25E09

Spatial Profile of the Energetic Particles in the Upstream of Collisionless Shock
衝撃波上流域での粒子拡散現象

Tooru Sugiyama
杉山　徹

Japan Agency for Marine-Earth Science and Technology
3173-25 Showa-machi, Kanazawa-ku, Yokohama　236-0001, Japan
（独）海洋研究開発機構　〒236-0001　横浜市金沢区昭和町 3173-25

We have studied the transport properties of energetic particles in the upstream region of parallel shocks considering the possibility of anomalous diffusion where the density decay profile has not an exponential profile but a power-law behavior. The results obtained from the hybrid simulation model show that the spatial profiles of the energetic ions are well fitted by a power law distribution. This implies that particle propagation can be described by a super-diffusion profile even though the power of the magnetic wave is sufficient large to scatter the particles.

1. General

Non-thermal energetic particles accelerated around collisionless shock waves have been deeply investigated and the main mechanism for this acceleration is now widely accepted as the standard diffusive shock acceleration (DSA) theory (e.g. [1]). The DSA model, based on the diffusion-convection equation, predicts that the obtained energy spectrum exhibits a power-law shape and that the spatial distribution of the particle density, especially in the upstream, decays exponentially with distance from the shock surface.

Recently, another explanation has been proposed, according to which the diffusion profiles are different from the normal Gaussian diffusion described by an exponential function as noted above. Perri & Zimbardo ([2-4]) have reported that the upstream density profiles of the energetic particles associated with the reverse shock of the corotational interaction region (CIR) and termination (TA) shock are not described by the normal Gaussian diffusion. They discussed the diffusion profiles with regard to the intensity of the magnetic field turbulence for particle scattering. Since a weak turbulence reduces the scattering efficiency, the super-diffusive profile is observed in the region with weak turbulence. Sugiyama & Shiota ([5,6]) have reported that the upstream density profiles of the CME-driven interplanetary shock (IP shock) are not described by the normal Gaussian diffusion. The essential differences in the particle dynamics between CIR, TA, and IP shocks are the wave-particle interaction processes. In the upstream of the IP shock, the amplitude of the magnetic field is sufficiently larger than that discussed around CIR and TA shocks. Non-linear wave-particle interaction processes should be considered as discussed in their paper, especially, with the point of no long trend of the spatial profile of the upstream wave amplitude. Here, we have reported the transport profiles of the shock-accelerated ions using a Hybrid numerical simulation. The results show that the motions of the accelerated particles seem not to be the normal Brownian motion.

2. Simulation Model

The Hybrid model used in this study treats the ions as macro-particles while the electrons are treated as a charge-neutralizing massless fluid. The simulations are one-dimensional in space (shock normal direction in X: positive X directs downstream) but fully three-dimensional in velocity. Initial magnetic field lies on X axis pointing to downstream region. All particles are referred as proton. Time, and length are normalized by the inverse of proton gyro-frequency Ω_{ci}, and the ion inertia length λ_i, respectively, based on the upstream parameters. A shock wave is set up by the conventional way (conductive wall method). The simulations are performed in the downstream-rest, normal-incident frame. Initially, there are no upstream turbulence in field and no seed particles in the upstream region, that is, a quiet-start model is used. The shock Mach Number M_A and shock angle are 9.6 and 0 degree. The grid-cell size and the time step size are 0.5 and 0.002, respectively, in the normalized unit. The simulation system length is 320,000 λ_i, long. Initially 500 particles per grid-cell are used for the unit density in the incoming thermal distribution. Because of this large system size and large number of particles compared with the previous runs, we can clearly follow the spatial and temporal feature of the energetic component with statistically reliable number of particles.

3. Results

Figure shows a particle orbit from the one of the accelerated particles in time and position plane. Shock is located at X=0, and negative values in X axis means that particle locates in the upstream region. Some characteristic profiles are observed; RUN and STAY time intervals, which clearly indicate the trajectory is far from the normal Brownian motion, but like Lévy flight. This leads the motion of the particles are not described by the normal Gaussian diffusion, but the non-classical diffusion of the super-diffusion. Details about the spatial profiles of the density of the accelerated particles and the wave power are discussed in presentation.

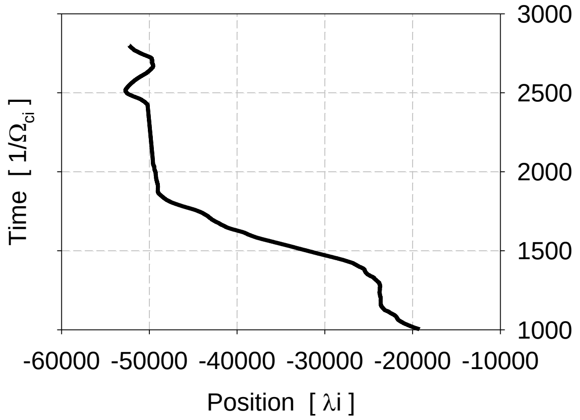

Fig.1. An orbit from one of the accelerated particles. RUN (T=~1400~1800) and STAY (T=~1200~1300, ~1800~2400) are observed.

Acknowledgments

The simulations are performed on the Earth Simulator on the project of “Space and Earth System Modeling”.

References

[1] R. D. Blandford and J. P. Ostriker: ApJ, **221** (1978) L29.
[2] S. Perri and G. Zimbardo: ApJ, **671** (2007) L177.
[3] S. Perri and G. Zimbardo: J. Geophys. Res. **113** (2008) A03107.
[4] S. Perri and G. Zimbardo: ApJ, **693** (2009) L118.
[5] T. Sugiyama and D. Shiota: ApJL. **731** (2011a) L34.
[6] T. Sugiyama and D. Shiota: AIP Conf. Pro. (2011b) in press.