ID: EX/P7-16

Modification of the Magneto-Hydro-Dynamic Equilibrium by the Lower-Hybrid Wave Driven Fast Electrons on the TST-2 Spherical Tokamak

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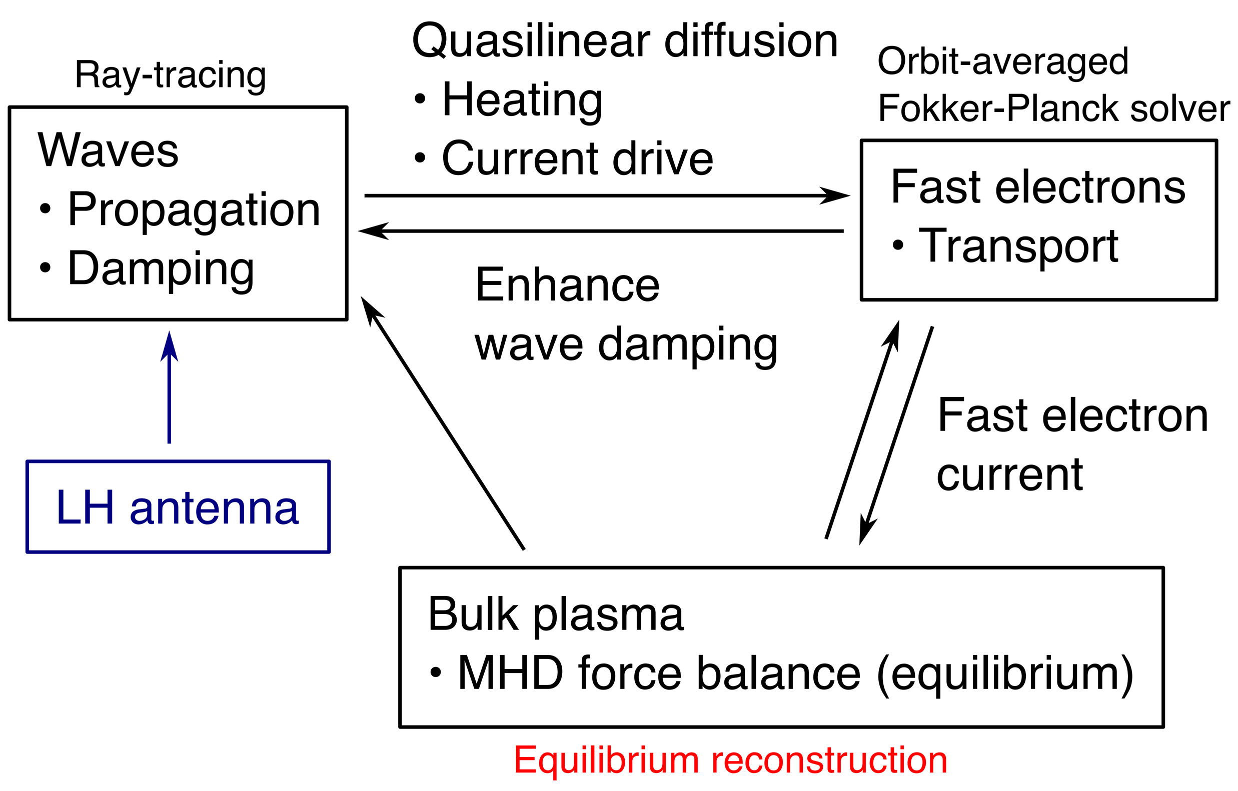
ABSTRACT

- A new equilibrium reconstruction method based on extended magneto-hydro dynamics (MHD) including fast electrons was applied to a non-inductive start-up plasma driven by lower-hybrid waves
- An MHD equilibrium and a global fast electron distribution function consistent with the magnetic and kinetic measurements were obtained
- The extended MHD equilibrium differed from the standard MHD equilibrium and agreed better with the measurements

BACKGROUND

- Lower-Hybrid (LH) waves can drive a tokamak plasma
  - ➢ Improve tokamak performance by removal of central solenoid



- Fast electron treatment needs to be improved to understand the system behavior quantitatively and optimize the LH start-up scenario
  - Non-thermal distribution function
  - Finite-orbit effects (orbit excursion from flux surfaced)
- ➢ Impact of fast electrons on MHD equilibrium was studied

CHALLENGES / METHODS / IMPLEMENTATION

CHALLENGES TO DESCRIBE INTERNAL EQUILIBRIUM

- First-principle calculations:
  - Quantitatively accurate description of all relevant physics required
    - ➢ Extremely challenging (work in progress…)
- Experimental measurement of internal magnetic field:
  - Motional Stark effect: requires beam
  - Polarimeter: challenging due to low density and current of the start-up plasma (under development)

METHOD

- Fit the parametrized solution of the stationary MHD equations to magnetic and kinetic measurements (equilibrium reconstruction)
- Unknowns
  - Two free functions: bulk pressure, bulk poloidal current
  - Fast electron distribution function

IMPLEMENTATION

Extended MHD equation (fast electron contribution in red)

$$-\frac{\Delta^*\psi}{R} = \mu_0 R\frac{\mathrm{d}P}{\mathrm{d}\psi} + \frac{H}{R}\frac{\mathrm{d}F}{\mathrm{d}\psi} + \mu_0 j_{\mathrm{f}\phi}, H = RB_\phi = F(\psi) + G$$

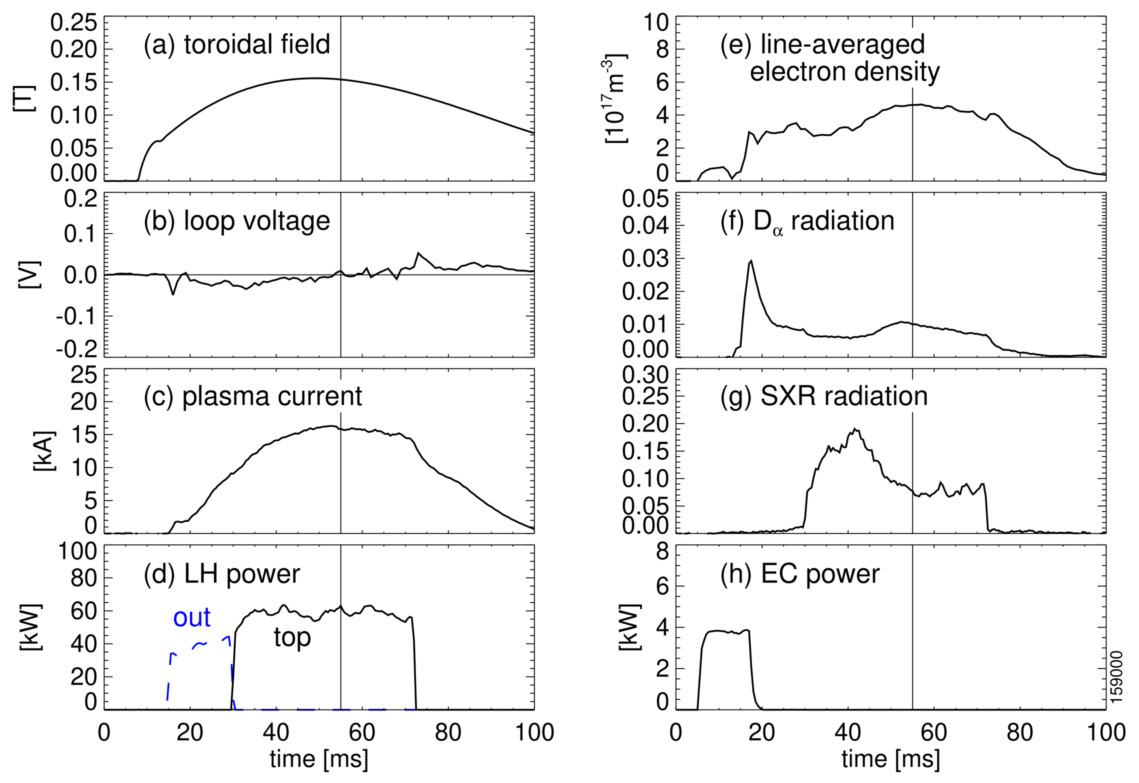
Fast electron distribution function

$$f_\mathrm{f} = N\exp\left(-\frac{\mu B_0}{T_{e0}}\right)\exp\left(-\frac{(\psi^* - \bar{\psi})^2}{\Delta\psi^2}\right), E_{min} < E < E_{max}, \sigma < 0$$

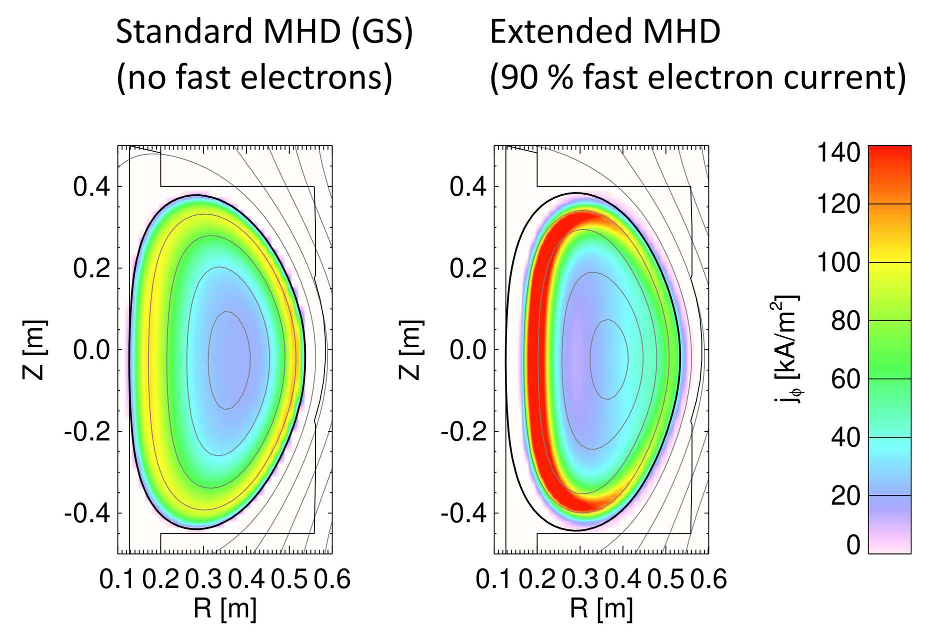
OUTCOME

TIME TRACES OF LH START-UP PLASMA ON TST-2

- Loop voltage < 0
  - Non-inductive
- I_p~16 kA
  - 15 % of Ohmic
- 60 kA LH power from top antenna
- N_e~$4\times10^{17}\,\mathrm{m}^{-3}$
- EC for pre-ionization



EQUILIBRIUM RECONSTRUCTION RESULTS



Reconstructed toroidal current density

β_p	0.46
l_i	0.30
q_a	40

Basic equilibrium parameters (GS)

- Fast electron current
  - Parallel current dominant: strong $1/R$ variation
  - Extended beyond LCFS on the low-field side
    - ➢ Replaced pressure function contribution
  - ➢ Current profile more concentrated on the high-field side

CONCLUSIONS AND FUTURE WORK

- A newly developed equilibrium reconstruction based on extended MHD including kinetic electrons was successfully applied to a LH driven plasma on TST-2
- Global fast electron distribution function quantitatively consistent with the extended MHD and magnetic and kinetic measurements was obtained
- Fitting improved when fast electrons were introduced
  - ➢ Implies fast electrons do modify the MHD equilibrium

Future work

- Study the dependence of the electron distribution function on plasma and rf parameters

ACKNOWLEDGEMENTS

- This work was supported by:
  - JSPS KAKENHI Grant Number 18K13524
  - NIFS Collaboration Research Programs NIFS18KOAR22 and NIFS12KUTR078
  - Japan/US Cooperation in Fusion Research and Development
- Work at General Atomics was supported by US DoE contract DE-AC03-97ER-54411.