

Non-diffusive effects in ion collisional transport in TJ-II

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Introduction

In the traditional local diffusive approach, the fluxes are linearly related with the thermodynamic forces via a transport coefficient matrix whose diagonal terms are the diffusivities. These coefficients are local: they depend on given values of the collisionality and the electrostatic potential. Since the parallel transport is assumed large enough to homogenize the magnetic surfaces, the coefficients become only function of the radial coordinate.

However, there may be particles which perform wide radial excursions from their original magnetic surfaces in a single collision time, and their contribution to the flux may make it non-diffusive. This happens particularly in TJ-II [1] a medium size flexible heliac with a complex magnetic configuration: in their excursions, the particles visit regions of the plasma with very different electrostatic potentials and collisionalities [2], and therefore the local ansatz does not hold.

The effect of these large radial excursions has been shown for a low density ECRH plasma in TJ-II [3], in the frame of a global study of transport in the absence of the assumptions of customary neoclassical models. In this work, a deeper insight is sought for three types of plasmas: an ECH low-collisionality plasma, an intermediate regime created by means of simultaneous ECH and NBI heating, and a high-collisionality NBI plasma. Extremely collisional plasmas have been also considered in order to explore the limit in which transport should be diffusive.

Calculation

We use ISDEP (Integrator of Differential Equations for Plasmas): like in [3], we calculate the distribution function f of the test ions in the guiding-centre approximation, considering collisions with a Maxwellian background composed of electrons and ions. The fact that we transform the Fokker-Planck equation describing the evolution of f into a set of Langevin equations allows us to avoid any assumption such as small radial excursions, energy conservation and local transport, which is crucial in this study. Furthermore, it allows for its use in the computing platform Zivis [4], and therefore great accuracy is achieved.

We undertake this calculation for three different regimes in TJ-II: ECH, NBI and ECH+NBI. The temperature, density and electrostatic potential profiles, taken similar to those experimentally measured, are shown in Fig. 1. The 3D magnetic configuration is considered by using a grid that fits the magnetic surfaces in real space.

In order to study the nature of ion transport, we calculate the guiding-center trajectories of a large number of ions starting at a fixed value of the radial position ρ (randomly distributed on the toroidal and poloidal coordinates) with a Maxwellian velocity distribution, and we measure the probability density function (pdf) of the radial displacements of ions. The evolution of the pdf is composed of a drift term and a dispersion term, and both are estimated.

Very different time scales are involved in this problem. Three of them can be considered fixed for the present calculations, and were calculated in [3]: the period of the oscillatory motion of a trapped particle in a banana orbit ($\sim 10^{-5}$ s), the time needed to complete a cycle around TJ-II ($\sim 10^{-4}$ s) and the time needed to react to changes in the electric field ($\sim 5 \times 10^{-3}$ s). The collision time ranks from $\sim 7 \times 10^{-5}$ s in the NBI plasma and $\sim 8 \times 10^{-5}$ s in the ECH+NBI plasma to $\sim 2 \times 10^{-4}$ s of the ECH plasma. There is also the typical exit time due to collisions with the groove or the vacuum chamber. Being of the order of ~ 0.01 s, it will highly depend on the conditions of the simulation, namely the radial position of the initial condition (the data shown here correspond to particles launched at $\rho = 0.4$), apart from the electric field and the collisionality. A study of the convergence of the algorithm used (by Kloeden and Pearson, see [3] for more details) has shown that a temporal step $dt = 2 \times 10^{-8}$ s is accurate enough for our calculation.

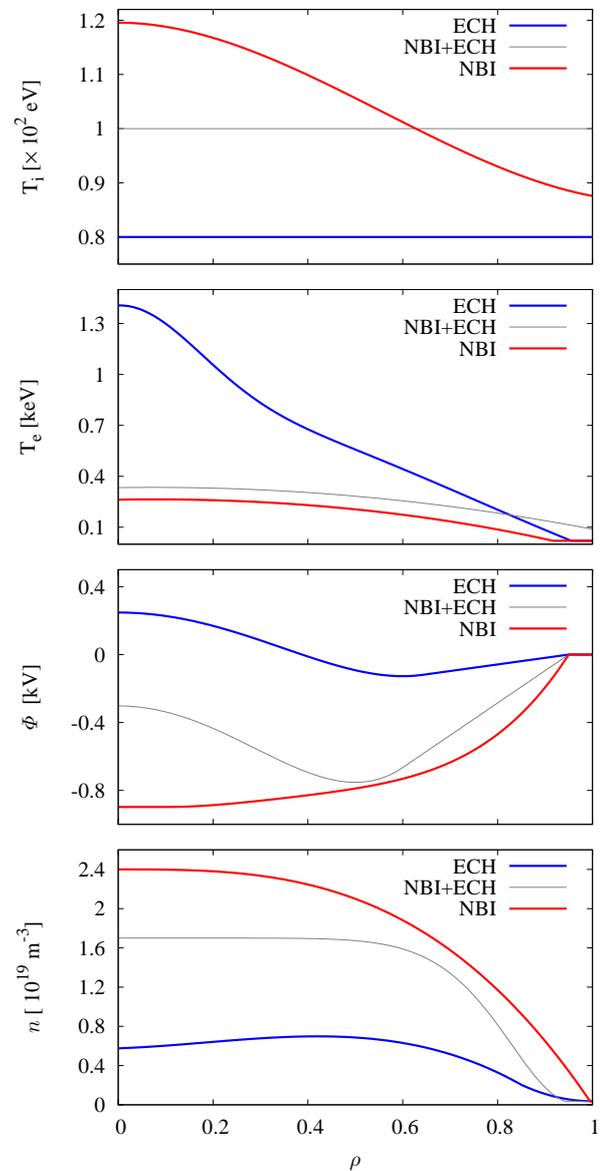


Figure 1: Plasma radial profiles

Results

In Fig. 2 we show the pdf for the ECH plasma for several selected times, with the x-scale is shifted by $\langle \rho \rangle$. One can see that at a time quite lower than the collision time, the pdf is nearly Gaussian. This is a consequence of the initial distribution of velocities, which is Maxwellian, since the selected time is smaller than all the relevant characteristic times discussed.

For a time of the order of the collision time, a long tail develops. Since

ρ takes values between 0 and 1, Fig. 2 shows how, in a single collision time, there are particles that arrive to the edge of the plasma. The asymmetry in the pdf should be attributed to the asymmetry in the electrostatic potential well, see Fig. 1.

In order to check this, the same calculation has been accomplished with zero electric field, and the results are plotted in Fig. 3 for time $t = 5 \times 10^{-4}$ s. One can see that the electric field acts reducing the orbit width, as expected. It is also clear that, although the characteristic time scale for the electric field acting on $\langle \rho \rangle$ is $\sim 5 \times 10^{-3}$ s [3], its effects on the pdf appear at shorter times, comparable with the collision time. As a consequence of this, the asymmetry in the pdf stays for several collision times: in Fig 2, for $t = 5 \times 10^{-4}$ s, the pdf is clearly non-Gaussian.

The NBI plasma, on the contrary, shows a nearly Gaussian pdf at a time of the order of the collision time, see Fig. 4. On the one hand, this effect can be understood once more in terms of competence of effects: for this high-collisionality plasma, the collision time is lower enough than

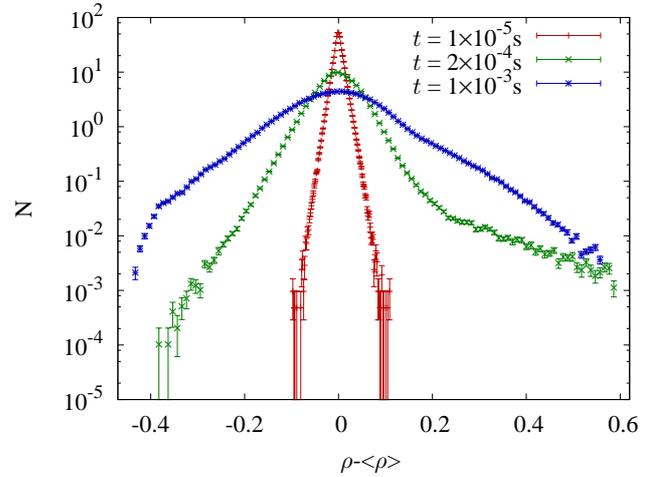


Figure 2: pdf for the ECH plasma

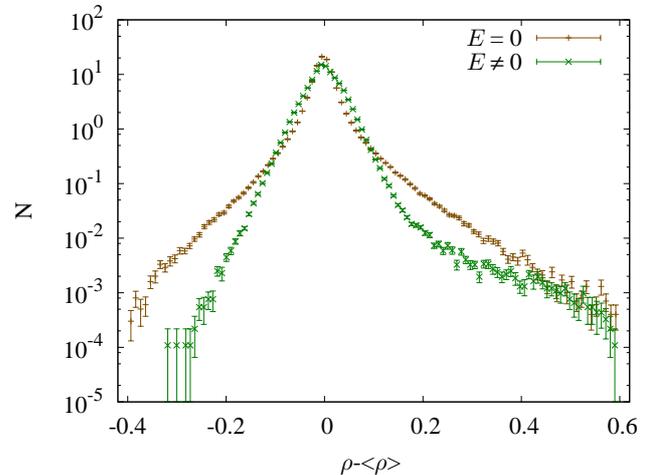


Figure 3: pdf with and without electric field

the characteristic reaction time to changes of the electrostatic field. Therefore, the former effect is the prevalent mechanism in the evolution of the pdf. On the other hand, the electric field is low in the region around $\rho = 0.4$, and negative in all the ρ range, so that it does not change the shape of the pdf.

An intermediate situation is seen in Fig. 5 for the ECH+NBI plasma. Here, the collisionality is higher than in the ECH case, and the potential well is more symmetric. The combined action of both effects avoids the formation of a tail such as that of the ECH case. Nevertheless, the pdf is asymmetric, and the tails extend almost to the edge of the plasma in a few collision times.

Conclusions

The probability density function (pdf) of the radial displacements of ions is calculated for several TJ-II plasmas of different collisionalities and electric fields. For all of them, it is shown how there is a number of ions that make wide excursions in the radial coordinate in a single collision time, therefore not fulfilling the local ansatz. The measured pdf is non-Gaussian, with a clear asymmetry caused by the electric field, which clearly shows that the transport is not diffusive. Further analysis are being carried out in order to extract systematic behaviour of the pdf and to study the impact that these findings have in the description of the heat and particle fluxes.

References

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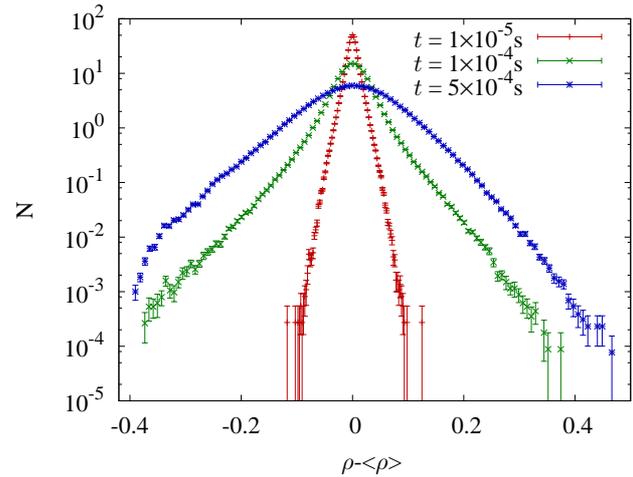


Figure 4: pdf for the NBI plasma

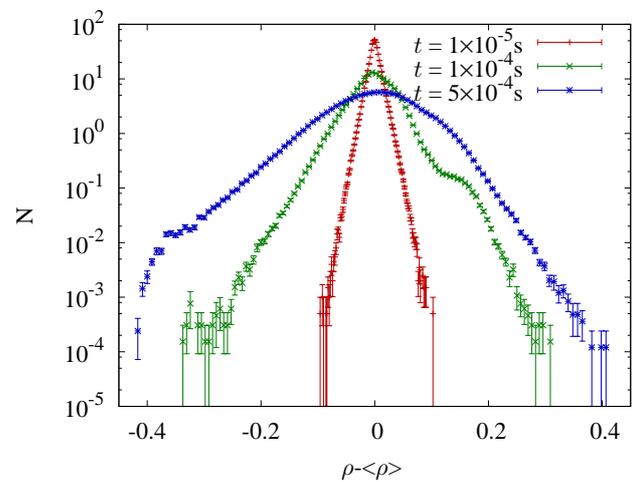


Figure 5: pdf for the ECH+NBI plasma