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Modeling of Inner-Outer SOL Asymmetry for ASDEX-Upgrade

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1. Introduction

Recently the onset of density asymmetry between LFS and HFS SOL during the rise of central plasma density has been observed in the ASDEX-Upgrade (AUG) H-mode shots [1]. When the core density exceeds a certain threshold value, the density integral along the vertical chord passing through the HFS SOL is larger than the value, predicted from the outer midplane measurements. The rise of the HFS SOL density is accompanied by the increase of the neutral pressure in the far inner SOL.

It is shown that the experimental findings can be understood from the B2SOLPS5.2 [2] modeling. In the modeling the transition to the detachment at the inner divertor plate during the rise of the core density leads to the abrupt rise of the density at the HFS midplane. The asymmetry between the HFS and LFS midplane is much more pronounced when the drifts are switched on. Moreover, both the transition to the power detachment and the start of the volume recombination happens at lower core densities if the drift effects are taken into account.

2. Modeling results

The geometry of the AUG H-mode shot #17151, Fig.1a, was chosen for the modeling of the SOL asymmetry. The density at the core boundary of calculation domain, at the flux surface 3.2 *cm* inside the separatrix (at the outer midplane) was varied in the range $4 \div 7 \times 10^{19}\, m^{-3}$ while the temperatures were kept constant $T_e\,|_{core} = 650\,eV$, $T_i\,|_{core} = 750\,eV$. The plasma current was I=1MA, the toroidal magnetic field B=2T. The integral of the plasma density along the vertical chord touching the separatrix (blue line in Fig.1a) was calculated together with the integral of the density traced back along the flux surface to the outer midplane. The difference of these integrals is shown in Fig. 1b. It reflects the difference between the density along the chord and the density at the same flux surfaces at the outer midplane. In the given geometry the chord does not intercept the divertor plate, therefore the difference between integrals gives no information about the density in the divertor region. On the contrary, the chord which was used in the experiment [1] passes through the divertor plate. So more representative is the integral of the density along the curve on the flux surface in the SOL (red line in Fig.1a) between the inner divertor plate and the top. The difference between this integral and the same integral but with LFS midplane density at this flux surface is also shown in Fig.1b.

In Fig. 1b there is a threshold value $4.7\times10^{19}\,m^{-3}$ for the density at the core boundary for the drifts switched on and $5.7\times10^{19}\,m^{-3}$ for the drifts switched off. Below the threshold the difference between the density along the integration line and at the outer midplane is negligible. At the threshold the jump in the density difference is observed in the simulations. The difference is increasing with the core density above the threshold. The difference is amplified for the flux surface integration (red curves on Fig.1b). The length of the flux surface section along which the integration is performed is 1.8 times larger than the chord length, while the integral is about 4 times larger than the integral along the chord. The absolute values of the density difference integrals are of the same order as were measured in the experiment [1] – $(2\div7)\times10^{19}\,m^{-2}$ when the drift effects are taken into account.

The analysis of the density profile shows that the major source of difference is the thin layer of plasma in the divertor vicinity; there the density is more than an order of magnitude larger than the density at the inner midplane. The poloidal profiles of plasma parameters just below (core density $4.6\times10^{19}\,m^{-3}$) and above the threshold (core density $4.9\times10^{19}\,m^{-3}$) are shown in Fig. 2. Here X=0 corresponds to the inner divertor, X=0.8 m to the inner midplane, and X=4.5 m to the outer divertor. These profiles demonstrate the onset of detachment. Above the threshold (blue curves) the electron density grows by an order of magnitude before the inner divertor together with the neutral density. The ion and a)

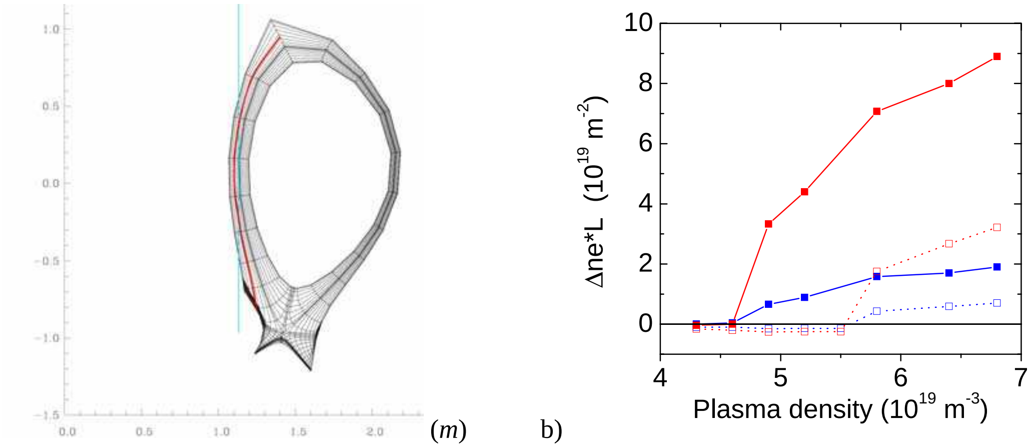

Fig.1. a) Modeling domain; blue is the chord touching the separatrix and red is the curve at the flux surface along which the density is integrated. b) Integral of the density difference along the chord as a function of plasma density at the core boundary of the calculation region – blue points; integral of the density difference along the flux surface 1.5 cm from separatrix – red points. Filled points for the drifts switched on; hollow points for the drift switched off.

electron temperatures near the inner divertor become coupled and decrease to 2 *eV*. The poloidal heat flow through the SOL towards the inner divertor decreases almost to zero on the last few centimeters before the plate for the higher density, while for the lower density the heat flow reaches the inner plate. The parallel momentum balance shows that in the case of the higher density the parallel pressure gradient is compensated mainly by the ion-neutral friction force, which is typical for detachment, while for the lower density the contribution of inertia is significant. The radial profiles of the density at the inner and outer midplanes are shown in Fig.3. While the density change at the outer midplane associated with the core density rise is modest, the density at the inner midplane changes abruptly, which correlates with the rise of the divertor density asymmetry.

It can be seen in Fig. 1b that without drifts the qualitative behavior of the density asymmetry is the same as with drifts, but the threshold core density is larger, and the level of the asymmetry is two or three times lower. Due to the low electron temperature during the detachment the plasma electric conductivity near the inner divertor is very low. The thermoelectric current is directed towards the inner plate. In order to carry it through the divertor region a big gradient of electrostatic potential which is proportional to the temperature at the outer divertor $\Delta\varphi \sim 3T_{e\,out}/e$ should exist, Fig.2b. The corresponding poloidal electric field causes the radial drift in the HFS direction. This radial drift enhances the radial transport of ions to the colder periphery and finally enhances the volume recombination and the neutral density near the wall. In the detached regime the major part of the radial plasma flow is transferred by the drift. In the low-density regime the influence of

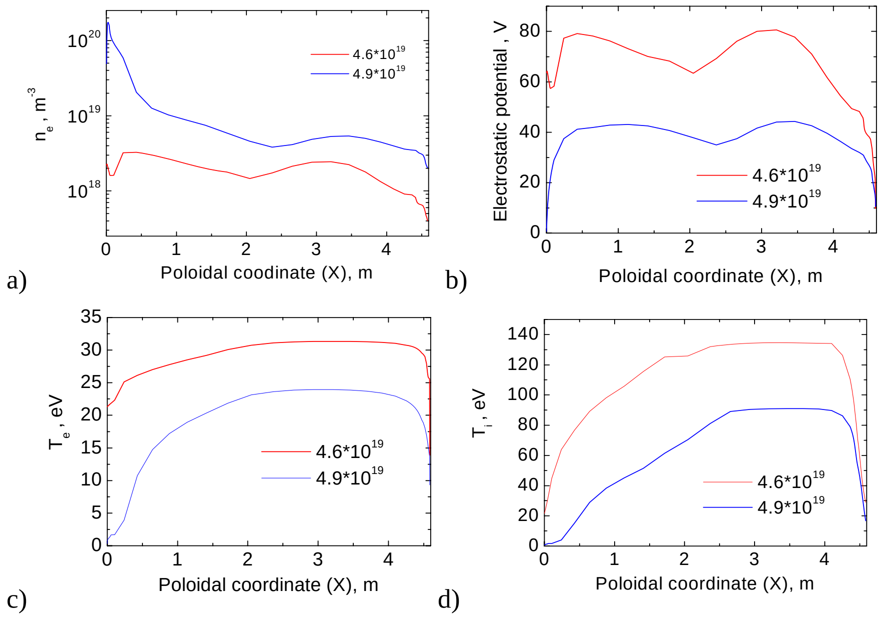

Fig.2. Poloidal profiles of the plasma parameters in the SOL 1.5 *cm* from the separatrix (traced to the outer midplane): a)Electron density; b)Electrostatic potential; c)Electron temperature; d)Ion temperature.

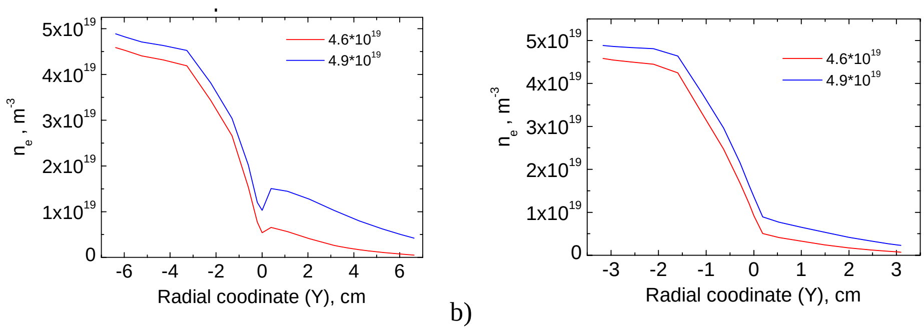

Fig.3. Radial profile of electron density a) inner midplane, b) outer midplane

the drifts is weaker but is still not negligible. This effect of $\vec{E}\times\vec{B}$ drift causes early transition to the detached solution for the inner divertor when the drifts are switched on.

The increase of the density asymmetry by the drifts can be explained by taking into account both the radial $\vec{E}\times\vec{B}$ drift and the ∇B drift heat flow. The analysis shows that the pressure and electron temperature asymmetry between the inner and outer midplane is negligible both for attached and detached inner divertor. The cause of the density asymmetry is the change of the ion temperature. Due to the radial $\vec{E}\times\vec{B}$ drift and the volume recombination the layer of cold plasma in front of the inner plate is wider and the inner SOL ions are colder. The ∇B drift heat flow of ions is directed downwards and causes the Pfirsch-Schlueter flow from the bottom to the top of the tokamak. In the HFS SOL it is directed against the parallel heat flow which closes the radial turbulent heat flow from the core and is directed towards the divertor plate. The superposition of these flows decreases the poloidal ion temperature gradient and makes the inner midplane temperature closer to the divertor temperature. As a result the HFS equatorial density is larger than the LFS one.

Conclusions

The inner-outer SOL asymmetry was modeled with the code B2SOLPS5.2. The asymmetry is associated with the onset of the detachment at the inner divertor. The drift effects increase the asymmetry considerably. The observed LFS-HFS equatorial density asymmetry is associated mainly with the drifts and is caused by the difference in the ion temperatures, while the total pressure is almost the same.

Acknowledgements

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References

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