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Kinetic approaches to non-linear particle acceleration at shock fronts

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Abstract. We review some recent progresses in semi–analytic kinetic approaches to the problem of non linear particle acceleration at non relativistic shock waves.

Keywords. acceleration of particles

Diffusive shock acceleration is thought to be responsible for acceleration of cosmic rays in several astrophysical environments. Despite the success of this theory, some issues are still subjects of much debate, for the theoretical and phenomenological implications that they may have. One of the most important of these is the reaction of the accelerated particles on the shock: the violation of the *test particle approximation* occurs when the acceleration process becomes sufficiently efficient that the pressure of the accelerated particles is comparable with the incoming gas kinetic pressure. Both the spectrum of the particles and the structure of the shock are changed by this phenomenon, which is therefore intrinsically non-linear (Malkov & Drury 2001). Non-linear effects in shock acceleration result in the appearance of multiple solutions in certain regions of the parameter space. This phenomenon is very general and was found in both the two-fluid and kinetic models. Using a semi-analytic model developed by Blasi (2002), we showed that the appearance of multiple solutions is dramatically reduced if a self consistent model for injection, so called *thermal leakage*, is adopted (Blasi *et al.* 2005). The model has been further developed in Amato & Blasi (2005), Amato & Blasi (2006), and Amato & Blasi (2006). We find that the phenomenology of particle acceleration at modified shocks is characterized by three main features:

1) The modification of the shock increases with the Mach number of the fluid. For low Mach numbers the quasi-linear solution is recovered, but departures from it are evident already at relatively low Mach numbers. The modification of the spectra manifests itself with a hardening at high momenta and a softening at low momenta. The $p^4 f_0(p)$ shows a characteristic dip at intermediate momenta, typically around $p/mc \simeq 1-100$.

2) The total efficiency for particle acceleration saturates at large Mach numbers at a number of order unity. However, the largest fraction of the energy is not advected downstream but rather escapes from upstream infinity at the maximum momentum.

3) The high efficiency for particle acceleration reflects in a reduced role of cosmic ray modified shocks in the heating of the background plasma.

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