Campaign Plenary Session (Monday afternoon)

Overview of Campaign Events (D. Webb)

SHINE encourages detailed studies of a few carefully selected events to help advance research focused on the connection between events and phenomena on the Sun and related solar wind structures and other in situ measurements in the inner heliosphere. Last year SHINE initiated Campaigns to focus effort on four CME events or periods and related science topics. CME events were chosen because CMEs are the primary transient phenomena that cause the largest interplanetary disturbances, drive shock waves that accelerate particles, and cause the largest geomagnetic storms. Specific questions addressed are: How are CMEs initiated; how do CMEs evolve or propagate; and how are CME-related solar energetic particles accelerated and transported? The Campaigns address these questions by confronting current and developing CME models with observational data and simulations, forcing comparisons between existing models and guiding the development and improvement of new models and simulations.

The four Campaign events were chosen based on reasonably complete data sets, both of the solar source regions and the heliospheric propagation of the CMEs. It is considered desirable but not essential that the events have been Earth-directed so that their in-situ and geoeffective characteristics can be studied. Each of the events has a leader(s) who reviewed the work on each event in terms of why it was selected, what study progress has been made, how the event is incorporated into this workshop including related poster papers, and what comes next. These reviews are summarized below. One of the main goals of the Event coordinator and leaders is to facilitate communications among researchers working on these particular events. With this in mind, a Website has been established at http://www.shinegroup.org/, "Campaign Events", or directly at http://cdaw.gsfc.nasa.gov/CME_list/SHINE2003/index.html. It contains a general discussion, with links to the individual event pages, each of which has an Introduction and Data, Presentations, and Links subpages. Each leader also maintains an email address list for email communication with the members of his Event study group. If you wish to become involved with studies of any of these events, please contact the appropriate Event leader.

The May 1997 Event (N. Arge)

This Campaign event is a key event in several collaborative campaigns including SHINE-GEM-CEDAR, MURI, and CISM. It involved a complete halo observed by LASCO from the only active region (AR 8038) on the entire disk. This AR was near disk center just north of central meridian (N21W08) and had new-cycle polarity. It was the site of all flaring and the CME was associated with the only major flare of the day. The flare had a smooth long-duration X-ray profile and consisted of a small, bright arcade that formed over a classic filament eruption. There were twin NE and SE dimming regions flanking the filament eruption and an EIT wave. Webb et al. (2000) interpreted these as being the footpoints of the subsequent flux rope seen at 1 AU.

At 1 AU the shock arrived at WIND on May 15th at 0115 UT, trailed by enhanced magnetic field lasting about a day. The ejecta was at the leading edge of a modest recurring stream. Prior to the shock/cloud arrival, the heat flux electrons flowed opposite to the field direction, which was directed toward the Sun. Just prior to the shock the electron flux became more bi-directional and the flux traveling parallel to the field increased. The associated magnetic cloud arrived 8 hrs after the shock, had an average transit speed of 548 km/s, sharply decreased proton temperature, and enhanced Helium abundance. But no bidirectional electron flux was observed, suggesting that the cloud was not connected at both ends to the Sun. The cloud was left-handed and to a good approximation fit the Lepping force-free model. The inferred cloud's axis was approximately in and parallel to the ecliptic plane, with southward field leading and north following. A modest high-speed stream, whose source was in the southern hemisphere, compressed the cloud from behind. The event produced a moderate geomagnetic storm (peak *Dst* = -115nT), and was associated with only a weak particle event at Earth.

Arge summarized the web page on this event and the many papers that have been written since 1998 on solar, heliospheric, magnetospheric, ionospheric and lower atmosphere aspects of the event. 26 people were listed as participating in SHINE studies involving this event. Five posters related to May 1997 were summarized. Y. Liu found photospheric magnetic field changes during the May 1997 event. He calculated small-scale changes as indicated by magnetic shear calculated from observed vector magnetograms, and large-scale changes were inferred from a modeled coronal magnetic field (PFSS) computed from the observed photospheric field. Using an LCT technique, Y. Li found observational evidence in this and other events for velocity convergence toward magnetic neutral lines as a factor in CME initiation. X. Bonnin also used magnetic element feature tracking using MDI data during May 1997 and a Monte Carlo model of random walk and flux cancellation to show that the flux cancelled when the elements got "too" close. N. Arge did a comparison of the stream structure and coronal sources of the solar wind during the April 7 and May 12, 1997 halo CMEs. Arge concluded that the moderate high-speed stream that followed behind the ICME came from a coronal hole extension from the south, consistent with that found independently by Odstrcil. M. Owens showed that solar wind flow deflections around fast ICMEs are consistent with flux rope models and show larger flow angles and minimum fields farther from the axis. This suggests ICMEs at 1 AU are very flattened; May 1997 fits this trend.

<u>The May 1998 Event(s) (B. Welsch)</u>

This Campaign "event" now includes two halo CMEs and their sources on 22:30 UT, May 1 and 13:30 UT, May 2, 1998. There is notable evolution in the active region, namely rotational motion that injects energy and helicity, and magnetic flux cancellation that may create a flux rope.

Active region flows are currently a hot topic. There are three new methods being used to find 3-component flows, e.g., ILCT (Inductive local correlation tracking). See below for more about these flows in the poster previews. The modelers are using these data to simulate eruptions.

Significant long magnetic connections with AR 8214 in the north are visible in Yohkoh SXT images. This suggests that CMEs can be global in scale, and that using a "model-in-box" approximation may be problematic. Also, what is the influence of a nearby coronal hole to the eruption?

Some results pertaining to the development of CME #1: The pre-event state has been studied by Sterling & Moore (2001) who found H-alpha/EIT crinkles away from the "core" indicative of breakout-type reconnection.

Some results pertaining to the development of CME #2: Ha Images from Kanzelhöhe Solar Observatory and EIT movies were studied by S. Pohjolainen et al. (2002) and interpreted as a blast (Moreton) wave. The radio sources associated with the event were also described by Pohjolainen et al. (2002). Dimmings in SXT were also observed. Warmuth et al. (2001) also studied the evolution of this blast wave in EIT data, and M. Will-Davey is analyzing TRACE data of the same wave.

In heliospheric and magnetospheric in situ data multiple ICMEs/ejecta were observed during a very disturbed solar wind environment. The effects due to CME #1 are difficult to discern in the ACE/WIND data. There was a shock and significant southward magnetic field. CME #2 was significantly geoeffective, partly due to compression with the existing solar wind conditions. There was a shock and significant southward magnetic field.

Why were these events chosen as SHINE Campaign events? CME #1 was also chosen as a MURI event. Its relatively good time series of Imaging Vector Magnetograph (IVM) data prior to the flare and eruption makes it a good case for driving coronal MHD codes from magnetograms. But the interpretation of CME #1's effects in situ as an ICME are not clear. CME #2 is well observed on the disk in multiple data sets, and was strongly geoeffective.

Our goal is to eventually generate a 'Consensus Report' on these events and possibly to write one or more papers for a special section issue of JGR, perhaps making this a 'Living'-type of article. However, much work has yet to be done.

Welsch invited 4 poster presenters to briefly summarize their work related to the May 1998 events. M. Georgolis discussed a technique for reconstruction of a photospheric velocity field consistent with the induction equation's normal component, independent of LCT results. Results for AR 8210 yielded believable results consistent with the magnetic field evolution. D. Longcope described another technique for deriving a photospheric velocity field from vector magnetograms, called the Minimum Energy Fit. He used this to derive the flow field in the May 1 events with the lowest integrated-square velocity consistent with the observed magnetic evolution. L. Lundquist used a steady state, non-linear force free energy balance model to calculate the coronal magnetic field and thermodynamics of coronal structure from photospheric magnetograms. These were used to create synthetic soft X-ray emission images to compare with different heating rates for AR 8210. I. Roussev summarized some results of his numerical model of the CME initiation and shock development of the May 2 event that was presented later (see Tuesday splinter session #2).

<u>The April and August 2002 Events (A. Tylka)</u>

The two 2002 events focus on a specific problem in current SEP research, the origin of variability at high energies. Below ~10 MeV/nucleon the SEP characteristics of these two events are very similar. But at higher energies the events diverge, so that the Fe/C ratio at ~60 MeV/nuc differs by two orders of magnitude. Compared to nominal coronal values, the April event is Fe-poor at high energies, while the August event is Fe-rich. Because both events originated from near the west limb, the high-energy particles likely reflect conditions near the Sun, probably below 15 Rs and quite possibly as low as just a few Rs. These SEP differences arose even though the associated CMEs and flares were ostensibly very similar in these two events.

The active regions that spawned these two events also produced several flares and CMEs in the ~10 proceeding days; AR 9906 generally produced fewer and significantly smaller flares than AR 0069. The strategy for studying these events is therefore twofold: 1) Comparative studies of the two active regions, including their earlier history, using SOHO, TRACE, RHESSI, and other solar observations to identify differences and to "brainstorm" about the possible relevance to SEPs. (These efforts were highlighted by the two talks in plenary session (below) by D. Alexander on the pre-event history of these active regions and by J. Raymond on SOHO UVCS observations of the events.); and 2) Energetic particle analyses and modeling, beginning with these two events, but also addressing the larger range of event-to-event variability, as seen in both SEP events and particles accelerated locally when a shock arrives at 1 AU. These energetic particle efforts were introduced in A.Tylka's plenary talk. They were also the focus of the WG3 Splinter Session #4 on Tuesday morning (see below).

<u>Energetic Particle Studies</u>

The high-energy variability exemplified by these two events has been a matter of intense debate in the SEP community. Current discussions center on three hypotheses: (1) a combination of differences in seed population and near-Sun shock geometry (quasi-parallel vs. quasi-perp); (2) seed population alone, with shock geometry being irrelevant; and (3) a direct flare component at high-energies in the August event, making both shock geometry and seed population irrelevant. As Tylka ruefully noted, there is one point on which the proponents of the various hypotheses all agree: at least two of the hypotheses are wrong!

Tylka reviewed differences between the SEP characteristics of the two Campaign events. These differences include not only the energy dependence of Fe/C but also the functional forms of the ion energy spectra. The April event exhibits power-law spectra that rollover exponentially at high-energies while, in the August event, the initial power-law steepens into a second power law at high energies. In the April event, Fe has a steeper exponential rollover than C, causing Fe/C to drop. In the August event Fe has a harder power-law than C at high energies (above 10 Mev/nuc), causing Fe/C to rise with increasing energy. The shapes of the proton timelines above 50 MeV are also different, with markedly shorter durations in the August event. Finally, the seed populations into which the CMEs launched were different for the two events, at least to the extent that they can be inferred from measurements at 1 AU. In the four days preceding the April event, Wind and ACE showed Fe/O ~ 0.1, while Fe/O ~ 1 in the four days before the August event. It is hoped that a successful hypothesis will take account of all of these differences.

Subsequent discussion also noted indirect indications that the SEP ionic charge states were substantially different in the two events. Spectral analyses of the April event suggest heavy-ion charge states consistent with a source plasma temperature of ~1.4 MK, with <QFe> ~ 12. There are no charge-state measurements or analyses for the August event. But its spectral and heavy-ion characteristics are very similar to those of the very large April 15, 2001 GLE. In that event, SAMPEX measured <QFe> increasing with energy, going from ~10 at ~1 MeV/nuc and reaching <QFe> ~20 above 30 MeV/nuc. These charge states are another important constraint for models.

Although the campaign events serve to stimulate thinking about high-energy variability, these two events are just a starting point. Accordingly, Tylka also reviewed recent results from statistical studies of large event samples. One important observation is that IP shocks at 1 AU, as reported by Desai et al., exhibit the same extremes in morphology as the SEP events, but at lower energies. Second, SEP events with high-energy Fe/O enhancements are observed from source regions with a much broader range of longitudes than found in classic flare-associated "impulsive" events. Third, the correlation between high-energy Fe/O and spectral shapes seen in the Campaign events is a general feature of the high-energy SEP data. Finally, the average value of Fe/O at high-energies in events with enhanced Fe/O is only about two-thirds of the average Fe/O observed in impulsive events. It remains to be seen whether any of these "additional facts" can be construed as conclusive evidence for or against any of the hypotheses. In any case, they are observational constraints that all of the hypotheses should address.

Solar Studies

D. Alexander reported on work done at Rice U. where a detailed comparison of the active regions (AR 9906 and AR 0069) in the build-up to the 21 April and 24 August 2002 SEP events was performed. Although the SEP signatures showed marked differences, the events themselves are difficult to distinguish in either their hard X-ray chromospheric emission or their coronal signatures. Alexander et al. examined the prior evolution of the two active regions to look for possible differences in the radiative (EUV corona), magnetic (closed/open field, large-scale connections to other active regions) or activity (flare/CME productivity) signatures of the active regions. They concentrated on signatures in the ambient corona, magnetic connectivities and flare/activity histories within the active regions. The aim was to attempt to find AR properties that might differentiate the solar conditions leading to the disparate particle signatures at 1 AU. They concluded that the August region was more flare-productive (both in number and size of flares) and the corona more active than the April region. The two active regions were also distinguished by the large-scale field topology. Potential field mapping of the field in AR 9906 (April) indicated the presence of large areas of open field in close proximity to the active region. AR 0069 (August) was notable by the lack of open field in and around the region and by its multiple connections to nearby active regions. While it is debatable whether either flare has a direct connection to Earth, the presence of open field in the April case gives more direct access to IP space than in August. Direct injection of flare particles to a shock for the April 21 event depends on the longitudinal extent of the shock. The August active region was also notable for its large-flare productivity, and evidence of expanding closed-field structures. It was speculated that long-term trapping of flare particles could provide a seed population for the August event.

J. Raymond discussed the SOHO UVCS observations of the 21 April and 24 August 2002 CMEs. As part of a Max Millenium campaign, UVCS obtained a series of 120-second exposures at a heliocentric distance of 1.64 solar radii at the position angle of each of these events. The spectral range included the lines of O VI, Si XII and [Fe XVIII], along with Lyβ and C III. The major results were: 1) Whereas most CMEs observed with UVCS show extremely bright emission in low-temperature emission lines such as Lyβ, C III and O VI, both of these events had very little low-temperature emission. Both showed strong emission in the [Fe XVIII] line, which is formed near 6 x 10^6 K. Either little cool gas was ejected, or it was heated very rapidly before it reached 1.64 solar radii. 2) The [Fe XVIII] morphology indicates a current sheet seen edge-on in the April 21 event and a loop of hot gas pushing the CME front in the August 24 event. 3) The streamers were rapidly disrupted, with the O VI lines showing Doppler shifts up to 800 km/s and the disturbances spreading along the slit at 1000 km/s. 4) The narrow line profiles of the O VI lines indicate that a shock had not formed when the CME front passed the UVCS slit at 1.64 solar radii.

Posters relevant to the 2002 Campaign Events

Ten posters were related to the 2002 Campaign events. Four posters were by David Alexander and his students, Antoun Daou, Rui Liu, and Aaron Coyner, and reported detailed comparison of the solar conditions in the active regions in the build-up to the two 2002 SEP events. Nat Gopalswamy reported on coronal and IP shock observations in the April 21, 2002 event and their implication for the CME onset time. Paul Evenson, John Bieber, et al. analyzed data collected by the 11-station Space-ship Earth neutron monitor network in the August 24, 2002 event. They derived and modeled the evolution of the particle density and anisotropy. They concluded that the onset of release of ~GeV particles from the Sun occurred ~13 minutes after the peak in the Hα emission and when the CME-driven shock was at ~3 or 4 Rs. Hilary Cane suggested that the SEP composition data at 1 AU indicate there are two distinct acceleration mechanisms operating in these events: flare and shock/CME. The latter dominates in the April event and the flare component in the August event. Allan Tylka et al. reviewed support for the shock-geometry/seed population hypothesis, based on both IP shock events at 1 AU with the same extreme morphologies as the Campaign events and correlation studies of the characteristics of the 43 largest proton events of Cycle 23. Kristi Keller et al. illustrated capabilities available at the Coordinated Community Modeling Center (CCMC) to model the Campaign events. Dusan Ostracil showed preliminary simulations of the interplanetary propagation of the CMEs in the Campaign events. Whereas the April 21, 2002 event showed a quasi-parallel shock as it traveled along the Sun-Earth field line, the August 24, 2002 event favored quasi-perpendicular configurations.

Campaign Splinter Sessions (Tuesday morning)

Session 1: Energetics of the Corona

The main purpose of this splinter session was to present recent work related to the energetics and structure of the corona associated with the April 21, 2002 Campaign event and the recent October/November 2003 (non-Campaign) events. Of particular focus was AR 0486, which showed extreme activity in October/November 2003. What were its energetics and coronal structure? We can now directly measure the free energy of the non-potential magnetic field using chromospheric vector magnetograms and the magnetic virial theorem.

David Alexander discussed the energetics of the April 21, 2002 event. Associated with many CMEs is a reconfiguration and energization of the low corona. In particular, solar flares are often the most energetic signatures of a CME in the low corona. The energetic signatures of the low corona in the aftermath of a CME were discussed with emphasis on the high-energy particle and photon emissions accompanying these events and their apparent association with topological structures in the magnetic field. It is necessary to include energy associated with accelerated particles, both electrons and ions, thermal emissions, both multi-thermal and including radiative losses, accelerated mass in the CME, and all integrated over time. RHESSI and TRACE data show that there is hot plasma (~20 MK) high in the corona during the April event. Gallagher, Lawrence and Dennis (2003) showed that the peak acceleration of the flare coincided with the peak of hard X-ray production. Alexander described the various forms of energy in the event including the magnetic field and that from the flare and CME. An important point is that the hard X-ray and gamma-ray emission tends to be relatively localized, indicating preferential sites of particle acceleration. We need to relate the physics of particle acceleration to the trigger and to the global magnetic topology to understand the energetics in these events.

Tom Metcalf described the chromospheric vector magnetic field data obtained at Mees Solar Observatory, Hawaii for AR 0486 in October/November 2003. He used these data to compute the magnetic free energy and its time variation for the AR, finding that there was plenty of free magnetic energy available to power the extreme activity in AR 0486. The extreme event of November 4 had an energy approaching 10^33 ergs.

Jim McTiernan discussed the magnetic structures of AR 0486 on October 29. He used a non-linear, force-free field optimization method to interpret the source patterns and motions seen in RHESSI and TRACE images.

Angelous Vourlidas discussed the energetics determined for the CMEs during October-November 2003 as well as methods used to measure the energy content of CMEs in general.

Session 2: Modeling Campaign Event CMEs

The main purpose of this splinter session was to compare several developing models of CME initiation and/or propagation as applied to one or more of the Campaign events.

Illia Roussev discussed his numerical model of CME initiation and shock development for the May 2, 1998 event, and the implications for the acceleration of GeV protons. The model incorporates magnetogram data from Wilcox Solar Observatory and a loss-of-equilibrium mechanism to initiate the solar eruption. The eruption is achieved by slowly evolving the boundary conditions for the magnetic field to account for sunspot rotation and magnetic flux cancellation. The model includes a coupled diffusion equation model for cosmic rays with the MHD coronal model. A CME-driven shock can develop close to Sun that is sufficiently strong to account for energetic solar protons up to a few GeV! The SEP acceleration by the diffuse-shock-acceleration mechanism occurs near the Sun at $R\sim(3\text{-}12)R_S$ and has a relatively short time scale (~2 hrs).

Zoran Mikic talked about progress and challenges in modeling the May 12, 1997 CME. He discussed five progressively more realistic cases (the first four of which he has actually conducted the model runs) involving a decreasing size of the active region and increasing magnetic field strength and density: Case 1: Axisymmetric dipole field, Case 2: Dipole field + bipole (relatively large scale), Case 3: Dipole field + bipole (intermediate scale), Case 4: Dipole field + bipole (small scale), Case 5: MDI magnetogram on May 11, 1997. His conclusions are that considerable progress has been made in modeling a more realistic field that includes an active region and that calculations with B ~ 1000 G are possible. Future work requires the need for better initialization of the plasma pressure and density, incorporation of the observed magnetic field on May 12, 1997, energization of the initial state (guidance from the constant alpha solution of Yang Liu), exploration of flux cancellation to disrupt the active region and generate a CME, and to follow the propagation of the CME in interplanetary space.

Dusan Odstrcil discussed heliospheric simulations of the Campaign events, specifically numerical modeling of the 21 April 2002 and 24 August 2002 events and the 12 May 1997 event

The SAIC 3-D MHD, steady-state coronal model as well as the CU/CIRES-NOAA/SEC potential field-Schatten current sheet model were coupled, independently, with the advanced ENLIL 3D MHD solar wind model. The Zhao CME cone model was used to generate solar transients. An important conclusion is that fine details of the observations and the simulations can be very important!

Session 3: In Situ Observations and Flux Rope Fitting for Campaign Events

Flux Rope Fitting:
B. Lynch and Q. Hu presented their different models of the May 1997 cloud observation and agree that the flux rope was approx. symmetric, that its axis was close to the ecliptic plane, and that WIND passed close to the center. It has a left-handed rotation. M. Owens modeled flow deflections ahead of the cloud and finds that the May 1997 cloud was highly flattened, almost concave-outward! Only Lynch modeled the May 1998 cloud observation. He finds that the axis was inclined N-S and along the Sun-Earth line and the rope was right-handed. The ACE spacecraft may have encountered one leg of the flux rope. T. Mulligan reviewed her work on non-force free, empirical modeling of multi-spacecraft observations of flux ropes. She found good reproducibility of results for textbook clouds, but greater variability when |B| was reduced or the impact parameter was large. She finds 4 categories of flux rope geometries: simple distortion, multiple ropes, those with twisted axes, and multiple ropes that are not interacting. I. Richardson commented that during the Helios period there were often 2-3 spacecraft observations of the same magnetic cloud; these should be examined and modeled.

Composition and In Situ Observations:
A. Reinard reviewed composition and charge state data for the May events. The composition data for May 1997 are questionable, e.g., Geotail was in the magnetotail. However, T. Zurbuchen commented that limited Wind composition data (MAS and STICS) are available and should be analyzed. The May 1998 cloud showed an unusual mixture of hot and cold charge states. He and Fe were very enhanced and of long duration. It is possible that the CME developed low in the corona and dragged material out with it. There were high He^{++}/p^{+} levels in May 1998 both ahead, during and behind the flux rope. The composition signatures correlate well with the cloud and the following complex event (Burlaga et al., 2001). I. Richardson discussed in-situ signatures of ICMEs and the May 1998 data. He emphasized that not all ICMEs are magnetic clouds, and that the depressed Tp flow is one of the best overall signatures. He described the May 1997 signatures in a GRL paper in 1998. The May 1998 cloud passed first followed by the complex ejecta. There were two Forbush cosmic ray decreases associated with the cloud and complex ejecta. There was discussion of 3 similar velocity and B peaks on May 5-6 that C. Farrugia ascribes to reconnection interfaces. More study was promised.

Space Weather/Coupling:
C. Goodrich reviewed the general concepts of space weather including magnetospheric activity parameters, which lead to geoeffectiveness. These include changes in the magnetic field, power input to the ionosphere through currents, and interactions of the radiation environment. The main solar wind sources are strong, southward IP field and kinetic pressure. May 1997 was a moderate storm and May 1998 had a smaller storm associated with the magnetic cloud followed by a major storm associated with the complex ejecta. C. Farrugia discussed the May 1998 event. For this disturbance, $B_Z < 0$ led to an erosion phase followed by a compression phase with an unprecedented increase in the Earth's magnetic field over the south pole. This produced 350 GWatts of power being input to the magnetosphere.

Session 4: What causes the energy-dependent Fe/O in large SEP events?

Allan Tylka and Marty Lee presented a heuristic model in which the injection threshold speed increases with shock normal angle. By averaging over a range of shock-normal angles as the shock moves out from the Sun, these simple calculations were able to reproduce both Fe/O energy dependence and the underlying variability in the spectral shapes. The model is also applicable to IP shocks at 1 AU. The model also reproduced some quantitative features of the high-energy SEP data, such as the average Fe/O value seen at high-energies in Fe-rich events. This highly simplified modeling may provide the first step toward understanding such events.

However, several issues remain unresolved. For instance, although the spectra and composition in ESP events correlated well with those of a variable suprathermal seed population, Mihir Desai reported that their relationship with the local shock properties was poor. Furthermore, there is a broad range of theoretical opinion about whether the injection threshold actually depends on shock-normal angle. Earlier papers by Jokipii (1987) and Webb et al. (1995) suggested that it should. But Joe Giacalone discussed recent calculations, which include large-scale magnetic field structure, that give different results.

Gang Li and Josef Kota reported very promising preliminary results from combined MHD simulations and particle acceleration. Li's results showed spectral rollovers with suppressed Fe/O reminiscent of the 2002 April 21 event, while Kota's simulations hinted at double-power-law spectra, similar to those seen in the 2002 August 24 event. We look forward to further development of both of these models and detailed comparisons with the data