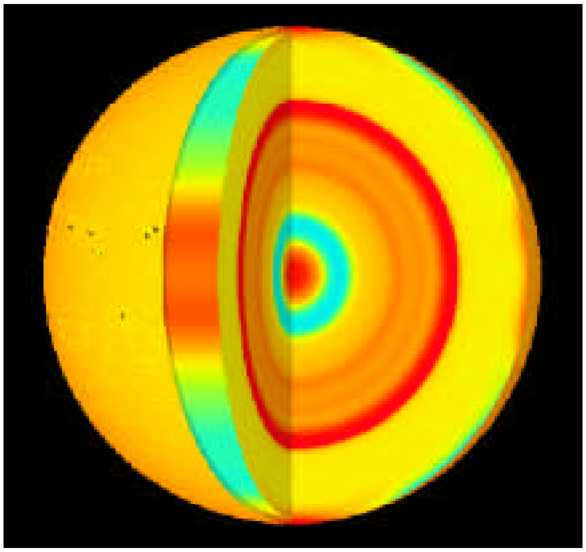
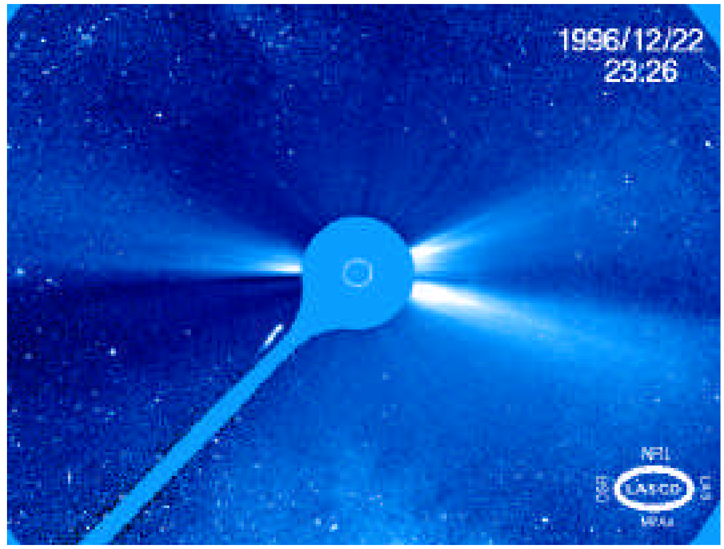
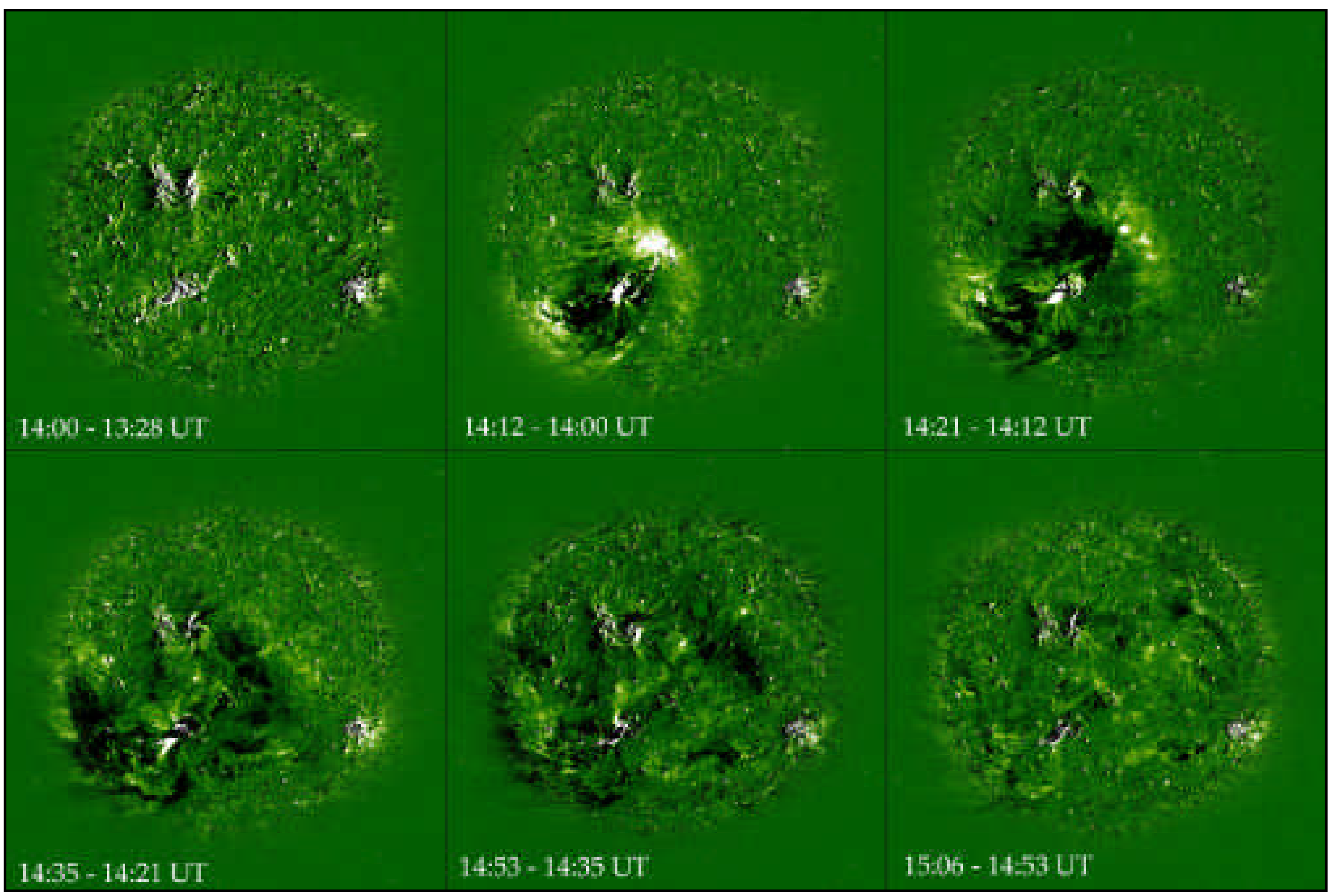





Proposal for

# SOHO Solar Maximum Science Program

May 1, 1997



## *I) Executive Summary*

The current Sun-Earth Connections complement of spacecraft provides humanity with an unprecedented opportunity to understand the Solar System in which we live. This understanding is essential if we are to understand the boundary conditions for the development of life and if we are to continue our expansion from the earth. While this proposal emphasizes the importance of the SOHO component of this system, we must use the opportunity to obtain adequate resources for the space physics community to continue our search for understanding of the Solar System. The elimination of or a major cut in any of the Sun-Earth Connections missions will represent the abandonment of a unique opportunity to make major strides in improving that understanding — an opportunity unlikely to present itself again in the foreseeable future.

The scientific return from SOHO has been spectacular even though we are just one year into the nominal mission. SOHO's power to shed new light on solar-terrestrial disturbances *when its measurements are combined with those from other space physics spacecraft* has been realized only during the last few months. Several discoveries from SOHO are discussed in the Overview (Section II) and Summary (Section VII), below.

In order both to extend our understanding of the effects of the rise phase of the solar cycle on the solar interior, surface magnetic fields, corona, and solar wind and to seize the opportunity for joint solar-terrestrial research provided by the combination of SOHO, GGS, Ulysses, and *Yohkoh*, we propose a four-year re-use of the existing SOHO resources: the SOHO Solar Maximum Science program. (The Scientific Programme Committee of ESA has unanimously approved an extension of the SOHO mission, an ESA "Horizon 2000" cornerstone mission, into CY 2003.)

The SOHO Solar Maximum Science program would combine cost-effective operation of all the SOHO instruments at their full scientific potential while significantly increasing the availability of SOHO data and the pool of resources to allow the US research community to analyze those data. In fact, the MDI and EIT PI's have announced their intention to place all their instruments' data in the public domain as soon as possible in a SOHO Solar Maximum Science program: there would be no proprietary data analysis period. The other SOHO PI's have similarly announced the public availability of a "solar variability" data set that will also be placed in the public domain with a minimum of delay.

While a Guest Investigator program is not part of the baseline budget proposal, a SOHO Solar Maximum Science program would only be able to achieve its potential for advancing our knowledge of the Sun-earth system if accompanied by a strong GI program. Likewise, the benefits of interdisciplinary science can only be realized if an integrated GI program covers the entire range of an extended ISTP program.

Finally, while SOHO has directed significant resources to public education and outreach activities with notable success, there is much more we could be doing in this area, which is crucial both to our nation's continued leadership in technology and to accountability to the taxpayers who make our scientific endeavor possible. We therefore propose a modest increase in education and outreach funding to enlarge the scope and impact of these activities.

The following individuals were among those involved in the writing of this proposal on behalf of the SOHO Science Working Team: A. Poland (GSFC), J. Gurman (GSFC), A. Title (LMMSC), J. Mariska (NRL), G. Brueckner (NRL), P. Scherrer (Stanford U.), J. Kohl (SAO), J. Raymond (SAO), A. Galvin (U. Maryland), F. Ipavich (U. Maryland), and P. Martens (ESA)

### *Cover figures*

*Upper left:* *Radial and latitudinal variations of sound speed, as determined from inverting SOHO-MDI observations, relative to values from a "standard" solar model. Red corresponds to positive difference, blue/green to negative.*

*Upper right:* *Electron-scattering image of the corona to 30 $R_{Sun}$ from the SOHO-LASCO C3 coronagraph, 1996 December 23. The bright, extended object just above the pylon to the southwest (lower left) of the occulting disk is sungrazing comet SOHO-6. The background is the center of the Galaxy. The small, white circle in the center of the occulting disk represents the disk of the Sun.*

*Bottom:* *Time series of first difference images from SOHO-EIT of a coronal Moreton wave expanding from the site of a small flare. The original images were obtained in the Fe XII emission line at 195 Å, formed at 1.5 MK.*

# II) Overview

## *The SOHO Mission and its Role within the ISTP*

***SOHO is part of ISTP*** The International Solar Terrestrial Physics (ISTP) program is a joint project of the United States, ESA, and Japan to understand the fundamental processes of the Earth-Sun system. These processes include stellar convection, magnetic dynamo action, generation of stellar winds, gravity, and fundamental particle physics. The Solar and Heliospheric Observatory (SOHO) is one of the ISTP system of spacecraft. SOHO's task in the endeavor is to study the Sun from its deep interior to just before the Earth's magnetosphere. By flying at L1, 1% of the distance to the Sun on the Sun-Earth line, SOHO is ideally situated continuously to monitor the Sun, the inner heliosphere, and the solar wind particles streaming toward the earth.

***ISTP is a Framework for Solar-Terrestrial Science*** Space physics has a variety of spacecraft to study the Sun-Earth system. The total system is beginning to function extremely well as is evidenced by our ability to observe and quickly bring together the total picture of mass ejections from when they leave the Sun to when they interact with the magnetosphere (cf. http://sohowww.nascom.nasa.gov/gallery/current). As we move toward solar maximum, expected in 2000 or 2001, this coordinated set of missions will greatly enhance our understanding of the Sun and the reaction of the earth and its environment to solar variations.

***SOHO and Space Weather*** While space weather monitoring is not a SOHO or ISTP science goal per se, the advanced warning provided by direct observations of solar disturbances, and the nearly one hour travel time for typical solar wind at L1 before it reaches the earth, has made both the remote and *in situ* SOHO observations a valuable input component for NOAA's SEC space weather prediction service. This is only possible because of the timeliness of the release of SOHO data to the public, typically within a day for snapshots of the solar images, and literally within minutes of realtime acquisition (and within hours for playback acquisition) for the solar wind proton parameters.

***SOHO's Goals*** The SOHO mission has three principal goals: to gain an understanding of the mechanisms responsible for the heating of the Sun's outer atmosphere; to determine where the solar wind originates and how it is accelerated; and to measure the properties of, and flows in, the solar interior. The goal of a re-use of SOHO — the SOHO Solar Maximum Science program — is to understand how the processes inside the Sun and its surrounding atmosphere change during the rise to and through an activity cycle maximum.

## *SOHO Science Goals: Historical Perspective*

***Scientific Relevance -Atmospheric Heating*** It has been nearly 60 years since the discovery that the outer atmosphere of the Sun is three orders of magnitude hotter than the surface, and nearly 40 years since mass flow from the Sun, a solar wind, was predicted. In the early 1960's the existence of the solar wind was confirmed on the first NASA/JPL *Mariner* Mission. The *Skylab* Mission in the early 1970's established that the high speed solar wind has its origin in unipolar magnetic regions that have an overlying atmosphere that emits lower than average EUV and soft X-ray flux — coronal holes. These observations established a causal connection between regions on the Sun and geomagnetic variations on the earth that had been observed since the middle of the 19th century. A few years later, the *Orbiting Solar Observatory-8 (OSO-8)* showed that the corona was NOT heated by acoustic waves, previously thought to be the most likely heating method. The *Solar Maximum Mission* (*SMM*) in the 1980's established that the Sun was a variable star whose total luminosity changed in phase with the solar magnetic cycle. The Japanese *Yohkoh* mission has shown that a significant fraction of coronal heating is spatially and temporally localized and most probably results from magnetic reconnection. Magnetic reconnection, previously thought to occur slowly if at all in the highly conducting outer atmosphere of the Sun, is now observed to occur on scales from the resolution limit of YOHKOH (~ 5 arc seconds) to a solar radius or more.

***Scientific Relevance -Solar Interior*** In the 1960's it was discovered that the entire surface of the Sun was constantly in motion and that local areas of the photosphere moved with a period of about five minutes. Initially the motions were thought to be local responses to convective plumes below the surface and the five minute period just the natural buoyancy frequency of the atmosphere. In the early 1970's theoreticians predicted that the oscillations were the atmosphere's response to global modes in the interior. Within a few years these predictions were verified and the discipline of helioseismology was born. By precisely measuring the frequencies of the modes it is possible to determine temperature, density, equation of state, elemental and isotopic abundances, interior mixing, interior rotation, and interior flow systems as a function of solar radius, longitude, and latitude. Therefore, it is possible to verify models of stellar interiors and stellar evolution by direct measurement. A secure understanding of the solar interior is essential to establishing whether the observed lower than expected solar neutrino flux is due to an incomplete understanding of conditions in the solar interior or of the fundamental physics of elementary particles. The measurements of flow patterns and rotation in the solar convection zone are key to the development of models of stellar convection and the generation of magnetic fields by dynamo action.

## *SOHO New Discoveries*

With the very earliest observations, SOHO's instruments verified once again that the variety of nature exceeds the human imagination. The coronal instruments, the Large Angle and Spectrometric Coronagraph (LASCO) and Ultraviolet Coronagraph Spectrometer (UVCS), revealed an unexpectedly dynamic and organized outer corona. The beauty of the coronal images is breathtaking (see cover, top right). The LASCO movie of a 30 solar diameter field around the Sun as it passes through the Milky Way, enhanced by the passage of a Sun grazing comet and a coronal mass ejection (CME) is simply glorious. UVCS has discovered coronal emission lines with excpetionally broad profiles, which could well be evidence for MHD wave damping in the corona. The magnetograph record (see Figure 1) of the Solar Oscillations Investigation (SOI) has revealed in detail a continuously erupting magnetic carpet on the Sun that is causing a reevaluation of how magnetic flux is distributed from active regions to the poles and hence how the solar cycle operates. The new technique of time-distance helioseismology has produced the first images of convection below the directly visible surface (see Figure 2). Because of SOHO's three-axis stabilization, CELIAS has been able to detect many previously unobserved isotopes, and to observe short time-scale changes in solar wind composition for the first time.

## *Operations, Data Access, and Instrument/Spacecraft Status*

***Operations*** The SOHO instruments (see Table 1) were selected to complement each other (cf. Figures 5, 6, and 7 of Domingo *et al.* 1995, *Solar Physics*, 162, 1). The helioseismology instruments on SOHO measure the surface magnetic fields, the surface flows, and flows and plumes below the surface. The coronal instruments provide both high spatial resolution maps of the locations of the energy releases and spectral diagnostics to determine the mechanisms of the release processes. The all sky H I Lyman α imager shows the region where the wind interacts with the interstellar neutral hydrogen and finally, the particle

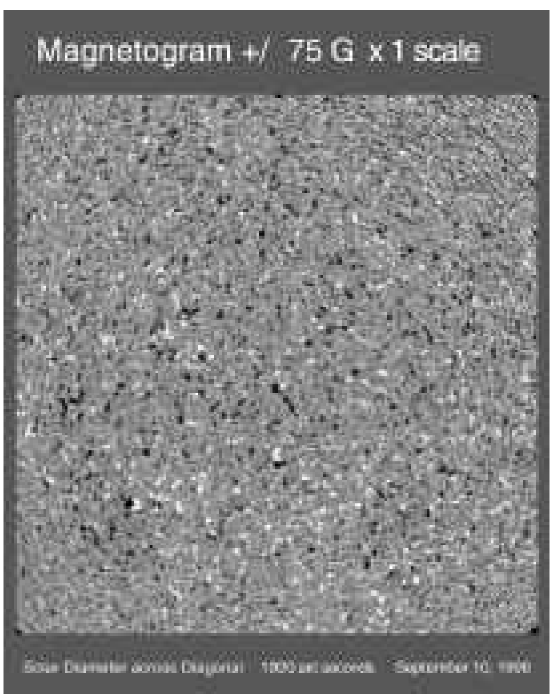



***Figure 1.*** *The longitudinal component of the "Quiet" Sun photospheric magnetic field, as measured every 96 minutes by SOHO-MDI. Dark and light areas represent fields of opposite polarity.*

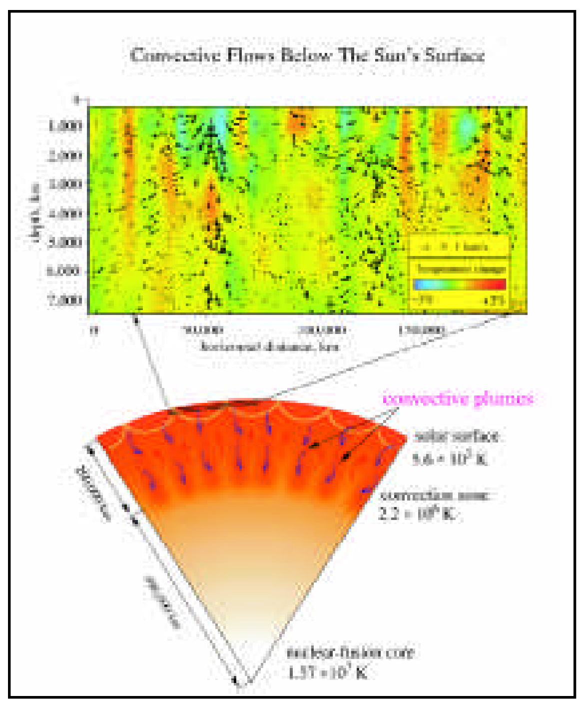



***Figure 2.*** *The first view of a stellar convection zone: an early result from a time-distance helioseismology inversion of SOHO-MDI/SOI observation*

detectors measure the energy and constitution of the particles accelerated toward the Earth. The data produced by all the instruments operating together provide strong constraints on possible coronal heating mechanisms as well as establishing the locations of the heating and acceleration regions. In addition, the coordinated mission concept included pre-mission coordination of data formats, analysis software, and instrument operation methods; an agreement to share the basic data in near real time, a joint central Experimenters' Operations Facility (EOF), and topical Workshops. In operation a regular schedule of joint planning sessions, and daily coordination of observations have made SOHO function as a science data system.

**Table I**

| | | |
|---|---|---|
| **Helioseismology** | | |
| GOLF (Europe) | Global Sun velocity oscillations (l=0-3) | Na-vapor resonant scattering cell. Doppler shift and circular polarization. |
| VIRGO(Europe) | Low degree (l=0-7) irradiance oscillations and solar constant | Global Sun and low resolution (12 pixels) imaging |
| MDI/SOI (U.S.) | Velocity oscillations, harmonic degree up to 4500. Also solar B field. | Fourier tachometer, angular resolution: 1.3 and 4" |
| **Solar Atmosphere Remote Sensing** | | |
| SUMER (European with significant U.S. Co-I) | Plasma flow characteristic (T, density, velocity) chromosphere through corona. | Normal incidence spectrometer 50-160nm, spectral res. 20,000 to 40,000; angular resolution ~ 1 arc sec |
| CDS (European with significant U.S. Co-I) | Temperature and density: transition region and corona | Normal and grazing incidence spectrometers, 15-80nm, spectr. res. 1,000-10,000, angular res. ~3" |
| EIT (European with significant U.S. Co-I) | Evolution of chromosphereic and coronal structures | Full disk images (42'x42' with 1024x1024 pixels) in He II, FeIX, FeXII and Fe XV. |
| UVCS (U.S. with significant European Co-I) | Electron and ion temperature, densities, velocities in corona (1.3-10Ro) | UV coronagraph; profiles and/or intensity of selected EUV lines (Ly-$\alpha$, OVI, etc.) |
| LASCO (U.S. with significant European Co-I) | Evolution, mass, momentum and energy transport in corona (1.1-30Ro) | 1 internally and 2 externally occulted cornagraphs; Fabry-Pérot spectrometer for 1.1-3Ro |
| SWAN (European with minor U.S. Co-I) | Solar wind mass flux anisotropies and its temporal variations | Scanning telescopes with hydrogen absorption cell for Ly-$\alpha$ light |
| **Solar Wind 'In Situ'** | | |
| CELIAS (European with significant U.S. Co-I) | Energy distribution and compostion (mass, charge, chargestate)(0.1-1000kevV/e) | Electrostatic deflection, time-of-flight measurements. Solid state detectors. |
| COSTEP (European with minor U.S. Co-I) | Energy distribution of ions(p,He) 0.04-53MeV | Solid state and plastic scintillator detectors. |
| ERNE (European with minor U.S. Co-I) | Energy distribution and isotopic composition of ions (p-Ni) 1.4-540MeV/n and electrons 5-60MeV | Solid state and plastic scintillator detectors |

**The SOHO Scientific Instruments**

***Data access*** Although it was not envisioned in 1988, the World-Wide Web has allowed the SOHO data to be widely and nearly instantaneously distributed to the international scientific community, students, and the general public. "Outreach" has been raised to a new level. By typing http://sohowww.nascom.nasa.gov/ anyone anywhere on the Internet can get immediate access to the daily SOHO data base as well as to a wealth of information, which includes current images, solar movies, observing plans, details of the mission, and descriptions of the instruments. Web tools allow anyone access to the record of SOHO observations and the means to request scientific data. The SOHO Data Archive is operational at GSFC and copies are in various stages of development in Europe at Institut d'Astrophysique Spatiale (IAS), Orsay (France), Rutherford-Appleton Laboratory

(UK) and Universita di Torino (Italy). The visibility and connectivity created by the SOHO Data Archive has allowed more scientific data to be distributed in a shorter time than any previous scientific mission.
***Instrument and Spacecraft Status*** All of the instruments on SOHO and the spacecraft itself are in excellent condition and engineering evaluations indicate they will continue to operate for at least the next five years. The ESA Solar System Working Group and the ESA Science Programme Committee have both advised ESA management that SOHO operation should be continued for an additional 5 years. The purpose of this proposal is a parallel recommendation to NASA management.

***Proposal Organization*** This proposal is divided into seven major parts - SOHO Science; Operations, Data Access, and Educa-tion/Outreach; Plans for the SOHO Solar Maximum Science program, Implementation of the SOHO Solar Maximum Science program, a Summary of Scientific Impact, and Programmatics. In the SOHO Science section, we describe how the SOHO instruments function as a system, the principal results of the first year of operation, and a sample solar event followed from the Sun to the Earth through the operation of the ISTP instrument set. In the Operations subsection, we describe the labor-intensive but scientifically rewarding science operations process, including the ways in which we involve the larger community in SOHO observations and data analysis. In the Data Access and Education/Outreach sections, we detail how both qualified investigators and the general public are able to use SOHO data. In the Plans for the SOHO Solar Maximum Science program section, a basic set of measurements used to characterize the dynamic Sun is defined and science plans for the rise to maximum and the period following maximum are presented. A brief Implementation plan describes how we will save development costs by achieving the Solar Maximum Science program goals with existing capabilities. In the Scientific Impact Section, we summarize some of the most interesting results from the mission so far, and what we hope to achieve in the SOHO Solar Maximum Science program. Finally, in the Programmatics section, we describe the current budget and that required for the “minimum viable” science program.

# *III) SOHO Science*

## *1. The Solar Interior and Solar Surface*

***The three interior and surface instruments*** on SOHO are GOLF, VIRGO, and MDI, all of which measure properties of the solar interior via the techniques of helioseismology. GOLF measures the net velocity fluctuations of the entire Sun, VIRGO measures the intensity variations of the Sun in a dozen zones, while MDI makes maps of the entire surface in velocity, intensity, and magnetic field on a grid of 1024 x 1024 points. The GOLF and VIRGO instruments are designed to achieve high absolute precision in velocity and intensity respectively in order to detect the *g*-modes. The results from VIRGO are used to calibrate the MDI measurements, while MDI maps of magnetic field and surface intensity are necessary for the interpretation of the GOLF and VIRGO frequencies and VIRGO radiometry. In addition VIRGO makes high precision measurements of the surface irradi-ance.

***GOLF, VIRGO, and MDI all operate continuously*** in gathering their basic data sets. In addition MDI takes data optimized for coordinated observations with the other SOHO experiments. In particular MDI follows the generation and evolution of mag-netic fields on the granulation to global scale with a spatial and time resolution sufficient to, for the first time, follow the life-cycle of magnetic fields. MDI also provides measurements of relative brightness of active and quiet regions to enable better understanding of the radiative flux balance data obtained by VIRGO and the behavior of the outer atmosphere followed by CDS, SUMER, EIT, UVCS, and LASCO. It also provides direct measurements of surface motions from meso-granulation through to global scales.

***Continuous observations are necessary*** for some of the primary helioseismology objectives. There are two fundamental rea-sons for this. The first, is that the *g*-mode signal, if present in the surface oscillation, has a submillimeter amplitude in the individual modes. To obtain the signal to noise ratio necessary to detect such low amplitude patterns requires long uninterrupted data sets. The second, is that reliable inferences about the structure and rotation of the solar interior from inversions of the p-mode data requires frequency accuracy of a few tens of nano-Hz. Because of the fundamental relation between frequency accuracy and measurement duration, years of observation are required. The region of the Solar interior that most needs a long duration is the energy generating core. The present limits of accuracy provide tantalizing hints of mixing. Other primary objectives need continuous sequences of days to months. These include the goals that can be addressed by the new science of Local Helioseismology, which allows imaging of the motions in the interior of the star.

***The key scientific issues of the interior and surface*** The data from the helioseismolgy instruments address global properties of the solar interior, variations of solar luminosity, interior and surface flows, and magnetic field evolution. These areas are obviously tightly coupled and a breakdown into categories is due largely to the experimental techniques used to study the topics. In the following subsections, we give the key goals of each major category, a brief overview of the rational for that task, and an indication of key progress in the first year of observations.

## *Global Properties of the Solar Interior*

***Radial Stratification of the Solar Interior***-Determine the spherically symmetric components of the mean radial structure of the Sun in pressure, density, composition, and sound speed. The structure of the solar interior is nearly spherically symmetric, so it is convenient to separate the radial stratification from any non-spherical effects. *p*-and *g*-mode seismology determine the spherical averages of pressure, density, temperature, and chemical composition as a function of depth. Since the determinations depend on the physics of the solar material - the equation of state and the opacity, interior mixing, and diffusion- accurate agreement of observation and theory requires accurate understanding of the interior properties. Fortunately, there is a rough spatial separation of effects in the Sun. In the bulk of the convection zone opacity plays a small role because the temperature gradient is essentially adiabatic. Beneath, the convection zone the principal contributors to the equation of state (H and He) are nearly fully ionized, causing the opacity part of the heavier elements to be the principal physical issue.

The first long series of medium-*l* *p*-mode data has now been analyzed. The spectral noise is much lower than corresponding groundbased data., which gives confidence that the noise is of solar origin. The inversions of this data shows a region of high sound speed not predicted by current models at the base of the convection zone (see Figure 3). The observation is consistent with additional turbulence at the bottom of the convection zone.

***Core Structure*** In order to be able to determine the mean physical parameters in the vicinity of the solar core it is necessary to detect and classify several low degree *g*-modes. Knowledge of the basic physical properties of the core will establish whether the solar neutrino problem is due to properties of the solar core or requires a better understanding of the particle physics. The core structure is dependent upon the degree of internal mixing during the solar evolution, which is of crucial importance for understanding of stellar evolution.

Because of the discovery nature of the *g*-mode search, the probability of success is difficult to estimate. A theoretical estimate of amplitude given by Kumar, Quataert and Bahcall (ApJ Letters, 458, L83-L85, 1996) is 0.03 cm/s for the lowest order modes. At this time GOLF can detect modes with an amplitude of 0.4 cm/s. GOLF has a chance of approaching the estimate of Kumar et al. It is also possible that the amplitude estimate based on the *p*-modes may not take into account all the properties of turbulence that could put energy

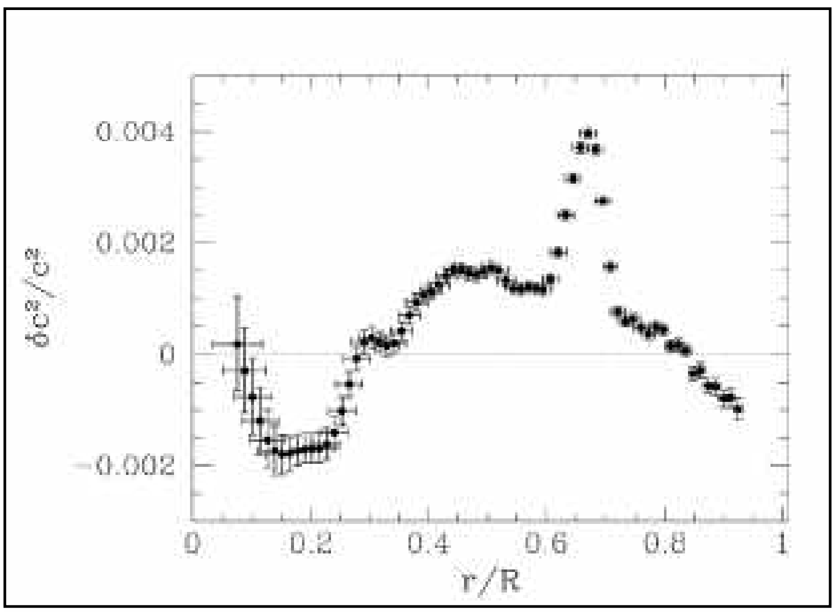



***Figure 3.*** *The relative differences between the squared sound speed in the Sun and in a standard solar model (using the most recent information on nuclear reaction rates,radiative opacity, and equation of state), inferred from two months of MDI medium-l (l < 300) data. The horizontal bars show the spatial resolution, and the vertical bars are error estimates. The peak just below 0.7 r/R is significant, but the dip near the core may be due to one of several possible systemmatic errors.*

into the much longer lived *g*-modes.

The principle difficulty in identifying the *g*-modes is the interference from incoherent solar processes which produce the observed background spectrum. The dominant process in the g-mode frequency band is thought to be the supergranulation. Because GOLF observes the entire Sun, rotation and limb darkening cause different parts of the solar disk to contribute by variable amounts to the observed Doppler signal. Consequently, the instrument does not respond uniformly to all of the supergranules on the surface. MDI provides separate velocities for each part of the solar image and this spatial information provides a mechanism to reduce the amplitude of the supergranule component of the noise signals. VIRGO produces data from 12 pixels so that the MDI derived correction can be verified if GOLF and VIRGO *g*-mode frequencies are identical.

***Internal Rotation***-Determine the rotation rate as a function of radius and latitude. Internal rotation causes splitting of the *g*- and *p*-modes. Inversion techniques using the measured splittings yield the radial and latitude dependence of the internal rotation. This knowledge is essential for understanding solar and stellar evolution. The interaction between rotation and convection is critical to understanding solar activity, the generation of magnetic fields, and the nature of the solar dynamo.

Shown in Figure 4 is the spherically symmetric solar interior rotation determined from the SOI medium-*l* data. The figure shows a shear layer in the region that separates the differentially rotating convection zone and the more rigidly rotating core. This result combined with the observation of greater turbulence in this layer is evidence for the site of the generation of the solar cycle dynamo. From low degree *p*-mode analysis there are currently no indications that the core region is spinning extremely rapidly; the most probable value is near the surface rotation rate.

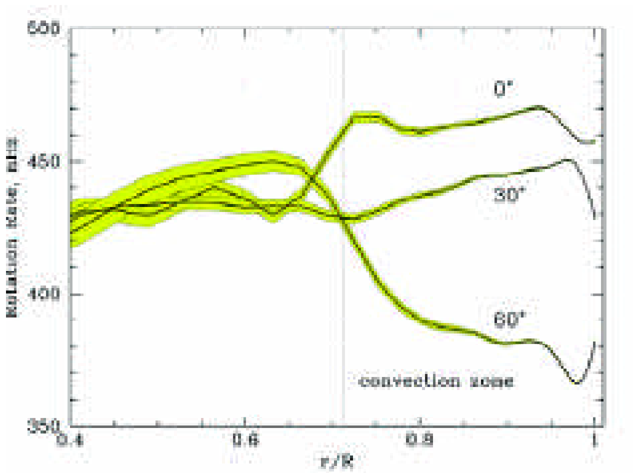



***Figure 4**. The solar rotation rate inferred from two months of SOHO-MDI medium-*l *(*l* < 300) solar* p*-mode observations, as a function of radius at three latitudes (0°, 30°, and 60°).*

***Excitation and Damping*** Explore the coupling of acoustic-gravity waves to turbulent convection. Determine mode lifetimes, and elucidate the driving mechanisms. It is now agreed that p-modes are excited by turbulent convection. Not only the dependence of the amplitude upon the frequency, but also the temporal modulation of solar *p*-modes can be well described as an ensemble of stochastic oscillators. The asymmetry in oscillatory line profiles provides information about the location and coupling of the source turbulence to waves. The lifetimes of modes are indicated by their line widths in the power spectrum. The damping of *p*-modes, however, depends on several effects: non-adiabatic interaction due to radiative transfer, coupling with the turbulent convection and scattering of the acoustic waves by turbulent flow fields. As the form of a line may be influenced by the way the time series are analyzed this method has yielded controversial results. The same may apply to the analysis of the amplitude modulation of modes.

Analysis of high frequency ridges and p-mode asymmetries observed in both velocity and intensity indicate that at this time in the solar cycle the sources of the acoustic waves are about 50 km below the surface. There are some indications that the excitation level varies with latitude currently peaking near 40 degrees north and south.

Comparison of MDI, GOLF, and Virgo data have verified that the time series and spectra of low degrees modes observed simultaneously in each quantity are virtually identical. This means that the spectral details observed by the instruments are due to the properties of the stochastic, excited, damped oscillations in the Sun rather than instrumental effects. Thus, analysis can proceed with confidence that solar sources and damping are being evaluated.

***Solar Background*** Determines the global characteristics of small scale solar surface phenomena. The shape, time variation and amplitude of the solar noise signal is directly dependent on the flux parameters of solar surface structures. From the study of this signal it is possible to deduce the global characteristics of granulation, mesogranulation, supergranulation and active regions. This information is necessary to estimate how surface velocity structures affect line profiles and line profile asymmetries on the Sun and other stars. Resolution of controversies on the existence of planets are dependent on the understanding of line profile shapes.

From low to high *l* the solar noise level has been reached and very careful analysis has begun to separate small systematic noise sources.

## *Variations of Solar Luminosity*

***Radiometry*** Determine spectral and total irradiance variations and the spectral and spatial distribution of radiation, to provide accurate input for heating of the solar outer atmosphere and for terrestrial climate modeling.Two decades of observations of solar irradiance show that the solar energy flux varies over a wide range of periodicities: from minutes to the 11-year solar activity cycle. Since we only observe the Sun's irradiance from one direction in space, we must determine whether the observed irradiance variations represent changes in the luminosity, or are a result of the angular distribution of the radiation from the structured photosphere. The solar cycle related long-term irradiance changes represent real luminosity changes, whereas the short-term variations from days to months caused by active regions via the combined effect of dark sunspots and bright faculae may have a large component due to the distribution of the radiation from these localized sources. Since variations in the solar energy flux - persistent over long periods of time - may trigger climate changes, it is fundamental to understand the underlying physical mechanisms.

Empirical models of total irradiance, solely based on surface magnetic field effects, underestimate the observed changes at the maxima of solar cycles 21 and 22. The origin of the discrepancy may be temporal changes in differential rotation in the interior, the magnetic fields near the base of the convective zone, large scale mixing flows, or large scale convective cells. The VIRGO total and spectral irradiance observations with the high resolution solar images and magnetograms from MDI and the low resolution LOI images will clarify which solar irradiance are related to the localized magnetic phenomena such as sunspots and faculae and diffuse bands with slight temperature differences. While the helioseismology data from GOLF, VIRGO, and MDI will determine how temperature structures propagate through the solar interior.

The spectral distribution of total irradiance variability is not yet known. Since the Sun's energy input is the main driver of the physical processes within the Earth's atmosphere, understanding the underlying physical mechanisms and determining the contribution of various spectral bands to the total flux variability are at the center of studying the climate impact of solar variability. The VIRGO integrated-light and spectral irradiance observations in the near-UV, visible, and near-IR, together with the UV observations of the UARS, NOAA-9, and NOAA-11 satellites and the EUV observations of SOHO's CELIAS/SEM, provide the first real opportunity to estimate the spectral distribution of the changes in the solar energy flux. The ultimate goal is to understand how, why, and on what time scales, the mechanism governing the solar energy flux varies. From this reconstruction and prediction of the solar induced climate changes might be possible.

***EUV Radiometry*** Determine, with more precise photometry than ever before achievable, the variation in the solar EUV bands most responsible for changes in the terrestrial thermosphere. The CELIAS SEM is a well calibrated EUV sensor that to date has measured the short-term (including flare-related) variations in the EUV irradiance, and the rotational modulation in that signal; as active regions rotate onto and off the visible hemisphere. Continued observations into the next phase of the solar cycle would be of extreme interest due to the expected increase in solar activity, both because most of the total luminosity variations over the solar cycle are believed (but not yet conclusively proven) to occur in the UV, and because very little is known of the solar EUV irradiance variation during the rising phase of the solar cycle.

***Figure of the Limb*** Study long-term variations in the figure of the limb.

The expected accuracy of limb shape determination has been realized. Results from the first SOHO roll observations produced the most precise determination of solar oblateness. There is no excess surface oblateness. The *p*-mode ridges are clearly visible in the limb data with individual mode amplitudes measurable in micro-arc-seconds (corresponding to a few meters).

Initial analyses of the shape of the Solar limb have been surprising. The data show evidence for a larger new component of the Solar figure - "mountains" on the sun with horizontal scales several times supergranule scales and height scales of hundreds of meters. Simultaneously we have seen evidence for similar scale structures in both direct Doppler data and in line-depth observations. We have not yet combined the three types of observations to see if this new component of structure is the tail of the supergranular spatial and temporal spectrum or if it is an indication of a previously unobserved phenomenon.

## *Interior and Surface Flows*

***Supergranulation*** Study the evolution of supergranular convection cells and magnetic network reorganization. The distribution of active region magnetic fields over the surface are thought to be due to the interaction of supergranules and magnetic fields.

Data from the very first high-resolution observations demonstrated the potential of the time-distance local helioseismology that allows imaging of the bulk motions on the meso-granulation to super-granulation scale well into the convection zone. The first results showed supergranules to have a shallow structure with a depth to width ratio of 1:10. Software has been developed to identify and track supergranulation cells. Initial results show that half the cells are lost in 20 hours. We are currently constructing high resolution data sets of 90 hours duration and will shortly have an initial estimate of the mechanisms for the evolution of supergranulation.

***Large-Scale Surface Flows*** Search for large-scale convection cells and associated thermal structures.

Both time-distance and ring analysis of this data have shown that there is a rotation shear in the top 0.5% of the Sun. Analysis of full disk data using time distance methods has shown that differential rotation differs in the north and south hemispheres, confirming inferences from magnetic field pattern rotation. Comparison with the surface flows directly observed in the Doppler signal shows nearly identical flow patterns.

***Active Region Seismology*** Measure the scattering and absorption of waves by active regions; search for wakes behind sunspots; search for pre-eruptive magnetic fields. At solar minimum, it has not been possible to obtain sufficient data to advance this area of study; further progress must await the accumulation of more active region data. Observations are currently underway.

## *Magnetic Evolution*

***Magnetic Fields*** Determine how the quiet and active magnetic fields evolve in time and space. The large scale pattern of magnetic fields over the solar surface is well explained by a model that takes as its source emerging active regions and as its distribution mechanism diffusion and meridional flow. The mechanism for diffusion is thought to be supergranulation evolution. In quiet Sun magnetic fields are observed everywhere. This field is due to local emergences that may not contribute to large scale field evolution, but do play a major role in heating of the outer atmosphere and generation of the solar wind.

A previously under-appreciated mechanism for renewal of the network field has emerged. Small magnetic bipolar flux element pairs are continually emerging at random locations within supergranules. The elements are rapidly swept to the cell boundaries, the two polarities moving independently to different sections of the network where they both cancel and replace the existing dominant polarity. This provides a mechanism to refresh the dominant polarity while at the same time changing the photospheric location of flux elements at a speed comparable to the horizontal flow speed rather than the much slower random walk time. The entire network flux is rearranged in less than a day by this mechanism, and the total flux in the quiet Sun is replaced in two to four days. There are profound implications for coronal heating.

At least 90% of the flux at minimum has an origin in local structures. It is now clear that this is not simply due to recycling of existing flux. There is sufficient flux emerging on the scale of ephemeral regions that there must be some mechanism for local generation. It is not presently clear if the continual rapid rearrangement of photospheric fields on supergranular scales is directly connected with the continuous stream of tiny CME's seen by LASCO or the jets and brightening seen by CDS and SUMER. However, cotemporal observations have been made and detailed analysis is in progress.

High cadence, multi-day series of magnetograms are leading to a new appreciation for the dynamics of magnetic field patterns. A movie has been prepared with the 96-minute cadence of full disk magnetograms from April to January. It clearly shows that the solar magnetic field is continuously changing even at Solar minimum.

***Summary of Status***

All of the helioseismology instruments are meeting or exceeding their design goals. The duration of the observations has not been long enough to discover *g*-modes, but the solar noise level in the *g*-mode band is lower and flatter than anticipated. The first year of observations has shown that the solar surface and the region ten to twenty thousand kilometers below the surface are much more complex than previously thought. There are rotational shears, evidence for a circumpolar jet, large scale flow patterns, evidence for fluctuations in surface height, evidence that the *p*-mode excitation is very near the surface, and evidence for local generation of magnetic fields. These surface phenomena are visible because of the seeing free and continuous viewing that SOHO provides. The new technique of time-distance helioseismology allows imaging of a most interesting region where the transition from convective to radiative transport occurs.

## 2. The Outer Solar Atmosphere and the Solar Wind

SOHO studies the outer atmosphere and solar wind with two groups of instruments: EIT, CDS, and SUMER study the transition region and inner corona at moderate to high spatial resolution and UVCS, LASCO, and SWAN provide data on the outer corona including the solar wind acceleration region. MDI supports these data sets by providing a record of the surface magnetic field and its evolution.

The primary goal of the coronal instruments is to investigate the physical mechanisms that heat the corona and accelerate the solar wind. While several space-based instruments have focused on these problems, SOHO's is the first comprehensive instrument system with sufficient time resolution to follow the dynamics, spatial resolution to image the many distinct features, and spectral resolution to determine accurately the temperature, density, and velocity. Previous satellite instruments have suggested that much of the energy that heats the corona is input on small spatial and temporal scales and that there are larger scale flows of energy toward and away from the surface. SOHO, with its unique combination of spatial, spectral, and temporal resolution, has finally revealed in detail the richness of the structure and dynamics of the quiet solar transition region and corona.

Although the first year of SOHO operation has not definitively answered the global questions of coronal heating and solar wind acceleration, the unprecedented detail it provides has led to significant new insights and understanding of the solar atmosphere. For example, while it is too early to be certain, it appears that the location of the accelerating region, and the rate of acceleration, for the low-latitude, slow solar wind have been discovered, and unprecedented spectroscopy of the extended corona is revealing evidence for MHD wave energy deposition as well as large differences from photospheric abundances. In what follows, we present some of the new results and insights derived from the SOHO data.

## Dynamics and Heating

***Transition Region Dynamics.*** Although highly dynamic events can show large upward mass flows, one of the great paradoxes of transition-region physics is that high spectral resolution observations show that most locations in the quiet solar transition region show redshifts—the plasma flow is predominately downward. Before SOHO, accurate transition-region flow velocities could only be measured up to temperatures of a little more than $10^5$ K. Now SUMER has extended those observations through the upper transition region to the low corona. These studies show that over most of the quiet solar surface the downflow velocity peaks at a temperature near $10^5$ K, but that persistent downflows remain up to the base of the corona. While explosive events produce some upflows, they do not appear to provide enough mass to account for the downflows. Only additional, detailed, coordinated observations among the transition-region and coronal instruments on SOHO will solve this puzzle.

***Active Regions.*** Even though SOHO is operating through the current solar minimum, it has observed many active regions from both the old and new solar cycles. These observations have enhanced our understanding of active region structure and dynamics. (See, for example, Figure 5.) Combined observations from EIT, CDS, and SUMER clearly show that active regions consist of collections of loops with a variety of properties in close physical proximity to each other. Many of the loops contain only transition-region plasma. CDS has found that active regions often contain very bright, compact areas seen at $2 \times 10^5$ K and $4 \times 10^5$ K (O V and Ne VI lines), sometimes extending in temperature up to $6 \times 10^5$ K (Mg VII line), but not reaching $9 \times 10^5$ K (Mg IX). The lifetimes of the bright sources are at least 12 hours, with one observed to last for more than five days. These intense compact sources are located very close to sunspots, overlying at least the sunspot penumbra, and sometimes also part of the umbra.

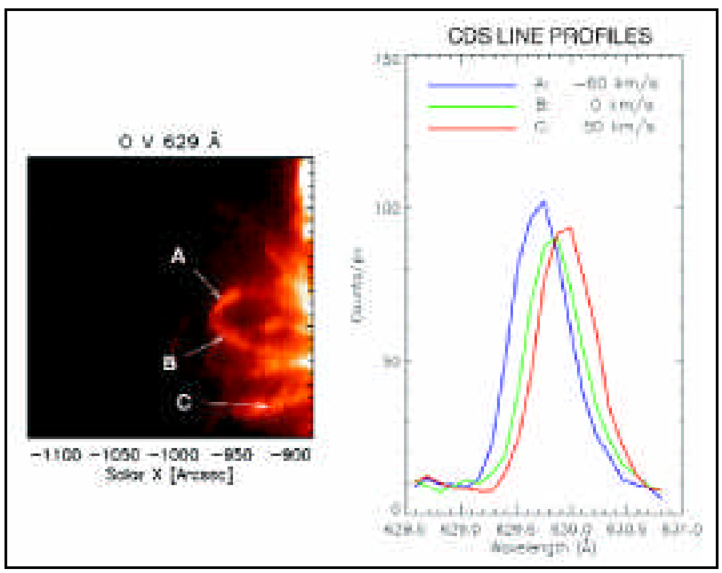



*Figure 5. SOHO-CDS image of a system of loops on the E limb of the Sun in O V 629 Å (formed at ~ 0.25 MK). Along any one loop, and from loop to loop, there are large differences in line-of-sight velocities. SOHO has given us the first opportunity to image such features in several temperature regimes simultaneously, while accumulating line profile information in every image pixel.*

In an effort to understand how active regions are heated, SOHO transition-region data are being explored to study various aspects of variability of active region emission lines and structures. For example, CDS observations with 30 s cadence show oscillations of He I ($2x10^5$ K) and O V ($2.5x10^5$ K) intensities taking place on time scales of 5-10 min. Amplitudes of the order of 10-15% are common, but intensity bursts with a 50% amplitude taking place in the legs of a magnetic loop have also been recorded. CDS has also observed other transient phenomena that are possible signatures of heating taking place in a large coronal loop over one hour period, resulting in changes in the intensity distributions along the loop; an appearance of a loop seen in all temperatures from $9x10^4$ to $10^6$ K, which was seen only for 36 minutes and decayed afterwards; and explosive brightenings taking place in small loops in an active region.

Ratios of EIT images can yield temperature information in the range 1.0 - 2.0 MK. Full-disk temperature maps (Figure 6) have revealed a startling result: the area of the corona in which active regions are responsible for enhanced heating is much larger than the bright loop systems visible in a single waveband (*i.e.*, where the density is enhanced). Work is in progress to obtain a better temperature calibration for EIT ratios in order to determine the net increase in coronal heating in the lower-density regions.

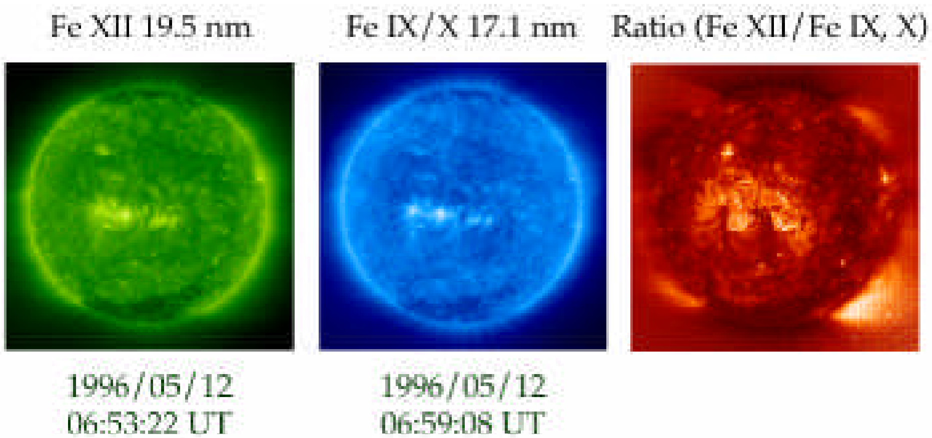



***Figure 6.*** *Nearly simultaneous SOHO-EIT images of the inner corona in 1.0 MK (*left*) and 1.5 MK (*center*) plasma. In the ratio (*right*), bright areas are hotter than dark areas; the area of active region heating is much more extensive than indicated by the bright (high density) loop structures in either intensity image.*

***Jets and Network Phenomena.*** Jets and other features of the quiet solar network may provide keys to the nature of both atmospheric heating and transition region mass balance. Both SUMER and CDS have studied jets and explosive events extensively. The SUMER observations have for the first time provided reliable statistics on the temperature and velocity distributions of these events as well as their birthrates. SUMER observations suggest that some jets display both the morphology and physical characteristics of magnetic reconnection. CDS has detected jets or explosive events at coronal temperatures. These are pockets of flows, with speeds over a few tens of km $s^{-1}$ to hundreds of km $s^{-1}$. However, they are usually seen in active region loops and are not as common as one may have expected from HRTS or SUMER data from cooler lines.

CDS has discovered so-called “blinker” events. These are sites in the network which show significant brightening over a few minutes at intermediate temperatures. They are found anywhere over the quiet Sun—with roughly 3000 present on the Sun at any time. Each contains only about $10^{25}$ ergs of thermal energy but they may be the visible part of more energetic events. Indeed, their global nature suggests that they may be related to global processes such as heating.

***MHD Wave Heating.*** MHD waves are one of the leading contenders for heating the solar corona. One way to search for these is to examine in detail the profiles of coronal emission lines. Using this technique, UVCS has measured velocity distributions of several particles of different mass and charge-to-mass ratio in the extended solar corona. At the base of equatorial streamers, which have the highest densities in the extended corona, the observed velocity distributions along the line of sight (LOS) nearly correspond to a single kinetic temperature. Large departures from a thermal distribution occur in lower density regions of both equatorial streamers and polar coronal holes. For example, at heliocentric heights of 3 $R_{sun}$ in polar coronal holes, $O^{5+}$ velocities at 1/e ($v_{1/e}$) are more than 2.5 times larger than those of protons (compared to the ten times smaller $O^{5+}$ value expected in a thermalized plasma). In such regions, the observed $v_{1/e}$ for $O^{5+}$ of 575 km $s^{-1}$ along the LOS would correspond to a temperature of 3.2 $10^8$ K in a thermalized plasma. The $v_{1/e}$ of the protons would correspond to a temperature of about 3 $10^6$ K and the electron temperature at that height in coronal holes is expected to be less than $10^6$ K. Similarly, in equatorial streamers, $v_{1/e}$ along the LOS for protons and $O^{5+}$ become equal at $4.7_{sun}$ at values corresponding to 1.3 $10^6$ K (protons) and 2.1 $10^7$ K ($O5^+$). In other words, not only are the kinetic temperatures larger for the higher mass particles, which is contrary to most earlier theoretical models, but also the velocities are extremely large.

The higher $O5^+$ velocities compared to protons in polar coronal holes can not be explained by transverse wave motions caused by MHD wave propagation through the corona. They are, however, consistent with theoretical models in which charged particles are accelerated about the coronal magnetic field through ion cyclotron resonant acceleration by relatively high frequency MHD waves, which are assumed to exist. Further evidence for the ion cyclotron resonance process in the corona has been obtained by deriving the $O^{5+}$ velocity distribution along the radial direction from the intensity ratio of the O VI 1032 and 1037 Å lines, which are formed by a combination of collisional excitation and resonant scattering. The radial velocities, which are expected to be parallel to the magnetic field lines in polar coronal holes, are at least a factor of 6 smaller than LOS values, which are expected to be approximately perpendicular to the magnetic field in polar coronal holes. The ion cyclotron resonance process appears to operate in both coronal holes and equatorial streamers. Thermalizing collisions may mask the evidence for the process in the highest density regions. Work is continuing to determine to what degree coronal heating can be explained by the ion cyclotron resonance process, and to search for independent evidence for the existence of the required high frequency MHD waves.

## *Large-Scale Coronal Structure and Events*

The vastly improved dynamic range of LASCO compared to previous coronagraphs and its 30 $R_{Sun}$ field of view are revolutionizing our concept of the solar corona. Presented in movie form the LASCO data have, for the first time, revealed the small scale jets, eruptions, and reconfigurations associated with both the gradual and disruptive evolution of coronal structures. At low altitudes, beneath the helmet streamer structure, the corona consists of large-scale magnetic loops associated with the small active regions present at this phase of the solar cycle. LASCO movies have shown that these loops are continually expanding outward. This continual expansion appears to provide sufficient mass and energy to completely regenerate the equatorial current sheet in a short period of time and to ultimately disrupt the streamer as a coronal mass ejection.

***Coronal Mass Ejections.*** LASCO observations are revolutionizing our view of coronal evolution. Earlier observations suggested that the corona evolved on time scales of days, with disruptions by large-scale CME’s. LASCO observations show that coronal mass ejections occur at a rate that is apparently more frequent than during previous solar minima. The CME’s can be large and as bright as those seen in the past, but in addition there are many smaller, less massive events. These observations show that coronal structures evolve continally in a manner consistent with the frequent generation of CME’s with a large range of sizes. UVCS spectroscopic observations of CME’s have shown bulk Doppler velocitiesof up to 200 km $s^{-1}$.

Many of the CME’s observed with LASCO indicate that a large portion of the solar corona must be involved in the CME process. These ‘global CME’s’ are accompanied by small but obvious ejecta on the opposite limb. How the corona organizes itself to generate such a global phenomenon is a major new problem for SOHO to attack.

## *Sources of the Solar Wind*

It is well known that the large scale magnetic structure of the Sun determines the overall structure of the corona. Compact active regions give rise to compact loops, which are imbedded in larger helmet-shaped regions, which are capped by long streamers. The low-speed solar wind originates from these streamer belts and perhaps from between the streamers. Much larger diffuse unipolar regions can generate open field regions in the corona—coronal holes. These open regions give rise to the high speed solar wind. While the locations of these wind components are understood in a global sense, only now is SOHO revealing the mechanisms that power the wind and the specific locations of the acceleration regions.

***Slow Speed Wind.*** Time-lapse sequences of coronal images obtained with LASCO have yielded important clues on the origin and acceleration of the slow speed wind. Because of LASCO’s sensitivity, dynamic range, and field of view, bits and fragments of material can be observed that appear to be torn off the tops of coronal streamers and carried passively outward like “leaves in the terrestrial wind.” The speed of the typical fragment doubles from 150 km $s^{-1}$ at 5 $R_{Sun}$ to 300 km $s^{-1}$ at 25 $R_{Sun}$. By tracking the outward movement and assuming that the fragments are tracers of a flow field, a constant acceleration of about 4 m $s^{-2}$ through the coronagraph’s 2-30 $R_{Sun}$ field of view is inferred. For a thermally driven wind, this implies that the coronal temperature does not fall off rapidly with radial distance as it would for an adiabatic expansion, but remains constant at about 1.1 MK out to 10-15 $R_{Sun}$ and that the sonic point is near 5 $R_{Sun}$.

UVCS images of streamers show striking differences between ions. Quantitative analysis yields abundances in the outer layers of the streamers in agreement with those observed in the slow solar wind. This supports a picture in which the slow solar wind originates from the sides of streamers as inferred from the LASCO tracer observations.

***Coronal Holes and High Speed Solar Wind.*** Observing the corona over the Sun's poles is a significant challenge. Here the corona consists of faint plumes aligned along the open magnetic field lines extending from the polar coronal hole. UVCS measurements of coronal hole outflows show speeds as high as 200 $kms^{-1}$ at 2 $R_{Sun}$. Time sequences of LASCO images show individual features in plumes with speeds of 350-500 $kms^{-1}$ compared to 100-150 km $s^{-1}$ at the same height in coronal streamers.

SOHO is now poised to exploit these breakthrough observations. As the mission continues, combining LASCO observations with those of MDI, EIT, CDS, SUMER, and UVCS should make it possible to learn in detail what maintains the coronal temperature as well as where the slow wind originates and how it is related to the Sun's magnetic field.

## *3.* IN SITU *SOLAR WIND*

***Solar Wind Plasma*** The CELIAS Proton Monitor (PM) measures ions *in situ* in the range 0.3 to 6 keV/e and generates values of the solar wind proton bulk speed, density, thermal speed, and north/south flow direction with a 30-second temporal resolution. With SOHO's position at L1, the Proton Monitor samples solar wind that has not been modified by the presence of the earth. (The solar wind plasma is decelerated and deflected in the presence of diffuse ion events in the earth's foreshock region.) Correlations of the "pristine" L1 solar wind with the near-earth ISTP solar wind data study the affect of the foreshock region on the solar wind. Spatial structures in the solar wind are also being studied using multiple spacecraft (SOHO, IMP, INTERBALL, WIND).

PM measurements of probable interplanetary shock waves were observed in early 1997. Preliminary evidence from other SOHO experiments (LASCO and/or EIT) suggests that these shocks may be associated with CME's (Coronal Mass Ejections). About 18 hours after the 1997 February 9 shock passage, the PM observed an unusual density rarefaction. (See Figure 7.) The density remained below 1 $cm^{-3}$ for about 5 hours, attaining a minimum value of ~ 0.2 $cm^{-3}$. These are the lowest densities observed by the PM in 14 months of operation. The very low solar wind ram pressure at this time would be expected to cause the earth's magnetopause and bow shock to expand to almost twice their nominal locations.

The CELIAS Proton Monitor solar wind data are provided within a few minutes (typically £ 30 min) of data acquisition to the solar-terrestrial space physics community and to the general public *via* the world wide web (http://umtof.umd.edu/pm). This site is in regular use by the NOAA SEL and the USAF for space weather predictions. For example, the Proton Monitor made and reported the first *in situ* measurements of the interplanetary manifestation of the CME event whose solar launch was observed by LASCO on January 6, 1997.

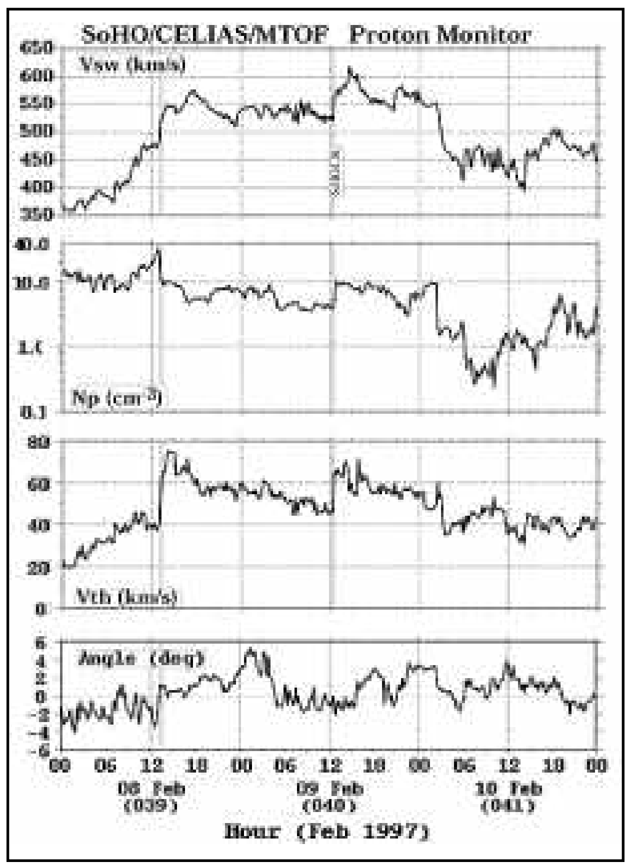



***Figure 7.*** *SOHO-CELIAS/PM measurements (10 min averages) for the 3-day period 1997 February 8-10. A high speed stream arrives on February 8, a shock on February 9, and the density rarefaction on February 10.*

***Solar Wind Elemental Abundances*** The CELIAS Mass Time-of-Flight (CELIAS/MTOF) sensor is a high resolution solar wind mass spectrometer ($M/\Delta M \geq 100$) which measures the elemental and isotopic composition of the solar wind over a wide range of solar wind bulk speeds. The MTOF sensor has met all design goals, and no degradation in instrument performance has been observed since launch. MTOF has already made observations of previously undetected species in the solar wind (Figure 8). The rare elements phosphorus, chlorine, potassium, titanium, chromium, manganese and nickel have been measured in the solar wind for the first time.

Some of these elements (P, Cl, K, Ti, Cr, and Mn) have no coronal spectroscopic measurements available. Hence, for these elements MTOF is in some sense providing the first "coronal observations", as the solar wind is the interplanetary extension of the corona. The MTOF sensor is routinely measuring isotopic abundance variations for several elements (neon, magnesium, silicon, sulfur, argon, calcium, iron, and nickel), some of which have never been previously observed in the solar wind, in solar energetic particle (SEP) populations, nor spectroscopically in the sun. Among the brand new isotopes are those of silicon, sulfur, calcium, chromium, and nickel. MTOF has presented the first fine time resolution of solar wind abundance variations for the elements Cr and Fe, and Fe isotopes.

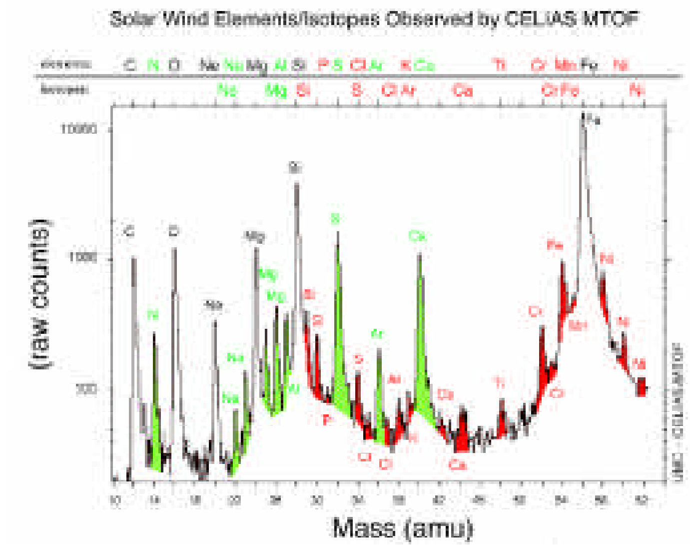



***Figure 8.*** *A SOHO-CELIAS/MTOF spectrum accumulated over three days period (uncorrected for efficiencies, but with the sensor set in a mode optimized for observing solar wind species with masses above that of sulfur).* Unshaded *peaks represent the elements commonly observed by* in situ *solar wind experiments; elements and isotopes in* green *are not observed routinely by conventional solar wind experiments; and elements and isotopes for which SOHO has made the first* in situ *spacecraft solar wind observations are in* red.

It is already established that solar wind and suprathermal (SEP) ion composition, both elemental and charge state, vary according to the source conditions. The so-called first ionization potential (FIP) effect, which reflects elemental fractionation in coronal and solar wind elemental abundances compared to photospheric values for elements with low FIP's ( < 10 eV ), has been observed using long time averages for slow and CME-related solar wind. The effect is much reduced in coronal hole solar wind. The reason for the "FIP effect" is not known, nor why it depends on solar wind flow type, but some of the current theories can be distinguished by what they predict for different elements based on different physical constants (e.g., in addition to FIP, there are theories involving the first ionization time, the ionization diffusion length, etc.). MTOF is making a unique contribution to this study, both in the number of elements that are observable for the first time by a solar wind experiment and by the time resolution of measurements. These include pivotal elements such as K, Na, Al, which have extremely low FIP's (< 6 eV), and S, P, and C which have FIPs in the transitional FIP region (near 10 eV).

Both chromium and iron are low FIP elements. The MTOF has obtained a slow solar wind elemental abundance ratio of $^{52}$Cr/$^{56}$Fe = 0.015 ± 0.003. This is similar to photospheric values and indicates that chromium behaves in the same manner as iron in the FIP fractionation process.

***Solar Wind Isotopic Abundances*** Solar wind isotopic measurements by CELIAS/MTOF are unique. Previous spacecraft measurements have been restricted to helium, and foil measurements from the manned lunar expeditions have given results only for helium, neon, and argon. The Apollo Foil Experiment indicated significant variations in the helium isotopic composition, but none were observed in the neon isotopic composition. It is generally assumed that the solar wind gives an unbiased sample of isotopic composition of the corona, and therefore the photosphere, which in turn is assumed to be representative of the outer solar convective zone. These compositions should then be close to the primordial composition of the solar nebula.

A strong isotopic fractionation in the solar wind is not expected, although weak effects may be caused by the ion-neutral separation process that takes place in the upper chromosphere/transition region, and potentially fractionation could result in the inner corona due to differences in Coulomb drag. The measurements from MTOF are being used to determine whether there are differences in relative isotopic abundances among different solar wind regimes (CME-related, coronal hole, or slow solar wind) or for the same type of solar wind, but as a function of solar cycle. Differences between different solar wind regimes or the absence of such differences can be taken as indicators of the faithfulness of solar wind particles of the solar surface composition.

**Solar Wind Charge State Abundances** The relative ionization states of ions in the corona depend on the local electron temperature and density, the ions' collisional ionization and radiative and dielectronic recombination rates, and the ions' outflow velocities. The local coronal density and temperature change with altitude, as observed by UVCS. As the solar wind expands outward, the coronal electron density decreases to the extent that the solar wind ion expansion time scale is short compared to the ionization and recombination time scales. The relative ionization states become constant, forever reflective of the conditions at the freezing-in altitude. The solar wind ions maintain their chemical and charge state identity as they continue to propagate through the outer solar atmosphere and into interplanetary space. Hence the charge state composition of *in situ* solar wind is used to infer coronal electron temperatures.

Fine time resolution charge state spectra for solar wind iron ions have been obtained with CELIAS CTOF while it was fully operational. The rapid and consistent changes in freezing-in temperature calculated from three different pairs of iron charge states indicates a patchy structure of the corona with length scales of some $10^4$ km and reveals the survival of these structures from a few solar radii to 1 AU. These structures had not been seen previously, because the necessary temporal resolution was not available before CTOF.

## *4.* IN SITU *SOLAR ENERGETIC PARTICLES*

The COSTEP and ERNE experiments on board SOHO are designed to detect energetic particles from several species over a range of energies. Electrons are recorded at energies from 44 keV to 50 MeV. Protons are recorded at energies from 44 keV to over 100 MeV. Alphas are recorded from a few MeV/nucleon to over 100 MeV/nucleon. Heavier elements, up to iron, can be identified up to 500 MeV/nucleon. Suprathermal ion charge state compositions on SOHO are measured by the CELIAS Suprathermal Time-of-Flight (CELIAS/STOF) sensor which measures the energy distribution of individual charge states of various elements in the energy range 20 keV/e to 3 MeV/e.

The best performance parameter of the ERNE instrument is the achieved mass resolution. In ERNE/HED all elements from hydrogen to nickel have been observed. In ERNE/LED, due to much lower collecting power, the statistics of the rare elements are still very low, but iron, e.g., can be clearly resolved. The full resolving power of various isotopes in both sensors is still to be demonstrated, but isotopes up to calcium have been observed in ERNE/HED. The “difficulty” has been the very low activity of the sun in producing energetic particles during this solar minimum, also emphasizing the galactic background.

During the first year of SOHO operation, the Sun was close to minimum levels of activity. As a result, the number of solar particle events was small. Nevertheless, there are already indications of different acceleration mechanisms in different flares. Moreover, there are indications of chemical fractionation in the solar atmosphere, and, most important, an estimate of the time-scale on which this fractionation operates.

As regards acceleration mechanisms in flares, it is also clear that the electron/proton ratio varies from one flare to the next. Quantitative modelling of the e/p ratios may help to identify which acceleration mechanism is dominant in each flare. Moreover, the ramp in the electron counts during 1996 July 8 and July 9, prior to the sharp increase in electrons, has no apparent counterpart in the p or alpha channel. This ramp suggests that a super-thermal electron population builds up in the pre-flare process for a period of days before the flare occurs. Key information about the physics of pre-flare heating will be obtained from a study of these ramps in active regions of various topology: this will become possible as solar activity increases.

## *5.* IN SITU *HELIOSPHERIC SCIENCE*

***Pickup Ions*** The flux of pickup ions in the solar wind depends on the local atom density and the ionization rate of the inflowing neutral gas. The local atom density (except for the case of hydrogen) is affected by the gravitational force of the sun, which acts as a lens for focusing the intensity of the gas in the downwind side (relative to movement by the heliosphere through the VLISM). The earth’s orbit (and hence SOHO) passes through this higher density section once per year. The ionization rates are affected by solar EUV fluxes and solar wind ion densities. These parameters are variable on both a short term scale, due to isolated solar activity, and on the longer time scale of the solar cycle. While CELIAS/CTOF measures the actual pickup ions, important input parameters for the pickup ion production rate are being simultaneously measured: CELIAS/PM provides the local solar wind density, the CELIAS/SEM provides the solar EUV measurements, and the SOHO orbit provides the “seasonal variation” - sampling through different neutral gas densities as a function of the gravitational focusing cone. These input parameters are important not only for pickup ion studies performed by CELIAS/CTOF, but also for those studies being carried out by time-of-flight spectrometers on the Ulysses, Wind, and (in the near future) ACE missions.

***Shock Acceleration at CIRs*** The pickup ions provide a suprathermal ion population in the heliosphere, which makes them candidate seed populations for shock-acceleration. It is now believed that $He^+$ is a significant component of energetic ion events associated with the forward and reverse interplanetary shocks that bound corotating interaction regions (CIRs) in the solar wind. (These are structures in the heliosphere that develop due to the interaction of fast and slow solar wind.) The likely source of accelerated $He^+$ is from the pickup ion population, since the solar wind normally contains only negligible amounts of $He^+$. In turn, it has been recently proposed that the accelerated pickup ions in CIRs become the seed population for the further shock acceleration at the heliospheric termination shock, thereby creating the anomalous cosmic ray (ACR) component.

The CIR events in 1996 (since the launch of SOHO) have been relatively weak events. However, CELIAS/STOF has made measurement of the $He^+$ content of CIR energetic ions for some selected intervals. The comparison of the CIR observations by SOHO, WIND and Ulysses (spacecraft at different locations) will provide spatial gradient information that will tightly constrain theories of shock acceleration and injection mechanisms. The results should help establish the origin of the ions as predominantly solar wind ions or interstellar pickup ions, the difference in the efficiency of shock acceleration at the forward and reverse shocks, and whether the spatial gradients and energy spectra are related as required by current theory.

***Planetary Science: Venus Tail Rays*** In 1996 June, Venus passed through a very close inferior conjunction with the Sun. At that time CELIAS/CTOF was measuring heavy ions in the solar wind ~$4.5 \times 10^7$ km downstream of Venus. During the passage of SOHO through the Venus wake, three encounters were made with unusual fluxes of $O^+$ and $C^+$ ions. Their energy distributions resembled those of the tail rays known to originate in the Venus nightside ionosphere. The $C^+$ abundance was ~10% of $O^+$. The observed $O^+$ speed was very close to the simultaneous solar wind speed and the $O^+$ temperature was a cool 5600 K/amu. The flux densities for the three events were $(2.1\text{-}4.4) \times 10^3$ $cm^{-2}$ $s^{-1}$.

## *6. The Sun-Earth Connection*

As an example of how the ISTP system is working, we summarize a very recent Sun-Earth Connection event: the flare and coronal mass ejection of April 7, 1997.

***An ISTP case study: The 1997 April 7-11 event*** On 1997 April 1, and again on 1997 April 7, SOHO-EIT was able to observe supersonic blast waves propagating outward from the site of a modest flare, across nearly the entire surface of the Sun in 1.5 MK coronal plasma. SOHO-MDI has been able to observe changes in the longitudinal field at the footpoints of these events. The soft x-ray signature of the flare was observed by SOHO-SEM and by GOES-8,9. The WIND-WAVES instrument detected Type III emissions at 13:59 UT on April 7, consistent with the SOHO observations of the flare. The April 7 event apparently led to two CME's: one directed away from the Sun-earth line, and a halo event. Since launch, SOHO-LASCO has observed several halo CMEs. These are CMEs that appear as a halo around the entire occulting disk, indicating that the event is directed either toward or away from Earth. As the April 7 event left the LASCO field of view, WAVES began tracking the progress of the event using Type II radio emissions. This type II emission, associated with the CME shock, was tracked from a fraction of a solar radii to ~10-12 solar radii and represents the first occassion that WAVES and LASCO/EIT have been able to make *simultaneous* observations.

The flare produced a solar energetic particle event (SEP) that was observed *in situ* by SOHO/ERNE beginning on April 7. The interplanetary shock observed by SOHO-CELIAS/PM at ~13 UT on April 10 is associated with a small peak in the ERNE particle intensity (1.6-3.2 MeV), and a large increase in the SOHO-CELIAS/STOF suprathermal helium flux (85-540 keV). The STOF composition indicates that interstellar pick up ions ($He^+$) are one of the important seed populations for the particles being locally accelerated at the shock, in fact a remarkable $He^+/He^{+2}$ ratio of ~1 is observed!

On April 11, the most intense auroral event (K of 8) since the launch of SOHO or POLAR occurred. Throughout its four-day evolution, the ISTP observatory effectively remained in observational contact with the eruption, collaborating with ground-based and geosynchronous satellites to capture the origin, propagation, geospace impact, and dissipation of the event. We believe that we have now, for the first time and *by combining observations in near realtime from SOHO, WIND, and POLAR,* observed a solar-terrestrial storm from its inception in the lower corona to its impact on the magnetosphere. While the initial news media coverage of this event was out of proportion to the probable seriousness of its terrestrial effects, the enormous response from both media and private citizens to the media coverage indicate that there is widespread interest in solar-terrestrial physics.

Coordination and dissemination of data sets for Sun Earth Connection Events are being done through ISTP workshops and the World Wide Web (which allows greater access to a wider user group). The event of 1997 April 7-11 is described at: http://www-istp.gsfc.nasa.gov/istp/cloud_apr97/ and http://sohowww.nascom.nasa.gov/gallery/current/ .

# IV. Operations, Data Access, and Education/Outreach

## 1. Operations

***Science and Operations planning*** SOHO science observing programs are planned through a regular, nested series of meetings that lead to an observing schedule that is both sufficiently predictable to prevent overburdening the experiment teams and flexible enough to allow rapid reaction to observing opportunities and requests.

The overall science policy and some general directions for science programs are set at the quarterly meetings of the Science Working Team (SWT), consisting of the SOHO PI's and the Project Scientists. Requests for joint observations by ground-based observers (GBO's) and other spacecraft, proposals for new Joint Observing Programs ( JOPs), for reruns of old ones, and plans for large scale campaigns, are collected by the Science Operations Coordinator (SOC). They are then and scheduled in the "SOHO Calendar" together with a weekly schedule for experiment planners and Science Operations Leaders (SOLs), as well as spacecraft activities. This is updated regularly and put on the WWW for anyone to see (http://sohowww.nascom.nasa.gov/operations/schedule/calendar.html).

At monthly meetings of the SOHO Science Planning Working Group (SPWG), consisting of representatives of all experiments, the SOC's and the Project Scientist Team, the results of the quarterly meeting is complemented with the plans and priorities of the individual experiments. The output of the monthly meeting is a day by day schedule of activities for the upcoming month, and the acceptance (or rejection) of newly submitted JOPs. The results of this meeting are also made public via the SOHO WWW pages for other observatories to use if they wish.

At weekly meetings of the Science Operations Team (SOT), consisting of the operators and planners of the experiments and the SOC's, a detailed timeline for all interactive experiments is laid out, including coordinated operations, spacecraft operations, and the schedule for real-time spacecraft contact. This daily timeline can be inspected at http://sohodb.nascom.nasa.gov/cgi-bin/mk_plan_form.

Finally, a brief daily meeting is held every day to report on the status of the spacecraft, experiments, ground system, and ongoing observing programs, to deal with any anomalies, and to coordinate selection of observing targets for the next few days. The science part of the daily meetings is chaired by a Science Operations Leader (SOL), who presents a report on the current status of the Sun, using the latest SOHO quicklook data and recent images from other sources. The SOL is responsible for maintaining a coherent program of coordinated observations. SOL's rotate on a weekly basis, and are selected from members of the SOHO experiment teams, and visiting scientists.

***Outside investigator participation*** Community participation in SOHO observations and data analysis is extensive and can arise in several ways. Joint observations with partners all over the world, usually involve mutual data access, and can often be arranged with a minimum of formality by the partner contacting the SOHO SOC's or experiment team members. Guest Investigators (GI's) selected under the ESA/NASA SOHO Guest Investigator Program (see http://sohowww.nascom.nasa.gov/operations/guest_investigators/ for first round selectees) are funded through NASA (US selectees) and the individual national funding agencies (Europe). Guest Investigations can range from new observing programs, to SOHO data analysis projects, and even purely theoretical studies relevant to SOHO observations. There are also frequent, informal Collective Data Analysis Workshops, (CDAW's) involving theorists and observers from various observatories and experiments. Two ISTP workshops have been held at GSFC, one in January and one in April 1997, both focused on earth-directed CME's. A "Whole Sun Month Workshop" was held in February, and the first SOHO-*Yohkoh* workshop took place in March, focusing on 6 filament eruptions/CME's/flares, well observed by both spacecraft and many GBO's. The SOHO EOF/EAF is an ideal location for such workshops, since there are ample and powerful workstations available, the SOHO and *Yohkoh* data archives are located at GSFC, and there is a critical mass of solar physicists already present. In addition there is the more formal series of SOHO workshops (held roughly annually), which has attracted participation from the whole Solar physics community on both sides of the Atlantic.

***Operations in a SOHO Solar Maximum Mission Science program*** In the proposed mission one may expect outside participation to increase through the three channels described above, while the direct on-line SOHO data availability via the SOHO archive at the EAF will provide an extra stimulus.

SOHO is unique among Solar physics missions in that data are received "live," and the experiments are commanded in near real time (NRT) directly from the EOF for about 8 hours a day. Scientists, from behind their workstations, can retarget and reprogram their experiments in a matter of minutes in response to events on the Sun. We expect this facility to be used more frequently as solar activity increases.

***SOHO coordinated observations, now and in a new mission*** SOHO was designed so that there would be significant coordination between the onboard instruments and between SOHO and ground based instruments. Coordinated observations come in various scales and formats. The largest campaigns are world-wide, multi-site, coordinated efforts of ground based observatories (GBO's), SOHO experiments, and other spacecraft, such as *Yohkoh*, Ulysses, WIND, POLAR, GEOTAIL, and SAMPEX. These campaigns are most often coordinated from the SOHO EOF at Goddard, with instantaneous exchange of observing plans, schedules, targets, and quicklook data, via the SOHO Web pages. One example is IACG campaign # 3, the "CME Onset Study", which has been run three times in the fall of 1996 (cf. http://sohowww.nascom.nasa.gov/operations/campaigns/soho/iacg3_a.txt). Smaller, more informal collaborations between SOHO experiments, a few GBO's, and often *Yohkoh*-SXT, are run routinely several times a week. Again, the long-term planning, as well as real-time coordination, is almost exclusively done from the SOHO EOF. There are also frequent intercalibrations between the SOHO experiments, occasionally supported with rocket underflights, and sometimes using well-calibrated stars as they pass near the Sun.

As of April 7, 1997, after about 1 year of science operations, the SOHO Campaign Catalog documents 211 campaign entries (including intercalibrations, and SOHO only collaborations), of which over 100 include GBO's, and more than 80 Yohkoh-SXT. SOHO campaigns vary in duration from 1 hour to several hours a day for more than a week. Typically 4 to 12 hours per day are devoted to joint observations of some sort. The SOHO Campaign Catalog, as part of the SOHO Archive, is freely accessible through the Web, and is also updated, in a controlled manner, through Web pages.

Many of the SOHO coordinated observing sequences have been written up as so-called Joint Observing Programs (JOPs), which describe the scientific background and goals of the program, and the detailed observing sequences for each SOHO experiment, often also for outside participants. Many JOPs are executed regularly, and the observing sequences are refined, and the JOP description updated, after several runs. So far there are 62 scientific and 11 intercalibration JOPs. JOP descriptions too are accessible via the SOHO Pages http://sohowww.nascom.nasa.gov/operations/JOPs/), and the JOP descriptions form an integral part of the SOHO archive.

The SOHO Calendar and SOHO JOPs have become a point of reference for Solar observatories worldwide, and for other solar missions, while the SOHO EOF has clearly established itself as a world center for coordination of solar observations. In the new mission this role will be maintained and even strengthened, as observations become more event-driven — and thus require more coordination — with the increase in magnetic activity in the rising cycle, and as two new NASA missions, TRACE and ACE, will share the EOF facilities, and SOHO planning infra-structure. TRACE science planning and analysis software will in fact be meshed with SOHO's. ACE, designed like SOHO to operate from an L1 halo orbit, will be commanded from the same Mission Operations Room (MOR) as SOHO.

In the new mission SOHO will continue to serve the community by providing ground based observers the opportunity for joint observations for any scientifically sound observing proposal. New ground-based observing facilities, such as the new French-Italian vector magnetograph THEMIS, the HAO Advanced Coronal Observing System, and NSO's SOLIS suite of instruments will become fully operational during the period of the proposed SOHO Solar Maximum Science program, and will benefit from collaboration with several of the SOHO instruments.

## 2. Data Access

The expense and extent of the SOHO mission cannot be justified if only the PI teams have access to the data obtained with the instruments. Likewise, the PI teams' efforts cannot be justified if they do not have well-defined access to the first results of their labors. The SOHO data access system was designed to balance these considerations.

***Web and summary (KP) data*** The SOHO team has made a serious effort to make our data available to as many people as possible. The information described here is available to the world via our Web pages. Daily images of the Sun (the imaging instruments' summary data contributions) and frequent updates to solar wind parameters are available via the Web as soon as they are received. (More frequent images are available via the LASCO and EIT Web pages.) The particle experiments' key parameter data are similarly nominally available via the ISTP CDHF (and the CELIAS proton monitor solar wind parameters are available more in close to real time via a team Web page). A catalog of all observations is searchable via a Web form. Data more than a year old are nominally open to the public, and more recent data are available with the PI's approval.

***The SOHO archive*** The SOHO archive is distributed: MDI high-rate data are stored in an archive at the PI institute because of volume (the data in fact are never flowed to the EOF), the LASCO archive is likewise maintained at NRL (with copies at each of three European Co-I institutes) until a final calibration has been achieved, and all other PI data are nominally served by the SOHO archive at the Solar Data Analysis Center (SDAC) at NASA Goddard. The goal is that all SOHO data, except MDI high rate data, be archived and catalogued at GSFC. A copy of the SOHO archive is maintained in France (MEDOC/CNES), the UK (RAL), and Italy (U. Torino).

***The SOHO online catalog*** Data and catalog entries from CDS, SUMER, EIT, and UVCS are currently being routinely deposited in this archive. The Web-searchable, RDBMS- based catalog was designed to allow as a final step (after point-and-click identification of relevant data sets) the download of the desired data, or at least the generation of a tape production request. Currently, the authentication interface for obtaining data within the proprietary period is still under development. (The PI's provide the SOHO Data Coordinator with a set of users and permissions: for example, a Guest Investigator will have access to data obtained for her/his program until the end of the proprietary program, or a publication has resulted from the GI work.)

Due to the large volume of MDI high rate data, all of those data are served on by a user friendly system at Stanford (cf. http://soi.stanford.edu/sssc/export_cams/cam_page.html , which is linked to the MDI home page and thus accessible from the SOHO Web pages). The LASCO team have elected to maintain a separate database of their images until they are satisfied with the calibration, but their catalog data and browse versions of the images are available via the Web as well.

Access to the SOHO main catalog and data are available via the SOHO home page: http://sohowww.nascom.nasa.gov/ .

***SOHO-related publications and presentations*** Although it is very early in the life-cycle of even the nominal mission for an accurate assessment of SOHO's impact by counting publications, a rough breakdown is available in the following Table.

**SOHO Publications and Presentations**
**1996 - 1997 April**

| **Type** | **Journal** | **Invited Talks** | **Conf. Proceedings** | **Oral & posters** | **Other** |
|---|---|---|---|---|---|
| **1996** | 20 | 23 | 16 | 121 | 9 |
| **1997** | 78 | 12 | 39 | 133 | 4 |
| **Total** | 98 | 35 | 55 | 254 | 13 |

***Improved public data access in a SOHO Solar Maximum Science mission*** *The MDI-SOI and EIT PI's have announced their intention to make all data from a SOHO Solar Maximum Science public as soon as the data are reformatted into scientifically useful formats. The UVCS PI has announced his intention to make all synoptic data (~60% of UVCS data) available on a daily basis.* The other PI's have announced their intention to release a "variability data set" to the public that will enable researchers to measure the nature of solar variability from solar minimum through solar maximum in a range of parameters that characterize the Sun and heliosphere from the deep interior to just upstream of the interaction with the earth's magnetosphere. The PI teams have all agreed on a preliminary set of basic measurements that form the variability data base. In the next few months the exact set of observations will be determined. This database will be available to all scientists in near real time together with any necessary calibration data needed to interpret the measurements fully. In the case of the helioseismology instruments, frequencies will be provided on 6 month centers.

**The Solar Variability Data Set for the SOHO Solar Maximum Science program**

| | |
|---|---|
| **GOLF** | Frequencies on 6 month basis |
| **VIRGO** | Daily intensities in all spectral bands and LOI daily averages. Frequencies on a 6 month basis. |
| **MDI** | Magnetograms on a 96 minute cadence.<br>Doppler Velocities averaged over 96 minutes every 96 minutes. Structure Program frequencies on a 6 month basis<br>LOI Proxies daily |
| **SUMER** | Full resolution spectra 465-1480 Å in both quiet and active Sun ( if possible) weekly |
| **LASCO** | Near real-time coronal images in C1-C2-C3 as MPEG movie available online.<br>Direct access to digital images that form movie |
| **UVCS** | Spectral atlas weekly; *all synoptic data daily* |
| **CDS** | Synoptic maps from daily North-South scans<br>Weekly spectral atlas at disk center |
| **EIT** | Full Sun Images in all spectral bands daily<br>*All image data* |
| **SWAN** | Full-sky map in Lyman $\alpha$ weekly (10° resolution) |
| **CELIAS** | Realtime EUV flux<br>Realtime and playback solar wind speed |

## *3. Educational and Public Outreach*

The SOHO mission team is engaged in numerous educational and public outreach activities. These include production of educational materials such as videos and posters, writing magazine articles and web sites, and serving as a resource for the public, teachers, and the press.

***Educational materials*** SOHO team members have participated in the filming of a number of videos concerning the Sun and solar wind, including the NASA Cutting Edge production *Fire & Life: The Sun-Earth Connection*, and other programs to be broadcast nationally and internationally. We are currently making an informative educational video to distribute to schools and the public. We are also planning a monthly video describing the changing conditions on the Sun and in the solar wind. The video will be distributed over NASA Select TV, and our primary target audience is television weather reporters, but we would also like it to be shown at science museums (including our own Visitor Center here at Goddard).

We have produced a poster concerning the Sun, SOHO, and solar-terrestrial science for high school students and teachers. Over 130,000 copies of the poster have been printed, and it will chiefly be distributed via the NASA Educator Resource Centers. Many individual instrument teams have also produced posters highlighting SOHO data.

***Person-to-person outreach*** Our scientists give presentations in schools, and work with teachers to design lesson plans and classroom activities. High school and undergraduate students and teachers have become directly involved with SOHO, working with the mission teams on spacecraft operations and data analysis.

***Web resources*** We are working with teachers to develop public outreach web pages directed at students ages 10-18, including exercises in which students can work with real SOHO data. The SOHO educational outreach pages can be found at http://sohowww.nascom.nasa.gov/explore/. Individual instrument teams, including SOI/MDI and CDS, are working on complimentary web projects. The SOI/MDI page is http://solar-center.stanford.edu/.

In addition, there are many web pages set up to display our data and results to the public. The main SOHO web page is http://sohowww.nascom.nasa.gov/. The SOHO gallery, containing some of the best images and data from each SOHO instrument, is http://sohowww.nascom.nasa.gov/gallery/. Recent movies of the Sun are available for viewing at http://sohowww.nascom.nasa.gov/synoptic/soho_movie.html.

With the cooperation of SOHO Goddard Space Flight Center is proposing an "Education Mall" on the Web. This site would be a resource designed to provide information for teachers based on their curriculum needs and national educational standards. SOHO would be closely involved in the Sun-Earth Connection part of this effort. Furthermore, NASA headquarters is considering the establishment of a number of "forums'' to serve as clearing houses for information concerning different NASA related topics. Goddard has proposed that the Sun-Earth Connection clearing house be at Goddard, with the participation of SOHO.

***Popular press and mass media*** SOHO-supported scientists have written articles appearing in popular-level science magazines including *Scientific American* and *Sky & Telescope*, and have supplied information for many journalists writing about the Sun and heliosphere. The level of interest in solar-terrestrial science and space weather in particular is evidenced by the enormous response to the halo CME/magnetic halo event of 1997 January 6 - 11 and the flare/halo CME/magnetic storm event of 1997 April 7 - 11. Most of the media requests for information were handled by an extremely effective team of young scientists from SOHO and GGS.

We have also interacted with the public at large by answering questions sent by e-mail and participating in live electronic chat sessions on the Internet organized by Rice University and Prodigy. SOHO scientists have been guests on nationally broadcast TV and radio programs.

***Interaction with the education profession*** SOHO team members have attended science teacher conferences including the National Science Teachers Association Meeting and NASA's Education Workshop for Math and Science Teachers, where we made presentations, distributed SOHO related materials, and interacted with teachers.

To summarize our plans for the future, we will:

- produce a monthly Sun-Weather video and distribute it over NASA select TV,
- produce educational videos showcasing SOHO data,
- participate in the Education Mall and Sun-Earth Connections forum if they are approved,
- continue to develop activities and other materials to be placed on the Web and distributed directly to classrooms, and
- interact individually with teachers and students.

## *V. The SOHO Solar Maximum Science program*

***The Science Promise.*** All of the physically meaningful parameters measured by SOHO instruments — eigenmode frequencies, EUV irradiance, CME rates, active region heating, &c. — vary with the solar activity cycle. Continuing to use the existing SOHO resources Solar Maximum Science program will extend those measurements into a domain of solar activity in which they have never been obtained with such precision or cotemporally with such an extensive array of other solar-terrestrial missions. There are currently no Sun-Earth Connection missions under development that would be able to make any of these measurements in the years 1999 - 2002. Continuing to use the existing SOHO resources therefore represents a relatively low risk method of obtaining data on the Sun and heliosphere that will not be available again before 2010 - 2013.

***Advancing the field.*** A SOHO Solar Maximum Science program willenable a fuller understanding of the complex changes in the solar interior and outer atmosphere during the rise to solar maximum than currently exists. Such a program will also allow us to amass a sufficient sample of earthward-directed coronal mass ejections to allow a principal-component analysis of the SOHO observables to determine which of those observables (presence of a flare, location on the disk of eruptive filament or flare, pre-existing coronal structures, following high-speed streams, and so on) are reliable predictors of geoeffectiveness. It cannot be sufficiently stressed that a SOHO Solar Maximum Science program, in conjunction with other ISTP missions, will allow us to make dramatic improvements in the quality of geomagnetic storm forecasts — *applied science* — over what is currently available. No other part of the Space Science endeavor offers the promise of advances in forecasting effects on the complex electronic communications environment upon which our civilization is ever more dependent.

***The Science Return from SOHO alone.*** By "alone," we mean without the enormous benefit to be realized by operating SOHO in conjunction with other Sun-Earth Connections (SEC) missions, but with the full resources of ground-based solar observatories. *We stress that we assess this scenario only because it was called for in the solicitation for this proposal: we believe that NASA should seize the unique opportunity offered by the existing ISTP missions and Yohkoh so that we can examine the entire range of Sun-Earth phenomena.* We would be able to observe solar irradiance, eigenmode frequency, interior rotation rate as a function of latitude and depth, subsurface convective energy transport, surface magnetic field, solar wind acceleration, plasma parameters of solar wind source regions, solar wind anisotropy, coronal hole area and location, large-scale coronal structure, coronal mass ejection frequency and distribution, and smaller-scale solar atmospheric phenomena changes with the change in phase of the solar cycle. We would be able to relate those changes to changes in effects at the earth through proxies or through other missions not considered under this review.

***The Science Return from SOHO in Conjunction with Other SEC Missions.*** With *Ulysses*, we could observe cycle-related changes in the high-latitude solar wind and relate them to possible changes in polar plumes and transients. With *Yohkoh*, we could determine whether the rise in > $2.5 \times 10^6$K plasma in active regions is spatially correlated with changes in lower-temperature (1 - $2.5 \times 10^6$ K ) emission observed in the EUV and electron-scattering coronal structures, and determine where more coronal heating really occurs: in the limited volumes of hotter (SXR) plasma or the larger areas of lower (EUV) temperature plasma, and in what sorts of structures. Collaboration with *Yohkoh* would also allow us to address the solar cycle variation of a whole range of solar phenomena: jets, X-ray/EUV bright points, CME's, &c. With GGS, we could achieve much better linkage between CME's, flares, filament eruptions, and other eruptive phenomena in the solar atmosphere and magnetic clouds and other geomagnetic events. (We assume that TRACE, ACE, and Cluster will all operate during the proposed Solar Maximum Science program, and each of these missions provides some, but by no means all, of the capabilities of the missions under review.)

***SOHO and the Outside Community.*** SOHO is already strongly engaging the worldwide solar physics community; this will only increase with the increase in solar activity and the improved, rapid access to SOHO data we propose here. If a Guest Investigator program of the size we propose is approved, support will be available for new researchers, including young Ph.D.'s, to analyze SOHO data for the first time. If, as we urge, the SOHO and GGS Guest Investigator programs are merged and emphasize interdisciplinary proposals, NASA will finally be able to leverage its investment in the ISTP. We have already discussed (cf. Data Access, above) proposed improvements in the timeliness and usefulness of data releases, including making the MDI and EIT data sets *completely open to the public*. We believe that this exceeds the open data compliance of any other PI-class mission in Space Science.

# *VI. Implementation of the SOHO Solar Maximum Science program*

As noted in the Programmatics section of this proposal, we are already operating at the "minimum viable" level of science operations. The only cost savings that we can achieve without sacrificing core science for a Solar Maximum Science program is to disenfranchise nearly all Co-Investigators who are not directly involved in science operations and instead allow them to compete with the other members of the SEC community for funds to do SOHO-related research. This we propose to do.

Implementation of the SOHO Solar Maximum Science program therefore entails no changes to *science* operations at the EOF or data archiving, and no changes in pipeline data processing, calibration, and validation. It is the considered opinion of the US PI's and lead Co-I's, as well as the Project Scientists, that any significant reduction in science operations resources will make the scientific operation moot.
A major re-engineering effort at NASA Goddard will effect enormous savings in *mission* operations, but with minimal impact

to the delivery of science data products to the PI teams. While a higher level of risk is assumed in such a scenario, we conclude that the assumption of such risk is appropriate for a re-use mission. This effort is already under way, and should be complete before the end of FY98.

## *VII) Summary of Scientific Impact*

***Some of the most distinctive discoveries of SOHO are:***

I) Helioseismology

- The first ever image of the convection zone of a star shows that convective cells in the Sun are shaped like pancakes, not spheres as assumed in mixing-length theory
- Differential rotation continues in depth to the bottom of the convection zone.
- Below the convection zone the Sun rotates as a solid sphere.
- There is a narrow shear zone at the bottom of the convection zone where the interior is very turbulent — this is the most likely region for the generation of the solar dynamo.

II) Solar Atmosphere and Corona

- The spectral lines of heavy elements in the corona have wider profiles than those of Hygrogen lines. This could be due to extremely broad velocity distributions along the line of sight; the most likely explanation for the higher velocities in heavier ions is the deposition of MHD wave energy in the corona *via* the ion cyclotron resonance process.
- Coronal mass ejection (CME) observations have a new dimension. We are often able to see the initiation in the lower atmosphere with EIT and follow its evolution out to 30 $R_{sun}$ wiyh LASCO. We are also seeing for the first time how globally such events affect the corona. With CELIAS, and the aid of other SEC missions, most particularly the other ISTP missions, we can follow earthward-directed disturbances all the way to the magnetosphere.
- For the first time, we can trace the slow speed solar wind near the equatorial current sheet, and have been able to measure both speed and acceleration.

III) Solar Wind

- The detection of elements and isotopes never seen before in the solar wind. The solar wind isotopic abundances should be close to the primordial composition of the solar nebula, before the planets were formed, and are important for many cosmochemical and astrophysical applications, including the study of the history of the solar system.
- Better time resolution in solar wind composition than has been possible before indicates a patchy structure of the corona with length scales of some $10^4$ km and reveals the survival of these structures from a few solar radii to 1 AU.

There is a wealth to be learned from continuing our study of the Sun as it evolves from solar minimum to solar maximum. SOHO along with the rest of the Sun-Earth Connections missions will greatly enhance our understanding of the space environment. ***A SOHO Solar Maximum Science program will allow us to:***

I) Helioseismology

- Determine whether we can probe the deepest interior of the Sun with *g*-modes and low-*l* *p*-modes
- Observe how the interior and convective transport evolve with the solar cycle and study the interaction between the magnetic cycle and the shear zone
- Understand where and how the dynamo really works

II) Solar Atmosphere and Corona

- Determine how the known changes in the basic structure of coronal streamers between solar minimum and maximum effects the acceleration of the solar wind? We will be able to observe this directly
- Discover whether there are more fundamental physical parameters underlying the known CME latitude and frequency distribution changes over the cycle
- Use SOHO's ability to observe magnetic fields and the upper atmosphere simultaneously, with no atmospheric distortion, to allow us better to understand the relationship between the emergence, submergence, and merging of magnetic fields and solar activity
- Determine whether we can detect high-frequency MHD wave deposition of energy in the corona

III) Solar Wind, Solar Energetic, and Heliospheric Particles

- Measure how the composition of the solar wind changes with the solar cycle
- Determine the relationship between solar magnetic features and solar wind speed and composition
- Distinguish the effects of more frequent CME's on suprathermal and energetic particle acceleration
- Assess the information from solar neutron decay products to determine whether they tell us about acceleration processes in the most energetic solar flares
- Measure a half-cycle's worth of $^3$He-rich solar particle events and high-energy heavy ions (C, N, O, Si, and Fe), to determine their origins
- Determine how the neutral gas distribution, ionization processes, and acceleration processes of interstellar pickup ions vary over the rise phase of the cycle. (No pickup ion studies yet exist covering the rise to solar maximum.)