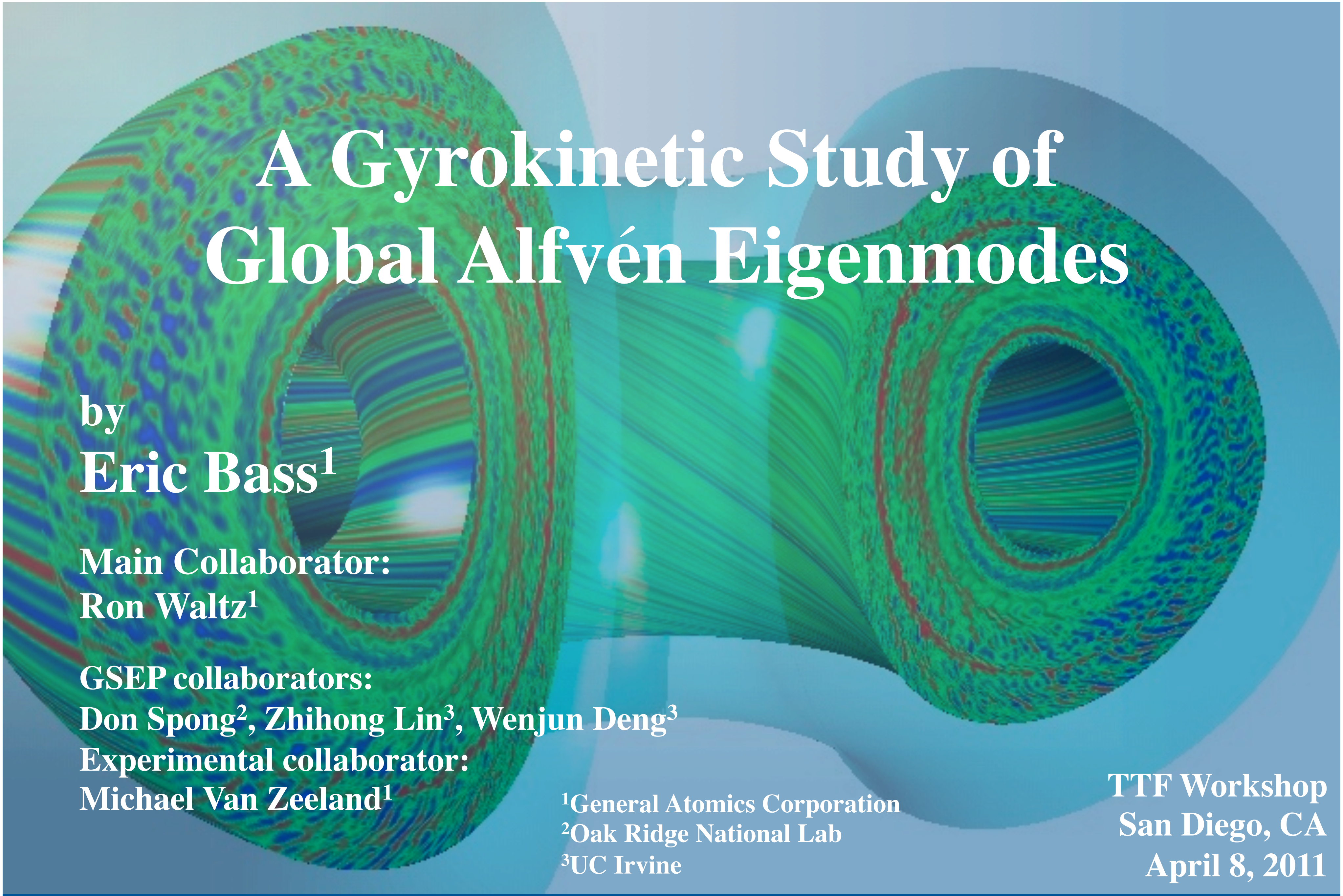

A Gyrokinetic Study of Global Alfvén Eigenmodes

by

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DIII-D
NATIONAL FUSION FACILITY

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GENERAL ATOMICS

Outline

I. Global Alfvén eigenmodes (AEs) in reverse-shear, beam-heated DIII-D discharge 142111

- Toroidal Aflvén eigenmodes (TAEs) and reverse shear Alfvén eigenmodes (RSAEs) in the experiment are excited by, and produce transport of, beam ions
- GYRO identifies TAEs and RSAEs seen in experiment. We may also see an energetic particle mode (EPM)
- High beam energetic particle pressure β_{EP} makes modes deviate from pure-MHD form

II. Sub-dominant AEs

- A massive **global eigenvalue solver** in GYRO is beginning to reveal sub-dominant modes
- Local eigenvalue solutions (much easier) reveal some key features of global modes

Simulated DIII-D Discharge 142111 Shows Active TAEs and RSAEs

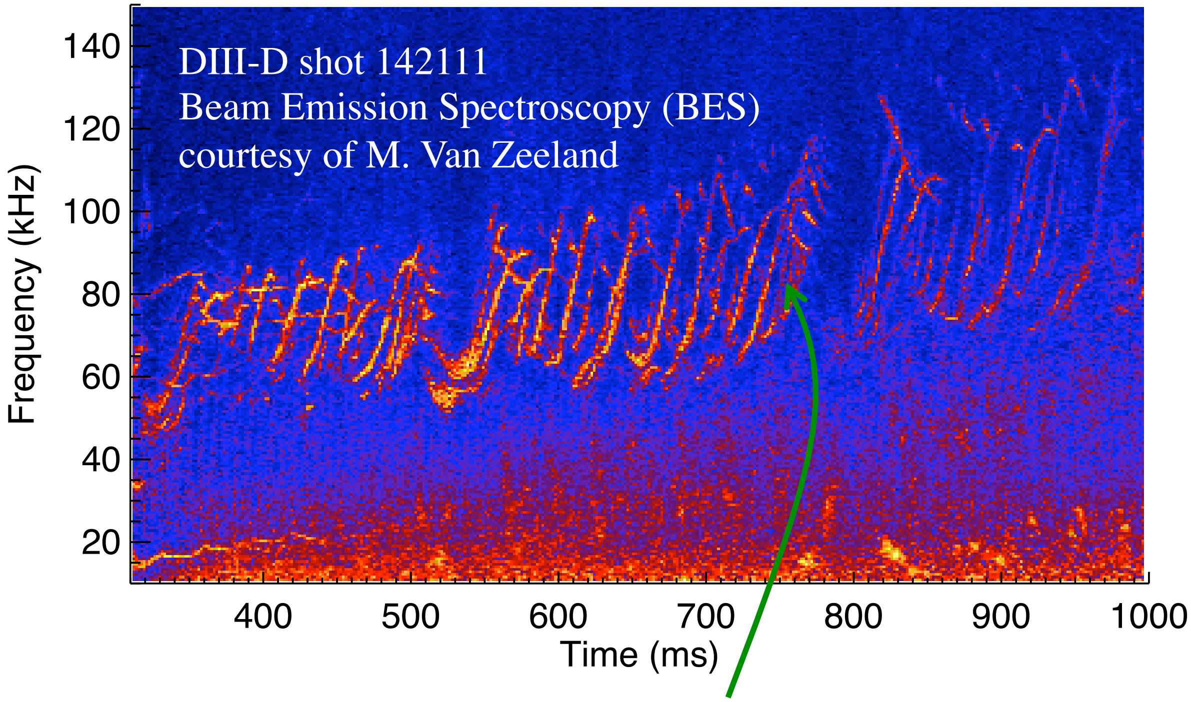
The heating beam in DIII-D discharge 142111 destabilzes a variety of Alfvén eigenmodes

TAEs lie within a toroidicity-induced gap in the Alfvén continuum around $\omega_{\mathrm{TAE}}=\mathrm{v}_{\mathrm{A}}/2qr$

RSAEs lie within the continuum gap induced by a minimum in the q profile, centered roughly around:

$$\omega_{\mathrm{RSAE}} \approx \frac{v_{\mathrm{A}}}{R}\left|\frac{m}{q_{\min}} - n\right|$$

The RSAE frequency sweeps as the q profile evolves in the discharge

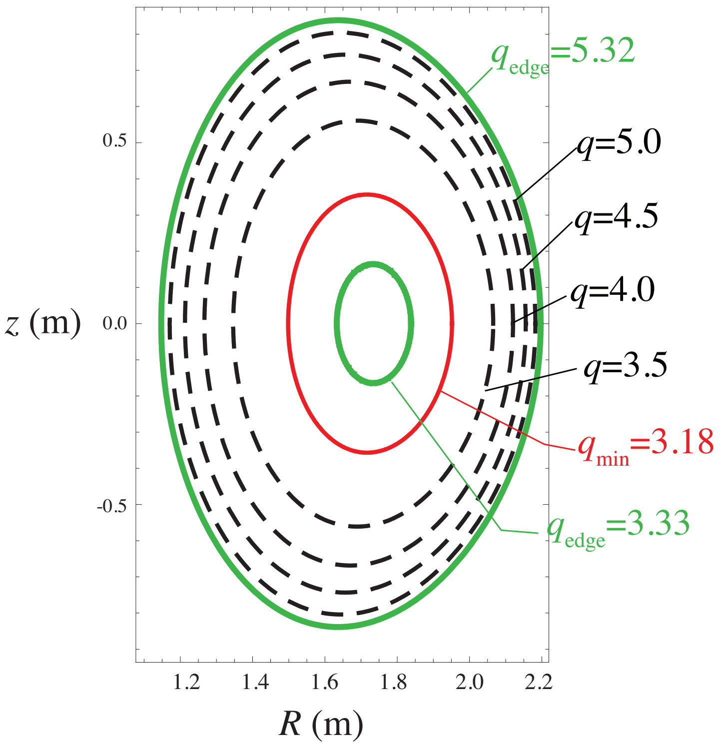


DIII-D shot 142111
Beam Emission Spectroscopy (BES)
courtesy of M. Van Zeeland

We focus on the plasma equilibrium near ***t*=750 ms**, where both TAEs and RSAEs are observed

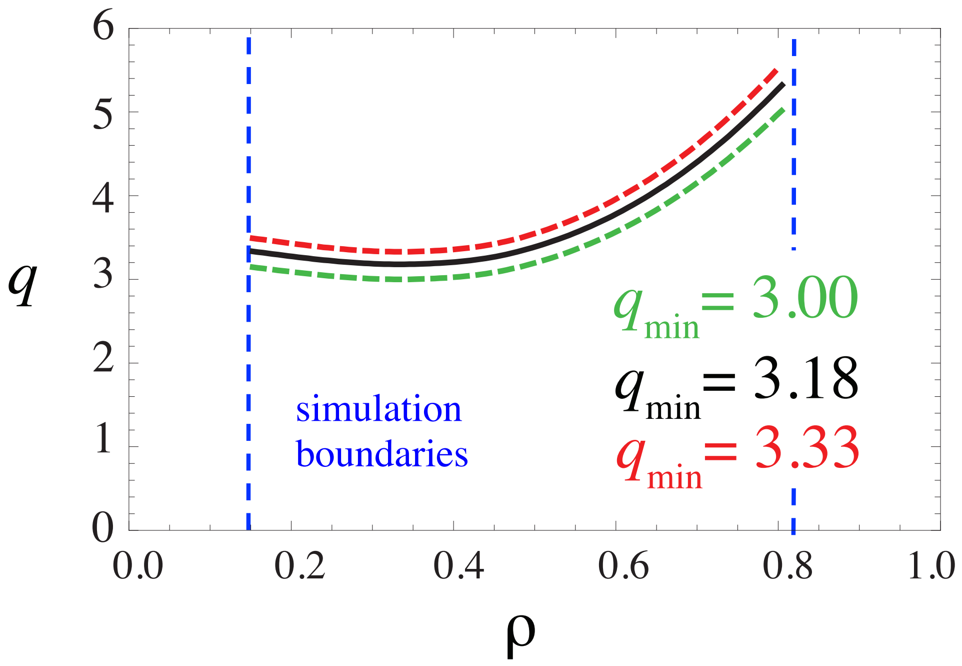
The active AEs are known to produce substantial beam transport, motivating this study

We Use an EFIT Equilibrium of DIII-D Discharge 142111 with Miller Geometry



An EFIT equilibrium is fit to Miller coefficients to give flux-surface geometry. The simulation covers $0.16<\rho<0.80$, with $\rho=\psi^{1/2}$

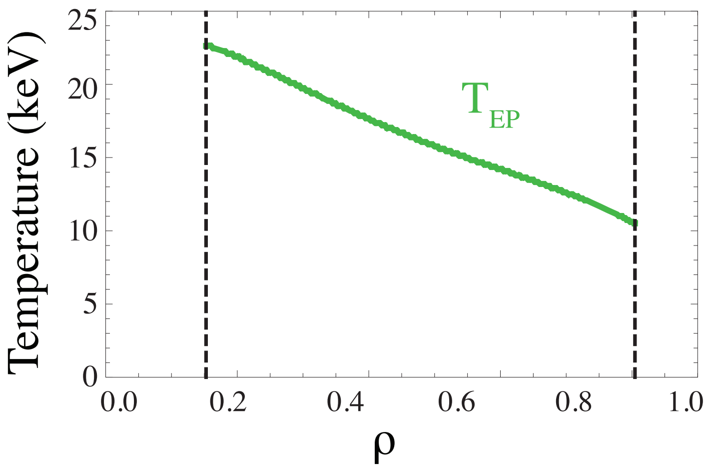
The safety factor q is scaled with a uniform multiplicative factor to adjust the value of its minimum value q_{min}. This approximation introduces minimal geometrical inconsistency

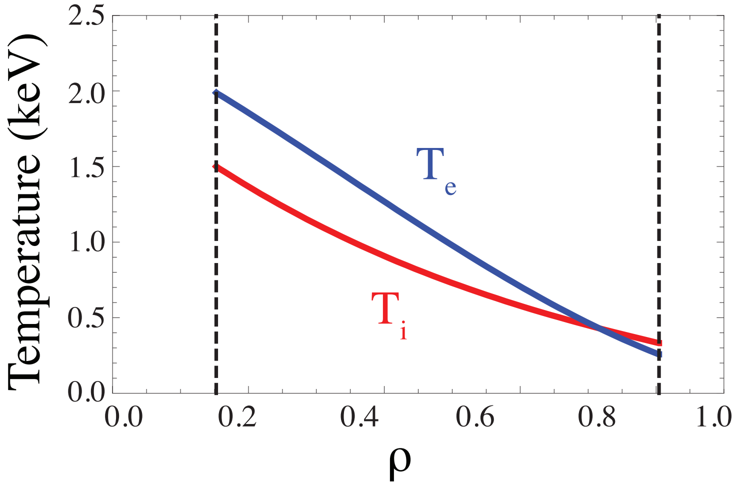


[1] Private communications with Michael Van Zeeland

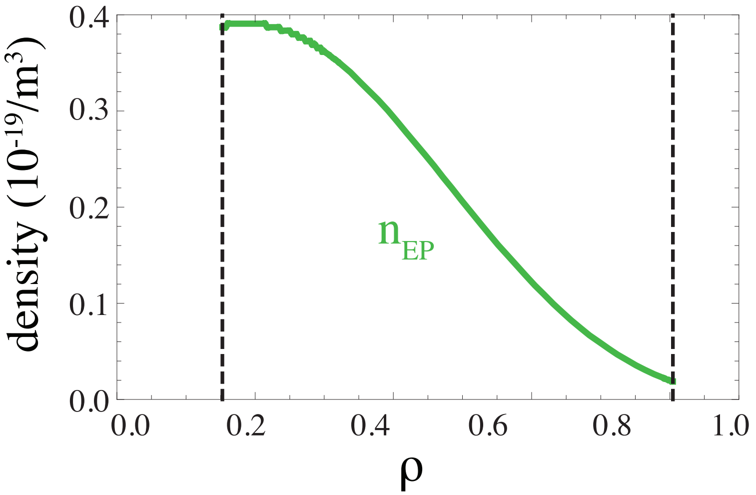
Density and Temperature Profiles Comes from EFIT, TRANSP, and Inferred Pressure Gradient

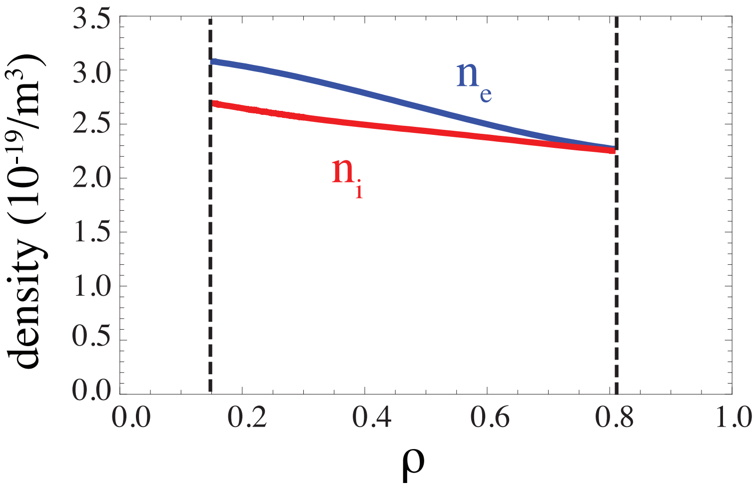
Deuterium energetic particle (EP) beam ion temperature comes from ONETWO. Usual experimental diagnostics give thermal species temperatures[1]





EP density below classical prediction (AE transport): Given from pressure and charge neutrality constraint: $n_{EP}+n_i=n_e$. The beam energetic particle (EP) density is adjusted to bring out the RSAE[2]





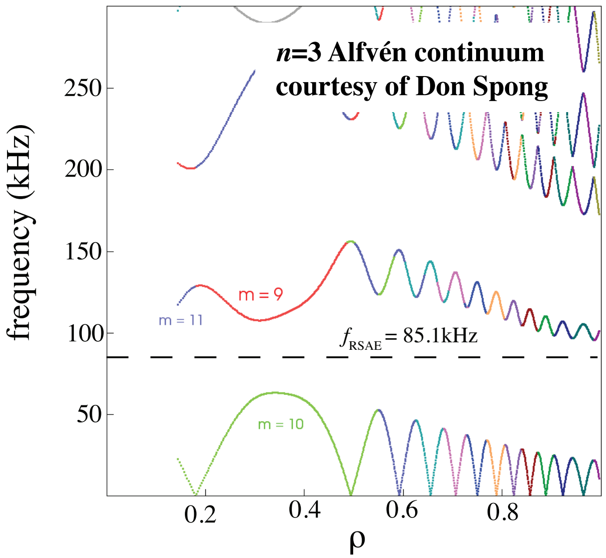
Note that $0.08\%=\beta_{EP}\approx\beta_{thermal}=0.13\%$

[1] Private communications with Michael Van Zeeland
[2] Private communications with Don Spong

Features and Limitations of the Present Model

- GYRO is a continuum, δf, gyrokinetic solver. Thermal and beam ions are fully gyrokinetic; electrons are drift kinetic
- Most damping mechanisms are automatically included in this self-consistent, fully-kinetic approach
- No rotation effects are included, e.g. (small) Doppler shift of frequency
- A "high-*n* ballooning mode" approximation ($k_{\|} / k_{\perp} << 0$) is employed and appears valid for the present cases, down to at least n=3
- The heating beams are simulated with an isotropic, Maxwellian distribution in velocity space. The EGAM, which is driven by velocity-space gradients $\partial f / \partial E > 0$, is precluded
- Full kinetic treatment means microturbulent instabilities (e.g., ion temperature gradient [ITG] and trapped electron mode [TEM]) are present, but with very low growth rate at the low toroidal *n* numbers studied here

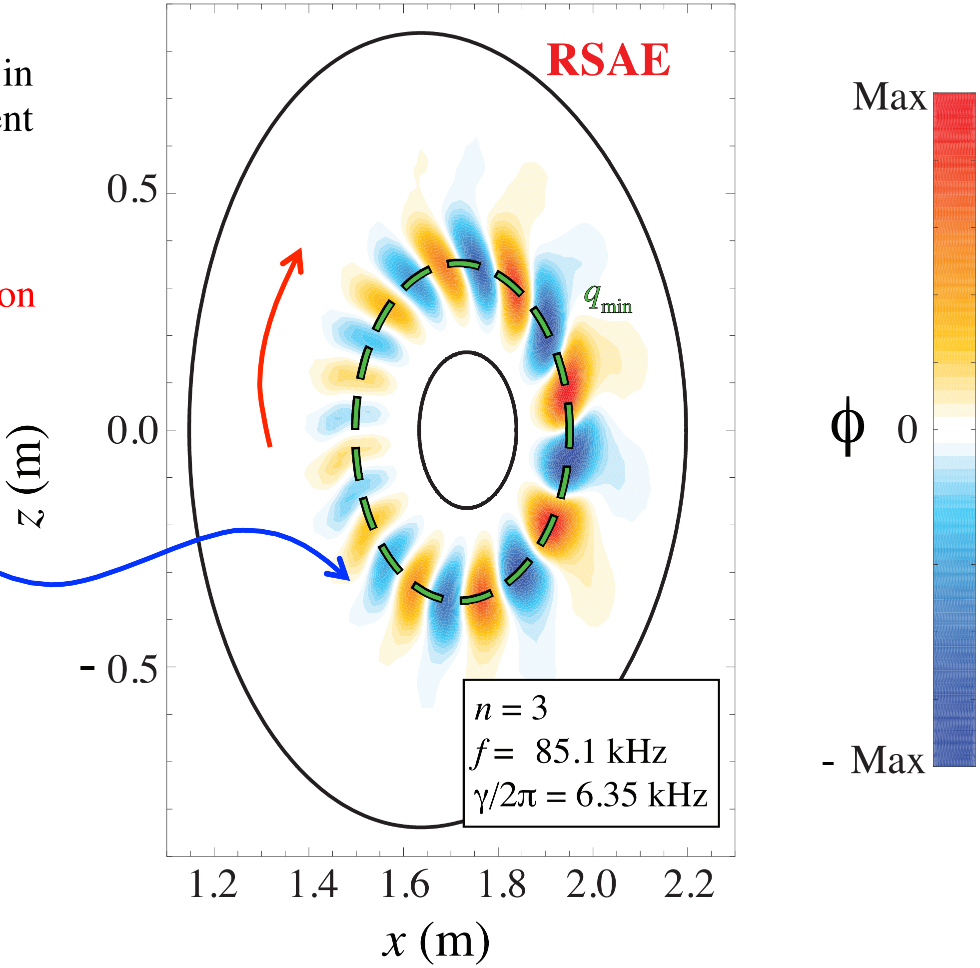
RSAEs are Observed on the $q_{\min}$ Surface

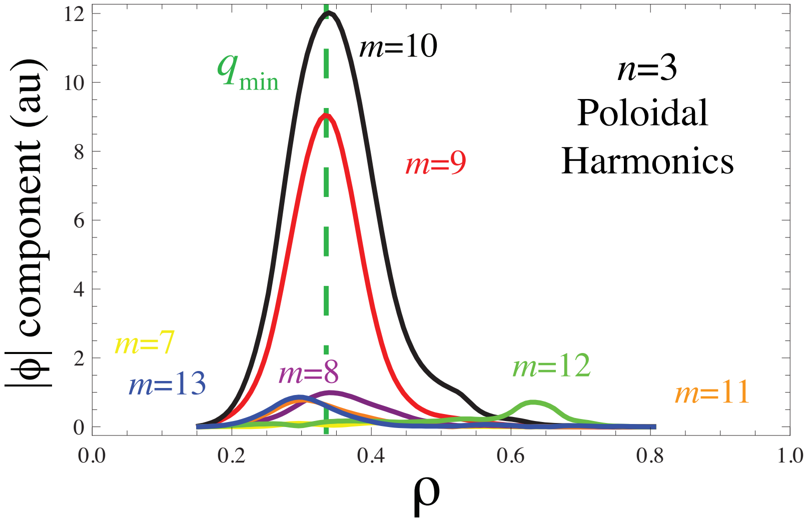


Real frequency in RSAE gap, consistent with experiment

Rotates in ion diamagnetic direction

Eigenfunction twist arises from beam ion profile effects[1,2]





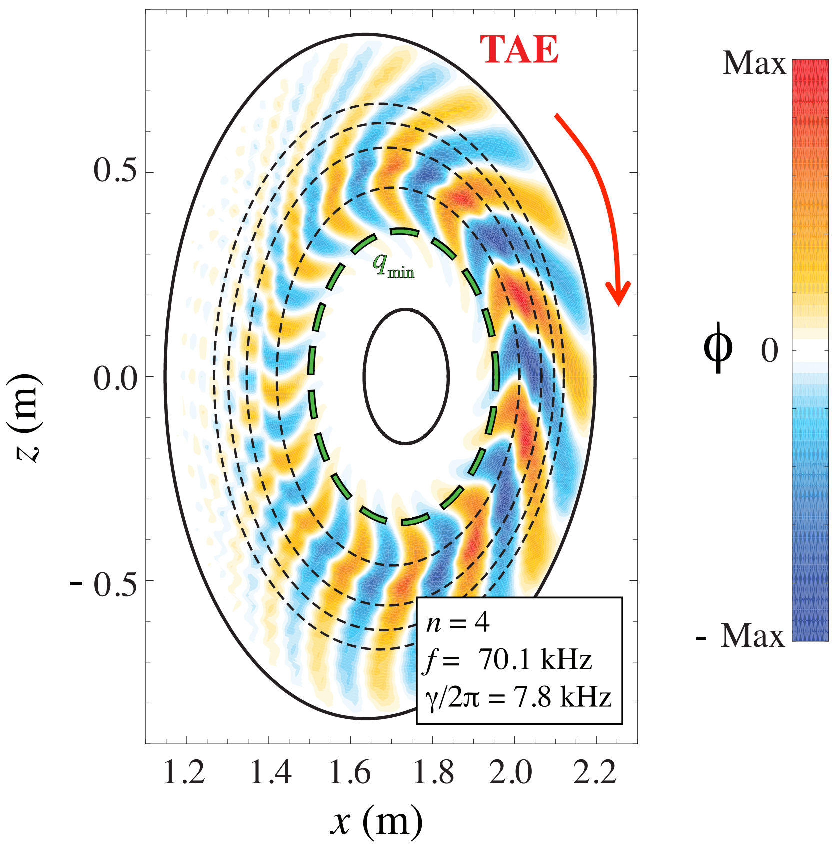
RSAE in DIII-D shot 142111 at t=750 ms, n=3, $q_{\min}$=3.18

[1] M. A. Van Zeeland et. al., Nucl. Fusion **49**, 065003 (2009)

[2] B. J. Tobias et. al., Phys. Rev. Lett. **106**, 075003 (2011)

Observed TAEs Span More Globally than RSAEs, with Peaks Usually Between Singular Surfaces

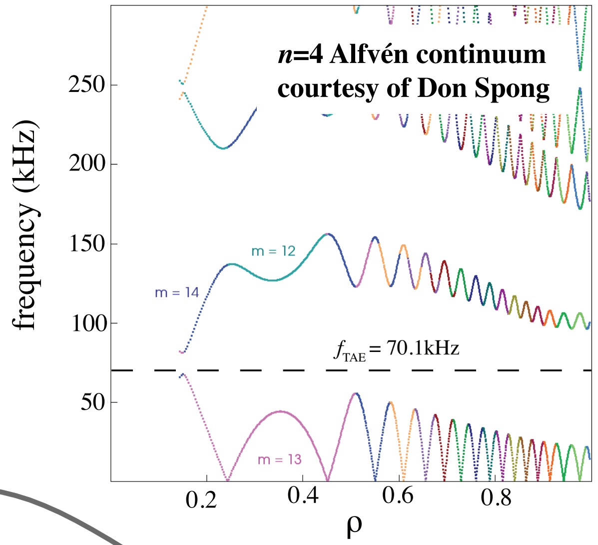
TAE in DIII-D shot 142111 at t=750 ms, n=3, $q_{\min}$=3.18

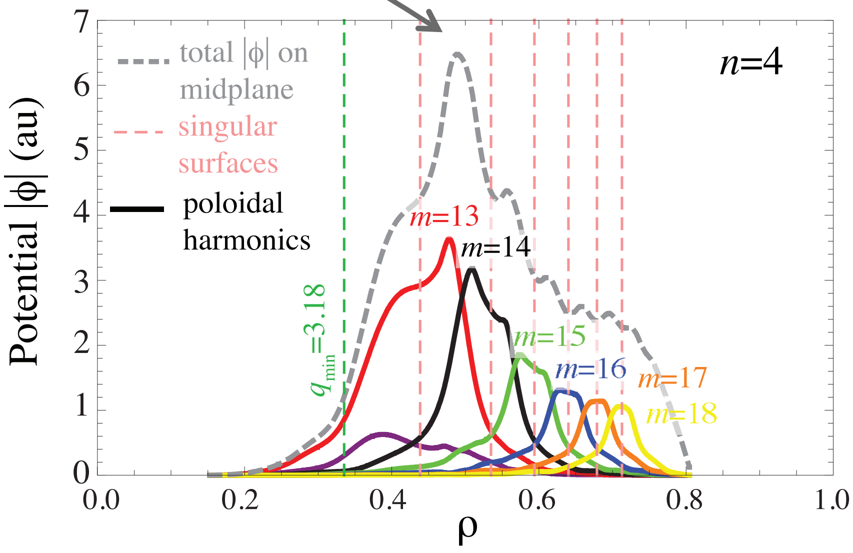


Frequency is within the TAE gap and consistent with experiment

Rotates in ion diamagnetic direction

Main peak dominates more the closer it is to $q_{\min}$





Peaks are between singular surfaces (TAE-like) and on singular surfaces (EPM-like). We can call these finite-β_{EP} modes TAE/EPM[1]

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[1] E.M. Bass and R.E. Waltz, Phys. Plasmas **17**, 112319 (2010)

A Global Eigenvalue Solver is Nearly Ready to Apply to the Alfvén Eigenmode Problem

A recent extension to the parallelization scheme in the GYRO eigenvalue solver now enables almost limitless parallelization

Old limit: 32 cores → New limit: 100,000+ cores

The new limits allow finding eigenvalues in the massive matrices associated with global simulations

Local Run
6 radial gridpoints
23,040×23,040 matrix

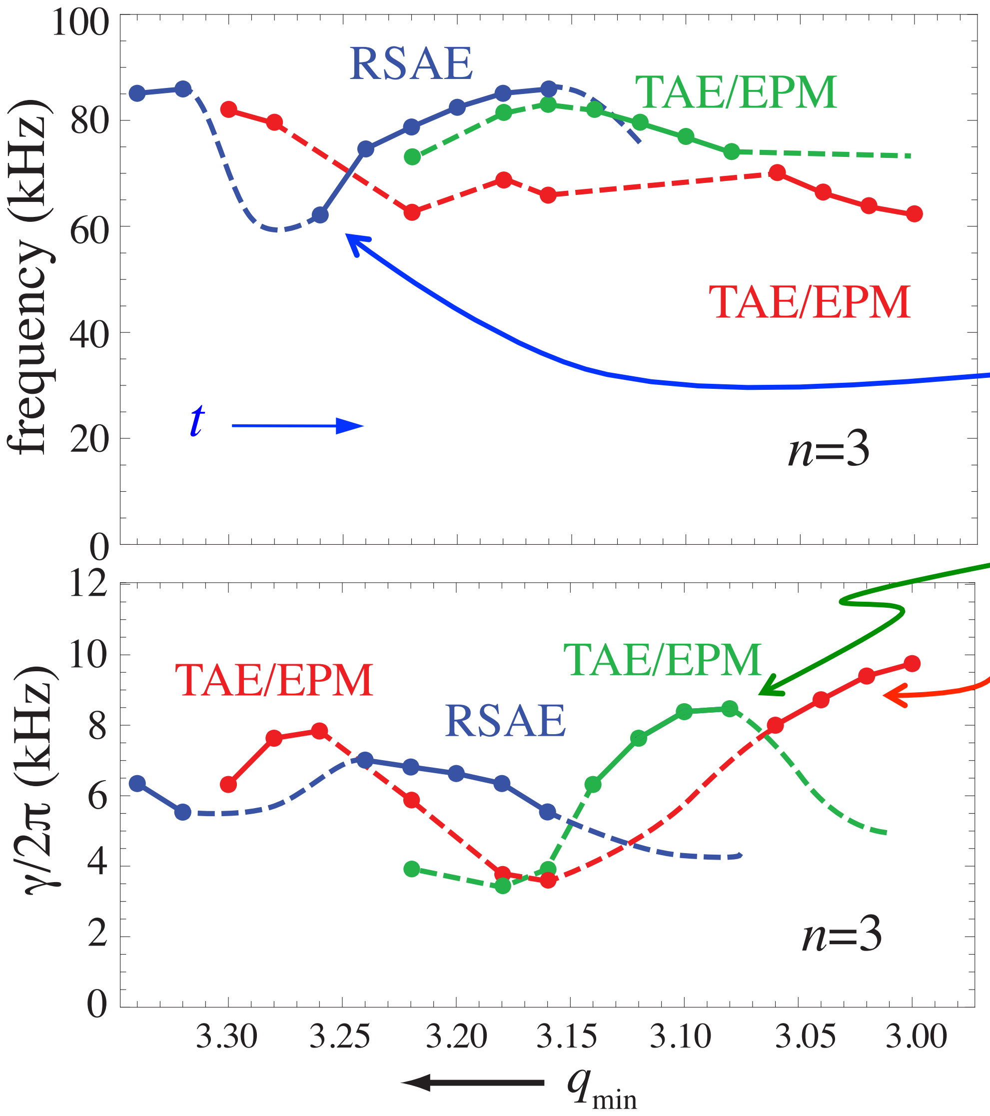
→

Global Run
300 radial gridpoints
1,152,000×1,152,000 matrix

Substantial challenges of high performance computing have been overcome, and the algorithm efficiency scales very well to high core counts. Local eigenvalue solutions have been massively accelerated (×20 speedup)

Sensible solutions of the true global eigenvalue problem (using 57,600 cores) are just now beginning to roll out

A Scan in q_{min} Shows RSAE-TAE/EPM Co-dominance



Each eigenmode is identified as a TAE/EPM or RSAE by its eigenfunction, particularly peak location(s)

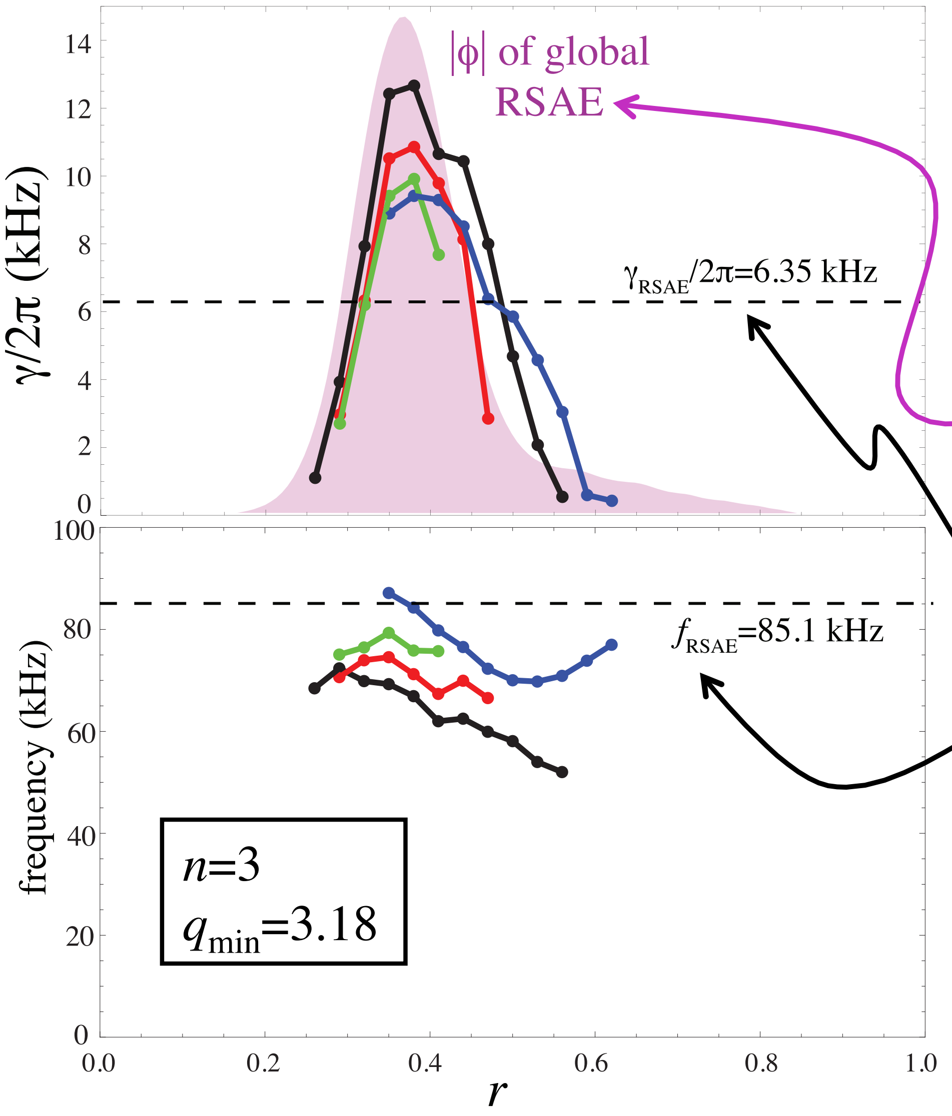
The RSAE is dominant in the frequency "upsweep" here. In the experiment, q_{min} decreases in time

At least two TAE/EPM-type modes are apparent

New sub-dominant mode data confirm the presence of three separate modes

As more sub-dominant data become available, a complete picture will emerge

Local Frequencies and Growth Rates can Reveal Basic Properties of Global Eigenmodes



A scan in local eigenvalues suggests at least four unstable eigenmodes. Do they correspond to unstable global eigenmodes?

The dominant mode’s eigenfunction roughly follows the local growth rates

The dominant mode has a frequency and growth rate in the vicinity of that suggested by local modes

Summary

Gyrokinetic codes like GYRO can find global eigenmodes, include Alfvén eigenmodes

TAEs and RSAEs destabilized by beam energetic particles (EPs) are observed in a simulated DIII-D discharge

Real frequency and eigenfunction are consistent with experimental observations

Some useful information about global eigenmodes can be discerned from spatial scans of local eigenvalues

A true global eigenvalue solver in GYRO is now being applied to the global Alfvén eigenmode problem, already revealing the presence of at least three global eigenmodes at n=3