Isotope-mixing at JET: experiments and modelling

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Experimental results

Understanding particle transport is important to be able to consistently model the behaviour of the plasma in a Tokamak. While a particle pinch has been demonstrated in L-mode, the analyisis of H-mode plasmas is more complicated, since the peaking could be caused either by the source and a small particle diffusion coefficient or by a large pinch. Various experiments [1], [2], [3] were already suggesting that the mixing of multiple ions can be fast, hinting to large transport coefficients.

Dedicated experiments were performed at JET [4] to understand the impact of the source on the isotopes profiles. Using Hydrogen and Deuterium, it is possible to measure the edge composition comparing the relative aplitude of Balmer H_α/D_α spectral lines, while the core amount of D can be inferred from the neutron rate. Knowing the profiles, in the case of several ion species convection and diffusion can be separated in a steady state plasma. The core and edge compositions in the discharges were found to be very similar, meaning peaked profiles for both isotopes despite the fact that there was no Hydrogen core source. This was interpreted as the diffusion and pinch coefficients for ions being much larger that the ones for electrons.

Integrated modelling

Nonlinear, quasilinear and analytical calculations based on the quasilinear formulations related the large ion transport coefficients to a resonant process [5], with ambipolarity respected thanks to the balance between, for example, a large outward diffusion and a large inward pinch. While this cannot be seen in a pure plasma, it becomes important for the ion mixing of a multiple isotope plasma, that will have a timescale on the order of the energy confinement time.

Dedicated integrated modelling using the JINTRAC suite [6], and QuaLiKiz [7] as the anomalous transport model was performed on the mixed isotopes experiments. While electron, hy-

drogen, deuterium and impurities density, together with electron and ion temperatures, were predicted, the momentum was not evolved. Since the radiation was quite low, NCLASS [8] was used as neoclassical transport model for Tungsten to provide a first approximation. The NBI heat and particle deposition was modelled with PENCIL [9], the equilibrium with EFIT, the impurities (Be, W) with SANCO [10]. Pedestal and puffs were not modelled and internal boundary conditions were taken at $\rho = 0.8$. The ratio $n_D/(n_D + n_H)$ was set to be equal to the one measured at the edge. The fits to the experimental data used for comparison and boundary conditions were done using Gaussian Process Regression [11], [12]. Additional transport was manually added inside $\rho < 0.2$ to match the experimental profiles and mock-up the time averaged effect of sawteeth, that were present in all three experiments. It is worth noting that in shot #91754 edge charge exchange and core CX do not agree around $0.7 < \rho < 0.9$. Since edge charge exchange is considered to be more precise in that region, and it suggests a T_i much closer to T_e at the boundary, as it could be expected from this relatively high collisionality regimes, $T_i = T_e$ was set at the edge. This same setting were used in 91232 and 91227, were edge CX is not available. The same settings for QuaLiKiz were used in all three cases.

The results are shown in figure 1, 2 and the agreement of the various profiles is shown in table 1, using simple RMS error. The electron density peaking, defined as in formula 1 is captured, as well as the peaking for the single isotopes. The particle source has only a small impact on the single isotope peaking, which instead follow the electron peaking.

$$P = \frac{n_{e(\rho=0.1)} - n_{e(\rho=0.8)}}{n_{e(\rho=0.8)}} \tag{1}$$

Case	Beam (Core fuel)	Puff (edge fuel)	Zeff	Power	Edge $\frac{n_D}{(n_D+n_H)}$	σT_e	σT_i	σn_e
91754	H	H + D	1.15	8MW	0.53	7.7%	18.2%	4.3%
91232	D	H	1.1	8MW	0.15	8.2%	14.7%	7.7%
91227	D	H + D	1.1	8MW	0.64	9.9%	7.3%	3.6%

Table 1: Discharge characteristics and agreement with JETTO-QuaLiKiz simulations

Sensitivity tests

A battery of sensitivity tests was run to assess the robustness of the small variation of the isotope ratio against the simulations settings.

First, boundary conditions were varied. For reasons of speed and simplicity, since the interest was only on the dependencies, it was chosen not to include impurities in the baseline for the sensitivity studies. The boundary conditions of the density and the electron and ion temperatures were changed by 10% to understand the influence on the profiles. Changing the density
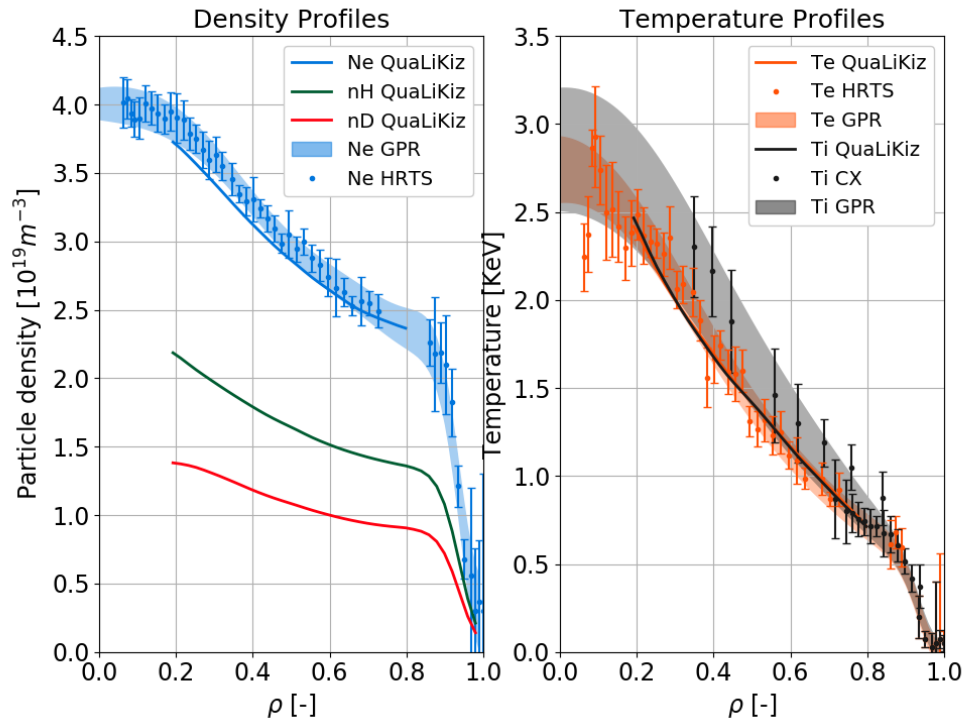
Figure 1: Density (left) and temperature (right) profiles for shot #91754, H beam, mixed H-D puff
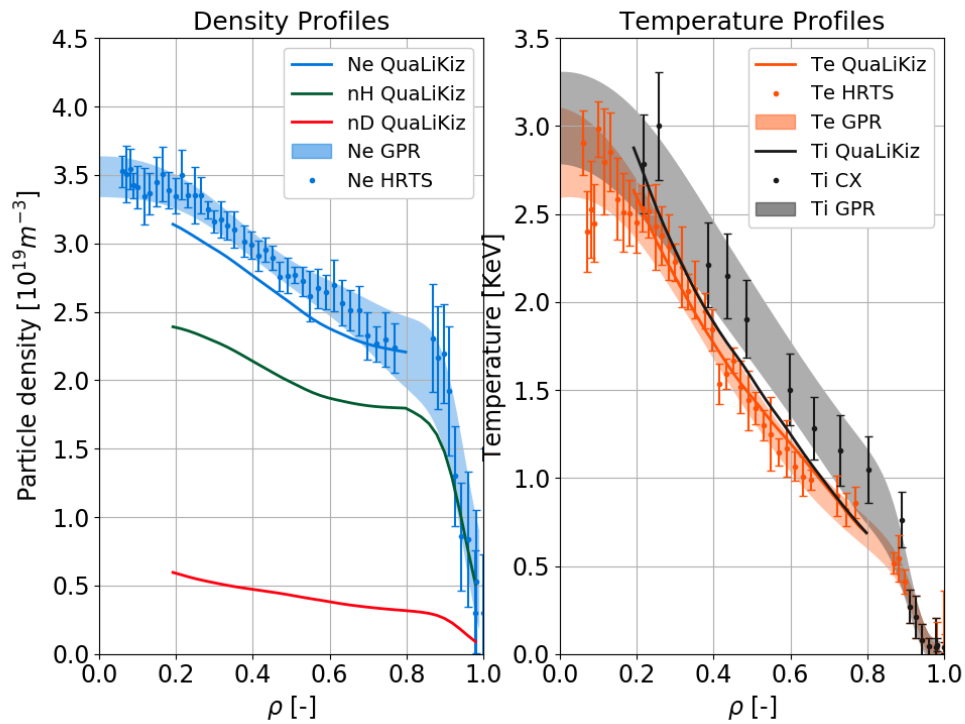

Figure 2: Density (left) and temperature (right) profiles for shot #91232, D beam, only H puff

boundary conditions resulted in a quite rigid translation of the profile, with minimal impact on the temperatures. A similar trend was observed while changing T_e and T_i at the same time. A large difference in the density peaking was instead observed changing only boundary T_i. This changes the edge T_i/T_e ratio, that is stabilizing for ITG for higer T_i/T_e and leads to an increase in the density peaking.

Then, some physics parameters were changed. ETG scale was turned off, resulting in a quite noticeable increase in the electron temperature. Rotation was turned off, affecting mostly the predicted density. The results are summarized in table . This sensitivity study was done for all three cases, with simlar qualitative trends. While the density peaking can change significantly, the isotope ratio in the core does not vary more than a few percent, strongly stating that, in the model, the isotope profile is weakly dependent on the source and follows the electron profile.

T_i/T_{i_0}	T_e/T_{e_0}	ETG	Rotation	n_e peaking	Edge $\frac{n_D}{(n_D+n_H)}$	Core $\frac{n_D}{(n_D+n_H)}$
1	1	On	On	0.50	0.14	0.19
0.9	1	On	On	0.37	0.14	0.17
1.1	1	On	On	0.68	0.14	0.20
1.1	1.1	On	On	0.49	0.14	0.18
1	1	Off	On	0.39	0.14	0.17
1	1	On	Off	0.34	0.14	0.16

Table 2: Simulations settings and peaking

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