NSTX

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Wave-Particle Interactions
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G. Taylor, *leader*

M. Podestà, *deputy*

N. Gorelenkov, *theory and modeling*

NSTX Mini Results Review

September 30, 2010

Culham Sci Ctr
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ASCR, Czech Rep
U Quebec

Overview

- FY10 research milestone R(10-2) to characterize HHFW heating, current drive, and current ramp-up in D_2 H-mode plasmas was not achieved:
  - Ran XMP26 HHFW plasma conditioning for 5.5 days in June & 2 days in August
  - Significant lithium-related influx during rf operations limited reliable coupled RF power to ~1.5 MW this year
  - Planning HHFW campaign in October with high priority on achieving $f_{NI} \sim 1$
- Only two RF 1st priority XP's (partly) run:
  - XP1009: "HHFW heating of low $T_e(0)$, I_p plasmas" (Taylor) – *1/2 day run time*
  - XP1017: "RF heating at the divertor SOL regions" (Hosea) – *1 hour run time*
  - XP1016: "HHFW power coupling vs ELMs" (Hosea) – *analysis of FY09 data*
- Three EP 1st priority XP's:
  - XP1011: "TAE/GAE avalanches studies in H-mode deuterium plasmas" (Fredrickson)
  - XP1013: "Investigation of *AE Induced Electron Transport" (Tritz)
  - XP1014: "Document the Angelfish Instability and Effect of HHFW" (Heidbrink)

HHFW Conditioning

RF Operations Summary for FY10 Campaign

- 2.1 MW of $k_\phi = -8\ m^{-1}$ for 200 ms into D NBI H-mode:
  - Also 2.7 MW for 160 ms & 2.9 MW for 50 ms
  - Performance was well below the ~ 4 MW operation achieved with new double end fed antenna in 2009
  - 1.6 MW of $k_\phi = -13\ m^{-1}$ for 170 ms into D NBI H-mode
- Vacuum conditioning between plasma shots has begun in effort to clean antennas:
  - All 6 transmitters recently run simultaneously between plasma shots using 500 ms pulses every 30 s
  - Previously antennas were conditioned two transmitters at a time in the evening before a run
  - Voltage hold off improves steadily, but a single plasma “event” can set us back significantly

J. Hosea, P. Ryan, G. Taylor

RF Operations During the FY11 Campaign

- For FY2011 HHFW campaign will combine vacuum conditioning between shots with RF plasma operations
  - May attempt this during the October campaign

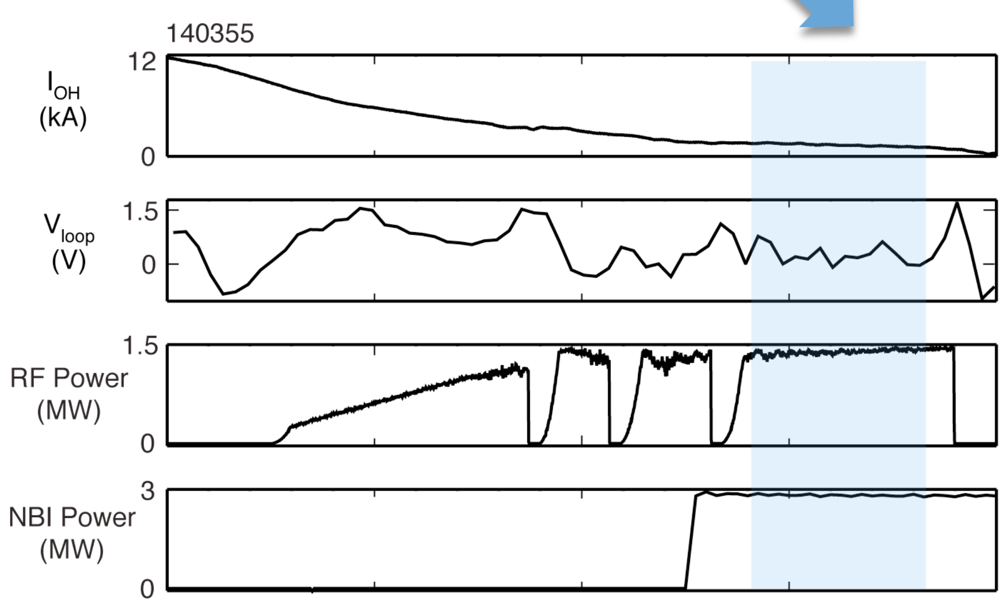
- Need to investigate shielding/cleaning plans for future operation:
  - Modify the boron nitride limiters?
  - Improve collimation on LITER closest to antennas?
  - Shield above the array?
  - Develop a plasma configuration that can “scrub” the antenna surface?
  - Should we consider baking the antenna?

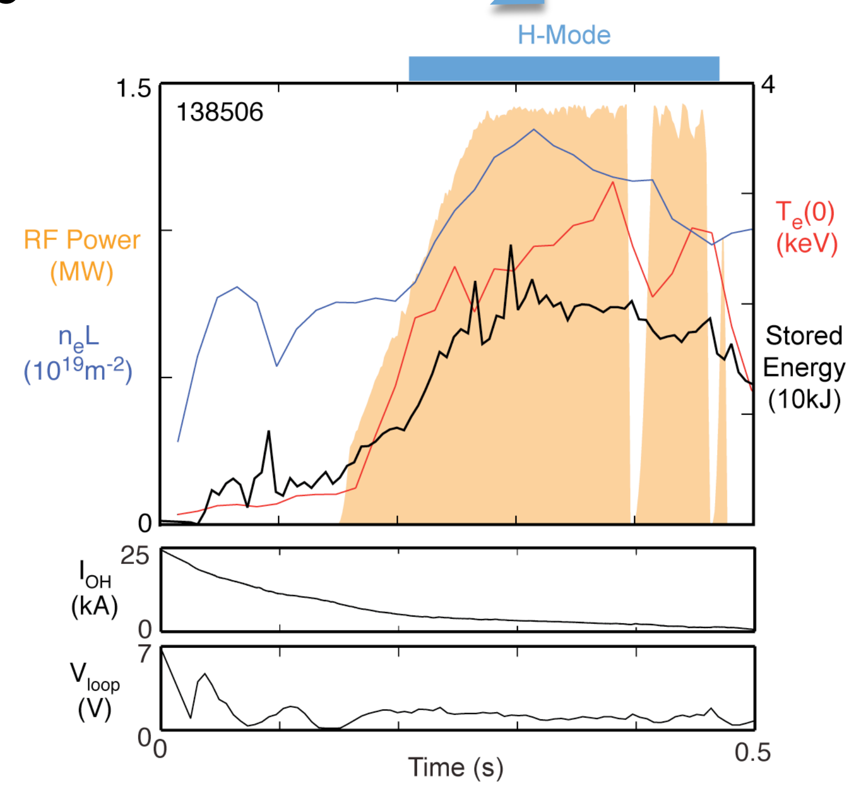
J. Hosea, P. Ryan, G. Taylor

Summary of Experimental Results

XP1009: RF heating at low I_p to generate non-inductive H-mode discharge at I_p ~ 200-300 kA

- Heated I_p = 300 kA plasma with 1.4 MW of $k_\phi = -8\ m^{-1}$ RF heating June 14 :
  - Measured good electron heating during RF H-mode (138506)
- Also Heated I_p = 300 kA plasma with 1.5 MW of $k_\phi = -8\ m^{-1}$ RF & 3 MW NBI heating August 25:
  - Measured V_{loop}~0 and dI_{OH}/dt~0 during RF + NBI heating (140355)





- P_{rf} limited to ~ 1.5 MW by Li influx

G. Taylor

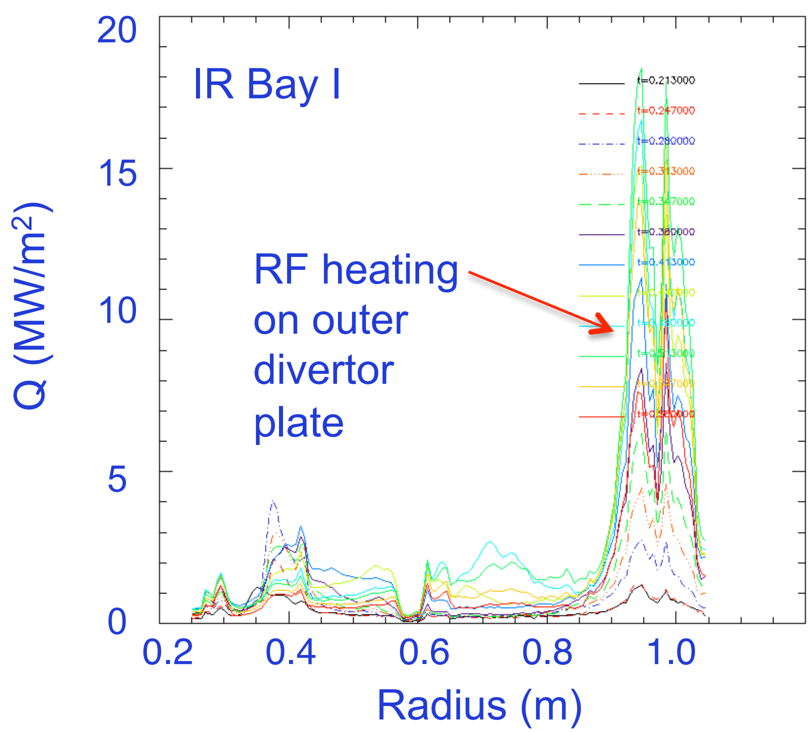
XP1009: Need P_{rf} ~ 3 MW at I_p = 300 kA to achieve non-inductive current drive fraction, f_{NI} ~ 1

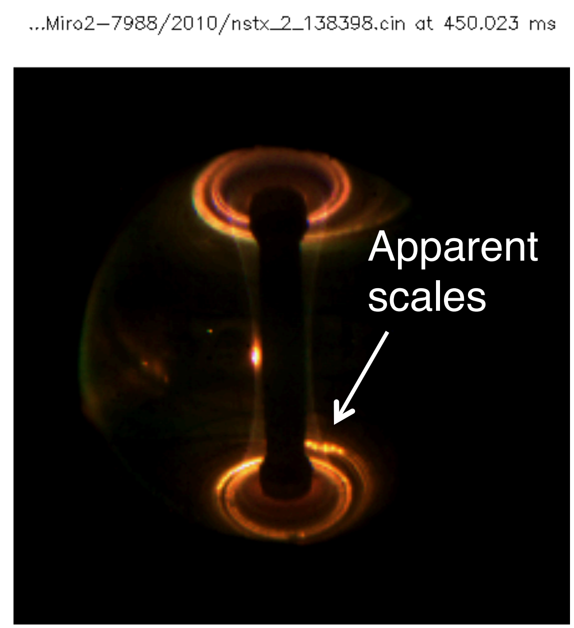
- Sustained RF H-mode, better plasma control than in 2005
- Achieved good electron heating and saw evidence for ITB on best shots
- TRANSP analysis of low I_p RF heating experiments with P_{rf} ~ 1.5 MW at I_p = 300 kA predicts f_{NI} ~ 0.6
- Probably need P_{rf} ~ 3 MW to achieve f_{NI} ~ 1 at I_p ~ 300 kA
- Plan to run XP1009 again in October, after extensive RF conditioning

G. Taylor

XP1017: RF Heating at Divertor/SOL Regions

- Scan of magnetic field pitch June 9 at P_{RF} = 2 MW
  - I_P(MA)/B_T(kG) = 0.8/5.5, 0.8/4.5, 0.9/4.5, 1.0/4.5
  - Divertor RF heating inner radius moves with pitch
  - IR measurement complicated by apparent lithium scales on outer divertor plate
  - Need to condition scales away
- RF power limited at present by lithium sputtering from antenna





J.Hosea

XP1016: HHFW Power Coupling vs ELMs

Background:

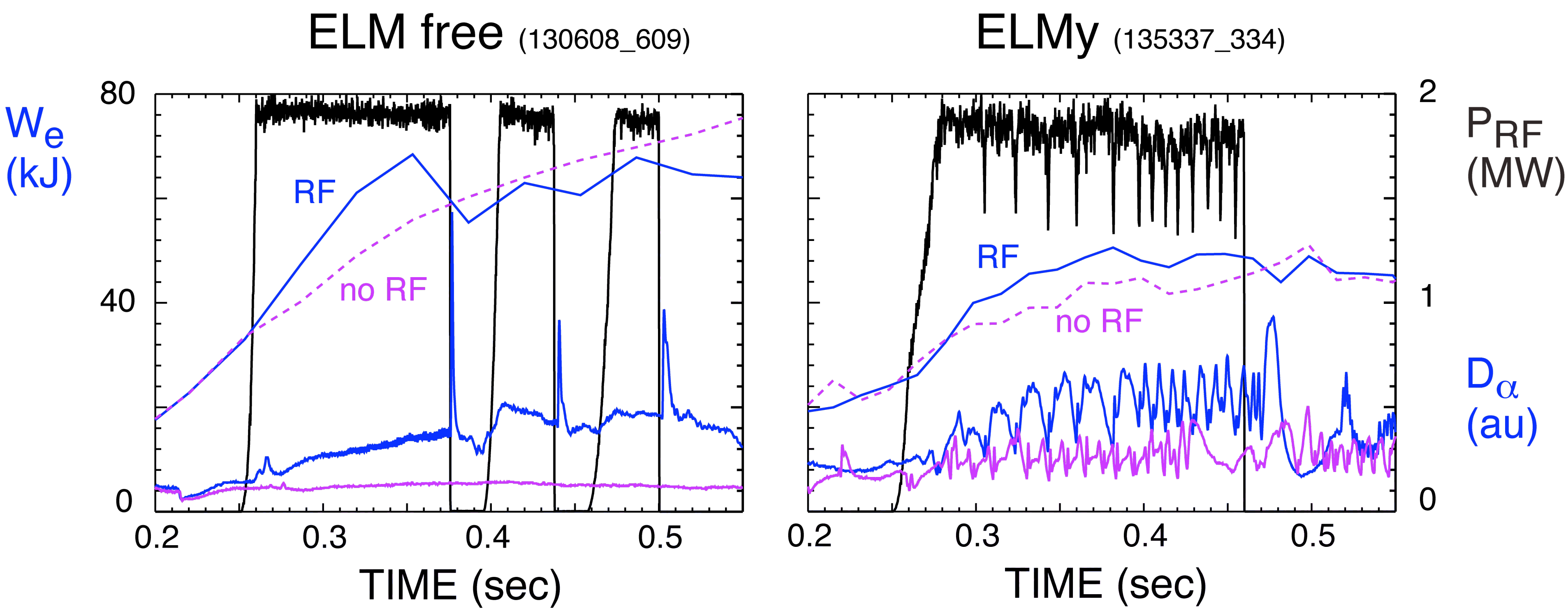
- ELMs reduce energy confinement and hence heating efficiency relative to no-ELM H-mode case
- ELMs increase edge density enhancing RF power losses in scrape off region to the outer divertor RF heated zone
- ELM energy deposition on outer divertor peaked around outer strike radius and appears to contribute little to the RF hot zone

XP1016 seeks to show that ELM deposition does not contribute significantly to hot zone produced by edge RF deposition

- Initial data from two-color fast IR camera still being analyzed
- More data desired during October run

J.Hosea

ELMs reduce plasma heating by ejecting energy (as for NBI) and by producing higher edge density

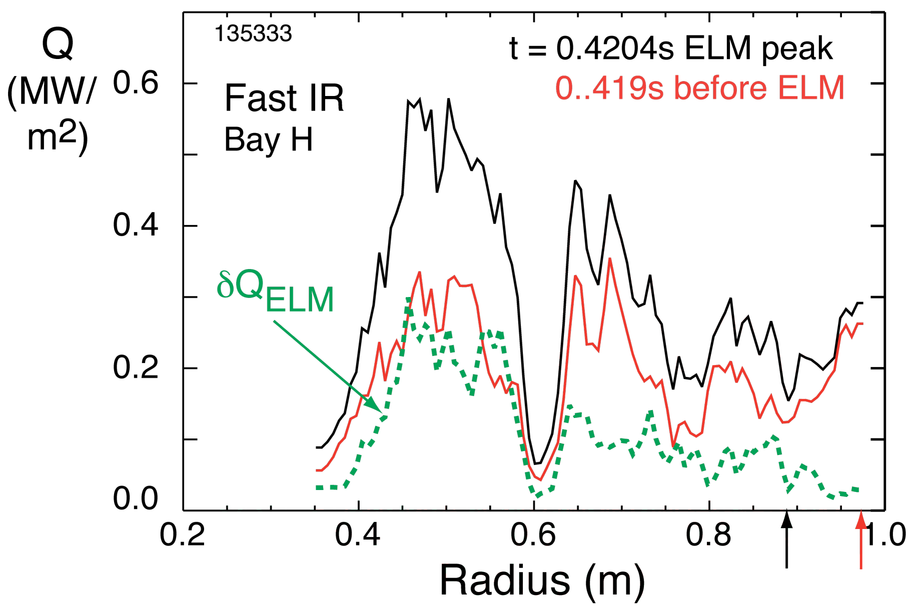


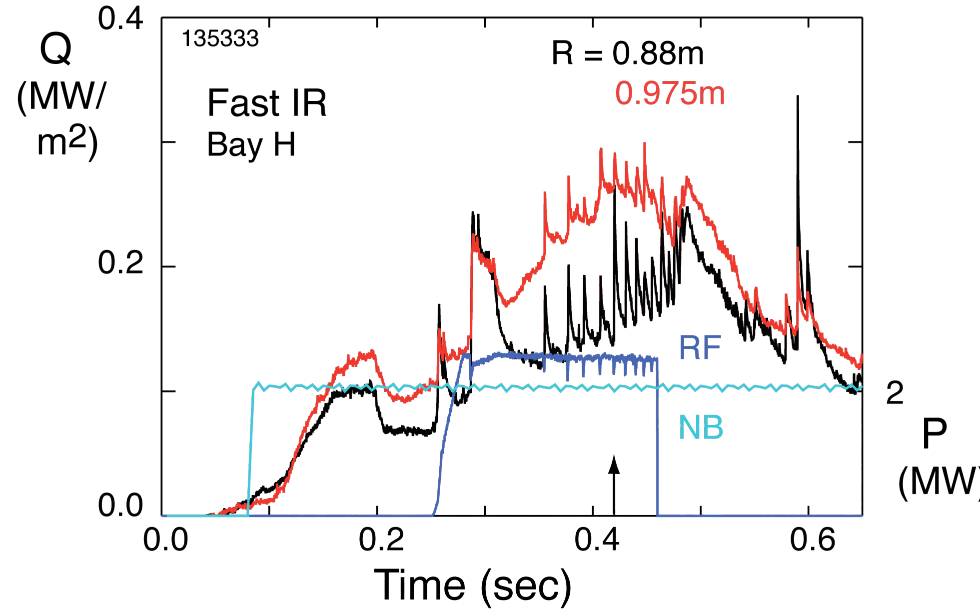
- ΔW_e and ΔW_{tot} for shot 135337 with ELMs are reduced by ~ 50% relative to shot 130608 ELM free case
- D_α indicates increased power deposition to divertor region with ELMs

J.Hosea

ELMs do not appear to enhance HHFW loss to divertor directly – ELM deposition peaked at strike radius

Fast IR at Bay H with Phase = -90°, B_T = 4.5 kG, I_P = 0.8 MA



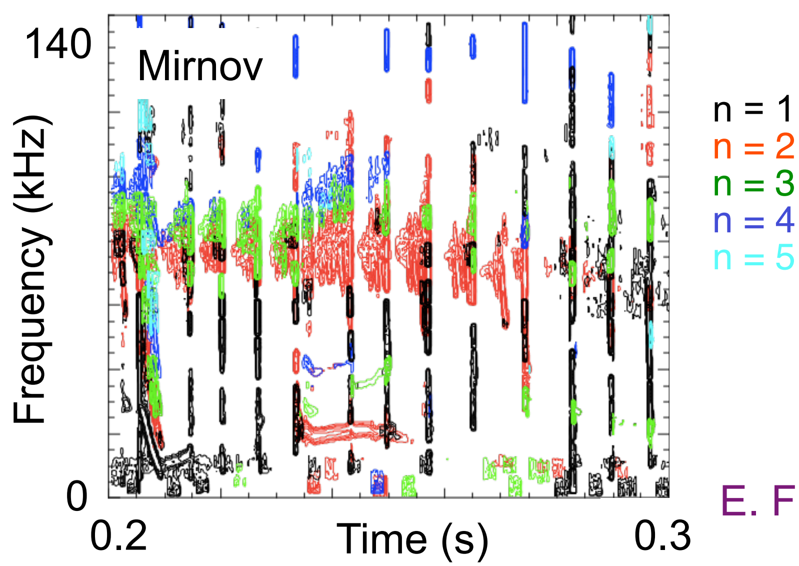


- Key question: does ELM contribute significant heat in the primary RF heated divertor zone? – *Probably not*
- Fast IR camera shows ELM heat deposition peaked at outer strike radius – falling to a low value towards the RF heated zone (R ~ 1.1 m)
- Future experiments are planned to determine the effect of ELMs on the primary RF edge heating zone at Bay H

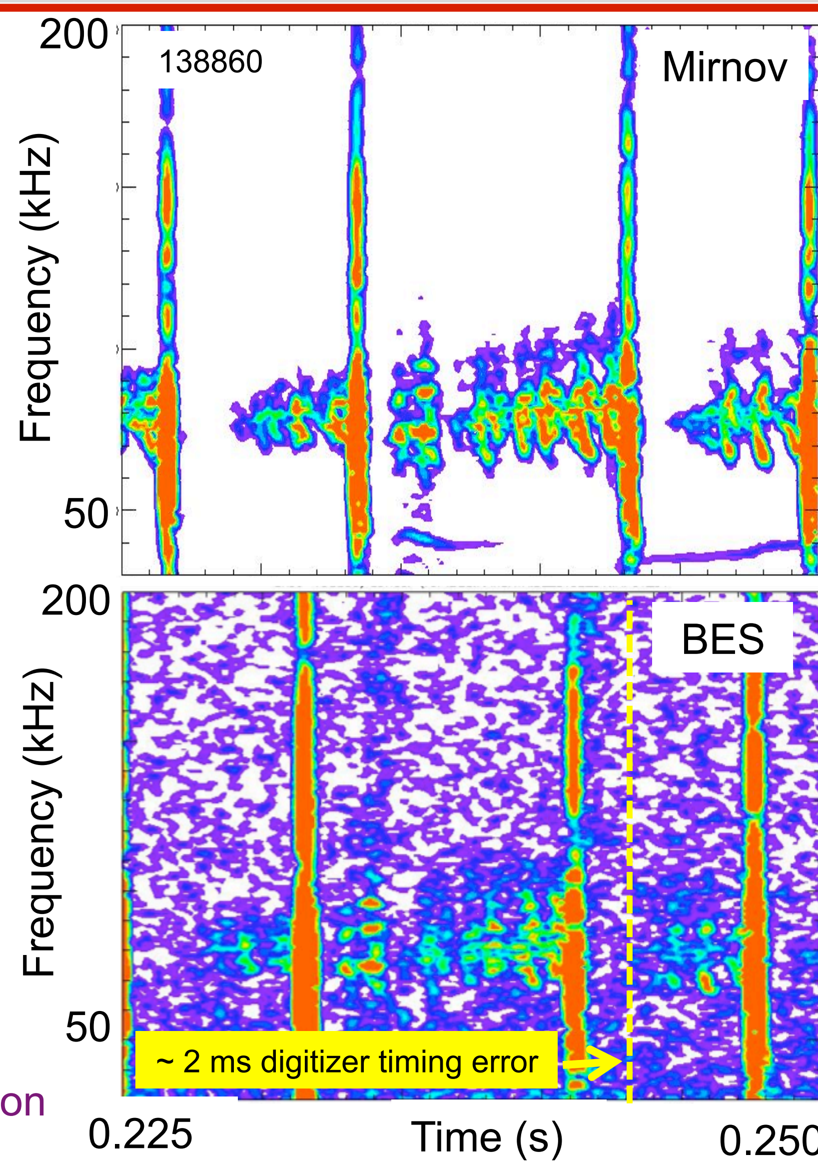
J.Hosea

XP1011: TAE avalanches in H-mode plasmas

- First BES measurements of internal amplitudes of TAE modes:
  - Only outer shutter operational for first run, full radial profile array acquired in later shots
- Observed evolution of dominant mode numbers:
  - Reduced outer gap - may suppress modes



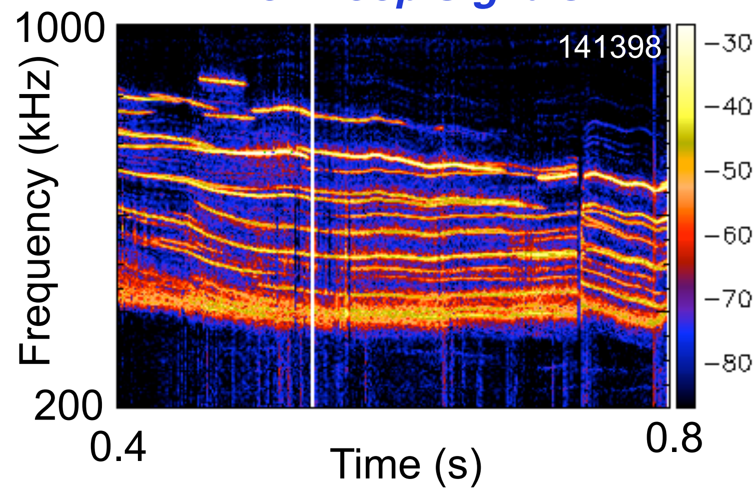
E. Fredrickson



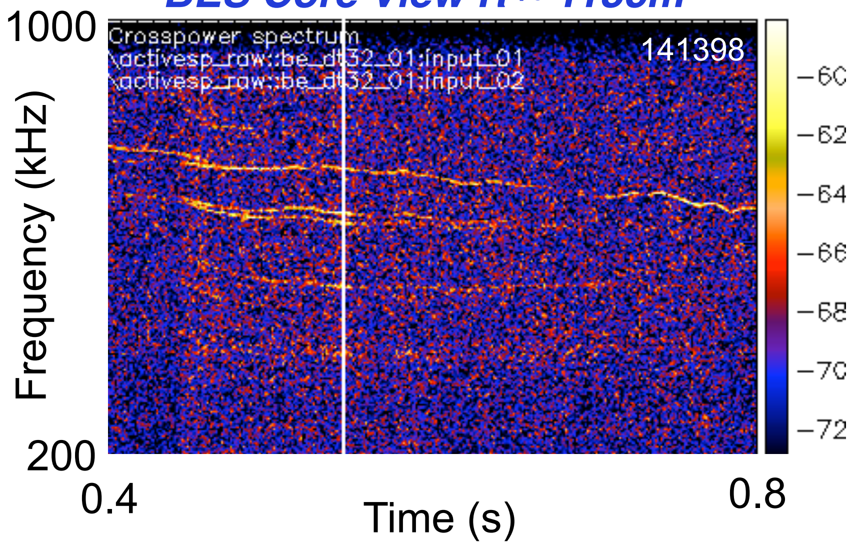
XP1013: *AE induced electron transport - I

- *AE modes clearly seen in core BES channels
- Lower-f mode amplitudes below BES noise floor

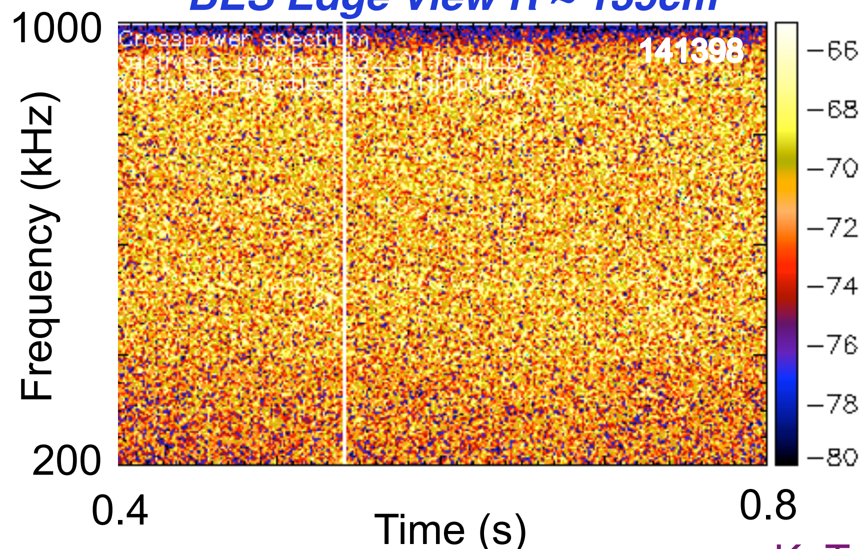
Mirnov Loop Signals



BES Core View R ~ 118cm

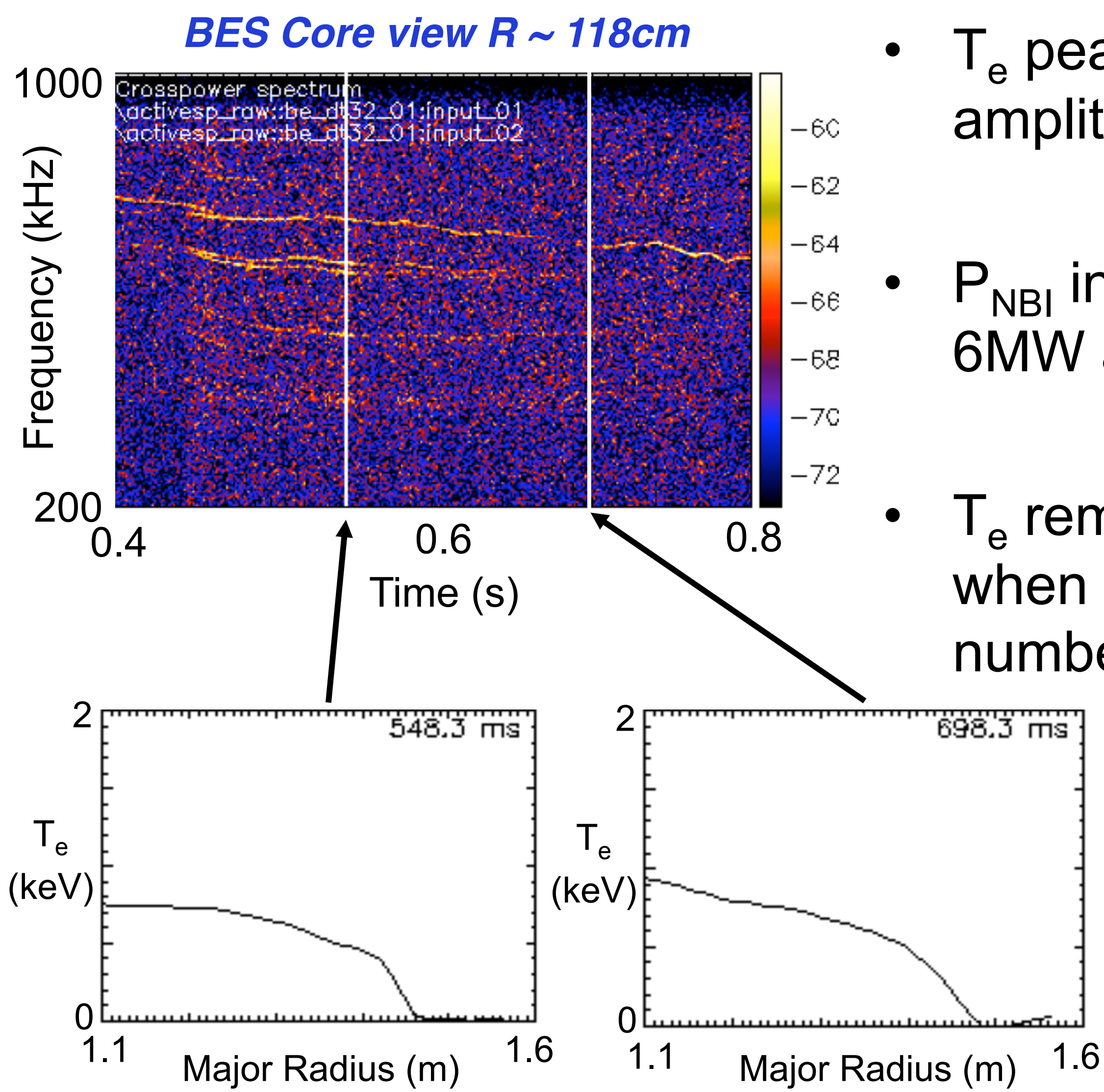


BES Edge View R ~ 135cm



K. Tritz

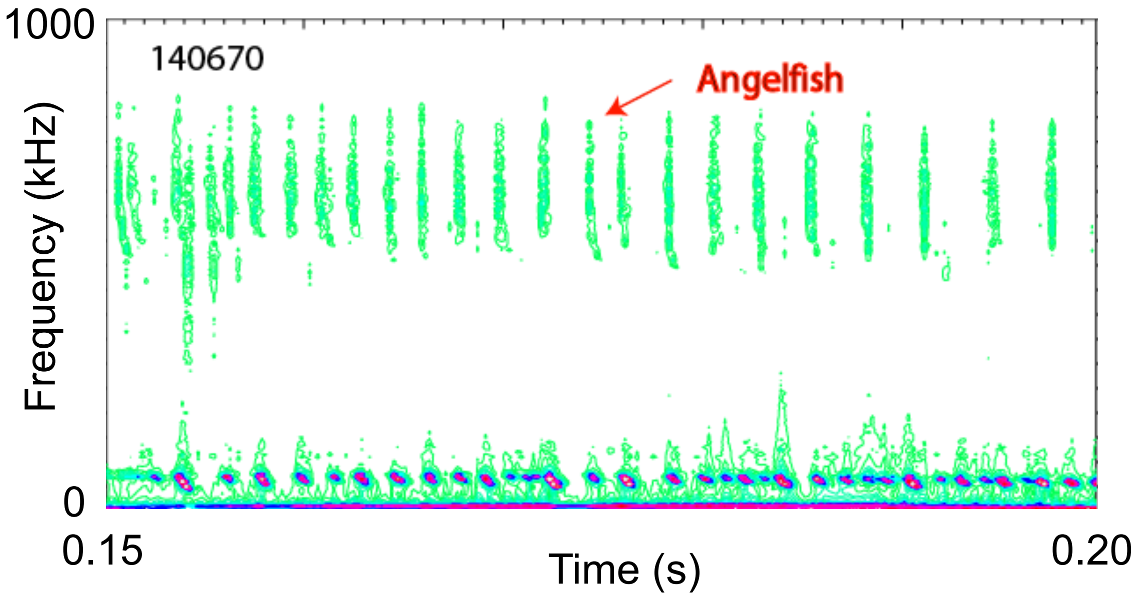
XP1013: *AE induced electron transport - II



- T_e peaking occurs as *AE amplitude is reduced
- P_{NBI} increases from 4MW to 6MW at 450ms
- T_e remains flat until ~ 650ms when *AE modes reduced in number/amplitude

K. Tritz

XP1014: Nonlinear Evolution of "Angelfish"



- Successfully made Angelfish at 3.7 kG
- Added short pulses of ~1.5 MW HHFW – no noticeable effect on Angelfish
- Failed to measure eigenfunction
- Saw effect on SSNPA - first direct observation of fast-ion transport
- Valuable beam modulation data for BES study

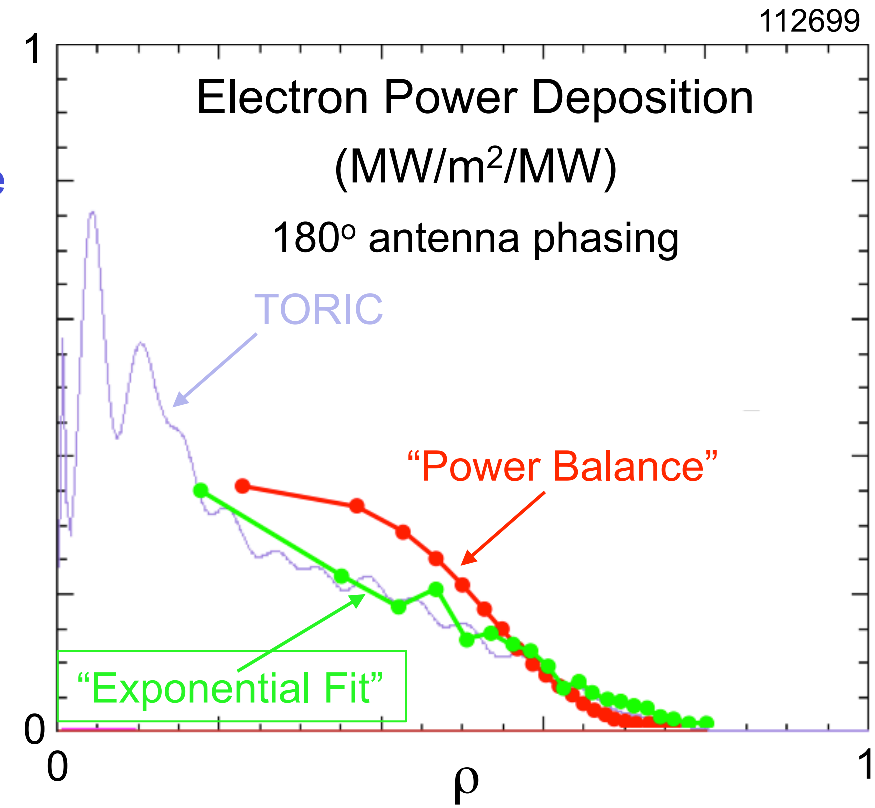
B. Heidbrink, UC Irvine

UCIrvine
University of California, Irvine

Summary of Modeling Results

"Exponential fit" analysis of electron power deposition, $P_e(\rho)$, using n_e & T_e data shows good agreement with TORIC

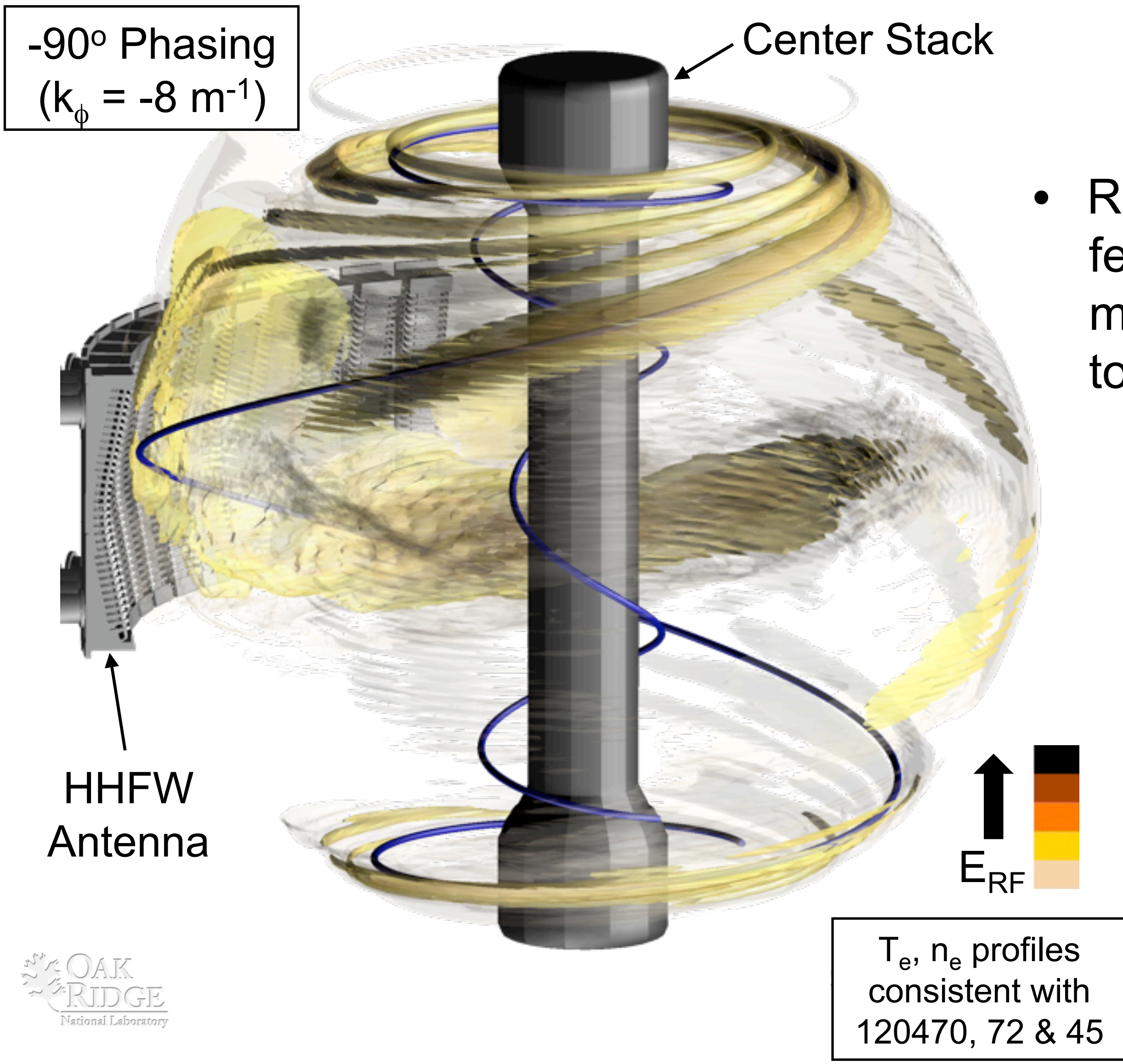
- Two methods can be used to deduce $P_e(\rho)$ from Thomson scattering data:
  - ➢ Solve "Power Balance" versus ρ using τ from volume-integrated power & evaluate time-derivative of rf-induced change in stored energy at each ρ
  - ➢ Perform an "Exponential Fit" analysis as function of ρ - can be more accurate than power balance analysis if data is clean enough for exponential fit
- Preliminary comparisons between $P_e(\rho)$ from exponential fit analysis and TORIC prediction are encouraging for 180° antenna phasing:



L. Berk (SULI student 2010)
C.K. Phillips, B. LeBlanc, J. Hosea

  - ➢ Comparisons for -90° antenna phasing are underway, but more difficult

3-D AORSA full wave simulations now being run for NSTX HHFW cases with boundary at limiter



- RF electric field (E_{RF}) features (yellow-black) follow magnetic field (blue) near top & bottom of plasma
  - Magnitude of E_{RF} features are larger for negative antenna phasing than positive phasing
  - For -30° phasing (k_ϕ = -3 m^{-1}) fast wave propagates outside LCFS to wall

D. Green, ORNL

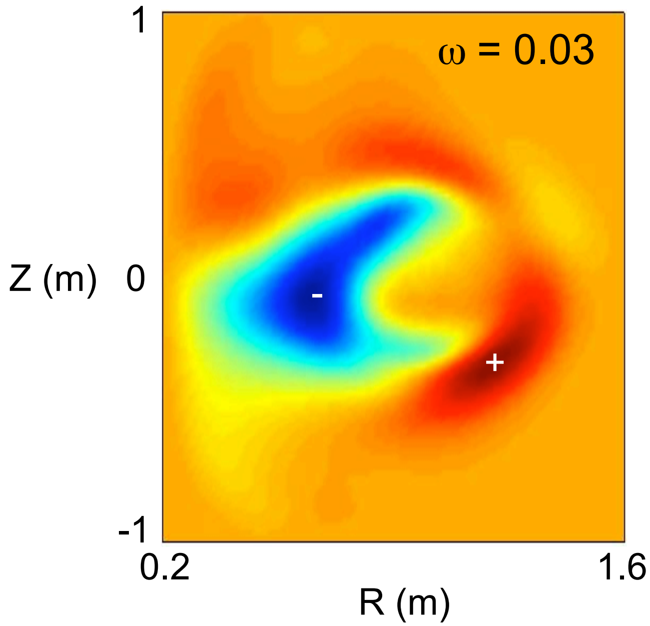
Effects of beam ions on non-resonant kink in NSTX

M3D-K Results for Shot #124379

Contours of streaming function for n = 1 linear eigenmode

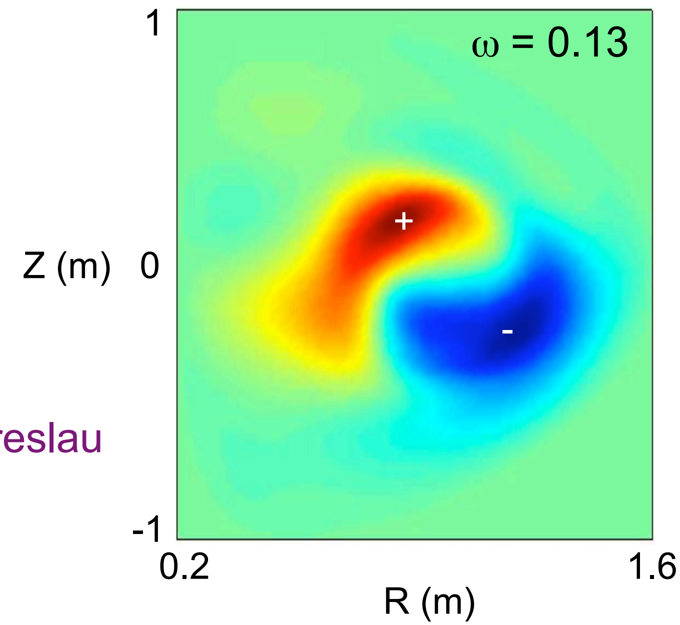
Anisotropic Beam Ion Distribution

Beam ion effects are weakly destabilizing



Isotropic Beam Ion Distribution

Beam ions can excite fishbone



G. Fu & J. Breslau

- Results are sensitive to details of distribution function
- Need to model realistic beam ion distribution in order to reach definitive results on beam ion effects on the non-resonant kink in NSTX
- Fishbone instability possible for q > 1 with sufficient trapped beam ions