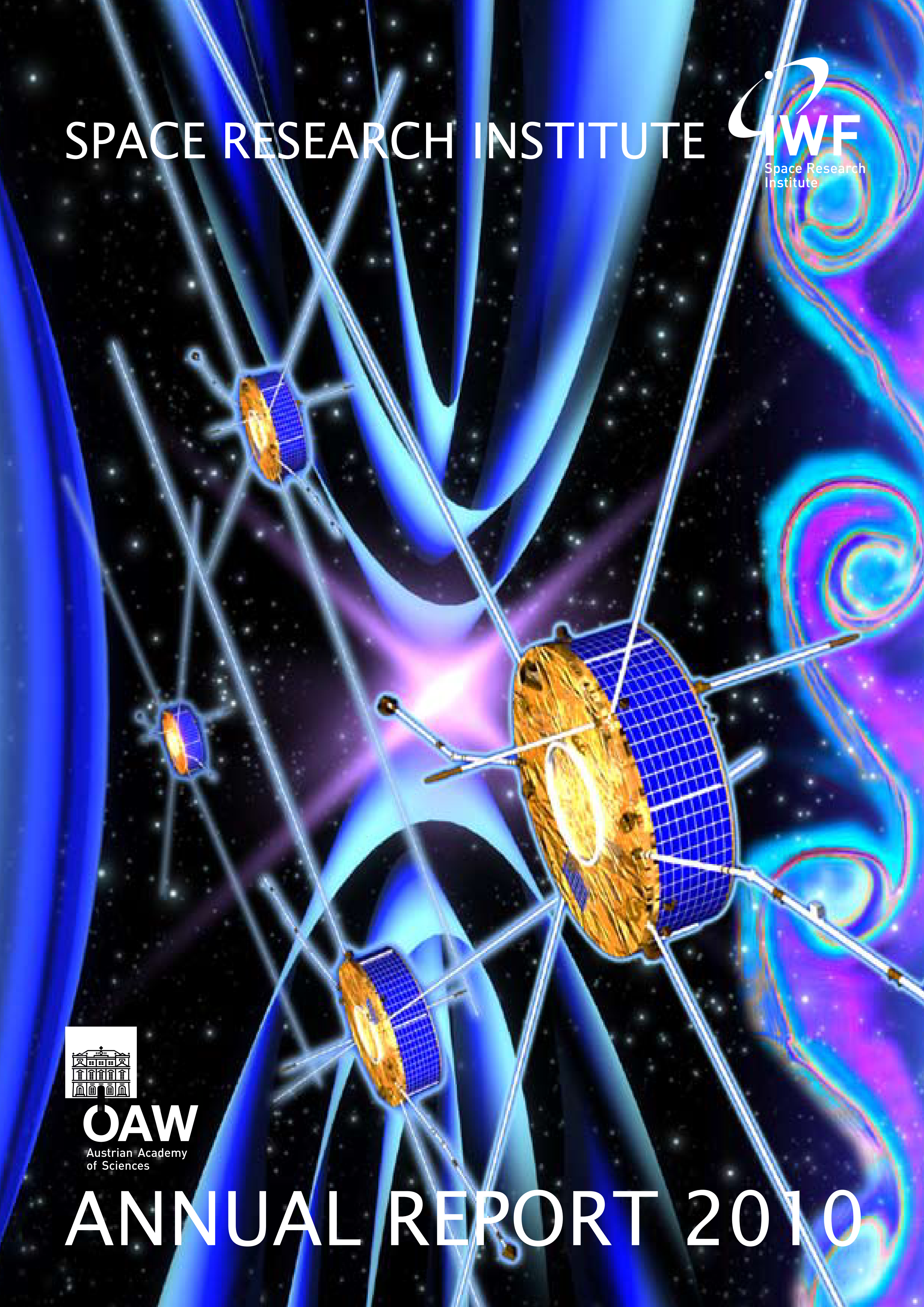
SPACE RESEARCH INSTITUTE

IWF
Space Research Institute



ÖAW
Austrian Academy of Sciences

ANNUAL REPORT 2010

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SPACE RESEARCH INSTITUTE GRAZ
AUSTRIAN ACADEMY OF SCIENCES

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Cover Image:

An artist's impression of Cluster in space created for the tenth anniversary of this mission. The image shows the four Cluster spacecraft located in V-shaped magnetic field lines, that reconnected in the bright centre, on the left is the Earth and on the right are the swirls of the Kelvin-Helmholtz instability on the magnetopause.

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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 interplanetary missions as well as in missions to Earth's near-space environment:

- *BepiColombo* will investigate the planet Mercury, using two orbiters specialised in magnetospheric studies and in remote sensing of the planet, respectively.
- *Cassini* will continue to explore Saturn's magnetosphere and its moons until 2017.
- *Cluster*, the four-spacecraft mission is still providing unique data leading to a new understanding of space plasmas.
- *COROT* searches for extra-solar planets and analyses oscillation modes of stars.
- *GOCE* is determining the structure of the terrestrial gravitational field with unprecedented accuracy.
- *JUNO* is a NASA mission dedicated to understand Jupiter's origin and evolution and will be launched August 2011.
- *MMS* will use four identically equipped spacecraft to explore the acceleration processes that govern the dynamics of the Earth's magnetosphere.
- *RBSP* (Radiation Belt Storm Probes) are two NASA spacecraft that will quantify processes in the Earth's radiation belts.
- *Resonance* is a Russian space mission of four identical spacecraft, orbiting partially within the same magnetic flux tube.
- *Rosetta* is on its way to comet 67P/Churyumov-Gerasimenko and will arrive in November 2014
- *Solar Orbiter* is to study along an innovative trajectory solar and heliospheric phenomena, planned for launch in 2017.
- STEREO studies solar(wind) structures with two spacecraft orbiting the Sun approximately at Earth distance, with both spacecraft now 90 degrees ahead and behind Earth's in its orbit.
- *THEMIS* has been reduced to a near-Earth three-spacecraft mission. The two other spacecraft are now orbiting the moon in the *ARTEMIS* mission.
- *Venus Express* explores the space plasma environment around Venus.
- *Yinghuo* is the first Chinese mission to Mars, planned for launch in October 2013.

IWF is naturally engaged in analyzing data from these and other space missions. This analysis is supported by theory, simulation, and laboratory experiments. Furthermore, at Lustbühel Observatory, 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.

Scientific highlights in 2010 were:

- In the near-Earth dipolar field region, the *THEMIS* spacecraft measured Earthward plasma flows which overshot the equilibrium of the magnetic field lines, rebounced, and started oscillating.
- Using *Venus Express* data, a hemispherical asymmetry in the magnetic field draping pattern has been found near Venus.
- A new kind of decametric radiation was found at Jupiter.
- The first *GOCE*-data only model of the Earth's gravity field has been derived.

In closing some numbers: in 2010 members of the institute published over 100 papers in refereed international journals, of which 29 were first author publications. During the same period, articles with authors from the institute were cited more than 2100 times in the international literature. In addition, over 290 talks and posters have been presented at international conferences by members of the IWF, including 22 by special invitation from the conveners. In national and international press media, the institute was mentioned almost 200 times.

Last but not least, institute members have organised one international meeting, and hosted one other, as well as 20 sessions at international meetings.

IWF structure and funding

IWF is, as a heritage since foundation, structured into three departments and the organigram below shows the administrative structure. All important decisions are taken jointly by an institute council consisting of the three research directors and three staff members.

Scientifically, there are no walls between departments and staff members from different departments work successfully together in many research groups.

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.

Director Wolfgang Baumjohann		
Department of Experimental Space Research **Research Director** Wolfgang Baumjohann	***Department of Extraterrestrial Physics*** **Research Director** Helmut Rucker	***Department of Satellite Geodesy*** **Research Director** Hans Sünkel

2 Solid Earth

In the recent decades space-based observations from numerous satellite missions have led to a considerable improvement in understanding the Earth system on a global scale.

Nearly all geodetic measurements depend in a fundamental way on the Earth's gravity field. Knowledge of the temporal and spatial variation of the Earth's shape is substantial for the investigation of the Earth's interior processes.

The main objectives of the Department of Satellite Geodesy in particular comprise the determination of the Earth's gravity field and atmosphere density, the measurement and modeling of regional geodynamical phenomena as well as Satellite Laser Ranging (SLR) to all relevant spacecraft.

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. An improvement of the gravity field accuracy and a homogenous data distribution has been achieved by the dedicated satellite missions CHAMP and GRACE. And the goal of the on-going GOCE mission is to deliver significant additional information.

GOCE

The satellite mission GOCE (Gravity field and steady-state Ocean Circulation Explorer) 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 the novelty of an on-board gradiometer provides its detailed structure (see Fig. 2.1).

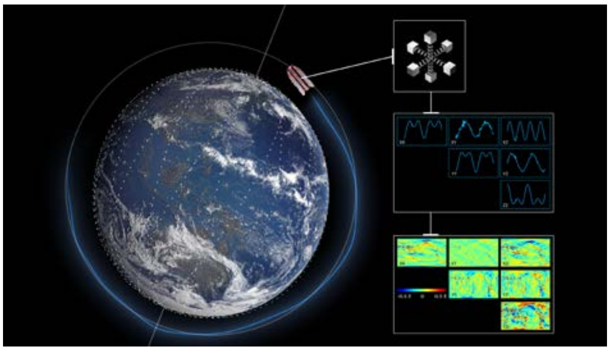

Fig. 2.1: Impression of GOCE satellite in orbit and depiction of SGG principle.

Data Processing

An operational hardware and software system for the scientific processing of GOCE data has been set up by a European consortium. One key component of this system is the processing of a spherical harmonic Earth gravity field model and the corresponding full variance-covariance matrix from the satellite's measurement data, which is operated by the GOCE team Graz (a co-operation of IWF with the Institute of Navigation and Satellite Geodesy of the Graz University of Technology, TU Graz).

First GOCE gravity field model

Data of the first 71 days of the mission from Nov. 2009 to Jan. 2010 have been used to derive the first GOCE only gravity field model.

The full SGG normal equations complete to degree/order (d/o) 224 have been assembled on a PC cluster of TU Graz using the 3 main diagonal components Vxx, Vyy, and Vzz. Finally, the combined solution was processed by addition of the SST and SGG normal equations, applying regularization and optimum weighting. The Spherical Cap Regularization Approach, which is dedicated to the specific problem of the non-polar orbit configuration and the resulting polar gaps, was applied. The stabilizing function is derived from an SST-only solution complete to d/o 50 based on the kinematic orbit. Due to the lower cut-off degree, such a solution is only slightly affected by the polar gaps. The spectral leakage effect, inherent in this SST-only solution, was estimated to be in the order of 2 m. Since the polar caps are filled again with GOCE information, this solution can be considered as unconstrained (cf. Fig 2.2).

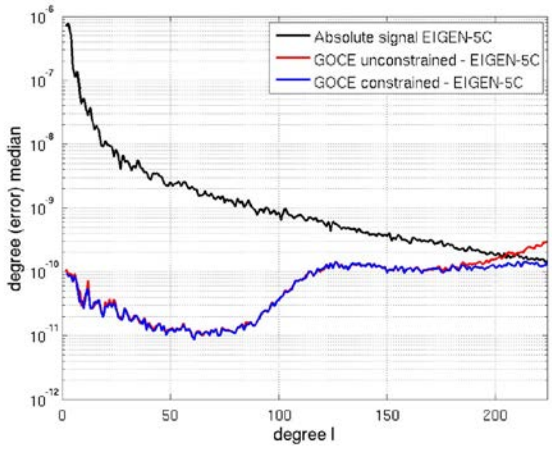

Fig. 2.2: Degree medians: constrained vs. unconstrained first GOCE solution

As a second approach, Kaula regularization was applied, but only to selected groups of coefficients. The first group involves all zonal and near-zonal coefficients affected by the polar gap. In addition, Kaula regularization was also applied to coefficients with degrees larger than 170 in order to improve the signal-to-noise ratio in the very high degrees. The solution is Kaula constrained towards a zero model, but not towards a reference gravity model. Fig. 2.2 demonstrates the effect of constraining the solution. It shows degree medians of the deviations of the GOCE solutions from the EIGEN-5C model. Compared to the unconstrained solution (red curve), the constrained Kaula solution (blue curve) shows significantly lower energy in the very high degrees.

Figure 2.3 displays the estimated standard deviations of the coefficients, representing the square root of the main diagonal elements of the variance-covariance matrix. Clearly visible is the deterioration of the coefficient estimates in the near zonals due to the polar gap and the absence of any a-priori information, and the decrease in the higher degrees due to the weak regularization chosen (i.e. no regularization towards existing models).

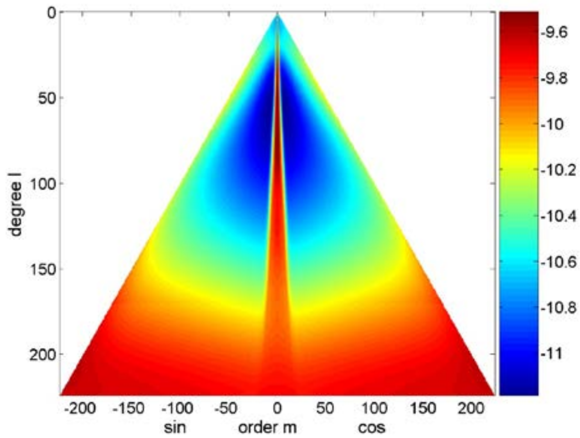

Fig. 2.3: Estimated coefficient standard deviations.

A remarkable characteristic of the new computed global satellite only gravity field is the higher spatial resolution in comparison to the gravity field models of previous satellite missions (see Fig. 2.4 for a map of global geoid height differences).

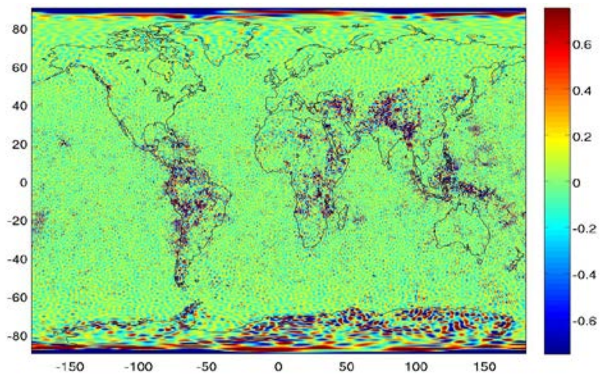

Fig. 2.4: Geoid height differences of first GOCE model d/o 224 w.r.t. EIGEN-5C (scale in meters).

One of the most important results of the comparison with existing Earth gravity models is the discovery of the occurrence of low-quality terrestrial data in the combined models EIGEN-5C and EGM2008 for some regions. Again this finding underpins the expected high spatial resolution of GOCE. The plot of geoid height differences compared to EIGEN-5C nicely shows these data anomalies or irregularities, clearly visible in South America, East Asia, or Antarctica.

The actually achieved gravity field accuracy of this 2-months GOCE solution is estimated to be the order of 10 cm in terms of geoid heights, and 3 mGal in terms of gravity anomalies, at a resolution of d/o 200. Projecting this onto a mission period of at least 18 months yields predictions of 3 cm/1 mGal.

GOCOnAUT

The main objective of this project is the generation of a combined high-degree gravity field solution including GRACE, GOCE, CHAMP, altimetric, terrestrial, air-borne and SLR data. IWF is responsible for the computation of low-degree gravity field coefficients using satellite laser ranges. Due to the higher orbital altitude of special geodetic satellites carrying retroreflectors, SLR is predestined for the determination of the low-frequency part of the gravity field. However, large data gaps above the oceans and poles as well as discontinuous satellite tracking make the normal equations ill-conditioned, a fact that demands special effort in the orbit generation process. Up to now, the low-degree coefficients have been estimated by means of approximately 1 million normal points collected over 3 years from stations all around the world to 4 geodetic satellites, namely Lageos-1 and -2, Ajisai and Stella. Figure 2.5 depicts the gravity anomalies evaluated at constant grid points. The characteristic low near the tip of India and the high at the Andes are well recognizable.

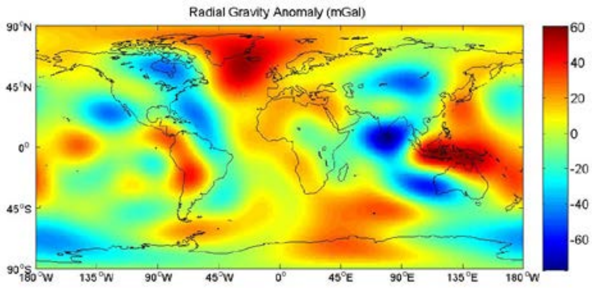

Fig. 2.5: Gravity anomalies deduced from a low-degree gravity field using SLR

2.2 Geodynamics

Horizontal velocities describing the movements of the Earth's crust are generally derived from the field of permanent GNSS stations. To understand the details of plate tectonics a good spatial resolution is needed. The global velocity field project therefore started to collect all network results which contain velocity estimations in order to combine them to a global field. IWF delivered velocity field solutions for Europe EPN (EUREF Permanent Network), CERGOP (Central European Regional Geodynamic Project), CEGRN (all CERGOP epoch sites reprocessed) and AMON (Austrian Monitoring Network). Additionally MON (Monitoring Oriental Network) was delivered for the velocities of Africa, even though most stations are situated in Asia and Europe. Figure 2.6 shows the good consistency within Central Europe of three different networks.

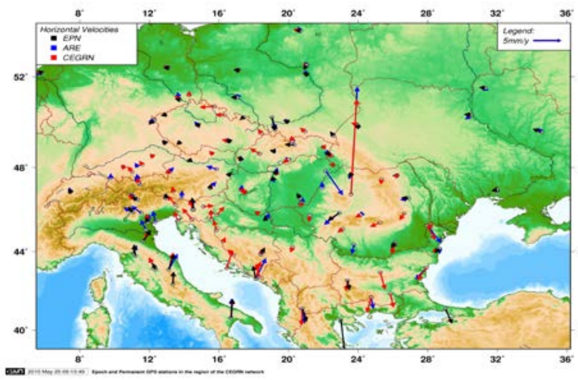

Fig. 2.6: Horizontal Velocities of EPN/CERGOP/CEGRN.

2.3 Atmosphere

Atmospheric Density

The investigation on the density response during extreme solar events in the upper atmosphere is based on in-situ acceleration measurements on-board of low Earth orbiting satellites CHAMP and GRACE. At low altitudes of about 400km the atmospheric drag is the main force acting on the spacecraft.

In the calculation of neutral densities a differentiation must be made between the term “drag coefficient” which is used in astrodynamics and denotes a fitting coefficient to force an atmospheric model to agree with the tracking data and the physical factor from which we can determine the force of the incident gas flow acting on the satellite. For the determination of this highly variable factor a macro model from each satellite has to be used to obtain knowledge from the angle between the incident atmospheric gas flow and each satellite plate. Taking also into account the co-rotating Earth atmosphere, a drag coefficient is obtained in the order of 2.7 – 3.7. This leads to a significant variation in neutral densities as shown in Figure 2.8.

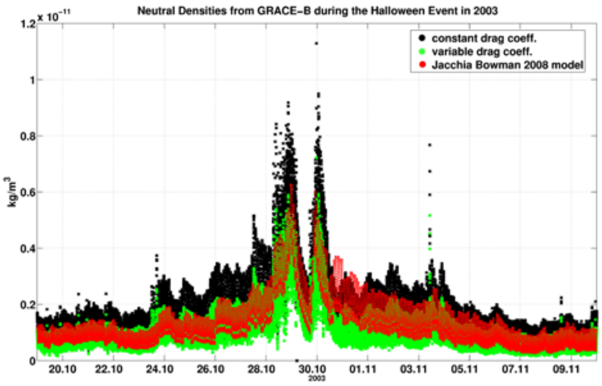

Fig. 2.8: Neutral densities during the Halloween Event in 2003 with constant (2.3) and variable drag coefficient.

Further investigations on this topic concentrated on possible correlation between neutral densities and various solar and geomagnetic indices as well as studies concerning the aurora regions.

Ionosphere

Ionosphere research was done for two targets, looking for earthquake precursors and improving navigation by means of refined models. For the national project OEGNOS, which had the goal to improve EGNOS-derived positions within Austria, the effects of the ionosphere during various solar activity conditions have been investigated. The research showed the importance of adding ionosphere corrections to reduce the position error from several meters to sub-meter level (cf. Figure 2.7) during solar maximum. The final product is a regional model of the ionosphere with a resolution of 1°x1°x1h in near real time.

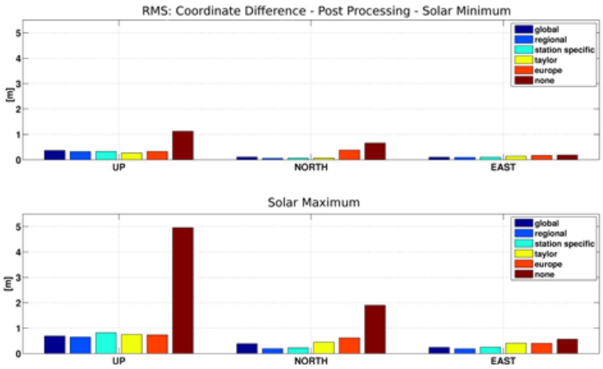

Fig. 2.7: Comparison of models reducing ionosphere effects on positioning during the last solar cycle.

Seismo-electromagnetism

Seismo-electromagnetic phenomena have been studied using ground-based and space-borne observations and theoretical modeling. The multi-parameter observations include sub-ionospheric and trans-ionospheric VLF, GPS and ground-based ULF methods. A major emphasis was put on the investigation of seismo-electromagnetic phenomena associated with the 6 April 2009 L’Aquila earthquake. An improved method has been used to analyse the GPS data measured in the area around L’Aquila. The Total Electron Content (TEC) map showed anomalous features few days before the earthquake. The TEC results have been compared with the VLF variations recorded by the electric field experiment aboard DEMETER (Fig. 2.9).

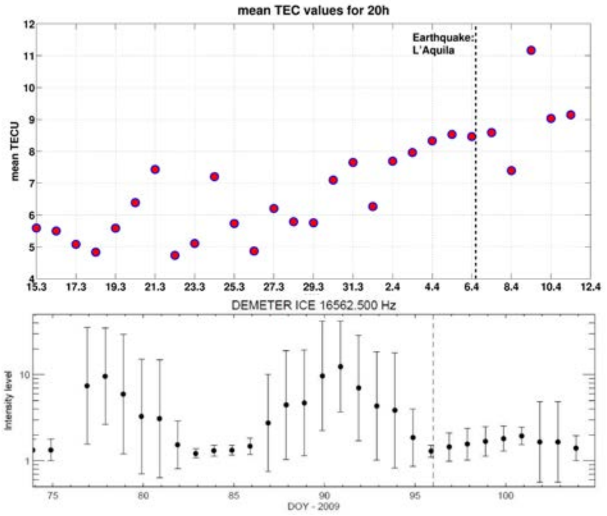

Fig 2.9: Comparison of TEC values with VLF variations recorded by DEMETER.

The drop in the VLF intensity was most probably caused by seismo-ionospheric disturbances along the ray path. In order to differentiate seismo-electromagnetic events from geomagnetic signatures in the analysis of sub-ionospheric VLF radio path data, a detailed study of various events has been performed. Data of the European seismo-VLF/LF electromagnetic network, including the station in Graz, have been used. Data of three ULF stations at distances up to 630 km from the epicenter region were analysed. Apart from indirect ionospheric effects, electromagnetic noise could originate from the lithosphere due to tectonic mechanisms in the earthquake focus. To estimate the amplitude of assumed lithospheric electromagnetic noise emission, calculations on the magneto-telluric effects in the crust's electrical conductivity in the L'Aquila region were performed.

2.4 Satellite Laser Ranging

Altimeter Calibration

The Department of Satellite Geodesy operates one of the worldwide very few radar transponders on Gavdos Island. Using our device an absolute calibration of the orbital height using radar signals is possible with centimetres accuracy. The transponder is located at the cross-over point of the satellites' orbit. The satellite operates in calibration mode, in order to be able to accept echo returns 250 metres above the sea surface, where the transponder is located. The transponder is remotely controlled via a GPRS modem for activation and telemetry. The results of the current JASON-2 mission are used to plan similar campaigns with the foreseen Sentinel 3 mission, also operated by CNES/ESA.

LEO Satellite Tracking

The SLR station Graz, in preparation for tracking the very low orbiting GOCE spacecraft, was already upgraded in 2009 for tracking such a difficult target. During 2010, a few more upgrades, e.g. adding full servo control to the field-of-view iris of the laser telescope and continuous software improvements, now allow efficient tracking of GOCE in its 250 km orbit. While still only about 50% of all SLR stations are able to track GOCE – and only a fraction of them succeeds with GOCE daylight tracking, the SLR station Graz collects more data per pass than all other stations. With the exception of Yarragadee in the Australian semi-desert, Graz measured about twice as many normal point observations than any other SLR station in 2010 (see Fig. 2.10).

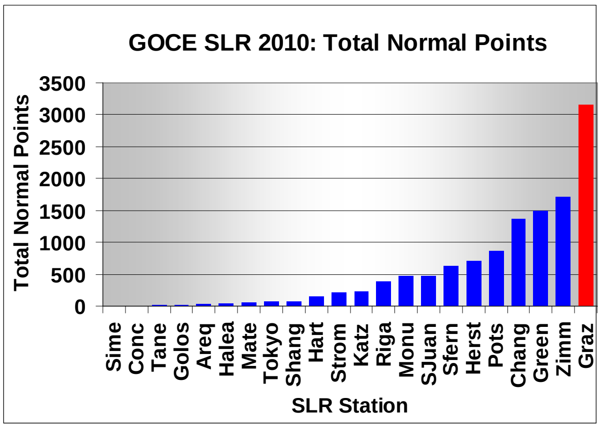

Fig. 2.10: SLR Graz: Successful GOCE tracking in 2010

Spin Parameter Determination

On the basis of Graz 2 kHz SLR data the spin axis precession of the fully passive, geodetic satellite Ajisai was determined (Fig. 2.11).

Ajisai's spin axis is almost parallel to Earth's spin axis and it is synchronised with the right ascension of the ascending node of the satellite orbit. The spin axis is precessing with a period of about 117 days, along a circle of 2.81° in diameter. This knowledge helps to improve the models of forces and torques which are influencing the orbital motion of the satellite. This will be used for the next generation laser time transfer experiments via the mirrors of Ajisai.

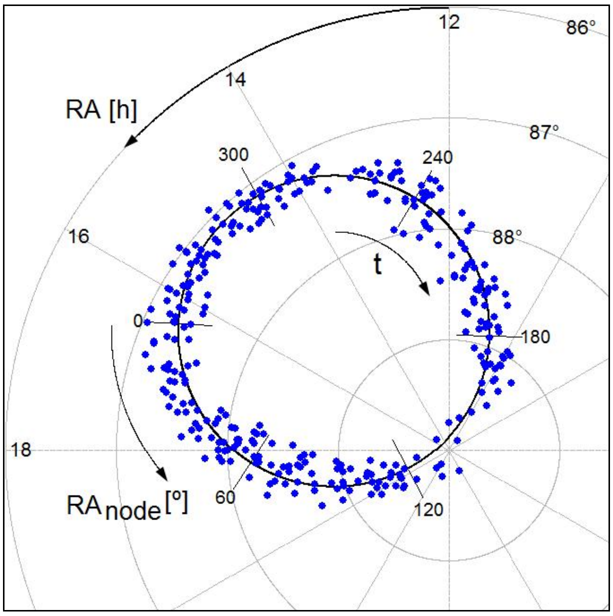

Fig. 2.11: Spin axis orientation (blue points) of Ajisai as determined from Graz 2 kHz SLR data (plotted in the inertial reference frame). The orientation of the spin axis follows t (time) direction, the right ascension of the ascending node (RA_{node}) is decreasing with time.

The Graz 2 kHz SLR system also measures the spin parameters of the nano-satellite BLITS (Ball Lens In The Space, launched in September 2009). The objective of this pioneering mission is an experimental verification of the spherical glass retro-reflector concept. Analysis of the SLR measurements to BLITS shows that the spin period remains constant. However, the orientation of the spin axis is not constant in the inertial reference frame and follows the satellite's orbit.

The spin information, obtained from SLR data, allows validation of the special-purpose separation system which was used for launching BLITS from the Meteor-M1 spacecraft.

Pulse Position Modulation

Within the scope of a bachelor's thesis, an efficient pulse position modulation scheme for the transmitted laser pulses was implemented. While this does not affect the routine SLR measurements it offers a possibility to transmit data to any satellite equipped with a suitable detector (optical uplink). The whole configuration was tested at Graz SLR using a terrestrial target (a simple retro reflector) at a distance of 4288 m from the station. Standard ASCII data were successfully transmitted with a data rate of 2 kByte/s which is already significantly more than some existing conventional microwave uplinks (e.g. CHAMP: 119 bytes/s). It would allow transmission of standard GSM (mobile phone) coded data (about 1.7 kB/s without redundancy).

The payload needed to use such an optical uplink channel to LEO satellites is a relatively simple optical detector. A Multi Pixel Photon Counter (MPPC) was used, a 5 ns time tagging unit, and a retro reflector to allow some feedback at the SLR station.

High Repetition Rate SLR

Since about 3 years Graz SLR is investigating possibilities for higher repetition rates (>2 kHz) through an upgrade of the laser system; solutions for event timer problems; software / Real Time control systems etc.

Because of limitations in laser power, any high repetition laser system will deliver less energy per pulse. First tests with 10 µJ (instead of our nominal 400 µJ) pulses successfully demonstrated very low energy SLR to LEO satellites.

3 Near-Earth Space

Near-Earth space is an ideal natural laboratory to study space plasmas physics with in-situ measurements of the charged particles together with electric and magnetic fields. The Earth's space environment is determined by the interaction between the solar wind, which is a supersonic plasma flow originally ejected from the upper atmosphere of the Sun, and the terrestrial magnetic field and plasmas confined by the magnetic field. The main structures that are created in this interaction region around the Earth 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. Understanding how the magnetic field and particle energies, which travel from the sun through the interplanetary space, enter and are further transported and processed in the magnetosphere, are the general themes of solar-terrestrial physics. Research on the near-Earth space at IWF is performed on experimental and theoretical bases and through data analysis of different magnetospheric missions.

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 analysing 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), of which a wealth of new and exciting data are obtained that lead to many new results. IWF is presently involved in building advanced instruments for the upcoming MMS mission (launch planned in 2014).

Cluster

The four *Cluster* spacecraft, launched in 2000, celebrated their 10th Anniversary this year. The 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 realised to be able to compare large scale (10000 km) with smaller scale processes (30 km - 3000 km). This ESA mission has now been extended until the end of 2014. As PI institution of *ASPOC* and holding Co-I status for four more instruments, IWF is maintaining the *Austrian Cluster Data Center* and is analyzing *Cluster* data in many studies, a part of which is introduced in the next subsection. The instrument team provided data to *Cluster Active Archive (CAA)*, which is a database consisting of all the *Cluster* high resolution data and other allied products such as data from *Double Star*.

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. The spacecraft measured numerous substorms during the tail science phases in the last two winter seasons 2007/2008 and 2008/2009 and completed the prime mission phase. As Co-I institution of the *FGM*, IWF is participating in processing and analyzing data. A part of these studies is introduced in the next subsection. The two outer spacecraft became a new mission, "Acceleration Reconnection and Turbulence and Electrodynamics of the Moon's Interaction with the Sun" (ARTEMIS), to study moon as well as magnetotail/solar wind sciences with its orbit changed to the Lunar Lagrange points starting from autumn 2010. The distances between the other three THEMIS spacecraft, on the other hand, became smaller (100 km) to study dynamics of the inner magnetosphere.

MMS

NASA's *MMS* mission *(Magnetospheric Multiscale)* will 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 energise plasmas in thin boundary and current layers. *MMS* is scheduled to be launched in 2014. IWF has taken the lead for the spacecraft potential control of the satellites (ASPOC) and is participating in the electron beam instrument (EDI) and the digital fluxgate magnetometer (DFG) which both belong to the FIELDS instrument package.

IWF worked together with Southwest Research Institute (SwRI) and Goddard Space Flight Center (GSFC) to finalise the specifications, test plans and procedures, and to complete various product assurance tasks. Plans and requirements had to be coordinated with ESA and industry. The procurement of the electronics parts for the Flight Models was a major effort due to the large number of components, delays at the manufacturers, and strict quality and screening requirements by the project.

Active Spacecraft Potential Control (ASPOC) instrument: The electronics of the Engineering-Qualification Model (EQM) has been delivered by RUAG Space Austria GmbH to IWF, where the integration with the ion emitter system provided by the Austrian Institute of Technology (AIT) was performed. Tests started with functional verification of the EQM shown in Fig. 3.1. During the mechanical verification of the launch environment an incompatibility between the ion emitters and the specifications of MMS was detected, which triggered extensive analysis and re-design activities at AIT, in which IWF was heavily involved in order to ensure the timely provision of emitters for the *EQM* and the Flight Models.

Fig. 3.1: Engineering-Qualification Model of ASPOC

The Critical Design Review (CDR) for ASPOC was successfully conducted in July 2010 pending the completion of the mechanical tests. The verification of the EQM continued with several tests under responsibility of IWF: static magnetic test, thermal vacuum test, EMC test of the electronics, as well as an interface test of the digital and power interfaces to the Central Instrument Data Processor at SwRI. Both the embedded boot code and software developed at IWF was tested to fulfil all requirements for the *EQM*.

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

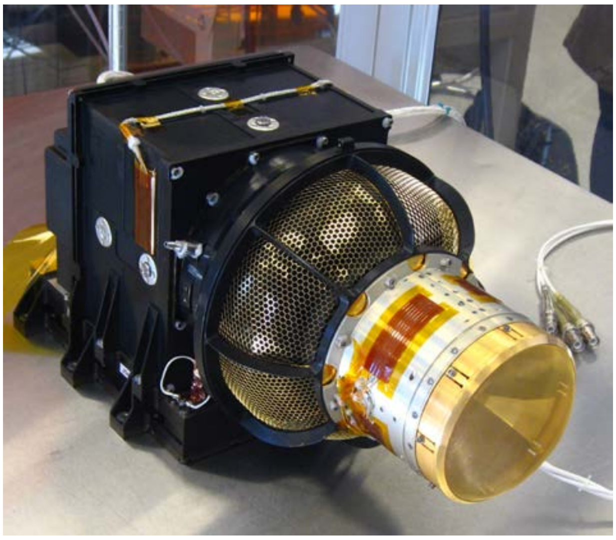

Fig. 3.2: The assembled EDI Gun Detector Unit ready for the qualification test campaign.

The EDI instrument for *MMS* is based on the *Cluster* development with several improvements. In 2010 the Engineering Model of the gun has been built, tested and calibrated. Due to problems with the Field Emission Cathode technology it was decided to come back to the CLUSTER solution and to use a classical filament as electron source.

The GDE was built and tested by industry, while the gun was built entirely in-house. Due to the change of the electron source the manufacturing was delayed and the calibration started in October. The instrument was delivered to the University of New Hampshire and integrated with the detector unit and the optics. The vibration test was successfully completed. Thermal vacuum test and EMC measurements were finished at the end of the year. Minor design changes are presently implemented which will lead to the manufacturing of the first flight model with begin 2011.

Digital Flux Gate magnetometer (DFG): DFG is based on a triaxial fluxgate sensor developed by the University of California, Los Angeles, and a front-end Application Specific Integrated Circuit (ASIC) for magnetic field sensors. The ASIC has been developed by IWF in cooperation with the Fraunhofer Institute for Integrated Circuits in order to reduce the size, mass and power consumption of the near sensor electronics.

In early 2010, screening and qualification of the packaged flight ASICs according to NASA's level 2 standard were finished. In parallel the Engineering Model (EM) of DFG was tested and calibrated. The integration of the EM electronics board into the Central Electronics Box of FIELDS took place in March. DFG passed the Critical Design Review together with the FIELDS instrument package in May 2010 which was also the official kick-off for the manufacturing of the flight models.

STEREO

STEREO/WAVES antenna calibration: The STEREO/WAVES experiment (SWAVES) onboard the two STEREO spacecraft is dedicated to the measurement of the non-thermal radio spectrum from the solar environment, at frequencies between a few kHz and 16 MHz. Three orthogonal monopole antennas, each 6 meters long, are attached on each spacecraft. With this configuration direction finding of radio sources is possible via the determination of the direction of arrival and the polarization state of incident radio waves.

For the evaluation of the SWAVES data the receiving properties of the antennas, influenced by the spacecraft body, have to be accurately known. These properties are represented by the so-called effective length vector. An in-flight calibration of the effective length vectors of the antennas was performed using observations of the terrestrial auroral kilometric radiation (AKR) in an early stage of the mission when the spacecraft, still close enough to Earth, performed a series of roll manoeuvres. A special least squares method was applied to find the effective length vectors which fit best the physical model describing the reception situation on the basis of the observations. The technique was combined with a specifically adapted genetic algorithm, in order to find not only a relative but the absolute minimum of the deviation from the observation model. The results are very accurate and are recommended as a basis for future evaluations of SWAVES data.

3.2 Physics

At IWF various data from ongoing missions are analysed and theoretical models are developed to describe the physical processes responsible for the formation of structures and phenomena in the sun-Earth system at different scales. Data analysis is performed using the high-resolution data provided by the ongoing missions introduced in previous section, such as *Cluster* and *THEMIS,* and also using other near-Earth's missions such as *Geotail, and GOES*, as well as the solar wind missions, *Wind and ACE.* The studies deal with large-scale interactions between solar wind and magnetosphere, meso-scale disturbances such as plasma flows and waves in the magnetotail, and also plasma instabilities and waves including magnetic reconnection and kinetic processes.

Double-onset substorm: One of the most dynamic energy conversion processes in near-Earth space is a substorm, where change in the field configuration (called dipolarization) and acceleration of the plasmas take place. Occasionally a substorm consists of multi-steps of activation, suggesting that the energy dissipation processes in the magnetosphere and the ionosphere develop stepwise to release the energy loaded in the magnetotail. Large-scale as well as local plasma processes during a substorm with clear double-onset are studied using the THEMIS and GOES spacecraft distributed between 6.6 and 18 R_E downtail and ground-based data as summarised in Fig. 3.1.

The first onset at 0220 UT took place when a well developed thin current sheet was extended near 10-11 R_E. After the onset Earthward fast flows with a dipolarization front were detected followed by signatures of magnetic flux pile-up.

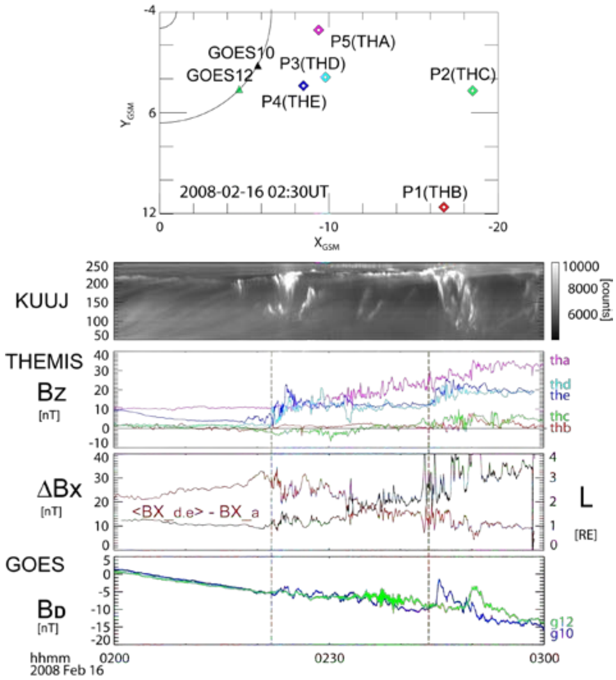

Fig. 3.3: (Upper panel) Spacecraft location in the equatorial plane. (Lower panel) Aurora keograms, THEMIS magnetic field observation: Bz for the five spacecraft, ΔBx for P3/P4, and P5 and estimated thickness of the current sheet, L, and GOES B_D (eastward) component. The vertical lines show the onset time of the two substorms.

The second onset at 0243 UT was more intense, involving both the midtail and near-Earth region. Detailed analysis in the near-Earth and midtail regions during these two substorms enabled identification of a possible reconfiguration of the near-Earth tail, which caused a favourable condition for a stronger activation during the second onset involving the midtail despite the rather weak IMF driver for this event.

Statistical study of dipolarization front: A statistical study of dipolarizations of the Earth's magnetotail has been performed using 7 years (2001 through 2007) of Cluster magnetic field and ion data. The dipolarization events are selected automatically using criteria for plasma and magnetic field configuration. In the selected data sets both events with and without high-speed earthward flows are included. To obtain the temporal profile of the dipolarization, a superposed epoch analysis was performed.

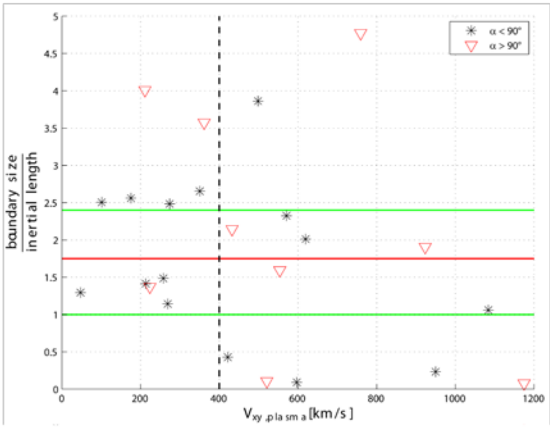

Fig. 3.4: The estimated boundary size of the magnetic structure normalised to the inertial length of the protons in the magnetic structure for the dipolarization events plotted against the maximum flow speed for each event. Those data points, where the angle between the normal velocity of dipolarization front and the plasma flow, α, is less(larger) than 90°, are marked with black stars(red triangles). The red(green) horizontal line(s) is(are) the median(upper and lower quartiles of the median) of the boundary size.

It was found that the temporal scale of the dipolarization tends to be decreasing with increasing velocity of the plasma flows. The spatial scale of the dipolarization, obtained by calculating the thickness of the dipolarization front of the magnetic structure using the four spacecraft timing velocity, is on average 440±20 km corresponding to an average inertial length of 340±10 km and showed no relationship to the plasma flow speed (see Fig. 3.4). These results suggest the importance of the kinetic processes maintaining these thin boundaries between the bulk-flow plasma and the ambient plasma ahead of the flow.

Oscillatory BBF braking: Bursty bulk flows (BBFs)—fast plasma flows inside the plasma sheet are often associated with substorms. BBFs occur in very localised channels up to 2–3 R_E wide. At around 10 R_E, BBFs are suddenly decelerated by the dominant dipolar magnetic field where pressure gradients are piled-up. MHD modeling has predicted that the interaction of an incident flow in the plasma sheet with the Earth's dipolar magnetic field lines would result in flow deflection and formation of plasma vortices. Theory also predicted that the earthward accelerated BBF overshoots its equilibrium position and executes a heavily damped oscillation about that position. For the first time, now, such multiple overshoot and rebound of a BBF is observed.

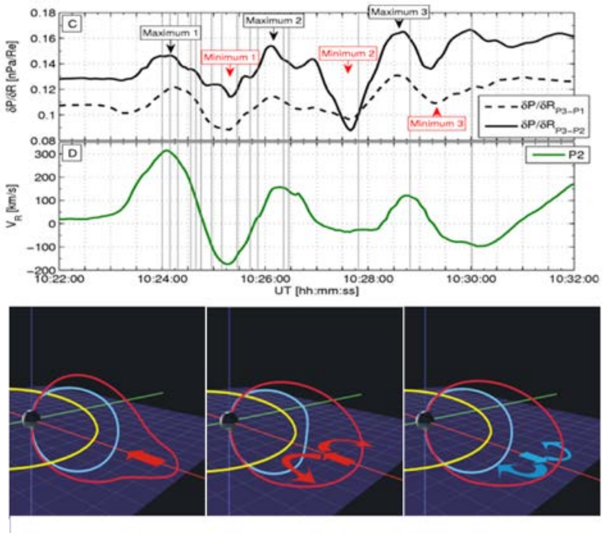

Fig. 3.5: (top) Radial pressure gradient dP/dR between P3 and P1 (dashed line), and between P3 and P2 (solid line). (middle) Radial velocity component for spacecraft P2 with positive values in the Earth's direction. (bottom) Cartoon illustrating BBF deceleration by the dominant dipolar magnetic field (left), flow deflection and formation of vortices (middle), and following tailward rebound of the flow burst with reversed sense of rotation of the vortices (right).

It was found that while the earthward BBF over-shootings are accompanied by enhanced radial pressure gradients, these gradients are depleted during the tailward rebounds of the BBF (cf.Fig. 3.5). In addition, changes of the flow burst propagation direction, from earthward to tailward, reversed the sense of rotation of the vortices on the two sides of the BBF.

Model of magnetic reconnection: In the close vicinity of the reconnection line (X-line) the Hall effect attains a critical significance, causing a Petschek-like configuration due to the generation of dispersive waves. Therefore, the Hall-MHD approximation turns out to be predominating in the close neighborhood of the

X-line, at length scales of the order of the proton inertial length. Inside this Hall-MHD domain there is an area where the proton velocity is small compared to that of the electron, so one may neglect the proton contribution in the electric current. This is the so-called electron Hall-MHD (EMHD) approximation. By using the EMHD formalism, a self-consistent analytical solution of the problem of steady-state magnetic reconnection in a collisionless compressible plasma is obtained.

The analytical model shows all essential features of anti-parallel reconnection, including the proton acceleration up to the Alfvén velocity, the quadrupole structure of the magnetic field (Fig. 3.6), and formation of layers of rarefied plasma in the vicinity of the separatrix. A strong transverse electric field, which forces electrons to accelerate into the out-of-plane direction up to the electron Alfvén velocity is located near the separatrix.

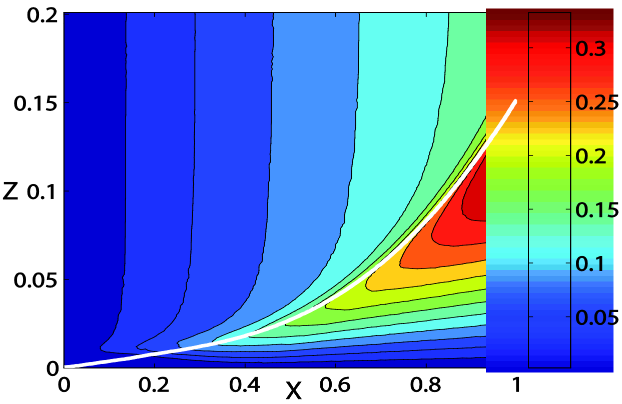

Fig. 3.6: Out-of-plane magnetic field B_y by color, and electron stream lines by black curves in the first quadrant. The white curve marks the magnetic separatrix.

Study of AKR source positions: Interball-2/Polrad triaxial polarimeter is used to determine AKR source positions on the auroral oval as well as for subsequent analysis of directivity pattern and geometrical properties of the AKR beams.

Detailed AKR visibility maps for a given position of spacecraft are introduced (Fig. 3.7).

These maps enable to compare geometrical properties of the AKR beams observed simultaneously with different spacecraft. Additionally both the azimuthal and elevation sizes of the AKR beams for each AKR sources are determined. For some AKR events an apparent motion of the AKR sources following Interball-2/Polrad motion along the orbit is seen in such a way that the spacecraft remains within the radiation beam. These findings are consistent with AKR beaming confined to a narrow plane tangent to the source's magnetic latitude circle and containing the local magnetic field vector.

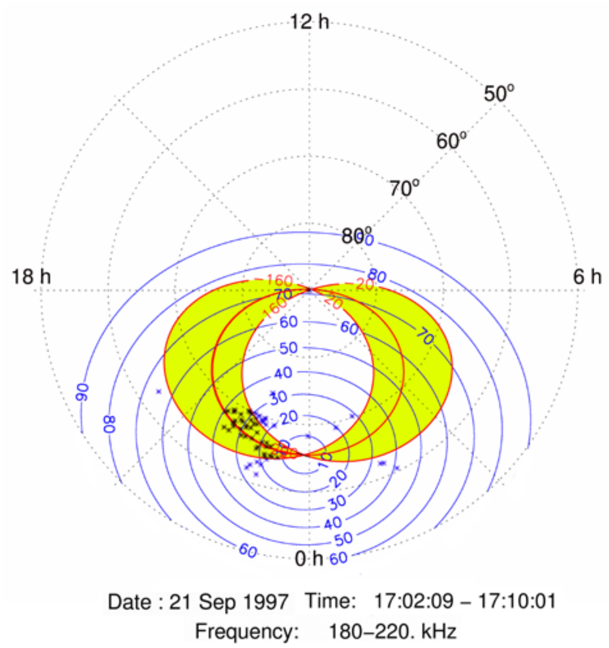

Fig. 3.7: AKR source positions (blue and black asterisks) in magnetic local time and invariant latitude coordinates and AKR visibility map (blue lines - latitude and red lines - azimuth). Yellow filled region indicates the tangent plane beaming model (±20° and ±160° of azimuth).

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 & Solar Wind

The Sun is the nearest star to the Earth. Its electromagnetic radiation, magnetic activity in an ~11 year cycle, and solar wind are strong drivers for various processes in the solar system.

Solar Orbiter

Solar Orbiter, an ESA mission, will be monitoring the sun and its close environment on a partially synchronous orbit around the Sun being able to observe solar phenomena at different wavelengths over longer periods of time. Among the various instruments on board Solar Orbiter the Radio and Plasma Wave experiment will be calibrated by our numerical analysis tools.

Physics

Polarization of Solar Drifting Pairs: During the July 2002 observation campaign, solar radio drifting pairs have extensively been observed and analysed using a combined UTR-2 and URAN-2 radio telescope network, the latter being able to provide radio polarimeter measurements. 'Forward' and 'Reverse' Drifting Pairs (FDP, RDP) can be discriminated by their spectral appearance (FDP: from high to low frequencies with increasing time). For the first time the polarization could be connected to the position of an active area (N 10030) on the solar disk, with a higher degree of circular polarization (~35%) when the area was close to the central meridian. Assuming northern polarity for the main solar spot the radio bursts can be considered as emission in the ordinary mode.

Solar Decameter Spikes: Solar decameter spikes are bursts of short duration of about 1s with a frequency bandwidth of 50-70 kHz. They are weak bursts with fluxes not exceeding 100 s.f.u. Their appearance in the dynamic spectrum (Fig. 4.1) displays an irregular behaviour. It is suggested that they are generated by fast electron beams with rather low electron density, their spatial sizes are strongly constrained.

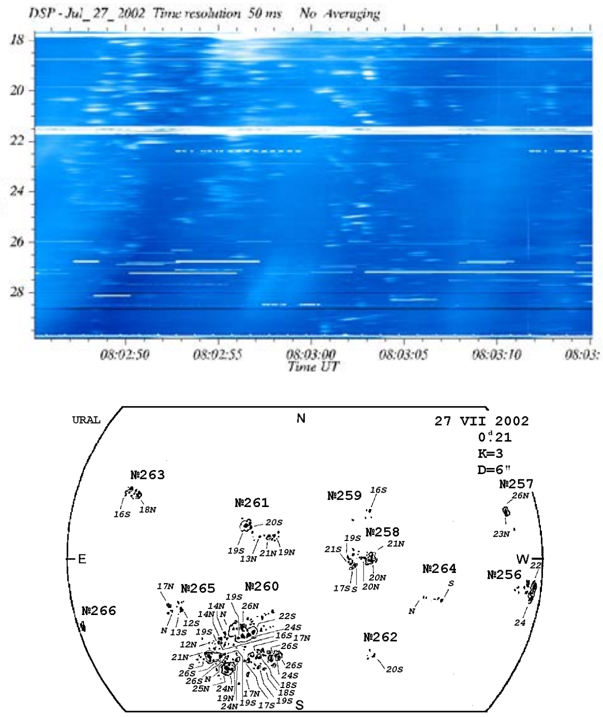

Fig. 4.1: (Top) Decameter solar spikes (the white blobs) as observed on July 27, 2002, at frequencies 18-30 MHz by UTR Kharkov. (Bottom) The position of the active region N260 on the solar disk on July 27, 2002.

The duration (i.e. spectral lifetime) of solar spikes is defined by the particle collision time in the solar corona plasma with a kinetic temperature of about one million degrees.

Observations by the radio telescope UTR-2 (Kharkov, Ukraine) enabled the definition of specific properties of the spikes which were found to be associated with the solar active region N260 (Fig. 4.1). This region crossed the solar disc from 22 July to 2 August 2002. The observed decameter spikes correspond to the positions of the active region from ~30 deg east to ~70 deg west of the central meridian. From these positions an estimate on the beaming of spike radio emission, not exceeding 50 deg, was derived.

First observed soliton in the solar atmosphere: A time series of the CaII H-line obtained at the solar limb with the Solar Optical Telescope (SOT) on board the Hinode spacecraft shows an intensity blob propagating upward in the solar chromosphere with 35 km s^{-1} apparent speed (Fig. 4.2). The blob speed, length to width ratio and relative intensity correspond to a slow sausage soliton propagating along a magnetic flux tube. The blob width increases with height corresponding to magnetic flux tube expansion in the stratified atmosphere. This propagating intensity blob is the first observational evidence for a soliton in the solar atmosphere.

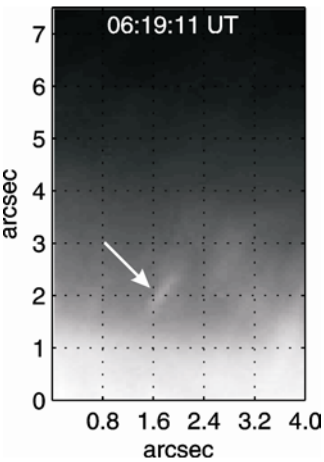

Fig. 4.2: CaII H-line image obtained with Hinode/SOT at 06:19:11 UT November 22, 2006. The white arrow indicates the observed soliton.

Kink instability in flaring active region: Multi-wavelength observations of the solar atmosphere (SOHO/MDI; SOT-Hinode/blue continuum 4504 Å, G band 4305 Å, CaII H 3968 Å; TRACE 171 Å) reveal a highly twisted magnetic loop in active region AR 10960 during a B5.0 flare on 4 June 2007. The total twist angle of the loop is estimated to be 12π, which is larger than the Kruskal-Shafranov instability criterion. A clear double structure observed near the loop top (Fig. 4.3) is consistent with a simulated kink instability in curved coronal loops. The kink instability of ta wisted coronal loop is considered to be the trigger for the B5.0 flare between 04:40 UT-04:51 UT on June 4, 2007.

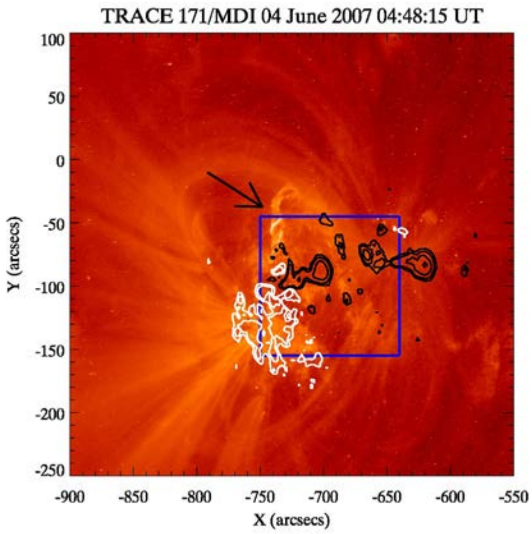

Fig. 4.3: Co-aligned MDI contours overlaid on TRACE 171 Å image of the active region AR 10960 at 04:48:15 UT on 2007 June 4. White (black) contours show the positive (negative) polarity of photospheric magnetic field. The loop with helical twist is indicated by a black arrow.

A glancing encounter of a fast CME with Earth: Coronal mass ejections (CMEs) are massive expulsions of plasma and magnetic fields from the outer solar atmosphere into the interplanetary medium. They are the cause of the strongest geomagnetic storms at Earth. The NASA STEREO mission consists of two spacecraft which are able to image Earth-directed CMEs seamlessly during their journey from the Sun to 1 AU, making it possible to pin down their complete velocity profiles with much increased accuracy. For the first fast and geo-effective CME (3-5 April 2010) of the new solar cycle, which lead to the loss of the Galaxy 15 telecommunication satellite, the measurements surprisingly showed that the CME decelerated little, from 1000 km/s near the Sun to 800 km/s near Earth. The CME was directed 20° southward of the ecliptic, and only its northern flank hit the Earth (Fig. 4.4), producing a geomagnetic storm of unusually long duration.

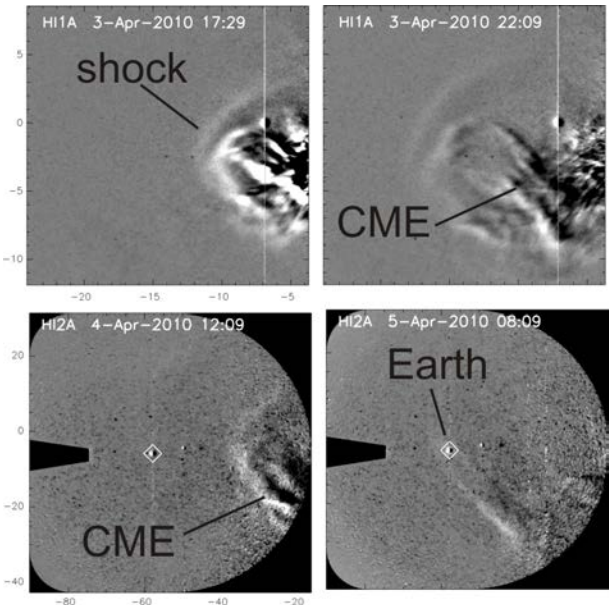

Fig. 4.4: Propagation of a CME driving a shock wave on 3-5 April 2010 between Sun and Earth.

This confirmed earlier hypotheses that long-duration CME intervals observed in the solar wind can be explained by the spacecraft trajectories through the CME flank, and that 3D aspects such as curvature cannot be ignored in these cases.

4.2 Mercury

Mercury is the planet closest to the Sun. The planet is most likely well differentiated and possesses an iron core and has a weak global magnetic field, which creates a mini-magnetosphere.

BepiColombo

The ESA/JAXA mission *BepiColombo* to be launched in 2014 will explore the planet and its environment with two spacecraft simultaneously: the Japanese *Magnetospheric (MMO)* and ESA's *Planetary Orbiter (MPO)*.

IWF plays a major role in developing the magnetometers for the two spacecraft: it is leading the magnetometer investigation aboard the *MMO* (MERMAG-M, see Fig. 4.5) and is responsible for the overall technical management of the *MPO* magnetometer (MERMAG-P). For *MPO,* IWF also leads the development of an ion mass spectrometer with imaging capability, which is part of the SERENA instrument suite, to explore the composition, structure, and dynamics of the exo-ionosphere.

In 2010, both, Engineering Model and Structural-Thermal Model of the magnetometer *MERMAG-P* have been delivered to the prime contractor of MPO. For *MERMAG-M*, the tests with the Qualification Model were finshed in early 2010, a successful Critical Design Review was held in Japan in April and the manufacturing of the Flight Model has been started.

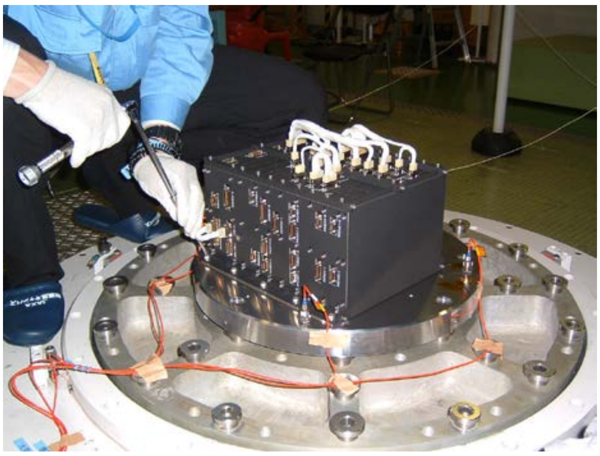

Fig. 4.5: Vibration test of the MMO common instrument electronics box.

For PICAM, IWF took additional responsibility in providing ion optics for the Structural-Thermal Model (STM) and the analyser part of the ion optics for the Flight Model. In 2010, the STM of *PICAM* has been built and tested for vibration loads (Fig. 4.6). The challenging thermal design providing efficient thermal isolation between the hot ion optics structure exposed to space and the electronics, while at the same time maintaining the required mechanical stability, has been successfully verified in a Solar Simulation Test.

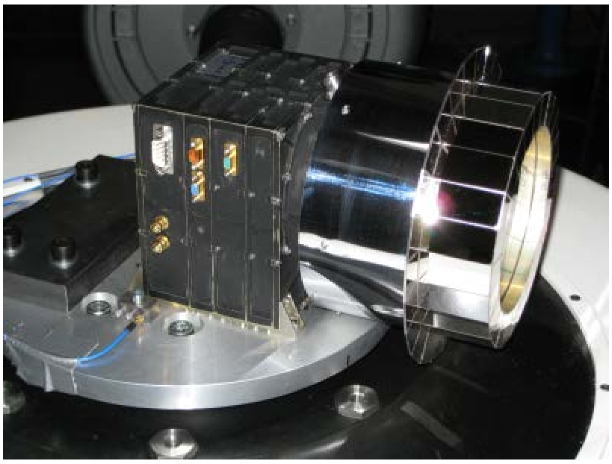

Fig. 4.6: The Structural-Thermal Model of PICAM during the vibration test.

The Engineering Model (EM) of PICAM has been built and tested as well. IWF provided the controller board with software and electrical load simulators. This unit is going to support the electrical and functional verification of the *MPO* spacecraft. Both the STM and EM have been delivered to Istituto di Fisica dello Spazio Interplanetario (Rome) for further combined testing of the SERENA instrument suite and subsequent delivery to ESA.

Besides the production of the deliverable units, modelling of the instrument performance in conjunction with optimisation of the ion optics and related controller design has been performed together with the continuing refinement of the PICAM Prototype Model for which IWF also built the electrostatic analyser. The vacuum test chamber for functional tests has been upgraded by a beam detector.

Physics

Mercury's sputtered exosphere in 3D: A study related to self consistent modelling of solar wind particle precipitation to Mercury's surface, sputtering of surface minerals and the formation of the planet's exosphere in 3D was carried out. It includes three coupled models: i) a 3D hybrid simulation of the solar wind interaction with Mercury's planetary magnetic environment is used for the 3D calculation of the proton flux precipitation over Mercury's surface; ii) a mineralogical surface map and the TRIM-sputtering code is used for the calculation of the released minerals; and iii) the released sputtered particles and their related velocity distributions are used for the input of a 3D exosphere model. The modelling chain and preliminary results for sputtered O, Zi and Mg are shown in Fig. 4.7. The main source and densities are related to the areas around the magnetic cusps. In future studies we will model the density of the various sputtered surface elements along the spacecraft trajectories of MESSENGER and BepiColombo during quiet and disturbed solar conditions.

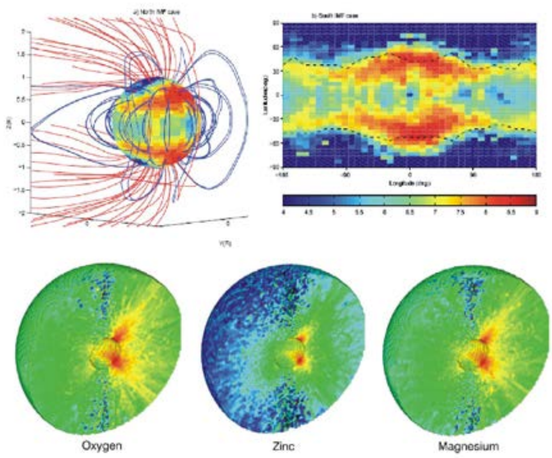

Fig. 4.7: (Upper panel) Hybrid simulation of solar wind proton precipitation to Mercury's surface. (Lower panel) Modelled sputter released surface elements (O, Zi, Mg) and exosphere formation.

4.3 Venus

Venus has a radius only slightly smaller than the Earth's and is differentiated, it does, however, not exhibit an internal magnetic field.

Venus Express

Venus Express, ESA's first mission to Venus, was launched successfully on 9 November 2005 in Baikonur. IWF takes the lead on one of the seven payload instruments, the magnetometer VEX-MAG which measures the magnetic field vector with a cadence of 128 Hz. It maps the magnetic properties in the magnetosheath, the magnetic barrier, the ionosphere, and the magnetotail. It is instrumented to identify the plasma boundaries between the various plasma regions and to study the solar wind and the solar wind interaction with the Venus's atmosphere.

During 2010, *Venus Express* continued to operate normally. The magnetometer remains on during the whole year and collects data both near Venus and in interplanetary space. Routine data processing and cleaning of the measurements is undertaken for 1 Hz data. It shows that the software for data cleaning and processing is robust. All data are cleaned and issued to the science community. Further cleaning of 32 Hz data has been performed for part of the data.

Archiving of all available data sets has been carried out and all data have been delivered to ESA's Planetary Science Archive.

The operation of *Venus Express* and its payload is in extension of the nominal mission until 2012 and a new extension of the mission into 2014 is proposed. Also, further new manoeuvres using air-braking are under consideration.

Physics

The solar wind interacts directly with the atmosphere of Venus in contrast to the situation at Earth, whose magnetic field protects the upper atmosphere. Still the Venus atmosphere is partially shielded by an induced magnetosphere and the effectiveness of this shield is studied. It is expected that the effectiveness varies with solar activity; however 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 an extension of understanding of the evolution of the Venus's atmosphere caused by the solar wind interaction.

The Venusian magnetotail: The solar wind interaction with a planetary atmosphere produces a magnetosphere-like structure near the planet whether or not the planet has an intrinsic global magnetic field. The Venusian magnetotail is formed by draping of interplanetary magnetic field lines. The near-planet and distant magnetotail regions have been sampled by various missions and the general magnetic features of the distant magnetotail are well established. The near wake region from about 1.3 to 3 Venus radii downstream of the planet remained unexplored until the Venus Express mission.

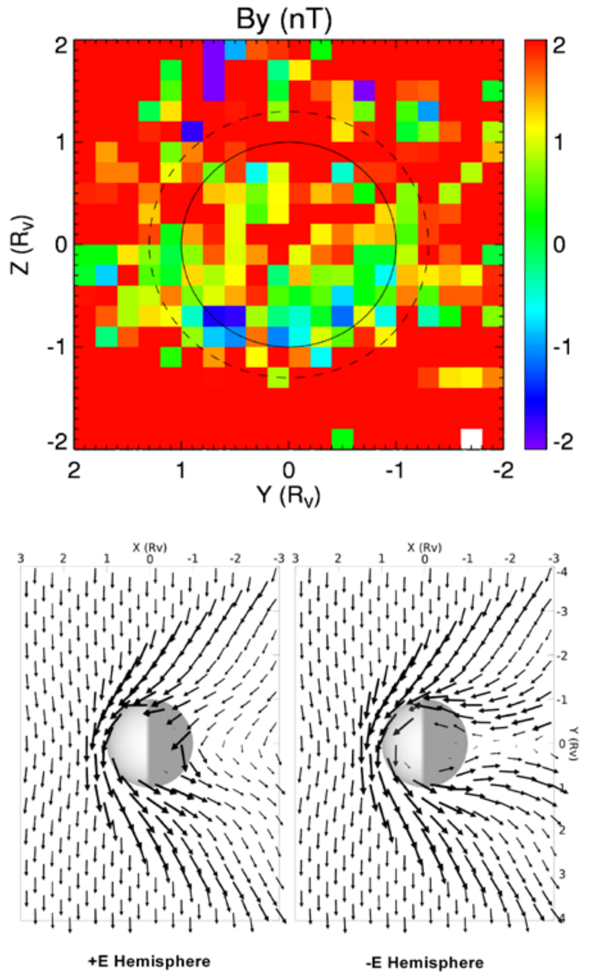

Fig. 4.8: (Top) Cross tail magnetic field component distribution in the near Venus magnetotail in magnetic coordinates in which the upstream IMF points in the Y direction. The inner circle is the limb of Venus and the outer circle is the approximate magnetotail. (Bottom) Average magnetic vectors calculated from hybrid simulation in X-Y for +E hemisphere (Z = 0.5 R_V cut section) and -E hemisphere (Z = - 0.5 R_V section). The vector length indicates the field strength in nT, but with an upper limit of 10 nT.

Unanticipated, a draped field reversal in one hemisphere of the near Venus tail was found. When ordered by the interplanetary electric field orientation, the magnetic field lines in the hemisphere with inward motional electric field apparently are wrapped more tightly around Venus than in the other hemisphere (see Fig. 4.8), thus forming a field reversal region in this portion of the near tail. A global hybrid simulation reproduces this and provides a three-dimensional view of the observed hemispherical asymmetry.

Venus O atom corona: The formation of the atomic hot oxygen corona of Venus is studied with a Monte Carlo model, which considers elastic, inelastic, and quenching collisions between the traced photo-chemically hot atoms and the ambient neutral atmosphere. The newly developed model considers the differential cross sections to determine the scattering angle in the collisions and includes also rotational and vibrational excitation energies for the calculation of the initial energy of the produced hot atoms.

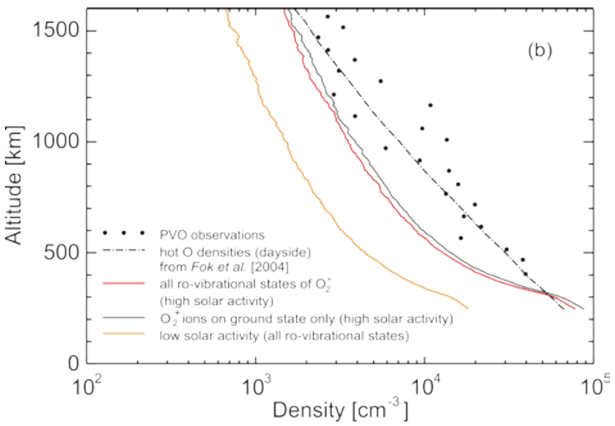

Fig. 4.9: Modelled hot O corona densities in Venus's exosphere related to solar activity and parameters. VEX conditions correspond to the orange line.

The differential cross sections and the fraction between elastic, inelastic and quenching collisions are the most sensitive parameters which affect the corona density. The hot O densities inferred from Pioneer Venus Orbiter (PVO) observations can only be reproduced during high solar activity based on a forward scattering model but without inelastic and quenching collisions (Fig. 4.9). The corona densities for low solar activity (VEX solar conditions) are about a factor of 2–3 smaller than for high solar activity which may be a reason that SPICAV (Spectroscopy for Investigation of Characteristics of the Atmosphere of Venus) did not reproduce the early PVO results so far.

4.4 Jupiter

Jupiter is the largest planet in the solar system. If magnetic fields would be visible to the eye, the Jovian magnetosphere would be the largest structure in the sky. Also, Jupiter is a strong source of radio emissions.

EJSM

The Europa Jupiter System Mission (EJSM) is a joint NASA-ESA mission candidate with a launch opportunity in 2020, where ESA would provide the Jupiter Ganymede Orbiter (JGO) and NASA would provide the Jupiter Europa Orbiter (JEO). JEO and JGO will execute an intricately choreographed exploration of the Jupiter System before settling into orbit around Europa and Ganymede, respectively.

IWF is participating in the design studies for the magnetic field instruments aboard EJSM. IWF is developing a worldwide unique scalar magnetometer jointly with the Institute of Experimental Physics of the Graz University of Technology: a Coupled Dark State Magnetometer. Its use aboard JGO would significantly enhance the precision of the magnetic field investigation in the Jupiter system.

Physics

Ion pickup near the Galilean satellites: The ion pick-up near the icy Galilean satellites is studied using ion cyclotron waves. Using Galileo magnetometer data, evidence is shown for the existence of ion cyclotron waves, which are generated by pick-up of freshly ionised particles. Near Europa, in the wake various kinds of ions are detected (Fig. 4.10), which were already predicted to be present on the moon.

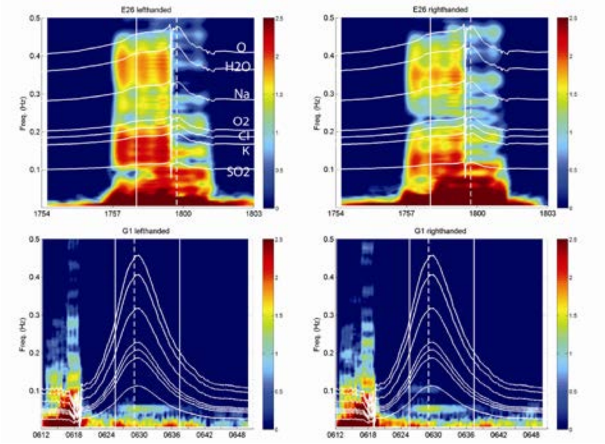

Fig. 4.10: Dynamic spectra of the left and right hand polarised waves for flybys of Europa and Ganymede. The ion cyclotron wave frequencies for various species are indicated by white lines.

Upstream of the moon there is evidence for water ion pick-up, which could facilitate the slowdown of the plasma flow through the pick-up currents and the associated j×B force. At Ganymede there is evidence for either water or oxygen pick up on the flanks of the magnetosphere. These species are present in Ganymede's magnetosphere, as observed by auroral emissions. Because of the screening-off of the surface by this magnetosphere not much sputtering and pick-up is expected. Near Callisto there is an indication of hydrogen pick-up from its atmosphere. The magnetospheric density is low as well as the magnetic field strength, therefore the sputtering and pick up rate will be low at Callisto as will be the gyrofrequency of the heavy ions, which will make them difficult to detect.

Synthetic spectra of narrowband DAM: Narrow-band (NB) events in dynamic spectra and their relation with Short (S) bursts are an unresolved enigma of the Jovian decametric emission (DAM). The S/NB-structure with timescales between 0.03 s and 0.3 s is the focus of this analysis. It is shown that the main S/NB-phenomenology can be reduced to three main ingredients which are: the dispersion delay of the radio emission; the motion of electrons emitting near the local gyrofrequency in the parallel electric field of the standing Alfvén wave; and the shadow effect. The converging Coulomb force at the sign inversion of the parallel electric field could entrap electrons at the antinode of the standing Alfvén wave in the Jovian ionosphere resonator. Such captures appear as the horizontal parts of the electron gyrofrequency curves in the synthetic and observed dynamic spectra of Jovian decametric emission (Fig. 4.11).

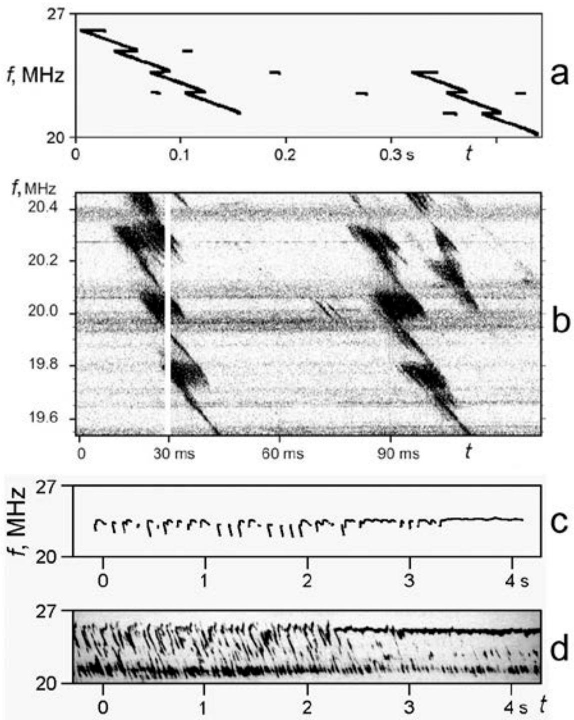

Fig. 4.11: Examples of synthetic spectra in (a) and (c) realistically reproduce the observed dynamic spectra of S/NB-emissions in (b) and (d). Here f is the frequency of radio emission, and t is the observation time.

A new type of periodic bursts of non-Io DAM: A new type of the periodic bursts of non-Io related Jovian decametric radio emission (non-Io DAM) has been found. The bursts visible in the dynamic radio spectra have been recorded by STEREO/WAVES, Wind/WAVES and Cassini/RPWS in a frequency range from ~5 MHz up to ~ 16 MHz in the years 2000-2010 (Fig. 4.12). The bursts typically recur during several Jovian days with a new period of ~10.07 hours (1.5% longer than the rotation of the Jovian magnetosphere). The occurrence of the periodic bursts correlates well with the occurrence of the strong non-Io 'storms' and intensification of the solar wind ram pressure. Radio sources of the periodic bursts subcorotate with Jupiter and are probably located on high-latitude auroral field lines at both the northern and southern hemisphere.

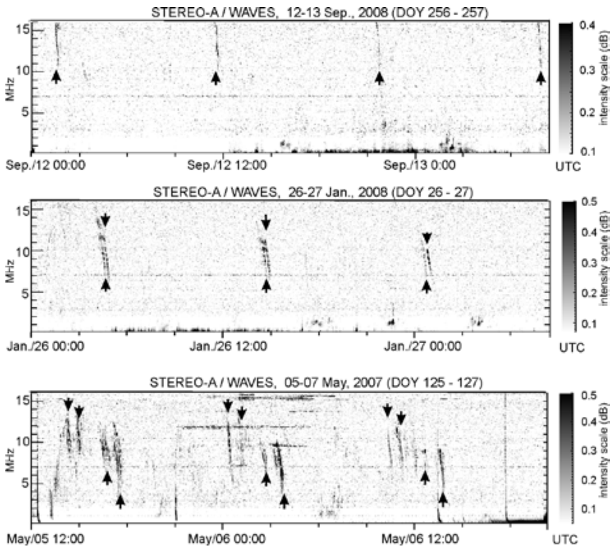

Fig. 4.12: Examples of the periodic burst observed by STEREO/WAVES.

4.5 Saturn

Saturn is the second largest planet in the solar system. This planet has one of the most dipole like magnetic fields in the solar system, with the dipole moment almost perfectly aligned with its rotational axis.

Cassini

The Cassini mission will continue to orbit Saturn until 2017. NASA has extended the duration of its successful flagship mission, and since September 2010 Cassini is in the so-called solstice mission phase.

Physics

Saturn narrowband (NB) emissions: The electromagnetic NB emissions are a powerful radio component that is measured by Cassini's *Radio and Plasma Wave Science* (RPWS) instrument near Saturn. NB emissions can be detected from 3 to 70 kHz with occurrence probability and intensity peaking at 5 kHz and 20 kHz. Passages of the spacecraft through the source region of the 20 kHz component have shown that it is generated by mode conversion of electrostatic upper hybrid waves on the boundary of Saturn's plasma torus. However, for the 5 kHz NB component, radio wave direction finding rather points to the auroral region as radio source.

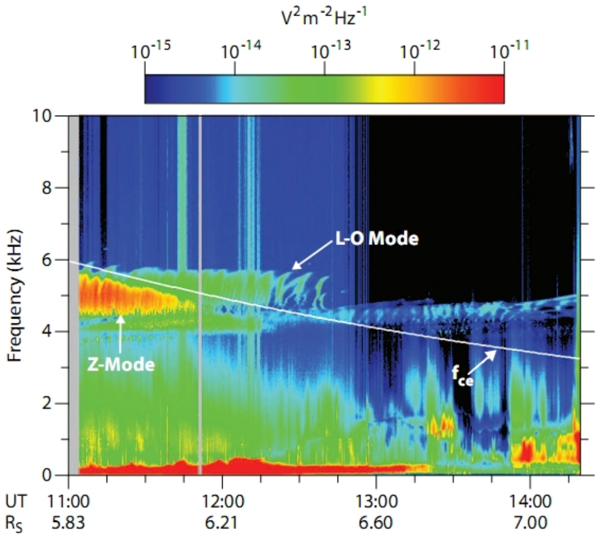

Fig. 4.13: 5 kHz Saturn narrowband emission observed by Cassini RPWS on October 17, 2008, below (Z mode) and above (L-O mode) the electron cyclotron frequency f_{ce}.

Fig. 4.13 shows 5 kHz emission, detected below and above the electron cyclotron frequency f_{ce} which is indicated by a white line. Polarization measurements have shown that it is in the Z mode which is trapped. However, it can mode-convert to the so-called L-O mode and then propagate to the spacecraft with an intensity that is reduced by 20 dB compared to the Z mode.

Lightning on Saturn: One of the recent highlights was the first optical detection of visible lightning flashes in August 2009. The Cassini camera made this detection on Saturn's night side during equinox when the ring-shine was at minimum. The size of the spots (see Fig. 4.14) has revealed a depth of the lightning source about 125 to 250 km below the cloud tops, most likely in the water clouds. From the brightness of the spots an optical energy of 10^9 J was derived corresponding to the total energy of a terrestrial flash. The optical detection was made in parallel with the detection of lightning radio signatures, the Saturn Electrostatic Discharges (SEDs).

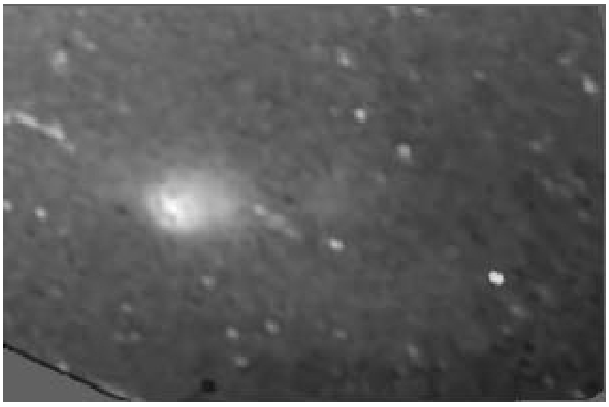

Fig. 4.14: An optical lightning flash detected by the Cassini camera on Saturn's night side on August 17, 2009. The center of the image is at 36° south and 11° west, and it spans a region of 3.5° in longitude (2900 km) and 2.0° in latitude (2000 km). The flash is the bright white spot with a size of a few hundred kilometers, whereas the small spots are due to cosmic ray hits.

The SED radio waves were used as a natural tool to probe Saturn's ionosphere and to retrieve its peak electron densities. It was found that the electron density at noon is above $10^5\,cm^{-3}$ and that its diurnal variation is 1-2 orders of magnitude which is smaller than the variation found by Voyager 1.

4.6 Comets

Comets are the most primitive objects in the solar system, which may have kept a record of the physical and chemical processes that occurred during the early stages of the evolution of our Sun and solar system. The knowledge of comets has dramatically improved over the last 20 years. Major milestones were the first fly-bys of Comet Halley by ESA's Giotto and the Russian Vega probes in 1986. Rosetta will be another milestone when it arrives at comet Churyumov-Gerasimenko in 2014 as this mission consists of both an orbiter and a lander.

Rosetta: ESA's *Rosetta* probe continues its journey to comet Churyumov-Gerasimenko, where it will arrive in 2014 to investigate the evolution of the comet during its approach to the Sun 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 soil strength of the cometary surface.

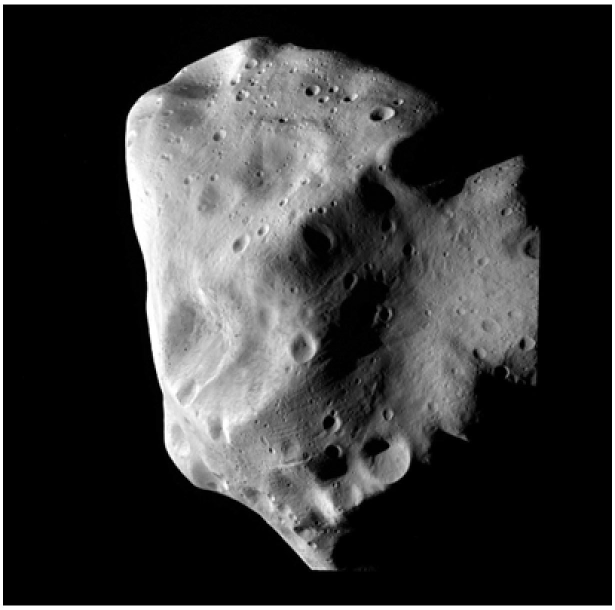

Fig. 4.15: Asteroid (21) Lutetia at closest approach.

The second and last flyby of the Rosetta mission at asteroid (21) Lutetia (Fig. 4.15) was conducted as planned on 10 July 2010. The spacecraft went through the delicate mission phase without any problem and all of the planned operations were executed.

About four hours before closest approach, the spacecraft performed a flip manoeuvre to acquire the correct attitude before the flyby and the spacecraft was readied to enter Asteroid Flyby Mode. The MIDAS instrument was operated during the asteroid flyby as was the Philae Lander with most of the instruments

4.7 Exoplanets

Exoplanets, i.e. planets in orbit around other stars than our Sun, are being detected regularly now with various missions like *CoRoT*. As of 11 November the number of detected exoplanets is 496, among which some super

Earths, e.g. Gliese 581 c, the most Earth-like planet at about 6 times the mass of the Earth.

Exoplanet-star plasma interaction: The stellar wind generated ENA-population is modelled around various magnetic obstacles for reproducing hydrogen-cloud observations in UV Lyman-α absorption around the exosolar gas giant HD 209458b (Fig. 4.16, top panel). Attenuation spectra obtained for transiting hydrogen-rich close-in gas giants can be used for gaining knowledge of the upper atmosphere structure, the planet's magnetosphere and stellar wind properties. A generalised paraboloid magnetosphere model has been developed, which includes the influence of magnetodisks in shaping the magnetospheres of exoplanets (bottom Fig. 4.16).

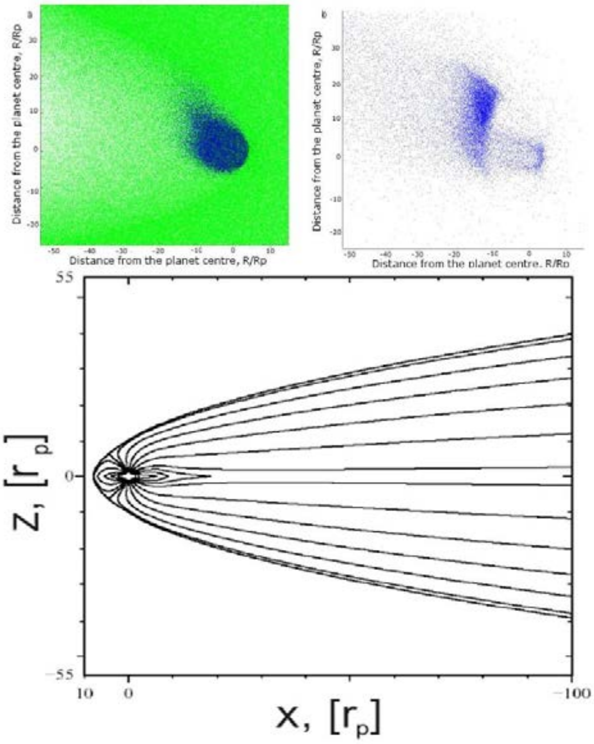

Fig. 4.16: (Top) Modelled stellar wind protons (green), planetary and hydrogen atoms (blue) around HD 209458b with an assumed magnetopause obstacle at 4.3 planetary radii, corresponding to a magnetic dynamo of about 0.4MJup which best fits Ly-α HST/STIS observations. (Bottom) Magnetic field line structure in the ZX-plane (ϕ = 0 plane).

5 Testing & Manufacturing

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.

Vacuum Chambers

The *Small Vacuum Chamber* is a manually controlled, cylindrical vacuum chamber (160 mm diameter, 300 mm length) for small electronic components or printed circuit boards. The system features a turbo molecular pump and a rotary dry scroll forepump. A pressure level of 10^{-10} mbar can be achieved.

The *Large Vacuum Chamber* features a stainless steel body and door with a horizontal cylindrical configuration, a vision panel, two turbo molecular pumps and a dry scroll forepump. A pressure of 10^{-7} mbar can be achieved. The cylinder has a diameter of 650 mm and a length of 1650 mm. During shutdown the chamber is vented with nitrogen. A target manipulator inside the chamber allows for computer-controlled rotation of the target around three mutually independent perpendicular axes. The vacuum chamber is enclosed by a permalloy layer for magnetic shielding. In order to enable the baking of structures and components to outgas volatile products and unwanted contaminations, the chamber is equipped with a heater placed symmetrically around the circumference.

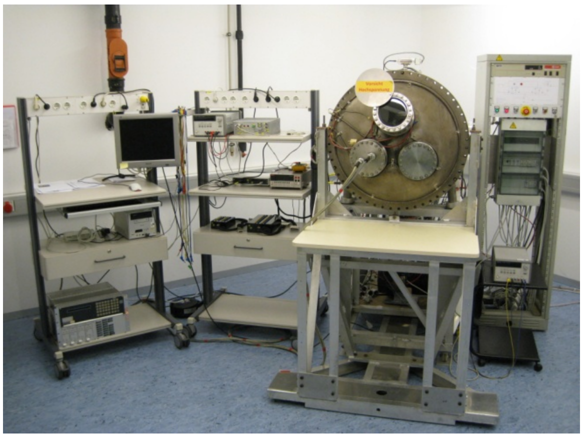

Fig. 5.1: Set-up for the ion gun connected to a vacuum chamber.

The *Thermal Vacuum Chamber* is fitted with a turbo molecular pump, a dry scroll forepump, and an ion getter pump, which together achieve a pressure level of 10^{-6} mbar and allow a quick change of components or devices to be tested. A thermal plate installed in the chamber and the use of nitrogen allow for thermal cycling in a temperature range between −90 °C and +140 °C. The vertically oriented cylindrical chamber allows a maximum experiment diameter of 410 mm and a maximum height of 320 mm.

The *Surface Laboratory Chamber,* dedicated to surface science research is cooled with liquid nitrogen. It has a diameter of 400 mm and a height of 400 mm, extendable to 800 and 1200 mm. Two rotary vane pumps and one turbo-molecular pump achieve a minimum pressure of 10^{-5} mbar.

The *Sample Chamber* contains an 8 µ particle filter and allows measurements of grain sample electrical permittivity. One rotary vane pump achieves a minimum pressure of 10^{-3} mbar.

Other Test Facilities

The *Temperature Test Chamber* 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.

The *Penetrometry Test Stand* is designed to measure mechanical soil properties, like bearing strength.

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

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

The *Magnetometer Temperature Test Facility* is used to test magnetic field sensors between -170 °C and +220 °C in a low field and low noise environment. Liquid nitrogen is the base substance for the regulation which is accurate to +/-0.1°C. A magnetic field of up to +/-100000 nT can be applied to the sensor during the test cycles.

Flight Hardware Production

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

Clean Bench: The laminar flow clean bench 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 internal dimensions are 1.18 x 0.60 x 0.56 metres.

Vapour Phase and IR Soldering Machine: The vapour phase soldering machine is suitable for mid size volume production. The maximum board size is 340 x 300 x 80 mm. Vapour phase soldering is currently the most flexible, simplest and most reliable method of soldering. It is ideally suited for all types of surface mounted device (SMD) components and base materials. It allows processing of all components without the need of any complicated calculations or having to maintain temperature profiles. For placing of fine pitch parts and rework of electronic boards an infrared soldering and precision placing system is utilised.

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 2010 and in the current winter term 2010/2011 the following lectures are given:

KFU Graz

Hydrodynamics (Biernat)

Magnetism and the Earth's magnetic field (Biernat)

Plasma Theory (Basics) (Biernat)

Plasmatheoretical Instabilities (Biernat)

Solar Wind - Magnetospheres - Ionospheres - Modelling (Biernat)

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

Introduction to Planetology (Kömle)

Astrophysical Data Analysis (Miklenic)

Introduction to Plasma Physics (Rucker)

Practical Course in Space Physics and Aeronomy (Rucker, Kargl, Biernat)

Practical Course in Astronomy (Voller, Weingrill)

TU Graz

Signal Processor Techniques (Magnes)

Active Plasma Experiments in Space (Torkar)

Measurement of Planetary and Interplanetary Magnetic Fields (Schwingenschuh)

JKU Linz

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

Advanced Course

The two-years post-graduate university course Space Sciences in cooperation with both KFU Graz and TU Graz leads to the internationally acknowledged Master of Science (MSc) "Space Sciences." Several members of IWF are lecturers of this inter-university course led by H.O. Rucker, which continued in 2010. A new Master studies curriculum has been prepared and finalized within the frame of the NAWI Graz (KFU Graz and TU Graz) "Space Sciences and Earth from Space" starting in 2011 at both universities.

7.2 Theses

Besides lecturing, members of the institute are supervising Bacherlor, Diploma, Master and Doctoral Theses. In 2010, the following theses have been completed:

Döller, R.: On electromagnetic emissions as earthquake precursors: Investigation of electric field measurements onboard DEMETER micro-satellite, Diploma Thesis, Karl-Franzens-Universität, Graz, 105 p., 2010.

Nakamura, R.: Flux transport and current sheet dynamics in the Earth's magnetotail, Habilitation Thesis, Karl-Franzens-Universität, Graz, 223 p., 2010

Oswald, T.: Antennas in plasma: Numerical calculation, Doctoral Thesis, Karl-Franzens-Universität Graz, 164 p., 2010

Rott, R., Reconnection events in the near-Earth magnetotail using Cluster data, Diploma Thesis, Technische Universität Graz, 88 p., 2010.

Sampl, M.: Experimental and numerical antenna calibration in the Resonance mission, Master Thesis, Karl-Franzens-Universität Graz, 71 p., 2010

Seiß, M. & Pachler, W.: Graz kHz SLR LIDAR, Bachelor Thesis, Technische Universität Graz, 67 p., 2010.

7.3 Meetings

From 13 to 15 September the 7th Science Working Team Meeting of the ESA/JAXA-Mission BepiColombo was hosted by the institute at Schloss Seggau with over 80 participants from all over the world.

From 15 to 17 September the PRE VII – Planetary, Solar and Heliospheric Radio Emissions meeting was held at the Meerscheinschlössl in Graz. The meeting was organized by Helmut Rucker and Georg Fischer and over 80 international scientists attended this meeting.

Also, M.Y. Boudjada, G. Fischer, G. Kargl, M.L. Khodachenko, H. Lammer, C. Möstl, R. Nakamura and H.O. Rucker organised 20 sessions at international meetings.

7.4 Awards and Recognition

Hans Sünkel received the „Großer Josef Krainer Preis“ for the project "Kooperation NAWI Graz" (Fig. 7.1) and was elected member of the Academia Europaea.

Fig. 7.1: The Josef Krainer Preis award ceremony

Wolfgang Baumjohann was elected as a member of the German National Academy of Sciences Leopoldina.

Furthermore, Gunter Laky, Klaus Torkar and Tielong Zhang received the „Laurel Award for Team Achievement“ (Double Star and Cluster Team) from the International Academy of Astronautics (IAA).

Fig. 7.2: Laurel Award ceremony with Tielong Zhang (third from the lef)t.

Georg Fischer was elected as Co-Investigator on the RPSW experiment on *Cassini.*

Rumi Nakamura was appointed Dozent at the Karl-Franzens Universität, Graz.

Tielong Zhang was elected corresponding member of the International Academy of Astronautics and was appointed Adjunct Professor at the University of Science and Technology in Hefei, China.

7.5 Public Outreach

In the summer the “Graz in Space Summer University 2010” was held at the Karl-Franzens University. Several members of IWF gave lectures on contemporary topics in space physics. The event was attended by approximately 45 students.

On two Fridays (8 and 15 October) IWF participated in the science network GrenzGenial. “Young scientists” from 10 to 12 years old could learn about the solar system and even drive a model of a Mars rover. Several school classes and many individuals showed up at the institute to play with and experience physics.

Fig. 7.3: Launch of a soda-candy powered rocket during GrenzGenial.

IWF members also supported the organization of several exhibitions:

- *Nordberg: Der Weg in den Weltraum*, in the Gerberhaus at Fehring
- *Orientierungen – der Blick zum Himmel gestern und heute* in the Pauluskapelle of the Basilika at Mariatrost
- *Strahlung – der ausgesetzte Mensch* at Schloss Pöllau

During summer time, three highschool students took the opportunity to perform an internship at IWF under the „Generation Innovation" programme, which is funded by the Austrian Reseach Promotion Agency (FFG). They studied photochemical processes in planetary atmospheres; the search for extraterrestrial planets; and GPS campaigns for Google-Maps.

8 Personnel

Alexandrova, Alexandra, MSc (P)
Amerstorfer, Ute, Dr. (P)
Aydogar, Özer, Dipl.-Ing. (E)
Baumjohann, Wolfgang, Prof. (E)
Baur, Oliver, Dr. (S)
Bentley, Mark, Dr. (P)
Berghofer, Gerhard, Ing. (E)
Besser, Bruno P., Dr. (E)
Biernat, Helfried K., Prof. (P)
Boudjada, Mohammed Y., Dr. (P)
Crailsheim, Hartwig, Dipl.-Ing. (E)
Delva, Magda, Dr. (E)
Du, Jian, PhD (E)
Eichelberger, Hans U., Dipl.-Ing. (E)
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)
Hagen, Christian, Dipl.-Ing. (E)
Hartl, Harald, Dr. (E)
Hasiba, Johann, Dipl.-Ing. (E)
Hausleitner, Walter, Dr. (S)
Höck, Eduard, Dipl.-Ing. (S)
Hütter, Erika, Mag. (P)
Jernej, Irmgard, Ing. (E)
Jeszenszky, Harald, Dipl.-Ing. (E)
Kargl, Günter, Dr. (P)
Khodachenko, Maxim L., Dr. (P)
Kirchner, Georg, Dr. (S)
Koidl, Franz, Ing. (S)
Korovinskiy, Daniil, Dr. (P)
Kögler, Gerald (A)
Kömle, Norbert I., Doz. (P)
Krauss, Sandro, Dipl.-Ing. (S)
Kucharski, Daniel, Dr. (S)
Kürbisch, Christoph, Ing. (E)
Laky, Gunter, Dipl.-Ing. (E)
Lammer, Helmut, Dr. (P)
Leichtfried, Mario (E)
Lichtenegger, Herbert I.M., Dr. (E)
Macher, Wolfgang, Dr. (P)
Magnes, Werner, Dr. (E)
Maier, Andrea, Dipl.-Ing. (S)
Močnik, Karl, Dr. (E)
Möstl, Christian, Dr. (P)
Nakamura, Rumi, Doz. (P)
Neukirchner, Sonja, Ing. (E)
Nischelwitzer-Fennes, Ute, Ing. (E)
Ottacher, Harald, Dipl.-Ing. (E)
Panchenko, Mykhaylo, Dr. (P)
Panov, Evgeny, Dr. (E)
Prattes, Gustav, Dipl.-Ing. (E)
Pregetter, Richard (E)
Rucker, Helmut O., Prof. (P)
Sampl, Manfred, Dipl.-Ing. (P)
Samsonov, Andrey, Dr. (P)
Scherf, Manuel, Mag. (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)
Stiegler, Alexander, (P)
Stieninger, Reinhard, Ing. (S)
Stöckler, Robert (P)
Sünkel, Hans, Prof. (S, BMWF)
Teh, Wai-Leong, Dr. (P)
Topf, Florian (P)
Torkar, Klaus M., Prof. (E)
Valavanoglou, Aris, Dipl.-Ing. (E)
Voller, Wolfgang G., Mag. (P)
Volwerk, Martin, Dr. (E)
Voronezhskaya, Anna (A)
Wallner, Robert, Ing. (E)
Wang, Rongsheng, Dr. (E)
Weingrill, Jörg, Mag. (S)
Zaqarashvili, Teimuraz, Dr. (P)
Zehetleitner, Sigrid, Mag. (A)
Zhang, Tie-Long, Prof. (E)
Zieger, Bertalan, Dr. (E)

As of 31 December 2010

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