

# Space Research in Finland

## Report to COSPAR 2004



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## Editors

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**COSPAR**

FINNISH NATIONAL COMMITTEE



ACADEMY OF FINLAND



**TEKES**

National Technology Agency

Helsinki 2004

**Front Cover:**

Envisat at the ESA ESTEC test facilities in Noordwijk, the Netherlands. Envisat is the primary Earth observation satellite of the European Space Agency. Finland has participated in the Envisat project by designing and building the GOMOS instrument. GOMOS measures the ozone depletion and global warming by monitoring star occultations in the Earth's atmosphere.

Southern Finland imaged by the Envisat MERIS instrument. In addition to the atmospheric studies, Finnish scientists use Envisat data products to detect algal growth and oil slicks at the Baltic Sea. During winter the knowledge about the sea ice conditions is important.

*Photos: ESA*

**Back Cover:**

The SMART-1 mission to Moon and the Mars Express mission to Mars. The SPEDE and XSM instruments of the SMART-1 are Finnish technology. Finnish scientists also work with the AMIE camera scientific program of SMART-1. With the Mars Express Finland has participated in the development of ASPERA-3, the Beagle 2 lander and satellite power electronics.

*Photos: ESA*

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**Tekes – your contact for Finnish technology**

Tekes, the National Technology Agency, is the main funding organisation for applied and industrial R&D in Finland. Funding is granted from the state budget.

Tekes' primary objective is to promote the competitiveness of Finnish industry and the service sector by technological means. Activities aim to diversify production structures, increase production and exports and create a foundation for employment and social well-being. Tekes finances applied and industrial R&D in Finland to the extent of about 400 million euros annually. The Tekes network in Finland and overseas offers excellent channels for cooperation with Finnish companies, universities and research institutes.

**Technology programmes – part of the innovation chain**

The technology programmes are an essential part of the Finnish innovation system. These programmes have proved to be an effective form of cooperation and networking for companies and the research sector for developing innovative products and processes. Technology programmes promote development in specific sectors of technology or industry, and the results of the research work are passed on to business systematically. The programmes also serve as excellent frameworks for international R&D cooperation. In 2004, 25 extensive technology programmes are under way.

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# Foreword

**T**his is the bi-annual report of Finnish Space Research to the Committee on Space Research (COSPAR) prepared jointly by the National Committee of COSPAR, the National Technology Agency (Tekes) and the Academy of Finland. The report describes the overall structure of Finnish space activities, the presently applied strategy, and main funding sources. The major space programmes are briefly listed. The main body of the report describes the progress during 2002–2003 in pure and applied space sciences within the domain of COSPAR activities.

During the last two years much of Finnish space research was conducted within the 3-year (2001–2004) research programme ANTARES of the Academy of Finland and Tekes. This programme included data analysis of the ESA satellites SOHO (Solar and Heliospheric Observatory), Cluster II, Integral and XMM-Newton, and preparations for several upcoming spacecraft. Finnish instruments were launched to space with Envisat (2002), Integral (2002), Mars Express (2003), SMART-1 (2003), and most recently with Rosetta (March 3, 2004).

The distinction between space-borne and ground-based astronomy is becoming increasingly obsolete, as modern astrophysics needs both components. An important step forward for the Finnish astronomy was the successful membership negotiation process with the European Southern Observatory (ESO), according to which Finland joins ESO on July 1, 2004.

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# 1 Overview of Finnish Space Activity

## 1.1 A short history

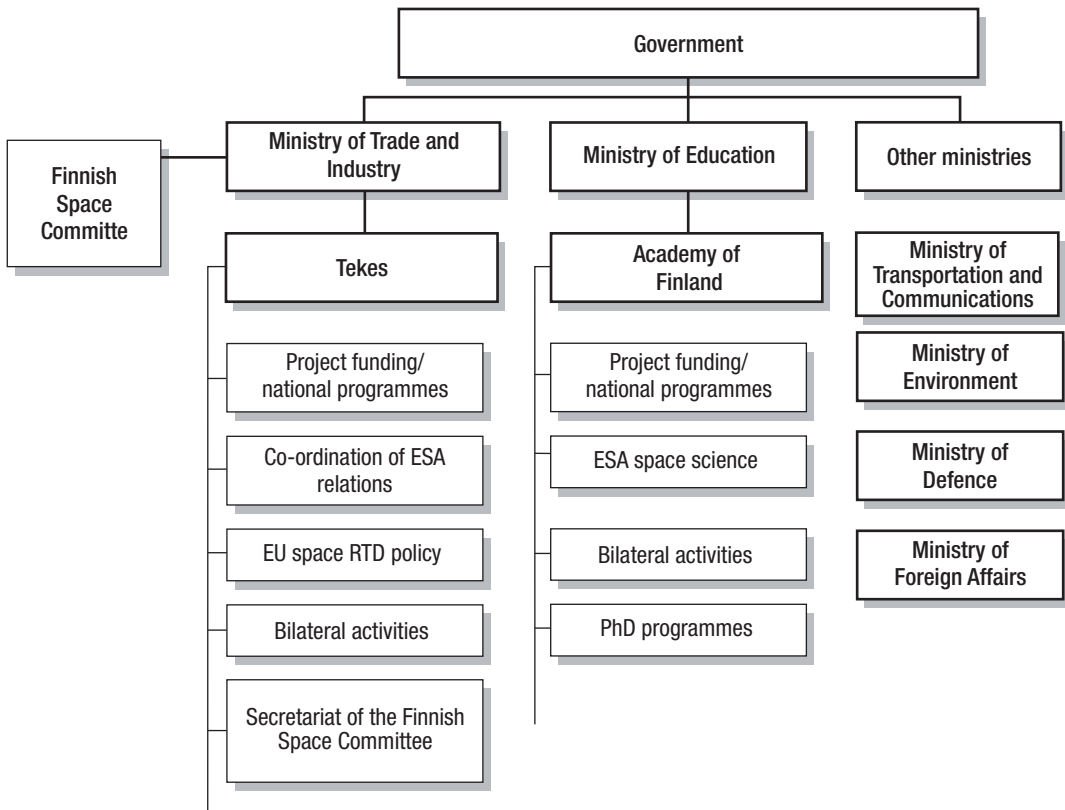
Finnish space research utilising space elements began with the first man-made satellites, whose orbital motions were used in studies of the Earth's gravitational field. The International Geophysical Year 1957–1958, which led to the establishment of the Committee on Space Research (COSPAR), also brought several ground-based space research instruments to Finland, in particular all-sky cameras whose modern successors are even today used in studies of the aurora borealis and the physics behind this magnificent phenomenon. Finland became a member of COSPAR a few years later in 1964 and for a long time COSPAR played the leading role in the international contacts in the field of space research.

During the first 20 years of COSPAR membership the Finnish space research used mainly ground-based tools in astronomy and ionospheric and magnetospheric physics with occasional collaboration with foreign groups utilising space-borne instruments. The first space instrument project with significant Finnish participation started in May 1985. It was the Swedish-Soviet-Finnish plasma analyser ASPERA for the Soviet Phobos mission. In 1989 ASPERA provided very successful observations of the solar wind plasma interaction with the Martian atmosphere. The project initiated a close co-operation with Sweden, and presently the fourth ASPERA instrument is being finalised for the Venus Express spacecraft of the European Space Agency to be launched in 2005. After this initial start the activities widened already within the Phobos programme to include several Finnish institutes and a wider international collaboration.

The expansion of Finnish space activities during the 1980's was extremely rapid, in particular in space science. In 1987 Finland became an Associate Member of the European Space Agency (ESA) and a full member of its Science Programme. By that time the co-operation with the Soviet Union had already broadened to include astronomy missions as well as projects involving remote sensing of the Earth. Unfortunately, the ambitious Soviet astronomy missions have not been completed. However, the involvement in the Spectrum-X-Gamma instrumentation paved the way for the presently very active participation in high-energy astrophysics missions, where the Finnish X-ray detector technology has had a central role.

Finnish research groups got an excellent start in the ESA Science Programme with the First Cornerstone missions SOHO and Cluster. Presently Finnish scientific institutes and high-tech companies play various roles (Principal Investigator, Co-Investigator, hardware supplier, system level contractor, etc.) in all ESA science missions. The second key line for Finland has been active participation in the Earth Observation Programme of ESA, where the Envisat mission and, in particular, its GOMOS instrument have had a large role. Today these activities cover a wide range of topics with scientific, societal, and technological interests.

Finally, in 1995 Finland became a full member of ESA. While space research itself was well established already during the associate membership, the new status was essential to enable Finnish companies to become involved in technology programmes within the ESA TRP, GSP, and GSTP schemes. At the same time national initiatives and co-operation with other countries and organisations have widened and strengthened.



**Figure 1.1.** Organisation for administration of space matters in Finland.

## 1.2 Summary of the Finnish space policy

Space activities in Finland are administrated in a decentralised way mainly involving Tekes (National Technology Agency), the Academy of Finland and the Ministry of Trade and Industry (MTI).

The Finnish Space Committee (established in 1983) acts as the overall coordinating body for the Finnish space activities. It makes propositions and proposals and gives statements on matters related to space research, education and industrial development, exploitation of knowledge derived from space activities, and national and international co-operation.

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The Committee is nominated according to MTI's proposal by the Government for a period of three years. It is chaired by MTI and has members from relevant ministries and main actors. The Committee meets on average six times per year. During 2002 and 2003 Finnish Space Committee members were:

<b>Chairman</b>	
Timo Kekkonen	Ministry of Trade and Industry
<b>Vice Chairman</b>	
Risto Pellinen	Finnish Meteorological Institute
<b>Members</b>	
Mirja Arajärvi	Ministry of Education
Jaakko Halttunen	Ministry of Foreign Affairs (replacing L. Maunula)
Juhani Lehmusvirta	Patria New Technologies
Anneli Pauli	Academy of Finland
Kari Tilli	Tekes
<b>Advisors</b>	
Heikki Fredriksson	Topographic Service of the Finnish Defence Forces
Heikki Huomo	Nokia
Jorma Immonen	Ministry of Trade and Industry
Antti Joensuu	Ministry of Trade and Industry
Alpo Julkunen	Topographic Service of the Finnish Defence Forces (repl. H. Fredriksson)
Jorma Kangas	University of Oulu
Väinö Kelhä	Technical Research Centre of Finland
Jarkko Koskinen	Finnish Meteorological Institute
Risto Kuittinen	Finnish Geodetic Institute
Raimo Kurki	Ministry of Transport and Communications (repl. R. Linna)
Rita Linna	Ministry of Transport and Communications
Esa Panula-Ontto	Tekes
Yrjö Sucksdorff	Finnish Environment Institute SYKE
Juha Vuorimies	Ministry of Environment
<b>Secretaries</b>	
Pauli Stigell	Tekes
Pentti Pulkkinen	Academy of Finland

### 1.3 Participation in international space organisations

While ESA and COSPAR are two central international organisations for Finnish space research, Finland participates also in several other international space organisations. Within the International Council of Scientific Unions (ICSU) Finland belongs to two other space related unions: the International Astronomical Union (IAU) and the International Union of Radio Science (URSI). Furthermore, Finland has also a national representative in the International Astronautical Federation (IAF).

In the field of magnetospheric and ionospheric research Finland is a member of the multinational European Incoherent Scatter radar association EISCAT. For astronomy the Nordic Optical Telescope (NOT) has been very important and on July 1, 2004 Finland will join the European Southern Observatory (ESO). Of the various remote sensing organisations Finland belongs to EUMETSAT (meteorology) and has a representation in EARSSEL (remote sensing). In the field of telecommunications Finland is a member of the International Telecommunication Union (ITU).

## 2 Finnish National Strategy for Space Research and Development

### 2.1 Vision and goals of Finnish space activities

In Finland the guiding principles in the space sector are the science and technology policy and the desire to satisfy the needs of the society using the means enabled by space technology. The benefits derived from investments in the space sector are seen in the form of accumulation of human capital, improvement in the international competitiveness of companies, more effective public services and improvements in the quality of life.

**The goals are:**

- collection of data and scientific research of the Earth's environment and objects and phenomena in outer space,
- improved technological competitiveness of industry and service sector thus supporting economical growth through more efficient service provision for society and increase of business activity
- production of information for the needs of environmental monitoring, protection and sustainable development.

### 2.2 Strategy for Finnish space activities

The national space strategy for years 2002–2004 is outlined in *The Space Activities in Finland, National Strategy and Development Objectives* that was published (in Finnish) in June 2002. Strategic areas of the public sector investment are space science, satellite Earth observation, satellite telecommunications, satellite navigation and the industrial production of equipment for space vehicles.

**The strategy for the development of space science is:**

- The high standard of Finnish space science will be maintained by participation in international projects in key research themes. Space science and earth observation research programme ANTARES has been the major tool to achieve this goal from 2001 to 2004. ANTARES has been funded together by Academy of Finland and Tekes by amount of 15 million euros.
- Utilisation of new satellite Earth observation methods will be increased in public sector data use and in geographic information systems. Collaboration agreement in this field was signed between Tekes and Canadian Space Agency in May 2003.
- International research cooperation concentrates on ESA and EU research projects and on bilateral research projects with e.g. Canada, Denmark, Sweden, Russia, and the United States.

## 2.3 Funding sources

The public funding responsibilities concerning space activities are divided between the Ministry of Trade and Industry, Tekes and the Academy of Finland, and several universities and research institutes.

### 2.3.1 Tekes



Tekes, the National Technology Agency (established in 1983), is the main financing organisation for applied and industrial R&D in Finland. Its funds are awarded from state budget. Tekes offers channels for cooperation with Finnish companies, universities and research institutes.

Tekes' primary objective is to promote the competitiveness of Finnish industry and the service sector by technological means. Activities diversify production structures, increase production and exports, and improve the foundation for employment and social well-being.

Tekes coordinates and offers financial support for participation in international technology initiatives, including EU research programmes, EU-REKA, research activities of OECD's energy organisation IEA (International Energy Agency), European Cooperation in Scientific and Technical research (COST), European Space Agency (ESA) and Nordic cooperation.

Technology programmes aim at gaining new technology expertise and product development options in the important future business areas. Programmes are an effective form of cooperation for companies and the research sector. In 2003 Tekes had 42 national technology programmes. Tekes and the Academy of Finland started in April 2001 a common programme, ANTARES, on space science and remote sensing science. In 2002 Tekes started AVALI space programme focused on commercialisation of space technology.

In 2003 Tekes total financing of national and international R&D programmes was 392 million euros. From this 18,5 million euros was provided for space activities (ESA, national and bilateral).

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### 2.3.2 Academy of Finland



The Academy of Finland is an expert organisation for research funding within the administrative sector of the Ministry of Education. The Academy has a board and four research councils, as well as an Administrative Office. The research councils are the Research Council for Biosciences and Environment, the Research Council for Culture and Society, the Research Council for Natural Sciences and Engineering, and the Research Council for Health.

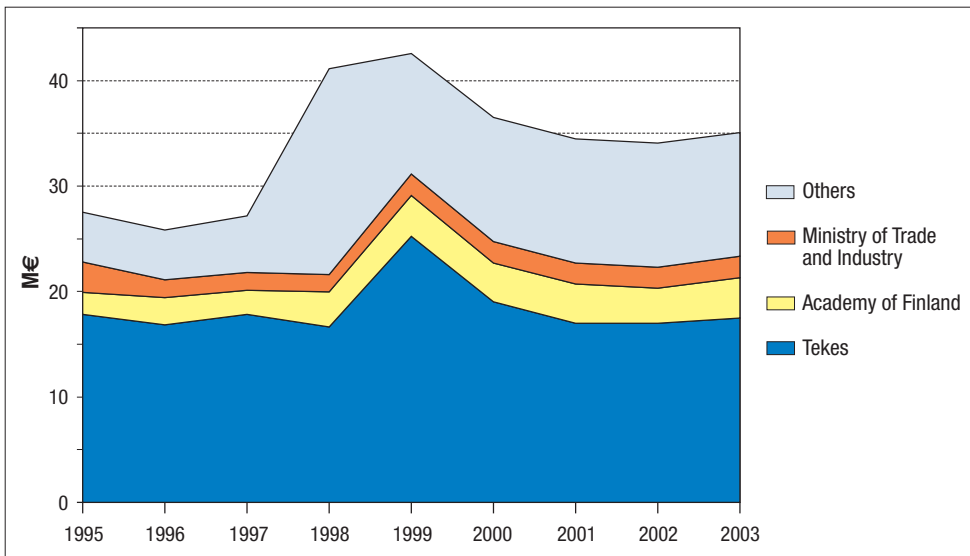
The Academy's function is to improve the quality and prestige of Finnish basic research through selective, long-term funding (typically 3–4 years) based on competition, systematic evaluation, and relevant science policy. The Academy's development initiatives focus on developing professional researcher careers and promoting creative research environments. The various forms of support for research, such as research posts, research projects, and research grants, provide opportunities for versatile funding of research in different disciplines.

The research funding of the Academy of Finland amounted during the period 2001–2003 to about 185 million euros annually. Funding to space research and astronomy has also been quite stable, at the level of about 3 million euros annually, excluding membership fees to international organizations (NOT, EISCAT, etc.), which make about 0,5 million euros annually. Examples of other international co-operation funded by the Academy include scientific research at EU, CERN, and UNESCO. In 2004 Finland is joining the European Southern Observatory (ESO), which will have an impact on Academy astronomy and space research funding.

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Graphic 2.1. Funding of Finnish space activities 1995–2003 (million euros).

## 2.4 The Finnish National Committee on Space Research

The Committee on Space Research (COSPAR) was established by the International Council of Scientific Unions (ICSU) in October 1958 to continue the co-operative programmes of rocket and satellite research successfully undertaken during the International Geophysical Year of 1957–1958. The ICSU resolution creating COSPAR stated that the primary purpose of COSPAR was to “provide the world scientific community with the means whereby it may exploit the possibilities of satellites and space probes of all kinds for scientific purposes, and exchange the resulting data on a co-operative basis.”

Consequently, COSPAR is an interdisciplinary scientific organisation concerned with the progress on an international scale of all kinds of scientific research carried out with space vehicles, rockets, and balloons. COSPAR’s objectives are carried out by the international community of scientists working through ICSU and its adhering National Academies and International Scientific Unions. Operating under the rules of ICSU, COSPAR ignores political considerations and considers all questions solely from the scientific viewpoint.

The Finnish National Committee of COSPAR has participated in the international and national co-operation of scientific space research since 1964 by submitting proposals, issuing statements, arranging meetings, and keeping contact with the international COSPAR and its subcommittees. The celebration of 40 years of Finnish COSPAR membership takes place on June 2, 2004, with the President of COSPAR, Prof. Roger Bonnet, as the main speaker.

The National Committee is an expert body nominated by the Delegation of the Finnish Academies of Science and Letters. The members of the National Committee represent the active community of space researchers in Finland. The members during 2002–2003 were:

### Chairman

*Hannu Koskinen*, University of Helsinki

### Members

*Martti Hallikainen*, Helsinki University of Technology

*Risto Kuittinen*, Finnish Geodetic Institute

*Viljo Kuosmanen*, Geological Survey of Finland

*Kari Lumme*, University of Helsinki

*Kalevi Mattila*, University of Helsinki

*Tuomo Nygrén*, University of Oulu

*Risto Pellinen*, Finnish Meteorological Institute

*Pekka Tanskanen*, University of Oulu

*Martti Tiuri*, Parliament of Finland

*Seppo Urpo*, Metsähovi Radio Observatory

*Esko Valtaoja*, University of Turku

*Martin Vermeer*, Helsinki University of Technology

### Secretary

*Matias Takala*, Helsinki University of Technology

At the beginning of 2004 *Risto Kuittinen* and *Viljo Kuosmanen* left the committee. They were replaced by *Juha Hyyppä*, Finnish Geodetic Institute, and *Erkki Tomppo*, Finnish Forest Research Institute.

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# 3 Space Programmes Supported by Finland

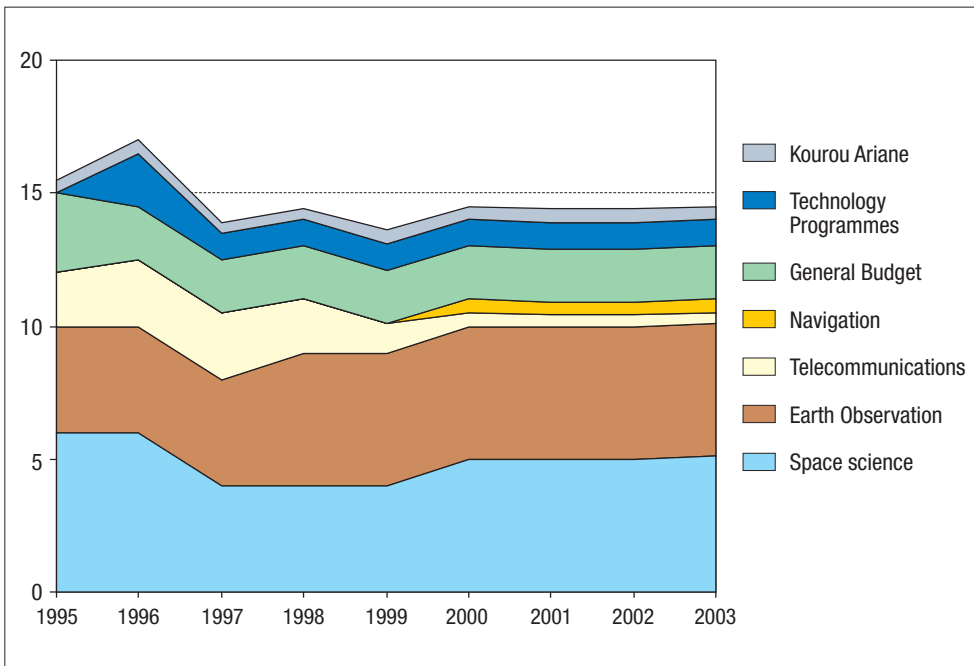
## 3.1 ESA Programmes supported by Finland



### Space science

Table 3.1 summarises the ESA space science missions in which Finland has participated either providing nationally funded scientific instruments or constructing of satellite platform equipment.

Finland participates in ESA’s space science, earth observation, telecommunications, navigation and technology R&D programmes.



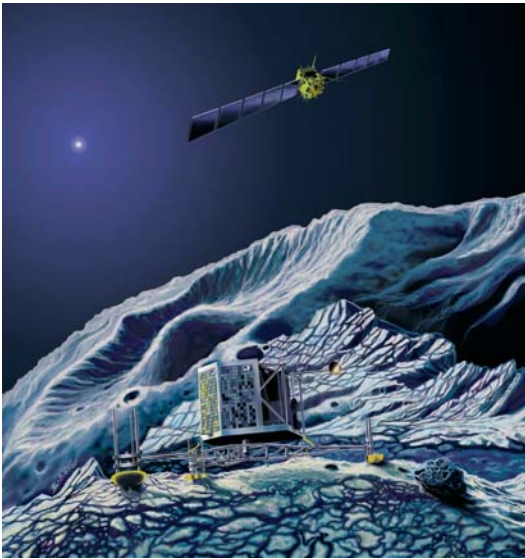
**Graphic 3.1.** Payments to ESA Programmes 1995-2003 by Tekes and Ministry of Trade and Industry (MTI); in million euros.

**Table 3.1.** Finnish space science instrumentation and industrial participation in ESA space science missions.

Programme	Finnish participation	Schedule
SOHO	SWAN and ERNE instruments	Launched 1995
Cluster / Cluster-2	EFW instruments, satellite power system, electronics units	Launch failure 1996, launched 2000
Huygens	HASI instrument, lander radar altimeter	Launched 1997
XMM-Newton	Telescope structure and satellite electronics	Launched 1999
Integral	JEM-X instrument	Launched 2002
Mars Express	ASPERA-3 instrument, participation in Beagle-2 lander, satellite power electronics	Launched 2003
SMART-1	XSM and SPEDE instruments	Launched 2003
Rosetta	Main S/C: COSIMA, ICA, LAP and MIP instruments, satellite power electronics, satellite structure; Philae lander: PP instrument CDMS mass memory	Launched 2004
Venus Express	ASPERA-4 instrument; power distribution units for spacecraft	Launch 2005
Herschel/Planck	LFI instrument for Planck; mirror for Herschel, onboard S/W for both	Launch 2007



**Figure 3.1.** During 2002–2003 three scientific spacecraft and one remote sensing satellite with Finnish participation were launched. Integral (left) used the Russian Proton launcher and Mars Express the Russian Soyuz launcher whereas SMART-1 (right) and Envisat were launched with the ESA Ariane 5. (Pictures ESA)



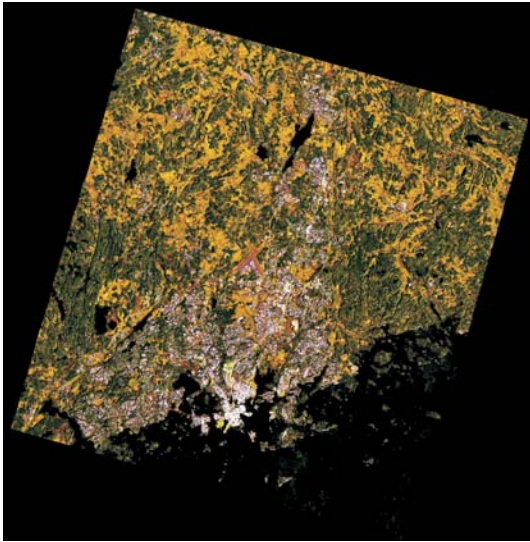
**Figure 3.2.** Finland has had a particularly wide participation in the ESA Cornerstone Mission Rosetta to comet Churyumov-Gerasimenko. The Finnish Meteorological Institute has provided subsystems to 4 scientific units onboard the main Rosetta spacecraft and is responsible for the permittivity probe (PP) and the solid-state mass memory of the lander Philae. Finnish industry has built the mechanical structure of Rosetta and the power distribution system. (Picture ESA)

### Earth observation

Table 3.2 summarises the ESA earth observation programmes and missions in which Finland has participated either in the construction of satellite platform units or remote sensing instruments.

**Table 3.2.** Finnish participation in ESA remote sensing programmes

Programme	Finnish participation	Schedule
ADM-Aeolus-mission	Atmospheric Dynamics Mission; instrument electronics	Launch 2007
Cryosat-mission	Radar altimetry mission; secondary structures	launch 2004
EO Envelope Programme Phase 2	Earth Observation Envelop Programme	1998–
EOPP Extension 2	Remote sensing technology programme.	1986–
Earth Watch – GMES	Global Monitoring of Environment and Security – collaborative programme by ESA and EU	2001–
Earth Watch – Infoterra/TerraSAR	Synthetic Aperture Radar mission development programme	2001–
GOCE mission	Gravity Field and Steady-State Ocean Circulation Mission; Onboard software	Launch 2006
Meteosat Second Generation MSG-1 satellite	Software for the satellite platform, hardware for the SEVIRI observation instrument.	Launched 2002
ENVISAT-1 satellite	Software and hardware for GOMOS observation instrument.	Launched 2002
METOP-1 (Phase C/D) mission	METOP satellite series, GOME-2 instrument electronics and satellite bus S/W development	Launch 2005
SMOS mission	Soil Moisture and Ocean Salinity; radiometer modules	Launch 2007



**Figure 3.3.** Due to its wide geographic area and the very sensitive Baltic Sea, remote sensing of the environment is an important element in the Finnish space research. This picture is an interpretation of synthetic aperture radar (SAR) data of the ERS satellite's interferometer. The picture shows Helsinki with its surroundings. The white regions are urban areas, green forests, yellow fields and black sea (the Gulf of Finland). (Picture LST/HUT)

### Telecommunications and navigation

Table 3.3 summarises the ESA telecommunication and navigation programmes in which Finland has participated.

### Technology programmes

Finland participates in the development of technologies for ESA's future science missions in the mandatory Basic Technology Research Programme (TRP) and General Studies Programme (GSTP), and in the optional General Support Technology Programme (GSTP).

**Table 3.3.** Finnish participation in ESA telecommunication programmes

Programme	Finnish participation	Schedule
ARTES Element 1	Basic specifications of the systems.	1993–
ARTES Element 5	Telecommunication systems and equipment programme.	1994–
ARTES Element 8	Large platform development for satellite telecommunications.	2002–
ARTES Element 9	Galileo satellite navigation system development.	1998–

### 3.2 Bilateral co-operation and programmes

In the mid-1980's Finland entered space activities through bilateral space science missions. Bilateral programmes, now including also Earth observation missions, have still an important role in the Finnish space strategy. A list of the operative bilateral programmes is given in table 3.4.

Furthermore, Finland had a significant role in the X-ray instrument of the Soviet Spectrum-X-Gamma satellite. The spacecraft was not completed and the Finnish project has been terminated.

### 3.3 Finnish national space programmes

#### ANTARES, 2001–2004

The ANTARES programme (Academy of Finland and National Technology Agency Research Programme for Space Research) addresses the Finnish space research strategy in the practical level. The programme started in 2001 and is carried out in the years 2001–2004 consisting of extensive projects established by consortia of research groups from universities and space research institutes. The programme is international in its nature, and many projects have relations to the programmes of ESA.

**Table 3.4.** The main Finnish bilateral space programmes

Programme	Main Partners	Finnish participation	Schedule
Phobos	USSR, SE, D	Electronics for ASPERA instrument and test system for LIMA-D instrument	Launched 1988, mission ended
Interball	USSR/RUS, SE	Electronics for ASPERA instrument	Launched in 1995 and 1996, mission ended
Freja	SE	Plasma and wave instruments	Launched 1992, mission ended
Polar	USA	Mechanisms for EFI instrument	Launched 1996
Cassini	USA	Hardware for IBS, CAPS and LEMS instruments	Launched 1997
Mars-96	RUS	Central electronics units, sensors and software for two landers	Launch failure in 1996
Metnet	RUS	New lander concept – currently a technology study	
Roemer	Denmark	Central processing unit for the satellite	Launch TBD
Odin	SE, F, CAN	119 GHz receiver and antenna measurements	Launched 2000
Stardust	USA	CIDA instrument	Launched 1999
EOS-Aura	USA	OMI instrument	Launch 2004
Space Shuttle	USA	AMS instrument	Launched 1998
Radioastron	RUS	22 GHz VLBI receiver	Launch TBD

ANTARES is funded jointly by the Academy of Finland and Tekes, the National Technology Agency. The focus of the ANTARES programme is in space science and in scientific environmental remote sensing.

The ANTARES programme supports especially projects which have been earlier committed to, or which are in the active development phase. In this way the continuation of long-term projects is ensured. The programme gives a possibility to analyse large data archives, as well as observations acquired in the current missions. Also developing new instrument concepts to be implemented in the future is a goal of the programme.

The ANTARES programme contains the following projects:

- Planck Surveyor Physics (PLANCK)
- High Energy Astrophysics and Space Astronomy (HESA)
- Space Based Studies of Dark Matter (DARKSTAR)
- Research of the Interstellar Medium and Star Formation (ISO-Odin)
- Space Weather in the ANTARES Programme (SWAP)
- Cluster II and MIRACLE: Mesoscale Structure of Coupled Solar Wind-Magnetosphere-Ionosphere system (C2M)
- Dust, Atmospheres, and Plasmas in the Solar System (DAPSS)
- Mars Small-Scale Weather (MSW)
- Chemical Aeronomy of the Mesosphere and Ozone in the Stratosphere (CHAMOS)
- New Modelling and Data Analysis for Satellite Based Forest Inventory (MODAFOR)
- Assimilation of Remote Sensing Data to Physical Models in Environmental Monitoring and Forecasting (ASSIMENVI)

The scientific progresses of these projects are presented in the descriptions of the scientific activities of the participating institutes in Chapters 4 and 5.

The ANTARES programme also strengthens Finnish educational potential in space science, as most of the research groups participating in ANTARES are also active in the national Graduate School in Astronomy and Space Physics. The graduate

school offers a versatile education programme with seminars and conferences. In the sense of the educational objective of the programme the seminars organised in the context of ANTARES have been open also to students in space sciences.

An important goal of the ANTARES programme is to increase awareness and visibility of the space science among the public and in the schools. The visibility strategy has been prepared according to the outreach plans made within the projects of the programme, for which a special allocation of funds has been allocated in the budgets of the consortia.

The Academy of Finland has committed EUR 4.5 million euros to all of the above listed projects during the years 2001–2004. Tekes funding of about 10.2 million euros is used mostly in the two large instrument projects PLANCK and HESA.

More information of ANTARES can be found at web sites:

<http://akseli.tekes.fi/Resource.phx/tivi/antares/index.htm>

<http://www.tekes.fi>

### **AVALI (1.3.2002–31.12.2005)**

The technology programme “Business opportunities from Space Technology” (AVALI) is focused on the creation of new business for industry through space activities derived technology that is transferable to terrestrial applications. AVALI enables the use of satellite telecommunications, navigation and remote sensing technologies for terrestrial applications. The development of equipment for commercial satellite markets is a key area for the programme. The goal of AVALI is the creation of new and viable business with the aid of space technology and its applications. AVALI’s budget is 15 million euros of which 7 million euros are funded by Tekes.

The more detailed objectives of AVALI programme are:

- Utilisation of space technology for terrestrial products and applications,
- Applications based upon space borne data and satellites,
- Satellite hardware and software,
- Ground segment hardware and software.

## 4 Space Research

### 4.1 Ionospheric and magnetospheric research

#### **Finnish Meteorological Institute, Geophysical Research (FMI/GEO)**

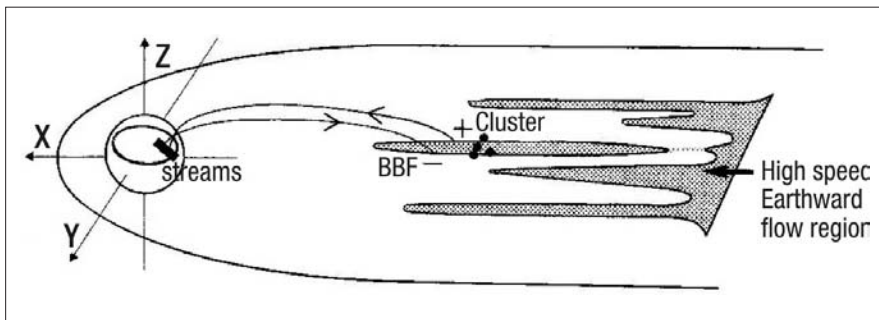
The ionospheric and magnetospheric research at FMI covers a wide range of topics ranging from space weather analyses in the global magnetospheric scale to detailed studies of auroral electrodynamics. The research programme focuses on ionospheric and magnetospheric dynamics, magnetosphere – ionosphere coupling, space plasma simulations, and space weather applications. The adopted research strategy emphasizes the importance of involvement in the full chain of research processes from instrument design, development and construction to data taking, analysis and interpretation. Special emphasis is paid to development of advanced data analysis methods, modelling and simulation techniques as well as theoretical models for maximal utilization of the available data. All research is conducted in wide international collaboration mostly with scientists from Europe, the United States, Russia, and Japan. The years 2002–2003 were especially active internationally: The EU and ESA joint space strategy opened new possibilities for space research within the GMES programme, and FMI scientists played an active role in promoting space weather into GMES. FMI represented Finland in the emerging International Living With a Star (ILWS) programme, which seeks inter-agency flight possibilities for space physics missions that have relevance to space weather science. Within ESA, the FMI director of space science acted as the Chairman of the agency's Science Programme Committee.

The key space science instrument is ESA's fleet of four Cluster spacecraft, whose data were analyzed together with measurements from other International Solar Terrestrial Physics (ISTP) programme satellites and from the MIRACLE ground-based instrument network. The FMI contribution to the Cluster mission is to provide data products from a

coordinated network of over 20 magnetometers, 8 all-sky cameras, and the STARE bistatic radar all located in the Scandinavian sector. While the instruments are not solely operated by FMI, FMI has accepted responsibility of gathering and distributing all the data in a common data format. Furthermore, FMI has invested considerable effort in developing analysis tools and modelling methods that allow interpretation of the combined set of measurements in terms of ionospheric electrodynamics. In particular, with this instrument setup it was possible to determine the ionospheric response to a fast plasma flow event observed in the mid-magnetotail by the Cluster fleet, which is significant in developing understanding of how the state, history and dynamics of the magnetosphere and ionosphere affect the coupled system evolution. The combined ground-based and space-based data analysis also allowed to resolve in detail the ionospheric and magnetospheric electrodynamics of a shear flow region and its associated particle signatures, which progresses our understanding of the large-scale current coupling between the two regions.

To complement the high-altitude, high-latitude Cluster measurements, China and ESA launched the first Double Star probe to a geosynchronous transfer orbit at the end of December 2003. The commissioning has been successful and data taking is in progress. This spacecraft, together with its sister probe to be launched in a polar orbit in June 2004, will complement the Cluster measurements by providing a view of the inner magnetosphere and the polar auroral regions. FMI is involved in the scientific analysis of the data, and continues to provide high-quality ground-based measurements for this mission also.

Two large research programmes funded by the Academy of Finland turned toward end in 2003. The ANTARES programme funded two efforts, one aimed at utilization of the Cluster and MIRACLE data sets (see above), and another focussed on



**Figure 4.1.** The Cluster measurements, ground-based instrumentation, and advanced modelling techniques have been utilized to unravel the magnetosphere – ionosphere coupling and plasma flows during magnetotail flow events.

the science of space weather. The MaDaMe programme, which ended in June 2003, has significantly boosted FMI's efforts in modelling the solar wind – magnetosphere – ionosphere interaction using global magnetohydrodynamic (MHD) simulation code GUMCIS-4.

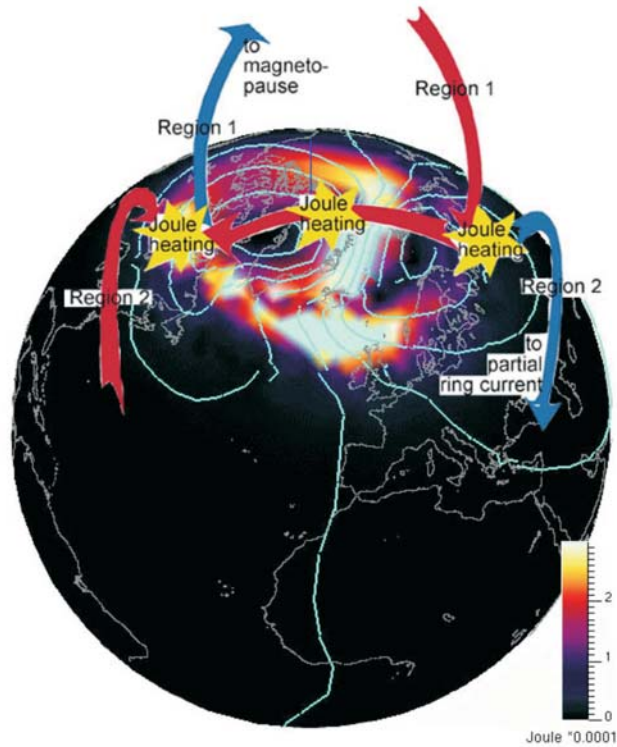
The space weather studies continued to focus on the solar and solar wind drivers of space weather as well as on the magnetospheric energy budget. The analysis involving the Sun and the solar wind was conducted in close collaboration with the University of Helsinki, while the energy budget analyses utilized results and tools from the Cluster-MIRACLE collaboration and the MHD simulation work at FMI. The research programme has led to improved understanding of the processes governing the solar energetic particle events as well as the magnetic cloud properties controlling their geoeffectiveness, but we still lack detailed understanding of where and when the largest ground disturbances, or GIC (geomagnetically induced current) events occur.

The magnetohydrodynamic (MHD) simulation work continued actively. The GUMICS-4 code simulates the near-Earth environment using MHD equations in the solar wind and the magnetosphere and electrostatic equations in the ionosphere. The MHD-magnetosphere is coupled to the three-dimensional electrostatic ionosphere via electron precipitation and the field-aligned currents that flow between the magnetosphere and the ionosphere; on the other hand the ionospheric potential

is used as a boundary condition in the magnetosphere. The main focus of the research during 2003 was on the solar wind and interplanetary magnetic field control of the energy dissipation in the ionosphere.

Several simulation runs were analyzed, and as a new feature the results revealed that in the simulation the ionospheric dissipation, which includes Joule heating and energy flux associated with electron precipitation, can be predicted from the solar wind magnetic field and kinetic energy flux with more than 80% probability. Furthermore, the simulation results indicated that the solar wind pressure has a more prominent role in the ionospheric Joule heating than has been assumed in earlier input-output analyses emphasizing the role of the interplanetary magnetic field. The result was observationally verified from a careful statistical analysis of solar wind pressure pulse events.

Two new space weather applications became available in 2003, when the ESA-funded space weather pilot project produced two monitoring systems Auroras Now! and Gasum Now!. Auroras Now! is an auroral monitoring and forecasting service developed for Northern Finland tourist resorts to be used in the hotel internal TV networks. The service provides recent all-sky camera images from a close-by station as well as the probability of seeing auroras, based on real-time magnetic measurements, along with a cloudiness report. Gasum Now! in turn provides a monitoring service of geomagnetically induced currents (GIC) in the



**Figure 4.2.** The ionospheric Joule heating as determined from the GUMICS-4 global MHD simulation. The arrows indicate schematically the ionospheric and field-aligned currents.

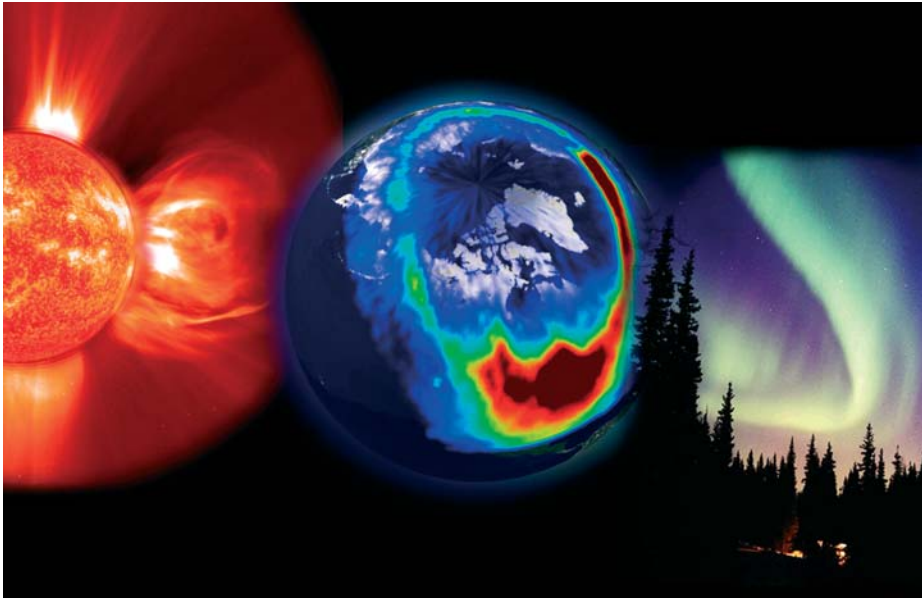
Finnish natural gas pipeline system. The service uses methods developed in connection with GIC research carried out during more than 20 years at the Finnish Meteorological Institute. Both services also have public parts available on the internet (<http://aurora.fmi.fi>).

FMI continued its strong role in graduate and undergraduate education under the auspices of the national graduate schools for Astronomy and Space Physics and Applied Electromagnetics. FMI contributes to classroom education by partially funding a space physics professorship at the University of Helsinki as well as by encouraging its senior staff to teach at the university. Each summer a number of undergraduate students works as summer trainees at FMI, and many of them continue later with research projects associated with their MSc thesis research. Furthermore, the research and space instrument hardware and software projects at FMI employed about 10 graduate students.

### University of Helsinki, Department of Physical Sciences

Magnetospheric research at the Department of Physical Sciences of the University of Helsinki (UH/PHYS) is conducted in close co-operation with the above reported activities at FMI. Graduate students employed by the University participate in studies on solar wind-magnetosphere interactions, physics of space storms and theory of MHD simulations.

In physics of space storms the UH/PHYS group is focusing on the solar and solar wind drivers of space weather, in particular on the geoefficiency of coronal mass ejections (CME) that are the main drivers of magnetospheric storms. This particular work is conducted in collaboration with scientists at Max Planck Institute for Aeronomy in Lindau, Germany, who are involved in the LASCO coronagraph onboard the SOHO spacecraft of ESA and NASA.



**Figure 4.3.** Solar activity and its consequences in the near-Earth environment form a common theme for Solar-Terrestrial physics at the Universities of Helsinki, Oulu and Turku, the Finnish Meteorological Institute and the Sodankylä Geophysical Observatory. (Picture ESA)

UH/PHYS has led the space weather consortium SWAP, with participation from FMI, and Universities of Oulu and Turku, in the ANTARES programme (2001–2004). The leading idea behind the SWAP project was to investigate the entire space weather chain from the Sun to the surface of the Earth. One of the first studies in the SWAP project made exactly this for the storm in April 2000 where the events from the coronal activity to the currents induced on ground systems were investigated. New results have also been achieved on the different response of the magnetospheric activity during CME- and shock-driven storms and on the storm and substorm energy budget.

In the joint space physics education scheme with FMI, the University of Helsinki provides the basic education in various topics of space physics both in undergraduate and post-graduate levels. The Master and Ph.D. theses are supervised jointly by the professor by the UH/PHYS and the FMI/GEO staff. All UH/PHYS space physics graduate students (presently 9), irrespective of their funding

source, are enrolled in the nation-wide Graduate School in Astronomy and Space Physics.

**University of Oulu,  
Department of Physical Sciences and  
Sodankylä Geophysical Observatory**

The Space Physics Group of the Department of Physical Sciences and the Sodankylä Geophysical Observatory (SGO) of the University of Oulu have a broad research program in ionospheric and magnetospheric physics, including observations from both ground-based and satellite instruments. This program is conducted in extensive national and international collaboration with several foreign institutes.

University of Oulu has a co-investigator status in the electric field instrument of the Polar satellite mission and in the EFW and RAPID instruments of the Cluster-2 mission. The Cluster satellites were successfully launched in 2000, and they still provide data. Experiments were earlier designed for the Cassini satellite, which will arrive at Saturn in 2004. Preliminary work on instrument design for

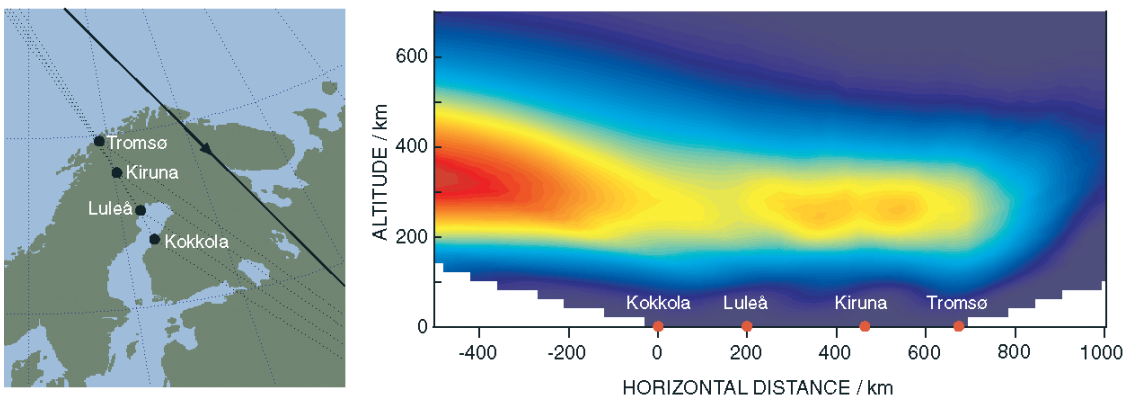
the MMS and BepiColombo missions has been carried out.

University of Oulu is engaged in continuous support and development of ground-based instrumentation. The magnetic field of the Earth is measured both in Sodankylä and the Oulujärvi site using FGE and TPM magnetometers. A network of search-coil magnetometers for pulsation research is operated with most of its instruments in Scandinavia and one on Crete. The optical equipment consists of 4 scanning photometers, 5 auroral TV cameras and a digital all-sky camera. One of the photometers is continuously operated at the Chinese base Zong Shan in Antarctica. Two of the TV cameras are highly sensitive digital instruments. The instrumentation working on radio frequencies consists of VLF receivers, an ionosonde and a riometer chain. An imaging riometer (IRIS) installed in Kilpisjärvi by Lancaster University is operated in conjunction with SGO. Construction of a meteor radar, an MST radar and a new ionosonde has been continued. A satellite tomographic chain of four receivers, extending from Kokkola (Finland) to Tromsø (Norway) has been installed and it has been operational on continuous basis from the beginning of 2003. Tomographic inversion of the data has been carried out and the resulting electron density plots from the vertical plane above the chain are available on web pages for quick-look purposes ([http://sgodata.sgo.fi/pub\\_tomo/tomo.html](http://sgodata.sgo.fi/pub_tomo/tomo.html)).

The development of incoherent scatter method and data analysis was continued. Sidelobe-free decoding of phase codes either by means of Fourier transforms or stochastic inversion was introduced. Stochastic inversion was also applied in removing range ambiguities and in combining a main lag profile and the surrounding fractional lag profiles to a single profile. A new EISCAT routine for measuring the D and lower E region was designed. This routine is based on a selected set of random codes and it gives a 600-m range resolution.

An EISCAT measurement campaign was arranged in November 2002. The UHF, VHF and ESR radars were used, as well as the heating facility. In addition, the optical and VLF instruments were operated, and they were supported by permanent ground-based instruments.

Radar, optical and particle observations were used in auroral studies. A multitude of different aspects in auroral physics were investigated. The arc studies include pre-noon auroral arcs, poleward moving near-noon arcs, the relation of electric fields and field-aligned currents to steadily drifting medium scale arcs in the evening sector, as well as azimuthal expansion of high-altitude arcs. These studies also include physical mechanisms associated with post-noon auroras, evening patches of auroral forms and convection and field-aligned currents within the region of the post-noon oval.



**Figure 4.4.** Left panel: Map of the Finnish tomographic chain with four receivers. The heavy line with an arrow indicates a satellite flight path on 18 Jan 2003 at 1135 UT. Right panel: Ionospheric electron density obtained by a tomographic reconstruction of data received on 18 Jan 2003 at 1135 UT.

Long-term trends in the ionospheric behaviour were investigated in terms of hmF2. It turned out that the trend varies from site to site; for instance at Sodankylä a negative trend of  $-0.4$  km/a was observed, while at Khabarovsk the trend is positive with a value of  $0.57$  km/a. Trends in geomagnetic activity were also studied in terms of the aa index. All phases of the solar cycle show an increase in storm activity since the end of cycle 14 in 1915. The prime cause of this trend is an increase in solar activity.

The Sodankylä Ion Chemistry model (SIC) was modified and extended into a detailed ion and neutral chemistry model of the mesosphere. The steady-state model (containing 55 ion species, 8 neutral species, and several hundred chemical reactions) was used to investigate the effect of the October 1989 solar proton event on odd nitrogen at altitudes between 50–90 km.

Studies of the ionospheric Alfvén resonator were continued both at Sodankylä (high latitudes) and on Crete (low latitudes). The main morphological properties of the spectral resonances in the geomagnetic field at Sodankylä could be explained in terms of the Alfvén resonator. Several new features were found on Crete. The observations could not be explained in terms of the standard Alfvén resonator model and it was concluded that the model requires a revision to be applicable at low latitudes. A numerical simulation of the ionospheric Alfvén resonator was made under non-stationary conditions using ionospheric plasma parameters from EISCAT observations.

Other investigations include research on the mesoscale structure of a morning sector ionospheric shear flow region using Cluster II and MIRACLE observations, studies of Pc1 and IPDP events in ULF observations as well as investigations of the diurnal occurrence of sporadic-E within the polar cap and of the claimed uneven weekly distribution of magnetic activity. Several other studies using Cluster data were initiated.

University of Oulu is in charge of the Finnish Graduate School in Astronomy and Space Physics,

which is a network including all astronomy and space physics units in Finland and sponsored by the Academy of Finland. A total of 12 graduate students receive their financing through the Graduate School, four of them at University of Oulu (two in astronomy and two in space physics).

## 4.2 Solar system research

### **Finnish Meteorological Institute, Geophysical Research (FMI/GEO)**

The solar system research at FMI includes solar system plasma physics and studies of planetary atmospheres. These two fields are closely interconnected both through the direct solar wind interaction with the atmospheres of non-magnetized planets as well as within cometary studies involving dusty environments and ionized and neutral particles. The solar system plasma physics focuses on the space environments of the Earthlike planets Mars, Venus, and Mercury, and recently the Saturn moon Titan, while the planetary atmosphere studies are presently focussed on Mars. The research strategy is based on involvement in the full chain of research processes from instrument design, development and construction to data taking, analysis and interpretation. Special emphasis has been paid to the development of a variety of simulation techniques, which can be utilized at more than one of the planetary environments. All research is conducted in wide international collaboration with scientists from Europe, United States, Russia, and Japan.

The year 2003 began with a big disappointment, when the Ariane-5 problems delayed the launch of ESA's Rosetta mission. The change of the launch to March 2, 2004, forced a change of target comet where the Rosetta lander Philae will land; the final target comet is Churyumov-Gerasimenko. The intervening year was used productively to make the changes required by the new programmatic situation. A taste for cometary data was obtained in late 2003, when NASA's Stardust probed the coma of comet Wild-2. FMI has participated in the CIDA dust analyzer, which recorded details of several dust particles in the comet's environment.

FMI's first PI instrument on an ESA mission was launched onboard the SMART-1 spacecraft in September 2003. SMART-1 is ESA's technology mission to the Moon with a primary objective to test newly developed ion propulsion motors. The SPEDE (Spacecraft Potential, Electrons, and Dust Experiment) instrument monitors the spacecraft plasma environment. When the ion engine is used, SPEDE monitors the outflowing gases and the effects on the spacecraft and its environment. When the ion propulsion is turned off, SPEDE functions as a traditional space plasma instrument providing information on the plasma density and electric field fluctuations. The instrument has been operating since the second day of the mission. Especially interesting results are to be awaited when SMART-1 reaches the orbit around Moon in early 2005.

ESA's Mars Express spacecraft began its 6-month journey to Mars in June 2003, and arrived at Mars during Christmas holidays. The ASPERA-3 ion mass spectrometer and neutral particle detector have already provided observations of escape

of oxygen from the Martian exosphere. These measurements are a key in determining whether water once abundant in Mars has escaped into space or is still bound in the Martian soil. Unfortunately, the Beagle 2 lander did not send any signals back, and thus the mission was left lacking direct measurements from the planetary surface. The group's exploration of planetary exospheres continues with a similar instrument, ASPERA-4, which was delivered for integration into Venus Express to be launched in 2005 to study the atmosphere and exosphere of Venus.

The MetNet prototyping project aims at development of miniaturized landers to carry atmospheric instrument networks to the Martian surface. The project is conducted in close collaboration with the Russian Space Research Institute and Babakin Space Center in Moscow, and is funded by the Russian dept conversion programme. In 2003, a new phase of this study was initiated, which aims at an atmospheric test launch from Siberia.



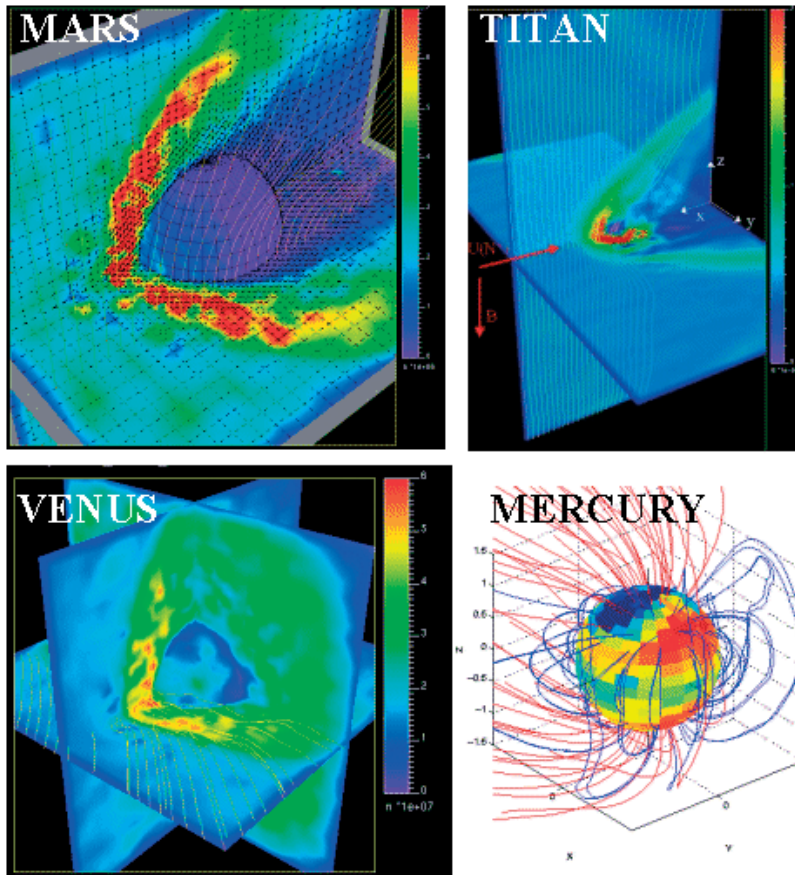
**Figure 4.5.** Artist's view of the MetNet landers.

ESA's next planetary mission will be the Bepi-Colombo mission to Mercury, the planet closest to the Sun. Throughout the year 2003, teams were collected for the various instrument consortia both onboard the planetary orbiter and the magnetospheric orbiter provided by the Japanese space agency ISAS. FMI participated in several of these planning activities, both in terms of instrument hardware and space plasma simulation development to be used for specification of the instrument design. The instrument selection process will take place during 2004.

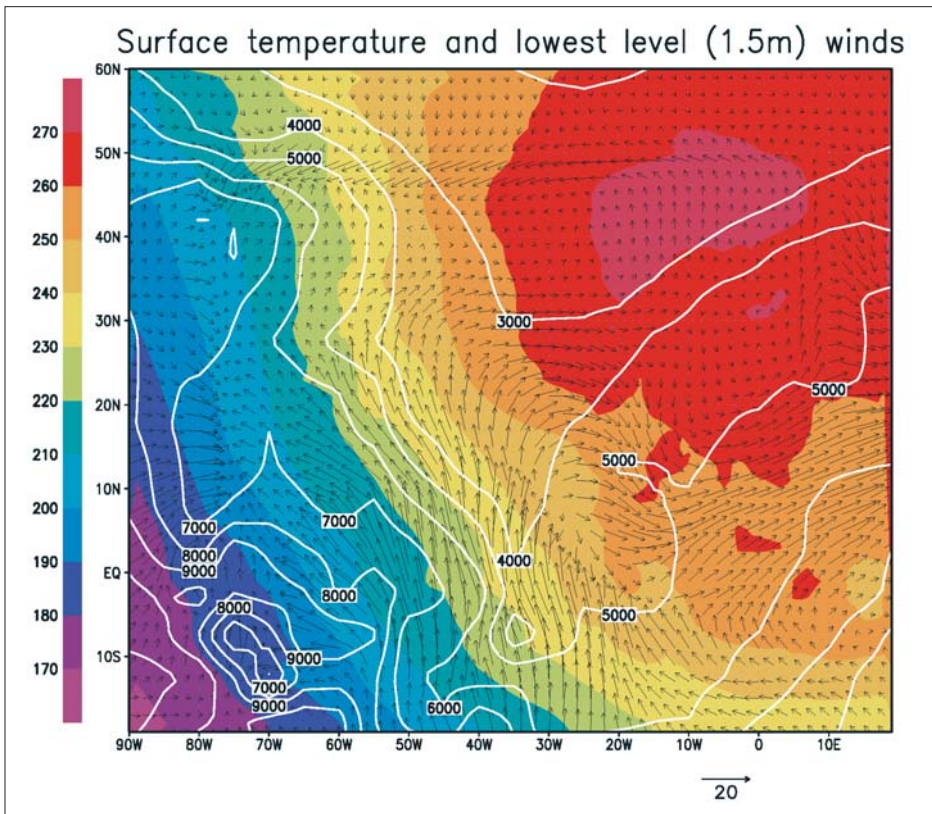
A significant portion of the solar system research was conducted through two projects within the Academy of Finland ANTARES programme, one

concentrating on planetary plasma physics and one on Martian small-scale weather phenomena. Furthermore, an Academy of Finland fellow position has been granted to this area of research at FMI, which has increased the resources in terms of a senior scientist and graduate students.

The planetary plasma physics programme at FMI has been highly successful, with novel results from the Martian environment since the first ASPERA instrument and significant efforts in development of numerical simulation methods for Mars, Venus, Mercury and recently Titan. While the Earth's magnetosphere is sufficiently large for the MHD approximation to be used to successfully, this is not true for the other Earthlike planets. To



**Figure 4.6.** Illustration of the applicability of the quasi-neutral hybrid model to study (Energetic Neutral Atoms around different solar system bodies. They will be measured for the first time at Mars and Venus by ASPERA-3/MarsExpress and ASPERA-4/VenusExpress instruments.



**Figure 4.7.** The MLAM-predicted surface temperature is shown in colour with the surface topography indicated. Horizontal winds are shown by arrows. The area shown includes the plains of Chryse and Acidalia and the northern cleft system of Mars' enormous canyon, Valles Marineris, and both the Viking and Pathfinder landing sites.

appropriately include the motions of the heavier ion species and the effects arising from the smaller sizes of the magnetospheres, hybrid simulations, which treat ions as particles and electrons as fluid elements, have been developed.

The Mars, Venus, Mercury and Titan models will be used to help to interpret data from Mars Express, Venus Express, BepiColombo, and Cassini/Huygens missions, respectively. Furthermore, the recently developed new quasi-neutral hybrid model version makes it possible to study self-consistently complicated space plasma systems that contain single and/or multiply charged ions, neutrals, and heavy (dust) particles. The improved new model version provides therefore several possibilities to study a variety of plasma physical processes that takes place near planets, their moons and comets.

The planetary atmospheric studies were strongly focussed on the Martian atmosphere during 2002–2003. In collaboration with the University of Helsinki, the development of a three-dimensional Mars Local Area Model (MLAM) was continued. The MLAM is based on the local area weather forecast model HIRLAM developed and operated and used operationally in several European countries. Test and research runs have been carried out in Northern hemisphere subtropical and mid-latitude conditions with highly satisfactory comparisons with Viking Lander and Mars Pathfinder observations as well as with other models in the first Mars mesoscale model inter comparison. In addition to MLAM work, a pilot 2-D model study on Mars mesoscale ensemble method applicability was initiated in 2003.

## University of Helsinki, Department of Physical Sciences (UH/PHYS)

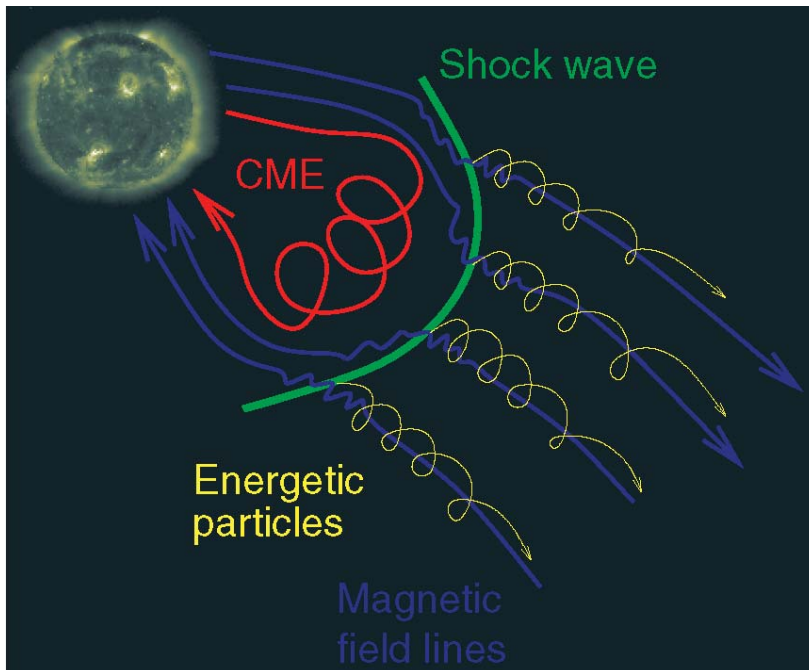
In the field of solar physics the space physics group of the University of Helsinki is concentrating on solar explosive phenomena and their propagation through the interplanetary space toward the Earth. In addition to what was discussed in the section “Magnetospheric and ionospheric research” the role of the CME-related shocks particle acceleration is also investigated in close co-operation with the University of Turku and the University of Bochum. The close relationship between theoretical studies and data analysis of the solar energetic particle observations of the University of Turku has led to significant progress in understanding the role of Alfvén waves in the particle acceleration and heating at the interplanetary shocks. This investigation was also a part of the space weather project in the ANTARES programme.

The meteorology group of UH/PHYS has had extensive co-operation with FMI in the studies of Martian meteorology under the envelope of the MSW project of the ANTARES programme as re-

ported under the FMI planetary research section above. This work is an excellent example where modelling tools for terrestrial purposes have been successfully adapted to use in another solar system environment.

As the space research at UH/PHYS is based on a large variety of skills within a multidisciplinary university department also solid-earth geophysics is involved in studies of the solar system. The group of geophysicists has been active in their research of terrestrial impact events focusing to lake

Suvasvesi South structure which was shown to be of impact origin. This structure is important in the framework of space research since it may form a unique doublet with its northern companion. One of the highlights of planetary geophysics research was the discovery of a new impact structure, Keurusselkä, in south central Finland, by amateur geologists. The group also continued their investigations of the rare Neuschwanstein E-chondritic meteorite and other recently fallen meteorites discovered in Sahara desert.



**Figure 4.8.** Schematic view of the CME-driven interplanetary shock and energetic particle orbits.

## University of Helsinki, Observatory (UHO)

Planetary-system research at the University of Helsinki Observatory (UHO) includes participation in observational, experimental, and theoretical studies on topics relevant to modern solar system science. UHO has two important contributions to the ESA SMART-1 mission: It has a PI status in the XSM (X-ray Solar Monitor) instrument that has been designed and built in Finland. It is used to calibrate the D-CIXS imaging X-ray spectrometer observations, but it also does independent science by providing long time series of coronal spectra of the Sun. The second contribution is in the science validation and interpretation of the visual AMIE camera observations of the Moon.

In the field of solar physics UHO participates in the SUMER spectrometer onboard SOHO. Using this instrument strong microflaring of a solar X-ray Bright Point (BP) was discovered. The magnetic filling factor inside BP was estimated as 10 per cent, similar to the average surfaces of moderately active solar type stars.

In Mars Express, UHO participates in the High-Resolution Spectral Camera (HRSC) experiment at a Co-I-level with the goal of developing new light scattering and radiative transfer algorithms that help in assessing the properties of small particles in the Martian atmosphere. Both SMART-1 and Mars Express were launched in 2003.

Furthermore, UHO participates in the Microgravity experiment ICAPS (Interactions in the Cosmic and Atmospheric Systems) aboard the ISS. ICAPS is now under the phase B study. Microgravity enables a construction of very fluffy structures that are met in the cosmic dust particles.

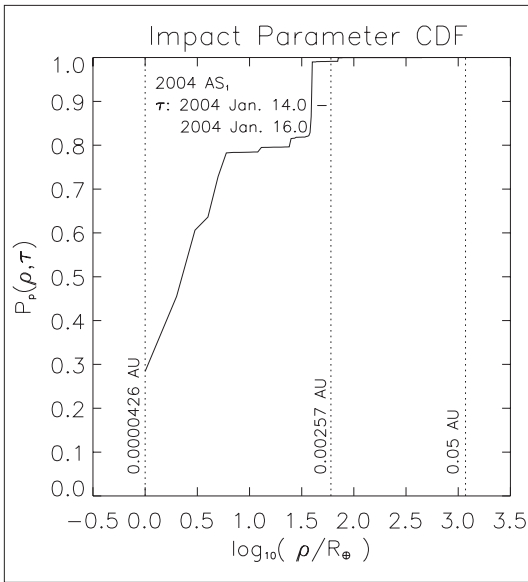
In fundamental planetary physics, UHO theoretical research is focussed on scattering and absorption of light by single small particles and by particulate media, and the celestial mechanics of the few-body problem. Experiments have been carried out to measure backscattering characteristics of particulate media. These measurements have comprised both laboratory and outdoors studies of snow. Recent results indicated that snow shows coherent-backscattering-type enhancement of inten-



**Figure 4.9.** Jyri Näränen and Seppo Heikkilä measuring light backscattering from Lunar analogue material in microgravity.

sity near zero phase angle (backscattering direction). The scatterometer was flown on ESA parabolic flight in July 2003 resulting in first photometric light backscattering measurements performed in microgravity environment.

UHO played a major role in the novel milestone Space Science Series book entitled “Asteroids III”. It lead-authored chapters on asteroid photometric and polarimetric phase effects and on lightcurve inversion of asteroid physical properties. In addition, UHO provided a substantial contribution to the chapter on asteroid orbit computation. UHO has continued its work on coherent backscattering of light by complex random media. Novel lightcurve inversion techniques have resulted in numerous physical asteroid models (e.g., model for the MUSES-C target asteroid).



**Figure 4.10.** On January 13th, 2004, one of the ongoing NEO search programs found a new asteroid, 2004 AS1. It was almost instantly recognized that this 50-meter (estimate at the time) piece of space rock could be on a collision course with the Earth within the next 36 hours. At the discovery moment, the object showed the highest ever estimated probability (almost 30%) for an Earth impact. However, new observations from the night following the discovery were enough to rule out the impact of this asteroid for the next century.

UHO has developed techniques for automated statistical determination of asteroid orbits and UHO is a task-leader in asteroid orbit determination and prediction for the ESA astrometric cornerstone mission GAIA. Particularly, the huge number of observations made by the satellite requires automated and efficient identification algorithms, which are under development.

A comparative, partly semiempirical study of the opposition effects for atmosphereless solar system bodies was carried out using a statistical, inversion-theoretical technique. Studies of the shadowing mechanism for the opposition effect were continued via numerical simulations.

Some of the planetary studies have direct applications in industrial processes. UHO has modelled industrial products like paper coatings for ideal light scattering on order to improve the paper quality. Light scattering by coatings is close to a problem of reflection of light from planetary regoliths. After participating in extensive measurements of scattering matrices (at the Free University of Amsterdam) for atmospheric aerosol particles and, as a pioneering achievement, UHO contributed to a successful interpretation of the measurements using ray optics treatment for Gaussian random particles. That work provides an example of inverse light scattering problems, where particle physical properties are derived from laboratory measurements of their scattering characteristics.

### University of Turku, Tuorla Observatory

Studies of celestial mechanics and few-body dynamics have been continued, with particular emphasis on chaotic motions and unusual Solar system orbits such as the so-called quasi-satellites of Earth and Venus. The numerical integration methods developed for these purposes have also been applied to spacecraft attitude dynamics in collaboration with the Surrey Space Centre (UK). Numerical methods have also been used to study the orbital dynamics of solar sails, in particular gravity-assisted flyby manoeuvres. The results have confirmed the great potential and unique performance of solar sails as space thrusters, especially in near-Sun regions.

The nature of radio-enhanced regions of the Sun has been under investigation using observations with the Metsähovi and Nobeyama radio telescopes, optical observations and data from the SOHO satellite. The radio enhancements appear to be corrected with chromospheric structures. Solar flares and coronal mass ejections have also been studied using X-ray and EUV data together with imaging and spectral observations at various radio wavelengths. Main topics have included the formation and signatures of shock waves, flare and CME precursors, sources of homologous flaring, and evolution of solar bright points.

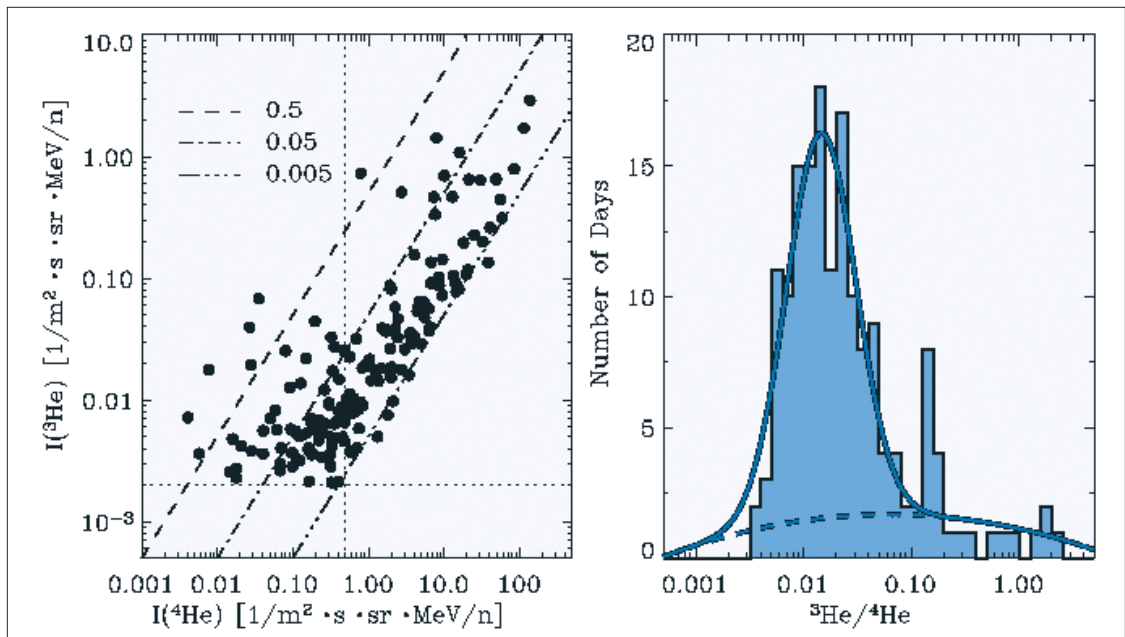
**University of Turku,  
Space Research Laboratory (SRL)**

Solar cosmic-ray studies remain as the main field of research at the Space Research Laboratory (SRL). The ERNE (Energetic and Relativistic Nuclei and Electron) experiment on the SOHO spacecraft continued trustworthily to provide observations of solar energetic particles (SEPs) associated with solar flares and coronal mass ejections (CMEs). Within the Väisälä Institute of Space Physics and Astronomy (VISPA) co-operation with Tuorla Observatory to advance common research of current problems in astrophysics and space science has continued during 2002–2003.

Recent scientific highlights include a discovery of a kind of interplanetary “highway” for SEPs. The ERNE observations of the proton flux anisotropy during the May 2–3, 1998 SEP event indicate that the magnetic flux-rope structure of the CME provides a highway for transport of solar energetic protons. The SEP anisotropy observed in the solar wind near Earth may be related to processes of the solar wind acceleration close to the Sun. There is

increasing evidence that acceleration of the normal solar wind is a result of the reconnection of open magnetic flux with coronal loops. If so, our observations may indicate that the closed flux of the magnetic rope has experienced much fewer reconnections than the open flux of normal solar wind, and for this reason there are fewer small-scale irregularities within CMEs from which to scatter high-energy protons.

Another discovery resulted from a survey of the ERNE observations of He isotopes for the period from 8 February 1999 to 7 December 2000. A histogram of the daily  $^3\text{He}/^4\text{He}$  abundance ratio revealed a common overabundance of  $^3\text{He}$ . We consider the  $^3\text{He}$  overabundance as a signature of impulsive processes during the development of the SEP-productive solar eruptions comprising CMEs and flares. The ERNE registered also less frequent  $^3\text{He}$ -rich events with super high enhancements of  $^3\text{He}/^4\text{He}$ . These high-energy  $^3\text{He}$ -rich events make up a new kind of hybrid SEP events. This group of solar particle events has not been identified in earlier observations. We have developed the first theo-



**Figure 4.11.** Scatter plot of  $^3\text{He}$  intensity vs.  $^4\text{He}$  intensity and the day-number distribution over the  $^3\text{He}/^4\text{He}$  ratio showing that the  $^3\text{He}$  abundance in solar particle events is surprisingly high.

retical model of interplanetary reacceleration of  $^3\text{He}$  that explains main properties of the new group of SEPs.

Theoretical research at SRL included the modeling of the SEP acceleration in solar corona and subsequent propagation in the interplanetary medium to 1 AU. We have performed the first modeling of SEP events inside corotating interaction regions (CIRs). The group has also initiated theoretical studies of coronal heating and acceleration of solar wind by plasma waves. The results obtained from this study have been used in the modeling of the particle acceleration and transport in the heliosphere. The first theoretical results indicate that more efforts are needed to bring consistency between the SEP observations and the models of solar wind. Currently, an improved theoretical model incorporating a more consistent description of the turbulent cascading of the wave energy is under development. Part of the theoretical studies have been conducted in co-operation with Ruhr-Universität Bochum, Germany, under the Academy of Finland and Deutscher Akademischer Austausch Dienst (DAAD) -funded project “Collective Processes in Astrophysical Plasmas: Waves, Heating, and Accelerated Particles”.

The SRL participated in the Space Weather for ANTARES Program (SWAP), funded by the ANTARES program of the Academy of Finland. The goal of the program was to improve the understanding of space weather effects and their predictability. SRL participated in the research by studying the energetic particle production and transport related to the potentially geoeffective CMEs, using both observations from ERNE and other spaceborne instruments, and theoretical considerations. The primary goal was to seek connection between the strength of the potentially resulting geomagnetic storm, and the energetic particle signatures of the solar-terrestrial events. It was found that the time-difference of the onsets of SEPs, accelerated at the Sun, and the energetic storm particles (ESPs), accelerated locally at the CME-driven shock front, correlates well with the storm strength. Properties of ESP events were also compared with theoretical predictions.

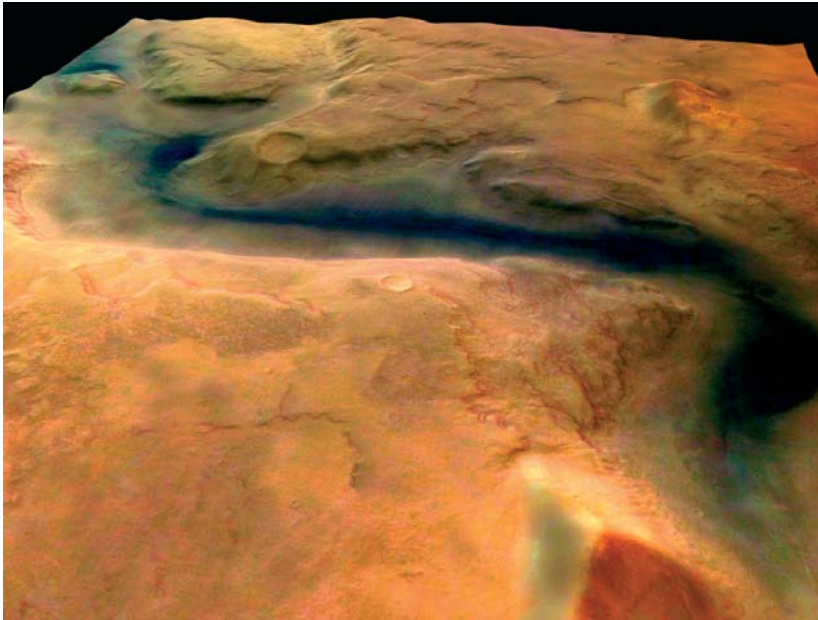
**University Of Oulu,  
Department of Physical Sciences,  
Division of Astronomy**

The Planetology Group of the University of Oulu is the only one in Finland to study terrestrial planets combining mission data and tools from space science, geosciences and remote sensing. The strategy of the Group is to adopt our expertise in the planetology co-work in order to gain a detailed view of the development of the surfaces of terrestrial planets as well as to contribute in the new mission initiatives. Our NASA-related planetary image archive is frequently supplied by the new NASA materials. This provides an excellent environment to participate in the European planetary initiatives and in Mars and Venus research.

The long-term Mars study of the Group is based on our previous research in planetology, geology, geophysics, physics and remote sensing. The Group participates in the Mars Express HRSC team and investigates Mars in detail. The HRSC data analyses have already begun and will continue with the cumulating data set. We will also participate in other European space activities within ESA's planetary initiatives.

Part of the work is devoted to qualitative study of volcanic units and terrains on Venus. The study has given new knowledge of development of morphologically different units. New methods of recognition and morphometry of volcanic features were used. The ESA-proposed future missions to Mars, Venus and Mercury will enrich the project by widening our perspectives into the direction of comparative planetology and by providing further challenges, especially for the young scientists in the Group.

We studied impactites and cosmic materials from the Popigai and Kara impact craters in Siberia and the Smerdyachee crater in central Russia. Impact diamonds and high-pressure mineral phases we identified from Lappajärvi impact crater. Suvasvesi S and Paasivesi were proved to be caused by cosmic impacts. The Saarijärvi pseudotachylites provided an extra proof of its impact origin. Cosmic spherules provided the first discovery of space materials from Novaja Zemlya.



**Figure 4.12.** Mars Express images obtained by the HRSC camera provide high resolution, 3D, and colour coverage over Martian surface. This perspective picture over Reull Vallis on the eastern rim of Hellas impact basin reveals compositional and structural details of the fluvial valley in a way that exceeds the capabilities of previous Martian data sets. The 60 km wide and 12 m per pixel resolution image with blue, green, red and infrared information is only a small part of the HRSC data coverage of the area. (Image credits: ESA/DLR/FU, and Gerhard Neukum and the HRSC Co-Investigator Team.)

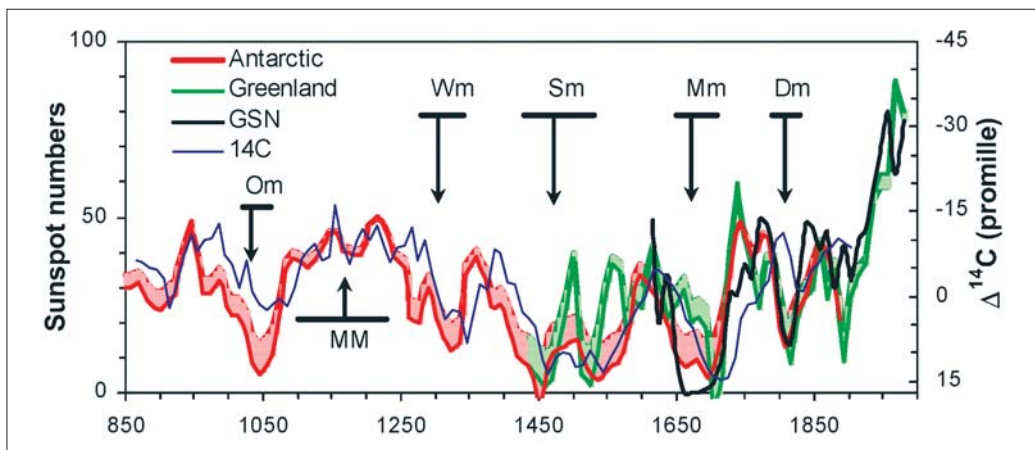
**University of Oulu,  
Department of Physical Sciences and  
Sodankylä Geophysical Observatory**

The Space Physics Group of the Department of Physical Sciences and the Sodankylä Geophysical Observatory of the University of Oulu (in brief: University of Oulu) are active in heliospheric and solar research. This research is mainly directed to the so called space climate which includes the analysis of long-term solar magnetic activity, its temporal behaviour at different time scales and spatial structures, its effects on the global structure and evolution of the heliosphere, long-term properties of the solar wind and interplanetary magnetic field, geomagnetic activity, and cosmic ray intensity.

University of Oulu carries two ground based experiments to measure cosmic rays. Oulu neutron

monitor has continuously measured the cosmic ray intensity since 1964. Its data, available via an on-line database (<http://cosmicrays oulu.fi>), are routinely used both for scientific and educational purposes and for a radiation hazard warning system and the calculation of radiation doses onboard trans-atlantic jets. A multi-level (0 m, 90 m and 210 m underground in the rocky soil) muon experiment in Pyhäsalmi mine, in co-operation within the CUPP project, measures high-energy (above TeV) cosmic rays since 2003.

Galactic cosmic rays are subject to heliospheric modulation, which results in changes in the intensity and spectrum of cosmic rays detected on Earth. Thus variations of cosmic ray intensity can be used to study the large-scale changes in solar/heliospheric conditions. In order to study modulation theoretically, a basic numerical model of cosmic ray transport in the heliosphere was developed.



**Figure 4.13.** Time series of sunspot number (SN) as reconstructed from  $^{10}\text{Be}$  concentrations in ice cores from Antarctica (red) and Greenland (green). Black curve: Observed group SN since 1610. Blue curve:  $^{14}\text{C}$  concentration in tree rings. The arrows indicate the times of Great Minima (Om, Wm, Sm, Mm and Dm) and Maxima (MM).

This model has been successfully applied to study long-term changes in the solar/heliospheric parameters. Using this model in a combination with a solar magnetic flux model, the cosmic ray intensity for the last 400 years was constructed. Inverting the model, the first physics-based reconstruction of sunspot activity since 850 AD was obtained, which shows that the present high activity period is unique for the last millennium.

The long-term evolution of sunspot activity was reanalysed. Sunspots were shown to be preferably formed in two persistent dominant longitudinal regions that migrate according to the Sun's differential rotation, thus making latitudinal and longitudinal distributions interrelated. A new oscillating pattern of north-south asymmetry in sunspot distribution was noted. A new probabilistic method was invented to evaluate the average sunspot activity level from sparse observations, which allows improving the reliability of early data. Thereby new evidence was found for the suggested lost sunspot cycle in the beginning of Dalton minimum. A review of recent developments in the long-term solar cycle evolution was prepared.

The long-term properties of solar wind, interplanetary magnetic field and geomagnetic activity were studied. It was shown that the north-south asymmetry in the solar wind at 1AU results from the dif-

ferent latitudinal gradients of solar wind distribution in the two magnetic hemispheres close to the equator. This leads to the systematic north-south displacement of the streamer belt. It was shown for the first time that the heliospheric current sheet (the ballerina skirt) is not planar but systematically shifted southwards during solar minimum times. This situation is aptly described by the new concept of the bashful ballerina. It was also shown that the dominance of the two IMF sectors at 1AU alternates with a period of about 3.2 years. This is most likely related to a similar alternation in the dominance of the two active solar longitudes. Moreover, periodicities in geomagnetic activity between 1–2 years were studied and their period was found to oscillate systematically and their amplitude was shown to be related to the long-term solar activity.

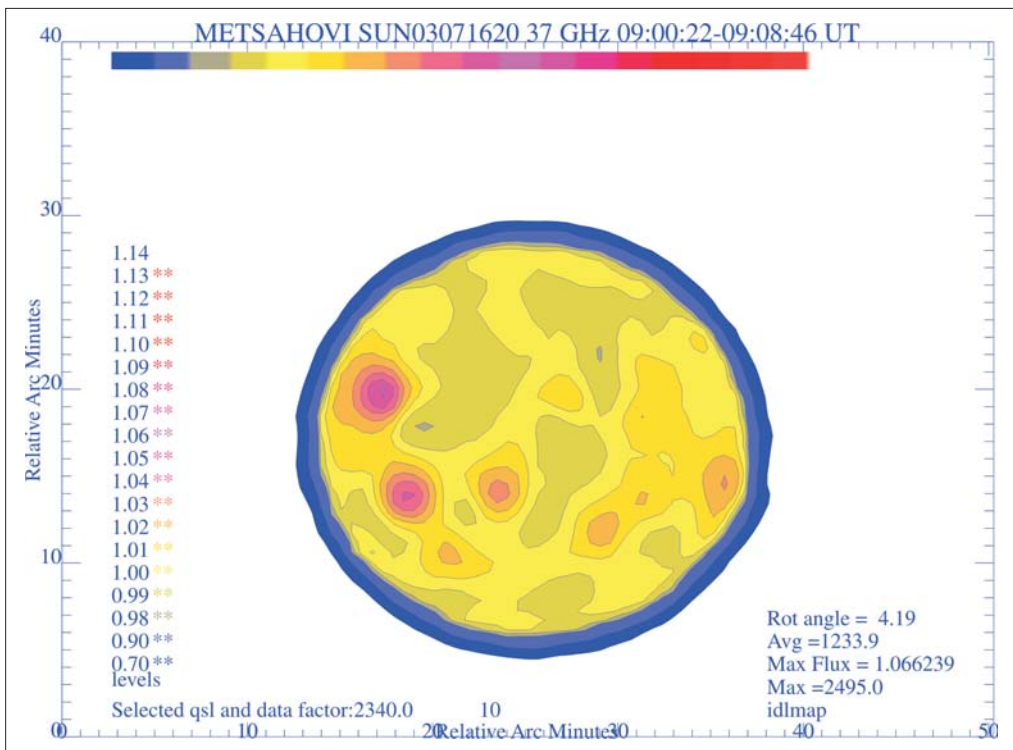
The group participates in the CAPS instrument project of the Cassini mission to Saturn, with the main responsibility in the ion beam sensor (IBS). Calibration runs for the IBS-instrument were compared with simulations for the instrument performance. First measurements by the instrument were obtained for analysis and instrument calibration and testing. All CAPS sensors are functioning as expected. The Cassini probe will reach its destination in 2004.

**Helsinki University of Technology,  
Metsähovi Radio Observatory**

A 14-metre radio telescope at Metsähovi Radio Observatory has been used for solar research. Ground based observations at 22, 37, and 90 GHz have been used in connection with several satellite campaigns. X-ray data from GOES, Yohkoh, and GRO/BATSE satellites have been used in comparison with Metsähovi measurements.

Metsähovi has a Co-investigator status in the ERNE team in the SOHO mission of ESA. SOHO EIT instrument images have been used at Metsähovi in the study of solar polar radio features at millimetre wavelengths.

A dedicated solar monitoring telescope started operation in 2002. System has a 1.8 meter telescope which is used at frequency of 11.7 GHz. Telescope is daily monitoring the whole disk of the Sun and it is sensitive enough to detect solar radio events down to the level of few SFU. The monitoring data of this telescope is used for space weather prediction. Data is also used to study solar radio energy releases in connection with other data from other telescopes, satellites and other wavelength measurements.



**Figure 4.14.** Solar radio map at the frequency of 37 GHz measured at the Metsähovi Radio Observatory on July 16, 2003.

## 4.3 Astronomy

### University of Helsinki Observatory (UHO)

#### High-energy astrophysics

The activities of high-energy astrophysics research at UHO are divided into two parts, fundamental science and development of new instruments. The first part consists of scientific return (guaranteed time) from the instrument projects (INTEGRAL, SMART-1), complemented by data from satellites already on orbit (e.g. XMM-Newton, HST, RXTE, Chandra). The second part is a continuation to the ongoing hardware projects including research also in detector physics.

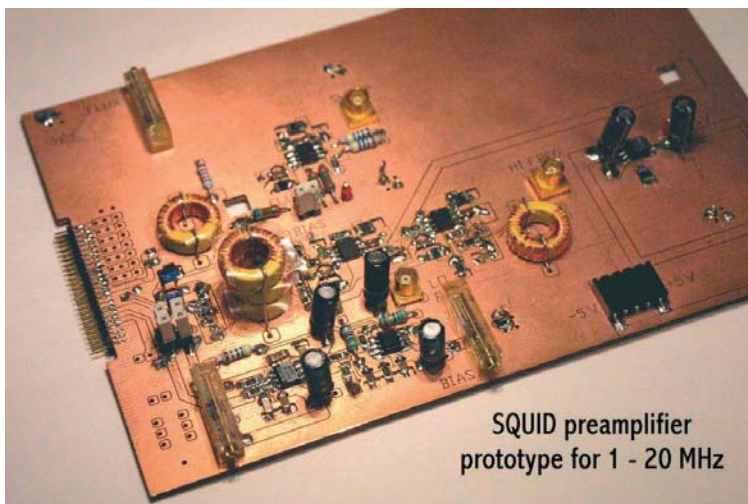
The science topics addressed include accretion discs and superorbital periods of Low Mass X-ray Binaries, multifrequency behaviour of microquasars and AGN's, coronae and flaring in active stars and the Sun, and X-ray scattering from the lunar surface. In particular, the very broad spectral coverage (INTEGRAL and the AGN-collaboration) and the possibility for a very long monitoring (SMART-1 cruise phase), coupled to the sophisticated modelling, are the key ingredients of the scientific programme.

Development of new instruments is a natural continuation to the ongoing projects, where UHO has gained experience, providing valuable access to the guaranteed time also in the future. The aim is to utilise the advances in instrument performances carried along with bigger telescopes, larger field-of-view and decreased noise of new systems in the future plans of ESA (XEUS, LOBSTER), and individual countries (ROEMER/Denmark, HEAWiFM/Finland). The specific improvements are:

- the huge enhancement of sensitivity and spectral resolution with XEUS, which enables studies of X-ray spectra of Galactic sources with the same quality we nowadays can investigate the solar corona, and
- almost full sky field-of-view in X-rays with moderate spectral resolution (LOBSTER/ISS, HEAWiFM)) giving a freedom to select targets of interest and study their temporal and spectral behaviour in all time scales from seconds to months.

The systems under development are:

- cryogenic X-ray microcalorimeter array based on superconducting Transition Edge Sensors (TES for XEUS)
- infrared bolometer array based on the same technology (e.g. for Submillimetron),



**Figure 4.15.** An assembled SQUID preamplifier prototype board. SQUID's have been developed at the Technical Research Centre of Finland for detectors in space astronomy within a project lead by UHO.

- hard X-ray detector array based on a compound semiconductor material (TIBr, for XEUS),
- a position sensitive gas-filled soft X-ray counter for astronomical use, based on a new sensor foil, Gas Electron Multiplier (GEM),
- efficient new type Command and Data Handling (CDH) computers for ROEMER and other potential missions.

The activities of UHO have resulted in the completion of two space science instruments, and a successful launch of INTEGRAL and SMART-1 missions with working hardware onboard. The scientific use of INTEGRAL has already resulted in a number of scientific papers published in 2003. At present, the scientific utilization of INTEGRAL continues.

Preparation for the start of SMART-1 cruise phase science, starting in the beginning of February 2004, is finalized. Observation programs with other satellites (RXTE, XMM-Newton, Chandra) and ground-based telescopes (e.g. NOT, ESO, ATCA) were continued. The activities have also evolved, and grown to a higher level of collaboration with new plans for instruments and satellites, which combine the expertise and experience of UHO and its collaborators. The wide scientific and technological expertise within this framework have made it possible to start planning bigger contributions in international space science programs (e.g. participation at PI level in the next ESA cornerstone mission BepiColombo) and start of planning the first Finnish national scientific satellite (HEAWiFM) based on LOBSTER-optics and GEM-detectors.

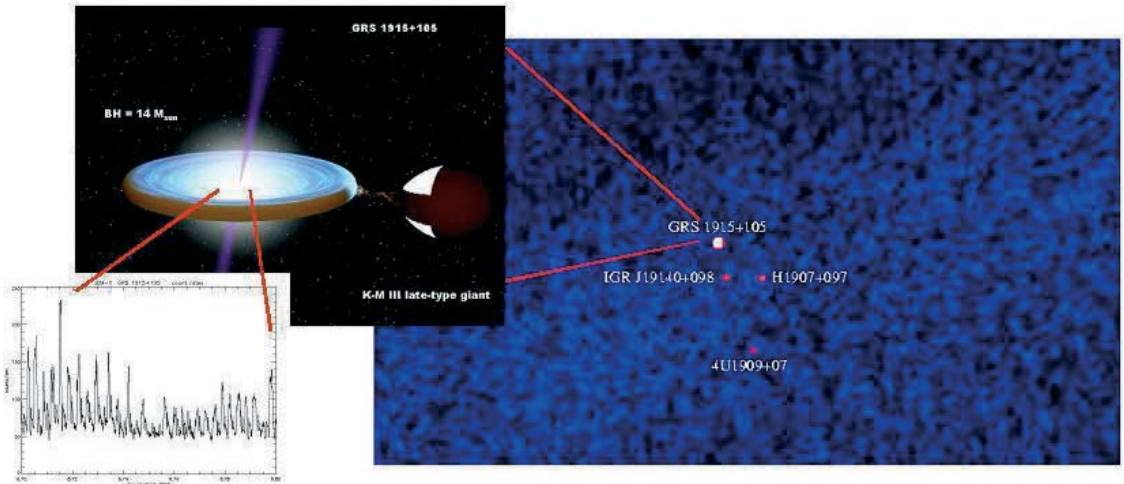
Deciphering the content of the jets from one black hole, Nova Muscae, using old GRANAT data, the UHO group concluded that there must be positrons and electrons (but no protons). It was determined that microquasars behave like quasars not only because of the jets from the vicinity of a central black hole, but also spectrally (in the radio) and temporally, when the radio data from GRO J1655-40 (microquasar) and 3C273 (well-known quasar) was compared.

Genetic algorithms were further developed at UHO and applied to streams and discs of several

magnetic cataclysmic variables and low mass X-ray binaries resolving their spatial structure. A new, versatile disk modelling code was developed, dedicated to exploring long-term periodic changes in the geometry of accretion disks. Light curves of selected short-period X-ray binaries, obtained at the Nordic Optical Telescope, have been shown to exhibit strong morphological evolution on super-orbital time scales. The recent discovery of the shortest period binary system known so far (orbital period 321 sec, using NOT-telescope by HESA group members), has created a wealth of interest in the interacting binary community.

The instrument background of JEM-X/INTEGRAL was determined by the UHO group based on observations of the Crab Nebula during February 2003. One of the brightest sources observed by INTEGRAL, the X-ray binary and microquasar GRS 1915+105 was extensively studied by UHO. The computation of mass transfer from GRS 1915+105 indicated that this 14 solar mass black hole must be a rapidly rotating Kerr-type hole with inner disc radius equal to one half of the Schwarzschild radius (as compared with a 6 times larger innermost stable orbit of a non-rotating hole). In addition the source contains a red giant star. INTEGRAL observations of GRS 1915+105, carried out in March 2003, also revealed a new phenomenon: an X-ray pulse repeating in about a 5-minute cycle. Probably the pulse represents a new type of instability in the disk of gas surrounding the black hole. In the very same images a new transient gamma-ray source IGR J19140+09 appeared during the March 2003 observations. At present this new target is intensively studied at all wavelengths and seems to be a black hole binary.

UHO has been actively involved in the INTEGRAL studies of the puzzling X-ray binary Cyg X-3. This source has effectively eluded all attempts to study its characteristics in detail due to its thick cocoon of dust, expelled by the companion Wolf Rayet-star. However, energetic gamma rays originating close to the compact star can more easily penetrate the cocoon and uncover the core of the binary system.



**Figure 4.16.** Presentation on GRS1915+105. Artists' view of the system (upper left) shows how a part of the hot gas spiraling in towards the black hole is expelled into a two-sided jet moving away from the system close to the speed of light, which is typical for Galactic microquasars. Lower left image shows the lightcurve with 5 minutes oscillation of X-ray brightness. Image in the right is an IBIS observation with GRS1915+105 in the centre. Also a new source, called IGR J19140+098, is clearly seen. Further images at visible light and infrared wavelengths have been obtained to reveal whether this source is another black hole binary, perhaps similar to GRS 1915+105.

### Interstellar medium and star formation

The goals of the Interstellar medium and star formation research group are in basic science, being directed towards the following central problems of today's Astronomy:

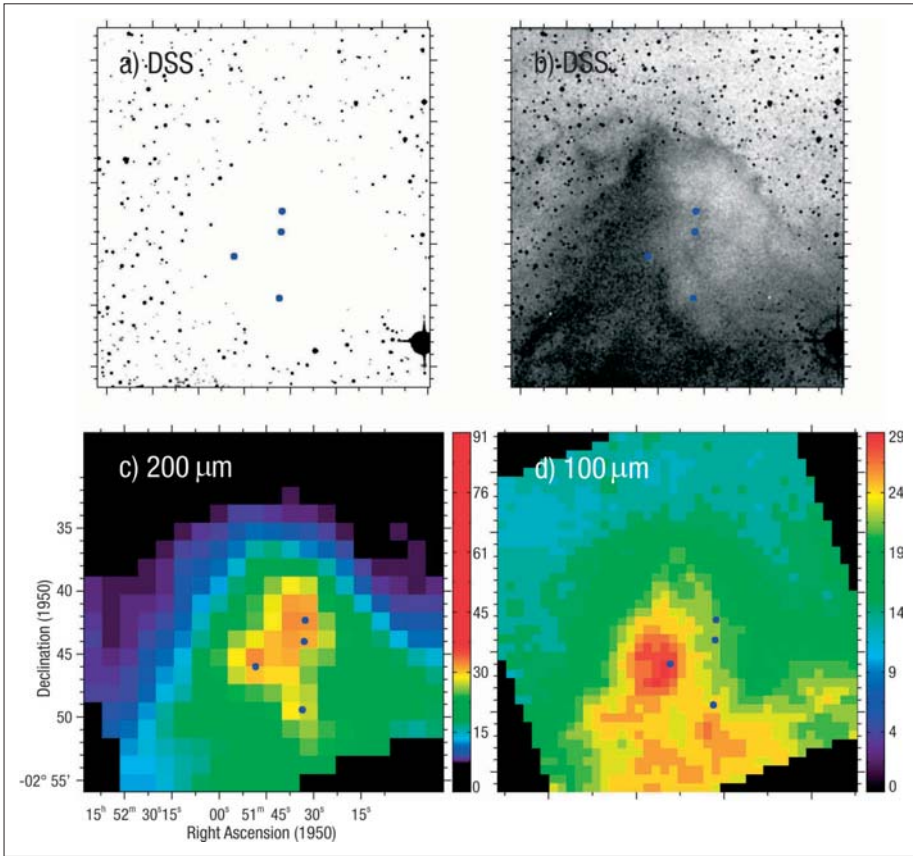
- the evolution of dust and molecular gas in interstellar clouds;
- the formation of protostars in dense molecular cloud cores;
- radiative transfer and magnetohydrodynamic (MHD) modelling of interstellar clouds; and
- star formation history and dust emission at high redshifts.

The group is following a multi-wavelength observational approach where top-class space borne and ground-based infrared, (sub)millimetre, and radio telescopes are being utilized. The two most important facilities for the group have been ESA's Infrared Space Observatory (ISO) and the Swedish-ESO Submillimetre Telescope (SEST) at ESO/La Silla. The launch of the Odin satellite in February 2001 has opened us a new and unique world-class

research opportunity. The more important ground-based radio and optical telescopes utilized by the group include: the 8.2-m ESO Very Large Telescope (VLT), The Australian Telescope Compact Array (ATCA), the Effelsberg 100-m and the Onsala 20-m radio telescopes.

Based on our long involvement in the ISO science projects, we are now participating in Planck Surveyor science projects. Preparatory work and scientific studies are being carried out to ensure immediate and efficient utilization of the Planck satellite data for studies of astronomical objects ranging from external dusty galaxies to local interstellar medium and regions of star formation. The preparations include e.g. development of new analysis tools and gathering of auxiliary data that will be used to aid in studies based on future Planck observations.

During 2002–2003 pre-protostellar and young stellar objects, still deeply embedded in their parental molecular clouds, have been detected and



**Figure 4.17.** Dark cloud L183. Upper row: Optical images from DSS. Lower row: ISOPHOT 200- and 100- $\mu\text{m}$  images. Blue dots indicate point sources.

physically characterised by extensive ISO far-IR mappings of nearby molecular clouds. Interaction between protostellar systems and their immediate surrounding ISM has been studied with the aid of high-resolution interferometric radio continuum observations at the Australian Telescope Compact Array ATCA.

The dynamical and chemical evolution of several nearby molecular clouds and globules have been studied by combining molecular line data from the SEST and Effelsberg radio telescopes with our far-IR dust emission surveys from ISO. Such studies have elucidated the conditions under which dense cores are forming, leading in some cases to further collapse into stars.

We have for the first time observed the distribution and properties of the Unidentified Interstellar Bands (UIBs) at 7.7, 8.6, and 11.3  $\mu\text{m}$  over the whole inner Galaxy, and compared it with our UIB survey of the disk of an external Sb galaxy similar to our own. We have completed an ISOPHOT study of the infrared emission over 3–200  $\mu\text{m}$  in G300.2–16.2, revealing strong abundance variations of the three dust components at different positions of this prototypical diffuse/translucent cloud.

New results on the structure, energy balance, and dense core formation in interstellar clouds have been achieved by applying MHD-modelling and 3-D radiative transfer codes, which have been developed for both the mm-wave molecular spectral

lines and optical- infrared continuum radiation in dust. These include:

1. interpretation and modelling of multi-line mm-wave CO observations of nearby molecular clouds and globules;
2. modelling of CO emission from starbursts in high-redshift protogalaxies;
3. modelling of protostellar core formation via turbulent shocks; and
4. photoelectric heating and spectral line ( $C^+$  158  $\mu\text{m}$ ) cooling models of translucent molecular clouds.

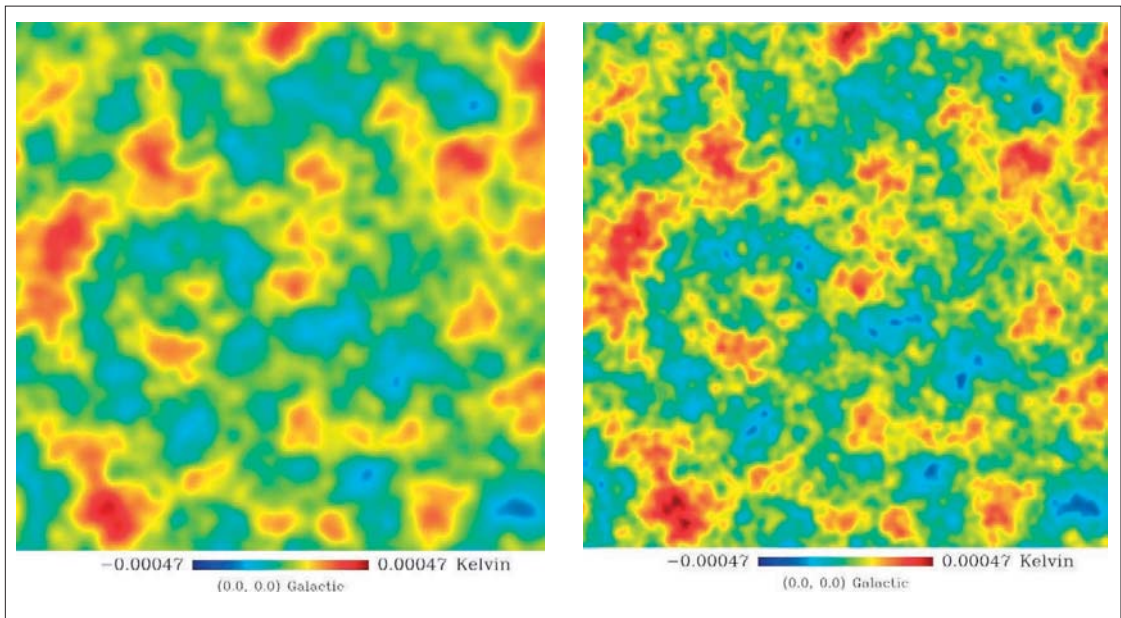
Utilising a wide-field near-IR survey of two ELAIS (European Large Area ISO Survey) fields observed with ISO, we have studied the star formation properties of 97 galaxies using their mid-IR and near-IR luminosities. The fields were also searched for EROs (Extremely Red Objects) and a number of exceptional mid-IR dominated EROs were detected, and were used to constrain models of galaxy formation.

Our group members were involved especially in the following Odin science results:

- Odin has provided a very low upper limit for the  $O_2$  abundance in dark clouds. This low limit is difficult to explain and issues a challenge to chemistry models.
- The central part of the Orion A cloud has been mapped in the ground state rotational line of  $H_2O$ . Various cloud components can be separated in this map. These data give new insights to the formation of  $H_2O$  in shocks and in quiescent gas. The corresponding line of  $NH_3$  has been detected in selected positions in this region.
- The ground rotational state  $NH_3$  line has been detected for the first time in a dark cloud

**University of Helsinki, Department of Physical Sciences (UH/PHYS)**

The participation of UH/PHYS in astrophysical space missions has been based on specific skills either in instrumentation or theory. On both sectors a close co-operation with Finnish and foreign astrophysics groups and with the Helsinki Institute of Physics (HIP) is an essential factor.



**Figure 4.18.** Comparison of the cosmic microwave background images on an area of 10 x 10 arc seconds from the NASA WMAP spacecraft (left) and the upcoming ESA Planck mission. Planck will also have a much better sensitivity, which is important in the determination of the angular spectrum of the polarisation.



**Figure 4.19.** Testing of the Solar X-ray Monitor of the SMART-1 spacecraft in the newly-established clean room at UH/PHYS.

One of the leading fields in theoretical physics at UH/PHYS and HIP is cosmology. During the years 2002–2003 the work of the cosmology group has been strongly guided by the activities within the Planck consortium of the ANTARES programme which is co-ordinated by UH/PHYS and the group’s active participation in the development of the data analysis software of the low-frequency instrument (LFI) of Planck. One of the long-term goals of this work is to understand the origins of the fluctuations after the big bang.

The Division of X-ray Physics and the Instrument Laboratory participate in development of various detectors used in high-energy astrophysics. These include the XSM and the GEM detectors discussed above under the HESA group of the UHO. In 2002 a specific clean room environment was established for space instrument purposes.

**University of Oulu, Department of Physical Sciences, Division of Astronomy**

The main observing effort with the SOFIN spectrograph at Nordic Optical Telescope during the last 10 years or more has been collecting data about the magnetic cycles of active rapidly rotating late-type stars. Nordic Telescope and the dedicated

SOFIN high resolution spectrograph has been ideal for that kind of work, with long observing runs, lasting from a week up to three weeks, sharing nights with different international programmes.

The major finding of these investigations has been the persistent two-spot structure in visible hemispheres, two large high latitude cool areas (spots) situated in opposite longitudes. Moreover, their strength varies in cyclic manner with a few years period, so-called “flip-flop” effect. In addition to the spectroscopic investigations using the Doppler imaging inversion methods, the behaviour is also confirmed by long-term photometric time series.

An advanced imaging technique has been developed and successfully tested with the simulated data and applied to various real observations. Also, recently first calculations have been made of the Zeeman effect of molecular lines, which are formed only in cool starspots and, thus, bear the information on physical conditions in spot interiors.

The recent dynamo models for rapidly rotating stars predict stable non-axisymmetric magnetic fields in form of active longitudes. The active longitudes in the same stellar hemisphere are pre-

dicted to be of opposite polarities. There are, however, no definite measurements of magnetic field strength and polarity of the two active longitudes for such stars. Also, there is no information on polarity changes during stellar cycles.

The effect is observed clearly in the TNG data of Oulu group (Galileo telescope, La Palma) of July 2002, with only two observed rotation phases of that star. In fact the preliminary, low accuracy, data of II Peg in 2002 with SOFIN suggest change of polarity sign during the rotation period.

The 2003 observing runs were concentrated for collecting and analyzing new observations of the object stars with known cyclic behaviour in order to measure the magnetic field strength and polarity of starspots and study evolution of surface magnetic fields. A new cross-dispersion prism and calcite plate installed in the SOFIN increases the order separation and allows for simultaneous recording of two polarization spectra.

The object stars represent a few typical active rapidly rotating late-type stars. Especially, the behaviour of a young, rapidly rotating, magnetically extremely active young solar analogue has also relevance to early solar evolution and its connection to the climate conditions on early Earth.

### **University of Turku, Tuorla Observatory**

Various studies to constrain the nature, distribution and kinematics of matter, as well as the age and the chemical evolution of our Galaxy, have been continued in the ANTARES DARKSTAR project using Hipparcos and Hubble Space Telescope data and computer simulations. It seems unlikely that either massive black holes or white dwarfs contribute significantly to the galactic dark halo. The studies have also enabled a precise indirect measurement of the cosmic production of helium since the Big Bang. The work on galactic kinematics and dynamics will also be extended to the GAIA satellite mission.

Research on active galactic nuclei remains the largest single field of study at Tuorla, with particular emphasis on multifrequency studies of blazars. Much of the work is done in close collaboration

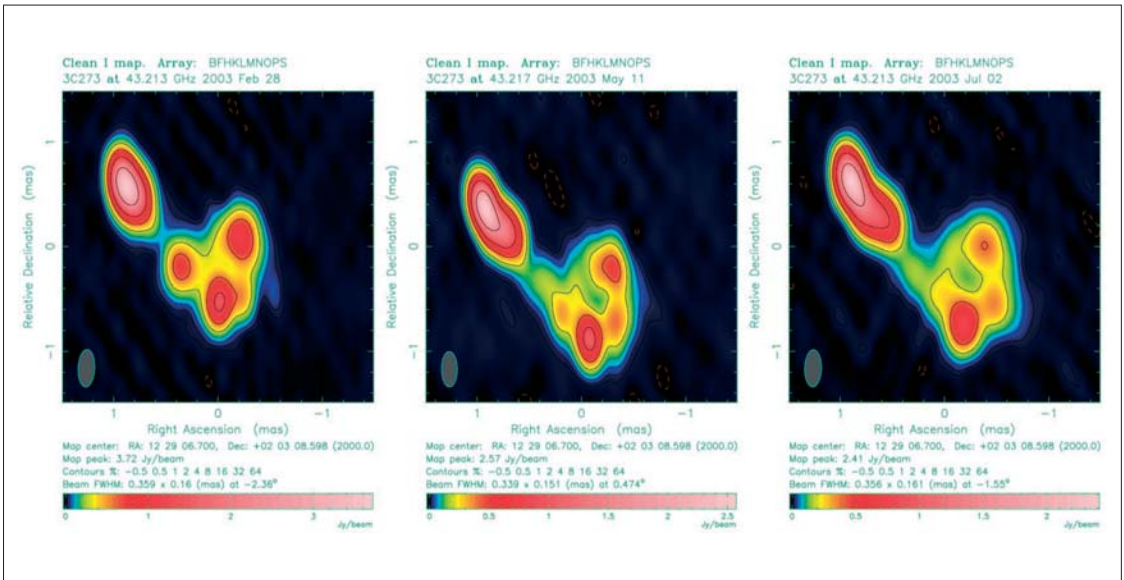
with Metsähovi Radio Observatory. The research is also preparatory work for the Planck satellite, with emphasis on extragalactic point source observations and their removal from the CMB maps (see the Metsähovi part for details). Tuorla is associated with the Planck LFI Consortium.

The main goals of the Tuorla HESA/ANTARES high energy project were to study the high-energy radiation processes in active galactic nuclei using Compton satellite (EGRET) data, to obtain new multifrequency data on AGN and their environments in order to understand the origin of high-energy radiation, to participate in new high-energy projects such as the INTEGRAL satellite and the MAGIC TeV telescope project, and to develop theoretical models for the high energy emission processes and to understand their relation to lower frequency phenomena.

We obtained INTEGRAL data in five large international AGN projects, altogether 1200 kiloseconds. Of these, projects on 3C273 and 3C279 were realized during AO-1, with very large amounts of supporting ground-based multifrequency and VLBI observations, as well as data from Chandra, XMM-Newton, and other high-energy satellites. Analysis of these observations is still ongoing, the main responsibility of Tuorla Observatory being the VLBA observations. We have also joined the MAGIC collaboration as a full member. MAGIC, the world's largest TeV telescope, was inaugurated in October 2003 on La Palma, Canary Islands. The telescope is operated by a consortium of 18 institutes. The main contribution of Tuorla observatory is to provide simultaneous optical observations with the KVA telescope adjacent to MAGIC.

The European Union TMR network ENIGMA (European Network for the Investigation of Galactic Nuclei through Multifrequency Analysis) started its operations in 2002. The first campaigns were organized in 2003: 3C66A (with RXTE satellite joining the campaign), A=0235+164 (with XMM), and 0716+714 (with INTEGRAL). We also obtained VLBA monitoring of the three targets.

Analysis EGRET data has shown that the synchrotron-self-Compton mechanism seems to be very important in strong gamma-ray blazars, contrary to



**Figure 4.20.** Total intensity images showing the inner 2 mas of the 3C 273 jet at 43 GHz at three different epochs (February 28, May 11 and July 2 2003). The ejection of a new component from the core and the advance of the components at about 1.5 mas down the jet are clearly visible. The observations are from the monitoring project carried out with the VLBA during the large multi-frequency campaign, which involved the high energy satellites INTEGRAL, XMM and RXTE.

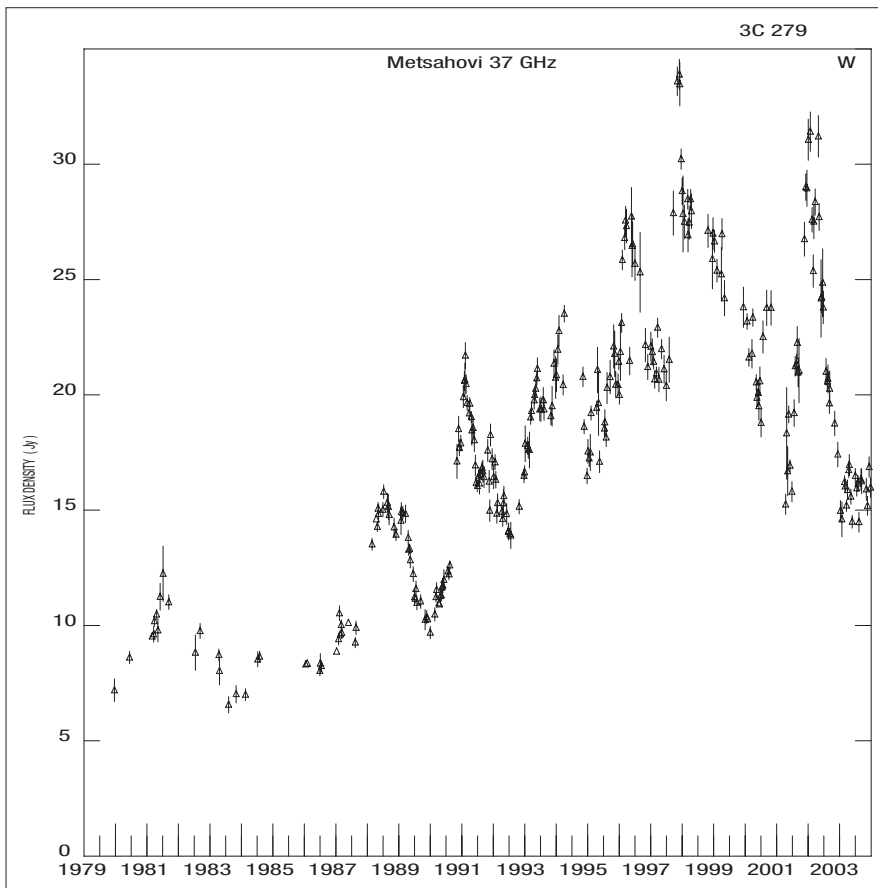
the current paradigm. Theoretical work on shock acceleration and inverse Compton mechanisms and their application to new MAGIC and INTEGRAL data is ongoing. Several research programs have continued to study samples of X- and gamma ray blazars and to monitor their spectra, flux, and polarization to gain an understanding of just what makes these AGN strong emitters. Other programs involve imaging and spectroscopy of AGN host galaxies to study their evolution, interactions, central black holes and their contribution to the infrared background.

Various cosmological investigations have also been continued, with emphasis on the distance scale, the Hubble flow, and the large-scale structure of the Universe. Much of this work is also preparatory for the Planck mission. One particular task, in collaboration with Tarto Observatory, is to develop so-called MLAPM (Multi Level Adaptive Particle Mesh) simulations for comparison with Planck and other survey data.

### **Helsinki University of Technology, Metsähovi Radio Observatory**

Data from Metsähovi monitoring of quasars and active galaxies have been used to select target-of-opportunity sources for X-ray and Gamma satellites. Metsähovi has used data from several satellites (Compton GRO, RXTE, Rosat, ASCA, and ISO) in the study of extragalactic radio sources.

Metsähovi group has studied the relationship between radio and gamma ray emission in active galactic nuclei to find out by which mechanism the gamma-ray emission is produced in these sources and to try to understand why some sources have been detected in the gamma rays. Metsähovi group has used gamma-ray data from the EGRET instrument that was onboard the CGRO satellite, and recently Metsähovi has participated in several observing projects with the INTEGRAL satellite.



**Figure 4.21.** Long-term monitoring of a well-known quasar 3C 279. It is one of the strongest quasars in the sky.

Metsähovi is a member of the LFI consortium, which is building for ESA Planck satellite a set of low frequency receivers. 70 GHz receivers are built in Finland and Metsähovi in receiver building team with the Millilab and Ylinen Electronics. Engineering model of the receiver was manufactured and tested in 2003. The flight models will be delivered in 2004.

Metsähovi scientists actively participate in the preparation for the Planck satellite. The launch is scheduled for February 2007. Currently our largest responsibility is in the development of the Quick Detection System, QDS, which will detect excep-

tionally bright point sources in the satellite data stream within one week from the initial observation. In addition, we are observing new source samples, already over 400 sources observed, for the Planck pre-launch catalogue. These samples include sources that have earlier been seldom observed at high radio frequencies, e.g. gigahertz peaked spectrum (GPS) sources and X-ray BL Lac objects (XBLs). All the data will also be thoroughly analysed, as the knowledge and understanding of the source populations and their properties is of utmost importance for the Planck mission.

## Millimetre Wave Laboratory of Finland (MilliLab)

Millimetre Wave Laboratory of Finland – MilliLab is a joint laboratory between VTT, Technical Research Centre of Finland and HUT, Helsinki University of Technology. MilliLab is also a European Space Agency Centre of Competence called *ESA External Laboratory on Millimetre Wave Technology*. MilliLab was established in 1995. Its main purpose is to support European space industry to meet the demands of future ESA missions, which will include an increasing number of millimetre wave instruments for astronomical and remote sensing applications.

MilliLab supplies services at millimetre wave frequencies in the field of device modelling, device characterisation, measurements, testing, research, and development. The parent organisations of MilliLab, VTT and HUT have a substantial amount experience and expertise in the field of microwave and millimetre wave technology. The total research personnel with experience in millimetre waves is over 25.

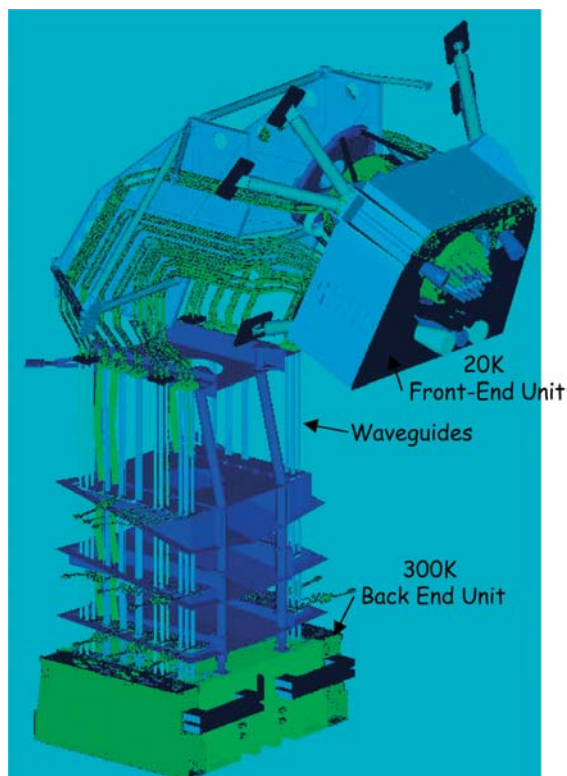
A low noise receiver for the ESA Planck-mission and an antenna test method for future mm-wave space telescopes are the main development projects in MilliLab, related to space applications. In the Planck Low Frequency Instrument (LFI) MilliLab's responsibility together with Ylinen Electronic Co. and Metsähovi Radio Observatory is to design and construct the 70 GHz receivers. In order to obtain maximum sensitivity, the receiver is divided into a front-end cooled to 20 K and a 300 K back-end. The most vital parts of the receiver are the Low Noise Amplifiers (LNA) to be realised by utilising the InP MMIC technology. The use of integrated circuits is important due to the large number of receivers in the LFI. Altogether 12 identical back- and front-end receiver chains will be made in Finland.

Presently at 70 GHz, development of the Elegant Breadboard Model (EBB) has been finished and designing, manufacturing, and testing of the Engineering Model (EM) is being completed. Furthermore, manufacturing of the Flight Model (FM) has been started and will be completed in Fall 2004. With the EBB, extremely low noise temperatures

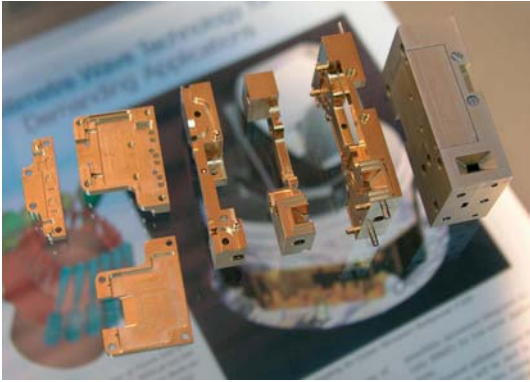
have been obtained. A front-end receiver noise temperature between 20–30 K has been measured over most of the required 63–77 GHz band.

The main scientific goal for European Space Agency's Planck mission is to measure Cosmic Microwave Background (CMB) radiation anisotropy. A consequence of the unprecedented angular resolution (10 arc minutes at 100 GHz) and the measurement sensitivity of the background radiation ( $\Delta T/T \approx 4 \times 10^{-6}$ ) is the possibility to uncover the wealth of cosmological information encoded in the anisotropy pattern.

In addition to the 1.5 m telescope and LFI, the Planck spacecraft will have the High Frequency Instrument (HFI) on board. The LFI comprises receivers for 30, 44, 70 and 100 GHz frequencies. The HFI, for its part, has receivers for frequencies of 100, 143, 217, 353, 545 and 857 GHz using bo-



**Figure 4.22.** Planck Low Frequency Instrument (LFI). The active parts of the LFI 70 GHz channel will be built by the Finnish team.



**Figure 4.23.** Half of a LFI 70 GHz Front-End Module (FEM) developed by MilliLab, Ylinen Electronics Co., and Metsähovi Radio Observatory. This compact match box size component houses four MMIC low noise amplifiers and two phase shifters. The total gain is 35 dB. Also, a small horn to the 4 K reference load is included.

lometers. Planck will be launched to the sun-earth synchronous L2 orbit in the end of 2007 together with the Herschel spacecraft.

Related to international collaboration and networking, one highlight of the year 2003 was the 3<sup>rd</sup> ESA Workshop on Millimetre Wave Technology and Applications, an international conference hosted by MilliLab, HUT, VTT and ESA/ESTEC, and held in Dipoli, Espoo on 21–23 May 2003.

### **Helsinki University of Technology, Radio Laboratory**

The HUT Radio Laboratory has carried out research in satellite application oriented antenna measurement techniques and instrumentation development at millimetre and submillimetre wavelengths. This work has been done together with MilliLab. The main focus has lately been in developing the hologram based compact antenna test range (CATR). As a major milestone in a project for ESA/ESTEC, in summer 2003 the radiation pattern measurements of ADMIRALS RTO (representative test object) large reflector antenna were successfully carried out at 322 GHz in a large hologram CATR realised in HUT premises.



**Figure 4.24.** A 3 m submillimetre wave hologram developed for 1.5 m diameter ADMIRALS Representative Test Object (RTO) telescope tests at 322 GHz. The same method is planned to be used for testing the Planck Telescope. In the photograph, ESA representatives and the research group are also shown.

## 5 Applied Space Research

### 5.1 Space geodesy

#### Finnish Geodetic Institute (FGI)

The Finnish permanent GPS network FinnRef® consists of 13 GPS stations. The network is the backbone of the Finnish realisation of the European-wide reference frame EUREF, referred as to EUREF-FIN. Four stations in the FinnRef network belong to the *EUREF permanent GPS-network* (EPN), and one station belongs to the network of the *International GPS Service* (IGS). Through these stations FinnRef® creates a connection to the global reference frames and the stations are used for maintaining global reference frames and global geodetic studies. The FinnRef® is also used for local studies on crustal movements as well as a reference for local and national GPS measurements. Determination of land uplift, but also studies on periodic effects on data, as well as deformation studies due to loading effects have been made using the permanent network.

GPS Virtual Reference Station (VRS) method was tested in 2003. The VRS concept has been used since 2000 in Finland and nowadays there are two different networks operational. A private Finnish company Geotrim Ltd. has started to establish a network to provide VRS service. Results of the extensive tests, covering accuracy and reliability of the method will be published in 2004.

A study on the usage of gravimetric satellites CHAMP, GRACE and GOCE in geoid determination, and space-borne geoid model accuracies in Finland was made. FGI has the co-investigator status of the CHAMP satellite. Co-operation with the University of Stuttgart continued, partly funded by the Academy of Finland.

The Metsähovi research station has become an essential part of the activities of the FGI. Currently, it is globally one of the most versatile space geodetic stations. The instrumentation covers the satellite laser ranging (SLR), geodetic VLBI, GPS and GLONASS receivers, DORIS beacon, supercon-



**Figure 5.1.** Geodetic VLBI observations were prepared in co-operation with the Metsähovi Radio Research Station of the Helsinki University of Technology (left). Metsähovi Satellite Laser Ranging facilities (right). (Photos M. Poutanen)

ducting gravimeter, seismometer and the fundamental absolute gravity point. The Metsähovi SLR continued its operation. During the year 2003 a total of 817 orbits of 17 satellites were observed. The development of the SLR was continued in a co-operation with the University of Latvia, Riga. Limited daytime observations were initiated. Metsähovi SLR is a part of the ILRS (International Laser Ranging Service) network. The Metsähovi GPS station continued as a part of the Finnish permanent GPS network, FinnRef. Data were submitted to the European permanent GPS network computation as well as IGS network. Also, data from Javad/Legacy GPS/GLONASS receiver were submitted to the GLONASS data centre for the IAG IGLOS (International Association of Geodesy GLONASS project). As a co-operation project with the Metsähovi Radio Research Station of the Helsinki University of Technology, preparations for geodetic VLBI installation were continued. First tests were made in 2003, and a regular observation schedule as a part of the IVS (International VLBI Service) network is expected for the year 2004.

Investigation of local crustal motions contained in a contract with Posiva Oy was continued on the candi-

date sites for final nuclear waste disposal. The local networks at Olkiluoto, Kivetty and Romuvaara were measured with GPS. Deformation studies made at Nuottavaara / Pasmajärvi region in Finnish Lapland was published. A new project under the umbrella of Geo-Satakunta was initiated. The purpose is to study crustal stresses in the Satakunta area. Other partners in the study are the Geological Survey of Finland, City of Pori, Posiva, and Rockplan Ltd.

Studies on periodic variations on the time series of the Finnish permanent GPS stations FinnRef were continued. This is in connection of the work made for the rebound studies with GPS and repeated levelling. The periodicity of GPS time series degrades the accuracy and resolution. Additional information using data of Metsähovi superconducting gravimeter, and ocean and atmospheric loading were used.

An international co-operation in project BIFROST (Baseline Inferences for Fennoscandian Rebound Observations, Sea Level and Tectonics) was continued. This is a co-operation project between the Massachusetts Institute of Technology, University of Toronto, University of Durham, Chalmers University of Technology, National Land Survey



**Figure 5.2.** Antenna mast of the Finnish Antarctic permanent GPS station. (Photo H. Koivula)



**Figure 5.3.** Working with the modernisation of the coordinate system near Lappeenranta.

of Sweden and the Finnish Geodetic Institute for better understanding the rebound process and to constrain the lithospheric structure and ice models.

A permanent GPS station at the Finnish Antarctic base Aboa was made in the beginning of the year 2003. During the next field expedition 2003/2004, the data of the whole year were collected, and a remeasurement of the absolute gravity was made. Using data from repeated absolute gravity measurements, GPS and local kinematic GPS determination of snow/ice changes, allows us later to estimate the direction of the vertical crustal motion and the behaviour of the surrounding glacier.

In co-operation with ESA a Ranging and Integrity Monitoring Station (RIMS) of the European Geostationary Navigation Overlay Service (EGNOS) was established in Virolahti, Finland. RIMS will ensure the quality of the EGNOS service in Fin-

land. The station is now in test operation. The development of a system to receive the EGNOS signal using a pocket PC was made under an ESA contract. The development work is important for the EGNOS users in Nordic countries because it will make it possible to access the EGNOS services on the fly over the wireless network and the Internet, without the limitation of the low elevation angles to the geostationary satellites

**Helsinki University of Technology,  
Department of Surveying**

In May 2003 HUT's Surveying Department's Institute of Geodesy was commissioned to re-measure (modernise) the base network of the city of Lappeenranta. This included the determination of transformation parameters from the local system to kkj (National Map Grid Co-ordinate System) and to the geocentric EUREF-FIN.

## 5.2 Remote sensing

### **Helsinki University of Technology, Laboratory of Space Technology (LST/HUT)**

The Laboratory of Space Technology at the Helsinki University of Technology is the only academic institution in Finland where it is possible to have an academic degree in space technology. The special field of interest of the laboratory is microwave remote sensing. The development of remote sensing equipment and data processing algorithms is mainly the responsibility of undergraduate and postgraduate students. The laboratory also participates in different remote sensing projects in collaboration with other academic and industrial partners. A short summary of completed and ongoing projects is below.

Snow Covered Area (SCA) estimation using space borne radar has been assessed with ERS-2 SAR and ENVISAT ASAR Data. The analysed SCA method has been developed at HUT Laboratory of Space Technology, and as a part of implementing the method for operative hydrological use, the statistical accuracy of the SCA method has been analysed. The results show reasonably high statistical accuracy for the method, and the evaluation of the method for different Space-borne radar image products is underway.

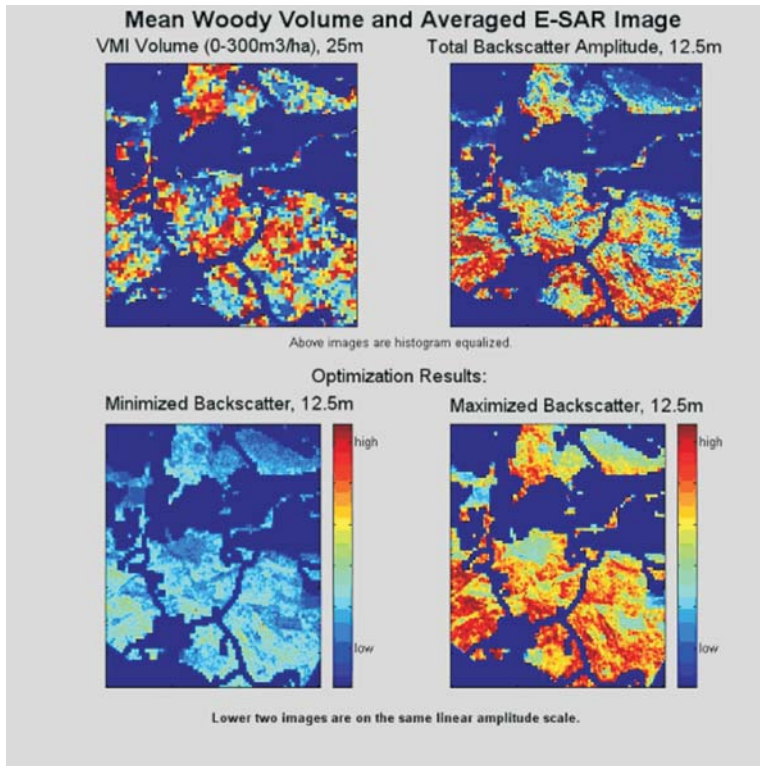
It is essential for winter shipping in the Baltic Sea to get reliable and up-to-date information of the rapidly changing ice conditions. Satellite SAR images are the only way to produce operational sea ice information in fine scale independent of daylight and weather conditions. ENVISAT ASAR increases the selection of different SAR images compared to RADARSAT-1 and ERS-2 by providing also e.g. cross-polarization images. New possibilities of ENVISAT ASAR are studied using selection of images acquired in 2003–2004 and with ground truth data and helicopter-borne scatterometer data acquired during a field campaign in February 2003. Automatic classification algorithms for the SAR images are developed and their usability is validated. Classifications are also delivered to the users at sea. Project partners are Finnish Institute of Marine Research, Laboratory of Space Technology of HUT (LST) and Technology

Development Centre. The project started in 2003 and lasts till mid 2005. It is funded by Tekes. LST compares empirical backscattering signatures of various ice types to theoretical backscatter models to find out dependencies between various physical sea ice parameters and backscattering signatures. This information can be utilized in the development of the SAR classification algorithms. LST also studies how spatial statistics of empirical backscattering signatures depend on the distance (fractal-like variation of backscattering coefficient) and whether this dependence can be utilized the SAR image classification.

Several projects of LST/HUT are dealing with the monitoring of boreal forest zone. The seasonal cycle and variations in liquid water content of trees and soil moisture have been investigated using SAR data in a Tekes-funded Envisat AO-project together with the Department of Forest Ecology of UH and the Institute of Photogrammetry and Remote Sensing of HUT.

In addition to water area monitoring applications, the project ASSIMENVI that has been part of the national ANTARES programme is concerned with the soil and snow hydrological processes. Especially, in the field of remote sensing of snow, new methods to apply Earth observation data together with ground-based information have been developed. The main co-operative partner in the ASSIMENVI project is SYKE. Within the ANTARES programme LST/HUT leads the Modafor (New Modeling and Data Analysis Methods for Satellite Based Forest Inventory) consortium. The Finnish partners in the project are Rolf Nevanlinna Institute (RNI), National Forest Institute (NFI) and Helsinki School of Economics.

Polarization analysis for forestry purposes has been studied, by comparing remotely sensed radar data in Kirkkonummi, Finland, to optical, satellite-based forest inventory results. Various polarimetric and forest parameters were studied. A theoretical polarization optimization method was developed. Polarimetric data improved the separability of different forest types. It seems that the feasibility of a single-polarization radar data may highly be dependent on the selected polarization states.



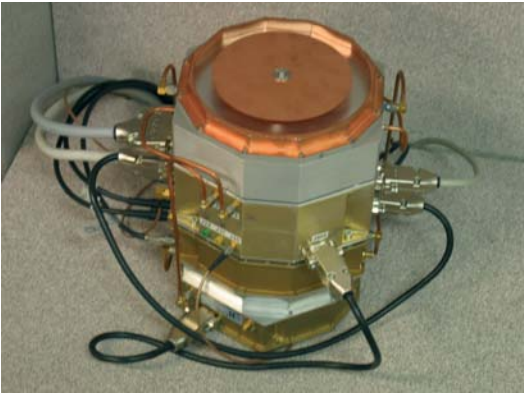
**Figure 5.4.** The Finnish National Forest Inventory (VMI) information on woody volume in comparison to total and optimized backscatter at L-band. The volume is divided into 2 m<sup>3</sup>/ha classes with a resolution of 25 m. The resolution of the radar image is 12.5 m.

LST/HUT has been involved in the various European Space Agency's SMOS (Soil Moisture and Ocean Salinity) satellite instrument demonstrator projects. The prototype of the instrument section was tested as a part of the MIRAS Pilot Project (Microwave Imaging Radiometer by Aperture Synthesis). Currently the SMOS mission is in phase C and HUT is participating in it as a subcontractor of Ylinen Engineering Ltd. Together with Ylinen HUT is responsible for the SMOS calibration subsystem and the noise injection radiometers used as reference receivers. The final instrument will consist of 69 L-band receivers in Y-shape geometry. The imaging instrument is based on the principle of aperture synthesis. The launch is scheduled for the year 2007.

HUT is also constructing an airborne radiometer similar to the SMOS satellite instrument in order to demonstrate the SMOS mission technology and to

develop data retrieval algorithms. Project is currently funded also by ESA. The airborne instrument is in the final phase and a test flight with the prototype section has been conducted.

LST/HUT is building the reference radiometer of the MIRAS (Microwave Imaging Radiometer by Aperture Synthesis), the principal instrument of the SMOS satellite, in cooperation with Ylinen Electronics Ltd. Laboratory of Space Technology has also built and tested the prototype of the reference radiometer in cooperation with Ylinen Electronics Ltd and Toikka Engineering Ltd. The purpose of the reference radiometer is to work as a reference in two aspects. It measures the average scene brightness temperature for MIRAS image map calibration and the internal calibration source of MIRAS for the calibration of individual receivers of MIRAS. Therefore the performance of the reference radiometer is a decisive factor of the

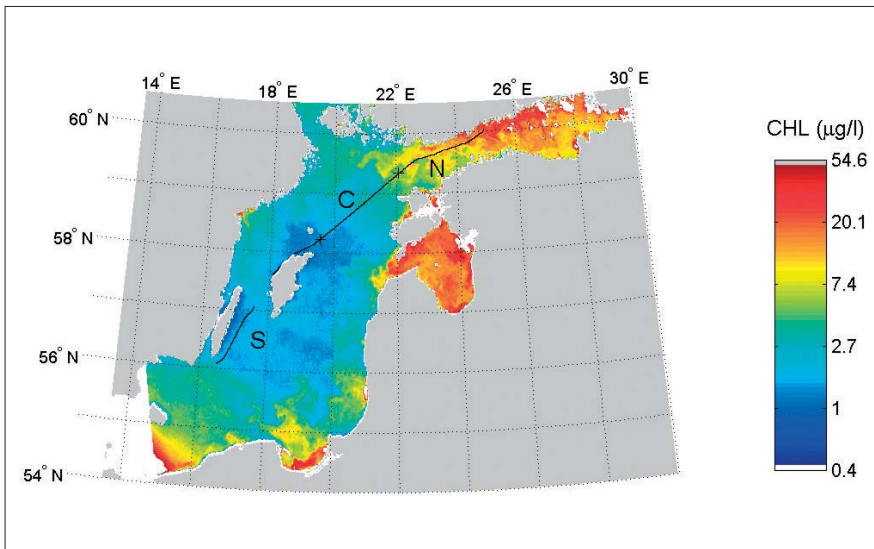


**Figure 5.5.** Prototype of the reference radiometer of MIRAS, an instrument of the SMOS satellite.

MIRAS performance. Scientific goals of the SMOS mission are technically challenging and the experience of the LST/HUT on microwave radiometers has made it possible to implement properties into the reference radiometer that are previously unprecedented.

The topics of the projects ASSIMENVI and OILI at the LST/HUT include the satellite-based monitoring of lakes and the Baltic Sea, in order to obtain information on water quality and to detect oil spills. The most important water quality characteristics measurable with optical space-borne instruments include the turbidity of water and chlorophyll a concentration that is directly related to algae biomass. Also the spatial mapping of surface floating algae blooms is an important application investigated in the ASSIMENVI project. The mapping of oil spills is possible with microwave SAR. This is investigated in the conditions of the Baltic Sea using Radarsat data in the project OILI. The methodologies developed in projects include new techniques to assimilate remote sensing data with distributed in situ reference information. The main research partners are the Finnish Environment Institute (SYKE) and the Finnish Institute of Marine Research (FIMR).

The traditional method used in the water quality classification of Finnish lakes includes the collec-



**Figure 5.6.** Chlorophyll a mapping for the Baltic Sea using assimilated SeaWiFS and Alg@line transect for May 20, 1999. The ship-of-opportunity transect observations are depicted by black line (regions S, C and N were used in algorithm testing). Clouds, missing data and coastal areas are depicted by white colour; masked-off land areas are shown by grey, respectively (a co-operative effort of LST/HUT, SYKE and FIMR)

tion of water samples and their laboratory analysis. Our results show that it is possible to acquire similar classification by reducing the amount of expensive fieldwork and laboratory analyses by using radiance values measured with the EOS Terra/Aqua MODerate resolution Imaging Spectroradiometer (MODIS).

The EnviSnow project started in January 2002 and will end in early 2005. The main goal of the project is the development of satellite-based methods for monitoring snow cover in Europe. The EnviSnow project will contribute to future progress in hydrological modelling and water management by developing, validating and bringing into operational use multisensor and multitemporal algorithms for satellite data and products applicable both for regional and global snow mapping.

The availability of adequate remote sensing data is essential for satellite-based model development and validation in hydrology. LST/HUT has developed algorithms to analyze snow and forest characteristics with laboratory's own airborne instruments, the data of which are directly comparable with ENVISAT ASAR-radar and MERIS-spectrometer data, as well as TERRA MODIS-spectrometer data.

Extensive field campaign activities have been performed in the winters of 2002 to 2004. LST/HUT conducted several airborne field campaigns in Finland using the AISA (Airborne Imaging Spectrometer for Applications) spectrometer onboard HUT research aircraft and HUTSCAT scatterometer onboard a helicopter.



**Figure 5.7.** Remote sensing of melting snow characteristics in May 2004 in Sodankylä boreal test site located in Northern Finland at latitude 67 N. Concurrent ground truth measurements and AISA imaging were carried out during snow melt period. AISA optical true colour image is obtained from an altitude of 1 km.

**Helsinki University of Technology,  
Institute of Photogrammetry and  
Remote Sensing**

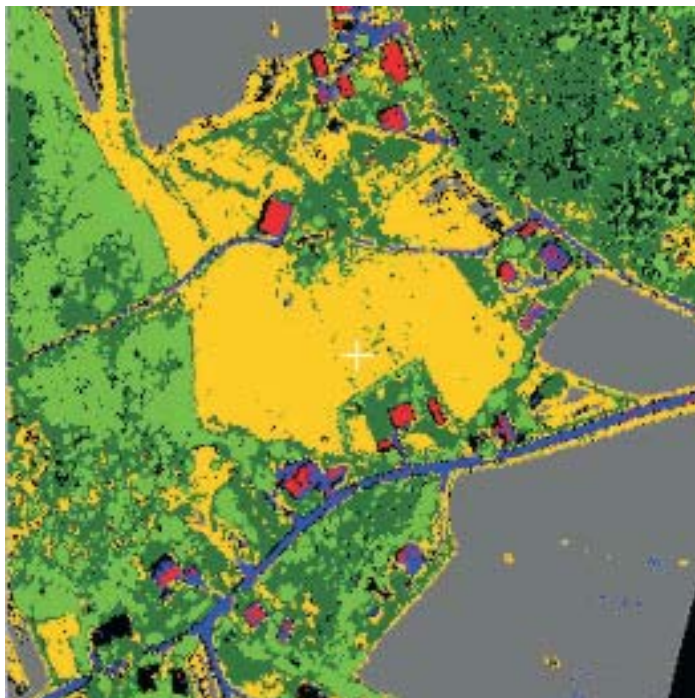
Photogrammetry and remote sensing are technologies of measurement, observation and control within the science of surveying and mapping. Basically, all activity is based on images used for both acquiring and managing geoinformation. The applications include environmental monitoring with satellite imagery, large-scale urban mapping with aerial imagery, 3D virtual modeling of buildings, industrial plants, and natural environment. The number of researchers on a pay-roll is about 20 persons, half of us being active postgraduates as well.

Our major interest and research topics are in image analysis and pattern recognition, photogrammetric mapping, digital photogrammetry, classification methods, automated measuring procedures, and system development for photogrammetric on-line control and 3-D digitizing. Our institute is a research unit with a remarkable national reputation and it is also internationally recognized from

works on areas such as application of laser scanning on rural and urban environment, three-dimensional digitizing using video imagery, use of projective transformations for analytical photogrammetry, networking of parallel processes in geometrical image analysis, and use of neural networks in classification of image information.

Our focus areas in remote sensing technologies have been:

1. Evaluation and utilization of terrestrial photogrammetric validation methods for airborne and satellite based operational glacier monitoring
2. 3-D modeling of archaeological landscape and excavation site
3. Quality Assessment of Laser Scanning data in urban areas.
4. New geodetic applications for INSAR and Permanent Scatterers techniques
5. Envisat
6. New classification methods for AISA hyperspectral images.



**Figure 5.8.** Classification and analysis of imaging with AISA spectrometer.

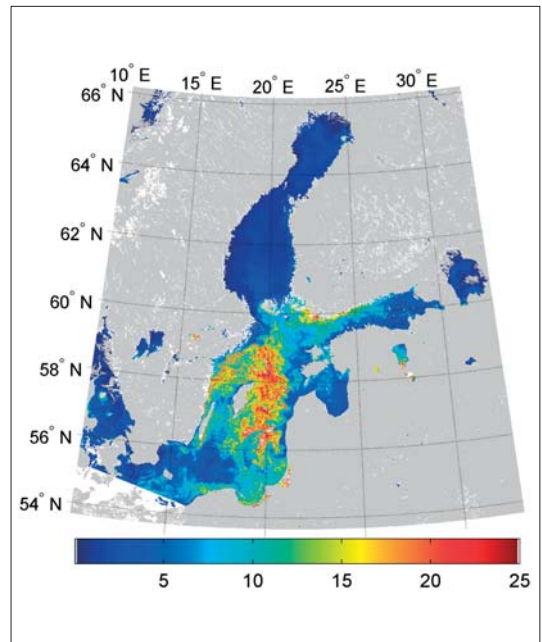
### **Finnish Environment Institute, Geoinformatics and Land Use Division**

The Finnish Environment Institute (FEI) is both a research institute, and a centre for environmental expertise serving whole Finnish environmental administration, local authorities, general public and private industry. The Geoinformatics and Land Use Division (GEO) looks after the Finnish Environmental Administration's geographical information systems and remote sensing data, while also maintaining and developing information systems related to land use in Finland. There are 30 people working at GEO, whom 8 people are dealing with remote sensing.

In Remote Sensing FEI concentrates on research and development aiming at operational environmental monitoring. The number of acquired satellite images in 2002–2003 was about 850 per year. Images are mainly low spatial resolution NOAA/AVHRR and MODIS-images, but higher resolution Landsat TM/ETM and Radarsat images are used when needed. The main operational tasks are snow-melt monitoring during spring-time and water temperature and algae monitoring during summer.

All research projects are co-operation projects with national and international research organizations. Main research topics during 2002–2003 have been:

- Oil spill detection in the Baltic Sea using Earth Observation data, near-real-time dissemination of information and combination with drifting models
- Database system for Earth Observation data
- Data assimilation between Earth Observation data, ground measurements and environmental models
- CORINE2000 land cover classification
- Water quality parameters (chlorophyll, turbidity, algae) for sea and lakes
- Snow melt monitoring covering whole Finland.



**Figure 5.9.** The total amount of algae calculated from maximum chlorophyll – values during 5 days in July, 2003. The image is processed from TERRA/MODIS imagery.

### **National Forest Inventory of Finland (NFI) at the Finnish Forest Research Institute (METLA)**

The Finnish Forest Research Institute, Metla, is an impartial state research organization founded in 1917. The National Forest Inventory (NFI) is one example of official duties of Metla. NFI has produced large-area forest resource information for over 80 years. Since late 1980's, the NFI has applied the multi-source forest inventory method that combines information from field measurements with satellite images and other numeric data sources (multi-source national forest inventory, MS-NFI). The objective of the NFI is to produce objective and up-to-date information on the forest resources, forest health conditions, forest biodiversity and carbon balance of forests for national, regional and industrial decision making.

The MS-NFI team is firmly established in the field of forest remote sensing. The MS-NFI method has been successfully applied also outside of Finland, and its further development work is going on in co-operation with institutions in other countries like Germany, New Zealand, Sweden, Norway and China. The USDA Forest Service has begun the development of a new inventory method, and co-operation with MS-NFI will contribute to further development of the method. Consequently, MS-NFI can serve as a prototype of a globally applicable forest resource inventory system using remote sensing techniques.

The current research activities of the MS-NFI team include:

- Maintaining Finnish forest resource information
- Developing of advanced multi-source estimation methods, examples are Bayesian methods and improved k-NN methods
- Updating of NFI -information by means of remote sensing data (an operative method has been developed and applied at regional level)
- Planning of inventory design by means of satellite image based theme maps
- Utilisation of imaging spectrometry in large area forest inventories
- Utilisation of SAR data in large area forest inventories
- Estimating carbon balance of forests.

### **University of Joensuu, Faculty of Forestry**

During recent years the research on remote sensing at the University of Joensuu, Faculty of Forestry has mostly concentrated on applications which utilize high resolution remote sensing data including satellites, digital photographs, video and laser scanning images. The most important projects are described below.

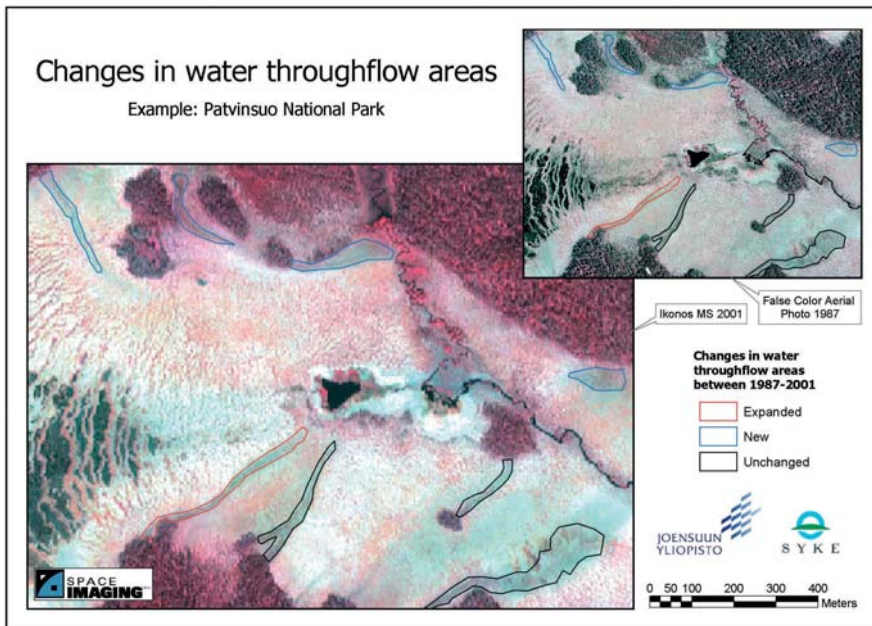
“Earth Observation for Natura 2000+ (EON2000+)” is an RTD project co-funded by the European Commission as part of the 5th Framework Programme. The project is a partnership of 14 members from seven European countries working for a duration of three years (2001–2004) and follows on from a Fourth Framework project. The Finnish partners are the Faculty of Forestry in the

University of Joensuu and the Finnish Environment Institute as an end-user.

The aim of the EON2000+ project is to develop and demonstrate integrated indicators of environmental state and socio-economic pressures for environmental protection purposes in support of the conventions on Biodiversity and European Biodiversity Strategy. The suitability of the Very High Resolution satellite data for the environmental monitoring was tested in Finland. Classification based on segmented Ikonos image was tested in the recognition of mire water throughflow areas and the comparison of Landsat and Ikonos data was carried out in order to predict species richness over large areas.

In Finland, initial data for forest planning is collected in stand-level field inventories. Because fieldwork is costly, there is an urgent need for more cost-efficient methods to replace or supplement traditional field inventories. Aerial photographs provide an attractive alternative to survey forest stands, since they are familiar for end-users, affordable, and their spatial and temporal resolution is high. ‘Forest Information Assessment and Updating’ was a project where methods based on remote sensing were sought for stand-level inventories in private forests. The project was funded by Finnish Ministry of Agriculture and Forestry and the participants were University of Joensuu, Finnish Forest Research Institute, Forestry Centre Pohjois-Savo and Forestry Development Centre Tapio. The work has then continued as a project ‘Aerial photographs in updating stand-level information on growing stock’.

At the University of Joensuu, three approaches to use aerial photos in forest inventories were examined. Visual interpretation coupled to updating of old inventory data proved to be a simple but working method and will be in operational use year 2004. In a more automatic method, *k*-nearest-neighbour (*knn*) estimation was utilized. Stand-level spectral and textural features calculated from aerial photographs and old inventory data were used as indicator variables. Though *knn* is routinely used in national forest inventory with Landsat TM and SPOT images, bidirectional reflectance and radial displacement present in aerial pho-



**Figure 5.10.** Changes in water throughflow areas in a part of Patvinsuo National Park between 1987 and 2001. EON2000+, Finland.

tographs caused problems that could not be totally solved. Finally, semi-automatic tree-level interpretation of aerial photographs was tested. Tree crowns were segmented with an application by Oy Arboreal Ltd. The results indicated underestimation of stand attributes, because only dominant and co-dominant trees were detected. The same result was achieved later, when another method to estimate number of stems was studied. In 2003, tests that aim to estimating canopy height applying image matching of aerial photographs were started. The first results have shown that estimated stand heights are likely biased but precise.

In addition to the above-mentioned projects pattern recognition of single trees using aerial and video images has been examined on other projects as well. Studies concerning digital photographs have concentrated on recognition of dead and defoliated trees and tree species classification. Field measurements and superresolution video images were used to develop specific method where forest stand characteristics were estimated by combining remote sensing image and a theoretical diameter distribution model. In general, superresolution methods take several images from the same loca-

tion and fuse these images to one image, called a superresolution image. If the fusion is carried out correctly, it is possible to recognize details from the superresolution image, which are not visible in the original images.

In the project ‘The Usability of Single Tree Laser Scanning in Forest Planning’, funded by the Academy of Finland, laser scanning data is used to produce height estimates of individual trees, which can then be used as a basis for the prediction of forest stand estimates. The other participant of the project is Finnish Geodetic institute, Department of Remote sensing and Photogrammetry.

The research has so far concentrated on the accuracy of laser scanning based forest resource estimates and development of more advanced tree crown detection and segmentation algorithms. To reduce data volume and enable use of image processing methods, a crown height image is first calculated from the original xyz-point data, produced by the laser scanner. Local maxima finding and variations of watershed segmentation algorithm are then used for tree detection and crown segmentation. However, knowing the height of each pixel

gives possibilities to make standard processing chains better. To improve tree detection, height based filtering as pre-processing and crown width based elimination of candidate tree locations have been tested. For the elimination method, crown width estimates are obtained from the relation between height and crown width. The same relation can also be used after segmentation in splitting and merging of candidate tree crown segments.

The accuracy of laser scanning has been found satisfactory for dominating tree layer but suppressed trees cannot be found using current tree identification methods. Therefore, estimates of height distribution of trees, which are based on combination of scanning laser altimetry and expected tree size distribution functions, were also produced. The accuracy of this approach was found to be as good as the conventional stand-level field inventory that is used in Finland. Finally, temporal change detection between two laser acquisitions has also been examined.

In the study ‘The use of a superresolution method in interpretation of forests from multiple NOAA/AVHRR images’ the objective was to clarify whether it is possible to recognize forested and non-forested areas from NOAA/AVHRR images more accurately using a superresolution method than when using the original images. The overall proportion of forest and the proportion of forest with a growing stock volume of over 50 m<sup>3</sup>/ha were calculated for each pixel and the results were evaluated by using RMSE and Landscape Indices. According to the results, superresolution estimates were better in all cases than estimates based on the original image material, but the improvement was marginal.

### **Geological Survey of Finland (GTK)**

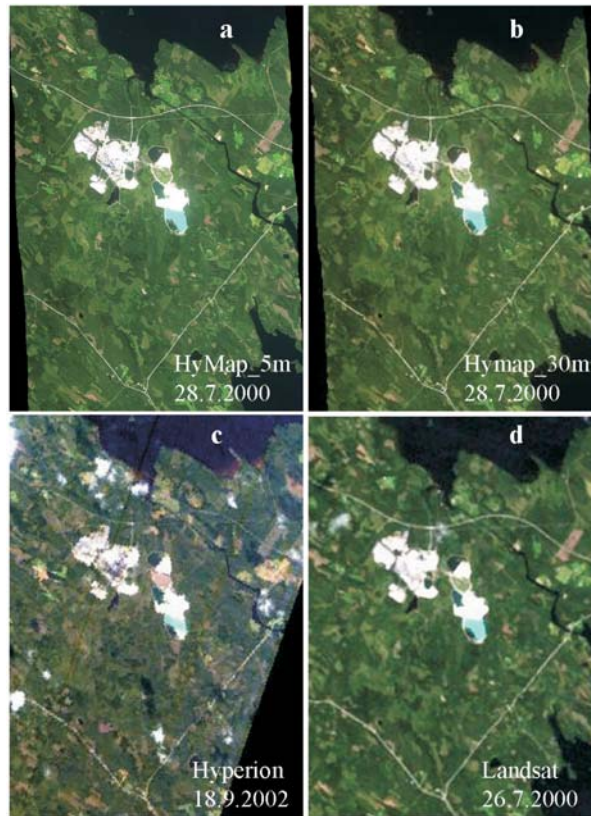
The Remote Sensing Laboratory of GTK acts as a base for mainly applied remote sensing survey projects concerning geology and environment. Remote detection of objects in these studies utilizes electromagnetic radiation with wavelengths between 400 and 2500 nanometers divided in (minimum) 126 bands. The respective images are called ‘hyperspectral images’.

The Remote Sensing Laboratory at the Geological Survey of Finland has during 2002–2003 accomplished, in co-operation with other European geological surveys, four major remote sensing projects:

- Assessing and monitoring the environmental impact of mining activities in Europe using advanced Earth Observation techniques (MINEO, 7 countries, funded by EU and the Geological Surveys).
- Hyperspectral Study of Mineral Indications and Mining Environments (HYDO, national project, funded by GTK, Tekes and 4 mining companies).
- Comparison of data from airborne imaging spectrometer HyMap and spaceborne Hyperion imaging spectrometer hyperspectral data of the Sotkamo talc mining area (National project, funded by GTK).
- Field mapping of ground truth data for hyperspectral remote sensing of kimberlitic (host rocks for diamonds) rocks in West Greenland (HyperGreen, funded by the Geological Survey of Denmark and Greenland and GTK).
- The main results of the first three projects are shortly summarized below.

The MINEO project has shown the high potential of hyperspectral imagery in remotely mapping mining-related impact over vegetated environments, either by direct mapping of potentially contaminating minerals and/or rocks or by indirect mapping through the stress on vegetation. MINEO has produced results, which can be used in the process of acknowledging this innovative technology to environmental authorities and regulatory bodies as well as extractive industry. Despite the technique still has to be matured, it opens new perspectives towards a regular mapping and monitoring of large parts of the territories to regularly update thematic layers for environmental database related to mining areas. These updated layers can be further used in the regular monitoring and control of mining environments by regulatory bodies, but also serve mining companies conducting Environmental Impact Assessments and Environmental Management Plans. Eventually, MINEO constitute a good starting point for further research and technology development projects in the frame of a growing interest for imaging spectroscopy in envi-

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**Figure 5.11.** RGB-composites of a) hyperspectral airborne HyMap 5m pixel image, b) HyMap 30 m pixel image, c) hyperspectral Hyperion satellite image and d) multispectral Landsat satellite image. Degradation of spectral and spatial resolution can be followed from a to d. Width of the area is about 5 km.

onmental studies (23 HyMap flight campaigns took place in summer 2003 in Europe) and initiated an increasing interest of the international scientific community for mining-related remote sensing studies. The MINEO project can also be seen as the initial point for forming a EU-wide reclamation task force related to mining, responsible for

- Rapid risk assessment by independent European experts
- Development and preparation of site-specific reclamation scenarios
- Cost assessment

Consultant activities in still active mining areas to avoid mistakes that could cause risks like AMD or other environment and health endangering factors

The following mineral mines were included in the HYDO study: the Parainen and Sipoo carbonate rock mines owned by Partek Nordkalk Oy Ab, the Pyhäsalmi and Mullikkoräme Zn, Cu, S mines owned by Outokumpu Mining Oy, the Elijärvi Cr mine owned by Avesta Polarit Oy and the Lahnaslampi and Horsmanaho talc mines owned by Mondo Minerals Oy. It has been shown that in the mineral mines of HYDO partners, ‘light’ minerals can be remotely identified and if all spectra of all end-members are known, also their quantities of the minerals can be calculated. This result also enables to remotely identify and delimit areas containing environmentally acid producing and neutralizing mineral materials. This technique enables detection and regional mapping of mining related

harmful 'Acid Mine Drainage' and its counterforce 'Buffering' using space borne remote sensing whenever true hyperspectral satellite imagery are available.

Used HyMap 5 m pixel data and there from-inferred 30 m pixel data can characterize the imaged mining environments in a detailed way. Field data is needed for training and validation. The following features are recognizable: Semi-quantitative mineral classes can be prepared. This is helpful especially for mapping Acid Mine Drainage and buffering. Semi-quantitative vegetation stress maps and vegetation change maps can be prepared. This is important for example for the estimation of extent the environmental impact of dust, seepage from tailings ponds, subsidence of the ground, rising ground water level and induced water stress.

Used Hyperion data can be compressed into 8 channels without losing relevant info. Therefore these data do not enable detection of environmentally relevant absorption features in mining areas.

### 5.3 Atmospheric sciences

#### **Finnish Meteorological Institute, Meteorological Research Division**

The Satellite Application Facility on Ozone Monitoring (O3M SAF) was initiated in June 1997. It is hosted by Finnish Meteorological Institute (FMI) and developed in co-operation with Koninklijk Nederlands Meteorologisch Instituut (KNMI), Deutsches Zentrum für Luft- und Raumfahrt (DLR), Deutscher Wetterdienst (DWD), Aristotle University of Thessaloniki (LAP), Hellenic National Meteorological Service (HNMS), Danish Meteorological Institute (DMI), Meteo-France (M-F) and Koninklijk Meteorologisch Instituut (KMI). The development phase of the project ended in June 2002.

The purpose of the O3M SAF is to produce a set of near real-time and offline products and validation services. Near real-time products are GOME-2 total ozone and ozone profiles, HIRS total ozone and UV clear-sky fields. Offline products derived from

GOME-2 data are total column amounts of ozone, NO<sub>2</sub>, BrO, ozone profiles, aerosol index and optical depth and UV fields including cloudiness and albedo. The ozone and UV data will be validated against ground-based observations of total ozone and UV as well as balloon borne, microwave and lidar observations of the vertical distribution of ozone. An important part of the O3M SAF activities has been related to scientific work to develop radiative transfer calculation methods and other algorithms used for satellite ozone and related data retrieval.

The METOP-1 launch delay (planned not sooner than mid 2005 instead of 2002) prohibits the O3M SAF from proceeding with the validation activities and operational phase after the development phase as it was originally planned. Due to this extension for development was started to cover the time period from June 2002 until the August 2006.

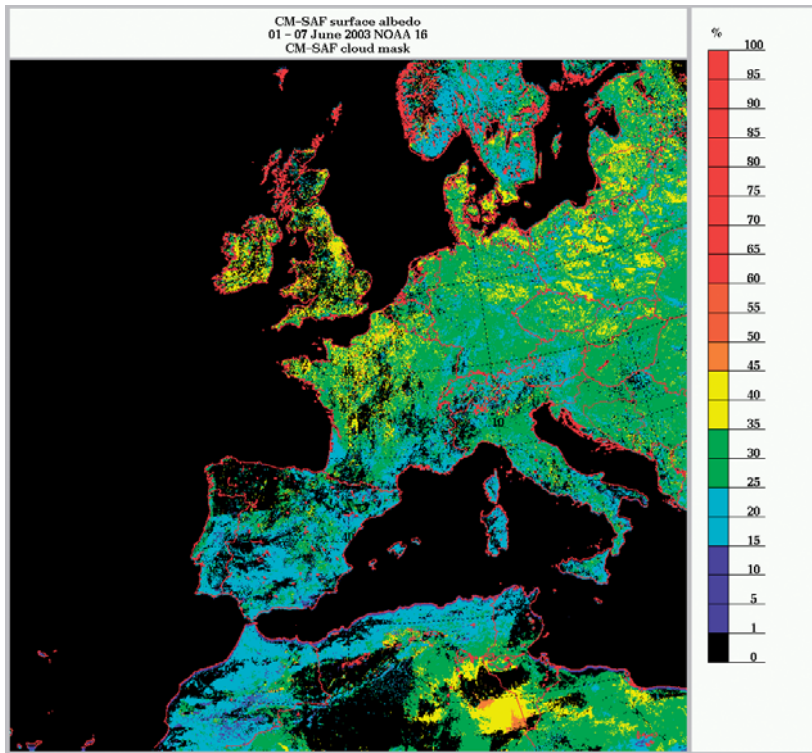
The purpose of the O3M SAF extension for development is:

- to continue research and development activities necessary to prepare for the use of Metop-1 data in O3M SAF products,
- to develop and disseminate pre-operational products,
- to perform research and development for the enhancement of the current O3M SAF products, taking into account recommendations expressed by users during the O3M SAF workshop.
- to reconcile the O3M SAF with the EPS CGS development and
- to complete all necessary verification and validation activities that were postponed from the current development phase because of the Metop-1 launch delay.

More information is available from following web sites:

[www.eumetsat.de](http://www.eumetsat.de)  
<http://o3saf.fmi.fi>

The Satellite Application Facility on Climate Monitoring (CM-SAF) is aiming to provide consistent and homogeneous sets of data in the highest possible quality, based mainly on input from operational meteorological satellites, in support to cli-



**Figure 5.12.** The surface albedo of central Europe in the first week of June processed from NOAA/AVHRR data by CM-SAF. Clouds and water are masked black.

mate monitoring, climate change detection and for assessing the climate variability. During 2003 the CM-SAF was accepted to start Initial Operations Phase. The Operations Leading Entity was selected to be Deutscher Wetterdienst (DWD). The co-operating institutes participating in research and development are from Finland, The Netherlands, Belgium and Sweden.

The operational product list consists of cloud parameter products, components of the surface radiation budget and humidity composite product. FMI continues development of the surface albedo product. It will be adapted to the SEVIRI instrument of MSG to benefit from the larger number of spectral channels. Also the geostationary orbit of MSG with frequent data delivery gives new possibilities for the operational processing of the surface albedo product. Investigations for enlargement of the processing area to global will be carried out.

### **Finnish Meteorological Institute, Geophysical Research Division**

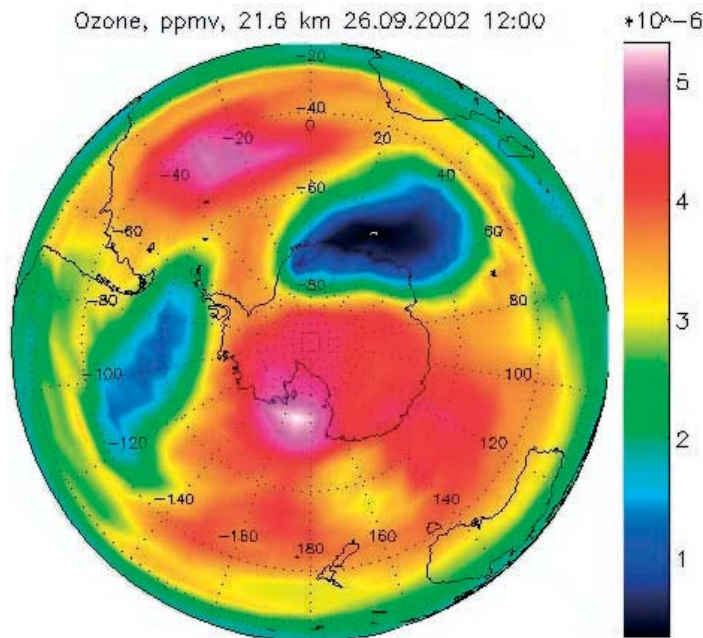
The work of the aeronomy group at the Geophysical Research Division has grown around three satellite instrument projects: GOMOS on Envisat, OSIRIS on Odin, and OMI on EOS-Aura. OSIRIS and GOMOS are already producing data in a continuous fashion whereas the OMI launch is expected to take place in summer 2004.

Odin was launched successfully on 20.2. 2001 and has continued successful measurements since. The mission has encountered a few problems concerning the pointing of the satellite but these problems have been solved. The validation work for aeronomy measurements has continued but also first scientific results have been published and new publications are in preparation. FMI's aeronomy group has continued the development of Level 2

data processing algorithms and the processing chain for the optical instrument OSIRIS. After a long and tedious verification the Level 2 OSIRIS processing chain started in February 2004 to produce ozone and minor constituent profiles at FMI's Arctic Research Centre in Sodankylä.

Envisat was launched successfully 1.3. 2002. GOMOS has measured over 100 000 ozone profiles. After the launch it was soon discovered that GOMOS CCD-detectors behaved differently from expectations. The detectors were found to be quite sensitive to proton precipitation from space, which increased the amount of noise in measurements. This derogative effect has been tried to minimize by decreasing the operating temperature of GOMOS but this has helped very little. The additional noise has, however, had no significant impact of the product quality. GOMOS encountered a serious functional difficulty in spring 2003 when the steering mirror was not able to turn through the whole angular scope. Because the wide steering is important for getting enough bright target stars

ESA decided to switch to the redundant electronic chain included in GOMOS. This worked fine and no steering problems have encountered since. Most of the work performed at the GOMOS Expert Support Laboratories (FMI is one of them) has been focused how to handle the detrimental effects from scintillations. The nature of scintillations has been an unpleasant surprise for the GOMOS team. Before the launch we expected that the fluctuations in the neutral density would be anisotropic in such a way that fluctuations could be described as layers in vertical direction. Scintillations arising from these fluctuations would generate transmission modulations that could be corrected by using data from two fast photometers on GOMOS. But already the first results showed that in many cases isotropic fluctuations dominate anisotropic scintillations. The impact on ozone profiles is small but it is quite substantial for other minor gases. On the other hand, the study of turbulence in the middle atmosphere will get a boost from GOMOS measurements.



**Figure 5.13.** Ozone mixing ratio at 21.6 km over Antarctica 26.9. 2002. The picture is a result from assimilation of OSIRIS ozone measurements with the FIN-ROSE model using FMI's assimilation code FASP.

OMI is a Dutch-Finnish instrument that will be flown on NASA's EOS-Aura mission in 2004. FMI's role is to lead the industry participation in Finland and to coordinate the scientific work in Finland. FMI is responsible for the developing a ground receiving station for OMI in Sodankylä and FMI will process global UV maps from OMI data.

In the scientific research we have continued work for inversion theory and algorithms, assimilation, radiative transfer problems and solar effects in the stratosphere and mesosphere. In the organizational change of the Finnish Meteorological Institute in

2004 a new aeronomy group will be formed. It will consist of the Aeronomy research group from the Geophysical Research and the Ozone and UV research group from the Meteorological Research. The new Aeronomy group involves about 25 persons and the activities include development of data services, development of higher order products, development of processing, remote sensing studies, satellite instruments, algorithms & inversion theory, validation, radiative transfer modelling, middle atmosphere processes, chemistry-transport models, ground-based instruments, UV-analysis, and UV influence studies.

## 6 Publications

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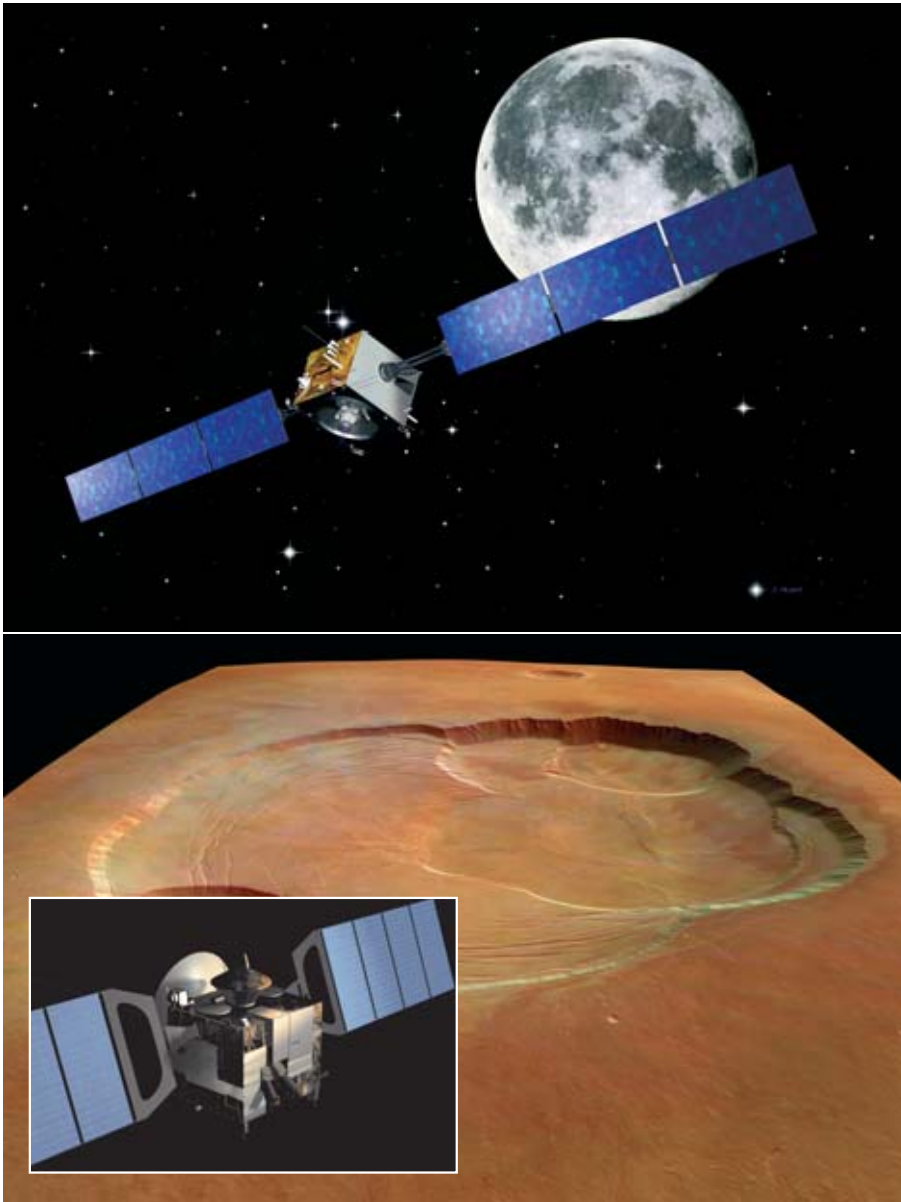
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