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Stable confinement of non-neutral plasma in a magnetospheric configuration

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The Ring Trap 1 (RT-1) device is an artificial magnetosphere generated by a levitated high-Tc superconducting magnet. RT-1 has taken a hint from diverse astrophysical phenomena in planetary magnetospheres and aims to realize high-performance confinement of plasmas. In this study, we report the recent progress of non-neutral (pure electron) plasma experiment in RT-1.
Fundamental properties of plasmas, such as particle transport, diffusion, waves, and vortex formations, have been precisely studied by using non-neutral plasmas. Recently, particle beam technology is rapidly developing, and today slow antiproton and positron beam sources are available. Aiming for the stringent test of the CPT symmetry and formation of an electron-positron pair plasma, new experiments are starting. The research area of non-neutral plasma physics is thus expanding in the boundary regions of atomic and particle physics and astrophysics, as well as in basic studies in plasma physics including collective phenomena of charged particles.
Linear geometries (such as a Penning-Malmberg trap) are most generally used for the confinement on non-neutral plasmas, where extremely stable confinement is realized. However, plasmas consists of different electric signs are not easily trapped in the linear geometries, because axial confinement is realized by electrostatic plugging potential. In a toroidal geometry, however, particle confinement is realized independent of the sign of electric charges, and we can in principal confine plasmas with arbitrary non-neutrality. Aiming for the aforementioned scientific applications of non-neutral plasma studies, we have started experiment on toroidal non-neutral plasma in the magnetopheric configuration RT-1.
Little is known about the equilibrium structure of non-neutral plasma in the strongly inhomogeneous dipole magnetic field. In RT-1, magnetic coil levitation has minimized the plasma disturbance, and the maximum stable confinement time of the electron plasma exceeds 300s. The observed trap time is as long as the classical diffusion time due to collisions of electrons with neutral molecules, indicating that extremely stable structure is generated. During the electron beam injection, the plasma has a turbulent-like large-amplitude fluctuation. After the end of the electron injection, the plasma is stabilized and it has a coherent small-amplitude fluctuation, suggesting rigid-rotor rotations. We have directly measured the radial electric field using multiple wall probes, and found that the long-lived plasma is trapped in the strong magnetic field region. In RT-1, electrons are injected from an electron gun located at the edge confinement region. In the stronger magnetic field region, the space potential exceeds the initial acceleration voltage of the electron gun. The canonical angular momentum of the charged particles is not conserved when the symmetry of the trap system breaks due to the diocotron (Kelvin-Helmholtz) instability. Then electrons can be radially transported across the magnetic surfaces, violating the third adiabatic invariant. The observed inward particle diffusion and energization can be explained by the conservation of the first and second invariants. The observed radial transport of particles by the symmetry breaking is easily realized by external electrodes, and it can be used as effective injection and extraction methods of toroidal non-neutral plasmas trapped in the closed magnetic surfaces. We also present the experimental results of wave propagation in the radial direction and particle transport process.