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Recent Advances in the Understanding of Fluctuation Activities of High-Beta Plasma in RT-1

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Abstract

- Low frequency fluctuations drive inward transport of particles and self-organization of high-beta peaked structures in RT-1 (Ring Trap 1) levitated dipole.
- It is observed that low-frequency electrostatic mode in low-beta plasma transition into electromagnetic modes in profile reconstruction phase of high-beta operation.
- In low-beta conditions, toroidal phase velocity of the fluctuations has no clear dependence on the magnetic surfaces, suggesting rigid-rotator like structure.
- In high-beta plasma, the fluctuation reverses its toroidal propagation direction according to plasma conditions, suggesting a similarity to the entropy mode.
- We also expanded the measurement frequency range of magnetic probes and identified fluctuations around and below the local electron cyclotron frequency.

Background

- Stable formation of very high-beta (>100%) plasma in a dipole magnetic field is potentially applicable to burning advanced fusion fuels such as D-D or D-^{3}He.
- RT-1 of U Tokyo and LDX of MIT/Columbia U have realized self-organization of high-beta plasma in a superconducting levitated dipole configuration.
- Efficient inward radial transport in the dipole field is driven by low-frequency fluctuations, which creates high-beta equilibrium peaked in a strong field region.
- In RT-1, spontaneous formation of low-frequency (~kHz) fluctuations are observed in the formation phase of high-beta plasma.
- The spatial structure and conditions of occurrence of these fluctuations are important to further understand their role on high-beta plasma formation process.

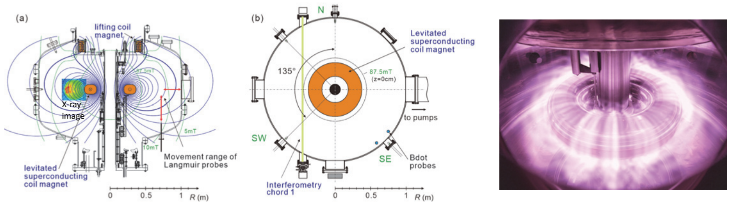
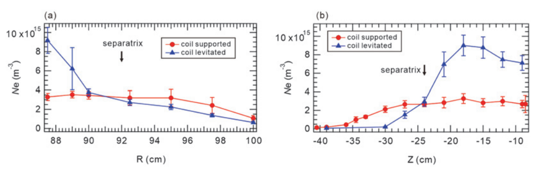


Fig.1: Ring Trap 1 (RT-1) levitated dipole and ECH plasma created around SC coil.

Spatial profile measurements with Langmuir probes

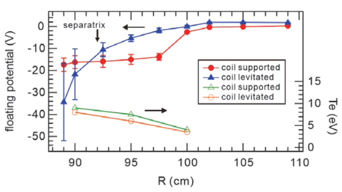
Langmuir probes capable of operating under high heat flux conditions

Measurement of spatial structures (N_e, T_e, and fluctuations) inside plasma in addition to previously-installed magnetic measurement by edge Bdot probes.



Steep density gradient is generated by the coil levitation.

Fig.2: Electron density profiles measure by radial and vertical probe scan.



Because the radial electric field estimated from

$$V_p = V_f + \frac{k_B T_e}{e}(3.3 + 0.5\ln\mu)$$

is < 100V/m, the E × B drift velocity is ~km/s, which is typically one order of magnitude smaller than the magnetic drift velocity.

Fig.3: Floating potential profiles.

Separation of electrostatic and magnetic fluctuations

Magnetic fluctuation probes (Bdot probes) with electrostatic component rejection

Fast Bdot probes with oppositely-winded loops used for fluctuation measurements.

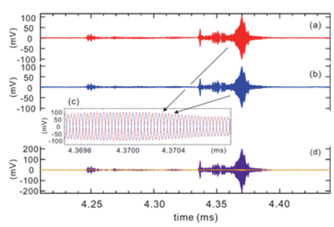


Fig.4 magnetic and electrostatic components are separately measured by subtracting and summing signals from two loops.

Electrostatic and electromagnetic nature of fluctuations

Conditions for the occurrence of electrostatic and electromagnetic fluctuations

- Low frequency modes at 0.7kHz and 1kHz have been identified as electromagnetic fluctuations appears only during density reconstruction after additional gas puffing.
- Even in magnetically quiet conditions, Langmuir probe measurements show the existence of electrostatic fluctuations with clear peak at 0.7kHz.

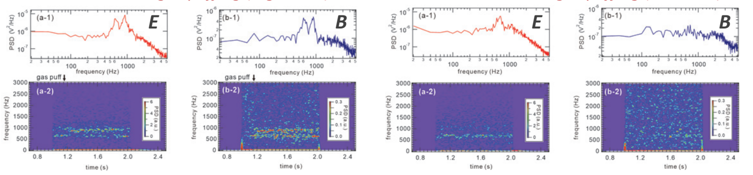


Fig.5 PSD and temporal evolution of electrostatic and magnetic fluctuations.

- Comparison of electrostatic and magnetic component of fluctuations indicate that 0.7 kHz fluctuation, which exists as an electrostatic wave, is transformed into a strong fluctuation with magnetic component, and a new electromagnetic 1 kHz wave emerges due to gas puffing, suggesting modified drift wave type modes.

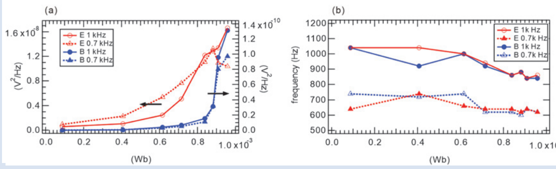


Fig.6 Intensity and center frequency of fluctuations for various plasma pressure.

Spatial structure of fluctuations and phase velocity reversal

- For low-beta conditions, electrostatic fluctuations of both 0.7 and 1 kHz have a toroidal mode number of 3 or 4, which does not strongly depend on the radial position of the measurement position (Fig. 7), suggesting semi rigid-rotation state.
- For higher-beta operation, as shown in Fig. 8, the toroidal direction of the phase velocity reversed according to the plasma parameters by inserting the probe structure inside the plasma, suggesting that the propagation direction is decided by N_e and T_e profiles. This property is similar to that of the so-called entropy mode.

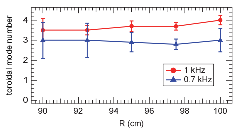


Fig.7 Toroidal mode Number of fluctuations for low-beta plasma.

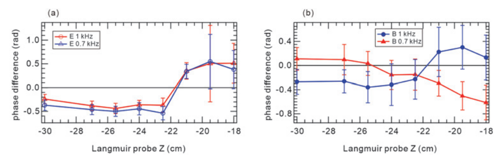


Fig.8 Phase difference of (a) electrostatic and (b) Magnetic fluctuations for different Langmuir probe positions.

Fluctuations in higher frequency range

- Higher frequency (~<f_{ce}) activities for hot-electron high-beta plasma of RT-1.
- The observed wave properties agree with whistler wave, which can efficiently accelerate electrons into relativistic chaotic trajectory regime.

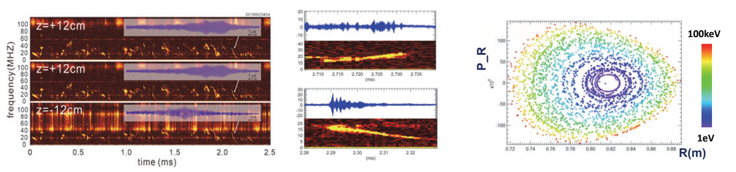


Fig.9 Electromagnetic mode in higher-frequency and electron acceleration.

Conclusion

- Electromagnetic low-frequency mode in the structure formation phase of high-beta plasma is excited as an electrostatic mode in low-beta plasma of RT-1 dipole.
- The wave propagation changes its toroidal direction according to plasma conditions.
- Similarity to the modified drift wave and the so-called entropy mode is suggested.
- In higher frequency range, spontaneous excitation of R-wave was observed, which can efficiently accelerate electrons to chaotic orbit.

Acknowledgements

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