8th Asia-Pacific Conference on Plasma Physics, 3-8 Nov, 2024 at Malacca

Global gyrokinetic modeling of energetic ion effects on plasma instabilities

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In nowadays tokamak, the energetic ions (EIs) not only excite Alfven eigenmodes (AEs) with positive growth rate, but also non-perturbatively alter the AE frequency and mode structure. In this work, we demonstrate the extension of the Landau-fluid model for bulk plasma in MAS code[1] with EIs described by gyrokinetic model, which form a comprehensive Landau-fluid and gyrokinetic hybrid model for analyzing the linear interactions between EIs and unstable/damped modes non-perturbatively in general geometry. A computational algorithm is developed for evaluating EI moments in MAS formulation in order to naturally incorporates finite Larmor radius (FLR) and finite orbit width (FOW) effects that are accurate in arbitrary wavelength regime[2,3]. These EI upgrades in MAS code has been verified by simulating EI-excited RSAE based on a well-benchmarked DIII-D equilibrium case[4], which exhibits good agreements with other codes on the mode structure and dispersion, and the FOW stabilization on RSAE is found to be important in the regime of $k_\perp \rho_{orbit} \gtrsim 1$.

Moreover, the EI modifications on various AE mode structure are analyzed using the upgraded MAS code. First, it is found that the triangularity shape of BAE mode structure can reverse the tip direction as EI density exceeds a certain threshold, which is consistent with earlier gyrokinetic simulation results [5]. Second, the radial profiles of poloidal phase angle of EI-driven RSAE-TAE hybrid mode are calculated for different qmin values, and the radial variation of phase angle is observed and found to closely connect to radial Poynting energy flow. A new model is proposed for calculating radial Poynting energy flow induced by AE electromagnetic fluctuations according to the shear Alfven wave polarization, which gives a much lower radial energy transport level compared to previous model that amplifies the compressional nature of AEs [6].

References

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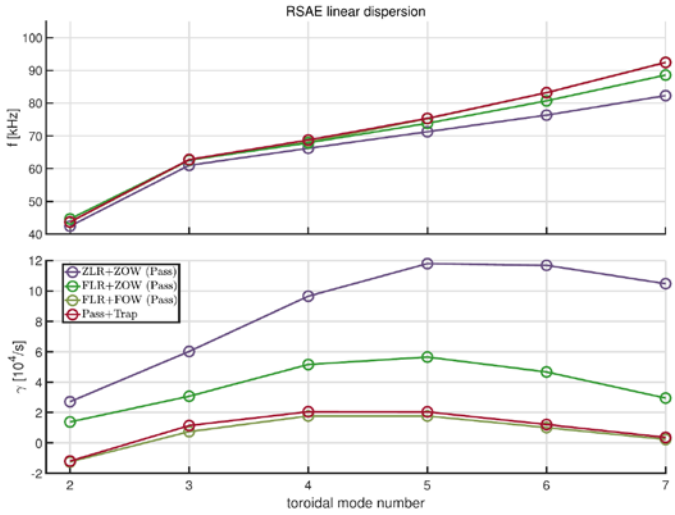

Figure 1. RSAE linear dispersion solved by upgraded-MAS with different toroidal mode numbers in experimental geometry of DIII-D shot 158243 at 805 ms.

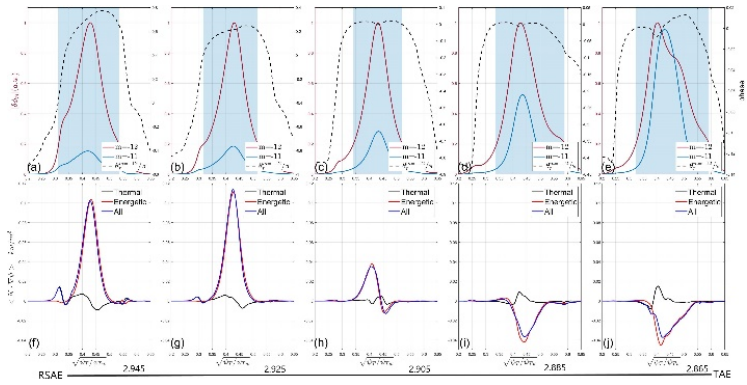

Figure 2. The RSAE-TAE hybrid modes at different qmin values. (a)-(e) Radial structures of $\delta\phi$ harmonics and corresponding poloidal phase angle. (f)-(g) Flux-surface averaged radial Poynting energy flow.