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# Nonlinear decay and plasma heating by toroidal Alfvén eigenmodes

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Gyrokinetic theory of nonlinear mode coupling as a mechanism for toroidal Alfv\'en eigenmode (TAE) saturation and thermal plasma heating in the fusion plasma related parameter regime is presented, including 1) parametric decay of TAE into lower kinetic TAE (LKTAE) and geodesic acoustic mode (GAM), and 2) enhanced TAE coupling to shear Alfv\'en wave (SAW) continuum via ion induced scattering. Nonlinear decay of TAE into a GAM and a LKTAE with the same toroidal/popoidal mode number is investigated due to its crucial implications on TAE nonlinear saturation, improved confinement, as well as energetic particle (EP) power channeling, including fusion-alpha power density to bulk thermal plasma heating. The parametric dispersion relation is derived and analyzed, and the parameter range for this process to occur and dominate over other mechanisms is discussed. The nonlinearly generated LKTAE and GAM can be dissipated via electron and ion Landau damping, respectively, leading to anomalous EP slowing down and channeling of EP power to thermal ion heating. The thermal plasma heating rates are also estimated. Furthermore, the nonlinearly generated GAM, as the finite frequency zonal flow, could contribute to regulating drift wave turbulence and consequently, improved confinement. The TAE frequency cascading via nonlinear ion induced scattering and saturation due to enhanced coupling to SAW continuum is also investigated. The wave-kinetic equation for the TAE spectrum evolution in the continuum limit is derived using nonlinear gyrokinetic theory, which is then solved to obtain the saturation spectrum of TAE, yielding a lower fluctuation level than previous drift-kinetic theoretical estimates, as a consequence of the enhanced nonlinear couplings in the short wavelength limit. The bulk ion heating rate from nonlinear ion Landau damping is also calculated. Our theory shows that, for TAE saturation in the parameter range of practical interest, several processes with comparable scattering cross sections can be equally important.

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