9th Asia-Pacific Conference on Plasma Physics, 21-26 Sep, 2025 at Fukuoka

Transition from electrostatic to electromagnetic instabilities in magnetised plasmas

C.K. Chai[1], X. Garbet[1, 2], Z.S. Qu[1], Y.W. Cho[1], Y. Sarazin[2], K. Lim[1]
[1] School of Physical and Mathematical Sciences, Nanyang Technological University, [2] CEA, IRFM
changkai001@e.ntu.edu.sg

To study the transition from electrostatic to electromagnetic instabilities in fusion plasmas [1,2,3,4], a kinetic model will serve as a better description since it covers effects that cannot be modeled using a fluid description. To confirm that the kinetic model we formulate in screw-pinch configuration indeed contains the correct physics, we reduce our results in the fluid limits to see if we can recover the required physics which is also observed in fluid simulation [5]. The dispersion relation from our kinetic model in the fluid limit matches exactly with reference [6], and we successfully observe the electromagnetic transition from the ion-temperature-gradient (ITG) mode to kinetic ballooning mode (KBM), as shown in figure 1, when the parameter β is varied, where β is the ratio of thermal pressure to magnetic pressure, and is a measure of electromagnetic effects in magnetised plasmas [7]. When the normalised poloidal wavenumber is large enough, where the wavenumber $k_\theta \rho_{Ti} \gtrsim 0.4$, it is observed that there is a range of β such that the growth rate is zero for all modes, which is important to understand since it is possible to optimise the confinement of fusion plasmas, a key factor that is crucial in realising a self-sustaining fusion reactor, when parameter β is within this region of "sweet spots". It is found that as we increase the poloidal wavenumber slightly, this region of "sweet spots" becomes larger, which is promising, and only the onset of KBM is observed. What comes as a surprise is a branch which is later identified as the electron-temperature-gradient (ETG) mode, which turns out to be one of the electromagnetic instabilities and becomes significant when $k_\theta \rho_{Ti} \gtrsim 0.5$, where the onset of KBM occurs at a much higher threshold compared to that of ETG. Once $k_\theta \rho_{Ti}$ exceeds this value, the region of "sweet spots" becomes smaller and eventually vanishes when $k_\theta \rho_{Ti} \approx 1.1$. In terms of the limit of β, we now have two different thresholds of β for electromagnetic instabilities to occur, one for the KBM to emerge when $k_\theta \rho_{Ti}$ is low, and the other one is responsible for the onset of the ETG mode, which occurs when $k_\theta \rho_{Ti}$ is higher. Recently, it is shown that using GYSELA code, which simulates globally the evolution of plasma distributions in a toroidal configuration, the transition from ITG to KBM is successfully obtained and benchmarked with reference [3], as shown in figure 2. Therefore, we aim to simulate the transition with a higher range of $k_\theta \rho_{Ti}$ and investigate the emergence of ETG mode. The underlying mechanism behind this "sweet spot" region is still being studied and is expected to play a crucial role in advancing the confinement of fusion plasmas.

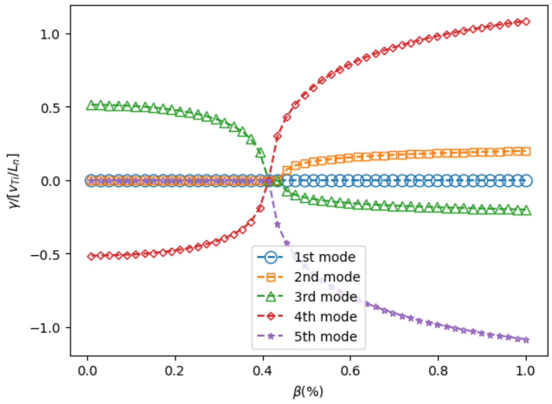

Figure 1: Transition from electrostatic instabilities (ITG) to electromagnetic instabilities (KBM and ETG) in screw-pinch configuration when $k_\theta \rho_{Ti} = 0.45$.

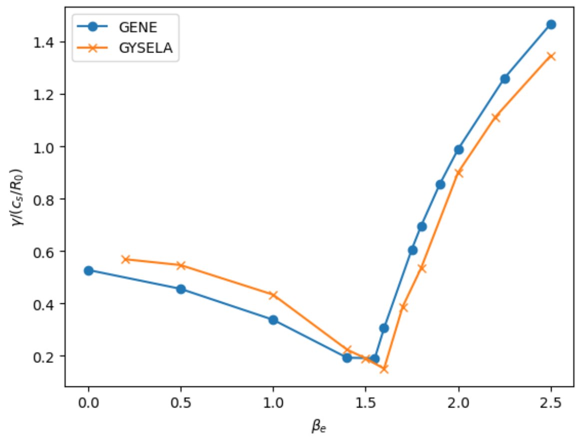

Figure 2: Comparison of ITG-KBM transition between GYSELA and GENE codes.

References

[1] Citrin J. and Mantica P. "Overview of tokamak turbulence stabilization by fast ions". In: Plasma Physics and Controlled Fusion 65.3 (2023), p. 033001.
[2] Garcia, J., and J. E. T. Contributors. "Electromagnetic and fast ions effects as a key mechanism for turbulent transport suppression at JET." Plasma Physics and Controlled Fusion 64.10 (2022): 104002.
[3] Görler, T., et al. "Intercode comparison of gyrokinetic global electromagnetic modes." Physics of Plasmas 23.7 (2016).
[4] Pueschel, M. J., and F. Jenko. "Transport properties of finite-β microturbulence." Physics of Plasmas 17.6 (2010).
[5] Snyder, P. B., and G. W. Hammett. "Electromagnetic effects on plasma microturbulence and transport." Physics of Plasmas 8.3 (2001): 744-749.
[6] Snyder, P. B. Gyrofluid theory and simulation of electromagnetic turbulence and transport in tokamak plasmas. Princeton University, 1999.
[7] Scott, B. "Three-dimensional computation of drift Alfvén turbulence." Plasma Physics and Controlled Fusion 39.10 (1997): 1635.