2nd Asia-Pacific Conference on Plasma Physics, 12-17,11.2018, Kanazawa, Japan

Non-thermal electron acceleration in the shock transition region

*Takuma Katou[1], Takanobu Amano[1]
[1] Department of Earth and Planetary Science, The University of Tokyo
e-mail : t.kato@eps.s.u-tokyo.ac.jp

The acceleration of non-thermal particles is one of the most important problems in astrophysics and space physics. Galactic cosmic rays with energies below 1 PeV are believed to be accelerated by the Diffusive Shock Acceleration (DSA) at supernova remnant (SNR) shocks (Blandford and Eichler 1987, Drury 1983). However, it is well known that the DSA is not efficient for non-relativistic electrons. Radio and X-ray observations of SNR shocks imply that there exists an efficient pre-acceleration mechanism that injects thermal electrons to relativistic energies. This problem is called the electron injection problem and remains yet to be resolved. The shock accelerated non-thermal electrons have also been observed at the Earth bow shock. We can carry out in-situ observations at this shock, and such non-thermal electrons with energies from 1 to 100 keV are observed (Gosling et.al 1989). Since this energy range is important for the electron injection at SNR shocks, in-situ observations at the Earth bow shock can be probes for investigating the electron injection process. A recent statistical analysis of in-situ satellite observations at the Earth bow shock showed that electrons interact with whistler waves by the cyclotron resonance (Oka et.al 2017). These results indicate that whistler waves play a role for the acceleration of non-thermal electrons.

We here propose a new acceleration mechanism that takes into account the effect of stochastic pitch-angle scatterings by whistler waves during the course of the Shock Drift Accelerations (SDA), which is an adiabatic acceleration process for small gyro-radius electrons at a quasi-perpendicular shock (Leroy and Mangeney 1984, Wu 1984). To simplify the analysis, we focus only on spatially integrated spectra and employ a box model in which only the dependence on the energy and pitch-angle of the distribution function is considered. We theoretically analyzed the energy spectrum of electrons in the limit of strong scattering. In this case, the pitch-angle distribution is isotropic and the energy spectrum becomes a power-law. We show that the spectral index is independent of the strength of pitch-angle scatterings, and it is roughly consistent with those measured in the bow shock. We find that the maximum energy attainable through the proposed mechanism scales linearly with the pitch-angle scattering coefficient. We also discuss Monte-Carlo simulation results for the proposed model to take into account the effect of an anisotropy in the pitch-angle distribution which should appear in general, in particular at around the maximum energy cutoff. We demonstrate that the simulation results agree quite well with the theoretical prediction in the strong scattering limit.

We also estimated the pitch-angle scattering coefficient at the bow shock from the observed power spectrum of magnetic fluctuations by using the quasi-linear theory. We discuss the consistency between the proposed model and the in-situ observations.

References

Drury, L. O. 1983, Reports on Progress in Physics, 46, 973

Blandford, R., & Eichler, D. 1987, PhR, 154, 1

Gosling, J. T., Thomsen, M. F., Bame, S. J., & Russell, C. T. 1989, J. Geophys. Res., 94, 10011

Oka, M., Wilson, III, L. B., Phan, T. D., et al. 2017, ApJL, 842, L11

Leroy, M. M., & Mangeney, A. 1984, Annales Geophysicae, 2, 449

Wu, C. S. 1984, J. Geophys. Res., 89, 8857