Project Details

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Project Title:
Energetic Particle Acceleration at CME-driven Shocks

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Summary:
We propose a three year program to analyze the energetic particle signatures produced by interplanetary shocks driven by coronal mass ejections (CMEs) at their arrival at 1 AU. We will use data from the magnetometers and solar wind experiments on board the Advanced Composition Explorer (ACE) and the Interplanetary Monitoring Platform (IMP-8) to determine the physical characteristics of such shocks (i.e., strength, normal vector orientation, Mach Number, magnetic compression ratio, and speed). In order to determine the effects that shocks have on energetic particle population, we will use energetic particle data from the Charged Particle Measurements Experiment (CPME) and Energetic Particle Experiment (EPE) on board IMP-8, the Energetic Proton Alpha Monitor (EPAM) and Ultra Low Energy Isotope Spectrometer (ULEIS) on board ACE, and the Energetic Particle Sensor (EPS) on board the Geostationary Operational Environmental Satellites (GOES). The large angular coverage and high-time resolution of ACE/EPAM will allow us to study the anisotropy flow of energetic ions in both the upstream and downstream regions of the shocks. The high-time resolution of the magnetometer on ACE will allow us to determine the level and frequencies of hydromagnetic wave turbulence associated with the shocks or generated by the energetic particles. The high sensitivity of ACE/ULEIS will allow us to determine the elemental abundances of the energetic particle enhancements observed in association with the shocks. We will correlate shock characteristics with the energetic particle effects. We will perform detail analyses of the most intense events and distinguish those events consistent with predictions of the current shock acceleration theories and those events in which additional mechanisms play important roles, such as trapping of particles around the shock, and/or contribution of additional sources of particles. We will also use an existing simulation model to understand the effects that the shock structure, the upstream medium and seed particle population have on the formation of ESP events. We will determine (1) the acceleration mechanisms working at the CME-driven shocks; (2) the seed particle population of the ESP events; (3) the energy gained by this seed particle population; (4) the effects of magnetic structures formed in the upstream and downstream regions of the shocks; and (5) the origin, characteristics, and effects of the hydromagnetic wave turbulence associated with the shocks.

Publication References:

Summary: ''

Reference: Lario, David JHU/APL - Energetic Particle Acceleration at CME-driven Shocks

Summary: Survey of proton and electron intensity-time profiles associated with interplanetary shocks has revealed the following: (1) intensity increases associated with a shock passage are more frequently observed in the low-energy ion fluxes; (2) electron shock events, which occur less frequently than ion shock events, are mainly spikes or step-like post-shock increases; and, (3) there is a large fraction of shock passages that do not show particle intensity enhancements.

Reference: Lario D.; Ho G. C.; Decker R. B.; Roelof E. C.; Desai M. I.; Smith C. W.; (2003). ACE Observations of Energetic Particles Associated with Transient Interplanetary Shocks. , 679, 640-643, doi: 10.1063/1.1618676

- **Investigation Type:** Data Analysis
- **Data Sources:** ACE:EPAM ACE:SWEPAM ACE:MAG

Summary: Shock interactions for >38 keV electrons at 1 AU are weak, implying that the strong interaction (i.e., multiple shock crossings) description is usually not applicable to explain electron ESP shock events.

Reference: Ho G. C.; Lario D.; Decker R. B.; Roelof E. C.; Desai M.; Smith C. W.; (2003). Energetic Electrons Associated with Transient Interplanetary Shocks: Evidence for Weak Interaction. International Cosmic Ray Conference, 6, 3689

- **Investigation Type:** Data Analysis
- **Data Sources:** ACE:EPAM ACE:SWEPAM ACE:MAG

Summary: At 1 AU and in the ecliptic plane, low-energy ion intensities usually peak at the arrival of shocks and the highest intensities are observed outside the ICMEs. By contrast, Ulysses, during its solar maximum polar passage and in high-speed solar wind streams, observed that the shocks were not efficient accelerators of energetic particles, and that the highest intensities were observed inside ICMEs. The possible origins of the energetic particles observed inside the ejecta, the possible mechanisms for confining these particles within the ejecta, and the effects that magnetic field structures had on modulating the energetic particle intensities observed by Ulysses were discussed.

Reference: Lario D.; Decker R. B.; Roelof E. C.; Reisenfeld D. B.; Sanderson T. R.; (2004). Low-energy particle response to CMEs during the Ulysses solar maximum northern polar passage. Journal of Geophysical Research (Space Physics), 109, A01107, doi: 10.1029/2003JA010071

- **Investigation Type:** Data Analysis
- **Data Sources:** ULYSSES:COSPIN ULYSSES:HISCALE ACE:EPAM ACE:SWEPAM ACE:MAG

Summary: The frequency distributions of shock parameters (speed, density compression ratio, magnetic field compression ratio, angle between the shock normal and the upstream magnetic field, Alfvenic Mach number) are presented. There is a trend for faster and stronger shocks to have greater effects on energetic particles. However, the parameters of the shock do not determine unequivocally the characteristics of the energetic particle event observed at the passage of the shock.

Reference: Lario D.; Hu Q.; Ho G. C.; Decker R. B.; Roelof E. C.; Smith C. W.; (2005). Statistical Properties of Fast Forward Transient Interplanetary Shocks and Associated Energetic Particle Events: ACE Observations. , 592, 81

- **Investigation Type:** Data Analysis
- **Data Sources:** ACE:EPAM ACE:SWEPAM ACE:MAG

Summary: Differences in the energetic particle signatures observed during the passage of interplanetary shocks at Wind and ACE are analyzed. Time delays in the passage of the shocks indicate that the shocks may not be spherically symmetric at 1 Au and/or they do not propagate radially. Most likely the shocks at 1 AU have some curvature (or even corrugated surface) on the order of the separation between spacecraft.

Reference: Ho G. C.; Lario D.; Decker R. B.; Desai M. I.; Hu Q.; Kasper J.; Vinas A.-F.; (2005). Multi-Spacecraft Observations of Interplanetary Shock Accelerated Particle Events. , 592, 421

- **Investigation Type:** Data Analysis
- **Data Sources:** ACE:EPAM ACE:SWEPAM ACE:MAG WIND:3DP WIND: MFI WIND: SWE

Summary: One of the few ESP events that show agreement with the predictions of the diffusive shock acceleration (DSA) theory is analyzed. Although many of the signatures of this event are consistent with the predictions of the diffusive shock-acceleration theory acting on a low-energy particle population, analyses of the elemental abundances of heavy ions from 4He to Fe measured by ACE/ULEIS indicate that the abundances of the accelerated ions are poorly correlated with those measured in the solar wind suggesting the contribution of suprathermal particles in the processes of particle acceleration at the shock.

Reference: Lario D.; Decker R. B.; Ho G. C.; Hu Q.; Smith C. W.; Desai M. I.; Vinas A.-F.; (2005). The Energetic Storm Particle Event on 2003 October 24: A Test of Diffusive Shock Acceleration Theory. , 781, 180-184, doi: 10.1063/1.2032693

- **Investigation Type:** Data Analysis
- **Data Sources:** ACE:ULEIS ACE:EPAM ACE:SWEPAM ACE:MAG

Summary: Time-intensity profiles of 20-126 keV ions across interplanetary shocks are studied using data from ACE and Wind to determine the dependence of the profiles on spacecraft separation. Each pair of time-intensity profiles is examined to determine whether or not the same features (flat, classic energetic storm particle (ESP) rise, spikes, step functions, or complex patterns) are seen at both spacecraft. The persistence of particle profile patterns has a scale length in the plane of the shock of ˜2.9 Mkm, but the scale length along the shock normal direction is not well determined.

Reference: Neugebauer M.; Giacalone J.; Chollet E.; Lario D.; (2006). Variability of low-energy ion flux profiles on interplanetary shock fronts. Journal of Geophysical Research (Space Physics), 111, A12107, doi: 10.1029/2006JA011832

- **Investigation Type:** Data Analysis
- **Data Sources:** ACE:EPAM ACE:SWEPAM ACE:MAG WIND:MFI WIND: 3DP WIND: SWE

Summary: A diffusive particle acceleration theory at perpendicular shocks is developed, including the nonlinear guiding center theory for the perpendicular spatial diffusion coefficient in the transport of energetic particles around the shocks. Both the injection energy and the acceleration timescale at highly perpendicular shocks are sensitive to assumptions about the ratio of the two-dimensional (2-D) correlation length scale to the slab correlation length scale.

Reference: Zank G. P.; Li G.; Florinski V.; Hu Q.; Lario D.; Smith C. W.; (2006). Particle acceleration at perpendicular shock waves: Model and observations. Journal of Geophysical Research (Space Physics), 111, A06108, doi: 10.1029/2005JA011524

- **Investigation Type:** Data Model Comparison
- **Names of models being tested or validated:** Diffusive particle acceleration at highly perpendicular shocks including nonlinear guiding center theory for the perpendicular spatial diffusion coefficient in the transport of energetic particles.
- **Datasources:** ACE:EPAM ACE:SWEPAM ACE:MAG

Summary: Analysis of the radial dependence of peak intensities and fluences of solar energetic particle (SEP) events in the framework of the focused transport theory.

Reference: Lario D.; Aran A.; Agueda N.; Sanahuja B.; (2007). Radial dependence of proton peak intensities and fluences in SEP events: Influence of the energetic particle transport parameters. Advances in Space Research, 40, 289-294, doi: 10.1016/j.asr.2007.01.057

- **Investigation Type:** Data Model Comparison
- **Names of models being tested or validated:** SEP transport model
- **Datasources:** ACE:EPAM

Summary: Classification of ESP events according to the temporal evolution of their time-intensity profiles and of their energy spectra indices. The majority of the measured spectral indices do not agree with the indices predicted by the diffusive shock-acceleration (DSA) theory, which depend only upon shock compression ratio. Ion spectra measured at the shock are often softer than the ion spectra measured well upstream of the shock.

Reference: Ho G. C.; Lario D.; Decker R. B.; Smith C. W.; Hu Q.; (2008). Transient Shocks and Associated Energetic Particle Distributions Observed by ACE during Cycle 23. , 1039, 184-189, doi: 10.1063/1.2982443

- **Investigation Type:** Data Analysis
- **Data Sources:** ACE:EPAM ACE:SWEPAM ACE:MAG

Summary: Study of the effect that large-scale interplanetary structures have on the propagation of shocks and energetic particles accelerated by these shocks.

Reference: Lario D.; Decker R. B.; Malandraki O. E.; Lanzerotti L. J.; (2008). Influence of large-scale interplanetary structures on energetic particle propagation: September 2004 event at Ulysses and ACE. Journal of Geophysical Research (Space Physics), 113, A03105, doi: 10.1029/2007JA012721

- **Investigation Type:** Data Analysis
- **Data Sources:** ACE:EPAM ACE:SWEPAM ACE:MAG ULYSSES:COSPIN ULYSSES:HISCALE

Summary: Monte Carlo method to model the transport of solar near-relativistic electrons in the interplanetary medium, including adiabatic focusing, pitch-angle dependent scattering, and solar wind effects. This model allows us to deconvolve the effects of the interplanetary transport and infer the underlying injection profile and the radial mean free path of the electrons. The resulting injection profile for the anisotropic event observed on 2000 May 1 consists of two main components, an initial component lasting 2-3 minutes and probably related to a type III radio burst, and a delayed component starting at the Sun around 10:35 UT with a typical injection decay timescale of ~0.5 hr. The delayed component may be related to the CME-driven shock.

Reference: Agueda N.; Vainio R.; Lario D.; Sanahuja B.; (2008). Injection and Interplanetary Transport of Near-Relativistic Electrons: Modeling the Impulsive Event on 2000 May 1. Astrophysical Journal, 675, 1601-1613, doi: 10.1086/527527

- **Investigation Type:** Data Model Comparison
- **Names of models being tested or validated:** SEP transport model
- **Datasources:** ACE:EPAM ACE:SWEPAM ACE:MAG