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EVALUATION OF FINNISH ASTRONOMY

- report of an Evaluation Panel established by the Academy of Finland

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Preface

In December 1999, the Research Council for Natural Sciences and Engineering in the Academy of Finland decided to follow the suggestion by the Finnish Science and Technology Policy Council that Finnish astronomy should be evaluated. Since joining the European Union and European Space Agency (ESA) in 1995, Finland has been systematically participating in projects of European scientific organizations. The beneficiary experience of the ESA membership to Finland's science and space technology has resulted participation in many long-lasting projects such as SOHO, Cluster, Integral, and Rosetta. Meanwhile, the successful cooperation with other Nordic Countries in the Nordic Optical Telescope Scientific Association has shown the capability of Finnish astronomers to operate international observatories. All that experience is important when the possibility of the next step in international organizations is considered; joining the European Southern Observatory (ESO). This very question was the key issue behind this evaluation.

The Research Council set up a local organizing group to prepare the evaluation. This team consisted of professors Pekka Hautojärvi, Risto Pellinen, and Vesa Ruuskanen of the Research Council, and Dr. Vilppu Piirola, director of Nordic Optical Telescope, as a member outside the Academy.

An international team was asked to carry out the evaluation. The members invited were: Dr. Paul Murdin (PPARC, UK, Chairman); Prof. Brian McBreen (University College Dublin, Ireland); Prof. Gianni Tofani (Arcetri Astrophysical Observatory, Italy). Scientific Secretary, Dr. Pentti Pulkkinen of the Academy of Finland acted as the secretary of the group.

In Finland, four institutes in universities of Helsinki, Turku, and Oulu, and Helsinki University of Technology are responsible for research and education in astronomy. These institutes were sent question forms where facts about the scientific publications, research group members, post graduate exams, and significant visits to and from abroad were asked. Moreover, each senior scientist was asked to describe his/her research and its possible connection and benefit with ESO-facilities.

The site visits were arranged in March 6 to 8, 2000. The schedule was as follows:

Monday, Mar 6	University of Oulu
Tuesday, Mar 7	University of Turku
Wednesday, Mar 8	University of Helsinki and Metsähovi Radio Laboratory

This report is a result of the analysis based on the impression the written material and site visits gave to the evaluation team.

Contents

1 *Introduction*

In March 2000 a committee of external experts carried out an evaluation of Finnish astronomy. The evaluation was at the invitation of the Academy of Finland. The Panel members who carried out the evaluation were

- Dr. Paul Murdin, Particle Physics and Astronomy Research Council, UK (chairman)
- Professor Brian McBreen, University College, Dublin, Ireland
- Professor Gianni Tofani, Osservatorio Astrofisico di Arcetri, Italy.

All Panel members are or have been research astronomers. All are active in their national and international astronomical programmes, and between them they have experience in many astronomical organisations, such the European Space Agency, the European Southern Observatory and other large-scale astronomical facilities, as researchers and policy makers, including at government level.

The Panel visited Finland during the week of 6 March 2000. We visited

- the University of Oulu (Monday March 6),
- the Tuorla Observatory near Turku (Tuesday March 7),
- Helsinki Observatory of the University of Helsinki (Wednesday March 8, a.m.) and
- the Helsinki University of Technology's Radio Laboratory at Metsähovi (Wednesday March 8, p.m.).

The Panel was supported by Dr. Pentti Pulkkinen, of the Research Council for Natural Sciences and Engineering of the Academy of Finland, who made the arrangements for the visits and who accompanied the Panel throughout.

Abbreviations and technical astronomical terms used in this Report are defined in a glossary.

2 Astronomy in Finland

2.1 The nature of astronomy and its place in the national agenda

The Panel was charged to evaluate astronomy as distinct from space physics and planetary exploration. This separation is organisational rather than scientific. In our general comments we consider astronomy to include astrophysics, space physics and planetary physics together.

In fact, astronomy is the study (by whatever technique) of everything that is more than about 100 km above the Earth, and the study of the Earth in its entirety as a planet. The aim of astronomy is to understand large-scale natural phenomena. It has the possibility to discover new science through the investigation of astronomical objects. In natural cosmic laboratories, conditions may be far from what can be reproduced in the terrestrial laboratory. Astronomy reveals, for example, general relativistic phenomena associated with binary black holes, radiation formed within mega-tesla magnetic fields, and the properties of dark matter (the unknown material that comprises some 90% of the Universe). All these fields are studied in Finland.

Astronomy is interdisciplinary and draws particularly on areas of

- physics such as
    - spectroscopy,
    - nuclear physics,
    - electromagnetism,
    - thermodynamics,
    - magneto-hydrodynamics,
    - atmospheric physics, etc.

It also draws from

- mathematics, including
  - celestial mechanics,
  - numerical methods and
  - statistics, etc.

It connects with

- geology,
- geophysics, and
- chemistry, etc.

Because astronomy expands the intellectual horizons and addresses fundamental questions of the nature of the Universe and its origins, it attracts young people. The broadening effect of astronomy's interdisciplinary nature is powerful in education. In many countries, therefore, astronomy is seen both as an attractor of students to the hard sciences and as a means to make the physical sciences more palatable.

Astronomy can not be very much an experimental science, and thus is very limited by observational techniques. There is much to study – 10^9 stars in the Galaxy, 10^{12} galaxies in the Universe, perhaps. Not all of these objects are equally interesting, so that theory plays an important role, not only by interpreting observations, but also in guiding astronomers to make significant observations. Finland has astronomy groups that contain both theoreticians and observers in actually and potentially fruitful collaborations, creating science of the highest quality.

Because the objects studied are so distant, astronomers use telescopes to gather radiation from these objects in order to discern their nature. In recent decades, astronomy has changed from a collection of specialists in telescope techniques applicable in one wavelength band (such as optical astronomy or millimetre wave astronomy) to a collection of specialists in astrophysical phenomena (such as active galactic nuclei or the interstellar medium). Modern astronomers work in teams using multi-wavelength studies of the phenomena of interest to elucidate the underlying science – the multi-wavelength approach substitutes in modern astronomy for the ability to change experimental circumstances in the phenomena, as a laboratory physicist would be able to do. Of course, technical specialists in telescope techniques are still necessary, but they are brought together into science-focused research teams to attack the science. Finland has rightly created such research teams, reported on by the present Evaluation Panel, with expertise in optical, millimetre and X-ray astronomy (to name only three of the most prominent wavelength bands), making multi-wavelength observations to discover physics.

Observatories and telescopes may survive up to a century and still be usable for modern science – provided new instrumentation is attached, and the telescope is pointed at the newly interesting places. The antique look of some telescopes, the individual techniques of astronomy and the specialised vocabulary, which often has its roots in historical tradition, together perhaps give astronomy an aura puzzling to physicists – even of quaintness. However, the celestial radiation flux at the Earth is limited and, to make scientific advances, telescopes must work at the limit of modern technology. Astronomy pulls technology development through the design of the optical and other telescopes, their instrumentation and their detectors. Inasmuch as the telescopes (and other equipment) are carried into space, it pulls space technology.

Because astronomy is observational, it develops the skills of data interpretation. These skills include sorting large populations to identify individual significant samples, reducing vast amounts of data to an understandable form, forming simulations of complex interactions, interpreting numerical data and forming conclusions by interpretation of incomplete data, testing the conclusions for consistency against established ideas. In these ways of working, astronomy has much in common with the rest of large-scale science, but perhaps to a greater degree, because of the nature of the subject. Its nearest cousin may be medical physics. In the way it has to interpret situations that may be beyond change, and about which knowledge is incomplete, astronomy is much like real life, for example the business world.

Much astronomical work is carried out through the use of computers, and students are trained as intelligent users of advanced computing systems. Astronomers form an accumulation of intellectual capital in computing, which in some countries has been re-applied to financial forecasting, interpretation of remote sensing data of the Earth (mineral prospecting), and data processing in medicine.

The most advanced astronomical equipment is big, complicated and expensive. It is built and operated by international teams, which may be large. The Cassini space mission to Saturn for example, brought together 4,000 skilled scientists and technologists from 14 countries. The Atacama Large Millimetre Array, ALMA, is proposed as the largest ground-based astronomical facility ever, for which the European contribution will be built through the European Southern Observatory, ESO (for a fuller consideration, see Section 4.1). Costing perhaps $500 million, ALMA will be of comparable scale to Cassini.

To be successful, an astronomer must work as a team member whether in projects this size or smaller, but usually in an international context. Again, in these respects, the practice of astronomy is like business. Indeed, astronomy is already a fully globalised ‘business’ of the sort becoming typical of the modern world, with astronomers and other Big Science physicists having invented and developed the electronic networks (the World Wide Web, STARLINK) by which e-commerce now works.

Sometimes astronomy pulls technology through into spin-off systems, as in the case of the optics facility at Tuorla, which successfully fulfils a mandate of the foundation of the Observatory to maintain such a facility for national and European benefit. ALMA can be expected to provide more than the usual technology pull for an astronomical project, since it consists of areas that are particularly suited to Finland’s capabilities and interests.

Probably, astronomy’s greater value as a national asset in the long term is to develop intellectual capital, both through astronomical education and in industrial delivery. This capital manifests itself in the form of highly trained, strongly motivated, numerate people and a body of knowledge capable of high added-value work for the national economy. The work at Helsinki Observatory on light scattering from the surfaces of planets, and from paper and painted surfaces is an example of this class of activity in action.

The vision of astronomy that is appropriate for Finland is that it should integrate its astronomical activities into a science that is

- forward looking,
- internationally calibrated,
- nationally unified,
- balanced in
  - observation,
  - theory and
  - instrumentation,
- multi-wavelength
- outward looking,
- physics based, and
- modern.

Finland is in broad terms doing the right things to reap the full scientific and national rewards from its recent, current and prospective investments in astronomy.

2.2 Instrumentation

Telescopes have a lifetime that may be 25-50 years, but the equipment and detectors that analyse and record the celestial radiation evolve on much shorter time-scales – perhaps 5-10 years. Because of the large investment that is necessary, and their exotic locations, major telescopes are provided internationally by a central organisation (such as ESO, or the European Space Agency, ESA), which has the capacity for such engineering. But analysis instrumentation for telescopes is smaller and intricate, and uses evolving, cutting-edge technology. For these reasons, often, consortia of small, advanced, national organisations provide instrumentation for telescopes. Such organisations are found in Finland. The participation in instrument building guarantees an intimate association with the data-taking process, and, consequently, a deeper scientific understanding for the astronomers, as well as technological development that can be of national benefit.

Scientists in Finland have the capability to contribute intellectually to such work in optical and radio astronomy instrumentation, and to work with industry in specification, design, fabrication, and software development – indeed the groups of astronomers which we evaluated are all doing so, to a greater or lesser degree.

Although realistically the direct economic benefits may be relatively small, Finnish industry and its universities will benefit indirectly from such collaborations, particularly (as maintained in Section 2.1) in the development of human capital in Finland. The collaborative atmosphere will also enhance the culture of both science and industry, on the one hand developing scientists' interest and participation in technology development of potential economic importance, and on the other hand broadening horizons and deepening intellectual knowledge in industry.

2.3 A perspective on the growth of Finnish astronomy

Bibliometric analysis confirms the self-evident growth in Finnish astronomy and its increasing sophistication and world-standing. Since the opening of the Nordic Optical Telescope (NOT) on La Palma in 1989, the Finnish output of papers in international refereed journals (in astronomy there are not many journals that are not international) has about tripled. (ISI's National Science Indicators, 1999 release, averages for the astrophysics classification). However it still lags the output, say, of Denmark, which is of similar size, and of acknowledged standing in the first rank of astronomical countries.

The number of citations given to a paper is often used as a measure of its impact, and is indicative of its quality, although there are some reservations about this, which it is unproductive for this Report to go into in detail. Because there is a delay between publication and citation, the citation-impact lags any actual changes in quality. A further factor contributing to a lag between investment and demonstrable impact in astrophysics is the long duration of astronomy and space projects. It was only in 1995 that Finland joined ESA and began to develop its access to European space astronomy. But, for example, the instrumental contributions being made in Helsinki to the INTEGRAL mission and in Metsähovi to Planck will not realise their full scientific potential until late in this decade.

On data available in 1999, the citation impact for Finnish astronomy can be said to be increasing rapidly, but the average cannot be shown to be yet comparable with the most advanced astronomical countries. From observation, however, there is no doubt by the Evaluation Panel that there is a substantial body of astronomical papers originating from Finland in the last few years, which are of the highest quality.

At the time of our evaluation, Finland is contemplating joining the European Southern Observatory, ESO. This decision comes at a time of rapid development in Finnish astronomy. If, as we recommend, the decision is positive, we can anticipate further increases in the world standing of astronomy in Finland.

3 Reports on the evaluated institutions

The four institutions provided the Evaluation Panel with descriptions of their work, and with lists and statistics about their staff, students and papers published (see Section 5.1), and with specimen papers. The staff of the institutions made presentations to the Panel during our visits, and we had the opportunity for general and for private discussions. The following reports follow the organisational structures given to us by the institutions, who themselves divided their research work into topics and teams. We follow a general description of the work at each institution (edited from material supplied to us) by an evaluation of each research Group.

3.1 Division of Astronomy, University of Oulu

The Department of Physical Sciences at University of Oulu consists of the four previously separate Departments of Astronomy, Biophysics, Physics and Theoretical Physics, now called Divisions. The activities of the Department are:

- conducting basics research on selected fields in astronomy, biophysics, physics and theoretical physics;
- offering undergraduate teaching for the grades of BSc and MSc, as well as for the teachers' examination within the Degree Programme of Physical Sciences;
- offering postgraduate education and research facilities for the grades of Ph.Lic. and PhD in astronomy, biophysics, physics and theoretical physics; and
- providing elementary physics courses also to students in other degree programmes in the faculty of Science as well as in the Faculty of Technology.

The Division of Astronomy consists of three research Groups: Astrophysics, Dynamics of

Planetary Rings and Galaxies, and Planetology. Work is financed principally by the Academy of Finland and the University.

3.1.1 Astrophysics

The Astrophysics Group led by Prof. Ilkka Tuominen is well-balanced between observational astronomy and the theory of magneto-hydrodynamics. The data has been used on problems related to the surface imaging of stars through the technique of spectroscopic tomography (the technique to deconvolve surface structure from the profile of spectral lines integrated over the rotating, visible surface of the star). Surface structure is related to magnetic activity, internal dynamos inside the stars, etc. As shown in an impressive presentation by Dr. Svetlana Berdyugina, the Group has major new results in relation to the cycles of magnetic field activity in late type stars. This work is particularly noted internationally.

The Group incorporates past experience in instrument production (various CCD cameras and SOFIN) with good expertise at a high level of instrument management, software development etc. It has a proven track record in observational astronomy, making good use of NOT (about one third of the Finnish time). NOT represents the source of a large data-base that has been well exploited by the Group, with a good publication output.

The models of stellar magnetic fields have been developed into magneto-hydrodynamic models of supernova explosions in the interstellar medium, and dynamo models for magnetic field configurations in other types of stars. The work in the effect of magnetic field structure in the interstellar medium, and calculations on how such explosions trigger star formation, could be further improved by access to larger computing power. Since this work seems to be a significant component of the CSC super-computer centre, limited by the amount of computing power available, the Evaluation Panel suggests that some consideration should be given to developing an astronomical connection to and participation in the decision-making process of the Supercomputing Board.

The astrophysics Group has to face the problem of future generation spectroscopy, an observational field where the Group has well-established expertise. There are plans for an upgrade of the SOFIN spectrograph as well as investigations of wireless communication between instruments on the telescope (NOT) and data analysis computers in the control room. If Finland joins ESO, the plan to upgrade SOFIN would have to be reconsidered. The Evaluation Panel suggests that the Group could seek external cooperation to propose and make a second generation instrument for the VLT such as a high resolution spectrometer. In any case, the Group will certainly be able scientifically to exploit ESO membership.

The astrophysics Group exploits the natural interest of several of its members in related astrophysical topics. One member is rightly working to reduce and exploit data on gamma ray bursters gathered while he was at NOT on La Palma. An expert in celestial mechanics provides support for the work on tomography, whose interpretation depends on knowledge of the orbits of the binary stars in which the spotty stars reside. And work on extra-solar planetary orbits has been used as a test for the performance of the spectrograph. The Group leader is skilfully encouraging and exploiting individual small rivers of interest without diluting too much the main streams of research flow of the Group.

3.1.2 Dynamics

Led by Dr. Heikki Salo, the Dynamics Group studies dynamical processes in gravity dominated systems. N-body simulations are used to investigate the processes that occur in natural astronomical situations. The work has a surprising breadth. The scale ranges upwards from planetary rings, in which the particles are rocks perhaps 1 metre in size and the system size is of order 10,000 km. It reaches galaxies where the component particles are stars, or groups of stars, of order $10^6 – 10^{13}$ km in dimension in systems perhaps 10^{18} km in size. The work developed in Oulu from an existing theoretical base associated with Prof. K.A. Hämeen-Anttila founded in the 1970’s and has been taken on to full confrontation with observations. This in turn has provoked further theoretical studies, in a very fruitful cycle. The simulations provide the stimulus to understand not only the relevant celestial mechanics but also gas hydrodynamics, the role and distribution of dark matter, the constitution of galaxies and planets, etc. These simulations involve 10^5-10^7 particles, a very large number, fully competitive in world terms. To be able to carry the simulations out on affordable workstations, the Group has developed special software. The output of the Group is high.

The Group evidently has something unique to offer to international colleagues. It has been able to attract important collaborations and has gained access to outstanding observational data. Its requirements in observational data are not however over-demanding, given access to an appropriately large telescope. The Group is in an excellent position to exploit possible future participation in ESO.

The most pressing need for the Oulu dynamics Group is for continuity in its human resources, particularly at post-doctoral level. We recommend that appropriate attention be given to resolve this issue to ensure the future of this research programme, important to science and to the participation of Finland in ESO.

3.1.3 Planetology

The Planetology Group, led by Prof. Jouko Raitala, has a wide range of interests, including astronomy, geology and geophysics. A large number of publications has resulted, including such topics as lunar tectonics, geology of Venus, martian tectonics and vulcanism, terrestrial impact craters and remote sensing. Much of this work has been possible because of access to data provided by many successful space missions e.g. various Mars missions and the Magellan mission to Venus. Very soon they will have also data from Clementine mission to the Moon. The Group participated in the study of the (as it turned out) unapproved ESA MORO lunar mission and will participate in future lunar initiatives. The scientific work of the small Group is widely spread, and it might benefit from more concentration on fewer topics. The current aims of the Group have turned from Venus to Mars and are correctly targeted at the Mars Netlander mission and, in the future, the expected ESA mission to Mercury. It is appropriate that the Group should focus on these new missions. Its proposed participation in the European graduate school in planetology with Kiel, Pescara and Barcelona is to be welcomed.

An important aspect of the Group concerns the Nordic Regional Planetary Image Facility (NRPIF) that is located in the Astronomy Division of the Department of Physical Sciences. This potentially important facility is based on an Memorandum of Agreement with NASA who provide planetary images and data, along with educational and public information materials while the University of Oulu provides room and equipment to support the archive and the study of the data. The goal of the NRPIF is to serve all who are interested in such data sets, and to support them in their work, including scientists, teachers, students (including school children) and journalists.

The main service area for the facility includes Finland, Scandinavia, Russia and the Baltic countries – it seems that the facility could be more actively used from other Nordic countries than it is. The theoretical work in progress in the planetary physics Group at Helsinki on the scattering properties of solid surfaces like planets may find real data in the NRPIF.

3.1.4 General comments

The Division of Astronomy at Oulu University is part of the Department of Physical Sciences. Other Divisions in the Department include Physics (including Space Physics, and Atomic and Molecular Physics, especially spectroscopy) and Theoretical Physics, all of which have a direct connection with astronomy (and even Biophysics would connect with Astrobiology and the Planetary Physics Group). The Evaluation Panel probed the relationship between the Astronomy Division and the others. We would have expected a synergy between many of these studies and techniques and the Division of Astronomy. Partly this would be because astronomy is a multidisciplinary study and partly because the subject matter of the Space Physics Group is so directly connected with the Astrophysics Group's subject matter. (Magnetospheric physics, ionospheric physics and heliophysics are the studies of the electrical and magnetic environment of the Earth and the Sun, its nearest star. These subjects have some affinity with the study of sunspots and similar phenomena on other stars.) We think there could be more contact and co-operation for the optimum benefit of all sides.

We also probed the extent of the Astronomy Division's participation in undergraduate teaching. Of the 700 students who take Basic Physics about 10% or less take a basic astronomy course. It seems that there is scope to increase the delivery of the astronomy component of the physical and mathematical sciences, and this might improve the integration of the Division in the University.

Although it appears that the Astronomy Division has grown rapidly on a time scale of a decade, it was apparent that the Division regrets the recent loss of two of its positions (the occupant of one of which moved to Tuorla and is well integrated into a new group). The Oulu Astronomy Division needs to develop a strategy that would guarantee its long-term development.

This small astronomy research Division has good people, good productivity and good ideas but is probably too compressed at local level in the environment of the much larger Physics Department. The Division could benefit from specific larger, possibly international, projects.

3.2 Tuorla Observatory, University of Turku

Tuorla Observatory is a national astronomical research institute belonging to the University of Turku. The Observatory is responsible for the astronomy education in the University as well as being a major research centre. Astronomy is identified as one of six areas of strength in the University. There are chairs in astronomy (held at Tuorla), and in Space Research (at Turku). A special task of the Observatory is to co-ordinate and support the research of Finnish astronomers in the Nordic Optical Telescope. It contains the headquarters of NOT and the office of its director Prof. Vilppu Piirola. It contains an optical laboratory and the National Laboratory of Metrology. The Observatory's Board of Directors contains representatives from across Finland. Work at Tuorla Observatory is funded by the Nordic Optical Telescope Scientific Association, by the Academy of Finland, by special projects from the Ministry of Education, and by funding from the University. The Observatory has being growing steadily.

3.2.1 Dark Matter Group

Led by Dr. Chris Flynn, the Group has recently grown by two new members, Hänninen from Oulu and Holmberg from Lund. This Group is focused on the problem of the missing mass in our Galaxy. They pursue different approaches, all based on the use of large amounts of data, mostly from recent space missions (Hubble Space Telescope and Hipparcos).

The Group has excellent international connections with qualified astronomers. The scientific production is good and highly cited, with several recent key findings on the distribution of dark matter in the galactic environment. There is the prospect for the Group to participate in the preparation of GAIA, one of the future ESA Cornerstone missions.

3.2.2 Cosmology in the local galaxy Universe

This Group, led by Prof. Pekka Teerikorpi, has based its activity on a long lasting collaboration with the Meudon and Lyon Observatories to exploit one of the largest samples of galaxies with measured cosmological parameters. The Group's project is oriented toward the determination of the cosmic distance scale, the Hubble constant, and the space distribution of galaxies.

The Group's contribution to the determination of the Hubble constant is one outstanding result. Their future activity looks very well planned, and open to further use of international facilities. The scientific production is very good, with refereed papers in international journals and reviews. The recent addition to the Group of Andrei Berdyugin from Oulu, should improve the Group's capabilities in the use of observational facilities.

3.2.3 Interacting bodies

Prof. Harry Lehto and Prof. Arthur Chernin lead work on gravitational theory, studying the three body problem in which a small intruder body ventures into a binary system. This work has applicability to a wide range of astronomical problems, including problems in the solar system, binary stars and binary black holes. The solar system problems include aspects of chaos theory (see also Section 3.2.9). The theory of binary black holes has been applied to the OJ 287 active galactic nucleus (AGN), whose light curve has been monitored in the OJ-94 project, and may be applicable to other AGNs. The outcome has potentially interesting relevance to general relativity, and gravitational radiation. The connection of the work with jets from stars such as R Aquarii is less convincing. The output of the Group is high and it is well cited.

This work has little direct connection with the issue of Finland's ESO membership, although no doubt interesting connections will emerge for the work if Finland joins. The work is limited by the computing power available, being carried out mostly on 133 MHz PCs. The Group needs faster dedicated PC computing power – the cost is modest, comparable with the cost of a couple of observing trips to La Palma, and producing roughly comparable scientific output, or even more.

3.2.4 Blazars – their variability and their host galaxies

The Group led by senior scientists Dr. Leo Takalo and Dr. Aimo Sillanpaä has one Post Doctoral Fellow and one PhD, and works in close collaboration with other groups at Tuorla and abroad. The Group leads the large international OJ-94 project that monitored the blazar OJ 287. Blazars are a manifestation of active galactic nuclei, and on the basis of its light curve and other data, OJ 287 has been proposed by Tuorla astronomers to be two black holes in a binary. Outbursts in about 1995 were predicted as a result of its orbital characteristics and the source was monitored intensively. During this outstanding project, the best light curve of any extragalactic source was obtained including confirmation of the predicted outbursts.

The observations have been expanded to include other blazars and to participate in multi-wavelength campaigns of TeV gamma ray sources for the HEGRA team. Further expansion will include the MAGIC array on La Palma. The work has considerable long term strategic importance to Finland, since binary black holes, if they do indeed exist, will be a major source of gravitational radiation detected by the ESA-NASA space interferometer, LISA, with its 50 million kilometre arms. This and Prof. Lehto's Group would have an insider position in LISA's scientific work.

The Group is using the NOT in a challenging program to image the host galaxies and near environment of a large sample of blazars and quasars. The sources include the 1 Jy BL Lac objects, and sources in the EGRET and ROSAT-Green Bank (RGB) catalogues. New algorithms have been developed for modelling the host galaxies. Initial results indicate that interactions and mergers are important in the blazar phenomenon. This active Group is also involved in identification of BL Lacertae-type sources in the RGB catalogue. Deep images and polarisation measurements are made on the NOT. They confirm that these RGB sources form a link or continuum between radio-selected and x-ray-selected BL Lacs, helping to limit the unified model of active galactic nuclei.

3.2.5 Active galaxies

The Group is led by Prof. Esko Valtaoja with two senior staff members, three graduate students and external associates from Helsinki University of Technology. There is a close collaboration with the Metsähovi Radio Research Station and close links with other Finnish and foreign groups. The multifrequency observations of active galaxies utilise Metsähovi, SEST and NOT telescopes. This dynamic Group is involved in many international programs using satellites such as Asca, XTE, Compton, and XMM and the global VLBI and millimetre VLBI networks. There is a particular focus on the data available from x-ray and gamma ray satellites. One key area is the relationship between VLBI structural changes and total flux density variations. The Group is wisely preparing for the FIRST/Planck and space interferometry missions. They are associates in the Planck CFI consortium and are currently engaged in programs related to foreground sources which will be surveyed as part of the mission. In combination with collaborators at Metsähovi, they are pioneering efforts to extend ground based VLBI to the mm regime.

3.2.6 Numerical simulation of merging galaxies etc

Led by Tuorla Observatory’s director, Prof. Mauri Valtonen, this small Group carries out simulations of the interaction of galaxies and of populations of smaller bodies in the solar system. The simulations are used, amongst other things, to study how black holes in the centres of galaxies feed and power active galaxies, grow and evolve.

The output of the Group and its impact are both very high indeed, and Prof. Valtonen is currently the most highly cited Finnish astronomer. The work has used NOT and has possible direct connection with important international facilities like XMM and, in the future, ALMA, if Finland joins ESO. The Evaluation Panel would encourage such participation since the interaction of theory and observational astronomy could only enhance what is already extremely high quality work of international standard.

3.2.7 Interacting binary stars

This outstanding body of work concentrates on close binary stars that show X-ray emission and polarised optical radiation due to the interaction of intense (up to mega-tesla) magnetic fields. It has been made possible and brought to international attention through a combination of instrumental expertise (the multichannel polarimeter), access to the NOT and other telescopes awarded on merit, collaboration with internationally prominent groups and coordination with other multi-wavelength data, particularly space observations. Led by Prof. Vilppu Piirola, the Group’s output of highly cited papers is extraordinarily high – it is the third highest cited astronomy group in Finland. This Group is in an excellent position to take advantage of access to ESO, and the large collecting area of the VLT will make it possible to expand the work on interacting stars into new, related fields.

3.2.8 Optics manufacturing and testing

Led by Tapio Korhonen and fulfilling a mandate of the Tuorla Observatory to maintain optics expertise, the small Group (essentially one person and one or two assistants) has developed methods for making and testing large telescope optics over about 20 cm in size, including new technology light-weight silicon carbide optics. These are especially suitable for space projects, and Tuorla has made a test mirror for ESA's FIRST mission. The success of this activity is visible, not in the usual scientific output of refereed publications, but in the optics facility in its cavern, filled with machines, blanks and the hum of machinery grinding away the backlog of orders for optics, amounting to almost a year's production. This facility could play a valuable role in and enhance Finland's participation in ESO. However, since the most important capitalisation of the facility is in human skills and experience, the Observatory, and Finland, will have to come to a strategic decision, succession planning the Group's long term future in the next decade, if it is to flourish after the retirement of Dr. Korhonen.

3.2.9 Celestial mechanics and dynamical astronomy

The Group consists of Prof. Seppo Mikkola and two co-workers. Prof. Mikkola's personal standing in celestial mechanics is high throughout the world. His work on Cruithne as a 'moon' of the Earth was of very high impact, identifying a new kind of 'horseshoe' orbit. His software is relied on widely. His output is high.

As a topic, celestial mechanics itself is a basic, underpinning subject, recently regarded with renewed interest after it was fully realised that its completely deterministic equations of motion give rise to chaotic solutions (work pioneered by Poincaré, in one of the first appearances of the scientific concept of chaos). The Group has a major problem in selling itself and attracting support – the challenge to the Group is further to turn its work to fulfil the needs of fellow scientists who would support its claim to resources. There may be possibilities to seek support in the European Space Agency. In discussion, the Evaluation Panel suggested a study of the design of the large sunshade of the Hubble Space Telescope's successor, the Next Generation Space Telescope, NGST, which may act as a solar sail – it could possibly be a nuisance tending to destabilise the satellite, or, on the contrary, an exploitable manoeuvring aid.

3.2.10 General comments

Tuorla is a long established, highly productive institute of international reputation, associated with the University of Turku. In a certain sense it is surprising that the connection with the University is so strong, given the physical separation. The institute has a number of senior members and its main problem might be succession planning, but the intellectual atmosphere at the observatory is young and vigorous. The Academy and the Observatory's Board of Directors might well feel that they should consider how to develop Tuorla, while carefully maintaining the lead position in Finnish astronomy of its outstanding astronomy groups.

Tuorla is also the location of the NOT's Nordic base, with Prof. Piirola the NOT director. In the opinion of the Evaluation Panel, NOT has moved under Prof. Piirola's leadership from being an excellent telescope, to become a major scientific success. The Finnish community, above all the Nordic countries, has taken a very positive attitude to NOT and reaped the major scientific reward from its participation.

NOT produces about 40 papers per year, compared with the 70-80 papers per year from the comparably sized Isaac Newton Telescope, also on La Palma. NOT's papers, which are often based on long observing programmes, are of excellent quality. About a third of its publications have Finnish authors.

Tuorla's connection with NOT puts it in a powerful position to exploit ESO membership. At the same time, the importance of NOT will change as attention concentrates on ESO. This will require some careful consideration by the Finnish community and Tuorla.

The recent take up by Finland of the Swedish 60-centimetre telescope on La Palma caused some surprise. The Evaluation Panel discussed this issue, in the light of the expected participation by Finland in the telescopes, large and small, of ESO and the readily available access by competition that is already available to Finland for ESO's smaller La Silla telescopes. This telescope should not divert attention away from the main directions of Finland's astronomy programme, whether in technical resources for maintenance and development or in observing resources as a common-user Finnish telescope. The telescope's place in Tuorla's portfolio of facilities is justified, at the appropriate scale, on a project-by-project basis, e.g. for access to the northern-hemisphere sky and for, e.g., the OJ-287 monitoring programme.

3.3 Helsinki Observatory, University of Helsinki

The Observatory at the University of Helsinki is the second largest of the four astronomy research institutes in Finland and is growing. The research groups at the Observatory collaborate actively with groups at other departments of the University (e.g., Theoretical Physics, Mathematics, High-Energy Physics), and with groups at other universities and research institutes (e.g., Helsinki University of Technology, Technical Research Centre of Finland). The Observatory concentrates on research and, besides basic astronomy education, on training researchers. Observational data are obtained using the Metsähovi Radio Telescope, the Nordic Optical Telescope, the Swedish-ESO Submillimetre Telescope, SEST, and other telescopes, as well as satellites, e.g., ROSAT, IUE, EUVE, ISO and HST. The Observatory participates in the space astronomy and astrophysics research programs of ESA, NASA, Sweden, and Russia.

3.3.1 High Energy Astrophysics

The High Energy Astrophysics Group conducts basic research in X-ray and gamma-ray astronomy and develops and constructs hardware for X-ray and gamma-ray space telescopes. The Group consists of three senior members (Prof. Osmi Vilhu, Juhani Huovelin and Pasi Hakala (University of Turku)), three Post Doctoral Fellows, three PhD students and four other students and staff. The Group is developing primarily x-ray instrumentation for three major scientific missions, Spectrum-X-Gamma, INTEGRAL and SMART-1. The participation in ESA missions is an excellent return on Finland's recent investment in ESA membership. The participation includes hardware project management, science data analysis software and preparation of the science programme. Current planning indicates the ESA missions will be launched between 2001 and 2003. Spectrum-X-gamma is a mission of the Russian Space and Aviation Agency and is heavily delayed, possibly until 2007. The Group should make plans to deal with the possible delay, making arrangements to store and maintain the Spectrum-X-Gamma instrumentation, preserve the intellectual capital associated with it, divert people to more productive work, and support international attempts to bring the mission back to a profitable schedule.

The Group has important collaborations with scientific institutes in Europe and USA and plans for participation in future ESA and NASA missions. The instrument development for space projects is long term and the weakness in Finland is that funds are approved on a much shorter term. As a matter of policy, Finland must take a decision to support appropriate exploitation of the scientific return from instrumental contributions of this nature.

The instrumental work is targeted towards the scientific study of the coronae of active stars, the Sun, x-ray binaries, microquasars, clusters of galaxies and radiation processes in the vicinity of black holes. The multiwavelength observations of galactic microquasars are particularly important. The work on Compton radiation has given understanding of the mechanism of jet formation and disk structure under super Eddington conditions (i.e. where the rate of release of gravitational potential energy from accretion produces a luminosity whose radiation pressure strongly interferes with the inflow, creating the outward flowing jets). The Group has a high scientific output and Prof. Vilhu is the second most cited astronomer in Finland.

They are actively involved in preparation of observing programs for the guaranteed times for the INTEGRAL core program that includes repeated mapping of the galactic plane, the cruise phase of SMART-1 and also Spectrum-X-Gamma. This Group should expect a rich scientific return from these future missions.

3.3.2 Interstellar medium and star formation

Prof. Kalevi Mattila is well known in the international community for his outstanding activities on the study of the interstellar medium and star formation. He now leads a Group having a long expertise in multi-wavelength observations and modelling of galactic sources in regions of star formation. In this multi-wavelength approach, the Group has made use of major facilities available to Finnish astronomers, from the Metsähovi Radio Observatory, through SEST (on which the Group takes most of the Finnish time), up to ISO (the Infrared Space Observatory), the most recent relevant ESA mission.

The Group has well defined programs in the area of the study of the initial conditions of the star formation process, with excellent scientific production. They look to be highly qualified for an active participation to future big international projects such as, for space, the ESA missions FIRST and Planck and, on the ground, the ALMA array. The Evaluation Panel found the Group very enthusiastic about the prospect of ESO membership.

3.3.3 Stellar Planetary Astronomy and Planetary Research Groups

Led by the Director, Dr. Karri Muinonen, and Prof. Kari Lumme, the two groups, here considered together because of the obvious affinity of the work, carry out research on the physical characteristics and dynamics of the planets and asteroids, extending the application of its mathematical analysis to late type stars. The work is firmly based on sound theoretical physics, as was evident in the presentations. The work on the deconvolution of asteroid light curves and light scattering from irregular bodies is at the cutting edge of the subject. The work is neatly coordinated and extended to spectroscopic tomography in collaboration with the Oulu Astrophysics Group. The light scattering calculations have applicability, for example applications to the control of active optics by laser guide-star systems, to industry (back-scattering from painted surfaces) and to planetary physics (the nature of reflection from planetary surfaces). The work's interest for planetary exploration has led to participation in the forthcoming SMART-1 lunar survey mission by ESA, and ESA's Mars Express mission. The output of the Group is high, and it has something valuable to offer to international collaborations.

3.3.4 General comments

The Helsinki Observatory is a historic building that stands on a hill at a distance from the main campus of the University. In spite of any immediate and superficial impression that this environment may give, its staff are young, dynamic, positive, outgoing and modern in outlook, and seemed to the Evaluation Panel to be well integrated into the requirements of university life, including teaching and research. The Evaluation Panel is not in a position to say whether the integration could be closer, but the Observatory is discussing a proposal for better integration into the University and would welcome closer ties. The proposal has to be practical, however, and to afford an appropriate level of facilities, such as accommodation. The work of the Observatory is based in traditional astronomy, but is carried out at a modern standard. The output of the Observatory is high, and it is highly regarded internationally. It would be one of the main exploiters of ESO membership, and would be in an excellent position to contribute intellectually to instrument development in collaboration with industry.

3.4 Metsähovi Radio Observatory, Helsinki University of Technology

The Metsähovi Radio Observatory is a research institute of the Helsinki University of Technology. It is energetically and enthusiastically directed by Prof. Seppo Urpo. It operates a 14 m. diameter radio telescope at Metsähovi, Kylmälä, Finland, about 35 km west from the university campus. The institute also has premises in the Electrical Engineering Faculty building, in Espoo. The main users of the station are the Helsinki University of Technology, the University of Helsinki, and the University of Turku. The Metsähovi Radio Observatory has been operational since 1974 and was upgraded in 1992-1994. The surface accuracy of the present telescope is 0.1mm (r.m.s.). The activities at Metsähovi are concentrated on millimetre and microwaves. The used frequencies are 5-120 GHz, the corresponding wavelengths are 6.0 cm-2.5 mm. The research in technology includes development of microwave receivers, development of receiving methods, development of data processing, including electronic equipment for space missions (AMS detector), and development of antenna technology.

The Metsähovi Radio Observatory is active in the following fields:

- Research in radio astronomy
- Development of instruments needed in radio astronomy
- Development of methods for radio astronomical measurements
- Propagation studies of radio waves for satellite communication applications
- Space research and
- Education.

Metsähovi participates in the education given at the Helsinki University of Technology by organising courses and exercises for students and graduate students can study for a licentiate's or doctor's degree at Metsähovi. Around 15 scientists, engineers, research assistants, and supporting personnel from the Helsinki University of Technology work at the institute. In addition about 10 students perform radio astronomical observations under guidance of Metsähovi permanent staff. Support comes from the University and from research projects financed mainly by the Academy of Finland.

3.4.1 Active galaxies – monitoring programme…

The Group led by Dr. Harri Terräsanta conducts long term monitoring of the nuclei of active galaxies (AGN) and makes extensive and excellent use of the radio facilities at the Metsähovi Observatory. This long-term program commenced in 1980 and currently includes 85 sources observed monthly at 22 and 37 GHz. A total of more than 43000 observations have been made. The variable sources are mainly strong, compact, flat-spectrum millimetre-sources. This is a unique and absolutely essential database on radio variability in AGN, and the work is highly cited. In addition to the long-term monitoring, the Group participates in numerous multi-frequency campaigns with space borne telescopes such as RXTE, Asca and EGRET. A new sample will be monitored during the operation of the gamma ray telescopes AGILE and GLAST. The simultaneous observations will be extremely important in elucidating the energy production mechanism in gamma ray AGN. The importance of understanding the variability properties of AGN has important consequences for ESA mission Planck (see Section 3.4.2). The use of the new 90 GHz band will be fully exploited by these programs.

The Group led by Dr. Merja Tornikoski uses the Metsähovi database and also multiwavelength data from the SEST telescope and others to study AGNs. These programs include correlation between the radio and optical outbursts of AGN and the connection between the radio and gamma ray flaring as observed by EGRET. The Group is making excellent use of the SEST telescope to observe southern and near equatorial sources selected as targets for the space-VLBI project VSOP. The combination of space-based and ground-based monitoring gives clear determination, covering the initial flare to the decaying phase. The combination of SEST and VSOP has resulted in several successful proposals for observations with VSOP. The SEST telescope is being used to study giga-hertz peaked sources to determine the contribution they make to the microwave background. This work has important implications for the Planck mission. In collaboration with Esko Valtaoja (now at University of Turku) they are observing compact steep spectrum radio sources using a wide range of facilities (NOT, VLA, MERLIN, VLBI) to determine their relationship to other radio galaxies.

3.4.2 …and the Planck survey

The Evaluation Panel found very interesting the work done at Metsähovi in conjunction with the participation of Finland in the ESA mission Planck. The Planck mission will fly in 2007 and will cover 95% of the entire sky in the mm/sub-mm spectrum with unprecedented resolution and accuracy. The major aim of Planck is a detailed knowledge of the Cosmic Microwave Background (CMB). At the same time the full-sky observation will produce an impressive amount of data on any type of source that appears in the foreground of the CMB, whether of galactic or extragalactic nature. These sources will be interesting in their own right, but also identifying them and being able to remove their effect from the map of the CMB are essential to the determination of the properties of the CMB, and thus to the ultimate aim of the Planck mission.

The activity on Planck in Metsähovi covers two different areas. The first one, more technological, deals with the design of the Low Noise Amplifiers and the Phase Shifters as part of the 'LFI' international consortium. These are critical components of Planck's 70 GHz receiver channel, under the responsibility of several of Finland's institutes (beside Metsähovi, the activity is going on at HUT, Millilab, Ylinen and Tuorla).

The area of astrophysical research to help analyse Planck data, carried out in Metsähovi, is even more interesting. The large data-base of quasar variability, compiled over a long time scale in the monitoring programme at Metsähovi, now represents a basic tool for the unambiguous detection of sources and source variability studies which will be invaluable intellectual capital for the Planck mission. This work could represent a unique foundation stone contributed by Finland to the success of the mission.

3.4.3 Solar research

20% of the observing time at Metsähovi is used to study the Sun, making millimetric observations. These wavelengths come from a region of rapid change of temperature in the solar atmosphere, and have helped identify interesting solar phenomena. Maps of the Sun are available on the internet. This work is often carried out as part of international coordinated campaigns. Given the current interest in ESA's satellite SOHO and the International Solar-Terrestrial Physics programme of which it is a part, this programme is valuable, and could well continue through the next solar maximum. Its long term future should be reconsidered, at the latest at the time ESA decides to discontinue SOHO operations (the mission is currently approved up to 2003).

3.4.4 Water masers

Tarja Liljeström and her collaborators have a dynamic program studying the 22 GHz water maser line that occurs in star forming regions, dense circumstellar shells around evolved stars and the exciting results of water maser emission from circumstellar disks around black holes in AGN. Novel methods are being used to get a better understanding of the physical conditions in the densest shocked regions near proto-stars and nuclei of active galaxies. This work is important for future use of ALMA. Tarja Liljeström is a leading scientist in the submillimetre space satellite ODIN that will be used to detect thermal water in the submillimetre region.

3.4.5 Instrumentation and VLBI

The Metsähovi participation in Planck is considered above. Its continuance is a very high scientific priority. Metsähovi's participation in the European VLBI Network (EVN) at millimetre wavelengths is key to the success of the project. Its participation in space VLBI is exciting for the future, and should bear fruit from a modest investment when the space experiments are successful. In this respect, one should not place too much reliance on the Radioastron project, since the Russian Space and Aviation Agency's space science programme is in disarray. The work on radio receivers is an integral part of the technical capability of the station.

3.4.6 General comments

Metsähovi looks like a scientific establishment: there is work going on at a technical level, there are students observing, and people are discussing data, heads together over a table of papers. The young researchers are keen, and responded to hard questions with enthusiasm, confidence and a scientific perspective that made the Evaluation Panel wish it was collectively twenty or thirty years younger, starting its research involvement again.

The establishment is poised to play a key role in Finland's participation in ALMA, as well as in the ongoing collaborations already set up, especially Planck. Within the resources available (experienced intellectual resources rather than money), participation in ALMA will mean that attention will be turned aside from current programmes to the new. Indeed, the main question which Metsähovi faces is when to terminate the current routine monitoring programmes, both for the Sun and for AGN. The Evaluation Panel is confident that Metsähovi will know what to do when the eventuality arises.

The Radio Observatory is staffed in a 'lean and mean' mode. In fact the Evaluation Panel suggests that the University reassesses its support for the Observatory, and gives consideration as to whether a modest increase in its longer term staffing could help the Observatory maintain its current productive state, while at the same time developing its considerable potential in relation to the forthcoming programmes (Planck and ALMA), which need to be carried through into the 2010 time frame and beyond.

4 General conclusions

4.1 European Southern Observatory

The European Southern Observatory is a treaty level organisation whose Member States are: Belgium, Denmark, France, Germany, Italy, the Netherlands, Portugal, Sweden and Switzerland, sharing the budget in GDP proportion. It operates a headquarters in Garching, Germany and the observatory at La Silla in Chile, which is the largest collection of optical and infrared telescopes in the world, with two 4-metre class telescopes. It is currently completing the Very Large Telescope (VLT) at its other observatory in Paranal. The VLT will consist of four 8-metre telescopes that can work independently, or can be combined into a 16-metre single telescope, or can be supplemented with three auxiliary 1 metre telescopes into an interferometer. Full operation of all VLT telescopes is expected shortly.

ESO will conduct the European participation in the Atacama Large Millimetre Array. ALMA is the name for the merger of several major millimetre array projects into one global project. This will be the largest ground-based astronomy project of the next decade after VLT, and, together with the Next Generation Space Telescope (NGST), is one of the two major new facilities for world astronomy coming into operation, perhaps by the end of the decade.

ALMA will detect and study the earliest and most distant galaxies, the epoch of the first light in the Universe. It will also look deep into the dust-obscured regions where stars are born, to examine the details of star and planet formation. In addition to these two main science drivers the array will make major contributions to virtually all fields of astronomical research.

ALMA will consist of some 64 12-metre sub-millimetre-quality antennas, with baselines extending up to 10 km. Its receivers will cover the range from 70 to 900 GHz. It will be located on the high-altitude (5000m) Zona de Chajnantor in Chile. This is an exceptional site for (sub)millimetre astronomy, possibly unique in the world. The cost of the project has been estimated at US$500M.

The Evaluation Panel paid particular attention to the question of whether Finland should join ESO, but we confine our comments to matters of a scientific and technical nature, omitting any political considerations. ESO is a potent organisation, which runs the most comprehensive collection of optical telescopes in the world, and will soon start the most powerful millimetre wave telescope project ever. All the groups that we visited showed an overwhelming majority (with scarcely any dissension at all) in favour of joining. It was recognised that the scientific benefits were clear. The Evaluation Panel agrees.

We also considered whether Finland is able to exploit its membership. Scientifically, and as a result of its development in the last decade, the Finnish community at all four of the institutes that we visited would certainly be able to benefit. Indeed, if having stepped up to 2.5 metre class optical telescopes or single dish millimetric astronomy, Finland does not keep up with global developments in astronomy, it will automatically fall back and waste the investment of the last years. The only option to participate in facilities of this scale is internationally and ESO is the obvious choice – even the UK, having held back from ESO for so long, has agreed its intention to associate with ESO in ALMA and will possibly join ESO as a full member.

To exploit fully its ESO membership, Finland will have to participate, not only scientifically, but also in technological activities in telescope and instrumental science, for the reasons explained above. Scientists in Tuorla, Oulu, Metsähovi and Helsinki have the capability to contribute intellectually to such work in optical and radio astronomy instrumentation.

It will not be necessary to belong to ESO to participate in the Atacama Large Millimetre Array, ALMA. ALMA is a global project in which many individual states, including the USA, Mexico, Canada and Japan, expect to participate, as well as European states. The UK, Spain and even France have announced their intention to participate in ALMA as European states in an association with ESO, if not as members. But most ESO member states will participate in ALMA through ESO and the ESO mechanisms, and, if Finland joins ESO, it will readily have the possibility to be directly involved in ALMA.

ALMA has industrial aspects that are unusual for an astronomical facility. It consists of 64 telescopes and high-frequency communications systems linked in an array formation to a central correlator of considerable processing power and speed (a specification as yet not attainable). It will thus be procured on the scale of a factory line process, at a scale intermediate between the single item typical of a scientific facility and the perhaps millions of items in a mass-market industrial process. In terms of its technology areas and its scale, ALMA may be particularly well matched to Finland's industrial capabilities. The scientists at the Metsähovi Radio Observatory, the Technical University of Helsinki, University of Turku, etc., are among those in a prime position to be able to participate in the science and technology projects of ALMA.

The Evaluation Panel did not systematically visit instrumentation fabrication facilities in Finland, whether in universities or industry, since this was outside the scope of our remit. Finland will need to consider how to focus its instrumentation-making capabilities in relation to ESO.

There will be an effect of ESO membership on Finland's current facilities. For example, there will be a change of status of the NOT or Metsähovi radio facility when attention is turned to 8-metre telescopes or ALMA, and the development of these facilities may slow down, losing their importance on the time scale of the developments associated with such large projects (at least a five year time scale). Even when we pressed these issues during visits to the groups that would be most affected, the vote in favour of ESO membership was overwhelmingly positive. Finland will however have to consider carefully the role of its existing facilities,

- as training telescopes,
- to give access to both hemispheres, and
- to exploit deep but niche science positions.

Both Metsähovi and NOT are run very economically, however, and, if they are kept operational there could not be major savings in running costs as a result of transfer of attention to ESO. Indeed, since other NOT partners have begun to consider withdrawal from NOT as a result of new astronomical investments, Finland will have to weigh carefully the balance between its continued and even expanded access to NOT and a possible increase in operating costs.

The funding of ESO membership is a serious issue. Not only is there a large entrance fee but even the annual subscription is a large fraction of the money available for astronomy in Finnish universities and institutes where the ESO membership will be exploited. There may be some small savings from an eventual reduction of the development programmes of the existing facilities. But it would certainly not make sense for Finland to participate in ESO as an 'international' organisation if the 'domestic' funding of the intellectual capability in Finland to benefit from ESO membership was, as a consequence, reduced. This means that funding of Finland's membership of ESO would have to be considered mostly as additional to and separate from the funding of the four institutes on this Evaluation.

4.2 National unity of astronomy

In our view, astronomy in Finland would improve its potential and international status if it would create a better internal coordination of its activities. This does not necessarily mean an overwhelming, rigid, central structure, but a flexible interface between the community and the government supporting bodies. In order to bring the Finnish astronomical community together across departments, subject areas, and funding bodies, we recommend that, say once per year and perhaps in association with another physics meetings, there should be a national, optical and radio astronomy and space science meeting. It could be an adaptation, to suit Finnish circumstances, of the National Astronomy Meetings and Royal Astronomical Society meetings in the UK, the Rat Deutsche Sternwarten and meetings of the Astronomische Gesellschaft in Germany, and the annual meeting (*les Journées*) of the Société Française d'Astronomie et d'Astrophysique and occasional (triennial?) *Prospectif* in France organised by

INSU. It would include science sessions by Finnish astronomers, including graduate students who would practice presentational skills in their home environment and develop a sense of community with their fellows. Such meetings would also represent a good opportunity to invite one or two external guests who could stimulate activity in topical fields. It could also include discussions of national policy by research and facility leaders, generally presented and also discussed in more select sessions. Such discussions could form the policy basis for a unified approach by the whole astronomical community for funding to the Academy of Finland and other funding bodies like TEKES.

4.3 Funding continuity

Decisions on funding of long programmes need to carry a certain continuity. In astronomy it is not unusual to have a monitoring programme whose length is set by long astronomical time scales (such as the OJ 287 monitoring programme – its period is 12 years). Space missions are also by their nature long term, and it may be a decade between starting to invest in instrumentation for a space mission and the time after launch when the scientific exploitation produces the return on investment. ALMA will be the same. Several groups that we visited paid tribute to the decision by the Academy of Finland to lengthen its funding commitments for major programmes to a three year period, but also mentioned that they still perceived discontinuities in policy and lack of consistency in funding for long programmes. We recommend that the Academy re-examine its practices, and perhaps uses the national meetings identified above as a means to develop long term strategies for astronomy that ensure satisfactory continuity.

4.4 Career management

Finnish astronomy has been going through a period of rapid expansion, during which a number of new appointments have been made from the population of PhD students and post-doctoral fellows then available. At some time soon the growth will begin to level off. Then the astronomical population of Finland will enter a steady state. At that time, teachers of astronomy, in particular supervisors of PhD students, will be training astronomers at a much faster rate than required to replace themselves. Most PhD students of astronomy will therefore be moving, eventually, into the national economy. The nature of the PhD training of astronomers should as a result develop to suit the new steady-state situation. PhD training should not only provide training for the opportunity to compete to carry on a career in astronomy, but also emphasise life-enhancing, general transferable skills appropriate for a career in the Finnish economy. This new situation will be a win-win situation for astronomy and Finland, for teachers and the taught.

5 *Statistics and data*

5.1 Finland's astronomy institutions

The following information is taken from the reports supplied by the four evaluated institutions and from information supplied by the Academy of Finland. All groups have support also from other sources than the Academy.

	Oulu, Astronomy Division	Tuorla Observatory	Helsinki Observatory	Metsähovi Radio Observatory
Professors + Senior Research Fellows	2+1	2+3	2+2	1
Research personnel (1994-2000)	25	38	33	13
Refereed scientific publications in international journals (1994-1999)	83	205	142	84
International edited works and conference proceedings	40	133	32	120
Monographs	-	3	13	-
Doctorates and licentiate degrees supervised (1994 -1999)	10	10	11	5
Annual funding by Academy of Finland (average 1998 – 2000; Finnish marks)	1.6M	2.0M	4.0M	1.9M

5.2 Finland's most cited astronomers

In the seventeenth century, the little-known English astronomer Thomas Harriot was the first astronomer to record sunspots, making 199 observations of the Sun over 3 years and discovering the Sun's rotation period. By contrast to Galileo, who published his book on his telescopic discoveries on sunspots within weeks of making them, Harriot published none of his discoveries and therefore had no influence on the development of astronomy, remaining a figure on the sidelines of astronomical history. The lesson is to publish, and thus help astronomy move on, both intellectually as a science and in terms of its national development. The most readily available measure of the impact of scientific work is the number of citations that its papers receive, although as a performance indicator this data should be taken in context, interpreted and given its due weight. The following information on the most cited astronomers in Finland is based on the astronomy abstract service (http://adsabs.hardvard.edu/abstract_service.html) as at February 2000.

OULU

Laurikainen, E.	277
Salo, H.	177
Tuominen, I.	442

METSÄHOVI

Teräsranta, H.	490
Tornikoski, M.	225
Urpo, S.	315

HELSINKI

Donner, K.	144
Harju, J.	139
Lumme, K.	277
Mattila, K.	500
Vilhu, O.	652

TURKU

Flynn, C.	440
Hakala, P.	126
Kotilainen, J.	296
Lainela, M.	122
Lehto, H.	364
Mikkola, S.	171
Nilsson, K.	209
Piirola, V.	541
Sillanpää, A.	241
Takalo, L.	327
Teerikorpi, P.	429
Valtaoja, E.	503
Valtonen, M.	779

5.3 Web sites

Each institution maintains a web site. The appearance, content, and orientation of a web site can be a revealing self-image. In many countries such sites are increasingly used by students and researchers, who are looking for information, contacts, courses and possibly jobs. We are not able to comment on the Finnish pages of the sites but we visited the English language versions, and our evaluation is as follows:

5.3.1 Tuorla `www.astro.utu.fi`

Tuorla's website has a unified, dignified, rather severe style. It contains up-to-date organisational material, pages on staff, and how to contact them (but no map), and the report of the Observatory from 1997-98. The main expository science material is in the research section of the report, formally presented. There is a password-protected archive of data from the OJ-94 monitoring project in 1993-5. There seemed to be little attempt to attract students or new researchers. Tuorla does host a mirror of the NOT site which is cheerful, up to the minute, astronomer-oriented and informative.

5.3.2 Oulu

`physics.oulu.fi/fysiikka/tahtitiede/eng/division_of_astronomy.htm`

Oulu's site is oriented towards the organisation of the university courses, in the rather formal manner of a university handbook. There are sections on research topics. The work of the astrophysics Group is briefly described without data and rather briefly. Public access to the section about the research of the dynamics Group is, curiously, forbidden. Professor Raitala's planetology pages are well illustrated, lively, didactic and science-driven. To aid further contact there was only a list of staff and email usernames. Rather few of the staff maintain home pages, of variable style and content, but Dr. Svetlana Berdyugina's pages ably display her science, for example her fascinating animated pictures of rotating stars.

5.3.3 Helsinki `www.astro.helsink.fi`

The Helsinki Observatory's site is attractive and comprehensive, with good material on the Observatory in general, how to contact people (including maps), reference material on the library, good science-oriented material, reference material on the instrumentation being made, descriptions of the research carried out, course work, links to the University, etc. The site is kept up to date and seems to be a working tool of the Observatory, as well as an attraction to students and potential research fellows.

5.3.4 Metsähovi `kurp-www.hut.fi`

The site is attractive and comprehensive, with didactic science-oriented material, how to contact staff (but no map), and course-material. There is the report from 1997. The schedules on the site are a year or more out of date and the site does not seem to be used as a working tool, at least not the publicly accessible parts.

6 Scientific biographies of the evaluators

Professor Brian McBreen

Brian McBreen studied at University College Dublin where he graduated with a BSc in 1964 and PhD in 1968. During 1968-1973 he was an Instructor, Research Associate, and subsequently Assistant Professor at Cornell University where he worked on a large balloon-borne gamma ray telescope. Between 1973 and 1978 he was a College Lecturer at University College, Dublin, and from 1978 to 1980 a Research Associate at Harvard University and the Center for Astrophysics. In 1986 he was appointed Associate Professor of Experimental Physics at University College, Dublin. He has participated in fifteen high-altitude balloon flights of a large gamma-ray telescope and a large one-metre infrared telescope. He has a broad range of astrophysical interests including Gamma Ray Bursts and ISO observations of clusters of galaxies and especially the faint lensed background sources.

Brian McBreen serves on several national and international committees dealing mainly with space research. He was chairman of the ESA Astronomy Working Group from 1993 to 1995 and member of the Space Science Advisory Committee for the same period. He is a member of the Royal Irish Academy.

Dr Paul Murdin

Paul Murdin is an astronomer who, during his research career, has worked at observatories in England, in Scotland, in the United States, in Australia, and in the Canary Islands, as well as with observatories in space. As a young man, he identified in 1971 the first black hole, in the X-ray star Cygnus X-1 and has published about 150 scientific papers, many based on work at the Anglo-Australian Observatory, at which he was one of the first staff members. He set up the operation of the UK's telescopes in the Canary Islands, for which he was honoured by the Queen in 1988 by the award of an OBE. He is now Head of Astronomy at the UK's Particle Physics and Astronomy Research Council and Director of Science at the British National Space Centre, responsible for organising British astronomy, on ground and in space. He participated in the Review of the Nordic Optical Telescope in 1995.

Paul Murdin was educated in England (Oxford University) and the United States (University of Rochester NY). He has been President of the European Astronomical Society and is a Councillor (soon to be Vice-President) of the Royal Astronomical Society. He represents the UK at the Science Programme Committee of the European Space Agency and is a member of the Visiting Committee of the European Southern Observatory. He was Director of the Royal Observatory, Edinburgh. He is a Senior Member of Wolfson College, Cambridge. He is a noted populariser of astronomy through books, articles, and broadcasts. He is a Trustee of the National Maritime Museum at Greenwich where he oversaw the development of the successful new display on the work of the Royal Observatory. He hopes to establish there the UK base for a new large telescope on Hawaii, which will be the largest telescope in the world used for astronomy education.

Professor Gianni Tofani

Gianni Tofani graduated (Laurea) in Electronic Engineering in 1964 at the University of Pisa. In 1968 he got the Libera Docenza (PhD) in radio-astronomy. His professional career started in the Consiglio Nazionale delle Ricerche as research scientist (1964-1982). From 1982 until 1986 he was associate professor of radio-astronomy at the University of Florence. Since 1986 he has been senior astronomer, Arcetri Astrophysical Observatory, Florence.

His research activity is mainly devoted to radio-astronomy techniques and he has played a leading role in the Italian VLBI (Very Long Baseline Interferometry) projects and in space projects such as FIRST, in which he is coordinator of the Italian consortium, and Planck. He is also involved in astrophysical research on the structure and dynamics of the interstellar medium, observed with high resolution radio interferometry. He is also involved in programmes of extended multi-wavelength observations of objects of recent star formation, such as molecular masers, high velocity outflows and IR sources. His publication list numbers more than 95 refereed papers.

Gianni Tofani has been Director of the Astronomy Group of the Italian National Research Council (CNR) (1979-1987). Since 1987 he has been Director of the Centre for Infrared Astronomy-CNR, Florence. He is a member of ESA’s Astronomy Working Group, a member of the Science and Technology Advisory Committee for the Large Millimeter Telescope (the USA-Mexico side of the ALMA project), and President of the Italian URSI Committee.

7 Glossary

AGILE Satellite-borne, gamma ray telescope mission, approved by Italian Space Agency.

AGN Active galactic nucleus; the central high-power region in some galaxies, manifesting itself as a bright source of optical, radio and X-ray radiation, bulk motion, etc, with the source of its energy thought to be accretion of material on to a massive black hole. See blazar, quasar.

ALMA Atacama Large Millimetre Array. Proposed 64-element interferometer working at millimetric wavelengths, to be established by a global consortium (ESO, the USA, several other countries) in the Atacama desert in Chile. See Section 4.1.

AMS Alpha Magnetic Spectrometer for cosmic ray detection. An instrument to be used on the ISS (International Space Station)

Asca Japanese X-ray astronomy satellite.

asteroid Small, usually irregular shaped, solid body orbiting the solar system like a planet, usually between Mars and Jupiter.

binary star Star system of one star in orbit around another. The stars interact, and produce phenomena that are interesting in their own right, as well as giving diagnostic clues as to the nature of stars in general.

binary black hole System of one black hole in orbit around another. Conjectured to exist, formed perhaps by the merger of galaxies containing a black hole nucleus, these systems would create strong sources of gravitational radiation.

black hole A star or star cluster whose size and mass create a gravitational field of such strength that radiation follows closed geodesics and remains confined to the region of the black hole. A phenomenon of General Relativity. See AGN.

blazar A manifestation of active galactic nuclei, thought to be an AGN viewed directly down its strongly beamed source of radiation.

BL Lacertae source Alternative name for a blazar, named after the prototype, BL Lacertae thought at one time to be a star.

Cassini The NASA-ESA space mission to Saturn and its moon Titan, launched 1997.

CCD Charged Coupled Device. The sensitive element in modern astronomical cameras.

celestial mechanics The study of the motions of bodies under the force of gravity.

circumstellar disk A disk of material (dust and gas) that has formed around a star (or black hole).

circumstellar shell A shell of material (dust and gas) that has formed around a star.

Clementine A 1994 NASA mission to the Moon that mapped it and determined altimetry data.

cluster of galaxies What the name implies, these objects are the largest structure in the Universe.

CMB Cosmic Microwave Background. The relic radiation of the Big Bang, redshifted into millimetre wavelengths and representing the state of the Universe some 300,000 years after its formation.

Compton Very successful NASA gamma ray obseravtory in space, launched 1991, near the end of its lifetime (see EGRET).

corona The hot atmosphere of a star, like the Sun or others.

cosmic distance scale The determination and calibration of the distances of galaxies as a means to determine the expansion rate of the Universe, its age, etc.

Cruithne An asteroid, accidentally having become a ‘moon’ of the Earth in a curious horseshoe shaped orbit.

dark matter 90% or more of the mass in the Universe, as determined from the effects of its gravitational pull, emits no form of radiation (light, infrared or radio waves) and is referred to as ‘dark matter’. Its nature is unknown to physics.

EGRET Energetic Gamma Ray Experiment Telescope on the Compton satellite, measures high energy gamma ray source positions and brightnesses.

ESA European Space Agency.

ESO European Southern Observatory.

extra-solar planet Planet orbiting a star other than the Sun. About 30 are known to exist as of early 2000.

EUVE Extreme Ultraviolet Explorer, satellite launched 1992, to make a produce a high-sensitivity "all-sky" survey.

EVN European Very-long baseline interferometry Network (includes Metsähovi).

FIRST Far Infra Red Space Telescope. An ESA mission due for launch about 2007.

GAIA One of the future ESA Cornerstone missions, a telescope system to measure the positions (and changes of the positions) of the stars and thus their distances, motions, orbits round unseen companions, etc.

galactic plane The central plane of our spiral galaxy, where many radio sources and stars lie.

galaxy Collection of stars, fundamental building block of the Universe.

gamma ray burster Object which produces a powerful burst of gamma rays, lasting a few
seconds, recently shown to lie in distant galaxies; origin unknown.

general relativity Einstein’s theory of gravity, or one of its competitors, superseding Newtonian theory and showing departures from Newtonian theory in the case when the gravitational field is strong.

gamma ray source Source of celestial gamma rays, showing interesting high energy phenomena.

gravitational radiation Prediction of Einstein theory of General Relativity, energy flow at the speed of light in space time, caused by time-varying gravitational fields. Its effects have been seen in one celestial source but such radiation has not yet been detected.

Green Bank in West Virginia, site of the largest fully steerable radio-telescope, the GBT (Green Bank Telescope).

GLAST Gamma-ray Large Area Space Telescope. NASA’s proposed satellite-borne gamma ray telescope proposed for launch in 2005.

heliophysics The science of the Sun.

Hipparcos ESA’s satellite-borne telescope system (1989-93), that determined the positions and motions of the nearer stars, yielding distances, orbits etc.

Hubble constant Parameter of the expansion of the Universe that describes the space distribution of galaxies, the age of the Universe etc.

Hubble Space Telescope NASA’s optical and ultraviolet telescope (1990-); ESA participated in the mission and astronomers in its Member States have access.

impact crater Crater on the Earth or other planet, caused by the impact of an asteroid. Finland has one of the largest concentrations of known impact craters on the Earth.

INTEGRAL International Gamma-Ray Astrophysics Laboratory. ESA’s gamma ray telescope being built now for launch in 2001.

instrumentation The systems and detectors fed by a telescope that analyse the incoming radiation; typically optical and X-ray systems, analogous to radio receivers.

International Solar-Terrestrial Physics programme A global multi-satellite programme currently in progress to study solar terrestrial physics and the effect of the Sun on the Earth, particularly its magnetosphere.

interstellar medium The dust, gas, plasma and any other material that occupies space between the stars.

ionospheric physics Study of the ionosphere and its systems.

ISO ESA's Infrared Space Observatory (1995-98), now defunct after using all its liquid helium coolant, data analysis still in train.

IUE ESA's International Ultraviolet Explorer, an ultraviolet-sensitive telescope. This long-lasting mission is now over, but its archive of observations is still very much used.

late type stars Cooler stars, much like our own Sun.

LISA Large Interferometer Space Antennae, a proposed ESA-NASA space interferometer with arms 50 million kilometres long, intended to detect gravitational radiation, being studied for launch about 2010.

Magellan The NASA mission to Venus that mapped its surface beneath its opaque atmosphere by means of synthetic aperture radar.

magnetospheric physics Study of the Earth's and other planets' magnetospheres.

magneto-hydrodynamics Study of ionised gases in motion.

Mars Express mission ESA's mission to Mars, due for launch in 2003.

Mars Netlander mission French proposed mission to Mars to establish a net of seismic sensors to determine the properties of Mars' interior.

MERLIN The UK's Multi-Element Radio Linked Interferometer Array, based at Jodrell Bank, giving resolutions comparable to the Hubble Space Telescope.

microquasars Stellar mass black holes, that display some characteristics of the supermassive black holes found at the centres of AGN, for example they have radio jets.

missing mass The dark matter in our Galaxy.

MORO An ESA lunar mission, proposed for a recent funding opportunity, unsuccessful.

multi-wavelength astronomy The study by radiation of whatever wavelength of astronomical phenomena.

NASA The US space agency.

NGST The NASA-ESA Next Generation Space Telescope, an 8-metre aperture infrared telescope planned for launch about 2009 and intended to study the 'Dark Ages' in the history of the Universe, between the epoch of the Cosmic Microwave background and the formation of the first galaxies of stars.

NOT Nordic Optical Telescope.

NRPIF Nordic Regional Planetary Image Facility. Archive of planetary data located at Oulu, Finland.

OJ 287 A particular Active Galactic Nucleus, named by its serial number in a catalogue of radio sources. Studied by the Tuorla Observatory.

Planck The ESA mission, planned for launch in 2007, to map the Cosmic Microwave Background and survey the sky for faint infrared/millimetre sources, named after the physicist.

planetary rings Systems of numerous small (metre-sized) solid bodies in orbit around some planets (like Saturn, of course, but also Neptune and Uranus).

quasar Acronym for quasi-stellar radio source; an active galactic nucleus. Quasars are powerful enough to be seen at large distances and so are used as probes of the distant and therefore the early Universe.

Radioastron A space project of the Russian Space and Aviation Agency to launch a radio telescope system; likely to follow Spectrum-X-gamma, i.e. indefinitely in the future.

remote sensing Determination of the properties of the Earth from space.

ROSAT Roentgen Satellite. A German-led X-ray telescope project.

RXTE Rossi X-ray Timing Explorer, NASA mission launched 1995 to study time variability in celestial X-ray sources.

SEST The Swedish-ESO Submillimetre Telescope.

SMART-1 ESA's Small Missions for Advanced Research in Technology are technology demonstrators. SMART-1 is the first in the series and, due for launch in 2002, will test electric propulsion by a mission to the

Moon. It will survey celestial X-ray sources and the surface of the Moon by X-ray spectroscopy (X-rays are emitted from lunar material, induced by the Sun, and reveal the Moon's composition).

SOFIN High Resolution Spectrograph for the NOT

SOHO ESA's SOlar and Helisopheric Observatory, currently on station and examining the Sun and its atmosphere (1995-2003?). Part of the International Solar-Terrestrial Physics programme.

spectroscopic tomography The technique to deconvolve surface structure from the profile of spectral lines integrated over the rotating, visible surface of a star.

Spectrum-X-Gamma A space project of the Russian Space and Aviation Agency to launch an X-ray/gamma ray telescope system, currently under constructions and heavily delayed by Russia's economic difficulties.

Sun The nearest star.

supernova A stellar explosion caused by the collapse of a star under its own weight when its supporting pressure disappears, e.g. because of a change of state of its interior material.

three body problem A class of problems in celestial mechanics on the orbits of three bodies; there are no general solutions, the orbits are 'chaotic' and there are still numerous unsolved aspects.

VLBI Very Long Baseline Interferometry. A radio technique that combined observations from radio telescopes separated by continental distances, or even distances into space. Provides high spatial resolution images of, say, AGN.

VLT ESO's Very Large Telescope. Four 8-metre telescopes at Paranal in Chile.

VSOP Japanese-led VLBI Space Observatory Programme, started with the HALCA satellite, launched 1997.

VLA Very Large Array. A radio interferometer in Socorro, New Mexico.

water maser Water molecules in the interstellar medium produce MASER emission (Microwave Amplification by Stimulated Emission Radiation), emitting photons due to transitions in their energy levels (mainly rotational transitions) and stimulating surrounding molecules to do the same.

XMM ESA's X-ray Multi-Mirror observatory, the largest X-ray telescope, currently in orbit.

XTE Name for RXTE before the label Rossi was added. See RXTE.

x-ray binaries Binary stars that emit X-rays, typically because one star loses material onto the other, which is massive but small. The infalling material loses a lot of gravitational potential energy and impacts at high temperature onto the compact star's surface. Often associated with magnetic phenomena.