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Self-organized States of AE and Zonal Modes

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When energetic particles strongly drive toroidal Alfvén eigenmodes (TAE), conventional saturation mechanisms, such as profile relaxation, can be ineffective. Thus, this novel theory of TAE-zonal mode (ZM) turbulence, self-regulated by cross-scale interactions, merits consideration. With the sustained EP profile and strongly excited TAE, the interactions between TAEs and directly driven ZM lead to an interesting self-organized state of the system, as shown in Figure 1, in which EP energy is deposited into thermals via ZM, along with the formation of a TAE-driven ITB for the thermals.

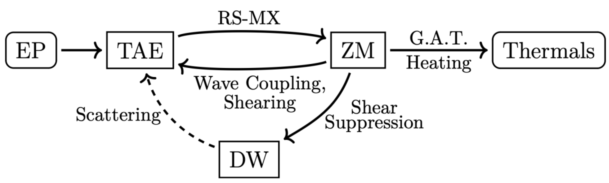

Figure 1. A feedback diagram for TAE and ZM with energy deposition from EP to thermals. ZM saturates TAE and sup- presses DW turbulence. Thermal plasma damps ZM and so is heated.

Zonal modes are directly driven by Reynolds and Maxwell stresses, without the onset of modulational instability, and are damped by collisional and collisionless drag processes. This, in turn, influences the evolution of the TAE via wave-ZM interaction. ZM damping regulates the TAE saturation level and the oscillations of TAE and ZM as they approach saturation. This regulation leads to bursty TAE spectral oscillations, which overshoot approaching saturation. The geodesic acoustic transference (GAT) is a relevant collisionless damping mechanism, which requires sufficient turbulent mixing to be effective. The saturated zonal shears are sufficient to suppress ambient drift-ITG turbulence, predicting a novel enhanced core confinement regime. Heating by both collisional and collisionless ZM damping ultimately deposits alpha particle energy into the thermal plasma, achieving effective alpha channeling. EP transport is connected to thermal turbulence by cross-scale interactions. This is the first theory to close all the feedback loops in this multi-scale problem.

References

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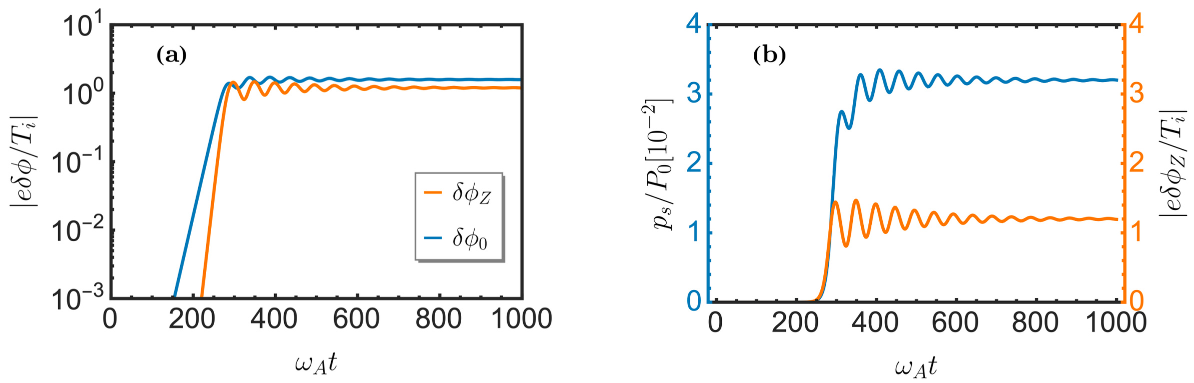

Figure 2.The evolution of TAE-ZM system with the geodesic acoustic transference as collisionless damping. Oscillations with frequency of ω_{GAM} are observed when $\tau_Z \sim \tau_{turb}$.