Gyrokinetic simulations of turbulent transport in JET-like plasmas

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Introduction

In this work turbulent transport in JET-like plasma discharges is analyzed, with main emphasis on impurity transport driven by ITG/TEM modes. Gyrokinetic (GK) simulations are performed using the GENE code [1, 2], in both quasilinear (QL) and nonlinear (NL) mode,[1] and the results are compared with a computationally efficient fluid model [3, 4]. Particle transport is quantified by locally finding density gradients (R/L_n) that yield zero particle flux, signifying a balance between convective and diffusive transport.

The impact of the magnetic equilibrium (circular, $s-\alpha$ and realistic magnetic geometry) on the various models is discussed, as well as the effects of collisionality (in both fluid and GK) and the inclusion of a (2%) Carbon background (in GK), as per JET CFC wall conditions. The effect of sheared toroidal rotation was also investigated and found to be important, although not for the particular JET discharge studied in this work.

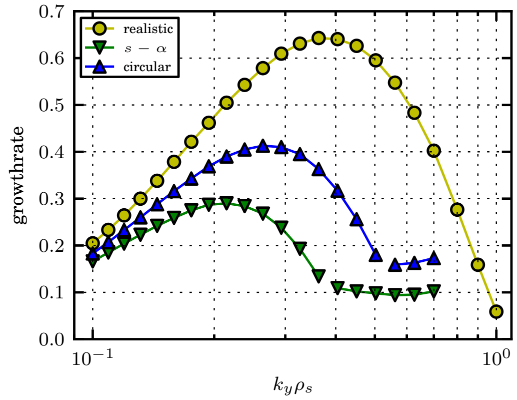
Impact of the equilibrium model on growthrate spectra

Simulations of impurity transport using a realistic JET-like magnetic equilibrium were compared to circular and $s-\alpha$ geometry for an ITG-dominated discharge. JET-like parameters were chosen in accordance with the *L-mode* discharge #67730 (see [4] for details). The main values are: $s = 0.8$, $q = 2.2$, $R/L_n = 2.7$, $R/L_{Ti,e} = 5.6$ and $\kappa = 1.37$, all taken at mid radius ($r/a = 0.5$).

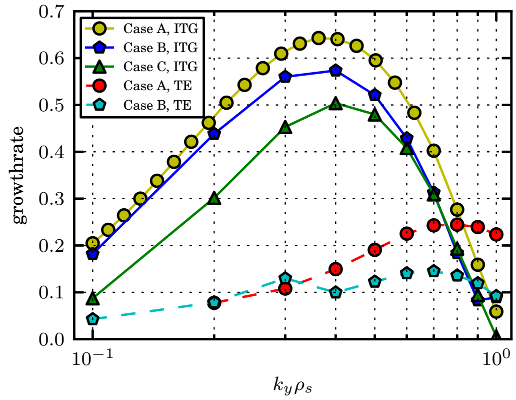
In Fig. 1a we see that the growthrate spectrum is destabilised when using the realistic magnetic geometry, shifting to higher values of $k_\theta \rho_s$. This is in accordance with previous results obtained using both a fluid model [5] and gyrokinetics [6]. We note that there is an inconsistency in the $s-\alpha$ model of order $\varepsilon = a/R$ [6]. In the considered discharge $\alpha \ll 1$ and thus the difference between using circular and $s-\alpha$ geometry will be due to the ε-order discrepancy. Therefore, when comparing circular and realistic geometry the differences will be due to shaping effects, mainly elongation.

With this caveat in mind, we observe that the growthrate spectrum when using the circular equilibrium is closer to the realistic geometry than the $s-\alpha$ one (Fig. 1a), also in agreement with

[1] See `http://www.ipp.mpg.de/~fsj/gene/` for details on the GENE code



(a) eigenvalue spectra for different geometry models



(b) eigenvalue spectra in realistic geometry with added effects

Figure 1: Growthrate spectra for circular, $s-\alpha$ and experimental magnetic equilibrium for an ITG-dominated case with JET-like parameters (left), and for the experimental equilibrium with added degrees of realism (right). For the latter, *case A* represents full geometry case with no added effects, in *case B* a background of 2%C was added, and in *case C* collisions are also added.

previous gyrokinetic results [6]. The addition of both collisions and a 2% carbon background have a stabilising effect (for the ITG mode and the sub-dominant TEM). This effect is stronger with the addition of collisions, in particular for lower $k_\theta \rho_s$ where most of the transport occurs, as seen in Fig. 1b.

Particle transport

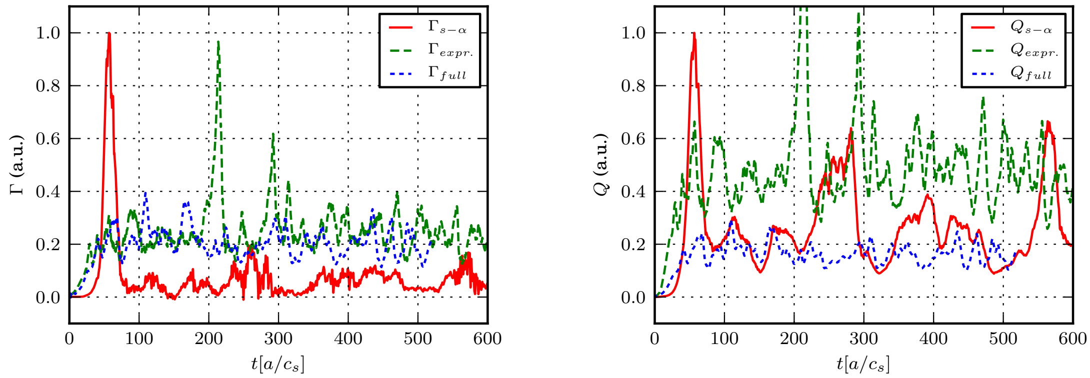
The stabilising effect of adding collisions and 2% C are reflected in the timeseries for the particle and heat fluxes obtained in NL gyrokinetic simulations (Fig. 2). In the realistic magnetic geometry (case A) transport levels are increased in comparison to the $s-\alpha$ equilibrium. The introduction of collisionality and 2%C (case C) causes a reduction of these levels. Both trends are consistent with the linear eigenvalue spectra in Fig. 1.

The peaking factor (PF) of an impurity species, j, is here defined [4, 7, 8] as the particle gradient that gives zero particle flux (Γ_j), assuming a trace impurity and a linear decomposition of the flux in a convective and a diffusive part:

$$\Gamma_j = -D_j \nabla n_j + n_j V_j, \tag{1}$$

where n_j is the impurity density. In the trace approximation (used in this work) D_j and V_j are independent of ∇n_j.

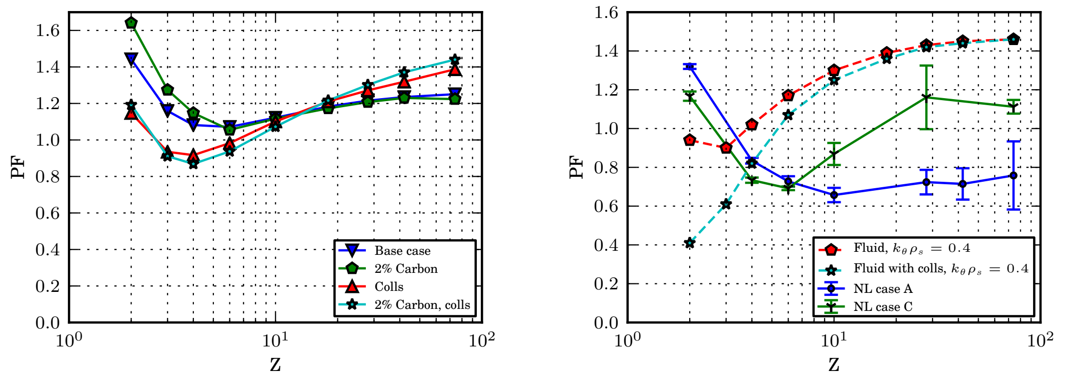
In order to assess the impact of the equilibrium model on the PF_Z values (for an impurity of charge Z), QL gyrokinetic simulations were compared with a fluid model [3, 4] for different



(a) timeseries of particle fluxes (Γ)

(b) timeseries of heat fluxes (Q)

Figure 2: Timeseries of main ion particle and heat fluxes for NL GENE simulations with $s-\alpha$, *case A* and *case C* (Fig. 1b). Normalisation is to the maximum of corresponding $s-\alpha$ case. Realistic geometry increases transport levels (compared to $s-\alpha$); extra added effects decrease them. Both trends consistent with the linear eigenvalue spectra.



(a) effects of added realism (QL GK) on *PF*

(b) comparison of NL GK base case and full case with fluid results

Figure 3: Scaling of impurity peaking factor (*PF*) with impurity charge (*Z*). Left: QL GK, effects of added realism. Right: NL GK simulations using realistic equilibrium (cases *A* and *C* in Fig. 1b), compared with fluid results (including elongation effects and also collisions). Error-bars indicate standard error of $\pm\sigma$.

values of $k_\theta \rho_s$. The $s-\alpha$ equilibrium was used in the fluid model, with shaping effects due to elongation also included. We found that in both fluid and GK the *PF* is reduced when using a more realistic equilibrium. In Fig. 3 we can also see the individual impact of the added effects on PF_Z. In particular, we have:

- in GK simulations, both QL (Fig. 3a) and NL (Fig. 3b), there is a lowering of *PF* for low

Z and an increase at high Z, when adding both collisions and 2% C;

- in the fluid model (Fig. 3b), there is a lowering of PF when adding collisions, for low Z but no noticeable effect at higher Z [9].

The effects of sheared toroidal rotation on the impurity PF were also studied. In realistic geometry this lead to a reversal of the impurity pinch at $\gamma_{E\times B} \simeq 0.23$ for both low and high Z. However, for this JET discharge the shearing rate was too small and the effect not included in the NL GK simulations. For more details on the effect of sheared rotation and predictive simulations of JET discharges see **P4.137** (D. Tegnered *et al.*).

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References

[1] Jenko F, Dorland W, Kotschenreuther M and Rogers B N 2000 *Phys. Plasmas* **7** 1904

[2] Merz F 2008 *Gyrokinetic Simulation of Multimode Plasma Turbulence* Ph.D. thesis (monography) Westfälischen Wilhelms-Universität Münster

[3] Weiland J 2000 *Collective Modes in Inhomogeneous Plasmas* (IoP Publishing)

[4] Nordman H, Skyman A, Strand P, Giroud C, Jenko F, Merz F, Naulin V, Tala T and the JET–EFDA contributors 2011 *Plasma Phys. Contr. F.* **53** 105005

[5] Anderson J, Nordman H and Weiland J 2000 *Plasma Phys. Contr. F.* **42** 545

[6] Lapillonne X, Brunner S, Dannert T, Jolliet S, Marioni A, Villard L, Görler T, Jenko F and Merz F 2009 *Phys. Plasmas* **16** 032308

[7] Skyman A, Nordman H and Strand P 2012 *Phys. Plasmas* **19** 032313

[8] Skyman A, Nordman H and Strand P 2012 *Nucl. Fusion* **52** 114015

[9] Moradi S, Tokar M Z, Singh R and Weyssow B 2009 *Nucl. Fusion* **49** 085007

[2] `http://www.pdc.kth.se/resources/computers/lindgren/`
[3] `http://www.iferc.org/csc/csc.html`