a lecture "*Le Soleil : notre étoile passionnante et indispensable*", Club 51 International, Hotel Bristol Stéphanie.
  - 10/12/04: F Clette gave a lecture "*Un Soleil sous la loupe*", Club Orion, Braine l'Alleud.
- **Data archive digitisation project:**
  - F. Clette updated the data sheets for the solar physics photographic collections on request of the Van Dijk consulting company (Oct. 2004)
- **BELSPO workshop on data storage:**
  - Several members of the department attended this workshop and D. Berghmans presented a contribution "Data storage needs of the Solar Physics/ROB group".
- **Department management and administration:**
  - F. Clette participated to the Base Co-ordination Committee Meetings (17/3, 27/5/04), as representative of ROB science staff (in replacement of P. Cugnon).
  - F. Clette (19/2, 13/5, 26/8) and R. Van der Linden (8/11) participated to meetings of the ROB Directing Functions
  - Edition of the Department 2003 annual report
  - Preparation and presentation of a summary of the Department 4 objectives and future science priorities for the ROB Scientific Council meeting of June 28, 2004
  - Organization of regular project-leader meetings.
  - Organization of regular planning meetings.
  - Staffing issues: many contract issues needed to be dealt with. For the permanent staff, actions were taken to investigate possible solutions to the problem of the permanent absences of D. Carré and C. Rondeaux for health reasons. F. Clette assisted in the candidate selection and recruiting for a permanent position of Constructor of Scientific Instruments (Eng. Technician in electronics) that was opened in 2004 by SELOR.
  - Following the descoping of the SDO/SHARPP-MAGRITTE instrument in 2003, F. Clette prepared and submitted to BelSPo (W. Verschueren, 1/3/04) a global plan for solar space activities of the Solar Physics Department for 2005-2008.

INTERDEPARTEMENTAL ACTIVITIES

A. Digitalisation

A.1. Operational project "D4A" (archiving and digitizing photographic plates)

A.1.1. Objectives

The aim of this pilot-project (FSP I2/AE/103, from 01/04 I2/KSB/103) is to preserve the historic-scientific information contained in the astrophotographic plate archive of the ROB and in the aerial photographic archives of the NGI and the RMCA. In collaboration with the astronomical institutes of the VUB and the UA, and AGFA-Gevaert a world-leader in photographic matters, the goal is to acquire the necessary know-how, hardware and software to digitise the information contained in the photographic plates, as well as the associated metadata. The project set out to offer the results to the public and to make them directly usable for scientific research through the modern techniques of the information society.

A.1.2. Progress and results

The D4A project is building a 2D digitiser facility of high geometric and radiometric resolution and precision. The air-bearing digitiser will be housed at the ROB in a temperature and humidity stabilised clean room with adjacent archive room. The ROB is financing this with a Lotto grant that became available in March 2003 and through a ROB donation. The Ministry of Public Works (Regie der Gebouwen) is doing the necessary renovations of the Telescope building that will house the climatised clean room and the plate archive in its basements.

J.-P. **De Cuyper** is project coordinator and directing official in charge of the buying of an air bearing XY-table and a temperature and humidity controlled clean room for the D4A digitiser facility. For both a negotiated buying procedure was followed in collaboration with D. De Swaef (jurist FSP). The contract for the climatisation was signed in April with Becker Reinraum Technik GmbH and for the air bearing XY-table, with add-ons: an automatic film roll transport and plate holder system, a plate stack/exchanger/ loader system and a turntable, in September with Aerotech after approval by the Minister. The climatisation was partly installed in December (air conducts, air treatment machine), allowing the finishing of the renovation works in the basements by the Regie. The detailed design of the add-ons was started with Aerotech. He visited Aerotech headquarters in Pittsburgh Pennsylvania in October for discussions. He follows-up the renovation works and worked out together with **Mark De Knijf** and **Eric Vander Putten** the technical specifications for the renovations.

Together with Lars Winter he developed further the design of the D4A digitiser. Lars Winter presented the different options for the camera (CCD vs. CMOS), the illumination system, the radiometric benchmark and the digitisation speed in a talk on May 25. They tested the BCi4 CMOS camera and the software driver of Vector International and a solid state illumination system using LumiLED's (1W/5W) for use on the D4A Digitiser. A total diffuse illumination was found to give an optimal reduction of the background plate noise in the digital images. A geometric and radiometric benchmark was worked out in detail as well as the first version of the reduction software needed to analyse the results.

The development of a digital, ODBC compliant, relational database describing the astrophotographic plate archive was continued in collaboration with G. De Decker the informatician of the D4A project.

G. Peeters and **D. Duval** extended the Excel lists of observational metadata for introduction into the database. The prescanning at 250 dpi of the 16 cm plates with the HiD scanner at the KSB was continued by **D. Duval** and of the 30 cm and 24cm plates with the XY15 scanner at the NGI by two jobstudents during the summer.

J.-P. De Cuyper worked together with the partners at the NGI, the RMCA and AGFA-Gevaert on digitisation methods for historic maps, using either a commercial roll scanner or an analogue reduction on duplication colour film (internegative), suitable for digitisation on the D4A digitiser.
Tests of the geometric properties of the AGFA-Gevaert CP710 high resolution colour duplication film were done at the facilities of Micro Technic in Willebroek, by making photographic copies with microfilm equipment of NGI hand drawn historic maps at different reduction scales. The photographic colour reproduction on paper provided by AGFA-Gevaert were found satisfactory both in geometric resolution and in colour representation.

A.1.3. Perspective for next years

In the coming year, the D4A project will extend the digital plate catalogue. A webserver, containing the metadata database will be set-up on Internet, after making a study of the available hardware and software systems in order to optimise the accessibility and the maintenance costs.
The construction of the climatised clean room and of the XY-table and the add-ons will be realised. The building the D4A digitiser will be finished by working out a diffuse LumiLED based colour illumination system with purpose build modular power supply and designing and constructing a cooled BCi4 CMOS camera. The necessary hardware and software for the digitisation and the data storage, handling and extraction will further be developed and/or acquired. Depending on the type of data contained in the photographs and their type of application, different calibrated end products will be made available.

A.1.4. Personnel involved

- Jean-Pierre De Cuyper (project coordinator)
- Thierry Pauwels (secretary of "Vast Bureau")

- Georges Peeters
- David Duval

- Eric Vander Putten
- Marc De Knijf
- Roger Peeters
- Francis Renders

- Frederik De Cuyper (jobstudent)
- Florian De Cuyper (jobstudent)

A.1.5. Partnerships

National Geographic Institute (NGI), Dir. Joost Vanommeslaeghe, Dir. Herman Prils.
Royal Museun of Central Africa (RMCA), Prof. Dr. Johan Lavreau, Dr. Max Fernandez.
AGFA-Gevaert, Mortsel, Aerial Photography & Engineering Devision.
Vrije Universiteit Brussel (VUB), Astronomical Institute, Prof. Dr. Christiaan Sterken
Universiteit Antwerpen (UA), Astronomical Institute, Prof. Dr. Mark David
Hamburg, Dr. Lars Winter
United States Naval Observatory, Washington DC, Dr. Norbert Zacharias, Dr. Sean Urban, Dr. Ted Rafferty

A.1.6. Publications

A.1.6.1. Publications with peer system

A.1.6.2. Publications without peer system

De Cuyper, J.-P., Winter L. and Vanommeslaeghe, J.
The D4A Digitiser
in Astronomical Data Analysis Software and Systems – ADASS XIII (eds. F. Ochsenbein, M. Allen and D. Egret), ASP Conf. Series, V341, pp 77-80.

De Cuyper, J.-P., Winter L. and Vanommeslaeghe, J.
The D4A Digitiser
The PDPP Newsletter 2, pp 27-30.

A.1.6.3. Publications in press, submitted

De Cuyper, J.-P. and Winter L.
The D4A Digitiser
in Astronomical Data Analysis Software and Systems – ADASS XIV (eds. P. Shopbell, M. Britten and R. Ebert), ASP Conf. Series, p 4.

De Cuyper, J.-P. and Winter L.
The D4A Digitiser
The PDPP Newsletter 3.

A.1.6.4. Reports, thesis, etc

D4A Evaluation Report March 2004

A.1.7. Missions

Research Missions: 1
Operational Missions: 40

A.2. Research project "Haalbaarheidsstudie die tegemoetkomt aan de eisen van de EIB in het kader van een onderzoek naar een aanvraag voor een lening conform de beslissing van de Ministerraad van 30 april 2004"

A.2.1. Objectives

POD Science Policy has ordered at the Bureau van Dijk a study about the needs of the Federal Scientific Institutes to digitize their heritage. The final report of this study was delivered in March 2003. Based on this report it was decided to implement the basic scenario (B0, for a total of 150,000,000 euros) over a time span of 10 years. To this end the Belgian government intended to loan 75 million euros from the European Investment Bank. However, before getting a loan, more details were needed concerning the commercial return of the digitisations and the possibilities to pay back. Therefore, a second study was ordered "Haalbaarheidsstudie die tegemoetkomt aan de eisen van de EIB in het kader van een onderzoek naar een aanvraag voor een lening conform de beslissing van de Ministerraad van 30 april 2004".

A.2.2. Progress and results

The POD Science Policy has assigned the task of the study to the Bureau van Dijk. The study started mid-2004. T. Pauwels represented the Royal Observatory of Belgium in the follow-up committee of this study. In April already, there was a query from Belspo to collect a few examples of collections to digitise, with their features, requirements and aims, in order to present a note to the Council of Ministers. T. Pauwels centralised this task for the Royal Observatory of Belgium. Later on, when the study had started, he helped Jan Moens to make more detailed project fiches of the collections to be digitised. This was in collaboration with the persons responsible for each collection at the ROB.

A.2.3. Perspective for next years

The study should be finished in early 2005. Based on the outcome, we hope that digitising projects will be financed. At present there is a pilot project (see "Archiving and digitising photographic plates") running at the ROB, aiming at establishing the procedure and installing the hardware for digitising our plate collections. This pilot project should normally end in 2006, after which we need to define new projects to start an operational phase. The cost of these operational projects has been included in the study by the Bureau van Dijk.

A.2.4. Personnel involved

Staff members of the ROB: T. Pauwels (with some help by P. Alexandre, J.-P. De Cuyper, F. Clette and K. Vanneste).

A.2.5. Partnerships

List of national and international partners:

The 10 Federal Scientific Institutions, the Filmarchief van België, the Federal Science Policy, the Bureau van Dijk.

Grants used for this research: none.

Visitors: 1

A.2.6. Publications

None

A.2.7. Missions

2 operational meetings

B. Public outreach

B.1. Operational project "The Yearbook"

B.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.

B.1.2. Progress and results

In 2004 the Yearbook for 2005 was published. It was produced by F. Clette, J. Cuypers, R. Dejaiffe, T. Pauwels, F. Roosbeek and J. Sauval, with the technical assistance of G. Evrard. The final editing was done by T. Pauwels. There are chapters about coordinates and constants, calendars, the Sun, the Moon, the planets, minor planets, comets, meteors, eclipses and transits, occultations and phenomena of the satellites of Jupiter. Most chapters are now produced using the DE405 ephemerides rather than the old DE200.

B.1.3. Perspective for next years

Publication of the Yearbooks 2006ff without major changes.

B.1.4. Personnel involved

F. Clette, J. Cuypers, R. Dejaiffe, T. Pauwels, F. Roosbeek, scientific staff members of the Observatory,
J. Sauval, honorary chief of section,
G. Evrard, technical staff member of the Observatory.

B.1.5. Partnerships

None.

B.1.6. Publications

B.1.6.1. Reports, thesis, etc

F. Clette, J. Cuypers, R. Dejaiffe, T. Pauwels, F. Roosbeek, J. Sauval
Annuaire de l'Observatoire royal de Belgique - Jaarboek van de Koninklijke Sterrenwacht van België 2005.

B.1.7. Missions

None.

B.2. Operational project "Web interface for the Yearbook"

B.2.1. Objectives

The paper version of the Yearbook of the Observatory gives data for Ukkel and for some phenomena also for a selection of places in Belgium. With the possibility of the internet, it is now easy to make these computations for any place anywhere in the world. Since the programmes already exist, it is sufficient to write a web interface to achieve the stated goal.

B.2.2. Progress and results

The commercial software that was present in the programmes has been replaced by own software, which was developed in the course of 2004. The programmes have still to be made "idiot-proof", to prevent blocking our server.

B.2.3. Perspective for next years

Once a core is operational, the interface can be made public with a few of the most popular programmes. After that it can be fine-tuned and expanded with more programmes.

B.2.4. Personnel involved

T. Pauwels, chief of section,
the sysadmin team, technical staff of the Observatory

Table of Contents

List of tables and figures