NSTX
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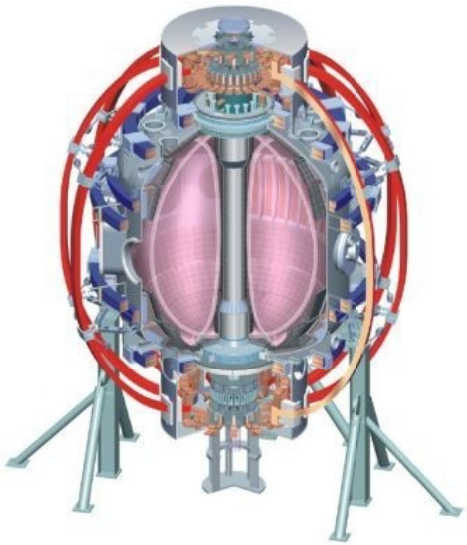
Effects of Global Alfvén Eigenmodes on Electron Thermal Transport in NSTX

Kevin Tritz
Johns Hopkins University

D. Stutman, M. Finkenthal (*JHU*)
R. Bell, E. Belova, E. Fredrickson, N. Gorelenkov, R. Kaita, S. Kaye, B. LeBlanc, E. Mazzucato, Y. Ren, R. White (*PPPL*)
N. Crocker, S. Kubota, W.A. Peebles (*UCLA*)
R. Fonck, G. McKee, D.R. Smith (*U. Wisc.*)
and the NSTX Team

52nd annual APS - DPP meeting
Chicago, IL 11/10/2010



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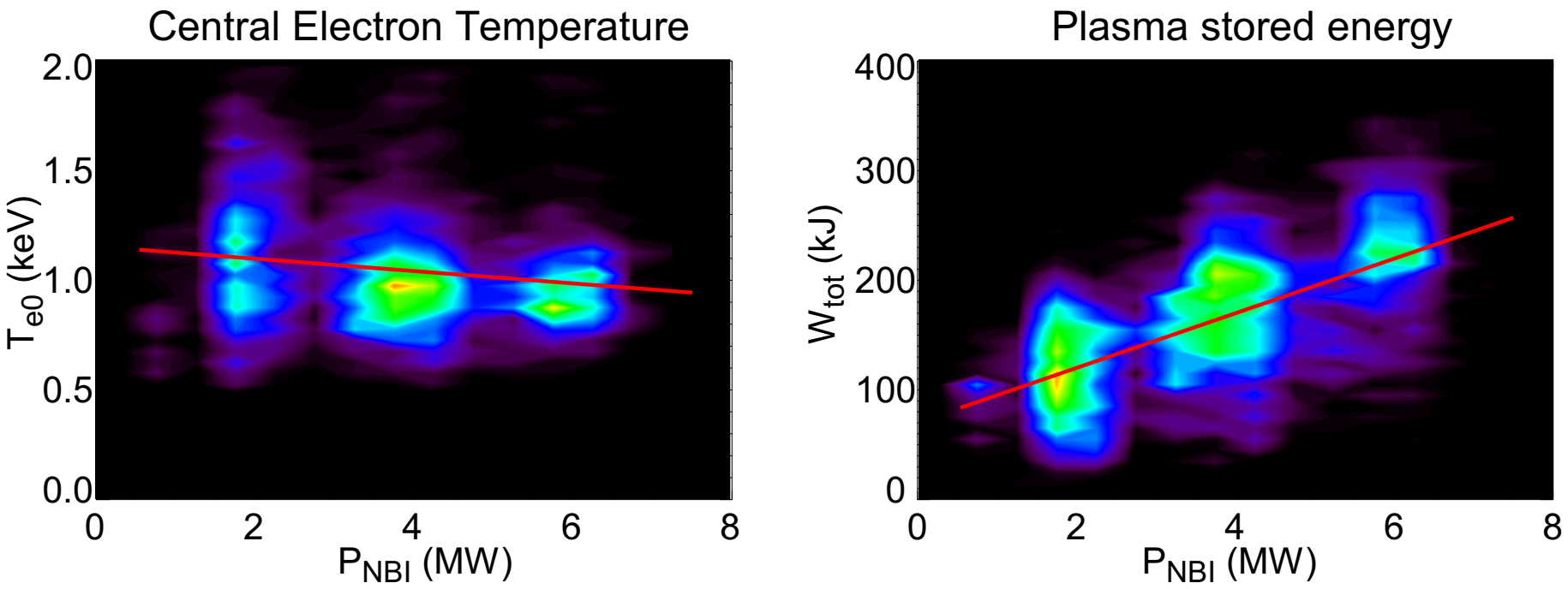
Fast ion-induced GAE modes are a good candidate to explain the unusually high levels of electron thermal transport in the core of high power H-mode NSTX plasmas.

Outline

- Background and Motivation
- Observations of GAEs and correlation to transport
- Numerical predictions of GAE-induced transport
- Experimental measurements of GAE mode structure
- Comparison to numerical predictions and theories
- Summary

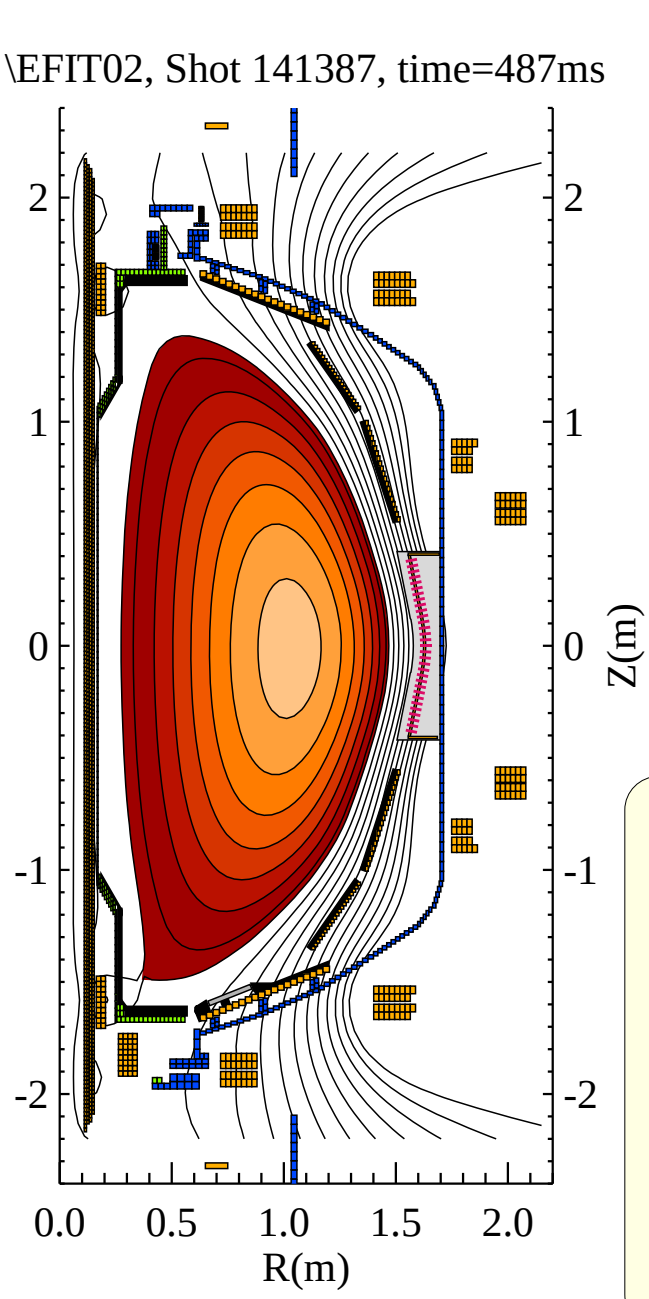
NB power has little effect on T_{e0}

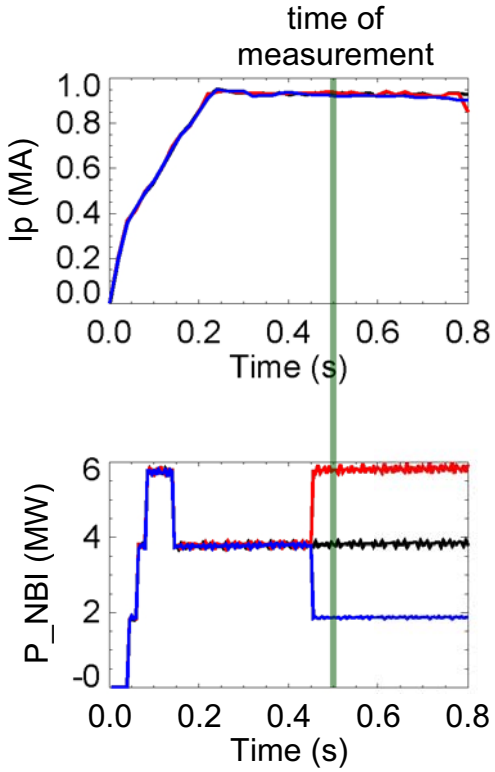
Plasma Discharge Histograms



- Database scan of >4000 NBI plasma discharges on NSTX
  - Identify central electron temperature at maximum stored energy
- Large scatter observed, wide range of plasma discharges
- Small but noticeable decrease in T_{e0} vs. P_{NBI}
  - Overall plasma stored energy increases with P_{NBI}

Experimental reference discharges use LSN H-mode with NBI preheat and beam steps for repeatable plasma conditions

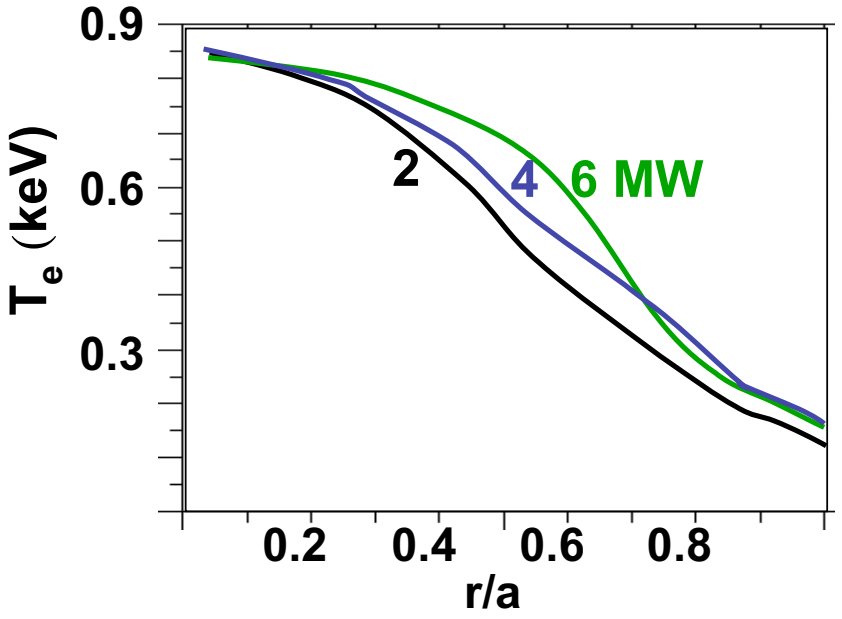


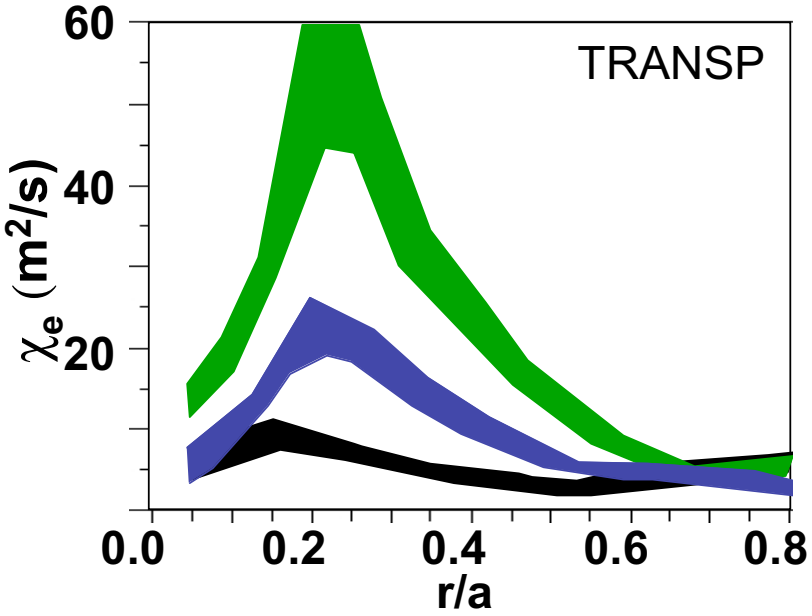


Mag. axis R_{mag}	1.03m
Aspect Ratio A	1.4
Elongation κ	2.4
Triangularity δ	~0.6
Plasma Current I_p	0.9MA
Toroidal Field B_T	0.45T
Pulse Length	~1s
P_{NB} (100keV)	2-6MW
$\beta_{T,tot}$	~15%

- NBI pre-heat used to 'freeze' in current profiles
- Beam steps at 0.45s used to change input power
- Measurements at ~0.5s before relaxation of current profile

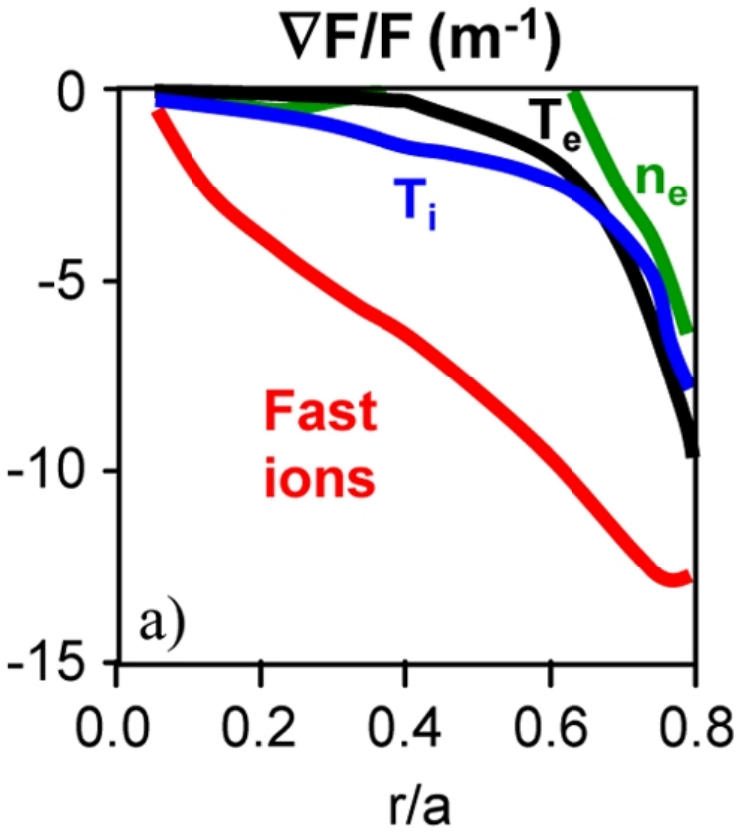
Strong enhancement of core transport is observed with increasing power in NBI discharges

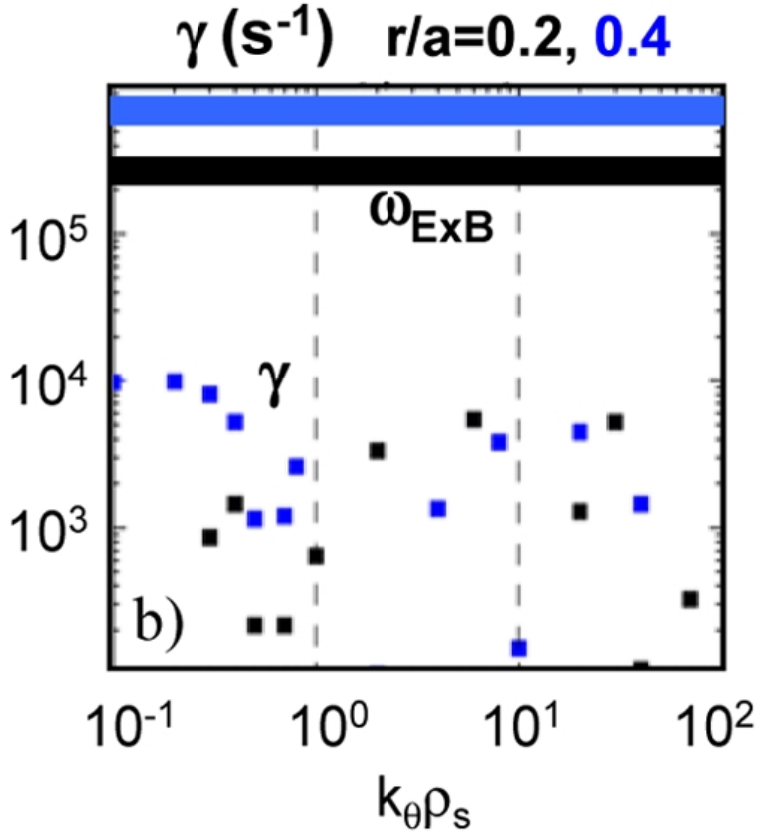




- 3x increase in P_{NBI} with no increase in T_{e0}
- Broader electron temperature profile consistent with database showing increase in W_{tot}
- TRANSP calculates high χ_e in region of flattened T_e
- Perturbative transport measurements consistent with core χ_e ~ 100m^2/s (*Tritz PoP 2008*)

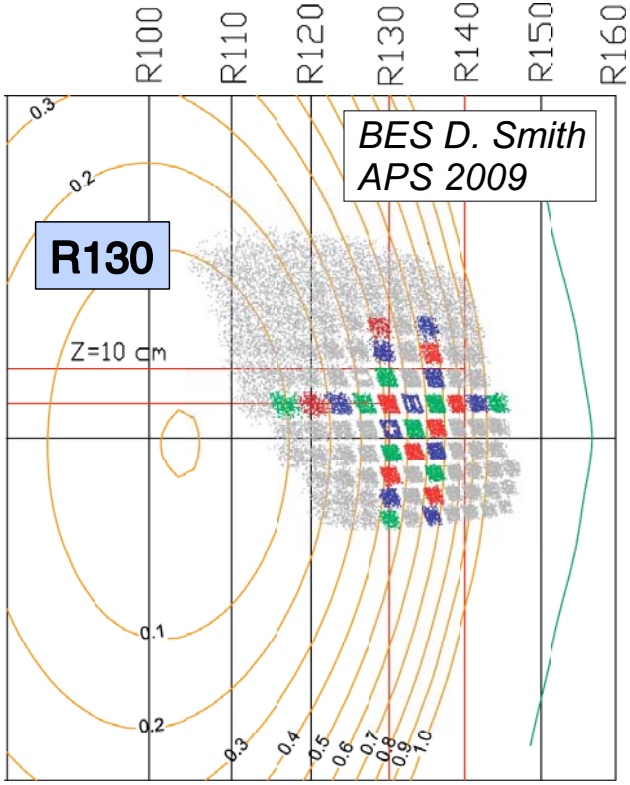
Flat plasma profiles and high rotation shear suggests electrostatic turbulence not responsible





- Linear GS2 calculations show growth rates 20-100x lower than shearing rate in plasma core over high and low-k range
- TRANSP calculated fast ion profile shows gradient which can drive fast ion modes in plasma

BES and high-k scattering systems available to measure high-f modes and turbulent fluctuations in plasma core



BES parameters

16 channels

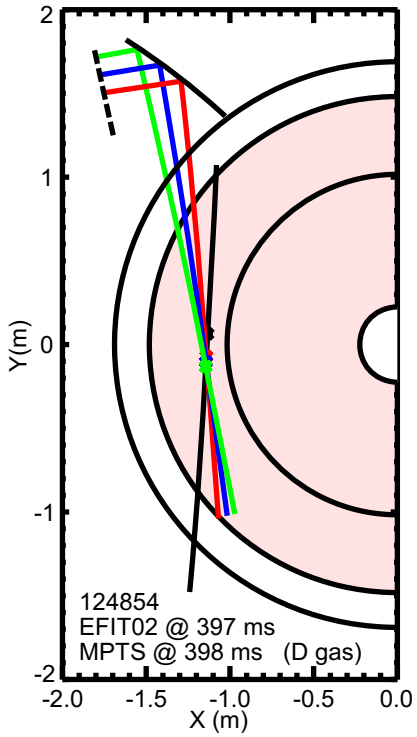
~3cm resolution

1MHz bandwidth

2MHz sampling
w/ x16 oversampling

'inner' view ~114-142cm
'outer' view ~131-155cm

k_r ? - ? cm^{-1}



High-k parameters

5 channels

+/- 3cm resolution

2MHz bandwidth

4MHz sampling

remote control over
radial position

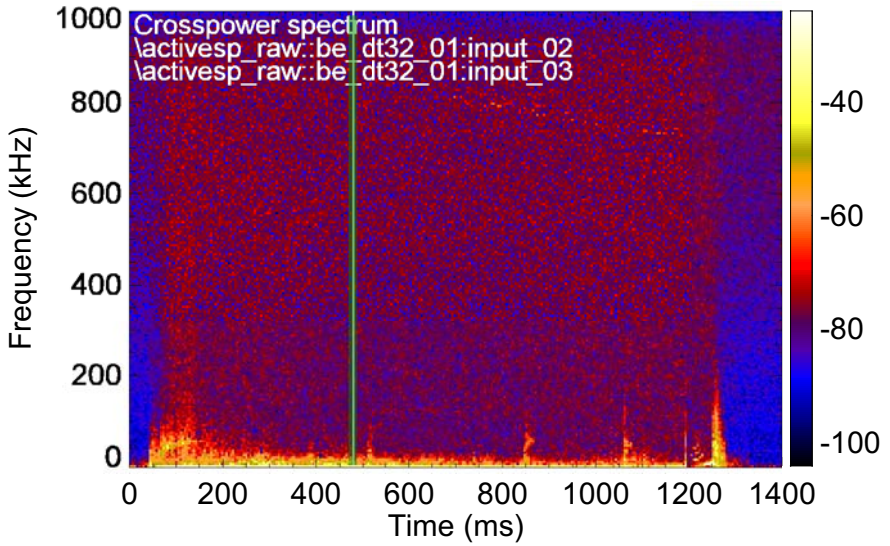
k_r ~ 4 - 24 cm^{-1}

- BES provides localized δn/n fluctuations in plasma
- High-k measures line-integrated density fluctuations in 'interferometric' mode in addition to high-k δn/n turbulence
- Combination of systems provides coverage of low/high k_r

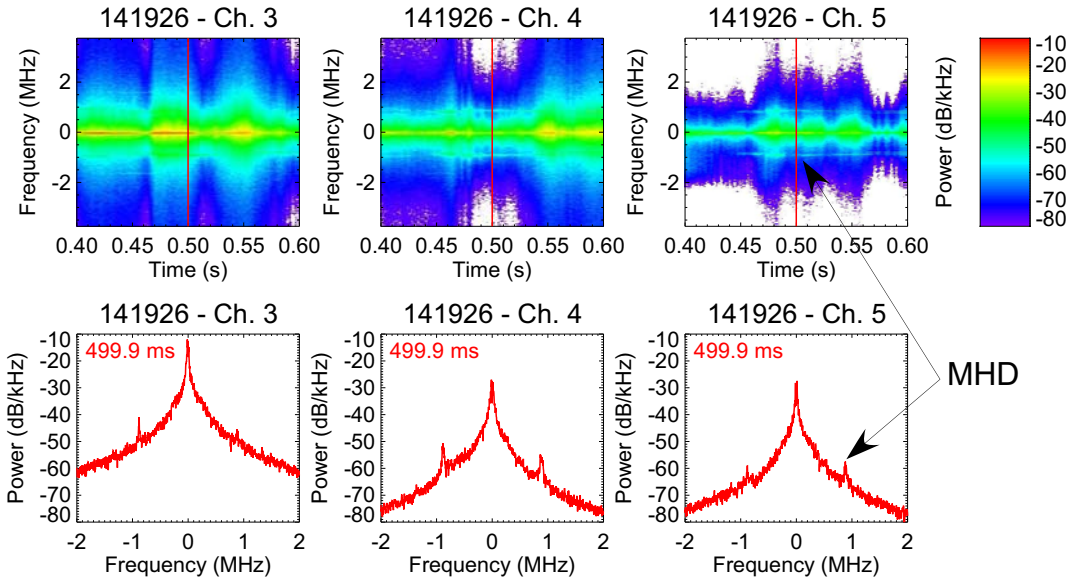
No evidence of short or long wavelength turbulence in core of NSTX plasmas during many NBI discharges

Preliminary BES data

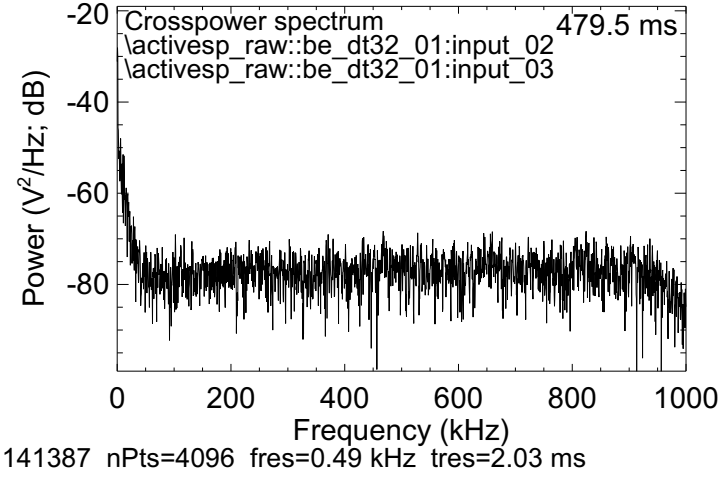
BES Cross-power spectrum R = 117&120cm



High-k fluctuation spectrum R=123cm k_r = 9-16 cm^{-1}

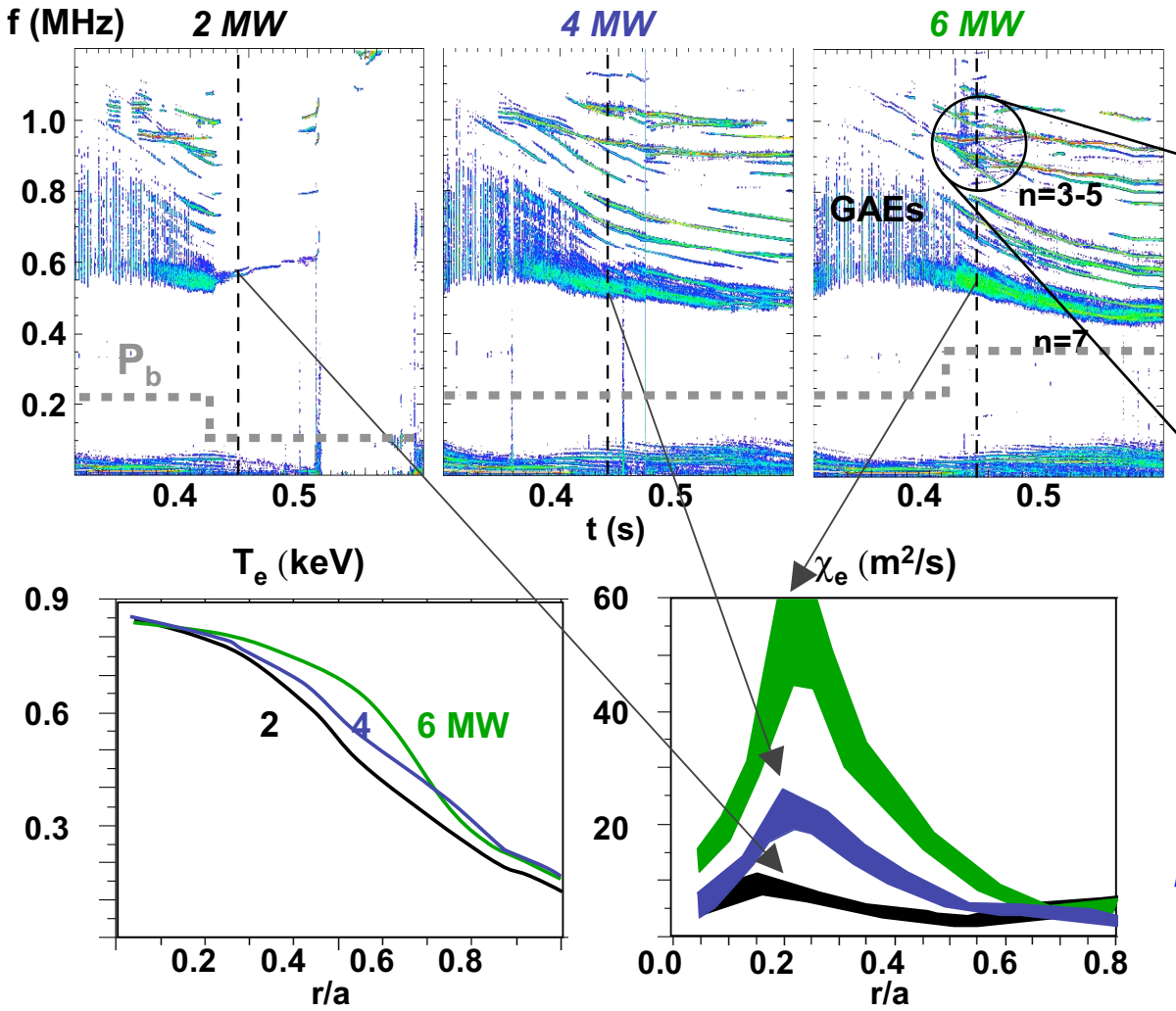


freq of rotation

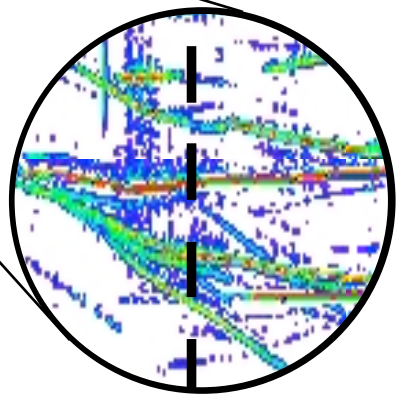


- No evidence of broadband low-k turbulent fluctuations on BES
- High-k system also shows little to no broadband high-k activity in plasma (R=123cm)

GAE modes proposed as possible mechanism for rapid electron thermal transport in plasma core



Power spectra from magnetic pickup coils



Convergence/divergence of mode frequencies evidence of GAEs

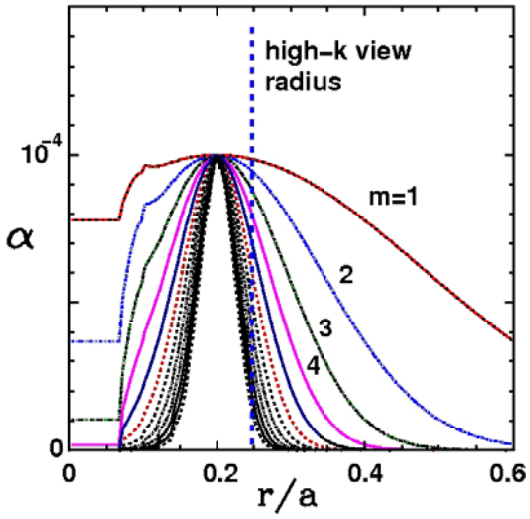
D. Stutman, PRL 2009

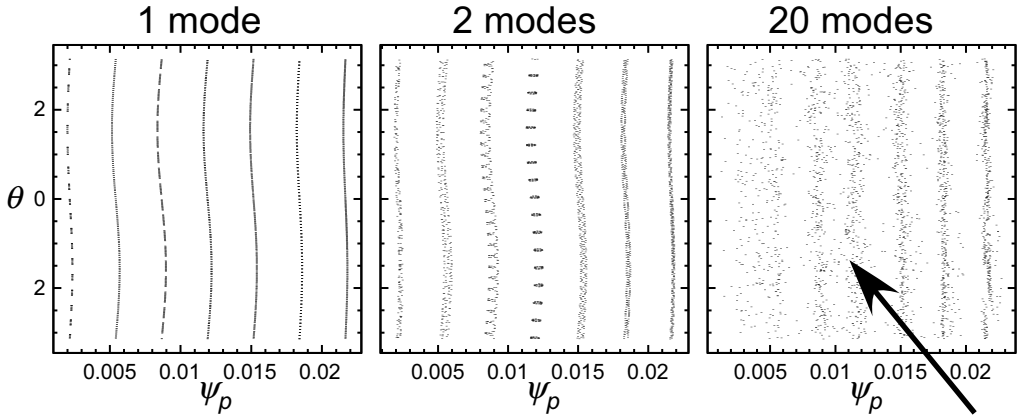
- GAE activity correlates strongly with P_{NBI} steps and enhanced core electron thermal transport

ORBIT guiding center code used to simulate GAE effects on electron thermal transport

N. Gorelenkov Nucl. Fus. 2010

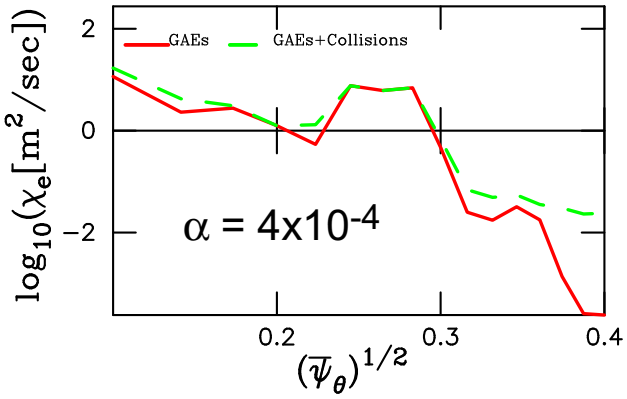
GAE Model used in ORBIT calculations





Poincaré plot of electron trajectory

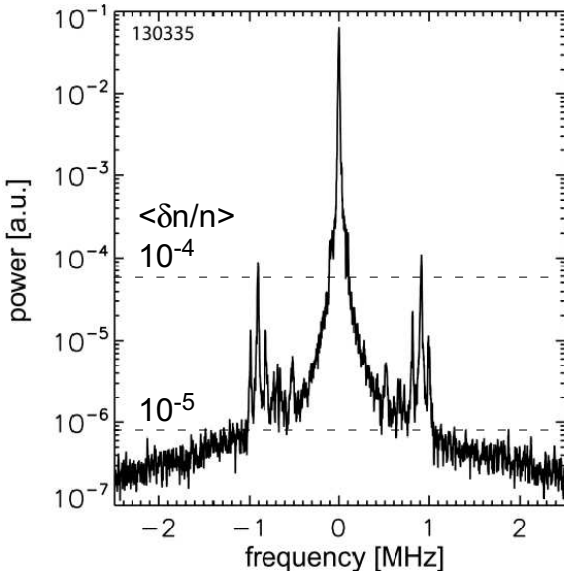
Simulated electron transport



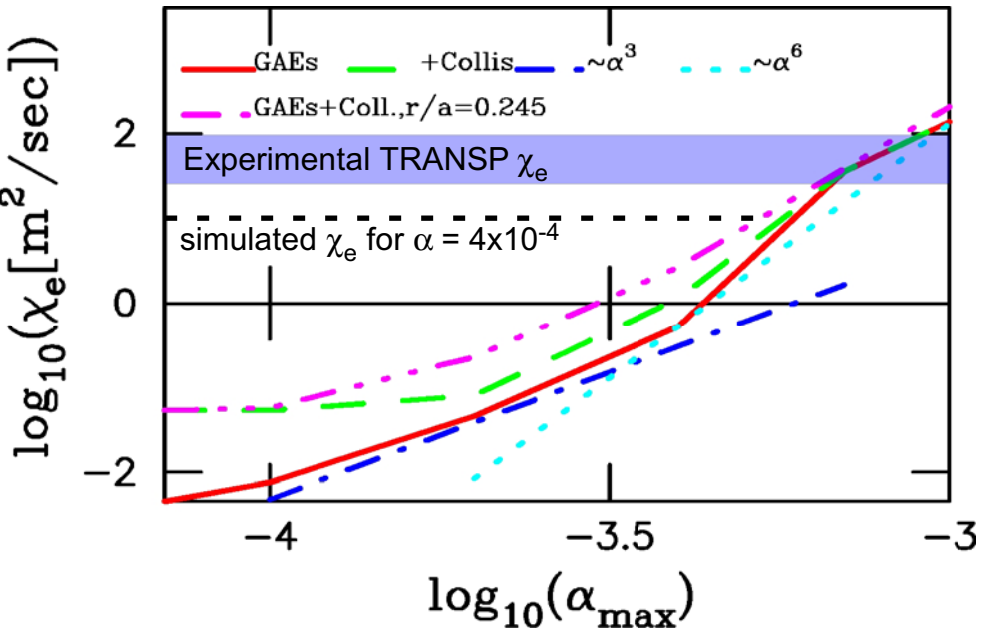
- Ad-hoc model used to study transport vs. mode amplitude and number
- $\chi_e > 10 m^2/s$ for $\alpha > 4x10^{-4}$, N > 16
- 'stochastic' transport sensitive to mode structure and amplitude (~α^6)

GAE ORBIT model using high-k interferometric amplitude measurements under-predicts TRANSP χ_e by x4-10

high-k power spectrum



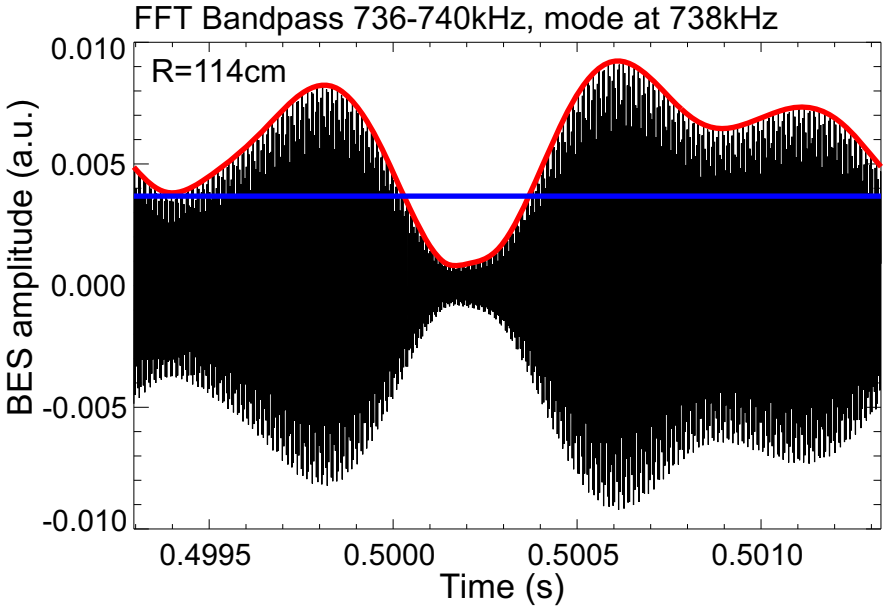
Simulated electron thermal transport

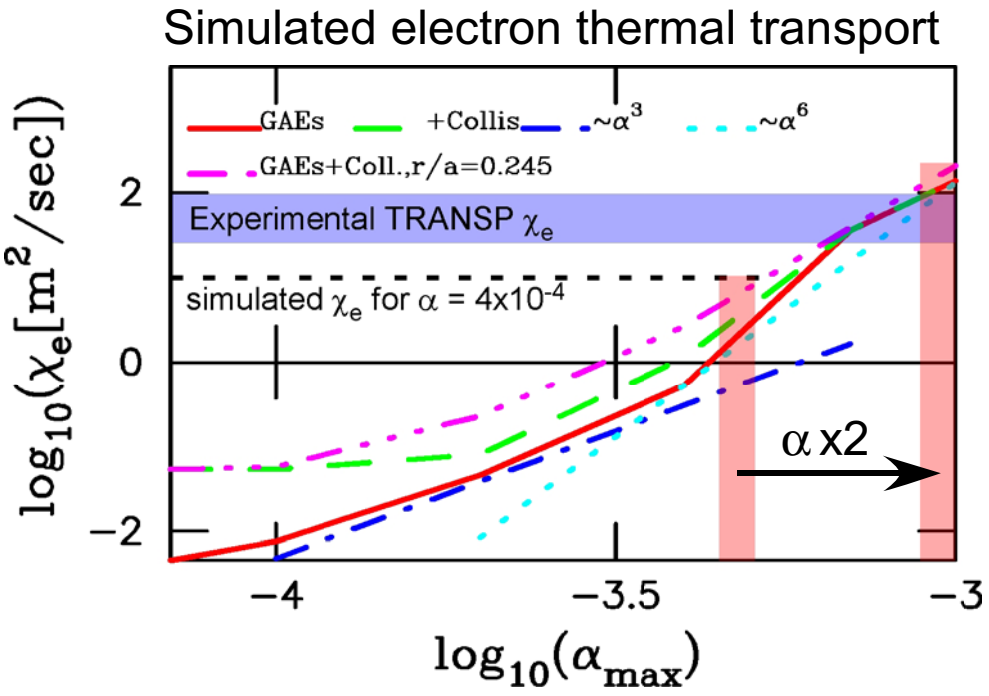


$\langle \delta n_{rms}/n \rangle \sim 1.5 \times 10^{-4} \rightarrow$ local $\delta n_{rms}/n \sim 6 \times 10^{-4}$

- $\alpha = 4 \times 10^{-4}$ used in simulation corresponds to $\zeta/R \sim \delta n/n \sim 10^{-3}$
- TRANSP experimental $\chi_e \sim$ 40-100 m^2/s or even higher
- Peak amplitudes and bursting of modes can be x2-3 higher than rms measured values
- Sensitivity to r/a indicates importance of mode structure

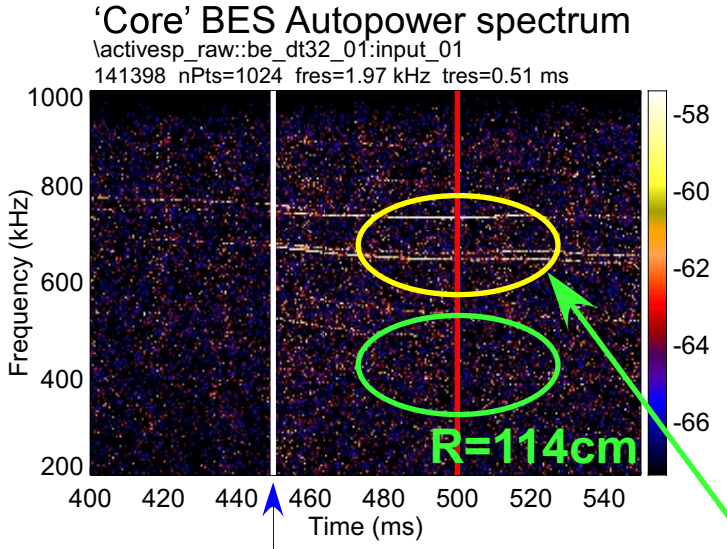
‘Bursting’ GAE mode activity may strongly affect predicted electron thermal transport

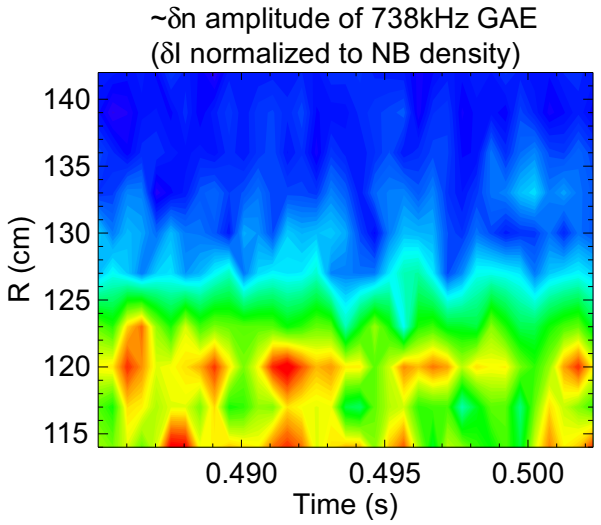


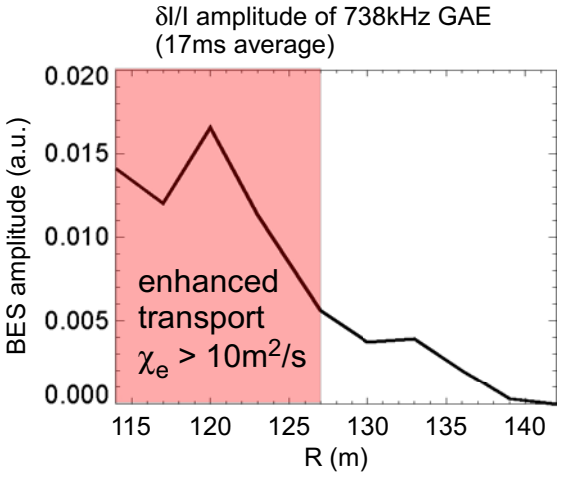


- Strong scaling of transport with α indicates mode amplitude peak values dominate χ_e
- Peak amplitudes ~x2-3 higher than rms from BES and magnetics
- Calculated electron thermal transport from peak GAE mode amplitudes roughly agrees with experimental TRANSP values

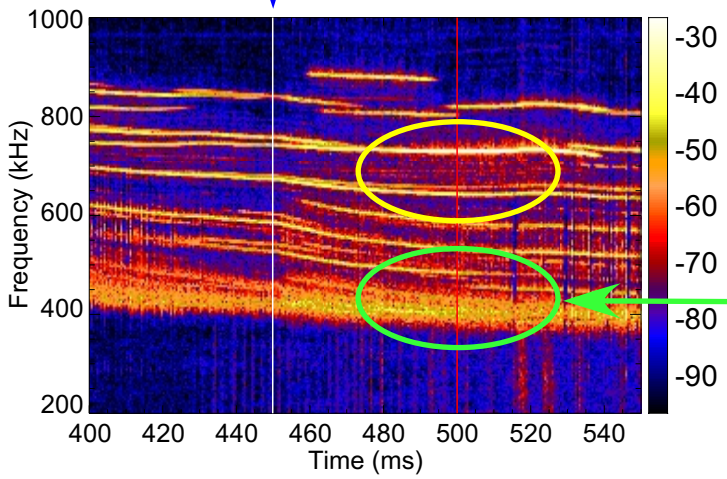
Initial BES measurements show GAE peaking at R~120cm (r/a ~ 0.36) in region of enhanced transport







PNBI 4->6MW

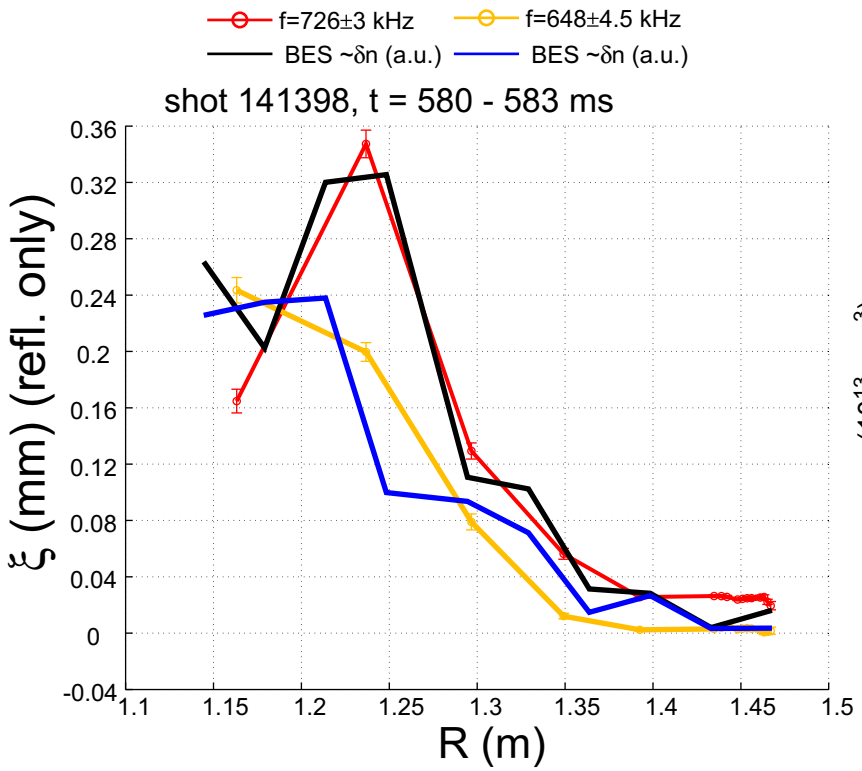


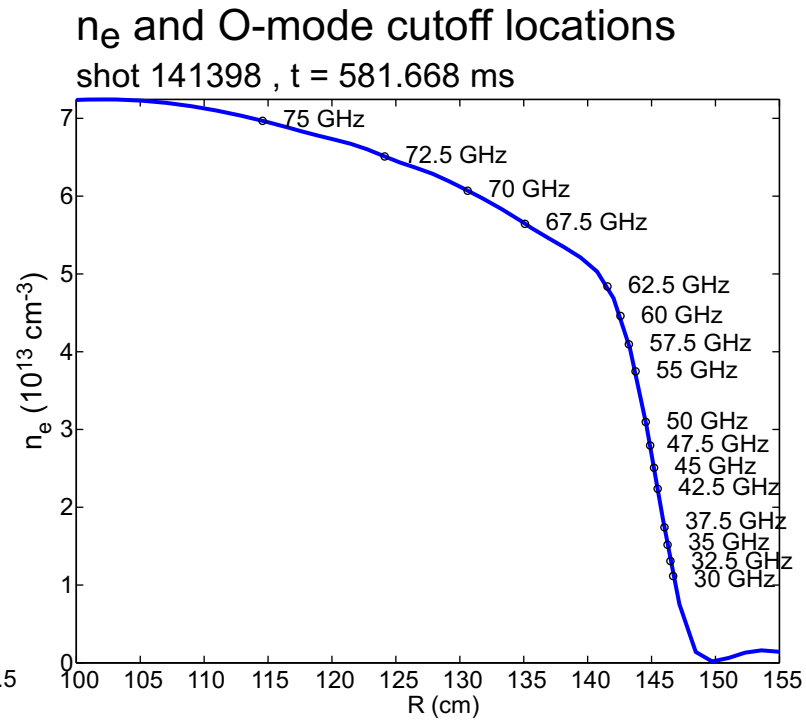
Mirnov magnetic pickup coil
141398 nPts=2048 fres=2.4 kHz tres=0.4 ms

- BES spectrogram shows high-intensity GAE modes R < ~135cm ~ 5-10dB above background
- BES SNR too low to measure lower amplitude modes and broader-band GAE activity

Measured mode displacement profiles from high-frequency reflectometry matches BES profile data

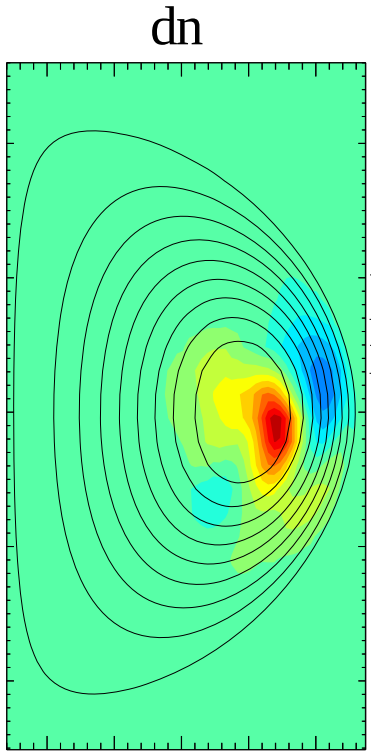
N. Crocker (UCLA) BP9.00058



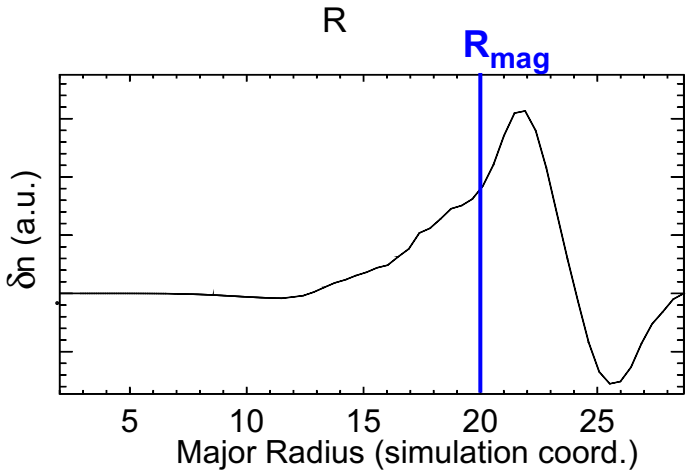


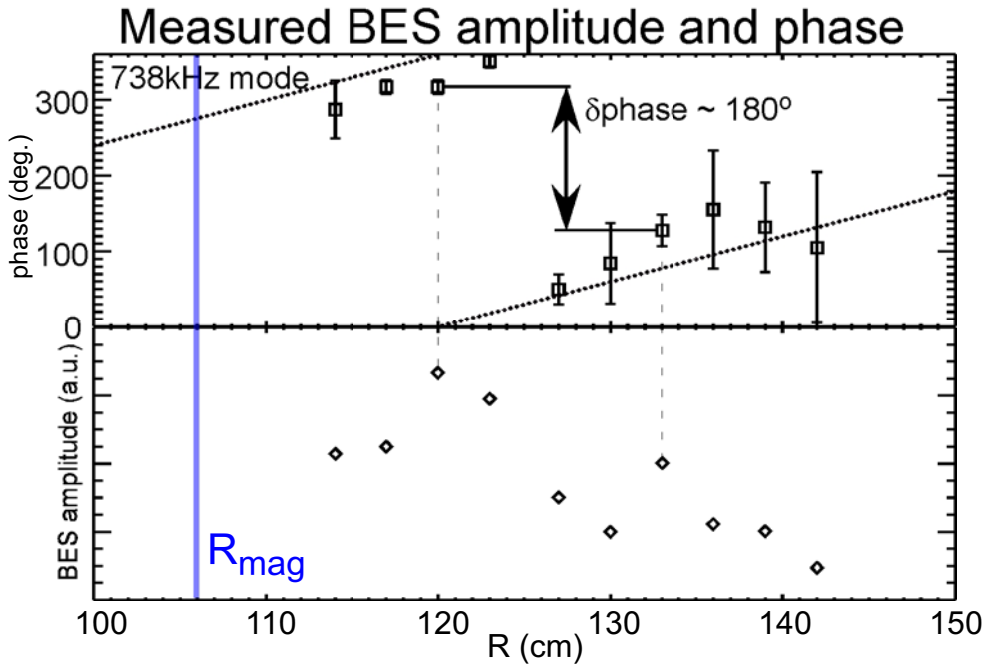
- Radial displacement of 0.35mm ($\zeta_{rms}/R \sim 3x10^{-4}$) indicates $\delta n_{rms}/n \sim 3.3x10^{-4}$ consistent with high-k in similar discharge
- Raw phase reflectometer signal shows strong 50kHz beating of 700kHz oscillation with maximum rms amplitude ~0.64mm

Measured phase of GAE mode structure consistent with predictions from HYbrid MHD (HYM) code



E. Belova

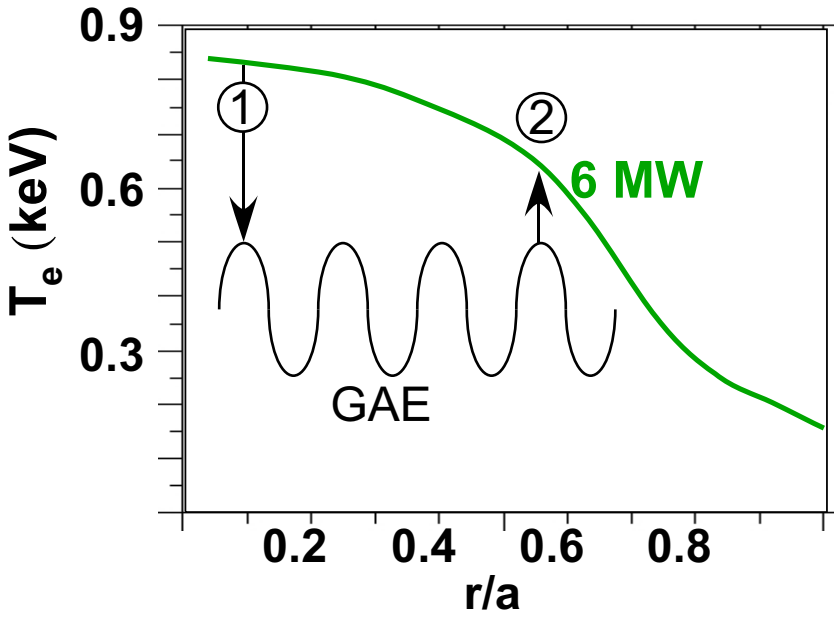




- HYM code predicts density inversion across plasma radius
- BES measures smooth radial phase variation with 180 degree inversion roughly matching HYM predictions

Alternative explanation invokes wave 'channeling' of thermal energy via GAE mode coupling

Kolesnichenko PRL 2010



1) GAE mode absorbs power from NBI
   $P_{GAE} \sim P_{NBI}$
   core T_e is lowered due to diverted power

2) GAE mode damps on electrons
   transfers energy to electrons at larger radius
   mid-radius T_e is raised

TRANSP estimates high χ_e - incorrect power balance

Complications

- GAE induced stochastic transport may be sufficient to explain TRANSP estimated χ_e, also supported with perturbative expts.
- Initial measurements of mode structure show small amplitude for r/a > 0.5, inconsistent with transfer of large P_{NBI}?
- Calibrated mode amplitudes may help distinguish mechanisms

Summary

- Flat core profiles and high χ_e not explained with electrostatic turbulence in high power NSTX H-modes
- Strong correlation of GAE activity with NBI power and high electron thermal transport
- Measured GAE mode structure and amplitude roughly consistent with predicted values of transport using ORBIT code

Future Work

- Calibrated amplitude and time history data will be used with ORBIT to further validate predictions of χ_e
- Validation of the HYM code using GAE mode structure and phase measurements
- JHU proposed Ultra-fast Bi-color SXR system will measure poloidal structure of GAE mode, δn and δT_e in NSTX-U plasmas