7th Asia-Pacific Conference on Plasma Physics, 12-17 Nov, 2023 at Port Messe Nagoya

Particle acceleration by a relativistic shock interacting with an inhomogeneous medium

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Cosmic Rays (CRs) are coming from both inside and outside our galaxy. Their highest energy reaches to 10^{20} eV, which is called Ultra-High-Energy Cosmic Rays (UHECRs). UHECRs are thought to come from extragalactic sources, but we do not know the origin of UHECRs.

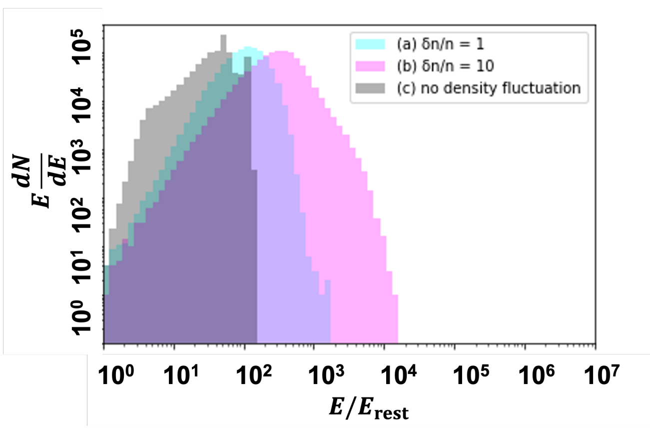
In the Hillas plot, some candidates of the UHECRs source have relativistic shocks driven by relativistic jets, such as gamma-ray bursts or active galactic nuclei. Therefore, UHECRs are expected to be accelerated by the relativistic shock, where they go back and forth around the shock many times. However, in a perpendicular relativistic shock which has a uniform and perpendicular magnetic field to the shock normal, particles cannot cross the shock front at most one time because they are swept away to the far downstream region [1]. On the other hand, it is shown that if particles are scattered in the downstream region, particles can cross the shock front many times because of the turbulence [2]. This the reason we must consider the turbulence around the shock front.

In this work, we consider density clumps in the shock upstream region. When they interact with the relativistic shock, some shear motion is driven. Then, in the downstream region, a turbulent field is generated by this shear. In this turbulence, particles are scattered, and their direction is changed to the upstream region. After all, the particles can cross the relativistic shock front several times and gain much energy by the 1st-order Fermi process. Although this mechanism of the turbulence generation is well confirmed in the case of a non-relativistic shock [3], this does not work efficiently in the case of a relativistic shock due to the Lorentz contraction [4]. In order to confirm whether this mechanism can make the downstream region turbulent enough for particles to be scattered and go back to the upstream region in the relativistic shock or not, we must calculate the numerical simulations. Then, we performed 3D relativistic MHD simulations and test-particle simulations and confirmed that particles are accelerated by these processes.

In this talk, we argue the parameters in the simulations that particles can gain their energy by the 1st-order Fermi process in a relativistic shock. We found that the amplitude of the density fluctuation is important for particles to be scattered in the downstream region. Furthermore, we found that the peak of the energy spectrum moves to higher energy, as the amplitude of the density fluctuation get larger. This might be the effect of the 2nd-order Fermi acceleration in the turbulent downstream region.

References

[1] M. Lemoine *et al*, ApJL, **645**, L129 (2006)
[2] M. Lemoine and B. Revenu, MNRAS, **366**, 635 (2006)
[3] T. Inoue *et al*, ApJ, **734**, 77 (2011)
[4] S. Tomita *et al*, ApJL, **936**, L9 (20222)



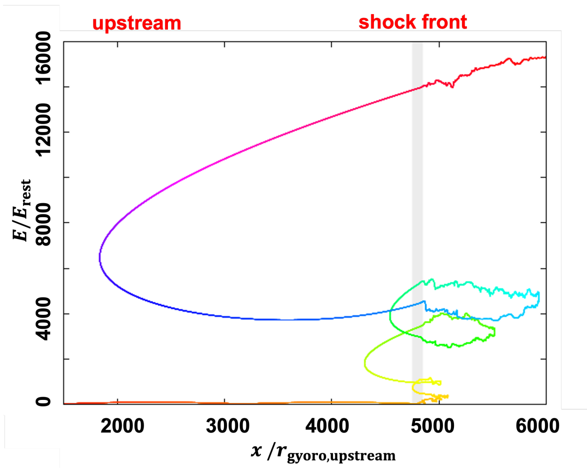


Figure 1 (left). The energy spectrum of the particles in the shock rest frame. The case (a) is the amplitude of the density clumps $\delta n/n = 1$, (b) is the case of the amplitude $\delta n/n = 10$, and (c) is the case of the no density fluctuation.
Figure 2 (right). The trajectory of the highest-energy particle in the test-particle simulations. The horizontal axis is the spatial coordinate in the x direction and the vertical axis is the energy of the particle. The particle crosses the shock front many times and gain their energy by 1st-order Fermi process.