Stability of cosmic ray modified shocks: two-fluid approach

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Observations of some supernova remnant (SNR) shocks indicate efficient production of cosmic rays (CRs), where CRs energy density may constitute a substantial fraction of the total energy density. We evaluate qualitatively the efficiency of the CR production in SNR shocks by considering the stability of a cosmic ray modified shock (CRMS).

In a CRMS, nonlinear feedback of CRs is taken into account. As a result of the nonlinearity, such a system almost always possesses up to three stationary solutions for given upstream parameters, which are characterized by CR production efficiencies (efficient, intermediate and inefficient branch).

By adopting a two-fluid model, we investigate the stability of CRMSs including these multiple solutions by means of time-dependent numerical simulations with variation of all parameters (Mach number, injection, a fraction of upstream pre-existing CRs) taken into account. 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. This feature is independent of any parameters, even when a self-consistent injection model is used. Therefore we conclude this bi-stable feature is the generic one regardless of the injection in the two-fluid model.

Furthermore, we investigate the time evolution from a gas dynamic shock with no initial pre-existing CRs. In this situation, as far as multiple solutions exist, the final steady states always settle on the inefficient branch (rather than the efficient branch). This strongly indicates that the CR production efficiency at SNR shocks may be lower than previously thought.