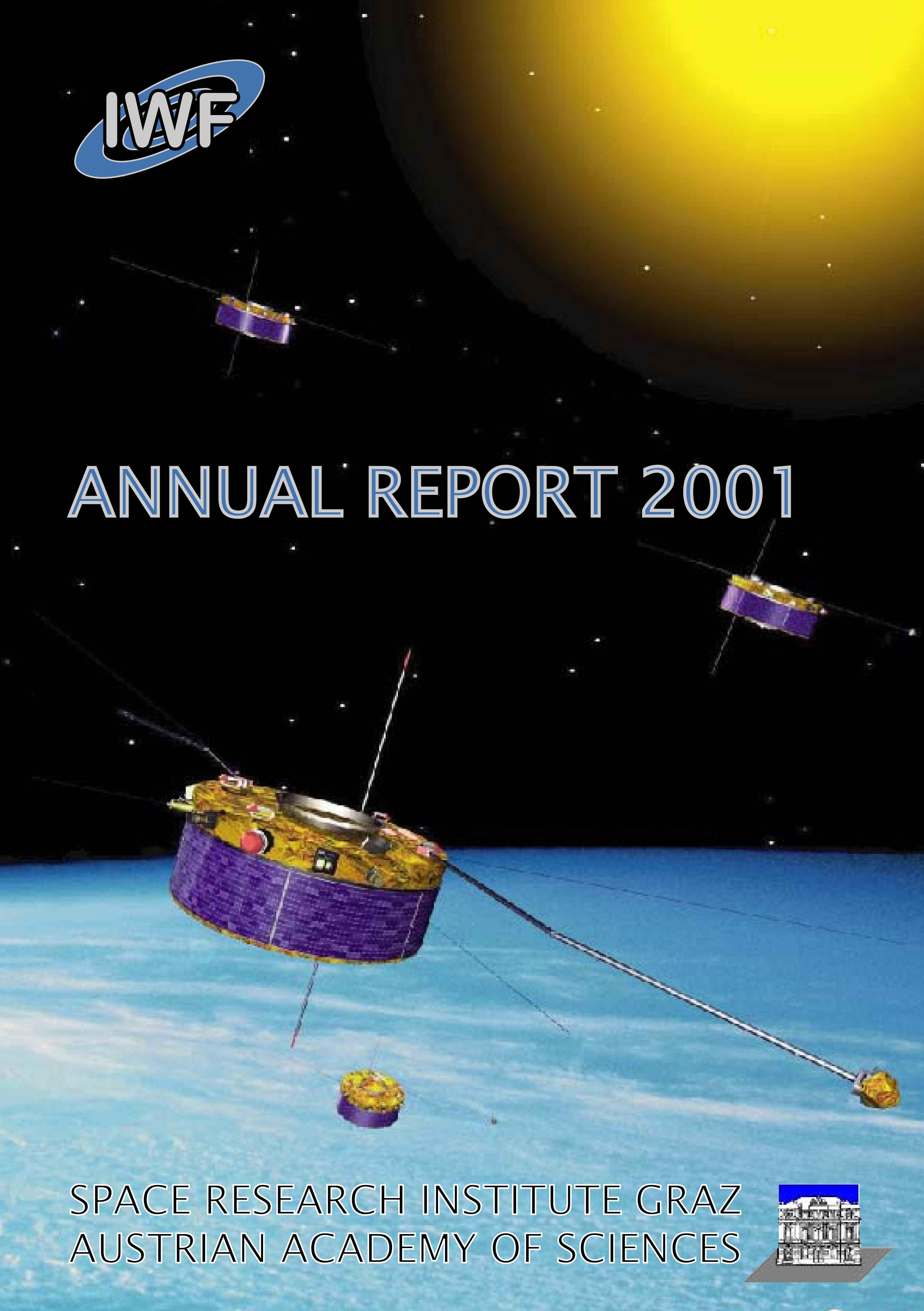


# ANNUAL REPORT 2001

SPACE RESEARCH INSTITUTE GRAZ
AUSTRIAN ACADEMY OF SCIENCES

# ANNUAL REPORT 2001

SPACE RESEARCH INSTITUTE GRAZ
AUSTRIAN ACADEMY OF SCIENCES

Institut für Weltraumforschung
Österreichische Akademie der Wissenschaften
Schmiedlstraße 6
8042 Graz, Austria
office.iwf@oeaw.ac.at
http://www.iwf.oeaw.ac.at

# Table of Contents


1 Introduction ........ 1
2 Solid Earth ........ 3
2.1 Gravity Field ........ 3
2.2 Geodynamics & Meteorology ........ 6
2.3 Satellite Laser Ranging ........ 10
2.4 Gravitomagnetics ........ 13
3 Near-Earth Space ........ 15
3.1 Missions ........ 15
3.2 Physics ........ 16
4 Solar System ........ 23
4.1 Sun ........ 23
4.2 Mercury ........ 23
4.3 Mars ........ 25
4.4 Jupiter and Io ........ 28
4.5 Titan ........ 31
4.6 Comets ........ 33
4.7 Solar Wind ........ 36
5 Other Instruments ........ 39
5.1 MMS ........ 39
5.2 Radio Antennas ........ 40
5.3 Exobiology ........ 41
5.4 COROT ........ 41
6 Publications & Talks ........ 43
6.1 Refereed Articles ........ 43
6.2 Proceedings and Book Chapters ........ 46
6.3 Books ........ 49
6.4 Other Publications ........ 49
6.5 Proposals ........ 50
6.6 Oral Presentations ........ 50
6.7 Poster ........ 52
7 Teaching & Workshops ........ 55
7.1 Lecturing ........ 55
7.2 Theses ........ 55
7.3 Workshops ........ 56
8 Personnel ........ 57

# 1 Introduction

The Space Research Institute (Institut für Weltraumforschung, IWF) of the Austrian Academy of Sciences (Österreichische Akademie der Wissenschaften, ÖAW) sees itself as a focus of Austrian space activities. It cooperates closely with space agencies all over the world, with the two universities located in Graz, with the Austrian Space Agency (ASA), and with numerous other national and international institutions. A particularly intense cooperation exists with the European Space Agency (ESA). The institute participates in various interplanetary missions as well as in missions dedicated to the exploration of our own planet Earth and its neighborhood. Missions with contributions "made in Graz" include:

- *Cluster* and *DoubleStar* are and will be exploring the space-time structure of the terrestrial magnetic field and the magnetospheric plasma in unprecedented detail.
- *GOCE* will determine with high accuracy the structure of the terrestrial gravitational field. These measurements are expected to contribute significantly to a better understanding of the Earth's interior, global ocean circulation, and heat transport mechanisms.
- *EnviSat*, due for launch shortly, will observe the Earth with the aid of a multi-sensor remote sensing system. This mission continues the successful Earth observation missions ERS-1 and ERS-2 with highly improved sensor techniques.
- *Netlander* will for the first time set up a network of long term seismic, meteorological and magnetic measurements on the surface of Mars.
- *BepiColombo* will investigate in detail the innermost planet Mercury, using a fleet of two orbiters and one lander.
- *Cassini/Huygens* is currently on the way to Saturn and its satellite system.
- *Rosetta* will investigate the coma and the nucleus of the comet P/Wirtanen. For the first time a soft landing on a cometary nucleus will be tried.

*Fig. 1.1: The "Forschungszentrum Graz".*

In addition, the institute performs a wealth of theoretical investigations, data analysis, and laboratory experiments on gravitational and magnetic fields, on atmospheres and on surface properties of solar system bodies. Moreover, at the observatory Graz-Lustbühel one of the most accurate laser ranging stations of the world is operated. It determines the trajectories of more than 30 satellites. Also located at Lustbühel Observatory is a system of antennas used to monitor the radio emissions of Jupiter and the Sun's. Finally, a network of seven permanent GPS stations is operated in order to monitor geodynamical movements in Austria and its vicinity.

In October 2000 the institute found a new home in a very attractive building, the "Forschungszentrum Graz" (Research Center Graz) of the Austrian Academy of Sciences (see Fig. 1.1). From January 2001 Prof. Dr. Hans Sünkel and Prof. Dr. Wolfgang Baumjohann followed Prof. Dr. Willibald Riedler as Managing Director of the institute and Head of the Department of Experimental Space Research, respectively. The structure of the institute with three departments was preserved:

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

The bulk of financial support for our research comes directly from the Austrian Academy of Sciences (Österreichische Akademie der Wissenschaften, ÖAW). Substantial support also comes from other national institutions, from the Austrian Space Agency (ASA), from the Austrian Science Fund (Fonds zur Förderung der wissenschaftlichen Forschung, FWF), and from the Austrian Academic Exchange Service (Österreichischer Akademischer Austauschdienst, ÖAD) and its partner institutions in other countries. Last but not least, European Institutions like the European Space Agency (under the PRODEX and GOCE Programs) and the European Union (under the INTAS and 5$^{th}$ FP Programs) contribute significantly.

# 2 Solid Earth

How is the actual status of the surface of the Earth and its near vicinity? Can permanent monitoring lead to a possible prediction of future global changes and, if yes, how?

Questions for our “blue planet” which find the answer in a nearly unlimited bulk of data placed at disposal by artificial satellites of different kind and layout, equipped with special sensors for different tasks. They outline a global image of our planet with an, up to now, unknown resolution which allows for the investigation of detailed structures. The task remains how to de-correlate individual phenomena and to pick out the specific elements which are required for the understanding of the basic physical processes.

For example, the precise knowledge of the *Earth’s gravity field* and its temporal changes contributes to the detection of the mechanisms leading to the building of the Earth’s crust, the evolution of the green house effect and the realization of the ocean and air currents. The repeated determination of precise station coordinates via *GPS* and *Satellite Laser Ranging* leads to the definition of a temporal changing velocity field which enables the investigation of the underlying driving forces and the energy transport in the Earth’s crust.

## 2.1 Gravity Field

The Earth’s gravity field is the response to the mass density distribution of the Earth and its rotation. Mass density anomalies are mapped onto gravity field anomalies. While the rotational contribution to gravity is very simple, the gravitational part is extremely difficult to model and not known with sufficient accuracy and resolution on a global scale. The gravitational field is harmonic outside the Earth’s surface and can be conveniently represented by a series of solid spherical harmonics. In order to model all of its irregularities (which are due to the irregularities of the Earth’s mass density distribution), strictly speaking an infinite number of parameters (e.g., harmonic coefficients) would be required. The estimation of these parameters requires data which are sensitive with respect to these parameters. Any finite data set can only provide an approximation to reality. The data type, data quality, and the spatial distribution of the data control the degree of approximation.

*Fig. 2.1: Mapping the Earth’s gravity field with GOCE.*

This gravitational field is the focus of attention of the dedicated gravity field missions *CHAMP*, *GRACE* and *GOCE*.

### GOCE Mission

The *GOCE* mission, as one of the dedicated gravity field satellite missions, is based on a sensor fusion concept: satellite-to-satellite tracking (SST) in the high-low mode using the GPS system, plus satellite gravity gradiometry (SGG). The planned *GOCE* mission, if successfully completed, will provide a huge data set consisting of tens of millions of orbit data (derived from SST) plus very precise in-orbit gravity gradiometry data. This data contains abundant information about the gravity field of the Earth on a global scale, from very low to high frequencies. Earth's gravity field can be represented by harmonic coefficients up to about degree and order 300 which corresponds to shortest half wavelength of less than 70 km.

The quality of the global gravity field is usually expressed in terms of standard errors of an individual geoid height or a mean gravity anomaly. If the *GOCE* mission will be completed as planned, the geoid will become known with an accuracy of better than 1 cm, and the gravity anomalies with an accuracy of better than 1 mGal on a global scale with some degradation over the polar caps.

The ground data coverage must be global and uniformly distributed. This leads to a repeat period for the ground tracks of equal or larger then 2 months. In addition, the perturbations from the external environment must be kept as small as possible. The selected *GOCE* orbit is nearly circular, at a nominal mean spherical altitude of 250 km.

The orbit is maintained by continuous thrust in the direction of motion. Even after drag control, such a 'nominally circular' orbit undergoes variations in eccentricity (hence altitude) due to the Earth's oblateness, with both short periodic (1 orbit) and long periodic (90 days) components. The magnitude of the eccentricity is less than $4.5 \cdot 10^{-3}$ and the peak-to-peak variation of the altitude can thus be up to 50 km. The orbit inclination at the given altitude is 96.5°.

The *GOCE* mission is designed to map the Earth's gravity field with both very high accuracy and resolution on a global scale. An indirect and a direct gravity field sensor ideally complement each other: The *GOCE* spacecraft will be tracked by both the global positioning system GPS and the global navigation satellite system *GLONASS* which will provide the orbit with an accuracy in the centimeter range. A three-axis gravity gradiometer as the core instrument on board the satellite will provide local gravity field information along the orbit in terms of second order derivatives of the gravitational potential along the orbit, plus linear and angular accelerations of the spacecraft which will be compensated for by ion and cold gas thrusters such that the spacecraft remains in the perfect free fall motion.

The irregularities of the orbit can be converted into gravity field structures with long to medium wavelength, while the gravity gradiometer delivers a map of the gravity field structures with medium to short wavelength. Based on the above mentioned instrument configurations, it is foreseen that *GOCE* will deliver the geoid as a unique equipotential surface at mean sea level with a resolution of 70 km half wavelength and with a design accuracy of 1 cm on an almost global scale. Converted to gravity anomalies this corresponds to an accuracy of better than 1 mGal, as already mentioned above.

The transformation of the *GPS/GLONASS* phase measurements plus the observed second order derivatives of the gravitational field (expressed in terms of Eötvös units, 1 E = 1 mGal/10 km), into Milligal, is a mathematically, numerically and statistically extraordinarily demanding task. It requires both the exploration of the entire arsenal of sophisticated preprocessing, processing, solution and analyzing techniques, and a close scientific cooperation of geoscientists across their individual educational boundaries. The Space Research Institute is actively involved in all aspects of *GOCE* preprocessing and processing techniques.

# E2mGal+ Project

In the scope of E2mGal+, the Institute is actively involved in (1) the elaboration of Satellite-to-Satellite Tracking (SST) observation equations for use in SST+SGG processing, and (2) the investigation of temporal variation effects on high-low SST observations.

In order to determine the spherical harmonics coefficients of the Earth's gravity field, one of the methods to be used is the SST determined positions and position differences of the *GOCE* satellite. Basically, there are several solution strategies for the recovery of the harmonic coefficients, each dependant on the techniques used in the determination of the Earth's gravity field coefficients.

- Numerical integration of orbit perturbations (classical concept)
- Evaluation of the energy equations based on the Jacobi integral
- Derivation of satellite accelerations.

The first two methods were investigated by our group and remarkable results were obtained so far. We developed our own orbit integration software which integrates the orbit together with the variational equations and takes into account many temporal variations of the Earth's gravity field which reflect themselves further in the satellite "disturbing" accelerations. The integration of the satellite variational equations delivers us the partial derivatives of the satellite positions (and velocities) with respect to the potential coefficients and after the least squares adjustment we get the set of adjusted coefficients.

In Fig. 2.3 the RMS error per degree per coefficient is presented, and in Fig. 2.2 the obtained normal equation matrix is shown. A closer look to Fig. 2.2 shows some interesting properties. It has almost a block diagonal structure, but also a horizontal and vertical off-diagonal bands can be distinguished. These resonance bands occur close to the orbit resonance orders at 0, 16, and 32, which represent the integer multipliers of the number of revolutions per day. We can also notice a wide range in magnitude of the normal equation matrix, indicating an unfavorable condition with a condition number in the order of $10^9$.

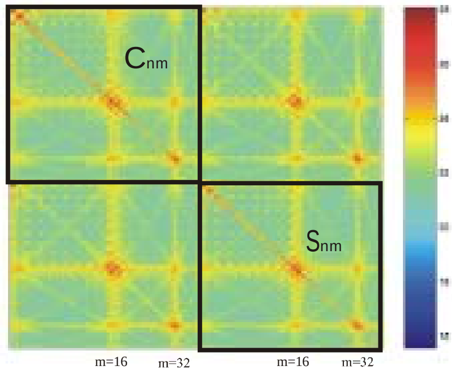



*Fig. 2.2: The normal equation matrix.*

Considering the Jacobi integral approach, or popularly called the energy integral approach, we also developed a working software for gravity field refinement based on that method which is currently in the test phase. It should be mentioned here also that the results obtained so far have surpassed our expectations and we strongly believe that this approach will adapt itself strongly in the GOCE final data processing software.

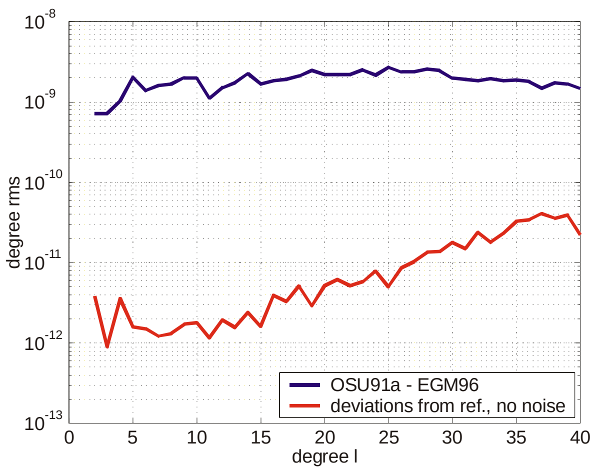



*Fig. 2.3: RMS per degree per coefficient.*

Furthermore, we performed a detailed study of the temporal variations of the Earth's gravity field caused mainly by the influence of the sun and moon on the mass redistribution. Our investigations mainly focus on the ocean tides, since they are identified as being the one of the main contributors to variations of the gravity field on a short time scale. Additionally favorable is the fact that they can be modeled very well, since their signal can be related to a single excitation frequency. Apart from this, the set of additional parameters, enlarging the system of a purely static gravity field solution, can be kept small, therefore it is well suited to gain an insight into the behavior of the resulting extended normal equations system.

As a second time varying component, we also consider seasonal variations caused by other phenomena such as ocean topography or land hydrology variations. The major goal was to investigate whether they map as a kind of bias to the static gravity field solution. It has been shown that most of the energy of the temporal variations phenomena is contributed to the long-wavelength components of the Earth's gravity field, and therefore the major signals can be expected to be inherent in the high-low SST observations, while the signals contributed to the SGG component are in the order of the noise level of the gradiometer. Therefore, these effect deserve special treatment when we process SST data and have to be somehow modeled in advance (which to a great extent depends on the quality of our a priori models) or these parameters have to be estimated together with the static gravity field unknowns. In this case, we speak about the parameterization of these effects, and we are favoring that approach in our investigations in the scope of the E2mGal+ project. We performed different combinations of the static and dynamic coefficients and different solutions have been investigated and are still being investigated at the moment with the goal to find the optimal combination of our static as well as the dynamic coefficients which will produce an optimal gravity field determination from the SST observations. The stability of the normal equations system is under current development as well as the studies on the correlation and de-correlation of these effects and numerical methods which will deliver us the optimal solution in terms of the obtainable accuracy and computational efforts.

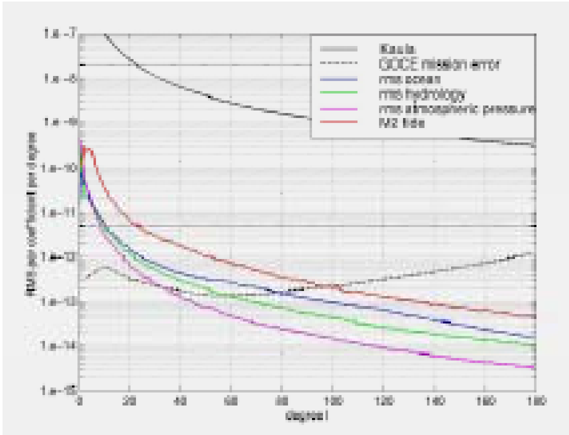



*Fig. 2.4: The energy contribution of different temporal variations phenomena to GOCE measurements.*

## 2.2 Geodynamics & Meteorology

The region where we can find life is a small spherical shell extending from 10 km below to about 8 km above sea level. This small layer is affected by various forces induced by the Earth itself, and by nearby extraterrestrial objects (sun, moon, meteorites, etc.). While slow variations of our environment have been mastered during the ongoing evolution we are not prepared to handle fast or even sudden changes; we just miss the necessary time for preparation and adaptation. Therefore, prediction is the keyword, an undertaking which requires understanding the underlying dynamics and must be based, by definition, on long term samples, which can only be shortened by increasing the accuracy.

We use the Global Positioning System GPS for our investigations, time series for coordinates and tropospheric parameters are now available for nearly one decade, the accuracy allows for the detection of velocities down to 1 mm/year.

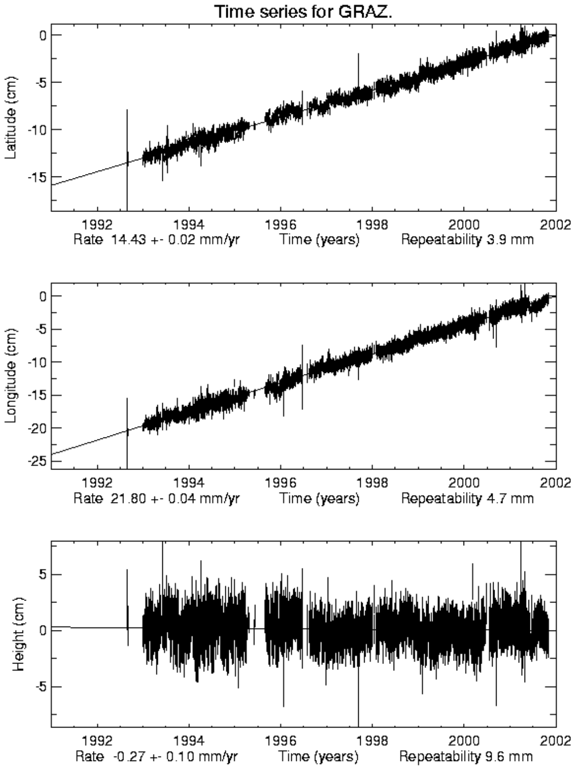



*Fig 2.5: Time series of Lustbühel station coordinates.*

# Geodynamics/Global

A network of more than 2000 permanent GPS stations covers our globe. Precise coordinates are delivered every week, leading to a velocity field which monitors the global, regional and even local movements (see e.g. in Japan or Southern California, the most seismic active regions on Earth). At present Austria contributes with a permanent network of 15 stations, 4 of them are embedded in global and continental networks. The following figure shows the coordinate time series of our fundamental station Graz-Lustbühel which is representing the Eurasian continental plate. The picture shows the north-east movement of Europe in a well certified way.

# Geodynamics/Regional

Most of the seismic events in Austria are induced by the north-west movement of the Adriatic Micro-plate (AM) which is responsible for the mountain building of the Alps. The AM is part of a large number of small plates which are driven by the north-ward movement of the African plate against the Eurasian plate.

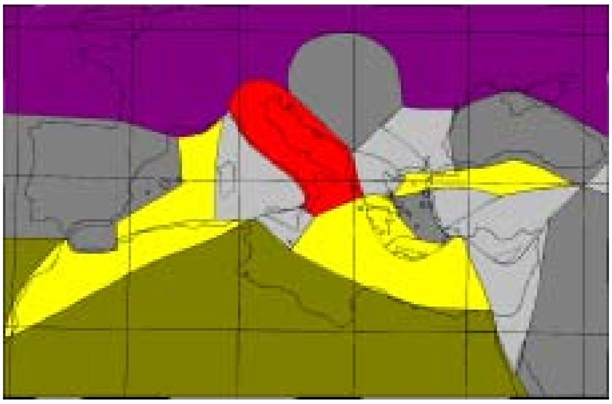


*Fig. 2.6: Plate boundaries in the Mediterranean, the red part describing the location of the Adriatic microplate.*

Like locked in pack-ice they move in this stress field in different directions, seismic activities in the Mediterranean area (historical and now) describe their boundaries (earthquakes in Agadir, Skopje, Friuli; recent earthquakes in Turkey, Italy, Slovenia; active volcanism like Aetna).

The project "Crustal dynamics of the East-Alpine and the adjacent Mediterranean Area" sponsored under the frame of IDNDR (International Decade of natural disaster reduction) during the last 10 years tries to find out the active northern boundary of AM (red) and its implications for Austria. As an example we show the results of our measurements carried out 1995 and 1998 (just after the earthquake in Western Slovenia).

The red vectors in Fig. 2.7 describe the horizontal movements (2.5 cm for the site RIBN right-down) during 3 years. No significant lateral movements can be seen at the Italian border indicating a change in velocity leading to energy transfer towards the Italian border which may have been a reason for this earthquake.

We consolidated this network with new stations (zero-measurements) and will extend it to the Croatian border in order to be prepared for the seismic events expected for that region. A new initiative within the project CERGOP-2 of the Central European Initiative, applied for EU-support in the 5th FP, aims at the extension of these monitoring studies to Croatia, Bosnia, Macedonia and Albania.

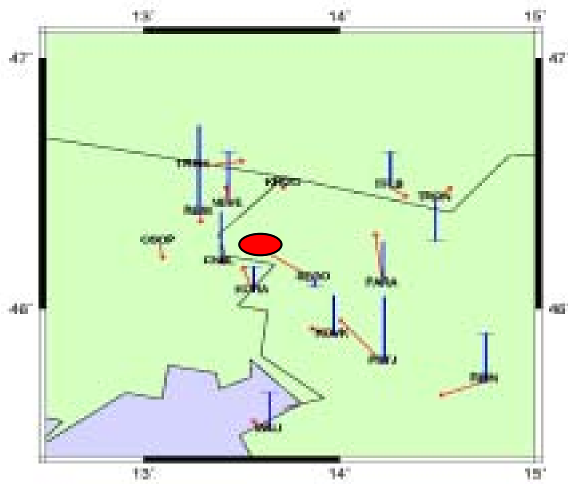


Fig. 2.7: Crustal movements at the northern boundary of the Adriatic microplate.

# Geodynamics/Local

The creation of precise coordinate time series presupposes the local stability of the reference sites for decades. Local movements may mask the required de-correlation of secular changes. As an example, we found out that the coordinate time series of the station Hafelekar north of Innsbruck shows lateral changes of seasonal character.

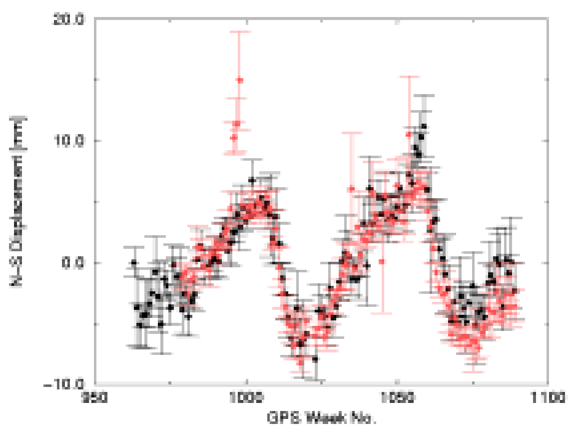



*Fig. 2.8: Coordinate time series of the station Hafelekar.*

As we do not know the origin of these movements we established a local network around this stations. The measurements during the forthcoming year will give an indication whether we have only a stability problem or a significant movement of the "Nordkette" itself.

It must be emphasized that these local studies are crucial for a proper interpretation of regional and global crustal movements.

# GPS and Meteorology

The signals transmitted by the GPS-satellites are delayed by the ionosphere and the troposphere. Whereas ionospheric effects can be reasonably monitored by using two carrier frequencies, the influence of the troposphere can only be modeled by assumptions based on physical laws and expertise. Especially the water vapor content of the troposphere above the station is changing rapidly, only digital weather forecast models give some estimate. The improper modeling of these influences leads to a degradation of the GPS height determination by a factor of up to 3, compared with the determination of horizontal coordinates.

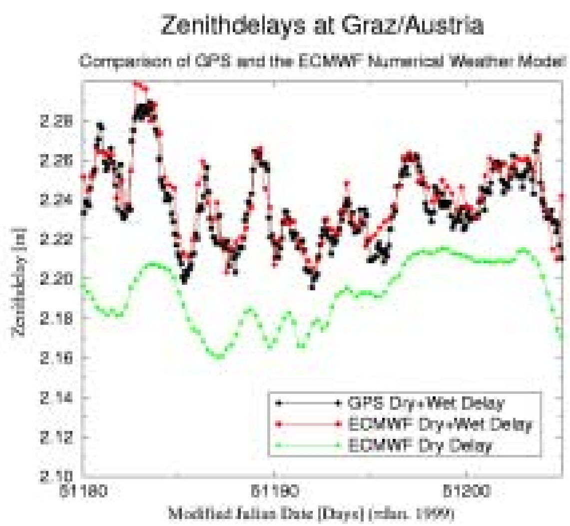



*Fig. 2.9: Zenith delays measured at Graz in comparison with the ECMWF Numerical Weather Model.*

On the other hand, we know that heights are not changing during a short period and all apparent height changes are due to modeling errors of the troposphere. Fig. 2.9 shows the high correlation between GPS-computed zenith delays and numerical weather forecast models.

We can conclude that GPS provides a suitable mean to compute also parameters of meteorological use which can supplement meteo-data acquisition in near real-time and on a low cost scale compared with the costly launch of radiosondes. These results will be of utmost use for climate research.

*Fig. 2.10: Water vapour radiometer on the roof of FZG.*

In order to verify the physical content of these routinely computed zenith delays, namely, to extract information on water vapor from the geometrical zenith delay, a water vapor radiometer (WVR) was recently installed in Graz (on loan) which will give the opportunity to compare the physical quantity "water vapor" derived from WVR, radiosondes and GPS for improving the modeling of troposphere for the sake of improving GPS height determination by a factor of 3.

# Altimeter Calibration

Transponders are useful for the calibration of satellite born altimeters as well as for height transfer if combined with precise GPS positioning, precise orbits, and suitable models of the ionosphere and troposphere. The geometrical vertical distance between the satellite borne radar altimeter and a terrestrial reference plane can be computed, at least theoretically, with the knowledge of the satellite orbit and the height of the reference plane. Altimeter measurements determine this vertical distance independently and can be used for the calibration of the on-board altimeter. In contrary to the ocean surface a transponder disposes of a stable and very precise reflection reference (few millimeters), which allows for a very precise determination of the vertical distance provided that the signal delays can be estimated properly.

The moving satellite altimeter transfers the height information from one foot print to another and connects not only individual points of the sea surface but also establishes connections between the dynamic sea surface and stable terrestrial targets (transponders) and also between two or more transponders.

Our instrument and knowledge will be used in a experiment on Gavdos island, south of Crete, for the calibration of the Jason-1 and Envisat altimeters and for an independent check of the tide gauges in that region.

*Fig. 2.11: Transponder for the EU-project GAVDOS.*

First experiments during the commissioning phase of *ERS-2* as well as the determination of the height of an oil platform in the North Sea showed that altimeter calibration and height transfer can be monitored with an accuracy of below 2 centimeters.

# 2.3 Satellite Laser Ranging

Satellite Laser Ranging (SLR) is a satellite tracking technique based on measuring the slant range between a ground-based satellite ranging facility and a satellite in orbit. A very short laser pulse is generated by the laser system at the ground station and emitted towards the spacecraft where it is reflected by means of onboard laser retro reflectors. An extremely precise counting unit which is triggered by the emission and detection of the laser pulse at the ground facility measures the 2-way time of flight and yields - by means of the well-known speed of light - the distance to the satellite orbiting in up to several thousand kilometers heights with an accuracy of down to a few millimeters.

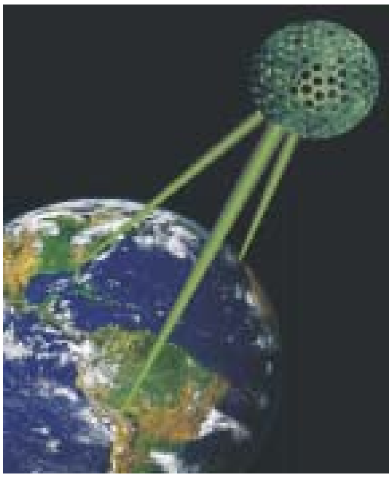


*Fig. 2.12: Simultaneous SLR Tracking of Lageos satellite.*

As one out of 5 Satellite Laser Ranging (SLR) reference stations worldwide Graz-Lustbühel is measuring distances to about 30 satellites as part of the global network comprising more then 30 stations. During 2001 we acquired data from about 4800 passes, an increase of more than 20%. This improvement, and also the increase in accuracy, is due to our ongoing efforts to improve the SLR system performance by implementing new technologies, new algorithms and new ideas.

*Fig. 2.13: SLR Graz laser system in operation.*

## Hardware

In September 1999, our new Event Timer (ET) was installed, and is fully operational since that time. In addition to some minor upgrades of this timing system, we have installed a third ET module, which will allow to simultaneously measure an additional laser stop pulse in the near future. The required software to include this Multi-Stop capability is under development.

*Fig. 2.14: Graz Event Timing System.*

With this new timer, the SLR station Graz now achieves an accuracy, where Multi-Color measurements, if performed simultaneously, are capable to deliver useful results. Thus, we have now started to design a new detection package, suitable for simultaneous Multi-Color / simultaneous Multi-Stop measurements. The optics of this new package should allow for doubling the optical receiver efficiency. The detection and electronics part consists of several different detectors, with an accuracy and stability in the range of a few picoseconds.

With the previously used cluster of Time Interval Counters, we were principally limited to wait for the return before starting the next laser shot (limiting e.g. measurement frequencies to GPS satellites to 5 Hz). The new Event Timer allows much higher shot rates – up to the kHz range – if an accurate range gate pulse can be produced at the same rate. For this purpose the design and development of a new high accuracy (resolution and accuracy < 500 ps) kHz Range Gate Generator has been started. Due to the complex requirements, this device will be implemented with Field Programmable Gate Arrays (FPGA's) and it will finally allow to handle multiple laser pulses in flight at the same time. This will then enable us (1) to range to GPS satellites with 10 Hz (instead of 5 Hz now) with the present laser and thus not only doubling return rate, but also significantly improving the acquisition and tracking of difficult targets, and (2) to implement any higher-frequency laser systems, as soon as they are available (kHz – Solid State Picosecond Lasers).

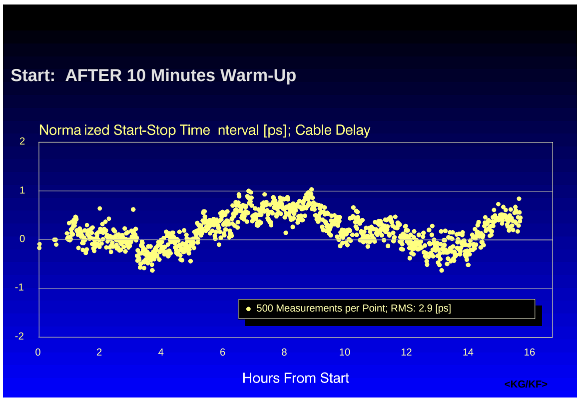



*Fig. 2.15: Half-Day Drift of the Graz Event Timer.*

# Software

To reduce operational working load, the complete process of downloading new IRV sets, calculating and checking new prediction sets as well as the data exchange between all 3 SLR station PCs, fully automatic routines have been designed, which now allow a very efficient and simple schedule of satellite passes. This finally results in a very high tracking efficiency (>98% of all possible passes are tracked successfully).

Up to now the whole software system for real time tracking and ranging, including most house keeping programs was based on track files containing Azimuth, Elevation, Ranges, and spline coefficients to allow Cubic spline Interpolations between pre-calculated points. This system was optimized at the beginning of the SLR Graz in order to optimize the data transfer rates and real time CPU requirements. But however, this system had some inherent disadvantages and the whole software was therefore completely redesigned. The Introduction of new track files, containing X/Y/Z coordinates, and applying 8-point Lagrange interpolation between these coordinates – where the Az/El/Range values are calculated after the interpolations – gives some significant improvements:

- No near-singularity in azimuth interpolations in high elevation passes (close to 90° elevation)
- No oscillations (during tracking in azimuth and post-processing in range) due to spline oscillations in such critical high elevation passes
- No rejection of critical passes which yields about 6% more possible passes,
- No rejection of satellite passes in far-from-circular orbits, like AO-40, LRE etc.
- Allows better Range Bias adjustments in post-processing.

The design of the new detection package requires a completely different method to align the 200 μm SPAD surface to detect each single photon returning from the satellite. One possible method involves tracking the moon, and using the "far field" photons from the sun-lit moon surface to align the SPAD. A special moon tracking program has been written.

Generally, low earth orbiting (LEO) satellites are difficult to track, due to the nearly unpredictable atmospheric drag forces and the unexpected solar activities which may cause significant changes of the time bias within a few hours. This makes daylight tracking activities extremely difficult (very low Field-of-View, Single Photon Sensitivity etc.). In order to improve the tracking efficiency the station PC of the Graz SLR now automatically collects all passes which have been recently observed by other stations and uses these normal points to calculate an estimated time bias for the next pass in Graz. This method has already significantly improved our daylight efficiency for these LEO satellites (*Champ* etc.).

# Operation & Results

All previously mentioned improvements made it possible for the SLR station Graz to deliver very high density, extremely reliable and utmost accurate data. In order to support ongoing research efforts for better atmospheric refraction determination, we have decided to track passes down to lowest possible elevations – usually, we try to start at elevations as low as 5° for most satellites. Due to the very smooth new Lagrange tracking system, this low elevation tracking – which is also supported by some other SLR stations – is very successful, and delivers the highest average data yield e.g. for ERS-2.

The GPS-35 and GPS-36 satellites produce the weakest return signals among all satellites tracked by the SLR Graz. The average return energy is somewhat below one photon and therefore the majority of SLR stations is not tracking this difficult satellite – at least not in daylight conditions. Due to the enormous sensitivity of the Graz detection package and the efficiency of the software packages, Graz is contributing a significant amount of data from the GPS satellites only surpassed by the Grasse Lunar Laser Ranging station (France), and the Australian SLR station in Yarragadee, located in the eastern desert territory.

Another important parameter for SLR data is its accuracy – a good measure is the Single Shot accuracy to the calibration target. Due to the new Event Timer System and the new Start Pulse Detection System this calibration accuracy could be improved again. Our routine calibration now achieves about 3.0 mm single shot RMS and – even more important – the distribution of these calibration returns is very symmetrical, with an average skewness of 0.01 remaining.

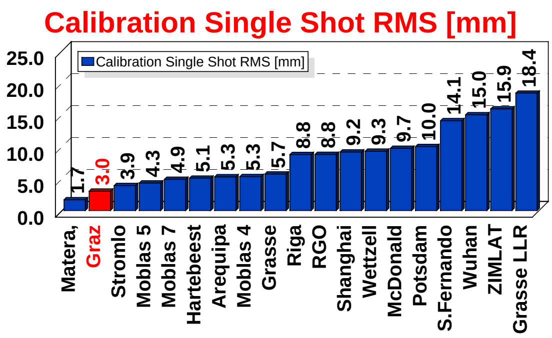



*Fig. 2.16: Calibration single shot RMS.*

Another major goal at the SLR Graz is the reliability of the SLR measurements. This involves a lot of automatic checks, recording and monitoring of relevant data as well as the supervision of all actions by software routines. The main tasks are to detect any system changes and drifts and to inform the observers about any hidden error conditions. To implement this, we try to eliminate any error we can detect in our or any other station's data and to check all future data against these errors.

This system has demonstrated in 2001 quite well its efficiency: Almost all passes have been accepted by the various international quality checks.

## SLR Data Quality Control

The tremendously improved level of accuracy of satellite laser ranging measurements over the past years facilitates an ever increasing number of applications in the field of geodesy and geodynamics. It goes without saying that for such demanding applications the provision of SLR data of utmost quality is of fundamental importance.

An SLR data quality assessment system was developed in close cooperation with the British Natural Environmental Research Council (former Royal Greenwich Observatory) which is capable to analyze normal point observations of the geodetic satellites *LAGEOS-1* and *-2* in order to assess the quality of the observations in a fully automated near real-time process.

The analysis procedure uses a short-arc orbital adjustment technique which exploits the geographically dense clustering of the European SLR stations which contribute about 40% of the global SLR data volume.

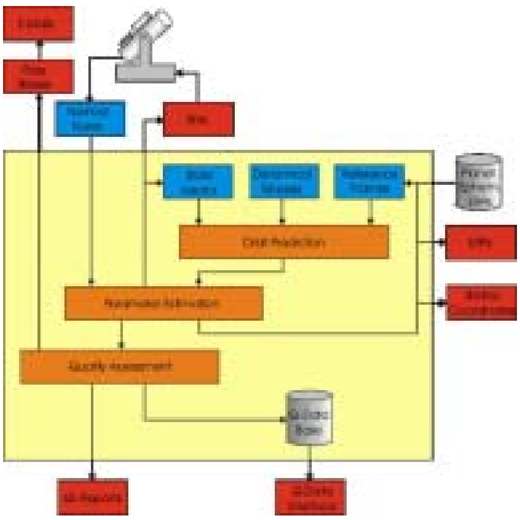


*Fig. 2.17: Sketch of data flow and products of the automatic SLR data assessment system.*

This system was constantly advanced during the past years and is now capable to

- process the global data volume on a daily and monthly basis
- monitor the SLR station tracking quality
- feed back tracking quality information to the individual stations
- generate Quick-look Analysis Reports
- provide a local quality information data base and a query interface for data downloads and
- generate satellite IRV predictions.

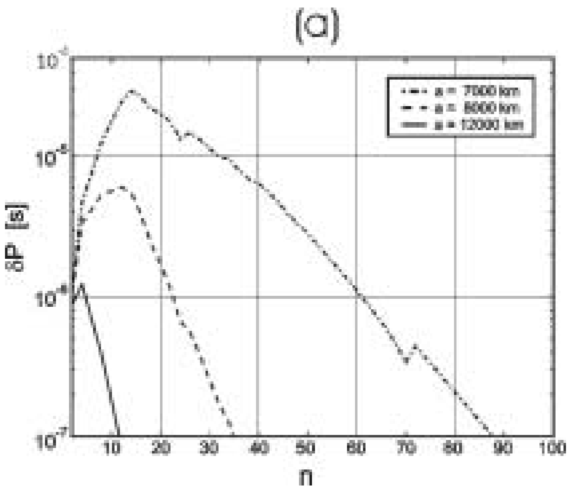
# 2.4 Gravitomagnetics

Today most modern theories of gravity are metric theories, i.e. gravitation is considered to reflect the metric properties of spacetime rather than being a force in the conventional sense. This interpretation is based on the fact that in a gravitational field all matter, irrespective of its composition, experience the same acceleration. Hence in a freely falling system, the effects of gravity cancel out locally and the system is equivalent to an inertial reference frame (equivalence principle). On a global scale, gravity cannot be transformed away since it shows up in tidal forces, which, in the geometrical view, can be regarded as the effect of spacetime curverture and which, albeit tiny, will lead to a number of phenomena foreign to Newtonian physics.

In particular the close formal analogy between Newton's law of gravitation and Coulomb's law of electricity implies that any theory of gravity compatible with Lorentz invariance will contain a gravitomagnetic field generated by the motion of matter in a similar way as a magnetic field by moving charges in electrodynamics. However, all standard tests of general relativity performed hitherto are related to post-Newtonian gravitoelectric corrections while gravitomagnetic phenomena still lack direct observational evidence due to their minute effects.

Among these new gravitomagnetic effects the coupling of the orbital motion of test bodies to the angular momentum of the source could underlie a novel experiment to detect the terrestrial gravitomagnetic field. The rotation of the Earth induces a difference in the proper periods of particles revolving along identical but opposite circular equatorial orbits and amounts to ~10-7 s per revolution. The verification of this difference and hence of the existence of the gravitomagnetic field could be furnished by an experiment which involves the accurate tracking of two ultra stable clocks carried by satellites along pro- and retrograde trajectories about the Earth.

The major difficulties of such a mission turn out to be the exact determination of the true orbits of the clocks and the modeling of the many perturbing forces acting on the satellites. Especially the latter is a difficult task since the non-sphericity of the Earth alone involves a change in the period of about 15 s for a satellite of 7000 km altitude. Therefore, to determine gravitomagnetic control on the difference in the periods, the gravitational potential of the Earth must be accurately known, only then the relativistic effect may be separated from all other perturbations. Upon expansion of the terrestrial gravity field in terms of spherical harmonics, it is found that the current uncertainty in the lower coefficients limits the calculation of the time of revolution of satellites orbiting in several thousand km altitude to an accuracy of $10^{-5}$–$10^{-6}$ s.



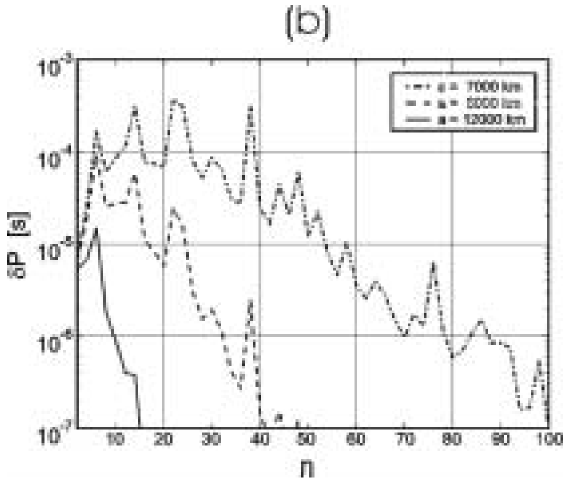




*Fig. 2.18: Errors of revolution time due to the uncertainties of spherical harmonic coefficients.*

Fig. 2.18 shows the error δP in the modeled period as (a) a function of the even zonal harmonics $C_{n0}$ and (b) due to the uncertainty in the sectorial (n=2) and tesseral (n>2) coefficients $C_{n2}$ and $S_{n2}$ of order 2 for 3 different orbital radii. We note that the perturbations induced by $C_{n2}$ and $S_{n2}$ are periodic and may cancel out after a sufficient number of revolutions, while the perturbations due to $C_{n0}$ are secular and must be handled carefully. Thus a clear observation of the gravitomagnetic clock effect requires an improvement in the determination of the gravitational field of the Earth which is likely to be achieved by upcoming geodetic space missions.

# 3 Near-Earth Space

The physics of the Earth's space environment is dominated by the interaction between the solar wind and the terrestrial magnetic field. The structures that are created in this interaction are: the bow shock, in which the supersonic solar wind is decelerated; a transition layer called the magnetosheath; the magnetopause, which is the boundary of the magnetosphere and the magnetosphere with its tail where the magnetic field from the Earth's dipole is dominating, and the ionosphere. In principle all these structures are magnetoplasmas, i.e., electrically charged particles (ions and electrons), where electric and magnetic fields dominate the physical processes.

## 3.1 Missions

In near-Earth space, the Institute is deeply involved in the *Cluster* mission, which was launched in 2000 and now yields a wealth of new and exciting data. At the same time, we are working on the hardware of the *DoubleStar* mission, which will be launched in 2003, and we are actively involved in three proposals for future NASA *MidEx* missions.

### Cluster

The *Cluster* satellite project is one of the core projects in the scientific program of the European Space Agency (ESA). Four identical satellites encircle the Earth in closely spaced trajectories. Simultaneous measurements at four points allow to distinguish between temporal and spatial effects and shed new light on our understanding of the processes in and around the Earth's magnetosphere, especially at the aforementioned boundaries.

The payloads of all four satellites are identical and consist of 11 instruments to measure magnetic and electric fields and charged particles over a wide range of energies. The Institute contributes to four of those instruments:

- *ASPOC* controls the s/c electric potential
- *FGM* measures magnetic fields
- *EDI* measures electric fields
- *PEACE* measures the electron plasma

These instruments are described on the Institute's home page.

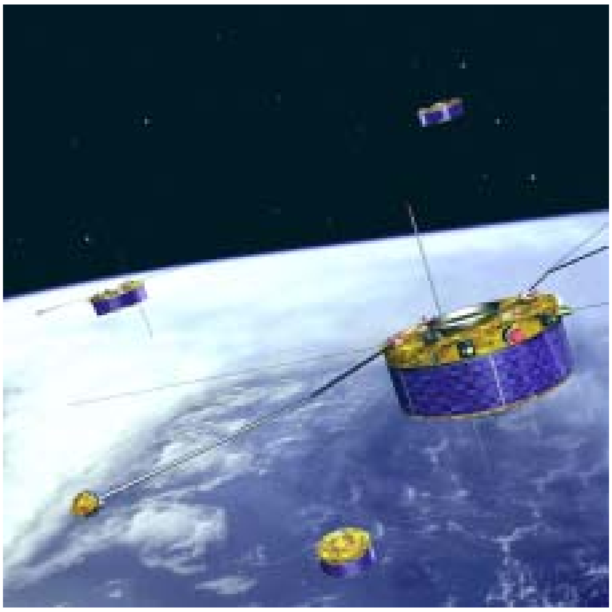


*Fig. 3.1: The Cluster Quartet.*

Related to the *Cluster* mission is the *Austrian Cluster Data Center*, which is part of a European consortium of national data centers, which collect and prepare the *Cluster* data and disseminate it to the scientists. As support to *Cluster* a network of ground-based magnetometers in China and Italy (*CHIMAG*) has been installed by the Institute and is maintained in cooperation with the Chinese Academy of Sciences and the University of Aquila.

# DoubleStar

China, in cooperation with ESA, has implemented the *DoubleStar* Project (DSP) to launch two satellites to study the Earth magnetosphere. *DSP-Equator* will be launched into an equatorial orbit with an apogee of 11 Earth radii in June 2003. *DSP-Polar* is expected to be launched in December 2003, with a polar orbit and an apogee of about 7 Earth radii. More than half of the DSP payload will be provided by European PIs. The European instruments are either spare flight models from the *Cluster* mission or newly refurbished and developed models. Joint studies using *Cluster* and *DoubleStar* data should increase the overall scientific return from both missions.

*Fig. 3.2: DoubleStar orbits.*

The Institute participates in this mission with two experiments:

- *DSP-ASPOC* will control the electric potential of the equatorial spacecraft.
- *DSP-FGM* will measure the magnetic field on both satellites.

*Flux-Gate Magnetometer (FGM):* Two identical magnetometers with two sensors each will be built for the two spacecraft. The leading institute for the *DSP-Polar* magnetometer is IWF and the leading institute of the *DSP-Equator* is Imperial College London. Together with TU Braunschweig, the Institute will built one of the sensors and its electronics for each of the satellites.

*Active Spacecraft Potential Control (ASPOC):* The objective of this instrument is to control and reduce the effects of spacecraft charging induced by solar UV. The instrument, which is similar to the *Cluster* instrument, is built in an international collaboration under the lead of the Institute. The Institute is also responsible for the complete digital electronics of the instrument. An important part, the Indium ion emitters, are built by the Austrian Research Centers Seibersdorf. The electronics for the power supply and high voltage generation is developed by Forsvarets Forskningsinstitutt in Kjeller, Norway. Instrument casing, lid and shutter mechanism for the ion emitter modules and test support are the responsibility of ESA/ESTEC.

# 3.2 Physics

Since ages experimental measurements and their analysis play an important role in the description of physical problems. For the description of the solar wind-magnetosphere interaction in near-Earth space plasma parameters of the solar wind as well as the strength and structure of the interplanetary magnetic field are of great importance. To get these parameters we use measurements of various spacecraft. These measurements are also as input to theoretical models, which try to explain the appearance of different phenomena in near-Earth space. The great amount of spacecraft launched in the last decades is essential for the progress in the description of the physics of near-Earth space. Solar wind parameters, e.g. velocity, density, temperature, composition, etc., and characteristics of the interplanetary field can be obtained from measurements of the spacecraft *ACE* and *Wind*. Measurements in and near the magnetosphere are available from the satellites *Geotail*, *AMPTE*, *Interball*, *Goes*, *Polar*, and others. Great expectations are set into the *Cluster* mission, which was launched in 2000. *Cluster* is a multi-spacecraft mission of four satellites orbiting the Earth in the constellation of a tetraeder.

The development of theoretical models and the analysis of spacecraft data at the Institute is done in co-operation with the State University of St. Petersburg (Russia), Institutes of the Russian Academy of Sciences in Krasnoyarsk and Moscow (Russia), the University of Sussex (England), the Max-Planck-Institut für extraterrestrische Physik in Garching (Germany), and the University of New Hampshire (USA).

# Bow Shock

The interaction of the solar wind, a supersonic charged particle stream, with the Earth's magnetosphere forms the so-called bow shock. At this fast shock the main part of the kinetic energy of the solar wind is converted into thermal energy downstream of the shock. Moreover, the plasma parameters and the interplanetary magnetic field change across the shock, i.e., there is an increase of density, temperature, pressure, and magnetic field strength, and a decrease of the velocity from upstream to downstream. Mathematically, these changes are described by the Rankine-Hugoniot equations. This set of equations is obtained by integrating the magnetohydrodynamic equations, containing the conservation of mass, the conservation of momentum, the conservation of energy, the conservation of the tangential component of the electric field, and the conservation of the normal component of the magnetic field.

The Graz group has developed a theoretical model taking into account various shock geometries as well as temperature anisotropies upstream and downstream of the shock wave. It is important to note that for anisotropic plasma conditions, the set of equations is underdetermined. As a matter of fact, one has to use an additional equation as a closure relation. Therefore, experimental studies of the thermal behavior of the magnetosheath, the region between the bow shock and the magnetopause, must be taken into account. E.g., *AMPTE/IRM* observations have shown that the double adiabatic equations do not hold in the magnetosheath and the analysis of Wind spacecraft data further have classified most parts of the magnetosheath as marginally mirror unstable.

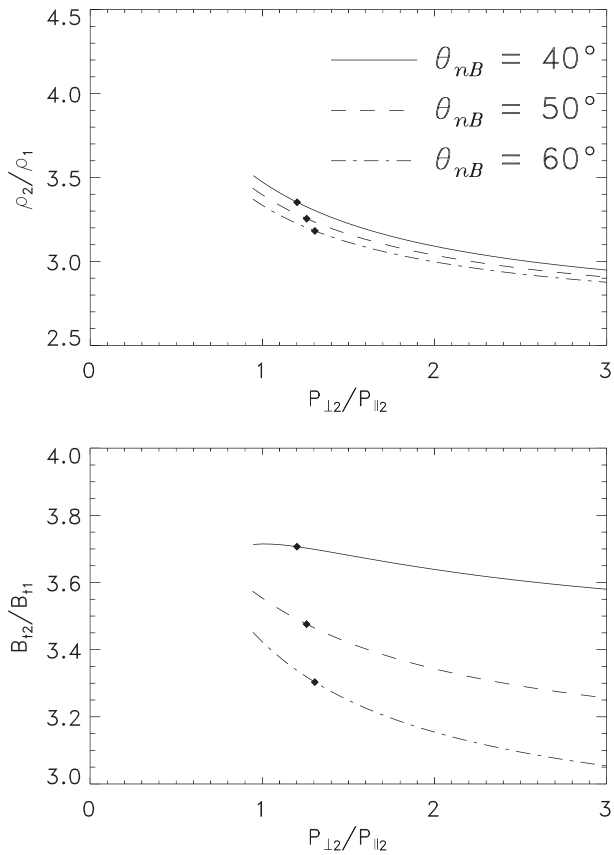



*Fig. 3.3: Variation of plasma density and tangential magnetic field component across the shock for different angles between magnetic field and shock normal (40, 50, and 60 degrees) as a function of downstream pressure anisotropy. Each curve starts with the threshold condition of the firehose instability and the black dots denote the corresponding values of the mirror instability.*

The criteria of the fire-hose and the mirror instability are used as additional equations to determine the pressure anisotropy downstream of the shock. These two threshold conditions give some additional restrictions to the behavior of the plasma upstream and downstream of the shock wave. Since the Rankine-Hugoniot equations can only be applied to regions close to the shock wave, the use of these plasma instabilities gives some boundaries for the pressure anisotropy on either side of the shock. We further note that the analysis allows the study of magnetosheath parameters as functions of upstream solar wind conditions in a wide range of Alfvén Mach numbers, specifically the variations of the perpendicular and parallel components of the temperature across the shock front. It is found that the variations of the parallel pressure, the parallel temperature, and the tangential component of the velocity are most sensitive to the pressure anisotropy.

As an illustrative example, Fig. 3.3 shows the variations of plasma density and the magnetic field strength for an Alfvénic Mach number of 10, a sonic Mach number of 8, and a pressure anisotropy of 0.5 in the solar wind for three different angles between the magnetic field vector and the shock normal, i.e., 40, 50, and 60 degrees, as functions of the pressure anisotropy downstream of the shock. We note that each curve starts from the criterion of the fire-hose instability and the black dots in each panel correspond to the solution obtained via the criterion of the mirror instability.

# Magnetosheath

The region between the bow shock and the magnetopause is the so-called magnetosheath. Characteristic features of the magnetosheath, e.g., the thermal behavior or its thickness, are influenced by solar wind parameters like the dynamic pressure. Spacecraft observations have shown the anisotropic nature of the magnetosheath, where the pressure perpendicular to the magnetic field is different to the parallel pressure. Thus the magnetosheath is prone to both the mirror and the electromagnetic ion cyclotron wave instabilities.

Taking into account the tensor nature of the plasma pressure, a three-dimensional and time-dependent model was developed at the Institute. For anisotropic conditions, the MHD equations are closed by a bounded anisotropy ansatz using the inverse correlation between the proton temperature anisotropy and the proton plasma beta parallel to the magnetic field. In addition, the variations of the plasma parameters and magnetic field strength across the shock by solving the Rankine-Hugoniot equations for anisotropic plasma conditions are used as input parameters to the numerical calculations. Thus the model provides the prediction of the magnetosheath parameters as functions of upstream solar wind conditions. We note that the aforementioned inverse correlation is related to the anisotropic ion cyclotron instability. In our approach, the total pressure is prescribed and thus included heuristically.

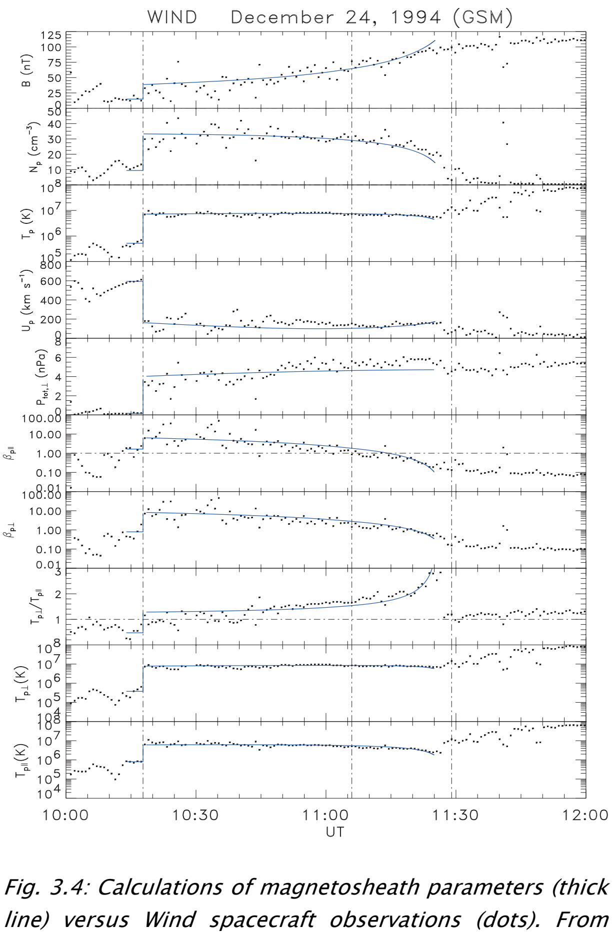



*Fig. 3.4: Calculations of magnetosheath parameters (thick line) versus Wind spacecraft observations (dots). From left, the first vertical dashed line in each panel denotes the bow shock, the second one the magnetic barrier and the third one the magnetopause.*

A further phenomenon found in the magnetosheath is the so-called magnetic barrier effect: The solar wind plasma is streaming around the magnetosphere and thus produces a stagnation zone close to the subsolar point of the magnetopause. As a matter of fact, the frozen-in condition of the magnetic field leads to an enhancement of the magnetic field and analogously to a decrease of the plasma density. Thus, this region is alternatively known as the plasma depletion layer.

Comparing our theoretical model with spacecraft observations, it can be seen from Fig. 3.4 that the calculations are in good agreement with spacecraft observations, indicating that the bounded anisotropy method of closing the magnetosheath equations is valid and reflects well the physics of the magnetosheath. In this example, we concentrate on magnetosheath parameters observed by the Wind spacecraft on December 24, 1994, whereas the curve in each panel corresponds to theoretical calculations.

Of further interest is the thermodynamic behavior of the anisotropic magnetosheath. A phenomenological approach based on double polytropic relations is useful to describe the thermodynamics: In most cases it is found that the perpendicular pressure is described via an isothermal law, whereas the polytropic index of the parallel degree of freedom exceeds unity.

# Magnetopause

Satellite data like those of the *Cluster* mission are important for the study of physical processes caused by the interaction between the interplanetary magnetic field (IMF) and the solar wind with the magnetosphere of Earth.

One of these processes is the so-called reconnection of magnetic field lines of the IMF and the terrestrial magnetic field at the magnetopause. The theoretical description of magnetic field line reconnection starts with antiparallel field lines separated by a tangential discontinuity. In a very small region, the so-called "diffusion region" (DR), where the local conductivity reaches a finite value, terrestrial field lines are opened and reconnected with field lines of the IMF. Regardless of the precise mechanism, the DR acts as a source of MHD waves, which propagate into the surrounding medium. Under special circumstances these waves steepen and may be considered as large-amplitude discontinuities. In this structure, incoming plasma from the magnetosheath is accelerated through a conversion of magnetic energy to kinetic energy along the magnetopause and is transported to the night side.

In the case of time dependent reconnection a reconnection pulse travels along the MP and can be identified in observations as so-called flux transfer events (FTE). This reduction of magnetic field at the dayside MP and the transport to the nightside is also called "erosion of the magnetopause". Erosion of the magnetopause is seen as an earthward motion of the MP and a large variety of inner magnetospheric signatures, such as an equatorward motion of the cusp, an increase of the auroral oval, the substorm growth phase, an increase in tail lobe magnetic flux, and others.

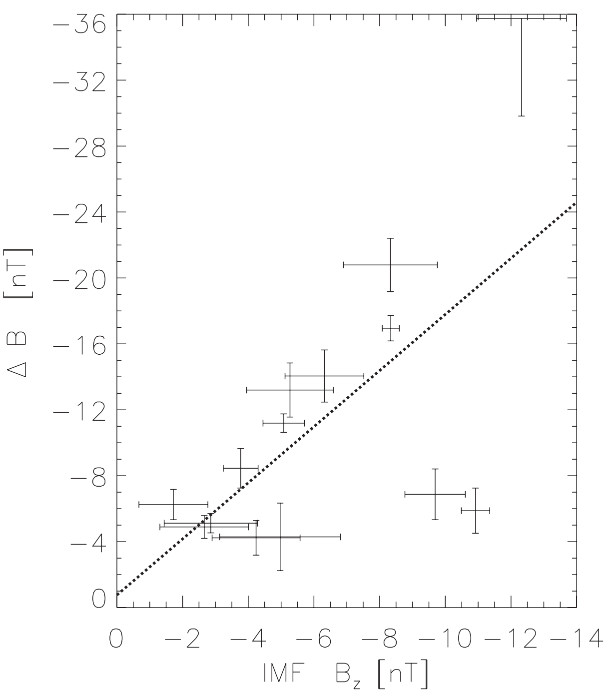



*Fig. 3.5: Magnetic field erosion at geostationary orbit (ΔB) versus negative IMF $B_z$.*

In cooperation with the University of New Hampshire, USA, we studied magnetic field line erosion at the geostationary orbit. One important cornerstone of this study was May 11, 1999, known to the space science community as "the day the solar wind almost disappeared". During a long period within this day the dynamic pressure of the solar wind was close to zero and the terrestrial magnetic field was a near-perfect dipole. We used this period to separate effects of dynamic pressure and southward interplanetary magnetic field at geostationary orbit using measurements of the *Goes 8*, *9*, and *10* satellites at geostationary orbit around magnetic noon. Including a correction for higher values of dynamic pressure, we finally obtained values of magnetic field line erosion on geostationary orbit, shown in Fig. 3.5 for 14 erosion events.

As a second aspect we developed a simple theoretical model of the erosion of magnetic field lines at the magnetopause on the basis of time-dependent reconnection. First numerical results show an inward motion of the magnetopause by about one Earth radius due to field line erosion.

Within the wide range of problems which deal with magnetic field line reconnection we also work on the following problems: (1) For the initiation of reconnection in the diffusion region. It was shown that whether Petschek or Sweet-Parker reconnection develops, depends on whether finite conductivity is restricted to a certain region or not. (2) Reconnection in an anisotropic plasma is extended to time-varying results. (3) Relativistic reconnection in a black hole is an additional process which can remove energy from the ergosphere of a black hole.

# Magnetotail

At our Institute, one of the main research areas in analyzing and interpreting spacecraft data, such as *Geotail*, *Equator-S*, and *Cluster*, is the study of the dynamics of the Earth's magnetotail, with special interest in the transport processes.

Since July 2001 *Cluster* has started to observe the magnetotail, covering regions between X = -10 and -19 Re. The continuous measurements with simultaneous observations from the four spacecraft enable us to differentiate spatial from temporal disturbances in the magnetotail and provide a chance to obtain essential parameters, which were not accessible before with a single spacecraft or from fortuitous multi-point observations.

A number of studies have been initiated in our team in terms of dynamics of the Earth's magnetotail. These include: (1) structure and evolution of plasma sheet flows, (2) global reconfiguration of the plasma sheet and convection near the plasma sheet during substorms, (3) configuration of the current sheet, (4) wave characteristics in the current sheet and in fast flows, and (5) structure and evolution of the reconnection region. A first result from the four-spacecraft analysis during a dipolarization event is shown below.

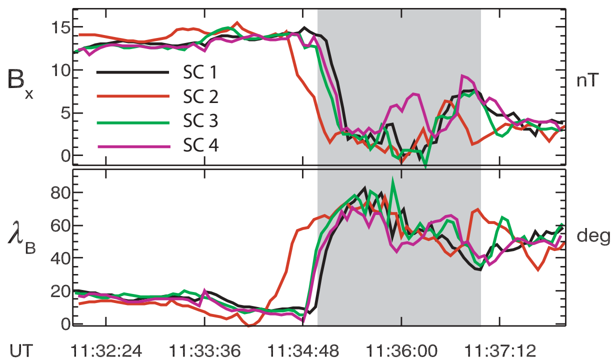



*Fig. 3.6: Magnetic field observations from the four Cluster spacecraft during a high speed flow interval (indicated by the shaded area).*

The role of the fast flows in substorm dynamics is a still much-debated issue among substorm researchers. A key to this problem is to identify the temporal and spatial relationship between the flows and magnetic disturbances associated with the dipolarization. By analyzing the plasma and magnetic field data from the four *Cluster* spacecraft, we succeeded to measure the expansion speed of the dipolarization region associated with the flow disturbance.

Fig. 3.6 shows the Earthward component, $B_x$, and the elevation angle, $\lambda_B$, of the magnetic field. The shaded interval shows when spacecraft (SC) 3 observed a high-speed plasma flow with up to 490 km/s perpendicular to the magnetic field. The flow event occurred in association with a dipolarization, which can be seen as an enhancement of $\lambda_B$ in the figure. There were differences in the timing of the dipolarization among the spacecraft, which we analyzed in detail by determining the dipolarization direction from a minimum variance analysis.

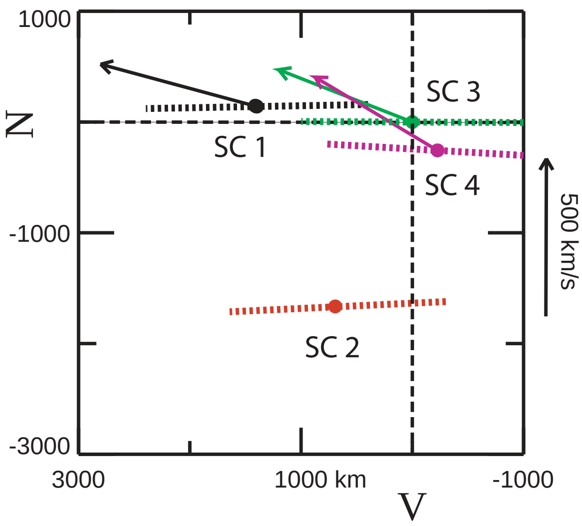



*Fig. 3.7: Location of the four spacecraft relative to the reference spacecraft (SC3) in a minimum variance coordinate system (see for detail in the text). The arrows indicate the flow direction (there are no flow measurements on SC2), whereas the dotted lines indicate the direction of the depolarization front.*

Fig. 3.7 shows the location of the four spacecraft in a coordinate system where N is the minimum variance direction, corresponding to the normal direction of the depolarization front, and V is the main flow direction projected onto the plane perpendicular to N. The flow vectors, shown as arrows, are directed mainly along the plane of the dipolarization (dotted line). The large time difference between SC 2 and the other 3 spacecraft shown in Fig. 3.6 can be well understood by the distribution of the satellites in the normal direction in Fig. 3.7. That is, the dipolarization front was expanding not only in the high-speed flow direction but also in a direction perpendicular to the main flow with a speed of ~60 km/s.

# Ionosphere

The high-latitude ionosphere is highly variable, partly because of the often unstable behavior of the neutral atmosphere (e.g. stratospheric warmings), but mainly due to the extremely variable ionization due to energetic charged particles. The resulting electron densities by far exceed those expected due to solar irradiance alone. The D-region part of these excess densities is responsible for the absorption measured by a riometer, which makes the latter a useful parameter to describe disturbances in the low ionosphere. Existing models such as the International Reference Ionosphere (IRI) only insufficiently describe the special conditions of the high latitude lower ionosphere.

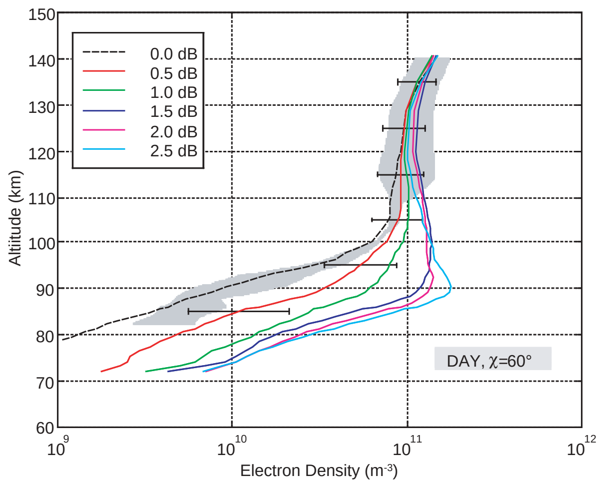



*Fig. 3.8: Modeled electron density profiles for daylight condition (60° solar zenith angle) and various levels of riometer absorption. Error bars correspond to the 1 σ level. The shaded area indicates the range of measured densities under quiet conditions.*

An empirical model of electron densities in the lower auroral ionosphere was developed at the Institute in co-operation with the Technical University Graz. It is based on wave propagation data from sounding rockets (over 100 altitude profiles) and incoherent scatter data from the EISCAT radar (about 65,000 profiles). By combining both data sets into one model one can take advantage of both the more accurate, but fewer wave propagation data down to low altitudes and the large number of radar profiles. In the model, electron density profiles are analyzed according to riometer absorption, and statistical profiles for various degrees of absorption, including 0 dB, are established both for day and night. An example is shown in Fig. 3.8. In order to reduce the seasonal variation of the neutral atmosphere in the present statistical analysis the data are carried out at fixed pressure surfaces instead of altitudes. An inclusion of these models into IRI is foreseen.

# Auroral Kilometric Radiation

During 2001, we investigated the terrestrial kilometric emission observed by the *AKR-X* and *POLRAD* experiments on board *Interball-Tail* and *Interball-Aurora*, respectively. For the first time the complete polarization parameters of the Auroral Kilometric Radiation (AKR) associated to the day- and nightside sources have been determined (see Fig. 3.9). Taking into account the hollow cone features associated with AKR, we derive the radio source localization. It could also be shown that the spectral structures (bursty and continuum) of AKR emission seem to depend on the geometry between the observer (satellite) and the source localization. Statistical studies show that the AKR occurrence is increasing and decreasing in the equinox and solstice periods, respectively.

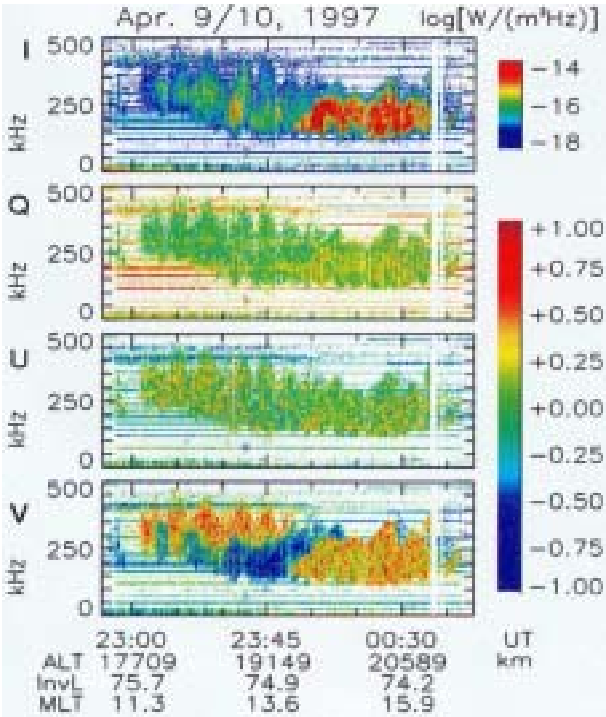



*Fig. 3.9: Dynamic spectra of the Stokes parameters for AKR observed in the dayside northern hemisphere.*

We further used *Interball* spacecraft positions to obtain possible source locations of AKR. The theoretical approach is based on geometrical considerations and was performed in a diploma thesis.

# 4 Solar System

The solar system is a gathering of nine planets, a yellow central star, 80+ moons and countless asteroids, and comets, circling the Sun in more or less elliptic orbits. It is filled by magnetic fields, radiation of all kind and a steady stream of charged solar wind particles. The Institute is engaged in many missions and studies on the solar system.

## 4.1 Sun

For us, the Sun is not only of interest as the producer of the solar wind, which is the key driver of much of the dynamics described in the present and the previous chapter, we are also interested in the central star of our system itself. We observe our Sun in the radio wave spectrum, from the ground and, hopefully, in the future also from space.

### Solar Decametric Radiation

Studies of the Sun are done at the Lustbühel radio station. In particular, solar activity in the decametric range was monitored. We observed the Sun two hours before and after the local transit meridian, by using in particular the digital spectro-polarimeter (DSP) in the frequency range 30-42.5 MHz with a time resolution of about 300 ms. A first analysis of the year 2000-observations provides an estimate on the interference situation in the surrounding of the Lustbühel radio station in the frequency range of the observed solar radio bursts.

In cooperation with Ukraine (Kharkov Radioastronomical Institute) and France (Observatoire de Paris-Meudon) a common observation campaign was carried out in spring 2001. During this period the Austrian DSP receiver was in operation at the Grakovo radio station (Ukraine) for the observation of solar decametric radio bursts, simultaneously with the other DSP receiver located at the Nançay Decametric Array (France). At present the observed dynamic solar burst spectra are analyzed.

### Solar Orbiter

*Solar Orbiter* is an ESA Flexi mission to Sun which is still in the planning phase. The spacecraft will orbit the Sun with a perihelion distance between 0.2 and 0.3 AU. A Radio and Plasma Wave Analyzer *(RPW)* to observe solar radio emissions will be incorporated in the spacecraft instrumentation. We made a feasibility study to determine which kind of antennas and receivers should be used and found that the optimum configuration depends on whether emphasis is put on direction finding, polarization measurements or spectral observations.

## 4.2 Mercury

Up to now only a few spacecraft have been sent to Mercury, the innermost planet of the solar system, and none of them tried a landing on its surface, which is a particular technical challenge due to the hot and harsh environment conditions expected.

### BepiColombo

The satellite mission *BepiColombo* (see Fig. 4.1) is in several respects new and unique:

not only it is the first European-Japanese cooperative mission – involving both ESA and the Japanese space agency ISAS – it is also for the first time that a small armada of space probes (two orbiters and one surface probe planned to land on Mercury's night-side) will simultaneously visit a planet. In preparation of planned IWF contributions to *BepiColombo* several activities have been initiated in 2001. These will serve as the basis for response to the announcement of opportunity expected to be released in 2002.

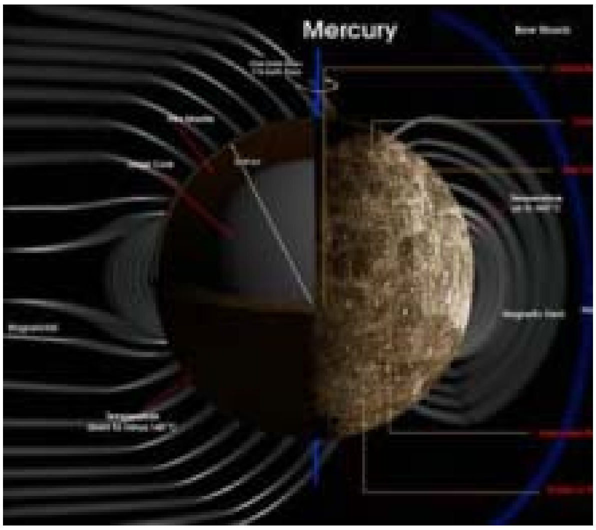



*Fig. 4.1: Mercury's surface and the expected structure of its magnetic field, to be investigated by ESA's Bepi-Colombo mission.*

*Lander and Orbiter/Magnetometers:* The Institute intends to participate in the development of magnetometers for all three spacecraft. In order to coordinate the activities the European-Japanese consortium MERMAG was created, where IWF participants are a major partner. A meeting of this consortium was held in Graz in August 2001.

*Lander/Mole:* One of the instruments proposed for the investigation of Mercury's sub-surface layers is a so-called "Mole" (Mobile Penetrometer). The sensors that will be implemented in this instrument will measure both thermal and mechanical properties of the regolith. A major goal is the determination of the global heat flux, which is a key parameter to understand the geological evolution of the planet. While the main responsibility for this instrument will rest with DLR Cologne and the University of Münster (Germany), the Institute has already significantly contributed to the general design and the evaluation of possible sensors to be implemented.

## Physics

*Exospheric sputtering:* A theoretical study analyzed various processes associated with Mercury's exosphere. There is a great difference in the energy distribution and surface number density if particle sputtering and/or micrometeorite- or photon-stimulated desorption are the relevant processes for Mercury's exosphere formation. The particles in our study were released from the planetary surface with a Monte Carlo simulated Maxwell distribution resembling the velocity distribution for photon-stimulated desorption (H, He, O, and Na), particle-induced surface sputtering (O, Na) and micrometeorite evaporation (Na, K). Since Mercury is so close to the Sun, solar heating of the surface implies that thermal desorption will also be an important source of exospheric Na. Solar wind ions impinging on the daytime surface are thought to be a major source of H and He atoms, become neutralized and then re-enter the exosphere.

Our simulated velocity distribution fits well with the distribution found by laboratory experiments. In cooperation with the University of Bern/Switzerland who will provide a sensor for ions and atoms (MAIA) on the planned Neutral Particle Analyzer (NPA) instrument on board of ESA's *MPO*, the model was used to provide input for a Monte Carlo simulation of Mercury's exosphere. These calculations showed that the *BepiColombo* planetary orbiter should be able to detect neutral H, He, O and Na atoms between its periherm (400 km) and apherm (1500 km).

An example is shown in Fig. 4.2. Heavy particles like O and Na only reach the spacecraft altitude if they originate by energetic source processes like particle sputtering or micrometeorite vaporization. Future studies will include the effect of the radiation pressure on particle trajectories and a study about the areas where the solar wind particles can reach Mercury's surface.

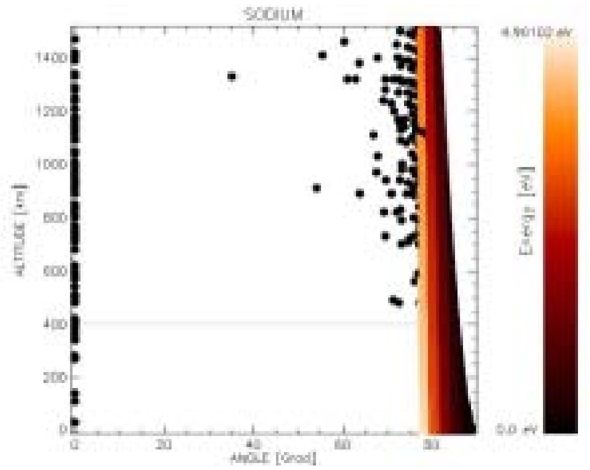



*Fig. 4.2: Simulated particle-sputtered sodium atoms at Mercury. The dotted line shows the periherm of ESA's BepiColombo planetary orbiter: A particle detector on board should be able to observe heavy atoms sputtered from Mercury's surface.*

# 4.3 Mars

The planet Mars was one of the major research topics in 2001, from the experimental viewpoint as well as in a number of more theoretical studies. Instruments to measure the surface magnetic field and the mechanical and thermal properties of the surface layers are co-developed by the Institute. Theoretical studies dealing with UV and particle fluxes at the Martian surface (both at present and in the distant past) as well as mineralogical investigations on Mars analogue samples were also performed.

## NetLander

The institute is involved in several experiments within the upcoming Mars mission *NetLander*, which is due for launch in 2007 and will set up for the first time a meteorological and seismic network on the Martian surface, employing 4 identical landers. Fig. 4.3 shows an artists view of one of the lander stations.

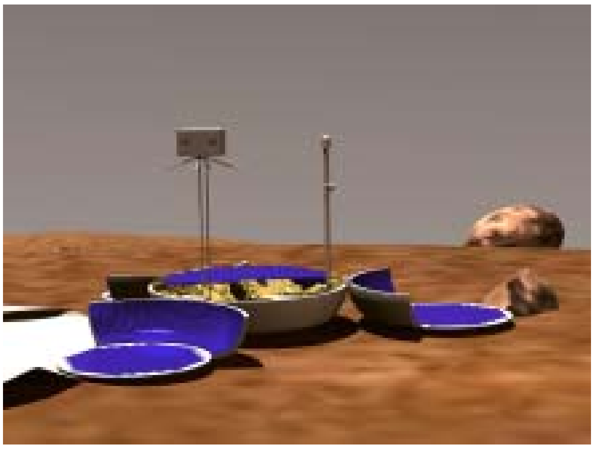


*Fig. 4.3: Artist's view of a NetLander station operating on the surface of Mars.*

*SPICE:* This experiment will measure temperature (and the daily and seasonal cycles) and the material strength in the uppermost centimeters of the surface. The latter is the main contribution of the Institute, while the former is managed by the University of Münster, Germany. Concerning the strength measurements, the basic design was developed in 2001. The sensor measuring the penetration force into the Martian surface will be integrated into the legs of the seismometer, which needs a good ground contact in order to detect seismic waves. These legs are pushed into the soil by a motor, allowing a small load cell to record the resistance force of the ground.

A mock-up to test the performance of strength measurements with different load cells in various test materials (sand, cemented soil, permafrost). has been installed in our laboratory at IWF. This device will be used in the following year to test the developed sensor tips and to investigate their performance in various Mars analogue materials. Fig. 4.4 shows some components used for the first development tests. Cooperation with the seismometer teams at IPGP Paris and at ETH Zurich is essential for this development work.

*Fig. 4.4: Some hardware built for first experiments on the material strength measurements to be performed on Mars in the frame of the SPICE experiment. Upper left: force measurement in a Mars soil analogue material. Upper right: One of the miniature force sensors used to measure the penetration force. Lower left: conical tip where the force sensor is integrated. Lower right: exploded view of the conical tip shown on the left side.*

*MagNet and ELF:* These key experiments will measure for the first time the magnetic and electric field at the surface of Mars. With the data to be recorded at the four lander sites, the magnetic anomalies detected by the *MGS* orbiter can be investigated directly. Moreover, the simultaneous measurement at four sites allows in addition to determine the electrical conductivity of the Martian surface. The combination of magnetic and low frequency electric field measurements may lead to a better understanding of sandstorms on Mars. *MagNet* consists of four fluxgate magnetometers designed to measure time variable fields up to 20 Hz. Cooperation with the *ELF* experiment team is essential. In 2001 preparatory work has been done.

# Physics

*Low-frequency electromagnetic waves:* A broad spectrum of electromagnetic waves is generated in the foreshock region and in the magnetosheath. We modeled the propagation of extremely low frequency electromagnetic waves (ELF) from the magnetosheath to the surface. A major task was the calculation of wave attenuation using the electron densities and collision frequencies from present neutral and ionospheric models. The ELF waves are essential for the electromagnetic sounding investigations planned for the NetLander mission.

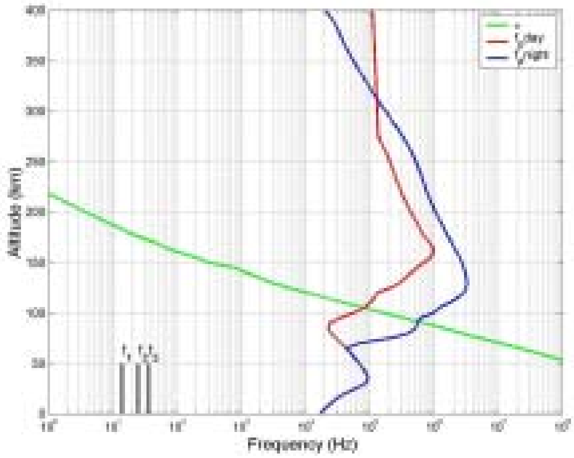



*Fig. 4.5: Plasma frequency and collision frequency. Schumann resonances (f1, f2 and f3) are also shown.*

The main results of these theoretical studies are: (1) Waves coming from the magnetosheath with f < 3 MHz are completely absorbed and cannot reach non-magnetized surface regions; (2) Very low-frequency Alfvénic waves could travel along the magnetic field lines produced by the crustal anomalies; (3) If wind over the strongly magnetized areas is able to produce currents by the “ionospheric dynamo effect” above 110 km, this wave phenomenon can be detected by the NetLander instruments on the ground at several Hz, (4) Waves produced near the surface by electrostatic discharge in dust storms (dust devils) or geological activity, can propagate below 100 km with a very low atmospheric attenuation.

*Energetic Neutral Atoms:* In view of the Japanese *Nozomi* and ESA’s *Mars Express* mission, which will both arrive at Mars in 2003, flux and energy distributions of planetary energetic hydrogen atoms around Mars for minimum and maximum solar wind conditions were investigated. It was shown that the energetic neutral atom distribution in the Martian environment is characterized by particles belonging to two different sources: one particle population originates from the solar wind while the second stems from the planetary atmosphere. Once the atmospheric constituents become ionized, they are treated as test particles and their motion in the external electric and magnetic field is determined. Some of these new-born planetary ions take part in a charge exchange reaction with particles of the upper Martian atmosphere and will be transformed into planetary energetic neutral atoms (Fig 4.6).

Our calculations suggest that the Energetic Neutral Particle (ENA) detector aboard the *Mars Express* spacecraft may be able to separate the planetary energetic hydrogen population from the solar wind population by a careful analysis of the particle energies. Such a separation is important for the study of the evolution of the Martian atmosphere and its water inventory.

*Surface Radiation Exposure:* Another study concentrated on galactic cosmic ray and solar UV radiation models on the ancient and present Martian surface. Since Mars is one of the prime targets in exobiology we investigated with a theoretical model the particle and UV surface fluxes and related effects on possible organic molecules which are essential for the evolution of microbial life-forms. We used a photochemical model for computing the vertical profiles of the Martian atmospheric compounds such as oxygen, ozone and $NO_2$ which are responsible for UV absorption in an ancient 1-bar $CO_2$ atmosphere calculated by considering atmospheric loss processes.

The results shown in Fig. 4.7 indicate that the molecules essential for life were protected against the incoming UV radiation during the early period 3.5 Ga ago. Moreover it was found that in such a dense Martian atmosphere only secondary cosmic ray particles reach the surface, while proton and neutron fluxes are negligibly small.

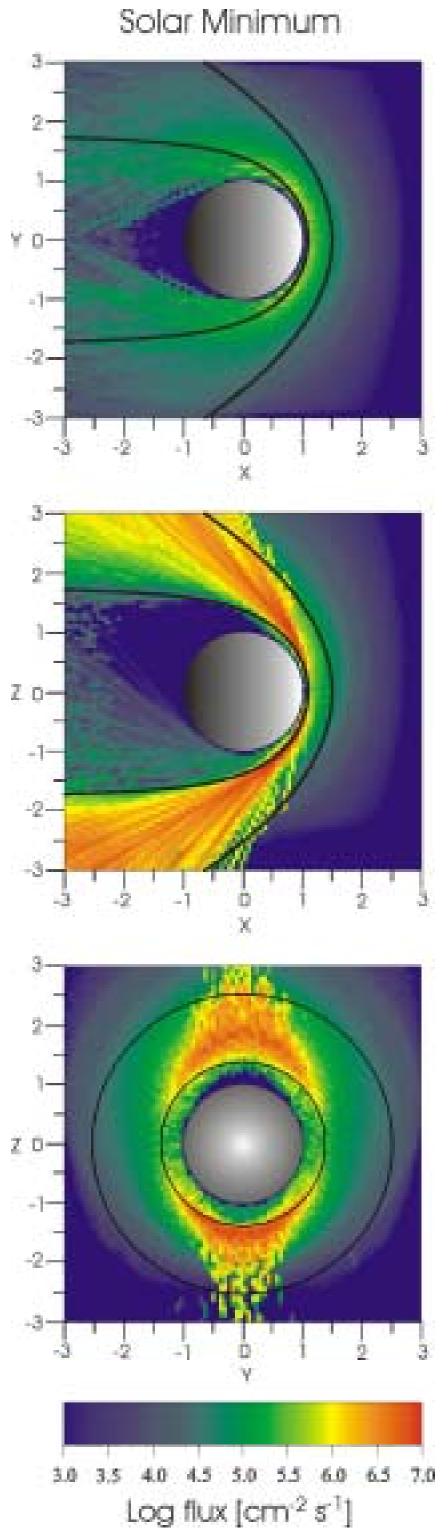



*Fig. 4.6: Total flux of energetic neutral atoms in three different planes: the x-y plane contains the interplanetary magnetic field, the x-z plane the solar wind electric field and the y-z plane is perpendicular to the Sun-planet direction; black lines display the obstacle boundary and the bow shock.*

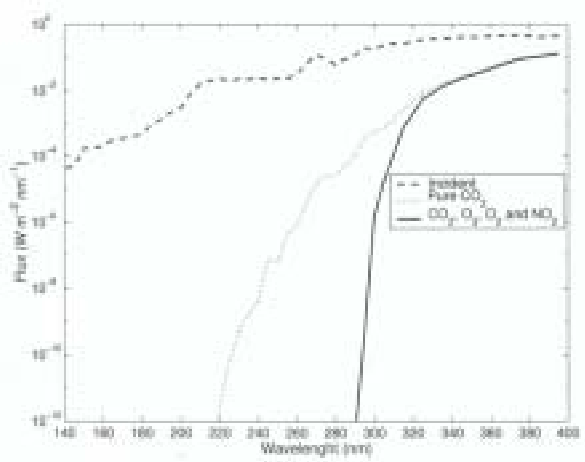



*Fig. 4.7: Solar UV flux on the ancient Martian surface in a pure $CO_2$ atmosphere (dotted line) and with inclusion of a more complex photochemical model which produces an ozone layer at about 60 km above the Martian surface. In such a case the atmosphere becomes transparent to UV radiation above wavelengths of 290 nm (solid line) .*

The study shows also that an ozone layer comparable to the Earth is produced via photochemical reactions and that $HO_x$ radicals in the ancient Martian atmosphere about 60 kilometers above the surface are absent. A 1-bar ancient Martian atmosphere becomes transparent to solar UV radiation above wavelengths of 290 nm if one includes UV absorbing constituents produced via photochemical reactions. For understanding the survival rate and the damaging effect to a number of molecules essential for life we calculated the survival rate and the functional and structural stability of such molecules and found that solar UV radiation was not dangerous on the ancient Martian surface for organic molecules.

*Surface Oxidation Potential:* For atmosphere-surface interaction studies in the frame of ESA's *Mars Express* mission an investigation of Mars soil analog-material with sediment-petrographic methods and subsequent magnetic separation of sieving-fractions was made. We determined the modal-mineralogy by means of optical microscopy and X-ray-diffraction and made a normative calculation of the mineral-content in fine fractions based on bulk chemistry. IR diffuse reflectivity experiments were conducted and an experimental arrangement for UV oxidation experiments in Mars simulation chambers with Martian precursor materials, as well as for UV-induced $O_2$ adsorption on Mars soil analogues were designed. A study where we try to fit the physico-chemical properties of the Martian soils (data of MP and MGS-TES missions) by mixing of analogue-materials with other natural or synthetic phases is under way.

# 4.4 Jupiter and Io

The giant planet Jupiter, its magnetosphere and the inherent plasma processes have extensively been investigated during the annual period of 2001. Main emphasis was put on studies of Jovian radio emission phenomena and the Io-Jupiter interaction within and in the environment of the Io flux tube.

## DAM Radio Observations

New decametric (DAM) radio observations as well as instrumental developments have been performed in a cooperative project among 4 European nations, France, Austria, Ukraine, and Russia. The main objectives are to develop and validate new concepts for high-sensitive ground-based measurements of natural radio sources like Jupiter, the Sun and pulsars. The project is based on the availability of several powerful decameter antennas, namely UTR-2 (Ukraine) and the Nancay Decameter Array (France), in combination with the newly available type of wide-band waveform digital receivers developed in Austria and France. This instrumentation enables unprecedented accuracy, resolution, and sensitivity and dynamic range (at least 70 dB) for measurements at decameter wavelengths.

In 2001 the third joint measurement campaign within the project "New Frontiers in Decameter Radio Astronomy" has been performed (from late April through mid of June 2001). Furthermore the development of a central data storage system at IWF was initiated.

*DAM modeling:* Data analysis of Jupiter millisecond radio bursts in the decameter range obtained during previously performed campaigns yielded new insights into this particular radio phenomenon. The studies are based on simultaneous observations at the radio stations UTR-2 in Kharkov (Ukraine) and the Reseau Decametrique in Nancay (France), where two digital spectro-polarimeters were used and time synchronization (down to microseconds) was obtained via GPS. The stations are widely separated by approximately 2½ hours in geographical longitude, giving good conditions to study the angular structure of the emission cone mantles.

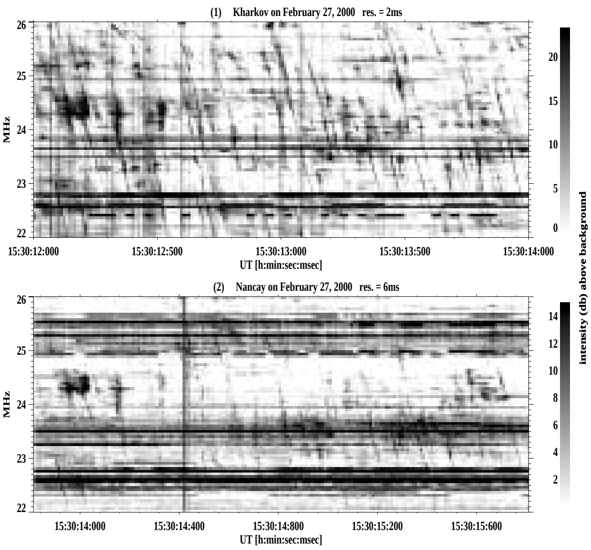



*Fig. 4.8: Dynamic spectrum of the Jupiter Io-B radio source, exhibiting single burst structures. The spectrum recorded at Kharkov (upper panel) shows more details than that recorded at Nancay (lower panel), due to higher sensitivity and time resolution.*

Cross correlation (Fig. 4.9) of simultaneously recorded spectra (Fig. 4.8) reveals that radio emission structures observed at Kharkov and Nancay have no time-delay within the given time-resolution of 2 ms. However, local effects are definitely visible in the spectra, first of all due to the different effective antenna areas and also as a consequence of variable local ionosphere conditions.

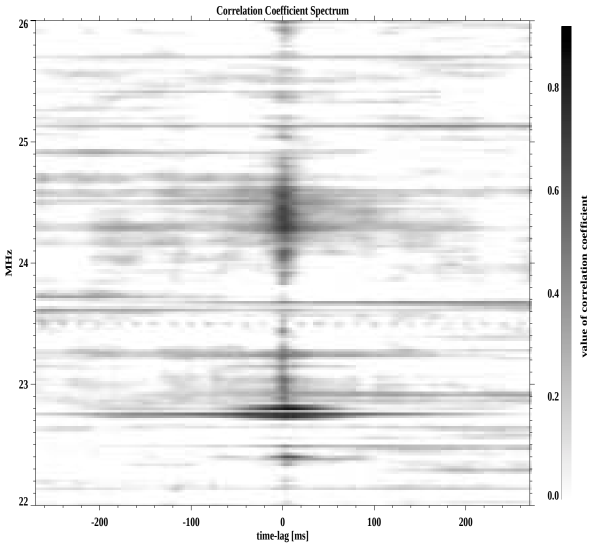



*Fig. 4.9: Correlation coefficient spectrum corresponding to the previous figure. The broadening of maximum correlation around zero delay time is very likely due to the different spectral recordings of both stations, whereas the slightly enhanced correlation at multiples of ±(40-60 ms) off the zero delay time mirrors the repetition rates of the shown S-bursts.*

*Waveform Analyzer:* Within the frame of a doctoral thesis a digital Wave Form Receiver (WFR) has been designed and developed, which, in connection with the digital spectro-polarimeter (DSP), can perform broadband high time and frequency resolution recordings of the complete wave signal information. This WFR is the first broadband receiving device reaching the maximum theoretically possible time and frequency resolution product. With a dynamical range of about 70 dB and a bandwidth of 25 MHz, the WFR is at the optimum for observations of radio phenomena in the decameter wavelength range. The only parameter of the WFR that still needs improvement is the short acquisition time (at present about 6 seconds for observations with high time and frequency resolutions leading to 100 MB of data per second).

*Wavelet analysis:* Waveform observations with this new WFR have been carried out at Kharkov and at Nancay. The ability to observe a bandwidth of up to 25 MHz and directly save waveform data for several seconds allows to perform Jovian millisecond burst substructure analysis. Fig. 4.10 shows a dynamic spectrum of such a burst and a wavelet scalogram of part of the burst in the microsecond time domain (indicated by an arrow). The scalogram reveals that the burst consists of several signal trains as short as 10 microseconds in time, with phase discontinuities in between.

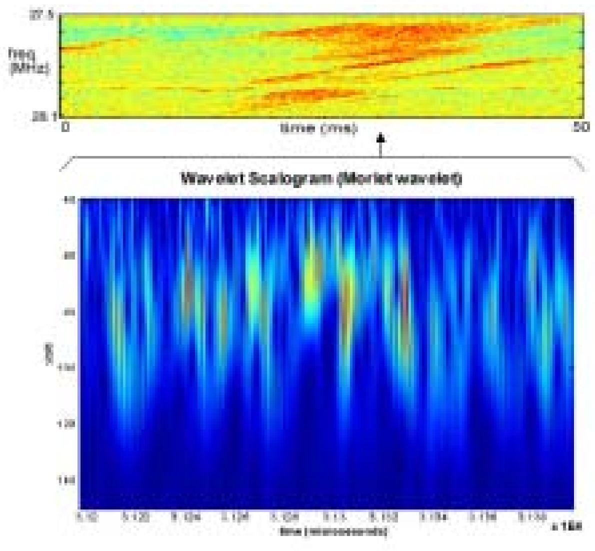



*Fig. 4.10: Dynamic spectrum (top) and wavelet scalogram (bottom) of a Jovian millisecond burst signal.*

## HOM Radio Observations

Further analysis was done using data of the *Galileo PWS* (in orbit around Jupiter) and the *Wind WAVES* experiment (in orbit around Earth) together with ground-based measurements. Jovian hectometric emission, in particular the HOM beam has been analyzed during periods of favorable conditions (Aug 31 through Oct 22, 1996). Generally, the overall structure of the HOM beam shape is persistent in both PWS and WAVES spectra, however internal structures (i.e. spectral arcs) are absent in the WAVES spectra, maybe due to distortion effects as these HOM radio waves propagate through the Io torus and through the interplanetary medium over more than 4 AU.

## Cassini Jupiter Flyby

The calibration of the antenna system of the Radio and Plasma Wave Science Experiment (*RPWS*) onboard the *Cassini/Huygens* spacecraft is an important goal on the way to Saturn where the IWF is deeply involved. A first attempt to determine the effective length vectors of the antennas was done some years ago at the Institute, based on the concept of rheometry. The results, of course, were obtained in laboratory studies, but the Jupiter flyby in December 2000 provided the possibility to obtain the effective length vectors via the measurement of Jupiter's radio emissions. Thus, several roll maneuvers during the inbound and outbound phase provided the possibility to determine maxima and minima of the RPWS antenna lobe patterns . As input parameters we used measured auto- and cross-correlated voltages of the 3 RPWS antennas and the angular position of Jupiter as seen from *Cassini*. Two steps had to be done in the analysis: First we searched for the wave parameters of the observed radio waves and second, the derived Stokes parameters were used as initial guess for the determination of the effective length vectors of the antennas. The obtained directions of the *u/v* antenna elements for high parameter resolution are in good agreement with those obtained by the concept of rheometry.

At the beginning of 2001, in analogy to the pre encounter orbit of *Cassini* at Jupiter, roll maneuvers were done to calibrate the third *RPWS* antenna element. A first analysis showed that the calibration of this electric monopole is more complicated, since it is closer to the spin axis of the spacecraft and thus more influenced by the spacecraft body.

## Io-Jupiter Interaction

The interaction of Jupiter with its satellite Io has been subject of theoretical and experimental research for many years. It is well known that the orbital motion of Io leads to the excitation of disturbances, traveling along the Jovian magnetic field towards the planet, and exciting some specific phenomena in the Jovian system such as non thermal radio emission and aurora on Jupiter (Fig. 4.11). In spite of the previous work in this subject explaining the energy transfer, which mainly works via Alfvén waves, we apply another approach based on MHD slow mode waves. These slow mode waves are generated by a pressure pulse in the vicinity of Io and propagate along the converging Jovian magnetic field accompanied by a supersonic flow. Due to decreasing cross section and the increasing magnetic field the bulk velocity of this plasma flow is enhanced.

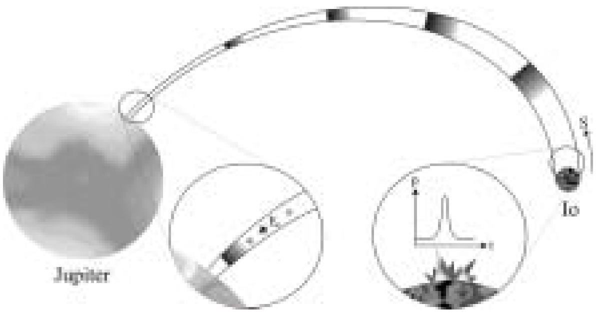



*Fig. 4.11: Schematic illustration of the development of a nonlinear slow-mode wave and a field-aligned electric field due to a pressure pulse at Io.*

Such plasma flows lead to the generation of an electric potential difference, which accelerates precipitating electrons as they pick up the potential drop energy when they fall through the potential. Such electron distributions are a crucial ingredient for the explanation of some magnetospheric phenomena. The main point is that the slow mode waves are much slower than the Alfvénic waves and can provide an explanation for the lag between some parts of the Jovian decameter emission and the Io flux tube which can be observed in experimental observations.

# 4.5 Titan

The Institute is strongly involved in the *Cassini/Huygens* mission to Saturn and its satellite Titan. It contributed to several instruments aboard the Titan entry probe *Huygens (HASI and ACP)*, whose descent through Titan's dense atmosphere will take place in Jan. 2005. In preparation to this event several theoretical studies associated with Titan's atmospheric layers have been conducted.

## Physics

*Electrical parameters of Titan's atmosphere:* The *PWA* (Permittivity, Wave and Altimetry) instrument is part of the *HASI* experiment and will investigate electrical properties and electric field fluctuations in the atmosphere and ionosphere of Titan below 170 km. We have modeled the ion and electron density, the electrical conductivity and the propagation of low frequency electromagnetic waves in the lower ionosphere (Fig. 4.12). The ionization in this altitude range (below 400 km) is mainly produced by galactic cosmic rays. Electromagnetic waves could be generated by lightning phenomena at very low altitudes, as discussed in more detail below.

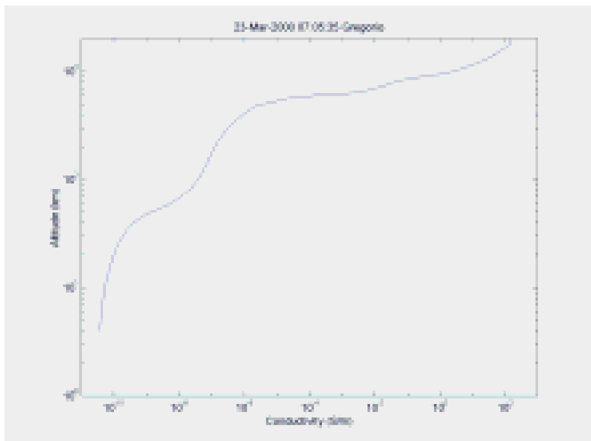


*Fig. 4.12: The calculated electrical conductivity profile in Titan's atmosphere.*

A major emphasis of our work was on the calculation of the wave attenuation using model electron densities and collision frequencies and including the influence of the surface electrical conductivity. The results were compared with measurements in the arctic and antarctic regions of Earth and with those obtained from terrestrial balloon flights.

*Lightning on Titan:* Titan lightning may provide the prime energy source for the generation of complex organic molecules which could be the seeds of primitive life. The formation of thunderclouds on Titan may be very rare due to the difficult methane condensation, but massive clouds can occasionally develop in the troposphere as is evident from recent telescopic cloud observations.

A study showed that a rapid development of thick, extensive methane clouds in the troposphere would attract a high number of free electrons, which are present due to the low abundance of electrophilic species. The entirely negative charge of the cloud may cause temporary maximum electric fields in excess of the breakdown field to initiate cloud-to-ground lightning flashes in the lowest 20 km of Titan's atmosphere.

Such lightning flashes may provide additional energy for the formation of some trace species including prebiotic molecules in the troposphere, where other chemical processes are inactive. The lightning strokes produce a transient hot channel in which high temperature chemistry (so-called Zel`dovich reactions) can take place. The sudden heating initiates dissociation of bonded molecules. Atoms and ions are in equilibrium as long as the channel is hot, but as the lightning channel begins to cool down by mixing with the surrounding air and expansion, various new molecules are formed by recombination of ions and atoms. Such molecules remain in excess of the equilibrium concentration during cooling because the rates of depletion reactions are greatly reduced (freeze-out of molecules). An estimate based on our Titan lightning studies suggests that a dissipation energy of about 2000 kJ gives a chemical yield per lightning flash of about $10^{22}$-$10^{23}$ HCN, $C_2H_2$, $C_2H_4$, and $C_2H_6$ and about $10^{10}$ $C_3H_8$ molecules. The significance of lightning generated biochemistry in Titan's atmosphere depends highly on the global lightning frequency.

In order to estimate the capability of the *Cassini/RPWS* instrument to detect lightning discharges during several close flybys, we estimated the radiated energy of Titan lightning strokes. We showed that the *RPWS* instrument should be able to detect electromagnetic signals from such strokes in a frequency range above approximately 500 kHz, depending on the ionospheric plasma density caused by micrometeorites.

*Meteoritic Ionization:* A model for studying the meteoroid ablation and the ionization of metallic ions in Titan's atmosphere was developed. We studied the ion-neutral chemistry of metallic ions and calculated the concentration of the most abundant metal ions and electrons. The study suggests that long-lived metallic ions considerably change the predictions of the electron density compared to models considering only solar radiation and electrons trapped in Saturn's magnetosphere. The inclusion of metallic ions in Titan's upper atmosphere leads to an increase in the electron concentration below 800 km. Our model shows that an ionospheric layer which is produced by micrometeoroids should be present at around 700 km altitude with an electron density peak similar in magnitude to the one produced by solar radiation at 1000 km or cosmic rays at 90 km.

*Ancient Solar Activity:* Our recent studies on isotope anomalies in planetary atmospheres, especially in Titan's atmosphere show an indication that our early Sun underwent during the first 600 million years after its origin a very active period called the Post-T-Tauri phase. The particle and radiation fluxes during such an early solar period were up to 1000 times higher than at present. A diploma thesis investigates how much such a strong solar wind outflow affects non or weakly magnetized planets and solar system bodies. Increased X-ray luminosity and particle outflow of the young Sun and enhanced solar EUV radiation will also affect the photoionization rates of the paleo-atmospheres of terrestrial planets and organic molecules during planetary formation.

# 4.6 Comets

The nuclei of comets are generally believed to contain the most 'primitive' matter of the solar system. Therefore the investigation of their chemical composition and physical structure is not only *per se* an interesting topic, but may also provide clues to understand the origin and evolution of the solar system.

## Rosetta

IWF participates in a number of experiments that will be flown aboard the ESA cornerstone mission *Rosetta*. This mission, due for launch in January 2003, is targeted at comet P/Wirtanen, whose activity will be observed from a low orbit over a long period. Moreover, *in situ* investigations on the nucleus' surface will be performed by the *Rosetta Lander*. The main contribution of IWF to the *Rosetta* mission is the experiment *MIDAS* aboard the *Rosetta Orbiter*, which will collect dust particles in the coma of the comet and investigates their structure with the aid of an atomic force microscope. In addition, there are contributions to the mass spectrometer *COSIMA* and to the magnetometer *RPC-MAG*.

For the *Lander* package, the Institute contributes to the *MUPUS* and *ROMAP* experiments and helped in the development of the *Rosetta Lander* anchoring system. *MUPUS* is a collection of sensors for investigating the thermal and mechanical properties of the near-surface layer, while *ROMAP* measures the magnetic field during the descent and its possible time variation after landing.

## MIDAS

A comet nucleus is emitting dust along with the subliming ices as soon as the comet approaches the Sun. The *MIDAS* (Micro-Imaging Dust Analysis System) instrument aboard *Rosetta* will investigate the physical parameters of cometary dust with an atomic force microscope (Fig. 4.13). It is developed under the leadership of IWF.

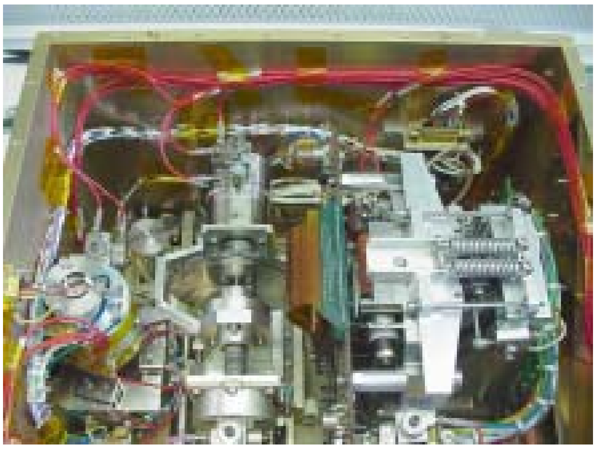


*Fig. 4.13: MIDAS, developed to perform extremely high resolution imaging of cometary dust particles.*

With the new method applied here, the texture of the dust particles can be measured with a resolution of down to several nanometers. The smallest particles (from micro- to nanometers) are very prevalent in the size distribution of the cometary dust. Based on structure one can deduce the contributions of rocky material and of light elements. *MIDAS* is expected to give conclusive results on the physical properties of comets as sources of dust emission. Above and beyond this the development of cometary activity during solar approach and the interaction between dust, gas and plasma in the surroundings of the comet will be investigated.

*MIDAS* consists of a dust collecting mechanism and an "Atomic Force Microscope", which provides three dimensional images of the dust particles. During this operation, a fine needle is brought very close to the sample until van-der-Waals and repulsive forces start to act, which get measured with a delicate sensor integrated in the cantilever supporting the needle (Fig. 4.14). The needle is guided along the height profile of the sample by a control loop, during which the surface gets measured linearly across the sample. *MIDAS* will gather, measure, image and statistically analyze the micro-dust particles. This highly accurate measurement of the particle's texture exceeds at similar boundary conditions the accuracy of an electron microscope. The imaging of particles is an important complement to the other methods of analysis in the *Rosetta* mission, especially to the mass spectrometer *COSIMA*.

*MIDAS* consists of a single mechanical unit of size 248 x 340 x 276 mm and a mass of 8 kg. The upper part contains the actual Atomic Force Microscope and the mechanisms that transport the collected dust particles to the sensors. The cone-shaped dust inlet sticks out of the outer surface of the spacecraft. The electronics are situated in the lower part of the casing. The microscope consists of a row of 16 sensors that can be finely adjusted around three axes through piezo-electrical actuators. The maximal extent of motion is 100 µm parallel to the imaging surface and 10 µm perpendicular to it. Each sensor consists of an approximately 0.5 mm long cantilever, which carries a needle of approximately 10 µm length at its end.

The needle tip's radius is approximately 10 nm. A piezo-electrical sensor at the base of the cantilever obtains an electrical signal through the bending of the cantilever, which is used to control the scanning distance.

In the commonly used dynamic operation mode the cantilever is put into vibration near its resonance frequency of 90 kHz. During intermittent contact between the needle and the target, but also without contact, the amplitude and phase of the vibration changes through damping. These parameters can be controlled remotely. Structures up to approximately 5 µm can be investigated with this atomic force microscope. The apparent resolution is limited by the accuracy of the steering system and the shape of the needle. The tested resolution is approximately 1 nm. Important international partners in the development of this instrument are ESA/ESTEC and Kassel University.

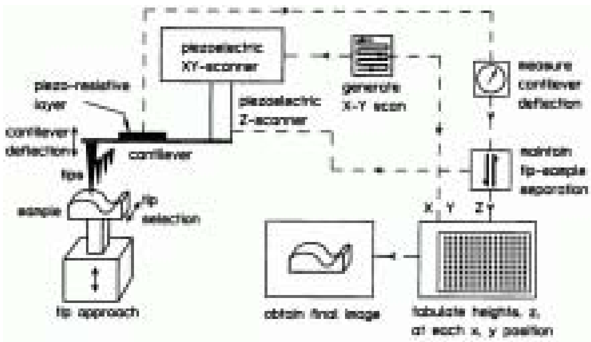



*Fig. 4.14: Working principle of the MIDAS atomic force microscope: An extremely fine needle scans the surface of dust particles and produces high resolution images.*

## COSIMA

The instrument *COSIMA* (COmetary Secondary Ion MAss Spectrometer) on board of the *Rosetta Orbiter* will chemically and isotopically analyze the dust particles that are captured in the coma of comet P/Wirtanen. The experiment works with secondary ion mass spectroscopy (SIMS). A high energy primary ion beam (Indium ions at 10 keV), hits the target and knocks off molecules, of which typically 0.1 to 10% are ionized, the so called secondary ions. A time-of-flight mass spectrometer is connected in order to enable the measurements over a large mass range. The target can be spatially resolved, limited by the cross section of the primary ion beam (ca. 10 µm).

*COSIMA* consists of a dust collector, a target manipulator, a light microscope for target inspection, the primary ion source and the mass spectrometer with its ion optics and ion detector. The development of the instrument is performed by an international collaboration chaired by the Max-Planck-Institut für extraterrestrische Physik in Garching, Germany. IWF is involved in the hardware and electronics for the primary ion beam system.

## MUPUS

*MUPUS* consists of a "penetrator" and shock accelerometers integrated in the anchoring harpoon system. For the latter IWF provided a major contribution. While the penetrator is a hollow tube of low thermal conductivity, hammered into the ground by a recoil-less hammering device, the anchoring system consists of a projectile shot into the ground immediately after landing. The integrated accelerometer measures the deceleration during penetration. From this measured signal the strength distribution with depth can be derived. Most of the shot tests with the harpoon system were performed at MPE Garching (the main contractor for the harpoon) using pressurized nitrogen gas as a driver. In 2001 the flight model harpoons were mounted to the landing gear and test-fired into sample material.

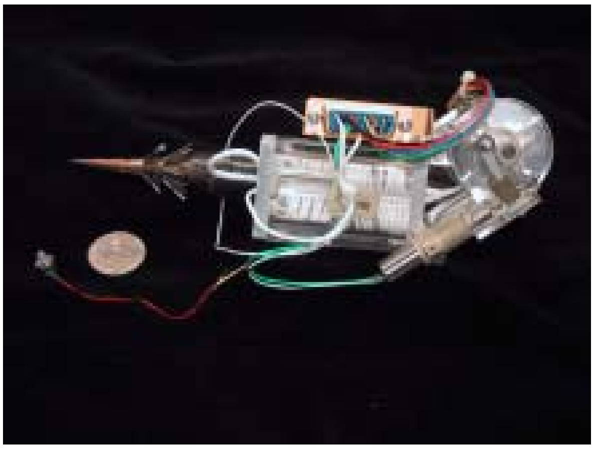


*Fig. 4.15: Rosetta Lander harpoon/anchor system. The accelerometer and temperature sensors are integrated in the tip of the anchoring projectile.*

## ROMAP

The experiment *ROMAP* (ROsetta Lander MAgnetometer and Plasma Monitor) aboard the *Rosetta Lander* is a multi-sensor experiment (Fig. 4.16). A fluxgate magnetometer (TU Braunschweig) investigates the magnetic field, ion and electron rates are detected with the help of an electrostatic analyzer (KFKI Budapest/MPAe Lindau) and the ambient pressure is measured by Pirani and Penning sensors. The different sensors and their accompanying electronics are controlled by the *ROMAP* Controller developed at IWF, which includes the instrument's telemetry interface. In 2001 the flight unit was completed, thermal/vacuum tested, and finally delivered. Moreover the software for the ground support equipment was completed.

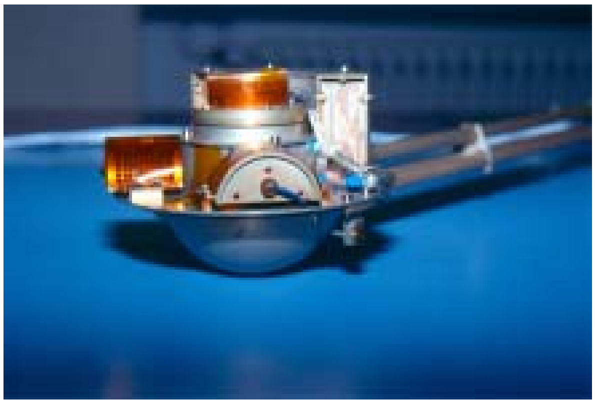


*Fig. 4.16: The ROMAP sensor on the Rosetta Lander in deployed position. This instrument will be used to measure the magnetic field in the near vicinity of the comet nucleus during the descent and after landing.*

## RPC-MAG

*RPC-MAG* is a fluxgate magnetometer built for the *Rosetta Orbiter* to measure the magnetic field in the vicinity of comet P/Wirtanen. It is based on the instrument flown on the *DS1* mission, which has recently measured the magnetic field near comet Borelly (see below). Fig. 4.17 shows the electronics board of an *RPC-MAG* prototype.

*Fig. 4.17: Prototype of the RPC-MAG electronics board.*

## Deep Space 1

*Deep Space 1* (DS1) is a NASA satellite developed to test some cutting-edge technologies and concepts. It was launched in October 1998, with a solar electric ion propulsion system. Under the lead of IGM/TU Braunschweig, a magnetic field experiment was developed to measure both the interplanetary magnetic field and the magnetic field produced by the ions emitting from the propulsion system. IWF is responsible for the ADC board of the *DS1* magnetometer.

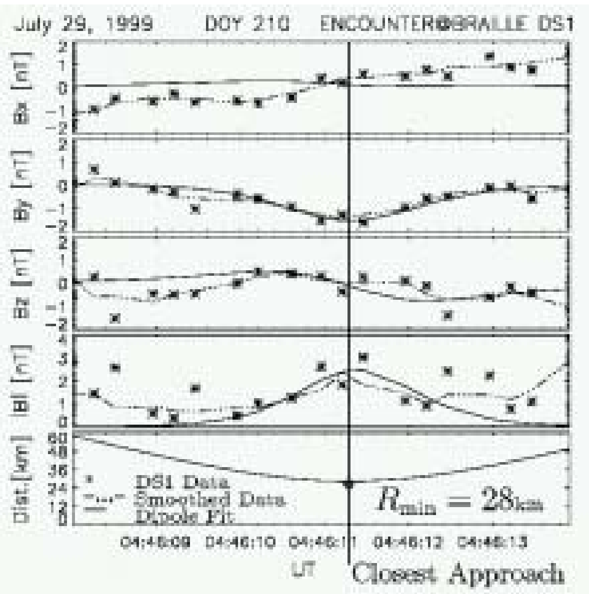



*Fig. 4.18: Magnetic field data measured in the vicinity of asteroid Braille.*

Data were obtained during the flybys at asteroid Braille (July 1999) and comet Borrelly (September 2001). The magnetic field around asteroid Braille is shown in Fig. 4.18. These data were used to determine the magnetic moment of the asteroid.

# 4.7 Solar Wind

The solar wind plasma consists mainly of protons, helium and electrons and continuously streams from the Sun into surrounding space. The particles get heated by magnetic reconnection, accelerated and expand into interplanetary space with supersonic speed up to the limit of our planetary system, the heliopause. The magnetic field is carried along with the plasma. Processes on the Sun, like coronal holes, solar flares and sunspots cause temporal and spatial disturbances in the solar wind and a sequence of fast and slow plasma streams. This results in the interactions of shock fronts.

## Instabilities

Various kinds of waves and instabilities exist in space plasmas. Small perturbations or wave-particle interaction in an equilibrium plasma state may lead to instabilities, characterized by the growth rate of the amplitude. We study in particular the Kelvin-Helmholtz instability at the magnetopause, the interchange instability, and the growth rate of mirror modes in the terrestrial magnetosheath.

As an illustrative example, Fig. 4.19 shows magnetic field and density fluctuations (points) from *AMPTE/IRM* observations in comparison with theoretical calculations, shown as envelope curves (for different wave numbers) in the first two panels. The position of the extrema of both curves correspond to regions where the threshold of the ion cyclotron instability is satisfied. The remaining part of the magnetosheath is identified as marginally mirror-unstable.

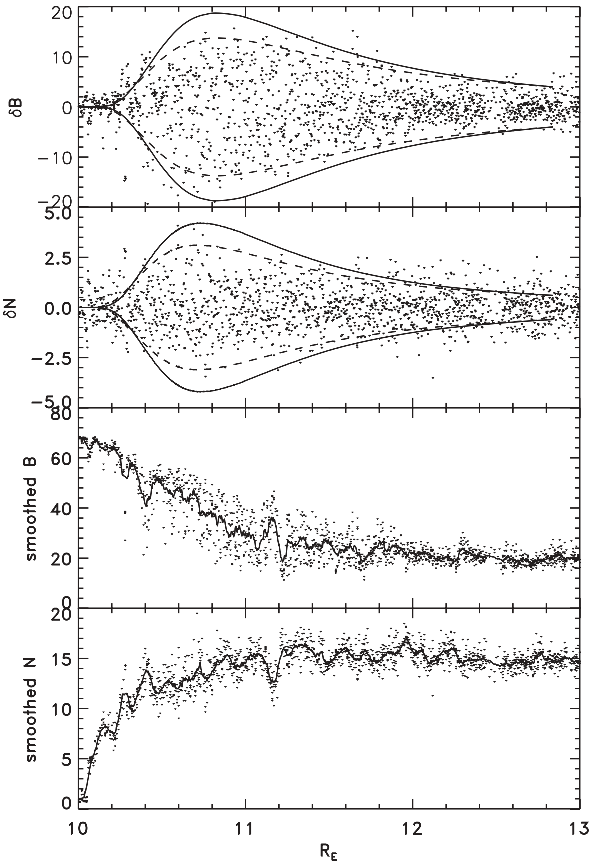



*Fig. 4.19: Magnetic field and plasma density fluctuations (top two panels) and smoothed profiles of AMPTE/IRM spacecraft observations in comparison with theoretical calculations.*

## Magnetic Clouds

Magnetic Clouds are produced in the solar wind when solar eruptions carry material off of the Sun along with embedded magnetic fields. These magnetic clouds can be detected in the solar wind through certain characteristics: (1) relatively strong average magnetic field, (2) large and smooth rotation of field direction, and (3) lower proton temperature than in the ambient plasma. Their passage over Earth usually lasts about 1-2 days and their dimension at 1 AU is ~ 0.25 AU. In a fast moving magnetic cloud, a shock front is formed. Between this shock front and the expanding structure of the cloud, a so-called sheath region develops.

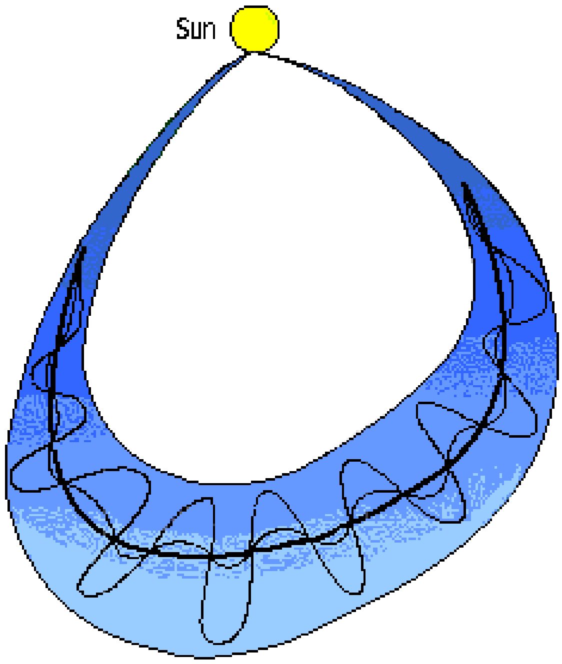



*Fig. 4.20: Sketch of a magnetic cloud, modeled as a cylindrical magnetic flux tube.*

If the cloud is modeled as a cylindrical magnetic flux tube (see Fig. 4.20), the characteristics of the cloud, i.e., the diameter, the magnetic field strength in the center of the cloud, the orientation of its axes, the helicity, and further parameters with regard to the position of the spacecraft, can be estimated. Specifically, *Wind* and *Ulysses* spacecraft observations are used for comparison.

# 5 Other Instruments

Besides building instruments for space missions and analyzing the data thereof, the Institute also makes its vast experience in the production of space-qualified instruments available to cooperating institutions. Furthermore, it helps with the in-flight calibration of radio antennas and improves and develops ground-based radio instrumentation. Last but not least, we use our facilities to perform exobiological laboratory experiments.

## 5.1 MMS

*Multi-Magnetometer-Sensing* (MMS) is a development activity carried out for ESA/ESTEC. It concerns the design of spacecraft with instruments for the measurement of space magnetic fields onboard. IWF started this task in 1998 and the end of the study is foreseen for early 2002.

*Fig. 5.1: S/C mock-up with coils, booms and magnetometers in the low-field chamber of IABG.*

In detail, *MMS* determines the optimal number and positioning of sensors on any spacecraft in such a way that the error in the determination of the ambient field, i.e. the space magnetic field, is minimized. Theoretical results are experimentally verified with a mock-up in a test-environment (see Fig. 5.1), and a prototype of a S/W tool for flight data analysis is developed. The methods and results of the study are implemented in a software package called POLYMAG, a stand-alone program which can be used as a design-tool for the development of spacecraft with now optimally positioned magnetometers on board.

In 2001, the theoretical results of the *MMS* study were experimentally verified using a mock-up in a test-environment and a prototype of a S/W tool for flight data analysis was developed. The mock-up consisted of coils for the magnetic dipoles and up to four magnetometers on several booms. It was designed and built together with sensor electronics and data acquisition and measurement software. The test campaign was performed in July 2001 in the test environment of IABG Ottobrunn (near Munich), which offers a near-zero ambient magnetic field. The data analysis of the tests showed a very good confirmation of the theoretical predictions.

Furthermore, a study-and-design software package was developed, containing all calculation methods and insights of the *MMS* study. Calculation and visualization software is in MATLAB, but the GUIs for data-input, selection and start of the chosen calculation-type as well as choice and performance of the visualization and documentation of the results is written in C, to allow a stand-alone program. The combination of MATLAB with a GUI in C represented a strong challenge to the programming techniques to be used, since such a combination is not yet state of the art.

However, the problems were solved in an outstanding way, resulting in a very powerful S/C design tool called POLYMAG, which is a standalone program for the development and design of spacecraft with magnetometers on board. Already in a very early stage of spacecraft design, the POLYMAG S/C design tool allows a determination of the optimal number and positions of the magnetometers, such that the ambient space magnetic field can be determined with a minimal error. With a final presentation for international audience at ESA/ESTEC in December 2001 or January 2002, as well as the delivery of the software and documentation, the *MMS* project will be completed.

# 5.2 Radio Antennas

Instruments for the observation of radio and plasma waves consist of several parts which define the signal path from the original quantities of interest to the actually recorded data. Each element in the propagation path has to be carefully calibrated so that the physical quantities can be accurately retrieved. Exact knowledge and calibration of sensors, transducers, converters and data processing devices improve observations not only from the scientific but also from the economic point of view: maximum information can be attained at minimum costs. The effort made to improve observation techniques comprises the determination of spacecraft antenna properties and the construction and use of special receivers for ground based observations.

*Rheometry:* The most important antenna quantity in analyzing received radio waves is the effective length vector which combines the effective antenna axis and the effective antenna length. It describes the antenna properties in the low-frequency range, taking into account the influence of the whole spacecraft body. Rheometry is an experimental method for the determination of the effective length vector, based on electrolytic tank measurements with a scale model. Such measurements have been performed for *Cassini* in recent years. In the year 2001 rheometry measurements for the POLRAD antennas onboard the *Interball* spacecraft have begun.

*Numerical Simulation of Antennas:* Numerical simulations of spacecraft antenna systems are more flexible than rheometry for the investigation of movable devices and changes of spacecraft parts. Therefore an antenna toolbox for the analysis of spacecraft antennas has been devised in the last years.

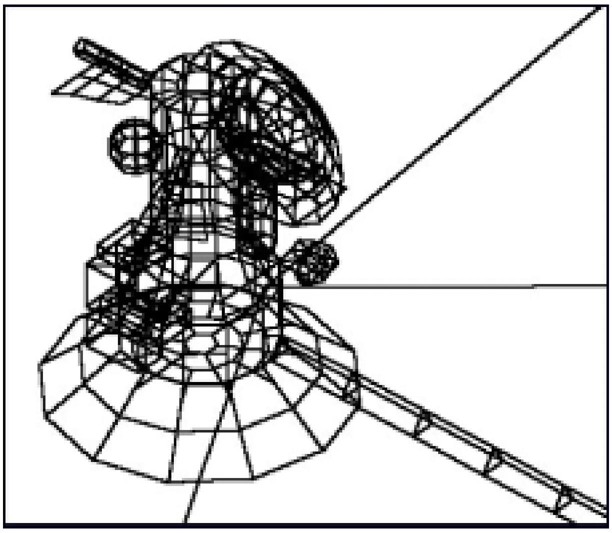


*Fig. 5.2: Cassini wire grid model for determining the reception properties of the RPWS antennas.*

In 2001 it has been extended by several new features which will be used in future research, for instance the investigation of the POLRAD antennas on *Interball*. One part of the extension consists of routines for the generation and handling of wire grid objects like shown in Fig. 5.2. As the most important part, the calculation of admittance and impedance matrices of the whole antenna system is implemented. This allows to estimate the influence of the antenna terminal zones and the receiver input impedances on the effective antenna reception properties. It is also used to implement a new concept of antenna description using transfer matrices, which is a generalization of the effective length vector concept.

Furthermore, for the antennas of the RPWS experiment onboard *Cassini*, it was shown that the magnetometer boom has an unexpectedly high influence. The results of these calculations are in good agreement with the method of rheometry (where the boom was included, but its influence not determined).

*Spectrum Analyzer:* Observations of Solar and Jovian radio emissions at the Lustbühel Radio Observatory require a new modern spectrum analyzer. A Labview software package for controlling this analyzer, including a special time-frequency analysis toolset for dynamic spectra, is being adapted and will be implemented in the near future.

# 5.3 Exobiology

First steps to establish future contributions to exobiological questions have been set in 2001. It is intended to use existing hardware (small cryo-vacuum chamber at the institute) to support exobiological experiments. For this purpose we cooperate with colleagues from the Hungarian Academy of Sciences on the Hungarian PUR (Phage and Uracil Response) exobiology project selected by ESA for flight on the International Space Station *Expose* facility.

*Fig. 5.3: Sample holder and Uracil samples inside the IWF space simulation chamber.*

The main goal of the project is to investigate and to quantify the effect of extraterrestrial solar radiation in anon-oxidative environment on nucleic acid models acting as molecules essential for life, well characterized in the laboratory and used for UV-dosimetry in terrestrial conditions. We tested the stability of phage T-7-DNA and uracil samples under vacuum conditions in the IWF space simulation chamber (Fig. 5.3). In the next stage the samples were irradiated by a high power Deuterium lamp (300 W) producing a UVC emission spectrum ($\lambda < 240$ nm) simulating the extraterrestrial solar UV radiation.

Our studies on the photoreaction of nucleotides imply that biologically harmful effects can be reduced by shorter wavelength UV radiation, which reduces also DNA damages caused by UV radiation in wavelength regions longer than 240 nm. This result may help to understand how primitive microorganisms might survive on planetary surfaces not protected by an ozone layer like on Mars or the early Earth 2.5 - 3.8 Ga ago.

# 5.4 COROT

In co-operation with the Institute for Astronomy, Vienna University, the Institute contributes to the French space telescope mission "COnvection, ROtation and Planetary Transit" (*COROT*). The scientific goal is the investigation of dynamic processes in the interior of stars and the search and survey of extrasolar planets. In both cases the variation of the brightness of stars is the key parameter. The determination of these variations is done by high precision photometry. In astroseismology, the amplitude and frequency of brightness variations is used to derive the oscillation mode and to determine the physical and chemical processes in the interior. Variations in the brightness caused by bypassing planets are used to identify extrasolar planets.

The *COROT* instrument is developed and built by an international consortium under the lead of the Observatoire de Paris, Meudon, and the

Centre National d'Etudes Spatiales. The institute develops the so-called extractor, a computer system with dedicated pre-processors for the selection and classification of image data. The pre-processors allow the identification of pixels, which are part of pre-defined image areas, up to a data rate of 200 kpixel/sec. The essential technology is hardware-supported data mining under the constraints of real-time operation. In addition to the development and assembly of the space-qualified hard- and software and the ground support equipment, the institute will participate in the integration and test campaign.

*Fig. 5.4: Artist's view of the COROT mission.*

# 6 Publications & Talks

## 6.1 Refereed Articles


Acuña, M. H., J. E. P. Connerney, P. Wasilewski, R. P. Lin, D. Mitchell, K. A. Anderson, C. W. Carlson, J. McFadden, H. Réme, C. Mazelle, D. Vignes, S. J. Bauer, P. Cloutier, N. F. Ness: Magnetic field of Mars: Summary of results from the aerobraking and mapping orbits, *J. Geophys. Res.*, **106**, 23403-23416 (2001)

Balogh, A., C. M. Carr, M. H. Acuña, M. W. Dunlop, T. J. Beek, P. Brown, K.-H. Fornaçon, E. Georgescu, K.-H. Glassmeier, J. Harris, G. Musmann, T. Oddy, K. Schwingenschuh: The Cluster Magnetic Field Investigation: overview of in-flight performance and initial results, *Ann. Geophys.*, **19**, 1207-1217 (2001)

Bauer, T. M., G. Paschmann, N. Sckopke, R. A. Treumann, W. Baumjohann, T.-D. Phan: Fluid and particle signatures of dayside reconnection, *Ann. Geophys.*, **19**, 1045-1063 (2001)

Bauer, T. M., R. A. Treumann, W. Baumjohann: Investigation of the outer and inner low-latitude boundary layers, *Ann. Geophys.*, **19**, 1065-1088 (2001)

Biernat, H. K., N. V. Erkaev, C. J. Farrugia: MHD effects in the Venus magnetosheath including mass loading, *Adv. Space Res.*, **28**, 833-839 (2001)

Boudjada, M. Y., P. H. M. Galopeau, H. O. Rucker: Jovian hectometric beam observed by PWS and WAVES experiments on board Galileo and Wind spacecraft, *Planet. Space Sci.*, **49**, 1151 (2001)

Crider, D., M. Acuña, J. Connerney, D. Mitchell, R. Lin, P. Cloutier, H. Rème, C. Mazelle, D. Brain, N. Ness, S. J. Bauer: Magnetic field draping around Mars: Mars Global Surveyor results, *Adv. Space Res.*, **27**, 1831-1836 (2001)

Croskey, C. L., J. D. Mitchell, M. Friedrich, K. M. Torkar, R. A. Goldberg: Charged particle measurements in the polar summer mesosphere obtained by the DROPPS sounding rockets, *Adv. Space Res.*, **28 (7)**, 1047-1052 (2001)

Croskey, C. L., J. D. Mitchell, M. Friedrich, K. M. Torkar, U.-P. Hoppe, R. A. Goldberg: Electrical structure of PMSE and NLC regions during the DROPPS program, *Geophys. Res. Lett.*, **28**, 1427-1430 (2001)

Czaykowska, A., T. M. Bauer, R. A. Treumann, W. Baumjohann: Magnetic field fluctuations across the Earth's bow shock, *Ann. Geophys.*, **19**, 275-287 (2001)

Erkaev, N. V., H. K. Biernat, D. F. Vogl, C. J. Farrugia: MHD modelling of the magnetosheath with anisotropic plasma pressure, *Adv. Space Res.*, **28**, 873-877 (2001)

Erkaev, N. V., V. S. Semenov, I. V. Alexeev, H. K. Biernat: Rate of steady-state reconnection in an incompressible plasma, *Physics of Plasmas*, **8**, 4800-4809 (2001)

Erkaev, N. V., V. S. Semenov, V. A. Shaidurov, D. Langmayr, H. K. Biernat, H. O. Rucker: Propagation of nonlinear slow waves produced by pressure pulses along the Io flux tube, *Adv. Space Res.*, **28**, 1481-1488 (2001)

Erkaev, N. V., W. Schaffenberger, H. K. Biernat, C. J. Farrugia, D. F. Vogl: Analysis of mirror modes convected from the bow shock to the magnetopause, *Planet. Space Sci.*, **49**, 1359-1364 (2001)

Farrugia, C. J., B. Vasquez, I. G. Richardson, R. B. Torbert, L. F. Burlaga, H. K. Biernat, S. Mühlbachler, K. W. Ogilvie R. P. Lepping, J. D. Scudder: A reconnection layer associated with a magnetic cloud, *Adv. Space Res.*, **28**, 759-764 (2001)

Farrugia, C. J., N. V. Erkaev, D. F. Vogl, H. K. Biernat: Anisotropic magnetosheath: Comparison of theory with Wind observations near the stagnation stream line, *J. Geophys. Res.*, **106**, 29,373-29,386 (2001)

Farrugia, C. J., S. Mühlbachler, H. K. Biernat, R. B. Torbert: Dayside erosion during intervals of tenuous solar wind, *J. Geophys. Res.*, **106**, 25517-25527 (2001)

Friedrich, M., K. M. Torkar: FIRI - A semiempirical model of the lower ionosphere, *J. Geophys. Res.*, **106**, 21409-21418 (2001)

Friedrich, M., R. Pilgram, K. M. Torkar: A novel concept for empirical D-region modelling, *Adv. Space Res.*, **27 (1)**, 5-12 (2001)

Gubchenko, V. M., H. K. Biernat, M. Goossens: Quasi-current-free approximation in the electrodynamics of a hot current-carrying collisionless plasma, *Radiophysics and Quantum Electronics*, **44**, 72-83 (2001)

Gubchenko, V. M., H. K. Biernat, M. Goossens: O kvasibestokovom priblizhenii v elektrodinamike goryachei tokonesushchei besstolnovitelnoi plazmy, *Radiofizika*, **44**, 77-89 (2001)

Kargl, G., W. Macher, N. I. Kömle, M. Thiel, C. Rohe, A. Ball: Accelerometry measurements using the Rosetta Lander's anchoring harpoon: Experimental set-up, data reduction and signal analysis, *Planet. Space Sci.*, **49**, 425-435 (2001)

Kivelson, M. G., K. K. Khurana, C. T. Russell, S. Joy, M. Volwerk, R. J. Walker, C. Zimmer, J. Linker: Magnetized or unmagnetized: Ambiguity persists following Galileo's encounters with Io in 1999 and 2000, *J. Geophys. Res.*, **106**, 26121-26136 (2001)

Kömle, N. I., A. J. Ball, G. Kargl, T. Keller, W. Macher, M. Thiel, J. Stöcker, C. Rohe: Impact penetrometry on a comet nucleus - interpretation of laboratory data using penetration models, *Planet. Space Sci.*, **49**, 575-598 (2001)

Kömle, N. I., G. Kargl, A. J. Ball: Determination of physical properties of planetary sub-surface layers by artificial impacts and penetrometry, *Adv. Space Res.*, **28**, 1539-1549 (2001)

Lammer, H., T. Tokano, G. Fischer, W. Stumptner, G. J. Molina-Cuberos, K. Schwingenschuh, H. O. Rucker: Lightning activity on Titan: Can Cassini detect it?, *Planet. Space Sci.*, **49**, 561-574 (2001)

Lucek, E. A., P. Cargill, M. W. Dunlop, L. M. Kistler, A. Balogh, W. Baumjohann, K.-H. Fornacon, E. Georgescu, G. Haerendel: Equator-S magnetopause crossings at high time resolution, *J. Geophys. Res.*, **106**, 25409-25418 (2001)

Lucek, E. A., P. Cargill, M. W. Dunlop, L. M. Kistler, A. Balogh, W. Baumjohann, K.-H. Fornacon, E. Georgescu, G. Haerendel: The magnetopause at ultra-high time resolution: Structure and lower-hybrid waves, *Geophys. Res. Lett.*, **28**, 681-684 (2001)

Mashhoon, B., L. Iorio, H. Lichtenegger: On the gravitomagnetic clock effect, *Phys. Lett. A*, **292**, 49-57 (2001)

Mishin, V. M., T. Saifudinova, A. Bazarzhapov, C. T. Russell, W. Baumjohann, R. Nakamura, M. Kubyshkina: Two distinct substorm onsets, *J. Geophys. Res.*, **106**, 13105-13118 (2001)

Molina-Cuberos, G. J., H. Lammer, W. Stumptner, K. Schwingenschuh, H. O. Rucker, J. J. Lopez-Moreno, R. Rodrigo, T. Tokano: Ionospheric layer induced by meteoritic ionization in Titan's atmosphere, *Planet. Space Sci.*, **49**, 143-153 (2001)

Molina-Cuberos, G. J., J. J. López-Moreno, R. Rodrigo, H. Lichtenegger, K. Schwingenschuh: A model of the Martian ionosphere below 70 km, *Adv. Space Res.*, **27**, 1801-1806 (2001)

Molina-Cuberos, G. J., J. J. Lopez-Moreno, R. Rodrigo, K. Schwingenschuh: Capability of Cassini/Huygens PWA-HASI to measure electrical conductivity at Titan, *Adv. Space Res.*, **28**, 1511-1516 (2001)

Nakamura, R., W. Baumjohann, M. Brittnacher, V. A. Sergeev, M. Kubyshkina, T. Mukai, K. Liou: Flow bursts and auroral activations: Onset timing and footpoint location, *J. Geophys. Res.*, **106**, 10777-10790 (2001)

Nakamura, R., W. Baumjohann, R. Schödel, M. Brittnacher, V. A. Sergeev, M. Kubyshkina, T. Mukai, K. Liou: Earthward flow bursts, auroral streamers and small expansions, *J. Geophys. Res.*, **106**, 10791-10801 (2001)

Neagu, E., S. P. Gary, J. E. Borovsky, W. Baumjohann, R. A. Treumann: Constraints on magnetic fluctuation energies in the plasma sheet, *Geophys. Res. Lett.*, **28**, 919-921 (2001)

Neudegg, D., S. W. H. Cowley, K. A. McWilliams, M. Lester, T. K. Yeoman, J. Sigwarth, G. Haerendel, W. Baumjohann, U. Auster, K.-H. Fornacon, E. Georgescu: The UV aurora and ionospheric flows during flux transfer events, *Ann. Geophys.*, **19**, 179-188 (2001)

Noda, H., T. Terasawa, Y. Saito, H. Hayakawa, A. Matsuoka, T. Mukai: Observation of the interstellar helium cone by the NOZOMI spacecraft, *Space Sci. Rev.*, 97, 423-426 (2001)

Paschmann, G., J. M. Quinn, R. B. Torbert, H. Vaith, C. E. McIlwain, G. Haerendel, O. H. Bauer, T. Bauer, W. Baumjohann, W. Fillius, M. Förster, S. Frey, E. Georgescu, S. S. Kerr, C. A. Kletzing, H. Matsui, P. Puhl-Quinn, E. C. Whipple: The Electron Drift Instrument on Cluster: overview of first results, *Ann. Geophys.*, 19, 1273-1288 (2001)

Petrukovich, A. A., W. Baumjohann, R. Nakamura, R. Schödel, T. Mukai: Are earthward bursty bulk flows convective of field-aligned, *J. Geophys. Res.*, 106, 21211-21216 (2001)

Phan, T. D., M. P. Freeman, L. M. Kistler, B. Klecker, G. Haerendel, G. Paschmann, B. U. Ö. Sonnerup, W. Baumjohann, M. B. Bavassano-Cattaneo, C. W. Carlson, A. M. DiLellis, K.-H. Fornacon, L. A. Frank, M. Fujimoto, E. Georgescu, S. Kokubun, E. Moebius, T. Mukai, W. R. Paterson, H. Reme: Evidence for an extended reconnection line at the dayside magnetopause, *Earth Planets Space*, 53, 619-625 (2001)

Pudovkin, M. I., B. P. Besser, S. A. Zaitseva, V. V. Lebedeva, C.-V. Meister: Magnetic barrier in case of a southward interplanetary magnetic field, *J. Atmos. Solar-Terr. Phys.*, 63, 1075-1083 (2001)

Quinn, J. M., G. Paschmann, R. B. Torbert, H. Vaith, C. E. McIlwain, G. Haerendel, O. Bauer, T. M. Bauer, W. Baumjohann, W. Fillius, M. Foerster, S. Frey, E. Georgescu, S. S. Kerr, C. A. Kletzing, H. Matsui, P. Puhl-Quinn, E. C. Whipple: Cluster EDI convection measurements across the high-latitude plasma sheet boundary at midnight, *Ann. Geophys.*, 19, 1669-1681 (2001)

Richter, I., E. Brinza, M. Cassel, K.-H. Glassmeier, F. Kuhnke, G. Musmann, C. Othmer, K. Schwingenschuh, B. T. Tsurutani: First Direct Magnetic Field Measurements of an Asteroidal Magnetic Field: DS1 at Braille, *Geophys. Res. Lett.*, 28, 1913-1916 (2001)

Rucker, H. O., M. Y. Boudjada, A. Lecacheux, M. Leitner, A. Konovalenko, P. H. M. Galopeau, V. Shaposhnikov, M. Aubier: Developments in Jovian radio emissions tomography and observations techniques, *Astrophys. Space Sci.*, 277, 325-328 (2001)

Schödel, R., W. Baumjohann, R. Nakamura, T. Mukai: Rapid flux transport and plasma sheet reconfiguration, *J. Geophys. Res.*, 106, 8381-8390 (2001)

Schödel, R., W. Baumjohann, R. Nakamura, V. A. Sergeev, T. Mukai: Rapid flux transport in the central plasma sheet, *J. Geophys. Res.*, 106, 301-314 (2001)

Schwingenschuh, K., G. J. Molina-Cuberos, H. U. Eichelberger, K. Torkar, M. Friedrich, R. Grard, P. Falkner, J. J. Lopez-Moreno, R. Rodrigo: Propagation of electromagnetic waves in the lower ionosphere of Titan, *Adv. Space Res.*, 28, 1505-1510 (2001)

Sergeev, V. A., M. Kubyshkina, K. Liou, P. Newell, G. Parks, R. Nakamura, T. Mukai: Substorm and convection bay compared: Auroral and magnetotail dynamics during convection bay, *J. Geophys. Res.*, 106, 18843-18855 (2001)

Sergeev, V. A., W. Baumjohann, G. Paschmann, K. Shiokawa: Bi-directional electron distributions associated with near-tail flux transport, *Geophys. Res. Lett.*, 28, 3813-3816 (2001)

Shaposhnikov, V. E., V. V. Zaitsev, H. O. Rucker, G. V. Litvinenko: Origin of ultraviolet emission source in the Jovian ionosphere at the feet of the Io flux tube, *J. Geophys. Res.*, 106, 26049 (2001)

Shi, J. K., K. Schwingenschuh, T. L. Zhang, K. Torkar, H. Lichtenegger, Z. X. Liu, W. Riedler, R. Schmidt, C. P. Escoubet: Theoretical distribution of $O^+$ ions in the Martian magnetosphere, *Adv. Space Res.*, 28, 891-896 (2001)

Shi, J. K., Z. X. Liu, T. L. Zhang: The $O^+$ ions flux in the Martian magnetosphere and Martian intrinsic moment, *Chin. J. Astron. Astrophys*, 1, 185-189 (2001)

Skorov, Yu. V., N. I. Kömle, H. U. Keller, G. Kargl, W. J. Markiewicz: A model of heat and mass transfer in a porous cometary nucleus based on a kinetic treatment of mass flow, *Icarus*, 153, 180-196 (2001)

Spohn, T., A. J. Ball, K. Seiferlin, V. Conzelmann, A. Hagermann, N. I. Kömle, G. Kargl: A heat flow and physical properties package for the surface of Mercury, *Planet. Space Sci.*, 49, 1571-1577 (2001)

Szita, S., A. N. Fazakerley, P. J. Carter, A. M. James, P. Trávnícek, G. Watson, M. André, A. Eriksson, K. Torkar: Cluster PEACE observations of electrons of spacecraft origin, *Ann. Geophys.*, **19**, 1721-1730 (2001)

Tokano, T., G. J. Molina-Cuberos, H. Lammer, W. Stumptner: Modelling of thunderclouds and lightning generation on Titan, *Planet. Space Sci.*, **49**, 539-560 (2001)

Torkar, K., W. Riedler, C. P. Escoubet, M. Fehringer, R. Schmidt, R. J. L. Grard, H. Arends, F. Rüdenauer, W. Steiger, B. T. Narheim, K. Svenes, R. Torbert, M. André, A. Fazakerley, R. Goldstein, R. C. Olsen, A. Pedersen, E. Whipple, H. Zhao: Active spacecraft potential control for Cluster - implementation and first results, *Ann. Geophys.*, **19**, 1289-1302 (2001)

Vaivads, A., W. Baumjohann, E. Georgescu, G. Haerendel, R. Nakamura, M. R. Lessard, P. Eglitis, L. M. Kistler, R. E. Ergun: Correlation studies of compressional Pc5 type pulsations in space and Ps6 pulsations on the ground, *J. Geophys. Res.*, **106**, 29797-29806 (2001)

Vaivads, A., W. Baumjohann, G. Haerendel, R. Nakamura, H. Kucharek, B. Klecker, M. R. Lessard, L. M. Kistler, T. Mukai, A. Nishida: Compressional Pc5 type pulsations in the morningside plasma sheet, *Ann. Geophys.*, **19**, 311-320 (2001)

Verigin, M. I., G. A. Kotova, A. P. Remizov, K. Szego, M. Tatrallyay, J. Slavin, H. Rosenbauer, S. Livi, W. Riedler, K. Schwingenschuh, T. L. Zhang: Evidence of the influence of equatorial Martian crustal magnetization on the position of the planetary magnetotail boundary by phobos 2 data, *Adv. Space Res.*, **28**, 885-889 (2001)

Vogl, D. F., H. K. Biernat, N. V. Erkaev, C. J. Farrugia, S. Mühlbachler: Jump conditions for pressure anisotropy and comparison with the Earth's bow shock, *Nonlin. Proc. Geophys.*, **8**, 167-174 (2001)

Vogl, D. F., N. V. Erkaev, H. K. Biernat, S. Mühlbachler, C. J. Farrugia: Jump conditions at fast shocks for an anisotropic plasma, *Adv. Space Res.*, **28**, 851-856 (2001)

Volwerk, M., M. G. Kivelson, K. K. Khurana: Wave activity in Europa's wake: Implications for ion pick-up, *J. Geophys. Res.*, **106**, 26033-26048 (2001)

# 6.2 Proceedings and Book Chapters

Arends, H., J. Gavira, J. Romstedt, B. Butler, K. Torkar, G. Fremuth, H. Jeszenszky, G. Coe, M. Yorck: The MIDAS experiment for the Rosetta mission, *ESA SP*-480, 67-74 (2001)

Auster, H-U., W. Magnes: Comparison of magnetic field measurement techniques on Earth, Mars, Mercury and Comet P/ Wirtanen. In: *Contributions to Geophysics and Geodesy 2001 Volume 31*, Eds. A. Prigancová, Z. Vörös, Slovak Academy of Sciences, Bratislava, 59-66 (2001)

Bauer, S. J.: Die Planetenatmosphären. In: *Erde und Planeten*, Ed. W. Raith, Walter de Gruyter, Berlin, 605-666 (2001)

Baumjohann, W., R. Nakamura: Updating the near-Earth neutral line model, *arXiv:physics*, **0111145**, 1-10 (2001)

Baumjohann, W.: Tagungsnachlese DGG-Tagung Hamburg: Extraterrestrische Physik, *Phys. Blätter*, **57**, 103 (2001)

Besser, B. P.: Friedrich Schmiedl - seine Raketenversuche. In: *Tagungsband, 30 Jahre Hermann-Oberth-Raumfahrtmuseum, Raumfahrtgeschichte V*, Ed. Hermann-Oberth-Raumfahrtmuseum e.V., Eigenverlag, Feucht, 65-70 (2001)

Bondarenko, V. G., V. M. Gubchenko, M. L. Khodachenko, V. E. Semenov: On Properties of the System Formed by a Hypersonic Body with Internal Degrees of Freedom and Weakly Ionized Gas. In: *Proceedings of the 2nd International Workshop on Magnetoplasma Aerodynamics in Aerospace Applications*, Ed. V. Bityurin, Russian Academy of Sciences, Moscow, 331-317 (2001)

Boudjada, M. Y., M. Aubier, P. H. M. Galopeau, H. O. Rucker, M. L. Kaiser, A. Lecacheux, P. Moreau: Ground and space observations of Jovian decametric emissions in the frequency band from 1 MHz to 40 MHz. In: *Planetary Radio Emissions V*, Eds. H. O. Rucker, M. L. Kaiser, Y. Leblanc, Austrian Academy of Sciences Press, Vienna, 173-178 (2001)

Boudjada, M. Y., P. H. M. Galopeau, H. O. Rucker, A. Lecacheux: Temporal evolution steps of Jovian narrow-band emissions. In: *Planetary Radio*

*Emissions V*, Eds. H. O. Rucker, M. L. Kaiser, Y. Leblanc, Austrian Academy of Sciences Press, Vienna, 187-194 (2001)

Boudjada, M. Y., P. H. M. Galopeau, H. O. Rucker: Spectral features of Jovian hectometric emission observed by Galileo and Wind spacecraft. In: *Planetary Radio Emissions V*, Eds. H. O. Rucker, M. L. Kaiser, Y. Leblanc, Austrian Academy of Sciences Press, Vienna, 147-154 (2001)

Boudjada, M. Y., V. N. Kuril'chik, H. O. Rucker, D. F. Vogl, E. Kaufmann: Spectral features in auroral kilometric radiation. In: *Planetary Radio Emissions V*, Eds. H. O. Rucker, M. L. Kaiser, Y. Leblanc, Austrian Academy of Sciences Press, Vienna, 289-294 (2001)

Erkaev, N. V., V. S. Semenov, V. A. Shaidurov, D. Langmayr, H. K. Biernat, H. O. Rucker: Effects of MHD slow shocks propagating along the Io flux tube. In: *Planetary Radio Emissions V*, Eds. H. O. Rucker, M. L. Kaiser, Y. Leblanc, Austrian Academy of Sciences Press, Vienna, 389-394 (2001)

Fischer, G., W. Macher, H. O. Rucker, H. P. Ladreiter, D. F. Vogl and the Cassini/RPWS Team: Wire-grid modeling of Cassini spacecraft for the determination of effective antenna length vectors of the RPWS antennas. In: *Planetary Radio Emissions V*, Eds. H. O. Rucker, M. L. Kaiser, Y. Leblanc, Austrian Academy of Sciences Press, Vienna, 347-356 (2001)

Friedrich, M., K. Torkar: Long-term trends and other residual features of the lower ionosphere, *ESA SP*-471, 357-362 (2001)

Galopeau, P. H., M. Y. Boudjada, H. O. Rucker: Efficiency of the cyclotron maser instability and occurrence probability of Jovian decameter radio emissions. In: *Planetary Radio Emissions V*, Eds. H. O. Rucker, M. L. Kaiser, Y. Leblanc, Austrian Academy of Sciences Press, Vienna, 195-204 (2001)

Gubchenko, V. M., V. V. Zaitsev, H. K. Biernat, H. O. Rucker: 3D coronal structures formation in a kinetic approach: Transients and rays. In: *Planetary Radio Emissions V*, Eds. H. O. Rucker, M. L. Kaiser, Y. Leblanc, Austrian Academy of Sciences Press, Vienna, 495-512 (2001)

Kargl, G., N. I. Kömle, T. Keller, H. Lammer, W. Stumptner: Influence of organic molecules on ice properties on solar system bodies. In: *Proc. First European Workshop on Exo-/Astrobiology,* Eds. P. Ehrenfreund, O. Angerer, B. Battrick, ESA Publications Division, Noordwijk, ESA SP-496, 353-356 (2001)

Kargl, G., T. Keller, N. I. Kömle: Interpretation of penetrometry experiments. In: *Penetrometry in the Solar System*, Eds. N. I. Kömle, G. Kargl, A. J. Ball, R. D. Lorenz, Austrian Academy of Sciences Press, Vienna, 151-160 (2001)

Kaufmann, E., D. F. Vogl, H. O. Rucker, H. K. Biernat, M. Y. Boudjada, S. Mühlbachler, D. Langmayr: Geomagnetic latitudes and longitudes of source locations of planetary radio emissions: Theoretical approach and spacecraft observations. In: *Planetary Radio Emissions V*, Eds. H. O. Rucker, M. L. Kaiser, Y. Leblanc, Austrian Academy of Sciences Press, Vienna, 317-324 (2001)

Khodachenko, M. L., D. Langmayr, H. O. Rucker: On the structure of electromagnetic field generated by a moving external current source in a magnetized plasma. In: *Planetary Radio Emissions V*, Eds. H. O. Rucker, M. L. Kaiser, Y. Leblanc, Austrian Academy of Sciences Press, Vienna, 367-374 (2001)

Khodachenko, M. L., D. Langmayr, H. O. Rucker, V. M. Gubchenko: Electromagnetic environment produced by a moving conducting body in a magnetized collisionless plasma. In: *Planetary Radio Emissions V*, Eds. H. O. Rucker, M. L. Kaiser, Y. Leblanc, Austrian Academy of Sciences Press, Vienna, 381-388 (2001)

Konovalenko, A. A., A. Lecacheux, C. Rosolen, H. O. Rucker: New Instrumentations and Methods for the Low Frequency Planetary Radio Astronomy. In: *Planetary Radio Emissions V*, Eds. H. O. Rucker, M. L. Kaiser, Y. Leblanc, Austrian Academy of Sciences Press, Vienna, 63-76 (2001)

Kuril'chik, V. N., M. Y. Boudjada, H. O. Rucker: Interball-1 observations of the plasmaspheric emissions, related to terrestrial "continuum" radio emissions. In: *Planetary Radio Emissions V*, Eds. H. O. Rucker, M. L. Kaiser, Y. Leblanc, Austrian Academy of Sciences Press, Vienna, 325-336 (2001)

Kuril'chik, V. N., M. Y. Boudjada, H. O. Rucker: Observations of the subauroral non-thermal radio emission (SANE) in 1995-1998. In: *Planetary Radio Emissions V*, Eds. H. O. Rucker, M. L. Kaiser, Y. Leblanc, Austrian Academy of Sciences Press, Vienna, 337-346 (2001)

Lammer, H., G. J. Molina-Cuberos, W. Stumptner, G. Kargl, F. Selsis, T. Kerékgyártó, A. Bérces: Exposure of the ancient Martian surface to extraterrestrial radiation and its implication for molecules essential for life. In: *First European Workshop for Exo-/Astro-Biology*, Eds. Ehrenfreund P., O. Angerer, B. Battrick, ESA Publications Division, Noordwijk, ESA SP-496, 363-366 (2001)

Lammer, H., T. Tokano, G. Fischer, G. J. Molina-Cuberos, W. Stumptner, K. Schwingenschuh, H. O. Rucker: Detection capability of Cassini for thundercloud generated lightning discharges on Titan. In: *Planetary Radio Emission V*, Eds. H. O. Rucker, M. L. Kaiser, Y. Leblanc, Austrian Academy of Sciences Press, Vienna, 261-270 (2001)

Lammer, H., T. Tokano, G. J. Molina-Cuberos, W. Stumptner, G. Fischer: Titan lightning: an energy source for biochemistry. In: *First European Workshop for Exo-/Astro-Biology*, Eds. Ehrenfreund, P., O. Angerer, B. Battrick, ESA Publications Division, Noordwijk, ESA SP-496, 155-158 (2001)

Lammer, H., W. Stumptner, G. J. Molina-Cuberos: Martian atmospheric evolution: implications of an ancient intrinsic magnetic field. In: *Astrobiology: The Quest for the Conditions of Life*, Eds. G. Horneck, C. Baumstark-Khan, Springer, Berlin, 203-216 (2001)

Langmayr, D., N. V. Erkaev, V. S. Semenov, V. A. Shaidurov, H. K. Biernat, H. O. Rucker, D. F. Vogl, S. Mühlbachler: Field-aligned electric field in the Io flux tube as a result of a pressure pulse near Io. In: *Planetary Radio Emissions V*, Eds. H. O. Rucker, M. L. Kaiser, Y. Leblanc, Austrian Academy of Sciences Press, Vienna, 375-380 (2001)

Leitner, M., H. O. Rucker: Waveform analysis techniques of Jovian S-burst observations. In: *Planetary Radio Emissions V*, Eds. H. O. Rucker, M. L. Kaiser, Y. Leblanc, Austrian Academy of Sciences Press, Vienna, 91-96 (2001)

Lichtenegger, H.: Raumzeit. In: *Zeitzauber*, Eds. W. R. Baier, F. M. Wuketits, dbv, Graz, 120-134 (2001)

Litvinenko, G. V., H. O. Rucker, V. V. Vinogradov, B. P. Ryabov, V. E. Shaposhnikov: Some results of the Jovian DAM emission investigation with wavelet analysis technique. In: *Planetary Radio Emissions V*, Eds. H. O. Rucker, M. L. Kaiser, Y. Leblanc, Austrian Academy of Sciences Press, Vienna, 113-118 (2001)

Magnes, W., H-U. Auster: Comparison of two digital flux-gate magnetometers developed for space application. In: *Contributions to Geophysics and Geodesy 2001 Volume 31*, Eds. A. Prigancová, Z. Vörös, Slovak Academy of Sciences, Bratislava, 67-74 (2001)

Mann, G., H. O. Rucker, J.-L. Bougeret: Scientific objectives of the radiospectrometer aboard Solar Orbiter. In: *Solar Encounter*, Eds. B. Battrick, H. Sawaya-Lacoste, ESA Publications Division, Noordwijk, ESA SP-493, 289-292 (2001)

Mashhoon, B., F. Gronwald, H. Lichtenegger: Gravitomagnetism and the clock effect. In: *Gyros, Clocks, Interferometers...: Testing Relativistic Gravity in Space*, Eds. C. Lämmerzahl, C. W. F. Everitt, F. W. Hehl, Springer, Berlin, 83-108 (2001)

Rothacher, M., D. Svehla, K. Arsov, W. Hausleitner, E. Höck, R. Pail: Effect of temporal variations on high-low SST observations. In: *From Eötvös to Milligal+, ESA Midterm Report*, Ed. H. Sünkel, Graz University of Technology, Theoretical Geodesy, Graz, 171-219 (2001)

Rucker, H. O., A. Lecacheux, A. A. Konovalenko, M. Leitner: New frontiers in decameter radio astronomy. In: *Planetary Radio Emissions V*, Eds. H. O. Rucker, M. L. Kaiser, Y. Leblanc, Austrian Academy of Sciences Press, Vienna, 51-62 (2001)

Rucker, H. O., W. Macher, G. Fischer, M. Boudjada, G. Mann: Antenna System considerations for Solar Orbiter. In: *Solar Encounter*, Eds. B. Battrick, H. Sawaya-Lacoste, ESA Publications Division, Noordwijk, ESA SP-493, 347-351 (2001)

Rucker, H. O.: Planetenmagnetosphären. In: *Bergmann-Schaefer, Lehrbuch der Experimentalphysik, Band 7, Erde und Planeten, 2nd revised edition*, Ed. W. Raith, Walter de Gruyter, Berlin, 527-604 (2001)

Rummel, R., P. Visser, R. Klees, H. Sünkel: GOCE-semi-analytical gravity modelling validation and quick-look analysis. In: *GOCE: Preparation of the GOCE level 1 to level 2 data processing, ESA Midterm Report*, Ed. H. Sünkel, Graz University of Technology, Theoretical Geodesy, Graz, 82-93 (2001)

Shaposhnikov, V. E., V. V. Zaitsev, H. O. Rucker, G. Litvinenko: Interaction of Io's ionosphere with the Jovian magnetic field: Is this a reason of depression in the background magnetic field recorded by Galileo? In: *Planetary Radio Emissions V*, Eds. H. O. Rucker, M. L. Kaiser, Y. Leblanc, Austrian Academy of Sciences Press, Vienna, 141-146 (2001)

Sünkel, H.: The Gravity Field Mission GOCE of ESA – Science and Application. In: *Proceedings of the International Workshop on Perspectives of Geodesy in South-East Europe*, Eds. H. Moritz, D. Medak, B. Pribicevic, Mitteilungen der geodätischen Institute der TU-Graz, Graz, 3-8 (2001)

Thiel, M., J. Stöcker, C. Rohe, O. Hillenmaier, N. I. Kömle, G. Kargl: The Rosetta Lander anchoring harpoon: subsystem and scientific instrument. In: *Penetrometry in the Solar System*, Eds. N. I. Kömle, et al., Austrian Academy of Sciences Press, Vienna, 137-149 (2001)

Torkar, K., W. Riedler, M. Fehringer, C. P. Escoubet, K. Svenes, B.T. Narheim, A. Fazakerley, S. Szita, M. André: Effects of active spacecraft potential control on Cluster plasma observations – first results, *ESA SP*–476, 255-260 (2001)

Vogl, D. F., H. P. Ladreiter, P. Zarka, H. O. Rucker, W. Macher, W. S. Kurth, D. A. Gurnett, G. Fischer: First results on the calibration of the Cassini RPWS antenna system. In: *Planetary Radio Emissions V*, Eds. H. O. Rucker, M. L. Kaiser, Y. Leblanc, Austrian Academy of Sciences Press, Vienna, 357-366 (2001)

Zhang, T. L., H. Zhao, J. K. Shi: Solar wind interaction with Venus and Mars. In: *Advances in Space Physics III*, Ed. Scientific Publisher, Scientific Publisher, Beijing, 245-286 (2001)

# 6.3 Books

Kömle, N. I., G. Kargl, A. J. Ball, R. D. Lorenz (Eds.): Penetrometry in the Solar System, Austrian Academy of Sciences Press, Vienna, 282 pages (2001)

Rucker, H. O., M. L. Kaiser, Y. Leblanc (Eds.): Planetary Radio Emissions V, Austrian Academy of Sciences Press, Vienna, 552 pages (2001)

Treumann, R. A., W. Baumjohann: Advanced Space Plasma Physics (Revised Edition), Imperial College Press, London, 381 pages (2001)

# 6.4 Other Publications

Allner, A., W. Baumjohann, P. W. Daly, G. Leistner, R. Nakamura: German Cluster Science Data Center, 32 pages (2001)

Aydogar, Ö., G. Musmann: RPC – MAG, GSE User Manual, IWF 2001/PD01, 22 pages (2001)

Besser, B. P.: Contributions of Austrian Pioneers to Early European Rocketry, AIAA Technical Paper 2001-0174, 9 pages (2001)

Delva, M., H. Feldhofer, K. Schwingenschuh: MMS – Technical Report, Phase I, MMS-IWF-TR-001/003, 145 pages (2001)

Delva, M., H. Feldhofer, K. Schwingenschuh: MMS Technical Report, Phase II, MMS-IWF-TR-004/007, 132 pages (2001)

Eichelberger, H., H. Feldhofer, K. Schwingenschuh, H. Schwarzl, A. Scherr, D. Stock, W. Magnes, K. Mocnik, O. Aydogar, T. L. Zhang, G. Berghofer, W. Koren, M. Stachel, I. Jernej, W. Baumjohann: Cluster-II FGM Compensation Filter According to the Digital Frequency Analysis, IWF 2001/01, 11 pages (2001)

Fischer, G., H. O. Rucker, V. Mostetschnig: How to work with the Multichannel System, IWF 113, 11 pages (2001)

Kolb, C., F. Bernhard, A. Popitsch, K. Wewerka, W. Gössler, H. Lammer: Mineralogy of Mars Soil Analogue material, IWF-137, 50 pages (2001)

Lammer, H., C. Kolb: Release processes of exospheric particles from Mercury's surface, IWF-136, 20 pages (2001)

Lammer, H., G. Ronto, T. Kerékgyátó, A. Bercés, S. Gáspár, A. Fekete, N. I. Kömle, G. Kargl, A. Hickel: Experiment verification tests for the PUR biological experiment on the EXPOSE facility of the International Space Station ISS, IWF 135, 29 pages (2001)

Lichtenegger, H.: On the magnetic and gravitomagnetic clock effect, IWF 2001/03, 14 pages (2001)

Magnes, W., H-U. Auster, G. Berghofer, K-H. Fornacon, I. Richter, K. Schwingenschuh: ROMAP, FM-2 calibration, IWF 2001/04, 14 pages (2001)

Musmann, G., H. Feldhofer, M. Delva et al.: Magnetic Design and Analysis Tool - MAGLAB, Proposal to ESTEC/ESA, IGAM-IWF-001, 42 pages (2001)

Schmieder, B., S. Basu, W. Baumjohann, J. Lean, T. Ono, R. Vincent, M. Geller, J. Allen: Climate and Weather of the Sun-Earth System: CAWSES, 32 pages (2001)

Spence, H., T. Moore, M. DiJoseph, R. Buchanan, B. Anderson, V. Angelopoulos, W. Baumjohann, J. Borovsky, R. Carovillano, P. Craven, J. Fennel, C. Goodrich, M. Hesse, X. Li, K. Lynch, P. Panetta, J. Raeder, G. Reeves, D. Sibeck, G. Siscoe, N. Tsyganenko, R. Vondrak, J. Slavin, J. Spann: Magnetospheric Constellation Mission DRACO, NASA/TM-2001-209985, 43 pages (2001)

Valavanoglou, A., W. Magnes, K. Mocnik, K. Schwingenschuh, W. Baumjohann: Fluxgate Sensor ARES_1, IWF 2001/02, 49 pages (2001)

Vogl, D. F., E. Kaufmann, H. O. Rucker, H. K. Biernat, M. Y. Boudjada, S. Mühlbachler, D. Langmayr: A mathematical approach to determine source locations of planetary radio emissions, IWF 124, 22 pages (2001)

Vogl, D. F., H. K. Biernat, N. V. Erkaev, C. J. Farrugia, M. T. Kiendl, S. Mühlbachler, D. Langmayr: The jumps of physical quantities at fast shocks under pressure anisotropy: Theory versus observations at the bow shock, IWF 123, 191 pages (2001)

Vogl, D. F., H. P. Ladreiter, P. Zarka, B. Cecconi, W. S. Kurth, W. Macher, H. O. Rucker, G. Fischer: Calibration of the Cassini RPWS antenna system: Roll maneuver on DOY 320, 2000, IWF 126, 185 pages (2001)

Vogl, D. F., H. P. Ladreiter, P. Zarka, B. Cecconi, W. S. Kurth, W. Macher, H. O. Rucker, G. Fischer: Calibration of the Cassini RPWS antenna system: Roll maneuver on DOY 325, 2000, IWF 127, 185 pages (2001)

Vogl, D. F., H. P. Ladreiter, P. Zarka, B. Cecconi, W. S. Kurth, W. Macher, H. O. Rucker, G. Fischer: Calibration of the Cassini RPWS antenna system: Roll maneuver on DOY 330, 2000, IWF 128, 185 pages (2001)

Vogl, D. F., H. P. Ladreiter, P. Zarka, B. Cecconi, W. S. Kurth, W. Macher, H. O. Rucker, G. Fischer: Calibration of the Cassini RPWS antenna system: Roll maneuver on DOY 335, 2000, IWF 129, 185 pages (2001)

Vogl, D. F., H. P. Ladreiter, P. Zarka, B. Cecconi, W. S. Kurth, W. Macher, H. O. Rucker, G. Fischer: Calibration of the Cassini RPWS antenna system: Roll maneuver on DOY 340, 2000, IWF 130, 185 pages (2001)

## 6.5 Proposals

Angelopoulos, V., C. W. Carlson, G. T. Delory, R. P. Lin, S. Mende, F. S. Mozer, G. K. Parks, T. D. Phan, M. A. Temerin, K. K. Khurana, M. G. Kivelson, J. Raeder, C. T. Russell, R. E. Ergun, X. Li, A. T. Y. Lui, D. Sibeck, U. Auster, K.-H. Glaßmeier, W. Baumjohann, R. Nakamura, K. Schwingenschuh, J. Büchner, O. LeContel, A. Roux, E. Donovan, O. Escoubet, H. Laakso, M. Fujimoto, C. J. Jacquey, D. LeQueau, J. Samson, I. Voronkov, V. Sergeev, H. J. Singer: THEMIS: Time History of Events and Macroscale Interactions during Substorms, Proposal to NASA, 45 pages (2001)

Baumjohann, W., R. Nakamura, W. Magnes, U. Auster, K.-H. Glaßmeier, A. Balogh: MERMAG-M: Magnetometer for the Magnetospheric Orbiter of the BepiColombo Mission to Mercury, Proposal to ESA/ISAS, 5 pages (2001)

Ergun, R., L. Andersson, Y.-J. Su, D. N. Baker, X. Li, S. Elkington, J. P. McFadden, D. E. Larson, T. Phan, C. W. Carlson, V. Angelopoulos, S. D. Bale, J. Bonnell, C. T. Russell, R. J. Strangeway, J. Raeder, P. A. Bernhardt, J.-L. H. Bougert, R. E. Manning, S. A. Fuselier, U. S. Inan, T. Bell, D. G. Sibeck, R. Nakamura, G. E. Paschmann, H. Matsumoto, W. K. Peterson, H. G. James, B. Gustavsson, M. McGrath, J. Westfall, R. Davis: MAGnetospheric Constellation and Tomography (MAGCaT), Proposal to NASA, 48 pages (2001)

Lammer, H.: Hydrogen and oxygen loss from Mars: implications for the planetary water inventory (MarsExpress RCL), Proposal to ESA, 53 pages (2001)

## 6.6 Oral Presentations

Baumjohann, W., et al.: The MERMAG-M Magnetometer (Invited), *BepiColombo Science Workshop*, Tokyo, Sep 2001.

Baumjohann, W.: Aktivitäten am IWF Graz (Invited), *Ringberg 2001*, Tegernsee, Feb 2001.

Baumjohann, W.: Cluster-Datenauswertung am IWF (Invited), *Deutsches Cluster-Meeting*, Katlenburg-Lindau, Nov 2001.

Baumjohann, W.: Das deutsche Cluster-Datenzentrum (Invited), *Deutsches Cluster-Meeting*, Katlenburg-Lindau, Nov 2001.

Baumjohann, W.: Gegenwart und Zukunft der russisch-österreichischen Zusammenarbeit in der Weltraumforschung (Invited), *40 Jahre Juri Gagarin Symposium*, Vienna, Apr 2001.

Baumjohann, W.: Modes of Transport in Geospace (Invited), *AGU Fall Meeting*, San Francisco, Dec 2001.

Besser, B. P.: Contributions of Austrian Pioneers to Early European Rocketry, *39th AIAA Aerospace Sciences Meeting*, Reno, Jan 2001.

Besser, B. P.: Friedrich Schmiedl – seine Raketenversuche, *5. Tag der Raumfahrtgeschichte*, Feucht, Jun 2001.

Biernat, H. K., et al.: Some signatures of magnetic field line reconnection, *Atmospheric and Ocean Optics VIII*, Irkutsk, Jun 2001.

Biernat, H. K.: Magnetic field line reconnection: Theory and Observations, Institute of Computational Modelling, Krasnoyarsk, Jul 2001.

Feldhofer, H., et al.: MMS Final Presentation, ESTEC/ESA, Noordwijk, Dec 2001.

Fischer, G., et al.: Wire-grid modeling of Cassini spacecraft for the determination of effective antenna length vectors of the RPWS antennas, *EGS General Assembly*, Nice, Apr 2001.

Khodachenko, M.: Electromagnetic Environment Produced by a Moving Conducting Body in a Magnetized Collisionless Plasma, *Planetary and Radio Emissions V*, Graz, Apr 2001.

Khodachenko, M.: Inductive electromagnetic effects in groups of solar current-carrying magnetic loops, Paul-Scherrer-Institute, Villingen, Sep 2001.

Khodachenko, M.: MHD reaction of a flaring magnetic tube disturbed by beams of fast particles. Possible relation to plasma heating during solar flares, Institute of Astronomy, ETH Zurich, Sep 2001.

Lammer, H., et al.: Neutral atom flux conditions during the Planet-B and Mars Express missions, *EGS General Assembly*, Nice, Mar 2001.

Lammer, H., et al.: Titan lightning: an energy source for biochemistry, *First European workshop on Exo-/Astro-Biology*, Frascati, May 2001.

Lammer, H., et al.: Was the ancient Martian Surface sterilized by radiation?, *Second Granada Workshop*, Granada, Jun 2001.

Lammer, H.: Die Exosphäre des Planeten Merkur (Invited), *NPA/MAIA Arbeitstreffen*, Bern, May 2001.

Lammer, H.: Evolution of the Martian water inventory, Physics Department, University of Aarhus, Nov 2001.

Lammer, H.: Loss of hydrogen and oxygen from Mars, Institut für Raumsimulation, DLR, Cologne, Nov 2001.

Lammer, H.: Particle ejection processes from Mercury's surface (Invited), *BepiColombo/MPO NPA-Proposal Kick-off Meeting*, Venice, Oct 2001.

Lammer, H.: The evolution of the Martian atmosphere, Instituto de Astrofísica de Andalucía, Granada, Dec 2001.

Langmayr, D., et al.: Generation of an electric potential difference due to MHD slow shocks propagating along the Io flux tube, *Atmospheric and Ocean Optics VIII*, Irkutsk, Jun 2001.

Langmayr, D.: Mathematical aspects of slow shocks in the Jupiter Io system, Institute of Computational Modelling, Krasnoyarsk, Jul 2001.

Lichtenegger, H.: Satelliten-Experimente und Allgemeine Relativitätstheorie, TU Braunschweig, Braunschweig, Nov 2001.

Magnes, W.: Digital fluxgate magnetometer used for scientific space missions, Center for Space Sciences and Applied Research, Beijing, Jun 2001.

Nakamura, R., et al.: Relationships between tail flows and auroral features (Invited), *IGPP Conference on the Nightside Magnetosphere*, Yellowstone, Oct 2001.

Nakamura, R., et al.: Substorm intensifications observed by Cluster, *AGU Fall Meeting*, San Francisco, Dec 2001.

Nakamura, R.: Cluster-Beobachtungen von Teilstürmen und Schweif-Jets (Invited), *Deutsches Cluster-Meeting*, Katlenburg-Lindau, Nov 2001.

Nakamura, R.: Plasma flows in the near-Earth magnetotail (Invited), *EGS General Assembly*, Nice, Apr 2001.

Nakamura, R.: Plasma sheet flows and associated ionospheric signatures (Invited), *AGU Fall Meeting*, San Francisco, Dec 2001.

Rucker, H.O.: Planetary Radio Emission investigations at IWF Graz, *Planetary and Radio Emissions V*, Graz, Apr 2001.

Rucker, H.O.: The Cassini Jupiter flyby and the International Jupiter Watch (Invited), *SSD Seminar*, ESTEC, Noordwijk, Feb 2001.

Steller, M.: COROT, Extractor Electronics, *COROT Science Week*, Vienna, Sep 2001.

Torkar, K., et al.: Effects of active spacecraft potential control on Cluster plasma observations - First results, *7th Spacecraft Charging Technology Conference*, ESTEC, Noordwijk, Apr 2001.

Torkar, K., et al.: First results from active spacecraft potential control onboard Cluster, *EGS*, Nice, Mar 2001.

Vogl, D. F. et al.: First results on the calibration of the RPWS antenna system, Department of Physics and Astronomy, University of Iowa, Mar 2001.

Vogl, D. F., et al.: The analysis of the inclined fast shock including pressure anisotropy, *Atmospheric and Ocean Optics VIII*, Irkutsk, Jun 2001.

Vogl, D. F.: The Earth bow shock including pressure anisotropy: Theory versus Observations, Institute of Computational Modelling, Krasnoyarsk, Jul 2001.

Zhang, T. L.: Determination of the resonant frequency of geomagnetic pulsations at low latitude gradient installations, *4th China Space Weather Workshop*, Chengdu, Sep 2001.

Zhang, T. L.: Magnetometer aboard Venus Express, *Venus Express Workshop*, ESTEC, Noordwijk, May 2001.

# 6.7 Poster

Boudjada, M. Y., et al.: Ground and Space Observations of Jovian Decametric Emissions in the Frequency Range from 1 MHz to 40 MHz, *Planetary and Radio Emissions V*, Graz, Apr 2001.

Boudjada, M. Y., et al.: Spectral Features in Auroral Kilometric Radiation, *Planetary Radio Emissions V*, Graz, Apr 2001.

Boudjada, M. Y., et al.: Temporal Evolution Steps of Jovian Narrow-band Emissions, *Planetary Radio Emissions V*, Graz, Apr 2001.

Eichelberger, H., et al.: Cluster-II FGM high frequency compensation, *SOLSPA 2001 Euroconference*, Vico Equense, Sep 2001.

Fischer, G., et al.: Wire-grid modeling of Cassini spacecraft for the determination of effective antenna length vectors of the RPWS antennas, *Planetary Radio Emissions V*, Graz, Apr 2001.

Kargl, G., et al.: Impact erosion of the ancient Martian atmosphere, *EGS General Assembly*, Nice, Mar 2001.

Kargl, G., et al.: Influence of organic molecules on ice properties on solar system bodies, *First European Workshop on Exo/Astrobiology*, Frascati, May 2001.

Kargl, G., et al.: Technical aspects of the SPICE experiment on Mars NetLander, *EGS General Assembly*, Nice, Mar 2001.

Khodachenko, M. L., et al.: On the Structure of Electromagnetic Fields Generated by a Moving External Current Source in a Magnetized Coll.-less Plasma, *Planetary Radio Emissions V*, Graz, Apr 2001.

Lammer, H., et al.: Detectability of possible Titan lightning by Cassini/RPWS, *EGS General Assembly*, Nice, Mar 2001.

Lammer, H., et al.: Detection Capability of Cassini for Thundercloud Generated Ligthning Discharges on Titan, *Planetary Radio Emissions V*, Graz, Apr 2001.

Lammer, H., et al.: Exposure of the ancient Martian surface to extraterrestrial radiation and its implication for molecules essential for life, *First European Workshop on Exo-/Astrobiology*, Frascati, May 2001.

Lammer, H., et al.: Exposure of the Martian surface of ultraviolet and cosmic radiation and the consequences for possible primitive lifeforms, *EGS General Assembly*, Nice, Mar 2001.

Lammer, H., et al.: From a Titan isotope anomaly to a new perspective on the early solar activity, *Second Granada Workshop*, Granada, Jun 2001.

Lammer, H., et al.: Mercury's surface sputtered exosphere: importance of penetrometry experiments, *EGS General Assembly*, Nice, Mar 2001.

Lammer, H., et al.: Titan's atmospheric evolution: an indicator for a more active ancient Sun, *EGS General Assembly*, Nice, Mar 2001.

Langmayr, D., et al.: Field-aligned Electric Field in the Io Flux Tube as a Result of a Pressure Pulse near Io, *Planetary Radio Emissions V*, Graz, Apr 2001.

Mühlbachler, S., et al.: Geostationary magnetic field signatures of erosion: WIND-GEOS observations, *SOLSPA 2001 Euroconference*, Vico Equense, Sep 2001.

Mühlbachler, S., et al.: Studies of dayside magnetopause erosion on geostationary orbit using WIND and GEOS data (1995-1998), *Atmospheric and Ocean Optics VIII*, Irkutsk, Jun 2001.

Rucker, H. O., et al.: Antenna systems considerations for Solar Orbiter, *1st ESA Solar Orbiter Workshop*, Puerto de la Cruz, May 2001.

Rucker, H. O., et al.: New frontiers in decameter radio astronomy, *Planetary Radio Emissions V*, Graz, Apr 2001.

Torkar, K., et al.: Spacecraft potential control for Cluster - a summary of year one, *AGU Fall Meeting*, San Francisco, Dec 2001.

Vogl, D. F., et al.: First results on the calibration of the Cassini RPWS antenna system, *Planetary Radio Emissions V*, Graz, Apr 2001.

Volwerk, M., et al.: Detection of Chlorine Ions in Europa’s Wake, *Jupiter: Planet, Satellites and Magnetosphere*, Boulder, Jun 2001.

Zhang, T. L.: Determination of the resonant frequency of geomagnetic pulsations at low latitude gradient installations, *EGS General Assembly*, Nice, Mar 2001.

# 7 Teaching & Workshops

## 7.1 Lecturing

Members of the Institute are actively engaged in teaching at three universities. In summer 2001 and in the current winter term 2001/2002 the following lectures are given, in addition to a number of practical exercises and seminars:

### KFU Graz

Cosmic Rays (Rucker)

Geophysical Measurement Methods III with exercises (Rucker)

Introduction to Plasma Physics (Rucker)

Planetary Magnetospheres (Rucker)

Introduction to Geophysics (Bauer)

Magnetohydrodynamics: Waves and Instabilities (Biernat)

Plasmaphysics: Elementary Waves (Biernat)

Hydrodynamics (Biernat)

Solar-Terrestrial Relations (Biernat)

Instruments and Data Processing in Geophysics and Space Physics (Boudjada)

Ice and Fire in the Solar System: Comets, Moons and Planetary Surfaces (Kömle)

### TU Graz

Mathematical Methods 1 (Sünkel)

Adjustment Theory 2 (Sünkel)

Advanced Topics of Mathematical Geodesy and Geo-Information Technology 1 with exercises (Sünkel)

Geo-Software Applications (Sünkel)

Dynamical Satellite Geodesy with exercises (Sünkel)

Geophysics & Geodynamics with exercises (Sünkel)

Antennas and Wave Propagation (Riedler)

High-Frequency Engineering 2 (Riedler)

### LMU München

Space Plasma Physics 1 (Baumjohann)

Space Plasma Physics 2 (Baumjohann)

### Advanced Course

The Institute is also very actively engaged in the Advanced Course *Space Sciences,* which is a joint two-years post-graduate course at both Karl-Franzens University of Graz and Graz University of Technology. It covers three main tracks, Space Physics, Remote Sensing, and Space Communication & Navigation, and ends with the degree “Master of Advanced Studies *Space Sciences*”. Scientific coordinator of this Advanced Course *Space Sciences* is H. O. Rucker.

## 7.2 Theses

Besides lecturing, members of the Institute are supervising Diploma and Doctoral theses. In 2001, the following theses have been completed:

Dierschke, K.: Die Auswirkung magnetischer Stürme auf die Plasmaschicht des Erdmagnetosphärenschweifs, Diploma Thesis, LMU München (Supervisor: W. Baumjohann)

Harrich, M.: Empirical modeling of electron densities in the high latitude mesosphere, Doctoral Thesis, TU Graz (Supervisor: K. Torkar)

Kaufmann, E.: Source Locations of the Auroral Kilometric Radiation: Theoretical Approach and Spacecraft Observations, Diploma Thesis, KFU Graz, (Supervisor: H. O. Rucker)

Leitner, M.: Waveform analysis techniques of Jovian S-burst observations, Doctoral Thesis, KFU Graz, (Supervisor: H. O. Rucker)

Neagu, E.: Magnetic field and plasma flow fluctuations in the near-Earth plasma sheet, Doctoral Thesis, LMU München (Supervisor: W. Baumjohann)

Schwarzl, H.: Development of a MATLAB Toolbox for Analysis of Planetary and Interplanetary Magnetic Fields, Diploma Thesis, TU Graz (Supervisor: K. Schwingenschuh)

# 7.3 Workshops

In April 2001, together with the Institute for Geophysics, Astrophysics and Meteorology of the KF University of Graz, the IWF hosted the *5th International Workshop on Planetary Radio Emissions* (PRE V). This workshop was organized by H. O. Rucker (IWF Graz), M. L. Kaiser (NASA/GSFC), and Y. Leblanc (Observatoire de Paris Meudon). About seventy participants from thirteen nations have attended this workshop. Corresponding proceedings have been published in Dec. 2001 by the Austrian Academy of Sciences Press, Vienna.

# 8 Personnel

Arsov, Kirčo, Dr. (S)
Aydogar, Özer, Dipl.-Ing. (E)
Badura, Thomas (S, ESA)
Bauer, Siegfried J., Prof. em. (P)
Baumjohann, Wolfgang, Prof. (E)
Berghofer, Gerhard, Ing. (E)
Besser, Bruno, Dr. (E)
Biernat, Helfried K., Prof. (P)
Boudjada Mohammed Y., Dr. (P)
Chwoika, Rudolf (S)
Cristea, Elena, Dipl.-Ing. (S)
Delva, Magda, Dr. (E)
Eichelberger, Hans U., Dipl.-Ing. (E)
Feldhofer, Helmut, Dipl.-Ing. (E, part. ESA)
Fischer, Georg, Dipl.-Ing. (P)
Fremuth, Gerhard, Dipl.-Ing. (E)
Giner, Franz, Dipl.-Ing. (E)
Graf, Christian, Ing. (S)
Grill, Claudia (S)
Harrich, Marcus, Dr. (E, FWF)
Hausleitner, Walter, Dr. (S)
Heihsler, Johann, Dipl.-Ing. (E, BMBWK)
Höck, Eduard, Dipl.-Ing. (S)
Jeszenszky, Harald, Dipl.-Ing. (E)
Jetzl, Ilse, Dr. (P)
Kargl, Günter, Dr. (P)
Khodachenko, Maxim, Dr. (P)
Kirchner, Georg, Dr. (S)
Kömle, Norbert, Dr. (P)
Kögler, Gerald (I)
Koidl, Franz, Ing. (S)
Kolb, Christoph, Mag. (P)
Koren, Wolfgang, Ing. (E)
Kürbisch, Christoph, Ing. (E)
Laky, Gunter, Dipl.-Ing. (E)
Lammer, Helmut, Dr. (P)
Langmayr, Daniel, Mag. (P, FWF)
Lichtenegger, Herbert I.M., Dr. (E)
Macher, Wolfgang, Dipl.-Ing. (P)
Magnes, Werner, Dr. (E)
Močnik, Karl, Dr. (E)
Mühlbachler, Stefan, Mag. (P, FWF)
Nakamura, Rumi, Dr. (P)
Neukirchner, Sonja, Ing. (E)
Nischelwitzer-Fennes, Ute, Ing. (E)
Noda, Hirotomo, Dr. (E)
Ottacher, Harald, Mag. (E, ESA & BMBWK)
Pešec, Peter, Dr. (S)
Riedler, Willibald, Prof. em. (E)
Rucker, Helmut O., Prof. (P)
Runov, Andrei V., Dr. (E)
Scherr, Alexandra, Mag. (I)
Schwingenschuh, Konrad, Dr. (E)
Seidel, Stefan (S)
Slamanig, Herwig, Dipl.-Ing. (E, I)
Stachel, Manfred, Ing. (E, ESA)
Stangl, Günter, Dipl.-Ing. (S, BEV)
Steiner, René, Dipl.-Ing. (E, FWF)
Steller, Manfred, Dr. (E)
Stock, Daniel (E)
Sucker, Michael, Dipl.-Ing. (S)
Sünkel, H., Prof. (S)
Torkar, Klaus M., Dr. (E)
Vogl, Dieter, Dr. (P)
Valavanoglou, Aris (E)
Voller, Wolfgang G., Mag. (P)
Volwerk, Martin, Dr. (E, MPE)
Wallner, Robert, Ing. (E)
Zehetleitner, Sigrid (S)
Zhang, Tie-Long, Dr. (E)

As of December 31, 2001

E: Experimental Space Research, P: Extraterrestrial Physics, S: Satellite Geodesy, I: Institute Administration. Most positions are directly funded through ÖAW, others as indicated by: BEV: Federal Office for Metrology and Surveying, BMBWK: Federal Ministry for Education, Science and Culture, ESA: European Space Agency, FWF: Austrian Science Fund, MPE: Max-Planck Institute for Extraterrestrial Physics.