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Diffusive Shock Acceleration of Cosmic Rays - Quasi-thermal and Non-thermal Particle Distributions

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A well-known paradigm about the origin of Galactic cosmic rays (CRs) is that these high-energy particles are accelerated in the process of diffusive shock acceleration (DSA) at collisionless shocks (at least up to the so-called "knee" energy of 10^{15} eV). Knowing the details of injection of electrons, protons and heavier nuclei into the DSA, their initial and the resulting spectrum, is extremely important in many "practical" applications of the CR astrophysics, e.g. in modelling of the gamma or synchrotron radio emission of astrophysical sources. In this lecture I we will give an overview of the DSA theory and the results of observations and kinetic Particle-In-Cell (PIC) simulations that support basic theoretical concepts. PIC simulations of quasi-parallel collisionless shocks show that thermal and supra-thermal proton distribution functions at the shock can be represented by a single quasi-thermal distribution – the κ-distribution that is commonly observed in out-of-equilibrium space plasmas. Farther downstream, index κ increases and the low-energy spectrum tends to Maxwell distribution. On the other hand, higher-energy particles continue through the acceleration process and the non-thermal particle spectrum takes a characteristic power-law form predicted by the linear DSA theory. At the end, I will show what modification of the spectra is expected in the non-linear DSA, when CR back-reaction to the shock is taken into account.

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