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

First-Principle Gyrokinetic Simulations of Turbulence-Driven Magnetic Islands in Tokamaks

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In fusion plasmas, the growth of magnetic islands can lead to degraded confinement and disruptions. While their growth is traditionally associated to the tearing mode instability, experimental observations revealed the appearance of large-scale magnetic islands even in absence of MHD events [1]. A possibility for the generation of magnetic islands in linearly tearing-stable plasmas is the nonlinear coupling of small-scale fluctuations as those typically produced by micro-instabilities. If sufficiently wide, such turbulence-driven islands could provide the “seed” for their further neoclassical growth.

We investigate the seeding process by turbulence in tokamaks through collisionless gyrokinetic simulations with the ORB5 [2] code turning off the linear drive for the tearing mode ($\Delta'<0$). Previous work showed the capability of ORB5 to self-consistently generate magnetic islands from unstable tearing modes ($\Delta'>0$) [3]. We show that the micro-instability induced ***E* x *B*** flows lead to the formation of small-scale islands whose number correlates with the amplitude of the dominant unstable mode. The seeding process is shown to occur in two phases, the first dominated by the beat-driven growth of the dominant large-scale mode, the second by the coalescence of the small-scale magnetic fluctuations. This pattern, which confirms the results of recent fluid simulations [4], is observed regardless of the kind of dominant micro-instability generating the turbulence. In particular, the parity of a mode can be converted from twisting to tearing through non-linear parity mixture. As turbulence saturates, the n=1 mode, responsible for the m/n=2/1 island formation, continues to grow and saturates at a later time than turbulence, with a significantly larger amplitude.

During the coalescence, the rotation frequency at the rational surface is observed to change from electron- to ion-diamagnetic drift direction as the large-scale island is formed. This behavior is found to correlate with the time evolution of the zonal flows velocity.

Finally, we find that the turbulence-driven islands become large enough to significantly perturb the equilibrium pressure profile. Across the island O-point, the profiles exhibit a reduction at the center and an increase at the separatrix. These findings are consistent with theoretical expectations and two-fluids simulations [5]. At the X-point, a slight increase in the equilibrium profiles is observed.

These findings demonstrate a viable mechanism for the formation of turbulence-driven magnetic island. The consequences for the stability of tearing modes in tokamkas are discussed.

References

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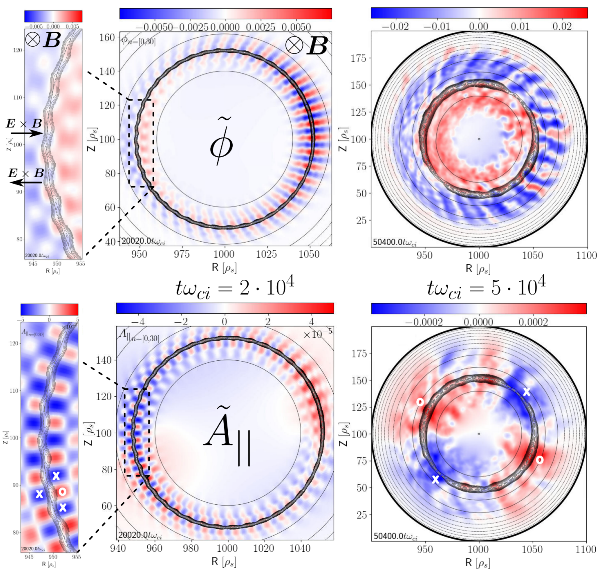

Figure 1: Electrostatic and magnetic potential fluctuations ϕ and $A_{||}$ during the micro-instability (TEM) growth (left column) and quasi-steady phase (right column). A m/n=2/1 magnetic island forms through the coalescence of small-scale islands induced by TEM-driven ***E****x****B*** *flows.*