SPACE RESEARCH INSTITUTE

IWF
Space Research Institute

ÖAW
Austrian Academy of Sciences

ANNUAL REPORT 2008

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SPACE RESEARCH INSTITUTE GRAZ
AUSTRIAN ACADEMY OF SCIENCES

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Cover Image:

THEMIS (Time History of Events and Macroscale Interactions during Substorms), a cluster of 5 similar space-craft, was launched in February 2007 to study the chain of processes called magnetospheric substorm and the origin of the aurora.

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1 Introduction

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

- *Cassini* is orbiting Saturn and exploring its system.
- *Cluster*, the four-spacecraft mission is still providing unique data leading to a new understanding of space plasmas.
- *Rosetta* is on its way to comet 67P/Churyumov-Gerasimenko.
- *Venus Express* explores the space plasma environment around Venus.
- *COROT* searches for extra-solar planets and analyzes oscillation modes of stars.
- *THEMIS* probes the chain of processes called magnetospheric substorm and the origin of the aurora; the first results have been published.
- *GOCE* will determine the structure of the terrestrial gravitational field with unprecedented accuracy.
- *Yinghuo* is the first Chinese mission to Mars, planned for launch in October 2009.
- *RBSP* (Radiation Belt Storm Probes) are two NASA spacecraft that will quantify processes in the Earth's radiation belts.
- *BepiColombo* will investigate the planet Mercury, using two orbiters: one with instruments specialized for magnetospheric studies, and the other for remote sensing of the planet.
- *MMS* will use four identically equipped spacecraft to explore the acceleration processes that govern the dynamics of the Earth's magnetosphere.
- *ExoMars* is an ESA rover and a lander to characterize the biological environment on Mars.
- *Resonance* is a Russian space mission of four identical spacecraft, orbiting within the same magnetic flux tube.

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

Scientific highlights in 2008 were:

- The *Venus Express* data show evidence for the loss of water from Venus not only through the magnetotail, but also through a much larger than expected hydrogen exosphere.
- *THEMIS* showed the propagation of a solar wind discontinuity through the Earth's bow shock and subsequently its expected deformation in the magnetosheath as it propagated downstream.

- *CoRoT* detected four Jupiter-type gas giants, and these measurements have been confirmed by ground-based follow-up measurements.

In closing some numbers: in 2008 members of the institute published 133 articles in refereed international journals, 34 of these as first author. During the same period, articles with authors from the institute were cited about 1610 times in the international literature. In addition, 178 talks and posters have been presented at international conferences by members of the IWF, including 38 by special invitation from the conveners. In national and international press media, the institute was mentioned about 167 times. Last but not least, institute members have organized one international conference, as well as 11 sessions at international meetings.

IWF structure and funding

IWF is structured into three departments:

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

Prof. Dr. Wolfgang Baumjohann serves as Executive Director.

The bulk of financial support for the research is provided by the ÖAW. Substantial support is also provided by other national institutions, the Austrian Research Promotion Agency (Österreichische Forschungsförderungsgesellschaft, FFG), the Province of Styria, and the Austrian Science Fund (Fonds zur Förderung der wissenschaftlichen Forschung, FWF). Furthermore, European institutions like ESA and the European Union contribute substantially.

2 Solid Earth

Precise knowledge of the Earth's gravity field and its time variations, based on ongoing and future dedicated satellite missions, will contribute to the detection and better understanding of the mechanisms provoking the dynamics of the Earth's crust. Repeated precise determination of station coordinates by means of GPS and Satellite Laser Ranging facilitates the investigation of the time rate of change of the station velocity field. This is a basic prerequisite to study the driving forces and the energy transport in the Earth's interior.

2.1 Gravity Field

Gravitation, the universal force of attraction exists between all mass particles in the universe. Its resultant on the Earth's surface forms the gravity field of the Earth, which is the direct response to its interior mass density distribution and the centrifugal force caused by its rotation. Its physical representation is given by a virtual surface at mean sea level called the geoid. This is the surface of equal gravitational potential of a hypothetical ocean at rest, and it serves as the classical reference for all topographical features.

GOCE

ESA's satellite mission *GOCE* (Gravity field and steady-state Ocean Circulation Explorer) employs for the first time a sensor fusion concept, using a combination of the principle of satellite gravity gradiometry (SGG) and satellite-to-satellite tracking (SST) relative to GPS satellites. The forthcoming *GOCE* mission will deliver a high-resolution gravity field model (see Fig. 2.1) for the satellite's image and the evolution of global gravity information with a geoid accuracy of about 1 cm at a new range of spatial scales in the order of 100 km half wavelength, which will make a deep impact on many branches of Earth Sciences.

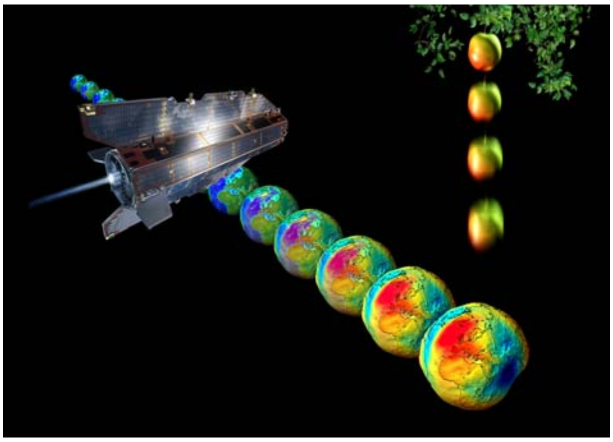

Fig. 2.1: The GOCE satellite – taking Newton's apple to space (Copyright: ESA-AOES Medialab).

Data Processing

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, is responsible for the processing of an Earth's gravity field model parameterized by spherical harmonic coefficients and the corresponding full variance-covariance matrix from the precise satellite orbit (SST data) and gradiometry (SGG data). This is embedded in the framework of the ESA-funded project "*GOCE* High-level Processing Facility" (*HPF*), an operational hardware and software system for the scientific processing (Level 1b to Level 2) of *GOCE* data.

Simulation studies

One of the studies involved the evaluation of the scenario of different mission operational profiles, i.e. constant satellite orbital height or slightly decaying, resp. increasing altitude, and the resulting impact on the resolved geoid accuracy. For this purpose several computations using the rigorous solver approach have been performed. On the basis of a 59-days SGG data set gravity field, models up to degree and order (d/o) 200 and 250 have been computed. Due to the computational time restrictions of the direct solver approach, even on parallel hardware, a modified data processing strategy was applied. To reduce the computational burden, by retaining nearly the full gravity information, a resampling of the original 1 Hz data set has been performed, yielding reduced data sets with 5 s sampling interval. To achieve this goal a filtering process had to be applied, in order to avoid aliasing effects on the subsampled data. A proper low-pass filter was used to tailor the information content of the re-computed gravity signals.

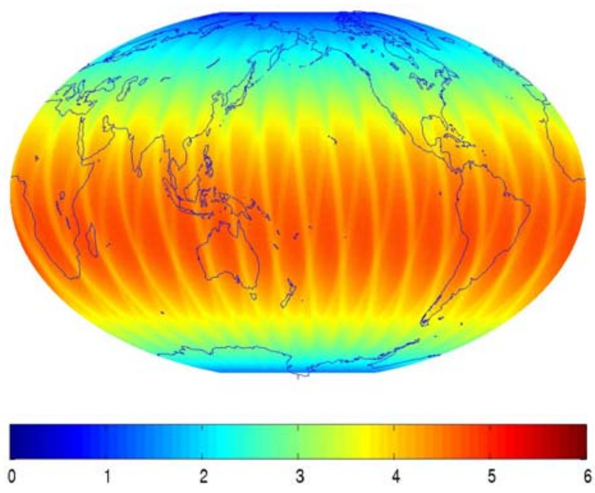

Fig. 2.2: Geoid height standard deviations [cm] at d/o 200 resulting from rigorous covariance propagation; orbit with approx. const. altitude.

The results for two different orbit profiles are compared in the sequel. The first mission profile contains a nearly constant average altitude of 268.6 km, whereas the second one is a decaying orbit with a mean altitude of 264.2 km. The corresponding gravity anomaly and geoid height errors of the d/o 200 solution are 1.03 mGal and 3.74 cm, resp. for the constant orbit, compared to 0.92 mGal / 3.37 cm for the orbit with decreasing altitude. Fig. 2.2 and Fig. 2.3 show the resulting propagated geoid height standard deviations on a global grid for the two simulation scenarios.

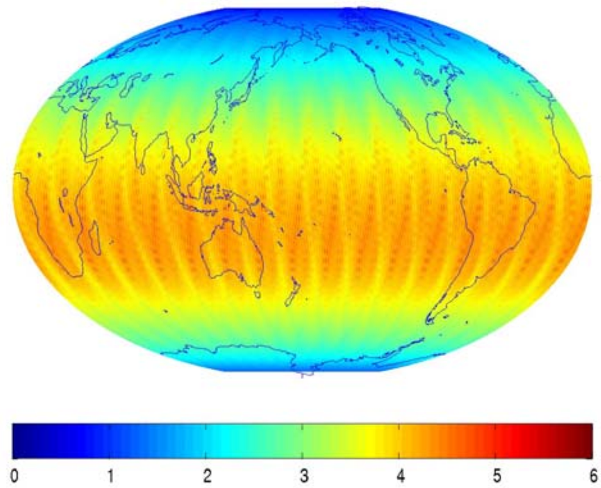

Fig. 2.3: Geoid height standard deviations [cm] at d/o 200 orbit decay due to const. neg. acceleration bias.

Compared to the d/o 200 solutions the error level of the d/o 250 results is significantly higher, but the spatial features remain similar.

2.2 Geodynamics

The GPS analysis group at IWF combines routine processing with scientific analysis. Focusing on contributions to international reference frames and plate movements there are four regions of interest: Europe in general, Central Europe between the Baltic and the Mediterranean Sea, the Eastern Mediterranean and the Arabian Plate and the Eastern Alps with a spatial resolution of 30 to 1000 km. Time series of coordinates are investigated for potential signals, like equipment, troposphere, tectonic and other effects. Whereas the horizontal movements of the crust can already be estimated with a precision of about 1 mm/year, the vertical ones suffer heavily from historical processing by differing models. Starting re-processing like other institutions globally showed that most equipment and troposphere modelling biases will vanish and improve the vertical component considerably from 5 mm/year to 2 mm/year. Within the coordinate time series analysis also the frequency domain was analyzed. The first step was to estimate the power spectrum of several time series. The result of this was quite natural as already seen in the spatial domain – the main amplitude mostly corresponded to the annual term of the signal. After applying a high pass filter to eliminate the annual term a much smoother signal remains (Fig. 2.4).

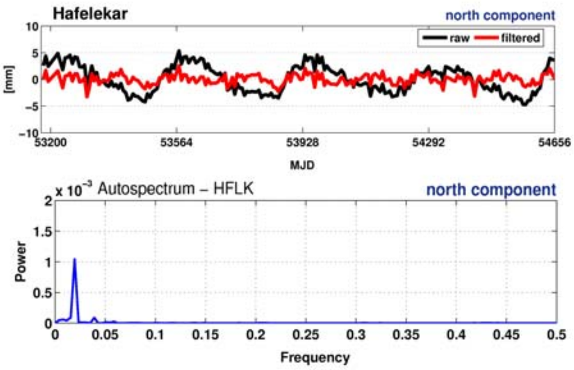

Fig. 2.4: PSD and Time series of Hafelekar.

More detailed investigations could show if such annual signals have their sources in natural surroundings or if partials of them are manmade, e.g. by the models used for processing, by effects of the constructions or by the behaviour of the antennas.

The co-seismic shift of a GNSS station by an earthquake was found, which is a rare event because most stations have a distance too large from the epicentre. The Greek station Riolas (RLS) was about 20 km away from the earthquake of June, 8th. The shift North of about 8 mm and Up of about 10 mm components are clearly seen in the time series (Fig. 2.5). The area around this earthquake is also investigated for potential precursors in the ionosphere (see Section 2.4).

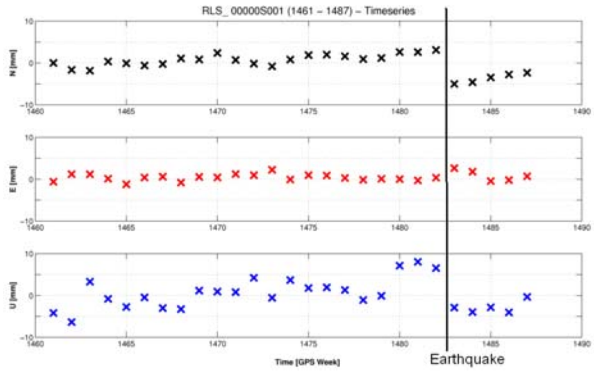

Fig. 2.5: Earthquake in Time Series of RLS.

Apart from the standard weekly analysis also a Near Real Time analysis within four hours was set up. The test bed included 14 GPS stations within the Austrian Monitoring Network. The process is fully automated and is based on the following data:

- Ultra Rapid Orbits from IGS
- Ionosphere models from CODE
- Hourly data from OLG server

In case of an error, a notification via email will be automatically transmitted. The resulting coordinates were in the range of 1-2 centimetres in the horizontal and up to 3 centimetres in the Up component. The prototype was developed to balance a quick monitoring with a need to detect misbehaving of stations below 5 centimetres. The prototype runs very stably now for about one year. Almost all false alarms are produced when the data amount within the 4h-bin becomes too small, a feature which can be easily corrected in practice.

2.3 Satellite Laser Ranging

Technology

The two event timers within our FPGA have been upgraded successfully to sub-nanosecond resolution, an RMS of about 200 ps, and a non-linearity of better than 100 ps. The two event timers are used for fast (few µs) determination of start and stop events, improving efficiency when ranging to very low orbiting satellites like *GOCE*.

The kHz SLR station Graz delivers about 2.5 mm single shot RMS for satellites like ENVISAT, CHAMP, ERS-2 etc. However, for certain satellites with a high satellite signature, the single shot accuracy is limited to 8 mm (LAGEOS) and several cm (AJISAI) due to the large "reflection depth" of these spheres.

One way to improve these results is to restrict all returns to single photons only. However, this is difficult to achieve and maintain during tracking and requires a reduction of the return rate to < 10% - thus losing a major advantage of a kHz system - and will almost always still result in a mixture of single-photon and few-photons returns.

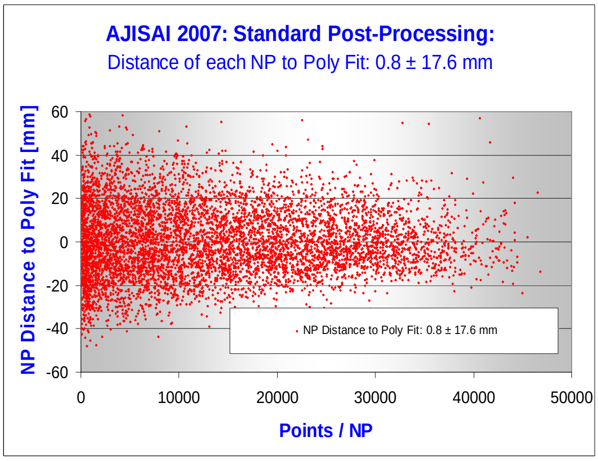

Fig. 2.6: Standard post-processing of AJISAI data. Normal points show large scatter, due to big return energy variations, and big satellite signature.

Therefore, a different approach is developed: the return rate is kept at a maximum, accepting all returns, regardless of energy. This reduces significantly the requirements for real-time tracking. However, it delivers a rather random mixture of return energies, causing in turn a big scatter of Normal Points (see Fig. 2.6).

To improve this, the clearly visible "Leading Edge" (LE) of returns (reflected by the nearest retro) is used as a reference line, and accept only returns from the next 20 mm after this reference line. All other returns are rejected. This reduces our returns per pass by about 30% average, but offers a lot of advantages:

- All NPs are now at 10 mm ± 0.2 mm from the reference line ("LE")
- NP scatter is reduced from ± 17 mm to ± 0.2 mm (AJISAI, Fig. 2.7)
- RMS is reduced from 15.8 ± 6.1 mm to 5.3 ± 0.2 mm (AJISAI)
- NPs are now geometrically "fixed" at a constant distance to the satellite's center. This results in a truly stable CoM (Centre of Mass) correction.

All corresponding values for *LAGEOS* are improved in a similar way.

For the first time, the spin rate evolution of *LAGEOS-1* (8 years) and *LAGEOS-2* (16 years, beginning with launch 1992) was determined, using full rate SLR data of all SLR stations. It can be shown that the spin rate slow-down is not a uniform phenomenon, but shows long-term and short-term periodical variations corresponding to gravity forces and spin axis orientation.

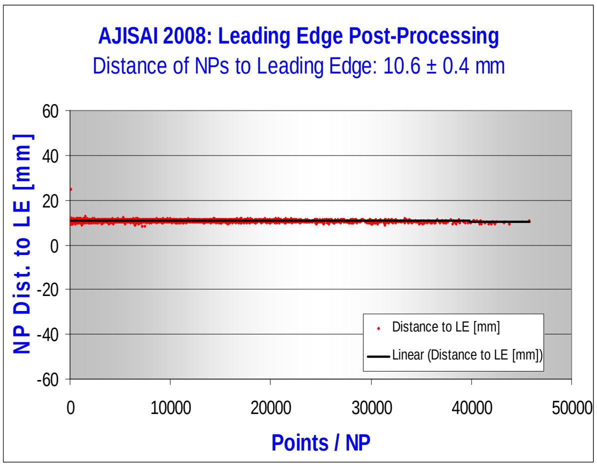

Fig. 2.7: Leading-edge post-processing of AJISAI data. Normal points are at stable distance from satellite's surface. NP scatter is reduced from ± 17 to ± 0.2 mm.

Our LIDAR system, using the backscatter of the transmitted laser, received first echoes from clouds in distances up to 8 km at full daylight conditions. Our work continues to use this as a byproduct during routine SLR activity.

LEO Tracking

Laser ranging to LEO satellites is significantly more difficult than tracking high orbiting satellites, because the angular speed is much higher, the visibilities from ground stations as well as the tracking elevations are lower. The LEO tracking efficiency of the Graz SLR station was significantly improved (wide angle search telescope with CCD camera, redesigned detection package, remote controlled filtering system). Especially for LEO missions SLR observations are very valuable independent data sources for the calibration of the onboard microwave tracking system and the validation of GPS orbits. The quality of LEO orbits was analyzed on the basis of real CHAMP tracking data and verified a post fit RMS of 1.5 cm with respect to a precise reference orbit. In view of the GOCE mission methods for a quick-look gravity field quality assessment based on SLR observations have been developed.

2.4 Atmosphere

Atmospheric Density

Low Earth Orbiters (LEOs) are essential instruments for the investigation of the current status of the Earth and its change. For such satellites the atmospheric drag is particularly difficult to model since it depends on the atmospheric density which highly varies with both time and space. In order to measure these perturbations, CHAMP or the GRACE A/B tandem mission carry high precision accelerometers onboard.

Furthermore the total mass densities from the in-situ measurements were compared with the Jacchia-Bowman 2008 model (Fig. 2.8). In particular, the focus was on variations of neutral atmospheric density during extreme solar events like the Halloween events which occurred in autumn 2003. Such events caused periods with magnetic activities up to Kp values of 9 resulting in density increases of up to 400% compared to densities at quiet conditions.

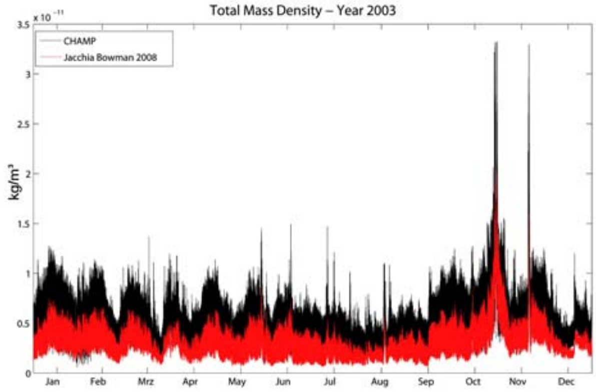

Fig. 2.8: Comparison of Total Mass Densities throughout 2003.

The correlation between extreme solar events and the activity of solar proxies also gives a basis for studies on the evolution of the Earth's atmosphere and for Earth-type atmospheres of exoplanets orbiting around active stars.

Atmospheric Electricity

Three main subjects have been investigated in the frame of the seismic predictions. The first study led to the development of a model which describes the penetration of a lithospheric electric field from the Earth's surface into the ionosphere. The penetration characteristics strongly depend on the conductivities of the atmosphere and ionosphere.

The magnitude of the ionospheric electric field depends on the value of the Pedersen conductivity. These values are on the order of 0.1 S and 10 S during night- and day-times, respectively. The horizontal electric field in the ionosphere at the DEMETER micro-satellite altitude (~ 800 km) is approximately 10 μV/m during the night-time period (Fig. 2.9).

The electric field penetration is approximately proportional to the atmospheric conductivity near the ground and inversely proportional to the integral ionospheric Pedersen conductivity.

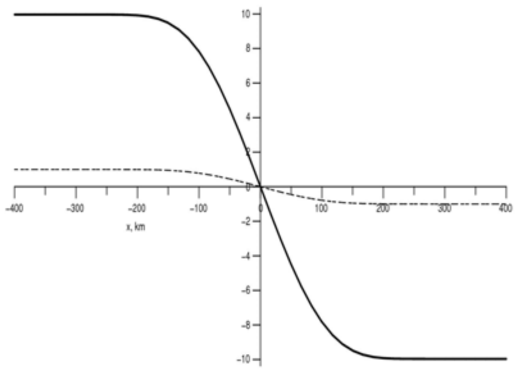

Fig. 2.9: Variation of the ionospheric electric field (expressed in μV/m) over seismic region during night-time (solid line) and day-time (dashed line).

In the second subject a Regional Ionosphere Map (RIM), based on carrier phase measurements, was estimated in the case of the earthquake which occurred in the Patras region (Greece) on 08 June 2008. The determinations were based on GPS data from 16 stations in the surrounding with a resolution of 1°x1°x1h (Fig. 2.10). In order to compare the RIM with the Global Ionosphere Maps produced by CODE the maps had to be interpolated in space and time. The RIMs were analyzed for oscillations and single events. A simulation of the propagation of ionosphere oscillations above the earthquake region indicated that the variations are limited to a cone within a few degrees above the epicenter or up to four pixels in one map.

No significant signal was detected in the given temporal or spatial frame. This might result from the previous smoothing of the signal due to interpolation or wrong gridding. Improvements for detecting an earthquake signal in the ionosphere by removing the daily variations caused by solar interactions might be possible. Another approach is the investigation on irregular grids (locally centered polynomials) which favor nearby GPS stations to the earthquake region.

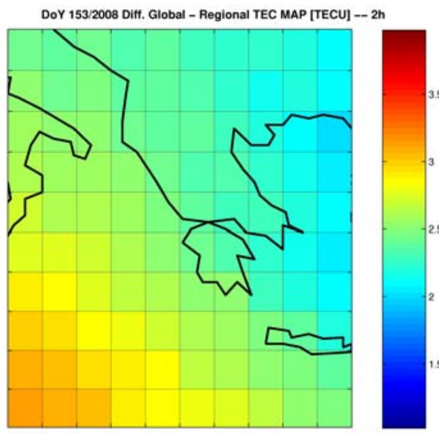

Fig. 2.10: Difference between RIM and GIM maps over Patras region (Greece) on 08 June 2008.

In the third subject, two Very Low Frequency (VLF) stations have been deployed during this year in Graz, one at the Space Research Institute and a second at the Lustbühel Observatory. These VLF stations provide daily observations of the amplitude and the phase of transmitter signals. These regular observations are made within the frame of earthquake prediction in Europe, in particular in the Balkan regions.

3 Near-Earth Space

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, and the magnetosphere itself, where the magnetic field from the Earth's dipole is dominating. Understanding how the magnetic field and particle energies, coming from the sun, enter and are further transported and processed in the magnetosphere, is the general themes of solar-terrestrial physics. The near-Earth space is also an ideal natural laboratory to study the physics of space plasmas with in-situ measurements of the charged particles together with electric and magnetic fields. Research on the near-Earth space at IWF is performed on experimental and theoretical bases and through data analysis.

3.1 Missions

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

Cluster

The four *Cluster* spacecraft are still in operation, taking data while circling the Earth in polar orbits. By now, the spacecraft have made observations in the Earth's magnetotail at several different separation distances of the tetrahedron, varying from 200 km to 10,000 km. Since 2005, modified configurations have been realized to be able to compare large scale (10000 km) with smaller scale processes (20 km – 3000 km). This ESA mission has now officially been extended until the end of 2011. As PI institution of *ASPOC* and holding CoI status for four more instruments, IWF is maintaining the *Austrian Cluster Data Center* and is analyzing *Cluster* data in many studies. The instrument team in IWF is processing and providing data to *Cluster Active Archive (CAA)*, which is a database consisting of all the *Cluster* high resolution data and other allied products.

THEMIS

The NASA mission *THEMIS (Time History of Events and Macroscale Interactions during Substorms)* is designed to explore the origin of magnetic storms and auroral phenomena. *THEMIS* was successfully launched in February 2007 and flies five identical satellites through different regions of the magnetosphere. Since March 2007 scientific data are provided nominally. The spacecraft successfully measured numerous substorms during the first tail science phase between December 2007 and March 2008. As Co-I institution of the *FGM*, IWF is participating in processing and analyzing data. Several of these studies are introduced in the next subsection.

MMS

The purpose of the NASA mission *MMS (Magnetospheric Multiscale)* is to explore the dynamics of the Earth's magnetosphere and its underlying energy transfer processes. Four identically equipped spacecraft are to carry out three-dimensional measurements in the Earth's magnetosphere. *MMS* will determine the small-scale basic plasma processes which transport, accelerate and energize plasmas in thin boundary and current layers – and which control the structure and dynamics of the Earth's magnetosphere. *MMS* is scheduled to be launched in 2014. IWF will take the lead for the spacecraft potential control of the satellites and participate in an electron beam instrument and a magnetometer. In mid 2008 the phase B for these instruments was started, which lasts approximately eight month.

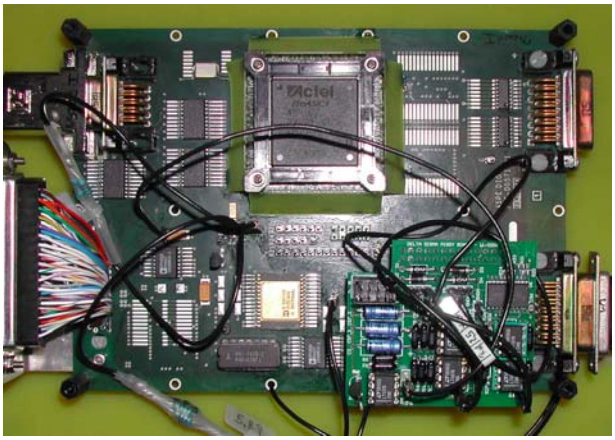

Fig. 3.1: The ASPOC IVM controller.

For the *Active Spacecraft Potential Control (ASPOC)* instruments the controller including software for the instrument and the ground support equipment was developed for an *Interface Verification Model (IVM)*. The main board shown in Fig. 3.1 communicates with the power converter and high voltage converter boards developed by Ruag Austria and the spacecraft interface simulator. It utilises a large Field Programmable Gate Array (RTAX2000S) with embedded processor core developed at IWF to fulfill its control and monitoring tasks.

The complete *IVM* electronics was verified together with ion emitters provided by ARC Seibersdorf. During Phase B the configuration, interfaces, and accommodation on the spacecraft as well as all plans for hardware and software development, testing and product assurance have been defined in co-operation with industry and the project partners in the USA.

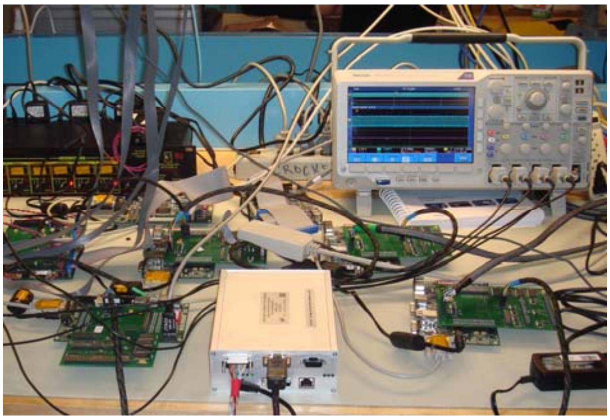

Fig. 3.2: In the centre the GDE Interface Verification Model during the integration at the University of New Hampshire.

IWF contributes to the *Electron Drift Instrument (EDI)* with the *Gun Detector Electronics (GDE,* Fig. 3.2*)* and the electron gun. The *GDE* is developed by Austrian industry in close cooperation with the institute, while the electron gun is entirely developed by IWF.

The *EDI* instrument for *MMS* is based on the *Cluster* development with several improvements. The major change for the gun is the usage of field emission cathodes as electron sources instead of filaments. The latest technology is made from *Carbon Nano Tubes (CNT)*. Extensive testing has been performed with both different types. The *CNT* technology turned out to be very robust, less sensitive to contamination. Even after a long term test over several thousand hours of operation, degradation was not an issue.

The *Digital Flux Gate (DFG)* magnetometer is based on a triaxial fluxgate sensor developed by the University of California, Los Angeles, and a front-end *ASIC* for magnetic field sensors, which has been developed by IWF in co-operation with the Fraunhofer Institute for Integrated Circuits (under an ESA contract) in order to reduce instrument size, mass and power consumption while increasing the radiation tolerance at the same time.

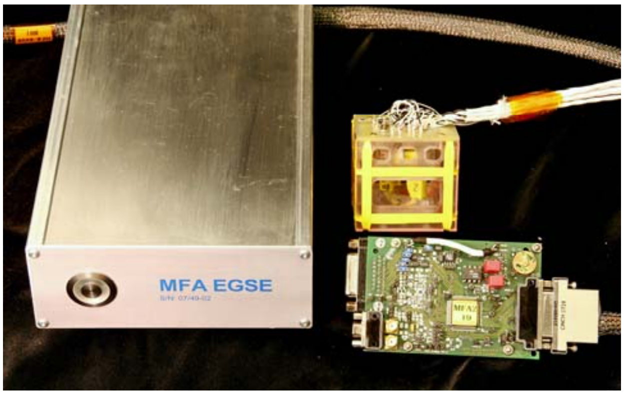

Fig. 3.3: DFG prototype test set-up with Electrical Ground Support Equipment (EGSE), fluxgate sensor from UCLA and MFA-2 based daughter board.

In 2008, the design of the flight *ASIC* was finished and the electrical interfaces have been verified with an *IVM*. Furthermore a prototype setup (see Fig. 3.3) was used for intensive performance tests (e.g. noise density: 5 pT/√Hz at 1Hz and just 3pT/√Hz at 10Hz).

Resonance

Resonance electric field sensors: The aim of the Resonance mission is the investigation of wave-particle interactions and plasma dynamics in the inner magnetosphere of the Earth, with the focus on phenomena occurring along a flux tube of the Earth's magnetic field. Four spacecraft will be launched (~2014) to perform the corresponding measurements and observations. Amongst a variety of instruments and probes several low- and high frequency electric and magnetic sensors will be onboard.

At IWF the electric field sensors are analyzed with a focus on the high-frequency electric sensors (antennas). For that purpose two different methods are applied, an experimental and a numerical one. The former, called rheometry, is essentially an electrolytic tank measurement. The latter consists of the numerical solution of the underlying field equations by means of well-proven electromagnetic computer codes written specifically for this purpose. A metallic scale model of the whole spacecraft including the antennas is built for rheometry (Fig. 3.4).

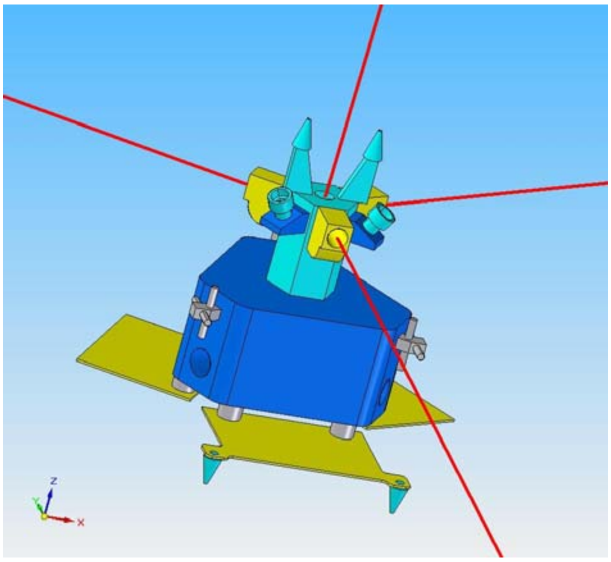

Fig. 3.4: Design of the Resonance spacecraft rheometry model. Antenna booms are indicated by red lines.

This model contains all features of the spacecraft that influence the reception properties of the antennas. The numerical computer simulations are based on corresponding wire grid or patch models. While rheometry gives a reference with regard to modelling accuracy, the computer simulations facilitate the study of the sensor performance in dependence of sensor geometry modifications. First results obtained by wire-grid modelling indicate that the solar panels push the effective axes of the boom antennas nearly 10 degrees away from their respective nominal (physical) directions.

3.2 Physics

High-resolution data are provided by the missions introduced in previous section, such as *Cluster* and *THEMIS,* and also from other near-Earth and solar wind missions. At IWF these various data are analyzed and theoretical models are developed to describe the physical processes responsible for the formation of structures and phenomena in near-Earth space. These studies deal with large-scale interaction between solar surface, solar wind and magnetosphere, meso-scale disturbance in the magnetotail, and the physics of magnetic reconnection.

The shape and origin of magnetic clouds: Magnetic clouds are huge magnetic structures expelled from the Sun during solar eruptions and are able to cause the strongest disturbances in Earth's magnetosphere. How these magnetic clouds, with their well-organized helical magnetic field lines, are created on the Sun, is still to be understood. Furthermore, it is still unclear how the local orientation of the cloud, which controls the response of the Earth's magnetosphere, is determined by nature. Solving these questions is also essential for any viable space weather forecasting.

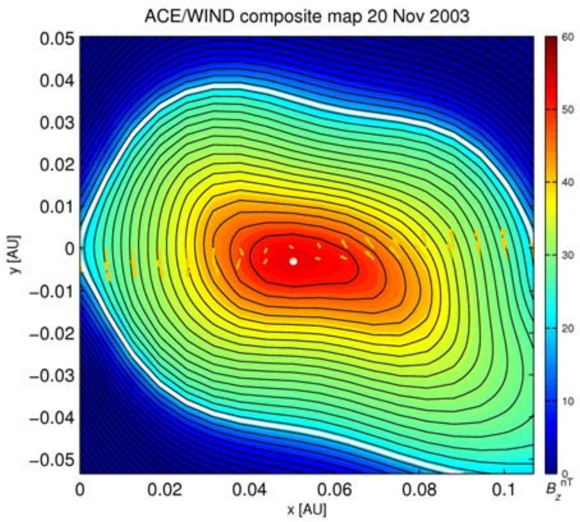

Fig. 3.5: Cross section of a magnetic cloud in the near Earth solar wind. Black contours are magnetic field lines in the paper plane, color coded is the magnetic field pointing out of the paper. The magnetic cloud axis is the white dot.

A study on the origin of the strongest geomagnetic storm of solar cycle 23 in November 2003 was conducted based on solar and interplanetary observations. It was found that the amount of reconnected magnetic field on the Sun closely matches the magnetic field content inside the cloud near Earth, hinting at a formation process during the eruption at the Sun.

Fig. 3.5 shows the reconstructed magnetic cloud from the observation of this storm. The strong tilt of the cloud axis to the ecliptic was explained by an interaction with the also strongly inclined sector boundary en route to Earth. Its high magnetic field strength is due to the cloud hitting Earth directly with its centre.

The solar source of the magnetic cloud: The reconnection flux in the flare on November 18, 2003 fits the poloidal flux in the associated magnetic cloud, observed at the Earth two days later. This supports the picture that magnetic clouds are highly twisted flux ropes and favours the scenario of the flux rope being formed in situ by magnetic reconnection during the flare/CME event.

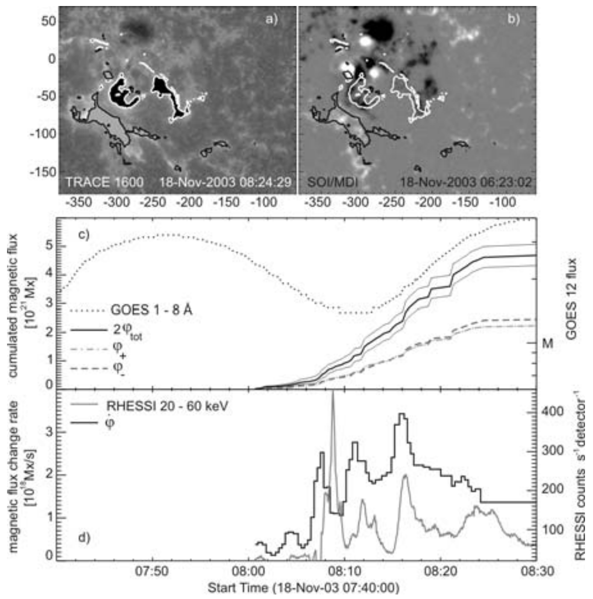

Fig. 3.6: Total flare area, soft X-ray flux, cumulated reconnection flux, observed nonthermal emission, as well as derived magnetic reconnection rate in a two-ribbon flare.

Fig. 3.6 outlines the area that brightened up in the course of the flare. Two separating flare ribbons were observed that swept areas of opposite magnetic polarity (cf. panel b, where the area contours are superimposed on the photospheric magnetogram of the flaring region). Panel c shows the GOES 1-8 Å soft X-ray emission and the cumulated reconnection flux (positive, negative and total). Panel d gives a temporal comparison of the derived magnetic reconnection rate and the observed nonthermal hard X-ray flare emission, which is used as a proxy for the energy release rate in a flare. The peaks in the nonthermal emission are clearly reflected in the magnetic reconnection rate.

Discontinuity-bow shock interaction: Sudden jumps of plasma quantities frequently appear in the solar wind. When a solar wind discontinuity hits the planetary bow shock, it is theoretically expected to be deformed and evolved downstream of the bow shock. On 21 June 2007, *THEMIS and Cluster* located downstream of the Earth's bow shock, observed a discontinuity with a density decrease and a magnetic field increase.

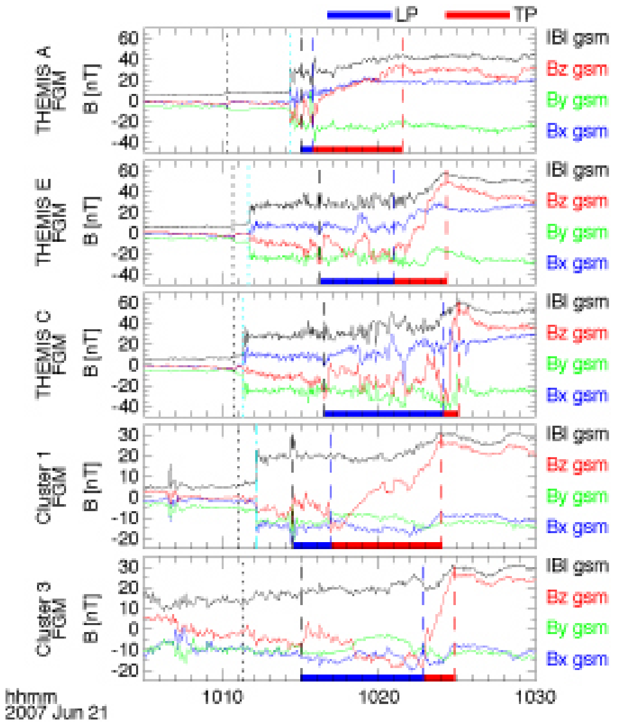

Fig. 3.7: Observations of the magnetic field (B). The blue and red bars denote the leading and trailing parts (LP and TP) of the discontinuity, respectively.

Magnetic field observed by all the spacecraft recorded a similar profile as shown in Fig. 3.7. Yet, the duration of the Leading Part LP (Trailing Part, TP) becomes longer (shorter) as a spacecraft is further away from the bow shock. This suggests that LP is expanding as the discontinuity propagates in the magnetosheath. The expansion is interpreted to be due to sunward motion of the bow shock which was initiated or enhanced by an impact of the discontinuity on the bow shock. TP was being compressed by the faster flow that follows the trailing edge of the discontinuity. The faster flow is likely due to the stopping or slowing down of the bow shock sunward motion. The observations also confirmed deformation of the discontinuity into a concave shape in the magnetosheath. Theoretical analysis and MHD simulations supported the conclusions.

Magnetic field dipolarization and currents: Magnetic field dipolarization is a sudden change of the magnetic field structure, from a stretched configuration (tail-like) toward a dipolar configuration, and is observed to be associated with fast plasma flows or substorms, which are the key energy conversion processes in the magnetotail. Based on observations during a good satellite conjunction with *Cluster* located near the magnetotail current sheet at 16 R_E and *DSP TC1* at 7 R_E in the lobe, a detailed study of magnetic field dipolarization is performed. A dipolarization, observed by *Cluster*, is accompanied by magnetic field variations that are due to a field-aligned current system, which is supported by the electron observations from the *PEACE* instrument. These field aligned currents are simultaneously observed by *TC1* in the magnetotail lobe.

After the dipolarization, the magnetic field returned to be tail-like again, with the plasma flow and magnetic flux transport going tailward. This means that there was local and remote sensing of this inward-outward motion of the magnetic flux and plasma flow in the magnetotail. With *TC1* in the magnetotail lobe, on field lines associated with the dipolarization, there is no evidence of magnetic field dipolarization. However, the plasma flow at *TC1* shows strong correlation with the plasma flow and flux transport measured by *Cluster*. It is therefore proposed that the inward-outward motion of the plasma and field at *Cluster* works as a piston, influencing the plasma motion at the location of *TC1*. A schematic view of this process is given in Fig. 3.8.

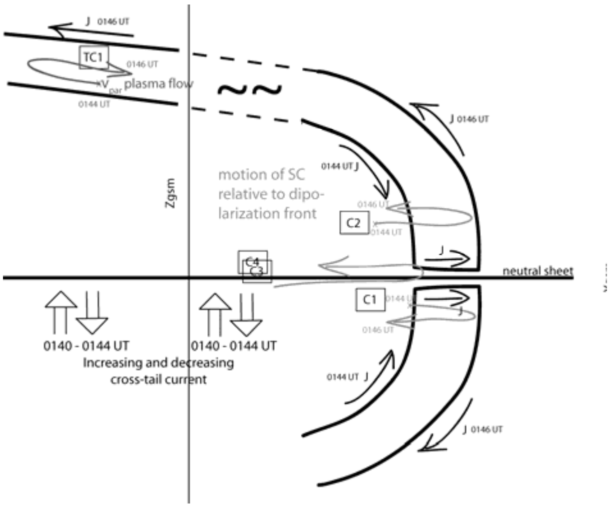

Fig. 3.8: A schematic view of the dipolarization, plasma flows and currents observed by Cluster and Double Star TC1.

Energetic electron acceleration during magnetic reconnection: During magnetic reconnection there is conversion of magnetic energy into kinetic and thermal plasma energy and a change in the magnetic field's topology takes place. Understanding how energetic electrons, with energies much larger than their thermal energy, are accelerated during reconnection is a key issue in plasma physics. Although many models have been proposed to explain such acceleration, very few *in situ* measurements of thin reconection current sheets have been reported, in which energetic electrons and electromagnetic fields were obtained simultaneously. *Cluster* provided such measurements in the magnetotail, in which acceleration of electrons (to 35-127 keV) during two consecutive thin current sheet crossings has been observed within fast flows as shown in Fig. 3.9.

The first crossing corresponds to a small-scale flux rope while the second occurs within the ion diffusion region of reconnection. The measurements show that the largest fluxes are observed in the flux rope (green bar), where electrons are mainly directed perpendicular to the magnetic field and electric field and waves are weak.

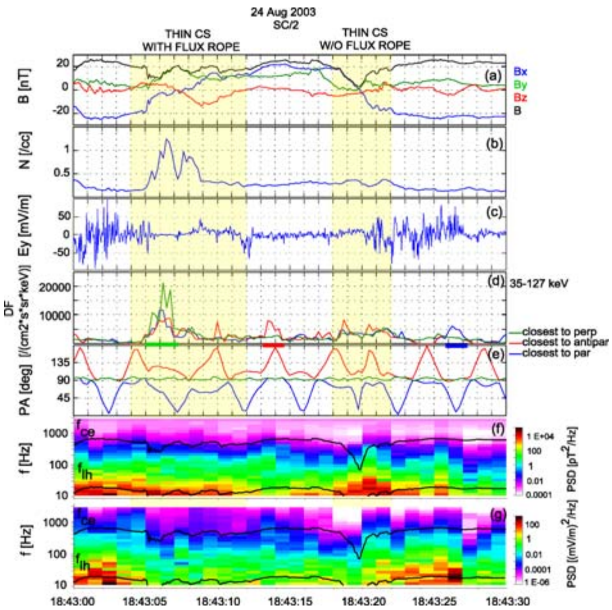

Fig. 3.9: Magnetic and electric fields, waves and energetic electron fluxes during the two crossings (shaded).

Smaller fluxes but harder spectra are observed at magnetic separatrices around the diffusion region (red and blue bars), while the electric field in the diffusion region E_y ~7 mV/m was much larger than typical steady reconnection values. The field-aligned electrons at separatrices are interpreted as being directly accelerated by the reconnection electric field in the diffusion region, whereas the perpendicular electrons as trapped within the flux rope and energized by a combination of betatron acceleration with non-adiabatic pitch-angle scattering. These observations indicate that thin current sheets during unsteady reconnection are important for the acceleration of energetic electrons.

Analytical reconnection model applied to THEMIS: As result of the reconnection process, plasma outflow regions can be identified, over which the magnetic field lines from opposite sides of the cross-tail current sheet are connected. These outflow regions cause bulges in the plasma sheet, leading to a compression of the lobe magnetic field. These Travelling Compression Regions (TCRs) propagate together with the plasma outflow regions and can be identified by typical bipolar variations in the magnetic field and plasma flow components. Using an analytical time-dependent Petschek-type reconnection model, these disturbances can be modelled and information about the location of the reconnection site, the amount of transported reconnected flux and the reconnection rate can be found. Due to their mid-tail location at about 20 to 30 R_E, the outermost *THEMIS* spacecraft *P1* and *P2* represent good observational points in order to apply the theoretical model.

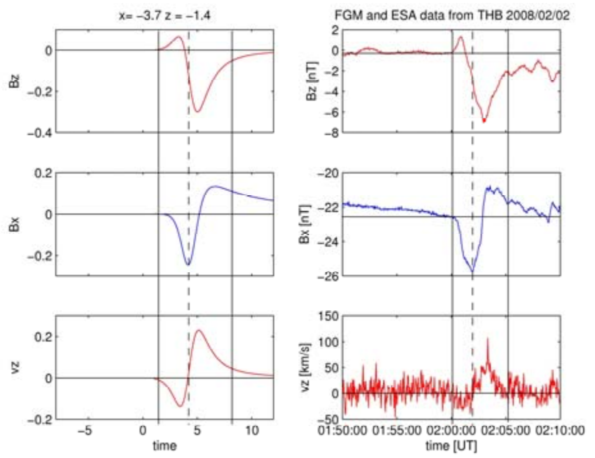

Fig. 3.10: Comparison of modelled reconnection-associated disturbances and observations by THEMIS spacecraft P1.

Fig. 3.10 shows a comparison of modelled disturbances in the magnetic field components B_x, B_z and plasma velocity v_x and observations made by *THEMIS* spacecraft *P1*. As can be seen, the model describes the observed perturbations very well. The model has been applied to several TCRs observed by *THEMIS* during the first tail season in the beginning of 2008. For three events in February 2008 the location of the reconnection site could be found to be at about 16, 17.5 and 18.5 R_E downtail, respectively, and the amount of reconnected flux to be in the order of 10^8 nTm. For a specific event, the reconnection rate was recovered to be highly time-varying with a peak value of 1.1 mV/m.

Estimation of linear wave polarization of the Auroral Kilometric Radiation: There is general agreement that the polarization of the terrestrial auroral kilometric radiation (AKR) is totally circular with dominating right-hand extraordinary mode and some admixture of the left-hand ordinary mode. Results of first statistical estimations of the AKR polarization parameters in the wave plane are presented. For a statistical study 198 AKR events recorded by Interball-2/Polrad triaxial polarimeter have been selected.

Statistical estimations show that the degree of the linear polarization of the AKR is small at a level of 0.07 ± 0.09 (Fig. 3.11). The total polarization degree of the AKR is estimated at a high level of 0.90 ± 0.08. Though the uncertainty of the determined parameters of the circular and total polarization degree are too large to conclude on the presence of some linear polarized or unpolarized components in AKR, the case study of a powerful AKR emission and detailed analysis of the errors of measurement allow us to suppose that AKR is 100 % circularly polarized with the linear polarization practically absent. Estimation of smaller amount of the unpolarized component observed for the weaker AKR is caused by the non-negligible contribution of the non-AKR background emissions like onboard interferences, instrumental noise and galactic background.

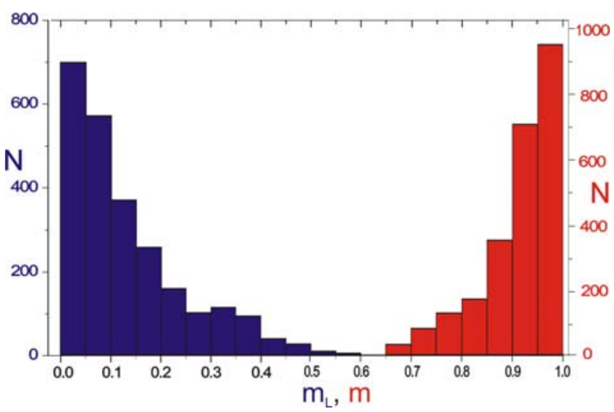

Fig. 3.11: Occurrence distribution of degree of linear polarization (mL, blue histogram) and total degree of AKR polarization (m, red histogram).

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 Solar Wind

Solar Type III-like bursts: For the first time “fast” Type III bursts (Type III-like bursts) at frequencies 10-30 MHz (Fig. 4.1) were observed with the giant radio telescope UTR-2. In the past, such bursts have been recorded only at frequencies above 300 MHz. The present investigation comprises more than 1000 bursts during 5 radio storms, registered in the years 2002-2004.

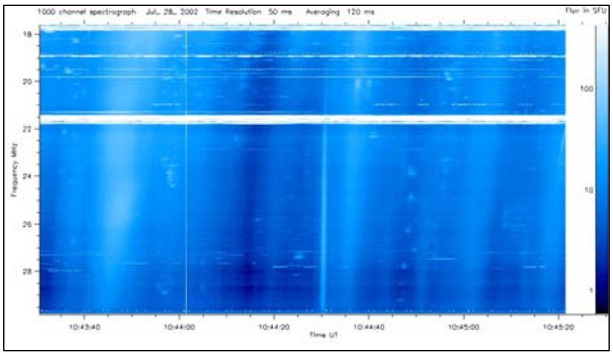

Fig. 4.1: Type III-like burst (10:44:30 UT) against a background of solar Type III burst storm.

Type III-like bursts are different from the usual Type III bursts with regard to their frequency drift rates and durations. Drift rates of these bursts may exceed the standard Type III bursts drift rate by a factor of 10, and their duration of 1 - 2 s is 4 times smaller than that of Type III bursts. As shown in Fig. 4.1 these fast solar Type III-like bursts are observed during day times, when the burst associated active region is located near the central meridian of the Sun. It is argued that the huge frequency drift rate of these bursts is connected with the radio source velocity, which is almost equal to the group velocity of the emitted electromagnetic waves.

Mirror mode structures in the solar wind: Venus Express, the first European spacecraft to Venus, is a planetary mission with its main scientific objective being a comprehensive investigation of Venus’s atmosphere and plasma environment. Due to the absence of any significant intrinsic magnetic field, the interaction of the solar wind with Venus is limited to a rather small volume in space. Thus *Venus Express* spends its majority orbital time, typically 20 to 22 hours per day, in the solar wind and it provides us an excellent opportunity to study space weather effects and solar wind properties at 0.72 AU.

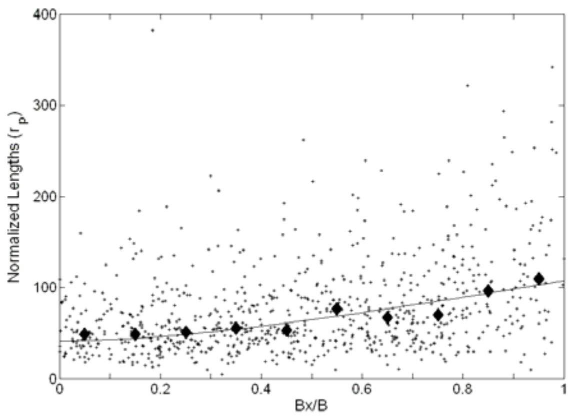

Fig. 4.2: Dependence of the normalized lengths of the mirror mode waves on the orientation of the magnetic field to the solar wind flow.

The mirror mode structures in the solar wind have been investigated. Their length in kilometre scale, or its normalized counterpart such as length in gyroradii, has been used to characterize the size of magnetic holes in previous studies. However the geometry of the mirror mode structures, like any structure in a plasma, is controlled by the magnetic field direction. An attempt is made, for the first time, to determine the characteristic size and shape of the mirror mode structures. It is found that the mirror mode structure in the solar wind is elongated along the field direction (see Fig. 4.2). The length along the field is about 3 times of that across the field.

4.2 Mercury

Mercury is the planet nearest to the Sun. It is a significantly dense planet, which suggests a large iron core and possesses a weak global magnetic field. The ESA/JAXA mission *BepiColombo* to Mercury will explore the planet in detail. Its launch is scheduled for 2014.

BepiColombo

BepiColombo is the first big joint European-Japanese satellite project. For the first time, two spacecraft – *Magnetospheric (MMO)* and *Planetary Orbiter (MPO)* – will be simultaneously flying to the innermost planet.

IWF plays a major role in developing the magnetometers for the two spacecraft: it is the lead institution for the magnetometer aboard the Japanese *MMO (MERMAG-M);* for the *MPO* magnetometer *(MERMAG-P)* IWF is responsible for the overall technical management.

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

In 2008, the preliminary designs of the magnetometers and the *PICAM* detector were finished. Special attention was paid to the thermal testing and modelling of the magnetometer sensors and the sensor head of *PICAM*. For example, the magnetometer sensor was successfully tested up to its maximum survival temperature of 200 °C (see Fig. 4.3) and the design of its thermal protection was verified using the 10-solar constant test facility at ISAS in Japan.

Fig. 4.3: Mounting of the MERMAG sensor in the magnetically shielded glas Dewar of the IWF test facility.

Physics

Mercury's exosphere: In a recent study the Na exosphere observations made during Mercury's transit of May 7, 2003 were compared with the results of numerical simulations. The observations show a Na maximum emission near the polar areas, with north prevalence, and the presence of a dawn-dusk asymmetry. The study indicates that this distribution is a resulting effect of two connected processes: the solar wind proton precipitation causing chemical alteration of the surface, freeing the sodium atoms from its bounds in the crystalline structure on the surface, and the subsequent photon-stimulated and thermal desorption of the sodium atoms. It was found that the velocity distribution of photon desorbed Na can explain the observed exosphere population, thermal desorption seems to play a minor role only causing a smearing at the locations where Na atoms are released on the dayside.

Additionally to the reproduction of Mercury's Na exosphere during the transit at May 07, 2003, the impact of multiply charged solar wind O^{7+} and Fe^{9+} ions on the surface of Mercury was also studied, by using a quasi-neutral hybrid model. The simulations showed that heavy O^{7+} and Fe^{9+} ions impact on the surface of Mercury non-homogenously, the highest flux being near the magnetic cusps, much as in the case of impacting solar wind protons (Fig. 4.4). However, in contrast to protons, the analyzed heavy ions do not create high ion impact flux regions near the open-closed magnetic field line boundary. Dawn-dusk asymmetry and the total ion impact flux were each found to increase with respect to the increasing mass per charge ratio for ions, suggesting that the Hermean magnetic field acts as a mass spectrometer for solar wind ions.

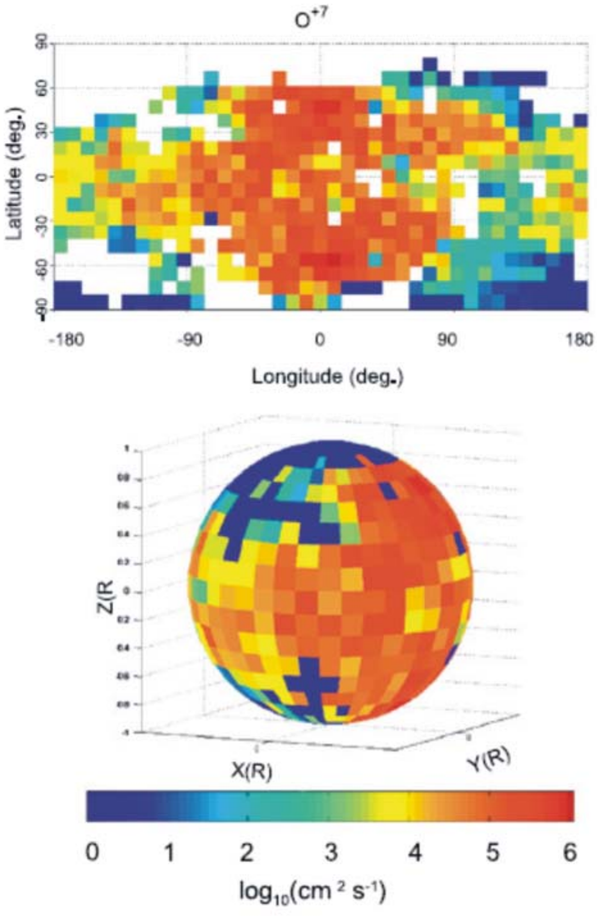

Fig. 4.4: The particle flux of impacting solar wind O^{7+} ions on the surface of Mercury. The flux of impacting ions is presented in a 2D altitude-longitude map.

4.3 Venus

The close proximity of Venus to Earth in 2006 opened a great opportunity to send a spacecraft over to investigate our neighbouring planet in detail. IWF has build the magnetometer for this mission, *Venus Express*, and has taken the lead into the cleaning of the magnetic field data. The spacecraft is not magnetically clean, and therefore disturbances from the spacecraft in the data are very strong. The data are now well calibrated.

Mission

Venus Express: The solar wind interacts directly with the atmosphere of Venus in contrast to the situation at the Earth where the planetary magnetic field protects the upper atmosphere. Still the Venus atmosphere is partially shielded by an induced magnetic field and the effecitiveness of the shield needs to be understood. The effectiveness is expected to vary with solar activity but current understanding of the solar wind interaction with Venus is derived from measurements at solar maximum. Venus Express, with improved instrumentation, a different orbital trajectory, and observations at solar minimum, enables the extension of understanding the evolution of the Venus atmosphere caused by the solar wind interaction.

Physics

Induced magnetosphere: It is well known that the solar wind interaction with a planet produces a magnetosphere-like structure near the planet with common features such as a bow shock, magnetosheath, magnetotail, and boundary layers. These magnetosphere-like structures are found at all planets in the solar system regardless if the planet has an intrinsic global magnetic field or not. In the case of planets like Mercury, Earth, Jupiter, Saturn, Uranus and Neptune, a magnetosphere is formed by the interaction of the solar wind with the planet's large intrinsic magnetic field.

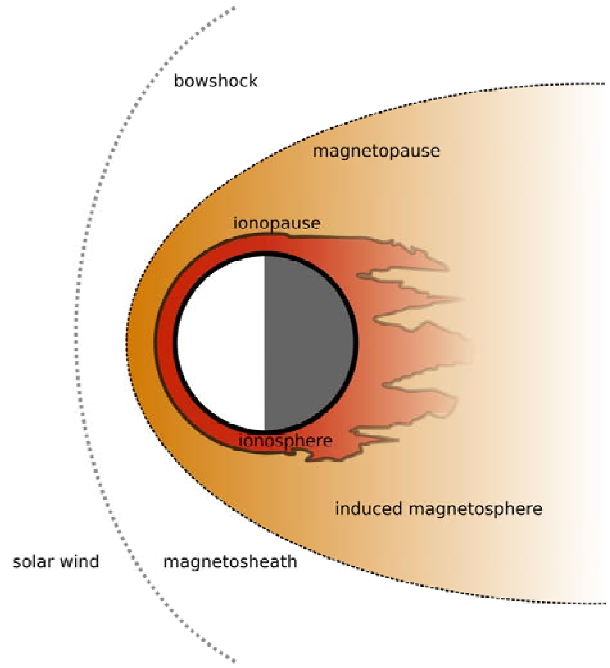

Fig. 4.5: Induced magnetosphere of Venus

For a planet like Venus or Mars, which has no global intrinsic magnetic field but with an atmosphere, an induced magnetosphere is created by the solar wind interaction with the highly conducting ionosphere. The induced magnetosphere is therefore analogous to the magnetosphere of an intrinsically magnetized planet, but occupies a smaller volume.

Fig. 4.5 illustrates the current understanding of Venus's induced magnetosphere and its boundaries. The outer boundary of the induced magnetosphere is the magnetopause and the inner boundary is the ionopause. The dayside portion of the induced magnetosphere is often called the magnetic barrier and the nightside portion of the induced magnetosphere the magnetotail.

Unusually distant bow shock: Understanding the response of the planetary environment to extreme solar conditions is crucial not only in space weather studies, but also in reconstructing the evolution of planetary atmospheres. On September 10-11, 2006 the *Venus Express* magnetometer detected an unusually strong Interplanetary Coronal Mass Ejection (ICME) event with an average field about 2 times higher than that for a typical ICME at 0.72 AU. While the effective obstacle to the solar wind is compressed to a smaller dimension during this ICME event, the bow shock expands far upstream of its nominal location. The observed shocks are weak and appear very dynamic. The location of shock crossing can be found all along the *Venus Express* trajectory which has an apocenter of 12 R_V, see Fig. 4.6. This is attributed to the unusual distant bow shock location as an effect of the extremely low Mach number during the ICME.

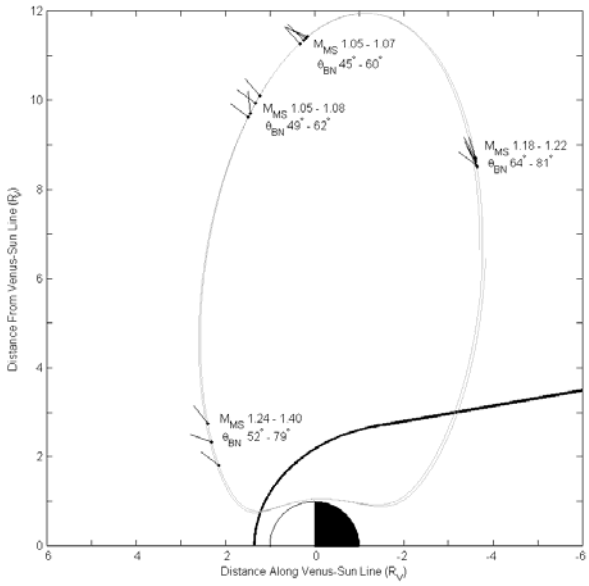

Fig. 4.6: Venus Express trajectories during the September 10 and 11, 2006, with mean bow shock. Small dots display the distant bow shock events during ICME passage. Short lines are the shock normal determined from coplanarity.

Upstream proton cyclotron waves: The escape of particles from planetary atmospheres, especially hydrogen, is an important key towards understanding the atmospheric composition and evolution over the lifetime of the solar system. For an unmagnetized planet such as Venus or Mars, when the neutral exosphere extends into the flowing solar wind plasma, loss of pick-up ions upstream of the bow shock can play a significant role in the escape process. Cyclotron waves from pickup of planetary hydrogen in the solar wind have been previously observed at Mars and other solar system bodies. At Venus, they were reported within the magnetosheath, but not upstream of the bow shock. The magnetometer aboard the *Venus Express* spacecraft indicates waves at the proton cyclotron frequency in the solar wind (see Fig. 4.7); this provides direct evidence that the solar wind is removing hydrogen from the planetary exosphere.

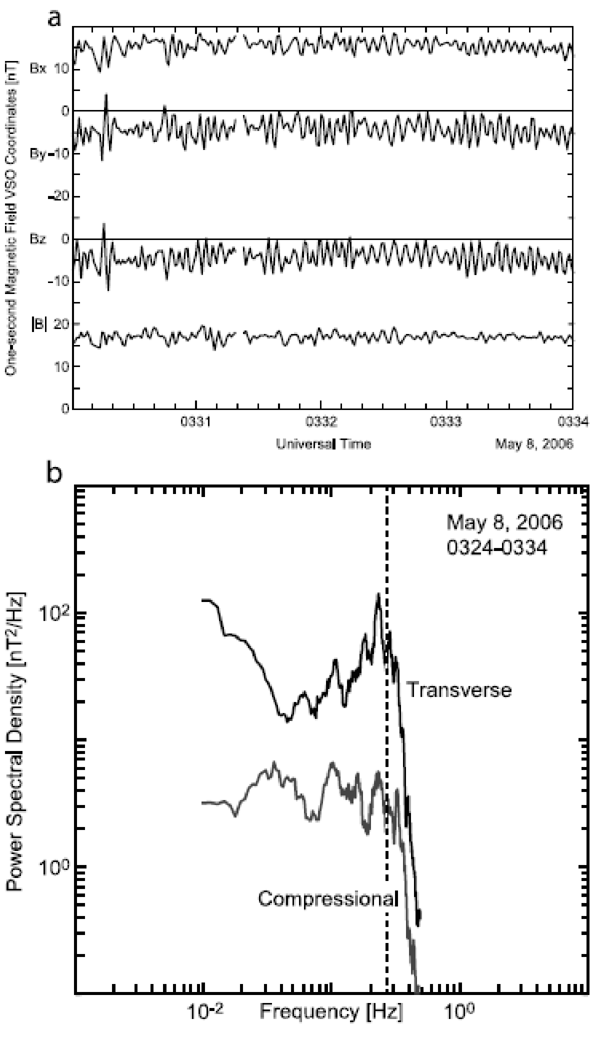

Fig. 4.7: Venus Express magnetometer data (top panel) showing ion cyclotron waves and a power spectrum (bottom panel) showing the peak of the cyclotron waves just below the proton cyclotron frequency.

4.4 Jupiter

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

Jupiter radio emissions: In dynamic spectra Jupiter millisecond short (S-)bursts exhibit themselves in complicated forms and are associated in randomly-spaced groups within which their spacing is approximately periodic. Attention was drawn to the correlation properties of S-bursts as an indicator of their hidden regularity. Thus the correlation coefficient was calculated between S-burst emission in all available frequency channels with different time shift and optimal resolution of 2 ms to 6 ms. The advantage of the correlation approach is the simple and effective extraction of regularity from chaos.

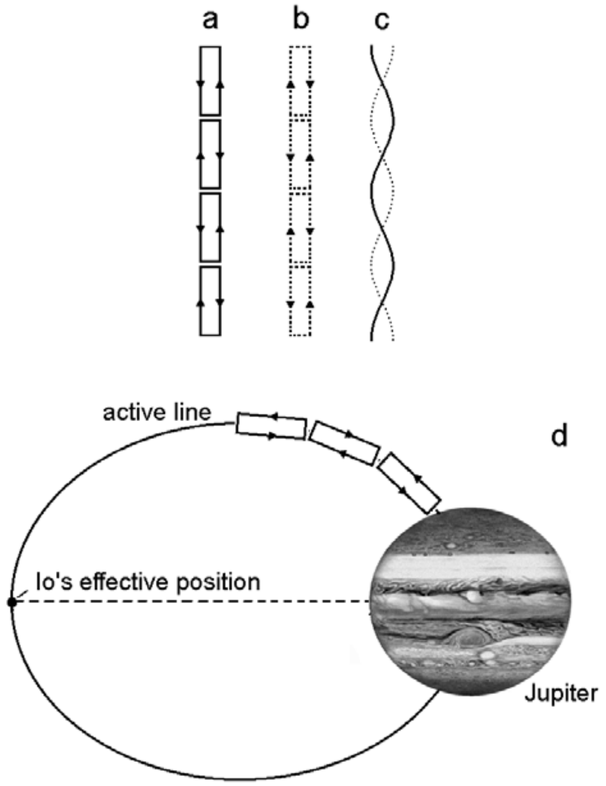

Fig. 4.8: Idealized scheme showing a standing Alfvén wave in the Io flux tube which. The chain of electric current loops (a,b) are associated with the transverse distortions of the active magnetic line (c). Such pairs of anti-parallel electrical currents near the wave nodes can incline the narrow radio beams to modulate the observation of S-bursts on the Earth. The visualization of the current loops is shown in (d).

As a result, the hidden regularity, unknown before, is found in the S-burst quasi-chaos as the double correlation pattern in form of two interlacing stripes of correlated and anti-correlated emissions. Such stable and significant correlation patterns correspond to the double radio source with anti-correlated components. These components can be identified with the pair of parallel but anti-directed electric currents of the standing Alfvén wave on the radio source magnetic shell (Fig. 4.8). The extreme frequency drift rate of S-bursts (i.e. the parallel velocity of radio wave emitting electrons) is associated with the nodes of the standing Alfvén wave as well as with S-burst bands at quasi-constant frequencies.

4.5 Saturn

In 2008 the *Cassini* orbiter has continued its investigation of the Saturnian system. Besides more Titan flybys, *Cassini* made several flybys at various other moons like Enceladus and Tethys. The mission has been extended for another 2 years.

Relations between SKR and solar wind activity: The intense auroral non-thermal Saturnian Kilometric Radiation (SKR) is strongly influenced by external forces, i.e. the solar wind and in particular the solar wind ram pressure. Recent *Cassini* observations essentially confirmed these relations. The strong correlation of SKR with the solar wind on the one hand, and the relatively poor solar wind plasma measurements of *Cassini* near Saturn on the other hand, led to the question on how SKR observations can be used for remote analysis of the near Saturn plasma. The data collected by *Cassini/RPWS* and *CAPS* and *Ulysses/SWOOPS* experiments during the year 2004 have been analyzed.

The periods lacking solar wind measurements from *Cassini* are substituted by *Ulysses* solar wind data which have been propagated over ~ 4 AU, applying ballistic and magneto-hydrodynamic propagation models. Cross correlation studies between radio emissions integrated over the SKR frequency range and solar wind bulk velocity as well as solar wind ram pressure (Fig. 4.9) showed that *Cassini* solar wind data can be supplemented by *Ulysses* measurements in a way that *Ulysses* solar wind observations may also be considered as a good predictor of the SKR activity. This is possible for specific periods of time, particularly when both *Ulysses* and Saturn are within a limited azimuthal sector. On the basis of a relatively small data set there is no reliable possibility however to derive the variation of solar wind parameters from SKR intensity profiles.

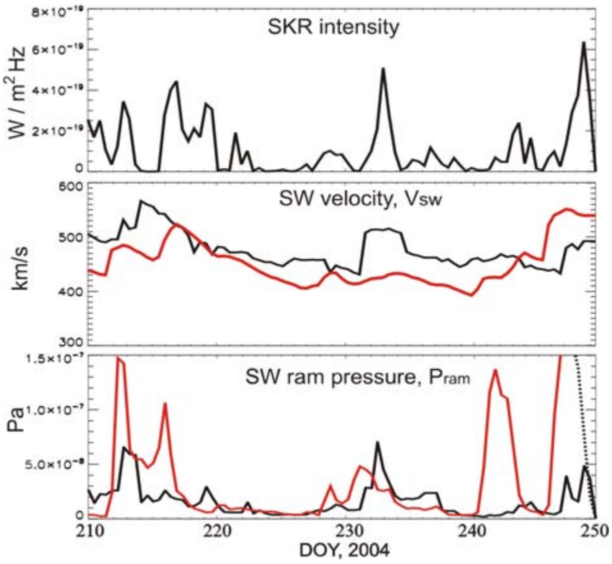

Fig. 4.9: Correlation analysis for SKR, SW bulk velocity and SW ram pressure measured by Cassini (black lines) and Ulysses (red lines). The Ulysses SW measurements have been propagated to Cassini orbit with an MHD model.

4.6 Comets

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

Both the spacecraft and the payload are still in good health. Another check-out of the payload and the spacecraft with real-time telemetry reception and commanding of critical activities was carried out in July 2008. This check-out was accompanied by a series of tests to identify any mutual interference between instruments. No major problems were found. It was the last but one opportunity before the hibernation phase in 2011 to 2014 to prepare the payload for the near-comet observations soon thereafter.

The highlight of this year was the first fly-by of an Asteroid (2867 Steins) in September where most of the instruments including the magnetometer took data. All *MIDAS* data sets for 2007 and earlier have been ingested into the mission's archive.

4.7 Exoplanets

CoRoT completed successfully the first season of long-time planet hunting last October. So far 4 Jupiter-type gas giants were officially confirmed via ground-based follow-up observations. About 250 transit-like-signals in each of the four observing sessions per year were picked up at all the targets accessible by *CoRoT*.

The evolution of close-in exoplanets strongly depends on the detailed X-ray / EUV luminosity history of their host stars, which varies over several orders of magnitude. Stars located in the high-energy tail of the luminosity distribution can evaporate most of these planets within 0.5 AU. These research activities are subject to several assumptions that will be verified with future space and ground based observations and more advanced modeling.

Another study explained the HST-observed transit-associated Ly-α hydrogen cloud absorption around the exoplanet HD 209458b which can be explained by the interaction between the exosphere and the stellar wind, and that radiation pressure alone cannot explain the observations. As the stellar wind protons are the source of the observed energetic neutral atoms (Fig. 4.10), this provides a new way of probing stellar wind conditions.

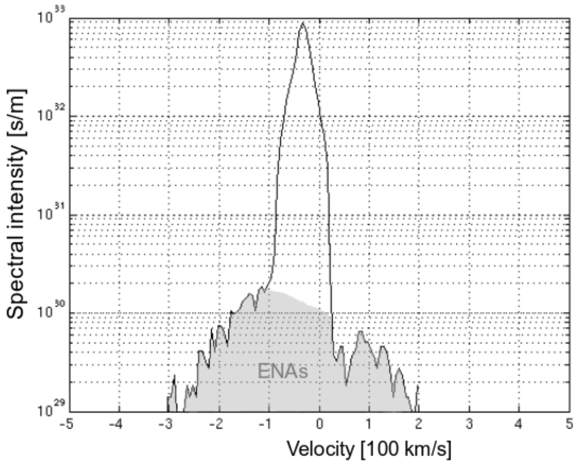

Fig. 4.10: The part of the distribution that is due to ENAs is shaded. Varying the stellar wind temperature and velocity in the model confirms that the width of this part of the distribution is proportional to the temperature of the stellar wind.

5 Engineering & Testing

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

5.1 Test Facilities

Vacuum Chambers

There are several vacuum chambers available at IWF for testing equipment and doing experiments.

Small Vacuum Chamber: A cylindrical vacuum chamber (160 mm diameter, 300 mm length) for small electronic components or printed circuit boards. A pressure level of 10^{-10} mbar can be achieved.

Large Vacuum Chamber: A large size vacuum chamber with a horizontal cylindrical configuration with a vacuum chamber pressure of 10^{-7} mbar. The cylinder has a diameter of 650 mm and a length of 1650 mm and is magnetically shielded. A target manipulator inside the chamber allows for rotation of the target around three mutually independent perpendicular axes, and the ability of baking structures and components to outgas volatiles through a heater placed symmetrically around the circumference.

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

Thermal Vacuum Chamber: A thermal vacuum chamber which has a turbo pump allowing for a quick change-over of components, a temperature range between -90 °C up to +140 °C at a pressure level of 10^{-6} mbar and a maximum experiment diameter of 410 mm and a maximum experiment height of 320 mm.

Fig. 5.1: Temperature Test Chamber.

Temperature Test Chamber: The temperature test chamber (Fig. 5.1) allows verifying the resistance of the electronic components and circuits to all temperature conditions that occur under natural conditions. The chamber has a test space of 190 litres and is equipped with a powerful 32-bit control and communication system. The temperature ranges from -40 °C to +180 °C.

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

Other Facilities

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

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

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

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

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

Temperature Test Facility: Magnetic field sensors can be tested over an extended temperature range from -170 °C up to +220 °C in a low field and low noise environment and a magnetic field of up to 100000 nT can be applied to the sensor.

5.2 New Instruments

Coupled Dark State Magnetometer (CDSM): In cooperation with the Graz University of Technology, IWF is prototyping a Coupled Dark State Magnetometer (CDSM, Fig. 5.2). IWF is responsible for the low frequency sensor electronics and the digital data processing.

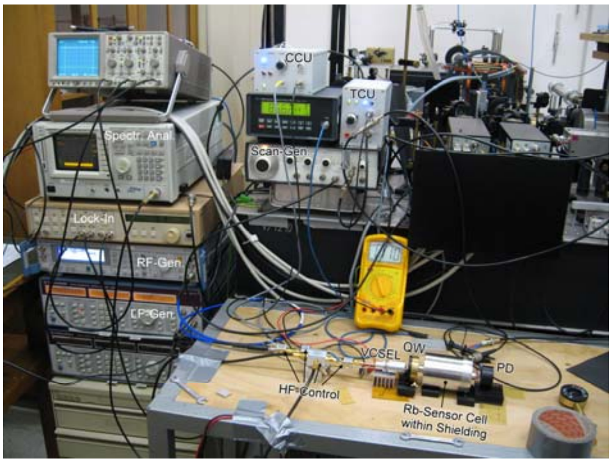

Fig. 5.2: The currently used CDSM measurement setup in the laser laboratory of TUG.

The measurement principle of the Coupled Dark State Magnetometer is based on two-photon-spectroscopy of free alkali atoms using a multi chromatic laser field. This way, the measurement of the scalar magnetic field is reduced to a frequency measurement which can be converted to magnetic field by applying the so called Breit-Rabi formula.

Thermal sensor for Regolith: The development of thermal sensors suitable for heat conductivity and heat flux measurements on future lunar Lander missions was pursued. For this purpose several measurement series with standard calibration materials as well as with various analog materials were performed. A particular topic was to evaluate the dependence of the thermal conductivity on the grain size under vacuum conditions in granular materials, as well as on the environmental gas pressure. A summary of the results obtained for glass beads in various size ranges is shown in Fig. 5.3. The dependence of the thermal conductivity on the grain size was found to be nearly linear in the pressure range investigated. In order to allow also the investigation of more coarse-grained materials, a cylindrically shaped sensor with larger dimensions was developed and built in cooperation with the Dutch company *Hukseflux*.

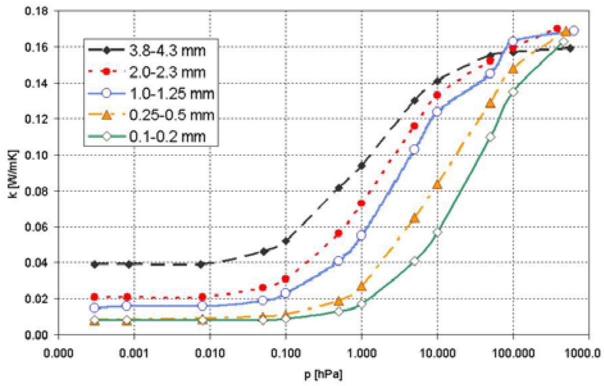

Fig. 5.3: Dependence of the thermal conductivity of glass beads on gas pressure and grain size.

Melting Probe: The melting probe development project which is performed in the frame of an ESA contract entered its final phase. Based on the insights gained with the first prototype, an improved model was designed and is currently being built.

HP³ Permittivity Probe: As a follow up of the previous work on the mutual impedance of Martian soil, IWF is participating in the *HP³* Instrument developed for *ExoMars*.The permittivity probe (HP3-PP) sensor will characterize the electrical properties of the surrounding soil up to a depth of five meters and 360° azimuth. With this sensor layers and inclusions below the surface will be detected and also the water content of the soil can be determined. Additionally the permittivity and conductivity of the material may serve as a ground reference point for orbiting "Ground Penetrating Radar" Instruments. IWF is responsible for the development of the PP, namely the front end electronics and the testing and calibration of the integrated sensor (Fig. 5.4).

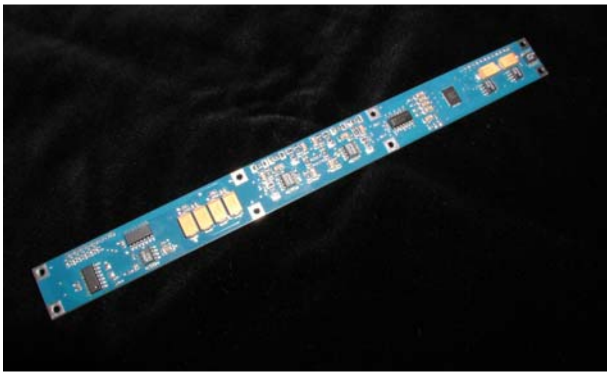

Fig. 5.4: HP³ permittivity probe breadboard electronics.

Antennas in plasmas: For a correct interpretation of the data of a space-born radio experiment the reception properties of the antenna have to be known with high accuracy. There are certain parameters which can be used to describe antenna behavior, like the effective length vectors, antenna impedances and radiation patterns. Unfortunately, the real behavior of the antennas is different than one would predict for the geometric configuration of the antennas. Due to the influence of the spacecraft body and the influence of the surrounding space plasma. Two different methods were considered to include the plasma effect in the numerical calculations. One of the methods is to manipulate permittivity, which is part of the governing equations which determine the behavior of the antenna.

The permittivity tensor can have several different forms. The whole model of the plasma can be included in this entity and when the set of equations can be solved, plasma effects are automatically included in the results. The second method is to only include the plasma sheath in the computations, which is created by the interaction of the plasma with the conducting skin of the spacecraft and the antennas. Even though the frequencies of interest were well above the plasma resonance frequencies, it was found that the inclusion of the plasma effect lead to notable changes of the reception behavior of the spacecraft antennas.

6 Publications & Talks

6.1 Refereed Articles

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7 Teaching & Workshops

7.1 Lecturing

IWF members are actively engaged in teaching at three universities. In summer 2008 and in the current winter term 2008/2009 the following lectures are given:

KFU Graz

Hydrodynamics (Biernat)

Solar-Terrestrial Relationships, incl. Space Weather (Biernat)

Solar Wind – Magnetospheres – Ionospheres – Modelling (Biernat)

Special Lectures Theoretical Physics (Biernat):

- Plasma Physics – Basics
- Plasma Physics – Transport
- Plasma Physics – Waves and Instabilities

Upper Atmosphere 1: Aeronomy of the Earth and the Planets (Biernat)

Acquisition and Calibration of Scientific Data (Kargl)

Measuring Methods in Space Physics and Aeronomy (Kargl, Rucker)

Introduction to Planetology (Kömle)

Gravity, Figure, Seismics and Structure of the Earth (Kömle)

Spectral Analysis (Macher)

Selected Topics of Space Physics and Aeronomy: Data Processing in Geophysics and Space Physics (Nakamura)

Solar System Plasma Physics (Nakamura, Rukker)

Introduction to Plasma Physics (Rucker)

Magnetism and the Magnetic Field of the Earth (Rucker)

Measuring Methods in Space Physics and Aeronomy (Rucker)

Planetary Magnetospheres (Rucker)

Selected Topics of Geophysics: Cosmic Rays (Rucker)

STEREO Hinode: Instruments and Data Reduction of Current Solar Physics Research Satellites (Temmer)

TU Graz

Space Plasma Physics (Baumjohann)

Advanced Space Plasma Physics (Baumjohann)

Dynamic Satellite Geodesy (Hausleitner et al.)

Signal Processor Techniques (Magnes)

Antennas and Wave Propagation (Riedler)

Measurement of Planetary and Interplanetary Magnetic Fields (Schwingenschuh)

Active Plasma Experiments in Space (Torkar)

JKU Linz

Mathematics for Computer Scientists in Economics II+I (Hausleitner)

Advanced Course

The two-years post-graduate university course Space Sciences in cooperation with both KFU Graz and TU Graz leads to the internationally acknowledged Master of Science (MSc) “Space Sciences.” Several members of IWF are lecturers of this inter-university course led by H.O. Rucker, which started in 2007 and continued in 2008.

7.2 Theses

Besides lecturing, members of the institute are supervising Diploma, Master and Doctoral Theses. In 2008, the following theses have been completed:

Herper, J.: Mercury´s environment under extreme solar conditions: an approach towards CME and SEP statistics, Diploma Thesis, Karl-Franzens-Universität Graz, 127 p., 2008.

Kiehas, S.: Transport of reconnected magnetic flux and magnetic energy due to magnetotail reconnection, Doctoral Thesis, Karl-Franzens-Universität Graz, 160 p., 2008.

Kucharski, D.: Spin parameters determination of LAGEOS-1 from laser observations, Doctoral Thesis, Space Research Center, Polish Academy of Sciences, 106 p., 2008.

Leitner, M.: Evolution of interplanetary magnetic clouds: conclusions from a force-free magnetic field model, Doctoral Thesis, Karl-Franzens-Universität Graz, 129 p., 2008.

Maierhofer, W.: Wavelet analysis of stellar occultation data for the study of planetary atmospheres, Master Thesis, Karl-Franzens-Universität Graz, 87 p., 2008.

Treffer, M.: Cryovolcanic processes in the solar system, Doctoral Thesis, Karl-Franzens-Universität Graz, 120 p., 2008.

7.3 Meetings

From 5 to 9 May the International Conference on Substorms, ICS9 meeting, organized by Rumi Nakamura, was held at Schloss Seggau, with over 100 participants (see Fig. 7.1) from all over the world.

In addition Boudjada, Kargl, Khodachenko, Kirchner, Lammer, Nakamura, Rucker, Stangl and Zhang organized 11 sessions at large international conferences.

Besides several project meetings with less than ten participants, one large meeting with international participation was organized at or by IWF/ÖAW in 2008: from 28 to 30 April a PICAM Team meeting was held at IWF with 15 participants from 5 different countries.

Fig. 7.1: The group picture of the ICS9 participants in the court yard of Schloss Seggau.

7.4 Awards and Recognition

In 2008 Christian Möstl (see Fig. 7.2) won the "JungforscherInnenpreis." He was also awarded the EGU "Young Scientist Outstanding Poster Presentation" award at the EGU General Assembly in Vienna, April 2008.

Fig. 7.2: The "JungforscherInnenpreis" winners, with Christian Möstl in the middle of the back row.

Furthermore, Rumi Nakamura has been elected as a corresponding member of the International Academy of Astronautics, while Helmut O. Rucker became deputy head of the Commission of Astronomy of the ÖAW.

7.5 Public Outreach

During summer three highschool students had the opportunity to do an internship at IWF in the framework of "Forschung macht Schule" funded by the the Austrian Research Promotion Agency (FFG). The intention was to find hidden talents and to spark incentives towards a scientific-technical career choice by integrating young people in current research activities.

On 8 November the "Lange Nacht der Forschung" took place in Austria from sunset until midnight. On this occasion IWF organized an event together with the other institutes of FZG. 600 enthusiasts from eight to eighty years old visited our research center (Fig. 7.3). The entertaining program of IWF included experiments, computer animations, movie shows, guided tours through the labs and an exhibition.

Fig. 7.3: 3D glasses during the "Lange Nacht der Forschung" to observe the solar wind interaction with the Earth's magnetosphere.

Furthermore, several classes and groups visited IWF throughout the year. During guided tours through the laboratories (Fig. 7.4) members of the institute have imparted the fascination of space to possible future scientists.

Fig. 7.4: One of the school classes visiting the surface physics laboratory.

The *Graz in Space, Summer University* (Fig. 7.5), was held at the Karl-Franz University, and discussed various topic in contemporary space physics.

Fig 7.5: Graz in Space Summer University.

8 Personnel

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

As of 31 December 2008
E: Experimental Space Research; P: Extraterrestrial Physics; S: Satellite Geodesy; A: Administration; BEV: Federal Office for Metrology and Surveying; BMWF: Federal Ministry for Science and Research