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Nonlinear reversed shear Alfvén eigenmode saturation due to spontaneous zonal current generation

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Energetic particles (EPs), especially alpha particles, can excite collective shear Alfvén wave (SAW) instability in tokamak plasmas, and in turn affects the behavior of EPs, resulting in EPs transport loss. Notably, reversed shear Alfvén eigenmodes (RSAE) can be preferentially excited by core localized EPs [1], with their frequency and radial localization directly determined by local safety factor minimum . Understanding the excitation, evolution and saturation of RSAE is important to the future study of magnetic confined controllable nuclear fusion.

The nonlinear zero frequency zonal structure (ZFZS) excitation by RSAE is an important channel of the RSAE saturation. The zonal structure (ZS), including the zonal flow (ZF) and the zonal current (ZC), are known to play important self-regulatory roles on microscale drift wave type instabilities by scattering drift waves into short radial wavelength stable domains [2,3].

RSAE frequency may sweep between those of toroidal Alfvén eigenmode (TAE) and beta-induced Alfvén eigenmode (BAE). Based on the work of the TAE [4] and BAE [5] nonlinearly exciting the ZFZS, in this work, we use the nonlinear gyrokinetic theory to study the nonlinear RSAE self-modulation due to ZFZS excitation. Different from TAE confined in the middle of two rational surfaces and BAE confined on the rational surface, the frequency and radial location of the RSAE is determined by , and we obtain a more general dispersion relation describing the modulational instability dispersion relation of ZFZS excitation by AEs. At the same time, we propose a unique channel of RSAE saturation, which is similar with the mechanisms proposed in [6,7] of TAE saturation. Due to the generation of ZC, the SAW continuum and q-profile may be directly modulated, which further modifies the coupling between RSAE and SAW continuum, resulting to RSAE nonlinear saturation.

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