Project Overview and PPPL Progress

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Project Overview

PEPSC Personnel:

- **PPPL**:
  G.Y. Fu (PI), S. Ethier, N. N. Gorelenkov, R. Samtaney ;
  Jianying Lang (12/01/08);
  J. Breslau, J. Chen (CEMM)
- **IFS**:
  H. L. Berk, B. N. Breizman, J. W. Van Dam;
  E. Chen (01/01/09)
- **Univ. of Colorado**: Y. Chen, S. E. Parker;
- **ORNL**: Scott A. Klasky

PEPSC Plan

- **Upgrade M3D-K code**: extension to 3D domain decomposition for particles; add source and sink.
- **Build a new gyrokinetic/MHD hybrid code GKM** (start from M3D-K) that uses gyrokinetic closure to include kinetic effects of thermal ions as well as energetic particles.
- **Implement advanced numerical methods**: nonlinear implicit method, high-order finite elements, and workflow method. Also, optimize code speed.
- **Explore reduced models** for comparison with GKM.
- **Apply codes to experiments** for code validation and physics understanding.
- **Apply GKM to ITER** for simulations of alpha particle-driven high-n TAEs.

Research Plan (2008-2009)

- Extend particle domain decomposition to 3D (scale to >1000 processors);
- Add source/sink (CU and PPPL);
- Formulate nonlinear GKM model (PPPL and IFS);
- Build GKM0 (initial GKM version);
- M3D-K simulations of beam-driven Alfven modes in NSTX.

PPPL Progress

- A simple model for the gyrokinetic/MHD code GKM has been formulated.
- The first version of GKM has been constructed and has been used successfully in simulating TAE and RSAE. Initial benchmark has been done with NOVA-K code.
- Work is in progress to extend particle domain decomposition to 3D.
- Nonlinear Simulation of EGAM shows bursting behavior.

Main equation (equivalent to perpendicular momentum equation derived from gyrokinetic equation)

$$-\frac{\boldsymbol{d}}{\boldsymbol{dt}}\nabla\cdot\left(\frac{1}{\boldsymbol{V}_{\boldsymbol{A}}^{2}}\nabla_{\perp}\Phi\right)+\boldsymbol{B}\cdot\nabla\frac{\boldsymbol{B}\cdot(\nabla\times\nabla\times\boldsymbol{A})}{\boldsymbol{B}^{2}}+(\nabla\boldsymbol{A}_{\parallel}\times\boldsymbol{b})\cdot\nabla\left(\frac{\boldsymbol{J}_{\parallel 0}}{\boldsymbol{B}}\right)$$

$$=\frac{1}{\boldsymbol{V}_{\boldsymbol{A}}^{2}}\left(\frac{3\mathbf{v}_{t}^{2}}{4\Omega^{2}}\right)\nabla_{\perp}^{4}\frac{\boldsymbol{d}\Phi}{\boldsymbol{dt}}+\boldsymbol{b}\times\sum_{j}\nabla\left(\frac{\boldsymbol{env}_{\boldsymbol{t}}^{2}}{2\boldsymbol{B}\Omega^{2}}\right)_{j}\cdot\nabla\nabla_{\perp}^{2}\Phi-\sum_{j}\int(\boldsymbol{e}\mathbf{v}_{\boldsymbol{d}}\cdot\nabla\boldsymbol{f})_{j}\,\boldsymbol{d}^{3}\boldsymbol{v}$$

The LHS represent ideal shear Alfven wave equation without the ballooning term. On the RHS, the first term is ion FLR, the second is diamagnetic drift, and the third contains all other kinetic terms from both thermal ion and fast ions. The third term gives the energetic particle destabilization and ion Landau damping. This term also gives the usual ballooning terms from all species.

The main equation is closed by $A_{||}$ equation, parallel Ohm's law, electron density equation, and parallel momentum equation.

$$\frac{\partial}{\partial t}A_{||} = -\nabla_{||}\Phi - E_{||}$$

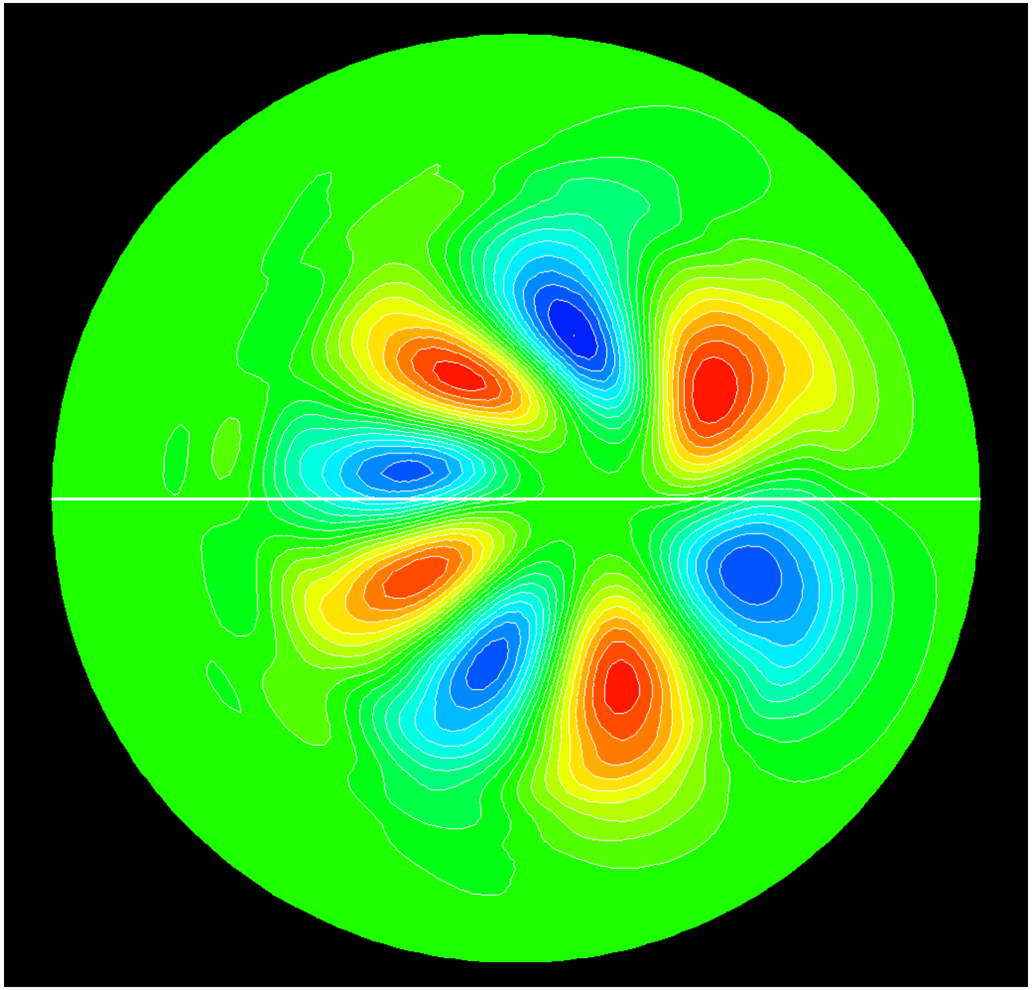
$$E_{||} = -\frac{1}{en_e}\nabla_{||}\delta P_e$$

$$\frac{\partial}{\partial t}n_e = -\nabla \cdot (\mathbf{V_e} n_e)$$

$$\mathbf{V_e} = \frac{\mathbf{E}\times\mathbf{B}}{B^2} - \frac{\delta\mathbf{J}_{||}}{en_e} + v_{||,i}\mathbf{b}$$

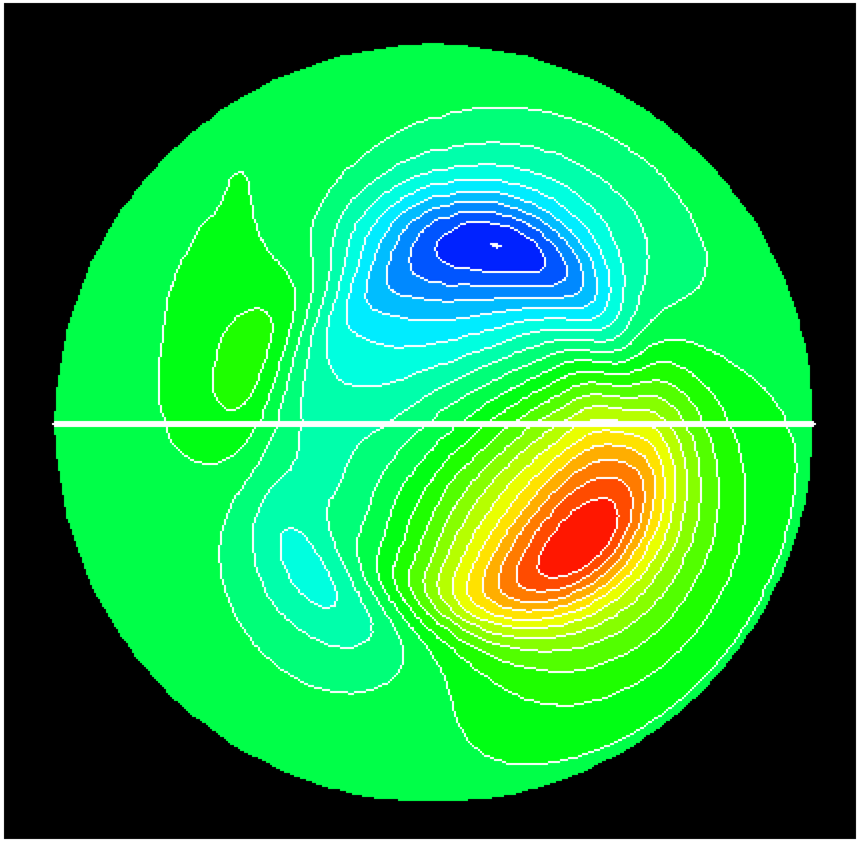
$$\rho\frac{\partial}{\partial t}v_{||,i} = \mathbf{b}\cdot(\mathbf{J}\times\delta\mathbf{B} - \nabla\cdot\delta\mathbf{P_{th}})$$

n=2 RSAE from GKM0

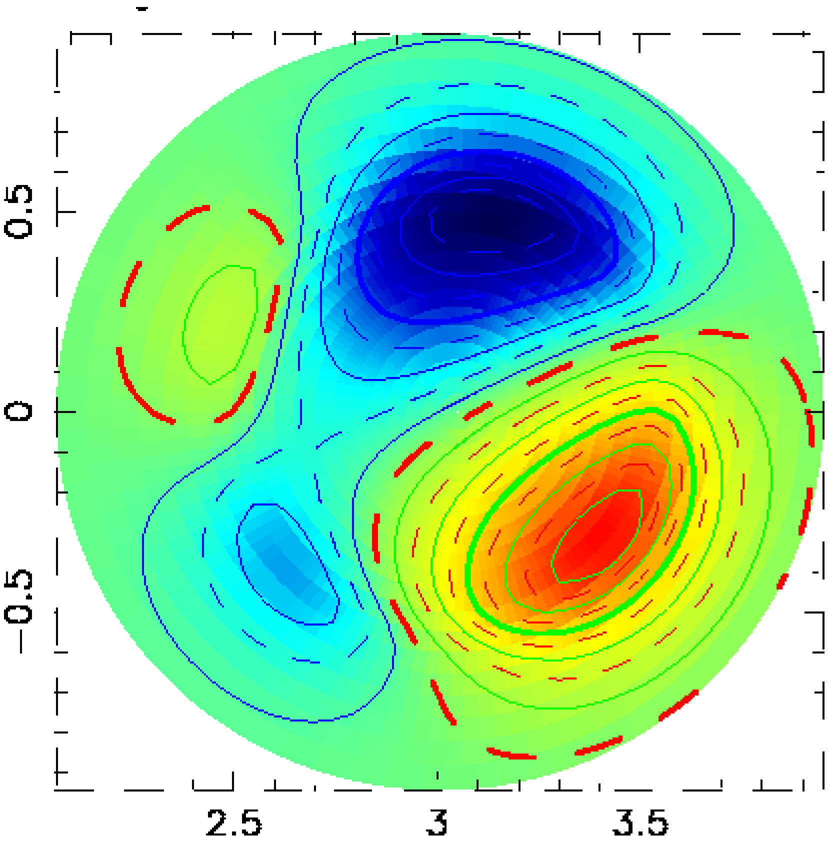


n=1 TAE from GKM0 and NOVA-K

GKM0

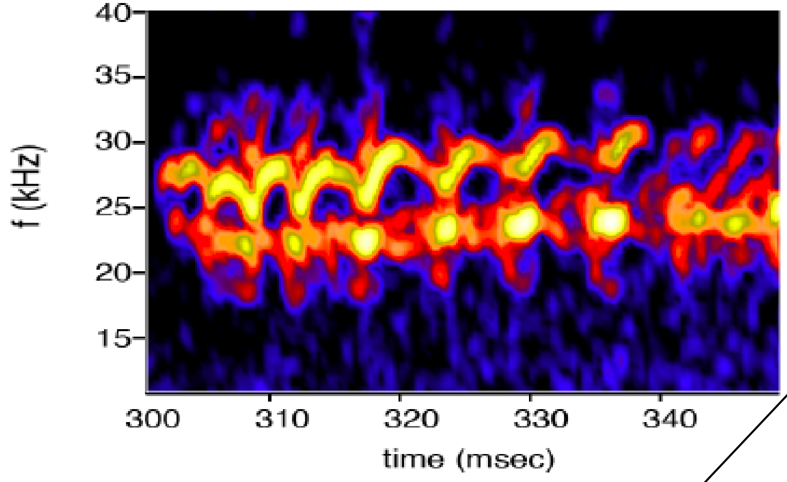


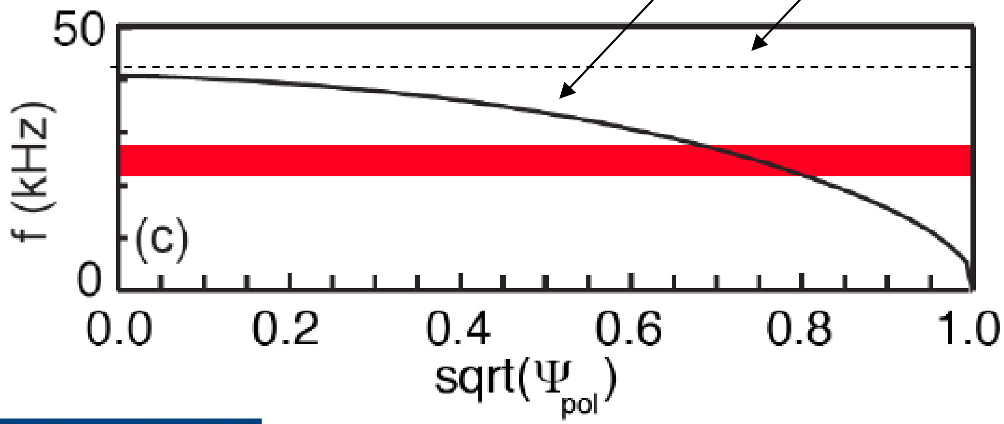
NOVA



Mode frequency is clearly inside the GAM continuum

$\delta B/B \sim 10^{-5}$, n=0 at wall





- n=0 GAM continuum

  $\omega \approx 2C_s/R$
- ideal GAM can only exist above the continuum
  - no NOVA solution
- Local GAM continuum (kinetic GAM) can be driven by turbulence
- Mode frequencies well below peak in the continuum
  - not the ideal GAM
- Mode structure is global, not the local kinetic GAM

Hybrid Model for GAM

Consider n=0 electrostatic perturbation

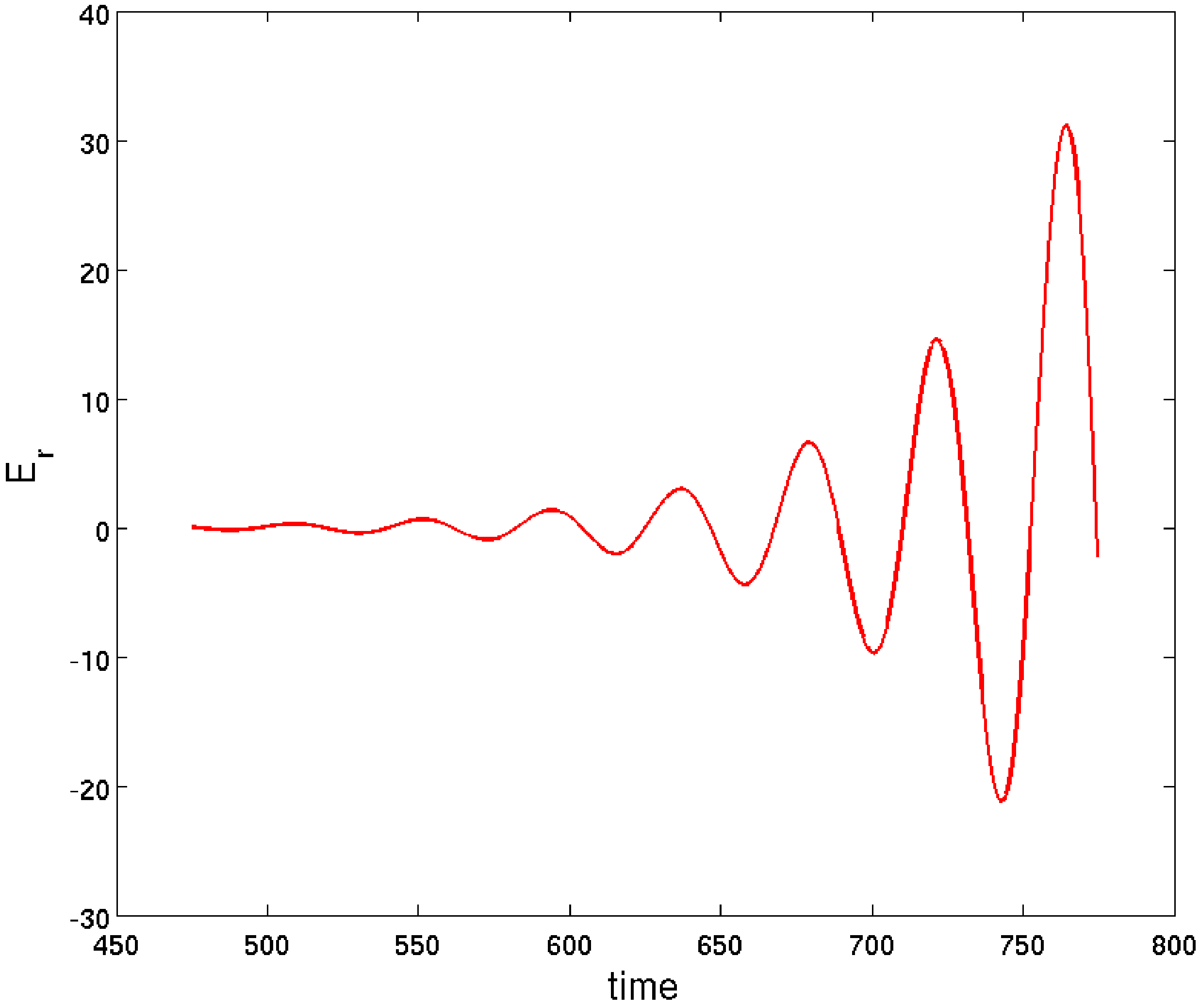
$$\rho \frac{\partial}{\partial t}\mathbf{v} = -\nabla \cdot \delta\mathbf{P} + \delta\mathbf{J} \times \mathbf{B}$$

$$\delta\mathbf{P} = \delta P_{\perp}\mathbf{I} + (\delta P_{||} - \delta P_{\perp})\mathbf{bb}$$

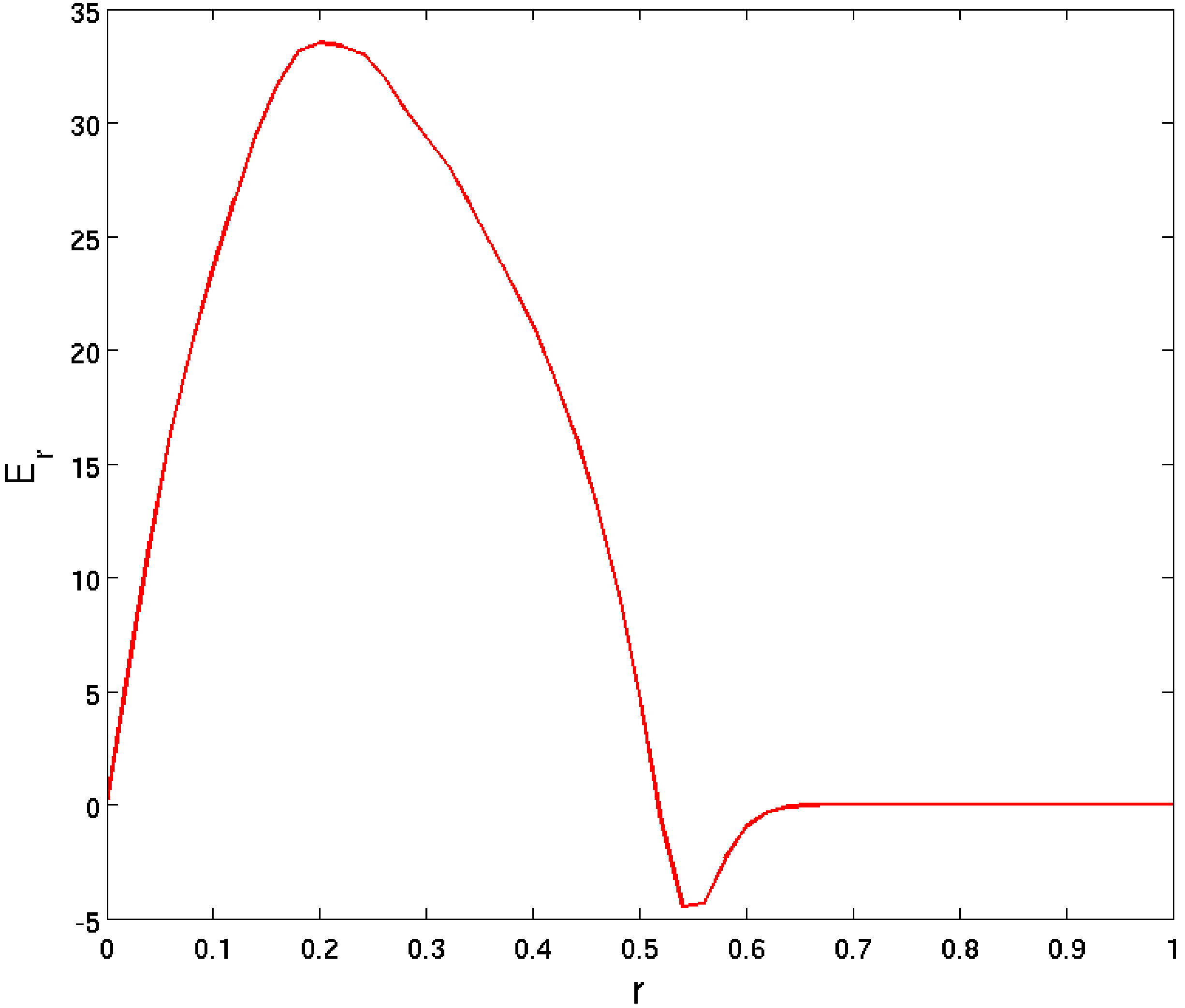
$$\mathbf{E} + \mathbf{v} \times \mathbf{B} = 0$$

Assume isothermal fluid model for electrons;
Use drift-kinetic equation to describe both thermal ions and energetic ions

Numerical Results: amplitude evolution

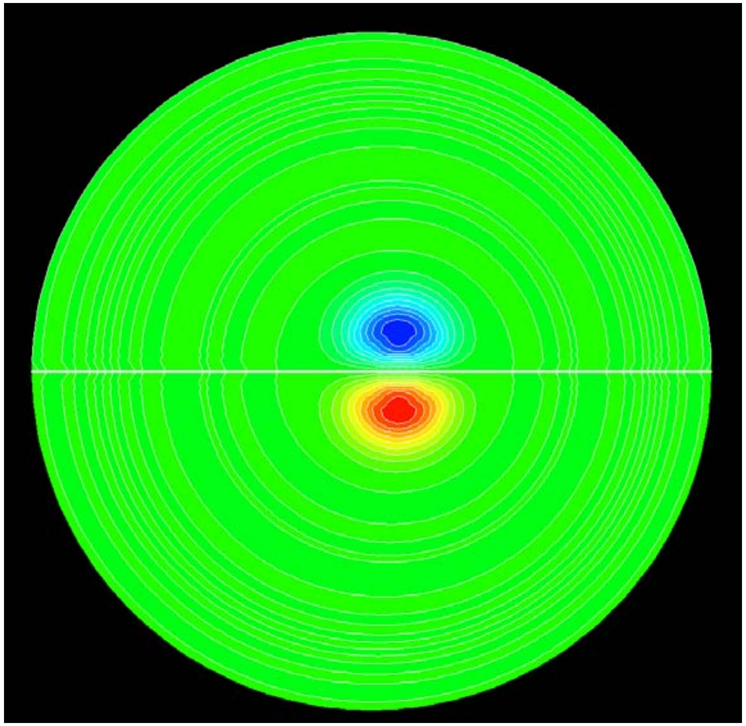


Numerical Results: Existence of global mode

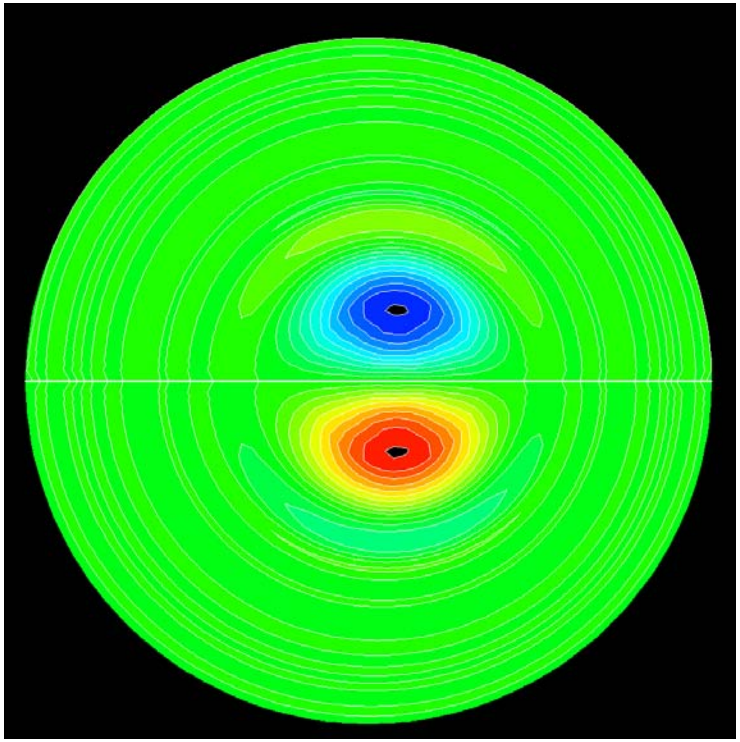


The mode width is determined by the particle orbit width

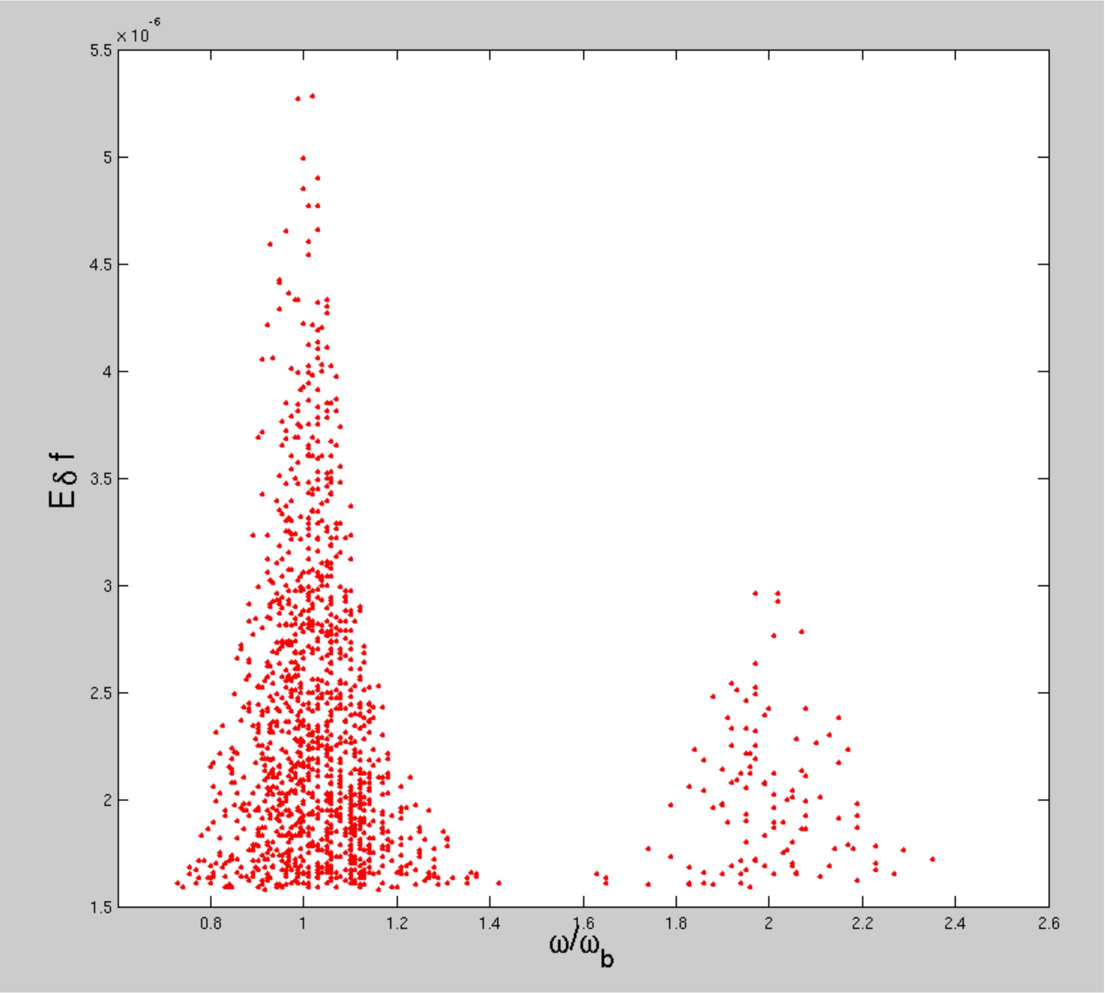
$\rho/a=0.006$



$\rho/a=0.016$



Wave-Particle Resonances



Initial nonlinear simulations show bursting behavior