SPACE RESEARCH INSTITUTE

IWF
Space Research Institute

ÖAW
Austrian Academy of Sciences

ANNUAL REPORT 2012

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Cover Image

An aurora in Whitehorse Yukon Canada that appeared in the sky in the early hours of 1 October 2012 due to the effects of a coronal mass ejection that erupted from the Sun three days earlier (Image Courtesy of Joseph Bradley/NASA). The Van Allen Probes were launched in summer 2012 to help us understand the Sun's influence on Earth and near-Earth space by studying the Earth's radiation belts on various scales of space and time. IWF participates as one of the Co-I institutes.

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Introduction

The Space Research Institute (Institut für Weltraumforschung, IWF) of the Austrian Academy of Sciences (Österreichische Akademie der Wissenschaften, ÖAW) in Graz focuses on the exploration of the solar system and satellite geodesy. With over 80 staff members from more than a dozen different nationalities it is the Austrian space research institute par excellence. 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, one specialized in magnetospheric studies and one in remote sensing.
- *Cassini* will continue to explore Saturn's magnetosphere and its moons until 2017.
- ESA's first S-class mission *CHEOPS (CHaracterizing ExOPlanets Satellite)* will characterize exoplanets in detail. Its launch is expected in 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.

Fig. 1: The Van Allen Probes-carrying Atlas 5 on its launch pad (Credit: United Launch Alliance/Pat Corkery).

- *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.
- The *Van Allen Probes* are two NASA spacecraft which were launched on 30 August 2012 to quantify processes in the Earth's radiation belts (Fig. 1).
- *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. It will arrive in summer 2014 and deposit a lander in November.
- *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. The angular distance from the Earth varies by ~22° per year.

- *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.

Scientific highlights in 2012

- Gravity field measurements by *GRACE* have shown that the Earth's sea level is increasing by 1.4 mm per year.
- For the first time, bistatic satellite laser ranging was tested successfully.
- Observation of a magnetic flux tube in Venus's magnetotail indicates the presence of magnetic reconnection.
- The kinetic ballooning instability has been identified in the near-Earth magnetotail.

The year 2012 in numbers

Members of the institute published almost 100 papers in refereed international journals, of which 27 were first author publications. During the same period, articles with authors from the institute were cited almost 2700 times in the international literature. In addition, over 160 talks and posters have been presented at international conferences by members of the IWF, including 25 by special invitation from the conveners. Last but not least, institute members organized 18 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 Director. All important decisions are considered by an institute council consisting of the three research directors and six 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).

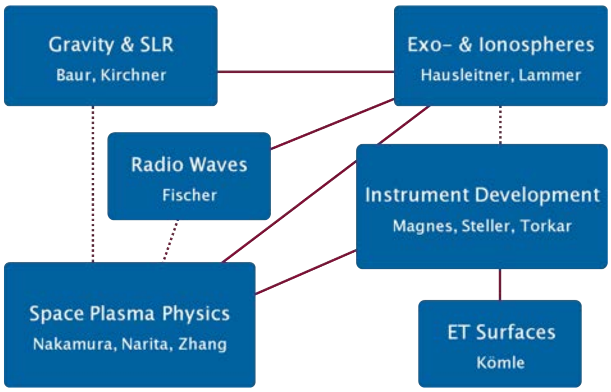

Fig. 2: IWF research fields and group leaders.

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

Sophisticated space-geodetic techniques are applied to monitor the dynamics of the solid Earth, the oceans, and the atmosphere. Numerous Earth observation satellite missions provide high quality data, which are nowadays indispensable for understanding the global change of the Earth system. IWF scientifically analyzes these data with a special focus on the determination of the Earth's gravity field, selected studies of the Earth's atmosphere and crustal dynamics, as well as satellite laser ranging to Earth orbiting spacecraft.

Gravity Field

Knowledge about the gravity field is the key to unlock geophysical processes on the surface and in the interior of a body. Furthermore, the gravity field is of fundamental importance for orbit determination and mission design, owing to the fact that satellite dynamics are dominated by gravity. At IWF, gravity field research activities include analysis of data collected by *GOCE*, *GRACE*, *LRO,* and SLR.

GOCE

The ESA 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. The instruments aboard the spacecraft are subject to a sensor fusion concept, combining two complementary gravity field recovery observables. *GOCE* orbit information is acquired by satellite-to-satellite tracking between the high-altitude GPS satellites and the low-orbiting *GOCE* satellite. These observations deliver the long- and medium-wavelength spectrum of the terrestrial gravity field. Satellite gravity gradiometry is able to resolve short-scale structures – down to features with spatial resolution of about 80 km. The satellite (see Fig. 3) was launched in 2009 and finished its nominal operation phase in mid-2012. During the extended mission phase, the orbital height will be lowered by about 20 km in order to additionally increase the observation sensitivity. The end of mission is expected in autumn 2013.

Fig. 3: Artist's view of the GOCE satellite (Credit: ESA).

Data processing: The computation of a spherical harmonic representation of the Earth's gravity field from the satellite data is the key task of the *GOCE* team Graz, which is a co-operation between IWF and the Institute of Theoretical and Satellite Geodesy of the Graz University of Technology (TU Graz). These activities are embedded in the official *GOCE* data analysis consortium.

GOCE gravity field models: The present computation of the Release 4 *GOCE* gravity field model is based on a full set of recently reprocessed gradiometer data. The model will cover the full measurement period of the nominal mission phase; thus, it will include about two years of data. The gravity field solution will be released in spring 2013. It is developed up to degree and order 250 in terms of spherical harmonics; the previously used energy balance approach for orbit analysis is replaced by a short-arc integral equation method.

Analysis of the reprocessed gradiometer data reveal improvements over the whole frequency range, with gravity model improvements to be expected in the medium- to short-wavelength parts (Fig. 4). For this data, still a slight performance degradation of the radial component persists (green line in Fig. 4).

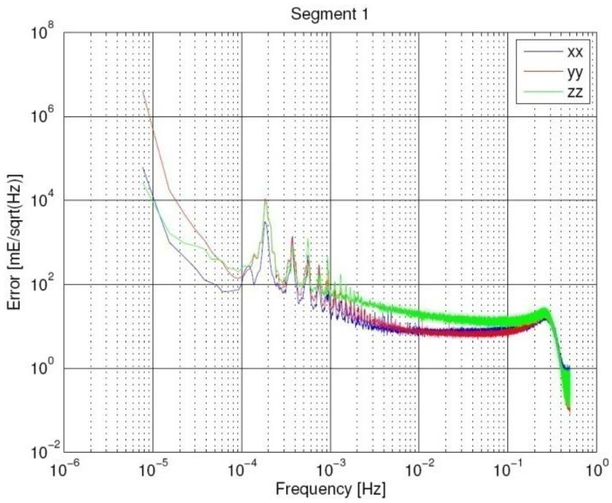

Fig. 4: Error power spectrum density of filtered (reprocessed) gradiometer data.

Orbit analysis: The restricted sensitivity of the *GOCE* gradiometer instrument requires satellite gradiometry to be supplemented by orbit analysis in order to resolve long-wavelength features of the terrestrial gravity field. As mentioned above, the energy conservation principle has been adopted by ESA to exploit GPS-based satellite-to-satellite tracking information. This turned out to be a sub-optimal choice. A suitable alternative is to estimate the low-frequency part of the gravity field by the point-wise solution of Newton's equation of motion, known as the acceleration approach. This method balances the gravitational vector with satellite accelerations, and hence is characterized by (second-order) numerical differentiation of the orbit position. Fig. 5 presents results from orbit analysis based on the acceleration approach (GIWF) against official ESA *GOCE*-only gravity field solutions (*GOCE*-TIM). The figure demonstrates that the latter can be improved in the long-wavelength spectrum up to degree ~25.

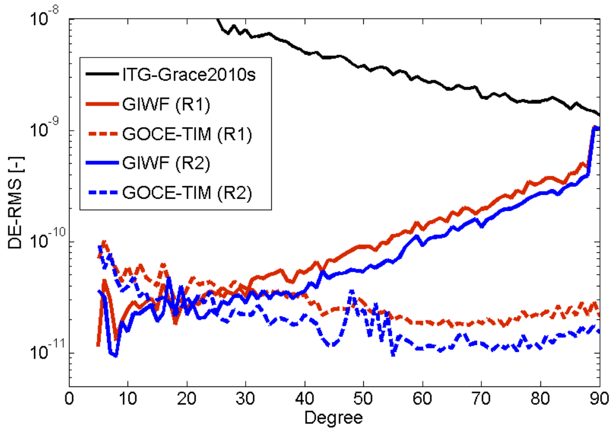

Fig. 5: GOCE real data results over the periods 1 November 2009 to 11 January 2010 (R1) and 1 November 2009 to 5 July 2010 (R2). Solid color graphs: GIWF degree-error RMS. Dashed graphs: GOCE-TIM degree-error RMS.

Combined gravity field models: As PI of the *GOCO (Gravity Observations COmbination)* project, IWF contributes to the development of gravity field combination models from various data sources. The S-series of these models includes data collected by *GOCE*, *GRACE*, *CHAMP*, and SLR. The latest release is *GOCO03S*. The first model of the C-series is currently under development; it will additionally include satellite altimetry data and ground measurements. The *GOCO* consortium is composed of scientific institutions in Germany, Switzerland, and Austria. IWF is responsible for the SLR component.

GRACE

Time-variable *GRACE (Gravity Recovery and Climate Experiment)* gravity field solutions are routinely exploited to derive secular and seasonal mass changes on and near the Earth's surface. However, the quantification of mass redistribution from space gravimetry is not a straightforward process; therefore, published mass variations (for instance, deglaciation rates of the Greenland ice sheets) vary considerably. Both the period of investigation and the adopted trend model (linear versus quadratic) have a strong impact on the quantification of mass variation from *GRACE* (Fig. 6). In order to circumvent misinterpretation, these trends should never be validated against each other unless they refer to the same period. Moreover, trend model estimation should routinely be accompanied by hypotheses testing and information criteria evaluation.

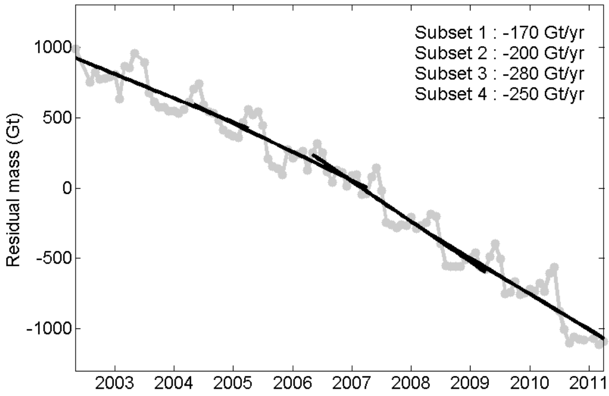

Fig. 6: Greenland mass-change trends. Monthly residual mass with respect to the temporal mean (gray graph), polynomial parts of least-squares fits to the time series over 3-year subsets (black graphs).

LRO

The gravity field of a planetary body provides insight into its interior, the thermal evolution, and rotational characteristics. Due to the Moon's closeness to the Earth, it has been orbited by a variety of artificial satellites. The *Lunar Reconnaissance Orbiter (LRO)* was launched in June 2009 to prepare for save robotic returns. Its polar, near-circular, low-altitude (50 km) orbit is ideal to derive the lunar gravity field from satellite orbit perturbation. *LRO* is the first spacecraft at the distance of the Moon which is tracked with optical laser ranges in addition to radiometric observations (Doppler frequency shifts).

At IWF, a series of simulation studies has been conducted to investigate the influence of various aspects (e.g., tracking data type, noise level, distribution of the tracking data on the lunar surface) on lunar gravity field recovery. Due to the Earth-Moon 1:1 spin-orbit resonance, *LRO* cannot be tracked at the far side of the Moon (see Fig. 7) which severely hampers the determination of the gravity field. The results of the simulation studies show that due to the lack of far-side tracking data, only coefficients of very low degree and order can be recovered. For higher degrees, a priori information (regularization) must be introduced.

First results from real data analysis indicate that using sparse optical laser ranges alone results in low-precision orbits. Better results are expected by processing laser ranges and radiometric observations together.

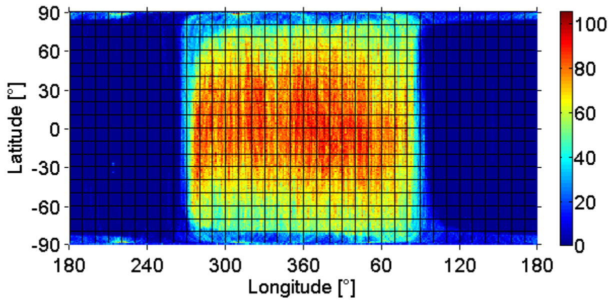

Fig. 7: Total number of Doppler range-rates to LRO during the nominal mission phase (12 months), averaged over a 1°x1° grid. The western limb of the Moon as seen from the Earth is located at 270° longitude.

Geodynamics

Crustal models: Plate modeling at a large scale is a well-established practice for the Earth's crust. Usually, velocities derived from GNSS time series or from geology are used to define a rotation pole and 2D-rotations around it to describe the motion of a plate. Together with the Universities of Salzburg and Padova a 3D-block model for small faults (50-200 km length) was developed and applied to faults of the Eastern Alps. The multidisciplinary approach unified the fault characteristics from geology and seismology with GNSS-derived surface movements from geodesy and the block model from geophysics. It turned out that a rigid block model leads to unrealistic large movements of several cm/yr with only few mm/yr movements at the surface. The first conclusion from the experiment is that a rigid model is not sufficient to describe the geodynamics. For example in the Tauern heat flow measurements confirm that temperatures at depths of 70 km may lead to a deformation of the dipping slab which consumes much of the assumed velocity.

Altimeter calibration: Satellite radar altimetry is regarded as the key technology for studying the sea level variation on a global scale. Precise altimeter calibration is an essential prerequisite for providing reliable range measurements. A new precise absolute altimeter calibration technique has been developed for the *Jason-2* mission using a dedicated microwave transponder, which acts as an altimeter signal repeater. In a close cooperation with CNES, Toulouse, the technical possibilities of a special altimeter mode (DIODE/DEM) were leveraged. It activated for a few seconds while the satellite passed the transponder site on Gavdos (GR), which was established in a long lasting cooperation with the Technical University of Crete. Four different retracking methods have been developed to analyze the altimeter waveforms (Fig. 8). The resulting biases show an rms of ≈3 mm being much more stable compared to conventional calibration techniques based on GPS buoys and tide gauges measurements.

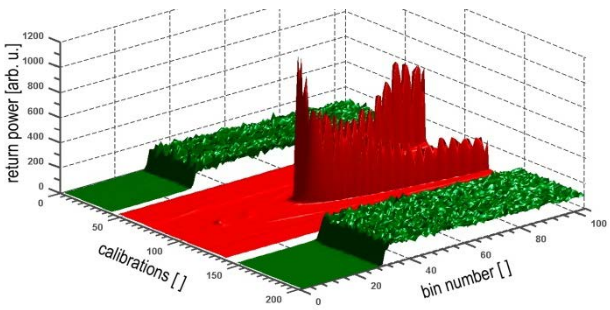

Fig. 8: Ocean (green) vs. transponder (red) generated altimeter waveforms.

Atmosphere

Atmospheric density: The escape and evolution of planetary atmospheres is related to the evolution of the soft X-ray and EUV radiation of the planet's host star. There exist a few theoretical models, which evaluate the impact of stronger solar EUV radiation on a terrestrial thermosphere (Fig. 9). Therefore, a validation of the models by LEO observations or empirical models is highly desirable. By using a sophisticated algorithm, which considers the gas-surface interaction between a satellite and its ambient atmosphere it is possible to determine atmospheric densities based on acceleration measurements made by the satellite *GRACE* at ~500 km.

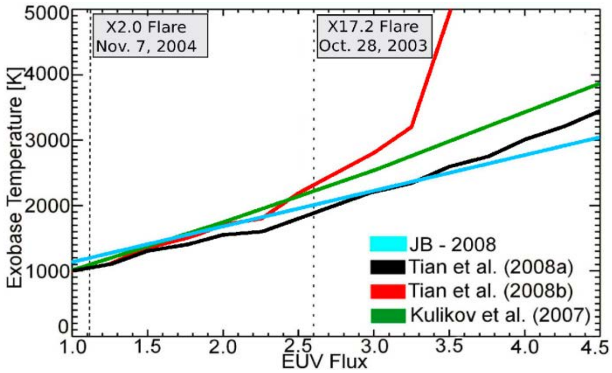

Fig. 9: Exobase temperatures obtained from empirical and theoretical thermosphere models during different EUV levels.

Through the additional analysis of spectral measurements from LEO TIMED during extreme solar flares a connection between the measured acceleration and theoretical models is established. Furthermore, the solar input parameters of the model are modified to reproduce different solar activity levels. The results indicate a good accordance to those deduced from various other sources.

Multipath: Satellite signals are transmitted not only on the direct way but may be also received as reflections. For GNSS receivers these reflections are reconstructed as pseudoranges assuming the direct distance of the line of sight. If not corrected or excluded it is obvious that this leads to a wrong position of several meters. Multipath reflections are most likely at plane or parabolic surfaces which transmit signals without much loss of strength.

On the institute's roof there is an existing metal construction, which is quite a good re flector for multipath effects. To enhance this and to be more flexible a copper plate was installed to serve as an artificial reflector (Fig. 10) allowing for adjustable angles.

Fig. 10: Reflectors for multipath generation on a GNSS antenna on the roof of IWF.

Seismo-electromagnetism: Earthquakes have been studied with a magnitude larger than 5.5 in Greece in 2008 and 2010. Using GNSS data the TEC values one week before and after the earthquake have been computed. To avoid the daily variations only the night-time values were used in order to search for precursors in the ionosphere. In only one out of eight cases a significant increase three days before the earthquake could be detected. Unfortunately the global index of geomagnetic disturbances K_p also showed an increase at that time. Therefore the feature cannot certainly be claimed as a precursor.

Sub-ionospheric VLF/LF radio links are an essential tool to investigate seismo-electromagnetic phenomena. In the frame work of a European VLF/LF network, radio paths between several transmitters and receivers were investigated, among them the Graz VLF facility. The main emphasis of the seismo-electromagnetic VLF/LF studies is on the L'Aquila earthquake from April 2009 with a magnitude of 6.3. In this analysis the influence of conductivity variations in the wave guide on the received VLF/LF amplitude have been considered. In addition the L'Aquila seismic event has been analyzed by the *South European Geomagnetic Array (SEGMA)*. Long term observations and station comparisons have shown the quality figure of each *SEGMA* station. The signal to noise ratio of the L'Aquila station was sufficiently high to detect magnetic variations. In comparison, no seismic signals were detected on the other *SEGMA* stations. Possible seismic signals can be detected with the *SEGMA* multi-station network approach if the environmental conditions can be characterized.

Satellite Laser Ranging

Tracking of HEO satellites was mainly improved in the Real Time Tracking Software. It now allows collecting at least 1000 returns significantly faster than the usual 5-minute Normal Point bin. Combined with the fast pass switching, now 3 to 4 different HEO satellites within one NP bin can be tracked.

Space debris is becoming a significant threat to space activities, especially in selected orbits which are heavily populated with active and inactive satellites, booster rocket stages, empty or exploded tanks. An estimated amount of more than half a million parts greater than 1 cm, are all dangerous due to their high velocity of more than 8 km/s. In order to test laser ranging possibilities to such space debris objects, a frequency doubled Nd:YAG pulse laser was installed with a 1 kHz repetition rate, a pulse width of 10 ns, and a pulse energy of 25 mJ at 532 nm (on loan from DLR). Low-noise single-photon detection units were developed and built to enable laser ranging to such targets with their inaccurate orbit predictions. The standard SLR software was adapted to include a few hundred space debris objects. With this configuration and within 13 early-evening sessions of about 1.5 h each, 85 passes of 43 different space debris targets were tracked. Their distances were between 600 km and up to more than 2500 km (Fig. 11) with an average precision of about 0.7 m RMS, radar cross sections from >15 m^2 down to <0.3 m^2. The main goal of this experiment was to prove the concept of laser ranging to non-cooperative targets, relying on diffuse reflections only.

The orbits of space debris objects are mainly determined by radar measurements, with limited accuracy: Up to ±1 km in range, and up to ±1 second in time. Nevertheless, this allows prediction of near miss scenarios several days ahead. Applying the more accurate laser distance measurements to the involved objects, the orbit accuracy could be significantly improved. This can help to avoid unnecessary collision avoidance maneuvers, thus saving the limited amount of fuel on board of active satellites, and extending their useful life time.

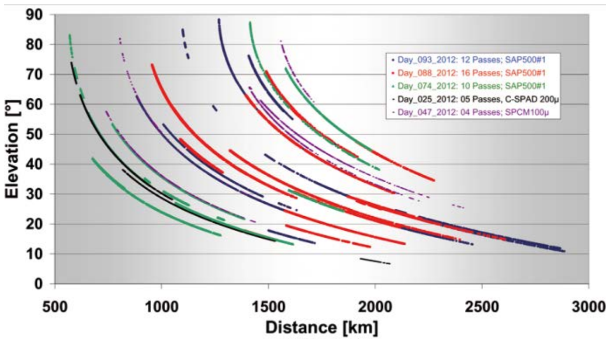

Fig. 11: Space debris pass examples.

Bistatic ranging to a space object (Fig. 12) was tested, for the first time. Graz fired with the DLR laser to a large space object – we selected *ENVISAT*, due to its size and its well known orbit – and received echoes as reflected from the satellite's retro-reflectors. At the same time, the Swiss SLR station Zimmerwald was synchronized to the Graz laser shots, and received single "Graz" photons, diffusely reflected from the surface of the satellite's body. Thus, the distances from the satellite to both SLR stations were measured simultaneously. The diffuse reflection allows more stations to participate in such measurements; and these stations could be relatively simple: no powerful laser, only accurate tracking, only passive detection of single photons, easy for fully automatic and unmanned operation etc. The resulting 3D-determination of the objects position in space allows for even more accurate orbit determination.

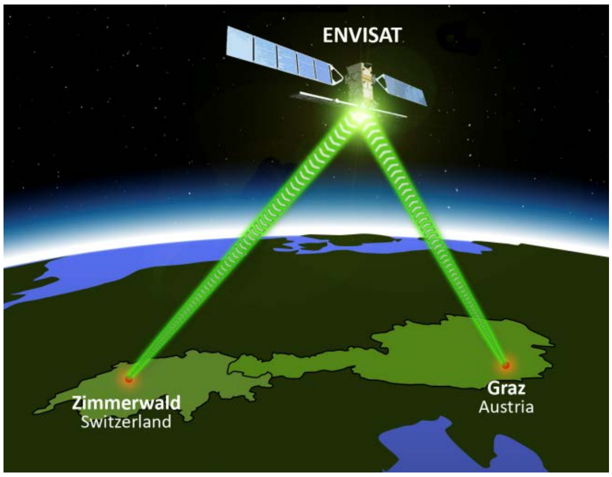

Fig. 12: Bistatic laser ranging scenario.

The spin parameters of *LARES* have been determined with high accuracy; and a possible reason for the unexpected interruptions of echoes (Fig. 13) from the spinning satellite has been identified: Most probably a small explosion during the ejection of *LARES* deposited a thin layer on a few retro-reflectors, significantly decreasing their transparency.

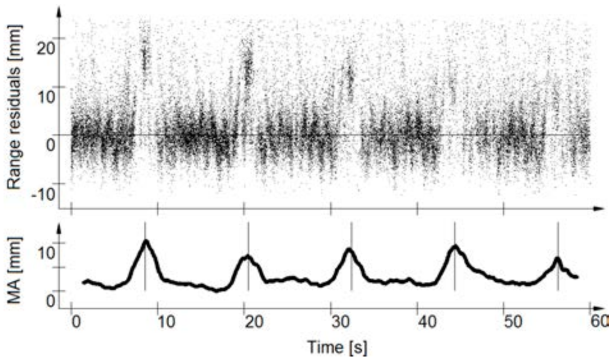

Fig. 13: Periodical interruptions of LARES echoes.

For the first time, there is an opportunity to range to a retro-reflector equipped Chinese Compass satellite in a geostationary orbit. Even with low energy (400 µJ) pulses, return rates of about 2% are obtained from this satellite in a distance of almost 40 000 km. In addition, a commercially available receiver for transponder signals of aircrafts within about 100 km around our SLR station was installed. The determine their position, combined with the pointing information of the telescope, the laser is switched off immediately and automatically if any aircraft is too close to the laser beam.

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. IWF both builds instruments for satellite missions that make measurements in this natural laboratory and analyses the data obtained by them, and participates in future planning.

Missions

The *Cluster* and *THEMIS/ARTEMIS* mission are providing a wealth of exciting data, which lead to many new scientific results. Furthermore, IWF is involved in the upcoming *MMS* mission.

Cluster

The four *Cluster* spacecraft, launched in 2000, 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

NASA's *THEMIS* mission, 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, *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.

Van Allen Probes

The *Van Allen Probes* (formerly known as the *Radiation Belt Storm Probes)*, successfully launched in 2012, will study the dynamics of the radiation belts essential for understanding the key component of the space weather system. The instruments on the two *Van Allen Probes* spacecraft will provide the measurements needed to characterize and quantify the processes that produce relativistic ions and electrons. As one of the science Co-I institutes, data analysis is planned at IWF combined with other magnetospheric missions and ground-based data.

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*, Fig. 14) and the digital fluxgate magnetometer *(DFG),* which both belong to the *FIELDS* instrument package.

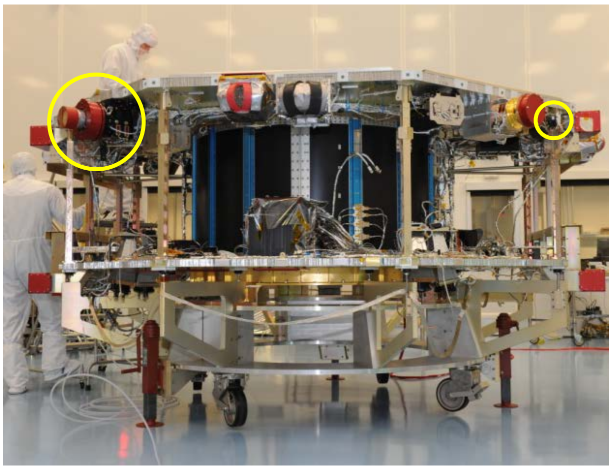

Fig. 14: Installation of instrument deck is complete on the second of four spacecraft being assembled in the special MMS cleanroom at NASA's Goddard Space Flight Center (GSFC); EDI (left) and ASPOC (right) are marked by yellow circles (Credits: ASRC Research and Technology/Barbara Lambert).

Active Spacecraft Potential Control (ASPOC) instrument: 2012 was the most intensive year for *MMS* related hardware activities hitherto. Assembly, integration, and testing at instrument level were followed by shipment to the US, integration into the Instrument Suite and Observatory, and functional, EMC, and performance tests at GSFC of most of the in total nine Flight Models. Only the first two Flight Models had already completed all test activities in 2011. At the end of 2012 the last two Flight Models stood in the midst of their environmental testing. All other models saw a complete sequence of integration of electronics with ion emitter modules, comprehensive performance testing, vibration, thermal vacuum, EMC, and magnetic tests. Before delivery of the units in pairs to the US, their data packages were compiled and reviewed. Environmental testing was uneventful with the exception of minor issues related to the ion emitters, which required partial re-testing of two Flight Models. Reporting, scheduling, and maintenance of data bases were done as necessary.

On the software side, a formal acceptance test was performed, and two revisions were implemented. In order to limit travel to tests in the US to an absolute minimum it was essential to develop and test ground software to communicate with the integration site at GSFC and the Operation Center at LASP. On-site participation to tests could thereby be limited to activities immediately following the respective hardware deliveries to the US. The preparations for system tests in 2013 and the in-flight commissioning in 2014 have started.

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

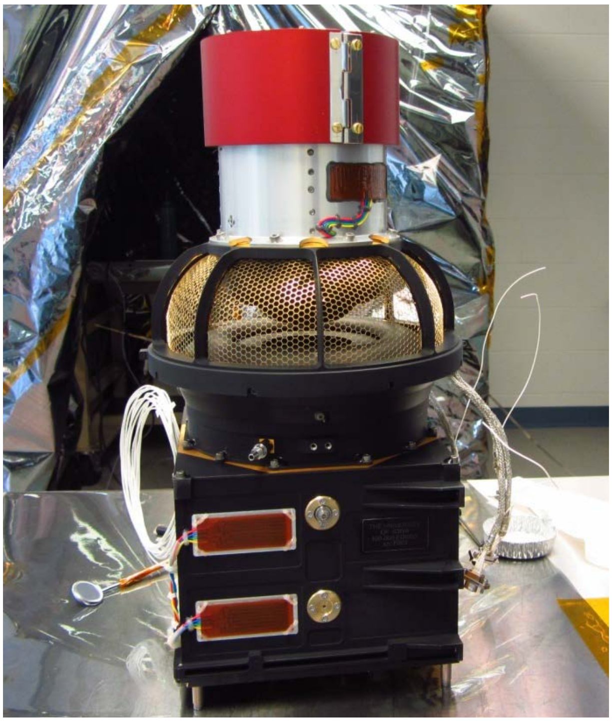

Fig. 15: EDI FM3, detector, optics and gun integrated into GDU.

The *EDI* instrument for *MMS* is based on the *Cluster* development with several improvements. In 2012 the first four flight units of the *EDI* gun have been manufactured and calibrated at the institute. The industry provided six fully tested units of the *GDE*. Three sets of *GDE* and gun have already been delivered to the University of New Hamsphire (UNH) for further integration. The *GDU* is integrated at UNH and consists of *GDE*, detector, optics and gun (Fig. 15).

The results of the calibration are much better than expected. The instrument emits a coded electron beam, steerable over 2π sr. The requirement is to provide a pointing accuracy of 1° for the electron beam. Except for a few positions at extreme polar angle (95°) an accuracy of 0.05° has been achieved. The dense packing of the electronics and the presence of high voltage up to 4 kV demands high class workmanship for the assembly and integration process.

Digital Flux Gate magnetometer (DFG): DFG is based on a triaxial fluxgate 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.

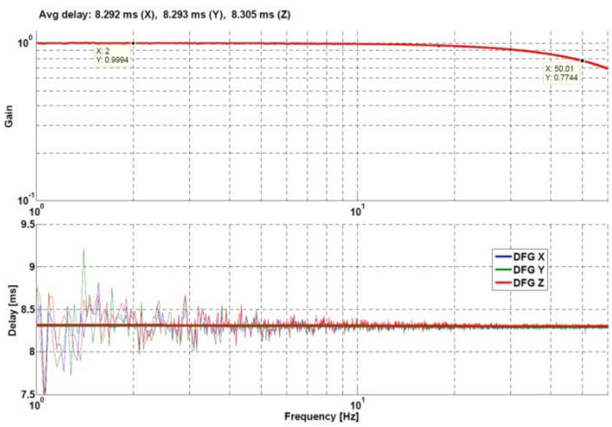

Fig. 16: Gain and delay response of DFG.

In 2012, the second, third and fourth flight model of *DFG* were assembled at IWF, calibrated at IWF and Technical University of Braunschweig and finally delivered to the University of New Hampshire. Parallel to the hardware activities, IWF is having 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. Test campaigns with flight models 1 and 2 took place in 2012. The DFG e.g. features a very constant group delay as illustrated in the lower plot of Fig. 16.

As part of the preparation for inflight magnetometer calibration activity, a new algorithm for determining spin axis offset of the flux magnetometers using absolute magnetic field values deduced from the time of flight data from the *EDI* measurements have been developed. The methods are tested using *Cluster FGM* and *EDI* data for selected *Cluster* orbits with apogee in the magnetotail.

Space Weather Magnetometer

The *Magnetometer Front-end ASIC* developed by IWF, together with *Anisotropic Magneto-Resistive (AMR)* sensors, is in use for the development of a service oriented magnetometer package for space weather measurements. It is a flexible design with up to six magnetic field sensors. The *MFA-AMR* combination is used for detecting and characterizing magnetic disturbers in the spacecraft body so that the data measured by the fluxgate sensor at the tip of an up to 2 m long boom (also part of the package) can be corrected for the spacecraft magnetic fields. It is planned to fly such magnetometers on missions which are not necessarily dedicated to scientific objectives but which go to orbits where space weather forecast measurements are useful.

Physics

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. Most of the data analysis is performed using data provided by the ongoing missions *Cluster* and *THEMIS,* but also other magnetospheric missions and ground-based observations. The studies deal with interactions between solar wind and magnetosphere, internal disturbances in the magnetosphere such as plasma flows and waves, and plasma instabilities including magnetic reconnection.

Kinetic interchange/ballooning instability: *THEMIS* observations are used to investigate the plasma sheet evolution during active times with strong magnetic field oscillations with periods of 100 s. Using multi-spacecraft analysis and an empirical plasma sheet model, both properties of the large-scale and the properties of the oscillations are determined.

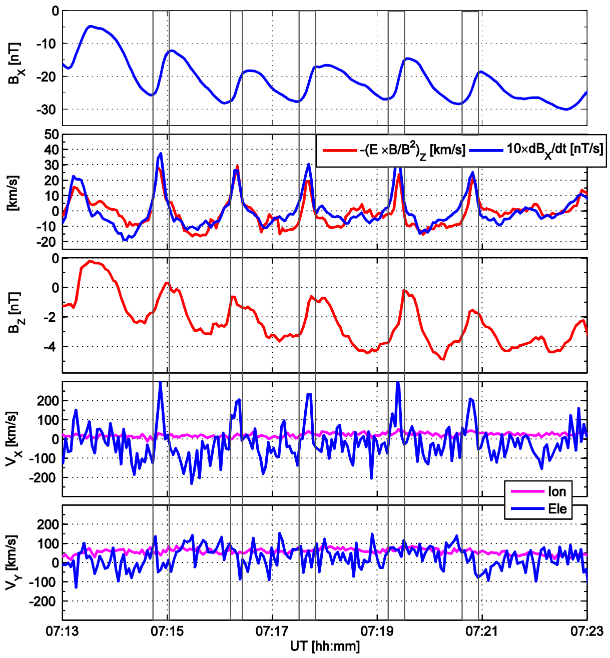

Fig. 17: X component of the magnetic field, Z component of the ExB-drift velocity (red) and time derivative of the X component of the magnetic field (blue), Z component of the magnetic field, X, and Y components of the ion (magenta) and the electron (blue) velocity measured by THEMIS P4 from top to bottom.

The oscillations exhibit signatures of kinetic ballooning/interchange instability fingers, which can develop in a bent current sheet. They contain a sausage structure, propagating duskward at a velocity of about 100 km/s, and are associated with fast radial electron flows (Fig. 17). A build up of a negative gradient of the current sheet normal component of the magnetic field along the tail axis is considered to be a free energy source for the kinetic ballooning/interchange instability.

After tens of minutes, a fast elongation of ballooning/interchange fingers is detected between 6 and 16 R_E downtail with a length-to-width ratio exceeding 20. The finger elongation ends with signatures of reconnection. These observations suggest a complex interplay between the midtail and near-Earth plasma sheet involving fluctuations in both cross-tail and radial directions before reconnection.

Double-gradient (flapping) oscillations: Flapping oscillations are the fast vertical oscillations of the Earth's magnetotail plasma sheet, which are detected in many current sheet crossings. The flapping oscillations tend to appear mostly in the central part of the tail, and the waves propagate predominantly from the center to the flanks (the y direction) perpendicular to the magnetic field lines. The MHD model called "magnetic double-gradient instability", predicts the characteristic flapping frequency, determined by a product of the two magnetic gradients – the tangential (B_x) and normal (B_z) magnetic field components along the normal (z) and tangential (x) directions, respectively. A positive product of these gradients yields a real oscillation frequency (a propagating flapping wave), whilst for a negative product the frequency is imaginary and purely growing perturbations should be observed.

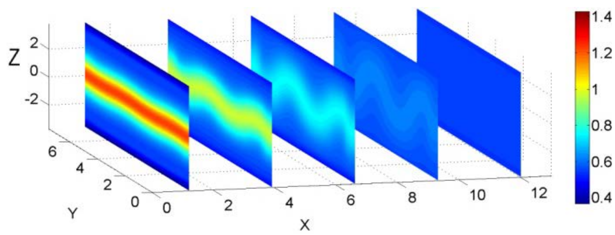

Fig. 18: Linear stage of the double-gradient (flapping) instability: x-slices of the number density.

The essential predictions of the double-gradient model (dispersion curve, typical frequency and wavelength) are confirmed by means of numerical simulations for both homogenous and non-homogenous current sheets. For the latter case, the fully three-dimensional MHD simulation has shown that existence of the stable segment yields the stabilizing effect for the whole computational domain as shown in Fig. 18, so that the numerically obtained growth rate is close to the analytical estimate averaged over the domain.

Effect of a weak guide field on magnetic reconnection: Reconnection is a universal phenomenon in space and laboratory plasma, by which magnetic energy can be converted into plasma kinetic and heat energy. Although less frequently compared to the magnetopause case, the magnetotail reconnection is also observed under the presence of a background magnetic field along the current direction, called the guide field, in the dawn-dusk direction. The guide field is expected to change the structure of reconnection diffusion region and the plasma dynamics within it.

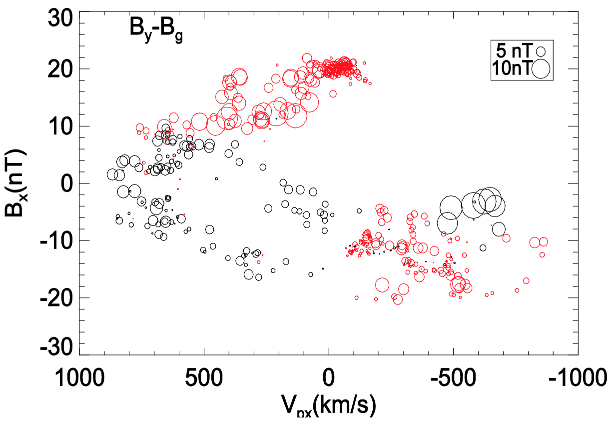

Fig. 19: B_y–B_g as a function of B_x and V_{px}. Black (red) circles correspond to B_y–B_g <(>)0.

Based on a detailed analysis using *Cluster* measurements, the effect of a guide field on reconnection has been investigated. The Hall quadrupolar magnetic structure within the ion diffusion region is shown to be distorted due to the addition of the guide field (Fig. 19). A clear north-south asymmetry in the current sheet structure is also observed within ion diffusion region. Furthermore, it is shown that electrons streaming into X-line along the separatrices are unexpectedly accelerated already before they enter into electron diffusion region.

Electron dynamics in the reconnection ion diffusion region: Magnetic reconnection is a process to change magnetic field topology in a localized diffusion region, which is scaled by the ion and electron inertia lengths. The ion motion is first to decouple from the magnetic field in the vicinity of the reconnection site at the ion diffusion region, whereas the electrons are still magnetized.

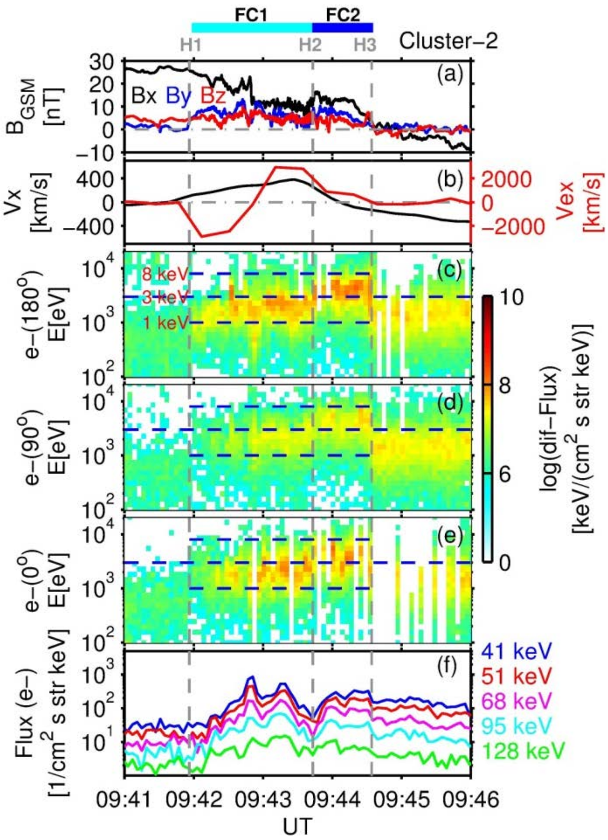

Fig. 20: (a) The 22 Hz magnetic field; (b) the x component of the ion (black) and electron (red) velocity; (c)–(e) PEACE electron spectrograms for pitch angles 180, 90, and 0 degrees; (f) RAPID electron fluxes for different energies.

A *Cluster* observation in the ion diffusion region has succeeded to reveal its electron dynamics in terms of energy and spatial structure (Fig. 20). The ion diffusion region is enclosed by the H1 and H3 dashed lines. The electron flows, V_{ex}, reverse in this region and are predominantly accelerated along the field-aligned directions (panel c–e). Two distinct regions FC1 and FC2 are identified, in which the electrons fall between 1–3 keV and 3–8 keV respectively. The energetic electrons (>40 keV) are enhanced inside the ion diffusion region (see panel f) with an interesting dip at the transition between FC1 and FC2. The ion diffusion region has been found to contain such fine substructures where the electrons are energized differently and therefore indicates different acceleration mechanisms acting simultaneously in ion diffusion region.

Remote estimation of reconnection parameters in the Earth's magnetotail: The rapid conversion of the stored magnetic energy to the particle energy is expected to occur in a small localized region in the magnetotail associated with reconnection. As a consequence fast transient flows propagate in the current sheet disturbing the surrounding medium. Such remote signals have been used to obtain characteristics of reconnection, i.e., the location of the reconnection and the amount of the reconnected magnetic flux based on a 2D MHD model of transient reconnection.

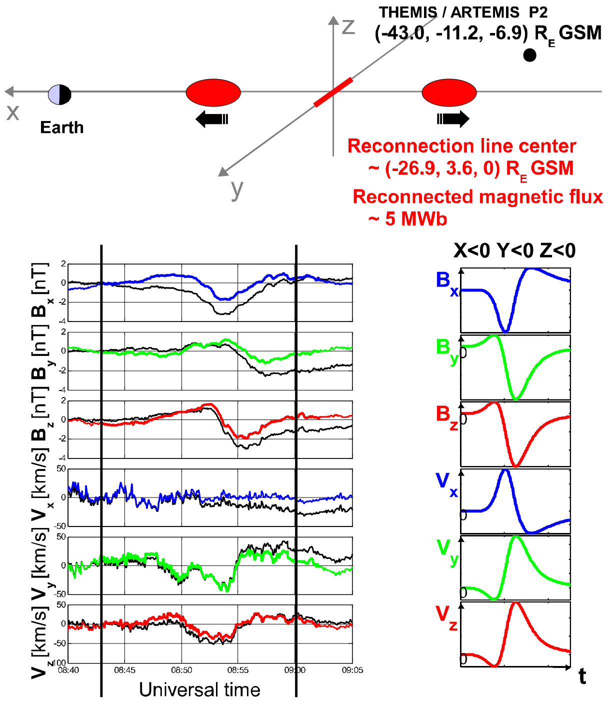

Fig. 21: Top: Reconnection region (red line), reconnection flows (red ovals), spacecraft location (black dot); left: ARTEMIS observations; right: Model prediction for the magnetic field and plasma velocity disturbances.

This model is now applied to a 3D case by introducing the locality of the reconnection region. The analytical solution relates the magnetic field and plasma velocity disturbances in the ambient of the reconnection flow space to the reconnection location and the reconnected flux. The method is successfully applied to *ARTEMIS* spacecraft observations (Fig. 21).

Kelvin-Helmholtz instability of reconnection exhausts: The initial tangential discontinuity (TD) associated with magnetic reconnection decays into a system of large amplitude waves such as shocks or rarefaction waves. An analytical model for finite X-line impulsive reconnection is developed based on the Rankine-Hugoniot system. An important feature of the model is that after some time most of the exhaust is expected to be bounded by the TD. Without the normal component of the magnetic field the TD surface can be Kelvin-Helmholtz (KH) unstable. The model is applied to discontinuity events observed by *Wind* as shown in Fig. 22. In this case, an exhaust region bounded by two TDs is found with the second TD being KH unstable and signatures of a vortex can be observed in the satellite data (blue trace).

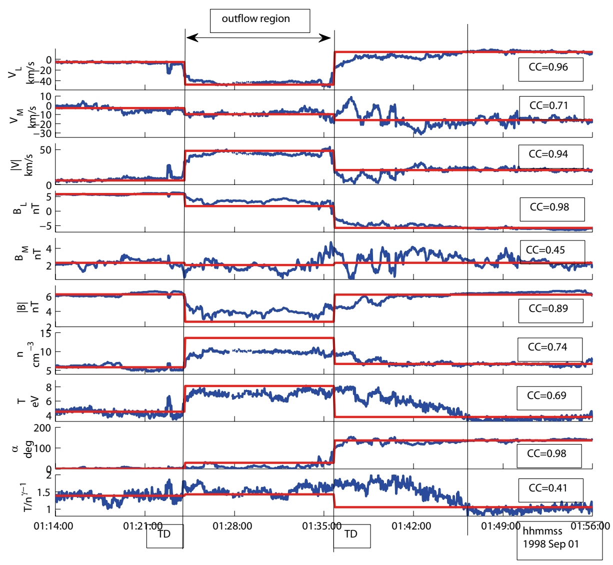

Fig. 22: Plasma and magnetic field paramaters observed by Wind spacecraft (blue) and obtained by the reconnection model (red). Vertical lines indicate the boundaries (TD) of the exhaust and the edge of a region with oscillations associated with KH instability.

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's electromagnetic radiation, magnetic activity, and the 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 and is scheduled for launch in 2017. IWF builds the digital processing unit (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.

Radio and Plasma Waves (RPW): *RPW* will measure the magnetic and electric fields at high time resolution and will determine the characteristics of the magnetic and electrostatic waves in the solar wind from almost DC to 20 MHz. Besides the large antennas and the AC magnetic field sensor, the instrument consists of four analyzers, the thermal noise and high frequency receiver, the time domain sampler, the low frequency receiver, and the bias unit for the antennas. The control of all analyzers and the communication with the spacecraft will be performed by the DPU.

The institute is responsible for the design of the DPU hardware and the boot software. In 2012 the detailed design concept for the DPU has been developed.

The E-field sensors (boom antennas) of the *RPW* instrument aboard the *Solar Orbiter* spacecraft are subject to severe influences of the conducting spacecraft body and other large structures such as the solar panels in close vicinity of the antennas. Compared to other spaceborne multiport scatterers, the antenna sensors aboard *Solar Orbiter* are more sophisticated in mechanical design with features including tubular shaped pipes with radiators along with several hinges. Combined with the challenging environment (closest proximity to Sun is about 0.29 AU, see Fig. 23), this makes finding the true properties even more pressing than with previous spaceborne radio astronomy observatories.

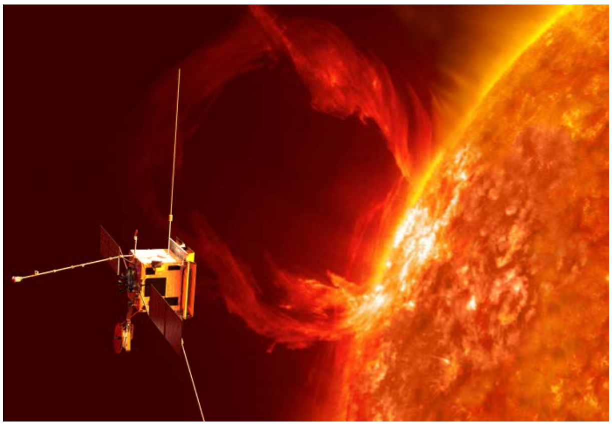

Fig. 23: Artist rendering of the Solar Orbiter spacecraft in close proximity of Sun. The thermal load on the antennas will cause severe mechanical deformation and bending of the antennas, which directly influences the antennas' reception properties.

The current focus is on obtaining calibration results from numerical computation of the governing field equations, resulting in surface current distributions from which the effective axes and lengths and impedance matrices for the quasi-static range are derived. This improves the instrument's performance in both remote sensing as well as in-situ capabilities. This will also complement efforts to compare with experimental data that will soon be available, including results from anechoic chamber studies performed with scale models, providing an important benchmark for the numerical results. The current calibration results are to provide useful input to goniopolarimetry techniques like polarization analysis, direction finding and ray tracing, all of which depend crucially on the effective axes, thus providing significant improvements to the corresponding data analysis.

Physics

Unusual solar radio bursts: An unusual radio burst has been observed by the radio telescopes UTR-2 (Kharkov, Ukraine) and URAN-2 (Poltava, Ukraine) at frequencies 16-27.5 MHz at 12:10 UT on 3 June 2011. This burst, as seen in Fig. 24, was registered by *STEREO A* at frequencies <15 MHz but was not seen by *STEREO B*. It differed from the usually observed solar emissions, such as type III and II bursts and others. It had duration 50-80 s and negative (-100 kHz/s) and positive (500 kHz/s) frequency drift rates. This unusual burst disappeared at a frequency of 27.5 MHz. Its polarization was about 10% and its maximum flux corresponded to an equivalent of 10^3 *sfu*.

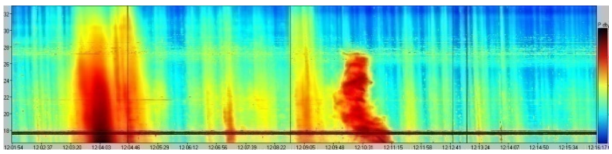

Fig. 24: Unusual burst observed by radio telescopes UTR-2 and URAN-2 at 12:10 UT on 3 June 2011. The horizontal time axis comprises 15 minutes starting at 12:01:54 UT, the vertical frequency axis defines 17-33 MHz.

Analysis shows that this unusual burst seemed to be initiated by a small ejection of electrons associated with an active region, which was located on the behind-the-limb west side of the Sun. Radio emission of this unusual burst was generated at the second harmonic of the local plasma frequency, which enabled the observations by ground-based radio telescopes and explained the cut-off of the burst at frequencies higher than 27.5 MHz.

Alfvén waves in the solar atmosphere: Alfvén waves play a significant role in the energy balance of the solar atmosphere as they transport the energy of photospheric granulation towards the chromosphere and corona. On the other hand, the chromospheric plasma is partially ionized containing significant amount of neutral atoms. Partially ionized plasma leads to the appearance of a cut-off wave number in single-fluid MHD equations i.e. the Alfvén waves with wave numbers higher than the cut-off value have zero real frequency, and are therefore evanescent (see Fig. 25).

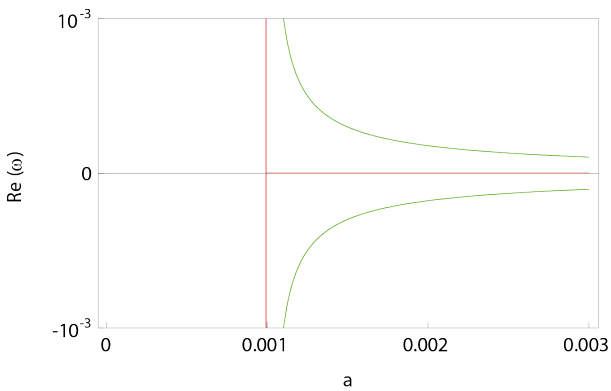

Fig. 25: Real part of the dimensionless wave frequency versus the dimensionless Alfvén frequency $a=kV_A/\omega_i$ in partially ionized plasmas, where ω_i is the ion gyrofrequency. Green (red) line corresponds to the single-fluid MHD equations with (without) Hall current.

Careful consecutive approximations from multi-fluid to single-fluid MHD equations show that the cut-off wave number of Alfvén waves in partially ionized plasma arises from neglecting the inertial and Hall terms. Therefore, the cut-off wave number is the result of approximation and it has no physical ground.

Thus, Alfvén waves with any frequency may propagate along the partially ionized solar chromosphere and can be damped there by collisions between ions and neutral atoms. Consequently, energy of the Alfvén waves can be dissipated in the chromosphere, leading to the heating of ambient plasma.

Supergiant complexes of Solar activity and convection zone: The global distribution of solar surface activity (active regions) is apparently connected with processes in the convection zone. The large-scale magnetic structures above the tachocline could be observable in the surface magnetic field. To get information regarding large-scale magnetic formations in the convection zone, a set of solar synoptic charts (Mount Wilson 1998 – 2004, Fe I, 525.02 nm) has been analyzed. The longitudinal dimensions and dynamics of super-giant complexes of solar surface activity carry valuable information about the processes in the convection zone of the Sun.

A Kolmogorov-type energy spectrum of the longitudinal variations of solar activity was found. This spectrum for non-photospheric scales of convection is a new "fingerprint" of turbulence in the deep layers of the solar convection zone. The preferred scales of longitudinal variations in surface solar activity are revealed. These are: ~24° (gigantic convection cells), 90°, 180°, and 360°. Similar scales are found in the mm radio-images (MetsÄahovi Radio Observatory 1994–1998, 37 and 87 GHz) and have prospects for remote sensing of the solar convection zone.

Kelvin-Helmholtz instability in twisted magnetic flux tubes on the Sun: Recent observations of Kelvin-Helmholtz vortices in the solar corona by SDO increased the interest to the flow instabilities in magnetic flux tubes on the Sun. It is shown that axial mass flows may trigger the Kelvin-Helmholtz instability of the kink-mode in weakly twisted magnetic tubes at critical Alfvén-Mach numbers lower than those in untwisted tubes. Therefore, Kelvin-Helmholtz vortices can be observed in twisted magnetic flux tubes of the solar photosphere and chromosphere.

Mercury

Mercury is now in the center of attention because of the current NASA *Messenger* mission and the upcoming ESA/JAXA *BepiColombo* mission. The planet has a weak intrinsic magnetic field and a mini-magnetosphere, which strongly interacts with the solar wind.

BepiColombo

Two spacecraft, to be launched in 2015, will simultaneously explore Mercury and its environment: the Japanese *Magnetospheric (MMO)* and ESA's *Planetary Orbiter (MPO)*.

IWF plays a major role in developing the magnetometers for this mission: 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 *PICAM,* 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 2012, the Flight Model of the *MERMAG-P* magnetometer was successfully assembled (see Fig. 26) and functional testing has been started. For *MERMAG-M*, the Flight Model electronics and sensor were delivered to Japan in September. In the following months a number of environmental tests like vibration and thermal cycling in vacuum were performed with the *MERMAG-M* units under the supervision of Japanese space companies.

For *PICAM*, initial electrical tests of the Qualification Model (QM) were carried out in January to verify the functionality and to characterize the high-frequency gating circuits, which are essential for the mass discrimination. The mechanical design of the gate electrodes was then improved, and several elements of the ion optics were strengthened as a result of mechanical dynamic and shock analysis. Tests with coatings for blackening have been performed. Ion beam testing of the QM has been carried out extensively along with numerous iterations of the unit to improve harness routings and other detail of the ion optics. Flight and EGSE software development have progressed together with intensified planning of operational scenarios – not an easy task to cope with the power and data rate constraints of this mission. An EMC test performed on the *SERENA* EM system revealed a few exceedances, which were coped with.

The flight version of the front-end ASIC has been radiation tested and showed an unexpected significant susceptibility for latch-up. Protection electronics has to be added to mitigate the effect. Design and test of such circuits have started. Partial go-ahead for flight model manufacturing of *PICAM* was given for elements unaffected by this issue.

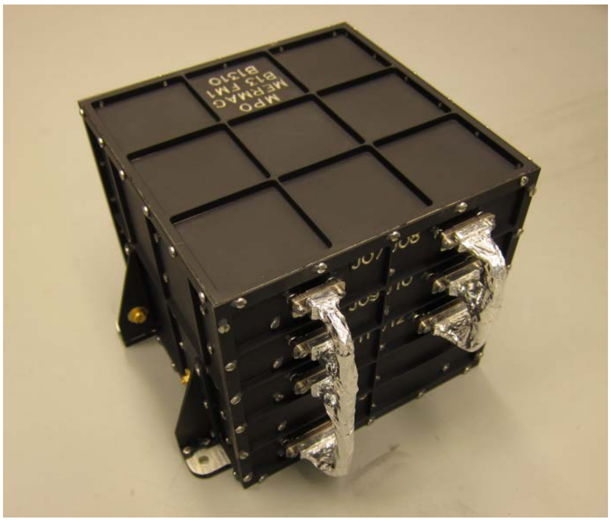

Fig. 26: Assembly of the MERMAG-M flight board (second slot from bottom right) into the MMO common electronics box.

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 first mission to Venus 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 2012, the *Venus Express* spacecraft continues operating normally. The magnetometer remains on during the whole year and collects both near Venus and interplanetary magnetic field data. Routine data processing and cleaning for the magnetic field measurements is undertaken for 1 Hz data. It shows that the software for data cleaning and processing is robust and error-free. All data are cleaned and issued to the science community. Further cleaning on 32 Hz data has been carried out for part of the data. Archiving of all available data has been carried out and all data have been delivered to ESA's Planetary Data System.

The *Venus Express* mission has been extended until the end of 2014, further new maneuvers in 2015 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 Venus's atmosphere is partially shielded by an induced magnetic field and this shield's effectiveness needs to be understood. The effectiveness is expected to vary with solar activity but current understanding of the solar wind interaction with Venus is derived from measurements at solar maximum. *Venus Express*, with improved instrumentation, a different orbital trajectory, and observations at solar minimum, furthers our understanding of the evolution of Venus's atmosphere caused by the solar wind interaction.

Reconnection in Venus's 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 the draping of interplanetary magnetic field lines. Observations with the *Venus Express* magnetometer and low-energy particle detector revealed magnetic field and plasma behavior in the near-Venus wake symptomatic of magnetic reconnection. This is a process that occurs in the Earth's magnetotail but is not expected in the magnetotail of a non-magnetized planet like Venus. Magnetic reconnection is a plasma process that changes the topology of the magnetic field (see Fig. 27) and results in energy exchange between the magnetic field and the plasma. Thus, the energetics of Venus's magnetotail resembles that of the terrestrial tail where energy is stored and later released from the magnetic field to the plasma. In other words, despite their very different magnetic envelopes, the plasma dynamics of Venus and Earth display many similar characteristics.

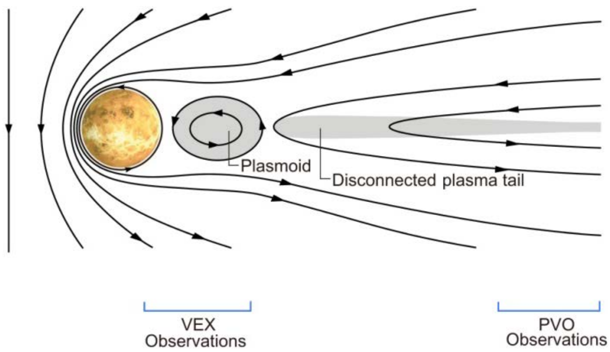

Fig. 27: Schematic illustration of the plasmoid formation and disconnected plasma tail events during the magnetic reconnection observed in the near Venusian tail. Field lines are indicated by solid lines. The region of observations by the Pioneer Venus mission (PVO) was in the distant tail in contrast to Venus Express (VEX) which observed the near tail.

Hot oxygen atoms in Venus's nightside exosphere: Chemical processes in the upper atmosphere can produce supra-thermal species which can move far beyond the bulk altitude of the atmosphere, thereby forming a corona of hot particles called the exosphere. Since the density of the exosphere depends mainly on the processes in the thermosphere, variations in the upper part of the atmosphere and ionosphere can also alter the exosphere densities. Based on a Monte Carlo approach, the nightside oxygen exosphere of Venus was investigated for low (LSA) and moderate (MSA) solar activity, where dissociative recombination of O2+ and NO+ ions as well as charge transfer processes between ionospheric O+ ions and neutral O and H atoms are assumed as sources of hot particles (Fig. 28). The simulations of the collisions between the hot particles and the background atmospheric constituents are based on energy dependent total and differential cross sections.

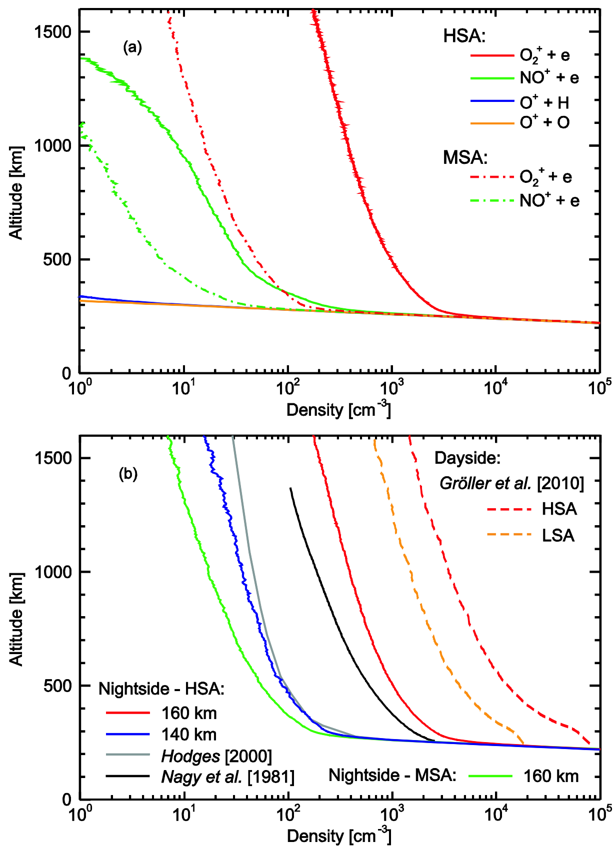

Fig. 28: Modeled hot O corona densities at Venus nightside exosphere related to solar activity (solid lines) and the dashed lines are densities for the dayside exosphere.

The results suggest that – similar as for the dayside – dissociative recombination of O_2^+ is the most efficient source of hot O atoms at the planet's nightside. For high solar activity (HSA), the nightside exospheric density of hot O atoms turns out to be about one order of magnitude lower than at the dayside, the exobase being predicted at about 160 km altitude. The results also indicate that allowing for energy dependent cross sections leads to lower exosphere densities than using constant cross sections as done in previous studies.

Jupiter

Jupiter has a large magnetic field and, unlike the Earth, a rotationally dominated magnetosphere and is a strong source of radio emissions.

JUICE

JUpiter ICy moons Explorer (JUICE) is the next ESA L-class mission, which is expected to be launched in 2022 and to arrive at Jupiter in 2030. The mission will explore the Jovian system and in its end phase will be placed in an orbit around the moon Ganymede. IWF is involved in several proposed instrument packages, which will be selected early 2013. For the *Jupiter Magnetic Field Package (J-MAG)* IWF develops, in collaboration with TU Graz, a scalar *Coupled Dark State Magnetometer (CDSM)*, and will participate in the development of flux gate magnetometers. For the plasma package *ChargEd Particle Analyzers for Galilean Environments (CEPAGE)* the institute is planning to build a DPA and for the *Radio and Plasma Wave Investigation (RPWI)* the calibration of the antennas is proposed.

Juno

Juno is a NASA mission to the gas giant Jupiter that was launched in 2011 and will enter into a Jovian orbit in 2016. The overarching goal is to understand Jupiter's origin and evolution. *Juno* is a spinning spacecraft and the first mission to Jupiter using solar panels. Another key scientific focus is Jupiter's polar magnetosphere, which is uncharted territory. IWF works on the antenna calibration of the *WAVES* instrument, which will investigate the auroral acceleration region and measure radio and plasma waves.

Juno/Waves calibration: The electric field dipole within the *Waves* instrument was analyzed. Two independent methods, experimental and numerical, were applied to determine the antenna properties. For the experimental technique (rheometry) a down-scaled model of the spacecraft antenna system on the scale 1:30 was built. It was used to measure the antenna properties in an electrolytic tank. The numerical simulations are based on computer codes for the solution of the underlying wave equations (electric and magnetic field integral equations). In this approach the spacecraft is modeled as a grid composed of wires and patches. The resulting quantities are surface currents, which are finally used to calculate the relevant antenna properties such as effective antenna vectors and directivity pattern (Fig. 29).

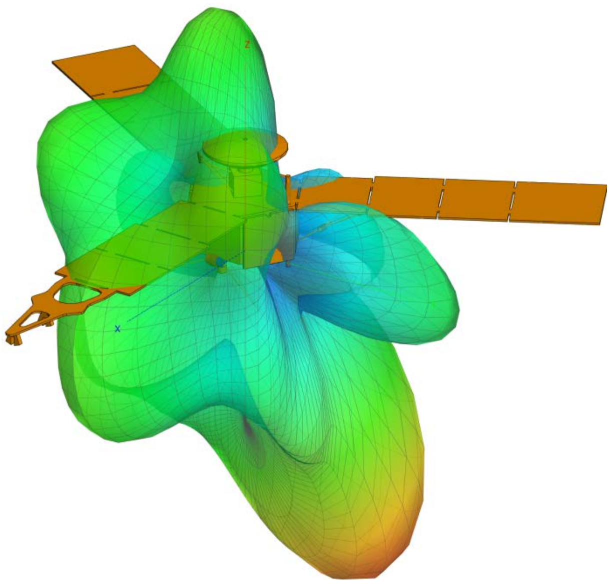

Fig. 29: Directivity pattern of the antenna system for 30 MHz; the color coding (linear scale) indicates the directivity, where red zones indicate favorable areas, which fade to blue areas of bad reception.

The results are particularly interesting because the Waves antennas have a very complex behavior for high frequencies and scientific data obtained by the instrument is highly dependent on the wave incident direction.

Physics

Jovian S-bursts: Two-dimensional correlation analysis reveals hidden patterns in the broad-band S-burst storms of Jovian decametric emission. The parameters of such patterns are used as a test of dominating hypotheses on the nature of S-bursts. Clear "fingerprints" of the low-altitude acceleration of the radio-sources in the standing dispersive Alfvén wave were found. This implies that the S-burst emission, like AKR near the Earth, is generated inside depleted cavities with tenuous and hot plasma. In addition, the morphological analysis of dynamic spectra of narrow-band Jovian emissions, the correlation patterns of radio storms and their modeling argue for negligible dispersion delay of S-burst emissions. The considerable dispersive drift of -17.3 ± 1.4 MHz/s at 25 MHz (Fig. 30) is found through correlation analysis of broadband S-bursts.

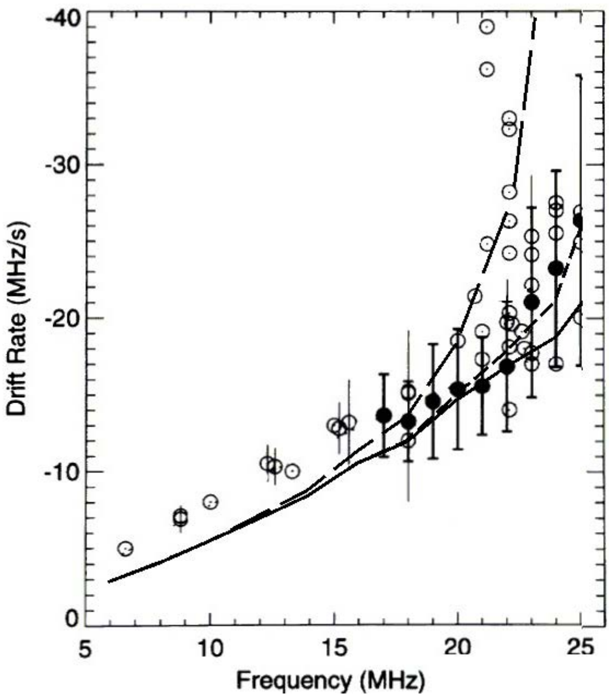

Fig. 30: Dispersion drift-rate curves, calculated for the cavity using different scale heights of ionosphere, are an approximation of S-burst drift measurements (circles correspond to: Zarka et al., 1996).

ULF waves in Ganymede's magnetosphere: Using two upstream flybys of the Jovian moon Ganymede by the *Galileo* spacecraft (shown in Fig. 31), the magnetic field data were studied for Ultra Low Frequency (ULF) waves. Deep inside Ganymede's magnetosphere evidence was found for field line resonances, which delivered the first in-situ measurements of plasma mass density. As expected deeper in the magnetosphere a larger density is found: 3 vs. 90 protons cm^{-3} at a radial distance of 2.1 and 1.5 Ganymede radii.

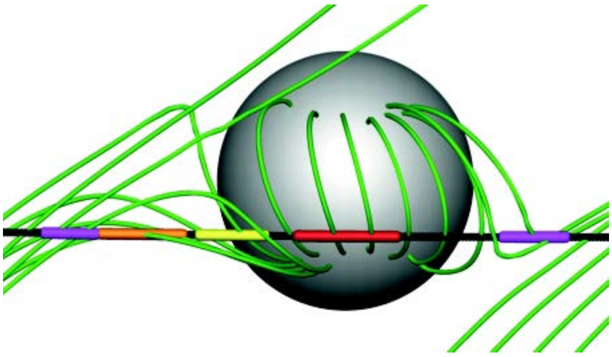

Fig. 31: G28 flyby of Ganymede by Galileo (black). The green lines show the magnetic field lines along the SC orbit. The colors show the different wave modes (red: field line resonances, orange: O^+, yellow: O_2^+ cyclotron waves, purple: magnetopause waves).

Exospheric mass loss through ion pickup can be detected through ion cyclotron waves. It was found that pickup of both O^+ and O_2^+ is taking place near Ganymede through the presence of cyclotron waves along the orbit of *Galileo*. At the flanks of the magnetopause strong oscillations were observed, which are most likely created by curved flux tubes created by bursty reconnection at the nose of the magnetopause.

Saturn & Titan

The *Cassini* spacecraft is still orbiting Saturn, the second largest planet in our solar system. Several *Cassini* flybys at the large moon Titan have been used in 2012 to bring the spacecraft again to high-inclination orbits. From autumn 2009 until spring 2012 *Cassini's* orbit had been mainly in Saturn's equatorial plane.

Physics

Lightning in Saturn's atmosphere: SEDs (short for Saturn Electrostatic Discharges) emit radio waves caused by the changing current flow within the lightning channel. The SED radio waves are unusually strong, about 10000 times stronger compared to terrestrial lightning in the frequency range of a few MHz. This makes them detectable with large ground-based radio telescopes since their spectral flux density at Earth can be up to several hundred Jansky. The first detection was made with the UTR-2 radio telescope in the Ukraine in 2006, and since then several SED storms have been observed. Fig. 32 shows a comparison between SED rates registered by the *Cassini Radio and Plasma Wave Science (RPWS)* instrument and by UTR-2. Selection criteria were developed to distinguish SEDs from radio interferences. SED storm observations by *Cassini* helped in choosing the right time for the ground-based observations, and the comparison of SED rates allowed verifying the UTR-2 detection algorithm. Several SEDs were even detected in parallel by UTR-2 and *Cassini RPWS*.

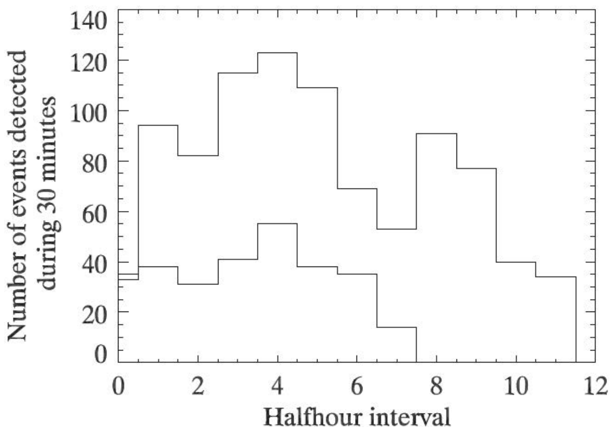

Fig. 32: SED activity in 30-minute intervals starting on 1 December 2007, 23:44 UT, observed by Cassini RPWS (upper line) and by UTR-2 (lower line). Cassini can observe the SEDs for a longer time (for about half a Saturn rotation).

In 2012 *Cassini* images still showed some cloud features at around 35° north latitude as remnants of the giant storm from 2010/2011. However, SED activity was not detectable from that region anymore. Instead, some weak SED activity was registered by *Cassini RPWS* in April and July 2012 that most likely originated from a convective cloud at 50° north latitude.

Comets

In recent years, successful space missions like *Giotto*, *VEGA*, *Stardust*, *Deep Impact* and others have dramatically increased our knowledge on comets and their nuclei. The next major milestone will be the arrival of *Rosetta* and its lander *Philae* in 2014.

Rosetta

ESA's *Rosetta* probe continues its journey to comet Churyumov-Gerasimenko, where it will arrive in summer 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 in November. IWF participates in five instruments aboard both orbiter and lander and concentrates now on preparatory work for data evaluation and interpretation. At the end of 2013 a "wake-up call" will be sent to the spacecraft.

Physics

Cometary outgassing: Comet encounters in the past have clearly shown that comets have a rough surface, covered by cracks and crevasses which might be preferred centers of gas and dust emissions. Therefore, a numerical model describing gas emission from such an ice-filled crack in response to the variable solar irradiation was developed.

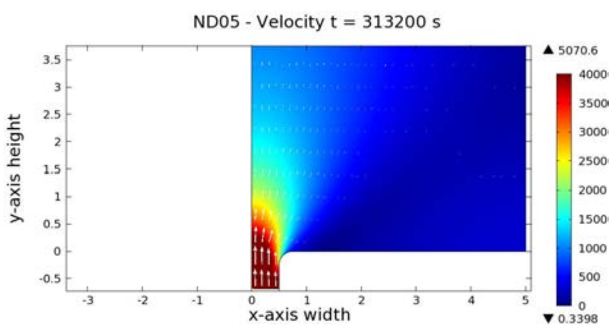

Fig. 33: Gas flow field at the exit of an ice-filled cometary crack.

Both surface sublimation of the ice in the crack and the possibility of amorphous to crystalline phase changes were taken into account. Fig. 33 shows the gas flow field at the exit of such an ice-filled cometary crevasse.

Another activity is performed in view of the upcoming landing of *Philae* on the comet's surface and the expected data from the *MUPUS* experiment. A new analytical approach was developed for the evaluation of the comet's thermal properties from data obtained by a non-ideal heat conductivity sensor. This new model allows e.g. the treatment of effects of contact thermal resistance between the probe surface and the external medium. Based on Laplace transform techniques a solution for the heated infinite cylinder has been obtained, taking into account a subdivision of the probe into core and sheath. The advantage of the analytic approach over numerical finite element simulations is computation-time reduction, which is essential for conductivity and heat capacity measurements. Fig. 34 shows the computed temperature evolution in the core and sheath of a cylindrical probe in a sample of moderate thermal conductivity.

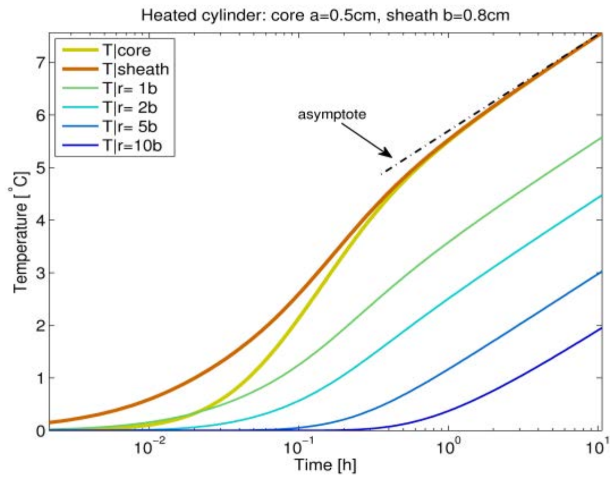

Fig. 34: Temperature rise in a heated cylindrical thermal conductivity sensor at different locations.

Exoplanets

The field of exoplanet (i.e. planets around stars other than our Sun) research has developed strongly, in the last years. Whereas this field started out with the findings of so-called hot-Jupiters in close orbit around their native stars, better observational methods have led to the finding of super-Earths like Kepler-20f, in close orbit around a star 945 light years away, and Earth-like planets like Kepler-20e. However, lately an Earth's "sister" was found (Kepler-22b) inside the habitable zone of its star, with a surface temperature of 22 °C. At this time more than 700 planets have been found around other stars.

CHEOPS

ESA's first S-class mission *CHEOPS (CHaracterizing ExOPlanets Satellite)* will be the first space mission dedicated to characterize exoplanets in detail (Fig. 35). It will focus on exoplanets with typical sizes ranging from Neptune down to Earth diameters orbiting bright stars, trying also to specify the components of their atmospheres.

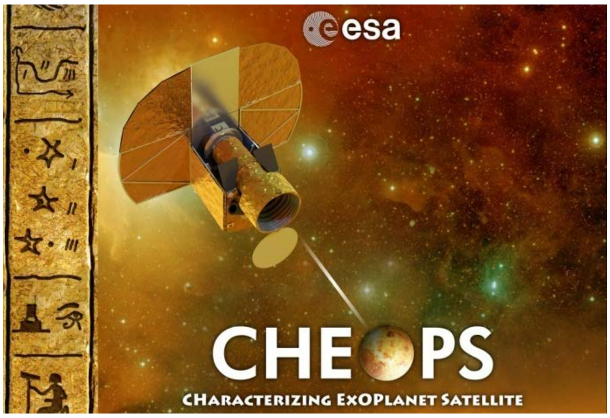

Fig. 35: ESA's first S-class mission CHEOPS is planned for launch in 2017.

CHEOPS will be implemented under the leadership of Willy Benz, University of Bern, Switzerland with Belgium, Italy, Sweden, UK, and Austria delivering substantial contributions. IWF Graz will build one of the two onboard computers, which will handle the complete data traffic and conduct the thermal control of the imaging sensor. It has a planned mission lifetime of 3.5 years, during which it will observe approx. 500 bright stars and characterize their planets.

Physics

Exoplanet plasma interaction studies: The interactions between the stellar wind plasma flow of a typical M star and hydrogen-rich upper atmospheres of an Earth-like exoplanet and a "super-Earth" with the radius of 2 R_{Earth} and a mass of 10 M_{Earth}, located within the habitable zone have been studied. The formation of extended atomic hydrogen coronae under the influence of the stellar soft X-ray and EUV flux, stellar wind density and velocity, shape of a planetary obstacle, and the heating efficiency on the evolution of the hydrogen-rich upper atmospheres as well as thermal and non-thermal escape rates have been calculated by a coupled Direct Simulation Monte Carlo - stellar wind plasma interaction model (see Fig. 36). The results indicate that thermal escape rates of outward flowing neutral atoms exceed the non-thermal ion loss rates several times. Non-thermal escape makes up <3 EO_H (ocean equivalent amounts of hydrogen) during a planet's lifetime, whilst thermal losses can be up to 11 EO_H over 4.5 Gyr.

Due to the star-exoplanet interaction, a magnetosphere with a magnetodisk can arise around the extrasolar planet if it is located in close orbital distances around the host star. At the Alfvén radius, R_A, the magnetic energy density is equal to the kinetic energy density, which can be considered as the inner boundary of the disk. The exoplanet's disk inner edge location at R_A, is considered in context of other astrophysical disks and for definite parameters, such as the existence of a strong magnetic field. Many disks have inner edges at R_A independent of the nature of origin of the disk's material and the motion of the disk. The distance from the host object to the disk's inner edge should be a key parameter of an exoplanet magnetosphere model, because studies have indicated that it determines the magnetic moment of the disk's current system, and as a consequence, the total magnetospheric magnetic field and the shape of the magnetosphere.

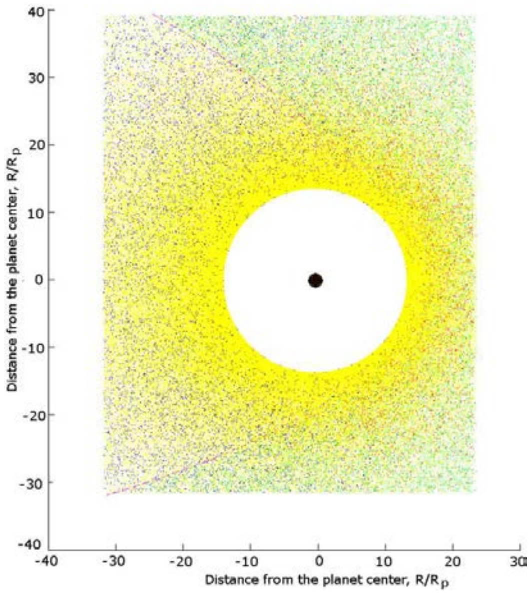

Fig. 36: Modeled atomic hydrogen coronae and its stellar wind plasma interaction around a "super-Earth" hydrogen-rich planet (green: protons, yellow: H atoms, blue ENAs flying away from the star, red: ENAs flying towards the star). XUV flux is 50 times higher than that of the present Sun.

Testing & Manufacturing

Instruments onboard spacecraft are exposed to harsh environments, e.g., vacuum (Fig. 37), 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.

Fig. 37: Both young and older visitors take the opportunety to learn more about vacuum through guided tours offered for example during the "Lange Nacht der Forschung".

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. One rotary vane pump and one turbo-molecular pump achieve a minimum pressure of 10^{-5} mbar. With an external thermostat the chamber temperature can optionally be controlled between -90°C and +50°C.

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.

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 340x300x80 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 used.

Publications & Talks

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Teaching & Workshops

Lecturing

IWF members are actively engaged in teaching at two universities. In summer 2012 and in the current winter term 2012/2013 the following lectures are given:

KFU Graz

Earth Magnetism and Magnetic Field (Biernat)

Magnetohydrodynamics and Solar-Terrestrial Modeling (Biernat)

Special Lecture on Theoretical Physics: Plasma Theory (Transport) (Biernat)

Introductory Aeronomy (Biernat)

Special Lecture on Theoretical Physics: Plasma Theory (Basics) (Biernat)

Introduction to Geophysics and Planetary Physics (Kargl)

Introduction to Planetology (Kömle)

Introduction to Plasma Physics (Rucker)

TU Graz

Space Plasma Physics (Baumjohann)

Advanced Satellite Geodesy (Baur, Hausleitner)

GGOS and Reference Systems (Baur)

Digital Audio Engineering, Practical Course (D. Fischer, Magnes)

Design and Development of Space Qualified Hardware (Magnes)

Signal Processor Techniques (Magnes)

HF-Engineering (Riedler)

Antennas and Wave Propagation (Riedler)

Measurement of Planetary and Interplanetary Magnetic Fields (Schwingenschuh)

Theory and Practice of Active Plasma Experiments in Space (Torkar)

Advanced Course

The new four semesters Master Studies curriculum "Space Sciences and Earth from Space" as a cooperative curriculum within the frame of NAWI (KFU and TU) Graz started in the winter term 2011/12 and will finalize its first sequence with first academic completion of studies in summer 2013.

Theses

Besides lecturing, members of the institute are supervising Bachelor, Diploma, Master and Doctoral Theses. In 2012, the following supervised theses have been completed:

Gröller, H.: Monte-Carlo simulation of the hot atom corona around terrestrial planets, Doctoral Thesis, Universität Graz, 180 pages (2012)

Hackl, H.: Evaluierung der Spannungsversorgung einer satellitengestützen Datenverarbeitungseinheit, Bachelor Thesis, TU Graz, 80 pages (2012)

Leitzinger, M.: Signatures of stellar mass ejections at radio and FUV wavelengths – implications for planetary mass loss, Doctoral Thesis, Universität Graz, 141 pages (2012)

Pfleger, M.: 3D Modelling of Particle Populations in Planetary Exospheres, Diploma Thesis, NAWI Graz, 123 pages (2012)

Qin, W.L.: GRAIL lunar gravity field recovery based on short-arc analysis, Diploma Thesis, Universität Stuttgart, 79 pages (2012)

Schmid, D.: A statistical and event study of magnetotail dipolarization fronts, Diploma Thesis, TU Graz, 82 pages (2012)

Stangl, A.: Geoeffectiveness: A statistical approach, Master Thesis, NAWI Graz, 76 pages (2012)

Stifter, M.: Mechanical Analysis and Optimization of a New Type of Magnetic Field Sensor, Diploma Thesis, FH Joanneum, 85 pages (2012)

Wirnsberger, H.: GOCE Gravitationsfeldbestimmung: Analyse kinematischer Orbits mit Variationsgleichungen, Diploma Thesis, TU Graz, 81 pages (2012)

Meetings

From 29 to 31 October the *Rosetta/Philae* Lander Science Working Team Meeting was hosted by the institute at Schloss Seggau with almost 80 participants from all over the world. The meeting was organized by Norbert Kömle and Günter Kargl.

Wolfgang Baumjohann served as Vice Director and Helmut Rucker on the Program Committee of the Summer School Alpbach, which took place between 24 July and 2 August and was dedicated to the „Exploration of the Giant Planets and their Systems“. Every year, 60 students and about 25 lecturers and tutors from among ESA's member states are invited to this meeting.

Additionaly, W. Baumjohann, B.P. Besser, H. Lammer, R. Nakamura, and H.O. Rucker were members of program and/or scientific organizing committees for ten international conferences/workshops. O. Baur, B.P. Besser, M.Y. Boudjada, G. Fischer, G. Kargl, M.L. Khodachenko, G. Kirchner, H. Lammer, R. Nakamura, M. Scherf, and G. Stangl organized 18 sessions at international meetings.

Awards and Recognition

In June, Hans Sünkel received the "Grand Decoration of Honor in Gold of the Land Styria" and in October, he became an honorary member of the "Österreichischen Gesellschaft für Vermessungswesen und Geoinformation".

In November, Konrad Schwingenschuh received the Austrian Cross of Honor for Science and Art I. Class in recognition of his achievements in the field of space sciences (Fig. 38).

Zoltan Vörös was elected as associated editor for the Journal of Geophysical Research.

Fig. 38: Governor Voves presented the Austrian Cross of Honour to Konrad Schwingenschuh (first from left) during a ceremony at the Old University (© Photo: Frankl).

Public Outreach

The year 2012 broke all records, as far as the number of visitors is concerned. On 27 April, almost 1500 people visited both IWF and the Lustbühel Observatory during the "Lange Nacht der Forschung". The program included experiments, movie shows, guided tours through the labs, observing through telescopes, a demonstration of the laser, and a remote controlled Mars Rover tour over a simulated surface of the red planet.

In April the "Topic of the Month" of the Austrian Academy of Sciences was "Cosmic rays", with contributions on space weather by Wolfgang Baumjohann and on cosmic particles by Bruno Besser.

On 26 June, there was a very prominent guest at IWF: US Ambassador William Eacho III and his son David (Fig. 39) visited the institute to get first-hand information on the progress of NASA's *MMS* mission.

Fig. 39: US Ambassador Eacho and his son, dressed in cleanroom coates, watching the instruments built at IWF for NASA's MMS mission.

Throughout the year, many different groups and school classes visited the institute. In May, pupils and high-school students of the Odilien Institut, VS Söding, and HTL-BULME Graz-Gösting were guided through the various laboratories to get a taste of what space research is about.

Additionally to "ordinary" guided tours, nine young ladies and gentlemen chose IWF to dive deeper into the field of space research. In February and May two kids from the secondary schools NMS Ferdinandeum and G.I.B.S. visited IWF for some work experience. From April until August an FH Joanneum student made his work experience at IWF and four female students from KFU and TU Graz worked at IWF in the framework of the "FEMtech" program of FFG.

During summer time, two high-school students from HTL-BULME Graz-Gösting and Akademisches Gymnasium took the opportunity to perform an internship at IWF under the "Talente-Praktika" program of FFG. They were involved in the preparation of mechanical parts for the electron gun of the *MMS/EDI* instrument and site specification for transponder deployment, respectively.

From 6-7 September, the Summer University "Graz in Space" was held at IWF. About 70 participants listened to several talks on this year's topics, which concentrated on the Earth from space, storms on Saturn, landing on a comet, and the search for Earth-like exoplanets. The Summer University closed with a ceremony on the occasion of the 80th anniversary of Willibald Riedler.

From 1-4 October, the Austrian radio station Ö1 broadcasted a series of interviews on Jupiter and its moons. Wolfgang Baumjohann, Helmut Lammer and Helmut Rucker talked about the gas giant and the upcoming ESA mission *JUICE*.

On 13 November, the Austrian broadcasting corporation ORF sent a camera team to IWF. They shot an interesting, child-oriented movie about the job profile of a space scientist for the children's TV program "Hallo okidoki" (Fig. 40).

Fig. 40: The nine years old Teresa gets explained what comets are made of ("Hallo okidoki", ORFeins, © ORF, 2012).

In the frame of the "Einstein-Junior" project of the Kinderbüro of the City of Graz, IWF participated in November in both the "Filmtage Mondscheinkinder", which took place in different movie cinemas, and a "Familiennachmittag" (Fig. 41) held at the institute.

On three days in December, ARGE KIWI (working group "Children and Science") invited almost 200 children and their parents to visit the laser station at Lustbühel Observatory in the frame of the project "Wissen schaf[f]t Durchblick", supported by FFG.

Last but not least, Wolfgang Baumjohann gave two talks in the Vienna City Hall and the Planetarium in Klagenfurt, where people had the chance to learn more about space weather and the Sun. Throughout the year, several URANIA series of lectures on different topics in space research were held by members of the institute.

Fig. 41: Laughter and happiness filled the institute during the "Einstein-Junior" family's afternoon.

Personnel

Alexandrova, Alexandra, MSc (P)
Al-Ubaidi, Tarek, Dipl.-Ing. (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)
Boakes Peter, Dr. (P)
Boudjada, Mohammed Y., Dr. (P)
Delva, Magda, Dr. (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, Dr. (P)
Hagen, Christian, Dipl.-Ing. (E)
Hartl, Harald, Dr. (E)
Hasiba, Johann, Dipl.-Ing. (E)
Hausleitner, Walter, Dr. (S)
Höck, Eduard, Dipl.-Ing. (S)
Hradecky, Doris (A)
Jernej, Irmgard, Ing. (E)
Jeszenszky, Harald, Dipl.-Ing. (E)
Kapper, Michael, Dr. (P)
Kargl, Günter, Dr. (P)
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