B. Science Goals of the IMPACT Investigation

STEREO's primary goal is the reconstruction of 3-dimensional physical pictures of coronal mass ejections (CMEs) headed toward the Earth, including the invisible particles and fields that affect Earth's space weather. The IMPACT investigation contributes the solar wind electron, interplanetary magnetic field, and solar energetic particle (SEP) measurements and models toward this goal. IMPACT measurements are also essential to other major STEREO objectives, especially for connecting the 3D corona and solar wind structure, advancing knowledge of the physics underlying SEP acceleration and propagation, unraveling the complex origins of geoeffective structures in interplanetary space, and further probing the relationship between CMEs and the solar magnetic cycle.

The IMPACT investigation instrumentation includes:

- Solar Wind and suprathermal electron detectors (SWEA, the solar wind plasma electron analyzer, and STE, the suprathermal electron telescope) to measure ~0-100 keV electrons with broad angular coverage (The plasma ions and composition are covered by the UNH-led PLASTIC investigation.)
- A Magnetometer (MAG) to measure the vector magnetic field in two ranges up to 65,536 nT and 500 nT
- A Solar Energetic Particle package (including SIT, a suprathermal ion telescope, SEPT, a solar electron and proton telescope, LET, a low energy telescope, and HET, a high energy telescope) to measure electrons from 0.02-6 MeV, protons from 0.02-100 MeV, Helium ions from .03-100 MeV/nucleon and heavier ions from .03-40 MeV/nucleon
- A common IDPU that interfaces with the UNH-PLASTIC solar wind ion composition investigation and the Paris Observatory SWAVES investigation

Changes from the originally proposed IMPACT investigation include the following:

- Selection of UNH-PLASTIC investigation replacing IMPACT's proposed plasma ion analyzer
- Inclusion of UNH-PLASTIC among the IMPACT IDPU clients, with IMPACT IDPU providing PLASTIC data processing functions and its spacecraft interface
- Addition of an IMPACT IDPU data transfer link to SWAVES through the spacecraft interface
- Physical separation of the out-of-ecliptic (N-S) telescope of the SEPT instrument from the SEP package box for FOV reasons
- Loss of the Waseda University (Japan) contributions to IMPACT SEP LET and HET, resulting in a proposed substitution by Caltech and GSFC team members to cover the science goals of IMPACT SEP
- Delegation by the Project of the IMPACT Boom/mast system to UCB

Figure B.1 illustrates the scope of IMPACT. The IMPACT plasma electron and energetic particle instruments, in combination with the magnetometer, give STEREO users access to bulk parameters of the

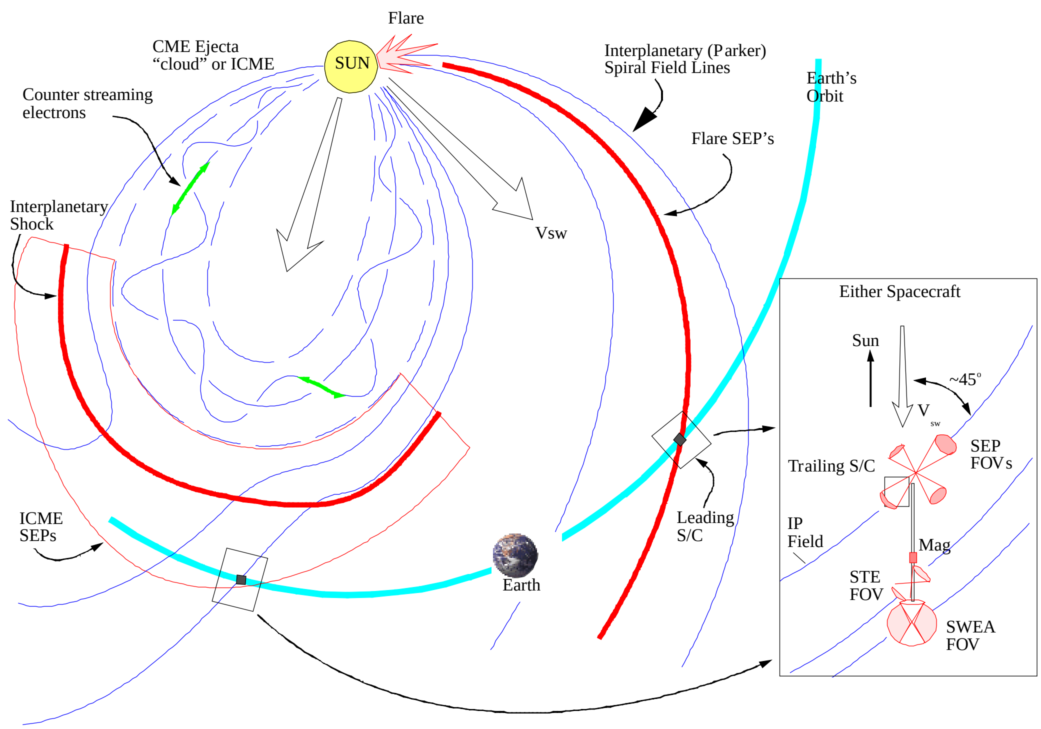

Fig. B.1 The measurement and science domain of the STEREO IMPACT investigation. IMPACT detects solar wind plasma electrons, including the heat flux electrons that can be used to trace magnetic field connections to the Sun, the local magnetic fields, and energetic ions and electrons generated at the Sun in flares and at CME-generated interplanetary shocks.

solar wind electrons, and the flux and energy distribution of energetic particles from solar wind energies up to many MeV, including elemental abundance. Figure B.2 summarizes IMPACT's coverage of the interplanetary particle population, that together with the UNH-PLASTIC investigation satisfies the STEREO in-situ measurement requirements.

The IMPACT instruments give the strength and orientation of the magnetic field at two different locations at 1 AU, and tell the user whether the local fields are rooted at the Sun at one or both ends or disconnected based on heat flux (several 100 eV) electron anisotropies. IMPACT Suprathermal electron and ion detectors add the capability to determine whether the local magnetic connections to the Sun include flaring active regions. The IMPACT SEP instruments provide directional information for remote sensing the CME-initiated shock location and shape, and for determining SEP maximum fluxes in cases where there is considerable anisotropy not in the direction of the nominal Parker Spiral magnetic field. They also give the SEP ion composition necessary for interpreting the SEP sources and acceleration processes. Partnerships between IMPACT and the UNH-PLASTIC solar wind ion composition investigation complete the STEREO solar wind measurement set, while connections to the Paris Observatory SWAVES investigation create opportunities for in-situ plasma microphysics diagnostics by combined use of the SWAVES antennas and IMPACT instruments. Integration with The SECCHI investigation images occurs on the ground through coordinated data displays and collaborative science analyses.

The changing geometry of the two spacecraft configuration determines the method or approach to be used during the mission. Identical measurements of the same interplanetary transient (the ICME) at the two locations flanking the Earth test ideas about the size and configuration of the structures that cause magnetic storms and SEP events. Measurements on one spacecraft of transients resulting from CMEs observed by the SECCHI imagers on the other spacecraft, when the two are well-separated (by >45 degrees), tell us how a particular structure observed near the Sun relates to the plasma and field disturbance in the interplanetary medium at 1 AU. The IMPACT SEP measurements, in their remote-sensing role, tell us about an ICME's location and strength even when the disturbance itself is not detected at a spacecraft's location. Available L1 (e.g. ACE, Triana) and other inner heliosphere in-situ measurements (e.g. by MESSENGER, NOZOMI) obtained at the same time can add more constraints to our 3D interpretations of the in-situ observations with STEREO IMPACT, as do solar images from L1 and Earth-orbiting spacecraft (e.g. Solar-B, LWS-SDO, GOES-M/SXI), and ground-based solar optical and radio observatories.

As part of the STEREO Space Weather Beacon, IMPACT supplies the plasma electron, magnetic field, and SEP key parameters currently available from the ACE RTSW system, with corresponding plasma ion quantities calculated in the IMPACT IDPU as part of the arrangement between IMPACT and UNH-PLASTIC. ACE real time solar wind plasma and magnetic field data are currently being used to drive space weather models that forecast the radiation environment, ionospheric dynamics, and general geomagnetic activity levels ~30-45 min ahead (see http://www.srl.caltech.edu/ACE/ASC/related_sites.html). As the STEREO Beacon data will come from the two spacecraft flanking the Earth at increasing distances, their potential applications may differ from those using

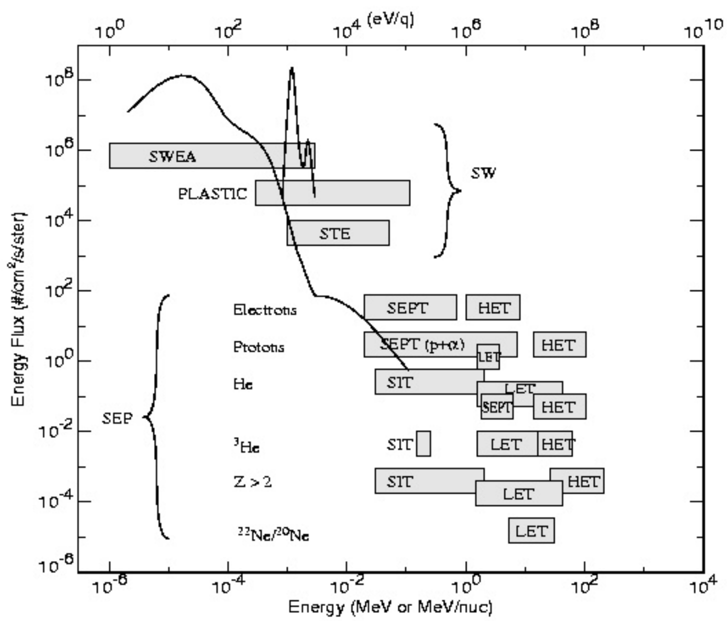

Fig. B.2 The energy and flux coverage of the STEREO IMPACT particle detectors and the UNH-PLASTIC instrument.

the L1 data alone. For example, corotating structures observed at the trailing spacecraft days in advance could ultimately produce geomagnetic disturbances at Earth, giving forecasts well ahead of the L1 point's <1 hr lead time. The availability of these in-situ data together with the SECCHI images will provide a new resource for forecasters whose challenge is to make these data sets work together to greatest advantage. In this respect, STEREO makes an important contribution toward NASA's Living With a Star initiative goals.

The success of IMPACT in its role on STEREO depends on the observation of a sufficient number of events that are either detected on both spacecraft, allowing structural diagnosis, or when the spacecraft are near quadrature (~90 degrees apart), allowing detailed comparisons between coronagraph images and in-situ measurements. The planned solar minimum period of the STEREO prime mission is advantageous for minimizing the ambiguity in identifying solar cause and interplanetary effect, but also reduces the number of events that will be detected in-situ. Figure B.3 makes the point that only one or two modelable flux ropes per month were observed on the WIND spacecraft during a similar period between cycles 22 and 23. Continuous operation will be necessary to collect several events that are well-sampled and simple enough in structure to constrain interpretations and reach the STEREO primary goal.

The success of both IMPACT and STEREO also depends on the planned IMPACT modeling activity that makes physical and geometrical connections between the SECCHI images and in-situ measurements which correlative data analysis by itself cannot provide. This activity integrates state-of-the-art realistic models of the global corona, solar wind, and SEPs: the SAIC 3D MHD corona model, a NOAA-SEC/U of Michigan 3D MHD adaptive grid solar wind and ICME transport model, and a GSFC SEP transport model that uses the MHD model results. The team members involved will work closely with the experimenters to put together 3D physically based Sun-to-1 AU pictures of the Sun-Earth connection. Overlapping membership between the IMPACT and SECCHI coronal modeling enables the treatment of the STEREO problem in its entirety. While our cost profile does not allow a significant pre-launch modeling effort for the IMPACT investigation, it is no less important toward achieving the IMPACT and STEREO science goals.

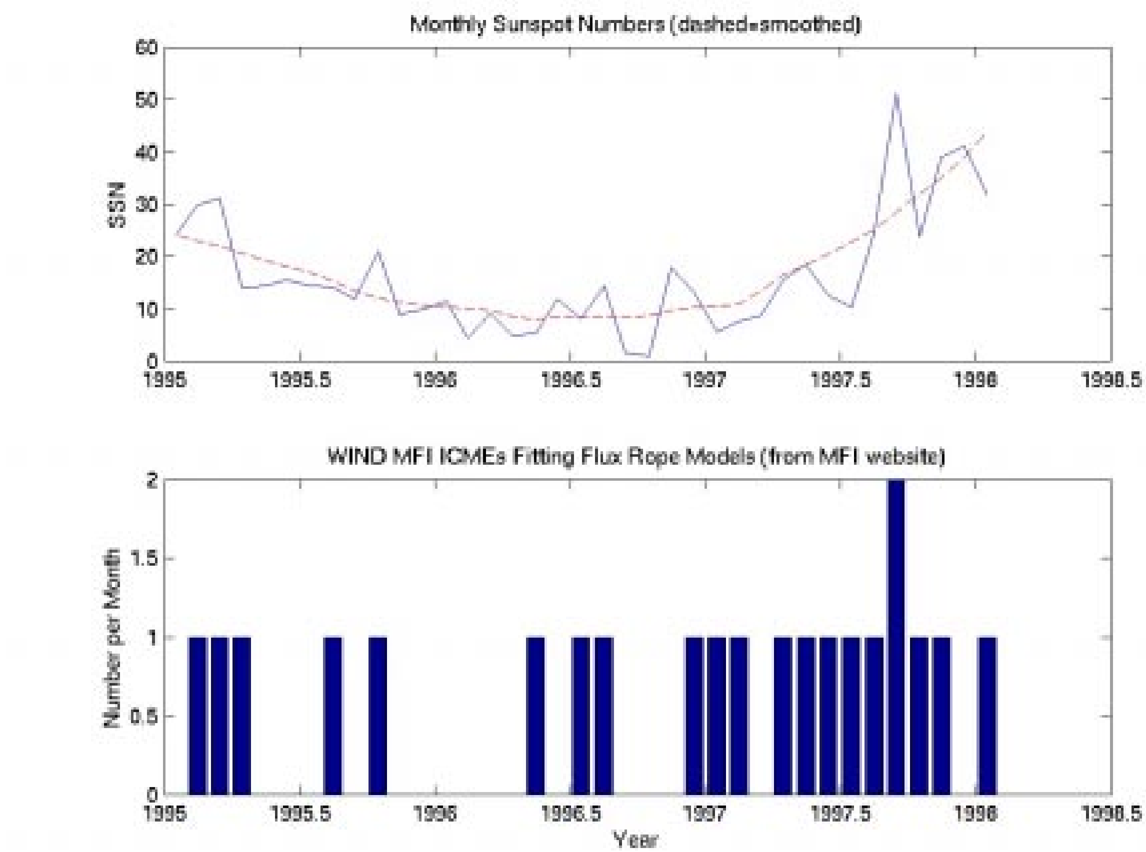

Fig. B.3 Occurrence of ICMEs observed with the WIND MFI magnetometer that can be fit at least moderately well with flux rope models (quality index <3 cases from the WIND MFI website http://lepmfi.gsfc.nasa.gov/mfi/windmfi.html). The top plot shows the sunspot number during this period, which corresponds to the same solar activity phase as the STEREO prime mission.

B.1 Reconstructing 3D Pictures of CMEs

B.1.a Solar Connections

Years of CME observations with coronagraphs on Skylab, Helios, Solwind, SMM and now SOHO-LASCO, as well as ground-based coronagraphs, have yielded no generally accepted paradigm for CME generation. Nonetheless, this substantial observational background provides the starting point for STEREO. Key solar imaging results include the observed association of CMEs with the coronal helmet streamer belt (Hundhausen, 1993), their solar cycle dependence (Webb and Howard, 1994), their frequent 3-part (core, cavity, loop) structure on the limb and association with filament or prominence activations or disruptions (Webb, 1998), their apparent temporal and spatial coincidence with soft x-ray sigmoidal structures and post-eruption arcades (Canfield et al., 1999), and SOHO-EIT waves in the EUV (Thompson et al., 1998). Another important observation from coronagraphs is the distribution of apparent CME speeds, which peaks at velocities well below the average solar wind velocity, but extends up to over 1000 km/s (Hundhausen et al., 1994).

ICME signatures add further constraints to this picture. As illustrated by Figure B.4, the magnetic flux rope models with which some ejecta can be fit have leading edge field orientations consistent with the prevailing helmet streamer belt field orientation, and inferred axes roughly parallel to the source surface neutral line (Mulligan et al., 1998). The handedness of the flux rope field rotation can sometimes be predicted from the apparent photospheric field geometry around an associated erupting filament, or the hemisphere in which it occurs (Bothmer and Schwenn, 1998; Kumar and Rust, 1996). Bidirectional or counterstreaming suprathermal electron anisotropies within the ICME ejecta imply at least partial connection of ICME fields to the Sun at both ends (see Figure B.1) - a picture consistent with the expanding loop structures in coronagraph images. But ICMEs may also contain unidirectionally streaming electrons and heat flux dropouts, suggesting an origin complicated by reconnection and disconnection of coronal fields (Gosling et al., 1995). The observation that they often do not even fit the flux rope model leaves open the question of whether the flux rope is sometimes not intercepted, or in fact does not describe the structure. Energetic particle flux anisotropies indicate at least occasional involvement of active regions either near the solar-connected footpoints of the ICME field lines or in the surrounding corona (Kahler and Reames, 1991; Larson et al., 1997). Finally, major, high-speed ICMEs tend to be preceded by both flares and CMEs (Feynman and Hundhausen, 1994), perhaps a reflection of the solar conditions that give rise to those events.

Other provocative findings come from groundbased observations and models. In particular, certain flux emergence patterns in the photosphere have been linked to filament disappearances, and by inference, to CMEs (Feynman and Martin, 1995). The observed solar cycle variability of CME occurrence is reproduced by the rate of increase of open solar flux at the source surface of potential field models based on magnetograms (Luhmann et al, 1998). These results complement what is known from the observations described above, especially in their suggestion that CMEs are linked to the evolution of the large scale coronal magnetic field (Harrison et al., 1990). They also pave the way for STEREO investigations of the influence of active region emergence on CME genesis

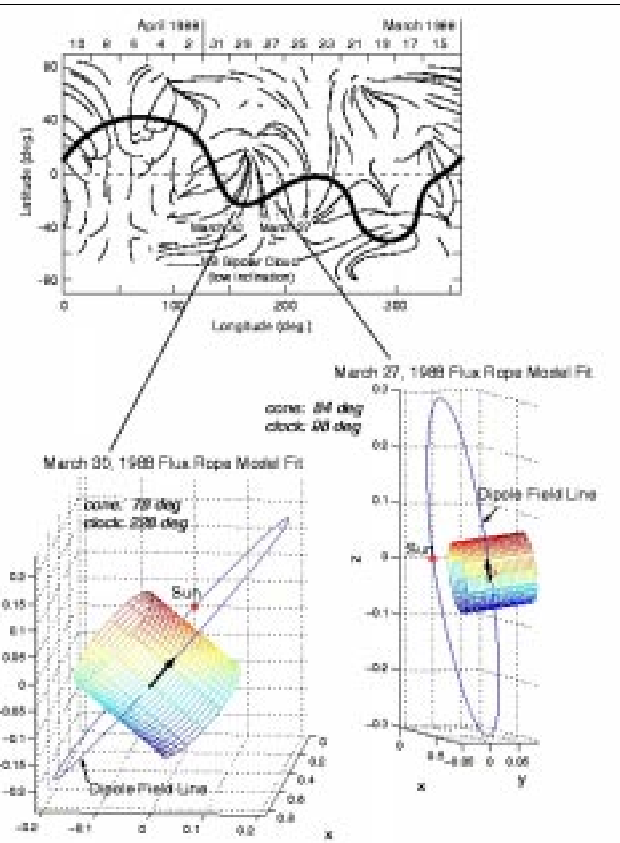

Fig. B.4 The cylinders show inferred ICME flux ropes. They appear to map back to the central disk orientation of the coronal helmet streamer belt on the day they occurred as seen in the field line projections from a potential field model at the top of the figure. (Figure adapted from an original by Tamitha Mulligan, UCLA.)

during the rise of cycle 24. **IMPACT adds to the constraints on CME initiation mechanisms through ICME magnetic topology measurements. The broad energy range of the electron anisotropy measurements allows ICME magnetic connections to the Sun to be inferred, including connections to active regions. The magnetic field measurements allow flux rope or other modeling of the ICME field for comparisons with the electron diagnostics and structures observed in the SECCHI images.**

We are also beyond the point where observations by themselves suffice in the quest for the answer to CME origins. The IMPACT investigation team modelers simulate the formation of large flux-ropes in the corona by changing the large-scale photospheric field underlying a sheared streamer belt structure from one polarity to the opposite polarity, or by shearing coronal arcades at their footpoints (Linker and Mikic, 1995). They model filament eruptions by emerging an opposing bipolar active region on the flanks of an existing bipolar active region, in a scenario that some observations suggest (e.g. Feynman and Martin, 1995) These structures and others from different initiation schemes, will be realistically transported to 1 AU using our interplanetary model codes. **With modeling that ties the solar CME structures to the ICME structures, IMPACT observations will test CME genesis models that predict how ICMEs from various CME generation mechanisms should differ.**

B.1.b Interplanetary consequences

The occasionally available quadrature observations comparing coronagraph images of CMEs and in-situ measurements of ICMEs, and their leading shocks, show that ejecta moving slower than the ambient solar wind are accelerated up to the solar wind speed while ejecta moving faster than the ambient solar wind are decelerated (e.g. Lindsay et al., 1999). This result, illustrated in Figure B.5, is supported by the statistics of coronagraph-derived CME speeds and in-situ measured ICME speeds (Gosling, 1997). The Ulysses high-latitude measurements of ICMEs in high speed polar coronal hole flows confirmed that ICMEs locally adopt at least the ambient solar wind speed, but also highlight the role of expansion in ICME evolution (Gosling and Riley, 1996). Comparisons between observations of the same ICME at high and low heliographic latitude illustrate that expansion sometimes dominates the ICME interaction with the solar wind, while at other times the bulk speed dominates (Gosling et al., 1995). L1 ICMEs typically show aspects of both expansion and compression, depending on their location within the ambient solar wind stream structure. They are often found at either the leading or trailing edge of a stream, consistent with the CME connection with the helmet streamer belt and with the frequent ICME association with the heliospheric current sheet (Crooker et al., 1998).

The interpretation of the in-situ observations of ICMEs including their preceding shocks, solar wind compressions or sheaths, and ejecta drivers, is not straightforward even if a fairly simple magnetic flux rope structure in the ejecta is involved. Figure B.6 shows an example of a well-studied event from the WIND spacecraft including electron and magnetic field measurements similar to those IMPACT will obtain. The problem is that what reaches 1 AU is a combination of what is ejected at the Sun and what happens in transit in the structured solar wind. In the simplest cases this ICME sheath is characterized by suddenly increased plasma speed, density, temperature, and magnetic field strength. The ambient magnetic field within this region of compression is reoriented and drapes about the ejecta. The ejecta slows as a result

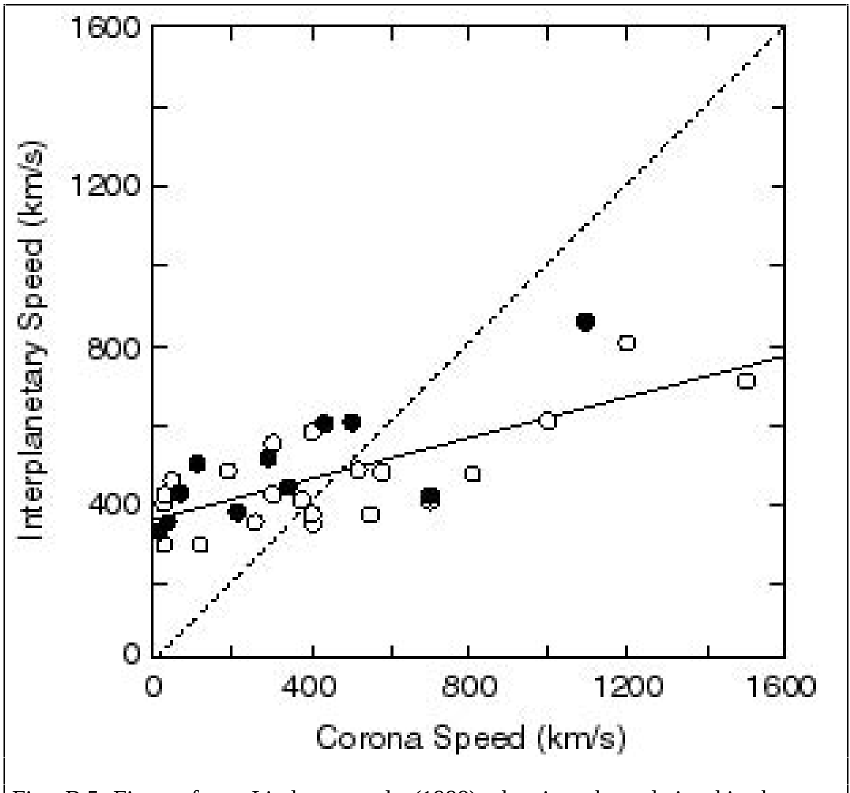

Fig. B.5 Figure from Lindsay et al. (1999) showing the relationship between coronagraph-derived CME speed and ICME speed measured at 0.7 or 1.0 AU. This figure was constructed from the fortuitous quadrature configurations available from the combination of SMM or SolWind coronagraphs and the Pioneer Venus Orbiter in-situ observations.

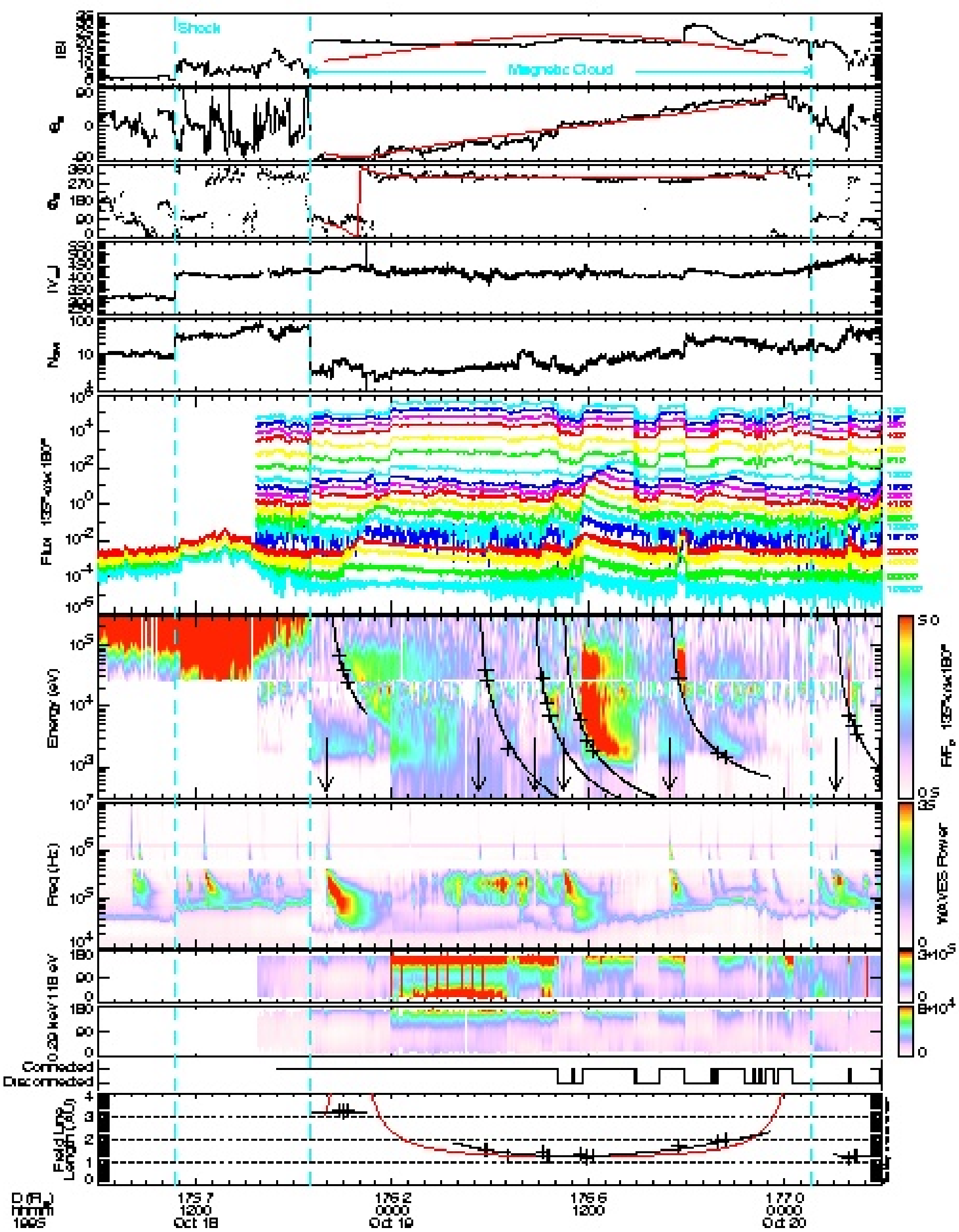

Fig. B.6 Example of the in-situ signatures that occur in IMPACT-like measurements on the WIND spacecraft during passage of an ICME. In this case, the magnetic field (top) could be fit with a flux rope model. The spectrograms of the heat flux electrons (second and third panels from the bottom) show only a period of counterstreaming at one of the energies, although counterstreaming is a widely used signature of ICME ejecta. In this example SWAVES-like radio data were available (fourth panel from bottom), and STE-like suprathermal electron dispersion could be used to infer both connections to active regions and field line length (bottom panel). (From Larson et al., 1997)

of the interaction while the ambient wind accelerates. If the ejecta originally moves faster than the trailing solar wind as well, a rarefaction forms behind the disturbance. In such cases pressure gradients associated with the rarefaction cause both an expansion and a deceleration of the rear portion of the ICME. In some cases counterstreaming heat flux electrons are observed in the sheath or trailing edge, suggesting reconnection between ejecta fields and ambient sheath fields occurs at the Sun or in interplanetary space. Compressions from behind by a trailing high speed solar wind stream are sometimes evident, as are compositional signs that a filament is contributing to the observed densities and pressures. Moreover, because the ambient solar wind is far from homogeneous, particularly at low heliographic latitudes, we know that ICMEs and the shocks they drive must become highly distorted as they propagate outward through the heliosphere (e.g., Riley et al., 1997; Odstrcil and Pizzo, 1999a,b).

It is thus somewhat surprising that about a third of observed ICMEs have magnetic field structures that can locally be fit to simple flux rope models as illustrated in Figure B.6 (also Lepping et al., 1990; Gosling, 1997). We have not been particularly successful in reconciling the apparently simple and complex aspects of ICME changes in transit, including the fate of the seemingly necessary legs attached to the Sun. It is clear that our simplistic cartoons of ICMEs between the Sun and Earth are grossly inadequate, and that sophisticated data-based numerical modeling of CME initiation and transport is required. **The combination of 3D reconstructions of the ejections from SECCHI images, and the multipoint perspective on both the ICMEs and surrounding solar wind structure provided by STEREO IMPACT measurements, will allow us to realistically model the complex interplanetary evolution that occurs in nature.**

A challenge related to the above questions is how best to identify the actual coronal ejecta using in situ observations. A variety of signatures (anomalously low plasma temperatures, counterstreaming suprathermal electrons, magnetic field rotations, unusually low-variance magnetic fields, energetic particle counterstreaming or flux decreases, some of which can be seen in Figure B.6), have proven useful for identifying the ejected material in the solar wind, but that identification remains more of an art than a science (e.g. Gosling, 1990; Neugebauer and Goldstein, 1997). These various signatures often poorly overlap within ejecta, varying from one event to the next or even within a given ICME. For example, The counterstreaming several hundred eV heat flux electrons in Figure B.6 occur sporadically within the time interval when the smoothly varying magnetic field of the flux rope is seen. Recent 2-point magnetometer measurements using NEAR and WIND suggest that the flux rope signature can vary significantly for longitudinal separations as small as 15 degrees (Mulligan et al., 1999). **The two-point measurements provided by STEREO using identical IMPACT instrumentation with increasing separation can reveal the spatial extent of various signatures, including magnetic topology, within ejecta passing over both spacecraft. Combined with UNH-PLASTIC plasma ion measurements, IMPACT measurements will better define ejecta and their boundaries**.

STEREO CME/ICME shock tracking and diagnosis (of radial speed profile, strength, extent, structure) from the Sun to 1 AU depends on IMPACT multipoint STE and SEP measurements and SWAVES radio data. Together, IMPACT and SWAVES allow us to derive more information from this remote-sensing information. In particular, the detection of radio and plasma waves by the SWAVES experiment, accompanied by shock-accelerated electrons measured by IMPACT, indicates connection to the source region of a Type II burst. The directionality and timing of the shock-accelerated electrons serve as a probe of the shock surface. Analysis of WIND observations using this technique suggests the surface of an ICME-driven shock can be highly corrugated, giving rise to multiple radio emission sites (Bale et al., 1999), Anticipated stereoscopic sounding of shocks using IMPACT STE and SEP measurements with SWAVES radio data adds the possibility of obtaining multidimensional information about the shock structures and particle populations corresponding to Type II sources.

Many questions related to CME/ICME evolution in the solar wind are closely connected to the questions of CME origins. For example, while most CMEs appear to expand as they propagate out through the heliosphere, there is not yet a consensus on what drives these expansions (e.g., Osherovich and Burlaga, 1997; Gosling, 1997). Like ion temperatures, the electron temperatures in ICMEs can be extremely cold (Larson et al., 1999), implying something yet to be determined about the ICME expansion and source region. Other issues relate to the role of reconnection in creating various magnetic topologies observed within ICMEs near 1 AU. Does the flux rope topology in some ICMEs arise directly from the solar source (e.g. Low, 1997), or from some coronal reconnection process (e.g., Gosling, 1990)? What role does reconnection play in producing the various mixtures of closed, open, and disconnected magnetic topologies inferred to be present within ICMEs based on suprathermal electron measurements (e.g. Gosling et al., 1995)? A few CMEs and the ICMEs they produce move faster than the highest speed solar wind. What causes this acceleration? Is it a result of direct dynamic interaction with the surrounding solar wind (e.g., Cargill et al., 1996; Gosling and Riley, 1996), or is the acceleration associated with the overall outward coronal pressure gradient? Is the flare or filament association of CMEs incidental or causal? **Questions about ICME evolution opened by earlier observations of CMEs/ICMEs, and left unanswered because of the incompleteness of Sun-to-1 AU observations and models can be addressed with STEREO IMPACT. In particular, IMPACT electron anisotropies characterize the CME source region and provide tracers to solar features observed in STEREO images**.

B.2 The 3D Corona Relationship to Solar Wind Structure

The dichotomous high speed and low speed nature of the solar wind was made especially clear by the Ulysses polar passes (Phillips et al., 1995). While high speed wind connections to large polar coronal holes is relatively well-established (Neugebauer, 1999), the nature of the slow wind remains under debate. The slow solar wind appears to originate from either the cusps of closed field regions making up the coronal streamer belt, or the edges of coronal holes. This origin accounts for its association with the heliospheric current sheet and magnetic sector boundary crossings.

The slow solar wind has a highly variable density and ion composition near Earth (e.g., Gosling, 1997) that may result from spatial inhomogenieties or temporal variability in the outflow from the Sun. The slow solar wind also has different characteristic electron anisotropies than the fast solar wind, including less intense heat flux electron beams (Ogilvie et al., 1999), and sometimes sunward directed anisotropies (Kahler et al., 1998) or heat flux dropouts (McComas et al., 1989). One suggestion is that the slow wind at least in part consists of transient events from magnetic reconnection at the coronal hole boundaries or the cusps of streamers (e.g., Crooker et al., 1996; Wang et al., 1998). The bright blobs observed by SOHO-LASCO emanating from coronal streamers (Sheeley et al., 1997; Wang et al., 1999) may be visible evidence of this process, but they have not yet been identified with specific features detected by in situ experiments. **The twin STEREO spacecraft offer the possibility of relating features seen by the coronagraph on one spacecraft with structure in the slow solar wind detected by IMPACT on the other. IMPACT electron measurements, far from the contaminating influence of Earth's bow shock, provide opportunities for uncontaminated analyses of the slow solar wind magnetic topology.**

During the STEREO mission, a knowledge of the prevailing ambient 3-dimensional coronal and solar wind structure is needed for providing the context of both CME origins in the corona and their propagation in the solar wind. **IMPACT's continuous 2-point measurements of the solar wind plasma and magnetic field, together with the imaging data, will allow the evaluation of coupled corona/solar wind 3D models as a means of inferring global from local behavior**. It is expected that L1 monitors like ACE and Triana will be operating at the time of the STEREO mission, in which case we will have 3 or 4-point measurements to examine for consistency. Moreover, the Mercury-bound MESSENGER spacecraft will be in its cruise phase, and NOZOMI will be orbiting Mars, with the possibility of providing information over an even wider heliolongitude range. Taking advantage of these gives an effective inner heliosphere constellation to help constrain the 3D solar wind structure needed for STEREO science analyses.

B.3 SEP Acceleration and Propagation

The large, gradual SEP events result from acceleration at fast CME-driven shock waves. Peak intensities of energetic particles in these events are strongly correlated with maximum CME speeds (Kahler et al. 1984). Correlating height-time profiles of CMEs with particle intensities at 1 AU, Kahler (1994) showed that acceleration peaks when the shock is at 5-10 solar radii for protons with energies up to ~21 GeV. However, acceleration of ~1 GeV protons and other ions can continue out to 1 AU and beyond in rare large events (Reames 1999). Large SEP events are seen in every year of the 11-year solar cycle, except about one year near solar minimum (Shea & Smart 1999).

Early observation of the longitude distribution of SEP events showed that they were of great spatial

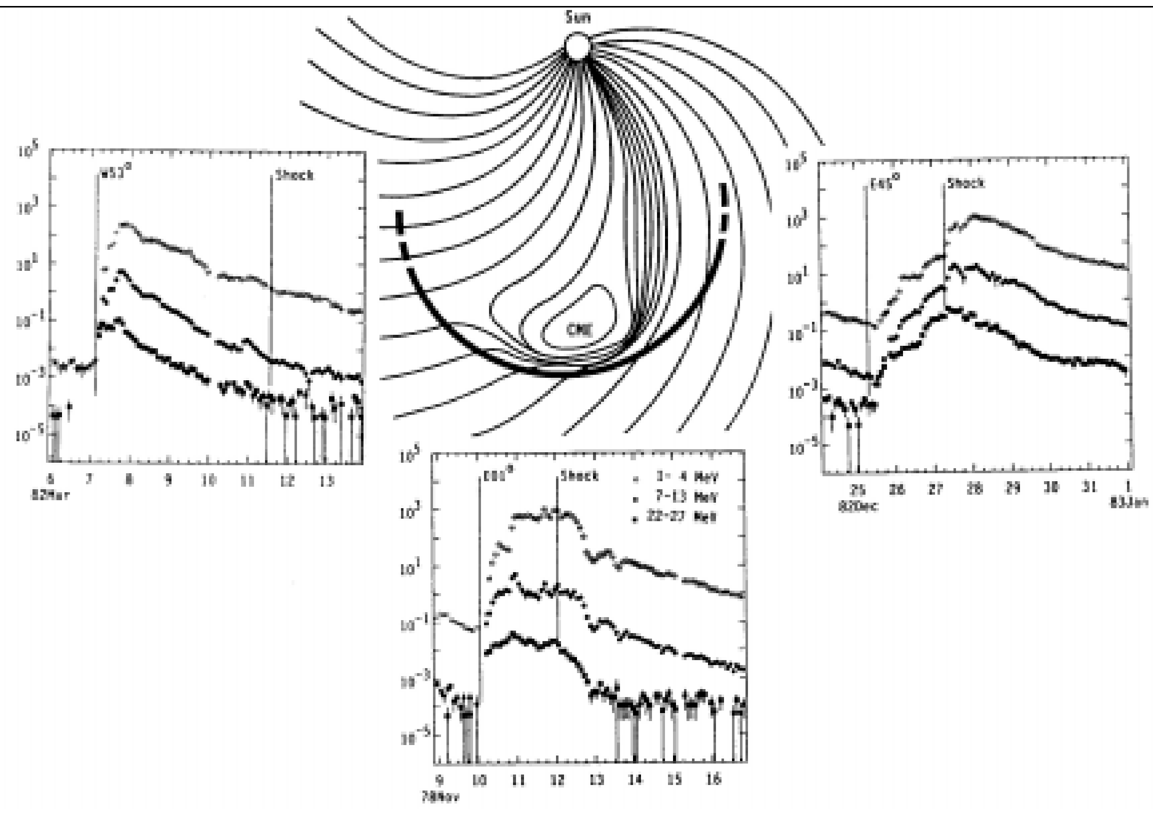

Fig. B.7 Typical intensity-time profiles at 3 longitudes around a CME (Reames 1999) extent, evidently spanning over 180 degrees in some cases (Cane, Reames, and von Rosenvinge 1988). Intensity-time profiles of the particles change markedly with longitude as shown in Figure B.7. Subsequent multi-spacecraft observations, using IMP-8 and the two Helios spacecraft, suggest that both shock speeds and particle intensities peak near the nose of the shock and decline on the flanks (Reames, Barbier, and Ng 1996). Intensity-time profiles at 3 longitudes are shown in Figure B.8 for a spatially-small gradual event, along with energy spectra at early and late times during the event. Because of the generally spiral nature of the interplanetary magnetic field, an observer's connection point to a shock swings eastward with time across the face of the shock through an angle of ~50-60 degrees. The observer remotely senses the particle acceleration at this connection point. **With IMPACT on the two STEREO spacecraft, the leading spacecraft encounters the same magnetic flux tubes that were sampled earlier by the trailing spacecraft. Simultaneous modeling of the CME and of the particle transport allows separation of the spatial dependence caused by the shock and interplanetary field geometry from true time dependence of the acceleration at a point on an expanding, weakening shock.**

Accelerated particles often become trapped in effective magnetic bottles consisting of old ICME

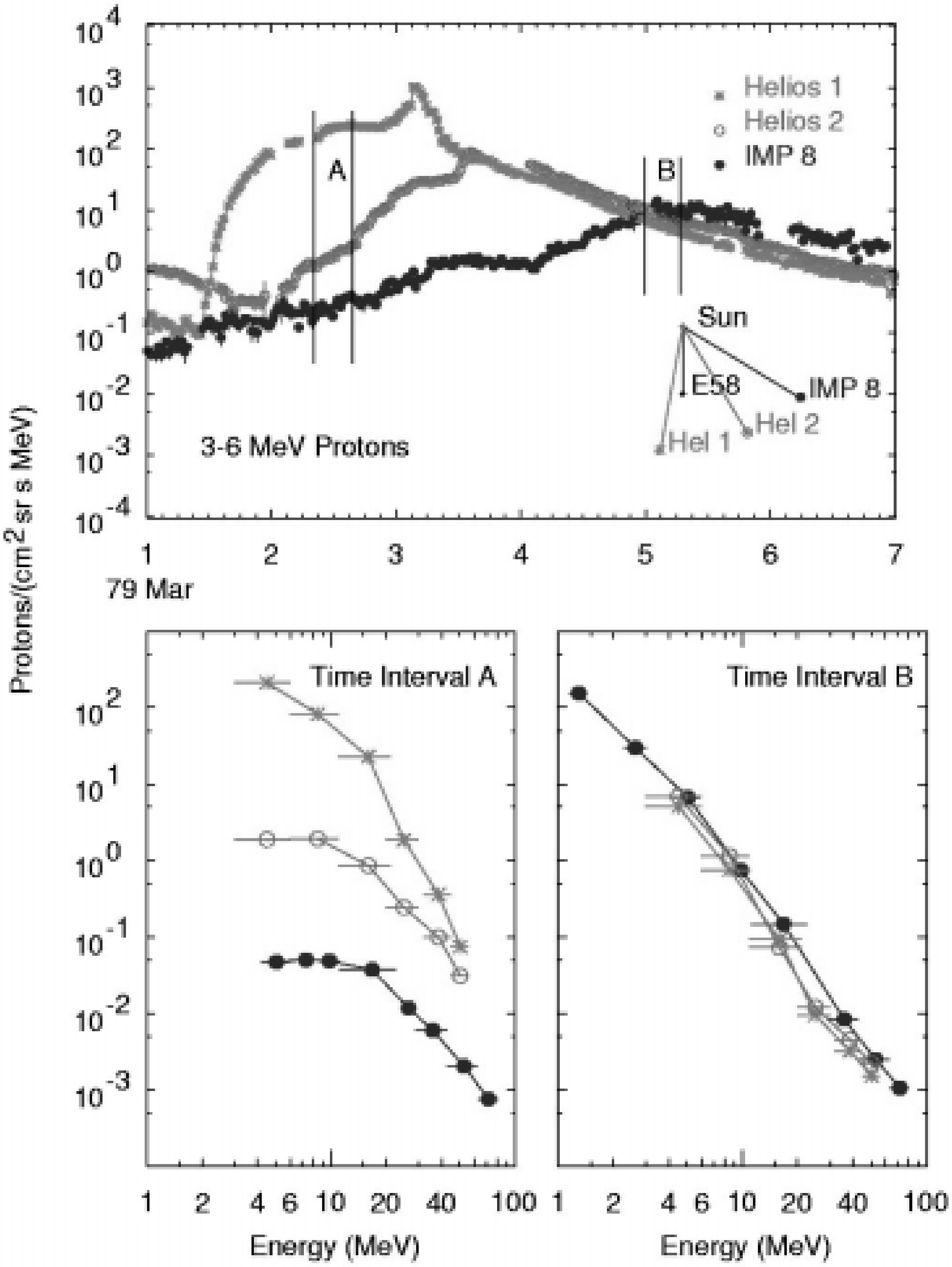

Fig. B.8 Multi-spacecraft observations of a small SEP event from longitudes shown on the inset. Energy spectra at the 3 locations are shown at times A and B. (Reames, Kahler, and Ng 1997).

loops or regions behind shocks. Here we observe particle spectra of the same intensity and shape over large spatial regions as seen in the right-hand spectral plot in Figure SEP-1. Reames, Kahler, and Ng (1997) show that this invariant-spectral region can extend up to 160 degrees in longitude in some cases. There is recent evidence that these trapped particles can form a seed population that is injected into the shock preceding a second fast CME near the sun. These second and following SEP events in a series have statistically higher intensities and thus are of interest for space weather forecasting.

However, our primary tool for understanding the acceleration physics in recent years has been the abundances of elements in SEPs and their variation in space and time along the shock. Adequate abundance measurements were not available on Helios. As protons stream away from the shock they generate Alfven waves that trap the particles that come behind, causing efficient acceleration to higher energies (Lee 1983). The spectrum of these self-generated waves is related to the proton spectrum and varies with space and time, throttling the flow of SEP ions away from the shock. Ions of the same velocity, but with different charge-to-mass ratios, Q/M, resonate with waves of different wave number, k. Thus, the relative abundances of different ions that leak away from the shock probe the shape of the wave spectrum. Systematic variations in abundance patterns, for events with different source longitudes, were first reported by Breneman and Stone (1985). Their results are shown in Figure B.9. Events at western longitudes tend to be Fe-rich since peak intensities occur early for ions that have leaked away from the shock, while central and eastern events are relatively Fe-poor, since they peak later, and hence contain larger contributions of particles trapped near or behind the shock.

More recently, it has been possible to measure the time dependence of these abundance variations (Tylka, Reames, & Ng 1999; Reames, Ng, & Tylka 2000), and we are beginning to develop time-dependent theoretical models of the acceleration and transport of SEPs (Ng, Reames, & Tylka 1999) that explain these variations. A comparison of observed and simulated abundance variations during the 1998 April 20 event is shown in Figure B.10. Figure B.11 compares the abundance variations of Fe/O and He/H in a small SEP event with those in a large event. The initial abundance variations depend strongly on the (unseen) spectrum and intensity of high-energy protons back at the shock, which is still near the sun. With IMPACT, we are trying to learn the quantitative relationship between shock parameters, proton spectra, and abundance variations. **With the knowledge gained, we will be able to invert the process and use SEP abundance observations to remotely sense the properties of an oncoming shock and forecast its subsequent behavior. STEREO IMPACT, with its SEP composition measurements, provides the first opportunity to study abundances**

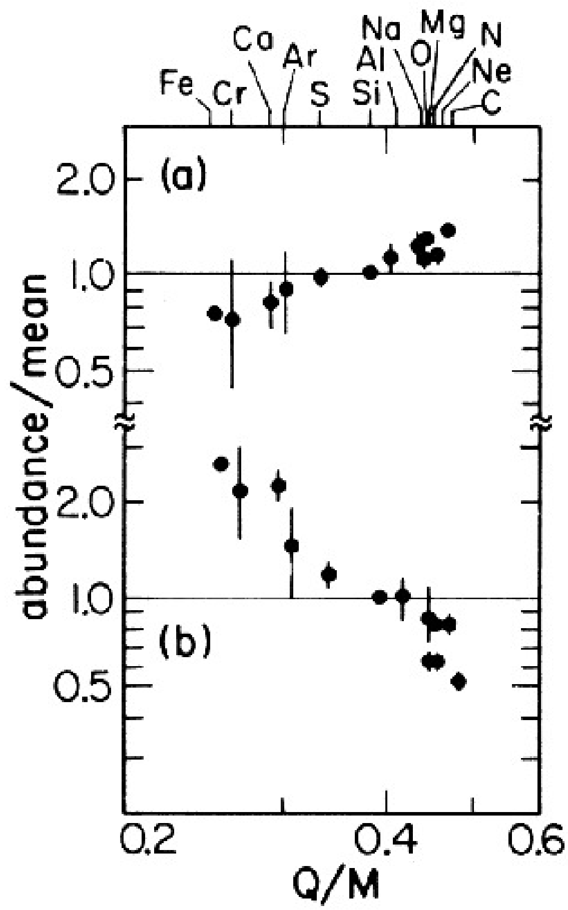

Fig. B.9 Averaged relative abundance enhancements vs. Q/M are shown contrasted for 13 elements in 2 different SEP events (Breneman & Stone 1985)

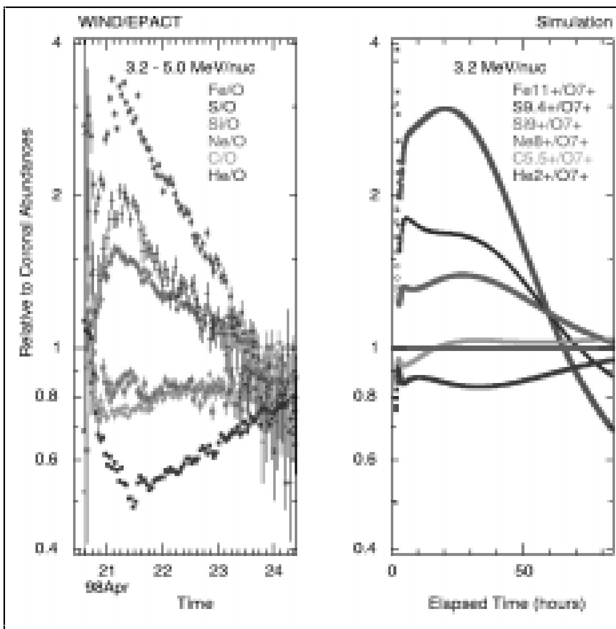

Fig. B.10 Correlated time variations observed during an SEP event (Tylka, Reames, & Ng 1999) are compared with theoretical simulations (Ng, Reames, & Tylka 1999).

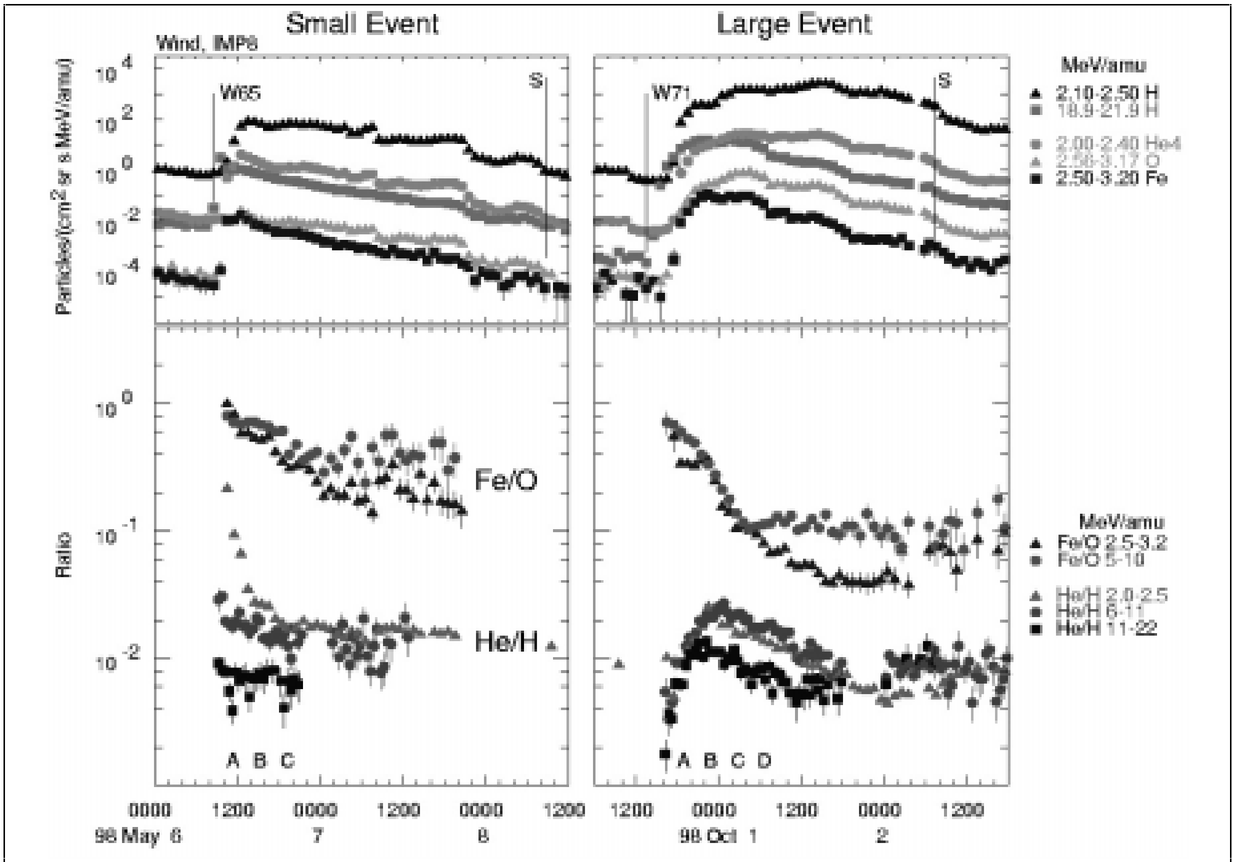

Fig. B.11. Initial behavior of abundance ratios, especially He/H, is modified by waves induced by high-energy protons streaming from the shock in SEP large events (Reames, Ng, and Tylka 2000).

on spatially separated spacecraft, allowing us to examine the spatial distribution of the wave spectrum along the surface of a remote shock and its evolution with time. We can measure the SEPs while simultaneously mapping the optical CME stereoscopically. Large separations of the spacecraft (20-180 degrees) are best for measurement of the extensive spatial structure of the gradual SEP events.

The shape of the high-energy proton spectrum in SEP events not only affects the initial He/H ratios, it is also important in determining the radiation hazard to astronauts on missions outside the Earth's magnetosphere. Proton energies above ~30 MeV begin to penetrate space suits and above ~150 MeV they penetrate substantial thicknesses of shielding. At some energy, protons begin to leak from the shock, and the spectrum steepens to form a spectral "knee". In some events the energy of this knee can be at 15 MeV, in others it is at 1 GeV. Understanding the relationship between the knee energy and the properties of the CME-driven shock, observed directly and revealed by abundance variations, is essential for determining the probability of rare, large SEP events that can occur during long-duration missions on the moon or Mars. **STEREO IMPACT will explore aspects of the physics of particle acceleration that are essential for the design of spacecraft and operational strategies for the mitigation of this severe hazard to human exploration in space**.

B.3.a SEP Acceleration in Solar Flares

Although most SEP events arise from the CME shock source, detection of the impulsive SEPs from flares yields other unique information. Electron acceleration is prevalent in flares. Electrons above 20 keV produce hard X-ray bursts when they are scattered into the footpoints of flaring loops and interact with the solar atmosphere. Those that stream outward on open field lines produce type III radio bursts. Current theory suggests that electron beams produce waves between the gyrofrequencies of H and 4He that are resonantly absorbed by the rare isotope 3He so as to enhance 3He/4He by factors of ~1000 in the flare-accelerated ions (Roth and Temerin 1997). Ten- fold enhancements are also produced in heavy elements such as Fe. **IMPACT investigation collects correlated SEP composition and coordinated SWAVES radio burst measurements, allowing in-depth analysis of flare acceleration process signatures for contrast with ICME acceleration signatures**. Recent work using energetic electron events and Type III radio bursts from WIND shows that there is often a large temporal offset between a flare, a Type III burst, and the associated SEP event (Krucker et al., 1999). In some cases this corresponds to the travel time of a coronal Moreton wave from the flare site to an interplanetary magnetic field line on the western limb. This suggests that these ions may be shock-accelerated while the electrons come from the impulsive flare. **With**

IMPACT and SWAVES investigations on the two spatially- separated STEREO spacecraft, SEP electrons and Type III radio bursts can be compared at two points. Mapping the onset times back to the Sun, we can remotely probe the structure of the injection site.

Energetic particles streaming out from a flare can also map the topology of magnetic field lines (Kahler and Reames, 1991; Bothmer et al., 1996), complementing solar-wind heat-flux electron observations, which often complicate interpretations with different signatures (Lin and Kahler, 1992). The detection of newly injected particles from solar events tells us that the field lines inside an ICME have not become detached from their source region at the Sun (Kahler and Reames 1991). Other SEP signatures show that some ICMEs exclude surrounding energetic particles instead of containing them (Mazur et al., 1998), probably depending on the order of events at the Sun as well as their spatial juxtaposition. Since heavy-ion enhancements are a strong signature of impulsive solar flares, these ions provide characteristic tracers from a known spatial origin. By plotting ion energy as a function of time for the elements C-Fe, as shown in Figure B.12, the velocity dispersion in the ion arrival times may be seen. Some events in this "swoosh plot" appear to be suddenly terminated because the magnetic connection to the event has been terminated before the low-energy ions have had time to propagate to 1 AU. **SEP populations in general are spatially related to the 3D structure of both the ICME and shock that STEREO IMPACT with SWAVES together define**. Measurement of the small-scale filamentary structure of the magnetic fields within an ICME is most effective for small separation of the STEREO spacecraft (<10 degrees).

B.4 The solar origins of geoeffectiveness

Magnetic indices based on ground magnetic perturbations, levels of ionospheric disturbance, magnetospheric relativistic electron and other radiation belt enhancements, and auroral activity are just a few of the commonly used measures of the geoeffectiveness of interplanetary conditions. The parameters from solar wind monitors most widely associated with disturbed conditions include one or more of high bulk speed, high density (or dynamic pressure), and large magnetic field, particularly in the southward component in GSM coordinates. While solar wind stream interaction regions contain enhanced values of the geoeffective parameters, the largest and longest-lived enhancements are from ICMEs (Lindsay et al., 1995) or combinations of stream interaction regions and ICMEs (Tsurutani et al., 1992). In particular, fast ICMEs preceded by interplanetary shocks produce the major geomagnetic storms (Gosling et al., 1990) because of their typically high density, sudden-onset sheath intervals, and large, steady southward field intervals in their ejecta, all of which are sometimes made more geoeffective by accompanying high bulk speeds. Thus the primary questions raised above about the physics behind the CME speed, and its solar wind stream structure context, are highly relevant to the geoeffectiveness issue.

The physics of geoeffectiveness is basically understood from the viewpoint of the solar wind-magnetosphere interaction (Kivelson and Russell, 1995), but it is not clear how geoeffective structures relate to the transients seen at the Sun. For example, sometimes an apparent halo event in LASCO images, thought to portend an Earth-bound ICME, is not followed by an L1 event. An ICME may change its speed and character as it propagates to Earth, as described above, rendering it less locally geoeffective than inferred from coronagraph images, or it may miss the Earth's heliolongitude altogether. Geoeffectiveness thus depends on the heliolongitude dependence of ICME properties**. IMPACT measurements of solar wind parameters, combined with UNH-PLASTIC and L1 measurements, provide 2 and 3-point information on the geoeffective extent of specific events observed by the imagers on STEREO**. For example, proxy calculations of geomagnetic indices such as Dst (Lindsay et al., 1999) and Kp (Detman and Joselyn, 1999) based on solar wind parameters for each

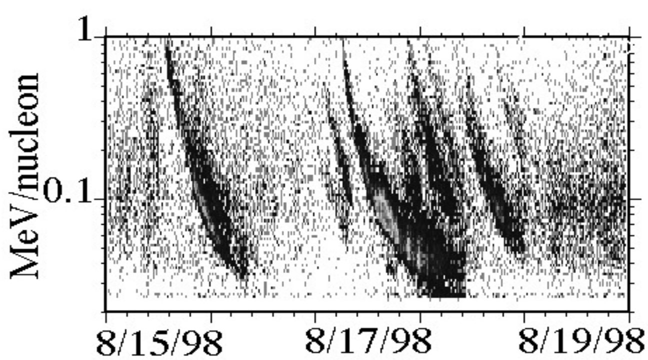

Fig. B.12. The pattern of particle energy vs. time of arrival from a flare can be suddenly truncated by a change in magnetic flux tubes (Mason, Mazur and Dwyer, 1999).

spacecraft can give a measure of the potential geoeffectiveness along a significant segment of Earth's orbit. **In combination with UNH-PLASTIC measurements, IMPACT multipoint solar wind and interplanetary field measurements and models of specific events will improve the observational and physical basis for relating geoeffectiveness to solar observations.**

L1 and other upstream monitors do not always give a good indication of the solar wind control of the magnetosphere because they are generally not on the stagnation streamline that reaches the magnetopause. Multispacecraft studies upstream of the bow shock suggest that the coherence length of solar wind structures is sometimes smaller than the separation of the monitors (Richardson et al., 1998), and studies of the orientations of the structures show that they do not always move in planar fronts perpendicular to the Earth-Sun line. Structures strongly influenced by the solar wind stream structure tend to align themselves along the Parker Spiral direction (Richardson and Paularena, 1998), while high speed transients with large internal pressures give the impression of perpendicular incidence (Lindsay et al., 1994). Numerical simulations of the magnetosphere-solar wind interaction in the meantime show that the angle of incidence of interplanetary structures affects the magnetosphere's response, while the simulations of ICME propagation in a structured solar wind show how complicated the structures can become in the course of their interplanetary evolution (as discussed above). **IMPACT observations in the STEREO configuration with an ever-widening baseline between spacecraft provide a controlled experiment for measurements of coherence scale lengths of solar wind structures, including ICMEs and solar wind stream features**. They also form the basis for determining the curvature of shocks and the changes in the appearance of ICMEs over the varying baseline, allowing reassessment of needs for positioning solar wind monitors and future interplanetary constellation spacecraft. **IMPACT models of the 3D solar wind and transient structures, used to drive 3D MHD magnetosphere models, will also provide insight into the Earth's response to realistic interplanetary structures**.

B.5 The solar magnetic cycle

The photospheric magnetic field is dominated by the cycle of emergence and decay of active regions that somehow participate in the periodic reversals of the global solar field. During the course of this dynamo-driven cycle, the amount of flux threading the photosphere changes by a factor of ~5 in the present epoch (e.g. Schrijver and Harvey, 1994). Eclipse and coronagraph observations and coronal models based on photospheric field observations show the corona responding, but it has been difficult to determine how the interplanetary field is involved (McComas et al., 1992, McComas, 1995). Both the loop-like appearance of CMEs and the measurements of counterstreaming electrons in ICMEs suggest that new solar flux opens into interplanetary space during transients, but on the average, newly opening solar flux must be counterbalanced by newly closing flux as the solar field does not become increasingly open with time. Yet interplanetary signatures of closing flux have been elusive. If flux tubes are completely disconnected from the Sun, electron heat flux dropouts would be expected, but these do not appear to be present in equal numbers with counterstreaming electron intervals, or are masked by some other process. Those dropouts that have been detected appear to be concentrated in the vicinity of the heliospheric neutral sheet in the slow solar wind (McComas et al., 1989)

IMPACT reopens the question of solar flux balance by providing sensitive measurements of suprathermal electron angular distributions over broad angle and energy ranges, together with interplanetary field measurements, at two low-heliolatitude sites removed from Earth's influence. IMPACT improves on previous measurements because it allows observations far from the Earth's bow shock where contamination by reflection and scattering is a problem, and unlike Ulysses, makes several years of continuous measurements at low heliolatitudes where both transients and slow solar wind are generally found around solar minimum (Gosling et al., 1995). The design of the IMPACT electron detectors, coupled with the time resolution with which the anisotropy measurements are made, provides the best opportunity to date to search for the signatures of the closing down of interplanetary field connections to the Sun, to evaluate the balance between opening and closing flux in ICME transients, and to determine whether the slow solar wind (and by inference, the coronal streamer belt) is an important participant in the flux balance problem. Coordination with the SWAVES experiment allows assessment of the effects of scattering at the locations of possible heat flux dropouts. **The dual-site measurement and imaging that STEREO affords make it possible to compare the levels of counterstreaming versus other suprathermal electron anisotropies to prevailing conditions on the Sun and in the corona**.

The solar dynamo also transforms poloidal field to toroidal field between polar field reversals. Eruption of the active region fields must eventually lead to a loss or relaxation of the toroidal fields, with CMEs playing a part in this process (e.g. Rust, 1994). Above it was pointed out that the magnetic structures of those ICMEs that can be described as flux ropes are related to the global solar magnetic polarity, with their leading edge fields corresponding to the orientation of the prevailing helmet streamer belt field (Bothmer and Rust, 1997; Mulligan et al., 1998). However, the handedness or twists of these structures is not clearly related to the magnetic cycle. In contrast, the magnetic fields observed around active region and polar crown filaments, whose eruptions often accompany CMEs, appear to have a definite organization of handedness. Right-handed fields seem to prevail in the southern hemisphere, while left-handed fields prevail in the north (Bothmer and Schwenn, 1994). The relationship between the magnetic field of the filament and its surroundings, and the magnetic field that is observed in an ICME, remains an open question. Some regard the filament and its local overlying fields as the source of the ICME flux ropes, while others consider the former is a small part of a much larger erupting coronal structure that supplies most of the interplanetary flux rope**. IMPACT measurements, coupled with UNH-PLASTIC measurements of the plasma ion composition, can be used to distinguish the magnetic fields in the filamentary material from those of other parts of the ICME structure, and examine their relationship.**

Additional insights into the solar magnetic cycle come from comparing the characteristics of both ICMEs and solar wind structure for different cycles given the behavior of the photospheric field. Fairly continuous interplanetary data sets from L1 exist from ISEE-3 (1978-1987), WIND (1996-1998) and ACE (1998-present) missions. Although the STEREO mission will have a lifetime limited by resources and telemetry capability, it will observe the 2004 minimum and can observe the rise to the cycle 24 maximum for comparison with the rise to cycle 21 maximum seen on ISEE-3 and the rise to cycle 23 maximum seen on WIND and ACE. The observed evolution of active regions, well-documented in ongoing solar observatory archives, can be compared with the activity observed over the life of the STEREO mission and to the number and nature of the ICMEs detected by IMPACT. While this study could also be carried out with an L1 monitor, the availablility of the STEREO multipoint view provides the basis for a clearer interpretation in terms of quantities such as the flux content of ICMEs that could then be used in retrospective studies of the earlier data. **IMPACT measurements of the ICMEs during the ascending phase of solar cycle 24 allow comparisons of their properties with those observed on ISEE-3, WIND and ACE during earlier cycle ascents. These will extend the records of information on features such as flux rope occurrence, polarity, orientation and handedness, providing an improved basis for comparisons with solar dynamo models and their coronal counterparts.**

B.6 Complementary Science Objectives

Space Plasma Microphysics. Even after many years of work, uncertainty remains regarding the physics of thermalization of solar wind electrons at collisionless shocks. As the electrons encounter the shock, they are thought to move adiabatically through the layer, leaving an unaccessible region of phase space downstream. It has recently been shown that this form of the downstream distribution function is unstable to the two-stream instability (Gedalin, 1999). Furthermore, intense nonlinear electrostatic waves and phase space holes have been observed near the overshoot of collisionless shocks (Bale et al., 1998), a possible signature of nonlinear evolution in a two-stream instability (Goldman et al., 1999). **As a shock passes over each STEREO spacecraft, IMPACT and SWAVES operating together in a burst mode can capture detailed distribution functions and plasma wave waveforms, allowing us to systematically study the evolution of both the waves and electrons in the shock.**

The radio emission observed during an IP Type II or III radio burst is generated at 1 f_{pe} and/or 2 f_{pe} by a process known as plasma emission. The microphysics of the plasma emission process is currently undergoing a paradigm shift due to WIND observations of elliptically polarized plasma waves at 1 f_{pe} in the source of these bursts, where longitudinally polarized Langmuir waves were expected (Bale et al., 1998; Kellogg et al., 1999). This observation implies strong scattering and WKB breakdown, or possibly wave trapping. The SWAVES experiment on STEREO will measure all 3 electric and one magnetic component of these waves, for the first time. IMPACT provides essential detailed information on the electron beams driving this process. Other recent observations indicate that we can actually probe the Type II source in-situ(Bale et al., 1999). The radio emission comes from near quasi-perpendicular connections to the ICME-driven shock, while the shock-accelerated electrons show the shock surface is highly structured, giving rise to multiple emission sites. **Together, SWAVES and IMPACT further resolve the Type II source nature, allowing us to better infer shock structure from remote particle and radio measurements.**

CIRs. From WIND experience, we know that CIRs are the source of much of the interplanetary energetic particle population during periods of low solar activity (Reames et al., 1999), but they nevertheless give us valuable information about SEP shock acceleration processes. CIRs are formed when high-speed solar-wind streams overtake low-speed solar wind emitted earlier in a solar rotation. A pair of shock waves forms at these regions, the forward shock propagating outward into the slow wind and a reverse shock propagating backward into the high-speed stream. The shocks generally form beyond 1 AU, with the strongest acceleration occurring at the reverse shock (e.g. McDonald et al. 1975). Recent observations on the WIND spacecraft show new abundance features in CIR energetic particles, with C/O abundances that depend upon stream speed (e.g. Mason et al 1997); evidence of cross-field particle transport in intense events (Dwyer et al. 1997), and spatial distributions of 1-10 MeV/amu particles extending over 226 degrees in solar longitude (Reames et al. 1997). **STEREO**

IMPACT provides a unique opportunity for multi-point composition measurements of the CIR-associated ions as these enormous 3D structures rotate about the Sun.

ACRs. ACRs are believed to be produced when interstellar pickup ions are carried out by the solar wind and accelerated at the heliospheric termination shock (Fisk et al., 1974). Subsequently they make their way back into the inner heliosphere against the flow of the solar wind. Because pickup ions are selectively accelerated by the termination shock primarily due to their high injection speeds, ACRs provide information on the role of the injection process in determining the maximum particle intensities of SEPs from CME/ICME-driven shocks. **IMPACT provides sensitive coverage of the low-energy (1-10 MeV/amu) ACR ions at a time in the solar cycle when their spectrum is least modified by interplanetary structures, giving a truer picture of their source spectrum at two heliospheric locations.**

B.7 Space Weather Applications

IMPACT team members are experienced in supplying data to the ACE RTSW system, an effective prototype for the STEREO beacon system. This experience is invaluable in implementing the IMPACT beacon mode of operation. Our team also includes a member from the NOAA Space Environment Center (SEC) who provides an interface between our investigation and their operation, a likely major user of STEREO beacon data.

IMPACT supplies low rate (~1 min) basic solar wind plasma electron, magnetic field, and SEP information processed on-board to conform to the designated telemetry allocation. Synchronized UNH-PLASTIC plasma ion beacon data are also produced in the IMPACT IDPU. The combined in-situ beacon data include plasma density, magnetic field vector components, and SEP fluxes. The plasma and field information from the trailing spacecraft can be used by forecasters to anticipate the arrival at Earth of corotating structures. The SEP beacon data allow forcasts of the arrival of an interplanetary shock and its ICME driver. In particular, if both leading and trailing spacecraft detect a gradual SEP event, the probability of the shock and ICME impacting Earth's magnetosphere squarely is very high. If an event observed at the trailing spacecraft has a rapid rise-time, it is likely the shock nose is between the two STEREO spacecraft - a situation favoring a geoeffective consequence. Any SEP information from upstream of Earth could be combined with this information to further diagnose the shock nose position with respect to the Sun-Earth line. Impulsive SEP events from flares, unless embedded in an ICME, are likely to be seen at only one STEREO location at a time. However, if an impulsive event is detected at the trailing spacecraft, and the associated active region at the Sun as seen by the SECCHI imagers seems long-lived, corotation projections can warn of potential impulsive events at Earth. This information would be especially useful to International Space Station operators.

UCB has available an 11m dish and tracking system that is used for FAST and IMAGE data downlink. The advantage of this facility is that it is housed at the Space Sciences Laboratory where operating costs are minimal. This system is available for listening to the STEREO Beacon, except that it does not currently have an X-band capability. Such an upgrade might be appropriately supported under NASA's Living With a Star program. Should that go forward, we will make such a proposal.

A forward-looking issue for NASA is concern over radiation safety during interplanetary human spaceflight, in particular to Mars. Reports dealing with the potential hazards (e.g. Turner, 1997) point out the need to monitor solar activity from many viewpoints to ensure adequate warnings of potential large SEP fluxes. Examination of the relative positions of Mars and the STEREO spacecraft over the course of the STEREO mission shows that IMPACT will provide an occasional upstream solar wind monitor for the NOZOMI and Mars Express missions, both of which are due to arrive at Mars in 2004 to study the Mars-solar wind interaction. NOZOMI includes a full complement of in-situ instrumentation, making coordinated studies of Mars space weather possible.

B.8 Relationships to Other Missions and Ground-based Observations

STEREO represents part of NASA's evolutionary sequence of solar/interplanetary missions in the SEC Roadmap that targets the 3D Sun and heliosphere, and space weather's underlying causes. STEREO IMPACT investigation measurements build on the information gained primarily from IMP-8, Helios ½, ISEE-3, PVO, Ulysses, WIND, and ACE, the latter three of which may still be operational when STEREO is launched in 2004. IMP-8 observations led to the first work on the magnetic flux rope models of ICMEs (Lepping et al., 1990 and references therein); ISEE-3 provided long-term detailed in-situ measurements at L1 from which solar cycle variations of ICME occurrence and internal information on ICMEs including electron anisotropies were derived (Gosling, 1997). Helios ½ enabled the first in-situ look at solar wind character and transients into 0.3 AU (Bothmer and Schwenn, 1998), leaving behind measurements that can still be mined for what they tell us about ICME inner heliosphere radial evolution. PVO provided an effective 0.7 AU outpost to measure solar wind behavior at Venus, allowing both evaluation of a closer solar wind monitor for space weather purposes (Lindsay et al, 1999a), and study of coronagraph CME/ICME relationships in a quadrature configuration with SMM and Solwind at Earth (Lindsay et al., 1999). Ulysses first explored the high latitude heliosphere during low solar activity conditions (Gosling et al., 1995) and now continues its measurements during high solar activity conditions, revolutionizing our in-situ view. Ulysses in-situ data and SOHO images were used in efforts to match solar signatures of CMEs with ICMEs (Funsten et al., 1999). However, WIND and SOHO provide what are perhaps the best examples of what can be accomplished with the planned STEREO imaging, SWAVES and IMPACT measurements in combination.

It is not certain what other missions will still be operating, or will be launched, by 2004. ACE has a potential extended operation plan. This plan would neatly marry ACE to STEREO IMPACT as a third point measurement since the ACE and IMPACT teams have significant overlap. Our team also includes members of the Triana solar wind monitor team, another potential extra point measurement. Triana's planned launch is in 2001. If Ulysses continues in its high inclination solar orbit, the IMPACT/SWAVES coordination will have a third-dimension viewpoint for shock remote sensing.

On the complementary imaging side, Yohkoh and SOHO are likely to be retired by 2004, TRACE does not have a projected lifetime long enough for STEREO coordination, and HESSI, planned for launch in 2000, may similarly not be confidently expected to be working contemporaneously with STEREO. However, SMEI may be providing wide-field coronagraph images from an Air Force satellite platform within a few years, and SXI on NOAA's GOES-M, to be launched in 2001, will approximate Yohkoh x-ray images at a 1-minute cadence in a softer, more sensitive x-ray band geared toward coronal studies. Both these imagers complement STEREO imaging, and help IMPACT science by providing a more complete description of the coronal transients preceding the detected ICMEs. Solar-B, with a 2004 launch planned and an active region focus adds a unique coordination capability in that it allows detailed looks at the interaction between localized and global solar/coronal activity. For example, the vector magnetic field measurements obtained with Solar B could be used to assess the importance of nonpotentiality of the involved active region fields in producing certain observed ICME structures. It may also be that the Living With a Star initiative moves forward at a pace such that SOHO is replaced by the Solar Dynamics Observatory (SDO) before the STEREO mission is over. SDO would provide full disk vector magnetograms that would add a key element to the solar connections analyses and IMPACT modeling. The SDO images are also expected to be returned at a higher rate than those from SOHO, showing more detail of the time-dependent solar and coronal features.

Opportunities also exist for possible informal coordinations of inner heliosphere constellations if interplanetary plasma, magnetic field, and SEP observations from several planetary missions are brought together. MESSENGER, like STEREO, is due for launch in 2004, but it is not yet certain whether in-situ particle and field measurements can be obtained during its cruise phase, which lasts until 2009. However, even in Mercury orbit MESSENGER provides another inner heliosphere outpost for space weather measurements. Similarly, the NOZOMI mission arrives at Mars in 2004, where it can observe the local space weather with its particle and field instrumentation. We plan to seek collaborations with the particles and fields investigators on these other missions. NASA OSS approval and support is necessary to enable the taking of cruise data on MESSENGER, and collaborations with NOZOMI investigators.

Significant ground-based instrument improvements will provide supporting information on solar magnetic fields that in some areas are key to STEREO's success. Two particular ground-based tools that deserve highlighting here because of their importance to STEREO-related modeling under IMPACT's investigation are the SOLIS full-disk vector magnetograph installations, and the GONG near-24 hr solar field monitoring network. The imminent SOLIS provision of vector magnetograms is expected to improve the capabilities of the IMPACT models to more accurately describe CME initiation. The GONG magnetograph data provide the best opportunity for steady coverage and high cadence magnetograms. KPNO, MWO and WSO magnetograms, MLSO coronagraph images, H-alpha and other measurements from NSO, ISOON and other active solar optical and radio observatories will contribute further information toward interpreting what is deduced from STEREO imaging and IMPACT together. Many of these facilities are supported by the NSF and DoD, who thus leverage STEREO science investments.

Examples of the necessity of ground-based data in the IMPACT investigation data analysis and modeling can be found at several sites on the WWW. In particular, photospheric magnetic field data, not available from the STEREO instrument set, are critical for connecting the solar and coronal observations to the in-situ observations. Photospheric field maps of the type needed for our 3D models are already in use at NOAA-SEC to make predictions of solar wind stream structure based on the Wang/Sheeley (Wang and Sheeley, 1990) approach (available at http://solar.sec.noaa.gov/~narge/), and at UCB where we keep track of newly opening coronal magnetic fields on an automated Web site (http://sprg.ssl.berkeley.edu/mf_evol). While the more physically rigorous STEREO IMPACT models, verified by the in-situ and SECCHI measurements, will improve upon these schemes by incorporating MHD effects and time-dependence, they cannot be exploited without magnetograph observations.

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