Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

PEM34-06 Room:503 Time:May 1 14:30-14:45

Pickup ion acceleration via multiple reflection between two successive CIRs

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Interstellar neutral particles, during their propagation inside the heliosphere, become ionized by the charge exchange with the solar wind (SW) plasma. The interplanetary magnetic field picks up these newborn ions, called "pickup ions" (PUIs), and carries them away into the outer heliosphere with SW. The gyrating velocity of PUIs around the magnetic field is equivalent to the SW flow speed, hundreds of km/s, which is much faster than the SW thermal velocity. This property enables PUIs to be accelerated more efficiently at the shock than the thermal SW particles. Thus PUIs are considered to be the dominant source of anomalous cosmic rays (ACRs) generated at the heliospheric termination shock.

However, the well-known diffusive shock acceleration (DSA) process alone is insufficient to raise the PUI energy up to the ACR range, typically in the order of MeV. This is because the primary PUI energy (10 keV at most) is still too low to be injected into DSA, where at least hundreds of keV is necessary. Therefore, some preacceleration should take place inside the heliosphere before SW and PUI reach the termination shock. Interplanetary shocks are the most possible source for it. In the present study, we focus on the shocks driven by the interaction of the fast SW with the ahead-flowing slow SW. The regions bounded by these shocks are called corotating interaction regions (CIRs); forward shock in the slow SW side and reverse shock in the fast SW side.

We demonstrate how particles are accelerated at this CIR system by performing hybrid simulations. The simulation results show that more efficient acceleration is identified in the PUI reflected at the shock than in those transmitted through the shock. The acceleration takes place while the PUI stays close to the shock surface. This situation is similar to the shock-drift or surfing acceleration mechanism. However, our results indicate that the acceleration is not dominant in the component transverse to the magnetic field, i.e., the direction of motional electric field. Rather, the net acceleration is confirmed in the field-aligned component. The mechanism will be discussed in terms of the characteristic of the Lorentz force balance acting on PUIs.

The periodic boundary condition applied in the present simulation virtually allows the successive appearance of two CIRs. After the reflected PUI travels the "inter-CIR" space, it encounters the shock of another CIR, where the reflection again takes place. While one reflection increases the PUI energy only a few times, this multiple reflection process yields the most energetic PUI with its maximum energy up to 100 keV, probably enough for the injection into DSA. Recent CIR observations have confirmed the presence of the energetic PUI in the solar wind between two CIRs, which may prove the present results.