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Comparison between 2D and 3D Transport in ITER using a Citizen Supercomputer

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Introduction

Most of the literature concerning ITER transport considers axisymmetry, but it is well known that ITER will have a small magnetic ripple that will depend on the nature of the Blanket Modules. In this work, we perform several simulations of the collisional ion transport in ITER, comparing the results obtained in 2D equilibrium with the ones of considering different magnetic ripples. In order to estimate the collisional ion transport properties, we use an orbit code called ISDEP (Integrator of Stochastic Differential Equations in Plasmas) that solves neoclassical transport using the equivalence between the linear Fokker-Planck and Langevin equations. ISDEP solves the guiding center equations of the ions and considers ion-ion and ion-electron collisions. Although ISDEP was originally designed for Stellarators, it works in 3D tokamaks with minor modifications. ISDEP solves the transport integrating the trajectories of test particles in a 5D phase space (2D in velocity space and 3D in real space). The statistical analysis of many test particles allow the measurements of different plasma parameters.

The main advantages of this code are the absence of approximations on the orbit size, the energy conservation or the diffusive nature of transport. ISDEP is suited to run in distributed computing architectures and a detailed description of the code and the techniques used to analyze the output data can be found in [1]. The computing power for this work is provided by the EGEE Fusion Grid, the EULER cluster at CIEMAT and, most of it ($\sim 2/3$), by Ibercivis [2], a recently developed volunteer computing platform based on BOINC (Berkeley Open Infrastructure for Network Computing).

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The ITER model

The 2D ITER equilibrium was calculated using the HELENA code [3] as a part of the code CRONOS [4]. The ripple is included as a small perturbation in the 2D equilibrium, following [5]. Let $\vec{B}^o(R,Z)$ be the 2D magnetic configuration in cylindrical coordinates (R,Z,ϕ). Then the new toroidal component is given by ($N_c = 18$ is the number of toroidal coils):

$$B_\phi(R,Z,\phi) = B^o_\phi(R,Z)\left(1-\left(\frac{R}{R_c}\right)^{N_c}\cos N_c\phi\right). \tag{1}$$

The parameter R_c gives the strength of the ripple. We fix it imposing the strength of the ripple in the border of the plasma on the low field side. Its toroidal maximun in the $\hat{R}$ direction is plotted in Fig. 1 (A). Also we plot the main radial profiles of the plasma (B). The electric potential is not calculated with the HELENA code, so we estimate it using the simplest MHD approximation and the perfect gas equation: $V[\mathrm{V}] = T[\mathrm{eV}]$ [6], since the density profile is almost flat. We consider only particles belonging to the plasma and when a particle reaches the last closed magnetic surface (effective radius $\rho = 1$) we consider it escaped.

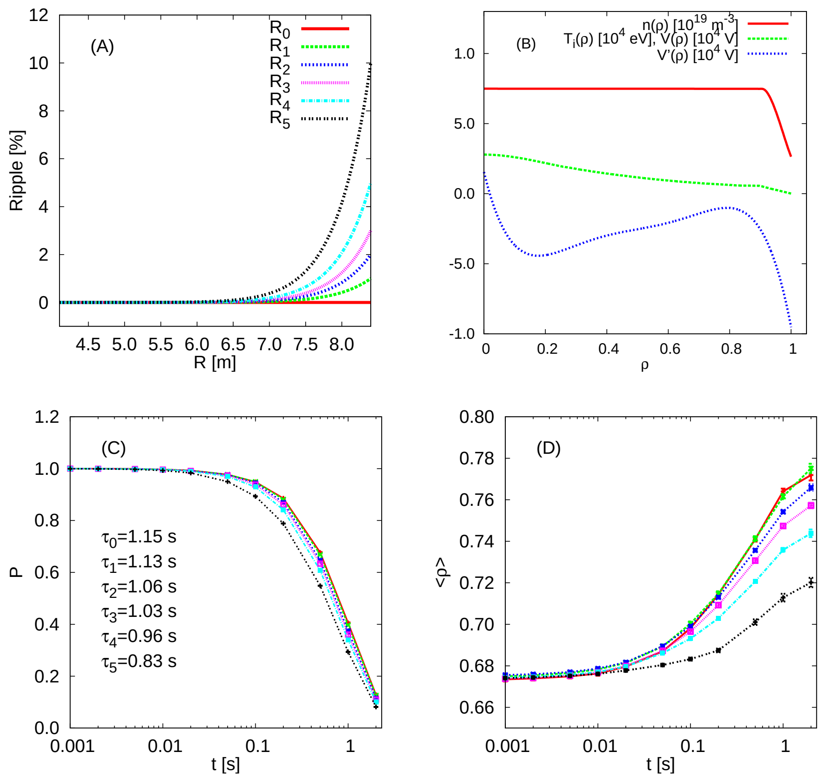

Figure 1: Strength of the ripple (A); radial profiles of the plasma (B); persistence of the test particles (C) and simulated evolution of the average effective radius (D).

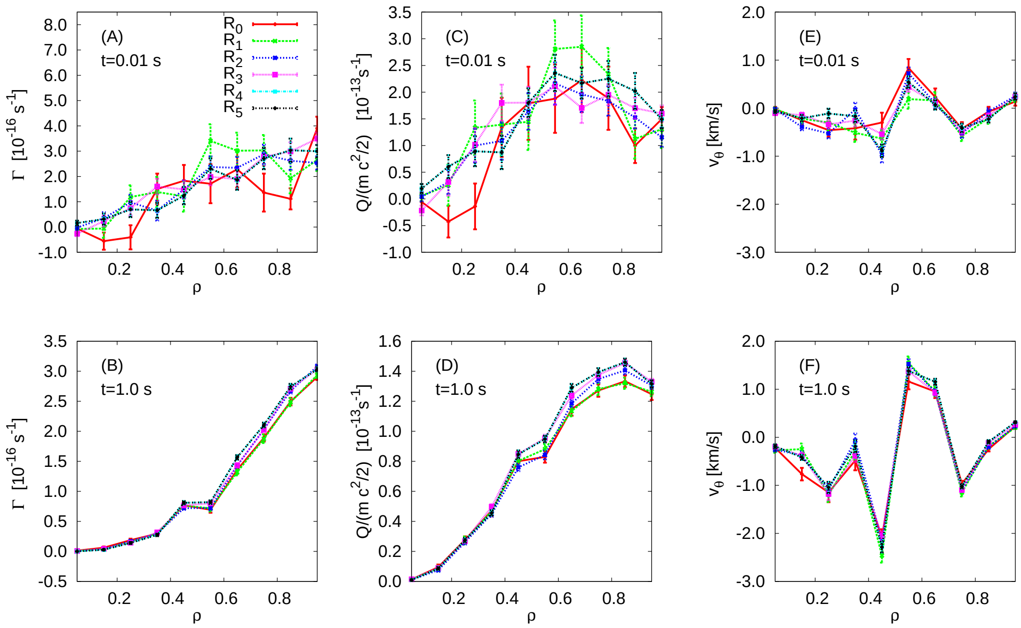

Figure 2: Radial particle fluxes at $t = 0.01$ s (A) and $t = 1.0$ s (B); radial energy fluxes at 0.01 s (C) and 1.0 s (D); poloidal velocity at 0.01 s (E) and 1.0 s (F).

Numerical Results

Most of the CPU time was taken from the Ibercivis computing platform. The ISDEP code had to be modified in order to take advantage of the computing power of Ibercivis. As an example, we had to limit the amount of RAM memory to $\sim$ 400 MB and to split all the simulations in small jobs less than 30 minutes long.

We use a 2$^{\text{nd}}$ Runge-Kutta method for stochastic differential equations [7] to integrate the trajectories. A single trajectory takes an average of 17 minutes in a single CPU, and we need around 125.000 trajectories for each simulation. On the whole we needed $\sim$ 30 CPU-years.

The main effect of the ripple is the deterioration of the particle confinement. In Fig. 1 (C) we can see that the persistence of the ions (fraction of surviving particles) decreases as we increase the ripple. We estimate the confinement time by fitting $P(t)$ to $e^{-t/\tau}$. Since the ripple is appreciable for $\rho > 0.5$, the external particles are more easily lost, causing the ion average effective radius $\langle\rho\rangle(t)$ to decrease (see Fig. 1, (D)). We can also calculate the outward particle ($\Gamma(\rho)$) and energy ($Q(\rho)$) flux profiles (Figs. 2 (A)-(D)). We measure in two times: a short one before the ripple influences the plasma and around one confinement time. Both fluxes become appreciable larger with the ripple, causing the particle losses. On the other hand, the poloidal rotation is not influenced in this model, Fig. 2 (E) and (G).

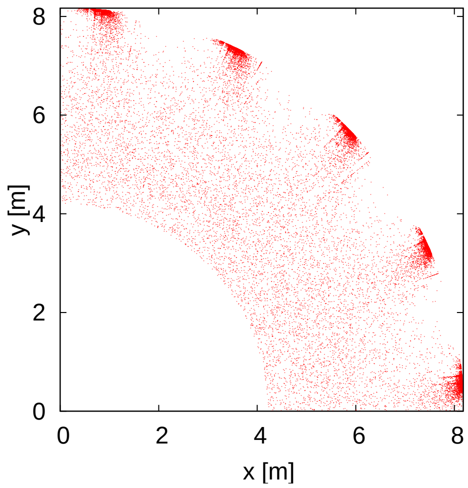

Figure 3: Upper view of the escape points for the simulation R_2.

Conclusions

The influence of the magnetic ripple on the ITER collisional transport has been studied using a linear kinetic code. We were able to estimate the rise of the radial fluxes and the drop of the confinement. At times of the order of the confinement time, the test particles no longer represent the plasma, but they still give a general idea of the evolution of the whole system. The conclusion is that the 3D geometry affects the transport in ITER. Althought the modification is not very large, for long pulses it may have a strong influence in the behaviour of the plasma, especially close to the edge, where ion loses can cause an increase of negative electric field. The rotation velocity is hardly affected for this values of the electric field and the ripple.

Many effects and plasma properties can be studied with this code. For example, the study of particle losses in space is useful to design the divertors and to calculate the load in the Blanket Modules (Fig 3). This work shows the capability and reliability of volunteer computing applied to fusion science.

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