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SPACE RESEARCH IN BELGIUM

1998 – 1999

Report to COSPAR – Meeting in Warsaw, Poland

16 – 23 July 2000

Preface

This report has been prepared on behalf of the Belgian National Committee on Space Research of the "Académie royale des Sciences, des Lettres et des Beaux-Arts de Belgique" and the "Koninklijke Vlaamse Academie van België voor Wetenschappen en Kunsten", for presentation at the 33rd Scientific Assembly of the Scientific Committee on Space Research (COSPAR), Warsaw, Poland, 16-23 July 2000.

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. The ORA experiment

The Occultation Radiometer (ORA) is a simple UV-visible instrument, developed by the Belgian Institute for Space Aeronomy and the Department for Atmospheric, Oceanic and Planetary Physics of the University of Oxford, that was launched in July 1992 on board the European Retrievable Carrier (EURECA) for a 1 year mission dedicated to the measurement of vertical profiles of O_3, NO_2, H_2O number densities as well as the stratospheric aerosols.

The data processing of the ORA experiment has reached its final phase. After a consolidation step where total extinction profiles have been compared with those obtained from SAGE II, an improved vertical inversion algorithm has been developed and the spectral inversion has been performed. Furthermore, a specific processing scheme has been applied to the UV (260 nm) channel which was know to suffer from a parasitic residual transmission at about 340 nm. Valuable data consisting of mesospheric ozone volume mixing ratio profiles in the upper atmosphere have been obtained and agree satisfactorily with results of HALOE (Halogen Occultation Experiment), MLS (Microwave Limb Sounder) and SME (Solar Mesospheric Explorer) instruments up to the mesopause.

We are presently focussing our attention on the stratospheric aerosol properties retrieved by ORA in the post-volcanic period that followed Mount Pinatubo eruption.

2. GOME

The Global Ozone Monitoring Experiment (GOME) is a UV-visible nadir viewing spectrometer launched in April 1995 on board of the European satellite ERS-2. GOME is a 4 chanel double monochromator covering the wavelength range of 230-800 nm with a spectral resolution of 0.2-0.4 nm. The main objective of GOME is the global measurement of ozone columns, but other trace gases such as NO_2, SO_2, HCHO, OClO and BrO can be retrieved from the spectra as well.

The main objectives at BISA for the period 1998-1999 were :

- Investigation of the consistency of major components of the global observing system for atmospheric ozone (O_3) and nitrogen dioxide (NO_2).
- Further development of O_3 and NO_2 retrieval algorithms for the operational GOME Data Processor (GDP).
- Development of a climatological model of atmospheric NO_2 profile
- Sensitivity study and development of Air Mass Factors for spaceborne and ground-based systems for total O_3 and NO_2 monitoring.
- Preparation of ENVISAT activities : transfer of GOME experience to SCIAMACHY.
- Development of a GOME BrO product.

2.1. Consistency and improvement of ozone monitoring instruments

The geophysical validation of atmospheric chemistry data records acquired by several spaceborne sensors has been carried out by means of the integrated use of ground-based and balloon observations associated with the Network for the Detection of Stratospheric Change (NDSC) : (i) ERS-2 GOME/GDP 2.0-2.3 and Earth Probe TOMS V7 total O3; (ii) GOME/FURM O3 profiles ; (iii) GOME/GDP 2.3 total NO_2; and (iv) UARS (Upper Atmospheric Research Satellite), HALOE (Halogen Occultation Experiment) stratospheric NO_2 data.

A combined characterisation of GOME GDP 2.0 and TOMS V7 (both TOMS Earth Probe and TOMS ADEOS) total ozone data has been carried out from pole to pole using SAOZ/UV-visible, Dobson and Brewer observations of the Network for the Detection of Stratospheric Change (NDSC). The comparisons with each spaceborne sensor have been combined altogether for investigating their respective solar zenith angle (SZA) dependence, dispersion, and difference of sensitivity. The satellite and ground-based data are found to be consistent. However, the analysis highlights for both GOME and TOMS several sources of discrepancies: (i) a SZA dependence with TOMS beyond 80° SZA; (ii) a seasonal SZA dependence with GOME beyond 70° SZA; (iii) a difference of sensitivity with GOME at high latitudes; (iv) a difference of sensitivity to low ozone values between satellite and SAOZ sensors around the southern tropics; (v) an apparent north/south difference of TOMS with the ground-based observations; and (vi) internal inconsistencies in GOME total ozone.

The characterisation of GOME GDP total ozone has been extended to its version 2.3 and to longer time-series. As expected from preliminary results of the Delta Validation Campaign 1998 (ESA/ESRIN APP/AEF/17/GB, 1998), no major difference is to date between GDP 2.0 and 2.3 ozone data.

2.2. Consistency and improvement of NO_2 monitoring instruments

A preliminary ground-based investigation of the hybrid GDP 2.0/2.3 total nitrogen dioxide data record was realized. Based on pole-to-pole observations from UV-visible and FTIR spectrometers of the NDSC, the study concluded that the GDP 2.0 total NO_2 data product is unreliable, mainly due to the use of a partially inadequate NO_2 profile database in the evaluation of air mass factors (AMF). Improved with a more acceptable atmospheric database, GDP 2.3 was investigated similarly. Pseudo-global investigation concludes that the GOME GDP 2.3 total NO_2 product has improved significantly compared to GDP 2.0, but that the geophysical consistency of low latitude data remains questionable.

Following recommendations drawn from GDP 2.0/2.3 validation results, possible solutions have been proposed and tested for the improvement of GDP algorithms and databases. Some improvements have been implemented in the operational GDP, calling for a delta validation campaign. Coordinated by the BISA, the Delta Validation Campaign 1999 has allowed further development of GDP NO_2 retrieval and has demonstrated the improvement of the NO_2 data product on the global scale.

NO_2 stratospheric columns derived from UARS HALOE profile measurements have been compared from pole to pole with NDSC/UV-visible observations of total NO_2. Preliminary comparisons show that HALOE NO_2 data from 1991 through 1999 are in reasonable agremeent with NDSC observations.

2.3. Validation of GOME ozone profiles

A representative set of GOME ozone profiles retrieved at IFE/U. Bremen with the FURM algorithm have been compared, at altitudes from ground to 60 km, with correlative profiles measured by ozonesonde, lidar, and microwave radiometer of the NDSC. From the ground up to 55 km, ozone profiles inferred from GOME data with the FURM algorithm are found to offer a reasonable agreement, within 5% to 15%, with correlative measurements acquired with three independent techniques. Between 15 km and 40 km, GOME/FURM ozone profiles contain information derived mainly from the measurement itself. At other altitudes, the contribution of the measurement is limited compared to the contribution of the *a priori* information used in the retrieval. Comparisons highlight a clear height-resolved dependence on the cloud fraction and on the solar zenith angle in the stratosphere, requiring further investigation.

2.4. Climatological model of atmospheric NO_2 profile

A model has been designed to describe the seasonal, latitudinal and sunrise/sunset variation of stratospheric NO_2 on a climatological basis. It relies on sunrise and sunset profiles measured since nearly a decade by the UARS Halogen Occultation Experiment (HALOE). HALOE data affected by Pinatubo aerosols have been rejected. To improve the accuracy of the model, climatological characteristics of major stratospheric NO_2 variations have been derived from long-term observations of total (stratospheric) NO_2 from a network of ground-based UV-visible spectrometers. The climatological characteristics determine the type of function to be used for the least-square fitting of low-pass filtered HALOE NO_2 profile time-series. The resulting climatological model provides stratospheric NO_2 as a function of latitude, altitude and time.

The climatological model stratospheric NO_2 is extended down to the ground using monthly means of tropospheric NO_2 profile provided by the 3D chemical transport model of the global troposphere named Intermediate Model of Global Evolution of Species (IMAGES). NO_2 profiles measured by the SAOZ-balloon experiment at middle and high northern latitudes in various seasons and in Brazil, provide useful information at altitudes where the accuracy of both HALOE data and IMAGES results might degrade. The resulting composite NO_2 climatology has been validated against ground-based UV-visible measurements of the NDSC and HALOE and ERS-2 GOME satellite overpass data.

2.5. Air mass factors for satellite and ground-based instruments

Atmospheric measurements based on the observation of the scattered light at zenith or nadir require the use of an optical enhancement factor or Air Mass Factor (AMF) to convert observed slant column amounts into vertical column amounts. The AMF is calculated using a radiative transfer model and assuming the vertical distribution of atmospheric parameters such as pressure, temperature and ozone. A study of GOME ozone AMFs based on extended ozonesonde data sets has demonstrated the need to revisit the GDP atmospheric profile database. Based on modelling results rather than on a real climatology of ozone and temperature profiles, the current GDP database might generate errors in both the fitting of slant column amounts of O_3 and their conversion to vertical columns. Among others, it might contribute significantly to the GOME SZA dependence at low sun elevation and to seasonally varying biases at all latitudes. The AMF study emphasises also the limits of the static, climatological approach adopted in operational GDP and GOFAP processors for the calculation of the GOME O_3 AMF and hence the derivation of GOME O_3 vertical columns.

Latitudinal and seasonal changes in stratospheric NO_2 as well as tropospheric emissions of NO_x distort the shape of the actual NO_2 vertical distribution and hence affect the Air Mass Factor to be calculated for the interpretation of scattered-light observations. To assess the resulting impact on the retrieved vertical column amount, a suitable NO_2 reference atmosphere has been built up, combining long-term satellite, balloon, and ground-based measurements and modelling results. The reference atmosphere has been used to investigate the sensitivity of both GOME and zenith-sky NO_2 AMFs to the vertical distribution of NO_2, pressure, temperature, and ozone. The study highlights periodic signatures in the AMF reflecting seasonal, latitudinal and sunrise/sunset changes of the atmospheric profiles, which need to be taken into account when retrieving NO_2 vertical columns from ground-based and satellite observations of scattered sunlight.

For GOME in particular, the investigation highlights the need to improve the GDP NO_2 database with seasonal/latitudinal stratospheric features and a consistent tropospheric background to get accurate AMFs under unpolluted conditions. The impact of tropospheric NO_x emissions on the GOME AMFs has been assessed using results from the 3D chemical-transport of the global troposphere called IMAGES. Accurate AMF evaluation under polluted conditions remains a real matter of concern.

2.6. GOME BrO product

GOME operational data products are generated at the German Remote Sensing Data Centre of the DLR (DLR-DFD), these comprise Level-1 (earthshine radiance and solar irradiance spectra) and Level-2 (O_3 and NO_2 total columns, plus fractional cloud cover) products. Among the additional research products (OClO, BrO, SO_2, CH_2O, H_2O, ...) that can be obtained through the exploitation of the full spectral information available from GOME, BrO is of major interest for both stratospheric and tropospheric studies. Over the past few years, significant progress have been achieved in several aspects of the data processing of GOME data and the potential of GOME for global mapping of BrO has been demonstrated. The result is that the development of an operational BrO product from GOME can now be envisaged.

In this context, a project has been started at the BISA in November 1998 which aims at the development of a state-of-the-art GOME BrO operational retrieval algorithm using the differential optical absorption technique. The project, includes algorithm developments and ground validation activities. During 1999, the existing BISA DOAS software suite has been modified and further developed to enable precise BrO slant column retrieval from GOME radiance/irradiance spectra. BrO fitting results have been validated through comparison with alternative scientific algorithms developed at the Universities of Bremen, Heidelberg and Harvard. For vertical column calculations, multiple scattering airmass factors (AMFs) have been calculated using available BrO profile data and the sensitivity to unknown atmospheric parameters has been studied. In addition, the impact of bromine photochemistry on the product has been investigated.

Validation activities are a key aspect of the project. These include comparisons with correlative ground-based and balloon BrO measurements, based on the exploitation of the link with the EU project "Stratospheric BrO". During 1999, time-series of GOME BrO vertical columns have been retrieved over the period 1998-1999 for ground pixels selected above relevant stations. Using this data set, the consistency between GOME, ground-based and balloon data has been studied.

3. Compilation of atmospheric observations in support of satellite measurements over Europe (COSE)

3.1. Introduction

The EC project COSE (contract ENV4-CT98-0750) started on the 1st of October 1998 and will end on Sept. 30, 2000. It is coordinated by the Belgian Institute for Space Aeronomy (BISA), and counts 14 additional partners. It includes some user representatives, like the THESEO (Third European Stratospheric Experiment on Ozone) and THESEO 2000 communities, databases like the Network for the Detection of Stratospheric Change (NDSC) and SPARC, and more especially satellite experiment teams like ENVISAT and SAGE-III. COSE addresses the needs of the Earth Observation (EO) community.

The first year of COSE has been devoted more particularly to

- the development of a better data documentation (Data Consolidation Document),
- the establishment of an appropriate harmonised data format and related relational database with catalogue,
- the improvement of NO_2 air mass factors for the UV-VIS DOAS community,
- the development of vertical inversion algorithms for high-resolution Fourier transform infrared (FTIR) measurements,
- support to the THESEO and THESEO 2000 campaigns, and important contributions to GOME validation
- the development of a WWW page, and the distribution of a COSE brochure, and
- the edition of regular observations status report for the benefits of the EO user communities

Principal project information and observations status reports can be found at the COSE Web page http://www.nilu.no/projects/nadir/cose/cose.html.

3.2. Data cataloguing and archiving

Together with NILU, BISA made an overview of available data formats in the atmospheric scientific community, looking for pros and contras. The CDF format has been selected. BISA made the initial draft versions of all data skeletons in collaboration with a representative per experimental technique, in winter 1999-2000. The skeletons will be fixed and will be defined such as to include the data documentation with the skeleton metadata.

3.3. Observations and model simulations of OClO slant column amounts at Harestua

Halogen oxides are playing a key role in the catalytic processes that control the O_3 abundance in the lower stratosphere. Chlorine compounds are involved through the ClO/BrO, the ClO/O and the ClO dimer (Cl_2O_2) cycles. OClO, which is mainly formed by the reaction of ClO and BrO, is an important although qualitative indicator of the degree of chlorine activation. This constituent has been monitored on a continuous basis during the COSE project by UV-visible spectrometry at the Harestua station (60°N, 10°E). Zenith-sky measurements have been performed using UV-visible spectrometers designed and assembled at BISA as part of the Belgian contribution to the Network for the Detection of Stratospheric Change (NDSC). Optimal sensitivity is obtained through use of cooled array detectors, thermal regulation of spectrometers, and zenith sky light depolarisation using fiber optics.

The retrieval of OClO from twilight observations by differential absorption spectroscopy (DOAS) is particularly difficult owing to the very low absorptions to be detected (typically a few hundreds of a percent). The optimisation of the data analysis is therefore an important task, which has been addressed in this project based on existing DOAS algorithms developed at BISA since the early nineties. The sensitivity of the retrieval to various analysis parameters has been investigated, including, (i), the choice of the spectral interval used for OClO fitting

spectral (where interferences between absorbers have to be avoided), and (ii), the choice of the most suitable absorption cross-sections and Ring effect data set. Optimal fits were obtained in the wavelength range from 358 to 380.5 nm, taking into account the spectral signatures of OClO, O_3, NO_2, BrO, O_4 and Ring effect.

Figure 1 shows the time-series of morning and evening OClO differential slant columns densities (DSCDs) measured from January 1998 until August 1999, for solar zenith angles 90° - 80° (solid and dotted curves). Such twilight DSCDs provide the highest sensitivity to stratospheric OClO which is largely photolysed during the day. The time-series of Harestua observations reveals events of largely enhanced OClO DSCD, which are associated with the advection of activated polar vortex air masses. Besides these peaks, the measurements also indicate the existence of a small but sizeable background of OClO present throughout the winter period, an observation not reported so far.

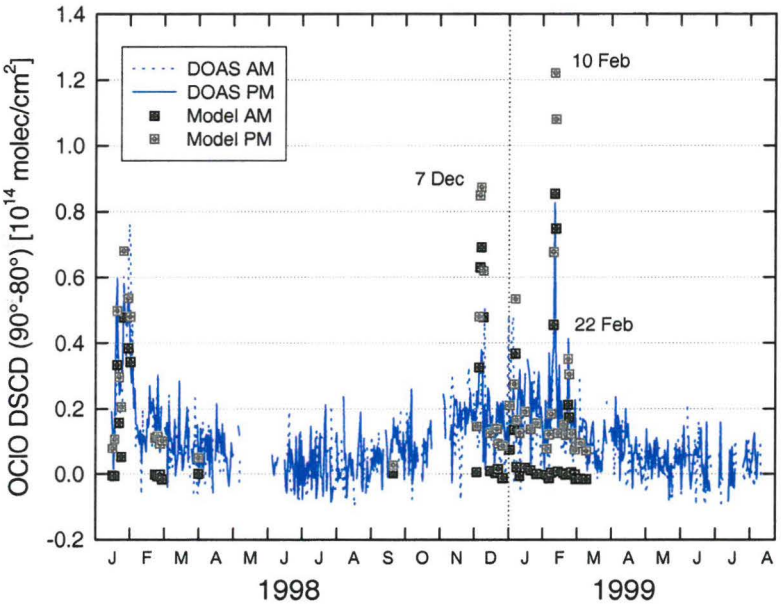

Figure 1. Comparison between morning and evening OClO differential slant column densities measured and modelled at Harestua (60°N) from January 1998 to August 1999.

In order to test these results against model calculations, simulations of OClO DSCDs have been performed by coupling outputs from the SLIMCAT 3D chemical transport model [Chipperfield and Sinnhuber, private communication], to a photochemical box-model and a single-scattering ray-tracing software both developed at BISA. Represented on top of the measurements in Fig. 1 (symbols), model results appear to be in good agreement with observations as to the timing of chlorine activation events, although OClO amounts inside the vortex tend to be overestimated, especially during winter 1998-1999. Likewise, the observed winter-time OClO background appears to be nicely captured by the model, but only for evening twilight conditions. In contrast with observations, model results indeed display very small OClO DSCDs in the morning, which we found to be due to a compensating effect: the decrease in geometrical enhancement between 90 and 80° SZA being compensated by an equivalent increase of the OClO column. Further work is needed to understand the origin of this behaviour.

These observations have been integrated in the THESEO related studies of chlorine activation (WP 3200).

4. Third European Stratospheric Experiment on Ozone (THESEO) : Stratospheric ozone destruction by bromine

The Stratospheric BrO project is one of the 13 core projects of the THird European Stratospheric Experiment on Ozone (THESEO). THESEO has been taking place during 1998 and 1999 and was extended in 2000 with the joint NASA/EU SOLVE/THESEO-2000 campaign. Its main aim is to improve our understanding of the causes of ozone depletion over Europe and other mid-latitude regions, where the ozone layer has been progressively depleted for the last 20-30 years. The campaign is an ambitious field programme of wide-ranging activities throughout the northern hemisphere with measurements being made by instruments on balloons, aircraft and the ground.

The Stratospheric BrO project is coordinated at BISA. The consortium includes seven European contractors: (1) Belgian Institute for Space Aeronomy; (2) Centre National de la Recherche Scientifique, Service d'Aéronomie (France); (3) Institute of Environmental Physics, University of Bremen (Germany); (4) University of Cambridge (UK); (5) Institute of Environmental Physics, University of Heidelberg (Germany); (6) Norwegian Institute for Air Research; and two non member state partners: (1) University of California at Irvine (USA); (2) National Institute of Water and Atmosphere (USA).

The main overall objective of the project is to combine all available BrO measurements from the ground, balloon and satellite, for deriving a clearer picturre of the behaviour of this species in the atmosphere and quantifying its role in the ozone destruction in the lower stratosphere.

Special goals are :

- to establish a homogeneous and validated data base of BrO column and concentration measurements on a 2-years period with a latitude coverage suitable to:
- document the diurnal, seasonal and latitudinal variations of BrO, and to investigate their origins;
- to contribute to the assessment and to the improvement of the accuracy of the BrO measurements using UV-visible spectroscopy either from the ground, satellite and balloons;
- to investigate the relative importance of BrO heterogeneous/homogeneous chemical modulation inside and outside the polar vortex and at lower latitudes;
- to contribute to the improvement of the understanding of the bromine photochemistry at mid- and high latitudes by testing photochemical/transport calculations against measurements;
- to provide an assessment of the impact of the bromine chemistry on ozone loss rate at different latitudes and seasons.

The contribution of BISA to the project includes ground-based observations of BrO from two stations in Europe: Harestua in southern Norway (60°N) and Observatoire de Haute Provence (OHP) in southern France (44°N). BISA also provides BrO total columns retrieved from the Global Ozone Monitoring Experiment (GOME, see Contribution to the Global Observaing System) and contributes to the interpretation of the measurements based on multi-dimensional model calculations.

5. Ground-based and laboratory measurements in the frame of the Belgian Programme for Global Change and Durable Development and the Network for Detection of Stratospheric Change

5.1.Observations at Harestua, the Jungfraujoch (ISSJ) and the Observatoire de Haute Provence (OHP)

Quasi-continuous monitoring of the atmosphere is performed at the Jungfraujoch, with UV-Vis zenith-sky observations (SAOZ measurements of O_3 and NO_2 total column abundances) and FTIR solar observations (in collaboration with the Institute of Astrophysics and Geophysics of the University of Liège). The list of molecules for which vertical columns (expressed as daily means, in number molecules per cm^2 above ISSJ) are derived routinely includes HCl, $ClONO_2$, HF, COF_2, NO, NO_2, HNO_3, O_3, N_2O, CH_4, CO, HCN, OCS, C_2H_2, C_2H_6, CO_2, N_2, SF_6, CFC-12 and HCFC-22.

Also at Harestua (Norway) and OHP (Southern France) regular monitoring of O_3, NO_2, OClO and BrO vertical abundances is performed using UV-Vis zenith sky spectrometers.

The spectral analyses and interpretation of these measurements requires some specific developments as undertaken in COSE or in the frame of other EC and national programmes.

The measurement results and analysis tools are used extensively for satellite validation purposes.

5.2.Development of PSCBOX, coupling a radiative-transfer to a photochemical box model

Model packages based on 1D photochemical box models coupled to ray tracing radiative transfer models enable the simulation with full diurnal cycle of slant column densities (SCD's) measurements of stratospheric constituents. A model package of this kind called PSCBOX has been developed at BISA primarily for simulating SCD's of fast diurnally varying species such as NO_2, BrO or OClO and according to both nadir and zenith geometry. These simulations are being used to interpret SCD's measured by differential optical absorption spectroscopy (DOAS) from ground-based stations operated by BISA (Harestua, Norway, 60°N, Observatoire de Haute Provence, France, 44°N and Jungfraujoch, Switzerland, 46°N). In addition, the model package PSCBOX is being used to calculate air mass factors for appropriate BrO retrieval from satellite-based instrument GOME (Global Ozone Monitoring Experiment) in polar winter conditions (high solar zenith angles).

6. SCIAMACHY

The SCIAMACHY instrument was accepted by ESA as an "Announcement of opportunity" instrument for the ENVISAT payload. SCIAMACHY is now a cooperative programme of Germany, the Netherlands and Belgium.

The primary objective of SCIAMACHY is to determine vertical and horizontal distributions of important atmospheric constituents and parameters (ozone and other trace species, aerosols, radiance, irradiance, clouds, temperature and pressure) from measurements of radiance combining scattered, absorbed and reflected light from the Earth's atmosphere and surface. Radiance measurements will be performed in different viewing geometries: nadir, limb and solar and lunar occultation.

These measurements will contribute to the better understanding of major climate and environmental issues:

- Tropospheric pollution including industrial emission and biomass burning
- Troposphere/stratosphere exchange processes
- Stratospheric ozone chemistry
- Climate change - chemistry interactions
- Volcanic eruptions
- Solar variability.

In 1998 and 1999, an extensive testing and calibration of the instrument was performed including the Polarisation Measuring Device. The instrument was delivered as a whole to ESA and is now integrated on the ENVISAT satellite scheduled for launch in 2001. The testing of the instrument revealed in some aspects performances beyond requirements and allows the extension of the spectral range to 220 nm in the UV leading to new scientific objectives.

BISA's scientific post-launch participation was formulated in terms of a strong response to the ENVISAT announcement of opportunity call. All proposals submitted by the institute and involving SCIAMACHY data were accepted. They revolve around a robust validation program and include: polarisation data, spectroscopic studies, UV products and atmospheric species (O_3, NO_2, BrO, OClO) data products development and exploitation, limb aerosol retrieval, as well as more fundamentally oriented airglow and eclipse studies. The main contributions to the nominal SCIAMACHY products can be summarised in the following list:

- Polarisation data
  - Studies based on synergy between GOME, POLDER and SCIAMACHY
- UV products

- Validation of SCIAMACHY level-1 products
- Development of a retrieval algorithm for solar Mg-II core-to-wing index
- Development of a retrieval algorithm for UV index at the surface
- Higher level products : maps of UV field and UV index at the surface
- NRT validation of UV products (ground-based networks)
- Database of space- and ground-based UV products

- Spectroscopic studies and databases

- Level 1b-to-2 retrieval algorithms
  - Contribution to the GOME and SCIAMACHY level 1b-to-2 algorithm development
  - Development of a BrO processing algorithm
  - UV-visible DOAS studies
  - Climatologies of atmospheric species
  - Radiative transfer studies
  - Air Mass Factor studies
  - Limb aerosol retrieval studies
  - Intensive validation of level-2 products based on the synergistic use of ground-based networks, balloons and satellites, in collaboration with institutes world-wide; synergy with GOMOS, MIPAS, SAGE-III and TOMS validation.

- Higher level products
  - Development of higher-level products using assimilation tools, radiative transfer models and chemical transport models (2D, 3D, and 4D-var, tropospheric and stratospheric), and their validation.

7. Contribution to the ESA Data User Programme

BISA carried out a two year project in the framework of ESA's Data User Programme (DUP) entitled: "Aerosol Mappping Algorithms for Satellite Data Users" (AMASDU, 1998-1999).

Present and near-future satellite experiments like GOME, 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 other important chemical species like HNO_3.

To this aim, tools are being developed to integrate, process and visualize level-2 satellite data from various sources.

A core task is the interpolation of the data over spatial, temporal and spectral dimensions. This interpolation is approached in two ways: (i) using a direct, model independent, interpolant construction, and (ii) using a model dependent 'smart' interpolation.

The first approach makes use of cubic splines over altitude and a new more elaborate 2D spherical interpolation method over longitude and latitude.

The second approach uses a space-time variational data assimilation technique to spatially and temporally interpolate and extrapolate data, based on a stratospheric chemical transport model, with given wind fields. The model developed at BISA currently handles 38 species and 145 chemical reactions, including all heterogeneous processes on sulphate aerosols and polar stratospheric clouds.

Spectral interpolation for aerosol data, is based on the anomalous diffraction approximation to Mie scattering theory.

A second task is to extract derived information from level-2 data, e.g. aerosol parameters such as the particle size distribution. In this respect, a new algorithm for spectral aerosol inversion was developed that allows the computation of the particle size distribution from forward spectral extinction measurements.

The developed methods have been applied to the ORA, SAGE II and CRISTA-1 data sets. Present activities focus on developing a web service to allow users to access these data and methods.

8. Atmospheric Modelling

A continuous effort is made to model the terrestrial atmosphere. These models deal with the different regions from ground level to lower thermosphere. The major objective is a good understanding of the various physical, chemical and dynamical processes. However, these models are also used for comparisons with experimental data and for validation purposes.

8.1. Troposphere

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 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.

The IMAGES model is increasingly used for the interpretation of existing global measurements of chemical species. A "colouring" technique is now being developed and used to study the global budget of carbon monoxide. The model results for nitrogen dioxide are exploited to help define a global tropospheric and stratospheric climatology for this species. The objective is to improve the algorithms used to retrieve NO_2 vertical columns from satellite instruments (GOME, ENVISAT).

8.2. Stratosphere

BISA has developed a variational data assimilation system for the composition of the stratosphere. The goal of an assimilation system is to constrain a model to reproduce a set of observations, in order to have an homogeneous information from heterogeneous data. In the variational method, one finds the best initial state of the model which will fit the measurements.

In the first phase, this system has been developed for the stratospheric aerosols. The aerosol assimilation system was applied to the 1.02 micron optical extinction data as measured by SAGE II (Stratospheric Aerosol and Gas Experiment). A very simple model, a minimal standard aerosol model, was used for either the evolution of aerosols and for the observational operator to map observations into model values.

In the second phase, the stratospheric chemistry was included in the assimilation scheme. We used a 3-D chemical transport model with precalculated dynamical fields by the United Kingdom Meteorological Office. The data were taken by the CRISTA (CRyogenic Infrared Spectrometer and Telescopes for the Atmosphere) instrument, during the mission 4-11 November 1994. The vertical profiles of Ozone, HNO_3, $ClONO_2$, N_2O_5, CH_4, CFC11 and N_2O were used to contrain the model. Analysis of the complete mission have shown the high abilities of the assimilation system to reproduce the data with less than 5% for Ozone, HNO_3, CFC11 and N_2O. Larger differencies, between 10 to 20%, are found for the other species, mainly due to the bigger uncertainties set on their measurements. Also, comparison with independant observations ,ATMOS and HALOE, show good agrement with the analysis for the constrained species as well for the other such like HCl and NO_x.

In the framework of European funded project, the chemical model was coupled with a microphysical model that calculates interactively the formation and evolution of the different polar stratospheric cloud particles, ternary solution, NAT and ice from the liquid background stratospheric aerosols. This coupling includes a detailed calculation of the heterogeneous reaction rates on these particles. This combined model has the capability of being used in Lagrangian or Eulerian model studies.

This model was run on a large amount of trajectories, within the polar vortex for the winter 1995-1996. The results were compared with Mesosphere and Lower Stratosphere (MLS) observations. The modelled ClO activation is consistent with the MLS observations. This leads to the model reproducing to a high degree the ozone decrease as observed by MLS.

8.3. Mesosphere and lower thermosphere

SOCRATES (Simulation of Chemistry, Radiation, and Transport of Enviromentally Species) is a time dependent two-dimensional model developped in collaboration with NCAR. It calculates the zonal means of the heat budget, winds, temperature and chemical composition of the atmosphere from the surface to 120km altitude, between latitudes 85 degrees South and 85 degrees North.

During 1998 and 1999, the model was still in development. The aim is to use it to study the chemistry and thermodynamics of the mesosphere and lower thermosphere. Our main point of interest is the time evolution of mesopause temperature as an early indicator of global change. Hower, the model will also be used for the analysis of the data expected from the NASA satellite TIMED which is scheduled for launch in 2000.

We have re-written the algorithm solving the vertical diffusion of chemical species, in order to calculate eddy and molecular diffusion in a consistent way. This allows an interactive calculation of molecular oxygen, which is necessary since atomic oxygen becomes a major constituent in the upper part of the model.

9. Ground based measurement of the penetration of the solar UV-visible radiation

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

Since March 1993, a full automatic station (SUVIM) for the monitoring of the solar irradiance in the UV-B (280-315 nm), UV-A (315-400 nm) and visible (400→600 nm) ranges, is operational at the site of the BISA at Uccle (51°48'N, 4°21'E). A schematic view of this station is given in Fig. 2.

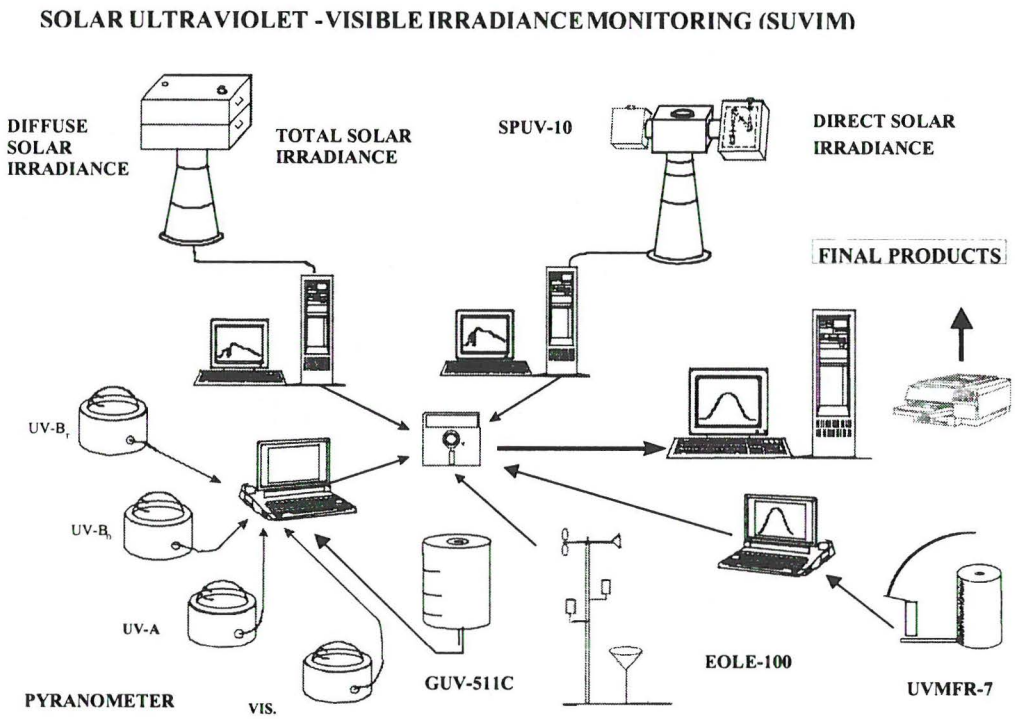

Figure 2. Schematic view of the Monitoring station in Uccle (Belgium).

a. Instrumentation: In addition to the spectral measurements performed every 15 minutes for solar zenith angles lower than 100°, integrated measurements of solar irradiance 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; it is used to determine the total columns of ozone and aerosol; a 4-channels filter radiometer (GUV-551c) measuring the global solar irradiance at 305, 320, 340 and 380 nm; and a 7-channels shadowed filter radiometer (UVMFR-7) measuring the total, direct and diffuse solar irradiance at 300, 305.5, 311.5, 317.5, 325, 332.5, and 368 nm. Main characteristics of the different instruments and their role into the station have already been presented in a previous report.

b. Calibration and Quality control of the data: Special care is taken of 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 ± 5 %.

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 the ozone total columns and the concentration profiles (measured by IRM), the detailed meteorological conditions (19 parameters), 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. Physical interpretations of the spectral measurements have been realised. A detailed study of the influence of the type of cloud cover (type of cloud, lower altitude, depth, single or multiple layers) 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.

Table 1 : Summary of the UV data produced in Uccle.

UV-B Spectral measurements :modified JOBIN-YVON HD-10

26-03-1993→15-03-2000 **2475 days** **→148000 scans**

Integrated measurements :

UV-B (total)	03/02/1995 → 15/03/2000 :	**1850 days**
UV-B (diffuse)	16/07/1996 → 15/03/2000 :	**1340 days**
UV-A	11/05/1995 → 15/03/2000 :	**1750 days**
TOTAL	25/07/1995 → 15/03/2000 :	**1680 days**

Filter radiometer measurements :

1. **10-CHANNEL SPUV-10 (Yankee Environment System)**

   21/03/1996 → (15/03/2000) : **1255 days**

2. **4-CHANNEL GUV-551 C (Biospherical Instruments)**

   23/05/1996 → (15/03/2000) : **1330 days**

3. **7-CHANNEL UVMFR 7 (Yankee Environment System)**

   10/08/1999 → (15/03/2000) : **220 days**

Figure 3 illustrates the times series of available data over the period 1993-2000.

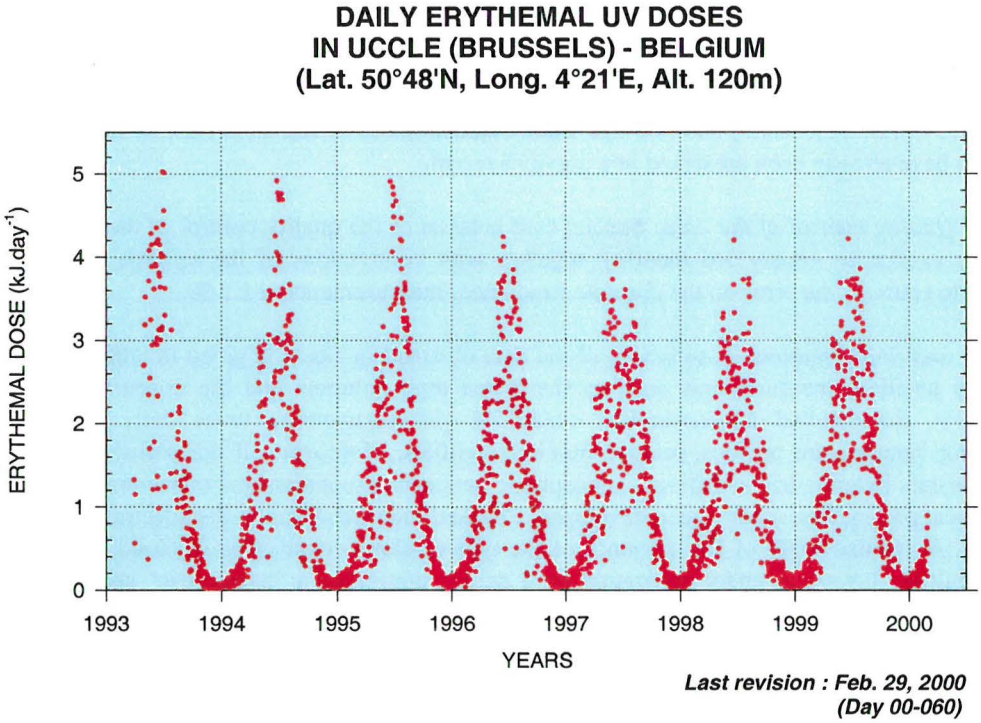

Figure 3. Daily biological effective UV doses measured at Uccle - Belgium during the period 1993-2000.

d. National and International collaborations: Some specific collaborations are established with the Royal Meteorology 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 irradiance measured at Lille and Brussels in order to verify the concept of regional networks.

9.2. The European Programs

a. "Scientific Ultraviolet Data Management" (SUVDAMA)

SUVDAMA is a three years programme supported by the European Commission. The principal aims of this project are: 1) the implementation of a data base including all the European spectral UV irradiance measurements and all their ancillary measurements including a relational data base, 2) the scientific validation of the submitted data, 3) the development of tools for a scientific use of these data (global interpretation, trend determination...) and/or general use (mapping...).

BISA is actively involved in the production of data (monitoring station) and the development of the relational data base. BISA developed the specific extraction tools for the "classical data base" in flextor format.

b. "Photochemical Activity and Ultraviolet Radiation Modulation Factors" (PAUR II)

PAUR II is a two years programme supported by the European Commission. The main aims of this programme are the characterisation of Mediterranean Aerosols (Saharan and oceanic aerosols) and the determination of their impact on the penetration of UV solar irradiance at the Earth surface. BISA was actively involved in a measurement campaign in Crete (Greece) during May 1999.

c. Cost Action 713 "UVB Forecasting"

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

10. SOLSPEC ISS

10.1. Introduction

SOLSPEC is a space qualified spectroradiometer dedicated to extraterrestrial and absolute solar spectral irradiance measurements from 180 nm to 3000 nm. It was designed in the years 70's in collaboration with CNRS/SA (France, PI G. Thuillier) and Heidelberg Observatory (Germany, CoI D. Labs). The most important scientific objectives are :

- The climatology of the VIS, IR and UV radiation during the solar cycle. The UV integrated irradiance may change by 10 % during this period and must be monitored.
- A contribution to atmospheric chemistry. Absolute measurements of the UV solar radiation with high accuracy (2 %) are of critical importance because of the role of this radiation on the wavelength dependent chemical processes occuring in the Stratosphere. Any change in the absolute UV spectral irradiance is able to modify the actual chemical equilibrium due to catalytic reactions.

SOLSPEC was first launched in 1983 during the flight SPACELAB 1 and has participated to a total of five NASA and ESA space missions. It is one of the reference instruments selected for the definition of a standard solar extraterrestrial spectrum.

Different external payloads for space research will be launched and transfered to the International Space Station (ISS) during the next years. One of them (the payload SOLAR) has been dedicated to solar physics. SOLAR is a grouping of three solar spectral and photometric instruments that will be installed on a pointing device (CPD) on the SOLAR pallet for a duration of 18 months : SOLSPEC, SOVIM and SOL-ACES. This selection offers the opportunity to update the SOLSPEC instrument : the electronic units will be upgrated, the mechanical interface will be adapted to the ISS payloads requirements and the optical design will be updated.

10.2. Optical design

a. Previous status

SOLSPEC is equipped with three double monochromators (UV, VIS and IR) using holographic gratings all mounted on the same mechanical shaft. A stepper moto-reductor provides an high wavelength positionning accuracy. The cooled detectors are photomultipliers for the UV and VIS channel and PbS photodiode for the IR. Quartz plates diffusors are used for the entrance optics in order to obtain uniform illumination of the gratings through the entrance slits. An internal calibration unit is integrated in SOLSPEC for ground and in flight monitoring of the spectrometer's responsivity and characteristics. Three kinds of lamps are used: hollow cathode lamp for the wavelength calibration, deuterium and tungsten lamps to control the relative responsivity of each channel. The absolute calibration of the spectrometers in radiometric units is ground performed using a black body and NIST standards of spectral irradiance (quartz-halogen lamps). The internal calibration unit has been designed for relative irradiance calibration.

b. New optical design

The three double spectrometers are fuly operational so that no changes will be performed for the integration on ISS. Only the internal calibration unit will receive a new design. Some improvments consecutive to the problems encountered during previous space flights have to be done on the lamp system arrangement. The list of new optical components integrated in the calibration unit are the following:

- Wavelength calibration: The hollow cathode lamp will have the same design as for SOLSPEC SPACELAB. A condensor and fiber optic will be used for the coupling between the lamp and the spectrometers instead of concave mirrors.
- Relative radiometric calibration: Two new deuterium lamps designed by the NPL will be used for the UV channel and four new ribbon tungsten lamps will be used for the VIS and IR channels (two per channel, one in operation, one as spare). The coupling between the lamps and the entrance optics will be performed by means of mirrors and fiber optics respectively for the UV and VIS-IR channels. Different protective quartz plates will be fixed on the filter wheel in front of the UV entrance optic.
- Position sensitive device: A new module including a PSD detector and imaging system will be used to monitor the angular position of the sun with respect to the optical axis of the spectrometers.

The internal arrangement of the calibration unit must be completely revised because of the numbers of new optical components. It explains also the choice of fiber optics for light transportation, to make the integration of all the optical components more easy.

10.3. Mechanical and electronical design

For the mechanics, major changes are needed to adapt the SOLSPEC instrument to the new interface on the coarse pointing device of the International Space Station. Moreover a new CPU processor and software will be used. The power supplies for the detectors, lamps and stepping-motors are changed and the IR channel electronics is completely revised.

11. Measurements of atmospheric constituents by selective ionization mass spectrometry (MACSIMS)

The MACSIMS project is a collaboration between the Belgian Institute for Space Aeronomy (BISA) the "Laboratoire de Physique et Chimie de l'Environnement du CNRS" (LPCE, Orléans, France) and the "Physikalisches Institut" of the University of Bern (PIUB, Switzerland), partly financed by the European Commission within the Environment program.

Its objective is to further develop and refine a method for the simultaneous in-situ measurement of stratospheric trace gases such as HNO_3, N_2O_5, $ClONO_2$ and possibly other (N_2O_5). The method used is chemical ionization mass spectrometry (CIMS), which relies upon the formation of specific product ions through ion-molecule reactions of atmospheric trace gases with precursor or parent ions produced by an external ion source, and carried to an ion mass spectrometer by a forced atmospheric gas flow. The analysis of the relative abundance of the precursor and product ions in the spectra obtained with the combined instrument (ion mass spectrometer and ion source) allows inferring the mixing ratios of the reactive trace gases.

To apply the CIMS method to the stratosphere, a balloon borne instrument has been developed, which is the combination of a flow tube equipped with specially designed ion sources (based on different ion-molecule reaction schemes) and of a magnetic double focusing Mattauch-Herzog mass spectrometer with simultaneous ion detection. The instrument which was flown for the first time in 1994 has been continuously improved in recent years, especially as a result of the addition of a new ion source based upon the use of CF_3O^- ions which react very selectively with a number of stratospheric trace gases.

The data analysis of the balloon flight of 1997 and the most recent balloon flight (June 1999 in Gap-Tallard) with the MACSIMS instrument have shown that HNO_3 profiles can be derived in the altitude region 32 down to 20 km from the spectrra obtained with the Cl_n^-, CO_3^- and CF_3O^- ion sources. Generally it can be concluded that the various methods used with the different ion sources lead to HNO_3 mixing rations, which are in good agreement with those derived from optical measurements.

The new CF_3O^- ion source also allows the detection of HCl and $ClONO_2$, the main part of the chlorine reservoir species in the stratosphere. However, the precise quantification of the measured profiles of these two last species, requires the measurement in the laboratory of some unknown kinetic parameters of the ion-molecule reactions involved. These measurements are presently in progress.

12. Study of space plasmas

12.1. Solar wind : Ulysses and Wind

The Belgian Institute for Space Aeronomy (BISA) was able to participate in the ULYSSES primary mission thanks to a PRODEX grant. The Space Plasma Physics group plays a leading role in the Interdisciplinary Study on Directional Discontinuities in the Solar Wind, 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 solar wind phenomena using observations from ULYSSES and WIND satellites and in-house modeling capabilities.

a. Flow shear across solar wind discontinuities

The tangential magnetic field and velocity shears across directional discontinuities (DDs) with significant change in magnetic field intensity observed by WIND in slow and fast solar wind streams have been examined. The magnetic field rotation sense in fast wind DDs is that predicted by theory for outward propagating rotational discontinuities (RDs), but flow shear magnitude and orientation do not always satisfy RD theory. Alternatively, DDs with small normal magnetic field can be regarded as tangential discontinuities (TDs); the observed shears imply that the length scale over which the proton velocity distribution changes at the discontinuity can be both smaller or larger than that of the electron distribution. The slow wind includes a larger fraction of DDs that disagree with RD theory. It is shown that the flow shear orientations allowed in a TD provide a continuous transition between the opposite orientations for RDs propagating along or against the magnetic field direction.

b. Ulysses observations of sector boundaries at aphelion

A sample of sector boundaries observed by ULYSSES near its early 1998 aphelion at 5.4 AU has been studied. These sector boundaries were related to the solar wind structure seen by WIND at 1 AU, guided by a hydrodynamic simulation (Fig. 4).

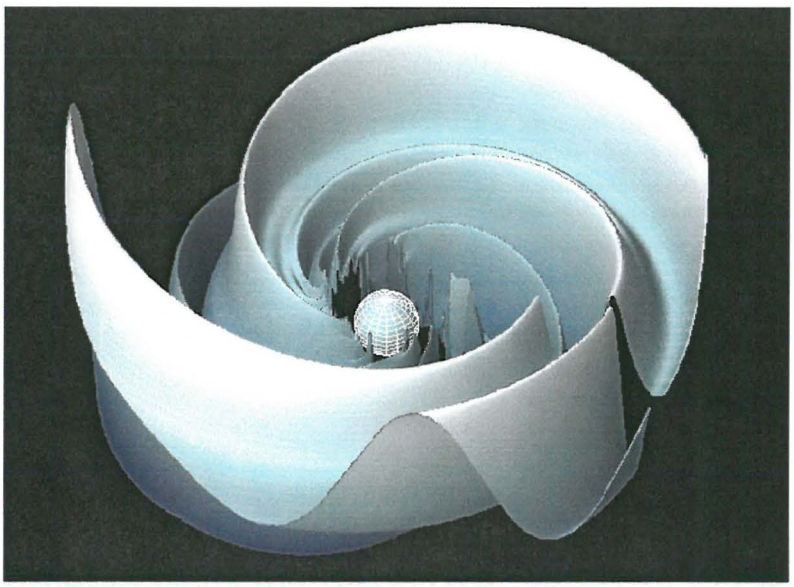

Figure 4. Qualitative reconstruction of the HCS surface between 1 and 5 AU. The plot presents the simulation results during February 1998, with temporal changes interpreted as longitudinal variations. The "cut" in the plotted surface separates data one solar rotation apart. Note that the size of the solar sphere is exaggerated (from De Keyser et al, J.G.R., 2000)

For each ULYSSES sector boundary a corresponding 1 AU sector boundary boundary could be identified, except when strong transients are present. Sector boundaries appear embedded in complex plasma structures that generally are in a state of pressure balance. Minimum variance analysis confirmed the tangential discontinuity nature of the heliospheric current sheet and indicates that the current sheet tends to be inclined more steeply than at 1 AU. Magnetic field depressions are characteristic features of the sector boundaries. They are attributed to particles that are magnetically confined inside the current sheet and that carry the diamagnetic current responsible for the large magnetic field rotation.

12.2. Solar wind MHD simulation

End 1999, an "unsolicited proposal" has been submitted to ESA by four Belgian research teams (Katholieke Universiteit Leuven, Belgian Institute of Space Aeronomy, Royal Observatory of Belgium and Von Karman Institute for Fluid Dynamics). Some aspects of Space Weather will be studied theoretically by various means, including global numerical simulations using the three-dimensional magnetohydrodynamics (MHD) equations on massively parallel computers, and observationally by means of thorough analysis and interpretation of a wide range of observational data gathered by ground observations and satellites, including SOHO, ULYSSES, ACE, and CLUSTER II.

12.3. Solar wind - magnetosphere interaction

a. INTERBALL

INTERBALL/TAIL and MAGION 4 observations of the flank magnetospheric boundary have been analysed. The transient behavior of the boundary has been interpreted in the past as the signature of both tailward traveling surface waves or of the penetration of isolated magnetosheath plasma entities into the magnetosphere. We have first examined the observational arguments in favor of these interpretations using high time resolution magnetic field and plasma data. We have further considered theoretical arguments regarding the stability of the LLBL inner edge and the penetrated plasma/magnetosphere interface. These satellite observations yield valuable constraints on surface wave generation and plasma penetration mechanisms.

b. CLUSTER II

In order to prepare the analysis of the CLUSTER data, the ISDAT and SWAN softwares have been studied and installed at BISA.

On the theoretical side, a study of resonant amplification of MHD waves in realistic subsolar magnetopause configurations has been performed. Broad-band ULF fluctuations are routinely observed throughout the magnetosheath; the fluctuation level peaks at the magnetopause and becomes very small in the magnetosphere. The study analyzes the propagation of magnetosheath waves and the transport of energy at the subsolar magnetopause by means of a linear perturbation analysis, in the limit of the MHD approximation.

The propagation of low frequency electromagnetic waves through the magnetopause has been studied and a software has been developed. The latter couples the kinetic model of tangential discontinuities with a wave propagation model based on the magneto-ionic theory.

12.4. Magnetospheric research

a. SEVEM

Global maps of the spatial and frequency distributions of ELF, VLF, and HF waves in the magnetosphere are needed to evaluate quantitatively the sources and losses of energetic particles trapped in the geomagnetic field and also to evaluate the electromagnetic noise levels in different frequency ranges in designing antennae for future space missions. Therefore a catalogue called SEVEM (Survey of ELF and VLF Experiments in the Magnetosphere) was created. It contains all missions and satellites in the terrestrial magnetosphere that were or are equipped with magnetometers and/or radio antennas. This catalogue has been implemented on the Web site http://www.magnet.oma.be/sevem/.

b. Analysis of the fluxes of energetic electrons injected in the magnetosphere during magnetically active periods using the Scintillating Fiber Detector (SFD) of the EQUATOR-S satellite

The data from the Scintillating Fibre Detector launched on board the EQUATOR-S satellite on December 9, 1997, have been extracted from the raw telemetry data, quality checked and reduced. This required the creation of special software tools (see Scintillating Fibre Detector EDC software Technical Note C. at http://www.oma.be/ BIRA-IASB/Scientific/Topics/Space Weather/Projects/Equators.html).

The measurements collected with the SFD on board EQUATOR-S has been analysed in collaboration with the Institut de Physique Nucléaire of the Université Catholoque de Louvain. The temporal evolution of the radial distribution of energetic electrons fluxes between L = 1.1 and 12 has been determined for the whole lifetime of this satellite. Numerous injections of energized electrons were detected during geomagnetic storms. They have been correlated with usual geomagnetic activity indexes.

13. Mars studies

In 1998 SPICAM-Light was accepted on board ESA Mars Express, to be launched mid 2003. The SPICAM-Light is a collaboration between the "Service d'Aéronomie" (PI, France), the BISA, the "Space Research Institute" (Russia), the "Laboratoire Météorologie Dynamique" (France), the "Centre d'Etudes des Environnements Terrestres et Planétaires" (France), the "Lunar and Planetary Laboratory" (USA) and the "SouthWets Research Institute" (USA).

Phase A of SPICAM-Light was started. SPICAM-Light consists off a UV spectrometer (118 - 320 nm) to be operated in three modes, stellar and solar occultation and nadir viewing. The UV spectrometer addresses key issues on ozone, its coupling with water vapour, aerosols, atmospheric vertical temperature structure and ionospheric studies. SPICAM-Light also consists off a IR spectrometer, for water vapour determination. Since the IR spectrometer will be based on the use of an accoustic optical tunable filter a full phase A study is performed. The IR instrument will be operated mainly in nadir viewing mode.

Supporting scientific activities have been initiated. The supporting scientific activities mainly encompass modelling of the chemical composition of the Martian atmosphere, using chemical transport models (2D and 3D). The development of the 3D CTM has started.

14. The Rosetta project - ROSINA

Rosetta is the third cornerstone mission in ESA's Horizon 2000+ program. Its goal is a rendez-vous with Comet 46/P Wirtanen to study the fabric of the comet and land a small probe (Rosetta Lander) on its surface. The prime scientific objective is to study the origin of comets, the relationship between cometary and interstellar material and its implications with regard to the origin of the solar system.

Rosetta is scheduled for launch from the Kuru base in French Guyana in January 2003 on board an Ariane-5 rocket. It will take eight years to reach Comet Wirtanen, and will then orbit it for the next two years. Rosetta will study the nucleus of comet Wirtanen and its environment in great detail for a period of approximately 18 months, the near-nucleus phase starting at a heliocentric distance of about 3.25 AU, with far-observation activities leading ultimately to close observation (from about 1 km distance). This would lead then to the nominal end of the mission in 2013.

One of the instruments of the Rosetta payload is ROSINA (Rosetta Orbiter Spectrometer for Ion and Neutral Analysis) for which the University of Bern (Switzerland) is the Principal Investigator. It is dedicated to the study of the composition and interactions in the cometary atmosphere and ionosphere. It consists of three sensors : the RTOF (Reflectron Time Of Flight mass spectrometer), the DFMS (Double Focusing Mass Spectrometer) and the COPS (Cometary Pressure Sensor). The Belgian Institute for Space Aeronomy is one of the co-investigators for DFMS.

The Double Focusing Mass Spectrometer is a state of the art high resolution mass spectrometer (resolution $m/\Delta m$ greater than 3000 at 1% peak height) with a high dynamic range and a good sensitivity. It is based on well proven design concepts that were optimized for mass resolution and dynamic range using modern methods for

calculating ion optical properties. The DFMS detects ions by means of three different detectors, located near the focal plane of the spectrometer :

- a Faraday cup detector for absolute ion current measurements;
- a multi-anode detector, a combination of a Micro Channel Plate (MCP) and a 512 double anode Linear Electron Detector Array (LEDA) chip;
- a Channel Electron Multiplier (CEM).

BISA is participating in the ROSINA instrument as a scientific co-investigator but is also responsible for the construction of a part of the DFMS sensor. In fact the main detector system, the Linear Electron Detector Array (LEDA) is designed and manufactured under the responsibility of BISA. Also the proximity electronics for both the LEDA and the Faraday Cup detector are under BISA's responsibility. Besides that, BISA is also in charge of the construction of part of the remote LEDA and Faraday Cup detector electronics.

In 1998 and 1999 the LEDA detector has been developped in close collaboration with IMEC. In a first stage a prototype chip has been produced and tested with only 48 anodes and simplified read-out electronics (LEDA48). In a second phase a LEDA with 512 anodes has been manufactured. The chip has been assembled with a ceramic LEDA support which enables it to be mounted on the DFMS detector flange. First an engeneering grade LEDA assembly was made and tested, afterwards a qualification model was manufactured. In the middle of 2000 the final flight model LEDA assembly will be available for functional and environmental tests.

Six printed circuit boards have been designed and layed-out in BISA. Several prototypes have been built and were tested together with the LEDA detector. At the end of 1999 BISA and OIP fabricated EQM (qualification grade) boards and mounted space qualified components. The boards have been tested functionally and underwent vibration and thermal vacuum tests.

The LEDA detector and the electronic boards will be integrated in the DFMS instrument in the beginning of 2000.

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

1. Diagnostics of the Jovian aurora from ultraviolet spectroscopy

A three-dimensional model is used to assess the role of the viewing geometry on the auroral color ratio. The simulations show that both an auroral arc with a geometry deduced from images obtained with the Hubble Space Telescope (HST) and a uniform polar cap emission produce no modulation or a minimum absorption when the longitude of the Jovian central meridian (CML) is close to 200°. This result is in contrast with the statistical measurements made with the International Ultraviolet Explorer (IUE) spectrograph that the hydrocarbon optical depth above the auroral emission maximizes for CMLs about 180°. In the frame of this simplified model, we examine a possible way to reconcile the model with the IUE data. An intrinsic longitudinal dependence of the column of methane above the level of the auroral emission is introduced in the simulation. It may result from a combination of a vigorous upwelling in sectors of strong and stable precipitation and/or a longitudinal dependence of the characteristic energy of the auroral particles.

A model coupling an electron energy degradation code with a detailed synthetic spectrum of the H_2 Lyman and Werner band system was developed to calculate the emerging auroral ultraviolet spectra from Jupiter's atmosphere excited by electrons with different initial energy distributions. The atmospheric model is adapted from the vertical P-T profile measured by the Galileo probe and mid-latitude model hydrocarbon photochemistry. Each altitude layer, with its own gas temperature, contributes to the emergent ultraviolet spectrum and the absorbers are vertically distributed within the source region of the auroral emissions. The model was applied to the analysis of seven HST/GHRS spectra of the 1200-1700 Å region obtained with 5 Å resolution at various locations in the north and south Jovian aurora. It was found that the characteristic energy of the assumed initial Maxwellian distribution ranges between 17 and 40 keV. A clear signature of acetylene absorption was observed near 1520, 1480 and 1440 Å where the C_2H_2 cross section shows strong absorption peaks. The acetylene column abundance overlying the emission peak varies from 0.02 to 0.2 of the methane column. A spectrum of the Io flux tube footprint and its trailing tail shows an ultraviolet color and hydrocarbon absorption quite similar to some of the main oval spectra. This observation suggests that the electrons of the Io flux tube are energized to a few tens of keV, similar to the electron precipitated in the main ovals and polar caps. Echelle spectra between 1216 and 1220 Å at 0.07 Å resolution are also compared with the model fitting best the mid-resolution spectra. It was found that the effective H_2 rovibrational temperature associated with the echelle spectra are significantly higher than predicted by the mid-latitude model. A large vertical temperature gradient just above the methane homopause due to large heating by auroral precipitation is a plausible explanation for this difference.

This assumption was tested using a one-dimensional model of the heat balance in the Jovian auroral thermosphere coupling the solution of auroral electron energy degradation and heat equation. One of the objectives was to derive the characteristics of the energy distribution which can meet the constrains set by the far-UV color ratio and the H_2 rovibrational temperature. H_3^+ plays an important thermostatic role and a similar compromise exists between the H_3^+ temperature and the observed H_3^+ IR emission intensity which also increases with the low energy component of the energy distribution. The auroral energy precipitated is not able to directly provide the necessary heat to balance the hydrocarbon cooling below the homopause but it is suggested that the auroral upper stratosphere is probably warmer than the equatorial upper stratosphere measured by Galileo. A kappa energy distribution, fitting in-situ Galileo measurements at the distance of Ganymede's orbit, does not produce results in agreement with observations. It probably does not reflect accelerating processes undergone by the auroral electrons along the magnetic field lines. A Maxwellian energy distribution with a total flux of 20 ergs cm^{-2} s^{-1} and a characteristic energy of 22 keV added to a soft Maxwellian component of 1 ergs cm^{-2} s^{-1} and a characteristic energy of 350 eV produces results in good agreement with thermospheric observations.

2. Nonthermal oxygen atoms in the Earth's thermosphere

A Monte Carlo stochastic model was used to calculate the energy distribution function of $O(^1D)$ atoms in the day- and nighttime thermosphere. Hot $O(^1D)$ atoms are produced by exothermic processes and their thermalization is controlled by the competition between radiation, collisional quenching and relaxation. It was found that the $O(^1D)$ temperature departs from the background gas temperature not only in the upper thermosphere but also in the region of the bulk 6300 Å emission. At 300 km, for low solar activity conditions, the model predicts an excess $O(^1D)$ temperature of ~ 180 K during daytime and ~ 950 K at night. The temperature departure persists at lower altitudes as a result of the major contribution of the O_2^+ dissociative recombination source of hot $O(^1D)$ atoms. It is concluded that temperatures deduced from the 6300-Å airglow line width may exceed the ambient gas temperature in a way depending on solar activity, local time and observation geometry.

An observational study of the effect of a thermospheric population of nonthermal $O(^1D)$ atoms on the 6300 Å emission was undertaken based on a comparison between daytime observations from space and theoretical simulations. Vertical temperature profiles deduced from 6300 Å airglow emission measurements using the Fabry-Perot Interferometer (FPI) instrument onboard the Dynamics Explorer 2 (DE-2) satellite are compared to the MSIS-90 model. Metastable $O(^1D)$ temperatures higher by ~ 150 K than the MSIS neutral kinetic temperature are deduced from the 6300 Å line profiles. A detailed comparison between observations and the theoretical results was described, including simulations of the FPI behavior in the presence of these nonthermal metastable oxygen atoms. Following sensitivity tests, it was concluded that the presence of nonthermal atoms in the instrument field of view is the most likely explanation of the observed discrepancy.

The role of nonthermal oxygen atoms in the vertical distribution of the O I 989 Å EUV multiplet intensity was investigated using a thermospheric radiative transfer code. The superthermal oxygen concentration and temperatures are derived from the energy distribution functions of the $O(^3P)$ atoms calculated by the Monte Carlo stochastic model, and their effect on UV radiative transfer was compared to sounding rocket observations. The calculated intensity increase associated with the perturbation of the Doppler profile by the presence of hot $O(^3P)$ atoms was shown to be insufficient to account for the set of sounding rocket EUV intensity data.

3. The Lyman-α line profile in the proton aurora

Global remote sensing of proton aurora through its ultraviolet signature makes it is increasingly important to relate the characteristics of the Lyman-α emission to the physical properties of the precipitated proton flux. In preparation to the analysis of the future observations with IMAGE/FUV, we developed a numerical model of proton and hydrogen flux transport and kinetics based on the Direct Simulation Monte Carlo method. In this approach, all elastic and inelastic processes are stochastically simulated as well as the production of Lyman-α photons with the associated Doppler velocity component. The model also includes collisional, geomagnetic and geometric spreading of the proton-hydrogen beam.

We showed that consideration of the stochastic character of the H atom velocity redistribution after collisions produces line profiles different from those obtained in the strictly forward or mean scattering angle approximations previously used in proton transport codes. In particular, the predicted fraction of photons due to backscattered particles is considerable larger when stochastic collision scattering is considered than in the strictly forward or mean scattering angle approximations. In contrast to the median wavelength, the position of the peak in the line profile shows an inverse dependence on the proton energy. The efficiency of the Lyman-α photon production per unit incident energy flux significantly drops as the mean proton energy increases. The line profile and the amount of blue-shifted (for satellite viewing) emission depends in a complex way on the initial energy and pitch angle distribution of the protons. The line profiles expected for the noon cusp and midnight proton aurora are shown to be significantly different.

4. ATMOS-based investigations of the atmosphere

The ATMOS (Atmospheric Trace Molecule Spectroscopy) instrument is a fast-scanning, fast-response Fourier transform infra-red (FTIR) spectrometer that has been operating in the solar occultation mode over the 650 to

4800 cm^{-1} infrared domain during four shuttle-based missions in 1985, 1992, 1993 and 1994. It remains the only instrument that produced chemically comprehensive sets of space-based mixing ratio profiles throughout the middle atmosphere for over 30 key atmospheric constituents. These data sets have allowed to investigate all important nitrogen- and halogen-containing species in the stratosphere and to evaluated family partitioning and trends over the 10-year time interval separating the extreme missions. Numerous related original investigations have been referenced and summarized in previous COSPAR reports.

During the past two years, various ATMOS-related investigations have been further undertaken, some of which we have actively contributed to. In particular, profile measurements of trace gases in the northern tropical and subtropical upper troposphere during the November 1994 mission have been derived for molecules such as HCN, CO, C_2H_2 and C_2H_6. Related mixing ratio enhancements of up to one order magnitude relative to unperturbed profiles have been observed. The enhancements in these species are correlated and appear to be associated with strong convective transport of near-surface emissions to the upper troposphere. The sources of such emissions are thought to be related to biomass burning at the end of the dry seasons in Africa and south America.

Another investigation has concerned the determination of vertical profiles of infrared cirrus cloud extinction in the tropical and subtropical upper troposphere and lower stratosphere (up to 50 mbar, or about 20 km altitude) during the same November 1994 mission. The magnitude of high-altitude cirrus clouds was assessed on the basis of the relative strength of broad extinction features in the 8-12 μm region resulting from the presence of small ice crystals. Comparison of these cirrus extinction measurements with calculations for randomly-oriented spheroidal ice crystals indicate an area-equivalent spherical radius of about 6 μm for the smallest ice crystals involved. Further studies of the ATMOS cloud extinction measurements are in progress.

Various correlation studies have further been performed on the basis of the ATMOS mixing ratio profiles of CH_4, N_2O, NO_y and O_3. Compact correlations have been demonstrated when data are sorted with respect to tropics, vortex, and extra-tropics/extra-vortex regions, and correlations for these regions are distinct. The combination of the set of correlations established among the species listed above has been shown to be a particularly powerful tool for studying the dynamical isolation and chemical distinction of tropical air masses from those in the extra-tropics. In order to facilitate applications of the results found here to modeling studies and data analyses, the polynomial fits to the correlations have been parameterized for the specific regions considered in the studies.

During the past years, the ATMOS Science Team has also worked on producing a "Version 3" (hereafter abbreviated by V3) geophysical data base derived from the observations made with the ATMOS instrument during all of its four shuttle-based missions.

With respect to the "Version 2" data base (publicly available via anonymous ftp at remus.jpl.nasa.gov in pub/atmos/version2) that contains volume mixing ratio profiles which were retrieved using a sequential onion-peeling approach for individual species, the V3 profiles are derived on the basis of a global fit approach for multiple species, which significantly eliminates error propagation in successive top-to-bottom mixing ratio retrievals. The new retrieval code is an adaptation from an algorithm developed at the Jet Propulsion Laboratory (Pasadena, CA, USA) for the analysis of MkIV balloon spectra. The main improvements resulting from this adaptation include the reliable extension of concentration profiles to lower altitudes, well into the free troposphere, as well as the retrieval of a couple of additional species such as CH_2O and HOCl.

The V3 data base is being evaluated quantitatively with respect to V2, and comparisons with data produced by other space-based instruments such as MAS (Millimeter-wave Atmospheric Sounder), HALOE (Halogen Occultation Experiment) and MLS (Microwave Limb Sounder), also with measurements performed by experiments aboard the NASA ER-2 airplane and with the MkIV-balloon FTIR are in progress.

5. Ground based versus Space observations of the atmosphere

Scientific atmospheric composition studies have been pursued at the University of Liège, based on the spectrometric analysis of infrared solar observations carried out at the international Scientific Station of the Jungfraujoch, Switzerland. These investigations currently return vertical column abundances (expressed in molecules par cm^2 above the observation site) of over 20 atmospheric constituents. Related objectives include :

(i) assessing the long-term evolution of these constituents , (ii) quantifying the relative role of transport/dynamics and chemistry in the variability observed at northern midlatitudes, and (iii) comparing the secular changes in the loading with source emission measurements at the ground through in situ monitoring networks such as AGAGE (Advanced Global Atmospheric Gases Experiment) and NOAA/CMDL (National Oceanic and Atmospheric Administrations/Climate Monitoring and Diagnostics Laboratory). As part of our commitment to the NDSC (Network for the Detection of Stratospheric Change), we have paid special attention to the total loadings of NO_y (combination of HNO_3, NO, NO_2 and $ClONO_2$ measurements), inorganic chlorine Cl_y (combination of HCl and $ClONO_2$ measurements) and inorganic fluorine F_y (combination of HF and COF_2 measurements). Related temporal evaluations during the 1990s indicate that NO_y has barely increased, that the rate of increase of Cl_y has steadily decreased to reach a maximum loading aroung 1996-97, and that F_y has continued to increase at a quasi-linear rate. The findings for Cl_y and F_y are consistent with expectations resulting from the application of the 1997-Montreal Protocol and subsequent Amendments that banned the most important chlorine-bearing source gases with strong ozone depletion potentials and their ensuing replacement by HCFCs, HFCs and FCs. The weak NO_y rate of change is statistically uncertain, but consistent with the rate of increase of its main source gas N_2O whose rate of increase during the 1990s was found to be equal to 0.2 ± 0.03 %/yr when taking into account a tropopause heightening of 16 ± 5 m per year during the past decades.

In addition to studies on the secular compositional changes in the stratosphere, investigations on the loading and evolution of many source gases with large global warming potentials (e.g., CO_2, CH_4, N_2O, CO, CCl_2F_2, $CHClF_2$, SF_6) have also been pursued; these monitorings are of relevance to the Kyoto Protocol seeking progressing reductions in the emissions of important greenhouse gases.

The activities evoked above have regularly been coordinated to support international campaigns organized at the level of the European Community (the most recent one being THESEO -Third European Stratospheric Experiment on Ozone- conducted during 1998 and 1999) as well as contributing independent data sets to validate space-based experiments (e.g., MAPS -Measurement of Air Pollution from Space-, CRISTA – Cryogenic Infrared Spectrometers and Telescopes for the Atmosphere-, HALOE -Halogen Experiment-, GOME -Global Ozone Monitoring Experiment-). The latter activity has been temporarily formalized within the frame of the EC project COSE (Compilation of atmospheric Observations in support of Satellite measurements over Europe) running from Oct. 1 1998 to Sept. 30, 2000.

Archiving of most Jungfraujoch results is updated regularly at the dedicated NDSC Data Host Facility of NOAA (http://www.ndsc.ncep.noaa.gov/) and at NADIR/NILU (htttp://www.nilu.no/projects/).

Financial support of both the ATMOS and Jungfraujoch activities evoked above has been provided primarily within the frame of the Belgian "Global Change-Durable Development" programme, coordinated by the Office of Scientific, Technical and Cultural Affairs, Brussels.

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C. Space Center of Liège

1. IMAGE - Far UV Spectrographic Imager (FUV-SI)

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) that 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.

In this programme, the CSL was responsible for delivering a protoflight of the optical subsystem of the FUV-SI, fully functional. The main mechanical parts were delivered to CSL in January 98 by Belgian industries. CSL, thanks to its vacuum chamber facilities, was able to perform the assembly, integration, alignment, and test of the instrument. Tests consisted in :

- Environmental tests : vibrations, thermal balance, thermal vacuum
- Calibrations : field of View, radiometric response

Tests were completed in July 98. Successful results were reached. The instrument performances are in perfect agreement with the scientific requirements.

The instrument was delivered to UCB in August 98. Since that time, our activity was limited to consulting in data understanding, in order to help UCB to finalize the instrument (mainly electronics).

2. Publications

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D. Royal Meteorological Institute of Belgium

1. Ionospheric studies

The Dourbes station pursued the hourly electronic profile measurements and transfered the results to the COST Action 251.

A program of measurements started on the recording of several low radio frequencies (16 to 78 kHz) of permanent transmitters in order to compare with the results of a local model of the D region.

The total solar eclipse of Augustus 11, 1999 was an opportunity to have a special campaign of measurements. Besides the vertical soundings (Digisonde), special low frequencies receivers were used to follow the changes in the D and E regions. A large campaign organized by the Belgian Radioamateur Union (UBA) with the co-operation of the Royal Meteorological Institute (RMI) allowed to more than one hundred people to receive signals from a special balise on 40 and 80 m with mostly numerical recordings.

Finally the ionospheric errors induced in the GPS system and the meteorological applications of this system were studied.

2. Solar constant and Earth's radiation budget

2.1. SOLCON/HITCHHIKER

The SOLCON experiment measuring the Solar constant has flown within the Hitchhiker programme of the Goddard Space Flight Center. The second (IEH-3) of the 4 planned missions occurred in October 1998 on board of the STS 95 shuttle.

2.2. ESA - SOHO Program

Solar constant data are routinely received at the RMI from the DIARAD (Differential Absolute Radiometer) installed on the VIRGO experiment. The experiment didn't yield any data during the loss of telemetry of SOHO from the 24th of June 1998 until the 7th of September 1998 after which it returned to a nominal mode. The second gap in the data is a result of the loss of the last SOHO gyro from the 20th of December 1998 until the 4th of February 1999 after which it returned to a nominal mode.

The DIARAD experiment gives excellent results with a light ageing of the instrument from the end of 1998 and insures the continuity of the monitoring of the Solar constant from the SOHO satellite. The data show the significant increasing of the solar activity during 1998-1999 as expected.

2.3. The Belgian Space Remote Operation Center (BSROC)

<u>ESA-SOHO mission</u>

BSROC supports the transfer of the SOHO mission DIARAD radiometer on VIRGO experiment.

<u>NASA - Hitchhiker mission</u>

BSROC supported the simulation and flight activities of SOLCON (mission IEH-3) on Hitchhiker launched in October 1998 with STS-95.

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II. Space Astronomy

A. Royal Observatory of Belgium

1. Infrared Space Observatory (ISO)

The reduction of ISOPHOT C100 observations suffers from an accumulation of various problems. Some of these problems were studied in collaboration with the "Katholieke Universiteit Leuven". Data from the ISO archive were used to gain a better understanding of the instrument, and to develop improved reduction techniques. In collaboration with the University of Liège, these techniques were applied to a set of their observations on Luminous Blue Variables in the Large Magellanic Cloud, in order to determine the mass of the dust present around these stars.

In collaboration with the stellar group at the "Katholieke Universiteit Leuven", infrared (ISO-SWS data) spectra of a few red giant stars were compared to synthetic spectra in order to get a better understanding of the atmospheres of cool giants.

2. X-ray Multimirror Mission (XMM)

The Observatory collaborated with the University of Liège in the preparation of an XMM observing proposal to study the nonthermal emission from single early-type stars. They also intend to collaborate on the reduction and interpretation of data from the Guaranteed Time observations of the University of Liège.

3. International Ultraviolet Explorer (IUE)

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. In 2000, this version will be superseded by the INES (IUE Newly Extracted Spectra) archive.

4. 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 (ROB), 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. Based on the list of identifications of solar line compiled by M. Geller in the spectral region 625 - 4800 cm^{-1}, a computer data base of atomic lines is in progress. The complete file will include a set of about 5000 atomic lines with the relevant parameters (excitation potential, gf value, ...) which reproduce rather well the infrared solar spectrum, taking other sets of molecular lines into account. Most of the gf values were empirically derived from a fit of the observed line intensities. This new atomic data bank should also be useful for the calculation of synthetic spectra of cool stars having nearly the solar chemical composition.

5. Solar and Heliospheric Observatory (SOHO)

Over the past two years, the Solar Physics Department continued its participation to the EIT experiment (Extreme-ultraviolet Imaging Telescope) on the SOHO mission (Solar and Heliospheric Observatory), as scientific Co-Investigators. The activities concentrated on four major axes:

- Scientific planning of the experiment and execution of special observing campaigns, in part from 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.
- Determination of the flat-field corrections of the instruments and in-flight monitoring of the radiation-induced ageing of the detector.
- Creation and maintenance of a local archive and catalogue of EIT data and participation in the data distribution process.

The results obtained in 98-99 can be summarised as follows:

5.1. In-flight support of the EIT experiment

Our group is responsible for the corrections of spatial non-uniformities in the response of the instrument. Those corrections must be determined in flight and evolve continuously with time due to radiation-induced ageing of optical and optoelectronic components. The changes are now under continuous monitoring, and an investigation of the physical mechanisms was undertaken in order to derive proper corrections. The results from the first CALROC sounding rocket experiment of the Naval Research Laboratory (USA), launched in October 1997, were processed together with simultaneous EIT images. Based on image ratios, some preliminary conclusions could be derived regarding the conversion of calibration images routinely made on-board EIT (visible light) into accurate EUV degradation factors in the 4 EIT bandpasses. Those results, presented at the November 1998 LASCO/EIT Consortium meeting, are now being refined. In December 1999, new flat-field calculations were made for the CALROCII payload that will be launched on a second sounding rocket flight in April 2000.

The scientific planning of the EIT observations was taken over by F. Clette and D. Berghmans during a one-month shift in April - May 1998. Besides the daily planning of EIT's observing sequences and the "Sun Status" briefings provided for the global planning of SOHO operations, another primary task was to care for the coordination of the JOP80 campaign initiated by the ROB.

5.2. Observing campaigns

A SOHO Joint Observing Program (JOP80) was proposed in February 1998 for the multispectral study of minor activity and short-lived transients inside solar active region loops. It was accepted by the SOHO Science Working Team in April and was finally run on May 13, 1998. This campaign relied on the use of the EIT experiment in a special very high cadence observing mode, which was fully tested and qualified for the first time. It involved the participation of 8 experiments in space (SOHO: CDS, SUMER, MDI; YOHKOH: SXT; TRACE) and on the ground (Sacramento Peak, La Palma: SVST) that, for many of them, were operating at their highest possible cadence.

Some data sets from this successful and productive campaign (EIT, SXT, and TRACE) have been analysed. From the image data in different temperature ranges, it was possible to identify several classes of transient and flows, and evidence of propagating magneto-acoustic waves was found in quasi-open loops at the edge of the active region. This research is susceptible to bring new insights in the issue of the coronal heating.

In 1999, the main event, that involved a lot of preparatory work at the ROB, was certainly the August 11, 1999 total solar eclipse. In the context of the Joint Organisation for Solar Observations (JOSO), a European consortium of solar astronomers, F. Clette created and coordinated a Trans-European Coronal Observing Network (TECONet). 30 stations distributed along the totality line, from France to Iran, carried out wide-field polarimetric observations of the visible-light corona. In that context, a coordinated observing sequence was proposed to and run by the EIT and LASCO coronal imagers on SOHO.

5.3. Archive, data distribution and research projects

The daily maintenance of the EIT archive at the ROB is now automated. The data are transferred from the primary archive at the Goddard Space Flight Center instead of the MEDOC at the Institut d'Astrophysique Spatiale (Orsay) which could not provide the service. By the end of 1999, the EIT archive had grown to the full capacity (200GB) of our magneto-optical disk archive. From now on, the oldest data will be kept off-line. Data sets were prepared and distributed to researchers, mainly in Eastern Europe.

The availability of the full archive in-line opens unique possibilities for searches spanning the whole duration of the SOHO mission. This is why a research proposal was submitted to the Belgian SSTC/DWTC (Service of the Scientific, Technical and Cultural Affairs). This new project will be based on the exploration of the whole EIT synoptic image series in search for all classes of structures and events in the corona and transition region, and for their evolution with the solar activity cycle. The proposal was approved at the end of 1999, and this long-term effort has now started. It will involve the application of advanced image processing methods.
Moreover, the ROB also took part in the proposals and science definitions of several future space missions (TRIANA/ASCE, STEREO for NASA; SPI for ESA).

6. HIPPARCOS Astrometric mission and double star astronomy

6.1. Final Hipparcos catalogue

Two additional CD ROM's, Celestia 2000 and Tycho-2, have been released in, respectively, 1998 and 1999. A critical analysis of the contents of the final catalogue regarding the data on double and multiple systems will soon be published. It may be considered as a complement to the Introduction of the Hipparcos Catalogue. Consecutively, the complete list of the double and multiple systems (18.644) as identified in the catalogue - version of January 1, 1996 - will be made available together with an explanatory paper. This list includes the 2.994 systems newly discovered by the satellite as well as the 155 new astrometric pairs and the 38 new astrometric components of known visual double stars and is formatted in the same way as the CCDM.

6.2. Catalogue of the Components of Double and Multiple Systems (CCDM)

The Catalogue of the Components of Double and Multiple Systems has been pursued in view of a second edition to appear in 2000. It should be regarded as complementary to the INDEX-Washington Double Star Catalogue (USNO) and be useful for various purposes. The search for accurate positions has these last two years been principally based on data from the Guide Star Catalogue (GSC - first and second editions). Meanwhile, the number of definitively identified systems has increased from 41.738 to 45.000 systems. The realisation of the CCDM is fully described in a paper with title "L'Histoire d'un Catalogue: le CCDM".

6.3. Double Star Astronomy

Two summary papers report on an international programme for multicolour ground-based CCD observations of "intermediate" Hipparcos double stars (with angular separations between 1 and 15 arcsec). The results of a first sample of almost 290 "intermediate" double stars are published. The additional results of a second sample of 250 double stars will soon be made available.

In the framework of an ESA/PRODEX project on Hipparcos Double Star Data Exploitation a study was performed of 38 double-lined spectroscopic-visual systems. For this, a computer code, originally developed for the determination of the classical orbital elements of visual binary stars, was further extended to also include radial velocity data.

For the 38 double-lined spectroscopic-visual systems we derived parallaxes independently from any ad hoc hypothesis. These parallaxes were next confronted to the corresponding Hipparcos parallaxes. The results on the thus derived new mass and parallax determinations were also presented in the context of a dissertation at the "Université de Liège". A new implication for understanding the structure of our nearest neighbour, the binary system α Centauri, has been proposed.

Attention was also given to the (re)determination of the orbital elements of pure visual binaries, for which no radial velocity orbital data exist. In combination with the highly accurate Hipparcos parallaxes and the differential magnitudes of the components derived from the Hipparcos photometry, we have shown that a mass-luminosity relation in the range $0 \leq M_{bol} \leq 7.5$ mag could be derived which agrees well with the previous determinations but which also points to some interesting discordant systems which would deserve further observation. In order to be able to select such interesting cases, the objective quality assessment of the orbits is a necessary and pertinent information. Realistic errors based on a statistical method called Bootstrap have been computed for the orbits of a large sample of visual binaries over a wide range of orbital periods. These results have formed the basis for a dissertation presented at the "Katholieke Universiteit Leuven". A direct result of these computations in combination with the new Hipparcos parallaxes is the derivation of total masses for some 500 visual binaries with realistic and objective error information.

6.4. Variable Star Astronomy

A search for variability was done among the photometric data of the Tycho Catalogue in collaboration with Drs. J.L. Halbwachs and S. Piquard (Observatoire de Strasbourg) and Prof. I. Andronov (Odessa, Oekraine). The selection of candidate variables and the subsequent period analyses are progressing.

A statistical study on the total number of observable variable stars in the Galaxy was started in collaboration with Dr. L. Eyer (K.U.Leuven). This research makes use of all the Hipparcos data and preliminary results have been presented in relation with GAIA, a future candidate astrometry space mission.

A study of the variability for both components of the wide double system HIP 115510 and HIP 115506 has been finalized. The Hipparcos astrometric data were used to establish the common space location and origin of the components. It was further shown that the Hipparcos epoch photometric data - even though with larger errors than normal due to the presence of the companion star - allow to retrieve periodicities with amplitudes as low as 0.01 mag, when they are submitted to a critical evaluation and selection.

6.5. GAIA, a future candidate astrometry space mission

Implications of a mission such as GAIA in the domains of double-star and variable-star astronomy were presented by members of the Royal Observatory during a national meeting on GAIA on November 26, 1999.

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B. Space Center of Liège

1. EIT: Extreme UV Imaging Telescope

The EIT instrument is operating on board the SOHO platform, orbiting at 1.500.000 km from earth. This telescope which was developed under CSL technical responsibility is producing images of the solar corona in 4 wavelengths of the EUV spectrum since its first light which occurred in Jan 96.

The Space Center of Liège ("Centre Spatial de Liège", CSL) worked on the characterization of the in-orbit response modifications, based on the detailed knowledge of the instrument gained during its development. A first important degradation of the entrance aluminium filters occurred in Feb-98. It had to be compensated by the addition of a back-up filter, which suppressed all the unwanted stray-lights but increased the exposure times.

In Jun-98, the control of the SOHO spacecraft is lost for 3 months. The instrument will be off-pointed for an extended period, with extreme cyclic thermal conditions. SOHO is recovered in Oct-98. The EIT instrument withstood successfully these conditions, showing an important improvement in the sensor response and a decrease in the sensor aging. Specific studies showed that the spacecraft spinning during this 3-month period provided an unexpected detector warming. This warming partly annealed the detector EUV radiation damages and released the contaminant that was accumulated on the cooled detector.

In Dec-98, SOHO looses its last operational gyroscope. Operations are stopped for 6 weeks, but the pointing remained controlled, ensuring stable thermal environment for the sun-pointing instruments. In Feb-99, SOHO observations are restored, using a new gyroless attitude control software. After this 6-week interruption, the EIT instrument did not show any degradation, demonstrating the absence of condensed contaminant on the cooled detector.

The remaining response degradation in EIT is due to the cumulated EUV irradiation, that locally damaged the CCD efficiency.

In order to support the SOHO-EIT calibration, a sounding rocket program (CALROC) has been set up. After a first calibration flight in Oct-97, a second CALROC mission is scheduled for spring 2000. CSL worked on the on-ground calibration of this new mission, and will support the final preparation in early 2000.

2. INTEGRAL-Optical Monitoring Camera (OMC)

The Optical Monitoring Camera (OMC) is an imaging system which forms part of the instrument package for INTEGRAL, an ESA medium-size mission (M2) to be launched in April 2002. A complete presentation of the Integral mission and status is available at URL: http://sci.esa.int/integral/. The OMC instrument consists of a Camera Unit and an Electronic Unit.

The OMC Camera Unit consists of a *focal plane assembly* using a passively cooled CCD (2048 x 1024 pixels, imaging area: 1024 x 1024 pixels) working in frame transfer mode. The CCD is located in the focal plane of an *optical system* including a Johnson V-filter to cover the 500 - 850 nm wavelength range. The optical system is held in a structural *main baffle* that is closed by a *cover system* (Fig. 1). The overall instrument will be covered by MLI thermal blankets, exception made of the radiators. The OMC will be mounted close to the top of the payload module structure.

The OMC will observe the optical emission from the prime targets of the Integral main gamma-ray instruments with the support of the X-Ray Monitor JEM-X.

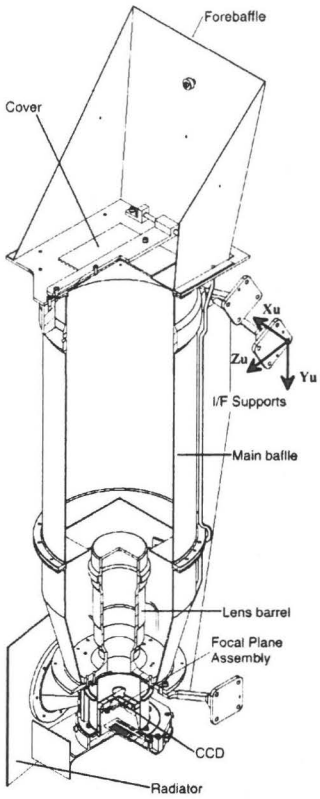

Figure 1. OMC general view (electronics not shown).

The OMC instrument is developed by an European Consortium including scientific institutions from Spain, Belgium, United Kingdom, and Ireland. In this programme CSL is responsible for the design, production, and verification of three sub-systems of OMC :

- the optical system;
- the cover system (door mechanism);
- the main baffle

3. XMM-Optical Monitor (OM)

The Optical Monitor (OM) instrument is operating on board the XMM spacecraft, which has been launched on 10 December 1999.

The OM is co-aligned with the spacecraft main telescope and has a field of view (17 x 17 arc min) matched to the one of the XMM X-ray cameras. After being focused by two mirrors, the light is directed towards one of two identical filter wheels and detector chains. In each, an ultra-compact electronic image intensifier amplifies the light signal a million times before it falls on a silicon detector chip (CCD) capable of registering 100 frames a second. Detailed imaging on the central region of a view is possible using a x4 magnifier situated on the filter wheels, which also incorporate two "grisms" for low resolution spectroscopy. Data is then processed and compressed before being sent back to Earth as part of the spacecraft telemetry.
The ability to observe X-ray targets simultaneously in the visible and UV will vastly increase the knowledge of the Universe, particularly about the prospect of better understanding the physical processes in quasars. These are the brightest and most distant known objects producing radiation covering the full range of the electromagnetic spectrum.

CSL is partner in the Optical Monitor consortium and was responsible for the delivery of 3 power supply units (Delivered in February 1998). CSL conducted the environmental (thermal and vibration) test of the instument (June 1998) and optical verification test (April 1999) in its facilities. CSL designed and provided specific ground support equipment for this test campaign.

4. FIRST - PACS: The Photoconductor Array Camera and Spectrometer for FIRST

The Photoconductor Array Camera and Spectrometer (PACS) is an imaging spectrometer-photometer which forms part of the science payload of the Far InfraRed and Submillimeter Telescope (FIRST), an ESA cornerstone mission (CS4) to be launched in 2007. FIRST will have a passively cooled ∅3.5 m Cassegrain/Ritchey-Chrétien telescope, to be provided by NASA, and a science payload of three instruments - HIFI, PACS, and SPIRE - which will be provided by Principal Investigators (PIs) and their consortia. The focal plane units of these instruments will be housed inside the payload module which provides a cryogenically cooled environment using the superfluid cryostat technology developed for the Infrared Space Observatory (ISO) mission. The PACS instrument is designed for imaging photometry, low- and medium-resolution spectroscopy in the wavelength region ranging from 60 to 210 μm. This instrument will enable the scientific community to deepen the researches on circumstellar physics, on star and galaxy formation, and more generally on the distant universe as a continuation of the ISO mission. A presentation of the FIRST mission and status is available at URL: http://sci.esa.int/first/.

PACS employs two 25×16 Ge:Ga detector arrays covering the three bands 60-90 μm, 90-130 μm, and 130-210 μm. The long-wavelength band array is stressed mechanically to improve its sensitivity at longer wavelengths. The photoconductor arrays operate at 1.7 K. The use of a dichroic beamsplitter and separate re-imaging optics enables PACS to perform photometry simultaneously in the three bands, covering ~1.5'×1' and ~3'×2' on the sky, while providing full beam sampling at respectively 90 μm and 180 μm. As a spectrometer PACS provides a resolving power R in the range 1500-2000 (Δv in the range 150-200 km s^{-1}) with an instantaneous coverage of ~1500 km s^{-1} and simultaneous imaging of a ~50"×50" field of view, resolved into 5×5 pixels. A flat diffraction grating of 8.5 lines/mm, used in a Littrow configuration, provides the required spectral dispersion.

The PACS instrument is developed by a European Consortium, led by the *Max-Planck-Institut für Extraterrestrische Physik* (MPE, Germany), including scientific institutions from Germany, Belgium, Italy, Spain, Austria, and France. In this program, CSL is responsible for the design, production and subsystem-level verification of the focal plane diffraction grating assembly, the mechanism and detector 'warm' control electronics, and the 'warm' interconnecting harness.

5. X-Ray Telescope testing

CSL is involved in the testing of the X-ray Multi mirror Mission (XMM) optics since 1994. The goals of the tests performed in 1998-1999 were:

- to measure the optical performance of the Flight Model Mirror Modules after simulated launch, and in orbit configurations;
- to perform the calibration of the Mirror Modules.

To achieve these goals, a full EUV (58.4 nm) collimated beam is used to assess the optical characteristics in a representative flight configuration. The X-ray performance is controlled by means of an X-ray pencil beam and an X-ray collimator. The pencil beam is used for the determination of the Mirror Shell position, wing scattering and X-ray reflectivity measurements; the X-ray collimator is dedicated to effective area measurement over 1.5 to 8 keV energy range. This is a complete and original way to experimentally work out effective areas of an X-ray telescope.

This project was funded by ESA. The project ended in 1999 with traditionnal and specific tests on a spare Flight Model Mirror Module to enable a further understanding of the image quality of an individual Mirror Shell with respect to the final Mirror Module performance. A last test was performed on a single thinned Mirror Shell fixed

on a 32 spokes spider (instead of the usual 16). These tests have shown the possibility to manufacture very thin MS of good optical quality.

6. Publications

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C. Astronomical Observatory of the University of Ghent

1. Dusty space plasmas

In the framework of our research in the physics of dusty space plasmas, more in particular that of wave propagation in such plasmas, several new aspects were investigated.

Dusty plasmas contain charged dust grains which are much more massive than protons or alpha particles, and usually carry high negative charges due to preferential capture of electrons. Recent efforts have gone into the modelling of possible self-gravitational forces, due to the heavy dust grains. Significant modifications of linear mode dispersion and of the relevant Jeans criteria for gravitational collapse have been obtained.

2. Cometary physics and related research

Some of these 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. In this respect, we have given a direct treatment of intermediate turbulence at comet 1P/Halley, for a frequency regime between the proton and oxygen gyrofrequencies.

3. Publications

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D. Astrophysical Institute of the "Vrije Universiteit Brussel"

1. Population synthesis in stellar aggregates with continuous star formation

Observations with the most powerful and modern telescopes reveal that at least 50 % of all stars are binaries. Our research group has a 30-years lasting experience with binary evolution. We have constructed an extended library containing the results of our binary evolution code on an almost complete sample of binaries with a large variety of primary masses, mass ratio's and periods. The results from these evolutionary calculations are used to study the influence of binary presence on the stellar content of a region characterized by continuous stellar formation over the last 50 million years. These results are -of course- compared with the observed population synthesis. We have focused our research on the formation of: Runaways, Wolf-Rayet stars, Röntgen binaries, Red Supergiants, Pulsars (single and binary), Supernova explosions.

2. Population synthesis in regions with only one starburst

A large fraction of all stars are born simultaniously in one single starburst. Observations with the HST (Hubble Space Telescope) show that such a burst contains a multiple of one hundred thousand stars. These stars evolve simultaniously and interact dynamically. Our group focusses its research mainly on the effects which are triggered by the massive stars in these bursts: The spectral evolution of starbursts, the evolution of X-rays which are produced in these bursts, the dynamical evolution of stars in those bursts and the possible production of runaways.

3. The chemical evolution of galaxies

At the end of their evolution, some stars give their material, which is enriched with elements heavier than He by nuclear fusion, back to the interstellar medium. As a consequence, the chemical composition of a galaxy is also altered as as function of time. Starting from a nebula containing mainly hydrogen and helium, our galaxy has attained a composition with solar abundances of the chemical elements.Thus, with 2 % of the mass made of elements heavier than He. Our group studies the influence of the presence of binaries on this chemical evolution.

4. Publications

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E. Institute for Astronomy and Astrophysics of the "Université Libre de Bruxelles"

Images at 12 μm of several 6' x 6' fields at different distances from the center of the globular cluser 47 Tuc have been obtained with ISOCAM onboard ISO. The aim of this project is to derive the evolution of the mass loss rate along the giant branch of 47 Tuc. All sources brighter than 0.7 mJy at 12 μm have been detected, which corresponds to stars above the horizontal branch. No dust-enshrouded stars with no visible counterparts have been detected.

A good mass indicator is the flux ratio F_{12}/F_2, which has been constructed by combining ISOCAM data with DENIS data providing the 2μm flux. It turns out that this ratio is consistent with photospheric colors for all stars on the giant branch, but the long-period variable stars, which exhibit large excesses at 12μm indicative of the presence of a circumstellar dust shell. This result strongly confirms the importance of Mira-type pulsations in triggering the mass loss in late-type giant stars.

Publications

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

1. Massive stars

During the period under consideration, the activities of the team « Massive Stars» linked to space astronomy have been essentially driven by the opportunities offered by the XMM satellite. XMM will be used to cover several aspects of the research linked to massive stars, and particularly to study various characteristics of the winds blowing from these massive objects. A considerable amount of time has been spent in the preparation of the observations which will be performed in the framework of the Guaranteed Time to which we have access. We also got observing time for our projects in the first open time competition for the use of the XMM satellite (AO-1).

2. Extragalactic astrophysics

During 1998-1999, members of the Liège team "Extragalactic astrophysics and space observations" have been involved in detailed studies of gravitational lenses and quasars using the Hubble Space Telescope (HST).

For the case of the bright quasar HE1104-1805, we have successfully identified the gravitational lens, at a redshift $z = 1.32$, responsible for the observed double QSO image. This is actually the most distant known gravitational lens.

The gravitational lensing effects (amplification bias, deflection of the light rays and reddening) induced by 'damped Ly-α' gas clouds and intervening galaxies have been investigated on the basis of spectroscopic observations and direct imaging collected with both HST and ground-based telescopes.

A non exhaustive bibliography on gravitational lensing (more than 2500 titles), direct HST images and a database of multiply imaged quasars are available via the URL: http://vela.astro.ulg.ac.be/grav_lens/.

Moreover, the lateral extent of the Ly-α giving rise to narrow absorption lines in the spectra of nearby quasars has been derived on the basis of spectra obtained with HST for the QSO pair Q1026-0045 A and B.

In addition, we have also been involved in the PRODEX project "HST observations of gravitational lenses" (observing time has been granted to us in 1998 and in 1999 with the Hubble Space Telescope) and a large team of astrophysicists from the Institute of Astrophysics and Geophysics (Liège University) is also involved, through both guaranteed and open observing time, in the preparation of a large survey of Large Scale Structures (galaxy clusters, quasars, AGN, ...) with the successfully launched Newton X-ray Multi Mirror (XMM) ESA satellite.

3. High energy astrophysics

In the frame of the ESA high-energy astrophysics mission "INTEGRAL" we are involved through PRODEX grants :

(i) in the INTEGRAL Science Data Center (ISDC) consortium (Geneva), as a participating institute, with a scientist working at ISDC in the role of a liaison between the project and the belgian astronomical community;
(ii) in the Optical Monitor Camera Science team (definition of core program, planning of specific observations, etc)

and through an INTAS-ESA grant in coordinating the "Implementation of an INTEGRAL Users' Support Center in Russia" (joint venture Liège-Utrecht-ISDC-Moscow-St. Petersburg).

Observing time on INTEGRAL is guaranteed both in the γ-ray and in the optical domain via (i) and (ii) in addition to what we may obtain in the frame of the guest observers' program.

4. Publications

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G. Astronomical Institute of the "Katholieke Universiteit Leuven"

1. Introduction

The Astronomical Institute of the "Katholieke Universiteit Leuven" has a tradition on theoretical studies of stellar structure and stability, in which a strong focus is now put on the interpretation of astronomical data in terms of theoretical concepts. The interest in space science of the institute is science-driven in the first place. Special emphasis is put on a "multiwavelength" approach towards astrophysical phenomena, and ground-based and space diagnostics are considered in the first place as a function of the scientific goals they may serve.

2. Pulsating Stars

Pulsating stars are interesting objects for probing the internal structure of stars, because of two reasons. First, the fact that a star presents an instability, includes hints to the physical processes inside the stars, which are not directly accessible to observational scrutiny. Second, the eigenmodes in which stars pulsate are directly linked to fundamental stellar parameters, and hence contain diagnostics about those.

The institute has been approached by the HIPPARCOS team to identify the various kinds of periodic variabilities discovered in the large photometric database gathered by this satellite. This database is of particular interest, because with respect to ground-based observations it is much less contaminated by observational selection effects which plague the interpretation of ground-based variable-star results. These efforts have led to a substantial increase of the amount of known pulsating stars in the classes of 'slowly pulsating B stars' and 'Gamma Doradus variables'. Both kinds of stars pulsate in g-modes, which penetrate more deeply into the stars as the usual p-modes, and hence are better probes of stellar interiors. This research in turn has triggered important ground-based programmes and international collaborations.

3. Fundamental data on cool stars

The institute has been heavily involved in the consortium around the "Short Wavelength Spectrometer" (SWS) for ESA's 'Infrared Space Observatory' ISO, both for scientific and data-analysis purposes. An ambitious project was developed to increase the reliability of the calibration of the instrument, through a thorough analysis of the spectra obtained for bright cool standard stars. The project involves an iterative process: indeed, the calibration of a new instrument relies on the observation of 'known' sources, but the fact that the instrument opens a new domain in spectral resolution implies that the "knowledge" of these sources has to rely on tests on how the previous knowledge can be extrapolated.

In the framework of this project, standard candles describing a range in spectral types have been observed by ISO at high signal-to-noise ratios, and state-of-the-art modeling was performed for each of them. The range in spectral type enabled to disentangle calibration effects from shortcomings of the modeling, and consequently to improve on both. As a result, the calibration files could be improved, so as to achieve an accuracy at the percent level, making the SWS the best calibrated of all ISO instruments. From a more astrophysical point of view, several improvements of the cool-star-atmosphere models could be suggested.

4. Circumstellar disks of young stars

The involvement of the institute in the SWS consortium brought with it a responsibility in the core programme of the satellite around the subject of the circumstellar media of young stars. The programme concentrated on spectra of the environments of young stars of a few solar masses (Herbig Ae/Be stars), which are considered as the progenitors of main-sequence stars with circumstellar disks such as Vega and Beta Pictoris.

The ISO-SWS spectra of these circumstellar disks proved to be much richer than was anticipated, providing clues to perform mineralogical studies about the early stages of solar systems. A well-publicized result is the

occurrence of crystalline silicates in the disks of already evolved disks. Such structured silicates are uncommon in the interstellar medium, but have been well documented in comets. A spectacular result is the close resemblance of the silicate spectrum of the disk of the young star HD100546 to that of the bright and dusty comet Hale-Bopp. Another remarkable result is the occurrence of large amounts of crystalline water ice close to the young star HD142527. Several (invited and contributed) papers were devoted to interpret these results in the framework of the cosmic dust cycle and the formation of solar systems in particular.

After IRAS unexpectedly detected circumstellar disks around main-sequence stars, the origin and statistics of the occurrence of such disks has received widespread attention, the more so that at the same time the occurrence of planets around other stars has become a matter of verified science. An ISOPHOT programme was conducted to search for circumstellar disks in the sample of G dwarfs which are scrutinized for planets by the Geneva group. The fraction of detected objects is similar to the one found for more massive stars, which - taking into account the critical dependence of stellar age on stellar mass - implies that the disks around lower-mass stars are also longer-lived. The detection of small infrared excesses with the ISOPHOT instrument requires extreme care with the data analysis, which has much benefited from a coordinated approach with scientists from the Royal Observatory.

5. Circumstellar disks of evolved stars

The starting point of the interest of the institute in infrared astronomy was the study of the outflows of evolved stars, which had been studied at optical wavelengths first. Through ground-based as well as space data the evolution of these final stages of evolution has been probed intensively.

It has turned out that various unusual evolved stars with peculiar aspects over the spectral range from UV (IUE, HST) over optical (ground-based) to IR (IRAS, ISO) turn out to be binaries, involving mass transfer along a mode which presently is not understood, and during which a peculiar process of separation of gas and dust is observed to have taken place. This particular evolutionary picture was shown to involve the formation of a long-lived disk surrounding the binary system. A spectacular result of the ISO observations now implies that also in these disks crystalline silicates, and probably also planetesimals, evolve, shedding new but unexpected light on the universality of structure formation in circumstellar disks.

6. Miscellaneous

Realizing that space-astronomy involves a technological component, the institute aims at investing in instrument-related work as close to the scientific exploitation as possible. In this context, various contributions to the data analysis software of the SWS instrument have been made. This has led to the involvement in various kinds of research in collaboration with other groups.

In this framework, a specific contribution concerned the "Post-Helium Programme" of SWS, which is the observation of some 300 sources of most diverse kinds in the non-thermal infrared during the two weeks after the helium boildown officially ended the life of the satellite. This project not only involves the study of the instrumental response under rapidly varying circumstances, but also a near-IR atlas of astronomical objects which contains astrophysical information in its own right, but also will serve as a database for future population studies with instruments such as NGST.

7. Preparing the future

The insititute is now involved at the co-PI level in the consortium around the "Photoconducting Array Photometer and Spectrometer" (PACS) for ESA's FIRST cornerstone mission. This involvement includes the coordination of the Belgian technological efforts for constructing the instrument, as well as the development of a contribution to the "Instrument Control Centre". We also have the ambition to prepare the national community to take advantage of this novel instrumentation, to redirect its projects towards the new possibilities far-IR and submm astronomy holds for probing the distant and early universe.

Finally, the institute is also involved in the preparation of several space missions in the field of stellar seismology, where various satellites will probe the stability of stars with unprecedented accuracy and with a time coverage which cannot be attained from the ground. Since variable-star research, both theoretically and observationally, remains the core interest of the group, initiatives will be taken to encourage these projects.

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III. Space geodesy

A. Royal Observatory of Belgium

1. Introduction

The space geodesy activities of the Section "Time, Earth Rotation and Space Geodesy" of the Royal Observatory of Belgium (ROB) comprise two main topics: the first one is related to the Global Positioning System and the second one concerns the study of the theoretical nutations for the Earth and Mars.

2. Global Positioning System

At the ROB, we investigate the use of permanent tracking stations of the Global Positioning System for different types of applications: reference frame maintenance, measurement of long-term ground deformations, time and frequency transfer, ionosphere monitoring and troposphere monitoring. This work is based on the data from seven permanent GPS stations in Belgium installed by the ROB. The GPS data from these permanent GPS are freely available and can be retrieved using Internet (http://homepage.oma.be/GPS/natntwrk.html).

2.1. Reference frame maintenance

One of the main objectives of the GPS team is the integration of Belgium in international reference frames. This is obtained through the integration of part of the ROB GPS stations into international GPS networks such as the IGS (International GPS Service) and the EUREF (European Reference Frame) networks. The station in Brussels belongs to the IGS network and the four stations Brussels, Dentergem, Dourbes and Waremme belong to the EUREF network.

The ROB operates also one of the EUREF Local Data Centres and it is computing on a daily basis the positions of a network of 27 European GPS stations. These solutions are submitted to EUREF and flow to the IGS and the International Earth Rotation Service (IERS).

The three remaining permanent stations of the ROB are dedicated to geophysics: two are on one and the other sides of a seismic fault and the other is collocated with a superconducting gravimeter.

In addition to this, the ROB is responsible for the coordination of the activities related to the permanent EUREF network, comprising of 95 permanent GPS stations and 12 analysis centres. The Central Bureau of the permanent EUREF network is hosted at the ROB (http://homepage.oma.be/euref).

Since the spring of 1998, the ROB has been operating a combined GPS/GLONASS receiver (3S-Navigation R100-30/T) on its premises. This receiver participates, since October 20,1998, to the international IGEX (International GLONASS experiment) observation campaign.
The first GLONASS code data have been processed in 1999.

2.2. Time and frequency transfer

The ROB operates one of the few Time Laboratories collocated with an IGS station. The ROB time lab is participating with 3 Caesium clocks to the realisation of TAI (International Atomic Time Scale) and as a result the ROB's IGS station located at Brussels, has been selected as one of "fiducial clock" stations within the IGS/BIPM project.

The IGS/BIPM project aims at taking advantage of the number of IGS receivers driven by stable atomic clocks to enlarge the network of stations participating to the realisation of TAI.
The ROB has also taken advantage of its rather unique collocation (contributing both to TAI and IGS) to study the use of multi-channel geodetic GPS receivers for time and frequency transfer applications. We have also

evaluated the critical aspects of the present set-up of the IGS receiver at Brussels, driven by a hydrogen maser, to contribute to the BIPM/IGS Pilot Project. We demonstrated that the main errors were caused by small temperature variations in the lab where the receiver was located. To remedy to this problem a high performance temperature control was installed in the summer of 1999 in the time laboratory.

2.3. Ionosphere monitoring

At the Royal Observatory of Belgium, the ionospheric activity is monitored, since April 1993, using the GPS measurements collected at Brussels.

Due to the increase of the solar activity, a very strong increase of the ionospheric activity has been observed in 1998 and during 1999:

- the Total Electron Content (TEC) has grown in a significant way; in 1998, the daily mean TEC was 2 times higher than in 1997.
- the number of irregular ionospheric phenomena (such as Travelling Ionospheric Disturbances and scintillation effects) has also grown in a significant way ; the number of ionospheric disturbances observed in January 1999 was 15 times higher than in January 1998.

The maximal solar activity, which has a cycle of about 11 years, is foreseen in the beginning of the year 2000.

2.4. Troposphere monitoring

Many geophysical GPS applications require an accuracy of 1 mm, as it is also the case for the ROB's study of the fault scarp discovered in the vicinity of Bree, where the expected movements are of the order of 1 mm per year. At present, the tropospheric refraction is one of the main error sources affecting GPS coordinate time series. This error mainly influences the height component. Therefore, in 1998, the ROB has started a study of the tropospheric refraction effect on GPS coordinate time series. This project aims at improving the correction of the tropospheric error. This error contains a wet and a dry component. The wet component is very difficult to correct because it depends on the water vapour content in the direction of the observed satellite. This parameter is highly variable both in space and time. The goal of the project is to use the measurements collected by a water vapour radiometer and by meteorological sensors to improve the correction of the wet component of the tropospheric error. At present, meteorological sensors are installed at Brussels and the water vapour radiometer will be operational mid 2000.

2.5. Redesign of the data flow within the permanent GPS network

Taking into account the growing interest of the Belgian GPS community for near real-time GPS geodesy, the original implementation of the ROB GPS network has been revised in 1998 and the new design has been implemented in 1999.

Presently, the data from the seven permanent GPS stations are made available to the Belgian user community with a delay of 1 to 6 hours (previously:1 day). The measurement interval of the data has been increased to 10 seconds (previously: 30 seconds).

This work is the result of collaboration between the Royal Military Academy and the ROB.

3. Theoretical nutations for Earth and Mars

The scientists of the Section "Time, Earth Rotation and Space Geodesy" have developed computer programs for computing nutations from different models of the interior of Mars as well as of the Earth. Their research is mainly dedicated to study of the impact of geophysical fluid, the core modelling, and the atmospheric effects on the nutations for both planets. We are now studying a strategy for obtaining the parameters of the physics of the interior of the planet Mars from the future observations of its orientation variations in space.

We are involved in a geodesy experiment on the planet Mars. The goal is to observe Mars' orientation in space and from these observations, to obtain Mars' rotation and precession/nutations (motion of the rotation axis in

space). The ultimo objectives are to derive information about the physics of Mars' interior and about the mass exchange between the atmosphere and the ice caps. This experiment called NEtlander Ionospheric and Geodesic Experiment (NEIGE) will be launch in 2005 with Mars Sample Return.

Simulations have shown that NEIGE will reach a precision better than 5 milliarcseconds (corresponding to 8 cm at the Martian surface). With such a precision and by using the strategy that we have recently developed, we will be able to answer the question whether the core of Mars is liquid or solid. From the nutation observations, we will obtain information about the state of the core, the dimension of the core, the flattening of the whole planet and of the core, the mineralogy and the thermal state of the planet. From the polar motion and the rotation, we shall get information about the mass exchange between the atmosphere and ice caps due to the condensation/sublimation process.

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IV. Material Sciences

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

1. Prodex DCCO (Diffusion Coefficient in Crude Oil) – NASA GAS Container (Space Shuttle) 1998-ESA

The objective of the DCCO experiment was to measure diffusion coefficients of ternary mixtures of organic compounds. The experimental data set included 9 different liquid mixtures mass fractions. The mixtures were composed of n-dodecane, tetrahydronaphtalene and isobutylbenzene. The principle of the experiment was to diffuse liquid A into liquid B by removing a slider gate separating both liquids. Liquids A and B were ternary mixtures with slightly different compositions. The diffusion process was designed to take three to five hours. Concentration gradients imposed diffusion through the experimental cell. From the resulting interferograms recorded on the still camera the concentration gradients are derived as a function of time.

The final integration of DCCO in the GAS canister was carried out in February 1998 at Kennedy Space Center (Florida, USA). Integration of the Get Away Special G-765 onto the Discovery orbiter was completed on March 1998. Discovery has been launched as flight STS-91 on June 2, 1998 and the payload was activated at mission elapsed time 3h52' and desactivated at mission elapsed time 2 days 23h28' after at total operating time of 67 hours and 36 minutes. Discovery landed back at Kennedy Space Center on June 12, 1998. Access to the payload after the shuttle landing was obtained on July 7, 1998 at Kennedy Space Center. A visual inspection showed that the payload was in excellent general condition.

Nevertheless, the flight was only a partial success due to the misfunction of two control modules - not belonging to DCCO - caused by high temperature. C-CORE (Center for Cold Ocean Resource Engineering, NF, Canada) responsible for the computer control investigated the failure and isolated the problem to a single programmable logic chip.

The interferograms recorded on the film were of excellent quality, indicating that the optics for the interferometer were behaving well during the mission. With the exception of the cell curtain breakages, the DCCO experiment performed well in orbit. A post-flight mission simulation indicates that DCCO worked correctly. On the 9 cells, 7 were successfully opened.

During the mission, a complete measurement run (44 recorded pictures) was obtained for the first cell (No.12) and a half run (22 recorded pictures) on the second cell (No.2). Due to the digital output module failure on APIX board No.1, no more results were recorded on the photographic film of DCCO. The number of pictures recorded for the first cell corresponds to the expected number as implemented in the experiment timing. Since the curtain in this cell was not withdrawn, no diffusion occurred in this cell. This is confirmed by the interference patterns that show a very stable fringe pattern over all 44 images. That means that the cell concept, using a reference part to make the measurements insensitive to thermal change, works well and can be maintained for future measurements. The pictures recorded with both infrared and visible laser radiations have quite good exposures indicating that both lasers worked perfectly without any misalignment. There is a light fogging of the photographic film that could be due to the long period of storage of the film at ambient temperature or incident cosmic rays during the flight. However, this effect is weak and its disturbance can be easily eliminated by image processing techniques.

The rotation stage placed the second cell at the correct location in the optical path. The curtain for the second cell was removed correctly. The 22 recorded pictures of interference patterns also have perfect exposure times for both IR and visible radiation. Comparison of the 22 interference patterns shows changes of the fringe shape due to the diffusion process. This process is slow enough to allow further analysis by image processing. However, the extraction of significant diffusion data would require measurements on the nominal number of cells.

The DCCO experiment delivers photographic films with fringe patterns that have been recorded by the dual wavelength interferometer working at 790nm and 650nm. The diffusion coefficient accuracy determination is directly related to the accuracies on the measures of the optical path changes due to the diffusion process.

The good performances of DCCO have led to the submission of a proposal for a reflight of the experiment.

2. Prodex Oscillatory Marangoni Instability - BDPU-LMS 1996 (Space Shuttle) - ESA

The Microgravity Research Center (MRC) has completed the detailed analysis of experimental data obtained on the LMS mission on the double and three layers system heated from the side. We have observed experimentally that the flow velocity is linearly related to the mean horizontal temperature gradient measured in the layer bulks. Qualitative and quantitative agreement between numerical data and experimental observation is achieved.

We are reviewing the existing modelling techniques of thermal diffusion in hydrocarbon mixtures. This review of the oil industry literature shows that the practical implementation of the thermal diffusion effect in thermodynamic software has not been achieved yet.

We studied the coupling between thermal diffusion and convection with an application to the problem of a binary mixture slowly flowing in a tube with a longitudinal temperature gradient. We show that in this case, one of the constituent of the mixture is trapped in the tube while the second one in transported by the flow. Both 1-D analytical and axial symmetric numerical models have been developed. Although, the quantity of liquid which is trapped by the temperature gradient is relatively small. These results open new directions of investigation for the development of Soret coefficient measurement methods.

3. Prodex BAMBI (Bifurcation Anomalies in Marangoni-Bénard Instabilities) - Fluidpac - Foton (retrievable capsule) 1999 - ESA

The BAMBI microgravity experiment has flown on board Fluidpac during the Foton 12 mission. A hardware failure stopped the runs and BAMBI had to be aborted. The payload came back with no damage and BAMBI is now perfectly ready to refly. We hope to obtain the authorisation to fly again on the FLUIDPAC facility on board Foton 13 or on Spacelab.

4. Prodex Jet Growth Motions in Aerosols - Maser 8 Sounding Rocket 1999-ESA

The microgravity experiment JET Growth Motion in Aerosol was successfully performed during the flight of the MASER 8 sounding rocket on May 14, 1999. Versatile tests in January-April 1999 preceded the experiment. They were aimed at the verification of the thermal, vacuum and optical parameters of the flight module, growth rate and injection probability at working temperatures.

The 2D-velocimeter was developed at MRC to provide real time analysis of the aerosol behaviour in the microgravity experiment by means of telescience. The velocimeter was tested on the aerosol simulator also designed at MRC.

After-flight evaluation of the results included quality control and optimisation of the digitising and image processing, analysis of the 3D-particle trajectories and their co-ordinates.

It was shown both theoretically and experimentally that a liquid drop may exhibit self-motion in another homogeneous liquid in presence of a chemical reaction on the liquid-liquid interface. Finally, it is the motion of the interface that leads to the displacement of such a drop with respect to the ambient liquid.

We questioned if solid aerosol particles might manifest the self-motion in presence of a physico-chemical reaction on their interface. Such aerosols are widely spread in the Universe; they are often cited with respect to the μg-related experiments. Obviously, the interface of solid particles does not move but, contrary to the drops, it is always irregular with respect to the reaction. The mass, impulse and momentum exchange with the gas

molecules appears to be not uniform and each particle acquires additional transitional and rotational velocity of such "chemojet" motion. Under normal gravity conditions, the accuracy of any investigation of the chemojet (CJ) motion is extremely low and interpretation is very limited. Experiments under μg conditions allow not only to investigate this newly described phenomenon but also to develop on its basis a highly sensitive, real-time, non-perturbative research tool for the analysis of physico-chemical reactions on the surface of aerosol particles. As an example of the chemical reaction we have chosen the growth of crystals. Irregularity of the growth rate in time and over crystal surface is a well-known fact.

a) Investigation approach

The main goal of the JET experiment was to perform the first direct observation of the CJ motion: detecting this type of motion and getting general information about how the particles move. Further investigation envisages quantitative verification of the theoretical models of the CJ motion. Finally, one may apply this phenomenon for the investigation of the heterogeneous reactions in aerosols. Particularly, we are looking for measuring the intensity of two-dimensional nucleation during crystal growth from the gas phase.

The main idea of the μg experimentation was to get 3D-trajectories of the particles in a uniform aerosol where CJ motion should dominate. Theoretically, CJ particles should have arbitrary orientation of the velocity vectors in space, high spread and time variation of both transitional and rotational velocities. In real experiments, one may not exclude perturbative influence of other types of motion due to μg disturbances, electrostatic charging, Brownian transitional and rotational movement, etc. Therefore, motion of particles has to be analysed by versatile methods and high accuracy providing the following major functions:

- Accurate measurements of 3D co-ordinates of about 1000 particles
- Discrimination between two types of particles
- Detection of particle rotation

These requirements were met by the development of a new photogrammetric set-up and subsequent image processing.

b) Optical design and image processing

A compact, rigid and easily adjustable optical system was designed to meet requirements of the JET experiment. Optical scheme of the set-up is based on the unique objective that collects the light, coming from different directions from the back and front illuminated aerosol, and transfers it on four different cameras. The 3D co-ordinates of up to 1000 microscopic aerosol particles are retrieved with the photogrammetric method. This method allows to track independently moving particles. The discrimination between the two kinds of particles is performed optically with appropriate coloured filters. Crystal rotation is controlled by the temporal analysis of the light intensity reflected by the crystals. The optical system provides an observation volume of about 0.6cm^3 with 1cm depth of focus. The optical resolution is kept constant along the complete depth of the reactor chamber by the balancing of diffraction and defocus effects. Standard deviation of the 3D co-ordinate determination was found being between 0.007 and 0.011 mm for the planimetry co-ordinates and from 0.017 to 0.025 mm for the co-ordinate along the optical axis. Due to correlation effects the accuracy of a velocity vector derived from particle trajectory are better than the accuracy of the absolute position. The combination of the compact optical system and the photogrammetric technique were successfully tested on the ground, during parabolic flights and during the MASER 8 flight.

It is worth mentioning that the optical system was developed to meet particular requirements of the JET experiment. Most of the achieved characteristics can be considerably changed or improved for other applications.

c) Experiment results

About 100 crystals and reference particles were injected in the reactor chamber in the μg experiment. Out of them, slightly more than 20 particles have been localised in the observation volume allowing 3D-trajectory reconstruction. It was less than the expected number but still enough for the conclusive analysis. The detailed

characterisation of the aerosol images is on the way at the Institute of Geodesy and Photogrammetry, Zurich and Microgravity Research Center, Brussels. Up to date preliminary results strongly indicate the existence of the CJ motion. Thus, most of the particles exhibited curved motion with velocity vectors widely spread in space (see Fig. 1). The mean particle velocity was of the order of magnitude close to the theoretically predicted for the CJ motion values of 10-50 μm/s, their rotation velocity was higher than that of the Brownian rotation. Several particles had helicoidal trajectories (see Fig 2). Particle velocity vectors are scattered in a wide range of angles; their absolute values independently change in time and space. At the same time, certain regular velocity components were found indicating that particles also had sources of displacement other than the CJ motion.

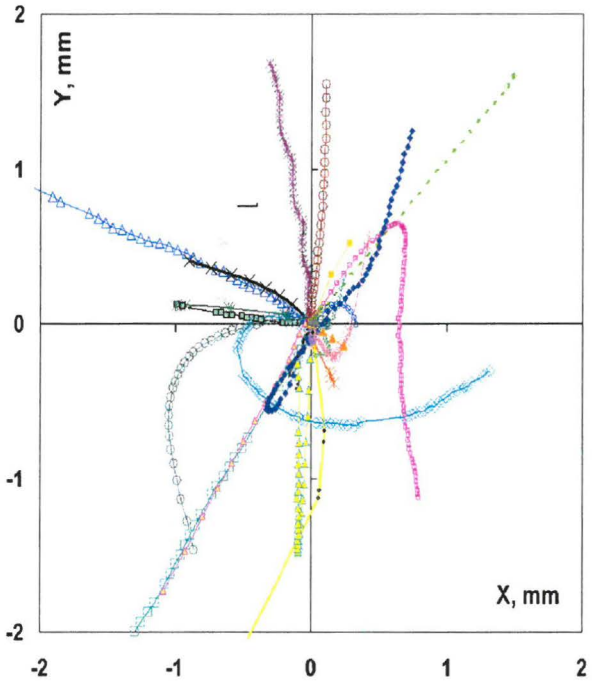

Figure 1: Particle trajectories plotted from one center.

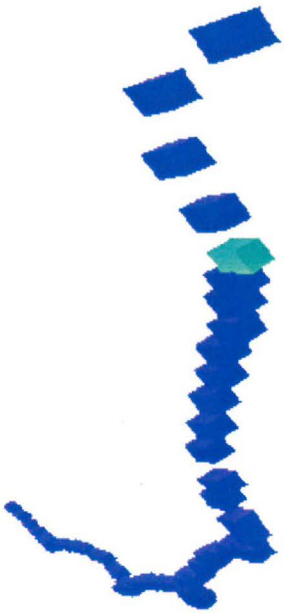

Figure 2: Helicoidal 3D-trajectory

d) Conclusions

Investigation of the CJ motion along with elaboration of the image analysis technique was focused on the development of highly sensitive, real time, non-perturbative analysis of the reactions on the surface of aerosol particles. New experimental data on the aerosol particle motion in presence of heterogeneous reaction are obtained. It may be stated already at this preliminary stage of the evaluation of the results that the existence of the chemojet motion is proven. The μg experiment revealed new effects resulting from the coupling of different motion driving forces. It opens a possibility to control motion of different particles selectively.

5. Prodex Telescience on Maser 8 sounding rocket and Foton retrievable capsule

Our new telescience room was inaugurated during the missions Maser 8 and Foton 12. From a telescience point of view these two missions were successful. All the data and the video were transferred to the Center at the Brussels University, and the team was able to follow the evolution of the experiments in quasi-real-time. This allowed us to train on this new mode of control of a space experiment which will be important for the International Space Station utilisation.

5.1. JET experiment

In the sounding rocket Maser 8 launched on May 14, 1999 from Esrange (Kiruna, Sweden), the JET experiment studied the jet growth motion of aerosol particles during the 6 minutes of microgravity. One of our scientists, was in the blockhouse during the flight together with the SSC engineers responsible for the Jet Module. He was able to send telecommand to the module. In order to help him to control the experiment, a 2 D real-time velocimeter and a Man Machine Interface (MMI) were developed.

The 2-D velocimeter gave in real-time a statistic on the velocity of the particles in the cell from one video channel. Different parameters were calculated: number of particles in the image versus time, number of moving particles versus time, mean velocity, mean vorticity, diagram showing the velocity vector distribution. Different parameters allowed us to control the velocimeter software during the process: choice of the camera, grey level threshold, maximum and minimum speed limit.

The MMI developed in Labview presented in one screen the evolution versus time of the different parameters of the cell: temperatures, temperature gradient, pressure, microgravity level, status of the shutters, Also all the results of the 2D velocimeter and the control of it were in the same MMI. Thank to this the scientist had all the information presented clearly to him on one screen. Through the ISDN lines the scientific data, the housekeeping data and the video signal were transferred in quasi real time to Brussels.

The same MMI was present in the blockhouse at Esrange and in our centre in Brussels where the control of the parameters of the velocimeter software was done in real-time. The data were selected from the general telemetry data stream by the use of software running on a QNX PC. We had the support from ESTEC for this software. All the data were put in a database and the MMI was reading the database on a dedicated JET network. Figure 3 shows the telescience set-up developed for the Maser 8 mission. The video was transfered to Brussels by two Codec through six ISDN lines. Brussels was in contact with the blockhouse by a phone line. This mission showed that the QNX database used as data selector solution was a very good choice and will be reused for future rocket mission.

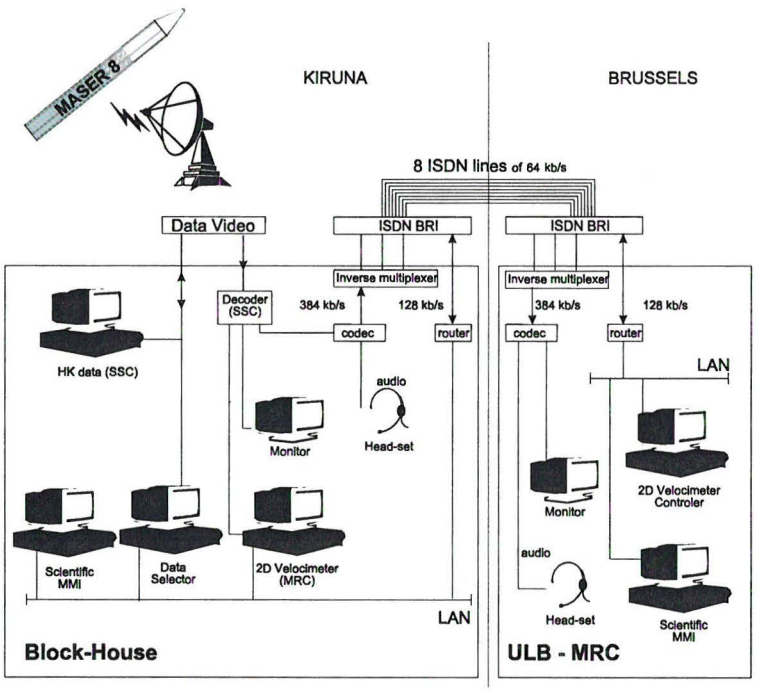

Figure 3. Telescience set-up for the Maser 8 – Jet mission

5.2. BAMBI Experiment

During the Foton 12 mission, the BAMBI experiment was implmented in the ESA FluidPac facility. The TeleSupport Unit (TSU) developed under ESA contract was connected to FluidPac and allowed to communicate with the facility during the mission. Telemetry and telecommand were performed from Esrange in Sweden and all the data were also sent to Brussels. During the 15 days of the mission, the satellite sent data at least four times per day. During each passage of Foton 12 above Esrange, housekeeping and scientific data including pictures from the cell were downloaded in one compressed file. All the data were received just after the passages of Foton 12 in our telescience room.

The transfer of data from and to Esrange was performed with an ISDN router using 8 lines. We had also a backup solution with a FTP server in Stockholm were all the data were stored during the mission. All the telescience hardware worked perfectly during the mission. We prepared a new parameter table for Bambi in Brussels that was sent with success to Foton 12. It showed that the TSU gives good possibilities to control the experiments in Foton 12 in spite of the very short covering due to a failure of the liquid injection system of the experiment.

6. SCCO (Soret Coefficient in Crude Oil) - ESA

The SCCO experiment, prepared in the frame of an international collaboration will fly in a NASA GAS container implemented on board the NASA space shuttle. SCCO aims to measure Soret coefficients of binary and ternary systems and to characterise the thermodiffusive process in oil reservoirs. This requires modelling of equilibrium properties of multicomponent systems, as well as modelling of transport processes in multicomponent systems.

Results from this program are geared towards increasing our understanding of the behaviour of fluids as it pertains to improving methods for enhanced oil recovery. The SCCO experiment and the research program that it represents are strongly supported by industry. The SCCO experiment is designed by the MRC with the assistance of C-CORE (Memorial University of Newfoundland, St. John's, Canada) and IVC-SEP (University of Lyngby, Denmark) and supported by Elf-EP (Pau, France), the European Space Agency and the Canadian Space Agency.

Optimum technical and economic development of an oil field requires accurate knowledge of the behaviour of the fluids that impregnate petroleum reservoirs and of their evolution during production. Many reservoirs being explored today are at sufficient depth to be close to critical pressure and temperature conditions. Therefore, they are very sensitive to applied forces of gravity plus temperature and pressure gradients. Compositional differences induced by such forces can be very significant. The thermodiffusion (Soret) process exists in the presence of a temperature gradient in fluid mixtures, inducing a mass flux. Very few numerical models of oil reservoirs, including the geothermal gradient of 3K per 100 meters, take into account the thermodiffusion process mainly due to a severe lack of Soret coefficients measured in crude oil. Soret coefficients of crude oil must be measured to provide for accurate numerical models.

The objective of the SCCO experiment is to measure thermodiffusion coefficients in microgravity conditions in selected crude oils plus binary and ternary solutions without the masking influence of convective motions due to gravity. The resulting data will be used in numerical models currently developed for oil reservoir predictions. The principle of the experiment is to fill a cylindrical tube with the experiment fluid, pressurise the tube and seal it. An accurate and constant temperature gradient is established between the two ends of this tube once microgravity is reached. The tube must then remain in microgravity for enough time to allow component separations through the thermodiffusion process. After this period and before the end of microgravity, the tube contents are separated into three volumes by the closing of two rotary check valves - two end sections and the centre section. The centre section is then depressurised through a pressure relief valve into an expansion chamber to ensure sealing of the check valves. The concentration differences among the two end chambers are then measured on the ground after retrieval of the experiment.

In February 99, a protoflight model has been built and tested in the MRC vacuum chamber. The Design of the experiment has been completed in April 1999 and approved by the European and Canadian Space Agencies allowing MRC and C-CORE to begin the construction of the hardware.

After assembly of the experiment, pressure tests have been performed, in the manufacturer premises and in Elf-EP. The "Preliminary Safety Data Package", first document of the NASA safety procedure, has been submitted to the European and Canadian Space Agencies in November 1999. We are on a good way to fly SCCO in a near future.

7. Prodex ITEL (Interfacial Turbulences in Evaporating Liquids) – Maser 9 sounding rocket

The study of ITEL is of particular interest for both scientific and industrial fields (heat pump, pharmaceutical, food). To have an improved understanding of the phenomenon, the accurate three-dimensional (3-D) structure of the fluid flow has been investigated. In particular it is necessary to measure the structure of the 3-D temperature field in the evaporating layer.

The measurement of the 3-D temperature field in an evaporating liquid such as ethanol will be done in a sounding rocket (MASER 9) in November 2001. The set-up is based on tomographic concept and its optical interferometric measurements.

Tomography is a technique of reconstruction from lower dimension projections to a higher dimensional distribution. It has been applied successfully to many fields. There is now a trend to implement the concept of tomography in interferometric diagnostics. Optical interferometry through transparent media measures the averaged optical path changes along the optical axis. In such situations, the measurements are 2D projections of 3D phenomena, giving rise to partial information. The tomography consists in using multiple 2D projections recorded simultaneously with different propagation directions, and use them as input to a computational process that performs the 3D refractive index reconstruction. This kind of measurements will give rise to a better knowledge of 3-D temperature fields dynamic in fluid physics experiments.

The experiment has the double objective to validate important and recent theoretical fluid physics results and to be an optical tomography demonstrator for fluid physics experiment. The set-up will be coupled to an additional Schlieren system to visualise the liquid-gas interface deformation in a direction perpendicular to the tomographic investigation direction. The role of the Schlieren will be to measure the surface deformation resulting from the evaporation. The Schlieren image will be downloaded on ground during the flight to follow the establishment of the instabilities, and help in the modification of some experimental parameters via telescience. The breadboard (B/b) of the experiment cell as well as the B/b and the Flight Model (FM) of the optical diagnostics will be prepared by Lambda-X Company in collaboration with the Swedish Space Corporation (SSC). The MRC will be in charge of the scientific aspects i.e. the definition and requirements of the fluid physics experiment, which is scheduled to fly on board the Maser 9 sounding rocket.

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1. Metal matrix composites

Metal matrix composites have many desirable characteristics for precision components: e.g. light weight, dimensional stability and high thermal conductivity. The understanding of the mechanisms and processes taking place at their production is of crucial importance, since these factors are important for the properties of the composite and its future application.
Casting is a 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.

1.1. In-situ composites

On a industrial scale a mixture of salts K_2TiF_6 and KBF_4 is added to an Al-liquid and results 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 aluminium alloys, one with boron and one with titanium, are joined by friction welding to form one sample. When this sample is molten above 800 °C the 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 disturbed by gravity. During the Spacehab flight in November 1998 four samples were resolidified, each with a different maximum temperature. The samples, containing 1at.%B and 0.5at.%Ti or 2at.%B and 1at.%Ti, resolidified on earth and in space were successful and show obvious the formation of TiB_2. The formed interface settles in the direction of the gravitation, resulting in a very heterogeneous distribution of the TiB_2 particles. For the space experiments the gravity was negligible and because of this the Ti and B only can be brought into contact by diffusion. Also the space experiments applied for a heterogeneous distribution of the formed particles, but this time a chain with TiB_2 can be found near to the transition between the two alloys, in the middle of the sample. All compound samples (earth and space) show a shrinkage of the sample near to the chain with the formed TiB_2.

Comparing the first two experiments, FM1 and FM2, with the same composition, the influence of the maximum temperature is clear. In FM1 the temperature of 800 °C was too low for the complete diffusion of the Ti and B to the border between the two alloys. Most of the Ti and B remained in his original position and only Ti and B close to the transition had diffused and reacted to TiB_2. In FM2 (900 °C) all the Ti and B is diffused and has reacted to TiB_2. This time the temperature was perfect for this composition, 0.5at.%Ti and 1at.%B. For a higher concentration of boron and titanium also a higher temperature is needed, as executed on sample number FM3 and FM4. In sample FM3 (1000 °C) not all the Ti and B has reacted. At 1070°C (FM4) all B and Ti has reacted to TiB_2, but this time the particles are coarsened, which is not favourable for the properties of the material.

Not only one chain but a multiple reaction zone with TiB_2 is found in all four samples (see Fig. 1). An explanation is found in the nucleation and growth rate, which is zero at the border between Al-Ti and Al-B. Just close to this transition the growth rate reaches his maximum, which means that the formed particles will grow most in these two regions. The amount and shape of the chains with reacted TiB_2 is the same for the space and ground experiments. Only the location differs due to the gravity.

1.2 Solidification aspects of metal matrix composites

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. We did an extensive study on these phenomena during two former space experiments at the Russian Space Station (MIR). A model in-situ material system, Al-TiB_2, was selected for the EuroMIR 94 experiment. For EuroMIR 95 we used an ex-situ

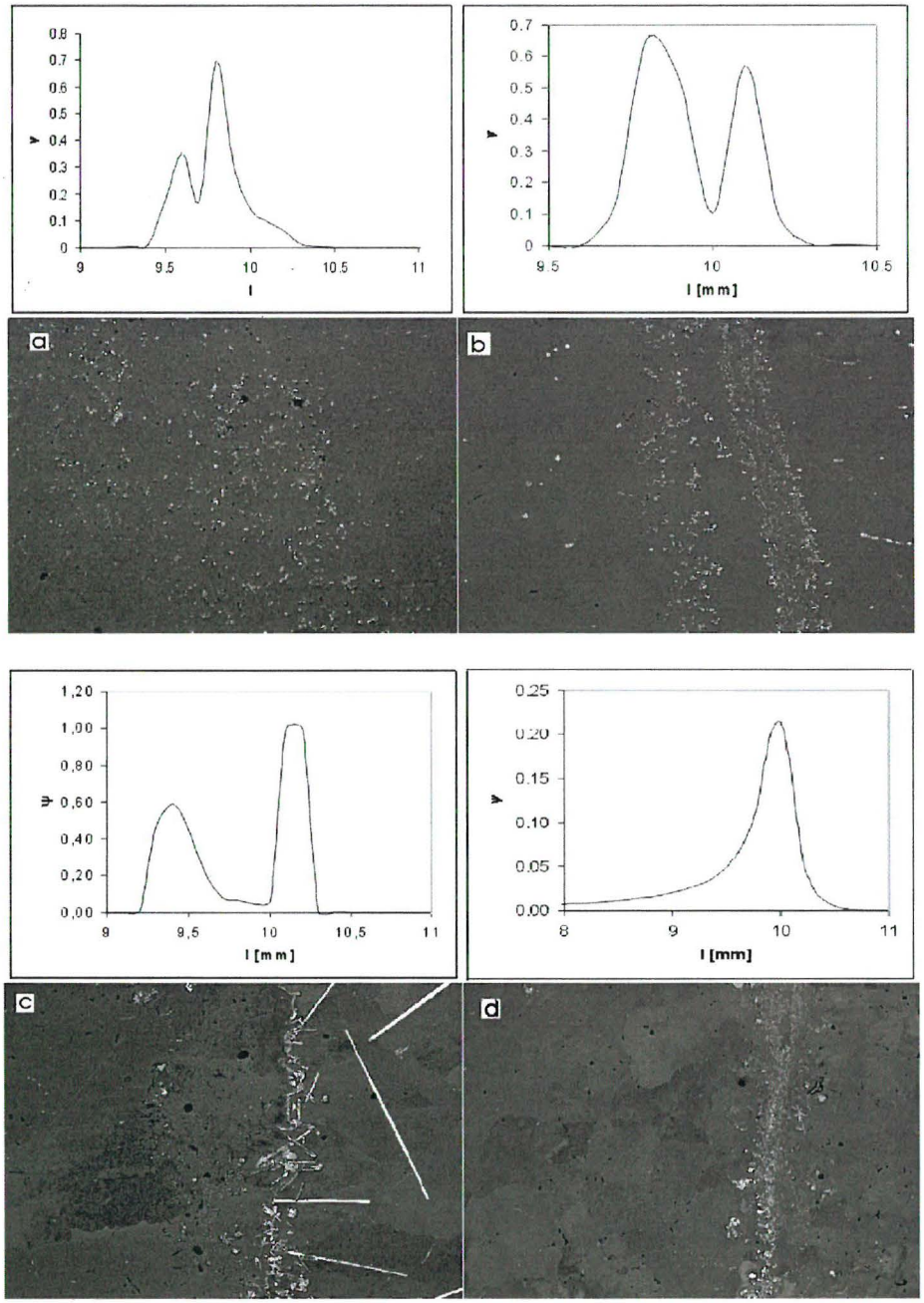

Figure 1. The zone with reacted TiB_2 particles in the middle of the four samples resolidified in Spacehab during the STS95 flight. From left to right the maximum temperature differed for each sample (a.800, b.900, c.1000 and d.1100 °C).

produced material, Duralcan[tm] (Al-Si matrix with SiC particles). Besides gravity, the influence of different cooling rates, concentrations and temperature gradients was investigated.

Since 1996 we are working with a high gradient furnace, ASPF (Advanced Solidification Processing Facility). For detection of the location, velocity and morphology of the solid/liquid interface, the measurement by the thermocouples is complemented by a new ultrasonic technique. After the use of some commercial transducers with a frequency of at least 750 kHz, we started with the production of a low frequency transducer (200 kHz). The

development of this detection technique is promising. Especially for the detection of the solid/liquid interface, but hopefully it will be possible in the near future to detect also the sedimentation of the particles in the melt.

1.3 Modelling

A theoretical model of the processes at diffusion controlled formation of TiB_2 in liquid Al under micro-gravity has been proposed. The main features of the developed model are:

-Mechanisms controlling the formation of the TiB_2;
-Degree of distribution of the dispersed TiB_2 particles;
-Mean size and size distribution of the dispersed TiB_2 particles.

The results obtained with the aid of the proposed model are in agreement with the experimental evidence (see Fig. 1). The model predicts correctly the TiB_2 particles distribution along the specimens and the characteristic split of the reaction zone observed experimentally.

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1. Introduction

Improvements in protein crystal perfection, size and resolution as a result of growth under microgravity conditions have been documented in the past by several laboratories. In some cases, the mosaicity of the crystals grown in such conditions has been improved by a factor of three to four as compared with the mosaicity of earth-grown crystals, resulting in a significant increase of the peak to background ratio in X-ray diffraction experiments.

2. Results

Background and objective: to improve the diffraction quality of the protein crystals in order to aid in structural determination.

2.1. Bacteriophage lambda lysozyme

The bacteriophage lambda lysozyme (λL) is a small protein of 158 amino acids. Like other known lysozymes, it is involved in the lysis of the bacterial peptidoglycan. This enzyme is remarkable in that its mechanism of action is different from the classical lysozyme mechanism. After many unsuccessful attempts to crystallize the native enzyme, a mutant where all the tryptophan residues have been replaced by aza-tryptophans has been crystallized during the Space Shuttle flights STS-63 and STS-67. The PCAM (Protein Crystallization Apparatus for Microgravity) experimental hardware (sitting drop, vapour diffusion) was used. For the first time, the crystals obtained were large enough for data collection. A 2.3 Å data set was collected at EMBL, Hamburg, Germany and used for crystal structure determination.

2.2. L-Alanine dehydrogenase from Bacillus subtilis

L-alanine dehydrogenase catalyses the reversible oxidative deamination of L-alanine to pyruvate and ammonia. This enzyme does not seem to share sequence similarity with other amino acid dehydrogenases. However, it seems to be structurally related to the transmembrane proton translocating pump, pyridine nucleotide transhydrogenase. Crystals were obtained from nearly all of the 35 PCAM experiments, some of which produced the largest crystals of this enzyme ever grown.

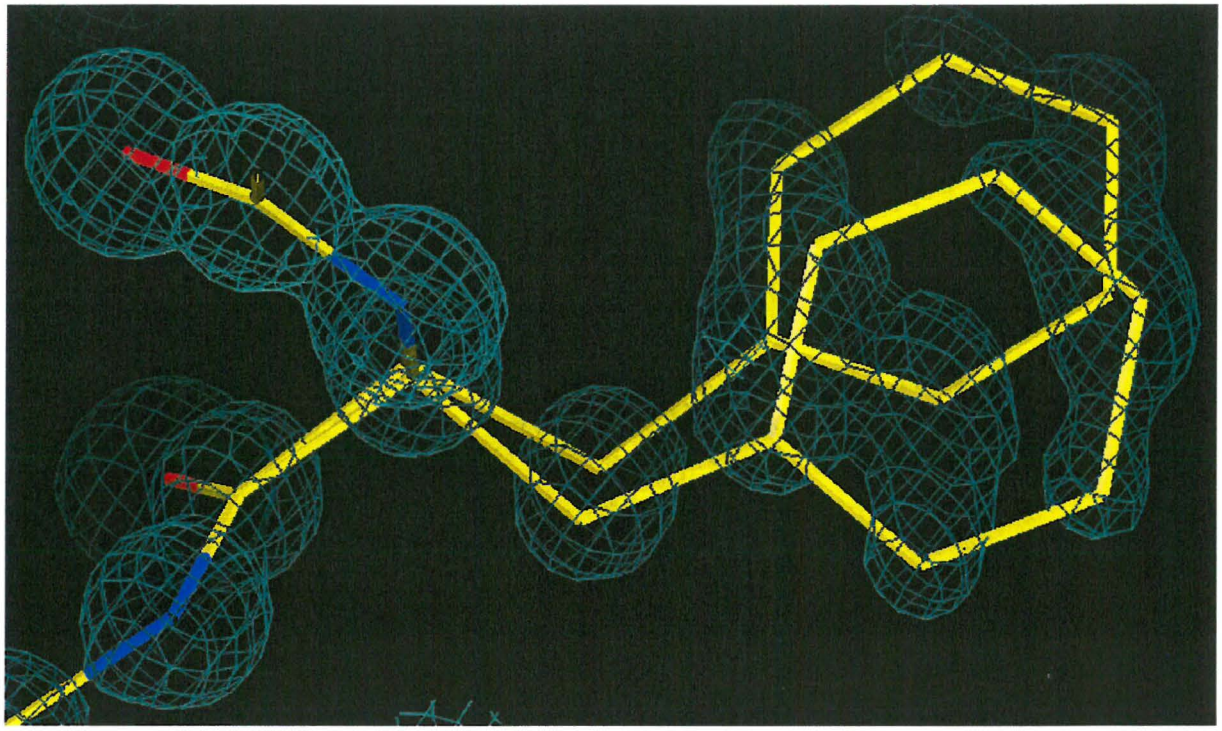
2.3. Pike parvalbumin

Crystals of pike parvalbumin were grown during the Space shuttle filghts STS-83, STS-94 and STS-95 using the PCAM hardware. The crystals gained improvements which moved the resolution into the ultra-high resolution category diffracting X-rays beyond 0.9 Å resolution at the Hamburg synchrotron. For a comparison, the Protein Data Bank contains 13 parvalbumin structures of which the highest resolution is 1.5 Å. This results in one of the highest resolution protein structures over 100 amino acids determined. The high quality of the resulting structure answered many questions concerning conformational states in the protein structure and calcium binding. The high accuracy allows the detection of well-defined alternate conformations, among which, six occupy an internal position within the hydrophobic core. This observation is of paramount importance for a better understanding of the effect of internal dynamics on the caption binding capacities of the protein.

2.4. The first successful crystallization of a prokaryotic extremely thermophilic outer surface layer glycoprotein

Methanothermus fervidus belongs to the group of hyperthermophilic Archaea, organisms living under environmental extremes, like high temperature, low pH or high salt concentration. The outer surface of the cells is covered by glycoprotein subunits (S-layer) directly exposed to the extreme environment. This protein has been successfully crystallized under microgravity conditions during the flight STS-95, using the APCF (Advanced

Protein Crystallization Facility) hardware developed by Dornier Gmbh for the European Space Agency (ESA). Using synchrotron radiation (EMBL Hamburg), diffraction spots were observed to a resolution of 4.2 Å, while the best earth-grown crystals diffracted X-rays to a resolution of only 9 Å.



3. Publications

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V. Life Sciences

A. Biomedical Physics Laboratory of the "Université Libre de Bruxelles"

1. Spacelab mission STS-90 "Neurolab"

1.1. Introduction

The Neurolab mission was proposed as a contribution to the "Decade of the Brain", and was launched on April 16th, 1998. During the 17-day mission, our laboratory participated in the experiment "Sleep and Respiration in Microgravity" (Principal Investigator : John West, University of California at San Diego, USA). This experiment consisted of two protocols : the "Astronaut Lung Function Experiment" was a set of respiratory maneuvers during daytime, and the sleep study consisted of the monitoring, for the first time, of sleeping astronauts during space flight.

1.2 Astronaut lung function experiment

The heart rate variability has been studied under controlled slow, controlled normal, and spontaneous uncontrolled breathing of the subjects. The influence of the level of gravity, the posture on ground (supine vs. standing) and the evolution in time during and after the space flight have been studied. The different breathing protocols allow the determination of the influence of respiration on the control of the heart rate, i.e. the respiratory sinus arrhythmia. The results show that measurements in supine position can model relatively well the effects of space flight on the heart rate but, even in supine position, a readaptation to gravity takes at least two weeks.

The pattern of breathing during both the controlled and the uncontrolled respiratory protocols, has been analyzed in terms of breathing frequency, volume, ventilation, ratio of inspiratory time to total respiration time and relative contribution of abdominal movement. The results are in agreement with earlier findings [Wantier, 1998].

1.3. Sleep study

During sleep, the electro-encephalogram, electro-oculogram, and electromyogram, as well as oxygen saturation, electrocardiogram, airflow, light, sound, and rib cage and abdomen movements were recorded. From the 4 crew members we obtained in total 64 full nights recordings (36 preflight, 16 in flight and 12 postflight). In addition, we had the opportunity to add two subjects to this sleep study during the STS-95 shuttle mission which was launched on October 29th, 1998 and which lasted 8 days.

2. Parabolic flights

A new test (helium and sulfur hexafluoride bolus wash-in) was performed in short-term microgravity. The results have shown that the paradoxical results which were previously obtained are primarily due to closure of the small airways [Dutrieue, 1999].

3. New index of ventilation perfusion mismatch

A new analysis of the cardiogenic oscillations during single-breath tests performed in microgravity [Lauson, 1998] led to new information on the ventilation-perfusion mismatch which has shown unexpected high values in space.

4. Ground-based studies

4.1 In vivo measurement of human diaphragm

The diaphragm is the main respiratory muscle in humans. Its pressure-generating capability determines to a large extend the respiratory function. We have studied the human diaphragm by spiral computed tomography in normal subjects and in patients who have undergone single lung transplantation [Cassart, 1999]. Diaphragm length, surface area and curvature have been related to lung volume.

4.2 Distribution of ventilation

The technique of multiple-breath washout used in microgravity [Prisk, 1998] was applied to 20 stable patients suffering from chronic obstructive pulmonary disease in order to evaluate the ventilation inhomogeneities in the conductive and acinar zones of the lungs [Verbanck, 1998]. It was shown that the alterations in both zones of the lungs are indeed independent. Furthermore, the same technique applied to 20 stable asthma patients showed that acinar ventilation inhomogeneity is abnormally high in this patients despite their normal diffusing capacity [Verbanck, 1999]. This acinar airway impairment was shown to be partially reversible after salbutamol inhalation. The same tests were used in the study of rats with emphysema [Rubio, 1998].

4.3 Home monitoring

The know-how of conducting human physiology experiments in space can find spin-offs wherever tests need to be performed on remote locations without the supervision of a medical doctor. In this perspective, a telemanagement system has been developed for the follow-up at home of asthmatic patients and lung transplant recipients [Morlion, 1999]. The patients perform a forced expiration maneuver with a commercial spirometer and the home terminal sends the data to the hospital by means of a secure medical electronic messaging system. At the hospital, the pneumologists can study trends and correlate the home data with the results of the exams which the patients undergo during their regular check-ups. At this moment (February 2000), 4 asthmatic patients and 16 lung transplant recipients are being monitored.

Furthermore, the developments of the 'Respiratory Inductive Plethysmograph' (RIP) for the D-2, Euromir-95 and LMS missions has led to the development of a baby pyjamas with incorporated respiratory movement and heart rate sensors for the monitoring of sleeping infants at home. At present, six healthy babies between 2 and 11 months old have been monitored during 16 nights at home.

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B. Orthopaedic Research Laboratory of the "Université Libre de Bruxelles"

1. Bone strains measurements in microgravity

1.1. Introduction

From the literature and from our previous experiments, the architecture and mechanical properties of bones can be considered the statistical consequence of the mechanical stimulation governing bone remodeling [Hinsenkamp, 1981, 1994; Marie, 2000; Vico, 2000].

Precise knowledge of the mechanical environment is necessary in order to understand the modifications of bone metabolism and structure. Determination of the mechanical strains both qualitatively (loading cycle, frequency, peak value, amplitude, etc) and quantitatively (mean loading, RMS, etc) is fundamental in order to characterize the difference between the microgravity and the usual 1G condition.

Comparison between the local bone strain regime in normal gravity and in microgravity conditions is a prerequisite to understand how bone formation and resorption is affected by microgravity and how those effects can be prevented.

Short periods of gravity (20 seconds) are sufficient to determine the acute modification of the mechanical environment. After more prolonged periods, slower modifications like muscles relaxation and finally muscles and bone atrophy will slightly worst the acute modification of the mechanical environment.

1.2. Material and Method

Our experiment flew on the 25th (1998), 26 and 27th (1999) parabolic flights campaigns of ESA on the Airbus A-300 of the CNES.

The first campaign was used to validate our protocol and to test the hardware. On the next two campaigns, we measured bone strain on three human subjects.

To realize the bone strain measurements, we need a direct mechanical fixation on bone. We are using the previously described model of fractured tibia treated by external fixation [Hinsenkamp, 1981; Burny, 1993].

The three subjects were followed and measured at regular interval at our out patient clinics. They were selected when the healing allowed them to walk without crushes and they participated to the flight on voluntary basis and with enthusiasm.

We measured the deformation of 5 strain gauges placed on the metallic rod bridging the fracture. During parabolas, the subject performs a set of physical exercises with the instrumented leg. There are two static positions, with or without support. When laying on his back, the subject is asked to move his leg up and down following a line (oscillations) or a circle (rotations). Both exercises are done at a slow (~1/4 Hz) and a fast (~1 Hz) pace. He is then projected with a calibrated rubber band against a wall of the cabin in order to measure the impact (jump simulation). Finally he is asked to move his leg again but in a standing position (again oscillations and rotations, fast and slow). The full serie of exercises is done on the ground the same day.

1.3. Discussion

The principle of the dynamic measurements is to differentiate the role of the induced acceleration at different frequencies for cyclic motion. Also to determine the contribution of the muscle contraction on the bone strain.

We now have a preliminary data set of recorded strains on the bone-fixator model. They show the significant effect of the microgravity with different consequences during slow and fast motion. The data set will be extended during the following campaign to be statistically treated. It will also be reproduced on a standardized

physical model (robot) and simulated with a mathematical model. The comparison between the human subjects and the robot will allow to precise the contribution of the muscle for the different exercises. At this stage, it already gave interesting and original informations to design preventive exercises able to restore the range of mechanical strains experienced by bone in normal activity in 1G conditions.

1.4. Present development

The observed curves are studied following the laws of mechanic and the evolution of the system in the gravity field (of changing intensity). Expressing the position of the fixator rod in systems of axis linked (1) to the airplane (only vertical gravity), (2) to the body of the subject (movement can be fully described by the one of the gravity center of the system, e.g. in the case of the rotation, the movement is easily described as a circle in polar coordinates), and (3) to the external fixator (this is the place where the measurements take place), and building the right transformation operators, it becomes relatively easy to express the influence of gravity during a given movement for a given gauge.

Knowing the mechanical characteristics of the instruments, it is possible to build the rheological model of the bone-fixator as a whole. Then to compute the values for deformation or strain at the bone level.

The instrumentation used will be improved for the 29th parabolic flight campaign. Presently, we are using an equipment used routinely to follow the fracture healing at the outpatient clinics. Five gauges are recorded and we would like to add 3 accelerometers, 3 goniometres, 1 thermometer and a videocamera.

We will develop some virtual instrumentation software based on open source software (OSS) and some data acquisition hardware from the industry.

1.5. Future projects

Our ongoing research on bone strain measurements investigate the "primum movens" of bone demineralization in microgravity. The consequence of the modification of the mechanical environment of bone need to be studied during longer periods of time. The International Space Station (ISS) offers an exceptional opportunity to observe at different level the effect of long term exposure to microgravity. We submitted to MAP program six projects studying the effect of microgravity at the cellular level, at the tissue level and on the human phosphocalcic metabolism in space and during bed rest. The extension of the present bone strains measurement is also proposed with the miniaturization of the transducer to be applied on rodents and on the base of the bone strain characteristics and their mathematical modelisation we proposed a physical exercise training program to prevent bone demineralization during space flights but also to be applied in clinics to disuse osteoporosis on ground. All of these six projects are interactive . The results obtained at one level will focus the scope of investigation of the other programs.

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C. Laboratory of Connective Tissues Biology of the University of Liège

1. Function of the focal adhesion plaque of connective tissue cells under microgravity

One of the main interest of the Laboratory of Connective Tissues Biology is to study the effects of mechanical forces and stress relaxation on the cell functions and survival and to investigate the molecular mechanisms operating in this regulation. Most cells of the organism are in close contact with their supporting extracellular matrix (ECM) made of a network of polymeric macromolecules that deliver mechanical and chemical signals to the cells. The mechanical information issued from the ECM as well as the mechanical tension generated by the cytoskeleton converge to transmembrane receptors, the integrins and the focal adhesion plaque (FAP), a complex assembly of structural and signaling proteins transducing the mechanical signals into an intracellular enzymatic cascade ending by the modulation of genes expression.

Ground experiments using human skin fibroblasts in three-dimensional culture models allowed us to demonstrate that integrins-FAP-mediated mechanical tension and relaxation are potent biological regulators of gene expression [Lambert et al., *Lab Invest* 66:444-451, 1992]. It was further shown that stress relaxation induced a tyrosine-kinase dependent up-regulation of the ECM-degrading enzymes, the matrix metalloproteinases MMP1 and MMP3. The inflammatory cytokine IL-6 mRNA level was also increased through an autocrine IL-1β loop [Lambert et al., *J Biol Chem* 273:23143-23149, 1998]. These observations were the scientific basis of the programme selected by the ESA/NASA Space Life Sciences Programme Committee to fly in the Discovery shuttle (STS-095) in october 1998. This programme aimed at investigating the effect of microgravity on the expression of these regulated genes as reporters of the status of the FAP function and signaling.

Three culture models of decreasing mechanical rigidity were used: culture of human dermal fibroblasts (75000 cells) in monolayer on collagen-coated Thermanox (Mono), in tethered three-dimensional (3-D) collagen gel (TCG) and in retracting 3-D collagen gel (RCG). Duplicate cultures in automatic plunger units (CCM, Neuenen, The Netherlands) were integrated in Type I/E containers in the Cis containers of the ESA facility, the Biobox incubator. Four pairs of samples of each experimental model were submitted to microgravity and 1 pair was centrifuged at 1g onboard. Parallel cultures were kept at 1g in the ground Biobox. An additional set of 4 Mono in microgravity, 1 Mono at 1g in the flight centrifuge and 4 Mono on ground was used for immunomorphological analysis of the FAP organization and state of phosphorylation. After, respectively, 48 or 96 hours of culture at 37°C and appropriate renewal of medium, cells were either fixed or lysed in flight and in parallel cultures on ground. The total RNA was purified and specific mRNAs were measured by quantitative RT-PCR assays specially designed during pre-flight technological developments. A synthetic RNA reverse-transcribed and amplified by the same primers as cellular mRNA but yielding a larger sized product was used as internal standard added to each RT-PCR to monitor the yield of the reaction. The data were expressed on a unit basis of mRNA coding for the house-keeping gene GAPDH.

Microgravity induced a significant increase of IL-6 mRNA level in Mono, (2.4-fold, $P < 0.06$, vs ground control and 3.6-fold, $P < 0.04$, vs centrifuge), in RCG (3.0-fold, $P < 0.03$, vs ground control and 3.4-fold, $P < 0.03$, vs centrifuge) and in TCG (2.2-fold, $P < 0.01$, vs ground control). A significant increase of MMP-1 mRNA level was also observed in RCG (2.0-fold, $P < 0.02$ vs ground control and 3.5 fold, $P < 0.05$ vs centrifuge). The level of the other tested mRNAs (α1(I) and α1(III) collagen, MMP2 and MMP3) was not significantly modified. These results support IL-6 as a suitable marker of microgravity-induced alterations of gene expression in human fibroblasts. Morphological data obtained by image analysis of immuno-labeling of vinculin and phosphotyrosine in FAP showing an alteration of their organization and phosphorylation are in agreement with these results. IL-6 expression will be further investigated in the next STS-107 flight using the same cells in confirmatory experiments and transformed (WI-26) fibroblasts as potential candidates for analyzing and engineering selected elements of the cellular signaling operating in the control of the IL-6 gene.

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VI. Remote Sensing

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

The activity of the laboratory is oriented towards geological remote sensing and exploitation of digital information sources and aims at identifying and studying geological phenomena. Data sources are optical and radar satellite or airborne imagery as well as geophysical or geochemical surveying.

1. 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 has been carried out from May 1996 till April 1998 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 study area is located in the northeastern part of the XinJiang Uygur autonomous region, close to the Gansu Province and Mongolia. It is situated south of Hami city, in the southern segment of the Tian Shan mountain belt. The aim 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 described area. The study consists in data integration and image processing as well as field controls.

The following results have been made 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;
- an ERS2 SAR image;
- aeromagnetic data relative to the area ca. between 93°-95°E and 41.5°-42.5°N;
- geochemical data with a density of ca. 5 points/km^2, for the following elements: Ag, As, Au, B, Ba, Bi, Co, Cr, Cu, Hg, Mn, Mo, Ni, Pb, Sb, Ti, V, Zn. The zone covered by these data lies between 94°-95°E / 41°50'-42°15'N.

A four weeks field campaign has been carried out in August 1997 in order to control the two prospects selected after the first field campaign (1996) and the Chinese-Belgian working session at the RMCA, Tervuren.

After the first step of the project, which focused on the study of the tectonic and metallogenic settings (1996), the two following steps have been carried out: the selection of prospects and the selection of targets for detailed mineral exploration within these prospects. On the basis of multi-source data integration, the second step has led to the selection of the Cuiling and the Shaquanzi prospects. Four targets for detailed mineral exploration have been identified in the North Shaquanzi prospect, on the basis of field investigations in the zones displaying geochemical and/or magnetic anomalies.

2. Human impact on boreal forest in the Krasnoyarsk region (Russia). Remote Sensing image processing and GIS integration

To preserve the natural environment it is necessary to collect knowledge on the spatial distribution and seasonal dynamics of the primary productive processes on the planet. For an evaluation of the state of primary production the measurement of temporal changeability can be used together with the measurement of a statical distribution of phytopigments. The present level of spectral scanning devices and methods of interpretation of spectral

measurements from space prove that it is possible to create a system of monitoring the primary production in the biosphere.

The problems treated are :

- technical opportunities for the use of satellite scan images with various space resolutions for an estimation of the vegetation variability (Landsat, Spot, Resours,..)
- technology of images overlapping using MSS, NOAA and other image data for the creation of the images with combining their better quality
- overlapping of the spectral images with elevation model
- determination of seasonal vegetation variability with use of standard statistical models
- classification of elements of the scan satellite images.

This remote sensing and GIS (Geophyiscal Information System) approach of the study of Human impact on boreal forest in the Krasnoyarsk region was achieved from 24 July to 24 August, 1997. The main techniques of information extraction from satellite imagery were explored and applied to the Angara area using IDRISI 2.0 for Windows 95 software. The last version of this package has been acquired in the frame of the project, including tutorial exercises and specific applications to forestry. GIS vector data was exported/imported from MapInfo. Two Landsat MSS scenes of August 18, 1989 have been chosen amongst existing archive data according to their good quality, absence of clouds and season of acquisition. No other equivalent quality MSS data was available for other years. The elevation data is provided by the NOAA world database, at a spatial resolution of 30'' lat/long. We used NDVI from NOAA (year 1995, months April, May, July, August) for merging of NOAA NDVI as colour and MSS as brightness and time series analysis.

3. Transitional Zone Between Gorny Altay and Zaysan Depression: Geomorphology and Morphotectonics

The territory under consideration is a transitional zone from Altay young collisional structures to the Zaysan depression marginal trough. Landsat MSS colour composites georeferenced in the UTM coordinates system helped to outline the boundaries between the different types of relief to a greater accuracy. The juxtaposition of the altitude model and Landsat images was used to find the precise position of scarps which mark the youngest tectonic movements by faults.
The studied area differs significantly from the central and South East Altay by the character of Cenozoic tectonic movements. In the early compression stages affecting this area, a smooth folding of the primary peneplane resulted in the formation of a system of North West striking swells and depressions. The latter were tectonically broken into blocks which were affected by significant displacements relative to each other in both horizontal and vertical directions.

Within the studied territory the brittle deformation break of the tectonically folded peneplane just started. So, the deformations in the southern Altay seem to have started earlier than in central Altay. The expansion of orogenesis involved the foretrough into the uplifting.

The highest Kurchum and Asu-Tay Ridges extending along the northern boundary began to form as early as Paleogene. In that time the whole low-hill area bounding the ridges from the south was still a part of the foretrough. This is evidenced by the presence of a large number of small depressions filled by Paleogene sediments. Different grade of erosion dissecting of the uplifted blocks and their bounding low-hills proves that the uplifting of these two structures started in different time. The oblique relicts of the peneplane at the tops of northern blocks experienced a strong erosion dissecting. The erosion network of the low-hills is still in its infancy.

So, the time is the main agent of erosion dissecting of rocks in this region. Therefore, the mountainous relief of the territory northern frame is older since it experienced the erosion dissecting for a long time. At present, the foretrough seems to be still involved in the Altay orogenesis. A zone of 20 to 40 m width is recognised along the Zaysan depression northern boundary and separated from the depression by a range of uplifts along the Black Irtysh right bank with exposed Paleozoic rocks.

Geophysical studies showed that the thickness of Late Cretaceous and Cenozoic sediments in this zone in less 300 m compared to more than 1000 m in the rest part of the Zaysan depression.

Relief surface of the northern zone shows the signs of starting denudation: in many sites the cover of Quaternary sediments is absent; Paleogene and Neogene sediments are exposed.

The morphotectonic evolution of the region is mainly defined by a long, relatively weak regional compression which is evidenced by the deformed Late Cretaceous and Paleogene sediments at the outcrops along the foot of tectonic scarps separating the low-hill area and the Zaysan depression.

4. Combination of spaceborne radar interferometry and Landsat TM imageries contributing to recent tectonic and geology studies in the Aswa lineament shear zone (Sudan)

The Aswa lineament zone, extending from SE Uganda into SW of Sudan has been considered until recently as tectonically at rest. However, from May 1990 to September 1991, a total of 64 earthquakes were recorded including one of the largest seism ever recorded in Africa (Ms=7.2); all these seismic events were concentrated in the North of the shear zone itself, nearby the Nile Valley in Sudan.

Preliminary studies performed on a Landsat-MSS image mosaic have shown various lineaments affecting lithological units dating from Archean to Recent likely to be connected to this activity.This has motivated a more detailed study of the present tectonic evolution of the Aswa lineament and adjacent regions in Sudan.

Due to the lack of accurate topographic and geological maps in that part of Sudan, SAR interferometry was chosen as a powerful tool to generate high resolution Digital Elevation Models (DEM). Such DEM provide good quality reference to analyse the geomorphology and the drainage patterns, in order to extract valuable tectonic information.

Taking benefit of an ESA research project AOT.B304, ERS1-2 tandem pairs have been purchased in order to produce a mosaic covering the area of observed earthquakes. The geographic location near the equator, the semi-arid environment (except in the Nile Valley itself), the short period between acquisition of ERS1 and ERS2, and the baseline which will be maintained in the range 120 to 300 meters, are optimal conditions for applying this technique.

The products of the interferometric processing such as amplitude images, interferograms, coherence maps, and DEM images provide us with valuable information over land use, vegetation and topography. This information can be then merged with the spectral processing of Landsat TM images of the same area. The spatial resolution of the interferometric products and the Landsat TM imagery combination is 30 by 30 meters while the height resolution is expected to approach 5 meters. The result of the merging contributes to a better understanding of the geological and tectonic phenomena of the studied area.

5. UNESCO/IUGS GARS-Asia Programme on A Remote Sensing and GIS-assisted study in the Philippines

There are more than 22 active volcanoes in the Philippines. One of the lesser-known volcanoes on the Luzon main Island is Mt. Bulusan. This volcano is an andesitic stratovolcano and forms part of the Bicol volcanic belt, which runs parallel to the Philippine trench, but approximately 250 kilometres more to the West. Records since 1852 show that the volcano erupted more than 15 times. The majority of these eruptions were mild phreatic eruptions and apart from tephra fall, no casualties and significant damage have been reported. Field evidence shows however, that Bulusan is capable of producing significant lava flows, lava domes and pyroclastic currents. Extensive lahar deposits, derived from the latter deposits have also been found. This proves that Bulusan volcano poses a potentially major risk to the population living near or at the footslopes of the volcano. Although the area is rural, the fertile valleys surrounding Mt. Bulusan are densely populated. This results in the volcano constantly being monitored with seismic equipment by a team of volcanologist from the Philippine Institute of Volcanology and Seismology (PHIVOLCS).

In order to mitigate the hazards posed by the volcano, a hazard analysis program needed to be set up. The problem in this area is that detailed and up-to-date geological and geographical information is lacking. Therefore is was chosen to use remote sensing techniques to assist the acquisition of information describing the geological and geographical environment. Landsat TM and JERS-1 SAR images, combined with the DTM of the area have been geologically and geomorphologically interpretated. Several months of fieldwork were carried out to check the interpretation of the remotely sensed images and to carry out some general geological field surveys. Geographical Information Systems (GIS) were used to store, manipulate and analyse all the compiled and acquired information.

In this way a reference GIS database was created at a medium scale, that contains the basic information covering a large area around Mt. Bulusan. The database was used for the development of preliminary hazard maps for each of the volcanic hazards that have been identified. An elementary approach, making use of the 'Energy cone' concept, was followed to outline the areas subject to potential pyroclastic flows and surges. Using the predictions on the extent and relative thickness of future pyroclastic flow deposits, a scenario was developed to define the areas that will be affected by lahar flow and deposition. A combination of factors defining the distance from the crater and the distance from the initial lava flow paths was used to produce a hazard zonation map for lava flows. Finally, combining the volcanic hazard maps with spatial information on population can greatly assist hazard mitigation efforts for this region.

The methodology applied here can also be adopted to map other unknown volcanoes in the Philippines. The GIS database on Bulusan can still be improved and further investigation is needed to achieve a better understanding of the geological history. Instead of a topo-map based DTM, SAR interferometry or stereo-radar techniques will be used to create a topographic model, that can replace or enhance the existing and partly inaccurate DTM of the area.

This project has been carried out in the framework of the IUGS/UNESCO GARS-Asia Programme, which encourages research and applications of remote sensing techniques in the field of geologic hazards.

6. ESA/ESRIN Data User Programme (DUP) on SAR-UGANDA. Local topographic mapping with SAR interferometry in Africa

Uganda is one of the countries in Africa that experiences a rapid growth and many efforts are undertaken to reconstruct infrastructure damaged during many years of civil war. Consequently there is a large demand for accurate and up-to-date topographic and other thematic information. Existing maps are often outdated or non-existent.

Using modern remote sensing and data integration techniques, an attempt is made to create updated maps at a 1:50,000 scale within a relative short period of time. The main technique that will be used is radar interferometry (InSAR) for the creation of Digital Terrain Models (DTM) using ERS1/2 tandem data.

Oriented towards a developing country and in complement to UNESCO's GARS programme, this project initiates the usage of SAR interferometry at local geological survey and mines departments. From DEM's covering local areas derived topography contour maps merged with thematic information will be generated. For the latter, the GIS know-how acquired in the frame of the GARS programme will be used.

One of the main techniques that are being applied is SAR interferometry (InSAR) using ERS interferometric tandem data. InSAR processing in used to create Digital Elevation Models of the project area. Fieldsurveys using Differential GPS equipment have been carried out to calibrate the interferometric data products. Calibration involves (horizontal) georeferencing using ground control. Vertical calibration using the DGPS elevation measurements is carried out to correct for the residual tilt in the InSAR DEM's.

7. Contribution of SAR interferometry to geomorphologic and tectonic studies in the Rukwa rift (SW Tanzania)

The last development of SAR interferometry and related tools offers new facilities for geological applications in regions where field access is rather limited or sometimes not possible at all. Interferometric products like Digital Elevation Models (DEM) open new possibilities for geomorphological interpretations in remote areas. SAR interferometry technique is explored here for the today evolution study of the Rukwa rift area For this purpose, two project supported by ESA were initiated and ERS tandem pairs covering the two sites have been acquired. Each pair is processed for the extraction of the interferogram which is unwrapped to give the slant range interferometric DEM. The geocoding operation is then performed to project the DEM on a ground range projection allowing any further interpretations.

The first investigated site is located in the Tanzanian Rukwa rift between the Tanganyika and Malawi tectonic troughs. The Rukwa rift is a deep NW-SE trending sedimentary basin where both normal and strike-slip movements were recorded in the recent times. Computed interferometric DEM allowed us during the last field campaign to evidence slight topographic features which are not visible on existing topographic maps and which are likely from tectonic origin.

8. Radar interferometry, optical remote sensing and GIS for the determination of geological risks in the routing and construction of large linear civil engineering works. Application to a pipe line in Jordan

The routing and construction of large linear-shaped civil engineering works such as pipelines, highways, railways and electric power lines require a detailed assessment of the geological risk in order to ensure their safety, and optimise the cost of construction and exploitation.

We intend to use SAR (ERS, JERS, possibly RadarSat) sensors, for the purpose of analysis of topographical and surface changes, in association with other (satellite derived or not) data sources, for updating or adapting the pertinent lithological, geophysical and geotechnical information , concerning a 300 km long corridor between Aqaba and Amman (Jordan), in order to create hazard maps and reports concerning the engineering work.

Hazard maps and safety reports will address the following specific risks :

- the seismic risk itself (i.e. the direct destructive effect of earthquake ground motion);
- the risk of surface rupture along active faults;
- the risk of slope instability in static conditions;
- the risk of landslides triggered by earthquakes;
- the risk linked to fast erosion induced by floods.

High resolution Digital Elevation Models (DEM) will be derived either from SAR interferometry or from radar stereogrammetry, according to the local conditions. Lithological information (including the presence of swelling clays and saline rocks) will be derived from optical imagery (Landsat TM) calibrated with field data. Tectonic information will also be derived from the analysis of the DEM, as well as slope maps.

The seismic properties of the area, particularly source size, activity and derived site effects, will be determined from the analysis of existing seismological and tectonic records together with the DEM. This will result in a seismic hazard map.

Geological and geotechnical mapping based on recorded data or on new observations will allow to define landslide prone areas. Processing of the latter together with seismic data will in turn allow to define zone at risk for earthquake triggered landslides.

All data will be integrated in a GIS. A specific layer will be devoted to environmental (archaeological or other protection areas) aspects.

9. Publications

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Fernandez-Alonso, M. and K. Theunissen, Airborne geophysics and geochemistry provide new insights in the intracontinental evolution of the Mesoproterozoic Kibaran belt (Central Africa), Geological Magazine, 135, 203-216, 1998.

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Slob, S., F. Kervyn, M. Fernandez-Alonso and M. Bornas, Volcanic hazard mapping in the Philippines using remote sensing and GIS. European Symposium on Remote Sensisng (EUROPTO), September, Barcelona, Proceedings of SPIE EUROPTO series, 3496, 54-66, 1998.

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

1. Microwave remote sensing

The research activities at the Telecommunication and Remote Sensing Laboratory (Electrical Engineering Department, UCL) are along four main directions : (1) communications systems, more particularly within complex environments, (2) image coding and processing for compression purposes in digital television and for medical applications, (3) secure multimedia networks and (4) Earth surface remote sensing from airborne and spaceborne platforms using microwave instruments. The present report is related to this last field.

The methodological approach selected in the remote sensing activity consists in exploiting and applying our expertise in electromagnetism and communication systems for the study of microwave remote sensing systems. The research topics are concerned with electromagnetic diffraction by random rough surfaces, such as the ocean or the soil, and from volume distributions of scatterers such as found in rain, vegetation, forest cover, etc... Our research efforts concentrate on the modelisation of both the propagation and the scattering of electromagnetic waves in the microwave range, in order to estimate the radar cross-sections and the brightness temperatures that would be measured by spaceborne or airborne radars or microwave radiometers, when observing a given scene. The modelisation effort has been extended up in a first step to the development of a pre-operational software tool in a modular way. In a second step this has been applied to the set up of tools of an inversion procedure for the retrieval of the surface, ocean, land, and atmospheric parameters.

Our first researches in microwave remote sensing started as early as 1978 and focused on the degradation produced by the atmosphere and by rain on Synthetic Aperture Radar (SAR) observations, the development of inversion algorithms for multifrequency and multipolarisation radiometers, and the correction of the altimeter retrieved distance from radiometric measurements.

Since the eighties our efforts have been concentrated towards the development of a unified electromagnetic interaction model for the ocean and the atmosphere. This model has been applied to the simulation of satellite microwave payloads and to the development of a synergy between active and passive instruments. A software package has been set up and delivered to the European Space Agency. Many comparisons between the models and various measurements have been and are still made for several kinds of airborne and spaceborne instruments. A special attention has been paid to the European Remote Sensing Satellites (ERS1 and ERS2) in particular the Tandem mission that allowed us, thanks the financial help of the Office for Scientific Technical and Cultural Affairs (OSTC), to prove the gain in information through the combined used of sensors looking at a same scene from different looking angles, in particular for the interpretation of scatterometer and altimeter data over mixed seas. The data from the Topex/Poseidon satellite supported the previous findings. They also allowed, in a collaboration with Ifremer (France), to analyse the perturbation of the altimetric waveform under rainy conditions. This represents an important step, since up to recently, satellite data contaminated by rain where merely discarded and thrown away.

Rain radar techniques have been also considered : the concept of ground meteorological radar extended to space observations for global measurements of precipitation characteristics has been practically implemented in the Tropical Rainfall Mapping Mission (TRMM) satellite by NASA and NASDA (Japan). In this context the analysis of the rain effects on ocean radar signatures is the subject of a cooperative research effort with NASA for years now. As a result of this expertise, our remote sensing team participated to the setup of a network of several European Union Laboratories in the field of Rain Radar Missions. A first network started in 1992 with 4 laboratories. It has been now extended to the so called EU Eurotrmm group of 9 institutions across Europe that organise and process the data from TRMM during the period 1998-2000.

Radiometry of the ocean surface and atmosphere is an important facet of these studies either. Presently the more intense effort in that field is performed with the "Centre de Recherche des Environnements Terrestres et Planétaires" (CETP, France) that also invested a significant effort to extend the applicability of our electromagnetic and sea surface models for a synergistic use of radar and microwave radiometric data. This collaboration was implemented by co-direction of Ph.D. theses. Results will be found in the reports of COST

712 and 714 actions very soon. In this context participation to the Environment Satellite (ENVISAT) mission and ocean salinity analysis are the subject of future collaborative studies.

Since 1991, we have developed in parallel a related area in the field of electromagnetic diffraction by soil and vegetation. The first efforts were directed towards the investigation of the dependence of soil scattering on its geometrical and constitutive properties. Then scattering by vegetation has been studied, for agricultural and forestry applications. Data of several airborne campaigns (MAESTRO 1989, EMAC 1994) and of the ERS SAR have been analysed. Calibration aspects were also taken into account (EMAC 1994).

In this area of land targets, the focus is placed on SAR data. Our main interest is not in the qualitative interpretation of SAR images through image analysis techniques, but in the quantitative interpretation of SAR data in terms of surface parameters of interest in the applications, such as : soil humidity, biomass, trunks volume, etc... This requires (1) that the radar backscattering coefficient be extracted from the SAR data, with due account of the speckle effects, and (2) that scattering models be applied for developing retrieval inversion techniques. Special interest is put in radar and SAR polarimetry, a technique that provides much more information about the observed targets. The SAR performances under rainy conditions also remains a subject of future studies.

We have been involved in several ESA-ERS pilot projects with OSTC support, for the analysis and processing of ERS SAR data e.a. : the interpretation of SAR observations above tropical regions, including such targets as tropical forests, savannahs and plantations, and the use of SAR data for agriculture monitoring in Europe. These projects have been conducted in collaboration with two UCL Laboratories, in Geography (GEOG) and in Agronomy (MILA), with the University of Ghent, and with the "Vlaamse Instelling voor Technisch Onderzoek" (VITO) in Mol. An on-going project, with the VITO, is concerned with the characterisation of tropical ecosystems using SAR satellite data. We are also involved with eight partners in an European concerted action called ERA-ORA for European radar-optical research assemblage, whose aim is to improve the radar data analysis and tools developed by European researchers, by making data and theoretical models mutually accessible through a distributed library.

2. Research Projects

2.1. Ocean and atmosphere

- Combination of altimeter and microwave radiometer data to improve the retrieval of geophysical products over sea (1995-1997) : Pilot project ESA ERS-1/2
  financing : ESA postdoctoral fellowship
  in collaboration with CETP (F) and continuing collaboration with CLS (Toulouse) (ends 2000).
- Space Technique applied in Research and Development of Ocean Wave and Monitoring (STARDOM) (1996-1999)
  European Concerted Action
  in collaboration with IFREMER (F) + CETP (F) + NORUT (N) + Meteo France (F)
- Synergic use of ERS Tandem mission for non-fully developed sea-state study (1997-1998) ESA Pilot project B301
  financing PRODEX 5
- Measurement of radar scattering signatures and sea surface changes due to rain (1992-1999) ; own project
  co-financing : UCL/FDS grant + Loterie Nationale grant (co-acquisition of a high speed video imaging and processing system)
  in collaboration with NASA (USA) / IMST (F)
- EUROTRMM : Exploitation of TRMM Data for an improved weather and climate forecast" EU Pilot Project
  and
  ESATRMM : Assimilation of satellite remote sensing data, ESA project (1998-2000) cofinanced by CR EU:ENV4-CT97-0421 and CR ESA-ESTEC 12561/97
  in collaboration with CETP (F) + RAL (UK) + UEssex (UK) + ECMWF (UK) + DLR (D) + FMA (IT) + Univ Munich (D) + Max Planck Inst. (D).
- Directional Spectra of Ocean Waves, COST 714 project (ongoing).

- Application of microwave radiometry to atmosphere research and monitoring, COST 712 project (expert). Final report : Radiative transfer model for microwave radiometry (EU Publication) (ends 2000).
- Project on sea salinity measurements from microwave radiometry
  in collaboration with CETP (F)
  financing : PhD fellowship.

2.2. Land and vegetation

- Tropical forest SAR observations processing (1995-1996) ESA Pilot project
  financing : CR SSTC T3/10/045
  in collaboration with GEOG (UCL).
- PhD thesis – Développement de modèles de rétrodiffusion polarimétrique et application à l'observation radar des forêts, Etienne Robin (1993-1997)
  financing : IRSIA-FRIA fellowship.
- Multritemporal SAR data for crop monitoring - Signal modelling and analysis of biophysical variables dynamics (1994-1996) ESA Pilot project.
- Biophysical characterization of tropical ecosystems by spaceborne synthetic aperture radar remote sensing – Backscattering modelisation and sensitivity analysis, 1st part : 1997-1999; 2nd part : 1999-2000.
  Financing : SSTC projects T4/DD/006 and T4/10/37.

3. Publications

3.1. Ocean and atmosphere

Craeye, C., Radar signature of the sea surface perturbed by rain, Ph.D. Thesis, Université Catholique de Louvain, December 1998.

Craeye, C., P. Sobieski, F.L. Bliven and A. Guissard, Ringwaves generated by water drops impacting on water surfaces at rest, IEEE Trans. Oceanographic Engineering, 24, 323-332, 1999.

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Lemaire, D., Non-Fully developed sea state characteristics from real aperture radar remote sensing, Ph.D. Thesis, Université Catholique de Louvain, December 1998.

Lemaire, D., P. Sobieski and A. Guissard, Full-range sea surface spectrum in non-fully developed conditions for scattering calculations, IEEE Tr. on Geoscience and Remote Sensing, 37, 1038-1051, 1999.

Sobieski, P., C. Craeye and F.L. Bliven, Scatterometric signatures of multivariate drop impacts on fresh and salt water surfaces, Int. Journal of Remote Sensing, 20, 2149-2166, 1999.

3.2. Land cover

Craeye, C., P. Sobieski, E. Robin and A. Guissard, Angular errors in trihedrals used for radar calibrations, Int. Journal of Remote Sensing, 18, 2683-2689, 1997.

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Robin, E. and A. Guissard, Trunks parameters retrieval from multifrequency polarimetric SAR data of coniferous forests, Proceedings of EARSeL Symposium 1997 : Future trends in Remote Sensing, Lyngby, Denmark, 17-20 June 1997, European Association of Remote Sensing Laboratories, 1997.

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Robin, E., A. Guissard, E. Aucquière and P. Defourny, A model of corn radar reflectivity at full growth stage, Proceedings IGARSS'99, Hamburg, Germany, 28 June-02 July 1999, IEEE GRS Society, IEEE, 1999.

Yordanov, O.I. and A. Guissard, Approximate self-affine model for cultivated soil roughness, Physica A : Statistical and Theoretical Physics, 238, 49-65, 1997.

C. National Geographic Institute

During the period 98 - 99, the remote sensing unit of the National Geographic Institute (NGI) took part in the MURBANDY project of the European Community.

This project aims at analyzing the landuse changes of great urban zones of Europe. The Belgian part of the project includes a classification of an IRS image (1997) over Brussels and three downdatings of this data. (mid 80's, end 60's and mid 50's).

The downdatings were done by treating orthophotographs produced by the NGI and 1:50 000 and 1:25 000 maps. The project has been lead in collaboration with the IGEAT of the Free University of Brussels.

The RSU also made tests about the updating of the 1:100 000 touristic map. The remote sensing is in charge of collecting landuse information. The operational phase, expected for 1998 has finally begun end 1999 and will continue in 2000.

The RSU took also part in the rasterisation in Lambert projection of the Digital Terrain Elevation Data (DTED) of the NGI.

Finally, the RSU took part in a study project over small scale mapping from satellite data without ground knowledge nor a-posteriori control.

D. Space Center of Liège

The activities of the "Space Environment and Remote Sensing" Group of the Space Center of Liège can be summarized as follows :

- Quality Assessment of InSAR Topographic Mapping - Evaluation of topographic mapping by interferometric radar techniques, ESA DUP Programme (1997-1998).
- Assessment of SAR Phasimetry by Case Studies in Tectonics and Agronomy - Use of data from the ERS-1/2 Tandem mission for interferometric purposes, ESA PRODEX programme (1996-1999).
- Spatial Organization of Hydrological Processes in Small Catchments Derived from Advanced SAR Image Processing - Use of data from the ERS-1/2 Tandem mission for interferometric purposes, ESA PRODEX programme (1996-2000).
- InSAR Baseline Combination for Topographical Phase Reference Generation - generation of reliable topographic phase references for radar differential interferometry, Belgian TELSAT-4 Programme (1998-2000).
- Investigation by Radar Imagery of Critical Parameters Influencing the Vulnerability of Dikes in Vietnam - Feasibility study, Belgian TELSAT-4 Programme (1999).
- Processing of Special Modes - Development of a high-resolution SAR processor, WEU EUCLID programme (1998-2001).
- Development of Interferometric SAR Processor— Industrialisation of a SAR interferometric, ESA GSTP programme (1999-2000).
- Improvement of radar interferometric processor functionnalities for tographic mapping and surface change measurements - Complementary research financed by the Walloon Region Ministery (1999-2000).
- Prevention of seismic risks by using differential interferometry applied to ERS-1/2 satellite imagery - programme FIRST financed by the Walloon Region Ministery (2000-2002).
- Optical processing of synthetic aperture radar imagery - programme INTAS (1997-2000).

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