Laboratory Magnetosphere RT-1: Self-organized magnetic confinement in most natural configuration

Z. Yoshida, M. Nishiura, N. Kenmochi, H. Saitoh, Y. Kawazura, N. Sato,
T. Sugata, K. Shirahata, S. Katsura, K. Nakamura

Department of Advanced Energy, University of Tokyo
Kashiwa, Chiba, Japan

The aim of the RT-1 project is to study the basic physics of magnetic confinement in its most natural realization, the magnetosphere. The mechanism of magnetic confinement is at the opposite pole of the other natural process occurring in stars. The gravitational mechanism is just the minimization of the energy. However, the magnetic mechanism is not so simple. Since the magnetic force does not change the energy of particles, the Boltzmann distribution is independent of the magnetic field. While there are recourses to non-equilibrium mechanisms, they fall short of understanding how magnetic dipoles self-organize long-lived confinement ubiquitously in the Universe. We have yet to understand what the actual equilibrium state of plasmas is.

Here we explain the mechanism of creation by the geometry of the phase space (not the energy). The essential role is played by the *topological constraints* that prevent the entropy to be maximized on the energy sphere; the effective phase space of the magnetospheric system is a leaf (sub-manifold) of the conventional phase space, on which the metric of canonical variables distribute heterogeneously. The maximum-entropy distribution function on the effective phase space is multiplied by the Jacobian when we evaluate the corresponding distribution function on a reference frame. What appears as a structure is, therefore, the Jacobian of the proper space in which particles live [1].

When particles are driven by low-frequency ($< \omega_c$) fluctuations, the diffusion of magnetized particles is topologically constrained to maintain the constancy of the magnetic moment. This constraint is the origin of all nontrivial physics of magnetospheres. Maximizing the entropy under the constraint of the magnetic moment, we obtain a Boltzmann distribution on a grand canonical ensemble:

$$f = f_0 \exp[-\beta(H - \gamma\mu)],$$

where H is the guiding center Hamiltonian, β is the inverse temperature, μ is the magnetic moment, and γ is the chemical potential measuring the energy per magnetic moment; hence particles accumulate near the magnetic dipole [2].

The relaxation into the aforementioned equilibrium appears as inward diffusion creating a steep density gradient. As a concomitant phenomenon, we observe betatron acceleration of particles [3].

References

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