Chapter 4

The Importance of Doing Space Science

INTRODUCTION

Over the past 300 years, accelerating advances in scientific theory and practice have aided man in remaking the world. As scientific descriptions of our surroundings become more detailed, the practical consequences of applying scientific results and techniques to the problems of everyday life become more far-reaching. As the effects of science move out of the theoretician's study and the experimenter's laboratory, it is important to reflect on the reasons for undertaking science at all. It is not in the province of this report to justify the national effort in science, but it is *never*theless appropriate to discuss the importance of the space science program as a component of all Federal expenditures. Indeed, much of the rationale for doing space science is a corollary for doing science in general.

Space science is an undertaking that satisfies the visionary and exploratory needs of the human race. "In the future, as in the past, our freedom, independence and national well-being will be tied to new achievements, new discoveries and pushing back frontiers."[1] It is a cultural as well as a scientific activity that seeks to understand the Earth's place in the solar system, the solar system's place in the Milky Way Galaxy, and our Galaxy's place in the Universe. In assisting man to gain a better understanding of his place in his surroundings, space science also explores the fine structure of the universe in the form of samples, either examined in situ or returned for study on Earth.

At the bottom of the Earth's atmosphere, our ability to sense the universe is restricted to the visible and radio portions of the electromagnetic spectrum, but our extended ability to observe from above the atmosphere by means of instruments aboard spacecraft has widened our scientific vista enormously, and has permitted observations to be made of celestial objects that could not have been made in any other way. We are now truly viewing the universe through a set of multispectral eyes.

[1]President Ronald Reagan, "State of Space" speech, July 4, 1982.

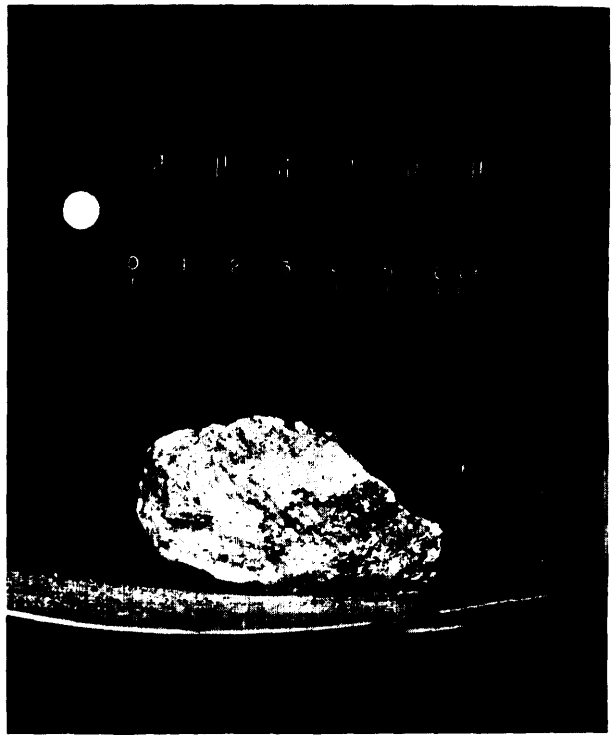
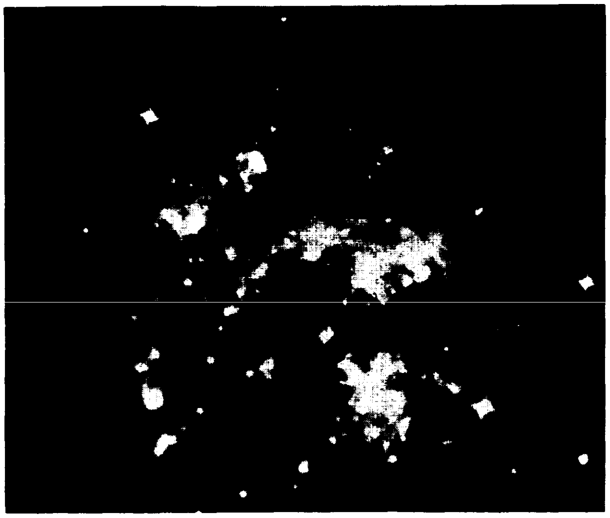


Photo credit: National Aeronautics and Space Administration

A lunar sample from Apollo 14 pictured in the Lunar Receiving Laboratory at the Manned Spaceflight Center, Houston, Tex.

Astronomy is only one of the fields of science of which instruments aboard spacecraft have *rev*olutionized our understanding. Others include the physics and chemistry of the Sun; energetic particles; the interplanetary medium; and the planetary sciences, whose purview properly includes Earth, as well as the Moon, the other planets and their satellites, and comets and asteroids. These fields have immediate importance for life on Earth. In fact, solar terrestrial physics and the planetary sciences as conducted from space have provided the basis for many of the important utilitarian applications for space technology--communications, navigation, meteorology, atmospheric physics.



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EXPENSE OF SPACE SCIENCE AND THE ROLE OF PUBLIC SUPPORT

Increasingly, there are those who believe that the pursuit of expensive science solely for the sake of understanding, particularly in the face of other urgent problems facing mankind, may not be defeasible. Because an expensive science project is a social product that depends on the common labor of many scientists, and because tax money must be allocated to support such an activity, the decision to pursue an expensive project and to allocate resources to it among competing alternatives necessarily entails political oversight.

More than ever before, a successful scientific career now depends on the support of public and private institutions. The days when individuals of independent means could make fundamental advances in science have mostly passed. The expense of pursuing fundamental research, particularly in the areas of so-called big science (e.g., high-energy physics, astronomy conducted with large telescopes, or space science), places these activities beyond the financial means of individuals. The costs of adequate scientific instrumentation are, for the most part, not borne by those who are to use them, but by Federal, State, and private laboratories—and ultimately by society as a whole. Thus, there is a kind of social contract between scientists and society, in which the pursuit of knowledge is exchanged for economic support.

Although the results of science have become part of our common heritage, the practice of science is becoming more and more a cooperative enterprise. Even though the individual genius will always be important in the process of scientific discovery, especially in purely theoretical work and in the practice of small-scale science, teams of scientists engaged in large-scale research projects are now quite common.

If society agrees to support science, the problem of just how that support should be apportioned remains complex. First, the very progress of science often leads to the need for more powerful instrumentation, especially in space science. As our understanding becomes more detailed, additional subdiscipline are founded, and each of them requires continued public support if it is to advance further. At the same time, other subdiscipline may be terminated, either because they reach a natural close or because they become too expensive to pursue further. In general, however, a situation where overall funding does not increase requires that some projects be delayed, stretched-out, or dropped, if others are to be supported.

Second, it is not possible to predict which scientific research programs will lead to improvement in the quality of human life. Applied science and engineering are undertaken with a view to producing relatively near-term benefits, but their productivity will soon become exhausted if a broad-scale program of basic research is not sustained.

It is important in this context to distinguish between further or continued research at a more or less constant level of funding and *expanded* research at a higher level of funding. In this report, OTA examines what value space science research has had in the past and is likely to have in the future, and what difficulties have arisen in maintaining a research effort at more or less constant overall funding levels; OTA has not considered the desirability of increasing funding levels for space science.

EARTH AND THE PLANETARY SCIENCES

The pursuit of planetary science has been of substantial importance to many of the geosciences, including geology, geochemistry, geophysics, geodesy, cartography, and photogrammetry. Exploration of other planets has returned results fundamental to understanding the evolution of Earth. These results derive, in large part, from the study of the crustal features and inferences about the interior of terrestrial (i.e., Earth-like) planetary bodies, including Mercury, Venus, Mars, and the satellites of Jupiter and Saturn.

The two principal drivers of planetary evolution are tectonism and vulcanism. Tectonism, the

Photo credit: National Aeronautics and Space Administration

Earth as a planet: the weather satellite GOES EAST shows two hurricanes bracketing Mexico, on Aug. 8, 1980

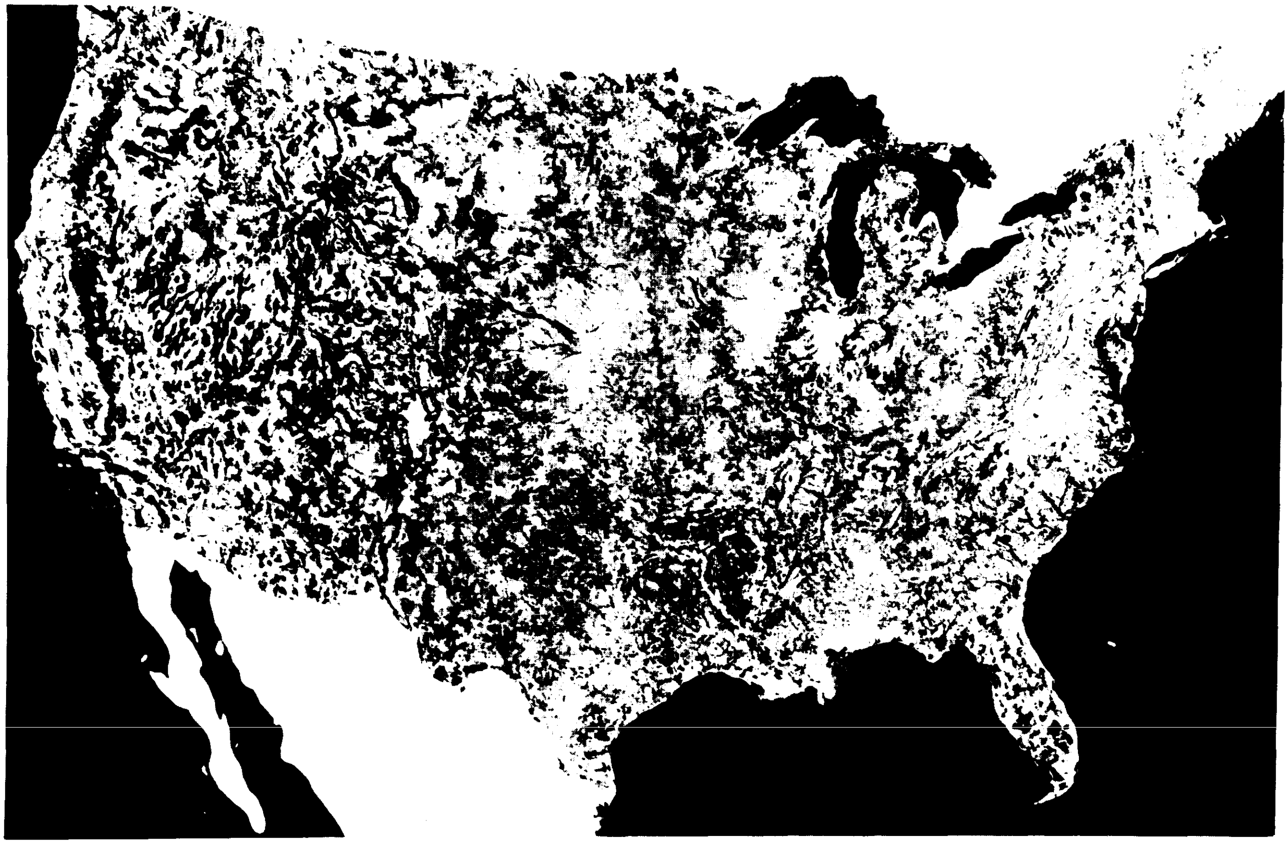


Photo credit: National Aeronautics and Space Administration

A giant photo map of the contiguous 48 States of the United States, the first ever assembled from satellite images. The images were produced by the Multispectral Scanner aboard Landsat I (formerly ERTS-1) between July 25 and Oct. 31, 1972

processes that determine how the crusts of planets deform and buckle, is important to understand for purposes of predicting and giving early warning of earthquakes; research into vulcanism, the processes whereby molten portions of a planet's interior emerge onto its surface (either on the seabed or on land, in the case of Earth), is a subject of practical importance because further understanding may eventually lead to prediction of volcanic eruptions.

Both earthquakes and volcanic eruptions remain major hazards in many parts of the world. The thorough devastation resulting from the recent eruption of Mt. St. Helen's in Washington State and the great loss of life in recent earthquakes in Italy and Central America attest to the power of these processes and their consequences for human life. Planetary science is providing revolutionary insight into these processes. The hyperactive vulcanism on the Jovian satellite Io, for example, follows an entirely different pattern from that of the Earth; study of these differences may be the key to understanding how volcanic processes work.

Planetary science, by furthering our understanding of the processes whereby mineral deposits are formed, may provide unexpected assistance in evaluating, seeking, and discovering these resources on Earth. Extensive research on Earth has revealed that mineral deposits are unevenly distributed; a fundamental problem in plate tectonics—the theory of how the continental land masses slowly move over the Earth's surface—is to explain the peculiar distribution of these deposits. Many of them are very ancient, formed when Earth was more like the Moon, Mars, or Venus;

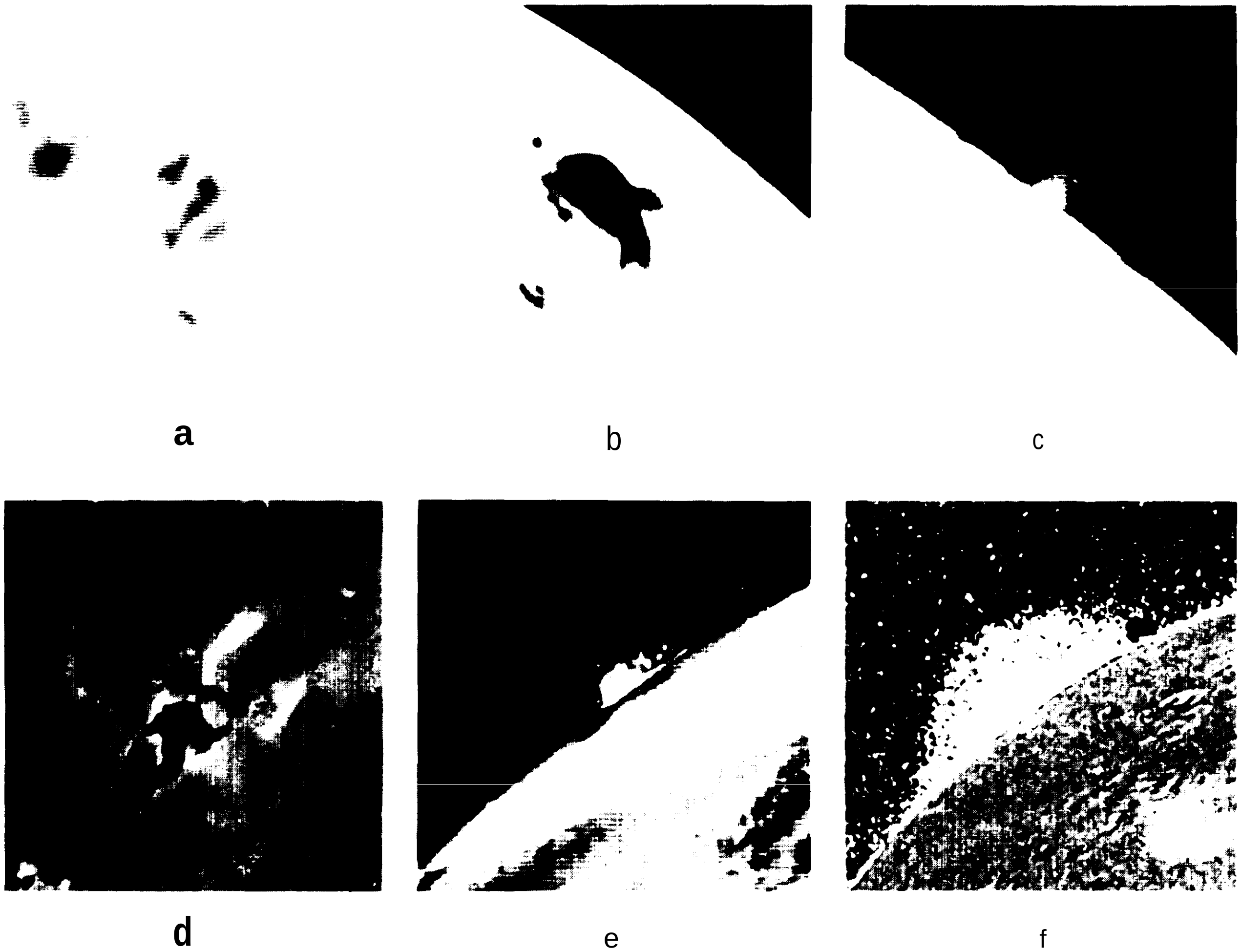


Photo credit: National Aeronautics and Space Administration

Successive images of volcanic plumes on 10, taken from the Voyager I spacecraft

some of these are no longer being formed; others are still being produced, by a combination of crustal movements and volcanic activity. Comparative studies of other terrestrial bodies are assisting in the resolution of these issues.

In many respects, Venus and Earth are twins, but they have taken radically different evolutionary paths. Scientists now think that Earth owes its particular course of development to the early formation of life. Life forms in the early ocean are thought to have pulled carbon dioxide out of the atmosphere and laid it down in limestone. Decreasing the level of carbon dioxide prevented the runaway greenhouse effect that characterizes the atmosphere of Venus, and this in turn preserved Earth's oceans. Recent evidence from Venus indicates that it once had oceans, too. Presumably, however, life did not appear at all there, or it did not become sufficiently widespread to remove much carbon dioxide.

The oceans are not a mere secondary feature of the Earth's surface; they permit continued evolution of its crust. Ocean water cools molten basalt emerging from the midocean ridges, thus making the basalt dense enough so that the continental plates can "float" above it. Without this oceanic cooling of basalt, the continents would freeze in place, as they have on Venus. In this view, sea floor spreading and plate tectonic motion, made possible by the presence of the oceans, provide the present dynamic control of Earth's evolution. Thus, the presence of life and the presence of the oceans make Earth unique, at least in our star system. Life and the oceans each owes their preservation to the other, and the oceans control the way Earth's crust forms and therefore, indirectly, the course of evolution of living things. Without a study of Venus—an opposite case, where some particular differences have made all the difference—it is unlikely that our understanding of Earth's evolution would have progressed as far as it has.

Planetary science, therefore, has enlarged and deepened our understanding of the fundamental processes molding the Earth. In addition, it has given evidence both of what kinds of results might be expected if the balance of Earth's system were disturbed, and of how a relatively small change could drive the whole system into a dry, dead end.

FORMATION OF THE OZONE LAYER

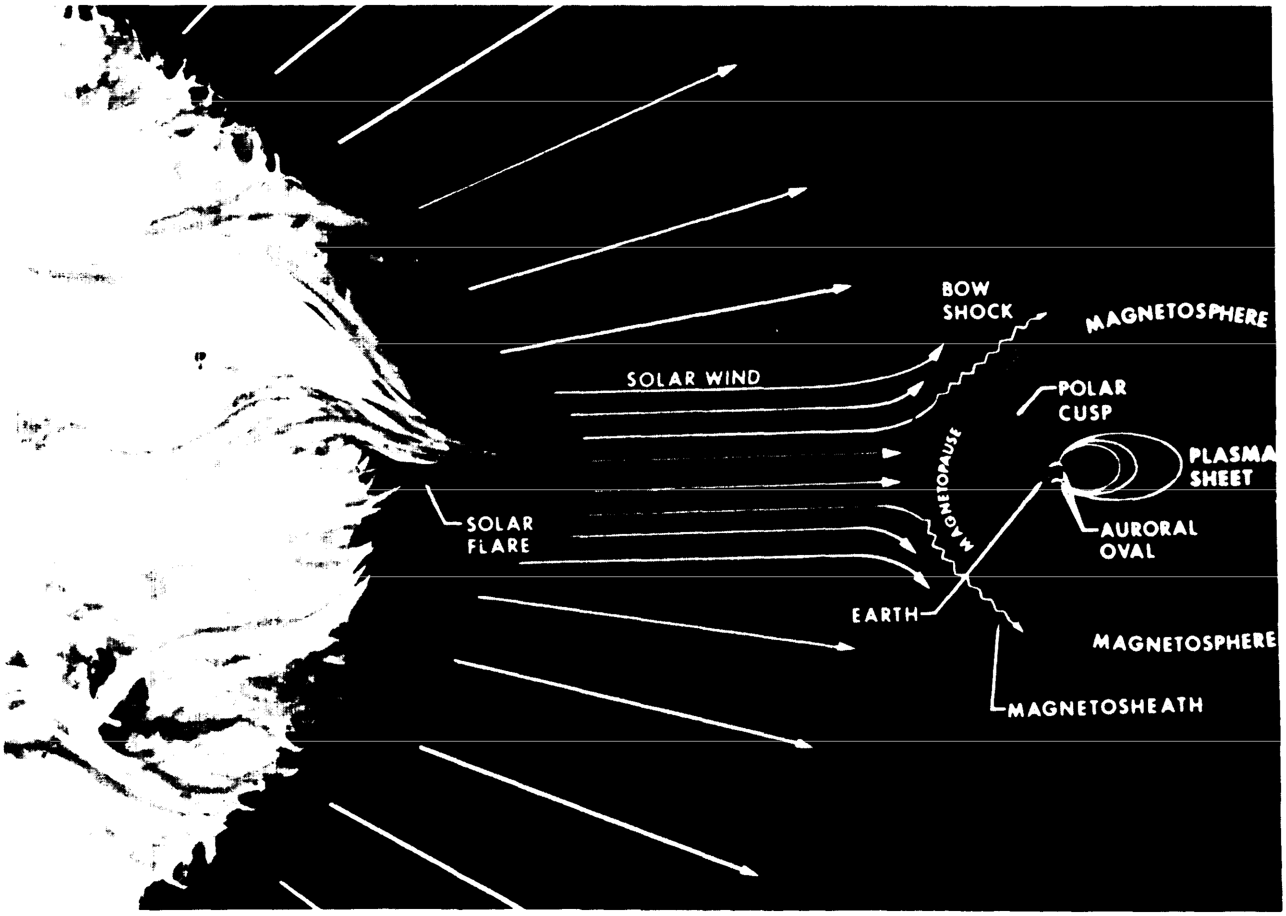
The monitoring of ozone is one example of a practical activity growing out of space science. Ozone is a small, but important constituent of the Earth's atmosphere: too little of it in the stratosphere allows dangerous levels of ultraviolet radiation to reach the Earth's surface; too much of it near the Earth's surface has more immediate deleterious effects on human health. The level of ozone in the stratosphere can be altered both through increased technological activity, which causes relatively slow changes, and through alterations in the level of solar ultraviolet radiation, which causes more rapid fluctuations. Whereas increased technological activity tends to add compounds to the atmosphere which decrease the stratospheric ozone, solar ultraviolet radiation produces additional ozone. The mechanisms by which stratospheric ozone is formed and maintained are still not thoroughly understood, and space research systems are being used not only to monitor ozone but to measure related parameters which are critical to increasing our knowledge.

SOLAR PARTICLE EMISSIONS

Space research systems are also useful for measuring the level at which high-energy protons, emitted from solar flares, bombard the Earth's atmosphere, particularly at high latitudes. Instruments aboard spacecraft can detect the emission of these particles early enough so that the routes of aircraft flying over the polar caps may be changed or manned satellites may take appropriate precautions. To perform well, these warning systems must be sufficiently accurate to differentiate between flares that have a major effect and those that have only minor effects. The flare signatures that will provide this separation are not well defined, and only further basic research from space vehicles will provide the answers.

WEATHER AND CLIMATE

Another example of the practical effects of space science is the observation of the Earth's climate and weather. The Earth's weather and secular or cyclic changes in its climatic conditions have a significant impact on commercial activity. Accurate weather predictions are very useful for a variety of purposes, and accurate climatic forecasts could be of great strategic value—in predicting energy consumption requirements, for exampie. Accurate predictions depend on a substantial monitoring system in which satellites play a major role. If these satellites are to succeed in their missions, they must monitor the most predictive sets of parameters, and their downward-looking



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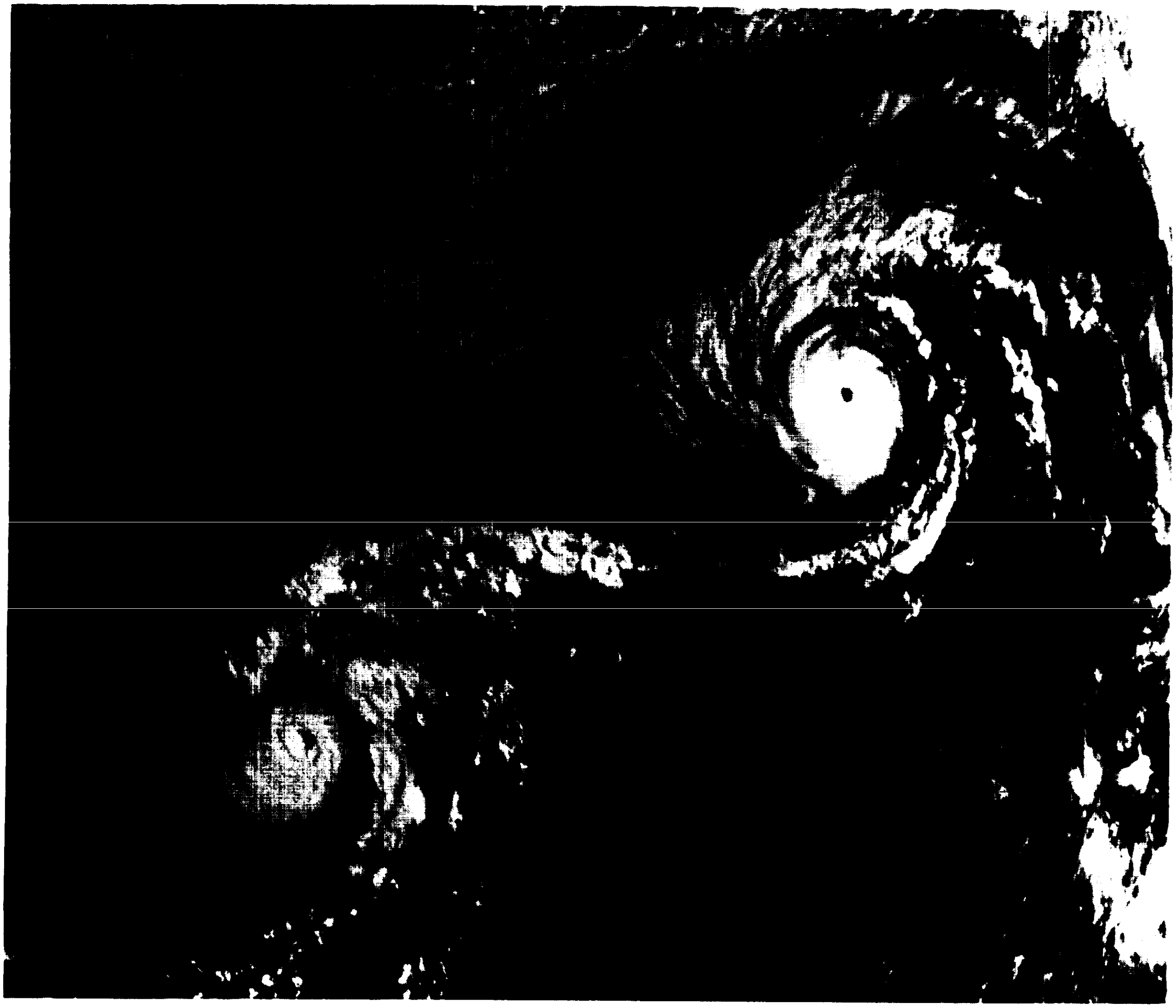
systems must measure cloud cover, infrared and visible radiation, temperature, and the changes in these parameters. Because the relative reliability of these parameters is still under investigation, there is need for a continuing basic research partnership in which observations made from space and studies made from the ground are correlated, the parameters most critical over long time sequences are identified, and the largest available computers are employed—if there is a determination that the national interest is well served by more accurate weather predictions and climate monitoring.

Prediction of the Earth's weather presents an extremely complicated problem. Weather prediction is still in its infancy, and progress to date has been dependent on an increasingly sophisticated sensing system, combined with elaborate computer analysis. Space scientists are gaining further insight into how planetary atmospheres originate, circulate and evolve, principally because of recent space research on the atmospheres of other planets (Venus, Mars, Jupiter, and Saturn). This insight promises to remove some of the uncertainty in our knowledge of the circulation patterns of the Earth's atmosphere.



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PROCESS INTERCHANGE IN THE EARTH'S ATMOSPHERE

Our life system on Earth is crucially dependent on a delicate balance and interchange of processes that occur at the interface of the Earth, the oceans, and the atmosphere. The presence of man and, in particular, the population explosion, compounded with the growth of industry, have begun to affect that balance in ways that are not yet understood. One primary means of monitoring and understanding these processes is through satellite remote sensing, an activity that is only a decade old.

Sampling the troposphere, the stratosphere, and much of the ionosphere can be done by Earth-based methods; the magnetosphere can be investigated only by space vehicles. The parameters of the "middle atmosphere, " the region from 30 or 40 to 100 km above the Earth's surface, are still uncertain, especially the composition and the electric fields of the region. If the effects that solar variations and the Van Allen Belt will have on spacecraft operating near the Earth are to be understood, the magnetosphere must be fully mapped throughout the solar cycle.

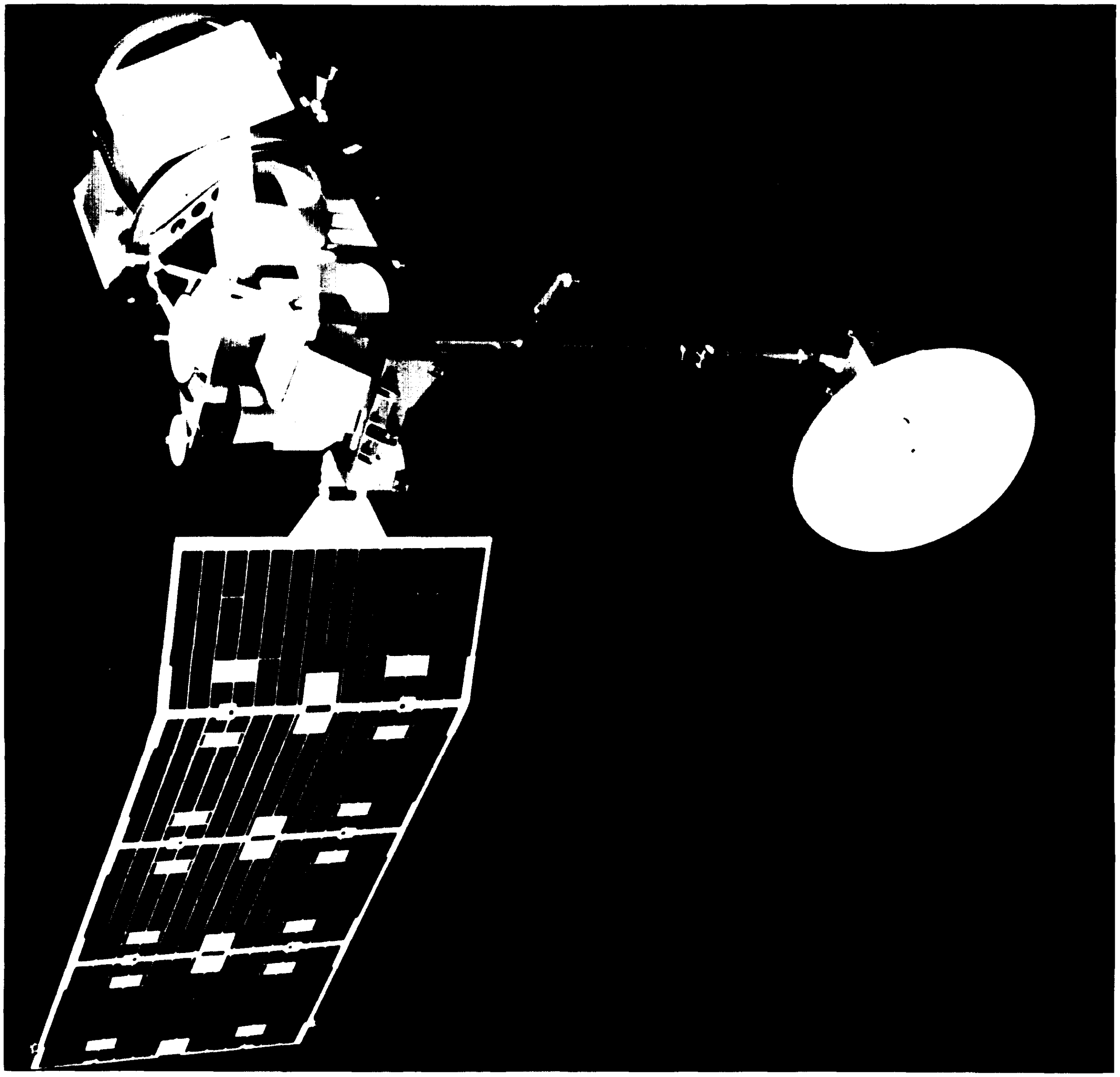

Photo credit: National Aeronautics and Space Administration

Landsat D—launched July 1982

EFFECTS OF SOLAR VARIATIONS ON COMMUNICATIONS

The Sun is the primary driving power underlying most processes on Earth, and its presence is an absolute necessity for our own existence. But the Sun is variable, and most of the variations that can occur have important effects on communications systems. Many of the important variations, however, can be seen only in regions of the spectrum accessible from above the Earth's atmosphere.

It had been known for decades that geomagnetic storms on the Earth seriously affect communications on the Earth, particularly at high latitudes. Geomagnetic storms result from streams of hot ionized gas that originate in solar storms, then are shot into interplanetary space, and finally impinge on the Earth's magnetosphere and disrupt communications. It is now known that the geomagnetic storms coincide with the arrival of streams of matter that travel much faster than the normal solar wind, and that these high-speed streams originate from regions on the Sun that do not emit X-rays, regions where there are "holes" in the low-energy X-ray emission, seen on photographs of the Sun taken in X-ray light. Thus, the presence of solar coronal holes, dark regions on an X-ray photograph of the solar disk, correlates significantly with geomagnetic storm activity on Earth.

Thus, there is a direct connection between the reliability of radio communications at high altitudes on Earth and our ability to monitor and study the Sun by X-ray satellites, by means of techniques not possible from the ground. The manifestations of this connection are not yet highly predictable, and the benefits of making them so will accrue only if basic research is continued.

SATELLITE RELIABILITY

Spacecraft operate in an environment that is largely foreign to us and virtually impossible to duplicate for study on the ground. In addition to the primary hazard of energetic particles in Earth's radiation belts, they are subject to differential charging, to emissions of electrons, protons, and other energetic particles from the Sun, to cosmic rays, and to high-energy solar and stellar ultraviolet, and X-ray and gamma ray radiation, any of which, if encountered in sufficient strength, can degrade the performance of the spacecraft. Damage may occur through irradiation of its detectors and electronics, electrostatic discharges, and the physical effects of collisions, including particle sputtering on mirror surfaces. As longer-lived satellites are orbited, degradation in performance because of environmental factors will be a more likely source of failure than will exhaustion of on-board energy sources.

The environment in which the now more than 4,000 manmade objects are orbiting the Earth is still not understood in detail. We do not yet know the time, frequency, or amplitude ranges over which variations in particulate bombardment and radiation take place. In the beginning of June 1980, for example, an unexpected increase in the flux of high-energy electrons at synchronous altitude particularly affected the performance of geostationary satellites. This result showed that the near-Earth space environment still held surprises and that instruments more immune to the effects of radiation had to be developed.

The requirement of the Department of Defense that the electronic components of its spacecraft be protected both against the natural radiation environment and, especially, against radiation from the explosion of nuclear devices has been the primary driver in the development of advanced "hardening" techniques. (The deep space probe Galileo, which must be able to withstand an environment of very high radiation around Jupiter, will be making use of some of these developmerits.) After these techniques are perfected, further study of the radiation environment around the Earth, particularly of the triggering mechanisms by which particles are dumped from the Earth's geomagnetic tail into the Earth's atmosphere, will be needed, if the national interest requires more assured satellite operations.

Common to civilian and military applications is the requirement to minimize payload weight while maximizing payload performance. This requirement has been the principal driving force behind the miniaturization of components, of which the development of tiny electronic circuits on silicon chips has been a major technological breakthrough. When these chips first found application on satellites, they were relatively large and not too densely packed. These features, combined with space hardening techniques, made the chips relatively reliable in the spacecraft environment. However, the technological state of the art in making chips has now progressed to the point where the chips are smaller and more densely packed, and have, size for size, orders of magnitude more capability than the previous generation of chips they will replace.

It is known that the new, high-density chips will be more susceptible to damage from radiation bombardment than were their predecessors, but it is not known how much more susceptible they will be. Here *is* another instance in which, if the answer is to be achieved, basic and applied research will both be needed: basic research to investigate the radiation environment, and applied research to investigate the effects of that environment on the new series of chips in order to predict how long they will last under various environmental conditions and under various degrees of radiation hardening.

COMMERCIAL IMPORTANCE OF NEAR= EARTH SPACE

The commercial importance of the space environment near the Earth has not yet been fully evaluated because, apart from the communications industry, there has been little involvement of the private sector. In the future, the investment of the private sector in space activities will almost certainly increase, particularly in satellite communications, remote sensing, and materials processing.

Materials processing in space (MPS) may be singled out as a new and interesting area for commercially oriented space research. In order to ease the way for industry to exploit the possibilities of MPS, NASA has developed the Joint Endeavor Agreement, in which the agency and industry share in the costs and the risks of the project: NASA provides technical advice and assumes the costs of the launch vehicle, including flight time, and industry provides the development funds.

One promising example of this Government-industry symbiosis is in drug manufacturing, where McDonnell Douglas Astronautics and the Ortho Pharmaceuticals Corp. of Johnson& Johnson are making a substantial investment in order to determine whether certain drugs can be manufactured in space more profitably than on the ground. Studies have shown that, by means of a process known as electrophoresis (a technique whereby a solution flows through an electric field in which molecules of different charges are separated from each other as a result of their migration in different directions at different speeds), it should be possible for cells to be separated from proteins about 100 to 400 times more quickly and with five times the product purity that can be obtained from the ground.

There are potential applications in the manufacture of interferon (a treatment for cancer), beta cells (a possible single-injection cure for diabetes), epidermal growth factor products (for treating burn patients), growth hormone products (for juvenile bone growth stimulation and the healing of ulcers), antitryspin products (for limiting the progress of emphysema), and antihemophilic products (for eliminating immunological reactions for hemophilia). In all these cases, there is promise that commercially viable quantities of these drugs can be made in the zero-gravity environment of space.

Materials processing is only one example of the possibilities of industrial use of near-Earth space. If these possibilities are to be exploited, scientists will require a better knowledge of the space parameters that may modify processes whose ground-based instances are well understood. If these developments are to be successful, continued interaction between pure space science and applied space science will be necessary.