Gyrokinetic simulations of collisionless damping of geodesic-acoustic modes in edge plasma pedestal*

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The fully nonlinear (full-f) 4D TEMPEST gyrokinetic continuum code produces geodesic-acoustic mode (GAM) frequencies and collisionless damping in excellent agreement with theory [1] with fully nonlinear Boltzmann electrons for the inverse aspect ratio ϵ-scan and the tokamak safety factor q-scan in homogeneous plasmas. We demonstrate that higher harmonic resonances significantly enhance the GAM damping at high-q, and are necessary to explain both the damping observed in our TEMPEST q-scans and experimental measurements on the scaling of the GAM amplitude with edge safety factor, q_{95} [2]. TEMPEST simulations show that the GAMs exist in the edge pedestal for steep density and temperature gradients in the form of outgoing waves.

The underlying physics mechanism of higher order collisionless damping of the GAM can be understood as follows. The radial equilibrium magnetic drift causes passing ions to interact with the GAM radial electric field, resulting in a change in kinetic energy (in additional to parallel acceleration by the parallel electric field) at all harmonics of the passing ion transit frequency. As the ratio of the drift-orbit width of thermal passing ions to the radial wavelength of the GAM ($k_r\rho_i q$) increases, the coupling to higher-harmonic resonances increases proportional to $R_n \propto (k_r\rho_i q)^{2n}\exp(-\alpha_0 q^2/n^2)$ with $k_r\rho_i q < 1$ and $\alpha_0 \simeq 1$. The higher-harmonic resonances involve passing ions with lower parallel velocity, $v_{\|}^{res}/v_{thi} \propto q/n$, where n is harmonic number. The reduced resonance velocity allows more passing particles participate due to the shape of the Maxwellian distribution ($f^{res} \sim exp(-\alpha_0 q^2/n^2)$), thus enhancing the GAM damping. The q-dependence of the GAM damping results from the competing effects of the finite orbit width and the shape of the Maxwellian distribution.

In this work, we will also present a benchmark of gyrokinetic code results from TEMPEST, EGK, GYRO, PG3EQ, and XGC simulations for (a) the collisionless damping rate vs q and (b) the identification of the roles on the resonant damping played by trapped and circulating particles vs q. The radial propagation of GAMs and the turbulent generation of GAM will be discussed.

[1] X. Q. Xu, Z. Xiong, Z. Gao, W. M. Nevins, and G. R. McKee, submitted to Phys. Rev. Lett.
[2] G. R. Mckee *et al.*, Plasma Phys. Control. Fusion **48**, s123(2006).

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