ICRF heating and turbulent transport modelling of the WEST L-mode plasma using ets: interpretative and predictive codevalidation

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Introduction & Background

- WEST [1,2], superconducting device, equipped with actively cooled divertor in full tungsten environment. D-D L-mode discharges in the flat top phase with ICRH additional heating are considered.
- European Transport Simulator (ETS) [3,4] can simulate full plasma discharges of any Tokamak device. Two main modules are concerned:
  - Cyrano [5] and StixRedist [6,7,8] as ICRF module
  - TGLF [9,10] as turbulent transport module
- Goals
  - Understand the core plasma dynamics in WEST with focus on the role of ICRH and plasma discharge optimization (efficient electron heating, avoid tungsten accumulation)
- First Steps
  - Verify and validate ICRF modules.
  - Determine the electron/ion heating ratio with minority and power scans
  - Compare predictive simulation with experiments and characterize the turbulence

ICRH modules used in interpretative mode

Verification & Validation

- Cyrano/StixRedist was compared to EVE/AQL on the shot #55799 giving a good agreement on the heating profiles (not shown).
- Comparison with Break In Slope (BIS) experimental profiles from ECE data with PICRF=1MW .
- To interpret the experimental power deposition profile in WEST needs to invoke the impact of transport. Figures below show that reasonable agreement can be obtained when a characteristic time of the order of few tens of ms is considered.
- Good agreement is obtained on the volume integrated power absorbed by the electrons *(fig 1. left).*

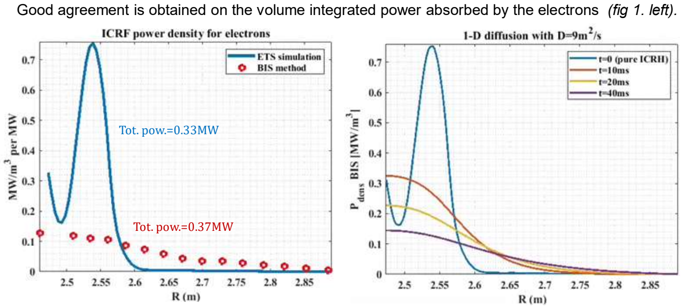

Fig.1: shot #54633 at 39s. (Left) comparison of ICRF electron power density profile between BIS method and ETS interpretative simulation and their integration over the plasma volume. (Right) Imitating BIS method with 1-D diffusion equation. Diffusion coefficient estimated at 9 m²/s from radial propagation of a sawtooth crash. ICRF electron heat diffusion for various time slice.

Neutron rate sensitivity to the ion temperature

- Ion temperature measurement is not yet available at WEST. An estimate is made based on the measured neutron rate (assuming Maxwellian ion distribution functions) [11]. Table 1 shows the high sensitivity of the neutron rate for typical T_i values in WEST due to the steep D-D fusion cross section as shown in *fig. 2.*

	Experiment	100% T_i	90% T_i	80% T_i	~60% T_i
Neutron rate (10^{11}neutrons/s)	~27	~57	~32	~17	~2
Discrepancy		111%	18%	-37%	-92%

Table 1: shot #55607 at 39s. Neutron rate sensitivity according to ion temperature amplitude.

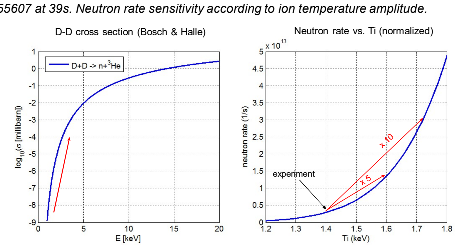

Fig 2: shot #55607 at 39s. (Left) Stiff D-D cross section at the interest region. (Right) Variation of neutron rate according to ion temperature.

- A minimization loop with Cyrano/StixRedist accounting for ICRF heated deuterium distributions and neutron rate computations suggests T_i to be 12% lower than the value obtained assuming purely Mawellian distributions.

Scan in power and H minority concentration

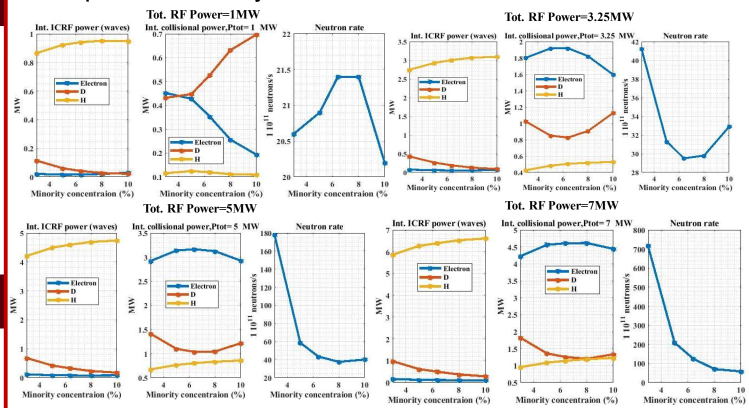

Fig 3: shot #55607 at 39s. H Minority scan for various ICRF power. For each power, plots of integrated direct absorption power, integrated collisional power and neutron rate.

- *Figure 3* shows that for low power (1MW), the collisional ion heating is dominant but the power is too low to impact the D-D neutron rate.
- For higher power (>3MW), electron heating is dominant but ion heating is strong enough to enhance the neutron rate, in particular at low concentration (enhanced N=2 D absorption). The neutron rate is limited at large H fraction due to dilution.
- The neutron enhancement comes from ICRF induced deuterium tails (thermal T_i constant). Finite orbit width effects and ripple losses not taken into account.

Transport modelling

Predictive simulation

- The kinetic profiles are predicted with NCLASS and TGLF respectively for computing the neoclassical and turbulent transport coefficients. The values of T_e, T_i, N_e and N_i are imposed at normalized ρ=0.8 as boundary condition. Impurity radiation profiles are prescribed from the bolometry data. Due to the presence of sawteeth up to ρ=0.35, ad-hoc transport coefficients are manually set to fit the electron temperature and density experimental data in that region.
- The initial T_i profile is provided by the method described in the previous section.

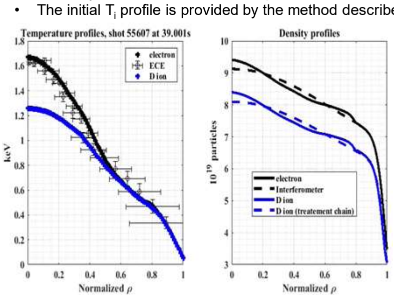

Fig 4: shot #55607 at 39s after 0.5s simulated time. Temperature and density profile compared with the electron cyclotron emission (ECE) and interferometer diagnostics

	Exp.	Sim.
W_{mhd} (MJ)	~0.37	0.31
Neutron rate (10^{11} neutrons/s)	~27	33

Table 2: shot #55607 at 39s after 0.5s simulated time. Comparison of stored energy and neutron rate with experimental data.

Turbulence characterization

- *Figure 5 (a) and (b)* show the presence of the high-k_y electron temperature gradient (ETG). The influence of trapped electron mode (TEM) is small (*fig. 5 (a) and (d)*). As shown in *fig. 5 (a) and (c)*, the turbulence is dominated by the ion temperature gradient (ITG) instability at low-k_y.

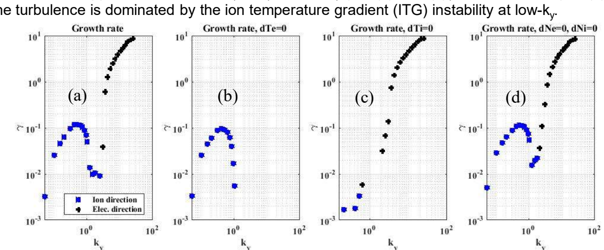

Fig 5: shot #55607 at 39s and normalized ρ=0.5. (a) Turbulent linear growth rate γ. (b) Turbulent linear growth rate when T_e gradient is set to 0. (c) Turbulent linear growth rate when T_i gradient is set to 0. (d) Turbulent linear growth rate when N_e and N_i gradients are set to 0. γ is in units of c_s/R with $c_s = \sqrt{T_e/m_i}$, m_i the main ion mass and k_y is the poloidal wave number.

Conclusion and Perspectives

- First validation of ICRF computation with BIS method show an agreement on the total electron heating at low ICRF power. Further investigations are ongoing.
- Power and minority scans show that electron heating is always dominant for PICRF>2-3MW in the studied conditions in particular with X[H]=5%-7%. Enhanced D-D neutron rate can be achieved at low H concentrations due to direct N=2 D absorption.
- Predictive simulation yields a good agreement with available measurements (electron and density temperature profiles, stored energy and neutron rate).
- The simulation suggests that turbulence is dominated by the ion temperature gradient (ITG) instability at low k_y.
- The next step would be to perform self-consistent impurity transport modelling.

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