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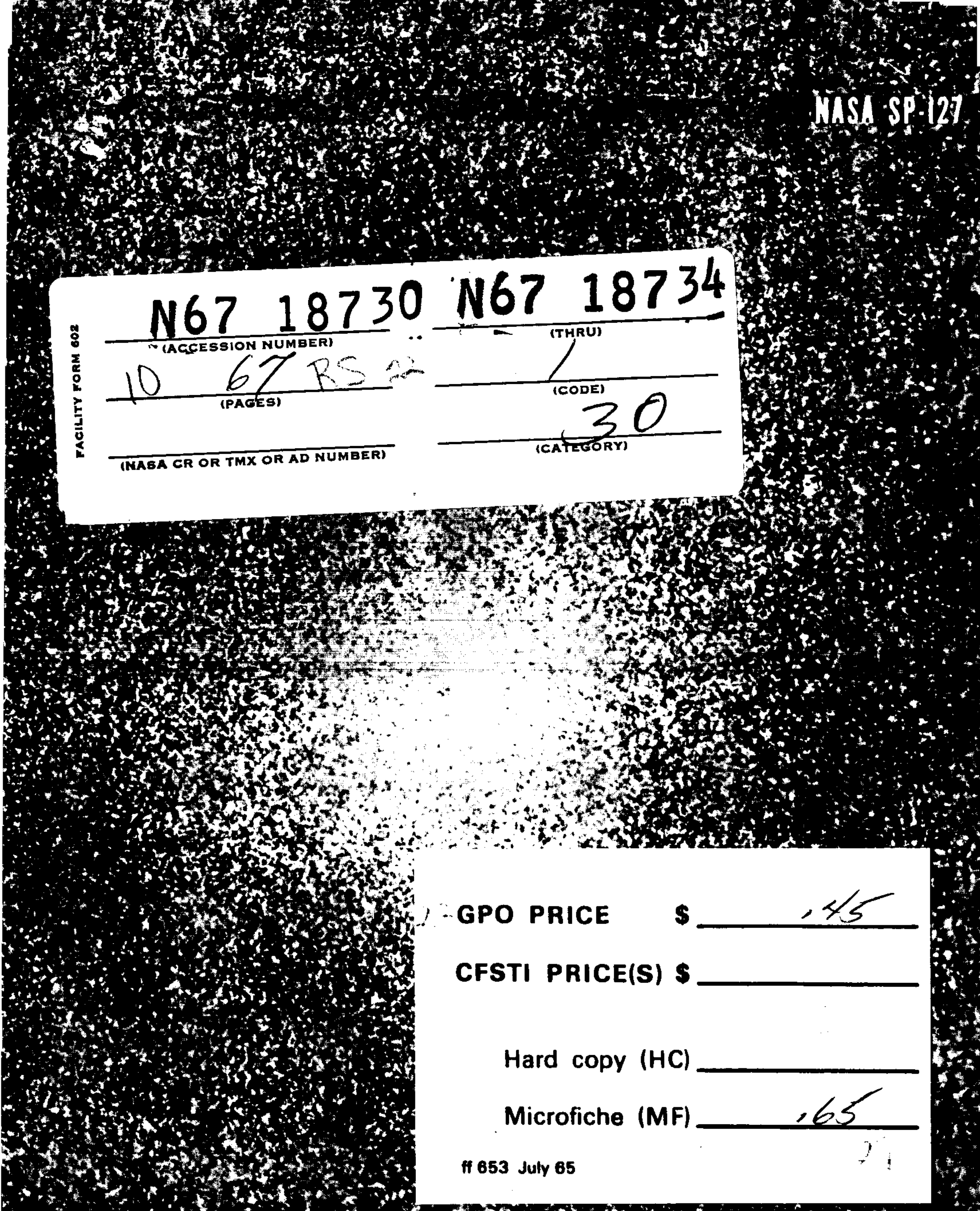

ASTRONOMY IN SPACE

Newell • Smith • Roman • Mueller

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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Homer E. Newell • Henry J. Smith
Nancy G. Roman • George E. Mueller

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FOREWORD

The publication of this book represents an effort to provide information on present and prospective results of placing astronomical instruments above the Earth's atmosphere. Interest in such information has been stimulated by the progress of the space astronomy programs of the National Aeronautics and Space Administration and by the comprehensive set of recommendations on space astronomy made at the 1965 Summer Study of the Space Science Board, National Academy of Sciences, at Woods Hole, Massachusetts, and published in January 1966 in Part II of the report of the Study, "Space Research—Directions for the Future."

The first three of the four papers herein were presented at the 121st Meeting of the American Astronomical Society at Hampton, Virginia, on March 30, 1966. The first paper, by Homer E. Newell, provides a view in perspective. The second paper, by Henry J. Smith, covers solar astronomy. The third, by Nancy G. Roman, deals with stellar and galactic astronomy. The fourth paper, by George E. Mueller, was presented at a meeting of the astronomers of the University of California on April 29, 1966, and deals with the results of the manned space flight program and the opportunities provided by the developing manned flight capability.

Robert C. Seamans, Jr.
Deputy Administrator
National Aeronautics and Space Administration

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SPACE ASTRONOMY PROGRAM OF THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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Scope of the Space Program

The expenditures for the United States Space Program in the 1966 fiscal year totaled $5.9 billion. The effort involved over 400 000 people in Government, industry, and universities. More than 20 000 industrial concerns took part. Between 20 and 25 percent of those engaged in the program were scientists and engineers—only 5.5 percent of the national total.

Of the $5.9 billion, about $719 million was allocated for the Space Science and Applications Program. Over 60 000 people were engaged in this part of the NASA effort, about one-fourth of them being scientists and engineers. Better than half of the space science effort in FY 1966 was more or less directly related to astronomy.

The space program began with the momentum derived from the International Geophysical Year and the impetus imparted by the launching of the first Sputnik in the fall of 1957. In those formative days of our space effort, we committed ourselves to a series of what might be called first-generation projects. Included among these first-generation commitments are such well-known projects as Mercury, Explorers, Ranger, Surveyor, Mariner, Tiros, Echo, Relay, Syncom, and many others. Most of these first-generation projects have already borne fruit, and indeed some of them have been completed and replaced by later more advanced efforts.

A surprisingly large number of these early projects lay in the field of astronomy. A small, but appreciable, number of sounding rockets have been fired each year with astronomical payloads. Explorer XI initiated satellite gamma ray astronomy in 1961. The Orbiting Solar Observatory, the Orbiting Astronomical Observatory, Ranger, Mariner, and Surveyor fall clearly under the banner of astronomy.

In addition, numerous other projects have had an important bearing on astronomical interests. The Explorers, Geophysical Observatories, and Pioneers investigating the magnetosphere and interplanetary medium have extended geophysics and physics into what was once the undisputed domain of astronomy. Indeed, one of the more exciting outcomes of space research during the past 10 years has been a drawing together of the disciplines of geoscience, physics, and astronomy into a close partnership that is mutually stimulating and beneficial. Indeed, this spectrum of activities, including the Ranger flights to the Moon and the Mariner flights to Venus and Mars, has served to generate a renewed interest in solar system astronomy, which is all to the good.

Once the first-generation projects were well underway, there came the opportunity in good time to consider a second-generation group of projects. Some of these have already borne fruit, while the rest are well underway. Included among these projects are Gemini, Apollo, Biosatellite, and the establishment of operational communications and weather satellite systems. These second-generation projects also include efforts of primary interest to the astronomy discipline. A Radio Astronomy Explorer is under development for launching in the years immediately ahead and Lunar Orbiter spacecraft are designed for photographic reconnaissance of the Moon.

And now a third generation of project and program possibilities demand attention in our thinking and planning. With the tremendous space capability that is developing, truly tremendous accomplishments can be achieved. The range of possibilities is wide and bewildering in variety and appeal. One may now consider large and complex orbiting observatories, orbiting manned stations, large-scale telescopes and antenna arrays in orbit, astronomical facilities on the Moon, unmanned missions, like Voyager, to various bodies and regions of the solar system, extended lunar exploration, solar probes, probes out of the interplanetary medium into the interstellar regions, advanced manned missions to other planets of the solar system, and advanced applications to practical uses in navigation, data collection and dissemination, air traffic surveillance and control, long-range weather forecasting, and so on.

These third-generation possibilities are characterized by complexity and very high cost. For many, the costs must be measured in the billions of dollars. It is not reasonable to think in terms of doing everything that one can in principle accomplish in the space arena. Choices must be made, and they will not be easy, from among the various opportunities and possibilities in the space field itself. But, also, choices must be made between space possibilities and other national interests and needs.

Because these choices can have an important bearing on the development and growth of science, it is very important for the scientific community to give thoughtful consideration to these matters. Because many of these opportunities lie in the domain of astronomy, the astronomical community should give careful consideration to the relative roles of space and ground facilities in the development of the astronomical discipline.

The Past and Current Contributions of the Space Program to Astronomy

Since the past is inevitably prologue to the future, it may be of value to sketch quickly some of the contributions already made by the space program to the field of astronomy.

When Galileo lifted his telescope to look at the Moon, he was able to resolve details some 30 times smaller than had been previously observed. With better telescopes, it became possible to resolve still finer detail until today we can photograph lunar objects smaller than 1 kilometer in diameter and visually observe objects as small as 0.2 kilometer. However, we have reached the limit of resolution possible from the surface of the Earth. In fact, a photographic Earth-orbiting telescope of the type of the Orbiting Astronomical Observatory could not resolve much more detail. This resolution limitation was bypassed by the Ranger spacecraft and its program of lunar photography. While it is true that the total area of the Moon observed in the Ranger program has been very limited, we have observed features as small as 1 meter in diameter. Other regions of the Moon will be photographed in similar detail as part of the Lunar Orbiter program. The Luna 9 spacecraft has transmitted pictures of the lunar surface showing structural details which are below the limits of resolution of the most detailed Ranger photographs.

Before the advent of the space program, astronomers believed that knowledge of the other side of the Moon would be unattainable. Today, as a result of Russian lunar spacecraft, especially Zond 3, we know that the general appearance of the back side of the Moon is quite different from that of the front side. This new knowledge of the Moon has, as is quite often the case in the discovery of new scientific data, raised more questions than it has answered. Study of the Moon, once the domain of astronomers alone, has now become important to many disciplines, especially those concerned with the Earth sciences.

This extension to other disciplines of a domain originally exclusive to the astronomers is even more obvious when the planets are considered. The payload of the Martian flyby spacecraft, Mariner IV, is a good example of the involvement of various disciplines in planetary studies. In addition to the well-publicized television pictures of the Martian surface, experiments were flown to detect properties of the planet's atmosphere, and magnetic field. Results of these experiments, all developed by nonastronomers, have added to our knowledge of Mars and will make future astronomical observations more meaningful.

The television pictures from Mariner, while showing only a small portion of the planet, have given much information on the nature of the Martian surface. While no definite answers were obtained to such questions as the existence of life or the existence of the long-debated canals, we now know more about the nature of some major surface features. In the approximately 1 percent of the total planetary surface that was observed, we have been able to detect details an order of magnitude smaller than ever observed before and two orders of magnitude smaller than have ever been photographed from the Earth.

By 1960 rocket astronomy had begun to come into its own. Not only did it produce one of the most exciting discoveries of the space science era, but it provided useful observational input to a number of long-standing problems in astronomy. The use of moderately large optical collecting areas and carefully calibrated detectors has led to consistent results for ultraviolet brightnesses of the brightest stars and to a revision of the stellar temperature scale for hot stars.

The development of a stabilization system which allows rocket instrumentation to point to an individual star for a relatively long period of time has enabled Donald Morton of Princeton to obtain photographic spectra of several hot stars, which show surprisingly that material appears to be leaving these stars at a significant rate. The use of relatively short antennae on sounding rockets and on satellites enabled radio astronomers to measure the integrated cosmic background down to frequencies as low as 0.75 MHz and to establish that the intensity decreases below 3 MHz.

Some of the most unexpected discoveries and exciting results in space astronomy have come from physicists who have been attracted to the field. In 1962 Ricardo Giacconi and Herbert Gursky, looking for X-ray scattering from the Moon, observed a bright source of X-ray emission not associated with either the Moon or any other optically identifiable object. It is now known as Scorpio X. Since then these and other observers, using both spinning and stabilized rockets, have measured perhaps two dozen additional sources. Until recently, the only X-ray source which could be identified with a previously known object was the Crab Nebula. X-ray emission from this source had been expected. The brightness of the source in X-rays indicates that it can be explained by an extension of the synchrotron spectrum into these short wavelengths. Herbert Friedman and his colleagues at the Naval Research Laboratory have identified two other radio stars, M87 and Cygnus A, as X-ray sources. Explaining the physical nature of these sources, identifying the X-ray stars with optically observed sources, and investigating the possible relation, if any, of the X-ray sources to the newly discovered quasars, should present intriguing space-age problems for the Earthbound astronomer.

Other physicists attracted by these exciting discoveries have pushed the spectra of these objects further into the gamma-ray region with observations from balloons. In these wavelength regions, techniques are more closely related to the particle observing techniques of cosmic-ray physicists than to the standard methods of optical astronomy. Therefore, physicists trained in this field are contributing actively to astronomical research.

Sounding rockets have played an important role in the observations of the Sun from space. The pioneering effort of space astronomy was, as mentioned previously, the mapping of the near ultraviolet solar spectrum, with unguided rockets carrying simple spectrographs and retrievable photographic film records. The need for longer exposure times than a spinning rocket could permit led to the early development of a two-axis rocket pointing control, with which an immense amount of fundamental exploratory solar observations have been made. The Sun's far ultraviolet and soft-X-ray spectra have been revealed and explored in progressively finer detail through a continuing series of milestone investigations. The new knowledge gained of the Sun's spectrum in the ultraviolet has advanced our understanding of the chromosphere and corona to a great degree. In addition these data have provided a much improved basis for understanding the influence of the Sun upon the Earth's upper atmosphere.

Identifying the solar cause and defining the detailed physical processes in the response of the ionosphere to solar flares was one of the outstanding episodes of early space astronomy. We now realize that the Sun is also a continuous emitter of X-rays, with a very wide range in total X-ray brightness and spectral distribution throughout the solar cycle and also throughout the evolutionary life or individual active regions. Magnificent Lyman-alpha spectroheliograms have been made by Dr. Tousey and his colleagues at the Naval Research Laboratory.

Fascinating observations have been obtained of the Sun in the ionized magnesium H and K lines with birefringent filters, of the chromosphere in neutral and ionized helium resonance lines with slitless spectrographs, and of the corona and active regions in soft X-rays, both with pinhole cameras and the novel grazing-incidence X-ray telescope. The Orbiting Solar Observatories are being used to patrol for the unpredictable, transient event, and to monitor continuously the slowly varying phenomena. A more detailed description of the solar experiments and their results is given in Dr. Smith's paper.

Concluding Remarks

Space science has progressed fastest in new directions for obvious reasons. Newly opened fields of research naturally attract a great deal of attention by their potential for a quick return of significant discoveries. Moreover, for the initial exploration in virgin fields, relatively simple instrumentation and limited scope research programs often suffice to permit rapid exploitation of new technologies and breakthroughs of understanding.

Rather more advanced technology and elaborate programs are required when one attempts to apply the technology of space research to the traditional areas of astronomy, such as making high-resolution spectrograms of faint sources in the ultraviolet or making high-resolution pictures of the Sun in ultraviolet and X-ray wavelengths. This results basically from the more advanced point of departure, because we must build on the accomplishments of decades of ground observations in visible wavelengths. Thus, we are forced to aim higher in our initial uses of space technology in classical investigations. The Orbiting Astronomical Observatory (OAO) and Orbiting Solar Observatory (OSO) already represent major investments in complex spacecraft developments, comparable to relatively large ground-based facilities of not many years ago. However, to match in space observations the versatility and refinement of modern major observatory instruments, we recognize the need even now to plan for the future more advanced facilities in space.

Early in our program, while building the first Orbiting Solar Observatory, we recognized the need for an advanced solar satellite, with roughly ten times the pointing and data capacity of OSO. The Advanced OSO demanded advancement of the state of technology in some fundamental areas, like thermal stabilization and attitude control. Parallel with that development we began an alternate approach, in which an astronaut in a manned space flight mission would replace part of the automated functions of AOSO and would in addition retrieve photographic film from specially constructed solar telescopes and spectrographs. This device, the Apollo Telescope Mount (ATM), is a step toward the next generation of space astronomical facilities. Similar developments will be undertaken in stellar and radio astronomy.

The future of space astronomy is limited only by the vision of the astronomers and their ability to convince their fellow Americans that astronomy is a worthwhile endeavor and that space astronomy is an important component of the whole. At the 1965 Summer Study at Woods Hole, astronomers indicated that they would like to have an optical telescope operating between the ultraviolet and the infrared with an image quality comparable to that of a diffraction-limited 120-inch telescope and a total aperture between 120 and 250 inches. They also indicated that they would like a radio array 20 kilometers on a side, a 100-foot parabolic dish for observations in the far infrared and submillimeter regions, and large sophisticated instrumentation for the gamma- and X-ray regions and for the study of the Sun. NASA is investigating the technological, the administrative, and the budgetary problems which the construction of such instrumentation will entail.

There are also proposals to send probes to study the magnetized plasma in the inner and outer reaches of the solar system, in the environments of planets and their satellites, and some day even in the galactic arm field beyond the dominant influence of the Sun. Planetary and lunar orbiters and landers are clearly indispensable tools in the exploitation of the near-solar system.

As mentioned previously, the costs of these programs are substantial and choices must be made. The simultaneous accomplishments of this whole program would require more resources than we could bring to bear at one time. It will be necessary to identify the priorities of space research effort in astronomy, considering such factors as the promise of significant accomplishments and the availability both of the scientist to do the job and of the technology to carry it out. As the program develops and moves into larger and more expensive units of effort, it will be necessary to seek an increasingly broadened consensus from the scientific community. In the past we have built our program around interested key scientists, with the concurrence and endorsement of their peers. However, for anything so large as a telescope comparable in size to our largest ground-based instruments or a lunar-based radio observatory, the cost to the Nation would be so great that the enthusiastic support and willing participation of an interested scientific community will be essential. An enlarged participation is essential not merely in the design, development, and operation of the space facilities but also in the pursuit of theoretical and laboratory research and of ground-based astronomical observations necessary to support the space program.

Space astronomy is not a new science. Space observations can provide data that are unobtainable from the ground, that will help us solve old problems; they will produce information in new fields. However, we at NASA recognize that space astronomy cannot proceed efficiently without the strong cooperation of strengthened ground-based astronomy and theoretical astrophysics. We agree that a balanced program of astronomical research must be maintained, with a corresponding augmentation of ground-based observations and theory necessary to support any enlargement of space astronomy. The next decades could well become the golden age of astronomy.

SOLAR ASTRONOMY

N67 18732

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NASA

A study of the Sun plays an important role in our program of space astronomy. In the very beginning of space science, the Sun offered the brightest and most convenient source of ultraviolet and gamma radiation. Solar physics represented the scientific discipline in which one could make the easiest application of the new technologies of space research. In addition, the Sun was obviously the driving influence in many of the phenomena encompassed in the general area of Sun-Earth relationships, which then and now occupy an important part of geophysical studies conducted with rockets and satellites.

Space vehicles enabled astronomers to carry telescopes, spectrographs, and photometers above the absorbing layers of the Earth's atmosphere, opening up to them the ultraviolet, X-ray, and gamma ray spectral regions, as well as the very low frequency radio region. It is significant that the Sun departs most notably from thermal and quasi-thermal equilibrium radiation in these extreme short and long wavelength regions. Thus space techniques enable the scientists to look with greater emphasis and less confusion of background radiation at the nonthermal radiative processes which characterize solar activity.

Another significant feature of space research provides an important rationale to the development of a future program of satellite missions—the expected improvement of observational conditions by the elimination of atmospheric seeing and scattered light sky brightness. Angular resolution with telescopes on the surface of the Earth is limited by atmospheric turbulence to about one-half arc-second under the best conditions, regardless of the aperture of the telescope. Similarly, even at the best mountain sites yet developed, the brightness of the sky a few arc-seconds from the limb is still of the order of a few millionths of the disk brightness of the Sun. The virtual absence of scattered sky light has stimulated the development of specialized stellar coronagraphs, which can reject disk light by nearly nine orders of magnitude—provided the contiguous background sky light is not any brighter.

It should be noted that space solar astronomy, as defined in this paper, excludes the study of energetic solar protons, and the less energetic continuous plasma emission sometimes called the solar wind. The *in situ* measurements of charged and neutral particles and the magnetic field associated with them require special vehicles, special measuring devices, and generally a different scientific disciplinary point of departure than telescope and spectrograph optical observations of the Sun.

In discussing NASA's space flight program in solar astronomy we shall consider solar observations in three general areas: "small vehicles"; the Orbiting Solar Observatory (OSO) satellite series; and the future flight program, including the proposed Advanced OSO (AOSO) and Apollo Telescope Mount (ATM).

"Small vehicles" include scientific research balloons, aircraft, sounding rockets, and the small special-purpose Explorer satellites. The scientific research unit effort in this area may range from a few thousand dollars and a few man-months up to several man-years. Nevertheless, the distinctive features of these types of missions are lower cost of individual pieces of research, and the shorter proposed review, administrative approval, and technical development time required. The short time scale between conceiving and conducting a piece of research makes small vehicles especially useful for a number of operations: student training in space research, testing of new technologies, and rapid exploitation of new breakthroughs in knowledge.

Balloons have played an important role in solar research for more than a decade. The pioneering efforts at Princeton University Observatory which culminated in the flight of "Stratoscope I" provided the authoritative observations of solar granulation and the fine structure of sunspots as observed in white light. NASA will participate in a follow-on program to develop this general area of solar observations. NASA, in collaboration with the Fraunhofer Institut of Freiburg, Germany, will undertake the investigation of fine structure and spectral line structure in the chromosphere in the light of the H-alpha line of hydrogen Balmer series. NASA has also participated in the High Altitude Observatory Project Coronascope, which launched a white light coronagraph on a balloon to observe the outer corona from the scattering-free region above the Earth's tropopause. Numerous university groups have employed balloons as part of the NASA supporting research and technology program to observe hard solar X-ray emission. Though no special effort is made to cultivate balloon techniques in pursuit of the study of the Sun, it is very likely that use of this method of escaping the handicaps of solar observation through the Earth's atmosphere will continue to find important application.

Aircraft have an important role in space astronomy, even though they do not fly so high as balloons, and they are subjected to severe kinematic disturbances. The X–15 aircraft, which flies at altitudes in excess of 38 000 meters (theoretically has a peak altitude of about 91 500 meters), has already been equipped with a stabilized platform (siderostat) which could be used for observations of the Sun. Though the flight profile yields only a few minutes of observing time above the bulk of the atmosphere, it presents a real opportunity for continuous observations of the Sun down to some wavelength shorter than the ground-based ozone absorption limit at 2910 angstroms. Of more direct interest to the solar astronomer, however, is the Convair 990 jet transport aircraft, which has been especially equipped to support scientific observations in the tropopause and tropospheric regions. This aircraft carried an expedition of astronomers to observe the total solar eclipse of May 30, 1965. Astronomers have already heard results from the scientific investigations carried out by the 10 research teams which participated in that expedition. In the future, the Convair 990 will be provided with a heliostat for infrared and high-resolution white light observations, and probably will be used to test airborne coronagraph techniques.

Sounding rockets have enabled pioneering research in space astronomy, with early missions providing high-resolution spectroscopic observations of the ultraviolet and X-ray solar emission. In the early days randomly oriented spinning rockets were able to glimpse the Sun and provide initial exploratory observations on which rocket solar astronomy was founded. However, the requirement for accurately stabilized pointing to form an image of the Sun, as well as continuous pointing to increase exposure time, generated the requirement for an attitude control system. Early in the era of space astronomy, a two-axis telescope pointing device was developed for the Aerobee rocket. By the maximum of the current solar cycle it is expected that a three-axis pointing control system will be available. At the present time the two-axis control system provides nominal angular resolution of about 1 arc minute. The system under development should improve this performance by roughly one order of magnitude. Common to all sounding rocket experiments is the opportunity to recover the observations in the form of photographic film. This is an important asset, since photographic data retrieval is unsurpassed as a means of bulk data storage, particularly when a very wide bandwidth receiver is used; one can increase the bandwidth of a detector merely by increasing the area of the film in the magazines. Now no satellite vehicle is capable of matching the sounding rocket or proposed manned space flight missions in this respect.

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It will be helpful to cite some of the accomplishments of rocket astronomy in the area of studying the Sun. A continuing series of rocket flights has provided a complete map of the Sun's spectrum down to wavelengths shorter than 1 angstrom. Each mission has improved the angular and spectroscopic resolution of earlier flights and has resulted in a continuously improved photometric basis. Solar X-rays were first discovered through sounding rocket observations, and they were shown to be the fundamental cause of the sudden ionospheric disturbance (SID).

A sounding rocket flown above the Earth's atmosphere carried a coronagraph with a scattered light rejection figure of roughly 8 orders of magnitude. The sounding rockets have carried instrumentation to produce spectroheliograms in resonance lines of hydrogen and neutral and ionized helium, in the H and K lines of ionized magnesium, and in soft X-ray wavelengths utilizing both pinhole cameras and grazing incidence compound reflecting telescopes. NASA plans, in future missions, to observe the Sun from sounding rockets with a variety of advanced spectrographs and telescopes. For example, two different groups will fly high-resolution scanning spectrometers to observe the Lyman-alpha and the Lyman-beta line and contiguous regions. A third university group is developing a wideband high-resolution spectrograph, based upon the principle of the Echelle system. A fourth group, also university, is developing specialized high-resolution spectrographs to observe the center-to-limb variation of critical ultraviolet wavelengths, especially in the continuum between 2000 and 3000 angstroms. Finally, novel wide-aperture X-ray detectors have been prepared to examine in detail the nonthermal (bremsstrahlung) radiation attributed to certain very energetic solar flares. The anticipated availability of a 5- to 10-arc-second, three-axis stabilized pointing platform for solar observations, coupled with the enhanced payload capability of the Aerobee 350 vehicle, certainly will increase the level of activity in rocket solar astronomy.

The earliest unmanned scientific satellites launched by the United States were the Explorer satellites. The Explorers continue to be used vigorously by space scientists. In November 1965 and as part of the International Quiet Sun Year program, NASA and the Naval Research Laboratory jointly launched a solar X-ray monitoring satellite, Explorer XXX (Solrad VIII). This satellite, the eighth in a continuing series of solar monitoring satellites produced by the scientists at NRL, included eight X-ray sensors covering the range from 0.1 Å to 60 Å. This mission was nominally in support of an international program to study the quiet Sun and associated geomagnetic and geophysical phenomena. NASA and NRL are planning a second joint launching in this series to take advantage of the peculiar development of the limited data magnetic tape recording system and simple attitude control system which have already been developed. At the maximum of the current solar cycle, NASA, in collaboration with Harvard College Observatory, plans to launch an Explorer satellite carrying a very low frequency solar burst radio spectrograph. This satellite, called "Pilgrim," will be designed to observe every few seconds the Sun's radio frequency spectrum in the range 0.25 to 16 MHz. In support of the geophysical research investigations which are the primary mission objectives of the geophysical observatories, most of the Orbiting Geophysical Observatory (OGO) satellites will carry either a solar X-ray or a solar ultraviolet photometer. Therefore, important solar data will become available from these continuous systematic surveys.

Besides the Earth-orbiting Explorer satellites, NASA is planning to launch the MIT-developed Sunblazer, a lightweight low-cost interplanetary probe. This probe is a 13.6-kilogram spacecraft which is to go into a heliocentric orbit with perihelion at roughly 0.5 AU. The initial Sunblazer flights will carry a two-frequency (100 and 300 MHz) pulsed radio transmitter to study the electron density gradient and inhomogeneities in the solar corona by observing the relative phase retardation at two frequencies.

Turning now to the current approved program mainstream, the Orbiting Solar Observatory (OSO) is the workhorse of our solar astronomy flight program. The OSO, shown in figure 1, is an Earth-orbital scientific satellite with the following specifications: the satellite consists of two basic sections—the wheel and the sail; the wheel section rotates at 30 rpm, with the plane of the rotating wheel constrained to within about 2° of the solar vector. Most of the time experiments in the five available wheel compartments point at the sky and then at the Earth and only sweep past the Sun at the rotational repetition rate. The sail section of the OSO points an instrument package, which is approximately 0.2 meter square and 1.0 meter long and can carry two, three, or four telescopes, continuously at the Sun during the sunlit portion of the orbit, with a precision of about 1 arc-minute. In addition, certain OSO missions also provide a capability of scanning out a raster image of the Sun with 40-line resolution.

The currently approved OSO program calls for eight flights (before flying, OSO is given a letter designation; after, a Roman numeral designation), two of which were successfully flown, one in March 1962 and one in February 1965. The third OSO, launched in August 1965, failed to go into orbit because of a vehicle defect. Another set of the scientific experiments onboard this unsuccessful mission has been rescheduled for flight on the fifth OSO. We are now considering experiments for flight on the eighth OSO, which will fly in 1969. We

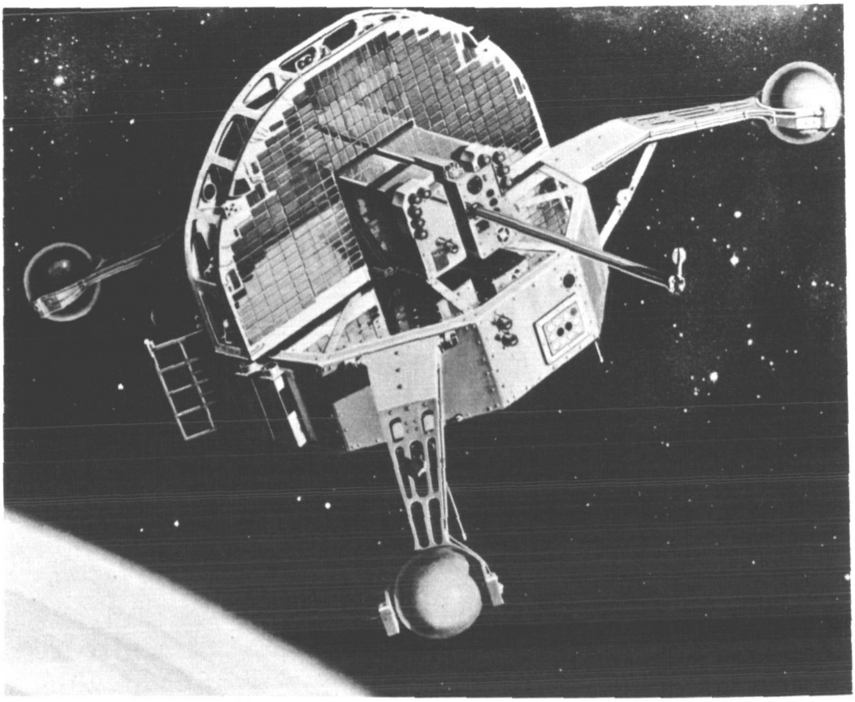

Figure 1.—Sketch of Orbiting Solar Observatory spacecraft.

are maintaining the option to continue this series beyond the approved eight, but will make that decision only when the evidence is clear that useful scientific results will be obtained by additional flights in this program. The option, however, is particularly attractive in the light of proposed improvements in the OSO, wherein the pointing capability would be upgraded, heavier and larger experiments could be accommodated, and possibly a full sunlit polar orbit could be substituted for the low-altitude partly occulted orbit.

Table I lists the instruments assigned to the first five OSO's. Emphasis has been placed upon spectrographs and image-forming spectroheliographs, which are the most powerful tools in the astronomer's workshop. However, a large number of experiments are devoted to monitoring the temporal variations of the whole-Sun brightness in ultraviolet, X-rays, and gamma rays. In addition, a number of experiments, listed under "Miscellaneous" in the table, are basically geophysical in character—for example, they will measure either the particle or proton environment of the Earth, or solar neutrons—or astronomical in nature, as, for example, the zodiacal light or the ultraviolet sky mapping survey.

TABLE I.—*OSO–I to OSO–F Experiment Summary*

[Parentheses indicate number of flights assigned]

Spectrometers:
- 300–1300 Å (2)
- 60–1300 Å (1)
- 1–400 Å (3)
- 1–8 Å (2)

Spectroheliographs:
- Lyman-alpha (2)
- 2–20 Å (3)

Photometers:
- Helium λ 304 Å (1)
- Lyman-alpha (2)
- Soft X-ray: $\lambda > 2$ Å (4)
- $\lambda < 2$ Å (2)
- Hard X-ray (10–100 keV)
- Low Energy γ-ray (100 MeV) (8)
- High Energy γ-ray (100 MeV) (5)

White Light Coronagraph (1)

Miscellaneous:
- Neutrons (1)
- Earth Albedo (1)
- Emissivity (3)
- Meteoroid Detector (1)
- Zodiacal Light (2)
- Ultraviolet Sky Spectrophotometer (1)
- Night Sky Glow

The experiments on a single mission, the seventh OSO, now designated OSO–G, are listed as follows:

(1) Harvard College Observatory—Spectrometer–Spectroheliometer (300–1300 Å).
(2) Naval Research Laboratory—Spectral, Burst and Mapping Measurements of Solar X-rays.
(3) Rutgers University—Study of the Zodiacal Light.
(4) Los Alamos Scientific Laboratories—Solar X-ray Monitoring in the 16–40 Å Region.
(5) University of Bologna—Solar X-ray Monitoring and Gamma Astronomy in the Energy Range 20–200 keV.
(6) University College, London—Study of the He I and He II Resonance Radiation.
(7) University of New Mexico—High Energy Neutron Flux in Space.

The X-ray burst photometer-spectrograph package is a refinement of the detector system flown many times by NRL on sounding rockets, Explorer satellites, and earlier OSO missions. This experiment package has been assigned to OSO–F to obtain, during solar maximum, as much information as possible on the short-lived transient X-ray bursts associated with the major flares, with particular emphasis upon their spectral distribution. The HCO 300- to 1300-Å scanning spectrometer-spectroheliograph, on its third flight in the OSO series, will yield fundamental information on temporal variation and spatial distribution of principal ultraviolet radiations from the Sun's chromosphere and corona. Mapping of the Sun's disk in selected radiations in the 300- to 1300-Å wavelength range will unfold the significant evolutionary development of specific centers of solar activity. Noteworthy among the experiments in the wheel section of the OSO–G mission is Rutgers' advanced zodiacal light photometer and polarimeter, which represent a great advancement over investigations which measured essentially similar phenomena with less detail on OSO–II and are planned for OSO–F. The University College, London, experiment with total Sun flux photometers for the resonance lines of neutral and ionized helium will monitor the variations of the fundamental solar input to the E and F regions of the Earth's ionosphere. These data will provide the basis for interpreting secular variations in the structure of the electron density profile. The University of Bologna's low energy gamma ray detector will study not only solar radiations in the 20- to 200-keV wavelength region, but also will detect and map on the sky cosmic sources of energetic photons. The University of New Mexico's detector of solar neutrons will look for these telltale indicators of nucleogenetic processes which are alleged to occur in the outer layers of the Sun during energetic solar flares. The variety in this payload is typical of that which the OSO spacecraft is capable of accommodating.

Significant results have already been obtained from the early OSO missions. The first mission, successfully launched in March 1962 and designated OSO–I, provided many weeks of continuous observation of the time variation of solar ultraviolet radiation (100 to 400 angstroms) and soft X-rays (2 to 20 angstroms). These data provided the first information on the changes in the intensities of various lines of successive stages of ionization of a given atom; for example, Fe XII through Fe XVI. These data proved especially important in the interpretation of the slow changes in the density profile of the upper atmosphere, as well as the electron density profile of the ionosphere of the Earth. In addition, they provided valuable insight into the nature of coronal heating by the elevation of activity over chromospheric active regions. Besides the ultraviolet observations, OSO–I data also showed how individual flares as well as whole regions of solar activity change the total X-ray flux of the Sun. Previously unsuspected short-term variations in X-rays created by solar flares were detected. Events of only a fraction of a second in duration were shown to be very frequent and energetically very important. In the middle ultraviolet spectrum, a photometer measured for the first time significant fluxes which could be attributed to localized heating of the chromosphere, the resultant reradiation by Lyman-alpha, and the resonance line of hydrogen.

Comparable results from the second Orbiting Solar Observatory, OSO–II, cannot be quoted at the present time, since the data are still being analyzed. However, it is known that OSO–II did yield the first spectroheliograms in neutral and ionized helium resonance lines, and did produce some significant maps of the solar corona. X-ray bursts from a large number of small flares were recorded, and initial exploratory observations of the zodiacal light and airglow were made. A projected map of bright sources of ultraviolet radiation from the whole sky yielded vast quantitites of data which are still being analyzed by digital computers. OSO–I survived only a short lifetime (2 months rather than the 6 months programed), and OSO–II, unfortunately, suffered from early failure of its major instruments; nevertheless, these two missions have already provided information which contributed new knowledge about the Sun, and charted vital new roads to be pursued in future research undertakings.

Even before the launch of the first OSO it was clear to solar astronomers that a spacecraft of higher performance capability was required to achieve even the most limited goals of solar research by space techniques. Following a number of planning meetings by the leading solar astronomers in the United States, an advanced solar satellite was conceived, called an Advanced Orbiting Solar Observatory (AOSO). An artist's conception is shown in figure 2. AOSO was to point three or more large telescopes at the Sun with quite high precision. These telescopes would be about 0.30 meter in diameter and 2.54 meters long, in order to achieve the nominal angular resolution indicated by the pointing accuracy. The spacecraft was to be designed to point at the Sun with a precision of ± 5 arc-seconds, located within a 40 arc-minute square centered at the Sun, as shown in figure 3. In addition, AOSO was required to perform a raster scan of the entire Sun over the 40 arc-minute square, or a fine scan raster over any arbitrarily located 5 arc-minute square within the 40 arc-minute square. To accommodate the vastly increased quantity of data, the AOSO data handling system was intended to have 20 million bits per orbit capacity which is roughly ten times that of OSO. AOSO was to fly in a full sunlit orbit, as compared with the partly occulted low-inclination orbits of the early OSO missions.

The AOSO program was planned for four flight missions during the period 1968 to 1971. Experiments had been selected for the first two missions (table II), and significant progress had been made in the development of the telescopes and spectrographs which had been selected. Because funds were not available to continue support of the AOSO spacecraft and experiments, the project was canceled in December 1965. This unfortunate situation will preclude obtaining high-resolution satellite observations of the Sun during the forthcoming solar maximum. Nevertheless, we are taking advantage of this hiatus for critical reevaluation of our solar research program goals and the technical specifications of the satellite which we will recommend to achieve those goals. An example of an alter-

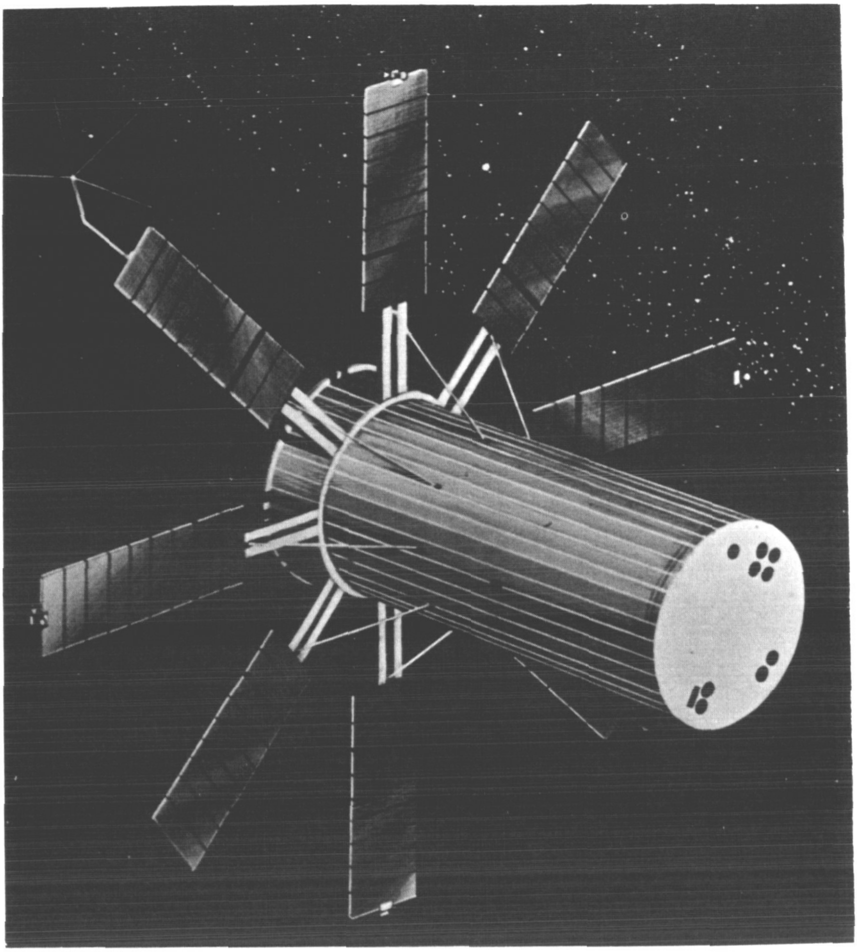

Figure 2.—Artist's concept of Advanced Orbiting Astronomical Observatory.

TABLE II.—*AOSO Experiments*

Organization	Principal investigator	Instrument (experiment)	Purpose
Harvard College Observatory	L. Goldberg	Normal Incidence Scanning Spectrometer	Study of chromosphere and corona structure

TABLE II.—*AOSO Experiments*—Continued

Organization	Principal investigator	Instrument (experiment)	Purpose
Goddard Space Flight Center	J. C. Lindsay	High Resolution X-ray Telescope	Study of dynamics of the solar atmosphere and comparison with ground-based visible and radio observations
High Altitude Observatory	G. Newkirk, Jr.	White Light Coronagraph	Study of coronal changes and their correlation with solar activity (spots, flares)
Naval Research Laboratory	J. D. Purcell	Ultraviolet Spectroheliograph	Mapping of chromosphere and corona in ultraviolet

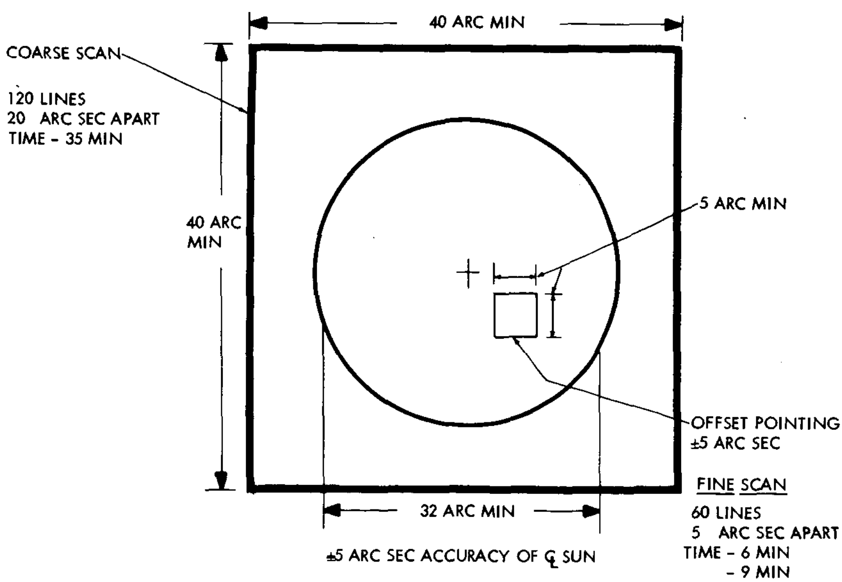

Figure 3.—Stabilization and control capability of the proposed Advanced Orbiting Solar Observatory spacecraft.

native to continuing the AOSO project would be to set up special missions of the Orbiting Astronomical Observatory (OAO), accepting as a deliberate sacrifice part of the functional performance of the planned AOSO in order to secure continuous satellite observations of the Sun at high resolution in an earlier time period than would be possible otherwise. At the same time, we are considering the importance and desirability as well as the technical feasibility of upgrading the performance specifications for an advanced solar satellite. For example, astronomers now agree that ideally the stabilization accuracy ought to be closer to 1 arc-second than to 5 arc-seconds but that some tradeoff can be accepted in the absolute coordinate specification or the coalinement of several experiments relative to the Sun sensor of the spacecraft.

Although it was necessary for budgetary reasons to terminate development of the AOSO spacecraft, it has been possible to maintain some level of effort in the definition of the scientific investigations through the design and partial development of experimental hardware. Four major investigations are being supported:

(1) The Harvard College Observatory scanning spectrometer (fig. 4), utilizing conventional normal incidence optical techniques, will observe the spectrum within the 500- to 1500-Å wavelength range from areas on the Sun as small as 5 arc-seconds square. By stopping the spectral scan at a chosen wavelength and performing a raster scan of the Sun, the instrument would function as a spectroheliograph, also at 5-arc-second resolution.

(2) The American Science and Engineering—Goddard Space Flight Center high resolution X-ray telescope (fig. 5) utilizes novel double reflection grazing incidence compound optics to form an image of the Sun in soft X-rays, between a wavelength of 3 and 60 Å. For the AOSO a small version of the same telescope would act as a pilot detector to define the brightest or most interesting X-ray region on the Sun for detailed analysis with a larger telescope.

(3) The High Altitude Observatory White Light Coronagraph (fig. 6) is a modification of the Evans version of the Lyot coronagraph. In the advanced version an apodized occulting disk external to the first objective rejects scattered disk light from the optical system to the very highest degree. With this instrument it is possible to study the polarization and brightness distribution of coronal structures in the range 2 to 6 Earth radii above the Sun's limb. For AOSO a biplexed data format was available so that one image tube would look at the east limb and another image tube would look at the west limb of the Sun.

(4) The Naval Research Laboratory coronal and chromospheric spectroheliographs (fig. 7) were intended to produce 5-arc-second-

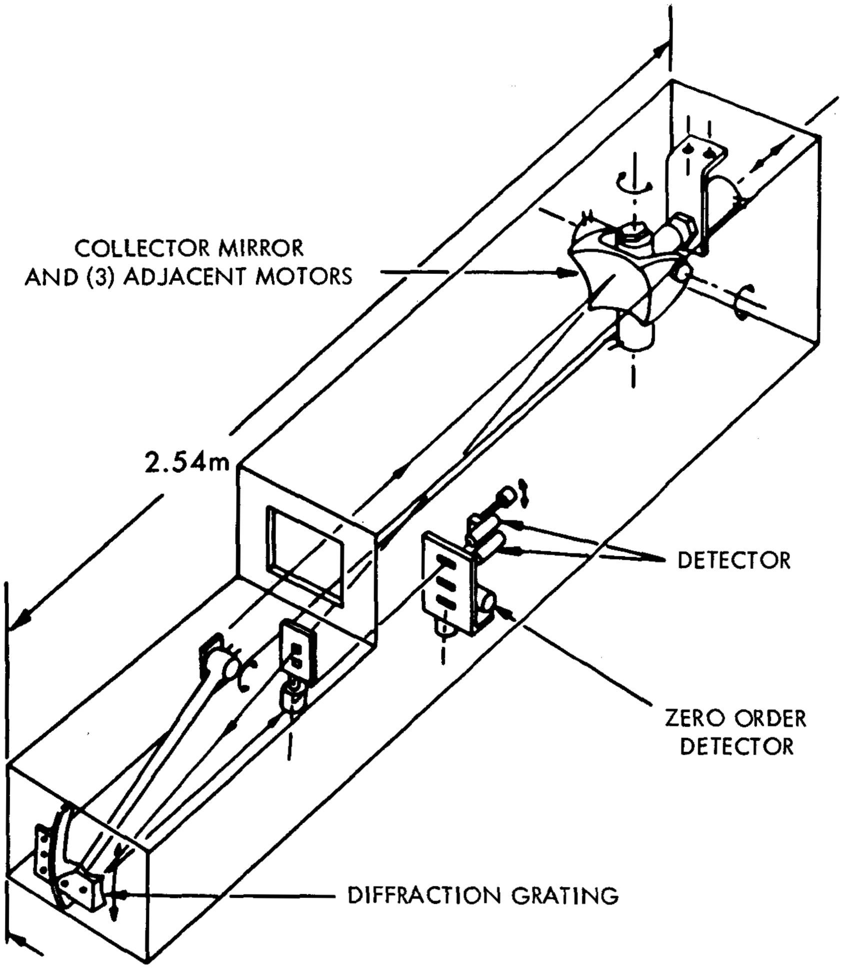

Figure 4.—Harvard College Observatory scanning spectrometer-spectroheliometer for AOSO, 500–1500 Å.

resolution images of the Sun in the resonance lines of hydrogen and neutral and ionized helium, and, in addition, the 284-Å line of Fe XV and the 335-Å line of Fe XVI with a wavelength selection capability in the Lyman-alpha line for profile analysis.

These instruments, though specifically designed to utilize the capabilities of AOSO, are nevertheless the general-purpose instruments that all solar astronomers use in one version or another to conduct their solar research from the ground, from rockets, and from the small satellites like OSO. Whether they fly on an OAO, or are operated

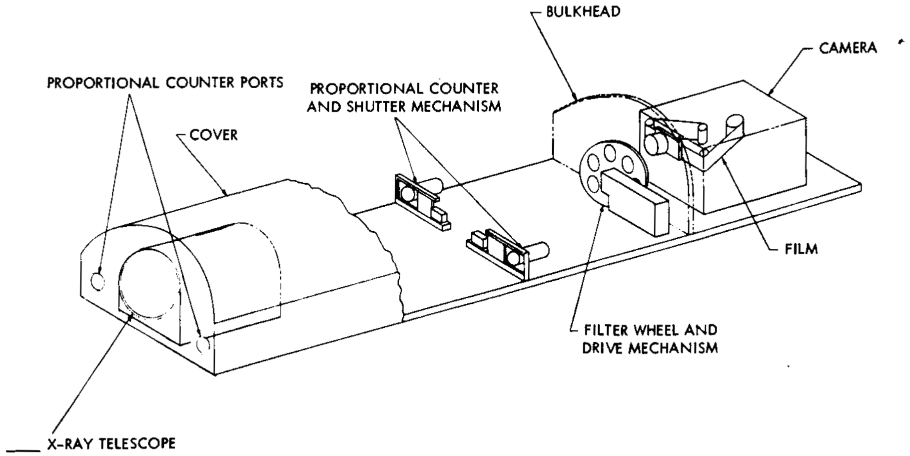

Figure 5.—Functional drawing of the American Science and Engineering—Goddard Space Flight Center high resolution X-ray telescope.

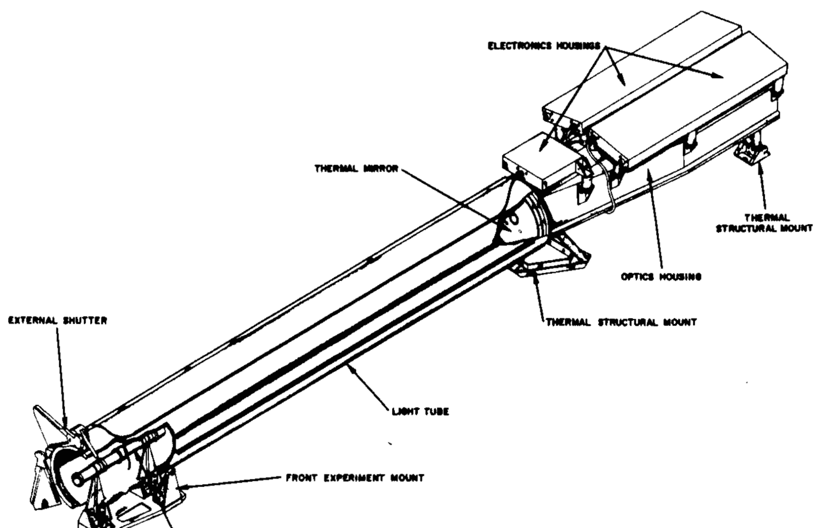

Figure 6.—Conceptual design of the White Light Coronagraph Experiment for the Advanced Orbiting Solar Observatory.

from a lunar-based observatory, they represent the minimum scientific program necessary to carry on our investigations of the structure and behavior of the Sun. The continued development of these experimental instruments is justified in the expectation that some means

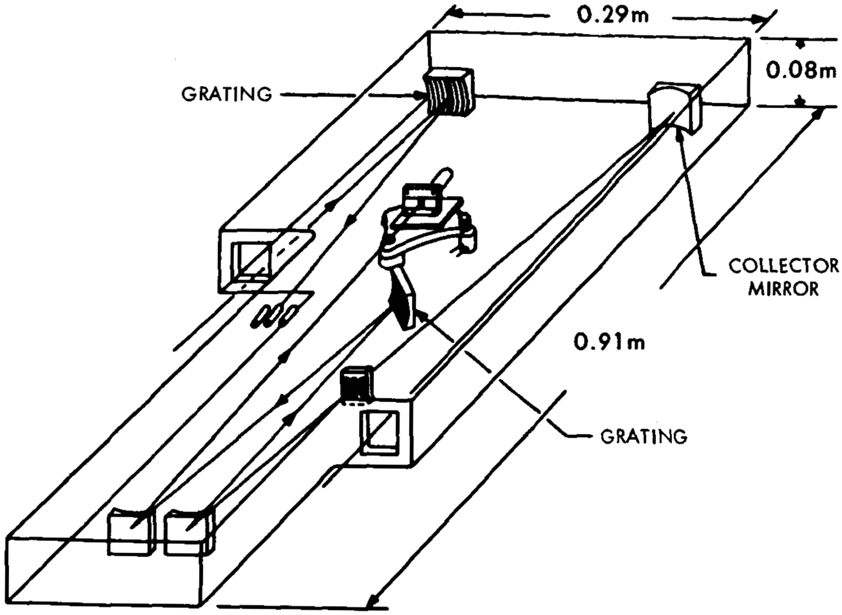

Figure 7.—Naval Research Laboratory ultraviolet coronal and chromospheric spectroheliographs. 1216 Å; 284 Å; 304 Å; 335 Å.

will be found to place these or derivative instruments above the atmosphere and to point them at the Sun with the necessary precision to achieve some degree of realization of the initial AOSO investigation objectives.

As the capability for manned space flight operations moves from the developmental to the applications phase it is inevitable that astronomers will take advantage of peculiar opportunities to do astronomy during manned space flight missions. At the present time very modest limited-scope experiments have been considered for the Apollo command module to operate through an airlock. One of these is NRL's ultraviolet spectral photography experiment, which essentially is a reflight of an instrument which has provided very significant data in the exploratory analysis of the Sun's ultraviolet spectrum.

More important investigations of the Sun would be possible with the Apollo Telescope Mount (ATM). This device is a spaceborne equivalent of the equatorial solar telescope mounting at solar observatories. One structure would carry several solar telescopes to point them at the Sun. The ATM currently under study would carry instruments up to 3.7 meters long, and would, it is hoped, provide stabilization as good as 5 arc-seconds. The expected short observing periods in a low-altitude low-inclination Earth orbit, and the requirement for an astronaut to give time and effort to each individual experiment, mean that a single investigation must be satisfied by intermittent operation with a low duty cycle of the order of an hour or two per day spread over several hours. The flight of AOSO-type experiments on the ATM would provide some of the data that could be obtained by those same experiments on a full-sunlit continuous-duty standby-mode AOSO flight. There is reason to hope that early flights of an Apollo Telescope Mount would provide some high-resolution data on solar activity near the maximum of the current solar cycle in 1968 and 1969.

Initial plans call for one ATM mission, primarily to fly the instruments derived from those which were under development for AOSO. It is important to note that these basic instruments must be used for somewhat different investigations than proposed for AOSO, since the mission profile is so drastically different. The successful realization of this phase of the ATM program very likely will create additional flight opportunities for other investigations in stellar astronomy as well as in solar physics.

The ATM, now being designed, will contain a long optical bench to support and direct the telescopes at selected areas of interest. An astronaut will point the device crudely at the Sun and then let automatic controls take over for final acquisition of the Sun by Sun sensor and servocontrol system. The astronaut will then single out one experiment and point it to a particular part of the Sun for detailed study, using the ATM control system. Each experiment would be serviced in turn; those requiring precise boresighting would be operated sequentially, while wide-field measuring instruments could operate simultaneously with others. Beyond the operation of the system as described, the astronaut will be required to recover the film from the telescopes at the end of the observation, and prior to the reentry maneuver.

The further development of space flight solar instrumentation beyond that planned for the early Apollo program occupies an important place in our planning. NASA realizes that using large optical telescopes in orbit is one of the most promising long range goals that has been suggested for the space science program. The special requirements of solar astronomy dictate that peculiar instrumentation be provided, such as grazing incidence optics, image-forming X-ray optics, and image-differentiating spectroheliographs for the XUV and X-ray ranges. The ultimate capability during manned space flight to extend, adjust, operate, and maintain such large telescopes means that the ultimate limitation of the Earth's atmosphere need no longer limit the kind or quantity of scientific information obtainable by telescope techniques required in the study of the Sun. No single configuration of a manned orbiting solar telescope has yet been defined; however, in our long range planning we shall develop conceptual instrument configurations in order to define performance capabilities and better to assess the scientific yield to be expected from the fulfillment of such plans.

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STELLAR AND GALACTIC ASTRONOMY

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NASA

At the spring meeting of the American Astronomical Society in 1959, I made a brief announcement about the space astronomy program which the National Aeronautics and Space Administration was organizing, and I invited members of the society and their colleagues to participate in this program. Since that time, we have made great progress. We have successfully launched a gamma-ray telescope and two solar observatories. The spinning rockets of 8 years ago have been replaced, for the most part, by the stabilized rockets of today which can point not only at the bright Sun, but also at individual stars or even regions of the sky which do not have an optical target. Since the solar program has been presented in detail in the paper by Smith and since most readers are familiar with the spectacular results of the Ranger and Mariner missions, my discussion deals primarily with NASA's stellar and galactic program.

At the beginning of NASA's astronomy program, several interested members of the astronomical community met to discuss the astronomer's needs in space instrumentation. We quickly concluded that we wanted to have in space as close as possible an analog of our terrestrial observatories, with the same versatility for making many types of observations of numerous celestial objects. We soon recognized that the optics for each satellite package would have to be designed separately in order to provide the highest efficiency and the simplest automatic operation. Nevertheless, it was obvious that there were many needs common to all astronomical observations which could best be handled in a standardized spacecraft. Primary among these was the need to direct the optical equipment to a particular star or region of space on command from the ground.

Since the Orbiting Astronomical Observatory (OAO) was designed to spend only a few minutes per orbit within sight of a ground station, the astronomer's first thought of an operation which would be under complete ground command and in which a television camera would

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be used to monitor the pointing was obviously impractical. Instead, it was necessary to provide the satellite with some type of stellar reference system. This has been done by means of six star trackers which can be used to orient the spacecraft within 1 minute of arc. To keep the satellite moments of inertia as equal as possible, thus reducing gravitational torques which would tend to disturb the precise pointing, balance booms have been added. A sun shield was included both to protect the experiment before the satellite is fully stabilized and to act as a shade against sunlight scattered into the observing tube. A central tube, 48 inches (1.2 meters) in diameter, was provided for the optical experiment equipment. By standardizing this tube and making it removable, we have attempted to give the

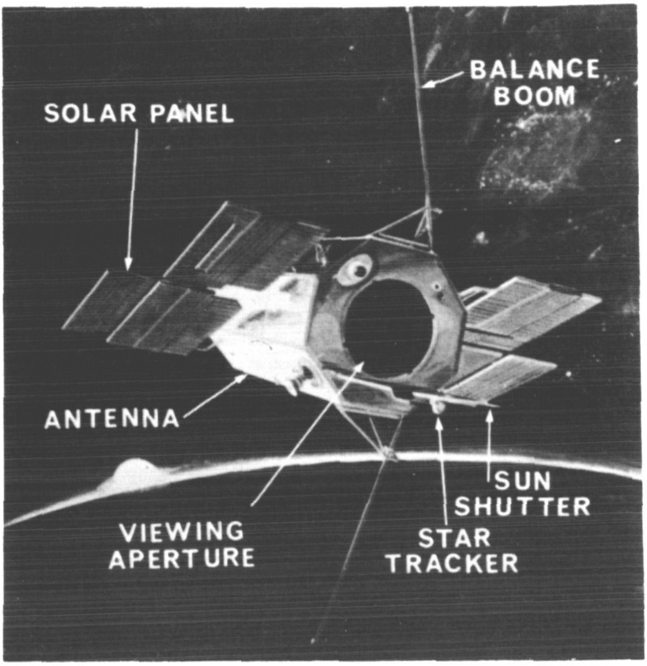

Figure 1.—Orbiting Astronomical Observatory.

Gross weight, kg	1770.
Instrument weight, kg	450.
Stabilization	Active 3 axes.
Launch vehicle	Atlas Agena.
Orbit:	
Type	Circular.
Altitude, km	800.
Inclination, deg	35.
Pointing-accuracy characteristics:	
Anywhere in celestial sphere, arc-min	1.
Star target, arc-sec	0.1.

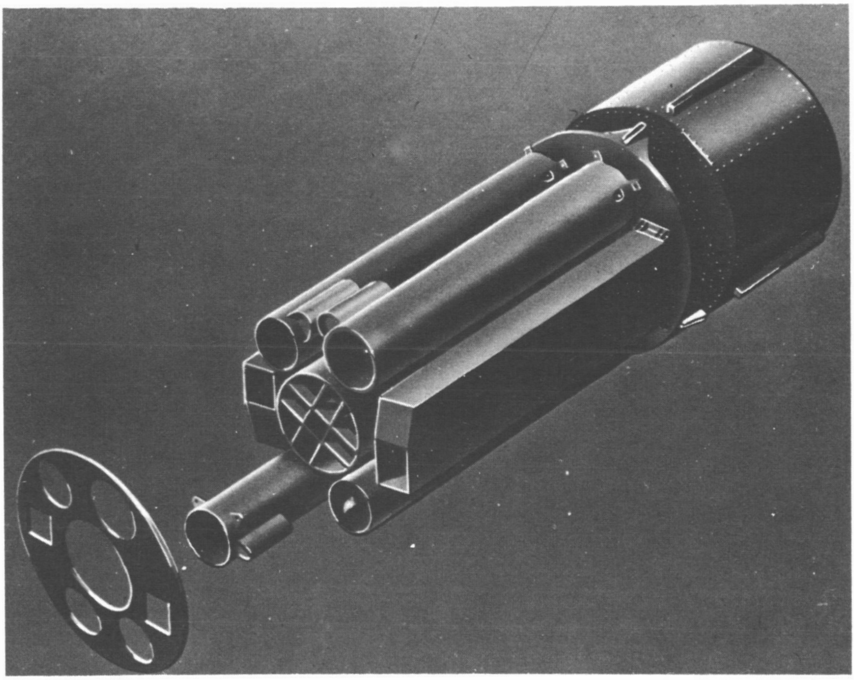

Figure 2.—University of Wisconsin Experiment Package for the first Orbiting Astronomical Observatory.

astronomer the maximum flexibility in the design of his optical systems.

The first OAO (fig. 1), which will be launched soon, will carry four experiments.[1] An ultraviolet experiment package (fig. 2), provided by Arthur Code and Theodore Houck and their colleagues at the University of Wisconsin, consists of four 8-inch (0.2 meter) diameter, f/4, off-axis parabolas with photometers at the prime foci; a 16-inch (0.4-meter) diameter, f/2, nebular photometer; and two objective grating spectrometers, each composed of a 6- by 8-inch (0.15- by 0.2-meter) objective plane grating and a 7- by 10-inch (0.18- by 0.25-meter), f/4, parabolic objective mirror. Each stellar photometer has a five-position filter wheel: one position permits a dark measurement, a second exposes the photomultiplier to an ultraviolet Cerenkov calibration source, and three positions introduce bandpass filters which

[1] The first OAO was launched April 8, 1966. A power failure which occurred after 2 days prevented the experiments from being performed; however, the star tracking system demonstrated the ability to stabilize the spacecraft. The University of Wisconsin experiment will be carried again on the second OAO. The payloads originally scheduled for the second (OAO–B) and third (OAO–A2) spacecraft will be interchanged.

isolate spectral bands of approximately 300 Å in width to cover wavelengths longer than about 1000 Å, with overlap not only between the longest wavelength photometer and the ground, but also between photometers.

The field of view of each photometer can be selected as either 2 or 10 minutes of arc, and the exposure time can be varied by command between ⅛ second and 64 seconds. In addition to the dark shield and the Cerenkov source, the nebular photometer filter wheel carries four filters with transmissions centered at 3300 Å, 2800 Å, 2500 Å, and 2000 Å. The field stop on this photometer may be adjusted to either 10 or 30 minutes of arc. One spectrophotometer covers the wavelength region from 2000 Å to 4000 Å, using a 300-line/mm grating blazed for 3000 Å and an exit slit which can be selected at either 20 Å or 200 Å. The other spectrometer, designed to operate between 1000 Å and 2000 Å, uses a grating blazed for 1500 Å and an exit slit corresponding to either 10 Å or 100 Å.

The Wisconsin experiment occupies only half of the experiment space; the other half is occupied by three experiments (fig. 3) in the gamma- and X-ray regions of the spectrum. Phillip Fisher of Lockheed Missiles and Space Division has prepared two identical arrays of

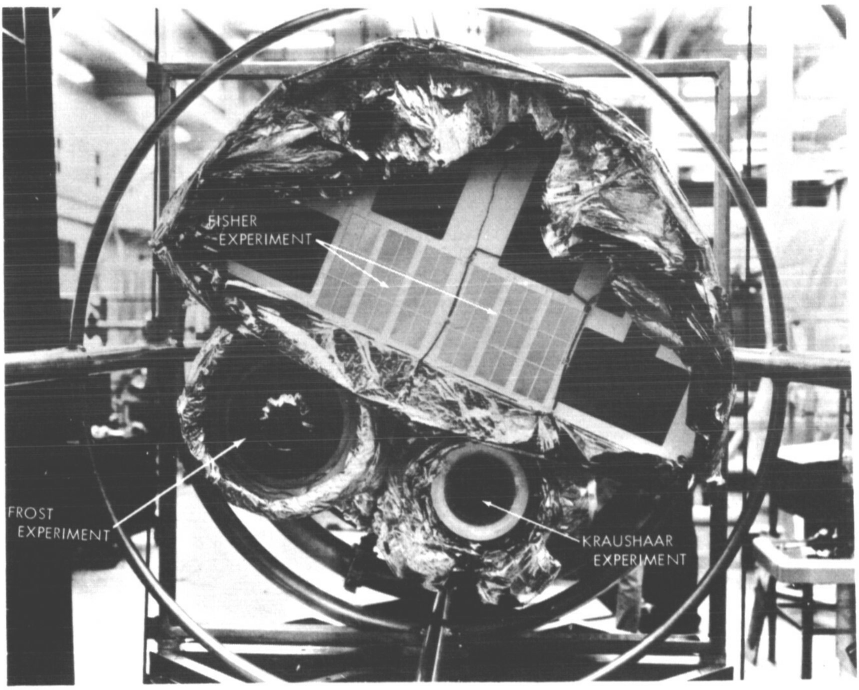

Figure 3.—Gamma- and X-ray experiments for the Orbiting Astronomical Observatory.

gas proportional counters, each of which has a geometrical aperture of 700 cm^2 and is equipped with anticoincidence scintillator shields. Each array can be operated with either a 16° square field for a wide field survey to discover new faint sources of X-rays in the 6 Å to 2.4 Å band, or a small 8° square field for more accurate location of brighter sources, hopefully, within 20 minutes of arc. An indication of the spectra of the sources will also be measured.

A survey of sources in the range of 2 to 150 keV will be conducted by Kenneth Frost and his colleagues at the Goddard Space Flight Center, using a detector originally designed for the Orbiting Solar Observatory series. A 78-cm^2 scintillating crystal of sodium iodide is surrounded by a large anticoincidence shield. A nine-channel pulse-height analyzer will provide spectral data on the events observed.

A third instrument to survey the sky for gamma-rays with energies greater than approximately 50 to 100 MeV has been built by William Kraushaar and his colleagues at the Massachusetts Institute of Technology. This instrument is actually the prototype for the experiment which was flown on the first of the astronomical satellites, Explorer XI. It consists of a cesium iodide, sodium iodide sandwich-type crystal scintillator followed by a Lucite Cerenkov counter. A large plastic anticoincidence scintillator surrounds the telescope to deactivate it during the passage of charged particles. It is hoped with this experiment both to detect point sources of these gamma-rays and to obtain a better measurement of the diffuse galactic background noted by Explorer XI.

The second Orbiting Astronomical Observatory will carry a 36-inch (0.91-meter) diameter telescope (fig. 4) designed by the Goddard Space Flight Center for spectrophotometry of stars as faint as 10th magnitude in a spectral range from 1050 Å to 4000 Å. A resolution of 2 Å, 8 Å, or 64 Å can be used. The optical elements of this telescope are made of beryllium, an innovation in major optical systems. Six photocells mounted approximately 600 Å apart will provide both redundancy and data collection efficiency for the instrument. The third OAO will carry a duplicate of the first University of Wisconsin experiment (fig. 5). It will also carry four telescopes designed by Fred Whipple and Robert Davis of the Smithsonian Astrophysical Observatory to map the sky in two ultraviolet wavelengths, using specially modified Vidicons operating at the foci of Schwarzschild cameras. The Vidicon has been modified for highly sensitive, blemish-free operation in the ultraviolet. The production of a suitable Vidicon, or Uvicon, for this purpose, proved to be sufficiently difficult that this experiment, originally intended for the first OAO, had to be delayed.

The fourth of the Orbiting Astronomical Observatories will carry a spectrometer (fig. 6), designed by Lyman Spitzer and John Rogerson

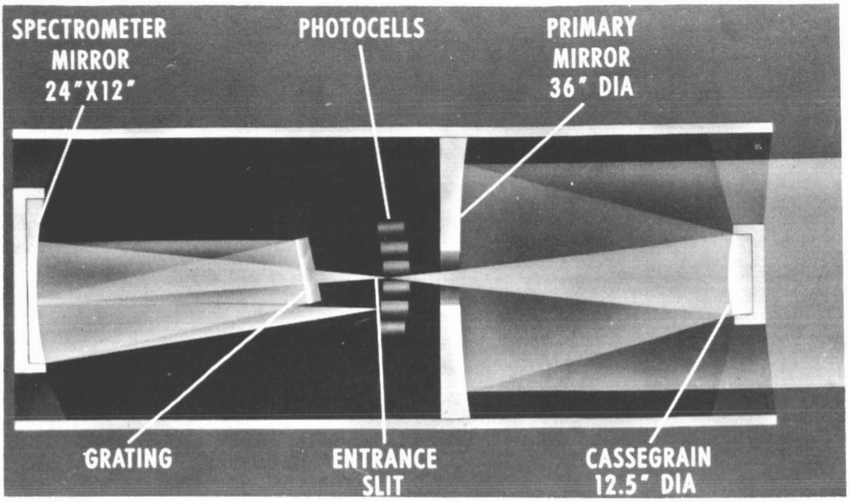

Figure 4.—Goddard experimental package for the Orbiting Astronomical Observatory.

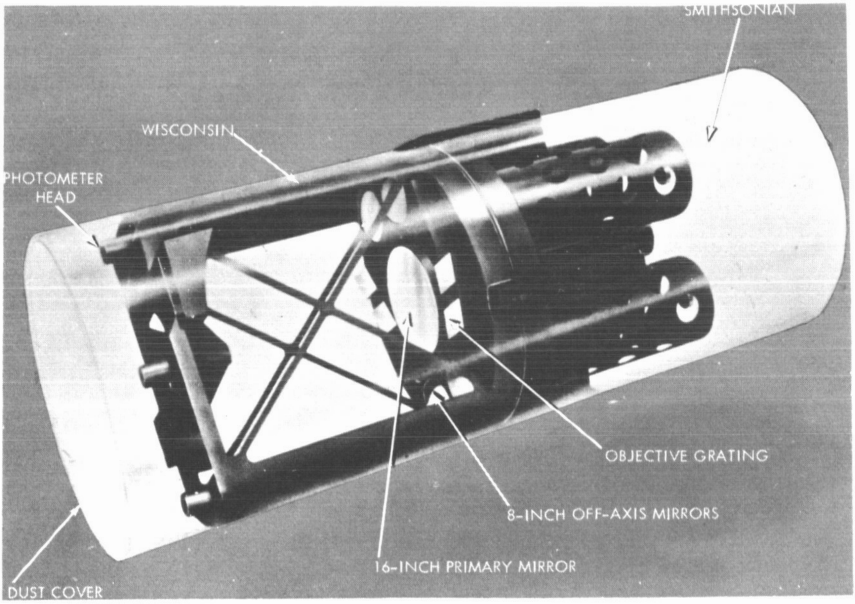

Figure 5.—Smithsonian and the Wisconsin experiment packages for the Orbiting Astronomical Observatory.

of Princeton University. The 32-inch (0.8 meter), f/3, quartz mirror uses an egg-crate construction to reduce its weight. The 2400-line/mm grating is blazed for 2200 Å and provides either a 0.1 Å or a 0.4 Å resolution. Two carriages which rotate along the Rowland circle with two photocells on each carriage cover the wavelength range from 800 Å to 3300 Å. Two monitoring detectors permit corrections of inaccurate guiding. This satellite will also carry a nest of three 8-inch (0.2-meter) parabolic collimators to observe the brighter X-ray sources with higher resolution at 3 to 9 Å, 8 to 18 Å, and 44 to 60 Å. This experiment is being prepared by R. L. F. Boyd of the University College, London, and F. A. Stewardson of Leicester University.

Although only four OAO flights have been authorized, NASA considers the OAO to be a standard spacecraft which will be useful for many years to come. A fifth OAO may carry a second model of the spectrophotometer being developed by the Goddard Space Flight Center for OAO–B, modified slightly to provide offset guidance and the capability of measuring appreciably fainter stars than those which can be observed with the OAO–B instrument. This will be primarily a guest-observer instrument; that is, observing time will be made available as far as possible to any qualified astronomer with a sound scientific program who wishes to obtain ultraviolet spectrophotometric

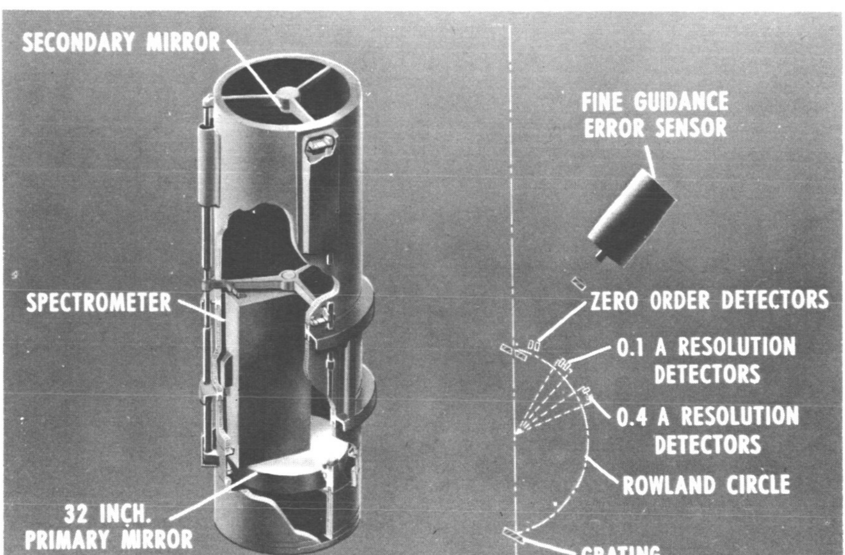

Figure 6.—Princeton experiment package for the Orbiting Astronomical Observatory.

data, in much the same way that the telescopes at the Kitt Peak Observatory are made available to guest investigators. We also hope to have a small, guest-investigator program on the earlier OAO's. In particular, if the ultraviolet experiment on the next OAO operates well, we shall be inviting proposals for guest investigators for a limited amount of the time available with this satellite. This policy will be followed with the later OAO's.

Most of the results in space astronomy have been obtained through the use of sounding rockets. Stellar pointing systems for the Aerobee 150 are now available; they permit the observer to point his equipment at from one to five targets per flight with an accuracy of about 2°. These pointing systems, which are still being improved, have not had the desired reliability, but as their reliability is increased, they are rapidly becoming almost standard in the stellar sounding rocket program. Broadband ultraviolet photometry results have now been obtained by a number of observers both in the United States and in Britain. In contrast to the situation several years ago, the results obtained by the various observers are in quite good agreement. As a result of the unexpectedly low ultraviolet brightness of the hotter stars, stellar expectedly low ultraviolet brightness of the hotter stars, stellar models have been revised to include a more realistic correction for line blanketing. These changes led, in turn, to a revision of the stellar temperature scale for hot stars, and the observations now agree well with the models. Sufficient data are now available for a reasonable extension of the interstellar reddening curve into the ultraviolet (ref. 1). The effect is illustrated in figure 7. A distinction between scatter that is intrinsic to extinction and the observational scatter is difficult, but there is some indication that the variations in extinction found for the visible and infrared by Harold Johnson of the University of Arizona (ref. 5) and others are responsible for some of the scatter in the ultraviolet as well. The observed ultraviolet extinction curve has lent some support to the recent revival of the theory that graphite grains are responsible for interstellar extinction. However, the presence of pure graphite grains does not appear to be adequate to explain the detailed course of the extinction with wavelength.

Narrowband photometry was introduced into rocket astronomy by Theodore Stecher and James Milligan of the Goddard Space Flight Center (ref. 6). They used objective gratings to observe the stars with a resolution of 100 Å, in the wavelength range from 1700 Å to 4000 Å. The roll of the rocket was used to provide the spectral scan. These spectra also clearly showed the ultraviolet deficiency evident in the broadband photometry. The first published photographic spectra of stars were obtained by Donald Morton and his colleagues at Princeton University in June of 1965 (ref. 7). These

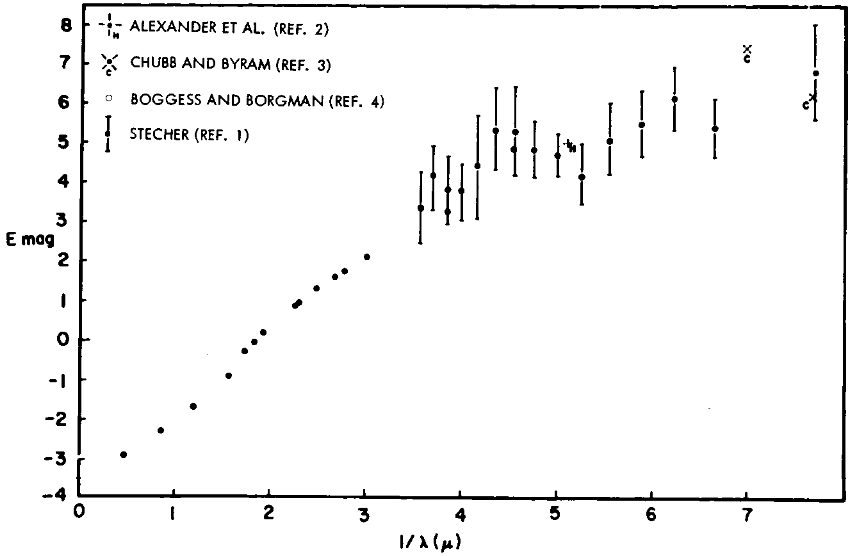

Figure 7.—Plot showing the extension of the interstellar extinction curve into the ultraviolet (ref.1).

observers detected weak spectra of Delta and Pi Scorpii at a dispersion of 64 Å per millimeter in the wavelength region between 1250 Å and 4000 Å. Twenty-three lines in the Delta Scorpii spectrum and 18 lines in the Pi Scorpii spectrum were identified. All of the lines were in absorption as had been predicted by theory. Spectral photometric scans of stars in Lupis and Canis Major by the Goddard Space Flight Center personnel also showed absorption features near 1500 Å. Perhaps the most exciting photographic spectra that have been obtained in the ultraviolet are those illustrated in figure 8, also by Donald Morton and his colleagues (ref. 8). Six spectra are visible. The black, nearly vertical lines are zero-order images of field stars. The exciting feature is that on the longward edge of the strong lines in Epsilon and Zeta Orionis, emission features are clearly visible. This indicates that these stars are apparently ejecting mass at a substantial rate.

One area of space astronomy not even thought of 8 years ago has come to the forefront of astrophysical importance. In 1962 Ricardo Giacconi, Herbert Gursky, and F.R. Paolini of the American Science and Engineering, Inc., and Bruno Rossi of the Massachusetts Institute of Technology first detected X-rays originating outside the solar system (ref. 9). Wide-field Geiger counters revealed the existence of a strong source in the constellation Scorpius, not far from the galactic center, and a possible secondary source in the constellation Cygnus. The Geiger counters also revealed a diffuse X-ray background which

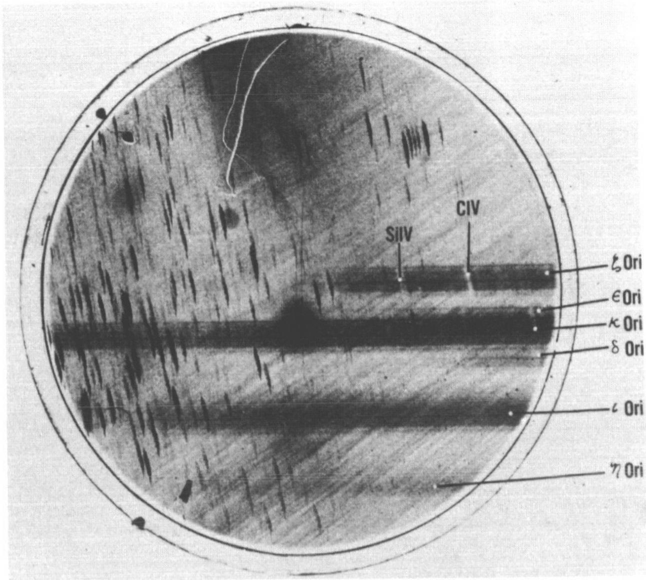

Figure 8.—Ultraviolet stellar spectrograph recovered from attitude-controlled Aerobee rocket flight (ref. 8).

was apparently also of celestial origin. The reality of these sources, whose locations are indicated in figure 9, has been confirmed by these investigators and others. Later flights showed seven or eight additional X-ray sources, including the Crab Nebula. These latter flights also proved conclusively that the galactic center was not a source of X-rays. In an ingenious observation in mid-July 1964, Friedman and his colleagues (ref. 10) showed that the X-ray source in Tauri is indeed coincident with the Crab Nebula and that it is approximately

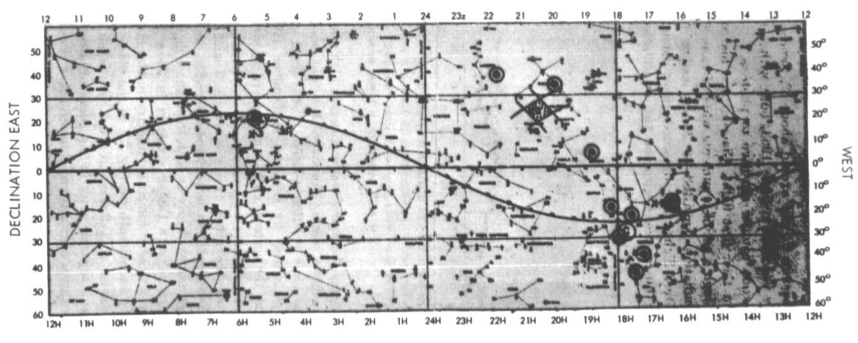

Figure 9.—Sounding rocket celestial map of X-ray sources.

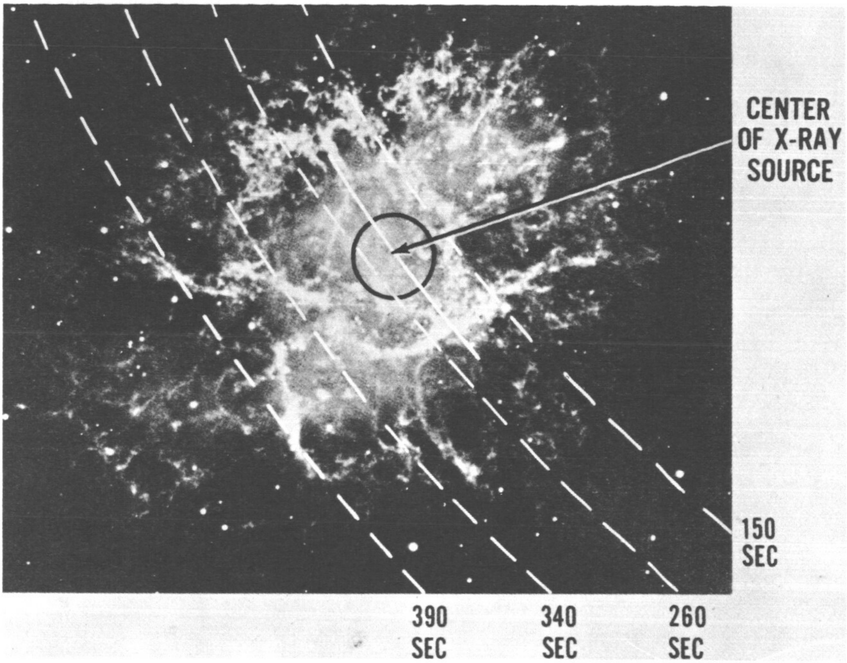

Figure 10.—Method used to locate the X-ray source in the Crab Nebula during a lunar occulation. Dashed lines indicate the position of edge of Moon at time shown; arrow indicates direction of motion of Moon.

1 arc-minute in diameter. The size was determined by measuring the decrease in the X-ray emission from Crab Nebula as the Moon moved across the Nebula (occultation indicated in fig. 10). Friedman (ref. 11) has recently discovered approximately a dozen additional X-ray sources and has identified two of these with the radio stars M87 and Cygnus A. Increasingly well collimated detectors have been used for X-ray sky surveys, and positions of the brighter sources are now known to within a fraction of a degree. However, as yet, optical identification has proved impossible for most of the sources. Most are well concentrated in the galactic plane, particularly the galactic center region.

Rockets and satellites do not provide the only platforms for space astronomy. For many purposes, balloons carry instrumentation to an altitude high enough for useful astronomical results. For some years, NASA has joined with the Office of Naval Research and the National Science Foundation in supporting the Stratoscope II balloon flights. Not only do we expect this project to produce valuable results, but the techniques being used to obtain high-resolution photographs remotely will also be applicable to high-resolution photography in satellites. NASA encouraged and supported modification of the Stratoscope II instrumentation for use with an infrared spectrometer in 1963. The first flight encountered many difficulties which limited the scientific results to those which were obtained at approximately the same time by other means. However, a second flight successfully recorded new infrared spectra of the Moon, Jupiter, Mu Cephei, and six other red giant stars (ref. 12). Water vapor absorption bands at 1.4 and 1.9 microns were found in five of the six stars (clearly shown in fig. 11 for Alpha Orionis). The sixth, Alpha Taurus, shows practically no water vapor bands but an intensity peak near 1.6 microns. The long-period variable, Omicron Ceti, also showed a water vapor band at 2.7 microns. Jupiter clearly showed the expected bands of CH_4, molecular hydrogen, and NH_3.

The highest balloons also attain an altitude sufficient for at least preliminary surveys in the soft gamma-ray region. George Clark and his colleagues at the Massachusetts Institute of Technology, Laurence Peterson at the University of California, and others at the Goddard Space Flight Center and elsewhere have flown gamma-ray detectors in balloons. Clark first observed the Crab Nebula in the energy range between 15 and 60 keV in July 1964 (ref. 13). Peterson

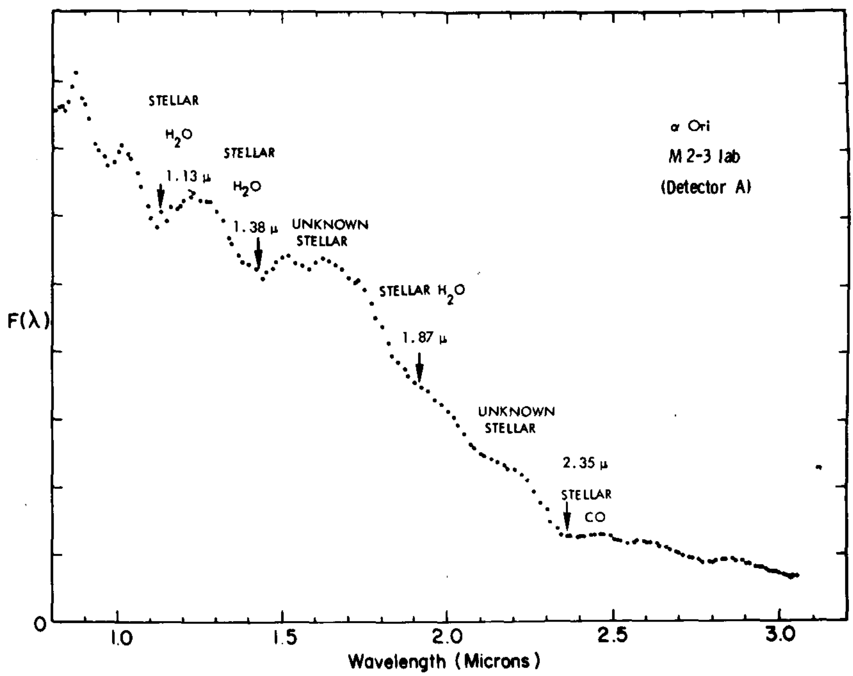

Figure 11.—Infrared spectrum of Alpha Orionis obtained by Stratoscope II (ref. 12).

also observed the Crab Nebula in the energy range between 16 and 120 keV in September 1965 (ref. 14) with a somewhat better spectral resolution (fig. 12). It is interesting to note that Crab Nebula presents a smooth spectrum for frequencies ranging from 10^7 Hz to 10^{18} Hz, with a gradual increase in slope in the infrared and visible regions. Upper limits have been established at frequencies up to 10^{29} Hz. These also fall near a smooth curve extrapolated from the X-ray and soft gamma-ray regions, indicating that improvements in sensitivity by a factor of 10 to 100 may be adequate to permit detection at these higher frequencies. The index of differential energy flux in the gamma- and X-ray regions appears to be near 0.9. Several groups are flying spark chambers in balloons to detect higher energy gamma-rays. As yet, I am unaware of any positive results from these flights, but the sources must be nearing the margin of detectability, a margin that should be crossed fairly readily at satellite altitudes.

As has been mentioned, the Explorer XI satellite, shown in figure 13, was designed to detect high-energy gamma-rays. The satellite, which was launched in 1961 by a Juno II rocket, was placed in too high an orbit. Because the anticoincidence shield deactivated the counter whenever a charged particle was detected, the instrument was turned off most of its time in the Van Allen belts, and consequently the amount of usable observing time was severely limited. No point sources were detected. However, an average gamma-ray background intensity of 3×10^{-4}/cm^2/sec/sterad was observed (ref. 15). Although no asymmetry which might be related to galactic concentration was observed, it seems highly probable that this flux did arise from outside of the solar system. This intensity of gamma-rays can be accounted for if a moderate intensity of high-energy electrons in intergalactic space is assumed. As mentioned previously for the Crab Nebula, the upper limits placed on the gamma-ray emission from the Andromeda Nebula and Magellanic clouds, the galactic center, and seven of the stronger radio sources may not be far above the actual value.

At the other end of the electromagnetic spectrum, significant progress has been made in the measurement of the spectrum of the cosmic background at frequencies between 1 and 5 MHz. Rockets have been flown by Fred Haddock and his colleagues at the University of Michigan (ref. 16) and by Robert Stone and Joseph Alexander at the Goddard Space Flight Center (ref. 17); Richard Huguenin and his colleagues at Harvard University (ref. 18) have designed experiments which have flown on several satellites; Theodore Hartz of the Canadian Defence Research Telecommunications Establishment (ref. 19) analyzed the results of the Alouette topside sounders

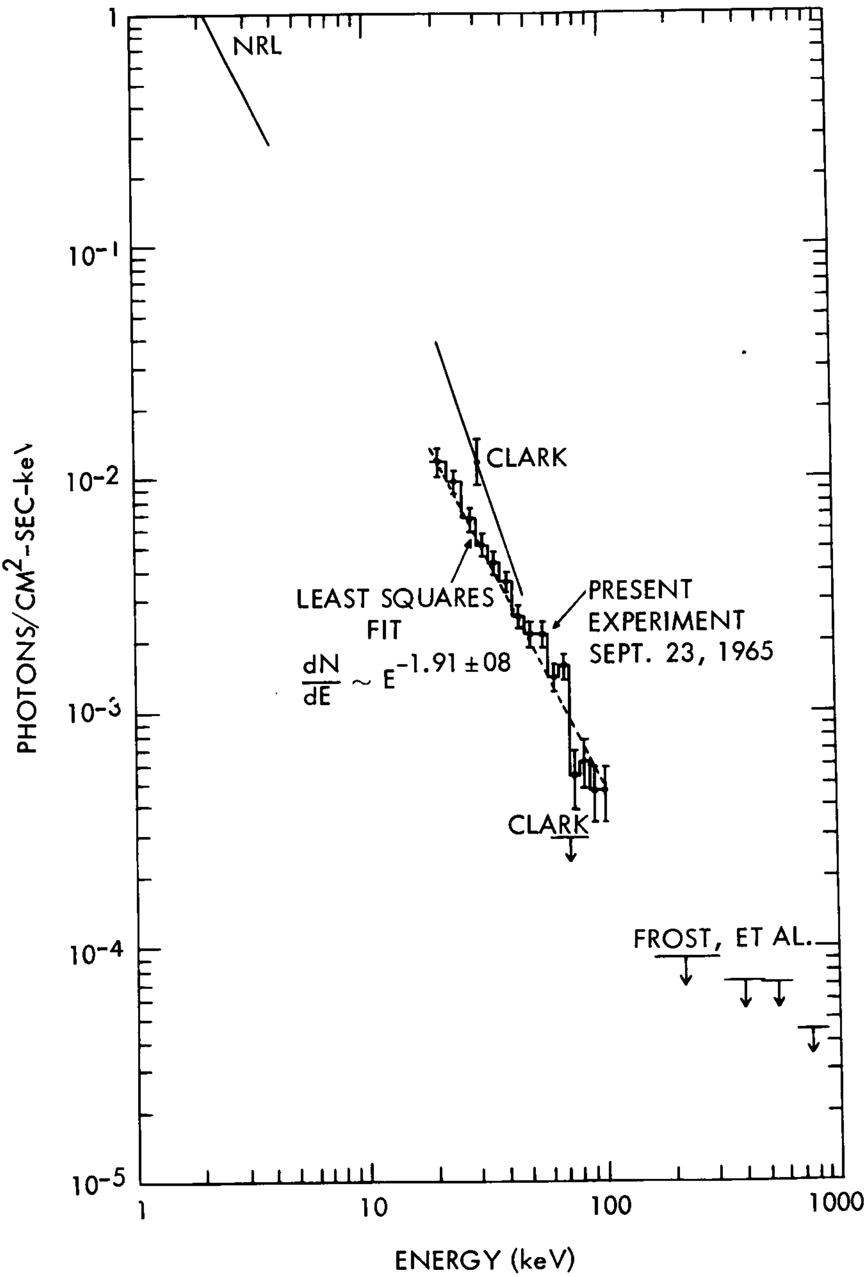

Figure 12.—Photon flux from the Crab Nebula versus photon energy in the X- and soft gamma-ray spectral region (ref. 14).

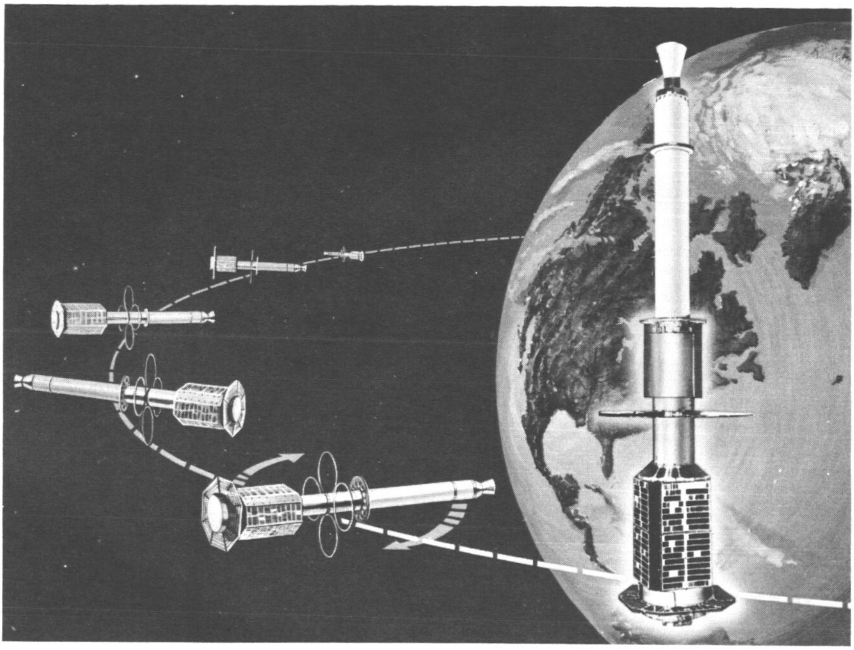

Figure 13.—Explorer XI gamma-ray satellite.

for intensity of galactic background emission; and Graham Smith and Haddock have flown receivers on Ariel II (ref. 20) and Orbiting Geophysical Observatories I and II, respectively. Each of these experimenters used short dipoles with almost no directivity. As figure 14 shows, the measurements agree reasonably well (ref. 21) in indicating that the maximum intensity of the galactic background occurs between 5 and 10 MHz, with a decided decrease at lower frequencies. Some of these experiments have also indicated that the ionosphere may be a significant source of noise, possibly emitting bursts of energy in a mode analogous to that of the Jupiter ionosphere. The first attempt to obtain even limited directivity at these frequencies will be made in 1967 with a Radio Astronomy Explorer (fig. 15) designed by Stone (ref. 22). This satellite will carry two V-antennas, each leg of which is 750 feet (230 meters) in length. These antennas will produce a beam of about 25° by 45° at 3¾ MHz, with a front-to-back ratio near 17 dB. Several Ryle-Vomberg multifrequency radiometers will be used in the frequency range of 250 kHz to 10 MHz. The satellite will carry also several multifrequency burst receivers and an antenna impedance probe. It was originally hoped to use 1000-foot (300-meter) antennas, but problems of gravity and thermal bending prevented the use of such long struc-

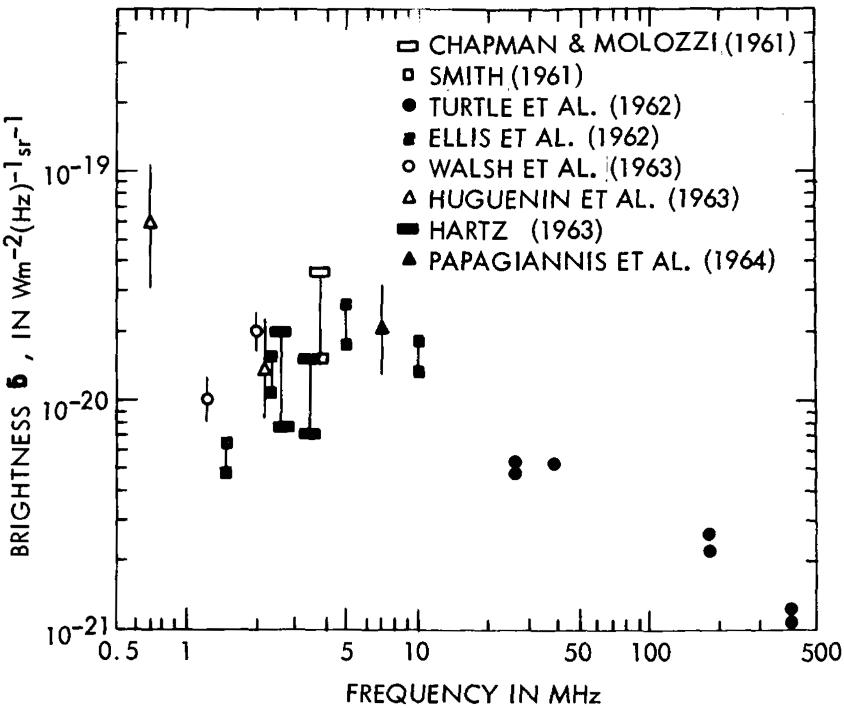

Figure 14.—Measured values reported for the mean cosmic background noise. All points represent measurements from rockets of satellites except those of Ellis (ref. 21).

tures. A TV Vidicon camera carried on the spacecraft will watch the tips of the antennas to correct the gain for the misalinement.

So far, all space astronomy has been automated. However, as the manned space program matures, plans are being made to incorporate the flexibility of manned operation into the program to an increasing extent. We hope to obtain both direct photographs, using interference filters, and objective prism spectra with a dispersion of 200 Å per millimeter down to 2000 Å, using an ultraviolet modification of the Mauer camera carried by the astronauts.[2] This arrangement is shown in figure 16. Only the very brightest stars will be observed spectroscopically. Karl B. Henize, of Northwestern University, who has been responsible for the design of this experiment, is planning a more sophisticated version to be flown on Apollo. A special 6-inch (0.15-meter) Ritchey-Chretien, f/3, camera with an objective prism will be inserted into an airlock and will be used to obtain a number of

[2] Excellent stellar photographs were obtained on Gemini missions X, XI, and XII.

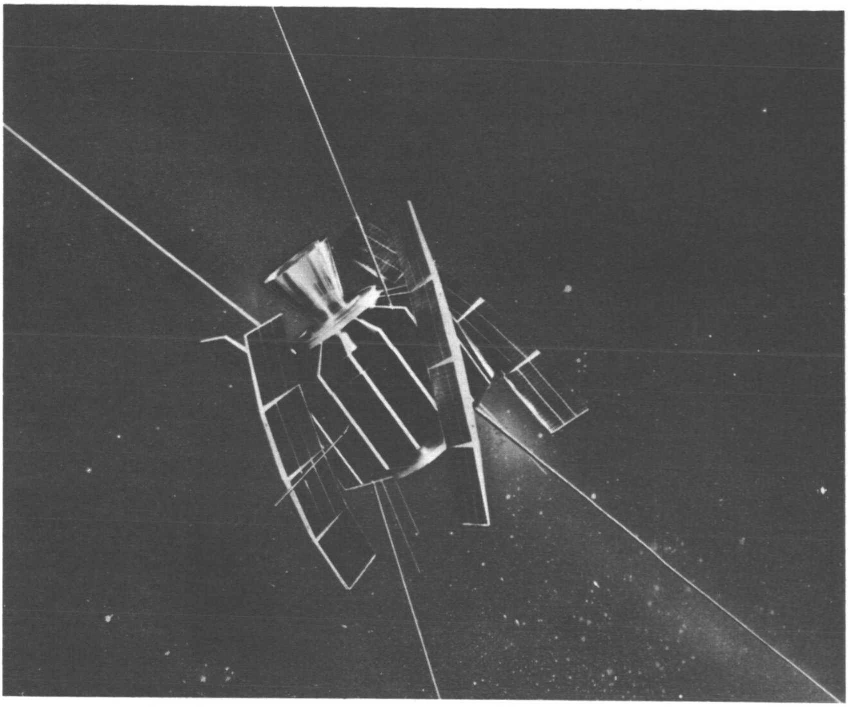

Figure 15.—Radio Astronomy Explorer.

objective prism spectra of early type stars with a dispersion near 370 Å per mm at 2000 Å. In addition, a low-dispersion prism will be used to observe a large number of stars with a resolution of 10 000 Å per mm at 2000 Å. An X-ray instrument is being designed by Giacconi, Waters, and their colleagues at American Science and Engineering, Inc., for flight on Apollo. It will be used to determine accurate positions of known X-ray sources and angular diameters of the larger X-ray sources, and for a general sky survey to find new X-ray sources in wavelengths between 5 Å and 50 Å. Two broadband detectors with fields of view of 20° by 4° will be flown as will a narrow-band detector, variable in angular resolution between 40 minutes and 38 seconds.

Any discussion of the NASA astronomy program would be incomplete without mention of laboratory, theoretical, and ground-based observational work. A detailed description of the sixty-odd projects in stellar and galactic astronomy alone is beyond the scope of this paper, but a few projects are mentioned here to give an idea of the range of these activities. NASA is, of course, supporting the development of more sophisticated experiments in the ultraviolet and X-ray regions and exciting experiments to test various aspects of the theory

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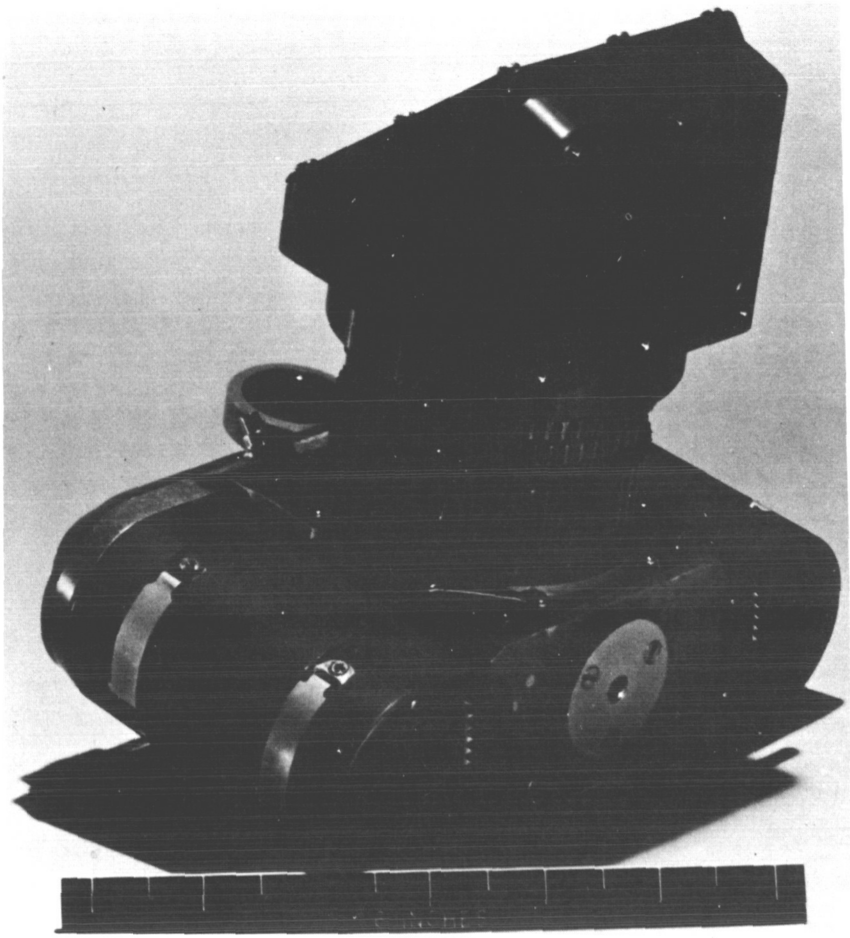

Figure 16.—Mauer camera with objective prism in place to be used by the astronauts during the Gemini X and XI flights to obtain direct and low resolution stellar photographs and spectra in the ultraviolet.

of relativity. Kenneth Andrew at Purdue is conducting a detailed laboratory analysis of atomic spectra, and Stanley Bashkin, at the University of Arizona, has been measuring lifetimes of highly ionized species of astrophysical interest. Willelm Luyten of the University of Minnesota is developing an automatic blink microscope for detecting and measuring stars of large proper motion. At the California Institute of Technology, we are supporting the modernization of their excellent telescopes and the application of modern techniques in data handling to increase the efficiency of these various astronomical instruments. Arno Landolt, at Louisiana State University, is studying the spectra of OB stars; Gerry Neugebauer at the California Institute of Technology is surveying the sky in the infrared and cataloging the many infrared stars he has observed. At the University of Indiana, Hollis Johnson is studying the details of stellar atmospheres and Morton, at Princeton, is doing theoretical astrophysical research in areas in which the ultraviolet observations planned for the Princeton OAO experiment will be most directly concerned. We are supporting the construction of a 105-inch (2.7-meter) telescope at the McDonald Observatory and an 84-inch (2.1-meter) telescope at the University of Hawaii. Moreover, NASA has also supported construction of a number of smaller ground-based instruments for both optical and radio observations. As an outgrowth of satellite tracking, the Smithsonian Astrophysical Observatory has compiled a catalogue combining numerous star catalogues and containing many newly computed proper motions. Obviously, space astronomy is not a new field, but simply a new tool for attacking traditional astronomical problems. Therefore, space astronomy cannot be conducted as an entity, but must be part of a coordinated program of research, most of which is conducted on the solid earth.

In 1959, we stood at the dawn of a new space astronomy program. Today we have accomplished many of the things we were planning at that time and have opened exciting new fields, but we may be at the dawn of an even more important space astronomy program. It is obvious that if we are going to exploit the possibilities of space astronomy, instruments such as those recommended in the National Academy of Sciences' Woods Hole Study of 1965 will be needed, and we are making the first tentative plans for such instrumentation. At the present time, if a transistor burns out or a battery dies, an unmanned spacecraft such as the OAO has taken an irremediable step toward death. Moreover, no changes can be made to update the instrumentation with which the spacecraft is launched. We recognize that even simple operations by man could greatly extend both the lifetime and the versatility of an OAO; therefore, we have been looking into the possibilities of using man in such maintenance activities. Such an operation is illustrated in figure 17. Looking further ahead, we also realize that eventually astronomers will want larger telescopes in space than are possible with the current series of OAO's. Therefore, we have had a study conducted on the possibility of building, mounting, and using in space a telescope of approximately 120 inches (3 meters) in diameter. The problems are far from trivial, but they also do not appear insurmountable, given the resources necessary for the job. Following the recommendation of the Woods Hole Summer

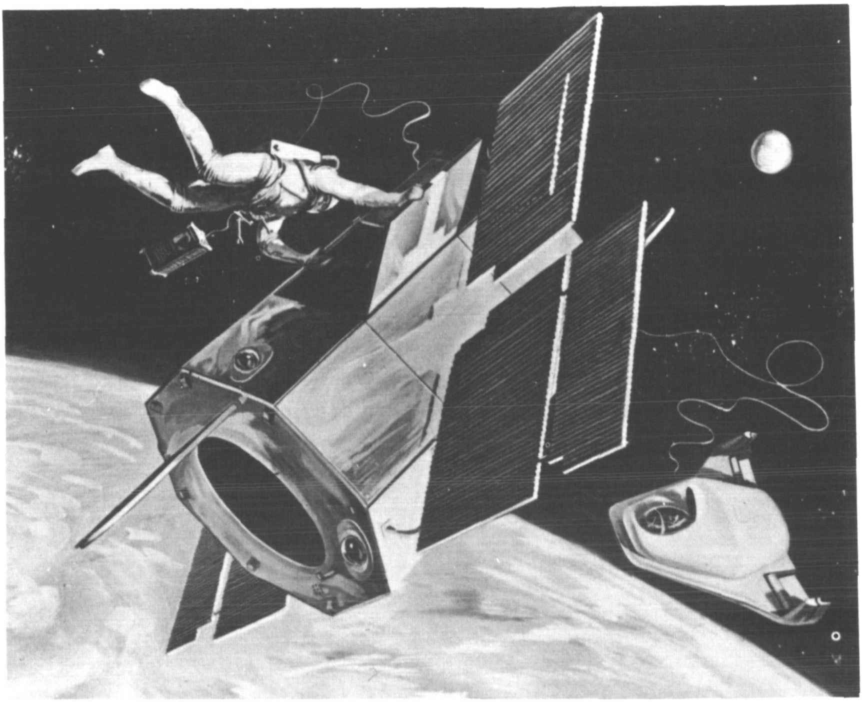

Figure 17.—The use of man to repair and maintain an Orbiting Astronomical Observatory.

Study, we are also investigating the possibility of flying low-frequency radio astronomy experiments with higher directivity than that of the Radio Astronomy Explorer. Studies are being conducted at the University of Michigan and at TRW Systems on aerial systems which can be spun out to sizes of the order of kilometers. Perhaps additional smaller antennas will be placed on the periphery of such structures. The Goddard Space Flight Center is considering the possibility of using a separate maneuverable satellite, together with an antenna carried on a synchronous orbiting Apollo, to map the celestial skies with reasonable directivity using aperture synthesis. We are also supporting Harvard for a ground-based test of obtaining directivity using sophisticated data analysis techniques. We have done less so far to implement the recommendations of the Woods Hole conference in the fields of gamma-ray and X-ray astronomy, although here also we are alert to the possibilities.

I repeat my invitation of 8 years ago. NASA is planning an exciting space astronomy program. We invite the participation of those astronomers who are interested in active observations from beyond the Earth's atmosphere and we request the support of those who share with us the belief that, when supported by an adequate program of ground-based astronomy, space-flight opportunities indeed add powerful tools to the astronomer's collection.

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EXPANDING VISTAS IN ASTRONOMY

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Expanding Vistas

The inherent advantages offered by placing instruments above the Earth's atmosphere are well known to astronomers. Within the atmosphere, scintillation prevents the resolution of small details of images in the sky, airglow and atmospherically scattered light interfere with observations of extended cosmic sources, and radiation is totally absorbed at both ends of the electromagnetic spectrum and partly absorbed in the middle regions. (See ref. 1.)

Thus, the limit of the performance of telescopes on Earth is set not by technology but by the characteristics of the atmosphere.

The avoidance of the atmospheric difficulties opens new vistas to the astronomer. These new vistas have been coming into view since October 10, 1946, when Richard Tousey of the Naval Research Laboratory obtained the first solar spectrum in the ultraviolet with instruments launched by a V-2 from White Sands. (See ref. 2.)

By the 1960's, unmanned satellites and space probes became available to the astronomer, extending the duration of observations beyond the short operational period of a ballistic trajectory. Advancing technology made it possible for man to begin the exploration of space, operating his instruments by remote control, or programing them to operate automatically.

Now, however, we are entering a new period in which it is becoming possible to place the astronomer in the space environment, near his instruments. Figures 1 to 3 illustrate the status of the development of man's ability to operate in this environment. Figure 1 shows Astronaut Edward White operating outside his Gemini IV spacecraft on June 3, 1965, and figure 2 shows a photograph taken during the rendezvous between two Gemini spacecraft on December 15, 1965. The first of the two spacecraft, Gemini VII, was launched on December 4. Eleven days later, Gemini VI was launched. After a series of maneuvers over a period of 5 hours, the two came together 298 kilometers above the Pacific Ocean.

The Agena target docking vehicle as seen from the command pilot's hatch window on the Gemini X spacecraft is shown in figure 3. The Gemini X mission occurred on July 18–21, 1966. The Gemini spacecraft achieved rendezvous with the unmanned Agena spacecraft, went on to an actual docking with the Agena, and then the Agena engine was employed as a propulsion stage to cause changes in the orbit.

Now what does man's presence add to the effectiveness of the man-machine system in space? His contributions can be classified into four areas—as a sensor, as a manipulator, as an evaluator, and as an investigator.

As a sensor, man may perform some tasks now performed by instruments. But instruments are available with greater abilities

Figure 1.—Gemini IV extravehicular activity.

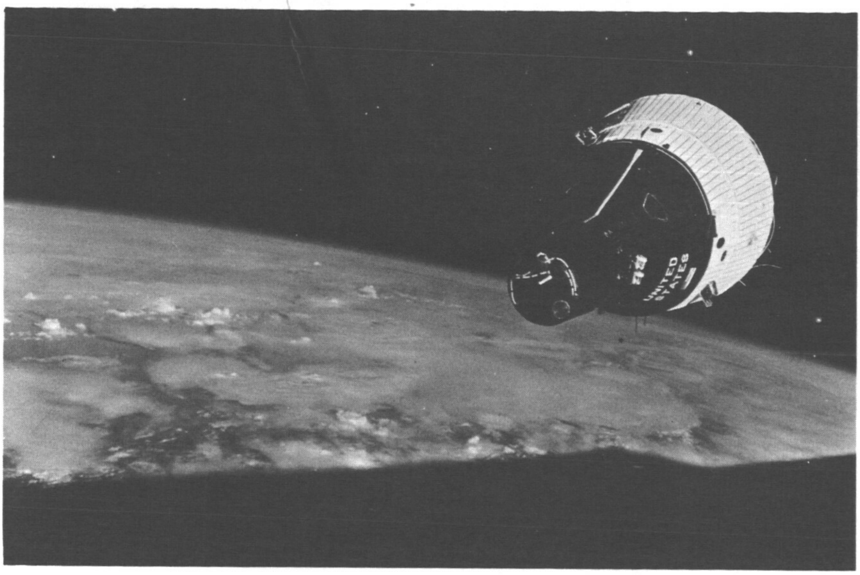

Figure 2.—Gemini VII–VI rendezvous.

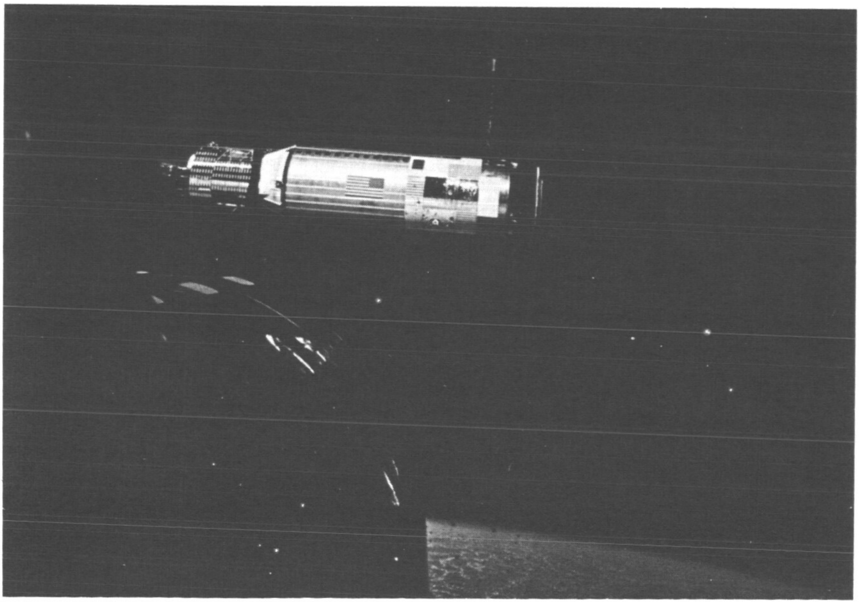

Figure 3.—Gemini X docking.

to see, hear, touch, measure temperature, and so on. Other instruments can measure such phenomena as radiation, electrical charge, and magnetism, which man's senses cannot perceive at all. Under the direction of the human brain, man's senses can be flexible and selective, but instruments appear to be superior for most sensing functions.

In the role of manipulator, man is actively involved in coping with the environment and is able to overcome or bypass equipment failures in programed activities. The control of the spacecraft orientation, for example, often is performed more effectively when man is in the spacecraft operating the equipment, rather than on the ground employing remote control.

Experience with the X-15 rocket aircraft and both the Mercury (table I) and Gemini (table II) manned space flight programs has demonstrated the essential role of man as a manipulator. In each of the manned Mercury and Gemini flights there was an equipment problem that would have caused a mission failure had not a man been aboard to back up the equipment. With the knowledge gained in the Mercury program, man has been designed into the system in the Gemini and Apollo programs. In these programs, the man-machine system is so designed that the man does things he is best qualified to do, within the time available to him, and the automatic equipment does those things that can be done better by machinery.

TABLE I.—*Corrective Actions by Astronauts on U.S. Manned Mercury Space Flights*

Mission and crew	Anomaly	Corrective action by crew
Mercury VI, Glenn	Yaw thruster automatic control failure	Controlled manually
	Erroneous indication of premature heat shield clamp release	Retained retropack during reentry
Mercury VII, Carpenter	Pitch horizon scanner circuitry failure	Controlled manually
Mercury VIII, Schirra	Excessive suit temperatures	Manually regulated coolant flow
Mercury IX, Cooper	Erroneous reentry indication by panel light during orbital flight	Manually conducted retrofire with aid from ground and observation of Shanghai city lights
	Automatic stabilization and control system inverter failure	Manually controlled orientation

TABLE II.—*Corrective Actions by Astronauts on U.S. Manned Gemini Space Flights*

Mission and crew	Anomaly	Corrective action by crew
Gemini III, Grissom and Young	dc–c converter failured	Activated secondary system
Gemini IV, McDivitt and White	Hatch closing difficulty	Worked handle back and forth until it closed properly
	Computer-instrument guidance system light failure indication	Manually controlled reentry
	Connector fault in blood pressure measuring device	Pressure cuff pumped up after repeated attempts
Gemini V, Cooper and Conrad	Pressure drop in reactant supply for fuel cell	Evaluated situation: Determined heater would continue to maintain pressure
	Loose suit fitting and damaged seal on blood pressure bulb	Replaced seals and tightened fitting
Gemini VII, Borman and Lovell	Moisture in suit inlet hose	Repositioned switches and valves, rolled spacecraft to throw water out of vent
	Low oxygen pressure in supply for fuel cell	Opened crossfeed valve to transfer oxygen from reserve supply
Gemini VI, Schirra and Stafford	Launch vehicle shutdown on pad	Evaluated situation and elected not to utilize seat-ejection abort system
Gemini VIII, Armstrong and Scott	Thruster failure in open position, causing rapid roll rates	Switches cycled to isolate cause, reducing rate to tolerable level

Man's relative importance as an evaluator in the man-machine system is increased considerably. With this ability, a "sensing and manipulating" individual achieves a substantial degree of self-reliance in controlling what he perceives and how he reacts. Frequently, he can alter the procedures of an experiment on the basis of early results, and direct his instruments toward unforeseen "targets of opportunity." When a man remembers, reflects, analyzes, compares, contrasts, and induces—when he understands, building on a foundation of knowledge—he has increased the degree to which data can be selectively obtained and translated into useful information.

In order to become better evaluators, all our astronauts participate in a scientific training program which includes instruction in astronomy, geology, and space physics. The current training program in astronomy, for example, is being carried out under the leadership of William Tifft at the University of Arizona and Karl Henize at Northwestern University.

But the most significant duty of man is that of an investigator who responds creatively to unexpected situations, postulating theories and hypotheses, and promptly devising and initiating desirable alterations of systematic programs and measurements. On this point, the Space Science Board of the National Academy of Sciences observed in a statement issued on August 7, 1961 ("Man's Role in the National Space Program"):

> Man can contribute critical elements of scientific judgment and discrimination in conducting the scientific exploration . . . which can never be fully supplied by instruments, however complex or sophisticated they may become.

In order to assure this kind of astronaut involvement in astronomy and other space science investigations, five young scientists have joined our flight crew pool. Altogether, there are more than 45 members of the astronaut team. Qualified scientists will continue to be added to the program to work as astronauts in close coordination with their ground-based colleagues.

Which of the astronauts will be investigators or co-investigators will depend on their motivation and the success of the scientific training, which will be demonstrated on the Apollo flights to the Moon. This training is incorporated in plans for all Apollo and post-Apollo missions for scientific purposes.

We have been learning in the early manned space flights how astronauts can participate in space astronomy. In the Mercury flights, they observed the night airglow band, the banded multicolor aspect of twilight, and stars to the fifth magnitude. On Gemini missions, identification was made of stars to the sixth magnitude and slightly beyond. In addition, Gemini astronauts have been able to observe the structure of nightglow, auroras, and meteors, and have obtained photographs of certain twilight bands. (See ref. 3.)

On the Gemini V mission, Astronauts Gordon Cooper and Charles Conrad obtained photographs of the zodiacal light and the gegenschein for E. P. Ney and W. F. Huch of the University of Minnesota. (See ref. 4.)

In the Apollo program, experiments planned for Earth-orbital flights include further airglow photography, X-ray astronomy by Ricardo Giacconi of American Science and Engineering, Inc., ultraviolet stellar astronomy by K. G. Henize of Northwestern University, and ultraviolet and X-ray solar photography by Richard Tousey. Dr. Roman has described two of these experiments.

Moving Onward

As background for our thoughts about the future possibilities in astronomy, a brief status report of the Apollo program and the capability of Apollo flight and ground equipment to perform other space missions than lunar exploration will be given.

The Apollo flight system comprises two major launch vehicles and a spacecraft consisting of three major systems. In addition, there are ground facilities at several locations in the United States, and a worldwide network of tracking and data acquisition facilities to support the Apollo program.

The first of the Apollo launch vehicles (fig. 4) is the two-stage uprated Saturn I. The second is the three-stage Saturn V. The uprated Saturn I can boost payloads of 18 metric tons into Earth orbit. The Saturn V is able to place 127 metric tons in Earth orbit or accelerate a 43-metric-ton spacecraft to the 11-kilometer-per-second velocity required for flight to the Moon.

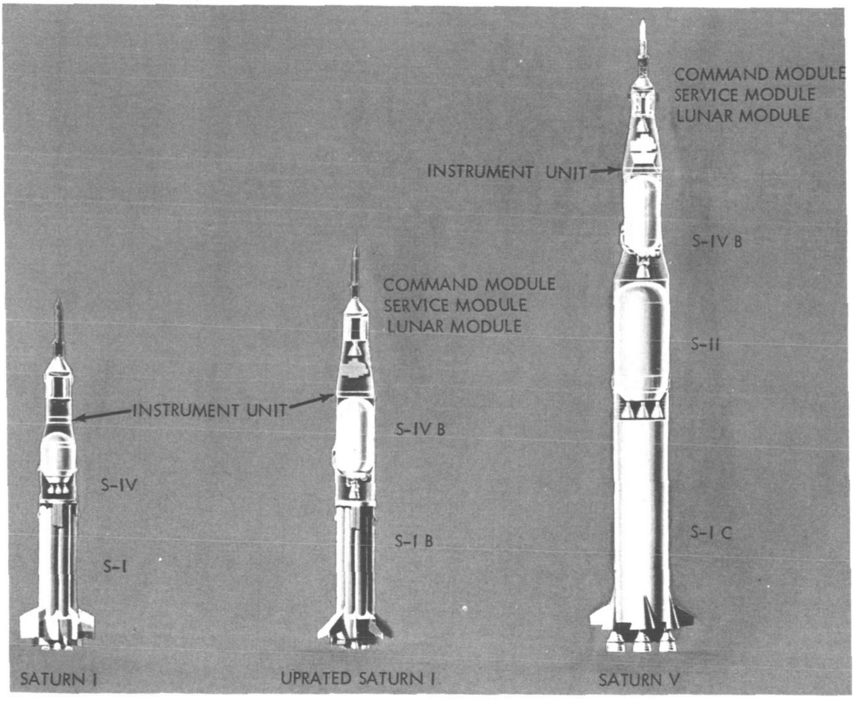

Figure 4.—Apollo launch vehicles.

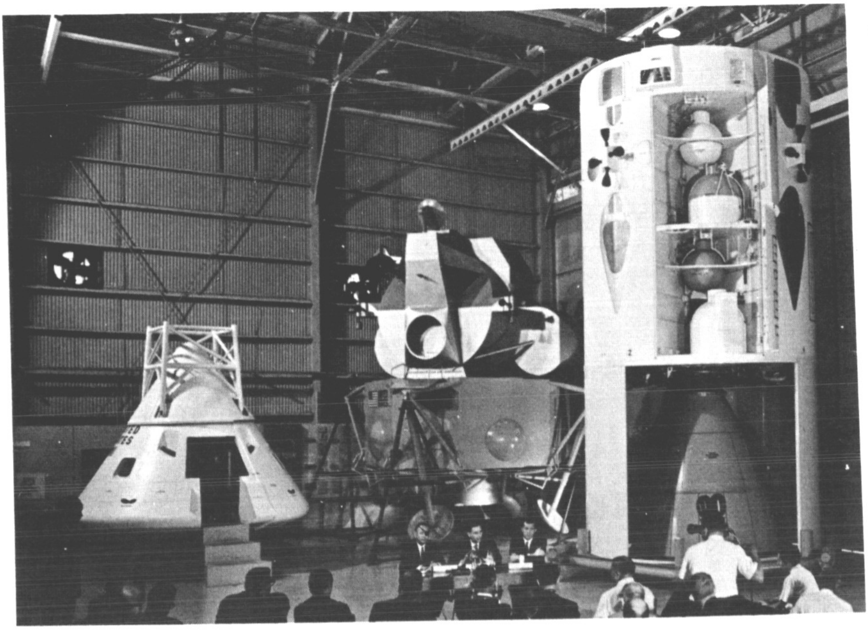

Figure 5.—Apollo spacecraft.

Figure 6.—Vehicle Assembly Building, Cape Kennedy.

The Apollo spacecraft (fig. 5) consists of the command module, the service module, and the lunar module. The command module, weighing 5400 kilograms, carries the three astronauts from Earth to lunar orbit, and then from lunar orbit back to Earth. A major feature of its construction is the heat shielding required to protect it from temperatures up to 5800° K generated on reentry into the atmosphere at 11 kilometers per second. The service module supplies propulsion, electrical power, and reserve oxygen. Its primary propulsion system is employed for course corrections en route to and from the Moon, for deboost into lunar orbit, and for acceleration from lunar orbit on the return trip to Earth. The service module also has a bay set aside for experimental devices.

The lunar module is a two-stage spacecraft in which two of the three astronauts travel between lunar orbit and the Moon. A descent stage provides propulsion and guidance for the trip down to the surface. At the conclusion of the stay on the surface, this stage becomes a launch pad for the ascent stage, which separates and returns to rendezvous and dock with the command and service modules in lunar orbit.

To accomplish the Apollo program we have established facilities for the manufacture, testing, assembly, and checkout of launch vehicles and spacecraft, for tracking and data acquisition, and for mission control.

Of particular interest are the Michoud plant in New Orleans where large launch vehicle stages are fabricated, the Mississippi Test Facility where acceptance test firings are conducted, the spacecraft test facilities at White Sands and Houston, the deep space tracking facilities of the Jet Propulsion Laboratory, the central switching terminal for the worldwide tracking network at Goddard Space Flight Center in Greenbelt, Maryland, and the Mission Control Center at Houston.

At the Kennedy Space Center in Florida, the Apollo-Saturn V space vehicle, which stands 110 meters in height, is assembled and checked out in an enclosed structure, the Vehicle Assembly Building (fig. 6), protected from weather and salt spray. This building is slightly more than 150 meters high. When the vehicle is ready to be moved to the launch pad, a crawler transporter carries it, together with a launch tower, in vertical position along more than 5 kilometers of special roadway.

In the Apollo program, the major activities of 1966 were the unmanned test flights of the Apollo spacecraft and the uprated Saturn I launch vehicle in preparation for manned Earth-orbital flights. The overall Apollo schedule for the decade called for the beginning of manned Earth orbital flights in 1967.

Another major Apollo milestone scheduled for 1967 is the first unmanned flight of the Apollo-Saturn V, the vehicle to be employed in the lunar missions. Qualification tests of the three stages of the launch vehicle and the spacecraft modules were made in 1966, and the launch complex in Florida was activated.

When the unmanned flight tests of the Apollo-Saturn V are completed, manned flights are to begin; this is planned for 1968. The first manned lunar mission and return are scheduled for 1969.

Altogether, the Apollo program includes 12 flights with the uprated Saturn I and 15 flights with the Saturn V. This number of vehicles is necessary to assure the accomplishment of the program's mission objective of beginning the manned exploration of the Moon in this decade.

The Apollo hardware is capable of a wide variety of missions other than the manned lunar landing. It can place spacecraft in both low and high Earth orbits and in lunar orbit, as well as send them to the lunar surface. The propulsion capability required for the maneuvers of the lunar landing and return mission can also be employed for other maneuvers in cislunar space. In addition, it would be possible to substitute additional payloads for some of the fuel and oxidizer needed for these maneuvers. There are also grounds for hope that the lunar landing milestone might be reached prior to the last of the presently programed Apollo-Saturn V flights.

With these facts in mind, we are planning alternate missions for the Apollo flight equipment to investigate the operating conditions of space flight and to determine how some advanced experiments and operations might be carried out. It should be remembered, however, that the Apollo program has first call on all the flight hardware. When it becomes evident that a vehicle is not required for the primary Apollo program, it will be allocated to an alternate mission. In this manner, we hope to carry out the Apollo program with a high degree of flexibility and incorporate late developments into our plans.

For an illustration, consider four possible alternate missions, outlined in table III. The first alternate mission would be an Earth orbit at 35 000 kilometers altitude with an orbital period of 24 hours. The orbit would be inclined 28.5° to the Equator; thus, although it would be synchronous with the Earth's rotation, it would not be stationary over a single point on Earth. In a 14-day flight it could develop the ability to fly manned synchronous orbits, use radar and photographic equipment for synoptic weather observations, and deploy a laboratory module for later use.

A second possible Earth-orbit mission could permit us to develop the procedures of resupply for a space station and to learn to transfer crew and materials between two spacecraft. For this mission, at an altitude of 300 kilometers, two uprated Saturn I launch vehicles would be required. One would orbit the command and service modules carrying three men and the other would orbit an unmanned lunar module. After the two spacecraft are joined together, the lunar module propulsion might be used for such maneuvers as the

TABLE III.—*Potential Apollo Alternate Missions*

Mission	Description	Altitude, km	Inclination, deg	Duration, days	Launch vehicle	Activities
A	Earth orbit	35 000	28. 5	14	Saturn V	Develop ability to fly synchronous orbits Wide-ranging weather observations Deploy lunar module for later use
B	Earth orbit	300	28. 5	14 to 28	Uprated Saturn I (two launches) 1st payload—command service modules (3 men) 2d payload—lunar module (unmanned)	Refine ability to conduct Earth-orbital rendezvous operations Resupply and mission extension Crew and material transfer Extravehicular activity, maneuvering Power-tool operations
C	Lunar orbit	50 to 80	90	14	Saturn V	Remote survey of the Moon's surface Seek potential sites for extended-duration surface missions Distant Earth photography
D	Lunar surface exploration at site of previous Apollo lunar surface mission			10 (total) 2 to 3 days on surface	Saturn V	Obtain samples of lunar material for return to Earth Emplace instruments for unattended operations Geological traverses Develop lunar surface rendezvous Utilize previously delivered equipment

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recovery of panels from a Pegasus spacecraft or operation with a spent second stage of the Saturn I.

A third type of mission would place the spacecraft in a polar lunar orbit for 2 weeks. Cameras and other sensing equipment could be used to survey the Moon's surface for potential landing sites for extended-duration surface missions and for later analysis by land-based geoscientists.

In the fourth possibility a spacecraft would be sent to the same place on the Moon's surface that a landing has already been made. Thus it would be possible to use some of the equipment left behind on the previous flight and to remain on the Moon for several days.

A second phase of Apollo applications might begin with the procurement of additional Apollo-Saturn I and Apollo-Saturn V vehicles for the period following the completion of the flights authorized for the basic Apollo program. In this period, extending at least through 1971, the duration of manned orbital flights could be increased by increments to several months. Thus we would be gaining experience needed for the development of the ability to operate in space.

Many applications as well as scientific investigations will be possible during Apollo applications missions. The scientific potential was explored during the summer of 1965 at two major conferences, the Summer Study of the Space Science Board of the National Academy of Sciences at Woods Hole, Massachusetts, and the NASA Summer Conference on Lunar Exploration and Science at Falmouth, Massachusetts. The reports of these conferences have been published in references 5 and 6. The discussion in the present paper will be limited to the implications for astronomy (ref. 5, Part II; ref. 6, pp. 52–55 and 367–393).

Now what is recommended in astronomy? At Woods Hole, some astronomers said that they would like to have an optical telescope in space operating between 800 Å in the ultraviolet and 1 millimeter in the infrared, with an image quality comparable to that of a diffraction-limited 120-inch (3.05-meter) telescope and a total aperture between 120 and 250 inches (3.05 and 6.35 meters). Also desirable would be an antenna array 20 kilometers on a side, a 30-meter parabolic dish for observations in the far infrared and submillimeter regions, and large sophisticated instrumentation for the gamma- and X-ray regions. In NASA, we have begun investigating the technological and administrative considerations related to the undertaking of such major efforts.

In considering whether or not these efforts are justified, it is interesting to recall the arguments of George E. Hale in his proposal nearly 40 years ago for the establishment of a 200-inch (5.08-meter) telescope. In an article published in 1928 in Harper's Magazine, Hale noted recent progress in astronomy and physics and suggested that a large telescope would open the way to a considerable advancement in the understanding of the structure of the universe, the evolution of stars, and the constitution of matter (ref. 7):

> I have never liked to predict the specific possibilities of large telescopes, but the present circumstances are so different from those of the past that less caution seems necessary.
>
> The development of new methods and instruments of research is one of the most effective means of advancing science. In hundreds of cases the utilization of some obvious principle, long known but completely neglected, has suddenly multiplied the possibilities of the investigator by opening new highways into previously inaccessible territory. The telescope, the microscope, and the spectroscope are perhaps the most striking illustrations of this fact, and the result has been a complete transformation of the astronomical observatory.

The degree to which Hale's predictions were fulfilled is well known to astronomers. (See ref. 8.) When we are able to exploit fully the possibilities of space astronomy, we can look forward to extensions of knowledge of even greater magnitude than those envisioned by Hale and now being realized by using the Hale telescope. Perhaps even less caution is needed today than in 1928.

The Next Steps

It is important to emphasize at this point that the first task to be performed, before man can operate astronomical instruments in space, is to learn to maneuver effectively and efficiently in that environment. We must investigate the conditions and the problems associated with operations in a vacuum under weightless conditions. To gain this experience, we must learn by doing, and by spending time in space.

In the Mercury and Gemini programs thus far, the manned flights have totaled almost 2000 man-hours in space. Before we can fully exploit these capabilities, we should multiply this experience to man-days and then to man-years in space. This can be done, according to present plans, in the Apollo program and during the period immediately following the initial lunar landings. During this time, we can plan to gain the necessary experience and develop advanced operational techniques.

Plans of the Apollo applications flights include placing in orbit near the end of the decade an astronomy facility that might constitute an initial step toward the development of a manned space observatory. Building on the experience of OSO and OAO, we would install a telescope mount on the Apollo spacecraft. The spacecraft could house the astronomer-astronaut and could enable him to perform research and observations for 14 days and perhaps longer. This initial space observatory is planned to operate in the 300-

kilometer altitude range at first. Somewhat later it may be raised to the 35 000-kilometer synchronous altitude.

What can be done with such equipment? Initially, the effectiveness of an astronaut in erecting, alining, and operating relatively large astronomical instruments and conducting other experiments over a period of time could be determined.

We will rely on the scientific community for advice as to the type of observations that might be made by, or the instrumentation that might be carried on, the Apollo telescope mount, which Dr. Smith has discussed. Plans for the first flight call for a concentration on solar observation, since it is expected to occur about the time of the solar maximum. Thus it will include some or all of the instrumentation that was contemplated for the Advanced Orbiting Solar Observatory (AOSO): a scanning spectrometer in the 300 to 1300 Å range, an X-ray telescope in the 3 to 60 Å range, a white light coronagraph for studying the polarization and brightness distribution of coronal structures in the range of 2 to 6 radii above the Sun's limb, and spectroheliographs for obtaining images of the Sun in the resonance lines of hydrogen and helium, as well as selected lines of Fe XV and XVI.

As the program progresses, we would hope that the use of such equipment would enable us to develop a reasonably versatile observatory that would provide an opportunity for photographic imagery as well as spectroscopy and photometry in the infrared, visible, and ultraviolet regions.

The Woods Hole conferees recommended that telescopes of intermediate aperture—40 to 80 inches (1.02 to 2.03 meters)—be launched in the Apollo applications flights in order to test at a relatively early stage the ability of man to adjust, maintain, repair, and occasionally operate such a telescope. One way to meet this need might be to carry a 38-inch (0.97-meter) telescope like that planned for the second OAO.

Presumably the principal interest in an instrument of this size results from its ability to see much fainter objects in the inaccessible regions of the spectrum beneath the Earth's atmosphere. But there also may be an improvement in our ability to reach out into the universe in the visible spectrum. Table IV shows a comparison of some of the characteristics of the Hale telescope on Mount Palomar with optical instruments of various sizes in orbit.

Airglow and background interference limit observable stellar magnitudes to about 23.5 from the ground, regardless of telescope diameter. However, it may be possible to improve this limit by 2.5 magnitudes with telescope apertures of 40 inches (1.02 meters) in Earth orbit with an exposure of about 10 hours. Such an increase would depend on general sky brightness in the area under observation.

TABLE IV.—*Optical Telescope Comparisons*

Mirror diameter, in. (m)	Effective resolution, km: Moon	Effective resolution, km: Mars	Detect star planets	Spectral range	Required stabilization (arc-sec)	Approximate weight, kg
Ground-based						
200 (5.08) (Mt. Palomar)	0. 5	80	No	Visual	±0. 1–0. 2	500 000
16 (0.41)	. 5	80	No	Visual	±0. 2	
In orbit						
16 (0.41)	0. 5	80	No	Visual plus infrared and ultraviolet	±0. 2	200
38 (0.97)	. 2	30	No		±0. 1	500
60 (1.52)	. 1	20	(?)		±0. 05	2000
120 (3.05)	. 1	10	Possibly		±0. 01	14 000

This improvement would be equivalent to an increase in brightness by a factor of 10 and in range by a factor of 3.3 in the absence of interstellar absorption. An improvement of this magnitude should be of interest to astronomers who are trying to solve the puzzles of the quasars.

Another factor that limits the Earth-based telescope is atmospheric turbulence. The maximum resolution achievable by ground-based telescopes is about 0.3 second of arc on rare occasions and an average of about 1 second of arc. A 38-inch (0.97-meter) telescope above the atmosphere might improve this resolution to about 0.15 second. In terms of pictures of astronomical bodies, the resolution would be reduced from 80 to 32 kilometers on Mars.

However, in order to take advantage of this resolution, we have to know how to stabilize the space telescope very precisely. To utilize a 38-inch (0.97-meter) telescope, a pointing accuracy of 0.1 arc-second is required. Consequently, telescope stabilization is a design feature of the OAO.

In response to the desires of astronomers at Woods Hole, we have also examined some of the potentials of orbiting telescopes of 60- and 120-inch (1.52- and 3.05-meter) diameters. The numbers in table IV refer to diffraction-limited telescopes; however, we should keep in mind that diffraction-limited telescopes of these sizes have not been constructed on Earth as yet. Thus we must retain a certain degree of skepticism as to whether or not the technology will really be available within the next decade or so. However, even non-diffraction-limited telescopes of larger size can improve one's ability to see into the universe.

No attempt has been made to indicate the stellar magnitudes that would be observable with 60- and 120-inch (1.52- and 3.05-meter) instruments. There are clearly too many unknowns regarding the sky brightness, optical technology, pointing accuracy, and the feasibility of holding a large instrument steady in space for lengthy periods. But if these unknown limitations are disregarded, one can conceive of extensions in seeing power that might enable the astronomer to begin to make rough measurements of such fundamental constants as the size and the age of the universe, to the extent that such constants have a meaning.

The table indicates the potential increases in resolution and required stabilization for the 60- and 120-inch (1.52- and 3.05-meter) telescopes, as well as a very rough approximation of the telescope weights. Some people speculate that one interesting result of the use of such a telescope might be the detection of planets of other stars and the revelation of the disks of some nearer stars.

Recently a study was made of the potential of the OAO in conjunction with a manned spacecraft or space station. Results showed that man can enhance the OAO mission in at least six ways. He can:

Maintain the OAO so that it performs maximally

Achieve course pointing by orienting the OAO through the spacecraft television system

Recover and evaluate the film

Reset the range of operation of instrumentation

Modify the optical system

Realine the optical system

This study indicated that it appears feasible to launch an Apollo applications spacecraft and an OAO with a Saturn I launch vehicle on a 30-day mission at an altitude of 483 kilometers and an orbital inclination of 32°. The OAO could be tethered to the spacecraft during the first 3 days. Then the OAO could be released to carry out a sky mapping experiment, for example, monitored by the spacecraft crew but free of any mechanical disturbances.

Another of the 1965 Summer Study observations worth consideration is that of the Astronomy Study Group of the NASA Summer Conference on Lunar Exploration and Science: that the Moon may well offer an attractive and possibly unique base for astronomical observations. The study group recommended that we begin as soon as possible to explore the lunar capabilities for astronomy; we should conduct engineering studies on Earth, environmental studies on the Moon, and tests with small telescopes on the Moon.

The recommendations of this group also included feasibility studies for a dish antenna of about 30 meters to be used between millimeter and infrared wavelengths above the Earth's atmosphere. The purpose of these studies would be to determine whether or not such an antenna should be placed in high Earth orbit or on the lunar surface.

Clearly, the first step to be taken in response to this group of recommendations is to obtain lunar environmental data in the Surveyor, Lunar Orbiter, and Apollo programs. In addition, methods of delivering astronomical equipment to the Moon should be investigated. An equipment item under examination for the Apollo applications lunar surface missions is an emplaced scientific station weighing about 140 kilograms (Earth weight) and having about 0.6 cubic meter of volume. One of the instruments that may possibly be incorporated in such a station is a 12-inch (0.30-meter) optical telescope.

Another study indicated that it may be feasible to incorporate a telescope into the lunar module payload for a lunar surface mission. In such a mission, the astronaut would set up the instrument and begin operation during the 14-day period of an Apollo applications lunar surface mission. Then the instrument could continue operating in an automatic mode after his departure.

These studies are mentioned for illustrative purposes; we know too little about the lunar environment to have very firm opinions at this time about whether or not the Moon will be an appropriate site for astronomical observations. But we are keeping the Moon in mind as we proceed with our studies.

Meanwhile, the necessity of improving technology must be realized if such programs as have been discussed in this paper are to be undertaken. We are presently examining how best to perform research that will give us information on the space environmental effects on optical mirror and substrate materials, their adhesive characteristics, means of control and monitoring to attain the required pointing accuracy, and methods of maintaining the optical integrity of a mirror under the temperature variations in space. It appears that some of these experiments can be carried out in the Apollo applications flights.

Conclusions

Previous papers in this book have given the results of the NASA program in astronomy. In this paper, we have surveyed the expanding vistas of astronomy made possible by space flight, the status of the development of future capabilities, and some of the ways these capabilities might be employed.

In the discussion of possible future steps, only schedules for events of the near future are discussed. For longer term goals, such as the Woods Hole recommendation of a large space telescope, we can only speculate as to possible schedules.

Discussion of costs has been totally omitted. Up to now, the relative importance of cost in determining our national decisions regarding space activities has been less than will soon be true. In the late 1950's and early 1960's, our decisions were influenced very strongly by a desire to increase our national capability in space at a rapid rate. Now that we have developed or are in a late stage of developing a strong capability, cost considerations are being applied much more rigorously in determining how that capability is to be employed.

The competition is keen for the placing of experiments aboard our vehicles, both manned and unmanned, as well as for the time of the astronauts. It is even more intense for funds and priority to develop new equipment for new missions.

There are many of us in NASA with a natural bias toward astronomy Many opportunities are now unfolding to learn answers to such fundamental questions as the age and size of the universe itself; but the degree to which these opportunities are seized will depend on the wishes of the astronomical community. Any such action would require the full participation of astronomers. Some of the participants would have to devote a decade or more of their lives, working with engineers and project managers through periods of failure and disappointment, to assure its ultimate success.

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