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Gyrokinetic full-f particle simulation of edge heat transport

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Abstract

Transport of particles and energy is mainly determined by the strength of plasma turbulence but can be significantly reduced in so-called transport barriers. In L–H transition of the edge transport, a transport barrier is created by external heating which is presently considered as an important part of reactor plasma operation. In order to self-consistently simulate a transport barrier generation both neoclassical and turbulence physics as well as proper boundary conditions and heating operator are required. Recently, a global 5D full f gyrokinetic particle simulation code ELMFIRE has been used to simulate FT–2 tokamak which is already very CPU-intensive. In this paper, extending such a simulation to middle-sized tokamaks is discussed.

Numerical techniques

In the present work, a global 5D full f GK particle simulation code ELMFIRE is used [1]. Such implicit GK particle solution method for the full f plasma quasi-neutrality provides a rigorous treatment of such global and dynamic transport phenomena like transport barrier generation, intermittence, and wide orbit effects. As full-f technique is used instead of delta-f technique, simulation of transport phenomena involving wide orbit effects, steep gradients, and rapid dynamic changes in profiles becomes possible to model, but at the same time requirement of CPU resources increases in order to reduce noise to acceptable level. The particle orbits are solved in time in the toroidal configuration in a 5-dimensional phase space, and a 3D electrostatic potential solver is included to capture turbulence that arises from ExB convective cells in the presence of pressure gradient and toroidicity in the plasma, resulting in enhanced transport. This code has recently shown to reproduce the neoclassical electric field [2] and has been benchmarked to experimental results on plasma rotation and turbulence spectra obtained from the FT–2 tokamak Doppler reflectometry diagnostic [3].

For the heating of plasma, a model where the test particles near the inner radius are left to collide with fixed background is tested. These collisions are in addition to the momentum and energy conserving binary collisions which are present in whole simulation region. In the heating region, the background for fixed background collisions is in higher temperature than the test particle ensemble thus feeding energy into the plasma.

Memory and CPU time characteristics

Extending a self-consistent full-f gyrokinetic simulation from small to medium size tokamaks is a computational challenge. ELMFIRE is a powerful code with excellent parallelization in most tasks and CPU time needed is directly related to the number of markers being treated in a single processor. However, slipping the memory usage among processors is much more cumbersome and much effort has been put to the optimization of matrix memory management. After latest code optimizations ELMFIRE could be run with 500 processors for a 100x600x32 grid using 500 particles per cell, acceptable for turbulence saturation studies in reasonably sized annular volumes inside the ASDEX Upgrade toroidal plasma. In typical test runs, 66 million ions and electrons (920 per cell) are followed in a 30x600x4 grid with 0.1 μs time steps run up to 200 μs in 12 hours with 256 processors. This takes 360 MB memory in each processor. Such simulations can be used for tentative analysis although longer simulations (1 ms or more) are important in order to see orbit effect with more realistic parameters.

Results of test runs

In this section, for tentative analysis, parameters similar as in ASDEX Upgrade are used. In Fig. 1, as an example of effect of heating model on results, it is shown how heat pulses initiated from strong heating at inner edge ($r = 42$ cm) reach the outer radii. However, in the simulations it is difficult to separate time behaviour of transport coefficients caused by the heating model from the linear growth which will occur even without heating.

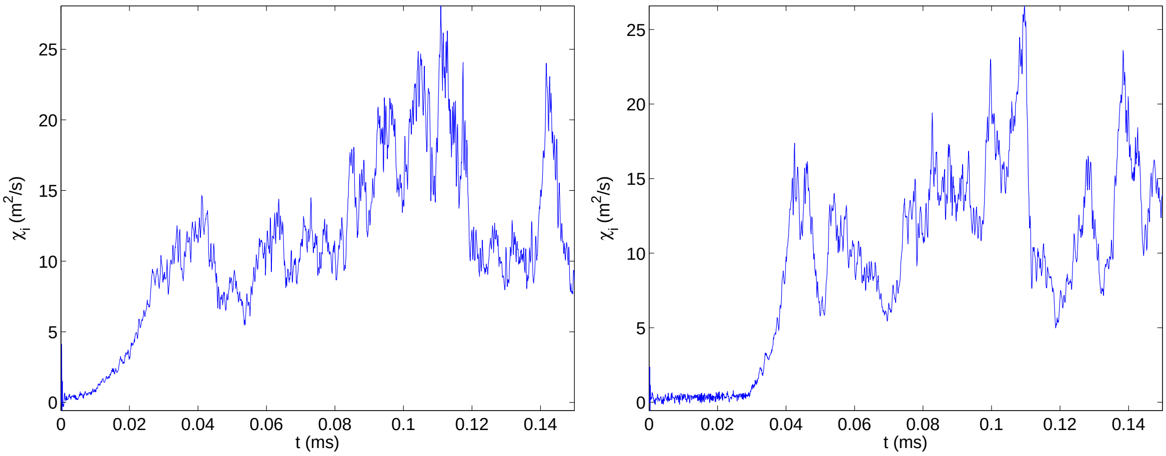

Figure 1. Heat transport starts to grow when heat pulse reaches outer radii. This happens earlier at $r = 44$ cm (left) and somewhat later an $r = 46$ cm (right).

In Fig. 2, a modest poloidal rotation is observed from the correlation analysis of the density data indicating L-mode condition. This rotation is mostly explained by $E \times B$ velocity as shown in Fig. 3. Near the outer edge where both physics effects and numerical effects due to boundary conditions affect the results discrepancy exists. The shear in poloidal rotation is still below the threshold for strong turbulence suppression unlike observed earlier in Ref.[4] where only neo-classical effects were taken into account. However, there the simulation time was long enough to take into account the ion orbit loss mechanism. Thus, longer simulations are needed.

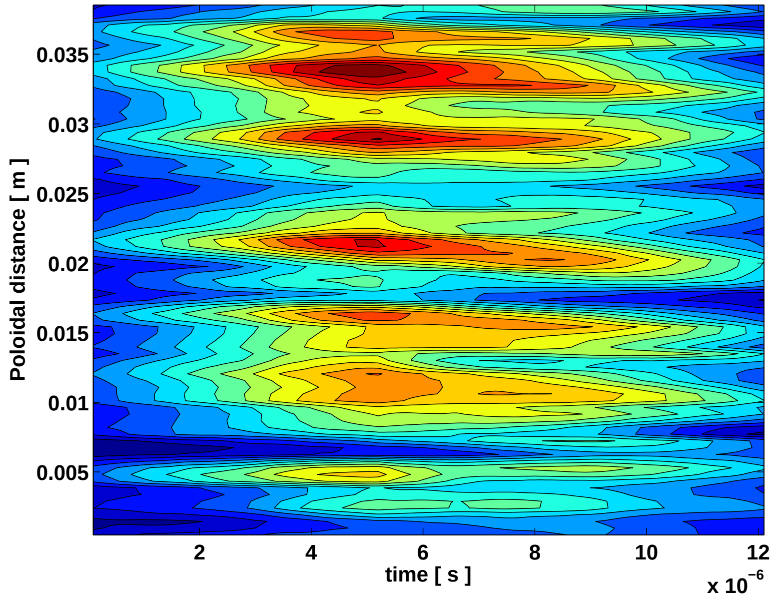

Figure 2. The correlation analysis of the density data indicates modest poloidal rotation.

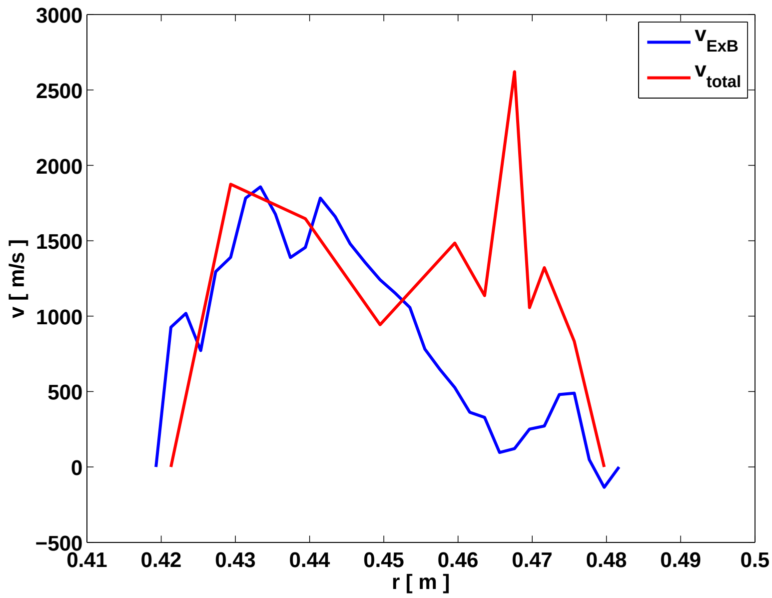

Figure 3. Rotation in Fig. 2 is mostly explained by $E \times B$ velocity.

Conclusions

Poloidal rotation and heat transport due to plasma turbulence and neoclassical physics have been simulated with a global 5D full f gyrokinetic particle simulation code ELMFIRE. Our study shows that simulation of both neoclassical and turbulence physics in order to study transport barriers in medium sized tokamaks with Elmfire is possible, although it is a computational challenge. However, as real transport time-scale simulations are not yet possible, results maybe sensitive to given initial profiles and more careful checking of the effect of numerical parameters, noise and initialization is needed. Parametric dependence of noise in density and potential fluctuations in gyrokinetic full-f simulations was earlier studied in Ref. [5]. There, it was pointed out that noise not only makes it difficult to isolate physical fluctuations of plasma density and electrostatic potential from those ensuing from the finite number of simulation particles but also creates unphysical particle and heat flux and demolishes the neoclassical equilibrium. Here, the contribution of this unphysical mechanism was prevented by a sufficient number of simulation particles.

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References

[1] J.A. Heikkinen, S.J. Janhunen, T.P. Kiviniemi and F. Ogando, Journal of Computational Physics **227** 5582 (2008).

[2] S.J. Janhunen, F. Ogando, J.A. Heikkinen, T.P. Kiviniemi, and S. Leerink, Nuclear Fusion **47** 875 (2007).

[3] S. Leerink, J.A. Heikkinen, S.J. Janhunen, T.P. Kiviniemi, M. Nora, and F. Ogando, submitted to Plasma Physics Reports; Leerink et al, this conference.

[4] J.A. Heikkinen, T.P. Kiviniemi, A.G. Peeters, Phys. Rev. Lett. **84** 487 (2000).

[5] T.P. Kiviniemi, J.A. Heikkinen, S.J. Janhunen, T. Korpilo, S. Leerink, M. Nora, F. Ogando, 34th EPS Conference on Plasma Physics, Europhysics Conference Abstracts Vol. 31I (2007) P-4.054.