Particle acceleration in laboratory magnetosphere

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Abstract

Magnetospheres are commonly seen objects in the universe that form natural plasma confinement devices. The study of magnetospheres has provided many insights for laboratory plasma. This talk will give overview of theoretical studies of magnetospheric plasma followed by recent results of magnetospheric plasma experiments.

One characteristic of magnetospheric plasma is a strongly inhomogeneous density distribution with planetward gradient. Such a self-organized structure is developed by an inward (or radial) diffusion process [1] which seemingly contradicts the maximum entropy principle. The key to understanding the inward diffusion is adiabatic invariants of magnetized particles: magnetic moment, bounce integral, and magnetic flux shell. Violation of the most fragile third invariant, while the other two invariants are kept constant, provokes the inward diffusion. One of the modern theoretical approaches to understanding the inward diffusion is regarding the adiabatic invariants as topological constraints in a phase space [2]. Following this approach, entropy is maximized on a topologically constrained (foliated) phase space instead of on Cartesian coordinates. The planetward density gradient on the Cartesian coordinate is equivalent to the uniform density on the foliated phase space [2, 3].

Experimental research has also advanced our understanding of magnetospheric plasma in recent years. The inward diffusion was observed in the ring trap 1 (RT-1) device [4, 5] and the Levitated Dipole Experiment (LDX) [6] that simulate laboratory magnetospheres via the levitated superconducting magnets. In these experiments the peaked density profile similar to the planetary magnetosphere was observed. Our most recent experiments observed the inward diffusion causing particle acceleration [7, 8]. A particle is energized when it is transported inward, with its first and second adiabatic invariants kept constant; conservation of the first adiabatic invariant increases the particle's perpendicular kinetic energy (betatron acceleration), and conservation of the second invariant increases its parallel energy (Fermi acceleration). These acceleration mechanisms are the primary generator of planetary radiation belts, and we proved that the former mechanism is responsible for ion heating in the RT-1.

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