ASTRONOMY IN GREECE AT THE GATES OF THE 21ST CENTURY

A Report to The Greek National Committee for Astronomy

by
An Appointed External Committee

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TABLE OF CONTENTS

I. INTRODUCTION

In the Fall of 1997 The Greek National Committee for Astronomy, through its President Dr. Evangelos Kontizas, appointed an External Committee to investigate and report on the possible directions of the Astronomical Sciences in the 21st century in Greece.

The full committee, with the exception of one person (LA), met at Cornell University in Ithaca, New York, on March 13-14, 1998, and reached consensus on the major suggestions and recommendations. Following numerous discussions by the entire committee over the next few months, the committee prepared a first draft of the report. Further input was provided when members of the committee visited Greece in the summer of 1998. During this process it became clear that it was difficult to assume that the available data to the committee were complete. Therefore, the committee wishes to make it very clear that we do not pretend to have seen a complete data set of the astronomical activities in Greece. In addition, in the few cases when we report quantitative data, such as number of faculty members, etc., we have reported our best knowledge of the information we have been able to collect. We hope to be forgiven if we have made major omissions. However, we feel that the available information is more than sufficient for us to have been able to reach the conclusions in this report.

In the process of our deliberations it also became clear that we could not make a detailed examination of the funding levels in the astronomical sciences in Greece and we strongly recommend that such a separate study be conducted in the near future.

In this report the committee presents an Executive Summary with a Vision of Astronomy in Greece (II); the Current Status (III); International Perspectives (IV); Major Recommendations (V); and Conclusions (VI).

II. EXECUTIVE SUMMARY

1. Vision for Astronomy in Greece

The committee believes strongly that a strategy for astronomy in Greece in the 21st Century must evolve from a vision that is shared not only by the astronomers and space scientists, but also by the policymakers, the funding agencies, and the at-large public. Since such a vision from constituent astronomical institutions in Greece is not known, we felt it necessary to offer one, to which our recommendations
can be ultimately traced. It is this committee's view that if the recommended actions
are changed substantially, then the vision must also be changed, so as to conform with the policies being pursued.

Vision for Astronomy in Greece:

"The object of Astronomy is to conduct forefront research, thereby expanding humanity's knowledge of the space environment and the cosmos. Astronomers in Greece share this purpose and

aspire to partake in cutting-edge research at the highest levels in a milieu where opportunities for participation are possible in both the national and global arena. Such participation accrues benefits to science, advances technology and education, and elevates the aspirations of the entire nation."

2. Recommendations

Having examined the current status of astronomy in Greece and the international perspective on observational astronomy, the committee proposes two sets of recommendations, one that would involve new funding and one to strengthen the overall conduct of astronomical sciences in Greece.

Primary Recommendations Requiring Major Resources in Order of Priority:

1. Join ESO
2. Strengthen observational/instrumental astronomy
3. Provide for merit based usage of any large national facilities and allocate resources for their use
4. Provide small optical telescopes
5. Join ESA

Recommendations to Strengthen the Conduct of Astronomical and Space Sciences:

1. Foster national and international collaboration
2. Enhance space-based science and technology programs
3. Broaden the scope of training graduate students to improve employment opportunities
4. Utilize existing astrophysical and space data
5. Maintain a strong theoretical astrophysics program
6. Make major upgrades in computing facilities
7. Strengthen the astronomical sciences at the major Greek universities

III. CURRENT STATUS

A. Astronomy and Astrophysics

There are eight institutions in Greece with departments or sections devoted to teaching and research in Astronomy and Astrophysics. Three are in Athens: the largest is the section within the Physics Department of the National Kapodistrian University, followed by the Astronomy Institute of the National Observatory of Athens, and the Astronomy section of the National Academy of Athens. Thessaloniki has a very small astrophysics group within the Geodetic Astronomy Department and a larger Astrophysics section within the Physics Department of the Aristotelion University. Crete has a very young, but well established Astronomy section in the Department of Physics in Heraklion, and Patras and Ioannina both have small but functioning groups in their Astronomy Sections. Activity relating to Cosmology also exists in the recently established Mathematics Department of the

University of the Aegean (not discussed below).

1. Academy of Athens

The Research Center for Astronomy and Applied Mathematics (RCAAM) in the Academy of Athens in 1990-94 consisted of 9 staff members (6 PhD and 3 support personnel) and 3 scientific collaborators. Their research is concentrated towards Solar and Space Physics with one individual conducting archeodating. There have been very significant recent new additions in Cosmology, Particle Physics and Dynamical Astronomy.

2. Astronomical Institute of the N.O.A.

The Astronomical Institute (AI) consists of 9 scientists, 5 graduate students and 15 support personnel. Their distribution in the hierarchical ladder is weighted towards the younger, postdoc level.

There is a large number of international collaborations with Institutes and Observatories concentrated mostly in Europe (6 in the US, and 1 in Australia). Besides research, the staff has a vigorous program in education and outreach, with several well funded programs in all three activities.

The AI supports the Astronomical Observatory in Kryonerion and also has been allocated EC and government funds to install a new 2.3-m telescope in Greece. The observations will be automated and will be performed by remote controls from individual institutions. This new important telescope is opening new exciting challenges for the Greek astronomical community.

3. University of Athens

The section of Astronomy, Astrophysics and Mechanics (AAM) of the Physics Department at the University of Athens was formed in the mid 1980s by merging the previously independent Chairs indicated in its name. The biggest part of the section is the Astrophysics and Astronomy staff; Mechanics is a rather small constituent. AAM is currently staffed by 22 faculty members who are distributed into the 4 teaching levels, with the highest concentration at the Assistant Professor level (13/22). The full Professor level in Astronomy and/or Astrophysics is vacant. There are 6 Associate Professors and 3 lecturers. It is noteworthy that the Department lacks gender diversity in the higher ranks.

The Department of Physics started a graduate school in 1994, within which AAM has its own Masters and PhD programs with 12 graduate courses. They report an impressive number of graduate students (35) active during 1995-1997. Overall AAM conducts research into about ten research areas.

There are few international collaborations and only a few members have been abroad for purposes other than a scientific meeting over the last few years.

In the years between 1990-1997, there have been 2 new hirings in the Section; these are presumably the only AAM members of an age less than 45 years. This is a source of major concern, as it would predictably result in a dramatic gap in the continuity of the function of the section in the (near) future.

In addition to the pursuit of astronomy, it should also be mentioned that the Physics Department of the University of Athens is involved in building a High Energy Neutrino telescope, known as NESTOR. This telescope is sensitive to very high energy neutrinos emitted from astrophysical objects, such as Active Galactic Nuclei.

4. University of Crete

The University of Crete (Heraklion) has a section of Astrophysics and Space Physics (ASP) in its Physics Department. It has 7 faculty members (3 full, 3 associate and 1 assistant professor) and 6 research staff on grant money. Their research covers a broad range in theoretical and observational studies. Observations for several astronomical projects are taken at the Skinakas Observatory, which is built and maintained by ASP staff. More observations are performed at international large telescopes, such as CTIO, AAT, VLBI, AT, HST. The researchers are also using multiple satellite data.

There has been a significant faculty participation in scientific meetings throughout the last 5 years. ASP shows an impressive record of funded projects via the European Union and NATO, and must account for at least a good part of the large number of their research faculty. Their research is up to date and centered on today's astrophysical forefronts.

The Physics Department has a graduate program through which astrophysics students can pursue their graduate studies.

5. University of Ioannina

This is the smallest group of Astronomy in Greece. It consists of a Laboratory of Astronomy with three faculty members (one full and one associate professor and one lecturer) and one support personnel. The staff performs significant research in solar physics and in multiwavelength observations of flare stars; they have several national and international collaborations and actively participate in scientific meetings.

6. University of Patras

The University of Patras has a Laboratory of Astronomy and a Section of Astronomy in the Division of Theoretical and Mathematical Physics in the Department of Physics. The Laboratory has one full and one assistant professor, one lecturer, one research assistant and one postgraduate student. The Section has one full and one associate professor and two postgraduate students. The faculty teach courses and conduct research in a few areas and there is an active theoretical group on celestial mechanics.

7. University of Thessaloniki

There are two departments in the University with activity in Astronomy. The smallest is the Department of Geodetic Astronomy with 2 members at the full Professor level. Their research is concentrated mainly on flare stars. The largest is the section of Astrophysics, Astronomy and Mechanics (AAM) of the Department of Physics, with 4 full, 5 associate, and 3 assistant professors, 1 lecturer and 10 support personnel.

The AAM in Thessaloniki is very active in several areas of research as well as in education and outreach. AAM staff have produced an extensive amount of lecture notes, and have participated in numerous scientific meetings and summer schools. There is involvement in several European Community funded projects, and they have strong Ph.D. and Visiting Scientists programs. The age distribution of the staff members may lead to future discontinuities in the function of the section. It is also noteworthy that this department lacks gender diversity.

B. Space Science

The principal institutions devoted to research and technical development in space sciences are the Laboratory of Space Electrodynamics (LSE) at the Demokritos University of Thrace, and the Institute for Ionospheric and Space Research (IISR) of the National Observatory of Athens. Significant research in ground-based ionospheric/atmospheric work is also a component of the overall Astrophysics and Space Science section at the University of Crete. Activity relating to space science also exists in the Astrophysics section of the University of Athens, and the Research Center for Astronomy in the Academy of Athens.

1. University of Crete

The work in the Astrophysics and Space Science Section at the University of Crete consists of both experimental and data analysis work and of theoretical work in space physics. The staff has substantial grant and programmatic support from the European Union and other international organizations.

2. Institute for Ionospheric and Space Research (IISR) of the N.O.A.

The IISR at the National Observatory has a permanent staff of 6 research scientists and 3 graduate students. IISR works in several research areas closely related to those of LSE and its staff analyzes spacecraft data from the same set of missions used at Demokritos.

3. University of Thrace

The LSE at Demokritos University of Thrace constitutes the largest institution, with 10 scientists, 2 post-doctoral fellows, support personnel, and 19 graduate and undergraduate students. The scientists are co-investigators or associated scientists on several international spacecraft

missions (e.g. Ulysses, Geotail, Cluster II, and others), successfully funded through European programs and bilateral collaborations with other countries, including the U.S. The group is active in conference participation.

The LSE has designed, developed and successfully flown particle experiments on a number of Russian spacecraft, as well as component systems to instruments involving data processing units and ASICs (Application Specific Integrated Circuits). Such high technology hardware capability in space instrumentation is unique within Greece. The LSE group, has expanded their activities to antennae and propagation, satellite communications, and other, related, areas.

C. Education

Formal graduate programs in the Astrophysical Sciences are very limited in Greek universities, however, we applaud the existing programs and recommend further developments along these lines. The majority of the graduate students, however, face the choice of going out of the country for quality higher level education. Given the fact that funding is not always available, Ph.D.'s within Greece are mostly in theoretical topics that need less resources. The lack of observers is reflected in the overall staffing of the Greek astronomical community that contains a large number of theorists.

D. Employment

The employment situation within Greece for a Ph.D. in Astronomy/Astrophysics is very grim, particularly for women scientists. The universities offer very few new positions, and the nationally trained Ph.D.'s have slim chances competing in the international arena. The top students are usually selecting the option of a foreign country Ph.D., and most often remain outside Greece for several years. As a result, in general, within the country there is lack of young, vigorous faculty to provide a healthy scientific community. Insufficient international collaborations, exchange programs and sabbatical visits, result, for some of the centers, in intellectual stagnation and obsolete science projects.

E. Conclusions

In summary, the astronomy/astrophysics research activity in Greece is underfunded and in many modern areas is dormant. With very few exceptions, there is a severe lack of younger faculty and international collaborations with major centers. The science activity in a few areas (theoretical mostly) is relatively competitive internationally; the observational potential is clearly under-utilized.

The research staff has an average publication rate of about one refereed publication per person per year and participate in few meetings due to the low research funding. Few Centers make use of the non-Greek and Greek channels for research funding and are able to show hiring in recent years.

Space science activity in Greece is competitive relative to that found elsewhere in Europe. The research staff has an average publication rate of about one refereed publication per person per

year, participates in international conferences and derives substantial funding support from sponsoring agencies outside Greece.

IV. OBSERVATIONAL ASTRONOMY: AN INTERNATIONAL PERSPECTIVE

A. Forefront Research & Facilities

Astronomy, as the science devoted to the study of space and the universe, is by necessity, a science driven largely by observations. The forefront research in astronomy involves, for the most part, observations with facilities (or telescopes of different kinds) of large size, high angular and/or spectral resolutions and also observations at frequencies of the electromagnetic (EM) spectrum previously unexplored. In addition, forefront astronomical research is often pursued by more modest means by reliance on the ingenuity of the observers who either exploit and apply existing technologies to domains not considered before, or conceive meaningful observational programs not requiring in general the largest available facilities.

As such, current international astronomical research covers about 17 decades of the EM spectrum from the radio (10^8 Hz) to the TeV (10^{25} Hz) regime. Along the same general framework of exploration of the macrocosmos, but not strictly within the realm of traditional astronomy which relies on electromagnetic waves, lies the exploration through detection of particles from space, namely the cosmic rays, whose spectrum covers at least 15 decades in energy, and also through the (under development) branches of neutrino and gravitational radiation astronomies.

Along with advances in astronomy, advances in computer technology in the last decade have also been spectacular and have greatly benefitted astronomical research. Indeed, adequate computer facilities and infrastructure are now necessary for every type of astronomical research and extend beyond purely numerical simulations. Observers need computational resources to reduce their data, instrumentalists to develop their instruments, theoreticians to make models or even help them with their algebraic or other analytical calculations. A further boost to astronomical and astrophysical science was provided by the development of the World Wide Web (WWW), which allows researchers and others to access data bases, retrieve data etc. High speed links are also essential for international collaborations, permitting fast exchange of ideas and real-time discussion, as well as remote accessing of computers. These facilities have become part of everyday scientific life, and it is hard to envisage research without them.

1. At the low frequency end of the EM spectrum, the radio frequencies, forefront research involves observations with increasingly higher angular resolution and sensitivity through the use of interferometry employing either large terrestrial networks of radio antennas (e.g. VLBA - Very Large Baseline Array) or by radio dishes in orbit (the Japanese VSOP) to maximize the baseline and therefore the angular resolution. Increase in the angular resolution of existing facilities is also pursued through the use of receivers of increasingly higher frequencies. Resolutions

more than 1,000 times that obtained at optical wavelengths are now common with Very Large Baseline Interferometry (VLBI) techniques. The twenty year old Very Large Array (VLA) continues to be the leading instrument of radio astronomy providing medium (arc sec) resolution of astrophysical sources very efficiently. The subjects of this area of research are galaxies, compact sources (black holes, neutron stars), active galactic nuclei and their associated jets, stars etc.

2. There has been a great thrust in the astronomy at mm wavelengths with the development of interferometry in this frequency band. By the year 2000 there will be 5 such arrays in the world (3 in the U.S., 1 in Europe, 1 in Japan; 4 are already operational). The presence of spectral lines associated with transitions of molecular compounds in this frequency regime makes this branch of astronomy the prime instrument for the study of the formation of stars and the structure of galaxies.

3. In the far infrared, observations require the location of the telescopes either in space, or above the troposphere through the use of observing airplanes or, at the minimum, observations from the top of sufficiently high mountains where the atmosphere is sufficiently devoid of humidity. This energy band is well covered by the Hubble Space Telescope, and will most likely be the band operated by the Next Generation Space Telescope (NGST) which will study galaxies at very large red shifts, and also by the Space Infrared Telescope Facility (SIRTF), and by the Stratospheric Observatory for Infrared Astronomy (SOFIA).

4. In the more traditional domain of astronomy, namely astronomy in the optical band, there has been indeed an explosion of new capabilities in the past decade and a half. This is due to both advances in detector technology (replacement of the traditional photographic plates and electronic cameras by CCD detectors) and the construction of telescope mirrors of progressively larger diameters.

The introduction of CCD detectors has had a twofold impact on astronomy: (a) Increased detector sensitivity, which allowed observations of fainter objects and (b) Collection of data in digital form, which allows their transportation and manipulation much faster and with greater ease. In this respect the information revolution came at the right time providing the means of dealing with the increased amount of digital information at relatively low cost.

The other advance, which is currently going on, is the construction of a large number of optical telescopes of diameter in excess of 7m and up to 10m. A number of them have been in fact constructed in tandem to allow the possibility of optical intensity interferometry. By the year 2000 there will be at least 12 such telescopes in place with 4 already operational with a most prominent position occupied by the two Keck Telescopes and ESO's VLT (Very Large Telescope). The increase in area and detector sensitivity has made possible the study of objects too faint to discern in the past, such as high redshift galaxies which can now be studied spectroscopically, and also spectroscopy of other astrophysical sources with very high spectral resolution.

In parallel with the construction of larger telescopes, there is also the development of techniques which will allow these or a number of smaller telescopes to perform interferometry measurements and thus achieve extremely high angular resolutions. This technique is currently being perfected and it already can provide measurement of the sizes of some of the nearest bright stars. When employed on larger telescopes it is expected that it may allow for searches of planets in such systems. Other techniques involve relatively small but dedicated telescopes to achieve rather specific goals. Such are the Sloan survey of galaxies and the study of stellar populations in our own through the use of gravitational lensing.

In parallel with the improvements in ground telescopes, observations from space will continue with HST for about another decade, while the Next Generation Space Telescope (NGST) is expected to provide great insights in the physics of young galaxies through diffraction limited observations in the IR. The HST has also ultraviolet capabilities and the NGST may also have similar provisions.

5. Observations in the X- and gamma-rays is the domain of what is termed High Energy Astrophysics. Astronomy in this energy regime, which covers approximately 7 - 8 decades in frequency (from a fraction of a keV to several GeV), can be performed only from space and its goal is the study of objects whose luminosity is emitted primarily in X- or gamma rays, such as supernova shocks (thought to be the acceleration sites of cosmic rays), accreting neutron stars and black holes, gamma ray bursts and quasars and other active galactic nuclei. The importance of observations of the latter classes of objects in the high energy regime lies in the fact that their luminosity is considered to be produced closest to the black holes which apparently power these objects.

There are several missions presently in orbit (CGRO, ASCA, XTE, ROSAT, BeppoSAX) which have been a continuous source of knowledge concerning the physics of black holes, gamma ray bursts and quasars as revealed in their timing and spectral observations from energies of several keV to several GeV. Missions of higher angular resolution (AXAF), spectral resolution (ASTRO-E), and sensitivity (XMM) are scheduled to be launched within the next 2-3 years.

6. At even higher energies (TeV) the number of photons from the high energy sources is so small that space based observations are impractical in that they require extremely large area detectors in orbit which are prohibitively expensive. However, the cascade of photons produced when a photon at these energies hits the top of the atmosphere can reach the ground and be collected. As such, the entire atmosphere can be used as a scintillation detector to observe astrophysical sources of interest. A number of the sources detected by CGRO have been discovered to emit in this energy band too and as the number of this sort of telescope becomes more common, the source number is likely to increase. There are a number of such telescopes presently around the world on almost all continents. Their low cost (U.S. $ 100K -200K) makes them an attractive alternative to the space based study of High Energy Astrophysics by parties of limited resources.

7. Finally, there are two branches of astronomy which do not involve the detection of photons, those of neutrino and gravitational wave astronomies.

Neutrinos have been detected from the Sun, and their apparent deficit constitutes one of the major unsolved puzzles in modern astrophysics, with potentially far reaching consequences. Furthermore, cosmic ray neutrino measurements in Super Kamiokande hint for the presence of neutrino mass. In addition, high (TeV) energy neutrinos are expected to be produced at the centers of active galaxies. At present there are two telescopes under construction for the detection of these neutrinos, AMANDA in the South Pole and NESTOR in southern Greece, the latter being the product of a mainly Greek effort by the university of Athens. These telescopes are expected to become operational within the next few years.

Emission and detection of gravitational radiation is expected to provide nformation about the terminal steps of the gravitational collapse of stars. The LIGO interferometers are currently under construction in the US while similar efforts are also being made by German and Italian groups.

All the above observational astronomical disciplines are supplemented by vigorous theoretical work in astronomy and astrophysics aimed at providing a systematic and unified understanding of the observational results and to provide predictions for new observations as progress is being made in our understanding of
the cosmos.

B. Resources for Support of Astronomy

At various countries, Astronomy programs are supported with government grants through competitive processes; with specific institutional support once a facility or department exists; as well as with private donations and endowments, support by foundations, etc.

For a meaningful study of resources needed to support astronomy in Greece, a separate special study should be conducted. In such a study, the support at other countries similar to Greece should be examined, analogies with Greece should be drawn and comprehensive metrics on how to evaluate support for Greek astronomy
should be provided. Due to limitations in space here but also because of the specific charge of our committee, we only outline here the possible means of funding basic research in astronomy.

Support for astronomy in Greece takes on the following forms:

- competitive grants from external agencies (e.g. EU, NATO, etc.)
- competitive grants from Greek sources (Greek Government)
- funds in support of instrumentation (Greek Government, such as the new 2.3 m telescope, etc.)--generally these are allocations.

In general, support should be as open as possible to competition with peer-review panels providing recommendations to funding agencies.

One important point needs to be made here: support for astronomy goes beyond salaries, teaching support and support for telescopes and observatories. It should include funds for travel, library

resources, and computer hardware and software (all of which tend to be minimal if non-existent in Greek budgets).

We believe that the financial and other support for the astronomical sciences in Greece should be made competitive with countries such as Italy, Spain, Israel and Turkey (which is planning for a 2+ meter telescope and has several existing small ones).

For the European Union, and other countries, the current trend in R&D (Research and Development) expenditures can also be examined (see e.g. issue 15, April 1998 of Newsletter of the European Astronomical Society which contains discussion of such trends and has a table of R&D appropriations in various countries). For example, statistics show that R&D funding for astronomy has had significant increases during the early years of this decade in Asian countries which are aspiring to become scientific powers.

Specifically we recommend increased funding for the astronomical sciences in Greece by a factor of about three to allow Greece to be competitive with its peers. Such new funds should give priority to new instrumentation, support personnel, particularly in technical and computer areas.

V. MAJOR RECOMMENDATIONS

A. Primary Recommendations Requiring Major Resources in Order of Priority

1. Join ESO

Modern astronomy and astrophysics research requires state-of-the-art technologically complex telescopes and instrumentation. Rarely can single nations afford the enormous expense of such devices and many European nations are now sharing outstanding facilities within a multi-nation organization, the European Southern Observatory (ESO), that provides observational facilities. Astronomers in Greece will profit enormously if Greece were to join ESO. It would not only provide guaranteed use of some of the world's best and largest telescopes, but it would also significantly strengthen the scientific collaborations between Greek and other European astronomers. We strongly recommend that the Greek Government make every effort to join the ESO organization.

2. Strengthen Observational/Instrumental Astronomy

Future research in astronomical sciences will probably rely heavily on novel observational techniques and technological advances in all wavelength bands which will enable new observations and discoveries. The new generation of astronomy students must be familiar with the issues and the fundamentals of modern observational astronomy and be familiar with the use, workings, and construction of sophisticated astronomical instrumentation. For this purpose we recommend that Greece

significantly enhance the opportunities and education in observational/instrumental astronomy. This can be done, for example, by creating
modern teaching techniques utilizing advanced astronomical laboratories, and providing programs where Greek astronomers can travel internationally to learn about and use astronomical facilities.

For telescopes inside Greece, efforts should be made for acquiring quality instrumentation since a telescope is of little use without adequate instrumentation. We thus recommend that every effort be made to equip the new 2.3m telescope, with appropriate photometric and spectroscopic instruments, such as high resolution two dimensional optical and IR photometric detectors, high resolution spectrometers as well as possibly Fabry-Perrot detectors. Financing should be provided not only for purchasing such equipment, but also for maintaining it in proper working condition with trained personnel.

Greece should also participate in international collaborations such as the new European Very Long Baseline Array[1] research by constructing a radio telescope, possibly on the island of Crete, to provide the longest baseline. A study of Greece's participation with recommendations should be conducted.

3. Provide for Merit Based Usage of any Large National Facilities and Allocate Resources for Their Use

We recognize that any large or expensive scientific research astronomical instrument, such as a telescope, is probably funded wholly or partially by the Greek
government with public funds. In such cases, as the future 2.3 m telescope, the astronomical community and the government must make sure that these instruments are used to their maximum potential. This can be done by assuring that a suitable site with excellent seeing be found following a study, as well as by merit based usage of these instruments resulting from competitive proposals open to the entire Greek scientific community. We recommend that telescope allocation committees

[1] VLBA is the world's foremost technique to achieve unprecedental angular resolutions in the study of radio emitting cosmic sources and would provide Greece with participation in forefront research. Such a project can indeed be interdisciplinary since it can also be very useful for the study of geology (movement of tectonic plates) and seismology. A radio telescope with dimensions of the order of 30 to 40 meters would be very desirable, since such an antenna could also be used as a stand alone useful instrument and can also participate in space Very Long Baseline Interferometry (VLBI). Such a project would use the talents of electrical engineers from Greece and would create a beneficial cooperation in various disciplines, including industry.

be set up from the Greek Astronomical Community to assure peer reviewed usage of these nationally-funded telescope facilities. We also recommend that the government provide sufficient funds for the operation and usage of these facilities.

4. Provide Small Optical Telescopes

At the present time Greece does not possess sufficient number of optical telescopes to train young scientists in the astronomical sciences, or to perform astronomical research. We recommend that the Greek government begin a program to provide for a few optical telescopes with apertures of about 0.5 to 1.0 meter each which at present can be purchased commercially at relatively modest cost. These telescopes should be distributed at suitable sites to some university astronomy departments or national centers and have as their primary purpose the training of graduate students and staff. In other words, such a program will provide necessary training in observational astronomy and will facilitate the learning and testing of new astronomical instrumentation. Modern, adequate instrumentation should be available at each site for both photometric and spectroscopic observations, allowing users to take full advantage of these telescopes as well as technical support.

5. Join ESA

Increasingly research in the astronomical and planetary sciences is being conducted from space with space based telescopes and interplanetary spacecraft. We recommend that the Greek government consider joining the European Space Agency to allow its astronomers and space scientists to actively participate in the ESA missions. This will have the added benefits of exposing Greece into many areas of high technology, including, for example, nanofabrication and high performance computing.

B. Recommendations to Strengthen the Conduct of Astronomical and Space Sciences

1. Foster National and International Collaboration

Modern astronomical and astrophysical research is increasingly requiring collaborative efforts extending beyond a single academic or observational facility and often crossing national boundaries. The reasons are many, including the fact that modern astronomy projects are often "large science" and expensive and also that few countries can afford a complete array of all resources needed. Moreover, cross-fertilization is critical in theoretical subjects as well. For Greek astronomy, these considerations are even more crucial. We recommend that increased institutional attention be given to collaborative efforts by Greek astronomers, astrophysicists, and space scientists, as well as international collaborations such as a possible new VLBA participation by Greek astronomers, participation in international programs such as multifrequency observations of variable sources, etc. These may involve specific funding requirements such as travel support and other expenses.

2. Enhance Space-Based Science and Technology Programs

Modern astronomy, astrophysics, planetary and space sciences require space-based

observations and associated technology. The benefits to Greek society extend beyond purely scientific reasons and relate to commercial and government programs. Technology benefits such as telecommunications, advanced manufacturing, computation and a variety of applications for the benefit of Greek society including remote sensing advances are all related to enhanced space-based programs. Greek astronomy and space sciences need to take advantage of these opportunities by becoming integrated and participating in European and international programs. Greek scientists, engineers and technologists can participate in international or local teams that compete for European grants, in instrumentation, mission, communications and computing aspects; these can take the form of long-term development programs or focused, mission-specific developments.

3. Broaden the Scope of Training Graduate Students to Improve Employment Opportunities

Science and technology, including astronomy and space sciences, are becoming increasingly interdisciplinary and multi-discipline oriented. Although training still requires traditional, focused approaches, today's markets and competitive environments also demand innovative, broadened skills. In particular, the advances in information, present opportunities as well as challenges: Scientists and engineers need to be skilled in the rapidly changing computing and information environments in order to be successful in their fields. For the younger generations, these are important not just for the conduct of their science but also to give them versatility in employment. For graduate students in the astronomical sciences, who already possess basic scientific and mathematical skills, broadened training in technical and computing areas can provide them with new opportunities. The benefits here are two-fold, such training will assure the viability of graduate training in university astronomy programs, i.e. demonstrate the relevance of enhanced astronomical training; and since pure astronomy jobs are by their nature limited, it will allow the exposure to astronomy to scientists and engineers working in related fields.

4. Utilize Existing Astrophysical and Space Data

The advances of the World Wide Web and the Internet afford Greek astronomers opportunities which did not exist a few years ago. Large amounts of astronomical, space sciences and remote sensing data are now freely available on the WWW or can be purchased at small costs. These include multi-year archival databases as well as newly acquired data sets. Access to such databases can yield many benefits and is relatively cheap to implement. Besides the obvious scientific returns, e.g. for multifrequency observations of celestial sources utilizing space-based and ground-based observations; high-energy astrophysics, etc., just to mention a couple of examples; there are additional technical benefits: University students can become trained in the access and usage of diverse databases and in Internet technology. These benefits can extend beyond astronomy itself to forefront computer and computational fields such as "data mining", distributed databases and knowledge

discovery and information. Finally, collection of data by amateur astronomers has proven of great value to astronomy world-wide. Ways should be explored to encourage participation by amateur astronomers in observing and data collection. This will have the added benefit of popularizing astronomy among the Greek public.

5. Maintain a Strong Theoretical Astrophysics Program

Theory provides strong foundations required in science, including astronomy and astrophysics. Theoretical research is the means by which observational or experimental information is converted to knowledge. Greek astronomy and astrophysics are particularly strong in theory. Modern advances as outlined above
should not detract from strong theory research and educational programs. What is needed is an increased emphasis in theoretical quality. Even though we have argued
for an increased emphasis in observational astronomy, care must be taken not to compromise the overall theoretical quality of astrophysics programs.

6. Make Major Upgrades in Computing Facilities

Readily available computing power is now the life blood of modern science. To retain the competitiveness of Greek astronomy and astrophysics, a major effort is necessary in this area. Resource allocations recommended here are necessary: Having professional computer engineers to install and maintain the computing hardware in departments; providing high speed links between each department or center and the outside world to foster national and international collaborations, and to enable use of the Internet as a means of exchanging ideas and accessing databases; purchasing and upgrading computing hardware to raise the equipment to a level attained elsewhere, with a number of low-cost workstations equal to the number of personnel and additional high-power workstations in sufficient number to carry out the CPU-intensive computing. Along with these resources, thorough training in computing would provide additional prospects for job opportunities for young people, and collaboration with computer science departments may lead to the construction of a low-cost parallel supercomputer useful for large scale modeling and numerical simulations, thereby strengthening the theoretical astronomy programs.

7. Strengthen the Astronomical Sciences at the Major Greek Universities

We recommend strengthening the astronomical sciences at major universities in Greece such as Athens, Crete and Thessaloniki to better respond to the demands of the astronomical community. Universities are the homes of learning and education for the future generations and these should be given special attention.

VI. CONCLUSIONS

During the last 50 years the astronomical and space sciences have played a dominant role in the world's scientific enterprise. The vast number of new discoveries and realizations about Nature and the Universe have greatly contributed to our understanding of ourselves and our environment.

Such progress has been possible primarily because of the ingenious application of basic sciences into the technology of building sophisticated instruments such as space telescopes, x-ray and radio telescopes, digital detectors, and superfast computers. This progress promises to continue and Greek astronomers and other scientists must continue to successfully contribute to this enterprise.

In this report we have briefly described the state of the astronomical sciences in Greece and we have made a few important specific recommendations (Section V.A.), with which we hope the Greek scientific community would agree, and the Greek Government would support. We have also made several other recommendations (Section V.B.) that would be crucial for the healthy progress of the astronomical sciences in Greece, in particular for the young new generation.

We consider that we have been privileged and honored to be able to prepare and present this report, and we wish to thank all our colleagues in Greece that have assisted us in so many ways.