Modeling shock acceleration and interplanetary transport of solar energetic particles

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Early in many gradual solar energetic particle (SEP) event, the SEPs are shock accelerated in $<\sim 10$ minutes close to the Sun. They are also transported to 1 AU on comparable time scale. These two facets of the SEP phenomenon require vastly different scattering conditions: mean free path $<\sim 10^{-5}$ AU for Fermi shock acceleration close to the Sun and $>\sim 0.3$ AU for transport in interplanetary space. Rapid and intense self-excitation of hydromagnetic waves by the SEPs in the shock's vicinity provides a consistent explanation of the different mean free paths required by fast local acceleration and fast interplanetary transport. Beyond the shock's vicinity, wave excitation in interplanetary space by streaming SEPs (dominated by energetic protons) is also an important factor influencing the evolving spatial distribution of SEPs, and the time variation of SEP intensities and elemental abundances at 1 AU.

Our time-dependent nonlinear model of SEP acceleration and transport has been undergoing continual improvement to incorporate more physical processes and more realistic environment. The current model simulates SEP scattering by Alfvén waves and self-consistently wave excitation/damping by streaming SEPs in an environment that varies with space and time as seen in the moving shock frame. It treats resonant wave-particle interaction with full pitch-angle dependence. It also includes focusing in a diverging magnetic field, adiabatic deceleration in an expanding plasma, wave propagation, and shock transmission and reflection of Alfvén waves.

We will present model calculations and describe how various plasma and shock parameters, physical processes, and model assumptions influence the predicted evolution of the energy spectra of SEP intensities and the wavenumber spectra of Alfvén wave intensities.