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Many aspects of plasma expansion physics in the magnetic nozzle and space applications

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Spontaneous plasma acceleration and momentum conversion processes in magnetic nozzles are ubiquitous in naturally occurring and artificial plasmas, and are further attempted to be utilized to a new type of plasma thruster for space propulsion [1]. A thrust force propelling the spacecraft is equal in magnitude and opposite in direction to the momentum flux exhausted from the system. Therefore the experimental identification of the thrust is indeed useful for not only performance assessment of thrusters but also understanding gain and loss processes of the plasma momentum.

Here the thrust generation and loss processes, which have been clarified by the direct thrust measurement and the individual measurements of the forces exerted to the magnetic nozzle [2,3] by a Lorentz force arising from an electron diamagnetic current [4] and the radial wall [5], are shown. The propulsive magnetic nozzle (increasing the thrust) is essentially due to the diamagnetism of the plasma flow (decreasing the axial magnetic fields and diverging the magnetic nozzle); the plasma flow state stretching the magnetic nozzle had not been observed in laboratory experiments. Here the stretch of the magnetic nozzle occurring at the axial location of the Alfven Mach number less than unity ($M_A < 1$) is observed [6], while maintaining the diamagnetic momentum gain near the thruster exit. The model discussed recently qualitatively explain the stretch of the magnetic nozzle at $M_A < 1$, while the change of the magnetic field strength is still small, being a few percent of the applied magnetic field. More detailed experiments exploring the condition that the magnetic nozzle and the plasma flow are drastically changed remains further issue.

In the helicon plasma thruster, the most of the external energy is coupled with the electrons and the non-equilibrium plasmas are sustained due to the low collisionality between the electrons and ions. Therefore the thermodynamic behavior of the electrons are significantly important to model the plasma expansion in the magnetic nozzle, while the laboratory experiments have always shown nearly isothermal behavior since they are trapped in the system by sheath and ambipolar electric fields. The special experiment is constructed to investigate the pure interaction between the electron gas and the magnetic nozzle, by removing all the electric field from the system. The precise measurement of the electron energy probability functions reveals the adiabatic expansion of the electron gas in the absence of the electric field in the system [7]. Finally, new application of the plasma thrusters for active space debris removal is demonstrated in a laboratory experiment [8].

References

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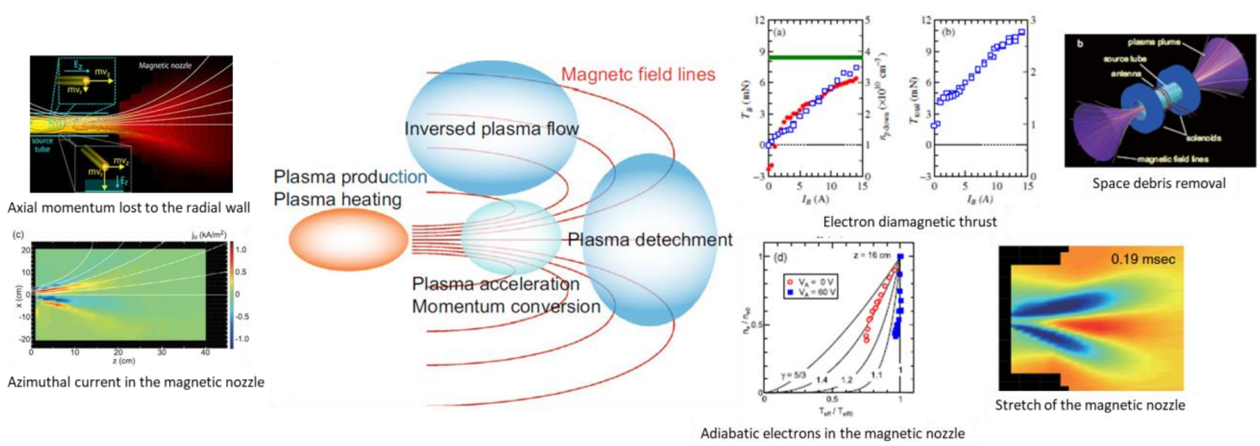

Figure 1: Many aspects of physics in the magnetic nozzle plasma