NSTX

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Effects of Global Alfvén Eigenmodes on Electron Thermal Transport in NSTX

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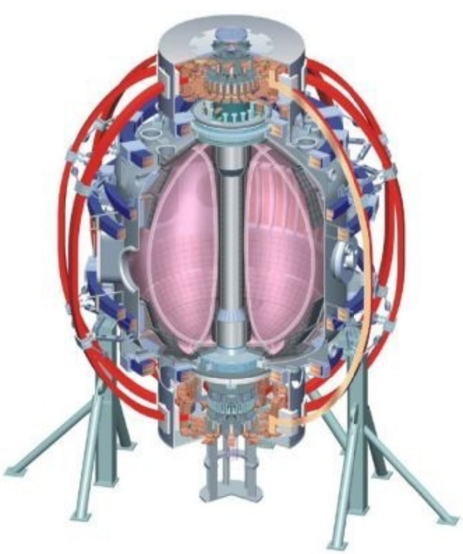

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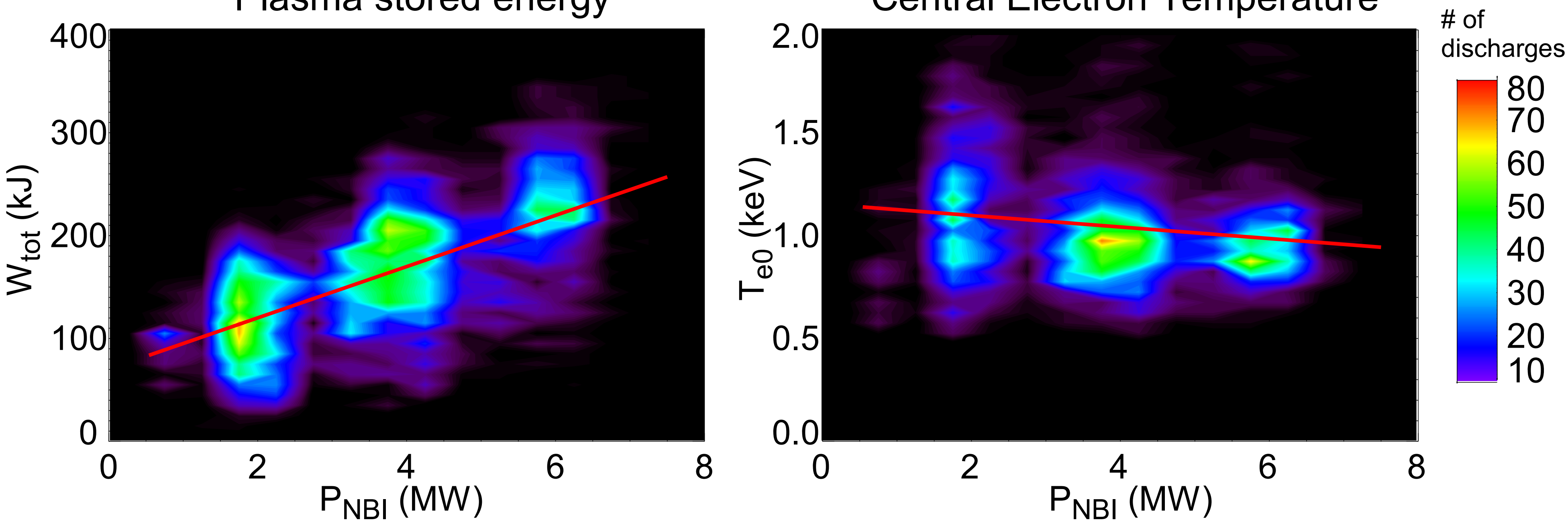
Fast ion-induced GAEs are a good candidate to explain the unusually high levels of electron thermal transport in the core of high power NBI heated H-mode NSTX plasmas.

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

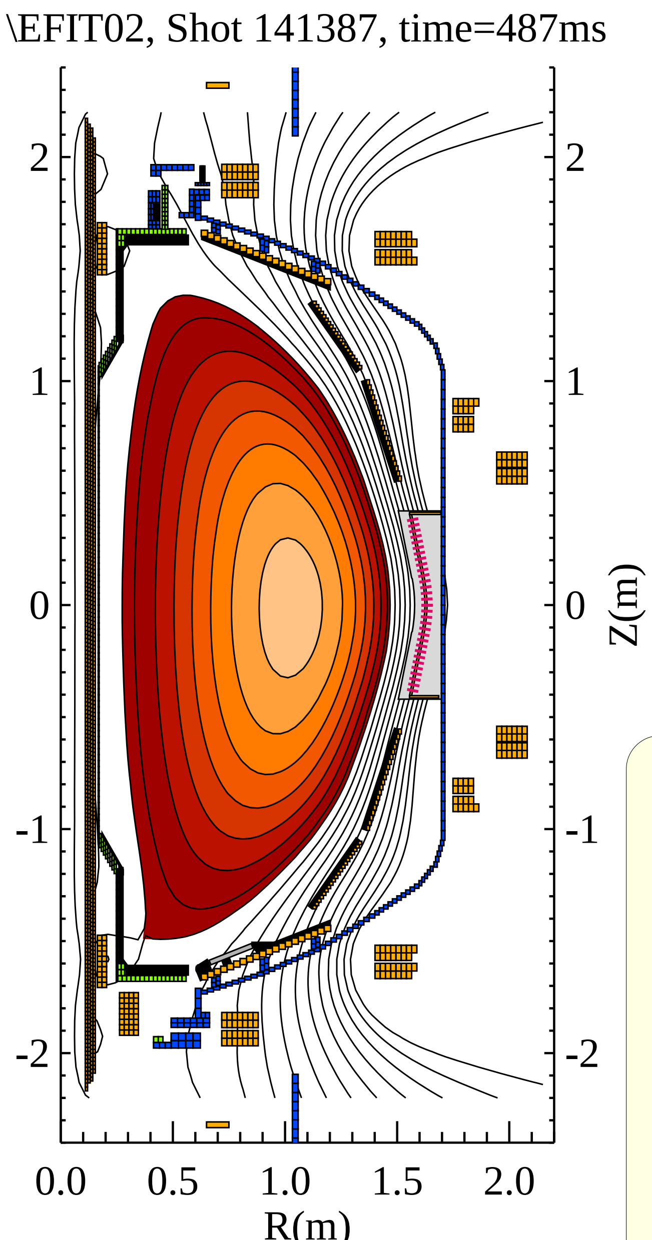
NB power has little effect on T_{e0}

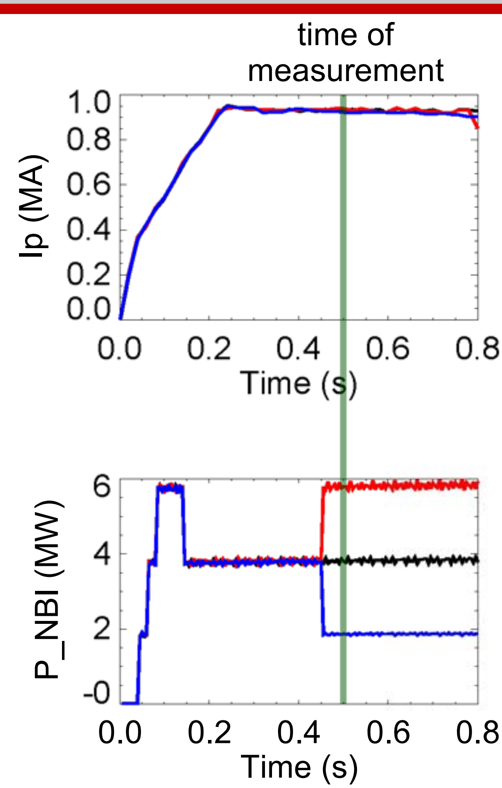
Plasma Discharge Histograms



- 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



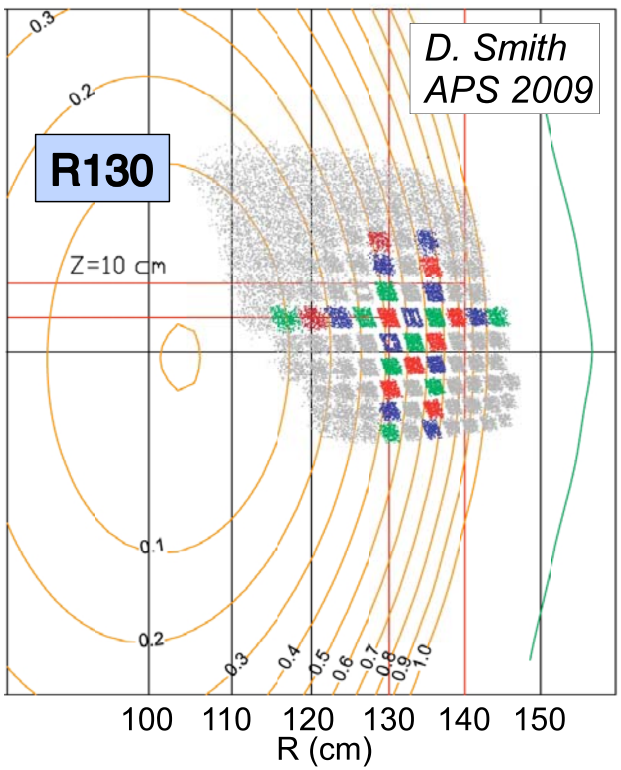


Mag. axis R_{mag}	1.03m
Aspect Ratio A	1.4
Elongation κ	2.4
Triangularity δ	~0.6
Plasma Current I_p	0.9MA
Toroidal Field B_T	0.45T
Pulse Length	~1s
P_{NB} (100keV)	2-6MW
$\beta_{T,tot}$	~15%

- NBI pre-heat used to ‘freeze’ in current profiles with $q_0 > 1$
- Beam steps at 0.45s used to change input power
- Measurements 50ms later, before relaxation of current profile

Low and high-k diagnostic systems available to measure high-f modes and turbulent fluctuations in plasma core

Beam Emission Spectroscopy



BES parameters

16 channels

~3cm resolution

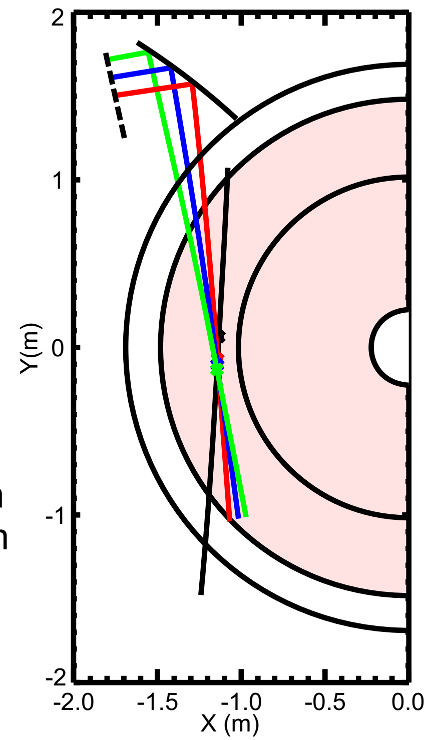
1MHz bandwidth

2MHz sampling
w/ x16 oversampling

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

$k_r \rho_i < 1\text{cm}^{-1}$

Microwave Scattering Diagnostic



μ-wave scattering parameters

5 channels

+/- 3cm resolution

2MHz bandwidth

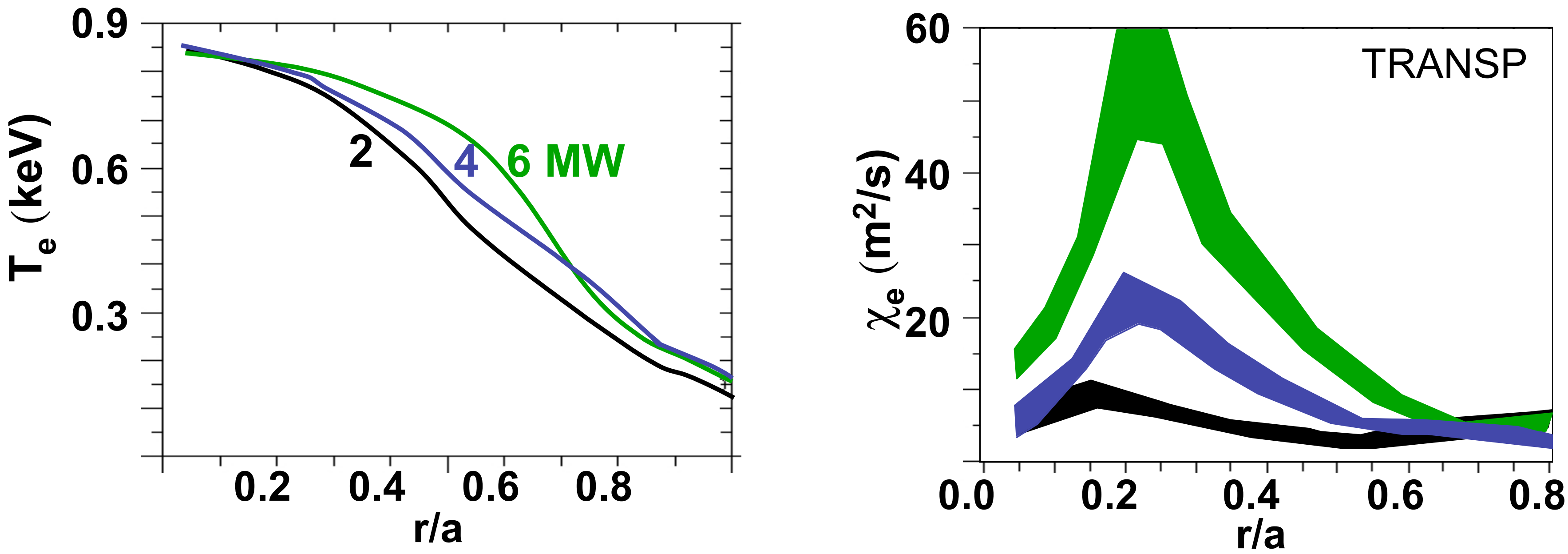
4MHz sampling

remote control over radial position

$k_r \sim 4 - 24\text{cm}^{-1}$

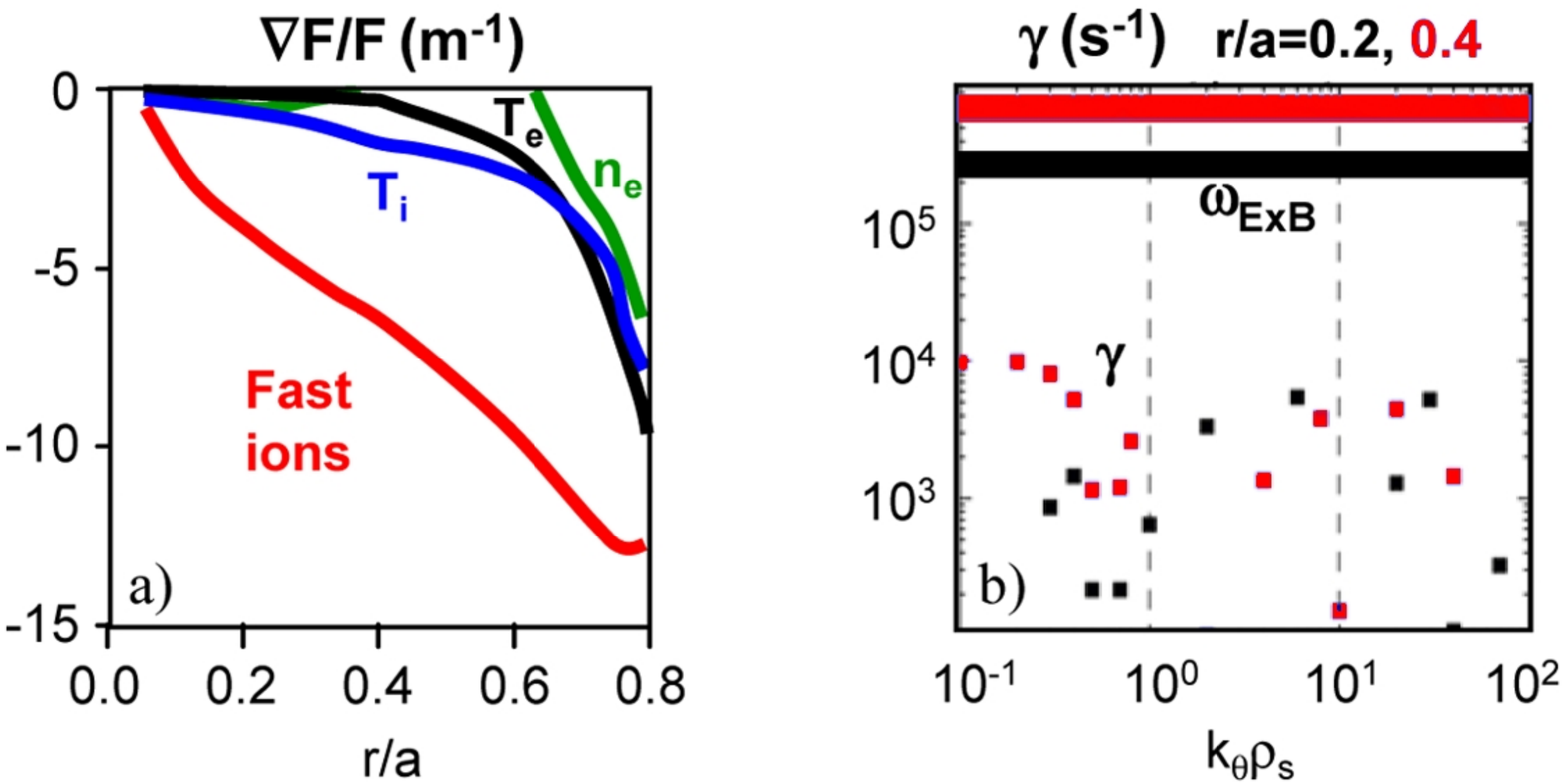
- BES provides low-k $\delta n/n$ fluctuations in plasma
- μ-wave system measures line-integrated density in 'interferometric' mode and scattered high-k $\delta n/n$ turbulence
- Combination of systems provides coverage of low/high k_r

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 $\chi_e \sim 100 m^2/s$ (*Tritz PoP 2008*)

Flat plasma profiles and high rotation shear suggest suppression of electrostatic turbulence

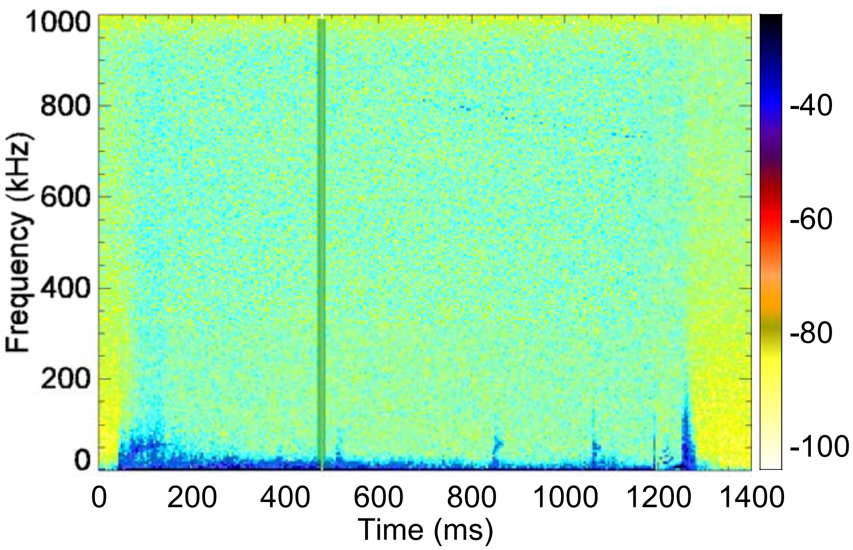


- Linear GS2 calculations show growth rates 20-100x lower than shearing rate in plasma core over high and low-k range
- TRANSP calculated fast ion profile shows gradient which can drive fast ion modes in plasma, no evidence of redistribution

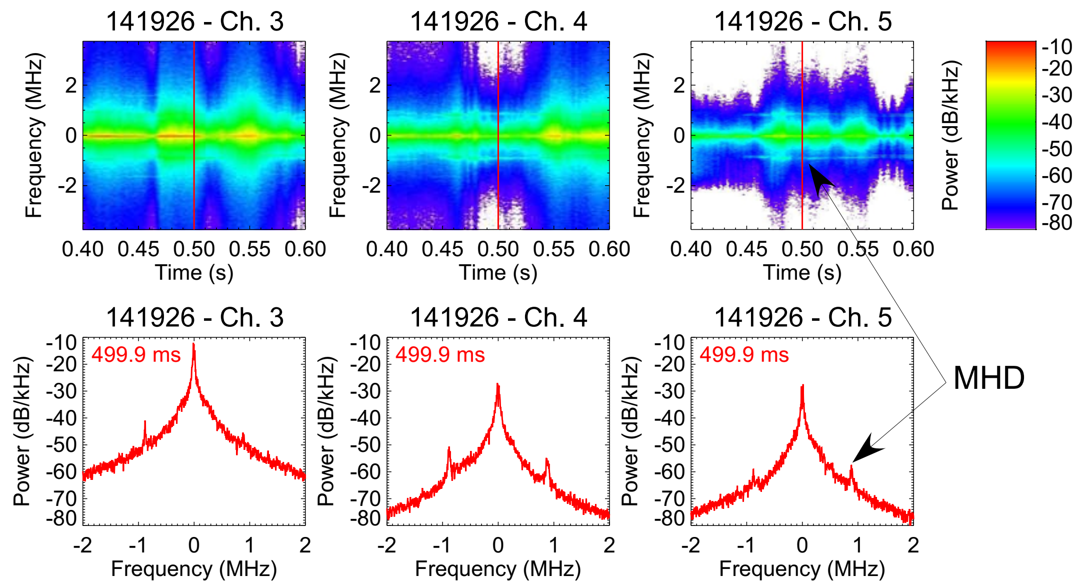
No evidence of short or long wavelength turbulence in core of many NBI-heated discharges in NSTX

Preliminary BES data

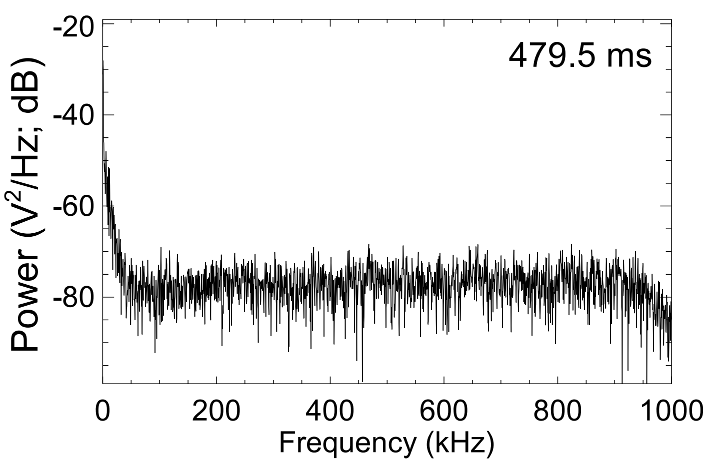
BES Cross-power spectrum R = 117&120cm



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



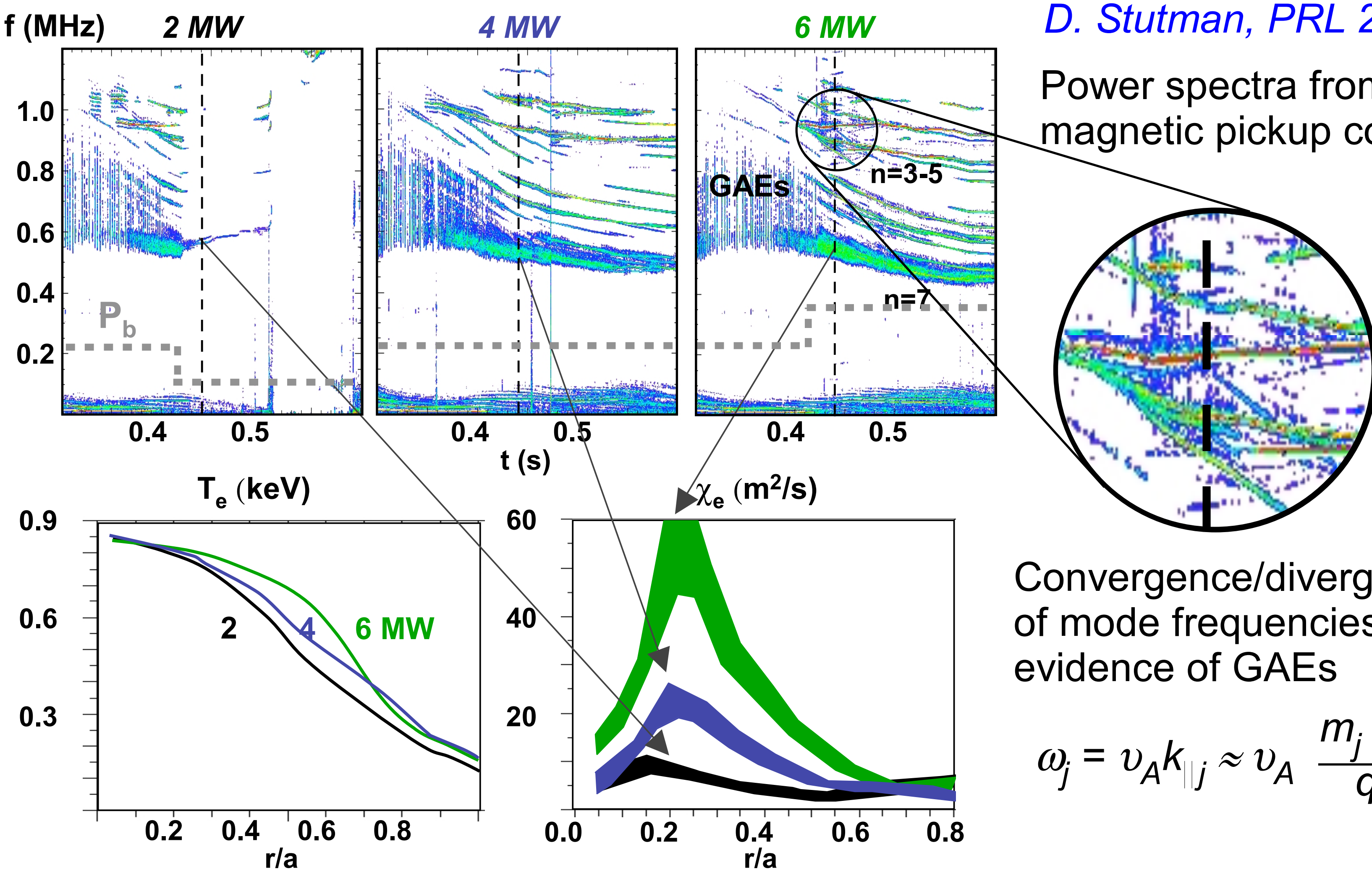
BES Cross-power spectrum R = 117&120cm



- 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

D. Stutman, PRL 2009



Power spectra from magnetic pickup coils

Convergence/divergence of mode frequencies evidence of GAEs

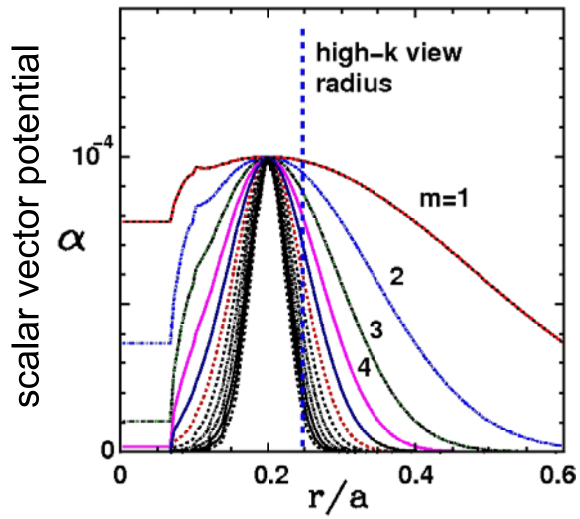
$$\omega_j = \upsilon_A k_{\|j} \approx \upsilon_A \frac{m_j - n_j q}{q R_0}$$

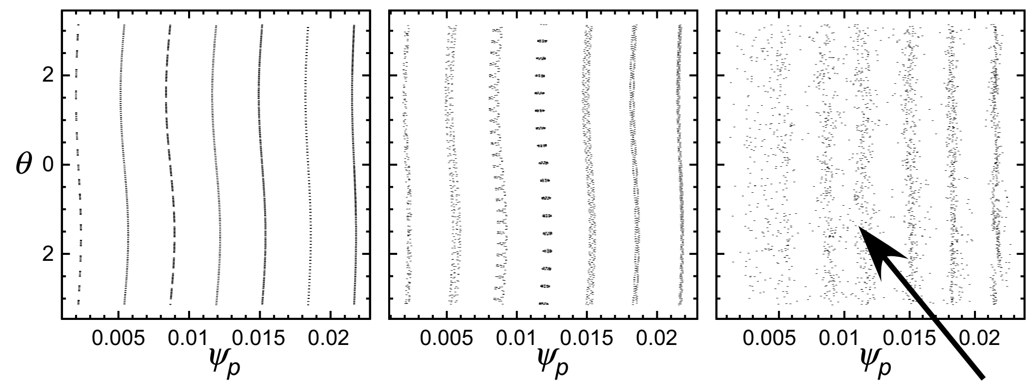
- GAE activity correlates strongly with P_{NBI} steps and enhanced core electron thermal transport

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

N. Gorelenkov Nucl. Fus. 2010

GAE Model used in ORBIT calculations

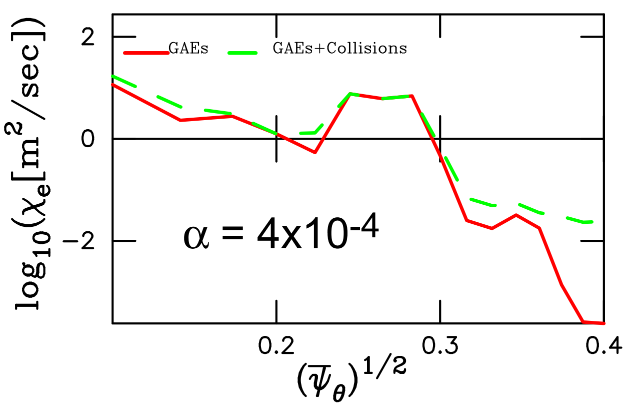




Poincaré plot of electron trajectory

stochastic particle trajectories

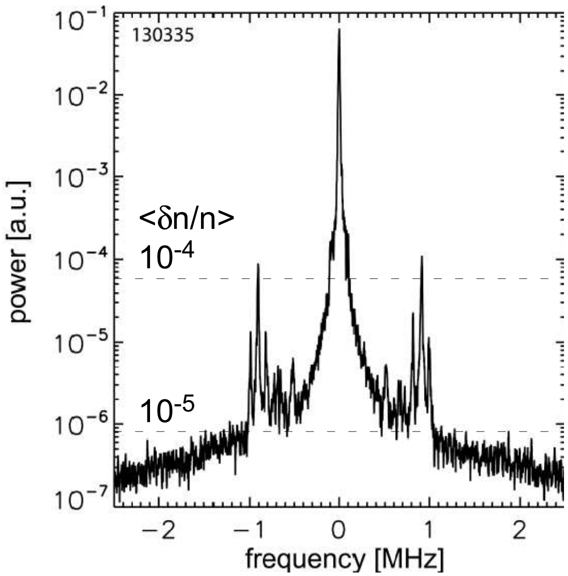
Simulated electron transport



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

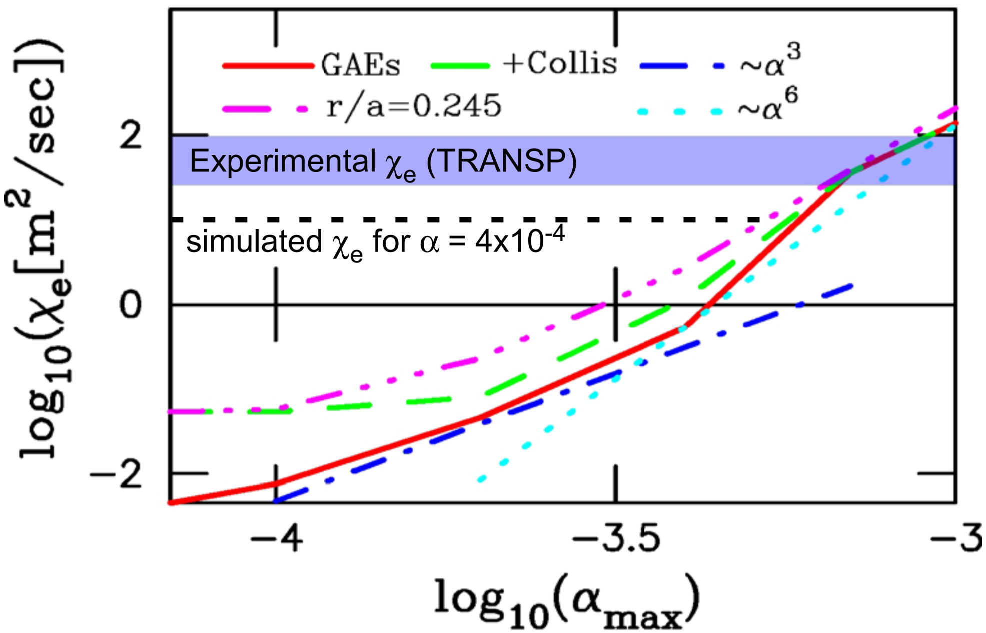
GAE ORBIT model using measured amplitudes under-predicts TRANSP χ_e by x4-10

high-k power spectrum



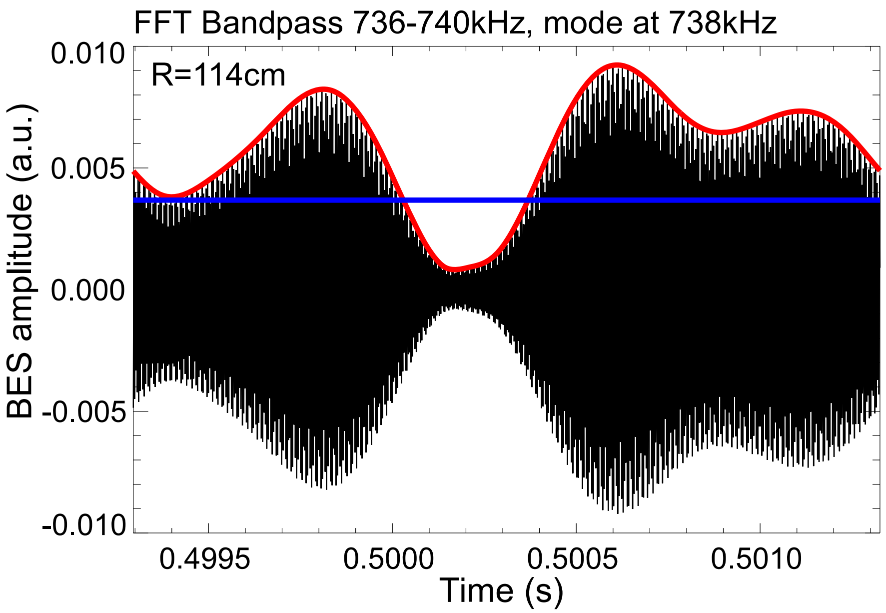
$\langle \delta n_{rms}/n \rangle \sim 1.5\times10^{-4} \rightarrow$ local $\delta n/n \sim 9\times10^{-4}$

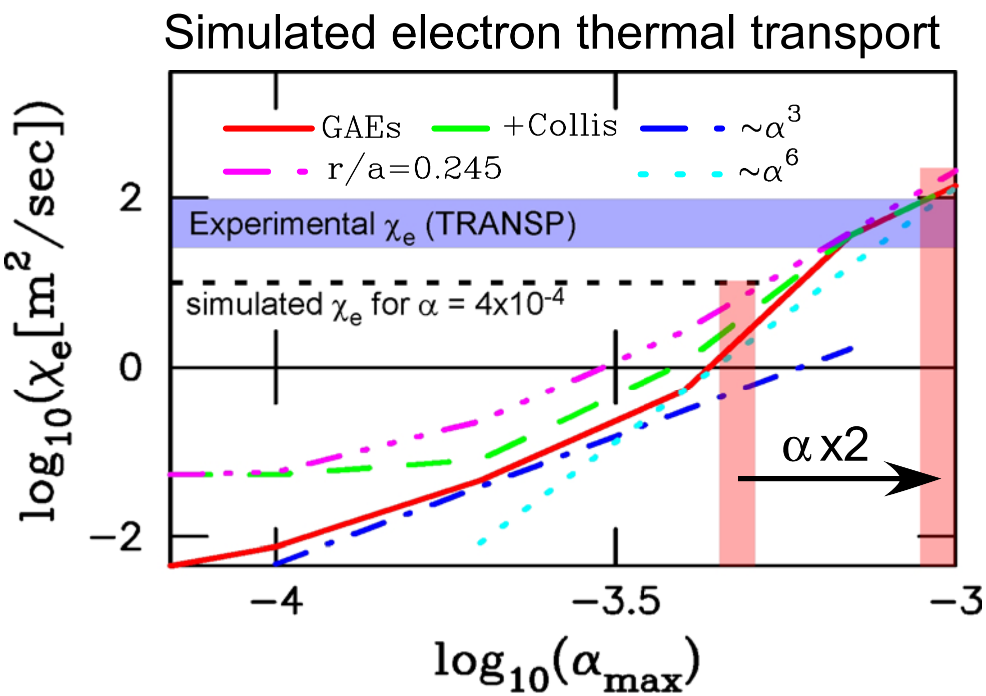
Simulated electron thermal transport



- $\alpha=4\times10^{-4}$ used in simulation corresponds to $\zeta/R \sim \delta n/n \sim 10^{-3}$
- TRANSP experimental $\chi_e \sim$ 40-100 m^2/s
- Peak amplitudes and bursting of modes can be x2-3 higher than measured rms, time-averaged values
- Sensitivity to r/a indicates importance of mode structure

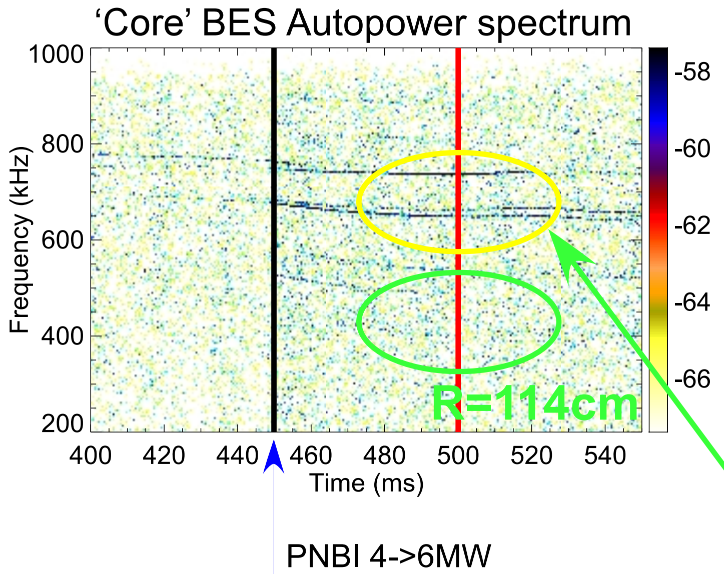
‘Bursting’ GAE mode activity may strongly affect predicted electron thermal transport

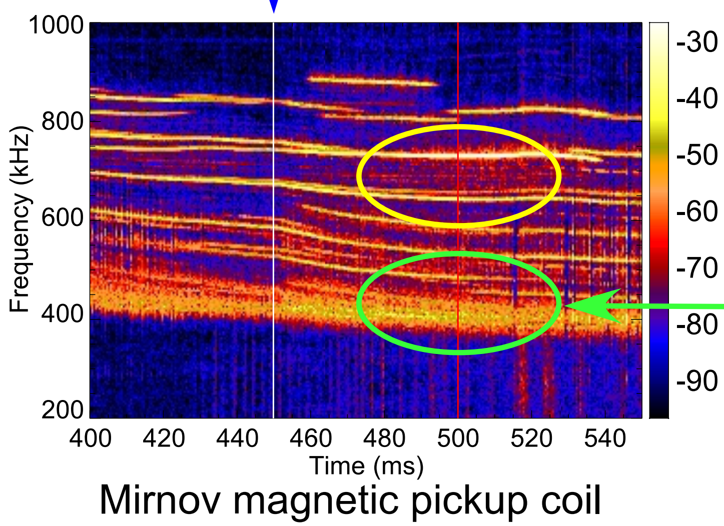


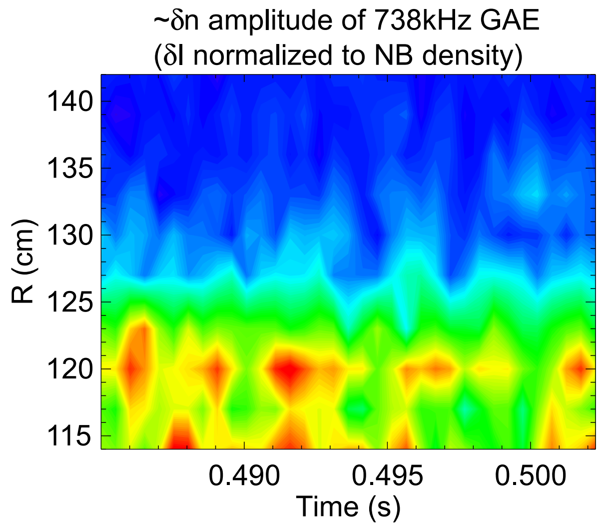


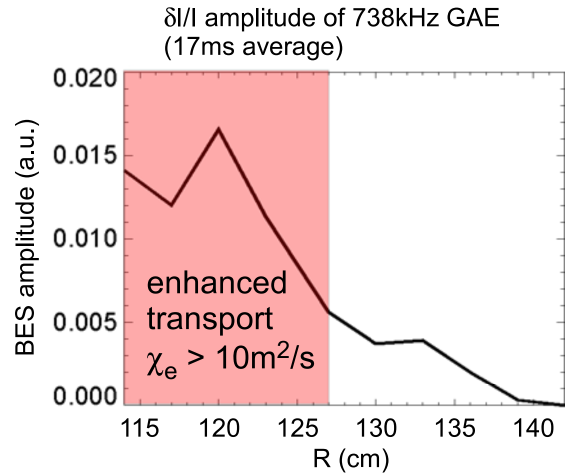
- Strong scaling of transport with α indicates mode amplitude peak values dominate χ_e
- Peak amplitudes ~ x2 to x3 higher than time-averaged, rms values from BES and magnetics
- Calculated electron thermal transport from peak GAE mode amplitudes roughly agrees with experimental TRANSP values

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





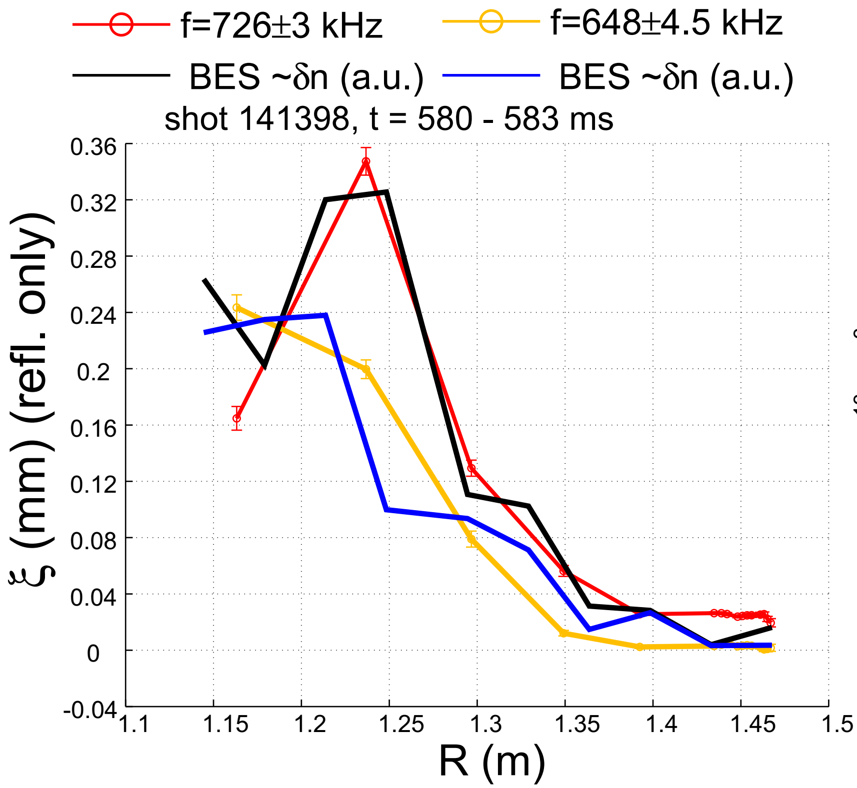


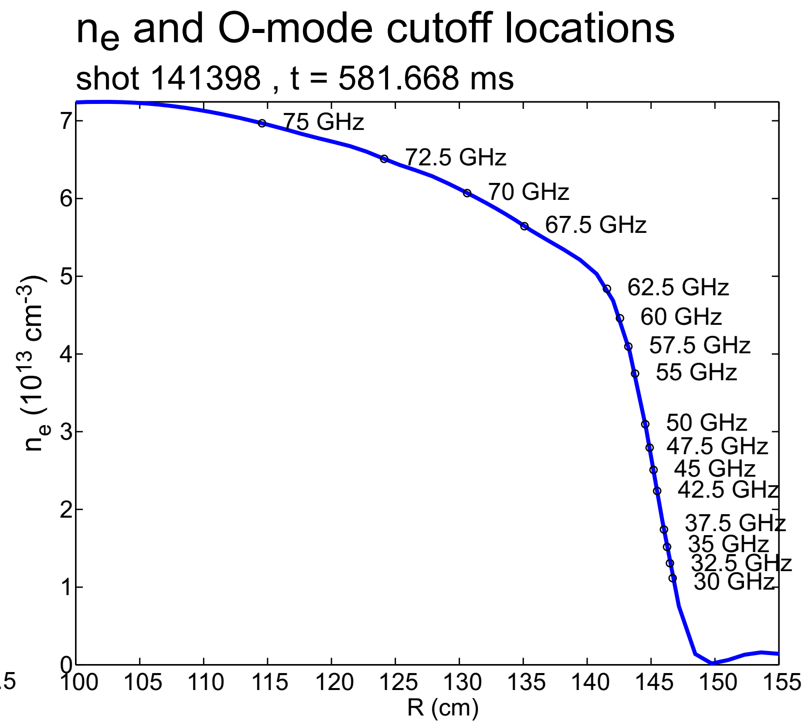


- BES spectrogram shows high-intensity GAE modes R < ~135cm ~ 5-10dB above background
- Mirnov pickup coils reveal additional, lower amplitude modes below BES detector limit

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

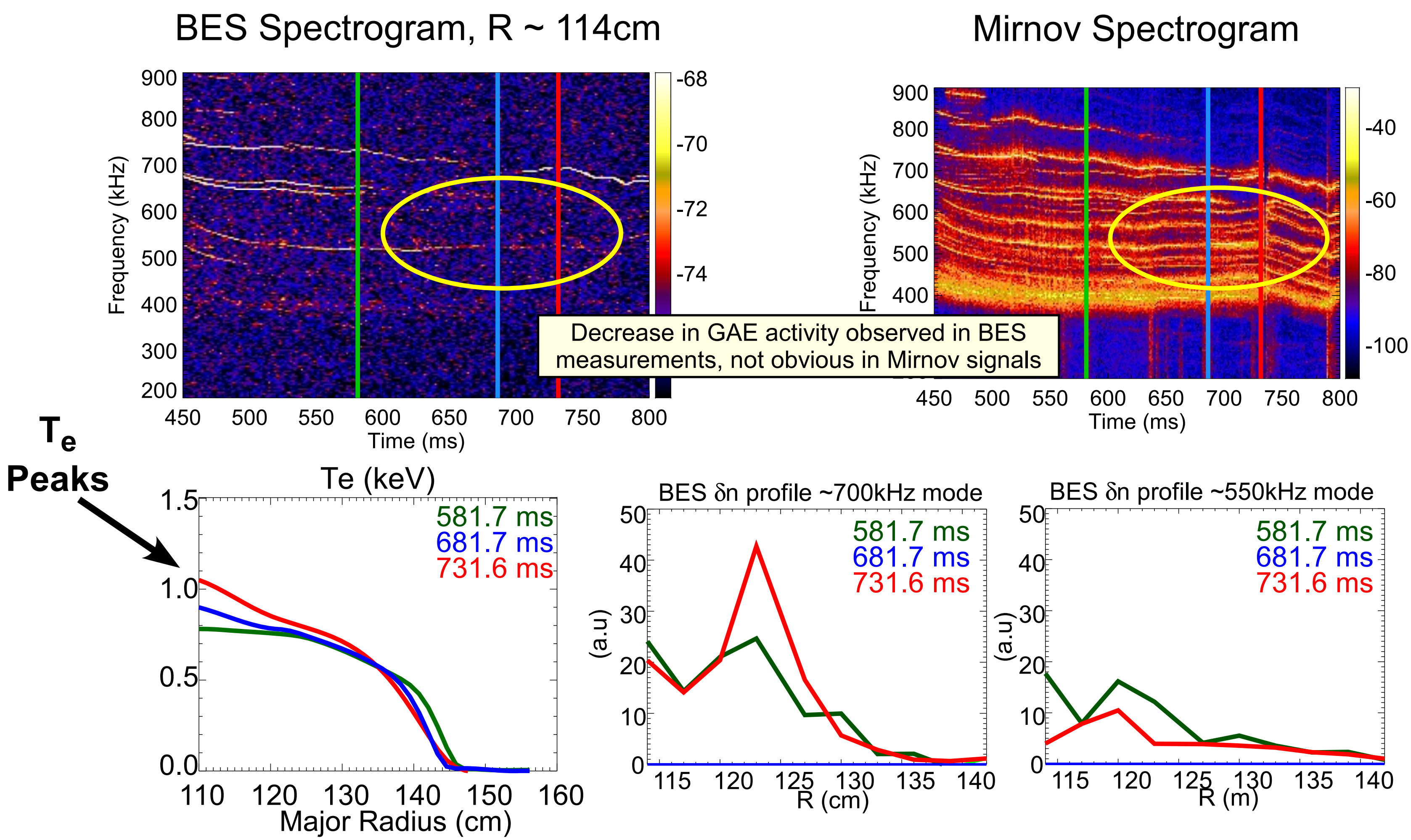
N. Crocker (UCLA) BP9.58





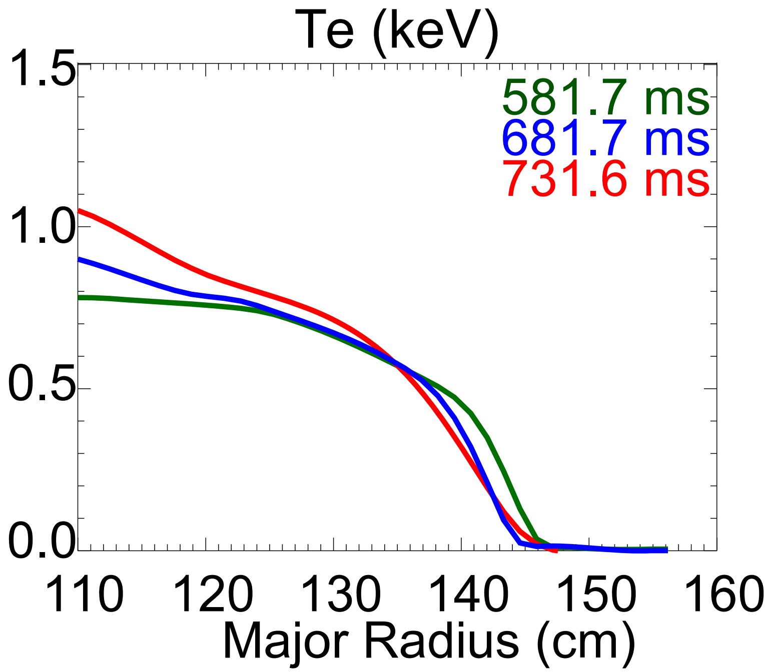
- Displacement of 0.35mm rms ($\zeta/R \sim 4\text{x}10^{-4}$) indicates $\delta n/n \sim 4.5\text{x}10^{-4}$ roughly consistent with high-k in similar discharge
- Raw phase reflectometer signal shows strong 50kHz beating of 700kHz oscillation with maximum amplitude ~0.9mm

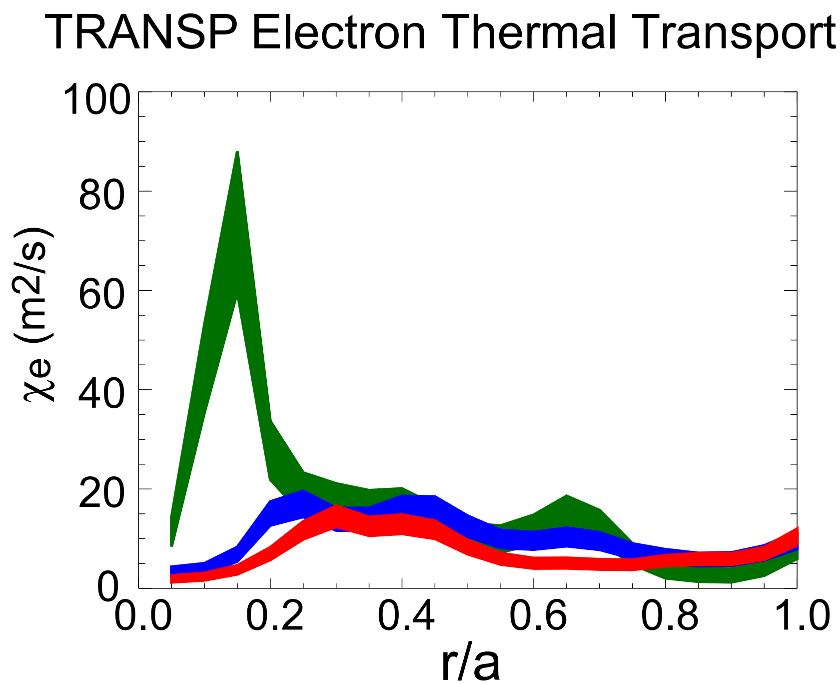
Decrease in GAE activity corresponds with peaking of central electron temperature



- T_e remains peaked even with large single mode (bulk GAEs still largely supressed)
- BES sensitivity to GAEs marginal at later times, density rise limits reflectometer data
- Need high-k core data to determine if high-k turbulence limits central T_e gradient

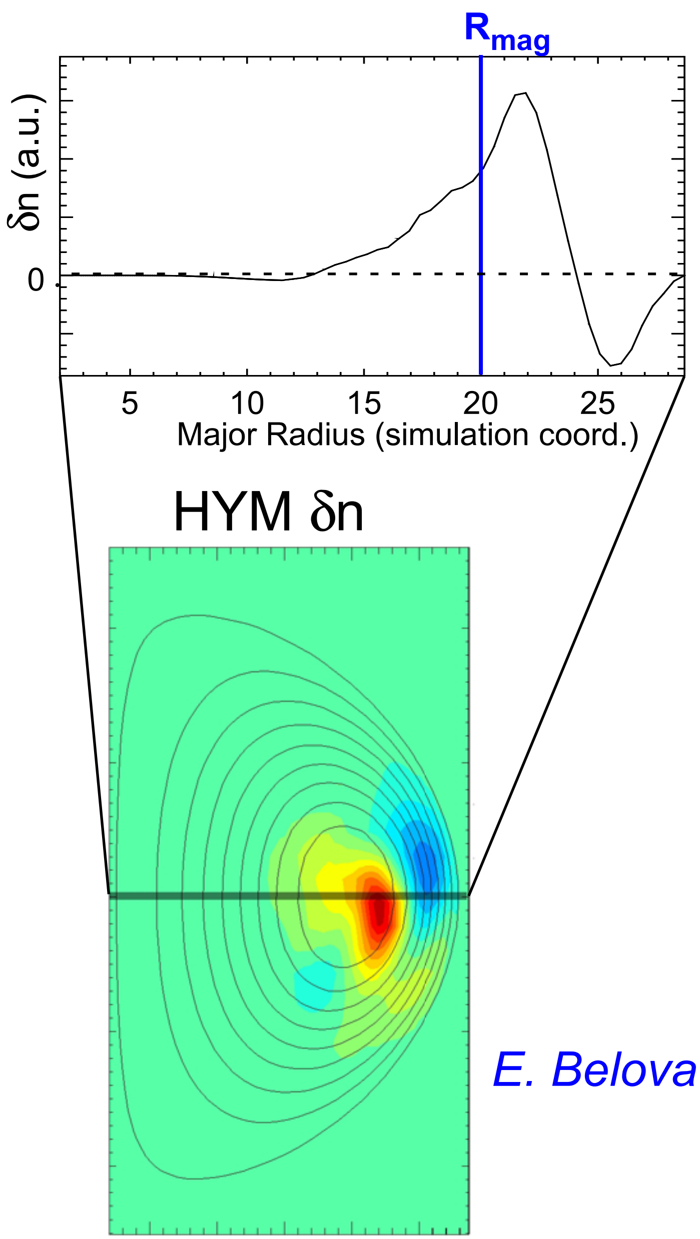
Reduced GAE drive corresponds with lowers thermal electron transport



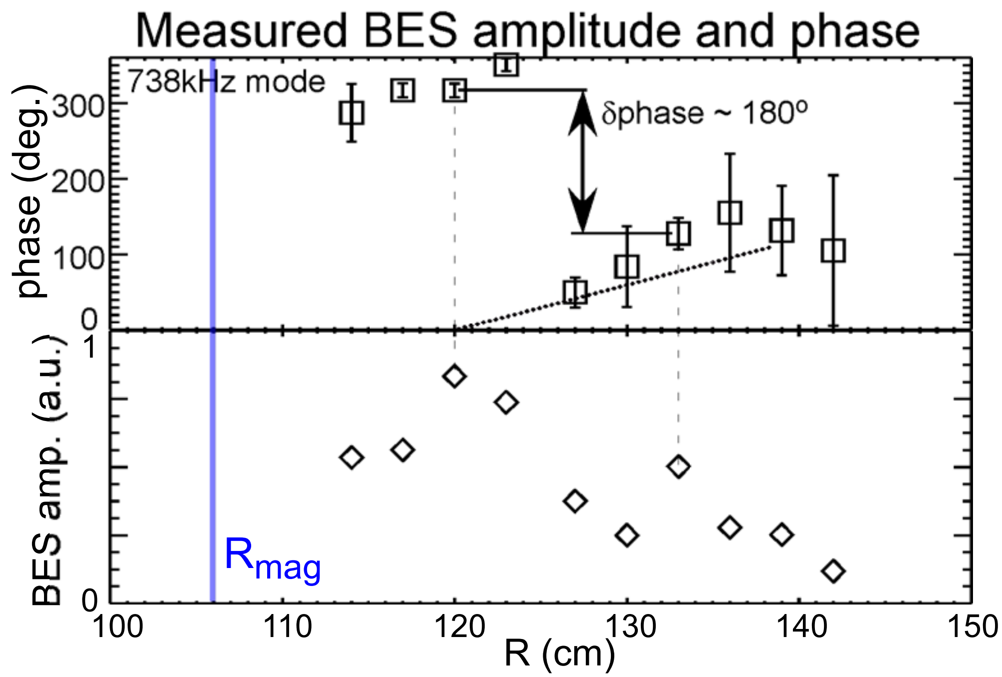


- Electron temperature likely limited by other anomalous transport mechanism
- No evidence of low-k electrostatic turbulence from BES measurements
- Possible ETG or micro-tearing modes present (see W. Guttenfelder)
- Future experiments will include high-k scattering diagnostic, polarimetry, density control to investigate interplay between GAEs and turbulent induced transport

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



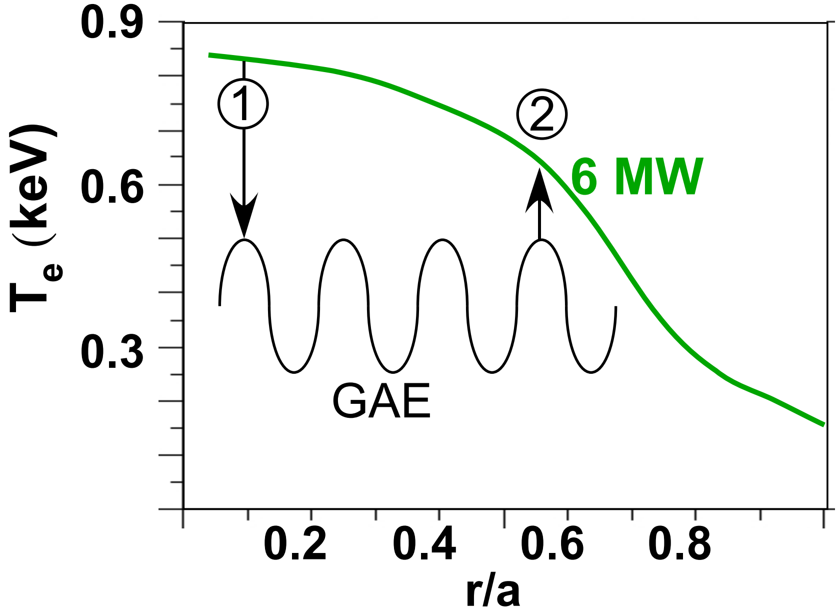
E. Belova



- HYM code predicts δn 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

given above mechanism: TRANSP estimates high χ_e from incorrect power balance

Complications

- High χ_e from GAE induced stochastic transport 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
- Upcoming experiment will measure GAEs and look for turbulence in plasma core to determine time history of transport mechanisms