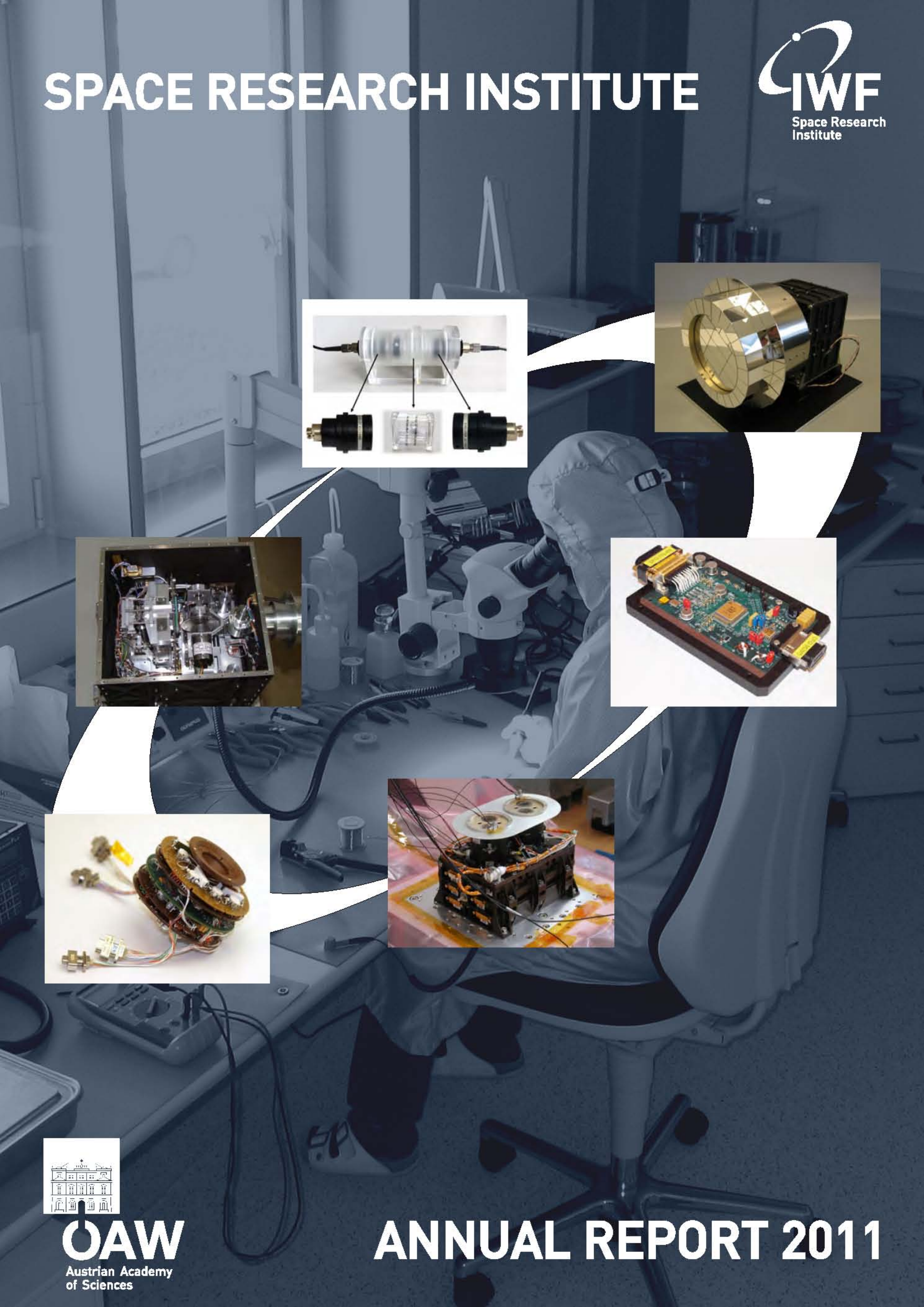
SPACE RESEARCH INSTITUTE

IWF
Space Research Institute



ÖAW
Austrian Academy of Sciences

ANNUAL REPORT 2011

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SPACE RESEARCH INSTITUTE GRAZ
AUSTRIAN ACADEMY OF SCIENCES

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Cover Image:

IWF Graz currently analyses data from instruments it has built for nine international space missions that presently are active and in orbit. Instruments for another six future missions are being developed. The cover shows PICAM (BepiColombo), DFG, ASPOC & EDI (MMS), MIDAS (Rosetta) and CDSM (clockwise, starting top right).

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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 be launched in 2015 to investigate planet Mercury, using two orbiters specialized in magnetospheric studies and in remote sensing of the planet.
- *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 was launched in August 2011 (Fig. 1).
- *MMS* will use four identically equipped spacecraft to explore the acceleration processes that govern the dynamics of the Earth's magnetosphere. It is scheduled for launch in 2014.

Fig. 1: An Atlas V rocket blasts off carrying NASA's Juno mission at Kennedy Space Center, on 5 August 2011 (Credit: Patrick H. Corkery/United Launch Alliance).

- *RBSP (Radiation Belt Storm Probes)* are two NASA spacecraft that will quantify processes in the Earth's radiation belts, planned for launch in 2012.
- *Resonance* is a Russian space mission of four identical spacecraft, orbiting partially within the same magnetic flux tube, scheduled for launch in 2015.
- *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's distance, but about 120° ahead and behind Earth 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.

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 2011:

- On Saturn the largest thunderstorm of the solar system was observed with lightning rates one order of magnitude larger than previously measured.
- Using a Hall-MHD reconstruction technique on *Cluster* data near a reconnection event, evidence was found for electron current loops producing the Hall magnetic field.
- High-resolution gravity field models from 18 months of *GOCE* data have been released.

The year 2011 in numbers: Members of the institute published almost 130 papers in refereed international journals, of which 38 were first author publications. During the same period, articles with authors from the institute were cited more than 2700 times in the international literature. In addition, over 230 talks and posters have been presented at international conferences by members of the IWF, including 19 by special invitation from the conveners. In national and international press media, IWF was mentioned over 300 times, institute members more than 400 times. Last but not least, institute members organized 21 sessions at international meetings.

IWF structure and funding: IWF is, as a heritage since foundation, structured into three departments:

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

Wolfgang Baumjohann serves as Managing Director. 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 the three departments. Staff members from different departments work successfully together in six research fields (Fig. 2).

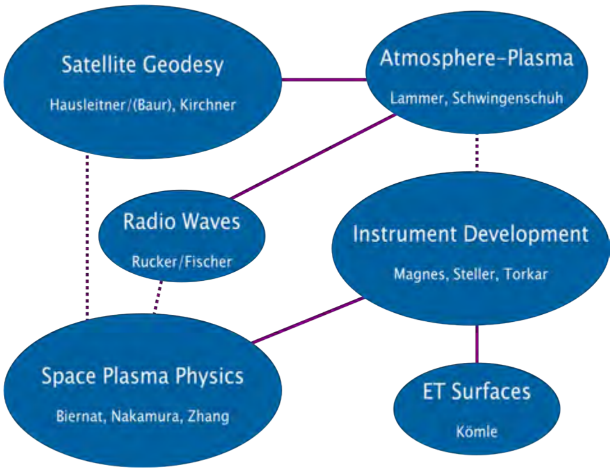

Fig. 2: IWF research fields and group leaders.

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

Solid Earth

The dynamics of the solid Earth, the oceans and the atmosphere are key factors for global change processes. Space based observation concepts are indispensable for gaining knowledge about these complex processes on a global scale. Accordingly sophisticated space-geodetic techniques are necessary to fully exploit the scientific information of Earth exploring mission data.

IWF is concerned with the analysis of these data especially focusing on the determination of the Earth's gravity field, crustal dynamics, selected studies of the Earth's atmosphere and ionosphere as well as satellite laser ranging to Earth orbiting spacecraft.

Static Gravity Field

The gravity field of the Earth is the sum of the gravitational and centrifugal force, with the first being the response to the Earth's interior density distribution, and the latter caused by its rotation. Its physical representation is given by a virtual surface at mean sea level called the geoid. This is the surface of equal gravity 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)* aims at a high-accuracy and high-resolution model of the Earth's static gravity field. Based on a sensor fusion concept the satellite's orbit information is exploited by GPS applying satellite-to-satellite tracking in high-low mode (hl-SST), delivering the long and medium wavelengths of the gravity field, while Satellite Gravity Gradiometry (SGG) provides its detailed structure (see Fig. 3). Since its launch in 2009 the satellite has delivered a wealth of hundreds of millions of gravity field observations.

Fig. 3: Artists view of satellite in orbit and evolution of geoid models from early stages (top) over CHAMP and GRACE to GOCE's detailed resolution (bottom).

Data Processing: Within the 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 has been set up by a European consortium. The computation of a spherical harmonic Earth's gravity field model and its corresponding full variance-covariance matrix from the satellite's measurement data is performed by the *GOCE* team Graz, which is a co-operation of IWF with the Institute of Theoretical and Satellite Geodesy of the Graz University of Technology (TU Graz).

GOCE gravity field models: Release 3 of the timewise *GOCE*-only gravity field model comprises the data from the nominal mission period from November 2009 until April 2011.

The full SGG normal equations complete to degree/order 250 have been assembled on a supercomputing cluster of TU Graz using the tensor components V_{xx}, V_{yy}, V_{zz} and additionally the off-diagonal component V_{xz}, which corresponds to about 120 million gradiometry observations. Finally, the combined solution was processed using an energy balance principle derived from SST solution of degree and order (d/o) 100 and the resultant d/o 250 SGG normal equations, applying regularization and optimum weighting.

Kaula regularization was applied to selected groups of coefficients. They comprise all zonal and near-zonal coefficients affected by the polar gap, due to the sun synchronicity of the orbit. Additionally, coefficients with degrees larger than 180 have been regularized in order to improve the signal-to-noise ratio in the very high degrees. This solution is Kaula constrained towards a zero model.

This *GOCE*-only model delivers new characteristic features and details of the Earth's static gravity field compared to already existing global models. On the one hand, it clearly identifies terrestrial areas of previously poor quality (e.g. South America, and especially Antarctica), and on the other side its finer resolution brings a more detailed view even to well observed areas, e.g. near coastal zones (see Fig. 4 for a gravity anomaly plot).

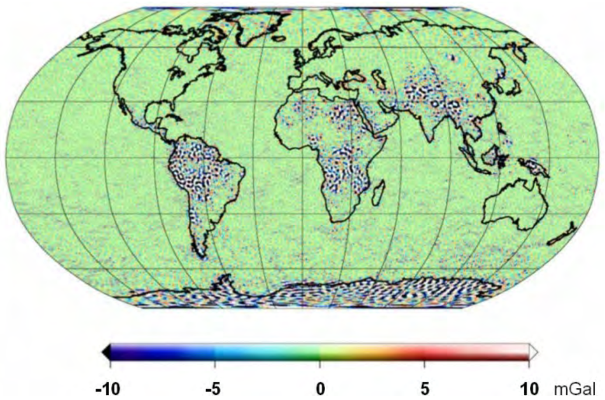

Fig. 4: Gravity anomaly differences at d/o 200 compared to EGM2008.

Comparing the three already computed releases of the *GOCE* models in terms of their error behavior nicely demonstrates the "one over square root number of measurements" rule of improvement. Fig. 5 depicts the series of the error covariance propagation to geoid heights for the three releases. The first release contained about two months of data, the second about six, and the latest 12 months of processed SGG data. The rms values are correspondingly decreasing from about 10 cm rms to nearly 7 cm and below 5 cm for the latest release. Projecting this onto the measurement lifetime of the satellite till the end of 2012 this yields a geoid height error at d/o 200 to be expected between 2 and 3 cm.

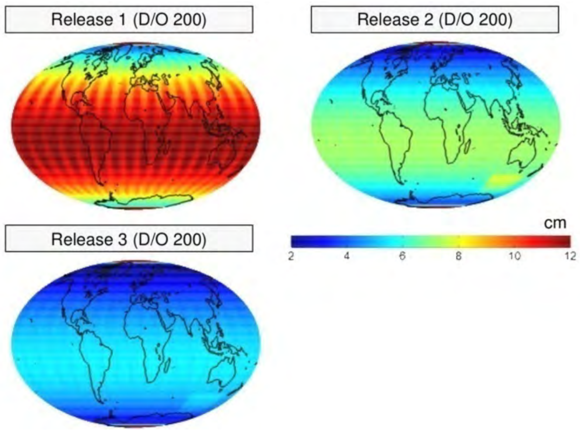

Fig. 5: Geoid height error estimates from covariance propagation (d/o 200) for the 3 gravity field releases.

Combined gravity field models: In the last decade, the dedicated space missions *CHAMP (CHAllenging Minisatellite Payload)*, *GRACE (Gravity Recovery and Climate Experiment)*, and *GOCE* provided outstanding information on the terrestrial gravity field. The objective of the *GOCO (Gravity Observations COmbination)* project is to consistently analyze this data together with observations provided by Satellite Laser Ranging (SLR), satellite altimetry, and ground measurements. IWF is responsible for the SLR component, i.e., the recovery of the very long-wavelength gravity field features (see next section for more details). The *GOCO* consortium is composed of scientific institutions in Germany, Switzerland, and Austria. The latest release of the *GOCO* gravity field series is the satellite-only *GOCO02S* model.

Variable Gravity Field

GRACE

Time-variable gravity: Since 2002, the *GRACE* mission allows the spatio-temporal determination of global mass variations, such as deglaciation in the cryosphere, from changes in the Earth gravitational pull. Mass transport in the Earth's system is one of the main indicators of present-day global climate change, most notably with regard to sea-level variation estimates and forecasts.

Uniform sea-level modeling translates mass gain or mass loss over land areas to homogeneous water changes over the world's oceans. Consequently, each mass-variation region of interest either contributes to sea-level rise (caused by continental mass loss) or sea-level fall (caused by continental mass gain).

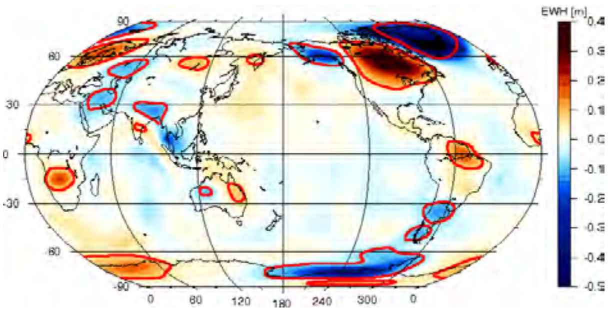

Fig. 6: Secular trends in terms of equivalent water height (EWH) from May 2002 to April 2011. Delineated areas indicate the regions with dominant signal.

To assess land-hydrological mass changes on a global scale, we quantified mass-change trends in 20 continental areas that exhibit a dominant signal (Fig. 6). During the nine-year period May 2002 to April 2011, mass gain and mass loss in these areas contributed, on average, to $-(0.79\pm0.25)$ mm/yr of uniform sea-level fall and $+(1.80\pm0.18)$ mm/yr of uniform sea-level rise, respectively. The net effect was $+(1.01\pm0.31)$ mm/yr. Ice melting over Greenland, Antarctica, Alaska and Patagonia was responsible for $+(1.28\pm0.18)$ mm/yr of the total balance. Hence, land-water mass accumulation compensated about 20% of the impact of ice-melt water influx to the oceans. Note that these rates have been corrected for glacial isostatic adjustment.

SLR-derived low order zonals: In the framework of the computation of the new combined satellite-only gravity field model *GOCO02S*, the long wavelengths of the Earth's gravity field have been determined with SLR data. Measurements to five geodetic satellites, namely *LAGEOS-1*, *LAGEOS-2*, *Ajisai*, *Stella*, and *Starlette*, over a period of five years (2006 to 2010) were analyzed. Fig. 7 depicts the spatial distribution of observations to the named spacecraft. There are large data gaps over oceanic areas and the polar regions.

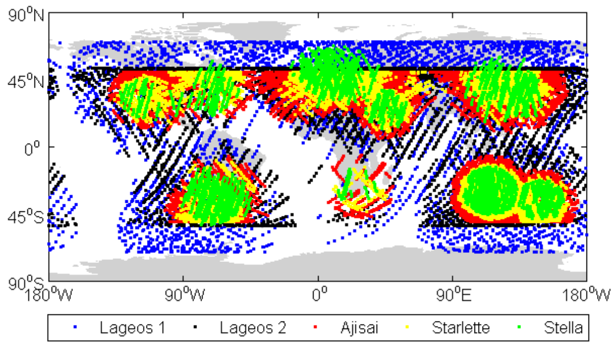

Fig. 7: Spatial distribution of observed ground tracks in January, 2007.

The Earth's gravity field can be described by means of spherical harmonic coefficients. SLR is the ideal measurement technique to recover the J2 term, which represents the Earth's flattening. Its precise estimation is crucial as this coefficient is about two orders of magnitude higher than all other coefficients. Closed-loop simulations showed that the normal equation system is ill-conditioned due to spatial data gaps and the high altitude of geodetic satellites. Thus, a small set of coefficients (up to degree and order 5) has been estimated from real data. To detect temporal changes, coefficients were computed on a monthly basis.

To visualize the temporal changes of the estimated zonal coefficients, i.e. order-zero terms, the geographical latitude was divided into an equatorial band, mid-latitude bands and polar bands. Fig. 8 shows the average geoid change per band. The result indicates that a large-scale mass redistribution from the poles to the equator has taken place during the five-year investigation period.

The SLR contribution to *GOCO02S* corresponds to the mean of all monthly sets of spherical harmonic coefficients, averaged over the five-year period.

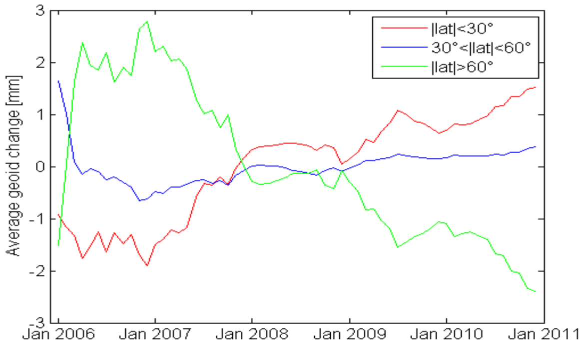

Fig. 8: Variations of spatially averaged geoid height in the equatorial band (red line), in the mid-latitude bands (blue line), and in the polar bands (green line).

Geodynamics

Velocity fields: Because all parts of the Earth are permanently changing no Earth-related position is constant with time. Velocity fields describe surface movements of well-defined stations. Because of the large number of stations, the mm-precision and the short time needed (usually 3 years), GNSS-derived velocities are preferred. The institute delivers velocity field solutions for parts of Africa, Asia and Europe, Europe, Central Europe, and Austria, with resolutions of about 1500, 200, 100 and 30 km. Velocity fields serve for dynamic references (e.g. in Austria) as well as for tectonic investigations (plates). Fig. 9 shows the network for Austria AMON with the vertical component, which was heavily improved in 2011.

Altimetry: Precise altimeter calibration is an essential prerequisite for providing reliable long-term information of ocean dynamics and sea-level variation. In close cooperation with the Technical University Crete and the altimeter instrumental science team of CNES, Toulouse, a long-term altimeter calibration campaign is performed using a dedicated microwave transponder. For every calibration cycle the onboard altimeter is switched to a special operation mode (DIODE/DEM) allowing for an absolute point target calibration at the instrument's full resolution of 20 Hz.

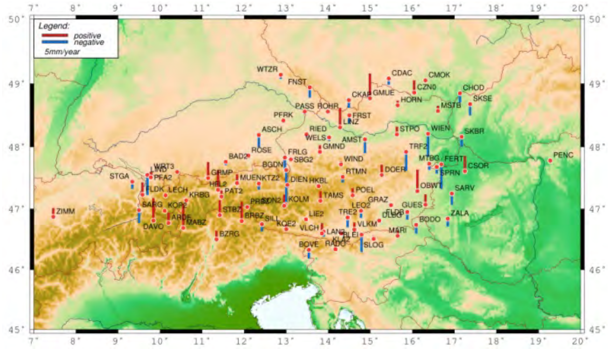

Fig. 9: Vertical velocities of AMON in Austria for the new Austrian geodetic reference.

Atmosphere

Atmospheric density: Coronal mass ejections (CME) and solar flares cause disturbances of the Earth's upper atmosphere leading to increased exobase densities and temperatures. High-precision accelerometers aboard of the *GRACE* spacecraft are used to investigate the variation of the neutral density. Taking into account the interaction between the satellite surface and the ambient atmosphere the total mass densities for a period of eight years (2003-2010) were determined. Presently, focus is on a X17.2 solar flare and the associated CME which occurred on 28 October 2003, and the impacting effects on the Earth's atmosphere.

Fig. 10 shows neutral densities from *GRACE* in a latitude-time plot during this period. Thereby, several irregularities appear which can be attributed to this geomagnetic storm. Shortly before 12:00 UT the first sudden density jump of approx. 60% compared to the preceding quiet density values is observed. Due to the elapsed time this increase can be related to the solar flare. The major impact appears 19 hours later, when the shock wave of the large CME disturbs the Earth's magnetic field. This leads to an increase of the neutral density of more than 300%. The lower feature in Fig. 10 shows a Traveling Atmospheric Disturbance (TAD) which propagates from high latitudes towards the equator within a few revolutions.

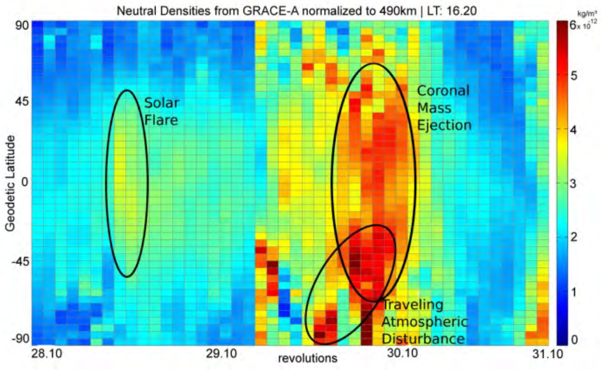

Fig. 10: Impact of the geomagnetic storm on the upper Earth atmosphere in terms of neutral densities determined from GRACE satellite accelerometers.2003 with constant (2.3) and variable drag coefficient.

Ionosphere: The ionosphere ranges from about 50-100 km to 2000 km. It is well known that the distribution of electrons has a sharp maximum between 300 and 450 km height where more than 90% of the Total Electron Content (TEC) is found. Because it is a dispersive medium radio waves split according to different frequencies. GNSS signals with at least two frequencies can be used to observe the ionosphere. From the different research areas IWF has specialized on positioning effects for Europe (mid-latitude), changes of the ionosphere in space and time as well as possible indicators of earthquakes in the ionosphere.

In 2011 a research project *GIOMO (next Generation near real-time IOnospheric MOdels)* was started to examine the existing models concerning their compliance with real conditions and their flexibility with respect to large disturbances, mainly originating from solar activity. The Klobuchar GPS-model shows a large disturbance where in reality there was none (Fig. 11). This figure also shows a significant bias between the "hardwired" models Klobuchar, Nequick (future Galileo), and those models which determine the TEC every 2 hours at least. The conclusion is that the "static" models derived from former solar cycles could be significantly improved by pure numeric models using permanent observations. Those models can also be used for alerts of sudden ionosphere impacts.

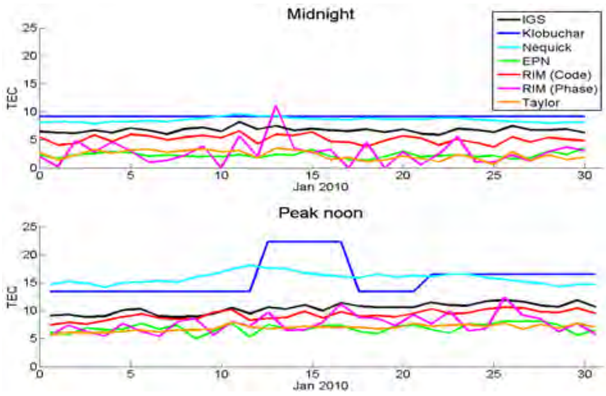

Fig. 11: Comparison of the TEC estimated by different ionosphere models twice a day (midnight lowest and peak noon highest) during January 2010.

Seismo-electromagnetism: The lithospheric-atmospheric-ionospheric coupling in the frame of the 2009 L'Aquila earthquake has been further investigated. In order to differentiate non-seismic from seismic events the influence of the solar and geomagnetic activity on the propagation of VLF signals from the ground to the *DEMETER* satellite has been analyzed. The low degree of correlation (less than 40%) allows us to conclude that the drop of VLF transmitter over seismic regions, as reported in several papers, may be related to the preparatory zone.

Recent GPS studies found earthquake anomaly enhancements in TEC measurements. Combining the ULF observations of three *SEGMA* stations, magnetic noise could be placed in the lithosphere due to tectonic mechanisms in the earthquake focus.

In the frame of the European VLF network for seismo-electro-magnetic studies the radio link between a transmitter in West-Turkey and Graz has been used to analyze earthquakes in the Balkan area with magnitudes below ML=5. It was found that multi-parameter studies are essential to analyze these weak earthquakes.

A future study will include ULF observations near Sofia/Bulgaria.

Satellite Laser Ranging

In preparation for the upcoming *GALILEO* satellite launches, the Graz SLR station was upgraded to track all available *GLONASS* satellites. It could be demonstrated that even with the low energy (400 µJ) of the Graz laser shots, at least 1000 returns can be accumulated within almost all 5-minute-bins from HEO satellites, day and night. The main upgrades were a new, polarization independent dichroic mirror in the main receiver telescope, and a new real-time algorithm to identify down to 0.1% good returns out of some MHz of noise during HEO daylight tracking. The accumulative result is an up to 10 times increased return rate (Fig. 12).

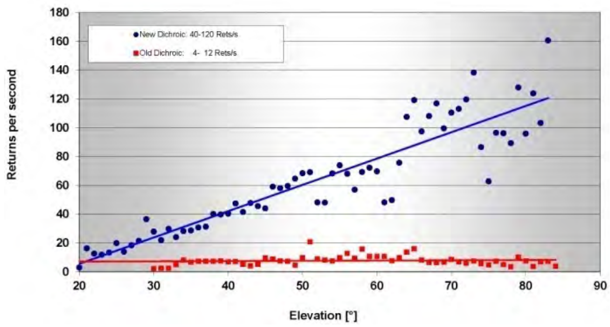

Fig. 12: Returns per second from Compass M1.

An experiment was set up to determine the influence of incident angle variations of the linearly polarized laser light on uncoated retro-reflectors, using the improved return signals. Theoretically, due to relativistic velocity aberration effects a range difference of up to a few mm is expected. Using a λ/4 wave plate, which is rotated every minute to switch the linear laser polarization plane parallel or perpendicular to the orbital velocity vector, this effect was demonstrated in a range from few mm down to about 0.2 mm (Fig. 13). To compensate this effect a λ/2 wave plate for circular beam polarization was installed.

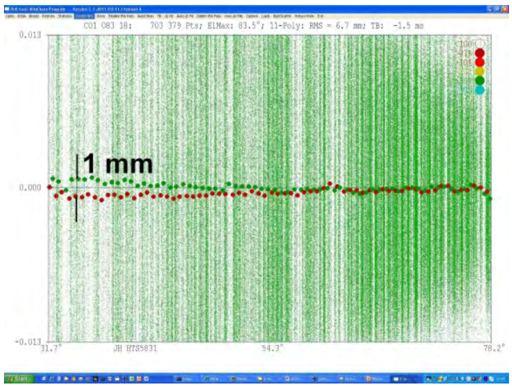

Fig. 13: Switching the orientation of the linear polarized laser beam along the orbit vector (red), or perpendicular to it (green) in 1-minute intervals, causes small changes in measured distances (due to relativistic velocity aberration effects); for the first time this could be measured and verified, down to about 0.2 mm.

The repetition rate is increased from 2 to 10 kHz. The advantages of higher repetition rates are not only an increase of data yield and accuracy, but also e.g. a much better spin phase determination of *Ajisai*, necessary for picosecond time transfer experiments via *Ajisai* mirrors, using these laser pulses.

Beyond that the LIDAR system was improved now allowing for measuring of clouds up to distances of more than 30 km.

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 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.

The Earth's magnetosphere and in particular the magnetotail are used as a natural laboratory for space plasma physics. The institute both builds instruments for satellite missions that make measurements in this natural laboratory and analyses the data obtained by them.

Missions

One of the important components of near-Earth space investigation at IWF is the active involvement in different missions throughout their entire phases, i.e., providing hardware, processing and analyzing the measured data, constructing new models, and participating in future planning.

The ongoing missions, *Cluster* and *THEMIS/ ARTEMIS*, are providing a wealth of exciting data which lead to many new scientific results. IWF is presently building advanced instruments for the upcoming *MMS* mission.

Cluster

The four *Cluster* spacecraft, launched in 2000, are to study small-scale structures of the magnetosphere and its environment in three dimensions. The spacecraft are taking data while circling the Earth in polar orbits. The separation distance of the spacecraft has been varied between 200 km and 10,000 km according to the key scientific regions. This ESA mission has been extended to 2014. IWF is PI of the spacecraft potential control and holds Co-I status on four more instruments.

THEMIS/ARTEMIS

The NASA mission *THEMIS (Time History of Events and Macroscale Interactions during Substorms)*, launched in 2007, is designed to explore the origin of magnetic storms and auroral phenomena. *THEMIS* flies five identical satellites through different regions of the magnetosphere. As Co-I institution of the magnetometer, IWF is participating in processing and analyzing data. 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 and magnetotail/solar wind from autumn 2010. The other three *THEMIS* spacecraft remained in their orbit to further study the 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 energize plasmas in thin boundary and current layers. *MMS* is scheduled for launch 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.

2011 was a critical year for the qualification of the instruments and the initiation of the production and test chain for the flight models. The final design of the units evolved in conjunction with intensive testing of prototypes and qualification units in parallel with refinements of the interface and verification requirements by Southwest Research Institute (SwRI), Goddard Space Flight Center (GSFC) and the University of New Hampshire (UNH).

Active Spacecraft Potential Control (ASPOC) instrument: IWF co-ordinated the design modifications of the ion emitters provided by FOTEC Wiener Neustadt and supported it by analyses. IWF re-integrated the Engineering-Qualification Model (EQM) electronics with the new emitters and successfully carried out all functional verifications followed by environmental testing. After vibration and shock testing at RUAG Space Austria GmbH (Fig. 14) a thermal cycling test in vacuum as well as a thermal balance test simulating the thermal environment during the mission was performed at IWF. Having completed the design qualification of *MMS ASPOC* in this way, green light was given to the manufacturing of the first flight models.

IWF – being responsible for the design of the digital processor board including its FPGA and all instrument and ground support software – programmed the flight FPGA's after intensive testing of the embedded code. Board level tests were performed by IWF after manufacturing of the boards by RUAG.

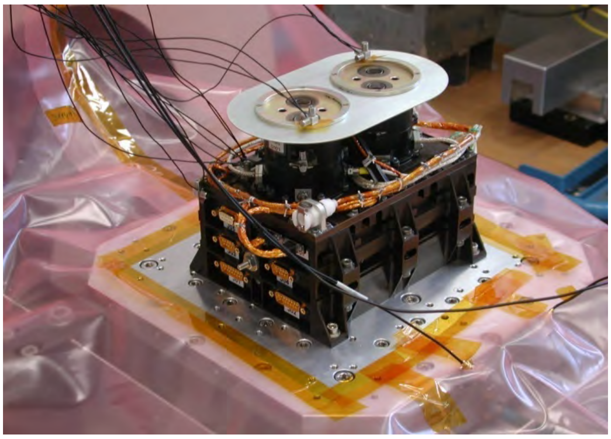

Fig. 14: Engineering-Qualification Model of ASPOC in the vibration test facility.

After the delivery of electronics and emitters for Flight Models 1 and 2, both units were integrated and functionally tested at IWF. After the Pre-Environmental Review conducted by GSFC the environmental testing could start. Vibration tests, thermal vacuum tests, and magnetic screening were performed. At the same time IWF programmed FPGA's for all remaining flight models and performed board level tests on three further controller boards.

Electron Drift Instrument (EDI): IWF contributes to *EDI* with the *Gun Detector Electronics (GDE)* and the electron gun (Fig. 15). 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. In 2011 the tests with the Engineering Model have been continued and successfully completed. For the thermal balance test, the fully assembled *GDU* has been operated at extremely low temperatures (−170°C) in the vacuum chamber.

In parallel the assembly and integration of the first two *EDI* gun flight models started. Minor design changes have been implemented to facilitate the assembly process and to improve the signal quality. The *EDI* gun electronics provides thirteen very accurate high voltage sources to supply the electron optics and the deflection system. The instrument emits a coded electron beam, steerable over 2π sr. The dense packing of the electronics (Fig. 15) and the presence of high voltage up to 4 kV demands high class workmanship for the assembly and integration process.

In January 2012 the calibrated *EDI* gun will be delivered to UNH for integration into the *GDU*. In parallel the assembly of the next two *EDI* guns will be performed.

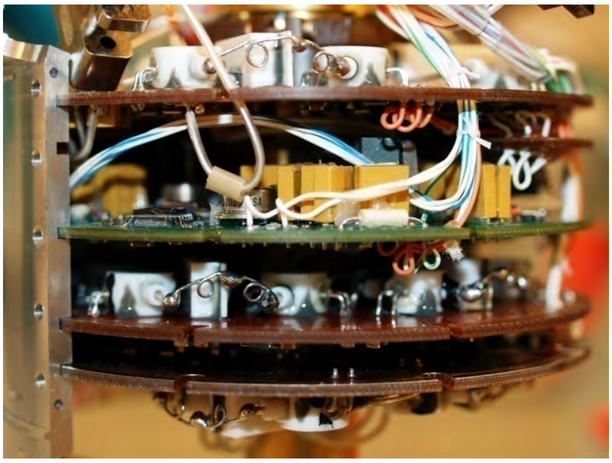

Fig. 15: The flight model of the EDI Gun electronics.

Digital Flux Gate magnetometer (DFG): *DFG* is based on a triaxial fluxgate sensor developed by UCLA 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 the first half of 2011, the first Flight Model (FM1) of *DFG* was assembled, calibrated and delivered. The noise level of the three sensor components is depicted in Fig. 16. All three axes are well below the required 10 pT/√Hz at 1 Hz. The integration of the FM electronics board into the Central Electronics Box of *FIELDS* took place in August 2011. At about the same time, the assembly and test of FMs 2 and 3 have been started. In parallel to the hardware activities, IWF has a leading role in the determination of the synchronous data acquisition of the three magnetic field sensors. It is done down to an accuracy level of 10 µs by test and modeling. Two test campaigns with the engineering models took place in 2011.

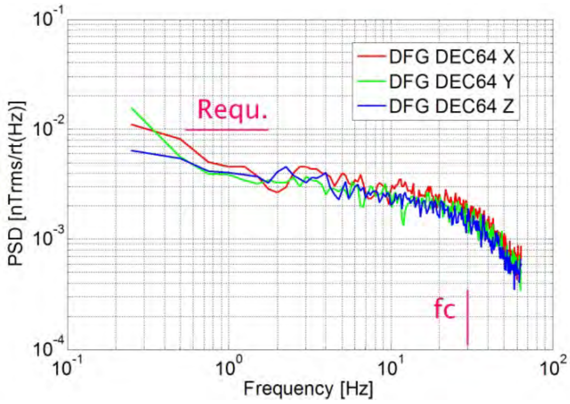

Fig. 16: Noise density plot of the DFG Flight Model 1 sensor components.

STEREO

STEREO/WAVES antenna calibration: The *STEREO/WAVES* experiment *(SWAVES)* onboard the two *STEREO* spacecraft measures the non-thermal radio spectrum from the solar environment, at frequencies between a few kHz and 16 MHz. Three orthogonal monopole antennas, each 6 m 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 maneuvers. 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.

Physics

At IWF various data from ongoing missions are analyzed 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 *Cluster* and *THEMIS,* and also other missions such as *Geotail*, *Double Star, Polar, GOES*, *Wind and Interball* and ground observations. The studies deal with large-scale interactions between solar wind and magnetosphere, meso-scale disturbances such as plasma flows and waves, and also plasma instabilities including magnetic reconnection.

Magnetospheric response to an interplanetary shock: Multipoint observations of an interplanetary shock's interaction with the Earth's magnetosphere are compared with results from global MHD simulations. The sudden impulse associated with the shock's arrival initiates global ultra-low frequency waves with periods from 2 to 5 minutes. It is suggested that these observations confirm the mode coupling theory. The interplanetary shock initiates compressional magnetospheric waves observed by *GOES 8* which oscillate between the ionosphere and magnetopause and gradually convert their energy into standing Alfvén waves. At the same time, *Polar* in the outer pre-dawn magnetosphere observed strong velocity oscillations and weak magnetic field oscillations with a ~4-min period. Global MHD models showed these oscillations and connected them to the Kelvin-Helmholtz instability which results in large flow vortices with sizes of about ten Earth radii. However, the global MHD models do not show the multiple compressional oscillations with the observed periods and therefore cannot readily explain the *GOES* observations.

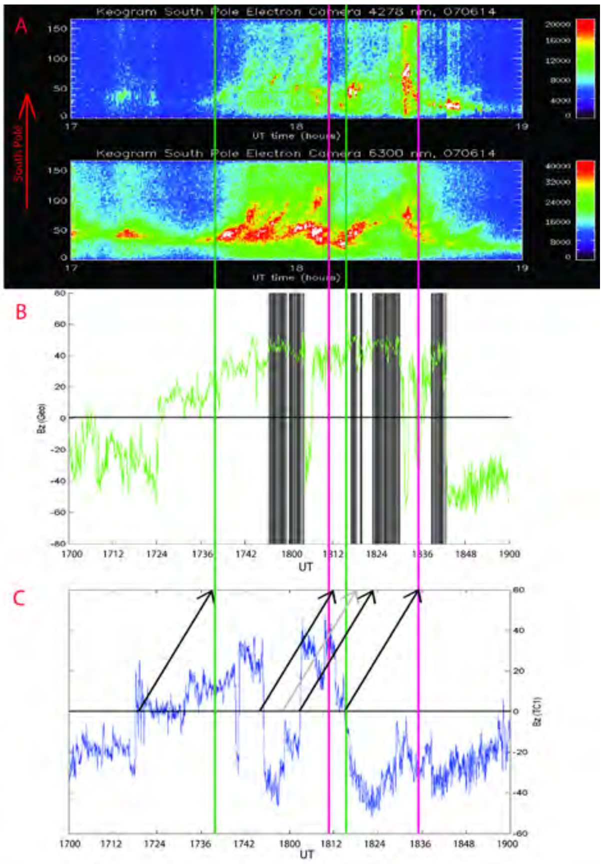

Fig. 17: (A) South-polar keograms for 4278 and 6300Å (B) Geotail Bz, black markings show intervals that the spacecraft is in the magnetosphere. (C) Double Star /TC1 Bz, with arrows pointing from Bz =0 crossing to change in aurora behaviour, showing the rapid response of the magnetosphere to the turning of Bz.

Magnetospheric response to IMF rotations: The interaction of interplanetary magnetic field (IMF) rotations with the Earth's magnetosphere is studied with full coverage over the dayside magnetosphere with multi-spacecraft missions from dawn to dusk, combined with ground based measurements. After a long period of southward IMF Bz and high dynamic pressure of the solar wind, the Earth's magnetosphere is eroded and compressed and reacts quickly to the turning of the magnetic field. It is found that the solar wind magnetic field drapes over the magnetopause, while still co-moving with the plasma flow at the flanks. The magnetopause reacts quickly to IMF Bz changes, setting up field aligned currents, poleward moving aurorae (Fig. 17) and strong ionospheric convection. Timing of the structures between the solar wind, magnetosheath and the ground shows that the advection time of the structures, using the solar wind velocity, correlates well with the timing differences between the spacecraft. The reaction time of the magnetopause and the ionospheric currents to changes in the magnetosheath Bz seem to be almost immediate, allowing for the advection of the structure measured by the spacecraft closest to the magnetopause.

The origin of Hall magnetic field for magnetic reconnection: In collisionless space plasmas, the two-scale diffusion region plays an important role in reconnection. In the ion diffusion region, the unmagnetized ions are decoupled from the magnetized electrons, thus causing an electron current flowing out of the reconnection region. This current closes the Hall current system. According to the Ampère's law, the resulting Hall current loops will generate the out-of-plane Hall magnetic field. *Cluster* observations of a reconnection event in the Earth's magnetotail are used in a newly developed Hall-MHD reconstruction technique. Evidence for the Hall electron current loops associated with the Hall magnetic field from reconnection is presented. The technique is to reconstruct two-dimensional pictures of a spatial field and plasma structure seen by a single spacecraft in the ion diffusion region.

Fig. 18 shows the reconstruction map of the magnetic field lines (black lines) and the electron streamlines (dashed white lines) with the out-of-plane magnetic field Bz in color for one *(C1)* of the four *Cluster* observations. The map demonstrates that the Hall magnetic field coded by the red is surrounded by the loops of the electron streamlines, which are the Hall current loops as predicted by the theory. In addition, the reconstructed electron current loops are confirmed by another *Cluster* satellite *(C2)* observations of electron velocity, in which the sign of the parallel electron velocity is reversed within the Hall magnetic field region.

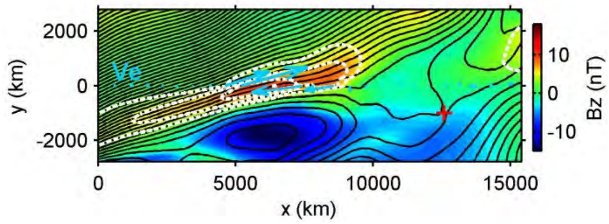

Fig. 18: Hall-MHD reconstruction map from C1 observations. The red plus denotes the magnetic X-point.

Kinetic effects of jet braking: Reconnection outflow jets in the Earth's magnetotail start to decelerate near Earth due to their interaction with the ambient plasma. Due to the magnetic flux pileup process ahead of the jet front, charged particles are accelerated through the betatron acceleration mechanism, which gives rise to the plasma higher temperatures perpendicular to the ambient magnetic field than parallel. Such ion temperature anisotropy would lead to the mirror instability provided that the effective plasma-β (the ratio between thermal and magnetic pressures) is sufficiently high. Such mirror mode structures with ion gyroradius-scales are identified for the first time in the pileup region ahead of a jet front based on *Cluster* observations (see Fig. 19).

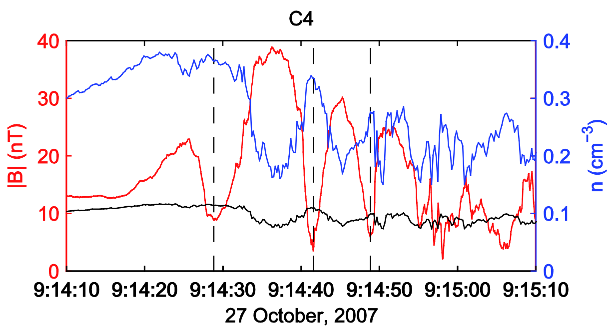

Fig. 19: Ion-scale mirror structure observed by Cluster. Black line indicates the linear mirror instability threshold in the ambient magnetic field.

Mirror modes generally appear as non-propagating magnetic holes or peaks that are in anti-correlation with the density variation, sustaining quasi-pressure balance. Ions are shown to be significantly heated within the mirror mode structure. Furthermore, evidence that non-linear mirror mode waves can steepen into shocklets is also found. These observations suggest that mirror mode structure as well as shocklets play an important role in transferring the plasma jet's kinetic energy into thermal energy.

Double-gradient magnetic instability in the magnetotail current sheet: Observations in the Earth's magnetotail current sheet indicate the presence of flapping oscillations. Wave perturbations propagate along the current sheet perpendicular to the magnetic fields, usually from the central part of the magnetotail toward the flanks. One theoretical approach for describing the flapping waves is the MHD "magnetic double-gradient mechanism". In this model the flapping mode appears due to the coexistence of two gradients of the magnetic field components across and along the current sheet, respectively.

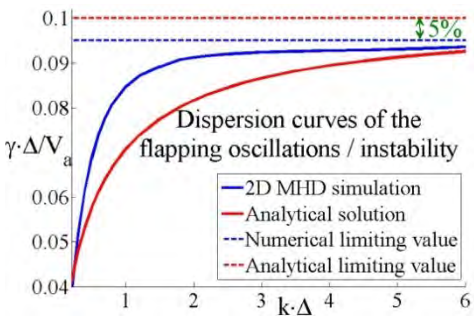

Fig. 20: Growth rate of the double-gradient magnetic instability γ as a function of the wave number k by 2D linearized MHD simulation and analytical solution. Here, Δ is the half-width of the sheet and V_a is the Alfvén velocity.

The model yields the flapping frequency determined by a (positive) product of two magnetic gradients. When this product is negative, the solution grows to the regime of instability. In this case, the dispersion curve depicts the dependence of the growth rate of the instability on the wave number. Linearized MHD numerical simulation is performed and compared with the analytical solution to confirm these gradient dependent characteristics of the oscillations as show in Fig. 20.

Study of Auroral Kilometric Radiation (AKR) source positions: The footpoint positions of AKR sources in the auroral oval were analyzed using data from the *Interball-2/Polrad* triaxial polarimeter. Each coordinate of the source positions for a two-hour data series – Invariant Latitude and Magnetic Local Time (MLT) pairs – were separately Fourier analyzed. Invariant latitude modulation with a period of about 9 minutes was found (see Fig. 21). For MLT there is no such modulation. At the moment there is apparently no explanation of this interesting finding as first comparisons with auroral activity as seen by the *UVI* experiment onboard *POLAR* are inconclusive.

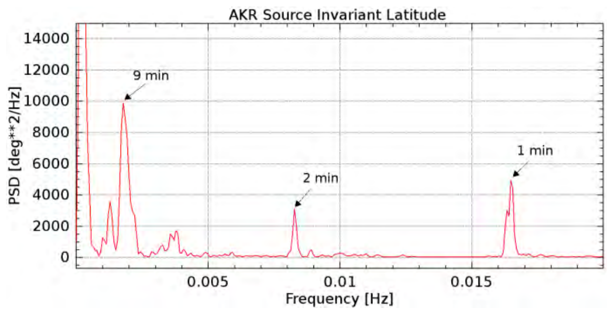

Fig. 21: Power density spectrum for Invariant Latitude positions of the AKR sources as measured by POLRAD experiment onboard Interball-2 s/c. The peaks corresponding to 1 and 2 minutes data modulation result from the s/c antenna system rotation, 9 minutes period remains at the present moment unexplained.

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.

Sun & Solar Wind

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

Solar Orbiter

Solar Orbiter is a future ESA space mission to investigate the Sun (planned launch in 2017). Flying a novel trajectory, with partial Sun spacecraft corotation, the mission is to investigate in-situ plasma properties of the near solar heliosphere. In addition, dedicated experiments will observe and characterize the Sun's magnetized atmosphere and polar regions. IWF builds the DPU for *Radio and Plasma Waves (RPW)* onboard *Solar Orbiter* and will calibrate the *RPW* antennas, using numerical analysis and anechoic chamber measurements. Furthermore, the institute contributes to the magnetometer.

Physics

Decameter "dog-leg" type III bursts: Unusual type III bursts have been observed by the radio telescope UTR-2 (Kharkov, Ukraine) in the decameter range. Their main and strange features are jumps of their frequency drift rate and their duration at certain frequencies. An example of such a "dog-leg" type III burst is shown in Fig. 22. In total 41 such bursts in the frequency band 10-30 MHz were analyzed.

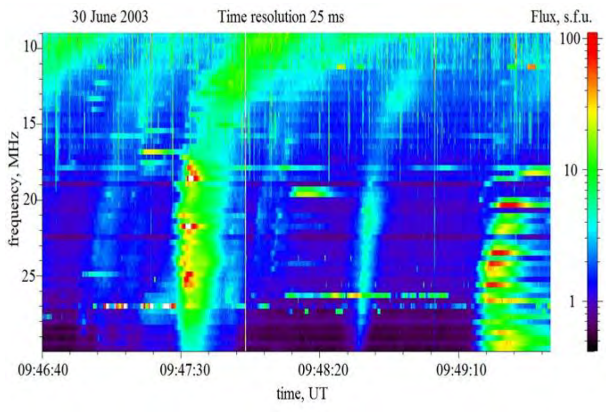

Fig. 22: "Dog-leg" type III burst observed at 09:47:30 UT.

The hinge-point in which the jump occurs is mainly at frequencies 16-17 MHz. This corresponds to heights in the solar corona of 2-2.5 R_S. The frequency drift rates "before" and "after" the hinge-point changes by a factor 4 to 12. These "dog-leg" type III are created by electrons with velocities smaller than those for usual type III bursts (0.08-0.16 c vs. 0.3 c). The most probable explanation for their appearance is an inhomogeneity of coronal plasma, i.e., the existence of regions with low density gradients.

CME at decameter wavelengths: SOHO and *STEREO* registered two CMEs on 7 April 2011. The second CME reached more than 1000 km/s. Radio emissions from this CME has been observed by the radio telescope URAN-2 (Poltava, Ukraine). It was accompanied by type IV and type II bursts in the decameter range. The type IV burst continued about 1.5 hours simultaneously with type II bursts. The type II bursts consisted of three bursts with different frequency drift rates, corresponding to linear velocities of 300 to 800 km/s. This can be interpreted as emission from different parts of the CME's shock.

All type II bursts exhibit second harmonics and have a fine structure in the form of tadpoles (Fig. 23) which drift from high to low frequencies at ~1.4 MHz/s. Durations of head and tails (0 and 30–40% polarization, resp.) are about 4 s and 2 s, respectively. The acceleration of electrons generating the bursts occurs in the tadpole heads. Radio emission of the tails however is generated by electrons leaving the regions of acceleration.

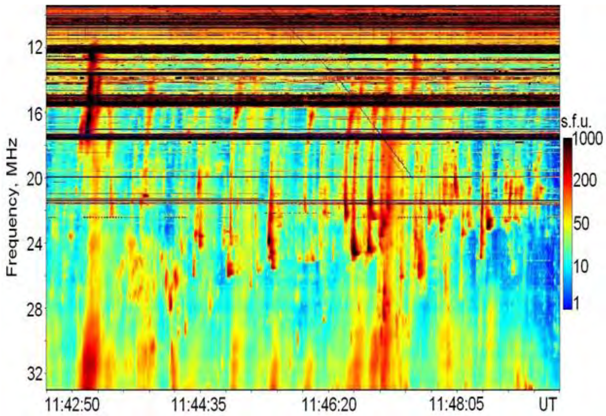

Fig. 23: Type II burst consisting of chains of tadpoles.

Manifestations of coronal loop transverse oscillations in solar microwave emission: Long period (minutes) modulations detected in microwave emissions in Metsähovi Radio Observatory (Finland) data during solar flare events were interpreted as signatures of large scale transverse oscillations of solar coronal loops. A properly located observer may detect a modulation at twice the frequency of the main frequency of the loop oscillation produced by modulation caused by the emission diagram pattern motion of the varying magnetic field. Modulation pairs have been identified in the dynamic spectra of solar microwave emission as well as their association with the oscillating coronal loops observed by *TRACE* in the EUV (see Fig. 24).

Five-min oscillations in the solar corona: Numerical simulations of 2D MHD equations show that a velocity pulse launched in the photosphere steepens into a leading shock. The nonlinear wake shock in the chromosphere leads to the formation of consecutive pulses. The time interval between the arrivals of two neighboring pulses to a detection point in the corona is ~5 min. Therefore, the consecutive pulses may result in the observed ~5-min oscillations in the solar corona.

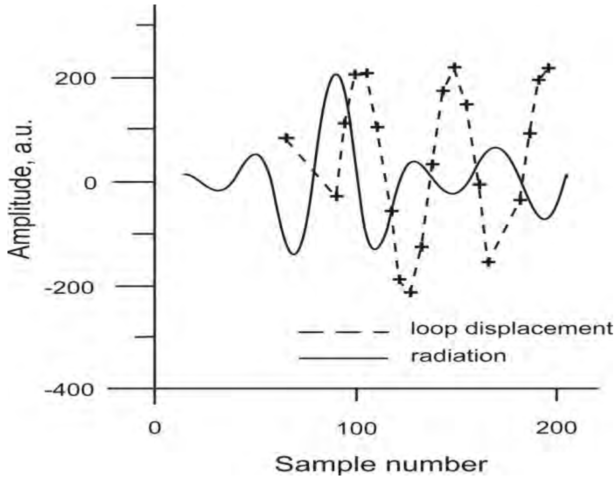

Fig. 24: 10 min modulation component of the 2000-Mar-23 microwave burst and the amplitude of the corresponding 615 s oscillation of the coronal loop observed with TRACE.

Mercury

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

BepiColombo

The ESA/JAXA mission *BepiColombo*, to be launched in 2015, 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)* 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 *(PICAM)*, which is part of the *SERENA* instrument suite, to explore the composition, structure, and dynamics of the exo-ionosphere.

In 2011, the Qualification Model of the *MERMAG-P* magnetometer has been successfully tested and finally accepted by ESA. Furthermore, an instrument level Critical Design Review was held in Germany in May and the manufacturing of the Flight Model has been started.

For *MERMAG-M*, the Flight Model electronics and sensor were delivered to Japan in April. Fig. 25 shows the assembly of the common electronics box which took place in Kyoto in July. In the following months a number of electrical and mechanical interface checks have been performed with the *MERMAG-M* units under the supervision of Japanese space companies.

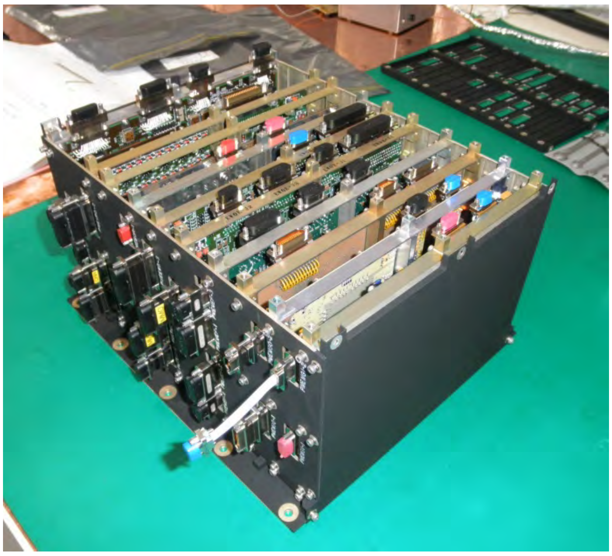

Fig. 25: Assembly of the MERMAG-M flight board (second slot from bottom right) into the MMO common electronics box.

The *PICAM* Engineering Model took part in the Integrated System Testing and System Functional Tests on the Electrical Test Bed of the spacecraft at Astrium Friedrichshafen. The Structural-Thermal Model was mounted on the *MPO* which passed the solar simulation test at ESTEC. The prototype *PICAM* ion optics was tested in the ion beam facility of IWF. The results of these tests and additional mechanical and thermal analyses flowed into the design of both the ion optics and the electronics of the Qualification Model (QM). Manufacturing and testing the QM were the major activities in 2011 which were rewarded by a successful Critical Design Review.

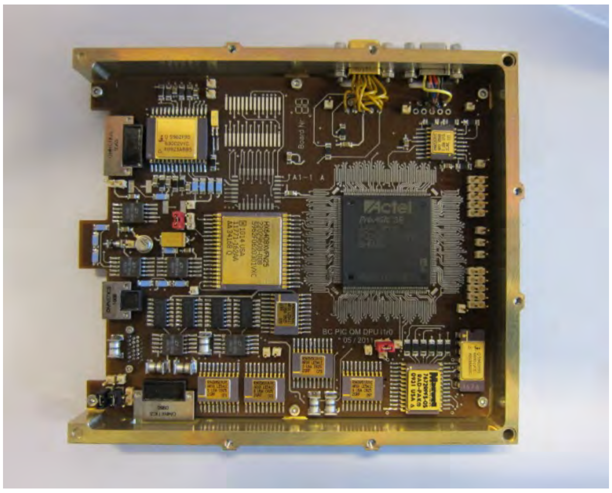

Fig. 26: Digital Processing Board of the PICAM Qualification Model.

The digital processing board (Fig. 26) of the QM was built and tested together with the electronics of the detector and the high and low voltage power supplies provided by the Consortium partners. The ion optics has the extremely challenging task to simultaneously provide high mass and angular resolution over a wide field of view in an extreme thermal environment between −130 °C during cruise to Mercury and +240 °C close to the planet. The fulfillment of all requirements resulted in a complicated piece of hardware which is close to completion.

Venus

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

Venus Express

ESA's *Venus Express* mission was launched in 2005. 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.

During 2011, *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.

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, furthers our understanding of the evolution of Venus' atmosphere caused by the solar wind interaction.

Plasma instabilities at Venus ionopause: The Kelvin-Helmholtz (KH) instability has been discussed as a loss process for planetary ions of unmagnetized planets by various authors. It is thought that waves on the dayside of a planetary boundary nonlinearly evolve into vortices around the terminator, where the vortices detach and form so-called plasma clouds. These plasma clouds contain ionospheric particles, which are therefore lost to the solar wind. Recent studies indicate that around Venus the KH instability is not able to reach the nonlinear phase neither on the ionopause nor on the magnetopause during solar minimum, due to low boundary layer altitudes and corresponding high density jumps, which exhibit a stabilizing effect on the instability (Fig. 27).

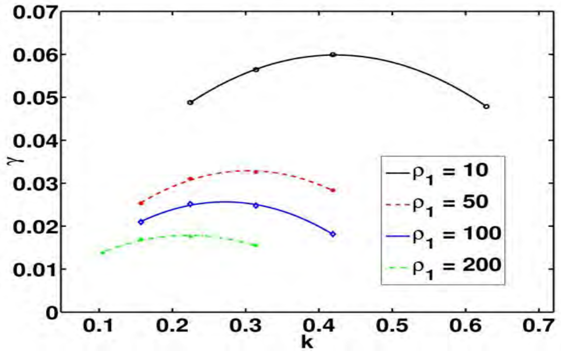

Fig. 27: Normalized growth rate γ as a function of the normalized wave number k for different density jumps ρ₁. The growth rate significantly decreases for large density jumps. At a planetary ionopause, the density increase is even larger than shown here.

Also for solar maximum conditions, the ionopause seems to be stable. The induced magnetopause might become unstable with regard to the KH instability, especially for high solar zenith angles, but there the density of planetary ions is not that large. Thus, it is concluded that the loss of planetary ions due to the KH instability is less than previously assumed in different studies.

Venus nightside hot oxygen atom corona: The nightside exosphere of Venus was studied for high and mean solar activity conditions by means of an advanced Monte-Carlo model. Hot O atoms are assumed to be produced by dissociative recombination of O_2^+ and NO^+ molecular ions, by charge transfer processes between ionospheric O^+ ions and neutral O and H atoms. The model includes rotational and vibrational excitation energy redistribution of the initial energy of hot O atoms in elastic, inelastic, and quenching collisions between the hot atoms and the ambient neutral atmosphere species, and uses differential cross sections for the determination of the scattering angle in the collisions.

The results indicate that dissociative recombination of O_2^+ is, similar as at Venus' dayside, the most efficient source of hot O atoms also at the nightside (see Fig. 28). For high solar activity, the nightside corona density of hot O atoms is about one order of magnitude lower compared to the dayside although between 2–10 times higher than in previous studies.

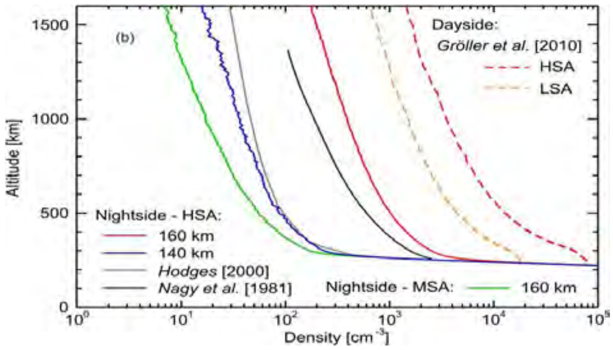

Fig. 28: Modeled hot O corona densities at Venus nightside exosphere related to solar activity (solid lines) and the dashed lines are densities for the dayside exosphere.

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.

JUICE

The *Jupiter Icy Moons Explorer (JUICE)* is undergoing a reformulation study following NASA's withdrawal from the joint *EJSM* mission. It is now planned as a stand-alone ESA spacecraft which will settle into a Ganymede orbit at the end of the mission. The down-selection of ESA's Cosmic Vision L missions (including *JUICE)* is planned for May 2012, followed by an announcement of opportunity for instrumentation.

IWF is part of the Swedish-led *Radio and Plasma Wave Instrument (RPWI)* team that plans to investigate Jupiter's magnetospheric radio and plasma waves. Using a patch model, first numerical antenna calibration studies have been performed to investigate the *RPWI* antenna reception properties and to help in finding a suitable place for the antenna triad.

IWF is developing a prototype of a worldwide unique scalar magnetometer jointly with the Institute of Experimental Physics of TU Graz: a *Coupled Dark State Magnetometer (CDSM)*. Its use aboard *JUICE* would significantly enhance the precision of the magnetic field investigation in the Jupiter system. Significant advantages of the *CDSM* are its rather simple sensor design (see Fig. 29: no excitation coils, mechanisms or active electronics parts), its high dynamic range of more than 6 decades and the omni-directional measurement capability.

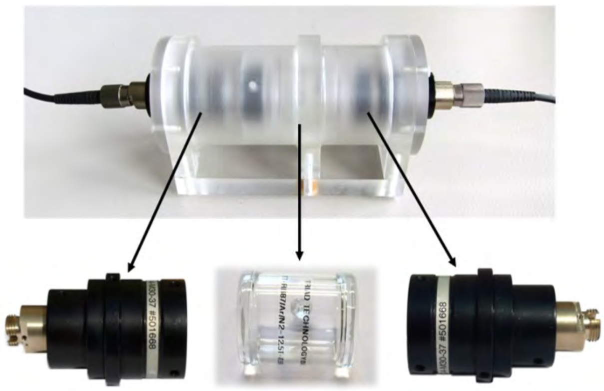

Fig. 29: Prototype of the CDSM sensor with fiber couplers (bottom right and left) and a 35 mm long rubidium glass cell (bottom center).

IWF is also participating in the development of the *flux gate magnetometer* with several European institutes and a *thermal plasma detector* with several French and Czech institutes.

Physics

Jovian hectometric (HOM) attenuation band: The capabilities of the *Cassini/RPWS* experiment enable the analysis of the intensity extinction of HOM radiation, the so-called attenuation band, and to distinguish different spectral aspects. These various aspects are linked to the way the Jovian HOM emission is partially or completely attenuated when it propagates through the Io torus. The intensity extinction is due to the refraction effect which occurs inside the plasma torus.

Fig. 30 shows the dependence of the attenuation band on the central meridian longitude (CML). The HOM intensity extinction occurs at two specific central meridian longitudes, ~20° and ~180°, which are close to the longitudes of the tip of the magnetic dipole in the southern hemisphere (40° CML) and in the northern hemisphere (200° CML), respectively. The attenuation of the HOM beam is asymmetric when comparing both hemispheres.

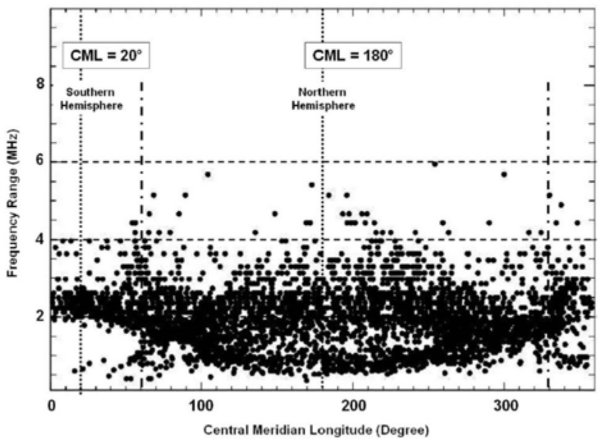

Fig. 30: Variation of the attenuation band frequency versus the central meridian longitude (CML). Each point specifies the frequency and the corresponding CML at which the Jovian hectometric emissions disappear. The vertical dash-dot-lines indicate the boundaries between the northern and southern hemispheres.

Alfvén waves in narrowband Jovian DAM: Alfvén waves are a valuable source of information about the ionosphere and magnetosphere of Jupiter. An indirect method is developed in order to study these waves via their modulation of narrow-band (NB) component of Jovian decametric emission (DAM).

The characteristic dash-line appearance of such narrow-band radiation in the dynamic spectrum can be considered as the result of superposition of numerous shadow events. To produce such shadows, a modulator is proposed. This activating or amplifying agent drifts in the dynamic spectrum toward lower frequencies and stimulates the generation process in the radio source. After the source interaction, the modulator is shielded and there is no stimulation of the emission afterwards. This "shadow effect" regularizes the NB-oscillations into a train of S-bursts in the dynamic spectrum.

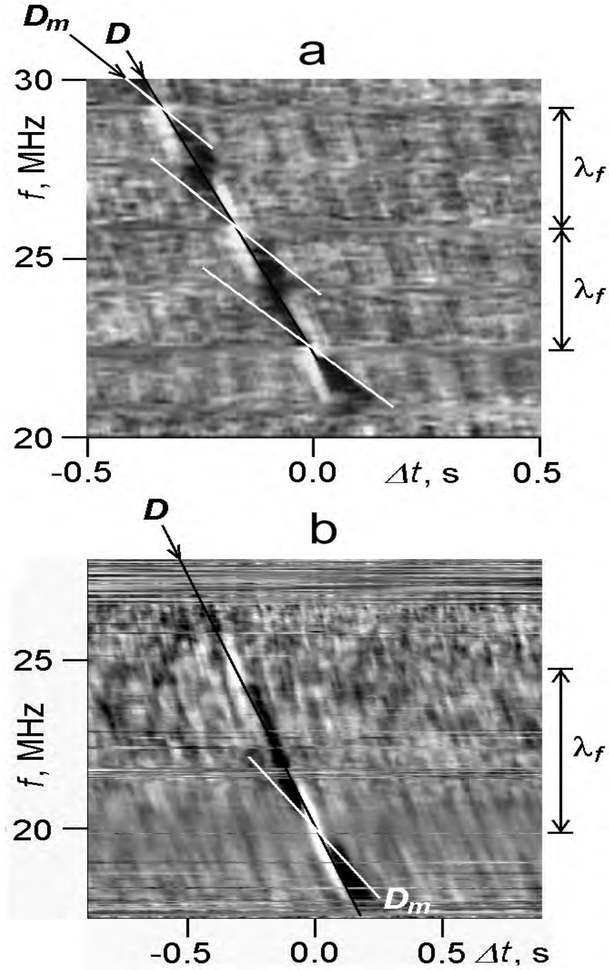

Fig. 31: Extraction of some parameters from the normalized 2D-correlation patterns of the synthetic (a) and real (b) dynamic spectra of Jovian S/NB-emissions: the Alfvén wavelength (λ_f), the dispersion drift rate (D), the modulator drift rate (D_m).

In numerical calculations the best resemblance between synthetic and real dynamic spectra of DAM has been achieved in the model of the ionospheric Alfvén resonator. Based on the 2D-correlation analysis of synthetic and real dynamic spectra of Jovian S/NB emissions, the dispersion of radio emission and the parameters of Alfvén waves in the Jovian low magnetosphere are determined. We apply these methods to the tangled pattern of highly sporadic emissions in the dynamic spectrum of 2 August 2002. For the first time the dispersion delay of emission and the dynamics of radio source in a very complicated radio storm are separated (Fig. 31).

Periodic non-Io DAM bursts triggered by the solar wind: Periodic radio bursts of the non-Io component of Jovian decametric radio emission (non-Io DAM) are characterized by a very periodical recurrence during several Jupiter rotations with a 1.5% longer period than the rotation rate of the Jovian magnetosphere. Using the *SWOOPS* observations of *Ulysses* during its second encounter with Jupiter the relation between solar wind activity and the appearance of the periodic non-Io DAM bursts have been investigated. The occurrence of these bursts is found to be strongly correlated with pulses of the solar wind ram pressure at Jupiter, i.e. the bursts were typically observed 1-2 Jovian days after a significant enhancement of the solar wind (Fig. 32).

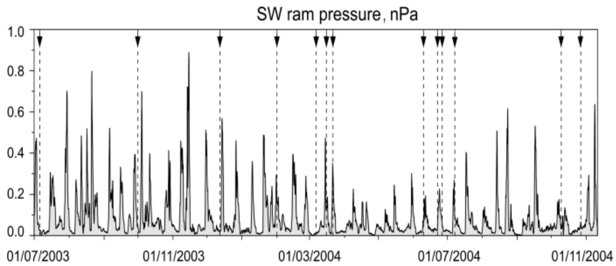

Fig. 32: Solar wind ram pressure measured by Ulysses/SWOOPS and ballistically propagated to Jupiter's orbit. The vertical dashed lines with arrows indicate the beginning of the episodes of periodic non-Io DAM bursts.

Moreover the periodic bursts exhibit a tendency to occur in groups every 25 days - i.e. related to the Sun's rotation. This suggests that periodic non-Io DAM bursts may originate at the end of the radially extended interchange fingers in the Io plasma torus triggered by the solar wind pulses.

Saturn & Titan

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. Titan is one of the largest moons in the solar system, and the only one that has a dense atmosphere.

Cassini

In 2011 the Saturn orbiting spacecraft *Cassini* made several equatorial orbits and flybys at Rhea, Titan and Enceladus. Since September 2010 *Cassini* is in the so-called solstice mission phase which will last until 2017. *Cassini's Radio and Plasma Wave Science (RPWS)* instrument has continued its long-term monitoring of Saturn's radio components like Saturn kilometric radiation (SKR) and narrowband emissions. The main highlight was the emerging of a gigantic lightning storm on Saturn that started in early December 2010 and lasted until end of August 2011.

Physics

Lightning on Saturn: Radio waves called Saturn Electrostatic Discharges (SEDs) measured by the *Cassini RPWS* instrument are the characteristic features of thunderstorms on Saturn. Convective storms of ~2000 km in size had been observed at a latitude of 35° south in recent years. The giant storm of 2010/2011 was the first thunderstorm at a latitude of 35° north in the *Cassini* era indicating a seasonal influence. Since Saturn experienced vernal equinox in August 2009 its thunderstorms might follow the summer hemisphere. The flash (SED) rates of the storm were an order of magnitude higher compared to previous ones and peak rates larger than 10 per second were recorded. The storm reached a latitudinal extension of 10000 km about three weeks after its start, and it developed an elongated eastward tail due to the eastward zonal wind speeds that were largely unperturbed by the huge disturbance. This means that Saturn's winds extend without decay deep down into the water cloud layer at 8-12 bars where the SEDs are thought to originate from.

The visible plume in Fig. 33 consists of high altitude clouds that overshoot the outermost ammonia cloud layer owing to strong vertical convection, as is typical for thunderstorms. The storm even influenced Saturn's stratosphere leading to a significant temperature increase and changes in the chemistry there. The total power of the storm is comparable to Saturn's total emitted power indicating that giant storms like this are a significant term in the internal heat budget of the planet.

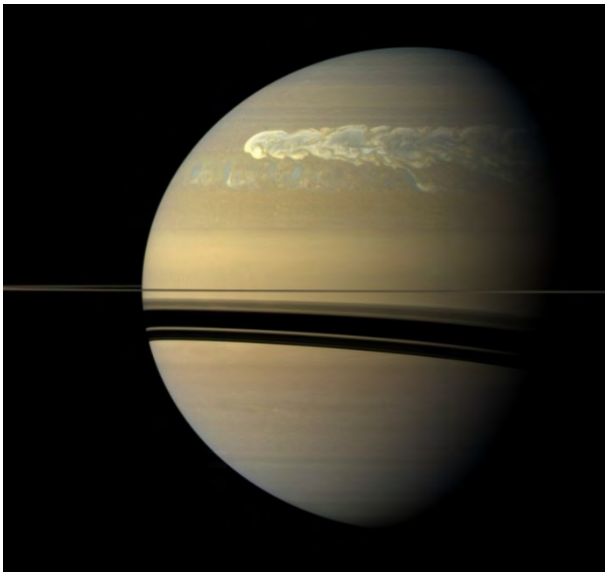

Fig. 33: The giant thunderstorm on Saturn observed by the Cassini camera on 25 February 2011. Such rare outbreaks of convective storms on Saturn are called "Great White Spots" (GWS) and usually happen once per Saturn year (29.5 Earth years). The thunderclouds formed a tail that encircled the whole planet, a distance of 300.000 km, and covered an area of 8 times the surface area of the Earth. This spectacular image made it onto the cover of Nature (issue of 7 July 2011, © NASA/JPL/SSI).

No lightning on Titan: *Cassini RPWS* also continued to search for radio emissions indicative of lightning in Titan's atmosphere. Although convective methane clouds are occasionally spotted on Titan, no lightning radio bursts were found. Many Saturn lightning bursts (SEDs) were detected during the Titan flybys, but they can be distinguished from potential Titan lightning since they don't fall off in intensity with increasing distance to Titan. Lightning on Titan is probably a very rare event if it exists at all.

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 as this mission consists of both an orbiter and a lander.

Rosetta

ESA's *Rosetta* probe (Fig. 34) 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. 34: IWF participates in five instruments aboard the Rosetta orbiter and lander.

On 8 June 2011 the spacecraft was put into hibernation mode, as due to the distance from the Sun, the solar arrays cannot provide enough energy for instrument operation. At the end of 2013 a "wake-up call" will be sent and the spacecraft should be operational in 2014 and start the approach to its target.

Exoplanets

Exoplanets, i.e. planets in orbit around other stars than our Sun, are being detected regularly now with missions like *COROT* (Fig. 35). As of November 2011 more than 500 exoplanets have been detected, among them some super Earths, e.g. Gliese 581c, the most Earth-like planet at about six times the mass of the Earth.

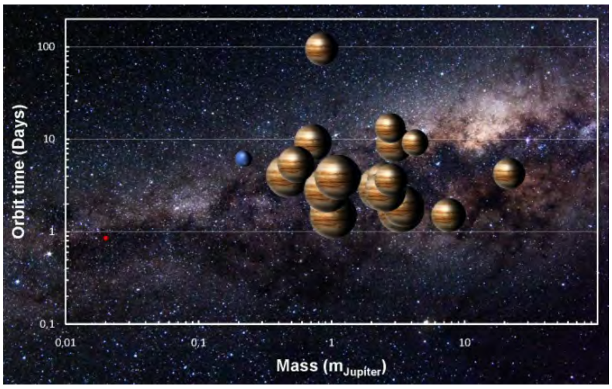

Fig. 35: Up to now COROT, in combination with Earth-bound observations, has determined all parameters for 24 exoplanets. Most of these exoplanets are gas giants, similar to Jupiter in our solar system.

Physics

Magnetic obstacle studies: UV transit observations of stellar Lyman-alpha absorption by Energetic Neutral Atoms (ENAs) around transiting exoplanets are studied. Together with advanced numerical test particle and Monte Carlo models for the exosphere and obstacle it was shown that this method can be used as a tool for estimating the theoretically studied magnetic obstacle sizes and the corresponding magnetic field strength (Fig. 36). In future studies accurate knowledge of the stellar plasma parameters and the planet's magnetic properties is expected, as well as the structure of the upper atmosphere.

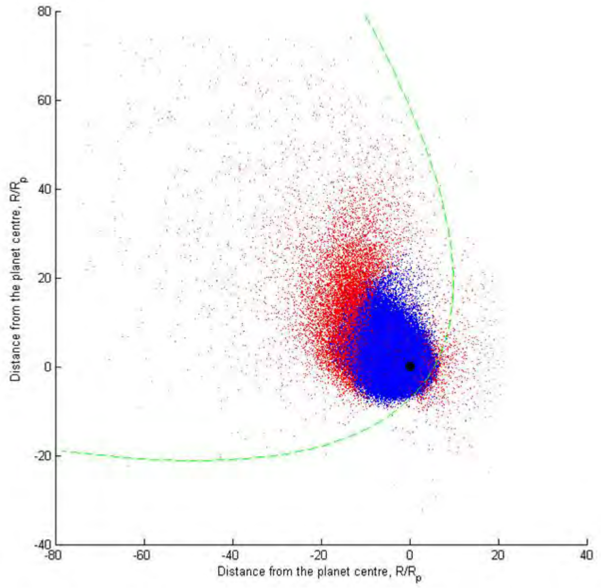

Fig. 36: Modeled stellar wind interaction with HD 209458b with an assumed magnetopause (dashed green line) sub-stellar obstacle at R=4.7 R_{pl}. The stellar wind protons are not plotted but flow around the magnetopause obstacle and interact with the planetary hydrogen exosphere (blue dots) and produce energetic neutral atoms (red dots).

Magnetodisk dominated magnetospheres of close-in giant exoplanets: A more complete view of the magnetosphere of a close orbit giant exoplanet, based on the Paraboloid Magnetospheric Model (PMM), is proposed. Besides the intrinsic planetary magnetic dipole, PMM also considers the electric current systems of the magnetotail, magnetopause and magnetodisk as magnetic field sources. The key element of the considered model consists in taking into account the effects of an expanding upper atmosphere of a Hot Jupiter heated by the stellar XUV radiation. The escaping atmospheric material is ionized and builds an extended magnetodisk around the planet.

The magnetic field produced by magnetodisk ring currents, dominates over the contribution of the intrinsic magnetic dipole and determines the size and shape of the whole magnetosphere as shown in Fig. 37. This creates a magnetic field strength that decreases more slowly than a dipole field resulting in 40-70%

larger scale. Such larger magnetospheres provide better protection of close-in planets against the erosive action of extreme stellar winds. Besides that, the size and shape of the magnetospheric obstacle of an exoplanet influence the character of the transit curve in EUV and in specific spectral lines. This opens a way for observational probing of exoplanetary magnetospheres and stellar winds parameters.

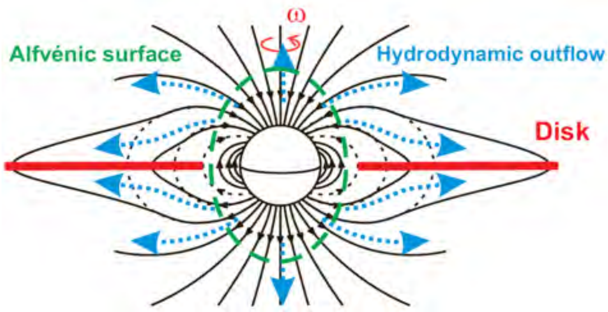

Fig. 37: Magnetic field topology for a Hot Jupiter's magnetosphere with a magnetodisk.

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. It features a turbo molecular pump and a rotary dry scroll forepump. A pressure level of 10^{-10} mbar can be achieved.

The *Medium Vacuum Chamber* has a cylindrical stainless steel body with the overall length of 850 mm and a diameter of 700 mm. A dry scroll forepump and a turbo molecular pump provide a pressure level of about 10^{-7} mbar. A target manipulator with two axes and an ion beam source are installed. This chamber mainly serves for functional tests of the ion mass spectrometer for *BepiColombo*.

The *Large Vacuum Chamber* has a horizontal cylindrical stainless steel body and door, 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. To enable the baking of structures and components (to outgas volatile products and unwanted contaminations), the chamber is equipped with a heater around the circumference.

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 quick change of components or devices to be tested. A thermal plate installed in the chamber and liquid nitrogen are used 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* is dedicated to surface science research and cooled with liquid nitrogen. It has a diameter of 400 mm and a height of 400 mm, extendable up to 1200 mm. Two rotary vane pumps and one turbo-molecular pump achieve a minimum pressure of 10^{-5} mbar.

The *Sample Chamber* contains an 8µ 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 electronic components and circuits to most temperature conditions that occur under natural conditions, i.e., −40 °C to +180 °C. The chamber has a test space of 190 litres and is equipped with a 32-bit control and communication system.

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, UV-B, UV-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 shielded volume is <10 nT and the remaining field noise is <2 pT/√Hz at 1 Hz. A special Helmholtz coil system allows generating field vectors 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 m^2. The laboratory is used for flight hardware assembling and testing and accommodates up to six engineers (Fig. 38).

Clean Bench: The laminar flow clean bench has its own filtered air supply. It provides product protection by ensuring that the work piece in the bench is exposed only to HEPA-filtered air (HEPA = High Efficiency Particulate Air). The internal dimensions are 118 x 60 x 56 cm^3.

Vapor Phase and IR Soldering Machine: The vapor phase soldering machine is suitable for mid size volume production. The maximum board size is 340 x 300 x 80 mm^3. Vapor 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 utilized.

Fig. 38: In the clean room the flight units of space experiments are integrated and tested.

Publications & Talks

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Zelenyi, L., A.V. Artemyev, A.A. Petrukovich, R. Nakamura: Magnetotail thermal electrons as tracers of thin current sheets fine structure, European Geosciences Union General Assembly 2011, Wien, Apr 2011.

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Teaching & Workshops

Lecturing

IWF members are actively engaged in teaching at two universities. In summer 2011 and in the current winter term 2011/2012 the following lectures are given:

KFU Graz

Plasma Theory Waves (Biernat)

Hydrodynamics (Biernat)

MHD Fundamentals (Biernat)

Plasmatheoretical Instabilities (Biernat)

Terrestrial and Planetary Ionospheres (Biernat)

Measurement Methods of Space Physics and Aeronomy (Kargl, Rucker)

Introduction to Geophysics and Planetary Physics (Kargl)

Gravity, Shape, Seismology, and Structure of the Earth (Kömle)

Ice, Water, Atmosphere: Comparison of Earth and Mars (Kömle)

Planetary Magnetospheres (Rucker)

Introduction to Plasma Physics (Rucker)

TU Graz

Space-Time Reference Systems (Baur)

GGOS and Reference Systems (Baur)

Practical Course in Digital Audio Processing (D. Fischer, Magnes)

Signal Processor Techniques (Magnes)

Advanced Course

The new Master studies curriculum „Space Sciences and Earth from Space", substituting and enlarging the former inter-university course „Space Sciences", started in the winter term 2011/12. It is a cooperative curriculum within the frame of NAWI (KFU and TU) Graz. This new regular university Master curriculum, comprising four semesters, provides three tracks „Solar System Physics", „Satellite Systems", and „Earth System from Space" and takes advantage of the competences of both universities as well as of IWF and Joanneum Research. It finalizes with the academic degree of either „Dipl.-Ing." or "Master of Science (MSc)".

Theses

Besides lecturing, members of the institute are supervising Bachelor, Diploma, Master and Doctoral Theses. In 2011, the following theses have been completed:

Domanović, B.: Earth magnetic flux tube investigation using Cluster data, Master Thesis, Universität Graz, 76 pages (2011)

Faßwald, J.: Laboratory Experiments Concerning the Suction of Dust Particles under Vacuum Conditions, Diploma Thesis, Universität Graz, 80 pages (2011)

Fichtinger, B.: Using Extreme Solar Events as Proxy for the Active Young Sun: Implications for Planetary Atmosphere Evolution, Diploma Thesis, Universität Graz, 76 pages (2011)

Hütter, E.S.: Development and Testing of Thermal Sensors for Planetary Applications, Doctoral Thesis, Universität Graz, 120 pages (2011)

Iqbal, F.: Investigations and Design Solutions of a High Repetition Rate Satellite Laser

Ranging (SLR) System, Doctoral Thesis, Technische Universität Graz, 73 pages (2011)

Jaffer, G.: Study of an Austrian lightning nano-satellite (LiNSAT): Space and ground segments, Doctoral Thesis, Technische Universität Graz, 185 pages (2011)

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Rubab, N.: Study of kinetic Alfvén wave instabilities in a Lorentzian multi-component plasma, Doctoral Thesis, Universität Graz, 135 pages (2011)

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Stiebler, M.: Positions- und Richtungsbestimmung von Flugzeug-Transpondern durch Messung von Laufzeit-Unterschieden, Diploma Thesis, Technische Universität Graz, 69 pages (2011)

Stiegler, A.: Mars Permittivity Probe Calibration and Instrument Performance Validation, Diploma Thesis, Technische Universität Graz, 96 pages (2011)

Weingrill, J.: Extrasolar Planets Orbiting Active Stars, Doctoral Thesis, Universität Graz, 113 pages (2011)

Zörweg, P.: Multi-spacecraft data analysis of Jovian radio emission, Diploma Thesis, Universität Graz, 67 pages (2011)

Meetings

M.Y. Boudjada, M. Delva, G. Fischer, G. Kargl, M.L. Khodachenko, G. Kirchner, H. Lammer, U. Möstl, R. Nakamura, H.O. Rucker, M. Volwerk, and T. Zaqarashvili organized 21 sessions at international meetings.

Awards and Recognition

Hans Sünkel received the “Grand Decoration of Honour in Gold for Services to the Republic of Austria” during the bicentennial celebration of TU Graz.

In recognition of her achievements in the field of space sciences, Rumi Nakamura was elected full member of the International Academy of Astronautics (IAA).

Last but not least, Alexandra Alexandrova and Michael Zellinger received the “Outstanding Student Poster (OSP) Award” for their posters entitled “The Influence of Gravity on the Evolution of the Kelvin-Helmholtz Instability around Venus” and “Three-dimensional non-steady magnetic reconnection signatures: Model and observations” presented at the European Geosciences Union (EGU) General Assembly 2011.

Public Outreach

On 15 May 2011, approximately 20 ANTARES members, an association of amateur astronomers, visited IWF in the frame of their annual excursion. Besides guided tours through the different labs, Helmut Lammer gave a talk about the evolution of the Earth’s atmosphere in comparison to Venus and Mars.

In early summer the URANIA series of lectures "Weltraumforschung in Österreich" were held at TU Graz. Several members of the institute gave lectures on different topics in space research.

On 13 July 2011, 60 children between six and thirteen years spent one day at IWF and learned more about the fascination of space in the frame of the “Applied Holidays” program organized by FH Joanneum.

During summer time, four high school students took the opportunity to perform an internship at IWF under the „Talente-Praktika“

program, which is funded by the Austrian Research Promotion Agency (FFG). They were involved in altimeter data analysis and gravity data retrieval, learned about magnetic field experiments, geophysical problems in space research, and radio astronomy.

In October the "Topic of the Month" of the Austrian Academy of Sciences was "Planetary Research", with an interview given by Helmut O. Rucker on the *Europlanet* project and contributions on the cooperation between scientists and amateur astronomers, the ESA/JAXA mission *BepiColombo,* as well as the rocky planets Mercury, Venus, Earth, and Mars, which appeared on the Academy's website.

Last but not least, four kids from secondary schools in Graz, Deutschlandsberg and Hartberg chose IWF for their work experience (Fig. 39). Members of the institute presented their work to the young people who had the opportunity to visit the different labs and get in touch with "real" scientists.

Fig. 39: A thirteen year old girl, interested in astronomy and particle physics, spent three days at IWF to learn more about the work of space researchers.

Personnel

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As of 31 December 2011

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