4th Asia-Pacific Conference on Plasma Physics, 26-31Oct, 2020, Remote e-conference

Numerical simulation of invading process of galactic cosmic rays into the heliosphere

Kotaro Yoshida[1], Kesuke Shimokawa[1], Shuichi Matsukiyo[2,3],
Haruichi Washimi[3] and Tohru Hada[2,3]
[1] Earth System Science and Technology, Kyushu University
[2] Faculty of Engineering Sciences, Kyushu University
[3] International Center for Space Weather Science and Education, Kyushu University
e-mail (speaker): yoshida@esst.kyushu-u.ac.jp

Most of galactic cosmic rays (GCRs) coming from interstellar space are prevented from entering the heliosphere. A fraction of them can propagate deep inside the heliosphere and be observed at the earth. The motion of a charged particle in the heliosphere is quite complex. The CRs are transported under the influence of convection and diffusion by complex magnetized solar wind. However, the so-called diffusion convection model does not represent particle trajectories. Our goal in this study is to understand the invading process of GCRs in the level of particle trajectory.

We perform three-dimensional relativistic test particle simulations using electromagnetic fields reproduced by the global MHD simulation of the heliosphere[1] to analyze trajectories of GCRs.

In MHD simulation, the solar wind velocity, density, magnetic field strength and temperature at 1 AU are assumed to be 400 km/s, 5.0 /cc, 35 μG and 10^5 K respectively. These quantities are simply extrapolated to the inner boundary at 50 AU. For the outer boundary at 900AU, the corresponding parameters in interstellar space are 23 km/s, 0.1/cc, 6,300K, and 3 μG respectively. Initially, 500,000 particles (protons) are homogeneously distributed on a sheet in the interstellar space. Their distribution function is given by mono-energetic shell distribution.

We show the results of the cases with $\gamma = 10$ (~10 GeV) and $\gamma = 1000$ (~1000 GeV)., where γ denotes the Lorentz factor. The results indicate that characteristics of particle trajectories change depending on the relative scales between particle Lamor radii and heliospheric magnetic structures.

- $\gamma = 10$ (~10 GeV)

Since Lamor radius is much smaller than heliospheric magnetic structures, particle trajectries are strongly affected by local electromagnetic fields. Most of particles following draping field lines are mirror reflected at the heliopause or skirt around the heliosphere. A few particles invade into the heliosphere from the side or the tail region of heliopause and propagate deep inside it along the solar wind current sheet. Some particles need very long time to reach the inner boundary, since they are trapped by the spiral solar wind magnetic field lines.

- $\gamma = 1000$ (~1000 GeV)

While most particles are mirror reflected at the heliopause or pass through the heliosphere, a large number of particles easily invade the heliosphere due to their large Larmor radius. Relatively larger number of particles enter the heliosphere from the nose region. Some of them reach the inner boundary with almost linear motion. Some other particles are once scattered in the tail region and back to the inner boundary.

We also estimate some statistical quantities and discuss interactions between GCRs and various characteristic structures of the heliosphere.

References

[1] H. Washimi, et al. : “ MHD modeling of the outer heliospheric structures around the heliopause “ ApJ 809 (2015)