Modeling of I-phase of ASDEX-Upgrade

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Introduction

In the recent years several new tokamak confinement regimes were found. A regime known as I-phase was observed at AUG [1] and might be considered as intermediate state. The I-phase consists of limit cycle oscillations induced by the interplay between turbulence and geodesic acoustic modes at the plasma edge which induce oscillations in the radial electric field and between high and low transport. To reach this regime one has to increase heating power from the L-mode but not sufficiently enough to reach the H-mode. No sharp barrier at the edge has been observed in I-phase. However, understanding of transport properties in this regime requires full 2D simulation of the edge plasma which has not been done before. It is also important to simulate average radial electric field to understand its role in the formation of the edge transport barrier (ETB).

The simulation of L-mode and I-phase for AUG shot was done with B2SOLPS5.2 code. It is demonstrated that in the I-phase the radial electric field remains close to the neoclassical electric field, as in the previous simulations of L and H-regimes. For the I-phase it was found that the best fit to the experimentally measured density and temperature profiles gives the modest transport barrier in density (drop of diffusion coefficient by a factor of two) and almost no drop in the electron and ion heat conductivity coefficients. The calculated radial electric field after spatial averaging is close to the electric field measured with Doppler reflectometry method in the period when it is maximal [1].

2. Modeling of the I phase

The AUG shot 24811 [1] where both L-regime and I phase were observed was chosen for simulation. The shot had the following parameters: $B_T = -2.3T,\ I_p = 0.8A,\ \overline{n} = 3\times 10^{19} m^{-3}$. Simulation was performed with B2SOLPS5.2 - EIRENE code for the deuterium plasma without impurities. To match the observed density and temperature profiles at the equatorial midplane the transport coefficients equal to $0.3m^2/s$ were chosen in the L-regime. The ion temperature profile has been simulated as well using the energy balance equation, however experimental profile was absent for this shot. Previous simulations, see e.g. [2], were able to reproduce measured ion temperature profile with reasonable accuracy. The ECRH power was $P = 0.39MW$, together with the Ohmic power the total power was 0.9 MW. The density, temperatures and radial electric field profiles are shown in Fig.1. The calculated E_r has the same shape as experimental one but is overall lower. This might be caused by overestimation of ion temperature in the simulation. Then the heating power was increased up to 1.1MW ($P_{tot} = 1.5MW$) and I-phase was reported [1]. In this regime GAMs were observed, so the radial electric field was oscillating. Here we present simulation of the medium radial electric field. The transport coefficients chosen are shown in Fig.2a. Modest drop of diffusion coefficient of the order of 2 is required to match the density profile, while the heat conductivity coefficients do not drop inside the barrier.

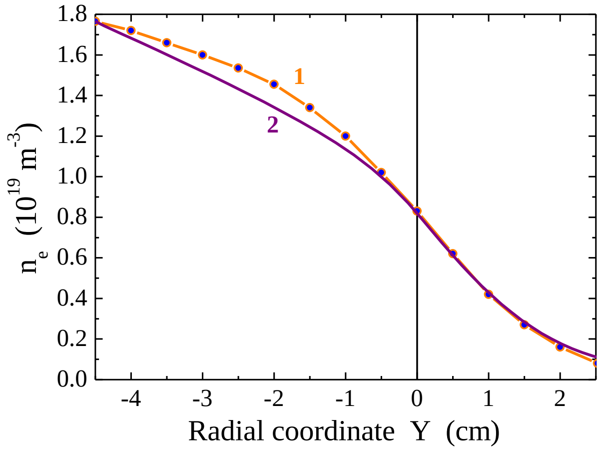

Fig.1a. L-mode. Density at the equatorial midplane. 1-experiment, 2-modeling.

The radial electric field as in the previous simulations of L and H-modes [2] is close to the neoclassical one, Fig.2d. Note that the radial electric field is to large extent determined by the ion temperature. It was calculated from $\nabla \cdot \vec{j} = 0$ equation with corresponding boundary conditions [2]. At the core side the ∇B driven currents are closed by parallel Pfirsch-Schlueter currents and electric field is close to neoclassical field as is observed. In the SOL ∇B driven currents are closed through the plates and electric field changes sign, for details see [2]. In the experiment the Doppler reflectometer measurements have a finite sample volume, of estimated 3-4mm width in these shots, so we apply a *LWMA* algorithm: $LWMA = \sum_{i=1}^{N} P_i \times W_i \ / \ \sum_{i=1}^{N} W_i$, P_i are values i-points back ($i_{current}$ = 1) and $W_i = |i - n - 1|$. The averaged electric field is in reasonable agreement with measurements.

The calculated neutral density both for L-mode and I-phase was compared with the fluxes of neutrals measured with ionization pressure gauges. The most representative fluxes for the I-phase are: gauge N8 (divertor) $5.20 \cdot 10^{21} \text{atom/m}^2\text{/s}$; gauge N15 (main chamber) $0.45 \cdot 10^{21} \text{atom/m}^2\text{/s}$, and the calculated flux to the respective nearest flux surface are $6.40 \cdot 10^{21} \text{atom/m}^2\text{/s}$ and $0.29 \cdot 10^{21} \text{atom/m}^2\text{/s}$, the agreement is reasonable.

3. Discussion

We see that the radial electric field is close to the neoclassical one and its absolute value is determined by the ion temperature. The calculated field differs from the measured one in a period when electric field is large, however after spatial averaging the simulated results are in reasonable agreement with the measurements. This gives a rough estimate for the resolution of the Doppler reflectrometry method to be of the order of 5mm. The obtained neoclassical character of radial electric field is consistent with the simulations of L and H modes [2-5].

The radial electric field in the I-phase has large turbulence driven variations during the limit cycle, in some cases, as the mean equilibrium driven value. The maximal electric field, Fig.2d, is larger than in the L-mode, Fig.1c, and is smaller than in the well-developed H-modes, see [2-5]. The density barrier is also modest – the drop in the diffusion coefficient inside the barrier is of the order of 2 while in the normal H-mode the corresponding drop is 5-10 [2]. In this sense the I-phase could be considered as intermediate regime between L and H-modes. It is still unclear why the transition to the pronounced H-mode with strong density barrier does not occur. One possibility is connected with GAMs; it might be that oscillating electric field does not let further suppression of the turbulence level.

There is no barrier for electron temperature (at least in the simulated shot) – electron heat conductivity inside the barrier is the same as outside of it. This is similar to the standard H-mode [2]. In other words, the turbulence, probably small scaled one, which is responsible for electron heat conductivity is not suppressed in the I-phase.

4. Conclusions

It is demonstrated that in the simulated regimes – L-mode and I-phase, radial electric field (in the period when it is large for I-phase) is of the order of the neoclassical electric field and is determined by the ion temperature as in the standard L and H-modes. The simulated I-phase shot has modest density transport barrier and no barrier in electron temperature and might be considered as intermediate regime between L and H-modes.

Acknowledgements

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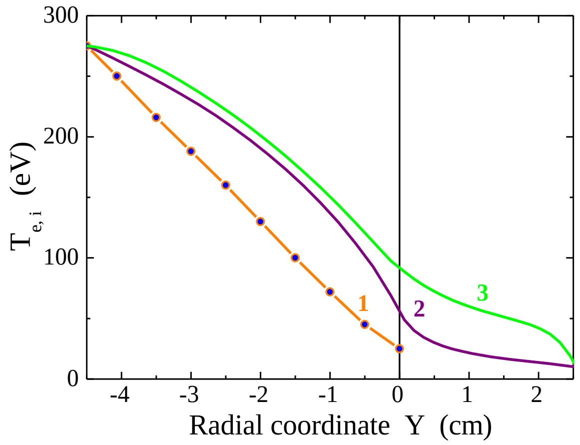


Fig.1b. L-mode. T_e, T_i at the equatorial midplane. 1-T_e experiment, 2- T_e modeling, 3- T_i modeling

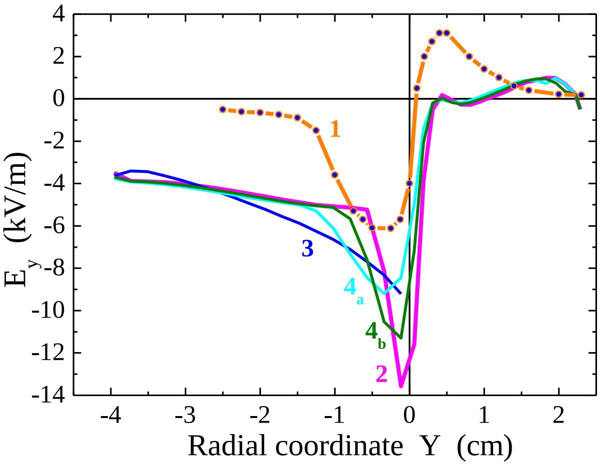


Fig.1c. L-mode Radial electric field at the outer midplane. 1-experiment, 2-modeling, 3-neoclassical electric field, 4-averaged modeling results: a-over 5 points, b-over 3 points.

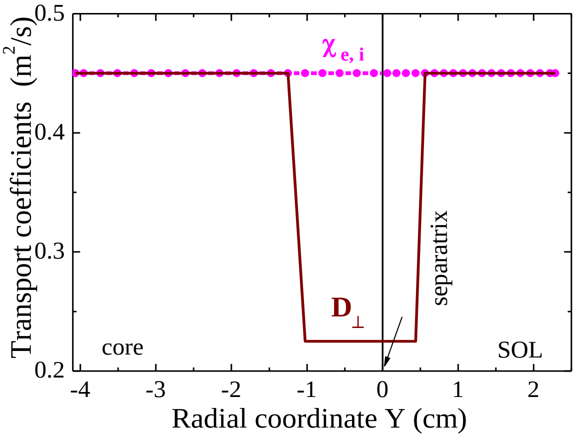


Fig.2a. I-phase. Transport coefficients at the outer midplane.

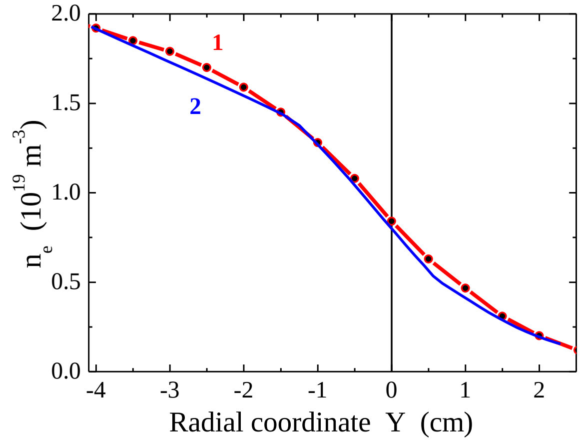
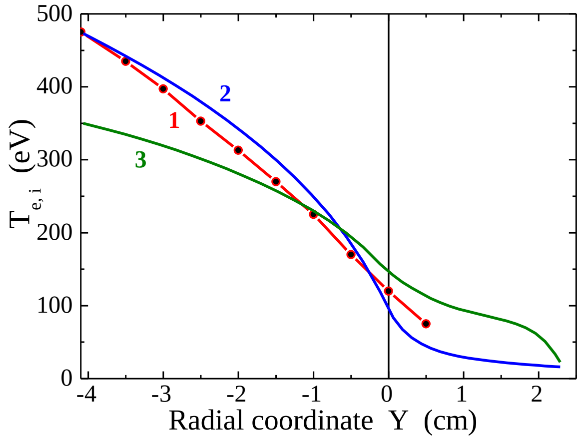


Fig.2b. I-phase. Density at the equatorial midplane. 1-experiment, 2-modeling.



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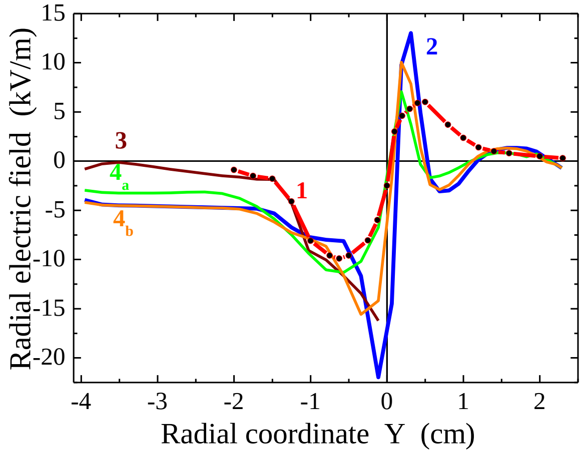

Fig.2d. I-phase. Radial electric field at the outer midplane. 1-experiment, 2-modeling, 3-neoclassical electric field, 4-averaged modeling results: a-over 5 points, b-over 3 points.