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Energy, momentum and particle balances of electrons in lower hybrid wave sustained plasmas on the TST-2 spherical tokamak

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ABSTRACT

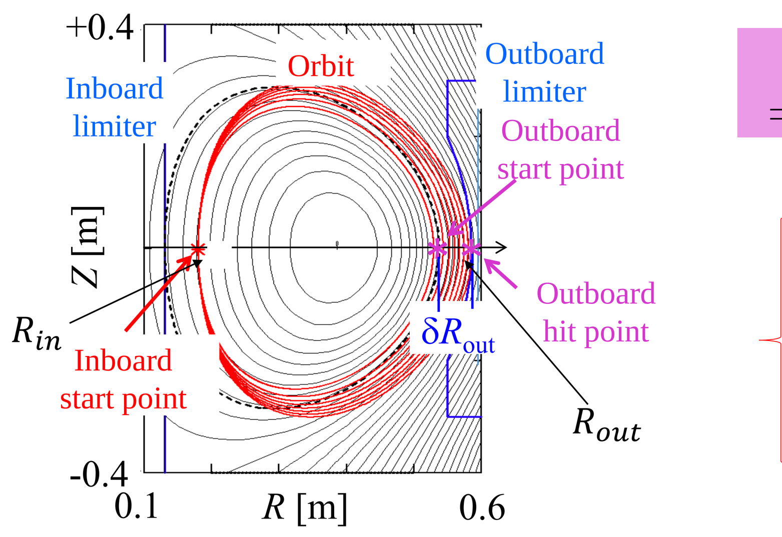
- Non-inductive start-up by lower-hybrid waves (200 MHz) has been studied in the TST-2 spherical tokamak (ST).
- An electron transport model is constructed to simulate electron diffusion in 2-dimensional phase space, and an X-ray emission model is constructed to simulate X-ray emissions.
- Comparison shows that a major part of the LHW deposition power is lost by fast electrons hitting the outboard limiter, while a minor part is used to heat cold bulk electrons.

BACKGROUND

- Noninductive plasma current start-up and sustainment is a critical issue in fusion research, particularly in spherical tokamak (ST) devices.
- In TST-2 ST device, a plasma current of 27 kA was achieved, but further study is necessary.
- Hard X-ray emission is believed to reflect the confined fast electrons, but the experiments in TST-2 indicate that a significant fraction of the measured hard X-ray emission is thick target X-ray, which is generated at a limiter when a fast electron hits it.
- In order to interpret the behaviours of the X-ray emission, we propose an RF induced transport model combined with an X-ray emission model. The objectives of the present study are the qualitative reproduction of the experimental features and the prediction of the order of the measured quantities which are believed to be related to fast electrons.

RF induced transport model

Electron orbits expand outward and hit the limiter and generate thick-target X-ray



Effect of inductive field

$$\Delta V_{\parallel} = \Delta\widetilde{V}_{\parallel} - \nu_{\parallel} V_{\parallel}\, \Delta t - \frac{eE}{m_e}\Delta t$$

LHW ⇒heating power

Collisional slowing down ⇒bulk electron heating power

Assumptions

$\Delta V_{\perp} = 0$,

$V_{\parallel} \approx V_{\phi}$,

Velocity kick only at the midplane

Conservation of toroidal momentum

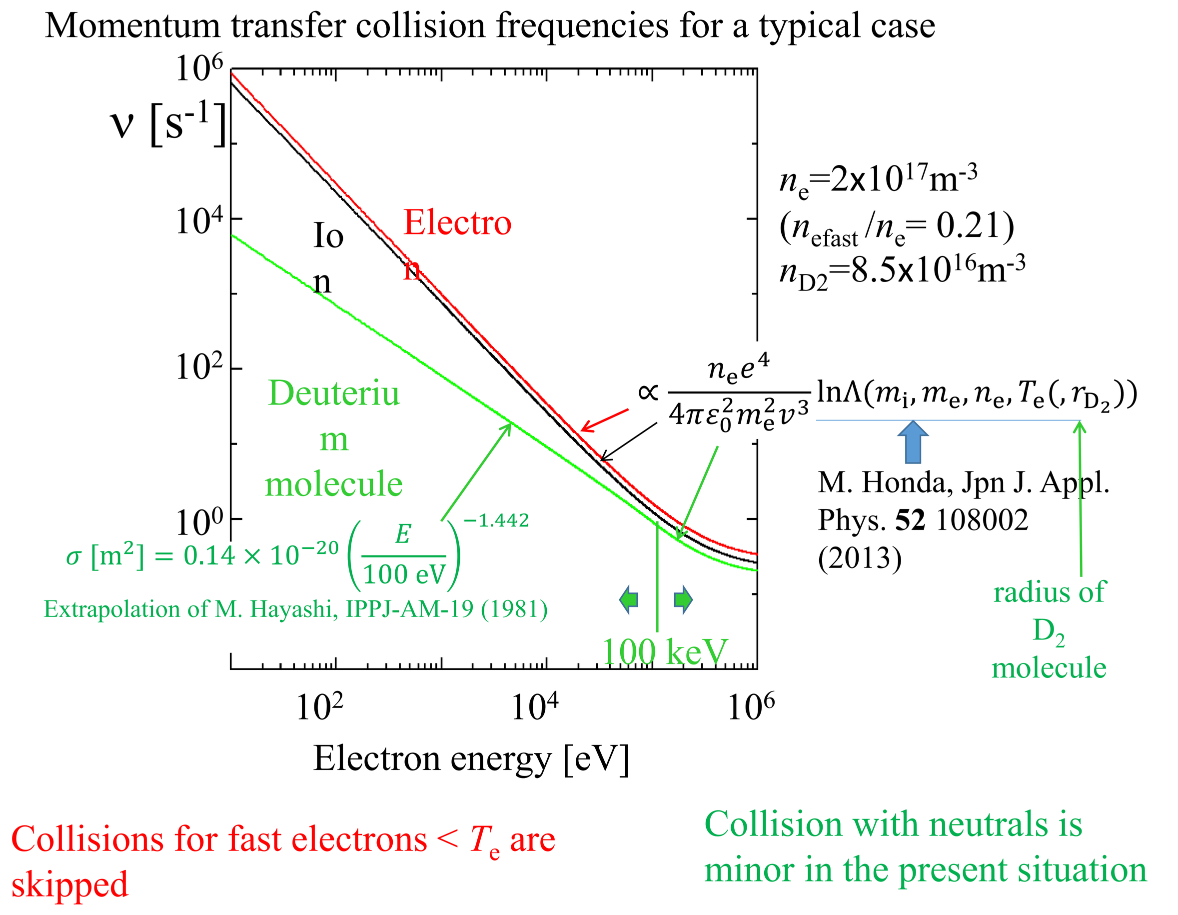
$$\Delta R_{out} = \frac{R_{in} - R_{out}}{V_{\parallel} + R_{out}\Omega_{ep}} \Delta V_{\parallel in}$$

$$\Delta R_{in} = \frac{R_{in} - R_{out}}{-V_{\parallel} + R_{in}\Omega_{ep}} \Delta V_{\parallel out}$$

RF induced transport

Slowing down by collisions with ion, electron and deuterium molecule

Momentum transfer collision frequencies for a typical case



Collisions for fast electrons < T_e are skipped

Collision with neutrals is minor in the present situation

Calculation of electron evolution

Number of simulated electrons is kept constant.

1: Birth (ionization) at $R_{sin} \pm \Delta R_s$, $R_{sout} \pm \Delta R_s$

2: RF induced acceleration (diffusion in velocity space $V_{\parallel}$) and transport in radial coordinate (R_{sin}, R_{sout})

or

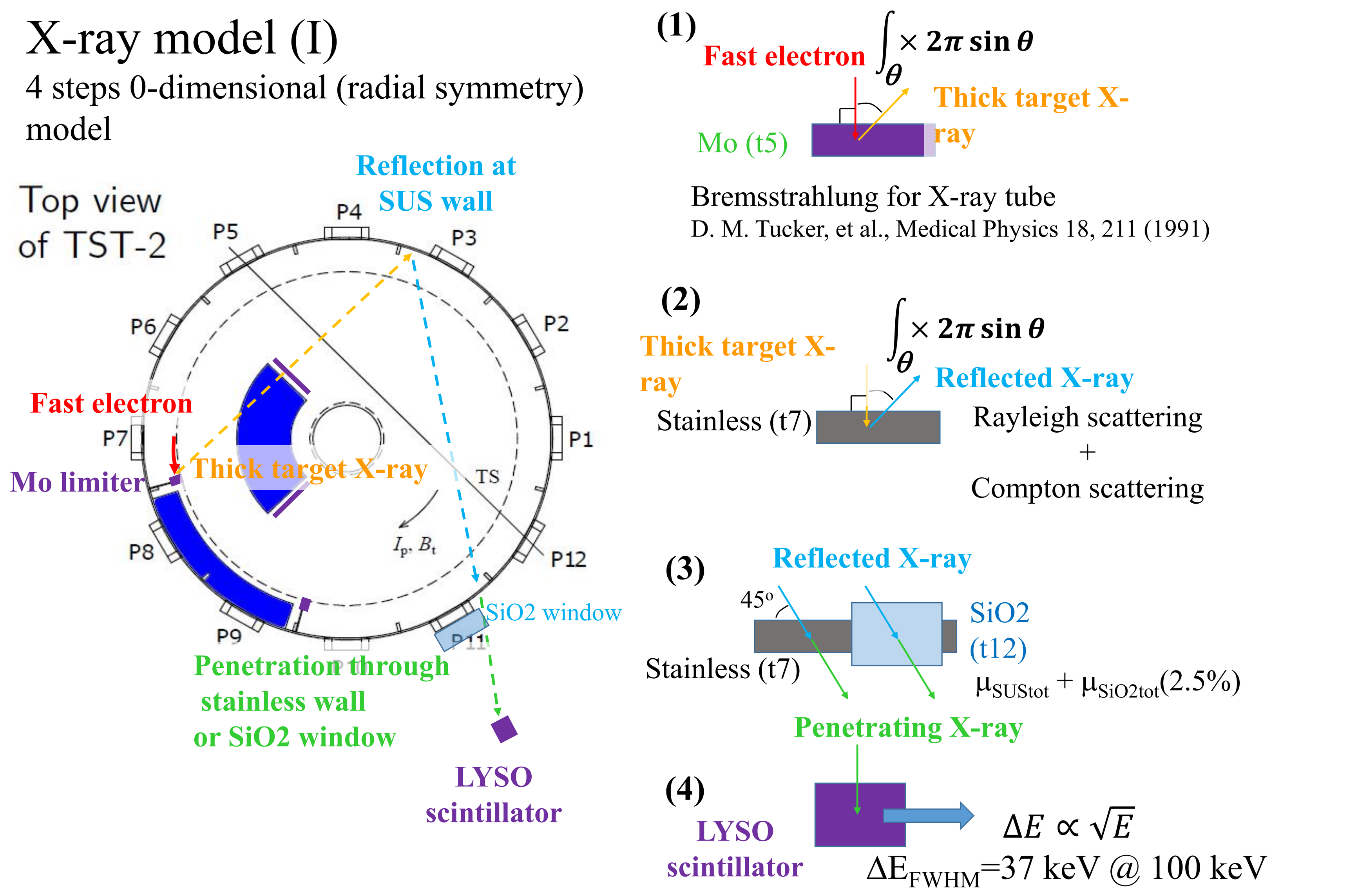
3: If the electron hit the limiters, it is lost at the limiters

4: Slowing down and inward drift by collisions with bulk (0-temperature) ion, electron and deuterium molecules

This process is skipped for bulk electrons ($E < T_e$), forming flat top bulk electron distribution

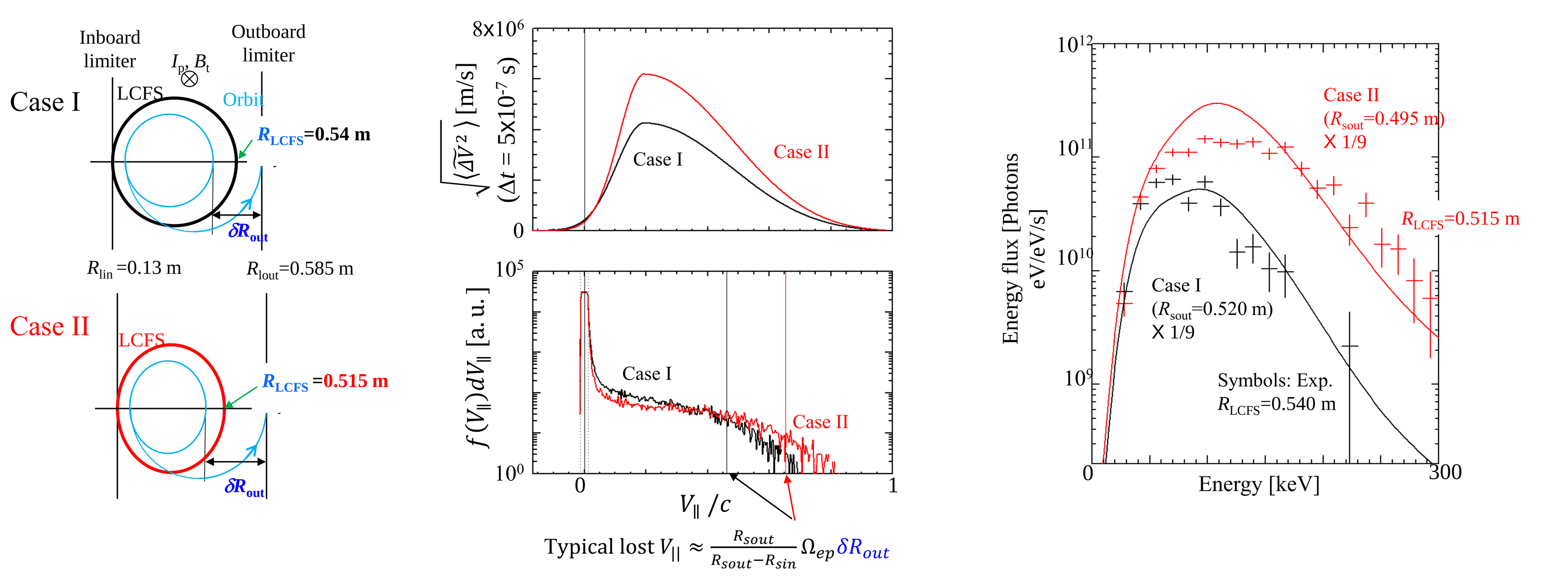
Electron impact ionization of neutrals by bulk temperature (T_e) electrons are dominant. Ionization is calculated based on Binary-Encounter-Bethe (BEB) model at NIST ;https://physics.nist.gov/PhysRefData/Ionization/intro.html

X-ray emission model

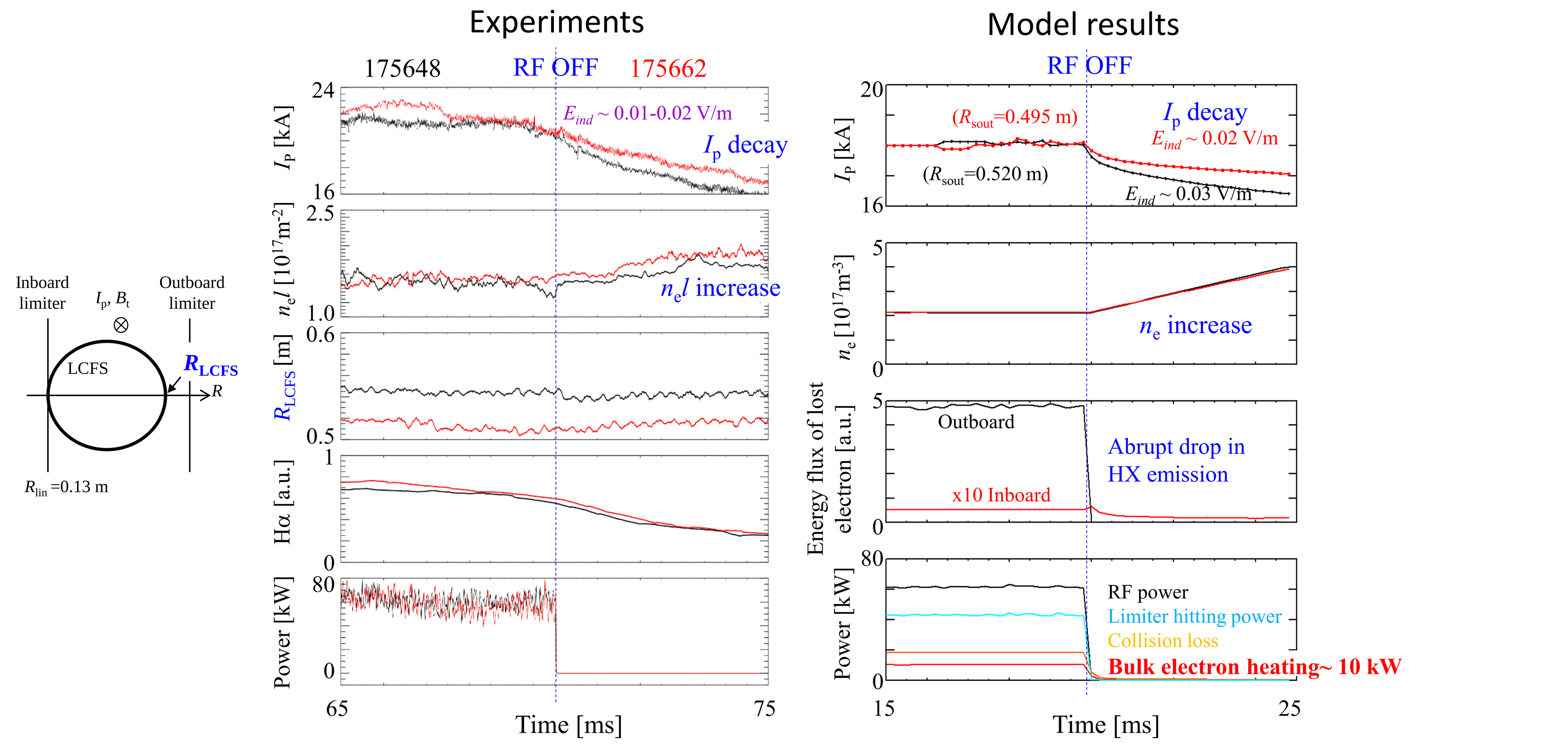


Results

Reproduction of the two experimental cases with R_{LCFS}=0.54 m, 0.515 m (0.025 m difference) by setting the same difference between R_{sout}=0.520 m, 0.495 m



Response of RF OFF: non steady state case



I_p decay, n_e increase, rapid drop in HX emission are reproduce qualitatively.

Inductive E_{ind} by the self inductance is considered, which increases the I_p decay time by a factor of servals

CONCLUSION

- An electron transport model is constructed to simulate fast electrons in TST-2 LHW sustained plasmas.
- Comparison of the model and experiments shows that a major part of the LHW deposition power is lost by fast electrons hitting the outboard limiter, while a minor part is used to heat cold bulk electrons. The estimated bulk electron heating power is reasonable.
- The model can interpret the major features of the fast electrons in LHW sustained TST-2 plasmas.

ACKNOWLEDGEMENTS

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