Formation, structure, evolution, and radiation of current sheets and filaments in collisionless relativistic plasma

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We review recent progress in analytic understanding of the origin and various properties of magnetic field configurations emerging in relativistic astrophysical shocks and jets. In a collisionless plasma, the main mechanism for magnetic field generation is the so-called Weibel instability, which has recently been analyzed in detail for a number of relativistic particle distribution functions. We discuss the saturation of this instability, which occurs at a sub-equipartition level of magnetic field energy and results in a substantial modification of particle distribution function.

In typical planar and cylindrical geometries, we find analytically a wide class of nonlinear stationary current structures which can be equally easy to realize in relativistic and non-relativistic collisionless plasma. These solutions are based on the method of integrals of motion, and extend far beyond the known generalizations of non-relativistic Harris model. The obtained Grad-Shafranov type equations allow us to analytically investigate and compare general properties and possible evolution of these structures. Among the properties of newly found stationary solutions we discuss the ratio of magnetic field energy to that of particles, the anisotropy of particle momentum distribution, the spatial scales and profiles, etc.

Also, we carry out the short wavelength instability analysis of these current sheets and filaments in the regions with small enough magnetic fields, where this instability is expected to be the most pronounced. We estimate typical spatial- and timescales of the instability which could develop in relativistic collisionless current configurations in active galactic nuclei, microquasars, gamma ray burst sources, and neutron star winds. We estimate the synchrotron radiation of relativistic particles in self-consistent current sheets and filaments, which makes it possible to study the structure and evolution of current structures based on their observed radiation.

We use our results for the interpretation of recent observations and numerical simulations of magnetic field evolution in relativistic plasma shocks.