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Research Programme for Space Research ANTARES 2001-2004

EVALUATION REPORT

ACADEMY OF FINLAND

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Julkaisun nimi	Research Programme for Space Research ANTARES. Evaluation Report.	
Tiivistelmä	Suomen Akatemian hallitus päätti kokouksessaan 21.3.2000 käynnistää kolmivuotisen avaruustutkimusohjelman (ANTARES). ANTARES –ohjelman aihealueet keskittyivät avaruustieteeseen ja ympäristön kaukokartoitukseen. Ohjelma ajoittui vuosille 2001-2004 ja se toteutettiin Suomen Akatemian ja Tekesin yhteisrahoitteisena ohjelmana. Akatemia ja Tekes sopivat alunperin rahoittavansa ohjelmaa samalla rahoitusvolyymillä, mutta Tekesin rahoitusosuus nousi kolmen vuoden aikana yli 10 miljoonaan euroon Akatemian osuuden pysyessä alkuperäisessä 4.6 miljoonassa eurossa. Tekes rahoitti pääasiassa avaruusinstrumenttihankkeita, joiden rahoituksesta noin 90% meni yrityksissä toteutettuun teknologiseen tutkimus- ja kehitystyöhön. Suomen Akatemia nimitti kansainvälisen arviointipaneelin arvioimaan ANTARES -tutkimusohjelmaa. Paneelia pyydettiin arvioimaan ohjelmaa pääasiassa kokonaisuutena ja keskittymään seuraaviin asioihin: tutkimusohjelman tulokset ja vaikutukset, ohjelman toteutus sekä suositukset Suomen Akatemialle ja Tekesille tulevaisuutta varten. Tämä raportti sisältää arviointipaneelin työn tulokset. ANTARES –ohjelmassa on tuotettu runsaasti hyvin dokumentoituja ja julkaistuja tieteellisiä tuloksia, jotka ovat tukeneet suomalaisten tutkijoiden tärkeää ja joissain tapauksissa johtavaa asemaa avaruustutkimuksen alalla. ANTARES –ohjelma oli selkeästi monitieteinen ohjelma, vaikkakin mukana olisi voinut olla enemmän yhteisiä aihealueita. Arviointipaneeliin teki erityisen vaikutuksen tutkimusryhmien, kokeneiden instrumenttien kehittäjien ja teollisuuden välinen läheinen yhteistyö kehityshankkeissa. Arviointipaneeli painotti, että avaruustutkimusyhteisö tulee tarvitsemaan vahvaa tukea myös tulevaisuudessa.	
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Description

Publisher	Academy of Finland	Date: 4 Nov. 2004
Author(s)	Final evaluation panel	
Title	Research Programme for Space Research ANTARES. Evaluation Report.	
Abstract	The board of the Academy of Finland decided on March 21, 2000 to launch a three-year research programme for space research (ANTARES). The focus of the ANTARES programme was on space science, and on scientific environmental remote sensing. The programme was carried out during 2001-2004 and it was jointly executed between the Academy of Finland and Tekes who initially agreed on a 50:50 share of the costs. In view of the high demand on this programme, Tekes raised its contribution to more than 10 million euros whereas the Academy supported it at the level of 4.6 million euros as originally foreseen. Tekes contribution was mainly focused on spacecraft science instrument projects in which 90% of the contribution went to technological research and development that took place mainly in companies. An international Evaluation Panel was appointed by the Academy of Finland to evaluate the ANTARES programme. The panel was asked to assess the programme as a whole with a special focus on the following issues: results, impacts and implementation of the research programme as well as recommendations to the Academy of Finland and Tekes for the future. This publication includes the report of the evaluation panel. The ANTARES programme has created a wealth of well-documented and well-publicised scientific results. This has underpinned the important, and in some cases leading role that Finnish scientists play in the field of space research. The ANTARES programme was without doubt an interdisciplinary programme, though even more topics of common interest could perhaps have been identified. The Evaluation Panel was particularly impressed by the fact that the development work has been carried out in close collaboration between the scientific groups that define the requirements, scientific/technical groups experienced in instrument developments, and the industry that brings the developments to maturity. The Evaluation Panel stressed that a strong support of the space research community will also be needed in the future.	
Key words	space research, space science, remote sensing, research programmes, evaluation, research funding	
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Contents

Preface

The idea of a common space research programme was initiated by the Academy of Finland as early as 1998. The programme was the first research programme planned and funded by the Academy of Finland together with the National Technology Agency (Tekes). The Academy Board decided on **13 June 2000** to appoint a working group to prepare the programme. This working group comprised members from the Academy, Tekes, universities, research institutes and from Finnish industry. The group with nine members was chaired by Professor Risto Pellinen.

On **29 September 2000** the working group issued a call for proposals. The large number of applications received in response to the call greatly exceeded the envisaged funding levels. An international Evaluation Panel with five members, chaired by Professor Bengt Hultqvist, helped to select 11 out of the initial 26 proposals for funding. The Board of the Academy of Finland decided on **13 February 2001** to launch a three-year Research Programme for Space Research, ANTARES, in **March 2001**. The budget to be financed by the Academy of Finland totalled about **4.6 million euros**.

The approved projects represent in a balanced and diversified way a wide spectrum of Finnish activities in space research. They range from the scientific exploitation of satellite and related ground based data, related laboratory and theoretical research, the development and fabrication of equipment and software for scientific instruments for new satellites under construction, to fundamental research and development activities in preparation for future missions. Scientifically, the programme included environmental studies of immediate relevance to our daily life on Earth, studies of the solar-terrestrial relationship, studies of special classes of objects in our Galactic neighbourhood, and it reached out to the most distant objects known in the Universe and questions of the origin of the Universe and its physical content.

An international Evaluation Panel was appointed by the Academy of Finland to review the programme. Members of this panel were Prof. Monique Bernier, INRS – Eau, Terre et Environnement, University of Quebec, Canada; Prof. Michael Grewing, Institut de Radioastronomie Millimetrique (IRAM), St.Martin d'Heres, France; Prof. em. Bengt Hultqvist, Swedish Institute of Space Physics, Kiruna, Sweden; and Dr Kari Leppälä, Provisec Ltd., Finland.

The Evaluation Panel was asked to address the following aspects:

1. Results and impacts

- *What is the scientific quality of the projects and the programme (innovations and significance)? Are there any scientific breakthroughs?*
- *How did the achieved results respond to the original research plans?*
- *Has the research programme increased educational opportunities in space science? Contributions to research training?*
- *Has the programme increased networking?*
- *Has the programme increased awareness and visibility of space science?*

– *Has the programme succeeded in integrating the results?*
– Are there any scientific, social, economic or technological impacts?

2. Implementation of the research programme
– *What is the added value of ANTARES compared to individual projects?*
– *How has the coordination and management of the programme succeeded?*
– *What has been the role of the Programme Steering Group during the course of the research programme? Has its work promoted the objectives of the programme?*
– *To what extent have researchers participated in the joint programme action?*

3. Recommendations for the future
– *How to improve future research programmes?*
– What are the methods to improve research conditions otherwise?
– *What are the greatest shortcomings, problem areas and needs?*

This publication includes the report of the Evaluation Panel. Documentation of the programme and projects is available on the website of the programme at http://akseli.tekes.fi/Resource.phx/tivi/antares/en/index.htx.

St.Martin d'Heres, September 2004,

Michael Grewing
Professor of Astronomy
Chair of the Evaluation Panel

1 The ANTARES Programme

1.1 Background

Finnish space research started early in the 20th century in universities and institutes working on auroral research and astronomy, and later on magnetospheric physics and astrophysics. The advent of Finland as a full-fledged space research nation became possible, when space programmes of the Soviet Union and of the European Space Agency ESA were opened for Finnish scientists in the late 1980s. Cooperation in funding was established on a project-by-project basis by the Academy of Finland and Tekes, and, additionally by universities and research institutes. Two Tekes space technology programmes for the years 1996-2000, the space instrument technology programme Space 2000 (about 12.6 million euros), and the remote sensing programme Globe 2000 (about 6.7 million euros) supported the rapid development of space research in Finland. For the years 1998-2000, the Academy of Finland granted an additional share of more than five million euros for space research performed in ESA projects.

The ANTARES programme for the years 2001-2004 was started with the aim to provide a continuation of the favourable development that began with the help of the preceding programmes and the extra grant in the latter half of the 1990s. ANTARES is the first cooperative programme in this series of special funding efforts. It is jointly executed between the Academy of Finland and Tekes who initially agreed on a 50:50 share of the costs. In view of the high demand on this programme, Tekes raised its contribution to more than 10 million euros whereas the Academy supported it at the level of 4.6 million euros as originally foreseen. Tekes contribution was mainly focused on spacecraft science instrument projects in which 90% of the contribution went to technological research and development that took place mainly in companies.

The ANTARES programme as it was finally executed is the result of a call for proposals to which 26 applications were received. The requests exceeded by far the amount of money available. Consequently, a selection process was carried out by an international Evaluation Panel consisting of Bengt Hultqvist, Sweden, as Chair; Angioletta Coradini, Italy; Jeffrey Linsky, USA; Mikhail Marov, Russia; and Helmut Rott, Austria. Even then some of the approved projects could not be funded fully but had to be cut. The goals of the projects had to be adjusted accordingly.

1.1.1 Objectives

The focus of the ANTARES programme was on space science, and on scientific environmental remote sensing. The objectives were:

- to achieve measurable results in Finnish space research
- to boost it to a higher level than ever
- to ensure the continuation of long-term projects
- to support those projects which are in an active development phase
- to enable the analysis of large data archives

- to enable observations acquired in the current running missions
- to develop new instrument concepts for implementation in the future
- to train researchers for the future needs of Finnish space science
- to increase both national and international networking
- to increase the awareness and visibility of space science

1.1.2 Contents of the programme

The project proposals can be divided into the following six categories according to their orientation and goals:

- International projects in ESA programmes
- Instrument development activities in bilateral and multilateral international research programmes
- Observational programmes that are based on operational or planned satellite missions
- Research programmes utilising space data archives
- Preparation of new space research programmes
- Development of space measurement methods and new technologies

As a result, the following wide range of projects was funded:

1. Planck Surveyor Physics (Planck)
2. High Energy Astrophysics (HESA)
3. Space Based Studies of Dark Matter (Darkstar)
5. Space Weather (SWAP)
6. Cluster II and Miracle (C2M)
7. Dust, Atmospheres and Plasmas in Solar System (DAPSS)
8. Micro- and Mesoscale Atmospheric Phenomena in Mars (MSW)
9. Chemical Aeronomy of the Mesosphere and Ozone in Stratosphere (Chamos)
10. New modelling and Data Analysis for Satellite Based Forest Inventory (Modafor)
11. Assimilation of Remote Sensing Data for Environmental Monitoring (Assimenvi)

1.2 Organization

Within the ANTARES programme, a total of 30 Finnish research groups from six universities and four research institutes collaborated closely. The participants came from 15 different national research institutes.

The universities involved were:

- University of Helsinki (HU), five institutes
- University of Turku (TU), one institute
- University of Joensuu (JoU), one institute
- University of Jyväskylä (JyU), one institute
- University of Oulu (OU), two institutes, and
- Helsinki University of Technology (HUT), one institute

The research institutes involved were:

- MilliLab, Technical Research Centre of Finland (VTT)
- Finnish Meteorological Institute (FMI)
- Finnish Environment Institute (SYKE), and
- Finnish Forest Research Institute (METLA)

The technical development work within the ANTARES programme was actively supported by the research institutes mentioned above, and through industrial partnerships with

- Metorex International
- Patria New Technologies
- Space Systems Finland
- Elektrobit / Ylinen Electronics
- AL Safety Design
- Kemijoki Ltd
- Nanoway Ltd
- Nanocom Ltd, and
- Environics Ltd.
- Suomen optomekaniikka

The execution of the projects listed in Section 1.1.2 implied by their very nature a large number of foreign partnerships in addition to the network that was set up within Finland.

Naturally, the big international space agencies ESA, NASA, RKA were involved, as well as 18 foreign research partners with whom very successful scientific and technical collaboration was established.

The wide range of ambitious projects to be executed, the large number of institutions and individual scientists and engineers involved, and the fact that they were not only distributed across Finland, but that the collaboration extended well throughout Europe and beyond, necessitated a strong and efficient management of the ANTARES programme. We will return to this point in Chapter 3.

2 The Evalution Procedure

The evaluation took place during a three-day meeting in Helsinki on June 10-12, 2004. The first two days were dedicated to discussions with members of the Steering Committee, and representatives from the consortia and individual projects. The discussions focused on what the groups considered to be their main achievements as a result of their participation in the ANTARES programme, and how they intended to continue their research and development work in the future (unless the work had come to a natural end point). On the third day, the Programme Coordinator Professor Väinö Kelhä, was heard by the evaluation panel.

In addition to the information received during the hearings and discussions mentioned above, the members of the Evaluation Panel had received and analyzed the following written information BEFORE the meeting:

1) General information
- List of the projects
- Programme Memorandum
- Final Programme Report
- Annual Programme Reports 2001 and 2002
- Three reports and self-evaluation documents by the Programme Coordinator

2) For each project:
- Applications and research plans
- Final project report (is also included in the Final Programme Report)
- Self-evaluation forms filled in by project and consortium leaders
- Publication lists and 1-8 publications that were considered by the project as the most important ones.

3 General Evaluation

3.1 Scientific quality, innovativeness, and interdisciplinarity

The ANTARES programme has brought together the leading Finnish groups active in space research. As it turned out, there was so much interest in participating in the ANTARES programme that in the end, less than half of the originally proposed projects were accepted for funding, despite the fact that Tekes made more funds available to the programme than was initially planned. The selection process was conducted by an international team of experts. This guaranteed that all the projects that received funding were of the highest scientific and/or technical quality.

Despite the fact that the number of projects had to be drastically reduced, the nature of the projects varied widely. The ANTARES programme included projects that were harvesting scientific data from satellites in orbit, projects that aimed at developing fully innovative new technologies and/or software tools for satellites under development, and technical developments for projects that have not yet been definitely selected but stand a very good chance to be approved in the next couple of years. The Evaluation Panel was particularly impressed by the fact that the development work has been carried out in close collaboration between the scientific groups that define the requirements, scientific/technical groups experienced in instrument developments, and the industry that brings the developments to maturity.

Looking at the scientific output proper from the ANTARES programme, the Evaluation Panel can only commend the groups that have worked in the fields of infrared, optical and high-energy astrophysics for the exciting results they have obtained. Similarly, it commends the groups that have worked on the atmosphere and magnetosphere of the Earth and of Mars, and the groups that aimed at a better understanding of solar-terrestrial phenomena. Finally, the remote sensing groups must be mentioned who successfully developed tools to further improve environmental monitoring techniques by integrating satellite data. The results are directly applicable. In arriving at these very positive statements, the Evaluation Panel has not ignored the fact that several of the ANTARES programme activities have actually started before 2001.

Given the widely different nature of the projects, representing a wide range of scientific interests, the ANTARES programme was without doubt an interdisciplinary programme. All participating groups emphasized in the hearings how much they enjoyed the multi-disciplinary environment, and in a few specific cases, productive cross-fertilization between projects was evident. In looking back, one could imagine that even more topics of common interest could perhaps have been identified. As an example, we mention that nearly all groups seem to have developed data handling and analysis programs. In many cases this is instrument-specific because of the way the instrument has been set up and the way the measurements are conducted, but at least in principle there is potential for generalisations and applications in other experiments.

3.2 Educational aspects

By their nature, space research activities are very attractive for young people. The fact that the projects are normally carried out in close collaboration with industry adds to the academic training an orientation towards application and industrialisation. Industry appreciates scientists, engineers and technicians with the broad range of competences that results from this kind of training.

The numbers of PhD students, B.Sc. and M.Sc. students that have been finishing their thesis work in the context of the ANTARES programme (or will soon do so) is very satisfactory. Their professional profiles obviously vary, and it would require a case-by-case analysis to judge in a more quantitative way the additional professional benefit the students got out of their participation in the ANTARES programme.

In parallel to the academic training of young people, there has been very active public outreach activity. This has been a clear success. Obviously, the Programme Coordinator made this one of his priorities, and he and the individual groups can only be commended for their successful efforts.

3.3 Cooperation inside and outside the ANTARES research programme

Groups from all areas of Finland cooperated in the ANTARES programme. This has brought together scientists, engineers and technicians from small university groups, large, well-established research institutes and industry. In addition, many of these groups form part of larger, international collaborations. The level at which the Finnish groups were able to participate in such joint projects was clearly enhanced by the ANTARES programme funding.

3.4 International networking

Because of its complexity and cost, space research is normally carried out in bilateral or multilateral cooperation. The Finnish groups have very successfully positioned themselves in this context, and their scientific competence, as well as the hard- and software contributions are highly appreciated for their quality and timeliness.

The proof that the Finnish space science community is fully integrated into the European and other international structures is evident when looking at the role of Finnish scientists and engineers as (co-)authors of scientific and technical reports.

3.5 Socio-economic impacts

The ANTARES programme could not have succeeded without the close collaboration between the different partners from academia and from industry, nor without the support from the funding agencies and their advisory structures.

Space research depends very much on technical developments which are, of course, driven by specific research or application interests. The material considered in

the evaluation process as well as the oral presentations were very much focused on these drivers, and did not enter deeply into descriptions of technology related tasks, manpower and funds allocated, and results of product tests and verification. We were informed that these aspects of the ANTARES programme have already been evaluated in the context of a larger review, organised by Tekes in 2003 (Kaupallistaminen ja innovaatiotavoitteet teknologiaohjelmissa, only in Finnish). Nevertheless, we comment on the main features and overall characteristics and on the quality of the technology elements.

Like in the case of many of the scientific projects, the majority of the technology development projects were a continuation from earlier projects. This is understandable when one considers that the life cycles of instruments and technology developments can be very long, especially when new technologies are developed or technologies are pushed to their limits. The duration of the ANTARES programme was in most cases too short as compared to these timescales, but it was the major Finnish technological space effort during the years 2000-2003.

Before giving our comments, a word of caution is, however, needed, because it is not possible, even in theory, to do an accurate evaluation of the efficiency and quality of the performed development work. This is because of the variable maturity of designs, special constraints of space missions, and the fact that entirely new designs and concepts have often been attempted.

As mentioned above, the success of the ANTARES programme, especially that of the technical development projects, depended crucially on the partnership between academia and industry. The industrial structure which is necessary for participation in space activities has several sectors: (1) the ordinary defence/aerospace industry, (2) synergic industries (instruments, automation, telecom, electronics), and (3) companies which provide specialised services and technologies for space projects. In the ANTARES programme, companies from all three sectors have been actively involved: the major aerospace/defence company in Finland, Patria New Technologies, several synergic companies, the most significant contributions being made by Metorex, Elektrobit /Ylinen, Environics and Nanoway. AL Safety Design (PA/QA) and Space Systems Finland provided specific project services and technologies.

The crucial role that some special laboratories and institutes have played in the ANTARES technology development projects must also be mentioned. This applies to VTT MilliLab, VTT Information technology, microelectronic laboratories of the University of Jyväskylä and the University of Joensuu, and the Inorganic laboratory of the University of Helsinki. These laboratories created significant new know-how and provided essential contributions e.g. to the HESA and Planck projects. The mission of these special laboratories has been to create and disseminate new technologies, and thus the impact of the results reaches far beyond the ANTARES programme.

Three of the participating institutes are specialized in environmental research: the Finnish Meteorological Institute (FMI), the Finnish Environment Institute (SYKE), and the Finnish Forest Research Institute (METLA). The ANTARES programme did

not only benefit from their project know-how and their large experience in building equipment (especially in the case of the FMI), but these institutes have also developed application-oriented methods that benefit environmental research by adding data obtained from space (METLA and SYKE).

3.6 Shaping the Finnish Research Area

As stated in an earlier chapter, the ANTARES programme was built on previous programmes. The groups that cooperated in this programme existed before, but they could not have carried out their projects in the same manner without the ANTARES funding.

The fact that the programme fostered collaboration between small university groups, groups at larger research institutions, and small and medium size industry is considered by the Evaluation Panel as a special achievement of the ANTARES programme, and a mechanism should be installed to encourage such collaborations also in the future.

While some of the groups that participated in the ANTARES programme obviously had and have access to other funding sources, other groups depended fully on the funds from the ANTARES programme to re-enforce their manpower by hiring additional staff on a temporary basis. This was essential for the efficient application of existing scientific data and for advancing the technical development work in a timely manner, but it raises, of course, the question how such groups will continue their work in the future. Obviously, not all groups have been equally successful in securing future funds.

3.7 Functioning and coordination

The ANTARES programme's attempt to integrate a wide range of Finnish space research activities into a single programme represented a special challenge and risk. Looking at the result, the Evaluation Panel felt that the goals which had been set out at the beginning of the programme were basically all met.

The participating groups started out each with their own goals and their own culture of doing things. Working together in the ANTARES programme has made these groups conscious of questions asked and techniques applied in other fields. This is a unique experience from which everybody will benefit, in particular the young people who have been involved in the programme.

3.8 Conclusions

The ANTARES programme has created a wealth of well documented and well publicised scientific results. This has underpinned the important, and in some cases leading role that Finnish scientists play in the field of space research. This is a remarkable achievement given that Finland has started its scientific and technical activities in this field relatively late.

Equally impressive work has been done within the ANTARES programme in conceiving, developing, and building hard- and software for space missions. Special know-how has been developed in the following areas:

- microcalorimeter X-ray detector arrays including transition edge sensors and squid amplifiers
- microbolometer arrays for the far infrared (FIR)
- micro-array readout electronics
- hot electron pump microcooler technology
- microtechnology based inductive grid IR filters
- gas electron multiplier detector technology
- TlBr crystal manufacturing technology for hard X-ray detectors
- MMIC low noise mm-wave amplifiers and phase shifters,

and the following technologies can be applied to support instrument developments:

- platform quality on-board computer technology
- lightweight and low-power on board controller technology, including configurable real-time on-board software
- distributed ground support systems based on open source software and commercial hardware.

Furthermore, nearly all groups seem to have developed special data handling and analysis programs

In summary, this is a remarkable outcome of the three-year running period of the ANTARES programme.

4 Statistics

The programme involved a total of well over 100 researchers (professors, senior researchers and junior researchers) and some 70 students (postgraduates and undergraduates). It produced a total of 756 publications (329 refereed journal articles, 105 non-refereed papers, 322 conference presentations) and 319 popular papers, TV and radio interviews, and press releases. It also contributed to the researcher training of 67 students (24 PhD degrees, 43 B.Sc./ M.Sc. degrees).

The following Table shows the breakdown of personnel in the various projects as far as the numbers could be retrieved. The figure in the 'Persons' column includes all the people who were involved in the respective project. 'FTE' stands for 'fulltime equivalents' (=total number of person-years). This figure takes into account that some of the collaborators worked only on a part-time basis within the ANTARES programme.

	Persons	FTEs	Refereed publications
1 Planck	28	39.8	27
2 HESA	25	36.0	64
3 Darkstar	7	~3.3	13
4 ISO+ODIN	11	18.0	59
5 SWAP			26
6 C2M	9+FMI	8.2+FMI	25
7 DAPSS	10	4.5+FMI	28
8 MSW	6	10.2	15
9 Chamos			4
10 Modafor	16		13
11 Assimenvi	14		25
TOTAL	**>>126**	**>>120**	**329**

These numbers demonstrate the great overall success of the ANTARES programme, but some of the groups have performed particularly well. Their productivity has been truly outstanding, even if one takes into account that the ANTARES programme was built on preceding programmes, and some of the results published between 2001 and 2004 could not have been achieved without the earlier activities. That naturally raises the question of continuity to which we shall return later.

5 Individual Evaluations

5.1 Progamme Coordinator

The ANTARES programme was monitored by a seven-member Steering Committee chaired by Professor Jorma Kangas.

The actual coordination of the programme was entrusted to Professor Väinö Kelhä from the Technical Research Centre of Finland (VTT). His task was the central coordination of the set of consortia and the individual projects.

Given the wide range of scientific topics that were included in the ANTARES programme, and the diversity of tools to be applied and/or to be developed for the research in the different fields, the coordination could not have worked without creating a certain common understanding of the motivations, aims and techniques of the different groups, their ambitions and the problems they had to overcome. A comprehensive reporting scheme and the organization of meetings were essential for this. The series of annual scientific seminars and the organization of additional meetings were obviously vital.

The Evaluation Panel considers that the technical coordination of the ANTARES programme was carried out in a professional way. The decision to establish an elaborate web-based information system with descriptions of the programme and the projects, with information notes, lists of publications, minutes of meetings and press releases is to be applauded.

The Evaluation Panel noted in particular the activities that aimed at the national and international visibility of the programme, and of the participating groups. This has been a clear success, as proven by the large number of public outreach events.

The programme's documentation has been comprehensive and informative. Both the annual reports and the final report presented by Professor Kelhä are well written and contain a huge amount of information. They witness the richness of the research and development work carried out within the ANTARES programme.

Understandably, the Programme Coordinator deplored the fact that he was only appointed after the contents of the ANTARES programme had already been defined. It seems that there is indeed room for optimising the interface and the interaction between the Steering Committee and the Programme Coordinator when setting up such ambitious and demanding programmes as the ANTARES programme.

5.2 Evaluation of the Research Projects

In evaluating the individual research projects, the panel compared the originally outlined goals of each project with the results obtained, considered the timeliness of the research and the development work carried out, the value and the perspective of new technical developments, the educational aspects, the wider context, including

the question how the projects will contribute to making Finland a valuable partner in international collaborations, and the future perspectives of each project.

5.2.1 Consortia

Planck Surveyor Physics (PLANCK)

Kari Enqvist, leader of the consortium, University of Helsinki
Kalevi Mattila, University of Helsinki
Jussi Tuovinen, VTT MilliLab
Seppo Urpo, Helsinki University of Technology (HUT)
Esko Valtaoja, University of Turku (TU)

Funding: Academy of Finland 846,000 euros, Tekes 5,131,000 euros, institutes 312,000 euros

The anisotropy of the Cosmic Microwave Background (CMB), i.e. variations in the intensity (temperature) and polarisation, reflect small energy density variations of the universe at the time the CMB was created. These variations are the "seeds of galaxies", from which the present structure (galaxies, galaxy clusters) of the universe emerged. The statistical properties of the variations provide information not only about 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.

ESA has decided to fly the Planck Surveyor Mission which is dedicated to the study of the CMB but will in addition provide an enormous amount of information on the energy distributions of individual objects in the mm- and sub-mm range of the electromagnetic spectrum.

Finland's decision to provide to ESA's Planck mission the 70 GHz receivers of the Low Frequency Instrument (LFI) and to participate strongly in the scientific preparation and exploitation of the Planck mission can only be applauded. The respective instrumental and scientific development efforts form a natural centre of gravity (one of two) inside the ANTARES programme.

As the Planck mission will not be launched before 2007, the project is naturally still at the developing stage, and the aim must be to complete the hard- and software developments on time and within cost limits, and to build up the necessary complement of scientific tools to exploit the mission. The latter task is shared between the participating institutes which pursue the following specific goals:

- The physics of the CMB fluctuations and their cosmological implications will be 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 will be studied by the team members at Metsähovi Radio Observatory of HUT and Tuorla Observatory of TU, which form a single team, and by the team at the Observatory of the University of Helsinki.

The Panel was impressed by the level of maturity of the technical developments, and by the performances achieved which meet the requirements set up by ESA. It noted with satisfaction that the project's responsible leader considered the support he had received and will receive as adequate, and that nothing has been found which could endanger the successful completion of the hardware development.

Similarly, on the scientific side, the competence of the Finnish groups involved in Planck seems excellent, and they are recognized at the international level as important leaders and collaborators in the various fields on which the Planck mission will make an impact.

The Planck project gave rise to 27 scientific papers in refereed journals, to 21 non-refereed publications, and to 34 conference presentations. The project contributed to two PhD and seven BSc and MSc theses. Public outreach included 63 popular articles/presentations, seven press releases, and 13 TV and radio interviews.

Special comments on the technical developments undertaken in the context of the Planck project: The main development activity concerned the 'low frequency' (LFI) 70 GHz channel of the ESA's Planck mission as part of the millimetre wave radiometer of the satellite. This project had started before the ANTARES programme, and it will receive further funding in the future in order to test, qualify and deliver flight hardware. The main effort was provided by VTT MilliLab and Ylinen Ltd, while processing is acquired from a commercial MMIC foundry.

The design task was challenging, as the receiver is partially cryogenic, and the noise specifications are ambitious. The main effort has been to model, design and implement very low noise MMIC components. The fact that the specifications have been met and exceeded and that the complicated project is nearly on schedule is a proof of the high level of engineering skills and technical knowledge.

The impact of the project is two-sided. VTT MilliLab is a highly specialized resource, devoted to research and dissemination of mm-wave technologies, so the benefit will be cumulative. Industrial spin-off occurs via Ylinen Ltd, which is part of a larger company, Elektrobit. They provide instruments, components and technology for the telecommunication industry. There is no direct commercial impact from the LFI components for Planck, but the achieved know-how has a large range of applications, e.g. in radio links and in traffic and automobile control radars.

Conclusion: The Panel found it gratifying to see that the ANTARES programme has helped to bring together all Finnish groups interested in the Planck mission because they have complementary experience and competence. This seems to be the best possible guarantee that Finland will get a full scientific return from the contributions it makes to ESA.

High Energy Astrophysics and Space Astronomy (HESA)

Osmi Vilhu, leader of the consortium, University of Helsinki (HU)
Juhani Huovelin, University of Helsinki
Karri Muinonen, University of Helsinki
Jukka Pekola, University of Jyväskylä (JyU)
Jari Turunen, University of Jyväskylä
Esko Valtaoja, University of Turku (TU)

Funding: Academy of Finland 865,000 euros, Tekes 4,621,000 euros, institutes 335,000 euros

The HESA consortium wanted to pursue two different goals:
1) to carry out fundamental research in high energy astrophysics, and
2) to develop new space instruments or instrument components in continuation of the very successful development programme that Finnish groups in institutes and industry have already carried out.

The fundamental research activities cover a broad range of topics. They comprise solar flare and coronal physics, studies of coronae and flares in other active stars, studies of accretion discs, observations of low-mass binaries, of microquasars with relativistic jets, of Active Galactic Nuclei, and of the afterglow of Gamma-ray burst sources. This is an extremely wide area, but the Finnish groups have been able to make significant contributions to many of these subjects, sometimes being the leading groups in the world. The high annual publication rate results, of course, partially from the network of international collaborations of which the Finnish groups are an important part.

This success did not come about by chance but results from a systematic use of the observing time on a large number of space missions, and also on large ground based facilities, and by setting up effective multi-wavelengths collaborations. The policy, to contribute e.g. to ESA missions' important instrumental components, and/or software, is paying off, and it is strongly recommended that this approach be continued.

For the near future there seems to be no danger because the scientific groups participating in HESA seem to be collecting huge amounts of data from the ongoing missions, but efforts must be made to preserve their scientific strength also in the future.

The new instrument developments are a natural continuation of the successfully implemented projects, through which the consortium has gained an enormous amount of experience. The aim is to utilise the advances in instrument performance, the higher sensitivities provided by bigger telescopes, larger fields-of-view and decreased noise of future missions, like the ESA XEUS projects. In view of the very broad range of instrumental developments that are under way already, and on which we comment below, there is, of course, a question of flight opportunities. It is understandable that the consortium looks to all possible mission proposals like ROEMER/Denmark, Submillimetron/Russia, and AXM/ARGOS-X from MIT/

NASA. The systems under development are: 1) a cryogenic X-ray microcalorimeter array based on superconducting Transition Edge Sensors (TES for XEUS), 2) an infrared bolometer array based on the same technology (e.g for Submillimetron), 3) a 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) In the ROEMER project, the instrument-share will be the detailed design of the Command and Data Handling (CDH) computers.

The HESA project gave rise to 64 scientific papers in refereed journals, to 27 non-refereed publications, and to 60 conference presentations. The project contributed to three PhD and 7 BSc and MSc theses. Public outreach included four popular articles/ presentations, eight press releases, and 20 TV and radio interviews.

Special comments on the technical developments undertaken in the context of the HESA project: This consortium has developed an extraordinarily large number of basic instrument technologies which are at present in different stages of maturity. They relate mostly to the detection of X-rays, and in one case of far infrared radiation. The main development and application activities are carried out by Metorex International, which has both direct and future commercial applications for the detector technology: for rapid chemical analysis, as well as for safety and security applications. VTT Information Technology provides advanced ideas and developments for applying microelectronics and squid technologies in radiation detectors. This expertise is combined with nanotechnology facilities and know-how that exists at the Universities of Jyväskylä and Joensuu. The microelectronic and gas electron multiplier technology is supplemented by a completely different technology that aims at the production of TlBr crystals for hard x-ray detectors.

The technology development work of the consortium is judged to be excellent, and the instrument scenarios are ambitious. Technology development, which has a strong research component, is targeted towards future high sensitivity and high spatial resolution detectors.

The development of new technologies and industrial cooperation had started before the ANTARES programme. It seems to work very well because both sides are highly motivated. Technological spin-offs can be utilised immediately within the commercial product lines of Metorex International.

Patria New Technologies has also participated in the project, the main achievement being the basic design of a new generation of on-board computers. The company's capability to implement platform quality level computers is a supporting element in the Finnish space structure. Such computers have commercial markets in many types of space missions.

From the space science viewpoint, technological capabilities have opened doors to ambitious missions like Integral. If the XEUS mission will be implemented, the consortium will be in a very good position, but the consortium is also looking for alternative flight opportunities for its instruments

Conclusion: The Panel is impressed with how close collaboration has been established between the scientific and the industrial groups participating in the ANTARES programme, and expresses its strong support for the continuation of this collaboration in the future.

Space Weather in the ANTARES Programme (SWAP)

Hannu Koskinen, leader of the consortium, University of Helsinki (HU)
Tuomo Nygren, University of Oulu (OU)
Risto Pirjola, Finnish Meteorological Institute (FMI)
Eino Valtonen, University of Turku (TU)

Funding: Academy of Finland 415,300 euros

The main goal of the SWAP project was to increase the scientific understanding of the entire space weather chain from the surface of the Sun to geomagnetically induced currents in technological systems on ground. The SWAP application identified six main areas where research was planned to be performed using the ANTARES funding. Of these, four areas were retained after the funding had to be cut:

1. *Solar and solar wind drivers of space weather:*
– the main objective was to distinguish the effects in the magnetosphere caused by different types of CMEs, shocks, and fast streams from each other.
2. *Magnetospheric energy budget:*
– the main objective was to clarify the relative roles of different energy dissipation channels and to propose more realistic descriptions of the energy transfer processes and the transport of magnetospheric particles during storms.
3. *Ionospheric tomography:*
– the main objective was to improve the knowledge about the ionospheric variability on time scales from about 15 minutes to hours.
4. *Geomagnetically induced currents:*
– the main objectives were to characterize the ionospheric current systems according to their GIC effectiveness, and to improve warning and forecasting methods.

Space weather-associated research aims at applying the understanding of the physics of the Sun-Earth system in predictions of the conditions in nearby space, and on Earth. All problem areas listed above are very important in this respect. Space weather research is internationally a rapidly expanding field of space research, and the project was therefore very timely.

The Committee considers that the scientific goals were met. While most of the studies used existing data, also a new system for tomographic measurements of the ionospheric dynamics was set up. Unexpected new results were found concerning sporadic-E layers in the polar cap and about the storm conditions originating on the Sun. A new effective method for calculating the intensity of geomagnetically induced currents in power lines and pipelines has the potential of direct applicability to issue advanced warnings.

The SWAP project gave rise to 26 scientific papers in refereed journals, to 11 non-refereed publications, and to 62 conference presentations. The project contributed to three PhD and four BSc and MSc theses. Besides the PhD and MSc students there were four other trainees. Public outreach included five popular articles/presentations, five press releases, and ten TV and radio interviews.

Conclusions: The consortium has shown that it is at the very forefront of international space weather research. The ANTARES programme has been crucial in forming the consortium. This kind of research will certainly continue internationally in the foreseeable future as part of the effort to improve space weather predictions.

CLUSTER II and MIRACLE: Mesoscale Structure of Coupled Solar Wind – Magnetosphere – Ionosphere System (C2M)

Kalevi Mursula, leader of the consortium, University of Oulu (OU)
Tuija Pulkkinen, Finnish Meteorological Institute (FMI)

Funding: Academy of Finland 567,100 euros

The central goal of the C2M project was the scientific analysis of simultaneous observations from the Cluster-2 mission 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.

Cluster-2 is the major European space-plasma physics mission delivering data since about the start of the ANTARES project, so the project was very timely. It represents the major part of the use of Cluster-2 scientific data by Finnish scientists during this period. The MIRACLE network of ground-based instruments is one of the best in the world and makes excellent use of the high latitude of northern Finland which is crucial for magnetospheric research.

The Committee considers that the project goals were fully met. Just to quote a few examples of particularly interesting results we mention that it has been possible for the first time to determine the extent of the region in the inner tail of the magnetosphere where the ultra-low frequency electromagnetic ion-cyclotron waves are produced. Also, it was demonstrated that the high-energy particles occurring frequently in the polar cusps of the magnetosphere are not accelerated to their high energies in the cusp-region, as earlier believed, but are coming from the nightside on magnetic field lines which are opened up by reconnection on the dayside.

The C2M project gave rise to 24 scientific papers in refereed journals, to fournon-refereed publications, and to 39 conference presentations. The project contributed to seven BSc and MSc theses. Public outreach included 15 popular articles/presentations, four press releases, and five TV and radio interviews.

Conclusions: The consortium has done excellent work so far. The ground has been prepared for further extensive studies with the continued use of the unique combination of data bases. The ANTARES programme has helped to form the consortium. It is important that the Cluster-2 data are exploited further in the next several years.

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

Esa Kallio, leader of the consortium, Finnish Meteorological Institute (FMI)
Kalevi Mursula, University of Oulu (OU)

Funding: Academy of Finland 461,300 euros, Tekes 206,600 euros, institutes 206,600 euros

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

Within the ANTARES programme, this consortium has mainly continued a number of ongoing projects which involve the development of instruments accepted for several international space projects. These will be launched in the coming few years. In addition, some scientific investigations based on available data have been carried out.

The FMI is recognised as a reliable and very much appreciated partner in several international hardware consortia. The hardware developments are accompanied by substantial modelling work, which will be needed to analyse the measurements when the data come in. The Committee noted with satisfaction the advanced state of software tools.

Among the most interesting results from the scientific studies which have been made, the discovery of a north-south asymmetry around the solar equator at solar minimum and an associated southward shift of the heliospheric current sheet merits special mention. The consortium has also investigated short-period (1-2 years) fluctuations in the solar wind and IMF related to variations in the solar dynamo. The goals of the project have been met.

The DAPSS project gave rise to 28 scientific papers in refereed journals, to five non-refereed publications, and to 42 conference presentations. The project contributed to one PhD thesis and four BSc and MSc theses. Public outreach included 16 popular articles/presentations, five press releases, and ten TV and radio interviews.

Special comments on the technical developments undertaken in the context of the DAPSS project: The consortium has developed a surprisingly large number of technical components for various space instruments and for testing

and ground support purposes. These developments are a continuation from earlier projects. The delivered elements are basically designed by FMI, with the help of hardware implementation services from Environics Ltd.

Perhaps technically the most interesting developments are the FPGA based, low power, low weight instrument controllers, and their configurable multi-thread real-time operating system. The design combines innovative aspects with economic implementation, although the interviewed persons could not comment on the originality and IPR rights. The EGSE units reflect established engineering, while the commercial hardware and open source software base provide the benefit of affordable costs for scientific groups who want to utilise them to test and control instruments.

The long-term continuity of FMI's technology development has created a kind of product line for instrument controllers and EGSE equipment – the team seems to be most cost-efficient in this field. This capability has an important effect in supporting FMI's space activities, and clearly opens the doors for participation in future space missions. Outside the space science community, there seem to be limited spin-offs for these developments. The developed instrument controllers are in sharp contrast with the mainstream computer technology which is getting more and more complex, but is also facing reliability problems. This may raise the interest in a compact and highly reliable technology. However, within the consortium there seems to be natural paths towards spin-offs.

Conclusions: This consortium is the main Finnish component within the European solar system space science programme, and, as mentioned already, very much appreciated by its international partners because of its proven capability to develop advanced instrumentation and software of highest quality. The competence of the scientists involved is very high. However, there is room for improvement in the balance between hardware and scientific analysis work. This is one of the reasons why the project needs continuous support for several more years in order to meet international obligations, but also to harvest the science from many years of preparatory work.

Micro- and Mesoscale Atmospheric Phenomena in Mars (MSW)

Hannu Savijärvi, leader of the consortium, University of Helsinki (HU)
Markku Kulmala, University of Helsinki
Tero Siili, Finnish Meteorological Institute (FMI)

Funding: Academy of Finland 509,400 euros

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.

This meteorological modelling project was timely with many Mars missions ongoing and several more being planned or discussed: Mars Express (launched in 2003) with the Beagle 2 lander, and the Netlander and the MarsNet as project proposals.

A 3-dimensional Mars Limited Area Model (MLAM) was developed based on the European numerical weather prediction model HIRLAM (High-Resolution Limited Area Model) which is in use by the Finnish Meteorological Institute (FMI). Also, 1-D and 2-D new models have been developed by the University of Helsinki. Several Martian meso-scale phenomena, like wind-patterns, have then been studied with the 2- and 3-D models. The 1-D model has been used for a very detailed study of the boundary layer and its mechanisms in the Mars Pathfinder site, together with the newest in-situ observations. They have also shown to be useful tools in analyzing landing phase safety and feasibility issues.

The university researchers worked closely with the Mars Mission related personal of FMI. Fourteen joint FMI/university publications were produced, as well as six refereed papers, nine conference papers, two non-refereed papers, and eight popular articles or presentations. The project contributed to two BSc theses and one MSc thesis. One PhD and one DSc (Tech) thesis are expected to be finished in 2004. Public outreach included eight popular articles/presentations, three press releases, and six TV and radio interviews.

Conclusions: The meso-scale models could be used for the planning of meteorological instruments, and to estimate the risks (or safety) for future landing mission on Mars. Unfortunately, the continuation of this project has not been funded by the Academy of Finland in 2004. The consortium is dissolving.

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

Lasse Holmström, leader of the consortium, University of Helsinki (HU)
Martti Hallikainen, Helsinki University of Technology (HUT)
Erkki Tomppo, Finnish Forest Research Institute (METLA)

Funding: Academy of Finland 365,300 euros

The aim was to advance the satellite based radar technology, statistical data analysis and mathematical modelling of electromagnetic scattering which all bear on problems of forest inventory activities. The strategy to achieve this has been to combine new data collection technologies with modern techniques of mathematical and statistical modelling.

Most of the goals of the project have been achieved but the research activities will continue during 2004. The results obtained so far included contributions to mathematical and statistical modelling and radar signal analysis and pertain to practical aspects of forest inventory. Specifically, new approaches to multiple-sources forest inventory techniques have been explored, and their further development continues at the National Forest Inventory of Finland (NFI). A tree growth model was

combined with a new polarimetric backscatter model and a new forest coherence modelling-based approach was established for the retrieval of stem volume from space-borne repeat pass interferometric SAR data. An SAR interferometry-based technique for the segmentation of homogenous areas, land use classification and stem volume retrieval was also successfully demonstrated. Finally, polarisation optimisation methods were developed to enhance the contrast between land use classes and to eliminate the effect of topography. By acquiring additional funding from other sources, and with the help of researchers not directly funded within the project, it has been possible to cover a wide spectrum of topics, and to open up several new directions of research.

This MODAFOR project was an active and fruitful collaboration between the three partners of the consortium: the Rolf Nevanlinna Institute (RNI), the National Forest Inventory of Finland (NFI), and the Laboratory of Space Technology (LST). The expertise of RNI in non-parametric smoothing has been applied to forest estimation tasks provided by NFI. The fully polarimetric scattering simulator designed at RSI was given to LST for validation and testing. Its further development will be a cooperative effort.

The MODAFOR project gave rise to 13 scientific papers in refereed journals, to four non-refereed publications, and to 12 conference presentations. Several PhD theses are underway. Public outreach included nine press releases.

Conclusions: ANTARES helped to bring together researchers with complementary experience, and as a consequence, the consortium has done excellent work. The results obtained so far have an impact on industry already. The output of NFI is utilized by the major Finnish forest industry companies in planning their activities. Also, the interferometry-based method for stem volume retrieval developed by LST gave good results even for fairly small forest stands, which is important in Finland. There seems to be, however, uncertainty as to how much basic research will be funded in the future in connection with remote sensing applications.

Assimilation of Remote Sensing Data to Physical Models in Environmental Monitoring and Forecasting (ASSIMENVI)

Jouni Pulliainen, leader of the consortium, Helsinki University of Technology (HUT)
Yrjö Sucksdorff, Finnish Environmental Institute (SYKE)

Funding: Academy of Finland 192,200 euros, Tekes 151,400 euros, institutes 1,083,000 euros

The objective was to develop novel methods:
(1) to integrate remote sensing data into environmental models, and
(2) to improve the quality of environmental monitoring information by using remote sensing data.

Remote sensing can benefit environmental monitoring, modelling and forecasting by providing spatially distributed information. Based on previous investigations, the

ASSIMENVI project was focused on two promising fields of application: hydrology and water quality monitoring.

Presently, a fundamental problem with the use of environmental models is the lack of information on the spatial distribution of model parameters and variables. It was the goal of the project to improve the accuracy of the environmental models and the quality of the monitoring data. The project was specifically interested in linking remote sensing observations with hydrological modelling and water quality monitoring systems that are currently in use, or under development at the Finnish Environment Institute (SYKE) and the Pirkanmaa Regional Environment Centre (PREC).

Significant progress was made to systematically introduce into the Finnish national hydrological forecasting system satellite data that allow to estimate the Snow Covered Areas (SCA). More specifically, a system that allows to assimilate optical satellite data (AVHRR) to the conceptual Watershed Simulation and Forecasting System (WSFS) was implemented in 2003. This covers almost all drainage areas of Finland managed by SYKE. The integration of the AVHRR data yields a substantial accuracy improvement in river discharge forecasts during the spring melting period. This has a significant economic impact for the hydropower industry, and bears on security issues in water management.

Another area where significant progress has been made concerns techniques that allow the combination of data from discrete monitoring stations (*in situ* measurements of snow parameters) with remote sensing spatial observations like SSM/I data. This specific technique combines *in situ* observations with satellite data by applying spatial data analysis techniques (kriging interpolation) and analytical modelling of satellite observations. Given the fact that the observations represent a time-series, it is possible to use these data in a spatial-temporal assimilation scheme. This technique was also used to combine space-borne optical spectrometer data (such as SeaWIFS, MODIS or MERIS (onboard Envisat)) with *in situ* chlorophyll data measured by flow-through fluorometers currently in operation in the Baltic Sea. The developed method allows to fully benefit from the high accuracy of *in situ* transect data in combination with the large spatial coverage of satellite observations. There are plans to make these software tools available on a commercial basis in 2004.

Another important topic that has been addressed concerns satellite measurements of chlorophyll and the errors that are caused by the atmosphere when sensors are used that operate at visible wavelengths. The aim was to study an atmospheric modelling-correction method. Up to now, the results show that the use of the atmospheric correction method improves the water quality algorithm, giving better estimates with smaller bias error. Also, a reflectance model (bio-optical) was parameterised and tested separately for lakes and for the Baltic Sea. The model also enables error analysis (error on reflectance, errors in the assimilation). Then, a combined model including the reflectance model and the atmospheric model was implemented. The work to assimilate the combined model together with a lake quality model using an extended Kalman filter is still under progress. Finally, a conceptual system of storing and retrieving EO data, *in situ* measurements, GIS information on water

bodies (lakes, Baltic sea), model parameters and derived estimation results along corresponding metadata was developed. The developed technology was patented during the ANTARES programme and the idea is to commercialise it.

The ASSIMENVI project clearly benefited from the close collaboration between HUT and SYKE.

The results from this project have already been published in eight refereed papers, 13 conference papers, and six non-refereed papers. In addition, 26 presentations were given at international conferences. As regards researcher training, seven post-graduate students participated in the ASSIMENVI project, although none of them finished their doctoral thesis before the end of the project. The public outreach included one popular article/presentation, three press releases, and three TV and radio interviews.

Conclusions: For further development of Earth Observation applications in geo/biophysical or climatological modelling or monitoring, the sources of funding seem limited in Finland (the Academy, Tekes, FMI) as well as at the ESA and through the EC. This is worrying, given the importance of the subject.

5.2.2 Individual Projects

Space Based Studies of Dark Matter (DARKSTAR)

Chris Flynn, University of Turku, Tuorla Observatory

Funding: 140,300 euros

The initial focus of the research was to place constraints on the nature of baryonic dark matter in the Milky Way galaxy, both in stellar form and as black holes. 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 to exist; the question is whether or not they exist in sufficient numbers.

This goal was achieved through observations with the Hubble Space Telescope and the ESA Hipparcos satellite. These data show that objects which have been proposed so far, i.e. brown dwarfs, white dwarfs, or black holes are definitely not numerous enough to account for the so called dark matter problem.

Realising that progress in this field will have to await the next generation of space experiments like GAIA and/or the JWST, the group focused on a different but equally exciting question, the enrichment of the material in the Universe in Helium and so called metals (that means in astrophysics all chemical elements heavier than Helium). This enrichment results from the production of Helium in the Big Bang and in stellar interiors where also the heavier elements are synthesized. The research group is now focusing on this field; and has already secured funds from the Academy of Finland to pursue this research even after the closing of the ANTARES programme.

The DARKSTAR project gave rise to 13 scientific papers in refereed journals, to six non-refereed publications, and to six conference presentations. The project contributed to two PhD theses, and to two BSc and MSc theses. Public outreach included three popular articles/presentations, 12 press releases, and three TV and radio interviews.

Conclusions: The project has focused on important astrophysical topics. The results obtained are significant and widely appreciated, not only in the scientific world but among the general public as well.

ISO- and ODIN-Related Research of the Interstellar Medium and Star Formation (ISO ODIN)

Kalevi Mattila, University of Helsinki (HU)

Funding: Academy of Finland 211,400 euros

The goals of the project were in basic science, focusing on the following central problems of today's astronomy:
- the evolution of dust and molecular gas in interstellar clouds;
- the formation of protostars in dense molecular cloud cores;
- radiative transfer and magnetohydrodynamic (MHD) modelling of interstellar clouds; and
- star formation history and dust emission at high redshifts

This is a very ambitious but very timely set of goals. All these subjects are in the focus of current astrophysical research, as far as both observational studies and theoretical model developments are concerned. Dr Mattila and Dr Harju have been very successful, together with their collaborators, to make substantial contributions to the field by studying molecular clouds that contain pre-protostellar and young stellar objects. Not only did they make excellent use of their access to unique data from the ISO and ODIN satellites, but they also applied successfully a number of diagnostic tools that reveal details of the physical and chemical processes that are important in dense molecular clouds.

It is well known that the study of the star formation process (and the formation of planets with the stars) is in every respect extremely demanding because high spatial resolution multi-wavelength observations are needed to constrain the model parameters. The work on the density distribution in a star forming region is a very good example of an important contribution from the University of Helsinki group.

This Helsinki group masters, like very few others, a variety of observing techniques and has also done successful work on theoretical tools, like the MHD and radiative transfer modelling. Given the limited size of the team, the turnout is truly remarkable, and compared to the amount of funding received in the ANTARES programme, outstanding.

The ISO-ODIN project gave rise to 59 scientific papers in refereed journals, to 17 non-refereed publications, and to 17 conference presentations. The project contributed to one PhD and one BSc or MSc thesis. Public outreach included four popular articles/ presentations, five press releases, and five TV and radio interviews.

Conclusions: The Panel urges that adequate funds be given to this group also in the future. The work that Dr Mattila and his group have started to do on external galaxies, including dusty star forming galaxies, will become of paramount importance a few years from now, when next generation instruments like the JWST and ALMA will start operating.

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

Esa Turunen, University of Oulu, Sodankylä Geophysical Observatory

Funding: 55,800 euros

The goal of this project was to study the effects of energetic particle events on the chemistry and composition of the middle atmosphere. More specifically, the aim was 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. The analysis was made by using a detailed chemical model of the atmosphere and data from the European space mission Envisat-1 and the Scandinavian satellite Odin, as well as other available space and ground-based data. Of special interest was the role of ion chemistry in relation the concentration of neutral constituents, in particular nitric oxide which affects ozone in the mesosphere and upper stratosphere.

The theoretical modelling tool, a detailed coupled ion and neutral chemistry model (Sodankylä Ion Chemistry model), was successfully developed further in order to obtain quantitative estimates of neutral composition changes for both proton and electron precipitation cases. These estimations show the importance of the ion-chemical processes for the variation of the concentration of neutral constituents. The role of negative ions in mesospheric and upper stratospheric ozone destruction is a new result. Due to a delay in the availability of satellite data, the first experimental data on the decrease of ozone during a solar proton event was presented only in 2003. The event under study was the November 2001 solar proton event and the instrument providing the data was the OSIRIS instrument onboard the Scandinavian satellite Odin. Major results concerning the analysis of data from the GOMOS instrument onboard the Envisat satellite are expected for 2004.

During the ANTARES funding period, a new collaboration started with one UK institute and the team was invited to join the European Research Training Programme (CAL) coordinated by the Danish Space Research Institute.

So far, the CHAMOS project has given rise to four scientific papers in refereed journals, to two non-refereed publications, and to one conference presentation. The

project contributed to one PhD thesis and two BSc/MSc theses. One press release has been issued, and 30 TV and radio interviews have contributed to the public outreach.

Conclusions: The project addressed an important and timely question. Because of the late arrival of crucial satellite data, the full application of the tools that have been developed is still to come.

6 General Recommendations to the Academy of Finland and Tekes

1. Many areas of present-day forefront research depend crucially on experiments that can only be carried out in space. Finland's decision to join other nations in their efforts to develop a space infrastructure and to carry out space research has given Finnish scientists and engineers the possibility to actively participate in this endeavour.

   The ANTARES programme has provided means to strengthen these activities and to form a space research community that works towards the same general goals despite its diversity of interests and the different roles that the partners from academia, large institutes and industry naturally have to play.

   Strong support of the space research community will also be needed in the future.

2. It has been a strength of the ANTARES programme that it allowed to integrate groups from all parts of Finland, coming from academia, Government research institutes and industry.

   Any future programme for space science should maintain this characteristic.

3. Space research is a motor for new technical developments. The ANTARES programme provides many excellent examples where close collaborations have been established between scientific groups, big research institutes, and small and medium size industry. This has been extremely fruitful.

   After the programme has ended, a mechanism seems to be lacking that could achieve the same kind of coordination and cross-fertilisation that the ANTARES programme generated.

   Collaborations like those established for the ANTARES programme should be continued.

4. The Evaluation Panel considers that coordinated efforts between the Academy of Finland and Tekes, like those made for the ANTARES programme, could produce similarly positive results also in other fields of science that crucially depend on advanced technologies.

   The coordinated support that the Academy of Finland and Tekes provided to the ANTARES programme could serve as a model for the support of other fields in which scientific progress and advanced technologies are closely coupled.

5. The ANTARES programme has done very well in supporting both the scientific exploitation of satellites in orbit AND the preparation of new missions. Maintaining a healthy balance between manpower and money available for hard- and software developments, and manpower and money available for the scientific exploitation of space missions is extremely important and requires high-level oversight and management. The fact that Tekes decided to adjust its contribution to ANTARES by doubling it as compared to the initial 50:50 agreement with the Academy can only be applauded.

   A mechanism should be implemented to establish a healthy balance between the exploitation of existing facilities, contributions to projects under development, and the preparation of new missions also in the future.

6. The ANTARES programme has been very successful in publicising the scientific and technical results obtained. Space science has a natural potential to gain wide public attention.

   The methods and contacts that have been established to publicise scientific and technical results should be used also in the future.

7. By developing high technology components (detectors/sensors, electronics, software), Finland has positioned itself as a very much appreciated and reliable international partner. This holds for individual scientists, for scientific institutes, and for Finnish industry. This position should not only be defended but expanded in the future. Given the long timescales involved, this requires a long-term plan for space science and the corresponding commitment of adequate funds.

   Projects in space research are indeed characterised by a long duration, high costs, and the need for international collaboration. In looking at who have been the actors to set up, review, finance and manage the four-year ANTARES programme, i.e. the Academy, Tekes, individual universities, and existing advisory bodies, it appears to the Evaluation Panel that something is missing to adequately deal with the specific requirements of space activities.

   The framework in which the ANTARES programme has been set up may be totally adequate for other fields of science where programmes of limited duration can create a major impact by starting up or accelerating research and development activities in certain areas, but the needs in the field of space research go beyond this.

   These needs result from the fact that Finland's participation in big international programmes, like the ESA Science Programme, requires a strong and stable national programme to fully benefit from the international effort. This in turn requires the availability of funds at a level that is some reasonable fraction of the contribution to ESA, and that can be firmly counted upon when defining scientific and technical priorities that correspond to the aspirations of Finnish scientists and engineers and the long-term goals of the institutes and companies to whom they belong.

The Evaluation Panel therefore recommends the creation of a "Space Science Board" that would report directly to the Government body that has the responsibility and the power to decide on the Finnish space programme and to allocate the necessary funds. If this responsibility and power are delegated by the Government to any other authority, the "Space Science Board" should directly report to this authority.

All communities with interest in active participation in space research should be represented in the "Space Science Board". This body should be charged with the definition of a long-term strategy and funding concept, and with monitoring its execution. The basis for its recommendations should be scientific excellence, technological interest, and strategic importance.

8. The evaluation of the ANTARES programme was very much science oriented. The written material provided to the Evaluation Panel as well as the hearings were focussed on scientific results and their publication. Details on the technical achievements were by comparison relatively scarce.

   If similar future evaluations are planned, it may be worth considering the possibility to provide similarly detailed technical information. Research papers related to technology developments had been included in project publications in some cases but undoubtedly more would have been possible and welcome.

The board of the Academy of Finland decided in spring 2000 to launch a three-year research programme for space research (ANTARES). The focus of the ANTARES programme was on space science, and on scientific environmental remote sensing. The programme was carried out during 2001-2004 and it was jointly executed between the Academy of Finland and Tekes.

The international evaluation panel was asked to assess the programme as a whole with a special focus on results, impacts and implementation of the research programme. This report of the international evaluation panel presents the findings and recommendations of the evaluation and also includes recommendations for the future.

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