Progress in gyrokinetic particle simulation of Alfvén instabilities

Z. Lin

University of California, Irvine, California 92697, USA

This paper reports recent progress in global gyrokinetic particle simulation of Alfvén instabilities excited by energetic particles (EP) in fusion plasmas, in particular, the nonlinear saturation of toroidal Alfvén eigenmode (TAE) by zonal fields and the excitation of beta-induced Alfvén-acoustic eigenmode (BAAE) by EP.

TAE saturation by zonal fields -- GTC simulations$^{1,2}$ of TAE in DIII-D shot #142111 near 525ms have been extended to nonlinear regime to test effects of EP nonlinearity, thermal plasma nonlinearity, and zonal fields (zonal flow and zonal current). When only EP nonlinearly is kept in the simulation (green line in figure), TAE saturates at a high amplitude due to the relaxation of EP density profiles. When thermal plasma nonlinearity is added in the simulation (red line), TAE saturates at a lower amplitude, indicating the importance of the thermal plasma nonlinearity. Finally, when zonal fields are self-consistently kept in the simulation (blue line), TAE saturates at a much lower amplitude and there is little relaxation in EP density profiles. The TAE mode structures are somewhat distorted by the zonal flow. The effects of zonal fields are mostly by the zonal flow, similar effects are observed in the nonlinear saturation of beta-induced Alfvén eigenmode (BAE)$^3$. Suppressing zonal current causes little difference in the TAE saturation amplitude. The collisionless skin depth effects likely suppress the modulational instability. The zonal field generation is thus via mode coupling, similar to earlier MHD-gyrokinetic simulations. The growth rate of zonal fields is slightly less than twice of TAE growth rate, indicating some damping of the zonal fields by thermal plasmas.

BAAE excitation by EP -- The existence of BAAE in toroidal plasmas is verified by GTC simulations. In the $T_i\ll T_e$ limit, where the BAAE is weakly damped, the existence of BAAE is verified in simulations using initial perturbation, antenna excitation, and energetic particle excitation, respectively. The damping rate of the BAAE is comparable to the real frequency in simulations with more realistic $T_i$-$T_e$ for both reversed shear and monotonic $q$ profiles. Surprisingly, the BAAE can be easily excited by modest EP density gradient due to the formation of the well-behaved eigenmode structure, which is very different from the singular structure of the heavily damped quasi-mode. The BAAE mode structure in the reversed shear $q$ profile has opposite triangle shape compared to the monotonic $q$ profile. The frequency sweeping of the BAAE is observed in the reversed shear $q$ profile, but not in the monotonic $q$ profile. In collaboration with SciDAC GSEP Center and GTC Team.