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Chapter 6

Report from Solar Physics

Panel: A.B.C. Walker, Chair; L. Acton, G. Brueckner, E.L. Chupp, H.S. Hudson and W. Roberts

6.1 The Nature of Solar Physics

The sun provides a laboratory in which the interaction of plasma, magnetic fields and gravitational fields occurs on scales, and in regimes of temperature and density which cannot be duplicated in the laboratory. The phenomena which occur on the sun, such as the solar activity cycle, the generation of energy by thermonuclear reactions, the nonthermally heated corona, the acceleration of particles to very high energy, and the generation of the solar wind are challenging and fascinating problems in fundamental physics. The core of the discipline of solar physics is the study of these phenomena. We have made significant progress in identifying the physical laws responsible for these phenomena, and in formulating more precisely the fundamental questions which must be addressed to achieve a deeper understanding of them.

The sun also represents the major source of energy in the solar system, and controls, or strongly influences, events in planetary atmospheres, magnetospheres, and ionospheres, via direct irradiation, and via the extended atmosphere of the sun, the heliosphere. The problems presented by the interaction of the sun with the Earth, in particular, solar-terrestrial relations, are of great importance. These problems are no less challenging or rewarding than those associated with the sun itself. They do, however, require solar observations of a different nature from those required to address the physics of the sun itself, along with measurements of the magnetospheric, ionospheric, or atmospheric phenomena of interest.

The sun is the only star that we can study in detail; the comparison of the sun and of other stars (especially with sun-like stars at different stages of evolution, or with stars of different mass or composition) is a powerful technique for stellar astronomy. The sun also represents a unique opportunity to study phenomena which we observe elsewhere in the galaxy, in sufficient detail to test fundamental physical laws. The comparative study of such phenomena on the sun and elsewhere in the galaxy or the universe can provide insights valuable both to the solar physicist and the stellar or galactic astronomer or cosmologist.

A complete and comprehensive solar program must embrace all four aspects of solar physics (Table 6-1); pure solar studies, solar-terrestrial studies, comparative solar/stellar studies, and the study of physical processes, such as particle acceleration, which play an important role in astronomical phenomena on many scales. The latter two aspects are sometimes referred to as "the study of the sun as a star".

The outer solar atmosphere becomes unexpectedly hot within the first several thousand km of altitude above the photosphere. This energization also impels the solar wind, which flows outwards to form the heliospheric cavity in the interstellar medium. The flow of the solar wind is regular and has continued over the lifetime of the sun, but it contains many complexities; these include a time variable neutral sheet, transient disturbances such as streamers, coronal mass ejections, and large scale shock waves, plus a component of zodiacal and cometary dust. In a sense this enormous volume (extending to at least 50 AU) should be considered to be an integral part of the volume of the sun, but one that is

Table 6-1. The Nature of Solar Physics

- "Pure" solar physics includes the study of:
  - Complex interaction of plasma, gravitational, and magnetic fields
  - The solar activity cycle
  - Coronal heating
  - Particle acceleration
  - Solar wind generation
- Solar-terrestrial relations make strong demands on our understanding of solar phenomena because:
  - Solar radiative and particulate fluxes energize the magnetospheres, atmospheres, and ionospheres of the planets, including earth
  - Understanding the nature and causes of solar variability is critical to modeling the variability of the earth's atmosphere, ionosphere, and magnetosphere
- Study of the sun as a star has important consequences for astrophysics because:
  - Activity cycles and coronae are common features of cool stars, therefore comparative studies of the sun and other sun-like stars are mutually beneficial
  - Many stellar and galactic phenomena (particle acceleration, winds, flares, etc.) can only be studied in detail by observing their solar manifestations

generally optically thin and that has interesting intrusions, such as cosmic rays, the planets and their magnetospheres; comets, etc.

The steady and varying properties of the heliospheric plasma have many direct effects on the terrestrial-plasma environment, ranging from the polar auroral displays to the generation of Earth currents during major magnetic storms. The structure of the heliospheric plasma modulates the galactic cosmic rays, as well as transporting the solar energetic particles directly to Earth. In these ways the detailed physics within the heliospheric volume plays a role in determining the terrestrial environment which may be as significant as the consequences of the solar irradiance variability.

The present status of heliospheric physics can best be described as "on hold" between missions; we are hoping for substantial progress via SOHO/Cluster and the Wind spacecraft, plus perhaps new selections of Explorer or small Explorer experiments, but there is very little observational activity from space at present. Indeed, the future missions that have been selected are not optimal for the specific needs of solar-terrestrial research, but are instead oriented more strongly towards the "pure" branches of solar physics and/or space plasma physics.

Future missions optimized for understanding the solar-terrestrial relationships should emphasize the synoptic (i.e., stable, long-term, systematic measurement of the most significant parameters). This must include extensive remote sensing or imaging data since truly comprehensive multipoint observations of heliospheric structure would be prohibitively expensive in terms of numbers of spacecraft.

6.2 Current Understanding and Anticipated Near-Term Progress

6.2.1 A Brief Review of Recent Advances in Solar Physics

In the past decade, observations of the sun from space and from the ground have led to profoundly important and frequently unexpected discoveries which have greatly enhanced our knowledge of solar phenomena and of their connections to the other disciplines cited above. Among the most significant of these discoveries are:

- The first direct experimental confirmation of the central role played by thermonuclear processes in stars, by the successful detection of neutrinos from the sun(1).

More importantly, the disagreement of the observed neutrino flux with that predicted by standard solar models has resulted in the planning of new observational approaches to test the assumptions and the detailed predictions of the resultant models more directly.

- The discovery that the 5-minute oscillations of the sun are a global seismic phenomenon that can be used as a probe of the structure and dynamical behavior of the solar interior(2).

The study of these oscillations, and of longer period oscillations whose existence has been recently reported, provides a unique and powerful method to probe solar (and therefore stellar) structure and evolution, and the transport of energy and the generation of magnetic fields in the sun's convection zone (and therefore in the convection zones of cool stars). More recently, Space Lab II observations have demonstrated the persistence of flow fields at mesogranulation and granulation scales in the photosphere. The role of this phenomenon in the evolution of the solar magnetic field is unknown.

- The discovery that the damping of solar atmospheric waves driven by convection cannot account for the energy(3) required to heat the corona and drive the solar wind.

The correlation between the level of intensity of coronal phenomena observed in other stars (which, like the sun, have convective envelopes) and their stellar rotation rate has reinforced the conclusion (drawn from solar observations) that magnetic effects underlie many of the active phenomena observed in stellar atmospheres.

- The discovery that, when viewed on a fine scale, the solar magnetic field is subdivided into individual flux tubes with field strengths exceeding 1000 gauss.

The physical size of these fundamental magnetic flux elements is smaller than can be resolved by any present telescope(4). The cause of this phenomenon is unknown. More recently, rocket observations have shown that the transition region contains very fine scale structures which are highly dynamic. These structures, which appear to be fundamental to atmospheric heating, are beyond the resolving power of present instruments.

- The demonstration that the large-scale solar-magnetic field is organized into two distinct types of structures: magnetically closed regions, in which hot plasma magnetically confined in loops largely generates the x-ray corona; and magnetically open regions, the so-called "coronal holes," which are the source of high speed streams in the solar wind (Figure 6-1a)(5).
- The confirmation of the evidence (provided initially by 17th century observations) that the sunspot cycle and associated active phenomena were largely absent for a period of 70 years in the 17th century.

This episode is known as the Maunder Minimum(2a, 6). We now know that such interruptions, along with periods of heightened activity, occur quasi-periodically and that there is a correlation between the general level of solar activity and the occurrence(6) of climatic changes on the Earth (Figure 6-1b). The cause of this modulation of the solar activity level is unknown. Recently, SMM observations have shown that the solar luminosity varies as a function of sunspot activity, and with the solar cycle; the implications of these variations for the Earth's climate are not known.

- The recognition, as a result of observations of hard x-rays, gamma rays, and energetic neutrons, that the energy released during the impulsive phase of a solar flare is initially largely, or entirely, contained in nonthermal particles accelerated during magnetic-reconnection processes in the coronal field(8).
- The discovery that the ejection of large clouds of gas called coronal mass transients(5) can occur in association with some flares.
- The discovery by SMM that the elemental abundances in x-ray emitting flare plasma vary during the flare event.

SMM observations have shown that both protons and electrons are accelerated promptly

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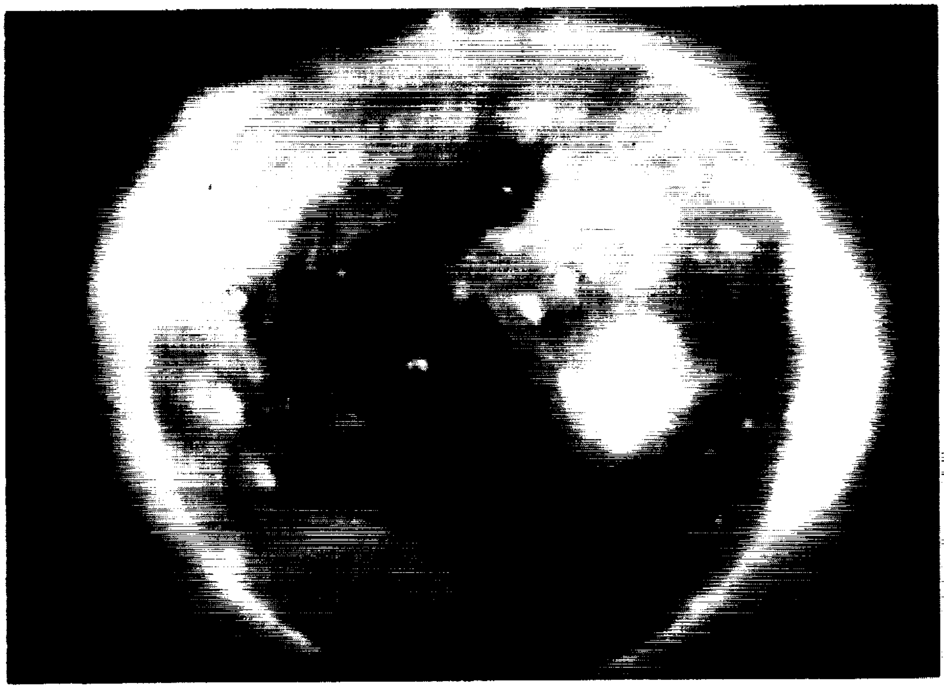

Figure 6-1a. X-ray Photograph of the Sun

This photo, taken August 21, 1973, with the American Science and Engineering instrument on Skylab, shows large coronal loop structures and many small bright points thought to be loops that are too small to be resolved. A large coronal hole extending from the north pole across the equator is plainly visible.

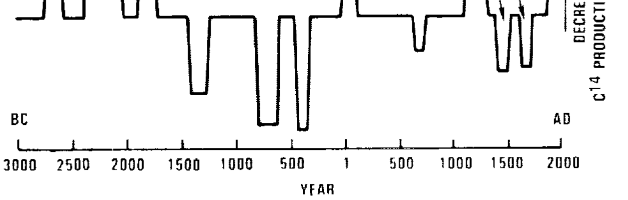

Figure 6-1b. Apparent Correlation of Solar Activity and Climate. The lower curve, based on tree-ring data, represents the rate of production of carbon-14 by cosmic ray bombardment of the upper atmosphere. This production varies inversely with solar activity. Plotted above are measures of mean European climate: the advance and retreat of alpine glaciers, historical inferences of mean annual temperature, and the recorded severity of northern European winters. The temporal coincidence of low solar activity and cool European climate suggests a casual connection between long-term solar behavior and climate, although other data indicate a more complex relationship.

during a flare. The electron acceleration mechanism demonstrates fine time structure (on a millisecond scale), and evidence for the production of bursts of beamed electrons which transport flare energy by propagating along coronal magnetic flux tubes.

A comprehensive review of the current status of solar physics is contained in the three volume set "The Physics of the Sun,"[8] which is recommended to those who wish to pursue in depth any of the specific topics mentioned above.

The profound impact of these and other discoveries on our appreciation of the complexity and diversity of solar phenomena has led to the maturing of solar physics as a scientific discipline. This new maturity has allowed solar physicists to formulate a much more precise theoretical and observational strategy for their discipline[9].

6.2.2 Solar Physics—Expected Accomplishments Through 1995 and a Plan for Continuing Advances into the 21st Century

The current plans for the study of the physics of the sun from space are, at best, modest, even considering initiatives of other countries. There is now no cohesive plan for extending the accomplishments of previous and current major space missions, such as Skylab, P78-1, SMM, and Hinotori. Without such a (US) plan, the vital unsolved scientific problems in solar physics will not be properly attacked. The only near-term programs which can investigate a limited number of solar physics problems are the Solar A and SOHO missions, rocket flights, and the Max 91 balloon program. We therefore first briefly review from a broad perspective the major scientific problems which we believe will remain unsolved by 1995.

Several reports which were written over the last 10 years have identified most of the questions that can be studied from the Earth and space. These are:

1) The Colgate Reports (*Space Plasma Physics: The Study of Solar System Plasmas,* 1978, and *The Physics of the Sun*, 1985).
2) The Kennel Report (*Solar-System Space Physics in the 1980's: A Research Strategy,* 1980).
3) *Solar-Terrestrial Research in the 1980's* (1981).
4) The Nature of Solar Physics: Chapter III of *"Challenges to Astronomy and Astrophysics: Working Documents of the Astronomy Survey Committee"*(1983).
5) *National Solar-Terrestrial Research Program* (1984).
6) *A Strategy for the Explorer Program for Solar and Space Physics* (1984).
7) *An Implementation Plan for Priorities in Solar-System Space Physics* (1985).
8) *The Advanced Solar Observatory* (Executive Summary, 1986).
9) "Solar and Space Physics" (*Space Science in the Twenty-First Century: Imperatives for the Decades 1995-2015,* 1988).

The consensus from all the studies identify the following set of broad scientific objectives:

- Structure and dynamics of the solar interior which includes problems of the magnetic cycle and the coupled dynamics of the convective envelope
- Structure and dynamics of the solar atmosphere and solar activity, including the development of active regions and flare and post-flare phenomena
- Coronal dynamics and coupling to the interplanetary medium, including the origin of the solar wind
- Solar-terrestrial relations which go beyond basic solar physics and consider the coupling of solar energy (both radiative and particulate) to Earth.

Table 6-2 lists the basic problems presented by these objectives and the tools required for attacking them. Column 5 lists the near-term missions which can make modest advances to 1995. Column 6 indicates the required space flight capabilities for the vital extension of studies of the sun. The missions listed are described in more detail below.

6.3 Problems and Objectives

6.3.1 A Scientific Strategy for "Pure" Solar Physics

The report of the Solar Physics Working Group of the Astronomy Survey Committee[9] has recommended three themes or areas of concentration as potentially the most productive for solar physics over the next decade. These three themes (Table 6-3) are: (1) development of observational techniques capable of probing the interior structure, dynamics, and composition of the sun; (2) study of the "active phenomena" such as flares, sunspots, the activity cycle, the chromosphere, the corona, and the solar wind, which are a consequence of solar magnetic variability; and (3) study of the role of the sun in shaping the three-dimensional structure and dynamics of the heliosphere. The last two themes will have important implications for our understanding of the Earth's space environment and climate[10]. We can formulate a coherent scientific program which addresses these themes as a series of seven

Table 6-2. Major Scientific Problems in Solar Physics

1. Objective	2. Area	3. Problem	4. Tools for Solution	5. Approved	6. Proposed
Structure and Dynamics of the Solar Interior	Interior dynamics	a) What is the rotation profile of the Solar Interior? b) Are there residual effects from possible primordial abundance inhomogeneities in the young sun? c) What is the temperature of the solar core?	Observation of the sun's radial and non-radial oscillations (a,b,c)	SO	GDI:HRTC
			Theory and modeling (a,b,c)	—	
			Observation of the Solar Neutrino Spectrum (b,c)	Galliur	
			Determination of the Solar Quadrupole Moment (a,b)	SOHO	Solar Probe
	Dynamics of the convective envelope	a) What role do convection and circulation play in the convective transport of energy in the envelope?	Extremely high sensitivity measures of velocity and rotation (a,b)	SOHO	OSL
		b) How does large scale circulation operate on sun and what are its effects?	High precision measurements of the brightness pattern of the solar surfaces (a,b)		OSL
			Theory and computer modeling (a,b)	—	GDI:HRTC
	Magnetic cycle	a) What is the origin of the solar magnetic field, and of its secular variation?	Observations of the non-radial oscillations of the sun to deduce the structure of the convection zone (a)	SOHO	GDI:HRTC
		b) What are the dynamics and energetics of sunspots and other manifestations of emerging flux?	Synoptic observations of solar magnetic field with modest resolution, velocity, and magnetic field observations of polar regions of sun (a,b,c)	SOHO	GDI:HRTC
		c) How rapidly and in what way do coronal fields evolve and dissipate?	ATM data analysis; coordinated synoptic x-ray/XUV and magnetograph data with adequate time resolution (minutes to hours?) (b,c)	Solar-A	HRTC Heliosphere
			Highly resolved magnetograms and EUV and optical data; theory plus time-resolved magnetograms, optical data (including velocities) (c)		OSL
Atmospheric Structure and Active Phenomena	Atmospheric structure and dynamics	a) What is the velocity field in the transition zone and corona? b) What is the role of magnetic fields in heating? c) Are time-dependent ionization effects important in the dynamically varying quiet sun? d) What is the relative role of magnetic dissipation and wave propagation in heating the chromosphere and corona? e) What is the role of spcules in the exchange of mass between the chromosphere and corona? f) What is the fine scale structure and dynamical behavior of the magnetic field?	XUV and ultraviolet spectroscopy with high spatial and spectral resolution Moderate time resolution; x-ray, XUV, radio imagery (a,b,c,d)	Solar-A	OSL, HRTC
			High-resolution magnetograph, visual, ultraviolet, XUV, x-ray data; ATM data analysis (b,f,e)	Solar-A	OSL, HRTC
			XUV and ultraviolet line ratio observations, theory (c)	0	OSL, HRTC
			High resolution measurements of the photospheric velocity field (d)		OSL
	Active regions	a) What is the nature of sunspots: why are sunspots and flare knots stable? b) What is the role of coronal bright points in the emergence or magnetic flux? c) How are coronal loops heated, how do they exchange mass with the chromosphere? Are they chemically homogenous? d) What is the role of prominences and coronal condensations in the energetics of the corona?	Theoretical studies of basic dynamical effects in sunspot structure; observational studies of wave fluxes from sunspots; very highly resolved magnetograms and optical data: theory (a,b,c,d)		OSL
			High-resolution visible, ultraviolet, XUV x-ray, and radio imaging, and spectrophotometry (a,b,c,d)	Solar-A	OSL, HRTC
			Synoptic studies at visible, radio, ultraviolet, and soft x-ray ranges (c,d)	Solar-A	HTRC
			Highest resolution EUV, visible, and radiobservations; theoretical studies (a,b,c)	SOHO	HTRC
	Flares and transients	a) How does stored energy build up in coronal fields and how is it released? b) What is the site of the impulsive energy release in flares, what are the details of reconnection and particle acceleration processes? c) How is the energy released in flares transported to other parts of the atmosphere and dissipated? d) What is the mechanism which triggers coronal transients? e) How does chemical and isotopic fractionation in flares occur?	Temporal and spatial magnetograph data with concurrent soft x-ray and radio imagery, theoretical dynamical studies (a,b,c)	Solar-A	HRTC, HEIC, P/OF
			Hard x-ray imaging and spectroscopy; gamma-ray and energetic beam impact-point observations, high-resolution microwave mappings; fast meter decameter radioheligraph (FeXXI, white light flares) (b,d)	Solar-A	HRTC, HEIC, P/OF HRTC, HEIC, P/OF
			High-resolution visible, ultraviolet, XUV, x-ray and centimeter-wave imaging and spectrophotometry (c)		OSL, HRTC, P/OF

Table 6-2. Major Scientific Problems in Solar Physics (Continued)

1. Objective	2. Area	3. Problem	4. Tools for Solution	5. Approved	6. Proposed
			Solar cosmic-ray observations with good elemental and isotopic resolution; gamma ray spectra with high resolution and sensitivity; XUV and soft x-ray abundance studies (b, e)	Solar-A	Heliosphere, Solar Probe
The Corona and the Interplanetary Medium	Coronal structure and dynamics	a) What are the processes responsible for heating and mass transport in the quiet corona and coronal holes? b) What role do coronal transients play in the energy and mass balance of the corona and solar wind? c) How does chemical fractionation in the corona arise and what is its relationship to abundance anomalies in flares and in the solar wind?	Imaging and spectroscopy in visible ultraviolet, XUV, x-rays; high-resolution magnetic fields; fast meter-decameter radio heliography (a,b,c)	SOHO, Solar-A	OSL, HRTC, P/OF
			Radio polarization observations, white light coronagraph polarization studies (a,b)	SOHO	P/OF
			Development and coordination of the theoretical modeling with empirical models; observation of coronal temperature and density structure with white-light and Lyman-α coronagraphs; ultraviolet, XUV and soft x-ray line profiles (a,b,c)	SOHO, Solar-A	HRTC, P/OF
	The solar wind	a) What is the structure and composition of the solar wind over coronal holes, over light bright points, and over active regions? b) How is the solar wind accelerated? c) What mechanisms are responsible for the observed variations in the composition and temperature of the solar wind? d) What is the angular momentum of the solar wind and what is its role in the evolution of the sun? e) What is the structure of the solar wind and interplanetary medium at mid and high heliocentric latitudes?	Complete coordinated data on corona and solar wind parameters; theory and computer modeling; extend interplanetary data closer to sun and out of the ecliptic (a,b)	SOHO	HRTC, P/OF
			Well-calibrated observations of angular momentum of solar wind, ultimately out of the ecliptic (d)	Ulysses	P/OF, Heliosphere Solar Probe
			Out-of-the-ecliptic measurements (e)	Ulysses	Solar Probe
			Better composition measurements of solar wind; theory of ionic diffusion in transition zone and separation in solar wind (c)	0	Heliosphere, Solar Probe
	Solar terrestrial relations	a) What mechanisms are responsible for the very long-term variations in solar activity which cause phenomena such as the Maunder Minimum b) Are there indicators which allow the prediction of long-term (activity cycle) variations in the trends and short-term (flares, transients) events on the sun which affect conditions on the earth? c) What is the best way to monitor the level of solar activity and the structure of the interplanetary medium in relation to ionospheric, magnetospheric and atmospheric physics? d) What are the mechanisms which are responsible for short-term and long-term variations in the solar constant? e) How do variations on the sun control the structure of the interplanetary medium?	Observation of the sun's and nonradial oscillations (a,b,d)	SOHO	HRTC
			Proxy studies of the level of solar activity over very long periods, studies of solar like stars (a)	—	
			Studies of the structure and evolution of the corona coupled with studies of the non-radial oscillations (e)	SOHO	HRTC, P/OF
			Synoptic observations of solar ultraviolet emission, upper atmosphere, magnetospheric studies (c)	UARS, EOS	SVO, Janus
			Improved atmospheric modeling (c)	—	
			Continue the coordination and statistical study of solar, interplanetary, and terrestrial conditions (c,e)	—	SVO, Janus SVO, Janus
			Precision synoptic observation of total solar luminosity (d)	UARS, EOS	SVO, Janus

— Theory
0 None planned

Key:

SOHO	Solar Heliospheric Observatory
ASO	Advanced Solar Observatory
P/OF	Pinhole Occulter Facility (Part of ASO)
HRTC	High Resolution Telescope Cluster (Part of ASO)
HEIC	High Energy Instrument Cluster (Part of ASO)
GDI	Global Dynamic Instruments (Part of ASO)
OSL	Orbiting Solar Laboratory
UARS	Upper Atmosphere Research Satellite
SVO	Solar Variability Observatory
Janus	A proposed Solar Terrestrial Observatory
Gallium	Search for low energy solar neutrinos with a gallium based detector
EOS	Earth Observation System

fundamental questions, which present an overview of the theoretical and observational issues which should be the focus of solar research over the next decade.

1. What are the fundamental properties of the solar core (where energy is generated) and the radiative interior (through which energy is transported to the sun's outer layers)? In particular, what is the sun's internal rotation rate, chemical composition, and temperature distribution, and what is the detailed process of nuclear energy generation and energy transport? How do these properties relate to current theories of stellar evolution?
2. What is the magnetohydrodynamic structure of the solar convection zone, and what is the

Table 6-3. "Pure" Solar Physics—Scientific Objectives

Themes from the report of the Solar Physics Working Group of the Astronomy Survey Committee
Structure and dynamics of the solar interior
Rotation profile, energy source
Nature of solar convection
Origin of solar magnetism
Atmospheric structure and active phenomena
Velocity fields, magnetic and acoustic dissipation, fine structure
Active regions (origin, heating, evolution)
Flares and transients (energy accumulation, trigger mechanism; high energy particle acceleration)
Recurrent phenomena (e.g., sun spots)
Corona and interplanetary medium
Structure and dynamics
Origin of solar wind

role of the convective scales observed on the sun, the granulation, the supergranulation, and the large-scale circulation, in transporting energy from the solar interior to the solar surface? Can a generalized theory of stellar convection in the presence of rotation and magnetic fields be developed which describes the structure of the sun's convective zone and predicts the observed convective scales?

3. What physical mechanisms drive the solar magnetic field and activity cycle, what resulting variations in the solar radiative and particulate output follow on various time-scales, and what is the effect of this variability on the Earth's atmosphere, ionosphere, and magnetosphere? What causes the long-term variations in the solar magnetic and activity cycles, such as occurred during the Maunder Minimum? How do these phenomena relate to activity and variability on other stars?
4. What processes, involving small scale velocity and magnetic fields and various wave modes, determine the thermal structure and dynamics of the solar photosphere, chromosphere, and corona, and what are the implications of such processes for stellar atmospheres in general?
5. What are the basic plasma-physics processes responsible for metastable energy storage, magnetic reconnection, particle acceleration, and energy deposition in solar flares and related nonthermal phenomena? What are the implications of these for other high energy processes in the Universe?
6. What are the large-scale structure and plasma dynamics of the solar corona, including the processes involved in heating various coronal structures and initiating the solar wind? What are the implications for stellar coronae and winds other astrophysical flows? What is the origin of coronal transients?
7. What are the implications of coronal structure for the three-dimensional structure and dynamics of the heliosphere and what are its implications for cosmic ray modulation and for the modulation of planetary atmospheres, ionospheres, and magnetospheres, including those of Earth?

6.3.2 Solar-Terrestrial Physics

The solar output at ultraviolet and x-ray wavelength has profound effects on the upper atmosphere of the earth (Table 6-4). The chemistry of the atmosphere, the energy budget, and perhaps the dynamics of the stratosphere and lower mesosphere, are solely determined by the incoming UV radiation in the 120 mm $<\lambda<300$ nm band, while XUV radiation at $15<\lambda<100$ nm determines the energy budget of the thermosphere. X-rays are absorbed or scattered in many layers. The solar cycle variations of the thermosphere are governed by the strongly variable solar XUV radiation. Ozone concentration in the stratosphere is dependent on the solar UV radiation between 180 and 300 nm. It has been

Table 6-4. Identification of Physical Mechanisms Long-Term Variability

Problems in Solar-Terrestrial Physics
• **Radiative coupling sun-upper earth atmosphere**
Energy, chemistry and dynamics of stratosphere, mesosphere and thermosphere
• **Coupling between solar wind and magnetosphere**
Reconnection processes
Trigger of magnetic substorms
Particle acceleration, plasmoid ejection
Aurora
Large scale electric field systems
• **Sun-earth weather**
Confirmation that apparent statistical correlations have a physical basis
Identification of physical mechanisms responsible for any correlations verified

estimated that a decrease of 5% of the solar radiation at 250 nm results in an ozone column density change of approximately 2.5%.

Solar cycle induced ozone column density variations are therefore comparable to long periodic variations caused by chemicals released from the surface of the Earth. It is impossible to distinguish between the two effects as long as no precise knowledge exists of the sun's 11-year variability at the critical UV wavelengths. The list below shows the required precision and accuracy of the solar UV spectral irradiance over a solar cycle, a solar rotation, and short intervals, such as flare-induced variations.

Time	0.1.5 - 15 nm Soft X-rays		15 - 100 nm XUV		180 - 300 nm EUV	
	Precision	Accuracy	Precision	Accuracy	Precision	Accuracy
11 Years	10%	20%	5%	10%	<1%	<5%
25 Days	5%	20%	2.5%	10%	<0.5%	<5%
~Minutes	5%	20%	2.5%	10%	<0.5%	<5%

Short-term solar UV variability (days to months) is caused in first order approximation by excess radiation of plages (UV intensity is modulated by the evolution of the plages, and by their passage across the solar disk as a result of the solar rotation). However, there are strong indications that a so-called third component may significantly contribute to the 11-year cycle variation. This third component may consist of small, isolated chromospheric brightnings distributed over the whole solar disk, or a uniform variability of chromospheric temperature. It is obvious that total solar irradiance measurements cannot distinguish between the two- or three-component model, however, the understanding of the solar cycle and its underlying magnetic variations requires a resolution of this problem.

Therefore, a need exists for synoptic observations of the sun over a solar cycle at all UV wavelengths with good spatial resolution (~1 arc second) and appropriate time resolution (~1 day).

The correlation of atmospheric parameters with the solar cycle, taking into account quasi biannual oscillations which were first found by Labitzke[11], has survived severe statistical tests. Furthermore, it has now also been detected in tropopause weather patterns. Although it is at present only a statistical correlation, solar terrestrial physics has the mandate to find a plausible mechanism which couples either solar constant variations, solar UV flux variations or changes in solar corpuscular emission with tropospheric weather patterns.

6.3.3 Solar/Stellar Relationships

One of the major discoveries of the first comprehensive x-ray observatory, the Einstein Observatory, was that stellar coronae are common phenomena, arising naturally in cool stars as a result of the convective transport of energy in the outer envelopes of these stars, and by a variety of mechanisms in other circumstances, such as close binary pairs. Another major discovery of Einstein was that the quasar phenomenon, like the coronal phenomena, is essentially a result of the generation of very high temperature plasmas (10^7 to 10^9 K) by nonthermal processes, which involve the acceleration of particles to very high energy. It is a fact that the extensive community of astronomers which has formed to study coronal and other nonthermal phenomena in stars has come essentially from solar-physics. Clearly, the comparative study of solar and stellar coronal phenomena, and the relationship of coronal parameters to basic stellar parameters (mass, age, surface temperature, rotation rate, etc.) is essential if an understanding of coronal phenomena, and activity cycles in stars is to be achieved. The objectives of comparative solar/stellar studies are summarized in Table 6-5.

Table 6-5. Solar Stellar Properties

Objectives of Solar/Stellar Studies
Scaling of coronal properties (temperature, density, filling factor) with fundamental stellar parameters
Mass
Surface temperature
Surface gravity
Rotation rate
Properties of stellar activity cycles, scaling of activity cycle characteristics with stellar parameters
Comparative properties of stellar winds and the solar wind
Comparative properties of solar and stellar flares
Flares in main sequence and giant stars
Flares in "pathological stars," i.e., flare stars, close binaries

6.4 Present Program

The present program is summarized in Table 6-6. The data base from previous years is an important resource. The near-term programs, and the presently operating missions (SMM, rockets) can address specific problems, however they do not provide the very high resolution (~0.1 arcsecond) necessary for many critical problems.

Table 6-6. Present Programs—Solar Physics

Resources and Operating/Near-Term Missions
Data base from previous missions – Skylab, OSO series, P78-1
Operating:
SMM – Continue acquiring data base for > one 11-year cycle
Rockets – 5 year now—desirable to increase
Near-Term (<1995):
SolarA – some advances for all objectives but a small explorer—high energy very limited
SOHO – some advances for all objectives but flares
Rockets – 5 year – desirable to increase
MAX91—some significant advances possible but limited by short duration
Conclusion: Existing program is inadequate!

6.5 Potential Implementation Modes

In order to accomplish the broad objectives of solar physics over the next 25, or so, years a number of modes (Table 6-7) are considered. Following is a list of these modes with a brief statement of the advantages derived through the use of these modes.

1. Rockets and balloons: These modes are the most responsive in terms of the time from concept to data analysis. They are most supportive of the "graduate student" approach to developing scientific research, and have proven an excellent means for the development of new instrument and investigation techniques.
2. Small Explorer missions: This mode may be used to support relatively small groups of diagnostic instruments and innovative instruments for longer time periods.
3. Moderate Explorer missions: This mode of implementation begins to allow for the development of more comprehensive instrument packages. Single large instruments or multiple instruments may be included which provide high time and spatial resolution of specific solar structures.
4. Major missions: The major missions employ large single or multiple instruments, which are expected (with periodic servicing) to remain in orbit and operation for at least 10 years. The instruments for these major missions may be changed and upgraded over the life of mission.
5. Shuttle attached payloads: This mode of implementation is most beneficial for the employment of large instruments which do not require long duration (less than 10 days) missions. This mode is also useful for the testing of new instruments and the development of investigation techniques. Launch schedule uncertainties are a major problem.
6. Space station attached payloads: This mode of implementation (although presently uncertain) may be most attractive for the deployment of multiple large observatory instruments. The space station should allow for the accommodation of instruments requiring large footprints, and will provide power, thermal control, data handling, commanding, and other resources. In addition the ability to recalibrate, repair, and upgrade these instruments will significantly enhance the scientific return. Problems which could occur include contamination, light scattering from station structures, and disturbances caused by shuttle dockings and other space station operations.

6.5.1 Modeling and Theory Programs

In order to maintain a balanced program in solar physics, it is essential that the observational programs be complemented with a significant modeling and theory component. Such programs should include both a "pure theory" emphasis independent of flight programs, and more concrete efforts aimed at directly understanding and predicting observational results. The development of solar models and theories must be infused with experimental results, and experiments should be developed with an eye toward verifying the models and theories.

6.5.2 Data Analysis Campaign

To allow effective utilization of the wealth of data which has been obtained from prior

Table 6-7. Potential Implementation Modes

Modes	Time (Concept to Implementation)	Cost*	Instrument Modality
Rockets and ballons	∿1 year	(1)	Quick response, graduate student support
Small explorers	∿5 years	(2)	Single or multiple small instruments
Explorers	∿10 years	(3)	Large or multiple instruments
Moderate missions	∿15 years	(3)	Large or multiple instruments with "strap-ons"
Major missions	∿20 years	(4)	Large instrument, long duration, upgrades
Shuttle attached	∿8 years	(2)	Large instruments, development, calibration
Space station attached	∿10 years	(3)	Large instruments, long duration, upgrades
Lagrangian point orbits	∿15 years	(4)	Multiple instruments
Lunar basing	∿20 years	(4)	Large instruments, long duration
<1 AU platforms	∿20 years	(4)	Multiple instruments, steroscopic observations
"Event emphasis" data analysis missions	∿1 year	(1)	Quick response, to include models and theory

*Cost
(1) ⩽$1M (3) ⩽$500M
(2) ⩽$100M (4) >$500M

missions such as Skylab, P78-1, SMM and Hinotori, a series of data analysis campaigns is most appropriate. These campaigns might be implemented at the rate of one or two per year with the objective of addressing specific solar features through the review and analysis of data compiled from prior missions. Teams of investigators could be selected to work on "special emphasis" scientific programs using existing data resources. Teams would include not only experimentalists, but also specialists in the modeling and theories relating to the features under study. We expect that the state of knowledge in solar physics could be significantly enhanced by the implementation and proper management of such an effort.

6.5.3 Observational Modes

A broad attack on the basic solar plysics problem after 1995 must first consider the possible available platforms and the unique capabilities and limitations of each platform. These are (with foreign collaboration encouraged):

- Earth orbiting free flyers: Precise pointing, long-term undisturbed observations—full wavelength coverage
- Space station utilization: Heavy payloads with modest SS impact—availability of manned support
- Space shuttle: Flights of opportunity—verification in space of key instrument advances, calibration, and quick-return before long-term placement in space
- Suborbital flights: Same advantages as space shuttle and in addition low in cost and good for training of young scientists
- Solar orbiting-free flyer (~1 AU): Stereoscopic observations
- Lunar basing or Lagrangian point: No atmospheric disturbances—weight and volume limitations, satisfactory, if manned base support
- Inner planet observations: $1/r^2$ advantages for angular resolution, stereoscopic observations, low energy neutron spectroscopy
- Heliosynchronous orbit (approximately 0.1 AU): $1/r^2$ advantage for angular resolution, stereoscopic observations, low energy neutron spectroscopy

- Near-sun orbit: $1/r^2$ advantage for angular resolution, stereoscopic and in-situ observations, low energy neutron spectroscopy
- Solar probe (one short mission): $1/r^2$ advantage for angular resolution, stereoscopic and in-situ observations, low energy neutron spectroscopy

Note: $1/r^2$ advantage refers to the improvement in resolution and sensitivity of solar structures achieved by placing an observing platform closer to the sun than 1 AU.

A few remarks regarding Shuttle Attached Payloads are appropriate. After the Challenger accident, most of the Spacelab payloads in the space physics discipline were cancelled. Seven years of development were discarded. This resulted not only in a tremendous loss of future science which could have been obtained from multiple flights of scheduled instruments, but also in a crisis of confidence between NASA and the impacted sectors of the scientific community. This trend must be reversed. Sustained efforts must be made to find flight opportunities for existing instruments or, if this is not possible, other means to carry out the investigations. However, there exists a *class of instruments which must be carried by the shuttle* because of the need for long-term (approximately solar cycle) measurements which require periodic reflights and calibrations between flights. Some of these experiments are scheduled on the ATLAS mission which must be flown periodically over the next 10 years simultaneously with the UARS satellite for calibration purposes.

6.6 Solar Physics Strategy

6.6.1 Introduction

We have identified three major goals of "pure" solar physics:

1. Understanding the phenomenology displayed by the sun, including the activity cycle, the generation of the corona and the solar wind, the acceleration of energetic particles in flares, and the structure and dynamics of the heliosphere.
2. Understanding the variability of the radiative and particulate output of the sun, and its effect on planetary ionospheres, atmospheres and magnetospheres, particulary those of the earth.
3. Understanding solar phenomena, such as particle acceleration, coronal heating and solar wind generation, in relation to similar phenomena in other astrophysical settings.

Each of the objectives will require specialized programs and specific measurements to address the outstanding problems. A basic solar physics strategy to obtain the necessary observations is presented in Table 6-8. The objectives of the missions listed in the table are summarized in Table 6-9. The study of solar phenomenology, for example, requires very high spatial and spectra resolution to achieve a physical model of the small scale structures which control the flow of mass and energy in the atmosphere. Also required are in-situ measurements of the microscopic conditions in the heliosphere, and remote observations of the global properties of the heliosphere.

The study of solar-terrestrial phenomena requires the precise measurement of solar outputs and their variation, and the understanding of the origins of this variation. Finally, direct measurement of coronal and other nonthermal phenomena on other stars is essential to an understanding of the sun in an astrophysical context. In the following discussion, we have specified the fundamental measurements which must be made, and commented on a strategy or strategies by which such measurements can be achieved.

6.6.2 Suggested Missions

We briefly describe each of the major goals identified above, and discuss missions by which these goals can be achieved.

The Solar Activity Cycle and the Magnetic Field

The thermodynamic structure and dynamics of the solar atmosphere are determined by the interaction of magnetic field and plasma on a very small scale. The objective of the Orbiting Solar Laboratory (OSL) is to provide the angular resolution, sensitivity, and stability to permit study of the fundamental interactions of solar surface wave and flow fields with the magnetic

Table 6-8. Solar Strategy

Strategy
• Orbital Solar Laboratory (OSL) is the top priority for solar physics
• Because Solar Physics has multiple objectives (solar phenomena, the heliosphere, solar terrestrial relations, astrophysical phenomena observable on the sun), several different types of solar measurements, and hence several types of solar observing capability, are required. The missions which are required are summarized below:
– Very high resolution instruments with diagnostic capability: OSL, High Resolution Telescope Cluster (HRTC), High Energy Instrument Cluster (HEIC) including the Pinhole/Occulter Facility (P/OF)
– Very high precision instruments for the study of the solar output and its variability: Solar Variability Observatory (SVO), Janus
– Multiple in situ and remote sensing (for global structure) instruments to study the heliosphere: Solar Probe, "Heliosphere"
– Comparative solar/stellar observations of coronal, cycles, etc.

Table 6-9. Summary of Solar Missions

Solar Physics	SOHO/ Cluster	OSL	HRTC	HEIC	Solar Probe Heliosphere	SVO Janus	Scout/ Explorer
Convection zone	✓						
Photosphere/chromosphere		✓		✓			
Transition reg./corona/ solar wind	✓		✓	✓			
Solar wind/heliosphere	✓		✓		✓		
Solar Terrestrial Relations							
Solar output/variability						✓	
Terrestrial response						✓	
Solar Stellar							
Stellar and solar corona, flares, winds							✓

Nature of Missions	Scout	Expl	Mod	Maj	Shuttle Attached	Space Station Attached
OSL			✓			
HRTC:P/OF			✓			✓
HEIC:P/OF			✓			✓
Solar probe				✓		
"Heliosphere"	✓		✓			
SVO/Janus			✓		✓	✓
Solar/stellar	✓	✓				

field at the scale of 100 km. OSL is complementary to Solar and Heliospheric Observatory (SOHO), Solar-A, the NOAA x-ray imaging monitor and the ground-based project in the primary objective of understanding the solar cycle.

OSL is the highest priority mission in the discipline of solar physics. The priority has been recently reaffirmed by the Space and Earth Science Advisory Committee. The future strategy for solar physics and the ability of the discipline to contribute with fundamental understanding to the "input" side of solar-terrestrial studies depend upon the early implementation of this keystone mission. The capabilities of OSL are summarized in Table 6-10.

Table 6-10. Orbiting Solar Laboratory (OSL)

OSL Major Facilities	
Photospheric magnetic and velocity field (visible light)	
High spatial, high spectral resolution	
0.1 arcsecond	$\lambda/\Delta\lambda$ >500,000
Long time sequences	~days (SS orbit)
Chromospheric and transition zone spectroscopy (UV)	
Spatial resolution	0.5 arcsecond
Spectral resolution	$\lambda/\Delta\lambda$ ~30,000
Coronal imaging and spectroscopy (XUV, x-ray)	
Spatial resolution	0.5 arcsecond
Spectral resolution	$\lambda/\Delta\lambda \gtrsim 100$

A thorough understanding of the convective conditions in the sun which underlie the solar activity cycle will require the study of the solar oscillations, which will be one of the objectives of the SOHO mission.

High-Energy Investigations of Solar Phenomena

The most striking accomplishments of the SMM and Hinotori missions have been the realization that the very efficient acceleration of individual electrons and ions to relativistic energies on short time scales is a fundamental property of solar flares and probably of other cosmic plasmas. An understanding of this phenomenon would have ramifications in the broadest astrophysical context. The specific parameters and observations needed are as follows:

- The species and maximum energies of accelerated particles. This information can be derived from measuring the spectra of x-rays, gamma rays, and high-energy neutrons with high time and energy resolution.
- The physical properties of the acceleration region, such as its location and composition. This requires precise imaging of hard x-ray and gamma ray emissions to MeV energies and measurement of gamma-ray spectra with the highest energy resolution.
- The geometry of the accelerator. This requires determining the angular distribution of secondary neutral emissions from individual flares and can be accomplished by high resolution imaging, stereoscopic observations, Doppler shifts of gamma-ray lines, and polarization measurements of bremsstrahlung and nuclear emissions.

By focusing strong effort on one of the most fundamental problems of solar flare physics, one can expect to advance to an understanding of how the flare itself is triggered and how the energy released is distributed in numerous other forms and transported throughout the solar atmosphere.

The properties of the high energy instruments necessary to address these objectives are summarized in Table 6-11. Some of the instruments required are high resolution gamma-ray and neutron spectrometers which can be accommodated on a platform with only modest pointing capabilities. This group of instruments is referred to as the High Energy Facility (HEF). The hard x-ray and gamma-ray imaging instruments will make use of coded aperature imaging techniques, and will be part of the Pinhole/Occulter Facility (P/OF) described below. Together, the high energy instruments are referred to as the High Energy Instrument Cluster (HEIC).

Table 6-11. High Energy Instrument Cluster [Thrust through 2002 (next solar maximum after 1991)]

Major objective—advance aggressively to an understanding of high energy particle acceleration
Parameters and measurements
Accelerated species and maximum energy of each species
High energy and high time resolution spectra of x-rays, γ-rays, neutrons
Acceleration region (e.g., location, composition...)
Imaging x-rays and γ-rays to 1 arc second
High energy resolution spectra
Geometry of accelerator
Angular distribution of emissions from:
High resolution imaging, stereoscopic observations
Nuclear line Doppler shifts and polarization
Bremsstrahlung polarization

High Resolution Studies of Chromospheric and Coronal Structure and Dynamics

The upper chromosphere, transition region, corona, and corona/solar wind interface span temperatures from 5 x 10^4 K to 10^7 K. During flares, plasma with quasi-thermal temperatures as high as 10^8 K are generated. These plasmas are confined to very small structures, especially in the early phase of flares. A cluster of high resolution hard x-ray, soft x-ray, x-ray ultraviolet (XUV) and EUV telescopes able to carry out diagnostic observations on spatial scales of ~50-100 km (~0.1 arc second) is necessary to address fundamental issues such as:

- Coronal heating of active regions loops
- Mass transport between coronal and chromospheric structures
- Generation of the solar wind

- Acceleration, transport, and thermalization of energetic particles.

Many of the required instruments can be incorporated in a High Resolution Telescope Cluster (HRTC), which can accommodate the required high resolution soft x-ray, XUV, and EUV telescopes. The measurement of the faint structures in the corona/solar wind inteface will require occulted telescopes, which are most effectively incorporated into the P/OF mentioned above. The hard x-ray imaging observations will require the use of coded aperature techniques, which can be accommodated on P/OF.

The Advanced Solar Observatory

Many of the problems pertaining to high energy phenomena on the sun will require the combined power of the OSL, and instruments described in the discussions of High Energy Investigations and High Resolution Studies. This set of instruments will have the highest resolution and sensitivity of any of the instruments envisioned in this report, and are collectively referred to as the Advanced Solar Observatory (ASO). The ASO instruments are most effectively packaged into four ensembles: the OSL, a Pinhole/Occulter Facility which makes use of Fourier transform imaging techniques and occulted coronal telescopes which use a remote (~50 meters) occulter/mask; a HEF which incorporates high energy gamma-ray and neutron spectrometers; and a HRTC. The properties of these ensembles are summarized in Table 6-12. The OSL is already NASA's highest priority for a moderate mission. The other ASO instrument ensembles (HEF, P/OF, HRTC) could be deployed on the manned space station, on a co-orbiting platform, or on two moderate size spacecraft, such as that planned for the OSL. Perhaps initial deployment on the space station, and later extended deployment on another platform is the most logical approach. The HRTC telescopes, the OSL, and the HEIC [including hard x-ray and gamma-ray imaging (i.e., P/OF)] must be capable of being operated as a single observatory, as described in the Advanced Solar Observatory SWG Report(12). Instruments for the HEF are described in a recent publication(13).

Heliospheric Studies

The solar corona (where the solar wind is formed) remains one of the most ill-observed regions of the solar-terrestrial environment, in spite of the fact that a total eclipse can make some of it directly visible to the naked eye. Some of the observational problems can be eased by new missions that emphasize (a) remote sensing; (b) stereoscopic viewing, to permit tomographic reconstruction of the corona's three-dimensional geometry; and (c) direct in-situ measurements of conditions in the heliosphere. These needs can be met by deep-space observatories (heliosynchronous, Lagrangian-point, or planet-based) carrying relatively low-resolution solar imaging instruments such as (a) white-light and UV coronal imagers, (b) soft x-ray telescopes, (c) low-frequency radio receivers and solar energetic particle and solar-wind particle measuring instruments, and by a probe of heliospheric conditions as close to the sun as possible.

The extended solar atmosphere (the heliosphere) is extensive and highly structured. To understand the dynamics of the heliosphere, it is necessary to observe the physical processes occurring on microscopic and macroscopic (meters to kilometers) scales, as well as the global structure and dynamics (i.e., coronal mass ejections). Accordingly, both in-situ missions such as a Solar Probe, capable of approaching the sun to within 4 solar radii, and a complex of remote sensing platforms which allow stereoscopic imaging of the far corona (e.g., ISPM) as well as in-situ sampling of heliospheric conditions both in and above (or below) the ecliptic are essential. We call the later complex of platforms "heliosphere"; heliosphere might include a "heliosynchronous orbiter" and an "interstellar probe" which could travel beyond 100 AU from the sun.

The Solar Probe would carry out the first in-situ exploration of the solar corona, penetrating to a height of about 4 solar radii above the photosphere. This innermost region of the solar wind approaches the "temperature maximum" of the corona, where the heating is the strongest, and remains one of the most inaccessible frontiers of

Table 6-12. ASO Instrument Ensembles

Instrument	Spectral Range	Aperture	Resolving Power			Field of View (arc min)
			Angular (arc sec)	Spectral (g) (E/ΔE)	Temporal (sec)	
High Resolution Telescope Cluster (HRTC)						
Soft X-Ray Telescopes[a]	1.5 - 170 Å	40 cm	0.15/0.4[f]	10,000	0.01	3.5' x 3.5'/12' x 12'[d]
XUV Telescopes[b]	150 - 310 Å	40 cm	0.1/0.4[f]	20,000	0.01	3.5' x 3.5'/12' x 12'[d]
EUV Telescope	550 - 1100 Å	40 cm	0.1/0.4[f]	30,000	0.1	3.5' x 3.5'/12' x 12'[d]
Gamma Ray Imaging Detector	2 - 1000 keV	60 cm	1.6	10	0.001	full sun
X-Ray Flare Spectrometer	1.5 25A	40 cm	1.0	10,000	0.01	full sun
Global Dynamics Instrumentation[c] (GDI)	3500 11,000 A	50 cm	0.5/5[c]	100,000[c]	1.0	full sun
Ultraviolet Telescope	1175 1700 A	60 cm	0.1	30,000	0.1	3.5' x 3.5'
High Energy Facility (HEF)						
Gamma Ray Line Spectrometers[e]	10 keV 10 MeV	30 cm/60 cm	—	400/20	1/0.25	full sun
High Energy Gamma Ray Spectrometer	10 MeV 100 MeV	100 cm	—	5	0.001	full sun
High Energy Neutron Spectrometer	10 MeV 1000 MeV	100 cm	—	5	0.001	full sun
Low Frequency Radio Spectrograph	1-20 MHz	30,000	90	200	1	full sun
Pinhole/Occulter Facility (P/OF)						
Coded Aperture Imager	2-70 keV	100 cm	4.0	10	0.001	full sun
Fourier Transform Imager	2-1000 keV	100 cm	0.2	10	0.001	full sun
White Light Coronagraph	1100-11,000 A	50 cm	1.0	5,000	1.0	full sun
EUV Coronagraph	300 1700 Å	50 cm	1.0	20,000	0.1	full sun
Orbiting Solar Laboratory (OSL)						
Optical Telescope	2000-1700 Å	100 cm	0.1	100,000	0.1	1.3' x 1.3'/3' x 3
Ultraviolet Telescope	1175 - 1700 Å	30 cm	0.5	30,000	0.1	4' x 4'

a Our strawman configuration envisions two soft x-ray telescopes with spectral coverage 1.5 - 2.5 Å and 10 - 170 Å
b Our strawman configuration envisions three XUV telescopes with spectral coverage 150 - 180 Å, and 280 - 310 Å
c The Global Dynamics Package includes four small telescopes
d Possible long-term future upgrade for the OSL ultraviolet telescope
e Entries refer to high resolution and high sensitivity spectrometers respectively
f Entries refer to high resolution and wide field modes respectively
g Figure refers to highest resolution mode. Other modes may have lower resolution.

corona, where the heating is the strongest, and remains one of the most inaccessible frontiers of the heliosphere. The Solar Probe should carry instrumentation for the measurement of the magnetic field and of the populations of thermal and energetic particles, including neutrals; it should also carry out spectrophotometry of the outer corona by viewing outwards from the sun.

Solar-Terrestrial Physics

The sun/heliosphere/Earth system forms a tightly coupled physical system, which must be studied as a single entity with simultaneous observations of the solar radiative and particulate outputs, the transport of the solar particulate output to the Earth, and the response of the Earth's magnetosphere, ionosphere and atmosphere to these inputs. An attempt will be made to measure the solar EUV ($120 < \lambda < 400$ nm) with the required precision and accuracy from the UARS satellite and the shuttle "Atlas" missions starting in 1991. However, because of the limited lifetime of UV photometers, *new instruments must be flown no later than 1995.* We propose a "Solar Variability Observatory" to carry out these important observations (Table 6-13). Any platform which can be pointed toward the sun is suited. The *space station* must be *favored* because its instruments can be exchanged

Table 6-13. Solar Variability Observatory Solar Component

	SMM	UARS	EOS	Space Station
Spectral irradiance $120<\lambda<400$ nm		XX 91-	XXX 95-	
Spectral irradiance 15kΛk120 nm				XXX 95-
Spectral irradiance Soft x-rays				XXX 95-
Imaging 120kΛk400 nm Imaging 15kΛk120 nm				XXX 95- XXX 95-
Imaging Soft x-rays				XXX 95-
Total solar const.	X	XX 91-	XXX 95-	

X Ongoing XX Future Effort XXX New Initiative periodically. It is necessary to *add high precision photometers for the XUV regime* because no efforts are ongoing at the time being. Table 6-13 lists planned solar irradiance measurements, and the components of a future Solar Variability Observatory.

To carry out a comprehensive measurement of the variation of the solar irradiance and particle output and of the response of the Earth's ionosphere, magnetosphere, and atmosphere to these variations, we purpose a two-spacecraft mission which we call Janus.

The Janus mission is named after the Roman god of gates and doorways who, having two faces, looked both ahead and behind. The name is appropriate because the primary spacecraft is to be located at the Lagrangian libration point L1 between the sun and the Earth and is equipped with both sun viewing and earthward looking instruments.

The objective of the Janus mission is the study of solar-terrestrial relationships from the global perspective. It utilizes both in-situ and remote sensing techniques to observe the solar input and global response of the earth's atmosphere. Absolute calibration of Janus instruments will be maintained by periodic comparison measurements on the space shuttle or space station, and calibrating the Earth's global photometry by using stars as calibration standards. This will produce a record of Earth's luminosity which should be extremely accurate and which can be reviewed in 100 years to detect long-term trends. Two spacecraft provide the necessary observing perspective, Janus L1 at the libration point and Janus Polar in high (ca. 18 hour) circular polar orbit.

The purpose of Janus L1 is to observe the solar electromagnetic, particle and magnetic field input to the Earth vicinity, and to carry remote sensing instruments to image the sunlit hemisphere of the Earth to obtain precise albedo measurements. The solar instruments are tailored to the particular solar-terrestrial task.

The Janus Polar satellite is intended to provide global remote sensing coverage of the polar regions, the day-night terminators and the dark side of the earth. In the course of a year Janus Polar will acquire detailed coverage of seasonal effects such as auroras, distribution of trace gases, ozone distribution, etc., in both hemispheres. The satellite will be equipped with appropriate in-situ particle and field sensors to trace the magnetospheric effects of the incident streams observed by Janus L1.

Although the Janus mission deserves careful and thorough definition, the two spacecraft will need to include instruments of the following types:

Janus L1
- Solar viewing:
  - Solar constant monitor
  - UV irradiance monitor
  - Soft x-ray photometers
  - Soft x-ray or XUV imager for coronal structure data
  - Wide angle coronagraph for mass ejection data
- Earth viewing:
  - Geocoronal imagers
- In-situ particle and field monitors

Janus Polar
- Earth viewing:
  - Auroral imager
  - Ozone imager
- In-situ particle and field monitors

The Janus concept is described in Table 6-14 and Figure 6-3.

Comparative Solar/Stellar Observations

A logical approach to the comparative study of coronal phenomena on the sun, and on other

Table 6-14. Solar-Terrestrial Mission "Janus"

Janus Concept
1. Earth as a "sun": Earth irradiance photometry
Global composition and physical properties of the earth
Global ozone and other minor constituants of the upper atmosphere
Global cloud coverage, thunderstorms
Global albedo of the solid earth
2. Earth as a planet: Earth imaging
Structure, dynamics of the atmosphere
Global hydrology oceans and atmosphere
Ocean temperature, ice caps, desertification
3. Earth as a "long-term variable star": Search for global changes

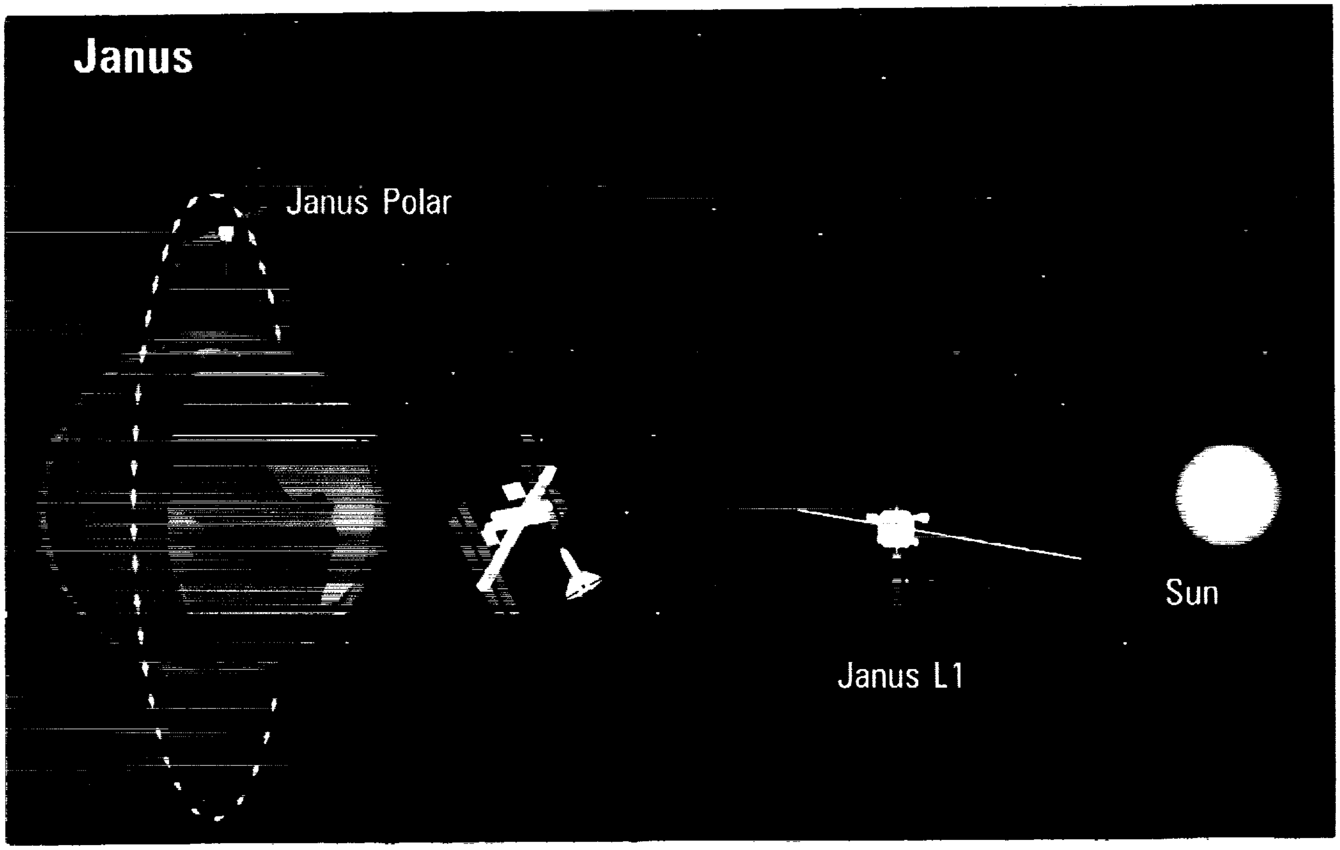

Figure 6-3. The Janus Mission

stars, is the development of a small dedicated spacecraft which can complement IUE (and the projected Lyman mission) by observing both the sun and nearby stars at XUV, EUV, and soft x-ray wavelengths.

6.7 Advanced Instrument Development

Most solar space instrumentation planned for flight on long-duration platforms in the next decade is based on technical developments which are 10 to 20 years old. Ten years ago, NASA substantially curtailed large-scale support of future technology. Examples of areas urgently in need of development funds are two-dimensional detector arrays for UV, x-ray, and gamma-ray wavelengths, and new optical technologies. Instruments now under construction for missions such as SOHO, may, therefore, carry considerable risk. Instruments planned for future missions, such as OSL, need a catch-up effort of uncertain outcome. Twenty years ago several industrial efforts were supported with research funds which resulted in useful products. Most of these efforts have disappeared. For example, images obtained by the Naval Research Laboratory (NRL) XUV monitor on board Skylab (flown 15 years ago), which were based on technology developed 20 years ago, have never been superceded. This is an extremely alarming trend that needs to be rectified by steady, generous support of future technology developments.

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