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Effects of heliospheric boundary in the behaviors of galactic and anomalous cosmic rays

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We discuss the effects of heliospheric boundary in the behaviors of cosmic rays entering or accelerated in the heliosphere.

First, we focus on the entering process of galactic cosmic rays (GCRs) into the heliosphere. GCRs are thought to be generated in our galaxy. While they have an energy of $10^{9-15.5}$ eV, most of them are prevented from entering the heliosphere due to the electromagnetic wall of the heliospheric bounday. Even if successfully entering the heliosphere, it is not easy for the GCRs to reach the Earth afterward due to the intricate electromagnetic field structures of the heliosphere and the effects of solar wind convection. The transport of GCRs has been extensively discussed in the context of the diffusion convection theory. But here, we introduce our approach to this problem focusing on the trajectories of a large number of GCR particles entering deep inside the heliosphere by using numerical simulation [1-2]. First, we reproduced global electromagnetic structures of heliosphere by using 3D MHD simulation. Then, the trajectories of GCR test particles initially distributed outside the heliosphere are traced. A variety of patterns of entering particle motion for different particle energy are reviewed in the presentation.

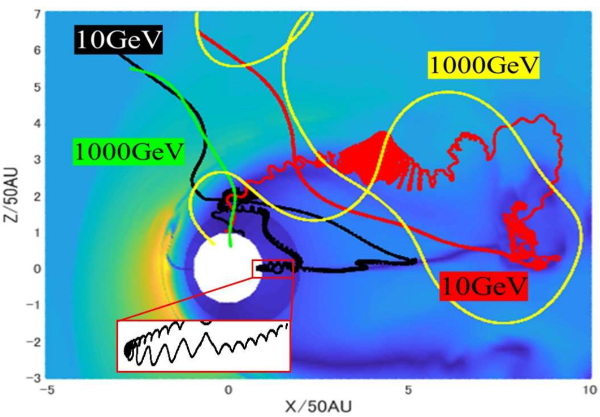

Figure 1. Trajectories of test particles entering the heliosphere reproduced by an MHD simulation.

In the second part of the presentation, the termination shock is focused. The termination shock is believed to be the acceleration site of the so-called anomalous cosmic rays (ACRs) which are observed near the Earth as a cosmic ray population with high flux in the energy range of several tens to hundred mega electron volts. The mechanism how the acceleration process is initiated has been a long-standing issue. This problem is investigated by using two-dimensional fully kinetic particle-in-cell (PIC) simulation mimicking the circumstance near the termination shock, where a local plasma contains pickup ions (PUIs) in addition to the background solar wind ions and electrons. Nonthermal particles are self-consistently reproduced by tracking long time evolution of shock with unprecedentedly large system size in the shock normal direction. Reflected PUIs drive upstream large amplitude waves through resonant instabilities. Convection of the large amplitude waves causes shock surface reformation and alters the downstream electromagnetic structure. A part of pickup ions are accelerated to nonthermal energy in the time scale of ~100 times inverse ion gyro frequency. The initial acceleration occurs through shock surfing acceleration mechanism followed by shock drift acceleration mechanism. Large electrostatic potential accompanied by the upstream waves enables the shock surfing acceleration to occur.

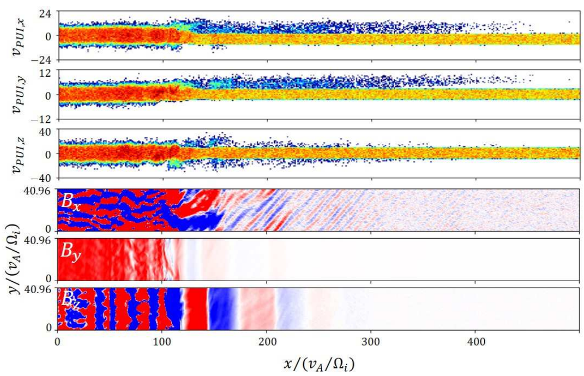

Figure 2. Kinetic structure of a termination shock obtained from PIC simulation. (Top three panels) Phase space distribution of PUIs and (Bottom three panels) magnetic field.

Reference

[1] Yoshida et al., *Astrophys. J.*, **916**, 29 (2021).

[2] Yoshida et al., *Acta Phys. Polon. Supp.*, **15**, 3-A20 (2022).