The stability of cosmic ray modified shocks with an effect of magnetic field

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It is a still controversial matter whether the production efficiency of cosmic rays (CRs) is relatively efficient or inefficient (e.g. Helder et al. 2009; Hughes et al. 2000; Fukui 2013). In upstream region of SNR shocks (the interstellar medium), the energy density of CRs is comparable to a substantial fraction of that of the thermal plasma (e.g. Ferriere 2001). In such a situation, CRs can possibly exert a back-reaction to the shocks and modify the global shock structure. These shocks are called cosmic ray modified shocks (CRMSs). In CRMSs, as a result of the nonlinear feedback, there are almost always up to three steady-state solutions for given upstream parameters, which are characterized by CR production efficiencies (efficient, intermediate and inefficient branch).

We evaluate qualitatively the efficiency of the CR production in SNR shocks by considering the stability of CRMS, under the effect of magnetic fields, which plays a significant role in efficiency of acceleration.

By adopting a magnetohydrodynamical two-fluid model (Webb et al., 1986), where MHD equations are coupled with a CR energy equation, we investigate the stability of CRMSs by means of time-dependent numerical simulations. As a result, we show explicitly the bi-stable feature of these multiple solutions, i.e., the efficient and inefficient branches are stable and the intermediate branch is unstable, and the intermediate branch transit to the inefficient one. This feature is independent of the shock angle.

Furthermore, we investigate the evolution from a magnetohydrodynamical shock to CRMS in a self-consistent manner, considering an anisotropy of diffusion coefficient of CRs and injection parameter.

From the results, we suggest qualitatively that the CR production efficiency at SNR shocks may be the least efficient.