Propagation of Cosmic Rays in Galactic turbulence

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The observed energy spectrum of galactic cosmic rays (CRs) is usually interpreted in terms of two ingredients: injection of primary particles (p, He, C) from acceleration sources (SNR shocks) in the Galaxy, following a power law $\propto R^{-\nu}$ (where R is the magnetic rigidity or the momentum to charge ratio) and propagating diffusively in the galactic halo, with a uniform diffusion coefficient also following a power law dependency $\propto R^{-\delta}$. As a result, the observed spectrum of the primary particles should follow the power law $R^{-\nu-\delta}$, while that of the secondary particles (e.g. B/C) would be $\propto R^{-\delta}$ (e.g. Grenier et al. 2015). The observational data is then used to constrain the spectral indices ν and δ. Recent measurement by the CREAM (Ahn et al. 2010), PAMELA (Adriani et al. 2011) and AMS-02 (Aguilar et al. 2015) experiments show deviations from a single power law in the observed spectrum of primary particles, with a hardening at $R \approx 300$ GV.

Different models based on injection or propagation were proposed to explain this deviation, as for example invoking effect of super-diffusion in the shock acceleration investigated in Lazarian & Yan (2014), which would affect only particles with $R >$ 300 GV (Khiali et al. 2016), or invoking a scenario in which the Galactic halo has two different environments with different diffusion coefficients (Tomassetti et al. 2015). However these phenomenological approaches which introduce new parameters to be fitted from observations provide loose connection with the fundamental physics of CR acceleration and diffusion. In addition, there are other mounting challenges from recent observational results, such as harder He spectrum compared to that of protons, the inconsistency between the EGRET data and locally measured spectra of CRs (Strong et al. 2007). It is becoming clear that the conventional approach of adopting an ad hoc diffusion is inadequate.

Proper treatment of CR propagation need to be based on actual properties of MHD turbulence, their variations with environments, and account for the both perturbation from large scale pre-existing turbulence and local generated turbulence through plasma instabilities (Yan 2015). Within this project, we will model the CR propagation in the Galaxy exploring the effects of the magnetohydrodynamic (MHD) turbulence which are also connected with the CR instabilities. A publicly available code for CR propagation in the Galaxy will be modified to introduce a diffusion coefficient dependent on the turbulence parameters in each region of the Galaxy. A refined diffusion model will be based on the up-to-date knowledge on physics of plasma particle interactions as well as observational studies of astrophysical turbulence. The transport equation will be solved in a 3D geometry, using a realistic gas distribution in the galaxy. Synthetic spectra of particles (primary and secondary) and gamma-ray fluxes will be produced to be compared with the observational data. We plan to model of the variation of CR spectral index over the Galaxy on the basis of a state-of-the art understanding of Galactic turbulence and CR transport to compare with observations (see, e.g., Yang et al. 2016).

By providing a comprehensive study of the basic interactions of CRs with turbulence both pre-existing and self-generated augmented with the observational analysis of actual properties of turbulence, this project will transform our knowledge of CR propagation in various astrophysical environments.

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