Simulation of Reverse Shear Alfven Eigenmodes using a gyrokinetic ion/fluid electron hybrid model

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Simulation Center

Outline

- Fluid electron model in GEM
- Experimental observation of RSAE in DIII-D
- GEM linear simulation results
- Conclusion

Mass-less fluid electrons

Electron continuity equation:

$$\frac{\partial n_e}{\partial t} + n_0 B \nabla_{\parallel} \frac{u_{\parallel e}}{B} + v_E . \nabla n_0 + \frac{1}{m_e w_e B^2} B \times \nabla B . \nabla (dp_{\perp} + dp_{\parallel}) + \frac{2 n_0}{B^3} B \times \nabla B . \nabla \phi = 0$$

Evolution equation for vector potential: $\frac{\partial A_{\parallel}}{\partial t} = -E_{\parallel} - \nabla_{\parallel} \phi$

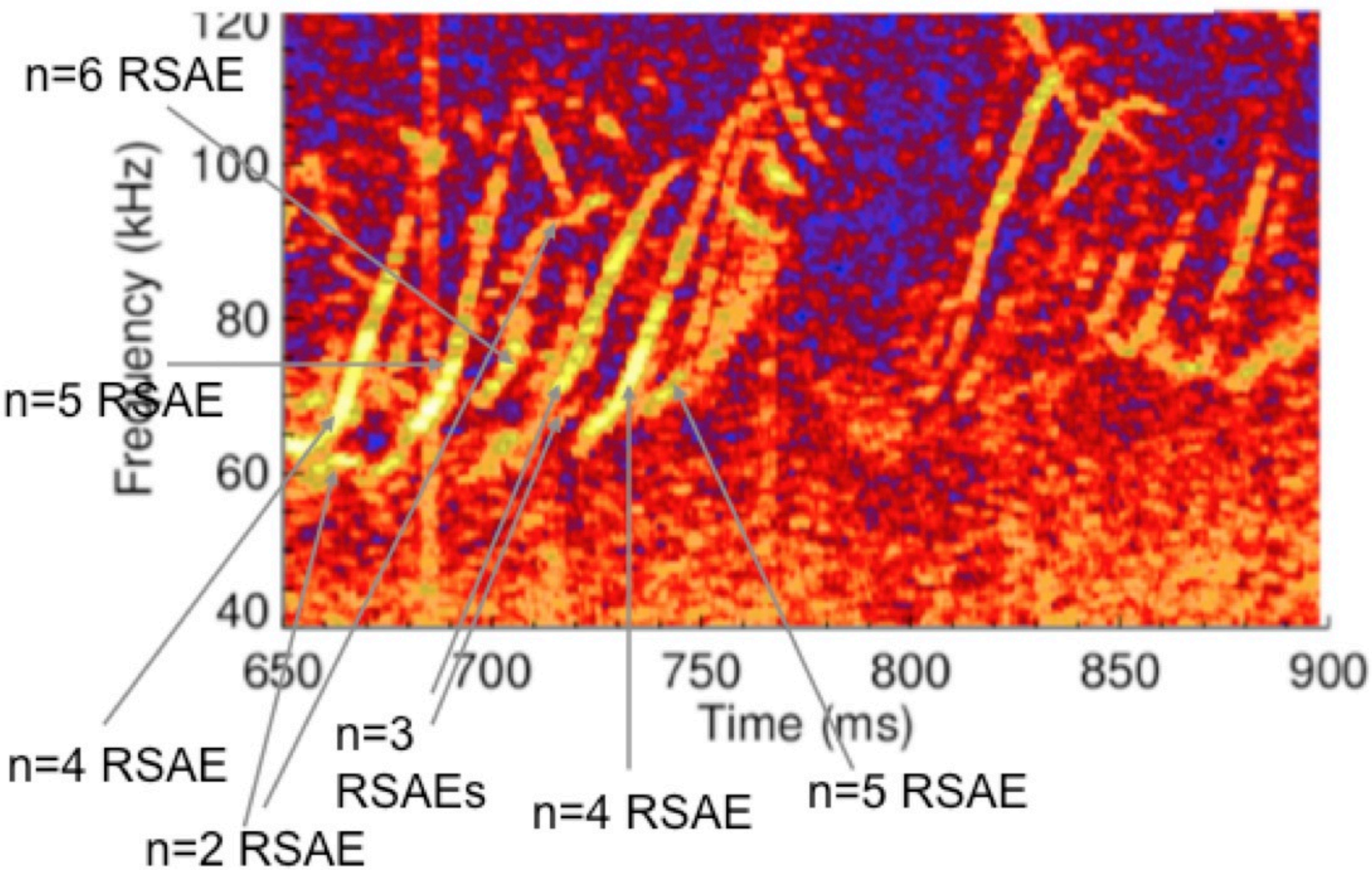
Ohm's law: $e n_0 E_{\parallel} = -\frac{\delta B_{\perp}}{B} . \nabla p_0 - b . \nabla \delta p_{\parallel e}$

Solve Ampere's law backwards: $u_{\parallel e} = \nabla_{\perp}{}^2 A_{\parallel} + u_{\parallel i}$

Obtain ϕ from quasi-neutrality

Gyrokinetic thermal ions and alpha particles -> $u_{\parallel i}$, δn_i

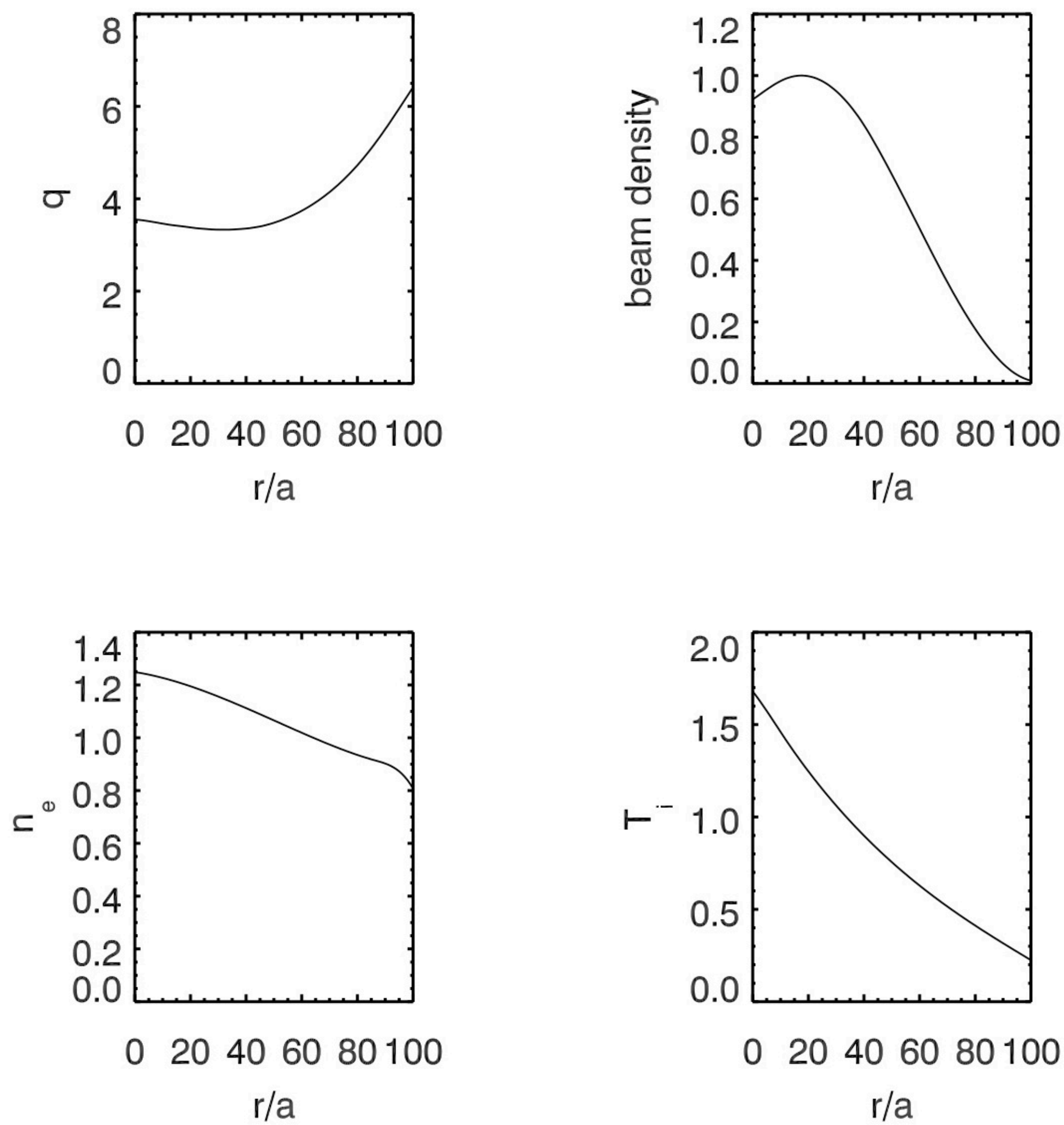
- DIII-D Shot #142111, t=725ms
- B0=2.01254 Tesla, a=0.63m, R0=1.65m
- Elongation=1.6, triangularity=0.08
- Main ion D, beam D



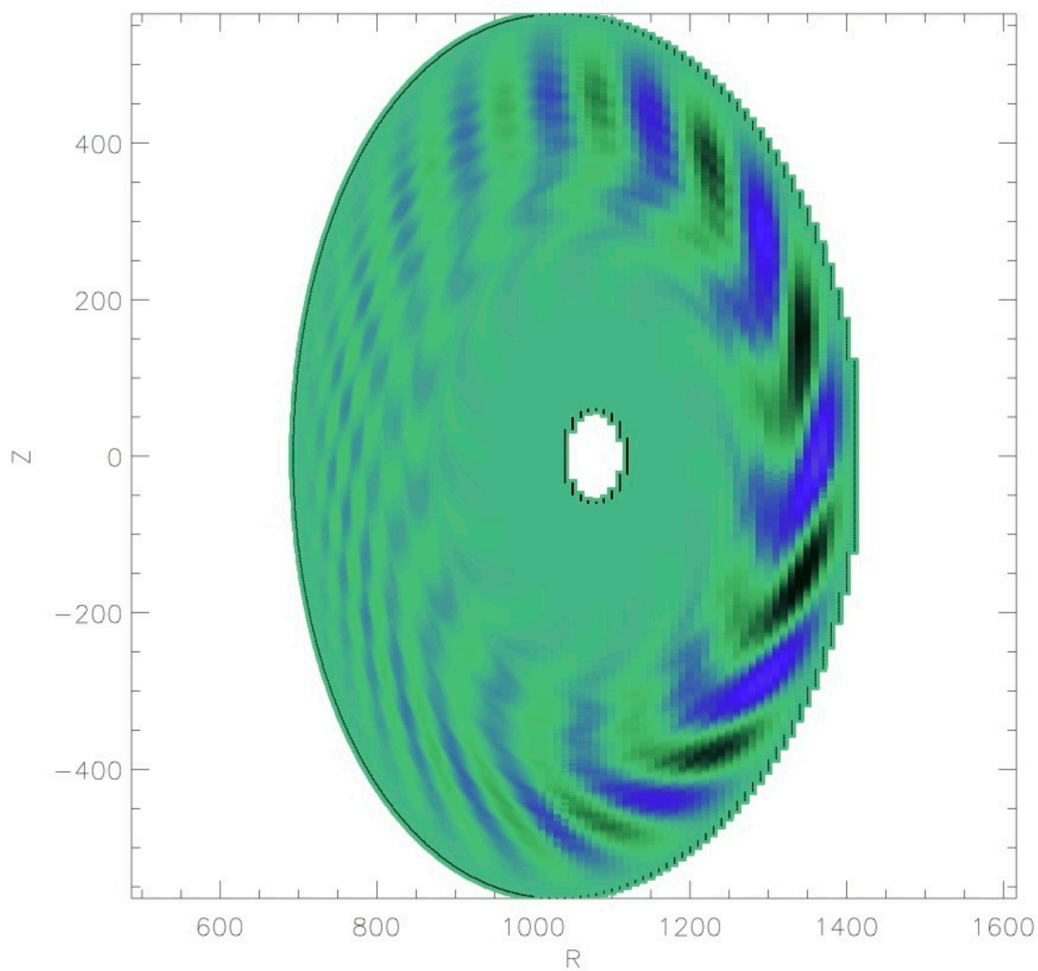
From M. Van Zeeland

Simulations are done for n=3 at t=725ms

Experimental profiles from TAEFL.142111.725.inp

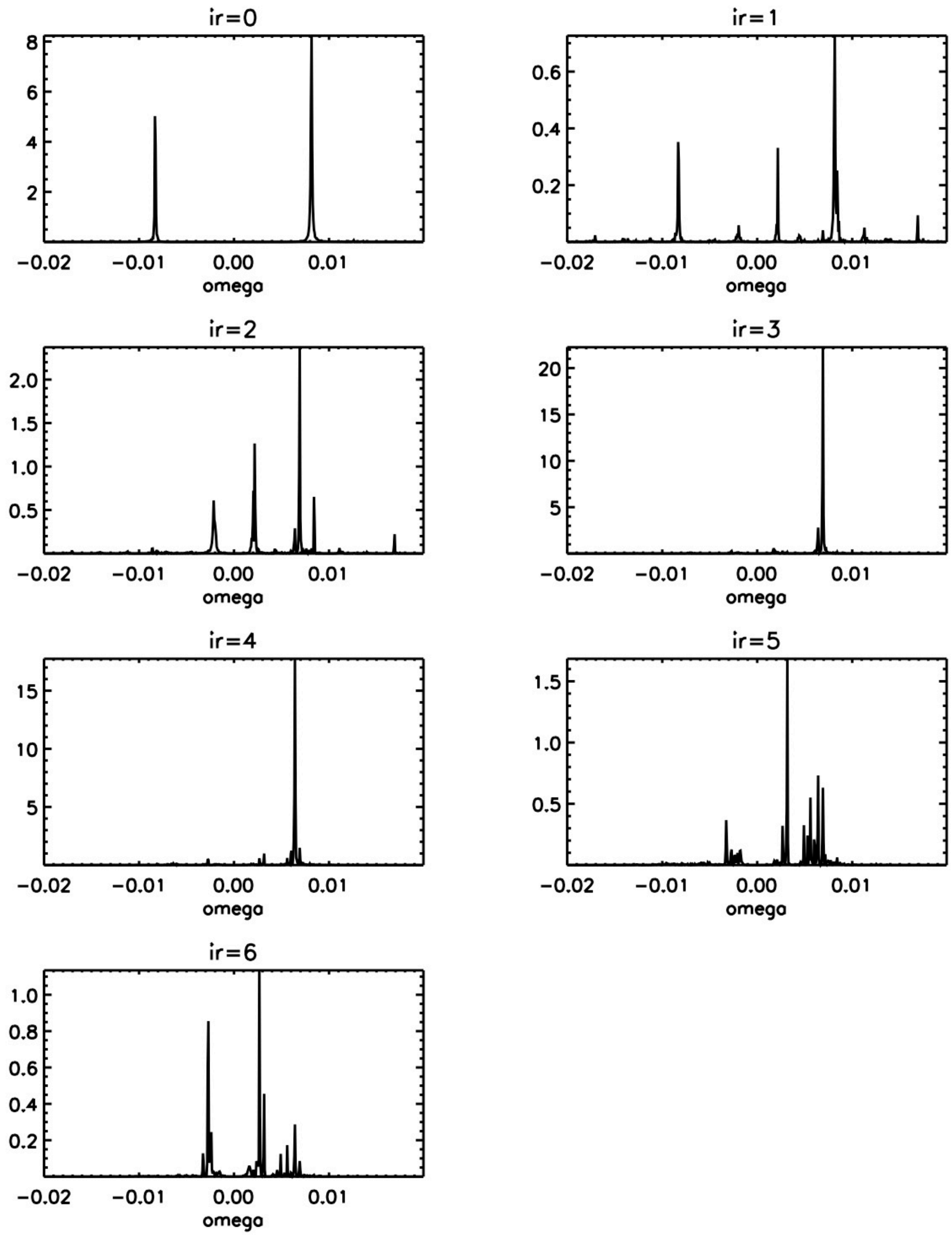


With experimental beam density, mode localized near r/a~0.75, f~56KHz

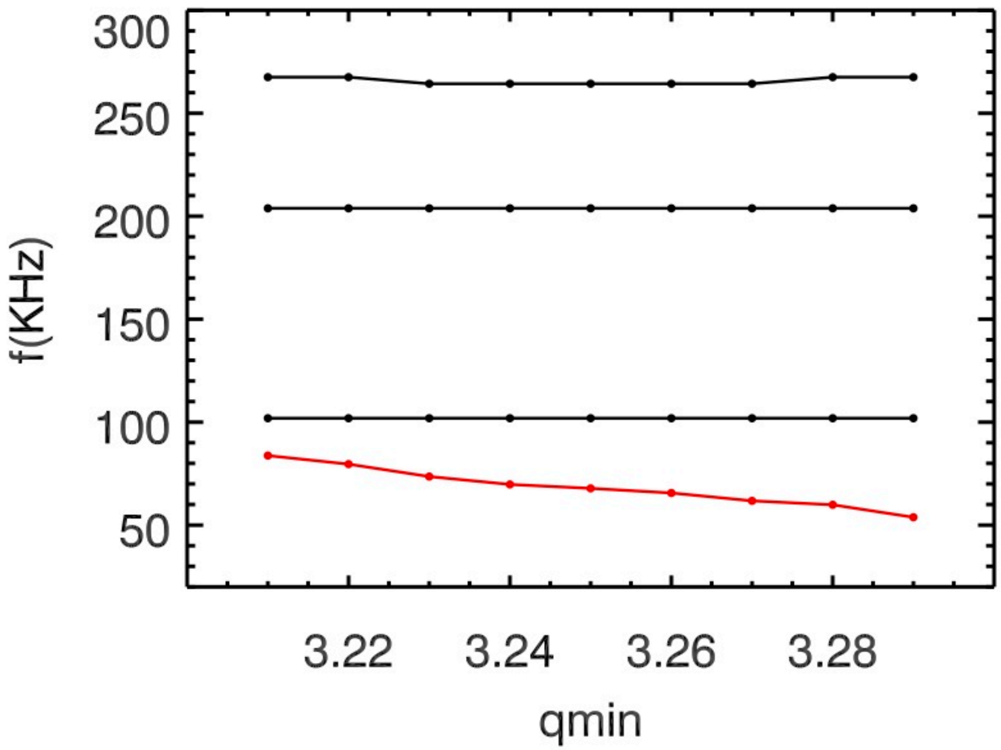


Are there chirping modes when beta_beam=0?

- Set $\beta_{beam} = 0$,
- Vary q(r) by adding a small constant
- Fourier transform $\phi(r_i, n = 3, \theta = 0, t)$ in time to find eigenmode frequencies


ir=0
ir=1
ir=2
ir=3
ir=4
ir=5
ir=6
omega
−0.02
−0.01
0.00
0.01

Only the lowest frequency wave chirps

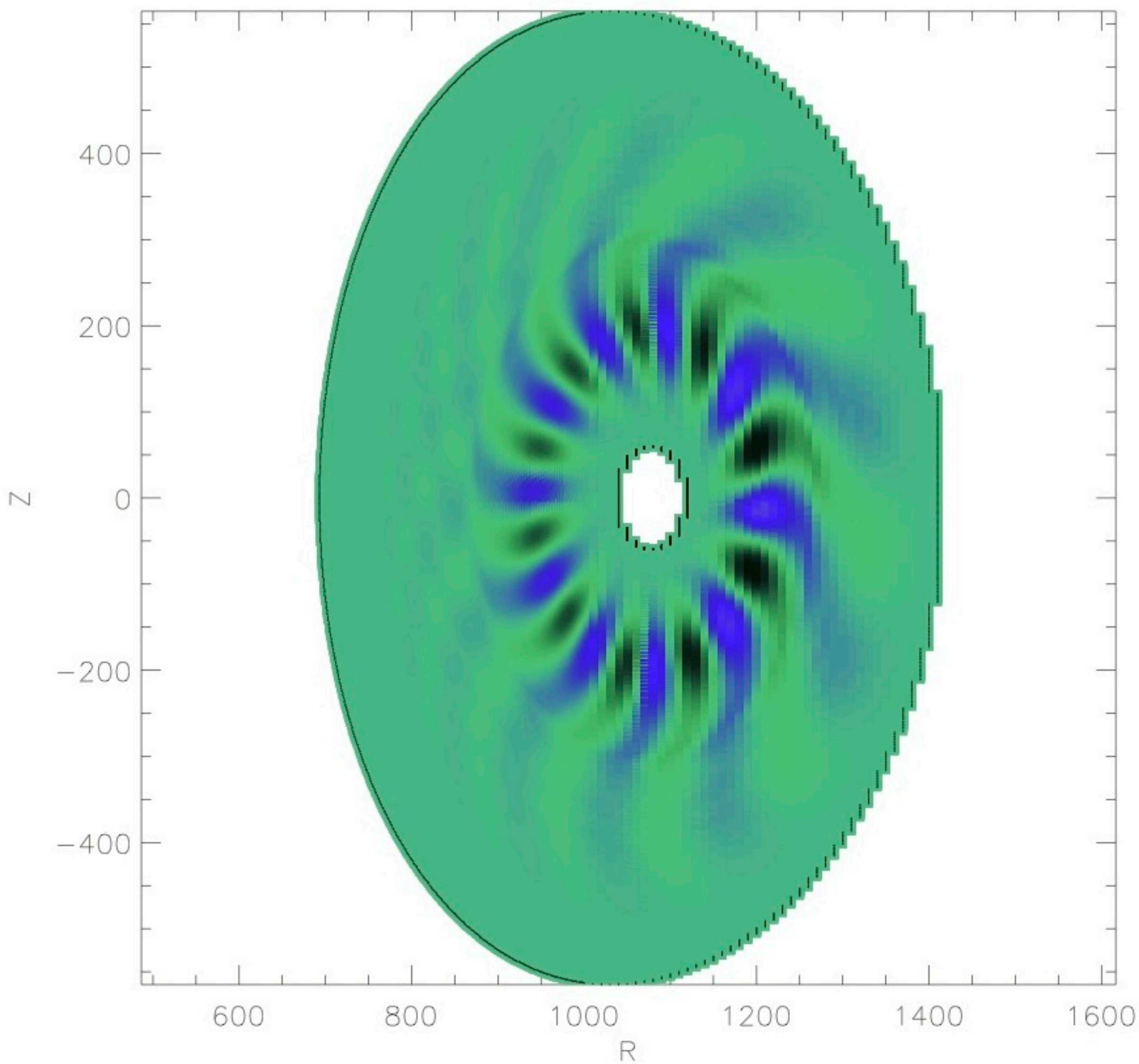


Can RSAE be exicited?

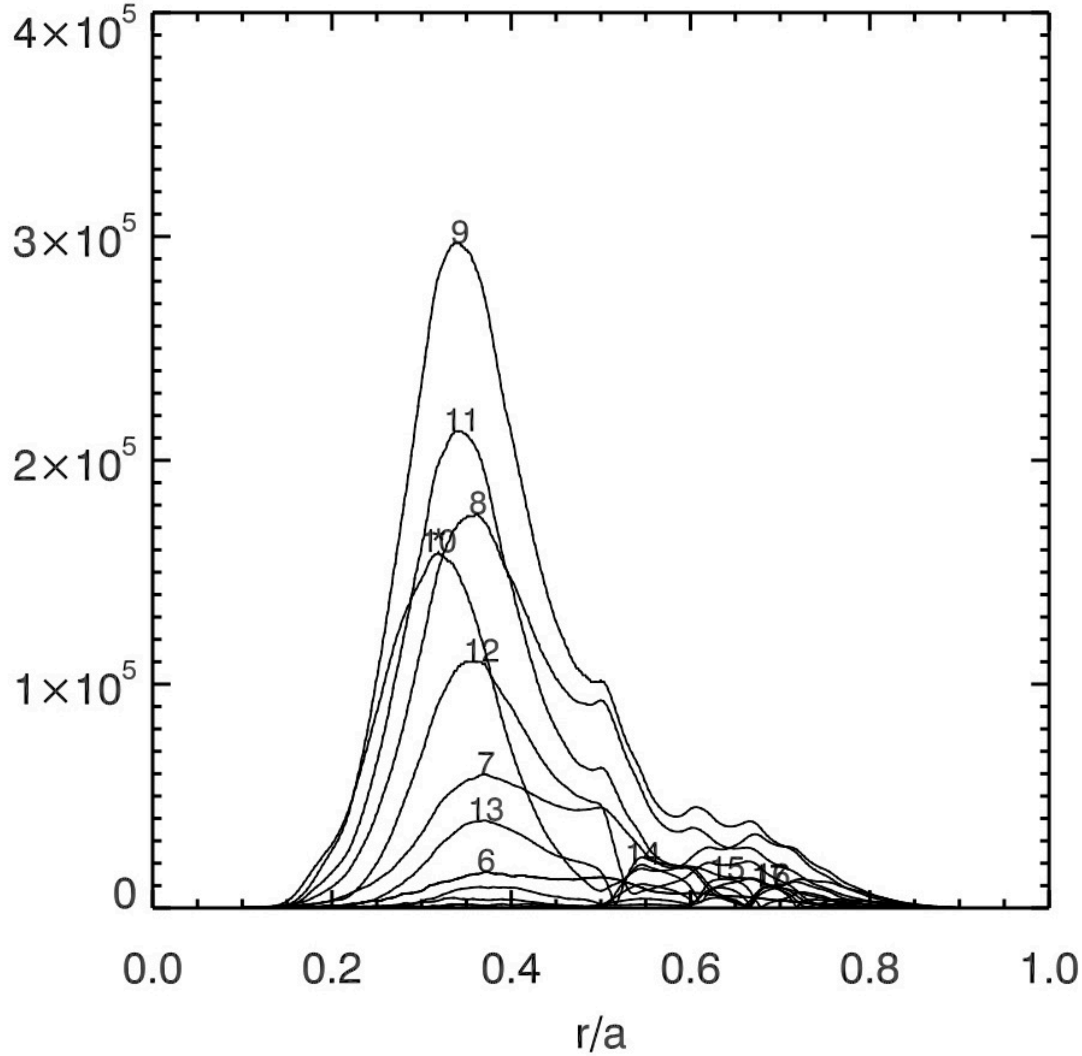
- Modify beam distribution according to

$$\beta_{beam}(r) = \beta_{beam}^{taefl}(r)\ \exp(-1.3r/a)$$

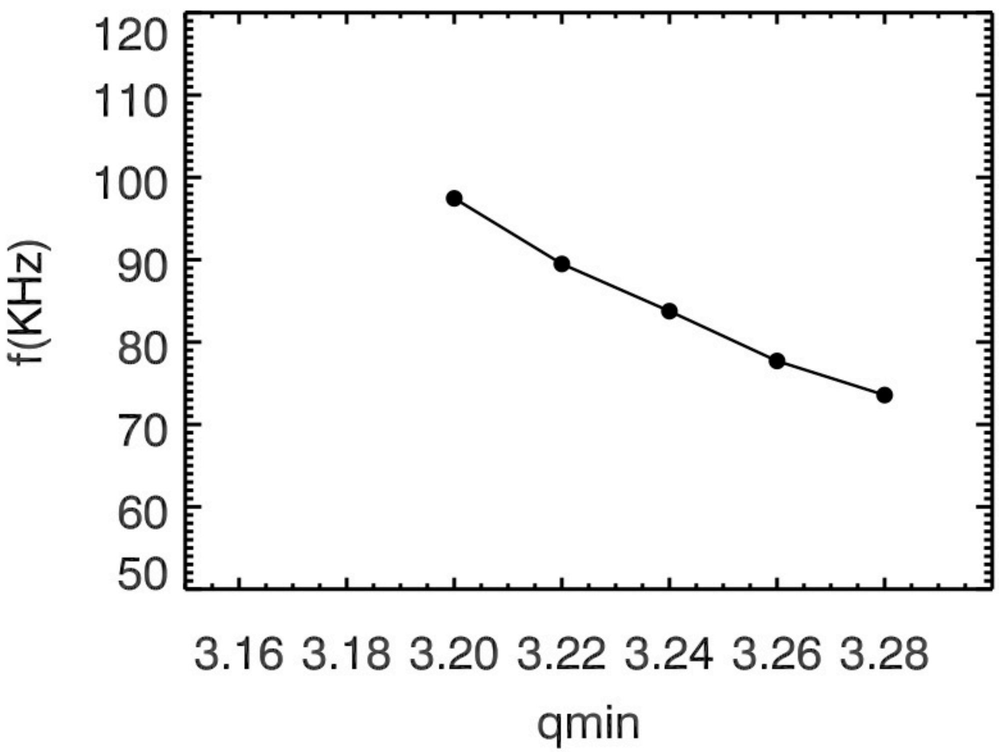
$q'(r) = q(r)-0.05$



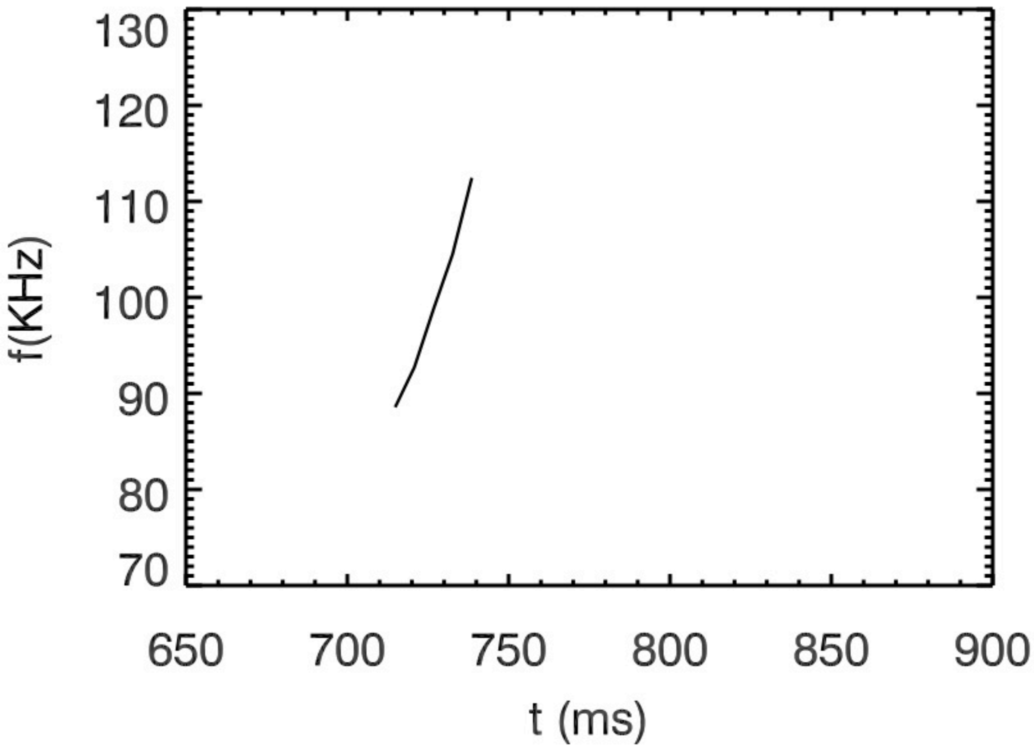
Mode not dominated by a single poloidal harmonics



Frequency vs. qmin



Chirping in time, Dopler shift of 15KHz assumed



$$q_{\min} = -0.00337(t - 700) + 3.33$$

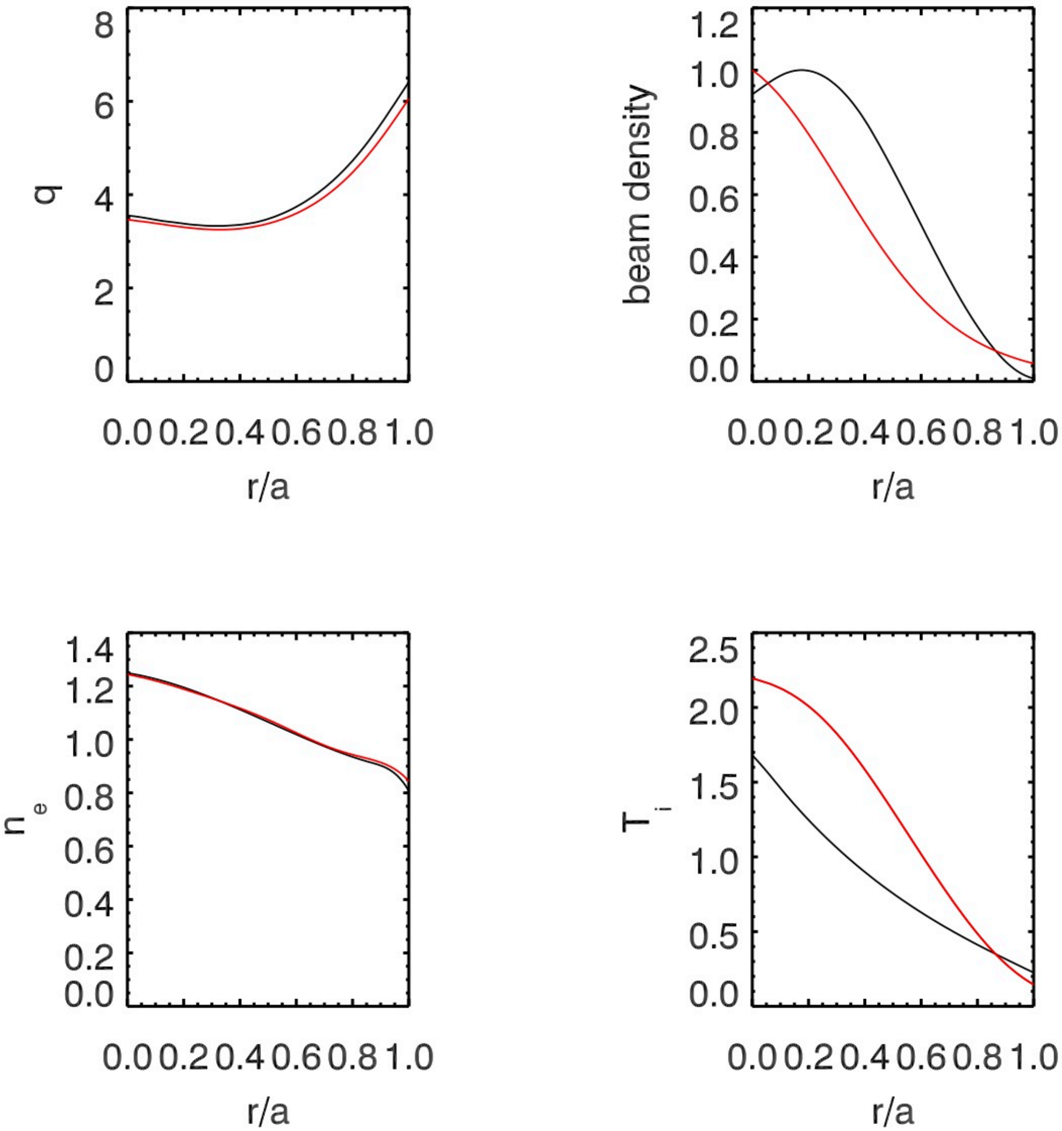
For a change of Δqmin=0.08, f chirp range=25KHz, comparable to experiment

Verification with M3D-K

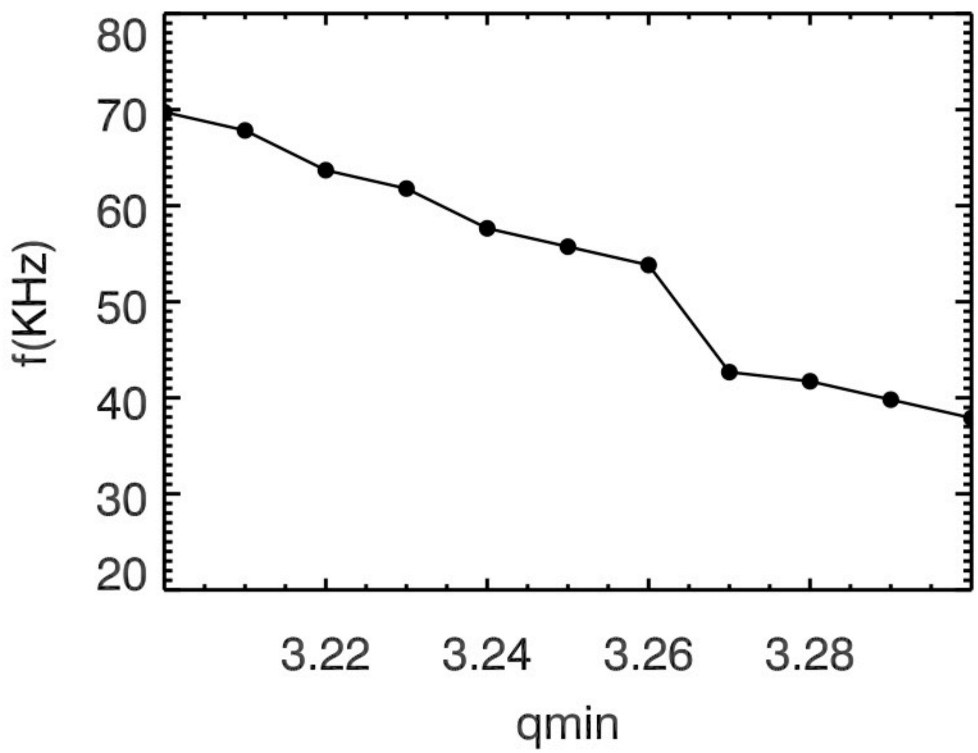
Use the same magnetic equilibrium, density and pressure profiles as in M3D-K

An analytic beam distribution

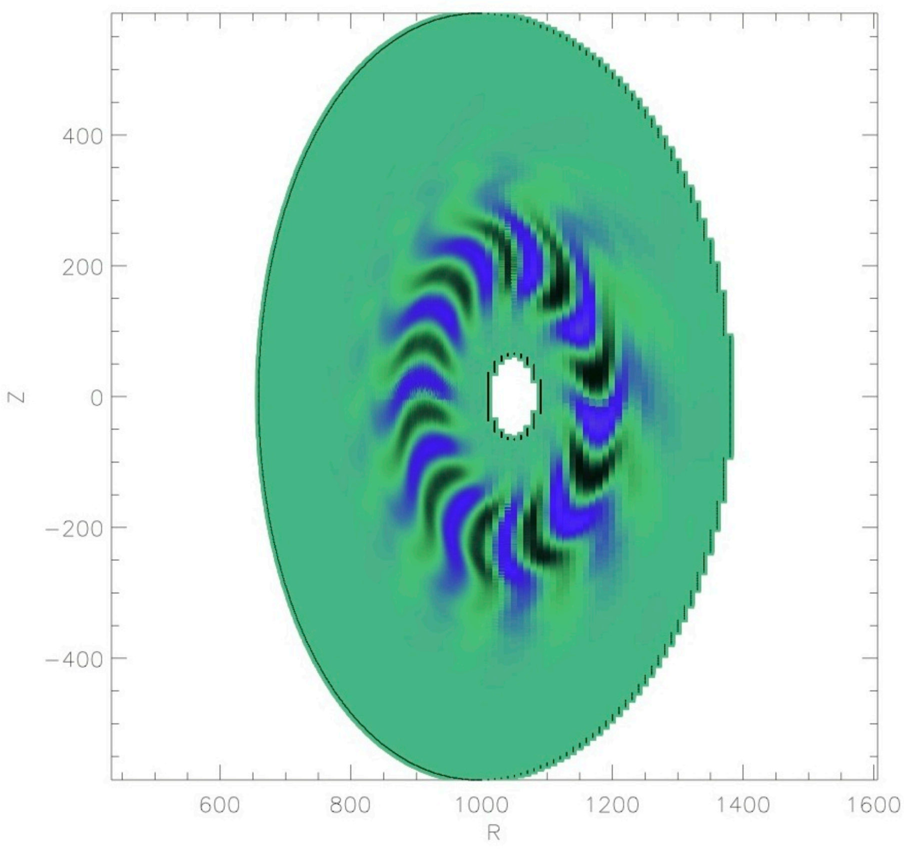
$$f = \left[1 + erf\left(\frac{v_i - v}{v_A/0.1}\right)\right]\exp(P_\varphi/0.25)$$


q
0
2
4
6
8
0.0
0.2
0.4
0.6
0.8
1.0
r/a
beam density
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0.0
0.2
0.4
0.6
0.8
1.0
r/a
n
e
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
0.0
0.2
0.4
0.6
0.8
1.0
r/a
T
i
0.0
0.5
1.0
1.5
2.0
2.5
0.0
0.2
0.4
0.6
0.8
1.0
r/a

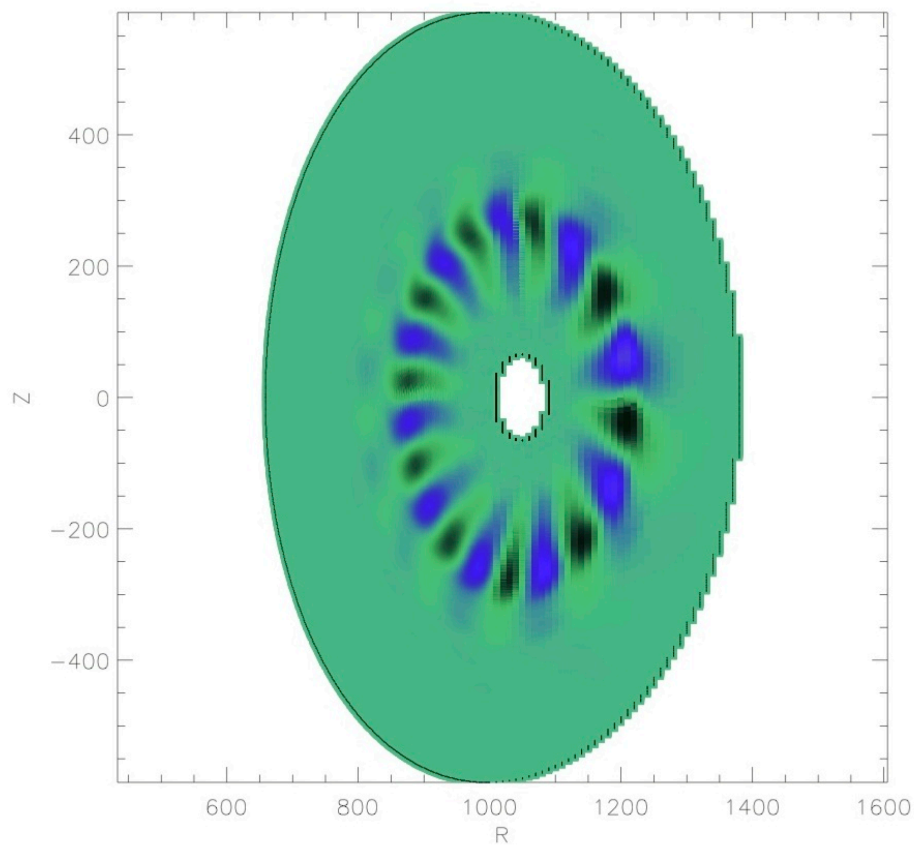
Frequency vs. qmin



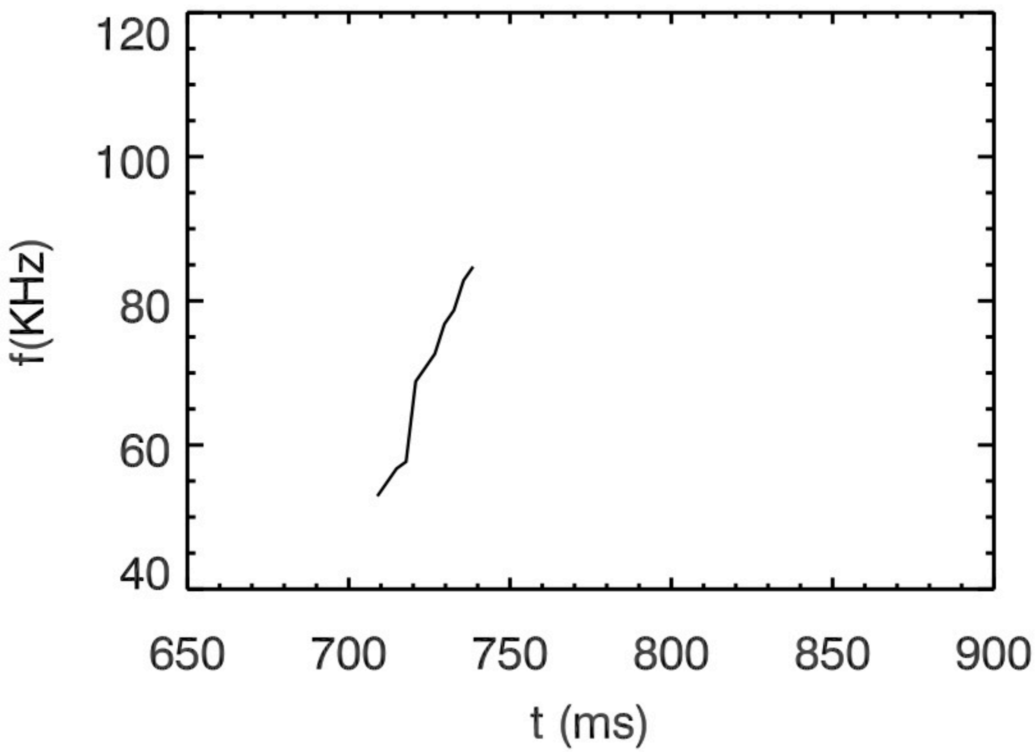
The steep drop at qmin=3.27 is due to change to a different mode qmin=3.23



qmin=3.27



Chirping in time, Dopler shift of 15KHz assumed



$$q_{\min} = -0.00337(t - 700) + 3.33$$

For a change of Δqmin=0.07, f chirp range=25KHz, comparable to experiment
However, simulation frequency appears to be ~15 KHz below experiment

Does the $A_{||}/\phi$ model have the pressure effect on RSAE frequency?

Breizman el. al. “Plasma pressure effect on Alfven Cascading Modes”, POP 12, 112506 (2005)

In GEM, $\delta B_{||}=0$
However, GEM has GAM

Summary

- Linear simulations of n=3
- Using experimental (TAEFL) profiles, most unstable mode near the edge, far from qmin
- Using more peaked beam distribution, chirping mode observed
- To do: Verification with M3D-K and validation with experimental beam distribution(?)