

SPACE RESEARCH IN BELGIUM

1996 - 1997

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Preface

This report has been prepared on behalf of the Belgian National Committee on Space Research of the "Académie Royale de Belgique" and the "Koninklijke Academie van België", for presentation at the 32nd Scientific Assembly of the Scientific Committee on Space Research (COSPAR), Nagoya, Japan, 12-19 July 1998.

It summarizes basic and applied space research undertaken by Belgian teams in various research institutes and universities. The names and addresses of these institutions are listed in Appendix of this report.

Contents	Page
I. EXTERNAL GEOPHYSICS	
A. Belgian Institute for Space Aeronomy	1
B. Institute of Astrophysics and Geophysics of the University of Liège	25
C. Space Center of Liège	33
D. Royal Meteorological Institute of Belgium	34
II. SPACE ASTRONOMY	
A. Royal Observatory of Belgium	38
B. Space Center of Liège	46
C. Astronomical Institute of the "Katholieke Universiteit Leuven"	49
D. Astronomical Observatory of the University of Ghent	55
E. Astrophysical and Spectroscopical Department of the University of Mons	57
III. SPACE GEODESY	
A. Royal Observatory of Belgium	64
B. Royal Military Academy	70
IV. MATERIAL SCIENCES	
A. Microgravity Research Center of the "Université Libre de Bruxelles"	71
B. Department of Metallurgy and Materials Engineering of the "Katholieke Universiteit Leuven"	77
V. LIFE SCIENCES	
A. Biomedical Physics Laboratory of the "Université Libre de Bruxelles"	80
VI. REMOTE SENSING	
A. Laboratory for Geological Remote Sensing and Information Management of the Royal Museum for Central Africa	84
B. Laboratory for Telecommunication and Remote Sensing of the "Université Catholique de Louvain"	96
C. National Geographic Institute	100
D. Royal Meteorological Institute of Belgium	101
VII. ADDRESSES	102

I. External Geophysics

A. Belgian Institute for Space Aeronomy

1. The ORA experiment

The Occultation Radiometer (ORA) project is a collaboration between the Belgian Institute of Space Aeronomy (BISA) and the Department for Atmospheric, Oceanic and Planetary Physics of the University of Oxford. It has a twofold objective. The first one is a simultaneous measurement of aerosols and NO₂ in the middle atmosphere in order to contribute to our understanding of the role of aerosols in atmospheric chemistry which became obvious since the discovery of the Antarctic ozone hole. The second objective of the ORA experiment is to measure the water vapour concentration in the mesosphere with the aim of investigating the detailed balance of upper atmospheric water vapour, which is still not fully understood.

The ORA instrument, was flown on the EURECA mission (31 July 1992 - 1 July 1993) and performed its measurements through the occultation technique or limb tomography method, which allows to derive an absolute quantity, namely the slant path optical thickness from a relative transmission measurement.

At this stage all measurements have been successfully inverted to vertical total extinction profiles, using the N.O.P.E.-method. The main goal is now, to perform a spectral inversion, which means the calculation of the extinction profiles for every chemical constituent separately.

2. Pole-to-pole geophysical validation of GOME and TOMS products using correlative observations associated with the Network for the Detection of Stratospheric Change (NDSC)

The global composition of the Earth's atmosphere is changing due to the increasing anthropogenic release of chemically and radiatively active species. A better knowledge of the global composition of the atmosphere as well as its long-term evolution are urgently needed to assess current and future changes. Remote-sensing from space only can yield the required continuous observation of relevant atmospheric trace species on the global scale. However, the measurements and retrieval algorithms of spaceborne instruments are sensitive to a variety of instrumental as well as atmospheric sources of uncertainty. Before being used for scientific studies, the relevance of the space-based measurements must be investigated carefully and independently by means of well-controlled correlative observations, at the global scale as well as on the long term. The link needed between sensors operating on different platforms must also be studied. The independent validation and calibration of satellite experiments is precisely a main goal of the Network for the Detection of Stratospheric Change (NDSC). By means of various observation techniques, this ground-based network of high-quality remote-

sounding stations provides, at all latitudes from the Arctic to the Antarctic, total column measurements of ozone, nitrogen dioxide and other key constituents, such as NO_y , ClO_y or CH_4 , as well as vertical distributions of ozone, temperature, water vapour, ClO and aerosols.

Correlative studies relying on observations associated with the NDSC have been carried out with the ozone (total columns and vertical profiles) and NO_2 (total columns) data from the Global Ozone Monitoring Experiment (GOME) onboard ERS-2 (from July 1995 onwards), and with the total ozone measurements from the two Total Ozone Mapping Spectrometers (TOMS) onboard the Earth Probe (from July 1996 onwards) and ADEOS (August 1996-June 1997) platforms. In particular, NDSC-based studies have played a major role during the maturation of the GOME Data Processor's developmental version GDP 1.x, and of its operational versions GDP 2.0 and 2.3. The ozone and NO_2 total columns recorded between summer 1995 and December 1997 by 18 SAOZ/UV-visible spectrometers distributed at all latitudes from the Arctic to the Antarctic, and by Dobson and Brewer spectrophotometers operating at selected sites of the NDSC Alpine and Antarctic stations, have been used for investigating the solar zenith angle (SZA) dependence, the dispersion, the time-dependent drift, and the possible differences of sensitivity of the three space-based sensors, from pole to pole, over a wide range of relevant geophysical conditions. The impact of these performances on specific atmospheric chemistry studies has been emphasised. A preliminary study of the height-resolved ozone derived from GOME data has also been performed using ozonesonde and lidar measurements in the Alps and in the Arctic.

For total ozone, although the comparison demonstrates an excellent agreement to within $\pm 2-4\%$ between all space-based and ground-based instruments at northern middle latitudes, it also reveals significant systematic features, such as: a SZA dependence with TOMS beyond 80° ; a seasonal SZA dependence with GOME beyond 70° ; a systematic bias of a few percent between satellite and SAOZ observations of low ozone columns at the southern Tropic; a difference in sensitivity to ozone between the GOME and ground-based sensors at high latitudes; and an interhemispheric difference of TOMS with the ground-based observations. Possible causes have been identified and possible solutions have been proposed. For total nitrogen dioxide, the comparison highlights some errors in the GOME Data Processor GDP 2.0, and the irrelevance of the NO_2 profile database used in the GOME retrieval algorithm. The resulting agreement between the GOME and ground-based total NO_2 data sets is found to depend strongly on the latitude, the season, and the tropospheric NO_2 content. Based on these findings, an improved version 2.3 of GDP, using the US Standard NO_2 profiles, and where major GDP errors are fixed, is now implemented for operational processing. Test case studies performed with GDP 2.3 show a better geophysical consistency, although, GOME total NO_2 generally underestimates ground-based data by about $1-2 \cdot 10^{15} \text{ molec.cm}^{-2}$.

This work was done in collaboration with : Service d'Aéronomie du CNRS (France), BAS (UK), CAO (Russia), DMI (Denmark), DWD (Germany), ETH-Zurich (Switzerland), FMI-Sodankylä (Finland), IRM-KMI (Belgium), NASA/GSFC (USA), NILU (Norway), NIWA (New Zealand), U. Bern (Switzerland), U. Bordeaux (France), U. Bremen (Germany), U. Kiev (Ukraine), U. Liege (Belgium), U. Natal (South Africa), U. Reims (France), U. Reunion (France), U. Sao Paulo (Brazil), U. Wales (UK)

3. GOME

The Global Ozone Monitoring Experiment (GOME) on board of the Earth Remote Sensing satellite (ERS-2) was launched by ESA on 21 April 1995 into an heliosynchronous polar orbit. Its main scientific objective is the study of trace constituents in the stratosphere and the troposphere.

GOME is a combination of four grating spectrometers observing the solar radiation scattered from the atmosphere or from the Earth's surface, covering the spectral range 240-790 nm. The instrument can directly measure the Earth's radiance scattered into its spectrometer, or in an alternate mode, using a slightly different optical paths, it can measure the solar irradiance arriving at the instrument. In both configurations, the optics of the spectrometer are the same, only a scanning mirror and diffuser are inserted for the direct solar measurement.

3.1. GOME MG II

The Mg~II core-to-wing index was first developed for the Nimbus 7 solar backscatter ultraviolet spectrometer as an indicator of temporal variation of the solar UV flux. It is of particular value because of its long-term precision and insensitivity to instrument artifacts.

For almost twenty years, solar activity monitoring from space has provided data from which the Mg~II index can be derived. The quality of each Mg~II index is related to the measurements signal-to-noise ratio, the wavelength stability, and the spectral resolution. The new GOME instrument on board the ERS-2 satellite provides daily solar spectrum observations between 240 and 790~nm. Due to its high spectral resolution of 0.2 nm at 280 nm we can expect a very precise Mg~II index from this instrument.

Preliminary results of the Mg~II index were derived from GOME using an algorithm taking advantage of its high spectral resolution. This algorithm is derived directly from UARS/SOLSTICE Mg~II index algorithm. A comparison with the SOLSTICE index has been done for the period July 96 – August 97 to demonstrate the quality of data from GOME.

3.2. GOME UV maps

The monitoring of UV radiation at the Earth's surface essentially relies on ground-based observations. Remote sensing is, however, the only way to achieve a global view of the radiative fields. The European GOME instrument on board of the ERS-2 satellites measures the radiation backscattered by the atmosphere and reflected by the ground. Its performances make it a potentially good instrument for providing valuable information for UV monitoring from space.

In addition to the usual atmospheric absorbers in the UV like oxygen and ozone, clouds have a dramatic screening effect on the incoming extraterrestrial fluxes from the Sun. Incoming flux is scattered by cloud droplets and the intensity reaching the ground is considerably reduced.

NASA/GSFC has provided since 1996 UV erythemal exposure maps derived from the 15 years (1978-1993) dataset of the TOMS/NIMBUS 7 instrument. The estimation of surface UV-B from GOME data can certainly benefit from the TOMS experience. Moreover, the GOME instrument provides additional information about the state of the atmosphere observed

by the spectrometer. In particular, it gives useful information about the cloud coverage of the observed scene.

In collaboration with the NASA/Goddard Space Flight Center, we have tested a preliminary release of the updated GSFC algorithm using GOME data. Figure 1 displays the UV erythemal dose at local noon from GOME data processed through a preliminary version of GSFC algorithm. The GOME inputs are the N values at 6 different channels (radiance/irradiance) for CCF computation, total ozone, satellite solar zenith angle and location. GOME provides an estimation of the cloud coverage of the observed pixel using the Initial Cloud Fitting Algorithm (ICFA). Cloud top pressure and pixel cloud coverage are estimated by comparing computed and measured radiances around the oxygen A-band (761 nm) and is a standard level 2 product.

To test the possible use of ICFA cloud coverage for UV-B estimation, we have build a simple model based on a 2-stream pseudo-spherical radiative transfer model making use of the ozone measurements from GOME as well as the cloud coverage and cloud top pressure from ICFA. When a cloudy scene is detected, the final surface flux is a linear combination of the clear sky estimated flux and fully cloudy scene flux. The cloudy scene is defined such that a water cloud layer of optical thickness 50 (at 550 nm) and physical depth of 1 km is inserted at the prescribed altitude. Basically, using this simple ICFA-based algorithm for cloud corrections underestimated the UV dose at high ICFA value. This means that the putative cloud optical thickness of 50 for fully cloudy scene is overestimated by 50% but gives otherwise satisfactory results for (almost) cloudless pixels.

Information about the cloud field can also be obtained from the 16 PMD measurements for each pixel. Such a product has already been developed at the DLR. It has the advantage to give a higher resolution of the cloud coverage, each PMD subpixels being 1/16 the size of a regular pixel. This approach has been tested successfully.

GOME UV/GSFC, July 10-13, 1996 (GDP V1.0)

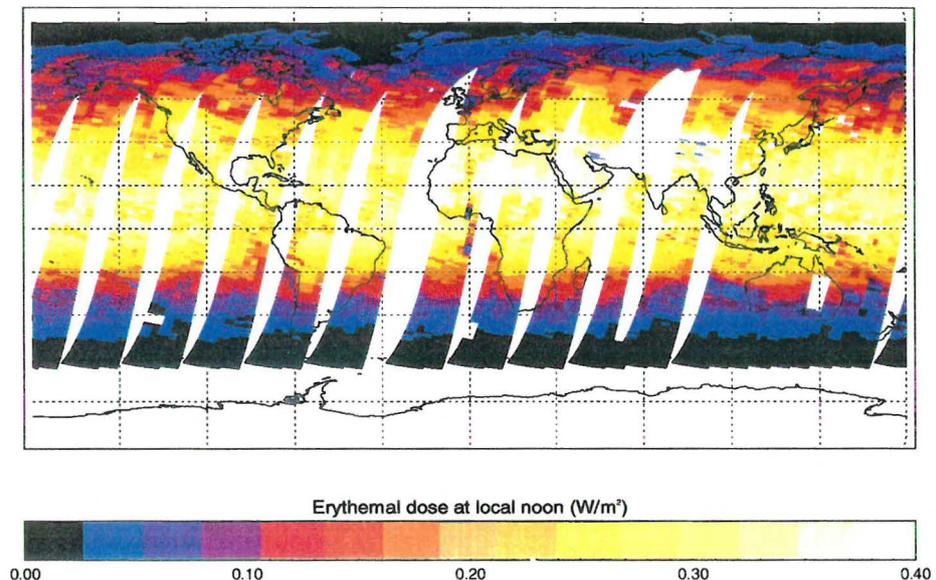


Fig. 1 Erythemal dose at local noon computed using GOME data and GSFC CCF algorithm.

4. Ground based measurements of the penetration of the solar UV-visible radiation

4.1. UV-B, UV-A and visible irradiance monitoring at the site of Uccle.

Since March 1993, a full automatic station (SUVIM) for the monitoring of the solar irradiances in the UV-B (280-315 nm), UV-A (315-400 nm) and visible (400 → 600 nm), is operational at the site of the BISA at Uccle. A schematic view of this station is given in figure 2.

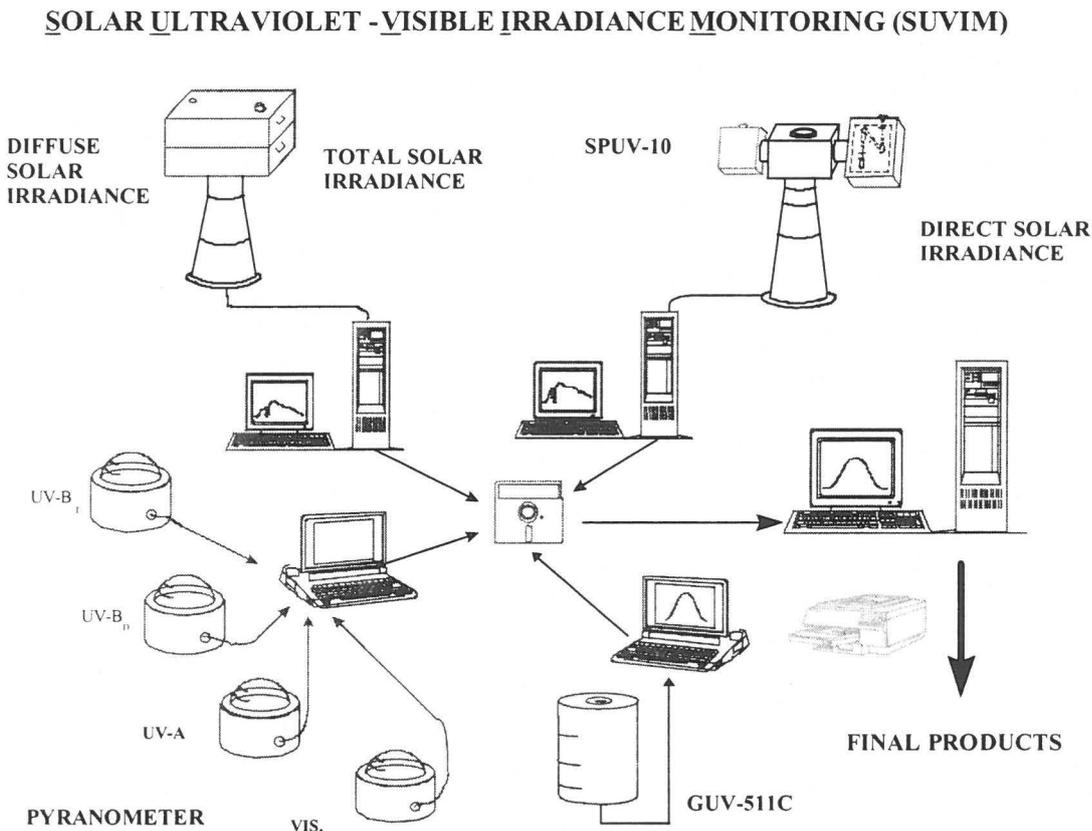


Figure 2. Schematic view of the UV-VIS. Monitoring Station in Uccle (Lat. 50° 48'N., Long. 4° 21'E. Alt. 120 m).

a. Instrumentation : In addition to the spectral measurements performed every 15 minutes for solar zenith angles lower than 100°, integrated measurements of solar irradiances in the UV-B, UV-A and total (300 nm → 3 μm) are taken every second by means of three pyranometers. The station includes also a 10-channels filter radiometer (SPUV-10) measuring the direct solar irradiance to determine the total columns of ozone and aerosol, and a 4-channels filter radiometer (GUUV-551c) measuring the global solar irradiance at 305, 320, 340 and 380 nm.

b. Calibration and Quality control of the data : A special care is taken in the quality control of the provided data. Periodical absolute calibration (every 3-6 months), together with

verifications of the relative stability of the instruments, allow to estimate the error on the absolute irradiances measurements to $\pm 5\%$. This error limit is confirmed by the results of comparison with model calculations (for clear sky conditions) and with comparison of measured and calculated UV-B/UV-A ratio presented in figure 3 for clear sky and cloudy sky conditions.

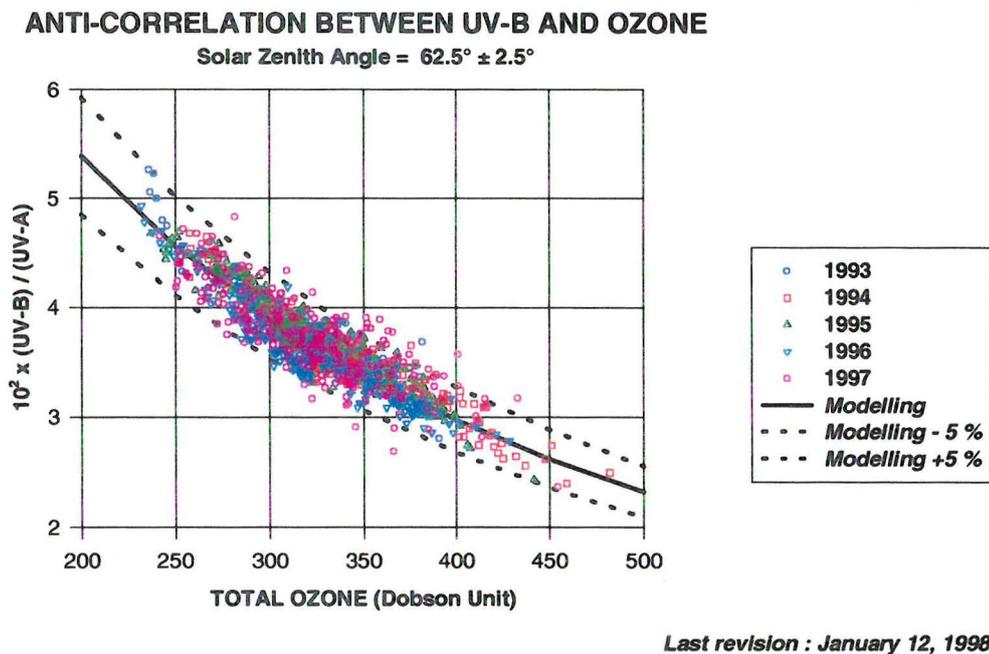


Figure 3. Anticorrelation between UV-B (corrected for cloud effect) and Ozone : Solar Zenith angle = $62.5^\circ \pm 2.5^\circ$.

c. Data processing and final products : A summary of the data obtained in Uccle is given in table 1. It is a data base completed by ancillary measurements such as ozone total columns and concentration profiles (measured at the Royal Meteorological Institute of Belgium), the detailed meteorological conditions (19 parameters every 3 hours for 21 stations in Belgium), twice daily meteorological soundings providing: temperature profiles, relative humidity profiles.

Moreover, all the software for a global interpretation of the data in terms of the different atmospheric parameters (contents and concentration profiles of ozone, meteorological parameters...) have been developed and a first physical interpretation of the spectral measurements has been realised. A detailed study of the influence of the type of cloud cover (type of cloud, lower altitude, depth, single or multiple layer) is under realisation by a double approach. A 'parametric' study based on a statistical analyse of the spectral measurements and a 'theoretical' approach based on the conclusions of the 'exact' atmospheric radiation transfer models.

d. National and International collaborations : Some specific collaborations are established with the Royal Meteorological Institute of Belgium for the measurements of the UV-Visible

solar irradiance, and the utilisation of the ozone measurements. A close collaboration is in place between our group and the team of Prof. J. Lenoble from the "Université des Sciences et Technologies de Lille" (France). The small distance between the two sites of measurements allows a relatively easy comparison of the solar irradiances measured at Lille and Brussels in order to verify the concept of a regional networks.

Table 1 : Summary of the UV data produced in Uccle (Lat. 50° 48'N, Long. 4° 21' E, Alt. 120 m)

UV-B spectral measurements : modified Jobin-Yvon HD-10	
26/03/1993 → (04/05/1998)	1790 days – 106682 scans
Integrated measurements	
UV-B (total)	03/02/1995 → (04/05/1998) : 1165 days
UV-B (diffuse)	16/07/1996 → (04/05/1998) : 656 days
UV-A	11/05/1995 → (04/05/1998) : 1065 days
TOTAL	25/07/1995 → (04/05/1998) : 998 days
Filter radiometric measurements	
1.	10-channel SPUV-10 (Yankee environment system) 21/03/1996 → (04/05/1998) 574 days
2.	4-channel GUV-551 C (Biospherical instrument) 23/05/1996 → (04/05/1998) 665 days

4.2. The European Programs

BISA was also involved in three major European Community environment projects viz. :

- Scientific Ultraviolet Data Management (SUVDAMA);
- Standardisation of ultraviolet spectroradiometry in preparation of an European Network (SUSPEN);
- Development of biological dosimetry systems for monitoring the impact of solar UV-B radiation on the biosphere and on the human health (BIODOS).

Finally, BISA collaborates in COST Action 713 "UV-B Forecasting" which is a self supported five years European programme, agreed by the European Commission. The main goal of this project is the prediction (24 h and/or 48 hours) of a UV index based on model calculations (ozone prediction model, climatologic and meteorologic models, ...). BISA, together with the Royal Meteorological Institute of Belgium, is involved in the comparison of radiation transfer models, and will later participate in the validation of the predictions with the help of experimental comparisons.

5. ENVISAT-1

5.1. *SCIAMACHY*

SCIAMACHY was selected by ESA as part of the ENVISAT Platform to be launched in December 1999. The development is managed by the German Aerospace Center (DLR) and the Netherlands Agency for Aerospace Programmes (NIVR) with a contribution from the Office of Science, Technical and Cultural Affairs and the Belgian Institute for Space Aeronomy.

SCIAMACHY is a passive remote sensing spectrometer observing backscattered, reflected, transmitted, or emitted light from the Earth between 240 and 2380 nm, in the following viewing geometries :

- Same atmospheric volume first in limb and after a short time (8 min.) in nadir;
- Atmosphere in solar or lunar occultation;
- Direct solar or lunar observations for in-flight calibration.

The primary objective of SCIAMACHY is to determine vertical and horizontal distributions of important stratospheric and tropospheric constituents and parameters (ozone and related trace gases, aerosols, Earth's radiance, solar irradiance, clouds, temperature and pressure).

An outline of the BISA scientific pre- and post-launch participations includes polarisation data, solar UV products, laboratory spectroscopic studies related to O₂ and NO₂, BrO algorithm, retrieval, validation activities.

5.2. *GOMOS*

GOMOS (Global Ozone Monitoring by Occultation of Stars) is an instrument which will be flown on board the European Space Agency's ENVISAT-1 satellite. GOMOS is a novel instrument concept: there have been only a few sporadic attempts to exploit stellar occultations for studies of the Earth's atmosphere. This means that most of the data processing algorithms are either completely new or they have been tailored for stellar occultations.

GOMOS is a medium resolution spectrometer covering the wavelength range from 250 nm to 950 nm. In the level 2, data products which have a direct applicability for atmospheric analysis are generated. The most important are the vertical profiles of various constituents like ozone, NO₂, aerosols, etc.

The GOMOS ground segment algorithm development has taken place under the authority and funding from ESA. The development team forms the so-called GOMOS Expert Support Laboratory-group (ESL). It consists of the following institutes: Finnish Meteorological Institute, Service d'Aéronomie (France) and BISA.

BISA is responsible for the development and testing of an algorithm capable of retrieving the aerosol extinction coefficient and its spectral properties. More technical information can be found at the following address: <http://envisat.estec.esa.nl/support-docs/index.html>.

In the frame of the GOMOS experiment, IASB is also involved in the project MSDOL (Monitoring of the Stratospheric Depletion of the Ozone Layer) funded by the E.C. It will consist in developing a system that couples the future GOMOS data processing to an evolutive 3D photochemical model.

6. Chemistry and climate related studies using the IASI/METOP-1 sensor

The IASI instrument (Infrared Atmospheric Sounding Interferometer) is scheduled for launch on the first mission of the EUMETSAT Polar System METOP series (METOP-1, 2001). It is a Michelson interferometer in the thermal infrared (3.4 → 15.5 micron, resolution $R \sim 2000$), designed for atmospheric emission measurements at nadir. Its objectives concern operational meteorology and climate on the one hand, and atmospheric research with a focus on climate and the troposphere on the other hand. In the latter field, its particular objectives are the sounding of temperature through the measurement of CO₂ lines, the retrieval of column amounts of H₂O, CO, O₃, CH₄, N₂O and possibly of CFCs, and of vertical profiles if feasible, and the measurement of atmospheric radiation. The Belgian Institute for Space Aeronomy contributes to the project 'Chemistry and climate related studies using the IASI sensor' (1995-2002), in collaboration with laboratories in France (IPSL/CNRS¹ and LPMA²) and in Belgium (ULG³ and LCPM-ULB⁴). BISA will participate in the development of an adequate inversion algorithm for the retrieval of CO, CH₄ and O₃ columns and possibly profiles, in ground-based validation by Fourier transform spectrometry, and in assimilation of the data in chemical-transport models.

In 1996-1997, the main activities focused on the retrieval of CO total column amounts from synthetic spectra, delivered by IPSL/CNRS, with three algorithms, developed independently at BISA, LPMA and IPSL/CNRS: the former two are based on non-linear-least squares fitting, while the latter one is based on a neural network approach. The BISA code for the retrieval of molecular concentrations (total column amounts) from solar absorption spectra in the IR has been modified in order to allow forward modelling of IASI emission spectra in the nadir-looking geometry, and consequent retrieval of the total column molecular amounts. Initially, only the fundamental physical processes have been taken into account. The forward model has been verified by comparing forward radiance simulations against FASCODE calculations made with about the same approximations, and against the delivered IASI simulations that were made in the same conditions. As to the inversion towards CO total column amounts: after verification that the code retrieves the parameters that have been used for the simulation, some preliminary tests have been performed as to the sensitivity to the actual CO profile, boundary emissivity and temperature, instrument spectral resolution and spectral range used for retrieval. The first comparisons with results of IPSL/CNRS and LPMA algorithms have been made. The sensitivity tests and mutual intercomparisons will be continued and extended; also the impact of the spectral sampling of the calculations will be investigated. The codes will be improved accordingly and the adequacy of the neural network algorithm for retrieval of the IASI data will be evaluated.

¹ Institut Pierre-Simon Laplace/ Centre National de Recherches Scientifiques, Paris-Jussieu, France

² Laboratoire de Physique Moléculaire et Atmosphérique, Université de Paris, Paris-Jussieu, France

³ Institut d'Astrophysique et de Géophysique, Université de Liège, Liège, Belgium

⁴ Laboratoire de Chimie Physique et Moléculaire, Université Libre de Bruxelles, Bruxelles, Belgium

7. Belgian contribution to the ESA Data User Programme

BISA has two projects in the framework of ESA's Data Users Programme (DUP) : (1) "Development of global aerosol mapping from satellites level 2 products "(DAMS2P, 1997), and (2) "Aerosol mapping algorithms for satellite data users" (AMASDU, 1998).

Present and near-future satellite experiments like GOME/ERS-2, UARS, and ENVISAT-1 substantially expand the wealth of atmospheric data related to the Earth's system. A serious effort is required to make these data more accessible and comprehensible for a wide user-community. The goal of the DUP projects is to prepare value-added products that may be suitable for interpretation by modellers, climatologists, policy makers, etc. The projects' particular objective is to prepare the production of global, time dependent maps of atmospheric aerosols, water vapour and most important chemical species like HNO_3 . Therefore, tools for integrating level-2 satellite data from several sources are being developed. This is done via 4D interpolation, the 4th dimension being the wavelength, and assimilation in an atmospheric transport model that includes a chemistry module for the modelling of aerosol microphysics. Subsequently, this 4D interpolated data space will be used for implementation of methods to obtain derived aerosol parameters (e.g., effective mean radius, specific surface area and volume, concentration profile and refractive index profile). Actually, the interpolation and assimilation have been limited to SAGEII and ORA aerosol extinction data at one wavelength. The interpolation method is based on (i) domain decomposition, using a Delaunay spherical triangulation, (ii) interpolant representation based on a truncated Multipoint Taylor series, (iii) local thin plate spline fit, for estimating all spatial derivatives, and (iv) final filtering to remove short scale variations below the sampling limit. This method solves the problem of interpolating experimental data on a random grid. The first aerosol data assimilations resulting from a pure transport model look very promising.

8. Measurement of atmospheric constituents by selective ionization mass spectrometry (MACSIMS)

The objective of the MACSIMS project, which is a cooperation between the Belgian Institute for Space Aeronomy (BISA), the Laboratoire de Physique et Chimie de l'Environnement (LPCE) of the Centre National de la Recherche Scientifique (France) in Orléans and the Physikalisches Institut of the University of Bern (Switzerland) is the development of a new chemical ionization (CIMS) method for the measurement of several stratospheric trace gases, such as HNO_3 , N_2O_5 , ClONO_2 and HCl , gases playing an important role in the stratospheric ozone chemistry.

The CIMS method relies upon the formation of specific product ions from reactions of atmospheric trace gases with precursor ions produced by an external ion source mounted in front of a balloon borne mass spectrometer. The mixing ratio of reactive trace gases can be derived from the analysis of the relative abundance of precursor and product ions in spectra, obtained with the ion source.

The balloon borne instrument with the switching ion source producing alternately I_n^- and Cl_n^- , which had been successfully flown in November 1995 in Leon, was modified to avoid formation of mixed chlorine-iodine cluster ions. To do so the two discharge ion sources have

been separated. A new balloon flight with the modified instrument, scheduled for the November balloon launching campaign in Leon in 1996, could not take place due to extremely bad meteorological conditions. To recover some of the delay caused by this setback the instrument was extended to measure ClONO_2 and HCl by adding a fourth ion source producing CF_3O^- ions. This extended instrument was successfully flown in June 1997. A preliminary data analysis has been performed and has shown the possibility of deriving profiles of HNO_3 , ClONO_2 and HCl from the new ion source. Further analysis and laboratory measurements of the ion-molecule reactions involved, however, are required to refine the method.

In parallel with the activities associated with the measurements with the balloon borne instrument, the measurements of ion-molecule reactions in the laboratory were continued. To study the impact of ions such as $\text{Cl}^- \cdot \text{HCl}$ and $\text{Cl}^- \cdot \text{H}_2\text{O}$, which were observed in previous flights, on the analysis of results of previous balloon flights, the reactions of these ions with HNO_3 and Cl_2 was studied. The ion molecule reaction of Cl^- with nitric acid, for which 2 different results were published in the literature, was also performed.

Present activities are focused on the preparation of a new balloon flight with the balloon borne CIMS instrument, which will be equipped with a more efficient ion source for CF_3O^- ions.

9. Tropospheric chemistry modeling

We know from the observational record that the composition of the troposphere is changing, largely as a result of human activities such as fossil fuel burning, biomass burning and land use changes. An important objective is to understand and quantify these perturbations and to explain their interaction with the natural environment.

Since 1988, BISA acquired a broad experience in tropospheric chemistry modelling. This expertise has been built, to a large extent, on our collaboration with the Atmospheric Chemistry Division (ACD) of the National Center for Atmospheric Research (NCAR) (Boulder, USA). Other collaborations have been developed, e.g. with the Service d'Aéronomie and the LMCE in France. Our work aims at (1) reduce the uncertainties in our understanding of the processes determining the tropospheric composition, and (2) estimate how this composition has changed in the past, and will change in the future, as a result of human activities.

A comprehensive model for tropospheric chemistry (the IMAGES model) has been developed in collaboration with NCAR. This model is now considered as being among the most advanced and documented for tropospheric chemistry studies. For example, it has been used to determine the impact of the subsonic aircraft fleet, in particular for the NASA/SASS program (see Fig. 4). More recently, we participated to the forthcoming IPCC report on aviation. IMAGES has been also used for the study of a variety of tropospheric chemistry problems, with a focus on the radiatively active gases (e.g. ozone, methane, and the sulfate aerosols). In order to investigate the possible evolution of the atmospheric composition, the anthropogenic emissions of trace gases have been estimated for the years 1850, 1990 and 2050. They have been introduced in the chemical model. The results show for example the largest future changes are expected to occur in the developing countries below the Tropics, such as South and South-east Asia.

A new model, the MOZART model, has been developed at NCAR, in collaboration with BISA. This model has the same chemistry and emissions parameterization as IMAGES, but it has a much more advanced treatment of the transport and dynamics. It is therefore more adapted to study the variability of the atmospheric composition, or the role of climatic perturbations on the composition.

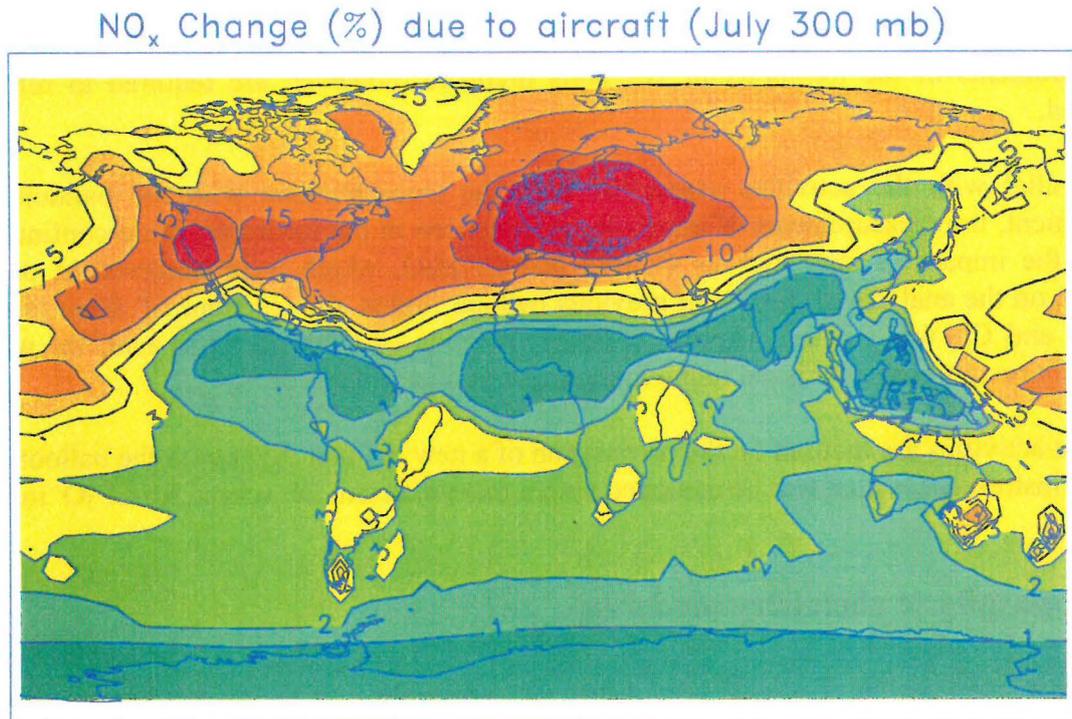


Figure 4. Calculated increase in the nitrogen oxides concentrations due to aircraft (1992 fleet). The results are given in percents for July. The nitrogen oxides enhance the chemical production of ozone. The calculated ozone increase is about 5-7% in July at 10 km altitude.

10. Solar Lyman-alpha absorption

In all two- and three-dimensional models the absorption of solar Lyman-alpha at 121.56 nm does not take into account the shape of the line. However, the presence of geocoronal atomic hydrogen modifies the initial Gaussian shape by inducing a central core which can be a factor of 4 smaller than the maximum solar flux value. Furthermore, the absorption cross section of the major absorber (molecular oxygen) is not constant over the width of the line. As a consequence, detailed computations taking these two facts into account would be extremely time consuming in multidimensional models. It is, therefore, necessary to develop accurate approximations which can replace detailed computations.

A new parameterization is developed to reproduce in atmospheric models the results of a high resolution calculation. The shape of the Lyman-alpha line is first approximated by a sum of three Gaussian profiles and the exact calculation is parameterized by a sum of exponentials depending of the molecular oxygen total content at a given height. The error made on the photodissociation coefficients of methane and water vapor never exceeds 1.5%, whereas the usual computations can lead to a large underestimation for these coefficients.

These results can easily be introduced in any multidimensional atmospheric model used for interpretation or validation of space observations.

11. Study of space plasmas

11.1. Radiation belt modelling

BISA is the main contractor in the TREND (Trapped Radiation ENvironment Development) project funded by ESA's Technology Research Programme. The aim of this project is to improve existing models of the trapped radiation belts and to develop new models. Using energetic proton measurements made onboard the AZUR, SAMPEX, and UARS satellites, BISA has developed three new models of the low-altitude trapped proton environment valid for three different phases of the solar cycle. These models have been added by BISA to the software package UNIRAD, which is used by ESA and other institutes (on a commercial basis) to predict radiation fluxes and doses for space missions.

In the TREND framework, BISA also has developed a new model of the anisotropy of the low-altitude trapped particle population. This model represents in a natural way the angular dependence of the trapped proton flux as a function of magnetic coordinates only. The model has been validated with data from the SAMPEX/PET and MIR/REM instruments, and has been shown to better represent the angular distribution than the existing models. A correct representation of the directionality of the trapped proton flux is vital in designing low-altitude missions, especially with respect to crew protection and placement of sensitive electronics equipment.

Moreover BISA is the main contractor for the development of ESA's SPace ENVironment Information System (SPENVIS), which provides a user friendly World Wide Web interface to many of the currently used models of the space environment. With SPENVIS, engineers can quickly and efficiently perform a mission analysis, including predictions of particle fluxes and doses, spacecraft charging, erosion by atomic oxygen, damage to solar panels and electronics, and impacts of meteoroids and debris. Currently, about one hundred registered users from all over the world use SPENVIS for their mission analysis and for educational purposes.

11.2. New kinetic models of the polar wind

The velocity distribution function (VDF) of protons diffusing across a background of O^+ ions in hydrostatic equilibrium, was been obtained by solving numerically the Fokker-Planck equation in the transition region between the collision dominated region of the topside ionosphere and the collisionless ion-exosphere. Lima type VDF's have been obtained. They are similar to the VDF obtained by Monte Carlo numerical methods.

11.3. Interpretation of COSMOS-900 observations

Using high resolution ion density and electron temperature observations obtained from the COSMOS-900 satellite, the earthward motion and erosion of the low altitude projection of the night side plasmopause during a geomagnetic storm has been studied in collaboration with V. Afonin from IKI (Moscow). The evolution of the associated sub auroral electron temperature enhancement during a geomagnetic storm has been observed and described in detail.

11.4. Magnetospheric driver of subauroral ion drifts

Subauroral ion drifts (SAID) are narrow layers of intense westward ionospheric flow observed during substorms. Evidence for the presence of hot injected plasma is found in simultaneous observations of SAID and magnetospheric particle flux dropouts (low density, high temperature regions). Other evidence consists of direct measurements of SAID-like electric fields in the magnetosphere. Numerical computations have demonstrated that the combined effect of thermo-electric and convection electric fields in a magnetospheric current sheet, when mapped down to the ionosphere, can account for the westward direction of the ion drift, the width and intensity of the drift speed peak, and the lifetime of SAID. The shear flow between the hot injected plasma and the cold plasmatrough controls the size and sense of the potential variations across the current sheet. Due to plasmaspheric corotation the azimuthal shear velocity at the interface of the cloud is largest in the pre-midnight sector.

Additionally, analysis of the internal structure of the interface shows that particularly intense electric fields are generated for the pre-midnight shear flow sense. The model can therefore explain why SAID occur mainly in the pre-midnight sector.

11.5. Equilibrium conditions and magnetic field rotation at the tangential discontinuity magnetopause

The study of the effect of velocity variations across a tangential discontinuity (TD) has serious implications for the study of the Earth's magnetopause. Using a tangential discontinuity model and assuming an empirical model for the solar wind flow around the magnetopause based on satellite observations, it was possible to predict which regions on the magnetopause correspond to equilibrium configurations for a given magnetic field rotation. These regions are indicated in figure 5 by shading on a plot of the dayside magnetopause for different angles of the magnetic field rotation. The following interesting results were found: (a) any magnetic field rotation is allowed near the stagnation point. This region of the magnetopause surface can therefore be in a state of tangential discontinuity equilibrium whatever the angle of magnetic field rotation; (b) there is a tendency for large positive rotations to occur predominantly in the northern hemisphere, while large negative rotations are expected predominantly in the southern hemisphere; (c) small, positive and negative rotations, i.e., less than 90° , are only possible on the dusk side; (d) no low magnetic shear (less than 90° equilibrium seems possible at the dawn side.

These theoretical predictions were verified using data from 45 crossings of the dayside magnetopause obtained by the AMPTE/IRM satellite. Especially the sense-of-rotation difference of the magnetic field between northern and southern hemispheres is important. This has been a debated subject since early studies based on Explorer 12 observations in 1968. As far as we know, only a theoretical analysis for wide crossings of the rotational discontinuity type is available to explain such a difference; our result for tangential discontinuities constitute a nice complement.

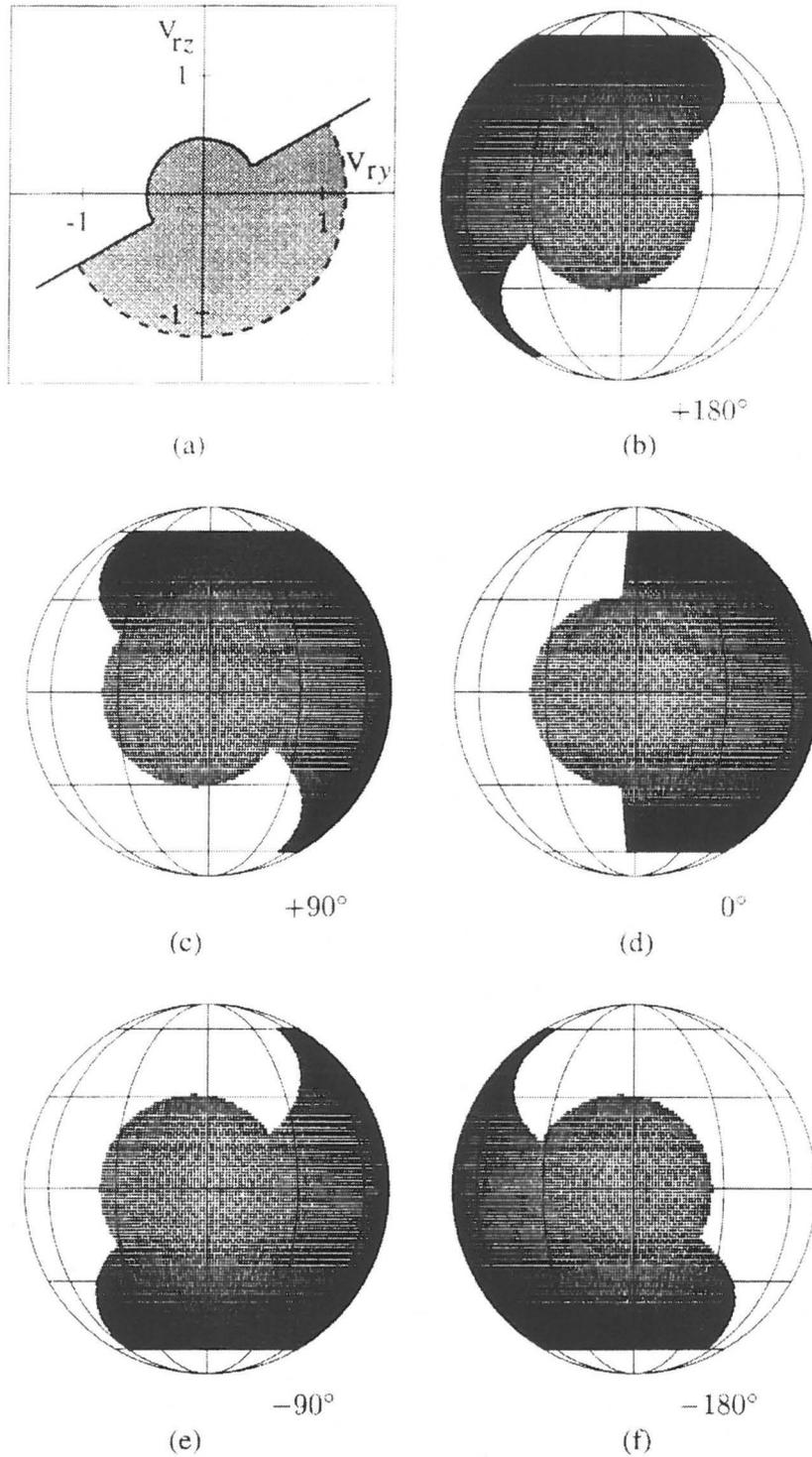


Figure 5 : Given a typical velocity jump domain as in panel (a) and assuming that the magnetosheath plasma is streaming radially away from the stagnation point, it is possible to predict where the dayside magnetopause may be in TD equilibrium for a given magnetic field rotation angle. The stagnation point is at its typical location 5° downward from the subsolar point, and the dipole tilt angle is zero. The shaded regions correspond to magnetic field rotation angles of (b) $+180^\circ$, (c) $+90^\circ$, (d) 0° , (e) -90° , (f) -180° (from De Keyser and Roth [1998a]).

11.6. Strong validation of the TD model with ISEE data

The subsolar magnetopause analysis represents a strong validation of the Tangential Discontinuities (TD) model. This model was able to explain electron density enhancements observed in high magnetic shear crossings of the subsolar magnetopause. The radio sounding experiment onboard ISEE-1 and ISEE-2 permitted the determination of the integrated electron density along the trajectory between the satellites at a rate of 8 to 32 Hz, but the internal structure of the transition was computed without using the electron density profile. Indeed, both the magnetic field depression and the magnetic field rotation angle fix the kinetic pressure of the inner populations. The excellent agreement between the electron density profile predicted by the simulation and the one actually observed, therefore constitutes a strong validation of the model.

11.7. Solar Wind Discontinuities: Ulysses

The Space Plasma Physics group of the Belgian Institute for Space Aeronomy was able to participate in the ULYSSES primary mission thanks to a PRODEX grant. The work carried out at BISA is the only Belgian contribution to the ULYSSES mission. The Space Plasma Physics group at BISA plays a leading role in the *Interdisciplinary Study on Directional Discontinuities in the Solar Wind* (Michel Roth is currently principal investigator for this study), which also involves the Space Sciences Department of Lockheed Palo Alto Research Labs, California, USA. The research conducted at the Belgian Institute for Space Aeronomy is oriented to the understanding of observations of solar wind phenomena using the in-house modeling capabilities.

The main instruments used in the interdisciplinary study are the magnetometer (Principal Investigator: A. Balogh, Imperial College, London, United Kingdom) and the plasma experiment (Principal Investigator : D. McComas, Los Alamos National Laboratory, New Mexico, USA). We have a lasting good working relationship with the magnetic field teams of A. Balogh (Imperial College, London, UK) and B.T. Tsurutani (Jet Propulsion Laboratory, NASA, Pasadena, California, USA) who provide us with high time resolution solar wind magnetic field data, as well as with the plasma team that provides us with data on the density, temperature and velocity of the solar wind. The group of S. Hoang at the Observatoire de Paris-Meudon, which participates in the plasma wave experiment (URAP, Unified Radio and Plasma Wave Experiment), makes its additional high resolution data on solar wind density and electron temperature available to us. We also collaborate with the Guest Investigator team of F. Neubauer (Universität Koln, Germany) which is working on discontinuities in collisionless plasmas.

During the Ulysses Primary Mission we have mainly addressed some fundamental aspects of the structure of tangential discontinuities. At BISA we have an in-house developed theoretical model of tangential discontinuities. The Primary Mission has led to the validation of this numerical model, as the model has been used extensively for the interpretation of ULYSSES data as well as observations from other satellites. This has contributed to our understanding of the reasons for the very existence of such layers in the solar wind, their structure, and their apparent stability.

11.7.1. The structure of discontinuities

In order to examine the structure of the magnetic field inside a discontinuity (which is a very thin layer in space) one must rely on data obtained with a high time resolution. ULYSSES data have allowed us to do so. Insight in the internal structure of the discontinuity was gained by confronting the observations with the in-house expertise on models of tangential discontinuities

11.7.2. The effect of plasma velocity variations

A study of the effect of velocity variations on the structure of tangential discontinuities has been undertaken. The Ulysses observations of the magnetic field above the Sun's poles turned out to be very useful here. Indeed, since solar wind composition, density and temperature are rather constant there, we found that velocity variations are the most important factor controlling the structure of discontinuities there.

11.8. The heliospheric current sheet

A particular feature in the solar wind is the heliospheric current sheet, a surface that separates the solar wind streaming away from the Sun's northern and southern hemispheres. This current sheet has a wavy form and its position changes with time. Often it can be regarded as a tangential discontinuity. In a preliminary study, we have analyzed the structure of this current sheet using data from the recent WIND spacecraft because the time resolution of its plasma data is better than on ULYSSES.

11.9. Radio Dust Analyser

A new method using a radioelectric antenna has been proposed for the detection of charged dust grains in a plasma. When the length of the radio antenna is comparable with the Debye length of the ambient plasma, the shape and duration electric voltage produced by a passing dust grain passing close to the antenna can be used to determine the velocity and other characteristics of the grains

11.10. Software calibration of the Scintillation Fiber Detector (SFD) of the satellite EQUATOR-S

A scintillation fibre detector (SFD) designed by L. Adams (ESTEC) has been re-calibrated at the "Université Catholique de Louvain" (UCL) using the software code GEANT used at CERN to simulate the response of nuclear physics detectors in a calibration beam of energetic protons or electrons. A Technical Note (TN-A) describing this detector and its implementation on the EQUATOR-S spacecraft has been prepared. This document has been delivered to ESA as part of fulfilment of a Work Order from ESTEC. The preliminary data from this instrument which is in orbit since December 1997, have been transferred to BISA and UCL where they will be analysed.

12. SPICAM-S

The SPICAM experiment ("Spectroscopie pour l'Investigation des Caractéristiques de l'Atmosphère de Mars") was a Belgian-French-Russian collaboration consisting of several instruments to be launched on board of the Russian interplanetary spacecraft Mars 96. One of them, SPICAM-S was developed and manufactured under the responsibility of BISA. It is an optical spectrometer using the solar occultation technique. A detailed technical description as well as the scientific goals of SPICAM-S were given in the previous COSPAR report (1994-1995).

The MARS-96 launch was scheduled for November 16, 1996. Previous to the launch several acceptance tests had to be carried out on the flight and the spare model. Delivery of these models was accomplished and flight scenarios were tested successfully, both for the transfer and for the orbital period. First real measurements during the transfer phase were foreseen for SPICAM-S in the beginning of December 1996, 24 days after launch.

a. The flight model : Thermal acceptance tests were carried out in ESTEC (Noordwijk - Netherlands) (January 17th - 19th 1996, March 4th - 8th 1996). EMI/EMC and vibration acceptance tests were performed at CNES (Toulouse - France) (March 10th - 22th 1996). A calibration session took place with the real Sun from an equatorial table at the Observatoire de Haute Provence (St.-Michel - France) (February 27th - March 1st 1996).

The Flight model was delivered to and accepted by IKI in April 1996. In Moscow integrated EMI/EMC-tests were carried out on the satellite (May 15th - 23th 1996) as well as cyclogram simulation tests (June 29th - July 5th 1996, September 15th - 22th 1996). From November 3th till November 16th the last pre-flight operations were established at the launch base (Kazakhstan).

b. The spare model : With the spare model thermal-vacuum acceptance tests were carried out in ESTEC (June 24th - 26th 1996) and vibration acceptance tests at LAS (Marseille - France) (July 8th - 10th 1996). A calibration session took place with the real Sun on an equatorial table at Pic du Midi (France) (June 16th - 23th 1996). The spare model was delivered to and accepted by IKI in July 1996.

c. The balloon flight : A balloon flight with the SPICAM-S instrument was possible thanks to the close cooperation with SA-CNRS (France). A slightly modified engineering model was used and installed onto a stabilized platform. The flight took place on October 3th 1996 from the CNES launch base for stratospheric balloons in Aire-sur-l'Adour (France). This balloon flight with SPICAM-S was planned aiming for : (a) the composition of a realistic data set in view of the further preparation for the analysis of the MARS-96 data; (b) getting to know the influence of the instrumental parameters in real working conditions; (c) taking reference spectra for calibration of the spectrometers at low temperature; (d) verifying the functioning of the instrument, especially the suntracker, in a real configuration (aboard a stabilized platform watching a real sunset).

d. Conclusions : Technically spoken the SPICAM-S project was conducted to a good end. All deliverable models were delivered. Flight and spare model were accepted after integration and testing on satellite level. Due to the crash of the MARS-96 mission on November 16, 1996, SPICAM-S did not produce scientific data.

13. ISO target of opportunity : observation of global dust storms on Mars

The Belgian Institute for Space Aeronomy proposed the observation of global dust storms on Mars with the ISO payload. This proposal made jointly with the SRON (Groningen) and IKI (Moscow) was accepted as a target of opportunity proposal. The goal was to measure the changes in chemistry of the Martian atmosphere in relation with the increase in temperature, dust and water vapour expected from the dust-storms, and interpret them in terms of a two dimensional model developed at the BISA. The launch of ISO was performed in November 1995. The observation parameters were encoded at the beginning of 1997, several months in advance of the storm season on Mars. A network of ground observations was combined with the Hubble Space Telescope, Pathfinder and Mars Global Surveyor in 1997. Despite several local storms and a Southern hemisphere large storm in November 1997, no global dust storm meeting the alert criteria took place. Nevertheless this project has led to new insights into the mechanisms of dust-storms which will remain a meaningful scientific target for future Mars observation campaigns.

14. The ESA Rosetta project – ROSINA

The Belgian Institute for Space Aeronomy is participating in the Rosetta mission, which is a planetary cornerstone of ESA's Horizon 2000 long term program. This mission aims the rendezvous with a comet (Wirtanen) and in situ investigation of the cometary matter and evolution of the comet structure as a function of its heliocentric distance.

ROSINA (Rosetta Orbiter Spectrometer for Ion and Neutral Analysis) is an international experiment (PI: Prof.H. Balsiger, University of Bern) consisting of three sensors for composition analysis: a double focusing magnetic mass spectrometer (DFMS), a reflectron time of flight mass spectrometer (RTOF) and a neutral and ion dynamics monitor (NIDM).

BISA is involved in the ROSINA-DFMS, the major scientific objectives of which are the determination of the elemental abundances in the cometary gas, the determination of the molecular and isotopic composition of the volatiles, and the characterization of the nucleus. The contribution of BISA to this project is the development of a linear electron detector array (LEDA) in collaboration with Belgian industry and of the electronics associated with the read-out of this detector.

The LEDA is presently under development at IMEC, Leuven, Belgium. A prototype of it mounted with a microchannel plate by CETP (Centre d'étude des Environnements Terrestre et Planétaires, St. Maur, France), who will develop the front part of the ion detector, will soon be tested in BISA, where a test set-up is presently being developed.

The associated electronics are in design and test phase.

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B. Institute of Astrophysics and Geophysics of the University of Liège

1. Hot atoms in Earth and Jupiter's upper atmospheres

New observations and reanalysis of previous satellite measurements suggest an upward revision of the measured thermospheric nitric oxide density. A previous model of NO production by fast $N(^4S)$ atom collisions with O_2 has been updated. New calculations indicate that the transfer of translational energy in $N + N_2$ collisions is less efficient than in the hard sphere approximation. This result leads to reevaluation of the energy dependent relaxation cross section and to an upward revision of the reacting efficiency of collisions of N with O_2 to form nitric oxide. The calculated peak NO density increases by a factor of ~ 2 when the effect of superthermal nitrogen atoms is included. The model response of the $N(^4S)$ energy distribution function and NO density to solar cycle variations was calculated.

Exothermic reactions involving metastable neutrals and ions were recently proposed as sources of hot oxygen atoms in addition to the classical O_2^+ and NO^+ dissociative recombination. It is shown that the calculated energy distribution functions of O atoms are significantly in nonequilibrium in the transition region between the thermosphere and the exosphere. The variation of the vertical distribution of hot O between solar maximum and minimum conditions was also evaluated and showed good agreement with the available experimental evidence.

The energy distribution functions of nonthermal thermospheric hydrogen atoms have been calculated for electron and proton precipitation in the Jovian aurora. The model is based on a Monte Carlo solution of the nonlinear Boltzmann equation for hot H atoms produced by electron and proton impact on H and H_2 and exothermic chemical reactions. The distribution functions show a much higher energy tail for proton than electron precipitation. It was shown that hot H atoms may play an important role in the formation of the Lyman α line profile. Multiple scattering in the wings of the Ly α line by the fast H atoms was shown to partly account for the broad Ly α profile observed in the Jovian aurora with the Hubble space telescope.

2. Ultraviolet observations of giants planets with the Hubble Space Telescope

2.1. Morphology of the Jovian UV aurora

Multispectral observations of the far ultraviolet Jovian aurora with the faint object camera (FOC) on board the Hubble Space Telescope were reported. They were used to describe and compare the morphology and the mean brightness of the H_2 Lyman and Werner bands observed at 153, 125, and 130 nm. It is shown that most of the emissions are confined inside the $6 R_J$ O_6 -GSFC auroral oval and fill a large fraction of the polar cap. During the ~ 50 hours time span of the observations following a very strong aurora, no bright arc was observed along

the oval mapping the 30 R_J O_6 oval. Hydrogen emissions at 125 and 130 nm are observed down to 50°N and somewhat below, a region not accessible to previous FOC observations at longer wavelengths.

Temporal variations have also been observed on timescales of hours to minutes with the WFPC2 camera. Most of the fast variations take place at high latitudes well inside the footprint of the 30 R_J magnetic field lines.

A model simulating Earth views of UV auroral arcs and diffuse emissions in the Jovian north polar region is described. It assumes a Chapman profile of vertical brightness distribution and various horizontal structures. The numerical simulation makes it possible to assess the importance of limb brightening and the contribution from high altitude auroral emission located behind the planetary limb. As an application of the simulation model, four images obtained with the Wide Field and Planetary Camera 2 (WFPC2) on board the Hubble Space Telescope have been used to determine the characteristics of their auroral (discrete and diffuse) structures. The apparent brightness distribution along the arcs may only be reproduced if intrinsic longitudinal (or local time) variations are introduced, in addition to the path length effects of the viewing geometry. A composite average auroral distribution was built by mapping ten WFPC2 images from the same dataset. It was shown that the equatorial auroral emission boundary is located between the 6 R_J and the 30 R_J magnetic field line footprints of the Goddard Space flight Center (GSFC) O_6 model.

2.2. Far ultraviolet spectroscopy

Ultraviolet spectra using HST/GHRS sampled between 1250 Å and 1680 Å at spectral resolution ≤ 0.57 Å are reported for characteristically bright regions of Jupiter's morning and afternoon northern aurora. We have searched for evidence that the primary precipitating particles exciting the aurora include the heavy ions known to exist in Jupiter's plasma torus and magnetosphere.

The theoretical sulfur and oxygen line shapes for ion precipitation were modelled and it was concluded that electron precipitation is responsible for most of the H_2 emissions. O^+ ions contributed < 13 % of the precipitating energy flux, and S^+ ions contributed < 50 %. This dominance suggests that field-aligned magnetospheric currents are more important than energization of energetic ions and subsequent scattering by plasma waves as a mechanism for generating the Jovian UV aurora. We set an upper limit over our spectra of 35--43 R to the emission from ambient oxygen and sulfur ions and their neutrals and no evidence was found for the accumulation of sulfur atoms in the auroral ionosphere.

Differences were observed in the auroral spectral hydrocarbon absorption at different locations which cannot be interpreted without ambiguity between auroral and atmospheric structural causes. It was found that the brighter emission in an auroral sector consistently shows more spectral hydrocarbon absorption than the dimmer emission.

2.3. Saturn's auroral UV emission and polar haze

Near simultaneous observations of the Saturnian H₂ north ultraviolet aurora and the polar haze were made at 153 nm and 210 nm respectively with the Faint Object Camera on board the Hubble Space Telescope. The auroral observations reveal the presence of an auroral emission near 80° N with a peak brightness of about 150 kR of total H₂ emission. The maximum vertical optical depth at 210 nm is found to be located ~ 5° equatorward of the auroral emission zone. The haze particles are presumably formed by hydrocarbon aerosols initiated by H₂⁺ auroral production. In this case, the 3 x 10¹⁰ W of H₂ emission observed with the FOC, combined with the deduced haze optical depth requires an efficiency of aerosol formation of about 7 %. This result indicates that auroral production of hydrocarbon aerosols is a viable source of high-latitude haze. New multicolor observations obtained with the WFPC2 camera are currently being analyzed.

3. ATMOS-related investigations

During the past two years, a large number of scientific contributions have resulted from further investigations of Shuttle-based remote observations with the ATMOS (Atmospheric Trace Molecule Spectroscopy)-Fourier transform infra-red (FTIR) spectrometer. These concern primarily additional characterization issues on the chemical and dynamical state of the Earth's middle atmosphere (15-70 km) as listed in the 1996 Belgian Report to COSPAR. Two further issues that have been thoroughly investigated deal with (i) the internal consistency in terms of partitioning among "families" of constituents (e.g., nitrogenated-, chlorinated- and fluorinated- gases) and conservation of their budgets versus altitude when combining source- sink and reservoir compounds; and (ii) intercomparisons of measurements made by different methods and techniques, in particular remote observations by ATMOS and HALOE/UARS (HALogen Occultation Experiment aboard the Upper Atmospheric Research Satellite) and in situ studies with the ACATS-IV (Airborne Chromatograph for Atmospheric Trace Species- Version IV) instrument operating aboard the high-altitude NASA ER-2 airplane.

As a consequence of priority changes in US national Space programs, and redirection of Shuttle mission assignments, the ATMOS-science team considered alternatives for ATMOS deployments (e.g., "Express Pallet" module for ISS-A), as well as a new FTIR instrument to be operated as an independent satellite instrument. The latter resulted in an ESSP (Earth System Science Pathfinder) proposal to NASA, entitled "Chemistry and Circulation Occultation Spectroscopy Mission" (CCOSM), the PI being Dr. M.J. Prather from the University of California at Irvine, and the Jet Propulsion Laboratory, Pasadena, CA, assuming the program management. Currently, CCOSM is an official "alternate mission" and it will have a chance to move to the development phase by the end of 1998. The CCOSM instrument is an integrated package combining an ATMOS-type FTIR for volume mixing ratio profile determinations of over 30 telluric compounds, and a MAST (Measurement of Aerosols in the Stratosphere and Troposphere)-UV/Vis grating spectrometer, both operating in the solar occultation mode on a 440 km altitude, 48° inclination orbit.

4. Ground-based versus Space observations of the atmosphere

Atmospheric composition monitoring activities by the "Groupe Infra-Rouge de Physique Atmosphérique et Solaire" (GIRPAS) of the University of Liège have continued at the International Scientific Station of the Jungfrauoch (ISSJ), Switzerland. They are currently based on the spectrometric analysis of target-gas specific absorption features measured in high-resolution solar observations made in the middle infra-red (about 2 to 15 micrometers) with two FTIR spectrometers; in this way, vertical column abundances (expressed in number molecules per square cm above the site altitude) for some 20 telluric constituents have been monitored for well over one decade, and their short-term variability and long-term evolution continue to be documented. A special attention has been devoted to changes in stratospheric reservoir and sink constituents (e.g., HCl, ClONO₂, NO, NO₂, HNO₃,) involved in the chemistry of the stratosphere, in particular the destruction of ozone via the Cl_x and NO_x catalytic cycles. These latter compounds are being studied within the frame of our commitment to the NDSC (Network for the Detection of Stratospheric Change) which assigned "primary" status to the Jungfrauoch FTIR instruments as part of the Primary NDSC Alpine Station. On many occasions, vertical column abundances determined above ISSJ have been intercompared with volume mixing ratio profiles integrated over various altitude regimes, as observed by HALOE for HCl and HF, CLAES (Cryogenic Limb Array Etalon Spectrometer, also aboard UARS) for ClONO₂ and HNO₃, and GOME (Global Ozone Monitoring Experiment, aboard the Earth Resource Satellite ERS-2) for NO₂ and O₃.

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C. Space Center of Liège

In the framework of the Belgian PRODEX programme, the Space Center of Liège ("Centre Spatial de Liège", CSL) has been selected for developing, in partnership with the University of Berkeley, California (UCB), the "Far Ultraviolet Spectrographic Imager" (FUV-SI). This is an experiment which forms part of the instrument package of the "Imager for Magnetopause-to-Aurora Global Exploration" (IMAGE), a NASA programme due for launch in 2000. Basically, the FUV-SI consists of a 15° Field of View spectro-imager, the mission of which is to separate the 1218Å and 1356Å bands of the entire auroral oval from a spinning spacecraft at 7 earth radius apogee. Those two images result from the proton and electron auroras, respectively. It will be the first instrument which will distinguish between both kinds of auroras.

In this programme, the CSL is responsible for delivering a protoflight of the optical subsystem of the FUV-SI, fully functional. Detailed optical design and preliminary mechanical design were realized by CSL during year 1996. Two subcontracts were signed in 1997 for the manufacturing of the two main sub-systems of the instrument by Belgian industries. CSL is responsible for aligning and testing the SI. Tests are :

Environmental tests :- Vibration
 - Thermal Balance, Thermal Vacuum
Calibration : - Field of View
 - Radiometric response

For that purpose, several ground support equipments were designed and installed on our test facility. The delivery of the two main subsystems took place on December 97 and January 98. Test are under progress. The instrument should be delivered to UCB on June 98.

Publications

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D. Royal Meteorological Institute of Belgium

1. Ionospheric studies

The near real-time determination of the electronic concentration profile from the ionogram is produced on a hourly routine basis. The latest results appear on the Web at the following address: <http://digisonde.oma.be>. The delay between the actual sounding and the validation of the results is now reduced to about a month. All past data are available by electronic means.

A study of the output of automatic scaling and manual scaling over almost five years of hourly data led to the conclusion that automatic scaling is valuable for most of the time. A vertical electron content called Ionospheric Electron Content (IEC) was computed from integration of the bottom part of the profile deduced from the digisonde measurement and integration of the top part from a fitted model. This IEC was compared to a total electron content (TEC) estimated from GPS measurements above the Dourbes station. A very good agreement (zero mean difference, two to three TEC units of variance) over two years of data was reached when using satellites with near vertical elevation.

2. External Geomagnetism

The department "Magnetism" of the Geophysics division made continuous observations of the Earth's Magnetic Field at the Observatories of Dourbes and Manhay. The sampling of the field components was at a rate of 1/minute and sometimes at 1/second. For special applications, a system with a 10 Hz rate is in development.

A dipolar model for the magnetic field over Belgium sets the magnetic thickness and the magnetisation change of the Earth's crust. The model results agree with the tectonic data on Belgium.

A modulation model for the magnetic solar cycle from 1650 to 1996 shows an harmonic oscillator subject to long term variations in phase and amplitude. The simulated Wolf number shows recurrent minima and maxima and accounts for 98% of the total variance.

Work on the automatic DIFlux continued. A special electronic device allowing the reading of angular encoders with an accuracy better than 0.1 arcsecond was adapted for having a zero magnetic signature. A demo with a first semi-automatic prototype was organised at the IAGA assembly in Uppsala (1997). This prototype was also tested during the Third Escuela Latino-Americana de Geomagnetismo in Huancayo, Peru. Additionally, work is under way for equipping the Automatic DIFlux with a non-magnetic gyroscopic North Seeker. A low-noise ($<10\text{pT}/\text{Hz}$) fluxgate electronics was also designed for the DIFlux.

The department "Magnetism" was also active in helping several countries (Argentina, Brazil, Mexico, Cuba, Bolivia, Angola) to run, modernise or repair their Magnetic Observatories facilities. This was done by lending, repairing and installing equipment and by training

courses. The goal is to have the Magnetic Observatories of those countries ready for the upcoming magnetic satellites like Oersted and Champ.

3. Solar constant and Earth's radiation budget

3.1. Solcon/Hitchhiker

The ATLAS programme of the NASA has been canceled after the ATLAS 3 mission, but the SOLCON experiment measuring the Solar constant is now scheduled to fly within the Hitchhiker programme of the Goddard Space Flight Center. The first of the 4 planned missions occurred in August 1997 on board of the STS 85 shuttle. The second flight is planned with IEH-3 on STS 95 to be launched at the end of October 1998.

3.2. ESA-SOHO program

Solar constant data are routinely received at the Royal Meteorological Institute of Belgium from the DIARAD (Differential Absolute Radiometer) installed on the VIRGO experiment. This experiment gives excellent results with no sensible aging of the instrument and so insures the continuity of the monitoring of the Solar constant from the SOHO satellite. The daily mean of the Solar constant is available about ten days after measurement at the address : <http://estirm2.oma.be/solarconstant/virgo/virgo.html>.

4. Publications

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II. Space Astronomy

A. Royal Observatory of Belgium

1. Atmospheric Trace Molecule Spectroscopy (ATMOS)

ATMOS (Atmospheric Trace Molecule Spectroscopy) is an experiment of JPL (Jet Propulsion Laboratory)/NASA. High resolution absorption spectra of the earth atmosphere were taken from the Space Shuttle in 1985, 1992, 1993 and 1994, using a very performant Fourier transform spectrometer, mainly to study the vertical distribution of molecular constituents of our atmosphere.

The solar team of the Royal Observatory of Belgium, in collaboration with solar spectroscopists of the University of Liège, is interested in the pure solar spectra, obtained with the sun high above the horizon, from 2 to 16 μm , free from any telluric absorption. The work consisted of measuring and interpreting the ATMOS solar spectra. The main results in solar physics based on these pure solar spectra include a new determination of the solar abundance of C, N, O and Fe, and a refined photospheric model based on atomic and molecular lines.

2. Infrared Space Observatory (ISO)

Observations were obtained with the ISOPHOT instrument for a sample of a few B-stars and Wolf-Rayet stars at 60, 90 and 160 μm . The data consist of oversampled maps, showing a large background and only a small contribution of the star. The data reduction of this type of observations is quite complicated and is, at the moment, hampered by insufficient knowledge of memory effects of the detector. Techniques were also developed to combine the data of the multiple low-resolution maps into a single map having higher spatial resolution.

Infrared (ISO-SWS data) spectra of the K2III giant α Boo and the M2.5III giant β Peg were compared to synthetic spectra generated by the use of the new Uppsala models. We hope that our results will not only contribute to a better convergence between the ISO-SWS data and the generated synthetic spectra, but also to a better understanding of the atmospheres of cool giants (Work in collaboration with the stellar group at the Katholieke Universiteit Leuven). A database of infrared lines including molecular lines of CO (40000 lines), OH (2600), CH (2700), NH (1450), HF (1000) and HCl (730) has been especially created.

3. International Ultraviolet Explorer (IUE) and Hubble Space Telescope (HST)

The Uniform Low Dispersion Archive (ULDA) of the ESA IUE Observatory can be consulted by means of the user-friendly software package USSP. In Belgium it is installed on the Vax

machines of the Royal Observatory, which acts as National Host. The archive can be consulted directly at the Observatory or by remote access. The format of the extracted spectra is compatible with MIDAS (Munich Image Data Analysis System). Version 4.0 of the Archive, which contains all low-resolution spectra up to Jan. 1, 1992, has been installed and is used regularly by Belgian astronomers.

For the study of the chemical abundances of iron-group elements in early B-type stars, high dispersion UV spectra are used. Such IUE data were retrieved from the NASA IUE Final Archive, while a set of HST spectra was obtained from the ESO HST-Archive, where they were processed using the fully automatic pipe-line reduction system. As a first result of this work it was shown that the B1.5V star HR 1781 has an iron abundance of 90% of the solar value. While the fits of theoretical non-LTE Fe III spectra to a HST spectrum in the wavelength range 2059 to 2070 Å were very good, it became clear that at lower wavelengths (< 1500 Å), more accurate and more complete sets of atomic data for the iron group elements are needed.

4. Solar and Heliospheric Observatory (SOHO)

During the last two years, the Solar Physics Department of the Royal Observatory continued its participation to the EIT experiment (Extreme-ultraviolet Imaging Telescope) on the SOHO mission as scientific co-investigators. The activities concentrated on four major axes :

- determination of the flat-field corrections of the instruments and in-flight monitoring of the radiation-induced aging of the detector;
- participation to the scientific planning of the experiment, involving special missions at SOHO's operation facilities at the Goddard Space Flight Center (NASA);
- development of a research program to study the micro-variability detected in high-cadence EIT image sequences;
- creation and maintenance of a local archive and catalog of EIT data and participation in the data distribution process.

The results obtained in 96-97 can be summarized as follows :

4.1. In-flight support of the EIT experiment

The Solar Physics Department is responsible for the corrections of spatial non-uniformities in the response of the instrument, which involves the determination of several independent contributions. Some of these corrections (laboratory CCD flat-field, filter grid) were incorporated in the standard software library developed to process raw transmitted images. Other defects, which evolve with time due to in-flight aging of optical and optoelectronic components, are now under continuous monitoring in order to derive proper corrections from the solar images themselves. Similar flat-field corrections were computed for the CALROC experiment of the Naval Research Laboratory (USA), which was launched in October 1997 on a sounding rocket to ensure the in-flight photometric calibration of EIT.

The coordinated scientific planning of the EIT observations was taken over by F. Clette during one-month shifts, in April - May 1996 and April - May 1997. This work involves controlling and monitoring of the instrument, scheduling of observing runs in coordination with other

SOHO instruments, support to scientists for the preparation and the execution of observing sequences, diffusion of the information (target selection, public relations).

4.2. Observing campaign and research project

In May 1997, during a planning mission to the operation facility, a new observing mode was defined and tested for the EIT. By using electronically controlled readouts of the CCD without operating the electromechanical shutter, it was demonstrated that EIT can produce image sequences at about 4 times the maximum rate achieved earlier in the mission. As this imaging mode allows to obtain a better time resolution, we set up and coordinated a joint observing campaign, involving the participation of the SUMER and CDS spectrographs on SOHO and dedicated to the study of fast phenomena in active regions. This campaign took place successfully on May 23, 1997 and the resulting data are now being analyzed. A similar but scaled-up campaign is in preparation for May 98, in coordination with additional instruments on different spacecrafts (YOHKOH, TRACE).

Starting in June 1997 a first research program based on EIT data was developed. Several high-cadence image sequences were studied in order to look for low-amplitude short-lived transients and oscillations in the quiet corona and transition region. This research, which addresses the problem of coronal heating, already lead to the discovery and the extensive statistical analysis of thousands of intermittent brightenings in EUV light. The wide spatial coverage of EIT allowed us to derive new conclusions concerning the turbulent dynamics of plasma at the base of the solar atmosphere.

4.3. Archive and data distribution

Since the early phase of the mission, a local copy of the EIT "Quicklook" archive was maintained at the Royal Observatory, together with a catalog in order to allow data set selections. Since early 1997, this archive was installed on a new dedicated HP 9000 workstation equipped with a 200 Gbyte magneto-optical disc library. The funding for this project was provided by the Belgian SSTC in the framework of the "Telescience" research support program. To complete this facility, an ISDN router was installed to allow "real time" downloading of planning data from the European SOHO archive (MEDOC, Orsay, France) during office hours, at the time of daily planning meetings at the SOHO operation center (Greenbelt, USA). This archive, which started as an internal resource, is now also used to pre-process and distribute data in response to external data requests.

Moreover, since the start of SOHO operations, P. Cugnion acted as the EIT Data Use Coordinator for Europe, by centralizing data requests from scientists outside the SOHO community and by organizing the internal reviewing process up to the final approval. In this process, an internal EIT collaborator is identified and the acquisition and distribution of the requested data is initiated.

5. HIPPARCOS astrometric mission and double star astronomy

5.1. *Input Catalogue*

Since the publication of the Hipparcos Input Catalogue in 1992, many more identifications of double and multiple stars have been found by using various lists of double stars as well as a special edition of the Index-WDS of double stars updated to 1994,0 and kindly communicated by C.E. WORLEY to the Double Star Working Group of the Hipparcos Science Team. These identifications, with some errata, have been published in two papers in the Bulletin du CDS (Strasbourg) and have all been introduced in the CCDM.

In order to establish a perfect and homogeneous link between the Input Catalogue and the CCDM, a specific version of this one (May 1996) was edited for internal use and communicated to the three Hipparcos consortia (INCA, FAST and NDAC). On this basis a new edition of the Input Catalogue was expected for release on one of the disks containing the machine-readable final Hipparcos catalogue recently published. Unfortunately for unknown reasons, this was not done by the Hipparcos staff in such a manner that the Input Catalogue, the Hipparcos Catalogue and CELESTIA 2000 are far to be complete concerning double stars.

5.2. *Catalogue of the components of double and multiple systems (CCDM)*

During the last two years, the CCDM has been completed by new double and multiple stars as well as by new data.

The first addition concerns the 2994 new double stars discovered by Hipparcos, flagged by a "H" in field H56 of the Hipparcos catalogue and by 155 probably new astrometric binaries and 38 probably new astrometric components of known classical double stars. They are included in the list of the 235 stars flagged "O" in field H59, 42 of them being already known.

The relative positions of the components being too often uncertain (for example : alternative solutions given in the notes) it has been decided – at the contrary of what we had foreseen – not to take these data into account in the CCDM in order to avoid any inhomogeneous completion. To do this job, a special investigation would be needed but it presently appears more urgent to pursue the completion of the CCDM by astrometric data of many non-Hipparcos systems on the basis of existing catalogues and especially by using the first and second editions of the Guide Star Catalogue (GSC).

As a consequence, the number of definitely identified systems has increased from 34864 to 41728 including the $2994 + 155 + 38 = 3187$ new binaries discovered by Hipparcos.

A second edition of the catalogue is now under preparation by J. Dommangeat and O. Nys. It will be the only correct and complete link between double stars and the Hipparcos final catalogue.

5.3. Final Hipparcos Catalogue

Two major astrometric catalogues, "The Hipparcos and Tycho Catalogues" (ESA, ESA-SP1200, 1997) are made publicly available since June '97. The final products of the mission are available:

- as a 17-volume set, consisting of a 16-volume hard-bound printed catalogue together with a set of 6 CD-ROMs;
- through the CDS data centre,
- via the Hipparcos Web page(<http://astro.estec.esa.nl/Hipparcos/>).

Only Celestia 2000 has not yet been released. Following this publication, all HIPPARCOS teams and Consortia were dissolved, as was also the case for the Double Star Working Group. In addition to the 3187 new pairs, which have been introduced in the CCDM, one should also mention that 11452 suspected binaries have been detected in the Hipparcos catalogue and are mentioned in field H59 by the flags : "G" (acceleration solutions), "V" (variability induced movers solutions) or X (stochastic solutions) and in field H61 by the flag : "S" (suspected non single). Before being accepted as real new pairs and thus introduced in the CCDM, they have to be confirmed as such by ground based observations.

5.4 Double Star Astronomy

The astrometric results of a complementary ground-based programme have been calibrated with the help of the satellite data. In addition, accurate and well-calibrated colour information for some 500 "intermediate" Hipparcos double stars (with separations between 1 and 15 arcsec) have been obtained. Extended error and statistical analyses have been presented.

The new Hipparcos parallaxes and photometric data have been used to determine individual masses and absolute (bolometric) magnitudes for the components of nearby visual binaries with good to very good orbits. The impact on the mass-luminosity relation in the range $0 < M_{\text{Bol}} < +7.5$ mag has been evaluated. A doubly weighted linear regression model was applied: a "mean" slope 3.82 ± 0.07 and zero point 4.94 ± 0.03 , assuming a linear relationship, was derived.

In the context of a work on Orbit Computations of Binaries, an attempt was made (but unsuccessfully) to derive relative positions at different epochs during the mission from the NDAC Consortium 's Transit Data.

A statistical study of the visual double stars of the Tycho Catalogue was made. A preliminary search for variability was also done among the photometric data of the Tycho Catalogue. This research will be made in collaboration with Drs. Halbwachs and Piquard from the Observatoire de Strasbourg (France).

Since Oct. 1997, an ESA/PRODEX project is underway on Hipparcos Double Star Data Exploitation. For this work, 38 spectroscopic-visual systems are being analysed for which the combined orbits have been derived. As a result, parallaxes are being obtained that will be confronted with the satellite parallaxes.

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B. Space Center of Liège

1. EIT 1996-1997

The EIT instrument is operating on board the SOHO platform, orbiting at 1 500 000 km from Earth. This telescope which was developed under the technical responsibility of the Space Center of Liège (CSL) is producing images of the solar corona in 4 wavelengths of the EUV spectrum since its first flight which occurred in Jan.1996.

More than 70 000 images have been taken during the first 2 years of observations (1996-1997). CSL is involved in the EIT consortium which is in charge of the instrument operations. The CSL team gained a very good knowledge of the instrument during its development before 1996, and has been contributing to the monitoring and the control of the instrument. CSL took part to the EIT Science Planner work at NASA-GSFC during October 1997.

Like most of the SOHO EUV instruments, the initial pre-flight calibration of the EIT sensor is no more valid after long exposures to the solar radiations. There remains important corrections to be applied on the recorded data. CSL studies methods to evaluate and diagnose the response changes that are occurring during the EIT mission.

In order to improve the SOHO-EIT calibration a sounding rocket program (CALROC) has been initiated under the scientific responsibility of the Naval Research Laboratory. The aim of this program is to build and calibrate a second EIT instrument, by using all the spare parts remaining from the SOHO program (optics and mechanisms). This second instrument will be flown in order to operate simultaneously with the SOHO-EIT sensor.

A new structure has been developed and realised under CSL's technical responsibility. Vibrations tests were performed at CSL premises, and the EUV calibration took place at IAS (Orsay-F). CSL gave support during the launch campaign at White Sands Missile Range (NM, USA). The CALROC payload was successfully launched on the 16 Oct 1997. The instrument took series of EUV solar images, together with the SOHO-EIT instrument. The comparison of both series gave very fruitful informations on the real status of the SOHO-EIT instrument, and confirmed the expected results of the methods studied by CSL on the SOHO-EIT instrument alone.

2. Integral-OMC 1996-1997

CSL is partner in the Optical Monitoring Camera consortium. OMC (Optical Monitoring Camera) is part of the INTEGRAL payload, to be launched in 2001. SCL is responsible of 3 major parts of the instrument : the optical system, the main baffle and structure, and the aperture mechanism. Moreover, CSL will perform the thermal, vacuum and optical tests of the complete instrument.

Since 1996, CSL improved and optimized the optical design of the instrument with the flight CCD detector that was finally selected by INTA (Madrid, Spain), the PI team. Since mid 1997, the industrial work started to manufacture and produce the flight optical system, under CSL's technical responsibility. The main features of the optical system are a very wide thermal operating range and specific glasses with high resistance to radiations. A detailed study was performed to design and optimize the main baffle of the instrument, according to the final design of all the optical components. The final theoretical performances meet the scientific requirements, with stray-light attenuations lower than 10^{-14} . CSL designed the structural thermal model (STM) of the baffle, to be manufactured and delivered beginning 1998.

The aperture mechanism is a very important subsystem, that requires a high level of reliability. It has to open only once and to remain open during all the mission. It has been extensively studied during 1997 in order to reach all the safety margins. The manufacturing of a development model is starting beginning 1998. A first flight standard model of the instrument will be built for mid 1998.

CSL has also been preparing the tests sequences, that will certify the flight instrument before its integration on the INTEGRAL spacecraft.

3. XMM-Optical Monitor

The XMM Optical Monitor is a UV/optical telescope which forms part of the instrument package for the XMM space observatory, an ESA Cornerstone mission due for launch in 1999.

The ^{XMM}OM is co-aligned to the three X-ray telescopes and designed to provide simultaneous visible and UV coverage of all sources viewed by the observatory in the X-ray band. The instrument consists of a Ø300 mm f/12.7 modified Ritchey-Chretien telescope.

A photon-counting detecting blue/UV camera operating from 170 nm to 600 nm is based around a microchannel-plate (MCP) intensified CCD. A Ø25mm MCP stack with 12µm pores is coupled to a phosphor screen, which in turn is focused to a 256 x 256 active section of a TV format high frame-rate CCD (23µm pixels) by a fiber-taper (image reducer). The photon splashes are centroided over several CCD pixel to an accuracy of 1/8 CCD pixel by real-time hardware. The image format is 2048 x 2048 detector pixels allowing a resolution of about 1 arcsec on the sky. The nominal frame rate of the CCD is 100 Hz which defines the time resolution. The field of view is about 25 arcmin on the diagonal.

The limiting faint magnitude at the 5σ level is $V = 24.5$ magnitude for a 1000 sec exposure in unfiltered light for a B0 star (while a A0 star is detected at 5σ in about 3000 sec). The limiting bright magnitude will be less than $V = 7$ with a σ level > 1000 .

Each detector has in front of it a filter wheel with eleven positions. One of these is a closed position to ensure the safety of the detectors. Two further positions are taken up by gratings (one operating in the UV and the other in the optical) and seven by filters (3 in the UV, 3 in the optical and one, the "white light filter" covering the UV and optical). The remaining position is taken up by a parfocal 4x magnifier, which will permit higher resolution observations of the centre of the field of view.

CSL contributes at three stages in this instrument :

1. CSL provides the power supplies for the detectors and mechanisms. Engineering and qualification models have been delivered to the PI in 1997. The flight models delivery is foreseen in February 1998.
2. CSL provides the ground support equipment for the optical verification test, qualification test of the full telescope structure. This activity is completed.
3. Test operator for the optical verification test and qualification test of the full telescope structure. These tests are scheduled in June 1998 for the FM.

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C. Astronomical Institute of the "Katholieke Universiteit Leuven"

1. Introduction

The research activities of the Institute are in the field of stellar astronomy and rely on ground-based observations and on observations from space. The institute is involved in the Short-Wavelength Spectrometer (SWS) of ESA's Infrared Space Observatory (ISO). Besides a major use of ISO we note also projects for which data obtained with IRAS, Hipparcos, and IUE were analysed.

2. Software development for ISO

In the framework of the participation of our group in the SWS consortium, we have contributed to the in-orbit calibration of the instrument, the Interactive Analysis software, the development of a distributed configuration control system and the operations of the instrument from the groundstation in Villafranca, Spain.

For the calibration of the instrument, the efforts of the institute were focussed on the in-orbit correction of the Relative Spectral Response Functions (RSRF) as measured prior to launch in the lab during the Instrument Level Tests. These measurements have a limited accuracy, hence a correction based on what is observed in-orbit is needed to bring the flux calibration uncertainty back to the few percent level. A method based on a weighted spline smoothing algorithm was devised which allows to correct the lab RSRF for only those differences between SWS spectra and model SEDs of standard stellar calibration sources which are understood not to be imperfections in the models.

The final calibration of the SWS instrument is based on the observations of bright cool stellar templates for which detailed atmosphere models can be constructed. However, the atmosphere models for cool stars have so far been tested essentially with optical and near-IR measurements, and the extrapolation of these models to the mid-IR domain requires new modelling efforts. It is then necessary to adopt an iterative strategy, in which at each step the models and the calibrated observations are confronted. The efforts of improving the models and the calibration are coordinated at our institute.

3. The circumstellar environment of young and main-sequence stars

A thorough analysis was made of the statistical incidence of the so-called Vega phenomenon, i.e. the occurrence of dusty debris disks around normal main-sequence stars. In the literature so far various estimates were made of this incidence, but none of them on a sound statistical basis. The analysis relies on the mathematical technique of "survey analysis of censored data", which is appropriate for the discussion of samples which are heavily affected by the detection limits of the instrumentation. The conclusion of the analysis of the relevant data from the IRAS satellite is that the Vega phenomenon occurs in about 13% of the main-sequence stars.

In the framework of the ISO-SWS central programme and of open-time programmes SWS and LWS spectra were obtained of the circumstellar disks of Herbig Ae/Be stars, which are pre-main-sequence and young main-sequence stars in the mass range between 2 and 8 solar masses, i.e. they are the natural progenitors of Vega-like stars and of Beta Pictoris. The spectra display a wealth of solid-state features, that are carbon-rich (PAHs) and oxygen-rich (silicates, FeO, water ice).

Most remarkable is the occurrence of solid-state bands from silicates in crystalline form. Before ISO it was generally thought that 'astronomical silicates' are amorphous, with the notable exceptions of crystalline silicates in solar-system objects (comets, meteorites, interplanetary dust particles) and in the dusty disks of objects such as Beta Pictoris. The resemblance of the SWS spectrum of the star HD100546 to that of the bright dusty comet Hale-Bopp is spectacular, and confirms the presence of huge comet swarms in the disks of Herbig Ae/Be stars. The youngest Herbig Ae/Be stars have SWS spectra characterized by amorphous silicates; the data then suggest that the crystallisation processes occur during the later evolution of the disk. An object such as HD100546 can then be viewed as a proto-planetary system caught in a critical phase where the Oort cloud is being formed.

Another important component of the circumstellar disks of Herbig Ae/Be stars is water ice, again in crystalline form. The presence of crystalline water ice in proto-solar disks sheds new light on the presence of this component in comets. Present studies also focus on the description of the PAH features and on the evolution of these features with time.

4. The circumstellar environment of evolved stars

The detection by IRAS of infrared excesses for normal G and K giants could mean that the Vega phenomenon can survive the main-sequence evolution of a star, which would be consistent with the large fraction of main-sequence stars showing such excesses. A statistical study of all giants in the IRAS Faint-Source Survey was made with the technique of survival analysis. The result is that the same fraction of stars with excesses, i.e. some 13%, was found for giants, confirming the hypothesis that both kind of excesses are similar in origin, and pleading for the persistence of the phenomenon throughout stellar evolution.

The SWS spectra of evolved stars, especially post-AGB stars, are rich in solid-state features. A new result is that also in post-AGB shells crystalline silicates occur. A spectacular example is the dusty disk surrounding the central binary in the Red Rectangle nebula. In this environment the lifetime of the disk is much longer than that of the expanding envelopes of single objects. From an observational point of view, the Red Rectangle disk is very similar to that of young stellar objects. The observation of cometary spectra in the Red Rectangle disk suggests that the processes that lead to planet formation operate in a variety of conditions, finally suggesting that the formation of planetary systems could be the rule rather than the exception.

Post-AGB stars present a rather unique opportunity to probe the characteristics of the same dust in absorption (IUE) and in emission (ISO). Indeed, the absorption characteristics of dust have so far mainly been determined from the extinction of the light of hot distant stars by the interstellar medium, while emission properties are mostly known from the dusty envelopes of cool stars and from star-forming regions. For the objects HR4049 and HD213985 the

confrontation of IUE, optical and infrared data leads to several interesting results: a positive correlation between the steep far-UV extinction rise and the presence of small PAH-like particles occurs for HR4049, while for HD213985 a variable circumstellar 220 nm extinction bump is observed.

5. Hot pulsating stars

The photometric experiment on board Hipparcos has revealed a large number of new periodic variable stars. We have classified the B stars in the sample. The interest of this sample is that it reveals in negative the observational bias of ground-based studies: in the Hipparcos data there is no bias with respect to spectral type, and, more importantly even, the sample is much less affected by the aliasing pattern which affects ground-based data and which works against the detection of variable stars with periods of the order of a day. While only a few new short-period pulsating stars of the Beta Cephei type were detected, a large amount of periodic supergiants was found, and the known number of slowly pulsating stars (SPBs) experienced a tenfold increase.

Ground-based follow-up observations of the SPBs discovered by Hipparcos have confirmed the pulsating nature of these objects. The SPBs are of particular importance for asteroseismology, since the multiple oscillation modes in these stars are g-modes, which penetrate deeply into the stellar interior. Studying these stars should provide constraints on the internal rotation law, the internal composition gradient, and the stellar mass. We have then also scrutinized the Hipparcos data base for lower-mass g-mode pulsators (Gamma Doradus stars) and again have found more candidates than were known so far.

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D. Astronomical Observatory of the University of Ghent

1. Dusty space plasmas

We continued during the past two years our systematic investigations of wave properties in dusty space plasmas. These plasmas contain charged dust grains which are much more massive than protons and usually carry high negative charges due to preferential capture of electrons. Linear and nonlinear modes have been described by modelling the dust dynamics by a number of cold, highly negatively charged and very massive fluids, besides ordinary electrons and protons. Several low-frequency motions occur which are typical for the dust components, some of them described by standard nonlinear evolution equations such as the derivative nonlinear Schrödinger equation for parallel electromagnetic waves or the Korteweg-de Vries equation for perpendicular magnetosonic modes.

One can include equilibrium drifts and even fluctuations in the grain charges due to perturbations in the plasma potentials. The dust grains act as sources or sinks for electrons and protons, with corresponding mass and momentum losses or gains which can render several modes unstable. Possible instabilities and related effects are discussed, including their quasilinear and even nonlinear evolution.

Many of the above analyses are relevant to different kinds of astrophysical and heliospheric plasmas, especially close to comets and in planetary rings, as investigated by different space missions.

2. Electron-positron plasmas in pulsars

As a byproduct of our investigations into multispecies descriptions needed for a proper rendering of dusty plasma modes, it turned out that some of the formalisms might be applied to electron-positron plasmas which play an important role in pulsar astrophysics. On the other hand, for some of the Alfvénic modes the description had to be done all over from scratch, due to the fact that in equal-mass plasmas some cancellations occur at levels which do not crop up in ordinary plasmas. A related effect is that the different space and time scales are merged for charged constituents of opposite signs but equal masses, whereas in ordinary plasmas the scales for ions are well separated from those for the electrons, and both are equally well separated from the ones associated with the dust. Hence the need for a careful investigation *ab initio*.

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E. Astrophysical and Spectroscopical Department of the University of Mons

1. Introduction

The investigation of atomic structures has known a considerable development during the past twenty years, the new contributions arising both from theory and from experiment. The large amount of new observational material generated by different spatial missions (OSO, SMM, HST, ATMOS,...) concerns all the spectral regions extending from the X-rays up to the far infrared. Many publications have been concentrated on the UV spectral range and have been motivated by the analysis of the spectra emitted by hot stars and registered by the Hubble Space Telescope.

Our research work during the period 1996-1998 has been concentrated on the use of different experimental techniques (cathodic sputtering and laser excitation, beam-foil-laser spectroscopy, fluorescence measurements after beam-laser excitation, Fourier Transform Spectroscopy,...) and theoretical methods (SST, HFR, MCHF, MCDF,...) for providing new accurate atomic data (wavelengths, energy levels, transition probabilities, hyperfine structure constants, ...) for neutral atoms or multicharged ions of astrophysical interest. Part of our scientific activities have been devoted also to the study of peculiar and normal B - type stars.

This research has been performed in the framework of international collaborations involving different laboratories or universities: CSIRO (Australia), Edmonton (Canada), Lund (Sweden), Kitt Peak Solar Observatory (USA), ENEA - Frascati (Italy), Moscow (Russia), Meudon; Belfast, Bruxelles, Rennes, Amsterdam, London, Nashville (USA).

2. Scientific Results in the field of space astrophysics

2.1. Forbidden transitions of astrophysical interest

Energy levels and radiative transition probabilities for magnetic dipole (M1) and electric quadrupole (E2) lines have been calculated for states within the $5p^k$ and $6p^k$ ($k=1-5$) configurations up to cerium and radon respectively. The motivation for performing these calculations was provided by the recent observations, in the planetary nebula NGC 7027, of several dozens of forbidden lines of krypton, xenon and other elements belonging to rows 4, 5 and 6 in the periodic table. This work represents a considerable extension of the forbidden transitions which have been reported so far for heavy elements from either laboratory or astrophysical observations.

The iron group elements play an important role in many areas of astrophysics. Our efforts have been concentrated on the E2 and M1 transitions in order to provide new sets of transition probabilities for forbidden lines in Cr II, Fe II, Fe III, Co II, Ni I and Ni II. Such lines have been observed in many astrophysical objects like novae, peculiar stars, planetary nebulae and supernova remnants.

2.2. Emission from cobalt in type Ia supernovae

A direct diagnostic of the physical conditions in type Ia supernovae (SN Ia) can be provided by modeling their nebular spectra. Although the synthetic spectra previously published did agree very well with the supernova spectra from about 200 days to 300 days since the supernova explosion, a significant discrepancy was observed at earlier times. We have constructed a better spectral model to reproduce the early-time nebular spectra of SN Ia. With these improvements, the early-time nebular spectra of SN Ia were indeed more closely reproduced. Major forbidden emission lines of cobalt ions in SN Ia were identified and the temporal evolution of their intensities provided spectroscopic evidence for the radioactive decay of $^{56}\text{Ni} \rightarrow ^{56}\text{Co} \rightarrow ^{56}\text{Fe}$ in the supernovae.

2.3. UV transitions of interest for the study of the interstellar medium (ISM)

The study of elemental abundances of heavy elements ($Z \geq 30$) in the ISM allows the exploration of the possible effects of local chemical enrichment and mixing in the interstellar gas and also the nature of the condensation of elements from the gas phase onto dust.

Starting in the 1970s, ultraviolet studies of the interstellar medium have been realized with the Copernicus satellite launched in 1972 and afterwards with the International Ultraviolet Explorer (IUE) launched in 1978. The high resolution gratings and the high signal-to-noise capabilities of the Goddard High Resolution Spectrograph (GHRS) aboard the Hubble Space Telescope (HST) allow now the detection of very weak absorption lines. Consequently, we have undertaken an extensive theoretical investigation of oscillator strengths for UV transitions of Ge II, As II and Se II of special interest for the study of the ISM.

Weak transitions of Mg II, affected by considerable cancellation effects, are observed in the ISM. They have been investigated and our data confirm previous CIV3 results but disagree with parameters derived from recent astrophysical observations, indicating that the problem needs additional efforts to be solved.

The resonance transitions of neutral chlorine have been studied and the new intensity parameters are probably the most accurate data presently available.

2.4. Radiative transitions in singly ionized rare earth elements.

Spectroscopic data for the lanthanides are needed to address astrophysical problems such as those related to the evolution of chemically peculiar stars. Interest in this area is increasing because of new technologies (large-aperture telescopes, new spectrometers and advanced CCD detector arrays) that make it possible to record many stellar spectra with high signal-to-noise ratio and high spectral resolution. The interest of Yb II and Tm II for the study of main sequence Ap stars and the fact that new accurate measured lifetimes have been published recently have motivated a detailed investigation of radiative transitions in these ions. Using the HFR method with the inclusion of core polarization effects, we have obtained theoretical lifetimes in Yb II and Tm II which are in good agreement with the most accurate experimental values.

2.5. Determination of high-*nl* Rydberg states in He I and in carbon ions.

About 20 000 transitions of He I of the types $1snl\ ^{1,3}L - 1sn'l'\ ^{1,3}L'$ ($2 \leq n, n' \leq 50$; $l, l' \leq 7$) have been considered in the framework of the Coulomb approximation and the numerical results (wavelengths, oscillator strengths) find applications in the study of Wolf - Rayet stars.

Recently, several dozens of lines involving intermediate and relatively large (n, l) levels in the low ionization stages of very common elements such as carbon, nitrogen and oxygen were observed in the spectrum of the planetary nebula NGC 7027 between 399 and 1050 nm. More particularly, owing to the large abundance of carbon in NGC 7027, several Rydberg series of C II, C III and C IV were probably detected up to the principal quantum number $n=30$. The aim of our work has been to provide predicted term energies for values of the principal quantum number up to 30 and orbital quantum numbers $l \geq 3$ in singly, doubly and triply ionized carbon using the Ritz and polarization formulae. Several of our predicted lines coincide with many lines observed in the unpublished NGC 7027 spectrum between 400 and 654 nm.

2.6. New atomic data and the chemical composition of the sun

The SST approach, with potential parameters determined from spectroscopic configurations and semi-empirical energy adjustments (TEC) introduced for refining the model, has appeared efficient for providing new weighted oscillator strengths for the $4s-4p$ transitions of P I and for the $\Delta n \geq 2$ transitions of neutral sulphur observed in the solar spectrum. On the basis of the new atomic data, the discrepancy previously observed between the solar and the meteoritic sulphur abundances has disappeared. In the case of phosphorus, the new photospheric result ($A_p = 5.45 \pm 0.06$, in the usual logarithmic scale) is still about 32% higher than the meteoritic result.

Accurate experimental transition probabilities obtained through the use of selective laser excitation have allowed to show that, for the iron-group elements (Cr II, Mn II, Fe II) and for heavy refractory elements (Dy II), photospheric abundances agree now closely with carbonaceous chondrites of type C I. In the case of Fe II, we have been able to solve the old controversy related to a possible discrepancy between the photosphere and meteorites for that element.

2.7. Hyperfine structure data and the chemical composition of the stars

It is well established that the chemical composition of the sun (and, more generally, of the stars) can be biased, for some elements, if the hyperfine structure of the profiles is not adequately taken into account. For that purpose, we have derived new magnetic dipole hyperfine constants for a large number of transitions in Al II, Sc I and V I. The infrared spectra, produced by hollow cathodes, have been registered using the FTS technique and the high resolution Kitt Peak interferometer. They cover the near infrared region up to roughly 5 μm .

3. Atmospheres of peculiar and normal B-type stars

3.1. Higher members of the Paschen series

Hydrogen line profiles have long been considered as an efficient tool for the determination of fundamental parameters of stellar atmospheres. Early Balmer lines have been almost exclusively used for evaluating spectral types, effective temperatures and principally surface gravities of stars in the O9-A9 range. The observation of Paschen line profiles has been much rarer in these objects. Earlier members of the recently developed CCD receivers allow us nowadays to observe properly calibrated spectra of early-type stars from P11 up to P20, as well as clean spectra in the region around 1 μm where P6 and P7 are located. We have made use of spectra obtained at the "Observatoire de Haute-Provence" (OHP) to find out whether suitable diagnostic criteria may be determined from measurable features in the spectrum. Model atmospheres have been interpolated in the grid of Kurucz. Hydrogen line opacities have been computed with a semi-empirical method introduced by Edmonds, Schlüter and Wells in 1967. We have recomputed the Stark broadening functions using recent data for the electric microfield distribution and applied this theory to the Paschen lines. Finally, we computed theoretical spectra in the 840.0-877.5 nm range and around the Paschen 7 line at 1004.9 nm with the parameters found in the literature. 84 Kurucz models have been used to compute the P7 line profiles for temperatures ranging from 6 000 to 40 000 K and for gravities ranging from $\log g = 2$ to 4.5. The general shape of the results indicates a rapid increase with temperature up to a maxima ranging from 0.9 to 1.9 nm depending on the gravity; then the equivalent width of the lines slowly decreases as in the case of other hydrogen lines. The observed curves agree very well with the computed values.

The pseudo-equivalent width of the 'purely hydrogenic' P14 line, which was defined by taking the nearest highest flux points on either side of the line center, has been computed for 68 Kurucz models, with temperatures ranging from 6 000 to 30 000 K and $\log g$ ranging from 2 to 4.5. It has been found that this pseudo-equivalent width decreases with increasing gravity. This is of course an effect of the very high blending of the components of the Paschen series. We also explored the effect of high rotational velocities on the P14 pseudo-equivalent width. The effect varies with $\log g$, but remains quite modest. At $V \sin i = 300$ km/s, the equivalent width is 2 per cent lower at $\log g = 2.5$, while, at $\log g = 4$, the effect is at most 4 per cent.

3.2. Elemental abundances in the Hg-Mn star γ Corvi

It is well known that the Hg-Mn stars exhibit very different elemental abundances especially for the iron-peak elements. The abundance anomalies patterns are however quite different and we have extended this research to one of the fastest rotators in this category. γ Corvi (HD106625) is a B8 III star of visual magnitude $m_v = 2.6$ which was only recognized as a Hg-Mn star in 1971. Our study is based upon several sources which cover a large part of γ Corvi's spectrum (e.g. : IUE, ESO, TD1, OHP). The spectrum synthesis was performed in the same way as the computation of the higher members of the Paschen series (see above). The effective temperature was determined combining the Strömgren uv by color indices system and the TD1 UV fluxes. We adopted $T_{\text{eff}} = 12\,000$ K. Surface gravity has been estimated from comparison of computed and observed hydrogen line profiles. The hydrogen H δ line, convoluted with a 36 km/s rotational velocity indicates a $\log g = 3.5$ (cgs), and this value has been confirmed by the observed profiles of the higher Paschen lines.

The UV (IUE) and visible (OHP, ESO) spectra were used to determine the chemical composition of γ Corvi. The helium abundance has been derived from the best defined lines in the blue-violet part of the spectrum at 402.62 and 447.15 nm. The best agreement between observed and computed spectra has been obtained with a helium abundance 0.7 times the solar value. This indicates a slight underabundance of this element in the atmosphere of γ Corvi. In the same manner, gallium, manganese and boron are not so overabundant than in most Hg-Mn stars, while silicium, carbon and nickel are much more underabundant. Even if the general trend of the chemical abundances is common to a Hg-Mn star, γ Corvi seems to be a peculiar object in its own stellar class and this could easily explain its late membership recognition.

3.3. Study of the LBV candidate MWC314

MWC314 (BD+14°3887) was discovered in 1927 by Merrill, who found hydrogen and Fe II emissions in its spectrum. Recently Miroshnichenko reported results of a new photometric and spectroscopic study of this object. He found that the object is variable in all photometric bands with a mean amplitude of 0.3 magnitude and detected no photospheric absorption lines. We have analyzed several high resolution observations made at the Observatoire de Haute Provence and at the Observatory of the Russian Academy of Sciences. These new data, obtained in a spectral range from 420.0 to 893.6 nm, allowed us to constrain the fundamental parameters of MWC314. Most of the spectral lines are in emission (H I, He II, Fe II, Ti II, ...). However, we have observed for the first time photospheric lines. From these lines, we derived a B3 spectral type for the star.

Several forbidden Fe II lines were also detected. An unusual chemical composition deduced from the absorption lines suggests a N/O overabundance which is similar to that observed in several LBV stars. The luminosity of the star was estimated to $\log(L/L_{\text{sun}}) = 6.1$ and showed us that MWC314 is an early B-type hypergiant close to the Eddington limit. The double-peaked shapes and the absence of the blue-shifted absorption components in most of the emission lines imply a non-spherical geometry of the stellar wind. As Miroshnichenko pointed it out, MWC314 could be the second LBV in the Northern Hemisphere, after P Cygni.

3.4. Present and future work

At the present time, we are modelling the surrounding envelope of MWC314. Even if the hydrogen and Fe II lines are mostly observed as double-peaked features, the helium lines are single peaked and have a weak blue shifted P-Cygni type absorption. Our future work will be a continuation of this modelling using the photospheric and Fe II spectrum we observed. We deduce also fundamental parameters for several Be stars observed with the Hipparcos satellite using several observation sources and we consider the effect of rotation on their visible and UV fluxes.

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III. Space Geodesy

A. Royal Observatory of Belgium

1. Introduction

The Royal Observatory of Belgium (ROB) has a long tradition of astronomical and geodetic international campaigns. The ROB participated to the BIH observations for time and latitude determinations and to the first European geodetic network (WEST) developed for satellite observations from 1966 to 1971. A TRANET station was operating on the same site from 1972 to October 1993.

2. The Permanent GPS Network of the ROB

The Royal Observatory of Belgium operated between 1994 and 1997 four permanent GPS stations in Belgium. All these stations are included in international permanent observation networks (IGS and EUREF).

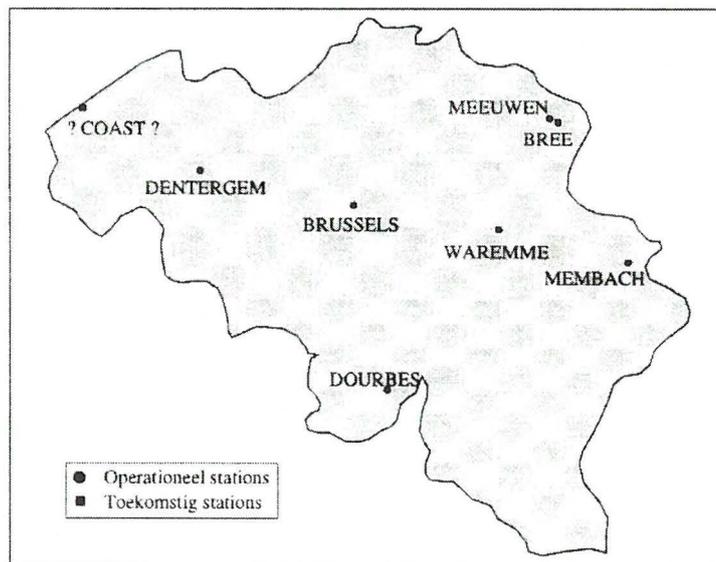


Figure 1 : The permanent GPS network of the ROB

The installation of three additional stations was done in 1997 (see Fig. 1). Two of them (Bree and Meeuwen) monitor ground deformations in the vicinity of Bree. Northern Europe is usually considered as a region where the seismic hazard is low. Nevertheless, after the occurrence of a $M_s = 5.3$ earthquake on April 13 1992 at Roermond (The Netherlands), fundamental questions concerning the seismotectonic activity in this region are being asked. For this reason, the Royal Observatory of Belgium recently began a research program aiming to study active faults in Belgium. Paleoseismic investigations realized in 1996 along a 10 km

long fault scarp near Bree indicate the occurrence of three earthquakes having produced coseismic surface faulting during the last 14000 years. The precise measurement of relative displacements across this fault would be an important contribution to a better understanding of the mechanical behaviour of the fault zone. Another station (Membach) is collocated with a superconducting gravimeter to compare changes in the station height observed by two independent instruments.

All stations are equipped with TurboRogue receivers and Dorne Margolin T antennas. The data of these stations is freely available on the Internet (URL=<http://www.oma.be/KSB-ORB/D1/GPS/main.html>).

3. EUREF Permanent Network Central Bureau

The IAG Subcommittee for the European Reference Frame (EUREF) is responsible for the maintenance and promotion of a three-dimensional reference frame for Europe. Taking into account the growing number of permanent GPS networks in Europe, the EUREF subcommittee decided in 1995 to coordinate the activities related to these local networks for the maintenance of the European Reference Frame.

The EUREF permanent GPS network presently consists of near 60 GPS stations, covering 21 countries all over Europe. The data from these stations are made available at seven local data centers and one regional data center. The processing scheme for the EUREF Permanent Network allows for distributed processing. Ten Local Analysis Centers each analyze a part of the EUREF network (voluntary contributions based on local interest) and forward the resulting free-network solutions to the International GPS Service.

The EUREF permanent network coordination is performed at the Royal Observatory of Belgium : a fully documented information system (including descriptions of the permanent GPS stations, Local Data Centres, Local Analysis Centres and their subnetworks) is operational and maintained. The consistency between the headers of the RINEX data files and the station description files in the database are weekly checked and station responsables are contacted if necessary.

The product availability is monitored and reports on the combined EUREF solution are made available as feedback to the contributing analysis centers.

4. Ongoing Research

The measurements collected in the Belgian permanent GPS network are also used for the following studies :

- **Ionosphere monitoring :**

A Ph. D. Thesis dedicated to the study of the ionospheric refraction influence on GPS signals has been prepared at ROB. The ionospheric refraction is one of the main factors limiting the precision achievable in relative positioning using GPS. The ionospheric error depends on two parameters: the Total Electron Content (TEC) and its gradients in space. In 1996, a new solar cycle has begun. In the next years, the solar activity is going to increase giving rise to a stronger ionospheric activity. Therefore, a methodology has been developed in order to compute the TEC and its irregular gradients in space. This method allowed to study the TEC behaviour above Brussels over a period of 8 year. In addition, an automatic detection of irregular ionospheric phenomena such as Travelling Ionospheric Disturbances (TIDs) and scintillation effects has been performed. These perturbations cause sudden fluctuations in the TEC that can give rise to large errors even on distances as short as 10 km.

- **Study of the effect of atmospheric pressure loading on GPS coordinates :**

Atmospheric pressure loading is the influence of the irregular and time varying distribution of the atmospheric pressure at the surface of the Earth on the coordinates of a station. This influence is mainly noticeable in the height component where it can reach a few centimeters. A four year project dedicated to this study was initiated in 1996.

- **GPS data quality analysis :**

Considering a future evolution towards real-time or near real-time applications, with high data rate, extensive tests are conducted on 1 s data output by the TurboRogue receivers. This research is conducted in the field of multipath mitigation and amelioration of the data quality when Anti-Spoofing is on. Together with the data analysis, new designs have been devised to store, transmit and distribute the larger amount of data expected for the future.

- **Contribution to EUREF Processing :**

In addition to the EUREF network coordination, the ROB is one of the EUREF analysis centers. The daily EUREF processing started at the ROB in January 1996 and includes all present and future EUREF and IGS stations in Belgium, Great-Britain, France and the Netherlands. Presently a subnetwork of 16 stations is processed daily. The internal consistency of the ROB solution is checked by comparison of the daily solutions and demonstrates 1 to 2 mm repeatability for the North and East components and 5 mm for the up-component.

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B. Royal Military Academy

In the framework of a project co-sponsored by the "Fonds voor Wetenschappelijk Onderzoek - VLAANDEREN" and the "Fonds National de la Recherche Scientifique", the Royal Military Academy (RMA) and the Royal Observatory of BELGIUM (ROB) perform co-research towards "The Development of a Differential Global Positioning System (DGPS) network in BELGIUM for Geophysical and Geodetic Applications and for the Navigation. At the start of this project in 1996, the GPS network of the ROB was equipped with Turbo Rogue dual frequency GPS receivers connected to a PC, running Ms-DOS. The GPS receivers log their measurements at a 30 s interval onto a memory flash card. Each day at midnight, the local PC downloads these data over a serial connection and sends them using a classical telephone/modem connected to a central processing facility situated at UCCLE. This data-transfer is sequentially initiated by the central controlling PC of UCCLE.

The research project affects all parts of the existing GPS network of the ROB :

1. At the reference station the frequency of the measurements is to be augmented to 1 Hz and a quality control should be performed in near real-time mode ;
2. The transfer interval of the data should be freely selectable between a near real-time transmission, over an hourly transfer down to one transfer each day ;
3. The central processing facility should be able to process simultaneously all reference stations.

The opportunities of such a restructuring of the GPS network should allow the modelisation of precise GPS satellite orbits, of tropospheric and ionospheric effects, permit a near real-time monitoring of the reference stations and allow users of these data to get more rapid and more frequent update of the measurements.

A study of the different transmission media (classical telephone/modem, ISDN and Internet) demonstrated that the Internet solution offers the best economic solution and permits the largest range of transfer rates. The team also decided that Ms-DOS has no longer the potential for supporting future developments and an analysis of new Operating Systems (OS) was performed. Finally LINUX was selected as the targeting platform for future developments due to :

1. the firm integration of the Internet Protocol (local and remote Inter Process Communication IPC) in its kernel ;
2. its multi-processing and multi-user capabilities ;
3. its flexible structure permitting it to run in a graphics or non-graphics mode. In this last mode it is possible to use LINUX on low-end or 486 based PCs.

At present, tests demonstrate the possibility to download the GPS measurements at a 1~Hz interval on both an Ashtech Z-XII and a Turbo-Rogue receiver. Since both institutes operate different GPS receivers a common measurement format was developed allowing to store the data in a more compact form permitting a direct access to each individual measurement. For transfer, this format is compressed based on the internal dependencies of the GPS data. More details about the permanent GPS network of the ROB can be found in Chap. III, A.

IV. Material Sciences

A. Microgravity Research Center of the "Université Libre de Bruxelles"

1. Experiments under microgravity conditions

1.1. Marangoni Convection in a Three-Layer System – BDPU - LMS Mission

Following the Spacelab IML 2 mission in 1994, the Microgravity Research Center (MRC) supported by a Prodex programme, performed the experiment "Oscillatory Marangoni Convection in a Three Layers System". That experiment has been implemented in the Bubble Drop and Particle Unit (BDPU) facility during the Life and Microgravity Sciences mission of the NASA space shuttle (1996). The mission debriefing was held in August 1997. Analysis of the experimental data for that multilayer convection experiment were as follow :

a) Lateral gradient : The numerical simulation code has been modified in order to include variable viscosity and computation on a non-uniform mesh. The analysis for this experiment is almost completed. Excellent quantitative and qualitative agreement between numerical and experimental data is found.

b) Vertical gradient : Efforts have been spent to model oscillatory convection in a symmetrical three-layer system that was observed experimentally. Although, a good agreement between numerical and experimental oscillation frequencies has been found, the critical Marangoni number for the onset of convection differs strongly. The reason for discrepancy is under investigation; it may be due to a slight pollution of the interface or to the confinement effect in the third dimension that can not be modelled up to now.

Moreover, the transition from regular oscillation to chaotic oscillation is not understood yet. Extensive simulations with varying lateral boundary conditions (free-rigid, insulating-conducting) and different aspects are still needed to fully understand this dynamical system.

1.2. Bifurcation Anomalies in Marangoni-Bénard Instabilities – Fluidpac - Foton retrievable capsule

The MRC is preparing, in the frame of the Prodex Programme, the experiment "Bifurcation Anomalies in Marangoni-Bénard Instabilities" (BAMBI) which will be implemented in the Fluidpac Facility during a Foton Russian capsule flight foreseen in 1999.

The ground preparation of the experiment is pursued both theoretically and experimentally. Theoretically, emphasis has been put on the accurate determination of the critical point (two-layer oil-helium analysis) and of the hysteresis amplitude, together with the prediction of the thermal behaviour of the experimental cell. The ground model of the cell has been tested for

helium leak-tightness during the time of the experiment (4 days). Moreover, thermal tests have been conducted on the breadboard model of the cell, using thermocouples and Pt100's, as well as the infrared camera. As some telescience possibility is currently developed by ESA, strategies have been elaborated to optimise the experimental run. The choice of parameters to be down-linked/up-linked is currently under study.

1.3. Diffusion Coefficient in Crude Oil— NASA GAS Container

The purpose of the "Diffusion Coefficient in Crude Oil" (DCCO) experiment that will be performed in June 1998 in collaboration with C-CORE (University of Newfoundland, Canada), is to measure accurately the diffusion coefficients of ternary systems in microgravity conditions. Funded by a Prodex support, the experiment will be implemented in a GAS container of the space shuttle. As the accuracy has to be very high, diffusion coefficients evaluations will result from measurements of the refractive index of the diffusing liquids with an interferometric technique. Due to the fact that ternary mixtures are studied, a bicolour interferometer has to be used. An interferometric design has been established in order to reduce the influence of temperature changes in the liquids. In order to reduce the sensitivity to the mechanical disturbances, it has been necessary to design a new configuration of the Mach Zehnder interferometer.

The mechanical concept and design has been studied and manufactured by PEDEO Techniek.

Diffusion in multicomponent systems is not well understood because too many approximations are assumed. The scientific work linked to the DCCO experiment is very fundamental. The developed studies analyse the approximations as diluted solutions, Onsager reciprocity relations, linear approximation of non-equilibrium thermodynamics.

The final integration of the DCCO instrument in a GAS container has been completed by C-CORE. 1997 was thus the final phase of realisation and preparation of this microgravity experiment. Tests on the different subsystems and cell filling have been performed with ternary solutions of different concentrations. The experiment is now ready to fly. After the flight, results will be extracted with the help of image processing techniques. The fringe images will be studied with the help of the Fourier transformation method to establish the concentration of the liquids in contact as a function of time.

1.4. Jet Growth Motions in Aerosols – MASER 8 Sounding Rocket

The Prodex programme supports the Jet Growth Motion in Aerosols experiment, which will be implemented in the Maser 8 sounding rocket. The flight is presently foreseen for spring 99. That study is devoted to the investigation of jet motions of particles in non equilibrium aerosols and the determination of the properties of the particles motions in aerosols in presence of surface physico-chemical processes. Based on the results of this microgravity experiment, recommendations will be formulated for taking into account the jet motions in on-earth aerosols during industrial processes, models of matter formation in the Universe and space experiments dealing with non-equilibrium aerosols.

The MRC has formulated and verified the requirements for the aerosols parameters, flight hardware, flight procedure, telecommunication exchange, ground support equipment and flight data analysis in real time, in collaboration with the Swedish Space Corporation.

1.5. Prodex Telescience on LMS and Foton - ESA

The MRC is supported to initiate a new kind of interaction between the on-earth investigators and the in-space experiment by remote science operation or "Telescience". Operation support for the LMS mission was a success and we are now studying the development of the telescience concept for our Jet Growth Motions and BAMBI experiments.

1.6. Capillary creeping in modelized porous media – Parabolic flights.

Immiscible displacement of one liquid by another in a porous medium is a complex process governed mainly by buoyancy and capillary forces. Capillary effects are partly shielded by gravity effects in ground based experiments. Accurate investigation of wettability effects in filtration processes requires elimination of disturbing effects. During the 24th ESA parabolic flights campaign the MRC investigated the influence of porosity and permeability gradients in one-phase and two-phases flows cases. Reliable experimental results will provide the possibility to complete the mathematical formulation of the problem taken into account the role of capillary forces.

2. Theoretical work to prepare future experiments

2.1. Marangoni-Bénard Instabilities in solutions with Soret effect (MBIS)

This is a proposed microgravity experiment studying the convective instabilities originated in the Bénard configuration by the variations of surface tension of solutions presenting Soret effect. The realisation of such an experiment in microgravity is the continuation of the experimental work performed to understand Marangoni-Bénard instabilities that have been evidenced at the present time only in presence of one diffusing agent. The presence of a second diffusing agent gives rise to very specific hydrodynamic regimes that MBIS aims to evidence.

The experimental tools required for this have all been tested, but different developments are still to be performed to reach space standards. Phenomena as capillary waves, non-linear Soret effect, adsorption, evaporation are analysed simultaneously.

This activity is performed in the frame of an ESA Topical Team on double diffusive instabilities coordinated by the MRC.

2.2. Studies in metallic melts

Pursuing the collaboration with the "Commissariat à l'Énergie Atomique" (CEA - Grenoble), results concerning a set of microgravity experiments has led to understand in a precise manner how thermosolutal convection in capillaries can be modelled.

Isotopic separation in liquids has been quantified precisely for the first time. Thanks to this and to other measurements performed in alloys, it has been possible to test kinetic theory of

dense gases and quantum theories of transport. The molecular interaction parameters could be determined with such an accuracy that improvement to theories could be proposed.

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B. Department of Metallurgy and Materials Engineering of the "Katholieke Universiteit Leuven"

1. Metal matrix components

1.1. In-Situ composites

Generally the processing of metal matrix composites can be split into liquid state (casting) or solid state (powder metallurgy) processing. Casting is the preferred processing route, because of the low cost, the almost unlimited freedom in design and the suitability for continuous processing. However, problems like heterogeneous particle distribution and bad matrix-particle interfaces can not be neglected. The advantages of the in-situ system are the strong mechanical bond between the particles and the matrix, a reduction in the particle size of the reinforcement and the low production cost. The validation of models describing the system behaviour is investigated with the help of our experiments.

On a commercial base a mixture of salts K_2TiF_6 and KBF_4 is added to an Al-liquid and will result in an Al matrix composite with TiB_2 particles. To get a more fundamental understanding of the process we study specific objectives in space as well on earth. Two samples, one with boron and one with titanium, are joined by friction welding to form one sample. When this sample is molten above $800^\circ C$ and Ti and B will form TiB_2 . On earth the diffusion process and also the final distribution of the particles in the matrix is mainly influenced by gravity. During the Spacehab (STS95) flight in October 1998, four of these special samples will be resolidified, each with a different maximum temperature and with a different cooling rate. The pre-actions are already executed in the last year and everything is ready for the flight experiment. The samples, containing 1 at % B and 0.5 at % Ti or 2 at % B and 1 at % Ti, resolidified on earth show a full reaction at the friction welded interface above $900^\circ C$. This interface settles in the direction of the gravitation, resulting in a very heterogeneous distribution of the TiB_2 particles. Other experiments with a higher concentration of Ti and B did not result in a full reaction, even above $1100^\circ C$: a zone reacted TiB_2 particles hinders further contact between the dissolved boron and titanium.

1.2. Solidification aspects of metal matrix components

To obtain a homogeneous composite material especially a good control of the solidification process is necessary. The sedimentation of the particles, the interaction of the particles with the solid/liquid interface, agglomeration, convection and the morphology of solidification influence the solidification process.

A model material system, Al- TiB_2 , was selected for the EuroMIR94 experiment at the space station MIR. Due to technical defects, this experiment could only be performed in January 1996. Al with 1.9 vol. % TiB_2 and 1.6 vol. % Al_3Ti (Sample 380_21) is nearly completely molten and resolidified in the CSK1 in MIR. The Al_3Ti particles are uniformly distributed over the sample and the TiB_2 particles are arranged at the grain boundaries in a skeletal structure. The settling of the TiB_2 particles in the ground reference sample results in a two third particles free zone of the molten part and a similar settlement of the Al_3Ti particles. Al

with 10 vol. % TiB_2 (Sample 380_22) shows a sharp distinction between the unmolten particles aligned according the extrusion direction- and molten part-particles as well inter-as intragranular forming a network. The zone in between is particle free, but in the rest the distribution is homogeneous. The ground experiments resulted in a 4% particle free zone of the molten part due to settling, and no clear "mushy" zone.

For EuroMIR95 the material Duralcan (Al-Si matrix with SiC particles) was selected because of his suitability for studying the effect of gravity and convection, since the particles sink and show explicit segregation behaviour. Besides gravity, the influence of different cooling rates and temperature gradients was investigated. In the EuroMIR 95 mission, four Al-SiC were (partially) molten and resolidified under different thermal conditions. In comparison with ground experiments, in which 50% of the molten zone is particle free, the segregation in the space processed samples clearly differs. The space processed samples give a rather homogeneous distribution of the particles in the matrix, only the last solidified part contains a higher volume fraction. This occurs especially in the sample with the high gradient and slow cooling rate, in which the volume fraction of particles is less just above the unmolten part. For samples with a low gradient the agglomeration is limited, but more pronounced in comparison with the starting material. A high gradient gives an increase of clusters from the cold to the hot side. The agglomeration degree was assessed by a quantitative image analyser.

The dedicated ASPF furnace is put into use since the end of 1995 and works very well. The maximum gradient is 170 K/cm, which is more than requested (100 K/cm). Especially experiments with the two systems used in EuroMIR 94 and 95 are executed, but also an Al-matrix with 1.9 vol. % TiB_2 and 5.8 vol. % TiAl_3 was investigated.

For detection of the location and morphology of the solid/liquid interface, the measurement by the thermocouples is completed by a new ultrasonic technique. The first tests gave a promising result. The transducer is put at the bottom of the sample (diameter 8 mm, length 25 cm) and 8 thermocouples at different heights check the temperatures. The experiments were executed on a sample of pure aluminium with 3 different transducers (5 MHz, 2.25 MHz and 600 KHz).

1.3. Modelling

Two simulation programs for prediction of the solidification of a material were applied; the Calcomon program (previously 3-MOS) from Calcom (Lausanne) and the Simtec simulation from RWP (Aachen). Both work in three dimensions and with the finite element method. Another model that takes into account the different phenomena during casting of MMC, like agglomeration and sedimentation, was developed in our department. This model has to be checked by the results of the samples resolidified in MIR and the experimental results of samples executed on earth. In a later stage one of the finite element programs will be combined with the model for metal matrix composites, to predict the finite microstructure and distribution of particles in a complex shape of a MMC.

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V. Life Sciences

A. Biomedical Physics Laboratory of the “Université Libre de Bruxelles”

1. Spacelab mission SLS-2

1.1 Gas diffusion

The experiments of mission SLS-2 extended those initiated on mission SLS-1. We performed multiple-breath helium and sulfur hexafluoride washout tests in 4 subjects exposed to 14 days of microgravity (μG) during the Spacelab flight SLS-2. Measurements were also made with the subjects standing and supine in 1G. Ventilatory inhomogeneities persist in μG and are located between units that are sufficient close that diffusion of He, but not N_2 or SF_6 is an efficient means of abolishing the concentrations gradients it produces. Thus non-gravitational inhomogeneities must exist between acini or groups of a few acini and this is the first known example where a scale has been applied to its identification (Prisk et al., 1998).

1.2 Ventilation-perfusion distribution

We studied the phase relationships of cardiogenic oscillations of He- SF_6 single-breath washouts in 1G and μG . For He and N_2 no change is observed between 1G and μG . In contrast; CO_2 reversed phase with He, suggesting that in μG , areas of high ventilation are associated with high ventilation-perfusion ratio (Lauzon et al., 1998). This may explain previous measurements of an overall unaltered range of ventilation-perfusion ratio in μG , despite more homogeneous distributions of both ventilation and perfusion.

2. Spacelab mission D-2

2.1 Specific ventilation

We studied the contribution of inter and intraregional inhomogeneity of specific ventilation or ventilation per unit of lung volume ($\Delta\text{V}/\text{VO}$) from the rebreathing inert gas trace in μG and on ground. The rebreathing maneuver consisted of eight reinspirations from a bag filled with 1.8 to 2.2L of test gas mixtures containing approximately 5% argon. The rate of argon equilibration in the rebreathing bag was quantified by determining the logarithm of the actual minus equilibrated argon concentration. The comparison between 1G and μG curves shows that gravity-independent $\Delta\text{V}/\text{VO}$ inhomogeneity is at least as large as gravity-dependent $\Delta\text{V}/\text{VO}$ inhomogeneity (Verbanck et al., 1996), which contradicts current views on the subject.

2.2 Pulmonary tissue volume

Pulmonary tissue volume (V_{ti}) was measured for the first time in space. Capillary blood flow and diffusing capacity were also measured in four subjects before, during and after 10 days of exposure to μG . Measurements were made by rebreathing a gas mixture containing small amounts of acetylene, carbon monoxide and argon. Measurements made early in flight in two subjects showed no change in V_{ti} despite large increases in the stroke volume (40%) and diffusing capacity (13%), consistent with increased pulmonary capillary blood volume. Late in-flight measurements in four subjects showed a 25% reduction in V_{ti} compared to preflight controls. These findings suggest that interstitial pulmonary edema does not result from exposure to μG (Verbanck et al., 1997a).

3. Mission Euromir-95

We assessed the effects of sustained μG on chest wall mechanics in two subjects before, during, and after the 180-day Euromir-95 mission. We measured flow and pressure at the mouth, and rib cage and abdominal volumes during resting breathing and during a passive expiration with the muscles relaxed. μG produces marked and consistent changes in the contribution of the abdomen to tidal volume, but no evolution was observed during the mission. When pooled together with three subjects of mission D-2, the abdominal contribution to tidal breathing increased from 31% at 1G to 58% in μG . In the two subjects of the Mir mission, the same variable was greater on postflight day 1 than on subsequent postflight days or preflight. The relaxation curves have shown that abdominal compliance increases in space, contrary to rib cage compliance, which does not change. These changes are similar to those observed on D-2 mission and during parabolic flights (Wantier et al., 1998).

4. Parabolic flights

4.1 Distribution of ventilation

During mission SLS-2, the single-breath washouts with He-SF₆ gave a very unexpected result, as the alveolar separation of these gases, expected to be gravity independent, disappeared in μG . The same protocol was repeated during parabolic flights with opposite results: the He-SF₆ separation increased. Changes in pulmonary blood volume distribution or cardiogenic mixing may explain the differences between the results found in short-term and sustained μG (Lauzon et al., 1997).

4.2 Aerosol deposition

Intrapulmonary deposition of 0.5 to 3 μm diameter particles was measured in four subjects on ground and both in μG and 1.6 G. Deposition was a nearly linear function of G level for 2 and 3 μm diameter particles, whereas for 0.5 and 1 μm particles, deposition increased less between μG and 1 G than between 1 G and 1.6 G. The higher deposition observed in μG compared with model predictions might be explained by a large deposition by diffusion, because of a higher alveolar concentration of aerosol in μG and to the non-reversibility of the flow, causing additional mixing of the aerosols (Darquenne et al., 1997b).

5. Ground based studies

5.1 Animal experiments

We have pursued respiratory experiments in rats, where the effect of gravity in the lung is negligible (Rubio et al., 1998). Multiple-breath washouts were performed for the first time in steers and the analogies observed with rat experiments suggests that the different observations in man may be related to the orientation of the lung in respect to the gravity field and not to its dimension (Rollin et al., 1996).

5.2 Measurements of the human diaphragm shape in vivo

The interpretation of our experiments in μG requires the knowledge of the shape of the diaphragm in vivo. We have performed a detailed analysis using spiral computed tomography, both in healthy subjects (Pettiaux et al., 1997) and in patients with chronic obstructive disease (Cassart et al., 1997).

5.3 Chest wall motion

Chest wall motion, during tidal breathing at a millimetrical scale, was measured in normal subjects from thirty-six markers positioned on the skin (De Groote et al., 1997).

5.4 Aerosol bolus studies

In view of future experiments where aerosol bolus experiments will be studied in μG , results of ground experiments were compared with model simulations (Darquenne et al., 1997).

5.5 Clinical applications

The experience gained from space experiments was applied on studies of ventilation distribution during histamine provocation in 20 asymptomatic nonsmoking subjects (Verbanck et al., 1997).

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VI. Remote Sensing

A. Laboratory for Geological Remote Sensing and Information Management of the Royal Museum for Central Africa

1. Detection and modelling of the injection and dispersion of volcanic ash plumes into the atmosphere using digital satellite data

This project is devoted to study the explosive activity of volcanoes that occurred during the last decade via satellite data. The main goals are: (1) to perform multispectral processing of satellite image data in order to detect and track volcanic ash clouds and (2) to describe and model the ascending and spreading dynamics of volcanic eruption clouds in the atmosphere. Only about 60 volcanoes are in eruption each year and among them, 3 to 4 are sufficiently explosive to inject ash and volcanic gases into the stratosphere. The global atmospheric impact of these explosive eruptions is not well known but has been observed in the case of the Tambora (Indonesia, 1815), El Chichon (Mexico, 1982), Mt St Helens (USA, 1982) Galunggung (Indonesia, 1983), Pinatubo (Philippines, 1991) eruptions and some others.

The atmospheric discharge of ash during volcanic eruptions is a significant hazard for civil air transport. Microscopic shards of silicate volcanic glass are highly abrasive causing severe damages to aircraft exterior surfaces and windshield, their melting properties (800-1200C) are also responsible of several engine failures. Because airborne radar aboard aircraft are unable to detect a dispersed volcanic ash cloud, numerous encounters of aircraft with volcanic plume have occurred during the past decade. These incidents were sometimes serious, as in Indonesia in 1982 when two Boeing 747s flying through the eruptive plume of Galunggung volcano at 11km altitude suffered engine failure resulting in emergency landings or in Alaska (Redoubt) in 1990.

Some of the recent volcanic eruptions (Agung, 1963; El Chichon, 1982 and Pinatubo, 1991) have also injected huge volumes (5-20MT) of SO₂ gas at high altitude. In the cold, oxidizing environment of the lower stratosphere, this SO₂ is converted into sulfuric acid droplets that remain suspended long after the larger silicate particles have settled down from the cloud. These long-lived stratospheric clouds of sulphate aerosols can affect global climate. These volcanic clouds can also trigger heterogeneous chemical reactions leading to stratospheric ozone depletion.

In the first step, we are interested in studying the latest large explosive eruptions of the Pinatubo (Philippines, June 1991), Hudson (Chile, August 1991) and Kamchatka volcanoes. We process existing satellite data, radio-sounding profiles and field data in order to model the behaviour of these volcanoes and their plumes. We use meteorological satellite data in both visible and infrared wavebands and enhanced detection techniques to analyse and monitor the subsequent ash clouds for any part of the earth. Imagery from the geostationary meteorological satellites, providing global coverage between latitudes 60N and 60S using visible and thermal infrared sensors (GOES, USA; GMS, Japan; Meteosat, Europe), is acquired approximatively

every hours in both the visible and thermal infrared bands at a maximum resolution of 8km. They provide information necessary to track the horizontal dispersion and long distance transport of volcanic plume.

The polar-orbiting meteorological satellites (NOAA satellite with AVHRR instrument) with visible and infrared sensors provide two daily global coverage of all volcanic areas. Measurements of infrared emission in the 10-12 μm window can be used to detect volcanic clouds during an eruption and in the days and weeks following it. Their signature can be recognized by multispectral image processing of the T4-T5 temperature differences and it is possible to use this as an operational tool to assist in the forecast of volcanic cloud hazards. Principal component analysis of the measurements (radiance in the visible, temperature in the thermal infrared) allows to calculate a 'volcanic component' discriminating among atmospheric and non-atmospheric components. The dynamics of a series of recent eruptions has thus be assessed.

Multispectral image processing of satellite data can be completed with field observations and conventional radiosounding data to determine the altitude of a volcanic eruption, the size, speed and position of the ash cloud and the direction the ash is spreading. The height of the ash cloud's top can be estimated from the temperature at the profile surface of the ash cloud and the air temperature around the volcano. The different plume isotherms are related to the vertical and horizontal plume morphologies. The duration of the discharge of gas and ash into the atmosphere for individual eruptions can be estimated from the length of seismic eruption noise recorded in the seismic station nearby the volcanoes combined with the satellite image observations. Using plume top heights on the infrared satellite image it is possible to calculate the thermal energy released necessary to drive an eruption plume to this altitude and the intensity of the eruption in a given atmosphere. Finally, the mass of injected particles in the plume can be calculated from the thermal energy released and the particles size distribution. A rough estimate of the minimum mass concentration of particule material contained in that eruption cloud can be made assuming that the particulate material consisted entirely of ash with no liquid or solid hydrometeors.

This study is supported by a FRFC and a FRIA grant.

2. Radar interferometry as support to geological applications: study of recent and present-day crust movements in the East-African Rift; the Rukwa rift (Tanzania)

SAR interferometry in its space application is a technique that makes use of two radar images of the same area obtained from two successive passes or by two satellites on the same orbit. However small, the difference between the two orbital positions (the interferometric base) at the time of image acquisition implies a difference in path and, consequently, a difference in phase. Knowing the horizontal and vertical components of the interferometric base it is possible to interpret the interferogram, i.e. the image of the phase difference, and obtain a measure of the topography of the targeted area. As satellite altitude, its distance to the target and the looking angle are rather constant parameters (the wavelength being strictly constant), it is mainly the interferometric base that rules the precision of the method. The base must

however remain within a limited range otherwise the geometric conditions and the coherence (degree of similitude) would be lost.

In the interferogram, each fringe corresponds to a change in altitude going along with an angular phase change of 2π . The 'unwrapping' of the phase, i.e. the addition at each point of the interferogram of an appropriate multiplier of 2π to the value of the phase difference, allows to generate a digital model of the terrain. The superposition of several interferograms of the same area allows, in particular cases, to evidence changes that may have occurred in the imaged surface. In the field of neotectonics, it is possible to identify the effect of a seism and to quantify the displacement with a millimetric precision. This particular technique is known as differential interferometry.

The region situated south-east of lake Rukwa (Tanzania) is the first to have been thoroughly studied among our study areas. A first field mission, performed while the imagery was acquired in 1995, allowed to recognise areas in the images where differences could be due to atmospheric perturbancies. A second trip in the field, in 1996, has been devoted to the verification on the ground, with the aid of a theodolite, of a series of topographic profiles. The results are now being processed; we hope to be able to assess both the sensitivity and the precision of the interferometric method.

3. Geological Applications of Remote Sensing and Database Management Program (GARS-DBM)

This program, realized on behalf of UNESCO, aims at :

- training teams of specialists in the management of geological databases in Ethiopia, Uganda, Tanzania, Zambia, Botswana, Swaziland;
- the installation of data processing equipment and software in these countries;
- the follow-up of scientific activities.

4. Setup of a Geographic Information System (GIS) and image processing station, and scientific collaboration with the laboratory of remote sensing of the United Institute for Geology, Geophysics and Mineralogy, Russian Academy of Sciences, Siberian Branch, Novosibirsk

This activity is an aspect of the collaboration between the Royal Museum for Central Africa (RMCA) and the Russian Academy of Sciences (RAS) in the frame of the INTAS program, in the domain of GIS and Remote Sensing applications for the study of continental basins (here Chuya-Kurai and Teletskoye). The collaboration started already in January -February 1995 with the presence of .N. Dobretsov and A.A. Milosnov at the Laboratory of Remote Sensing of the RMCA. The GIS Center is now partly equiped and its development is going on. All the required capabilities will be met in a close future for input (scanner, digitizing tablets), processing (PCI, Arc Info, Idrisi and specific software developed at the Center) and output (colour and B/W printers).

The present work includes:

- Preparation of additional remote sensing. material for the field work of 1995
 - scanning of 3 aerial photographs (Chuya-Kurai)
 - extraction of 2 SPOT sub scene (metamorphic): Sofiysky glacier area and Bougouzour (from SPOT original CD ROMs)
- Image processing of SPOT subscenes
 - geometric correction and map projection UTM 45 U E012
 - principal component analysis
 - printing laser IV+ B/W 600 dpi, scales 1/100 000 and 1/50 000
- Coregistration SPOT-Air photos (image tie-down), production of mixed images: SPOT colours, high spatial resolution of the air photo (direct and inverse IHS transform).
- Printing of B/W scanned air-photos for the field geomorphology and neotectonics by I.Novikov (scales 1/35 000 and 1/5 000).
- Explanation/ visit/ demos of the GIS centre, by N.N. Dobretsov and team: Igor Zabadayev, Alexei Khorev, Sergei Krivanov, Slava Dementev and Ivan Zalnikov Geomorphology and image processing, Southern region of Lake Teletskoye.
- Processing of an air photo of Kurai depression (lake shores, glacier, giant ripples) and integration of 3D:

In the present form of the INTAS program, the different approaches are still separated. Individual data sets (original observations or results of interpretation) can be combined using the GIS tool in the following domains: Remote sensing, Geomorphology, Neotectonics, Quaternary geology (glacial,...), Geophysics, Metamorphism /inheritance.

The building up of a full data base of raw (original) data can be too heavy to achieve in a relatively short time. For this reason, it is suggested to introduce thematic data in an already elaborated form (e.g. structural trends and stress rather than basic observations). It was decided to test the full GIS approach in the Chuya basin, when the available data is the more complete. Other complementary works can be achieved on local topics in two main directions: support to other teams (e.g. production of 3D models, integration of R.S. images) and specific applications of image processing for geomorphology (classifications, spatial filtering, integration satellite/air photos).

For the main application on the Chuya depression, the basic cartographic support should be a 3 D map at the scale 1/50 000 obtained by digitizing the topographic maps at the scale 1/25 000. Differing from the "casual" 3D models used in local applications (now the area of lake Teletskoye), a high cartographic accuracy has to be reached, on the basis of ground control points, and a cartographic projection system has to be chosen (UTM or Gauss Kruger). The GIS center of the United Institute of Geology, Geophysics and Mineralogy will be in charge digitizing the 3D basemap. During and after this work, the factual data will be gathered and formatted at RMAC and GIS Center, in order to be archived in thematic layers of the GIS model. The thematic results can be elaborated according to "natural groups" taking into account the complementarity of approaches, e.g. :

- geometry of basin formation including stratigraphy, paleomagnetism, kinematic model, geomorphology
- dynamic aspects including stress field, neotectonics
- inheritance aspects, general geology, metamorphism,...

5. Mapping surface rocks in Morocco

The presence of calcrete at low depth limits the agricultural development of the Sahel des Doukkala, situated at the South-East of the city of El Jadida. The planification of the mechanical dislocation and the removal of the duricrust of a zone as large as 100,000 hectares requires a specific mapping of the crusts and of the stony component of the soil surface. This mapping was achieved through satellite remote sensing, using image processing of multispectral and panchromatic SPOT, Landsat Thematic Mapper and radar ERS1.

A field survey has been performed in April 1995 in order to define the most significant parameters of the problem: the presence of calcrete, its depth and thickness, its relationship with the distribution of stones on the surface, the geological composition of the bedrock, the nature of the soils, the topography, the agricultural landuse and the progress of stone removal. The main soils of the region developed on Quaternary dune sandstone with carbonaceous matrix consist in fersiallitic red soils in the South (complex profiles with sandy surface layer, or clayey composition of the surface layer due to erosion) and calcimagnesian soils in the North. Vertisols are found in some depressions, whereas the top of the dunes are mainly occupied by stony soils, outcrops of calcrete or eroded soils. Though rather moderate, the topographic variations control the variations of the duricrusts, the surficial stone component, and soil composition. Moreover, zones covered by sand deposits are numerous and well evidenced on SPOT imagery.

The images were processed on the basis of the conclusions of the field survey. The analysis of color composites and supervised classifications provided a map of the main types of soils and of their surficial stone content. The best classification result has been checked in the field. After improving the classification, a general accuracy of 78 % was reached. A final guide map was obtained by aggregation of the classes of soils and stone contents. It provides the delimitation of different areas where the duricrust can be broken and removed. In order to increase the classification score, neural network techniques have been tested and applied, increasing the general accuracy to over 80 %.

Another Landsat TM (acquisition September) image has likewise been tested, thus completing a data set originally comprising both Landsat TM (acquisition April) and Spot XS (acquisition September), since it had been demonstrated that the seasonal effects are of prime importance for the quality (meaningfulness) of the classification. The significance of the classification based on Spot XS was higher than the one based on Landsat TM (from the same season), probably as a result of spatial resolution.

This scientific study is a development of a former study carried out as an operational project of co-operation between this laboratory and the Ministry for Agriculture of Morocco, under the supervision of the Belgian administration for technical co-operation AGCD/ABOS.

6. China-Belgium joint project on the use of remote sensing for copper exploration in Henan Province, China

This two years study (Feb. 1994-Jan. 1996) was carried out under the auspices of the Belgian Ministry of Science Policy, Federal Scientific, Technical and Cultural Affairs (OSTC), as a cooperative program with the China National Non-ferrous Metal Industry Corporation (CNNC). The aim of the study is to test how remote sensing and GIS techniques can contribute to help in defining high Cu potential target zones and to introduce new geological guidelines for further mineral exploration. The study area is located in southwestern part of Henan Province (Central China), in the median part of the QinLing orogenic belt. The QinLing-Dabie orogenic belt occurs between the North-China and Yangtze Cratons, and is limited to the east by the Tancheng-Lujian active fault system.

This study both consists in data integration and image processing as well as field controls. The following data have been processed and partly integrated :

- geological map at scale 1:200 000;

Image data

- Landsat TM image covering the whole study area;
- a SPOT-Panchromatic image of the central of the study area;
- an ERS-1 SAR image of the northeastern part of the study area;

Non image data

- the result of a Cu geochemical campaign on stream sediments (16 000 analyses);
- airborne K-U-Th radiometry;
- aeromagnetism.

The field controls have shown the need to reconsider basically the metallogenic models initially proposed. In particular the Kuroko model, currently mentioned in attempting to link sulfide mineralization with paleovolcanic structures appears here hazardous. No field evidence can be pointed out to suggest such an origin for the ore deposits. It also appeared that the ore bodies were characterized by small size and low Cu grade.

Data processing and analyzing, in association with field control, led to two main results:

1. The definition of zones of converging favourable conditions for mineralization, allowing a selection of three targets areas for further exploration. The three areas, located in XiXia County, in the western part of the study area, are MeiZige, LujiaPing and ZhuoYue. These zones were selected on the basis of : a dense network of quartz veins and faults; Cu geochemical anomalies; - cross-cutting WNW and NNE to NE trending tectonic structures.
2. The reconsideration of the metallogenic models explaining some known deposits. New detailed geological survey of the study area with special care to the structural context is necessary. Relations between mineralization, lithology and tectonics have to be established. Metamorphism, structural control and intrusive magmatic activity are

phenomenon to take into account in elaborating genetic models. The presence of thrusts and tectonic slices will also have to be considered in elaborating stratigraphic correlations in this part of the QinLing orogenic belt.

7. China-Belgium joint project on the use of multi-source data integration and remote sensing for the prospection of Au-Cu polymetallic deposits in eastern Xinjiang Uygur autonomous Region, China

This program is carried out under the auspices of the Federal Office for Scientific, Technical and Cultural Affairs, as a cooperative program with the Center of Remote Sensing for Geology and the Beijing Institute of Geology and Mineral Resources of the China National Non-ferrous Metal Industry Corporation (CNNC). The aim of the study which will be carried out over two years (May 1996 – April 1998), is to develop a methodology for information processing based on remote sensing and GIS techniques for studying the regional metallogenic conditions and prognosis of Au-Cu polymetallic deposits of the study area.

The study area is located in the northeastern part of the XinJiang Uygur autonomous region, close to the Gansu Province and the Mongolia. It is situated south of Hami city , in the south TienShan mountains.

This study both consists in data integration and image processing as well as field controls. The following are now available :

- published geological map at scale 1:200 000 (12 sheets);
- Landsat TM image covering the whole study area (17 scenes);
- four SPOT-Panchromatic images;
- a JERS-1 SAR image;
- aeromagnetic data relative to the area between about 93°-95°E and about 41.5°-42.5°N.

Raw geochemical data will soon be provided . The density of the data is 5 points/km², and the concerned elements are Cu, Zn, Pb, Au, Ag, Co, Ni, C, Sb, Bi, As etc.

A five weeks field campaign was carried out in August and September 1996 in order to control the lithology and the tectonic style of the study area, and to try to establish a connection with features already studied by the geological team of RMCA in Russia, Kazakhstan and Kirghizistan.. Ore deposits and mining centers were also visited. The main types of gold deposits pointed out are :

- deposits in ductile shear zones (KanGuer);
- Jasperoidal types deposits linked to Carboniferous volcanic-sedimentary series (CuiLing);
- volcanic-hosted epithermal deposits (XiTan);
- subvolcanic hydrothermal deposits (MaZhuangShan);
- Cu-Ni deposits occurs in mafic-ultramafic intrusive bodies of Hercynian age (HuangShan).

Data processing and analysis lead now to the elaboration of an advanced structural and lithological interpretation of targets zones as well as of the whole study area. The next step will consist in digitizing the structural and lithological interpretation and in overlaying the geochemical and geophysical data.

8. The cartographic database

As a service to the public and to scientists, the Department holds an important collection of maps devoted to earth sciences (geological *sensu lato*) and other disciplines (topography, hydrology etc.), mainly covering Africa but also other parts of the world. New maps are regularly purchased in order to keep this documentation up to date. At present, the most important collection items are

- Geological maps:
Africa (individual countries and international maps); some maps exist as well from other continents
- Topographic maps:
Zaire, Rwanda, Burundi, Tanzania at various scales; some maps from other African countries.

The management of this collection has up to now been performed in an unstructured way, which is quite unsatisfactory since it relies heavily on the experience of the librarian. A creation of a database has therefore been decided, so that internal and external (also Internet) request for information can be satisfied.

In order to make a structure as straightforward and user friendly as possible, the database relies on a limited amount of scientific descriptors. These fields are:

- Theme: geology, geophysics, topography etc. (from a limited list).
- Title (general): as published.
- Translated title: the same, in English, if the original is in another language.
- Country or continent (or subdivision of a continent).
- Sheet title: name of a geographic subdivision
- Sheet number: same if such numbering exists.
- Geographic co-ordinates of NE corner of the map.
- Geographic co-ordinates of SW corner of the map.
- Scale.
- Publisher.
- Year of publication.
- Presence of explanatory notice (and reference of this document).
- Id. number: identification number in our collection.

Other fields could be added according to new criteria.

The fields "Country" and the "Corners" make geography-based queries easy. The corners also allow to position the map in a Geographic Information System.

At present 4000 maps from Africa and North America have been entered in the database.

9. Perspectives of spectral geology

The spectral geologic approach is based on the assumptions that mineral objects can be identified by their spectral signature measured with high spectral resolution and that the spectral properties of the natural surfaces can be used:

- to determine the mineralogical composition of rocks by high spectral resolution reflectance measurements in the field or the laboratory
- to discriminate lithologic bodies on the basis of medium spectral resolution satellite data.
- to identify and map the lithologic compositions on the basis of hyperspectral airborne imagery.

The spectral approach of geologic remote sensing has been particularly developed in the laboratory since 1987 in the frame of the IGCP 264 (International Geological Correlation Program from UNESCO) working group "Remote Sensing Spectral Properties" (1987-1991). A 2 years research program involving 3 full time scientists was devoted to the development of spectral geology and applications in arid, semi-arid and tropical areas (1990 - 1993) in the frame of the Belgian national research institution SPPS (Service de Programmation de la Politique Scientifique).

Two recent developments will contribute to the operational application of spectral geology in the close future: the availability of complete spectral databases and expert systems for the automatic analysis of spectral signatures, and new airborne sensors with hyperspectral performances, such as the DAIS large-scale Facility experiment.

This research will apply to the multidisciplinary study of three Cainozoic basins of Siberian Altai (Chuya basin), Kazakstan (Zaisan basin) and Kyrgyzstan (Issik Kul basin), which are tectono-sedimentary depressions related to the India-Eurasia collision. The spectral geologic approach can be used in this application to determine the lithologic composition of the Tertiary sediments related to their specific deposit environment (cross checked and completed by X ray diffraction for the clay minerals) and to make the link with remote sensing. The semi-arid conditions, with sparse vegetation cover in the depressions (whereas the mountainous edges are covered by dense forest, snow and glaciers) are very favourable for a remote sensing approach.

First experiments in the Chuya basin have begun in 1996, on the basis of laboratory spectroradiometric measurements on well determined samples of weathered Devonian shales and Neogene clays. The identification of clay minerals is possible in the most favourable cases.

10. Spectroradiometry database of minerals, rocks and soils

10.1 General scope

Whether applied to laboratory measurements or to remotely sensed imagery, the interpretation and identification of spectral signature needs, necessarily, reference spectra obtained on well known materials. This is rather obvious for laboratory data but, notwithstanding their limited spectral resolution, satellite multispectral images, properly calibrated in reflectance, also yield

spectra that can be compared with reference spectra from databases. Existing airborne sensors and future orbital sensors will provide 64, 128 spectral bands making these sensors more and more comparable with laboratory equipment.

Setting up reference spectral databases has been a goal for several laboratories during the last decade. The USGS and the JPL have acted as pioneers in that respect. Application programs have also been designed. At present, PCI provides data from USGS's database, while JPL's database is used for reference by GER's spectroradiometer.

10.2 Existing databases

These databases concern powders of pure minerals presented with different grain sizes because it seems, in several cases, that the total reflectance (for a defined mineral) is proportional with grain size of the powder. On the other hand, intensity of absorption seems to be in inverse ratio of this fineness. In other words, signature contrast seems to be better when granulation of powder is coarse even if the total reflectance is lower. These observation, added with other properties as transparency, pleochroism and complex interactions problems, may explain the difficulty to simulate the response of a given rock simply by blending its own constituent parts. For this reason, it is necessary to constitute locale database which can be different in function of the end of the work, analysis capabilities etc.

10.3. Local databases

Local databases are fully justified when areas studied in different programs shows specific conditions resulting from regional lithology or soils development. Moreover, non-geologic databases, for instance those relative to monuments and their weathering are other typical elements of local databases.

10.4. Applications

Reference databases are at present developped in relation with different programs in Siberia (Quaternary geology), China (Metallogeny) and Africa (Cartography).

11. Monitoring of volcanic hazards in the Philippines

The Philippines are infamous for their many active volcanoes along the "Ring of Fire"; the subduction zone of the Pacific oceanic plate. The 1991 eruption of the Pinatubo volcano brought death and disaster in a wide area due to ashfall and subsequent laharic floods. The Taal and Mayon volcano are also well-known for their destructive reputation. One of the least known in the chain of volcanoes on the Luzon main island is the Bulusan volcano, in the Sorsogon Province, part of Bicol district. Although no major disastrous eruptions have been recorded, this volcano is active, with frequent ash- and freatic eruptions.

In order to predict the potential volcanic- and related geological hazards present in the Bulusan volcanic area, a medium-scale hazard mapping program has been undertaken. Due to the relative poor quality and availability of existing geo-information for this area, acquisition of the majority of the information and data is undertaken with the help of remote sensing and fieldwork. Emphasis is placed upon geomorphologic mapping, i.e. recognition and outlining

of ancient lava flows, lahar deposits and pyroclastic flows by study of their geomorphologic characteristics. The major obstacle is the abundant tropical vegetation in the area. While the lower areas are used for agriculture, the steeper (volcanic) slopes are covered by lush tropical forest. Also the climate in the area hampers acquisition of good-quality (cloud-free) optical satellite imagery.

Landsat TM imagery is used for the identification of the different geological and geomorphologic units present in the study area. JERS 1-SAR imagery is utilised as an additional source for identification of structural features, and is particularly useful in this case, because no problems are encountered due to cloud coverage. Advanced radar interferometry techniques, applied to JERS 1- and ERS-SAR data are employed to obtain an accurate digital terrain model for the study area. The image processing is carried out with special remote sensing software. Data input, -processing and -analysis is done with Geographical Information Systems (GIS).

This project falls within the framework of UNESCO's GARS-Asia programme (GARS: Geological Application of Remote Sensing), which is being carried out in co-operation with the Philippine Institute of Volcanology and Seismology (PHIVOLCS). The general objective of the GARS-Asia programme is to demonstrate the use of advanced remote sensing techniques and related technological developments, such as GIS and GPS, in the field of geological hazard analysis and -mitigation. The final goal of the project in the Bulusan volcano area is to design a methodology for volcanic hazard mapping, with the help of remote sensing and GIS, which can be applied to other relative unknown volcanoes in the Philippines.

12. Publications

- Deblond, A.,** The Kabanga-Musongati mafic-ultramafic belt in Burundi. An illustration: the Mukanda-Buhoro-Musongati complex. *Intraplate Magmatism and Tectonics of Southern Africa & The 17th Coll. On African Geology, Harare. Abstract vol.*, 9-11, 1997.
- Deblond, A., Z. He, M. Hanon, R.Y. Tang and J.S. Wu,** Copper exploration in Henan, China. A contribution of remote sensing and GIS multisource data integration. *Abstract. Eleventh Thematic Conference and Workshop: Applied Geologic Remote Sensing. Las Vegas (USA)* 365-369, 1996.
- Deblond, A., M. Hanon, Z.G. Wang and J.S. Zhang,** The contribution of remote sensing and GIS multisource data integration to copper exploration in Henan, China. *Abstract at the 30th International Geological Congress, Beijing (China)* 453, 1996.
- Deblond, A. et J. Lavreau,** Apport de l'imagerie radar à l'étude géologique d'une région montagneuse du Henan (Chine). *Mus. roy. Afr. cent., Dép. Géol. et Min., Rapp. Ann., 1995-1996, sous presse*, 1997.
- Fernandez-Alonso, M., D. Delvaux, F. Kervyn and P. Tréfois,** Structural Lineaments in the ASWA Shear Zone Area (Uganda and Sudan). *Proc. of the ERIM Eleventh Thematic Conference on Geologic Remote Sensing, Las Vegas, 27-29 February 1996, vol. I*, p. 109-117, 1996.
- Lavreau, J.,** The GARS-Transfer program: Past and Future. *Proc. of the seminar and workshop: environmentally sound management and exploitation of mineral resources, and Geological Applications of Remote Sensing. Dept. Geol. Survey and Mines, Uganda*, 269-272, 1996.

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- Tréfois, Ph., N. Dobretsov, I. Novikov, A. Milosnov and A. Mistryukov**, SPOT Image Processing, Spectral Data Measured in the Field and GIS Integration for the Geological Study of the Chuya Depression in Gorno Altai, South Siberia (Russia). *Proc. of the ERIM Eleventh Thematic Conference on Geologic Remote Sensing, Las Vegas*, 27-29 February 1996, vol. II, p. 88-97, 1996.

B. Laboratory for Telecommunication and Remote Sensing of the "Université Catholique de Louvain"

The laboratory has an important activity in the field of microwave remote sensing of the Earth surface and of the atmosphere from space since 1978. We are involved in the analysis of atmospheric propagation effects and of scattering by random rough surfaces and vegetation, for electromagnetic waves in the range 1 to 200 GHz. Our interest lies in the interpretation of both radar (including SAR's) and radiometric measurements and in the development of a synergy between various kinds of microwave sensors.

These research activities concentrate on the ocean surface, on soil surfaces and on vegetation covered soils, on atmospheric constituents (water vapor and liquid water), and on rain. The main goal is to analyse the microwave signatures of the various targets and to determine the corresponding geophysical parameters. The atmospheric and surface characteristics are thus obtained by appropriate inversion procedures of the radioelectrical measurements. The resulting modelisations are implemented as simulation and inversion algorithms. The results are compared with real data collected during airborne campaigns as MARSS, or from space observations obtained e.g. from such satellites as ERS-1, ERS-2, SSM/I, TOPEX, and more recently NSCAT. As during the preceding period, the research activities have been concentrated along two main axis : ocean and land.

Over the ocean, our interest lies in the proper interpretation of altimeter and scatterometer signatures under non-fully developed sea conditions and in the presence of rain. We have shown, e.g., that the altimeter echo is sensitive not only to the wind speed, but also to a parameter describing the surface geometry. We have also shown how the scatterometer response can be perturbed when crossed sea conditions are observed. Another project is concerned with rain observation above the ocean, including both the detection of rain back-scattering and surface smoothing effects by rain. Detailed experiments of drops impact effects on the surface and on the related radar echoes have been made. They are used to drive modelling effort of scattering by the sea surface roughened by both wind and rain. Moreover our rain model is implemented in new rain radar retrieval algorithms from space in the framework of an ESA study that is performed in cooperation with other European Laboratories and has now started. Finally we are also comparing brightness temperatures calculated by our electromagnetic models with measurements taken above the ocean with microwave radiometers onboard of satellites : SSM/I, ERS1 and TOPEX as well as of aircrafts : MARSS.

The second axis of research is concerned with the observation of land targets, mainly with SAR instruments. A PhD thesis has been presented in 1997 on the polarimetric observation of forest targets. It is based on data collected during the MAESTRO campaign of 1989, and the EMAC campaign of 1994. During the first one, the NSA/JPL airborne polarimetric SAR was flown above several test-sites in Europe and the data from the Fribourg forest area have been processed and compared to the output of our polarimetric backscattering models. During the EMAC campaign, the ESAR instrument of DLT (Germany) was flown above the Belgian test-site of the Zwalbeek. Several corner reflectors have been designed, calibrated and deployed.

They have been used for calibration testing during overflights of the EMAC aircraft and the SIR-C shuttle. The thesis presents in particular an original approach for the separation of canopy and trunks contributions to the measured radar echo and for the inversion of these measurements. On the other hand two studies are related respectively to the interpretation of ERS-1 SAR data above the tropical forest in Côte d'Ivoire, and to the analysis of images taken above the Hesbaye in Belgium. In the first case, the interest lies in the determination of forest areas and of the importance of deforestation, and in the second case in the follow-up of cultivations. These projects are on-going in collaboration with VITO in Mol and with the Faculty of Agronomy of the "Université Catholique de Louvain" respectively.

These studies are financially supported by the European Space Agency, the Federal Services of the Belgian Scientific Office, and the FRIA fellowships. They are performed in collaboration with several European Research Centers and NASA, as well as with several other Laboratories of the University.

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C. National Geographic Institute

Two land cover maps of Belgium have been published at the scale of 1:300 000 and 1:500 000 (the latter for the National Atlas of Belgium). These two maps have been produced using the CORINE land cover geographical database that the remote sensing unit of the National Geographic Institute had completed in 1995. These maps show a great amount of details while giving a clear synthetic view of the whole country on a single map sheet.

The remote sensing unit of the National Geographic Institute also took part in the LACOAST project of the Commission of the European Communities. This project aims at analysing the land cover changes of the European coastal zones. The Belgian part of LACOAST included an updating and three "downdatings" of an improved CORINE land cover database for the Belgian coast zone. It was done by photo-interpretation of archived satellite data and of aerial photographs. The analysis workpackage was carried out in co-operation with the IGEAT of the Free University of Brussels.

An updating and improvement of the topographic-touristic 1:100 000 map series of the National Geographic Institute is in progress. The remote sensing unit is in charge of collecting the change data for the topographic map and of producing a "satellite-like" background image to map the touristic information. The operational phase of this project will begin in 1998. The first map to be published is GTI-113 in the East of Belgium.

D. Royal Meteorological Institute of Belgium

During the period 1991-1994, a method has been developed to assess the actual evapotranspiration (ETR) over the Belgian territory by means of remote sensing (Gellens-Meulenberghs, 1997). It combines meteorological as well as Meteosat satellite data. It is run daily by means of an automatic computer procedure in order to obtain quasi-real time results. Unfortunately, unexpected errors may be present in the meteorological input data and the automatic check of the inputs needs still to be improved. At this stage, a manual verification of all the procedure steps is performed monthly and the data are reprocessed if necessary.

ETR results have been analysed in function of the synoptic and climatic conditions (Gellens-Meulenberghs and Roulin, 1996a). Sensitivity tests of the method (Gellens-Meulenberghs and Roulin, 1996b) and comparisons of the results with the values obtained by means of a hydrological model (Gellens-Meulenberghs et al. 1997) have also been achieved.

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VII. Addresses

- 1. Astronomical Institute of the "Katholieke Universiteit Leuven"**
Celestijnenlaan 200B, B-3001 Leuven
Tel : 32-16-32.70.36 Fax : 32-16-32.79.99
- 2. Astronomical Observatory of the University of Gent**
Krijgslaan 281, B-9000 Gent
Tel : 32-9-264.47.99 Fax : 32-9-264.49.89
- 3. Astrophysical and Spectroscopical Department of the University of Mons**
Place du Parc 20, B-7000 Mons
Tel : 32-65-37.37.27 Fax : 32-65-37.30.54
- 4. Belgian Institute for Space Aeronomy**
Avenue Circulaire 3, B-1180 Brussels
Tel : 32-2-375.15.79 Fax : 32-2-374.84.23
- 5. Biomedical Physics Laboratory of the "Université Libre de Bruxelles"**
Campus Hôpital Erasme
Route de Lennik 808, CP 613, B-1070 Brussels
Tel : 32-2-555.62.73 Fax : 32-2-555.61.62
- 6. Department of Metallurgy and Materials Engineering of the "Katholieke Universiteit Leuven"**
de Croylaan 2, B-3001 Heverlee
Tel : 32-16-32.12.70 Fax : 32-16-32.19.92
- 7. Institute of Astrophysics and Geophysics of the University of Liège**
Avenue de Cointe 5, B-4000 Liège
Tel : 32-4-252.99.80 Fax : 32-4-252.74.74
- 8. Laboratory for Geological Remote Sensing and Information Management of the Royal Museum for Central Africa**
Steenweg of Leuven 13, B-3080 Tervuren
Tel : 32-2-769.52.11 Fax : 32-2-769.54.32
- 9. Laboratory for Telecommunication and Remote Sensing of the "Université Catholique de Louvain"**
Place du Levant 2, B-1348 Louvain-la-Neuve
Tel : 32-10-47.23.00 Fax : 32-10-47.20.89

10. Microgravity Research Center of the "Université Libre de Bruxelles"

Avenue F.D. Roosevelt 50, CP 165, B-1050 Brussels

Tel : 32-2-650.31.41

Fax : 32-2-650.31.26

11. National Geographic Institute

Abdij Ter Kameren 13, B-1000 Brussel

Tel : 32-2-629.82.11

Fax : 32-2-629.82.12

12. Royal Meteorological Institute of Belgium

Avenue Circulaire 3, B-1180 Brussels

Tel : 32-2-373.06.11

Fax : 32-2-374.67.88

13. Royal Military Academy

Renaissancelaan 30, B-1000 Brussels

Tel : 32-2-737.63.40

Fax : 32-2-737.61.21

14. Royal Observatory of Belgium

Avenue Circulaire 3, B-1180 Brussels

Tel : 32-2-373.02.11

Fax : 32-2-374.98.22

15. Space Center of Liège

Parc Scientifique du Sart-Tilman

Avenue du Pré-Aily, B-4031 Angleur-Liège

Tel : 32-4-367.66.68

Fax : 32-4-367.56.13