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EXPLORING THE SOLAR SYSTEM

JOHN E. NAUGLE
Director
Geophysics and Astronomy Program
NASA Office of Space Science
and Applications

Exploring the solar system is a formidable topic to cover in one paper. Fortunately, Dr. Pickering has discussed the kind of exploration done by going directly to a planet; and Dr. Dessler has described the systematic studies which are underway on one planet's magnetosphere. So this paper can be confined to the kind of research undertaken to gain a better understanding of the Sun and its influence on the environment of the Earth and interplanetary space; it will also contain a brief review of the work underway in astronomy.

The following list shows some of our interests in space science:

- The space environment
- Sun-Earth relations
- Geodetic properties of the Earth
- Physical properties of the Moon
- Properties of the planets
- The fundamental physical nature of the universe
- The presence and behavior of life in space

We want to know and understand the space environment because of the interesting phenomena which take place there. We have to operate spacecraft in space and, therefore, have to know the environment. The area of Sun-Earth relations is a particularly important one. We need to know and understand the processes that take place on the Sun because the Sun controls the properties of the space environment. We are interested in the fundamental physical nature of the universe. Dr. Pickering already has discussed the work underway on the physical properties of the Moon and the planets. (NASA also has a program to study the presence and behavior of life in space; however, this can not be discussed in the brief time available.)

How do we go about exploring the solar system? How do we plan our program? In the geophysics and astronomy program, the study of solar physics is the unifying theme which ties much of our program together. Solar radiation and the solar wind determine the quiescent conditions in interplanetary space. Solar protons determine the radiation environment in space. The solar wind interacts with and distorts the magnetosphere. There are trapped particles in the magnetosphere which arise from solar flares. X-rays from solar flares affect the electron density in the ionosphere. The structure of the whole atmosphere fluctuates with an 11-year cycle of sunspot activity.

The Sun is the driving force behind much of the phenomena which we study in space; so, we must study the Sun, measure its radiation, and understand its temporal and spatial fluctuations before we can begin to interpret the data which NASA spacecraft collect on the magnetosphere, interplanetary space, atmosphere, and ionosphere.

This paper is concerned with (1) our solar physics program; (2) the measurements that we are making in interplanetary space; (3) briefly, the continuing studies of the magnetosphere; and (4) a brief description of the astronomy program. This will be a picture of the total NASA program in these areas, the rationale for it, some of our problems, and a look at the future program.

SOLAR PHYSICS

Figure 1 shows the sunspot cycle of the Sun—a plot of the number of sunspots as a function of time. This number reaches a maximum every 11 years, and we are presently at the minimum of the sunspot cycle. We do not know what the level of activity of

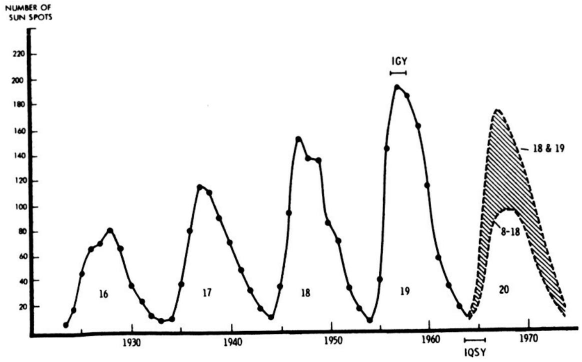

FIGURE 1.—Sunspot cycle.

the Sun will be during the next cycle. The upper curve shows the average of the last two cycles, the lower graph is an average of the last 10 solar cycles, and the next cycle should lie in the shaded region. Much of the thinking and planning within NASA must be phased to the solar cycle. We are presently preparing to fly spacecraft to study solar-terrestrial phenomena at solar minimum. NASA's flight program is established through 1966 and well into 1967; we have finished our planning for the spacecraft to be used during the transition from solar minimum to maximum. We are just beginning to work with the scientists and engineers to determine which projects and experiments need to be performed at the next solar maximum.

Why should we go to the expense and effort to place a telescope in orbit in order to study the Sun when there are numerous solar observatories scattered around the earth and scientists have been studying the Sun for over 400 years? The following are some of the several fundamental reasons why we must study the Sun in this way—with an observatory outside the atmosphere.

The curve on the bottom of figure 2 shows a rough plot of the solar intensity as a function of wavelength or color. The broad band in the middle shows the

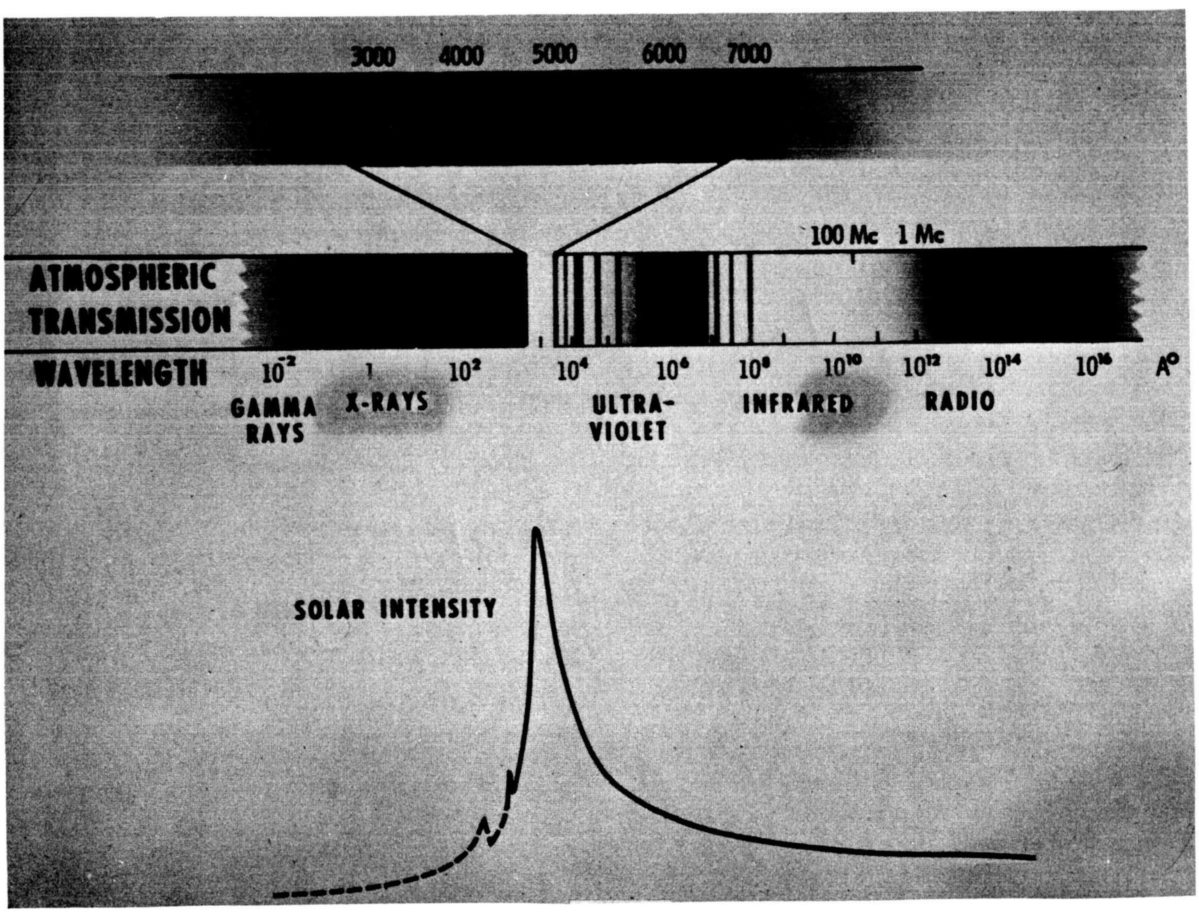

FIGURE 2.—Electromagnetic spectrum.

atmospheric transmission. The dark areas are the wavelengths which are absorbed by the atmosphere. The light regions are those wavelengths which can penetrate through the atmosphere to the surface of the Earth. There is a relatively narrow wavelength band centered around the peak in the solar intensity which is transmitted; this is the visible region of the spectrum, and at the top of the chart this is expanded. The regions of the spectrum which are absorbed by the atmosphere are much greater than those transmitted. The only way we can study the ultraviolet, gamma ray, and X-ray region of the solar spectrum is by placing our instruments above the atmosphere. In addition, these particular parts of the spectrum are highly variable. X-rays may change by many orders of magnitude during the solar flare. Certain regions of the ultraviolet vary with the existence of active regions on the Sun. Therefore, much of the information about the processes which take place on the Sun is contained in this portion of the solar spectrum. The ultraviolet light from the Sun produces the ionosphere, which is used for short-wave communication.

How do we observe the Sun? What does a solar observatory in space look like? Figure 3 depicts the Orbiting Solar Observatory (OSO). This is, and will continue to be our major project in the solar physics program. Originally we planned to have 8 OSO's. The first of these was launched in 1962. The second was at the launch pad early in April when a tragic explosion seriously damaged the spacecraft. At this time, we do not know exactly when the second OSO can be launched. The third will be ready for launch early in 1965. The remainder of these are scheduled to be launched at 9-month intervals.

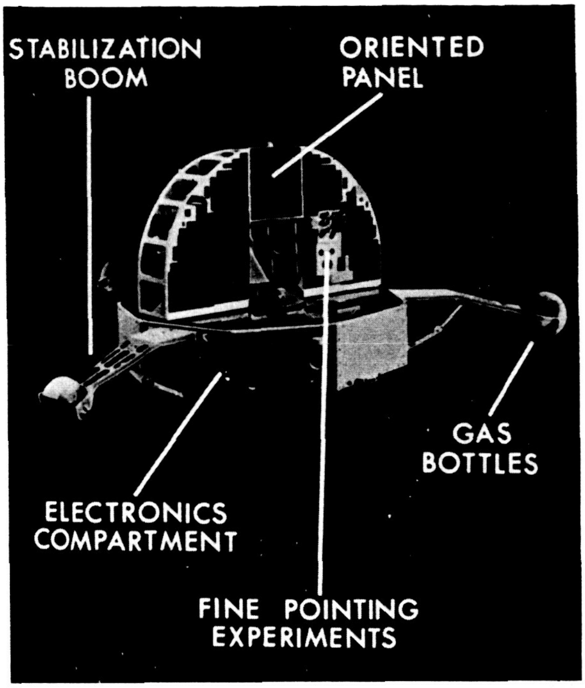

FIGURE 3.—The Orbiting Solar Observatory.

Gross weight	454 lb
Instrument weight	173 lb
Investigations	two-pointed
Power	16 watts
Stabilization	spin
Design life	6 months
Launch vehicle	Delta
Orbit:	
Apogee	370.30 miles
Perigee	343.85 miles
Inclination	33 deg
Status	launches in 1962 and 1964

The OSO consists of two parts: a sail or oriented panel, which points continuously at the Sun as long as the Sun is visible from the satellite; and a rotating section or electronic compartment, to provide stability. The major experiments are carried in a rectangular box pivoted in the sail. These experiments are pointed at the center of the Sun with an accuracy of about 1 minute of arc. Three gas bottles are placed on hinged booms to increase the moment of inertia about the spin axis. The first solar observatory was pointed at the center of the Sun continuously. The second solar observatory was planned to scan back and forth across the Sun to build up an image of the Sun in several wavelengths.

Figure 4 shows the kind of measurements that can be made on the Sun with a 1-minute pointing accuracy. The diameter of the Sun, as viewed from the vicinity of the Earth, is about 30 arc minutes; this is a typical picture of the Sun at solar maximum with several large sunspots visible. The middle picture is an enlargement of an active center on the Sun; the dark blotches on the left are sunspot groups. This picture was taken by a balloon-borne telescope; the square is 1-minute of arc on a side. Instruments on the present OSO will average the radiation coming from this total square. This pointing capability will enable us to study the radiation coming from a particular active center, but we cannot study the details of a particular sunspot. We need to resolve such

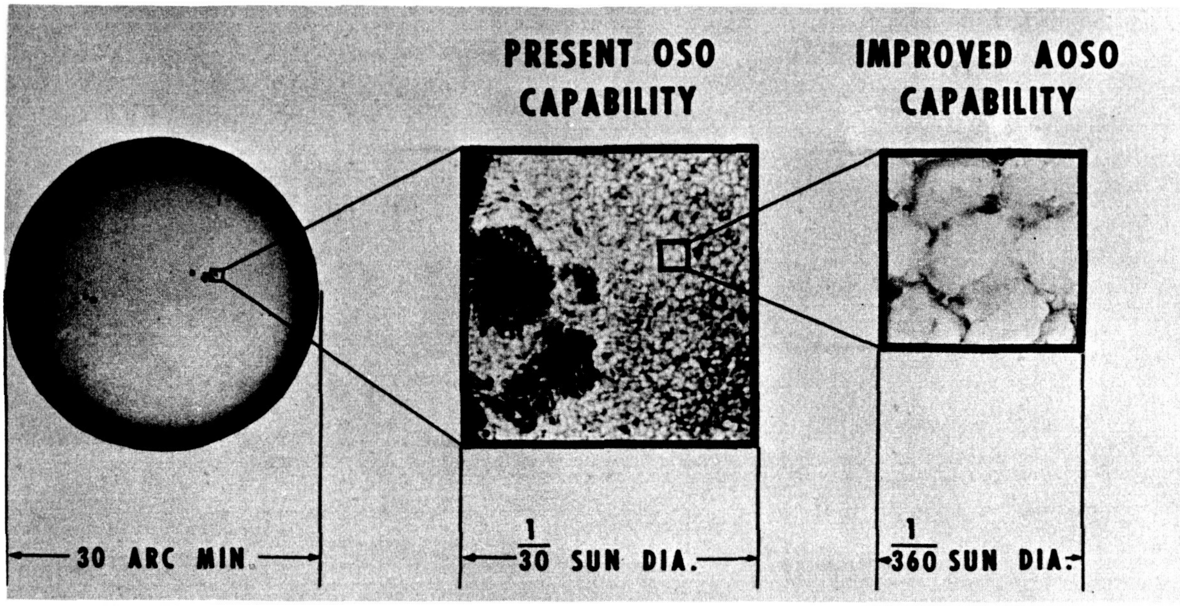

FIGURE 4.—Solar detail.

details. The picture on the right shows the resolution we expect from an Advanced Orbiting Solar Observatory, AOSO, which is being designed. The AOSO will have a pointing accuracy of 5 arc seconds.

To the right of figure 5 is an Advanced Orbiting Solar Observatory (AOSO) which will weigh about 900 pounds. The entire spacecraft will point continuously at the Sun; it will be launched into a polar orbit by a Thor-Agena. If Congress authorizes and appropriates the funds required, we will launch the first AOSO in 1968. We want AOSO to be operational during the next solar maximum.

Information on the radiation from the Sun will be provided by OSO and AOSO.

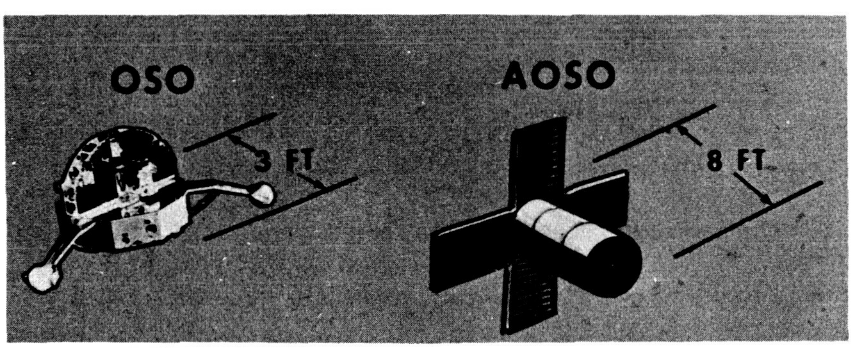

FIGURE 5.—Orbiting Solar Observatory (OSO) and Advanced Orbiting Solar Observatory (AOSO).

	OSO	*AOSO*
Weight, lb	500	1,000
Point accuracy, fraction of Sun dia.	$\frac{1}{30}$	$\frac{1}{360}$
Launch vehicle	Delta	Thor-Agena

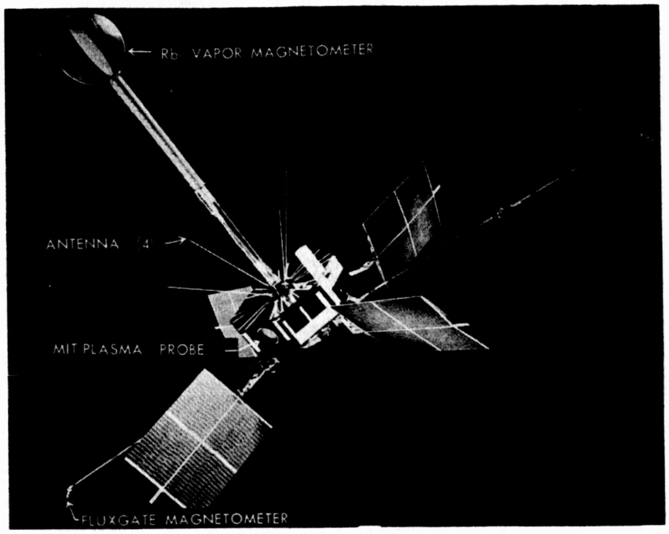

FIGURE 6.—The Interplanetary Monitoring Platform (IMP).

INTERPLANETARY PHYSICS

How does this radiation affect the environment? How do we study the environment? How do we use the data from OSO and OASO in these studies?

The answers to some of these questions are coming from our interplanetary physics program. There are three phenomena of interest in interplanetary space: the magnetic field, the plasma or "solar wind," and cosmic rays. All three are related and must be studied together; all three are strongly influenced by solar activity. The Sun continually emits clouds of electrons and protons which stream outward; this is the *solar wind*. The solar wind determines the shape of the magnetic field in space. The weak interplanetary magnetic field in turn, acting over large distances in space, determines the trajectories of cosmic rays. During major solar flares the Sun emits large numbers of high-energy protons, solar cosmic rays, which raise the radiation levels in space. The Interplanetary Monitoring Platform, or IMP as it is commonly known, was designed to measure these three parameters (fig. 6). It has two magnetometers, three plasma probes, and several energetic particle detectors. IMP is one of the flight projects in our program to study and to understand the environment in interplanetary space and in the Earth's magnetosphere. Seven IMP's were in the original program. The first was successfully launched in November and continues to operate. It was placed in a highly eccentric orbit; the maximum altitude is about 120,000 miles. The next two IMP's will have identical instrumentation and will be placed in similar highly eccentric orbits. The fourth and fifth will have different experiments and will be placed in eccentric orbits around the Moon. The remaining two will have the same trajectories as the first three but slightly different experiments.

Pioneer, IMP's partner in the exploration of interplanetary space is shown in figure 7. Pioneer has instrumentation similar to IMP; it will be fired into an escape trajectory from Earth. The combined measurements made by IMP and Pioneer will give us information on the configuration of the interplanetary field. It will help determine how a solar disturbance propagates, and it will begin to give information on the spatial configuration of solar proton events. Four Pioneers are scheduled. The first two will be placed on a trajectory which moves toward the Sun and will carry the Pioneer payload into about 0.8 or 0.9 AU. The payload and trajectories of the other two have not been decided. We will choose a payload late this spring and, on the basis of that payload, will decide on the trajectories. We might want to place them into a trajectory which will carry them out to perhaps 1.1 or 1.2 AU.

In addition to these two spacecraft, which are designed specifically to study interplanetary physics, the various planetary missions such as Mariner C and the Mars mission in 1966 will carry experiments in interplanetary physics.

We will need to use simultaneous measurements from OSO and ground observatories together with other ground-based measurements of the geomagnetic field, aurora, radio noise, and the ionosphere to understand the complex interrelations between a solar flare, the propagation of the disturbance into the corona and interplanetary space, and the attendant effects on the magnetosphere and atmosphere of the Earth.

Figure 8 gives the two possible trajectories of Pioneer and the relative location of the Earth. If we fired two Pioneers simultaneously and kept an IMP in orbit around the Earth, we would be able to measure the azimuthal and radial gradients of the environment in interplanetary space. The seven IMP's and four Pioneers that we have scheduled will provide coverage from now to about 1967.

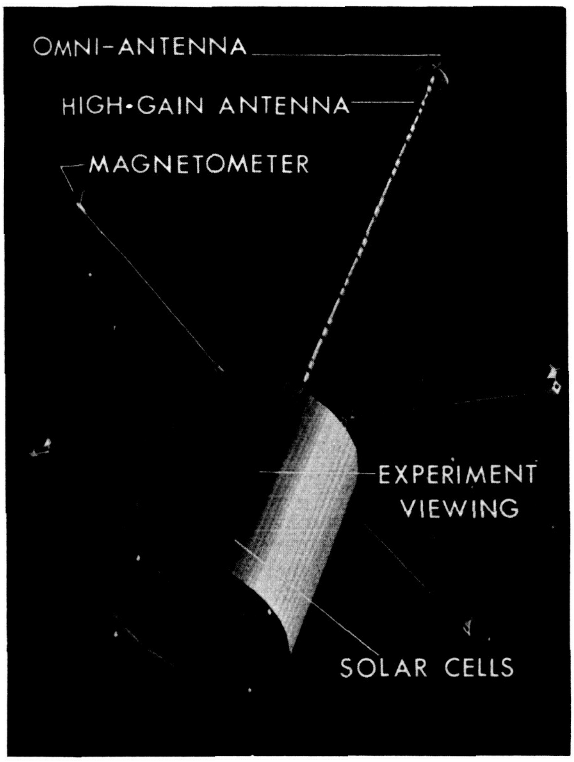

FIGURE 7.—Pioneer.

Gross weight	140 lb
Instrument weight	30 lb
Investigations	particles and fields
Power	50 watts
Stabilization	spin
Design life	6 months
Launch vehicle	thrust-augmented Delta
Mission	60 million miles from Earth 0.8 to 1.2 AU from Sun
Status	design completed first launch early in 1965

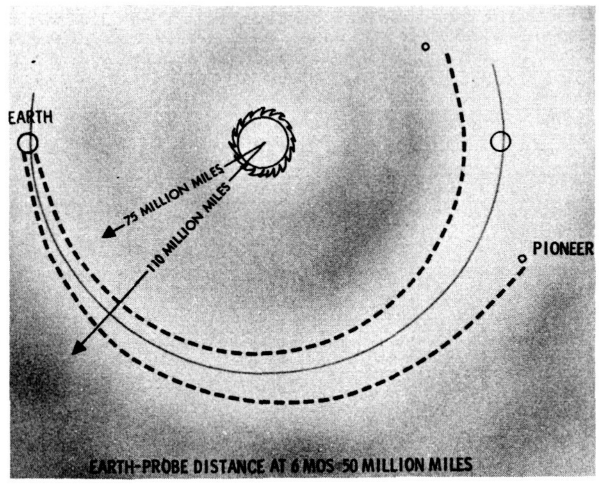

FIGURE 8.—Pioneer orbits.

Where do we go from here? Will they provide all the data on interplanetary environment which we need? The answer is no. There are a number of other questions which we cannot answer with this coverage. What is the electron density and the magnetic configuration close to the Sun? How far from the Sun are the conditions in interplanetary space controlled by the Sun and its radiation? How far from the Sun do we have to go until we reach galactic space?

We think that complex configuration of plumes or streamers of the solar corona represent material flowing along the magnetic field. How can we begin to investigate this region of the solar corona? It requires a great deal of energy to send a spacecraft this close to the Sun, instruments will get very hot, and the radio noise from the Sun makes communication difficult.

Figure 9 depicts some possible trajectories of spacecraft launched from the Earth in such a way that they either move in close to the Sun or out from it. This chart shows the relative location of the Earth. By sending a spacecraft on a trajectory toward the Sun and by placing a radio transmitter aboard, we can begin to study the electron density in the corona by measuring the attenuation of the radio signal from the satellite as it passes behind the Sun.

We would like to begin an exploration of a new region of space with a simple spacecraft and a cheap

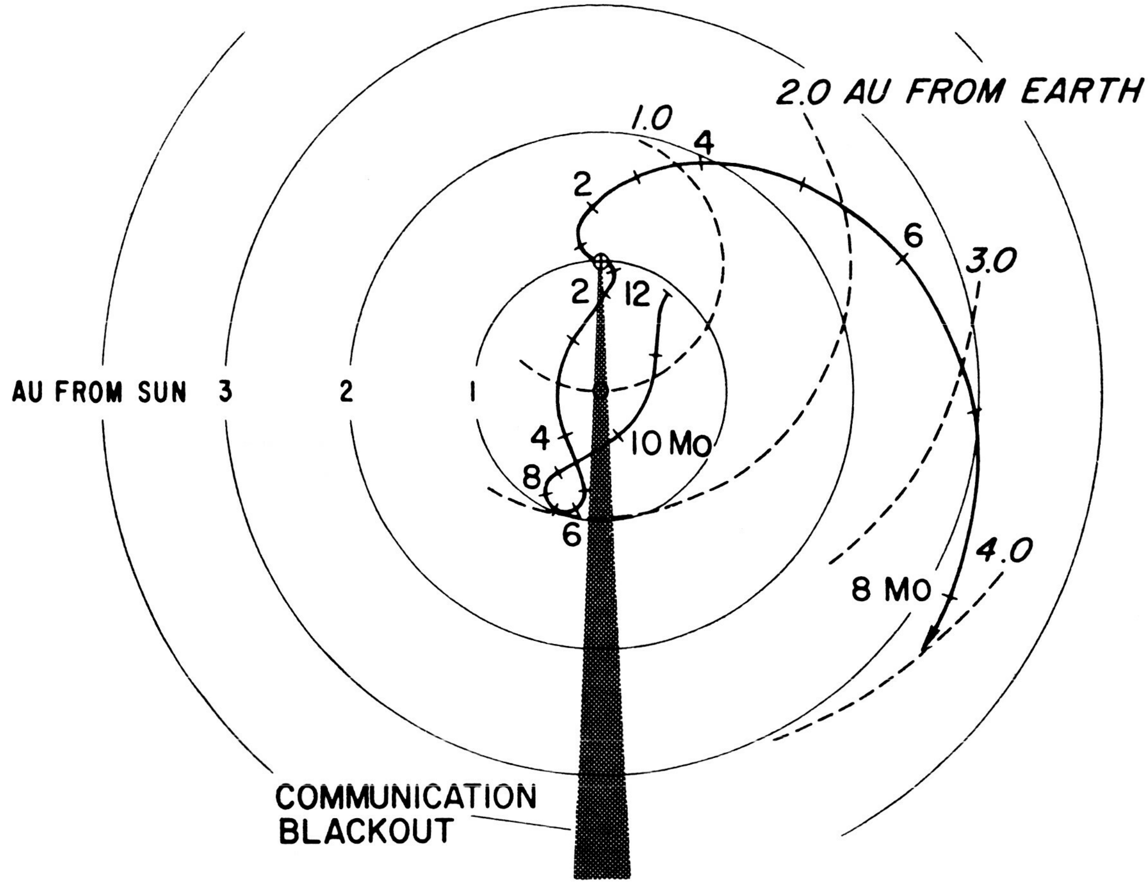

FIGURE 9.—Some possible trajectories of Earth-launched spacecraft.

launch vehicle. The first satellite which Van Allen used was a small satellite that weighed only a few pounds; yet it showed very interesting phenomena which we did not know existed. The data from that satellite were then used to design and build more complicated spacecraft to study the phenomena in detail. Perhaps we may do a similar job in the case of the solar corona. We have studies underway to use small multistage rockets to carry a small payload on a trajectory which passes behind the Sun to study the attenuation of the radio signal from that satellite.

PHYSICS OF THE MAGNETOSPHERE

NASA has a program to study the magnetosphere. Dr. Dessler already has discussed the scientific results which have been obtained over the past few years, and he has outlined some of the problems which remain to be solved. I will discuss the program which we have underway to solve these problems.

Figure 10 shows the behavior of the trajectory of a highly eccentric satellite such as IMP. The white dotted line roughly represents the magnetosphere, blown out into a *teardrop* shape by the solar wind. The solid line in each sketch shows the orbit of an eccentric satellite about the Earth; it remains fixed in inertial space. As the Earth moves around the Sun, the satellite on its trajectory covers various portions of the magnetosphere. This figure shows the relative orientation of the orbit of the satellite and the magnetosphere of the Earth as a function of the time of year (A, B, C, D).

NASA has had a systematic program underway for a number of years to explore the magnetosphere. Figure 11 is a chart looking down at the north pole of the Earth. The Sun is off to the left; the various cross-hatchings show the region of space which our satellites have explored. Since this figure was made, IMP has continued to work and has moved around

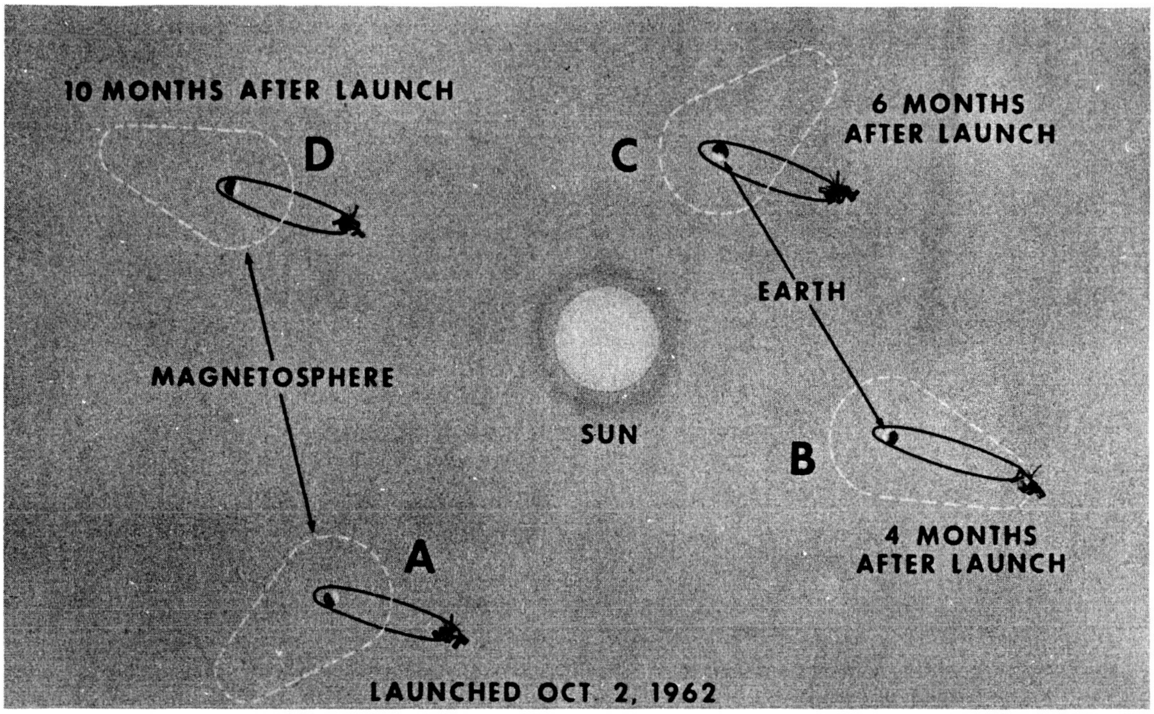

FIGURE 10.—Explorer XIV mission.

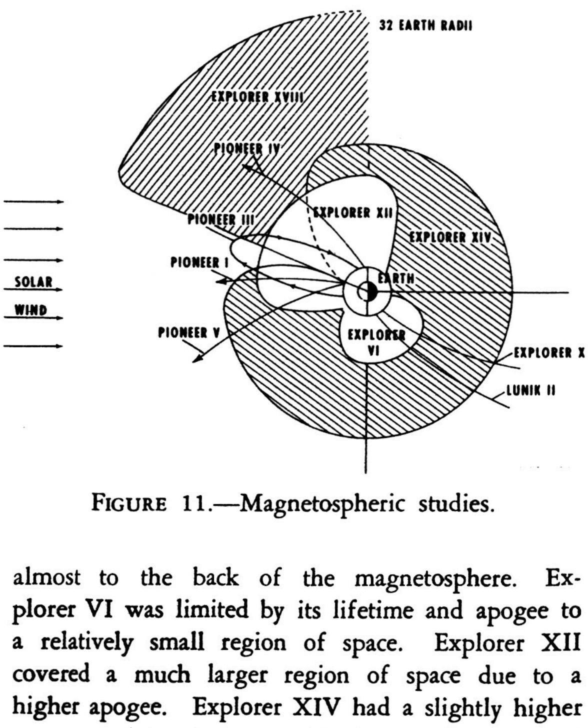

FIGURE 11.—Magnetospheric studies.

almost to the back of the magnetosphere. Explorer VI was limited by its lifetime and apogee to a relatively small region of space. Explorer XII covered a much larger region of space due to a higher apogee. Explorer XIV had a slightly higher apogee and lived considerably longer; it swept out almost the whole region of the magnetosphere. However, Explorer XIV spent very little time in interplanetary space. Explorer XVIII (IMP) was launched at a small angle to the Earth's Sunline. It has moved around to an angle of 90 degrees with respect to the Earth's Sunline. You will recall that five of the seven IMP's which are scheduled will be placed in highly eccentric orbits around the Earth and, as they sweep back and forth through the magnetosphere, they will give us information on the changes in the shape of the magnetosphere as a function of solar activity. However, the major effort to understand the magnetosphere in the future will be undertaken by the Orbiting Geophysical Observatory (OGO). The remaining problems of the magnetosphere are complex. We need to understand the origin of the trapped radiation and its lifetime; we need to understand how hydromagnetic waves propagate. All of these problems require simultaneous measurement of a large number of parameters and the transmission of a great deal of data back to the Earth.

Figure 12 shows OGO, which was designed for this purpose; it is a stabilized spacecraft weighing about 1,000 pounds and carrying 150 pounds of experiments. It is instrumented with magnetometers, with energetic particle measurements, with aurora and airglow experiments, and with experiments designed

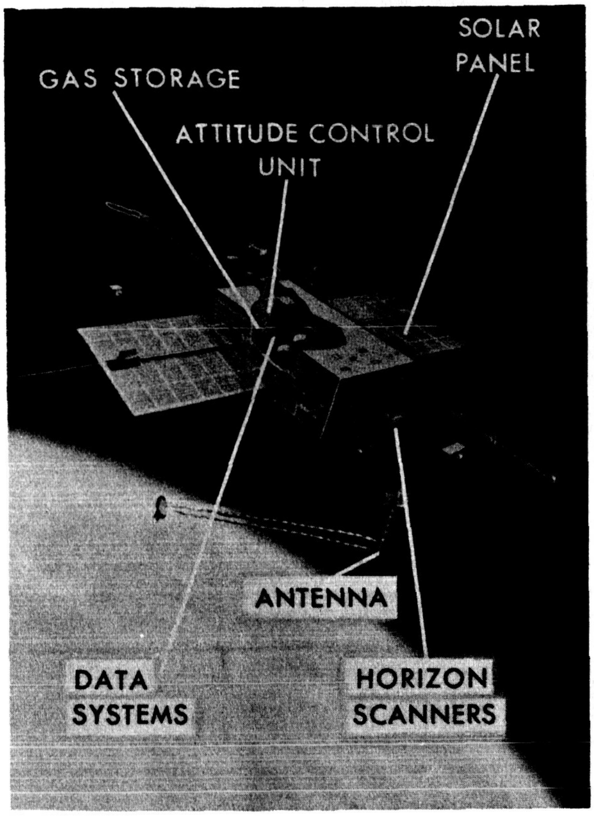

FIGURE 12.—The Orbiting Geophysical Observatory.

Gross weight	1,000 lb
Instrument weight	150 lb
Investigations	20 per spacecraft
Power	500 watts
Stabilization	active 3-axis
Design life	1 year
Launch vehicles	Atlas-Agena Thor-Agena
Orbits:	
Highly elliptical inclined orbit	
Near-circular polar orbit	
Plan	first flight in 1964

to study the ionosphere. A major interdisciplinary attack will be made on all the problems of the magnetosphere and ionosphere. The data rate of OGO enables scientists to study hydromagnetic waves and to correlate magnetic fluctuations observed in the satellite with those observed on the ground.

The first OGO will be launched late this summer. There are two types of missions scheduled for OGO as shown in figure 13. EGO, the Eccentric Orbiting Geophysical Observatory, has a mission similar to Explorers XII, XIV, and IMP—a highly eccentric orbit going out to about 140,000 km. POGO, the Polar Orbiting Geophysical Observatory, will be placed in a low-altitude polar orbit to study the ionosphere and atmosphere.

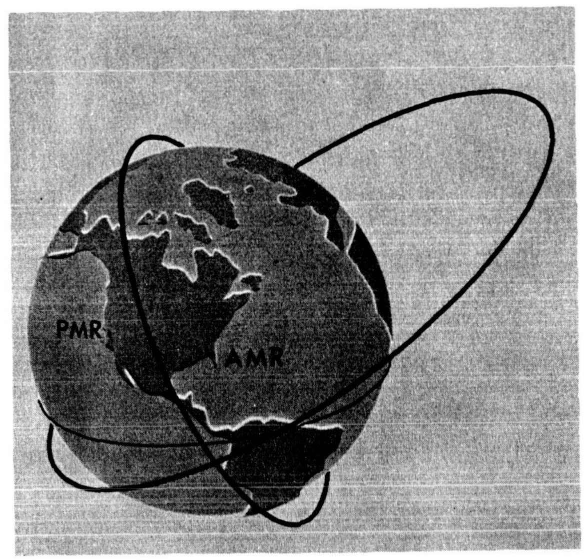

FIGURE 13.—The Orbiting Geophysical Observatory missions.

	OGO-A (EGO)	OGO-C (POGO)
Apogee, naut. miles	60,000	500
Perigee, naut. miles	140	150
Inclination, degrees	31	82-90

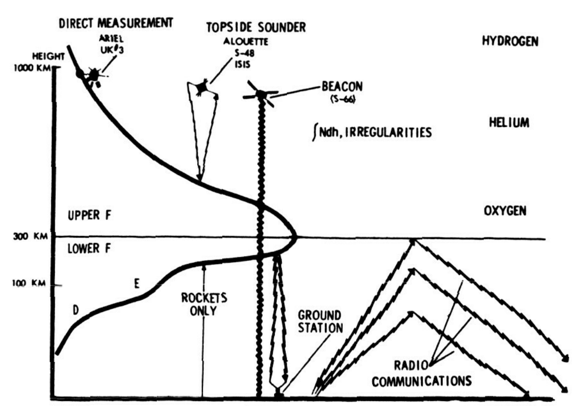

FIGURE 14.—Techniques for study of the ionosphere.

UPPER ATMOSPHERE AND IONOSPHERE

Closer to the Earth is the ionosphere and upper atmosphere program. Figure 14 shows the various techniques used to study the ionosphere. Prior to the advent of Earth satellites we studied the ionosphere by using a transmitter on the ground to send a signal vertically upward. Studies made this way showed that the electron density increased and apparently reached a maximum at about 300 km. However, it was not possible to use this technique to study the shape of the ionosphere above the maximum. Accordingly, one of the early satellites was designed to carry a *topside sounder* into orbit. This first satellite was Alouette, a Canadian satellite. It was highly successful and is still in operation.

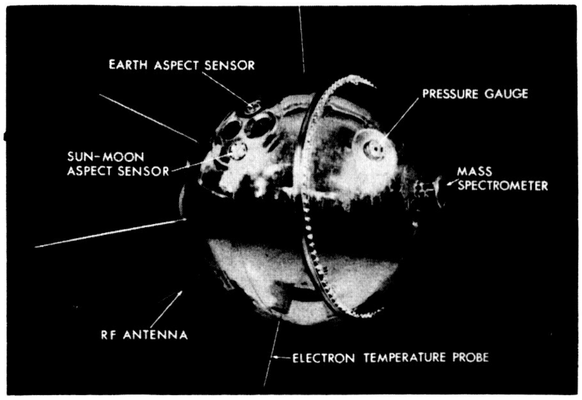

FIGURE 15.—The Atmospheric Structure Satellite.

However, Alouette has certain limitations. It continuously sweeps in frequency to build up the profile of the top side of the ionosphere. Consequently, it averages over fairly large regions of space. We have two satellites designed to study the spatial irregularities. The first of these is the fixed frequency topside sounder, which will be launched later this year. In this case, instead of transmitting a continuously changing frequency, we will fly a series of fixed frequencies. We will also fly what we call the Beacon satellite, a very simple satellite which will transmit a number of frequencies to be monitored by ground stations. By studying the relative attenuation and phases of these signals we will be able to measure the total number of electrons between the satellite and receiving station. We have already planned our fu-

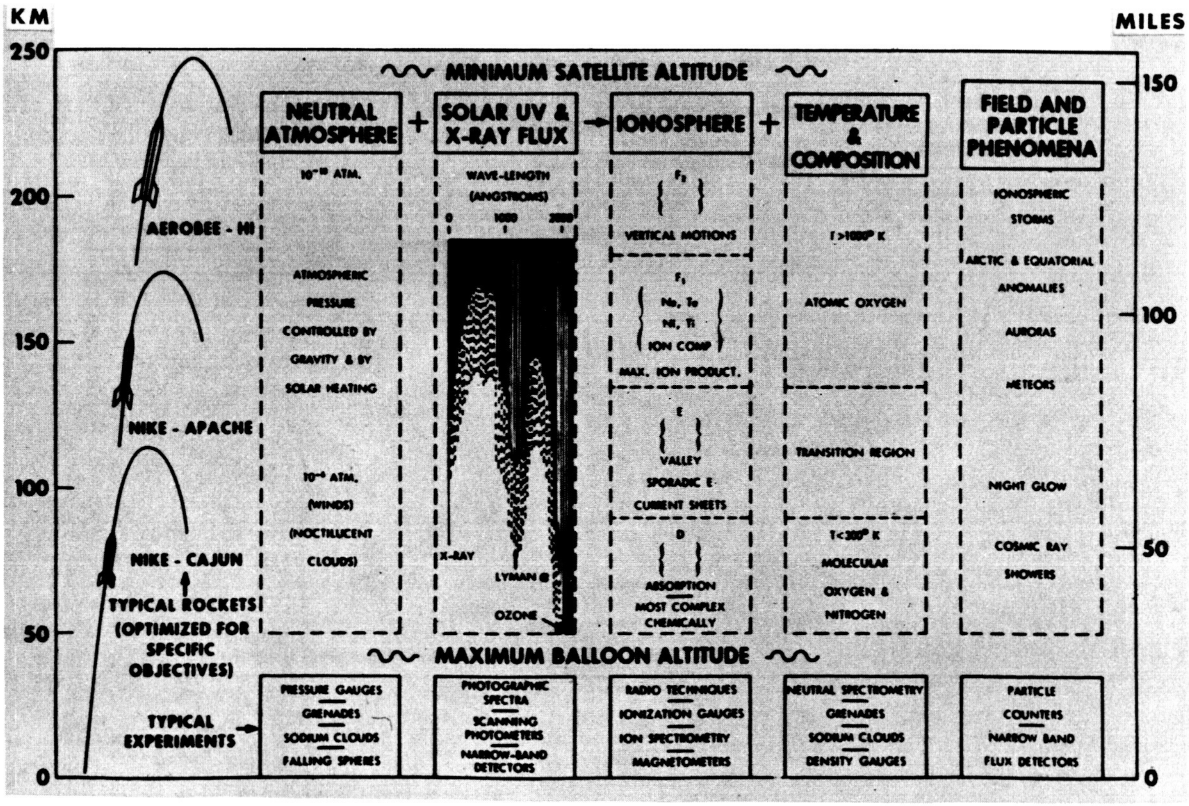

FIGURE 16.—Basic research requiring low-altitude sounding rockets.

ture work in the ionosphere over the next 4 years. We plan to continue a cooperative program with the Canadians. They will build the satellites, we will furnish the boosters, and both countries will share the data from the satellites. The name of this program is Isis (International Satellite for Ionospheric Studies). Four launches are scheduled in the Isis program. These four shots include a repeat of Alouette and three launches of a new satellite.

The various satellites shown are all different; they each have different missions and have certain peculiarities. Figure 15 depicts the Atmospheric Structure Satellite (S–6a) which can be regarded as a vacuum chamber turned inside out. It is quite a problem to obtain a high vacuum on Earth; the vacuum in space at satellite altitude is comparable to the very highest conditions obtainable on Earth. Therefore, in order to study the composition and structure of the atmosphere at that altitude, we must prevent contamination by the satellite of the surrounding region of space. The S–6a consists of a stainless steel, vacuum-tight shell with all the instruments, the battery, and telemetry transmitter sealed inside, and with only the mass spectrometers and other detectors exposed to the ambient conditions. The first Atmospheric Structure Satellite was successfully flown early this year. The second Atmospheric Structure Satellite will be flown early in 1965. The first satellite was placed in a low-inclination orbit, and the second will be placed in a polar orbit.

One of the major questions, from both a scientific standpoint and the standpoint of knowing and understanding the behavior of a satellite in orbit, is the determination of the atmospheric drag. Early measurements have shown that the drag on a satellite varied with solar activity, and it appears that the entire atmosphere expands and contracts over the 11-year solar cycle. To study this phenomenon, we use large lightweight balloons. Two 12-foot spheres have been launched: one in a low-inclination orbit, and another in a polar orbit. The first of these recently reentered the atmosphere after giving measurements for over 2 years. We plan to launch two more 12-foot balloons later this year to study atmospheric density. These will be launched together with two Injun Explorers to study the effect of precipitation of trapped radiation on the atmosphere. We will track the 12-foot balloons to determine the density of the atmosphere. The Injun satellite will measure the flux of the trapped radiation.

Most of our work on the structure of the atmosphere must be done with sounding rockets. Balloons can reach an altitutde of only about 40 km. Satellites, on the other hand, can operate only about 250 km; if they come much below this altitude, the drag is such that they will reenter the atmosphere after only a few days. Therefore, to make direct measurements in this region, it is necessary to use sounding rockets.

Figure 16 illustrates some of the basic research which we have underway with low-altitude sounding rockets. We use sounding rockets to study the neutral atmosphere, to measure the electron density directly, to study the temperature and composition, and for certain energetic particles for the astronomy program. So far, we have discussed the interplanetary space and the immediate environment of the Earth.

ASTRONOMY

Astronomy may be one of the most important programs we have. Why should we go through the

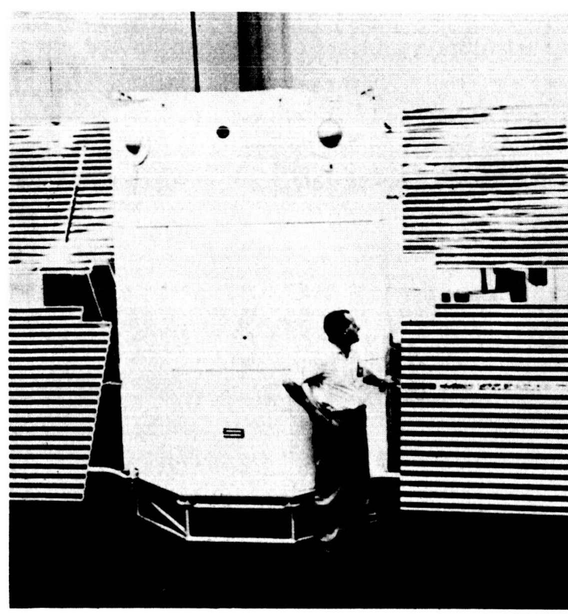

FIGURE 17.—The Orbiting Astronomical Observatory.

- Four 12-inch Smithsonian telescopes to map entire sky in ultraviolet
- Four 8-inch and one 16-inch Wisconsin telescopes to study bright stars and nebulae
- 3-foot Goddard telescope studies 5,000 stars and nebulae
- 32-inch Princeton telescope studies interstellar matter
- Ultimate pointing accuracy of 1/36,000 of 1 deg
- 3,600 lb in 500-mile circular orbit

trouble and expense of placing a large observatory in orbit when we have such magnificent facilities as the 200-inch telescope at Mt. Palomar? The reason is much the same as the reason for studying the Sun. There are a large number of stars which radiate the bulk of their energy in either the ultraviolet or the infrared portion of the spectrum. To study stars at all stages in their evolution, we must be able to measure their light in both the infrared and ultraviolet. In the very early processes, when a star is forming, it is cool and radiates in the infrared. Later in their evolution stars are hot and radiate most of their light in the ultraviolet. We think that these stars in the ultraviolet and infrared light will provide fundamental data which will help in understanding stellar processes and the nature and history of the universe.

The OAO, shown in Figure 17, is easily the most complex and most expensive scientific spacecraft which we have under development. It will weigh 3,600 pounds and is designed to point experiments to an accuracy of a 10th of a second of arc. At present three spacecraft and four separate sets of experiments are being built. The first OAO, which is scheduled for launch in late 1965, will carry two sets of experiments. One experiment, supplied by the Smithsonian Astrophysical Observatory, consists of four 12-inch telescopes to map the sky in ultraviolet light. A second experiment, from the University of Wisconsin, consists of four 8-inch and one 10-inch telescopes to study bright stars and nebulae. The second OAO is planned to carry a 3-foot telescope, provided by the Goddard Space Flight Center, to be used to study some 5,000 stars and nebulae. The third OAO will carry a 32-inch Princeton University telescope to study interstellar matter.

SUMMARY

In summary:

1. NASA has a vigorous program to explore the solar system. This is a program which requires simultaneous measurement of the Sun and its radiation together with measurements at widely separated points in interplanetary space, in the magnetosphere, and in the ionosphere. This program will have to be augmented during the period of next solar maximum, 1967–72.

2. There is an opportunity in this program for fundamental discovery with new insights into stellar processes and stellar evolution.

3. We hope to proceed from simple missions with simple spacecraft to more complex and difficult missions.