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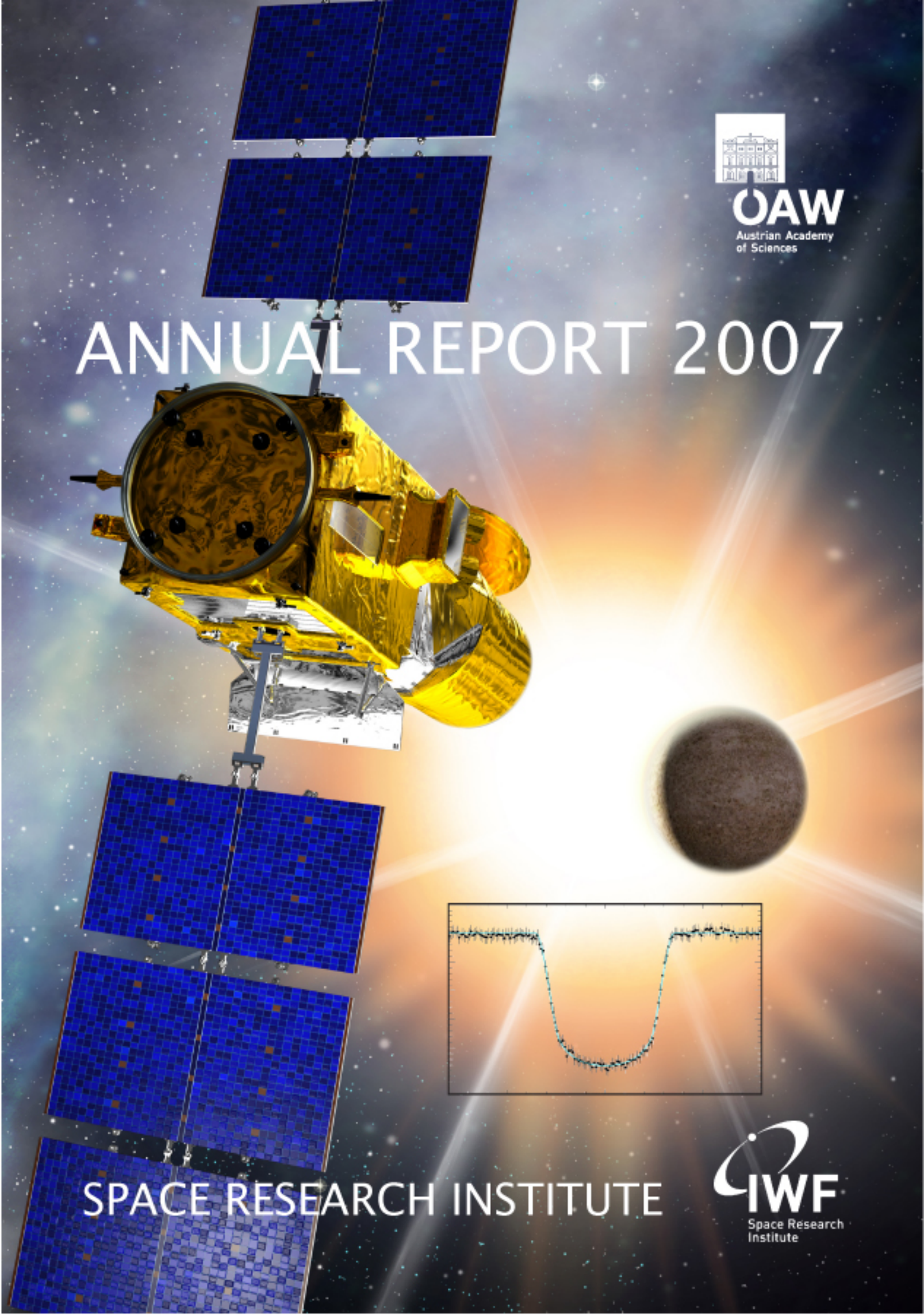
ANNUAL REPORT 2007



SPACE RESEARCH INSTITUTE

IWF
Space Research Institute

ANNUAL REPORT 2007

SPACE RESEARCH INSTITUTE GRAZ
AUSTRIAN ACADEMY OF SCIENCES

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Cover Image:

COROT was sent to space to search for extra-solar planets and to analyze the oscillation modes of stars. In the figure an artist's impression of an extra-solar planet eclipsing its star is shown with *COROT* observing. The inset panel shows the light curve of a star with a planet crossing the disk of the star measured by *COROT*.

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1 Introduction

The Space Research Institute (Institut für Weltraumforschung, IWF) of the Austrian Academy of Sciences (Österreichische Akademie der Wissenschaften, ÖAW) is the focus of Austria's scientific space activities. It cooperates closely with space agencies all over the world and with numerous other national and international research institutions. A particularly intense cooperation exists with the European Space Agency (ESA). IWF participates in various interplanetary missions as well as in missions dedicated to the exploration of our own planet Earth and its neighbourhood:

- *Cassini* is orbiting Saturn and exploring its system.
- *Cluster*, the four-spacecraft mission is still working well. The data from this unique mission has resulted in a new understanding of space plasmas.
- *Double Star*, the Chinese-European magnetospheric mission, is taking data in collaboration with the *Cluster* mission.
- *Rosetta* is on its way to comet 67P/Churyumov-Gerasimenko.
- *Demeter* is making measurements in near-Earth space to search for electromagnetic signatures of seismic activity.
- *Venus Express* explores the space environment around the planet. First results have just appeared in *Nature*.
- *COROT* started to search for extra-solar planets and analyze the oscillation modes of stars.
- *THEMIS* was launched on 17 February 2007 (Fig.1.1). The five identical microsatellites now probe the chain of processes called magnetospheric substorm and the origin of the aurora.

Fig:1.1: The launch of THEMIS.

- *GOCE* will determine the structure of the terrestrial gravitational field to better understand the Earth's interior and to map ocean currents.
- *Yinghuo* is the first Chinese mission to Mars, planned for launch in October 2009.
- *RBSP (Radiation Belt Storm Probes)* are two NASA spacecraft that will quantify the source, loss, and transport processes that generate the radiation belts and cause them to decay.
- *BepiColombo* will investigate in detail the innermost planet Mercury, using two orbiters: one with instruments specialized

for magnetospheric studies, and the other for remote sensing of the planet.

- *MMS* will carry out 3D measurements, using four identically equipped spacecraft, to explore the acceleration processes that govern the dynamics of the Earth's magnetosphere.
- *ExoMars* is an ESA rover to characterize the biological environment on Mars.
- *Resonance* is a Russian space mission of four identical spacecraft, orbiting within the same magnetic flux tube.

Highlight in 2007 was the successful launch of THEMIS on 17 February with a Delta II rocket from Cape Canaveral.

IWF is naturally engaged in analyzing data from these and other space missions. This analysis is supported by theory, simulation, and laboratory experiments. Moreover, at the Lustbühel Observatory in Graz, one of the most accurate laser ranging stations of the world is operated. Its data are used to determine the orbits of more than 30 satellites. Also a network of four permanent GPS stations is operated by IWF.

Scientific highlights in 2007 were:

- At Venus the first observations of hydrogen and oxygen escaping from the atmosphere were made in the foreshock region and wake by Venus Express (see Sect. 4.3) and also the first confirmation of lightning at Venus was obtained. These results were published in three “Nature” papers;
- Cluster has measured for the first time the fine structure of the Earth’s magnetotail current sheet during reconnection (see Sect. 3.2);
- The modulation of Saturn’s radio clock by so-lar wind speed has been shown and published in “Nature.”

In closing some numbers: in 2007 members of the institute published 91 articles in refereed international journals, 27 of these as first author. During the same period, articles with authors from the institute were cited about 1200 times in the international literature. In addition, 139 talks and posters have been presented at international conferences by members of the IWF, including 33 by special invitation from the convener. In national and international press media, the institute was mentioned about 300 times. Last but not least, institute members have organized five international symposia, as well as 17 sessions at international conferences.

IWF structure and funding

IWF is structured into three departments:

- Experimental Space Research (Head: Prof. Dr. Wolfgang Baumjohann)
- Extraterrestrial Physics (Head: Prof. Dr. Helmut O. Rucker)
- Satellite Geodesy (Head: Prof. Dr. Hans Sünkel)

Prof. Dr. Wolfgang Baumjohann serves as Executive Director.

The bulk of financial support for the research comes from ÖAW. Substantial support is also provided by other national institutions, the Austrian Research Promotion Agency (Österreichische Forschungsförderungsgesellschaft, FFG), the State of Styria, the Austrian Science Fund (Fonds zur Förderung der wissenschaftlichen Forschung, FWF), and by the Austrian Academic Exchange Service (Österreichischer Akademischer Austauschdienst, ÖAD) and its partner institutions in other countries. Last but not least, European institutions like ESA and the European Union contribute substantially.

2 Solid Earth

Detailed knowledge of the dynamics of the Earth is a basic prerequisite for understanding the Earth system on a global scale. Satellite-based instruments are a global and cost-effective means to provide a valuable data set for Earth scientists over a wide range of spatial and temporal scales.

Measurements of the Earth's gravity field and its variations based on dedicated satellite missions contribute to a better understanding of the mechanisms leading to the building of the Earth's crust and the flow of ocean currents. Global permanent position monitoring (GPS) and satellite laser ranging (SLR) contribute to the realization of reference frames, which are important to describe the driving forces of the Earth's interior processes.

2.1 Gravity Field

The gravity field of the Earth is the sum of the gravitational and centrifugal force, with the first being the response to the Earth's interior density distribution and the latter caused by its rotation. The forthcoming *GOCE* mission will substantially improve the spatial resolution of the global gravity field models.

GOCE

The satellite gravity mission *GOCE* (Gravity field and steady-state Ocean Circulation Explorer), the first core Earth Explorer mission of ESA's Living Planet Programme, strives for a high-accuracy, high-resolution model of the Earth's static gravity field (see Fig 2.1). *GOCE* is based on a sensor fusion concept: the satellite's orbit information is exploited applying satellite-to-satellite tracking in high-low mode (hl-SST) using GPS, delivering the long and medium wavelengths of the Earth's gravity field, while satellite gravity gradiometry (SGG) using an on-board gradiometer will provide its detailed structure.

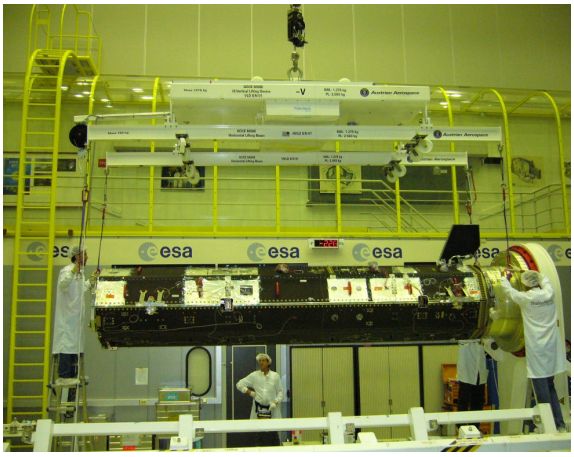

Fig. 2.1: Finalization of the GOCE satellite at ESA.

Data Processing

An operational hardware and software system for the scientific processing of *GOCE* data has been set up by the European *GOCE* Gravity Consortium EGG-C. One key component of this software system is the processing of a spherical harmonic Earth's gravity field model and the corresponding full variance-covariance matrix from the satellite's precise orbit (SST data) and SGG data. This key component is operated by the *GOCE* team Graz, which is a close co-operation of IWF with the Institute of Navigation and Satellite Geodesy of the Graz University of Technology. As one main component a rigorous solver approach is implemented, which solves the very large linear equation systems.

Data Gap Simulations

In real *GOCE* observation time series the occurrence of data gaps has to be expected, e.g. due to instrument calibration. This case study addresses the treatment of data gaps within the gradiometer measurement series, with special emphasis on the impact of the spatial distribution of data gaps on the gravity field solutions. One has to distinguish between short and long data gaps, which have to be treated separately during the gravity field processing. For small data gaps tailored strategies can be applied to fill these data gaps by re-sampled information. This information allows an uninterrupted filter process (remark: the filter represents the spectral error characteristics of the gradiometer) and therefore a smooth transition from one measurement series to the other. In contrast, large data gaps imply a restart of the filter procedure.

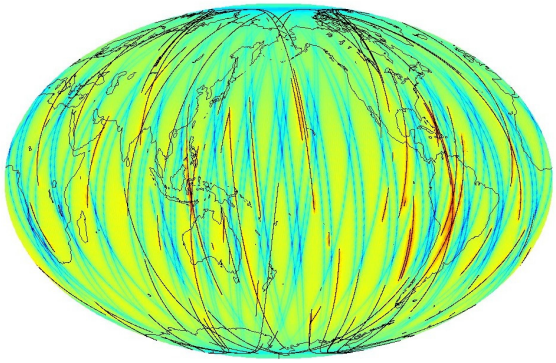

Fig. 2.2: Differences in the propagated geoid height standard deviations [cm] of the short data gaps test set with respect to the full reference solution.

In a numerical case study, which is based on the data of an ESA *GOCE* end-to-end simulation (59 days of SGG observations), gravity field solutions complete to degree/order (d/o) 200 have been computed to demonstrate the effect of short and long data gaps.

Based on a test data scenario of 100 short data gaps (seconds to minutes time period; approx. 1% of missing data), gravity field solutions have been computed. To allow for a continuous filter process fill-in signals have been computed using a-priori gravity field information (from a quick-look gravity field model) plus modelling the stochastic noise behaviour. This way the recursive digital filter process does not have to be interrupted. The only impact on the gravity field processing is that these fill-in data are flagged and subsequently ignored in the assembling process. The result of the gravity field solution error propagation is shown in Fig 2.2, where the distribution of the data gaps is overlayed.

The effect of short data gaps on the gravity field recovery is small, if they are adequately treated by means of a fill-in strategy. This is mainly due to the fact that also short data gaps are usually spatially distributed over the whole globe, so that the impact is mainly a slightly reduced redundancy in certain regions. The only exception is a case when unluckily a spatial clustering of data gaps occurs, leading to a region without or with only a reduced number of observations. Such a situation might lead to significantly increased gravity field errors in this region, which, however, are indicated by the corresponding statistical error estimates (see Fig. 2.3 for a regional example).

In the case of long data gaps, the results show that these gaps do not have a severe impact on the gravity field solution, as long as the spatial resolution composed by the existing observations is sufficiently large, with a reasonable ground coverage of the orbit.

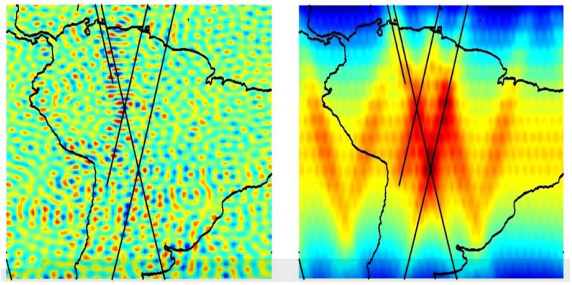

Fig. 2.3: Cumulative geoid height errors (left); geoid height standard deviations (right) propagated from the full variance-covariance matrix of the gravity field coefficients of the short data gaps test set: regional case study South America.

2.2 Geodynamics

IWF hosts the second largest data centre in Europe and within the top 10 of the whole world concerning GNSS data. It is also hosting national and international campaign data as well as all the data analysis.

The analysis is centred on three regions of geodynamic interest and on one for the European reference frame EUREF. According to international guidelines which are also partly developed under assistance of the institute's network of permanent stations are processed and analyzed. Among a total of 16 Analysis Centres for EUREF, IWF is one of the three leading ones. The geodetic approach consists of maintaining the dynamic reference frames of Europe and Austria by refining the results, applying filters of numerical mathematics to the results. Beyond that the time series of coordinates of the three regions are checked for detecting different provinces of geokinematics. Velocity fields are estimated and related to tectonic units. End of 2006 the international community switched from relative calibration of the GNSS antennas to absolute ones allowing a better modelling. Together with some minor improvements in modelling the troposphere the height determination should be improved.

The Eastern Alps are very densely covered by stations which were built in the last three years. Given the precision of 1–2 mm in the horizontal components estimation of velocities stabilize within two years at the 1 mm/yr level. This allows now to discern between some regions with different movements (North Alpine Forelands, Bohemian Massif, Tauern Chain, new block between Alps and Dinarides). The vertical component is more complicated because there are several influences to be modelled (antenna calibration, near field effects, troposphere). Only after filtering the instrumental and environmental effects a probably tectonic movement can be analyzed. Therefore only an upper boundary can be given, like a maximum of 3 mm/yr for the uplift of the Alps.

It is easier for regions with larger movements to come to quick and estimable results if there would not be the problem of poor coverage. This is especially a problem for the Eastern Mediterranean and the Arabian Plate where stations are sparse and frequently stop measurements (especially Turkey and the Arabian countries). The goal is to find major plate boundaries together which should fit into the seismic zones which are much better defined. The number of installed stations increases only slowly. In 2007 only two stations in Africa (Addis Ababa, Nairobi) and one in Arabia (revitalized, the second closed after some months) could be added while all the six stations in Iraq vanished. A better model than 2006 could only be derived by applying the new antenna calibrations which give only a minor (10%) improvement of precision, however.

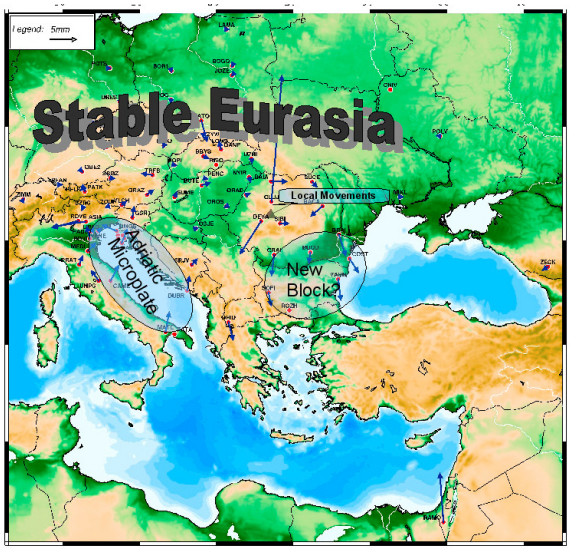

Fig. 2.4: Block structure of Central- and East European region.

The best results could be achieved at the Central European network (Fig. 2.4) where the campaigns since 1994 were recomputed.

Besides the removal of two Transylvanian stations with local movements and confirming

the motion of the Adriatic Microplate (without resolving the problem of the collision and/or rotation due to the Alps) a potential new block was found, rotating counter-clockwise with about 2-3 mm/yr. This must be checked with the seismic behaviour of the region because the geodynamic interpretation is still unclear.

Troposphere

The troposphere comprises 80% of the atmospheric mass and is the place where weather relevant phenomena occur. Looking at the path of the microwave signals it can be detected that the signal becomes slightly delayed when traversing the troposphere because of the so called tropospheric delay. This delay can be split into a wet part and a hydrostatic part. The hydrostatic delay is quite stable and can be modelled very accurate. In contrast the wet part is highly variable and depends on temperature, pressure and humidity. Various models which take this delay into account exist since quite a long time. In the last years a new approach was proposed which uses values from numerical weather models like those from the European Centre for Medium-Range Weather Forecasts.

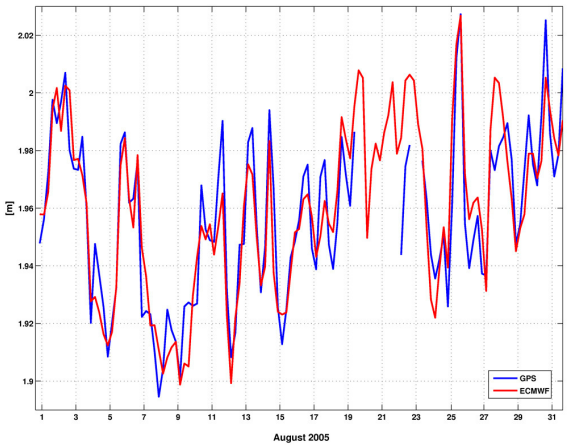

Fig. 2.5: Comparison GPS-derived and calculated ZTD.

So far zenith total delays (ZTD) from such a model were determined with a horizontal resolution of 0.3°x0.3° for about 70 stations in Austria. Fig. 2.5 shows the comparison between GPS-derived and calculated delays. The differences are in the range from a few to 20 millimetres.

2.3 Satellite Laser Ranging

During 2007 several upgrades have been implemented at the Graz station – still the only operational kHz SLR station – both in hardware and in software. The FPGA (Field Programmable Gate Array) based PC board (Fig. 2.6), developed and used at the Graz SLR station, has been upgraded again, now replacing two obsolete digital boards and offering new features: It measures start and stop event times with 5 ns resolution (<1 ns resolution in development) to allow for fast range gate settings (within a few µs after e.g. a start event). This is especially important for very low orbiting satellites like GOCE which require range gate settings within less than 1 ms after laser fire. The high resolution and high precision event timer, which is used for high accuracy epoch time determination, needs more than 0.4 ms to do that.

Other upgrades within the FPGA now allow making full use of the integrated 64 bit serial buses for digital I/O. This in turn will allow a fully automatic control of field-of-view, laser beam divergence settings, laser beam pointing control, receive energy control etc.

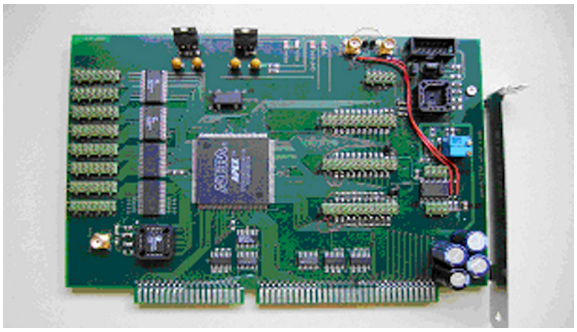

Fig. 2.6: PC card with FPGA.

A new time scale has also been implemented in the FPGA, which is synchronized with the GPS clock, allowing a fast determination of the absolute epoch time with 1 µs resolution.

The scientific results of the kHz SLR measurements are now constantly increasing. As mentioned already in the previous report, one of the main results is the determination of spin parameters. During this year, we were able to determine spin periods of ETALON-1 and ETALON-2 (Fig. 2.7). This is especially remarkable regarding their high orbits (>20000 km), which give less than 0.1% average return rates. Nevertheless, comparing simulated and measured SLR data of these two identical satellites, we were able to use the gaps between the different sets of retroreflectors to derive the spin periods for the last three years.

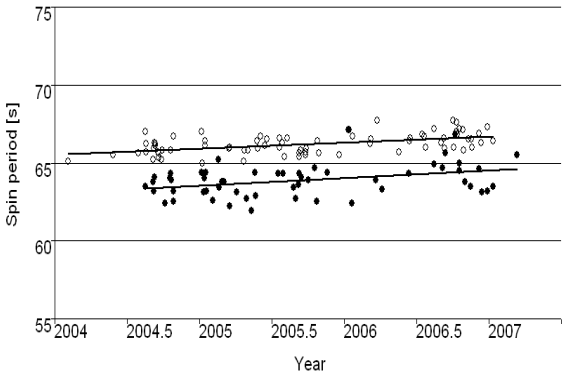

Fig. 2.7: Spin period behaviour of ETALON-1/2.

Several other projects are in a development phase. We are implementing a LIDAR system into the SLR station, using the backscatter of the transmitted laser beam to determine haze, clouds, vapour trails, atmospheric layers, as a side effect during routine SLR activity. Another device developed at the department continuously monitors the laser beam pointing deviations due to atmospheric seeing, and derives and stores the seeing values automatically during SLR night-time operation.

LEO Tracking

Laser tracking of Low Earth Orbiters (LEOs) is for many reasons significantly more difficult than tracking high orbiting satellites (HEO) because the angular speed is much higher, the visibility from ground stations as well as the tracking elevation is lower. From these and other reasons it is expected that only about 50% of the SLR stations will be able to track *GOCE*-like orbits yielding a tremendously low amount of data. In order to optimize the LEO tracking efficiency the Graz SLR station was upgraded: By means of special electron multiplying CCD cameras (EM-CCD) it is now possible to track low orbiting S/C during day and night. Real time corrections and alignments of the laser beam increase the return rate and an automatic control of the receiver sensitivity allows to set longer range gates which is vital for successful tracking.

2.4 Demeter

Several approaches have been performed to investigate electromagnetic precursors of seismic activity. A first approach is devoted to a theoretical study of the electrostatic field penetration from lithospheric origin into the ionosphere. It is shown that the field penetration can be damped because of atmospheric conductivity variations at the altitude of *DEMETER*. A second analysis estimated the ratio of the vertical to the horizontal magnetic field power (polarization ratio) which is expected to be high (~1) for seismic active periods.

Fig. 2.8 shows a time series variation of the geomagnetic activity (upper panel) and the estimated polarization ratio observed in the ULF frequency range by three *SEGMA* stations (2nd, 3rd and 4th panels).

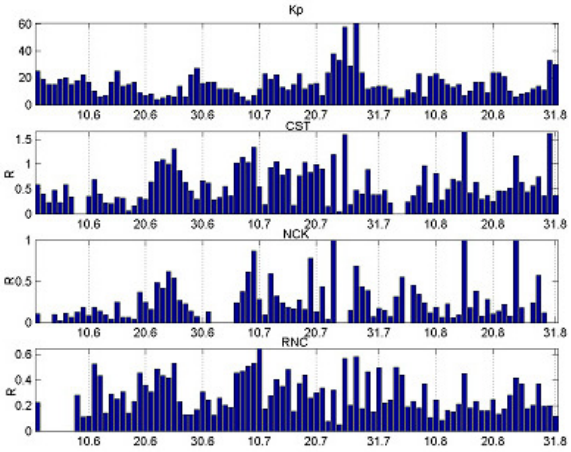

Fig. 2.8: Polarization ratio R using one day averaging.

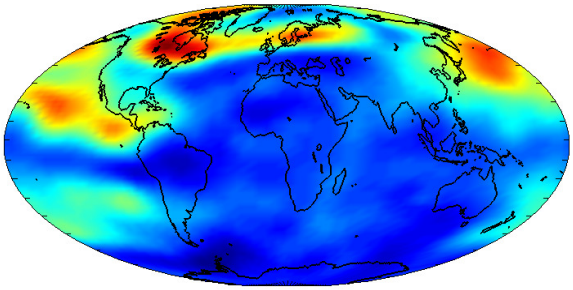

Fig. 2.9: Extreme TEC values in % of the weekly average according to a storm.

It is found that, three weeks before the occurrence of the Bovec earthquake on July 12th, 2004 (M = 5.5, depth = 10 km) the ratio is greater then one for the Castello Tesino station which is closest to the epicentre. A third recent study is devoted to examine the variation of the ionospheric total electron content (TEC) before, during and after earthquakes. GNSS satellites are used concerning ionosphere research. While filtering away the influence during positioning the TEC along the ray paths can be estimated. This is done as a service by International GNSS Service (IGS), producing a global Vertical TEC map with a resolution of 5°x2.5°x2h (latitude/longitude/time). These TEC maps were used to develop a program searching for big disturbances like in Fig. 2.9.

The aim was to study the TEC range on Earth in comparison to other similar planets (exoplanets). Changing strength of the ionosphere before, during and after earthquakes will be studied in the near future. For this a test area was designed around the Adriatic Sea.

The *DEMETER* satellite and low frequency receivers also cover the area which gives the possibility to compare the detected changes. The regional resolution of estimated VTEC should be 1°x1° with a temporal resolution of one hour.

3 Near-Earth Space

Near-Earth space is an ideal environment to study the physics of space plasmas, i.e., electrically charged particles (ions and electrons), where electric and magnetic fields dominate the physical processes. The Earth's space environment is dominated by the interaction between the solar wind and the terrestrial magnetic field. The structures that are created in this interaction are the bow shock, in which the supersonic solar wind is decelerated, a transition layer called the magnetosheath, the magnetopause (the boundary of the magnetosphere), and the magnetosphere itself, where the magnetic field from the Earth's dipole is dominating. Research on the near-Earth space at IWF is performed on experimental and theoretical bases and through data analysis.

3.1 Missions

One of the important components of the investigation of the near-Earth space at IWF is the active involvement in different spacecraft missions throughout their entire phases, i.e., providing hardware, processing and analysing the measured data, constructing new models, and participating in future planning. These include the ongoing missions, *Cluster* (launched in 2000) and *Double Star* (launched in 2004), newly launched mission, *THEMIS* (in 2007), in which wealth of new and exciting data are taken and lead to successful new results, and also the future mission, *MMS* (launch planned in 2014), in which IWF is presently involved in building instruments.

Cluster

The four *Cluster* spacecraft, launched in 2000, are still in operation, taking data while circling the Earth in polar orbits. By now, the spacecraft have made observations in the Earth's magnetotail at several different separation distances of the thetrahedron, varying from 200 km to 10,000 km. Since 2005, modified configurations have been realized to be able to compare large scale (10000 km) with small scale processes (20 km – 1000 km). This ESA mission has now officially been extended until the end of 2009. *Cluster* can be combined with the Chinese-European *Double Star* mission, which provides an extra dimension, and with the new spacecraft configuration, many new results on plasma processes at different spatial scales come out of this mission. As P-I institution of *ASPOC* and holding Co-Istatus for four more instruments, IWF is maintaining the *Austrian Cluster Data Center* and is analysing *Cluster* data in many studies introduced in the next section.

All of the *Cluster* high resolution data and other allied products are archived in database called the *Cluster Active Archive (CAA)*, which is currently operating and is maintained by ESA. The instrument team in IWF is processing and providing data to *CAA*. A web interface of *CAA* has been completed and became accessible to the wider science community since mid 2006.

Double Star

Within the *Double Star Project (DSP)*, two satellites, TC1 and TC2, are observing the Earth's magnetosphere on near-equatorial and polar orbits. Launched in 2004 and 2005, the original one-year mission was extended until late 2007. TC1 completed its mission in October 2007 when it entered the atmosphere.

IWF participates in this mission with two experiments, *DSP-ASPOC to* control the electric potential of the equatorial spacecraft, and *DSP-FGM* to measure the magnetic field on both satellites. IWF is also Co-Investigator for the European electron experiment *PEACE,* plasma experiment *HIA* and the search-coil magnetometer *STAFF* and various Chinese experiments and is playing an active role in data analysis. IWF further provides two core services for the exchange of data: *European Double Star Data Distribution System (EDDS)* and the *Austrian Double Star Data Centre (ADC)*. Currently IWF is also preparing data for the final archive.

THEMIS

The NASA mission *THEMIS (Time History of Events and Macroscale Interactions during Substorms)* is designed to explore the origin of magnetic storms and auroral phenomena. *THEMIS* was successfully launched in February 2007 and flies five identical micro-satellites through different regions of the magnetosphere.

IWF participates in *THEMIS* by providing science support. It has also contributed to the mission concept design as well as the instrument development of the fluxgate magnetometer *FGM*, which has been developed under the leadership of TU Braunschweig.

Since March 2007, after successful instrument commissioning, scientific data are provided nominally. The first seven months after launch, all spacecraft are lined up with the same apogee at 15.4 R_E. The orbits were changed successfully to fit the requirements for the tail science phase, which starts in December 2007 and will have apogees of Probe 1 at 30 R_E, Probe 2 at 20 R_E, Probes 3 and 4 at 12 R_E, and Probe 5 at 10 R_E. Since March 2007, IWF is participating in processing and analysing data. An example of the THEMIS data is shown in the summary plot in Fig. 3.1.

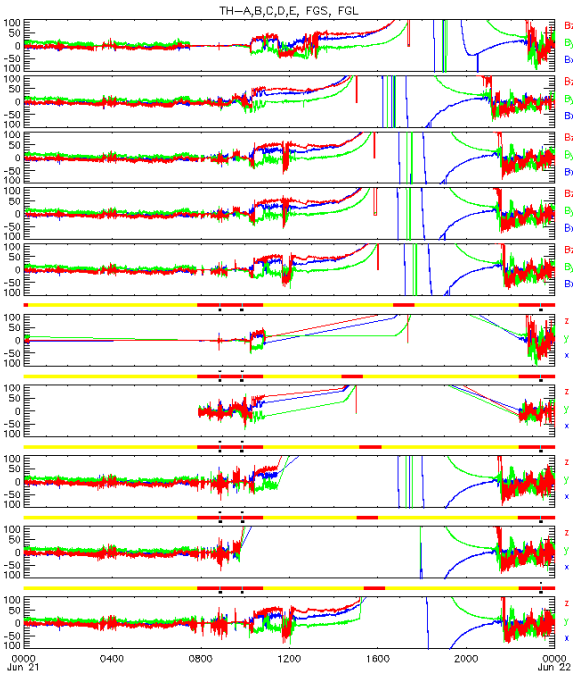

Fig. 3.1: An example of the magnetic field data plot from the five THEMIS spacecraft obtained on June 21, 2007.

MMS

A flexible Electrical Ground Support Equipment (EGSE) platform usable for several applications was developed, a General Purpose EGSE, Fig. 3.2. After the analysis of typical EGSE applications, a stand-alone device with standard interfaces, USB and Ethernet, was built, to communicate with a computer. The present design is built around the XILINX VIRTEX-II series, providing space for logic design up to an equivalent gate count of two million system gates.

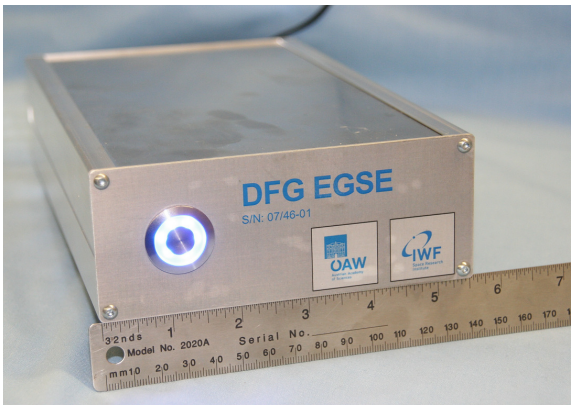

Fig. 3.2: The EGSE for the magnetic field sensor onboard MMS, based on the general purpose platform.

Four connectors provide 148 digital I/O lines interfacing to application specific daughter boards with necessary interface drivers or analogue circuitries. To facilitate the logic design, the 16-bit full duplex FIFO (Firs In First Out) based data interface is provided as VHDL (Very high speed Hardware Description Language) code. The driver routines at the PC side and a basic LabView application for configuration and operation of the GP-EGSE are provided, too.

Presently dedicated EGSEs for the Digital FluxGate magnetometer and the Electron Drift Instrument are under development, using this platform.

3.2 Physics

In the Earth's magnetosphere a fleet of spacecraft provides an enormous amount of data representing the plasma and magnetic field behaviour in this region. In near-Earth space, high-resolution data from the plasma and magnetic/electric field measurements are provided by missions introduced in previous section, such as *Cluster*, *Double Star*, and *THEMIS,* and also from other missions such as *Geotail*, *Interball,* and *Polar*. At IWF these various data are analyzed and theoretical models are developed to describe the physical processes responsible for the formation of structures and phenomena in near-Earth space. These studies deal with large-scale interaction between solar wind and magnetosphere, meso-scale disturbance in the magnetotail, magnetotail-ionosphere coupling, and physics of the magnetic reconnection, and turbulence properties.

Guide field reconnection: Magnetic reconnection is one of the key processes taking place in a thin current sheet in the magnetotail. In contrast to magnetopause reconnection, where the shear component can be significant, magnetotail reconnection has been considered to have a 2-D geometry. However, such 2-D reconnection should not always be the case, as is suggested by a Cluster observation, when a strong guide field was observed during a fast flow interval. During the event, an intense current layer was created (Fig. 3.3). A peak current density of 182 nA/m^2 was detected (panel c), which was the largest current density obtained from the four-point Cluster analysis in the magnetotail. In this thin layer, which had a scale size comparable to the ion-inertia length, the current was flowing mainly antiparallel to the field (panel c). The event was associated with asymmetric parallel heating of electrons (panels a and b), which suggests that electrons moving along the field lines can contribute to a strong dawn-to-dusk current.

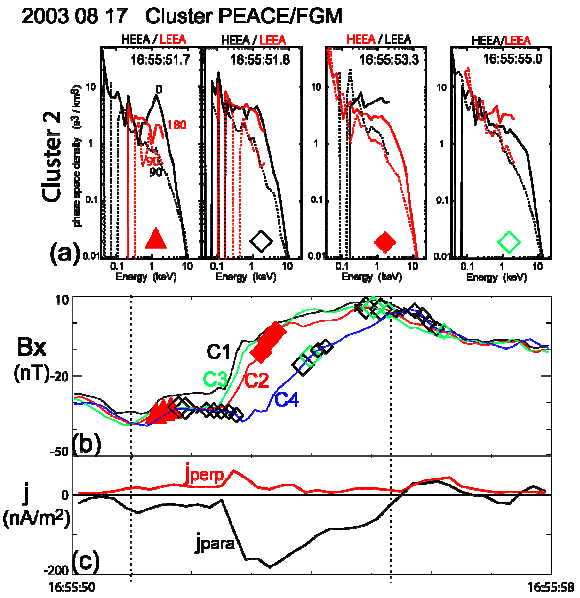

Fig. 3.3: Observation of an Intense current layer (a) Electron distribution parallel (0°), anti-parallel (180°) and perpendicular (90°) to the magnetic field (b) Bx during current sheet crossing. Different types of electron distribution shown in panel (a) are presented with symbols. (c) current density parallel, jpar, and perpendicular, jperp, to the magnetic field.

Reconnection inverse problem: The model of time-dependent Petschek-type reconnection generalizes the classic Petschek mechanism for the non-stationary regime. The non-stationary solution allows to investigate the dynamics of the process depending on a variable reconnection rate. It predicts signatures typical for such observational phenomena like

flux transfer events (FTEs) and travelling compression regions (TCRs): a bipolar B_z-variation and a B_x-compression. Since the non-stationary solution is analytical, it can be inverted, i.e. the reconnection rate can be recovered from given magnetic perturbations. On the basis of this model two methods for reconstructing the reconnection rate, flux and X-line location from spacecraft observations have been developed. The first method (based on the inverse solution) utilises single-spacecraft magnetic field data as an input and provides the reconnection rate and the location of the X-line as an output. The second determination procedure of the reconnection site's location is based on a minimization routine, in which a rough estimate of the location is used to avoid ambiguous results. This method is based on the change of the B_z signature with increasing distance to the initial reconnection site. Combining these two methods, a very powerful tool for the reconstruction of the reconnection rate, the reconnected flux and the determination of the reconnection line's initial location is created.

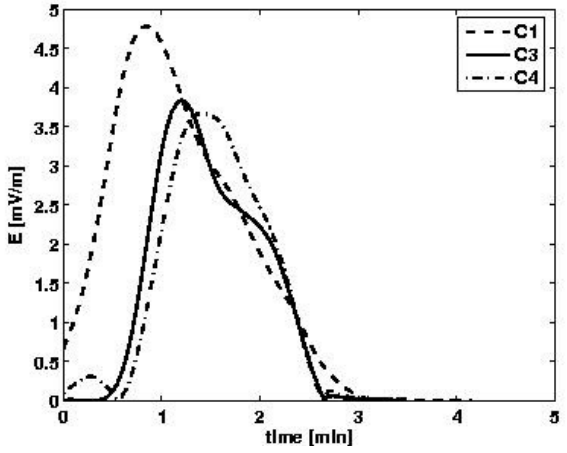

Fig. 3.4: Reconnection pulse reconstructed from the data obtained by three Cluster spacecraft

The methods have been successfully applied to a series of reconnection events observed by Cluster spacecraft in the Earth's magnetotail and at the dayside magnetopause. An example of a reconstructed reconnection pulse is shown in Fig. 3.4

Shock propagation: Changes in solar wind conditions have an impact on plasma and field phenomena in the magnetotail. An interplanetary shock causes a sudden compression of the magnetotail, creating a global aurora brightening and sometimes triggering of a substorm. In order to understand the response of the magnetotail to the compression, it is necessary to identify how disturbances generated by inward motion of the magnetopause are propagating through the magnetotail.

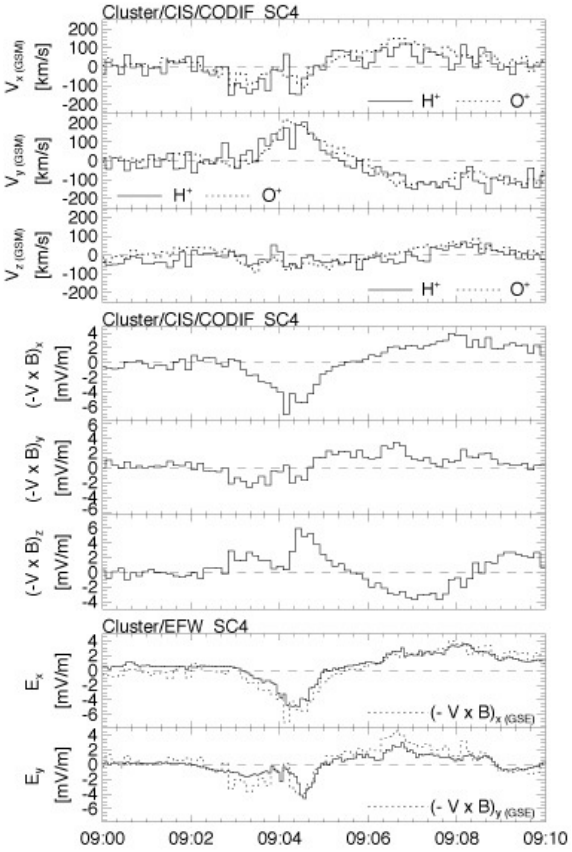

Fig. 3.5: Cluster plasma and electric field data.

On 24 August 2005, an interplanetary shock arrived at the dayside magnetopause. Cluster C4 in the dawnside plasma sheet observed tailward followed by duskward flow (Fig. 3.5). Calculating the VxB electric field for C4 and assuming that the electric field in at the front of the disturbances, the front normal changes from $\phi \sim 180°$ to $\phi = 107°$, where ϕ is the longitude in GSM coordinates. Timing analysis

applied to magnetic field data from all four Cluster spacecraft gives a front normal of $\phi = 131°$ at the second disturbance. Shock-associated magnetic and electric field disturbances propagating from both the dayside and flank magnetopause are detected in the plasma sheet; the latter makes the dominant contribution.

Turbulence: The multi-scale signatures of magnetic reconnection in the terrestrial magnetotail include reconnection, outflow associated fluctuations and turbulence. Far from boundaries, but under the influence of a mean magnetic field, spectral anisotropy is dynamically and robustly generated in magnetohydrodynamic cascading turbulence. The anisotropy increases towards small scales and it can be expressed in terms of the so-called Shebalin's anisotropy angles. The larger the angle, the stronger 2D fluctuations develop.

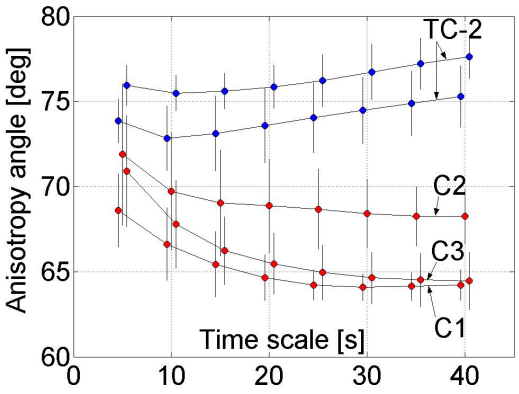

Fig. 3.6: Scale-dependency of Shebalin's anisotropy angles at the positions of Cluster and DSP(TC-2) spacecraft.

This is the case of fluctuations associated with reconnection outflows at the position of Cluster spacecraft, where the plasma flow can freely propagate tailward. On the Earthward side, at the position of Double Star TC-2, however, the flows are more affected by the obstacle represented by the magnetic wall – a stronger near-Earth magnetic field. The anisotropies, shown in Fig. 3.6 are stronger, but exhibit a tendency to increase with the time scale or show no scale-dependency at all. The main processes driving turbulence are associated with flow breaking and mixing. The comparisons provide further evidence for asymmetry of physical processes in Earthward/tailward reconnection outflow regions.

AKR: The terrestrial Auroral Kilometric Radiation (AKR) is electromagnetic emission generated between 20 and 1000 kHz with its sources mainly located in the auroral region of the Earth's magnetosphere. Two methods of direction finding have been applied to the simultaneous observations by Interball-2 and Polar. One method uses three orthogonal antennas; the other is a new "geometrical" method based on mapping the AKR emission cone onto the dynamic spectrum (see Fig. 3.7).

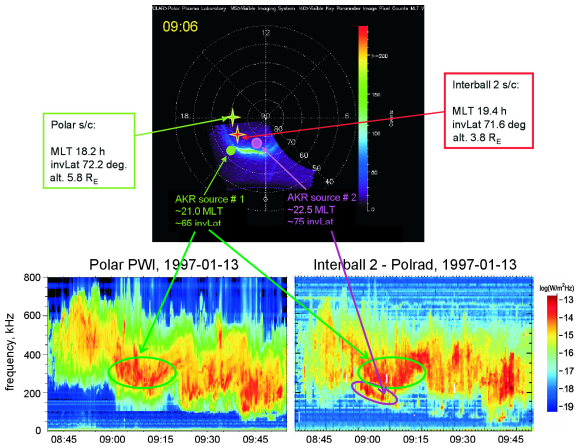

Fig. 3.7: Example of the determination of the locations and beaming characteristics of the AKR sources. Top panel presents the UVI image of the aurora oval observed by Polar Ultraviolet Imager (UVI) and calculated positions of the two separated AKR sources simultaneously measured by Polar/PWI and Interball-2/Polrad. The bottom panels show the dynamic spectra of the AKR intensity. The simultaneous observations have been used for the determination of the AKR emission cone geometry.

This helps to interpretate the morphological features of AKR dynamic spectra, beaming and directivity diagrams of the emission. It has been shown that analyzed AKR emission originates from two separated AKR sources. Both isolated sources radiated AKR which propagated in very narrow (~ 5-10 deg) hollow emission cones with an opening angle between 45 and 50 deg.

4 Solar System

IWF is engaged in many missions, experiments and corresponding data analysis addressing solar system phenomena. The physics of the Sun and the solar wind, its interaction with solar system bodies, and various kinds of planetary atmosphere/surface interactions are under investigation.

4.1 Sun

The Sun is a strong source of radio waves. IWF investigates these emissions, as well as the complex dynamics near the Sun's surface.

STEREO

The *STEREO* grid models have been rebuilt to cope with newly designed and implemented features of our antenna calibration toolbox. The results from previous calculations could be verified with the new model. The newly introduced features include an alternate method to calculate the effective length vectors from the electric field data rather than from the current distribution. This helps to verify the results of this procedure. Full support of the surface based patch methods to be used in combination with the Concept II software is now available.

In addition, the effect of the surrounding space plasma in our computations is included by using two simple models. One of the methods uses a cold plasma model as surrounding medium. This model was included in the numerical procedure to compute the effective length vectors and the impedance matrices. Further, the plasma sheath, which is a result of the space plasma interacting with the conducting surface of the spacecraft, was included in the calculation. Results of these investigations show a slight shift of the second resonance frequency (f ~ 16 MHz) to a higher frequency, which brings the numerical results closer to the measured results. The effective length vectors are slightly longer when the plasma effect is included, while the direction is hardly effected.

Physics

MHD simulation of solar/stellar winds and CMEs: A 3D MHD model for simulating solar/stellar winds and propagating coronal mass ejections (CMEs) has been developed. The model is based on VAC code (Versatile Advection Code), which is a powerful tool for solving the set of the non-relativistic MHD equations. Distances between 0.1 and 10 AU have been considered.

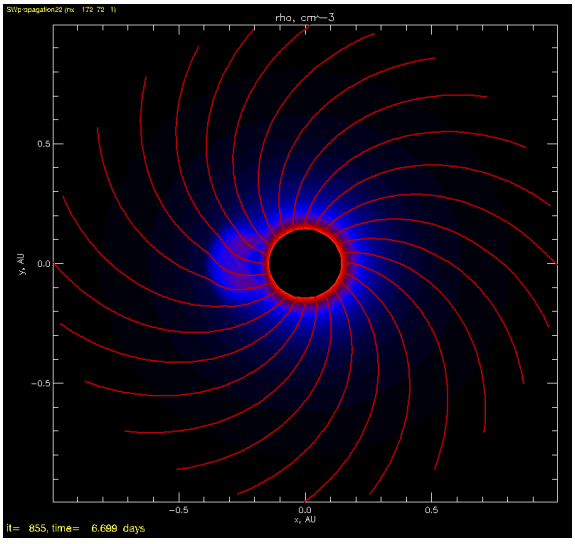

Fig. 4.1: Modelled CME in the solar wind. Coloured areas (red and blue) indicate the plasma density. Red lines are magnetic field lines.

The first step of the simulation is to define the ambient state of the solar/stellar wind plasma

with the self-consistent frozen spiral interplanetary magnetic field. In the second step the CMEs are modelled as injections of hot and dense plasma clouds into the ambient stellar wind. Variation of the main CME parameters with the distance from the Sun/star has been obtained for typical solar/stellar wind conditions. The outcome of this study, shown in Fig. 4.1, is used to investigate the solar wind influences on the dynamical features of SKR; and to simulate planetary atmospheric erosion, which is important for investigating the evolution of atmospheres of exoplanets.

Solar Type IV bursts: By means of the giant radio telescopes UTR-2 and URAN-2 (Ukraine) detection of Type IV solar radio bursts, usually associated with CMEs, has been performed in the wide frequency band from 10 to 30 MHz. Fine structures in form of zebra stripes have been detected with unprecedented high sensitivity and time resolution. Both positive and negative, as well as infinite drift rates were found. Fig. 4.2 displays three separate groups of zebra patterns which occur both in emission and in absorption.

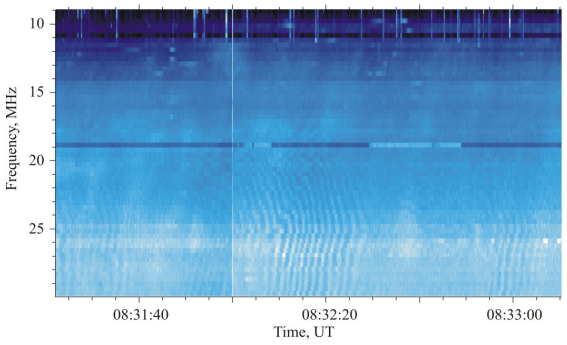

Fig. 4.2: Decameter zebra-patterns as a fine structure of Type IV burst observed on July 22, 2004.

4.2 Mercury

Mercury is the planet nearest to the Sun. It is a significantly dense planet, which suggests a large iron core and possesses a weak global magnetic field. The ESA/JAXA mission *Bepi Colombo* to Mercury will explore the planet in detail.

BepiColombo

The satellite mission *BepiColombo* to Mercury, the planet closest to the Sun, is not only the first big joint European-Japanese satellite project, it is also the first time that two spacecraft – *Magnetospheric (MMO*) and *Planetary Orbiter (MPO)* – are simultaneously flying to this innermost planet. *BepiColombo* is scheduled for launch in 2013 (see Fig. 4.3).

Within the scope of the European-Japanese magnetometer consortium *MERMAG*, IWF is the lead institution for the magnetometer aboard the Japanese *MMO (MERMAG-M)* and for the *MPO* magnetometer *(MERMAG-P).* IWF is responsible for the overall technical management.

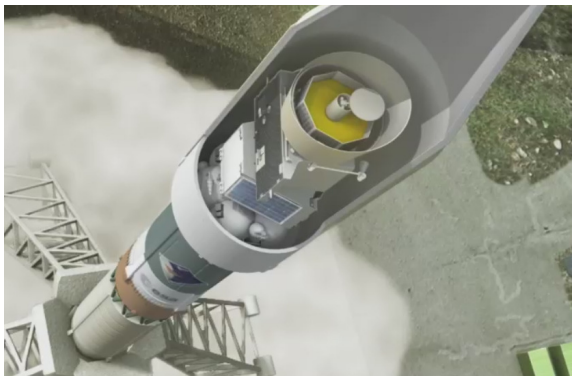

Fig. 4.3: Mercury composite spacecraft (MCS) in launch configuration.

IWF also leads the building of a particle analyzer for ESA's *MPO*. The instrument *PICAM*, which is part of the *SERENA* instrument suite, is an ion mass spectrometer operating as an all-sky camera for ions in the energy range up to 3 keV in the environment of Mercury.

In 2007, the preliminary design of the magnetometers as well as of PICAM has been pressed ahead. As the definition of the spacecraft evolved, the mechanical configuration of PICAM had to be revised (see Fig. 4.4) to meet the new accommodation requirements. The Science Requirement Reviews for all instruments on the MPO were held between April and September 2007. The Preliminary Design Review (PDR) of the MERMAG-M instrument

already took place in November 2007. The PDRs for MERMAG-P and PICAM will follow in April and June 2008, respectively.

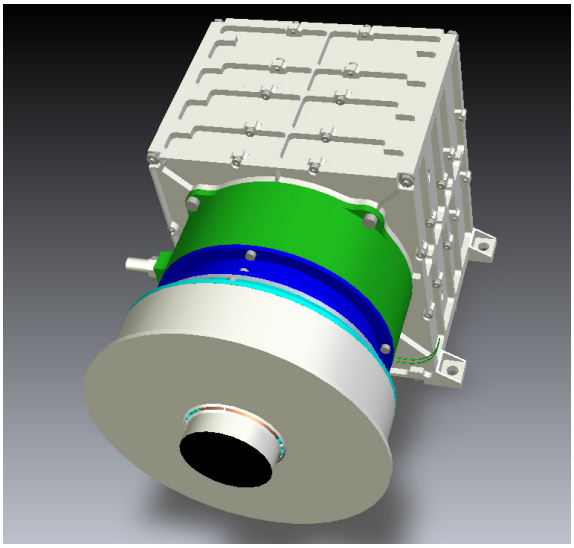

Fig. 4.4: The Planetary Ion Camera (PICAM) for MPO.

4.3 Venus

Venus, the second planet from the Sun is now under great scrutiny after the arrival of *Venus Express*.

Venus Express

Venus Express, ESA's first mission to Venus, arrived at Venus in April 2006. IWF takes the lead on one of the seven payload instruments; the magnetometer *VEX-MAG*. The *Venus Express* magnetometer MAG measures the magnetic field vector with a cadence of 128 Hz. It will map the magnetic properties in the magnetosheath, the magnetic barrier, the ionosphere, and the magnetotail. It is developed to identify the plasma boundaries between the various plasma regions and to study the solar wind interaction with Venus' atmosphere.

During 2007, *Venus Express* continues to operate normally. The magnetometer remains ON during the whole year and collects both near-Venus and interplanetary magnetic field data. Data processing and cleaning for the magnetic field measurements is undertaken. Fuzzy logic and neural network algorithms have been built to automatically recognize patterns of disturbed magnetic field caused by spacecraft stray fields. Various models, with the help of spacecraft housekeeping data, have been built to remove the spacecraft field disturbances. The complete software package for data processing has been tested and finalized. All data are cleaned and issued to the science community.

Physics

The solar wind interacts directly with the atmosphere of Venus in contrast to the situation at Earth, where the internal magnetic field protects the upper atmosphere. Still, Venus' atmosphere is partially shielded by an induced magnetic field. It is expected that the effectiveness of this shielding varies with solar activity. However, the current understanding of the solar wind interaction with Venus is derived from measurements at solar maximum with *Pioneer Venus Orbiter (PVO)*. It is not known how well the magnetic barrier works at solar minimum. *Venus Express*, with improved instrumentation, a different orbital trajectory compared to *PVO*, and observations at solar minimum, enable the extension of understanding the evolution of Venus' atmosphere caused by the solar wind interaction.

Barrier against the solar wind: As all planets in the solar system, Venus is hit by the solar wind, a million km/hr stream of charged particles coming from the Sun. Our Earth is protected from this continuous solar bombardment by its magnetic field, which deflects the charged particles around the planet, leaving an intact and therefore habitable atmosphere.

Venus however, has no magnetic field, so the solar wind impacts directly on the outer atmospheric layers. From previous space missions, it is known that during times of strong magnetic activity in the 11-years solar cycle, a strong barrier builds up in the Venus ionosphere and withstands access of the solar wind to the atmosphere. For times of low so-

lar activity, details of the interaction are less well understood.

Now for the *Venus Express* mission solar minimum conditions prevail, offering an excellent opportunity for further study. The analysis of the magnetometer data of VEXMAG proves the development of a strong enough magnetic shield in the ionosphere (see Fig. 4.5), preventing the solar wind from entering the atmosphere also at solar minimum.

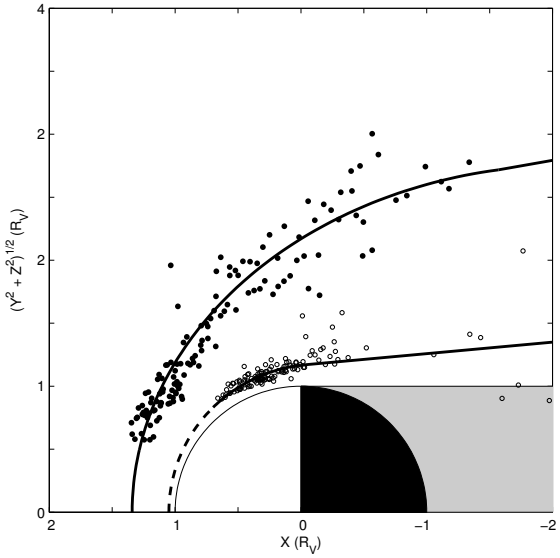

Fig. 4.5: Venus Express data with a fit for the bowshock and magnetopause.

Therefore, we can say that the Venus ionosphere is able to build up an efficient barrier to the solar wind for all regimes of solar wind activity.

Lightning in the Venusian atmosphere: The occurrence of lightning in a planetary atmosphere leads to chemical processes, which would not occur under standard temperatures and pressures. Lightning breaks up molecules into single fragments that can then join to form other chemical substances, resulting in a changed composition of the atmosphere. On Earth, lightning is important for the production of nitric oxides, which play a dominant role in the generation of pre-biotic molecules.

From the magnetometer data of *VEXMAG*, lightning was proved to occur in Venus' atmosphere, which was not really sure from previous missions. *Venus Express* now proved that there is in fact lightning activity all over the planet. The VEXMAG high-resolution data show the magnetic part of bursts of electromagnetic waves in the upper ionosphere, being produced by lightning in the lower atmosphere.

Whistler mode waves generated by lightning have a typical frequency variation which starts with a high tone, which turns increasingly lower, sounding like a whistle. This effect is due to the dispersional propagation of waves in Venus' atmosphere: high frequency waves move faster and therefore reach the upper layers (and VEXMAG) first, lower frequencies arrive later. The same effect is found on Earth: a short wave receiver allows hearing the whistlers from lightning on the other side of the Earth.

Loss of water from Venus' atmosphere: Venus has a dense and hot atmosphere and a hot and dry surface; there is no liquid water and the amount of water vapour in the clouds is very low. These conditions are totally different from what we have on Earth. It is even more puzzling, regarding the common origin of Venus and Earth at times of formation of the solar system, where the composition of the planetary body and its atmosphere was supposedly very similar for both planets. So if Venus had originally as much water as Earth, how could it disappear from the planet?

An answer to this fundamental question is now given by the Venus Express mission: In the magnetometer data of VEXMAG, first traces of planetary hydrogen can be found in the up-stream solar wind, still before this fast stream of charged solar particles is decelerated at the planet's bow shock and meets the outskirts of the atmosphere. In the outer layers of the exosphere intense solar UV-irradiation leads to ionisation of escaping hydrogen atoms, creating "newly born" protons. Interaction with the interplanetary magnetic

field from the solar wind accelerates these protons and some of them can even leave the close neighbourhood of the planet. Their trace is now detected as characteristic waves in the measured magnetic field up to large distances from the planet. This is the first proof that Venus looses hydrogen directly to the solar wind, in a volume much larger than expected. The upstream loss may have a significant contribution to the total water loss over the age of the solar system.

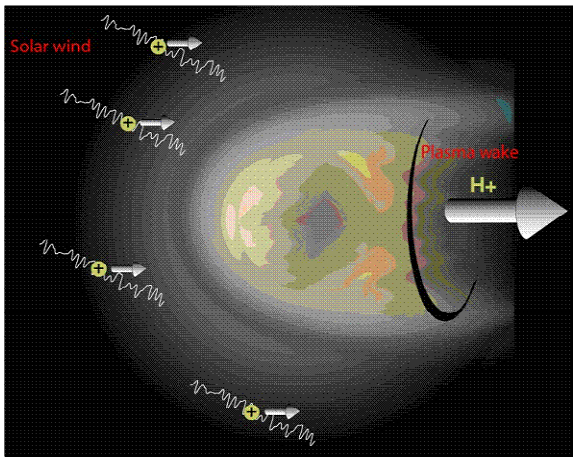

Fig. 4.6: Hydrogen loss at Venus.

The particle instrument *ASPERA* (IRF Kiruna, Sweden) measures the flux of charged particles in the close neighbourhood of the planet. Analysis of the *ASPERA* data together with the *VEXMAG* data shows that on Venus' night side a massive loss of hydrogen and oxygen ions takes place: the solar wind blows the ions over the poles into the plasma tail behind the planet and further into the depths of interplanetary space. The amounts of particle-loss of hydrogen and oxygen have the ratio of 2:1, indicating that it is really water (H2O) which is lost. This mechanism to strip off water from the planet on the night-side is supposed to be the main reason for the lack of water on present Venus.

Proton cyclotron waves (PCW) upstream of the Venus bow shock: The escape of particles from planetary atmospheres, especially hydrogen, is an important key towards understanding the atmospheric composition and evolution. For an unmagnetized planet, such as Venus or Mars, where the neutral exosphere extends into the flowing solar wind plasma, loss of pick-up ions upstream of the bow shock can play a significant role in the escape process. Cyclotron waves from pick-up of planetary hydrogen in the solar wind have been previously observed at Mars and other solar system bodies. At Venus, they were reported within the magnetosheath, but not upstream of the bow shock. With the magnetometer aboard Venus Express, upstream waves at the proton cyclotron frequency (Fig. 4.7) were detected for the first time ever at Venus. The occurrence of the left hand polarized waves at or just below the proton cyclotron frequency in the spacecraft frame proves their generation by freshly picked-up planetary hydrogen.

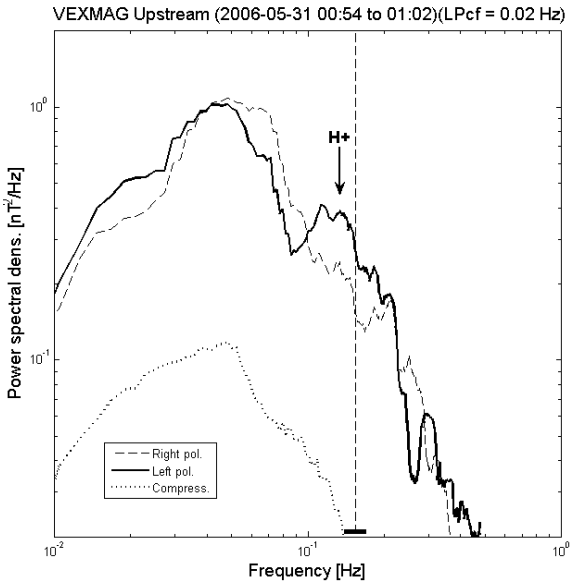

Fig. 4.7: Power spectrum of magnetic field data with enhanced power just below the local proton cyclotron frequency in the left hand transverse component.

The waves occur for short time-intervals of 5-10 mins and till large distances (6 Rv) from the planet. The observations provide direct evidence that the solar wind is removing hydrogen from a much larger volume of the planetary exosphere than known before. This may have impact on the evolution of the Venus atmosphere over the age of the solar system.

4.4 Jupiter

Jupiter, the largest planet of our solar system, is a strong source of radio emissions. Some of these are generated by an interaction with the satellite Io, others also by the interaction of the solar wind with the strong Jovian magnetic field.

Jovian DAM modulation effects: There are theoretical and experimental arguments for a stimulation or modulation of Jovian decametric S-bursts by standing Alfvén waves in the regions of Jovian radio sources (Fig. 4.8). S-bands seem to be generated around nodes of a standing Alfvén wave. Empirical tests have confirmed these suggestions. The standing wave model leads to an anti-correlation of radio fluxes with short time scales (<0.1 s) in adjacent S-bands or to a positive correlation with the closest train of S-bursts.

The wide-band dynamic spectra of the Jovian decameter emission, obtained by the high-frequency and high-time-resolution equipment (DSP and Waveform receiver) on UTR-2 (Kharkov, Ukraine) have been analyzed. The modulation effect is found in S-storms (e.g. August 2 and 9, 2002). Complex modulation structures of the signals are inherent in the spectra, whereby in each specific case the nature of modulation can differ. In the zoom 1 and zoom 2 fragments of Fig. 4.8 (top and bottom panels) are visualized demonstrating the different modulation lane structures as a result of changes of the mechanism of modulation even over a short period of signal time duration.

Europa's Alfvén Wings: The interaction of the magnetic field of Jupiter with the moon Europa leads to the creation of Alfvén wings (AW). The contact of the magnetic field with the moon gets transported along the magnetic field with the Alfvén velocity and the field itself is transported by the rotation of Jupiter. This leads to two current carrying "cylinders" that move away from Europa under a specific angle. The presence of an induced magnetic field in the subsurface ocean of Europa modifies the AW: the induction offsets and shrinks the AW.

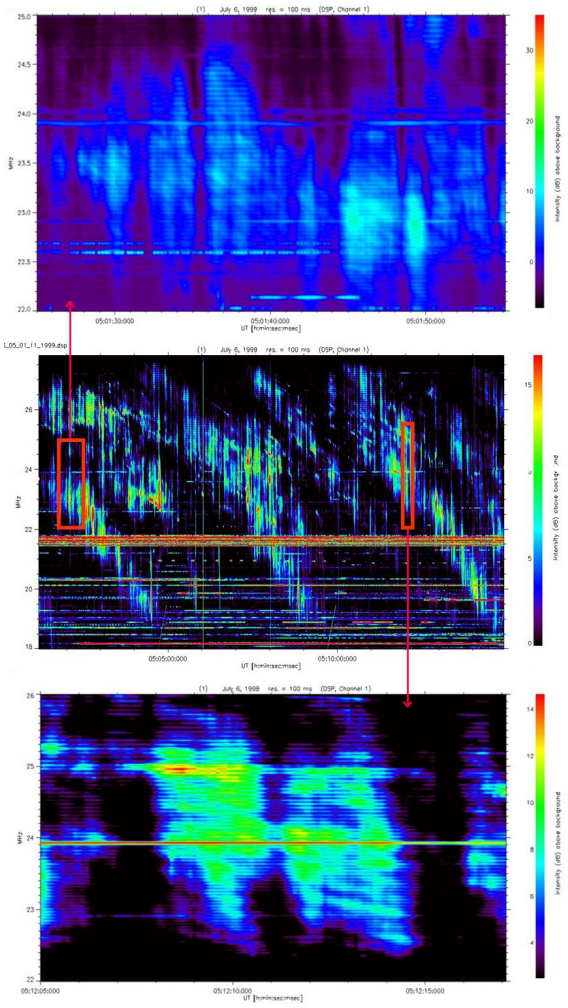

Fig. 4.8: Modulation of S-emission flux by the radiation pattern swinging in the nodes of standing Alfvén wave.

During three flybys of *Galileo* by Europa, the spacecraft crossed the AW and the magnetic field data were used to determine the location of the AW along the orbit of *Galileo*. An ellipse describing the AW was fitted to the entry and exit points, which gives information on the angle under which the AW moves away. This angle can also be used to calculate the local plasma density through the Alfvén velocity.

Field line tracing shows that the AW angle is determined rather well and Fig. 4.9 shows that the AW (red area) is offset when compared with the absence of an inductive field

(black oval). The plasma density inferred for E17 (measurements taken at Europa in the 17th orbit of Galileo around Jupiter) shows that ion pick-up near Europa is very important and the estimated pick-up rate agrees well with estimates from numerical models.

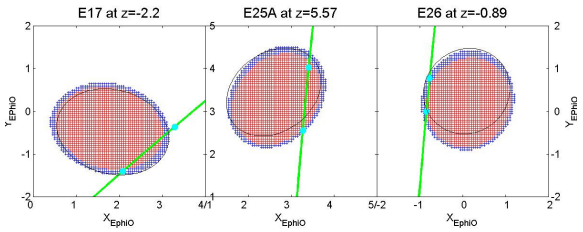

Fig. 4.9: The cross section of the Alfvén wing for three flybys of Galileo. The black oval is the AW when no induced magnetic field is present. The red area shows the field lines that intersect the moon, the blue area shows the field lines that intersect a possible ionosphere at 150 km, the magenta dots show the entry and exit points of Galileo.

4.5 Saturn and Titan

In 2007 *Cassini* has continued its investigation of the Saturnian system and has made several flybys of the moon Titan and various others like Enceladus and Tethys. After the successful landing of the European *Huygens* probe on Saturn's largest moon Titan, the data of the various experiments are now being processed and interpreted.

IWF is strongly involved in the *Radio and Plasma Wave Science Experiment (RPWS)* onboard the *Cassini* orbiter as well as the *Huygens Atmospheric Structure Instrument (HASI),* the *Aerosol Collector and Pyrolyser (ACP)*, and the *Surface Science Package (SSP)* aboard *Huygens*.

Physics

Solar influences on SKR: Since the Voyager mission it is known that the Saturn Kilometric Radiation (SKR) is strongly influenced by the solar wind. Manifestations of the solar periodicities in the modulations of SKR were studied in detail. The analyzed SKR data record covers the years 2004-2005.

A combined data analysis algorithm based on a "sliding window" Fourier (SWF) procedure and the nonlinear Wigner-Ville (WV) method is applied. It has been found that SKR has well pronounced 7-8 days, 9-10 days, 12-13 days and 25-26 days modulation components, associated with the analogous periodicities in the solar wind detected by SWF-WV method in the *Ulysses/SWOOPS* data, shown in Fig. 4.10.

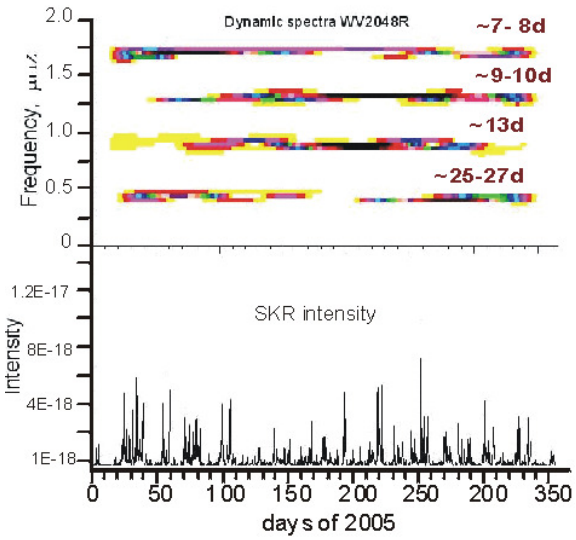

Fig. 4.10: Filtered SWF-WV spectra of the SKR intensity measured by Cassini/RPWS

Additionally to that, profiles of the solar wind parameters measured by Ulysses at 5 AU were projected onto the Cassini orbit at ~9.5 AU by means of an MHD simulation. Strong correlation between SKR and solar wind variations has been shown. Thus the remote observations of the solar wind by Ulysses may also serve as a good predictor of SKR activity.

Huygens

There is a long lasting debate about atmospheric electricity phenomena and the existence of ionized layers in the lower atmosphere of Titan. During the descent of the *Huygens* probe through the atmosphere of Titan the *Huygens Atmosphere Structure Instrument (HASI)* measured for the first time in-situ the electrical conductivity and the electric field fluctuations below 140 km. A layer with increased electron and positive ion

concentrations has been found between 60 and 70 km (Fig. 4.11).

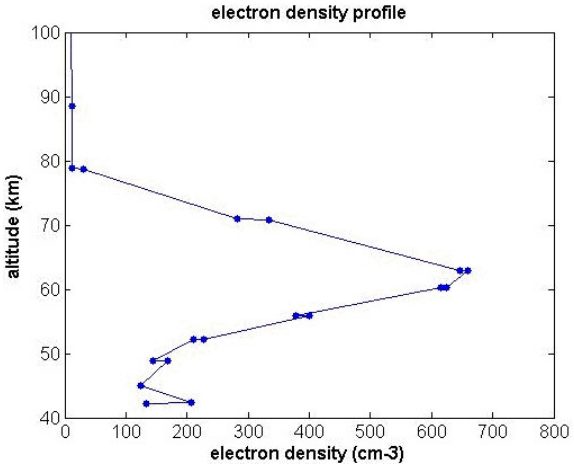

Fig. 4.11: Electron density in the lower ionosphere of Titan derived from Huygens electrical conductivity measurements

An electron density of about 700 cm^{-3} was derived from the *HASI* conductivity measurements of about 3×10^{-9} S/m. The ion density was found to be one order of magnitude higher, indicating the attachment of free electrons to electrophilic species like aerosols or heavy molecules with low mobility. The distribution of aerosols can be estimated from the ratio of the observed electron and positive ion density.

The observed conductivity profile, the surface of Titan and the upper ionosphere investigated by the *Cassini* orbiter form a complicated cavity for Schumann resonances triggered by internal sources, e.g. lightning, or by external sources, like the corotating plasma flow of Saturn's magnetosphere.

A planetary, global electric circuit is composed of the conducting surface, the conducting atmosphere and ionospheric layers. The current in this global electric circuit is driven by lightning and rainfall of charged droplets. The global voltage drop across the conducting atmosphere depends on the fair-weather field and the atmospheric conductivity. The parameters of a possible global electric circuit at Titan are different from Earth. The surface, atmospheric and ionospheric conductivities are smaller. The estimated maximum lightning rate is several orders of magnitude below the terrestrial, only methane drizzle has been proposed by various authors.

4.6 Comets

Rosetta

ESA's *Rosetta* probe continues its journey to comet Churyumov-Gerasimenko, where it will arrive in 2014 to investigate the evolution of the comet during its approach to the Sun from an orbiter and by a landing module which will be dropped onto its nucleus. Under the leadership of IWF an atomic force microscope *MIDAS* was built. Furthermore, the institute has built parts of the mass spectrometer *COSIMA*, parts of the two magnetometers *RPC-MAG* and *ROMAP* on both orbiter and lander, and participated in developing and building the penetrometer *MUPUS*, which will measure the heat conduction and elasticity of the cometary surface.

Both the spacecraft and the payload are in good health. A check-out of the payload and the spacecraft without real-time contact was carried out in May 2007, followed by an "active" check-out in September with real-time telemetry reception and commanding of critical activities. One of the objectives of the check-outs is to demonstrate the readiness of the payload for near-comet observations and to debug operational procedures already before the about 3-year hibernation phase in 2011 to 2014.

A swing-by of Mars in February 2007 provided an opportunity for measurements by RPC-MAG and other instruments near Mars. The second of three Earth swing-bys took place in November 2007 which put Rosetta into the right trajectory to meet the asteroid Steins in September 2008. The data set definitions for the mission archive have been reviewed, and the ingestion of data has started.

4.7 Exoplanets

Exoplanets, i.e., planets around stars other than our Sun, have become a new and exciting research topic since their discovery in the late 1990s. Many have been found (at present approximately 200), it started with "super Jupiters" in close orbits around their star, but as techniques improved, smaller and more distant planets have been observed.

COROT

In co-operation with the Institute for Astronomy, University of Vienna, IWF contributes to the French space telescope *COROT (Convection, Rotation and Planetary Transit)*.

The scientific goal is the investigation of dynamic processes in the interior of stars and the search and survey of extrasolar planets.

The *COROT* mission was launched successfully 27th December 2006. After the comissioning phase the first long term observation in the galactic centre was commenced in April, lasting until October. The first exoplanet was already discovered during the first month of observation. The onboard systems are working significantly better than expected. Approximately 12.000 light curves have been obtained, with almost uninterrupted data. In October the spacecraft has been re-oriented to perform observations in the antigalactic centre for the upcoming six months.

Physics

Roche Lobe effects in the close exoplanets evolution: A detailed study of the thermal mass loss enhancement for very close "Hot Jupiters" due to the gravitational field of their host stars was carried out. The influence of the proximity to an exoplanet of the Roche lobe boundary on the critical temperature for thermal blow-off conditions has been studied. This allows estimation of the increase of the planetary mass loss rate through hydrodynamic blow-off. We consider the gravitational potential for a star and a planet along the line that joins their mass centres and the energy balance equation for an evaporating planetary atmosphere including the effect of the stellar tidal force on atmospheric escape. By studying the effect of the Roche lobe on the atmospheric loss from short-periodic gas giants we derived reasonably accurate formulas for estimation of atmospheric loss enhancement due to the action of tidal forces on a "Hot Jupiter" and to calculate the critical temperature for the onset of "geometrical blow-off", which are valid for any physical values of the Roche lobe radial distance. By using these formulas, we found that the stellar tidal forces can enhance the hydrodynamic evaporation rate from TreS-1 and OGLE-TR-56b by about 2 times, while for HD 209458b we found an enhancement of about 50%. For similar exoplanets which are closer to their host star than OGLE-TR-56b, the mass loss enhancement can be even larger.

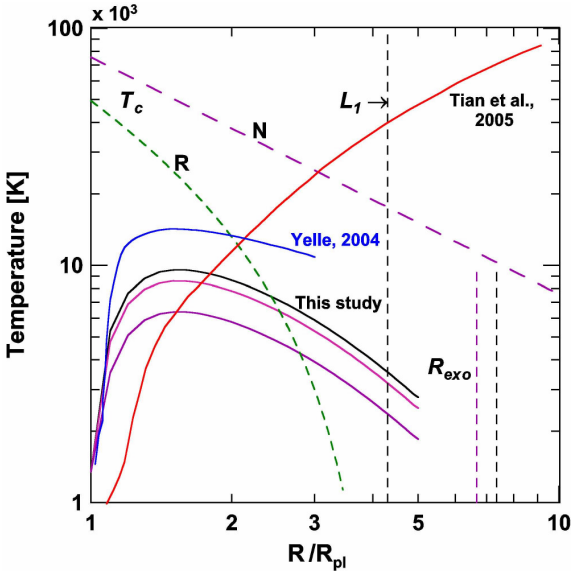

Fig. 4.12: A comparison of the model results of the upper atmosphere temperature obtained by our study with previous studies for the planet HD 209458b.

Fig. 4.12 compares our results with previous studies by Yelle 2004 and Tian et al. 2005. The difference between our results and the previous ones follows from the high Newto-

nian gravitational potential barrier assumed at the upper boundary in these models.

As one can see in Fig. 4.12 we found that the effect of the Roche lobe allows "Hot Jupiters" to reach blow-off conditions at temperatures which are less than expected due to the stellar X-ray and EUV (XUV) heating. For massive and more distant exoplanets exposed to less intense stellar XUV fluxes the exobase temperatures can be less than the critical temperature for the onset of blow-off. This will result in stable upper atmospheres which experience much slower Jeans thermal escape. The results of our study have to be included in the statistical mass-radius analysis of hot exoplanets expected to be detected during the *COROT* mission.

5 Engineering & Testing

Instruments onboard spacecraft are exposed to harsh environments, e.g., vacuum, large temperature ranges, radiation and high mechanical loads during launch. Furthermore, these instruments are expected to be highly reliable, providing full functionality over the entire mission time, which could last for even more than ten years.

5.1 Test Facilities

Vacuum Chambers

Small Size Vacuum Chamber: This is a manually controlled, cylindrical vacuum chamber (dimensions: 160 mm diameter, 300 mm length) for small electronic components or printed circuit boards. The system features a turbo molecular pump and an oil lubricated rotary vane fore pump. A pressure level of 10^{-10} mbar can be achieved. Installed electrical feed-troughs are a 19-pin circular connector and 14 high voltage connectors.

Large Vacuum Chamber: This large size vacuum chamber features a stainless steel body and door with a horizontal cylindrical configuration, a vision panel, two turbo molecular pumps (500 litres/s each) and a dry scroll forepump (500 litres/min). A vacuum chamber pressure of 10^{-7} mbar can be achieved. The cylinder has a diameter of 650 mm and a length of 1650 mm. During shutdown the chamber is vented with nitrogen. Electrical feed-through to the experiments is provided by sub-D connectors as well as light wave conductor plugs. A target manipulator inside the chamber allows for computer-controlled rotation of the target around three mutually independent perpendicular axes. The vacuum chamber is enclosed by a permalloy layer for magnetic shielding. In order to enable the baking of structures and components to outgas volatile products and unwanted contaminations, the chamber is equipped with a heater placed symmetrically around the circumference.

Fig. 5.1: A new small size vacuum chamber in preparation for the PICAM project.

Thermal Vacuum Chamber: This thermal vacuum chamber is fitted with a turbo pumping system which allows quick change-over of components. The test chamber supports a temperature range between -90 °C up to +140 °C at a pressure level of 10^{-6} mbar. The vertically oriented cylindrical chamber allows a maximum experiment di-

ameter of 410 mm and a maximum experiment height of 320 mm. The system is equipped with a turbo molecular pump, a dry scroll forepump (300 litres/min), and an ion getter pump (500 litres/s). A thermal plate is installed in the chamber which is used for the thermal cycling of electronic boxes and other components. Nitrogen is used for cooling and venting. Several electrical feedthroughs are installed (1 x 37-pin sub D connector, 1 x 61-pin sub D connector, 2 x Space Wire; 2 x 8-pin connectors).

Temperature Test Chamber: The temperature test chamber allows to verify the resistance of the electronic components and circuits to all temperature conditions that occur under natural conditions. The chamber has a test space of 190 litres and is equipped with a powerful 32-bit control and communication system. The temperature ranges from -40 °C to +180 °C.

Chamber Surface Laboratory: Dedicated to surface science research, LN2 cooled. Diameter 40 cm, height 40 cm with extensions to 80 and 120 cm. Two rotary vane pumps, one turbo-molecular pump, minimum pressure 10^{-5} mbar.

Sample chamber: Dedicated to the measurement of sample electrical permittivity. One rotary vane pump, minimum pressure 10^{-3} mbar, 8µ particle filter.

Other Facilities

Clean Bench: The laminar flow clean bench is a work bench which has its own filtered air supply. It provides product protection by ensuring that the work in the bench is exposed only to HEPA-filtered air (HEPA = High Efficiency Particulate Air). The clean bench is class B certified according to the EG-GMP regulations. The internal dimensions are 1.18 x 0.60 x 0.56 metres.

Vapour Phase Soldering Machine: The vapour phase soldering machine IBL SLC304 for inline use is suitable for mid size volume production. The maximum board size is 340 x 300 x 80 mm. Vapour phase soldering, also known as VP soldering, or vapour phase reflow, is currently the most flexible, simplest and most reliable method of soldering. It is ideally suited for all types of surface mounted device (SMD) components and base materials. It allows processing of all components without the need of any complicated calculations or having to maintain temperature profiles.

Clean Room: Class 10000 (according to U.S. Federal Standard 209e) certified laboratory with a total area of 30 square metres. The laboratory is used for flight hardware assembling and testing and accommodates up to six engineers.

Penetrometry Test Stand: A penetrometry test facility designed to measure mechanical soil properties, like bearing strength, is available since January 2004.

UV Exposure Facility: The UV exposure facility is capable to produce radiation between 200-400 nm (UV-A, B, C).

Magnetometer Calibration: A three-layer magnetic shielding made from mu-metal is used for all basic magnetometer performance and calibration tests. The remaining DC field in the shielding is <10 nT and the remaining field noise is <2 pT/√Hz at 1 Hz. A special coil system allows the generation of a 3-D field vector with an absolute value of up to +/-30000 nT around the sensor under test.

Temperature Test Facility: With the IWF temperature test facility magnetic field sensors can be tested over an extended temperature range from -170 °C up to +220 °C in a low field and low noise environment. Liquid nitrogen is the base substance for the regulation which is accurate to +/-0.1°C. A magnetic field of up to +/-100000 nT can be applied to the sensor during the test cycles.

5.2 New Instruments

ERSA IR 550: This is an IR rework system. The safe and proven medium wavelength IR heating technology allows for uniform heat distribution from the top and bottom side across the printed circuit board (PCB) and component without the use of hot-air nozzles. The DynamicIR technology allows for maximum use of the system power via the dynamic control of the top (800 W / 60 mm x 60 mm) and bottom (800 W / 135 mm x 260 mm) IR heaters, depending on the actual temperature of the component, and where it is in the temperature profile. Combined with the enhanced capability to run an extended or flat peak, this instrument will produce the lowest temperature deltas across the component, and greatly reduces PCB warpage. Precise control of the temperature profile on the board and component is an advantage and the actual component temperature is acquired, through an infrared sensor, and is used as the primary control mechanism for the dynamic heating system.

ERSA PL 550: This is a precision placement system for positioning all types of fine pitch BGA/SMT components in sizes from 1 mm x 1 mm to 40 mm x 40 mm. The integrated high resolution CCD motorized zoom camera makes precise alignment of the components by means of two superimposed images extremely simple. The images can be brought into alignment through X / Y and rotational fine adjustments.

Melting Probe: The melting probe development project which is performed in the frame of an ESA contract entered its second phase. There were two major activities in 2007: (i) melting tests in the IWF vacuum chamber with the first prototype built in 2006 and (ii) design of a new improved prototype. In the test series mentioned under the first point different sample materials were used, in particular compact water ice and porous ice with a snow-like texture. The experiments brought a better understanding of the heat transfer process between probe and ice, which controls the speed of penetration. Comparing the heating cycles of the probe in the two different samples, it was found (see Fig. 5.2) that in compact ice alternating modes of melting and sublimation occur, while in the porous sample only sublimation is observed.

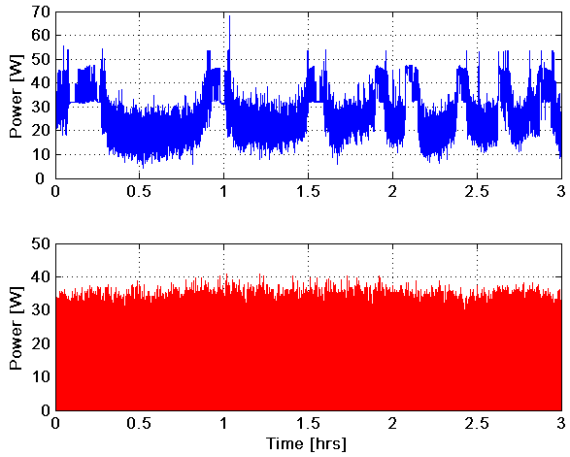

Fig. 5.2: Heating rates during melting probe penetration into compact ice (upper panel) and porous ice (lower panel).

Antennas in Plasma: The reception properties of spacecraft antennas are strongly influenced by the surrounding space plasma. Even though the most influence is in the low frequency range, near and below the characteristic plasma frequencies, we could show that even in the higher frequency regions the effect is strong enough that it should be considered in the antenna calibration procedures.

We included two simple models of space plasma in our numerical antenna calibration. One method uses a simple isotropic cold plasma which is completely described by the form of the dyadic Green's function. By using this special Green's function in the system of equations describing the antenna behaviour, its effect is completely included in the resulting fields, impedances and radiation patterns.

Another approach is to include the plasma sheath in the calculation, which is formed when the surrounding space plasma interacts with the conducting surface of the spacecraft. Corresponding equations were derived to model this plasma sheath, and subsequently included in the numerical calibration process.

Both methods where applied at a simple dipole and at the *STEREO* antenna system with the aim to study the effects on the antenna parameters.

HP3 Permittivity Probe: As a follow up of the previous work on the mutual impedance of Martian soil the IWF is now participating on the HP3 Instrument developed for the *ExoMars* mission.

HP3 is an instrumented mole (self hammering penetrator, Fig. 5.3) as a part of the *ExoMars* Humbold station, carrying a suite of sensors to measure the planetary heat flow and physical properties of the Martian soil.

The permittivity probe (PP) sensor will characterize the electrical properties of the surrounding soil up to a depth of five meters and 360° azimuth. With this sensor layers and inclusions below the surface will be detected and also the water content of the soil can be determined. Additionally the permittivity and conductivity of the material may serve as a ground reference point for orbiting "Ground Penetrating Radar" Instruments.

Fig. 5.3: HP3 mole with permittivity probe electrodes mounted on the outer mantle.

IWF is responsible for the development of the PP, namely the front end electronics and the testing and calibration of the integrated sensor.

6 Publications & Talks

6.1 Refereed Articles

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7 Teaching & Workshops

7.1 Lecturing

IWF members are actively engaged in teaching at three universities. In summer 2007 and in the current winter term 2007/2008 the following lectures are given:

KFU Graz

Plasma Physics (Transport) (Biernat)

Selected Topics of Space Physics Research (Biernat, Rucker)

Selected Topics of Space Physics and Aeronomy (Solar Wind – Magnetosphere Modelling) (Biernat)

Theoretical Hydrodynamics (Biernat)

Upper Atmospheres 1 (Aeronomy of the Earth and the Planets) (Biernat)

Seismics and Structure of the Earth (Kömle)

Gravity and Shape of the Earth (Kömle)

Selected Topics of Space Physics and Aeronomy (Ice, Water, Air: Earth and Mars in Comparison) (Kömle)

Planning, Organization and Management of Geophysics Projects (Rucker)

Planetary Radio and Plasma Waves (Rucker)

Introduction to Space Sciences (Rucker et al.)

Planetary Magnetospheres (Rucker)

Selected Topics of Geophysics (Introduction to Plasma Physics) (Rucker)

Astronomical Training (Voller)

TU Graz

Signal Processor Techniques (Magnes)

Information Techniques (Magnes et al.)

HF Techniques 1 (Riedler)

Selected Topics of Space Research (Riedler)

Antennas and Wave Propagation (Riedler)

Audio Signal Processing (Magnes et al.)

Dynamic Satellite Geodesy (Hausleitner et al.)

JKU Linz

Mathematics for Students of Computer Sciences in Economics I+II (Hausleitner)

Advanced Course

The two-years post-graduate university course Space Sciences in cooperation with both KFU Graz and TU Graz leads to the internationally acknowledged Master of Science (MSc) "Space Sciences." Several members of IWF are lecturers of this inter-university course led by H.O. Rucker.

7.2 Theses

Besides lecturing, members of the Institute are supervising Diploma, Master and Doctoral Theses. In 2007, the following theses have been completed:

Amerstorfer, U.: The Kelvin-Helmholtz instability in magnetohydrodynamics with finite Larmor radius effects and applications to Venus, Doctoral Thesis, Universität Graz, 107, 2007.

Horn, M.: On electromagnetic emissions occuring before earthquakes: Theoretical and experimental approaches, Diploma Thesis, Universität Graz, 131, 2007.

Hütter, E.: Determination of the Effective Thermal Conductivity of Granular Materials under Atmospheric and Vacuum Conditions, Diploma Thesis, Universität Graz, 103, 2007.

Niedermayr, A.: Permittivity measurements of rocks and Martian soil analogue materials, Diploma Thesis, Universität Graz, 117, 2007.

Pollinger, A.: Design of a communication and power supply system providing the space-borne magnetometer front-end ASIC at remote locations, Diploma Thesis, Technische Universität Graz, 71, 2007.

Prattes, G.: Signal analysis of ground-based seismo-magnetic ULF events in the frame of the SEGMA and DEMETER projects, Diploma Thesis, Technische Universität Graz, 125, 2007.

Shala, K.: Code generator and correlator design for the space plasma instrument EDI, Diploma Thesis, Technische Universität Graz, 77, 2007.

7.3 Science Meetings

In regards of the "International Heliospheric Year" H.O. Rucker organized a meeting at the Vienna International Center on 19 and at the Austrian Academy of Sciences in Vienna on 20 February.

From 19 to 23 March a Magnetometer Workshop, organized by W. Magnes, was held at Klippitztörl, with participants from Austria Germany, Great Britain, and Japan.

Within the framework of EUROPLANET, several Science Meetings with 10 to 30 participants have been organized and co-organized by IWF's EUROPLANET N3 Graz team (H.O. Rucker, M. Boudjada, M. Khodachenko, H. Lammer, W. Maierhofer, R. Nakamura, K. Schwingenschuh):

- 2nd Cluster Ground-based Workshop "Evolution of flows/flux ropes" in London, UK
- 3rd Meteor Workshop "Coordinated meteor observations" in Armagh, Ireland
- Strategic FP7 Workshop and General Assembly at ESTEC, Noordwijk, the Netherlands
- 1st Strategic Workshop "Stellar occultation studies" in Paris, France
- 1st Strategic Workshop "Earthquakes: Ground-based and space observations" at IWF in Graz, Austria

In addition W. Baumjohann, M. Boudjada, H. Lammer, G. Kirchner, R. Nakamura, H.O. Rucker and M. Volwerk organized ten sessions at large international conferences.

7.4 Project Meetings

Besides several project meetings with less than ten participants, 5 larger meetings with international participation were organized at or by IWF/ÖAW in 2007.

CERGOP Governing Board Meeting on 22 and 23 October with 25 participants.

A progress meeting for *BepiColombo-MPO* was held at IWF on 6 and 7 November with 14 participants from Austria, Germany, Great Britain and the Netherlands.

There were two *EDI* meetings held at IWF on 15-19 April and on 3-4 December with participants from Austria, Germany and USA.

On 23 and 24 May there was the *Jupiter-Europa* project meeting at IWF with participants from Austria, France, Germany, Great Britain, Japan, USA.

On 12 and 13 April there was the *MMS* SWG meeting at IWF, with 20 participants from Austria, France, Germany, Sweden and USA.

7.5 Awards and Recognition

In 2007 Wolfgang Baumjohann became a Corresponding Member of the Austrian Academy of Sciences and he received the "Österreichisches Ehrenkreuz für Wissenschaft und Kunst 1. Klasse" (Austrian Cross of Honour for Science and Art, First Class). He also became a member of ESA's Earth Science Advisory Committee.

Prof. Hans Sünkel was elected full member of the "International Academy of Astronautics" (IAA).

Ute Amerstorfer was awarded the "L'Oréal Österreich Stipendium" by L'Oréal Austria, the UNESCO committee and the Austrian Academy of Sciences.

Rumi Nakamura became topical editor for Annales Geophysicae and associated editor for Geophysical Research Letters.

7.6 Public Outreach

On 9 March the winners of the *COROT* model building contest (Fig. 7.1) were taken on a trip to Vienna to visit Austrian Aerospace and the Praterstern Planetarium.

Fig. 7.1: The winners of the COROT model building competition in clean suits at Austrian Aerospace.

On 6 and 11 June, Helmut O. Rucker organized an Open Day at IWF and Lustbühel Observatory on the occasion of the "International Heliophysical Year". Approximately 60 visitors could listen to lectures concerning the sun, space weather, space missions, and exoplanets as well as participate in guided tours through the institute and the observatory.

Fig. 7.2: Visiting schools during the space weather day.

In the frame of the EU project "Space Weather and Europe – an Education Tool with the Sun (SWEETS)" on 15 October, Rumi Nakamura organized the "Space Weather Day – Wetterleuchten im All" (Fig. 7.2). Over 300 space enthusiasts from eight to eighty years visited IWF. The entertaining programme included several talks, movie shows, guided tours, a space weather exhibition, telescope observations of the sun as well as many different games for the younger audience.

Fig. 7.3: Drs. Hahn and Baumjohann.

The Austrian minister for Science and Research, Dr. Johannes Hahn (Fig. 7.3), visited IWF on 5 November.

Fig. 7.4: Austrian EUROPLANET postal stamp.

Furthermore, several classes from 5 different schools visited IWF throughout the year. During guided tours through the labs members of the institute have imparted the fascination of space to future scientists.

In honour of EUROPLANET a special Austrian postal stamp (Fig. 7.4) was created, which was distributed on a postcard during the ESPC meeting in Potsdam, Germany.

8 Personnel

Aichhorn, Cornelia, Dipl.-Ing. (S)
Aydogar, Özer, Mag. Dipl.-Ing. (E)
Baumjohann, Wolfgang, Prof. (E)
Berghofer, Gerhard, Ing. (E)
Besser, Bruno P., Dr. (E)
Biernat, Helfried K., Prof. (P)
Boudjada, Mohammed Y., Dr. (P)
Crailsheim, Hartwig (E, ESA)
Cristea, Elena, Dr. (S, on maternity leave)
Delva, Magda, Dr. (E)
Eichelberger, Hans U., Dipl.-Ing. (E, BMVIT)
Fischer, David, Dipl.-Ing. (E, ESA)
Flock, Barbara, Mag. (A)
Fremuth, Gerhard, Dipl.-Ing. (E)
Giner, Franz, Dipl.-Ing. (E)
Graf, Christian, Ing. (S)
Grill, Claudia (A)
Hagen, Christian (A)
Hasiba, Johann, Dipl.-Ing. (E)
Hausleitner, Walter, Dr. (S)
Hütter, Erika, Mag. (P, FWF)
Höck, Eduard, Dipl.-Ing. (S)
Ivanova, Victoria, Dr. (P)
Jernej, Irmgard, Ing. (E)
Jeszenszky, Harald, Dipl.-Ing. (E)
Kargl, Günter, Dr. (P)
Kaufmann, Erika, Dr. (P, ESA)
Keika, Kunihiro, Dr. (E)
Khodachenko, Maxim L., Dr. (P)
Kiehas, Stefan, Mag. (E)
Kirchner, Georg, Dr. (S)
Koidl, Franz, Ing. (S)
Krauss, Sandro, Dipl.-Ing. (S)
Kucharski, Daniel, Mag. (S)
Kögler, Gerald (A)
Kömle, Norbert I., Univ.-Doz. (P)
Kürbisch, Christoph, Ing. (E)
Laky, Gunter, Dipl.-Ing. (E)
Lammer, Helmut, Dr. (P)
Lichtenegger, Herbert I.M., Dr. (E)
Macher, Wolfgang, Dr. (P)
Magnes, Werner, Dr. (E)
Miklenic, Christiane, Mag. (P, FWF)
Močnik, Karl, Dr. (E)
Nakamura, Rumi, Dr. (P)
Neukirchner, Sonja, Ing. (E)
Nischelwitzer-Fennes, Ute, Ing. (E)
Oswald, Thomas, MSc (P, ASAP)
Ottacher, Harald, Mag. Dipl.-Ing. (E)
Panchenko, Mykhaylo, Dr. (P, Oelzelt)
Pfister, Harald, Dipl.-Ing. (E, ESA)
Retinò, Alessandro, Dr. (E)
Rieger, Sonja, Mag. (FH) (A)
Rucker, Helmut O., Prof. (P)
Sampl, Manfred, Dipl.-Ing. (P, ASAP)
Scherr, Alexandra, Mag. (A)
Schwingenschuh, Konrad, Dr. (E)
Shala, Karin, Dipl.-Ing. (E, ESA)
Stachel, Manfred, Dipl.-Ing. (A)
Stangl, Günter, Dipl.-Ing. (S, BEV)
Steller, Manfred B., Dr. (E)
Stieninger, Reinhard, Ing. (S)
Sünkel, Hans, Prof. (S, BMWF)
Tatschl, Florian (E, ESA)
Temmer, Manuela, Dr. (P, FWF)
Topf, Florian, (P, EU)
Torkar, Klaus M., Prof. (E)
Valavanoglou, Aris, Dipl.-Ing. (E)
Voller, Wolfgang G., Mag. (P)
Volwerk, Martin, Dr. (E, MPE)
Vörös, Zoltán, Dr. (E)
Wallner, Robert, Ing. (E)
Weingrill, Jörg, Mag. (S)
Zambelli, Werner, Dipl.-Ing. (E)
Zehetleitner, Sigrid (A)
Zhang, Tie-Long, Dr. (E)

As of 31 December 2007

E: Experimental Space Research, P: Extraterrestrial Physics, S: Satellite Geodesy, A: Administration.

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