The topic of this work is turbulent transport of main ions and impurities driven by ion ETG and electron modes (TE and electron scale ETG) in tokamaks. Regions relevant to the pedestal of H-mode plasmas (i.e., steep density gradients) are of particular interest. Using the code GENE [1–3], quasilinear (QL) and nonlinear (NL) gyrokinetic simulations are performed. Results are compared with a computationally efficient fluid model [4].

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 and TE mode turbulence, and conditions for zero main ion flux is investigated for ETG. Further, the quality of He ash removal is studied.

**Particle transport**

Particle transport for species $j$ is derived from:

$$\Gamma_j = (q, p, F_j, b_j),$$  

where $(\cdot)$ means a spatial averaging [5, 6].

This is divided into a diffusive and a convective part:

$$\Gamma_j = - D_j \nabla n_j + n_j V_j$$

where $\Gamma_j$ is the flux and $n_j$ the density of the species [5].

For the domain studied $\nabla n_j$ and $\nabla V_j$ are constant:

- $-\nabla n_j/n_j = 1/L_n$,
- $-\nabla V_j/V_j = 1/L_p$.

The flux can thus be written:

$$R_j = D_j \frac{R}{L_j} \nabla n_j + R_j$$

with $R$ the major radius.

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

$$0 = D_j \frac{R}{L_j} \nabla n_j \Rightarrow \frac{R_j}{V_j} \frac{D_j}{L_j} = \frac{R}{L_j} \Rightarrow \Gamma_j$$

Thus $\Gamma_j$ is interpreted as the gradient of zero flux.

For trace impurities $D_j$ and $V_j$ are independent of $\nabla n_j$. Eq. (1) is then linear in $R/L_n$ and $P_F$ can be found by fitting a straight line to flux data. This is illustrated in Fig. 1.

**Effects of realistic geometry on ITG turbulence**

Simulations of impurity transport using a realistic JET-like magnetic equilibrium were compared to a—geometry for an ITG dominated discharge. Parameters were chosen to correspond closely to JET L-mode discharge 467730; see [6] for parameters.

- with the realistic geometry the growthrate spectrum:
  - is destabilised
  - shifts to higher $k_y$
  - due to modified curvature and FLR effects
  - consistent with fluid results in [7]

**Steep gradients in TEM dominated turbulence**

Simulations were performed of steep gradients where $n = 0.60$.

- reduction of $P_F$ for high $\chi$ in realistic case
  - lower levels due to change in curvature pinch
  - QL results overestimate $P_F$ for high $\chi$
  - change in sign of (outward) thermospin for low $\chi$
  - $\chi$ increase in $P_F$ for He impurity in realistic case

NL and QL impurity pinch qualitatively agree with [6, 8]

**Results**

**Equation (5)**

For a simple comparison between ITG and TE cases an estimate of $D_{\text{ef}}/D_{\text{ii}}$ is sufficient [8]. Results from NL GENE indicate that TE is at least as efficient as ITG mode turbulence at removing He ash for the parameters studied:

$$D_{\text{ef}}/D_{\text{ii}} \approx 1.7$$

**ETG turbulence in barriers**

For ETG modes focus is on the density gradient leading to zero main ion particle flux, related to the formation and sustainment of the edge pedestal. Parameters are chosen to correspond to barrier like parameters for ASDEX Upgrade [11], with zero flux observed at very steep gradients:

- in line with fluid results in 11.103 (R. Singh)
- for ETG fluctuation and transport level estimates see: P2.061 (J. Anderson) and 11.103 (R. Singh)

**References**


The simulations were performed on resources provided on the Landgren [12] and HPC-FF [13] high performance computers, by the Swedish National Infrastructure for Computing (SNIC), at Cray Jordsand (DAC) and the European Fusion Development Agreement (EFDA), respectively.