SH12C MC: 302 Monday 1330h

Shocks and Shock Manifestations Over the Solar Cycle: Energetic Particles

Presiding: **D Reames,** NASA/Goddard Space Flight Center**; K W Ogilvie,** NASA/GSFC

SH12C-01 1330h INVITED

Energy Spectra of Shock-Accelerated Solar Energetic Particles

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We review recent studies of the energy spectra in large, gradual solar energetic particle events, in which the primary accelerator is believed to be shocks driven by fast coronal mass ejections (CMEs). By combining measurements from instruments on Wind, ACE, and IMP8, the observed spectra cover all major species (from protons through Fe) and extend over nearly four orders of magnitude in energy. We show how the general characteristics of these spectra conform to theoretical expectations based on shock theory and transport through proton-amplified Alfven waves. We particularly emphasize exponential rollovers or knees, which provide a kind of remote sensing, through which scattering conditions in the near-shock region can be diagnosed even when the shock is still far from Earth. We also show how these spectral knees (particularly for Fe) can be used to investigate the seed population from which the energetic particles are accelerated.

SH12C-02 1350h

The Seed Population for Energetic (>50 keV/nucleon) Ions Accelerated at Interplanetary Shocks

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It is presently believed that the energetic (>50 keV/nucleon) ion population accelerated at interplanetary (IP) shocks driven by fast coronal mass ejections or CMEs originates predominantly from the bulk solar wind. The sophisticated set of high sensitivity mass spectrometers on board the Advanced Composition Explorer (ACE) spacecraft has provided us with detailed composition measurements that have enabled us to address the question of the origin of the source population for such IP shocks. We have surveyed the 0.05-10.0 MeV/nucleon elemental abundances of 48 IP shocks observed by the Ultra Low Energy Isotope Spectrometer (ULEIS) on board ACE from October 1997 through November 2000. Our survey shows that ^{3}He ions are accelerated at 25 IP shocks with the ^{3}He/^{4}He ratio being enhanced between factors of ∼3-600 over the solar wind value. Our results also show that the mean abundances of heavier elements such as C, N, O, Ne, Mg, Si, S, Ca, and Fe are markedly different when compared with the corresponding abundances measured in the solar wind. We also find that the elemental composition of IP shocks is remarkably similar to that of the energetic ions present in the interplanetary medium upstream of the shocks. We conclude that the ^{3}He and heavy ion enhancements at IP shocks cannot be attributed to shock acceleration of thermal solar wind ions. We suggest that IP shocks accelerate a suprathermal or energetic seed population comprising ions left over from impulsive solar flares as suggested by Mason et al. (1999), as well as those left over from large gradual solar energetic particle events or SEPs.

SH12C-03 1405h

SEP Fe Charge States in 3He-Rich Interplanetary Shock Events

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3He/4He enhancements have been detected with the ACE/ULEIS instrument in several interplanetary shock events. These enhancements have been interpreted by Desai et al (2001) as reaccelerated suprathermal ions originally accelerated in flare events at the Sun.

Another signature of flare-associated ions is highly ionized Fe. The ionic charge state of Fe at approximately 0.25 MeV/nuc has been measured for these events by the ACE/SEPICA instrument. An initial study of eight of the events showed a tendency for high charge state Fe (Q>12+) to be enhanced when the 3He/4He ratio was highest. This result is consistent with the Desai (2001) interpretation. This work extends the initial study to the entire set of 3He-enriched events selected by Desai et al (2001). In addition to a suprathermal ion source for these solar energetic particles, the possible role of CME-type solar wind will also be discussed.

SH12C-04 1420h

Abundance Variations of Energetic He+ in CME Related SEP Events

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We have investigated several CME related SEP events with unusually high abundance in He+ in the energetic particle population which have been observed between 1998 and 2000 with ACE SEPICA and SOHO CELIAS. Usually the abundance of He+ is below a few percent whereas at these times the He+/He2+ ratio can be closer to one. Possible sources for He+ are interstellar pickup ions or cold solar ejecta in CMEs. The temporal evolution and the energy spectra of these events have been investigated in detail. The maximum of the He+/He2+ ratio usually coincides with the arrival of the shock or a discontinuity. This seems to suggest local acceleration of these ions. The He+ enhancement does not seem to be associated with cold ejecta in the CME. Therefore, most probably interstellar pickup ions are the source for the He+ enhancement. Furthermore, the He+/He2+ ratio appears to be consistently lower at higher energies, and the observed temporal variability decreases with increasing energy. This seems to indicate two different populations for He+ and He2+ with different energy spectra.

SH12C-05 1435h

High Energy Ionic Charge State Measurements from Recent Solar Energetic Particle Events of 2000-2001

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The ionic charge states of solar energetic particles (SEPs) provide information on the temperature of the source region and on conditions of acceleration and transport during which additional electron stripping may occur. Measurements of SEP charge states at relatively high energies (> 15 MeV/nucleon) have been made using the Mass Spectrometer Telescope (MAST) on board the Solar, Anomalous, and Magnetospheric Particle Explorer (SAMPEX) satellite with the geomagnetic rigidity filter technique. We have measured the geomagnetic cutoff latitudes in recent SEP events from July 2000 and March and April 2001 (see Leske et al., this meeting), and we present ionic charge states derived from these measurements in combination with our charge state measurements for other large SEP events from solar cycle 23. We find some relatively high Fe charge states of around 20 for events which are most likely gradual, and we find that higher Fe charge states correlate with higher Fe/O abundance ratios.

This work is supported in part by NASA under contract NAS5-30704 and grant NAGW-1919.

SH12C-06 1450h

Charge-to-mass fractionation during injection and acceleration of suprathermal particles associated with the Bastille Day event: SOHO/CELIAS/HSTOF data

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We present SOHO/CELIAS/HSTOF data on suprathermal H, He, CNO, and Fe ions associated with the Bastille Day event, July 14–15, 2000. We observe a temporal evolution of the spectra in the energy range 0.05–2 MeV/amu. Before the passage of the strong interplanetary shock of this event, we observe power law distributions with equal spectral indices for all species. After the shock passage and in the initial portion of the following magnetic cloud, the spectral shapes vary significantly and depend strongly on the charge-to-mass ratio of the ion species.

SH12C-07 1525h

On the Acceleration of Pickup He$^+$ at 1 AU

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We investigate the variation of suprathermal He$^+$/He^{2+} abundances in the energy range 85-280 keV during the years 1997 to 2001 at 1 AU, using data from the CELIAS/STOF experiment onboard SOHO. It has been shown that the He$^+$ ions in this energy range form the suprathermal tail of accelerated pickup helium of interstellar origin. We observe a large variability of the He$^+$ abundance ranging from He$^+$/He^{2+} <5% to

He^+/He^{2+} >1. We correlate 12 hour averages of the He^+ abundance at suprathermal energies for all days with significant He^+ flux with solar wind parameters and find a general anti-correlation of He^+ abundance with the solar wind velocity and the solar wind thermal velocity. We discuss possible causes of this variability, in particular variations of the source strength of pickup ions and solar wind alphas and variations of the acceleration efficiency for He^+ and He^{2+}.

SH12C-08 1540h

Energetic Storm Particle Events Observed on ACE from September 1997 to December 2000

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Energetic Storm Particle (ESP) events are increases of energetic charged particle intensities that are observed upstream and downstream of interplanetary (IP) shocks. ESP events are observed most commonly in ion intensities and have time scales ∼hours. The solar wind plasma and magnetic field instruments on the ACE spacecraft (at the L1 Lagrangian point ∼230 Re upstream of the Earth) have detected over 200 IP shocks during the period September 1997 to December 2000. More than half of these shocks produced ESP signatures in the intensities of ions >47 keV and electrons >38 keV, as measured by the Electron Proton and Alpha Monitor (EPAM) instrument on ACE. Most of the observed ion ESP signatures fall within three classes: 1) gradual, monotonic intensity increases and decreases before and after the shock; 2) spike-like intensity increases around the shock; 3) step-like intensity increases across the shock. Typical intensity enhancements of ions 47-65 keV range from ∼1 to 100. While intensity enhancements of electrons 38-53 keV were also observed at some of these shocks, such enhancements varied only from ∼1 to 30. There is no apparent correlation between the intensity enhancement factor of the ions and electrons. That is, large enhancements of ion intensities do not always correspond to large enhancements of the electron intensities. In this paper we investigate the solar-cycle dependence of these ESP events, and use ACE/EPAM data to examine the ion energy spectra and angular distributions observed for some of these events.

SH12C-09 1555h INVITED

The Theory of Particle Acceleration at Coronal/Interplanetary Shocks

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The basic processes controlling the diffusive shock acceleration of particles at coronal/interplanetary shocks are first described: adiabatic deceleration of the particles in the diverging solar wind, magnetic focusing of the particles in the interplanetary magnetic field, wave excitation by the accelerated protons, and particle injection at the shock front. A review of theoretical work on the shock acceleration of solar energetic particles in large gradual events is presented with emphasis on a particular recent calculation [M.A. Lee, EOS Supplement, 82, 20, S334, 2001 (Abstract)]. This calculation is based on the approximation that the particle acceleration timescale is small compared with the evolutionary timescale of the shock. The results of the calculation for the ion omnidirectional distribution functions, the ion anisotropies, and the wave intensity are presented with emphasis on new predictions for the time profiles of the ion intensities and anisotropies at Earth orbit and the ion intensities downstream of the shock. Certain features of the calculation will be discussed in the context of recent observations: the form of the ion cutoff at high energies, ion compositional variations upstream of the shock, and the sensitivity of the ion intensity time profiles to the plasma and shock characteristics near the Sun.

SH12C-10 1615h

Propagation of Energetic Charged Particles in the Presence of Multiple Shocks(Coronal Mass Ejections)

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Interplanetary transport of energetic charged particles normally is treated in terms of focusing in the large scale magnetic field and pitch angle scattering at magnetic field inhomogenities. We have incorporated shocks as particle sources and shells of enhanced interplanetary scattering as well as coronal mass ejections (CMEs) as deformations of the interplanetary magnetic field into a numerical solution of the standard focued transport model to study particle propagation in the presence of multiple shocks and CMEs. Special attention is paid to the storage of particles betwenn pairs of shocks/CMEs because this seems to be important for particle acceleration and the creation of unusually large particle events. The reflection of particles from the leading shock has been identified as crucial parameter. Different physical scenarios (scattering in downstream turbulence, reflection at the converging field yround the CME) for this reflection are discussed.

SH12C-11 1630h

Electron Acceleration and Heating Influenced by Whistler Wave Packets at Quasi-Parallel Shock Waves

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The acceleration and heating processes of electrons at quasi-parallel shock waves are studied by means of a one-dimensional full particle computer simulation. Our simulation shows that the ion beam instability due to the anomalous cyclotron resonance excites whistler mode waves in the upstream region. When the Mach number becomes large beyond a critical value, the whistler wave packets do not appear. The electron acceleration parallel to the magnetic field results from the parallel electric fields caused by both the whistler mode waves and the electrostatic shock potential. The Mach number dependence of the potential concerning the parallel electric field exhibits different tendency on reaching the critical Mach number as to whether whistler mode waves appear in the upstream region or not. This verifies that the contribution of the whistler waves to the parallel acceleration is as important as that of the electrostatic shock potential. Also, the spatial profile of the potential concerning the parallel electric field is clearly correlated with the magnetic field profile. In the downstream region, the electron temperature tends to be anisotropic and the parallel temperature becomes larger than the perpendicular temperature. Since we cannot see the clear correlation between the parallel temperature and the macroscopic electric potential, it is concluded that the parallel heating of electrons occurs primarily owing to the wave-particle interaction (current-driven instability) rather than the adiabatic motion of electrons in the macroscopic field.

SH12C-12 1645h

Diffusive Electron Acceleration at Interplanetary CME Shocks: Comparison between events on 21 Feb 1994 and 15 July 2000

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While the diffusive shock acceleration (DSA) process of electrons has significant astrophysical importance, reports of in situ observations of such process accompanying with interplanetary CME shocks at 1 AU have been limited to several big events, such as those on 21 Feb 1994 and 15 July 2000 [Shimada et al., ASS, 1999; Terasawa et al., ICRC, 2001]. In this presentation, we will present the results of comparative studies of these important events based on the GEOTAIL measurements. Common features of these events are, (1) high average propagation speeds from the sun to 1AU (∼1300 km/s and ∼1500 km/s), (2) high local propagation speeds at 1 AU (∼920 km/s and ∼1100 km/s), (3) exponential upstream time profiles of nonthermal electrons (up to 40 keV), and (4) nearly power-law energy spectrum. Despite these similarities, one noticeable difference among them was the relative flux increases of accelerated electrons: In the energy range of several keV to 20 keV nearly two-order of magnitude flux increases were observed at the former shock, while the corresponding increase at the latter shock was only a factor of ∼3. We are now trying to identify the origin of this difference: One possibility is the different shock angles (∼68 deg for the former, and ∼48 deg for the latter). Further search for the difference in scattering agents of these electrons is also under way (For the former shock, intensification of whistler waves of several Hz was identified.)

SH21A MC: Hall D Tuesday 0830h

Waves and Turbulence

Presiding: **J Giacalone,** University of Arizona

SH21A-0721 0830h POSTER

Evidence for Compressive MHD Waves in the Solar Wind Near the Sun

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Radio scattering observations in the inner solar wind provide a measure of the density fluctuations on scales of 2 to 50 km. Measurements with antenna arrays, such as the VLA and GMRT, show that this "microscale turbulence" is highly field-aligned, and the axial ratio of the structure decreases with increasing solar distance. In contrast, density fluctuations at scales between 1000 and 10,000 km appear to be almost isotropic. The microscale fluctuations also have a flatter spatial spectrum than the larger scale fluctuations (which have a Kolmogorov spectral exponent). Here we will present observations of multiple antenna intensity scintillation in the fast polar streams, which indicate that the speed of the microscale fluctuations is higher than the flow speed by approximately the Alfven speed. The observations, taken together, provide strong support for the suggestion (Harmon, 1989) that the microscale density fluctuations are caused by obliquely propagating Alfven waves. Detailed modeling shows that the observations are consistent with a mixture of Alfvén waves and slow magneto-acoustic waves, both of which must propagate obliquely outwards.

SH21A-0722 0830h POSTER

Radio Scattering Signature of High-Frequency Alfvén (Ion Cyclotron) Waves in the Inner Solar Wind

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Recent modeling results by Coles on near-Sun IPS velocities has led us to revive an earlier suggestion (Harmon, 1989) that obliquely propagating Alfvén waves produce observable effects at the high-frequency end of the plasma density spectrum inferred from radio scattering. The idea that the high-frequency flattening of the density spectrum is an Alfvén compressibility effect is consistent with (1) the absence of such flattening in spacecraft B-field spectra and (2) the degree of flattening expected based on an inward extrapolation of Helios B-field spectra. This presumes that the density spectrum is a composite of a high-frequency Alfvén compressibility component and a Kolmogorov component (e.g., pressure balance or pseudosound fluctuations) riding on the Alfvénic turbulence. Our wave damping calculations show that passive erosion of outgoing WKB Alfvén waves produces an inner scale larger than that observed. However, we find that introducing a turbulent cascade at the Kolmogorov rate pushes the inner scale out to the ion inertial length, in better agreement with observations. Associated with this