Canadian Association of Physicists

Association canadienne des physiciens et physiciennes

Contribution ID: **475**

Type: **Invited Speaker / Conférencier(ère) invité(e)**

# (I) Global simulations of ion temperature gradient modes, from characteristic eigen-structures to turbulent transport

*Tuesday 8 June 2021 17:25 (25 minutes)*

Energy loss in magnetic confinement fusion is dominated by plasma turbulence — turbulent transport can surpass all other mechanisms by several orders of magnitude. Instability, driven by the Ion Temperature Gradient (ITG) mode is a key contributor to such turbulence, and is the topic of this work. Simulating such small-scale, $\mathcal{O}(\mathrm{mm})$, turbulence over an $\mathcal{O}(\mathrm{m})$ tokamak is computationally intensive, particularly with the 6 or 7-D kinetic models used to clearly capture velocity-space effects, e.g. Landau damping. To mitigate computational demands, these models have often focused on thin annular flux-tubes, which reduces the radial domain to $\mathcal{O}(\mathrm{cm})$.

Fluid modeling (4-D), the approach adopted here, also provides a formidable decrease in computational demands. This permits diverse (high numeracy) global (full-domain) investigations of both large-scale interactions with the equilibrium profiles/gradients, and meso-scale mode-mode coupling. The former is especially important in X-point geometry, where the poloidal boundary is shaped to exhibit a discontinuity which can interact nonlocally with regions well inside the tokamak.

This project extensively characterizes global ITG behavior in realistic devices of both circular[1] and X-point geometry. In the linear growth phase, several distinct types of eigen-structure are found, described, and quantified. Thorough investigation of the poloidal mode spectra uncovered a significant shift in mode location, with respect to resonant surfaces, which was unexpected and yet-unreported. The possibility for such behavior was subsequently found within a previously published gyrokinetic model.[1,2] Notably, linear investigations also clearly demonstrate the suppression of instability by localized neoclassical flows, identifying that they can play a significant role in transport barriers.

In the turbulent phase, study focuses on the energy spectra, nonlinear radial heat flux (from transport coefficients to evolution and structures), and the behavior and traits of turbulent eddies. Even with broadly similar parameters, different X-point devices demonstrated a great diversity in their spectra and structures. Clear power law relations, some common to all cases, some characteristic to particular devices, are detailed. Under certain conditions, interaction with the X-point was found to qualitatively affect the mode throughout the domain.

[1] J. Zielinski, M. Becoulet, A. I. Smolyakov, X. Garbet, G. T. A. Huijsmans, P. Beyer, and S. Benkadda, "Global itg eigenmodes: From ballooning angle and radial shift to reynolds stress and nonlinear saturation," Physics of Plasmas, vol. 27, no. 7, p. 072507, 2020.

[2] X. Garbet, Y. Asahi, P. Donnel, C. Ehrlacher, G. Dif-Pradalier, P. Ghendrih, V. Grandgirard, and Y. Sarazin, "Impact of poloidal convective cells on momentum flux in tokamaks," New Journal of Physics, vol. 19, no. 1, p. 015011, 2017.

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**Session Classification:** TS-3 Plasma Physics Symposium (DPP) / Symposium de physique des plasmas (DPP)

**Track Classification:** Symposia Day (DPP) - Low temperature plasmas/Fusion plasmas (magnetic and inertial confinement)/ Laser plasmas/Basic plasmas