Tokamak edge turbulence & L-H transition studies with global 3D Braginskii model
Manuare Franciscuez, Ben Zhu, Barrett Rogers
Dartmouth College, Hanover, NH 03755, USA

In the tokamak edge, gradients between cool scrape-off-layer (SOL) and hot core plasmas are a source of free energy that drive turbulence. This turbulence impacts machine performance and is believed to cause the transport suppression observed in high confinement modes (H-mode). The transition from low confinement mode (L-mode) to H-mode has not been understood from first principles. With the goal of informing alternative explanations of the L-H transition, plasma turbulence in the tokamak edge is explored in this work with a drift-reduced Braginskii model [1]. These fluid-like equations are valid in the SOL where collisionality is high and kinetic effects are small. In the closed-flux region their underlying assumptions break down, but despite their inaccurate estimation of core transport, the model may still offer valuable qualitative insight.

### Drift-reduced Braginskii model

In the limit $\alpha \gg 1$, $d/da \ll \omega_{pe}$, Braginskii’s transport equations for the study of collisional, low-frequency electromagnetic turbulence become:

$$\begin{align*}
\frac{\partial n}{\partial t} - \frac{1}{\rho_e} \frac{\partial}{\partial r} (\rho_e n \phi) &= \frac{1}{\tau_{ne}} (n - \bar{n}) - \nabla \cdot \mathbf{J}_e \\
\frac{\partial T_e}{\partial t} - \frac{1}{\rho_e c_s^2} \frac{\partial}{\partial r} (\rho_e c_s^2 T_e \phi) &= \frac{1}{\tau_{Te}} (T_e - \bar{T}_e) - \nabla \cdot \mathbf{J}_{Te} \\
\frac{\partial T_i}{\partial t} - \frac{1}{\rho_i c_s^2} \frac{\partial}{\partial r} (\rho_i c_s^2 T_i \phi) &= \frac{1}{\tau_{Ti}} (T_i - \bar{T}_i) - \nabla \cdot \mathbf{J}_{Ti}
\end{align*}$$

where:

- $\phi = \psi - \chi$.
- $\frac{\partial}{\partial r} (\rho_e n \phi) = n - \bar{n}$.
- $\frac{\partial}{\partial r} (\rho_e c_s^2 T_e \phi) = T_e - \bar{T}_e$.
- $\frac{\partial}{\partial r} (\rho_i c_s^2 T_i \phi) = T_i - \bar{T}_i$.

Equilibrium and fluctuating contributions are not separated $\Rightarrow O(1)$ perturbations considered.

- Perpendicular electric field assumed electrostatic.
- Bousinesq approximation in the vorticity equation is avoided.

### L-mode turbulence

Approximate fits to density and temperature profiles are used to calculate a current that is in approximate MHD equilibrium. These initial profiles are randomly perturbed and allowed to evolve. L-mode plasmas have been stably simulated into their saturated, turbulent state.

- In L-mode simulations resistive ballooning turbulence dominates.
- O(1) structures interchange hot core and cool SOL plasmas and flatten pressure profiles.

### Towards simulations of H-mode plasmas

L-H transitions occur on confinement time scales $\sim 10^5$ ms, but curvature driven turbulence needs to be resolved at the ballooning time scale $\sim 10^3$ ms. Self-consistent simulation of L-H evolution is therefore very computationally demanding. As an intermediate step, the current model and numerical techniques are being tested in L-H and H mode regimes.

- Increased input core temperatures ($\sim$ those observed at the L-H transition).
- The model is able to stably evolve the plasma until saturation.
- Reduced fluctuations and fluxes are observed.
- Increased input density and temperature profiles.
- Temperature profiles steepen further as simulation advances.
- $B \times \mathbf{E}$ exhibits sharp peak at the outer edge (balancing strong diamagnetic flows).

### Summary and future plans

Tokamak edge turbulence is studied with a reduced Braginskii model and the numerics used stably evolve both L and H-mode turbulence into saturated states. The profiles are flattened by large convective structures as expected, but no $B \times \mathbf{E}$ shear is obtained, even in H-mode regimes. This is likely related to our choice of $\phi$ boundary condition and pressure boundary clamping. We have begun implementing a limiter region which should impose a natural boundary condition at the wall. Other current development projects include:

- Explore a $\phi$ boundary condition inside (also prevents injection of angular momentum).
- Simulate the entire L-H transition (heat the core, freely evolve the density).
- Accelerate the simulations with the use of CUDA/OpenACC.

### References