9th Asia-Pacific Conference on Plasma Physics, 21-26 Sep, 2025 at Fukuoka

Cosmic ray acceleration and maximum energy in core-collapse supernova remnants

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The origin of cosmic rays (CRs) is the longstanding problem since CRs are discovered in 1912. It is believed that CRs below 3 PeV are accelerated by diffusive shock acceleration (DSA) in Galactic supernova remnants (SNRs). The acceleration rate of the DSA depends on the angle between the magnetic field and shock normal direction. To accelerate particles up to the PeV scale in parallel shocks, where the shock normal direction is parallel to the magnetic field, the magnetic field amplification in the shock upstream region is required [1]. However, the upstream magnetic field amplification is still unclear. On the other hand, perpendicular shocks, where the shock normal direction is perpendicular to the magnetic field, can rapidly accelerate particles by the gyration up to the PeV scale without the magnetic field amplification in the shock upstream region [2, 3].

In addition to acceleration, escape of particles from accelerators is important to determine the maximum attainable energy of particles [4]. Previous studies about CR escape used the diffusion approximation [4]. The CR escape from perpendicular shocks is unclear because we cannot treat the gyration under the diffusion approximation. Perpendicular shocks can be dominant for core-collapse SNRs propagating in the stellar wind with the Parker-spiral magnetic field and wind termination shock (WTS). Then, the escape process from core-collapse SNRs and maximum attainable energy are unclear.

We performed global test particle simulations for CR acceleration in core-collapse SNRs propagating in the stellar wind with the Parker-spiral magnetic field, current sheet, and WTS. We show that particles are rapidly accelerated in the perpendicular shock region and that escape to the far upstream region while moving along the equator (poles) [5]. The typical escape-limited maximum energy is about 10-100 TeV [5]. We found that particles escaped from the SNR shock move along the WTS and return to the SNR shock and that the particle energy is boosted by this cycle motion between the SNR and WTS [6]. In this presentation, we will report the maximum attainable energy of CRs for core-collapse SNRs propagating in the stellar wind with the Parker-spiral magnetic field, current sheet, and WTS.

References

[1] A. R. Bell, Mon. Not. R. Astron. Soc. **353**, 550 (2004)
[2] J. R. Jokipii, Astrophys. J., **313**, 842 (1987)
[3] S. F. Kamijima, Y. Ohira, and R. Yamazaki, Astrophys. J., **897**, 116 (2020)
[4] Y. Ohira, K. Murase, and R. Yamazaki, Mon. Not. R. Astron. Soc. **410**, 1157 (2011)
[5] S. F. Kamijima and Y. Ohira, Phys. Rev. D, **106**, 123025 (2022).
[6] S. F. Kamijima and Y. Ohira, Phys. Rev. D, **110**, 043046 (2024).

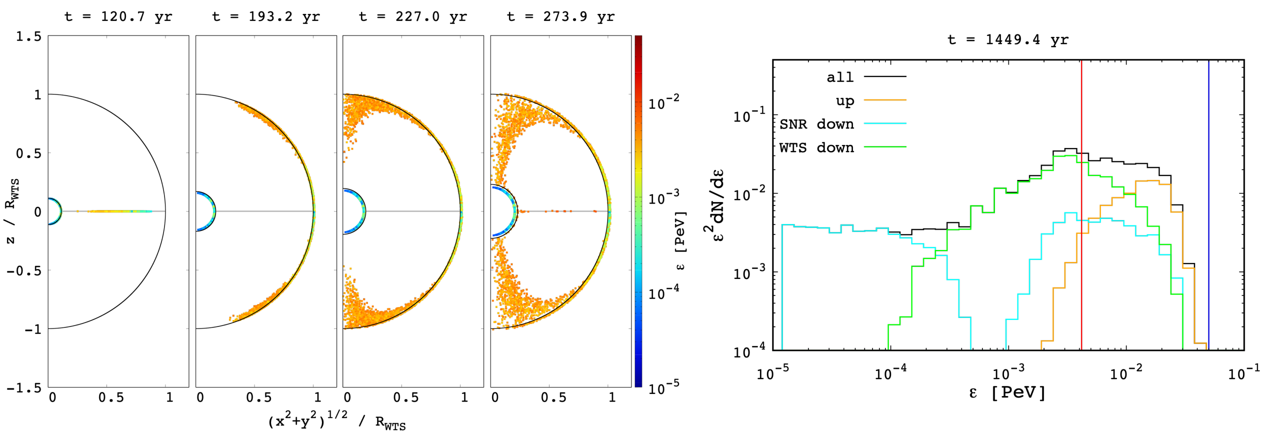

Figure 1 Time evolution of the particle distribution (Left) and energy spectrum of simulation particles at the time when the SNR shock collides with the WTS (Right). Particles accelerated at the SNR shock and escape from the SNR shock. Escaped particles interact with the WTS and return to the SNR shock. High energy particles experience the cyclic motions between the SNR shock and WTS. The attainable maximum energy of particles is 10-100 TeV.