Alpha-Driven MHD and MHD-Induced Alpha Loss in TFTR DT Experiments

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Introduction

- Alpha particles can drive and/or be expelled by MHD in a D-T reactor.

- In ITER:
  - > 5% alpha-loss may damage first wall.
  - large alpha-loss will reduce ignition margin.

- Two important observations in recent TFTR D-T experiments:

(1) *Alpha-driven toroidal Alfven Eigenmodes (TAEs)*

(2) *Alpha-loss induced by kinetic ballooning modes (KBMs)*

Alpha-driven TAEs in TFTR

- Alpha-driven TAE not observed in previous TFTR D-T experiments.
  - Fusion power < 10.7 MW, β_α < 0.3 %.

    (expect β_α ~0.5-1% in ITER)

- Theory predicts TAE can be more unstable for:
  - Reduce beam and thermal ion Damping

    (look in post NBI phase)

  - Low central magnetic shear [G. Fu et al]
  - High central q [D. Spong]

α-TAE Observed in TFTR

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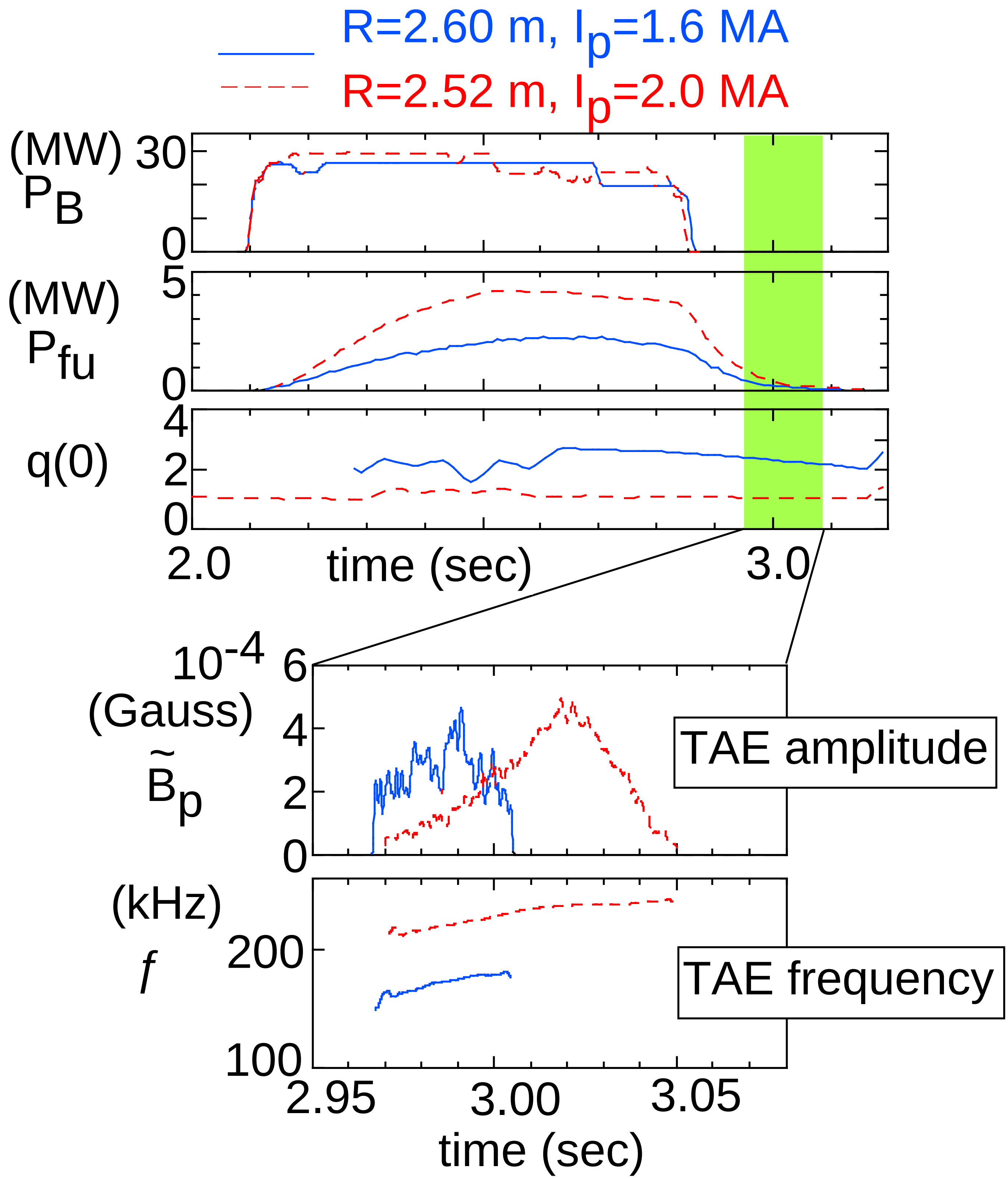
- α-TAE observed in post neutral beam phase.



[R. Nazikian et al, '96 IAEA, submitted to P

Mode Frequency Consistent with TAE Frequency

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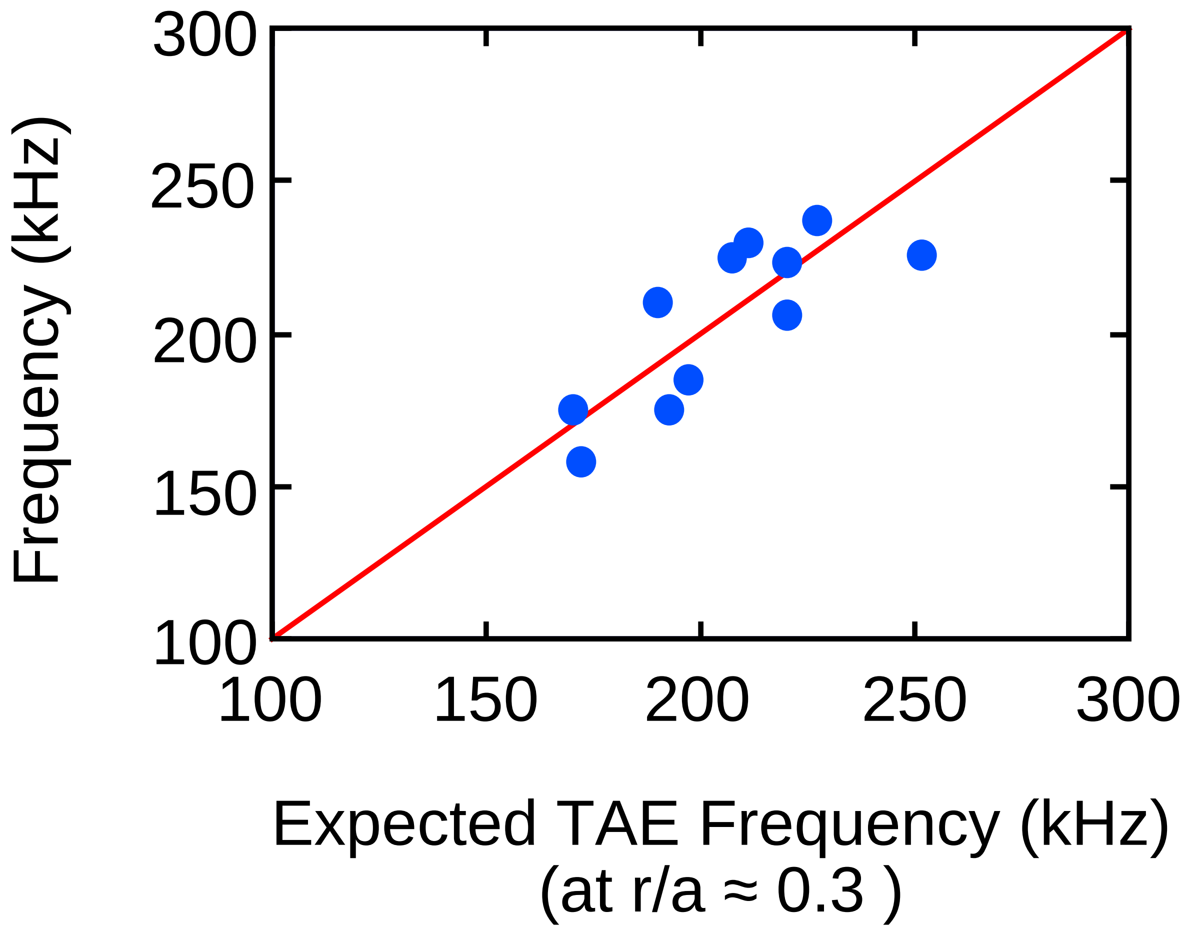

- $f_{TAE} = V_A / 4\pi qR$
- High and low q(0) included

α-TAE Located in Plasma Core

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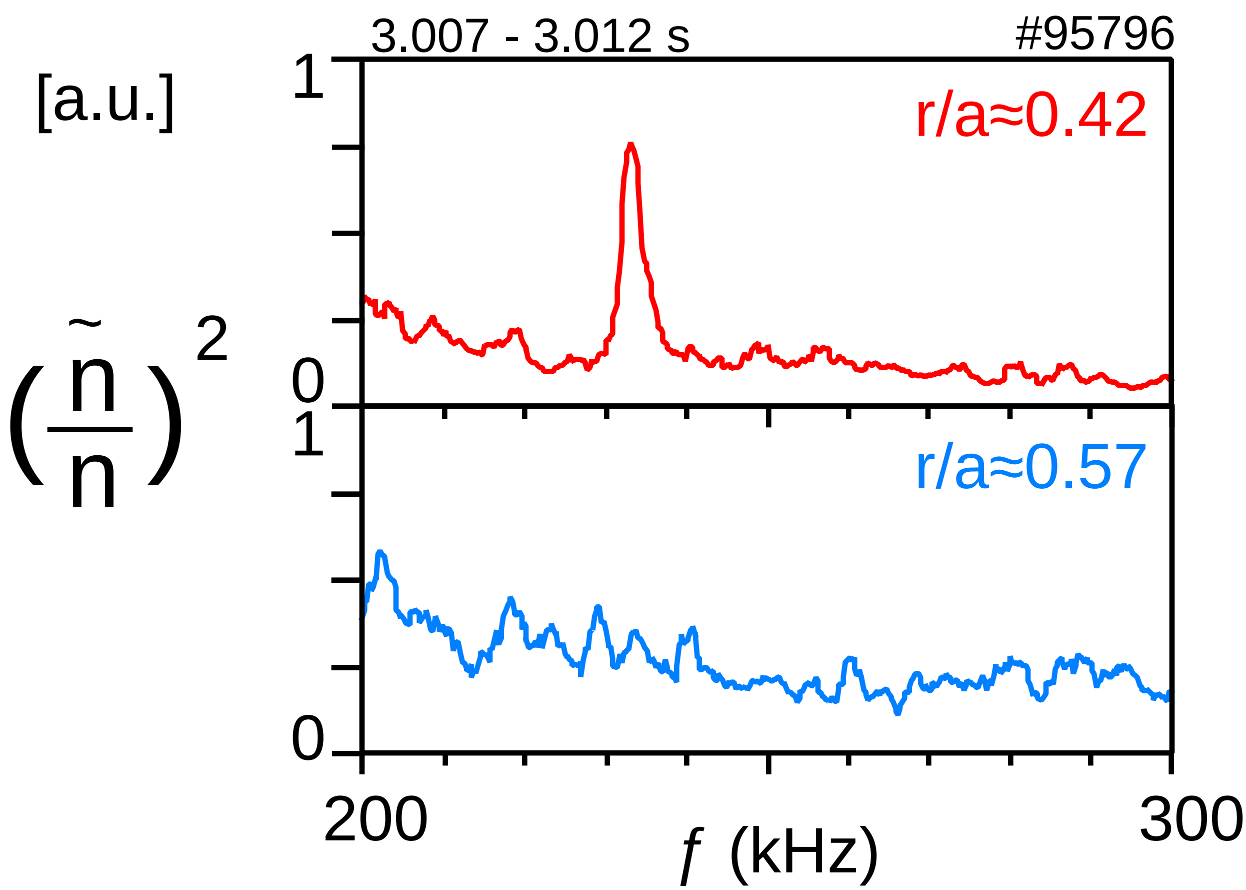
- n=3 TAE observed on Core Reflectometer Channel



- Density perturbation analysis gives mode location :

  0.25<r/a<0.45

- $\tilde{n}/n \approx 10^{-4}$ at r/a≈0.42 --> $\tilde{B}/B \sim 10^{-5}$

  (external $\tilde{B}/B \sim 10^{-8}$)

High q(0) has Lower Threshold β_α

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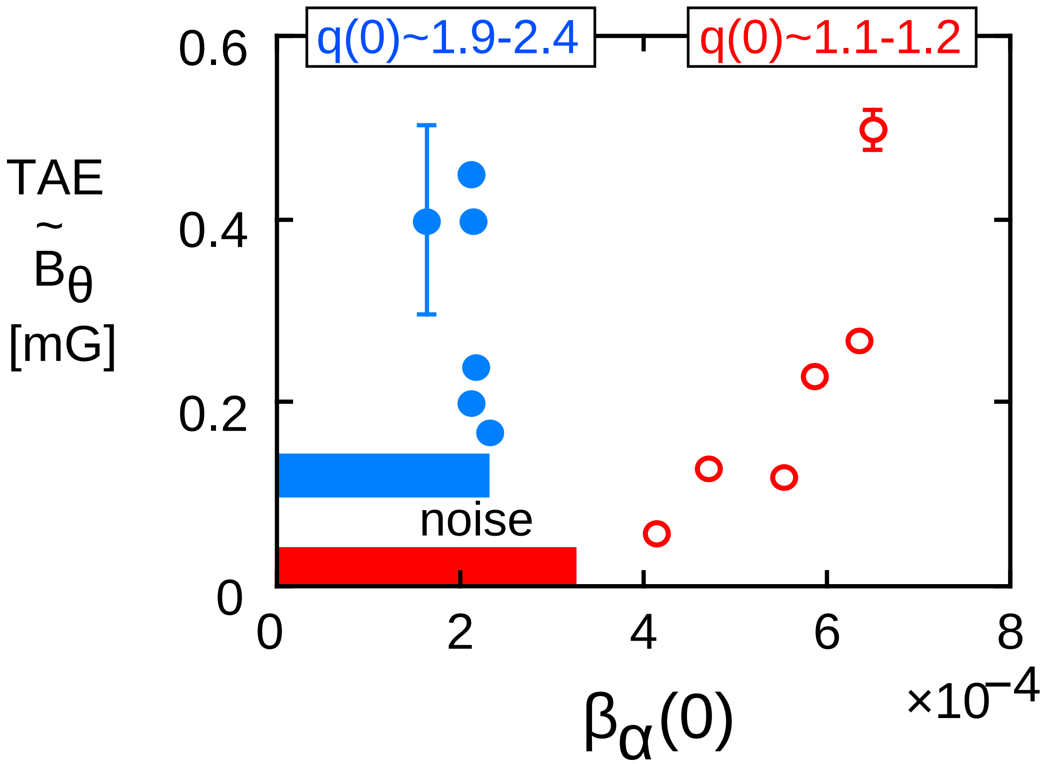
- Threshold β_α is a factor of 2 lower in high q_0 plasmas.



Importance of High Central q

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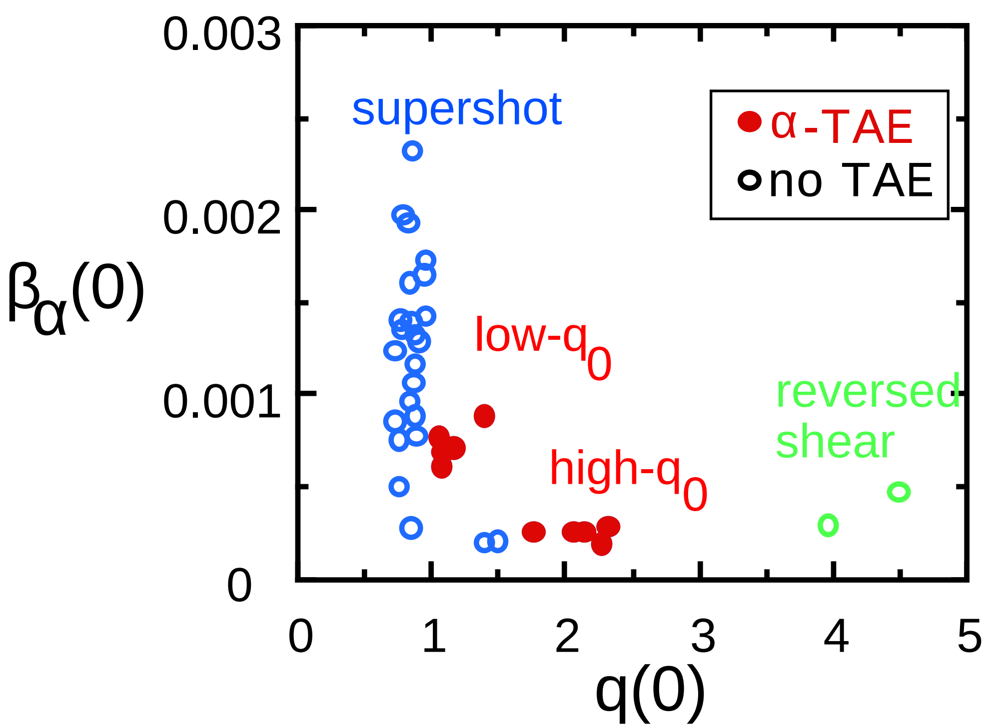
- α-TAE plasmas have lower β_α than supershot
- High q_0 reduces the β_α threshold.



140 ms post-beam

- q_0 is not the only parameter for α-TAE.

Mode Frequency Lies Inside Calculated Gap in n=3 Alfvén Continuum

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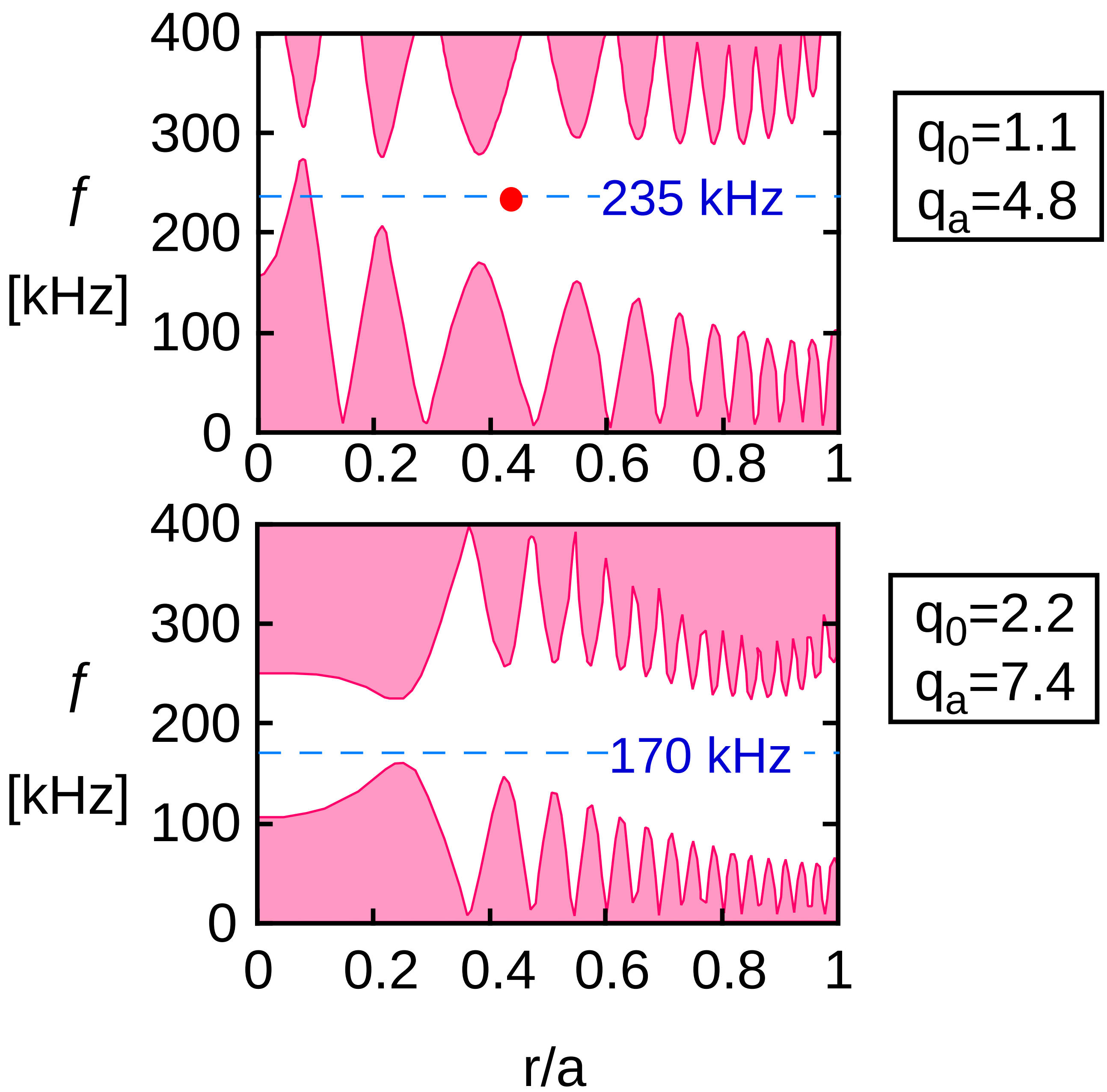
NOVA-K code: Fu



- Stability analysis identifies dominant n=3 mode.

α−TAE Calculated Unstable in High q(0) plasma

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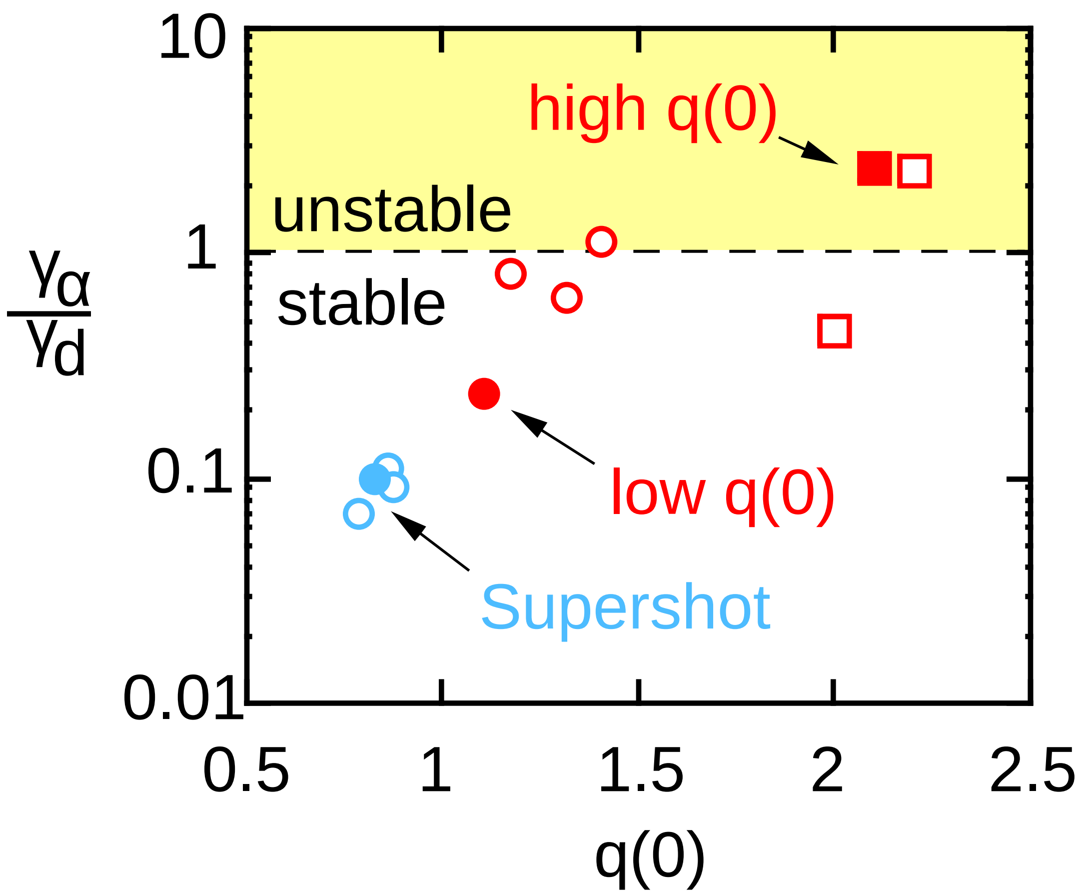
NOVA-K code: Fu

- Low shear and high q(0) are destabilizing.
- Stability is sensitive to small change in q(0).



[For more discussion, refer poster 1S29 by Fu]

α-TAE Peaks on High-Field Side

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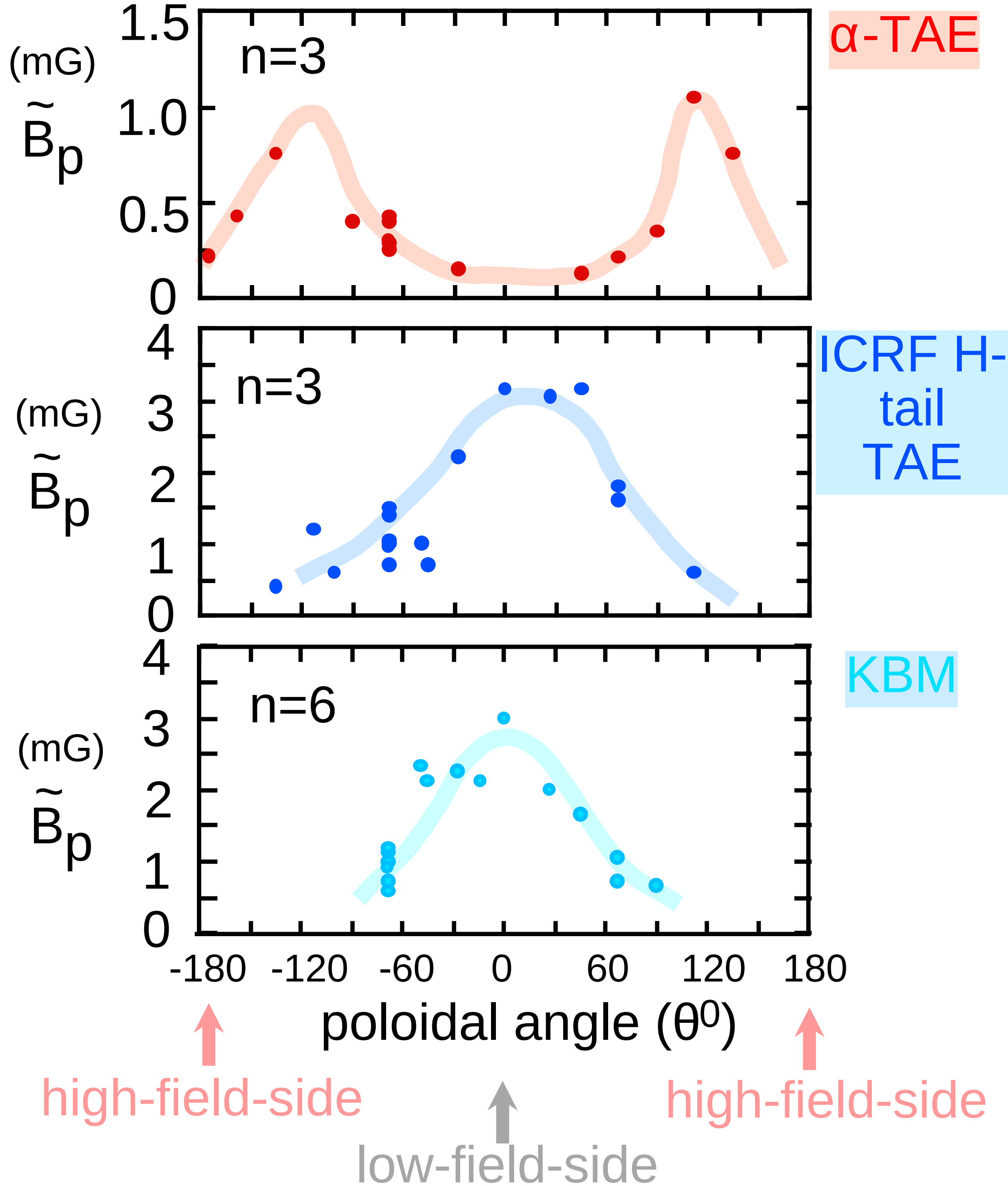
- Normal ballooning Structure for ICRF-TAE and KBM



No Alpha Loss due to α-TAE

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- Both fast-ion loss scaling and particle simulation show:
  - Present α-TAE too weak to cause measurable alpha loss.

Alpha Loss due to KBM Observed

- Significant alpha-loss enhancement observed in kinetic-ballooning-mode (KBM) case.

Alpha Loss Correlated with KBM

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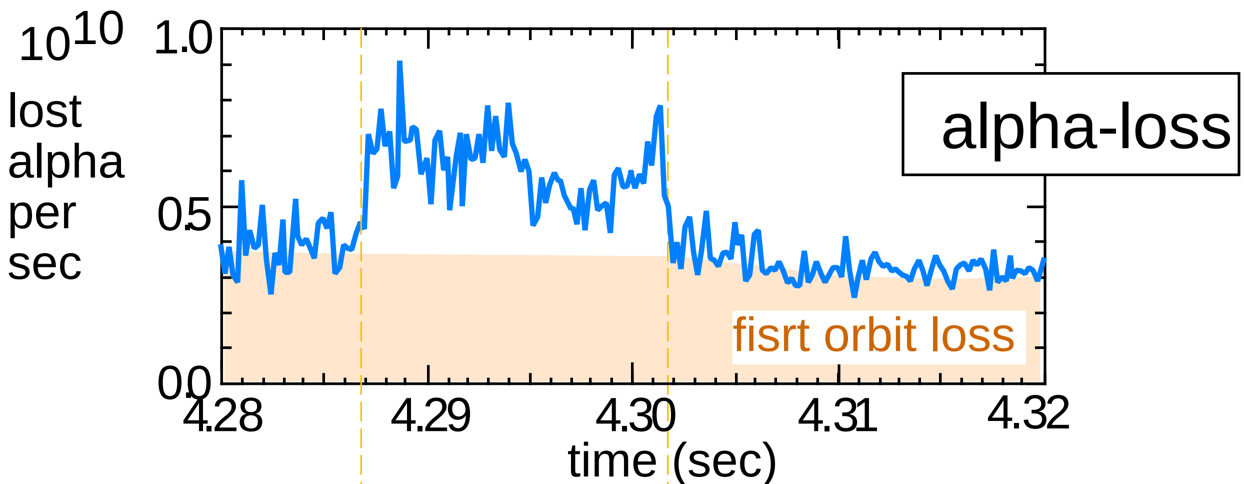
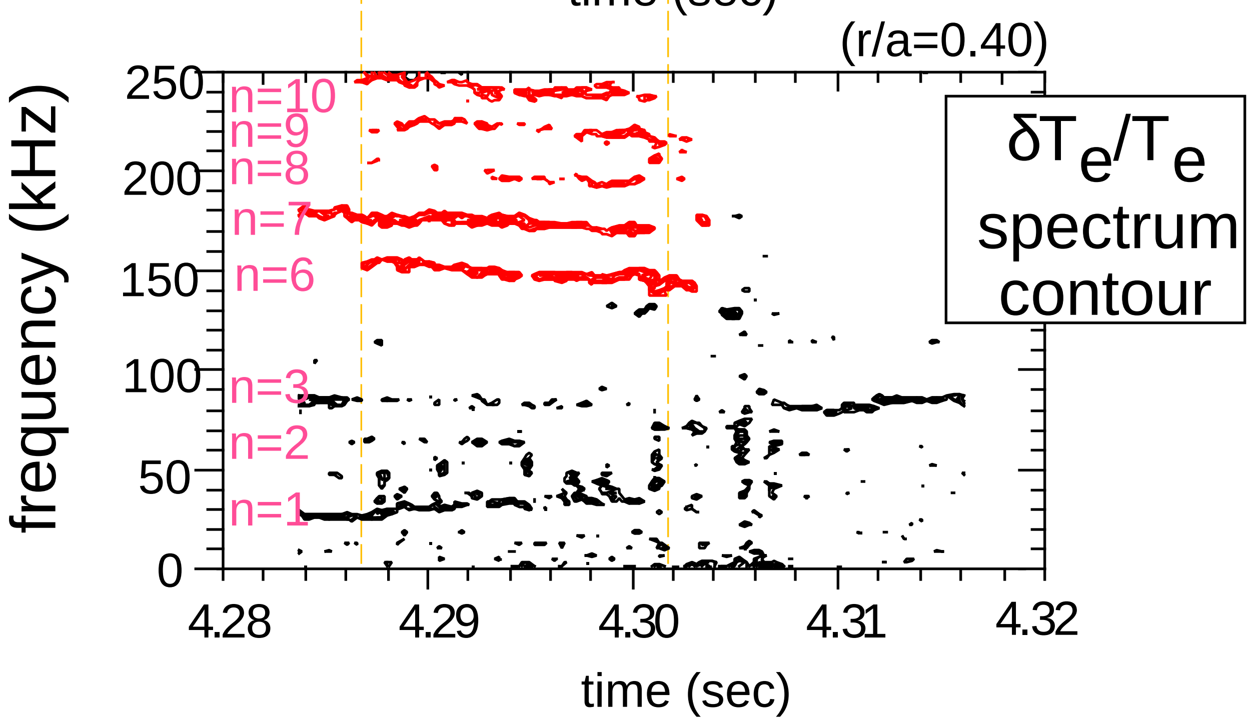
- Large enhanced loss observed in high-beta high-power DT plasmas.





- A factor of 2 loss increase due to n≥6 KBM.

The Ballooning Modes Locate around Maximum P

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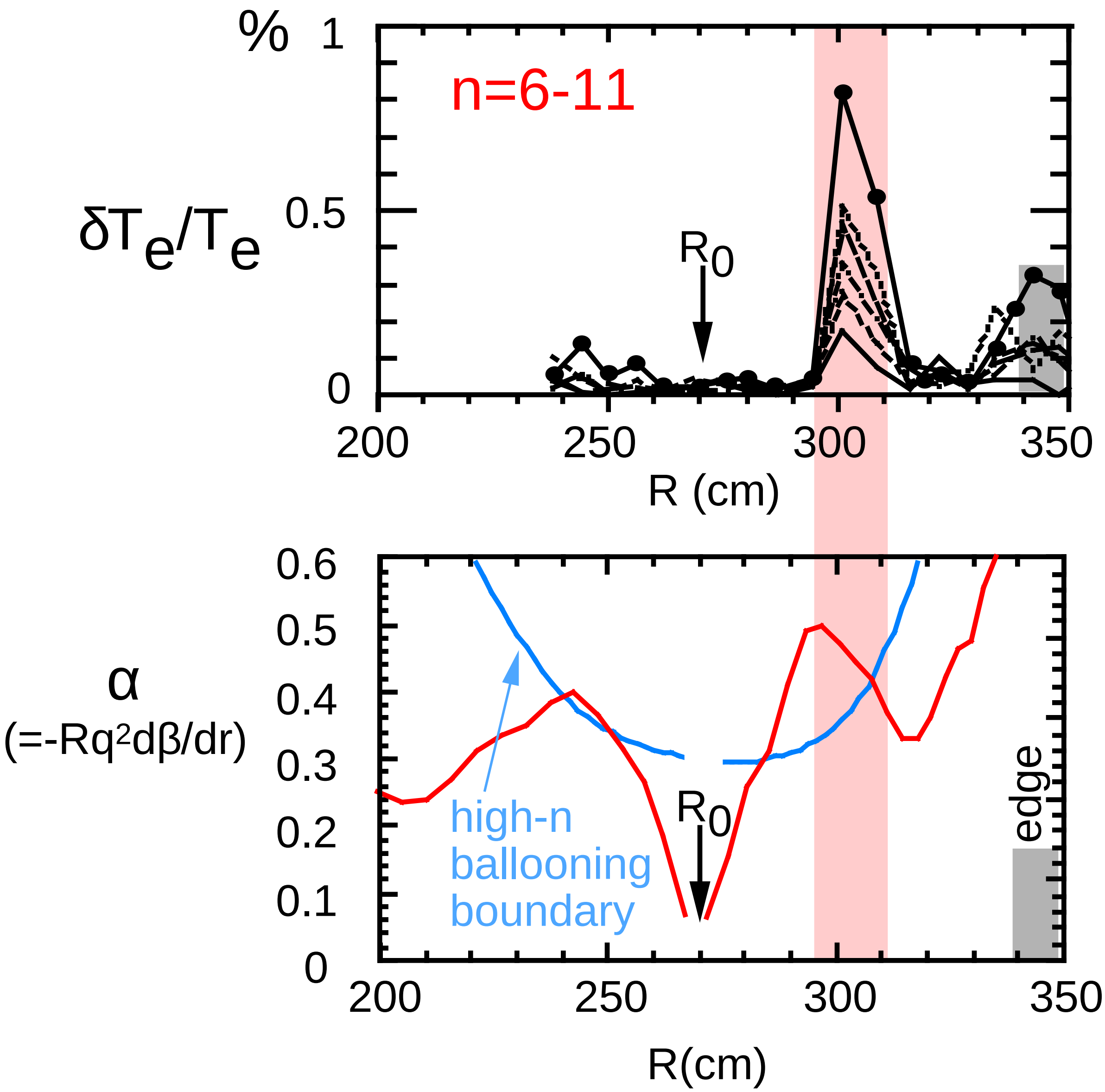

- Ballooning feature also observed from Mirnov coils.

Results of KBM Stability Analysis

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- *Mode classification*
  - Not TAEs. (f_{TAE} ~ 300 kHz)
  - Not BAEs (beam-driven Alfven eigenmodes):

    $\omega \sim \omega_{*pi}/ 2$ --- *KBM scaling*
  - Different from idea ballooning disruption precursor

  ==> Kinetic ballooning modes

- *Kinetic FULL code calculation*

  --- G. Rewoldt and W. Tang
  - Driven by background pressure gradient.
  - Effects from beam-ion and alpha are small.
  - Mode location agrees with experiment.
  - Maximum linear growth rate has n=14.

    (nonlinear effects may down-shift n.)

- *Two-fluid calculation* --- L. Zakharov
  - Ballooning unstable.
  - High n (>10) modes suppressed by ω_{*i} effects.

Simulation of Wave-Particle Interaction

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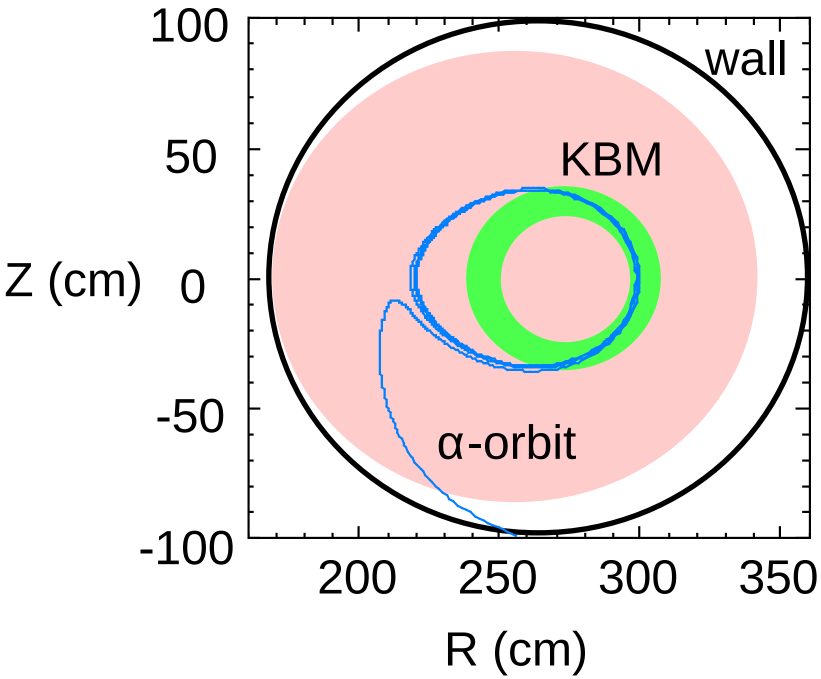
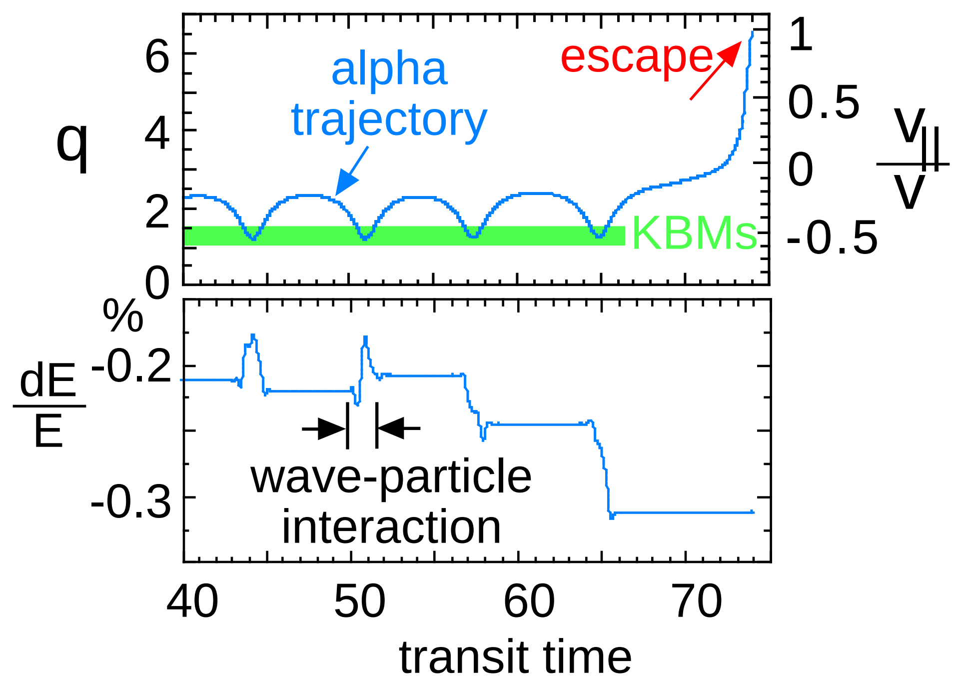
ORBIT code simulation --- R. White

- Basic feature:

  passing alpha + KBMs → lose energy to KBM, change pitch angle → trapped → escape





- KBMs can cause ~100% increase in lost alphas.

  --- consistent with experiment.
- Global modes will be more dangerous.

Conclusions

Alpha-driven TAE

- Observation of alpha-driven TAE opened a new chapter in fusion plasma physics.

- Initial analysis showed good agreement between theory and experiment (frequency, resonance, mode structure, stability, ...).

KBM-induced alpha loss

- KBM in high-beta D-T plasmas caused substantial alpha loss (a factor of 2 enhancement).

- Particle simulation quantitatively demonstrated the alpha loss mechanism.

RL]