Gyrokinetic simulations of turbulent transport in JET-like plasmas

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Introduction

The topic of this work is turbulent transport of main ions and impurities driven by ion (**ITG**) and electron modes (**TEM**) in tokamaks. The code GENE [1–3] was used for quasi-linear (QL) and nonlinear (NL) gyrokinetic (GK) simulations.

Results are compared with a computationally efficient fluid model [4]. We look at the effect of different equilibrium models: concentric circular geometry, $s-\alpha$ and magnetic geometry obtained from the **JET L-mode** discharge **#67730**.

For the NL GK simulations two sets of JET-like parameters are considered. Both use the realistic equilibrium, then the second set (**case C below**) has in addition:

- introduction of collisions (Landau-Boltzmann type)
- a 2% Carbon background
- inclusion of finite β effects.

Particle transport is quantified by the density gradient of zero particle flux, related to the **balance of convection and diffusion**. This measure of the impurity peaking is calculated for ITG/TEM turbulence and the effects of the equilibrium model are shown.

Particle transport

Particle transport for species j is derived from:

$$\Gamma_{nj} = \langle \delta n_j \boldsymbol{v}_{\boldsymbol{E}\times\boldsymbol{B}} \rangle, \qquad (1)$$

where $\langle\cdot\rangle$ means a spatial averaging [5, 6].

This is divided into a **diffusive** and a **convective** part:

$$\Gamma_j = -D_j \nabla n_j + n_j V_j \qquad (2)$$

where Γ_j is the flux and n_j the density of the species [5].

For constant ∇n_j and ∇T_j, the flux can be written as:

$$\frac{R\Gamma_j}{n_j} = D_j \frac{R}{L_{n_j}} + RV_j, \qquad (3)$$

with R the major radius and $1/L_{n_j} \equiv -\nabla n_j / n_j$.

In the core region convection ("pinch") and diffusion balance to give zero flux. The **zero flux peaking factor** quantifies this:

$$0 = D_j \frac{R}{L_{n_j}} + RV_j \Leftrightarrow -\frac{RV_j}{D_j}\bigg|_{\Gamma_j=0} = \frac{R}{L_{n_j}}\bigg|_{\Gamma_j=0} \equiv PF_j \qquad (4)$$

Thus PF_j is interpreted as the **gradient of zero flux**.

For **trace impurities** D_Z and V_Z are independent of ∇n_Z. *Eq.* (3) is then linear in R/L_{nZ}, and PF_Z can be found by fitting a straight line to flux data. This is illustrated in *Fig.* 1.

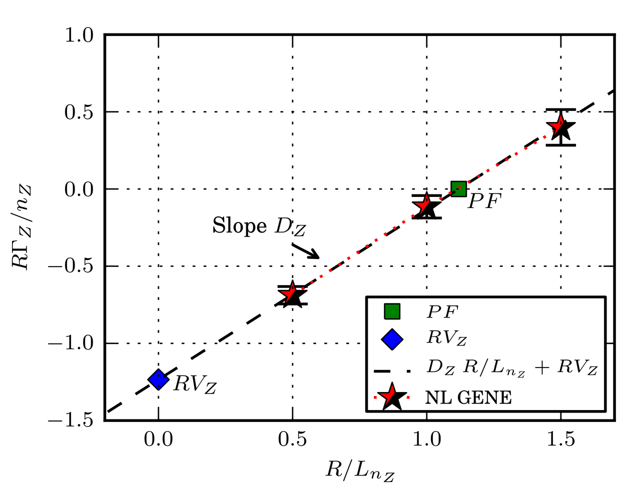

FIGURE 1: The **impurity flux dependence** on ∇n_Z, illustrating PF_Z and validity of linearity assumption, eq. (3), for trace impurities (charge Z). Data from NL GENE simulations.

In general, D_j and V_j may depend on ∇n_j, and PF_j has to be found explicitly from the zero flux condition.

Results

Effects of the equilibrium model on impurity transport: Simulations of impurity transport using a realistic *JET*-like magnetic equilibrium are compared to circular and $s-\alpha$ geometry for an **ITG** dominated discharge. JET-like parameters are chosen in accordance with *L-mode discharge #67730* (see [6] for details).

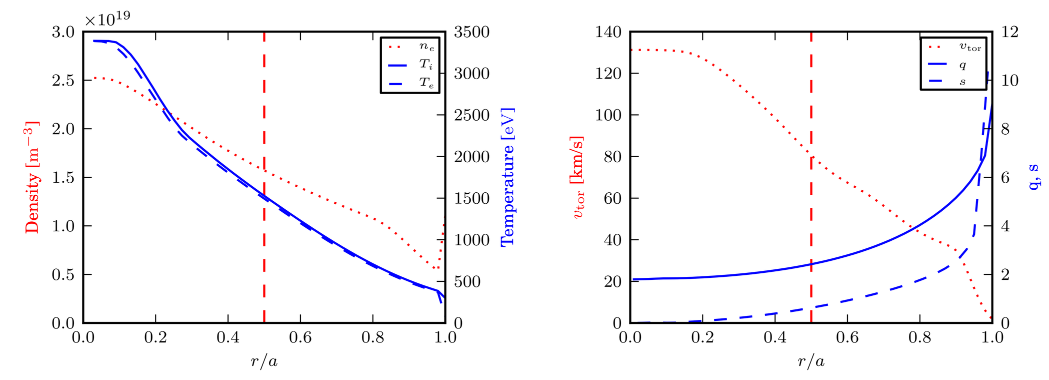

FIGURE 2: Radial profiles of the background parameters for **JET discharge #67730** at $t = 47.5$s. All simulations performed at mid-radius ($r/a = 0.5$; indicated).

With realistic geometry the growthrate (γ) spectrum:

- is destabilised
- shifts to higher $k_\theta \rho_s$.

This is consistent with previous results obtained using a fluid model [7] and results in larger heat and particle transport (NL GK).

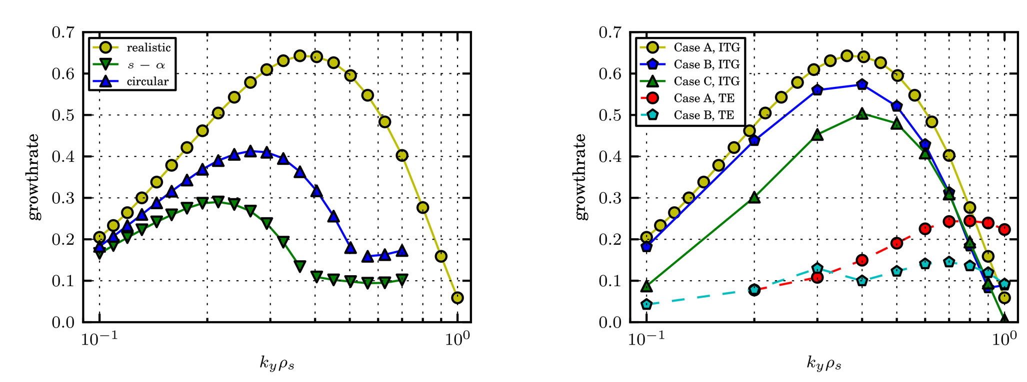

FIGURE 3: Left: growthrate spectra for $s-\alpha$, circular and experimental magnetic equilibrium for ITG mode-dominated case with JET-like parameters. Right: experimental equilibrium with **added degrees of realism**. ***Case A*** - full geometry with no added effects; *case B* - 2%C background added; ***case C*** - collisions also added.

The eigenvalue spectra also show that:

- γ for **circular equilibrium** is closer to the realistic geometry than the $s-\alpha$ one, in agreement with [8];
- both collisions and 2% carbon have a **stabilising effect** (in both ITG and sub-dominant TEM).

The stabilization effect is **stronger with the addition of collisions**, in particular for lower $k_\theta\rho_s$, where most of the transport occurs.

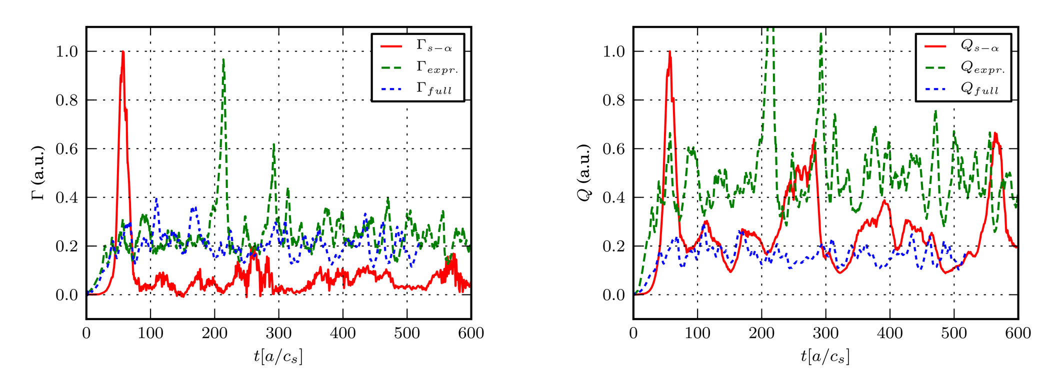

FIGURE 4: Timeseries of particle (left) and heat (right) fluxes for NL GENE simulations with $s-\alpha$, *case A* and *case C*. Normalisation is to the maximum of corresponding $s-\alpha$ case. Realistic geometry increases transport levels (compared to $s-\alpha$); **extra added effects** decrease them. Both trends consistent with the linear eigenvalue spectra.

Comparison between fluid and GK results: The results of QL GK simulations were compared with the fluid model for different values of $k_\theta\rho_s$. The **equilibrium model** was seen to have a definite effect on the PF scaling with Z. For the fluid model the $s-\alpha$ equilibrium was considered, with shaping effects due to elongation included.

- In both fluid and GK the PF is **reduced** when using a more realistic equilibrium
- fluid model gives higher PFs than GK, as also seen previously [6, 9, 10].

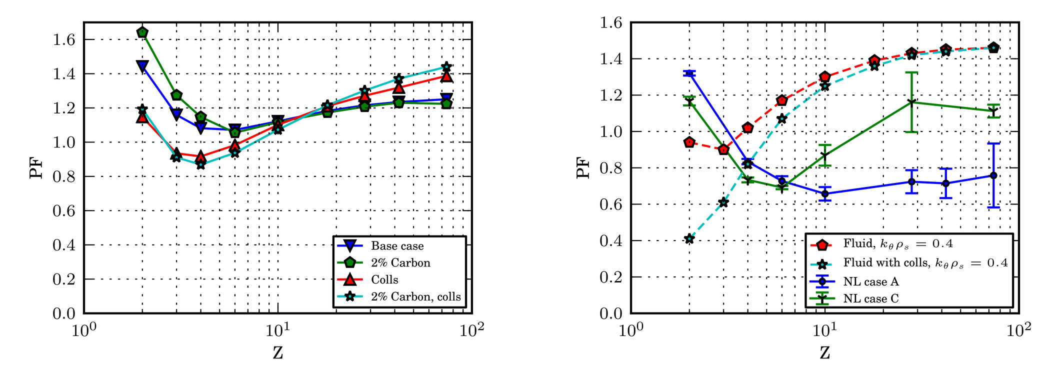

FIGURE 5: Scaling of impurity peaking factor (PF) with impurity charge (Z). Left: QL, **effects of added realism**. Right: **NL GENE cases *A* and *C***, compared with fluid results (including elongation effects and also collisions). Error-bars indicate standard error of $\pm\sigma$.

Result of the added effects on the PF:

- in GK (QL and NL) **lowering for low** Z **and increase at high** Z, when adding collisions + 2% C;
- in fluid model, **lowering with collisions** for low Z; no noticeable effect at higher Z.

Effects of sheared toroidal rotation on impurity PF were also studied. In realistic geometry this lead to a **reversal of the impurity pinch** at $\gamma_{E\times B} = 0.23$ for both low and high Z. For this JET discharge the shearing rate is too small and the effect is not included in NL GK simulations.

⇒ For the effect of **sheared rotation** on the PF and **predictive simulations** of JET discharges see **P4.137** (D. Tegnered *et al.*)

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