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Recent Results on Particle Acceleration at Non-relativistic Shocks

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Shock waves in cosmic plasma are generally considered as most appropriate candidates for the role of particle accelerators, being the possible sources of relativistic electrons responsible for the non-thermal electromagnetic radiation (radio, X-rays, gamma) as well as cosmic rays (CR). They can be found in numerous astrophysical objects widely varying in scales, from Earth's bow shock and solar flares, through supernova remnant (SNR) shocks, up to Mpc-scale merger shocks in galaxy clusters.
The details of particle acceleration at astrophysical shocks are not fully understood yet, and they still remain the subject of investigations. A dominant acceleration mechanism assumed to operate at non-relativistic shock waves is diffusive shock acceleration (DSA), also known as first-order Fermi process. However, the unresolved question still remains in DSA theory, known as "injection problem": it works only for particles with a Larmor radius larger than thickness of the shock transition. Some pre-acceleration is thus required, in particular for electrons because of their smaller mass. The possible mechanisms of initial particle energization strongly depend on physical conditions, which can vary in a very wide range for the different types of shocks. According to the recent investigations, particle pre-acceleration necessary for injection to DSA can be realized either through the plasma instabilities (e.g. Buneman instability) or other acceleration mechanisms, such as shock surfing acceleration (SSA) or shock drift acceleration (SDA). The latter can work even for very slow shocks with Mach numbers $M << 10$ (e.g. merger shocks). In particular, in our recent studies with numerical kinetic simulations, we demonstrate that multi-wavelength magnetic turbulence increases the efficiency of the electron pre-acceleration at SDA. The acceleration process at such conditions is is stochastic SDA (SSDA), when particles are confined in the shock transition region by pitch-angle scattering off magnetic turbulence. The SSDA process has been found to be a plausible mechanism for the electron injection to DSA. This is consistent with observations of X-ray and radio emission that indicate the efficient electron acceleration at this kind of shocks.

Primary author: Dr KOBZAR, Oleh (Astronomical Observatory of the Jagiellonian University)

Presenter: Dr KOBZAR, Oleh (Astronomical Observatory of the Jagiellonian University)

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