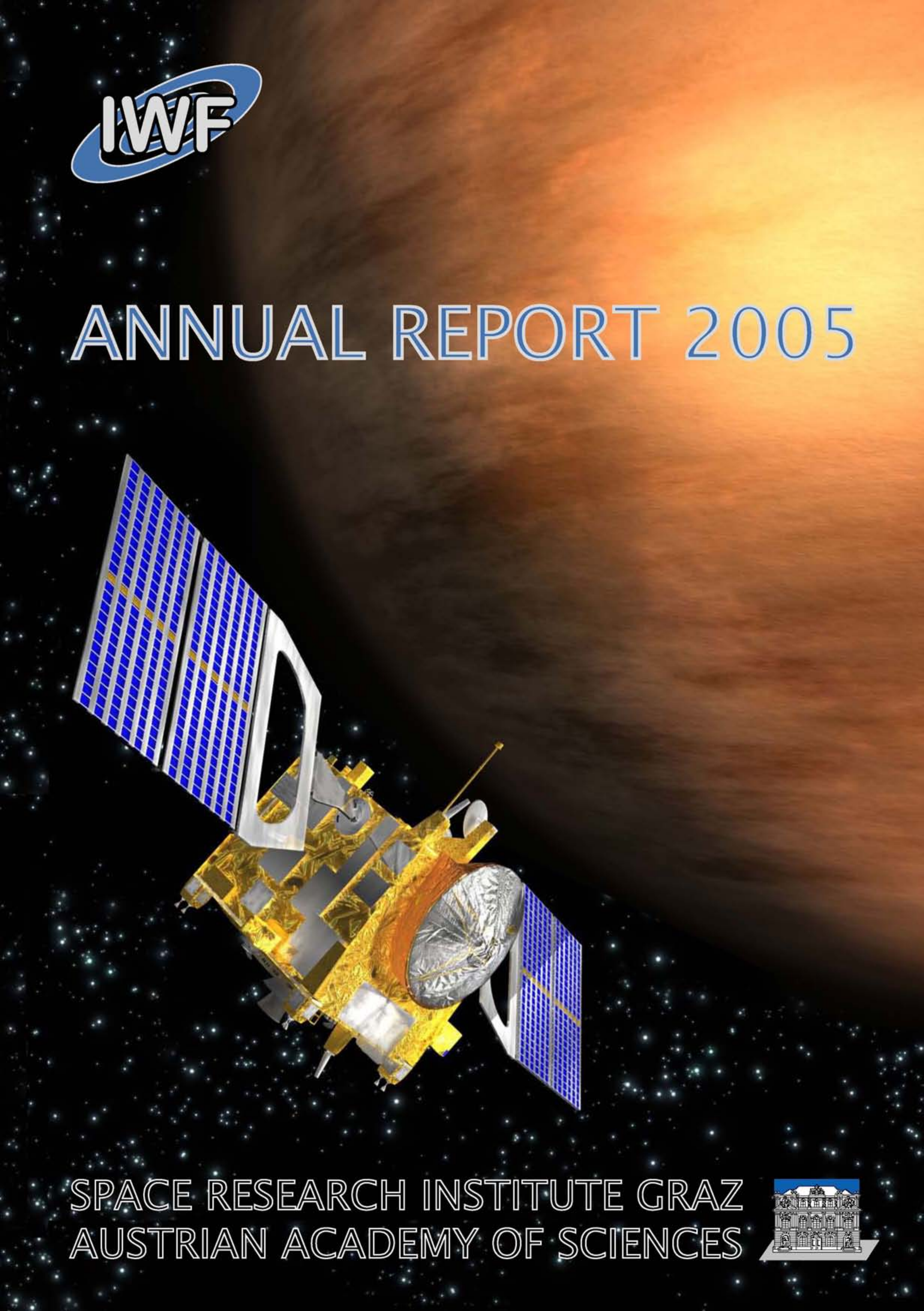
IWF

ANNUAL REPORT 2005



SPACE RESEARCH INSTITUTE GRAZ
AUSTRIAN ACADEMY OF SCIENCES

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Cover Image:

On 9 November 2005 the European spacecraft *Venus Express* was successfully launched by a Soyuz-Fregat rocket, from the Baikonur Cosmodrome in Kazakhstan. It was then placed into a trajectory that will take it on its journey from Earth towards its destination of the planet Venus, which will be reached next April. (see p. 18, Photo: ESA).

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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) understands itself as a focus of Austrian space activities. It cooperates closely with space agencies all over the world, with universities located in Graz, and with numerous other national and international 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.
- *Huygens* has landed successfully on Titan on 14 January 2005.
- *Cluster*, the four-spacecraft mission is still working well and gathering data. The mission has been extended until 2009.
- *Mars Express* has begun its search for water under the surface of Mars using the radar.
- *Double Star*, the Chinese-European magnetospheric mission is taking data in good collaboration with the *Cluster* mission.
- *Rosetta* is on its way to comet 67P/Churyumov-Gerasimenko.
- *Venus Express* has been launched on 9 November 2005, and is now on its way to Venus. The IWF magnetometer was the first instrument on the spacecraft brought into operation.

Fig. 1.1: Almost 300 space enthusiasts followed the Huygens Event at IWF.

- *STEREO* will provide stereoscopic measurements of the Sun and Coronal Mass Ejections (CMEs) and in particular of solar radio emissions.
- *COROT* will search for extra-solar planets and analyze the oscillation modes of stars.
- *GOCE* will determine the structure of the terrestrial gravitational field to better understand the Earth's interior, to map ocean currents, and to contribute to a unification of regional height systems.
- *THEMIS* will fly five identical microsatellites to probe the causal relationship in the chain of processes called magnetospheric substorm and the origin of auroral phenomena.
- *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.

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)

Its managing director is Prof. Dr. Wolfgang Baumjohann.

The bulk of financial support for our 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.

Highlights in 2005 were clearly the landing of *Huygens* on Saturn's moon Titan on 14 January. Almost 300 guests (Fig. 1.1) from all over Austria visited IWF to see live images from ESOC, Darmstadt, where IWF scientists followed the probe's descent and obtained the first data from their onboard instruments.

Furthermore, on 9 November *Venus Express* was launched from Baikonur (Fig. 1.2) taking with it the IWF-lead magnetometer. Approximately 100 guests visited the institute to watch the live broadcast of the launch. On 18 November the magnetometer was switched on and a health-check of the instrument was performed and shown to be in tip-top shape.

Fig. 1.2: Venus Express was launched aboard a Soyuz-Fregat rocket on 9 November 2005.

IWF, of course, is also very much 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 located at Lustbühel Observatory is a system of antennas used to test new radio wave equipment. Finally, a network of nine permanent GPS stations is operated by IWF to monitor geodynamical movements in Austria and its vicinity.

Last but not least, IWF also organized three international conferences with about 60, 80, and 140 participants from five continents.

2 Solid Earth

The knowledge of the dynamics of the solid Earth enables a global view of Earth sciences. Satellite-based measurements are global and cost-effective and produce systematic data sets, over a wide range in space and time.

Measurements of the Earth's gravity field and its variation based on dedicated satellite missions contribute to a better understanding of mechanisms leading to the building of the Earth's crust and ocean topography. The repeated precise determination of coordinates and satellite orbits via GPS and Satellite Laser Ranging (SLR) defines reference frames, which give us clues about the driving forces and the energy transport in the Earth's interior.

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. An accuracy improvement of the gravity field on a global scale has already been achieved by the dedicated satellite missions *CHAMP* and *GRACE*, and the forthcoming *GOCE* mission will even revolutionize our current gravity knowledge.

The numerous Earth sciences applications benefiting from the knowledge of the gravity field, represented by the geoid, will include the modelling of large-scale ocean circulation, the monitoring of ice motion and sea-level changes and the study of physical and dynamical processes in the Earth's interior (see Fig. 2.1, clockwise quarters).

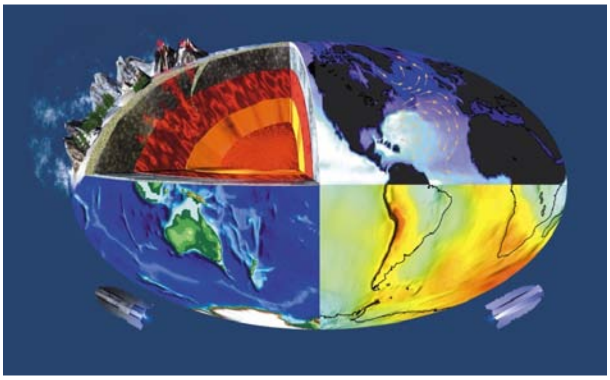

Fig. 2.1: Variety of gravity field applications in view of the GOCE satellite.

GOCE

The satellite gravity mission *GOCE* (Gravity field and steady-state Ocean Circulation Explorer), the first core mission of ESA's Living Planet Programme, strives for a high-accuracy, high-resolution model of the Earth's static gravity field. *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.

Data Processing

Within the official scientific processing of *GOCE* data, done by the European *GOCE* Gravity Consortium, the Graz facility as part of the consortium will be responsible for the implementation of an operational software system. This software will be used to process the measured data into a high-accuracy, high-resolution gravity field model.

Two processing strategies will be used 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 (TUG), to compute the *GOCE* geoid model (see Fig. 2.2): A fast approximative solution strategy, primarily intended for quality control purposes, and a rigorous solver approach, which solves the huge linear equation systems using parallel processing.

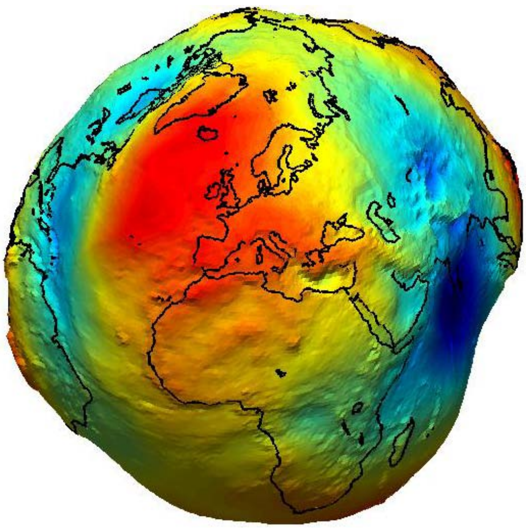

Fig. 2.2: 3D artist's impression of a GOCE geoid model (deviations from spherical shape strongly scaled up).

Core solver: The Earth's gravity field is mathematically described by a spherical harmonic series expansion up to a maximum degree and order (d/o) with the harmonic coefficients as the building blocks. In the case of the *GOCE* mission an expansion of d/o 250 will be the final computational goal, which corresponds to approx. 63000 unknowns. The core puzzle pieces shall be presented here by a d/o 150 example simulation data set. The quality of the solution is represented by coefficient deviations ("triangle plots") from the true simulation model.

SGG solution: Using only SGG observations for computing the gravity field coefficients two problems are still identifiable. The first is the weak determination of the lower degree harmonics, due to the high-pass characteristic of the measurement sensor (in Fig. 2.3 left, top of triangle), and secondly the occurrence of apparent errors in the zonal coefficient bands (Fig 2.3 left, banded structure around the vertical symmetry axis in the triangle), caused by the polar data gaps due to the Sun-synchronous orbit configuration.

SST Solution: The information content of the SST data is utilized by making use of precise *GOCE* orbits expressed in terms of position and velocity information. The principle of energy conservation is applied as the baseline strategy in the SST processing. Combining the SGG and SST normal equations applying optimum weighting techniques, the lower harmonics can be well resolved (Fig. 2.3 (right), top of triangle).

Regularization: The ill-posedness of the normal equations due to the polar gaps and the downward continuation has to be managed by an optimized regularization technique. The so-called Spherical Cap Regularization approach addresses directly this problem and stabilizes the solution only at those regions where no measurements are available. Choosing an appropriate regularization parameter in the simulated test case the final combined solution is depicted in Fig. 2.3 (right).

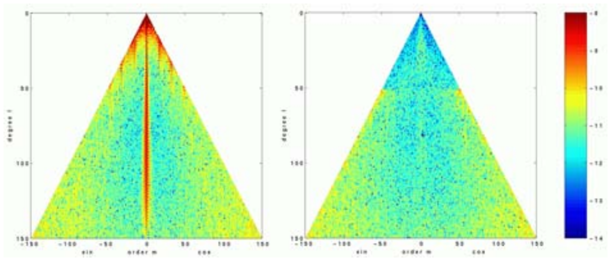

Fig. 2.3: Coefficient differences SGG-only (d/o 150, left) and regularized combined SGG+SST (d/o 150, right).

SST data processing: For the SST data processing two basic strategies were applied: Energy integral and numerical integration of the satellite orbit as well as variational equations.

While the energy integral is very sensitive to satellite velocity errors, the numerical integration method – although very accurate in static harmonics coefficients estimation – is hampered by the fact that a considerably large amount of CPU time is needed. To illustrate this, we give an example where on a single P4 machine a 2 month solution of *GOCE* precise orbit data needs about 1.5 months to be processed and produces a single gravity SST solution up to and including degree and order 80. To overcome this difficulty and to reasonably reduce the computation time, we started to implement a cluster of computers which are dedicated to SST numerical integration computation of the *GOCE*-based gravity field. Due to the nature of the numerical integration method, it may of course be adapted later to other satellite missions, which deliver SST data (e.g. *CHAMP* and *GRACE*). At the moment, we are in the early stages of this implementation. Presently we have 7 operable nodes which work with adapted numerical integration software for near parallel computation and we obtained test results which encourage us to continue with this implementation, i.e. to increase the number of nodes and to further optimize both, software and hardware for an optimal SST solution.

2.2 Geodynamics

Satellite Geodesy disposes of very precise coordinates for terrestrial points, continuous information for the sea level as well as real time data for weather forecast and climate research. The final aim is to determine satellite orbits, to compute velocity vectors, to develop hazard indicators for geodynamic changes (forces and energy transfer), to monitor sea surface changes in coastal regions and to contribute to real time weather data services and climate research.

Reference Frames

The steady update of the coordinates of selected global terrestrial stations (International GPS Service IGS; Austria: Graz and Hafelekar) and the European EUREF network (Austria: Graz, Hafelekar, Pfänder, Salzburg, Trafelberg) gives a representation of a timely varying frame at mm-accuracy which allows for the derivation of coordinates and velocities and their changes in space and time. Graz acts as the second regional data centre for all Austrian and EUREF stations and computes weekly coordinates of about 60 stations (Fig. 2.4).

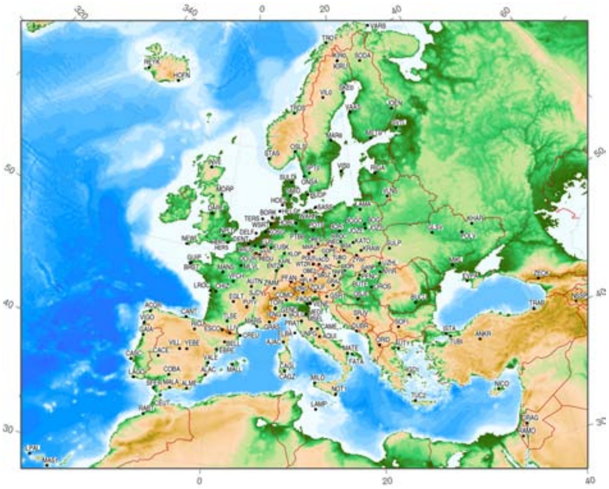

Fig. 2.4: Current EUREF station distribution.

ISDR

ISDR (International Strategy of Disaster Reduction) gave part of the required funding for maintaining and updating the Austrian station array which has been established together with the Federal Office for Metrology, Vienna (Fig. 2.5). The demand for real time data access forced the installation of new receivers at some sites for reducing the delay time. Graz and Hafelekar were equipped with new NETRS receivers; the receiver at Pfänder was replaced. Graz analyses all Austrian data on a daily/weekly basis.

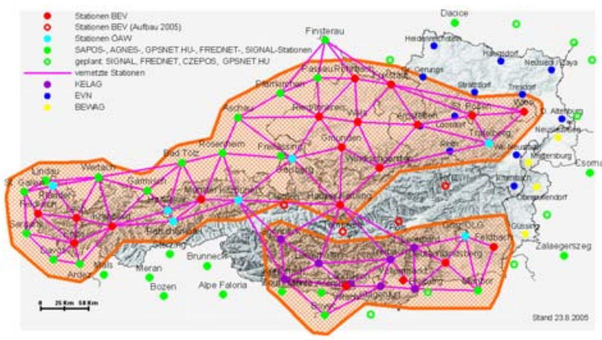

Fig. 2.5: Austrian Positioning Service (APOS).

CERGOP-2/Environment

The aim of this EU project is the establishment, maintenance and monitoring of a reference frame for current geodynamic research and later hazard mitigation. Local investigations in seismic active regions of Eastern Europe supplement the overall objectives. The final output is a timely varying velocity field to be used as a backbone for geodynamic research during the next six years, i.e. allocation of sudden velocity changes for explaining the nature of the underlying forces and the energy transfer leading to seismic events and earthquakes. Thirteen countries covering 15% of the European area and combined in the Central European Initiative (mainly the central and east-European region) contribute to this project coordinated by IWF. This project is also highly correlated with the INTERREG initiative for monitoring the complete alpine region.

Considerable project milestones are:

- Continuation of permanent measurements and station update
- Establishment of a data base in Graz for storing all data, results, and reports
- CEGRN-2005 campaign in June 2005; data acquisition and start of analysis
- Monitoring of station time series and landslides
- Investigation of the security of CEGRN stations (monument stability, interferences, communication)
- New stations in Italy, Romania, Bulgaria, Czech Republic, Slovakia, and Ukraine

Gavdos

IWF contributed to the *Gavdos* project in the satellite altimeter calibration using a ground-based microwave transponder. The analysis of the transponder's return signal allows to calculate the absolute range to the satellite and further to calibrate the altimeter. This is necessary for precise monitoring of the ocean surface affected by the global climate change. The *Gavdos* project ended November 2005, but according to an agreement with all partners the total scientific equipment will be kept operational for the time being.

In 2005, nine valid transponder waveforms of *Envisat* were recorded. *Envisat* orbits in a 35-days exact repeat mission configuration. A calibration bias of +34 cm was calculated for the onboard altimeter using transponder data only. This value is in quite good agreement with similar global studies.

IWF also prearranged participation to the calibration of *Cryosat*, a European polar mission, whose launch failed in October 2005.

Satellite Laser Ranging

The kHz satellite laser ranging system in Graz: The kHz SLR system was fully operational during 2005 and is still the only kHz system worldwide. However, the impressive results of Graz are motivating more and more other SLR stations of the global network to start upgrading to kHz systems.

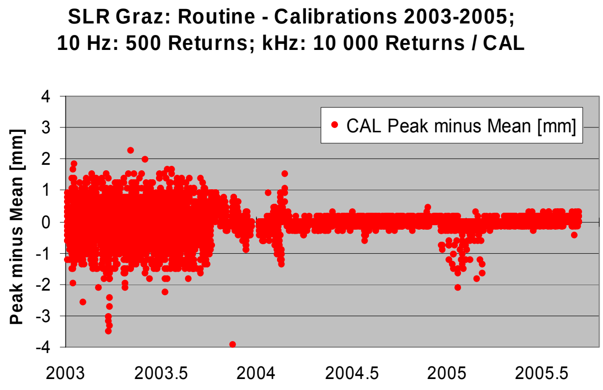

Fig. 2.6: Stability of 10 Hz vs. 2 kHz laser system.

The most obvious advantage of the new kHz system is the dramatic increase in returns per pass, or in returns per normal point (NP). Up to 1 million returns for a single pass of *AJISAI* or *LAGEOS* have been measured, with more than 100,000 single shots compressed to a single NP. The single shot precision is reaching down to about 2-3 mm for some satellites, and as the measurement jitter depends on the inverse square root of the number of returns, the resulting NP precision is now far below 1 mm.

Even more important is the stability of the new kHz system results. Because the laser is now a complete Solid State Diode Pumped Laser (SSDPL) – in contrast to the previous flash-lamp pumped 10 Hz laser – the stability of the measurements has been improved significantly. This can be seen in Fig. 2.6 which shows the improvement of the stability of peak-minus-mean values of routine calibrations with 10 Hz and kHz laser.

For high orbiting satellites like GPS-35 the advantage of a kHz laser system is not so obvious: Due to the very low energy per pulse (400 µJ) compared to the 35 mJ of the previous 10 Hz laser, we expect very low return rates, which makes ranging to such satellites very difficult. However, applying efficient real time software filter techniques, it is now possible to reliably identify even 1 photon out of 1000 noise points. Using these improvements, we are now detecting more returns per normal point than any other SLR station (Fig. 2.7).

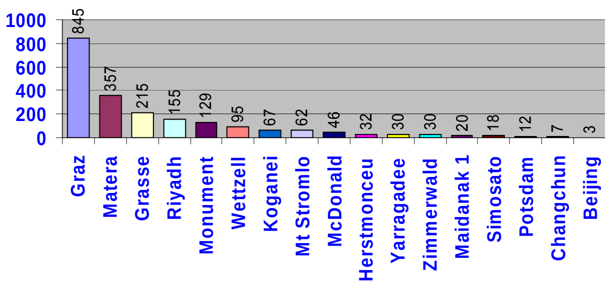

Fig. 2.7: Average number of single shots/NP for GPS-35.

One of the major tasks in 2005 was the design and production of a completely new PC card for kHz laser ranging. Although the present system works nearly perfect, every system component is working at its limit, which makes any changes, upgrades, add-ons etc. extremely difficult. This prompted a new concept, which mainly consists of a new PC card with a big FPGA (Field Programmable Gate Array) and some glue logic on it. This card was designed to perform most tasks to be carried out in kHz SLR stations.

The card communicates with the control PC via the standard 16 bit ISA bus, which is fast enough for the required data rates. External communication is performed via more than 150 digital I/O lines, each one fully programmable (Fig. 2.8).

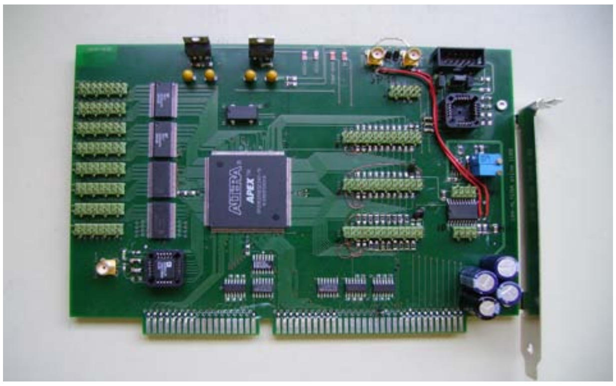

Fig. 2.8: PC card with FPGA.

The card contains also the complete Range Gate Generator (RGG), which can handle up to 300 range gate epoch times automatically with a resolution of 0.5 ns. This high number of range gates is necessary, because on high orbiting satellites (HEOP, like GPS) up to 300 pulses are on its way up to and down from the satellite simultaneously, and the resolution is required for the tight control of range gates, which have to be set 65 ns before arrival of single photons from the satellite. This PC card also completely controls the kHz laser (firing pulse, pump diode management, creating separate pulses for the post amplifier, adjusting repetition rates from 10 Hz up to 2000 Hz, etc.).

All transmit/receive overlap avoidance circuits are implemented within the FPGA: With kHz firing rates, it happens sometimes that a photon returning from satellite arrives at the same time when another laser pulse is just fired. The photon would be most likely undetectable due to heavy back-scatter of the transmitted pulse. In order to avoid this situation, the circuit checks the separation, and slightly shifts the laser firing command if the transmit/receive pulses are closer than about 50 µs.

Satellite spin rate determination: KHz SLR is a powerful new technique, not only for its original purpose of measuring the distances to satellites with mm-precision and stability, but also to determine spin parameters of rotating spherical satellites. These results are obtained without any additional hardware, but just by using the available regular SLR observations. The whole process can be performed fully automatically during the SLR data post-processing, which delivers the spin parameters after each pass in near-real time. This has been investigated and verified in detail for the *AJISAI* Satellite, a passive sphere of 2.15 m diameter. In 1986 *AJISAI* was injected into the orbit with a spin rate of 0.67 Hz and is presently rotating with a 0.505 Hz rate as we have determined from passes between October 2003 and June 2005 with very high precision. The slow down of the spin rate, caused by Eddy currents, i.e. interactions of the satellite's metallic parts with the magnetic field of the Earth, during this period was 0.00810178 Hz per year (Fig. 2.9).

Compared to other methods (e.g. photometric), the Graz results give at least similar high accuracy, but can be performed during day and night and the satellite needs not be sunlit. This method puts no restrictions or additional requirements on the SLR station operation itself, but just needs SLR passes with maximized return rate.

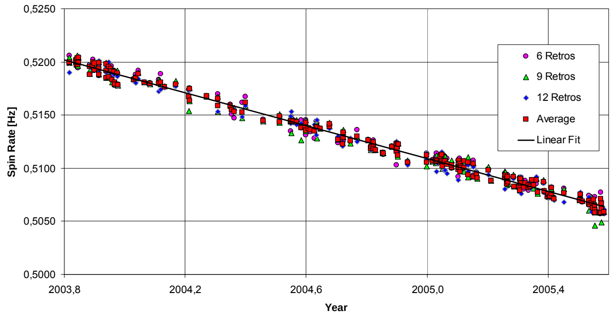

Fig. 2.9: AJISAI spin rate decrease determined from Graz kHz SLR observations.

DEMETER

DEMETER (Detection of Electro-Magnetic Emissions Transmitted from Earthquake Regions) is a satellite that analyses the electromagnetic waves generated during the earthquakes.

Given the fact that such electromagnetic waves can be observed before the seismic events, *DEMETER* data is combined with GPS and ULF ground observations corresponding to two earthquakes occurring in the North Adriatic region. The combination of the three types of measurements did not allow a conclusion about a clear correlation with the seismic events. Further analysis will focus on 1 Hz GPS data analysis, GPS ionosphere analysis and continuous ULF magnetometer data from the Mediterranean area.

3 Near-Earth Space

The physics of 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. In principle all these structures are magnetoplasmas, i.e., electrically charged particles (ions and electrons), where electric and magnetic fields dominate the physical processes.

3.1 Missions

In near-Earth space physics IWF is deeply involved in the *Cluster* mission, which was launched in 2000 and still yields a wealth of new and exciting data. The data from the recently launched *Double Star* mission corroborates the *Cluster* data. In addition, IWF is presently involved in building instruments for other magnetospheric missions, called *THEMIS* and *MMS*.

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, varying from 500 km to 10,000 km. This ESA mission has now officially been extended until the end of 2009. Many new results come out of this mission, and now combined with the Chinese-European *Double Star* mission an extra dimension is added to the investigation of the magnetotail.

Double Star

Within the *Double Star Project (DSP)*, two satellites are observing the Earth's magnetosphere on near-equatorial and polar orbits. The TC-1 and TC-2 spacecraft, launched in 2004 and 2005, have had their initial one year missions extended until the end of 2006 and mid 2006, respectively.

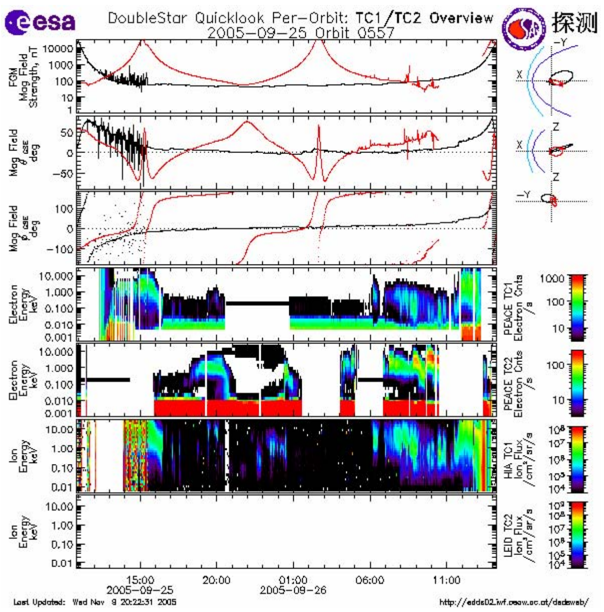

Fig. 3.1: Double Star quicklook plot of TC-1 and TC-2 data combined.

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 *PEACE*, *HIA* and *STAFF* instruments and various Chinese experiments.

European Double Star Data Distribution System (EDDS): As part of its commitments for *Double Star*, IWF provides two core services for the exchange of data between China and Europe: *EDDS* assures the disposition of scientific and auxiliary raw data, the *Austrian Double Star Data Centre* offers tools for the production of some of the *DSP* standard data products as well as for the exchange of and the access to these spin and minute averaged science data (Fig. 3.1).

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* will be launched in 2006 and fly five identical micro-satellites through different regions of the magnetosphere.

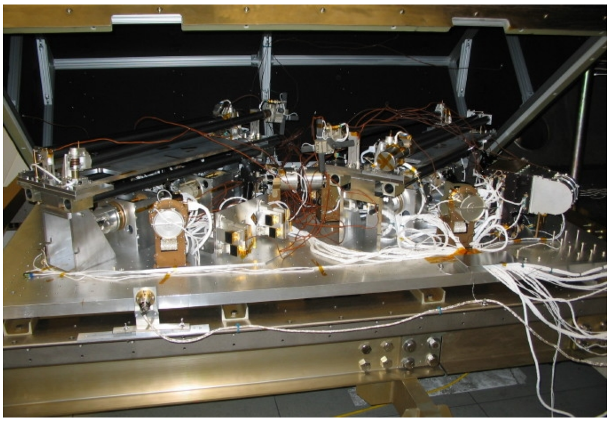

Fig. 3.2: One of the five flight model suites, with the FGM sensor mounted to the 2 m long carbon-fiber boom, waiting for the probe integration.

IWF participates in *THEMIS* by providing a magnetometer, which is developed under the leadership of TU Braunschweig (TUBS). Within the magnetometer team, IWF is responsible, jointly with TUBS, for the development of the interface electronics to the instrument processor as well as for the magnetometer calibration, qualification and integration. In 2005, the calibration and instrument level integration of the remaining flight models (Fig. 3.2) three to five (plus one spare instrument) have been finished.

MMS

The next multi-spacecraft mission in which IWF is involved is the NASA *MMS* (Magnetospheric Multiscale) mission, consisting of four identically equipped spacecraft (Fig. 3.3) flying at closer separation distances than the *Cluster* spacecraft. *MMS* will carry out 3D measurements to explore the acceleration processes that govern the dynamics of the Earth's magnetosphere.

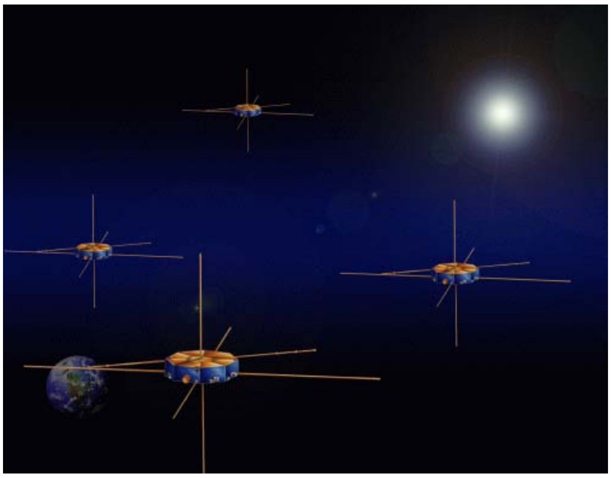

Fig. 3.3: Artist's impression of the four MMS spacecraft.

IWF will take the lead for the spacecraft potential control and participate in the electron beam instrument and the magnetometers. *MMS* is due for launch in 2013.

3.2 Physics

A fleet of spacecraft within the terrestrial magnetosphere and in near-Earth interplanetary space, like *Cluster*, *Double Star*, *Geotail*, and *Interball* provides us with an enormous amount of data representing the plasma and magnetic field behaviour in this region. Data were analyzed and various theoretical models were developed to describe the physical processes responsible for the formation of structures and phenomena in near-Earth space.

Magnetotail

The dynamics of the Earth's magnetotail is extensively studied in IWF by combining data analysis of spacecraft observations and development of relevant theoretical models. Such studies, mainly based on two ongoing missions, *Cluster* and *Double Star*, where IWF has also strongly participated in its hardware development, obtained new results on current sheet dynamics, flux transport, reconnection and its consequences.

Large-scale current sheet structure: The launch of the two *Double Star* satellites, TC-1 and TC-2, enabled the study of large scale dynamics of the current sheet with multipoint observations by combining simultaneous *Cluster* measurements. On 5 August 2004, multiple crossings of the neutral sheet, as indicated by the reversal of the B_X polarity, have been observed simultaneously by both the *Cluster* and TC-1 satellites in the magnetotail. The normal direction and the motion of the neutral sheet were determined using minimum variance and timing analysis.

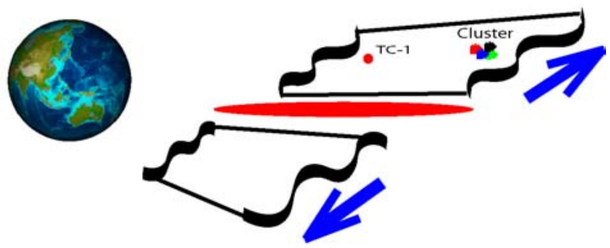

Fig. 3.4: Schematic view of the kink-like wave emitted from the central part of the magnetotail and propagating toward the tail flanks. The TC-1 and Cluster were located 5 R_E apart at same local time. For the first time, the wave has been observed at two different magnetotail locations simultaneously.

Reconstruction of the reconnection rate: Magnetic field reconnection in the magnetotail is considered to be initiated in a region between 15 and 30 R_E downtail. The process causes features like accelerated particles or nightside flux transfer events (NFTEs). NFTEs are short-term events in the substorm-time plasma sheet, which can be described by impulsive variations of the reconnection rate in models of transient reconnection. They are characterized as a bipolar variation of the normal component of the magnetic field and a deflection of the tangential components. Additionally, the velocity shows an upward flow of plasma in the beginning, followed by a strong flow directed downward to the current sheet.

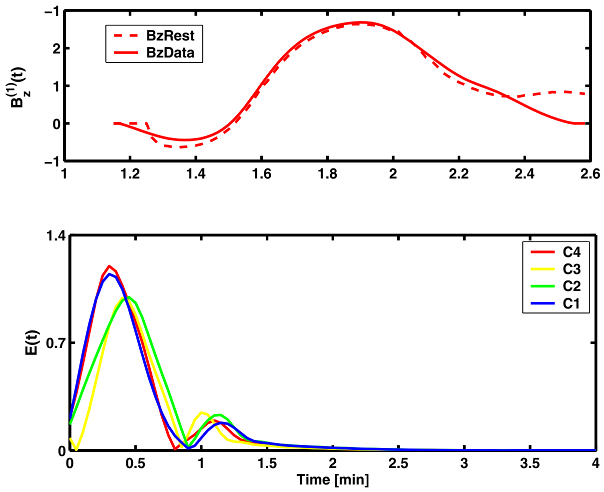

Fig. 3.5: Initial and reconstructed z-component of the magnetic field (top panel) and the reconstructed reconnection electric field (bottom panel) from the four Cluster satellites for a NFTE at 8 September 2002. The electric field reached almost 1 mV/m. The reconnection site was located about 25 R_E down the tail.

An ideal magnetohydrodynamic (MHD) model for a compressible plasma is used to analyze several NFTEs occurring on 8 September 2002, which were observed by the *Cluster* satellites (Fig. 3.5 top panel). Using the Cagniard-deHoop method, it is possible to represent the solution for the magnetic field disturbances as a convolution integral of a kernel, containing information about the field configuration, and the reconnection electric field. By solving the inverse problem using Tikhonov regularization, it is possible to calculate the reconnection electric field out of the observed magnetic field variations (Fig 3.5 bottom). Additionally, a minimization routine was developed to determine the x-distance between the satellite and the reconnection site. This method allows for the first time to reconstruct the reconnection rate and site out of satellite measurements by using a time-dependent model of magnetic reconnection.

Motion of a reconnection line: In the frame of magnetized plasmas, reconnection appears as an essential process for the description of plasma acceleration and changing magnetic field topology. Under certain conditions, a Near Earth Neutral Line (NENL) is free to evolve in the current sheet of the Earth's magnetotail. This leads to the formation of Earthward and tailward propagating plasma bulges, which can be detected by the *Cluster* or *Geotail* spacecraft. Observations give rise to the assumption that the evolved reconnection line does not show a steady-state behaviour, but is propagating towards the tail.

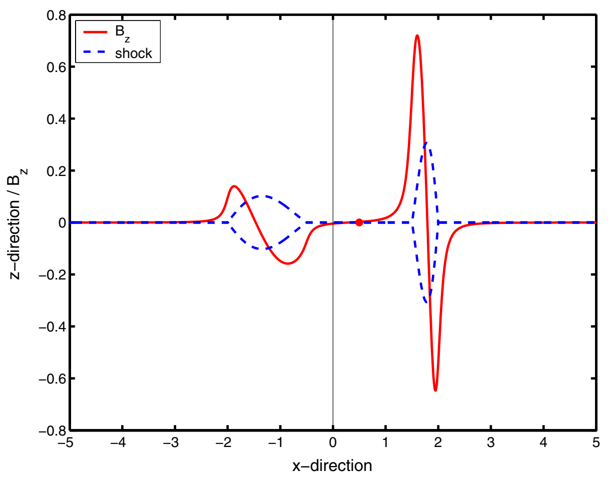

Fig. 3.6: Petschek shocks and B_z in the inflow region for an X-line velocity $U=0.5$ v_A and $t=2$.

Therefore, an extension of the time-dependent Petschek-type reconnection model for the case of a moving reconnection line is necessary. In the Petschek-model the magnetic field lines are connected via shocks, which evolve in the diffusion region during active reconnection and detach themselves from the initial reconnection site. In the case of a fixed X-line, the left- and rightward propagating shocks are symmetric with respect to the initial reconnection site. Under the assumption of an unsteady X-line behaviour, the shock structures lose their symmetric behaviour. The degree of asymmetry increases with the velocity of the X-line. The typical bipolar behaviour of the magnetic field z-component is adapted by an asymmetric behaviour, as can be seen in Fig. 3.6.

Alfvén waves in the magnetotail lobe: The magnetotail lobe was believed to be a quiet and an empty region for a long time. However, for a special condition, namely when an O^+-rich plasma is present, *Cluster* magnetic and electric field instruments may observe sub-storm-associated electromagnetic fluctuations close to the Plasma Sheet Boundary Layer (PSBL). Detailed analysis clarifies the characteristics of these waves and suggests possible source mechanisms, e.g. the leakage of PSBL kinetic Alfvén waves or reconnection-associated waves.

As shown in Fig. 3.7 (a), the Poynting flux of the waves is almost field-aligned and earthward, suggesting that the wave source is tailward of spacecraft and the wave energy is transported towards the Earth. The ΔE/ΔB in Fig. 3.7 (b) almost corresponds to the local Alfvén velocity, which means that the waves are Alfvénic.

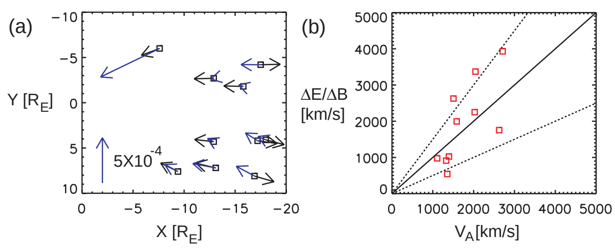

Fig. 3.7: (a) The Poynting flux [mW/m²] (blue arrows) is shown as a vector in the X-Y plane (AGSM coordinates). Black arrows represent the unit vectors of the background magnetic field at that point. (b) |ΔE|/|ΔB| plotted against the local Alfvén velocity, v_A. Dashed lines mark the range of ±50% values of v_A.

Magnetosphere-Ionosphere coupling of bursty bulk flows: To understand the magnetic flux transport processes in the magnetosphere, it is crucial to quantify the bursty bulk flow (BBF) signatures. *Cluster* multi-point observations of BBFs combined with conjugate observations on the ground during an isolated BBF event on 1 September 2002 enabled for the first time to discuss the spatial structure of the disturbances simultaneously in the ionosphere and the magnetosphere.

Cluster observed the dusk side part of a localized flow channel in the plasma sheet (Fig. 3.8 left) with a flow shear at the front. The observed direction of the flow shears indicated field-aligned currents out of the ionosphere. In the ionosphere the equivalent current pattern and possible field-aligned current location showed a localized pattern similar to auroral streamers (Fig. 3.8 right), i.e. upward current at the dusk side and downward current at the dawnside. The location of the *Cluster* foot point was located in the region of the upward field-aligned current side. These observations confirm that localized enhanced flow in the magnetosphere produces a field-aligned current system at the conjugate ionosphere.

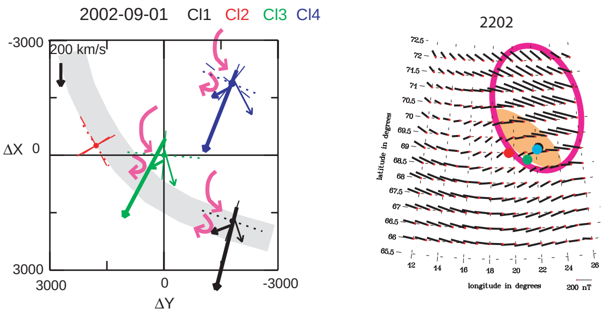

Fig. 3.8: Left: Possible shape of the dipolarization front illustrated on top of the relative location of the four Cluster spacecrafts in GSM X-Y plane with flow vectors at three different sequences of BBF. The pink arrows show the sense of the flow shear ahead and behind the dipolarization front. Right: Equivalent current pattern at 2202 UT together with the foot points of Cluster. The most likely location of the conjugate region of the flow channel (pink) and most likely centre of auroral precipitation region (orange) is illustrated.

Terrestrial Radio Emissions

The terrestrial auroral kilometric radiation (AKR) is a strongly polarized variable electromagnetic emission. It is generated at frequencies between 20 and 1000 kHz in the Earth's magnetosphere from sources located along auroral field lines at altitudes from 2000 to 19000 km above the Earth. It is emitted near the local gyro-frequency of electrons in low-density source cavities, which are identified with acceleration regions characterized by upward directed parallel electric fields. AKR is associated with bright discrete auroral structures and strongly correlated with processes of particles acceleration along magnetic field lines during substorms.

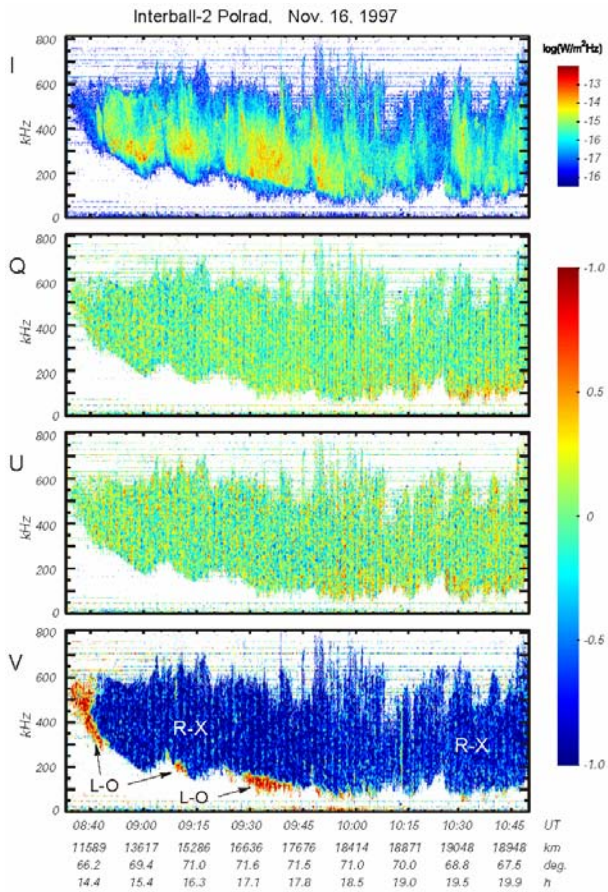

Fig. 3.9: The dynamic spectra of the Stokes parameters, determined in the spacecraft plane orthogonal to the AKR source direction. The bottom panel shows the circular polarisation. Regions of occurrence of right-hand extraordinary (R-X) and left-hand ordinary mode (L-O) are indicated.

An important property of AKR is its polarization. Most frequently it is dominated by the extra-ordinary right-handed (R-X) wave mode. Polarization measurements of AKR often also show a small contribution of the left-hand ordinary (L-O) mode. AKR is observed in both hemispheres. Direction-finding measurements have shown that AKR sources are mainly located in the nightside region of the Earth's magnetosphere. Less intense dayside sources are also observed. The electron cyclotron maser instability (ECMI) is widely accepted for the explanation of AKR. It predicts the observed emission near the gyro-frequency of electrons, and the domination of the R–X wave mode of the AKR emission.

Interball-2 was launched on 29 August 1996, to study the energy transfer to the auroral magnetosphere and the corresponding dissipation processes. It operated until 28 January 1999. One of *Interball-2* experiments was the *Polrad* instrument, aimed at measuring all Stokes parameters of AKR polarisation. *Polrad* was a step frequency analyser, which swept a frequency range from 4 to 1000 kHz with a step resolution of 4.096 kHz and step duration of 25 or 50 ms for sweep periods of 6 or 12 s. The *Polrad* antenna system consisted of three orthogonal short electric dipoles. An example of the determination of the AKR Stokes parameters is shown in Fig. 3.9. The AKR polarization parameters (Stokes parameters) provide information about the mechanism of AKR generation. In addition, the determination of the Stokes parameters enables the separation of the R–X and L–O modes of AKR. Since plasma conditions for the generation and propagation of the R–X and L–O modes are different the polarization parameters can be used for an evaluation of the AKR sources characteristics.

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 *WAVES* experiment aboard the *STEREO* spacecraft measures the non-thermal radio spectrum from the solar environment, ranging from a few kHz up to 16 MHz. Three orthogonal monopole antennas, each 6 m long, are used to determine the arrival direction and the polarization state of incident radio waves.

For accurate direction finding the receiving properties, mainly described by the effective antenna lengths and axes, have to be known. These quantities are significantly changed by the spacecraft body, which requires a detailed analysis. Our wire-grid simulations of the antenna-spacecraft system showed that the solar panels and the boom change the reception properties considerably. When included, the base capacitances reduce the effective lengths of the antennas down to one meter.

Besides the wire-grid modelling of the antennas, an experimental approach was also realized. The so-called rheometry uses an electrolytic tank to measure the effective length vectors and capacitances of the antennas. A model of the antenna-spacecraft system (Fig. 4.1) is immersed into tap water, in which a homogeneous electric field is sustained. The effective length vectors can be determined from the voltages induced in the antennas.

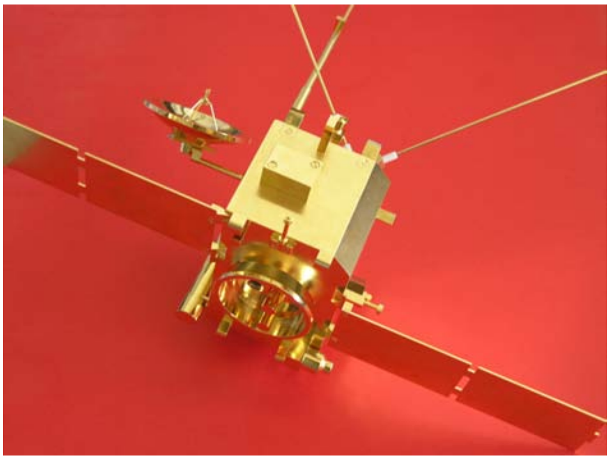

Fig. 4.1: STEREO/SWAVES antenna-spacecraft model for rheometry measurements on scale 1:20.

The measurements yielded effective antenna axes for the quasi-static range which are in good agreement with the wire-grid modelling. The effective lengths are slightly different, probably due to the fact that the feed zones and radii of the antennas could not be modelled with the same accuracy in both approaches.

Solar Orbiter

The scientific aims and features of the *Radio Plasma Waves (RPW)* analyzer on board of the future mission *Solar Orbiter* are under consideration. IWF emphasizes on the solar radio observations, in particular at hectometric, decametric and metric wavelengths. The *RPW* experiment provides an excellent opportunity towards a better understanding of solar corona physics, in particular on micro-scale phenomena.

Physics

Solar coronal magnetic loop oscillations and low-frequency modulations in microwaves: Studies of the low-frequency (LF) fluctuations of solar microwave radiation have continued. A "sliding window" Fourier analysis is combined with the Wigner-Ville technique. Slow variations of the electric current and associated magnetic fields in a source of solar microwave emissions can modulate the intensity of the received signal. Also a large-scale motion of the source can create modulations.

Emissions from the active regions, where the *TRACE* EUV telescope observed large scale oscillations of coronal loops, were analyzed. Besides the oscillations with periods close to those detected by *TRACE* (~10 min), the applied data analysis technique allows for additional detection of several shorter period oscillations (Fig. 4.2). These could not be resolved by *TRACE*. The short period modulations could be associated with oscillations of small loops, as well as with specific excited wave modes (sausage mode). There are strong indications that in this particular 10 min the modulation of the intensity of microwave emissions was caused by a large scale motion of the loop containing the microwave source.

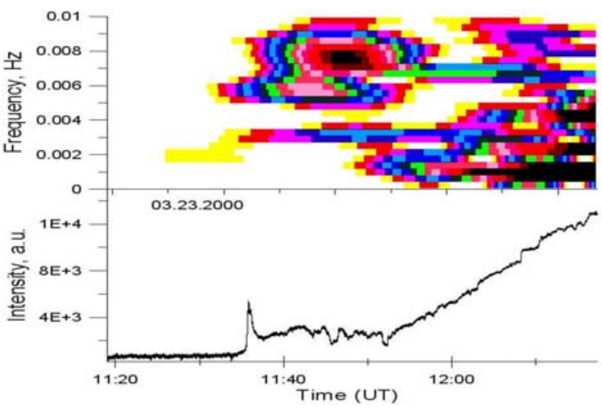

Fig. 4.2: Intensity profile and LF modulation spectrum of the microwave radiation on 2000-Mar-23 at 11:30-12:00 when TRACE observed 10-min oscillating loops in EUV.

Solar radio emissions: The properties of so-called solar drift pair bursts (DP) have been studied from observations by the radio telescope UTR-2 (Kharkov, Ukraine) with the use of new band-end facilities (digital spectral polarimeter and 60-channel spectrometer). The statistical analysis of more than 700 Type III bursts registered on 13-15 July (Fig. 4.3) showed that the number of "forward" and "reverse" drift pairs is approximately equal. Most likely DPs originate from the interaction of Langmuir waves with magnetosonic waves, each with equal phase and group velocities. Magnetosonic waves are generated by electron or ion beams which travel in the heterogeneous coronal plasmas.

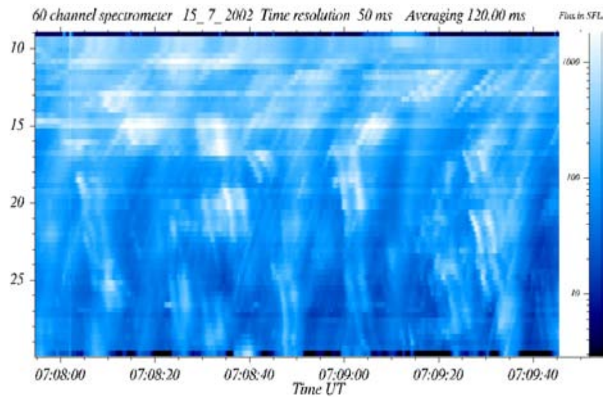

Fig. 4.3: Fragment of DPs storm of 15 July 2002.

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. ESA's mission *BepiColombo* 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*, Fig. 4.4) and *Planetary Orbiter (MPO)* – are simultaneously flying to this innermost planet. *BepiColombo* is scheduled for launch in 2013.

Within the scope of the European-Japanese *MERMAG* Consortium, magnetometers have been proposed and selected for both satellites. For the magnetometer aboard the Japanese *MMO (MERMAG-M)*, IWF is the lead institution. For the *MPO* magnetometer *(MERMAG-P)* IWF is responsible for the overall technical management.

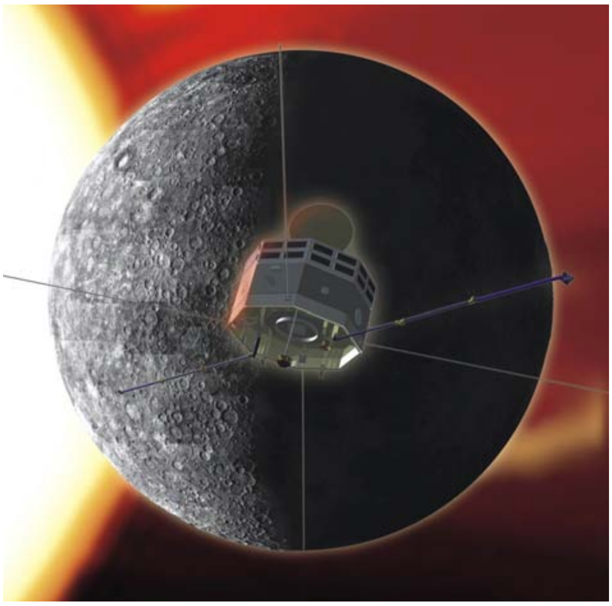

Fig. 4.4: Artist's impression of the Japanese MMO spacecraft with IWF-built magnetometer.

IWF also leads the building of a particle analyzer for ESA's *MPO*. The instrument *PICAM*, which 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.

Physics

Antennas in plasma: The response of antenna sensors to incident electromagnetic waves depends on the ambient medium. Especially a plasma environment can change the antenna reception properties crucially. Still more drastic alteration of properties is to be expected for magnetized plasmas. The magnetic field introduces an anisotropy in the equations of the plasma, so the environment becomes non-reciprocal. This implies additional complications. By a thorough investigation of reciprocity principles, and their application to the representation of antenna properties, it was found how even non-reciprocal media can be described on the basis of appropriate effective length vectors. The consequences for magnetized plasmas and for the numerical wire-grid modelling of space borne antennas will be investigated in the near future. Missions like *BepiColombo,* with plasma wave instruments, allow to cross-check these studies with measured signals. The aim is to implement the plasma influence in the antenna description and thereby improve the evaluation of signals received by space borne antenna sensors.

Mercury surface mineralogy and 3D exosphere simulation: The chemical composition of Mercury's surface should be measured remotely by exospheric particle densities with the *SERENA* instruments on board of the *BepiColombo* planetary orbiter. Because the expected exospheric densities are small and various source processes are located at different geographical locations over Mercury's surface, we made an assessment of a potential Mercury surface composition considering lunar surface regolith and mineralogical compositions adjusted to spectroscopic observations as analogues for Mercury's surface. Furthermore, we developed a 3D exospheric test particle model to see whether measurement of released surface elements by the particle detectors is feasible along the *MPO* orbit.

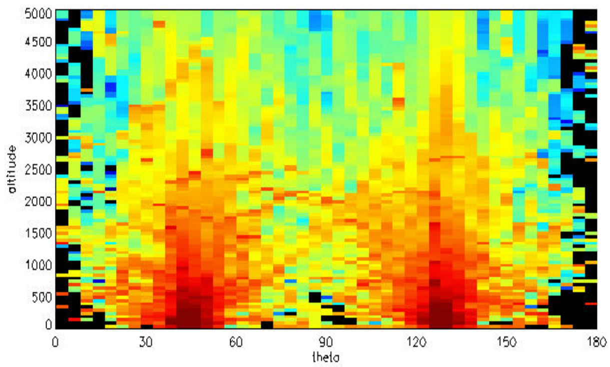

Fig. 4.5: Simulation of sputtered oxygen atoms which are released from Mercury's surface as a function of geographical coordinates and altitude.

The energy and ejection angle distributions of the released minerals at the surface were modelled (Fig. 4.5), with the emission process determining the actual distribution functions. The model follows the trajectory of each particle by numerical integration until the particle hits Mercury's surface again or escapes from the calculation domain. Bulk parameters of the exospheric gas can be derived using a large set of these trajectories.

4.3 Venus

The close proximity of Venus to Earth opened a great opportunity to send a spacecraft over to investigate our neighbouring planet in detail.

Venus Express

Venus Express, ESA's first mission to Venus, was launched successfully on 9 November 2005 from the Baikonur Cosmodrome in Kazakhstan. IWF takes the lead on one of the seven payload instruments, the magnetometer *VEX-MAG* (Fig. 4.6). *VEX-MAG* measures the magnetic field vector with a cadence of 128 Hz. It will identify the boundaries between the various plasma regions (magnetosheath, the ionosphere, and magnetotail) and will study the solar wind interaction with Venus' atmosphere.

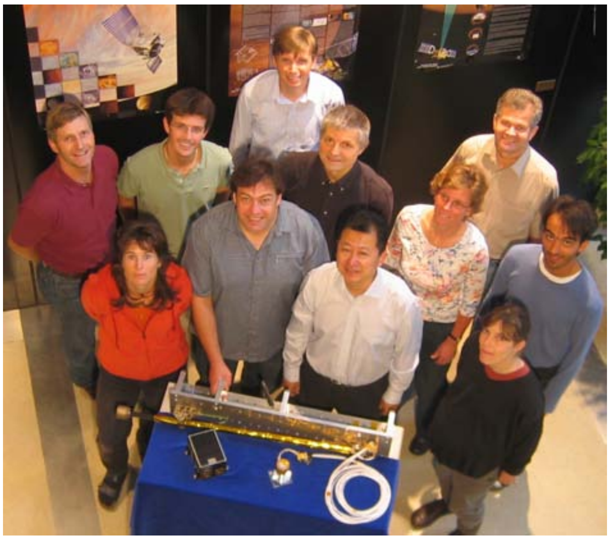

Fig. 4.6: The IWF VEX-MAG hardware team which built the instrument in 12,000 working hours together with colleagues at TU Braunschweig, Germany and Imperial College London, UK.

On 18 November, *VEX-MAG* was switched on and the boom deployed successfully during the near Earth commissioning phase. The instrument remains switched on and performs nominally. Parallel to the hardware activities, data processing preparation for the magnetic field measurements is undertaken. A neural network algorithm has been built to automatically recognize patterns of disturbed magnetic field caused by spacecraft stray fields. Good progress has been made by testing the model against simulated data.

Physics

Evolution of the Venusian atmosphere and water inventory: Several studies suggest that Venus should have lost most of its water early in its history. Using multi-wavelength X-ray, EUV (XUV), and solar wind densities observed from young Sun-like stars the heat budget of Venus' thermosphere over the planet's history can be studied. This budget is changed through photo dissociation and ionization processes, due to exothermic chemical reactions and IR-cooling of CO_2. The simulations result in expanded thermospheres with exobase altitudes between ~200 km at present and ~2200 km 4.5 Gyr ago, yielding high exospheric temperatures of ~8000 K during the active phase of the Sun. The duration of a hydrodynamic escape phase for H depended on the mixing ratios of CO_2, N_2 and H_2O and could have lasted up to several hundred Myr.

The loss of O^+ through ion pick up was studied over Venus' history with a test particle model (Fig. 4.7). Depending on expected solar wind parameters, ion pick up on a non-magnetized Venus can erode more than an equivalent amount of one terrestrial ocean (250 bar).

Plasma instabilities at the ionopause of Venus: Previous observations of the plasma environment around Venus indicate that the Kelvin-Helmholtz instability (KHI) can develop at the ionopause of Venus. KHI may manifest itself in the production of so-called plasma clouds ejected by the ionosphere, through which ionospheric plasma can escape and lead to a significant contribution to the loss of particles. KHI is studied by numerically solving the compressible, ideal MHD equations and including a transition layer between the solar wind and the ionosphere. Across this boundary layer of finite thickness the velocity and the density of the flow change. The finite thickness of the boundary layer stabilizes it for short wavelengths.

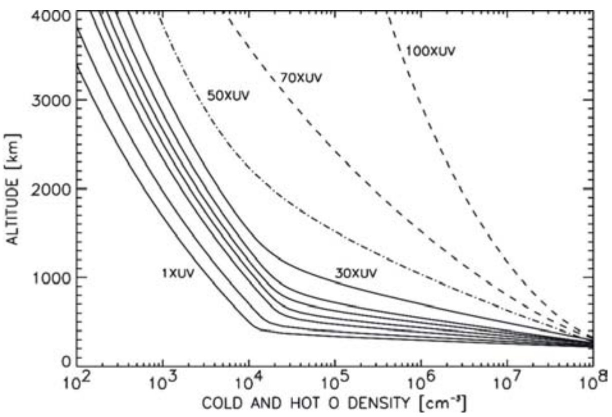

Fig. 4.7: Sum of expanded "cold" and "hot" oxygen number density as a function of altitude and different solar XUV flux values.

4.4 Mars

Mars has been investigated by many missions in the last years. Optical observations have shown that there has been liquid water on the Martian surface. At the end of 2005 the *Mars Express* radar has been switched on, to search for water, also under the surface of this unmagnetized planet.

Mars Express

The *MARSIS* (Mars Advanced Radar for Subsurface and Ionosphere Sounding) experiment aboard *Mars Express* started its measurements in summer 2005, after an uncertain phase of antenna deployment was finalized successfully. *MARSIS* is dedicated to the investigation of the Martian surface/subsurface structure and ionosphere. The ground penetrating radar uses a special technique to separate clutters from the subsurface main signals by means of a secondary monopole antenna. Our analysis of the *MARSIS* antenna system has shown that the polarization mismatch between the echoes and the monopole is favourable to the clutter cancellation technique (however, the resulting improvement will depend on the surface properties). So an adjustment of the spacecraft attitude (which was originally planned in order to point the minimum gain direction of the monopole towards nadir) is not necessary, which is a pleasant result also for the other experiments aboard *Mars Express*. First measurements proved the instrument to work well and showed promising new results.

4.5 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 auroral emissions: The flux density variation of the Jovian hectometric emissions (HOM) observed from 31 August to 24 October 1996 are studied by combining *Galileo/PWS* and *Wind/WAVES* observations. HOM emissions present periodic features, so-called "HOM events". The fluctuations of the Jovian hectometric emissions and the solar wind parameters are found to exhibit quasi-similar variations with a time lag of about 153 days. Also ''HOM enhancements'' are found to occur at some specific Jovian longitudes. The occurrence of these magnetospheric events increases at two "active longitudes" at 45° and 180° CML. The solar wind seems to be at the origin of both phenomena. Solar wind particles enter the polar regions where they interact with the Jovian magnetic field which leads to an increase of Jovian hectometric emissions and/or injection events.

Ground-based decametre radio observations: The Jovian decametre radio emission exhibits a very complex structure in the dynamic spectrum. Based on observations of the Jovian S-burst radiation by the largest existing radio telescopes (UTR-2 and URAN-2 in Poltava, NDA in Nançay) used with new high performance receivers and processing methods, a variety of modulation events have been found.

The new features include S-bursts fine properties (1 ms/10 kHz or less), modulation lanes (~100 ms/~100 kHz), and other kinds of modulation generated in the radiation source as well as along the propagation path, as shown in Fig. 4.8.

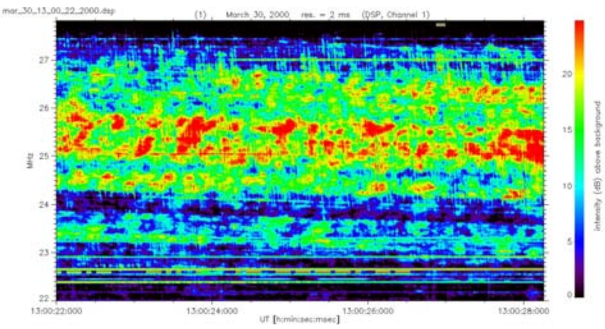

Fig. 4.8: High time resolution (2 ms) dynamic spectrum. Spotty, very intense structures are superposed on S-bursts (narrow near vertical stripes) and intersected by modulation lanes of low drift rate.

4.6 Saturn and Titan

In 2005 *Cassini/Huygens* has continued its investigation of the Saturnian system. Besides the successful landing of the European *Huygens* probe on Titan, Saturn's largest moon, on 14 January and seven more Titan flybys, the *Cassini* orbiter made several flybys at various other moons like Enceladus and Tethys.

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*.

Cassini/Huygens

After a seven years cruise to the Saturnian system and two close Titan encounters the *Cassini* orbiter released the *Huygens* probe on 25 December 2004. The orbit of the *Huygens* probe has been reconstructed using the data of the entry phase and of the descent under the parachute. Part of this work has been carried out at IWF.

HASI: On 14 January 2005 the atmosphere of Titan was first detected by the *HASI* accelerometers at an altitude of about 1500 km. About five minutes later at an altitude of 155 km the main parachute was deployed and the probe started to transmit data of the fully operational payload. About 2.5 hours later the probe landed near the equator of Titan and continued to collect data for about one hour.

The electric field sensor of *HASI* took measurements during the descent (2 hours and 27 minutes) and on the surface (32 minutes), approximately 3200 spectra in two frequency ranges: 0-100 Hz and 0-11 kHz. Major emphasis of the data analysis is on the detection of electric and acoustic phenomena related to lightning.

Three methods are used to identify lightning in the atmosphere of Titan:

- Measurement of the low frequency electric field fluctuations produced by lightning strokes
- Detection of resonance frequencies of the ionospheric cavity
- Determination of the DC fair weather field of the global circuitry driven by lightning.

The *HASI* lightning channel observed impulsive electric field events, shown in Fig. 4.9 for a 5 dB threshold. Several events were found to be similar to terrestrial sferics and are most likely produced by lightning. Large convective clouds have been observed near the South Pole during the summer season and lightning-generated low-frequency electromagnetic waves can easily propagate by ionospheric reflection to the equatorial region.

The existence of lightning would also be consistent with the detection of signals in the Schumann range and a very small fair weather field, but confirmation by the radio wave experiment aboard the *Cassini* orbiter is still missing. The acoustic unit *(ACU)* was included in the *HASI* experiment in order to investigate acoustic activities during the descent and after landing, e.g. thunderclaps produced by lightning in the close vicinity of the probe.

The changes of the turbulence level observed during the descent of the probe depend on the variations of density, temperature and acoustic impedance of the *ACU*. A correlation was also found between haze variations and *ACU* measurements in the lower troposphere of Titan. The turbulence level after landing is under investigation and will be used together with wind tunnel experiments to infer an upper limit of the horizontal wind velocity.

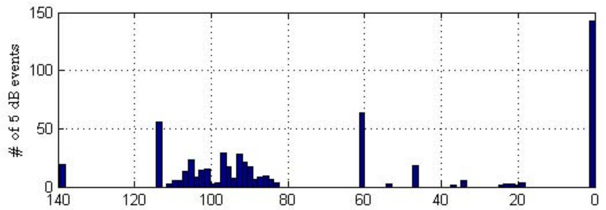

Fig. 4.9: Histogram of impulsive electric field events above a 5 dB threshold.

ACP: IWF was strongly involved in the development of the *ACP* instrument. First data analysis showed NH_3 and HCN as pyrolysis products for refractory aerosol material. Further detailed and systematic laboratory investigations are needed to derive the composition of the aerosol material.

SSP: Although not directly contributing to the instrument hardware of *SSP*, IWF was involved in the calibration of the flight data from the surface penetrator sensor *(ACC-E*, Fig. 4.10) and the impact accelerometer *(ACC-I)*. By comparing the flight data with reference experiments from PSSRI (UK) and IWF, properties of Titans surface could be inferred. The landing site features geological structures similar to a fluvial plain and the data structure of the penetration experiment can be reproduced best by an impact into wet sand mixed with cm-sized pebbles.

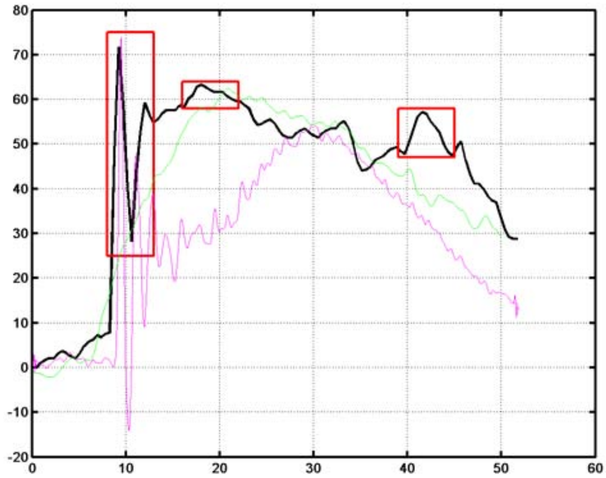

Fig. 4.10: SSP-ACC-E sensor data in comparison with laboratory data. Moderately wet sand (green) gives the most similar signal structure, whereas embedded cm-sized pebbles (cyan) can explain the ringing features of the signal. The ACC-E penetrator probably hit several small pebbles during the impact event (red boxes).

Physics

Lightning on Saturn: Cassini's RPWS has detected intensive lightning activity only from the middle of July until the end of September 2004. Since then flashes from storms in Saturn's atmosphere were practically absent with the exception of a short intensive lightning storm lasting for about one week in early June 2005. The lightning activity from 2004 revealed a total number of about 5400 flashes organized in four storm systems with 95 episodes (mean duration about three hours). Additionally, the intensity of the lightning flashes was calculated using the *RPWS* antennas in the high frequency range. A mean intensity of 50 W/Hz was found.

Images taken by the optical camera onboard *Cassini* show a particularly active region at latitude 35° south where bright storm eruptions are correlated with lightning flashes (see Fig. 4.11). There is a phase shift of 0.2 Saturn rotations between the appearance of lightning and the visible cloud features which can be explained by ionospheric effects.

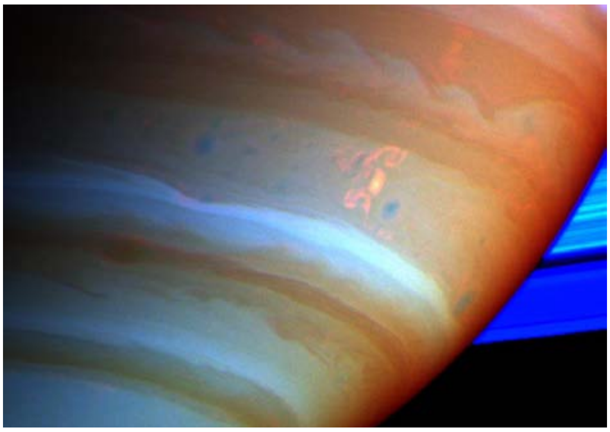

Fig. 4.11: The "dragon storm" in Saturn's atmosphere as imaged by Cassini on 13 September 2004 (Photo: NASA).

Search for lightning on Titan: Although the existence of clouds in Titan's atmosphere has been impressively shown with *Cassini* images, lightning on Titan should be a rare event. Even now with about 10 close Titan flybys, *RPWS* detected no clear radio signals of Titan lightning activity. There were some sporadic bursts at the flybys TB and T3, but they cannot be clearly attributed to lightning activity.

Linear prediction for solar wind control of Saturn kilometric radiation (SKR): The external control of SKR intensity variations has been investigated using new data obtained by three different experiments on board the *Cassini* spacecraft. The *RPWS* experiment yields continuous measurements of SKR. The *CAPS* and *MAG* experiments monitor the solar wind plasma and the interplanetary magnetic field. The Linear Prediction Theory (LPT) uses an enhanced correlation analysis to quantify correlations between input signals and output signals. The input signals are time profiles describing the solar wind; the output signal is a time profile of the integrated SKR intensity. The LPT computations give an efficiency parameter which quantifies the linear relation between input and output.

Fig. 4.12 displays the efficiencies of four different inputs as a function of temporal shift. All four quantities arrive at the same plateau level (~55% efficiency), so, four quantities may trigger SKR emission. The lag times associated with these quantities are completely different, indicating different reaction times of SKR to the input.

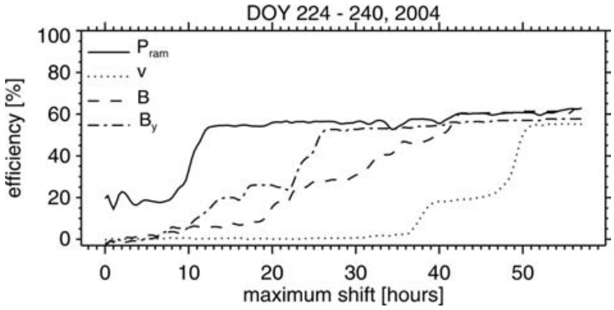

Fig. 4.12: Efficiency of four solar wind parameters in producing SKR: solar wind ram pressure (P_{ram}), bulk velocity (v), interplanetary magnetic field strength (B), and the y-component of the magnetic field (B_y).

4.7 Comets

Rosetta

ESA's *Rosetta* mission was launched in 2004. In 2014, it will enter an orbit around comet Churyumov-Gerasimenko and put down a landing module 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.

Thermal conductivity measurements: With IWF involvement in *MUPUS* a new interdisciplinary field devoted to terrestrial thermal conductivity measurements was initiated together with the Institute for Planetology (Münster, Germany), the Space Research Centre (Warsaw, Poland), and the Cold and Arid Regions Environmental and Engineering Institute (Lanzhou, China). The laboratory tests, performed in summer 2005 in Lanzhou, used two types of sensors: (a) Probes based on the "heated wire" method, which allow the direct measurement of the thermal conductivity of a homogeneous media and (b) so-called *EXTASE* probes developed from the *MUPUS* experiment. Both probes complement each other, i.e. the heated wire probes can be used to calibrate and crosscheck the *EXTASE* probes.

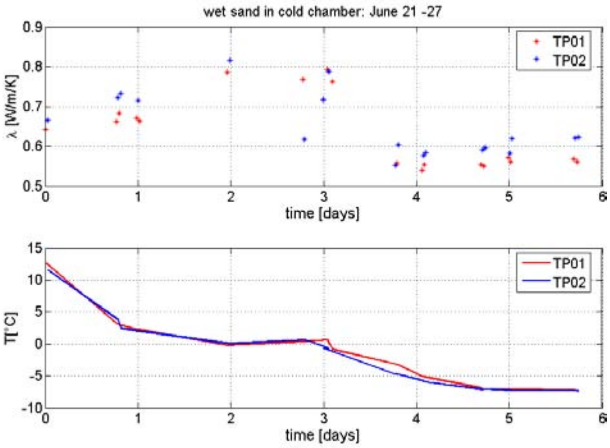

Fig. 4.13: Thermal conductivity data obtained from measurements in wet sand during an experiment of several days duration in the climate chamber of Lanzhou at different temperature and humidity levels.

The measured samples were mainly associated with materials used for road and railway construction in permafrost areas, e.g. on the Quinghai-Tibet high plateau. The values obtained from the thermal conductivity measurements (Fig. 4.13) are intended to be used in engineering models for roadway construction. In addition, the measurements will be useful for the calibration of the future cometary soil data, because these measurements were performed both with standard sensors and with *MUPUS*-type probes.

4.8 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. About 170 have been found by the end of 2005.

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). *COROT* will investigate the dynamic processes in the interior of stars and will perform the search and survey of extrasolar planets. The variation of the brightness of stars is the key parameter for astroseismology and exoplanetology. High precision photometry determines these variations, with a resolution better than 10 ppm. In astroseismology, the amplitude and frequency of brightness variations are used to derive the oscillation mode and to determine the physical and chemical processes in the interior. Brightness variations can also be caused by bypassing planets. To distinguish variations due to oscillations from bypassing planets, spectral analysis is performed.

Fig. 4.14: Flight models integrated in the COROT electronics compartment.

IWF developed and built the so-called extractor *BEX* (Boîtiers Extracteur), a computer system with dedicated pre-processors for the selection and classification of image data (Fig. 4.14). In-house developed pre-processors identify pixels, which are part of pre-defined image area. The essential technology is hardware supported data mining under the constraints for real-time operation.

This year the last flight model was delivered. Two *BEX* units are integrated in *COROT*, while the third one remains as spare. Parallel to the tests on instrument and spacecraft level, software tests for the pre-processing chain have been performed. IWF supports these activities with complementary tests with the spare model in case of unexpected behaviour.

Physics

Stellar-interaction with close-in exoplanets: A numerical, hydrodynamic evaporation model for hot exoplanets is under development. The model simulates the number density, velocity and temperature of evaporating atmospheres and will be applied to mass loss of exoplanets, discovered by *COROT*, as well as to terrestrial planetary atmospheres which are exposed by high XUV fluxes.

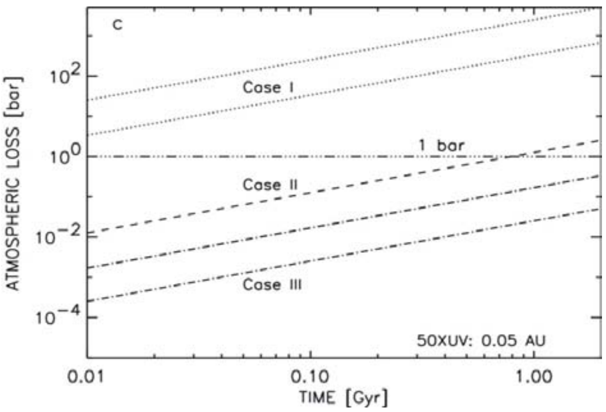

Fig. 4.15: Time dependent atmospheric loss as function of minimum (lower lines) and maximum (upper lines) CME plasma flux within the habitable zone of an XUV active M star at 0.05 AU. Case I (dotted lines): Venus-like interaction; Case II (dashed lines): magnetopause at 0.5 Earth radii; Case III (dashed-dotted lines): magnetopause at one Earth radius above the planetary surface.

The exposure of XUV-heated CO_2-rich atmospheres to Coronal Mass Ejections (CMEs) is studied for Earth-like exoplanets within "close-in" habitable zones (HZs) of low mass M stars. Existing observational data of CMEs by *SOHO* were used and extrapolated for dwarf stars. It was found that exoplanets within close-in HZs should experience a continuous dense plasma exposure over long time periods. Furthermore the close location of these planets to their central star results in tidal-locking. Low rotation periods produce weaker intrinsic magnetic moments and smaller magnetospheres. A numerical test particle, ion pick model was applied to extended exospheres with the inferred minimum and maximum CME plasma parameters. Earth-like exoplanets with no, or weak magnetic moments may lose tens to hundreds of bars, or even their whole atmosphere at orbital distances ≤0.2 AU (Fig. 4.15).

Search for radio emission from exoplanets: Planetary radio emission is a typical magnetospheric auroral phenomenon which enables the remote sensing of fundamental planetary properties, e.g. magnetic field strength and rotation periods. Theoretical investigations show that exoplanet radio emissions would be detectable from Earth by giant radio telescopes as the UTR-2, located at Kharkov (Ukraine). From non-thermal planetary radio emissions one can obtain knowledge of the existence of an exoplanetary magnetic field, which is essential for the definition of a habitable zone considering the shielding effect against cosmic rays.

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.

The development of space born instruments typically starts with a laboratory model, to verify the general concept. The next step is the engineering model, the first model fulfilling the main parameters as dimension, mass and power consumption.

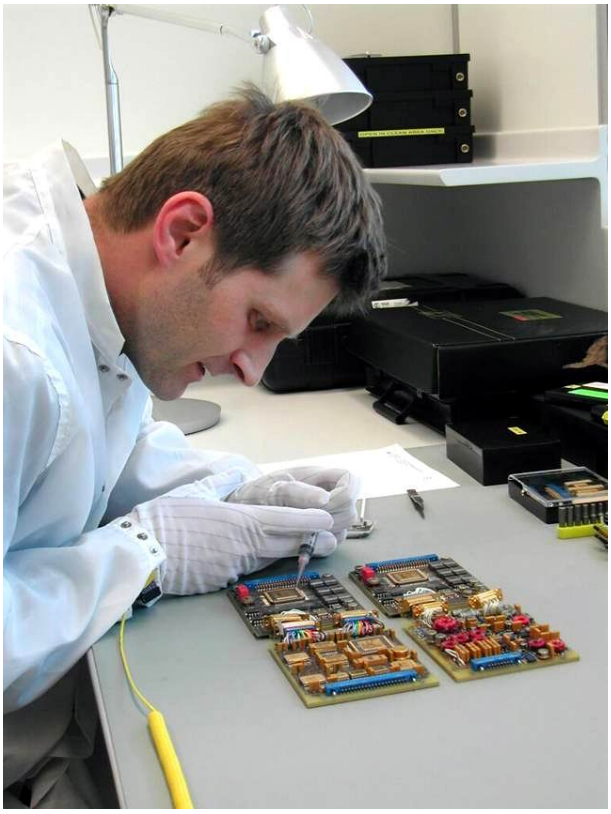

Fig. 5.1: In the cleanroom the flight units of space experiments are integrated and tested.

A dedicated model, the so-called qualification model, is tested in a simulated space environment to demonstrate the compliance with these specified conditions. IWF owns several test chambers for simulating thermal and vacuum conditions. Finally, following the completion of all design and test activities, the flight models, which will be integrated on the spacecraft, are built, using especially hardened electronic components (Fig. 5.1).

5.1 Test Facilities

Vacuum Chambers

For simulating the stress on space instruments due to environmental conditions, a dedicated test chamber providing vacuum and extreme temperatures is available at IWF. The thermally controlled mounting plate and the surrounding mantle can be either electrically heated or cooled by liquid nitrogen. The test chamber supports a temperature range between −80 °C and +120 °C at a pressure level of 10^{-5} mbar. Automatic test sequences are controlled by a computer program and supervised by two independent safety protection systems.

For the development and testing of particle analyzers and active electron or ion sources a large vacuum chamber is available. The inbuilt numerically controlled manipulator with three degrees of freedom, together with a two axis sensitive Faraday cup supports the calibration of active instruments.

For the measurement of electrical properties of soil materials a new test facility was implemented. It combines a small vacuum chamber with an impedance spectrometer (Fig. 5.2). Thus, electrical properties of e.g.

Martian soil analogues can be studied in space environment conditions.

Fig. 5.2: The newest in-house vacuum chamber.

Penetrometry Test Stand

A penetrometry facility designed to measure mechanical soil properties is available since January 2004 at the comet laboratory. This facility is used for experiments on mostly Martian soil analogues and the calibration of numerical models for granular materials.

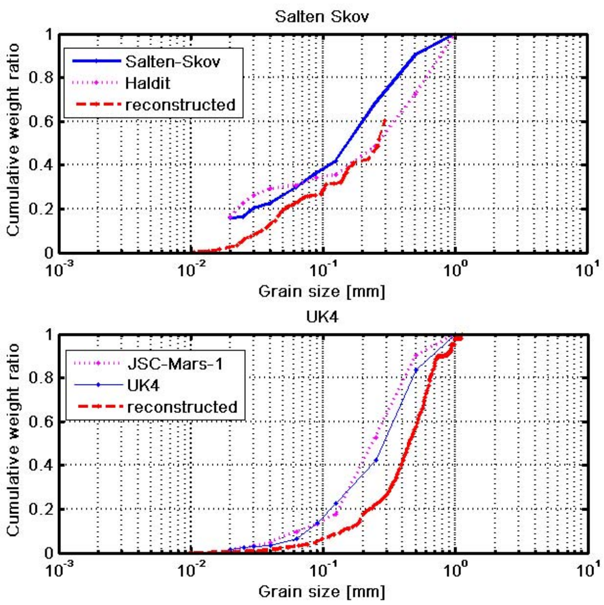

Fig. 5.3: Reconstruction of grain size distribution from penetrometry measurements in Martian analogue materials (Haldit and UK4).

A new method was developed which allows the reconstruction of the grain size distribution, through a statistical analysis of the penetrometry data (Fig. 5.3).

UV Exposure Facility

The UV exposure facility, which is capable to reproduce the modelled Martian UV surface radiation between 200-400 nm (UV-A, B, C), has already been successfully employed in several astrobiology related labs across Europe. These campaigns take place within the frame of ESA's topical team *ROME (Response of organisms to the Martian environment)*.

Magnetometer Calibration

Two sets of three-layer magnetic shielding cans (including different kinds of calibration coils) and a temperature test facility, with which magnetic field sensor can be tested over an extended temperature range from -170 °C up to +200 °C in a low field environment, are used for in-house calibration and testing of diverse magnetometer instruments.

During 2005, the test facilities have been used for the calibration of four *THEMIS* flight sensors as well as for several test measurements in the frame of the *Venus Express* magnetometer and the *Magnetometer Front-end ASIC (MFA)* projects.

Temperature Test Facility

During space missions, scientific sensors mounted outside of the spacecraft are usually exposed to extreme temperature conditions. It can be very hot for missions going closer to the Sun (Venus and Mercury) and very cold when being in eclipse or somewhere in the outer solar system. With the temperature test facility at IWF, magnetic field sensors can be tested over an extended temperature range from −170 °C up to +200 °C in a low field environment.

5.2 New Instruments

Magnetometer Chip

The development of an instrument front-end ASIC for magnetic field sensors (fluxgate principle) was proposed by IWF in cooperation with the Fraunhofer Institute for Integrated Circuits and the Institute of Geophysics and Planetary Physics/UCLA in order to reduce instrument size, mass and power consumption while increasing the radiation tolerance at the same time.

A contract for the development of such an ASIC – including one re-design – was signed with ESA/ESTEC in autumn 2004. The project will last for about two years with the final presentation in September 2006.

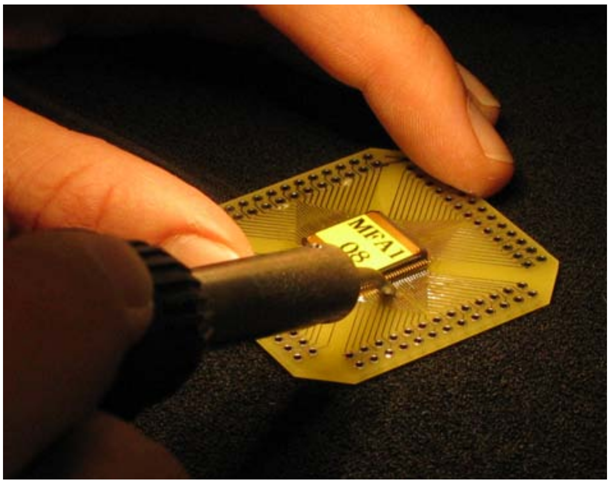

Fig. 5.4: Magnetometer front-end ASIC soldered to the adapter board.

In 2005, the system level development of the first chip (0.35 μm CMOS process from Austria Microsystems, Fig. 5.4) was finished followed by chip manufacturing and testing.

The first test results obtained in autumn 2005 have been very encouraging:

- Full functionality of the digital and analog part (three magnetic field plus one housekeeping channel with 8-1 multiplexer) with only minor anomalies
- Power consumption of less than 50 mW
- Full 16-bit quality of the housekeeping channel
- Radiation tolerant to more than 200 krad of total ionization dose.

Also the three fluxgate channels, for which the chip has been designed, show very good functionality but with some increased noise (about a factor of two) in the frequency band below 5 Hz, which needs further investigation and testing. Based on these first test results, the chip has already become a candidate for NASA's *Magnetospheric Multiscale Mission (MMS)*.

Melting Probe

The preparatory work on the development of a melting probe for planetary ice layers continued in 2005. This project has first become a major issue by the end of this year, when an ESA contract devoted to this task was granted. In the meantime a simple prototype representing the major dimensions of the prototype to be developed next year has been built and its thermal behaviour when heated in an ice layer was modelled with the aid of a FEMLAB program. A modelling result based on the assumption that the probe is initially enclosed in compact ice and heated with a power of 60 W is shown in Fig. 5.5.

In addition, some laboratory tests with different heating rates under vacuum conditions have been performed. The final aim of the project is to provide an instrumented probe suitable for exploring the sub-surface ices of the Martian polar areas and/or the Jovian satellite Europa.

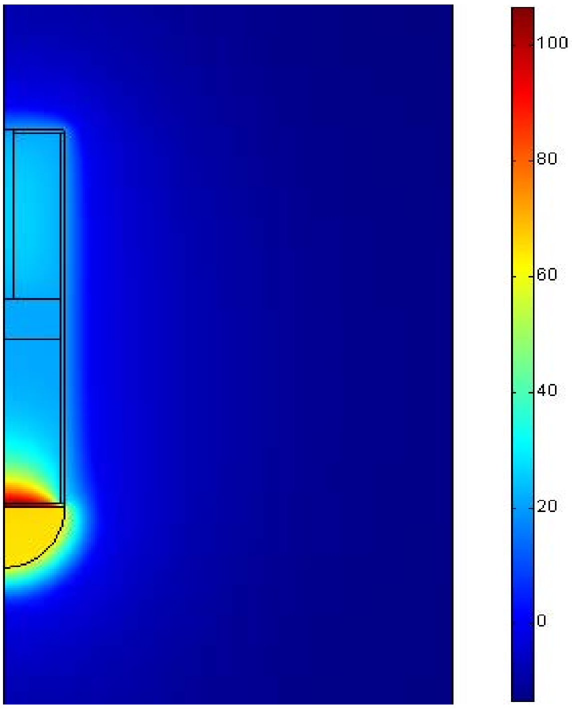

Fig. 5.5: Temperature distribution and phase change (melting) in an ice block surrounding the melting probe, when the probe is heated with a power of 60 W (the scale on the right is given in °C.

Impedance Measurements

In order to extend the physical methods used for the characterisation of planetary surface layers, a study towards the development of a so-called "mutual impedance probe" was initiated. Such a probe could serve as a valuable supplement for a surface science package devoted to the determination of physical properties like soil strength, thermal parameters, and mechanical parameters including texture. As a starting point an existing simple prototype provided by ESTEC was used. The long term plan is to implement such a device into the drilling system of the planned *EXOMARS* rover. An experimental setup for laboratory measurements on various relevant materials has already been built and first measurements were performed.

6 Publications & Talks

6.1 Refereed Articles

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Asano, Y.: Field aligned current structure and intensity with/without fast flows, *Workshop on Thin Current Sheets*, Tarusa, Russia, Feb 2005.

Asano, Y., R. Nakamura, A.V. Runov, T. Takada, W. Baumjohann, A. Balogh, B. Klecker, H. Rème: Dynamical structure of the cross-tail current sheet in substorms observed by Cluster, *SGEPSS Fall Meeting*, Kyoto, Japan, Sep 2005.

Asano, Y., et al.: Current sheet evolution: Plasma dynamics in substorms before and during fast flows, *Workshop on Thin Current Sheets*, Tarusa, Russia, Feb 2005.

Baumjohann, W.: Dynamics of the current sheet in the magnetotail, *Workshop on Energetic Particle Phenomena in the Magnetosphere*, Tokyo, Japan, Mar 2005.

Baumjohann, W.: Erforschung des Weltraums, *Raumfahrt & Recht. Faszination Weltraum*, Graz, Austria, Nov 2005.

Baumjohann, W.: From Saturn to Mercury, Solar System Exploration in Austria, *Space Day Austria*, Salzburg, Austria, Oct 2005.

Baumjohann, W.: Future European magnetospheric missions, *Cluster and Double Star Symp.*, Noordwijk, Netherlands, Sep 2005.

Baumjohann, W.: Huygens and other Graz Activities, *Ringberg Meeting*, Rottach-Egern, Germany, Jan 2005.

Baumjohann, W.: MERMAG-MGF: the magnetometer on the MMO, *Workshop on Magnetometer Measurements on BepiColombo*, Noordwijk, Netherlands, Feb 2005.

Baumjohann, W.: Space policy in today's European landscape, *First ESPI Conf.*, Vienna, Austria, Sep 2005.

Baumjohann, W., A. Matsuoka: The Magnetic Field Experiment for BepiColombo MMO, *AOGS 2005*, Singapore, Jun 2005.

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Besser, B.P.: National space history: Austria, *Concluding Workshop Extended ESA History Project*, Paris, France, Apr 2005.

Besser, B.P.: Physics from seismology to atmospheric electricity – a balancing act: Hans Benndorf, *EGU General Assembly*, Vienna, Austria, Apr 2005.

Besser, B.P., R. Huber: Karl Weyprecht und die internationalen Polarstationen – eine Idee von globaler Bedeutung, *DGG Jahrestagung*, Graz, Austria, Feb 2005.

Delva, M.: The space environment around Venus and what about the night side? *ESA/Space Science talks*, Madrid, Spain, Sep 2005.

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Khodachenko, M.L., A.G. Kislyakov, W. Weiss, T. Kallinger, H. Lammer, H.O. Rucker: Modulations in stellar light curves. Fourier-Wigner-Ville test analysis of MOST data, *9th COROT Week*, Noordwijk, Netherlands, Dec 2005.

Khodachenko, M.L., H.O. Rucker, B. Kazeminejad: Europlanet/N3: Coordination of ground-based and space-based planetary observations, *Cassini PSG Meeting*, London, UK, Aug 2005.

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Nakamura, R.: Characteristics of fast plasma flows in the Earth's magnetotail, *SGEPSS Fall Meeting*, Kyoto, Japan, Sep 2005.

Nakamura, R.: Cluster activities at Graz, *Ringberg Meeting*, Rottach-Egern, Germany, Jan 2005.

Nakamura, R.: Dynamics of the magnetotail, *IAGA*, Toulouse, France, Jul 2005.

Nakamura, R.: Gender Equality in European Research Institution, *2005 Joint Meeting for Earth and Planetary Science*, Makuhari, Japan, May 2005.

Nakamura, R.: Magnetotail reconnection and its consequences, *Workshop on Energetic Particle*

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Nakamura, R.: Substorms and their solar wind causes, *Solar Dynamics and its Effects on the Heliosphere and Earth*, Bern, Switzerland, Apr 2005.

Nakamura, R.: Tail reconnection and plasma sheet fast flows, *Cluster and Double Star Symp.*, Noordwijk, Netherlands, Sep 2005.

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Torkar, K.M.: Spacecraft potential control, *IAGA*, Toulouse, France, Jul 2005.

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Delva, M.: Unter den Wolken der Venus, Katholisches Bildungshaus, Tainach, Austria, Nov 2005.

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6.7 Posters

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7 Teaching & Workshops

7.1 Lecturing

IWF members are actively engaged in teaching at three universities. In summer 2005 and in the current winter term 2005/2006 the following lectures are given:

KFU Graz

Theoretical Hydrodynamics (Biernat)

Two Component Effects in the Solar System Plasma (Biernat)

Plasma Theory (Basics) (Biernat)

Solar-Terrestial Relations (including Waves and Instabilities) (Biernat)

Planetary Atmospheres (Lammer)

Introduction to Space Sciences (Rucker et al.)

Planetary Magnetospheres (Rucker)

Planning, Organization, and Management of Geophysics Projects (Rucker)

Geo- and Space Physics Projects (Rucker)

Introduction to Plasma Physics (Rucker)

TU Graz

Space-Time Reference Systems (Arsov)

Signal Processor Techniques (Magnes)

HF-Engineering 1+2 (Riedler)

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, already the third in the series of these university courses, which leads to the internationally acknowledged Master of Science (MSc), started in fall 2005. Several members of IWF are lecturers of this inter-university course led by H.O. Rucker.

Corresponding Master Theses of the second course have analysed the concept of a first Austrian satellite CubeSat, the Saturn radio emission as observed by *Cassini*, and have performed antenna calibration studies of the upcoming *STEREO* mission.

7.2 Theses

Besides lecturing, members of the Institute are supervising Diploma, Master and Doctoral Theses. In 2005, the following theses have been completed:

Endler, S.: Theoretical aspects of the stellar influence on short-periodic exoplanets, Diploma Thesis, KFU Graz, 94 pages (2005)

Heidorn, D.: Magnetic oscillations induced by bursty bulk flows in the magnetotail, Diploma Thesis, KFU Graz, 76 pages (2005)

Kaufmann, E.: Experimental investigation of the solid state greenhouse effect in planetary ices, Doctoral Thesis, KFU Graz, 107 pages (2005)

Kazeminejad, B.: Methodology development for the reconstruction of the ESA Huygens probe entry and descent trajectory, Doctoral Thesis, KFU Graz, 160 pages (2005)

Kiehas, S.A.: Time dependent Petschek-type magnetic reconnection for a moving x-line with applications to Earth's magnetotail, Diploma Thesis, KFU Graz, 90 pages (2005)

Kolb, C.: Mars surface materials, Doctoral Thesis, KFU Graz, 215 pages (2005)

Macher, W.: Transfer matrix description of multiport antennas and its application to the Mars Express/MARSIS radar, Doctoral Thesis, TU Graz, 206 pages (2005)

Oswald, T.: Electromagnetic waves in space and the STEREO/SWAVES experiment, Master Thesis, KFU Graz, 101 pages (2005)

Ottacher, H.: Entwicklung einer Programmier- und Testumgebung für den Mikrokontroller RTX2010 für HF-Weltraumexperimente, Diploma Thesis, TU Graz, 60 pages (2005)

Penz, T.: Habitable planets in the universe: An interdisciplinary approach regarding the origin and distribution of life, Diploma Thesis, KFU Graz, 132 pages (2005)

Rosc, J.: Antennas in radio astronomy, Diploma Thesis, KFU Graz, 100 pages (2005)

7.3 Science Meetings

From 20-22 April the 6th International Workshop on Planetary and Solar Radio Emissions (PRE VI) took place in Graz. It was jointly organized by IWF/ÖAW and the Institute of Physics (IGAM) of KFU Graz. About 80 scientists from 16 nations participated in this workshop.

Fig. 7.1: WSEF participants in the gardens of Schloss Seggau, near Graz.

From 2-6 May the 2nd World Space Environment Forum (WSEF) was held in Schloss Seggau. It was organized jointly by IWF/ÖAW, the World Institute for Space Environment Research at the National Institute for Space Research, Brazil, and the Institute for Astrophysics at the University of Innsbruck, Austria. About 60 scientists from 21 nations participated in this forum (Fig. 7.1).

From 1-4 June the EUREF Symposium was organized in cooperation with BEV. 145 scientists participated in this symposium, which was held in the ÖAW Festivity Hall in Vienna.

From 13-16 September IWF hosted the UN/Austria/ESA Symposium "Space Systems – Protecting and Restoring Water Resources" with 75 participants from all over the world.

From 14-18 November the Dark Energy Dark Matter Workshop was held at IWF with 14 participants from nine different nations.

In addition, T.L. Zhang organized a session at the International Space Weather Conference in Macau and at the AOGS in Singapore. R. Nakamura organized sessions at the EGU in Vienna, the AOGS in Singapore, and at the AGU in San Francisco.

7.4 Project Meetings

Besides several meetings with less than ten participants, 14 larger meetings with international participation were organized at IWF/ÖAW in 2005.

From 12-14 January the *PICAM* Kick-Off Meeting took place at IWF with 15 participants from Belgium, France, Germany, Hungary, Ireland, Russia, and The Netherlands.

From 10-13 February the *HASI/PWA* Meeting was held at IWF with 14 participants from France, Spain, and The Netherlands.

On 1 March the *COROT-BEX* Flight Model Delivery Review was held at IWF with 10 participants from CNES, LESIA, and IWF.

Fig. 7.2: The Cassini RPWS Team in the IWF atrium.

On 9 March the *EUROPLANET N3* Kickoff Meeting was held at IWF. It was attended by 20 participants from France, Germany, Greece, Italy, The Netherlands, UK, and USA.

On 23 April the *Cassini/RPWS* Team Meeting took place at IWF with 16 participants (Fig. 7.2), including people from France, Sweden, UK, and USA.

On 24 April the *EUROPLANET* General Assembly took place at ÖAW with 80 participants from Europe.

On 30 April the *Venus Express MAG* Team Meeting was held at IWF with 12 participants, including people from China, Europe, and USA.

On 21 May the *ROME* Topical Team Meeting was held at IWF with 15 participants from Denmark, Finland, Germany, Hungary, Spain, The Netherlands, and UK.

From 6-7 June the *M³* Meeting was held at IWF with 13 participants from France, Japan, Sweden, The Netherlands, and UK.

From 6-8 June the *PICAM* Meeting took place at IWF with 10 participants from Belgium, France, Russia, and The Netherlands.

From 4-5 October the *MIDAS* Workshop "The Rosetta Grains" was held at IWF with 10 participants from France and The Netherlands.

The *EUROPLANET N3* Strategic Workshops on "Comparative Meteor Studies on Terrestrial Planets" and on "Saturn's Aurorae" were held at IWF from 11-12 and from 25-26 November. Both were attended by 18 and 25 participants, respectively. The latter workshop was attended by scientists from Belgium, France, Germany, UK, and USA.

From 28-30 November the *Solar Orbiter* and *STEREO* Meeting took place at IWF with the participation of 12 persons from France, Russia, and Ukraine.

From 5-7 December 12 participants from France, Germany, Russia, and Ukraine attended the *INTAS* Meeting ("using world-largest decametre radio telescopes as probe and basis for developing the LOFAR concept") held at IWF.

7.5 Awards

In 2005, several prizes and awards were granted to IWF staff members.

In May, Rumi Nakamura received the "Tanakadate Award" from the Society of Geomagnetism and Earth, Planetary and Space Sciences in her home country Japan. Furthermore, an interdisciplinary Austrian jury selected her as FEMtech (women in research and technology) researcher of May.

In September, about two dozen IWF staff members received an ESA award in recognition of their outstanding contributions to the *Cluster* project.

In November, Bobby Kazeminejad was awarded the "Ing. Friedrich Schmiedl - Forschungspreis" for his doctoral thesis by Mayor Siegfried Nagl and TUG Rector Hans Sünkel.

In December, Cardinal Christoph Schönborn awarded the "Kardinal Innitzer Preis" to former IWF director Willibald Riedler.

Additionally, Helmut O. Rucker became a Corresponding Member of ÖAW and Wolfgang Baumjohann was elected as Editor of Journal of Geophysical Research.

7.6 Public Outreach

In 2005 IWF participated in numerous space exhibitions: "Lange Nacht der Physik" and "Weltkulturerbefest" in Graz' city centre, as well as "Lange Nacht der Museen" at BRG Kepler.

Huygens' landing on Titan and the *Venus Express* launch marked highlights in 2005.

On 14 January, IWF organized the "Huygens Event: Descent to an unknown world". It was attended by almost 300 persons who followed the "live" broadcast of *Huygens'* descent to Saturn's moon Titan. Telescopes from the Styrian Astronomers Club were pointed at the starry sky to observe Saturn and Titan, as well as craters on the Earth's moon.

On 9 November, despite the very early hour – 04:33 CET – about 100 space enthusiasts accepted the invitation from IWF Graz to follow the live transmission of the launch of ESA's *Venus Express* during a "Space Brunch" sponsored by ALR/FFG and Austrospace. For this special occasion schoolchildren of BORG Monsbergergasse, Graz performed the fantasy story "Solaris will nicht sterben" (Fig. 7.3) which was greatly appreciated by the viewers.

Fig. 7.3: Solaris and Nostradamus trying to find humans on Earth.

8 Personnel

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Besser, Bruno P., Dr. (E)
Biernat, Helfried K., Prof. (P)
Boudjada, Mohammed Y., Dr. (P)
Chwoika, Rudolf (S)
Crailsheim, Hartwig (E, ESA)
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Haslinger, Cornelia, Dipl.-Ing. (S, EU)
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As of 31 December 2005

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