

Full f gyrokinetic modelling of neoclassical radial electric field

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Introduction: Sheared radial electric field profiles have been attributed to the reduction of turbulent transport in tokamak plasmas through shearing of convective cells. While such electric fields may arise through wave-wave interactions in drift wave turbulence, it is widely known that neoclassical processes produce significant dynamic (e.g., geodesic acoustic modes) and equilibrium radial and poloidal electric field structures[1]. The interplay of drift wave turbulence and neoclassical physics is therefore of considerable interest for modelling and interpreting current advanced experimental regimes where various transport barrier structures have been observed. Such interplay has been investigated with δf codes, in Refs.[2] to name just a few. In this work, we present full f gyrokinetic modelling of neo-classical physics in the presence of turbulence.

Transport simulations of FT-2 tokamak: The FT-2 tokamak was taken as a test case for simulations of turbulent and neo-classical simulation (for extended discussion of full f modelling in FT-2 tokamak, see Refs. [4]). The simulation was performed by initializing the distribution function f for specified density ($n_{e,i}$) and temperature ($T_{e,i}$) profiles as shown in Fig. 2. The current profile was taken as parabolic $j(r) = j_0(1 + (r/a)^2)$ with total plasma current of 55 kA in co-centric circular geometry. With these profiles, the run was allowed to develop self-consistently (using the electrostatic model in Refs. [3]) with turbulence, trapped particle effects and realistic collisions. The density perturbations (with profiles in Fig. 2) due to turbulence are shown in Fig. 1. The neo-classical radial electric field in Fig. 3 was analytically estimated from the Hazeltine-Hinton [5] model using measured simulation parameters (HH) for comparison with the flux-surface averaged value from the 3D electric field of the gyro-kinetic (GK) model, also taking into account the changing of collisional regimes in the simulation region. The particle and heat fluxes were evaluated directly from the simulation particles, and the transport coefficients (shown in Fig. 4) were evaluated using the fluid moments of the distribution function. In this case we have relatively wide banana orbits (2-4 cm, minor radius $a = 8$ cm).

Discussion of results: Early in the simulation a linear transport burst (maximum near $13 \mu\text{s}$) is observed, after which non-linear saturation takes place. Although this burst is mainly an artefact of the turbulence simulation (as no proper initializations for turbulence exist), we see large transient fluctuations associated with it (see Fig. 1). During this phase of the simulation,

the system is everywhere far from neo-classical equilibrium (as seen from Fig. 3). However, relatively quickly we observe convergence to the analytically estimated E_r in the regions where fluctuations in density are weak. In the outer region the strong level of fluctuations are assumed to be behind the difference seen in the outer regions of the simulation (motivated by Ref. [6]), where turbulent transport is appears to be modulated by a damping geodesic acoustic (GAM) oscillation.

A noise contribution to the radial electric field of 1.5 kV/m has been estimated. From Fig. 3 it can be seen, that this contribution is not sufficient for explaining the difference between the analytical and simulated values, however this contribution does correspond with the slight difference between the mean value of the GK value and HH value.

Conclusions: Gyro-kinetic simulations of trapped particle effects and collisions were performed. In this investigation, reasonable agreement with the analytical Hazeltine-Hinton model for radial electric field has been obtained in regions where density deviations are weak relative to the flux-surface averaged density. The calculated radial electric field from particle noise of 1.5 kV/m was not enough to contribute the observed difference between the analytical estimate and the gyro-kinetic simulation in near the outer radial boundary.

Acknowledgements: The computations presented in this document have been made with CSC's computing environment. CSC is the Finnish IT center for science and is owned by the Ministry of Education. This work, supported by the European Communities under the contract of Association between EURATOM/Tekes, was carried out within the framework of the European Fusion Development Agreement. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

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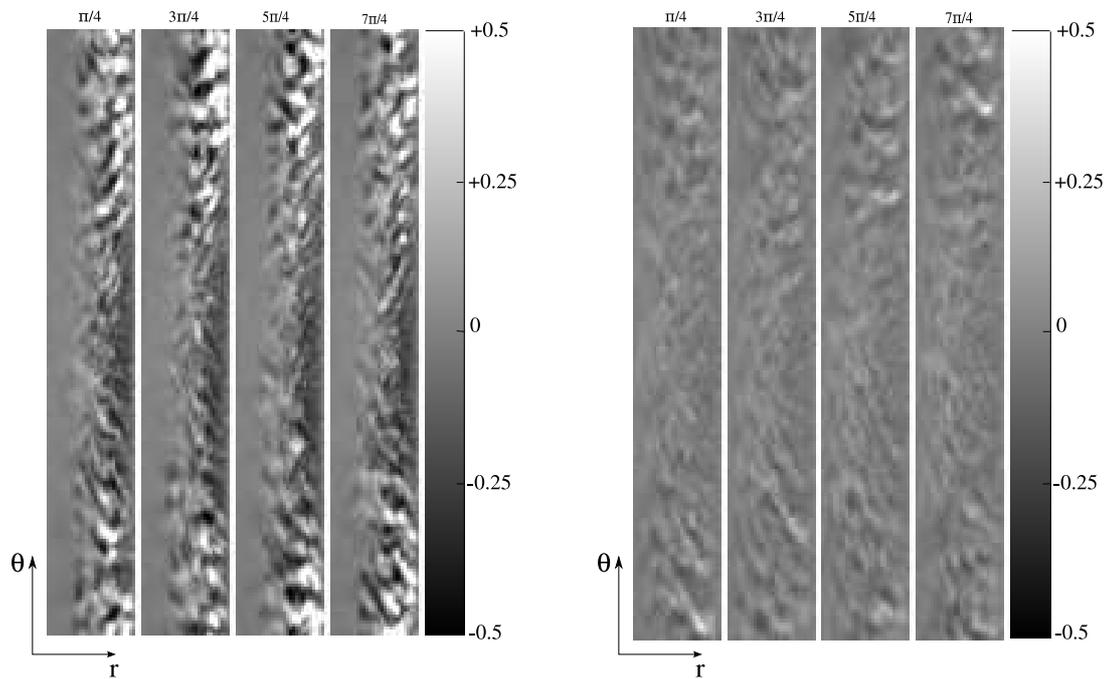


Figure 1: Density variations $(n_i - \langle n_i \rangle) / \langle n_i \rangle$ for four toroidal slices (toroidal angle ζ in radians indicated at the top) at times $13 \mu\text{s}$ (left) and $125 \mu\text{s}$ (right) for the simulated region. The left picture was chosen from the time of maximal χ_i while the right picture is taken well after non-linear saturation (see Fig. 4).

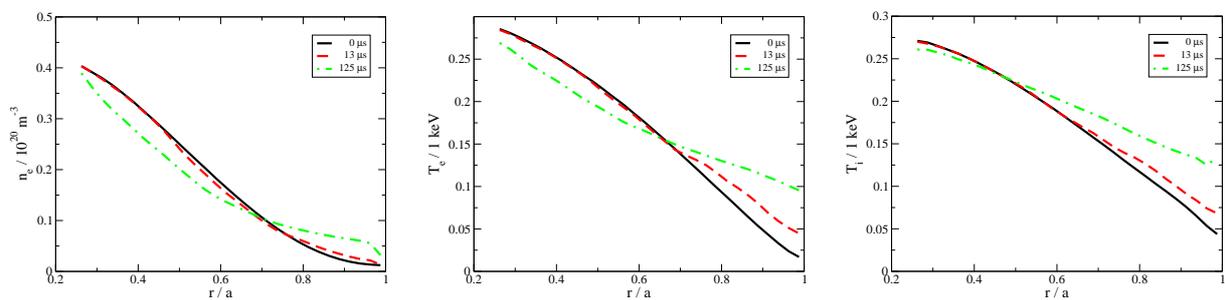


Figure 2: Flux surface averaged profiles: electron density ($n_i = n_e$), electron and ion temperature. The initialized profiles and the evolved profiles at times $13 \mu\text{s}$ and $125 \mu\text{s}$ (right) are shown.

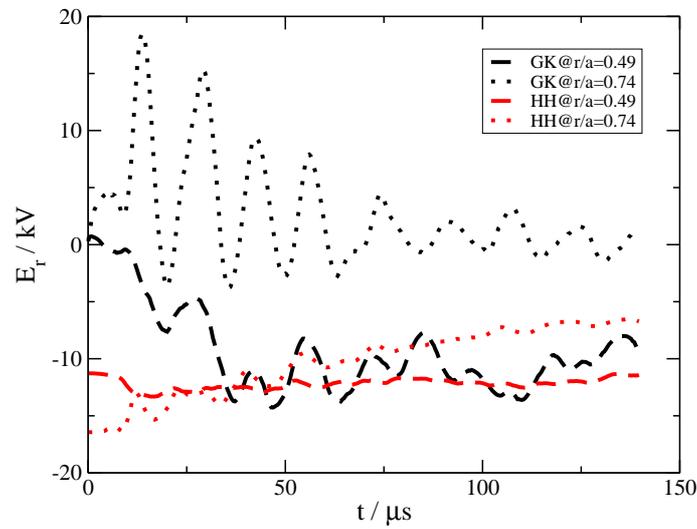


Figure 3: Comparison between Hazeltine-Hinton [5] E_r and that observed in ELMFIRE (taken as a flux surface average) at different radii of the simulated region.

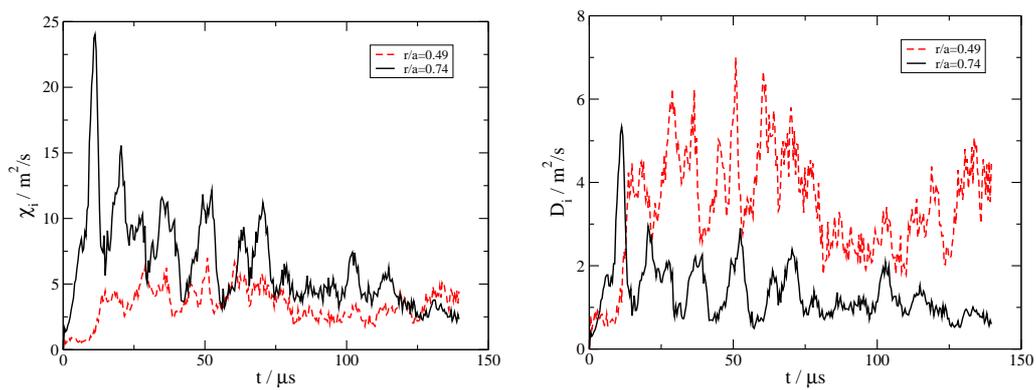


Figure 4: Evolution of ion heat transport coefficient χ_i and particle diffusion coefficient D_i as a function of time. The same radial positions as in Fig. 3 are used.