Validation of the TGLF model against Ohmic confinement transition and impurity transport experiment in ASDEX Upgrade

I. Erofeev, E. Fable, C. Angioni, P.T. Lang, R.M. McDermott and the ASDEX Upgrade Team

Max-Planck-Institut für Plasmaphysik, Garching, Germany

Introduction

As has been observed in many tokamaks, the energy confinement of ohmically heated L-mode plasma scales linearly with the density until a critical value is reached, after which the confinement stays constants or even degrades. The two regimes are called Linear and Saturated Ohmic Confinement (LOC and SOC). It has been suggested to link them to a shift in turbulence regime from TEM-dominated to ITG-dominated, that modifies transport [1, 2]. The critical density of the LOC-SOC transition was found to be close to the value at which the spontaneous plasma toroidal rotation flips from co- to counter-current, and the rollover in density peaking occurs. While it is obvious that the single governing engineering parameter is the plasma density, there is still no definite proof to whether the three are connected to the same fundamental mechanism.

Within the given framework, the most important ingredient for the modeling is the correct treatment of turbulence throughout the confined plasma, since the dominant mode transition from TEM to ITG is believed to begin at the edge and move towards the core (due to higher collisionality and R/L_{T_i} at the edge). Along with self-consistent evolution of plasma profiles, such as temperature and density, this poses a demanding simulation task. We use the ASTRA transport code [3, 4] which accounts for various aspects of transport processes in the plasma, coupled to the TGLF transport model [5]. In order to validate this scheme also with relation to impurity transport, it was attempted to simulate a well-documented test case of a lithium pellet propagation and diffusion in the confinement region of a typical H-mode plasma.

Energy confinement

A series of experiments with L-mode plasma, only marginally heated with ECR, has been conducted in the ASDEX Upgrade, thats results have been collected up into a database [6]. It contains data on plasma discharges with a variety of control parameters such as the magnetic field B_φ and the plasma current I_p. From the database analysis the critical density $\tilde{n}_e^{crit} \sim I_p$, which suggests to select for modeling two cases with different I_p values: one with $I_p = 1.04\,MA$ (at $B_t = 2.51\,T$, case I), the other with $I_p = 0.63\,MA$ (at $B_t = 1.96\,T$, case II).

The comparison between the experimental (calculated with power balance) and simulated energy confinement time as a function of the electron density is presented in Fig. 1.

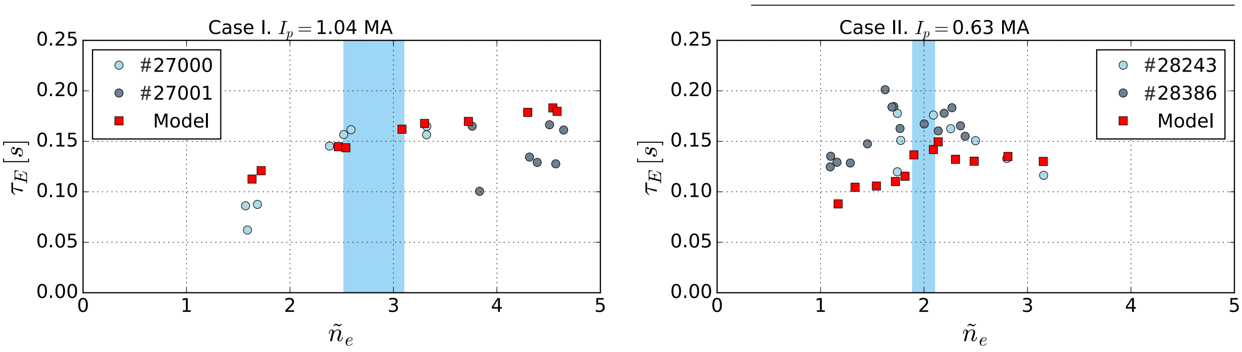

Figure 1: *Energy confinement time as a function of line integrated electron density for the case I (left) and II (right). Transition regions are shaded.*

The linear and saturated regions can be distinguished in both sequences of points, though the experimental confinement time degrades in the SOC regime.

Turbulence regimes

In order to validate the hypothesis that the dominant turbulent mode switches from TEM to ITG, one needs to see the behavior of its frequency, as well as the heat transport in both species channels. Figure 2 presents the spectral characteristics of the turbulence at the scales of interest at radial position $r/a = 0.6$ for the lower current case II. The first feature to notice is that the frequency ω changes sign. At low densities it stays roughly constant, and after the transition its absolute value starts to grow from significantly lower values. The turbulence intensity ϕ^2 in this linear model is proportional to the growth rate γ for each k_y and therefore reflects the turbulence drive. The scales $k_y\rho_s = 0.3..0.8$ show the most rapid relative growth at the critical density. The electron heat flux Q_e for each k_y drops heavily at frequency transitions, showing a increase growth afterwards. The reason for that is, the TEM-driven electron heat transport is resonant, the turbulent structures propagate in the same direction as the electrons. After the domi-

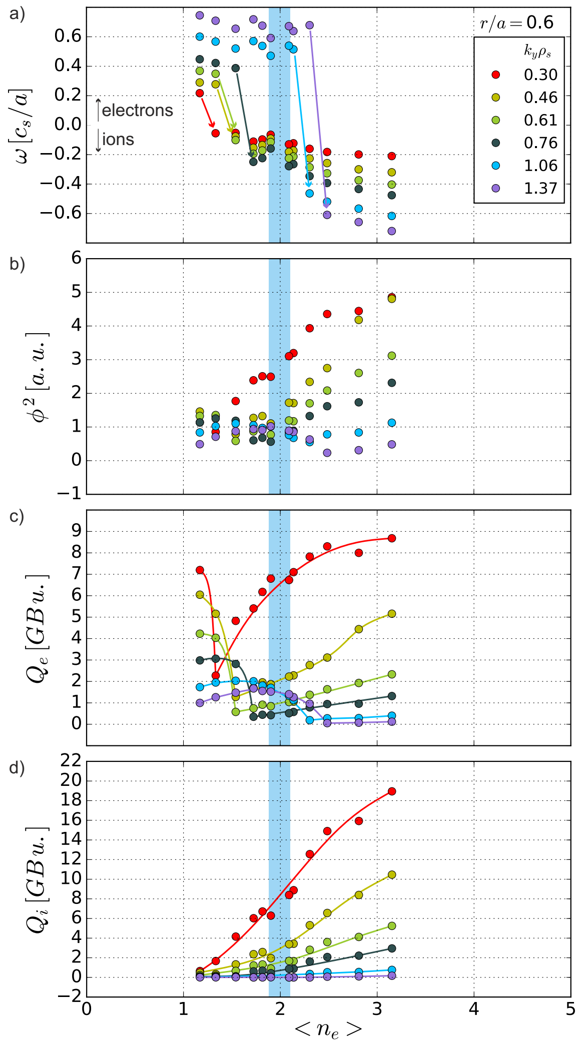

Figure 2: *Spectral charachteristics of the turbulence for the case II. Transition region is shaded.*

nant mode switches to ITG, electron transport becomes non-resonant and hence much weaker. Q_i, in turn, grows gradually with the density, as the equipartition raises ion temperature and its logarithmic gradient, and the impurity ion fraction reduces. This phenomenology allows us to confirm the hypothesis of the dominant turbulence mode transition under the given plasma conditions.

It is instructive to modify relevant plasma parameters independently and see how each of them affects the turbulence characteristics, namely the turbulent heat fluxes. Figure 3 shows the results of the substitution of several quantities from SOC regime into LOC plasma, when either plasma current or average density was kept the same. Q_e is mostly sensitive to the local shear $\partial q/\partial r$ (accounted for together with the local safety factor q), R/L_{T_e}, the temperature ratio T_i/T_e ($Temp$) and the collisionality ν_*, while Q_i highly depends on R/L_{T_i} and the plasma composition $Comp$ due to ion dilution effect (in this model we scale the impurity content identifier $Z_{eff} = 1 + 2.3 I_p/\tilde{n}_e$). The fact that the behavior of Q_i is more universal as the confinement saturates, allows us to assume that it is mainly the ion turbulence that defines the confinement regime, while the dominant mode transition from TEM to ITG is less relevant.

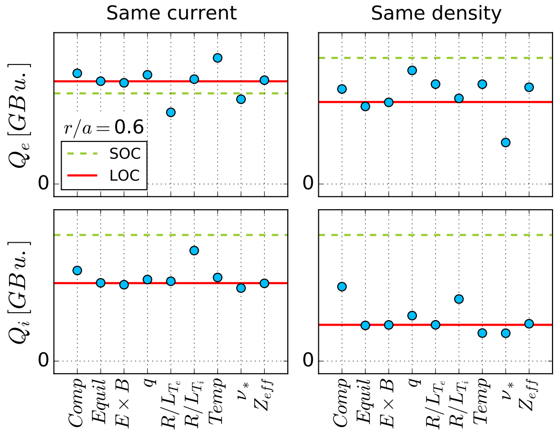

Figure 3: *Variation of total heat fluxes Q_e and Q_i at $r/a = 0.6$ due to parameter substitution from SOC to LOC plasma.*

Impurity transport

The modeling of impurity transport is based on the experiment with lithium pellet injection into H-mode plasmas in the ASDEX Upgrade [7], discharge #31949, pellet at $t = 5.53s$. The plasma parameters are as follows: $B_t = 2.48T$, $I_p = 0.84MA$, $\tilde{n}_e = 5.9 \times 10^{19} m^{-3}$, $P_{ECR} = 1.18MW$, $P_{NBI} = 7.66MW$. A pellet containing 10^{20} Li atoms is injected at $V = 600m/s$. The simulation features both neoclassical and turbulent transport of all species; a background impurity (boron) density is set so that the scaling introduced in the previous section is fulfilled; the radiation is treated accordingly and fits well to the measured levels.

The experimental and simulated densities of electrons and lithium ions are presented in Figure 4, the diffusion and pinch coefficients for lithium are shown in Figure 5. The overall dynamics are reproduced well, however, the impurity tends to relax towards the core region on time scales $\sim 0.02s$, filling in the core hollowness. Electron and ion temperatures drop by $30-40\%$ and recover to original values as the impurity density decreases, the corresponding heat conductivities follow the same trend (Figure 6). The diffusion coefficient for lithium increases as the density (and so the collisionality) decays, just as expected for turbulent transport. Diffusion and pinch outside $r/a = 0.8$ should not be considered as relevant, since the transport at the edge is patched due to TGLF not handling that region realistically.

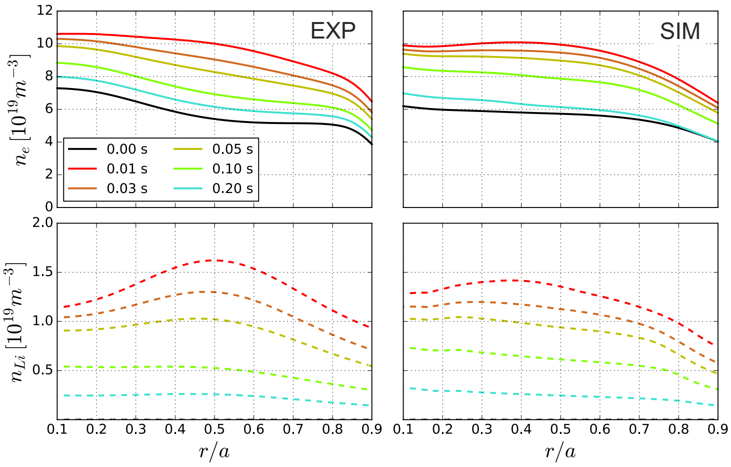

Figure 4: *Electron and lithium density profiles evolution as measured experimentally (left) and obtained in the simulation (right).*

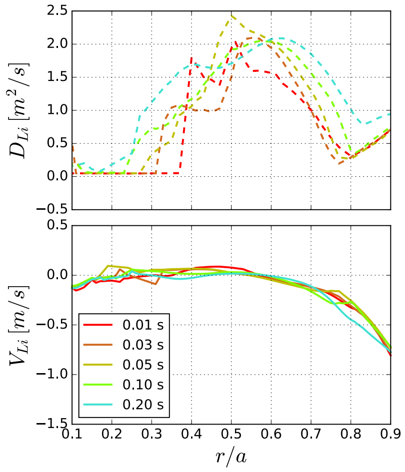

Figure 5: *Diffusion and pinch of lithium during the simulation.*

Conclusions

The TGLF module for ASTRA serves as a useful tool in turbulence analysis and reproduces many features relevant for both main species and impurities turbulent transport. The lithium pellet diffusion simulation resulted in a good reconstruction of the evolution of impurity and electron density. The results for Ohmic confinement parameters study show that the LOC-SOC transition is linked to a significant increase in the ion transport channel due to growing R/L_{T_i} and decreasing impurity content, the TEM to ITG transition is less relevant.

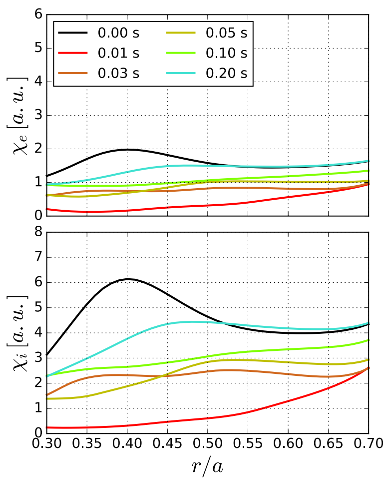

Figure 6: *Evolution of heat transport coefficients χ_e, χ_i.*

References

[1] F. Romanelli *et al*, Nucl. Fusion **26** 1515 (1986)

[2] C. Angioni *et al.*, PRL **107**, 215003 (2011)

[3] G. V. Pereverzev and Y. P. Yushmanov, IPP Report 5/42 (1991)

[4] E. Fable *et al.*, PPCF **55**, 12402 (2013)

[5] G. M. Staebler *et al.*, POP **12**, 102508 (2005)

[6] R. M. McDermott *et al.*, Nucl. Fusion **54**, 043009 (2014)

[7] P. T. Lang *et al.*, EPS Conference on Plasma Physics 2016