Properties of anomalous ion heating in lower hybrid wave sustained plasmas

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Background and Objectives

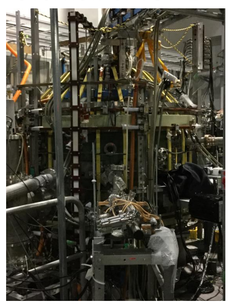
- In the TST-2 spherical tokamak device, non-inductive start-up experiment by Lower-Hybrid waves (LHW) is conducted. $T_e > 10$ eV and $T_i \sim 10$ eV is observed.
- The LHW can couple with electrons, but not with ions due to the relation between particle velocities and wave phase velocity. Thus, the LHW can directly heat electrons, not ions.
- Because density is very low, the effect of collision with electrons is considered to be small.
- Power modulation experiment was conducted to investigate the response of ion temperature to LHW.

TST-2

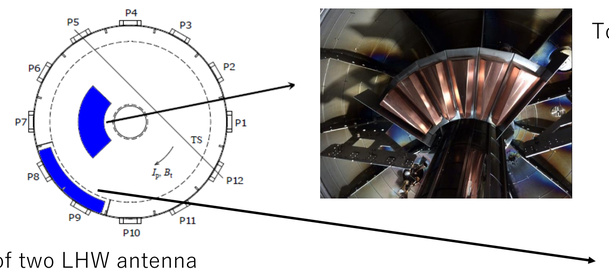
Main parameter

- Major radius $R_0 = 0.36$ m
- Minor radius $a = 0.23$ m
- Toroidal filed $B_t = 0.16$ T
- Plasma current $I_p < 27$ kA
- Duration $t < 100$ ms
- Electron density $n_e < 1 \times 10^{18}$ m^{-3}

Overview of TST-2



There are two capacitively coupled combine antenna to excite LHW (200.1 MHz).



Location of two LHW antenna projected on toroidal cross section

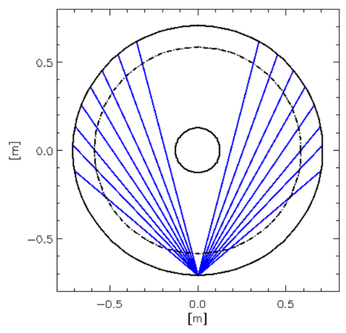
Top launched antenna

Outboard launched antenna

Visible spectroscopy

- Czerny-Turner spectrometer
- 16 CH PMT
  0.2 nm/CH, Measurable: 200-500nm
- I-V convertor : < 0.01 ms
- 8 sights ($R_{\tan}$=180-540mm) are available to measure to change them for each shot
- Impurity : C^{2+} (CIII, 464.74 nm)

Picture of each sight on toroidal cross section



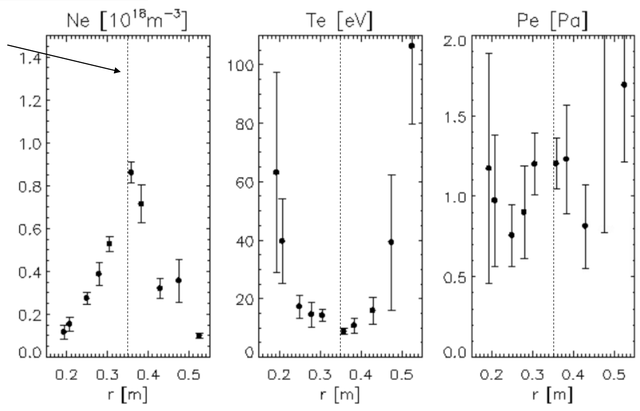
Profiles of electrons and ions

Magnetic axis

Density : center peak

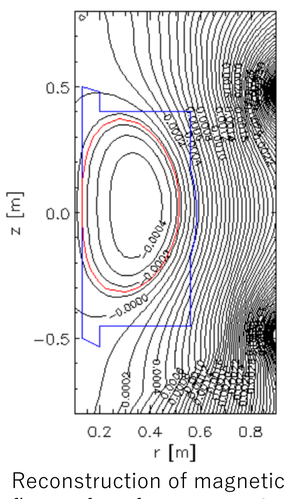
T_e : Hollow (10-50 [eV])

T_i : Flat or hollow (~10 [eV])

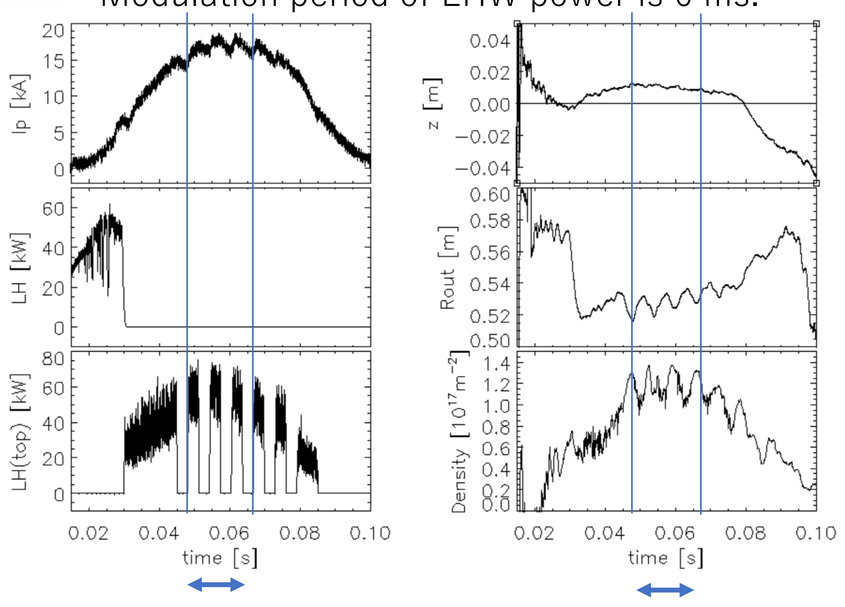


Analyzed Waveforms

Modulation period of LHW power is 6 ms.

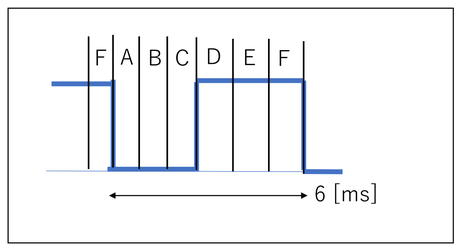


Reconstruction of magnetic flux surface from magnetic probes calculated at 60 ms.



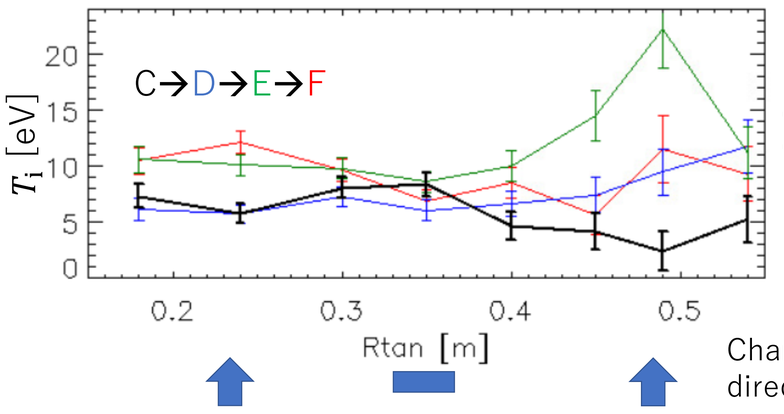
Method

Because emission from LHW plasma is weak, signal is analyzed by using a cycle averaged method. (3 times)
Each phase of modulation is named A to F like right figure.

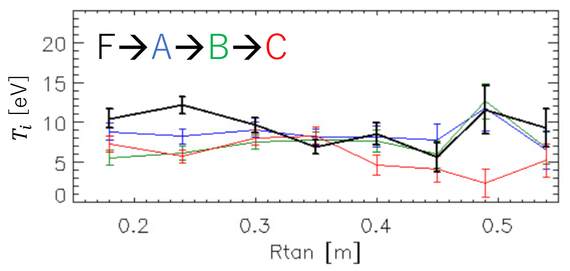


Results

Time development after LH power is ON.



Time development after LH power is OFF.



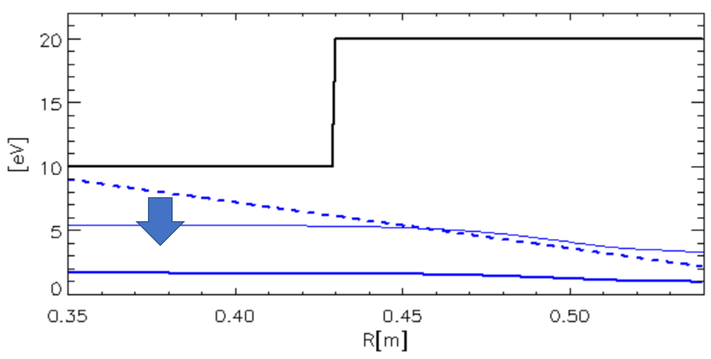
Change direction

Discussion

Solve 1-dimensional heat diffusion equation

$$\frac{\partial}{\partial t}\tilde{n}T_i = \underbrace{\frac{1}{\rho}\frac{\partial}{\partial \rho}\left(\rho \chi_{neo}\tilde{n}\frac{\partial T_i}{\partial \rho}\right)}_{\text{heat diffusion}} + \underbrace{P_{coll}}_{\text{collision with electrons}} + P_{adj}$$

χ_{neo} : Neoclassical heat diffusion coefficient
P_{coll} : Collision between electrons and ions
P_{adj} : Adjustable power which reproduce experiments

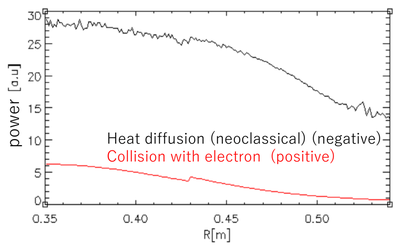


[i] $P_{adj} = 0$

Dotted blue line : initial T_i profile (roughly same as C on above figure.)
Blue line : Developed T_i (thin : 0.05ms after, thick : 1 ms after)
Black line : T_e profile

T_i gets about 2 eV (< 10 eV) in steady state.

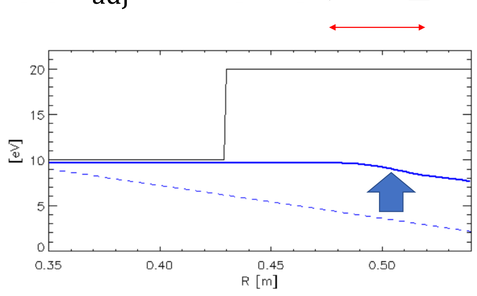
Comparison of absolute value of heat flux (Calculated 0.05ms after initial state)



- Power of heat diffusion is much higher than power of collision with bulk electrons.
- Collision cannot sustain measured T_i.

- High energy electrons generated by LHW is considered to be dense on peripheral region, but collision with this fast electrons is further small.
- Other terms which can cool ions are not included. (e.g. charge-exchange) T_i could be lower than 2 eV.

[ii] $P_{adj} = 1.5$ [kW] $(0.48 \le R \le 0.52)$

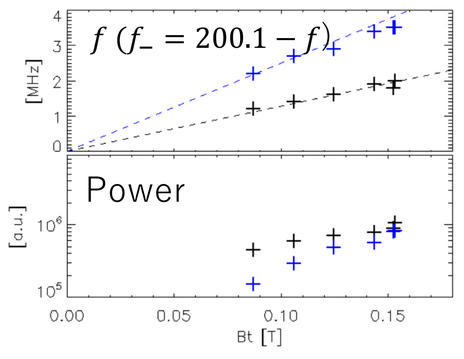


- Flat profile (~10eV) is reproduced when proper power on peripheral region is added.
- More power makes hollow profile. (E)
- Power in center region leads to center peak profile, cannot make hollow profile.

Ion heating seems to occur on peripheral region.

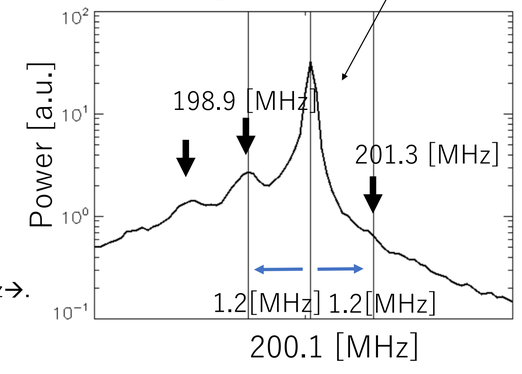
Parametric Decay Instability (PDI)

In TST-2, PDI is often observed. Ion cyclotron (Landau) damping of a wave generated by PDI is one candidate for ion heating.



← Power of lower sideband increase with toroidal magnetic field.

Spectrum near 200 MHz→.



・Ion temperature is expected to increase with toroidal magnetic field.

Conclusion and Future work

- Ion temperature responds to LHW modulation at peripheral region, does not respond near magnetic axis.
- Collision with electrons is very weak to explain the experimental results, other ion heating mechanism is needed on peripheral region.
- PDI is one candidate for ion heating and investigating the correlation between them is future work.

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