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Committee on the Peaceful Uses of Outer Space

Report on the Ninth United Nations/European Space Agency Workshop on Basic Space Science: Satellites and Networks of Telescopes—Tools for Global Participation in the Study of the Universe

(Toulouse, France, 27-30 June 2000)

Contents

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I. Introduction

A. Background and objectives

1. The Third United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE III) and the Vienna Declaration on Space and Human Development recommended that activities of the United Nations Programme on Space Applications promote collaborative participation among Member States at both the regional and international levels, emphasizing the development of knowledge and skills in developing countries.[1]

2. At its forty-second session, in 1999, the Committee on the Peaceful Uses of Outer Space endorsed the programme of workshops, training courses, symposia and conferences planned for 2000.[2] Subsequently, the General Assembly, in its resolution 54/67 of 6 December 1999, endorsed the United Nations Programme on Space Applications for 2000.

3. Pursuant to resolution 54/67 and in accordance with the recommendation of UNISPACE III, the Ninth United Nations/European Space Agency (ESA) Workshop on Basic Space Science: Satellites and Networks of Telescopes—Tools for Global Participation in the Study of the Universe was organized by the United Nations, ESA and the Government of France at the Centre national d'études spatiales (CNES), in Toulouse, France, from 27 to 30 June 2000. The workshop was co-organized by the Austrian Space Agency, CNES, the Committee on Space Research, ESA, the German Space Agency, the International Astronomical Union, the National Aeronautics and Space Administration (NASA) of the United States of America and the United Nations. CNES acted as host of the workshop on behalf of the Government of France.

4. The workshop continued the series of United Nations/ESA workshops on basic space science organized for the benefit of developing countries in India in 1991 and Sri Lanka in 1996 for Asia and the Pacific (see A/AC.105/489 and A/AC.105/640); in Colombia and Costa Rica in 1992 and Honduras in 1997 for Latin America and the Caribbean (see A/AC.105/530 and A/AC.105/682); in Nigeria in 1993 for Africa (see A/AC.105/560/Add.1); in Egypt in 1994 and Jordan in 1999 for western Asia (see A/AC.105/580 and A/AC.105/723); and in Germany in 1996 for Europe (see A/AC.105/657).

5. The main objective of the workshop was to provide a forum to highlight recent scientific results obtained using major space-based observatories in studies of the stars and the far reaches of the universe. Such satellite missions constitute an impressive means of studying all aspects of basic space science from space as a complement to studies being done from the ground. The question of the large volumes of data generated by such missions was discussed in relation to changing research needs within the scientific community, as was how access to the important databases maintained by major space agencies could be facilitated. The importance of data research and education based on space missions was discussed, together with the relevance of such missions to the needs of developing countries wishing to participate actively in the voyage of discovery through the universe. Future access to space by means, for example, of a world space observatory was seen as crucial. Anticipated long-term developments will necessitate early planning and an examination of the capabilities associated with the running of such an observatory.

6. The present report was prepared for submission to the Committee on the Peaceful Uses of Outer Space at its forty-fourth session and to its Scientific and Technical Subcommittee at its thirty-eighth session.

B. Programme

7. At the opening of the workshop, introductory statements were made by representatives of CNES, ESA and the United Nations. The workshop was divided into scientific sessions, each focusing on a specific issue. Presentations by invited speakers describing the status of their findings in research and education were followed by brief discussions. Sixty papers were presented by invited speakers from both developing and industrialized countries.

8. The workshop sessions focused on (a) archives of space missions and new observations from space and how to access them; (b) astrophysical data systems and how to utilize them; (c) in situ and remote exploration of the solar system; (d) experience with, results from and the need for networks of optical astronomical telescopes; and (e) the benefits of space science to society. Poster sessions provided an opportunity to focus on specific problems and projects in basic space science. Preceding the workshop, a World Space Observatory/Ultraviolet (WSO/UV) Interest Meeting was held at the venue of the workshop on 26 June 2000.

C. Attendance

9. Researchers and educators from developing and industrialized countries in all economic regions, but in particular from western Asia and Africa, were invited by the United Nations and ESA to participate in the workshop. Participants held positions at universities, research institutions, observatories, national space agencies and international organizations and in private industry, and were involved in all the aspects of basic space science covered by the workshop. Participants were selected on the basis of their scientific background and their experience with programmes and projects in which basic space science played a leading role.

10. Funds provided by the United Nations, ESA and CNES were used to cover travel and other costs of participants from developing countries. Some 80 specialists in basic space science attended the workshop.

11. The following 34 Member States were represented at the workshop: Algeria, Austria, Denmark, Ethiopia, France, Germany, India, Israel, Japan, Jordan, Kuwait, Lebanon, Malaysia, Mauritius, Pakistan, Paraguay, Peru, Poland, Romania, Russian Federation, Saudi Arabia, South Africa, Spain, Sudan, Syrian Arab Republic, Tajikistan, Togo, Tunisia, Uganda, Ukraine, United Kingdom of Great Britain and Northern Ireland, United States of America, Viet Nam and Yemen.

II. Observations and recommendations

12. Considering the current maturity of communications technology and the associated rapid evolution of possible benefits through improvements in available services, it is important to maintain the forward movement over the past 10 years in basic space science in the developing countries by expanding the communications capabilities to ensure that the service benefits supplied to the world by the major space agencies are not missed.

13. Technological advances in telescope and instrument design over the last 10 years, coupled with the exponential increase in computer and communications capability, have caused a dramatic change in the character of astronomical research. Large-scale surveys of the sky from space and ground are being initiated at wavelengths from radio to x-ray, thereby generating for the first time a panchromatic view of the universe. With these new capabilities at hand it now becomes feasible to initiate studies of the “virtual observatory” concept for mining astronomical data. Using this concept, the astronomical researcher will not only have access to the terabyte and pentabyte data sets, but will also be able to employ a full range of tools to exploit those data. The creation of a virtual observatory will require new collaboration between the astronomical and computer science communities. It will also provide an opportunity for further collaboration with other disciplines facing similar challenges and will be a venue for educational outreach. The virtual observatory must be globally oriented—as regards both access to archives and the interface to the researcher.

14. A stronger emphasis on international and regional cooperation needs to be developed to implement the network concepts associated with the telescopes distributed in the developing countries. Unless such cooperation efforts in strengthening basic space

science are further exploited, differences in regional development levels will be extremely difficult to overcome and could create sustainability problems in the development process of many developing countries.

15. The participants noted with satisfaction that the stimulus supplied by this series of workshops to the development of basic space science had been recognized by UNISPACE III in its support for the role of basic space science in laying a solid foundation for continued sustainable and accelerated development.

16. The participants also noted the progress made in increasing the active participation of developing countries in front-line space sciences, as had been emphasized in the assessment evaluation of the world space observatory concept carried out for WSO/UV.

17. The participants agreed that WSO/UV presented an opportunity for a major step forward, which could create a new and sustainable stimulus for basic space science on a worldwide scale, as well as open up new and unique opportunities to implement worldwide collaboration. Those opportunities could extend beyond the level of industrialization of participating countries in ways unique in the contemporary world.

18. The participants recommended that efforts be made to take advantage of the new opportunity to create possibilities for intellectual development in parallel with the progress made in sustainable development.

19. The setting up of amateur astronomical societies in countries where they did not already exist was of greatest importance and should be brought to the attention of those bodies which could facilitate it.

20. The participants appreciated the decisions taken by the International Telecommunication Union (ITU) at the World Radio Conference, held in Istanbul in 2000, concerning the extension of frequency bands for the benefit of the international astronomical community.[3]

21. Because of bandwidth limitations, the possibility for widely distributed availability of quality educational material in basic space science and its regular review with regard to relevance has been severely restricted.

22. The participants considered that the project to unify astronomical databases and to make combined information available to astronomical researchers and educators worldwide would create a very valuable resource for the international community.

23. The international astronomical community should be encouraged to consider the inclusion of information from photographic plate archives in future virtual observatory programmes by scanning and calibrating photographic information. This would expand the time period available to users of such a facility since information existed from more than 100 years ago.

24. The participants recognized the importance of the activities developed by the Working Group on Space Sciences in Africa since 1996 (see A/AC.105/657, para. 19), considered that those activities should be expanded and strongly recommended continued support for its work.

25. The participants were pleased to note the progress made in the implementation of the Network of Oriental Robotic Telescopes (NORT) project.

26. The participants noted with satisfaction the number of national observatory projects, which indicated a rising interest in western Asia. Their incorporation into the NORT project in the future was highly desirable, as it would reinforce education and research in astronomy in the region and would stimulate astronomical activities throughout all levels of society.

27. The participants recognized the activities of the Arab Union for Astronomy and Space Sciences (AUASS), which were bringing together individual and group interests throughout the region of western Asia.

III. Summary of presentations

A. Space astronomy, current missions and trends in the next millennium

28. Space astronomy allows access to wavelength regions that are not available to ground-based observatories. Collecting and analysing radiation emitted by phenomena throughout the entire electromagnetic spectrum, NASA's four "Great Observatories" will perform astronomical studies over many different wavelengths and overlapping in time, making possible concurrent observations. The Chandra X-Ray Observatory, deployed in July 1999, will observe x-ray

images and spectra of violent, high-temperature events and objects to help understand black holes, quasars and high-temperature gases. The Space Infrared Telescope Facility (SIRTF) to be launched in December 2001, is capable of observing in the near infrared, 3-180 micron wavelength range and will provide for imaging, photometry and spectroscopy. The primary science themes of the telescope are the detection and study of brown dwarfs and super-planets, proto-planetary and planetary debris disks, ultra-luminous galaxies and active galactic nuclei and deep surveys of the early universe. The detector arrays offer orders of magnitude improvements in capability over past infrared detectors.

29. Astronomical missions scheduled for 2005 and beyond are made possible by advanced technology development. The Space Interferometry Mission (SIM) will use optical interferometry technology, while the Next Generation Space Telescope (NGST) will require large, ultra-light and deformable mirrors and very sensitive instruments. SIM will determine the positions and distances of stars several hundred times more accurately than any previous programme, which will allow the mission to probe nearby stars for Earth-sized planets. SIM will also pioneer a technique to block out the light of bright stars to take images of areas close in to the stars. NGST, to be launched in 2007, will study how galaxies evolve, how stars and planetary systems form and evolve and what the life cycle of matter is in the universe. SIRTF, SIM and NGST are part of NASA's Origins programme and the Chandra Observatory is part of NASA's Structure and Evolution of the Universe programme.

B. Advanced projects design team

30. The NASA Jet Propulsion Laboratory (JPL) pioneered the concept of concurrent engineering by creating the Advanced Projects Design Team (Team X) in April 1995.

31. The objectives of Team X are:

(a) To improve the speed and quality of JPL mission concepts and to create a continuing study process with dedicated facilities, equipment, procedures and tools to produce the best possible proposals;

(b) To develop an initial mission requirements database that can be continually updated and tapped for future project phases;

(c) To develop experienced engineers into mission generalists.

32. Team X enables mission principal investigators and their design teams to plan new mission proposals efficiently.

33. Team X consists of 15 mission design individuals, plus a team leader and a documentarian. Each assigned engineer is responsible for presenting his discipline's expertise and interests. The team leader coordinates and leads the study and is the customer's primary contact before, during and after study sessions. The documentarian establishes electronic files, records significant technical discussions and ensures that study results are properly documented.

34. Team X products are mission design feasibility studies and reviews. A study lasts one to two weeks and results in a 30-80-page report that includes equipment lists, mass and power budgets, system and subsystem descriptions and a projected mission cost estimate. A review is a one- or two-day discussion of a proposal a request for information, a request for proposal, or similar activity. Each team member summarizes his or her view during the final hour and an abbreviated report is the product.

35. During the workshop, a 2½-hour live video conference was conducted with Team X in Pasadena on the development of a satellite mission to planet Mars.

C. Exploration of the Sun

36. In the investigation of the Sun, instruments aboard spacecraft play an important role as they allow the observation of electromagnetic radiation that cannot be received by ground observatories owing to the blocking effect of the Earth's atmosphere. The particle emissions of the Sun, in particular the solar wind, can only be observed from spacecraft that are outside the magnetosphere. In the early 1970s most of the general characteristics of the solar atmosphere above the photosphere and of the solar wind were established by a number of exploratory spacecraft. (NASA's Orbiting Solar Observatory (OSO) satellites and the Skylab Apollo telescopes, together with

plasma- and particle-detection spacecraft from space agencies, were determinant in the knowledge of the solar corona and its relation with the solar wind.)

37. Since that time, space missions have been designed to investigate the physics of the phenomena that had been observed in the exploratory period. The Solar Maximum Mission (SMM) in the 1970s and 1980s specialized in the study of solar flares and led to the discovery of the total solar irradiance variation.

38. Since 1991, the Yohkoh satellite has been studying the very hot solar atmosphere by producing solar images in x-ray and gamma-ray spectra. A complete solar cycle has already been observed and imaged by Yohkoh.

39. Since 1996, the joint ESA/NASA Solar and Heliospheric Observatory (SOHO) mission has been carrying out the most comprehensive space investigation of the Sun by means of a coordinated set of instruments that study the interior solar structure and solar dynamics by helioseismology (solar oscillations), the solar irradiance, the physical phenomena in the solar atmosphere that heat the corona and give rise to the solar wind (extreme UV (EUV) images and spectra), the composition of the hot solar atmosphere and of the solar wind (mass and charge spectroscopy) and the extension of the solar wind to form the heliosphere (H Lyman-alpha mapping of the sky). Since 1998, the Transition Region and Coronal Explorer (TRACE) has complemented the SOHO observations of the solar EUV atmosphere by producing very high resolution images at selected wavelengths.

D. Planet Mars

40. NASA's Mars Global Surveyor (MGS) spacecraft was launched in November 1996 and reached Mars in September 1997. The spacecraft then spent the next 18 months in alternating periods of aerobraking and science data collection as the orbit was modified to the desired near-polar, approximately circular, two-hour period required for mapping. The average altitude above the Martian surface is currently some 400 kilometres. MGS began systematic mapping of the planet in March 1999, using a variety of scientific instruments that include a magnetometer/electron reflectometer (MAG), thermal emission spectrometer (TES), Mars orbiter laser altimeter (MOLA) and Mars orbiter camera (MOC). After one year of mapping, those instruments continue to reveal a number of fundamental surprises about the evolution of Mars as a planet.

41. For example, the MAG instrument has identified regions characterized by contrasting polarity bands whose intensity locally exceeds 1,500 nanotesla. In the Sirenum region, those linear anomalies extend for up to 2,000 kilometres in length and confirm that Mars' internal dynamo shut off very early in the planet's history. TES measures energy emitted from Mars in the middle portion of the thermal infrared part of the electromagnetic spectrum. TES has collected more than 44 million spectra of Mars with a spatial resolution of up to 3 kilometres. Interpretation of those spectra demonstrates that there are isolated occurrences of coarse-grained hematite that may have formed in standing bodies of water. In addition, TES indicates fundamental differences between the volcanic compositions within the northern plains (andesitic) and the southern highlands (basaltic) that provide additional clues regarding the evolution of the planet.

42. The MOLA instrument obtained more than 330 million measurements of the Martian topography during the first year of mapping. The results reveal a regional slope towards the northern lowlands, the tallest volcano in the solar system at 26 kilometres in height (Olympus Mons) and one of the largest known impact basins at 2,100 kilometres across and 9 kilometres deep (Hellas). Such topography data play an important role in gravity studies, which confirm the presence of a thinner, stronger surface layer in the north whose southern extent is not well correlated with the global topographic dichotomy. Moreover, the gravity signature associated with the Tharsis region does not include Olympus Mons, thereby confirming the relative youth of the volcano. Finally, signatures associated with the Chryse region indicate that buried portions of the large outflow channels extend well out into the northern plains. MOC has imaged many local portions of the Martian surface at a resolution of as high as 2-3 metres per pixel. To date, more than 20,000 such images have been released to the public and indicate a startling array of landforms ranging from bizarre polar landscapes to widespread wind-sculpted terrains to heavily modified, ancient water-carved valleys that were formed over an extended period of time.

43. The current MGS mapping mission is scheduled to continue until February 2001 and should ultimately provide data leading to a better understanding of how Mars has evolved over time. Spacecraft operations throughout the mission have been conducted by JPL.

E. Virtual observatory concept

44. Technological advances in telescope and instrument design over the last 10 years, coupled with the exponential increase in computer and communications capability, have caused a dramatic change in the character of astronomical research. Large-scale surveys of the sky from space and ground are being initiated at wavelengths from radio to x-ray, thereby generating for the first time a panchromatic view of the universe. With these new capabilities at hand it now becomes feasible to initiate studies of the "virtual observatory" concept for mining the vast astronomical archives and creating a new engine of discovery for astronomy.

45. Using this concept, the astronomical researcher will not only have access to the terabyte and pentabyte data sets, but will also be able to employ a full range of tools to exploit those data.

46. The creation of a virtual observatory will require new collaboration between the astronomical and computer science communities. It will also provide an opportunity for further collaboration with other disciplines facing similar challenges and will be a venue for educational outreach. The virtual observatory must be globally oriented—as regards both access to archives and the interface to the researcher.

F. Archives of space missions

47. The Strasbourg Astronomical Data Centre (CDS) is dedicated to the collection and worldwide distribution of astronomical data and related information. It is located at the Strasbourg Astronomical Observatory in France.

48. CDS hosts the Set of Identifications, Measurements and Bibliography for Astronomical Data (SIMBAD) astronomical database, the world reference database for the identification of astronomical objects.

49. The goals of CDS are:

(a) To collect all useful information concerning astronomical objects that is available in computerized form: observational data produced by observatories around the world, on the ground or in space;

(b) To upgrade those data by critical evaluation and comparison;

(c) To distribute the results to the astronomical community;

(d) To conduct research based on the data.

50. CDS has signed international exchange agreements with the NASA Astrophysics Data Center; the National Astronomical Observatory of Japan in Tokyo; the Russian Academy of Sciences; the Starlink network of the Particle Physics and Astronomy Research Council of the United Kingdom; the Beijing Observatory; the University of Porto Allegre, Brazil; the University of La Plata, Argentina; and the InterUniversity Centre for Astronomy and Astrophysics of India.

51. CDS plays, or has played, a part in most of the major astronomical space missions: generating guide star catalogues (the European X-Ray Observatory Satellite (EXOSAT), the Infrared Astronomical Satellite (IRAS), Hipparcos, the Hubble Space Telescope, the Infrared Space Observatory (ISO) and the X-Ray Astronomy Satellite (SAX)), helping to identify observed sources (Hipparcos, Tycho and the Roentgen Satellite (ROSAT)) or to organize access to the archives (International Ultraviolet Explorer (IUE)) and so on. CDS contributes to the X-Ray Multi-Mirror (XMM) mission Survey Science Centre, with the High-Energy Team at the Strasbourg Astronomical Observatory.

G. Astrophysical data system

52. The NASA Astrophysics Data System (ADS) provides access to abstracts and scanned articles of the astronomical literature. Funded by NASA, the project provides free access to those abstracts and articles to anybody with Internet access worldwide. There are three databases in ADS: (a) the physics database, containing almost 900,000 references; (b) the astronomy database, with almost 550,000 references; and (c) the instrumentation database, which has almost

600,000 references. The abstracts can be searched through a sophisticated search system.

53. The scanned articles in the ADS article service are increasing in number continuously. ADS has almost 1 million pages scanned so far. All major and most smaller astronomical journals have been scanned back to volume 1. The *Monthly Notices of the Royal Astronomical Society* are currently being scanned back to volume 1. This is the last major journal to be completely scanned and on-line. In cooperation with a conservation project of the Harvard libraries, ADS is currently scanning microfilms of historical observatory literature. This will provide access to an important part of the historical literature.

H. Networks of optical astronomical telescopes

54. The development towards larger and larger telescopes has lead to discussions about the future of many smaller telescopes. Not all science can be done with a few nights on a giant telescope. At the same time, the advances in automation and communications open up opportunities for more efficient and time-saving observing schemes, which means that very large data sets can be obtained and handled. Yet a much larger community can participate and do real scientific work. Amateurs and students become part of the scientific community and can contribute in a significant way in certain areas of astrophysics. This development is particularly important for modern studies of variable stars and the monitoring of the sky for near-Earth objects and other special events.

55. Under the umbrella of AUASS, the NORT proposes, as a first step, to implement university courses in astrophysics and space sciences by telescope training in national observatories with 60 cm-1 metre diameter class telescopes. As a second step, the project proposes a network of 2 metre class robotic telescopes to monitor mainly variable stars and near-Earth objects in photometry, spectrography and polarimetry.

56. The NORT project will be open for cooperation with similar telescope facilities in other regions. At the workshop, projects for and results from optical astronomical telescope facilities have been presented by the following countries: Algeria, Ethiopia, India, Jordan, Lebanon, Malaysia, Mauritius, Pakistan, Paraguay, Peru, Saudi Arabia, South Africa, the Syrian Arab Republic, Togo and Tunisia.

I. Hands-on astrophysics

57. The hands-on astrophysics material uses the unique variable star database of the American Association of Variable Star Observers (AAVSO). It is a curriculum suitable for college and university science, mathematics, and computer science classes and directly involves students and teachers in the scientific process.

58. Hands-on astrophysics helps students acquire fundamental science skills and develop an understanding of basic astronomy concepts; it provides interdisciplinary connections and takes students through the whole scientific process while working with real data. The curriculum also informs students about variable stars and their importance to the professional astronomical community and gives them the necessary information and skills to study variable star behaviour or to become amateur variable star observers.

59. Students learn the necessary skills to make observations, analyse their data with graphing and statistical techniques, make predictions and compare predicted and observational values, as well as how to develop sophisticated mathematical models. Students will learn about variable stars by using the activities, software, charts, slide sets and videos that accompany the teacher and student manual. Students will be able to access the AAVSO database and share their investigations and observations with other students via an Internet site specially developed for the project.

60. The study of variable stars is particularly suited to science, mathematics and computer education. Students can observe variable stars and analyse the brightness changes in the stars they observe by using the database of 600,000 observations and the computer programs provided. The amount of data and the mathematical refinement techniques will give reasonably accurate results. Students will understand that their observations can be reliable and that their data can be useful enough to be used by professional astronomers.

61. In 1999, the hands-on astrophysics material was provided by AAVSO to a number of telescope facilities inaugurated or supported by United Nations/ESA

workshops on basic space science for use with the telescopes and in the teaching curricula (Honduras, Jordan, Morocco, Paraguay, Philippines and Sri Lanka).

J. Astrophysics for university physics courses: a teaching module developed for the United Nations/European Space Agency workshops on basic space science

62. A teaching module was developed for the United Nations/ESA workshops on basic space science presenting an array of astrophysical problems, any one or a few of which can be selected and used within existing physics courses on elementary mechanics or on heat and radiation, kinetic theory, electrical currents and in some more advanced courses. The module presents an answer to the problem of how to introduce astrophysics in physics courses at the university level, in particular in developing countries.

63. Such astrophysics problems are designed to be an interesting and challenging extension of existing physics courses, to determine the student's understanding of physics by testing it in new realms and to stretch the student's imagination. A brief tutorial on astrophysics is provided with each problem so that the physics teacher can present the problem in class. The higher-level problems start with a brief introduction to the physics involved.

64. The teaching module is structured into the following key sections: orbits and Kepler's third law; the solar system; neutron stars and clusters of galaxies; thermal radiation; the lives of stars; cosmic magnetic fields; and high-energy astrophysics.

65. All the problems require compact algebraic and numerical solutions that can easily be translated into physics. For many problems, the solution is shorter than the statement of the problem.

66. Astrophysics is an attractive science not only because it stretches the imagination but also because it is highly interdisciplinary. Astrophysics involves atomic physics, nuclear physics, fluid and plasma physics, solid state physics, chaos theory, organic chemistry, special and general relativity and more. Students are trained in solving specific problems, however, and they acquire a broad view of science largely through solving many kinds of specific problems. Thus, the problems in this teaching module provide a focus for students to which the broader astrophysical challenges can be linked. Most of the text provided with each problem is designed to highlight the broader questions and challenges, which are then crystallized in the given specific problems that are to be solved by the students.

Astrophysics as a frontier science

67. Even students can formulate good questions suitable for research. Some observations made by the Hubble Space Telescope have been requested and will be investigated by high-school students. The frontier nature of astrophysics makes teaching it difficult, however. Even the professional astrophysicist soon learns to admit to some students' questions that he or she does not know and preferably also to suggest that they study the problem together. Indeed, the problems in the teaching module will be difficult to teach because students will inevitably ask questions that go well beyond the specific problem and the tutorial astrophysics provided. Nevertheless, the value of students' formulating questions far exceeds the discomfort of the teacher admitting that he or she does not know. Many physics students merely memorize their physics. The astrophysics breaks them out of memorization and gets them to think independently. Students' questions are a sign of their progress.

Didactics

68. In approaching the theoretical examination of a newly observed phenomenon one should not start with a computer but by determining which kinds of physics are relevant. It is essential to select a few physical parameters and construct a minimum of analytical equations that contain the essential physics. These are often called "back-of-the-envelope" calculations. In astrophysics, one first considers appropriate forms of energy without worrying at the outset about the detailed forces that lead to those energies. One needs to ascertain whether gravitational, nuclear, kinetic or electromagnetic energies or some exchange between two of them are in play and what the main parameters are, such as size or mass of an object, that influence these energies. Sometimes answers can be found by dimensional analysis. It matters little if the numerical coefficients in such estimates may be off by a factor of

two or three. Several of the problems in the teaching module emphasize order of magnitude of analysis and dimensional analysis. In particular, some problems ask students to solve differential equations by a one-step integration, which explicitly brings out the main physical parameters.

Group collaborative learning

69. Frontier science is a collaborative venture. Discussion is an integral part of learning and research in astrophysics. If necessary, the problems in the teaching module can be presented and solved as part of a lecture, but they are selected and written so that they can be discussed and solved by small groups of students, preferably during a class period. Groups of two, three or four students work well, depending in part on the physical limits of the seating arrangement.

70. Students working in groups take much time. The teacher can lecture about three problems in the time that student groups need to do one. Compared with pure lecture courses, some topics of the course must be omitted because the time is no longer available. Nevertheless, assuredly the students will understand the one problem they solved and the teacher will have evidence of it. This is much more useful to the student, in the long run, than some additional material stored incompletely in his or her memory.

71. The teaching module is currently under review at telescope facilities inaugurated or supported by and hosts of United Nations/ESA workshops on basic space science (Colombia, Costa Rica, Egypt, France, Germany, Honduras, India, Jordan, Mauritius, Nigeria, Paraguay, Philippines and Sri Lanka).

IV. World space observatory

72. The United Nations, through its Office for Outer Space Affairs, and ESA have jointly organized a series of workshops on basic space science since 1991 (see para. 3). The implementation of the recommendations of those workshops has strengthened the scientific infrastructure in developing countries. One of the proposals from the workshop participants is the concept of a world space observatory, a satellite mission focusing on the ultraviolet part of the electromagnetic spectrum, with international participation, including that of developing countries.[4]

73. The results of a study to evaluate a World Space Observatory (WSO/UV) reference mission (CDF-05(A)), carried out under the ESA General Studies Programme (Long-Term Planning) were presented to the workshop participants and showed the feasibility of a WSO/UV on a time scale of some six years. The possibility of a joint interest mission involving both the developing countries and the more advanced countries is clearly a more productive approach than a mission that would be of interest only to the developing countries. Such a mission with a broader scope would actually generate a mutually beneficial synergy in the worldwide community of basic space scientists and would thus be a far more effective stimulus for its sustainability. The WSO/UV project model incorporates a 1.7-metre telescope, spectrographs and imagers, orbiting in the Lagrange Point L.2. The study determined that a real opportunity existed at the present time, with a possible launch in 2006. To utilize that opportunity, further avenues to organize broad and early participation need to be explored with urgency and a further study needs to be made of implementation details and associated funding sources. Future workshops could make an important contribution to further exploration of the practical aspects associated with the implementation of the broad multinational participation, in particular for developing countries, both in the project development phase and the operational phases of such a WSO/UV concept mission.

Notes

[1] See *Report of the Third United Nations Conference on the Exploration and Peaceful Uses of Outer Space, Vienna, 19-30 July 1999* (United Nations publication, Sales No. E.00.I.3), chap. I, resolution 1, para. 1 (e) (ii), and chap. II, para. 409 (d) (i).

[2] *Official Records of the General Assembly, Fifty-fourth Session, Supplement No. 20* and corrigendum (A/54/20 and Corr.1), para. 52.

[3] See J. Andersen, “Astronomy and the degrading environment”, *Science*, vol. 288, 21 April 2000, pp. 443 and 444.

[4] See *Report of the Third United Nations Conference ...*, op. cit., chap. II, para. 207).

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3. *Contact addresses of astronomical telescope facilities inaugurated or supported through the United Nations/European Space Agency workshops on basic space science*

Centro Internacional de Física, Universidad de los Andes, Apartado Postal 49490, Bogotá, Colombia.
http://aether.lbl.gov/www/projects/GEM/

National Research Institute of Astronomy and Geophysics, Kottamia Observatory, Helwan, Cairo, Egypt.
http://www.sti.sci.eg/scrci/nriag.html

Universidad Nacional Autónoma de Honduras, Apartado Postal 4432, Tegucigalpa M.D.C., Honduras.
http://www.unah.hn

Higher Institute of Astronomy and Space Sciences, Al al-Bayt University, P.O. Box 130302, Mafraq, Jordan.
http://www.aabu.edu.jo/

Universidad Nacional de Asunción, Ciudad Universitaria, San Lorenzo, Paraguay.
http://www.una.py/

Philippine Atmospheric, Geophysical and Astronomical Services Administration, Asia Trust Building, 1424 Quezon Avenue, Quezon City, The Philippines.
http://w3.itri.org.tw/k0000/apec/Philipin/P14.htm

Arthur C. Clarke Institute for Modern Technologies, Katubedda, Moratuwa, Sri Lanka.
http://www.slt.lk/accimt/