Nonlinear damping of Reverse Shear Alfven Eigenmodes induced by electron streaming along the perturbed field line

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Alfven eigenmodes can be excited by energetic particles (EP) and cause anomalous EP transport. Predicting the amplitude of these modes is a great challenge for direct gyrokinetic simulation. For near marginal instabilities, the dominant saturation mechanism is the trapping of resonant particles in the wave field. In this case reduced models can be used for computational efficiency. As the growth rate increases, thermal species nonlinearity leads to the generarion of zonal structures and change the nonlinear behavior. GEM simulations of the Reverse Shear Alfven Eigenmodes (RSAE) with fluid electrons [Chen et. al. Physics of Plasmas 25, 032304 (2018)] show that zonal structures are force generated, and significantly reduce the saturation amplitude. This strong nonlinear effect occurs at moderate mode amplitude, $\delta B_r/B < 10^{-3}$. The reduction in the saturation amplitude is not caused by the zonal flow shearing of the RSAE, but by the force-generated n=0 component in the distribution function. These findings are verified with kinetic electrons using the split-weight scheme [Chen and Parker, J. Comp. Phys. 220, 839 (2007)]. The difficulty with kinetic electrons for low-n electromagnetic modes is well known. We have implemented Mishchenko's mixed variable method [Phys. Plasmas 21,092110 (2014)] in the GEM code, and verified the split-weight scheme. Nonlinear simulations reveal that the strong damping of the thermal nonlinearity comes from the electron magnetic fluttering effect, $v_\parallel \frac{\delta \mathbf{B}_\perp}{B} \cdot \nabla \delta f$ in the electron drift-kinetic equation. For instance, this nonlinear term leads to the self-coupling of an $n = 4$ RSAE and generates $n = 0, 8$ components in the electron distribution. These $n = 0, 8$ components have short radial structures and readily modifies the RSAE mode structure, leads to nonlinear damping.