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Understanding particle acceleration at supernova shocks

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One century after the pioneering discovery of cosmic rays by V. Hess, the present generation of X- and gamma-ray telescopes is finally unravelling the origin of such an extraterrestrial radiation, at least for what concerns particles with energies below $\sim 10^8$ GeV, which are thought to be accelerated at the forward shocks of Galactic supernova remnants (SNRs). I discuss the present theoretical understanding of efficient particle acceleration at non-relativistic, collisionless shocks, addressing with both analytical and numerical (particle-in-cell) techniques the crucial interplay between accelerated ions and magnetic turbulence. In SNRs, in fact, magnetic fields turn out to be a factor of 10-100 larger than in the interstellar medium, because of plasma instabilities triggered by energetic particles. In particular, I show 2D and 3D hybrid (fluid electrons - kinetic ions) simulations of non-relativistic collisionless shocks, pointing out the efficiency of Fermi acceleration and the role of the cosmic-ray-induced filamentation instability in amplifying the magnetic field up to the levels inferred at the blast waves of young Galactic remnants. Finally, I outline the observational counterparts of such a theory of particle acceleration at strong shocks in terms of SNR multi-wavelength emission, with a special attention to Tycho's SNR, arguably the best laboratory where to test hadron acceleration.