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

On electromagnetic perturbations of geodesic acoustic modes in anisotropic tokamak plasmas

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Geodesic acoustic modes (GAMs) are low-frequency oscillations in tokamaks that play a key role in regulating turbulence and transport. Typically characterized by $n = 0$ and $m \approx 0$ (n/m denoting the toroidal/poloidal mode number), GAMs also include poloidally asymmetric ($m \neq 0$) sidebands, such as poloidal magnetic field perturbation with $m = 2$ [1],which is a key characteristic for GAM identification.

With intense auxiliary heating, the effects of anisotropy become significant and cannot be neglected. Ion temperature anisotropy, defined as the ratio of perpendicular to parallel ion temperatures ($\sigma \equiv T_\perp/T_\parallel$), has a substantial impact on plasma behavior. It is found that weak anisotropy could introduce additional poloidal magnetic field perturbation of GAM with $m = 1$ structure [2], which is absent in the isotropic case [1]. However, the self-consistent anisotropy-induced equilibrium electrostatic potential [3] was not considered in Ref. [2]. Therefore, it is crucial to examine the impact of this potential and the effects of strong anisotropy, which are the main objectives of this work.

In this work, electromagnetic GAMs in tokamak plasmas with anisotropy are analytically investigated using gyro-kinetic equations and a rigorously self-consistent anisotropic distribution. By including first-order finite-orbit-width and finite-Larmor-radius effects, it is demonstrated that anisotropy of arbitrary strength does not induce A_1, the $m = 1$ harmonic of $A_{||}$, where $A_{||}$ represents the parallel component of the perturbed magnetic vector potential. The equilibrium electrostatic field induced by self-consistent anisotropy is poloidally asymmetric, which induces an additional $\vec{E} \times \vec{B}$ drift term in the gyro-kinetic equation. This equilibrium electrostatic field inhibits the anisotropy from generating a non-zero $m = 1$ harmonic of $A_{||}$.

Electromagnetic perturbations are derived as follows:

$$A_1 = 0,$$

$$\phi_1 = \frac{i\tau}{2\sqrt{(\tau+1)}}\frac{1}{\sqrt{1+(2+\sigma^2)(1+\tau)/(\sigma+2\tau+1)^2}}k_r\rho^i\phi_0,$$

$$v_T^i A_2 = \frac{1}{8}\left[2+\sigma^2+\frac{(\sigma+2\tau+1)^2}{1+\tau}\right]^{1/2} q\beta_i\phi_0,$$

$$\phi_2 = \frac{1}{32}\left[2+\sigma^2+\frac{(\sigma+2\tau+1)^2}{1+\tau}\right] q^2\beta_i\phi_0 - \frac{\tau}{4}(k_r\rho^i)^2\phi_0.$$

Here, ϕ_0, ϕ_1, ϕ_2 are $m = 0,1,2$ harmonics of the perturbed electrostatic potential, $\tau \equiv T_e/T_{||}$, k_r is the radial wavenumber, $\rho^i \equiv v_T^i/\omega_c^i$ represents the ion Larmor radius, $v_T^i \equiv \sqrt{2T_{||}/m_i}$, q is the safety factor $\beta_i \equiv 2\mu_0 n_0^i T_{||}/B^2$. Figure 1 demonstrates that incorporating anisotropy self-consistently into the equilibrium quantitatively affects ϕ_1, ϕ_2, and A_2.

This work was supported by the National Natural Science Foundation of China under Grant No. 12175228.

References

[1] D. Zhou, Phys. Plasmas **14**, 104502 (2007)
[2] M. Zhang and D. Zhou, Plasma Sci. Technol. **12,** 6 (2010)
[3] H. Ren, Phys. Plasmas **22**, 072502 (2015)

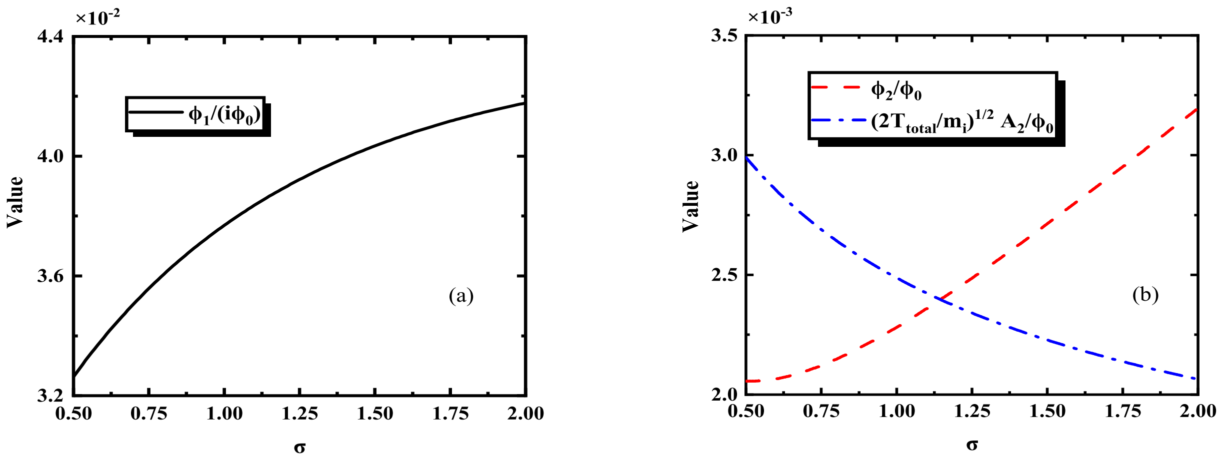

FIG. 1. The dependence of normalized electromagnetic perturbations on the anisotropy parameter σ. We define $T_{\text{total}} \equiv \frac{2}{3}T_\perp + \frac{1}{3}T_\parallel$ as the total temperature of ions. Lines are according to analytical expressions, with the following parameter values: $T_e = T_{\text{total}} = \text{constant}, q = 3, k_r\rho^i = 0.125\sqrt{\frac{3}{1+2\sigma}}, \beta_i = 0.2\% \times \frac{3}{1+2\sigma}$.