Observation of Fluctuation-Induced Particle Transport Phenomena in the RT-1 Levitated Dipole

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ABSTRACT: Background and objectives

- RT-1 aims to understand the formation mechanism of stable high-beta state in dipole magnetic configuration, toward the realization of advanced fusion
- While several fluctuation modes have been observed, their roles and effects on particle transport and the self-organization process were unclear
- To understand the interaction between fluctuations and particle transport, we investigate the radial particle flux caused by low-frequency fluctuations and the electron loss effects induced by whistler-mode chorus emissions

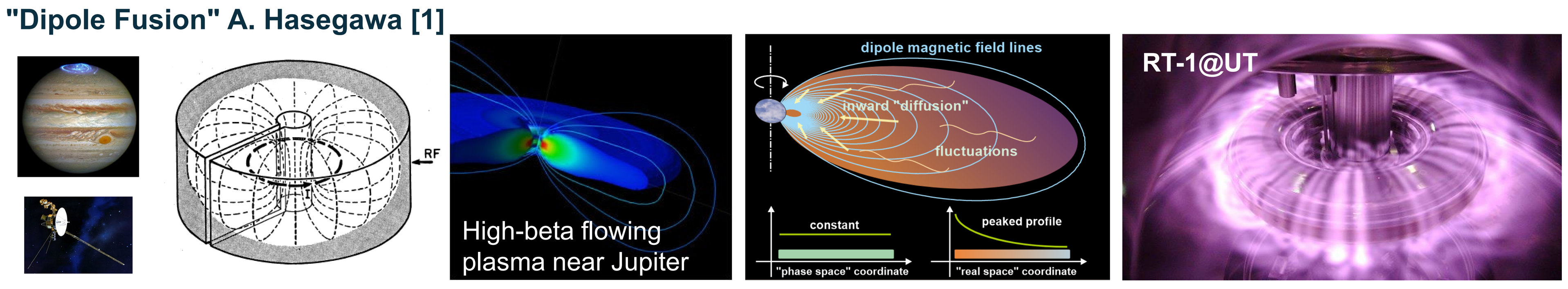
Results and conclusion

- Simultaneous measurements with electric and density fluctuations showed inward particle flux caused by low-frequency fluctuations for the first time
- Escaping fast electrons were detected near the chamber wall during the abrupt onset of whistler-mode chorus emissions
- These direct measurements showed fluctuations play roles in the radial particle transport in the dipole magnetic field configuration. Future work includes quantitative evaluation of their effects on self-organization process

BACKGROUND: Magnetospheric levitated dipole confinement

- Dipole confinement concept motivated by planetary magnetosphereres

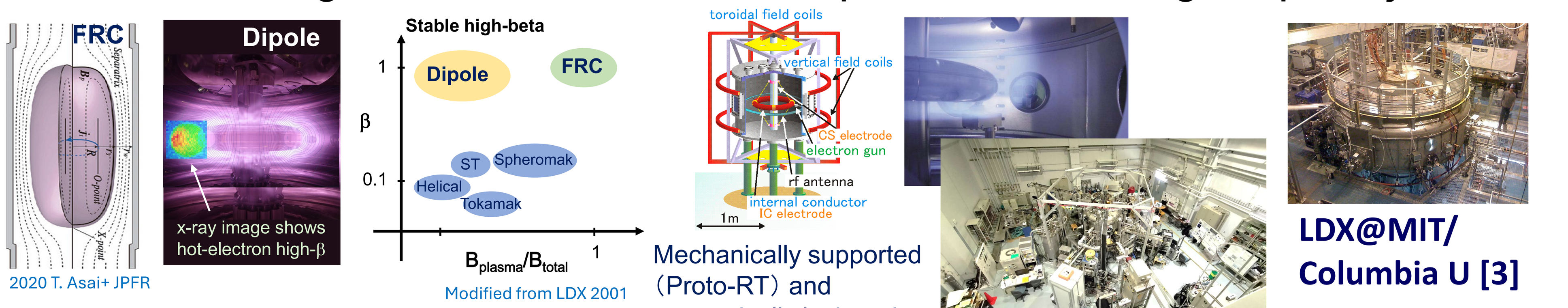
"Dipole Fusion" A. Hasegawa [1]



High-β (>>1) plasma near Jupiter — Flowing high-β plasma — "Flattening" in phase space — ECH plasma in levitated dipole

- Ultra high-beta plasma for advanced fusion
- Geospace phenomena like chorus emissions
- Wave particle interaction and self-organization
- Non-neutral and antimatter (e-/e+) plasmas

- Innovative high-beta confinement in Dipole and the Ring Trap Project



Stable β~100% state for more than 1s without using plasma current

Mechanically supported (Proto-RT) and magnetically levitated (Mini-RT, RT-1) experiments

Proto-RT, Mini-RT, and RT-1@Utokyo [2,5,6]

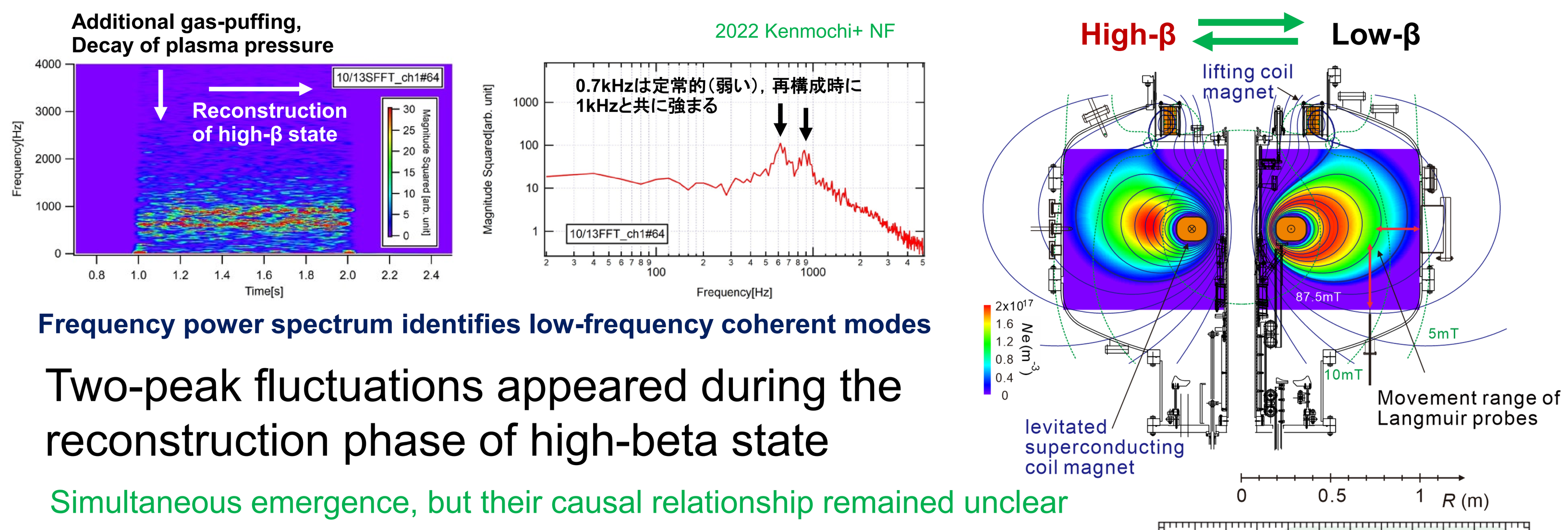
LDX@MIT/ Columbia U [3]

OpenStar in NZ

APEX@IPP/TUM

Fluctuation and self-organization studies at RT-1 [4]

- Low-frequency (~toroidal circulation) fluctuations

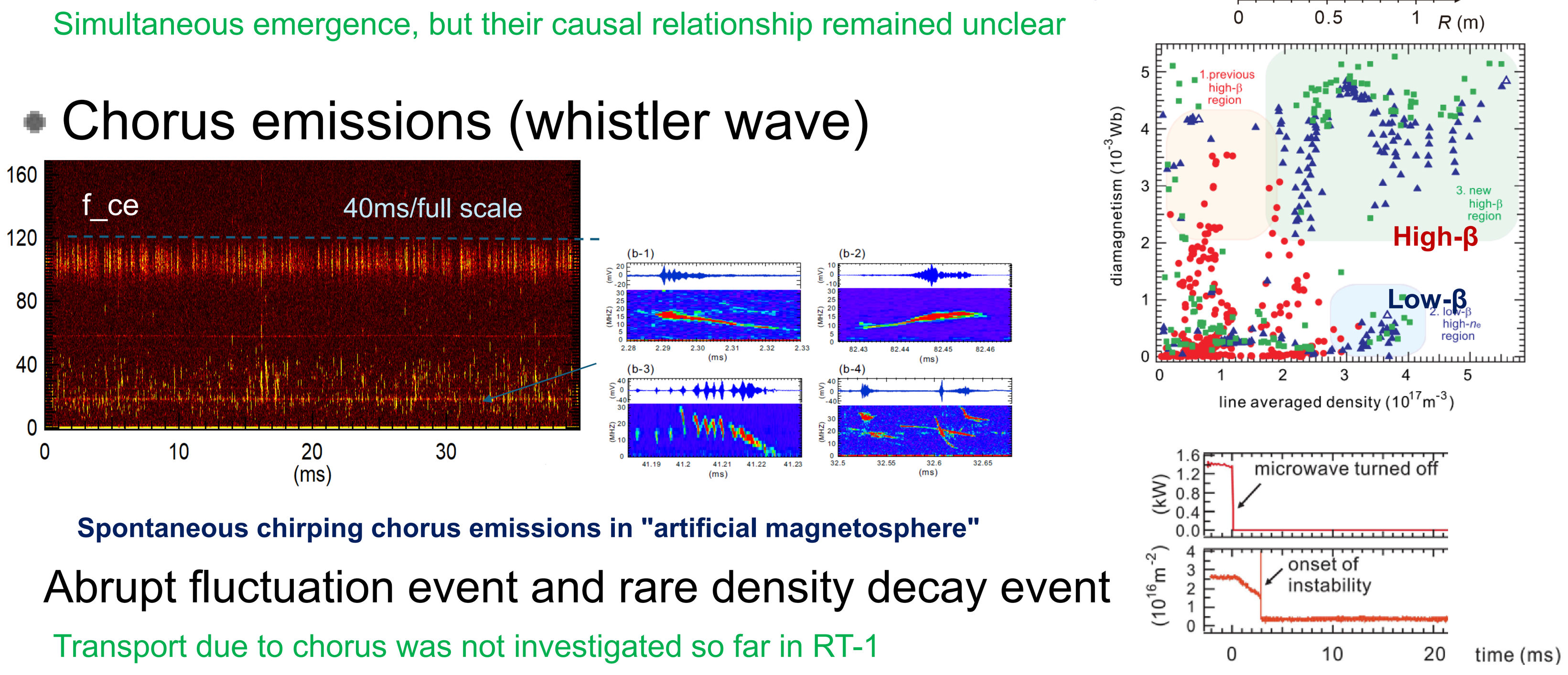


Frequency power spectrum identifies low-frequency coherent modes

Two-peak fluctuations appeared during the reconstruction phase of high-beta state

Simultaneous emergence, but their causal relationship remained unclear

- Chorus emissions (whistler wave)



Spontaneous chirping chorus emissions in "artificial magnetosphere"

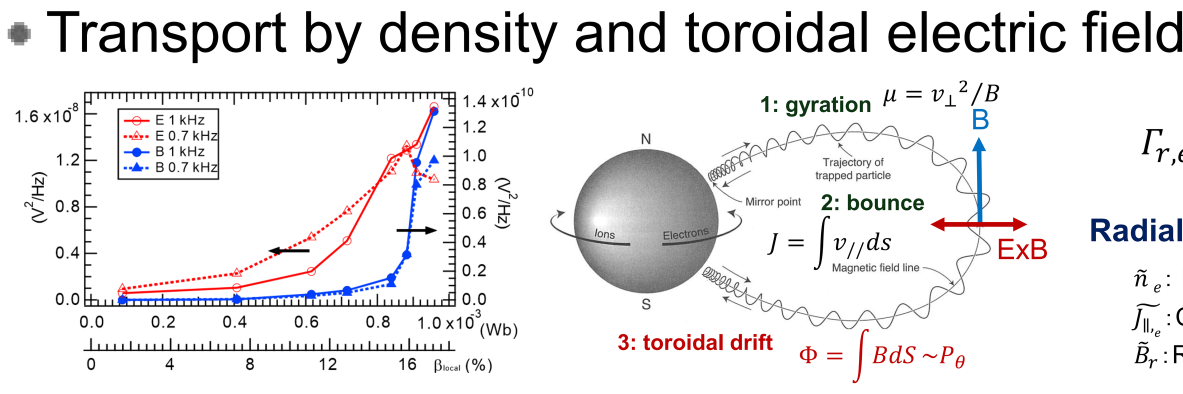
Abrupt fluctuation event and rare density decay event

Transport due to chorus was not investigated so far in RT-1

CHALLENGES / METHODS / IMPLEMENTATION:

Low-frequency fluctuations and radial particle transport

- Transport by density and toroidal electric field fluctuations



$$\Gamma_{r,e} = \langle \tilde{n}\tilde{v} \rangle = \frac{\langle \tilde{n}_e \tilde{E}_{tr} \rangle}{B} - \frac{\langle \tilde{J}_{\parallel,e} \tilde{B}_r \rangle}{eB}$$

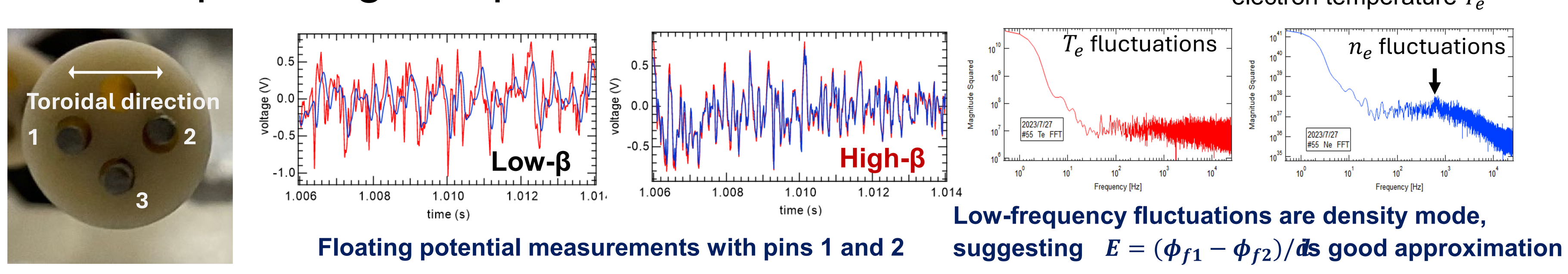
Radial particle flux by electrostatic fluctuations

$\tilde{n}_e$: Density fluctuations, $\tilde{E}_\theta$: Toroidal E fluctuations
$\tilde{J}_{\parallel_e}$: Current fluctuations parallel to magnetic field
$\tilde{B}_r$: Radial B fluctuations, B: magnetic field strength

Fluctuations contain electric component — Toroidal electric field creates radial transport

- Three-pin Langmuir probe measurements

$\phi_s = \phi_f + \alpha T_e$ for floating potential ϕ_f, space potential ϕ_s, electron temperature T_e

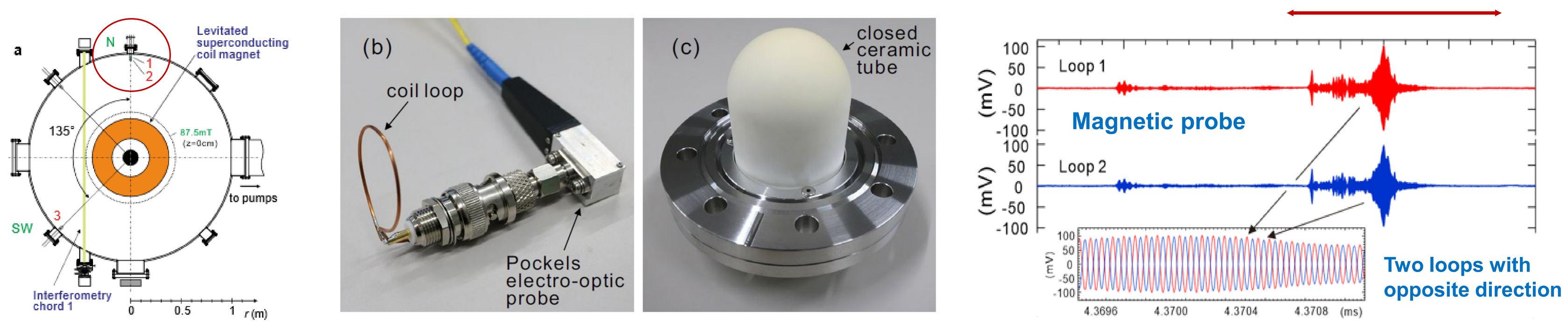


Floating potential measurements with pins 1 and 2

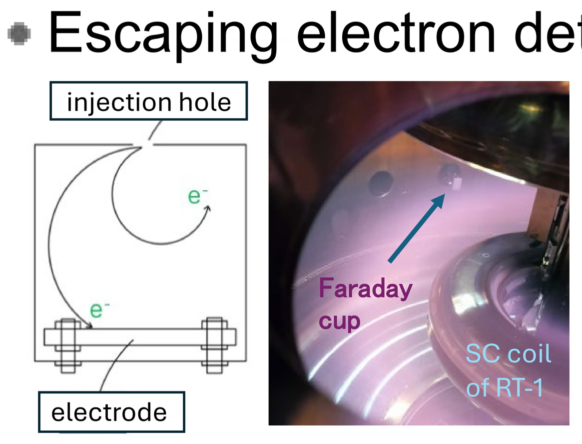
Low-frequency fluctuations are density mode, suggesting $E = (\phi_{f1} - \phi_{f2})/ds$ good approximation

Whistler mode chorus emission activities [7]

- Fast Bdot probe measurements

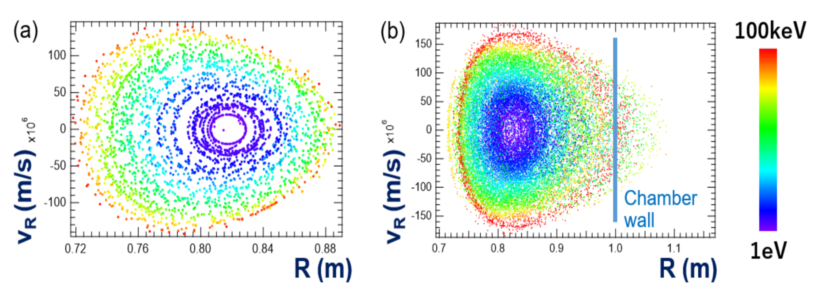


- Escaping electron detection



Initial experiments: Faraday cup sensitive to >~3keV escaping electrons

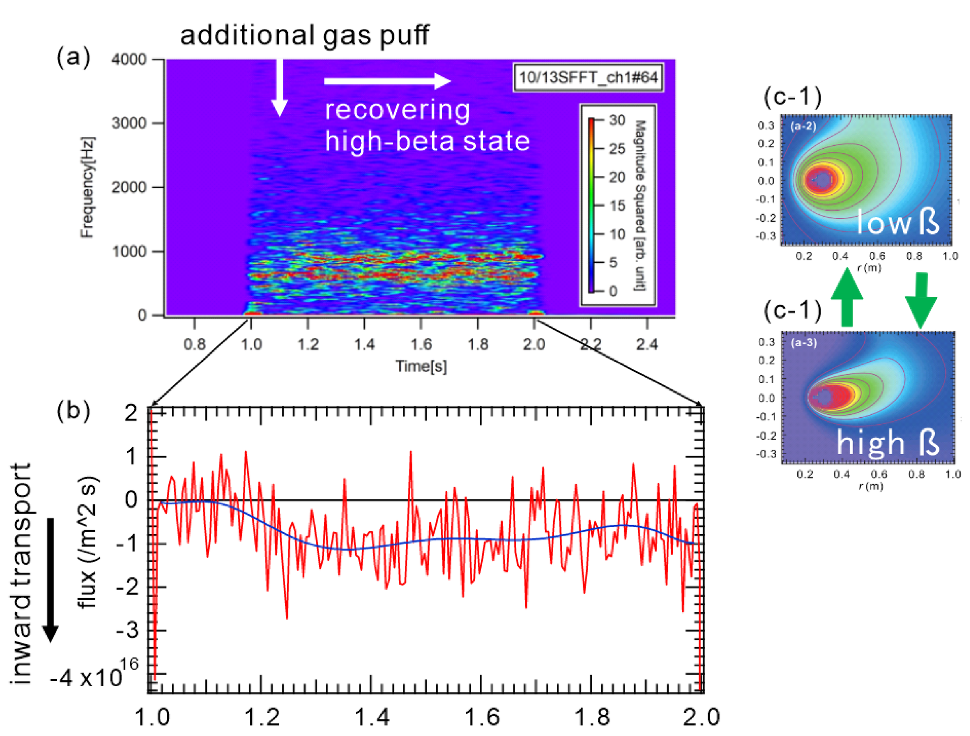
- Acceleration by R wave



Poincaré plot shows efficient acceleration of electrons to chaotic untrapped orbit by whistler wave events

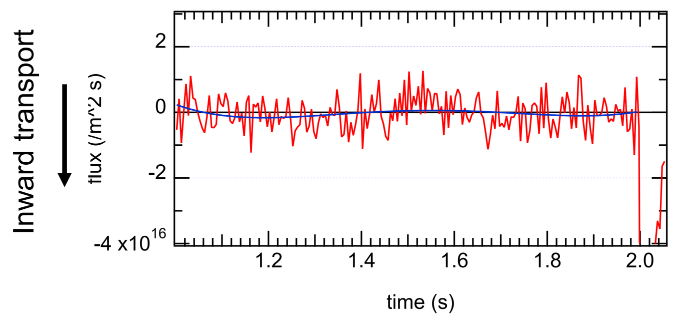
OUTCOME:

Low frequency fluctuations and radial particle transport

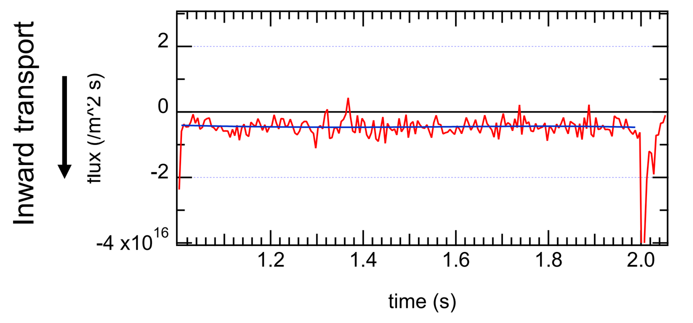


(a) Frequency power spectrum for gas-puffing experiment on ECH plasma, (b) radial particle flux evaluated by electrostatic probe, and (c) mode transition between low and high beta cases

Time averaged inward particle flux was observed during the reconstruction of high-beta peaked state



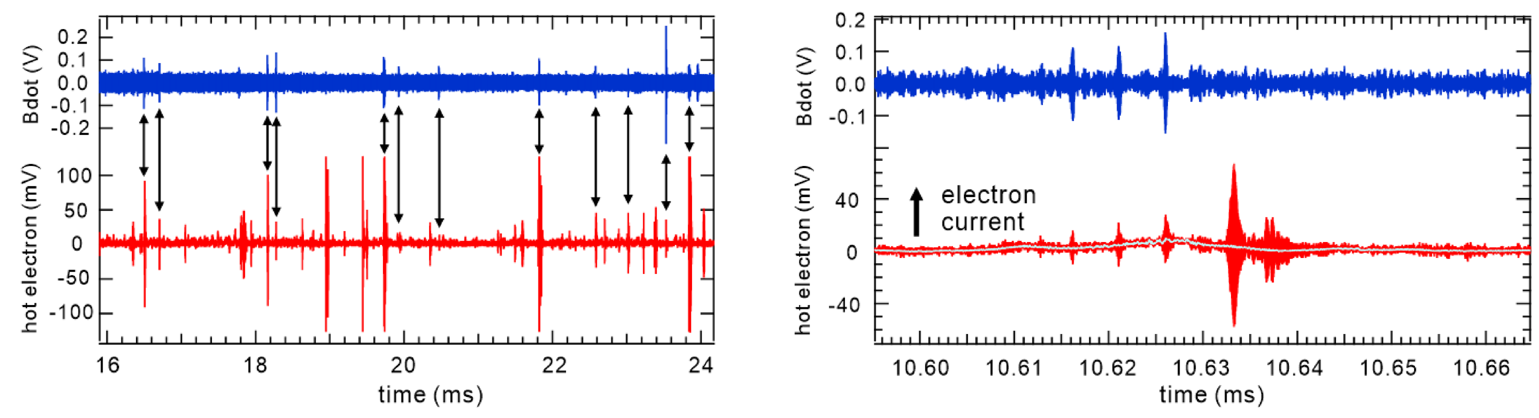
High-beta case without gas-puffing



Low-beta case without gas-puffing

Inward particle flux exits as long as the peaked high density state [8] is "not yet" organized

Low frequency fluctuations and radial particle transport



(a) Magnetic field fluctuations measured by the B-dot probe (top, blue) and electron current (bottom, red) at the plasma periphery measured by a high-energy electron probe. (b) Enlarged view of the fluctuation signal detected by the high-energy electron probe (bottom, red), along with its numerically low-pass filtered waveform (light blue), in comparison with the B-dot probe signal (top, blue).

Time averaged escaping electron current for chorus emission events

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