Stabilization of interchange g-modes with gyroviscosity

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Motivations

discrepancies between NIMROD and existing theory

- g mode stabilization wasn't observed with gyroviscosity (Dalton's case with nimrod3.2)
  - $\omega^*/\gamma_{mhd} = 10$ was unstable
- FLR stabilization was seen with nimuw (Ping)
  - However 2-fluid stabilization was not seen

some ideas

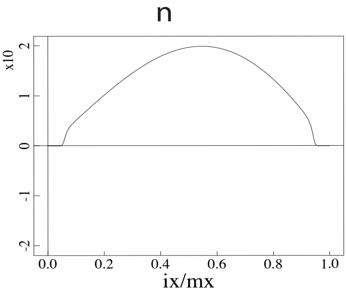
- problem might be related to the two versions of the code
- analytical local approximation not valid in Dalton's case
- should revisit local dispersion relation (Roberts & Taylor)

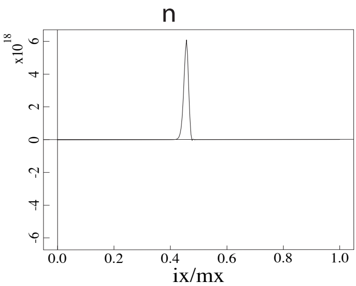
The third idea turned out to be fruitful.

Different physics cases

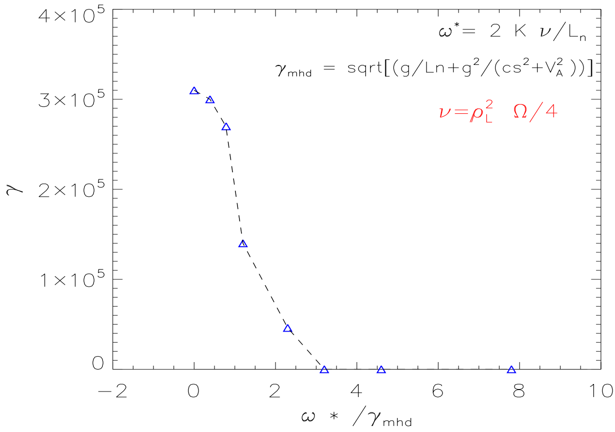
exponential case	tanh case
• non-isothermal	• isothermal
• uniform magnetic field	• non-uniform magnetic field
• global mode structure close to the walls	• local mode structure (localized density gradient)

density perturbations:



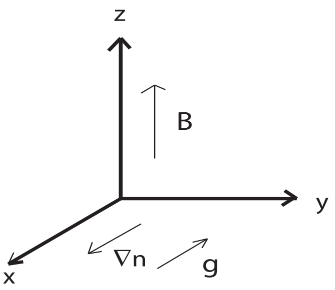


FLR stabilization for tanh case, (based on Roberts & Taylor theory - incompressible)



FLR stabilization effect arises because large-orbit ions drift slower than the electrons in an in homogeneous electric field.

geometry and assumptions



- $(p + B^2/2\mu_0)' = -mng$
- $n = nexp(x/L_n)$,
- local approximation (x dependence is ignored) $kL_n \gg (k\partial/\partial x \gg 1$,

here:

- consider compressibility $\nabla \cdot v \neq 0$
- uniform B, but non-isothermal

The dispersion relation with compressibility

$$\frac{\partial n}{\partial t} + \nabla \cdot (nV) = 0$$
$$\frac{\partial p}{\partial t} + \Gamma p \nabla \cdot V + V \cdot \nabla p = 0$$

$$\frac{\partial B}{\partial t} = (B \cdot \nabla) V - (V \cdot \nabla) B - B(\nabla \cdot V)$$
$$mn \frac{\partial V}{\partial t} = -\nabla (p + \frac{B^2}{2\mu_0}) + mn\bar{g} + \nu \bar{\lambda}$$

$$\lambda_x = \frac{\partial}{\partial x}(\Pi_{yy}) - \frac{\partial}{\partial y}(\Pi_{xy}), \qquad \lambda_y = -\frac{\partial}{\partial y}(\Pi_{yy}) - \frac{\partial}{\partial x}(\Pi_{xy})$$

$$\Pi_{yy} = -\Pi_{xx} = \frac{nT}{2\Omega}(\frac{\partial V_y}{\partial x} + \frac{\partial V_x}{\partial y}), \qquad \Pi_{xy} = \frac{nT}{2\Omega}(\frac{\partial V_x}{\partial x} - \frac{\partial V_y}{\partial y})$$

λ = anisotropic ion pressure tensor, $\nu = \rho_L^2 \Omega / 4 = \frac{T}{2m\Omega}$

The dispersion relation with compressibility

local dispersion relation with gyroviscosity and compressibility:

$$\omega^2(\omega^2 - \frac{2\nu k}{L_n}\omega - \frac{2\nu k}{L_T}\omega + \frac{2\nu k}{L_B}\omega + \frac{g}{L_n}) = (g - \nu k\omega)(\frac{\omega^2}{L_n} + k^2 g - \nu k^3\omega + \frac{2\nu k\omega}{L_B L_n} - \frac{\nu k\omega}{L_n^2} - \frac{\nu k\omega}{L_B^2}) + (k^2 c_s^2 + k^2 v_A^2 + \frac{\nu k}{L_n}\omega + \frac{\nu k}{L_T}\omega - \frac{\nu k}{L_B}\omega)(\omega^2 - \frac{2\nu k}{L_n}\omega - \frac{2\nu k}{L_T}\omega + \frac{2\nu k\omega}{L_B} + \frac{g}{L_n})$$

without gyroviscosity $\nu = 0$: MHD growth rate is

$$\omega^2 = -[\frac{g}{L_n} + \frac{g^2}{(c_s^2 + V_A^2)}] = -\gamma_{MHD}^2$$

For uniform magnetic field and non-isothermal:

$$\omega^2 + \omega^* \omega + \gamma_{mhd}^{*2} = 0$$

where,

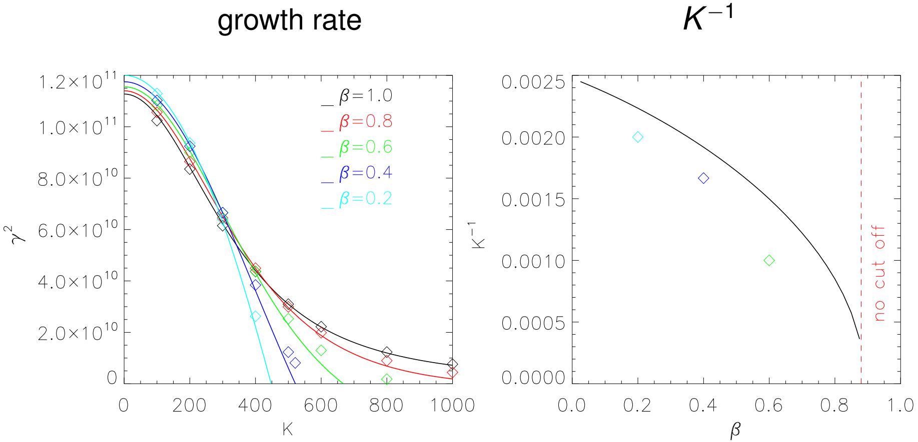
$$\omega^* = -2\nu k \frac{\left(\frac{1}{L_n} + \frac{1}{L_T} + \frac{g}{(c_s^2 + V_A^2)}\right)}{\left(1 + \frac{\nu^2 k^2}{(c_s^2 + V_A^2)}\right)} = -k \frac{\left(-2\frac{g}{\Omega} + \frac{\beta g}{2\Omega(1+\Gamma\beta/2)}\right)}{\left(1 + k^2 \rho_L^2 \frac{\beta}{16(1+\Gamma\beta/2)}\right)}$$

and

$$\gamma_{MHD}^{*2} = \frac{\frac{g}{L_n} + \frac{g^2}{(c_s^2 + V_A^2)}}{1 + \frac{\nu^2 k^2}{(c_s^2 + V_A^2)}} = \frac{\frac{g}{L_n} + \frac{g^2}{(c_s^2 + V_A^2)}}{\left(1 + k^2 \rho_L^2 \frac{\beta}{16(1+\Gamma\beta/2)}\right)}$$

In the limit of incompressible plasma, $\Gamma \to \infty$, and $L_T \to \infty$, Roberts & Taylor is recovered, $\omega^* = -k\rho_L^2\Omega/2L_n$.

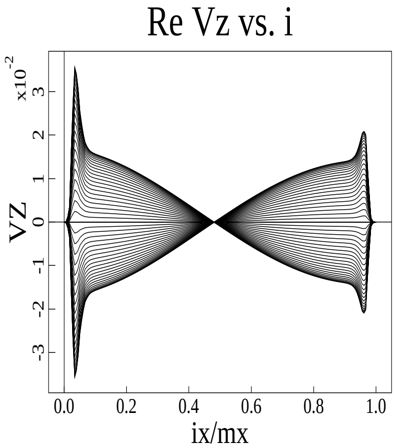
Results



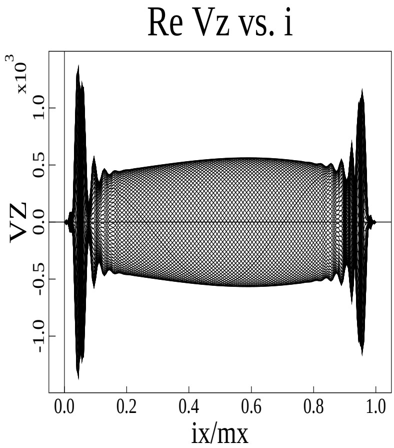
- solid lines analytic ; symbols nimrod
- $\beta = 0.6 - 0.8$ at high k reveal oscillatory behavior (convergence study underway)

Some examples of mode structure with gyroviscosity at high k (k=800)

MHD$(\omega^*/\gamma^*_{mhd} = 0)$

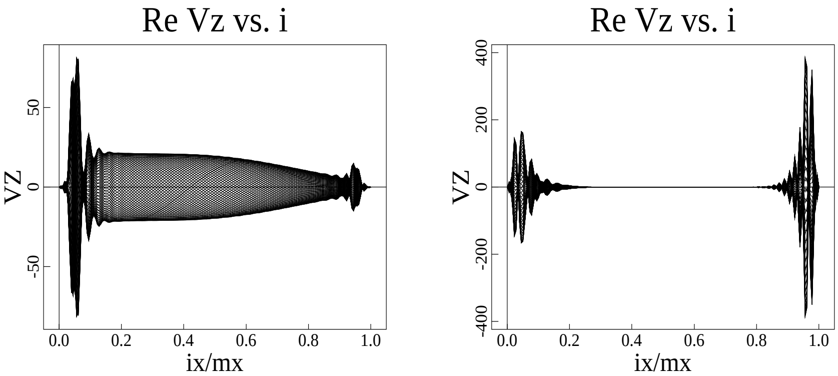


$\beta = 1$ $(\omega^*/\gamma^*_{mhd} = 0.8)$



Some examples of mode structure with gyroviscosity at high k (k=800)

$\beta = 0.8 (\omega^*/\gamma^*_{mhd} = 1.)$ $\beta = 0.6\ (\omega^*/\gamma^*_{mhd} = 1.5)$



might need more spatial resolution.

Possible next steps

- gyroviscosity effect at high k
- FLR effect on $k_{||}$ modes, quasi-interchange (Suzuki)