Comparison of the ion heat transport properties of ASDEX Upgrade H-mode plasmas with theory-based transport models

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1 Introduction

Ion heat transport in tokamaks is widely considered to be produced by Ion Temperature Gradient (ITG) driven turbulence. However, the relevant threshold in critical gradient length (R/L_{T_i}) and the extent of the strong increase at higher gradients are far from being constant, even under experimental ranges of variations of plasma collisionality or T_e/T_i. Trends are observed in the experiments, providing a good test for existing theory-based transport models, thus assessing their predictive capability also in view of future devices. In this paper we model a set of H-mode plasmas featuring an ion heat flux-scan, obtained using on- versus off-axis Neutral Beam Injection (NBI) heating in different time intervals of the discharge. These NBI power deposition scans are performed at two different levels of background Electron Cyclotron Resonant Heating (ECRH), as shown in Fig. 1.

This set of experiments provides also a perfect framework for comparing models both for transport and for sources. The status of the implementation of the relevant modules into ASTRA and their validation is discussed in this paper. The aim is to have unique, verified installations of libraries common to all users, which was achieved for most coupled codes within this work.

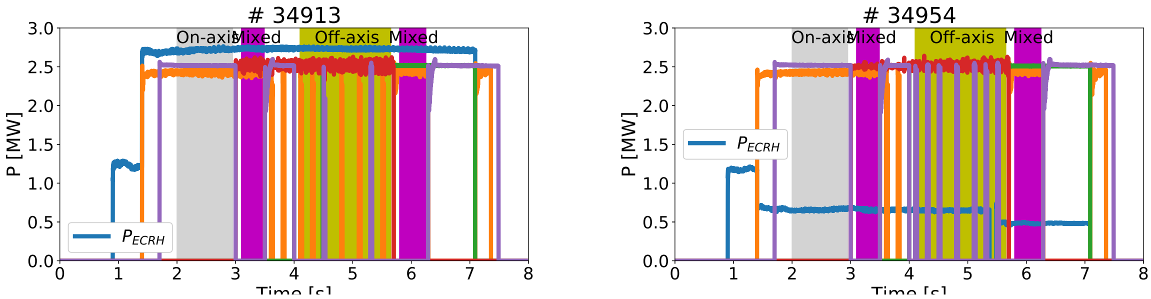

Figure 1. Time traces of the auxiliary heating for #34913 (a) and #34954 (b), with lower P_{ECRH}. In both discharges, NBI is moved from on- to off-axis. Colours refer to different NBI sources. Shaded regions: on-axis NBI (grey), mixed (magenta), off-axis (light green).

2 ASTRA development

To assess the extent of profiles stiffness, it's of course important to explore the variation range of the heat and particle sources. The source profiles can be either computed using the experimental kinetic profiles as input, or modelled self-consistently with the evolving simulated profiles. In the frame of the present work, we have coupled the TORBEAM [3] code for ECRH and the RABBIT code [4] for NBI. The relevant geometry and setting parameters are now unified in a single namelist, containing the settings also for the equilibrium calculation and the input for the previous NBI pencil-wise routine. The namelist

can be created with a GUI-based tool, available for all ASDEX Upgrade users, which also collects the necessary physics input (equilibrium boundary, time traces and kinetic profiles) as u-files.
The TORBEAM code was implemented successfully, the deposition occurs at the expected location and all gyrotrons are predicted to deliver the nominal power without any failure. Typical heating and current drive profiles for #34913 ($P_{ECRH} \approx 2.75$ MW) and #34954 ($P_{ECRH} \approx 0.65$ MW) are shown in Fig. 2.

A systematic validation against stand-alone TORBEAM runs is in progress. Similarly, the implementation of the RABBIT code is now robust and realistic, in terms of deposition profile and power losses. An extended benchmark with the stand-alone version is underway. Moreover, for NBI reconstruction there are several available options, namely the current NBI routine in ASTRA and the NUBEAM/TRANSP package [5]. In Fig. 3 the three modules are compared, for $P_{NBI,i}$ (a) and $P_{NBI,e}$ (b), in the on-axis and off-axis NBI phases, respectively.

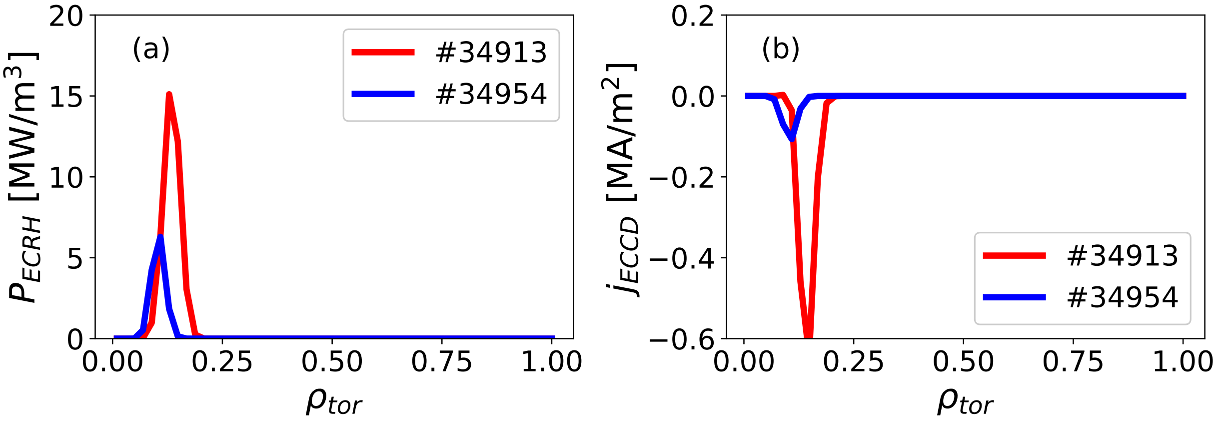

Figure 2. TORBEAM prediction for P_{ECRH} (a) and EC current density (b)

As Fig. 3 shows, there is substantial agreement between the different codes, with a slight more inward trend for TRANSP/NUBEAM, possibly due to a more complete orbit

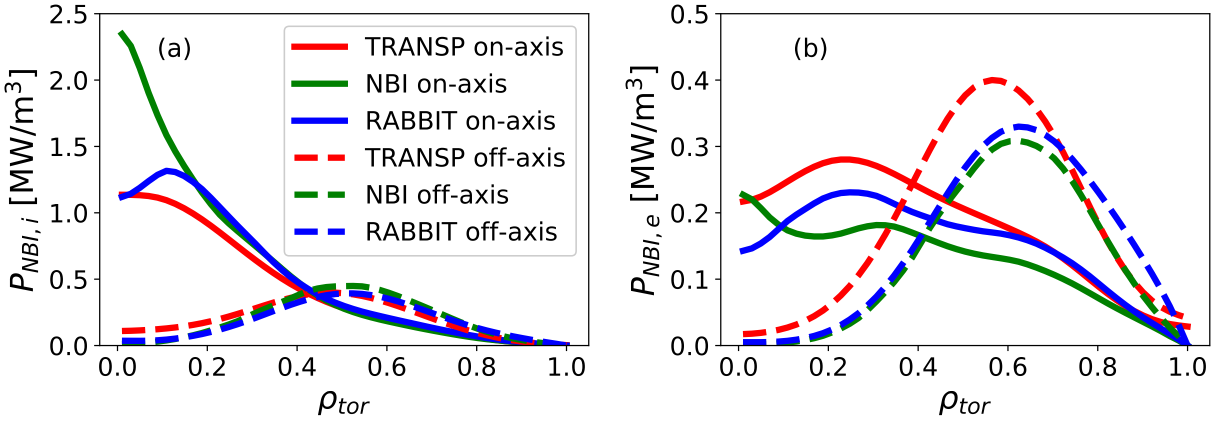

Figure 3. RABBIT (blue), NUBEAM (red) and NBI (green) predictions for on-axis (continous) and off-axis (dashed) NBI deposition. $P_{NBI,i}$ (a) and $P_{NBI,e}$ (b)

treatment.

3 Modelling with theory-based models

The main tool for predicting the kinetic profile used here is the TGLF-SAT1 model [6], implemented in ASTRA and largely validated on several tokamaks in the last years. A larger profile resilience is expected in discharge #34913, with high P_{ECRH}, dut to the strong dependence of ITG transport on T_e/T_i.

All n_e, T_e and T_i profiles were modelled inside ρ_{tor}=0.85. We asumed $Z_{eff} \approx 1.1$. Moreover, the measured c_W was taken as input, of the order of 10^{-5}. The resulting radiated power is $0.5 - 0.7MW$, distributed on a flat profile over the whole plasma core. The simulation results for discharge #34913 are shown in Fig. 4.

The density peaking is perfectly matched, which is a signature of a correct prediction of the dominant mode for transport - in this case, the ITG mode. T_i is slightly too peaked in the central region, while the T_e peaking is even more overpredicted.

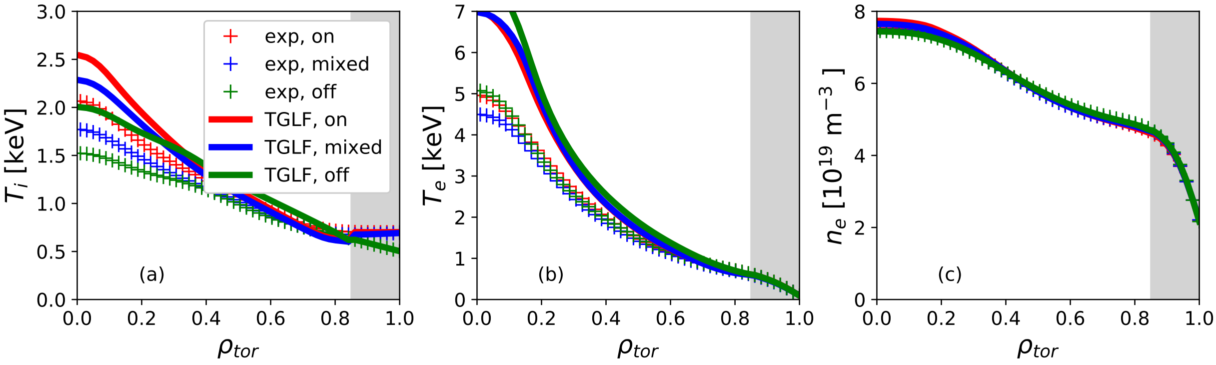

Figure 4. Kinetic profiles of #34913 (high P_{ECRH}) predicted with TGLF-SAT1. Red (on-axis NBI), blue (mixed), green (off-axis). T_i (a), T_e (b), n_e (c).

The case with lower electron heating is shown in Fig. 5.

The prediction is extremely accurate for all channels in all phases, no overestimated temperature peaking is observed in the low P_{ECRH} discharge. The modelled ion stiffness is compared to the experimental one in Fig. 6. The variation in R/L_{T_i} is matched to a high degree for the low P_{ECRH} case, whereas at high P_{ECRH} the TGLF model appears to underpredict the slope of Q_i versus R/L_{T_i}.

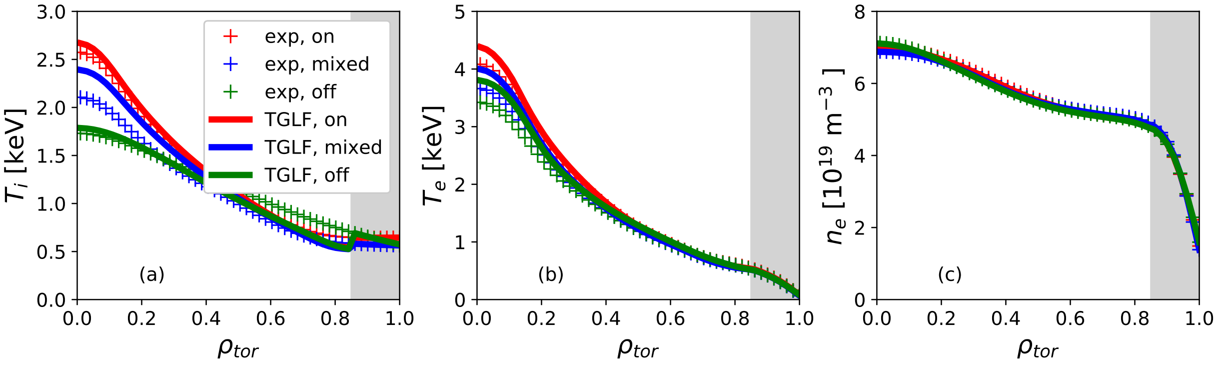

Figure 5. Modelling as in Fig. 4, for discharge #34954 (low P_{ECRH}).

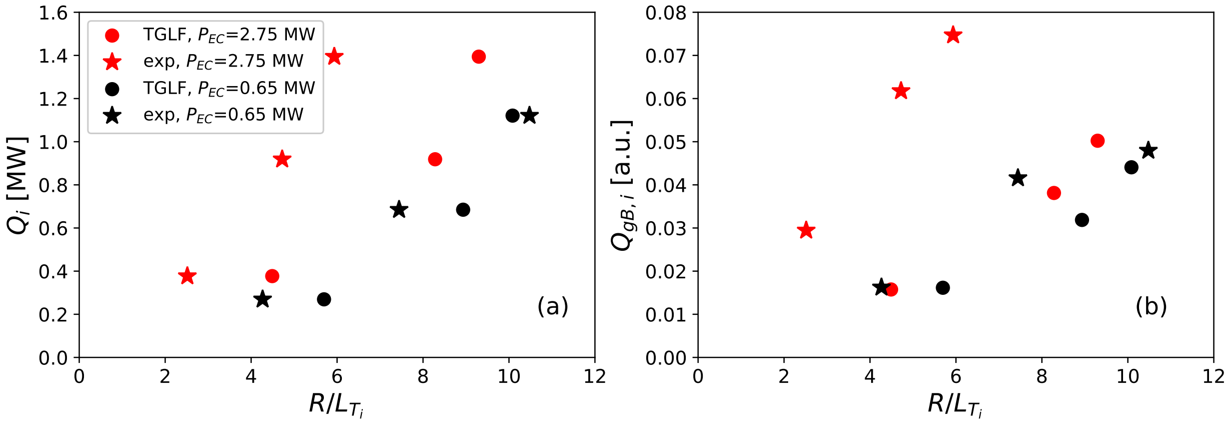

Figure 6. Ion heat flux Q_i *vs* R/L_{T_i} *at* $\rho_{tor} = 0.27$ *(a);* $Q_{gB,i} = Q_i/(n_e T_i^{2.5})$ *(b).*

4 Conclusions

The ASTRA code has been extended to include source modules like TORBEAM and RABBIT, using external libraries shared with all users. Also, the necessary tool for integrated input generation is now available. This development is largely overlapping with the interface between AUG data and IMAS structures, bridging the gap towards modelling ASDEX Upgrade discharges with the European Transport Solver.

The TGLF model is applied to a pair of ASDEX Upgrade H-mode discharges, both featuring an ion heat flux scan by moving NBI from on- to off-axis, at different T_e/T_i levels obtained by varying P_{ECRH}. At lower P_{ECRH} the modelling results are extremely accurate for all channels. At higher P_{ECRH}, instead, the temperature profiles peaking is overpredicted and the trend increases with higher ion heat flux, indicating that stiffness is too low in the TGLF-SAT1 model.

Gyro-kinetic calculations [1] provide an interpretation of these results, suggesting that the TGLF model is less stiff in general. For $T_e/T_i >> 1$ the de-stiffening effect of fast ions (missing in the TGLF model) is negligible [1], therefore the TGLF model predicts lower stiffness than the experiment. In the $T_e/T_i \geq 1$ case, where fast ions play a significant de-stiffening role in the gyro-kinetic calculations, the lesser stiffness of the TGLF model compensates that missing effect, resulting in an accurate prediction of the experimental ion heat flux scan.

References

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