Self-consistent predictive transport simulations of JET-ILW plasmas with different isotopes: a core performance sensitivity study to boundary conditions

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The core transport properties of JET-ILW hybrid plasmas have been studied performing 4 channels (electron and ion heat, particle and momentum) electrostatic predictive simulations with TRANSP+TGLF(SAT1)[1]. The main aim of this work is to compare the resulting profiles when an isotope change in the main ion and NBI specie occurs, merging in a self-consistent simulation, the change in the transport properties with other collinear effects as the modification of the sources, the increase of the plasma inertia, etc. Indeed gradient driven gyrokinetic simulations of the plasma core (ρ=0.33) have already demonstrate that the turbulent transport is reduced for heavier isotopes [2,3], but the impact on the global profiles cannot be clearly assessed without self-consistent simulations that includes such additional effects. The followed strategy starts from predicting the core profiles (ρ=[0;0.8]) of a hybrid-like pure Deuterium JET plasma, taken as reference case. Once obtained a proper match with the experimental profiles, a new simulation has been performed, changing the main gas isotope and the NBI gas from Deuterium (DD) to Tritium (TT). The boundary conditions for electron and ion temperature, density and rotation (respectively, $T_e(0.8)$, $T_i(0.8)$, $n_e(0.8)$ and $\omega(0.8)$) have not been changed, not including any pedestal isotope effect. Finally, to evaluate the impact of the pedestal isotope effect on the prediction for core TT plasma, a sensitivity scan on pedestal parameters has been performed, exploring increasing values of T_i/T_e, n_e and pedestal β.

The main outcome is that, despite the lower transport in TT than in DD, the n_e, T_i and T_e profiles are only partially affected by the isotope change because of the reduction of their core sources in TT. A momentum transport barrier (MTB) is, instead, present at ρ=[0.6-0.8], where also the torque injection is larger in TT than in DD: this combination produces a faster rotating TT plasma, despite the higher mass. The sensitivity scan highlights that the MTB weakens at higher T_i/T_e, but it is re-established increasing β. The pedestal β increase is expected according with the pedestal scaling for heavier isotopes [4].

DD reference case and comparison with TT simulation

The reference predictive simulation aims at reproducing the T_e, T_i, n_e and ω core radial profiles of a high β_N=2.7 hybrid JET-ILW Deuterium pulse: JPN84545 has 1.4MA of plasma current, toroidal field B_t=1.7T, 13MW of additional input power from neutral beam only. It shows good confinement properties (H98y>1.15) with a steady phase lasting for about 2s.

This plasma shows T_i/T_e>1.1 from the pedestal to the very inner core, a peaked density profile $n_e(0)/\langle n_e\rangle \sim 1.24$ and fast toroidal rotation velocity $\omega(0)\sim$130 krad/s. The TT equivalent simulation has been performed changing the mass of the bulk ion specie as well as the NBI gas from Deuterium to Tritium. The NBI voltage has not been changed because, at about 95kV, the total power delivered by the two isotopes is almost identical for JET NBI system.

The resulting profiles from the predictive simulation are reported in Figure 1, DD case is in blue and TT one is magenta. In the temperatures plot (a), solid line represents T_e and the dashed one is for T_i. The DD profiles are in agreement with experimental quantities (not shown) within the error bars. Also the synthetic interferometric data, the predicted neutron rate and stored energy well agree with the equivalent experimental quantities, confirming the good quality of the prediction.

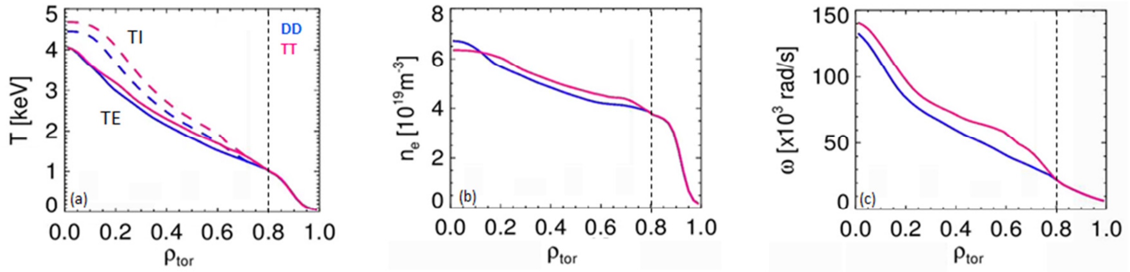

Figure 1 predicted profiles for DD (blue) and TT (magenta) case, with the same pedestal and NBI voltage. In panel (a), the T_e is in solid line, the T_i is in dashed one. The profiles are averaged in the time window [5.0-5.5].s

The electron temperature profile is not modified by the isotope change, neither is the n_e profile, resulting only slightly less peaked in TT than in DD. The ion temperature and, in particular the rotation profile, shows a clear increase in the whole integration domain.

Figure 2 shows the particle (a) and momentum (b) sources: both are more off-axis located in TT than in DD because of the lower neutral velocity of the heavier specie. In particular torque in TT is larger than in DD for ρ>0.4. The similar density profiles and the lack of particle source at ρ<0.5 clearly indicate a reduced particle transport in TT. The ion and electron heating profiles (not shown) are very similar in DD and TT, since the lower core deposition is partially compensated by the longer slowing down time of the Tritium fast particles.

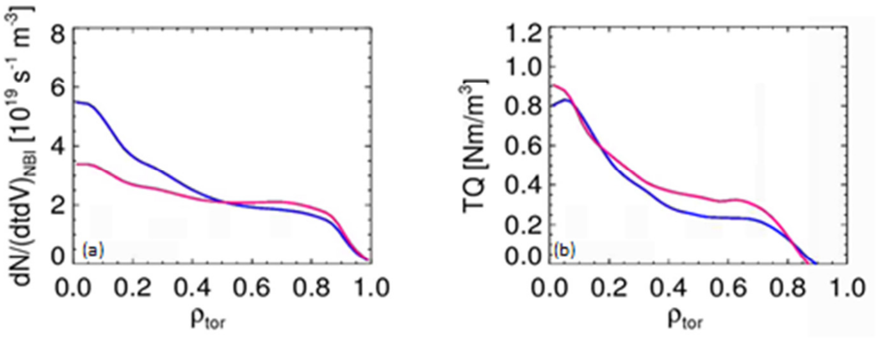

Figure 2 particle source from NBI (a) and torque injected (b), for DD (blue) and TT (magenta) case with the same colour code of figure 1. Tritium sources are more off-axis located because of the lower penetration of the T neutrals, for a given beam energy.

The electron and ion heat diffusivities, as well as the particle diffusivity are lower in TT than in DD in the whole domain. Also the momentum diffusivity χ_{phi} is similarly reduced, but the region ρ=[0.6,0.8] shows a strong decrease by a factor 4 for TT with respect to DD (Figure 3), highlighting the presence of a momentum transport barrier (MTB). The location of the MTB corresponds to the position of large torque injection: these two ingredients are responsible for the increase of toroidal rotation in the external part, obtained in TT.

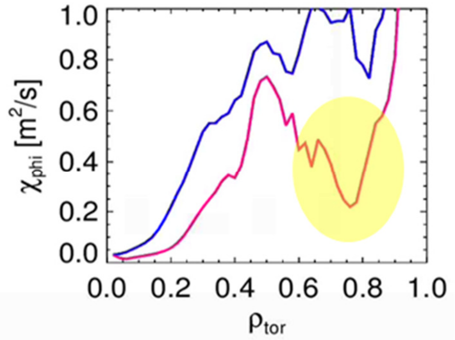

Figure 3 momentum diffusivity radial profile with the MTB highlighted for the TT case.

The turbulence analysis at ρ=0.5 provided by TGLF shows that the plasma is dominated by ITG modes, with subdominant TEM contribution in the DD case. The TT growth rate spectrum shows similar feature, with a stronger stabilization of the TEM part. The quasi-linear fluxes spectra confirm that the transport is largely ITG dominated, with only minor contribution of TEM and ETG for both isotopes. The TT flux spectra are reduced for electron heat, particle and momentum, whereas the ion heat flux spectrum is narrower, with stabilized ITGs for k_y>0.5.

Boundary condition sensitivity scan

In order to partially include the pedestal isotope effect on the boundary conditions, a sensitivity scan has been performed: n_e, T_i and T_e profiles in ρ=[0.8-1.0] have been independently multiplied by C_{ne}, C_{TI}, C_{TE} factors. The multiplying factors for electron density and temperature have been derived by the most recent pedestal JET-ILW scaling [4], being the isotope mass exponents for n_e and T_e, respectively, $\alpha_{ne}=0.3\pm0.24$ $\alpha_{Te}=0.15\pm0.25$).

Nevertheless the scaling database has been built with Hydrogen and Deuterium main gas data only; hence the Tritium values are extrapolated from such scaling. For this reason, not only the scaled factor has been tested but also the value that corresponds to the upper extreme of the scaling law error bar. Such scaling cannot be applied to T_i, hence for the T_i/T_e scan the value at $\rho=0.8$ has been multiplied by 1.2 and 1.4, covering the pedestal temperature ratio range obtained in the recent hybrid JET experimental campaign [5].

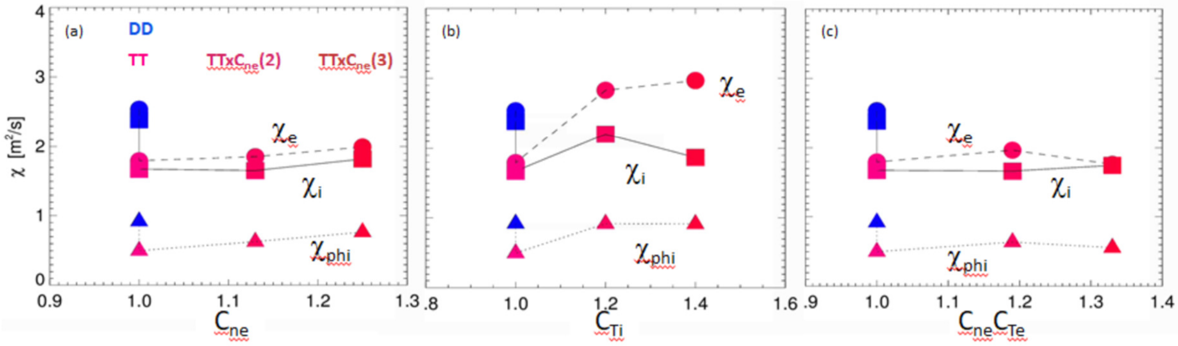

Figure 4 density (a), T_i/T_e (b) and β (c) sensitivity scan results on diffusivities: blue symbols are for DD, magenta one for TT and reddish magenta dots are for scaled TT. Full circle represent the χ_e, squares the χ_i and triangles the χ_{phi}.

Figure 4 shows the scan results on the heat ion, electron and momentum diffusivities. The change of the isotope clearly produces a drop in every channel. The density scan (a) does not show an increase in heat transport. The MTB is still present and it only mildly weakens at higher density. On the contrary, increasing the T_i/T_e -panel (b)-, χ_e and χ_{phi} increase by 30%: higher ion temperature increases the electron heating via ion-electron coupling, resulting in larger ETG growth rates. The MTB disappears and also TT the rotation profiles turn out to be similar to DD when $C_{Ti}>1$. Also χ_i increases, but it results stabilized again at the highest value. The β scan (c) performed at $C_{Ti}=1$ combines the results of the scans shown in panels (a) and (b): no diffusivities increase and the MTB results not spoiled at larger β.

Since pedestal scaling provides increased density and temperatures for TT plasma, these results open to further positive isotope effect that propagates also to the plasma core.

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