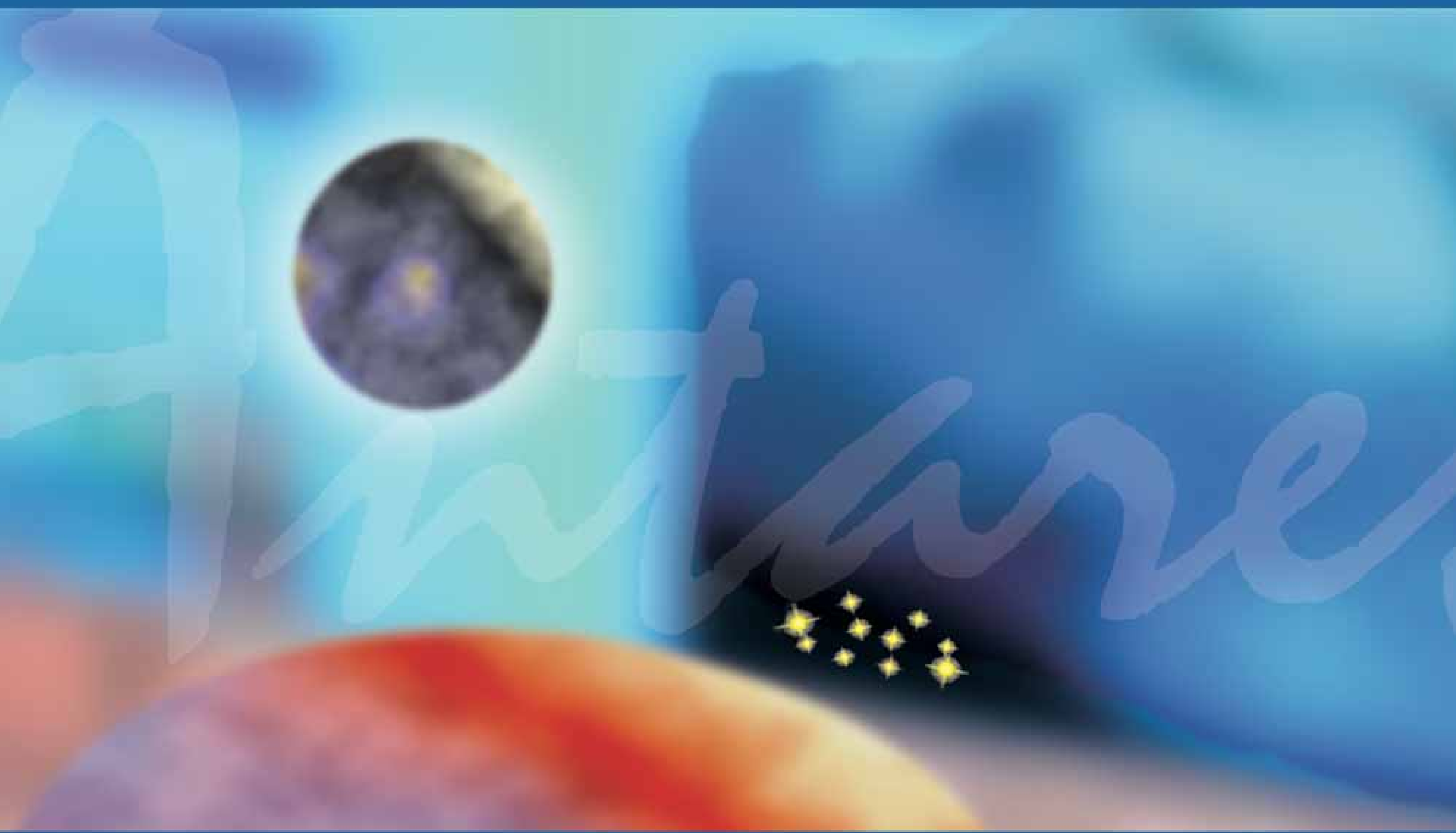
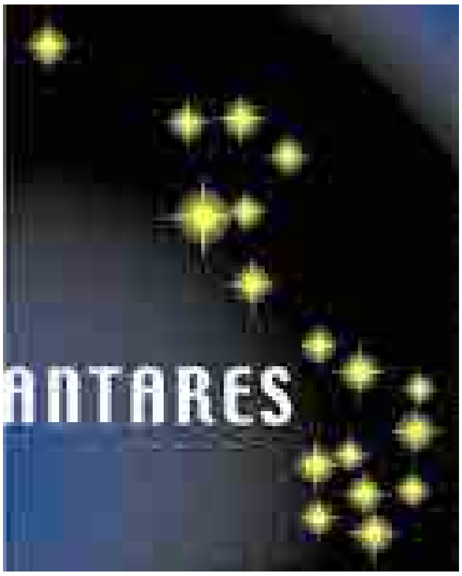
ANTARES

Space Research Programme

Final Programme Report





ANTARES FINAL PROGRAMME REPORT

ANTARES - Finnish Research Programme for Space Research

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Espoo April 13, 2004

ISBN 951-715-518-2 (print)
ISBN 951-715-519-0 (pdf)

Painopörssi, Helsinki 2004

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1 SUMMARY

The ANTARES programme consists of 11 projects utilising more than 50 satellites and 25 Finnish space instruments. The research subjects are astrophysics, space physics, the Sun and the solar system, remote sensing (water, forests), and space instrument technology. The funding for the whole ANTARES programme totals 16.8 M€ shared by the Academy of Finland, Tekes and the participating institutes. The programme started on March 1, 2001 and is planned to end on March 31, 2004.

The ANTARES web site http://akseli.tekes.fi/Resource.phx/tivi/ANTARES/index.htx has been updated during the running of the programme. The site consists of the description of the programme and the projects with the links to the homepages of the projects. During the programme, 45 information notes (i.e. press releases) in Finnish and 22 in English have been released. Altogether 434 scientific papers and 322 conference presentations have been written or presented during 2001-2003. The ANTARES programme has been presented 117 times on TV and on radio. In the connection with the ANTARES programme 24 people have prepared or completed their PhD and 43 their M.Sc. studies. The total amount of training in universities has been 89 person-years.

The third and final scientific annual seminar was held in Helsinki on October 30, 2003. A press conference with three major press releases was arranged in connection with the seminar. As a result, news of the seminar was published in several newspapers and on the Finnish television. ANTARES also presented a session of space science in 'The Science Days' (Tieteen päivät) at the University of Helsinki in 2003.

ANTARES has achieved several new results in astronomy and in space physics, in solar and planetary science, in mm-wave-, X-ray- and SQUID technology and in remote sensing applications of water and forests.

ANTARES scientists found two new black holes, Cyg X-3 and IGR 19140+098, in the Milky Way by using ESA's Integral satellite and its gamma detectors made in Finland. One of the brightest sources observed by INTEGRAL, an X-ray binary and microquasar GRS 1915+105, was extensively studied by the HESA group. The newest black hole is located near to this microquasar. The developed new X-ray detector technology offers good possibilities to industrial business and can be applied not only to space research but also to ground-based security and analysis applications.

The ANTARES programme has developed the most sensitive 70 GHz mm-wave receivers for the LFI radiometer on PLANCK mission to be launched in 2007. PLANCK Surveyor Mission is an ESA satellite. Its main operational purpose is to provide a detailed temperature map of the cosmic microwave background (CMB). The temperature fluctuations of the microwave background reflect the properties of matter at the time of recombination, about 300,000 years after the Big Bang. The developed new technology can also be used in ground-based security, airfield and car traffic applications creating new possibilities for business.

ANTARES scientists developed a new assimilation technique to apply space-borne data to improve the environmental monitoring and forecasting for the applications of water quality and snow melt assessment and hydrological planning. As the estimates on snow-covered area were imported to run-off/discharge model, the accuracy of river discharge predictions substantially improved during the spring-melt period. As satellite observations of the Baltic Sea were assimilated to ship-borne observations on chlorophyll, the performance of mapping the phytoplankton biomass improved remarkably.

Concluding, the ANTARES research programme has been, from the point of view of the project teams, a very useful and successful period in the Finnish space research. However, its final significance can only be evaluated after it is seen how the related research will continue in the future. Here an essential feature is how the future funding can be arranged.

2 INTRODUCTION

The national space research programme of Finland, ANTARES, focuses on space science and environmental remote sensing. It is scientific and technological in its nature. The programme is being carried out in the years 2001-2004, and consists of extensive projects established by consortia of space research institutes. Also, the programme is international, and many projects are being operated in conjunction with programmes of the European Space Agency (ESA).

The programme consists of 11 projects utilising more than 50 satellites. The research subjects are astrophysics, sun and solid bodies, remote sensing (water, forests), and space instruments. The funding for the whole ANTARES programme totals 16.8 M€ and is shared by the Academy of Finland (4.6 M€), Tekes (10.2 M€) and the participating institutes (2.0 M€). The programme started on March 1, 2001, and is presently planned to terminate on March 31, 2004. At the beginning of the programme, the Academy of Finland made the decision to fund the projects for the whole programme duration, i.e. until 2004. Tekes made first its funding decisions for the years 2001-2002 only and made later the further funding decisions annually.

The co-ordination of the programme has been assigned to VTT by Tekes. VTT's primary tasks include the co-ordination of scientific and administrative matters, the arrangement of annual seminars, the promotion of collaboration, dissemination of information and reporting, compiling and maintenance of the web site, preparation of the final report upon completion of the programme, contacts to industry and international research, and data collection for evaluation.

The scientific and technological results have been presented and reported in the Fall Seminars annually, in 756 scientific publications and conference presentations, and in 319 popular papers, TV and radio interviews, and press releases.

3 ANTARES - AN OVERVIEW

3.1 The foundations of ANTARES

Space is part of everyday life in modern society. Increasingly often, technological and scientific breakthroughs are results of space-related activities and, indeed, many of mankind’s fundamental problems will be solved through exploiting the possibilities these activities offer. Participation in present-day space research requires long-term commitments and funding, but builds up the expertise that will be needed in the near future. Finland has joined the international community for space research and the results are about to be seen. Finnish activities have already an important and central international position in the selected areas of emphasis: space science, remote sensing and space technologies.

Finnish research groups in different universities and research institutes have participated, together with industry, in international projects in space science and remote sensing for nearly 20 years. Current activities are based on the National Space Strategy (2002), generated by the Finnish Space Committee (‘Space Activities in Finland, National Strategy and Objectives’; Reports of the Ministry of Trade and Industry 1/2002). The major part of Finnish space activity has been carried out in programmes of the European Space Agency (ESA), but at the same time significant projects have been carried out in national programmes of Sweden, Russia, the USA, and Japan. Finland’s activities in ESA’s science programmes as well as co-operation with Russian space research institutes are based on bilateral agreements that oblige Finnish authorities to maintain competitive national research activity in Finland.

Figure 1. Cassini with Finnish instruments was launched for the mission to Saturn and to its moon Titan in 1997

The Finnish space industry was largely born from the needs raised by the research groups in instrument design and manufacturing, e.g. instruments for Saturn-Titan mission (Figure 1). The goal-directed funding policy of the National Technology Agency (Tekes) has contributed to the launching of new companies. Moreover, co-operation within ESA has demanded strong interest and participation by industry, which it has done in a commendable way. By the end of 1999, the ESA science programme industry feedback to Finland achieved the target level that was set already in the long-term plan of 1987, when Finland joined ESA operations.

The rapid rise of Finland to a full-fledged space research nation has been possible only through strong funding co-operation by the Academy of Finland and Tekes, and, additionally, by universities and research institutes. For the years 1998-2000, the Academy of Finland granted an additional share of more than 5 M€ for space research performed in ESA projects. The three Tekes space technology programmes for the years 1996-2005, i.e. the Space Equipment technology programme 'Space 2000' (12.5 M€), the Remote sensing programme 'Globe 2000' (6.7 M€), and 'AVALI - Business Opportunities from Space Technology' (12 M€, 2003-2005) have also supported the rapid development of Finnish space research.

The ANTARES research programme for the years 2001-2004 is the first research programme planned, funded and carried out with close co-operation between the Academy of Finland and Tekes. The aim was to provide a continuation of the favourable development that began with the help of preceding programmes and the extra funding in the later half of the 1990's. The centres of emphasis were ESA programmes and large bi- and multilateral projects with important space nations and organisations. Basic targets for study were entities in which both the Academy of Finland and Tekes had common interests. But they could also be responded to in projects that utilise important data archives in scientific studies and their applications, or that develop new measurement and data analysis methods for space projects.

3.2 The planning and initiation of the programme

The idea of the common new space research programme was initiated by the Academy of Finland (SA) as early as in 1998. The preparation for the decision started in the spring 2000. The new programme would be the first research programme planned and funded together with the Academy of Finland and Tekes. The representatives of the both funding agencies visited ESA and ESA's directorate of science in ESTEC on January 19, 2000. The Research Council for Natural Sciences and Engineering proposed 8.3 M€ for the share of the Academy of Finland, and the Academy Board decided to allocate 4.6 M€ for the new programme. The Board also decided to enlarge the scope of the programme into scientific remote sensing.

The Board decided on June 13, 2000 to appoint a working group to prepare the programme. The members of the group were from SA, Tekes, universities, research institutes and from the Finnish industry. The group with nine members was chaired by Professor Risto Pellinen. The working group gave a call for one round applications for space science on September 29, 2000.

3.3 Objectives of the research programme

The ANTARES research programme addresses the Finnish space strategy at a very practical level. The essential areas of the strategy are scientific and technological research work based on satellite observations, and satellite remote sensing. Common features in these areas are instrument and sensor building, and development of observational and analytical methods. Thus, the focus of the ANTARES programme is on space science and on scientific environmental remote sensing. The objective is to achieve measurable results in the Finnish space research and to boost it to more remarkable level than ever.

The technology programme supports in particular those projects which have been earlier committed to, and which are in an active development phase. In this way the continuation of long-term projects has been ensured. The technology programme enables the analysis of large data archives, as well as observations acquired in the current running missions. Just as important, developing new instrument concepts for implementation in the future is one goal of the technology programme.

The ANTARES programme is also designed to educate for the future of Finnish space science both through making the seminar series open to students and through research training (i.e. M.Sc.'s and Ph.D.'s). The technology programme increases both national and international networking. The networking has been facilitated by collecting consortia of several national and international research groups, which serve effectively the objectives of the programme. The ANTARES programme will increase the awareness and visibility of space science among the public and in the schools.

3.4 Selection of the projects

For selection of the projects an international evaluation panel was established with the following members:

Bengt Hultqvist, Sweden, chairman,	(near Earth, magnetosphere)
Angioletta Coradini, Italy	(planets, solar system)
Jeffrey Linsky, USA	(astrophysics, satellite missions)
Mikhail Marov, Russia	(planets, aeronomy)
Helmut Rott, Austria	(remote sensing)

There were 26 applications, 15 consortia and 11 single applicants. The total sum applied from the Academy was 15.5 M€; in 9 applications additional funding was applied also from Tekes.

The panel had a meeting on November 16, 2000. The applications, which got the grade 5 or 4.5, applied for the total amount of 9.3 M€. The working group decided in its meeting on December 14, 2000 to propose eight consortia and three single applications to be accepted. Because the granted funding of 4.6 M€ was only half of the applied funding, the goals of the projects had to be changed.

A new ‘Programme group’ or steering committee was nominated on January 16, 2001 after the change of the Academy's Research Councils. The group with seven members was chaired by Professor Jorma Kangas. The funding decisions of the programme were made on February 13, 2001. The ANTARES programme started on March 1, 2001 and will end on March 31, 2004. The members of the ‘Programme group’ were:

Jorma Kangas	Professor, University of Oulu
Iiro Hartimo	Professor, Helsinki University of Technology
Pekka Hautojärvi	Professor, Helsinki University of Technology
Seppo Korpela	Managing Director, Space Systems Finland
Risto Pellinen	Professor, Finnish Meteorological Institute
Pasi Puttonen	Professor, University of Helsinki
Pauli Stigell	Senior Technology Adviser, Tekes
Merja Tornikoski	Director, Metsähovi Radio Observatory, HUT

Väinö Kelhä	Research Professor, VTT, was nominated as the coordinator of the programme.

3.5 Programme funding

In addition to the funding of 4.6 M€ granted by the Academy of Finland, Tekes promised to allocate 4.6 M€ to four projects which involved development of technology or fabrication of instruments. The funding decisions of Tekes were made annually, and at the end of the programme the total amount of funding allocated by Tekes was 10.2 M€. Tekes also granted funding for three scientific seminars arranged during the programme.

Thus the total funding for the eleven projects amounted to 16.8 M€, the share of SA being 4.6 M€, the share of Tekes 10.2 M€, and the share of the participating institutes 2.0 M€.

3.6 The selected projects

The eleven research projects that were selected to form the programme are listed below. The names of the science and technology projects are mentioned with consortium leaders.

NAME OF PROJECTS	PROJECT TEAM	ALLOCATED FUNDING
1A) PLANCK Surveyor Physics (PLANCK) *1B) PLANCK LFI 70 GHz Phase III: Cryogenic Microwave Test*	Enqvist Kari, HU Mattila Kalevi, HU Tuovinen Jussi, VTT Urpo Seppo, HUT Valtaoja Esko, TU	SA 846 k€ *Tekes 5,131 k€* *Institutes 312 k€* *Total 6,289 k€*
2A) High Energy Astrophysics and Space Astronomy (HESA) *2B) Instrument development for XEUS, AXM and Roemer, SIXA for SRG, X-ray filters for XEUS, GEM technology for XEUS and AXM*	Vilhu Osmi, HU Huovelin Juhani, HU Muinonen Karri, HU Pekola Jukka, JyU/HUT Turunen Jari, JoU Valtaoja Esko, TU	SA 865 k€ *Tekes 4,621 k€* *Institutes 335 k€* *Total 5,821 k€*
3) Space Based Studies of Dark Matter (DARKSTAR)	Flynn Chris, TU	SA 140.3 k€
4) ISO- and Odin- Related Research of the Interstellar Medium and Star Formation (ISO_ODIN)	Mattila, Kalevi, HU	SA 211.4 k€
5) Space Weather in the ANTARES Programme (SWAP)	Koskinen Hannu, HU Nygren Tuomo, OU Pirjola Risto, FMI Valtonen Eino, TU	SA 415.3 k€
6) CLUSTER II and MIRACLE: Mesoscale Structure of Coupled Solar Wind-Magnetosphere-Ionosphere System (C2M)	Mursula Kalevi, OU Pulkkinen Tuija, FMI	SA 567.1 k€
7A) Dust, Atmospheres, and Plasmas in the Solar System (DAPSS) *7B) SPEDE Spacecraft Potential, Electron and Dust Experiment*	Kallio Esa, FMI Mursula Kalevi, OU	SA 461.3 k€, *Tekes 206.6 k€* *Institutes 206.6* *Total 874 k€*
8) Micro- and Mesoscale Atmospheric Phenomena in Mars (MSW)	Savijärvi Hannu, HU Kulmala Markku, HU Siili Tero, FMI	SA 509.4 k€
9) Chemical Aeronomy of the Mesosphere and Ozone in the Stratosphere (CHAMOS)	Turunen Esa, OU	SA 55.8 k€
10) New Modelling and Data Analysis Methods for Satellite Based Forest Inventory (MODAFOR)	Holmström Lasse, HU Hallikainen Martti, HUT Tomppo Erkki, Metla	SA 365.3 k€
11) Assimilation of Remote Sensing Data to Physical Models in Environmental Monitoring and Forecasting (ASSIMENVI)	Pulliainen Jouni, HUT Sucksdorff Yrjö, Syke	SA 192.2 k€ *Tekes 151.4 k€* *Institutes 1,083 k€* *Total 1,426 k€*
Total: SA Total: Tekes Total: institutes GRAND TOTAL		SA 4629.4 k€ *Tekes 10,233 k€* *Institutes 1,938 k€* Total 16,800 k€

In projects 1, 2 and 7, Tekes funding was granted for development of technology and for instrument fabrication.

4 SCIENTIFIC RESULTS

The ANTARES programme has achieved several new results in astronomy and in space physics, in solar and planetary science, in mm-wave-, X-ray- and SQUID technology and in remote sensing applications of water and forests. The following introduces the highlights of the best results of the programme.

4.1 Black holes and the Big Bang

ANTARES scientists (HESA) found a new black hole IGR 19140+098 and found new evidence for the BH-nature of Cyg X-3 in the Milky Way by using ESA's Integral satellite and its X-ray/gamma detectors made in Finland, Denmark and other participating countries. One of the brightest sources observed by INTEGRAL, an X-ray binary and microquasar GRS 1915+105, was extensively studied by the HESA group and a novel accretion disc instability mode was discovered. The newest black hole IGR 19140+098 is located near to this microquasar. The developed new detector technology has been applied not only to space research but also to ground-based security and analysis applications.

The microquasar GRS 1915+105 contains a black hole weighing more than 10 solar masses and a red giant star. INTEGRAL observations 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.

The ANTARES programme (PLANCK) has developed the most sensitive 70 GHz mm-wave receivers of the LFI radiometer for PLANCK mission to be launched in 2007. PLANCK Surveyor Mission is an ESA satellite. Its main operational purpose is to provide a detailed temperature map of the cosmic microwave background (CMB). The temperature fluctuations of the microwave background reflect the properties of matter at the time of recombination, about 300,000 years after the Big Bang. The developed new technology can also be used in ground-based security, airfield and car traffic applications creating new possibilities for business.

The primary mission of the Planck satellite is to measure the CMB. However, at the same time it will observe all other radio foreground sources in the sky, including quasars and active galactic nuclei. Along the lines of the dual nature of the mission, the Planck team has promptly analysed these observations to reveal surprising results. The idea was to study new source populations and to get an estimate of how they affect the Planck mission. In the past most of these sources have been excluded from high frequency studies because they are believed to be weak in the radio domain. However, the new observations performed by the quasar team show that many hundreds of these sources are so bright that the Planck satellite can easily detect them.

4.2 Dark matter, interstellar medium and star-formation

Our Milky Way disk consists of a few 100 billion stars. The disk is remarkably thin, but it is not perfectly thin; stars are moving up and down within the disk and give it a thickness of several hundred light years from side to side. DARKSTAR researchers have completed computer simulations of the processes in the Milky Way, both for Giant Molecular Clouds (GMCs) and millions of these putative black holes. The team used archival data from the Hipparcos satellite, which measures how thick the disk has become over its 10 billion year history; furthermore, the simulations followed the whole disk of the galaxy, not just those parts close to the Sun. Remarkably, the scenario of GMCs and black holes is not particularly easy to rule out with certainty, although the team concluded that black holes remain a possible source of disk heating, it is not the only one. The mass of the adopted black holes is a very important factor in the simulations. If the black holes are too heavy, they can destroy the disk completely; if they are too light they are unable to affect the orbits of the disk stars at all. Black holes with a mass of about two million times that of the Sun seem to be about right, and produce effects which are broadly and in some cases in detailed agreement with our best available (space-based) observations.

DARKSTAR has made an accurate measurement of the production rate of Helium in the universe by using the data from Hipparcos satellite and so-called K dwarf stars. These stars have changed very little of their initial supply of hydrogen into helium during their long lives. The research team has used computer models to predict how brightly such stars should shine depending on how much hydrogen, helium and heavier elements they contain. Now, the comparison of the model computations with the real stars reveals, indirectly, the amount of helium they contain. The team has found that over the billions of years since the Universe was born, stars have produced just about exactly twice as much helium as everything else. Stars are primarily helium factories!

In the ISO_Odin project preprotostellar and young stellar objects, still deeply embedded in their parental molecular clouds, have been detected and physically characterised by extensive ISO far infrared mappings. High-resolution radio interferometer observations have been used to reveal the detailed structure of two key objects in Chamaeleon and Corona Australis. The dynamical and chemical evolution of nearby molecular clouds and globules have been studied by combining molecular line data from radio spectroscopy with far infrared dust emission surveys from ISO. These studies have elucidated the conditions under which dense cores are forming, leading in some cases to further collapse into stars. The ISO_Odin project has for the first time observed the distribution and properties of the Unidentified Interstellar Bands at 7.7, 8.6, and 11.3 μm over the whole Galaxy. The project has completed a study of the 3-200 μm infrared emission in a representative interstellar cloud, revealing strong abundance variations of the three main dust components. 3-dimensional radiative transfer models have been developed for the photoelectric heating and spectral line cooling via the C+ 158 μm line of tanslucent molecular clouds.

4.3 Sun and solid bodies – Space Weather and new instruments

MSW project has developed and tested high-resolution small-area models, which can be used to study the small-scale weather phenomena in Mars, such as mountain-, crater- and icecap-driven local winds and dust devils, the various physical processes and their best numerical representation for Mars' atmospheric models, and the way the weather forecasts for Mars and Earth may gain from all this. Near the polar ice cap edges we predict sea breeze-type local afternoon winds during spring and summer. The many craters, hills and valleys create local wind systems in Mars, some of which can be quite strong. Their existence limits the sites considered safe for landing. We made a landing weather forecast for the British Beagle 2 probe.

New instruments are ready for action (DAPSS). MarsExpress spacecraft was launched successfully in June 2, 2003. It includes the *ASPERA-3* particle instrument, which will measure the escape of Martian atmospheric particles, that is, the atmospheric erosion. An identical replica of the instrument, *ASPERA-4*, onboard ESA's VenusExpress mission to Venus will perform similar measurements at Venus starting at the beginning of 2006. In September 27, 2003 the SMART-1 spacecraft started its journey toward the Moon with the *SPEDE* instrument. ESA's Rosetta cometary mission to comet Churyumov-Gerasimenko includes several scientific instruments that have much Finnish space science know-how: *PP*, *COSIMA*, *MIP*, *LAP* and *ICA* instruments. The successful launch of Rosetta was on March 2, 2004.

CIDA instrument on Stardust mission, made the fly-by of comet Wild-2 on January 2, 2004. Team Stardust, NASA's first dedicated sample return mission to a comet, passed a huge milestone by successfully navigating through the particle and gas-laden coma around comet Wild 2. During the hazardous traverse, the spacecraft flew within 240 km of the comet, catching samples of comet particles and scoring detailed pictures of Wild 2's pockmarked surface. The Cometary and Interstellar Dust Analyzer (CIDA) instrument intercepts dust and performs real-time compositional analysis for transmission back to Earth. Software for the CIDA instrument was developed by the DAPSS project.

The research results of the SWAP Space Weather project and C2M-project include: a comprehensive end-to-end analysis from the Sun to the Earth of one of the largest space storms during the present 11-year sunspot cycle in April 2000; new understanding of the efficiency of different solar wind structures as drivers of magnetic storms (Figure 2); significant progress in studies of acceleration of energetic solar particles; new information on the energy budget of magnetic and auroral storms; an establishment of a new instrument chain to measure disturbances in the auroral region; and development of increasingly efficient methods to calculate the perturbations on ground. Together these achievements support attempts to develop better and more reliable ways to predict the effects of space storms and means to minimise the damage caused by the storms.

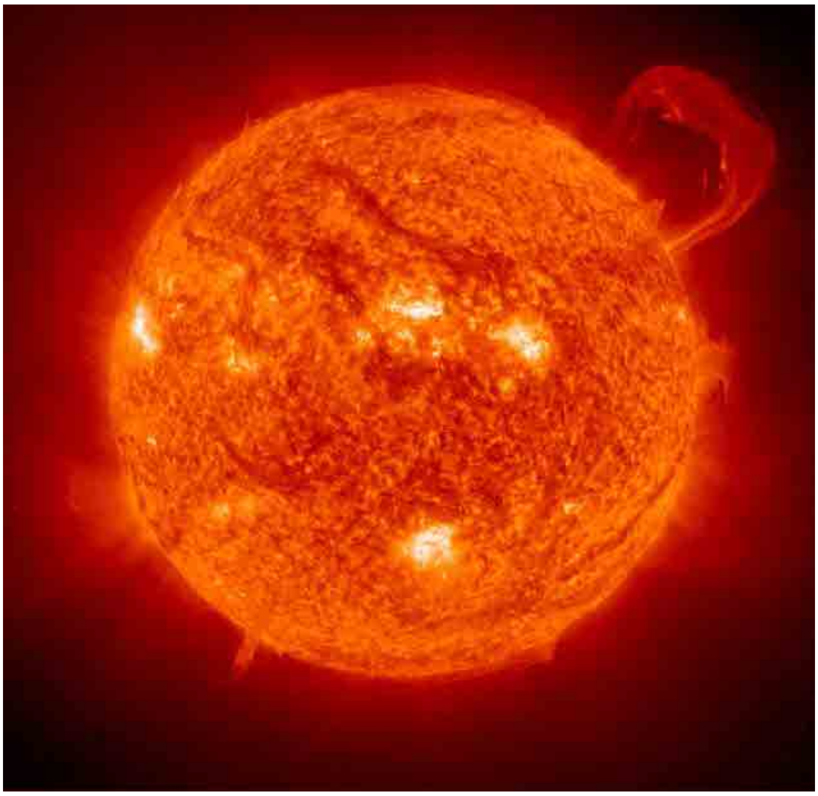

Figure 2. Solar Mass Ejection observed by SOHO

In a model study of the solar proton event in November 2001, the negative ions were seen to destroy neutral ozone at altitudes below 80 km (CHAMOS). The process is very efficient contributing up to the maximum of 40%of the ozone loss at the altitude of 63 km. This is an important new finding. In the analysis of experimental satellite data, ozone decrease as a result of an observed solar proton event was detected. The event under study was the November 2001 solar proton event, and the instrument providing the data was the OSIRIS instrument onboard the Odin satellite. Decrease in the order of 20%in the concentration of ozone was seen in the analysed data.

4.4 Improved methods for monitoring of the environment

ANTARES scientists (ASSIMENVI) developed a new *assimilation techniques* to apply space-borne data to improve the environmental monitoring and forecasting for the applications of water quality and snow melt assessment and hydrological planning. As the estimates on snow-covered area were imported to run-off/discharge model, the accuracy of river discharge predictions substantially improved during the spring-melt period. As satellite observations of the Baltic Sea were assimilated to ship-borne observations on chlorophyll, the performance of mapping the phytoplankton biomass improved remarkably.

As a result of the MODAFOR project, a new and better *forest parameter estimation method* was developed and put into operative use in multi-source forest inventory. A practical tool for investigating the polarimetric response of boreal forest was developed by combining the polarimetric backscatter model with a realistic tree growth model. Software were developed and implemented to examine the feasibility of polarimetric decomposition schemes for forest classification. A new forest coherence modeling-based approach was established for the retrieval of stem volume from space-borne repeat pass interferometric SAR observations. Moreover, a SAR interferometry-based technique for the combined segmentation of homogenous areas, segment-wise land-use classification and stem volume retrieval was successfully demonstrated.

4.5 List of the results

The list of the most important results achieved in the programme:

- ANTARES found a new black hole IGR 19140+098 and found new evidence for the black hole nature of Cyg X-3 (HESA)
- A novel disc instability mode was found in the microquasar GRS 1915+10 (HESA)
- The space telescope INTEGRAL and JEM-X X-ray monitor launched on October 17, 2002 (HESA)
- The discovery of the shortest period binary system known, orbital period 321 sec (HESA)
- Development of mm-wave technology for PLANCK mission 2007 (PLANCK)
- Fabrication of the most sensitive 70 GHz receivers for radiometer ever made (PLANCK)
- The mm-wave technology has security, motor and airfield traffic and telecommunications applications (PLANCK)
- Lunar probe SMART-1 with X-ray solar monitor XSM launched in 2003 (HESA)
- The sensor-technology has commercial security and analysis applications (HESA)
- Breakthroughs in instrument and SQUID development for XEUS (HESA)
- GEM (Gas Electron Multiplier) detectors built with good test results (HESA)
- A new tool for measuring Helium content and the distances of stars invented (DARKSTAR)
- ENVISAT-1 environment satellite with Gomos ozone monitor launched in 2002 (CHAMOS)
- Preprotostellar and young stellar objects have been detected and characterised (ISO-ODIN)
- Forecast of space weather became more accurate (SWAP)
- The dayside structure of magnetosphere has been found to be very dynamic (C2M)
- Seven instruments to Mars, to the Moon, and to the comet Churyumov-Gerasimenko (DAPSS)
- CIDA instrument on Stardust mission made the fly-by of comet Wild-2 on January 2, 2004 (DAPSS)
- Launch of Rosetta with five instruments on on March 2, 2004 (DAPSS)
- A new model for simulation of Mars's weather (MSW)
- A new approach to the estimation of forest parameters (MODAFOR)
- A new technique for estimating forest stem volume from radar data (MODAFOR)
- A new polarimetric scattering simulator for forests was designed (MODAFOR)
- A new assimilation method to improve the regional snow depth mapping (ASSIMENVI)
- A new assimilation method for environmental monitoring (ASSIMENVI)

5 DEVELOPMENT OF TECHNOLOGY

5.1 New sensor technology

The development of technology was one of the goals of the five ANTARES projects for which Tekes has allocated 10.2 M€ funding. In the programme new *x-ray-, SQUID- and millimetre wave technology* has been developed for space applications. Spin-offs of this technology can also be utilised outside of space markets in security and analysis applications providing possibilities to new business. These technologies have been developed in PLANCK and HESA projects.

PLANCK satellite technology makes security checks effective and measures the cosmos.

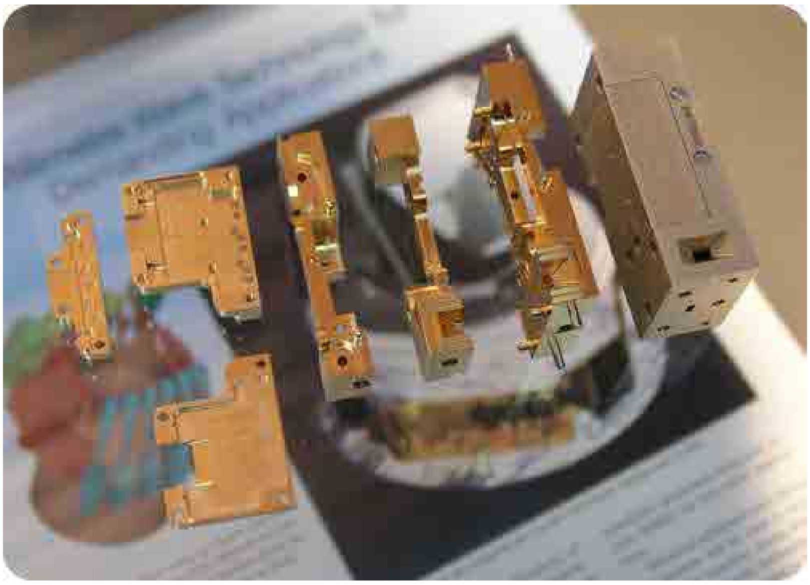

Figure 3. Low Frequency Instrument LFI 70 GHz Front-End Module. This compact matchbox size component houses four MMIC low noise amplifiers and two-phase shifters.

The Finnish team has developed the world's most sensitive matchbox-sized 70 GHz *microwave receiver* for ESA's PLANCK satellite Figure 3. PLANCK, which will be launched into space in 2007, measures cosmic microwave background radiation. This background radiation is a weak echo of the Big Bang over 13 billion years ago. Researchers expect the project to generate detailed information on the age, size and structure of the universe. The microwave technology developed in the research is ready for commercial markets. PLANCK satellite technology can also be used in everyday life. The technology detects plastic and metal items hidden under clothing during airport security checks and helps cars to navigate in a fog. It can also be utilised in developing cloud radars and in data communications applications in the future.

In *SQUID development* made by VTT the major scientific result is demonstration of a noise level in the order of 10^{-7} $\Phi_0/\sqrt{Hz}$ and energy resolution in the order of 40 for a SQUID, which are among the best values in the literature. The theoretical comparison of the TDM and FDM techniques at the fundamental level is also of scientific value.

In *bolometer research* made by Metorex International the excess noise mechanism in X-ray micro-calorimeters has been studied and a novel interpretation given. The excess noise is shown to arise from fluctuation superconductivity in regions of the TES just above the critical temperature. The sensitivity of the 4 K superconducting hot-spot micro-bolometer is ten times better than the state of the art. Metorex International is now one of the leading companies in space applications of X-ray detectors.

Development of X-ray filters for XEUS was made by the University of Joensuu and Metorex International in HESA project. Deep understanding of the behaviour of different metals in inductive grids was obtained at room temperature. Since the detector will actually obtain at cryogenic temperatures, more calculations will be performed in 2004 for inductive grids at lower temperatures (to the extent allowed by the availability of complex refractive index data). Better performance is obtained at low temperatures because the conductivity of metals increases when the temperature decreases. Preliminary theoretical results have been obtained by extending the rigorous electromagnetic diffraction analysis to the X-ray region and we soon expect to determine the limit where the complex-amplitude transmittance method can be used instead of the numerically heavy rigorous approach.

University of Helsinki (Department of Physical Sciences and Observatory), Helsinki Institute of Physics (HIP) and Metorex have developed and tested the *GEM (Gas Electron Multiplier)* technology, including GEM-foils, in good co-operation with MIT and CERN. The reported properties include very good spatial resolution, fairly good energy resolution, very large active area, a high count rate capability and a robust structure. GEM-detectors are ideal for wide field X-ray astronomy in missions like LOBSTER/ISS and the planned Finnish X-ray microsatellite HEAWiFM (High Energy Astrophysics with a Wide Field Monitor).

5.2 New remote sensing technology

The new remote sensing methods developed by MODAFOR and ASSIMENVI projects improve the exploitation of forests, snow and water resources and enable more accurate control and follow-up of environmental changes.

Path-breaking methods and applications for environmental monitoring were developed in the ASSIMENVI remote-sensing project. Satellites provide much more accurate information on the environment than before. For example, the effect of snowmelt on river flows can be forecast accurately by combining satellite monitoring directly with forecasting systems. Thus satellite remote sensing considerably increases the amount of environmental information available. In the project, Snow Covered Area (SCA) estimates were assimilated into the watershed simulation and forecasting system of the Finnish Environment Institute. Now, Finnish river flow estimates can be considerably improved during the snowmelt season in the spring, which is an important time for hydroelectric power production and flood prevention. The new method can bring about substantial economic profit in the production of electricity at hydroelectric power stations.

In another case, satellite observations were combined with chlorophyll concentration monitored regularly by the Finnish Institute of Marine Research in shipping lanes between Finland and Germany on the Baltic Sea. This enabled more accurate estimates of the amount of algae and eutrophication on the Baltic Sea than would otherwise have been possible through using only shipping lane or satellite monitoring.

The MODAFOR project has investigated the feasibility of two emerging radar techniques, radar polarimetry and interferometry, to remote sensing of forest. The final goal is to employ data from satellite radars for forest inventory. Polarimetric SAR (Synthetic Aperture Radar) data are presently available only from airborne sensors, but near-future satellites will carry fully polarimetric SAR instruments. Interferometric data from space-borne SAR sensors have been available for several years; however, the use of these data for various applications is still in research phase. Both techniques SAR radar that provides good spatial resolution from a satellite and is capable of producing images through clouds and regardless of lighting conditions (day/night).

Comparisons between the results from the theoretical polarimetric radar model for forest and data from airborne polarimetric radar indicate that the model produces realistic results for pine forest. Moreover, results from the polarimetric classification scheme show that simulated radar results are classified to the same categories as actual SAR data. Model simulations provide a good basis for utilising images from next-generation fully polarimetric satellite SAR sensors for remote sensing of forests. A new method for combined land-cover mapping and forest stem volume/biomass retrieval has been developed and tested. The obtained stem volume estimation results indicate that multi-temporal interferometric SAR data are feasible for operative forest assessment purposes even at forest stand level.

The results of the MODAFOR are already having an impact on industry. The output of MS-NFI is utilised by the major Finnish forest industry companies in planning their activities and also in practical timber procurement. The annual turnover of the Finnish forest industry is some 20-25 billion euros. The operations needed for this turnover are supported by MS-NFI. Also, the interferometry-based method for stem volume retrieval developed by LST was demonstrated to provide good results even for fairly small forest stands, which is important in Finland.

5.3 New instruments

ANTARES has played an important role in the developing, testing, and building hardware and software for space instruments. This work has been made in HESA, DAPSS and PLANCK projects. Two instruments were completed within the HESA consortium during the programme: *JEM-X sensor package* was assembled and delivered for launch with INTEGRAL by Metorex International on October 17. 2002 and the *X-ray Solar Monitor* (XSM) was designed, produced and assembled by Metorex International, and delivered to ESA for launch with SMART-1 on September 27 2003.

MarsExpress spacecraft was launched successfully on June 2, 2003. It includes the *ASPERA-3 particle instrument*, which will measure the escape of Martian atmospheric particles, that is, the atmospheric erosion. An identical replica of the instrument, *ASPERA-4*, onboard ESA's VenusExpress mission will perform similar measurements at Venus starting at the beginning of 2006. On September 27, 2003, the SMART-1 spacecraft started its journey toward the Moon with the *SPEDE* instrument. ESA's Rosetta cometary mission to comet Churyumov-Gerasimenko includes several scientific instruments with much Finnish space science know-how: *PP*, *COSIMA*, *MIP*, *LAP* and *ICA* instruments. The launch of Rosetta was successful on March 2, 2004. *CIDA* instrument on Stardust mission made a successful fly-by of comet Wild-2 on January 2, 2004. CIDA is a mass spectrometer, which determines the size of ions by comparing differences in their flight times.

In the PLANCK Surveyor Mission, the 70 GHz receivers of the *Low Frequency Instrument* (LFI) are developed. The receivers consist of Front End Modules operating at 20 K and Back End Modules (BEMs) operating at 300 K. The critical components in the receivers are the monolithic millimetre wave integrated circuits (MMIC): low noise amplifiers (LNAs) and phase shifters. During ANTARES programme, the fabrication of the Engineering Model was finalised, and the MMIC LNAs and phase shifters for the 70 GHz receivers were manufactured. Comparative tests with small amount of LNAs showed that the MMICs had excellent performance, achieving world record performance of a 35 dB gain, a 22.5 K system noise temperature, and a 25 mHz 1/f noise knee frequency.

The HESA consortium activities have grown to a higher level of collaboration with new plans for instruments and satellites, which combine the expertise and experience of the consortium members. The success and the very wide scientific and technological expertise within the consortium have made it possible to start the planning of the first *Finnish national scientific satellite HEAWiFM* (High Energy Astrophysics with a Wide Field Monitor). It can be stated that collaboration within HESA consortium has already the extent and features that are more typical of permanent organisations than of a few-year project.

6 PUBLICITY AND INFORMATION DISSEMINATION

Our work for scientific research, launch of new satellites, and technology development has gained high publicity with a great number of TV and radio interviews, and newspaper and popular magazine articles during the ANTARES programme. The total amount of popular articles, presentations and TV and radio interviews of ANTARES scientists is 252, and they have issued 67 press releases.

The ANTARES web site was opened at http://akseli.tekes.fi/Resource.phx/tivi/ANTARES/index.htx. The site consists of extensive ongoing descriptions of the programme and the projects, as well as links to the home pages of the projects. It also includes 45 information notes (i.e. press releases) in Finnish and 22 in English, a list of publications, project plans, minutes of the meetings, handouts and 63 presentations given at the fall seminars. The web pages were managed by the coordinator and the web master Seppo Väätäinen from VTT. In the beginning, the software of the pages (Tekes server) was unsatisfactory, but now the pages work quite well and all the documents produced by the ANTARES programme are saved on the pages.

The first annual scientific seminar was arranged in Helsinki in connection with the 'Space 2001 exhibition'. ANTARES scientists gave several presentations for the public during the exhibition. The exhibition was visited by more than 25,000 people.. The second scientific annual seminar 'Fall seminar'02, was arranged in Oulu on October 30, 2002 in connection with the Cospar space science meeting organised by the University of Oulu. The Science Days ('Tieteen päivät'), with several ANTARES presentations were arranged in the University of Helsinki in 2003. The space exhibition 'Open questions – Miracles of Space' was arranged in Heureka Science Park in 2003. The third, final seminar was arranged in Finlandia Hall in Helsinki, in connection with the 'Space 2003' exhibition. The 'Space 2003' exhibition was visited by some 20,000 people, and in all 13 presentations and lectures were given to the public by ANTARES researchers.

Press conferences with nine major press releases were arranged in connection with the seminars. As a result, news of the seminars were published in several major Finnish newspapers (Helsingin Sanomat, Turun Sanomat, Aamulehti, Iltalehti, Kansan Uutiset) and news about space science, space activities and space technology was published in local newspapers (e.g. Oulu-lehti) and in the more specialised journals (A'propos, Avaruusuutiset, Tekniikka & Talous, Avaruusluotain, Forum för ekonomi och teknik, Tekniikan Maailma, Nordic Space Activities, Apu) and on the Finnish television (MTV-3, TV-Nelonen, YLE, YLE News on the net, YLE24 Online). The ANTARES programme was also reported at the Espoo and Järvenpää Rotary Clubs, at the Helsinki University of Technology, at the Oulu Open University, at the Finnish Space Committee, at Oulu secondary school, Vantaa Seniors, and at the URSA astronomical society, Helsinki. The Academy of Finland and Tekes has also provided information of the programme in their web pages.

Scientific results were published in 434 international publications and 322 conference presentations. The list of publications is available on the ANTARES web site. The results were also published in 135 popular articles and presentations in Finnish newspapers and magazines. 117 interviews were given for the Finnish TV and radio. In connection with the ANTARES projects, in all 24 PhD and 43 M.Sc degrees were prepared or achieved. The total amount of training in space science and technology in universities was 107 person-years.

The following press releases were published in English in 2003:

- Pioneering methods and instruments result from the ANTARES space programme: Space technology can also be of use in everyday life. (Coordinator)
- Improved forecasting and assessment of the status of environment through the use of remote sensing satellites (ASSIMENVI)
- Instruments to planets, to moons, and to comets (DAPSS)
- Infrared Halo Frames a Newborn Star (ISO-ODIN)
- Mars Small-Scale Weather (MSW)

- The feasibility of two emerging radar techniques, radar polarimetry and interferometry, to remote sensing of forest (MODAFOR)
- Quasar researchers ensure the success of the PLANCK satellite: new source samples show more foreground noise than expected (PLANCK)
- ANTARES and Space Weather (SWAP)
- Weighing the Milky Way Disk (DARKSTAR)
- HESA Consortium chases black holes (HESA)
- New technology detectors for space and Earth-based applications (HESA)
- The production of cosmic Helium (DARKSTAR)

Table 1. Information dissemination of the ANTARES programme

	Refereed papers	**non-refereed papers**	**Conf. presentations *)**	**PhD thesis**	**B.Sc, M.Sc thesis**	**Press release**	**Popular articles presentations**	**TV and radio interviews**	**Training person years**
PLANCK	**27**	**21**	**34**	**2 (+5)**	**7 (+6)**	**7**	**63**	**13**	**10**
HESA	**64**	**27**	**60**	**3**	**7**	**8**	**4**	**20**	**-**
DARKSTAR	**13**	**6**	**6**	**2**	**2**	**12**	**3**	**3**	**10**
ISO_ODIN	**59**	**17**	**17**	**1 (+3)**	**1 (+1)**	**5**	**5**	**5**	**12**
SWAP	**26**	**11**	**62**	**3**	**4**	**5**	**5**	**10**	**12**
C2M	**25**	**4**	**39**	**-**	**7**	**4**	**15**	**5**	**7**
DAPSS	**28**	**5**	**42**	**1**	**4**	**5**	**16**	**10**	**9**
MSW	**15**	**2**	**20**	**-**	**2**	**3**	**8**	**6**	**0.25**
CHAMOS	**4**	**2**	**13**	**1**	**2**	**1**	**-**	**30**	**6.5**
MODAFOR	**13**	**4**	**12**	**(+3)**	**-**	**9**	**-**	**-**	**5.3**
ASSIMENVI	**25**	**6**	**26**	**-**	**-**	**3**	**1**	**3**	**7**
Co-ordinator	**-**	**-**	**3**	**-**	**-**	**5**	**15**	**12**	**-**
TOTAL	**329**	**105**	**322**	**24**	**43**	**67**	**135**	**117**	**89**

*) including 63 presentations in the ANTARES Fall Seminars
(+) still under work

7 ACTIVITIES IN THE PROGRAMME

7.1 Projects and consortia

The projects funded by ANTARES are extensive, mainly proposed by consortia of research institutes which have close connections with international organisations. Priority has been given to the proposals which operate in relation with ESA programmes. Altogether, the projects utilise data from more than 50 European and American satellites. The projects can be divided into the following three categories according to their contents: astrophysics, the Sun and solid bodies, and remote sensing. The detailed progress and final reports are maintained on the ANTARES website. The current projects and project managers within the ANTARES programme are:

Astrophysics:
1. PLANCK Surveyor Physics PLANCK, Kari Enqvist HU and Jussi Tuovinen Millilab, VTT
2. High energy astrophysics and space astronomy HESA, Osmi Vilhu, University of Helsinki HU
3. Space based studies of dark matter DARKSTAR, Chris Flynn, University of Turku TU
4. Interstellar medium and star formation ISO-ODIN, Kalevi Mattila HU

The Sun and the solar system:
5. Space weather SWAP, Hannu Koskinen HU
6. Cluster II and Miracle: mesosacle structure of solar wind C2M, Kalevi Mursula, University of Oulu OU
7. Dust, atmospheres and plasmas in the solar system DAPSS, Esa Kallio, FMI
8. Micro- and mesoscale atmospheric phenomena in Mars MSW, Hannu Savijärvi HU

Remote sensing:
9. Chemical aeronomy of the mesosphere and ozone CHAMOS, Esa Turunen OU
10. Modelling and methods for forest inventory MODAFOR, Lasse Holmström HU
11. Assimilation of data for environmental monitor ASSIMENVI, Jouni Pulliainen, Helsinki University of Technology HUT

The consortia mentioned above include 30 different research groups e from the following 15 different national research institutes:

Finnish Environment Institute (SYKE)
Finnish Meteorological Institute, Geophysical Research (FMI)
Department of Physical Sciences, University of Oulu (OU)
Department of Physics, University of Joensuu (JoU)
Department of Physics, University of Jyväskylä (JyU)
Helsinki Institute of Physics HIP, University of Helsinki (HU)
Laboratory of Space Technology, Helsinki University of Technology (HUT)
Millilab, VTT Information Technology (VTT)
National Forest Inventory of Finland, Finnish Forest Research Institute (Metla)
Observatory, University of Helsinki (HU)
Physics Department, University of Helsinki (HU)
Rolf Nevanlinna Institute RNI, University of Helsinki (HU)
Sodankylä geophysical observatory SGO, University of Oulu (OU)
Tuorla Observatory, University of Turku (TU)
X-ray Lab at the Physics Department, University of Helsinki (HU)

7.2 Networking, partners and contractors

In the ANTARES programme 30 Finnish research groups from six universities (Universities of Helsinki HU, Turku TU, Joensuu JoU, Jyväskylä JyU, and Oulu OU, and Helsinki University of Technology HUT), and from four research institutes (VTT, Finnish Meteorological Institute FMI, Finnish Environment Institute SYKE, and Finnish Forest Research Institute Metla) are in close scientific collaboration together and also with international space research organisations, European, American and Russian space agencies ESA, NASA and RKA (Figure 4). The detailed report 'ANTARES – Networking'' can be found on the ANTARES web site at 'Scientific results'.

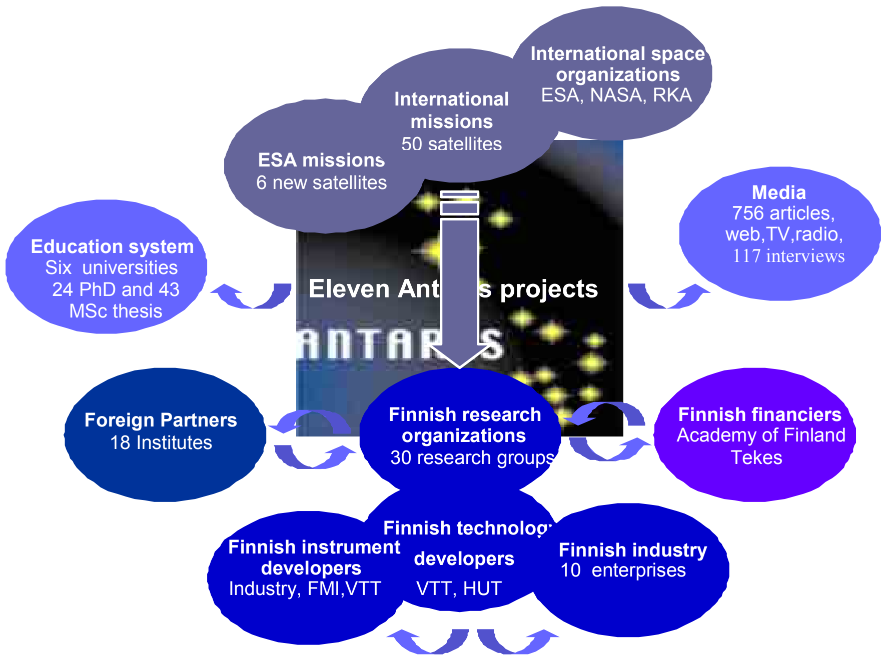

Figure 4. ANTARES network

Collaboration is also carried out with 18 foreign external co-operative partners or research institutes. For the international collaboration it is characteristic to utilise the data of more than 50 space missions e.g. PLANCK Surveyor, Integral, ISO, XMM, Smart-1, HST, Hipparcos, SOHO, Cluster, Cassini-Huygens, Mars Express, Rosetta, and Envisat-1. Collaboration has also been extended into the development of technology and the construction of the scientific instruments used on these missions. The ANTARES programme has six technological (VTT, MilliLab, FMI, HU, SEFO, HUT) and ten industrial partners (Metorex International, Patria Advanced Solutions, Patria Finavicomp, Space Systems Finland, Ylinen Electronics, Al Safety Design, Kemijoki Ltd, Nanoway Ltd, Nanocomp Ltd, Environics Ltd).

Close collaboration between the research institutes (especially FMI, VTT and the University of Helsinki) and the Finnish industry has resulted in development and utilisation of 25 Finnish scientific instruments for the ANTARES programme (JEM-X, XSM, GEM, XEUS X-ray detectors, LFI microwave receiver, Spede, Aspera, IBS and PP probe for planetary research).

ANTARES has also worked for scientific education. 67 university degrees have been under preparation or achieved by the work made within the projects. The amount of training in space science and in space technology has been 89 person-years. The results of the programme have been disseminated in 756 international scientific articles or conference presentations. The ANTARES web site at http://akseli.tekes.fi/Resource.phx/tivi/ANTARES/en/contact.htx site has had more than 45,000 visitors. ANTARES has also published in the Finnish newspapers, TV and radio 252 popular articles, presentations and interviews.

The following 18 foreign external co-operative partners or research institutes have collaborated with the Finnish consortia:

Astrophysics Division, ESA/ESTEC (Noordwijk, Netherlands)
Astro Space Center of the Russian Academy of Sciences (Russia)
Danish Space Research Institute (DSRI, Denmark)
German Aerospace Center DLR (Germany)
Integral Science Data Center ISDC (Switzerland)
Jet Propulsion Laboratory JPL (USA)
Universities of Leicester and Southampton (UK)
Massachusetts Institute of Technology MIT (USA)
Max-PLANCK-Institut fuer Astronomie (Germany)
Rutherford Appleton Laboratories (UK)
Space Research Institute IKI (Moscow, Russia)
Space Research Organisation of Netherlands SRON (Utrecht, Netherlands))
University of Kanazawa (Japan)
University of Santa Barbara (USA)
Universities of Stockholm and Chalmers (Sweden)
University of Tartu (Estonia)
University of Uppsala (Sweden)

Also, the following 17 Finnish industrial and technological co-operative partners or contractors have worked for the programme:

Al Safety Ltd
Environics Ltd
Kemijoki Ltd
Metorex International Ltd
Nanocomp Oy
Nanoway Ltd
Patria Advanced Solutions (former Patria New Technologies)
Patria Finavicomp Ltd
Space Systems Finland Ltd (SSF)
Ylinen Electronics Ltd

Helsinki University of Technology (HUT)
High Energy Physics Division, University of Helsinki Faculty of Science (SEFO)
Inorganic Chemistry Laboratory of the University of Helsinki (HU)
University of Joensuu (JoU)
University of Jyväskylä (JyU)
VTT Information Technology and VTT Electronics (VTT)

7.3 Scientific instruments for the ANTARES programme

7.3.1 GENERAL

Several Finnish scientific space instruments have been developed in context of the ANTARES programme in order to carry out the 11 scientific ANTARES projects. Finnish companies and research institutes have designed, fabricated and tested 25 instruments for Earth observation, for studies of the solar system and the cosmos. These instruments have been designed or partly completed before the end of the programme.

The year 2002 marked a milestone for 13 Finnish space instrument projects. One instrument has been completed for ESA's Mars Express spacecraft, two instruments for the SMART-1 lunar mission, one for Envisat-1, one for Integral, and five instruments for the Rosetta comet mission. The instruments will study phenomena occurring in the whole range of objects from the neighbourhood of the Earth to distant galaxies. In addition, there has been progress in the development of instruments for the PLANCK Surveyor mission, and advanced sensor technology development for XEUS, both missions aiming at studies of the early Universe and cosmology. The detailed report 'Scientific Instruments' can be found on the ANTARES web site at 'Technological development'.

7.3.2 INSTRUMENTS FOR ASTROPHYSICS

The following list summarises instrument development for astrophysics in the HESA and PLANCK consortia:

- JEM-X X-ray monitor/INTEGRAL (Metorex International)
- XSM X-ray solar monitor/SMART-1 (Metorex International)
- LFI microwave receiver for PLANCK (VTT, Ylinen Electronics, Al Safety Design, HUT)
- GEM (Gas Electron Multiplier Detector) for LOBSTER and HEAWiFM (Metorex, SEFO, HIP)
- GEM detector for Lobster all-sky monitor onboard ISS International Space Station (Metorex International)
- Imaging X-ray fluorescence spectrometer and solar monitors for the BepiColombo mission to Mercury
- CDH computer for Danish Roemer satellite (Patria Advanced Solutions)
- Data evaluation software for Integral (Space Systems Finland)
- XSM semiconductor X-ray Solar Monitor for SMART-1 lunar mission (Metorex)
- TES Transition Edge Sensor with SQUID readout arrays and diffractive IR filters for
- XEUS X-ray observatory (VTT, Metorex, Patria, University of Jyväskylä)
- TlBr hard X-ray detector for XEUS (Metorex, Department of Chemistry of HU)
- Inductive grid filters (University of Joensuu, Metorex)
- Control electronics for XEUS (Patria Advanced Solutions)

7.3.3 INSTRUMENTS FOR PLANETARY RESEARCH

The DAPSS project has fabricated or utilised several instruments for SMART-1, Mars Express, Rosetta, Venus Express, Contour, Stardust, Huygens and Netlander missions:

- SPEDE Spacecraft potential experiment for SMART-1
- ASPERA-3 Energetic Neutral Atoms Analyser for Mars Express mission to Mars
- ASPERA-4 for Venus Express
- GOMOS ozone monitor for Envisat-1 (Patria and VTT)
- PPI/HASI pressure and permittivity probe for Huygens
- IBS Ion Beam Spectrometer for CASSINI
- PP Permittivity Probe electronics for ROSETTA lander mission rendezvous with comet
- COSIMA Cometary Secondary Ion Mass Analyser s/w for ROSETTA orbiter
- MIP (Mutual Impedance Probe) EGSE for ROSETTA orbiter
- LAP Langmuir Probe electronics for ROSETTA orbiter
- ICA Ion Composition Analyser electronics for ROSETTA orbiter
- CIDA-2 dust sensor for Contour
- CIDA dust sensor for Stardust
- ATMIS Atmospheric Instrument for Mars landers on NETLANDER mission

Fabrication of the instruments and parts of the spacecraft have been made by FMI, Patria Advanced Solutions, Patria Finavicomp, VTT and Environics Ltd.

7.4 Collaboration

7.4.1 PLANCK PROJECT

A PLANCK data analysis team was established in Helsinki in 2001. The team has by now been well established as part of the CTP working group of PLANCK, which is responsible for two central data analysis tasks: 1) production of maps of the microwave sky radiation temperature and polarization from "time-ordered" data (TOD) from PLANCK; 2) calculation of the angular power spectra (denoted C (l)) of these maps. The CTP group leaders are already counting on the Finnish team for continuing for the duration of the PLANCK mission. The team is working in close cooperation with the PLANCK Data Processing Center (DPC) in Trieste. DPC will eventually incorporate the software produced by the various working groups in the PLANCK data analysis pipeline.

The members of our collaboration have been working either in Metsähovi or Tuorla depending on their personal interests and regardless of their formal attachment. The thesis work of students may be carried out at either observatory. On the cosmological side, collaboration between Tuorla Observatory and Tartu Observatory, Estonia (Academician Jaan Einasto's cosmology group) was successfully established to strengthen common research interests and to launch and expand international cooperation between cosmologists. The cosmologists in our group are studying the large-scale structures (clusters of galaxies and superclusters) of the Universe.

One of the benefits of a large satellite project like the PLANCK is the extensive collaboration network it introduces. This brings exciting prospects especially for young scientists who possibly for the first time are involved in an extensive international science project. For the PLANCK project we have been able to exploit our existing international collaboration networks as well as to establish new ones. Especially the PLANCK Extragalactic Working Group works closely together, arranging observations, and delivering results, with frequent e-mails and monthly teleconferences.

The ANTARES programme has also provided connections within the Finnish physics and astronomy institutes. The members of our team have enjoyed this rather rare cooperation between different science branches. It has brought about a wider understanding of the requirements and goals of the entire project, and, we hope, also enduring professional relationships. Metsähovi has also been in the fortunate position of taking part in the building of the 70 GHz receiver for the PLANCK, thus making us the only institute in Finland involved both in the technical development and the science.

The three years of ANTARES funding has made it possible to establish a solid foundation from which we can continue to prepare for PLANCK science in Finland. This is a major achievement. It has enabled considerable and visible Finnish participation in the PLANCK LFI Consortium. This has clearly created synergy benefits and increased cross-disciplinary interactions within the various teams involved. After the termination of the ANTARES programme, the Finnish PLANCK Surveyor Consortium is expected to continue operating as an informal entity dedicated to the common goal. At this stage, the main scientific results can be associated with the foreground studies and with theoretical considerations related to the nature and origin of the cosmic microwave perturbation.

7.4.2 HESA AND SWAP PROJECTS

The HESA consortium activities have also evolved, and the activities have grown to a higher level of collaboration with new plans for instruments and satellites, which combine the expertise and experience of the consortium members. The success and very wide scientific and technological expertise within our consortium have made it possible to start planning for bigger contributions for international space science programmes (e.g. participation at PI level in the next ESA cornerstone mission *BepiColombo*), participate in the LOBSTER all sky monitor onboard ISS and start of planning the first Finnish national scientific satellite (HEAWiFM). It can be stated that the collaboration within our consortium has already the extent and features that are more typical of permanent organisations than of a few-year project.

It was realised at the beginning of the ANTARES programme that the instrument development for XEUS, which was a major driver in combining the technology development projects in the Universities of Helsinki, Jyväskylä and Joensuu, VTT, and several commercial companies, will not be completed during the three-year period of ANTARES. The original development work has progressed well, but it has been necessary, due to the long time until XEUS realisation, to create a closer goal for the development work. This goal is a high resolution soft X-ray TES spectrometer for laboratory physics, which has almost the same characteristics of the original idea for the XEUS TES instrument. The laboratory instrument will thus serve as a prototype for the XEUS spectrometer, but will also be independently useful for laboratory physicists and potential small space missions in this decade. The GEM-detectors developed in the Observatory and High Energy Physics division of the University of Helsinki, Helsinki Institute of Physics and Metorex International have good prospects to be used in the Finnish microsatellite HEAFiFM and LOBSTER/ISS of ESA.

The ANTARES programme gave the SWAP project decisive impetus to build a national collaborative network to study the entire chain of space weather phenomena from the Sun to the Earth. Although the limited resources of the project required focusing on the four topics listed above, this integrated approach has benefited the project and also made us stronger in the international competition. While there was not much scientific interaction with the other projects in the programme, the joint ANTARES seminars were useful forums for learning about other Finnish space research projects and for making our research better known within the community.

The SWAP project was build around the existing close co-operation between the University of Helsinki and the Finnish Meteorological Institute. SWAP students working at FMI have been doctoral students from the University. Collaboration between the Universities of Helsinki and Turku strengthened strongly during the project. The SWAP project has organised joint workshops annually and also the ANTARES seminars have increased interaction within the project. In all ANTARES seminars the SWAP project was presented as a unified entity by common plenary talks, whereas the individual achievements were presented in the form of posters.

7.4.3 CLUSTER, DAPSS AND MSW

One of the aims of the ANTARES programme was to initiate and nurture national collaboration. This aim has been successfully realised within the C2M consortium. The initial idea was to join the expertise of the Oulu team on Cluster data and the expertise of the FMI team on MIRACLE data and modelling of various magnetospheric phenomena. This has worked fairly well and a number of common publications have been published. Unfortunately, the intended extent of common studies could not be completely fulfilled, partly because of missing manpower in both teams, partly because of the delay needed for the nearly completely renewed Oulu team to reach sufficient expertise. However, perhaps the most important type of added value created by the C2M project is beyond the specific scientific topics of the C2M project itself. Viz., the C2M project has greatly increased the overall discussion between the two main research teams on magnetospheric physics in Finland, including important topics such as planning of future satellite projects, collaboration on research and education, etc.

Moreover, the C2M project has enabled scientists working in Finland to significantly contribute to the work and success of the international Cluster scientific communities. These communities meet regularly in international workshops and conferences. This and other international cooperation have led to a substantial number of joint scientific publications.

DAPSS and the ANTARES programme initiated in spring 2001 collaboration between teams at FMI and OU to study the Saturnian environment, in particular the Titan-plasma interaction. This collaboration made it possible to combine FMI’s experience in large scale global numerical modelling and OU’s experience in CAPS/IBS Cassini instrument. During 2002-2003, a global model to study the interaction of plasma with Titan’s atmosphere was developed and initial results were presented in spring 2003. The consortium will continue this collaboration during 2004-2006 in the PAPSS project funded by the Academy of Finland.

The activity of the DAPSS consortium has also resulted in international collaborations. The consortium has started collaboration with the MIMI/Cassini instrument team so that the developed global Titan model will be used to interpret ENA (Energetic Neutral Atoms) images of Titan. This provides unique synergy to interpret the first ever ENA images at Mars, Venus and Titan by similar global quasi-neutral hybrid models. Accordingly, detailed ENA studies can be performed by these models.

The four quasi-neutral hybrid models developed by the DAPSS project have received wide interest and resulted in new collaborations expected to produce new science and technological achievements during the following years. Some of the most important of these collaborations have yielded a Co-I status in two instruments in BepiColombo/MPO, a Co-I status in a BepiColombo/MMO instrument, and collaboration within an international Titan team.

There has been more interaction and collaboration between MSW project and some other ANTARES projects (DAPSS, SWAP, and ASSIMENVI) than would have been without the programme.
MSW has worked in close contact with the space technology and Mars mission-related personnel of FMI for Mars missions (NetLander, Mars Express, MarsNet). Matters about the project and Mars atmosphere in general have been presented in many public outreach events and occasions including meetings of Finnish geophysicists and physicists, teacher education, Space Exhibitions in 2001 and 2003, TV and radio programs, seminars in FMI and HU.

Concluding, the ANTARES research programme has been, from the point of view of the project teams, a very useful and successful period in the Finnish space research. However, its final significance can only be evaluated after it has been seen how the related research will continue in the future. An essential feature here is how the future funding can be arranged in order to avoid problems met at the start of the C2M project.

7.5 Education

The ANTARES programme has contributed significantly to the higher education in space physics, in remote sensing, and in space technology. So far 21 doctoral theses, completed or forthcoming post-graduate studies, are connected to the ANTARES programme. The number of forthcoming or com-pleted MSc theses is 42. Furthermore, several summer trainees have worked in ANTARES projects and will do so also in 2004. The total amount of training in space science or in space technology has been 107 person-years.

7.5.1 PLANCK AND HESA

The PLANCK project has arranged several radio astronomical courses at the Helsinki University of Technology that have emphasised the PLANCK satellite. The members of our Metsähovi/Tuorla team have given a very large number of lectures to students and school children as well as adult students during the ANTARES project. We have employed several students in addition to the now full- time students. We are proud to have so many women in our PLANCK team – two senior scientists, two M.Sc./PhD students and three summer students. We feel that we have been able to create a welcoming atmosphere also for female students who might be particularly drawn to a group that is coordinated by women as well.

The European Network for the Investigation of Galactic nuclei through Multifrequency Analysis (ENIGMA) is a network on AGN research, funded by the European Commission via the ‘Training and Mobility through Research’ programme. Metsähovi and Tuorla are active members of this network. The main advantages of the ENIGMA network for the PLANCK project are the multifrequency observation campaign possibilities and the student exchange programme. Our goal has also been to integrate as many students as possible into the project, both full time (M.Sc./PhD students) and part time (summer/M.Sc. students, some of which have also worked part time during university term).

From an educational point of view, the HESA project has produced (or still under work) seven Master's theses and five PhD dissertations during this project; the figures for the PLANCK project are 7 and 13 respectively. The educational goals of the projects have been met and scientifically speaking with great success.

7.5.2 SWAP and CLUSTER

The SWAP project has contributed significantly to the higher education in space physics. So far three SWAP PhD's have completed their post-graduate studies and the fourth thesis is expected to be ready by the end of 2004. The number of completed MSc theses from the project by the end of 2003 is four. Furthermore, several summer trainees have worked in the project and will do so also in 2004.

The situation with respect to training and education has been very different in the two teams of the C2M consortium. The C2M team at FMI has only included two senior PhD level researchers who have concentrated on using Cluster and MIRACLE data in the scientific research of their own expertise. Although no MSc or PhD students were directly funded by the project at FMI, three PhD students and two master students at FMI have participated in the analysis of these results and thus the project has contributed to their scientific training.

On the other hand, the Oulu team has involved a number of students on the team. These students have been trained from the start of the C2M project in the various aspects of data handling and scientific data analysis. Also, three of these students have already completed their MSc degree on satellite data analysis and the last one is expected to be finished in 2004. Also, in Oulu, two PhD researchers whose earlier expertise was mainly in the ground instrumentation were included in the Cluster team and have been educated during the project in these skills, each concentrating on one of the two Cluster co-I instruments. While useful for the long-term development of the satellite team in Oulu, the lack of readily available experts in the team at the start of the project caused considerable delay in scientific return. Anyway, the C2M project has so far resulted in four BSc theses and three MSc theses, with one more MSc thesis being expected in 2004. One of the recent MSc students has already started his PhD studies and research using Cluster data.

The DAPSS program has trained a few software experts and provided training for several students. The flight software for ASPERA-3 and ASPERA-4 instruments have been developed by MSc *Tuukka Säles* at FMI. His PhD thesis of real time programming will be completed during 2004. MSc Ilkka Sillanpää is developing a quasi-neutral hybrid model for Titan that will be used to analyse Cassini particle data. That work will lead to an PhD thesis, which is anticipated to be completed in 2006. MSc Teemu Hiltula was trained as an expert in analysing solar wind data and finished his MSc thesis in 2003. Jari Vilppola was expertised in instrument simulation and data analysis, finishing his PhD thesis in 2003. The project has so far resulted in two B.Sc, two M.Sc theses, one PhD thesis and provided several short-term activities for students.

7.5.3 MODAFOR AND ASSIMENVI

The amount of raining of space technology in Helsinki University of Technology has been very high, 5.3 person-years. Three doctoral theses are connected with the MODAFOR project. The work concerning SAR interferometry forms the main contribution to the forthcoming doctoral thesis of M.Sc. Marcus Engdahl. The work concerning the development and application of the forest polarimetric backscattering model forms a major contribution to the forthcoming doctoral thesis of M.Sc. Jaan Praks. The work concerning the development and application of the forest polarimetric backscattering model forms a major contribution to the forthcoming doctoral thesis of Lic. Sc. (Tech.) Teemu Tares. At RNI, some work was also integrated into undergraduate training.

7.6 Funding

The amount of funding for the ANTARES programme has been satisfactory. Though, the amount of the accepted funding granted by the Academy of Finland was only 50% of the applied money, the funding allocated by Tekes has been more than the cutting made by the Academy. The total funding has been 16.8 M€. Now, the greatest concern is how the funding for space research can be kept on that level also in the future.

Funding issues of PLANCK project has been successfully settled, and the 70 GHz PLANCK programme is now fully funded. Since the ISO project grant allocation for 2001-04 (210 k€ total) covered only part of our needs, we have applied for more funding from the Academy of Finland. Our funding applications to the Academy , to cover the years 2003-06, were reviewed very favourably by international expert panels. No further funding for the 2003 applications was granted. The funding now available for 2004 is not sufficient to sustain the present research personnel of ISO project.

Despite the very good overall outcome, some external and internal factors appeared during the C2M project that reduced the volume of work that could be devoted to each of the science tasks and thereby the aimed extent of scientific results. Common to both teams of the consortium was that the funding received for the project was only one half of the amount applied and planned. Therefore, the unique scientific opportunities given by the data sets could not be used to the extent and at the pace of the initial plans.

There were also other factors affecting the Oulu team. One was the delay in the selection of ANTARES projects and at the start of the funding period of the ANTARES programme. Since almost the whole Cluster team in Oulu has always been funded from external sources, the uncertainty and the critical delay of a few months in the continuation of funding and, eventually, the reduction of funding roughly into one half led to a loss of three of the most experienced researchers just before the start of the ANTARES project. In fact, except the team leader, no senior researcher remained in the project. This change was also accelerated by the unprecedented attraction of educated personnel by the high-tech companies (mainly Nokia and its subcontractors) in Oulu at that time (2000-2001). Thus, almost the whole Cluster group in Oulu had to be re-created at the start of the C2M project. This caused, e.g., a dramatic and unexpected need of education for the new group and a delay in the scientific analysis of Cluster data. In this unexpected situation the team leader applied several times for a temporary research position of the Academy in order to free himself from the r duties related to his university position. Unfortunately, all these applications were rejected. Also, because of the rules of Academy funding, it was not possible to use the project money for this purpose, not even temporarily over the most critical period.

The MSW project adapted to the available level of funding. Unfortunately, although the reviews were really excellent, continuation to this project was not funded at all by the Academy of Finland for 2004-2007. In the worst case, this means an end to this very successful Finnish Mars project at the very moment when all the tools are finally ready and available for a fruitful period of Mars research. We consider this as a significant failure of the Finnish funding system.

The ASSIMENVI project obtained a partial funding from the ANTARES programme, about 68% of the total applied external funding was granted for the project by the programme. Other national and international research funding covered partially the funding gap. However, the project personnel had to accomplish other affiliations than those of the project, which caused delays.

8 PROJECT REPORTS

8.1 Finnish PLANCK Surveyor Consortium (PLANCK)

Professor Kari Enqvist, University of Helsinki
Research Professor Jussi Tuovinen, VTT MilliLab

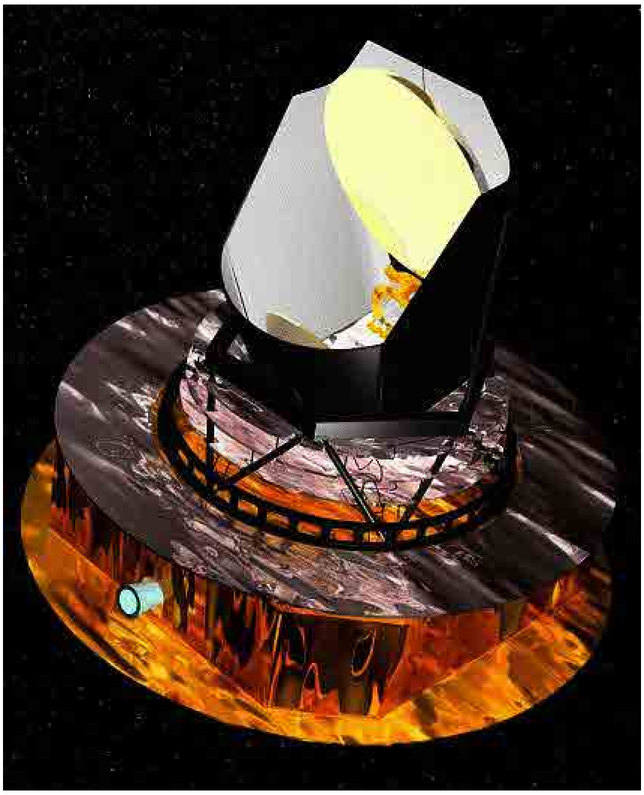

Figure 5. PLANCK satellite will be launched in 2007

8.1.1 INTRODUCTION

8.1.1.1. The Cosmic Microwave Background

During the last 10 years, cosmology has become a precision science. This is due to measurements of the cosmic microwave background (CMB), first by the COBE satellite in 1992, followed by balloon flights such as Boomerang and Maxima, and most recently by the WMAP satellite. The anisotropy of the CMB, i.e., variations in the intensity (temperature) and polarization reflect small energy density variations of the universe at the time CMB was created. These are the “seeds of galaxies”, from which the present structure (galaxies, galaxy clusters) of the universe grew out. The statistical properties of the variations provide information not only of all the essential cosmological parameters but also about the particle physics mechanisms, which originally were responsible for the primordial perturbations.

The study of the CMB is thus a cross-disciplinary field between traditional cosmology and particle physics. Interpretation of the CMB data relies on models of particle physics, in particular theories of inflation, and can yield information of physics at extremely small length scales, and possibly even of theories of quantum gravity.

8.1.1.2. The PLANCK Surveyor Mission

After the great success of WMAP, expectations for the PLANCK Surveyor Mission (Figure 5) of the European Space Agency (ESA) are high. PLANCK is designed to measure the primordial cosmological signal with an accuracy that exceeds that of WMAP; in particular, PLANCK is expected to perform much better polarization measurements.

PLANCK has two detectors, called the Low Frequency Instrument (LFI) and the High Frequency Instrument (HFI). Their integrated data will provide temperature and polarization maps of the primordial microwave sky. Finland belongs to the LFI Consortium (PI Reno Mandolesi) and designs, tests and builds the detectors of the LFI 70 GHz channel. Instrument building is directed by Professor Jussi Tuovinen (MilliLab and VTT Information Technology) and funded by Tekes. This has opened up a unique opportunity for the Finnish scientific community to participate in one of the most exciting cosmological experiments of the decade. PLANCK is the first large-scale cosmological experiment that Finland is involved in. After the recent descoping of the 100 GHz channel, the Finnish role in LFI has now become quite prominent, also in the light of the WMAP results, which indicate that the best primordial signal-to-noise ratio is obtained at about 70 GHz.

The Finnish high-energy physics and astronomy communities are both involved in the LFI Consortium. The foreground of diffuse radiation, dust, stars and galaxies, which is of scientific interest to the astronomers, is background to the primordial signal and should be properly understood. This requires a detailed understanding of the astronomical foreground objects ranging from quasars and external galaxies to local interstellar medium and regions of star formation. The PLANCK data itself can also be used to provide information on various astronomical objects. Hence PLANCK is a highly interdisciplinary enterprise, bringing together engineers, astronomers, cosmologists and particle physicists. The scientific aspects of PLANCK-related work in Finland are being coordinated by Professor Kari Enqvist. Enqvist and Tuovinen are the two Finnish Co-Investigators in the LFI Consortium. The Co-I's have the right to suggest new members ("associates") in the LFI team and are responsible for the overall management of the whole Finnish LFI effort.

The Finnish participants in PLANCK LFI have, under the auspices of the ANTARES Space Science Programme, organised themselves into a Finnish PLANCK Consortium. The institutes involved in PLANCK science are (with the main person in charge) are:

1) Dept. of Physical Sciences, Univ. of Helsinki and Helsinki Institute of Physics (Kari Enqvist);
2) Metsähovi Radio Observatory, Helsinki Univ. of Technology (Anne Lähteenmäki);
3) Tuorla Observatory, Univ. of Turku (Esko Valtaoja);
4) Observatory, Univ. of Helsinki (Kalevi Mattila).

Physics of the CMB fluctuations and their cosmological implications are being studied by the team members at the Department of Physical Sciences, University of Helsinki, and at the Helsinki Institute of Physics. The physics of the foreground objects is being studied by the team members at Metsähovi Radio Observatory and Tuorla Observatory, which form a single team, and by the team at the Observatory of the University of Helsinki.

8.1.2 PLANCK 70 GHZ LOW FREQUENCY INSTRUMENT DEVELOPMENT

8.1.2.1 Goals of the project

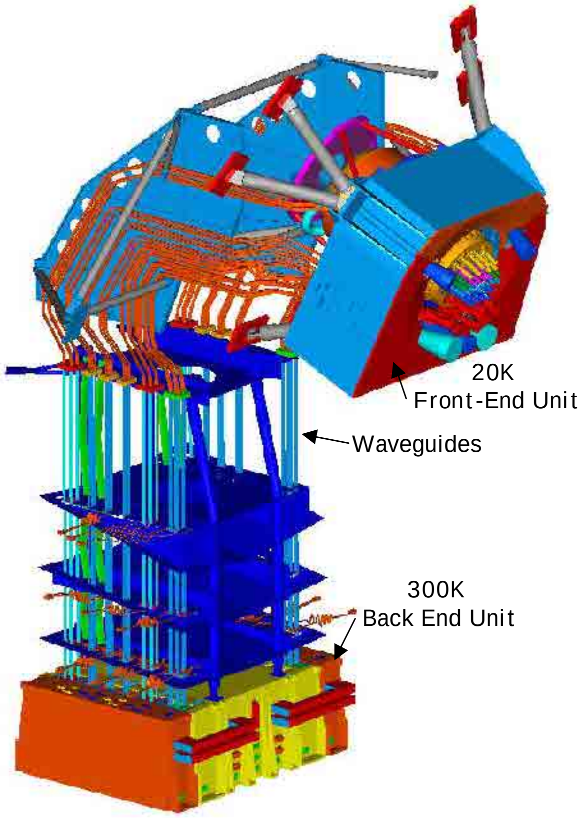

Figure 6. Planck Low Frequency Instrument (LFI). The active parts of the LFI 70 GHz channel will be built by the Finnish team.

In the PLANCK Surveyor Mission, the 70 GHz receivers of the Low Frequency Instrument (LFI) (Figure 6) are developed by the Finnish Instrument Team consisting of MilliLab - VTT Information Technology, Ylinen Electronics, Ltd., and AL Safety Design, Ltd. The receivers consist of Front End Modules (FEMs) operating at 20 K and Back End Modules (BEMs) operating at 300 K. The critical components in the receivers are the monolithic millimetre wave integrated circuits (MMICs), of which there are two kinds: low noise amplifiers (LNAs) and phase shifters. The LNAs amplify the very weak Cosmic Microwave Background (CMB) signal while adding noise themselves as little as possible, and the phase shifters are used for rejecting 1/f noise in the receivers. Therefore, the most important performance criteria for the 70 GHz receivers are the FEM gain, the overall radiometer noise temperature and the 1/f noise knee frequency. The requirements for these criteria are 35 dB, 29.2 K and 50 mHz respectively.

8.1.2.2 Technological achievements

During 2003, the development of the EM was finalized, and the MMIC LNAs and phase shifters for the 70 GHz PFM receivers were manufactured. Comparative tests with small amount of LNAs showed that the PFM MMICs had as good as performance as the MMICs used for the 70 GHz Elegant Breadboard Model receiver, which achieved world record performance of a 35 dB gain, a 22.5 K system noise temperature, and a 25 mHz 1/f noise knee frequency. Unfortunately, the MMICs available for the EM were not of the same high quality, and thus the performance of the EM was poorer.

8.1.3 PHYSICS OF THE COSMIC MICROWAVE BACKGROUND

8.1.3.1 Goals of the project

The primary goal of the project is to measure the properties of the cosmic microwave background and to deduce from them the main properties of the universe, its geometry, composition, and evolution, and in particular the nature of the primordial perturbations, which formed the seed for the formation of structure in the universe (stars, galaxies, and clusters of galaxies). This knowledge of the nature of primordial perturbations will then help us in finding out the physical mechanism responsible for generating them in the very early universe.

In preparation for the PLANCK Surveyor mission, the team at the University of Helsinki and the Helsinki Institute of Physics has two shorter-term goals:

1) To develop methods for analyzing the PLANCK data.
This includes methods for making maps of the CMB temperature and polarization fluctuations on the sky and methods for estimating the angular power spectrum (denoted C_l) of such maps. From these power spectra the cosmological parameters can then be estimated. These methods are to be implemented as software packages which will be incorporated in the PLANCK data analysis pipeline maintained by the PLANCK DPC's (Data Processing Centers).

2) To obtain the constraints on the nature of primordial perturbations from existing CMB data.

Cosmological Parameters

There is considerable effort worldwide to determine cosmological information from the both existing and forthcoming CMB data. The ANTARES group has therefore focused its research on one particular segment, the nature of the initial density perturbations. In simplest models of inflation, only so-called adiabatic perturbations are possible; these are perturbations in the energy density of the primordial plasma. However, in general there can arise both adiabatic and isocurvature perturbations; the latter are entropy perturbations and are generated in many models of inflation. We have shown that already the balloon experiment data rule out the possibility that the primordial perturbations are purely isocurvature. A mixture of adiabatic and isocurvature remains both a theoretical and observational possibility. Theoretically, adiabatic and isocurvature perturbations may also be correlated. An eventual analysis of the PLANCK data (or for that matter, any CMB data) that aims at an unbiased determination of the cosmological parameters should allow for generic initial perturbations.

Indeed, in a recent paper V. Muhonen and J. Väliviita, two graduate students in the Helsinki group, pointed out that the WMAP analysis of the mixture of adiabatic and isocurvature perturbations in their data set was done under certain theoretically unfounded restrictions. Such considerations, while scientifically significant as such, also count as important preparatory work for PLANCK data analysis.

8.1.3.2 Scientific results

CMB data analysis

We have derived a maximum-likelihood based destriping method for removing low-frequency noise from time-ordered data.

We have developed a C_l–estimation method which combines the Master approach with destriping as the map-making method. We have discovered a bias effect on the C_l–spectrum, due to the distribution of detector pointings on map pixels, and developed a method to correct for this effect.

Nature of primordial perturbations

We have obtained results and constraints on the nature of primordial perturbations using existing CMB data. We have concluded that pure isocurvature perturbations are ruled out already by the pre-WMAP data, even allowing for arbitrary tilts for the perturbation power spectra and for open or closed geometry for the universe. The data allows pure adiabatic perturbations and adiabatic+isocurvature mixtures. Using the WMAP 1^{st} year data, we have obtained constraints on both correlated and uncorrelated adiabatic+isocurvature mixtures. The limits from the present data are not yet very restrictive. (We indeed need PLANCK to get good estimates of the properties of the primordial perturbations.) The 2-sigma upper limit for the isocurvature contribution to the primordial perturbations at the k^{-1} = 20 Mpc scale is 84% of the adiabatic contribution for uncorrelated perturbations. For correlated perturbations the upper limit is tighter.

Theoretical studies

CMB results have important ramifications for models of particle physics, which should provide the ultimate explanation for e.g. the origin of structure. Presently cosmic inflation is greatly favoured as the generator of primordial density perturbations. Increasingly accurate CMB results will differentiate between models of inflation, or alternatives such as the ekpyrotic scenario, and hence provide important information about the structure of matter at very small distance scales.

There is a plethora of theoretical possibilities that can be tested with the PLANCK data. Examples include the non-gaussian features of the perturbation spectrum of certain (hybrid) inflation models; models where the primordial perturbations are not produced by the inflation but by some other field, the curvaton; pre-Big Bang models of string cosmology, which were long thought to produce only isocurvature fluctuations but which actually may also give rise to an adiabatic spectrum, as was shown by Enqvist and Sloth. Many of these model considerations lead to a mixture of adiabatic and isocurvature perturbations and hence are very much connected with the effort in cosmological parameter determination and data analysis method development.

8.1.4 THE FOREGROUND: EXTRAGALACTIC POINT SOURCES

8.1.4.1 Goals of the project

The main goals for the Metsähovi/Tuorla active galactic nuclei (AGN) collaboration in the PLANCK project have been to secure the development of the Quick Detection System, to participate in the construction of the PLANCK Pre-launch Catalog, to thoroughly analyse new and existing AGN variability data, and to participate in all scientific activities of the PLANCK Working Group 6 (Extragalactic point sources). The latter includes, for example, studying the high frequency radio behaviour of both well-known and previously little studied AGNs with several observing facilities around the world in order to prepare for the extragalactic point source science case of the PLANCK mission and to aid in the cleaning of the CMB foreground contamination. The goals of our cosmological collaboration with the Tartu Observatory within the PLANCK Working Group 5 (Large-scale structures) have been to investigate evolutionary effects of galaxies and galaxy systems, to study the spatial distribution of galaxies using light-cone simulations, to investigate properties of galaxy clusters and superclusters, to construct light-cone mock catalogs, and to study the properties of luminous matter in dark matter halos.

8.1.4.2. Scientific Results

The Metsähovi/Tuorla team has started new observing and data analysis programmes for the PLANCK project. The source samples include objects that have never been observed at these frequencies before, and the amount of data analysed is unprecedented. Not only are the observations for the Pre-launch Catalog important in themselves, but we need to know the behaviour and physics at work in these sources as well. This knowledge is required both for the success of the CMB mapping as well as for the non-CMB science.

The idea was to study new source populations and to get an estimate of how they affect the PLANCK mission. In the past most of these sources have been excluded from high frequency studies because they are believed to be weak in the radio domain. However, our new observations show that many – possibly hundreds – of these sources are so bright in their active state that the PLANCK satellite can easily detect them.

BL Lac Objects (BLOs)

We started to observe a large sample of BLOs in 2001 with the Metsähovi telescope at 37 GHz. Most of the X-ray selected and intermediate BLOs have never been observed at high radio frequencies before and we wanted to see whether this is justified or not. By autumn 2003 we had covered 98% of the sample (about 400 sources). Of all of these, *more than one third* were detected and, *about one third* of the X-ray and intermediate BLOs, too, that have previously been thought to be too weak at radio frequencies! The detection rate is higher than expected, and, some high-peaking BLOs seem to be well detectable also at lower frequencies, at least in their active state. This automatically means that these sources can also be detected by the PLANCK satellite!

Gigahertz-peaked spectrum (GPS) sources
We have been observing new samples of GPS sources with the Metsähovi telescope at 37 GHz and with the SEST at 90 GHz. The purpose is to search for new high-peaked sources, to study the variability of the "bona fide" GPS sources and the models used for describing them, and to study the impact of our findings to the PLANCK mission. Our group has identified several new extreme peaking GPS sources. It seems that the number of the sources with inverted spectra and thus being bright in the mm wavelength domain - previously excluded from high frequency studies -–is *larger* that earlier assumed. Tornikoski et al. have shown that many sources currently identified as "bona fide" GPS sources and candidates in the literature actually are ordinary flat spectrum sources with high variability that have inverted spectra *only* during flares. Our current working hypothesis is that the number of genuine GPS sources is smaller than the estimates given in the literature. However, the number of sources that sometimes, i.e. during their active state, peak at high radio frequencies seems to be *higher* than earlier assumed. This result is also of great importance for the PLANCK mission, because these sources can at times be extremely bright at the PLANCK frequency range. This emphasizes the importance of the prediction of source activity states during the mission, as well as the role of the radio flare modelling.

Variability analysis and statistics
One of the tasks in both defining the parameters for our Quick Detection System as well as in planning multifrequency AGN observing campaigns during the PLANCK mission, is to study the long term millimetre variability of a large sample of sources and so better understand their variability and variability timescale behaviour. Typical variability timescales of AGNs at 22 and 37 GHz have been studied earlier by our team, and currently we are studying a complete set of high-frequency radio data at 90 and 230 GHz of ca. 150 sources. As a special interest for the PLANCK project, we are also looking at the possibility of predicting activity in a source based either on statistics or observed flux behaviour of the source.

Large-scales structures and cosmology
In our recent papers we have calculated and used the density field of the Las Campanas Redshift Survey and Sloan Digital Sky surveys to find clusters and superclusters of galaxies, and to investigate their properties and environmental effects. This work provides a database of observed galaxy complexes for the PLANCK mission, and the results will be compared with the results found in numerical simulations.

8.1.5 THE FOREGROUND: GALACTIC DUST AND DUSTY GALAXIES

8.1.5.1 Goals of the project

The Helsinki University Observatory participates in the PLANCK satellite project. Preparatory work and scientific studies are now being carried out to ensure immediate and efficient utilization of the satellite data for studies of astronomical objects ranging from external 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. Active participation in PLANCK organization is essential for appropriation of data rights so that researcher get access to PLANCK data immediately and not only after a proprietary period of two years.

8.1.5.2 Scientific results

Technical work group "*Simulation of diffuse interstellar emission*" produces template maps of diffuse Galactic emission. The project has worked on template maps of the so-called anomalous microwave emission (Figure 7), which is often attributed to small, rapidly rotating dust grains. The first version of the template was delivered in 2003. Currently first full set of templates (dust, free-free, and synchrotron emission) is being collected by the work group and made available within the PLANCK community.

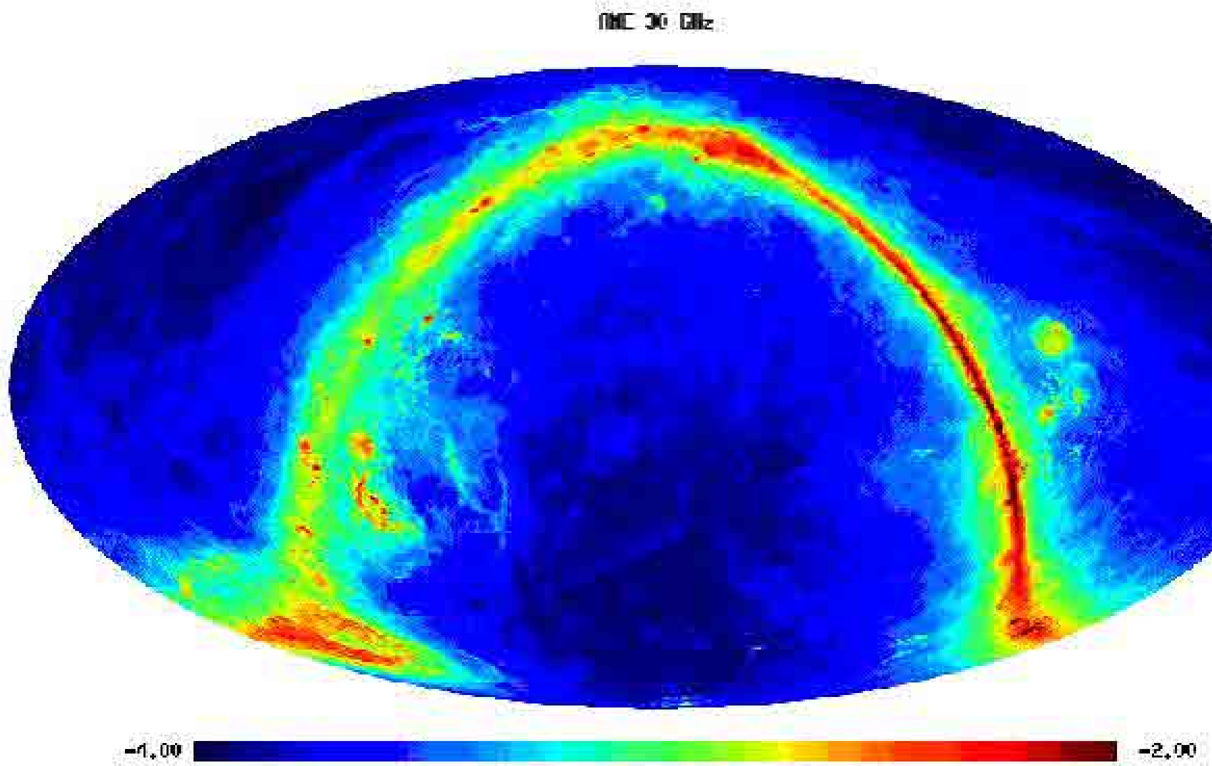

Figure 7. Template map for anomalous microwave emission from spinning dust particles. Map is in ecliptic coordinates with the plane of the Galaxy showing as a bright arc.

The project has worked on the modelling of emission from interstellar dust clouds. The work is based on three-dimensional magnetohydrodynamic simulations of interstellar clouds, and new methods are being developed for radiative transfer of continuum radiation (Figure 8). For example, an approximate method was created making it possible to predict emission from transiently heated grains even in the case of models consisting of millions of cells.

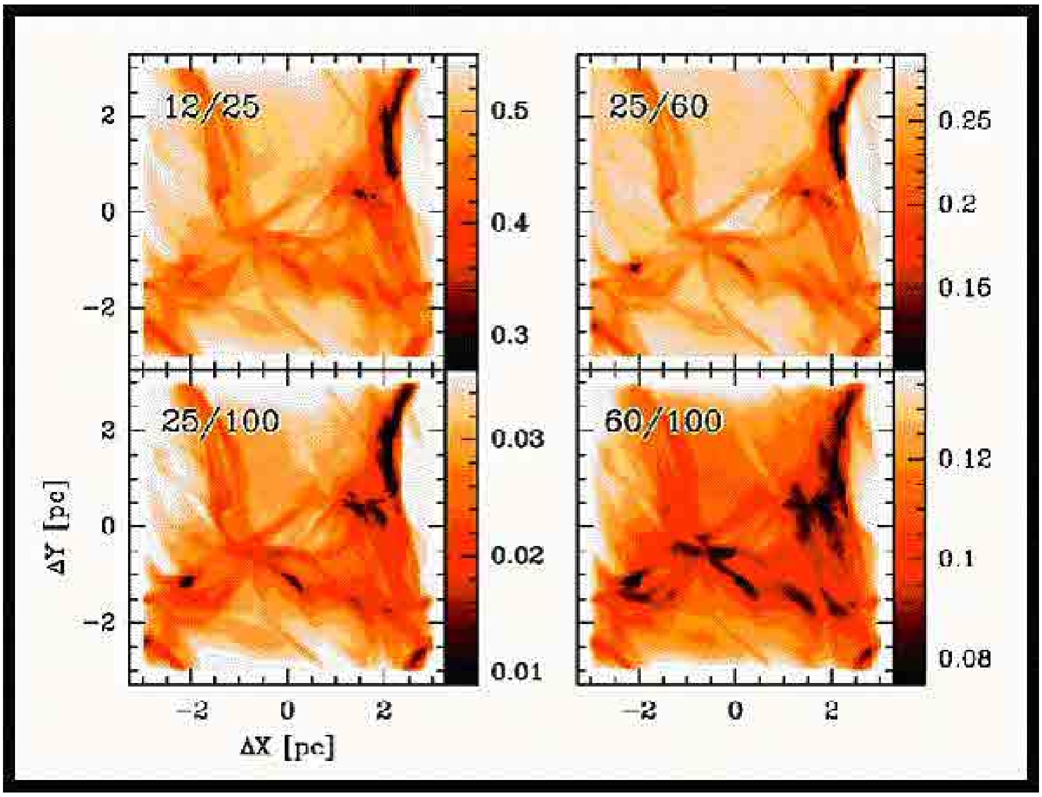

Figure 8. Intensity ratios between 12, 25, 60 and 100µm infrared bands computed for a three-dimensional MHD model cloud

The project has studied the use of Multilinear Engine program in the separation of different emission components from PLANCK observation. Preliminary results have been presented in PLANCK work group meetings and a publication is in preparation.

PLANCK is expected to detect a number of dense and cold cores in interstellar clouds. These will be studied by the PLANCK work group '*Cold Cores*' which is being coordinated by *Mattila*. Because of the low temperature of the cores the dust emission takes place at very long wavelengths and the objects were invisible to previous all-sky infrared surveys. If the objects are very numerous they may even form a significant fraction of the so-called missing mass of galaxies. A preparatory survey has been started using a number of such objects identified from the ISOPHOT Serendipity Survey. The sources are now being studied with radio observations. Many objects have been observed in molecular lines (e.g. CO isotopes, NH_3 and N_2H^+) using e.g. Onsala and SEST radio telescopes. Detailed studies of two sources, clouds B217 and B68 have been published (Figure 9). Currently observations cover more than 40 cores and the studies will continue.

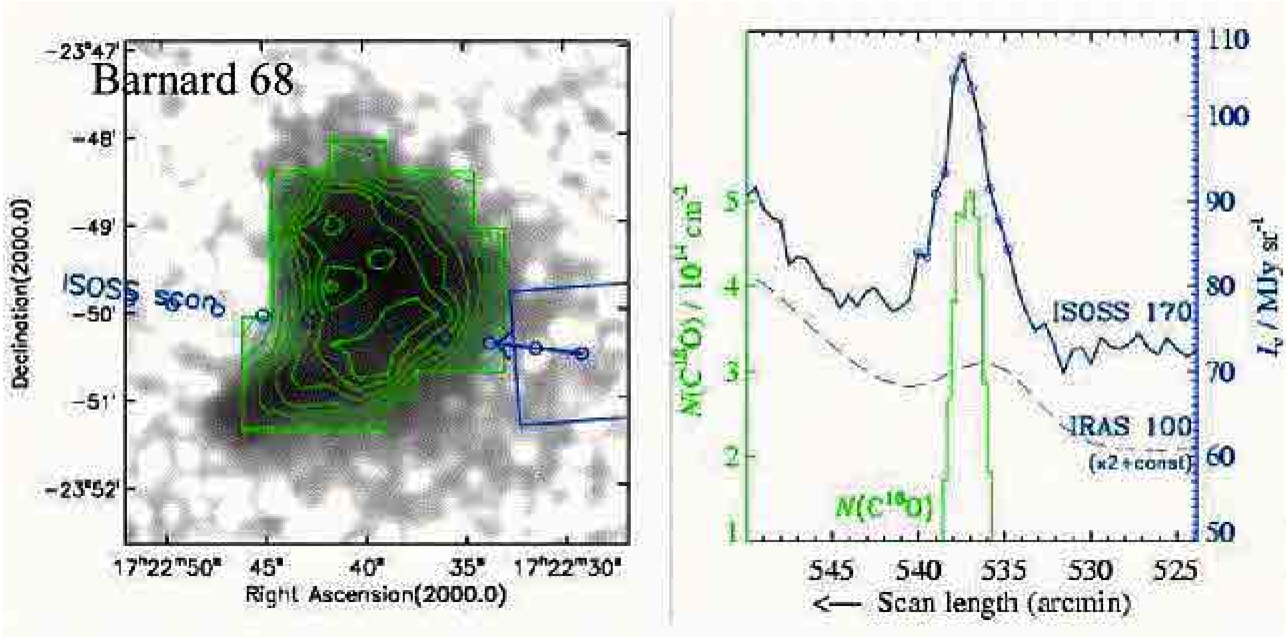

Figure 9. Dark Cloud B68: Left: the intensity of $C^{18}O$ line emission. Blue circles show the line observed in ISOPHOT Serendipity Survey. ***Right*****: intensities at 170μm (ISOSS), 100μm (IRAS) and $C^{18}O$ column density.**

8.1.6 SUMMARY

Three years of ANTARES funding has made it possible to establish a solid foundation from which one can continue to prepare for PLANCK science in Finland. This is a major achievement. It has enabled a considerable and visible Finnish participation in the PLANCK LFI Consortium. This has clearly created synergy benefits and increased cross-disciplinary interactions within the various teams involved. After the termination of the ANTARES programme, the Finnish PLANCK Surveyor Consortium is expected to continue to operate as an informal entity dedicated to the common goal.

At this stage, the main scientific results can be associated with the foreground studies and with theoretical considerations related to the nature and origin of the cosmic microwave perturbation. The Consortium has also been very active in propagating the scientific information to the public at large. Much attention has been dedicated to teaching and research training activities.

8.2 *High Energy Astrophysics and Space Astronomy (HESA)*

Docent Osmi Vilhu, University of Helsinki, Observatory

Figure 10. Launch of Integral in October 2002

8.2.1 GOALS OF THE PROJECT

The activities of HESA consortium can be divided into two parts: 1. *Fundamental science* and *2. Development and building new instruments*. The first part consists of scientific return from the instrument projects (*INTEGRAL, SMART-1*), complemented by data from other satellites (e.g. *XMM-Newton, RXTE, Chandra, Compton archive data*) and from the ground-based multiwavelength collaboration (*AGILE, MAGIC, NOT, ESO, VLA, GMRT, Ryle, ATCA*). The second part is a continuation to the hardware projects in INTEGRAL and SMART-1 including also research in detector physics.

8.2.1.1 Fundamental science

The work for the Finnish hardware part of *INTEGRAL* (Figure 10) and *SMART-1* was funded by the Finnish Technology Agency Tekes. In addition to the successful finalisation of the instruments, an efficient scientific return was obtained in the early phases of these missions.

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 and the possibility for a very long monitoring (*SMART-1* cruise phase), coupled to the sophisticated modelling, are the key ingredients of the science programme.

The main goals of the Tuorla HESA/ANTARES project are 1) to study the high-energy radiation processes in active galactic nuclei using Compton satellite (EGRET) data, 2) to obtain new multifrequency data on AGN and their environments in order to understand the origin of high-energy radiation, 3) to participate in new high-energy projects such as the INTEGRAL satellite and the MAGIC TeV telescope project, 4) to study the energetic processes in the Sun, and 5) to develop theoretical models for the high energy emission processes and to understand their relation to lower frequency phenomena.

8.2.1.2 Development of new instruments

Development of new instruments was a natural continuation to the INTEGRAL and SMART-1, where the consortium 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 the planned Finnish national microsatellite *HEAFiFM.* The specific improvements which are meaningful are: 1) 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, 2) large sky field-of-view in X-rays with moderate spectral resolution *(LOBSTER, HEAFiFM*) 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 developed are: 1) cryogenic X-ray microcalorimeter array based on superconducting Transition Edge Sensors (*TES for XEUS*), 2) infrared bolometer array based on the same technology (e.g for Submillimetron), 3) hard X-ray detector array based on a compound semiconductor material (*TlBr for XEUS*), 4) a position sensitive gas-filled soft X-ray counter for astronomical use, based on a new sensor foil, Gas Electron Multiplier (*GEM*). 5) efficient new type Command and Data Handling (*CDH*) computers for ROEMER and other potential missions.
The XEUS instrument development work (1-3) includes several subprojects, and their individual goals are described below. The goal of the *SQUID* development work by VTT together with Metorex and University of Jyväskylä was to develop a super-sensitive readout array suitable for a cryogenic TES X-ray sensor array in XEUS. The development work has been going on in close collaboration with SRON and the ESA, and supported strongly by the ESA TRP funding. The SQUID development at VTT is the biggest and most important part in the whole Finnish activity for XEUS instruments.

The goal of the project involving University of Jyväskylä together with Metorex International was to develop *ultra-sensitive technologies* from X-ray to submillimeter-wave detectors for satellite based astronomy missions. This included also development of *solid-state coolers*, which can improve the performance of bolometric detection. The work concentrated on low-temperature detectors utilizing properties of superconducting materials, and the lowest operating temperatures used were approx. 100 mK. The X-ray devices have an energy resolution below 10 eV at 5.9 keV and suit well to X-ray spectroscopy, and the microbolometers functioning at sub-millimetre waves use the same basic technique as the X-ray sensors.

The XEUS mission is characterised by ambitious science goals in also hard X-ray astronomy. Search and development of compound semiconductors is a task in this activity. Thallium bromide is promising as room temperature *detector for hard X-rays*, and the goal of the project of Department of Chemistry/University of Helsinki together with Metorex International is to develop high purity TlBr for use in hard X-ray detectors, which would be suitable for use in XEUS.

The goal of the project for *IR-filters* by University of Joensuu together with Metorex International was to develop inductive grid filter for rejection of infrared radiation. The filter is to be placed in front of the X-ray detector of XEUS to protect it from radiative heating. The metallic mesh filters were to be fabricated using lithographic techniques, the final goal being a self-standing structure.

One goal was to develop also room temperature electronics (*DCE*) for the TES/SQUID array detector in a project by Patria Advanced Solutions together with VTT. The beginning of this work was foreseen for later phases of ANTARES programme (definition requires SQUID development to be at advanced phase).

The goal of the Gas Electron Multiplier (GEM) project (4) by the University of Helsinki and Metorex International was to develop a position sensitive gas sensor for X-ray astronomy based on the use of lightweight, very high spatial resolution *GEM foil technology*. The potential platform at the time of the beginning was the all sky monitor ASM-plan of MIT/NASA, at present the Finnish *microsatellite and LOBSTER* of ESA deserve more solid prospects. These both are complementary and support each other, both in science and technology. At present, the GEM-detector is added also to XEUS-instrumentation due to its capability to measure X-ray polarization with an extremely high sensitivity.

The goal of the Danish *ROEMER* project by Patria Advanced Solutions (5) was to make a detailed design of the Command and Data Handling (*CDH*) computers, and also to build the hardware, based on a novel type microprocessor. The scientific motive for this purely technological work was to receive by this investment a significant share of the scientific use of ROEMER. The CDH developed is also applicable e.g. to the GAIA-mission of ESA.

8.2.2 SCIENTIFIC RESULTS

8.2.2.1 INTEGRAL studies

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

Mass transfer from the prototype microquasar GRS 1915+105 was computed and a 10 per cent duty cycle found. The results also 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 (compared with a 6 times larger innermost stable orbit of a non-rotating hole).

Deciphering the content of the jets from one black hole, Nova Muscae, using old GRANAT data, the project group concluded that there must be positrons and electrons (and 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 and temporally, when the radio data from GRO J1655-40 microquasar and 3C273 well-known quasar was compared.

Genetic algorithms were further developed 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 superorbital 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 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 (Figure 11). This source contains a black hole weighing more than 10 solar masses and 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 of the disk of gas surrounding the black hole. In the very same observations a new transient gamma-ray source IGR J19140+09 was discovered. At present this new target is intensively studied at all wavelengths. It is a very variable hard X-ray source with strong Radio-emission. Possibly it is a new microquasar.

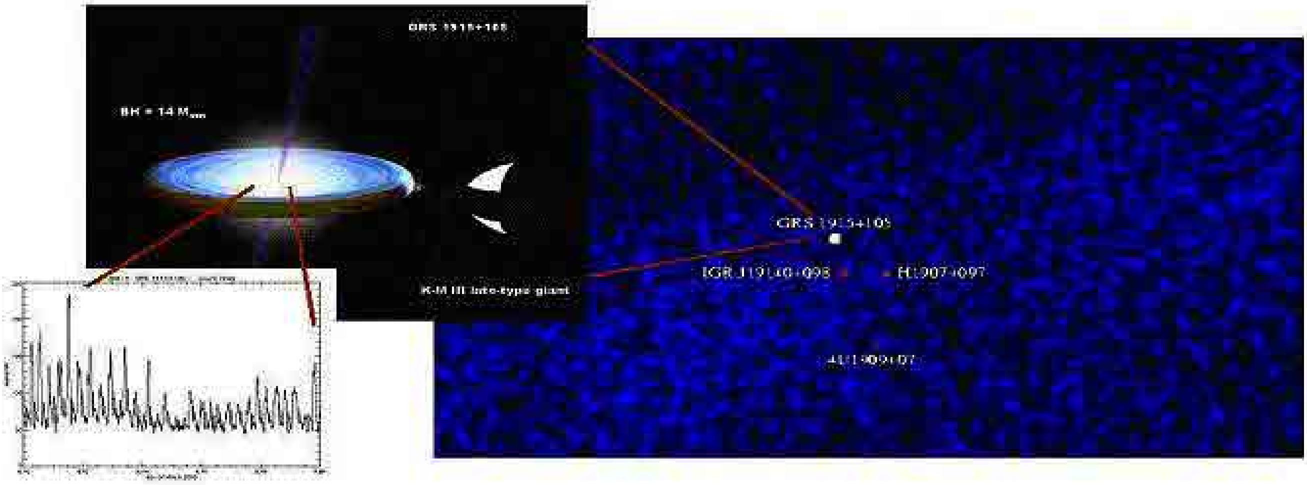

Figure 11. Presentation on GRS1915+105. Artists' view of the system (upper left). Lower left: lightcurve with 5 minutes oscillation of X-ray brightness. Right: IBIS observation with GRS1915+105 and IGR J19140+09

The HESA group has been actively involved in the INTEGRAL studies of the puzzling X-ray binary Cyg X-3 (Figure 12). This source has effectively eluded 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. The spectral form and variability suggest that Cyg X-3 contains a black hole comparing with other black holes like Cyg X-1 and GRS 1915+105.

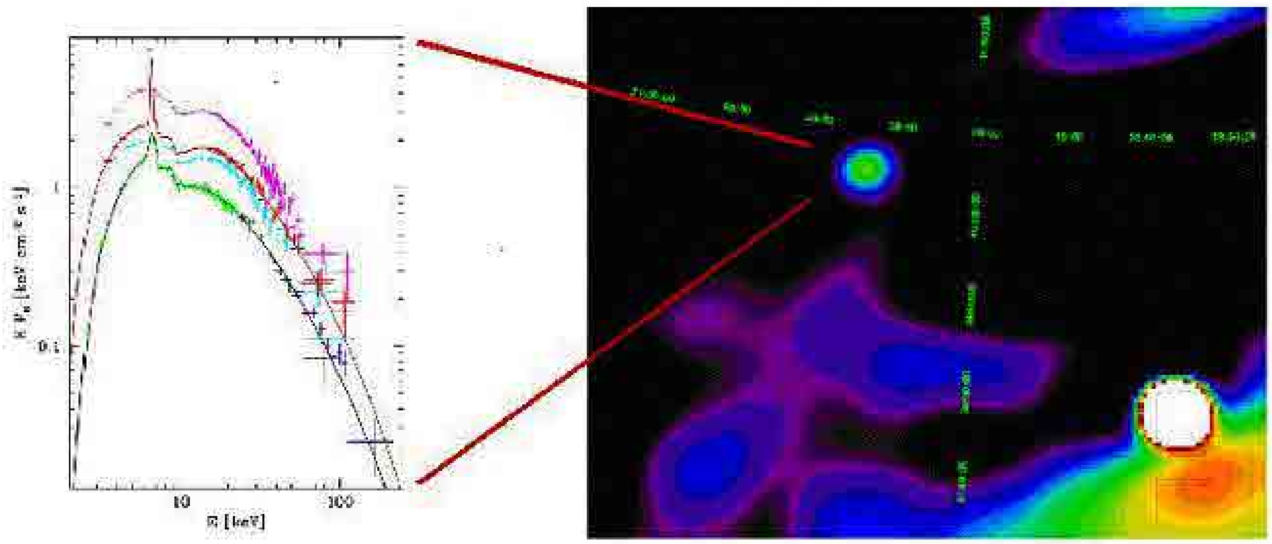

Figure 12. INTEGRAL gamma-ray image from the constellation Cygnus. The bright dot at lower right is a massive X-ray binary Cyg X-1. Upper left: black hole Cyg X-3. The diagram shows the X-ray intensity versus energy.

The group of Tuorla Observatory 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 ongoing).

Analysis of older EGRET data has shown that the synchrotron-self-Compton mechanism seems to be very important in strong gamma-ray blazars, contrary to the current paradigm. Theoretical work on shock acceleration and inverse Compton mechanisms and their application to new MAGIC and INTEGRAL data is ongoing. The analytical and numerical methods we have developed will also be applied to galactic miniquasars. 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. High-energy solar phenomena have been studied, concentrating on connections to lower energy phenomena, both believed to be different manifestations of same explosive magnetic events.

8.2.2.2 XEUS technology

In *SQUID development* made by VTT the major scientific result was the demonstration of a noise level in the order of $10^{-7}\ \Phi_0/\sqrt{Hz}$ and energy resolution in the order of 4000 for a SQUID, which are among the best values in the literature. The theoretical comparison of the TDM and FDM techniques at the fundamental level is also of scientific value.

In *bolometer research* made by Metorex International the excess noise mechanism in X-ray micro-calorimeters has been studied and a novel interpretation given. The excess noise is shown to arise from fluctuation superconductivity in regions of the TES just above the critical temperature. The sensitivity of the 4 K superconducting hot-spot micro-bolometer is ten times better than the state of the art.

In *calorimeter and bolometer research* made by University of Jyväskylä the main scientific results can be divided into three groups: 1) results on X-ray calorimetric detector development, 2) work on hot-electron bolometers and 3) work on solid-state coolers.

1) X-ray detection

The group developed a superconducting Transition Edge Sensor (TES) operating at 150 mK with energy resolution 9 eV at 6 keV energy. This is quite close to the best sensors anywhere in the world. Specifically, different detector geometries and noise processes limiting the resolution were studied, with a very significant result: The previously uncharacterised so called ‘excess noise’ is evidently caused by the fluctuations in the superconducting-normal metal boundary, due to the basic thermodynamic fluctuations in the order parameter of a second order phase transition.

2) Hot-electron bolometers

Novel superconducting antenna-coupled micro-bolometers were also developed. This design was based on a suspended Niobium or Titanium micro-bridge structures operating at 4.2 K and room temperature. For the 4.2 K device, an order of magnitude improvement was achieved in the noise equivalent power compared to commercial bolometers.

3) Solid-state cooling

In conjunction with the direct detector development, it is highly beneficial to study methods to cool the detectors further electronically. This would simplify the cooling systems drastically, a very critical issue for space-borne missions. In this project, higher power electronic superconductor-normal metal tunnel junction coolers were developed, giving 20 pW cooling power when electrons in Cu were cooled from 300 mK to 100 mK. This is already significant for milli-K region detectors. In addition, indirect cooling of lattice was studied, and also cooling of highly doped Si with the help of Schottky-barriers showed promising results.

Growth of TlBr crystals for astrophysics applications was made by Department of Chemistry, University of Helsinki. TlBr synthesis under hydrothermal conditions supplies the material of the same order of purity as the crystals grown from melt. Since the material is easily dissolved and recrystallised at 150-170° C, the hydrothermal conditions were effective for removing of impurity elements under concern (20 elements). Both hydrothermal synthesis and re-crystallisation could be used for the raw material production. An annealing of large crystals grown from melt in pure water under hydrothermal conditions results in:

1. Removing of the impurities from the crystal without its dissolving.
2. Improving of the crystal perfection
3. Surface modification and "clearing" of the crystal

Study of different crystals produced by melt technology has shown that samples with variable impurity contents and photo conductance behaviour were formed. The photocoefficient was found to depend on the total sum of atomic concentration of impurities. The effect could be used as preliminary examination during the detector fabrication. Successfully produced detector was surprisingly most contaminated. Possibly, the fortunate combination of impurities provided sufficient electron conductivity and the trap-compensation, as well. During studies, the crystals and materials were characterised by X-ray rocking curve and powder diffraction (XRD), Fourier transform infrared spectroscopy (FTIR), I-V measurements and trace element analysis by using high-resolution inductively coupled plasma mass spectrometry (HR-ICPMS).

Development of X-ray filters for XEUS was made by University of Joensuu and Metorex International. Deep understanding of the behaviour of different metals in inductive grids was obtained at room temperature. Since the detector will actually obtain at cryogenic temperatures, more calculations will be performed in 2004 for inductive grids at lower temperatures (to the extent allowed by the availability of complex refractive index data). Better performance is obtained at low temperatures because the conductivity of metals increases when the temperature decreases. Preliminary theoretical results have been obtained by extending the rigorous electromagnetic diffraction analysis to the X-ray region and we soon expect to determine the limit where the complex-amplitude transmittance method can be used instead of the numerically heavy rigorous approach.

8.2.3 TECHNOLOGICAL ACHIEVEMENTS

Space borne instruments

Two instruments were completed within the HESA consortium during ANTARES program.

1) JEM-X sensor package was assembled and delivered for launch with INTEGRAL by Metorex International in 2002 (Figure 13).

Figure 13. The JEM-X X-ray monitor sensor package for the INTEGRAL mission. The diameter of the collimator grid is close to 30 cm.

2) The X-ray Solar Monitor (XSM) was designed, produced and assembled by Metorex International, and delivered to ESA in 2003 for launch with SMART-1 (Figure 14).

Figure 14. SMART-1 X-ray Solar Monitor sensor with the front-end electronics. The total size of the system is of the order of a mobile phone.

Both above projects were coordinated and managed by the leading organisation of HESA consortium, the Observatory, University of Helsinki.

Technology for XEUS mission

There are a number of technological results in *SQUID development:*

1) Availability of a superconductive thin film fabrication process, compatible with sub-kelvin devices.
2) Development of SQUID devices with sufficient characteristics to be used as building blocks of a practical frequency-domain multiplexer. It must be remembered that requirements for the SQUIDs in multiplexing applications are extreme, requiring simultaneously low noise temperature, large bandwidth, large dynamic range, and low power dissipation.
3) Development of a room-temperature LNA for SQUIDs in 1 – 20 MHz frequency range, capable of $10^{-6}\ \Phi_0/\sqrt{Hz}$ noise level at the moment, but with room for improvement.
4) Si_3N_4 –insulated capacitors with superconductive plates, having the required milli-ohm range series resistance at a few MHz. These are the key building blocks for the cryogenic noise-blocking filters.
5) Purchase and setting up an Adiabatic Demagnetisation Refrigerator for sub-kelvin experiments.
6) Strong theoretical understanding of practical SQUID-based multiplexer circuits, including the parasitic effects. This understanding has been partially obtained through the results of the experiments on ac-biased TESes performed by SRON in the Netherlands.
7) Finding of the baseband feedback method, a novel way to expand the dynamic range of the SQUID readout electronics (Figure 15, Figure 16).

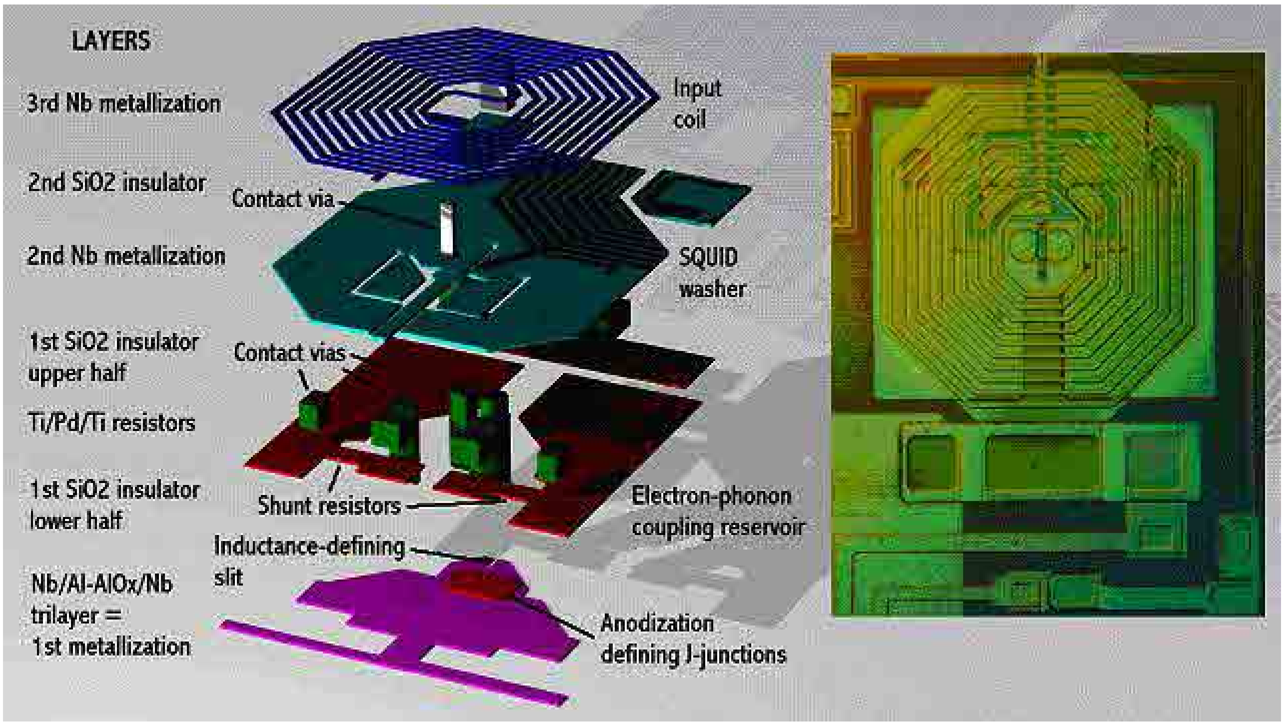

Figure 15. An explosion view of the structure of a SQUID pre-amplifier designed by VTT.

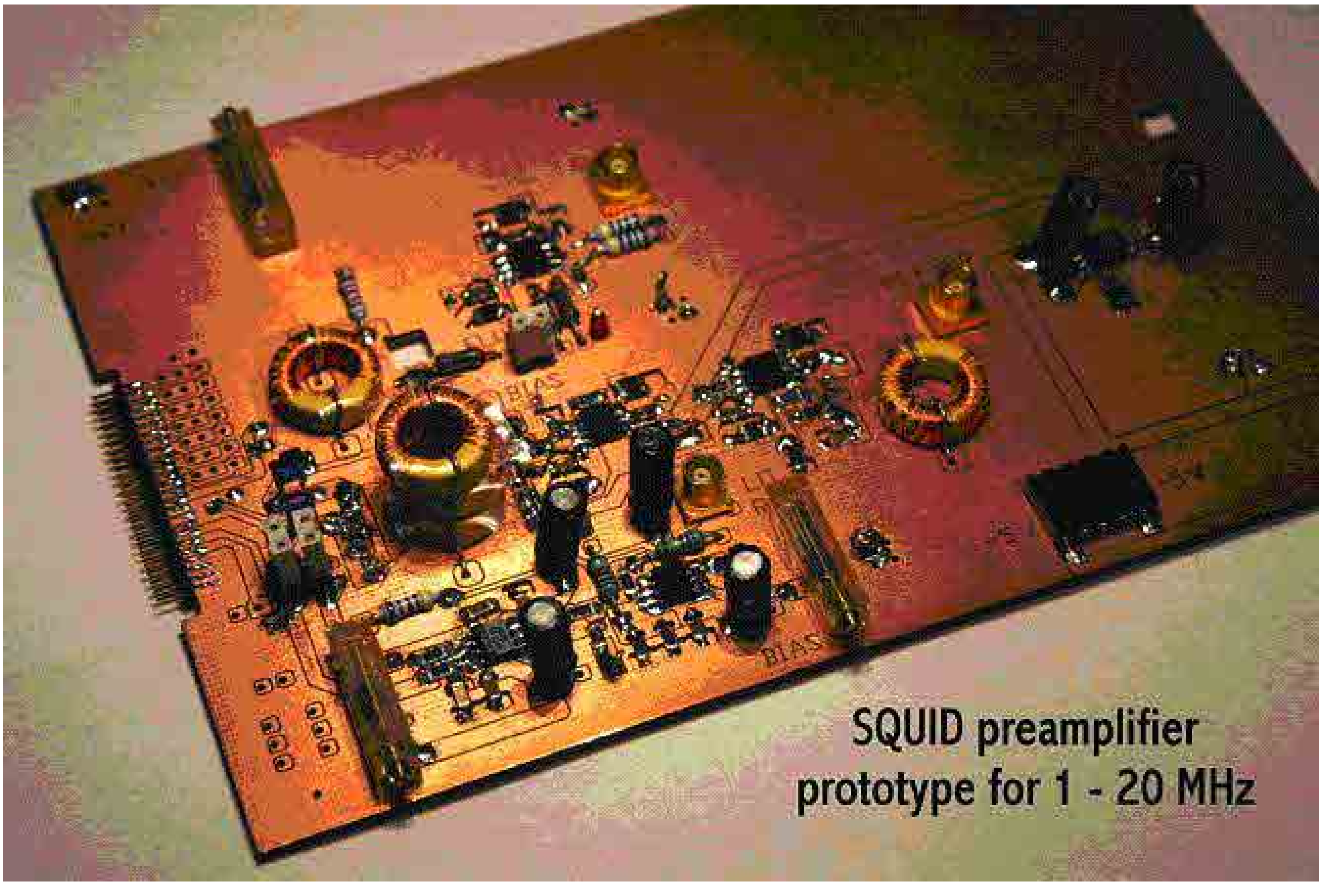

Figure 16. An assembled SQUID preamplifier prototype board (VTT).

To achieve the goal of high sensitivity on *bolometer research* all the links in the measurement chain of the sensor have to be optimised. The material selection, processing, and operating temperature all affect the results. The sensor itself has to be matched to the absorber and read-out electronics and the noise minimised. The cryogenic measurement system itself is a very complicated instrument. All this has been a very demanding task and never done before in Finland.

Growth of TlBr Crystals for Astrophysics: Purification from the melt was technically realised by two devices: degassing and TMZ set-ups. Degassing set-up was designed for the preliminary treatment and melting of TlBr. The construction can be characterised by the following achievements:

1. TlBr raw material degassing (200^{o} C, $5*10^{-3}$ mbar)
2. Melting of TlBr (500^{o} C, 500-1200 mbar of Ar)
3. Purification using TlBr evaporation/condensation
4. Film deposition from vapour onto Al and Si substrates

The TMZ set-up comprises additionally a moving heating ring and software controlling the movement and heating. Currently, TlBr melt tests are carrying out. During hydrothermal treatments, the influence of various detergents and pH of medium to TlBr quality and its stability was studied. The filter materials and filtration techniques were tested *in situ* at hydrothermal conditions, and the principal technological goals were achieved

The project *X-ray filters for XEUS* has allowed the University of Joensuu and Metorex International to develop substantially the lithographic fabrication technology of metallic nanostructures, and therefore it has much wider implications than the particular application to XEUS. Several completely new processes have been developed. Metorex has gained knowledge on wet etching through a silicon wafer. Atomic Layer Deposition (ALD) will offer an interesting new method for fabrication of a variety of metallic nanostructures, but it will require further investigation to determine the smallest features it can be applied to, and to find the best way to remove the excess metal from the top of the structure.

GEM detector development

The GEM detector is a new type of a gaseous radiation detector, where the charge amplification is based on a large amount of tiny holes perforated on a thin foil. Large active area, robust structure, reasonable energy resolution, good spatial resolution and high counting capability make them ideal to study the highly variable X-ray sky and cosmic explosions (X-ray transients and Novae, accretion disc instabilities, stellar flares, Gamma-ray bursts). Further, it has been shown recently that GEM's offer an accurate way to measure the polarization of incoming X-ray photons, giving a new window to study radiation mechanisms and geometries.

Three prototypes of GEM's were designed and constructed by HIP, SEFO and METOREX. A stable operation with gas amplification of several tens of thousands was achieved. The outgassing properties of the detector and foil materials were systematically studied. To avoid outgassing, the selection of correct materials (like ceramics) is essential for the stability and long life of the detector. Several GEM-foil manufacturing and hole-making methods were investigated and the properties of foils measured. Read-out electronics have been developed and two types of read-out boards manufactured (Si and LTCC). A custom made chip (ASIC) for the read-out electronics was designed and the development of a pixel read-out, necessary for polarimetry, initiated.

At present LOBSTER and HEAFiFM are the potential two missions where GEM-technology can be applied. Lobster is the imaging X-ray monitor to be installed on the Columbus facility on board the International Space Station (ISS). Recently, the phase A study of ESA was finalised. Lobster contains several modules of detectors with microchannel plate optics. It will map in soft X-rays (0.1 – 3.5 keV) nearly the whole sky every 90 minutes. The Finnish consortium has negotiated a share of the detector work with the Goddard Space Flight Center and University of Leicester.

The planned Finnish microsatellite HEAFiFM (High Energy Astrophysics with a Wide Field Monitor) contains essentially one Lobster-module. It can perform long uninterrupted observation of selected Sky-regions with 20 degrees field of view (like Cygnus and LMC) to study variabilities in timescales ranging from seconds to months. HEAFiFM and Lobster are not only technologically complementary, their science goals also complete each other. During ANTARES a Pre-Study Plan of the microsatellite was prepared by the Observatory, University of Helsinki, Patria New Technologies, Metorex International, Space Systems Finland and University of Joensuu. The plan includes a commercial

Russian launcher and platform to be funded within the framework of the Ex-USSR debt conversion program for Finland.

Command and Data Handling Computers (CDH)
The starting point of the project was to build CDH-computers (Patria) for the Danish ROEMER satellite aimed to study oscillations of solar type stars via highly accurate optical photometry and to receive observing time in share via this investment. However, the Danish funding to realize the satellite is open. The Engineering Breadboard Model EBB has been manufactured and tested. The radiation test results performed in Jyväskylä Acceleration Laboratory (RADEF) have raised interest among the industry. The command and data handling computer itself (PowerCDH) is based on a novel technology and is superior to existing European flight qualified microprocessors (TSC695, TSC21020) with considerable saving in power and mass. It can be used also elsewhere, e.g. in the GAIA mission.

8.3 Space Based Studies of Dark Matter (DARKSTAR)

Academy Research Fellow Chris Flynn, University of Turku, Tuorla Observatory

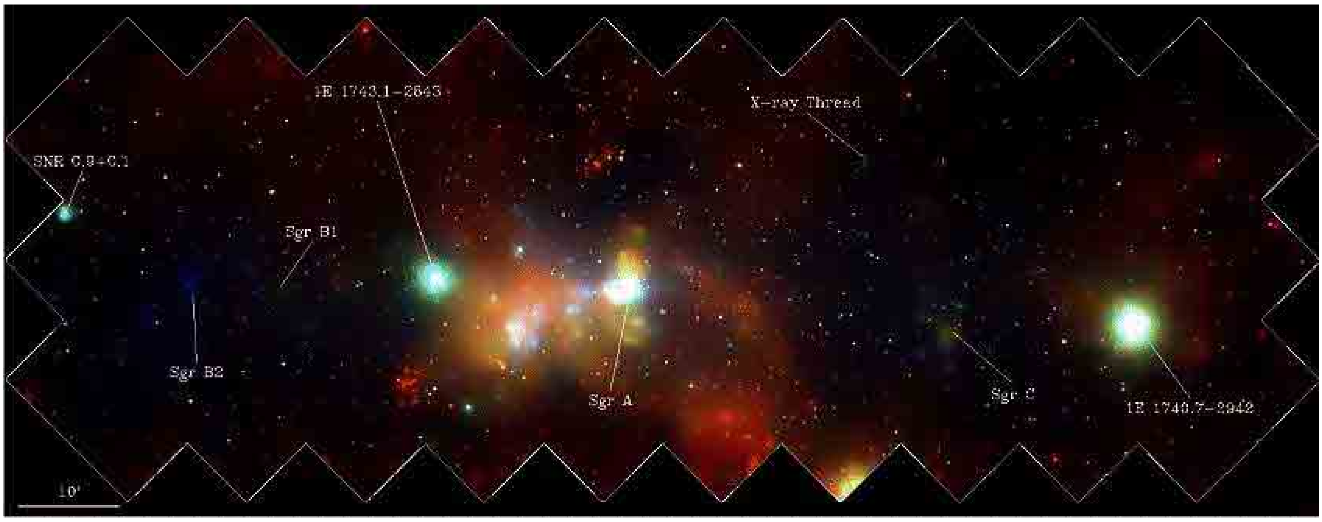

Figure 17. DARKSTAR X-ray mosaic image of the centrum of the Milky Way

8.3.1 GOALS OF THE PROJECT

The focus of the research was to place constraints on the nature of baryonic dark matter in the Milky Way galaxy (Figure 17). The project achieved its objectives of putting fresh constraints of the nature of dark matter in the Milky Way, both in stellar form and as black holes.

We made a serendipitous discovery while studying low mass stars which has led us into a new field of research, that of the production of Helium in the Big Bang and in stellar interiors. The research group is now focused on this field; it is this we will mainly pursue after the ANTARES programme closes. Fresh funding has been won through the Academy of Finland for this purpose.

8.3.2 SCIENTIFIC RESULTS

8.3.2.1 Introduction

For centuries, astronomers have delighted in the powerful method of finding new objects in space through the effects of their gravity, before the objects themselves are observed directly. The first great success of this technique was the discovery of Neptune, by computing where it must be in the Solar System in order to produce the observed gravitational perturbations of the orbits of the other planets. Similarly, the inference that some of the bright nearby stars must be circled by faint but heavy companions lead to the discovery of so-called white dwarfs, stars which have ceased to produce energy via nuclear fusion.

The technique remains in use still. It is currently being used to infer the existance of large amounts of yet unseen matter around galaxies, in clusters of galaxies, and perhaps even dominating the Cosmos as a whole. In other words, observations indicate that most of the matter in the cosmos is in some as yet unseen form. In the case of galaxies, that part of the matter, which we can see, is observed to be moving so rapidly that without dark matter as well the galaxies ought simply to fly apart. A similar conclusion pertains to clusters of galaxies.

The question of what this matter is composed of remains very much open. Conservative options, drawn from research in astrophysics, center on dim objects, which we know, certainly do exist; the question is just whether they exist in sufficient numbers. The candidates for dark matter of this type are cool stars; very dim either because of their low mass (i.e. stars on the so-called "lower main sequence" which are converting matter into energy rather slowly) or because they have used their supply of stellar fuel and are slowly fading from view (i.e. white dwarf stars). The only other stellar candidate for dark matter are neutron stars; while very dim and difficult to detect, making them good as a dark matter candidate, the processes via which these stars are produced (supernovae explosions) have a great many observationally testable consequences which likely rule them out. As described in the next section, the DARKSTAR project has focused on the first two of these astrophysically motivated dark matter candidates, mainly using data from space-based observatories such as the European Space Agency's Hipparcos satellite and the NASA/ESA Hubble Space Telescope.

A less conservative option is that the dark matter is in the form of black holes. In this scenario a few million black holes would enshroud the Milky Way galaxy; very difficult to detect directly, their gravity would nevertheless be responsible for holding the Milky Way together. Such black holes would have specific effects on the orbits of stars in the flattened disk-like part of the Milky Way; DARKSTAR has investigated these effects via computer simulations and compared the results to data obtained with the European Space Agency's Hipparcos satellite. These studies are described below.

In order to pursue low mass stellar candidates for the dark matter, we investigated in detail the properties of known stars in this class; as a result of the highly accurate data provided by the Hipparcos satellite, the luminosities of lower main sequence (i.e. stars from about the mass of the Sun to about one half the mass of the Sun) have been revealed to be a very simple function of their Hydrogen, Helium and ‘metal’ (i.e. all the remaining elements in the periodic table) content. The unexpectedly tight relationship was followed up by the DARKSTAR team and was used to get the first accurate measurement of the amount of Helium which has been produced in stars during the lifetime of the Universe, as well as the amount of Helium produced in the Big Bang at the Universe's beginning. A further spin-off was that the metal content of these stars was measurable; this lead to a first measurement using low mass stars as a kind of stellar fossil record of the amount of metals which have been produced in stars over the lifetime of the cosmos; this measurement confirms a classical issue in astronomy called the ‘G dwarf problem’; it has wide application in the understanding of the formation and evolution of galaxies; in particular it indicates that galaxy formation is an on-going process with significant amounts of matter falling into galaxies still today. Intensive searches have been underway for some decades to find this material, which is likely in gaseous form, surrounding our galaxy and other galaxies. The results are described further below.

Finally, in studying the distribution and possible composition of the large amounts of matter in the Milky Way which we cannot see, one must also ask are we quite sure we have correctly measured the amount of matter which we can actually see; i.e. what is the amount and distribution of the visible matter (stars, gas and dust) in the Milky Way? As described in detail below, DARKSTAR used the ESA Hipparcos satellite and the NASA/ESA Hubble Space Telescope to re-measure and significantly improve upon the classical studies of the visible matter content of the Milky Way.

8.3.2.2 Low mass stars as dark matter candidates

Our Milky Way is a typical spiral galaxy containing a rapidly rotating disk of stars; like all known spirals, measurements of its rotation shows it to be much heavier than it appears, i.e. it is embedded in a gravitating system of ‘dark matter’. One solution to this so-called dark matter problem would be that there are a lot of very dim stars out there, which we have yet to detect with our telescopes.

There are two types of star, which would fit the bill --- the so-called red dwarfs and the white dwarfs. Both types of star are a little less massive than the Sun, but are very much fainter; even at modest distances from the Earth, they become very difficult to detect. Are there huge numbers of them floating out there?

When the Hubble Space Telescope was launched, one of its tasks was to look for such stars; they would be so faint that seeing them with regular ground-based telescopes is too difficult; only the superior resolution of space allows one to tell the difference between very faint stars and the very much more numerous faint galaxies. We found in 1996 that the number of red dwarfs in images taken with the Space Telescope is very small --- much smaller than needed to explain the dark matter problem. So that ruled out red dwarfs.

This question has been readdressed by the DARKSTAR research team. Tuorla Observatory and Lund Observatory have looked at the other possibility, the so-called white dwarf stars. White dwarfs are stellar remnants; they are left over after a star has used up its initial supply of Hydrogen fuel; the Sun will become a white dwarf in the far distant future.

The team created a model of the distribution of the low-mass stars around the Sun, including the colours, luminosities and space motions of the stars. They compared their model to two very large surveys of the fastest moving and faintest detectable stars on the sky. Such stars are good candidates for the dark matter; firstly, whatever the dark matter is made of, it is expected to be moving rapidly (if it were not, its own gravity would pull it into the center of the galaxy): secondly, the stars are intrinsically dim.

The team concluded that, although a few quite interesting stars have turned up in the two biggest surveys to date, there are certainly not enough to explain the dark matter component of the galaxy. While the conclusions were quite strong, there is still hope for white dwarfs; they need only be a bit dimmer than the limits of the existing surveys to have been missed. New large surveys are being planned and may yet find them, if they are there.

8.3.2.3 Millions of black holes in the Milky Way dark halo?

Our Milky Way disk consists of a few 100 billion stars. The disk is remarkably thin, but it is not perfectly thin; stars are moving up and down within the disk and give it a thickness of several hundred light years from side to side. Interestingly, it was discovered many decades ago that the older the stars, the larger the motions up and down: in other words, the youngest stars in the Milky Way disk lie in a very thin layer --- intermediate stars lie in a thicker layer, and the oldest stars in a thicker layer still.

Why are older stars moving faster than younger stars? We know that young stars are born in gas clouds which have collapsed under their own gravity: also the gas in the Milky Way lies in a much thinner layer than most of the stars; it is therefore no surprise that the youngest stars and the gas are closely associated. As stars move around the galaxy, their orbits would hardly change (like orbits of the planets in the Solar System) if the galaxy were made of stars alone. However, the galaxy also contains gas, which is not uniformly distributed, but rather clumpy. Some of these clumps (called giant molecular clouds) have the mass of several million stars put together. As stars pass by these clumps, their orbits are bent slightly; as time passes, older stars will have passed by many of these GMCs and their orbits randomly perturbed many times; in general stars that start in a thin layer will develop into a thicker and thicker layer with time.

However, calculations already made several decades ago have shown that the gas clumps are insufficient to explain why the older stars in the disk move as they do. One proposal, dating from about 20 years ago, is that the dark matter which surrounds the Milky Way is made of millions of black holes. Hard to see, certainly! But could these black holes have an effect on the stars in the disk of the Galaxy as they pass through it, thickening the stellar disk with time?

DARKSTAR researchers have completed computer simulations of this process in the Milky Way, both for Giant Molecular Clouds (GMCs) and millions of these putative black holes. The team used archival data from the European Space Agency's Hipparcos satellite, which measures how thick the disk has become over its 10 billion year history; furthermore, the simulations followed the whole disk of the galaxy, not just those parts close to the Sun. Remarkably, the scenario of GMCs and black holes is not particularly easy to rule out with certainty, although the team concluded that black holes remain a possible source of disk heating, it is not the only one. The mass of the adopted black holes is a very important factor in the simulations. If the black holes are too heavy, they can destroy the disk completely; if they are too light they are unable to affect the orbits of the disk stars at all. Black holes with a mass of about 2 million times that of the Sun seem to be about right, and produce effects which are broadly and in some cases in detailed agreement with our best available (space-based) observations.

8.3.2.4 The production of cosmic Helium

Hydrogen and helium are the most abundant elements – together they account for about 98% of the mass of all the atoms in the Universe today. The remaining 2% consists of all the other elements put together – for example, all the iron, calcium, nitrogen and carbon present in our bodies, and the oxygen in the air we breath.

It wasn't always so. Astronomers can easily identify stars, which are very young, and those, which are very old. In the oldest stars known, the amount of these heavier-than-helium elements is very small, much less than the 2% found in the youngest stars. In really old stars, hydrogen and helium together account for some 99.99% of their composition.

What happened since these oldest of stars were formed is that those elements upon which our existence depends were created in the central furnaces of successive generations of stars; supernovae and hot winds blew these elements back into the surrounding gas clouds which float between the stars; and new stars were born which were enriched with these heavier elements.

Most stars shine by fusing Hydrogen atoms into Helium atoms, as the Sun does; other stars, having used up their Hydrogen supply, convert helium into carbon, or carbon into heavier elements still, and release energy in that way. As stars are born, grow old and die, the amount of helium and the amount of the other heavier elements has been slowly increasing in the Universe.

Measuring the amount of helium and heavier elements tells us much about the stars: the number which have been born and have died; the processes which cause them to shine; and how they enrich the Universe with the elements they have created.

DARKSTAR has made an accurate measurement of the production rate of Helium in the universe. The team has used data from the European Space Agency's Hipparcos satellite and so-called K dwarf stars. These stars are cooler and fainter than the Sun and are essentially stellar fossils. They have changed very little of their initial supply of hydrogen into helium during their long lives; in other words the hydrogen, helium and heavy elements we see in them today is the same as when they were born. We can follow the production of helium and heavy metals with a set of these stars. The Hipparcos satellite measures very accurately the real energy output of these stars. The research team have used computer models to predict how brightly such stars should shine depending on how much hydrogen, helium and heavier elements they contain. Measuring the amount of heavier elements using telescopes can be done very easily -- it is the amount of helium in stars, which has been very difficult to measure. Now, the comparison of the model computations with the real stars reveals, indirectly, the amount of helium they contain.

The team has found that over the billions of years since the Universe was born, stars have produced just about exactly twice as much helium as everything else. Stars are primarily helium factories!

8.3.2.5 The K dwarf problem

Most stars are known to consist mostly of Hydrogen, some Helium and a very little of everything else, the so-called ‘metals’. The metals typically add up to only a few percent of the star by weight.

DARKSTAR has measured the amount of the metals in a very representative set of stars near the Sun, more accurately than ever before. The distribution confirms a major puzzle: metals are not distributed among stars at all like one would expect from simple ideas about how metals are produced in galactic environments.

The team used archival data from the European Space Agency's Hipparcos satellite. The team examined K dwarfs stars, which are much like the Sun except that they are cooler and not quite as heavy. The stars are very plentiful, so getting a good sample of all the nearby ones wasn't difficult. While analysing the stars, they discovered that there is a simple and elegant relation between the luminosity of the stars and their metallicity. The relationship uncovered is remarkably tight – and has since been used for to measure not just the metallicity of the stars, but also their Helium content (see above). The relationship with metallicity has long been predicted by stellar theory: this study produced the first observational confirmation.

The surprise about the distribution of elements in nearby stars is that it doesn't follow the expectations of the simplest theories of how the stars in the Milky Way galaxy were born and developed during its long lifetime of some 10 billion years. Our picture of how galaxies were born is that they were assembled from massive gas clouds, which collapsed under gravitational attraction. At first, the gas was mainly Hydrogen and Helium: i.e. very little of the other, heavier elements was created in the Big Bang. As time progresses, stars are born and die, and they produce elements in their cores; these elements, many critical to life on Earth (such as Carbon, Oxygen, Iron, Magnesium and Silicon) are spread back into the surrounding gas clouds when the some of the stars explode as supernovae (and similar processes). Over the history of the Milky Way, the amount of these heavy elements has been slowly building up -- there should be quite a range of metallicities from the youngest to the oldest stars. At least, that was the expectation: in fact, most stars near the Sun have a metal content very much like the Sun: this was first noticed in the 1960s and was prosaically termed the ‘G-dwarf problem’, after the type of star (G dwarfs) in which it was seen.

The team at Tuorla has now shown that the same problem exists in K dwarfs: they see exactly the same effect as the G dwarfs. K dwarfs have a definite advantage over G dwarfs though. They have lower masses and are dimmer than G dwarfs; as a consequence, they have hardly changed inside since they were born, even if they were born as long as 10 billion years ago: they are a true fossil record still of what they were like when they were born. We can really use them to follow how star formation, metal production and the amount of gas in the Milky Way has been changing since the galaxy was born.

8.3.2.6 Mass of the Milky Way disk

Our Milky Way galaxy is a collection of some 100 billion stars; the Sun is just one fairly typical member. While we can count up the number of stars by doing surveys of the sky with large telescopes, one can always wonder: are there still a lot of uncounted stars out there that we have not yet seen; stars which would be too dim to see even with our best telescopes?

This question has been addressed by the DARKSTAR research team at Tuorla Observatory. Most of the stars in the galaxy travel in orbits in a flat system (called the disk) around a central, spherical region (called the bulge). The Sun itself follows a near-circular orbit located about halfway between the center and the outer edge. A simple question to ask is how much gravity do stars near the Sun experience; how much total gravitating mass is there? To answer this, the project has used data from the Hipparcos satellite on so-called K giant stars. These stars are cooler but much brighter than the Sun; indeed, the Sun is expected to become a K giant itself some 5 billion years from now.

The Hipparcos satellite measures very accurately the distances and speeds of nearby K giant stars; the research team have applied these measurements to much more distant K giants directly 'above' the Sun (i.e. perpendicular to the Milky Way disk) in order to determine accurate distances to these stars too. The data they used was first collected in the mid-1980's using the 100 year old Oddie 5" telescope on Mount Stromlo Observatory in Australia. It wasn't until the results of the Hipparcos satellite could be utilised to measure the distances to the stars with real precision.

The thickness of the Milky Way's disk is a balance between the total gravity of all the stars in it, and how fast they are individually moving. A given star, moving with a certain speed near the Sun, will rise upwards through the surrounding disk stars until the total gravity of all the stars below it pulls it back down again. All the stars are doing this at the same time, bobbing up and down in each other's gravitational field.

The team measured the speed at which the stars are moving and at the same time the thickness of the layer of stars, which form the Milky Way's disk. Their new precise results confirmed their analysis from almost 20 years ago: the thickness of the disk is exactly what is expected if the visible stars control the motion of each individual star. In other words, we understand how many stars are out there and how they are all moving around. And that leads us back to our initial question --- are a lot of the stars around the Sun missing from our census? The answer is almost certainly not!

8.4 ISO- and Odin-related research of the interstellar medium and star formation (ISO-ODIN)

Professor Kalevi Mattila, University of Helsinki, Observatory

8.4.1 GOALS OF THE PROJECT

The goals of the project 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) modeling 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 spaceborne 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, and the 2.5-m Nordic Optical Telescope.

8.4.2 SCIENTIFIC RESULTS

8.4.2.1 Highlights of scientific results 2001-2003

• Pre-protostellar and young stellar objects, still deeply embedded in their parental molecular clouds, have been detected and physically characterised by extensive ISO far-IR mappings of nearby molecular clouds. Interaction between protostellar systems and their immediate surrounding ISM have 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.

• The group has for the first time observed the distribution and properties of the Unidentified Interstellar Bands at 7.7, 8.6, and 11.3μm 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 3-200μm 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^+ 158μm) 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, the group has 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). A number of exeptional mid-IR dominated EROs were detected, and all EROs were used to constrain models of galaxy formation.

• The 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.

8.4.2.2 ISO-, Odin-, and ground-based studies of interstellar clouds

The evolution of molecular clouds and the star formation process taking place within them are linked to the characteristics of molecular gas and dust. Interaction between these two components affects the cloud dynamics e.g. via the various heating and cooling mechanisms, freezing-out and formation of molecules on the surface of dust particles. Dust is also important because it screens cloud interiors against the InterStellar Radiation Field (ISRF) impinging on the cloud surface. To gain understanding of these processes it is necessary to study the emission and the properties of the different dust populations, and their connection to the conditions prevailing in the molecular gas.

Dust and molecular gas properties in dark clouds

ISO, a highly successful satellite of ESA, was operational between November 1995-April 1998. More than 50% of the data, now located in the ISO Archive, are still unpublished, and form a real treasure trove in all fields of astronomy. ISO was the first astronomical satellite that could make pointed, high sensitivity observations at far-infrared wavelengths up to 240μm, thus enabling the study of very cold dust at a temperature of 10–15 K. We have taken strong advantage of this ISO property in our studies of a large sample of nearby molecular and star forming clouds.

The project has derived results for the dark clouds Lynds 183 and Lynds 1642 and a pair of globules, DC303.8-14.2 and the Thumbprint Nebula, showing the presence of very cold dust, $T_{dust}\approx$12-14 K. Work is in progress on: Chamaeleon I, R Corona Australis, L 1780, and the Draco Molecular Cloud. For most of the clouds we have also performed with SEST molecular line mapping of CO isotopomers. We have compared and correlated the dust and molecular gas properties in these clouds in order to study e.g. the depletion of molecules on dust grains in the dense central condensations of the clouds.

UIR bands/PAHs

The Unidentified Infrared (UIR) emission features are thought to be caused by Polycyclic Aromatic Hydrocarbons (PAH) which are a constituent between the largest interstellar molecules identified so far and the "classical" interstellar grains (ca. 0.05 to 0.3μm in size). The PAHs are probably the main source of photoelectron emission in diffuse and translucent clouds, and thus a very important agent for the energy balance of gas. They are also important in terms of the radiation energy that they absorb from UV-optical star light and re-emit in the mid-IR: this is about 20-25% of the total. Prior to ISO, the UIR features (with the exception of 3.3 and 6.2μm) had been detected only in very bright nebulae, and it was not clear whether they were also present in the normal diffuse interstellar medium.

The diffuse emission of the inner Galaxy between 5.8 and 11.6μm has been observed by us using the ISO low-resolution spectrometer PHOT-S, complemented by filter photometry at longer wavelengths. The 50 selected positions are representative of the galactic radiation away from bright discrete sources. The UIR band ratios and their strength with respect to the far-IR emission along the same sightlines are surprisingly similar to the edge-on Sb spiral galaxy NGC891 and to other Galactic environments, e.g. reflection nebulae.

The results for the prototypical diffuse/translucent cloud G300.2-16.8 have recently been completed (Figure 18). Three different sightlines in the cloud have been completely covered with the ISOPHOT instruments from 3-200μm. Spectral energy distributions are displayed in the accompanying figure. In this project it is essential that we combine the mid-IR UIR band data with mid- and far-IR ISOPHOT photometry data along the same lines of sight, thus being able to study the connections between the PAHs, the very small grain and the "classical" large grain dust populations. While indicating substantial variations in the abundance of the three dust components our observed SEDs will form a fundamental test bench for the modelling of interstellar dust in future.

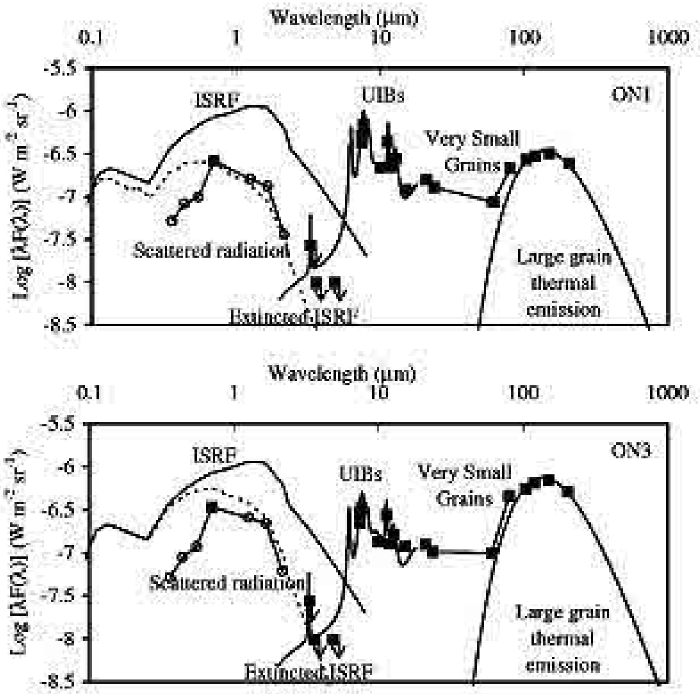

Figure 18. Spectral energy distributions for two positions in G300.3-16.8

Energy balance of gas in translucent clouds
An important aspect of cloud physics is the gas heating mechanism through UV-induced photoelectric emission from small dust grains. We have recently applied the 3-D radiative transfer code of *Juvela* and Padoan (2003) to clumpy dust cloud models and have obtained a good presentation of the high latitude translucent cloud data set for C^+ 158μm line vs. 100μm continuum emission. Analysis of this problem has been continued using a dedicated ISO data set consisting of multi-band mid- and far-IR photometry and far-IR C^+ 158μm line spectroscopy in the translucent high latitude cloud L 1780. Since the C^+ cooling line is expected to be strong where the gas heating is strong the correlation of the 158 μm line with the small grain mid-IR emission is a crucial test for the photoelectric heating model.

Chemistry and evolution of dense cores
The formation of dense cores of molecular clouds and their dynamical behaviour are connected to the chemical evolution. In particular, the degree of ionization determines the time-scale of ambipolar diffusion (decoupling from the interstellar magnetic fields), and the freezing-out of molecules onto dust grains affects the cooling rate of the gas. Both the ionization and depletion degrees can be determined with the aid of radio spectral line and continuum observations.

We have studied the use of chemical composition, including the degree of depletion, as a diagnostic tool of cloud evolution and of the first steps of star formation. Careful abundance estimates require knowledge of the physical conditions (temperature and density). We have developed further the methods used to derive these. The kinetic temperature is estimated using lines of symmetric rotor molecules, such as ammonia (NH_3) and methyl acetylene (CH_3CCH). Molecules expected to be either susceptible or resistant to freezing-out have been included (e.g. N_2H^+, SO, CS, HCS^+, H_2CO), to compare their abundances with those predicted by chemistry models.

In the course of this study we have tried to identify the most suitable molecular tracers of a particular evolutionary stage and to determine their fractional abundances. For example, the observations suggest that the fractional NH_3 abundance is enhanced in the centres of pre-stellar dense cores. Motivated by this finding we have recently made interferometric ammonia line and 1.2 cm continuum observations towards dense cores with the ATCA.

Odin dark cloud programme
The importance of gaseous H_2O and O_2 to the interstellar chemistry and molecular cloud cooling is not well understood yet. The Submillimeter Wave Astronomy Satellite (SWAS) of NASA has detected the ground level line of H_2O towards Giant Molecular Cloud cores and outflows, but the submillimetre line of O_2 has remained undetected, and the derived upper limits for the O_2 abundance fall below the predictions of most chemistry models.

The sensitivity of Odin is clearly higher than that of SWAS at submillimetre wavelengths, which has enabled the detection of the rare $H_2^{18}O$ isotopomer of water. The fact that Odin has a sensitive receiver for the lowest ($N_J=1_1\rightarrow1_0$) transition of O_2 at 119 GHz is another great advantage over SWAS. Moreover, the instantaneous bandwidth of Odin is large enough to cover possible broad line wings. Odin has determined H_2O abundances and derived sensitive O_2 upper limits in various interstellar objects, including nearby molecular clouds. In conjunction with ground based observations of other oxygen bearing molecules, the Odin dark cloud programme has been very useful for the understanding of interstellar oxygen chemistry.

In order to study the dependence of O_2 and H_2O abundances on physical conditions and the evolutionary stage of the cloud, we have selected targets with different chemical compositions and degrees of star formation activity. In the course of the observations we have measured a selection of dense core positions in well-studied cloud complexes within 500 pc from the Sun. The first set of Odin publications has just appeared (A&A, Vol. 403, II, May 2003).

8.4.2.3 Star formation

Initial conditions and early evolutionary phases
The fragmentation of a molecular cloud into dense clumps is the first stage of star formation. The dynamical states of clumps, their mass spectra and typical separations are connected to the stellar initial mass function (IMF) and star formation efficiency (SFE). The stellar populations of nearby molecular complexes have been studied extensively during recent years. These infrared surveys are sensitive to very low-mass objects (near the H burning limit) and contribute towards the finalization of the stellar IMF in the clouds. The study of the properties of stellar progenitors, i.e. dense 'clumps' within these clouds, can be therefore seen as the next obvious step.

The structure of molecular clouds and the distribution and statistical properties of dense clumps in them can be studied with the aid of dust continuum, molecular spectral line maps, and extinction maps. $C^{18}O$ is considered to be a good tracer of the total H_2 column density except for the very cold and dense regions, where it is frozen onto the dust grains (Figure 19). In the latter regions the dust continuum gives the most reliable total column density estimate, provided that the dust emission characteristics are known. The ideal way to derive these is to use both far-infrared and (sub)millimetre observations. Spectral line observations are, however, necessary for studying the cloud kinematics, i.e. systematic and turbulent motions, which give invaluable information of the nature of the fragmentation process.

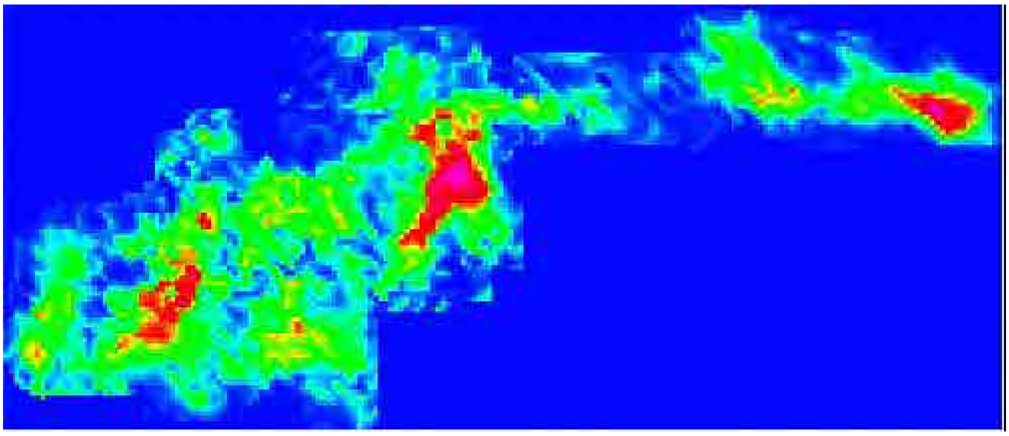

Figure 19. Clumpy filaments in the Chamaeleon I molecular cloud as seen in the $C^{18}O$ (J=1-0) spectral line area map (east is up, north is to the right).

Along with the recent advances in magnetohydrodynamic (MHD) modelling it has become evident that the most likely explanation for the morphology and kinematics observed in molecular clouds is that they arise from random supersonic motions at various scales. Models of turbulent fragmentation and star formation can be tested by comparing the predicted and observationally derived stellar IMF. In a more direct way we have compared the predicted and observed properties of dense pre-stellar clumps and interclump medium. According to the model of Padoan & Nordlund the differences in the characteristic mass are due to different Mach numbers of the turbulent flow driving the cloud fragmentation. For example, in Cha III this number should be about four times larger than in R CrA.

Pre-stellar cores and protostars

Pre-protostellar cores in dense clumps of molecular clouds, and hydrostatic protostars formed at later stages, emit most of their energy in the far-IR. The ISO observations between 80-200µm provide an excellent database for the following studies: 1) Searches for newly formed embedded stars including the earliest stages of star formation (pre-protostellar cores). 2) Analysis of their evolutionary status using the spectral energy distributions (SEDs). 3) Determination of dust temperature and dust mass, which enable us to estimate the dynamical state of cores and clouds. 4) Analysis of dust distribution and dust properties near the newly formed stars.

In the course of an extensive mapping programme of the Chamaeleon I molecular cloud complex at 80, 100, 150, and 200µm we have studied the young stellar objects associated with the reflection nebula Cederblad 110. The spectral energy distribution and bolometric temperature of the 1.3-mm continuum source Cha-MMS1 was derived and it was proven to be a Class 0 object (that is a protostar, which has not yet accumulated its final mass).

We have verified the presence of two gravitationally bound pre-protostellar sources at the core of the dark cloud Lynds 183, and detected two previously unknown pointlike far-IR sources in their vicinity (Figure 20). The latter are good candidates for (pre)-protostellar sources. Optical, and ISO far-IR maps at 100 and 200µm of the L183 are shown in the attached figure (DSS=Digitized Sky Survey). The four pointlike sources detected by us at 200µm are marked as blue dots.

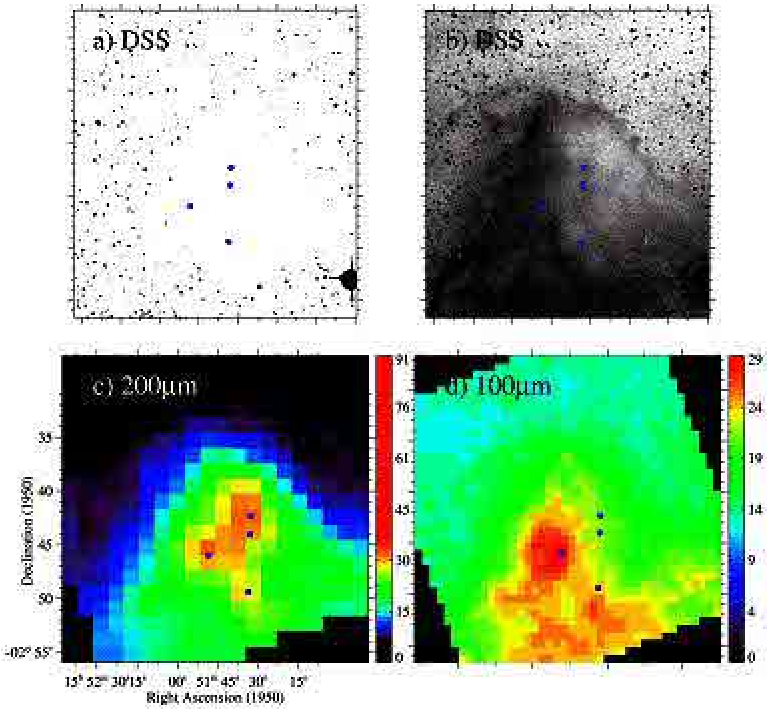

Figure 20. Dark Cloud L183. Upper row: optical images from DSS.
Lower row: ISOPHOT 200 and 100µm images. Blue dots indicate point sources

Radial density distribution
The radial density distribution, ρ(r), is a critical parameter for theories of isolated, low-mass star formation because it determines the mass infall in the beginning of the collapse phase. In the so-called 'standard protostellar model' for singular isothermal collapse, the density distribution has the form $\rho(r)\propto r^{-2}$ out to large radii. Other models which take a pressure-confined Bonnor-Ebert sphere as an initial condition for collapse, or which take ambipolar diffusion and magnetic fields into account, predict pre-stellar cores with flat inner density profiles.

We have been studying the density structure and dust properties of two morphologically similar, almost spherical globules located in the Chamaeleon II/III complex. One of them shows no signs of star formation, while the other one has an embedded point source within (DC303.8-14.2, Figure 21).

We are using three different observational techniques to determine the density distributions in these two globules:

1) Near-IR J, H and K-band extinction measurements of background stars visible through the clouds. The observations for this project have been successfully performed in 2002 with ESO's VLT (Very Large Telescope) using the ISAAC (Infrared Spectrometer And Array Camera) instrument. The extinction through the clouds has been determined with about 10 arcsec resolution.

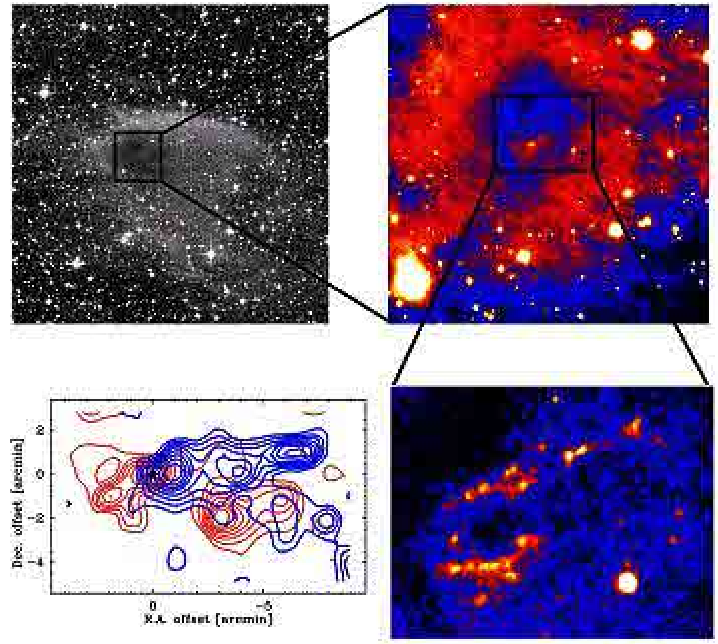

Figure 21. Globule DC303.8-14.2 in visible and near-infrared, and in molecular lines.
<u>Top left</u>: The bright rim – dark core <u>Top right</u>: Near-infrared H-band (1.65μm).
<u>Bottom right:</u> Near-infrared -2.2μm <u>Bottom left:</u> $^{12}CO(J=1\text{-}0)$ molecular line map.

2) Millimeter-wavelength continuum emission from cold dust grains in the clouds. For this project we have performed observations with the SEST/SIMBA telescope in July 2002. The intensity of the continuum emission depends on both the radial temperature and density distribution of dust.

3) Modelling the observed surface brightness profiles at optical and near-IR wavelengths. As has been shown by Lehtinen & Mattila, the surface brightness profiles can be effectively used to derive the radial density profile of the cloud, through modelling radiative transfer in a spherical cloud. Although this method is very powerful, it has been rarely used so far. At present we are applying this method to TPN and DC303 at near-IR (see the attached figure showing the bright rim of the surface brightness), and will extend the study to other small dark clouds.

Protostars and their interaction with the surrounding cloud

Our investigations of the star-formation process further include: 1) high-resolution molecular line observations of dense gas in the nuclei of pre-stellar condensations and accretion disks, and in shocks caused by protostellar jets; and 2) high-resolution radio interferometric observations of continuum emission arising in ionized gas in protostellar winds and shocks. The first task requires finding appropriate molecular lines tracing very dense gas in the cloud interiors, for which it is necessary to perform radiative transfer modelling. The requirement of high resolution underlines the use of interferometric techniques.

In most cases, continuum radiation from young stellar objects has been attributed to free-free emission from ionized winds or accretion surfaces. The recent detection of circularly polarized continuum emission from pre-main sequence stars shows, however, that the synchrotron mechanism is also possible in the vicinity of the protostellar surface. Evidence for extended synchrotron jets has been presented for a couple of cases.

We have recently imaged two star forming regions, one in the Corona Australis cloud, and the other in the Chamaeleon I cloud in the radio continuum at 3.6, 6 and 21cm with the Australian Telescope Compact Array (ATCA). The purpose of these observations is to search for new protostellar candidates and identify the radio counterparts of IR sources. Radio flux measurements complement the existing mm-IR spectral energy distributions, and permit the determination of more accurate luminosities. The spectral indices and limits for the degree of polarization are used to distinguish between the various emission mechanisms and to estimate the evolutionary stages of the detected young stellar objects. A particular task is to study the nature of the double source CrA/IRS7 and the associated radio lobes.

8.4.2.4 MHD modelling and radiative transfer

Modelling of molecular line emission and cloud cooling
The radiative transfer problem defines the relationships between the physical conditions in a source and the observed properties of its radiation. Source properties can be determined by constructing a physical model, solving the radiative transfer problem and comparing the results with observations. In the case of interstellar clouds the molecular line observations are traditionally analyzed either assuming a homogeneous source with LTE (local thermodynamic equilibrium) conditions or by using LVG (large velocity gradient) models. These approximations are often unjustified. Interstellar clouds are known to be clumpy and small-scale density and velocity fluctuations affect strongly both the intensities and profiles of the observed lines. These effects can be studied only with three-dimensional models. We have developed a computer program that can be used for solving the radiative transfer problem in three-dimensional cloud models with arbitrary density and velocity structure. The program is based on Monte Carlo simulation and it has been used in several publications, and it has been made publicly available.

In conjunction with three-dimensional magnetohydrodynamic (MHD) simulations the radiative transfer modelling has been used to study the structure and physical parameters of large molecular clouds. Radiative transfer calculations make it possible to predict line spectra that can directly be compared with observations. This way the parameters and basic assumptions of the MHD models can be tested, e.g. concerning the magnetic fields and the nature of the turbulence. Molecular line emission is the main cooling process in dense clouds and therefore essential for the evolution of dense cloud cores, and for the star formation. The cooling rates can be estimated only by solving the radiative transfer problem. Studies of the cooling efficiency of inhomogeneous clouds have been started and for the first time MHD simulations are being used to provide a realistic description of the cloud structure.

Modelling of infrared emission from interstellar dust and dusty galaxies
Mid- and far-infrared continuum emission of interstellar clouds originates from dust grains heated by the interstellar radiation field and by embedded or nearby stars. Large dust particles are in temperature equilibrium with the radiation field and emit mostly in the far-infrared. In the near- and mid-infrared the radiation comes mainly from small dust particles and possibly from large molecules (e.g. polyaromatic hydrocarbons, PAHs). The temperature of small particles is not constant and the absorption of a single photon can heat them transiently to very high temperatures. Therefore, compared with the large grains most of the emission takes place at shorter wavelengths.

The properties of interstellar dust are not well known. There is strong evidence that e.g. the grain size distributions do change even within individual clouds. In cold cloud cores molecules can freeze out onto the dust surfaces and this links the dust models to the gas phase chemistry relevant to molecular line observations. Dust affects cloud temperatures through UV shielding, photoelectric emission, and the effect it has on molecular abundances. Infrared observations combined with molecular line observations make it possible to study these connections. The studies require radiative transfer modelling that takes into account the different dust populations and the inhomogeneity of the clouds.

We have used our radiative transfer programs to study continuum emission at infrared wavelengths and light scattering in optical and ultraviolet regions, both caused by interstellar dust grains. We have mapped several Galactic molecular clouds with the ISO satellite in the far-infrared, and radiative transfer modelling has been used to determine the properties of the emitting dust particles and to assist in the derivation of the relevant physical parameters.

Continuum radiative transfer has been incorporated into studies based on MHD simulations of interstellar clouds. In an inhomogeneous cloud the UV/optical photons are able to penetrate deep into the cloud and modelling will allow the estimation of the true heating rates caused by this radiation. Radiative transfer calculations have also provided input for chemical modelling and allowed the estimation of molecular abundance variations. The inclusion of transiently heated particles makes direct computation of the IR emission extremely time-consuming. We have, however, developed methods that make it possible to predict accurately the dust emission from near-infrared to sub-mm, even in the case of three-dimensional models consisting of millions of cells. With the help of this program we are able to study the large scale emission from interstellar clouds and model such phenomena as the increased FIR emissivity of dense clouds and the observed anticorrelation between the FIR-submm spectral index and the dust temperature.

On a galactic scale, we have used a separate Monte Carlo code to predict the optical and infrared continuum emission. The program uses three-dimensional models for the galaxies and takes the inhomogeneous dust distribution and stellar population gradients fully into account. The program has already been used to model ISO FIR observations of the galaxy NGC253.

8.4.2.5 Infrared galaxies, star formation history, and Extragalactic Background Radiation

The star formation history of the Universe is one of the central areas of observational cosmology today. The study of the far-infrared and optical/near-IR background radiations is of crucial importance since they can probe the emission sources beyond the detection limit of individual galaxies. The balance between the two background components, optical/NIR vs. FIR, depends mainly on the dust content of galaxies in their early evolutionary phases.

Far infrared cosmic background radiation

The very important COBE/DIRBE detection of the FIR background at 140 and 240μm needs confirmation by an independent measurement. ISOPHOT offers complementary properties as compared with COBE for the disentanglement of the foreground components, i.e. the zodiacal emission, the galactic starlight and the interstellar cirrus. An extensive program has been carried out with ISO.

As a first step, the very dark sky areas mapped in this ISOPHOT EBL project at 90, 150, and 180μm have been searched for point sources. Some 60 sources (galaxies) have been detected. Galaxy counts have been derived, and their summation results in a background radiation level of 20 to 30% of the COBE/DIRBE measured background.

In the second step of the project we have performed an optical, near-IR, and radio observing campaign using NOT and VLA to identify and analyse the sources responsible for the bright tail of the FIR background. Initial results indicate that up to 30% of them are fairly local star forming galaxies. The rest are thought to be distant dust-enshrouded galaxies in a strongly star-forming phase.

Neutral hydrogen 21-cm observations have recently been performed with the Effelsberg 100-m radio telescope in Germany, and they serve as a sensitive measure for the remaining interstellar medium contribution. We have studied in one of the very darkest patches on sky near the North Galactic Pole, the correlation of the 150μm surface brightness vs. the HI 21-cm line area. An extrapolation to zero line area suggests a 150μm offset of ~3 MJy sr^{-1}. After subtraction of the Zodiacal Emission component (~1.2 MJy sr^{-1}), the remaining extragalactic background is ~1.8 MJy sr^{-1}, in good agreement with the COBE/DIRBE results.

Another line of investigation is the separation of the fluctuations of the FIR extragalactic sky background from the foreground Galactic cirrus component.

Study of dusty star forming galaxies

Utilizing a wide-field near-IR survey of fields observed with ISO, we studied the star-forming properties of ISO-detected galaxies using their near and mid-IR properties. In the same fields we searched for Extremely Red Objects (EROs), which typically are very distant massive early type galaxies and thus a powerful window into early galaxy formation in the universe. Dusty galaxies, however, contaminate the ERO population, and we used for the first time mid-IR fluxes from ISO to separate EROs into different types. We find that in bright ERO samples ellipticals are the predominant ERO type. Moreover, we find EROs to be strongly clustered around mid-IR galaxies thus identifying sites where galaxies and proto-clusters are forming at high redshifts. Finally, EROs which are mid-IR sources have high 15μm to near-IR flux ratios, implying AGN contribution – an aspect thus far neglected – to their luminosities in addition to starbursts. The handful of spectroscopically confirmed dusty EROs intriguingly have properties similar to both ultraluminous, dusty local IR-galaxies and the enigmatic FIR/sub-mm source population. The mid-IR galaxy counts of the ELAIS were also utilized in a study to predict the confusion limit for deep galaxy surveys to be performed with SIRTF.

8.5 Space Weather in the ANTARES Programme (SWAP)

Professor Hannu Koskinen, University of Helsinki

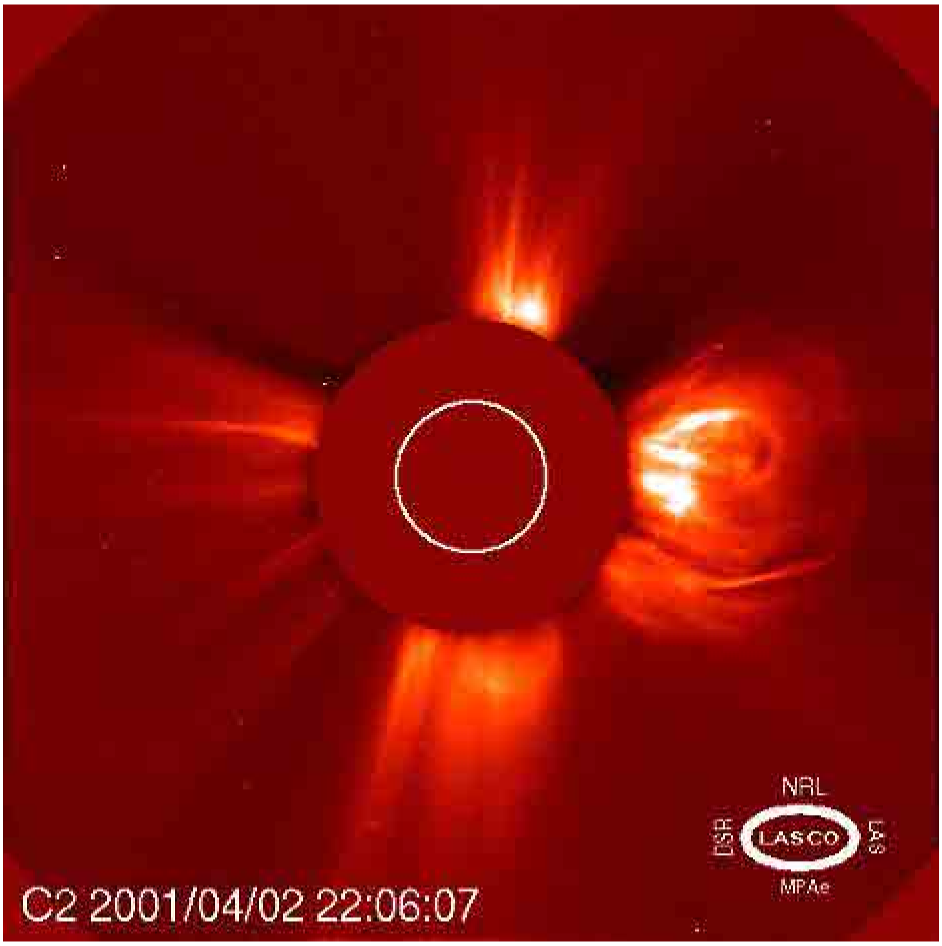

Figure 22. Solar flares measured by SOHO spacecraft

8.5.1 GOALS OF THE PROJECT

The main goal of the SWAP project was to increase scientific understanding of the entire space weather chain from the surface of the Sun (Figure 22) to the geomagnetically induced currents in the technological systems on ground. The SWAP application identified 6 main areas where research was planned to performed using the ANTARES funding:

A. Solar and solar wind drivers of space weather
- distinguish the magnetospheric consequences of different types of CMEs, shocks, and fast streams from each other

B. Magnetospheric energy budget
- clarify relative roles of different energy dissipation channels
- more realistic views on storm-time energisation and transport of magnetospheric particles

C. Ring current and radiation belt dynamics
- improved understanding through observational and modelling studies
- improved forecasts for space weather

D. Ionospheric tomography
- improved picture of ionospheric variability in time scales from about 15 min to hours
- set up a satellite tomography chain (funding not applied from the ANTARES programme)

E. Geomagnetically induced currents
- characterisation of ionospheric current systems according to their GIC effectiveness
- improved warning and forecasting methods

F. Charged Particle Telescope (CPT)
- final design
- instrument production

As the funding applied from the Academy was strongly reduced item C was entirely removed from the SWAP project. Furthermore, item F depended critically on technology funding from Tekes and as no funding was granted, it had to be removed from the menu of the project. All the other fields were retained in project and its success has to be assessed according to the academic measures.

8.5.2 SCIENTIFIC RESULTS

As noted in Section 4, most of the scientific output has come from the fields of
- solar and solar wind drivers of space weather
- magnetospheric energy budget
- geomagnetically induced currents

As the ionospheric tomography chain became operational only in 2003, its scientific outcome will start to appear only in the years 2004-2005. Due to the delay, the research programme was partly reorganized and a large fraction of the funds will be used only in 2004. A new research topic on the polar cap sporadic-E was started. The results are still unpublished, but it is already clear that the direction of the interplanetary magnetic field controls the appearance of polar cap sporadic-E. This is a new mechanism of space weather affecting e.g. the radio wave propagation at high latitudes.

8.5.2.1 Solar and solar wind drivers of space weather

This topic has been studied from different viewpoints by the groups at the Universities of Helsinki and Turku and at FMI.

The UH-FMI collaboration selected the strong space storm in April 2000 as the first target for an end-to-end analysis of the geoefficiency of CMEs. It was found that the storm was driven by the strongly shocked solar wind whereas the magnetic cloud itself appears to have missed the Earth's magnetosphere. This storm analysis also contained a large global study of ionospheric current systems where the methods discussed in section 5.3 were used.

In this context intriguing behaviour of storm-time activations was identified, where some of the activations were clear substorm onsets whereas others showed clear auroral activations but did not follow conventional development. This has led to further studies on other storm events, whose results have so far presented at some conferences.

CMEs with their associated shocks drive very variable responses on the magnetosphere. In order to investigate these, all clear (Dst < -50 nT) since the last solar minimum until the end of 2000 have been classified and studied statistically. An important finding was that the magnetic clouds tend to have a stronger effect at low latitudes (Dst index) whereas the shock and sheath regions favour higher latitudes (Kp) index. When the geoefficiency of differently rotating magnetic clouds has been considered, it has become apparent that the magnetic clouds themselves are of less importance as magnetospheric storm drivers than the shocks driven by them.

Energetic particle production in coronal mass ejection driven shocks has been studied by the UT-UH collaboration. Energetic particle observations provide information on the lift-off and coronal evolution of potentially geoeffective interplanetary CMEs and thus are important for understanding the global scenario of the solar-terrestrial events.

A solar wind wave-heating model has been created. In an application of the model to study the coronal energetic particle acceleration and interplanetary transport, the transport was found to be orders of magnitude too slow, compared to observations. However, the coronal energetic particle acceleration was found efficient. In order to improve the modelling, Laitinen and Vainio (2004) improved the energetic particle model by incorporating non-linear wave-wave-interactions, which reduced the wave power significantly. Thus a more reasonable interplanetary transport was obtained, already consistent with some observed energetic particle events. The coronal energetic particle acceleration efficiency, however, was somewhat reduced.

The feasibility of energetic particle observations as an additional source of information in predicting occurrence of geomagnetic storms was demonstrated. A proxy for the CME transit time from the Sun to the Earth was derived. Analysis by using data from the rising phase of the present solar cycle indicated that the time difference between the onsets of a primary particle event and a particle shock peak in interplanetary space correlates strongly with the strength of geomagnetic storms. The energetic particle studies formed the major part of the PhD thesis by Timo Laitinen at the University of Turku in 2003.

8.5.2.2 Magnetospheric energy budget

The magnetospheric energy budget is a tricky issue, as there is no direct way of determining, how much energy enters to the magnetosphere from the solar wind nor how it is distributed within the system.

In the SWAP project the energy budget was studied by the FMI-UH collaboration. The energy input was estimated from solar wind observations the ionospheric dissipation was calculated using methods based on auroral electrojet indices. Also an analysis of the widely used Akasofu's energy input parameter epsilon was conducted. The results of these investigations were consistent with some other resent findings that the ionosphere is relatively a more important substorm and storm energy sink than was anticipated only ten years ago. These studies formed a major part of the PhD thesis by Eija Tanskanen at the University of Helsinki in 2002.

8.5.2.3. Geomagnetically induced currents

Studies of geomagnetically induced currents (GICs) are under the responsibility of the FMI group. There have been two main tasks in this sector: the development of the fast calculation method of GICs, and a start of a detailed analysis of ionospheric drivers of large GICs. These both goals utilise the method of spherical elementary currents systems (SECS), which was in parallel shown to be a superior tool in modelling ionospheric equivalent currents.

The fast computation technique uses ground magnetometer data, which are interpreted in terms of ionospheric currents. This allows for interpolating and extrapolating the ground field in the area of interest. The geoelectric field is obtained by multiplying the magnetic field by the local surface impedance known from solid earth studies. The usefulness of the method has been demonstrated by direct comparisons between modelled and measured geoelectric field in Fennoscandia and GICs in the Finnish high-voltage power system and in the Finnish natural gas pipeline.

Calculation of GICs using geophysical measurements as input is now a routine work and the results of these studies have led to improved tools for warning and nowcasting of GICs in electric power systems and gas pipeline networks. The real challenge is to understand the physical processes in the near space beyond large GIC events. The natural step upward from the earth's surface is to analyse ionospheric currents during GIC storms. The first detailed investigation dealt with the storm mentioned in section 5.1 (April 6-7, 2000), during which large GICs were observed everywhere in North Europe. This study gave further support to previous statistical results that small-scale rapidly changing currents play a major role in the GIC sense. A necessary requirement for significant GIC events seems to be an overall high regional or global geomagnetic activity. A variety of both very localised ionospheric currents structures, as well as relatively large scale propagating structures, are observed during peak times of GIC. The typical duration of intense GIC sequences varies between 2-15 minutes.

The GIC studies were the topic of the PhD thesis by Antti Pulkkinen at the University of Helsinki in 2003.

8.6 CLUSTER-MIRACLE: Mesoscale structure of the solar wind-magnetosphere-ionosphere system (C2M)

Professor Kalevi Mursula: Consortium leader, team leader at University of Oulu (OU).
Professor Tuija Pulkkinen: Team leader at the Finnish Meteorological Institute (FMI).

Figure 23. Cluster satellites

8.6.1 GOALS OF THE PROJECT

The central goal of the C2M project was the scientific analysis of simultaneous observations from the Cluster-2 mission (Figure 23) and the MIRACLE network of ground-based instruments, and the development of data handling and scientific analysis methods for that purpose. Specific scientific goals were the investigation of magnetospheric boundaries, UFL wave phenomena, the magnetosphere-ionosphere coupling via field-aligned currents, and the dynamics of magnetospheric storms.

8.6.2 SCIENTIFIC RESULTS

The C2M project has contributed significantly to the understanding of the physics of the solar wind-magnetosphere-ionosphere system. The four Cluster spacecraft have, for the first time in the history of magnetospheric physics, allowed to unambigously separate spatial and temporal variations in the system. This capability has been used in several studies of different space processes and environments. E.g., it was used in an explicit way in the first spatial-temporal analysis of the equatorial growth region of electromagnetic ion cyclotron (EMIC) waves. The Cluster multi-satellite observations could conclusively demonstrate that the short-term differences in the observations between the satellites were mainly due to spatial rather than temporal variations, and that the spatial extent of the EMIC wave source was limited by magnetic rather than invariant latitude. The wave source was located almost symmetrically around the magnetic equator within 18 degrees of magnetic latitude. It was shown that this spatial occurrence was due to the waves suffering a mode conversion at the ends of the source region, thus being no longer guided by the magnetic field at higher magnetic latitudes. The wave source remained spatially fairly stable during the 1.5h interval of observations but the wave frequency decreased slowly from 3.2Hz to 2.4Hz during this time. It was demonstrated that observations of this wave source by one satellite only would have given an erroneous view of the spatial occurrence of waves, and would have left unexplained several facts that were due to the slow temporal development of the wave growth region. In another study of EMIC waves the Cluster observations gave important information on how a new class of EMIC waves with exceptionally large frequency range is generated. They also contributed to reject the earlier standard model for producing EMIC wave packets in space.

The capability of Cluster to separate temporal and spatial variations was also used in a study of energetic particles in the high-latitude dayside. Contrary to earlier observations of high fluxes of energetic particles in the high-altitude cusp, a very low flux of energetic particles was found in this region during a strongly positive IMF Bz conditions. Moreover, using the above described method of comparing energetic particle fluxes in the four satellites, the speed and direction of the moving dayside magnetopause was determined. It was also noted that the moving magnetopause was often found to be connected with an increase of energetic electron flux while the stagnant MP was effectively a sink to energetic particles, giving indirect evidence for reconnection.

Using the versatile set of instruments in the four Cluster satellites one can now reliably determine in which region of the dynamic magnetosphere the satellites are at any particular time. This development allows, for the first time, to do reliable statistical comparisons in the constantly moving and spatially rather limited regions of the dayside magnetosphere. We have exploited this possibility to study the fluxes of energetic particles in the cusp and in the high-latitude dayside plasmasheet (HLPS), and their dependence on the external conditions (solar wind and IMF). Such a study is well motivated by the persistent dispute on the origin of these particles at the dayside, and on the related question of particle acceleration mechanisms. Using all the Cluster dayside passes around the vernal equinox in 2003 we have found interesting new relations between the particle fluxes in the two regions and the IMF conditions. The obtained results can be consistently interpreted in terms of the effects of dayside reconnection whose location is changing with varying IMF conditions. We found, e.g., that when the magnitude of IMF By component is large and reconnection cannot produce new closed field lines in the dayside even if Bz is positive, the energetic particles are seen on open field lines in the exterior cusp. For small By and positive Bz when the production of new closed field lines on the dayside is effective the energetic particle fluxes are higher in HLPS. The findings suggest that the energetic particles seen in the exterior cusp have been released from magnetospheric closed field lines due to changing reconnection. Accordingly, recent theories claiming a local acceleration of energetic particles in the cusp are now strongly disfavoured.

The C2M project has generated considerable new knowledge also on the magnetosphere-ionosphere coupling via field-aligned currents, and the dynamics of magnetospheric storms. In addition, new scientific analysis methods were devised which make it possible to exploit the full strength of the multi-spacecraft data. Two novel methods were developed specifically for combined Cluster/ ground-based data analysis. Both methods make use of the fact that with the four Cluster satellites, for the first time, the field-aligned current (FAC) patterns can be observed spatially and instantaneously: The FAC-based method of characteristics combines such data with spatial ionospheric electric field measurements by ground-based coherent scatter radars like STARE (part of MIRACLE), without the need for ground magnetometer data as input. Using an estimate of the Hall-to-Pedersen conductance ratio, the method allows to infer the ionospheric Hall and Pedersen conductances, as well as true (not equivalent) ionospheric current densities. This method has recently been applied in Marchaudon et al. (2002). The elementary current method combines the spatial FAC data with observations of a two-dimensional ground magnetometer network like the IMAGE network (part of MIRACLE). This method allows to compute the true ionospheric currents, without the need of ionospheric electric field data input. If in addition such electric field data are available, the full set of macroscopic electrodynamic parameters of the ionosphere can be calculated without that any of these parameters needs to be assumed.

Related to the science goal of the investigation of magnetospheric boundaries, the project established the relation between the region 1 FAC that were observed by Cluster at their generation region at the magnetopause and the related auroral signatures on the ground. It was found that both the FAC and the auroral signatures show a direct response to changes in the interplanetary magnetic field (IMF). Amm et al. (2003) explored the detailed electrodynamics of an early morning side magnetospheric shear flow region. They found that a double structure of FAC exists in the vicinity of the shear flow region, with one FAC sheet caused by the divergence of the electric field and a second, more equatorward one caused by gradients of the ionospheric conductance. Further they found that the open-closed field line boundary can be shifted significantly from the convection reversal boundary.

In addition to the above studies, which also deal with the magnetosphere-ionosphere coupling via FAC, this coupling has been studied earlier on the dayside. These studies identified the ionospheric and magnetospheric signatures of bursty reconnection on the dayside magnetosphere in response to changes of the IMF, and the associated motions of the magnetospheric cusp. The combination of Cluster and ground-based allowed to estimate the width of the channel in the magnetotail in which flux was transported earthward over the Cluster spacecraft.

The scientific advances reached during the project will substantially support the development of tools for aftercasting, nowcasting and forecasting of space weather effects. These effects are important for the industry and economy, as they may influence ground systems like power and gas networks, communication systems, and the operation of satellites. However, the main goal of the project is basic research, i.e., the production of knowledge. As history has shown, on the longer run the production of knowledge tends to influence the society much stronger than any specific industrial, technological, or economic developments.

8.7 Dust, Atmospheres, and Plasmas in the Solar System (DAPSS)

Dr. Esa Kallio, Finnish Meteorological Institute (FMI)

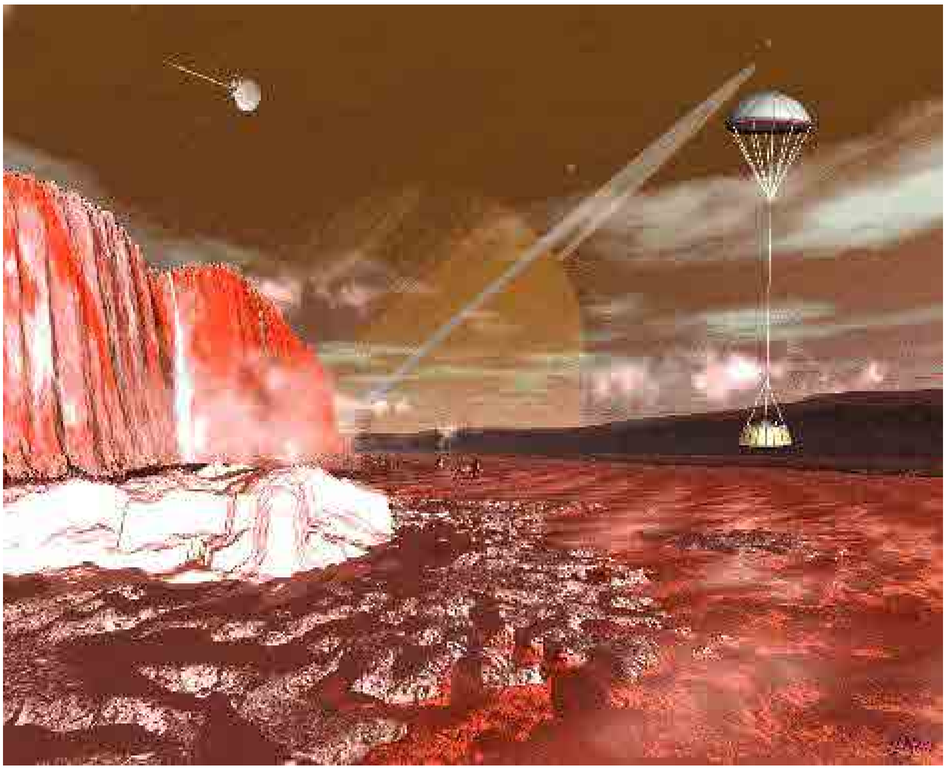

Figure 24. Huygens probe will be landing in January 2005 on Titan, the moon of Saturn

8.7.1 GOALS OF THE PROJECT

The goals of the DAPSS project for years 2001-2003 was to (1) accomplish space instruments and related software to study several solar system objects (Figure 24), (2) to use existing data and observations for scientific research, and to (3) develop global space plasma models that will be used in data analysis mostly after the end of the project, also in forthcoming space science projects.

8.7.2 STATUS OF THE PROJECT

8.7.2.1 Overwiew of the DAPSS project

The work during the period 2001-2003 has included a full chain of different steps involved in the space science research: A successful instrument proposal (ASPERA-4), development, manufacturing, and testing of several space instruments, data analysis (CIDA, SPEDE), and preparation for the forthcoming data by numerical and analytical models (Figure 25).

Figure 25. High lines for the DAPSS project and its three main phases: Instruments, Data analysis and Modelling phases

The years 2001-2003 marked a milestone for several Finnish space projects included in DAPSS. During the year 2002 one instrument on the MarsExpress spacecraft, one instrument on the SMART-1 Lunar mission, and five instruments on the Rosetta comet mission were completed. MarsExpress was launched successfully in June 2, 2003. It includes the ASPERA-3 particle instrument, which will measure the erosion of the Martian atmosphere. An identical replica of the instrument, ASPERA-4, onboard the VenusExpress mission to Venus will perform similar measurements at Venus starting in April 2006. In September 2003 the SMART-1 spacecraft carried the SPEDE instrument toward the Moon. ESA's cometary mission to comet Churyumov-Gerasimenko, Rosetta, includes the following five DAPSS instruments: PP, COSIMA, MIP, LAP and ICA. These space instruments are anticipated to provide new unique data during 2004-2015.

One of the instruments of DAPSS consortium is the Ion Beam Spectrometer (IBS) of the Cassini Plasma Spectrometer (CAPS) on board the Cassini probe that is currently on its way to the planet Saturn. CAPS will be used to study the Saturnian plasma environment and the Saturn-Titan system after Cassini arrival at Saturn in July 2004.

8.7.2.2 Realization of the goals of the project

Developing space instrumentation formed a large part of the DAPSS project (see Figure 21). The consortium is involved in eleven scientific instruments providing hardware, flight software or both: Spede instrument on Smart-1 mission to the Moon, ASPERA-3 instrument on MarsExpress to Mars, CIDA instrument on Stardust comet mission, IBS instrument on CASSINI orbiter to Saturn, PPI instrument on Huygens probe to Titan moon, ASPERA-4 instrument on VenusExpress to Venus, and five scientific instruments on Rosetta cometary mission to comet Churyumovin-Gerasimenko.

One of the main scientific objectives of DAPSS is to study the properties of the solar wind and how the solar wind interacts with various solar system bodies. While interesting new results have been obtained about the solar wind, the set of successfully completed space instruments will make it possible to soon obtain new information on its interaction with Venus, the Moon, Mars, comet Wild-2, Saturn, its moon Titan and later with comet Churyumov-Gerasimenko (see Figure 1, "DATA"). The analysis of the forthcoming data will focus to study the global interaction processes between plasma and the various solar system bodies. Preparatory work for the data analysis by developing four global models forms the third phase of the DAPSS project (Figure 26).

The realization of all the goals of the original DAPSS project plan was not, however, possible because the DAPSS consortium received only about half of the applied funding. Due to this cut, new scientists could not be hired to work on cometary (Stardust and Rosetta projects) and Moon (SPEDE instrument) science as planned and, consequently, these studies were excluded in the revised DAPSS research plan issued in August 2001. Also, the analysis of CAPS/IBS data during the Jovian flyby had to be neglected. The cut hit especially severely the scientific aims of DAPSS because the majority of the available manpower had to used to fulfill the many commitments to deliver space instruments during 2001-2002. Fortunately, this manpower problem affecting the scientific objectives was partly circumvented by using other funding sources. Nevertheless, the reduced funding had a negative impact on the science outcome from the DAPSS project during the official time span of the ANTARES programme.

8.7.3 SCIENTIFIC RESULTS

8.7.3.1 The Sun and the solar wind

Several important results were obtained on the basic properties of the solar wind and the interplanetary magnetic field. We have found that the dominating IMF sector alternates at the period of about 3.2 years. This interesting new periodicity relates to the so-called flip-flop periodicity of active solar longitudes found in some stars and is the first definite observation for the Sun. We have found that the solar wind distribution is systematically north-south asymmetric around the solar equator during solar minima. Also, the heliospheric current sheet was found to be shifted southward during solar minima, leading to a new concept of a "bashful ballerina". We have also studied 1-2-year fluctuations in solar wind and IMF using all available data from the many heliopsheric probes to have the widest global view. These fluctuations are related to the activity of the solar dynamo and depict interesting systematic changes and latitudinal organization. These findings have initiated several other global solar and heliospheric studies, e.g., by the SOHO satellite. They also allow new methods for a more reliable long-term forecasting of solar activity and heliopsheric structure.

8.7.3.2 Modelling of the solar wind interaction with solar system bodies

DAPSS consortium has developed four global quasi-neutral hybrid (QNH) models: QNH model for Mars, *the first ever* realistic (subsonic) QNH model for Titan, QNH model for Venus, and *the first ever* QNH model for Mercury.

1) ***Mars model***: Will be used to interpret ASPERA-3/MarsExpress particle measurements starting in January 2004.

2) ***Titan model***: Will be used to interpret CAPS/IBS/Cassini and MIMI/Cassini measurements starting in July 2004. The model is the first ever quasi-neutral hybrid model for Titan that uses realistic plasma parameters (subsonic flow) for the Saturnian co-rotating plasma.

3) ***Venus model***: Will be used to interpret ASPERA-4/VenusExpress particle and magnetic field measurements starting in April 2006.

The common feature for all these three objects is that they do not have a noticeable global intrinsic magnetic field but that they do have an atmosphere and exosphere which interacts directly with the space plasma that flows near the objects. One consequence of the direct plasma-neutral interaction is the formation of energetic neutral atoms, ENAs, which takes a place when fast ions take electrons from neutral atoms. One of the main scientific application for the developed global models (Figure 26) is to interpret the so called ENA images that will be obtained for the first time at Mars by ASPERA-3 instrument, at Titan from MIMI instrument, and at Venus by ASPERA-4 instrument. The interpretation of the obtained ENA images (so called ENA inversion that gives the properties of the plasma that generate ENAs) relies strongly on global 3-D models.

However, although Mars does not have a global intrinsic magnetic field it has localised strong crustal magnetic anomalies, which affect its interaction with the solar wind. The fourth developed quasi-neutral hybrid model contains the object's intrinsic magnetic field:

4) ***Mercury model***: Will be used to interpret the role of the Martian crustal magnetic fields in ASPERA-3/MarsExpress particle data.

After the DAPSS project the developed Mercury model will be used to study Mercury and to interpret BepiColombo Mercury missions data (arrives at Mercury ~2014) that perform the first ever ENA measurements at Mercury.

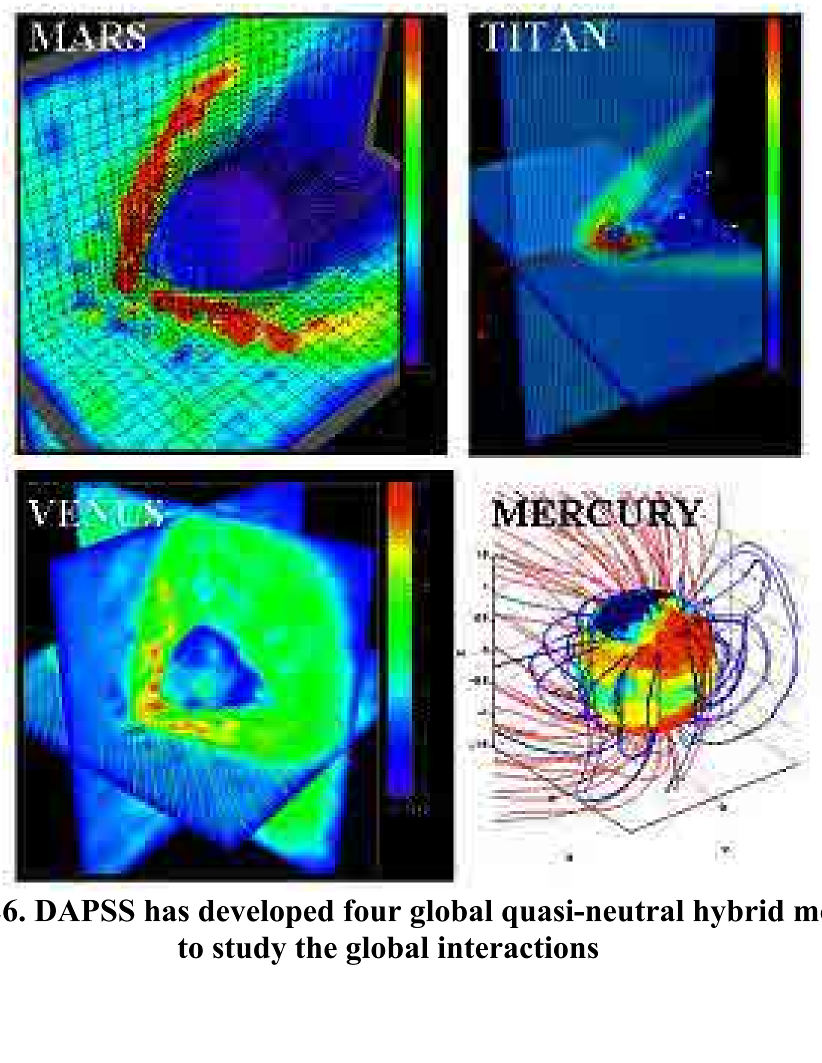

Figure 26. DAPSS has developed four global quasi-neutral hybrid models to study the global interactions

As emphasised earlier, the interpretation of ENA images relies largely on the global Mars-solar wind interaction models. DAPSS has developed four global models to study Mars-solar wind and Venus-solar wind interaction: (1) *analytical ENA models* for Mars and Venus and (2*) quasi-neutral hybrid ENA models* for Mars and Venus. The former, non-self consistent parametric models, are developed to provide a tool for ENA inversion of ASPERA-3/MEX and ASPERA-4/VEX ENA images. The latter models are computationally much more expensive approaches as the analytical parametric models but they provide a possibility to study several Martian and Venusian plasma physical processes self-consistently.

In the analytical models the solar wind flow around Mars and Venus is described by analytical functions that depend on a set of free parameters. The modelled flow provides a possibility to determine other plasma parameters while conservation laws and approximations are applied. The flux of energetic hydrogen atoms, H-ENAs, is then calculated by a line-of-sight, LOS, integration. Figure 27a illustrates the flux of H-ENAs at Mars based on the analytical Mars model. In the quasi-neutral hybrid model ENA images are obtained by implementing virtual ENA instruments in to the model that record the hit of ENAs. The quasi-neutral hybrid model produces automatically both H-ENA and oxygen ENA (O-ENA) images. Figure 27b depicts the flux of O-ENA at Mars based on the quasi-neutral hybrid model. In the ongoing data analysis the simulated ENA images are compared with ASPERA-3 ENA measurements.

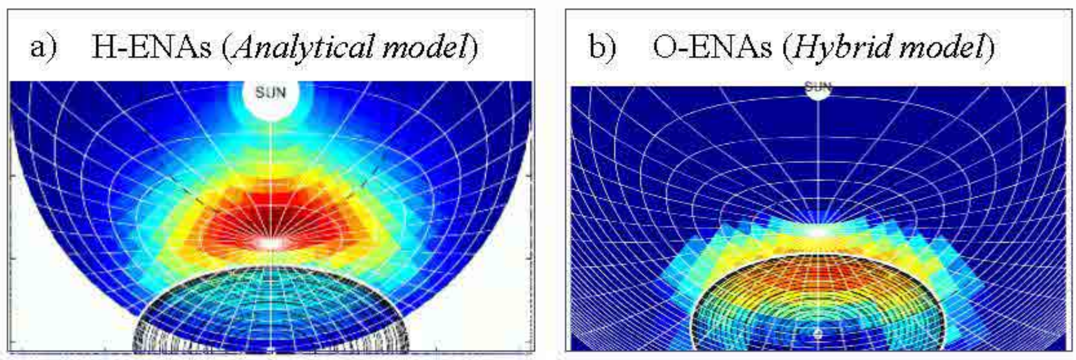

Figure 27. Simulated Energetic Neutral Atom, ENA, images based on two global models developed by DAPSS.

8.7.3.3 New measurements: Mars and Wild-2

The main scientific results concerning the interaction of plasma with solar system objects are to come during 2004-2006 when the new data become available. The data analysis will then focus to study global features taking place when the solar wind interacts with a weakly magnetised or a non-magnetised object, either in its exosphere, its atmosphere or its surface. However, succesful measurements of ASPERA-3/MarsExpress and CIDA/Starduts and the preliminary analysis has already now resulted a deeper understanding of these objects.

ASPERA-3/MarsExpress

ASPERA-3 instrument started particle measurements at Mars in January 2004. By now, all of its four individual sub-instruments, Neutral Atom Imager (IMA), Neutral Atom Analyser (NPA), Ion Mass Analyser (IMA), and Electron Spectrometer (ELS), has provided data from several orbits.

IMA measurements made by so far has confirmed the observations made by ASPERA/Phobos-2 in 1989 according to which an intensive atmospheric erosion takes place at Mars (Figure 28). A detailed estimation of the global atmospheric loss will be obtained when more data from different sites of the planet are collected and when the data are compared with global simulations.

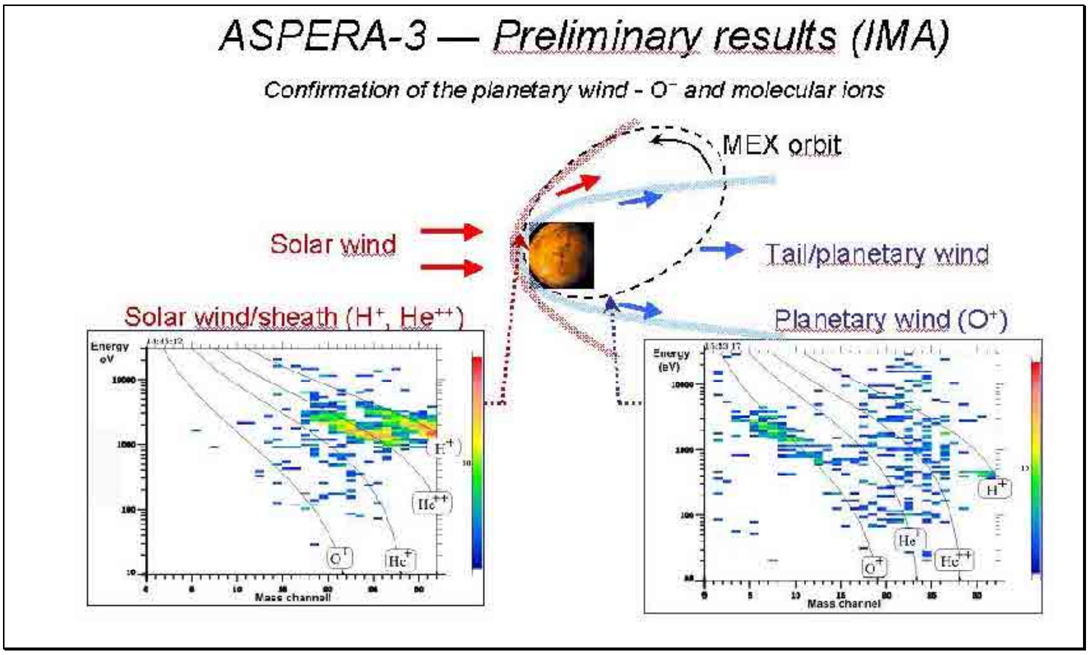

Figure 28. An illustration of the ion measurements at Mars made by ASPERA-3 instrument on MarsExpress. ASPERA-3 can distinguish the escaping planetary ions.

CIDA/Stardust

Stardust measured successfully the dust environment of comet Wild-2 in January 2, 2004. CIDA dust instrument measured the mass spectra of dust particles during the flyby (Figure 29). Data analysis of the obtained mass spectra has begun by comparing the measurements with laboratory measurements. The measurements will later also be compared with the dust samples made by Stardust which will be deployed to Earth in 2006.

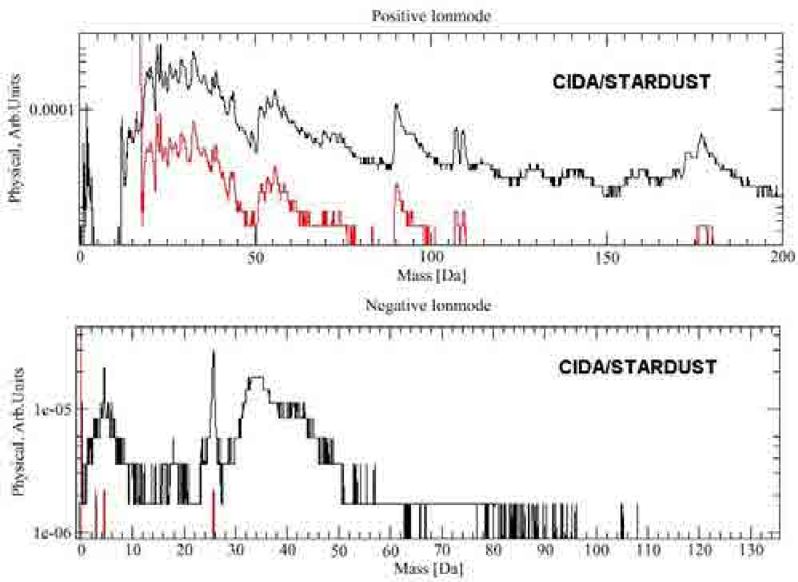

Figure 29. The mass spectra of comet Wind-2 in January 2, 2004: (top) the mass spectra of a dust particle containing minerals, and (bottom) the first ever negative ion spectra.

8.7.4 TECHNOLOGICAL ACHIEVEMENTS

Within the DAPSS/ANTARES programme the following instruments were developed, completed, delivered and partly also deployed in space:

- *Stardust /CIDA*: *(launched in February 2001)*

  A new approach to flight software development was implemented. Using a multi-threaded operating system with adjustable look-up tables for software functions, adjustments to the software during flight became easier and safer.

  The Electrical Ground Support Equipment (EGSE) was developed on the basis of a freely re-programmable commercial Universal Serial Bus (USB) interface connecting to any computer without need for specialized devices. The software implemented on a Linux platform and using a distributed process control language (ERLANG) allows safe remote support of test campaigns from the developer's home location minimizing the need for travelling.

- *Mars Express/Aspera-3*: *(launched in June 2, 2003)*

  The developed control electronics was designed around a few radiation hardened Field Programmable Gate Arrays (FPGA), minimizing mass, space and development time. This approach made hardware adjustments possible as late as during the final integration of the 5 different flight detectors delivered from different countries. With earlier technology the complete electronics board would have to be re-designed and manufactured when interface mismatches were discovered.

  The EGSE approach allowed distributed testing by separate groups across country borders irrespective of where the hardware was physically located at any given time.

  The flight software was built following the CIDA approach, but developing the implementation further, using different levels of automatic fallback solutions in case the more complex implementation failed. An included macro-process allows automatic generation of complex sets of commands adjusted from ground during flight with a minimized amount of telecommands needed.

- *Venus Express/Aspera-4*: *(to be launched in November 2005)*

  Identical replica of *Mars Express/Aspera-3* instrument. The flight model was delivered to PI institute (IRF Kiruna) in November 2003. The instrument also contains the same flight software than ASPERA-3.

- *SMART-1/SPEDE*: *(launched in September 2003)*

  Built on developments for the ESA Rosetta mission, the amount of power consuming analog electronics and processor circuits was minimized. A complete RISK processor including boot code was implemented on the same FPGA controlling the measurement timing, analog control and digitalization of measurement data. This approach will make the implementation of the complete instrument's electronics in just one small low-power hybrid circuit possible.

  The sensors, mounted at the tip of 2 tube-like shock-resistant lightweight carbon fibre booms, consist of thin Titan Nitrid foils. The manufacturing process and the material assure that the sensor surface does not change its characteristics during flight as a consequence of contamination or illumination. The complete instrument including the 60cm long booms, thick radiation shielding and long double shielded cabling has a mass of less than 800g.

  The software for the implemented processor is so efficient, that the complete operating system including operations control and data compression takes less than 10kByte space. In SPEDE a set of 8 different alternative program versions are stored in its none-volatile memory to overcome possible program failure problems and allow simple and safe software updates. In future versions the complete software can be coded directly into the same FPGA making the need for external none-volatile memory obsolete.

- *Rosetta-Lander/PP: (launched in February 2004)*

  Digitally generated transmitter frequencies with digital receiver signal filtering allowed low-mass implementation of a wide range of freely selectable signal frequencies down to 10 Hz, where earlier the analog filter groups defined the available frequencies with the mass budget limiting the low end of the frequency range. Insulated sensor material of arbitrary shape allowed the mounting of the sensor electrodes on any available surface without impact on the measurements, where a special guarding technique minimized the influence of the needed long cables.

A freely programmable control sequencer, implemented in a radiation hardened low-power FPGA, activates its own clock signal and the various analog power lines on a need basis according to operational requirements, minimizing the used total energy of the CMOS-based electronics.

The originally developed dedicated EGSE hardware was finally replaced by the same USB-based generic small size interface as in CIDA and COSIMA for simplified field calibration campaigns.

- *Rosetta-Lander/System Mass Memory*: *(launched in February 2004)*
  A densely packed board with in-chip radiation protected memory is controlled by an intelligent memory management system, implemented in a radiation hardened FPGA. All Lander data are stored on this board before they are uplinked to the orbiter. Automatic redundancy line control and error correction ensures functional and data integrity. All data are also retained if the power is completely lost during cometary night. During data retrieval the autonomous memory management part repeats automatically earlier sent data packets in case of a link error. Data read-out and write speed are independent, both processes can be active simultaneously.
- *Rosetta/ICA + LAP*: *(launched in February 2004)*
  For this instrument's control electronics the then new FPGA technology in space projects was implemented for the first time, reducing the need of complex electronics boxes to a single small board. After this pilot project, the same technology was used in all subsequent space projects. Using a generic approach, the control electronics could be made identical for two rather different instruments, reducing development cost and time.
- *Rosetta/COSIMA*: *(launch planned for February 2004)*
  The software and EGSE approach, developed for CIDA, was re-utilized for this instrument with a much higher level of complexity.

8.8 *Mars Small-Scale Weather by Numerical modelling (MSW)*

Professor Hannu Savijärvi, University of Helsinki

Figure 30. Mars Express with Beagle 2 lander was launched in June 2003

8.8.1 GOALS OF THE PROJECT

The main goal was to design and apply a hierarchy of numerical atmospheric models (1-, 2- and 3-dimensional), in order to study 1) Martian meso-scale circulation phenomena, 2) the Martian boundary layer and atmosphere-surface interactions, and 3) aerosols and cloud microphysics in the Martian atmosphere.

The 3-dimensional Mars Limited Area Model (MLAM), developed in this project, is based on the European numerical weather prediction model HIRLAM (High-Resolution Limited Area Model); more precisely on the operational HIRLAM version used in the Finnish Meteorological Institute. The 1- and 2-D models are new and developed versions of the University of Helsinki Mars models.

8.8.2 SCIENTIFIC RESULTS:

8.8.2.1 Martian meso-scale phenomena

The 2-D meso-scale model has been further developed (with improvements in its water cycle physics and radiation scheme) and used to study many surface-difference driven flows. The ice-covered slopes of the polar caps give rise to katabatic Antarctic-type flows, which as such and according to the model predictions appear to be quite strong and steady in direction and strength. These flows are modified by sea breeze-type circulations at the ice edge, not only at the ice-regolith (bare land) boundary, but also (in the northern polar region) at the CO_2 ice – H_2O ice internal edge, the location of which varies seasonally. These meso-scale circulations also interact with the larger-scale flow, such as created by the annual sublimation and freezing of the polar cap. In-valley flows, such as in the deep Chasma Borealis within the north polar cap, have also been studied with our models. Also crater flows e.g. in the big Hellas crater have been studied in different scenarios, where the crater top, slopes and bottom are variously covered by CO_2 or H_2O ice, or both, as may be the case during the Martian year. The complex meso-scale wind patterns (too detailed to be described even briefly here) have not yet been observed, nor are they resolved by global-scale models (General Circulation Model, GCM), so these results remain novel scientific predictions to be verified later.

In all these simulations the water cycle and transport has been included. This has given a semi-quantitative picture and prediction of the regional water transport by meso-scale flows. They appear to be fairly important (and they are not present in GCM results).

The fast 2-D model has also been used in novel ensemble-type experiments, where the parameter space for the less-known variables has been charted systematically (and in suitable cases, also sampled randomly), to obtain estimates of the sensitivity of the results to each varied variable. The work has just begun but it already points out the remarkable steadiness of the polar cap wind to the parameter variations.

The 3-D model development and implementation have taken more time than expected, but the model is now working. It has been used so far to map the local winds and weather around the three landing sites (Viking 1, 2 and Pathfinder), in 10 km horizontal resolution. The correspondence to the point observations is good and suggests that larger-scale winds, local winds and thermal tides all are important (although in different ways) in creating the diurnal and very repeatable pattern in the surface pressure and winds. The near-surface temperatures in turn are mainly driven by radiation (as shown also by the 1-D simulations, see below). The diurnal local winds themselves are quite variable from place to place, as the forcings for them (topography, heat capacity, heat conductivity, albedo and ice coverages of the ground) vary a lot in Mars, much more strongly and in smaller scales than on the Earth.

The 3-D model (MLAM) experiments are now very much ongoing, for instance for the Beagle 2 site at the time of landing, but the results are not yet ready. The initial condition and horizontal boundary values for MLAM are (at present) taken or derived from the results of the European Mars ‘Oxford/Paris’ GCM.

8.8.2.2 The Martian boundary layer and surface-atmosphere interactions.

The physical processes and their parameterisations in Mars models have been studied using newest Pathfinder data (courtesy of New Mexico State University) and high-resolution 1-D models. For radiation, accurate reference line-by-line calculations with a JPL scheme (D. Crisp) for an ‘average’ Mars case were made available. The UH model schemes were improved by this comparison, and other GCM schemes joined into an international comparison of Mars radiation schemes. In particular, an improvement in the delta-two-stream approximation could be made, which can prove useful also for the Earth’s climate and Numerical Weather Prediction (NWP) models. The global albedo of Mars was studied as the function of the dust load, dust optics, and surface albedo; also this work may have relevance for the Earth’s ‘antigreenhouse’ effect of aerosols.

With the validated, fairly accurate new radiation scheme the UH 1-D model was used to simulate the Pathfinder observed diurnal cycle near the surface using several turbulence schemes. The usual similarity scheme for the surface layer proved best, no iteration was necessary there, and the Dyer-Businger stability functions gave good results, too. The model predicted a full hydrologic cycle as well, with nighttime frost forming at the surface and water ice fog from 0200 (local time) onward, which appears to be verified by the Pathfinder camera observations.

Sensitivity studies were made as well. Despite the strong daytime turbulence indicated by the Path-finder observations and model alike, it is the longwave radiation, which is the most important driver of the near-surface temperature cycle (unlike on the Earth), while the daytime surface temperature is mainly determined by net solar radiation and night-time surface temperature by net longwave radiation at the surface (for fixed ground properties). Therefore quite accurate radiation schemes are necessary for all Mars models, underlining the importance of the intercomparison initiated and led by the MSW project.

A weather prediction for Beagle 2 was made with the 1-D model, forced by the Mars Climate Database large-scale data. This promises fairly weak diurnal winds, and near-surface temperatures much like at VL-1 for the season (northern spring in Mars) at the subtropical targeted landing site (90E, 10N). This is now due to verification by the successful Mars Express Mission with Beagle 2 (Figure 30).

8.8.2.3 Aerosols and cloud microphysics in the Martian atmosphere

Dust is the most common aerosol in the Martian atmosphere. Its important effects on the solar and thermal radiation have been studied in the radiation intercomparisons, and by using dust interactively in the 1-D model. Here, the presently known mean optical properties and size distributions have been assumed. Sensitivity studies have been made as well.

Also particle formation from condensable vapours in the Martian atmosphere has been studied. This is basic research as not much has been known about the nucleation microphysics in the cold and low-pressure conditions typical of Mars. Our studies rule out homogeneous one-component nucleation of water as well as of carbon dioxide as an important particle production mechanism, but they show instead that in favourable conditions these vapours can nucleate heterogeneously on the surface of dust particles, and can form ice clouds.

8.9 Chemical Aeronomy of the Mesosphere and Ozone in the Stratosphere (CHAMOS)

PhD Esa Turunen, University of Oulu, Sodankylä Geophysical Observatory

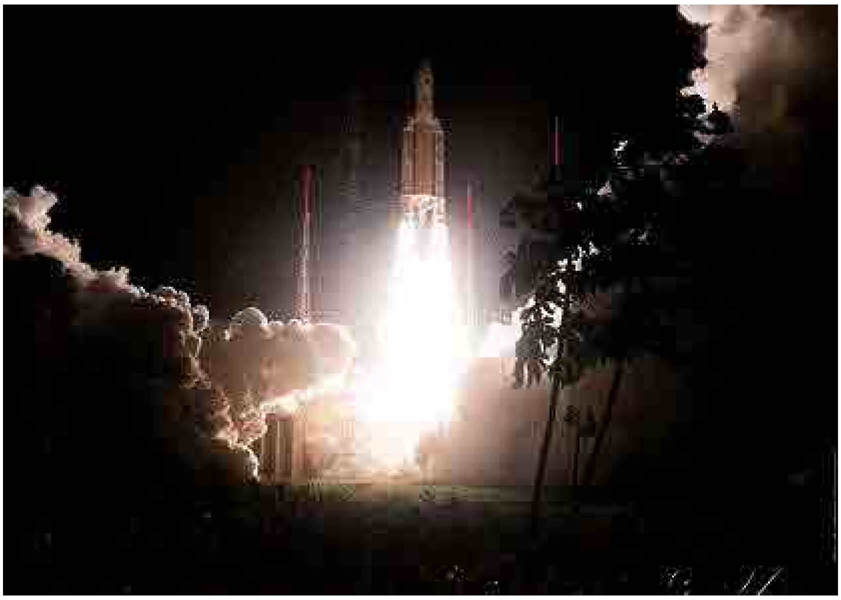

Figure 31. Envisat environmental satellite was launched on March 1, 2002

8.9.1 GOALS OF THE PROJECT

In this project we are studying the effects of energetic particle events on the chemistry and composition of the middle atmosphere. The aim is to determine the impact of solar and magnetospheric energetic particles on the chemistry by quantifying the contribution of energetic particle precipitation to the destruction of ozone in the mesosphere and upper stratosphere by using a detailed chemical model of the atmosphere and data from the European space mission ENVISAT-1 (Figure 31) and the Scandinavian satellite Odin, as well as other available space and ground-based data. Of special interest is the role of ion chemistry in relation to neutral constituent concentrations and especially the variation of atmospheric odd nitrogen which affects ozone in the mesosphere and upper stratosphere. We are looking for answers to these questions:

1) How much and where is odd nitrogen produced during particle events?
2) How significant is the produced odd nitrogen to the ozone budget?

8.9.2 SCIENTIFIC RESULTS

1) The role of ionic reactions in producing neutral nitric oxide during a selected solar proton event was shown to be of importance. Earlier model estimates of particle effects on neutrals have used a constant parametrization for the production via ionisation processes. The approach in the project is a detailed model calculation, adapting to the variability in the nature of the ionisation sources.

2) The effect of excess ionisation on the concentrations of minor neutral constituents, among others nitric oxide and ozone, was quantified both in a steady state approach for daytime conditions, as well as in a time dependent calculation, which aimed for detecting the forcing by particle precipitation, taking into account the diurnal variations due to changing solar illumination conditions.

3) The effect of secondary electrons dissociating neutrals in the upper atmosphere during a solar proton event was quantified. The results of a Monte Carlo calculation were used to justify a parametrization adaptation of the process in the final modelling tool. The results of the new Monte Carlo calculation agree with earlier estimates by other means.

4) As a summary of the quantifications of the particle precipitation effects seen in a real solar proton event on October 23, 1989, we note that ionic reactions produce 10-25% of odd nitrogen during events studied.

5) In a model study of the solar proton event in November 2001, the negative ions were seen to destroy neutral ozone at altitudes below 80 km. The process is very efficient contributing up to the maximum of 40% of the ozone loss at the altitude of 63 km. This is an important new finding.

6) In the analysis of experimental satellite data, ozone decrease as a result of an observed solar proton event was detected. The event under study was the November 2001 solar proton event and the instrument providing the data was the OSIRIS instrument onboard the Odin satellite. Decrease in the order of 20% in the concentration of ozone was seen in the analysed data. Further studies on this and similar observations are under progress.

7) In a theoretical study of a representative auroral electron precipitation event, energetic auroral electrons in the pre-midnight sector were seen to cause a significant increase of NO, leading to severe disturbances, e.g. in electron density profiles. Any measurement of electron density during a geophysically quiet time would serve as a detection of the disturbance in the concentration of the neutral nitric oxide, since the neutral NO is ionised by solar Lyman-alpha radiation in daytime. This is an important quantification of a known process. Increased amount of nitric oxide due to a short lasting but strong auroral activity in the pre-midnight sector caused a 4-fold increase in the electron density at the altitude of 95 km. This would have implications on radio wave propagation.

8) An example of a real short lasting (duration being in the order of 10 minutes) pulsating aurora event was seen to produce a 10% variation in the neutral NO. The case was selected since there was simultaneous incoherent scatter data available.

9) For the first time in the history of the analysis of incoherent scatter (ISR) experiments the sunset effects seen in ISR data in the mesosphere were modeled using a detailed chemistry model. Time development and shape of the height profile of the spectral information in the ISR signal were seen to be consistent in the model and the experimental data, while absolute values showed deviations, which need further studies.

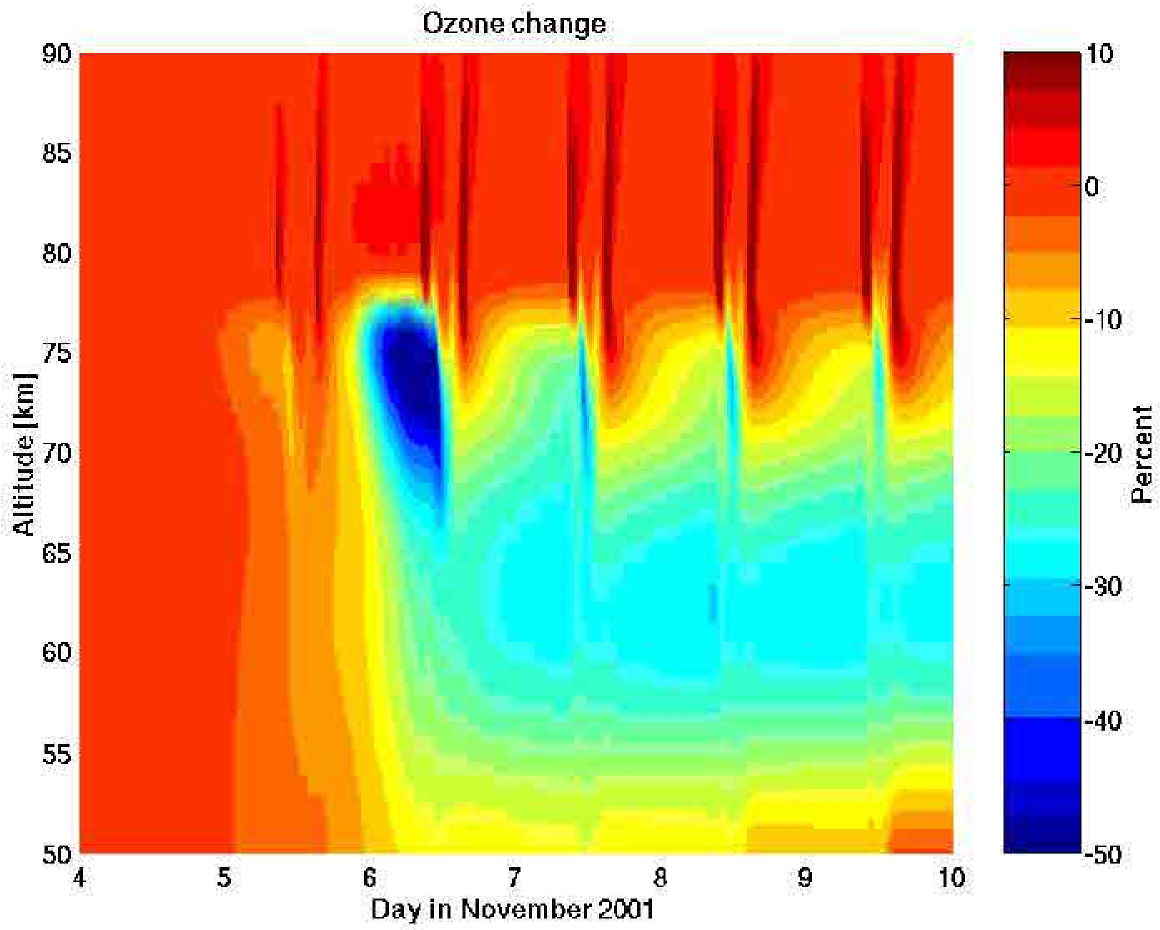

Figure 32. An example of ozone destruction due to a solar proton event, SIC model calculation for November 2001.

The November 2001 solar proton event started on 4th at 1700 UT (Figure 32). Ozone decreases by 20-30% around 63 km. The 'stripes' of increase around 80 km are effects of sunrise/sunset and are connected to atomic oxygen increase.

8.10 New Modeling and Data Analysis Methods for Satellite Based Forest Inventory (MODAFOR)

Professor Lasse Holmström, University of Helsinki, Rolf Nevanlinna Institute

8.10.1 GOALS OF THE PROJECT

The collaboration has aimed at bringing advances in satellite based radar technology, statistical data analysis and mathematical modeling of electromagnetic scattering to bear on problems of forest inventory. The strategy to achieve this has been to combine new data collection technologies with modern techniques of mathematical and statistical modeling.

The currently used Finnish multi-source inventory method (MS-NFI) developed at the National Forest Inventory of Finland was originally designed to produce forest resource estimates for areas of about 10,000 ha. However, due to the concern over the loss of biological diversity and the simultaneous pressure to increase wood consumption, information is needed on much smaller areas of order 1 ha, i.e., at the forest stand and vegetation patch level. This requires utilization of the improving resolution of new optical remote sensing instruments which in turn presupposes the development of new statistical methodology for data analysis.

A need was also seen for the development of better image analysis methods for MS-NFI to monitor ecological information and change such as forest landscape diversity and forest fragmentation related to habitat diversity.

The fact that cloud cover often prevents acquisition of optical images at exactly the desired time has prompted interest also in microwave sensors that provide all-weather capability, independence from lighting conditions and at the same time offer spatial resolution comparable to that of optical spaceborne sensors. While recent results strongly suggest that the frequency of present orbiting synthetic aperture radars (SAR) (C-band; 5.3 GHz) is not optimal for forest inventory, other sensors will provide new observation capabilities including the polarimetric (Radarsat 2, PalSAR) and interferometric (ASAR, Radarsat 2, PalSAR) observation mode. Then new methods based on advanced mathematical and statistical modeling and non-intensity-based techniques are needed to best employ radar data for forest inventory purposes. Such new approaches considered in this project have included radar polarimetry and radar interferometry. To fully capture the promise of the new sensors the partners proposed to develop and employ an accurate, flexible, and computationally efficient electromagnetic scattering model for forests.

The general goals of the project can be summarized as follows:

- To develop new parameter estimation and image processing tools for optical and microwave sensor based forest inventory using state-of-the-art statistical methodology.
- To develop a new microwave scattering model for forest imaging using mathematical modeling and efficient computational implementation.
- To apply the scattering model and improved data-analysis tools to fully utilize the new type of data being made available by the emerging sensor technologies.

8.10.2 SCIENTIFIC RESULTS

8.10.2.1 Scientific and technological results

The work was divided into seven Work Packages as described in Section 8.10.2.2. The main contributions of Rolf Nevanlinna Institute (RNI) were in Work Packages 1 and 4, where the goals set in the project were achieved. At the National Forest Inventory (NFI) of the Finnish Forest Research Institute, three different topics were studied: further improvement of *k*-NN estimation, inexact image segmentation and feature analysis, and Bayesian estimation methods. NFI participated also in the work of RNI on the use of the local linear ridge regression method in forest variable prediction. An improvement of *k*-NN estimation led to an application that is already in operative use in forest inventory. The goals of the other topics were also achieved. Completely new approaches to multi-source forest inventory were discovered and their further development continues as normal research work at NFI.

The work of the Laboratory of Space Technology (LST) of the Helsinki University of Technology involved Work Packages 4-7. A tree growth model was combined with the polarimetric backscatter model providing general agreement between biomass and backscatter parameters. A new forest coherence modeling-based approach was established for the retrieval of stem volume (forest biomass) from space-borne repeat pass interferometric SAR observations. Moreover, a SAR interferometry-based technique for the combined (1) segmentation of homogenous areas, (2) segment-wise land use classification and (3) stem volume retrieval was successfully demonstrated. Polarization optimization methods were developed to enhance the contrast between various forest and land use classes, and to eliminate the effect of topography.

8.10.2.2 Work packages

The work was divided into seven Work Packages and progress in each of them is described below.

1. Further Development of Nonparametric Estimators for Forest Inventory

The *k* nearest neighbour (*k*-NN) estimator is currently used in the MS-NFI system to estimate forest resources using sparse but accurate field plot data as well as data from satellite images. The *k*-NN method is nonparametric in that it does not rely on a parametric statistical model of the data. Although the method is simple, it uses certain tuning parameters whose values affect the possible bias and reliability of the estimates. The accuracy of the estimates can be noticeably improved if, in addition to satellite image, other digital information such as digital maps, are available. Tuning parameter selection has been addressed and reduction of the bias has been considered in earlier research work and publications of the NFI team.

Researchers from RNI and NFI developed a new nonparametric regression technique for forest inventory analyses based on field plot and satellite image data. The approach uses local linear ridge regression and region-wise cross-validation for tuning parameter optimization. This new approach to tuning parameter selection takes into account spatial correlation to some extent and it is also directed towards the actual goal, estimation of regional averages, instead of considering only pixel-wise values of forest parameters as is done in the current approach. Initial comparison with the *k*-NN estimator shows that the new method has potential to improve forest parameter estimation. Further tests will be conducted especially with smaller forest areas.

In a separate development, a new and improved *k*-NN approach for forest inventory was developed by the NFI team. The method introduces two innovations. The first innovation is that the large-scale variation of forest variables is used as ancillary data that are added to the variables of the multi-source *k*-NN estimation. These data are assigned weights in a way similar to the spectral information of satellite images when defining the applied distance metric. The second innovation is that ‘optimal’ weights for spectral data, as well as ancillary data, are computed by means of a genetic algorithm. Tests with practical forest inventory data show that the method performs noticeably better than other applications of *k*-NN estimation in forest inventories and that, for example, the problem of biases of the species volume predictions can almost completely be solved. The method was taken into operative use and the entire area of Finland, except Lapland, has been processed using it. The research work to further fine-tune the parameters of the genetic algorithm will continue as normal research of the NFI team.

2. Inexact Image Segmentation and Feature Analysis

This work package has primarily attempted to produce very concrete results in a task of practical importance for NFI: improving the accuracy of MS-NFI. However, the methods being developed for this task are also more widely applicable in image analysis.

The MS-NFI uses the field data together with digital map data to compute small area estimates for several important forest variables. The information is represented in digital form using 25 by 25 meter pixel size. The methods have to deal with many kinds of uncertainty in the input data, some of which are listed below:

- The forest stands are not homogeneous.
- Because of the small size of the stands, many field plots and satellite image pixels fall into the borders between stands.
- The field data consists of precise observations based on a very small area (current maximum field plot radius is 12.52 m), even compared to the Landsat TM pixel (size about 30 meters).
- The satellite image pixel location and the field plot center are not at exactly the same location on ground. This is due to errors in field plot location measurements, geometric processing of the satellite images and different alignment of the field plot and satellite image pixel grids. This is especially relevant at stand borders.

The new methods examined in this Work Package were compared against the current operational methods used in MS-NFI. Although most of the studies and experiments did not lead into publishable results during this project, the insights obtained into the various uncertainties will be useful both in the development of the operational MS-NFI system and in further research. Still, partially based on the experiments in this Work Package, a new method for locating regeneration cuts without new field data was developed. The technique was later extended to use old field data for pre-screening and it is currently in operational use at NFI.

As for the various studies carried out, the locational errors were considered both qualitatively and quantitatively. This resulted in some suggestions to improve the geometric processing of the satellite images in NFI.

One basic problem in MS-NFI is the stand borders, which may produce mixed pixels with image information from two of more stands. Theoretically, these mixed pixels can be modeled using pure classes representing the adjacent stands. Our studies showed that because of the large number of different stand types and inhomogeneity within stands, no usable 'pure' classes could be defined.

Image features using both spatial and spectral information weighted around the centre location of the feature were not developed because there would be no field data that could be reliably associated with these features. A better approach is to use pixel-based features and to take into account the spatial dependencies later. Different non-statistical formulations for the spatial dependencies of forest variables were examined, including fuzzy set formulation.

3. Flexible Bayesian Methodology for Map Production, Image Segmentation and Classification

The main aim of this work package was to construct model-based multi-source predictions of forest variables and to assess uncertainty in them in terms of probabilities. To this end, the applicability of modern nonparametric Bayesian methods were studied. A flexible data-driven Bayesian approach was introduced for pixel-level inference by modifying the general partition modeling paradigm earlier proposed in the literature. The new method can be seen as a Bayesian counterpart of the *k*-NN method, currently operational in MS-NFI.

The method was designed so that it is possible to estimate a spatially varying relationship between image data and field observations and assess uncertainty in it. Further modifications were suggested and tested to treat specific properties of inventory material in an appropriate manner. From the modeling perspective, challenging properties of multi-source inventory data include skewness and heteroscedasticity of field measurements and also a relatively large fraction of zeroes among ground observations of continuous (non-negative) forest variables, such as the timber volume. Convenient techniques for visualizing the model fit and thereby understanding the model performance were also developed.

It was observed that the suggested modeling approach is applicable even in moderately high-dimensional situations. In the current application, high dimensionality arises from utilizing as predictors all spectral channels of the image data as well as the spatial coordinates.

The method was applied in the prediction of the values of both continuous and categorical forest variables. Measured by RMSE, the nonparametric Bayesian method was seen to be competitive with the *k*-NN technique. The results are promising and they show that simulation-based Bayesian inference is applicable and practical in multi-source inventories.

A multivariate analogue to the univariate approach was introduced. The objective is to make full use of all available image material to account for field plot location errors and understand the implications of these errors. Several forest variables are used simultaneously to estimate the correct field plot location. With the Bayesian method, the uncertainty in plot locations is automatically accounted for when constructing predictive distributions for forest variables.

4. Electromagnetic Modeling for Forest Remote Sensing

The goal of this work package was to develop an electromagnetic scattering model that would provide the association between forest characteristics and spaceborne or airborne backscatter measurements. To fully capture the capability of emerging sensor technology, such as polarimetric and interferometric measurements, the availability of an accurate, flexible and computationally efficient scattering model is highly desirable.

The simulator, EMFORSIM, as it is now called, was successfully designed and implemented in Matlab code by the RNI group. The model represents trees as collections of cylinders and various forms of scattering (direct, ground bounces) are taken into account. Efficient computational implementation allows the use very realistic tree models that consist even of tens of thousands of cylinders. The software package developed includes also some tools for generating simple computer models of trees and forests.

Experiments with simulated forest stands based on L-systems showed that the model is able to detect differences in tree structure. The simulator was then made available for the LST team for further experimentation, validation and development. Comparison of model values with experimental data showed that, in general, the model provides realistic results for boreal forest. The assumption of specular ground was found to cause some inaccuracy in the ground/tree contribution. However, direct backscatter from tree crowns is the dominating mechanism.

In order to reduce computing time the original cylinder model of the tree was simplified by merging cylinders (large branches) and by neglecting the contribution from very small cylinders (small branches). Model simulations with various degrees of simplification were made to assure that the effect to the simulated scattering properties is negligible. The simplified tree model consists of approximately 6000 cylinders.

5. Application of the New Polarimetric Scattering Model to the Retrieval of Forest Characteristics from Space-Borne SAR Data

Due to the delay in launching the fully polarimetric Radarsat-2 radar sensor no comparison between the backscatter values simulated with EMFORSIM and those observed by a satellite was possible. Hence LST concentrated in this Work Package on gaining a good understanding of the behavior of forest polarimetric backscatter, its simulation and the potential of polarimetric radar for forest inventory. The EMFORSIM and the previously developed and validated HUT semi-empirical backscattering model were compared by examining the amplitudes of the three main backscattering contributions from each model: tree tops, ground and tree/ground. The modeled values at C-band agree well with each other as a function of stem volume, when the ground surface is assumed to be somewhat rough instead of specular. This indicates that the EMFORSIM model provides realistic values for radar backscatter from a forest stand.

Direct comparison of model-derived backscatter values with experimental polarimetric radar data for forest is difficult because of the substantial non-homogeneity of forest stands. A new method for this comparison was developed based on (1) a realistic tree growth model and (2) an averaged covariance matrix classification approach. The LIGNUM pine tree growth model, obtained from the Finnish Forest Research Institute, was used to simulate the architecture of trees of various sizes by scaling the tree parameters based on tree age. The averaged covariance matrix method preserves the coherent polarimetric nature of backscatter and allows identification of the target's polarimetric descriptors. In order to make the simulated forest stand as realistic as possible, various tree sizes and azimuth orientations along with slightly bent trees were used, (Figure 33).

Model simulations were compared with L-band images acquired by the Danish EMISAR polarimetric synthetic aperture (SAR) radar near Oulu in 1995. The results show that the modeled backscatter is highly sensitive to tree orientation (as observed in the JRC/European Microwave Signature Laboratory tests of a single tree) and, consequently, the covariance matrix has to be computed as an average value over at least 100 azimuth looks one degree apart. Examination of simulated amplitude and phase distribution histograms indicates that look direction statistics closely follow those of real SAR data. Comparison of simulated and experimental effect of increasing stem volume using the scattering mechanism (alpha angle) and entropy decomposition scheme shows that the simulated total backscatter behaves realistically in the entropy-alpha classification space, but the level of ground/tree interaction is too low; this shows up as underestimation of entropy.

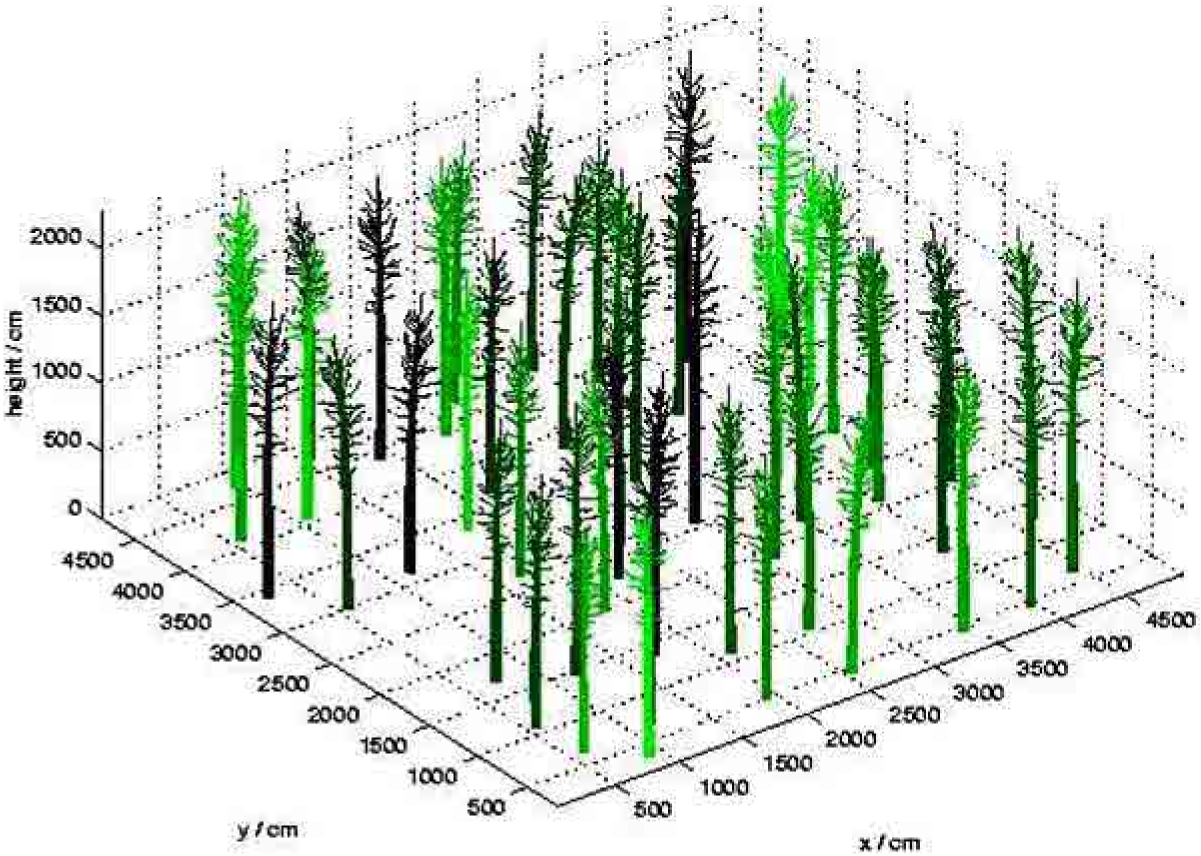

Figure 33. A simulated pine tree stand including various tree heights and orientations.

The results on the investigation of additional aspects of forest backscatter, including polarimetric and temporal coherence, show that forest backscatter is more random than the model prediction. However, the EMFORSIM together with a realistic tree growth model provides a useful tool for further investigation of polarimetric scattering properties of boreal forests.

6. Application of Theoretical and Semi-Empirical Scattering Models in SAR Interferometry

The coherence modeling of boreal forests was investigated and further developed in order to describe the coherence observed through the use of space-borne repeat-pass SAR interferometry. The applied model describes the coherence as a function of forest stem volume (biomass) based on the employment of the previously developed semi-empirical HUT forest backscattering model. The HUT backscattering model describes the quantitative effects of forest floor and vegetation canopy to the observed backscattered intensity. These signatures are employed by the coherence model to determine the response of SAR-derived interferometric coherence to stem volume.

The feasibility of SAR interferometry for stem volume/biomass mapping was investigated using a large experimental data set for the Tuusula site, southern Finland. The results obtained indicate that C-band SAR interferometry is a highly promising tool even for small area forest assessments, especially if wintertime coherence observations are available. The repeat-pass interferometric data used in investigations include 14 complex image pairs from subsequent dates within a year. However, the results also indicate that in some special cases weather-related environmental conditions can corrupt the usability of interferometric coherence data.

The same site was used for the development and testing of a new stem volume retrieval method that is based on the use of coherence data. According to the results, reliable estimates on stem volume are obtained if the size of compartments, for which the results are determined, is larger than about 1.5 hectares. The results also show that a multi-temporal set of two or three interferometric images is sufficient for stem volume estimation, if the images are acquired for proper conditions. Based on the results, the proper conditions can be identified either from standard weather station based meteorological information or by checking some simple quantitative characteristics from the available images. A semi-automatic method that segments multi-temporal coherence images classifies segments to various land cover categories and estimates the stem volume for each forest segment: An example of obtained results is shown in Figure 34.

7. Polarimetric Enhancement of SAR Imagery for Forest Inventory

The LST team made visual and statistical comparisons between various polarimetric parameters in order to search for optimum methods to be used in the development of radar algorithms for forest inventory. Software packages were implemented for this purpose. Methods for polarization and backscatter histogram separability optimization were developed. Multi-polarization data were shown to improve the separability of different types of vegetation covers. Speckle and scatterer orientation effects are substantially reduced from those in single polarization data. Forest behavior as a random scatterer tends to handicap the use of polarimetric analysis and classification based on scattering types. By diminishing the power variation with averaging, forest classification was improved. Intensity was determined to be highly dependent (by a factor of ten) on transmit polarization.

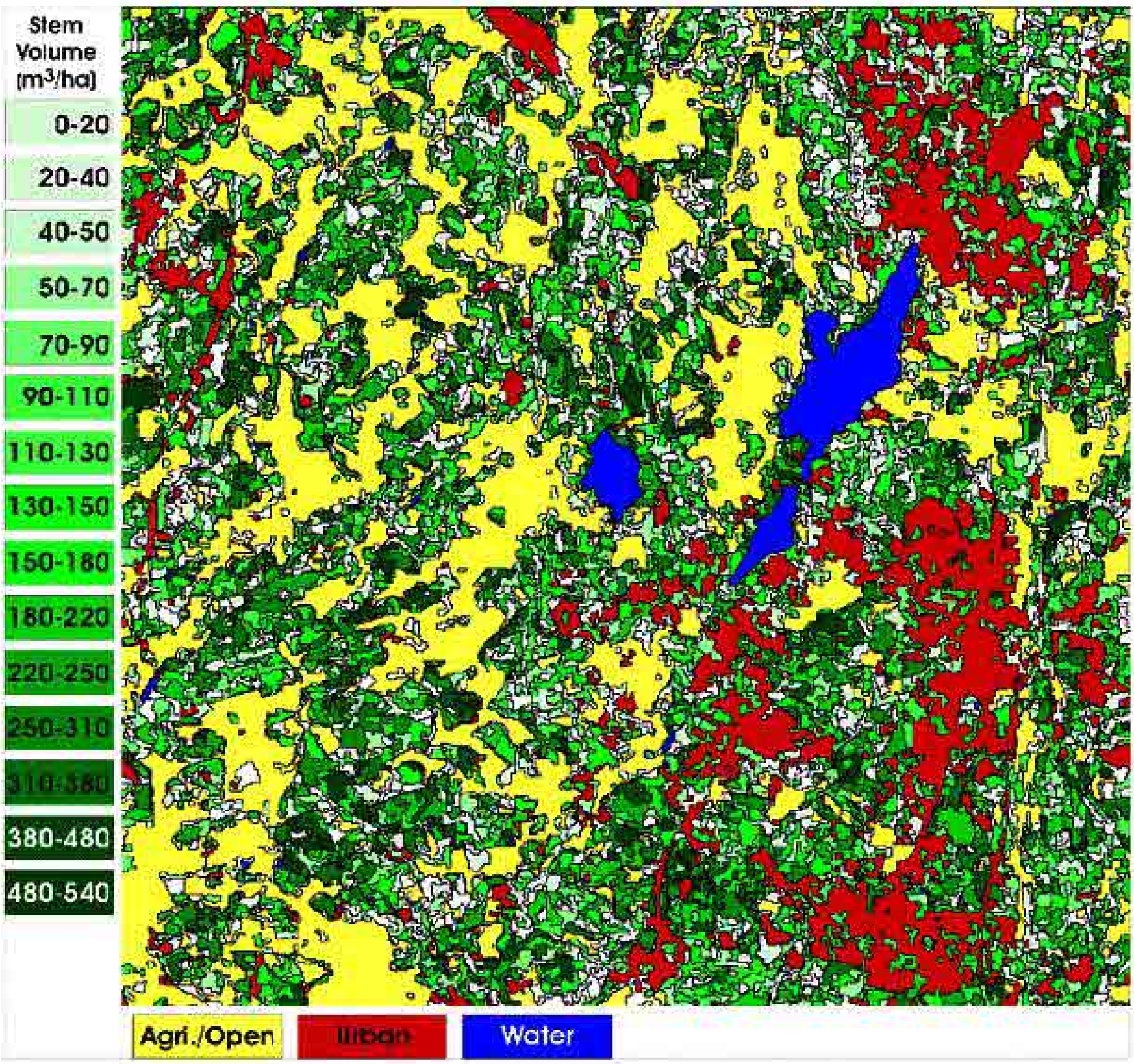

Figure 34. A combined land use / stem volume classification result obtained with SAR interferometry for the Tuusula test site.

Also, theoretical polarization optimization methods were developed: A point scatterer transforms transmit polarization into backscattered polarization through a rational function of first degree. A similar function relates backscattered power to transmitted power and polarization. An example of the obtained results is shown in Figure 35. NFI information on woody volume divided into 2 m3/ha classes (resolution 25 meters) is compared with various radar backscatter parameters averaged into 12.5-meter resolution. The total backscattered amplitude and maximized backscatter (using for each pixel the polarization that maximized backscattered power) show spatial features similar to those of NFI data.

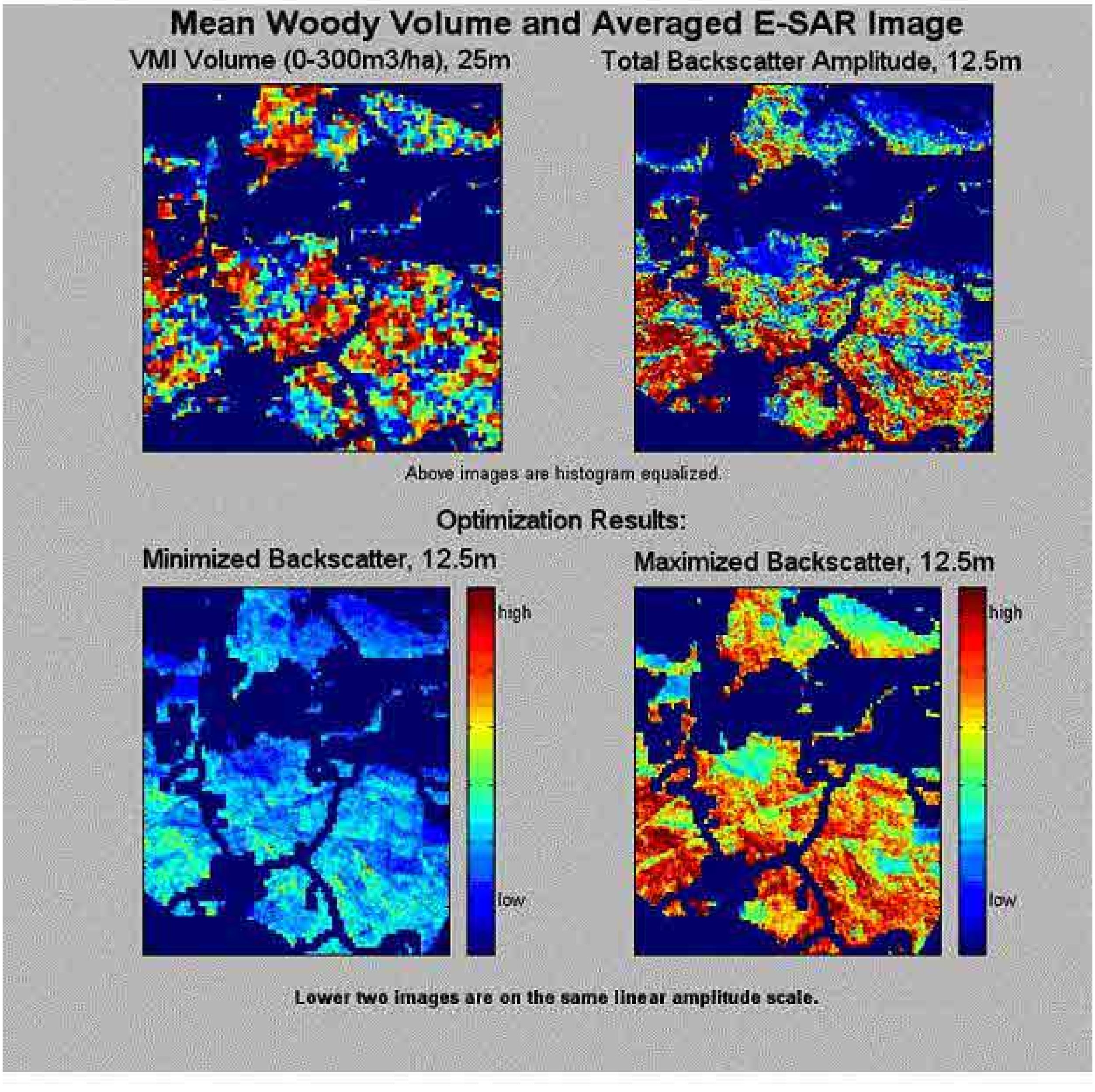

Figure 35. National Forest Inventory volume based on Landsat 7 data compared with total and optimized backscatter at L-band for the Kirkkonummi test site.

A closer examination reveals that backscatter is well described by tree age and pine volume, but not by the total volume (pine and spruce). ESAR data show that the difference between maximized and minimized backscatter may be 10 dB. This means that the feasibility of single-polarization radar for forest inventory is highly dependent on the selected polarization.

Data from E-SAR (L-band) and AIRSAR (P-, L-, and C-band) polarimetric SAR sensors have been used to test the feasibility of eliminating the effect of topography in radar images. Especially the use of three frequencies and multiple polarization optimization by forming ratios of equal frequency bands at optimal polarizations provides good results. It was envisaged that backscatter at some polarizations would depend on slope in such a way that when taking their ratios separately at each frequency, the variations due to the slope could cancel out.

8.10.3 TECHNOLOGICAL ACHIEVEMENTS

As a result of the MODAFOR project, a new and better forest parameter estimation method was developed and put into operative use in multi-source forest inventory.

A practical tool for investigating the polarimetric response of boreal forest was developed by combining the polarimetric backscatter model with a realistic tree growth model. Software were developed and implemented to examine the feasibility of polarimetric decomposition schemes for forest classification.

A new forest coherence modeling-based approach was established for the retrieval of stem volume from space-borne repeat pass interferometric SAR observations. Moreover, a SAR interferometry-based technique for the combined (1) segmentation of homogenous areas, (2) segment-wise land-use classification and (3) stem volume retrieval was successfully demonstrated.

Software was developed and implemented to search for optimum polarizations for radar data enhancement in forest inventory. Electric Field Ratio representation was used and determined to be a better definition for polarization computations than the commonly used Polarization Ellipse. In electric field ratio formalism, the Poincaré sphere reduces onto two-dimensional polarization circle, which is an advantage. A practical Polarimetric Radar Equation pair was derived.

8.11 Assimilation of remote sensing data to physical models in environmental monitoring (ASSIMENVI)

Professor Jouni Pulliainen, Helsinki University of Technology

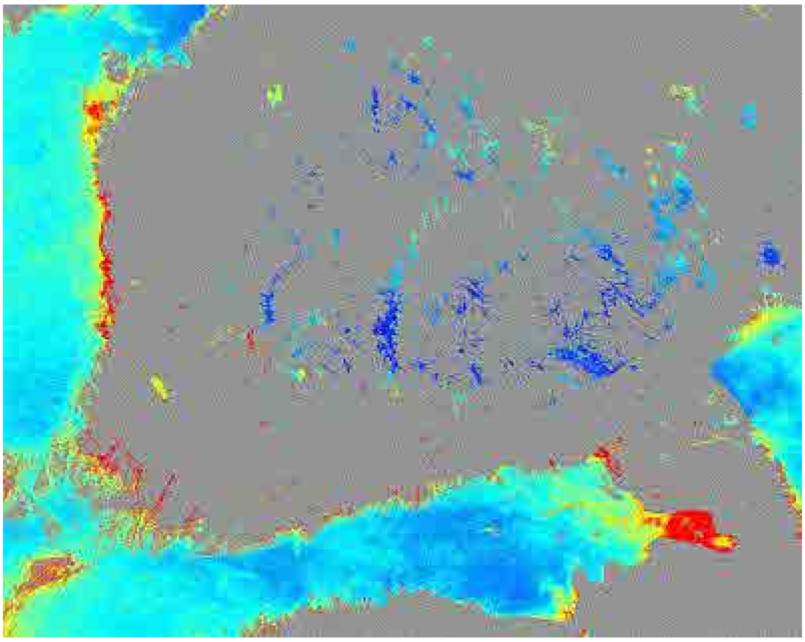

Figure 36. Water turbidity map of Finland and Baltic Sea

8.11.1 GOALS OF THE PROJECT

The objective was to develop novel methods (1) to assimilate remote sensing data to environmental models and (2) to improve the quality of environmental monitoring information by using remote sensing data. Remote sensing can benefit environmental monitoring, modeling and forecasting by providing spatially distributed information. Presently, a fundamental problem with the use of environmental models is the lack of information on the spatial distribution of model parameters and variables. Based on previous investigations, the ASSIMENVI project was focused to two promising fields of application: hydrology and water quality monitoring (Figure 36).

When remote sensing data are combined with environmental models by taking into account the stochastic accuracy characteristics of both information sources, the combination technique can be called as data assimilation. Especially, an important feature in this respect is the consideration of accumulative, with time propagating errors of environmental models. Another important aspect is the combination of spatially distributed remote sensing information with point-wise (or small area/transect-observed) monitoring information.

The overall goal of the project was to develop methods that provide accuracy improvement to present environmental models or monitoring data. Thus, the objective was to develop methods that are feasible for operational use enabling the implementation of new remote sensing-aided environmental forecasting/monitoring products.

The project was specifically interested in linking remote sensing observations with water quality and hydrological models, and monitoring systems that are in operative use or under development at SYKE and PREC. The specific applications were:

- Water quality monitoring and prediction in Finnish lake areas and in the Baltic Sea.
- Hydrological monitoring and forecasting, including runoff monitoring and river discharge forecasting in summer and winter conditions and soil moisture/evapotransipiration estimation under summer conditions.

8.11.2 SCIENTIFIC RESULTS

Up-to-date the most advanced results were obtained in the operational assimilation of satellite data based Snow Covered Area (SCA) estimate to the Finnish national hydrological forecasting system during the spring-melt period. The system assimilating optical satellite data to the conceptual Watershed Simulation and Forecasting System of SYKE was implemented in 2003 covering almost all drainage areas of Finland. The data assimilation was shown to provide a substantial accuracy improvement in river discharge forecasts during the spring melt period, which is highly important for hydropower industry and water management.

The other main result is the development of an assimilation technique that combines data from discrete monitoring stations or transects with remote sensing observations. First papers concerning this technique were published in 2002. This specific technique assimilates discrete *in situ* observations with satellite data by applying spatial data analysis techniques (kriging interpolation) and analytical modelling of satellite observations. The time-series of observations can be also applied resulting to a spatio-temporal assimilation scheme. The technique was first demonstrated in combining SSM/I space-borne microwave radiometer observations with weather station-based snow depth observations at the northern Eurasia (using daily values for the winter of 1993/94). However, the developed technique is also feasible for other applications, such as the monitoring of water temperature or chlorophyll-*a* concentration of water bodies (algae biomass). This was demonstrated for the application of assessing the status of the Baltic Sea.

8.11.2.1 Snow related research

Assimilation of SCA estimate to hydrological Watershed Simulation and Forecasting System of SYKE (WSFS)

The implemented assimilation technique is based on the use of Snow Covered Area (SCA) estimates obtained nowadays operationally at SYKE using optical space-borne remote sensing data (AVHRR and MODIS). The monitoring results during the snowmelt season 2003 were assimilated with the Finnish national hydrological forecasting system in order to obtain best possible forecasts, (see Figure 37). The satellite databased SCA estimation method applies a semi-empirical reflectance model, where reflectance from target area is expressed as a function of apparent forest transmissivity, SCA and three major reflectance contributors (snow, snow-free ground, and forest canopy). The developed assimilation procedure employs information on the accuracy of each SCA-estimate for weighting the different information sources. In case of applying the reflectance model, these weighting values are obtained by applying the standard law of error propagation using empirically gained standard deviations for all parameters of the model. The success of the joint use of remote sensing and hydrological modelling was quantitatively demonstrated for two large drainage basins located in southern and northern Finland. The results obtained using NOAA AVHRR observations indicate that spatial information on SCA can drastically improve the run-off and river discharge forecasting accuracy, particularly at the end of the melting season. In addition to the employment optical space-borne observations, microwave SAR observations have been used for testing the assimilation.

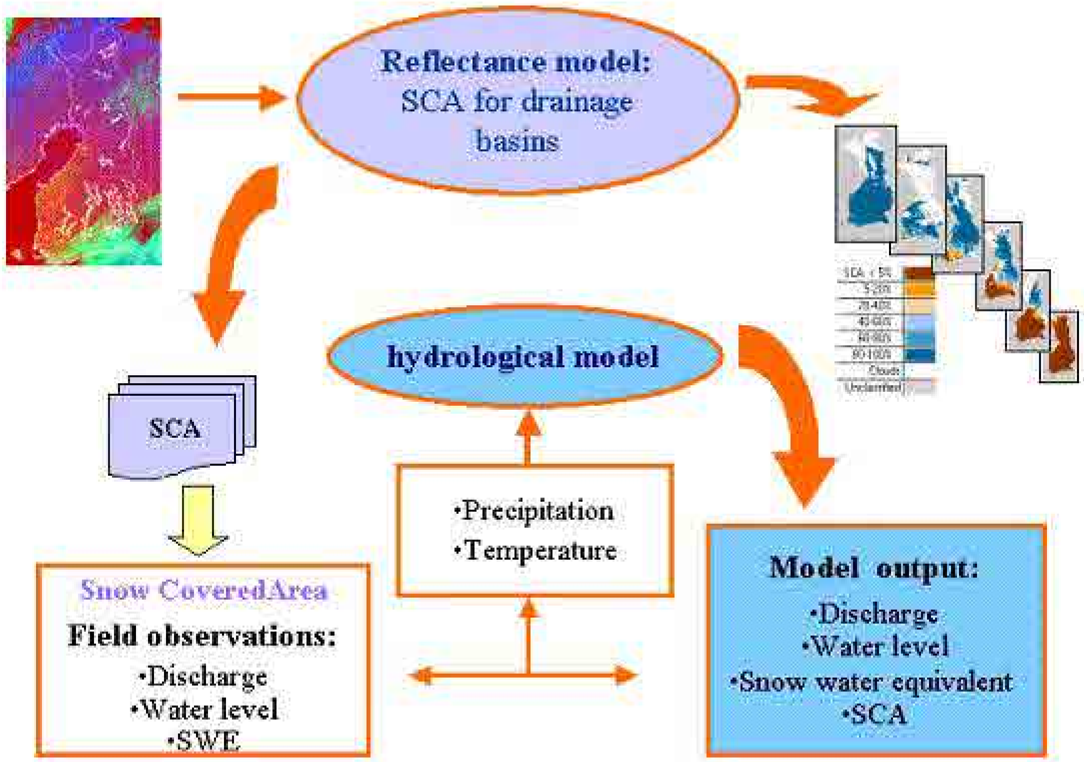

Figure 37. Schematic diagram of the implemented SCA assimilation procedure. The hydrological model is corrected by satellite data observations.

An example of assimilation results is depicted in Figure 38. In this case, daily forecasts for total accumulated discharge of the river Porvoonjoki are illustrated. The initial snow water equivalent was set to be 30% too high on March 15. Four different forecasts were made with four input data sets: 1) only discharge observations (Q) were used, 2) discharge and remotely sensed snow covered area (SCA) were used, 3) discharge and snow water equivalent (SWE) observations were used and 4) all of these (Q, SWE and SCA) were used. In the first case, we can see that the error of the forecast stays high until it decreases rapidly on April 20. In the second case, the model benefits from SCA-information in the end of March indicating the first snowmelt and decreases the forecast error accordingly. In the third case, the use of *in situ* snow water equivalent leads to clear decrease in the forecasting error (this is self-explanatory as in this test, the initial SWE was set too high). In the fourth case the error was still decreased, being very small already 20 days before the end of the period.

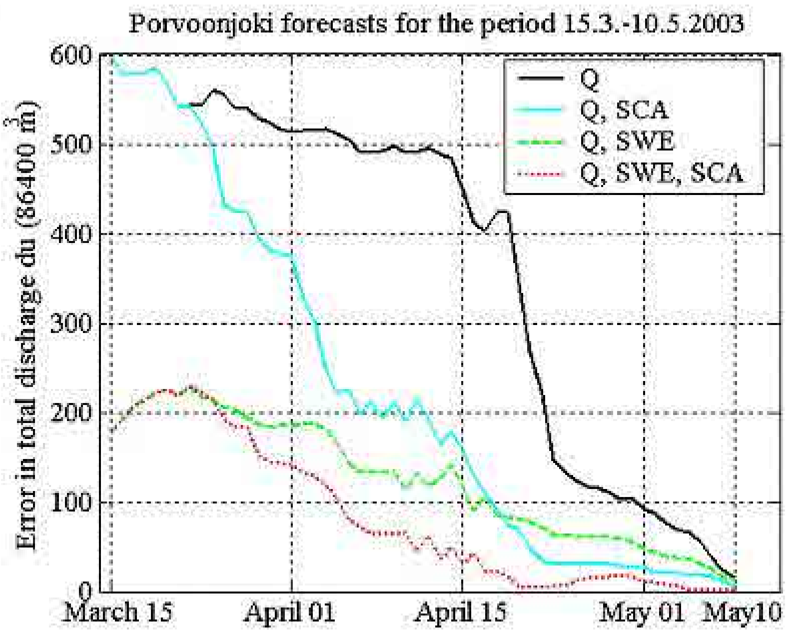

Figure 38. Error in forecasting the total accumulated discharge for the simulation period from the 15th of March to the 10th of May, 2003.

Assimilation of satellite observations to discrete environmental monitoring data

The technique developed in the project assimilates *in situ* observations with satellite data by applying temporal and spatial data analysis techniques (kriging interpolation in the spatial analysis) and analytical modelling of satellite observations. The technique was first demonstrated for combining SSM/I satellite microwave radiometer observations with weather station-based snow depth observations at the northern Eurasia (daily values for the winter of 1993/94). The results indicate that the employment of satellite radiometer data in addition to snow depth observations at weather stations improves the accuracy of assessing the regional or total amount of seasonal snow, which is beneficial for climate monitoring and climate trend analyses. An example on the effect of assimilation is presented in Figure 39 for a single location.

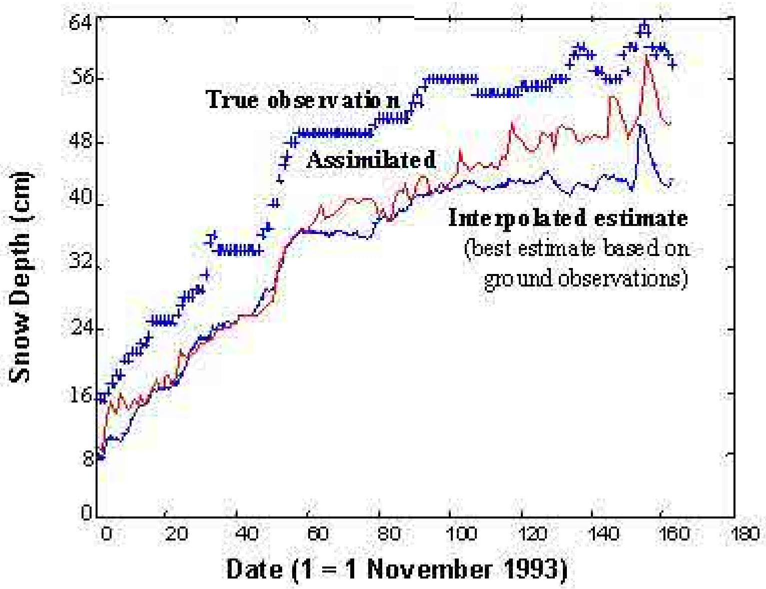

Figure 39. Improvement of snow depth estimation accuracy for a single test station (Siberia) obtained by assimilation of SSM/I data to interpolated snow depth value.

8.11.2.2 Water quality related investigations

Assimilation methodology testing

The developed technique to assimilate discrete monitoring data with satellite observations is as well feasible for other applications than snow mapping. The potential applications include the monitoring of water temperature or chlorophyll concentration of surface water layer. This was demonstrated by introducing a technique that combines space-borne optical spectrometer data (such as SeaWiFS, MODIS or MERIS observations) with *in situ* chlorophyll observations.

Unattended flow-through fluorometers are currently operatively employed in the Baltic Sea by the Finnish Institute of Marine Research (FIMR) to provide information on chlorophyll *a* concentration and distribution. This information is collected on daily basis at merchant and passenger vessels operating at the region (automated Alg@line sampling system of FIMR). The observations can be used for the general assessment of the status of the Baltic Sea, as chlorophyll *a* (chl-*a*) concentration is one of the key factors of water quality. However, the spatial coverage of these ship-of-opportunity data is restricted to transects cruised by vessels. The optimum method to improve the spatial quality of these data is the assimilation of remote sensing observations with transect data (observations of optical spectrometers are highly correlated with chl-*a*). The developed method takes an advantage of the high accuracy of Alg@line transect data together with the full spatial coverage of satellite observations. It is shown that the introduced technique significantly improves the quantitative regional water quality assessment accuracy when compared with the use of (a) only the transect data or (b) only the space-borne data based retrieval algorithms. An example of data assimilation for the Baltic Sea is shown Figure 40.

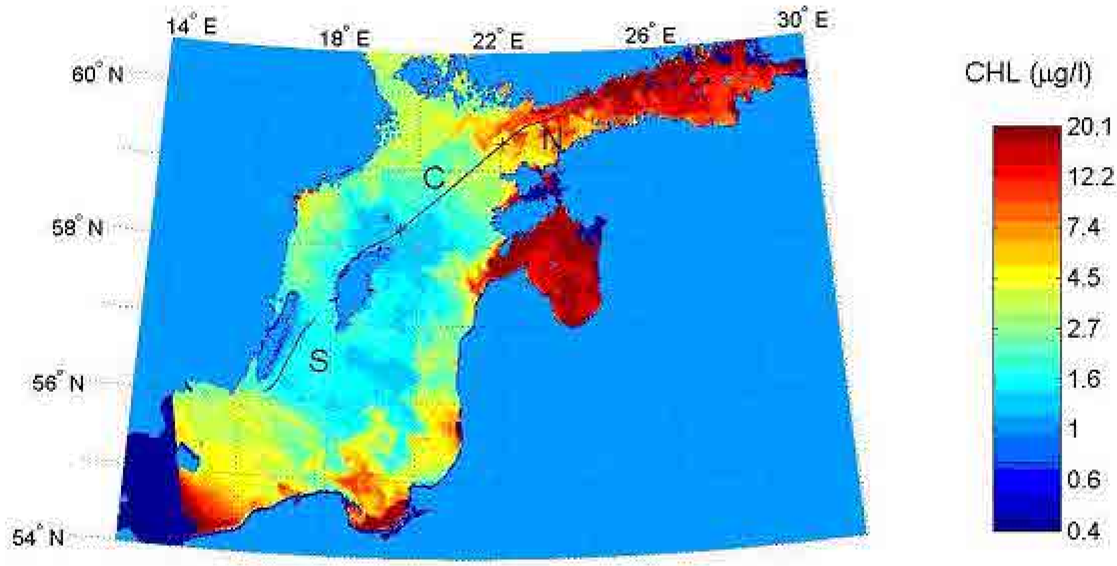

Figure 40. Assimilation of Alg@line transect to SeaWiFS observations in 2000. Chlorophyll *a* concentration is shown in absolute scale (µg/l). The locations of employed Alg@line transect observations are also shown.

Development of remote sensing modelling

The assimilation approach applies empirical modelling of remote sensing observations as a function of chl-*a*. This approach was validated using extensive multi-temporal Alg@line and satellite data sets. An empirical relation for chl-*a* that was based on Alg@line measurements and a channel ratio algorithm for satellite data yield an overall coefficient of determination of 80%. Also, the employment of neural networks was found to be feasible for the mapping of such water quality related characteristics as chl-*a*, turbidity and Secchi depth. Both SeaWiFS and MODIS instruments were applied and they were found to give similar results. Optically the Baltic Sea is characterised by high concentrations of the coloured dissolved organic matter (CDOM) and suspended particulate matter (SPM), which hampers the use of global algorithms for chl-*a* determination. The semi-enclosed, turbid and CDOM-rich Baltic Sea is highly different from oceanic waters for which the global chl-*a* algorithms are basically made for.

In the framework of ASSIMENVI project, an atmospheric modelling/correction method was developed to study the errors caused by the atmosphere. In general, the assimilation of remote sensing data and environmental models requires the quantitative determination of measurement/modelling errors. Atmosphere often causes the bias error to remote sensing data retrieval results, as well as the bias error to assimilated estimates. The determination of bias error is critical for the algorithm functionality as it represents the systematic error. The atmospheric correction method was studied for MODIS data at the water quality monitoring stations located at the coastal area of Finland. The correction method is based on combining a bio-optical model and a statistical, principal component analysis-based (PCA) atmospheric correction model. The bio-optical model describes the reflectance at the top of the water surface according to the water quality measurements (chl-*a*, turbidity and a_{cdom}) at the monitoring stations. The atmospheric correction method models the influence of the atmosphere between the reflectance at the top of the water surface and the reflectance measured by the satellite instrument, i.e. the top-of-atmosphere reflectance. The method was validated using simultaneous visibility observations from the proximate meteorological stations. The results indicate that the joint use of bio-optical model and atmospheric correction model was able to describe the transmissivity of the atmosphere at the measurement time within the limits of the proximate visibility observations. It is thus expected that the use of the atmospheric correction method in water quality algorithm development will give better estimates with smaller bias error.

Bio-optical reflectance modelling was used to calculate subsurface reflectance spectrum from the concentration of optically active substances (suspended solids, chlorophyll *a* and humic substances) from their spectral absorption and backscattering properties. In assimilation, the reflectance model is a link between water quality and remote sensing measurements. During the ASSIMENVI project the bio-optical model was parametrizised and tested separately for lakes and for the Baltic Sea. The estimation of spectral optical properties needed in the model was based on a series of optical measurements carried out in lakes in Southern Finland and in Finnish Lapland as well as in the Gulf of Finland. The developed reflectance model can be used in both forward and inversion mode. The model also enables error analyses (e.g. the effect of optical properties estimation error on reflectance) and to take into account the estimation errors in the assimilation. A combined model including the bio-optical model and the atmospheric modelling discussed above was implemented. This enables the statistical modelling of space-borne observed radiance or top-of-atmosphere reflectance. The work to assimilate the combined model together with a lake water quality model using an extended Kalman filter is currently under progress.

8.11.2.3 Soil hydrology related research

Regarding the soil hydrology investigations in forested areas, the C-band SAR data appears to be complex. It seems to be that the most reliable data are obtained in the areas with minor tree coverage. In densely forested areas, the backscattering coefficient, which reflects the moisture situation, is strongly affected by the foliage or underbrush moisture condition. Relative humidity and precipitation data explained some inconsistencies between satellite data and ground truth measurements but unfortunately not all. The study shows that in peat areas, where tree density is lower and soil moisture variation larger, the ground soil moisture measurements correspond satisfactorily with the satellite soil moisture data. In rocky and densely forested areas the signal of the soil moisture situation is blurred by external noises.

The soil moisture content based on satellite data varied from 10 vol-% to 28.5 vol-% while the average range measured with TDR method varied between 16.4 and 37.5 vol-% in the Rudbäck area. According to the hydrological ASTIM model simulations the smaller the growing stock density, the drier the soil moisture condition is at the end of August (at soil moisture minimum). This behavior was also seen with satellite data obtained from Hyytiälä. Extensive ground truth soil moisture data were also available from Hyytiälä site to affirm this phenomenon. One point decreasing the comparability between satellite and TDR data is the fact that TDR data represents the average moisture condition of the 0.2 m layer from the soil surface while satellite data represents the soil moisture content of 0-0.02 m layer. There might be more diurnal soil moisture variation in the vicinity of the soil surface than what can be observed in the deeper layers.

8.11.3 TECHNOLOGICAL ACHIEVEMENTS

- The developed method assimilating SCA estimates from satellite data to the WSFS model that forecasts river discharges among with other hydrological variables is now in operative use at SYKE. This application has direct impact on hydropower industry, especially in northern Finland.
- The developed method to assimilate discrete or regional *in situ* data with remote sensing data will be published as a commercial software tool in 2004.
- A conceptual system of storing and retrieving Earth observation data, other relevant *in situ* measurements, GIS information on the modelled water bodies, model parameters and derived estimation/assimilation results along with corresponding metadata was developed. The concept includes predefining target areas (water bodies) of a certain area, in this case Finnish lakes and coastal Baltic Sea of the Finnish territory. These defined areas and their combinations are the entities of interest for modelling. The system enables creation and use of different numerical models of these entities, as well as access to relevant in-situ and Earth observation data and entity specific parameter data. The design was realised as a relational database system called as ULAPPA on Microsoft SQL2000 servers. The developed technology was patented during the project, and its commercialisation has been started.

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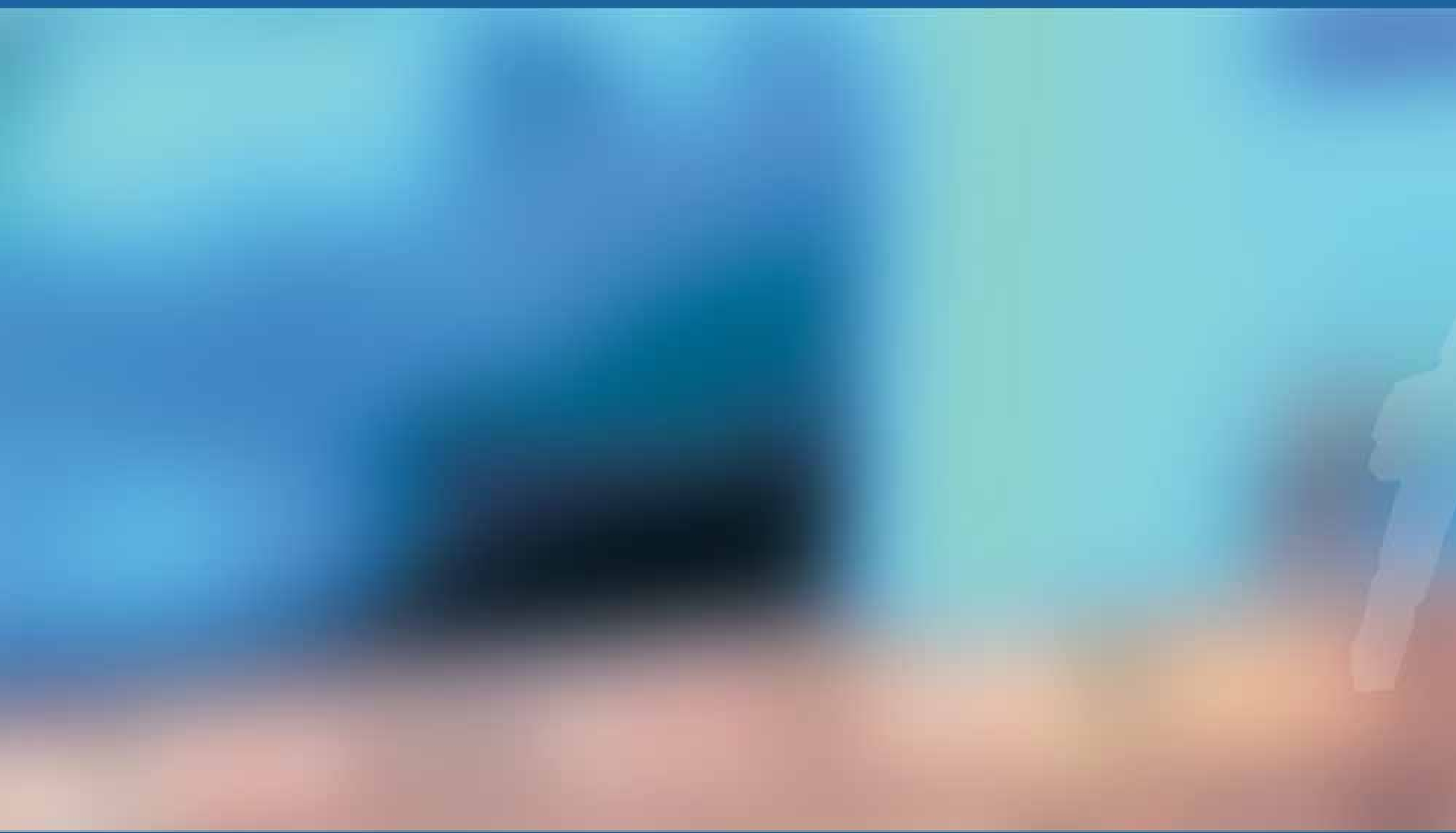
The ANTARES Space Research Programme (2001-2004) consisted of 11 projects utilising more than 50 satellites and 25 Finnish space instruments. The research subjects were astrophysics, space physics, the Sun and the solar system, remote sensing (water, forests), and space instrument technology. The funding for the whole ANTARES programme totalled 16.8 MEUR shared by the Academy of Finland, Tekes and the participating institutes.

The ANTARES programme achieved several new results in astronomy and in space physics, in solar and planetary science, in mm-wave-, X-ray- and SQUID technology and in remote sensing applications of water and forests. This report introduces the highlights of the best results of the programme.



ISBN: 951-715-518-2 (print)
951-715-519-0 (pdf)

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