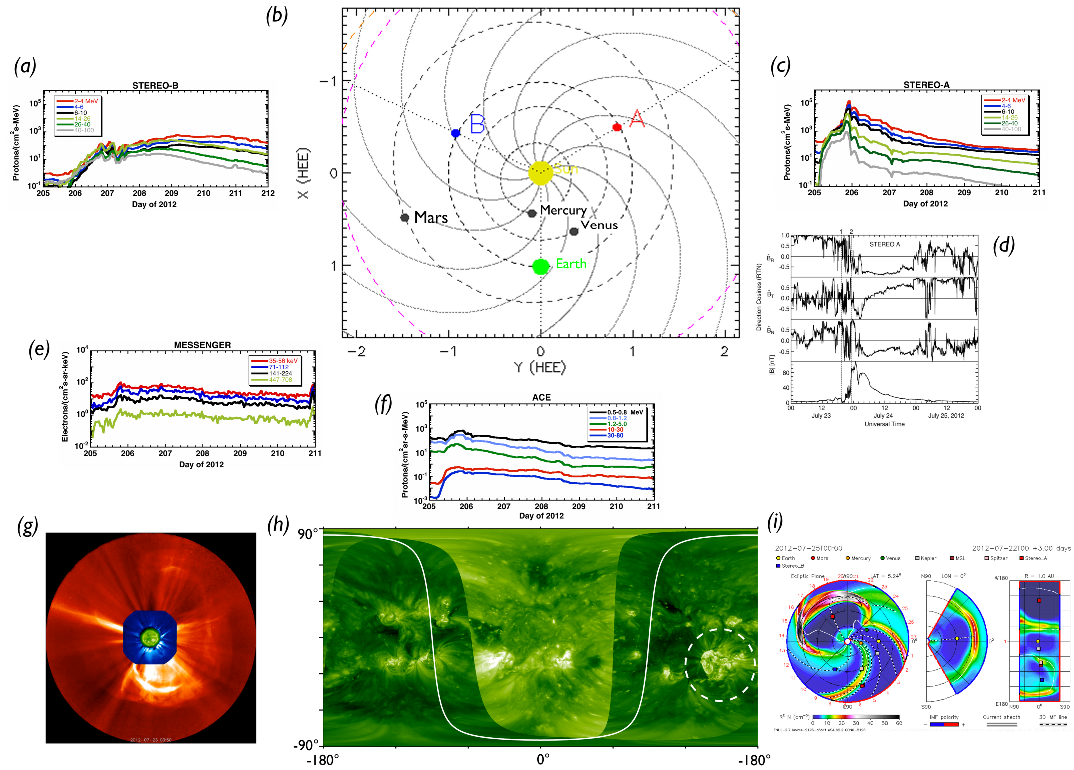
STEREO :

*"What lies behind the Sun"**



(a) STEREO Behind energetic proton measurements for late July, 2012; (b) the locations of the STEREO spacecraft and inner planets on 2012 July 23; (c) as (a), but for STEREO Ahead, which was directly in front of the extraordinarily large and fast ICME; (d) magnetic field measurements from STEREO Ahead; (e) energetic electrons measured by MESSENGER; (f) energetic protons measured by ACE; (g) a SECCHI EUV and visible-light composite of the event, as seen from STEREO Ahead; (h) a Carrington map of the entire Sun on 2012 July 23, assembled from 195 Å images from both STEREO spacecraft and a 193 Å image from SDO (centered on the earth-facing central meridian, and showing in the dashed circle the location of the active region – invisible from earth – in which the CME originated); and (i) a simulation of the ICME's propagation from the GSFC CCMC, showing the unusual breadth and density of the shock front.

A PROPOSAL TO THE SENIOR REVIEW OF HELIOPHYSICS OPERATING MISSIONS, 2013 MARCH.

* *"O brothers," I said, "who through a hundred thousand perils have reached the west, to this so little vigil of our senses that remains, do not choose to deny the experience of [what lies] behind the sun, of the world without human beings. Consider your seed [the race you spring from]: you were not made to live like brutes, but to follow virtue and knowledge."*

– Dante Alighieri, l'Inverno, Canto XXVI

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Solar TErrestrial RElations Observatory (STEREO)

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I. Executive Summary

The STEREO mission has transformed the way both researchers and space weather forecasters work, by making possible observations of the Sun, the solar wind, and solar energetic particles from multiple viewpoints near 1 AU. The farside view of the solar surface has allowed testing the usefulness of L5 observations for predictive purposes, and the STEREO-Ahead spacecraft has been able to observe the farside coronal disturbances to which the earth may be magnetically connected along the Parker spiral interplanetary field. These can be the source of the major solar energetic particle (SEPs) episodes with hard spectral content that produce Ground Level Events (GLEs). As the two spacecraft approach superior conjunction in 2015, they will continue to provide unique and invaluable viewpoints for the characterization of space weather throughout the inner heliosphere, as well as unique input for determining the conditions at the boundaries of the heliosphere.

The STEREO mission completed its prime phase in 2009 January, after nearly two years of heliocentric operations. STEREO is a significant component of the Heliophysics System Observatory, and there has been significant uptake of STEREO measurements by the solar and heliospheric communities, as well as groups working in related fields. Data from the mission are being freely served by the STEREO Science Center and instrument team Websites, and as of this writing, over 580 STEREO publications have appeared in the refereed literature, including 100 of those in 2010, 121 in 2011, and 150 in 2012.

Our scientific insights are grouped into descriptions of progress in understanding CME and ICME structure, solar energetic particles and extreme space weather, and characterizing the heliospheric plasma. In each case, we give one or more letter-number combinations referencing Research Focus Areas in the 2009 Heliophysics Roadmap (Appendix E) to indicate the relevance to Heliophysics objectives.

Our Prioritized Science Goals (PSGs) also fall into three, broad categories: Characterizing space weather throughout the inner heliosphere, what we can learn from 360° coverage of the solar corona, and what we can learn from coverage of the full heliosphere.

Section IIa describes the accessibility of STEREO data from a multiplicity of online resources. As can be seen in the Section IIb, a number of exciting scientific insights have been achieved during the rise to solar maximum over the last three years. In Section IIc, we describe and prioritize the most prominent scientific goals we intend to address during the next five years. Section III provides a brief overview of technical and budget issues. Mandatory appendices address education and public outreach (A) and the mission archive plan (B). Additional appendices cover publications (C), spacecraft and instrument status (D), Roadmap research focus areas (E), and acronyms (F).

The following individuals were among those involved in the writing of this proposal on behalf of the STEREO Science Working Group: J. Luhmann (UCB), R. Mewaldt (Caltech), A. Galvin and C. Farrugia (UNH), A. Vourlidas (NRL), R. MacDowall, T. A. Kucera, E. Christian, and J.B. Gurman (GSFC). Numerous members of the Principal Investigator (PI) teams submitted early drafts of the material used here, and we thank them sincerely for their effort.

II. Science and Science Implementation

IIa. Data Accessibility

A Note on Hyperlinks: Rather than spelling out URL's, which tends to introduce awkward line breaks in the text, we provide a hyperlink (in blue and underlined) for each Internet-accessible resource mentioned in this proposal. The hyperlinks should be clickable in the PDF version of this document.

Research and space weather uptake. Data from STEREO have been incorporated into many scientific investigations, and some of the same services currently using observations from older assets of the Heliophysics System Observatory (HSO). Since the launch of STEREO in 2006 October, some 580 refereed publications have made use of STEREO data (see Appendix C). There have been 23 Science Working Group meetings, and a combined workshop with SDO and *SOHO* was held in Kiel, Germany in 2011 July, as well as the second in a series of combined, in-situ workshops with *ACE*, *SOHO*, and *WIND* in Laurel, MD in 2012 September. A special issue of *Solar Physics* in 2012 covered the results of the Kiel meeting, with 18 papers involving STEREO. 17 articles on the 3D structure of CMEs using STEREO appeared in a special issue of the *Journal of Atmospheric and Solar-Terrestrial Physics* in 2011. Among the services using STEREO data include the Solar Weather Browser from the Royal Observatory of Belgium, the SolarSoft Latest Events service maintained by the Lockheed-Martin Solar and Astrophysics Laboratory, and the Integrated Space Weather Analysis System from NASA Goddard Space Flight Center. The NOAA Space Weather Prediction Center uses STEREO Beacon data on a regular basis, and serves them *via* a Website similar to that used for serving ACE realtime solar wind data. In China, University of Science and Technology's DREAMS Website includes a SECCHI EUVI 304 Å eruptive event database as well as a mirror of the STEREO Science Center (SSC) movie site. Also, the asteroid and comet-hunting communities have become avid users of the STEREO data, and even the variable star community has found the data valuable.

Accessibility. All STEREO science data are accessible on the Web through the STEREO Science Center (SSC) archive and Principal Investigator (PI) sites. The data in the SSC archive are identical to those on the PI sites, and are maintained by regular mirror processes running several times per day. ***The STEREO and SSC Websites together served over 35 Tbyte of data per year in the period 2010 - 2012.***

Adherence to standards has allowed STEREO data to be easily incorporated into a number of online browse tools. Interactive plots of in-situ and radio data, together with the data themselves, are available through the CDAWeb. The Heliophysics Data Portal (formerly "VSPO") maintains an extensive list of STEREO-related services. STEREO image data are incorporated into the tools listed above, under "uptake."

Although tools for accessibility are already in existence, a number of browse tools that enhance accessibility have been developed by the instrument teams. In addition to the NOAA beacon mode site noted above, a daily browse tool based on the SECCHI images and beacon in-situ data is maintained on the SSC website. Customized browse pages are also available from the SECCHI, IMPACT, PLASTIC, and S/WAVES instrument sites. For example, daily Javascript movies from the SECCHI telescopes can be viewed at various resolutions at a SECCHI movies Webpage. Additional S/WAVES data are available from the Centre de Données de la Physique des Plasmas in France. The SECCHI/COR1, SECCHI/HI, and S/WAVES teams are providing higher-level data products (e.g. event catalogs) to direct researchers to the most interesting data sets. Additional event lists combine IMPACT and PLASTIC data on shocks, ICMEs, stream interactions, and SEP events, and another list of suprathermal events is provided by the PLASTIC team. These latter lists are archived on the SSC website as Level 3 data products. The STEREO Space Weather website at NRL, accessible through the SSC website, contains links to ancillary data for major events observed by many of the STEREO instruments.

Research access. The Virtual Solar Observatory (VSO; Hill *et al.*, 2009) acts as the primary access point for all STEREO data, with the SSC as the data provider. This maximizes the use of existing resources without duplication, and enables collaborative data analysis with other solar observatories. The Virtual Heliospheric Observatory (VHO; Merka, Narock, and Szabo, 2008) serves PLASTIC solar wind, IMPACT magnetometer and particle data, and S/WAVES intensity spectra. The Heliophysics Data Portal provides access to STEREO data from many different sources, including the VSO and VHO. SPASE descriptions for most STEREO data products have been registered within the Space Physics Data Facility, and the few exceptions (mainly the newer products) are actively being pursued.

Data are available from the individual PI and Co-Investigator (Co-I) institutions, and in the case of some of the in-situ and radio data at the CDAWeb website at the Space Physics Data Facility (SPDF). A list of all access sites is maintained on the STEREO Science Center Website.

A number of additional data products have been made available since the last Senior Review. The IMPACT Level 1 data set is now complete with the addition of the HET CDF data files. A Level 2 product containing IMPACT LET, SEPT, STE, and SIT data in CDF format will be available in the next six months. Level 2 SECCHI/HI processed images are now available. PLASTIC has released Level 3 data products containing suprathermal event lists and He^+ relative fluxes. All these data products are archived within the SSC.

Space weather. In addition to the normal science data provided by the instrument teams, STEREO also provides instantaneous beacon data to the space weather community. These data are used extensively by the NOAA Space Weather Prediction Center, as well as the NASA Goddard Space Weather Research Center. The Community Coordinated Modeling Center (CCMC) is modeling both the ambient solar wind and selected eruptive events in support of STEREO data interpretation. The Global Oscillation Network Group (GONG) is providing daily updated magnetograms, synoptic maps and potential field source surface models that can be used in analyzing prevailing coronal magnetic field geometry and solar wind sources on a near real-time basis. A number of space weather apps for smart phone and tablet devices now incorporate STEREO data, including 3D Sun developed with NASA support for the iPhone/iPad, and which combines STEREO and *SDO* imagery into a browsable map of the entire solar surface.

Publications. The SSC maintains a database of published journal articles and proceedings on the SSC Website. Many pre-publication works are made available by the authors through the Solar Physics E-Print Archive.

IIb. Scientific Insights from STEREO*, 2010 - 2012*

In Appendix E, we reproduce Appendix E of the 2006 Heliophysics Roadmap, which lists the research focus areas (RFAs) in each of three general goal areas: Frontier (F), Home in Space (H), and Journey of Exploration (J). Each insight described below is identified by goal letter and RFA number within the goal. The 2006 RFAs are cited in the 2010 Roadmap and so are assumed still to be current.

CME and ICME structure (J3)

Multipoint observations. With heliospheric multipoint in-situ measurements and multiperspective imaging now available, in significant part from STEREO observations, it is an unprecedented time to test our ability to reconstruct the spatial and temporal details of interplanetary disturbances from solar events. An active period in 2010 August was the focus of a detailed analysis that used remote sensing information from STEREO, SOHO and SDO imagers, together with solar wind plasma and field measurements on STEREO, ACE, WIND and ARTEMIS at 1 AU and on Messenger and Venus Express between the Earth's orbit and the Sun. One challenge of this period is that multiple coronal mass ejections (CMEs) occurred. As this is a fairly common occurrence even when the Sun is modestly active, it provided a real-world case study for both interpretation of such collected observations and models to explain them.

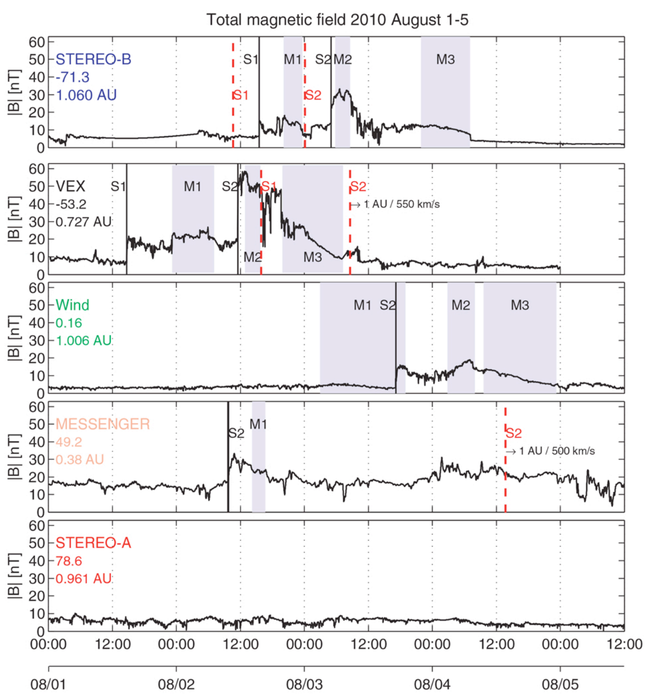

Figure II-1: The magnetic field magnitudes observed by various in-situ instruments with vertical lines and labels marking key features such as shock arrivals (S#) and magnetic cloud/eject fields (M#) associated with three CMEs in early 2010 August.

Figure II-1, left, shows the various in situ measurements of magnetic field magnitudes at each of five spacecraft, ranging from STEREO-B to the east to STEREO-A to the west of the Sun-earth line. These provide an overview of the disturbances seen at the different locations and their relative timings, including shock arrivals and the detection of magnetic cloud/flux-rope like CME ejecta. Figure II-2, below, summarizes the results of the analysis in the form of cylinders suggesting flux rope fittings of the magnetic cloud features based on the vector field measurements. This figure is a good illustration of the non-ideal behavior of real events, and the difficulty in sorting out imaged and in-situ disturbances during active periods - even with the benefit of multipoint measurements and images. Among the conclusions of Möstl *et al.* (2012) are: CME-CME interactions are very likely given their angular extent and frequency, and the existence of a prior CME significantly modifies what happens to a following event or events as they propagate outward, for example alterations of shock structure and Interplanetary CME (ICME) shape and direction. In addition, flux rope fitting of the magnetic clouds observed in the ICMEs shows that properties including size and inclination can significantly vary from point to point for a structure from the same coronal ejection.

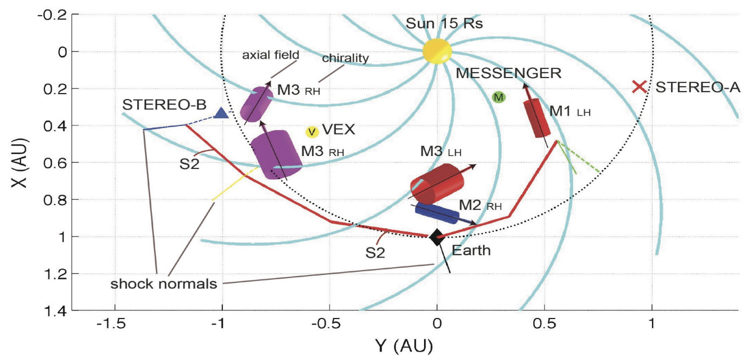

Figure II-2. View of the ecliptic plane on 2010 August 3 17:05 UT, showing the global configuration of magnetic flux ropes (MFRs) and shape of the shock surface. Cylinders indicate sizes and orientations of large-scale MFRs which could be successfully modeled. Similar cylinder colors indicate structures being part of the same larger MFR. The red solid line is the approximate shape of a shock front, which can be reconstructed by connecting the arrivals at the different locations.

While the results of STEREO multipoint studies are still generally consistent with viewing ICMEs as shock-driving, large-scale flux ropes, warpings and distortions from ICME-interstream compression region interactions like those reported by Farrugia et al. (2011) appear to be common. These authors reported a comprehensive analysis of in situ observations made by Wind MFI and SWE and the STEREO PLASTIC and IMPACT suites on both STEREO-Ahead and STEREO-Behind of a complex interaction between a corotating interaction region (CIR) and a magnetic cloud occurring near the heliospheric current sheet. They conclude that the formation of compound streams is a common feature of interplanetary space, requiring numerical simulations to unravel. In addition, Ruffenach *et al.* (2012) inferred the existence of a reconnection geometry between an ICME flux rope and its surroundings. Their quantitative analysis using combined, multi-point observations of the same ICME by STEREO A, B, ACE, WIND and ARTEMIS allowed evaluation of an azimuthal magnetic flux imbalance inside the flux rope argued to stem from erosion at the cloud's front boundary. In the case analyzed, it was estimated that over 40% of the original flux rope had reconnected with ambient fields on the way to 1 AU. Overall these results demonstrate the complexity even of cases where individual solar events and their ICMEs can be identified. This has implications for CME tracking and space weather forecasting as well as for modeling observed events. Except at the quietest times, allowances must generally be made for such realistic scenarios where prior event history cannot be neglected.

Remote Measurements of the Coronal and Interplanetary Magnetic Field from SECCHI Imaging Observations of CME-driven Shocks and Their Standoff Distances (H1, J1, J3). Research over the last two years demonstrates that STEREO offers an exciting opportunity to measure magnetic field upstream of a CME in the inner heliosphere. Such measurements are essential for understanding CME initiation and propagation and are a key goal of the upcoming Solar Probe Plus (SPP) and Solar Orbiter missions.

Using measurements of the standoff distance between a shock and its CME driver, Gopalswamy and Yashiro (2011) were able to use SECCHI and SOHO/LASCO images of the 2008 March 25 CME to infer the background coronal magnetic field (Figure II-3, left). They measured the standoff distance, shock speed, flux rope radius of curvature, and background density to determine the Alfvénic Mach number and thus the coronal magnetic field as a function of the ratio of specific heats γ. The estimated magnetic field decreases from ~48 mG around 6 R_{Sun} to 8 mG at 23 R_{Sun}. Poomvises *et al.* (2012) extended the magnetic field strength measurements to heliocentric distances up to 120 solar radii using data from SECCHI COR2 and HI1 and compared their results to Helios and ACE measurements (Fig

II-3, right). They found that the SECCHI-derived magnetic field profiles, based on $\gamma = 5/3$, match well the radial evolution seen by Helios and the ACE in-situ measurements at 1 AU. These results demonstrate that the SECCHI imagers can provide reliable measurements of both coronal and interplanetary magnetic fields upstream of fast, shock-driving, and hence likely geoeffective, CMEs.

This is a rapidly growing area of heliophysics research with clear basic research and operational benefits. It is currently being expanded to include radio tracking of the shock from S/WAVES which will improve the 3D localization of the shock and result in more accurate measurements of the standoff distance and upstream density. It will also provide considerable support to the SPP and Solar Orbiter science objectives.

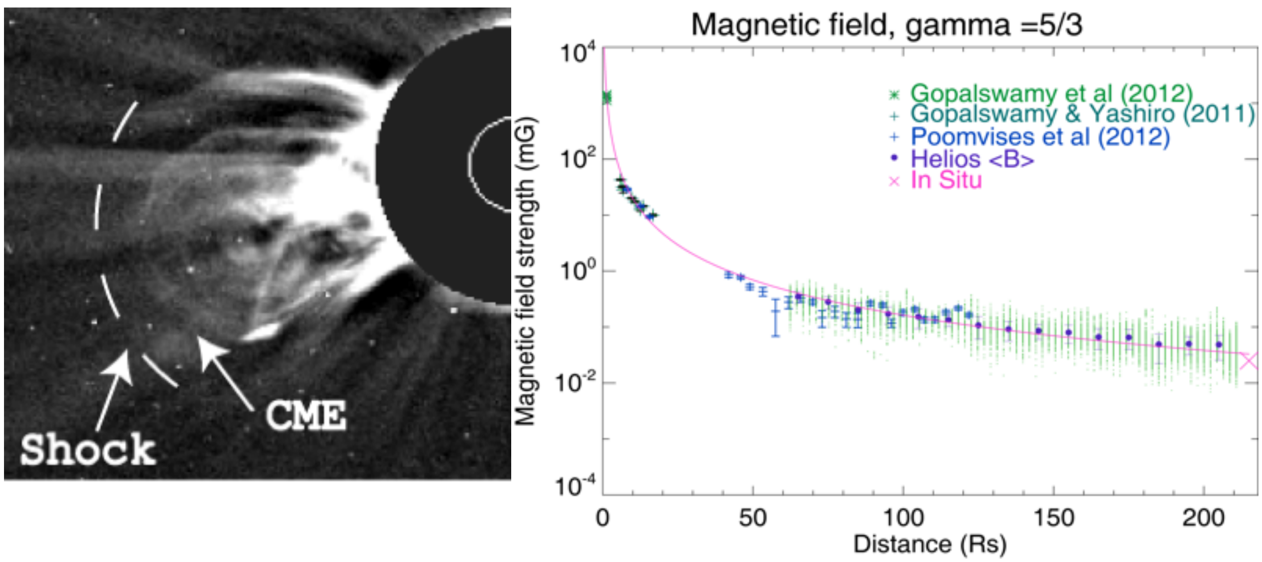

Figure II-3. (Left) CME-shock structure in the 2008 March 25 event. The difference between the shock and CME heights is the standoff distance. (Right) Magnetic field estimates from the lower corona to 1 AU. The first three points are from Gopalswamy et al. (2012), based on EUV imaging of the standoff distance from the Solar Dynamics Observatory (SDO). The dark green asterisks are from Gopalswamy & Yashiro (2011), LASCO/C2 and STEREO/COR2 observations of the CME in the left panel. The blue plus symbols (+) denote the data from COR2 and HI1 from Poomvises et al (2012). The green dots show the Helios 1 and 2 data and the solid blue circles represent the average magnetic field at Helios. Finally, the pink cross shows the average magnetic field strength from in situ measurements from the Advanced Composition Explorer (ACE).

Solar Energetic Particles and Extreme Space Weather

The spatial extent of solar energetic particle events (F2, J2, J3). The prevailing view of ^{3}He-rich solar energetic particle (SEP) events prior to STEREO was that particle acceleration in these small flare-associated events occurs in spatially compact regions where magnetic reconnection takes place. The compact nature of the source suggested that escaping particles would span a narrow angular range at 1 AU. (e.g. a Gaussian with $\sigma \approx 20°$; Reames et al., 1995). It was therefore surprising that a systematic search for ^{3}He events in 2007-2010 (Wiedenbeck et al. 2010) showed more than 50% of the events detected by one or both STEREO/LET instruments were also observed at ACE, including STEREO-ACE longitudinal separations of ~90°. A striking example detected at all three spacecraft when they spanned 136° in longitude is shown in Figure II-4(a). The strong dependence of the ^{3}He fluence on angular separation (Figure II-4(b)), along with less ^{3}He sensitivity may have contributed to the narrower distributions found earlier. The reasons for the unexpected extent of these localized source events is still under investigation (e.g. Giacalone and Jokipii 2012).

On January 17, 2010 both STEREOs and SOHO detected energetic electrons and protons from an East-limb event for STEREO-B, corresponding to "farside" events for Earth and STEREO-A (Dresing et al. 2012). The nominal magnetic footpoints of all spacecraft at the Sun were >100° from the flare site, suggesting a ~360°-wide SEP distribution. This event included type II and type III radio emission, an EUV wave, and CME. Suggestions for explaining events of such angular extent include connections to a wide source such as a coronal shock or CME-driven interplanetary shock, or major cross-field diffusion across coronal or heliospheric fields from a localized solar source. The authors found that, if diffusion is invoked, extraordinarily strong cross-field diffusion would be required to explain this event. Thus these multipoint gradual SEP events, like the localized flare events described above, present challenges for models of SEP sources and propagation.

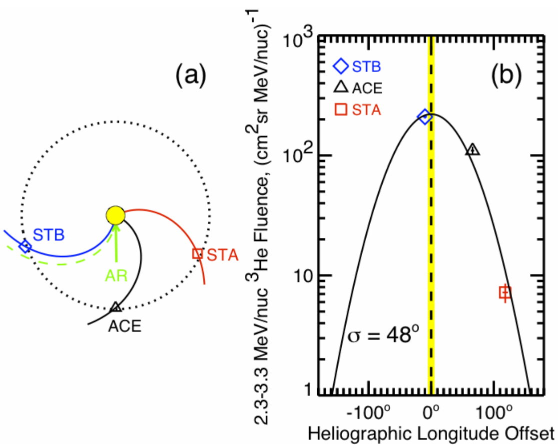

Figure II-4. (a): Configuration of the STEREO and ACE spacecraft and flare site for the 7 Feb 2010 ^{3}He-rich event. (b) ^{3}He fluence vs. separation from the best-connected longitude at 1 AU.

In a related study, Rouillard et al. (2012) combined imaging data from STEREO and SOHO with in situ data from STEREO, ACE and SOHO to analyze the relation between the CME eruption and evolution of an EUV wave with the SEP onsets at STEREO-A and L1. The EUV disturbance was found to initially track the flank of the laterally expanding driver gas. The measured SEP onset at L1 (~132° east of the flare site), ~30 minutes later than at STEREO-A, was consistent with the time for the CME to perturb the corona over a wide range of longitudes. The implication that lateral expansion of the CME can very quickly lead to SEP acceleration helps explain the broad SEP distribution issues raised above, at least for major, gradual events.

While it is well known that SEP events with source regions (e.g. CME locations) to the west have rapid intensity rises and those from eastern sources exhibit more gradual increases, there was little known about SEP source regions well beyond the western limb. The 360° view provided by STEREO has revealed several instances of rapid SEP onsets from farside events, such as the event in Figure II-5 (Cohen et al. 2013; *cf.* Mewaldt *et al.* 2013). In this case the inferred source was ~45° behind the west limb with respect to STEREO-B. In addition to still undetermined implications for SEP transport, these observations are important for improving space weather forecasts for events that originate beyond the visible disk.

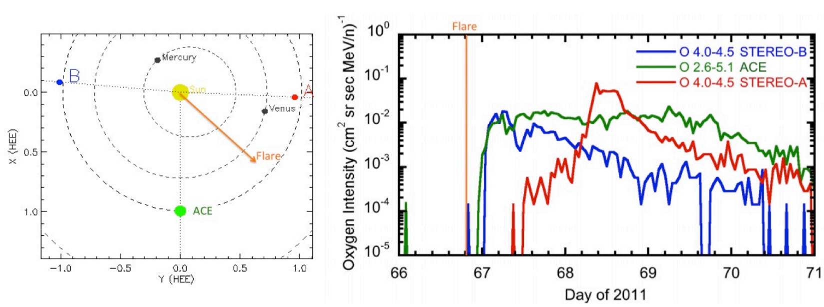

Figure II-5. (Left) Relative positioning of STEREO-A and –B, ACE, and the 7 March 2011 flare. (Right) SEP oxygen intensities observed by STEREO/LET and ACE. Notice the relatively rapid intensity increase at ACE, which was 'well connected' by a nominal Parker Spiral magnetic field and also at STEREO-B, for which the solar event was well beyond the western limb (Cohen et al. 2012).

Directional information can reveal a great deal about SEP sources and transport, but this information is not always available. The IMPACT Low Energy Telescope (LET) on STEREO measures particle intensities in 16 viewing directions in the ecliptic (see the color wheel legend in Figure II-6). Often SEPs have nearly equal intensities from all directions (although sometimes a focused particle "beam" appears for a few hours at the onset). However, during an event on 18 August 2010, STEREO-A LET saw large anisotropies that persisted for ~17 hours. Particle intensities were highest along the magnetic field direction (gray lines in the Figure II-n+7 inset), lowest perpendicular to the field, and they were bidirectional, moving in both directions along the field. STEREO-A was passing through a magnetic cloud produced 4 days earlier when the 18 August event erupted, presumably sending particles up both legs of this structure in a tight beam with minimal scattering. Further examples of unusual anisotropies in magnetic clouds suggest that the presence of magnetic structure from an earlier ICME may play an important role in SEP transport, perhaps helping to account for some of the large longitudinal spreads.

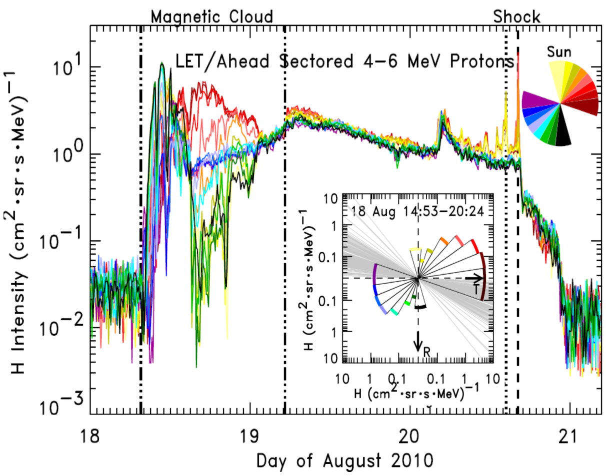

Figure II-6. SEP proton intensities observed by the STEREO-A LET during a solar event in August 2010, showing huge intensity differences in different directions early in the event (Leske et al. 2012).

Type III radio burst generation and Langmuir waves (F2). Beams of electrons with energies of order 10-100 eV are frequently accelerated by solar flares and may escape the region on open magnetic field lines. These beamed electrons drive plasma instabilities that lead to growth of electron plasma oscillations, also known as Langmuir waves, with subsequent emission of solar radio bursts, known as type III bursts. The specific mechanism by which Langmuir waves are converted into type III radio emission is a sixty year-old puzzle lacking observations that definitively distinguish among the theoretical possibilities. S/WAVES is the first electric field instrument able to observe solar wind Langmuir waves in three-dimensions with waveform captures longer than 100 ms. Using this unique capability, it has been possible to elucidate a number of characteristics of the Langmuir waves and their decay, bringing us closer to a clear understanding of the emission mechanism(s), which apply throughout the plasma universe. Using this unique capability, it has been found that a large fraction of type III Langmuir waves share waveform envelope morphology such that the spatial- and frequency-domain signatures are well described as Hermite-Gauss eigenmodes trapped in parabolic density wells. This suggests the possibility of antenna radiation from intense, localized Langmuir wave eigenmodes (Malaspina *et al.*, 2010). The type III burst Langmuir waves also show complex 3-D polarization when the driving electron beam is fast (> 0.08 c), but show simple one dimensional polarization along the local magnetic field direction when the driving electron beam is slow (< 0.08c). The complex polarization during fast beams is likely due to conversion of normal Langmuir waves into Langmuir/z-mode waves through interactions with solar wind density turbulence, providing another mechanism for radio wave emission (Malaspina *et al.*, 2011).

In studies by Thejappa et al. (2012a-d), bispectral and trispectral analysis show that the four wave interaction, called the oscillating two stream instability, is responsible for stabilization of at least some of the type III electron beams. The second harmonic radio emissions are presumed to be due to coalescence of Langmuir waves trapped in the density cavities associated with Langmuir envelope solitons. The third harmonic emissions observed in a few intense events are due to coalescence of the trapped Langmuir waves with second harmonic electromagnetic waves. A survey of 167 Langmuir waveforms observed by S/WAVES from eight different type III source regions, however, suggested that none of the observed waveforms had fields consistent with wave packet collapse (Graham *et al.*, 2012a, b). Detailed fitting to localized Langmuir waveforms revealed that approximately 30% had structure consistent with the known structure of collapsing wave packets but the fields were too small for collapse to proceed.

Although these results are not yet fully unified, and it may be that the type III electron beam can be stabilized in more than one way, it is clear that STEREO observations of type III burst waveforms offer major steps forward in understanding the electron beam stabilization and other aspects of type III burst emission.

RF triangulation of Type II bursts (F2). While RF triangulation of Type III bursts is well established, it has rarely been used in the study of the weaker type II bursts, produced by energetic electrons accelerated by the CME shock by mechanisms similar to Type III emission. Martinez-Oliveros *et al.* (2012), however, successfully applied radio direction-finding to the 2010 August 1 type II radio burst and determined the direction of arrival of the radio emission . Their analysis shows that the radio source locations are spread over a large area covering about 4^{o}, suggesting that the radio source has an extended and complex structure. There was good consistency between the STEREO-B COR2 white-light positions and the Wind-STEREO-B triangulated positions. This provides a powerful tool for STEREO, because the radio frequencies are related to density, and so, provides additional 3-D location of the CME and shock.

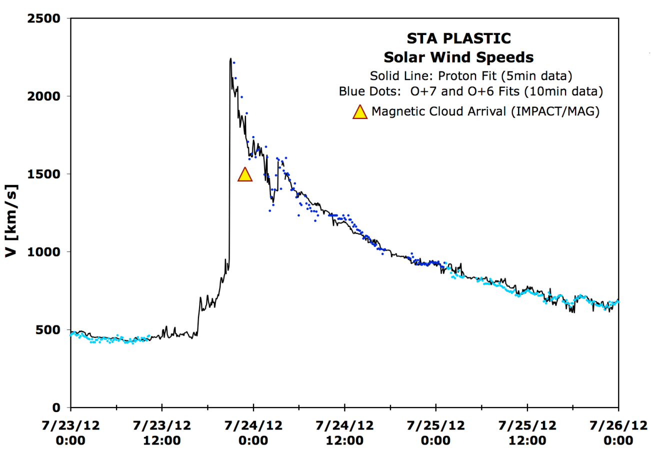

Figure II-7. STEREO-Ahead PLASTIC measurements of solar wind speeds during the remarkable, farside event of 2012 July 23 - 25. Estimates of the SEP contribution to the overall pressure in the ESP event suggest that they are comparable to the thermal plasma contribution, a behavior normally associated with supernova shocks rather than interplanetary shocks.

An Extreme CME and SEP event (F1, F2, H1, J1, J2, J3). The observation of a near-record speed halo-CME and its resulting ICME by STEREO-A in July 2012 was the biggest surprise so far of the rise of solar cycle 24 (Figure II-7 and cover figure). Considering that the solar field has been weaker than during the two previous space-age cycles since it decreased to unprecedented levels in the long cycle 23-24 minimum, the detection by coronagraphs of a ~2400 km/s CME followed by a >1400 km/

s Interplanetary CME or ICME (by timing alone) by the STEREO-A magnetometer (the plasma data are still under scrutiny because of the extreme conditions, but preliminary values for solar wind speeds after the shock are in excess of 2200 km/s), was remarkable. While this event was noted in a NASA News item, it would certainly have drawn more attention (and had greater impact on humans) had it been Earth-directed. An estimated peak Dst storm index of ~1000 nT would have occurred given its speed, and >100 nT strength magnetic fields with a long-duration, significant southward component (panel *(d)* of the figure on the cover of the proposal).

The details of this event provide a physical perspective on extreme solar events. The ICME leading front in paricular is unusual: While a huge shock jump in the magnetic field might be expected given the event's size and speed, the magnetic fields increased only gradually at the event arrival at STEREO-A (see cover figure, panel (d)), and peaked later with the pile-up of ambient field and arrival of the magnetic cloud or ejecta portion of the ICME. This may be understood by considering the SEP intensities (cover figure, panel (c)), which were so high during the energetic solar particle (ESP) event that their pressure sometimes exceeded the magnetic pressure. It has been suggested that intense SEP levels in a shock can modify the shock structure, but such effects are usually discussed in the context of anomalous cosmic ray acceleration at the heliospheric termination shock or galactic cosmic ray acceleration in supernova shocks. A space weather consequence is that extreme events of this kind may not produce extreme ground-induced currents associated with the rapid changes in magnetic field for strong leading ICME shocks. While the large magnetic fields, high plasma velocities, and SEP fluxes can still have major impacts including strong ring current injections and their consequences, strong magnetospheric and ionospheric convection, and major auroral and SEP precipitation effects, including atmospheric ozone depletion, the driver of dangerous early induced currents could be much weaker than anticipated.

Comparison of Methods for Real-Time CME Arrival Prediction (J3). An important goal of NASA's STEREO mission is to investigate the feasibility of forecasting the direction, arrival time, and internal structure of ICMEs from a vantage point outside of the Sun-Earth line. In one example of a study of arrival time estimation, Davis *et al.* (2011) used real-time STEREO beacon data from the Earth-directed CME launched on 2010 April 8 to evaluate six different methods of predicting ICME arrival time. They found that the most accurate technique, which predicted the shock arrival time at ACE with an error of 3.25 hours, used STEREO coronagraph data to determine speed and direction of the CME close to the Sun combined with a solar wind model to predict variations of CME speed further from the Sun. STEREO/HI data can also be used to the track changes in acceleration beyond the range of the coronagraphs, but in this case only the science quality data, as opposed to the Beacon data, had sufficient temporal and spatial resolution to be used in this way.

When in situ observations are used to constrain remote sensing techniques, their predictions of ICME direction and arrival time can be substantially improved. Möstl *et al.* (2011) present a case study for 2009 February 13-18 (Figure II-8). Two techniques that make different assumptions about the shape of the front are compared: Fixed-Φ (FPF) and Harmonic Mean (HM). The former assumes a point-like or negligibly narrow shape of the ICME front; the latter models the front as a circle attached to the Sun at one end. Both methods are based on imaging data from a single spacecraft, and assume constant velocity of propagation and a constant propagation direction. Their respective predictions using SECCHI images are compared with observations made by PLASTIC and IMPACT. Möstl *et al.* (2011) found that the HM technique predicts a more accurate arrival time by 12 hr. The improvement is ascribed to the assumed ICME front shape, which is believed to be more accurately described by the HM technique for an ICME – such as this one – whose symmetry axis has a low inclination to the ecliptic plane. A side benefit of the investigation is that a new formula is derived which is suitable for use in both the HM method as well as a triangulation technique (*e.g.* Liu et al., 2010) if the latter assumes the same geometry.

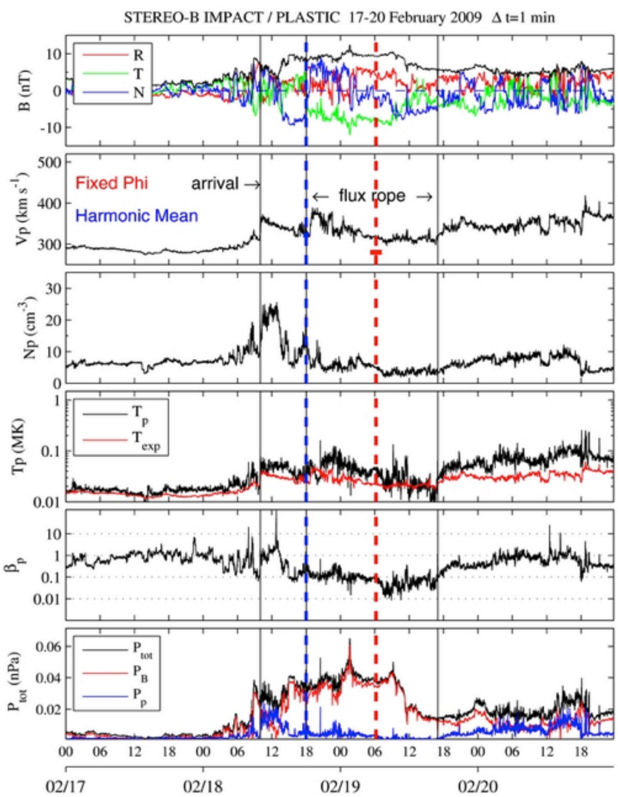

Figure II-8. Magnetic field and plasma data from IMPACT and PLASTIC on STEREO-B for 2009 Feb 17-20, showing arrival time of the flux rope compared to predictions made using two methods. From top to bottom: the magnetic field strength and vector in RTN coordinates, proton bulk flow speed, number density and temperature (black) (in red: expected temperature), proton β, and the total, magnetic and thermal plasma pressures. The first solid line marks the approximate arrival time of the density front. The second and third solid lines bracket the flux rope interval. The arrival times from the FPF and HM methods are shown in red and blue lines, respectively, and the fit velocities VFP and VHMI are given by the red and blue horizontal bars, which indicate the extent of the arrival time error +/- 54 min (FPF) and +/- 20 min, which are derived from the complete ICME track.

More multiple-technique analyses similar to the above examples will strengthen our abilities to make accurate ICME arrival time predictions.

Comparison of Methods for Active Region Predictions: Validating helioseismic tomography of the far side of the Sun (J2). STEREO / SECCHI / EUVI observations of far-side solar activity are being used to test the reliability of predictions of far-side active regions from GONG's helioseismic observations. Predictions of far-side active regions using only near side Dopplergrams are a valuable tool for space weather forecasting, but until STEREO was able to see the full far-side of the Sun, the predictions could only be tested using re-appearing active regions. Using STEREO 's direct images of the far-side chromosphere and corona from February to July 2011, Liewer *et al.* (2012) tested the reliability of GONG's predictions using two procedures (Figure II-9).

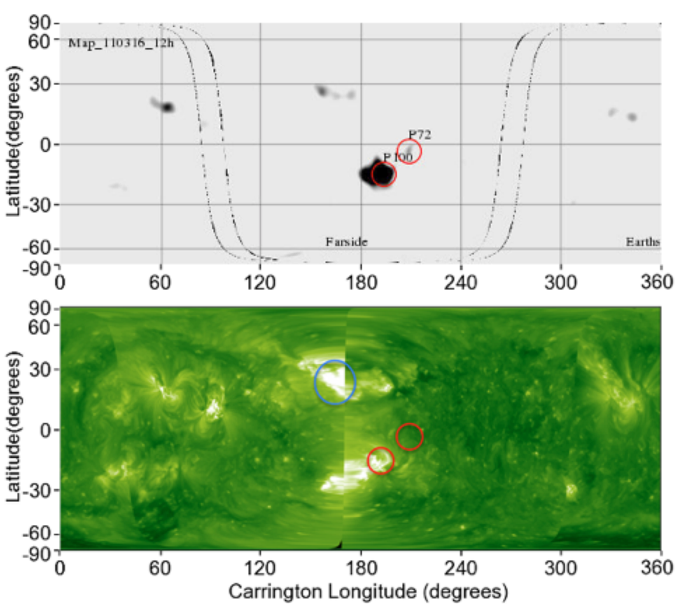

Figure II-9. Comparison of Carrington maps from GONG (top) and EUV 195 Å (bottom) for 16 March 2011 at 12 UT. For one GONG prediction (P100), activity was seen in EUV, and for the other prediction (P72), no activity was observed in EUV. Major activity is seen in EUV at the location circled in blue but GONG does not detect strong fields in this area.

First, they asked whether STEREO saw activity, as indicated by brightening in the EUV images, at the far-side locations predicted in GONG's calibrated seismic Carrington maps. Second, they investigated GONG's success at predicting large active regions before they appear at the east limb as viewed from Earth. Of 15 such east-limb active regions, eight were predicted by GONG at least once in the seven days preceding their Earth-side appearance. STEREO-B observations of activity in the days preceding the appearance of the other seven large East-limb active regions indicated that while three were possibly too small for GONG to make a prediction, four seemed as large and active as other active regions and should have been predicted by GONG. GONG predictions are limited by a low duty cycle. Future analyses with SDO / HMI data, which has fewer data gaps, will help explore the full capabilities of the far-side imaging techniques.

Characterizing the Heliospheric Plasma

Nonlinear coupling between electron and ion dynamics: STEREO as a density probe (F2). In order to study the nonlinear coupling between electron and ion dynamics, one must observe both the electric field and density at high rates. Measuring electric field is not a problem; the issue is to measure plasma density at the same time. Henri et al. (2011) developed a new technique to observe in situ plasma density fluctuations in a frequency range well above what is currently available in space instrumentation. The method is based on the dependence of the spacecraft floating potential on the surrounding plasma density and uses monopole antennas that act as a ground in the frequency range of interest.

This new technique has been applied to S/WAVES antennas used in monopole configuration; the STEREO spacecraft itself is used as the density probe. It provides, for the first time, direct, in situ observations of density fluctuations in the solar wind at high frequency (in the electrostatic frequency domain, above the electron cyclotron frequency).

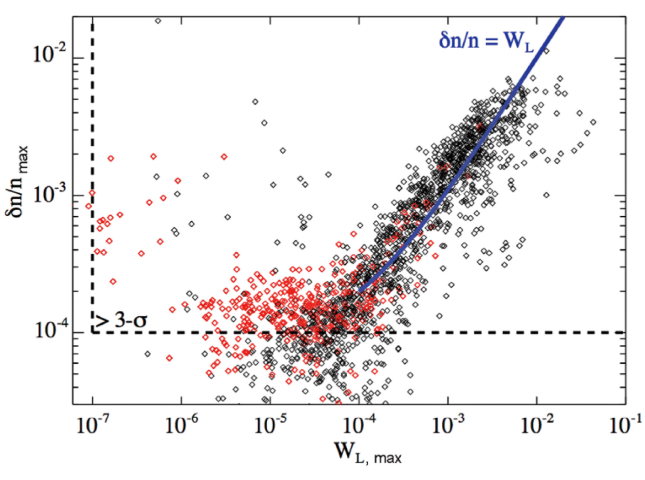

Figure II-10. Maximum observed density fluctuations $\delta n/n_{max}$ vs. the maximum electric energy of electron plasma waves $W_{L,max}$, in the electron foreshock (black diamonds) and the free solar wind (red diamonds). The blue line represents the expected level of density fluctuations generated by Langmuir nonlinear ponderomotive effects. The black dashed lines show the 3-sigma detection levels. More than three years of S/WAVES data are summarized in this plot.

By coupling in situ observations of the electric field associated with electron plasma waves to in situ observations of plasma density (using the newly developed technique), we observe the nonlinear coupling between electron plasma waves and density fluctuations. The coupling is an electrostatic ponderomotive effect and is characteristic of electrostatic turbulence. It is observed to be particularly efficient in the Earth electron foreshock. This work opens new opportunities to study nonlinear processes in the solar wind as well as extend turbulence studies to the electrostatic frequency domain.

Small-scale structures in the solar wind: origins and processes (F1, F2, H1, J1, J3). Solar wind flows with speeds below 400 km/s make a significant contribution to the interplanetary medium, constituting over 40% of the solar wind by time in recent years, and 80% in 2009 (Galvin et al. 2012). STEREO and SOHO coronagraph images indicate a contribution of coronal streamer-related transients ("blobs") to the slow wind (Sheeley et al., 1997; Rouillard et al., 2010a,b). Probing the nature of these and other slow solar wind features of the heliospheric current sheet (HCS) and heliospheric plasma sheet (HPS) found at interplanetary magnetic field sector boundaries is ideally suited to the STEREO mission.

With multi-spacecraft in situ observations, Foullon et al. (2011) examined a HCS as it co-rotated past STEREO Behind, near-Earth spacecraft, and STA in January 2008. They reported the first in situ evidence of a detached plasmoid within the HPS, observed at STB (see Figure II-11). The plasmoid observations were associated with slow, small-scale streamer ejecta that were remotely observed by STB/SECCHI and SOHO/LASCO and tracked via triangulation. Statistical studies of small transients (STs) as a subset for slow solar wind have been done by Yu et al. (2013), enlarging and differentiating from the earlier work of Kilpua et al. (2009). They undertook a systematic search for STs (duration 1-12 hours) with signatures of small magnetic clouds and found 45 examples in the 2009 dataset.

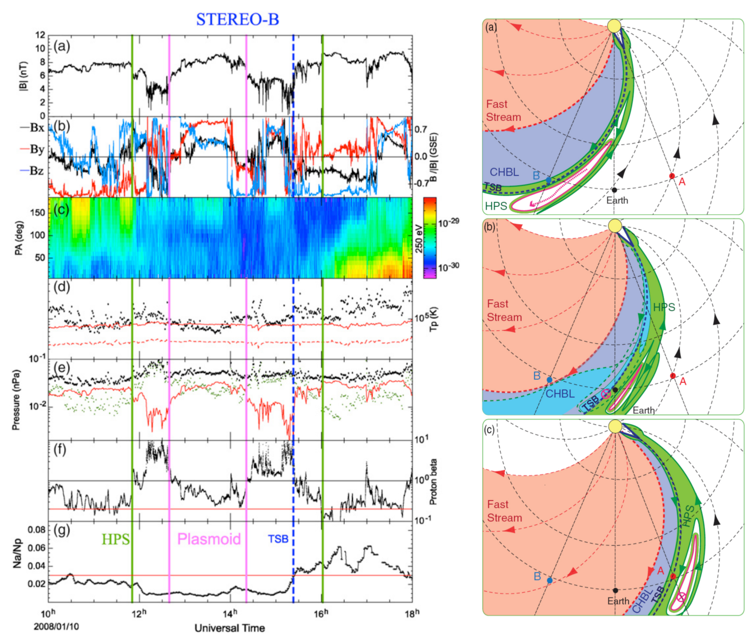

Figure II-11. First reported evidence of an embedded plasmoid in the HPS, taken from Foullon et al. (2011). The STEREO spacecraft, combined with near-Earth satellites, allowed large longitudinal coverage of this co-rotating event.

The HPS is often observed on just one side of the HCS, rather than encompassing it. Simunac et al. (2012a, 2012b) examined the time dependence of the HPS, taking advantage of the unique orbits of the STEREO and Wind spacecraft to compare in situ properties of the same HPS at different heliographic longitudes. Large-scale features such as the location of the HCS within the HPS and the absence or, if present, location of 'one-sidedness' were found to usually agree at the three different longitudes, indicating a quasi-stationary (rather than intermittent) nature on the time scales considered.

Solar wind reconnection exhausts at bifurcated current sheets, and occasionally in the HCS, highlight the possibility of additional heliospheric origins for some of the in-situ transients found in the solar wind, as reported by Gosling (2012). Multi-spacecraft observations from STEREO-A/B, ACE, Wind, and Geotail indicated a persistence of 320 minutes for one reconnection event observed over 1800 Re. If observations had been limited to a single spacecraft, the observed event interval would have been only known to less than 7 minutes (Gosling, 2012; Lavraud et al., 2009).

On smaller spatial scales, there are magnetic discontinuities and magnetic-hole structures within the solar wind. Taking advantage of the STEREO spacecraft configuration, Malaspina and Gosling (2012) used a newly developed computer algorithm to identify several tens of thousands of directional discontinuities (DD) within the first four months of the STEREO mission. When the spacecraft separation was small (< 2 x 10^4 km), approximately half of those DDs observed by Ahead were also observed by Behind. As separation increased, this fraction fell significantly. In general, the probability of observing the same DD at both spacecraft increased as the discontinuity thickness increased, as the magnetic shear angle increased, and as the current sheets observed by a single spacecraft were more widely spaced in time. Malaspina and Gosling concluded that the current sheets observed by multiple spacecraft could often be interpreted as the walls of solar wind flux tubes.

Magnetic holes (depressions) are sometimes associated with magnetic discontinuities, and their presence can affect the transport properties of the particles. A multi-spacecraft study (Cluster and STEREO) by Briand et al. (2010) showed that waves are generated inside the holes. Their presence is strongly correlated with the presence of a well-developed electron strahl in the distribution of electrons of the ambient solar wind, and the electrons are more isotropic inside the hole than in the surrounding solar wind. These observations indicate that suprathermal electrons penetrate the magnetic hole that is convected by the solar wind. They then undergo magnetic focusing and particle drift associated with magnetic field gradient and electric field inside the hole. The plasma may thus become unstable and waves occur. The new aspect of this model compared to previous ones is the importance of the strahl electrons for the generation of a bump in the electron distribution function.

In summary, longitudinal separation of the STEREO observatories and near-Earth satellites has provided a unique opportunity for multi-spacecraft studies of solar wind flows and the structures within. STEREO remote and in situ instruments are contributing to the identification and understanding the role of small transients in the solar wind, including transients as a component of the slow solar wind. However, the type and dominance of structures in the solar wind are linked to the phase of the solar cycle. What longitudinal trends will we observe of these structures as the STA and STB converge once more on the far side of the Sun as solar activity increases?

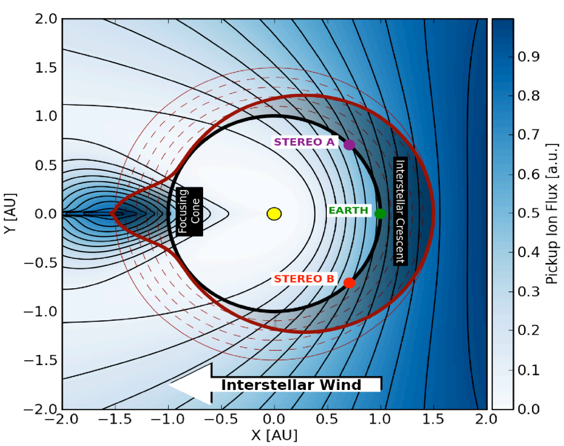

Figure II-12. A schematic of the pickup ion flux (color-coded contour). Interstellar neutrals enter the heliosphere from the right and generate regions of enhanced interstellar material in the well-known focusing cone and the newly discovered crescent.

Pickup ion discoveries: Our voyage through the interstellar medium (F2, F3, J1). Pickup ions (PUI) are generated when neutral atoms or molecules become ionized primarily by charge exchange with the solar wind protons or by photoionization from solar ultraviolet radiation. They are distinguished from other particle populations based upon their composition, ionic charge (singly charged), and velocity distribution. There are several sources for pickup ions, including penetration of neutrals from the very local interstellar medium (VLISM) and local sources such as outgassing or sputtering from moons, comets, and dust grains. In-situ observations of pickup ions at 1 AU provide an excellent although indirect tool for characterizing physical parameters and composition of particle populations originating from close to the Sun to beyond (outside) the heliosphere.

A particular feature for interstellar neutrals that penetrate to 1 AU before becoming ionized is that they are pulled by the Sun's gravitational attraction and focused behind the Sun with respect to the direction from which they arrived. Prior to STEREO, only interstellar helium had been observed having a gravitational focusing cone. With the large geometrical factor of the STEREO PLASTIC instrument, we have discovered a similar downwind focusing cone for interstellar neon (Drews et al., 2010) and a hitherto predicted (Vasyliunas and Siscoe, 1976) but previously unobserved upwind feature called the “interstellar crescent” (Fig. II-12). The crescent is a region of enhanced interstellar material located upwind of the Sun that spans nearly 180º. We have now measured the crescent for interstellar helium, neon, and oxygen (Figure II-13, from Drews *et al.*, 2012). Oxygen, with its elevated ionization probability, has a well-developed crescent, while helium’s crescent is less developed due to its lower ionization probability.

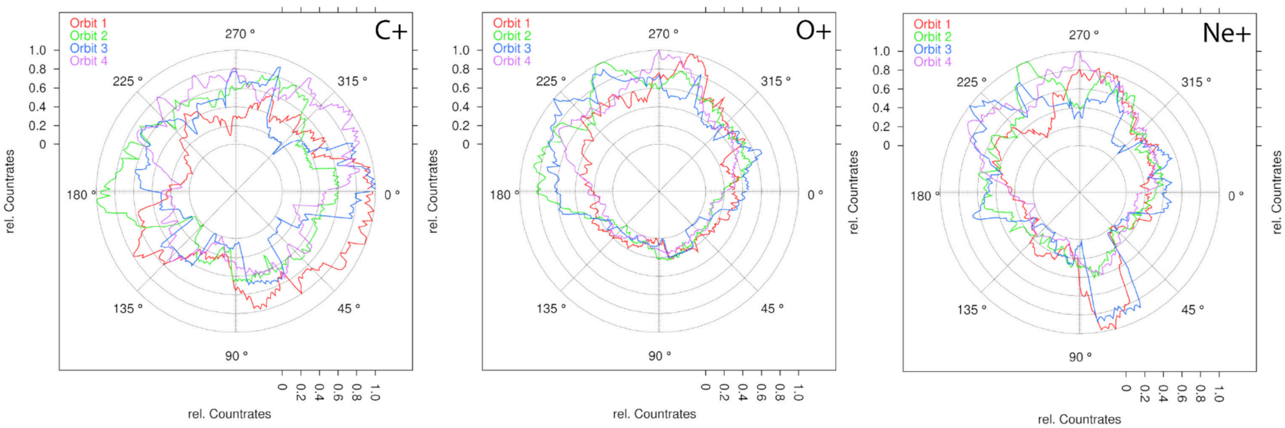

Figure II-13. Four orbits of the STEREO-A providing longitudinal observations for pickup ions C+, O+, and Ne+. The focusing cone for interstellar neon is seen near 77º, similar to that for He+ (not shown). The newly discovered interstellar crescent for He+, Ne+ and O+ spans nearly 180º in the upwind region, and provides a best estimate inflow direction in the range of 78.9 º - 80.4 º. Both structures are aligned around the inflow direction of interstellar neutrals. In contrast, pickup carbon is statistically consistent with an isotropic distribution, as expected for an inner source.

The crescent formation results from the enduring depletion of interstellar neutrals during their flight through the heliosphere combined with a geometric effect. Neutrals at ecliptic longitudes that are not aligned with the axis of the inflowing material have had a longer exposure to solar radiation and to the solar wind if they are observed at a fixed distance from the sun. As a result the observed PUI intensity shows a clear longitudinal dependency that resembles the form of a crescent if viewed in polar coordinates (thick red line in Figure II-12). *Both the focusing cone and interstellar crescent are aligned along the inflow axis of the interstellar medium, with some modest deviations from systematic transport effects.* The STEREO results of inflow directions for the cone and the crescent (Figure II-13) are important for interpreting earlier results from Ulysses, Prognoz 6, and ACE in the context of the recent IBEX results for the inflow direction.

Dust in the inner heliosphere (F2, F3). Dust particles of varying sizes are detected by instruments on STEREO, as short duration spikes in the measured electric field (S/WAVES) or as debris clouds imaged following dust impacts on the thermal blanketing (SECCHI). Of particular interest are nanoparticles, which lie near the low end of the mass distribution, at the frontier between macroscopic objects and atomic structures. Unlike larger size objects, the dynamics of which are mainly controlled by the gravitational field of the Sun and its radiation pressure, the nanodust grains have a high electric charge relative to their mass and therefore strongly interact with the solar wind’s magnetic field. Consequently, they are accelerated away from the Sun and reach velocities of hundreds of kilometer per second near the Earth orbit. Nano-grain impacts on spacecraft at a high velocity crater out and ionize some of the spacecraft surface material. The free electric charges thereby generated produce an electric field that can locally perturb the complex equilibrium that determines the electrical potential of the antennas. The detection of these electric signals enabled the first nanodust detections from wave instruments - on board STEREO in the solar wind (Meyer-Vernet et al. 2009a) and on Cassini near Jupiter (Meyer-Vernet et al. 2009b).

Recent papers by Pantellini et al. (2012a, b) and Zaslavsky et al. (2012) have suggested an improved model of interaction of the ejected cloud with the antenna, as the cloud does not induce sufficient potential change to produce the measured signal directly. Instead the passage of the cloud disrupts the photoelectrons from the antenna, which then cannot return because their new angular momentum does not allow it (Figure II-14).

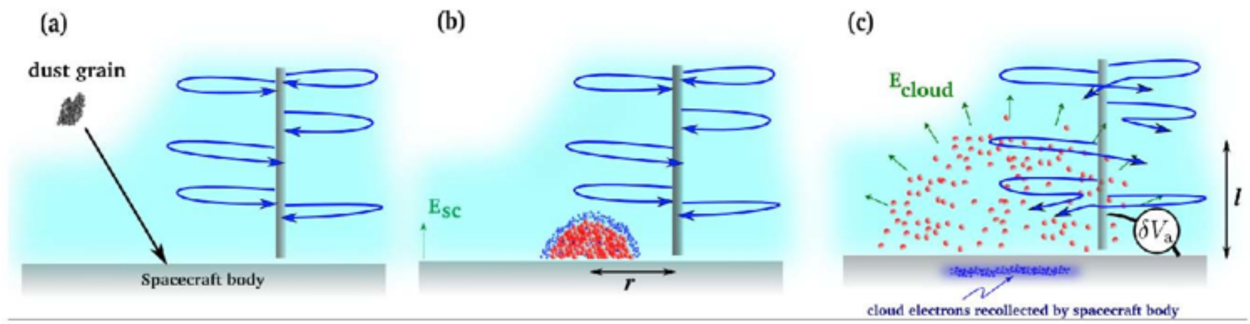

Figure II-14. Following a dust impact on a spacecraft (a) a plasma cloud expands radially from the impact point (b) at some distance r from a boom antenna. The cloud electrons are quickly recollected by the spacecraft under the effect of its electrostatic field (c). This field is strong enough to perturb the photoelectrons moving on highly eccentric orbits so that they are no longer collected by the antenna. The antenna thus increases its positive charge so that its voltage rises by δ*Va. (From Pantellini et al. 2013, Solar Wind 13, in press)*

The resulting net photoelectron current is strong enough to allow for a fast positive charging of the antenna, which is compatible with the measured field intensities on the S/WAVES antennas. The study by Zaslavsky et al (2012) also found that the dust-generated signals are observed to occur in two ranges, corresponding to impacts of dust from distinctly different mass ranges. Calibration formulas for these signals are derived that demonstrate the application of S/WAVES as a dust detector with results in both the nanometer and micrometer size ranges, covering the mass intervals ~10^{-22} – 10^{-20} kg and ~10^{-17} – 5 x10^{-16} kg (Figure II-15). In the latter interval, the orbital motion of the spacecraft permits identification of separate interstellar (IS) and interplanetary (IP) dust components, and measurement of the IS dust direction of arrival (Belheouane *et al.* 2012).

Correlations between the strongest S/WAVES voltage spikes and SECCHI images contaminated by streaks consistent with debris close to the spacecraft were reported by St Cyr *et al.* (2009). Recently, the distribution of dust in the ecliptic plane between 0.96 and 1.04 AU has been inferred from impacts on the two STEREO spacecraft through observation of secondary particle trails and unexpected off-points by the heliospheric imager (HI) cameras (Davis *et al.*, 2012). The different position of the HI instrument on the two *STEREO* spacecraft leads to each sampling different populations of dust particles. The asymmetry in the number of trails seen by each spacecraft and the significantly larger number of off-points in HI-B than in HI-A indicates that the majority of impacts are coming from the apex direction.

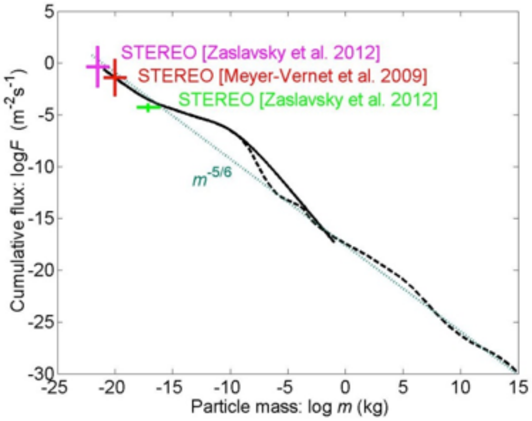

Figure II-15. Cumulative flux of the interplanetary dust and bodies at an astronomical unit from the Sun. The flux measured by S/WAVES in different mass ranges are indicated as colored crosses. The black lines show interplanetary dust flux models by Grün et al. (1985) (solid) and Ceplacha et al. (1998) (dashed). (From Meyer-Vernet and Zaslavsky, 2012)

The dust detection results from STEREO are important in many ways. Cosmic dust plays a role in various physical processes – serving as the substrate on which chemical reactions occur, weathering the surfaces of airless bodies, participating in charge exchange, etc. Understanding the growth and destruction of dust, its internal evolution, as well as the optical properties and the detection of nanoparticles is of fundamental importance for astrophysical research. Solar system studies of IP and IS dust using in situ detection provides baseline data for other astrophysical environments. The STEREO results have motivated studies by other missions such as the Wind spacecraft. Future missions such as Solar Orbiter and Solar Probe Plus are *very* interested in the dust environment inside of 1 AU.

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IIc. Prioritized Science Goals, FY14 - FY18

Goal Set 1: Characterize Space Weather throughout the Inner Heliosphere

PSG 1-1: Understand the large-scale structure of ICMEs (F2, J3, J4). Understanding the global structure of ICMEs is a main science goal of the STEREO mission. Because ICMEs are large (typically ~0.2 AU in the Sun-Earth direction), single–spacecraft observations, on which we relied almost exclusively before the STEREO era, constitute an extreme under-sampling and little can be inferred on the global structure of these transients. Much better prospects are offered by multi-spacecraft observations, particularly if complemented with remote sensing such as is possible with STEREO/SECCHI. In this spirit, during the first mission stage many important investigations on ICME structure were carried out, combining data from STEREO and an L1 probe (e.g. Kilpua et al., 2011 and references therein). Analysis techniques were developed to render these studies more scientifically productive, such as the numerical Grad-Shafranov code (Hu and Sonnerup, 2002), which reconstructs the magnetic structure of static configurations with an invariant direction (an axis). Möstl et al. (2009a, b) merged data from two spacecraft to optimize results. While advancing our knowledge of the 3D structure of isolated ICMEs or interacting ICMEs, multi-spacecraft studies have also raised basic questions challenging entrenched ideas.

Now is the time to address these *in a systematic fashion*. From mid-2014 to mid-2016, in the descending phase of solar cycle 24, the STEREO spacecraft will be less than 50° apart, a separation less than or comparable to the expected longitudinal width of ICMEs with a low inclination to the ecliptic. The gradual decrease followed by an increase in separation as the probes pass in 2015 affords us a unique opportunity of carrying out a systematic study of several multi-spacecraft observations of ICMEs. There will also be opportunities for coordinated observations with Venus Express (VEX; ~0.7 AU) and Messenger (~0.3 AU), sometimes in near-alignment. Together with the expertise gained and key issues raised in the (few) examples analyzed so far with STEREO, this is a unique opportunity for advancing our knowledge of the global structure of ICMEs: What is the nature of magnetic cloud-like (MCL) structures, *i.e.*, those magnetic clouds (MCs) in whose trailing part there is a near-steady, non-rotating magnetic field vector? When are they due to a crossing by the spacecraft of the MC flank (Marubashi and Lepping, 2007; Möstl *et al.*, 2010; Wood *et al.*, 2011)? And when are they, rather, a signature of reconnection of the ICME with the ambient solar wind, producing an excess of azimuthal flux which piles up at the back of the MC (Dasso *et al.*, 2006; Ruffenach *et al.*, 2012)? Using spacecraft near-alignments we can derive the radial evolution in the inner heliosphere of ICMEs. CME properties can be derived from STEREO A/B SECCHI, and models can be tested which predict the successive arrivals, or directly infer the kinematics of the CME, *i.e.*, speed as a function of heliospheric distance. Boundary conditions set at the Sun *and* in the interplanetary medium pose more stringent constraints on any CME model.

It was a multi-spacecraft analysis of the same MC by four spacecraft which led Burlaga *et al.* (1981) to propose the magnetic flux rope (MFR) model of MCs, a subset of ICMEs. This model has served as a paradigm for three decades and has spawned a wealth of research into analytical and numerical modeling of MCs. Simultaneously, it has raised the question of whether magnetic flux ropes are also associated with ICMEs. Do all ICMEs contain a magnetic flux rope? Does this relate to the three-part structure of CMEs at the Sun are supposed to exhibit (Illing and Hundhausen, 1985; see also Vourlidas *et al.*, 2012)? Is it really a question of spacecraft trajectory relative to the ICME which determines whether a probe will observe an MFR at all (Jian *et al.*, 2006)? Recently, Vourlidas *et al.* (2012) presented a comprehensive synthesis of several years of CME observations by LASCO, coronagraph data from STEREO and SDO complemented by 3D MHD simulations. From this novel and detailed approach involving a significant amount of data and statistical bases they concluded that 40% of CMEs exhibit clear flux rope signatures. What happens to them as they propagate? Are they the products of erosion, as suggested by Dasso *et al.* (2007)? Observations of ICMEs by spacecraft in near-radial alignments should be able to test this model.

PSG 1-2: Understand the physics of ICME interactions (F2). Around peak solar activity we expect several instances of ICME interactions in the inner heliosphere. Open questions raised by previous research on these interactions: How does the trailing shock travel through the leading ICME? Does it become evanescent when its speed relative to the transient becomes sub-Alfvenic ? (Farrugia and Berdichevsky, 2004; Liu *et al.*, 2012). Is it always the trailing shock which is responsible for the energy transfer to the leading ejecta, for homogenizing the speed profile of the (partial) merger, and for strengthening the leading shock with which it merges? (Lugaz et al., 2005). For the energy transfer between the ejecta, different scenarios have been proposed ranging from elastic to totally inelastic (See Farrugia and Berdichevsky, 2004; Liu et al., 2011; Lugaz et al., 2005, 2012). All scenarios may occur for different types of ICMEs, depending on their speed relative to the solar wind (presence or absence of CME-driven shocks) and on the field strength in the leading ICME. Can multi-spacecraft observations furnish evidence of different forms of energy transfer between interacting ejecta?

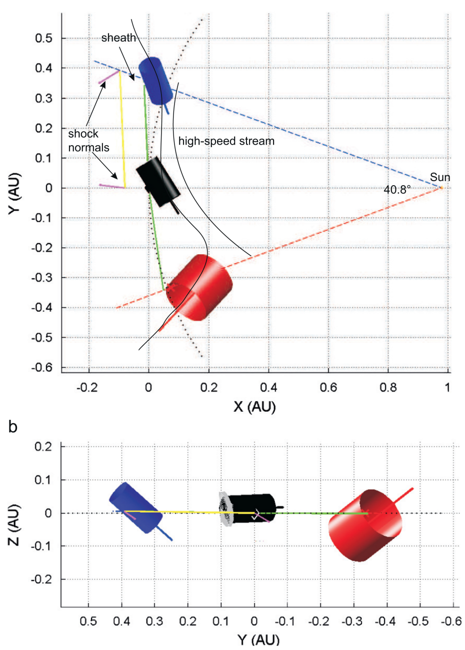

Figure II-16. Sketch of the global shape of a magnetic cloud (MC). Top: Looking down from ecliptic north in a solar ecliptic coordinate system (SE) centered on Wind. The blue cylinder indicates the size and orientation of the MC at STEREO-B, the black cylinder at Wind, and the red at STEREO-A. The green line connects the MC front boundary locations corrected for the timing difference. The yellow line connects the shock locations. (b): The same as seen in the SE plane looking towards the Sun (along + X). This was for a 2007 case; reverse the positions of the spacecraft for 2014, the same again in 2016, but both on the far side of the Sun.

ICME interactions/collisions may even involve several ICMEs/MCs. Other questions then concern the global shock and flux rope configurations. The groundwork study of Moestl *et al.* (2012) on the 2010 August 1 events when **four** ICMEs were launched towards a flotilla of spacecraft highlighted these questions: What is the global shape of the shock? The approximate shape of the shock was shown to be non-spherical, albeit still convex around the Sun. This non-spherical shape was hypothesized to be caused both by parts of the shock propagating into a medium carved out by the previous ICME, and by a higher initial speed ICME speed of eruptions on the eastern solar hemisphere. The global shock shape can be extrapolated from the orientations of the shock normal at the different locations. What is the global ICME/MC shape? The model of a magnetic flux tube bent on a large scale is supported by many models. While the longitudinal picture was consistent with the classical paradigm, however, some of the flux rope inclinations to the ecliptic were inconsistent. This might point to alterations of the flux rope picture as locally "warped" rather than locally straight. Interestingly, studying a multi-point ICME-CIR (corotating interaction region) interaction, a similar result was reached (Farrugia *et al.*, 2011 and Figure II-16). More examples, however, are needed to validate these conclusions. If the flux rope is indeed locally warped, does this explain the discrepancies often seen in models which assume the flux rope is locally straight? Coordinated STEREO/VEX/Messenger observations will test models of ICME fronts and shock shapes, for example, with approximations such as a self-similarly expanding circle (Möstl and Davies, 2012). Our models have increased in sophistication to the point where it is no longer only a question of when will the ICME reach 1 AU, but also which part (nose/flank) and where.

In summary, with multi-spacecraft observations we will capitalize on knowledge gained in the early part of the mission (during solar minimum) to exploit a phase where many ICME – ICME interactions are expected. ICMEs are central to inner heliospheric activity. This effort bears directly on space weather at Earth because, for example, ICME-ICME and ICME-CIR interactions are known to intensify and prolong geomagnetic activity (Dst index).

PSG 1-3: Understand how solar energetic particles are distributed so efficiently around the Sun (F2, H1, J1, J2, J3). The prolonged solar minimum delayed STEREO multi-spacecraft studies of large SEP events until mid-2010. New observations during 2010-2012 show that SEPs are distributed in longitude much more efficiently than expected from single-point observations or theory, sometimes extending over ~360° within an hour of an eruption (Section IIb). This raises several questions that can only be addressed with the 360° view provided by STEREO.

Imaging and in situ studies have provided evidence that lateral expansion of CME shocks near the Sun can accelerate particles over a wide range of field lines (Rouillard et al. 2012), but additional examples are needed to bolster this picture and test theoretical predictions of how SEP spectra and composition depend on shock geometry. Particle transport across field lines is suggested, but where does it take place? And how does it happen so quickly? Flare-related events can test this possibility during 2014-2018; can diffusion coefficients derived from events with smaller angular separations also explain large-scale events observed at STEREO and L1? STEREO observations with <60° separation can also test the role of field-line migration. Finally, is it possible that widely-distributed SEP events are due to a conspiracy of synchronous eruptive activity that suddenly accelerates SEPs from multiple sites?

Answering these questions will have important space weather consequences, particularly to NASA robotic and human exploration away from the vicinity of the earth. It now appears that ~20% of SEP events at Earth originate beyond the visible disk with little warning, including some fast-rising ground-level events. Multi-spacecraft observations explore the value of an L5 or L4 mission that could provide permanent multi-point observations. A recent study using near-Earth observations found that, on average, ~4% of the CME kinetic energy goes into accelerating particles, important for forecasting SEP fluences. Multi-spacecraft studies are improving the accuracy of both SEP and CME energy estimates; the observed broader longitude distributions increase SEP energy estimates by up to ~70%. Multi-point observations of suprathermal seed particles can test the claim that SEP fluences are limited by seed-particle densities. Finally, only the combination of STEREO and near-Earth imaging/in-situ assets can discover if rapid SEP onsets over ~360° result from synchronous eruptive activity. In short, the powerful 360° view provided by STEREO enables a unique opportunity to test the physics of SEP events and improve forecasts of their space weather consequences.

PSG 1-4: Radio and in situ multi-spacecraft measurements of solar type III bursts (F2, J2, J3). The radio burst signatures of solar flares are the fast-drifting type III radio bursts that extend from near the flare site outward beyond 1 AU. The radio emission is generated by a plasma wave process, in which energetic, flare-accelerated electron beams traveling outward along open magnetic field lines cause of the growth of plasma oscillations known as Langmuir waves. The specific mechanism by which Langmuir waves are converted into the observed type III radio emission is a puzzle that STEREO is helping to answer. Multi-spacecraft observations of the bursts when the two STEREO spacecraft are separated by less than 30° would be valuable for both radio and in situ electric field and particle observations.

Early in the STEREO mission, the spacecraft were at relatively small angular separation, and there was a paucity of type III solar radio bursts during solar minimum. Since then, due to the wide angular separation of the STEREO spacecraft, it has only been possible to make in situ measurements of the solar type III electron exciter beams and their associated Langmuir waves from one or the other of the STEREO spacecraft, because of the limited angular extent of the type III burst.

From the fall of 2014 until 2016 February, however, the angular separation of the the STEREO spacecraft will be less than 30°. With the Sun still near solar maximum, there is a good probability that the two spacecraft will both be within the electron beam for many individual type III bursts. This will provide a unique opportunity to make the first detailed spatial observations and analyses of the characteristics of the electron exciter beam and its associated Langmuir waves, to more fully answer long-standing questions such as: What is the longitudinal width of the electron exciter beam and how does the beam vary azimuthally? If, when the spacecraft are very close, and one observes Langmuir waves while the other does not, what does this imply about plasma conditions favorable to the generation of type III radio emissions? How do interplanetary plasma structures, like ICMEs and high-speed streams, affect the path of the exciter beam and the radio burst intensity?

During this time interval, the angular separation of the spacecraft relative to the sun will also make it possible to locate the type III radio sources in the solar wind by triangulation. The triangulation of the emission locations as a function of frequency will enhance the in situ studies and help to resolve questions about type III burst beaming and emission modes (fundamental or harmonic). These observations, combined with those from Wind/WAVES on the opposite side of the Sun, will provide new insights into the controversies over the dominance and beaming characteristics of fundamental versus harmonic radiation associated with the type III radio bursts.

PSG 1-5: Characterize space weather throughout the inner heliosphere (F2, J1, J3, J4). Among the new questions raised by STEREO observations so far are: How do energetic particles spread around the Sun so quickly and effectively? Are heavy ions distributed as broadly as protons and electrons? Is large scale, synchronous, eruptive activity common and does it produce the widely distributed, in situ events? We have a very capable set of instruments that are providing a 360° view of the Sun during a time of the solar cycle when we expect both large and small SEP events. As the STEREO spacecraft approach conjunction, we can finally look at events at the small angular separations that were simply not occurring during the unusually deep 2007-2009 solar minimum. Based on the survey of Kilpua et al. (2011) of events from 2007 April to 2008 March, we expect 12 - 15 events observable by multiple spacecraft while the angular separation of the STEREO spacecraft is less than 50°. In the next five years, STEREO, in conjunction with not only near-Earth spacecraft of the Heliophysics System Observatory but also with sensors on planetary and small body missions, will give us an unprecedented opportunity to establish *space weather situational awareness throughout the inner heliosphere*.

Planetary viewpoints. Among those perspectives is Mercury, which is exposed to more extreme space weather at ~0.3 AU location, and Messenger is obtaining measurements of its response. Messenger's plasma instruments cannot point toward the Sun, and the STEREO spacecraft provide downstream, in-situ measurements for use in interpreting the planet's response, together with imaging of CMEs headed toward Mercury in quadrature-like perspectives different from Earth's. Likewise, Venus Express, Mars Express, and MAVEN (scheduled to launch in 2013 November) carry plasma and in some cases magnetic field instrumentation that are (or will be in MAVEN's case) observing the solar wind interaction at our weakly magnetized terrestrial planet neighbors and its consequences. These studies are and will continue to benefit from downstream (Venus) or upstream (Mars) plasma and field measurements from STEREO, especially when they are closer to the planet-Sun line than is Earth. Most recently, the MSL landed on the surface of Mars with the RAD detector to measure energetic particle radiation there, including SEPs. A magnetometer may be placed on the Martian surface with the InSight Discovery mission lander in 2016. STEREO's widespread inner solar system measurements and the models they enable are invaluable input for the science investigations on these new missions and also contribute to NASA's planning for possible, future, human exploration of Mars.

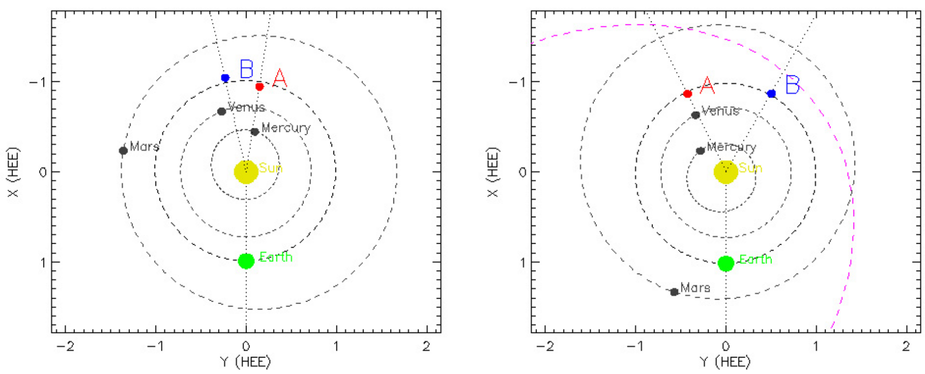

Figure II-17. Two examples of times when alignments between STEREO spacecraft and the inner planets provide possibilities for special investigations. Left: 2014 December 1, when Venus (and Venus Express) and Mercury (and Messenger), and STEREO Behind and Ahead, respectively, will be in near-conjunction; Right: 2016 July 18, when both Mercury and Venus will be in conjunction with STEREO Ahead (which will probably need to be renamed before then).

Space weather at comets and asteroids. STEREO-Ahead SECCHI HI observations of a tail disconnection event in Comet 2P/Encke have been linked to in situ measurements of an ICME (Jia *et al.* 2009). Other comets have permitted triangulation (Thompson, 2009) and studies of solar wind and interplanetary magnetic field interactions with the comets themselves (Clover *et al.* 2010, Shi *et al.* 2011). We anticipate that the 360° coverage provided by STEREO and *SOHO* coronagraphs will improve the interpretations of observed cometary brightening, outbursts, tail deflections and reconfigurations of multiple comets in FY14 - FY18, including comet 67P/Churyumov-Gerasimenko during its 19 month visit by the ESA Rosetta mission in 2014 - 2015. The Dawn mission has now left Vesta and is on its way to Ceres where it will go into orbit in 2015 February. Ceres, orbiting the Sun at 2.5-2.9 AU, is considered the canonical dwarf or minor planet. When Dawn arrives Ceres will be located where it is affected by events on the solar far side that will be observable by both STEREO spacecraft at the time.

Outer planets. Cassini's orbit around Saturn does not provide much opportunity for in-situ solar wind measurement and so investigations of responses of the Saturn magnetosphere to its space environment often depend on 1 AU measurements and model extrapolations. In the past it was only possible to use this method when Saturn was appropriately located within a fairly narrow angular range of the Earth-Sun line where L1 measurements are available. The widespread placement of the STEREO spacecraft greatly extends the longitudinal range of this type of investigation that can be used, for example, to relate observed Saturn auroral and dayside magnetopause responses to ICMEs. The

New Horizons instruments, which include solar wind and energetic particle detectors, will also be activated sometime prior to Pluto encounter in 2015.

Planetary Spacecraft in Transit. The GSFC space weather forecast center has taken on the task of space weather characterization for NASA planetary missions and spacecraft in their cruise phases as well as at their destinations. The use of STEREO observations for this task takes multiple roles, with STEREO imaging used in conjunction with SOHO and SDO imaging to obtain 'cone model' CME parameters for WSA-ENLIL simulations, and STEREO in-situ observations for both model validation as well as 'ground truth' information for the missions near alignment with the spacecraft. Thus Juno enroute to Jupiter, Dawn enroute to Ceres, and soon MAVEN, InSight and the asteroid-sampling Osiris Rex (launches in 2013, 2016, and 2016 respectively) will all benefit from this combined data use and modeling of the solar system-wide space environment enabled by STEREO as they travel toward their targets and arrive at their destinations. The cover figure is an illustration from a 2012 July SEP event, showing the collection of widespread SEP information obtained from four spacecraft including both STEREO spacecraft. Such solar-system wide picture will enable both global and local science as well as practical insights for all of these missions.

Goal set 2: What can we learn from 360° coverage of the solar corona?

PSG 2-1: Uncover the large-scale couplings in solar eruptive events (F1, F2, H1, J1, J2, J3). Since the end of 2010, Heliophysics scientists possess a unique capability, unparalleled in astronomy--- the continuous 360° coverage of the activity of a stellar atmosphere, the solar corona in this case. This accomplishment was made possible via the STEREO and SDO EUV imagers and via the STEREO and SOHO white light coronagraphs and is a prime example of the power of the Heliophysics Systems Observatory (HSO). The full Sun observations reveal flaring activity occurring in close temporal proximity across large longitudinal separations (e.g., 2011 September 4), and trace long-distance magnetic connectivity that seems to lead to successive CMEs from different active regions and even hemispheres (*e.g.* the 2010 August 1 and 2011 December 25 events). The research on 'sympathetic' and 'homologous' events is becoming an increasingly hot topic in Heliophysics. Are these apparent connections simply chance occurrences due to the increased activity? Do they trigger each other by altering the large-scale magnetic flux distribution, as suggested in Torok *et al.* (2012)? Or are we witnessing the side-effects of a more fundamental process; namely, the reconfiguration of the global magnetic field as it evolves towards the maximum? What happens as the field relaxes towards its minimum state?

The answers to these questions have the potential to revolutionize our understanding of eruptive phenomena. Our ability to image the full EUV corona without areal gaps or projection effects extends through June 2019 when the STEREO A and B spacecraft reach opposition again. Late 2019 is also the nominal timeframe for the minimum of Cycle 24, approximately 11 years after the Cycle 23 sunspot minimum (December 2008). Therefore, the combined observations from STEREO, SOHO, and SDO (with support from *Hinode*, RHESSI, and upcoming IRIS) from FY14 to FY18 offer the unique and possibly ultimate opportunity to study the evolution of the coronal activity as it descends towards solar minimum. The potential implications extend from the interior dynamo theories to space weather.

PSG 2-2: Understand the lifetime of active regions, coronal holes, filaments, and filament channels (F1, F4, H1, H3, J1, J2). To understand how large-scale structures like active regions (ARs), coronal holes (CHs), filaments and filament channels, and streamers originate, evolve, and decay, it is essential to be able to track them over 360^0. It is especially important to observe the effect of an emerging AR on the large-scale coronal structure during the 1–2 rotations from the moment that it starts to emerge. Emerging ARs result in the formation of small CHs at their peripheries, in the distortion of nearby CH and streamer boundaries, in the formation of equatorward extensions of the polar holes, and/or in the formation of new streamers and pseudostreamers.

The distortion of the CH and streamer boundaries is believed to be due to interchange reconnection with AR fields. It is extremely hard to observe these processes without continuous tracking over a solar rotation and/or simultaneous views from widely different angles. For example, the formation of a CH or the distortion of a CH boundary necessarily entails a change in the structure of the adjacent streamers (through the opening-up, closing-down, or interchange of coronal loops). However, CHs are best observed near disk center, whereas streamers and CMEs are best observed at the limb. It's mainly for this reason that we have never been able to determine how/whether CMEs are involved in the formation of long-lived (non-transient) CHs. More generally, we have never been able to observe the opening-up of coronal loops during the formation of a CH, or the closing-down of loops during its decay, even though we expect this to occur. This is an important question because some people claim that the amount of open flux on the Sun never changes.

To understand how filaments and filament channels form and evolve, we must track them continuously as they rotate around the Sun. This is because they are strongly affected by surface transport processes like differential rotation and flux cancellation, which occur on timescales of many days to several weeks. Do filaments progressively evolve from sheared arcades into flux ropes as flux cancellation at the polarity inversion line (PIL proceeds)? Do they gradually rise as they evolve and then become unstable? Do coronal/filament cavities progressively evolve from semicircular structures (as viewed at the limb) into detached O-shaped cavities as the underlying filament evolves into a flux rope? Only STEREO can answer these questions.

Goal Set 3: What can we learn from coverage of the full heliosphere?

PSG 3-1: Provide longitudinal coverage of the solar wind and transients that can affect the outer heliosphere (F2, F4, J1). The location of solar wind termination shock near ~90 AU is the result of a pressure balance between the out-flowing solar wind and the pressure of the local interstellar medium. Changes in the solar wind create a movement or "breathing" of these boundaries - the solar wind of today affects next year's heliospheric boundaries. Before STEREO, MHD models of the heliosphere were primarily based on single-point near-Earth solar-wind measurements. The combination of 3-point solar wind measurements from STEREO and L1 can greatly improve estimates of the heliospheric boundary motions during a critical period when Voyager 1 is apparently approaching the heliopause. In addition, multipoint measurements are crucial to understanding correlations of IBEX energetic neutral atom (ENA) fluxes with changes in the solar wind (McComas et al. 2012), which is the key to determining the origin of the IBEX ENA emissions.

Solar wind transients due to CMEs also affect the outer heliosphere. Indeed, during periods when solar activity remains high for 1-2 weeks (e.g. Halloween, 2003), a global merged interaction region (GMIR) can encircle the Sun and form a moving barrier to cosmic rays, causing "Forbush decreases" in cosmic-ray intensity as far away as the heliosheath (Burlaga et al. 2011). The present 360° view of the Sun provides much more complete measurements of the CMEs causing these transients and of the strong magnetic fields that they carry. The better longitudinal coverage of in-situ measurements and imaging may provide clues to how and when GMIRs form.

PSG 3-2: Pickup Ions (F2, F3, J1); supports current missions IBEX, ACE, and future missions SSP and Solar Orbiter. Pickup ion generation is subject to solar cycle influences, such as the cycle variations in the ultraviolet flux and proton flux that effect ionization rates. Recent data available with spacecraft at different longitudes (STEREO A, STEREO B, ACE) indicate that large-scale solar wind structures (shocks, SIRs) during solar minimum introduced effects that played a role in temporal variations. STEREO PLASTIC is able to detect pickup ion fluence in statistically significant quantities allowing higher temporal resolution for determining spectral variations. With STEREO data, this will be the first time such high-temporal data will be available under solar maximum conditions, with associated ICME event periods.

Continued data collection will allow us to investigate differences in the He+ and newly discovered Ne+ focusing cones. Differences in the inflow speeds and temperatures of helium and neon in the very local interstellar medium can be inferred by comparing the shape of their respective pickup ion cones. The hotter the VLISM and the slower the inflow speed, the wider focusing cone. One must also take into account the effect of rapidly varying solar wind conditions such as stream interfaces and coronal mass ejections – for this one needs a combination of data from at least two spacecraft at different longitudes and multiple encounters with the focusing cone. In this respect it should also be noted that STEREO provides proton flux, solar wind speeds, and interstellar pickup ion data that support the IBEX measurements of interstellar neutrals. IBEX measures the neutral inflow, while STEREO measures the ionized component.

While we have emphasized the interstellar source for pickup ions, STEREO is also making unique contributions to understanding of the so-called inner source. Inner source pickup ions are believed to originate from solar wind interaction with dust grains close to the Sun. The interaction process and even the location of the dust grains are an open matter of discussion. Future missions such as Solar Probe Plus (targeted launch in 2018) and Solar Orbiter (targeted launch 2017) will approach the inner source region (believed to be within 30 solar radii) but current knowledge and planning for these missions rely on theory based on observational constraints from Ulysses and more recently from ACE and STEREO. Inner source pickup ions are also subject to solar cycle variations. As seen in Figure II-13, STEREO is capable of providing longitudinal and temporal analysis of inner source carbon on spatial scales and time durations hitherto not available and will continue to do so through the solar cycle. In addition, preliminary analysis indicates STEREO is observing Fe+. For this potential inner source pickup ion longer accumulation time scales are necessary, but this brings a new species to the studies of the inner source.

PSG 3-3: Improve our understanding of dust in the inner heliosphere. Additional S/WAVES dust detection will play a key role in understanding the evolution of the dust flux with time and with increasing distance from Earth. Some models indicate that such effects should be seen. As seen in Figure II-18, the cumulative flux, as detected by the S/WAVES LFR on STEREO-A is decreasing, suggesting a change in the spacecraft as dust detector with time. Differences in the dust detection rates at the two spacecraft are not understood. It will be valuable to have dust detection data after the spacecraft are flipped post-opposition, allowing each spacecraft to present different faces to the ram direction.

NASA has recently funded a proposal to examine STEREO materials (blanketing, solar arrays, etc.) in the laboratory setting to answer some of the outstanding questions about the dust before the launch of Solar Orbiter and Solar Probe Plus.

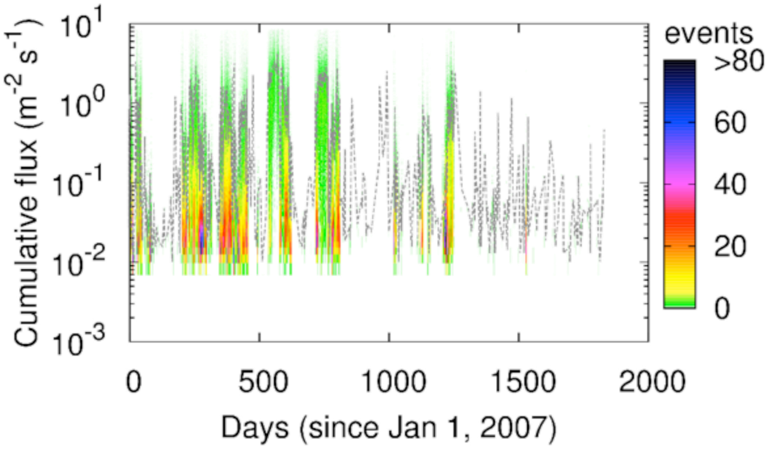

Figure II-18. Variation with time of the cumulative flux of particles of mass greater than 10^{-20} kg measured by the STEREO-A/WAVES Low Frequency Receiver (LFR) between 2007 and 2011. The color scale of the cumulative flux distribution has been chosen to emphasize the daily most probable value of the flux. The dotted gray line corresponds to the daily mean of the measured nanodust flux. (From Le Chat et al., submitted 2012.)

Coordinated studies with dust detection by the Waves instrument on Wind – a spinning spacecraft with short (6 m and 7.5 m) and long (50 m) electric field antennas – have begun. Recently, triggering of the Wind Waves TDS waveform sampler was switched from the long X-antenna signals to the shorter Y-antenna (both are in the spin plane). Subsequently, triggering from the Z-antenna (spin axis aligned) will be implemented. These changes may allow Wind to simulate the S/WAVES results, providing a comparison data set. Also, the surface of Wind is mainly Indium Tin Oxide over glass, whereas the surface of STEREO near the antenna bases is thermal blanket of Mylar with a vacuum deposited layer of germanium. The dust impact-induced plasma clouds will have different ion compositions, which may also provide useful information.

It is apparent that the full analysis and understanding of the range of dust impact phenomena observed by STEREO has only begun. Continued observation will provide new parameter space for the dust studies, and the expanded understanding will contribute to both heliophysics and astrophysics.

References *may be found at the end of section IIb.*

III. Technical and Budget, FY14 - FY18

III.A Technical Risk Areas

Telemetry. As the STEREO spacecrafts' orbits carry them farther from the earth, a reduction in telemetry rates was expected, and all instruments have methods of deceasing sampling to produce less data. Although occasional 70-meter and high-elevation 34-m DSN contacts still allow higher telemetry bandwidth (typically 240 - 720 kbps and 160 kbps, respectively), most STEREO downlink is currently or soon will be carried out at 120 kbps. Thanks to reducing earlier, overly conservative margins, APL missions ops personnel are confident that we will never have to reduce the rate below 120 kbps. That represents a significant increase in telemetry while the STEREO spacecraft are on the far side of the Sun during FY14 - FY16: we expected to have to reduce telemetry rates to 60 kbps or less in the original planning. With 8 hours of DSN contact per day, we should be able to continue recovering over 2 Gbit of data per day.

A serious exception to this regime, however, occurred in late 2012 and early 2013, when two, independent effects – most of the missions served by the DSN were in the same quadrant of the sky, including the STEREO spacecraft, and extended maintenance/reconstruction downtime for two DSN antennae – combined to produce almost daily shortfalls in recovering data from one or both spacecraft. Ahead was, in general, more severely affected, with data recovery dropping as low as 1.3 Gbit per week in mid-January, 2013. Although the antenna downtime is not expected to be as severe, the hour angle clumping of target missions will recur in late 2013 as well. As in the 2012 - 2013 period, mission ops will attempt to minimize data loss whenever possible with ESA "cross-support," that is, the return payment in kind for DSN support of ESA missions or mission components. Since ESA charges tracking costs to individual missions, however, that support has to be considered to be in some risk due to ESA's current mission operations budget issues. Overall, however, we do not consider the recovery of STEREO telemetry to be a risk area of concern.

Rate (kbps)	Ahead	Behind	Daily Telemetry Volume (Gbit)	Pass duration (hr)
720	2007/01	2007/01	5	4
480	2008/10	2008/09	5	5
360	2009/05	2009/06	5	6
240	2010/04	2009/12	4	7
160	2011/06	2011/07	2.7	8
120	2013/05	2012/11	2.1	8
160	2017/07	2017/07	2.7	8

Table III-1. STEREO telemetry rates and start dates. Projected date in grey. The 720 kbps rate was the rate at heliocentric orbit insertion. Pass duration increases as rates decrease. Daily telemetry volume indicates a requirement; mission ops has surpassed these figures consistently during the mission to date, with the exception of the early 2013 contention period.

Spacecraft. As noted in Appendix D, the primary IMU laser ring gyros on Ahead (2007 April) and Behind (2012 October) fell victim to a known lifetime issue. Both spacecraft are operating with backup IMUs, and a IMU-less operation scheme involving the use of the SECCHI guide telescope has been written, uplinked, and tested. We thus do not consider attitude a significant risk area.

There are no other spacecraft degradation issues.

Mission ops ground system. The ground system is over seven years old. APL mission ops has budgeted for replacing critical ground system components, and has begin the porting of the older systems to sustainable platforms. A small number of failures has occurred in the past year, but in all cases, backups and spares were used to replace the failed units.

III.B Budget

Baseline budget. As can be seen from Table III-2, below, there is adequate funding for all instrument teams and mission operations in the proposal period. The mission operations budget includes contingency in FY14 - early FY16 for modifying and testing software and procedures for the 1 - 3 month periods when each spacecraft will be out of contact as the angle between it and the Sun becomes too small to allow adequate signal to noise for error-free data recovery. Among the changes that will need to be tested is a change to the keep-alive timer that sends a spacecraft into safehold if it has not been in received a command for a period of time – the time will have to be lengthened significantly beyond the current 60 (initial autosafing) to 72 hours (complete autosafing).

The proposed team budgets are on the order of 60% of the prime Phase E levels. We would use any savings on the mission operations contingencies to increase the funding for science analysis activities. We expect the first two years, at least, of the proposal period to be marked by a continued, moderate level of solar activity.

Notes on Table III-2. Labor breakdown (section IIa): The entire contractor workforce is at APL, where the STEREO Mission Operations Center (MOC) is located. The NASA civil service science labor includes fractional Co-Investigator FTEs for S/WAVES, SECCHI, and IMPACT, as well as the project scientist and a resource analyst. The civil service labor under mission operations represents the Mission Director. (Note that the civil service labor figures do not include employees of the Naval Research Laboratory, who are considered contractors for the purposes of this budget.)

Project Name:	STEREO				
I. FY14 - FY18 NASA Full-cost Guidelines:					
	FY14 Budget ($k)	FY15 Budget ($k)	FY16 Budget ($k)	FY17 Budget ($k)	FY18 Budget ($k)
Total	9,637.0	9,603.0	9,693.0	9,708.0	9,708.0
II. FY14 - FY18 '5-way' Functional Breakdown:					
	FY14 Budget ($k)	FY15 Budget ($k)	FY16 Budget ($k)	FY17 Budget ($k)	FY18 Budget ($k)
1. Development	260.0	148.0	35.0	0.0	0.0
2.a Space Communications Services	108.0	111.0	114.0	113.0	112.0
2.b Mission Services	3,611.4	3,749.4	3,673.0	3,468.8	3,570.8
2.c Other Mission Operations	60.7	62.2	67.6	77.3	66.5
3. Science Operations Functions	3,402.0	3,372.0	3,567.0	3,721.3	3,632.2
4.a Science Data Analysis	2,075.8	2,045.2	2,119.3	2,206.5	2,206.8
4.b Guest Observer Funding	0.0	0.0	0.0	0.0	0.0
5. E/PO	119.1	115.0	117.5	120.7	119.6
Total*	9,637	9,603	9,693	9,708	9,708
*Totals for Table II should be identical to totals in Table I.					
IIa. FY14 - FY18 Labor breakdown:	FTEs/WYEs	FTEs/WYEs	FTEs/WYEs	FTEs/WYEs	FTEs/WYEs
1. Mission Operations	8.9	8.9	8.9	8.9	8.9
1.a CS Labor	0.2	0.2	0.2	0.2	0.2
1.b WYE (Contractor) Labor	8.7	8.7	8.7	8.7	8.7
2. Science Operations and Data Analy:	30.3	29.4	29.7	30.0	29.7
2.a CS Labor	1.7	1.7	1.7	1.7	1.7
2.b WYE (Contractor) Labor	28.6	27.7	28.0	28.3	28.0
III. FY14 - FY18 Instrument team breakdown					
	FY14 Budget ($k)	FY15 Budget ($k)	FY16 Budget ($k)	FY17 Budget ($k)	FY18 Budget ($k)
1. DA - PLASTIC	588.0	577.0	609.6	627.6	645.0
2. DA- IMPACT	1,392.3	1,370.8	1,440.1	1,461.7	1,462.0
3. DA - SWAVES	549.4	540.5	570.0	587.6	587.7
4. DA - SECCHI	2,526.9	2,492.7	2,619.9	2,685.9	2,675.6
DA - SSC and project scientist	606.9	621.9	676.5	773.4	665.0
Other mission expenses	3,973.4	4,000.4	3,777.0	3,571.8	3,672.8
Total**	9,637	9,603	9,693	9,708	9,708
**Totals for Table III should be identical to totals in Table I.					
IV. FY14 - FY18 '5-way' Breakdown for in-Kind contributions:					
	FY14 Budget ($k)	FY15 Budget ($k)	FY16 Budget ($k)	FY17 Budget ($k)	FY18 Budget ($k)
1. Development	260.0	148.0	35.0	0.0	0.0
2.a Space Communications Services	14,236.0	14,663.0	15,103.0	15,556.0	16,022.0
2.b Mission Services	0.0	0.0	0.0	0.0	0.0
2.c Other Mission Operations	0.0	62.2	67.6	77.3	66.5
3. Science Operations Functions	0.0	0.0	0.0	0.0	0.0
4.a Science Data Analysis	0.0	0.0	0.0	0.0	0.0
4.b Guest Investigator Funding	0.0	0.0	0.0	0.0	0.0
Total	14,496.0	14,873.2	15,205.6	15,633.3	16,088.5

Table III-2. STEREO five-way budget breakdown, FY14 - FY18.
The "Development" line in section II includes funds for modifying flight software for conjunction operations (FY14 and FY15) and porting the SSC servers to sustainable platforms (FY16).

Appendix A. Education and Public Outreach

Since the spacecraft were launched in late 2006, the many and varied STEREO E/PO efforts have touched upon people in just about every state and in many foreign countries as well. From classroom activities to public events, unique imagery for museums to student internships, the story of the first 3D solar mission has captured interest and engaged the public in the field of solar science. The STEREO project is involved in a diverse array of educational activities in the areas of formal and informal education. This is partly because three of the instrument teams and the STEREO Science Center (SSC) each have their own E/PO efforts, each with an E/PO lead. Deputy Project Scientist T. Kucera is the overall lead. The different STEREO teams and partners communicate by telecon and email, and support each other according to their specialties. Below we describe highlights of the work of the STEREO E/PO teams.

The STEREO Science Center

STEREO Content for Museums and Science Centers. As part of the *SOHO/STEREO* Pick of the Week feature, *STEREO* images and movies are sent out two to four times a month to over 300 museums and science centers through ViewSpace kiosks and the American Museum of Natural History (AMNH)'s AstroBulletins. These movies are also made available and archived on the *STEREO* and *SOHO* web sites, and related video and stills have been featured on the Astronomy Picture of the Day and Spaceweather.com sites. This activity is being carried out in partnership with the Living With a Star program.

360° Sun. Since February 2011 the STEREO spacecraft have been able to observe the far side of the Sun. This has made it possible to produce full 360° views of the entire Sun, something never before possible in history. STEREO marked this occasion with events organized through the NASA Museum Alliance and a Twitter question and answer session. STEREO and SDO now produce a combined full Sun data product which is made available to the Science on a Sphere (SOS) network, a NOAA program involving 80 installations of the SOS spherical display system. These movies can be adapted to other spherical display systems. For instance, STEREO's SECCHI team members at JPL (see below) have made a movie formatted for the Magic Planet's spherical display system, and Sun 360° data is also featured in smart phone and tablet applications.

The Sun Today is a social media site featuring data from STEREO and other solar missions. The goal of The Sun Today is to develop a community of solar and helio-enthusiasts from the general public, educators and students. The effort includes a website, blog, Twitter, Facebook, Google Plus, Pinterest, and YouTube components. The narrated YouTube videos have viewerships in the thousands and, in one case, over 200,000. Evaluation is done through statistics provided by these social media sites and allow for a better understanding of what sorts of techniques increase interest in particular items. For instance, narration or even annotations added to a video significantly enhance viewership and sharing. As a social media effort, the Sun Today is interactive and linked to the Helioviewer.org web site that allows the public to produce customized movies from STEREO and SDO data. Initially funded by STEREO, as of summer 2012 the Sun Today is supported by Goddard's Heliophysics Science Division.

STEREO web site. The STEREO public website supports many of the above activities. It is a source for the publicly available data, including the STEREO 360° images. Content has been regularly added, including a selection of highlights for The Best of STEREO Gallery and a YouTube channel, space weather section, overview video clips, links, new activities, graphics, online posters, incremental additions to the Newsroom and What's New sections. Visitors can access all of the images in the archive and even see movies on the spot for any period they select. The data is accessed by other web sites for educational purposes, including the Sun Today and Helioviewer.

SECCHI

STEREO's SECCHI team members at JPL produce high quality, HD daily and weekly movies for museums using the data from STEREO's SECCHI imaging suite. The movies are available to members of NASA's Museum Alliance through the SolarMuse web site. They also produce and make available through SolarMuse movies of coronal mass ejections and other interesting events, some of which are also hosted on the SSC website and YouTube channel. A new SECCHI product is a high resolution Sun 360° movie constructed from STEREO and SECCHI EUV data for Magic Planet, a spherical projection system that is used in many museums and science centers. These will be available on the SolarMuse website for Museum Alliance members (user=Science_Team; password = secchi07) and also the SSC web site. They will also produce video of such targets of opportunity as comet ISON, which will near the Sun in 2013 November.

IMPACT

The STEREO/IMPACT team at UCB has been conducting many E/PO activities in partnership with NASA's Wind mission. STEREO/IMPACT and Wind team members routinely presented science hands-on lessons for middle school students in the San Francisco Bay Area between 2009-2012. An estimated 800 or more students were reached in total. The students participated in an activity where, on their own, they discovered how to build a spacecraft with a magnetometer (i.e. putting it on a boom away from the rest of the electronics), like STEREO. They also heard about the heliophysics science and missions, including STEREO, and saw a brief presentation from a NASA scientist. The classroom visits were incorporated into the MASERS (Math, Science, and Engineering Resource Support) Program, which is a part of Community Resources for Science (CRS) effort to provide scientist "role model" presentations at schools throughout the East Bay. Teachers indicated that the science lessons were well received by their students and many of the students clearly understood the purpose of the magnetometer booms on STEREO.

STEREO/Impact and Wind partnered with the Surfin' the Solar Wind (EPOESS) project to develop an interactive videogame exhibit called the CME Launcher. The game, which was designed with critical input from teenagers, engages participants in learning about the connection between magnetism and CMEs, and how space weather impacts people on Earth. Preliminary testing and evaluation has shown that the activity is meeting the goal of engaging underserved teens in out-of-school environments, and effectively changing their knowledge and attitudes about space weather.

STEREO/Impact and Wind team members also undertook three small outreach programs, a solar wind website dedicated to the science and discoveries of the solar wind; a sonification software program to turn STEREO Wind data into sounds, now available as open-source on the solar wind website for further development by the Max/MSP (Max Signal Processing) community; and a partnership with the National Park Service for a public event for the May 20, 2012 annular solar eclipse, presenting hands-on act activities and distributed NASA materials at a viewing event at Petroglyph National Monument near Albuquerque, New Mexico. Over 200 people attended the event. STEREO also joined several other Heliophysics missions to present in the week-long Heliophysics Educator Ambassador (HEA) teacher workshops in 2009, 2010, and 2011. About 90, mostly-middle school HEA teachers from around the U.S. were reached directly (with measurable gains in Heliophysics content), with most of them teaching middle school. A majority of them went on to present their own workshops to their colleagues in their local districts. The program has already reached hundreds of teachers and the overall impact continues to grow.

PLASTIC

The STEREO/PLASTIC team participates in a program for student interns in partnership with the Space Science Center of the Institute for the Study of Earth, Oceans and Space at the University of New Hampshire. The program includes a series of in-house lectures and facilities tours geared toward the students. The lectures provide students with hardware, data analysis and theory backgrounds on the science projects they are working on and enhances their interest so that they are more likely to decide to stay in STEM and perhaps become graduate students in our field. The intern student pool includes other regional colleges and high schools in the area around Durham, including southern Maine, northern Massachusetts, and southern and central New Hampshire.

In the summer of 2010 the PLASTIC team sponsored a week long Summer Solar Science Symposium for K-12 educators in partnership with the McAuliffe Shepard Discovery Center (MSDC). Twenty-four educators participated, and all but one rated the workshop as very good to excellent in post-workshop surveys.

PLASTIC team members participated in a number of other outreach programs. In the last two years these included co-teaching a teacher workshop in Gorham, NH in partnership with a faculty member from the UNH Department of Education and giving lectures at the MSDC's annual Aerospacefest. A PLASTIC scientist also participated in a Woman in Science and Technology (WIST) Forum, sponsored by Space Grant and held in the White Mountains Community College in the north country of New Hampshire. The WIST program allows middle and high school girls from this rural area to meet and talk with professional women in STEM fields.

Evaluation. Because the activities by STEREO are so diverse our evaluation process is diverse as well. Some evaluation results are described above. In addition, many of the individual programs in which STEREO participates perform their own evaluations. Overall, the STEREO project finds that their E/PO efforts are meeting the needs of the audiences for which the program is designed. As described above, over the past 2.5 years this program has reached potentially millions of people who attend museums around the country, hundreds of thousands of members of the public through on-line efforts, hundreds of teachers through teacher professional development efforts, and over a thousand of middle, high school, and undergraduate students directly.

Partnerships. STEREO's partnerships with both educational and science outreach organizations are extensive. As described above, STEREO partners with formal educational institutions, such as the Berkeley and Oakland middle schools involved in MASER. Our team is integrated into outreach efforts at University of New Hampshire and the University of California, Berkeley. Our materials for museums and science centers are distributed with the help of the AMNH, the Hubble Space Telescope Institute's ViewSpace, NASA's Museum Alliance, and NOAA's SOS. STEREO has particular partnerships with the SDO and Wind missions. STEREO participates in activities of NASA's Heliophysics Education Forum, which is headed by UC Berkeley's Center for Science Education, the group responsible for the E/PO activities of our IMPACT Team.

We see such partnerships as being an important part of our E/PO and a key part of these programs – as a NASA mission STEREO is optimally placed to bring the excitement of the latest NASA data to various outreach settings. Such programs are highly leveraged as we are contributing content and sometimes financing to programs also supported by other NASA missions, NASA Space Grant Funds, and local educational institutions. We judge the need for our efforts by the needs expressed by our partners in informal and formal educational institutions.

Future Plans. The STEREO Team plans to continue many of the ongoing programs described above. The SSC at Goddard and the SECCHI team members at JPL will continue to provide high quality

STEREO imagery to museums and science centers and web based outreach efforts. The PLASTIC team will continue to support the internship program at UNH and PLASTIC scientists will give lectures at teacher workshops and events at the MSDC. The SSC will also support an undergraduate summer intern in partnership with the Goddard Office of Education.

New IMPACT activities include Cal Day Open House, described below, as well as contributions to the Community of Practice (CoP) effort led by the NASA Science Mission Directorate Heliophysics Science Education and Public Outreach Forum. CoPs are groups of people who share a concern, a set of problems, or a passion about a topic, and who deepen their knowledge and expertise in this area by interacting on an ongoing basis (Wenger, 1998); in this case, the people involved are middle and high school teachers who have been a part of individual mission E/PO education programs and networks who want to deepen their heliophysics content knowledge, increase their STEM teaching skills, support their students in learning STEM, and interact with other heliophysics educators.

Cal Day STEREO/IMPACT funding will also support the planning and implementing of a public outreach event at the Space Sciences Laboratory at UC Berkeley in 2014 and 2015. This already established, once-a-year event, called Cal Day, includes free tours of the lab, a special program in the Mission Operations Center where satellites are monitored, science talks about on-going space missions (including STEREO), a career panel, multiple booths with related fun hands-on activities, a solar telescope, and more. The CME launcher interactive videogame exhibit will be showcased in 2014 and 2015, and the activities used the NPS Petroglyph Monument eclipse outreach event will be used again. This day is a day for high school students and families to learn more about UC Berkeley and possible career paths and college tracks.

In 2010, 2011, and 2012, Cal Day attracted 350, 500, and 500 participants, respectively. In the written evaluations collected, over 97% of the respondents stated that the event was a good use of their time, and a higher percentage said they would recommend it to a friend. Some notable quotes were "It was incredibly cool. I came for my science class and learned a bunch," "I was able to learn more about space and the Sun," "...the career panel and black hole lecture were great," and "It was really interesting. I got to hear about NASA projects I didn't know about."

STEREO – SDO Partnership: Think Scientifically Educator Professional Development Program. The STEREO SSC plans to embark on a partnership with the Solar Dynamics Observatory (SDO) in which STEREO will support the dissemination of the Think Scientifically book series developed by the SDO E/PO team and a related on-line professional development program.

Due to the emphasis on math and reading in public schools, science regularly takes a back seat (Griffith & Scharmann, 2008), especially at the elementary school level. By providing ways for science to easily integrate with the math and reading curriculum the deficit in elementary science education can be corrected. The Think Scientifically story-based science literature program integrates a classic storybook format with solid science to make an educational product that meets state literacy standards, helping to bring a stronger emphasis on science into elementary classrooms, while still fulfilling curriculum requirements. The books are aligned to the National Science Education Standards and the Common Core State Standards for English Arts and Literacy. The goals of the project are to 1) increase time spent on science content in elementary classrooms, 2) increase elementary teacher comfort with science content and pedagogy, and 3) increase student achievement in learning objectives addressed by the curriculum.

The series is comprised of three books, all teaching a different component of elementary level solar science. The first book and second book, both complete, address the Sun as the source of energy for our planet and examines the Earth's position in space and the Sun as the cause of the seasons respectively. The third book, currently in development, will teach about the Sun as the driver of the water cycle. All books can be used as a part of story time, a dedicated reading or language arts lesson, or in activity stations. Formal evaluation for the project is being carried out by Magnolia Consulting, and the books are being tested in elementary schools in Adelphi, Maryland and Washington, DC.

A "Content Enhancement Lesson Plan" accompanies each book, including a hands-on lab and activities that teachers can easily conduct in their classrooms with minimal training and materials. In addition, there are math connections that relate directly to the story and are grade level appropriate, language arts extensions, science and reading comprehension questions as well as detailed background information to extend the teacher's knowledge.

The books have thus far been distributed through teacher workshops and elementary school partnerships, through partnerships with the Heliophysics Educator Ambassador (HEA) program, and at industry conferences like the National Science Teacher Association (NSTA) conference. The STEREO-SDO partnership will expand that distribution by producing a Think Scientifically Educator Professional Development (EPD) program that will include both on-line and in-person development for elementary educators. This SDO EPD program will provide the training and resources for educators to increase the time spent on science in their classroom, specifically space science, with a focus on beginning elementary teachers who often avoid teaching science altogether (Appleton & Kindt, 2002). The books will also be made available in ePublish format, which can be read by all commonly available electronic book readers.

Online professional development is important to US school districts, especially the many that face budget cuts (Davis, 2009). Our free online EPD program will help take this stress off schools and allow teachers to increase their skills without taking time away from their classroom teaching. The project will include the development of Educator Professional development programs for each of the three Think Scientifically books. The sessions will be filmed, edited and disseminated in a pedagogically appropriate online format. These sessions will be supported by on-line forums in which educators ask questions and get more information.

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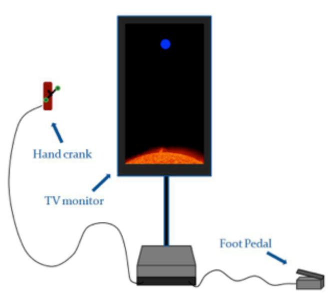

The CME Launcher is a new, portable, interactive videogame exhibit that engages participants in learning how Coronal Mass Ejections can affect us here on Earth. The exhibit was developed by educators and teenagers in the Surfin' the Solar Wind project along with members of the STEREO E/PO team.

STEREO E/PO budget

		FY14	FY15	FY16	FY17	FY18
SSC, GSFC	STEREO-SDO: Think Scientifically	37.2	40.1			
	E/PO Lead activities	4.3	4.4	4.5	4.6	4.7
	SSC Web Site Maintenance	17.3	17.3	17.6	17.9	18.3
	Undergraduate Intern	9.4	9.6	9.8	10.0	10.2
	E/PO collaborations			37.7	36.6	35.4
IMPACT, UC Berkeley	Cal Day	11.0	11.0	11.2	11.4	11.7
PLASTIC, UNH	Summer Intern program	5.9	5.9	6.0	6.1	6.3
SECCHI, JPL	SECCHI imagery for museums	10.0	10.0	10.2	10.4	10.6
Total		**95.1**	**98.2**	**97.0**	**97.2**	**97.2**

Table A-1. Proposed STEREO E/PO budget, FY14 - FY18.
All figures in $K.

Budget discussion. LWS is now providing the funding for Steele Hill's work in coordination with the Pick of the Week video, with STEREO Science Center personnel suggesting events of interest and providing input on the content of the captions. Similarly, funding for the time spent by STEREO science team member Alex Young to work on the The Sun Today will be provided by Goddard's Heliophysics Science division.

Relevant overhead amounts have been included for all institutions.

Think Scientifically Educator Professional Development Program FY2014-2015					
Description	**Cost**	**Multi-plier**	**Multiplier unit**	**Total**	**Deliverable**
EPD Session (FY14)					
EPD Development	$47.49	120	hours	$5,699	Initial user guides and evaluation plan
Pilot testing	$47.49	160	hours	$7,599	Finalized User guides
Evaluation	$3,500.00	1	reports	$3,500	Pilot Evaluation Report
Updates to User guides and pro-gram	$47.49	60	hours	$2,850	and evaluation based-updates to user guides and EPD program
User guide Materi-als	$60.00	50	guides	$3,000	50 complete user guides to be used during pilot dissemination
Dissemination	$47.49	120	hours	$5,699	50 Classroom teachers trained to use TS in classroom
Travel to HEA	$2,000.00	1	trip	$2,000	HEA workshop
Travel to NSTA	$2,000.00	1	trip	$2,000	NSTA Workshop
		Sub Total		$32,347	
Goddard overhead				$4,852	
		Total		**$37,199**	
Development of Online EPD (FY15)					
eBook development	$60.62	160	hours	$9,699	3 TS book online as
eBook editing	$56.71	15	hours	$851	eBooks
Filming	$150.00	10	hours	$1,500	Rough cut of EPD Online session
Editing	$250.00	15	hours	$3,750	Finalized EPD online ses-sion
Web Development and Maintenance	$60.62	160	hours	$9,699	Dissemination Website
Dissemination	$48.92	120	hours	$5,870	Online forum for feed-back and classroom users
Evaluation	$3,500.00	1	report	$3,500	Final Evaluation Report
		Sub Total		$34,869	
Goddard overhead				$5,230	
		Total		**$40,099**	

Table A-2. Proposed STEREO-SDO "Think Scientifically" budget, FY14 and FY15. All cost figures in dollars. This budget is broken out because it is the largest single element in the STEREO E/PO budget for FY14 and FY15.

Appendix B. Mission Archive Plan

Mission-wide Data and Software

The STEREO Science Center (SSC), located at NASA Goddard, serves as the main archive for all STEREO data. The primary source of ancillary data products for the STEREO mission is the STEREO Data Server (SDS) maintained as part of the Mission Operations Center at the Johns Hopkins University Applied Physics Laboratory. These data, which include all operational and engineering data and reports shared between the operations and instrument teams, are mirrored over to the SSC several times per day for archiving. All the ancillary data products are made available online except for the telemetry dictionaries which are archived separately for security reasons, and the DSN Schedule Change reports which are not made public because they include email addresses. The DSN Schedule Change reports are not archived because the information in them is included in the subsequent DSN schedule files. Event lists maintained by the PI teams and others are available at the SSC Website.

Telemetry, Ephemerides, and Attitude History. Final level-0 telemetry files are archived by the SSC for each of the instruments and spacecraft subsystems. All STEREO ephemerides and attitude history files are provided as SPICE kernels. SPICE is a standard ephemeris package provided by the Jet Propulsion Laboratory's Navigation and Ancillary Information Facility (NAIF), and used by many interplanetary and heliospheric missions. Information about SPICE and the SPICE software package can be obtained from the NAIF Website. The SPICE kernels archived by the SSC are in ASCII transfer format, which can then be compiled into machine-readable form for any supported platform.

SolarSoft. Data analysis software is distributed as part of the Solar Software Library, also known as SolarSoft. This multi-mission software library is used extensively within the solar physics community, and enables cross-mission data analysis. The primary emphasis is on Interactive Data Language (IDL) software, but source code for other languages is also distributed using the SolarSoft mechanism. Together with the large generic library supplied with SolarSoft, each instrument team provides software for analyzing their own data. Also provided are the most current ephemeris and attitude history files for the entire mission, and software to manipulate them in a large variety of standard coordinate systems.

Instrument resources. Resource pages are available for each of the STEREO instruments, using a standardized format first developed for the SOHO mission, and are accessible from the SSC Website.

Mission Documentation. A special issue (Volume 136) of Space Science Reviews (SSR) is devoted to the STEREO mission. In that issue are extensive descriptions of the spacecraft, instruments, and ground systems.

Data Distribution. The SSC resides within the Solar Data Analysis Center (SDAC) at the Goddard Space Flight Center. The SDAC is a multi-mission Resident Archive with extensive experience distributing data for a number of missions, including SOHO, TRACE, RHESSI, Hinode, SDO, and others, as well as archiving data for older missions such as the Solar Maximum Mission. The SDAC will act as the active Resident Archive for the lifetime of the mission and beyond. Ultimately, the data will be delivered to the Permanent Archive designated by NASA Heliophysics MO&DA management.

The Virtual Solar Observatory (VSO) acts as the primary access point for all STEREO data, with the SSC as the data provider. This maximizes the use of existing resources without duplication, and enables collaborative data analysis with other solar observatories. IMPACT magnetometer and particle data, as well as S/WAVES intensity spectra, are also available through the Virtual Heliospheric Observatory (VHO). An extensive list of all access sites, including those at the individual PI and Co-I institutions, is maintained on the SSC Website.

IMPACT

Scientific Data Products. The IMPACT investigation provides several levels of science data products. The primary, "Level 1" science products, include all science data at highest time resolution and in scientific units and coordinates. These products are produced at UC-Berkeley upon transfer of the Level 0 telemetry files from the SSC and validated by the IMPACT Co-Investigators within one month of generation. Once validated, these files are made publicly available (see below). Level 1 data files are in ISTP-compliant CDF format and intended to be self-documenting. The full complement of ISTP-required metadata are included within these files. All IMPACT Level 1 files are archived within the SSC. Appropriate metadata have been developed for each Level 1 data product, and incorporated into the VHO.

Level 2 data are a merged data set, including data from the IMPACT and PLASTIC investigations, and averaged to ensure identical time cadences (1-minute, 1-hour and 1-day). These data are intended for quick browsing and are integrated with an online plotting and ASCII listing service hosted at UCLA. Level 3 data are list-type data such as event lists compiled by the IMPACT team. They are in PDF and Excel formats. Appropriate metadata are being incorporated into the VHO to enable searching on the data.

Currently, the IMPACT investigation provides Level 1 data for all instruments. Level 2 data including MAG and PLASTIC moments are being served at UCLA and Level 2 data from the SEP suite (HET, LET, SIT, SEPT) will soon be available through the UCLA server. Level 2 data in ascii and CDF formats are also available for the SEP suite instruments through the SSC, UC Berkeley (for CDF) and Caltech and Kiel (for ascii). Level 3 event lists are served by UCLA, and archived within the SSC.

Documentation. The SSR special issue includes complete information regarding the IMPACT instruments and data products. In addition, documentation is served online through the IMPACT instrument resource page. Information about calibrations and software versions used in the production of Level 1 data products are listed on this website and included in the internal documentation of the CDF files themselves.

Analysis Tools. The IMPACT investigation provides data products in ISTP-compliant CDF and ASCII formats to ensure easy integration with users' native analysis environments. In addition, the IMPACT team provides custom software through the instrument resource page based on the UC-Berkeley TPLOT library. This is an IDL-based set of analysis routines designed specifically for in situ measurements.

Online browsers and plotters hosted by UCLA, UC-Berkeley, the University of Kiel, and the Institut de Recherche en Astrophysique et Planétologie (IRAP) provide tools on the web. At UC-Berkeley, a traditional browse-type, static plot tool is available. This tool links IMPACT and ACE plots and data with images and models. A real-time space weather has also been developed at UC-Berkeley which integrates STEREO Beacon, SDO and ACE plots.

Data Distribution. The IMPACT data sets are available through the main IMPACT UC-Berkeley instrument resource web site listed above. In addition, all data are mirrored by the SSC and available there. Data are also mirrored and available through CDAWeb. IMPACT data are being included in the VHO interface. Space Physics Archive Search and Extract (SPASE) descriptions of the IMPACT Level 1 data products have been written.

Together with the above, Caltech hosts a site specific to the Solar Energetic Particle (SEP) suite. This site provides SEP and some ancillary data (notably, orbit and attitude information) in ASCII format. A site hosted by the IRAP includes additional data products and analysis tools for the SWEA instrument.

PLASTIC

Scientific Data Products. Level 1 data are the highest-resolution, complete data set. They have the epoch time and instrument section decommutated, counts decompressed, and entries separated into meaningful products (solar wind proton moment array, reduced proton and alpha distributions, heavy ion species count rate arrays, pulse height data, housekeeping, etc.), but are not fully converted into physical units (such as flux) that require the incorporation of detection efficiencies which may change over the life of the mission (due to gain changes in the detectors). Level 1 data products are produced at UNH within 24 hours of receipt of Level 0 telemetry files. Software and calibration/efficiency files to convert the data into physical units, along with appropriate documentation, are delivered electronically to the SSC archive. Level 1 data products are in ISTP-compliant CDF files.

Level 2 data products include the most frequently used quantities from PLASTIC in physical units. These data products are accessible on the PLASTIC Website (menu link to "Resources") and include both browse quality (typically available within 1 day of Level 1) and validated (updated monthly) products. Validated Level 2 products currently available on the UNH site as ASCII files include solar wind protons, alphas, selected minor ions, and helium pickup ions. Selected key parameters (such as solar wind bulk parameters, ion charge state distributions, and He+ intensities) are also provided on the UNH-hosted PLASTIC online browser as daily and/or monthly time series plots. Verified and validated products undergo both automatic and science personnel quality checks. These archival quality data are added to ISTP-compliant Level 2 CDFs and mirrored at the SSC. The validated PLASTIC proton moments are also included as a merged plasma plus magnetic field product courtesy of the IMPACT/MAG site at UCLA.

Level 2 products are continuing to be created and deployed, with associated data processing software and calibration files under development. Continuing Level 2 software development will allow the future inclusion of additional species and higher time resolution products. Updates to calibration files will be ongoing through the length of the mission.

Level 3 data products typically result from directed scientific analysis, and include specific intervals (such as identified ICMEs) and other value-added products. A list of suprathermal event periods is available through the SSC website, as are daily averaged He+ spectra, both in ASCII format.

Documentation. Full descriptions of the PLASTIC instruments and the Level 1 data products can be accessed through the Instrument Resource webpage at the UNH website. Metadata relevant to particular data products are also available within the CDF files. ASCII products either have the product information contained within the file header, or else a Readme file is provided. The instrument and data products are fully described in the PLASTIC instrument paper in the SSR special issue. This paper is available online, free-of-charge to the public, and is linked through the PLASTIC Resource page.

Analysis Tools. PLASTIC data are available in ISTP-compliant CDFs such that they can be easily integrated into existing analysis and search tools, such as the VHO and SolarSoft. In addition, the PLASTIC team has extended the UC-Berkeley TPLOT library, (see IMPACT section, above), into the IDL-based SPLAT (Stereo PLastic Analysis Tool) that further enables integration of data sets. SPLAT and other IDL programs, including those that support composition analysis and those that create specialized ASCII files from the CDF files, are distributed through the SolarSoft library.

Data Distribution. PLASTIC Levels 1 and validated Level 2 data are available both via the UNH-hosted Website and at the mirrored SSC instrument data site. PLASTIC archival data is also available at the CDAWeb, the VSO, the VHO, and the Virtual Space Physics Observatory (VSPO).

SECCHI

Scientific data products. All SECCHI image telemetry data are converted to FITS files upon receipt of version 02 of the Level-0 telemetry files, about 2 days from the date of observation. This processing is done at the SECCHI Payload Operations Center (POC), located at NRL. The FITS headers contain all instrument parameter and spacecraft pointing information. The images have been oriented to put the spacecraft north, which usually corresponds to ecliptic north, at the top of the image, but no interpolations are done at this Level0.5 stage. The images may be converted to Level-1 by the user using a SolarSoft IDL procedure, SECCHI_PREP, which performs all of the calibration functions using the latest calibrations. Image header metadata are avail3able in a database, accessible from the SECCHI Website, which can be also used to download specific FITS files. In addition to the FITS data, the SECCHI Website serves a large number of Level-2+ data products for science and public use. These products currently include: (1) Browse images in PNG format (2) Javascript movies for user-defined intervals (1-36 hours) and (1-9 days). (3) Synoptic browse movies (individual or combined, 1, 2 or 4 weeks) in MPEG format. (4) PNG anaglyphs and stereo pairs of all EUVI data suitable for stereo viewing, (5) synoptic maps of EUVI, COR1, COR2 accessible in a variety of forms, (6) auto-generated CACTus CME lists for SECCHI, and (8) EUVI synchronic 360º maps in Carrington coordinates (195Å, 284Å, 304Å). Additional Level-2+ data products are readily available by request: (1) EUVI wavelet-enhanced dual-wavelength combined movies, (2) EUVI wavelet-enhanced images for the full mission, (3) EUVI+SDO synchronic maps in cos-lat projection, (4) COR2 total brightness and % polarization FITS files. The SECCHI team will add another set of high level data products (J-maps, flux rope CME list with 3D properties) within the year as resources allow.

Calibration activities for the SECCHI telescopes are almost complete. Pointing and flat-fielding (including vignetting) calibrations have been established for all telescopes. Geometric distortion corrections have been implemented for all applicable telescopes (COR2, HI1, and HI2), as have the shutterless readout corrections for HI1 and HI2. Photometric calibrations have been implemented for EUVI, COR1, COR2, and HI1. Work is proceeding on the HI2 photometric calibration. A preliminary HI2 calibration was published in Halain *et al.*, 2011, and a more detailed calibration was implemented in the software in 2013 January.

Housekeeping. Selected SECCHI instrument housekeeping telemetry is also available via web interface to a database at NRL. Plots may be extracted from this database of various engineering parameters such as temperatures, currents, voltages, door position, guide telescope pointing and HK events. Table definitions and table structure are described on the SECCHI web site.

Documentation. The SECCHI Website serves: Science (FSW) Operations Manual, FSW documentation, image telemetry completeness data, instrument status, image scheduling details, various instrument and operations event logs, software user's guides, SECCHI FITS Keyword Definition, and the SECCHI Data Management Plan. A description of the instrument is given in the SSR special issue. SECCHI operations and data documentation is maintained in a wiki site. The wiki pages are updated as information becomes available.

Analysis Tools. SECCHI analysis tools, and most of the pipeline software, are freely available through SolarSoft. The following tools are currently available via SolarSoft: data browsers, data calibration, movie generation and display, image enhancement and visualization, polarized image processing, star-removal, height-time plots, raytracing, CME detection, tomography. As these tools are improved and future tools developed, they will be added to the SolarSoft library. In addition, there are some stereographic visualization tools which currently require specialized hardware. At NRL all software is under Concurrent Versions System management.

Final Data Set. The SECCHI Level-0.5 data is "final" after the FITS files have been updated with any additional telemetry received in the final (+30-day) Level-0 telemetry from APL. Currently, the Level-1 (calibrated) product is the combination of the Level-0.5 FITS images and the SECCHI_PREP IDL routine and data files available in Solar- Soft. This allows the user to take advantage of the evolving calibration of the various telescopes. At the end of the mission, the calibration files and parameters that are used in this package will be revalidated to ensure that they are up to date and able to generate Level-1 FITS files of calibrated images, polarized brightness, and brightness images. Calibration will include corrections for instrumental artifacts such as stray light, vignetting, shutterless readout, and conversion to physical units. (Geometric distortion is described by header keywords together with the World Coordinate System standard algorithms.) Complete documentation, transparent software code, and non-proprietary data formats ensure that calibration can be properly applied to Level-0.5 data into the foreseeable future. The final archive will contain both the calibrated Level-1 files and the original Level-0.5 files.

Data availability. The primary site for storage of Level-0.5 FITS image data is the NRL Solar Physics Branch (PI home institution). The primary means of querying data for analysis is by utilizing summary flat-files which are read by SolarSoft tools. Besides being available on-site, the data is freely available (in relatively small quantities) from NRL via database query at the SECCHI website. All of the data are also synchronized hourly to the SSC. In addition, other partner institutions – LMSAL (California), RAL (UK), IAS (France), MPS (Germany) – mirror STEREO data. These all serve as backups for the complete data set.

Virtual Observatory Access. The SSC is now serving SECCHI data through the VSO at GSFC/SDAC, which is intended to be the gateway to other Virtual Observatories. The SECCHI data are fully accessible to the wider VO community. VSO is committed to community interoperability efforts, such as the SPASE data model.

S/WAVES

Scientific Data products. The S/WAVES investigation provides several levels of science data products. Access to the Level 0 data is achieved through a processing system called TMlib, based on a similar system (WindLib) successfully used since the early 1990s for the Wind/WAVES (W/WAVES) data. The TMlib can be downloaded from the University of Minnesota (send request to goetz@umn.edu).

Daily summary plots showing all frequency-domain receivers and summaries of the time domain receivers are available from the SSC and S/WAVES Webpage. Both of these sources also serve 1-minute averages in both ASCII and IDL save format of all frequency-domain receivers. These 1-minute averages are also served by the CDAWeb. The CDAWeb site includes customized plotting capabilities. Both the daily summary plots and the 1-minute averages are produced automatically upon receipt of the data, so are available usually within 24-hours of real-time.

The French IRAP Plasma Physics Data Center (CDPP) also serves daily summary plots of the frequency domain receivers in a different format than those from the U.S sites. CDPP will also serve in the future the higher level S/WAVES products associated with direction finding and wave polarization capability. This site requires a password (due to French security regulations), but this is freely given upon request.

Additional higher level data includes the Type II/IV catalog maintained by the Wind/WAVES team and now including S/WAVES data. This site has been in existence since the late 1990s and is a valuable resource for solar researchers. The years covering the STEREO mission are archived on the SSC website.

Documentation. Three papers of importance to S/WAVES data processing are in the SSR special issue, one providing a complete description of the S/WAVES instrument, another discussing the antennas, and a third describing the direction finding technique used by S/WAVES. Pointers to these articles as well as to a description of the 1-minute average data are on the S/WAVES instrument resource page referenced by the SSC. The direction finding and wave polarization parameters, when available, will be documented on the CDPP Web site mentioned above.

Analysis tools. The customized plotting capability available at the CDAWeb is based on the same program used by the S/WAVES team. This original IDL program is available from the instrument resource site at the SSC. Future customized plots of polarization and direction of arrival will be available from the CDPP Web site.

Data Distribution. S/WAVES data, as mentioned above, are available directly from the team's US Web site, from the SSC, from CDAWeb, and from CDPP. The S/WAVES event lists can be obtained from the Type II/IV catalog Web site, from the SSC website, and through interface with the VSO.

Appendix C. STEREO publication record, 2006 - 2012

STEREO refereed journal (not conference proceedings) rates through the first few weeks of calendar year 2013 can be found in Table C-1.

Calendar Year	Refereed Journals only
2006	1
2007	11
2008	63
2009	122
2010	100
2011	121
2012	150
2013 through February 21	12
Total	580

Table C-1. STEREO refereed papers

Here, a "STEREO paper" is taken to mean any paper using STEREO data, or concerning models or theoretical interpretations of STEREO measurements.

Publication rate. The STEREO publication rate grew dramatically in 2009 as special issues of *Solar Physics* (two issues, with a total of 51 papers) and *Annales Geophysicae* (23 papers based on work first reported at the "Three Eyes on the Sun" conference in 2009 April/May), then fell back again but started to rise in 2011 as more solar activity led to more analyses. The 2012 figure include the special issue of *Solar Physics* (Volume 281, Issue 1) on The Sun 360 that includes 29 papers, most of them based on work presented at the 2011 workshop of the same name at Christian-Albrechts-Universität zu Kiel organized by STEREO, *SOHO*, and SDO.

Bibliography*.* An interactively searchable database of STEREO publications, which can be limited to refereed journals, conference proceedings, etc. can be found on the SSC Website. A list of refereed publications in 2010 - 2012 is also available.

Appendix D. Spacecraft and Instrument Status, 2013 March 1

SPACECRAFT

Both spacecraft are performing nominally. As the laser intensity monitor in the X-axis inertial measurement unit (IMU) gyro was degrading on the BEHIND spacecraft, the redundant IMU unit was placed on-line in October 2012 to save remaining life. On the AHEAD spacecraft, the X-axis IMU gyro failed in April 2007. Both spacecraft have been using the backup IMU without issue, and the mission operations team has crafted and tested a backup attitude control scheme using the SECCHI guide telescope and star tracker.

The first major refresh of the Mission Operations Center (MOC) hardware is under way and planned to be completed in 2013.

IMPACT

Flight hardware. In 2012, onboard flight code was switched from RAM to EEPROM to mitigate SEU effects. The STE-U detectors, unusable from launch because of light contamination, have been powered down to avoid triggering high current autonomy rules. The other boom instruments, STE-D, MAG, and SWEA, continue to perform nominally, as do the SIT and SEPT telescopes in the SEP suite. SEP events in 2011 provided the first high-rate conditions for LET, and caused it to lock up (on both spacecraft) in 2011 June. A software issue was identified and patched, and a separate issue with heavy elements and live-time determination was resolved by changing observing parameters. similarly, a patches are now being tested to correct HET He and heavier ion data and calibration stim event effects; otherwise, both HET teelscopes continue to perform nominally.

GSE. The low-cost Windows PCs used to command the IMPACT instruments from our POCs are showing signs of imminent failure and will be replaced by new, low-cost machines.

PLASTIC

Both PLASTIC instruments are fully operational. Post-launch analysis determined that the entrance system design did not meet geometrical factor specifications for the solar wind sector. The higher geometrical factors contribute to microchannel plate gain degradation. Partial compensation is achieved by commanding increases to the bias level. Regular updates to instrument response algorithms are also implemented. When the spacecraft flip in 2015, the detector exposures will also flip, increasing the gain back toward earlier mission levels.

Due to increasing distance from Earth, there is a reduction in telemetry. New DPU software was recently implemented, which allows partial compensation by increased time accumulations in selected rates, or by deletion of entire rates.

SECCHI

"Watchdog" resets (18 on Behind, 28 on Ahead over the course of the mission) generated in the SECCHI Electronics Boxes (SEBs) each result in a few hours' of lost observing time. Anomalies in the EUVI quadrant selector on Ahead were corrected by adjusting the encode timing delay in 2011 October. The COR1 polarizer wheel on Behind began to show some jitter at the end of 2012; mitigation efforts currently focus on adjusting the mechanism delay settings.

S/WAVES

Both S/WAVES instruments continue to function nominally. Interference on the Behind spacecraft, probably due to a faulty ground wire associated with the IMPACT boom, affects the S/WAVES at 16 kHz and 100 kHz. This limits the ability of S/WAVES to carry out three-antenna direction finding on all but the strongest solar events. This is not, however, a serious limitation, as time-of-flight direction finding and the use of Wind/WAVES direction finding mitigate this issue. New S/WAVES flight software was developed and up-loaded to correct a problem relating to long operating periods. New operating modes were implemented allowing a reduced telemetry allocation with minimal reduction in science return.

Appendix E. Research Focus Areas, NASA Heliophysics Roadmap, 2009 - 2030

Research Focus Areas

- **F1** Magnetic reconnection
- **F2** Particle acceleration and transport
- **F3** Ion-neutral interactions
- **F4** Creation and variability of magnetic dynamos

Open the Frontier to Space Environmental Prediction

The Sun, our solar system, and the universe consist primarily of plasma. Plasmas are more complex than solids, liquids, and gases because the motions of electrons and ions produce both electric and magnetic fields. The electric fields accelerate particles, sometimes to very high energies, and the magnetic fields guide their motions. This results in a rich set of interacting physical processes, including intricate exchanges with the neutral gas in planetary atmospheres.

Although physicists know the laws governing the interaction of electrically charged particles, the collective behavior of the plasma state leads to complex and often surprising physical phenomena. As the foundation for our long-term research program, we will develop a comprehensive scientific understanding of the fundamental physical processes that control our space environment.

The processes of interest occur in many locations, though with vastly different magnitudes of energy, size, and time. By quantitatively examining similar phenomena occurring in different regimes with a variety of techniques, we can identify the important controlling mechanisms and rigorously test our developing knowledge. Both remote sensing and in situ observations will be utilized to provide the complementary three-dimensional, large-scale perspective and the detailed small-scale microphysics view necessary to see the complete picture.

Research Focus Areas

- **H1** Causes and evolution of solar activity
- **H2** Earth's magnetosphere, ionosphere, and upper atmosphere
- **H3** Role of the Sun in driving change in the Earth's atmosphere
- **H4** Apply our knowledge to understand other regions

Understand the Nature of Our Home in Space

Humankind does not live in isolation; we are intimately coupled with the space environment through our technological needs, the solar system bodies we plan to explore, and ultimately the fate of our Earth itself. We regularly experience how variability in the near-Earth space environment affects the activities that underpin our society. We are living with a star.

We plan to better understand our place in the solar system by investigating the interaction of the space environment with the Earth and the effect of this interaction on humankind. We plan to characterize and develop a knowledge of the impact of the space environment on our planet, technology, and society. Our goal is to understand the web of linked physical processes connecting Earth with the space environment.

Even a casual scan of the solar system is sufficient to discover that habitability, particularly for humankind, requires a rare confluence of many factors. At least some of these factors, especially the role of magnetic fields in shielding planetary atmospheres, are subjects of immense interest to heliophysics. Lessons learned in the study of planetary environments can be applied to our home on Earth, and vise versa, the study of our own atmosphere supports the exploration of other planets.

Research Focus Areas

- **J1** Variability, extremes, and boundary conditions
- **J2** Capability to predict the origin, onset, and level of solar activity
- **J3** Capability to predict the propagation and evolution of solar disturbances
- **J4** Effects on and within planetary environments

Safeguard the Journey of Exploration

NASA's robotic spacecraft continue to explore the Earth's neighborhood and other targets in the heliosphere. Humans are expected once again to venture onto the surface of the Moon and one day onto the surface of Mars. This exploration brings challenges and hazards. We plan to help safeguard these space journeys by developing predictive and forecasting strategies for space environmental hazards.

This work will aid in the optimization of habitats, spacecraft, and instrumentation, and for planning mission operation scenarios, ultimately increasing mission productivity. We will analyze the complex influence of the Sun and the space environment, from origin to the destination, on critical conditions at and in the vicinity of human and robotic spacecraft. Collaborations between heliophysics scientists and those preparing for human and robotic exploration will be fostered through interdisciplinary research programs and the common use of NASA research assets in space.

Appendix F. Acronyms *(including acronyms used in the E/PO section)*

ACE	Advanced Composition Explorer
AMNH	American Museum of Natural History
APL	Johns Hopkins University Applied Physics Laboratory
AR	Active Region
ASCII	American Standard Code for Information Interchange
AU	Astronomical Unit
CACTUS	Computer Aided CME Tracking
CCMC	Community Coordinated Modeling Center
CDAWeb	Coordinated Data Analysis
CDF	Common Data Format
CDPP	Centre de Données de la Physique des Plasmas (France)
CIR	Co-rotating interaction regions
CME	Coronal Mass Ejection
Co-I	Co-Investigator
CoP	Community of Practice
CO3R1	SECCHI Inner Coronagraph
COR2	SECHHI Outer Coronagraph
CRS	Community Resources for Science
DSA	Deep Space Antenna (ESA)
DSN	Deep Space Network
EPD	Educator Professional Development
E/PO	Education and Public Outreach
EPOESS	Education and Public Outreach in Earth and Space Science
ENA	Energetic neutral atom
ESA	European Space Agency
ESP	Energetic solar particle
EUV	Extreme UltraViolet
EUVI	SECCHI Extreme UltraViolet Imager
FY	Fiscal Year
GONG	Global Oscillation Network Group
GSE	Ground support equipment
GSFC	Goddard Space Flight Center
HCS	Heliospheric current sheet
HEA	Heliophysics Educator Ambassador
HET	IMPACT High Energy Telescope
HI	SECCHI Heliospheric Imager
HPS	Heliospheric plasma sheet
IBEX	Interstellar Boundary Explorer
IAS	Institut d'Astrophysique Spatiale (France)
ICME	Interplanetary coronal mass ejection
IDL	Interactive Data Language™
IMPACT	In-situ Measurements of Particles and CME Transients Investigation
ISTP	International Solar Terrestrial Physics program
JPL	Jet Propulsion Laboratory
kbps	Kilobits per second

L1	First Lagrangian Point
LASCO	SOHO Large Angle and Spectrometric Coronagraph
LET	IMPACT Low Energy Telescope
LMSAL	Lockheed Martin Solar and Astrophysics Laboratory
MAG	IMPACT Magnetometer
MASERS	MAth, Science, and Engineering Resource Support
MAVEN	Mars Atmosphere and Volatile EvolutioN
Max/MSP	Max Signal Processing
MFI	WIND Magnetic Field Investigation
MHD	Magnetohydrodynamics
MO&DA	Mission Operations and Data Analysis
MOC	Mission Operations Center
MPS	Max Planck Institut für Sonnensystemforschung (Germany)
MSDC	McAuliffe Shepard Discovery Center
NAIF	Navigation and Ancillary Information Facility
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
NRL	Naval Research Laboratory
PI	Principal Investigator
PLASTIC	PLAsma and SupraThermal Ion Composition Investigation
RAL	Rutherford Appleton Laboratory
RF	Radio frequency
RHESSI	Reuven Ramaty High Energy Solar Spectroscopic Imager
SDAC	Solar Data Analysis Center
SDO	Solar Dynamics Observatory
SDS	STEREO Data Server
SECCHI	Sun Earth Connection Coronal and Heliospheric Investigation
SEP	Solar Energetic Particle
SEPT	IMPACT Solar Electron Proton Telescope
SIT	IMPACT Suprathermal Ion Telescope
SOHO	Solar and Heliospheric Observatory
SOS	Science on a Sphere
SPASE	Space Physics Archive Search and Extract
SPDF	NASA Space Physics Data Facility
SPICE	Spacecraft, Planet, Instrument, C-Matrix, Events
SPLAT	STEREO PLASTIC Analysis Tool
SSC	STEREO Science Center
ST	Small transiente
STA	STEREO-Ahead
STB	STEREO-Behind
STE	IMPACT Suprathermal Electron Telescope
STEM	Science, Technology, Engineering, and Mathematics
STEREO	Solar TErrestrial RElations Observatory
S/WAVES	STEREO Waves Investigation
SWEA	IMPACT Solar Wind Electron Analyzer
UC	University of California
UNH	University of New Hampshire

VHO	Virtual Heliospheric Observatory
VSO	Virtual Solar Observatory
VSPO	Virtual Space Physics Observatory (now the Heliophysics Data Portal)
WIST	Women in Science and Technology
WSA	Wang-Sheeley-Arge

STEREO instrument and instrument subsystem names are in blue.