Gyrokinetic investigation of the dynamics of geodesic acoustic mode

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Background of the study

Winsor et al *Phys. of Fluids 11, 2448 (1968)*, using ideal MHD first studied GAMs.($\omega_{GAM} \sim \omega_{sound}$).
GAMs have largely been studied in litterature i.e theoretically(MHD, kinetic), numerically, and experimentally.
key properties of GAMs:

1. GAM frequency depends on the electron to ion temperature ratio and the safety factor
2. The major damping mechanism of GAMs is collisionless Landau damping(see analytical expression in H. Sugama et al *Plasma Phys. 72 825 (2006)*)
3. GAM can be linearly excited by energetic particles and non linearly by drift waves

Hypothesis: Temperature isotropy, plasma species decribed by maxwellian distributions

Background of the study

1. Temperature anisotropy can be introduced in tokamaks via auxillary heating such as NBI and ICRH.
2. K. Sasaki et al *Plasma Phys. Control. Fusion 39333–338 (1997)* measured reasonably high ion temperature anisotropy in EXTRAP-T2
3. H.Ren et al *Phys. of Plasmas 21,122512 (2014)*, studied the linear dynamics of GAMs in an anisotropic plasma in the limit of a vanishing electron to ion temperature

How is the linear dynamics of GAMs modified in an anisotropic plasma with a general value of the electron to ion temperature ratio?

objectives

1. Derive a linear dispersion relation of GAMs in an anisotropic plasma with a finite electron to ion temperature ratio.
2. Study the effects of ion temperature anisotropy on the linear dynamics of GAMs in the presence of a finite electron to ion temperature ratio.

Theoretical model

Assumptions:

1. We consider adiabatic electrons
2. Neglect magnetic fluctuations
3. Used flat density and temperature profiles.

Model equations in standard notation:

$$\delta f_s = Z_s e J_{0,s} \frac{\partial f_{0,s}}{\partial E} \phi + h_s \tag{1}$$

$$\left(\omega_{t,s} \frac{\partial}{\partial \theta} - i(\omega + \omega_{d,s}) \right) h_s = i\omega Z_s e J_{0,s} \phi \frac{\partial f_{0,s}}{\partial E} \tag{2}$$

$$-\vec{\nabla} \cdot \left(\frac{n_{0,i} m_i c^2}{B^2} \nabla_\perp \phi \right) = \int dW_i Z_i e J_{0,i} \delta f_i - \int dW_e e \delta f_e \tag{3}$$

Results

Using a Bi-maxwellian as the ion equilibrium distribution function enables us to introduce temperature anisotropy in the GAM theory.

$$f_{0,i} = \left(\frac{m_i}{2\pi T_{||,i}}\right)^{\frac{1}{2}} \left(\frac{m_i}{2\pi T_{\perp,i}}\right) \exp\left[-\frac{m_i}{2}\left(\frac{v_{||}^2}{T_{||,i}} + \frac{v_{\perp}^2}{T_{\perp,i}}\right)\right] \tag{4}$$

GAM dispersion relation in anisotropic plasma with finite electron to ion temperature ratio:

$$y + q^2\left[F(y) - \frac{N^2(y)}{D(y)}\right] = 0 \tag{5}$$

With,

$$F(y) = \frac{y}{2} + y^3 + y\chi + \left(\frac{\chi^2}{2} + y^2\chi + y^4\right) Z(y) \tag{6}$$

$$N(y) = y + \left(\frac{\chi}{2} + y^2\right) Z(y) \tag{7}$$

Results

$$D(y) = \frac{1}{y}\left(1 + \frac{1}{\tau b}\right) + Z(y) \tag{8}$$

With q, the safety factor, $\chi = \frac{T_{\perp,i}}{T_{||,i}}$, $b = \frac{2\chi+1}{3}$, $\tau = \frac{T_e}{T_i}$, $y = \frac{\omega}{\omega_0}$ and $\omega_0 = \frac{v_t}{qR_0\sqrt{b}}$

In the limit of $\chi \longrightarrow 1$, we recover the linear dispersion relation for GAMs in the isotropic case.(see F. Zonca et al, *EPL 83 35001 (2006)*)

Results

Comparison with H. Ren et al, *Phys. of Plasmas 21,122512 (2014)*

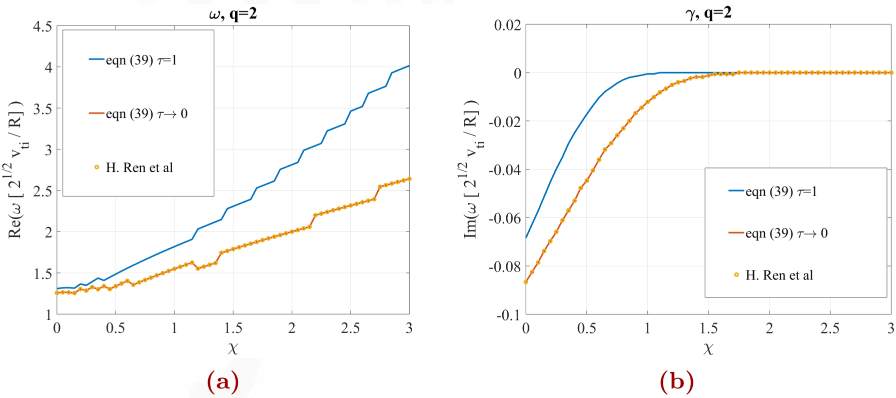

Figure 1: : (a)Frequency (b)Growth rate

Results

Effect of finite electron to ion temperature ratio on GAM frequency and growth rate:

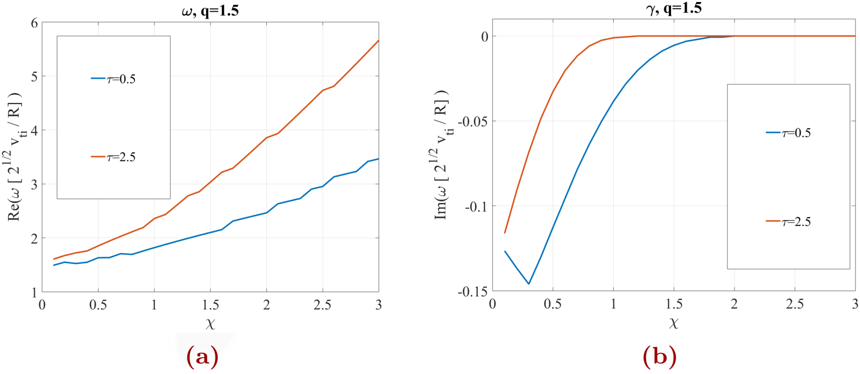

Figure 2: : (a)Frequency (b)Growth rate

Conclusion

1. For a complete linear description of GAM dynamics in anisotropic plasmas, the electron to ion temperature ratio must be retained in the theory.

Link to arXiv:https://doi.org/10.48550/arXiv.2209.14874

Future work

A. Biancalani et al (EPS-2019, PPCF-2021), observed a strong excitation of zonal flows when energetic particles were injected in the non-linear phase of an electromagnetic simulation.

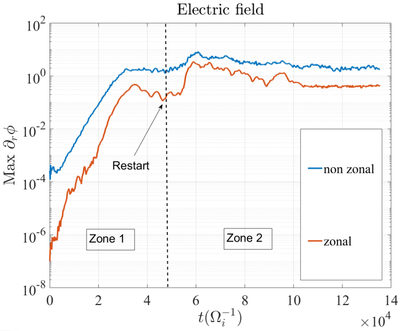

Figure 3: Time evolution of electric field

Future work

Although a strong interest has been captured in the last years by the problem of the interaction of EPs and turbulence, nevertheless, a comprehensive study investigating the roles of the zonal flows has not been performed.

1. A more recent analysis on these simulations has shown that the zonal flows in these simulations are excited by both the Alfven modes and turbulence
2. Both finite-frequency GAMs and zero-frequency zonal flows are observed
3. Their radial structure is strongly determined by the driving mode

A paper is in preparation focusing on the effects of these zonal structures on the turbulence reduction

Thank You!

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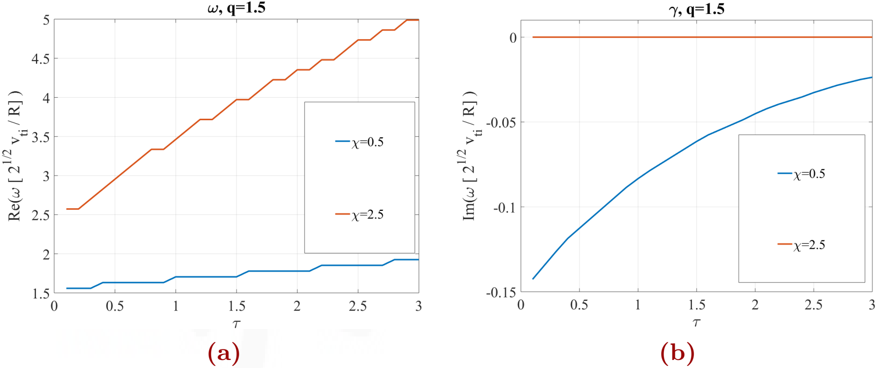

Figure 4: :(a) Frequency ,(b) growth rate