

The origin of energetic particles is a long-standing problem in astrophysics. High-energy charged particles produce intense nonthermal radio, X-ray, and gamma-ray emissions observed from astronomical objects. They are also registered in copious amounts at the Earth and known as cosmic rays. Detected cosmic ray energies reach 10^{21} eV, and must be even higher at sources, since part of CR energy is lost during propagation in intergalactic and/or interstellar media.

High-energy particles are often assumed to be accelerated at shock waves. Shocks are ubiquitous in the Universe. They are found in a number of astrophysical objects, ranging in size from the Earth's bow shock, through solar flares, termination shock of the solar wind, supernova remnant shocks, and large-scale structures, such as gamma-ray burst shocks and merger shocks in galaxy clusters.

The aim of this project is to study processes that lead to production of energetic charged particles at shock waves in cosmic plasmas. We will investigate nonrelativistic and relativistic shocks in astrophysical environments. Though general mechanisms of particle acceleration at shocks have long been identified, we are far from a complete understanding which of these processes are allowed to operate under physical conditions at sources, and what are their efficiencies.

Astrophysical plasma is a complex system, in which energetic particles, electromagnetic radiation, and particles of the thermal plasma are strongly coupled. Appropriate method is thus needed to study such a system. The most precise such a tool are state-of-the-art Particle-in-Cell (PIC) numerical simulations. It is based on a simple idea to follow trajectories of individual plasma particles on the computational grid, on which electromagnetic fields are also defined and their evolution can be traced by solving the well known Maxwell's equations. This method allows studying plasma at smallest – electron – scales. However, in a strongly coupled plasma system, these microphysical scales can in a long run shape the processes that occur on much larger macro-scales of astrophysical objects. Therefore studying microphysical plasma processes is crucial for understanding the physics of astronomical objects that host collisionless shocks.

In this project we are interested in particle energization. We will investigate these processes in two distinct and poorly explored shock and ambient plasma parameter regimes. The issue we want to study for nonrelativistic systems is how electrons and protons of the thermal plasma can be pre-accelerated at shocks to energies, at which the internal structure of the shock can no longer influence their interactions with the shock discontinuity. These particle injection processes will be investigated at weak and slow, but huge shocks formed during mergers of galaxy clusters that move in very hot plasmas of intra-cluster medium. In relativistic shock studies we are interested in processes that allow electrons and protons gain enormous energies through interactions with large-amplitude electromagnetic waves that can be formed upstream of shocks. Such relativistic shocks can be found in jets of active galaxies or gamma-ray bursts, in which plasma may be magnetized.

The PIC simulations planned in this project will be performed on supercomputers with large computational power, using advanced high-performance massively parallel numerical codes.