# An Implementation Plan for Priorities in Solar-System Space Physics: Executive Summary

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Committee on Solar and Space Physics, Space Science Board, Commission on Physical Sciences, Mathematics, and Resources, National Research Council

# AN IMPLEMENTATION PLAN FOR PRIORITIES IN SOLAR-SYSTEM SPACE PHYSICS

## EXECUTIVE SUMMARY

**Committee on Solar and Space Physics**
**Space Science Board**
**Commission on Physical Sciences, Mathematics, and Resources**
**National Research Council**

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Washington, D.C. 1985

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This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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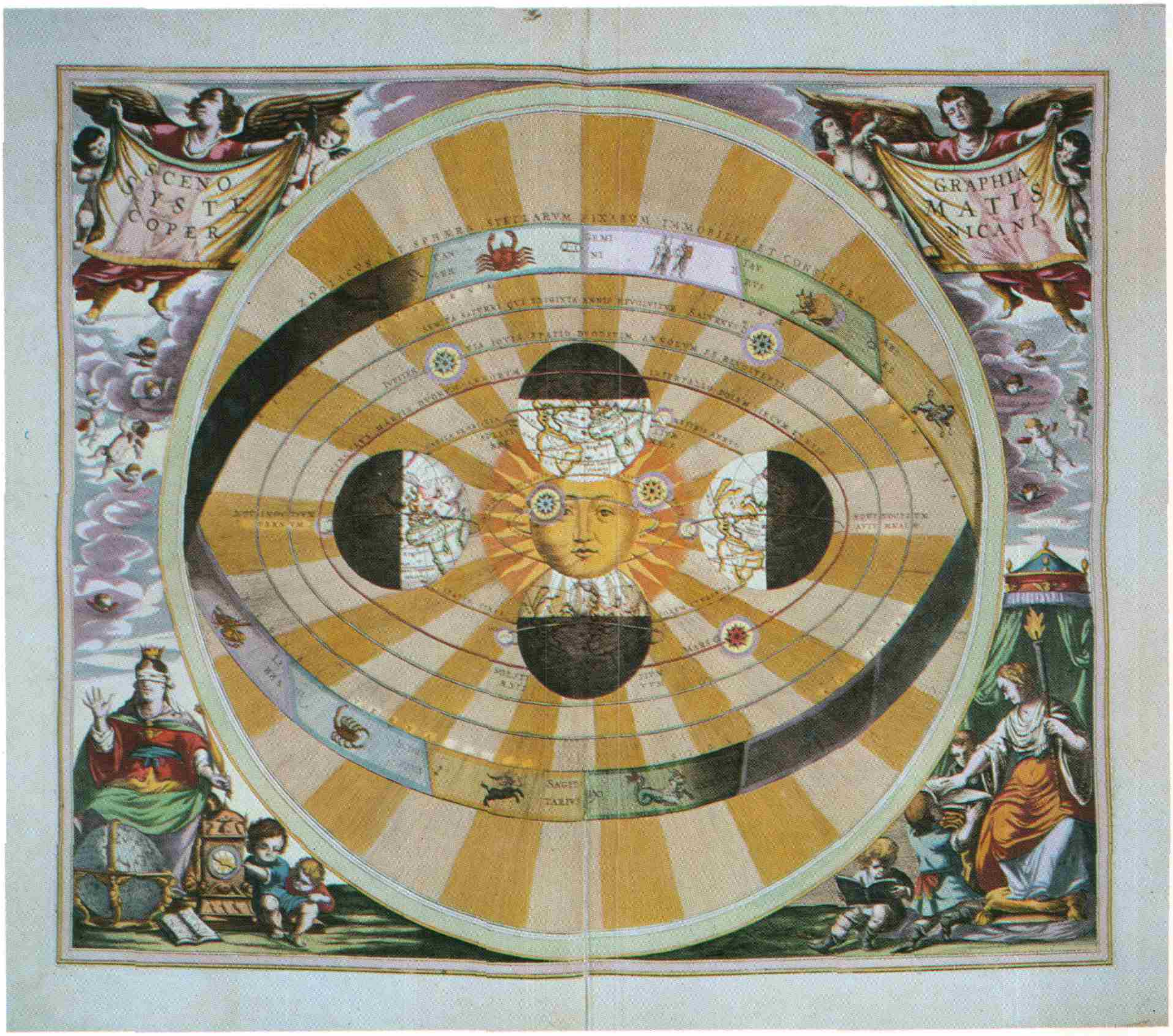


**"Systematis Copernicani" from *Harmonia Macrocosmica* (1661). Andreas Cellarius.**

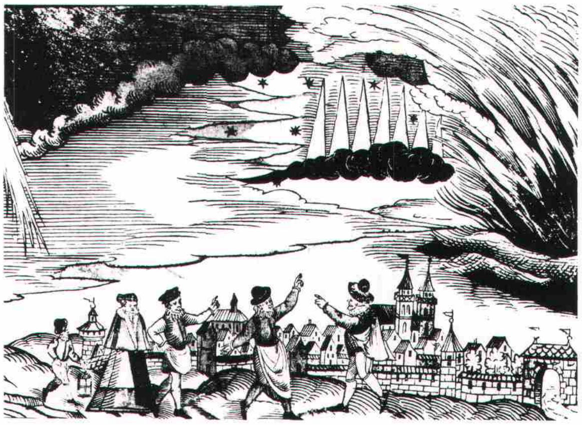
## FOREWORD

For the last several years the Space Science Board (SSB) has been developing strategies for guiding future research programs in the various scientific disciplines involved in space research. This report, however, has a somewhat different character. While it does specify the scientific objectives of the field (thereby updating the previous report, *Solar-System Space Physics in the 1980's: A Research Strategy*, NAS, 1980), it goes further and describes the plan for implementing the objectives. In this sense, the report more closely follows the methodology of two recent reports that have received wide acclaim for establishing priorities in related fields of research—*Astronomy and Astrophysics for the 1980's* (NAS, 1982) and *Planetary Exploration Through Year 2000* (NASA, 1983).

The SSB adopted this different approach for this report for two reasons. First, with the appearance of the astronomy and planetary priorities reports, a need was established to do something similar in solar and space physics. Secondly, with NASA currently involved in preparing a priorities report for the Earth sciences, it was decided that the SSB could provide a valuable service for this broad-based effort by undertaking a part of the subject matter for which the Board was admirably suited through the Committee on Solar and Space Physics (CSSP). NASA concurred in this decision.

Thus, in November 1983, the Board directed the CSSP to develop a priorities-based study of solar and space physics, using the 1980 research strategy as a basis. The Committee produced the following report, which was reviewed and approved by the Board in November 1984.

Thomas M. Donahue
Chairman, Space Science Board



The spectacular displays of light in the polar skies, known as the aurora, predate recorded history. Scholars claim references to the aurora in the Old Testament, in writings of Greek philosophers including Aristotle's *Meteorologica*, and possibly in ancient Chinese writings before 2000 BC. The picture above shows multiple rayed auroral bands near Fairbanks, Alaska.

It has been suggested that the earliest records of the aurora might be found in the serpentine meanders of Stone Age man. The figure at left shows a representation of the aurora borealis seen in Nürnberg, Germany, on October 5, 1591. This early "model" of the aurora suggests an explanation in terms of heavenly fires.

## PREFACE

In carrying out the charge of the Space Science Board, the Committee on Solar and Space Physics (CSSP) proceeded by organizing three separate panels: solar and heliospheric physics, under George L. Withbroe; magnetospheric plasma physics, under Robert W. Fredricks; and upper atmosphere physics, under Darrell F. Strobel. Each panel was asked to solicit inputs from the scientific community in each discipline area on what constitutes the highest priority science and the optimum means for carrying it out.

The resulting sets of science objectives and programmatic priorities, along with estimated costs, were organized on a timeline from FY 1986 through the year 2000 by each panel. The full committee examined critically the work of the panels and, after several iterations, a composite Implementation Plan was agreed upon. This preliminary plan was presented by committee members to several scientific groups beginning in the spring of 1984; during these sessions comments and suggestions were solicited. The inputs thus received were considered by the committee, and a draft version of the report was circulated to over 70 colleagues representing most institutions active in the field of solar and space physics. Comments and suggestions were received from about half, and the committee redrafted the document in October of 1984 for presentation to the SSB's November meeting for approval. This extensive interaction with the community has produced a prioritized Implementation Plan that is supported by most members of the scientific disciplines involved.

Our report is published in two parts: the Executive Summary and the main body.

The Executive Summary presents the prioritized program, summaries of the scientific objectives and recommended missions, near-term budget decisions, and connections to basic physics, astrophysics, and Earth system studies. This part is intended to quickly familiarize the reader with the substance of the science being addressed and the essential conclusions and recommendations of this study. Although it can stand alone, it should be read in conjunction with the main body.

The main body of the report describes the detailed science objectives for future research, the most significant accomplishments of past research, the way in which the Implementation Plan was constructed, the detailed mission plans of each of the major subdisciplines of solar and space physics research, and some additional thoughts on the general health and conduct of our science.

An undertaking of this magnitude required the assistance of many individuals and institutions, too numerous to mention. We owe special thanks to the Marshall Space Flight Center for hosting one of our meetings, to the Goddard Space Flight Center and the Jet Propulsion Laboratory for assistance on cost estimates for some projects, and, most importantly, to NASA Headquarters for providing the background information necessary for putting together the Implementation Plan. We are grateful to Drs. J. D. Bohlin and S. D. Shawhan of NASA who participated in some of our meetings and provided important information whenever needed. Dr. T. M. Donahue, Chairman of the SSB, gave us important guidance in the formulation of this plan. Many of our colleagues commented on several drafts of this document. We are especially grateful to Dr. D. J. Williams for assistance in the selection and placing of figures included in this report. Finally, we are grateful to our Executive Secretary, Dr. Richard C. Hart, whose untiring efforts and advice were invaluable to the completion of this report.

The work of Mrs. C. Chamberlain and Mrs. P. Johnson in typing the innumerable drafts of this report are most appreciated. Mrs. Angelika Peck did the design and art layout of the Executive Summary.

S. M. Krimigis, Chairman
Committee on Solar and Space Physics

THE SUN FINAL

1ST U. S. SATELLITE LAUNCHED, ORBITS IN SPACE WITH SPUTNIK

DEFENSE NO VOTE ISSUE, NIXON SAYS

He Tells Republicans

PROBERS LINK HEAD OF UNION TO MOBSTERS

Also Report Maloney Received 5 Cadillacs From Labor Units

NEW MOON IS LOFTED TO SKY-RIDING PATH BY JUPITER-C MISSILE

Latest Space Explorer Soars To 2,000 Miles At Farthest Point And 230 At Nearest—Attains Speed Of 19,400 Miles An Hour

IKE INFORMED OF SATELLITE

Satellites Reveal Intense Radiation High Above Earth

Unidentified radiation so intense as to overwhelm cosmic ray counters aboard Explorers I and III was revealed today at a special joint meeting of the National Academy of Sciences and the American Physical society in Washington.

In the satellites' reports from the far reaches of their orbits — beyond 1,000 miles out — counts of particle pulses per second soared to rates hundreds of times greater than had been expected, University of Iowa Physicist James A. Van Allen reported.

Professor Van Allen, head of the S.U.I. physics department and chairman of the national working group on internal instrumentation for the U.S. satellite program for International Geophysical Year. His report, "Observation of High Intensity Radiation by Satellites 1958 Alpha and Gamma," was the work of four university physicists — Van Allen, George H. Ludwig, E. C. Ray and C. E. McIlwain.

Intense Radiation Belt Found in Space

U.S. Satellites Detect Barrier to Flights 600 Miles Up

By JOHN W. FINNEY

Special to The New York Times

WASHINGTON, May 1—United States satellites have detected a mysterious band of extremely intense radiation some 600 miles in space.

performed by the Soviet Union's two satellites.

The findings of the Soviet satellites seem closely to the sions drawn States satellit gram, such as expected te density in sp new in the S the effect of lessness on an ment not yet United States. The second

SCIENCE NOTES

Intense Radiation Is Reported by Explorer Satellites

DATA FROM SPACE—

Explorers I and III have sent down messages from outer space the existence out there of d radiations so intense whelm cosmic ray count. Preliminary reports on sterious powerful radiae presented last week at meeting at the National of Sciences by Dr. James Allen, Dr. G. H. Ludwig, Ray, and Dr. C. E. Mciversity of Iowa physican altitude of 1,000 miles, particle pulses per second, Allen reported, soared to sands of time greater than xpected. While cosmic ray Explorer I ran about 30 second some 200 to 300 e southern California obations, the counts climbed han 35,000 per second at t altitude of both satelthese were above South nd adjoining waters, he In fact, he added, the became so intense that at ammed the Geiger tube did not put out any counts "it took some detective nd out what was going these tremendously high rates are produced by at may be produced by from the sun, the rates

**The launch of Explorer I on January 31, 1958, began the era of space exploration for the United States. Data from this satellite and from Explorer III led James A. Van Allen and his colleagues to the discovery of the Earth's Van Allen Belts, the penetrating radiation belts encircling the Earth like giant donuts, as depicted in this early sketch (inset). Announcement of the discovery produced newspaper headlines throughout the United States and the world.**

# OVERVIEW

## Some Early History

Space physics as an identifiable discipline began with the launch of the first Earth satellites in the late 1950's and the discovery in 1958 of the Van Allen radiation belts. During the decade of the 1960's, most of NASA's space science program consisted primarily of investigations in solar and space plasma physics with the launch of such spacecraft as the Orbiting Geophysical Observatories (OGO), the Orbiting Solar Observatories (OSO), and a number of Explorer missions that were used to explore, investigate, and study in some detail the near-Earth and near-interplanetary space environment. Discoveries during these years revolutionized our view of the Earth's environment beyond 100 km altitude, including (in addition to the radiation belts): the identification of a collisionless shock on the Earth's sunward side, the Earth's magnetic tail, the connection between the trapped radiation and the energy deposited over the Earth's polar caps, the observation of electric currents flowing along magnetic field lines, and the intimate connection between the flowing solar wind and the dynamical phenomena observed within the Earth's magnetosphere. Interpretation of these observations provided breakthroughs in our understanding of the physics of collisionless shocks and of new mechanisms of particle acceleration including shock acceleration, magnetic reconnection, and double layers.

The solar wind is now known to retain structure at 1 AU imposed by activity occurring in the solar chromosphere and the corona, including transient mass ejections from the corona, x-ray emitting magnetic loops associated with flares at temperatures of hundreds of millions of degrees, and recurrent high-speed solar wind streams associated with coronal holes. These discoveries served to highlight the solar-terrestrial and solar-planetary interaction chain which begins at the Sun and extends through the interplanetary medium to the magnetospheres and the upper atmospheres of the Earth and the planets. We now know that this linkage causes significant changes in the ion and neutral composition, photochemistry, and dynamics of the thermosphere in response to solar and geomagnetic activity. In the polar thermosphere, we discovered that nitric oxide (NO) can be produced by solar proton events and aurorae, with subsequent transport to the mesosphere and probably to the stratosphere, where it can affect ozone concentrations.

During the early and mid-1970's NASA sought advice from the Space Science Board (SSB) on how and in what direction this newly established field of science would produce substantial additional scientific progress. In other words, as the preliminary phase of phenomenological research was transforming the discipline into a quantitative science, what were the prospects that additional missions of increasing sophistication would produce understanding of fundamental plasma physics processes? The answer was provided by the Academy's "Colgate Committee" (*Space Plasma Physics: The Study of Solar-System Plasmas*, NAS, 1978) in the first-ever peer review by outside scientists of a NASA science discipline. The review committee concluded that continued study of solar system plasma physics* should be pursued

**"as an important branch of science, concerned with problems of true intellectual significance that may be studied effectively in space and whose importance extends to laboratory physics as well as large-scale astrophysics."**

That report also recommended that the SSB's Committee on Solar and Space Physics (CSSP) undertake the definition of a research strategy for implementation of

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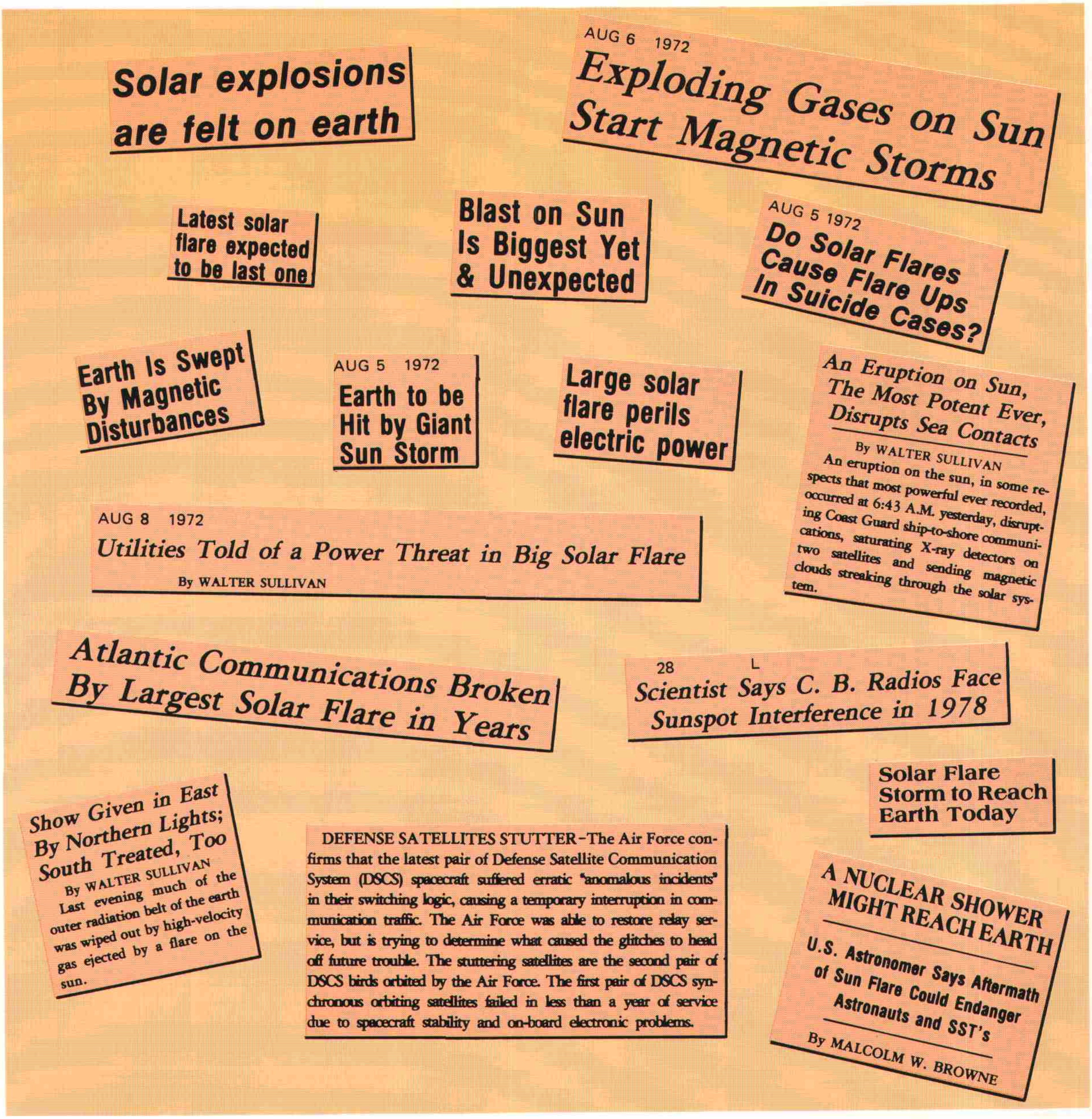
*The term "solar-system plasma physics" includes solar and heliosphere physics; and magnetospheres, ionospheres, and upper atmospheres of the Earth and planets.



Solar explosions
are felt on earth

AUG 6 1972

Exploding Gases on Sun
Start Magnetic Storms

Latest solar
flare expected
to be last one

Blast on Sun
Is Biggest Yet
& Unexpected

AUG 5 1972

Do Solar Flares
Cause Flare Ups
In Suicide Cases?

Earth Is Swept
By Magnetic
Disturbances

AUG 5 1972

Earth to be
Hit by Giant
Sun Storm

Large solar
flare perils
electric power

An Eruption on Sun,
The Most Potent Ever,
Disrupts Sea Contacts

By WALTER SULLIVAN

An eruption on the sun, in some respects that most powerful ever recorded, occurred at 6:43 A.M. yesterday, disrupting Coast Guard ship-to-shore communications, saturating X-ray detectors on two satellites and sending magnetic clouds streaking through the solar system.

AUG 8 1972

Utilities Told of a Power Threat in Big Solar Flare

By WALTER SULLIVAN

Atlantic Communications Broken
By Largest Solar Flare in Years

28 L

Scientist Says C. B. Radios Face
Sunspot Interference in 1978

Solar Flare
Storm to Reach
Earth Today

Show Given in East
By Northern Lights;
South Treated, Too

By WALTER SULLIVAN

Last evening much of the outer radiation belt of the earth was wiped out by high-velocity gas ejected by a flare on the sun.

DEFENSE SATELLITES STUTTER–The Air Force confirms that the latest pair of Defense Satellite Communication System (DSCS) spacecraft suffered erratic "anomalous incidents" in their switching logic, causing a temporary interruption in communication traffic. The Air Force was able to restore relay service, but is trying to determine what caused the glitches to head off future trouble. The stuttering satellites are the second pair of DSCS birds orbited by the Air Force. The first pair of DSCS synchronous orbiting satellites failed in less than a year of service due to spacecraft stability and on-board electronic problems.

A NUCLEAR SHOWER
MIGHT REACH EARTH

U.S. Astronomer Says Aftermath
of Sun Flare Could Endanger
Astronauts and SST's

By MALCOLM W. BROWNE

**Solar eruptions, magnetic storms, and auroral displays affect many facets of our everyday existence. Newspapers and magazines take note of such activities (above). These phenomena can affect communications, operational satellite systems, power distribution grids, and other essential services. It is now recognized that knowledge of "Space Weather" may become as essential to our complex technological systems as Earth weather is to our everyday activities.**

the discipline's science objectives during the 1980's. Such a strategy was issued by the Board in 1980 (*Solar System Space Physics in the 1980's: A Research Strategy*, NAS, 1980) and is known as the Kennel Report.

## Goals and Connections

The basic goals of solar system space research can be stated as follows:

**(1) To understand the physics of the Sun; the heliosphere; and the magnetospheres, ionospheres, and upper atmospheres of the Earth, other planets, and comets.**

**(2) To study the interactive processes that generate solar variations and link these to the Earth, because such processes reveal basic physical mechanisms and have useful applications in many areas of human endeavor.**

It is essential to recognize the enduring nature of these research goals that, in turn, dictate a commitment to long-term funding, as this report suggests. First, there are the basic physics/astrophysics connections: because of its proximity, the Sun is the only star whose interior structure and atmospheric physics can be studied at high resolution, thereby providing unique information about physical processes important to all stars. Very soon, it will be possible to make the first in-situ measurement of the stellar corona. Magnetospheres, the magnetized plasma atmospheres of the Earth and planets, are now known to exist around pulsars, radio galaxies, and accretion stars, among others. The study of plasma processes regulating the structure and dynamics of the planets' magnetospheres has contributed significantly to the development of basic plasma physics.

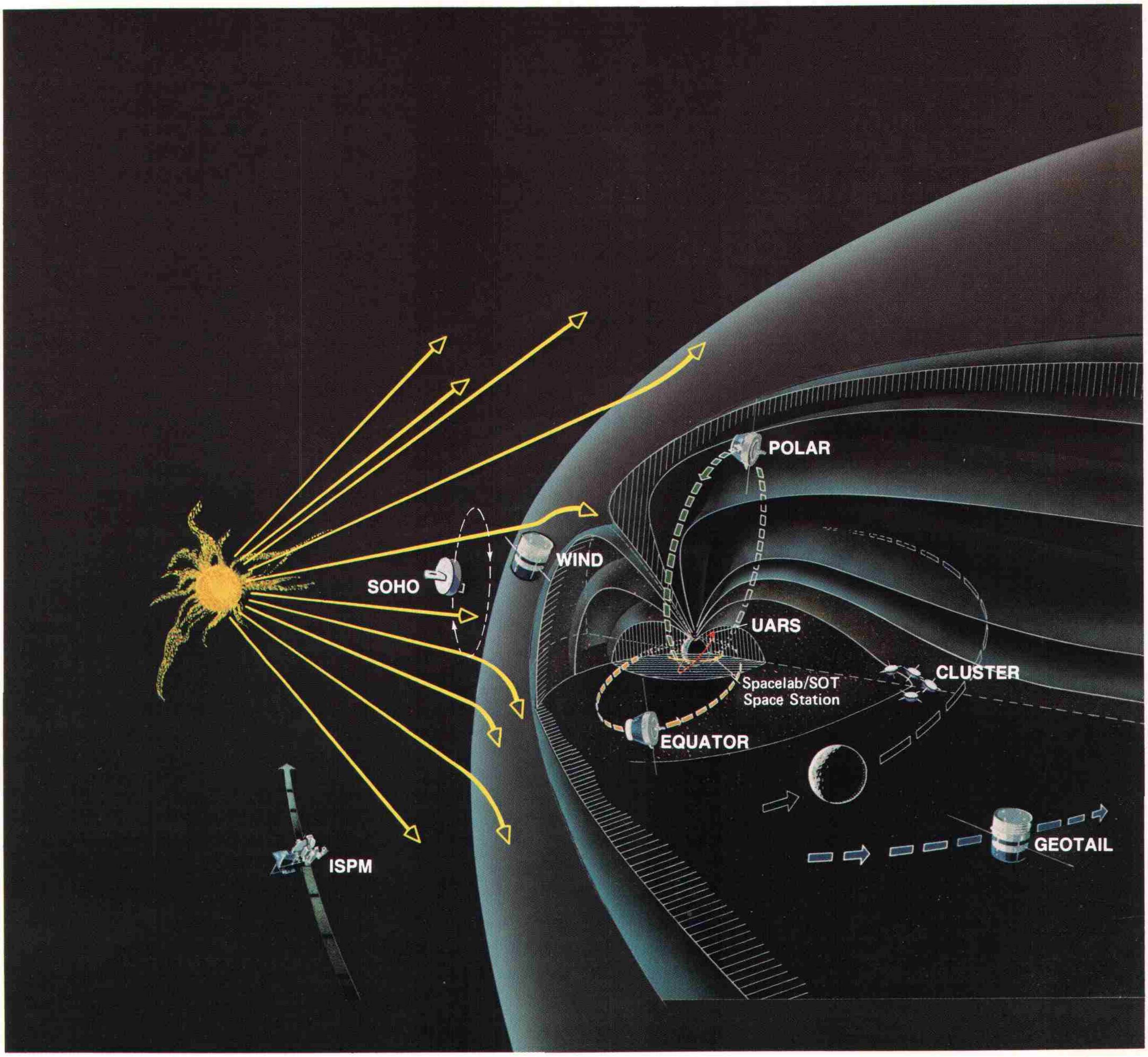
Second, there are important connections between solar and space physics and Earth system studies. Variations in solar luminosity and/or irradiance may well affect the Earth's weather and climate; stratosphere and mesosphere ozone responses to incoming charged particles have been observed and documented; variations in solar output of radiation and particles have substantial effects on the magnetosphere, ionosphere, and upper atmosphere.

Finally, the understanding of the near-Earth space environment is not only a basic research enterprise, but also has extremely important practical aspects. Space is being used increasingly for many different scientific, commercial, and national security purposes. Well known examples include communications and surveillance satellites and such scientific platforms as the Space Telescope and the Space Station. These space vehicles must function continuously in the near-Earth environment, subject to the dynamic variations of the Sun, the magnetosphere, and the upper atmosphere. In addition to the effects of the dynamics on the electronic and power systems of spacecraft, these aspects of the near-Earth environment become particularly important in view of the planned long-term presence of man in space. The complement of programs outlined in this report will allow us to model the global geospace environment and will thus allow us to develop a global *predictive* capability. This, in turn, should permit substantial improvements in our abilities to operate all space-based systems in the near-Earth region.

## Summary of Recommendations

**Constrained budgets in the early 1980's did not allow significant progress in the implementation of the research strategy contained in the Kennel Report. Thus, our purpose in this report is to update the strategy and design a prioritized *implementation plan* that provides a focus for addressing the highest priority scientific questions identified for this field of research.**

In the process of designing this plan, the CSSP evolved the following guidelines: (1) To advance understanding in each of the domains of solar and space physics (the Sun, heliosphere, magnetospheres, ionospheres, and upper atmospheres) and the chain of interaction among them, a broad scientific attack is necessary. This requires a major thrust in each of the central disciplines (solar and heliospheric



The International Solar-Terrestrial Physics (ISTP) Program is the highest priority new program planned for solar and space plasma physics. Planned jointly by Japan, Europe (European Space Agency), and the U.S., the space segment of the ISTP consists of WIND (U.S.), POLAR (U.S.), EQUATOR (U.S.), and GEOTAIL (Japan) to measure the energy, mass, and momentum flow throughout the earth's magnetosphere; SOHO (Europe) to measure solar oscillations and the energy output of the sun; and CLUSTER (Europe) to measure plasma turbulence over a range of spatial scales in the Earth's magnetospheric system. The Upper Atmosphere Research Satellite (UARS), scheduled to fly concurrently with ISTP, will measure the chemistry and energy input into the atmosphere. Eventually, instrumentation on the Space Station will provide more detailed measurements in the early 1990's.

physics, magnetospheric plasma physics, and upper atmospheric and ionospheric physics). (2) There is a need for major missions for detailed studies on a global scale; moderate missions for specific, detailed problems; quick response techniques and experiments of opportunity (best accommodated by suborbital flights and the Shuttle); and facility-class instruments that will evolve toward space platforms. (3) It is essential to reestablish a level of flight activity necessary to address significant scientific issues. (4) The plan must be accommodated within a realistic budget level that can remain stable over a period of several years and allow the planning and analysis essential to a successful research program.

With these guidelines, the CSSP has developed the following recommendations:

A. Continue implementation of the following programs:

- Upper Atmosphere Research Satellite
- Solar Optical Telescope

B. Begin development of the International Solar Terrestrial Physics program as the highest priority new start.

C. Plan for later major free-flying missions and carry out the technology development they require. These are:

- Solar Probe (target launch date 1995).
- Solar Polar Orbiter (target launch date 2000).

D. Launch an average of one solar-and-space-physics Explorer satellite per year, beginning in the early 1990's.

E. Enhance current Shuttle/Spacelab programs in this discipline, especially in the field of active experiments/space plasma lab type missions, Spacelab/Sunlab instruments, and Spartans that make optimum use of Shuttle capabilities.

F. Develop facility-class instrumentation for first use on the Shuttle and later evolution into a Solar Terrestrial Observatory and an Advanced Solar Observatory on Space Station/Platform and develop mission operations and data analysis plans for these observatories.

G. Augment the solar terrestrial theory program by FY 1990.

H. Support a computer modeling program, including access to supercomputers as recommended by the Academy's Physics Survey Committee report.

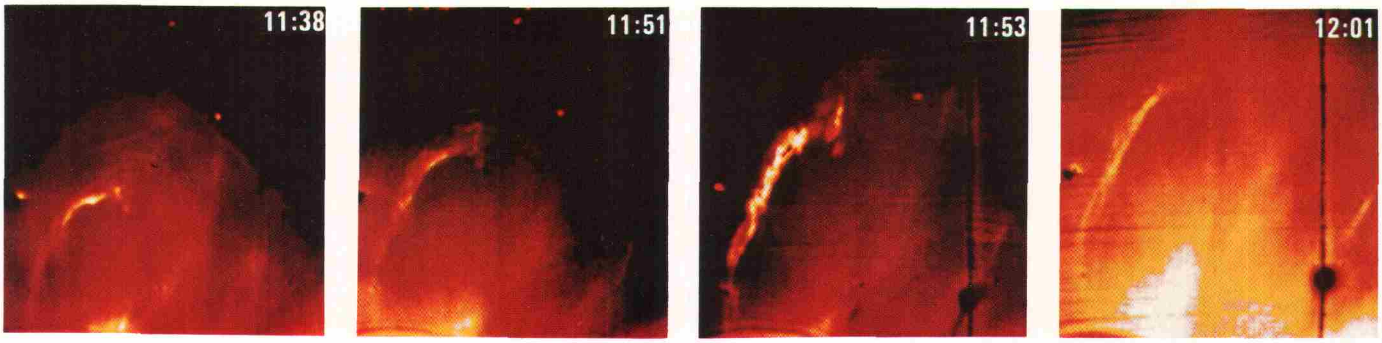
I. Strengthen the research and analysis program.

J. Maintain a stable suborbital program for flexible, quick-turn-around science objectives in upper atmospheric and space plasma physics.

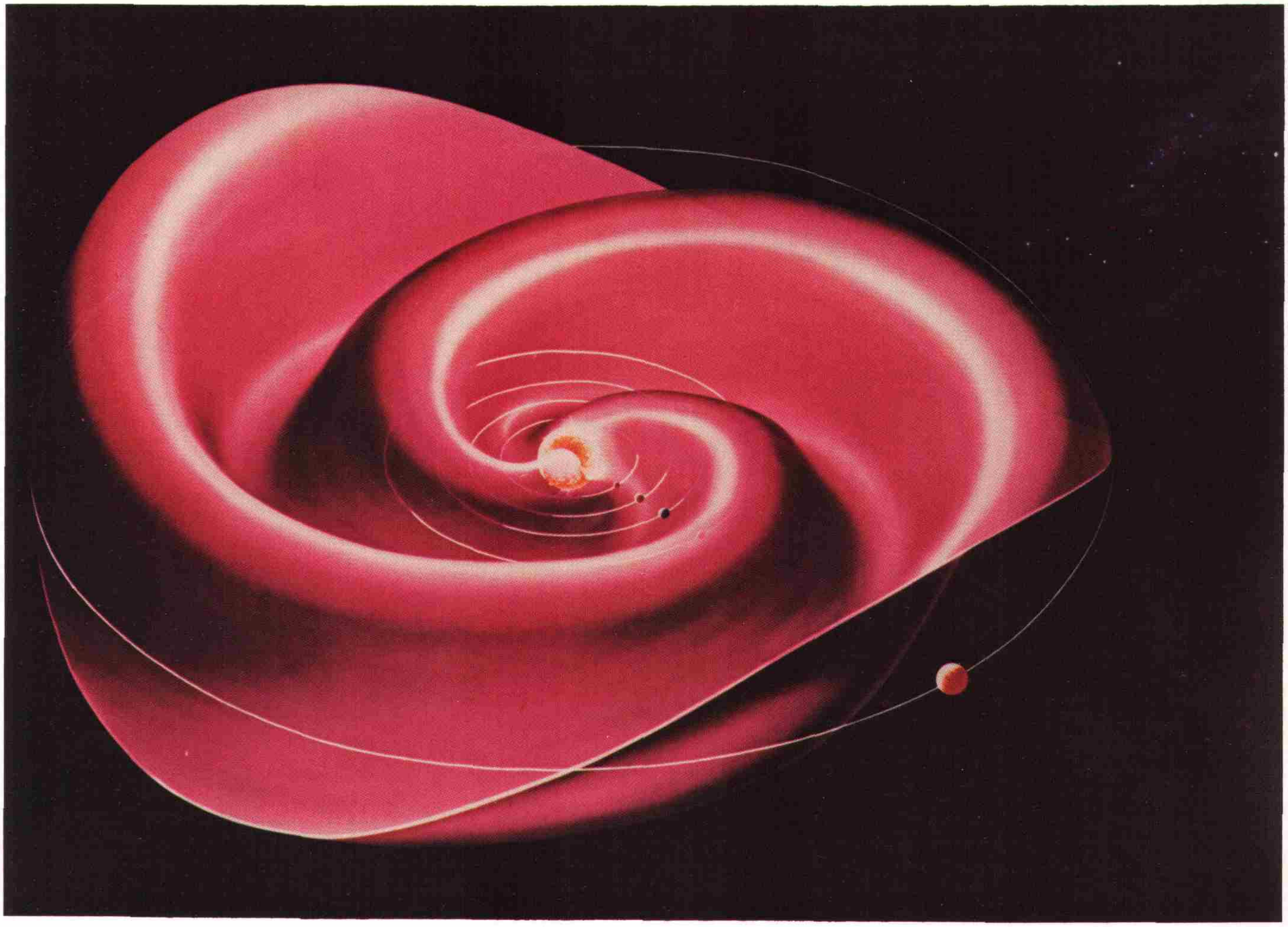
K. Continue mission operations and data analysis funding for existing spacecraft, in particular for studies of the heliosphere (IMP-8, Pioneer 10 and 11, Voyager 1 and 2), the terrestrial environment (ISEE 1 and 2, Dynamics Explorer, SME, and AMPTE), and the Sun (SMM).

All of the missions recommended for the 1980's and most of the missions recommended for the 1990's can be implemented with existing spacecraft technology. The exceptions are the requirement for a heat shield for the Solar Probe and advanced propulsion for the Solar Polar Orbiter. We recommend that NASA proceed with these developments to meet planned new-start dates of 1991 and 1997 for the Solar Probe and the Solar Polar Orbiter, respectively.

**The Committee feels that the program outlined above will result in a healthy and vigorous research effort and will allow the United States to maintain its leadership at a time of increased international attention to this area of science. Our national interest will be well served by increasing our efforts to understand our space environment. The program envisioned in this report is scientifically challenging, technologically achievable, and reflects the natural evolution of a scientific field that was the first to be explored when the nation ventured into space. The implementation plan proposes a constant yearly funding level and distributes the new starts over a number of years.**



On May 5, 1980, a telescope on the Solar Maximum Mission obtained this series of four photographs (at times shown in the upper right corner of each panel). The bright knots are cool (8000 degree), dense gas being ejected through the hot (2 million degree), tenuous solar corona. At 12:01, the skein of cool material stretched to about half the sun's diameter of 1.4 million kilometers. About a billion kilograms of matter was ejected into space. Here, the deep red to white color scale indicates relative brightness. In reality, the cool knots are reddish-violet and the surrounding corona is pearly white.



Alfven's "ballerina skirt" model of the heliosphere, that part of our galaxy dominated by the sun and its hot, outflowing gas called the solar wind. This wind, blowing radially outward at speeds of some 1.5 million kilometers per hour, drags along the solar magnetic field into gigantic spirals, as indicated by the artist. The "skirt" represents a sheet of electrical current, with the magnetic field being predominantly positive (negative) above and negative (positive) below, depending on the solar cycle. The orbits of the inner planets and of Jupiter are drawn in. The current sheet can be deformed by shocks emitted following solar flare eruptions on the sun. It is estimated that the boundary of this heliosphere is much beyond the distance of any of the planets, perhaps as far as 100 astronomical units (1 AU equals the distance between the Earth and the sun, about 150 million kilometers).

# SCIENTIFIC OBJECTIVES FOR SOLAR AND SPACE PHYSICS RESEARCH

The scientific content of solar and space physics is broad, involving the Sun, heliosphere, magnetosphere, ionosphere, upper atmosphere) and the complex interactions among them (solar-terrestrial and solar-planetary relations). Review of the current status of the subjects has resulted in a set of scientific objectives that can be summarized as follows:

## A. Solar Physics

To better understand all the processes linking the solar interior to the corona, we need to study the following:

- The Sun's global circulation, how it reflects interior dynamics, is linked to luminosity modifications, and is related to the solar cycle;
- The interactions of solar plasma with strong magnetic fields—active regions, sunspots, and fine-scale magnetic knots—and how solar flare energy is released to the heliosphere;
- The energy sources and composition of the solar atmosphere and corona and the physics of the Sun's large-scale weak magnetic field.

## B. Physics of the Heliosphere

The Sun has the only stellar exosphere where complex phenomena common to all stars can be studied in-situ. Observations of the Sun and heliosphere, the plasma envelope of the Sun extending from the corona to the interstellar medium, provide the basis for interpreting a variety of phenomena ranging from production of x-ray and gamma ray radiation to cyclical activity and long-term evolution. To understand better the transport of energy, momentum, energetic particles, plasma, and magnetic field through interplanetary space, we need to study the following:

- First and foremost, the solar processes that govern the generation, structure, and variability of the solar wind;
- The three-dimensional properties of the solar wind and heliosphere;
- The plasma processes that regulate solar wind flows and accelerate and transport energetic particles throughout the heliosphere.

## C. Magnetospheric Physics

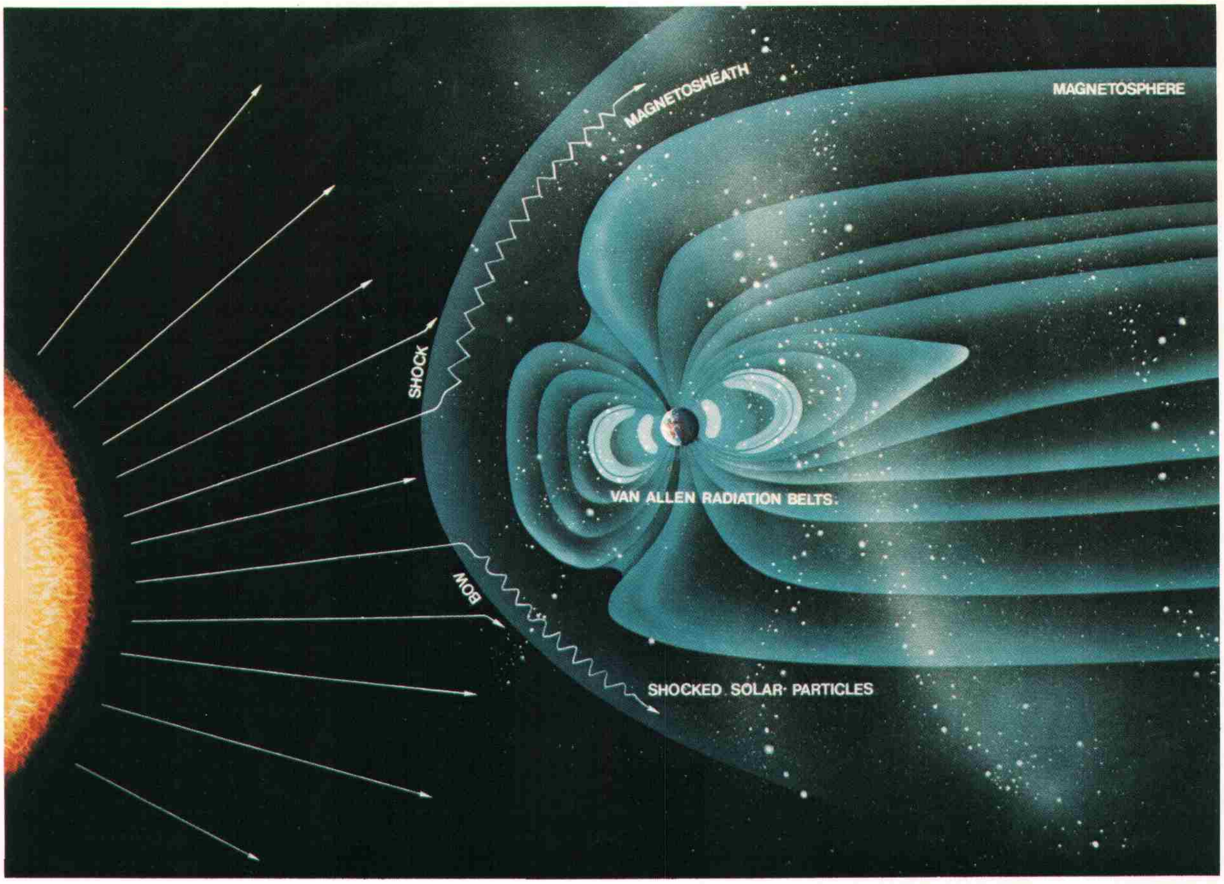
The relationship between energy circulating in the magnetosphere, the energy dissipated in the atmosphere, and the concurrent state of the solar wind is not well understood and has not been unambiguously quantified. To understand the time-dependent interaction between the solar wind and Earth, we need to study the following:

- The transport of energy, momentum, plasma, and magnetic and electric fields across the magnetopause, through the magnetosphere and ionosphere, and into or out of the upper atmosphere;
- The storage and release of energy in the Earth's magnetic tail;
- The origin and fate of the plasmas within the magnetosphere;
- The physical processes that control interactions of the Earth's magnetosphere, ionosphere, and atmosphere.

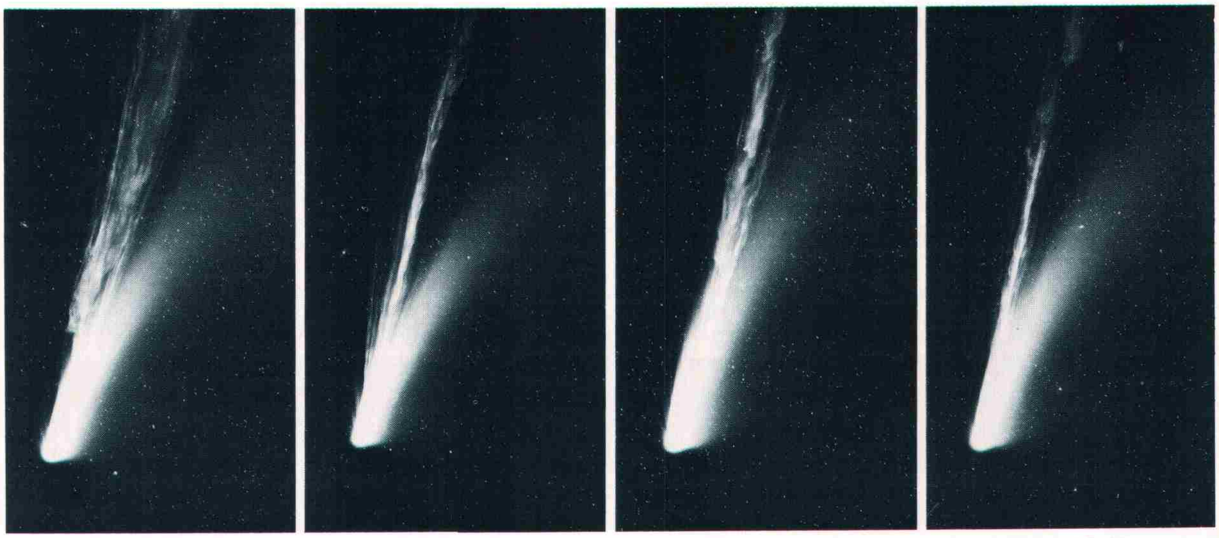
## D. Upper Atmosphere Physics

The Earth's upper atmosphere has traditionally been divided into the stratosphere, mesosphere, thermosphere (and ionosphere), and exosphere, in order of increasing altitude. Present understanding makes it clear that these regions and their chemistry, dynamics, and transport are coupled. To understand more fully the entire upper atmosphere and its relationship to the Sun and magnetosphere, we should study the following:

- The radiant energy balance, chemistry, and dynamics of the mesosphere and stratosphere and their interactions with atmospheric regions above and below;



**A schematic of the Earth's magnetosphere as formed by the interaction of the radially outflowing solar wind plasma (arrows) with the Earth's intrinsic dipole magnetic field. This interaction produces a bow shock, a region of shocked and thermalized solar wind (magnetosheath) and a structure greatly elongated in the antisolar direction containing the intrinsic magnetic field of the Earth and a variety of energized particle populations (e.g., the Van Allen radiation belts) that are produced in not yet fully understood ways by the initial interaction process.**



AUGUST 22 AUGUST 24 AUGUST 26 AUGUST 27

1957

**This series of photographs of Comet Mrkos shows a well-known feature of many comets: a broad, diffuse tail due to solar radiation pressure, and a long, straight tail consisting of ions and due to the solar wind. It was this tail that caused L. Bierman in 1950 to suggest that it could only be explained by a constant outflow of particles from the sun, the solar wind. Note that the ion tail seems to be disrupted from time to time, due to the interactions between the cometary and solar wind plasmas.**

- The global effects of the magnetosphere's interaction with the polar thermosphere and mesosphere and the role of electric fields in the Earth's atmosphere and space environment;
- The effects of variable photon and energetic particle fluxes on the thermosphere and on chemically active minor constituents of the mesosphere and stratosphere.

## E. Solar-Terrestrial Coupling

Solar-terrestrial coupling is concerned with the influence of changes in the Sun on the solar wind, the Earth's magnetosphere, ionosphere, and atmosphere. To understand better this chain of cause and effect, linking solar activity to processes on the Earth, we need to:

- Provide to the extent possible simultaneous measurements on many links of the chain of interactions coupling solar perturbations to their terrestrial response;
- Create and test increasingly comprehensive quantitative models of these processes.

To quantify solar-terrestrial influence on Earth's weather and climate, we need to:

- Determine if variations in solar luminosity and spectral irradiance sufficient to modify weather and climate exist and understand the solar physics that controls these variations;
- Ascertain whether any processes involving solar, heliospheric, and magnetospheric variability can cause measurable changes in the Earth's lower atmosphere.

## F. Comparative Planetary Studies

Comparative studies of the interaction of the solar wind with planets and comets highlight the physics pertinent to each and put solar-terrestrial interactions in a broader scientific context. To understand better the interactions of the solar wind with solar system bodies other than Earth, and from their diversity learn about astrophysical magnetospheres in general, we need to:

- Investigate in-situ Mars' solar wind interaction in order to fill an important gap in comparative magnetosphere and upper-atmosphere studies—previous missions provided little such information;
- Make the first in-situ measurements of the plasmas, electric and magnetic fields, and neutral gases near a comet;
- Increase our understanding of rapidly rotating magnetospheres involving strong atmospheric and satellite interactions;
- Determine the role of atmospheres in substorms and other magnetospheric processes by orbital studies of Mercury—the only known magnetized planet without a significant atmosphere.

The Solar Probe spacecraft is shown at perihelion, at an altitude of three solar radii or about 2.1 million kilometers above the sun's surface. The shape is dominated by the conical thermal shield that is 4 meters in diameter and 7 meters long. The shadow or umbra cast by the shield is itself conical and contains the spacecraft components. Three rectangular shaped Radio-Isotope Thermonuclear Generators (RTG) are located just below the shield with their radiator wrapped around the upper umbra. Across from the RTG and also wrapped around the umbra is the spacecraft bus containing many of the engineering subsystems. Many of the instruments can be seen mounted on the spinning disc located near the bottom of the umbra. Refractory metal whip antennas are shown outside the umbra and would be used to measure plasma wave phenomena near perihelion.

# MISSIONS IN THE RECOMMENDED PROGRAM

**The diversity of environments represented within the discipline of solar and space physics demands a broad mix of programs to implement the stated science objectives. Major missions are necessary for detailed studies on a global scale, as well as for exploration of previously unexamined regions (e.g., the environment near the sun); moderate missions (Explorer class) are needed to attack specific detailed problems; facility-class instruments that are developed for high-resolution measurements on Shuttle but which will evolve towards space platforms that will become part of the Space Station concept and finally balloons, rockets, and experiments of opportunity on shuttle are necessary for quick response techniques. The missions identified below have been selected on the basis of the priority of the science questions which can be addressed, technological readiness, programmatic feasibility, and, above all, the necessity to fit within an overall budgetary level for the entire discipline.**

## Major Missions

### Approved Programs

- Upper Atmosphere Research Satellite (UARS)
- Solar Optical Telescope (SOT)

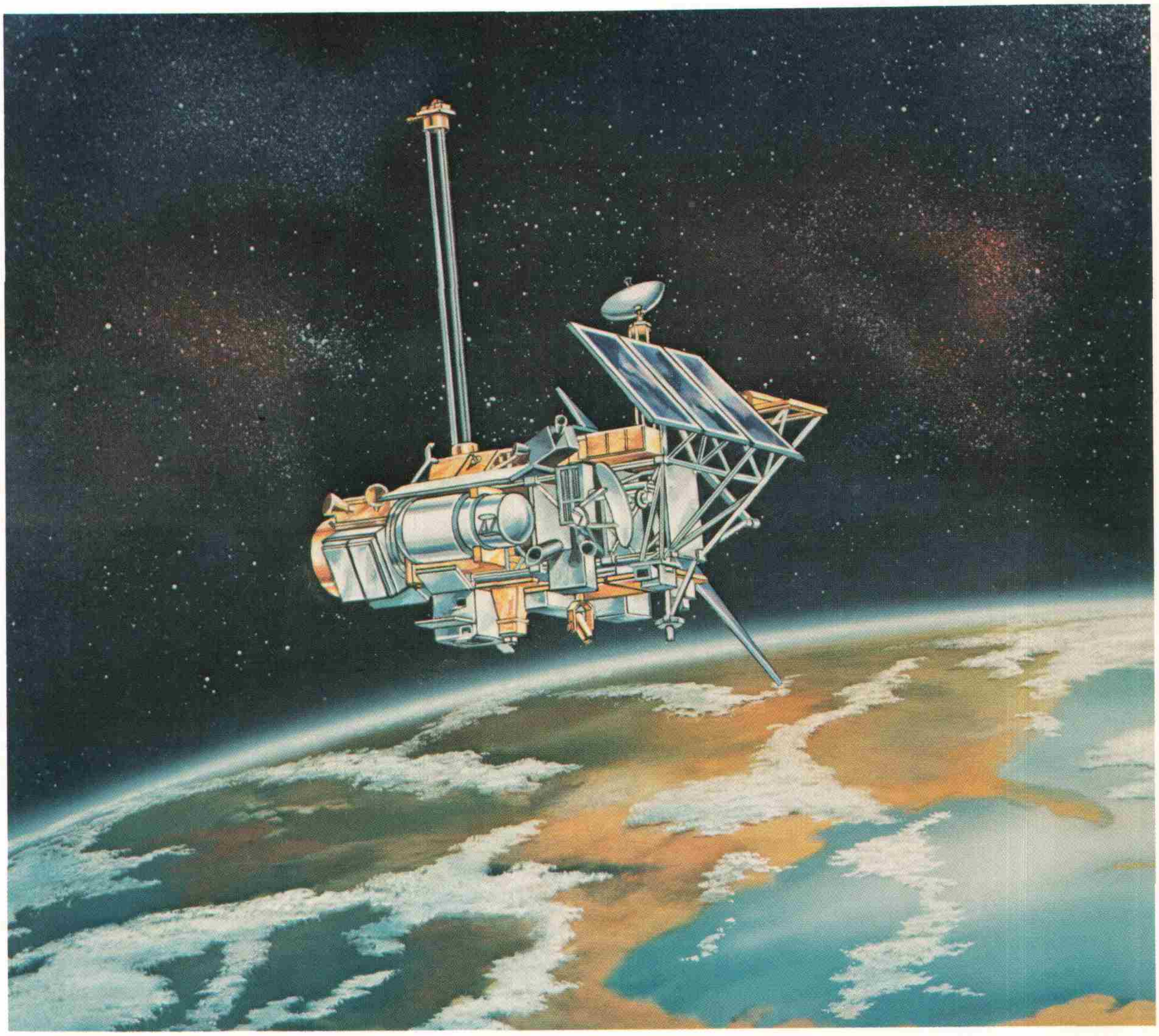
### Free Flyers

- International Solar Terrestrial Physics Program (ISTP)
- Solar Probe (SP)
- Solar Polar Orbiter (SPO)

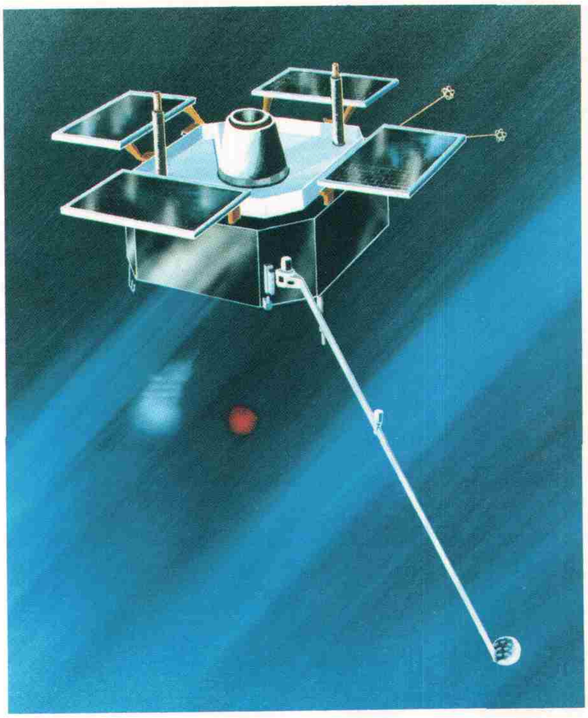
First on our list of missions is the *Upper Atmosphere Research Satellite* (UARS), now a new start in FY 1985. The UARS spacecraft will provide for the first time an almost global data set on the chemistry, dynamics, and energy inputs and losses in the 10-70 km region of the atmosphere, i.e., the stratosphere and lower mesosphere. The goals of the UARS program are to understand processes that control the structure of this region of the atmosphere and its response to natural and human perturbations. The UARS data will help define the role of the upper atmosphere in climate variability. The UARS spacecraft can be retrieved by the Shuttle and is designed to be refurbished.

The *Solar Optical Telescope* (SOT) consists of a 1.25 m aperture telescope, with 0.1 arc sec resolution, that will provide sufficient resolution to observe levels in the solar atmosphere ranging from the photosphere to the transition region. The critical problems to be studied include plasma-magnetic field interactions related to the solar dynamo and studies of energy transport in the solar atmosphere. SOT, being a facility-class instrument, is expected to form the basis for an Advanced Solar Observatory on a Space Station platform.

The highest priority planned (unfunded) mission is the *International Solar Terrestrial Physics Program* (ISTP). ISTP is being planned together by the U.S., Japan, and ESA as a cooperative effort with launches beginning in 1989 and with operations continuing into the mid-1990's. The program consists of six spacecraft missions of which three are provided by NASA, two by ESA, and one by ISAS (Institute of Space and Astronautical Science), with the data base accessible to all investigator groups. The overall scientific objectives of ISTP are to develop a comprehensive, global understanding of the generation and flow of energy from the Sun, through the interplanetary medium, and into the Earth's space environment, and to define the cause and effect relationships between the physical processes that link different regions of this dynamic environment. ISTP will also provide complementary measurements for several other spacecraft, Shuttle/Spacelab missions, sub-orbital and ground-based investigations that are being conducted in the same time interval.



Examples of "major" and "moderate" mission satellites. (Top) The Upper Atmosphere Research Satellite (UARS) to be launched into a 600 kilometer, 57 degree inclination orbit in October 1989. UARS supports 11 instruments, weighs 5500 kilograms, and requires 1600 watts provided by the 3 by 9.1 meter solar cell array. A 5.5 meter astromast boom is attached to the 9.1 by 4.6 meter main body. (Right) The Charge Composition Explorer (CCE) was launched on 16 August 1984 into 4.8 degree inclination, 8.8 $R_E$ apogee, 1108 kilometer perigee orbit. The CCE supports five instruments, weighs 243 kilograms, and requires 100 watts from its solar panels. A 2.2 meter boom is attached to the 1.4 by 0.4 meter main body.



*Solar Probe* (SP) is a mission to study the unexplored region between 4 and 60 solar radii from the Sun. The basic scientific goal is to explore the solar atmosphere where the solar wind becomes supersonic. The mission should carry a complement of particle and field instruments to measure density, velocity, and composition of the thermal solar wind plasma, as well as the magnetic fields, plasma waves, and energetic particles present in this unexplored region of the heliosphere.

*Solar Polar Orbiter* (SPO) is intended to study the three-dimensional properties of the heliosphere in greater detail than can be achieved with the exploratory ISPM mission. SPO, in a near-circular orbit about the solar poles at heliocentric distance of about 1 AU, will be able to study latitude variations at a fixed distance from the Sun, to distinguish spatial from temporal effects by comparing data from many orbits, and to study the latitude effects of features at different phases of the solar cycle.

## Moderate Missions

In the context of solar and space physics research, "Moderate Missions" have traditionally involved Explorer-class spacecraft. Explorer missions have addressed well-defined scientific problems of high current interest in a timely fashion. Explorers may also be used productively in conjunction with the global programs required by solar and space physics research, as identified in "Major Missions" above. The basic strategy for use of the Explorer program in solar and space physics is contained in a recent NAS report (*A Strategy for the Explorer Program for Solar and Space Physics,* NAS, 1984). That SSB report lists more than ten examples of high-priority scientific missions that merit an average of approximately one Explorer satellite opportunity per year for the foreseeable future.

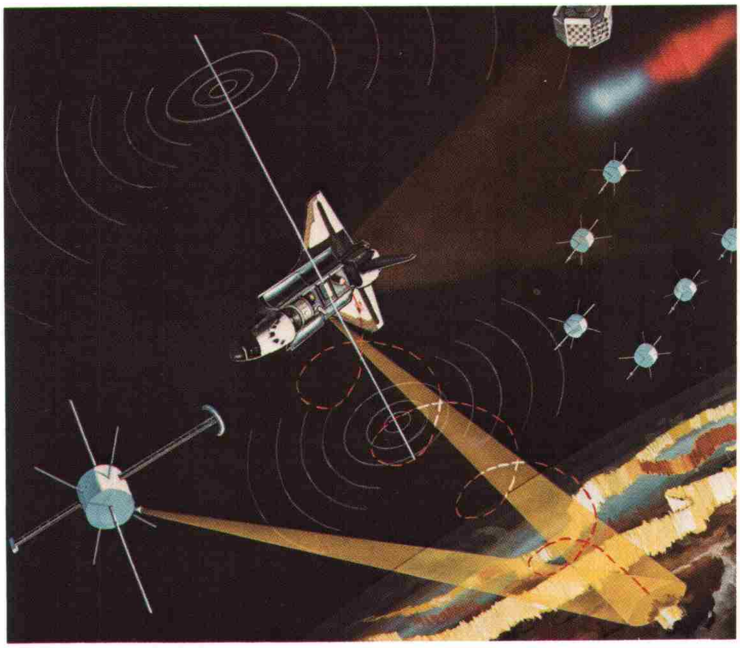
These recommendations have been incorporated in the strategy of this report with a flight frequency of about one launch per year, to be shared as appropriate by solar/heliospheric, magnetospheric, and upper atmosphere disciplines. In order to accomplish this and serve the other science disciplines that utilize Explorers, the present budget of $52 million per year will have to be augmented.

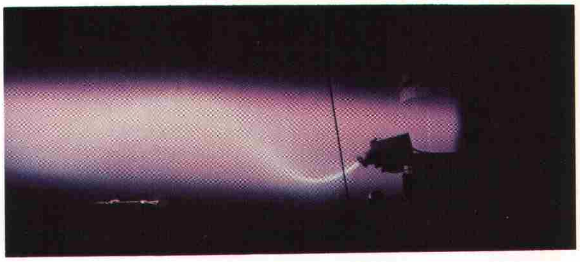
## Spacelab/Space Station Payload Evolution

Initial utilization of the Space Shuttle for solar and space physics investigations through Spacelab 1 and Spacelab 2 is to be followed in the 1986 through 1990 interval by Sunlab, Space Plasma Lab, Tether, and Solar Optical Telescope (SOT). Instruments and investigation techniques developed for these Shuttle missions form the basis for two solar and space physics facilities on the Space Station—the Advanced Solar Observatory (ASO) and the Solar Terrestrial Observatory (STO), both of which have already been studied extensively by NASA.

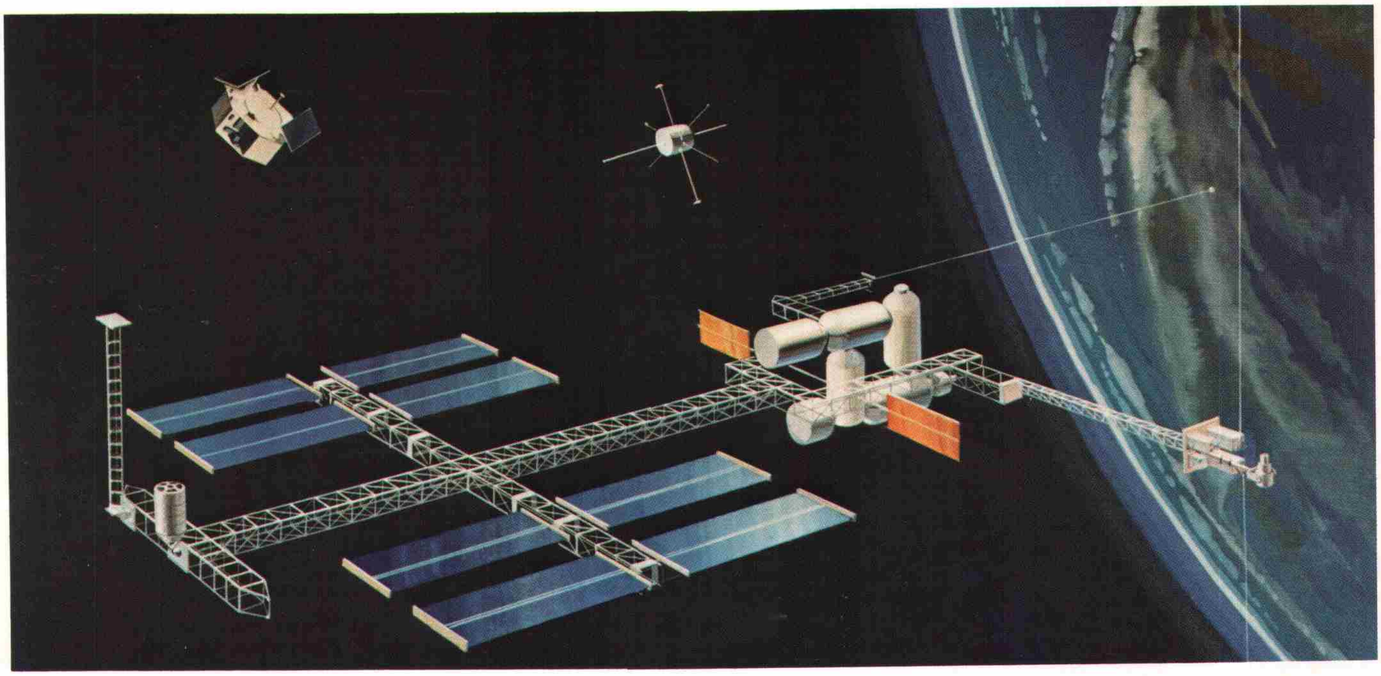
The early Shuttle/Spacelab missions will carry solar instruments to measure the total solar irradiance variation on short and long time scales, and instruments to measure the emission spectra, the magnetic field configuration, and the spatial patterns of solar active regions. Later missions should include instruments in the x-ray and extreme ultraviolet wavelength ranges to examine the range of processes in the sub-arc-second spatial scale and a Pinhole Occulter Facility (POF) so that hard x-rays produced by energetic electrons accelerated in solar flares and coronal transients can be imaged on the sub-arc-second scale and so that the solar corona can be imaged and analyzed over a wide wavelength range.

The early Shuttle/Spacelab space plasma missions have emphasized active space plasma experiments utilizing electron beams, energetic plasma sources, and neutral gas releases. These plasma perturbation techniques and associated diagnostic instruments will become part of the Space Plasma Lab mission that will have, in addition, VLF and HF wave generation systems. The addition of a Tether satellite capability in 1987 will offer the opportunity to excite long-wavelength, low-





Active experimentation in space marks an important departure from the first twenty years of space investigations, where passive observation of the environment was the norm. This artist's concept (left) depicts a laser beam mounted on the Shuttle illuminating a particular region of the atmosphere over the auroral zone and the emission of waves which, in turn, cause electrons to spiral along the magnetic field and deposit their energy in the upper atmosphere. A formation of small plasma probes to the right is performing measurements, while at the upper right chemical releases of barium and lithium are used to study the formation of magnetic field contours and the acceleration of the ions under the influence of local electric fields. Electron beams generated in space can be used to probe natural plasma phenomena in the same manner as beams are used in the laboratory (top) for such studies.



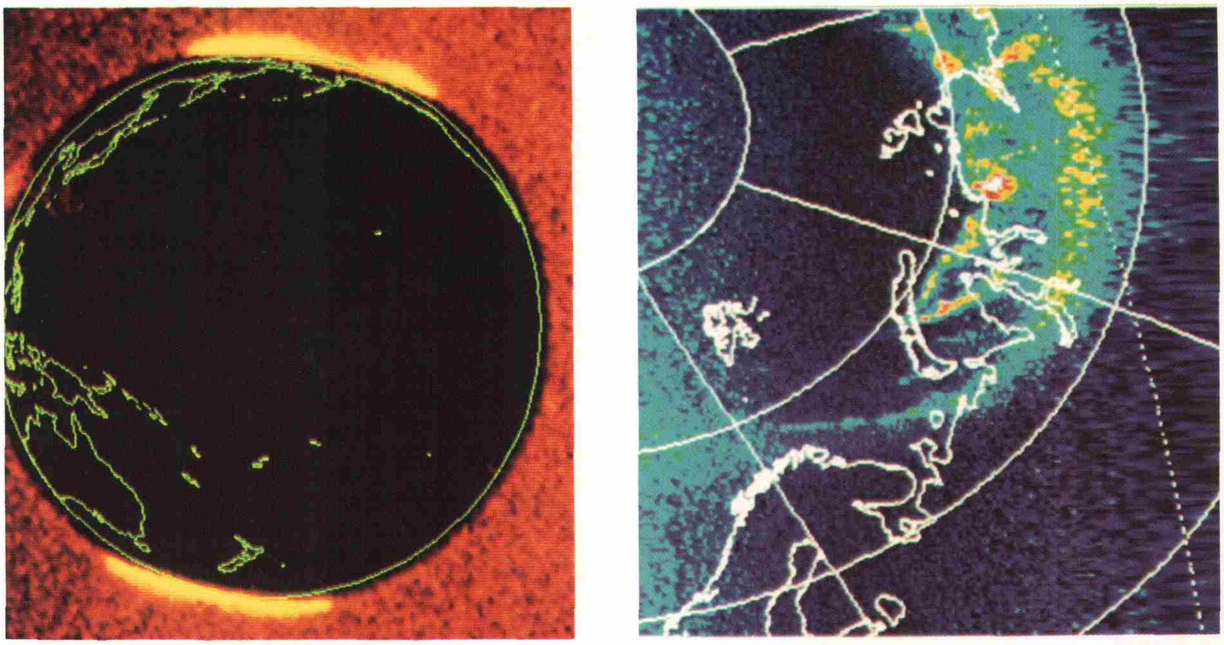
This artist's concept shows the current reference configuration of the manned space station with some of the initial solar terrestrial instruments. Attached to the bottom section of the space station is a boom to deploy a pallet of "active" instruments: the wave injector instrument with the 300 meter tip-to-tip dipole antenna, a plasma accelerator and an electron accelerator, and a low light level imaging system. On the opposite side of the bottom of the space station is a pallet with a long (approx. 30 kilometer) tethered subsatellite deployed to perform electrodynamic experiments. At the top (anti-earth) T structure, two solar instruments are shown attached; the pinhole/occulter facility with the long boom and occulting mask (used for solar hard x-ray imaging and observations of the solar corona) and the solar high resolution telescope cluster (with telescopes covering the optical spectrum, EUV, soft x-ray, and ultraviolet). At the top left is a chemical release subsatellite that will release selected chemicals and gasses in coordination with observational instruments on the space station and on the ground. At the top center is a recoverable subsatellite with numerous diagnostic instruments measuring several plasma parameters.

frequency waves, create a controlled plasma wake, and alter the electrodynamics of the ionospheric medium. With a nonconducting, downward Tether it becomes possible to drag an atmospheric satellite at 130 km altitude—a region previously inaccessible on a global scale.

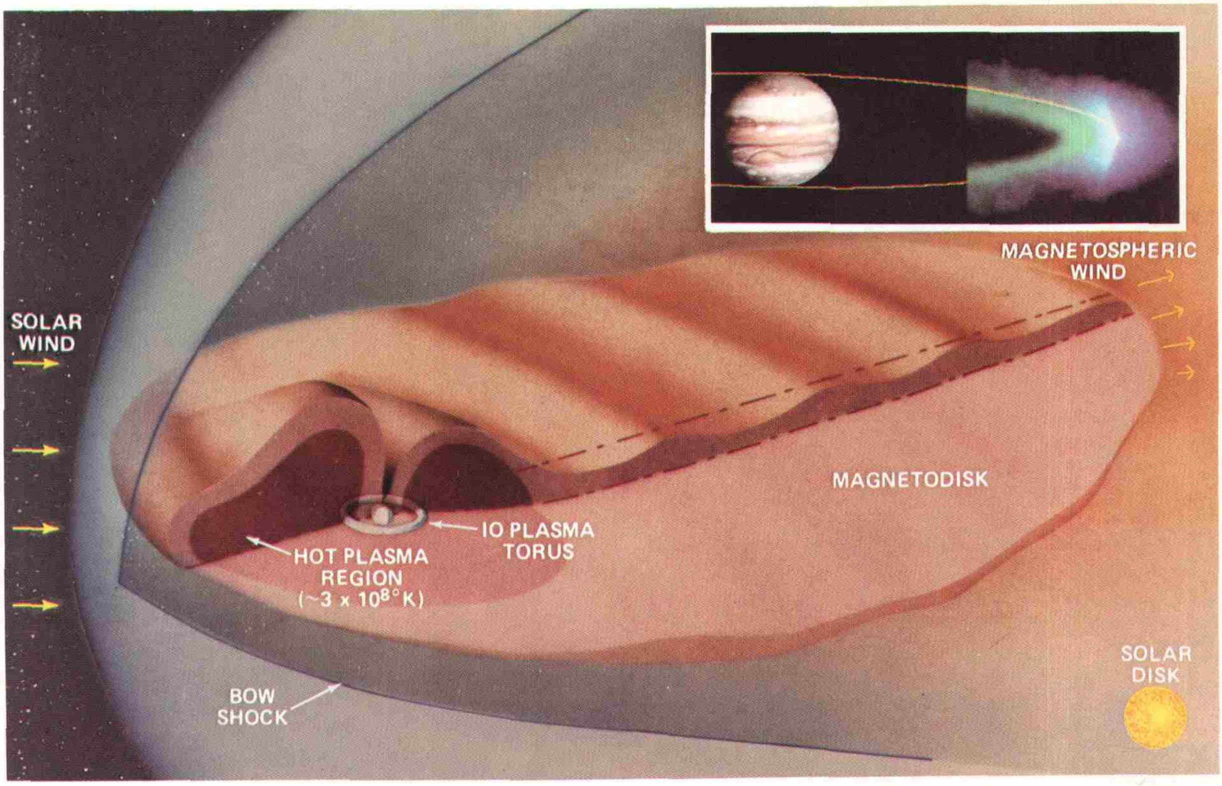
Finally there is a need to obtain extended measurements of the upper atmosphere environment with advanced state-of-the-art instrumentation to obtain global coverage of important free radicals, together with ozone densities and temperatures. The Space Station and/or its platforms may prove to be the best method for remote sensing of the atmosphere in the mid and late 1990's.

Thus, the solar, space plasma, and upper atmosphere facility-class instrumentation developed in the late 1980's and early 1990's should be combined into derivatives and/or combinations of the Advanced Solar Observatory and the Solar Terrestrial Observatory. The nature and scope of ASO and STO should be based upon the results of Shuttle flights of the individual instruments. The establishment of a line item in the budget for the development of such instrumentation beginning in FY 1988 is recommended.

The missions described above, supplemented with a strong sub-orbital program, theory, and computer modeling, adequate mission operations and data analysis funds, and appropriate research and analysis, represent a constrained but adequate program of research between now and the year 2000. It is important to emphasize here that the prime determinant in selecting these missions for implementation was the necessity to keep the program within a tight but stable overall funding profile through the year 2000. Several missions of high science value, and technically feasible within the foreseeable future, have been deferred to implementation beyond this time interval; these include a probe to the heliosphere boundary with the interstellar medium, a sun-synchronous orbiter, measurements with a large number of spacecraft within the magnetosphere to map the structure of its currents, and a Mercury orbiter to study the only planetary magnetosphere in existence in the absence of an atmosphere.



Pictures of the Earth's aurora in visible and ultraviolet light. (Top left), taken "edge-on" with a spacecraft from the nightside of earth, shows the aurora borealis (northern hemisphere) and the aurora australis (southern hemisphere) simultaneously. (Top right), obtained in broad daylight, shows part of an auroral arc over the northern part of the Soviet Union. The aurora is a semi-permanent feature around the Earth's polar caps, becoming more or less intense, depending on solar activity. Up to 100 billion watts of power are dissipated over the polar caps during moderately intense auroral activity.



A schematic view of Jupiter's magnetosphere, the largest planetary envelope in the solar system (the size of a full solar disk is shown for comparison). Volcanic emissions from Io result in formation of a sulfur and oxygen plasma torus (insert) which, in turn, feeds plasma into the entire magnetosphere. The rapid rotation of the planet (about 10 hours) provides the energy that heats some of the plasma to a few hundred million degrees as it tries to rotate with the planet. Eventually this "magnetodisk" is disrupted and hot plasma flows away from the planet at high speeds (about one million kilometers per hour) to form a magnetospheric wind.

# PRIORITIES OF IMPLEMENTATION

**Having agreed on the highest priority science, and having identified the candidate missions, the Committee established the following guidelines in determining priorities for an implementation plan. *First,* that a major thrust in each of the discipline areas (i.e., solar, magnetosphere, upper atmosphere) is essential to maintain progress in the field. *Second,* that an adequate level of flight activity must be maintained throughout the program to assure continuity. *Third,* the long-term funding level must be stable to assure appropriate planning activity and to allow development of instrumentation and advancement of modeling necessary for progress in the field.**

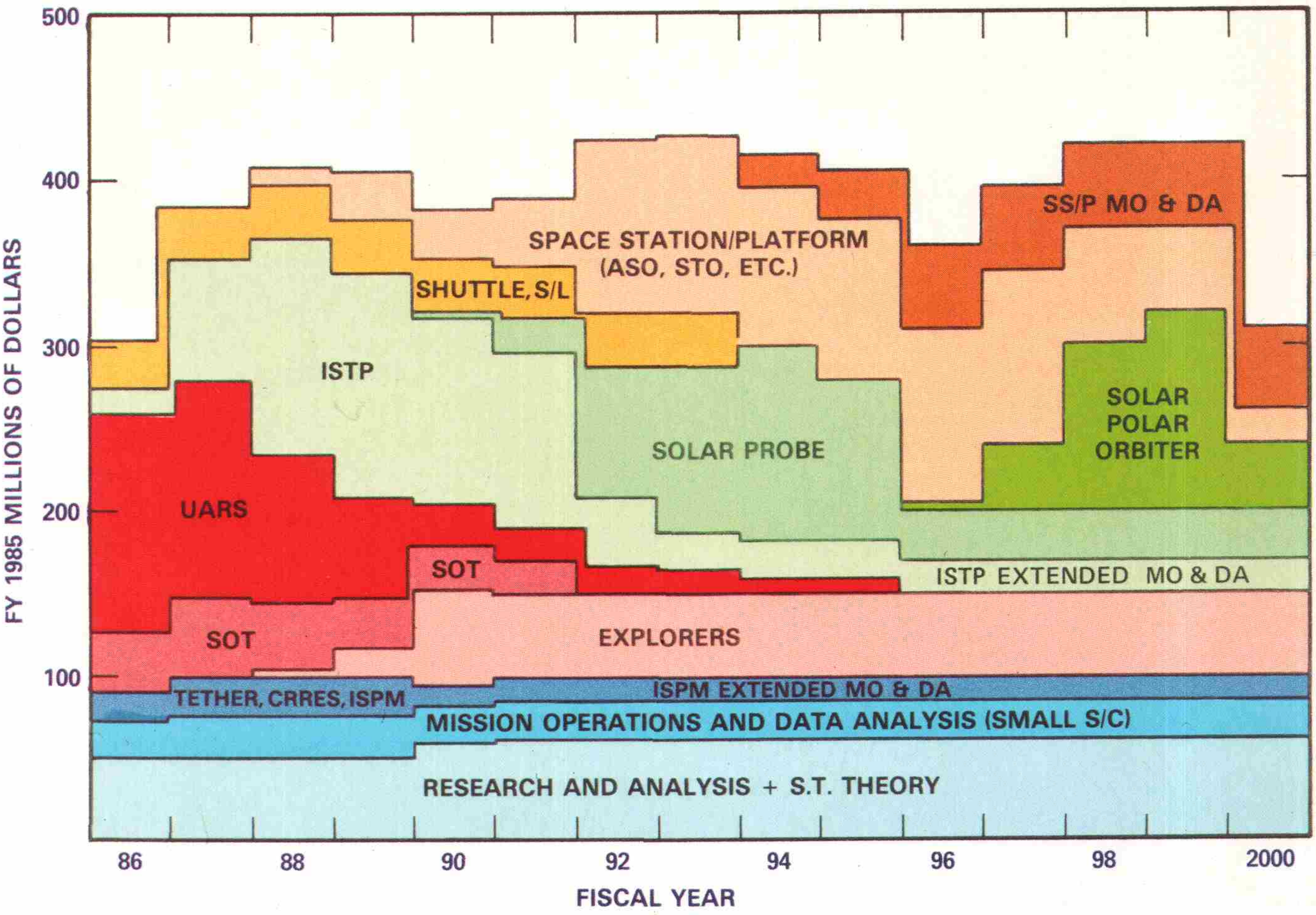
As noted earlier, the major thrust in upper atmosphere research is approved as an FY 1985 new start (UARS), while the major thrust in solar physics (SOT) is scheduled for implementation with significant FY 1985 funding. These two programs, together with research and analysis, mission operations and data analysis, and Shuttle/Spacelab payload activity in this discipline area add up to a budget somewhat more than $300 million (FY 1985 dollars) by fiscal year 1987. The start of the International Solar Terrestrial Physics program and the beginning of a development program for Space Station/platform facility-class instrumentation increase the funding level by approximately 30 percent to $400 million (FY 1985 dollars) by FY 1988. This level is adequate to accomplish the highest priority science objectives in solar and space physics through the end of the century. The overall funding plan for the entire period is depicted in the accompanying figure.

The funding timeline shown in the figure incorporates those programs already approved in FY 1985, anticipates implementation of phase 1 of the ISTP program in the near future, and foresees utilizing Explorer program funding for solar and space physics beginning in FY 1988. In the area of major programs in the longer term, the timeline foresees implementation of the Solar Probe, a mission initially recommended in the late 1970's. Later in the 1990's a Solar Polar Orbiter is included to be launched by the year 2000.

In the area of Space Shuttle instrumentation, the currently planned program (Spacelab 1 and 2, Space Plasma Lab, Earth Observation Missions, Sun Lab) stays at a constant funding level through the early 1990's. In the late 1980's, facility-class instruments are developed which have been studied previously as part of the Solar Terrestrial Observatory (STO) and the Advanced Solar Observatory (ASO). The instruments will eventually be assembled into science platforms that presumably will become part of the Space Station in the mid-1990's. The budget timeline also specifically includes mission operations (MO) and data analysis (DA) funds for the Space Station activity in recognition of the high costs likely to be involved in operating such facilities.

The solar and space physics programs shown in the figure are currently managed by several divisions within NASA, including Astrophysics, Earth Science and Applications, Shuttle Payload Engineering, and Solar System Exploration. The Committee has specifically excluded from these budget projections the significant funds that need to be allocated for experiment payloads on planetary spacecraft that are recommended for studies of the magnetospheres and upper atmospheres of the planets. These funds have traditionally been included as part of the overall budget of planetary missions.

In establishing future program priorities based upon cost and budget projections, there is some risk that the projections are not completely accurate. Such is the case for this report. While we have attempted to obtain the best possible information and



Projected budget in FY 1985 dollars through the year 2000. Blue colors denote the baseline program and missions approved prior to FY 1985; red colors show currently approved programs; green colors are proposed free-flyers; yellowish colors show currently planned Shuttle/Spacelab activity and recommended facility-class instrument development and mission operations into the Space Station era.

program costs, we realize that they are at best only estimates and are likely to change as project definition proceeds. Thus, our approach of establishing temporal priorities is, we believe, still valid because the mission sequences and program emphasis are based on relative costs compared to a reasonable budget allowance.

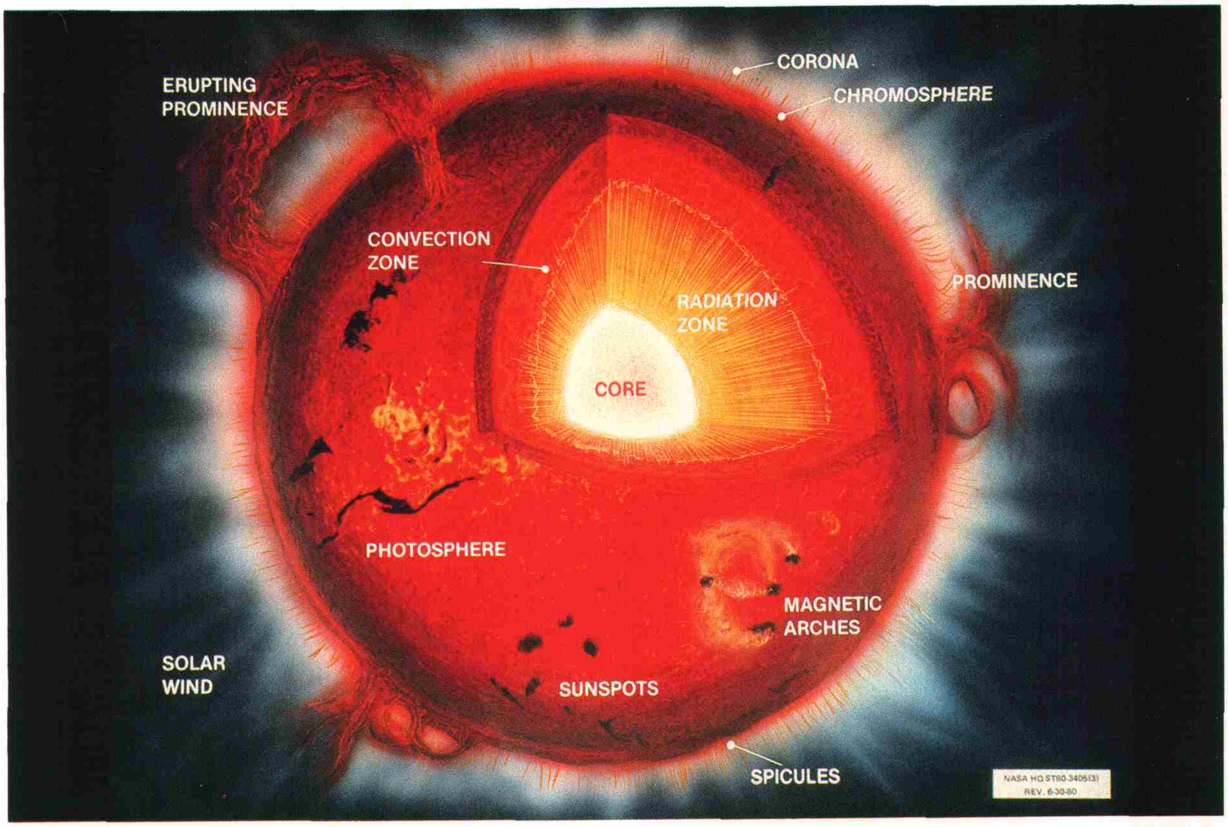
**TABLE**
**TIMETABLE FOR MISSIONS**

| MISSION | LAUNCH | DATA RETURN |
|---|---|---|
| A. Approved Programs | | |
| Upper Atmosphere Research Satellite | 1989 | 1989-1992 |
| Solar Optical Telescope | 1990 | 1990, 91, 92 |
| B. Major Missions/Free Flyers | | |
| International Solar Terrestrial Physics | 1989-1993 | 1989-1996 |
| Solar Probe | 1995 | 1995-2000 |
| Solar Polar Orbiter | 2000 | 2000-2005 |
| C. Moderate Missions | | |
| Explorers (one per year) | 1991-2000 | 1991-2000 |
| D. Shuttle/Space Station | | |
| Continuing Shuttle Program | 1985-1993 | 1985-1993 |
| Solar-Ter. Obs./Adv. Solar Obs. (initial configuration) | 1992 | 1992 |
| Solar-Ter. Obs./Adv. Solar Obs. (final configuration) | 1995 | 1995 |

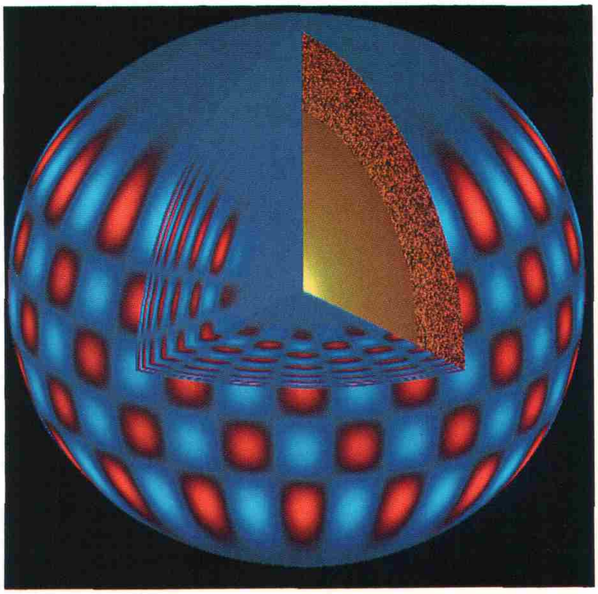
## NEAR-TERM BUDGET DECISIONS

The implementation plan recommended in this report requires the following budget decisions during the next three years:

- Development funding for the Solar Optical Telescope (SOT) must commence immediately (FY 1985).
- Initiation of the International Solar Terrestrial Physics (ISTP) program to allow in-ecliptic measurements during polar passage of the Solar Polar (ISPM) spacecraft in late 1989 is of highest priority.
- Augmentation of research and analysis (R & A) funding in the space plasma physics area is required to address significant scientific problems, reverse a long-term decline, and restore activity to levels of the late 1970's.
- Plans must be made for development of Explorer payloads in this discipline area to permit yearly starts beginning in FY 1988.
- Advanced technology effort must be expended in developing an appropriate thermal shield for the Solar Probe mission.



Solar energy derives from nuclear reactions in a very hot core (about 16 million degrees). This energy is first transmitted through the radiation zone and then the convection zone (outer 200,000 kilometers out of a total solar radius of 700,000 kilometers). The rotation and convection combine to produce dynamo action where electric currents and magnetic fields are generated and change with a 22 year cycle. The magnetic field leads to the formation of sunspots that combine to form active regions together with the surrounding gas. Such regions often explode into solar flares that generate intense local heating and large numbers of energetic particles, and can cause coronal transients which expand into space, envelop the Earth, and generate magnetic storms, including intense auroral displays. Visible solar radiation comes from the thin cool (about 6000 degrees) layer called the photosphere. The chromosphere is somewhat hotter (about 10,000 degrees), while the corona is so hot (about 1 million degrees) that it expands continuously into space.



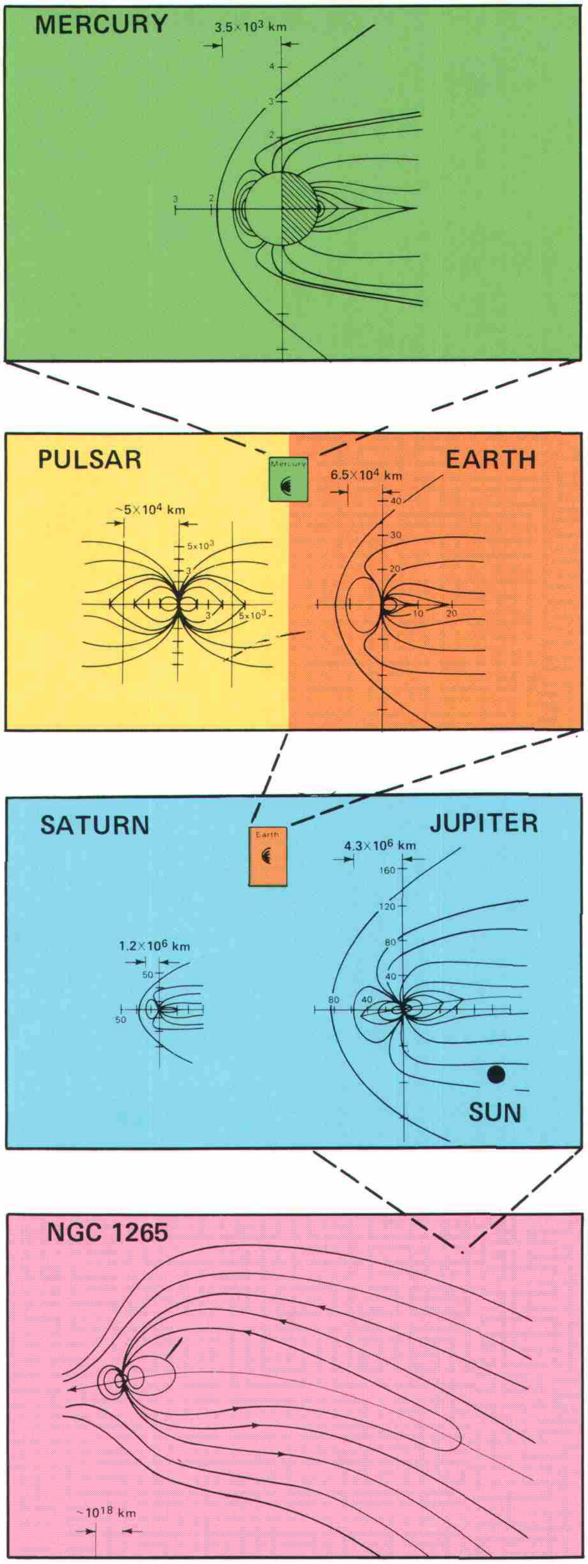
The surface distribution of one of the 10 million modes of solar oscillation. The cutaway shows the distribution of the displacement of material—scaled by the square root of the density—on the equatorial and the left-hand meridional plane, the energy generation (per gram) in the solar core, and the location of the convection zone on the right-hand meridional plane. This mode has a latitudinal order (l) of 20, an azimuthal order (m) of 16, and a radial order (n) of 15. Its frequency is 3 millihertz, that is, a period of 5 minutes.

## ANTICIPATED RESULTS

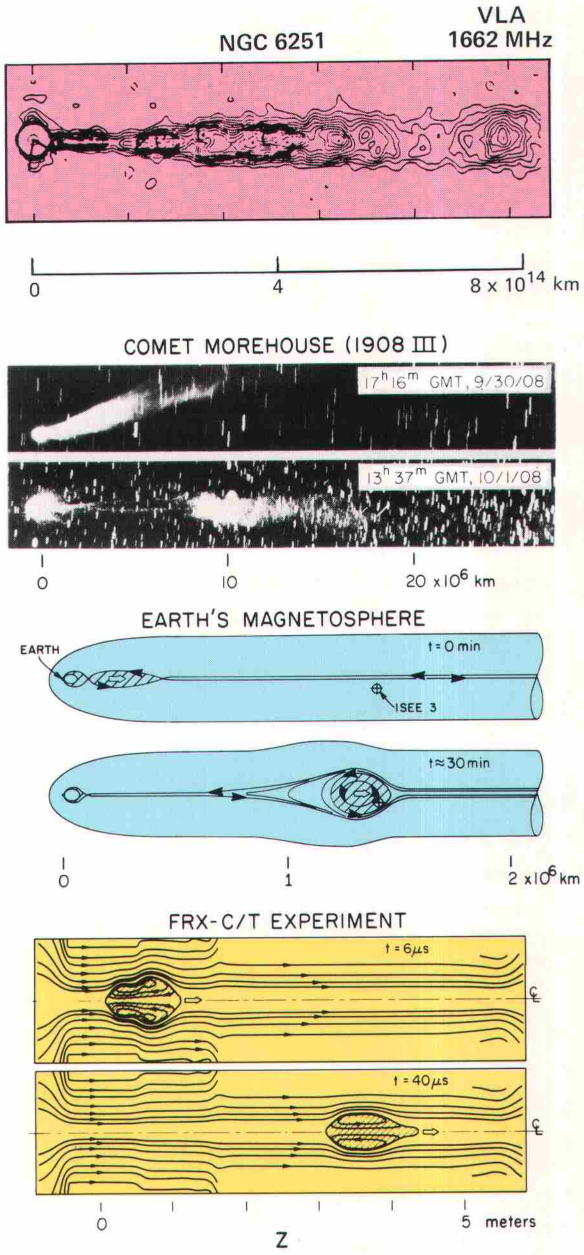
**The missions recommended in this implementation plan will accomplish forefront research in all disciplines of solar and space physics. Progress will be made towards a quantitative understanding of the generation, evolution, and interactions of naturally occurring plasmas on a cosmic scale (i.e., that of our solar system) and the relationship of this knowledge to similar processes on both a laboratory and an astrophysical scale. In addition, the exploration of the near-environment of the Sun including its polar regions will commence.**

A list of some of the anticipated results is given below:

- Exploration of the generation region of the solar wind through a fly-by at a minimum approach distance of 4 solar radii.
- Intensive exploration of the high-latitude solar wind and progress in detailed understanding of polar coronal holes.
- Solar observations with 0.1 arc sec resolution, leading to studies of plasma-magnetic field interactions related to the solar dynamo.
- Probe of the solar interior from the core to the solar "surface" or photosphere and measurement of the solar quadrupole moment through the use of solar oscillations.
- Comprehensive, global understanding of the generation and flow of energy from the Sun, through the interplanetary medium, into and through the Earth's space environment.
- Detailed study of the plasma environment and energy storage in the Earth's magnetic tail.
- Exploration of the turbulent boundary layer phenomena in the magnetosphere and magnetohydrodynamic turbulence in the solar wind through coordinated measurements of electromagnetic and plasma phenomena on four spacecraft.
- Determination of mechanisms which control middle atmospheric structure and processes and the response of the upper atmosphere to natural and human perturbations.
- Evaluation of the extent to which ozone depletion in the upper atmosphere caused by human activities can affect climate.
- Understanding of the nature of coupling between dynamics and chemistry in the stratosphere and mesosphere.
- Understanding of plasma interactions via active probing of the ionosphere utilizing electron beams, wave generators, and neutral gas releases.
- Performance of electrodynamic investigations at shuttle altitudes with the Tethered satellite through excitement of long-wavelength, low-frequency waves to study plasma wakes and alter the electrodynamics of the ionospheric medium.
- Exploration of the atmospheric environment at low (approximately 130 km) altitudes via use of a non-conducting Tether spacecraft.
- Performance of plasma tracer and modification experiments throughout the near-Earth solar-terrestrial system.
- Development of extensive simulation models with predictive capability on the interaction chain in the solar-terrestrial environment.



**Magnetosphere-like systems are common not only in our solar system but in all probability throughout the universe. Plasma conditions, characteristic features, and scale sizes vary over a wide range. In this figure, for example, scale sizes range from 3.5(10)$^3$ kilometers at Mercury to ~ 10$^{18}$ kilometers for the radio galaxy NGC 1265. Note that in our solar system the size of Jupiter's magnetosphere dwarfs the physical size of the sun.**



**The lower three panels show the motion of self-contained plasma structures through larger-scale plasma regions. The bottom panel shows a plasmoid observed moving rapidly toward the right of the panel due to magnetic reconnection in a laboratory plasma device (field-reversed pinch). The second panel from the bottom shows a very similar physical effect on a much larger spatial scale inferred from ISEE-3 measurements to be occurring in the Earth's magnetotail. The formation of magnetotail plasmoids bears many similarities to cometary tail disconnection events (third panel from the bottom); in particular, both magnetotail plasmoids and cometary tail disconnections are thought to be due to magnetic reconnection processes. As shown in the top panel, the highly structured character of galactic radio jets may be due to reconnection processes similar to those occurring in the terrestrial magnetotail.**

# THE BASIC PHYSICS/ ASTROPHYSICS CONNECTION

The first discoveries of the space age made it clear that the exploration and future understanding of the Sun's and Earth's space environment would be couched in part in terms of plasma physics—a discipline of physics that had lain relatively dormant until called forth by human need and curiosity. Since 1960, plasma physics has developed in two separate but parallel directions:

Controlled thermonuclear fusion research seeks a source of clean energy that can last for a time comparable to the age of Earth; the main obstacle to achieving nuclear fusion lies in our imperfect understanding not of nuclear physics but of plasma physics.

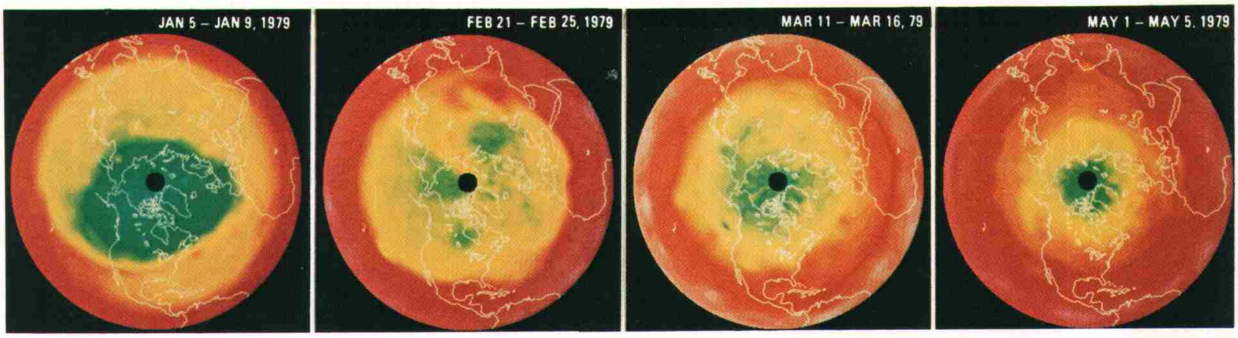
Solar system space research seeks useful comprehension of nature's processes on a global, indeed solar-system, scale, in recognition of man's intimate and sensitive dependence on his environment.

**It is both symbolically and substantially significant that the same discipline—plasma physics—defines a basic language used in both fusion and space research.**

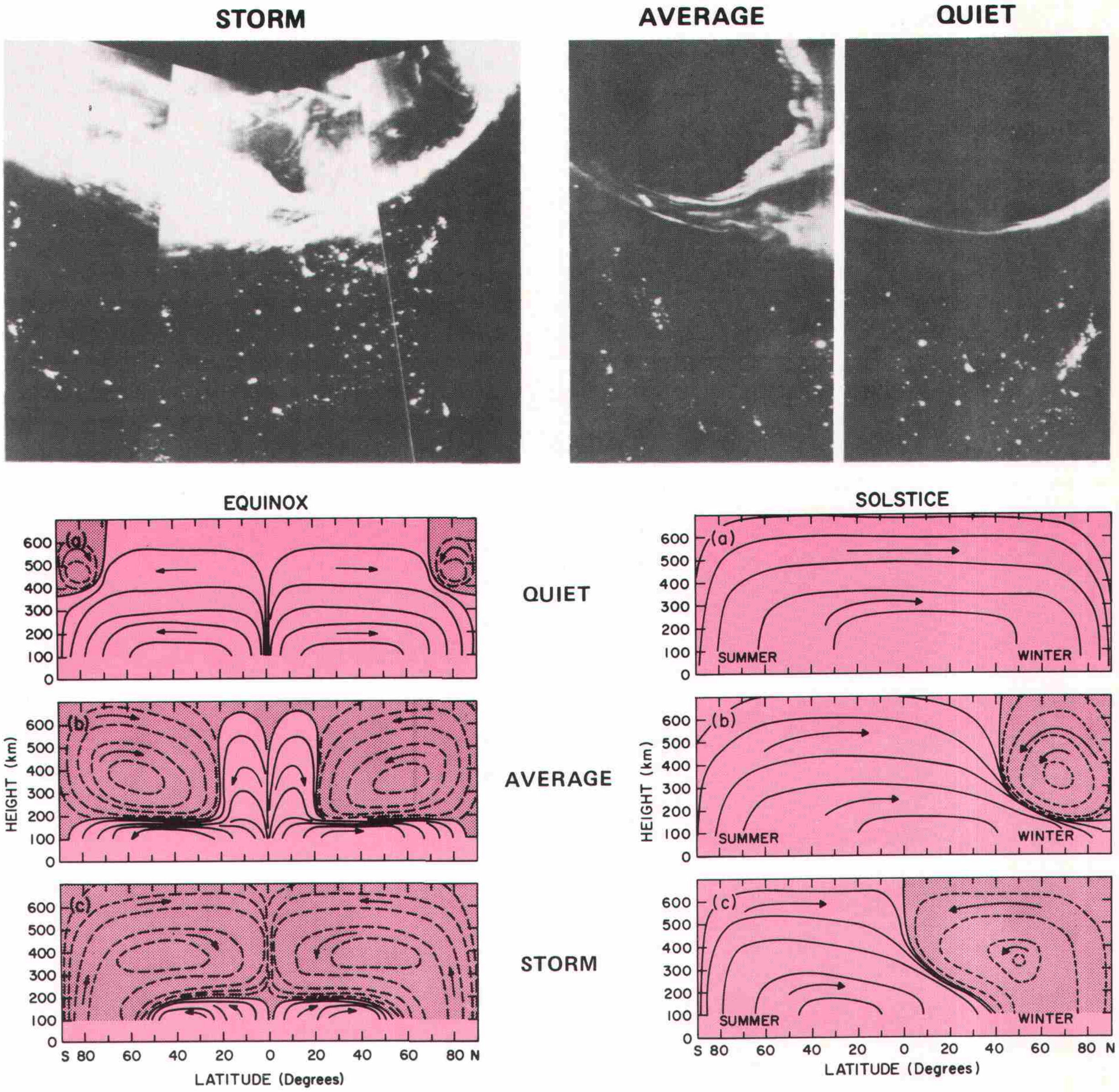
Twenty-five years of space research have taught us that many of the physical processes observed in the Sun, in the solar wind and at Earth occur throughout the astrophysical universe. The detailed analysis and understanding, made possible by close-range and in-situ observation, serve to inform and constrain our studies of more-distant astrophysical phenomena.

As selected examples of such phenomena we cite the following:

- Studies of the three-dimensional structure of the solar wind will impact several problems where progress is dependent on plasma outflow. Aside from application to the apparently quite similar phenomena of stellar and galactic winds, there are poorly understood outflows inferred in quasars, active galactic nuclei, double radio sources, pulsars, supernova remnants, and even molecular clouds and star-formation regions.
- Observation of shock acceleration of energetic particles in the solar system has application to the acceleration of energetic particles in many astrophysical contexts, ranging from supernova blast waves to jets associated with powerful extragalactic radio sources.
- Terrestrial magnetospheric physics provided a coherent framework for understanding the magnetospheres of Mercury, Jupiter, and Saturn. Studies of pulsars and other compact radio sources will benefit from our understanding of solar system magnetospheres.
- Magnetic field generation by turbulent dynamo processes is critical to the understanding of many rapidly rotating astrophysical bodies such as white dwarfs, neutron stars, black holes, etc. The Sun provides the only accessible laboratory in which the dynamo mechanism in a highly conducting plasma can be observed and against which our theoretical models tested.



Satellite observations of ozone at 10 mb (about 30 kilometers) showing seasonal variations in $O_3$ abundances at high latitudes. From the LIMS satellite experiment onboard NIMBUS 7.



Upper atmosphere circulation patterns for varying conditions of geomagnetic activity. Top panels show auroral activity as observed from USAF DMSP satellites for geomagnetic quiet, average, and storm conditions. Large changes in spatial extent and intensity of the auroral features are evident. The bottom panels show model calculations of neutral atmospheric circulation patterns above 100 km obtained for the same set of magnetic activity conditions shown in the top panels. Results are shown for equinox and solstice. It is clear that geomagnetic activity often dominates the effects of solar heating in determining the behavior of the high altitude neutral atmosphere.

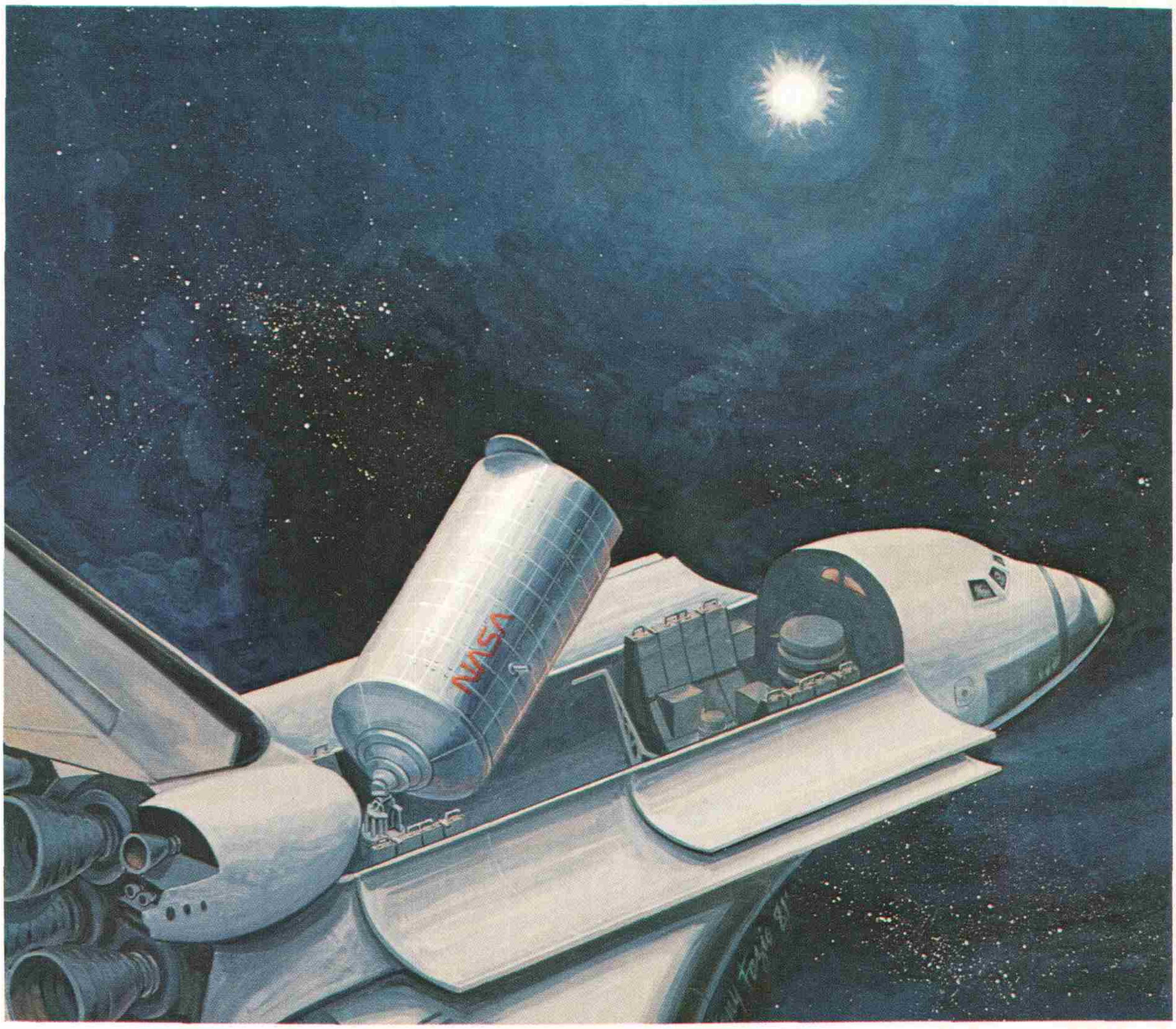
## CONNECTIONS TO EARTH SYSTEM STUDIES

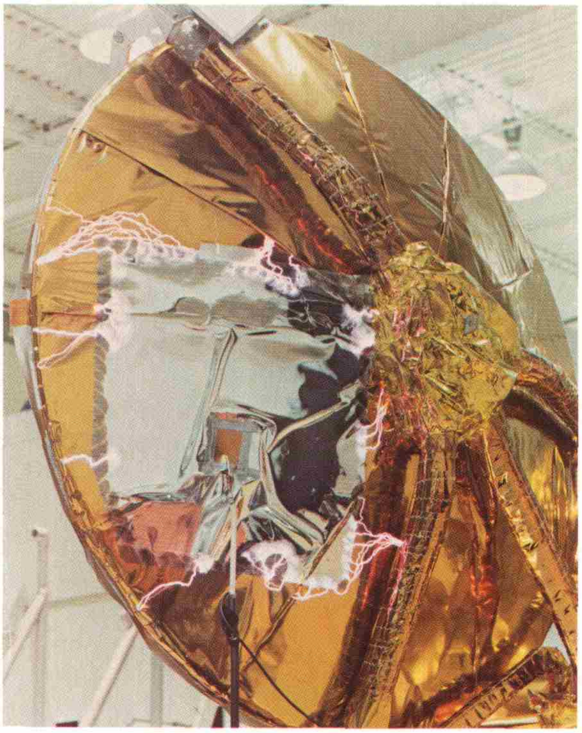
There is a growing international effort to study the Earth as an integrated system—to study the global climate, the biosphere, and the biogeochemical cycles; to determine how the Earth's atmosphere, oceans, land surfaces, and biota interact. The International Geosphere Biosphere Program is an international effort directed toward the study of the entire Earth system, specifically including the interactions of the biosphere with the physical systems. The Earth Science Study Committee (ESSC) of NASA is in the process of defining the agency's role in earth science and developing a research program for the integrated study of Earth.

**Solar and space physics is the study of variations, and the mechanisms that control these variations in the inputs of energy into the Earth system. Small but sustained variations in solar luminosity and/or irradiance may well affect the Earth's weather and climate; variations in the solar output of radiation and particles have substantial effects on the magnetosphere and ionosphere; solar irradiance variations and particle precipitation can affect the upper, and perhaps lower, atmosphere.**

Upper atmospheric studies have already led to important solar connections as well as to improved understanding of tropospheric phenomena; for example, stratosphere and mesosphere ozone responses to incoming charged particles have been observed and documented. Further, partly as a result of stratospheric studies, it has been recognized that trace gases such as $CF_2C_{12}$ and perhaps $CH_4$ are increasing, and that these species may influence global climate as well as stratospheric chemistry in the future. The study of perturbations in stratospheric ozone (both solar and anthropogenic) certainly represents an integral component in the study of the Earth as a system.

The recommended basic program will provide measurements of solar luminosity and irradiance, particle outputs, and magnetospheric precipitation. Of more significance, the program will study the basic plasma physics of the Sun, heliosphere, and magnetosphere that control variations in these quantities. For example, SOT and SOHO will provide information on the solar magnetic dynamo; Solar Probe will study the acceleration region of the solar wind; ISPM, WIND, and Solar Polar Orbiter, the flow of the solar wind through the heliosphere; ISTP, the flow of energy, momentum, and mass through the magnetosphere; and UARS, the response of the upper atmosphere.



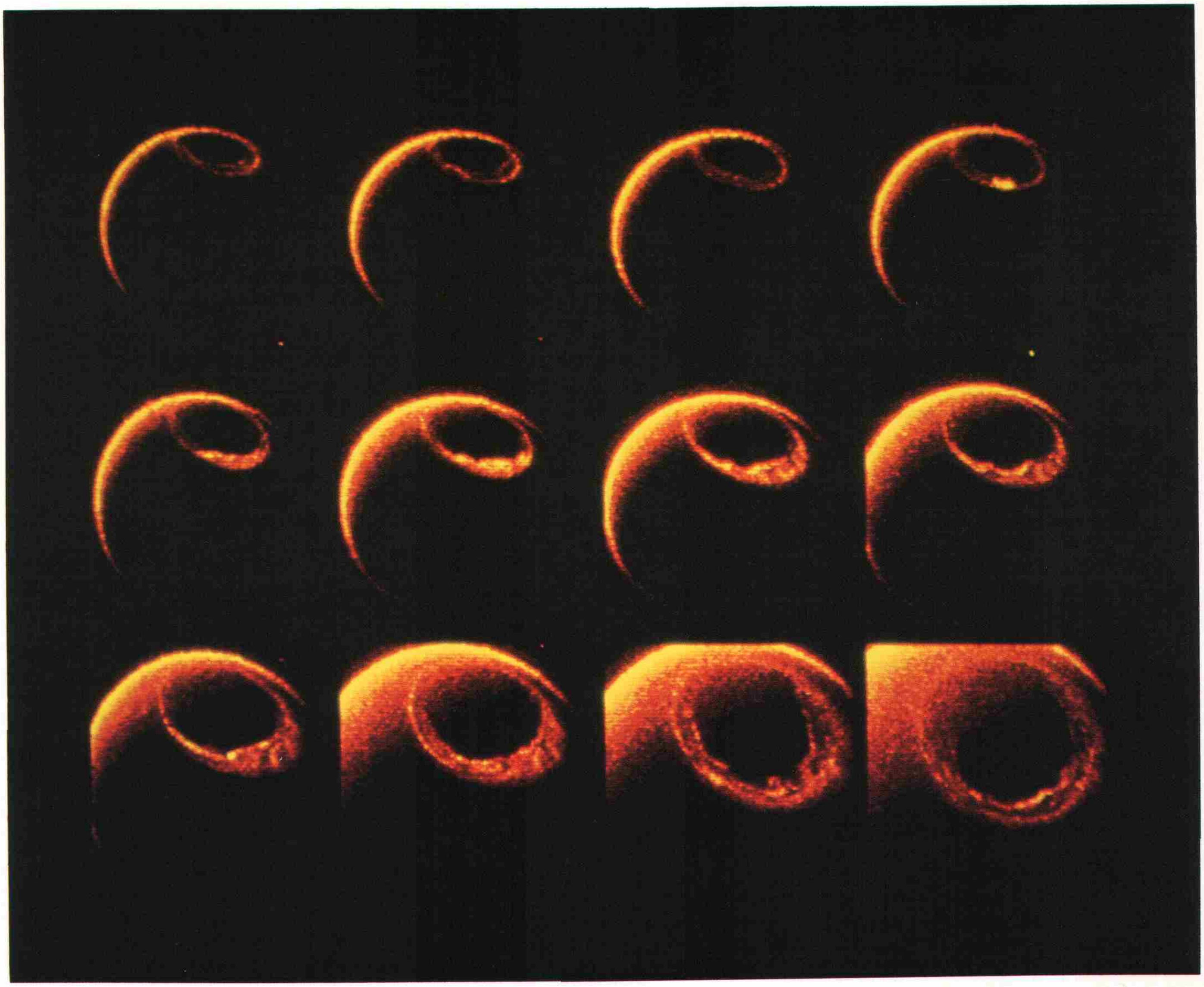


Artist's concept of the NASA Solar Optical Telescope (SOT), to be launched in 1990 to study solar physics in detail never before possible. SOT will have an aperture of 1.32 meters and resolve solar structures as small as 0.1 arc-second across (equal to 75 km or 47 statute miles on the sun). It will sense radiation from the deep ultraviolet to the near infrared and enable astronomers to study solar phenomena from the photosphere to the corona. The sun, our nearest star, can serve as a unique plasma physics laboratory, and SOT will be one of the essential laboratory instruments.

Arc immunity test of the DSCS-2 spacecraft at TRW. Potentials of several kilovolts are used to induce arcing and to test spacecraft and subsystem immunity to the resulting electrical arcs. Such potentials occur in the Earth's magnetosphere during periods of magnetic activity called substorms. Satellite malfunctions and partial failures have occurred during these periods.

## ORGANIZATIONAL STRUCTURE

A major intellectual thread linking several recent NAS/NRC advisory committee reports has been the essential unity of the discipline comprising solar and space physics. The implementation plan recommended in this report contains program elements currently administered by four separate divisions within NASA Headquarters. For example, Explorers and the science management for SOT and ISPM are in the Astrophysics Division; program management for ISPM is in the Solar System Exploration Division; UARS, Tether, and CRRES are in the Earth Science and Applications Division; and management of Shuttle instruments is in the Shuttle Payloads Engineering Division. It is the consensus of the community that an increased level of coordination of such a broad program would be an effective way to address the science objectives and strive for the necessary balance within a constrained budget. It is, therefore, recommended that NASA consider whether the current management structure is best suited to implement the proposed program.



Twelve consecutive false-color images of the northern auroral oval recording the onset and evolution of a substorm as Dynamics Explorer 1 proceeds inbound from apogee during the period 0529 through 0755 UT on 2 April 1982. Each image is taken and telemetered in a twelve-minute interval. Initial substorm effects in the aurora are first seen in the fourth image, which begins at 0605 UT. Following this, auroral structures can be seen moving westward and eastward as the entire auroral oval becomes active. The sunlit hemisphere is visible at the upper left in each image. The passband of the optical filter is 123-155 nanometers, for which the dominant responses are from atomic oxygen at 130.4 and 135.6 nanometers. The spacecraft location for the first image (upper left-hand corner) is 23° N geographic latitude and 22 hours local time, and the altitude is 3.67 $R_E$. The spacecraft is directly over the auroral oval as the last image frame is telemetered, at an altitude of 2.17 $R_E$.

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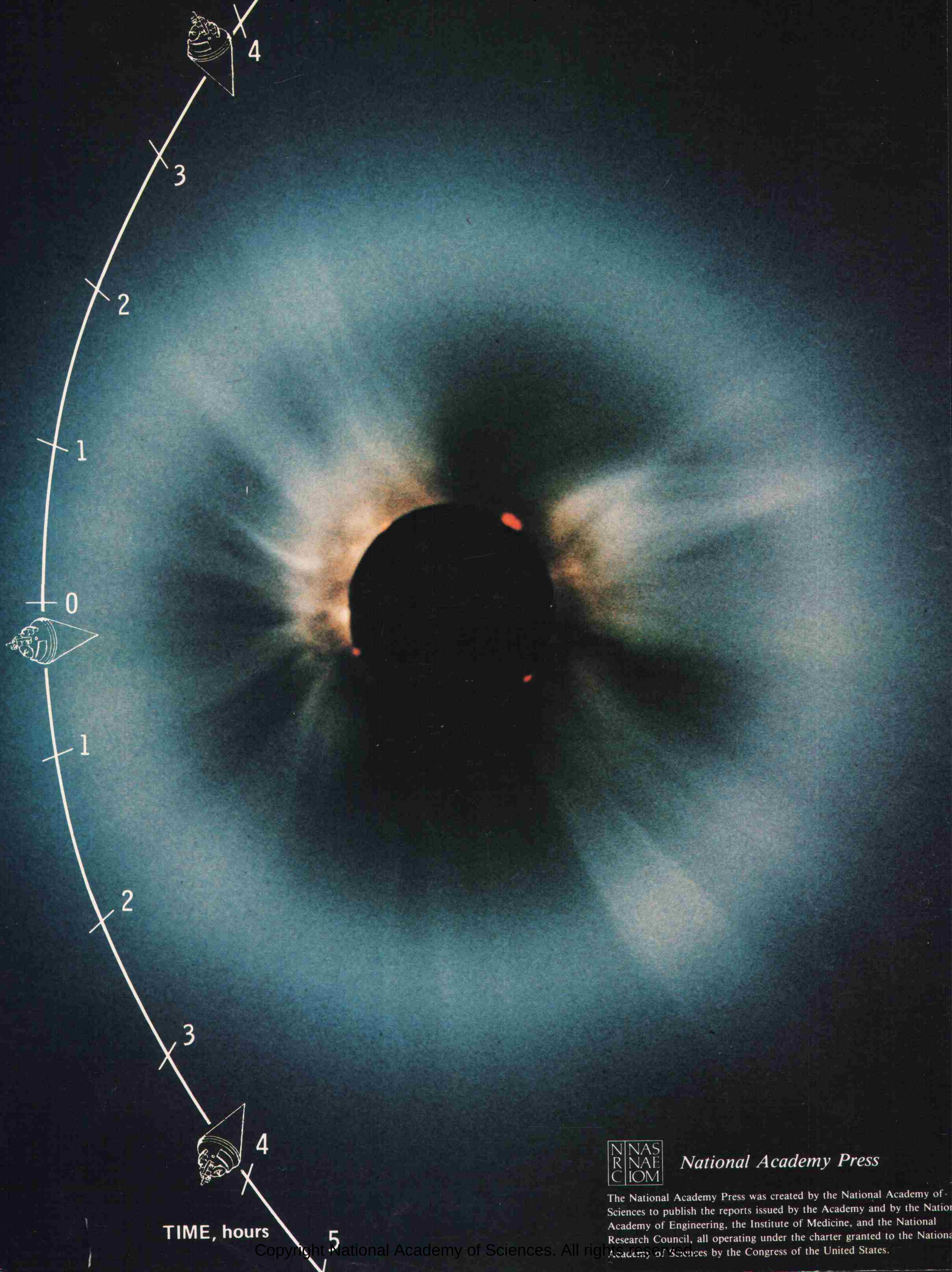
**Front Cover**

A giant ejection of matter from the sun (blue color) as observed by the Solar Maximum Mission. Each eruption ejects about one billion tons of matter into interplanetary space. These clouds of matter travel at speeds of about three million kilometers per hour and cause global magnetic storms on Earth that produce intense auroral displays over the poles. A typical aurora viewed from the Dynamics Explorer satellite is shown in the larger inset to the left. Up to one hundred billion watts is deposited in the upper atmosphere during such displays. The solar atmosphere is so hot (over a million degrees) that it blows away from the sun as a steady wind at about a million kilometers per hour past all the known planets. The presence of this wind was originally inferred from comet tails, which always point away from the sun. The lower inset shows the first man-made comet, formed recently by a release of barium from one of the Active Magnetosphere Particle Tracer Explorers spacecraft.

**Back Cover**

The trajectory of Solar Probe superimposed on a picture of the sun taken during an eclipse. The pearly-white streamers are shaped by the sun's magnetic field and the solar wind and, in some eclipse pictures, can be seen to distances of over 7 million kilometers from the sun. The red prominences visible over the moon's shadow are cool gas condensations suspended in the corona, which is one hundred times as hot. The Solar Probe spacecraft would explore the sun's vicinity for the first time and approach to within about 2 million kilometers of the solar "surface." The time marks on the trajectory show that the near-sun traversal would last for 10 hours, with the spacecraft traveling at a speed of some 300 kilometers per second (over a million kilometers per hour) at closest approach. The probe would intersect many of the closed and open magnetic field structures, as is evident in the picture. The total flight time could be as short as 2.7 years, depending on available propulsion systems.



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