

Self-organization and flow in high-beta magnetized plasmas

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The self-organized plasmas with high-beta such as spheromaks have the common features as magnetic reconnection, kinking behavior, particle acceleration and shock wave which are observed in space phenomena. Dynamical process of explosive plasmoid ejection, magnetic field's twisting and reconnection could account for the various phenomena called astrophysical jets, solar coronal loops and Jupiter's zonal flow driven by thermal convection. As for fusion plasmas, to control externally plasma flow or rotation plays an important role on maintaining high-beta confinements with an optimized pressure gradient. It is well known that for example, the H-mode transition in tokamak plasmas is created by inward radial electric field and poloidal shear flow. The diamagnetic configuration like Field Reversed Confinement (FRC) with super high beta, in which ion flows generate currents, is normally analyzed based on two-fluid MHD relaxation model. In helicity-driven system, non-axisymmetric dynamic processes create current due to the dynamo action in the plasmas and relax them toward certain minimum energy equilibria. The non-axisymmetric behavior, which arises from a helical kink instability on the open flux, could be responsible for the formation and sustainment of the configurations by helicity injection [1]. In this conference, we will present recent topics about dynamics and relaxed states relevant to MHD relaxations, plasmoid ejection, dynamo and kinking behavior which are recognized as analogical phenomena in astrophysical and fusion plasmas.

It is possible to replicate astrophysical plasma phenomena in the laboratory because MHD has no intrinsic scale. The governing MHD equations can be expressed in a dimensionless form that is equally applicable to systems having scale lengths with many orders of range. Now, a point is how to produce flexibly plasmoid eruptions like solar flares by taking critical issues of geometry and topology into consideration. We will introduce the magnetized coaxial plasma gun (MCPG) to make it possible to investigate such a bubble burst-like behavior. The MCPG is often used to produce spheromaks with poloidal and toroidal magnetic fields generated by internal current. Historically the spheromak was for the first time produced by Alfvén et al. by using the MCPG.

The driven-relaxed configurations with open field lines, as well as closed systems, are described by the force-free equilibrium (Jensen-Chu) equation, $\nabla \times \mathbf{B} = \lambda \mathbf{B}$, where λ is the force-free parameter. The nature of the relaxed states in helicity-driven systems is characterized by the strength of the external toroidal field and the value of λ determined by coupling to the MCPG. Note that in the doubly connected helicity-driven system, the flipped spherical torus (ST) state appears in the regime of $\lambda < \lambda_e$, where λ_e is the lowest eigenvalue, so that it could be observed in laboratory experiments. The structural formation of the flipped field configuration incorporates the self-reversal process of the toroidal and poloidal fields. This self-organizing phenomenon may have some analogy to reversal of the dipole field of Earth generated by a dynamo action. It is fundamentally important to elucidate a current-reversal phenomenon occurring in space and laboratory plasmas. We have observed this novel current-reversal phenomenon in our HIST experiment [2, 3]. The most important discovery of this experiment is that spherical torus plasmas tend to self-organize to the flipped states while reversing the direction of the external toroidal field [2, 3]. This experimental finding provides, for the first time, evidence for the existence of the relaxed states which were theoretically predicted.

References

- [1] M. Nagata et al., Phys. Rev. Lett. 71, 4342 (1993)
- [2] M. Nagata et al., Phys. Rev. Lett. 90, 225001 (2003)
- [3] M. Nagata et al., Phys. Plasmas 10, 2932 (2003)

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