Inward diffusion driven by low frequency fluctuations in self-organizing magnetospheric plasma

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ABSTRACT

- The new findings for dynamic process of inward diffusion in the magnetospheric plasma are reported on the RT-1 experiment:
- (i) The evolution of local density profile in the self-organized process has been analyzed by the newly developed tomographic reconstruction applying a deep learning method.
- (ii) The impact of neutral-gas injection excites low-frequency fluctuations, which continues until the peaked density profile recovers. The fluctuations have magnetic components (suggesting the high-beta effect) which have two different frequencies and propagation directions.

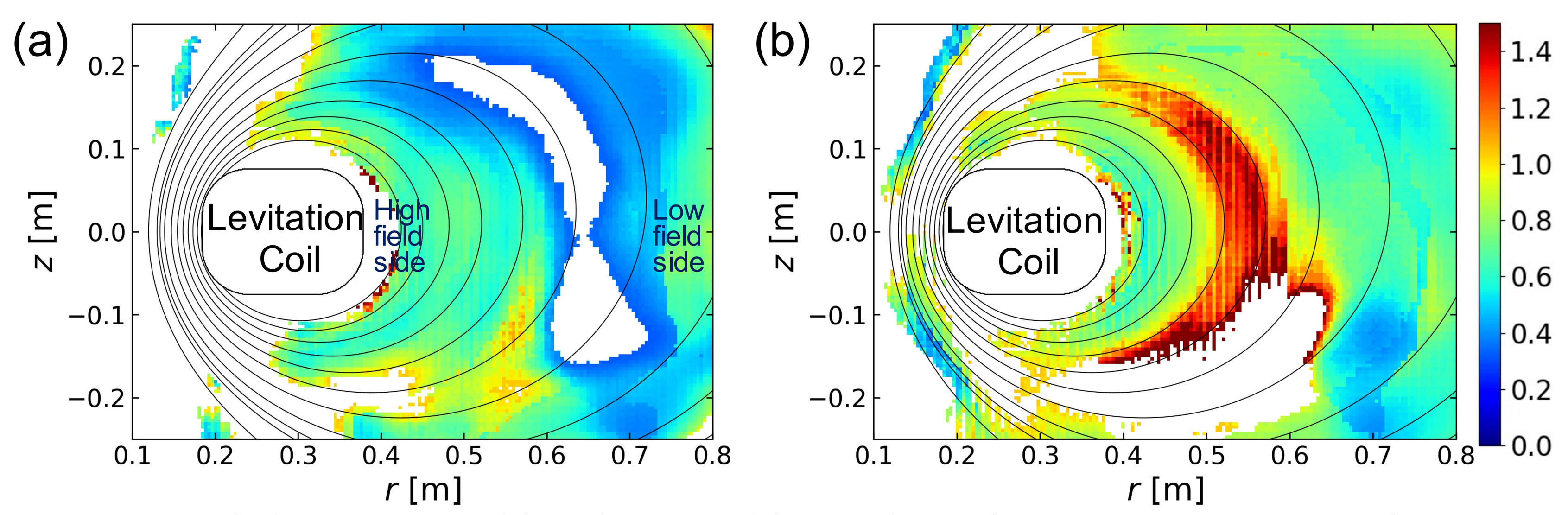
INTRODUCTION

- ✓ The Ring Trap 1 (RT-1) device is a laboratory magnetosphere that is realized by a levitated superconducting ring magnet in vacuum.
- ✓ The spontaneous confinement of high-beta plasma in the magnetospheric configuration results from the inward (or uphill) diffusion driven by "low-frequency" fluctuation; the relevant frequency must be in the ion drift frequency range so that the constancy of the angular momentum is broken, while the actions of the bounce and gyro motions are conserved.
- ✓ The topological constraints due to these adiabatic invariants explain the inward diffusion.
- ✓ The RT-1 device confines a high-beta plasma (local electron beta ~1) in a dipole magnetic field.
- ✓ The density has a strongly peaked profile that is explained as the homogenization of particle number among different magnetic flux tubes.

FORMATION OF SELF-ORGANIZED PLASMAS

- ✓ Perturbing the density profile by neutral-gas injection, we demonstrate the excitation of low-frequency fluctuations which persist until the inward diffusion reproduces the self-organized density profile.
- ✓ A tomographic reconstruction method using a deep learning technique has been developed to obtain local-intensity profiles from imaging-diagnostic data.
- ✓ Using a pair of emission lines of neutral helium with wavelengths of 388 nm and 447 nm, each line-of-sight integrated image measured by a high-speed camera is reconstructed to a local-intensity profile by the tomographic method.
- ✓ The local value of the electron density is obtained by line ratio spectroscopy by taking the ratio of these two local-intensity profiles.
- ✓ The local density profile shows that a peak density profile is formed in the high magnetic field side near the levitation coil as the result of inward diffusion.

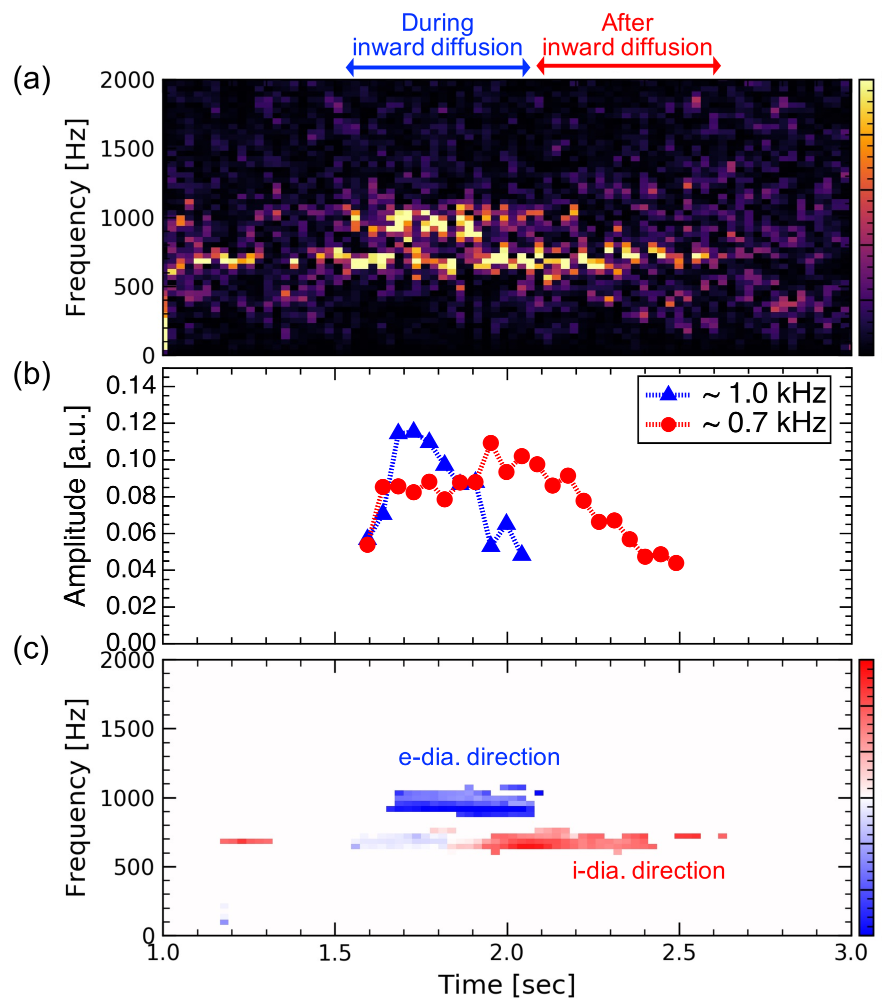
Before inward diffusion　　**After** inward diffusion



Local density profile obtained by a deep learning tomography. (a) and (b) is the local density profile before and after the inward diffusion, respectively.

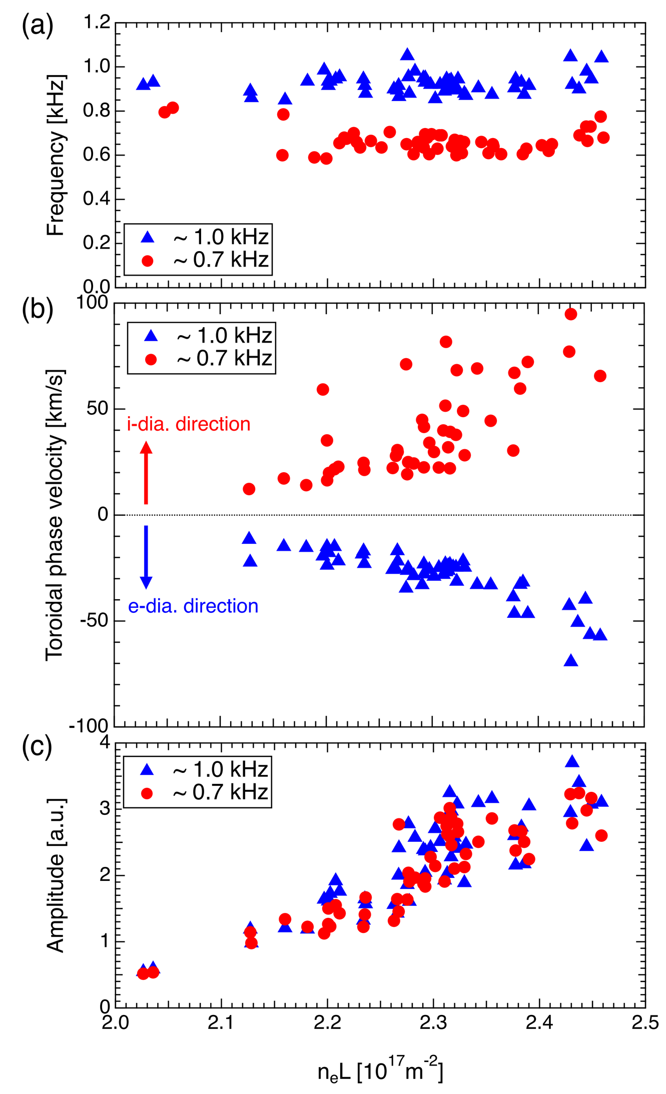
CHARACTERISTICS OF LOW-FREQUENCY FLUCTUATION WITH INWARD DIFFUSION

- ✓ Simultaneous excitation of low-frequency fluctuations during the inward diffusion are observed in electrostatic potential, electron density, and magnetic field ($B_{\parallel}$ direction).
- ✓ The typical phase velocities for the low-frequency fluctuation in toroidal and z-direction are 30 km/s (k⊥= 0.003 cm-1, k⊥ ρi~0.02) and 2 km/s (k‖= 0.02 cm-1, k‖ ρi~0.2), respectively.
- ✓ A neutral gas is injected at *t* = 1.56 sec and the inward diffusion occurs until *t* ~2.1 sec.
- ✓ During the inward diffusion, the fluctuation intensity of 1 kHz component is dominant.
- ✓ After the inward diffusion, the fluctuation of 1 kHz component decays, while the fluctuation of 0.7 kHz increases in intensity.
- ✓ This results suggests that the energy transfers from 1 kHz component to 0.7 kHz component with the progress of inward diffusion.
- ✓ The propagation direction depends on the density profiles, suggests that the drift wave instability is a candidate for the low-frequency



Time evolution of (a) the power spectral density of magnetic fluctuation, (b) the intensity and (c) phase difference of two magnetic probes toroidally separated by Δφ = 45 degrees

The electron density dependence of (a) the frequency of magnetic fluctuations, (b) the toroidal phase velocity, and (c) intensity.



- ✓ The phase velocity in toroidal direction of the low-frequency fluctuations, which were of the order of diamagnetic drift velocity of 10^4 m/s of the RT-1, increase with an increase in the electron density.
- ✓ The intensity of both fluctuations is strongly dependent on the electron density rather than the plasma pressure, suggesting that the "free energy" causing the fluctuation is the distortion of the density profile.

CONCLUSION

- (i) The self-organized peak density profile after the inward diffusion has been visualized by the tomography with deep learning technique.
- (ii) The low-frequency fluctuation which drives inward diffusion has been discovered and its physical characteristics have been revealed.
- These results advance our understanding of transport and self-organization not only in dipole plasmas, but also in general magnetic confinement systems relevant to fusion plasmas.

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