Direct and indirect cross-scale couplings in burning plasmas mediated by energetic particles

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Energetic particle (EP) related physics, including fusion alpha particles, are expected to play crucial roles in burning plasma of future reactors [1]. In particular, EPs act as mediators of cross-scale couplings among the rich spatiotemporal scales characterizing burning plasmas [2]. On the one hand, while EP profiles are determined by bulk plasma and/or external heating, they provide feedback to the thermal plasma profiles via fusion power deposition. On the other hand, EPs and the typically macro- or meso-scale collective instabilities excited by them, can couple directly and/or indirectly with oscillations at different scales, and affect the overall plasma confinement.

In this presentation, taking the well-known toroidal Alfvén eigenmode (TAE) [3] as example, it is shown that TAE can interact with micro-scale drift wave turbulence (DWT) via both direct and in-direct channels. Specifically:1) given typical DWT with $e\delta\phi/T_e \sim O(10^{-2})$, TAE instabilities can be effectively reduced or even suppressed by ambient stationary DWT due to stimulated absorption via direct-scatterings into short-wavelength electron Landau damped kinetic Alfvén waves (KAWs) [4]; 2) in the "reverse" process of DWT scattering by ambient stationary TAEs with typical amplitude $|\delta B_\theta/B_0|^2 \sim O(10^{-7})$, direct nonlinear scatterings to KAWs have a negligible damping effect on DWT due to the cancellation of stimulated absorption via the upper-sideband KAW and spontaneous emission via the lower-sideband KAW [5]; and 3) TAE can in-directly regulate the DWT intensity via the nonlinearly excited zonal field structures [1] and phase-space zonal structures [6]. These findings illuminate the richness of interesting nonlinear plasma physics that underly these processes. Furthermore, they provide the knowledge for understanding recent experimental and numerical results of improved plasma performance in the presence of EPs.

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