GYRO-KINETIC SIMULATION OF ENERGETIC PARTICLE DRIVEN TAE MODES

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GENERAL ATOMICS

OUTLINE

- **Motivation and Introduction**
  - Energetic Particles Expected to Induce New Instabilities
  - Significantly Affect the Nature of Turbulence and Transport
  - The Gyro-Code and Assumptions in the Simulation
- **Very Localized TAE Modes**
  - Identification of the TAE Mode
  - Dependence of ω and γ on density gradient of α and toroidal mode number n
  - Dependence of ω and γ on β of background
- **More Extended TAE Modes**
  - Identification of the extended TAE mode with zero boundary condition
  - Comparison with NOVA
  - Dependence of ω and γ on magnetic shear and α density gradient
  - Dependence of ω and γ on density and thermal velocity of α
- **Conclusion**

Energetic Particles are expected to significantly affect the Turbulence and Transport in Reacting Plasmas

- In reacting plasma, the α particles have been predicted to interact with the Alfven waves and excite the TAE Modes
- The dynamics of α particle motion is at a different length scale – ρ_{α} and is expected to introduce a new scale to the electrostatic and electromagnetic instabilities and transport
- In order to understand transport in a reacting plasma, we need to include the α particles self-consistently in simulations of turbulence
- The present work is a first effort in this direction. We study the TAE modes (and other modes) with full dynamics of the background electrons and ions

THE GYRO CODE AND SIMULATION MODEL

GYRO

- Nonlinear gyrokinetic –Maxwell equations
- Employs time-explicit, Eulerian numerical scheme
- Drift-kinetic electrons
- Profile variations allowed
- Transverse electromagnetic effects included
- Benched against analytic theory, linear eigenmode codes, nonlinear electrostatic PIC codes
- $\beta/\beta crit < 0.5$

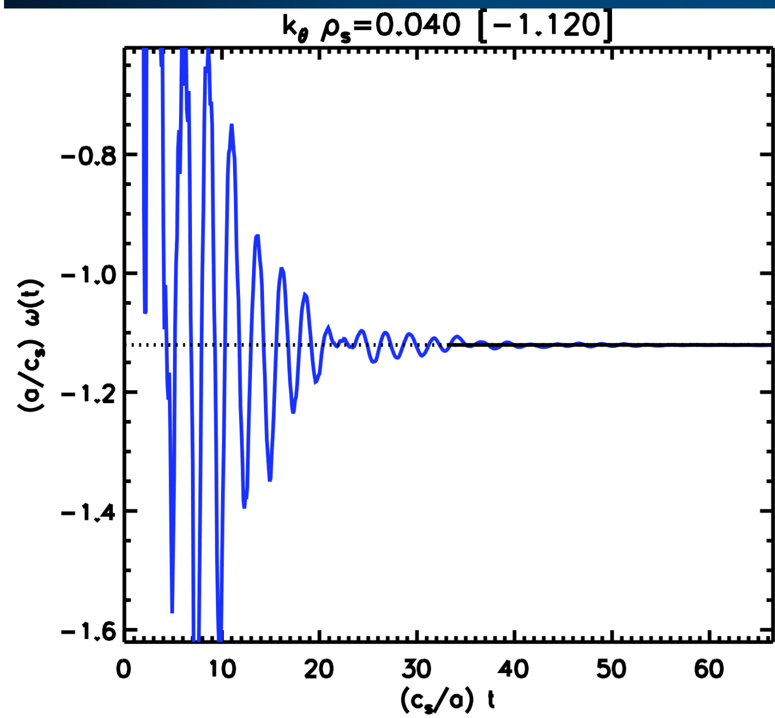
J. Candy, R.E. Waltz, JCP 186 545 (2003)

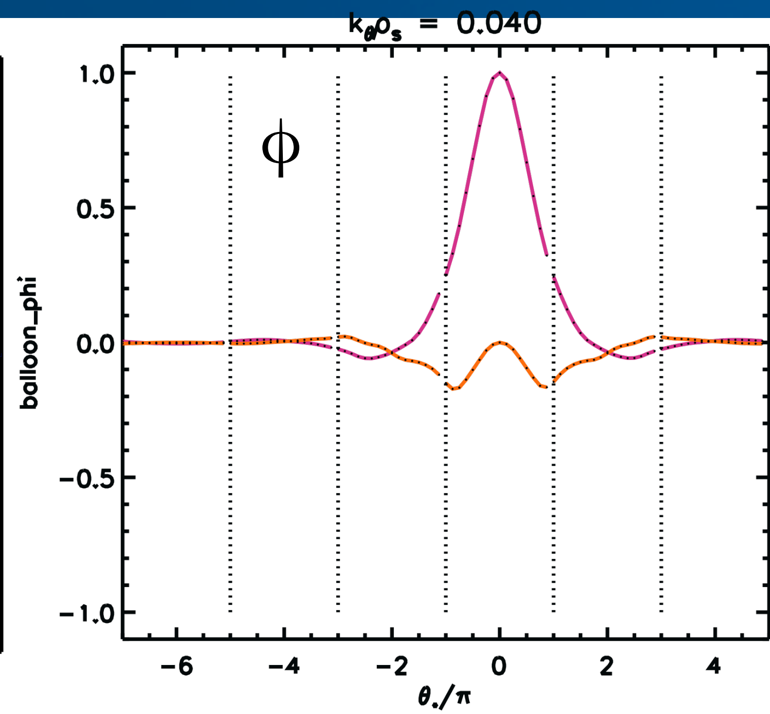
SIMULATION MODEL

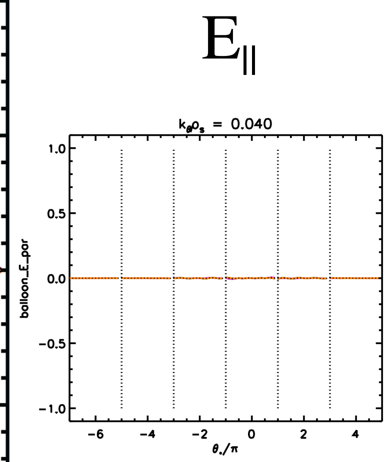
- Maxwellian α particle distribution
- Flux tube in a circular plasma
- T_e=T_i=constant: no plasma temperature gradient
- N_e=constant :flat background density profile.

- **Simulation Results for a Thin Flux Tube**

Identification of the TAE Mode in Thin Flux Tube







$$q=2,\ s=\frac{r}{q}\frac{dq}{dr}=1,\ D_\alpha=\frac{a}{n_\alpha}\frac{dn_\alpha}{dr}=4,\beta_e=2\%,\ \frac{T_\alpha}{T_e}=100,\frac{n_\alpha}{n_e}=.5\%,\ \frac{\rho_s}{a}=.25\%\quad\frac{\rho_\alpha}{a}=2.5\%$$

$$R/a=3,\ r_1/a=.46875,\ r_2/a=.520833,\ \frac{v_\alpha}{v_A}=1,\text{s-}\alpha\ \text{equilibrium},\ \frac{\gamma a}{c_s}\sim .11$$

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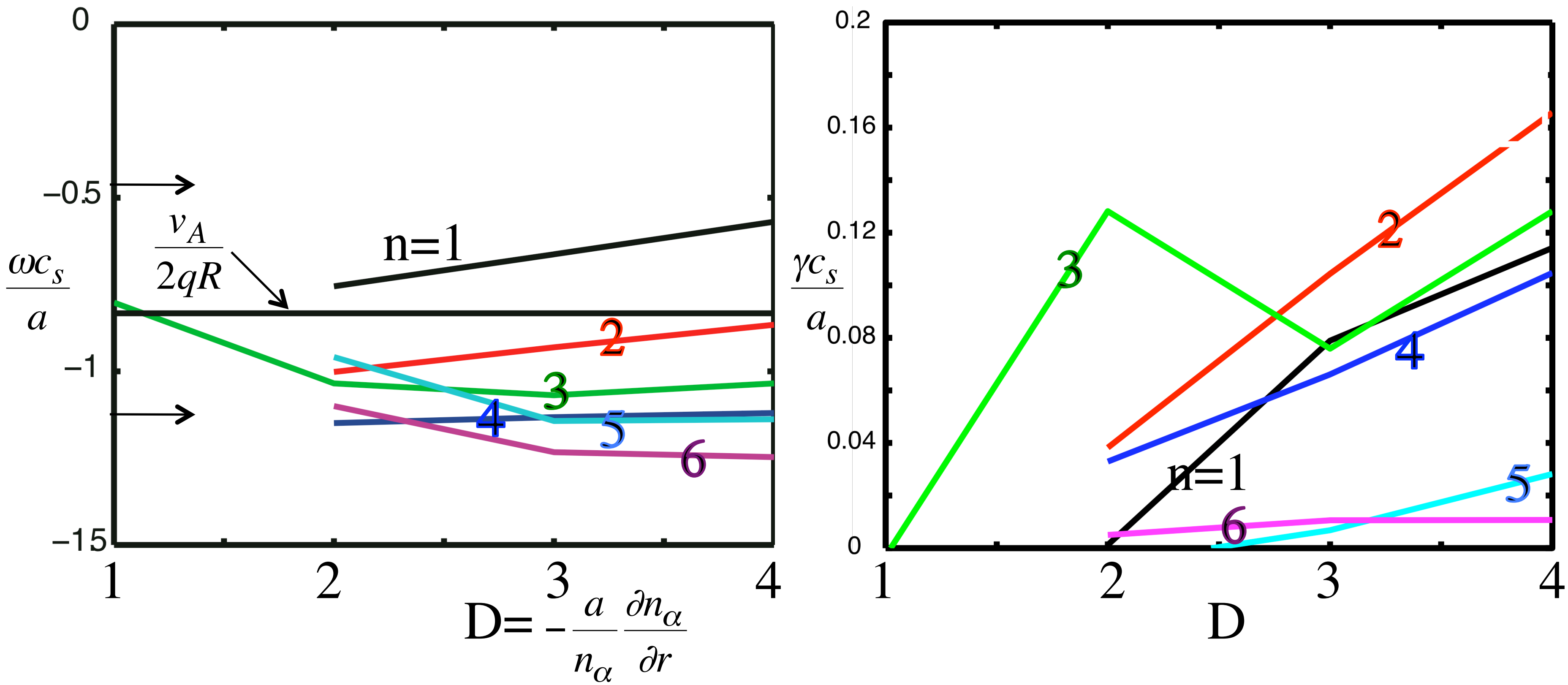
Dependence of ω, γ of TAE on density gradient of α particles and toroidal mode number n



Higher α density gradient leads to lower frequency at low n, but gradually an increase in frequency at higher n

Higher α density gradient in general leads to larger growth rate

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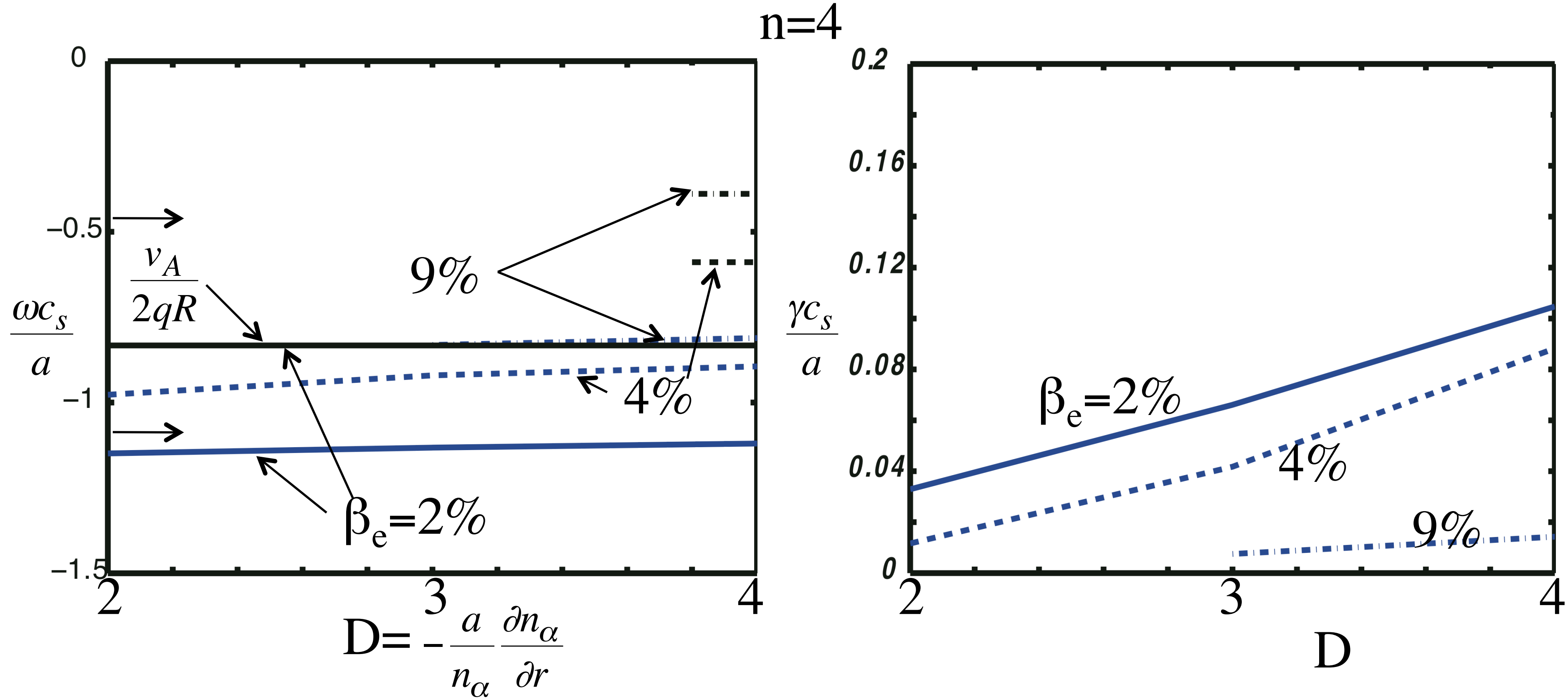
Dependence of ω and γ of TAE on β of Background Plasma



Increase in background β leads to higher ω but lower γ
indicating a modification of the gap frequency and increase in damping

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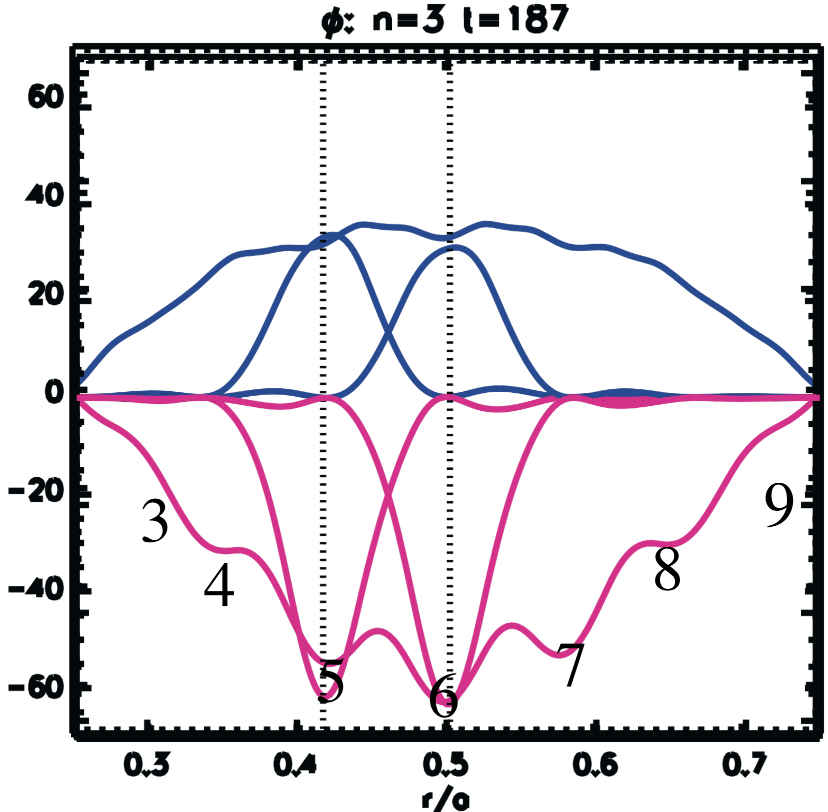
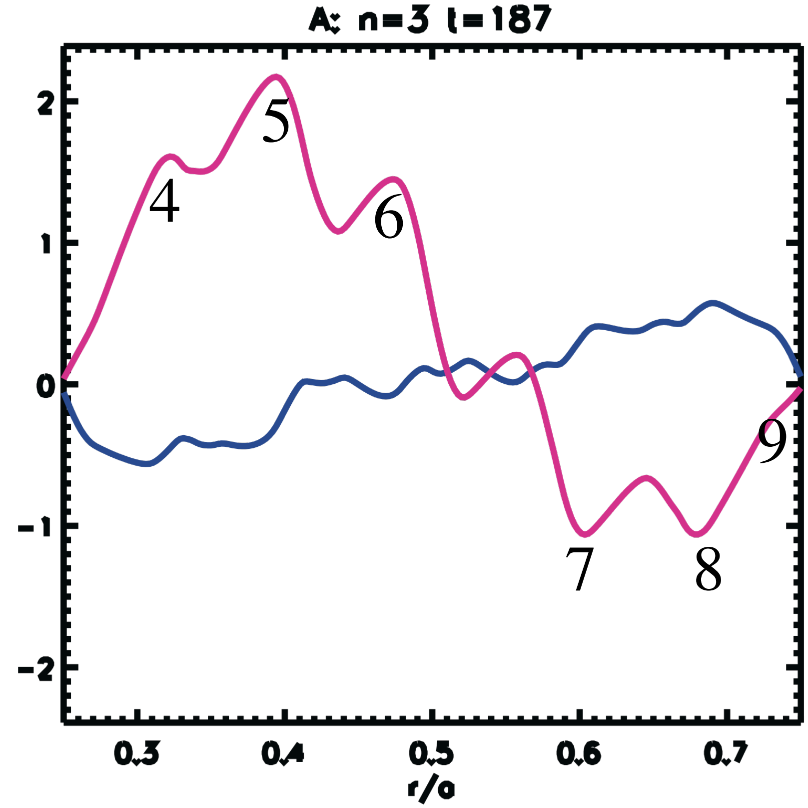
- **Simulation Results for a Thick Flux Tube**

Identification of the TAE Mode in a Thick Flux Tube





q=1-3, s= $\frac{r}{q}\frac{dq}{dr}$ =1, $D_\alpha = \frac{a}{n_\alpha}\frac{dn_\alpha}{dr}$ =8, β_e=2%, $\frac{T_\alpha}{T_e} = 100$, $\frac{n_\alpha}{n_e} = .5\%$, $\frac{\rho_s}{a} = .25\%$

R/a=3, $\frac{v_\alpha}{v_A} = 1$, $\frac{\rho_\alpha}{a} = 2.5\%$, $k_\vartheta \rho_s = .03$, Miller type equilibrium

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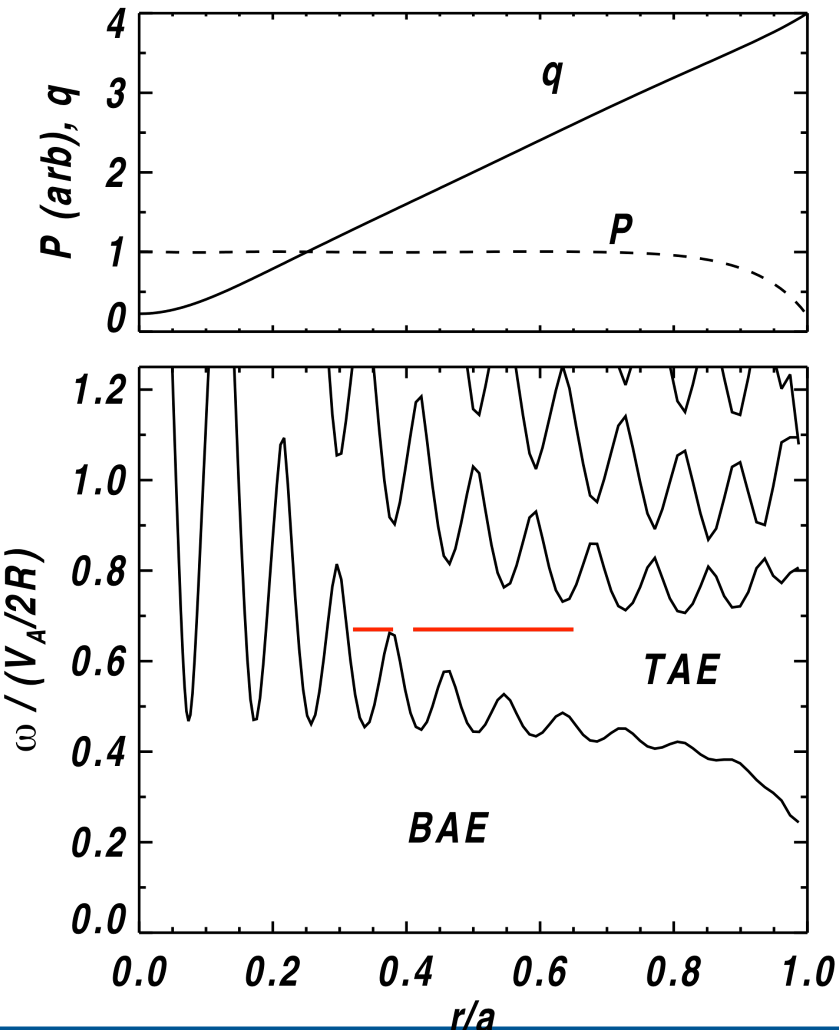
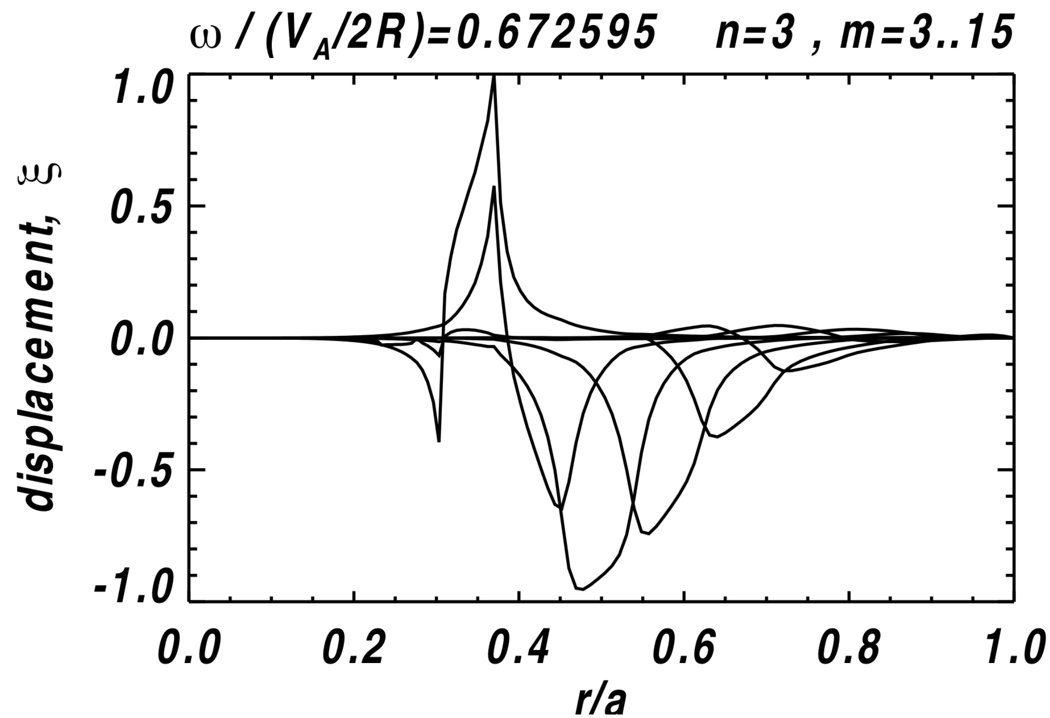
Comparison with Results from NOVA

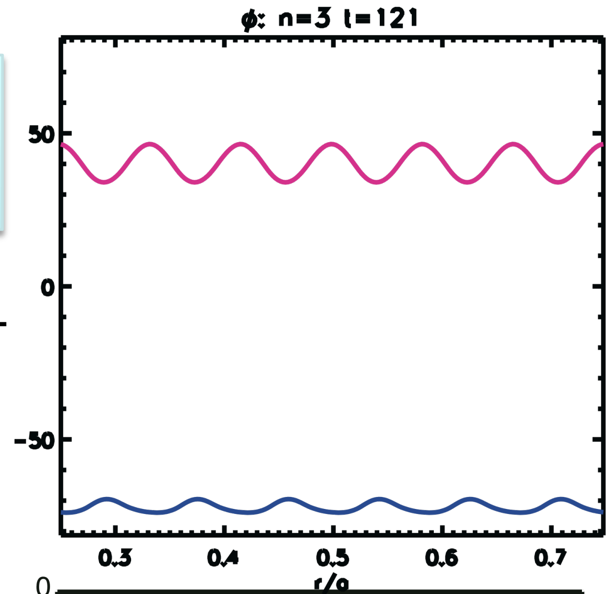


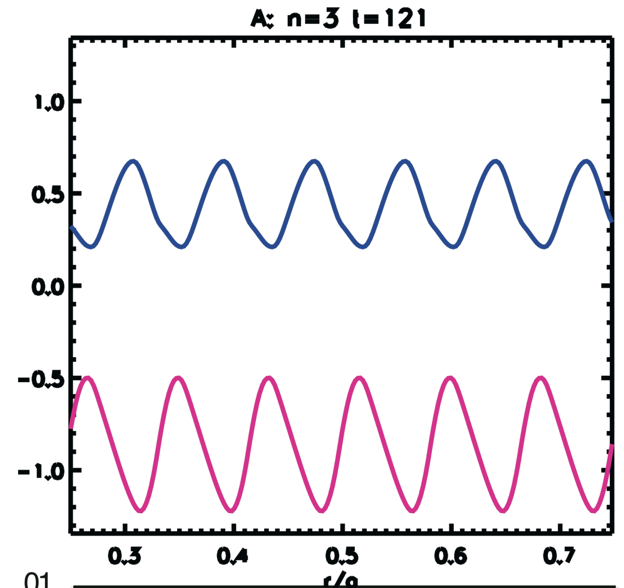


Courtesy of M. VanZeeland

Effect of Boundary Condition and Dependence of ω and γ on Density Gradient of α

Periodic B.C.

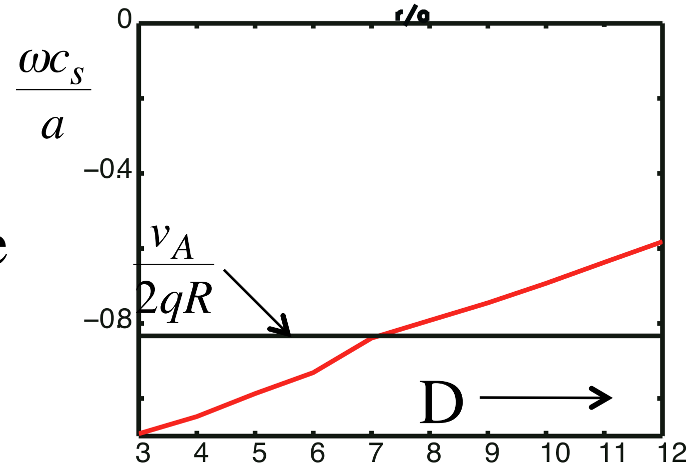


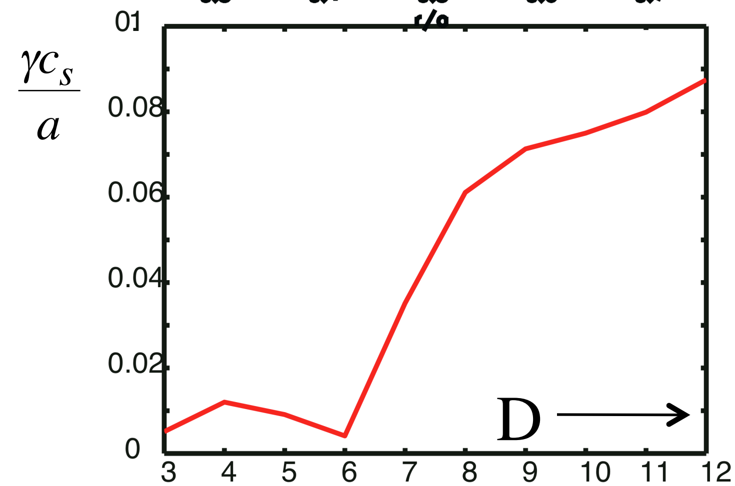


ω=.766, γ=.1004

vs

ω=.792, γ=.0611





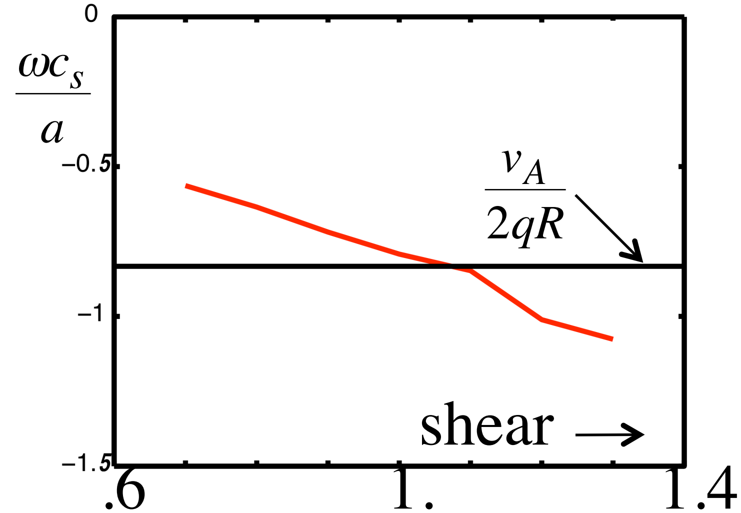
Higher drive lowers ω increases γ

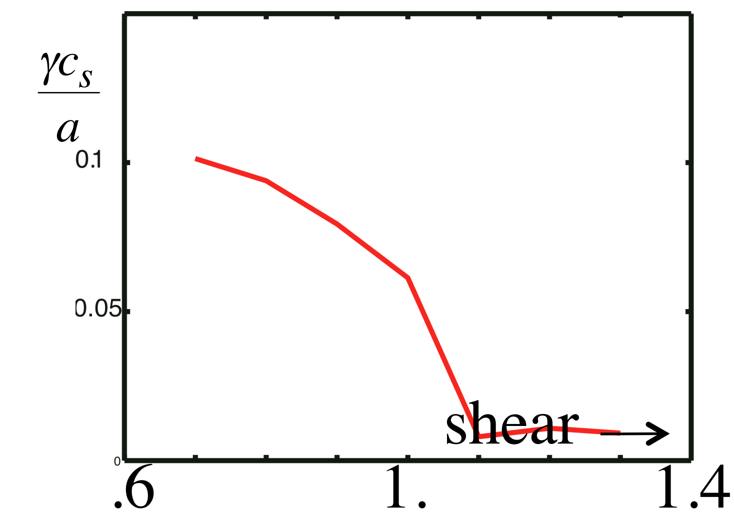
Dependence of ω and γ on shear and toroidal mode number n

β_e=2%

n=3

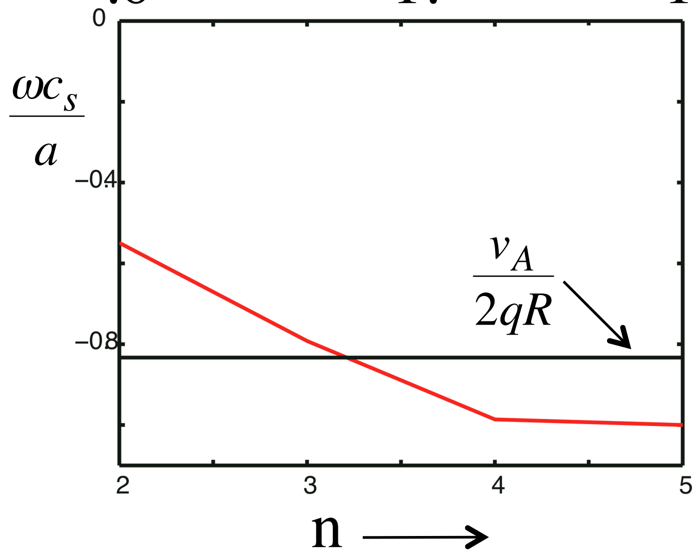
increase in s
increases ω
lowers γ

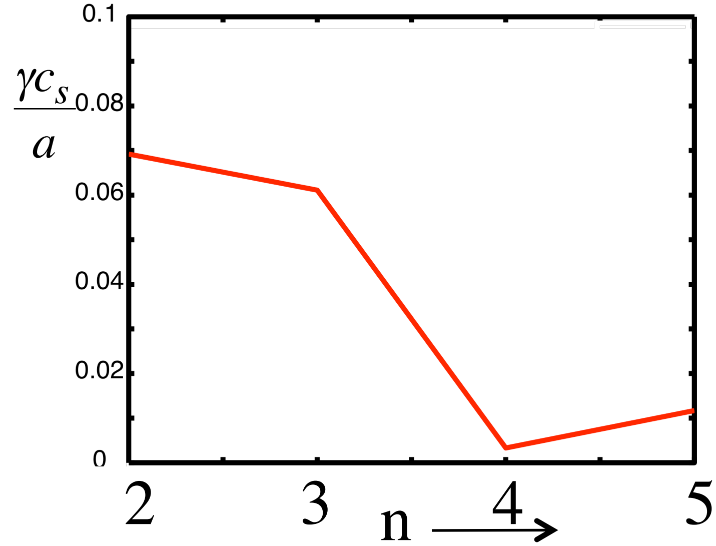




shear=1

increase in n
increases ω
lowers γ



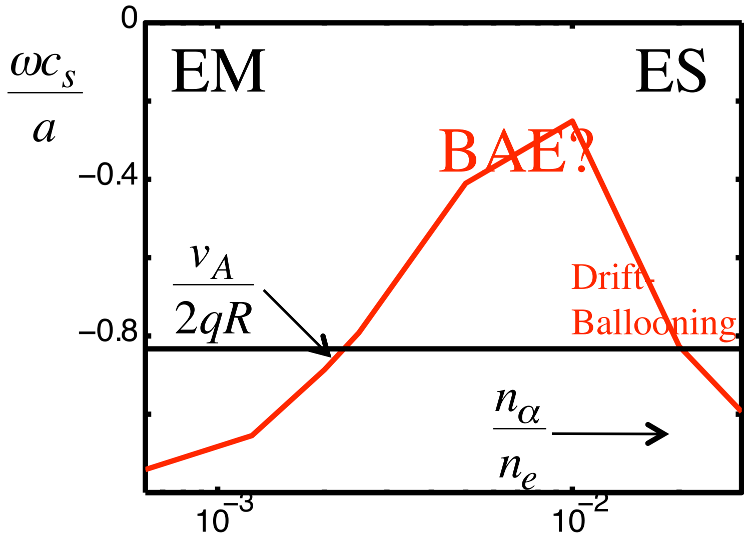


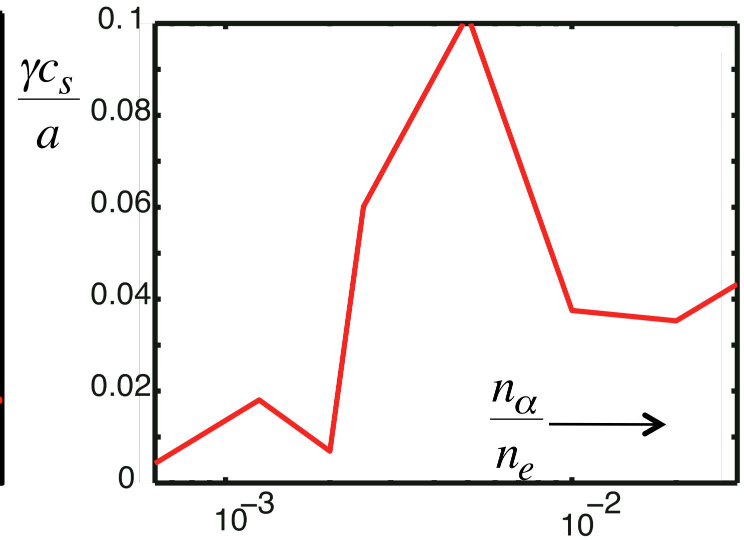
Dependence of ω and γ on density and thermal speed of α

$\frac{v_\alpha}{v_A} = 1$

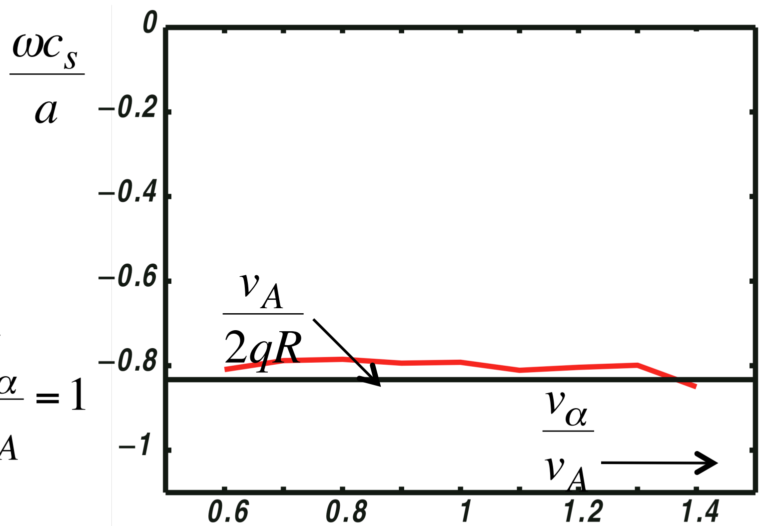
low $\frac{n_\alpha}{n_e}$ EM

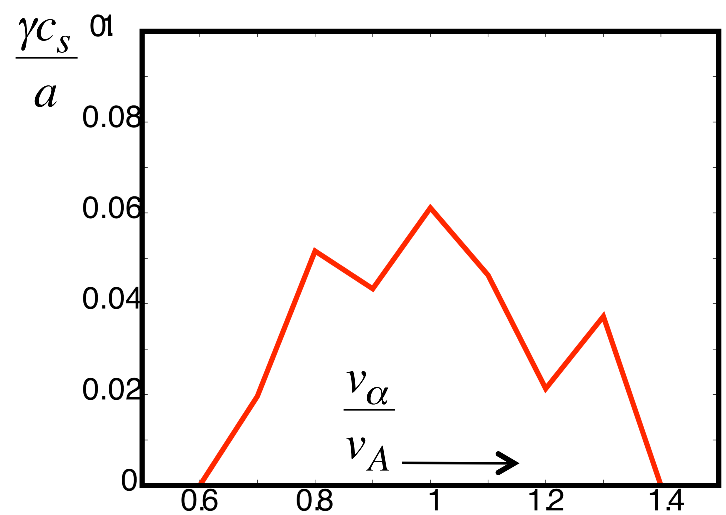
high $\frac{n_\alpha}{n_e}$ ES





$\frac{n_\alpha}{n_e} = .25\%$





growth rate highest if $\frac{v_\alpha}{v_A} = 1$

Conclusion

- TAE Mode driven by α particles with a Maxwellian distribution has been identified in a full kinetic plasma simulation using GYRO.
- The dependence of the frequency ω and growth rate γ on various relevant plasma and α particle parameters have been studied and shown to follow the predictions from previous MHD theories.
- The new added features of the simulation is that the parallel electric field does not have to be zero and also allow the interaction of the TAE mode with other instabilities.
- The next step is to include more reality of the plasma conditions: full plasma geometry, general α distribution function, nonlinear plasma-mode interactions.