WIND
2008 Senior Review Proposal

Adam Szabo
NASA GSFC
Project Scientist/Presenter

Michael R. Collier
NASA GSFC
Deputy Project Scientist

EXECUTIVE SUMMARY

The *Wind* spacecraft was launched in November, 1994 to the Earth's L1 Lagrange point as the interplanetary component of the Global Geospace Science Program within the International Solar Terrestrial Physics (ISTP) program. The spin stabilized spacecraft, with its spin axis pointing ecliptic north, carries eight instrument suites that provide comprehensive measurement of particles from solar wind thermal populations to the solar energetic component, and of fields from DC magnetic to radio waves and γ-rays. All of the instrument suites continue to provide valuable scientific observations largely available to the public, with the exception of one of the γ-ray instruments (TGRS).

The comprehensive *Wind* instrument complement, that measures the solar wind with multiple redundant instruments, provides an accurately calibrated and reliable set of measurements unsurpassed by any other mission. Moreover, *Wind* is the only near-Earth spacecraft equipped with radio waves instrumentation. Thus, together with its robust solar wind observations, *Wind* is an ideal 3rd vantage point for the STEREO mission. As the two STEREO spacecraft continue to increase their longitudinal separation from Earth, *Wind* – located half way between them – will enable 3-point solar wind structure and radio triangulation studies (see Figure 1). *Wind*, together with SOHO, will also serve as a backup to one of the STEREO spacecraft.

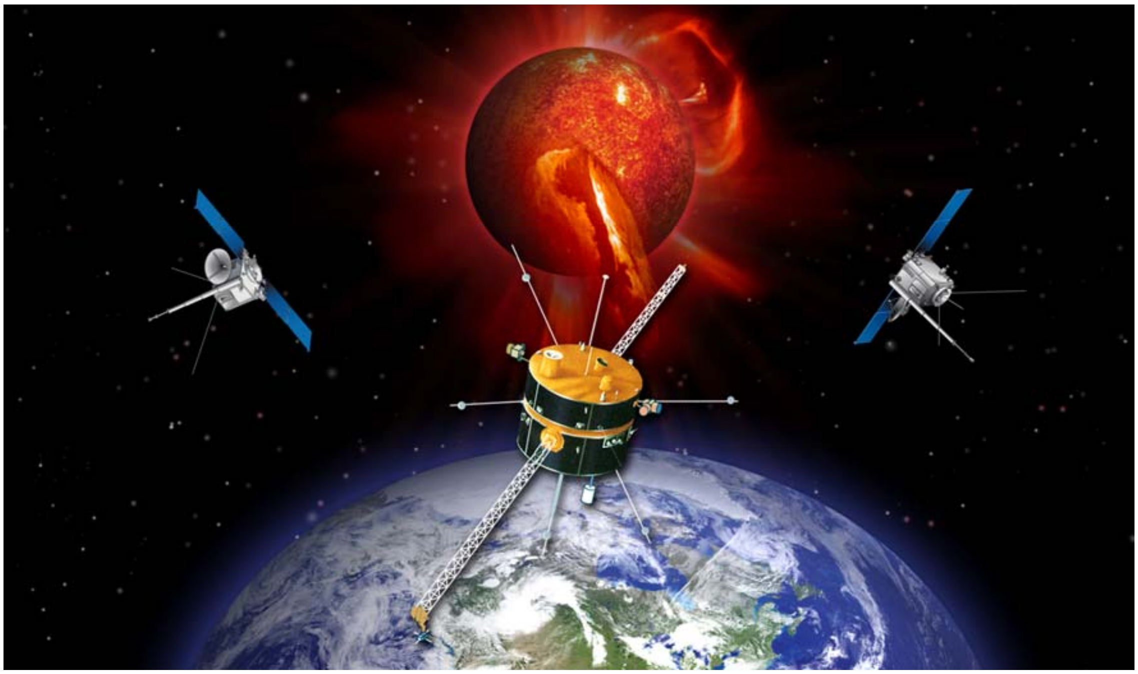

Figure 1. *Wind* will provide a 3rd point of solar wind observations enhancing the science return of the STEREO mission as well as continuing to monitor the solar wind input for geospace studies. [artwork by *J. Rumburg*]

Wind provides the community with a unique dataset with high time resolution and accuracy and from an important vantage point at L1. *Wind* data has been critical to a wide range of studies ranging from solar-heliosphere and heliosphere-magnetosphere connection along with fundamental space research resulting in over 200 publications since the last Senior Review (only 2 years ago), listed on the new *Wind* project Web page. The new results span all three heliophysics research objectives as described in the *Science Plan for NASA's Science Mission Directorate 2007-2016* and include the discovery of extremely long and stable solar wind reconnection X-lines, new compositional signatures of solar energetic particle acceleration and the heightened geomagnetic impact of interacting interplanetary coronal mass ejections (ICMEs).

Though some of the new results stem from *Wind* observations alone, most capitalize on multi-spacecraft measurements that treat all the heliophysics assets as a single great observatory. In fact, *Wind* team members have been leading the development of the new, distributed heliophysics data environment, including the Virtual Heliophysics Observatory (VHO) that connects the elements of the Heliophysics Great Observatory into a single system.

Even though *Wind* is now more than 13 years old, the mission promises a host of new discoveries besides those expected from STEREO collaborations. For example, the time period covered by this proposal includes the rise to the next solar maximum. Because of its longevity, *Wind* observations will allow researchers to compare solar wind activity between solar cycle 23 and 24 without needing to compensate for changing instrumentation and calibration. With its ample fuel reserves, *Wind* will also continue to provide accurate solar wind input for magnetospheric studies (supporting THEMIS and RBSP) and serve as the 1 AU reference point for both inner heliospheric (MESSENGER, *Solar Orbiter*, *Sentinels* and *Solar Probe*) and outer heliospheric (*Voyager*) investigations. Finally, *Wind* will continue to critically support other NASA missions, such as RHESSI, ACE, LRO and SWIFT.

Rationale for Continuing the *Wind* Mission

- *Wind* continues to provide unique and robust solar wind measurements
- *Wind* is a 3rd solar wind vantage point for STEREO providing a backup capability and enhanced science return for 3-point studies.
- *Wind* and ACE together provide a reasonable probability of maintaining near-Earth solar wind monitoring capabilities for NASA into the next decade.
- *Wind* and ACE are complementary not identical. Thus both are needed to continue to provide complete near-Earth, 1 AU baseline observations for current and future NASA deep space missions.
- *Wind's* scientific productivity remains high and its observations continue to lead to significant scientific discoveries for all three research objectives of NASA's SMD.

The *Wind* science data products are publicly served directly from the instrument team sites. To aid the science user community, a single project web page has been developed with links to and descriptions of the large number of *Wind* data products. In addition, *Wind* is an active participant in the development of the VHO that will make data queries even more user friendly. Finally, under an optimal budget scenario, we propose to develop a modest *Wind* Science Center as an augmentation of the STEREO IMPACT Data Center at the University of California, Berkeley. This will further simplify using STEREO and *Wind* data together.

Wind Project Web page: http://wind.nasa.gov

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1. INTRODUCTION

1.1 Historical Background

The *Wind* spacecraft was launched in November, 1994 as the interplanetary component of the Global Geospace Science (GGS) Program within ISTP. *Wind*'s original purpose was (1) to make accurate in situ measurements of interplanetary conditions upstream of the magnetosphere to complement measurements made in the magnetosphere by *Polar* and *Geotail* and (2) to remotely sense interplanetary disturbances for possible future predictive purposes. The instruments were therefore designed to make highly accurate solar wind measurements.

After a number of years at the L1 Lagrange point, *Wind* performed a series of orbital maneuvers to take it to various scientifically valuable observational points. In 1999, *Wind* executed a number of magnetospheric petal orbits that took it to the rarely sampled geomagnetic high latitudes. Between 2000 and 2002, *Wind* moved further and further away from the Sun-earth line (and ACE) reaching 350 R_E to the side in a distant prograde orbit. Finally, in 2003, it completed an L2 campaign taking the spacecraft more than 250 R_E downstream of Earth and ~500 R_E downstream of ACE to investigate solar wind evolution and magnetotail phenomena. Since 2004, *Wind* has remained at L1 where it will stay for the foreseeable future.

1.2 Current Status

The *Wind* spacecraft continues to operate in very good health. In 2000, the team successfully reconfigured the communications system to enhance the telemetry margin. Reliance on a single digital tape recorder since 1997 has never hampered operations, and the team took measures to minimize its use in order to extend tape recorder life as long as possible.

Seven of the eight *Wind* instruments, and all of the particles and fields instruments, remain largely or fully operational. Specifically, the EPACT, high energy particle and SMS solar wind composition instruments suffered some degradation, but both continue to provide valuable measurements. The SWE electron instrument required some reconfiguration to maintain its capabilities and the TGRS γ-ray detector, well beyond its design life, has been turned off. For technical details see Section 4.2. All the other instrument capabilities are nominal. Thus, the net loss in capability remains minimal and the *Wind* instruments continue to provide definitive and continuous measurements of the solar wind.

Wind never had a dedicated science center. However, under an optimal budget scenario, we propose to develop one as an augmentation to the Berkeley STEREO IMPACT science center. As described in later sections, the *Wind* solar wind and radio waves measurements will provide a third point for STEREO research. To further enable such 3-point studies, we would present relevant *Wind* data products in fully compliant STEREO data format.

The joint *Wind-Polar-Geotail* mission operation center resides at Goddard. However, with the imminent retirement of the *Polar* spacecraft, maintaining this legacy system will no longer remain cost effective. Design work is already in progress to combine *Wind*, ACE and SOHO mission operations into a single center. Further details of this development effort are provided in the technical section of this proposal.

In conclusion, *Wind* is operationally healthy and continues to maintain a large fuel reserve, capable of sustaining the spacecraft at L1 for more than another decade.

1.3 *Wind* Unique Capabilities

Wind's complement of instruments was optimized for studies of solar wind plasma, interplanetary magnetic field, radio and plasma waves, and low energetic particles. It is by no means equivalent to that on ACE. Rather, the two missions, by design, are very complementary. ACE - launched a few years after *Wind* - focuses on the detailed investigation of high energy particles for which *Wind* has limited capabilities. Therefore, several of the *Wind* solar wind, suprathermal particle, and especially radio and plasma wave instruments are unique. The *Wind* instrument capabilities are summarized in Table 1 and compared to ACE and STEREO. *For solar wind, low energy particle and radio waves observations, Wind is the only near-Earth spacecraft that can match those provided by STEREO*. A more detailed discussion of the unique *Wind* capabilities follows in the next paragraphs.

Collaborating with STEREO, *Wind*/WAVES provides an essential third vantage point along the Sun-Earth line, allowing the unambiguous localization of inner heliospheric radio sources and the determination of their corresponding beam patterns as described in the science results section below. Moreover, the WAVES frequency coverage extends to the thermal noise regime, where it provides an independent measurement of the solar wind electron plasma frequency. This quantity is directly proportional to the square root of the solar wind electron plasma density. Thus the density, normally obtained as a moment or fit of the distribution function from SWE and 3DP, can also be accurately and independently derived from the WAVES instrument and used to refine the calibration of the plasma instruments.

Table 1. The measurement capabilities of *Wind* compared to STEREO and ACE. The table illustrates the complementarity of *Wind* and ACE. While at high energies ACE clearly dominates, for the thermal plasma, low energy particles and radio waves *Wind* is the only near-Earth spacecraft providing measurements that can match those obtained by STEREO.

Measurement	WIND	STEREO	ACE	Comments for Wind
DC Magnetic Field	MFI 1/22 sec	MAG 1/8 sec	MAG 1 sec	Highest time resolution measurements
Radio and Plasma Waves	WAVES 4kHz–14MHz	SWAVES 10kHz-16MHz		Low frequency measurements to obtain electron density
Solar Wind Ions	3DP moments: 3sec distr.: 24sec burst: 3sec SWE Moments:92sec	PLASTIC moments: 1min	SWEPAM moments: 64s	Highest time resolution observations Robust and redundant observations under solar storm conditions
Solar Wind Electrons	3DP – 3 sec SWE – 9 sec	SWEA – 2 sec	SWEPAM 128 sec	High time resolution observations
Solar Wind Composition	SMS/STICS 1≤Z≤56 8-230 keV/Q	PLASTIC	SWICS 1≤Z≤30 0.5-100keV/Q	Unique observations for the >100keV/Q range
Solar Wind Mass Spectrometry	SMS/MASS 2≤Z≤28 0.5-12 keV/Q		SWIMS 2≤Z≤30 0.5-20keV/Q	Comparable to ACE observations
Low Energy Electrons	3DP ~0 – 400 keV	STE ~0 – 100 keV	SWEPAM ~0 – 1.35keV	Unique coverage of electrons up to 400 keV
Low Energy Ions	3DP 3eV-11 MeV	SEP/SEPT 60 keV - 7 MeV	ULEIS 20keV–14MeV	Comparable observations
High Energy Particles	EPACT/LEMP 40 keV-50 MeV/nuc	SEP 30 keV- 100 MeV/nuc	ULES/SIS 20 keV – 167 MeV/nuc	Robust, high geometrical factor directional observations

The *Wind*/3DP instrument detects solar energetic particle events, in particular, impulsive electron events, from ~1 keV (sometimes ~0.1 keV) to ~400 keV. Electrons in this energy range produce most of the flare hard X-rays detected and imaged by RHESSI (>3 keV). *No instrument on any other spacecraft has the high sensitivity required for solar/heliospheric electron measurements from a few to 40 keV.* In addition, the *Wind* electron measurements from 40 keV to ~400 keV are the most sensitive of any instrument currently operating, and only 3DP provides full 3D measurements. This are crucial measurements because solar electrons from ~0.1 to ~100 keV are excellent tracers of the structure and topology of interplanetary magnetic field lines. Finally, the 3DP 3-second high time resolution plasma observations are unequaled by any other spacecraft and are essential for microphysics studies.

With 3DP and SWE, Wind is the only spacecraft capable of measuring full 3D distributions of ions and electrons continuously from thermal plasma to MeV energies. A unique capability of the SWE Faraday Cup is its accuracy and stability even during large solar storm events when other instrument types have difficulty making measurements.

Wind also carries unique solar wind composition instruments. Currently, the STICS sensor on *Wind*/SMS provides the only measurements at 1AU of ion composition up to 200 keV/q.

Because of its great dynamic range, *Wind*'s energetic particle instruments (EPACT) have a proven capability of measuring solar energetic particles (SEPs) during particularly enhanced solar storm conditions without the inherent saturation problems of other instruments. The EPACT Low Energy Matrix Telescopes (LEMTs) cover an energy range for observing elemental abundances of SEPs, which is just between that of ULEIS and SIS (both on ACE). The EPACT/STEP instrument on *Wind*, although it does not have the isotopic resolution of ULEIS, does have comparable sensitivity and fast on-board identification of elements from He to above Fe**.** LEMT has a very large collection power and identifies particle species and incident energy on-board at rates up to tens of thousands of particles per second. This permits the observation of temporal variations in elemental abundances on short time scales. Finally, due to *Wind*'s spin within the ecliptic plane and because of the instruments' large field-of-view, EPACT provides comprehensive SEP ion anisotropy measurements that are unavailable from any other spacecraft.

1.4 *Wind* in the Heliophysics Great Observatory

Wind plays an active role in the Heliophysics Great Observatory (HGO). *Wind* achieved many of its recent scientific discoveries in collaboration with other spacecraft as described in more detail in the Science Accomplishments section below. However, the HGO is more than just the occasional comparison of data from multiple platforms. It is a data environment where such comparisons can be readily performed. As the Heliophysics Data Policy outlines, this data environment requires the presence of in-depth metadata for each data product based on a uniform standard (the SPASE dictionary). It also envisions the eventual connection of the current distributed data repositories by a number of virtual observatories enabling the location and downloading of the desired data. *Wind* plays a leadership role in the deployment of the Virtual Heliospheric Observatory (VHO), the heliospheric portion of this environment, and the generation of the corresponding metadata. Even though the VHO is still under construction, almost all *Wind* instruments already have VHO compliant data services. It is expected that by the delivery date of the first complete VHO (just over a year from now), more *Wind* data with more description will be available through VHO than via traditional means. Moreover, since *Wind* has many well developed software libraries, *Wind* will also lead in the next phase of data environment development: customizable data services.

In order to even more closely integrate *Wind* data products with their STEREO counterparts (under an optimal funding scenario) we propose to recast various key products into the same format used by STEREO. This immediately enables the use of *Wind* data in the currently developed STEREO software environment. Thus *Wind* and STEREO will function as a single unified observatory. The technical section below describes the details of this option.

1.5 *Wind* in the Living With a Star Program

The Living With a Star (LWS) program seeks to better understand the Sun-Earth connected system with the aim of developing reliable space weather forecasting capabilities. The program architecture plan calls for a near-Earth solar wind monitor to connect the solar (SDO) and inner heliospheric (Sentinels, Solar Orbiter and Solar Probe) observations with geomagnetic ones (RBSP). However, NASA has no current plans for a new solar wind monitoring mission, rather NASA assumes that *Wind*, ACE or both will survive into the 2012-2022 time frame. Because both *Wind* and ACE are well past their prime missions and design lifetimes, the lowest risk option to satisfy the near-Earth solar wind monitoring requirement of LWS is to sustain both *Wind* and ACE, either of which can satisfy the LWS measurement requirements. Though we again point out that *Wind* and ACE are not duplicate spacecraft but rather serve complementary roles. Thus, the most prudent course of action involves preserving both spacecraft.

1.6 *Wind* Supporting the NASA Exploration Program

Until actual human flights to the Moon (not likely before 2020) the NASA Exploration program will primarily focus on design and testing of the new flight capabilities. Critical to this effort is the proper characterization of the radiation environment of a cis-lunar orbit. The soon-to-be-launched Lunar Reconnaissance Orbiter (LRO) will provide some of the necessary information. LRO, however, does not have all the necessary instrumentation to carry out this mandate by itself and will have to rely on high energy particle measurements from both ACE and *Wind*. While *Wind* does not have the capability to directly measure the most relevant 10-100 MeV/nuc particles, the EPACT and 3DP instruments will contribute robust measurements of particles just below this critical range and the solar wind instruments will provide context information warning of incoming interplanetary shocks. Thus, *Wind* is needed to carry out a critical task in support of the human exploration program in the 2009-2012 time frame.

2. SCIENCE ACCOMPLISHMENTS AND GOALS

Due to its comprehensive instrumentation and critically important location at Earth's L1 Lagrange point, *Wind* observations continued to result in significant discoveries both in basic research and in applied space weather prediction capabilities during the last three years. During the same time period, *Wind* data was used for the thesis work of three graduate students, and half a dozen undergraduate students and post doctoral fellows relied on it for their research. In this section, we highlight recent discoveries organizing them along the three heliophysics research objective areas. Moreover, we demonstrate that as a result of newly developed theories and models and due to new observational opportunities presented by the recently launched STEREO mission, *Wind* will continue to contribute significantly to new discoveries and understanding of the Sun-heliosphere-magnetosphere connected system. Our detailed science plans for the 2009-2012 time frame are outlined at the end of each science subsection.

2.1 HELIOPHYSICS OBJECTIVE #1: Fundamental Physical Processes

The first research objective of heliophysics, as articulated by the *Science Plan for NASA's Science Mission Directorate 2007-1016* is to understand the fundamental physical processes of the space environment from the Sun to Earth. *Wind* observations were key to making progress in two of the focus areas of this objective: (1) understanding magnetic reconnection; and (2) understanding the plasma processes that accelerate and transport particles.

2.1.1 Understanding magnetic reconnection

Magnetic reconnection, an important mechanism for converting magnetic energy into bulk flow and plasma heating, is now known to occur frequently in the solar wind. *Wind* measurements have played an increasingly important role in studying reconnection as it occurs in the solar wind at least partially because of the unique 3-second time resolution of the 3DP plasma experiment. This allows *Wind* to identify numerous reconnection exhausts that cannot be resolved by plasma experiments on other spacecraft. Present estimates of reconnection X-line extents and reconnection persistence are lower limits constrained by available spacecraft separations. These estimates are important because, along with reconnection rates, they reveal how much magnetic flux is reconnected in an event.

Observations of accelerated plasma flows with near-Alfvenic velocities confined to magnetic field reversal regions (usually in the form of bifurcated current sheets) have provided convincing direct evidence for local magnetic reconnection in the solar wind. Originally identified in ACE 64-second plasma and magnetic field data [*Gosling et al.,* 2005], these so-called reconnection exhausts are embedded within the solar wind flow and are convected past the spacecraft on a variety of time scales. *Wind* measurements have played an increasingly important role in studying these events.

(1) *First detections of oppositely directed reconnection jets in a solar wind current sheet*

Although reconnection produces bi-directional jets emanating from the X-line, reports of the detection of both jets are rare. *Wind*, in conjunction with ACE, STEREO, and Geotail, provided two such exceptional sets of observations. *Davis et al.* [2006] reported the first such occurrence in the solar wind where *Wind* and ACE (separated by 200 R_E or 1.3 million km along the reconnection outflow direction) detected oppositely directed jets. *Gosling et al.* [2007d] reported the other event that relied on observations from five spacecraft (*Wind*, STEREO A-B, ACE, and *Geotail*) underscoring the importance of using the existing heliospheric assets as a single observatory. These observations provide perhaps the most complete evidence for reconnection in the solar wind.

(2) *Evidence for extremely long reconnection X-lines*

Wind, in conjunction with other spacecraft, provided evidence for extremely long reconnection X-lines which reconnection theories had not predicted. Such observations could not be made in the Earth's magnetosphere. *Phan et al.* [2006] reported an X-line extending at least 390 R_E (2.5 million km) detected by *Wind*, ACE and *Cluster*. *Gosling et al.* [2007d] reported an even more spectacular event in which five spacecraft (*Wind*, STEREO A-B, ACE, and *Geotail*) detected an X-line extending more than 4.3 million kilometers (0.0284 AU) even in the presence of a relatively strong and variable guide field (see Figure 2). These observations imply that reconnection is fundamentally a large-scale process, as opposed to being patchy as had been inferred from some observations in the Earth's magnetosphere.

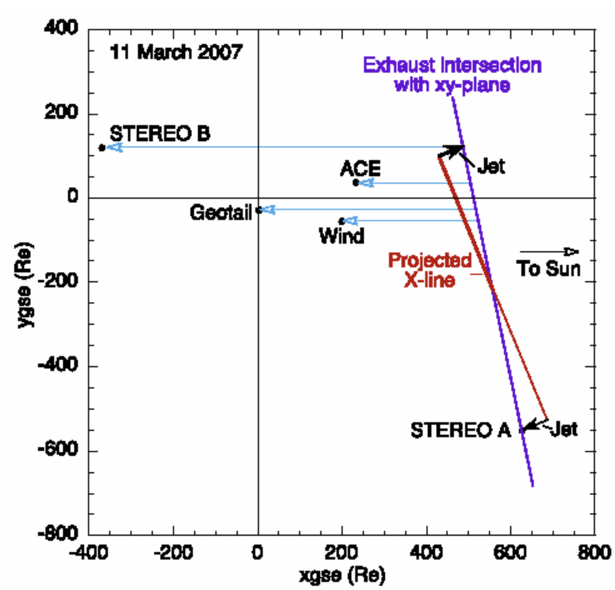

Figure 2. *Wind* as a part of an interplanetary team of spacecraft provides essential measurements on magnetic reconnection in the solar wind. The purple line indicates the intersection of the 11 March 2007 reconnection exhaust with the xy-plane at the time when STEREO-A encountered the exhaust. The red line shows the projection of the reconnection X-line onto the xy-plane at that time. [from *Gosling et al., 2007d*]

(3) *Evidence for quasi-steady reconnection*

Observations by another flotilla of five spacecraft (*Wind*, ACE, SOHO, *Genesis*, and *Geotail*) obtained during a grazing encounter with an exceptionally broad solar wind reconnection exhaust have provided the most direct evidence to date of prolonged (at least 5 hours) and quasi-steady reconnection at a continuous X-line [*Gosling et al.*, 2007a]. *Wind* was immersed (uninterruptedly) within the reconnection exhaust for more than 3 hours. At least 1.2 x 10^{24} ergs, comparable to the energy released in a large geomagnetic storm, were extracted from the current sheet and converted to kinetic and thermal energy of the exhaust plasma in this event. This observation also revealed, surprisingly, that reconnection can operate in a quasi-steady manner even when undriven by the external flow.

(4) *Evidence for component reconnection and in turbulent solar wind*

Initial ACE studies suggested that solar wind reconnection is a relatively rare phenomenon that occurs preferentially in association with ICMEs at relatively large local field shear angles [*Gosling et al.,* 2005]. With the development of improved techniques for recognizing reconnection exhausts in the data and taking advantage of the 3-second measurement capability of the 3DP plasma experiment on *Wind*, this viewpoint has changed remarkably. Recent studies using the *Wind* 3-second data [*Gosling,* 2007; *Gosling et al.,* 2007b; 2007c] reveal that the large majority of reconnection exhausts are too narrow to be resolved by most existing solar wind plasma instrumentation with the exception of 3DP. Although reconnection in the solar wind occurs most frequently at field shear angles < 90˚, *Wind* detected at least one event at a local field shear angle of only 24˚ arguing for component reconnection. With few exceptions, each exhaust in the high-speed wind is directly embedded within a relatively sharp, outward-propagating Alfvenic fluctuation associated with MHD turbulence. This *Wind* observations demonstrate that reconnection is one way in which solar wind turbulence is dissipated, although it is not yet clear how effective reconnection is overall in this regard.

(5) Microphysics of magnetic reconnection

The high time resolution 3DP three-dimensional particle distributions have revealed two, previously theoretically unpredicted, adjacent electron layers during the July 22, 1999 solar wind reconnection event [*Huttunen et al*., 2008]. These electron layers were observed around the reconnection separatrices where the electron flow changed from field-aligned to anti-field-aligned, resulting in a current system that is opposite to the standard Hall current system previously observed closer to the X-line. This current system is a new discovery and indicates that our understanding of the reconnection process is incomplete.

***Future Plans*:**

Opportunities for considerably extending our present estimates of reconnection processes to greater spatial and temporal scales will occur in coming years as the STEREO spacecraft drift ever farther from the Sun-Earth line (where *Wind* resides). The best opportunities for these studies probably will occur during encounters with the heliospheric current sheet and with the leading edges of ICMEs. Because of the high temporal cadence of the 3DP and MFI measurements, the *Wind* observations will play a central role in almost all studies of reconnection as it occurs in the solar wind in the near future.

The time period 2009-2012 includes the rise to the next solar maximum. Most of the solar wind reconnection events reported took place during solar minimum. Thus *Wind* will have an opportunity to investigate the solar cycle dependence of this basic physical process.

As described above, the signatures of reconnection exhausts are hard to detect and previous studies often required multiple refinements of the data calibrations. Therefore, this line of research requires the continued involvement of the instrument PI teams.

2.1.2 Understanding Particle Acceleration

Energetic particle radiation constitutes a potential hazard for both human and robotic exploration. Today it is known that SEPs have multiple sources, some accelerated by flares, others by CME driven shocks or even by turbulent wave activity. However, the exact mechanism of particle acceleration is still the subject of much theory and speculation. Even though the primary location of SEP acceleration is in the innermost heliosphere, *Wind* provided key measurements resulting in significant advances in this area of research by observing local shock acceleration at 1 AU, tracking interplanetary shocks in the inner heliosphere, inferring their characteristics, and directly measuring compositional markers of various mechanisms.

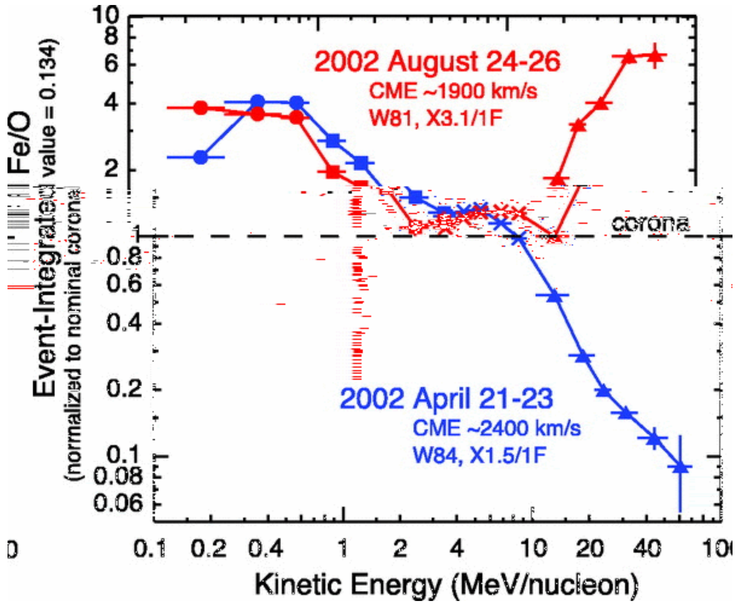

Figure 3. *Wind* provides critical high energy particle data essential for a correct interpretation of ACE data. The compositional spectra for the two events look almost identical for energies below 10 MeV, there is a dramatic difference at higher energies. While most of the data is from ACE, *Wind*/EPACT provided the critical 2-10 MeV energy range illustrating the complementarity of *Wind* and ACE [from *Tylka et al*., 2006].

Variable elemental composition of large gradual events

Large gradual SEP events, even with very similar solar progenitors (such as fast CMEs), are highly variable in their compositional spectral characteristics at the highest energies (> 10s MeV/nuc) [*Tylka, et al.*, 2005; 2006]. Studies have linked differences in the energy dependence of enhancements in Fe/O to the preferential acceleration of impulsive suprathermal ions in quasi-perpendicular shock waves (see Figure 3). Quasi-perpendicular shocks also produce the hard energy spectra of protons seen in many large SEP events [see *Tylka and Lee,* 2006]. In these studies, *Wind* and ACE played complementary roles with *Wind*/EPACT/LEMT measurements at ~1-10 MeV/nucleon filling a gap in the observations by ACE instruments.

Electron/^{3}He-rich events

Impulsive SEP events are dominated by ~1-100 keV electrons and by low energy, ~0.01 to ~10 MeV/nuc ions that are highly enriched in ^{3}He [*Mason et al*., 2000] and in heavy ions (e.g., Fe) with high charge states [e.g. *Luhn et al*., 1987]. Solar type III radio emissions and sometimes with small flares occur in association with these events. Near solar maximum, about 10^4 events/year occur over the whole Sun [*Wang et al*., in preparation], making these the most common solar particle events. Although the location and mechanism of acceleration still remain controversial, *Wind* observations have fostered significant progress.

Using high sensitivity *Wind*/3DP electron data (~1-400 keV) and ACE/ULEIS ion data (~0.02-10 MeV/nuc), *Wang et al.* [in preparation] compiled a systematic survey of 1100 solar electron events and 140 ^{3}He-rich (^{3}He/^{4}He > 1%) ion events with clear velocity dispersion. They found that ~ 1 MeV/nuc, ^{3}He-rich ion emissions accompany ~80% of solar electron events, and that their occurrence frequency is similar to that for sunspots (see Figure 4). Furthermore, an impulsive electron event accompanies over 93% of the 140 ^{3}He-rich ion events. This suggests a close association of the acceleration mechanism of ^{3}He-rich ions to that of electrons. They also found that most of the eleven electron/^{3}He-rich events were not associated with GOES SXR flares, but were accompanied by a narrow CME or jet [*Yi-Ming Wang et al.* 2006] limiting the possible acceleration mechanisms. However, the location of injection remains unclear as the observations of impulsive electrons down to ~400 eV imply a source high in the corona, but the ion high charge states favor a low-corona source.

Electron Acceleration Near the Sun

Comparison of *Wind* measurements of energetic electrons in solar impulsive events with the electrons producing the flare X-ray emission at the Sun observed by RHESSI provides unique information on the energetic electron acceleration and escape processes. For prompt events (where the injection of the electrons at the Sun, inferred from their velocity dispersion, is simultaneous with the X-ray burst) we find a close correlation between the power-law exponents of the spectra of the electrons at 1AU and those of the X-ray producing electrons (see Figure 5), suggesting a common source [*Krucker et al.*, 2007]. However, a simple model, where the electrons observed at 1 AU escape directly from the acceleration source while the downward going accelerated electrons produce the X-rays while losing all their energy to collisions in the dense lower solar atmosphere, does not fit. Some additional acceleration of the downward-propagating electrons may be occurring; if magnetic reconnection does the initial acceleration, possibly the downward-propagating electrons are further accelerated by Fermi and betatron processes as the newly closed field line becomes more dipolar. For several of these events, RHESSI's X-ray imaging together with TRACE imaging of lower temperature plasma, show accompanying jets consistent with reconnection of an open field line with a closed loop.

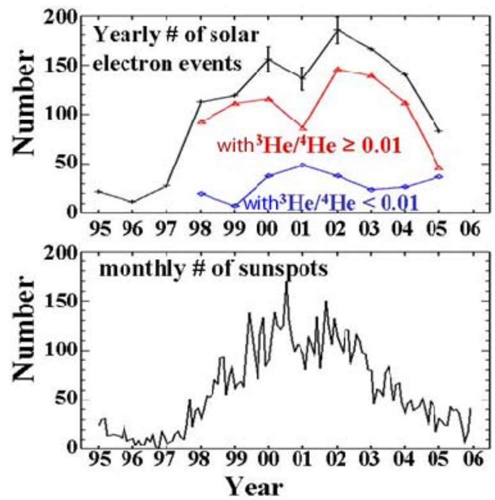

Figure 4. Time distribution over one solar cycle: solar electron events (top) and sunspots (bottom). In top panel, the black curve shows the yearly number of electron events, the red curve shows electron events associated with ^{3}He-rich ions, and the blue curve electron events with ^{3}He /^{4}He < 0.01. Only by combining *Wind* and ACE observations can we obtain a complete picture of solar wind electron and ^{3}He-rich ion events. [from *Whang et al., in preparation*]

The Suprathermal Tail

Observations from *Ulysses* and ACE have revealed the presence of a power-law tail in ion velocity distributions in the suprathermal energy range [*Gloeckler et al.*, 2000; *Gloeckler* 2003]. These suprathermal tails are known to be composed of accelerated ions. The tails persist through quiet time conditions and may be the product of a stochastic acceleration mechanism. *Fisk and Gloeckler* [2006]

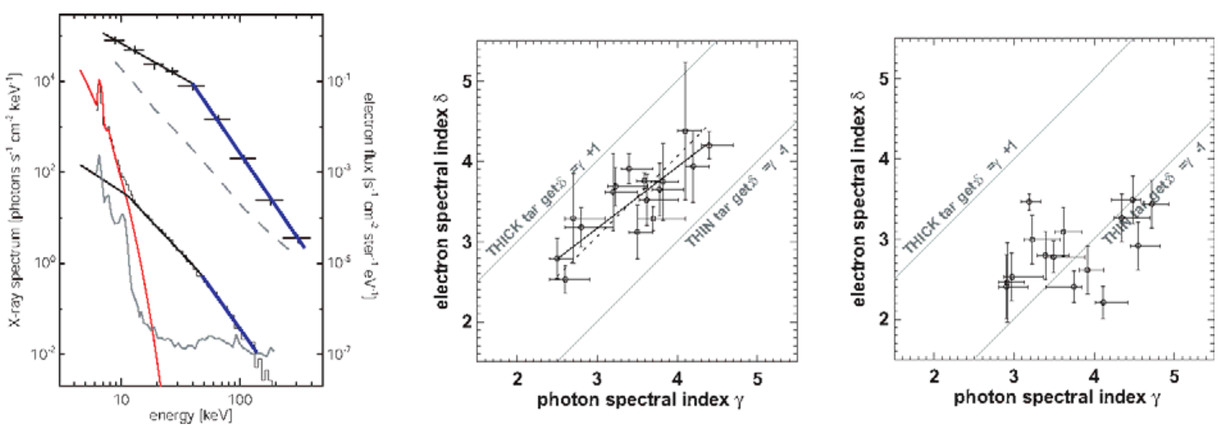

Figure 5. **Left:** Example of an in-situ electron spectrum measured by *Wind* and a hard X-ray photon spectrum from RHESSI of a prompt impulsive electron event (April 14, 2002). The two very similar broken power law spectra (black and blue) suggest a common source of the two electron populations. **Center and Right**: Correlation plot of the photon spectral index γ and electron spectral index δ above ~50 keV for 16 prompt events (middle) and 16 delayed events (right). A positive correlation is found only for the prompt events [from *Krucker et al*. 2007].

noted that the spectra of these suprathermal ions are not only always power-law in form, but also have a consistent v^{-5} spectrum in velocity space.

Fisk and Gloeckler [2006] introduced a new mechanism for the acceleration of the suprathermal particles in the quiet-time solar wind that postulates that suprathermal tails result from a cascade mechanism, analogous to turbulent cascades, in which the energetic particles are accelerated by compression turbulence and perform an equal amount of work on the turbulence. The mechanism yields a power law spectrum of spectral index -5, when expressed as a distribution function in velocity space.

In order to gain further insight into this acceleration mechanism, suprathermal tails can be analyzed on a range of time scales and over a range of solar wind regimes. Studies using the *Wind* SMS/STICS sensor, which extends the previous analysis to a higher energy range, have also revealed that this unique spectral shape is ubiquitous in the solar wind.

Long accumulation times (~50-100 days) limited previous studies of suprathermal particles using ACE and *Ulysses* due to the fact that the energy range of these instruments is not ideally suited for detection of suprathermal particles, but rather for the bulk solar wind. *Wind* STICS with its extended energy band, ~30 – 230 keV/q, allows clear observations of particles in the suprathermal energy range at much shorter time scales. Analyzing proton and alpha distribution functions obtained by STICS during 2005 at time scales as short as 2 and 12 hours (previous studies were done at 1 day resolution) demonstrates that a simple power law fits the bulk solar wind velocity. Allowing the spectral index to vary, and under a variety of solar wind conditions, the value of the fitted spectral index was most often -5, in line with the proposed theory of *Fisk and Gloeckler* [2006].

Thus the value of the spectral index does not vary significantly with solar wind conditions, nor does it vary across species. The results suggest that there is a fundamental aspect to the k=-5 power law behavior of suprathermal ions in collisionless plasmas which is valid on temporal scales within the turbulence inertial range.

The source of the slow solar wind

On the low end of the energy scale, studying the slow solar wind, *Kasper et al.* [2007] have discovered evidence for two source regions for the acceleration of these particles. This was a follow up to an earlier study by *Aellig et al.* [2001], who demonstrated that the dependence of helium abundance on speed changes over the solar cycle. *Kasper et al*. calculated the values of A_{He}, the ratio of helium to hydrogen number densities in 25 speed intervals and averaged over each ~27 day Carrington rotation using Faraday cup observations from the *Wind* spacecraft between 1995 and 2005. They found that for solar wind speeds between 350 and 415 km/s, A_{He} varied with a clear six month periodicity, with a minimum value at the heliographic equatorial plane and a typical gradient of 1% per degree in latitude. Once the gradient was subtracted, A_{He} was found to be a remarkably linear function of solar wind speed, as shown in Figure 6. The implied speed at which A_{He} goes to zero is 259 +/- 12 km/s corresponding to the minimum solar wind speed

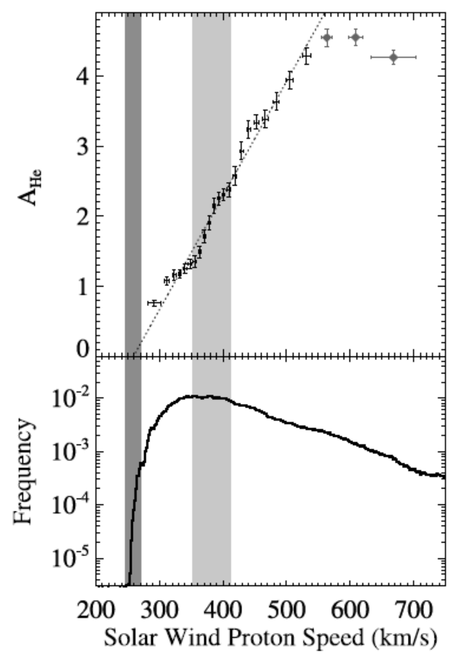

Figure 6. Top: Plot of A_{He}, the percent ratio of the helium to hydrogen number density as a function of solar wind speed collected over ten years (1995-2005). The dotted line is the best fit to the slow speed component, which omits the three highest speed points. The fit for slow wind projects that A_{He} goes to zero at a proton speed of 259 +/- 12 km s^{-1}. This vanishing speed is indicated in both panels with a dark gray band. Bottom: Histogram of all solar wind speeds measured by *Wind* over the course of its mission. Only by continuing the long baseline established by *Wind* can we assure future discoveries on long term solar wind properties. [from *Kasper et al., 2007*]

observed at 1 AU. The vanishing speed may be related to previous theoretical work in which enhancements of coronal helium lead to stagnation of the escaping proton flux. During solar maximum the A_{He} dependences on speed and latitude disappear. This is interpreted as evidence for two source regions for slow solar wind in the ecliptic plane, one being the solar minimum streamer belt and the other likely being active regions. This study was only possible because of the accurate and very long duration, continuous solar wind observations of *Wind*. Validating or confuting the two-source region solar wind theory requires observations of this effect during the next solar cycle.

Future Plans:

The continued operation of *Wind* will enable many new studies investigating the process of particle acceleration in the inner heliosphere besides the continuation of the above outlined research. Combining *Wind*, ACE, and STEREO, together with CME modeling, will map quasi-parallel and quasi-perpendicular regions around the CME-driven shock to interplanetary SEP abundance and spectral observations at different spacecraft locations. The resulting correlations will quantitatively limit which acceleration theories are viable.

Moreover, the longitudinal separation between the two STEREO spacecraft and *Wind* will allow the determination of the local curvature of interplanetary shock surfaces at 1 AU on a variety of scale-lengths. Combining this result with electron, magnetic field and radio observations and global field line mapping, it may be possible to determine to what degree shock surface or interplanetary magnetic field line curvature is responsible for the intermittency of electron acceleration and type II radio emissions.

Finally, combining RHESSI observations of energetic electron source regions with in-situ electron measurements, which are now available not only from *Wind* but also from STEREO, will allow the determination of the precise beam widths of the electron radiation and constrain theories for their acceleration.

2.2 HELIOPHYSICS OBJECTIVE #2: Evolution of Solar Transients in the Heliosphere

The second research objective of heliophysics, as described by the *Science Plan for NASA's Science Mission Directorate 2007-1016,* focuses on how the heliospheric manifestations of solar activity evolve before reaching Earth and what their impacts are on the magnetosphere. The Sun's output varies on many time scales. *Wind*'s high time resolution measurements and its over 13 year long stable and reliable observations have significantly contributed to studies of all scale-lengths ranging from turbulent energy cascade, to solar wind stream structures, to the propagation of coronal mass ejections and shocks, and up to solar cycle variations. This section highlights some of the outstanding *Wind* results from this area with our future plans again detailed at the end of each subsection.

2.2.1 Solar Wind MHD Turbulence and Intermittency

On the shortest of time scales, a nonlinear cascade process moves energy from large, "energy containing" structures to smaller solar wind variations, ultimately reaching the regime we call turbulence where we presume dissipation via kinetic effects acts. Two of the primary aspects of solar wind MHD turbulence that still remain a puzzle concern the nature of the energy cascade and the strong intermittent character of solar wind fluctuations in the inertial range. *Wind* has a unique ability to address these problems due to the continuous high quality 3-second time resolution ion moments from the 3DP instrument. This temporal resolution is 20 times faster than what is available from ACE and reaches the critical inertial range of solar wind MHD turbulence.

Recently, new spectral methods based on wavelet transforms have been used on 3-second *Wind* magnetic field and ion moments from the MFI and the 3DP experiments, respectively. *Salem et al.* [2007, 2008a,b] performed a multi-scale analysis of solar wind fluctuations and extracted intermittency from a given time series in order to show experimentally its effects on the analysis. Such methods allow the identification and suppression of the effects of large and localized intermittent fluctuations on the statistics of standard fluctuations, thus recovering the actual scaling properties of the fluctuations in the inertial range. Furthermore, this technique allows for a direct and systematic identification of the most active, singular structures responsible for the intermittency in the solar wind. *Salem et al.* [2008b] showed that these structures appear to be Alfvénic, i.e. with a strong correlation between the velocity and magnetic field fluctuations with a larger fraction propagating outward.

Future Plans:

Intermittency exists at different scales, randomly distributed within a data set. We will use a newly-developed wavelet technique [*Salem* et al., 2008b], to undertake a systematic search to identify the intermittent structures in the solar wind data sets. We will fully investigate their physical nature and properties both individually and statistically, as well as how they are related to dissipation. It is important to understand how these structures form and whence they originate to determine the physical process of energy flow in the heliosphere. It is still an open question whether these coherent structures originate at the Sun or are locally generated by turbulence dynamics. We will investigate the latter process directly by analyzing the high time resolution *Wind* data sets.

2.2.2 Solar Wind Coherence Scale

Understanding the evolution of solar wind structures on the 10-100 R_E scale-length is particularly important for the development of an accurate space weather forecasting capability. This scale is the dimension of the orbital radius of a typical upstream monitor, hence the distance that it may be from solar wind parcels impinging on the subsolar point of the magnetosphere. Also given the 30-40 R_E magnetospheric cross-section, variations on this scale can introduce gradients in solar wind input. *Wind* has been ideally positioned to address this question due to its long-term, high quality and continuous observations and due to its L1 location.

A recent study by *Ogilvie et al*. [2007] of the solar wind plasma correlation scale-length extended the results of previous works by using a significantly longer time period, 1996-2005, (nearly a complete solar cycle) and the larger range of spatial separation between SOHO and *Wind*. A bimodal distribution of correlation as a function of the inter-spacecraft separation perpendicular to the Sun-Earth line resulted. The larger correlation coefficient is likely due to coherent solar wind structures, such as shocks and discontinuities and is less prominent during solar minimum years.

Future Plans:

In the near future, the scientific dividend from long baseline correlation studies will increase further as the STEREO spacecraft offer even longer baselines. Whereas to date studies have characterized scale lengths near Earth in the range of 10 - 100 R_E, the future promises to provide characterization of these scale lengths up to ~ 1 AU sizes. *Wind* will continue to play a critical role, as we

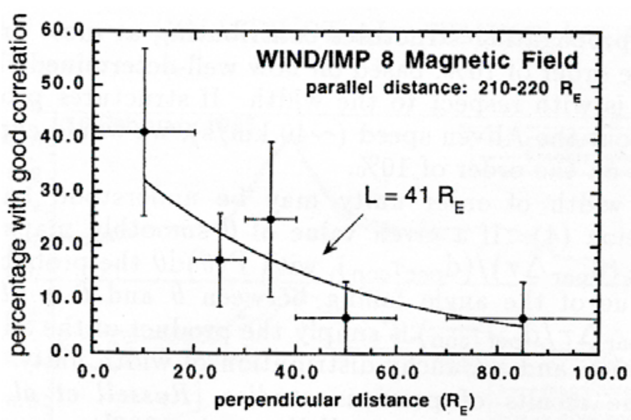

Figure 7. Solar wind magnetic field correlation scale-lengths as a function of the separation distance between *Wind* and IMP 8 perpendicular to the Sun-Earth line. Note that a simple extrapolation of the trend would suggest a complete lack of solar wind correlation at distances larger than 100 R_E. However, this study was carried out using short analysis time windows. More recent studies, suggest that longer time windows would result in higher correlations at even large separations such as now being explored by STEREO and *Wind*. [from *Collier et al.* 1998]

will need STEREO-like instrumentation at intermediate positions between the two STEREO spacecraft to validate the results. One of the fundamental questions will be to determine whether solar wind correlation completely disappears at the larger separation distances as the results of *Collier et al*. [1998], carried out over short, 2-hour windows, would suggest (see Figure 7) or will the large and more coherent structures (like shocks and discontinuities) maintain correlation over longer (days) time intervals as hinted by the recent study of *Ogilvie et al.* [2007].

2.2.3 Tracking Interplanetary Shocks in the Inner Heliosphere

The most geoeffective solar phenomena are coronal mass ejections (CMEs) and the interplanetary shocks they often drive. Tracking their evolution beyond the fields of view of coronagraphs has been traditionally accomplished by observing the radio emissions they generate. *Wind* is the only spacecraft located near Earth which constantly monitors the low-frequency radio emissions from the solar corona and from interplanetary space with its WAVES instrument. Moreover, sue to its spin, its unique radio direction-finding capabilities enable it to locate these radio sources in the inner heliosphere and the extremely long wire antennas (50m) allow their tracking all the way to Earth. Furthermore, unlike previous radio receivers, those on *Wind* and *Ulysses* include the capability to measure the complete wave polarization state of the incoming radiation. These more comprehensive radio measurements have greatly advanced our knowledge and understanding of the nature of transient solar radio sources.

The most significant recent result based on these *Wind*/WAVES measurements was the first quantitative and comprehensive estimation of the deceleration profiles for individual CMEs from the Sun to Earth. We have known for more than 30 years that CMEs must decelerate as they traverse the interplanetary medium. Yet all previous methods, including the white-light LASCO coronagraph observations, have failed to quantitatively detect and characterize the CME deceleration profiles. On the other hand, *Wind*/WAVES data have made it possible to quantify when, where, and how fast radio producing CMEs decelerate as they travel from the Sun to Earth [*Reiner et al.* 2007]. These results will provide improved predictions of the arrival times of CMEs and their associated shocks at Earth. These shocks are often the cause of the most severe transient radiation environment encountered by astronauts.

Locating the radio source requires at least 3 different spacecraft to establish the direction of the radiation. Triangulation techniques can then identify the precise source locations. Figure 8 illustrates this for a solar radio source at 425 kHz that was observed on July 26, 2007. Clearly the two lines of sight from the STEREO spacecraft will always intersect at some point. However, the third line of sight derived using the direction-finding techniques on *Wind* provides a decisive check and likely refinement of the source location in 3D space. This third independent measurement from *Wind*/WAVES is particularly compelling since on *Wind*, which is a spinning spacecraft, the radio source direction is derived in a completely different way than on the 3-axis-stabilized twin STEREO spacecraft. Radio source direction finding from spinning spacecraft such as *Wind* has a much longer tradition of development and refinement and is intrinsically a simpler measurement to make. Indeed, analyses of the *Wind*/WAVES data are currently being used to help calibrate the radio receivers on STEREO.

***Future Plan*:**

The new white-light observations from the STEREO Heliospheric Imagers (HI) of the SECCHI experiment promise the possibility of visible tracking of interplanetary CMEs (ICMEs) in the inner heliosphere. The data analysis, however, is not trivial and will still require the traditional radio and 1 AU in situ observations, along with global MHD modeling to develop a fully 3-dimensional picture. The HI images are line-of-sight observations providing only the cumulative density along a particular direction. To deconvolve the third dimension requires at least a few marker points in space, where the time and 3D location of ICME passage is known accurately. At 1 AU, the minimum 3 marker points will be provided by the two STEREO spacecraft and *Wind* and ACE together near Earth. Until the flight of *Solar Orbiter*

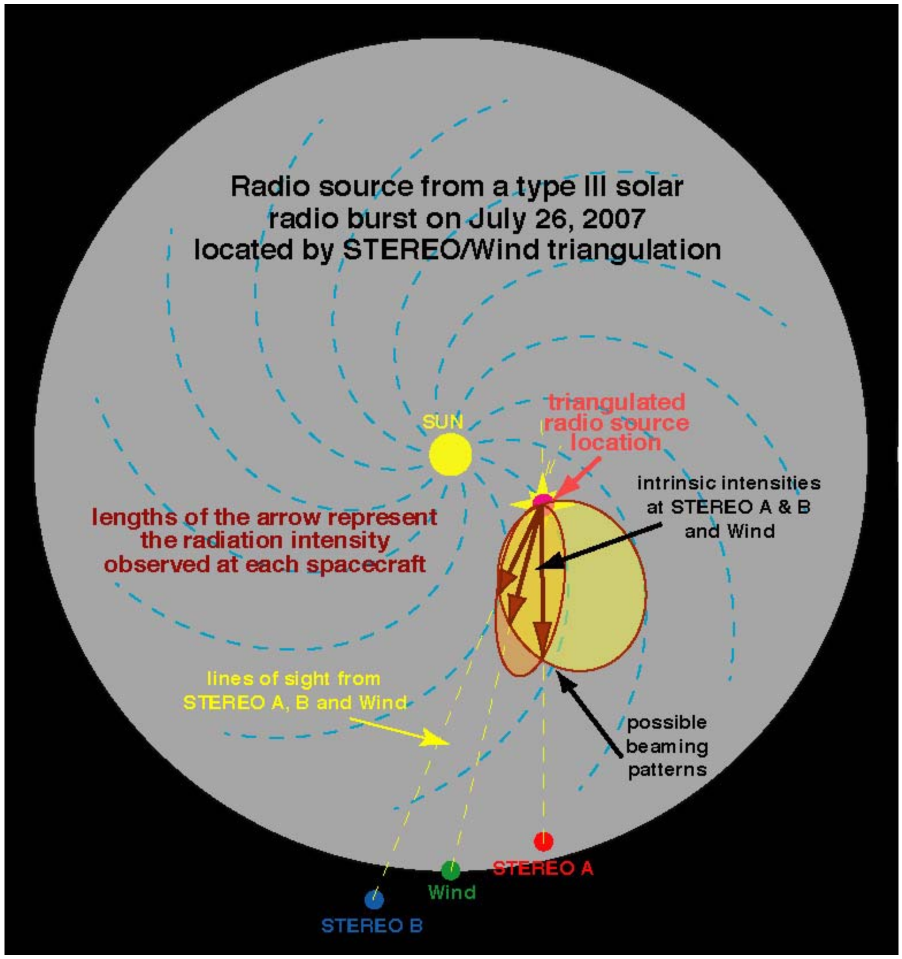

Figure 8. Illustration of triangulation technique of inner heliospheric radio sources using *Wind* and STEREO. Only by employing *Wind*'s "third eye" can we establish precise source locations and beaming patterns. [Courtesy *M. Reiner*]

and *Sentinels*, only the *Wind* and STEREO radio source location outlined above can obtain inner heliospheric markers. To connect these observations, we will execute a global heliospheric MHD model with an artificially launched CME such that the model result will match the marker point measurements. We will then generate synthetic white-light images to compare to the STEREO HI observations. Adjustment of the artificial CME launching characteristics (shape, extent, speed) is performed until a match is achieved with observations. This will provide a new level of understanding of ICME evolution in the inner heliosphere.

Radio type II emission from ICME shocks is known to emanate from highly localized regions. It often happens that a radio event observed by *Wind* is not detected by *Ulysses*, and visa versa, indicating the possibility of narrow beaming patterns. As illustrated schematically in Figure 8, the unique combination of *Wind* and the two spatially separated STEREO spacecraft (all with accurately inter-calibrated radio receivers) will have, for the first time, a means for obtaining a quantitative measure of the intrinsic beaming pattern of radio sources in the interplanetary medium and thus gain confidence in our source location analysis. The Sun has not been kind to us since the launch of STEREO providing only a few events. However, with the rising solar cycle, an abundance of events is inevitable.

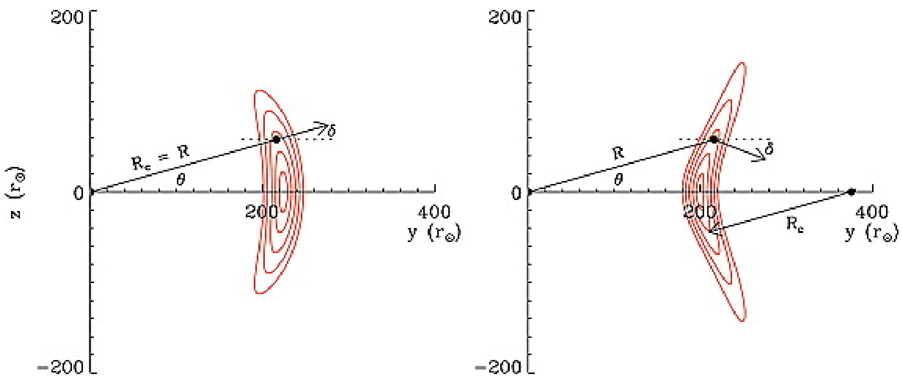

Figure 9. Schematic diagram of MCs at 1 AU in the solar meridianal plane with axes perpendicular to the radial and transverse directions, illustrating the large latitudinal extent and curvature in a uniform (left, corresponding to solar maximum) and structured solar wind (right, corresponding to solar minimum). Recent *Wind* and other 1 AU spacecraft observations suggest that such dramatic deviation from cylindrical symmetry is not uncommon. [from *Liu et al.* 2006]

2.2.4 Interplanetary Coronal Mass Ejections at 1 AU

A large fraction of the energy released by solar activity is carried by ICMEs and their driven shocks. Accurate determination of the global and internal structure of ICMEs, and in particular, that of magnetic clouds (MCs), is necessary to determine the magnetic fluxes and helicities that they carry from the Sun into interplanetary space. Moreover, knowing the characteristics of ICMEs places a considerable constraint on the possible CME-initiation models, and thus will critically contribute to the development of accurate forecasting capability of these active structures.

Lepping et al. [2006] and *Leitner et al*. [2007] applied a non-linear force-free fluxrope fitting procedure to all 100 MCs observed by *Wind* to date. The fitted time intervals are also publicly available at: http://lepmfi.gsfc.nasa.gov/mfi/mag_cloud_pub1.html. A detailed comparison of the best 50 fits with the actual observations revealed that, while the field directions are very well approximated, a large fraction of cases has significant magnetic field magnitude deviations indicating large compressions and expansion, i.e., departure from simple cylindrical geometry [*Lepping et al*., 2008a].

The newer, Grad-Shafranov technique relaxes the force-free assumption and reconstructs the cross section of MCs in the plane perpendicular to the cloud's axis without prescribing the geometry [*Hu and Sonnerup*, 2002; *Liu et al*., 2006]. In fact, *Wind*, ACE and *Ulysses* observations of the same MCs and the deflected solar wind flows around them suggest that the cloud cross sections are significantly elongated in the latitudinal directions and can be significantly convex or concave outward depending on how structured the solar wind flow is near the ecliptic (see Figure 9) [*Liu et al*., 2006; 2008]. Studying the sheath regions ahead of MCs, *Lepping et al*. [2008b] found that, as expected, they get thicker with distance from the ramming nose, while *Marubashi and Lepping* [2008] showed that quantitatively they are not consistent with a simple cylindrical geometry. In fact, *Kasper and Manchester* [2008] have found that the flow deflections behind MC driven shocks during solar minimum are more consistent with the bent over geometry depicted in the right pane of Figure 9. These are significant discoveries, as they are the very first observational evidence, supporting dramatic evolution of ICME cross-sections long predicted by global MHD models [e.g., *Odstrcil et al*., 2004; *Manchester et al*. 2004].

Future Plans:

With the increasing longitudinal separation of the STEREO spacecraft from the Sun-Earth line, a new opportunity presents itself for determining the evolved large-scale geometry of magnetic clouds (both along and perpendicular to the cloud axis). New techniques are being developed to take advantage of these revolutionary observations. For example, one can apply the Grad-Shafranov technique separately to each individual crossing of the same MC. And by taking geometrical factors, such as spacecraft positions and timing into account the separate results can be combined into a single 3D picture in what is called "contrasting". This will provide us with a wealth of new information on the global spatial structure of MCs. It will be possible for the first time to extend studies of coherence lengths of ejecta [*Farrugia et al.*, 2005 a,b] into the few $\times 10^3$ R_E range, and investigate MC spatial structure over several degrees of longitude. As an example, Figure 10 shows an application of the technique to the May 22, 2007 MC observed by *Wind* and STEREO-B when the two spacecraft were separated by ~1200 R_E. *Wind* observations are critical for this kind of study as the two STEREO spacecraft are already too widely separated to often be immersed in the same magnetic cloud. With the increasing solar activity levels more examples like this will be forthcoming.

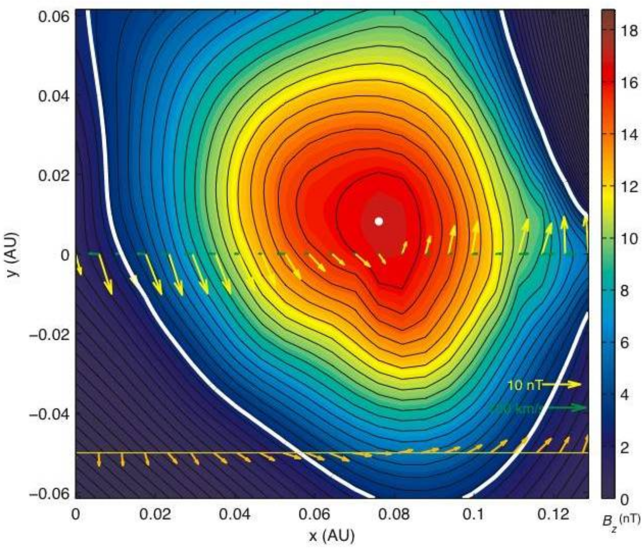

Figure 10. Grad-Shafranov reconstruction of the May 22, 2007 magnetic cloud cross section observed by *Wind* and STEREO-B. The color contours show constant magnetic field strengths along the cloud axis. The *Wind* and STEREO-B trajectories are depicted with the observed magnetic field directions. This is the first example of applying in-situ data collected at significant longitudinal separation to this technique yielding a more reliable picture of cross-sectional distortions. [Courtesy of *Mostl and Farrugia*].

2.2.5 Interplanetary Shocks at 1 AU

Fast ICMEs often drive interplanetary (IP) shocks in front of them in the solar wind. When reaching Earth, the shocks compress the magnetosphere, cause sudden commencements and initiate adverse geomagnetic activities. IP shocks are also known accelerators of solar energetic particles. Thus their investigation at 1 AU, where they are accessible, is critical for space weather studies. The *Wind* online database of IP shocks, the largest of its kind containing over 300 fitted cases, serves as a useful starting point for space weather studies (http://space.mit.edu/home/jck/shockdb/shockdb.htm).

The *Wind* shock database was used for studying shock microphysics [*Wilson et al.*, 2007], correlations with geomagnetic storms [*Zhang et al.*, 2005], stream interactions [*Richardson et al.*, 2007], and led to the first measurements of strong electric fields at IP shocks [*Wilson et al.*, 2007].

In order to improve the accuracy of IP shock fitting and to obtain more reliable shock normal directions and speeds, and hence a better characterization of the shock properties (such as θ_{Bn}), the non-linear least squares fitting techniques of *Vinas and Scudder* [1986] and *Szabo* [1994] have been improved by including the solar wind proton temperature anisotropies [*Koval et al.*, 2008]. Though the updated technique usually does not change the shock normal direction by more than a few degrees, it has provided increased confidence in the validity of shock surface undulations observed by multi-spacecraft studies in the past.

An interesting subclass of IP shocks are shocks internal to magnetic clouds. Almost 10% of the *Wind* observed magnetic clouds show evidence of internal shocks [*Collier et al.*, 2007]. These may be due to different causes, but the most promising scenario is that they are due to the interaction of multiple ICMEs when the shock driven by a cloud rams into a leading ejecta.

Future Plans:

Current work is underway to further improve the non-linear shock fitting technique by explicitly including the helium component of the solar wind to take advantage of the now regularly available *Wind* SWE proton/alpha anisotropic Maxwellian fitted data set. In combination with STEREO and ACE data, this will provide unprecedented accuracy for IP shock surface determination, a necessary input for both particle acceleration and new magnetospheric input studies.

A deeper understanding of shock microphysics is necessary to establish the correct shock particle acceleration process. Therefore, the highest resolution *Wind* magnetic field observations (22 vectors/sec) will be recalibrated to further reduce spin tone contamination. We will exploit this unprecedented high resolution data, combined with the 3-second 3DP plasma observations, to study the kinetic microstructure of the IP shocks in the extensive *Wind* database.

2.3 HELIOPHYSICS OBJECTIVE #3: Extreme Conditions and Geomagnetic Impact

The third and final heliophysics research objective of the *Science Plan for NASA's Science Mission Directorate 2007-1016* concerns safeguarding the journey of exploration. To maximize the safety and productivity of human and robotic explorers, we must characterize the extreme conditions in the solar wind and establish the geomagnetic impact of solar activity (as manifested in the 1 AU solar wind) to the point that the development of forecasting capabilities becomes a possibility. This objective also benefits from the ICME and shock studies described in the previous section.

2.3.1 Radiation Environment Near Earth

Large solar energetic particle (SEP) events pose a significant radiation hazard to astronauts and essential equipment as NASA plans increased exploration to the Moon and Mars. Prediction of these events and their properties does not come easily. The effects of the events depend upon the intensity and hardness of the energy spectrum, and the event duration. These in situ properties depend upon the physics of particle acceleration and the subsequent transport and trapping in the interplanetary environment.

In just the last two years, the *Wind* EPACT/LEMT telescope has revealed an entirely new aspect of SEP transport behavior, namely, a late-phase reversal in the flow direction of the minor ions such as He, O, and Fe, but *not* protons of the same velocity [*Tan, Reames and Ng,* 2007, 2008]. This discovery is entirely unique to *Wind* due to its ecliptic north oriented spin axis. This reversal, producing ions that flow sunward along the field in the solar-wind reference frame, appears to be related to reflection of the ions from the magnetic barrier produced by a previous CME or by earlier shock waves that are now beyond 1 AU.

Future Plans:

The IMPACT/LET telescopes on STEREO are smaller versions of LEMT that cover almost identical particle species and energy intervals. LEMT has over 10 times the sensitivity of the LETs and full directional coverage since *Wind* is a spinning spacecraft. Combining the data from *Wind* and STEREO in large SEP events, together with field and plasma observations, will provide a basis for mapping the spatial distribution of the particle flows over a large region of the heliosphere, and will allow us to model the extent of these SEP containment regions in space. Also collecting events during the new solar cycle will allow us to distinguish solar cycle effects from basic physical processes and thus facilitate the development of reliable space weather forecasting capabilities.

2.3.2 Solar Wind Impact on Magnetospheric Boundaries

Merka et al. [2005] identified a complete list of bow shock crossings (11,455 records) observed by the IMP 8 satellite during almost three decades of operation and employed this database to evaluate six empirical bow shock models. The more reliable *Wind* solar wind parameters were used to establish the appropriate upstream conditions corresponding to each crossing in the 1995-2000 time frame. The limitations of the various empirical and MHD bow shock models have been discussed in that study. For example, Figure 11 shows the wide spread between empirical (purple and cyan lines) and MHD model

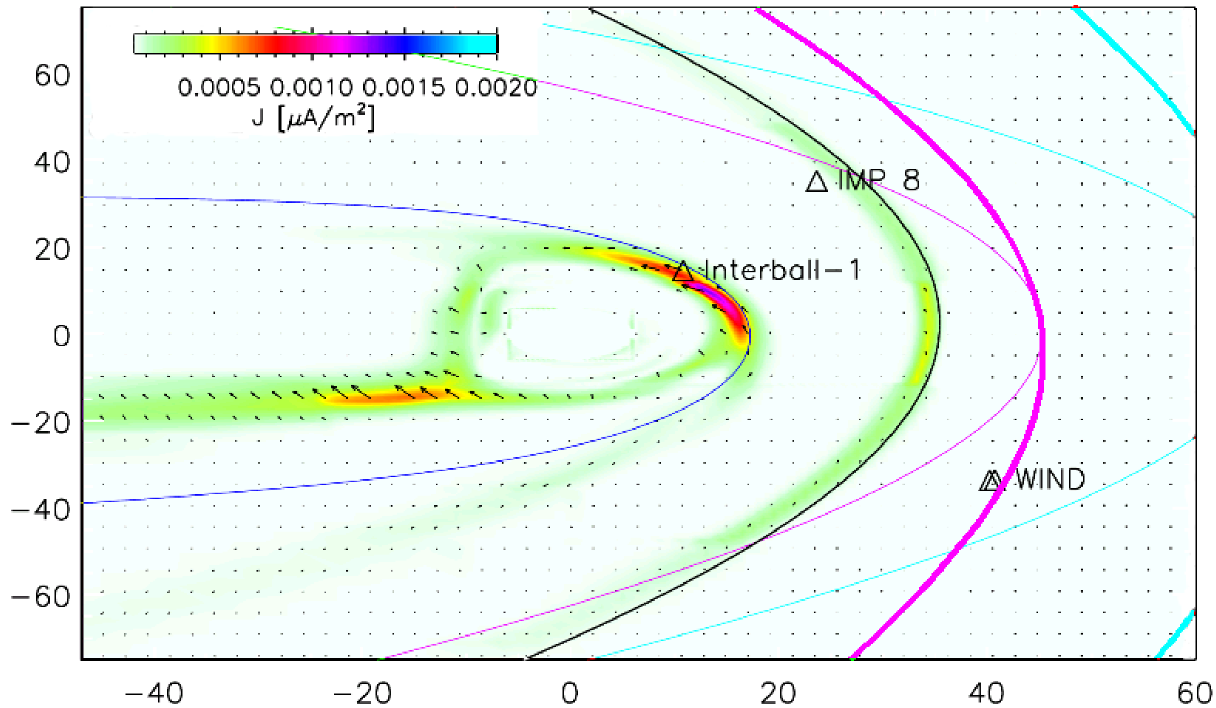

Figure 11. Empirical (purple and cyan lines) and MHD model (color contours and black line) predictions of the Earth's bow shock for the May 11, 1999 low density solar wind event. IMP 8 and *Wind* bow shock crossings are indicated. [from *Merka et al.* 2005]

(color contours and black line) predictions of the bow shock position and shape for May 11, 1999 when the solar wind had unusually low density (~0.2 cm^{-3}). The actual IMP 8 and *Wind* bow shock crossings (not matching any of the model predictions) are marked illustrating that our understanding of the motion of the bow shock to extreme solar wind conditions is still inadequate.

Future Plans:

During the first decade of its life, *Wind* had performed a number of unusual petal phasing orbits bringing the spacecraft to bow shock crossing points not normally sampled by other spacecraft. We plan in the next couple of years a detailed retrospective study of the *Wind* bow shock crossings. The rapidly moving bow shock is often encountered multiple times in a span of a couple of minutes. Therefore, the proper identification of each shock crossing and its characteristics requires the involvement of the individual *Wind* instrument teams to provide calibration refinements and interpretation of the data. Preliminary analysis suggests that about one thousand identifiable crossings are present in the *Wind* data set. Providing data points at the unusual high latitude crossing locations will significantly improve the accuracy of the empirical bow shock models.

2.3.3 Geomagnetic Impact

Wind observations resulted in a number of important discoveries establishing the geomagnetic impact of various solar wind conditions and of solar transients. For example, a *Wind*-ACE-GOES statistical investigation (316 cases in 1996-2004) [*Muehlbachler et al*., 2005] established that the erosion of the dayside magnetosphere saturates, i.e., becomes independent of IMF Bz for large Bz. *Wind* also provided noteworthy insight into the solar wind-magnetosphere coupling using intervals of tenuous solar wind conditions [*Farrugia et al*., 2007].

Wind's complete coverage of more than one solar cycle has permitted statistical studies relating large geomagnetic effects to their solar and interplanetary sources. With a sample of 99 *Wind* MCs, *Gopalswamy et al*. [2007] studied solar sources and geoeffectiveness (here defined by Dst < -50 nT) over the period 1995-2005. They found that MC-associated CMEs originate from close to the central meridian (within ±30 degrees in latitude and longitude). The solar sources of MCs follow a butterfly pattern, i.e., in both hemispheres their latitudes have a clear decreasing trend as the solar cycle progresses. They also confirmed the odd-cycle behavior of SN versus NS clouds. As regards geoeffectiveness, two-thirds of MCs were geoeffective; many (55%) only through their sheaths (in agreement with *Huttunen et al*. [2005]). The average speed of geoeffective MCs was only slightly greater than the slow solar wind speed at 1 AU because of the strong coupling between solar wind and the ICMEs in the IP medium. The non-geoeffective clouds occurred mostly in the rising phase of the cycle. A noteworthy finding is that the Dst index is highly correlated with the product of the average MC speed and magnetic field strength.

Farrugia et al. [2006] discussed an ICME merger observed by *Wind* on March 31, 2001 and its impact on the magnetosphere/ionosphere. A double-dip great storm resulted, i.e., the Dst time profile had two minima, a signature of the strongest of Dst events. It is suggested that the merged ejecta, with their enhanced plasma densities, are a new interplanetary source of major geomagnetic storms.

Future Plans:

A significant difficulty in accurately predicting the time of geomagnetic activity as a result of an arriving ICME is that often not only the fluxrope itself, but the driven sheath region in front of it is the cause of the activity. While there is much observational data and theoretical analyses regarding the standoff distance of Earth's bow shock, little is known about how this standoff distance (the thickness of the driven sheath region) for CMEs varies from one CME to another and of how it varies as a function of heliocentric distance. To determine this standoff distance, the *Wind* and STEREO radio measurements will have to be combined with the STEREO SECCHI heliospheric imager data. It is generally assumed that the radio emissions originate from the driven shock, while the white-light observations are presumably related to the dense CME driver material. The *Wind*/WAVES observations are crucially important for these analyses because, due to the great sensitivity provided by its very long (50m) wire radio antennas, it is able to readily detect the extremely weak frequency-drifting radio emissions that are known to be generated upstream of the driven shock [*Bale et al*, 1999]. Some such preliminary analyses were previously made between *Wind*/WAVES and the all-sky white-light cameras, SMEI, on the *Coriolis* spacecraft validating the technique [*Reiner et al*, 2005].

3. *WIND* SUPPORT FOR OTHER MISSIONS

As part of the Heliospheric Great Observatory, *Wind* has been contributing to numerous science investigations that rely on multi-spacecraft observations. Many of these have been described in the preceding sections. In addition, *Wind* observations are critical to enabling and enhancing the mission success of many other spacecraft. In this section we outline some of these functions *Wind* serves.

3.1 Wind and STEREO

Because *Wind* carries the WAVES and the high time resolution 3DP solar wind experiments, it is the only near-Earth spacecraft that can serve as backup for the STEREO in-situ and radio observations. Together with SOHO, *Wind* can recover all of the scientific objectives of the STEREO mission should one of the twin spacecraft become incapacitated.

Even assuming a long and healthy life for STEREO, the two spacecraft separating at 44 degrees/year from each other will be too far separated in longitude for ideal observations. For example, by the end of 2010, the STEREO spacecraft will be 180 degrees apart, on the opposite sides of the Sun. Clearly by this time, and long before it, the heliospheric imager of one cannot see the solar wind structures that flow past the other. However, *Wind*, being half way between them, will be ideally positioned to carry out the in-situ observations for both spacecraft. Thus *Wind* will be crucial for the success of a STEREO extended mission.

Even before the two STEREO spacecraft reach large longitudinal separations, *Wind* in-situ observations are critical for solar wind structure investigations, as they all require at least three longitudinally separated points of observation, as has been extensively discussed in Section 2.2.4. Moreover, this third vantage point for radio observations is essential for source location and beam pattern studies as was outlined in Section 2.2.3. Thus, ***Wind is in essence the third in-situ "eye" of the STEREO mission***.

3.2 Wind and ACE

Wind and ACE, often in combination with the SOHO plasma instrument, have been involved in a long and fruitful collaboration of multi-point studies of solar wind correlation scale lengths and of the characteristics of 1 AU transient structure. The continuation of these studies will be particularly important as the STEREO observations will reveal information about larger, ~1 AU scale-lengths. Concurrent determination of the 10-100 R_E behavior will be essential to identify differences on the larger scale-lengths.

Wind and ACE have been also mutually supporting each other in refining the calibrations of their instrumentation. Since *Wind* determines and intercalibrates its solar wind measurements from three different instruments that operate based on different physical principles (SWE, 3DP and WAVES plasma frequency), it supplies these highly accurate and independent estimates of thermal plasma key parameters. In addition, the SWE instrument can operate through the high energy particle showers associated with flares and CMEs. Thus the *Wind* data is very robust. The ACE SWEPAM team takes full advantage of the *Wind* solar wind plasma observations to improve their calibrations. This cooperation is expected to continue through the upcoming years.

Magnetic field measurement also mutually benefit from intercalibrations between *Wind* and ACE. In spinning spacecraft, the highest accuracies are achieved in the spacecraft spin plane. Since the *Wind* and ACE spin axis are mutually perpendicular, the lower quality, spin axis component calibrations can be improved by comparing them to the appropriate spin plane component from the other spacecraft whenever they are sufficiently close to each other.

Finally, while ACE dominates high energy particle observations, the *Wind* EPACT/LEMT telescope fills an important gap in the 1-10 MeV/nucleon range between the ULEIS and SIS instruments on ACE. Moreover, because of its high dynamic range, EPACT can measure solar energetic particles even through particularly intense solar storms without the inherent saturation problems of other instrument types. In summary, ***Wind provides significant calibrational information to ACE, complements its measurements and facilitates collaborative, multi-spacecraft studies***.

3.3 Wind and RHESSI

RHESSI provides imaging and spectroscopy of the hard X-ray/gamma-ray continuum and gamma-ray lines emitted by energetic electrons and ions, respectively. RHESSI accurately locates these particles at the Sun, and its precise spectral measurements provide information on the spectra of the parent electrons and ions, and on the ion composition. *Wind*, using the 3DP and EPACT experiments, provides unique in-situ measurements of the energetic electrons and ions that reach ~1 AU, and, with WAVES, of the radio emission produced by the energetic electrons while traveling from the Sun to 1 AU. With these unique measurements, *Wind* addresses the important and yet unresolved question of the mapping of interplanetary field lines from the flare sites to 1 AU. *Wind* will continue to support RHESSI as the solar activity rises during the beginning of the next solar cycle.

3.4 Wind and Voyagers, Ulysses and MESSENGER

Since the IMP 8 magnetometer stopped returning data in 2000, the *Wind* observations have usually supplied the 1 AU baseline for deep space observations such as those by the *Voyagers*, *Ulysses* and more recently MESSENGER. The robust and continuous *Wind* solar wind measurements are essential for studies ranging from the predicted position of the termination shock to the evolution of solar wind transients from the inner heliosphere. As MESSENGER will settle into a Mercury orbit and turn on its full instrumentation, a new class of solar wind transient evolution studies will be supported by the 1 AU *Wind* observations.

3.5 Wind and RBSP, THEMIS and Cluster

During the period covered by this review, three to four THEMIS spacecraft will be located in nearly identical orbits with apogees of 12 R_E and one to two spacecraft will enter lunar orbit. At apogee, separation distances between the spacecraft with apogees of 12 R_E will diminish from ~2 R_E to several hundred km during successive years from 2009 to 2012. These spacecraft will survey conditions in the dayside magnetosheath, on the dayside and flank magnetopause, and in the near-Earth magnetotail. Topics for joint *Wind*/THEMIS study include reconnection in general and, in particular, on interplanetary current sheets transmitted into the magnetosheath, the generation of flux transfer events, and the Kelvin-Helmholtz instability on the magnetopause, and current disruption and ballooning instabilities in the near-Earth magnetotail. Studies of these phenomena require simultaneous high time resolution solar wind observations to identify possible triggers and to determine occurrence patterns.

Simultaneous solar wind observations will also be important for the THEMIS spacecraft at lunar distance. When the Moon is in the solar wind, a comparison of their observations with those by *Wind* will help determine the characteristics of the lunar wake. When the Moon lies near the bow shock, a comparison of the THEMIS and *Wind* observations will determine the characteristics of the foreshock. And when the Moon lies within the Earths magnetotail, numerical simulations and models will use *Wind* observations to predict the characteristics of reconnection (flux ropes, plasmoids, high speed flows) in the mid-magnetotail, where they will be observed by the THEMIS spacecraft.

The launch of the two RBSP spacecraft is presently scheduled for March 2012, i.e. during the final period under consideration by this Senior Review. In its detailed description of the scientific objectives for the mission, the RBSP Science Working Group has identified a need for solar wind observations to determine the occurrence patterns of the various acceleration, transport, and loss processes for relativistic, near-relativistic, and ring current particles within the Earth's inner magnetosphere. *Wind* observations of the solar wind plasma and magnetic field will prove ideal for this purpose. In fact, the recent RBSP Mission Definition Review identified a need for continued solar wind observations.

3.6 Wind and LRO

The Lunar Reconnaissance Orbiter (LRO) is expected to be launched in late 2008. It will carry a dedicated instrument (CRaTER) to characterize the global lunar radiation environment and its biological impacts. To accomplish this task, LRO will require an upstream energetic particle monitor to measure the relative abundances and energy spectra. Since these upstream measurements will occur at considerable distance from LRO (100-200 R_E perpendicular to the magnetic field lines), two monitors are needed to establish the cross-field gradients. Thus LRO will need both ACE and *Wind* to provide these observations. In particular the *Wind* EPACT instrument will provide proton and helium measurements from 1 MeV to 10 MeV.

3.7 Wind and Swift

Cosmic gamma ray bursts (GRBs) are transients of large red-shift, and take place at least 600 times per year from the entire visible universe. GRBs have time durations of seconds or more, with photon energies from the hard X-ray to very high energy gamma-ray. Only 1 GRB is ever seen from any 1 source (since each is presumably a stellar birth/death signal).

Soft gamma repeaters (SGRs) are of somewhat less visible intensity, but with orders of magnitude less absolute magnitude, since their sources are in our Milky Way galaxy and its immediate neighbors, including the Magellanic Clouds. SGRs repeat at random, often or rarely, from a few times up to hundreds of times over spans from days to months. There are only half a dozen SGR sources known.

Giant Flares (GFs) are of greater apparent intensity than GRBs and are very rare, averaging once per decade. GFs are emitted from the source objects of the SGRs, one or none from each source, to date.

The KONUS instrument on *Wind* was designed to study GRBs, SGRs, and GFs, with omnidirectional sensitivity to all gamma-ray transients. Its scientific data fall roughly into the following categoties: KONUS detects on the average the brightest 120 GRBs per year, thus providing comparison data for many of the Swift GRBs. In particular, Konus provides the higher energy determination that is beyond Swift's energy range. Secondly, KONUS is a key vertex in the Interplanetary GRB Network (IPN), composed of Swift, R-XTE, *Ulysses*, *Mars Odyssey*, MESSENGER, INTEGRAL, AGILE, *Suzaku*, and HETE-2. The IPN finds the source directions of transients by virtue of its timing geometry, independently of oriented telescopes. KONUS is generally the most sensitive of these to SGRs, an advantage that result from its lack of collimation. Due to the rarity of these astrophysical events, an additional four years of *Wind* KONUS observations will significantly enhance the events collected by Swift and the IPN.

4. TECHNICAL AND BUDGET SECTION

4.1 Spacecraft Health

The *Wind* spacecraft continues in very good health. The communication system was successfully reconfigured in 2000 to realize an enhancement in telemetry margin. Reliance on a single digital tape recorder since the 1997 failure of the backup unit has never hampered operations, and measures were taken to minimize its use to extend its life. During the past few years, the spacecraft experienced a few system resets most likely due to high energy particle single event upsets. These events served to exercise the spacecraft and instrument recovery procedures and showed that within a couple of days, all instruments can be brought back to full science operations. None of these events appear to have lasting impacts.

Wind continues to have a large fuel reserve. The latest analysis shows that 59 kg fuel remains, which is equivalent of approximately 120 m/sec of radial delta-V assuming normal thruster operations. To maintain its current orbit around the L1 point, *Wind* needs to carry out four station keeping maneuvers every year. These maneuvers are very similar and require about 0.5 m/sec delta-V each. Thus, barring any other cause, *Wind* has enough fuel to maintain its orbit for the next 60 years.

4.2 Instrument Status

Seven of the eight *Wind* instruments, including all of the fields and particles suits, remain largely or fully functional. The only instrument turned off is the TGRS γ-ray instrument that was designed for only a few years of operations. The general status of all instruments is summarized in Table 2.

The specific degradations in instrument capabilities are the following: The APE and IT detectors of the EPACT instrument, covering the highest energy ranges, do not work. But the LEMT and STEP telescopes of the same instrument continue to operate normally, providing crucial and unique observations of solar energetic particles up to 10 MeV in energy. On the SMS instrument the SWICS solar wind composition sensor had to be turned off in May 2000, but the STICS and MASS sensors still provide supra-thermal ion distribution functions in 3D and high-mass resolution ($M/\delta M > 100$) measurements of the solar wind elemental abundances. Finally, the VEIS thermal electron detectors on the SWE instrument experienced high voltage problems in November, 2001. This problem was resolved by reprogramming the SWE Strahl sensor to recover most of the original functions. Moreover, the 3DP instrument also covers the impacted electron measurements making these observations still redundant and hence robust. All of the other instruments continue to function fully.

Table 2. The status of the instruments

Instrument	Principal Investigator	Institution	Status
SWE	K. W. Ogilvie	Electrons: GSFC, UNH Faraday Cup: MIT	Strahl detector reconfigured Faraday Cup fully operational
3DP	R. P. Lin	UC Berkeley	Fully operational
MFI	A. Szabo	GSFC	Fully operational
SMS	G. Gloeckler	U. Michigan	SWICS turned off STICS, MASS operational
EPACT	T. Von Rosenvinge	GSFC	APE, IT turned off LEMT, STEP operational
WAVES	M. Kaiser/J.-L. Bougeret	GSFC/Paris Observatory	Fully operational
KONUS	E. Mazets	Ioffe Institute, Russia	Fully operational
TGRS	B. Teegarden	GSFC	Turned off

4.3 Ground Operations

Wind ground operations take place at Goddard and currently are joint with that of *Polar* and *Geotail*. Over the past years a number of improvements have been introduced to reduce costs. Automation of routine tasks and streamlining processes have enabled single shift Monday through Friday operations. The *Polar* mission will be decommissioned by April 30, 2008, which will require changes to the current operations concept to avoid cost growth. A re-engineering project has begun for *Wind* that will include the upgrade of outdated hardware and software, as well as the consolidation of *Wind* operations with several other SSMO missions (TRACE, ACE, and SOHO). Through the successful consolidation of the *Wind* operations team into a common Multi-Mission MOC (MMOC) facility, expected to be operational in FY09, resources can be shared and thereby enable cost savings over a stand alone *Wind* mission.

This reengineering effort addresses hardware and software obsolescence and includes the telemetry and command system (TPOCC), the automation architecture, and voice and data network concerns that will reduce life cycle maintenance costs. The *Wind* operations team will support requirements definition, component and system testing, as well as final acceptance testing prior to transitioning the new ground system into operations.

The distribution and archiving of all level zero files and the production of the quick-look key parameter (KP) files will continued to be carried out at the Goddard *Polar-Wind-Geotal* (PWG) system. The recently reengineered PWG system, operated directly under Code 600 control, is not expected to change.

The current operation of *Wind* requires one ~2 hour DSN support per day. This allows the uplinking of the daily Stored Command Table load and the playback of the Digital Tape Recorder. *Wind* also maintains real-time solar wind monitoring during these 2 hour contacts. In 2001, an attempt was made to reduce the number of DSN contacts, and hence the cost of operations, by scheduling DSN time only once every three days, albeit for longer durations. Reducing the number of contacts saves the lengthy setup and reset times. After extensive testing, it was concluded that this scenario did not provide significant savings and introduced critical risks to the mission. Three days is the longest *Wind* can go without ground contact to avoid significant data loss (80% data recovery). Hence the current flexibility to negotiate contact time with DSN was eliminated. Also, all of these infrequent contacts had to be fully attended regardless of the time of day. Currently about half of the contacts are completely automated allowing the operation staff to keep day schedules. Thus, the current daily contact scenario is considered optimal.

4.4 In-Guide Budget

The in-guide budget described in this section will fund the mission operations necessary to continue the safe operation of the *Wind* spacecraft along with basic data reduction and validation processes performed at the various instrument institutions. As in the previous years, the scientific research outlined in the previous sections are expected to be funded through the Guest Investigator program with each element individually proposed and peer reviewed.

4.4.1 Mission Operations

The inputs in the budget spreadsheet Table II & Table V are the direct costs to the *Wind* project. Line 1 represents using the so-called Multi-mission offset money in FY08 to reengineer the TPOCC based ground system to the ITOS telemetry and command system. It is anticipated that while major releases will be completed in FY08, that full operations conversion would not occur until late in FY09. Line 2a represents the purchase and installation of 3 MOVE keysets which are the voice instruments replacing the obsolete VDS system. The switch over from the legacy system to the new system is set to occur from FY08-FY09. Line 2b is Mission Services and includes the flight operations team at a contractor WYE level of 3.5 in FY09, with a reduction to 3.0 planned in FY10 through FY12, as a result of the ground system re-engineering effort. Also included in Line 2b is support from flight dynamics for orbit determination and station keeping maneuvers at a contractor WYE level of .5, and sustaining engineering support to both the control center and the flight dynamics facility. This sustaining engineering cost is new to *Wind* as a direct charge but is absorbed into the in-guide allocation. It was previously covered by Multi-mission, but in agreement with the Program Executive, will now be direct charged to the Project. Line 2c represents the civil servant salary for a Mission Director, which is charged at .3 of an FTE.

Table IV provides the "In Kind" costs. These are services provide to *Wind* that are funded by other sources. These costs are allocated to *Wind*, but are not supported with project funds. Line 1a is continued transition of the ground system, supported by Multi-mission funds. Line 2a includes the use of the Deep Space Network apertures as well as the cost of voice and data connections at GSFC. This latter cost element is being worked in detail with Code 700, and is expected to be transitioned to the Project as a direct charge by the start of FY09 along with the associated funding. Line 2b includes control center and flight dynamics sustaining engineering costs in FY08 and some transition support for the reengineering in FY09, and an allocation of costs for Uninterruptible Power Systems and building engineers in the Mission Operations Building at GSFC. Line 2c represents costs allocated by the SSMO Project for all the elements associated with Project Management and for use of the Mission Operations and Mission Services contract.

Maintaining the *Wind* portion of the reengineered PWG system will require the support of a civil service software engineer at the 0.3 FTE level along with a contract technician also at the 0.3 FTE level. Based on past experience, hardware replacements will be necessary at the $50-$70K/year level to maintain operations. These costs are listed under project management, since it operates under direct Code 600 supervision. The overall Goddard project management costs have been significantly reduced and besides the PWG system, it includes only 0.2-0.3 FTE of time shared between the project scientist and deputy project scientist and 0.2 FTE for a resource analyst. Even with this reduction, almost 50% of the in-guide funding is needed for mission operations (40%) and project management (9%).

4.4.2 Science Data Production

The other half of the requested in-guide funding is allocated to the generation, calibration and validation of the various *Wind* instrument data products. After receiving the level zero instrument data along with housekeeping and ephemeris information, the instrument teams are responsible for the generation of science quality data that is fully calibrated and validated typically through the performance of well established scientific analysis. In addition, they have to provide full, data granule level description and intermediate-term archiving (i.e., guaranteed backups till final submission to the NSSDC). In addition, the occasional *Wind* maneuvers (about 4 a year for station keeping) necessitate instrument level commanding that the instrument teams are required to support. Thus, besides data production expertise, the teams have to maintain a low level engineering capability that can support routine and emergency operations. Finally, since *Wind* does not have a project level science center, the instrument teams are responsible for the public dissemination of their data through the maintaining of Web pages.

Due to the limited funding available, the instrument teams optimized their operation to stay roughly within 1 FTE for all aspects of operation. All fully functional instruments (MFI, SWE/Electron, SWE/Faraday Cup, WAVES, 3DP) are allocated almost exactly the same amount of support, regardless whether they are Goddard civil service full cost accounted or university operations. It should be noted that SWE is composed of two independent instruments: the Goddard electron instrument and the MIT Faraday Cup. They each have the same allocation, but are reported together.

The two partially functioning instruments (EPACT and SMS) are allocated about a third as much as their data production requirements are significantly diminished. However, they still continue to produce valuable data, therefore their continued support at this reduced level is still requested. The astrophysical KONUS instrument received in the past a minimal amount of funding ($20K) mostly to support project level documentation. This instrument receives independent funding from the astrophysics division and no new funding is requested for them in this proposal.

The final budget elements is education and public outreach that is combined for all instruments and is at the ~1% level of the project total. As it is described in the E/PO section, this funding is proposed to be combined with that of the STEREO project for a more substantial effort.

4.5 Optimal Budget

Under an optimal budget scenario, the only additional funding that is requested is a modest increase for the development of a *Wind* Science Center as an extension of the existing STEREO IMPACT Science Center at the University of California, Berkeley. The *Wind* mission does not have a dedicated science center where all the instrument data products are combined for ease of access and uniformity. At this late stage, it does not appear economical to start building a separate *Wind* science center. Since most of the proposed scientific research topics for *Wind* includes significant collaborations with STEREO and specifically with the in-situ suite of IMPACT, the most cost effective solution appears to be a simple augmentation of the already existing STEREO IMPACT Science Center at Berkeley. It would require only a couple of extra hard drives and the slight reformatting and new presentation of the existing *Wind* data products. Preparing an instrument's primary data would require 0.1 FTE of a scientific expert and 0.3 FTE technical support (~$50K). Adopting a phased approach, MFI, SWE proton and some 3DP data would be developed during the first year (2009). The cost of this, with a one time initial hardware and web page setup, is $200K. The second year would feature WAVES and SWE and 3DP electron data sets for $150K. During the third year, STICS composition, EPACT and 3DP SST high energy particle data would be incorporated for another $150K. Finally, during the fourth and final year, MFI high resolution data and SWE proton distribution functions would be added for $100K. All the reformatted data would be readily usable with existing STEREO software greatly simplifying collaborative efforts.

5. EDUCATION AND PUBLIC OUTREACH

The *Wind* team will partner with one of the two STEREO E/PO proposals to make the limited *Wind* E/PO funding more effective. This STEREO E/PO proposal, to be submitted this coming summer, is lead by Laura Peticolas of the IMPACT Team at the University of Berkeley. It will propose to create space weather "event-templates" for local and regional events at science centers that incorporate sonification and magnetism materials the group has already developed. A limited amount of funding will continue to support our existing University of Michigan E/PO effort at the Detroit Museum of Science. The total E/PO budget will be 1% of the total *Wind* funding.

REFERENCES

Aellig, M. R., A.J. Lazarus and J.T. Steinberg (2001) The solar wind helium abundance: Variation with wind speed and solar cycle, *Geophys. Res. Lett*., **28**, 2767-2770.

Bale, S. D., M.J. Reiner, J.-L. Bougeret, M.L. Kaiser, S. Krucker, D.E. Larson, and R.P. Lin (1999) The source region of an interplanetary type II radio burst, *Geophys. Res. Lett.*, **26**, 1573.

Collier, Michael R., J.A. Slavin, R.P. Lepping, A. Szabo, and K. Ogilvie (1998), Timing accuracy for the simple planar propagation of magnetic field structures in the solar wind, *Geophys. Res. Lett*., **25**, 2509-2512.

Collier, M. R., R. P. Lepping, and D. Berdichevsky (2007) A statistical study of interplanetary shocks and pressure pulses internal to magnetic clouds, *J. Geophys. Res*., **112**, A06102, doi:101029/2006JA011714.

Davis, M. S., T. D. Phan, J. T. Gosing, and R. M. Skoug (2006) Detection of oppositely directed reconnection jets in a solar wind current sheet, *Geophys. Res. Lett.*, **33**, 19, doi: 10.1029/2006GL026735.

Farrugia, C.J., H. Matsui, H. Kucharek, R.B. Torbert, C.W. Smith, V.K. Jordanova, K.W. Ogilvie, R.P. Lepping, D.B. Berdichevsky, T. Tarasawa, J. Kasper, T. Mukai, Y. Saito and R. Skoug (2005a) Interplanetary coronal mass ejection and ambient interplanetary magnetic field correlations during the Sun-Earth connection events of October-November 2003, *J. Geophys. Res*., **110**(A9), A09S13.

Farrugia, C.J., F.T. Gratton, G. Gnavi, H. Matsui, R.B. Torbert, D.H. Fairfield, K.W. Ogilvie, R.P. Lepping, T. Terasawa, T. Mukai, and Y. Saito (2005b) Magnetosheath waves under very low solar wind dynamic pressure: Wind/Geotail observations, *Annales Geophys*., **23**, 1317-1333.

Farrugia, C.J., V.K. Jordanova, M.F. Thomsen, G. Lu, S.W.H. Cowley, and K.W. Ogilvie (2006) A two-ejecta event associated with a two-step geomagnetic storm, *J. Geophys. Res*., **111**(A11), A11104.

Farrugia, C.J., A. Grocott, P.E. Sandholt, S.W.H. Cowley, Y. Miyoshi, F.J. Rich, V.K. Jordanova, R.B. Torbert, and A. Sharma (2007) The magnetosphere under weak solar wind forcing, *Annales Geophys*., **25**, 191-205.

Fisk, L. A. and G. Gloeckler (2006) The common spectrum for accelerated ions in the quiet-time solar wind, *Astrophys. J. (Lett*), **640**, doi: 10.1086/503293, L79 - L82.

Gloeckler, G. (2003) Ubiquitous suprathermal tails on the solar wind and pickup ion distributions. *Solar Wind Ten: AIP Conf. Proc.* **679**. 583.

Gloeckler, G., L.A. Fisk, T.H. Zurbuchen, and N.A. Schwardon (2000) in AIP Conf. Proc. 528, Acceleration and Transport of Energetic Particles Observed in the Heliosphere: Proc. Of the ACE-2000 Symp., ed. R. A. Mewaldt et al. (Melville: AIP), 221.

Gopalswamy, N., S. Akiyama, S Yashiro, G. Michalek, and R. P. Lepping (2007) Solar sources of geospace: Consequences of interplanetary magnetic clouds observed during solar cycle 23, *J. Atmos. and Solar-Ter. Phys.*, doi:j.jastp.2007.08.070.

Gosling, J. T. (2007) Observations of magnetic reconnection in the turbulent high-speed solar wind, *Astrophys. J.,* **671,** L73-76.

Gosling, J. T., R. M. Skoug, D. J. McComas, and C. W. Smith (2005) Direct evidence for magnetic reconnection in the solar wind near 1 AU, *J. Geophys. Res.,* **110,** A01107, doi:10.1029/2004JA010809.

Gosling, J. T., S. Eriksson, T. D. Phan, D. E. Larson, R. M. Skoug, and D. J. McComas (2007a) Direct evidence for prolonged magnetic reconnection at a continuous x-line within the heliospheric current sheet, *Geophys. Res. Lett.,* **34**, L06102, doi10.1029/2006GL029033.

Gosling, J. T., S. Eriksson, D. J. McComas, T. D. Phan, and R. M. Skoug (2007b) Multiple magnetic reconnection sites associated with a coronal mass ejection in the solar wind, *J. Geophys. Res.,* **112,** A08106, doi:10.1029/2007JA012418.

Gosling, J. T., T. D. Phan, R. P. Lin, and A. Szabo (2007c) Prevalence of magnetic reconnection at small field shear angles in the solar wind, *Geophys. Res. Lett.,* **34,** L15110, doi:10.1029/2007GL030706.

Gosling, J. T., S. Eriksson, L. Blush, T. D. Phan, J. G. Luhmann, D. J. McComas, R. M. Skoug, M. H. Acuna, C. T. Russell, and K. D. Simunac (2007d) Five spacecraft observations of oppositely directed exhaust jets from a magnetic reconnection x-line extending > 4.26 x 10^6 km in the solar wind at 1 AU, *Geophys. Res. Lett.,* **34,** L20108, doi:10.1029/2007GL031492.

Hu, Q. and B.U.O. Sonnerup (2002) Reconstruction of magnetic clouds in the solar wind: Orientations and configurations, *J. Geophys. Res*., **107**, 1142.

Huttunen, K.E.J., R. Schwenn, V. Bothmer and H.E.J. Koskinen (2005) Properties and geoeffectiveness of magnetic clouds in the rising, maximum and early declining phases of solar cycle 23, *Annales Geophys*., **23**, 625-641.

Huttunen, K.E.J., S.D. Bale, and C. Salem (2008) Wind observations of low energy particles within a solar wind reconnection region, submitted to Annales Geophysicae.

Kasper, J.C. and W. Manchester (2008) Curvature and flow deflection at solar minimum interplanetary shocks, *Astrophys. J*., submitted.

Kasper, J.C., M. Stevens, A.J. Lazarus, J.T. Steinberg, and K.W. Ogilvie (2007) The solar wind helium abundance as a function of speed and heliographic latitude, *Astrophys. J*., **660**, 901-910.

Koval et al. (2008), Allowing anisotropy in the Rankine-Hugoniot fitting of interplanetary shocks, in preparation.

Krucker, S., E.P. Kontar, S. Christe and R.P. Lin (2007) Solar flare electron spectra at the sun and near the earth, *Astrophys. J.*, **663**, L109-L112.

Leitner M, C.J. Farrugia, C. Mostl, K.W. Ogilvie, A.B. Galvin, R. Schwenn and H.K. Biernat, (2007) Consequences of he force-free model of magnetic clouds for their heliospheric evolution, *J. Geophys. Res*., **112** (A6), A06113.

Lepping, R. P., D. B. Berdichevsky, C.-C. Wu, A. Szabo, T. Narock, F. Mariani, A. J. Lazarus, and A. J. Quivers (2006) A summary of WIND magnetic clouds for the years 1995 - 2003: Model-fitted parameters, associated errors, and classifications, *Annales Geophysicae,* **24**, 215 - 245. Sref-ID: 1432 - 0576/ag/2006-24-215.

Lepping, R. P., T. W. Narock, and H. Chen (2008a) Comparison of magnetic field observations of an average magnetic cloud with a simple force free model: The importance of field compression and expansion, *Ann. Geophysicae*, **25**, in press.

Lepping, R. P., C.-C. Wu, N. Gopalswamy, and D. B. Berdichevsky (2008b) Average thickness of magnetosheath upstream of magnetic clouds at 1 AU vs. solar longitude of source, *Solar Phys*., in press.

Liu, Y., J. D. Richardson, J. W. Belcher, C. Wang, Q. Hu, and J. C. Kasper (2006) Constraints on the global structure of magnetic clouds: Transverse size and curvature, *J. Geophys. Res*., **111**, A12S03, doi:10.1029/2006JA011890.

Liu Y., J. D. Richardson, W. B. Manchester IV, J. G. Luhmann, R. P. Lin, and S. D. Bale (2008) Deflection flows ahead of ICMEs as an indicator of curvature and geoeffectiveness, *J. Geophys. Res*., in press.

Luhn, A., B. Klecker, D. Hovestadt, and E. Moebius (1987) The mean ionic charge of silicon in ^{3}He -rich solar flares, *Astrophys. J*., **317**, 951.

Manchester, W.B., T.I. Gombosi, I. Roussev, D.L. De Zeeuw, I.V. Sokolov, K.G. Powell, G. Toth and M. Opher (2004) Three-dimesional MHD simulation of a flux rope driven CME, *J. Geophys. Res*., **109**(A1), A01102.

Marubashi, K. and R.P. Lepping (2008) Long-duration magnetic clouds: A comparison of analyses using torus- and cylindrical-shaped flux rope models, *Ann. Geophysicae*, in press.

Mason, G. M., J. R. Dwyer, and J.E. Mazur (2000) New properties of ^{3}He-rich solar flares deduced from low-energy particle spectra, *Astrophys. J*., **545**, L157.

Merka, J., A. Szabo, T.W. Narock, J.D. Richardson and J.H. King (2005) Three decades of bow shock observations by IMP 8 and model predictions, *Planet. Space Sci*., **53**, 79-84.

Muehlbachler, S., C. J. Farrugia, J. Raeder, H. K. Biernat, and R. B. Torbert (2005) A statistical investigation of dayside magnetosphere erosion showing saturation of response, *J. Geophys. Res*., **110**, A11207, doi:10.1029/2005JA011177.

Odstrcil, D., P. Riley and X.P. Zhao (2004) Numerical simulation of the 12 May 1997 interplanetary CME event, *J. Geophys. Res*., **109**(A2), A02116.

Ogilvie, K.W., M.A. Coplan, D.A. Roberts, and F. Ipavich (2007) Solar wind structure suggested by bimodal correlations of solar wind speed and density between the spacecraft SOHO and Wind, *J. Geophys. Res*., **112**(A8), A08104.

Phan, T. D. et al. (2006) A magnetic reconnection X-line extending more than 390 Earth radii in the solar wind, *Nature,* **439**, 175-178, doi:10.1038/nature04393.

Reiner, M. J., B.V. Jackson, D.F. Webb, D.R. Mizuno, M.L. Kaiser, J.-L. Bougeret (2005) Coronal mass ejection kinematics deduced from white light (Solar Mass Ejection Imager) and radio (Wind/WAVES) observations, *J. Geophys. Res*., **110**, A09S14.

Reiner, M. J., M.L. Kaiser, and J.-L. Bougeret (2007) Coronal and interplanetary propagation of CME/shocks from radio, in situ and white-light observations, *Astrophys. J*., **663**, 1369.

Richardson, I.G., D.F. Webb, J. Zhang, D.B. Berdichevsky, D.A. Biesecker, J.C. Kasper, R. Kataoka, J.T. Steinberg, B.J. Thompson, C.C. Wu and A.N. Zhukov (2007) Major geomagnetic storms (Dst <= -100 nT) generated by corotating interaction regions, *J. Geophys. Res*., **112**, A12105.

Salem C., A. Mangeney, S.D. Bale, P. Veltri, and R. Bruno (2007) Anomalous scaling and the role of intermittency in solar wind MHD turbulence: New insights, in *Turbulence and Nonlinear Processes in Asrtophysical Plasmas*, 6th Annual International Astrophysics Conference, Eds. D. Shaikh and G. P. Zank, American Institute of Physics, New York, pp. 75-82.

Salem C., A. Mangeney, S. D. Bale, B. Cecconi, and P. Veltri (2008a) Solar wind MHD turbulence I: Anomalous scaling and role of intermittency, *Astrophys. J*., in preparation.

Salem C., A. Mangeney, and S. D. Bale (2008b) Solar wind MHD turbulence II: Nature and properties of intermittency, *Astrophys. J.*, in preparation.

Szabo, A. (1994) An improved solution to the Rankine-Hugoniot problem, *J. Geophys. Res*., **99**(A8), 14737-14746.

Tan, L.C., D.V. Reames and C.K. Ng (2007) Bulk flow velocity and first-order anisotropy of solar energetic particles observed on the Wind spacecraft: Overview of three "gradual" particle events, *Astrophys. J*., **661**, 1297-1310.

Tan, L.C., D.V. Reames and C.K. Ng (2008) Ion anisotropy and high-energy variability of large solar particle events: A comparative study, *Astrophys. J*., in press.

Tylka, A.J. and M.A. Lee (2006) A model for spectral and compositional variability at high energies in large, gradual solar particle events, *Astrophys. J*., **646**, 1319-1334.

Tylka A.J, C.M.S. Cohen, W.F. Dierich, M.A.Lee, C.G. Maclennan, R.A. Mewaldt, C.K. Ng, D.V. Reames (2005) Shock geometry, seed populations, and the origin of variable elemental composition at high energies in large gradual solar particle events, *Astrophys. J.,* **625**, 474-495.

Tylka, A.J., C.M.S. Cohen, W.F. Dietrich, M.A. Lee, C.G. MacLennan, R.A. Mewaldt, C.K. Ng and D.V. Reames (2006) A comparative study of ion characteristics in the large gradual solar energetic particle events of 2002 April 21 and 2002 August 24, *Astrophys. J., Suppl. Ser*., **164**, 536-551.

Vinas, A.F. and J.D. Scudder (1986) Fast and optimal solution to the Rankine-Hugoniot problem, *J. Geophys. Res*., **91**(A1), 39-58.

Wang, Y.-M., M. Pick, and G.M. Mason (2006), Coronal holes, jets, and the origin of ^{3}He-rich particle events, *Astrophys. J*., 639, 495.

Wang et al. (2008), The occurrence rate of solar electron/^{3}He-rich events, in preparation.

Wilson, L. B. III, et al. (2007) Waves in interplanetary shocks: A Wind/WAVES study, *Phys. Rev. Lett*., **99**, 041101.

Zhang, X.X., J.D. Perez, T. Chen, C. Wang, P.C. Brandt, D.G. Mitchell, and Y.L. Wang (2005) Proton temperatures in the ring current from ENA images and in situ measurements, *Geophys. Res. Lett*., **32**, L16101.

ACRONYMS

3D	three-dimensional
3DP	3D Plasma (experiment)
ACE	Advanced Composition Explorer
AGILE	Astrorivelatore Gamma ad Immagini LEggero (satellite)
APE	Alpha-Proton-Electron (telescope)
AU	Astronomical Unit
CME	Coronal Mass Ejection
CRaTER	Cosmic Ray Telescope for the Effects of Radiation
DSN	Deep Space Network
Dst	Dynamic - Storm Time
EPACT	Energetic Particles: Acceleration, Composition, and Transport
E/PO	Education and Public Outreach
FTE	Full Time Equivalent
GF	Giant Flares
GGS	Global Geospace Science
GOES	Geostationary Operational Environmental Satellites
GRBs	Gamma Ray Bursts
GSFC	Goddard Space Flight Center
HETE-2	High Energy Transient Explorer-2
HGO	Heliophysics Great Observatory
HI	Heliospheric Imagers
ICME	Interplanetary Coronal Mass Ejection
IMF	Interplanetary Magnetic Field
IMPACT	In-situ Measurements of Particles and CME Transients (suite)
INTEGRAL	INTErnational Gamma-Ray Astrophysics Laboratory
IP	Interplanetary
IPN	Interplanetary GRB Network
ISTP	International Solar-Terrestrial Physics
IT (detector)	Isotope Telescope
ITOS	Integrated Test and Operations System
keV	kilo-electron volt
KONUS	Gamma-Ray Spectrometer
LASCO	Large Angle and Spectrometric COronagraph
LEMT	Low Energy Matrix Telescopes
LET	Low Energy Telescope
LRO	Lunar Reconnaissance Orbiter
LWS	Living With a Star
MC	Magnetic Cloud
MESSENGER	Mercury Surface Space Environment Geochemistry and Ranging
MeV	Mega-electron volt
MHD	Magnetohydrodynamic
MMOC	Multi-Mission Operations Center

MOVE	Mission Operations Voice Enhancement
NASA	National Aeronautics and Space Administration
NSSDC	National Space Science Data Center
PWG	Polar Wind Geotail ground system
RBSP	Radiation Belt Storm Probes
RHESSI	Reuven Ramaty High Energy Solar Spectroscopic Imager
R-XTE	Rossi X-ray Timing Explorer
SDO	Solar Dynamics Observatory
SECCHI	Sun Earth Connection Coronal and Heliospheric Investigation
SEPs	Solar Energetic Particles
SGR	Soft Gamma Repeaters
SIS	Solar Isotope Spectrometer
SMEI	Solar Mass Ejection Imager
SMD	Science Mission Directorate
SMS	SWICS-MASS-STICS (package on Wind)
SOHO	SOlar and Heliospheric Observatory
SPASE	Space Physics Archive Search and Extract
SSMO	Space Science Mission Operations
STEP	SupraThermal Energetic Particle Telescope
STEREO	Solar-Terrestrial Relations Observatory
STICS	SupraThermal Ion Composition Spectrometer
SWE	Solar Wind Experiment
SWICS	Solar Wind Ion Composition Spectrometer
TGRS	Transient Gamma-Ray Spectrometer
THEMIS	Time History of Events and Macroscale Interactions During Substorms
TPOCC	Transportable Payload Operations Control Center
TRACE	Transition Region And Coronal Explorer
ULEIS	Ultra Low Energy Isotope Spectrometer
VDS	Voice/Video Distribution System
VEIS	Vector Ion-Electron Spectrometers
VHO	Virtual Heliophysics Observatory
WYE	Work Year Equivalent