VII

SUMMARY

The Astronomy Missions Board (AMB) was established by the National Aeronautics and Space Administration in the fall of 1967 and charged with the creation of an exciting, significant, and forward-looking long-range program in space astronomy. The Board was asked to formulate the major unsolved problems of astronomy, to define the measurements from space that would assist in their solution, and to specify the types of instruments, spacecraft, and missions needed to perform the required measurements.

ASTRONOMY AND SPACE RESEARCH

Astronomy has a far greater potential for advancement by the space program than any other branch of science. Telescopes working on the surface of the Earth can only observe those portions of the electromagnetic spectrum that penetrate through the Earth's atmosphere, chiefly those of visible light, and radio waves in the band from a few millimeters to about 20 m in wavelength. Astronomical instruments located in space can now reach the remaining regions of the electromagnetic spectrum. Thus, by coordinated programs of observation, in which the same object is observed over the entire range of the electromagnetic spectrum by telescopes in space and on the ground, the most fundamental problems of astronomy may be brought within range of solution.

The new multiwavelength approach to astronomy requires the combined efforts of scientists working in many fields of the natural sciences, since radically different experimental and theoretical techniques are needed to observe and interpret radiation from different parts of the spectrum. In order of decreasing energy, the principal subdivisions of the spectrum are: gamma rays, X-rays, ultraviolet radiation, visible light, infrared, and radio waves. The measurement of particles and magnetic fields in space has also come to be recognized as a major tool for the exploration of the universe. The acquisition of the data alone involves the application of talent from many different branches of experimental physics and engineering. Moreover, the data are of keen interest not only to astronomers but to research workers in many branches of theoretical physics, chemistry, mathematics, geology, and geophysics, and perhaps also biology. Thus, the multiwavelength approach is also a multidisciplinary approach and space astronomy is an activity that promotes the unification of science.

Because of the specialized nature of the instrumentation employed in different spectral regions and the special requirements of solar and planetary observations, the Board carries on its work with the aid of seven specialized panels, each concerned with a different subdiscipline of astronomy: solar, planetary, particles and fields, X-ray and gamma-ray, ultraviolet, infrared, and radio. In addition, several working groups are engaged in studying the needs of supporting research and technology, complementary ground-based research, education and training of scientific manpower, and the role of man in space astronomy.

THE MAJOR UNSOLVED PROBLEMS IN ASTRONOMY

Each of the seven panels began its work by formulating the major questions it was seeking to answer by the application of its special techniques and by showing how space astronomy could make unique contributions to their solution in the next 10 years. Full discussion of these scientific questions will be found in the reports of the panels and only two examples will be given here.

The Crab Nebula is a fine example of the usefulness of space observations. This enormous cloud of glowing gas, left over from the explosion of a star in A.D. 1054, radiates in all regions of the spectrum from long radio waves to X-rays. Close to the center of the nebula is a pulsar which may be a neutron star, in which matter is compressed to a density of about 10 billion tons per cubic inch, probably resulting from the collapse of the central core of the exploding star. The pulses have now been observed in radio waves, visible light, and X-rays. Taken together, the combined observations show that the total rate of energy radiated by the pulsar is over 100 times greater than that radiated by the sun, despite the fact that the pulsar is only 6 miles or so in diameter.

A second set of measurements suggests that we may be able to observe the cosmic fireball that occurred at the beginning of the expansion of the universe. Radio-astronomy measurements made on the ground at many wavelengths between 3 mm and 79 cm have shown that space is filled with blackbody radiation with a temperature of about 3° K. Such a background of microwave radiation was predicted by George Gamow to arise naturally from an early hot phase in an evolving universe, and if the radiation is indeed found to have a cosmological origin it would provide strong evidence in favor of an evolving model of the universe and against steady-state models in which matter is being continuously created. The peak intensity of the microwave background occurs at a wavelength of about 1 mm. Since the Earth's atmosphere is opaque at this and shorter wavelengths, it has been impossible with ground-based equipment to verify whether the intensity at shorter wavelengths does indeed decrease as predicted. As a fundamental cosmological phenomenon, the microwave background has a high priority for study from space.

The foregoing are only two examples of the many astronomical mysteries that can be cleared up by the methods of space astronomy. The most pressing of these problems form the basis for the design of a long-range program. A much longer list of problems is given in the subdiscipline reports of part II. They are representative of the many well-defined scientific problems which can now be solved by the multiwavelength approach.

A second major justification for space astronomy consists of the many unexpected discoveries that are sure to be made, as they always are, when a new region of the spectrum is first explored or when a new instrument of unprecedented power is put into operation. The recent history of astronomy is full of examples of such unexpected discoveries. For example, the first radio and X-ray sources were both discovered accidentally, and many of the recent discoveries of strong emitters of infrared radiation could not have been predicted in advance.

PREPARATION OF THE LONG-RANGE PLAN

Once the scientific problems had been formulated, each panel considered how its special techniques could be applied to acquire knowledge in an orderly, systematic fashion by a series of space missions involving equipment of increasing size and sophistication. Each panel was in fact asked to draw up so-called minimum and maximum programs, the former being defined to proceed at the minimum rate necessary to attract and retain the interest of the leading workers in the field. Conversely, the maximum program was designed to proceed at the fastest possible rate consistent with available scientific and technical manpower. The full Board accepted the judgment of each panel as to the order in which they should be flown. But the rate at which each of the panels' programs was recommended for implementation was decided by the Board, after examining carefully the competing claims of the separate panels.

In effect, the Board decided the percentages of the budget to be allocated to each of the subdisciplines in a given year. In fact, two such programs are presented in this report. The first is a so-called minimum balanced program, which recommends an annual expenditure of $250 million for an average year in the mid-1970's (fiscal years 1974 to 1976 time period). The Board believes that this is the minimum figure at which viable long-range programs in all of the subdisciplines can be supported. The second, or optimum program, calls for an average annual expenditure of $500 million during the same period and is envisaged as the optimum program that can be supported with available manpower. Both the optimum and minimum balanced program cost figures do not include provision for the cost of the largest instruments, among them a 120-inch diffraction-limited telescope for optical stellar astronomy, which are planned for a National Astronomical Space Observatory (NASO) envisaged for the early 1980's.

SOME NEW DIRECTIONS

Comparisons with the current NASA space-astronomy program reveal some of the new directions which will be required to implement the AMB plan. Perhaps the most significant change is an increased effort in X-ray and gamma-ray astronomy. Less than 10 percent of the current NASA effort, X- and γ-ray astronomy amounts to about a quarter of the AMB program, which assigns approximately equal levels of effort to optical, solar, and high-energy astronomy. The increase needed in the minimum balanced program is a major start in fiscal year 1971 on a new spacecraft with the pointing, telemetry, and general sophistication of an Explorer-class spacecraft but with a payload size capable of carrying large area X-ray detectors, spark chambers, and Cerenkov telescopes, as well as particles and fields experiments in the 1- to 5-ton range. Also included is the adaptation of a future OAO spacecraft or an equivalent vehicle to carry a state-of-the-art stellar X-ray imaging instrument comparable to existing solar instrumentation. Later, stellar imaging X-ray telescopes of about 1-m aperture, 10-meter focal length will be required.

The optical ultraviolet astronomy program has as a mid-1970's goal observations requiring the equivalent of a 1- to 1.5-m telescope with diffraction-limited performance, as an essential intermediate scientific and technological step toward the 3-meter large space telescope of the 1980's. This could be achieved either through a new spacecraft design or by upgrading an evolutionary OAO program. Also possible would be an early developmental model of the 3-meter telescope, structurally similar but with degraded pointing, mirror quality, etc. providing performance equivalent to a 1.0 to 1.5 meter diffraction-limited telescope.

The infrared astronomy program has a most pressing need for research and development of detectors and small cooling systems which will permit infrared observations with much greater efficiency, as is commonplace at both shorter and longer wavelengths. Such advances could continue the present high rate of discovery of new classes of astrophysical phenomena from the ground and from airplane observatories.

Observations of astrophysical objects in the longwave radio portion of the spectrum with the minimum angular resolution required to distinguish individual sources may require an antenna made of wires surrounding an enormous area 6 miles in diameter. However, a remote possibility of making similar observations by "supersynthesis" interferometric techniques must be studied before this large electronically filled aperture is initiated.

The continuing need for observation of the solar surface with an effective angular resolution of 5 arcsec will require the development of a ground-controlled solar spacecraft with the instrumental sophistication of the ATM–A. This spacecraft may evolve through a series of upgraded missions to achieve effective 1 arcsec performance by the late 1970's, or an entirely new 1 arcsec spacecraft will be needed. This, too, is an essential scientific and technological step needed to acquire solar observations with spatial, spectral, and time resolution intermediate between the ATM–A and the 0.1 arcsec solar telescopes of the National Astronomical Space Observatories of the 1980's.

Observations of the planets from Earth orbit will be accomplished with the instruments of the planned OAO's and a Small Astronomy Satellite optimized for planetary observations.

The acquisition of data on cosmic-ray particles and fields in the interplanetary medium requires a careful programing of small fractions of the missions to the planets, and the joint use of the "heavy Explorer" spacecraft for high-energy astronomy.

An important element in the balanced acquisition of essential astrophysical data in the AMB plan is the continuing requirement for the smaller space experiments—the aircraft, balloons, rockets, and small Explorer-class satellites. Though less dramatic and unimposing by their nature, they have a great potential for economic and timely measurements of important data that can complement the other space-based and ground-based wavelength observations.

An essential part of the AMB endeavor to project the level of space astronomical research as far as possible into the future was an assessment of the availability and enthusiastic interest of excellent people—scientists and supporting specialists, including several engineering and technical groups skilled in the measurement of astronomical radiation. Continuity, breadth, and active competition for flight opportunities among these groups must be maintained by a strong NASA program in Supporting Research and Technology (SR&T).

Both SR&T and NASA's Advanced Research and Technology (AR&T) program must press forward to develop essential instrumentation such as lightweight optical mirrors, improved X-ray reflectors and detectors, X-ray photometric standards, electronic imaging systems, improved grating technology, infrared sensors, and small cryogenic systems, devices which will be useful in ground-based observatories of the future as well as space experiments. Support is also essential for the experimental and theoretical research in related areas of atomic and nuclear physics that will insure progress in analyzing the new observations resulting from these technological advances.

In a properly integrated program of federally supported astronomy, NASA should have a responsibility to support particular ground-based instruments, especially those which are most closely and directly related to NASA's mission. Specific instruments, which are of comparable expense to some spacecraft and might be defended as separate line items in the NASA budget, should include special-purpose monitoring telescopes of intermediate (60- to 100-inch) aperture, large optical telescopes in both hemispheres, and a large steerable paraboloid radio telescope.

The Astronomy Missions Board believes that the long-range program described in this position paper fully complies with NASA's request for the creation of a worthwhile and imaginative long-range program in space astronomy. It includes a careful assignment of priorities and balanced allocation of resources in order to optimize scientific progress on such problems as the origin of the universe, the course of stellar evolution including the ultimate destiny of the Sun and solar system, the existence of other planetary systems, some of which may support other forms of intelligent life, and other problems with deep philosophical significance which are of great interest to everyone and are therefore properly supported by public expenditure. The Board proposes this program to NASA and to the country with its unanimous and enthusiastic endorsement. We believe that the program is one in which scientists from many disciplines will want to participate, and that its implementation will result in a vast accumulation of new and fundamental scientific knowledge.

Finally, we again wish to point out that we regard this report as an ongoing working paper to be reviewed and then revised and updated as necessary, so that it always reflects the best judgment of the scientific community and the march of scientific discovery.

Appendixes

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APPENDIX B

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