

# A NEW LABORATORY

## HOW TO WORK IN IT

The techniques of basic research in the space program, once primarily of geophysical interest, are finding new applications in other scientific areas. The question treated here is what promise do they hold for an experimental science like physics?

*By Homer E. Newell*

It is not my intention to parade before you long lists of space missions, launch vehicles, spacecraft, and other hardware, budgets, schedules, and such—inseparable though these may be from space activities. Rather, the discussion to follow will dwell on science, with only just enough reference to those other aspects of the space program to illustrate how our growing national space capability is providing valuable tools, techniques, and opportunities for scientific research.

Indeed, science is a fundamental part of NASA's mission. The very first of the eight specific requirements placed upon the National Aeronautics and Space Administration in the Space Act of 1958 calls for the expansion of human knowledge of the atmosphere and space. Our research in support of this assignment has come to be known as space science.

It is important, however, to keep in mind that space science is not something apart from the remainder of science. Rather, it is an extension of numerous scientific disciplines into the domain of space by means of sounding rockets, satellites, and deep-space probes. Space science is viable, vital, and productive only as it concerns itself with problems of genuine substance and importance to the total body of science.

The NASA space science program began with the momentum contributed by the International Geophysical Year, and a major portion of the early planning focused on geophysics and astronomy. The program has been conceived and developed in NASA as a basic research effort in the truest sense of the term. Its prime motivation is the expansion of scientific knowledge and understanding.

It is quite natural that the early years of the space science program have been devoted to the observation and investigation of naturally occurring phenomena. Although there have been some

more-or-less controlled experiments conducted in the past, for the most part that phase of the space effort still lies ahead of us. But the space tools and techniques have now developed to such a stage that it is legitimate to ask, "What can the space program do for experimental sciences like physics?"

It is my hope that I can, in these pages, provide you with some basis for answering that question. It is my belief that some of you will find in the future potential of the space program significant areas of personal and professional interest.

### *The new laboratory of space*

In approaching this question, it may be useful and illuminating to consider the impact that space techniques are having and have already had on the sister discipline of geophysics. This impact is three-fold in character. First, the geophysicist finds in the space program powerful tools to use in a new approach to solving old problems. Secondly, the application of space techniques to geophysics has already turned up a number of exciting new problems, greatly broadening the scope of the discipline. Thirdly, as space probes, and eventually men, reach other bodies of the solar system such as the moon and planets, the domain of geophysics grows beyond the confines of a single body of the solar system. Let us consider each of these extensions to geophysics a little further.

First, as we have said, space techniques have provided new tools for studying old problems of geophysics. Geodesy, meteorology, upper-atmospheric physics, ionospheric research, and sun-earth relationships have all benefited from the application of space techniques. In the case of geodesy, the influence of the earth upon the orbits of

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various artificial satellites has been measured by careful radio, radar, and optical tracking and used to obtain quantitative measures of the various harmonics in the expansion of the earth's gravitational potential. As a consequence of such measurements it has been found that the earth's equatorial bulge is some 70 meters greater than one would expect for a perfectly plastic earth rotating at the present rate. It is the bulge that a plastic earth would exhibit for the rotation rate of 50 million years ago when the earth was spinning faster, with a day of about  $23\frac{1}{2}$  hours.

Other departures of the geoid from the figure of hydrostatic equilibrium have also been determined from these satellite measurements. Longitudinal variations have been measured from the orbits of Vanguards II and III, the Echo I rocket casing, and the Geodetic Satellite ANNA I, among others. The second-order longitudinal variation gives an equatorial ellipse with a difference of axes equal to 80 meters.

These measurements, in turn, have important implications for the distribution of matter within the earth, and for the internal strength of the earth's mantle. The latter has been characterized by John O'Keefe, using a theory of Jeffries, as roughly equivalent to that of an ordinary brick wall, capable of supporting stresses as great as  $2 \times 10^7$  dynes/cm<sup>2</sup>.

Reintegrating all these results from satellite observations, one obtains a figure for the earth which shows a hump in the Western Pacific near Indonesia and the Philippines, and a depression in the Indian Ocean. Although the hump and the depression are only slight in absolute numbers, amounting to about 60 meters, they are, nevertheless, significant. Moreover, it is interesting to note that, whereas the average heat flow through the earth's crust is about 60 ergs per square centimeter per second, in the vicinity of the Indian Ocean depression the total heat flow is on the order of 80 ergs/cm<sup>2</sup>/sec. At that elevation in the Western Pacific region, the heat flow is about 40 ergs/cm<sup>2</sup>/sec. These facts lead to interesting speculations about phenomena in the interior of the earth, including the possibility of very slow convection in the earth's mantle.

It is, however, not our task to pursue these thoughts further here. I believe the case has been made that satellite techniques have indeed become a powerful tool in the hand of the geodesist.

The power of the satellite for meteorological observations is quite clear from the many thousands of cloud-cover pictures obtained by the Tiros and Nimbus satellites. Similarly, the

sounding rocket and artificial satellite have proven extremely powerful in investigating the upper atmosphere. Only a few decades ago, textbooks described the upper atmosphere as quiet, isothermal, and uninteresting. Even at that time, the textbooks were somewhat out of date, since the ionosphere was being discovered, and the presence of marked temperature and chemical changes was being revealed by various ground-based studies. Now, a wealth of information about the upper atmosphere and ionosphere is available, a large part from sounding rockets and satellites which have provided direct measurements of temperatures, pressures, densities, composition, and winds as a function of altitude; they have also provided identification of chemical and ionic constituents, the revelation of a helium layer in the upper reaches of the atmosphere and of a layer of hydrogen still farther out, and measurements of electron density in the ionosphere together with spatial and temporal variations of all these quantities. At the same time, the satellite and sounding rocket have made possible the observation and measurement of the solar radiations entering the earth's atmosphere and being absorbed there.

This by no means tells the whole story of the contribution of space techniques to the solution of old problems in geophysics. The point, however, has been made by the illustrations already given. So let us turn to the second influence of space research on geophysics, namely, the broadening of the scope of the discipline.

The discovery of the Van Allen radiation belts added a whole new collection of important problems. The investigation of these radiation belts led to the acceptance of a new concept, namely, that of the magnetosphere. It pointed to relationships among the solar wind, which was discovered by instruments in space probes, the magnetosphere, the radiation belts, the aurora, magnetic storms, ionospheric disturbances, and possibly even some influences of particle radiations on our weather. Here is a whole new addition to the field of geophysics which, in addition to being complex and challenging in itself, promises to furnish the required perspective in which to view a wide variety of atmospheric phenomena.

The extension of geophysics to new domains as our spacecraft reach the moon and planets needs very little elaboration. Clearly many of the techniques and theories to be applied in the investigation of these bodies will be those of geophysics. We will ask of these objects the same questions that we ask about the earth. And as we obtain answers to our questions, we will be in a position



to make comparisons which should be more illuminating than the study of our earth alone.

I have intentionally dwelt at length upon the impact of space research on geophysics, because of the fact that throughout these new investigations there constantly appears the opportunity to do good physics. Of especial interest is the fact that these geophysical studies have revealed an exciting new laboratory in space for physics research. This may perhaps be better understood by a further look at the results of magnetospheric and interplanetary research.

A steady stream of solar protons and alpha particles moving with a velocity of 300 to 500 kilometers per second arrives at the earth and carries with it a magnetic field, which is roughly 10 gamma. Two boundaries are produced by the interaction of the solar wind with the terrestrial magnetic field.

Roughly 65 000 kilometers away from the earth in the solar direction exists the magnetospheric boundary which was already observed by Explorers XII and XIV. At 90 000 kilometers, Explorer XVIII found a second boundary which constitutes a shock front and separates the region of undisturbed solar wind from the largely disordered flow produced by the interaction with the earth's magnetic field. The properties of the solar wind plasma in the transition region (65 000 to 90 000 kilometers) are being measured with instruments on Explorers XVIII and XXI and OGO-I. An interesting observation was made on December 14 and 15, 1964, when the moon was near the earth-sun line. The magnetometer observations taken at that time can be interpreted to mean that the spacecraft found itself in the wake the moon produced in the flow of solar wind.

The terrestrial magnetic field is swept out by the solar wind behind the earth. Instruments on Explorer XVIII have mapped this magnetospheric tail out to 210 000 kilometers, or more than half the distance to the moon. Indications are that the tail extends well beyond the moon. In this region, the earth's magnetic field is pulled straight back and a neutral sheath separates the Northern and Southern Hemispheres. Here, regions of intense electron fluxes have been found, but these electrons are not permanently trapped as in the Van Allen belts.

The region inside the closed magnetic-field lines encompasses the trapped radiation belts. At an altitude of about 2500 kilometers is the heart of the energetic proton belt. Just below it are the remnants of the artificial electron belt produced in the July 9, 1962, high-altitude nuclear test.

The remainder of the trapping region contains primarily low-energy protons and electrons. Their fluxes are subject to large temporal variations and we are continuing to investigate the mechanisms which are responsible for these fluctuations.

In the regions within and beyond the magnetosphere, there is an opportunity to study matter under conditions unobtainable in the laboratory. Plasma physics and magnetohydrodynamics should profit by such research.

Astronomy is another discipline to which the space program is giving a new dimension and in which the physicist may find a number of important areas of interest. The ability to make observations above the filtering, distorting atmosphere, and in wavelengths not hitherto observable, promises exciting new discoveries.

The potential value of this opening up of the observable spectrum is indicated by the very theory that astronomy has developed from ground-based optical observations. Such theory indicates that the most important information about the birth, evolution, and demise of stellar bodies is to be found in the infrared and ultraviolet wavelengths. That this is no empty promise is already borne out by early observations by means of sounding rockets in both the ultraviolet and x-ray wavelengths. Goddard Space Flight Center measurements of very hot stars indicated a marked deficit in the expected ultraviolet intensity. This sparked further theoretical research which led to the conclusion that the temperatures previously assigned to these stars were too high.

Particularly interesting is the discovery of some ten sources of x-ray radiations in the depths of our galaxy, while at the other end of the spectrum are the newly discovered, relatively cold, infrared stars. The study of the stellar x-ray sources promises to be both exciting and challenging. Stellar x-ray sources were first discovered in 1962. The intensities of these x-ray sources are very low compared to intensities one is used to in the laboratory. One needs detectors with large apertures which, in turn, makes it difficult to obtain accurate positions and good spectra. Nevertheless, we now know that there are at least ten such sources whose locations have been measured to an accuracy of about a degree.

These sources emit x rays in the one- to ten-keV range, but little is known about this energy spectrum and the mechanism by which they are produced. This is an area of space research which is particularly suited to physicists. The tools and techniques which must be used are those of nuclear physics. The processes which produce the



x-rays will most likely be understood within the theoretical framework of nuclear physics. The effort to explain stellar x-ray sources involves not only conventional theories of nuclear forces, but, as we consider stellar objects whose densities approach and even exceed that of a nucleon, it will involve basic theories of the nature of matter. At least three competent groups have been working in this young field for three or four years: the Rossi-Giaconni group in Boston, the Naval Research Laboratory group under Friedman, and the Lockheed group under Fisher.

Likewise, gamma-ray astronomy is only in its infancy. Kraushaar and Clark, using Explorer XI, measured a rather uniform intensity over the celestial sphere, except for the earth and sun, but at a very low intensity.

Solid-state and surface physicists should find the nature of the moon's surface to be of considerable interest. The lunar surface is the only surface available for study which has been in a high vacuum for millions or billions of years, during which it has been subjected to bombardment by solar electromagnetic radiations, cosmic rays, solar protons, the solar wind, and micrometeorites.

As the space program goes on, the exploration and observation phase will continue. But as the new space tools come to fit the hand better, the phase of controlled experimenting should begin. There is, with rockets, satellites, and space probes, the opportunity to conduct experiments on the scale of the solar system, as opposed to the very much smaller scale of the terrestrial laboratory. Also looking further to the future, orbiting laboratories will provide the opportunity to conduct laboratory-type experiments under space conditions, including those of weightlessness. What this may mean to physics is not yet clear, but now is the time for scientists to think through the full implications of these coming opportunities.

For example, properly designed satellites launched in suitably chosen orbits can serve as gravitational clocks. By comparing the timekeeping of these gravitational clocks with nuclear clocks, it may be possible to extend the precision with which gravitational and nuclear time may be regarded as equivalent, or to demonstrate a measurable difference. Such comparisons over an extended period of time may reveal a changing value for Newton's gravitational constant,  $G$ .

There are a number of definitive experiments in relativity which need to be done. Many of them are extremely difficult, requiring, for example, measuring the precision of a gyroscope to an accuracy of seven seconds of arc over a period

of a year while the gyroscope is in orbit. It would appear to be worth while to measure accurately the effect of gravitational potential upon the characteristic frequency of an atomic oscillator, thus providing an additional check on the experiment conducted a few years ago by Pound using the Mössbauer effect. Pound found the ratio of the observed to the theoretically expected shift in frequency to be about  $0.97 \pm 0.035$  for a change in height at the surface of the earth of about 21 meters. The possible systematic error is estimated not greater than about ten percent.

In this connection, as pointed out by a well-known theoretical physicist, it is amusing to note that the moon ages about four hours more than earth every  $10^6$  years. The change in clocks between one in synchronous orbit around the earth and one on the surface has been computed to be of the order of 45 microseconds per day. Thus a clock with an accuracy of one part in  $10^{13}$ , which now seems feasible, should build up significant statistics in a short time.

With an increase in accuracy to one part in  $10^{14}$  or  $10^{15}$  one might hope to measure the relative change in metric due to a distant gravitational disturbance (as in the quasars), if one can separate clocks by an astronomical unit and still read them.

It appears that for a real study of gravitational waves, we may have to use the moon-earth system as a couple for observation of the weak forces involved.

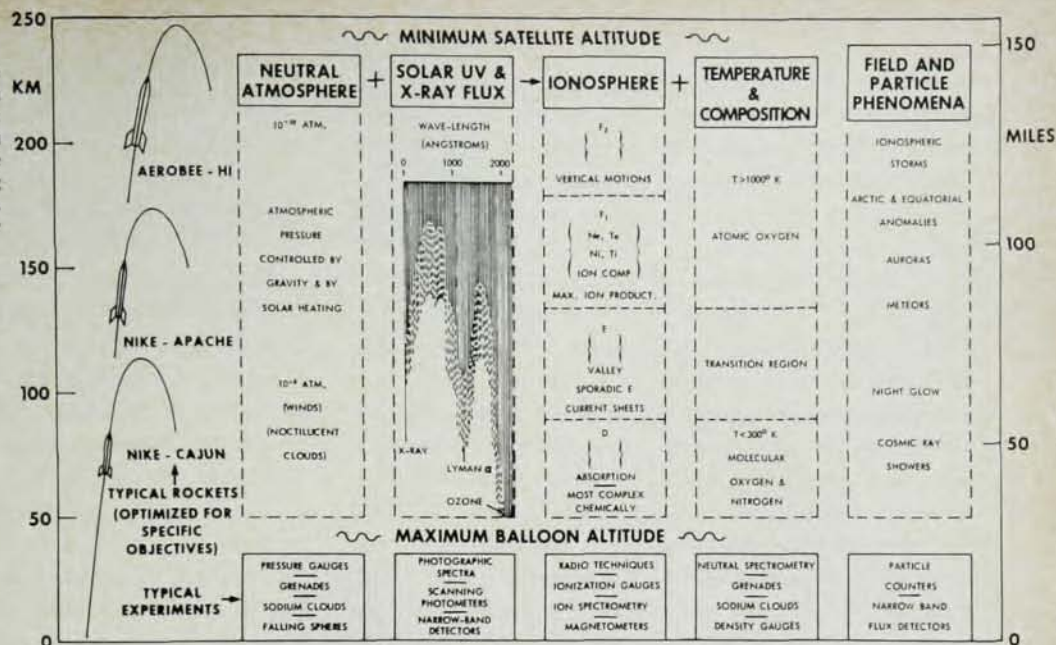
Of possible interest is the fact that cosmic rays in space provide a source of particles of energies per nucleon far greater than can be obtained in earth-based accelerators. Calculations indicate that for many important experiments usable statistics can be obtained in reasonable periods of time with particle energies up to  $10^{12}$  electron volts. Thus, the study of the interaction of such particles with matter becomes a good possibility.

#### *Tools for space research*

Sounding rockets are useful for investigating the atmosphere and ionosphere, especially those regions not accessible to balloons and satellites, and for making exploratory space measurements. In comparison with satellites and deep-space probes, sounding rockets are relatively simple, and they also afford a good means for entering into space research. Preparation of a sounding-rocket experiment enables one to learn how to design experimental hardware so that it can stand the environment of a rocket launch and of a brief exposure to space. One learns the techniques of encoding experimental information so that it can



Basic research involving the atmosphere and ionosphere in regions between the maximum altitude attainable by balloon and minimum satellite altitude is the domain of the sounding rockets in the space program. (J. E. Jackson, Goddard Space Flight Center)



be telemetered to the ground. Also, sounding rockets can be used to check out the design of an experiment to establish calibration and intensity levels, and to try out prototype equipment.

Explorer-type satellites, which we launch at the rate of about ten per year, are of moderate size, a few hundred pounds in weight. Explorers provide considerable flexibility in choice of orbit, timing of launch, data rates, and groupings of experiments.

The orbiting observatories—geophysical, solar, and astronomical—are large, high-capacity, stabilized spacecraft. Solar and astronomical observatories may be pointed to within minutes or fractions of a second of arc. While (in comparison with the Explorer satellites) the observatories provide more space and payload weight, larger power supplies, and data rates of as much as thousands of bits per second, they are less flexible in the choice of orbit into which they are launched. We plan to launch about one solar, one astronomical, and two geophysical observatories per year.

The Surveyor and Lunar Orbiter will provide means for doing research on and about the moon, a capability which will be extended by Apollo landings on the moon. For interplanetary and planetary investigations, Pioneer and Voyager are under preparation. Pioneer will be a relatively simple spinning spacecraft for deep-space interplanetary measurements. Voyager will weigh several tons, and is conceived of as a flexible spacecraft system for exploration of the solar system.



Artist's conception of possible configuration for Voyager spacecraft and capsule for planetary missions. (Caltech Jet Propulsion Laboratory)

It will be used to take advantage of various opportunities to send spacecraft to different planets and to explore the far reaches of the solar system.

Ultimately, there will be manned space stations, some of which will be usable as space laboratories. Initially, these will probably be based on Apollo hardware. At the present time a thorough study is being made of these potentialities. Although it is too early to provide any details, it is probably not too early to start thinking about how one might make use of such an orbiting platform when it does become available.

Such are the space tools that have been developed and are available for scientific research. But it is the scientific community that can best say what these tools can accomplish. We hope that you will find in the opportunities provided by NASA something of interest to you in carrying on your researches. If you have found something of potential interest, you may wish to hear a few words about the way in which we undertake to support space research.

#### NASA support of space science

In the space-science area, NASA regards the resources made available to it as a national trust, to be managed in such a way as to draw from our national capability the very best of which the country is capable. We have felt that the most effective way in which to do this is to carry the program in a way that strengthens the universities and other groups participating in the program.

Twice a year we issue a document describing the opportunities available to the nation to carry out experiments on satellites and deep-space probes. We emphasize that these opportunities are opportunities for scientists to pursue their



ideas in solving problems which *they* judge to be of scientific importance. A common basis of interest is prerequisite and we must, of course, undertake to pull together payloads that make sense in toto, but when we accept a proposal to carry out a space experiment, we do contract to support the investigator in such a way as to preserve the validity and integrity of his experiment.

We recognize that the conduct of experiments in satellites and space probes is not easy. We recognize further that it tends to create special problems for universities and colleges. Nevertheless, we insist that there are important benefits to science and education in participating in satellite and space probe programs. To help profit by these opportunities, NASA undertakes to provide engineering support for the preparation of flight experiments to universities that do not wish to do their own engineering. This support may be provided directly by a NASA Center, or funds may be included in the grant to the university so that an engineering contractor may be hired. We do insist, however, that the scientist accept full responsibility for the conduct of his experiment.

NASA also recognizes the need to assume some share of the burden of supporting, in a general way, research in the areas pertinent to the NASA program. Although we do not support as much of this broader type of activity as many would like to see supported by NASA, nevertheless, NASA does contribute significantly. Our program offices do support a sizable amount of ground-based and laboratory research and theoretical studies, occasionally providing special instruments, such as telescopes, radio antennas, computers, and laboratory equipment.

NASA insists on open publication of results obtained by scientists in the NASA program. We require that these results be reported in the scientific literature appropriate to the particular discipline concerned, as well as at meetings of scientific societies and at specialized symposia.

You may be interested in what your chances are for selection for flight of your experiment on a scientific spacecraft. We were able to fly about one-third of the experiments which were proposed for the third and fourth Orbiting Geophysical Observatories. We expect to fly about two-thirds of those proposed for the fifth OGO. In the case of the smaller Explorers we have been able to fly about half of the experiments proposed. These figures include all of the proposed experiments, whether judged suitable or not by our advisory committees. Our experience has shown that, although competition is keen, every competent sci-

entist who has seriously committed himself to space research has been able to qualify for a substantial fraction of the space-flight opportunities for which he has proposed experiments.

The proposals received by NASA are reviewed by one or more of our scientific advisory committees. After the review by the committees, the responsible program director, and the NASA Field Center that will carry out the flight, our Space Science Steering Committee makes a recommendation to me. On the basis of these reviews and recommendations I then make a final selection of experiments to be flown.

An important question that one has to face up to is how long it takes to conduct an experiment in space. It takes much longer than we would like. For a new *laboratory* experiment I would judge that it takes three months to a year to complete a research project. In high-energy physics, much longer times are not uncommon. In experiments designed for space flight, the required time may stretch to periods comparable to those required for the development of a new ground-based astronomical telescope or a large accelerator. With the first Orbiting Geophysical Observatory, 33 months passed after NASA received a proposal. During those 33 months, experiments were selected, contracts negotiated, instruments developed, tested, and integrated into the spacecraft, and then the experiment was flown. We will be able to shorten this time somewhat. However, the fundamental limitation at present is the length of time the experimenter requires to get his experiment ready for flight; this generally turns out to be about two years.

Nevertheless, those who have been working in the space program have found it exciting, challenging, and productive of important results; especially where there is an important problem that can be tackled in no other way, the effort can be most rewarding. If you are interested in taking the plunge, and have a proposal that you wish considered, please send your proposal to the National Aeronautics and Space Administration, Office of Space Science and Applications, Washington, D.C.

I hope, in the foregoing, that you have acquired some concept of the new laboratory in space in which you may find it exciting to work. You might find it fun to examine what happens when you change the linear dimension of your experimenting from  $10^{-13}$  centimeters to  $10^{13}$  centimeters and more. The gravitational force difficult to study in terrestrial laboratories may turn out to be more easily examined in the cosmic laboratory which we are trying to make available for your use.