SCIENCE IN SPACE

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PREFACE

The spectacular growth of space activity since the launching of Sputnik I on October 4, 1957, requires careful assessment of the opportunities that space exploration provides so that emphasis on those opportunities is reasonably optimized. Among the space activities of exploration, application, and scientific research, the last is precedent to man's other space endeavors. Space applications and man-in-space ventures depend for their success on adequate knowledge of space. Consequently, the necessary antecedent research must be completed before dependent space activities can be most effectively pursued. In addition, space offers a whole new vista of scientific advancement which before was inaccessible. Scientific experiments in many exciting fields of knowledge can now be planned, and these can supplement older methods of research in a very critical way.

This volume presents a review of the new scientific opportunities offered by space science. It is directed to research workers whose scientific activities may be influenced by the new opportunities for experiment offered by growing access to space. In some cases, such as astronomy, new opportunities promise to revolutionize the science. In other cases, space research can critically supplement existing methods. Therefore this volume endeavors to put these new opportunities afforded by space science in some perspective. If our space science program is to be optimized, it must take root across a broad segment of scientific activity in our universities, our scientific laboratories, and our industrial life.

This volume may also be of interest to general readers who are concerned about the national space effort. While some of the chapters admittedly are somewhat technical, others present few if any difficulties. They will suggest the nature of the scientific challenges afforded by the tools of the space age, the types of applications in the offing, and the questions that must be faced if our space endeavors are to be well conceived and executed.

The material of this volume has been contributed from a broad spectrum of American and foreign scientists. All members of the Space Science Board and of its committees have contributed through discussion, criticism, and editorial comment. In addition, many scientists outside the formal organization of the Board have given freely of their time and assistance. Therefore, full recognition to all those who have taken part in writing the volume is beyond the capabilities of the editors. We particularly express our appreciation to the President of the Academy, Dr. Detlev W. Bronk, who has sat with the Board during critical discussions, for his advice and guidance.

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A GENERAL REVIEW

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DIMENSIONS AND PROBLEMS

L. V. Berkner and Hugh Odishaw

1. THE NATURE OF SPACE ACTIVITY

Perhaps no venture in man's history has proclaimed its immediate challenges and problems as quickly and clearly as space exploration. In part this has come about because there are at hand and in the offing rocket systems capable of reaching out far into the solar system with significant cargoes. This capability points directly and compellingly to a host of important scientific problems and applications whose solutions call for satellites and space probes.

In the past, man has been tied to the Earth. What he has learned of the universe until very recent times has been based upon Earth-bound observations. From these observations, he nonetheless has learned much about the very high atmosphere, the solar system, stars in our own galaxy, and about galaxies beyond. When we consider the remarkable knowledge of the universe attained by astronomers, dependent upon only a thin slit in the electromagnetic spectrum, we can sense the excitement engendered by prospects of more direct contact with the universe. Even if we add the radio-frequency window to the narrow light-wave window, the sum gives astronomy about twenty octaves (about 100 kilocycles per second) of the electromagnetic spectrum with which to investigate the universe from the Earth because atmospheric attenuation precludes use of the whole spectrum. Yet an additional forty octaves are in principle available to instruments flown just above the Earth's masking atmosphere. The radiations in this heretofore hidden spectrum contain some of the most important information that the universe provides.

Space tools afford even further opportunities. They permit the transport of measuring devices into interplanetary space, there to record directly particles, fields, and radiations. They can carry instruments to the moon and to other planets for *in situ* detection and measurement. They will ultimately take men to these regions and bodies. In short, space carriers open up prospects that lead to the following generalization, if we are to sense how it is that the current challenges of space science are so clear and compelling: in the past man has largely had immediately before him the small, finite Earth alone, along with its lower atmosphere, for *direct* investigation; he now has, in principle, an infinite volume of space and matter accessible to him.

Consequently this ability to penetrate directly into the interplanetary medium and to reach other bodies in the solar system has a special meaning. It means a vast extension of opportunities for detection and observation above the Earth's interfering atmosphere. But even more, it means that man is now equipped to *conduct experiments* in contrast to *making observations*. The conduct of controlled experiments leads to deduction; the passive taking of observations only permits inference.

Observation is characterized in most fields of the geophysical sciences by superimposition of many variables in the collected data. Thus voluminous quantities of data are required, over years and centuries, if the many parameters are to be separated and defined; and the data reduction and processes of analysis are complex, protracted, and arduous. A specific phenomenon under study may be buried in the mass of accompanying other variables, analogous to the presence of a desired but weak radio signal in a "hash" of radio noise: the high noise level masks the wanted signal.

The ability to conduct an experiment, however, permits the gifted experimenter to devise his measurements in such a fashion as to separate the variable of interest from the many unwanted ones. Perhaps after decades and perhaps centuries of conventional observations, the Van Allen Radiation Belts might have been inferred, but the conduct of appropriate experiments quickly and directly established their existence and defined their character. Similarly the Argus experiment, by injecting into the high atmosphere a *known* quantity of charged particles at a *known* time and place permitted the conduct of a unique experiment dealing with the control mechanism of the Earth's magnetic field. The interior structure of the Moon and other planets will never be within reach until seismic and related experiments can be conducted from their surfaces: no amount of observation from the Earth can ever penetrate these mysteries.

Science is not the only claimant upon the energies that man is even now devoting to space efforts. Tools at hand, and projects already under way, point to three principal and overlapping areas of space activity:

First, *exploration.*

Second, *application.*

Third, *research.*

In spite of the inevitable overlap among these three categories, each can be said to have its own rationale and urgency, and each is best considered independently from the point of view of support.

Exploration. Perhaps the basic motivation behind the exploration of space affecting the generality of mankind is adventure. Even if space endeavors did not embrace science and application, this unparalleled adventure would be pursued, for man's history is at least in part a recital of the curiosity which has led him to voyages of exploration and discovery on his own planet from ancient days to the present. But exploration is more than adventure: it is the act of searching, the quest for discovery; and exploration has no lasting value except for critical studies that advance man's knowledge step by step. The hazards and cost of adventure and leadership through space exploration call for careful and critical analysis by the makers of policy: the effort and priority in this area should not be for personal aggrandizement at the expense of important work that lies before man in research and application.

Thus the pursuit of even this activity—exploration by man—should be integrated as closely as possible with research. The reasons are several and self-explicit. For example, if we had been able to launch man into space five years ago and had done it successfully, without prior physical experiments, man would have perished there, a victim of our lack of knowledge of certain radiations in space. Sound exploration must go hand in hand with research.

Application. It is patently clear that several applications are within grasp: no new principles, yet to be discovered, are called for; no recondite technological problems stand in our way. Rather straightforward problems in rocket-vehicle systems and technology, amenable to reasonably prompt solution, are all that we face—plus the decision to pursue the objectives with vigor. The applications include meteorology (and here TIROS I is the brilliant precursor), communications, and geodesy.

Weather satellites, reporting cloud cover and storm patterns, are of obvious day-to-day significance to the peoples of the world. Communications satellites afford the promise of extending, in effect, the available frequency spectrum by as much as several orders of magnitude. Geodetic satellites will provide more accurate means for navigation and mapping.

Research. From unique information about the solid Earth itself to new insights into extragalactic astronomy, space research affords innumerable opportunities for advances in science. To these opportunities and problems are devoted the bulk of this book, which suggests how much can be undertaken if suitable spacecraft are available, if a broad program of background and flight-directed research is undertaken, and if the full potential of creativity among scientists throughout the nation is developed. Achievements in this area are ultimately the proper first objectives of space efforts and the basis of true exploration. Their attainment —whether as contributions to knowledge, or ultimately to applications, or to national leadership—represents substantive accomplishment as against the ephemeral and already discounted "stunts" that are attempted from time to time.

What has been learned of the upper atmosphere and near space so far? What does this knowledge mean as a guide to further efforts? What is the status of development of space systems upon which future efforts depend? What are the prospects of practical applications of Earth satellites? What is the role of man in space? Why is science deeply concerned about the research prospects afforded by spacecraft? How can we best go about the complicated business of properly and economically planning and conducting meaningful space activities? These and similar questions are pertinent and timely. Yet answers are not easy because the sum total of all that is involved in our current space endeavors represents an evolving, intricate complex of interests, forces, and activities. Yet answers to questions such as those above must be pursued, and the remainder of this chapter is concerned with such problems in a preliminary, tentative way in the hope that responsible public debate may be stimulated.

2. ROCKETS, SATELLITES, AND PROBES

The use of sounding rockets, which rise almost vertically and return to Earth directly, for measurements in the upper atmosphere is significant because it has yielded important and unique data and because it was the necessary precursor to space systems. Moreover, satellites and space probes do not relegate sounding rockets to obsolescence, for sounding rockets have unique virtues in studies of the lower and higher reaches of the atmosphere. They provide a means for examining a large region above the reach of balloons and below the altitudes where satellites can long endure. They permit the investigation of events and processes as a function of altitude. They also afford a useful tool for trying out, in a meaningful way, space instruments before their commitment to more expensive space flights.

Direct access to the upper atmosphere for scientific observation and experiment has come only in the past two decades. Before then, knowledge of the upper atmosphere depended upon *indirect* measurements. For example, scientists had probed the ionized layers of the atmosphere between some 80 and 500 km above the Earth's surface, largely by sending short bursts of radio energy skyward and by examining the reflections. From these reflections, which yielded the virtual heights of the reflecting layers as a function of frequency, the gross features of the ionosphere and its behavior were mapped. The knowledge gained thereby has been helpful to man's utilization of radio waves in their many forms and applications. Yet this hard-won knowledge has depended upon indireet observations: the region itself was not penetrated and thus *in situ* measurements were impossible. These limitations have been removed with the advent of atmospheric sounding rockets.

Following the first, military utilization of large rockets by the Germans during World War II, the application of sounding rockets to research was developed by several nations, particularly the United States. These experiments led to important advances in our knowledge of the atmosphere, the ionosphere, and the Sun. Early rocket experiments demonstrated the feasibility of obtaining cross-sectional measurements through the atmosphere, thus yielding connecting relationships in the troposphere, stratosphere, mesosphere, and ionosphere.

The results of sounding rocket research are extensive, and a few examples will suggest this. The detection of X rays and of auroral particles in the upper atmosphere and of the penetration of equatorial ionospheric current sheets were made possible by sounding rockets. The first detailed photograph of the solar ultraviolet spectrum was made possible by rocket-borne instrumentation. The first photograph of an earth-invisible, gigantic tropical storm was achieved by rocket technology, presaging the pictorial mapping transmitted by TIROS I.

Pressure, temperature, density, and composition have been measured through cross sections of the atmosphere to altitudes extending some 300 km over many rocket-launching sites. In the ionosphere, electron density data have been obtained, and the diffusive separation of the components of the atmosphere below and above the E-region have been measured. Rockets have soared directly into active auroras, permitting the study of the electromagnetic and particle radiations. Such studies have shown, for example, that the soft radiation flux above 40 km is many times that of the primary cosmic ray count. Rockets have significantly augmented investigations of secondary cosmic rays on ground and of primaries by means of balloons: intensities and compositions of the primary radiations have been determined by instruments above the denser layers of the atmosphere with which the primaries react. The Earth's magnetic field has been measured in the auroral regions while in the equatorial regions electric currents have been observed through their magnetic effect.

Fields of science other than those directly concerned with the upper atmosphere have profited from rocketry. From above the masking layers of the atmosphere, astronomy has gained new knowledge of solar radiations and their spectra and of stellar ultraviolet radiation. Rockets have also made possible the conduct of man-made experiments in the upper atmosphere. The ejection of sodium vapor, for example, has permitted the measurement of its radiations under the stimulus of particle and radiation impact, of atmospheric winds as the vapor was carried along, and of its diffusion. The injection of electrons into the upper atmosphere in the Argus experiment contributed markedly to an understanding of the trapping of charged particles by the Earth's magnetic field.

Some of the above findings were made in the years immediately following the last war, and many were made during the intensified research period of the International Geophysical Year. During the planning of the IGY—an unprecedented attack on problems of our planet and its spatial environment—it was clear that rocket vehicles afforded powerful tools for exploring the upper atmosphere. Accordingly, strong endorsement to sounding rocket programs was given by the international scientific community planning the IGY. But more than this took place: the established body of new knowledge of the high atmosphere, wrested from Nature only by sounding rockets, suggested clearly that extensions of the technique offered even greater insights into the nature of near space, the relationships between solar activity and events and processes near Earth, and into the cosmos itself. These prospects, about which some technically sound conjectures had been made some years earlier, took on a more hopeful aspect because technological advances in rocket system design and construction, in guidance and control, and in related engineering devices and techniques suggested the imminent feasibility of satellites.

Thus the IGY incorporated recommendations advocating geophysical research using space vehicles. The impetus was simple: while sounding rockets provide directly sensed data of the upper atmosphere, their lives are brief and their spatial coverage restricted to a "line slice." Yet the parameters of events in space vary extensively with space and with time: keenly desired were tools of long life, able to map out variations of many phenomena throughout the expanse of space in the vicinity of the Earth and over appreciable periods of time.

Less than four years have passed since the first satellite was launched into near space. During that interval some very significant results have been obtained. Four are noted here not only because they are of intrinsic interest in themselves but because they demonstrate the power of space tools in garnering important data about space and about Earth.

The discovery of the Van Allen Radiation Belts, in which both satellites and deep space probes were used, stands as one of the great discoveries in the history of geophysics. The achievement entails not only the discovery of two vast regions of space and of the particle population of these regions but also provides the basis for a unified description of variations of the Earth's magnetic field, the aurora, and solar particles in a much more realistic and exciting way.

The inner Van Allen Belt was first publicly reported on May 1, 1958, at the National Academy of Sciences in Washington, based on measurements aboard the early Explorer satellites. The Van Allen particles appear above 120 km in northern latitudes and 360 km above the equator and extend over the equator out to about 4000 km. Stoermer's theoretical studies postulated long ago that charged particles could be trapped in the Earth's field and forced to spiral between northern and southern mirror points. But without experiment, the applicability of Stoermer's calculations could not be assessed. Now we find that over a period of time, the number of captured particles can increase appreciably, accounting for the formation of a Van Allen Belt. It is probable that at least some of the Van Allen particles in the inner belt arise from beta decay of cosmic ray neutrons.

Van Allen and his colleagues obtained further striking results from space probes Pioneer III and IV: the second Van Allen Belt was discovered to range from 10,000 to 60,000 km beyond the Earth's surface. The structure and composition of this outer zone are not clear. Solar disturbances appear to play a role. Plasma clouds from the Sun, bearing protons and electrons, reach the vicinity of the Earth and interact with its magnetic field. Particles from the outer zone are released by this interaction into the atmosphere, and this is followed by an increase in the number of electrons (of energy 10 kev or higher) within the outer zone.

The energy has its source in the kinetic energy of the plasma cloud: how the energy is transferred remains unknown, and much further research is called for before the nature of the structure and composition of the outer Van Allen Belt can be satisfactorily established. Yet the existence of the belts and that which is known about their properties are of fundamental significance: first, because a major feature of near space has been discovered and its general nature outlined and, second, because the belts suggest the prospect of an integrating concept of a variety of geophysical phenomena and processes.

The second great achievement made possible by IGY satellites relates to the shape of Earth. Here the first small Vanguard satellite has permitted O'Keefe and his associates to make detailed studies of its orbits. Their findings resulted in the postulation of a "pear-shaped" model of the Earth. The apparent variation from the previous theoretical model is small even in comparison to the 21 km difference between equatorial and polar radii, but it is extremely important in terms of the Earth's structure and surface loading. Moreover, this initial study points out the scientific value of satellites in studying the solid Earth itself because eventual checks on surface distortion may have a profound effect on theories of isostasy and of internal structure and mass distribution.

Satellites of both the U.S.S.R. and the United States also provided valuable data on drag and density and on satellite environmental conditions—e.g., temperatures. Soviet satellites, with transmissions at 20 and 40 megacycles, afford an opportunity for ionospheric studies when the receptions can be coupled with precise positional data. One of the most striking findings in the field of near-space structure relates to drag. Jacchia has established a correlation between the drag on a satellite and solar activity: the correlation between Vanguard I drag and (*a*) solar flux index at 10.7 cm wavelengths and (*b*) magnetic activity index is remarkable.

The fourth advance is concerned with meteorology. Rocket photography had some years ago revealed cloud cover over thousands of square miles and had betrayed the birth of a major storm in the structure of cloud patterns—a storm unsuspected from ground observations. Two IGY satellites were devoted to meteorological problems: one to a scan of clouds, the other to measurements of the Earth's radiation balance. With the launching of TIROS I, however, the great potential of meteorological satellites was demonstrated. The striking photographic coverage, over vast expanses and about the Earth, provide data for research as well as information for storm warning purposes. A major initial step