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Simulation of L and H regimes for spherical tokamak Globus-M with ASTRA transport code

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Introduction

In recent years a reliable and reproducible L-H transition was achieved on the spherical tokamak Globus-M both with and without auxiliary heating (NBI) [1]. Below presented are the results of simulations performed with the help of the ASTRA transport code [2]. Special attention is paid to effective anomalous transport coefficients and to the radial electric field and its shear, which are, most likely, responsible for the anomalous transport suppression and the transport barrier formation.

Model

The transport model consist of continuity equation for plasma density, ion and electron energy balance equations and an equation for the poloidal flux solved together with the Grad-Shafranov equation in a real geometry of spherical tokamak Globus-M. The boundary value of poloidal flux comes from the condition that the total plasma current should be equal to the measured one, and for conductivity used is neoclassical value calculated by the neoclassical code NCLASS [3]. The last close flux surface is set by its center R_0, half-width in equatorial midplane a_b, Shafranov shift Δ_b, elongation λ_b and triangularity δ_b. These values are taken from the equilibrium reconstruction performed with the help of EFIT code, subscript b denotes boundary values. For certain regime (L- or H-mode) a steady-state solution has been obtained; the transport coefficient were fitted in such a way that the density and temperature profiles and the loop voltage agree with experimental data (Thomson scattering data for T_e and n_e, neutral particle energy analyzer data for central T_i)

L-mode

Modeling is performed for typical Globus-M discharge #19518 (plasma current $I_p \approx 0.2$ MA, $B_{tor} \approx 0.4$ T), in which NBI heating ($P_{NBI} \approx 350-450$ kW, neutrals of energy $E_N \approx 25$ keV are launched in a midplane in a co-current direction) was applied after the

Ohmic L-mode phase (see also [3]).

For the L-mode measured and fitted density and temperature profiles are shown in Figs. 1 and 2, the corresponding transport coefficients – in Fig. 3. The normalized minor radius is defined as a/a_b, where a is a half-width of flux surface in a midplane, a_b is its boundary value.

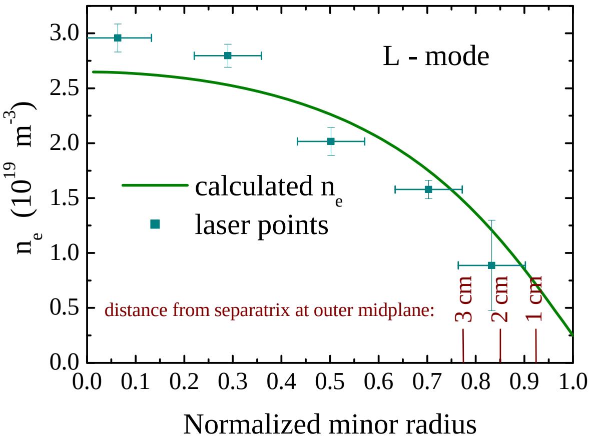

Figure 1.

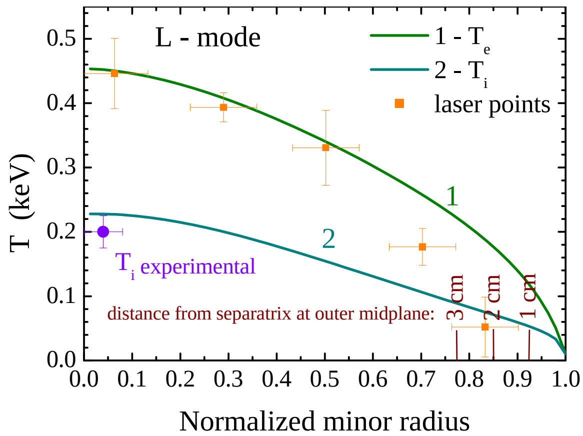

Figure 2.

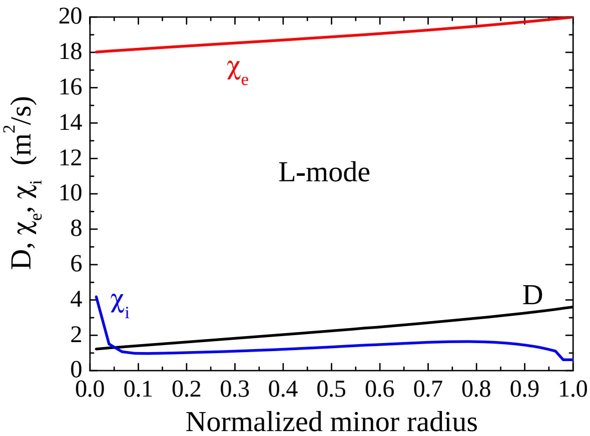

Figure 3.

It is demonstrated that in the L-mode the particle and electron energy transport are anomalous with an effective diffusion coefficient of the order of $2\,\mathrm{m}^2/\mathrm{s}$ and electron heat conductivity coefficient of the order of $(18-20)\,\mathrm{m}^2/\mathrm{s}$. The ion energy transport was described using NCLASS [3] and the ion heat conductivity coefficient for Globus-M was of the order of $(1\text{-}2)\ \mathrm{m}^2/\mathrm{s}$. The calculated energy confinement time $\tau_E = 1.9\,\mathrm{ms}$ is consistent with the ITER scaling for L-modes [4]. Note that the neoclassical electric field and its shear (see Figs. 4 - 5) in the L-mode near the separatrix are of the same order as those in the typical L-mode shots in ASDEX-Upgrade and MAST [5], i.e. the value of shear is below the L-H transition threshold.

H-mode

Experimental and calculated discharge parameters and transport coefficients for H-mode are shown in Figs. 6 - 8. Radial neoclassical electric field and its shear for both L- and H-modes are shown in Figs. 4 and 5. Figure 9 demonstrates the equilibrium flux surfaces together with laser points and a projection of the neutral beam.

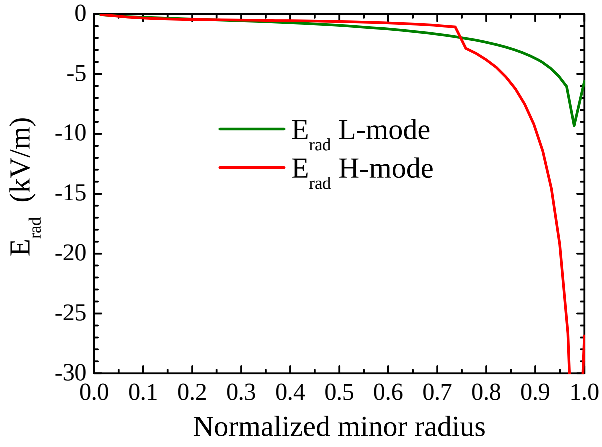

Figure 4.

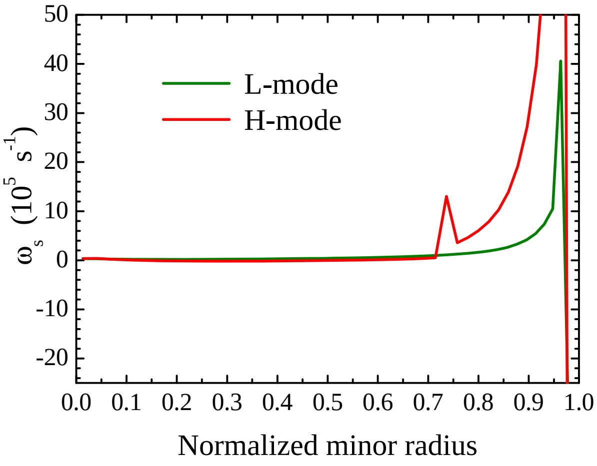

Figure 5.

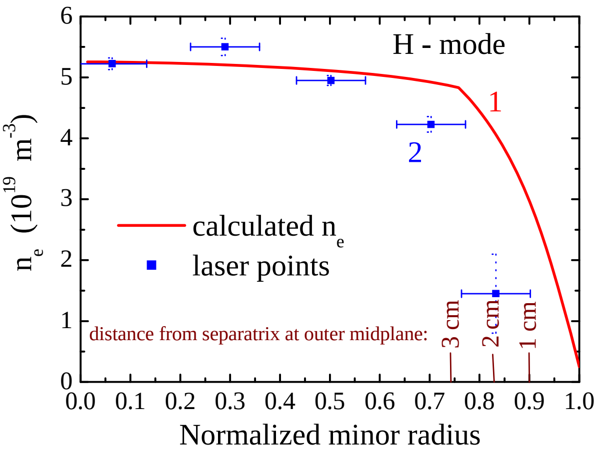

Figure 6.

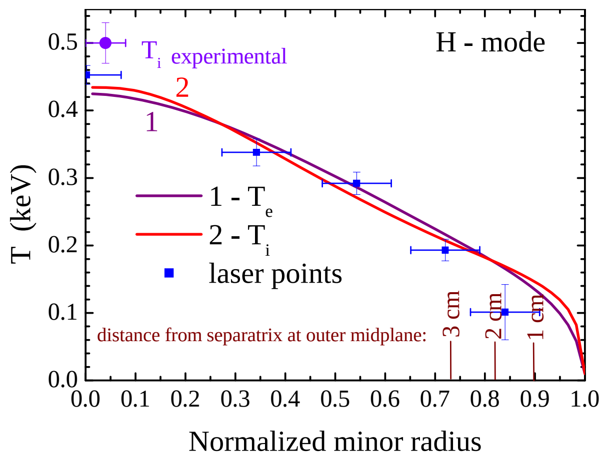

Figure 7.

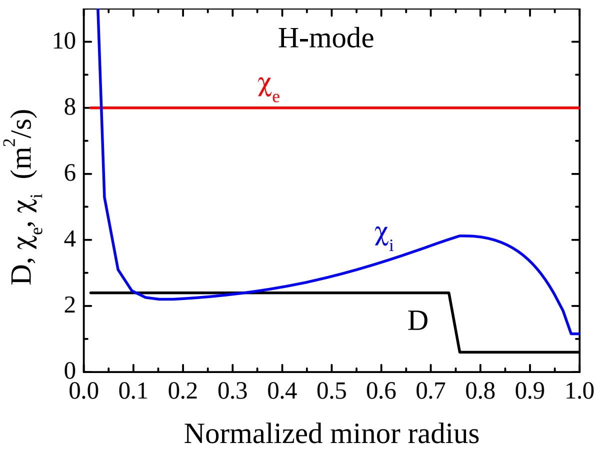

Figure 8.

One can see that in the H-mode with NBI auxiliary heating the ion heat conductivity remains neoclassical and no barrier is formed for the ion temperature. The particle diffusion coefficient is reduced up to the values $(0.5\text{-}0.7)\ \mathrm{m^2/s}$ inside the transport barrier near the separatrix. No barrier is observed for the electron temperature profile.

The calculated energy confinement time is $\tau_E = 4.8\,\mathrm{ms}$, while $\tau_{IPB98(y,2)} = 5.7\ \mathrm{ms}$.

Discussion

One can see that L-H transition is followed mainly by the transport barrier formation for particle flux. It is accompanied by an increase of the electric field shear, which coincides with the conception of the turbulent transport suppression. The L-H transition starts when the power in the ion channel exceeds the transition power threshold. According to the international database [4] for Globus-M it is $P_{LH} \approx 70$ kW. The calculated power balance in the L-mode is the following: $P_{OH} = 390$ kW, the electron-ion power exchange is $P_{ei} = 24$ kW. In the H-mode $P_{OH} \approx 300$ kW, the absorbed NBI power is $P_{NBI} = P^{e}_{NBI} + P^{i}_{NBI} \approx 2 \cdot P^{i}_{NBI} \approx 200$ kW and therefore the ion power source $P_i = P_{ei} + P^{i}_{NBI} \approx 100$ kW is indeed well above the threshold. The calculated pedestal pressure $p^{(calc)}_{ped} \approx 3.5$ kPa is less than the ballooning mode stability criterion $p^{(crit)}_{ped} \approx 9.9$ kPa [4].

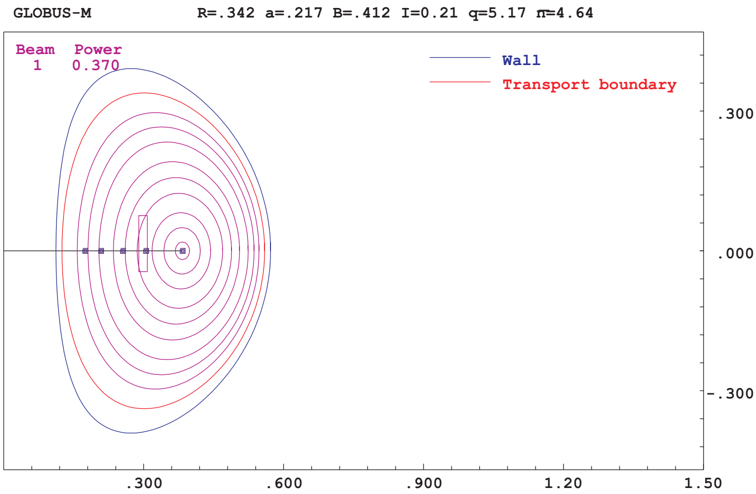

Figure 9. Equilibrium flux surfaces in H-mode. Bars show laser poins, rectangle – the projection of NB. Lengths are in meters.

Good agreement between measured and calculated profiles at the plasma edge requires rise of the transport coefficients up to $D, \chi_e \approx 40$ m^2/s outside the barrier both for L- and H-modes, which most probably does not exist in reality, especially for H-mode. This inconsistency is probably related to the deviation between measured and calculated loop voltage ($U^{(L)}_{calc} = 1.7$ V, $U^{(L)}_{\exp} = 1.9$ V, $U^{(H)}_{calc} = 1.36$ V, $U^{(H)}_{\exp} = 1.41$ V) and plasma total stored energy. Further investigations are required.

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