Numerical modeling of Solar Energetic Particle acceleration and propagation

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Solar Energetic Particles (SEPs) are distinct enhancement of particle flux in space. They are associated with solar events such as flares, filament eruptions, and Coronal Mass Ejection (CME), and their energy is well above the thermal energy in the solar corona (a few hundreds of eV). They have a strong impact on Space Weather through the radiation hazard to humans and spacecraft, and the ionization of the Earth atmosphere. Therefore, understanding the physics of SEPs, generation and propagation toward the Earth, is essential for Space Weather forecasting.

Depending on the source of energetic particles, SEP events are classified into two types; impulsive and gradual events (Reames 1999). The impulsive events, lasting only a few hours and being rich in electrons and heavy ions, originate from flares. The gradual events, on the other hand, continue to several days and are proton-rich. They are well associated with CMEs. Because of their relatively large impact on Space Weather, we especially focus on the understanding of energetic particle dynamics in the gradual SEP events.

Energetic particles in the gradual SEPs are thought to be produced mainly at the interplanetary CME-driven shock, and then propagate along the magnetic field line toward the Earth. Based on this scenario, a numerical model for particle transport from the shock front to the observer at 1 AU is proposed (focused transport equation by Ruffulo 1995). Lario et al (1998) have combined this model with the MHD simulation of CME propagation. They give energetic particle injection at the shock front to find some empirical relationships between the injection parameters and the shock parameters (e.g., downstream-upstream velocity ratio), through comparison between the numerical model and the observation. We advance the above model by including the particle acceleration simultaneously (not treated as the injection). Our model is a combination of the focused transport equation and the drift-kinetic equation (Minoshima et al. 2010), which describes drift and Fermi accelerations at the shock. The acceleration can be stochastically occurred when the pitch-angle scattering is included. This talk presents our new strategy in detail. The coupling between the model and state-of-the-art data-driven MHD simulation of CME propagation (Shiota et al. 2016) will be presented.