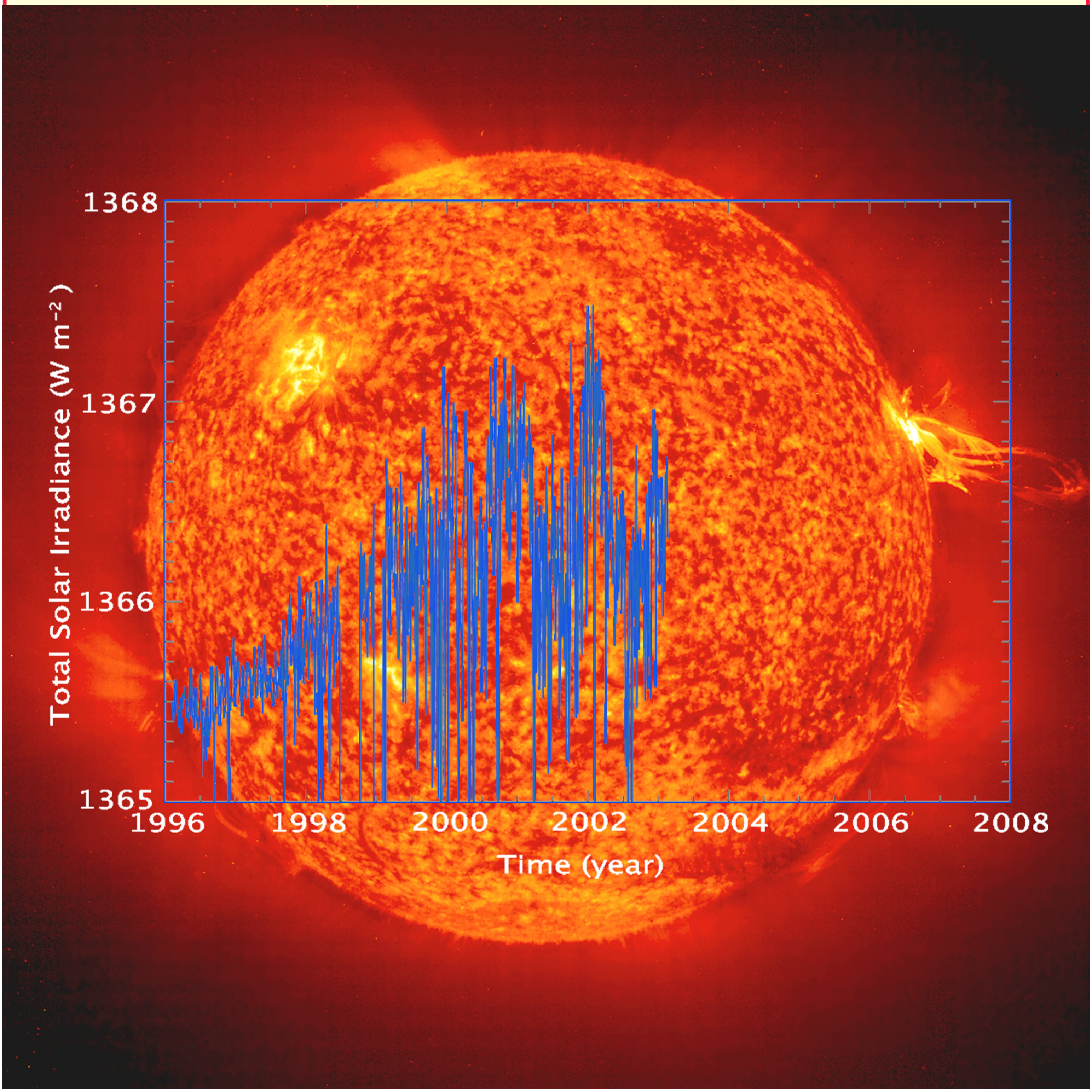
SOHO: Tracking a Solar Cycle

A Proposal to the 2003 Senior Review
of Sun-Earth Connections Operating Missions



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Cover. An image in the 304 Å bandpass of the SOHO EIT on 1998 May 28. As can be seen from the superposed plot of SOHO VIRGO DIARAD measurements, at least in Total Solar Irradiance (TSI), we will soon be at a level of solar activity similar to that at the time the EIT image was obtained. Emission in the 304 Å region of the solar spectrum is one of the major sources of heating in the terrestrial thermosphere.

Solar and Heliospheric Observatory (SOHO)

Presenters: J.B. Gurman, US Project Scientist for *SOHO*

I. Executive Summary

The current complement of Sun-Earth Connections spacecraft provides an unprecedented opportunity to understand the physical conditions in our solar system, from the deep interior of the Sun to the borders of interplanetary space. Until the advent of the follow-on missions of the Solar-Terrestrial Physics Probes and Living With a Star programs, the current SEC spacecraft can continue to provide new insights into those conditions and the physical processes that shape them. Even after the new programs commence, there will be complementarity between *SOHO* and the new missions.

In the next section of this proposal (Section II), we discuss how closely aligned the *SOHO* scientific program is with NASA's current strategic goals and objectives for space science. In addition, we describe the accessibility of *SOHO* data.

We discuss a few of the many scientific insights gained from *SOHO,* often in conjunction with measure-ments from other spacecraft or ground-based facilities, in Section III. We believe that research using *SOHO* observations has made major strides toward understanding the solar interior, the heating of the corona, and the acceleration and composition of the solar wind — but much remains to be done.

In Section IV, we give just a few examples of the scientific promise of continuing the *SOHO* Solar Cycle Mission.

In Section V, we summarize the rationale for a further continuation of the *SOHO* mission.

Section VI contains the "technical/budget" information for the current baseline and enhanced options for continued scientific and mission operations. The minimal level is equivalent to the current level, with some allowance for inflation during the last six years, which has not been addressed during that time. The enhanced budget requests sufficient funds to assure adequate management of risks to instrument health and safety and data quality. We also seek a modest enhancement for education and outreach activities.

In Section VII, we describe some of the wide range of education and public outreach efforts carried out by *SOHO* scientists and the *SOHO* media specialist, with emphasis on those activities that carry a high "multiplier" for dissemination to the largest possible audience.

Appendices summarize the *SOHO* publication record (Appendix A) and the status of the *SOHO* instru-ments (Appendix B). Appendices C and D contain the acronym list and budget spreadsheet, respectively.

The following individuals were among those involved in the writing of this proposal on behalf of the *SOHO* Science Working Team: J.B. Gurman (GSFC), N. Gopalswamy and T. Kucera (NASA GSFC), J. Kohl, S. Cranmer, J. Raymond, L. Strachan (SAO), F. Ipavich (U. Md.), E. Moebius (UNH), P. Scherrer and A. Kosovichev (Stanford U.), and G. Lawrence and S. Yashiro (CUA). We had many helpful comments, and substantial scientific input from our European colleagues B. Fleck (ESA), P. Bochsler (U. Bern), Eric Quémerais (SdA), W. Curdt (MPAe), J.P. Delaboudinière (IAS), C. Fröhlich (PMOD/WRC), A. Gabriel (IAS), R. Harrison and A. Fludra (RAL), H. Kunow (U. Kiel), and J. Torsti (U. Turku). We would also like to thank several SEC Guest Investigators who provided material for this proposal.

II. Goals: SOHO and NASA

SOHO's Goals As stated in our 1997 Senior Review proposal, "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." Over the last seven years, the community of scientists using *SOHO* data has made remarkable strides toward all three of these goals — but much remains to be done. We therefore propose to continue the "*SOHO* Solar Cycle Mission" put forth in our 2001 proposal, to take advantage of the unique capabilities of *SOHO* through the next four years. This phase of the solar cycle will see the most geoeffective disturbances propagate through the inner heliosphere, a radical redistribution of the large-scale solar magnetic field and heliospheric current sheet, and the stirrings of a new magnetic cycle at high latitudes.

SOHO and Strategic Goals The first "Mission Goal" of NASA's 2003 Strategic Plan is "[t]o understand Earth's system and…. improve the prediction of climate, weather, and natural hazards," and the Sun-Earth Connections Theme of the Space Science Enterprise is listed as making a primary contribution to the achievement of that goal. As the Plan notes, "Phenomena in the nearby space environment also have a major effect on planet Earth. Solar variability causes space weather that can affect satellite operations, human space activities, and electrical power grids on Earth. Long-term changes in the Sun's brightness, though small, affect our climate…. NASA is engaged in a long-term, systematic study of the Sun to understand its effects on Earth and society."

These statements, of course, define the *SOHO* solar cycle mission: understanding the sources of solar variability, starting with the interior of the Sun and extending through the corona to the solar wind. To do so, *SOHO* will provide a complete solar activity cycle of measurements of solar *p*-mode oscillations and their modulation over the cycle; total and spectral solar irradiance; the photospheric magnetic field, which controls the structure and physical processes in the outer atmosphere; the corona, including coronal mass ejections; and the solar wind, both near the Sun *via* remote sensing and *in situ* at L1. If *SOHO*'s mission is extended to overlap by, say, a year with that of the Living With a Star (LWS) Solar Dynamics Observatory (SDO) mission, the helioseismology, magnetic field, and coronal time series could cover much of a full, 22-year, solar magnetic cycle.

The third Mission in the Strategic Plan, "[t]o inspire the next generation of explorers," consists of two goals: "Inspire and motivate students to pursue careers in science, technology, engineering, and mathematics," and "Engage the public in shaping and sharing the experience of exploration and discovery." Sun-Earth Connections is expected to make supporting contributions to both of these goals. *SOHO* continues to inspire students and maintain the public visibility of Sun-Earth Connections science. The PI team at the Smithsonian Astrophysical Observatory has involved students at Southern University, the largest of the Historically Black Colleges and Universities (HBCU's), in analyzing data from *SOHO* UVCS, and is now involved in the establishment of an astronomy and astrophysics program at Southern, and the Southern students in the program in turn have involved local public school students in astronomy through a public observatory in Baton Rouge, Louisiana. We continue to hire and train high-school, undergraduate, and graduate students to work with the PI teams and at the *SOHO* operations and analysis facilities.

We have met, both working on our own and through the SEC Education Forum, the objective of engaging the public through two Space Science Updates (and contributions to others highlighting other missions), numerous press releases, hyperactive Web sites, teacher curriculum development workshops, public talks, the continuing provision of time-lapse movies of *SOHO* images to broadcast and narrowcast providers of video, and the excitement of cometary discovery. The contributions of *SOHO*, *Yohkoh*, TRACE, and POLAR to the awesome vision of the IMAX film SOLARMAX both showcase images of astounding aesthetic value and make large numbers of the public aware of the origins and effects of space weather in a way no other medium could. *SOHO* scientists answer questions from any and all who take advantage of the "Ask Dr. SOHO" Website, and participate in Webcasts and Internet chats on solar and heliospheric science. In addition, we continue to produce and update effective educational media (CD-ROM's, lithograph sets, posters, and Web sites), and give seminars at teacher workshops and NSTA and regional teachers' conferences — activities with proven multiplier effects.

Section VII provides more detail on current *SOHO* education and outreach activities; there, too, we outline a proposal to expand our marginally-funded efforts in order to reach a wider community "as only NASA can."

SOHO and Roadmap Objectives The 2002 *Sun-Earth Connections Roadmap* lists as primary scientific objectives:

- Understand the changing flow of energy and matter throughout the Sun, heliosphere, and planetary environments;
- explore the fundamental properties of plasma systems; and
- define the origins and impacts of variability in the Sun-Earth system.

SOHO science is rooted in all three of these objectives. As several examples in the next Section will demonstrate, the science done with SOHO is helping to elucidate the flow of energy and matter from the solar interior, through the corona and heliosphere, to 1 AU — and beyond, in work on both pickup ions and the interstellar wind. As part of our search for understanding of the Sun-Earth system, we are continually confronted with basic problems in plasma physics, such as the differentiation of acceleration mechanisms for the solar wind. Finally, we are beginning to understand the origins of the variability in solar internal convection, meridional flow, and even subsurface "weather."

Data Accessibility

Ubiquity *SOHO* enjoys a remarkable "market share" in the worldwide solar physics community: over 1,400 papers in refereed journals since launch (not counting refereed conference proceedings, which generally duplicate journal articles), representing the work of over 1,500 scientists. Even accounting for the number of heliospheric papers and authors in those numbers, it is not too much of an exaggeration to say that virtually every living solar physicist has had access to *SOHO* data.

Accessibility. We can assert that with confidence because all the *SOHO* experiments make all their data available, online, on the Web, through the *SOHO* archive and PI sites. A typical PI site, the EIT Web catalog, has served over 420 Gbyte of data since the last Senior Review — and the EIT database is only 260 Gbyte as of 2003 April; the larger MDI database, which includes several levels of computationally expensive, higher-level data products, contains some 118 *Tbyte* of data products, and has served over 6.7 Tbyte of online data requests in the last two years. (This total does not include larger data exports shipped to Co-Investigator and Guest Investigator sites on tape.) In addition to professional access, amateurs routinely download LASCO FITS files and GIF images to search for new comets. As a result, 596 of the 1646 comets for which orbital elements have been determined (since 1761) were discovered by *SOHO*, *over two thirds of those by amateurs accessing LASCO data via the Web*. Similarly, 780,000 people across the world have downloaded the *SOHO* screensavers that continually update their views of the Sun.

Research access. All SOHO instruments scientific data are accessible through a single interface, http://sohowww.nascom.nasa.gov/catalog/ . This searches both the general SOHO archive at the Solar Data Analysis Center (SDAC) at Goddard, and the MDI high-rate helioseismology archive at Stanford. (MDI magnetograms obtained every 96 minutes are part of the general archive, because of their usefulness for solar activity-related research.) In both archives, the holdings are identical to the best used by the PI teams, and are current (i.e. to within a month or two before present, to allow time for "Level-Zero" data delivery.) The only exceptions at the time of this writing are the particle experiments COSTEP and ERNE, which are in the process of catching up.

CME catalog. A catalog of all coronal mass ejections observed by LASCO between 1996-2001, including geometrical and dynamical information, is available at http://cdaw.gsfc.nasa.gov/CME_list/index.html, and Yashiro *et al.* (2003) describe the catalog's compilation and present a statistical analysis of the database. For each CME, the catalog provides the time of first appearance in LASCO images; the height-time data; central position angle and angular width; plots of best first- and second order fits to the height as a function of time and derived speeds; and a variety of movies highlighting the CME in LASCO and EIT images. The data for 2002 and 2003 are being added, and once complete the catalog will be augmented in close to real time.

Shock catalog. Similarly, a catalog of interplanetary shocks observed by the CELIAS MTOF proton monitor is available at http://umtof.umd.edu/pm/figs.html . These events are detected with the automated Shockspotter facility developed by the CELIAS MTOF team.

Solar EUV flux. The recently-developed SEM Flux web page (http://umtof.umd.edu/semflux) is an automatically-updated page that contains plots of the 1st-order flux from SEM (which measures the absolute solar EUV flux in a passband of ±40 Å about the 304 Å He II line) and the zero-order EUV flux (which is the absolute solar EUV flux in a passband of 170-700 Å) as well as a dimensionless index which is a measure of solar X-ray activity.

General public access. In addition to archive interfaces designed primarily for use by research scientists, there are several *SOHO* data services on the Web designed to meet the needs of more general audiences, or both scientists and other types of users. Publicly-accessible Web pages display: real-time solar wind parameters (http://umtof.umd.edu/pm/) from the SOHO CELIAS proton monitor, LASCO comet discoveries (http://sungrazer.nascom.nasa.gov/), EIT imagery (http://umbra.nascom.nasa.gov/eit/eit_full_res.html), collections of news, education, and popular science resources (*e.g.* http://solar-center.stanford.edu/), and latest science and outreach news from *SOHO* (http://soho.nascom.nasa.gov/hotshots/). When the last site ran stories on "How to make your own UFO" (after a fraudulent attempt to pass off image processing artifacts as UFO's) and Come NEAT (C/2002 V1), hit rates on the *SOHO* Webserver exceeded 22 million a month, and the total downloads from the site exceeded 1.5 Terabyte a month.

III. Scientific Insights from SOHO, 2001 - 2003

The following, brief descriptions of scientific insights gained from *SOHO* have been gleaned from papers published in, or recently submitted to, refereed journals. Scientific insights from the prime phase of the mission (FY1996 – FY1997) were covered in the proposal to the 1997 Senior Review, and from the first four years of the extended mission (FY1998 – FY2002) in the proposal to the 2001 Senior Review.

The Solar Interior and Total Irradiance

Total solar irradiance variations. The total solar irradiance (TSI) is measured by the VIRGO experiment with two type of radiometers, PMO6V and DIARAD; this makes possible the first independent and internally consistent determination of possible long-term changes, such as degradation. This allows us not only to understand how such radiometers degrade, but also to *quantify* the uncertainty of the long-term precision of the TSI time series (Fröhlich 2003). This uncertainty is estimated to be about 0.6 ppm (parts per million)/yr (1σ level), but this value is compromised by the uncertainty over the gap when *SOHO* was out of operation in 1998. The final value of the uncertainty must instead be determined from comparison with ACRIM-II on UARS. Over the seven years of *SOHO* VIRGO operation, this adds to the slightly more than 4 ppm another 10 ppm, which demonstrates how important gaps in TSI measurements can be in influencing the uncertainty. Nevertheless, the total uncertainty over the *SOHO* lifetime to date is less than ±15 ppm or about 2 ppm/yr.
This result also provides evidence that *e.g.* observations from the ACRIM's, which track those from

VIRGO very well, have similar uncertainties, although it is not possible to demonstrate that directly from the ACRIM data alone. Unfortunately, the absolute uncertainty alone is not sufficient for joining time series of TSI from different, non-overlapping experiments. Thus, we still need overlapping measurements from different platforms to provide long-term uncertainties of the order of what has been demonstrated with VIRGO.

The composite TSI, updated with the contribution of VIRGO for the last 7 years, is shown in Figure 1. The most important result is the fact that there is no significant trend of TSI over the past 24 years. Willson and Mordvinov (2003), who neglect the corrections of the NIMBUS-7 HF instrument data set during the period of the gap between ACRIM-I and II, disagree; they instead claim a secular increase of TSI of about the amount of the HF correction. Interpretation of the TSI record, whether as a steady cycle with no underlying secular change or as showing an increasing trend, has broad social and political impacts as governments make decisions on their responses (if any) to global warming.

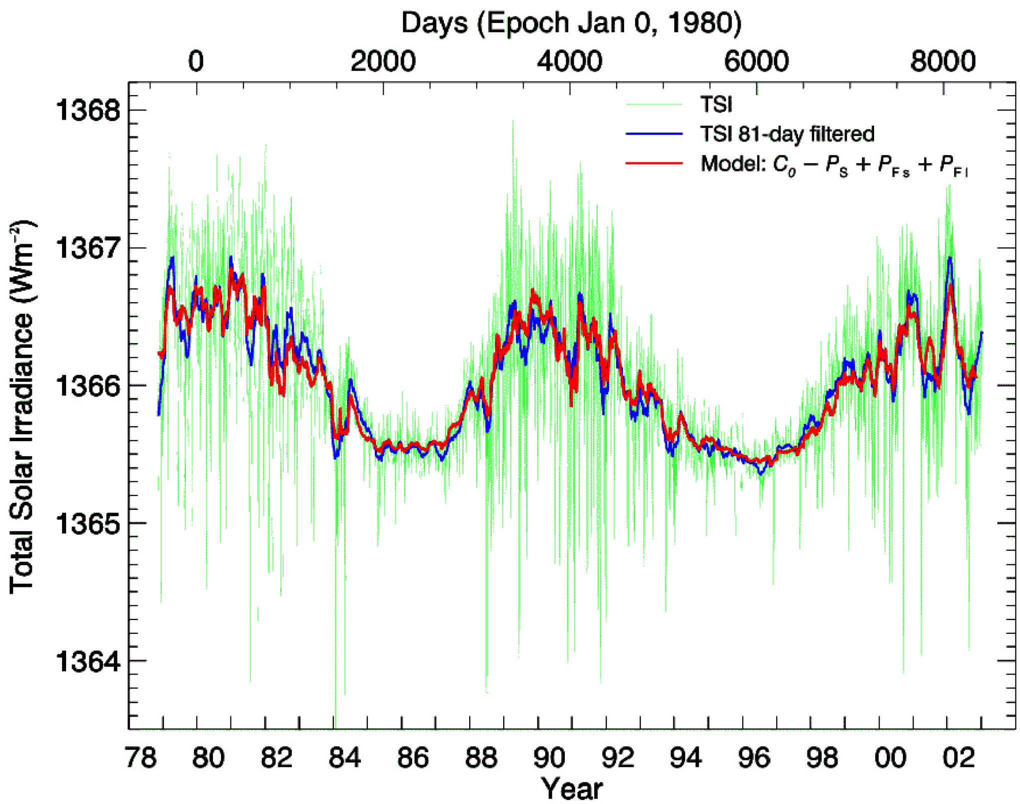

Figure 1. *Daily values of total solar irradiance from 1978 to present. The data labelled TSI are a composite of observations from HF on NIMBUS-7, ACRIM-I on SMM, ACRIM-II on UARS and from the VIRGO radiometers on SOHO. For comparison, the 81-day filtered proxy model (blue curve) from Fröhlich and Lean (2002), discussed in the text is also plotted.*

TSI modeling. The last two years have seen significant effort in modeling the TSI variations by several groups (see e.g. Krivova *et al.* 2003, and references therein). Their models reconstruct irradiance variations from model atmospheres for the quiet Sun, sunspot umbra and penumbra, and faculae, with a contrast depending on the field strength. The areas of faculae and network are determined empirically from *SOHO* MDI magnetograms, and the areas of sunspot umbrae and penumbrae from MDI intensity images. While some would argue that such a "superficialist" interpretation of the origin of irradiance variations ignores potentially important subsurface physics, the agreement of model and observation in Figure 2 is remarkable.

Still no g-modes. Gabriel *et al.* (2002) have examined five years of GOLF data and concluded that there is still no statistically significant evidence for *g*-mode (buoyancy) oscillations in the observed range of 150 – 400 μHz in the deep solar interior. A recent, conservative hypothesis predicts *g*-mode amplitudes of no more than 6 mm/s, while the data analysis has a 100% chance of detecting modes with 8 mm/s or higher amplitude.

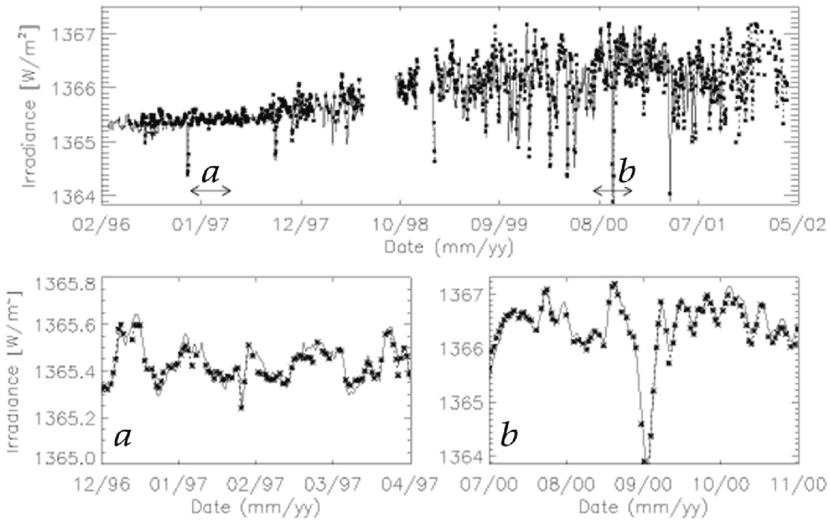

Figure 2. *Top: Reconstruction (asterisks connected by dotted curve when there are no data gaps) of total solar irradiance for about 1500 individual days between 1996 and 2002, i.e. from the minimum of cycle 23 to its maximum (top panel). The irradiance record measured by VIRGO is represented by the solid line. The bottom panels show a zoom-in to two shorter intervals at different activity levels labeled a and b in the top panel*

The tachocline. Using MDI data, Howe (2003) demonstrated that the 1.3-year variations of the rotation rate in the tachocline are persistent through the first half of the solar cycle (Figure 3). It is intriguing that the expected 11-year variation has not been detected. The 1.3-year variations can be explained by a non-linear mechanism of spatiotemporal fragmentation (Covas *et al.* 2001), and have been detected in the solar activity data by Krivova and Solanki (2002) who suggested that this periodicity can be related to the well-known 156-day period of solar activity. These results indicate that there is a broad range of dynamic time scales of solar variability associated with the surface magnetic activity and magnetic dynamo in the tachocline, and that these scales are linked through nonlinear interactions. Therefore, one of the priorities of the continuing *SOHO* solar cycle mission is the investigation of the spectrum of solar variability in the period range of 0.5-11 years.

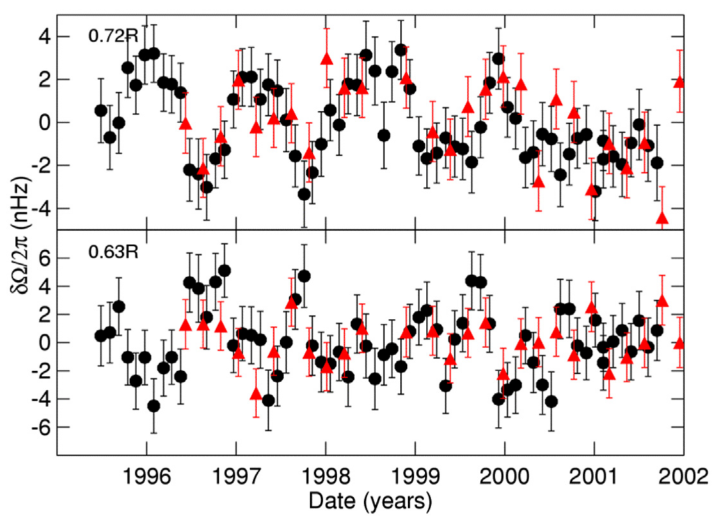

Figure 3. *Variations with time of the difference of the rotation rate from the temporal mean at two radii deep within the Sun, with the site at 0.72 R located above the tachocline and that at 0.63 R below it, both sampling speeding up and slowing down in the equatorial region. Results obtained from MDI data for two different inversions are shown with red symbols, those from GONG with black symbols (Howe 2003).*

The global circulation of the Sun. Vorontsov *et al.* (2002) applied a novel inversion method to the

MDI rotational splitting data of 1996-2002, and found evidence that the zonal shear flows ("torsional oscillation") can penetrate to the bottom of the convection zone. It appears that the entire solar convective envelope is involved in the torsional oscillations, with phase propagating poleward and equatorward from midlatitudes at all depths (Figure 4). This challenges the previous models of torsional oscillations as a secondary effect of migrating sunspot zones. Several methods of local helioseismology have used to measure the meridional flows in the upper convection zone and their changes with the solar cycle. These flows play a key role in flux-transport dynamo models of the cycle, by transporting the magnetic flux to the polar regions and causing the polarity reversals. The common result is that the meridional circulation slows down when the activity level is higher because of the additional flows converging around active regions in the activity belts (Beck *et al.* 2002; Zhao and Kosovichev 2003; Haber *et al.* 2002). In addition, Haber *et al.* (2002) have studied how meridional circulation varies with depth, and found surprising evidence of double circulation cells forming during a rising phase of the solar cycle. The complex evolution of the global circulation of the Sun is another challenge for dynamo theories and future observations.

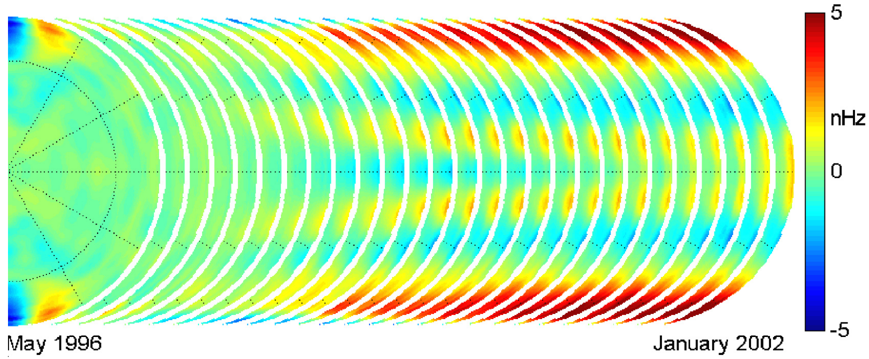

Figure 4*. Variation of the solar internal rotation relative to 1996 when the Sun's activity was at its 11-year minimum. Results at 72-day intervals are shown over the first nearly six years of MDI measurements from SOHO. The equatorward migration of the low-latitude branch of the torsional oscillation, and the strengthening of the high-latitude branch, are visible. Red indicates the regions that have speeded up, blue those that have slowed down. The units are nanoHz: the corresponding changes in linear speed are a few m/s. Dotted lines indicate the base of the convection zone and the 0 degree, 30 degree and 60 degree latitudes (Vorontsov et al. 2002).*

Solar Subsurface "Weather." Analysis of the MDI Dynamics data by methods of local helioseismology has revealed persistent patterns of large-scale flows in the upper convection zone (Gizon *et al.* 2001; Haber *et al.* 2002; Zhao and Kosovichev 2003b). These results led to a new concept of Solar Subsurface Weather (SSW) connecting the effects of these synoptic flows to the development of solar activity. The initial results (*e.g.* Figure 5) are promising, and may result in a new approach to the long-term space weather forecast, based on the dynamics of the upper convection zone.

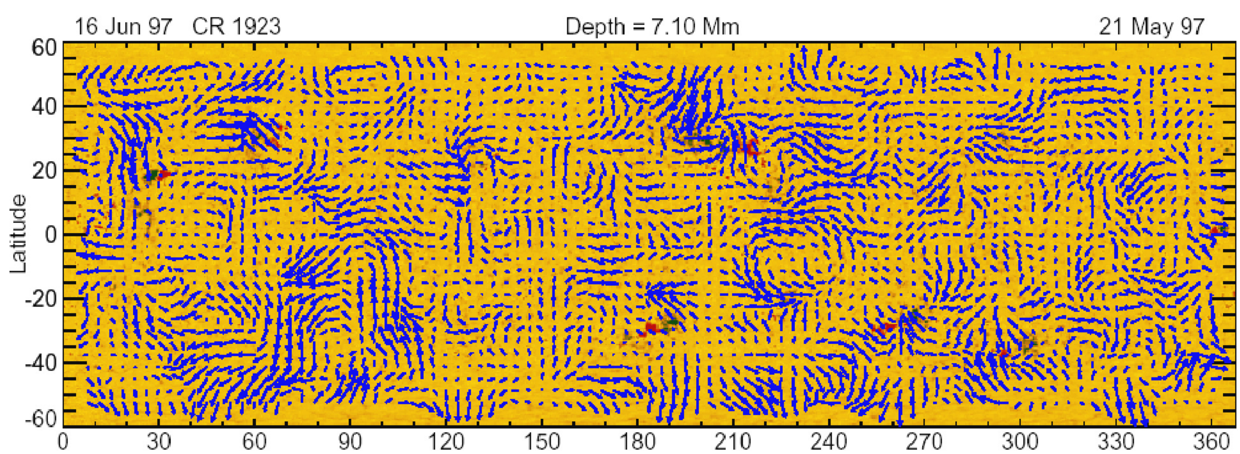

Figure 5*. Synoptic map of large-scale flows in the upper convection zone for Carrington Rotation 1923 (May 21-June 16, 1997) obtained by local-area helioseismology from the MDI data. The background color map is the MDI synoptic map of photospheric magnetic fields (Haber et al. 2002)*

Helioseismic imaging of the solar farside. In the 2001 *SOHO* proposal, we noted an astonishing result: the first successful, holographic reconstruction of solar farside features from p -modes observed on the visible hemisphere with MDI. The astonishing has now become routine, and the *SOHO* MDI team offers daily farside images on the Web at `http://soi.stanford.edu/data/farside/`).

The internal structure and dynamics of sunspots. The high-resolution data from SOHO/MDI have allowed us to investigate the structures and flows beneath sunspots to be investigated in some detail (Kosovichev *et al.* 2000; Zhao *et al.* 2001). The results reveal that magnetic connectivity among sunspot structures may exist below the surface, at a depth of 4 Mm. In Figure 5, maps of the sound-speed variations show the large central sunspot connected to small pores, with the same magnetic polarity as the main spot, while a pore with opposite polarity field is not connected. This suggests that sunspots represent a tree-like structure in the upper convection zone. In the typical flow maps at a depth of 0-3 Mm, one can clearly identify a ring of strong downflows around the sunspot, with relatively weaker downflows inside

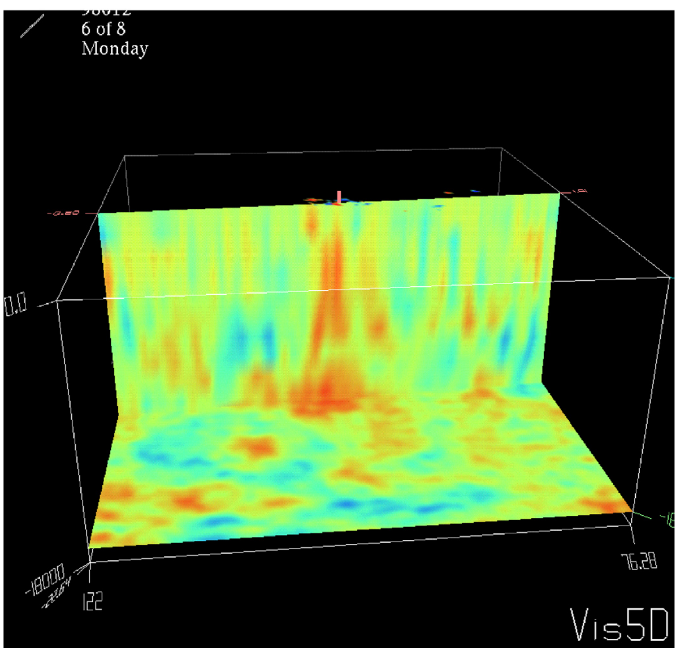

Figure 6. *Image of the acoustic wave speed in an emerging active region in the solar convection zone obtained from the SOHO Michelson Doppler Imager (MDI) data on January 12, 1998, from 02:00 to 04:00 UT, using time-distance helioseismology. The horizontal size of the box is approximately 560 Mm, and the exaggerated depth is 18 Mm. The (mostly) transparent panel on the top is an MDI magnetogram showing the surface magnetic field of positive (red) and negative (blue) polarities stronger than 200 Gauss. The vertical and bottom panels show perturbations of the sound speed which are approximately in the range from -1.3 to +1.3 km/s. The positive variations are shown in red, and the negative ones in blue. A large active region formed at this location within a day after these observations (Kosovichev et al. 2002).*

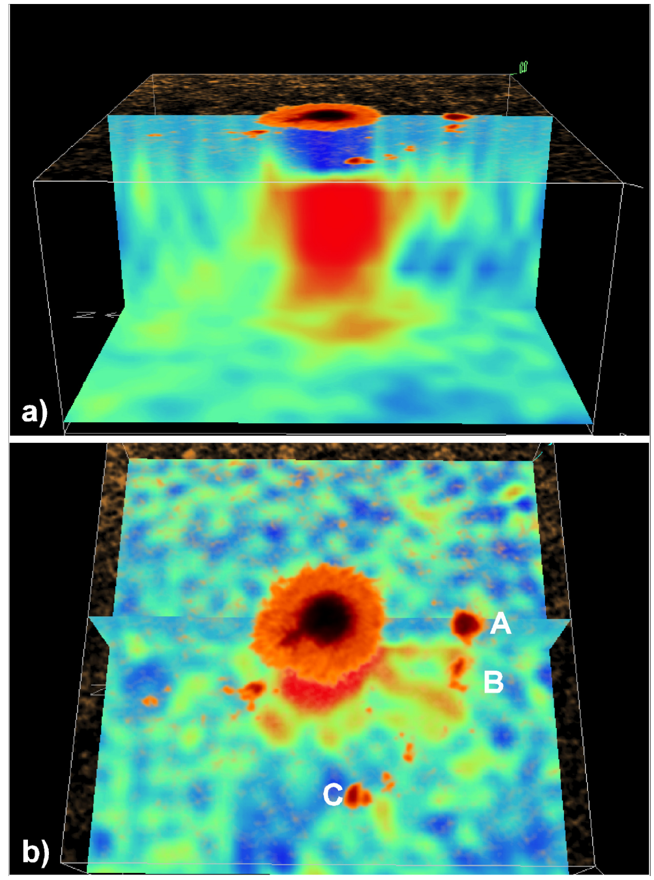

Figure 5. *The sound-speed perturbation in a large sunspot are shown as vertical and horizontal cuts. The horizontal size of the box is 13° (158 Mm), the exaggerated depth is 24 Mm. Positive variations of the sound speed are shown in red, and negative variations (just beneath the sunspot) in blue. The upper, semitransparent panel is the surface intensity image (dark color shows umbra, and light color shows penumbra). In the lower panel the horizontal sound-speed plane is located at a depth of 4 Mm, and shows long, narrow structures ("fingers") connecting the main sunspot structure with surrounding pores of the same magnetic polarity.Pores of the opposite polarity are not connected to the spot (Kosovichev et al. 2000)*

the ring. Converging flows can also be seen beneath the umbra. In deeper laers, 6-9 Mm, the sunspot region is occupied by a ring of upflows with almost zero velocity at the center. These results are consistent with theoretical ideas (Parker 1979), and may help us understand the origin of sunspots. More such high-resolution observations are needed to study sunspots at different stages of their evolution.

Emerging active regions. A time-distance analysis of MDI data, (Kosovichev *et al.* 2002a) attempted to detect emerging active regions in the convection zone before they appeared on the surface. The sound-speed images (Figure 6) show that the emerging flux propagates very rapidly in the upper 20 Mm, with a speed exceeding 1 km/s. Early detection of emerging active regions, therefore, may prove difficult without probing deeper into the convection zone. Kosovichev *et al.* (2002b) have also investigated the flow patterns associated with the emergence and evolution of a large active region, NOAA 9393, in March-May, 2001. They showed that there was no specific large-scale flow pattern prior to the emergence. Once a significant portion of the magnetic flux appeared on the surface, they observed the formation of long-living converging downflows. In the decay phase, there is a tendency for diverging flows. This active region continued to evolve over a significant period of its lifetime, during which time numerous emergence events occurred in the upper convection zone. These results challenge the models of active regions as emerging large-scale Omega-loops breaking apart near the surface. The investigation of the life cycle of active regions is one of our principal priorities.

Supergranulation. The importance of supergranular flows for the distribution of solar magnetic flux and the formation of magnetic network is well known. By using long series (up to 9 days) of subsurface flow maps obtained from the MDI Dynamics data by time-distance helioseismology, Gizon *et al.* (2003) have studied the global dynamics of the supergranular flow pattern. They concluded that it has a significant, wave-like component that may explain why this pattern rotates faster than magnetic features in the photosphere, and also why advection may be suppressed by meridional flows (Figure 7). However, the physics of this phenomenon is not understood, and requires studying the details of supergranular dynamics, both observationally and by numerical simulations. This is one the fundamental problems of solar physics and a great challenge.

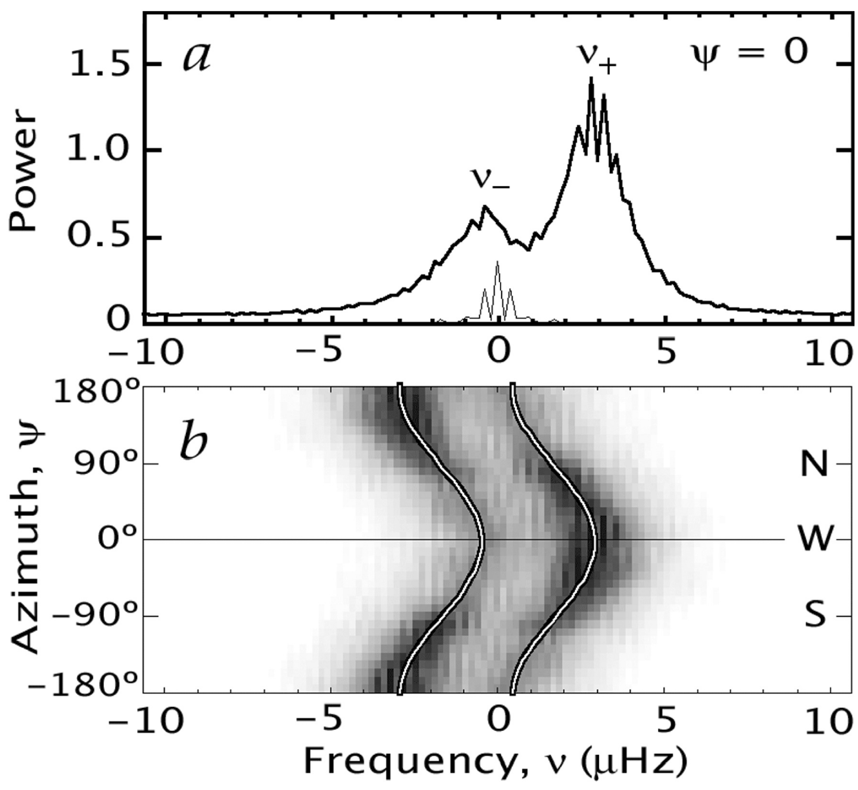

Figure 7. *Power spectra of the supergranulation signal demonstrating the wave-like behavior. The thick curve in the top panel is the power spectrum near the equator for the wave vector pointing in the direction of solar rotation. There are two peaks, ν- and ν+, corresponding to two Fourier components propagating with different speed. The lower panel shows variations of these peaks with latitude (Gizon et al. 2003).*

The Solar Atmosphere

Magnetic shadows. Judge, Tarbell, and Wilhelm (2001) used SUMER spectra, in conjunction with TRACE image time series, to identify internetwork regions with low levels of both EUV intensity and ~ 5 mHz oscillatory power. McIntosh and Judge (2001) use MDI magnetograms obtained at the same time to interpret these “magnetic shadows” as areas where magnetic field closes close to the chromosphere, rather than extending into the corona.

CME-driven Shock Waves. A few shock waves have been observed simultaneously as Type II radio bursts and as changes in the UVCS emission line profiles and intensities (Raymond *et al.* 2000; Mancuso *et al.* 2002). The densities inferred from radio and UVCS observations agree, but the shock speeds inferred from the radio observations fall well below the speeds measured from LASCO images. This is largely due to the use of average coronal density profiles for converting the Type II frequency drift rate into a speed. Using instead the densities derived from UVCS synoptic measurements, Mancuso *et al.* (2003) derived more realistic speeds for 37 Type II radio bursts. The combination of shock speed, density, and the condition that the shock exceed the fast mode speed leads to a lower limit to the plasma β for each event, typically in the range 0.1 to 1. Thus far we have observed only three coronal shocks, so more examples are badly needed.

Current Sheets. Models of CME's rely heavily on reconnection in current sheets, either trailing beneath the ejected magnetic flux rope or creating the flux rope in the first place (e.g., Lin and Forbes 2000; Antiochos *et al.* 1999). UVCS has observed current sheets in the wakes of two CME's (Ciaravella *et al.* 2000; Ko *et al.* 2003). They appear as geometrically narrow features in the high temperature emission lines of [Fe XVIII] and [Ca XIV]. These observations test the overall energetics predicted by the idea that the current sheets power the post-flare arcades observed in X-rays and EIT images. The duration and temporal extent of the current sheets test specific models (Lin 2003). Recent MHD models make specific predictions about post-eruption reconnection and the associated outflow (Riley *et al.* 2002). The existing observations pertain only to a single height in each instance, and because of onboard binning of the data (using the available telemetry to explore a broad range of spectral lines) they did not reach the full spatial resolution of UVCS.

Helical Structure in CME's. The approximate conservation of magnetic helicity is a powerful tool for the analysis of laboratory plasmas, and it may determine the evolution of CME's as they travel through interplanetary space (Kumar and Rust 1996). The buildup of helicity might stop the solar dynamo were the Sun not able to shed helicity by means of CME's (*e.g.* Low 2001). LASCO images often show an apparently helical structure in CME cores. Doppler shift measurements with UVCS, CDS, and SUMER provide the velocity signatures to show that the structures are indeed helical and, more importantly, to determine whether the structures are unwinding or merely stretching out. The combination of velocity and imaging information provides a picture of the 3D structure of the CME material (Ciaravella *et al.* 1997) and in several cases shows the structure to be rotating (Pike and Mason 2002, Ciaravella *et al.* 2000). Lin *et al.* (2003) have computed the magnetic flux added to the flux rope by reconnection during the ejection. This suggests rotational motion, but that does not yet constrain the rotation rate. The Doppler shifts also determine the chirality (handedness) of the helix for comparison with that of the pre-CME prominence. In one case this worked out as expected (Ciaravella *et al.* 2000), but in another, the chirality is reversed. The chirality is important for space weather predictions, and the connection between prominence chirality and CME chirality is a key feature of some CME models (*e.g.* Rust 2001). MHD models are beginning to predict rotational motions at the level needed for comparison with UVCS data (*e.g.* Gombosi *et al.* 2002).

Jets and Narrow CME's. The accepted picture of coronal jets, whether high-temperature jets from active regions or cooler jets in coronal holes, is reconnection between open and closed field lines (Shibata *et al.* 1992). It is fundamentally different from the popular models of coronal mass ejections, which all involve a sudden disruption of a closed magnetic field configuration. UVCS observations of jets have shown that the plasma is continuously heated after the initial ejection (Dobrzycka *et al.* 2000). UVCS has also revealed the existence of an intermediate class of events, sometimes called "narrow CME's," that cannot be easily classified as either jets or CME's (Dobrzycka *et al.* 2003).

Energy Budget. White light coronagraph observations of CME's provide the masses and the speeds in the plane of the sky. Doppler shift measurements with UVCS, SUMER, and CDS provide the velocity in the other dimension, and therefore the velocity in 3D and the kinetic energy. UVCS measurements of UV line intensity ratios give tight constraints on density, temperature, and ionization state of the expanding CME plasma. In the events analyzed thus far, plasma expelled from the solar surface cannot reach the physical conditions observed without continued heating (Ciaravella et al 2002; Akmal *et al.* 2001). UVCS and LASCO data show that in order to balance adiabatic expansion and radiative losses, heating well above the solar surface is required. The integrated heating rate by the time the plasma reaches 1.5 to 3.5

R_{Sun}, where it is observed, implies a thermal energy input comparable to the kinetic energy. This startling result was predicted by Kumar and Rust (1996) on the basis of conservation of magnetic helicity, though in detail their specific model deposits too much heat too quickly at the start of the eruption. Their self-similar model predicts such intense heating that elements such as carbon and oxygen would be more highly ionized than observed by UVCS. The energy budget analysis requires a fairly complete observation of the CME, both in terms of spectral coverage and time, and only a few events are well enough observed so far.

CME Acceleration. The question of where in the corona CME's are accelerated, and what is the peak value and maximum range of this acceleration, was a working group topic at the SHINE 2002 workshop, and will be again in 2003. Statistical studies based on the Yashiro *et al.* (2003) CME catalog (see URL in Section II, above) suggest that the majority of CME's exhibit a small acceleration throughout the LASCO field of view. Even the most extreme acceleration inferred from LASCO data alone, however, cannot account for the high-speed tail to the speed distribution. Zhang *et al.* (2001), Neupert *et al.* (2001), Alexander *et al.* (2002), and Gallagher *et al.* (2003) all study examples where low coronal data are available from, *e.g.* EIT, LASCO-C1, *Yohkoh* SXT, and TRACE, and find evidence for rapid acceleration phases (between ~0.5 and 4 km s^{-2}), in each case ending prior to the CME entering the LASCO C2 field of view. It therefore appears ever more certain that most of the acceleration of CME's occurs below $3R_{Sun}$.

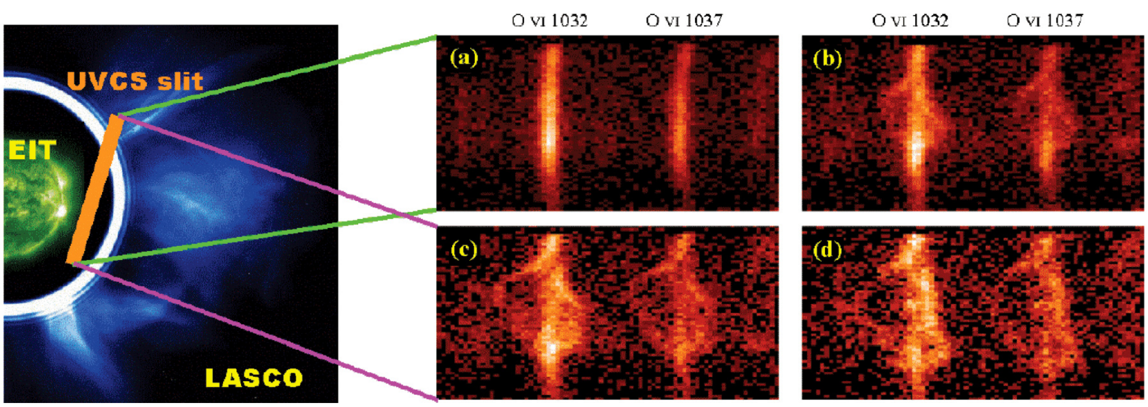

Figure 8. *UVCS, together with other SOHO and in situ instruments, observed a massive streamer disruption following the CME and X-class flare on April 21, 2002. The streamer was disrupted not only by the 2000 km/s outward motion, but also by motions along the line-of-sight. The four spectra shown on the right are individual snapshots taken within a 17-minute time period, sequentially from (a) to (d), when the CME was crossing the UVCS slit. Note the extremely strong Doppler shifts in the spectral ``wiggles" corresponding to CME loops with line-of-sight velocities between -850 km/s and +500 km/s.*

CME's related to X-Class Flares. The RHESSI satellite has observed several X-class flares during Major Flare Alerts from the Max Millennium campaign. UVCS participates in these campaigns when the target is within 20 degrees longitude of the solar limb. In all 3 such campaigns thus far, UVCS has caught an exceptionally fast CME, with a speed above 2000 km/s. The three CME's were similar to each other and different from other CME's in two ways. First, all showed very high temperature emission from [Fe XVIII], seen in the CME front or void in only one previous CME. This must be related to the high ionization states measured *in situ* only in magnetic clouds from CME's. Second, the pre-CME streamer is disrupted in a spectacular manner, with O VI line profiles suddenly split by 1300 km/s and the splitting propagating rapidly along the slit. The O VI lines remain narrow, indicating a lack of shock heating. The combination of the lack of a shock with the densities of the pre-shock streamers gives a lower limit of 4 Gauss for the April 21, 2002 event (Raymond *et al.* 2002), because the CME speed must be less than the Alfvén speed (see Figure 8). While the CME's from X-Class Flares appear to be a distinct class, we have only three examples. While the rate of CME's will continue to fall over the next four years, the next two years should see enough X-flares (the frequency of which changes little over the declining phase of the cycle) and CME's to allow the analysis of further examples.

Coronal heating in active region loops. How energy is deposited in coronal loop structures is generally viewed as critical to understanding the heating of the corona. A currently controversial issue is the temperature distribution along active region loops: researchers using data from broadband instruments such as EIT and TRACE report isothermal coronal loops, but those working with spectrographs that sample spectral lines emitted at different temperatures are able to calculate a differential emission measure (DEM) at each point along the coronal loop. Schmelz *et al.* (2001) and Schmelz (2002) derived DEM as a function of line formation temperature for a well observed, isolated coronal loop and found multi-thermal distributions in single CDS pixels at each of 13 points along the loop. They conclude that there is a strong temperature gradient along the loop, and the loop is certainly not isothermal. A detailed comparison of conductive and radiative losses shows that neither of the two energy loss mechanisms dominates, thus contradicting earlier results that claimed the predominance of either conductive or radiative losses. These results are directly contradicted by Aschwanden (2002), however, who questions the technique used for DEM fits. The fine donnybrook between those who maintain that DEM is a useful approach to interpreting solar atmospheric structures and physical processes, and those who find too many weaknesses in the method, continues unabated.

A parallel effort in solving the coronal heating problem is a direct search for a theoretical explanation of how coronal loops are heated. Fludra and Ireland (2003a) found a relationship between the intensity of the Fe XVI 360.8 Å line in individual coronal loops measured with CDS, and the magnetic flux density at the loop footpoints, measured by MDI. This power-law relationship can be further analyzed using coronal loop models to derive the dependence of the heating rate E_H on the magnetic field strength B. Fludra and Ireland (2002a,b; 2003b) have found that the heating rate is approximately proportional to B, confirming the result of Gurman *et al.* (1974) from observations at ~6 times lower spatial resolution, which were unable to resolve individual loops. This important result rules out many models of coronal heating that predict an $E_H \propto B^2$ dependence for the heating rate.

Erupting flux ropes. CDS carried out the first spectroscopic and imaging observations of an erupting flux rope, lifting off at the onset of a CME (Foley *et al.* 2001, Pike and Mason 2001). CDS serendipitously recorded a transit of the ejected flux rope through its field of view during a regular synoptic observation. Using multi-component fits to the line profile of the O V 629.7 Å line, Pike and Mason (2002) present a detailed history of the velocity components. Some features reach transverse velocities in excess of 800 km/s. The nature of the spectral line profiles suggests that a rotational motion of ±350 km/s was superimposed upon a general outward expansion of approximately 150 km/s. The ejected material had a constant acceleration and is interpreted as a flare spray whose helical structure is determined by the pre-flare magnetic topology.

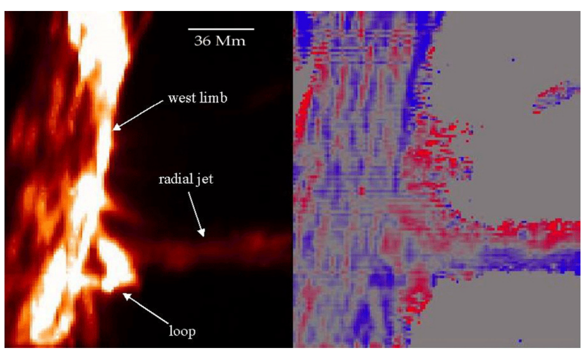

Figure 9. *A twisting jet observed with SOHO CDS by Harrison et al. (2001) on 2000 January 22. The structure, over 100 Mm in length, extends horizontally off the right edge of the field of view; it was also observed by the SOHO LASCO C2 coronagraph. The intensity in O V 629 Å, formed at temperatures ~ 250,000 K, is show at left, and the Doppler shift in the same line, on the right. The greatest redshift is ~ +50 km/s, and the greatest blueshift, ~ -25 km/s.*

A cool jet. Another rare observation of a jet of twisting plasma was reported by Harrison *et al.* (2001). This observation was made above an active region on the solar limb and provided a side view of a short-lived, confined column of relatively cool (250,000 K) plasma (Figure 9). The CDS line profiles show blue- and red-shifts along the edges of the jet, clearly indicating a rotating structure. The authors propose that this phenomenon can be explained by reconnection of an expanding eruption with a lower-lying, magnetic arcade .

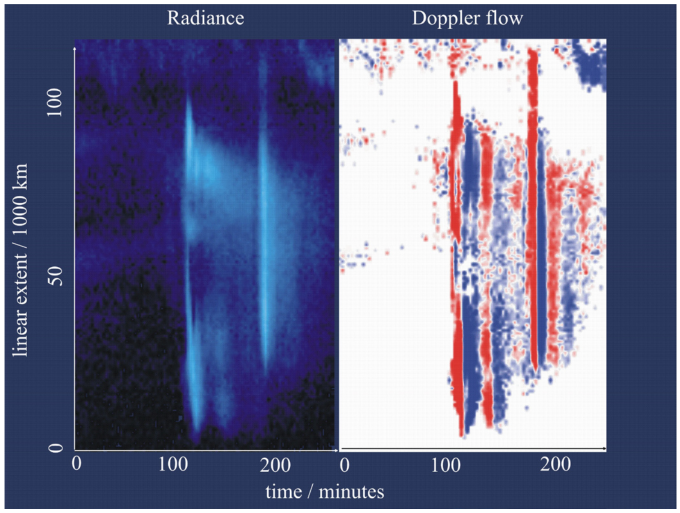

***Figure 10**. Intensity map and velocity map (scaled to ±50 km/s) of a typical recurring oscillation event, observed in the Fe XIX line at 1118 Å by SOHO SUMER.*

Flares: Oscillations in hot coronal features. Recently SUMER has observed strongly damped Doppler flow oscillations (Figure 10) in hot active region loops (Kliem *et al.* 2002). Ofman and Wang (2002) interpret these observation as evidence for the damping of slow magnetosonic waves by thermal conduction, and Wang *et al.* (2003) point out that the quarter-wave phase difference between velocity and intensity is evidence for standing slow-mode waves in the loops. These new and previously unexpected results may help us to understand the heating of coronal loops, and open a new area of coronal seismology.

Coronal Holes and the Fast Solar Wind

Plasma Properties of Coronal Holes over the Solar Cycle. UVCS has been used to measure the heating and acceleration of the fast solar wind in a variety of large coronal holes from 1996 to 2003 (Miralles *et al.* 2001, 2002; Poletto *et al.* 2002). A pattern is beginning to emerge, in that coronal holes with lower densities at a given heliocentric height tend to exhibit faster ion outflow and higher ion temperatures (Kohl *et al.* 2001). However, all of the coronal holes observed by both UVCS and *in situ* instruments were found to have roughly similar outflow speeds in interplanetary space. *Thus, the densities and ion temperatures measured in the extended corona seem to be indicators of the solar wind acceleration as a function of heliocentric height*. This information has been useful in gaining further insight into identifying the processes that generate the fast solar wind, but only a subset of the full range of plasma properties has been probed.

Helium abundance. Laming and Feldman (2003) have used SUMER measurement to determine that the He II/H abundance ratio in coronal holes varies from near that measured *in situ* in fast solar wind streams to a factor of two less. They interpret this measurement as implying that ionized He flows outward through the hole as fast as the protons, which reinforces the ion cyclotron resonance model for solar wind acceleration.

Theory impact on other fields: ion cyclotron resonance. The surprisingly extreme plasma conditions observed by UVCS in coronal holes have guided theorists to discard some candidate physical processes and further investigate others (*cf.* Cranmer 2002). Hollweg and Isenberg (2002) state in a review paper that, "We have seen that the information provided by UVCS has been pivotal in defining how research has proceeded during the past few years." Indeed, the UVCS results and subsequent theoretical investigations have been cited increasingly in literature devoted to other plasma environments, such as the Earth's aurora (Gavrishchaka *et al.* 2000), and they have guided new investigations in pure plasma physics (e.g., Mizuta and Hoshino 2001; Chen *et al.* 2001).

Polar plumes and jets over the solar cycle. The plasma properties derived from UVCS observations of filamentary inhomogeneities (*i.e.*, plumes and jets) in coronal holes provide constraints on how much of the solar wind comes from impulsive reconnection events at the base of the corona. A study of transient "polar jets" with UVCS, EIT, and LASCO (both at solar minimum and during the rising phase of solar cycle 23) found that jets have higher densities, faster outflow, and lower electron temperatures than the surrounding coronal hole plasma (Dobrzycka *et al.* 2002). These observations seem to be consistent with the idea that jets are the result of short-lived bursts of base heating, while polar plumes are the result of base-heating events that last longer than several hours. It is still not clear, though, whether there is a significant solar wind outflow in plumes (Gabriel *et al.* 2003) or if the plumes are relatively hydrostatic structures embedded in an outflowing "interplume" medium (e.g., Teriaca *et al.* 2003).

Streamers and the Slow Solar Wind

Preferential Ion Heating and Temperature Anisotropies. The analysis of UVCS data has led to evidence that the fast and slow wind share the same physical processes. Frazin *et al.* (2003) determined that O^{5+} ions in the bright edges — or "legs"— of equatorial streamers have significantly higher kinetic temperatures than hydrogen and exhibit anisotropic velocity distributions with $T_{\perp} > T_{||}$, much like coronal holes. However, the central streamer "core" (typically identified with closed magnetic loops below the heliospheric current sheet) exhibits neither the preferential heating of oxygen nor the temperature anisotropy. This is consistent with other UVCS evidence that points to the bulk of the slow solar wind arising from the streamer legs (Raymond *et al.* 1997) and not from the closed streamer core (see Figure 11). Joint theoretical studies of physical processes such as ion cyclotron resonance that apply to both the fast and slow solar wind are ongoing (e.g., Chen and Hu 2001).

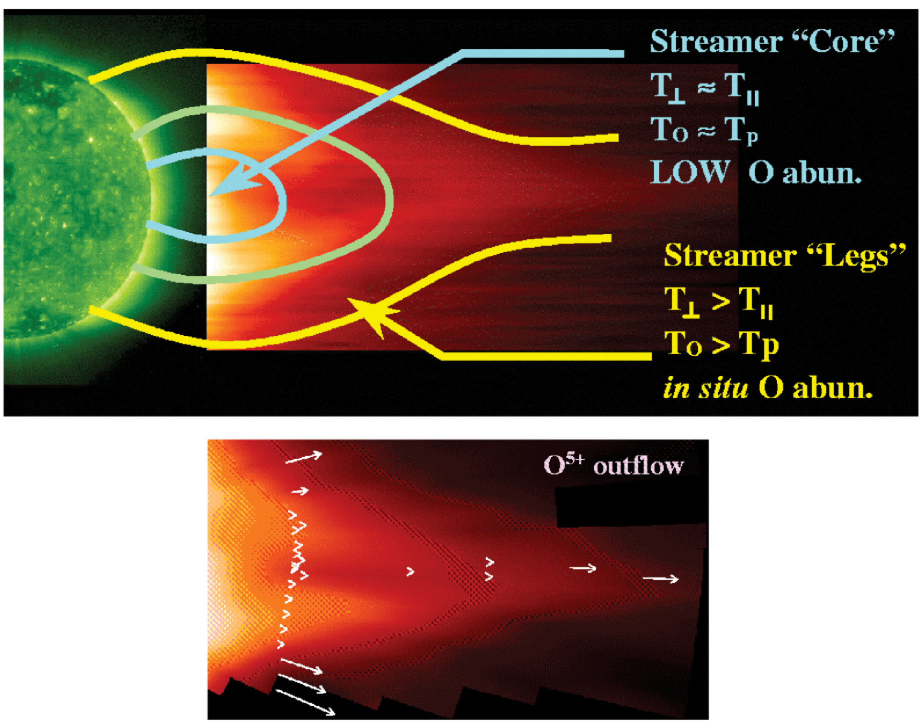

Figure 11. *UVCS observed equatorial streamers at solar minimum (1996--1997), and recent analysis has revealed striking differences between the closed-field "streamer core'" and the open-field "legs" (Strachan et al. 2002; Frazin et al. 2003). The legs exhibit preferential ion heating, ion temperature anisotropies, and abundances and outflow speeds consistent with the slow solar wind at 1 AU. The core exhibits temperature equilibrium between protons and ions, isotropic ion velocity distributions, no outflow, and anomalously low ion abundances.*

The Geometry of Solar Wind Flow from Streamers. Strachan *et al.* (2002) used UVCS and LASCO observations to map out the spatial properties of the slow solar wind in the solar minimum streamer belt. The magnetic cusp that divides the closed-field streamer core from the open-field streamer legs was determined via the Doppler dimming technique to be between the heights of 3.6 and 4.1 R_{Sun}. The latitudinal pattern of O^{5+} outflow speed was found to be consistent with the bulk of the slow wind emerging along the northern and southern edges of the streamer and merging above the cusp (see Figure 11). This empirical information provides hard constraints for MHD models of the source regions of the slow solar wind.

Streamer Abundances and the FIP Effect. One of the most striking discoveries made during the past 7 years of UVCS measurements is the large variation of elemental abundances in streamers (*cf.* Raymond 1999). UVCS has observed the relative enhancement of low-FIP (first ionization potential) elements such as Si and Mg in streamers, but UV spectroscopy also provides the absolute abundances (*i.e.*, relative to hydrogen). These diagnostics show a wider variety of abundance enhancement, depletion, and radial dependence than could have been detected with abundance ratios relative to elements other than hydrogen (*e.g.* Parenti *et al.* 2000; Ko *et al.* 2002; Uzzo *et al.* 2003). Absolute abundances measured with UVCS and CELIAS are key constraints on models of gravitational settling, magnetic reconnection, and the overall coronal origin of the slow solar wind in streamers.

In situ-remote sensing quadrature studies. The optimum type of coordinated observation is one that samples the same plasma both close to and far from the Sun. This is achievable only with a combination of remote-sensing observations and *in situ* instruments that are in quadrature with the line joining the Sun and the remote-sensing instruments. The only spacecraft currently in this kind of configuration is Ulysses. As of 2003 there have been 9 coordinated observation campaigns between *SOHO* and Ulysses. UVCS and LASCO observations of the boundary between coronal holes and streamers have led to the determination that the boundary between fast and slow wind in 1997 was essentially radial and nondiffusive between 5 R_{Sun} and 5 AU (Suess *et al.* 2000). The rotation-tracking of coronal holes and CME's with UVCS has produced the first true calibration of ballistic ``feature mapping'' of *in situ* data back to the solar disk (Poletto *et al.* 2002).

Abundance mapping as a probe of coronal source regions. Coordinated measurements of elemental abundances in the corona and interplanetary space are valuable constraints on where various solar wind features originate in the corona. A broad consistency between UVCS and *in situ* abundances has been found using Ulysses (Parenti *et al.* 2001), ACE (Ko *et al.* 2001), and *SOHO* CELIAS (Uzzo *et al.* 2003). However, there are many cases where there seems to be substantial radial evolution of the abundances between the heights sampled by UVCS and the *in situ* measurements.

Kinetic theory constrained by coronal and in-situ measurements. It is becoming increasingly clear that similar physical processes are acting in the extended corona and in interplanetary space. Coordinated simulations of wave-particle interactions (such as, but not limited to, ion cyclotron resonance) are thus being performed for both environments (e.g., Gary *et al.* 2001a, b; Ofman *et al.* 2001). The ion temperature properties of the fast wind seem to be shaped by the damping of ion cyclotron waves in the extended corona and by the unstable generation of ion cyclotron waves in interplanetary space. UVCS constraints on temperature anisotropies have led to new interpretations of the *in situ* anisotropies, which used to be considered purely local phenomena but now are believed to be connected to the corona (*cf.* Hollweg and Isenberg 2002).

The Heliosphere: Energetic Particles

Energetic particles and CME's. Production of solar energetic particles (SEPs) in the range 10-100 MeV/nucleon has been studied with both remote sensing and *in situ* instruments (EIT, LASCO, SUMER; ERNE/HED) onboard *SOHO*. Coronal mass ejections and near-surface phenomena, including flares, were carefully studied for the time periods of the SEP events registered with ERNE. A recent series of investigations consists of individual case studies (Torsti *et al.* 2001, 2002b; Laitinen *et al.* 2000), a statistical analysis (Kocharov *et al.* 2001), and their interpretation (Kocharov and Torsti 2002). A SEP-producing eruption typically consists of both a flare and a CME. The multi-wavelength studies demonstrate the importance of the eruption history to the production of solar energetic particles. Frequently, SEP-productive events involve an impulsive CME liftoff that triggers, in the lower corona, both flares and the global waves that start the particle acceleration, which continues later at interplanetary shocks driven by CME's. This finding suggests that a forecasting of the high-energy particle fluxes at 1 AU requires broad-band data from a set of the spaceborne telescopes, like those on *SOHO*.

Energetic particles: ^{3}He-rich events. ERNE has measured ^{3}He and ^{4}He fluxes beyond 10 MeV/nucleon with good statistical resolution, and a survey of ERNE data for 1999-2000 has revealed a new group of SEP events with ^{3}He/^{4}He > 0.2 (Torsti *et al.* 2002, 2003). In the event of 2000 October 29, a very strong ^{3}He enhancement persists over the high-energy range up to 50 MeV/nucleon. This is the first time that the ^{3}He/^{4}He >1 has been recorded at above 10 MeV/nucleon. ERNE obtained the first measurement of the ^{3}He energy spectrum in such an event (Torsti *et al.* 2002a). The particle event was associated with an impulsive flare and interplanetary shock wave, and a Type II radio burst was observed with WIND-WAVES before and then simultaneously with the ^{3}He-rich event registered with ERNE. Analysis of these events shows that the high-energy, ^{3}He-rich events are flare-related material reaccelerated on the flank of interplanetary coronal mass ejections (ICME). Onsets of the high-energy ^{3}He-rich events were observed in the far upstream regions, when the CME-driven shocks were at about 0.3 AU from the Sun. Numerical modeling (Kocharov and Torsti 2003) supports an interpretation of these observations involving ^{3}He reacceleration in oblique shocks driven by the CME's.

Suprathermals. Recently SOHO/CELIAS/(H)STOF was used to analyze the time period around the large CME event of May 2-3, 1998 (Bamert *et al.* 2002). The charge-state distribution of energetic He, the CNO group, and Fe were studied, and the energy dependence of the mean ionic charge states of Fe in the energy-per-nucleon range 12-100 keV/amu was investigated, together with the energy spectra of H+, He++, and He+ and the variations in the elemental abundance ratios He/H, He/CNO, and Fe/CNO. These observations greatly extended the energy range in which particles associated with this time period have been measured. Because of their elevated energies, suprathermal particles are the prime seed population for further acceleration in "gradual" events. Interstellar pick-up ions were identified as an important non-solar seed population. The observed low mean ionic charge states of Fe and the small Fe/CNO ratio were typical for large gradual events. The energy dependence of the Fe charge states may have been a result of the presence of different iron populations or of the thermal history of the accelerated material. The temporal variations of Fe/CNO and He/CNO indicated a stronger confinement of low-rigidity particles at the acceleration site.

Solar cycle variations. Continuing investigation of the energy dependence of energetic particle charge states will reveal whether there is a solar cycle variation in this dependence. With the declining phase and eventual solar minimum, more Corotating Interaction Regions (CIRs) will emerge. SOHO/CELIAS/STOF could be used to study the charge states of strong CIRs, thus gaining an insight into their variant compositions. STOF will also make composition measurements of SEPs in this phase of the solar cycle. These projects will be enhanced by collaboration with ACE and/or STEREO.

The Heliosphere: Solar Wind

First ionization potential effects. As noted in our 2001 proposal, *SOHO* CELIAS/MTOF measurements have shown that Al, the element with the fastest ionization time, has an enhancement that is similar to other low-FIP (First Ionization Potential) elements in the slow solar wind (Bochsler *et al.* 2000). Ongoing analysis indicates that Na, the element with the smallest FIP, has a similar enhancement. These results place constraints on models that attempt to explain the enhancement of low- FIP elements via neutral-ion separation in the lower solar atmosphere.

MTOF was also used to derive the first solar wind measurements of Cr/Fe (Paquette *et al.* 2001), as well as the relative abundance of three Fe isotopes (Ipavich *et al.* 2001). Results thus far are consistent with meteoritic values. An ongoing calibration program with the MTOF spare unit is expected to improve the results. The Ar/Ca ratio in different solar wind flow types was found to be consistent with previously published studies from gradual solar energetic particle events and spectroscopy (Weygand *et al.* 2001). The Ca/O and Ca/H ratios were studied in both fast and slow solar wind in a recent paper (Wurz *et al.* 2003). A strong FIP effect was seen in the Ca/O ratio, as expected for calcium, which has a low FIP.

Composition and magnetic clouds. A study (Wurz *et al.* 2001) of solar wind composition in magnetic clouds revealed a mass-dependent enrichment of the heavy ions (C through Fe) which increased monotonically with mass. When compared to nominal solar wind composition the lighter species (He through O) are systematically depleted. Both of these results can be explained by a theoretical model that assumes that coronal plasma loops are the precursors of magnetic clouds.

Hot and tenuous solar wind. A current study of the composition in very-low solar wind density time periods uses the CELIAS/PM to identify these unusual events (with H^+ densities 1 to 2 orders of magnitude below nominal). He^{++} densities are obtained from the ACE/SWICS instrument. Preliminary results indicate the He/H ratio is significantly depressed in these events; *i.e.*, the density depression of He is even more severe than for H. In addition the temperature of the plasma in these events is unusually hot, and the He^{++} speed is much larger than the H^+ speed.

The Heliosphere: Pickup Ions

Ubiquitous variations of interstellar pickup ions. After ionization by solar UV, charge exchange with the solar wind and through electron impact, interstellar neutral gas forms pickup ions typically with a spherical distribution that is centered on the solar wind velocity and fills the phase space from 0 to twice the solar wind speed. Although the source, the interstellar neutral gas distribution in interplanetary space, is relatively homogenous and steady, the pickup ion distributions are known to be highly variable in flux and shape. As these pickup ions are messengers of the interstellar gas on one hand and the seed population for further particle acceleration on the other, it would be very useful to understand these variations. Among the known reasons for these variations are temporal variations of the ionization rates and incomplete pitch-angle scattering to twice the solar wind speed in the case of radial interplanetary magnetic field (IMF). However, huge variations up to one of magnitude in flux are still unexplained. With the large collecting power of CELIAS CTOF a highly valuable pickup ion data set with excellent statistics and thus good time resolution is available. In a systematic study using solar wind

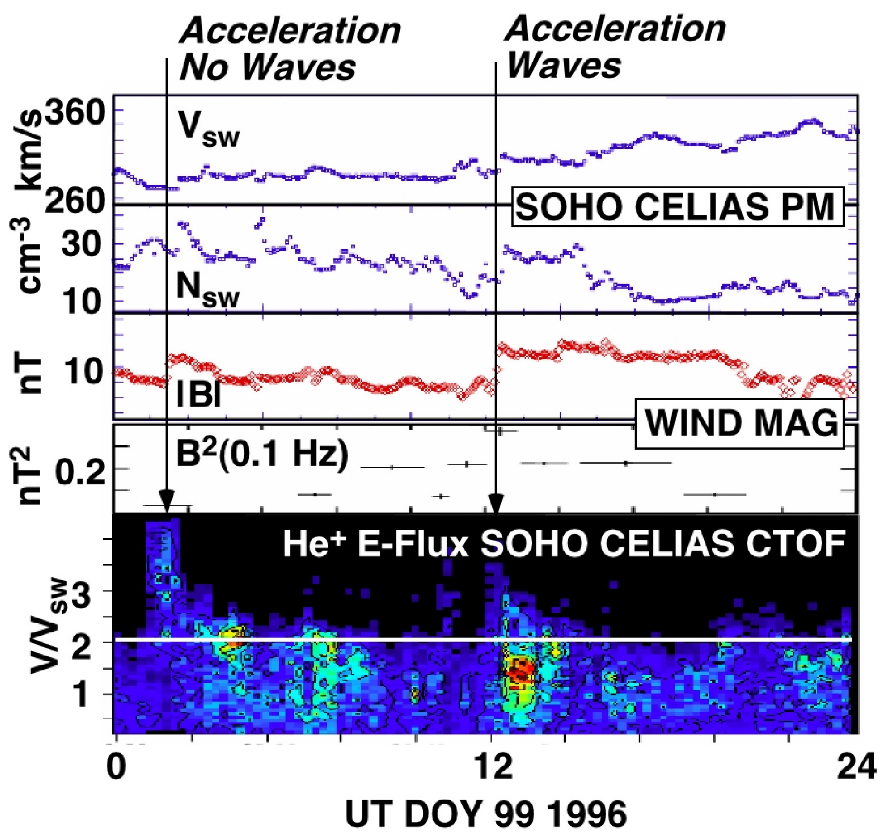

Figure 12. Two acceleration events of He+ pickup ions — extension of the velocity distribution beyond the cut-off at $v/v_{SW} = 2$ — are shown in the bottom panel (indicated by the arrows). Shown in addition from top to bottom are: solar wind speed, solar wind density, magnetic field strength, and wave power. While the accelerated pickup ions appear to coincide with the increased wave power in the second event, they are found mainly in front of a solar wind discontinuity without enhanced wave activity in the first event.

plasma properties from the CELIAS MTOF proton monitor (PM) and magnetic field measurements from WIND MAG, it was found that the pickup ion fluxes also correlate with solar wind density and magnetic field strength. Most notably the flux is enhanced in compression regions, as had been pointed out earlier from Ulysses SWICS observations of individual events. Significantly, it was found that the presence of magnetic field compressions was often accompanied by brief shift in the cutoff velocity of the pickup ions, which is equivalent to a heating of the distribution. This was interpreted as an adiabatic effect, by which the ions are accelerated by the changing field under conservation the first adiabatic invariant (Saul ***et al.*** 2003). Such compressions were also identified as places for further acceleration to higher energies with the formation of suprathermal tails. Interestingly enough acceleration occurred in some cases simply through the presence of a solar wind compression, while in other cases it appears to be associated with the presence of waves in the frequency range that is resonant with pickup ions. Figure 12 shows illustrative example for the behavior of the solar wind speed and density, magnetic field strength and wave power around 0.1 Hz, and the He+ energy flux density as a function of v/v_{sw} versus time. Flux density increases at compressions are seen, as well as two prominent cases of acceleration. The second of these accelerations is associated with wave power. The causes of the acceleration are still under investigation.

Comets

Biesecker *et al.* (2002) used LASCO observations of comets to obtain quantitative light curves of sungrazing comets. The light curves reveal an anomalous brightening as the comets approach the Sun, followed by a rapid dimming when the comets pass beyond ~ $11R_{Sun}$. The same study and an earlier one by Uzzo *et al.* (2001) find that fluctuating sungrazer brightness within ~ $7R_{Sun}$ suggests breakup. Sekanina (2002) found that "runaway" fragmentation of the Kreutz group sungrazers observed by LASCO occurs throughout their orbits.

Outbursts were observed in Comet 2P/Encke by Lamy *et al.* (2003) with LASCO and in comet C/2002 X5 (Kudo-Fujikawa) with UVCS (not yet published). The latter comet brightened by a factor of three in H I Lyman α as it passed perihelion, and also showed an ion tail containing C^{2+}, the first reported instance of a doubly ionized species in a comet.

Radiometric Calibration

Many of the results reported above would have been impossible without the superb photometric calibration work carried out by members of the CDS, SUMER, UVCS, SWAN, CELIAS SEM, and EIT teams. Their labors culminated in two workshops at the International Space Science Institute in 2001 February and October, and are reported in a series of papers published in a single volume (Pauluhn, Huber, and v. Steiger, eds. 2002).

IV. Continuing the SOHO Solar Cycle Mission, 2003 – 2007

The casual reader might wonder what *SOHO* has not yet seen, or why the mission is worth continuing for another four years, given the wealth of insight gained from solar minimum to solar maximum. Although there are many individual answers, which follow, there are two classes of arguments: we have observed some phenomena too infrequently, and simply need more observations to be able to have confidence in the physical explanations; and conditions during the decline from solar maximum — in the convection zone, the corona, and the heliosphere — are simply not the same as those in the rise to maximum. In addition, the extended maximum of Cycle 23 (see Figure 13) has meant that only in 2003 have we begun to be able to observe off-maximum conditions. We therefore present a small selection of the questions we propose to answer if we are allowed to complete the *SOHO* Solar Cycle Mission proposed to the 2001 Senior Review.

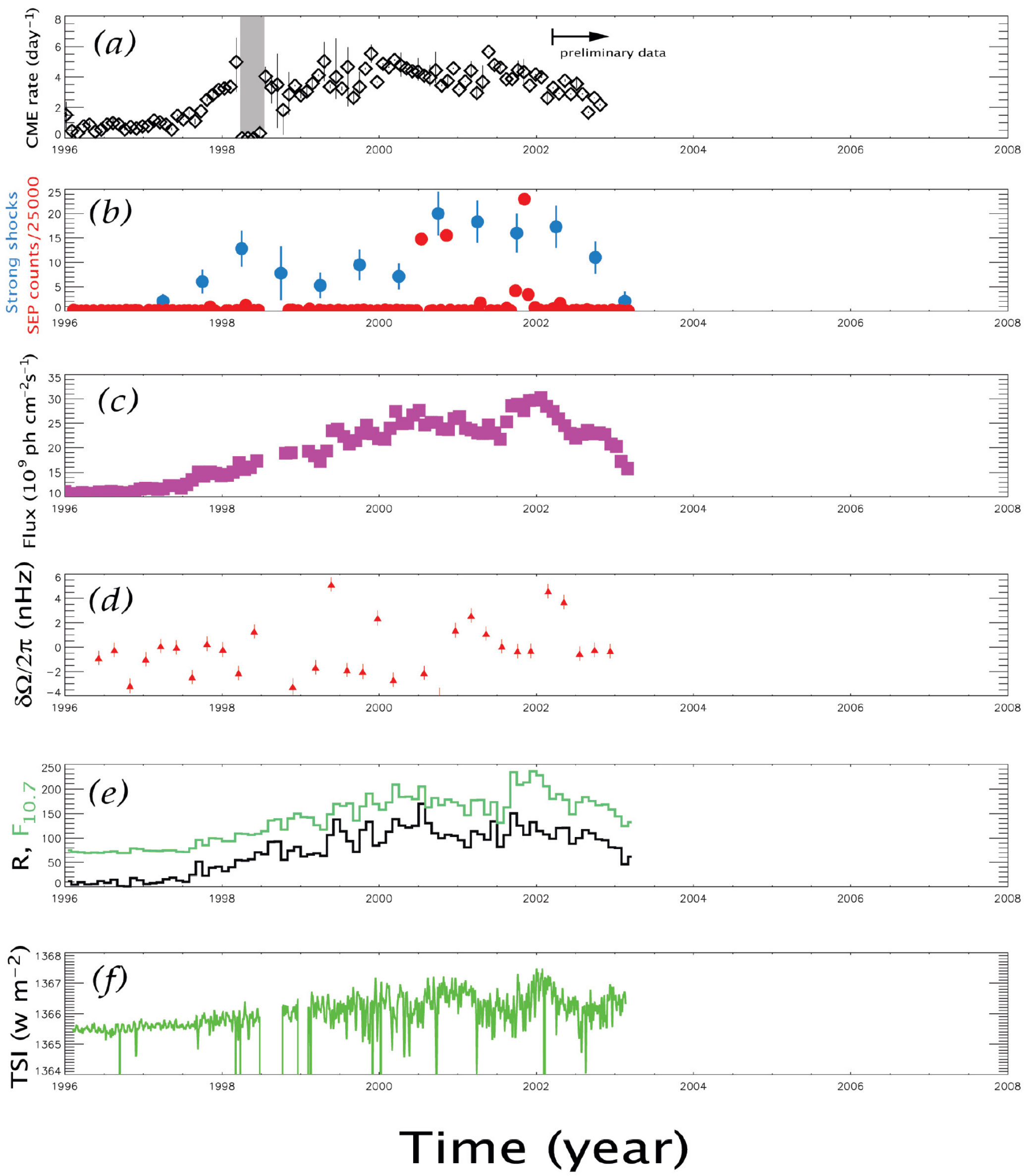

Figure 13. A selection of solar and heliospheric measurements over the first six years of the current cycle. (a) The number of coronal mass ejections per day, averaged over individual Carrington rotations (from SOHO LASCO); (b) from the SOHO CELIAS proton monitor: in blue, the frequency of strong shocks at L1, in red, the solar energetic particle (> 50 MeV) count rate (divided by 25000) from the largest event in each Carrington rotation; (c) integrated EUV flux in an 8 nm bandpass about He II 30.4 nm (SOHOCELIAS SEM); (d) changes in the internal rotation rate at 0.72 solar radii (from SOHO MDI) – an apparent 13-month periodicity at solar minimum is not evident around maximum; (e) the solar 10.7 cm flux and unsmoothed sunspot number; and (f)the total solar irradiance (SOHO VIRGO DIARAD, calibration v2.0).

Total Solar Irradiance. These observations must continue without gaps in order to cross-calibrate existing and future measurements, and we must continually test whether "superficialist," empirical models of the sources of TSI variability remain valid throughout the current cycle.

The search for g-modes. While we cannot decrease the inherent, solar noise, four more years of observations with GOLF, LOI, and MDI will allow us to say whether the predicted *g*-mode strengths remain below the limit of detectability, or whether the theory is inadequate.

Taking the measure of the tachocline. By continuing MDI observations of global *p*-modes, we will be able to determine not only whether the apparent periodicity in sound speed variations around the tachocline returns at the next solar minimum, but whether there are other telltales of cyclic behavior in the area where the deep dynamo is believed to operate.

Global internal circulation. How long will the double circulation cells observed in the meridional circulation persist? As active regions grow less frequent, will the double cells merge, and at what depth with the merging commence?

Solar subsurface weather. Will the SSW flows give us enough information to be able to predict the rise of Cycle 24, since there is always overlap in the activity?

Emerging active regions. Is the absence of signatures of emerging active regions universal — that is, do all active regions cross the convection zone as quickly as those observed by Kosovichev *et al.* (2002a, b)? Can we specify the depth in the convection zone to which we need to probe to "see" such fast emergence in time to predict it, or do we simply need to wait for data from HMI on board SDO?

Supergranulation. Can further study and modeling of supergranular dynamics produce a coherent view of this ubiquitous phenomenon?

Plasma processes in collisionless, CME-driven shock waves. Can we build on the success of the instances of Max Millenium Major Flare Alerts in coordinating observations of fast CME's by UVCS with synoptic LASCO and EIT observations to test the fundamental plasma physics of electron heating in fast shock waves? Can we finally understand the relationship of such events to Type II radio bursts?

The role of current sheets in CME eruptions. Current sheets are central to many models of energy release in flares and post-CME relaxation of the magnetic field. Can we leverage the same optimization of multiple-instrument observations to detect enough high-temperature, post-CME current-sheets to allow us to describe the temporal and spatial evolution of these structures?

Conservation of magnetic helicity and CME evolution. To obtain a better understanding of helical magnetic structures in CME's, more simultaneous, high-cadence UVCS and CDS spectra are needed. Will detailed spectroscopy of a wider variety of CME's, folded together with ongoing improvements in models (both full MHD simulations and simpler phenomenological tools), show evidence of magnetic helicity changes with height? Will the apparent trend of decreasing rotation speed with height turnout to be significant?

The nature of coronal jets. Only several years into the *SOHO* mission was an optimal method for observing coronal hole jets with UVCS developed; by then, the polar coronal holes had disappeared with the expansion of the corona toward higher latitudes. In the next four years, as the polar coronal holes grow in size, will the combination of UVCS spectroscopy, and EIT He II 304 Å imagery (which isolate the cool jet plasma) make it possible to establish the relative contributions of these jets to the energy and mass balance of coronal holes?

Energy budget of CME plasma. The relative distribution of thermal, kinetic, turbulent, and magnetic energy is fundamental to any physical understanding of CME's, and UVCS observations have found several cases where the thermal energy was comparable to the outflow kinetic energy. Those observations can be improved by adding CDS spectroscopy to extend the available temperature and density diagnostics, as a function of height. Will the energy partition found so far hold up in such a sample?

Solar wind from coronal holes: resurgence of extreme ion properties. UVCS has observed preferential ion heating and acceleration in coronal holes at all phases of the solar cycle, but the strength and radial onset of these properties varies significantly. A pattern is beginning to emerge in observations of large coronal holes, with an apparent anticorrelation between density and the ion heating and acceleration rates. Theoretical models are being developed with the goal of explaining the observed relationships among these parameters, but observations of coronal holes having as wide a range of properties as possible are needed. Will observations including the approach to solar minimum, in which minor ion properties have never before been measured, support the case for ions being heated and accelerated by a specific process, *e.g.* ion cyclotron resonance?

Solar wind from coronal holes: particles and composition. The largest trans-equatorial coronal holes tend to occur during the declining phase of the solar cycle, somewhat before solar minimum. In the previous solar cycle the longest-lasting, highest-speed corotating solar wind streams were observed in 1994 and 1995, before the launch of *SOHO*. *SOHO* has not yet been able to sample this phase of the solar cycle, which represents the best opportunity for studies of CIR-generated energetic particles and also for analysis of coronal-hole associated solar wind. For example, the degree (if any) of FIP-bias in very high speed coronal hole flows is not well known and could be addressed by measurements with the CELIAS/MTOF sensor.

Solar wind from streamers. We cannot predict how or when the dense streamers of the active Sun will evolve back to the equatorial solar-minimum streamer belt. UVCS measurements have shown that equatorial streamers exhibit similar preferential ion heating to that in coronal holes, but the more active mid-latitude streamers do not. During the approach to solar minimum, how does the corona effect this change? What conditions facilitate it?

Solar wind quadrature studies. Valuable coordinated studies have been performed with SOHO and various *in situ* instruments. Continuing the ongoing SOHO-Ulysses quadrature observations will alow us to continue to sample the same parcels of plasma at a wide range of heliocentric distances. In 2004-2007, Ulysses is expected to be increasingly immersed in the fast solar wind as it crosses the ecliptic (early 2004) and heads to southern polar latitudes. Can UVCS and Ulysses measurements resolve individual polar plumes, both by remote sensing the corona and *in situ*? Can we constrain models of the radial evolution of CME's using both UVCS and LASCO measurements in conjunction with Ulysses observations of associated ICME's?

Comets. LASCO has observed nearly 600 comets during the SOHO mission, and UVCS has measured detailed plasma properties of several comets per year. Additional measurements of outgassing rates, bow-shock properties, and near-Sun breakup events would be valuable. Could further spectroscopic observations of comets provide new constraints on the energy budget of the fast and slow solar wind at distances unobservable by any other means?

Helium focusing cone. Interstellar helium atoms penetrate the heliosphere, and solar gravity focuses their trajectories on a line in the downwind direction from the Sun. Annual UVCS observations of photons scattered from this focusing cone have tracked the gradual filling of the heliosphere by slow and dense solar wind during the rise to solar maximum. The observed brightness was lower than expected based on CELIAS/SEM photoionization rates, but the combined data sets have yielded new insights on these physical processes. Continued observations during the approach to solar minimum will (for the first time) map the angular distribution of the cone. Will the results confirm earlier results (*e.g.* from SWAN) on the kinetic temperature of helium in the local interstellar medium?

V. Why keep SOHO going?

Cycle 23 has been marked by some four years (1998 – 2001) of maximum-like activity, as seen in several solar and heliospheric measures (Figure C-1). Only now can ***the combination of SOHO and other, unique SEC assets currently operating can give us new and deeper insights into the cycle dependency of phenomena as diverse as coronal mass ejections, the acceleration of the solar wind in a variety of coronal conditions, the evolution of the solar and heliospheric magnetic field, the heliopause, the solar tachocline and zonal flows.***

NASA is in a unique position of attempting to deploy a broad series of follow-on missions to the SEC missions ACE, WIND, POLAR, and *SOHO*. We believe that ***the scientific usefulness of the Solar-Terrestrial Probes and LWS missions will be severely compromised if we do not avail ourselves of the opportunity to extend unique observing capabilities through an entire solar cycle.***

Early in FY2006, NASA plans to launch two STEREO spacecraft into near-1 AU, heliocentric orbits. As noted by Davila (1994), the likelihood of reconstructing coronal features (and mass ejection morphology) from three, separated viewpoints is significantly better than that from just two. When ***combined with the STEREO SECCHI coronagraphs and EUV Imager, SOHO LASCO and EIT data will substantially improve our understanding of the structure and evolution of both closed magnetic field features and CME's***.

As we learned inadvertently when *SOHO* was lost during the summer of 1998, ***there is a recognition within NASA and other US agencies that SOHO's space weather predictive capabilities are national and international resources that should continue uninterrupted.*** Until at least the launch of the STEREO spacecraft at the end of 2005, there are no similar capabilities planned.

The combination of *SOHO,* TRACE, and SMEI is likewise unique in characterizing solar activity, and with the addition of RHESSI, we have the once-in-a-lifetime ability to cover ***all temporal scales of solar activity from milliseconds to a solar cycle, and all spatial scales from "moss" to the entire, inner heliosphere.*** The interactions of processes on different spatial and temporal scales may never again be accessible in this much detail.

We should also point out that some measurements, such as the search for solar *g*-modes, the determination of whether periodic changes in the sound speed near the tachocline return near solar minimum, and the spatial distribution of solar irradiance variations in the EUV, simply ***require more years of observing before conclusive results can be obtained.*** In addition, measurements with the same set of instruments over a full cycle enable analysis without the difficulties of cross-calibration.

The best reason to continue *SOHO* science and operations, however, is that while we have made considerable progress, we have still not realized the full potential of *SOHO* to explore the diverse parameter space offered by the solar cycle:

We have learned many new things about the solar interior, but still do not understand whether the convergence zones for active region flows drive the latitudinal distribution of the regions over the cycle, or whether there are *g*-modes in the deep interior.

We have been able for the first time to see the effect of coronal mass ejections on the lowest layers of the corona, to study the Doppler motions and heating characteristics of CME ejecta, and to begin to understand where CME's are accelerated, but we still do not know what causes CME's to erupt, nor how they are accelerated, nor whether the variation in the rate is the same from cycle to cycle.

We have made significant progress in understanding the solar wind plasma at solar minimum and at solar maximum, but we still do not understand how the quiescent, solar minimum state arises from the more chaotic solar maximum state, nor do we have sufficient observations of a wide enough range of solar wind source regions to allow us to narrow even further the list of possible theoretical models for the acceleration of both fast and slow wind. We also need to understand how the spatial distribution of the wind originates and varies over a full cycle.

In short, we propose that NASA continue to contribute the costs of operating *SOHO* and the US-funded PI and lead Co-I science operations tasks throughout the period FY2004 – FY2007 ***to fulfill the scientific promise of SOHO to answer fundamental questions about the Sun and heliosphere.***

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later through the heroic efforts of an ESA-NASA-contractor-university team. All 12 scientific instruments

VII. Education and Public Outreach

Multiplier activities in education

In addition to numerous classroom visits reaching over a thousand students, some in conjunction with the Astronomical Society of the Pacific's Project Astro and Challenger Centers' Journey Through the Universe, the *SOHO* PI team scientists and the *SOHO* media specialist have engaged in numerous educational activities with more significant multiplier values:

- continued to mentor students at the largest HBCU system in the country under the auspices of NASA's Minority Education and Research Partnership Initiative, involved the students directly in *SOHO* data analysis, and participated in plans for the revitalization of an astrophysics program at the university,
- reprinted the constructible spectrometer poster; more than 16,000 distributed since 2001 April,
- developed and produced live webcasts in cooperation with the NASA's Learning Technologies Channel program at NASA Ames Research Center; the Sun-Earth Day presentation in 2001 reached approx 10,000 people. The 2002 show reached 100,000 since it was aired on NASA-TV,
- developed and run teacher workshops at the National Science Teachers Association (NSTA) conference, NASA Ames, San Jose State University, Tucson, and the University of Arkansas Science Day: these train teachers to use *SOHO* and other SEC resources, *and to train other teachers*,
- participated in Sun-Earth Days 2002 and 2003: dozens of PI team members and colleagues gave popular talks in public venues across the US and Europe, some of them televised,
- contributed a former project scientist to the new Passport to Knowledge series of three PBS television programs (Live from the Aurora), with teacher's kits and a related Web site,
- produced six versions of the educational CD-ROM, *The Dynamic Sun* (over 185,000 distributed to date); the most recent edition includes Spanish as well as English text,
- produced four new or revised posters; in addition to over 100,000 classroom posters distributed before the last Senior Review:
    - *Aurora* (20,000), in conjunction with the Sun-Earth Connection Education forum
    - *New Views of the Sun* (40,000)
    - *Storms from the Sun*, reprinted (English and Spanish; 40,000 and 15,000 respectively)
    - *Our Star, the Sun*, an elementary level poster (10,000), and
- created and updated artwork and educational text for the widely used *SOHO* lithograph portfolio (over 30,000 sets distributed).

Outreach Products

- New, postcard-sized lenticular, of a coronal mass ejection time series; back features text and images explaining some of the science involved
- Four new or revised posters (see previous section)
- Set of three light-weight, pop-up banners (3 ft. x 8 ft.) with images and text that describe the SOHO mission and *SOHO* science. These can be set up in less than a minute for booths/presentations at schools, conferences, or other interactions with the public.
- The *SOHO Exploring the Sun* CD-ROM was updated and expanded in 2003, with a run of 20,000. We also maintain an inventory of stickers and web cards for distribution to audiences at conferences and presentations.
- Almost all of our outreach products are made available on our web site as well, usually in PDF format for easy downloading and viewing.
- Exhibit development:
    - *SOHO* has collaborated with dozens of museums to help them incorporate our movies and images into their exhibits and planetarium shows. One recent example is a new (April 2003) solar multimedia module called "Helios," jointly developed with HST, which becomes part of the Space Telescope Science Institute's View Space offering for museums. View Space, offered at no charge, is an ever-changing loop of short media modules dedicated to aspects of HST. Detailed images, minimally intrusive text, mesmerizing space music, clips and animations combine to deliver a quiet, inspiring experience of beauty and wonder. This is their first expansion to a subject area beyond HST.
    - *SOHO* is the dominant mission featured in the Space Weather Center, a traveling exhibit now at its eleventh museum venue. This was developed by Goddard SEC missions and the Space Science Institute. Also, a SOHO exhibit has been presented on several occasions

in the U.S. When not in use elsewhere, it resides at the Visitor Center at GSFC. The exhibit consists of a 1:4 scale SOHO model, ESA/SOHO backdrop walls, and computers displaying real-time images and the SOHO Exploring the Sun CD. The *SOHO* model is currently (2003 March) being refurbished at NASA Goddard for loan to the Maryland Science Center in Baltimore's Inner Harbor.

- We continue to produce weekly *SOHO* video updates for the (New York) American Museum of Natural History's Rose Center, where the video, a still image, and an explanatory caption are shown on a 13-foot video display

SOHO on the Web

The *SOHO* Web site, largely maintained by the able ESA *SOHO* Project Scientist's office and the *SOHO* media specialist, regularly produces "Hot Shots" on new solar events or science stories. The site averaged over 6 million hits per month in 2002, but this figure jumped to 16 million when the awesome imagery of Comet NEAT (C/2002 V1) obtained by LASCO C3 became available in 2003 February. In that month alone, we served over 1.6 Tbyte of movies, images, and information — or an average of 52 Mbps. The current average is over 10 million hits/month. In addition to our own site, *SOHO* images have been featured on the popular Astronomy Picture of the Day site fifteen times over the past two years. In the last two years, we have added a movie section and several Spanish components have been added to the *SOHO* site as well.

In 2002, we held a public competition, allowing contestants to guess the date and time of the 500th *SOHO* comet. Some 1300 entries from around the world helped to engage a wider audience and media interest since anyone could review the "live" LASCO C3 data and participate. Finally, our Website offers a "Dr. SOHO" area where anyone can pose questions to the SOHO scientists; most are answered within one or two days. SOHO scientists answered over 2,000 such inquiries over the last two years.

Web-to-other media crossover. Since 2001 March, a *SOHO* "Pick of the Week" has appeared not only on our site, but also in the American Museum of Natural History Rose Center's Astronomical Update video wall display. The images and digital movies on the *SOHO* Website regularly find their way to CNN.com, Space.com, and other heavily trafficked Web sites, which provide yet another method of repeated public exposure to the concept of space weather. Many of these sites, in turn, are Web outlets for broadcast and print media, who also then use *SOHO* imagery to carry the message of space weather to a broad audience.

SOHO in the Media

A number of articles about SOHO have appeared in several popular magazines such as *Scientific American*, *Discover*, *Aerospace America*, *Spaceflight*, *Astronomy Now*, *Astronomy*, *Ciel & Espace*, *Sterne und Weltraum*, and *Orione*, and *SOHO* images have been featured on the covers of several of these. (See *SOHO* News page at `http://soho.nascom.nasa.gov/newsroom/`.) We are providing SOHO imagery for a *National Geographic* magazine article on recent discoveries about the Sun to be published in late 2003.

Several film and TV crews have visited the *SOHO* operations facility (Japanese, Danish, UK, and US), and *SOHO* has been featured in a number of science programs. In particular, there have been several programs on the topic of the Sun and space weather such as "Savage Sun" (Discovery Channel), "Solar Blast" (National Geographic), "Live from the Sun" (3 one-hour shows on PBS), "Aurora: Living with a Star" (PBS), and "The Planets" (BBC). We have supported some two dozen special or premiere screenings of the 42-minute IMAX documentary "SolarMax" in the U.S. and Europe with lectures and tele-lectures. A number of other commercial and educational products have featured *SOHO* movies and images, including "The Universe DVD" and "Solar Eclipse."

Official visits and events

We have organized numerous tours of GSFC and *SOHO* EOF for leadership groups, including a class from the National Defense University, the Executive Director of the U.S. Chamber of Commerce, the

National Federation for the Blind, the Space Enterprise Council, and several other industry leaders in the District of Columbia. Delegations from several European Embassies in D.C. have toured GSFC, including the Norwegian Ambassador, Knut Vollebæk. The SOHO operations area has been upgraded with numerous images, monitors with live data, outreach materials, and explanatory captioning to make the visitor experience more rewarding.

SOHO and the popular imagination

Thanks to the quality of *SOHO* imagery, and the dynamic nature of the features visible in time-lapse animations from those images in a videophilic age, *SOHO* has become part of the popular imagination in a way the science community did not anticipate. *SOHO* movies are used in skin cancer awareness messages; *SOHO* images are used as stock file photos, labeled only, "The Sun," on news Websites; *SOHO* images are used in free giveaways at fast-food chains and as cover art on classical, popular, and avant-garde music CD's. When coupled with the diagnostic capabilities of ACE and *SOHO*'s sister ISTP spacecraft, *SOHO* imagery has made space weather a household term. Postdocs working on *SOHO* have been featured in numerous television documentaries and "live shot" interviews, and the experience in dealing with the media they have gained at an early stage in their career has enabled them to become public explicators of Sun-Earth Connections science. Such activities can only benefit public support for SEC programs in the future.

SOHO education and outreach plan

Our most important commitment, already begun late in FY2003, is to support the development of *Touch the Sun*, a book of *SOHO* and other solar imagery for the visually impaired, to be written and published by the team that produced *Touch the Universe*. *SOHO* will provide partial funding, as well as image data and scientific consulting. The book will be distributed free to blind students and educational institutions, as well as being offered for sale to the general public by the Joseph Henry Press of the National Academy of Sciences.

Much of the rich variety of information on the *SOHO* Website is not well organized for educational use. We propose to:

- hire a science educator specialist to assist in the development of interactive educational modules for the SOHO web site; to plan and lead a SOHO/Sun-Earth Connection Education Forum workshop for pre-service teachers; to assist in the development of new education products; and to develop ties and partnerships with schools and universities.

In addition, we propose to continue to produce and distribute novel and thought-provoking materials for public outreach, including:

- a "Best of *SOHO*" DVD, to include dozens of the best of SOHO time-lapse imagery at DVD quality
- outreach and educational material for Sun-Earth Day, 2004, which will be timed to coincide with the transit of Venus, and
- a new lenticular featuring the Sun as seen in visible light, EUV, and through magnetographs and coronagraphs

Appendix A. SOHO publication record, 1996 – 2003Q1

SOHO refereed publication rates through the first quarter of calendar year 2003, can be found in Table A-1.

Calendar Year	Ref. Journals Only
1996	**34**
1997	**132**
1998	**180**
1999	**307**
2000	**301**
2001	**210**
2002	**208**
2003Q1	**64**
Total	**1436**

Table A-1. *SOHO* refereed papers

Here, a "*SOHO* paper" is taken to mean any paper using *SOHO* data, or concerning models of theoretical interpretations of *SOHO* measurements. The first-quarter CY2003 figures can be assumed to be lagging well behind actual numbers, since we are still receiving input on CY2002 papers. Based on past reporting rates and time lag, we can forecast a CY2003 publication rate roughly equal to that in CY2002.

A listing of SOHO papers published in refereed journals since 2001 can be found at http://umbra.nascom.nasa.gov/soho/sr03/soho_publ_2001-2003.html . More selective or current information can be found at the SOHO online publication database, http://soho.nascom.nasa.gov/cgi-bin/bib_ui .

"Market share" In the years since the launch of *SOHO*, there were 1,517 authors and co-authors of *SOHO* papers. Since *SOHO* carries both *in situ* and remote sensing instruments, there is a large potential pool of authors. Considering just the remote sensing instruments, there are roughly 600 members of the AAS Solar Physics Division and a roughly equal number of active solar physicists in Europe and Asia (combined). Past experience indicates that approximately 75% of those are "active," in the sense of publishing at least one refereed paper per year. If this is an accurate model of the solar physics community, we can assert that *SOHO* has reached a good approximation to serving 100% of the active solar physics community — and a substantial share of the heliospheric community as well.

We are convinced that this success is based on the open and convenient accessibility of *SOHO* data and analysis software. Only a data policy of this type is likely to draw in the widest possible scientific community — including amateurs — to the enterprise of mining SEC data for their maximum scientific return.

Appendix B. Instrument Status as of 2003 April 7

GOLF

- Operating nominally
- Progressive, expected fall-off in throughput not worrying, and will not prevent GOLF from observing an entire solar cycle
- Continuous observations in red wing of Na D line since *SOHO* recovery
- In 2002 October, moved the polarizers to optimize data quality for the remainder of the *SOHO* observing time:
  - switched to the blue wing of the line, to improve signal to noise ratio and insensitivity to activity, and
  - reduced the residual GOLF sensitivity to real circular polarization due to solar magnetic fields
- Longer observing period (1 year?) is necessary to validate these improvements.
- Reserve: redundant data channel validated but unused

VIRGO

All VIRGO instruments (the two types of radiometers: PMO6V and DIARAD, the filter radiometers SPM, and the luminosity oscillation imager LOI), are fully operational and perform very well. The degradation of sensitivity is still relatively small and for all instruments the margin to provide valuable scientific output will not be reached before many more years. Although the tested lifetime for the mechanisms has been reached they show still no change in performance.

MDI

- 70,500,000 images; after on-board computations, > 11,000,000 raw data imaged downlinked
- Expected degradation in total light throughput due to changes in the front window; compensated *via* increased exposure time. Through 2003 March:
  - total degradation: 25%
  - mean annual degradation: 3.2%
- Exposure time uniformity: sudden drop in 2000 March, from one part in 12000 to one part in 4000
  - affects helioseismology on for degree $l < 4$
  - adds some noise to zero point of photsopheric magnetic field measurements, which can be corrected by examination of the data (Liu *et al.* 2002)
  - performance improved when optics package temperature reduced
  - if further degradation, could reduce shutter usage (loss of observing support to other instruments)
- No detected change in the CCD flat field except for variations with focus change. The drift in central wavelength of the Michelson's has nearly stopped.
- The drift in best focus position has moved the nominal focus setting back almost to the design point. Shortly after launch it was at the limit of the adjustment range. This drift has also apparently stopped.
- In summary, with the possible exception of the shutter jitter, there is no known limit to MDI's useful life within the *SOHO* expected fuel life.

SUMER

SUMER is operated exclusively in campaign mode, usually several times a year.
These observations employ detector A, since detector B, although still fully operational, has reached its highest gain level and is only available for specific tasks that can only performed in the short-wavelength, first-order range of this detector. The east-west drive of the telescope mirror - working in high-current mode - caused no difficulties in any of the pointing operations, but cannot be used for raster scans anymore.

The PI team is implementing use of an area of the detector that has seen much less use than the rest of the detector area. This will provide an option with limited spatial coverage, but greatly enhanced throughput.

CDS

- GIS nominal; no recalibration or changes to high voltages have been necessary in the past 18 months.
- NIS nominal; no adjustments have been necessary in the past two years. Continual monitoring of ciritcal parameters such as microchannel plate high voltage.
- Electronics nominal
- Mechanisms: Movement of the GIS slit mechanism, when used in a rastering mode, appears to become 'sticky' when entering a certain but short positive range. The slit frees itself and catches up as movement exits this area. A restriction on the range of movements when rastering the slit has therefore been imposed. All other mechanisms are nominal.
- Thermal: As with all other components of *SOHO*, the sunward side of CDS shows a secular increase in temperature, but analysis of the science data shows that the NIS wavelength calibration remains within tolerances.
- Onboard software: No issues

EIT

- EIT is nominal
- Instrument throughput continues to decrease slowly
  - Only the reduction in charge collection efficiency (CCE) in the CCD due to EUV-induced damage continues
  - CCE loss can be tracked accurately with calibration lamp images
  - Degradation now well understood and modeled
  - Degradation rate controlled with regular (~ 2.5 month cadence) CCD bakeouts
  - Present exposure times range from 12 s (195 Å) to 2 m (284 Å): lots of latitude left
  - S/N still high; net degradation since beginning of 2001 less than 1/2 that between launch and 2001 January

UVCS

UVCS is expected to continue performing at full scientific capability for many more years.

- **O VI detector:** There has been no significant decrease in efficiency in the O VI detector. Detector efficiency loss is carefully tracked with an increase in high voltage of 5 engineering units that is carried out when the loss approaches 5%. The period between such increases depends on the accumulated Lyα dose and at current rates is more than 1.2 years. A voltage increase from the current setting of 210 to 215 is expected soon, and a maximum high voltage of 250 allows seven increases (step size of 5) beyond 215.
- **Lyα detector:** This detector has been turned off since November 1998 because it draws about 50% of the maximum current and has regions of elevated background. The detector is still operational and is treated as a back-up detector for Lyα observations.
- **Mechanisms:** All mechanisms continue to behave nominally except for the Lyα grating drive, which is slow to respond when commanded.This condition has no effect on current or planned science activity since the Lyα detector is turned off.
- **Response:** Changes in overall system responsivity have been observed (*e.g.* radiometric responsivity is currently at 60% of the original value for the vignetted aperture that is used for observations at 2.5 R_{Sun}) and are being accurately tracked using observations of stars (see Gardner *et al.* 2002).

LASCO

The LASCO/C2 and C3 coronagraphs continue to operate with no degradation, other than a decrease in photometric sensitivity of 3% since launch. The Fabry Pérot interferometer in the LASCO/C1 coronagraph did not survive the extreme cold the instrument experienced (-80C) during the 1998 *SOHO* offpointing.

CELIAS

- MTOF/PM, STOF/HSTOF, SEM nominal
- CTOF impaired since 1996 October (HV power supply hardware failure)

COSTEP

COSTEP consists of two sensors, the Low-Energy Ion and Electron Instrument (LION), and the Electron, Proton, and Helium Instrument (EPHIN). Both instruments have been working very stably during the last three years without major degradation. Detector degradation during the first year of the mission could be largely recovered by additional programming and calibration effort. The COSTEP experiment still fulfils its scientific goals with minor degradation in resolution for a few energy channels.

- **LION status:** Despite the unexpectedly high noise level in the LION detectors since shortly after launch, detailed analysis shows that the scientific goal for LION can be achieved by using additional calibration and calculation, though with the disadvantage of a higher trigger level for small events. Otherwise, LION remains nominal.
- **EPHIN status:** Detector E of the EPHIN instrument showed steadily increasing noise levels throughout 1996, and had to be switched off (on 1996 October 31) to guarantee reliable measurements with the instrument in the future. By changing the instrument configuration, the measurements of EPHIN can still be achieved with slightly degraded resolution. No significant degradation of the scientific goals of EPHIN are caused by this detector failure.

ERNE

All *SOHO* instruments are subject to a secular increase in temperature. The slow but continuous temperature increase of the ERNE instrument has become of some concern, since the Sensor Unit is nearing its design limit of 35 C. The temperature increase is obviously mainly due to the degradation of the thermal hardware of the ERNE Sensor Unit. Unfortunately, switching off the payload module (PLM) heaters does not seem to have had any significant effect on ERNE temperatures. Until now, however, the elevated temperatures have not shown any impact on the scientific performance of the instrument.

SWAN

General Status :

All subsystems are functional except south sensor (-Z side) hydrogen cell; no problems with the scanning motors since 1999. Observations are performed 24 hours a day except during spacecraft maneuvers.

- **Detectors:** North sensor (+Z side) stable except for an abrupt loss of sensitivity (about 50 %) after the 1998 incident, when the detector was exposed to direct sunlight. Following this incident, the sensor has also become slightly more sensitive to near visible light (less solar blind) and so has become more sensitive to stray light. It also shows an increase in counts when the filaments in the hydrogen cell are activated (correctible). The current setting of the +Z sensor high voltage is 120 with a maximum of 255. The south sensor (-Z side) is slowly losing sensitivity with a slope of roughly 10% per year. The current setting of the –Z sensor high voltage is 140 with a maximum of 255, and will be increased when this becomes necessary.
- **Hydrogen cells:** North (+Z) sensor hydrogen cell is performing nominally almost no change since launch. South (-Z) sensor hydrogen cell no longer absorbing. The reason for this is not certain but cell probably lost its hydrogen at some point in 2000. The south sensor H cell functioned nominally between 1996 and 2000.

Appendix C. Acronyms

CDS	Coronal Diagnostic Spectrometer
CELIAS	Charge, Element, and Isotope Analysis System
COSTEP	Comprehensive Suprathermal and Energetic Particle Analyzer
CTOF	Charge Time-Of-Flight sensor of CELIAS
DIARAD	DIfferential Absolute RADiometer (active cavity radiometer) component of VIRGO
EAF	Experimenters' Analysis Facility
EIT	Extreme ultraviolet Imaging Telescope
ERNE	Energetic and Relativistic Nuclei and Electron experiment
EOF	Experimenters' Operations Facility
ESA	European Space Agency
GIS	Grazing Incidence Spectrograph of CDS
GOLF	Global Oscillations at Low Frequencies
HBCU	Historically Black College and University
LASCO	Large-Angle and Spectrometric Coronagraph
LOI	Luminosity Oscillations Imager component of VIRGO
MDI	Michelson Doppler Imager
MTOF	Mass Time-of-Flight mass spectrometer of CELIAS
NIS	Normal Incidence Spectrograph of CDS
PM	Proton Monitor of CELIAS
PM06	Twin-cavity radiometer component of VIRGO
RHESSI	Ramaty High Energy Solar Spectroscopic Imager
SMEI	Solar Mass Ejection Imager
SOHO	Solar and Heliospheric Observatory
SOI	Solar Oscillations Investigation
SPM	Spectral irradiance monitor component of VIRGO
STOF	Suprathermal Time-of-Flight ion telescope, part of CELIAS
SUMER	Solar Ultraviolet Measurements of Emitted Radiation (UV spectrometer)
TRACE	TRansition Region And Coronal Explorer
SWAN	Solar Wind Anisotropies
UVCS	Ultraviolet Coronagraph Spectrometer
VIRGO	Variability of Solar Irradiance and Gravity Oscillations
VSO	Virtual Solar Observatory

SOHO instrument names are in blue.


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