NSTX JOHNS HOPKINS UNIVERSITY

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Global Alfvén Eigenmodes Induced Electron Thermal Transport in NSTX

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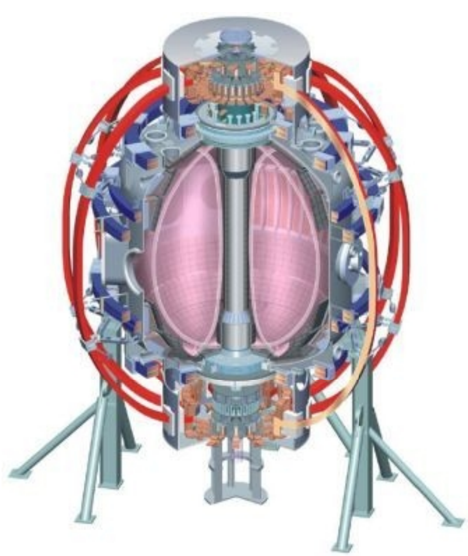
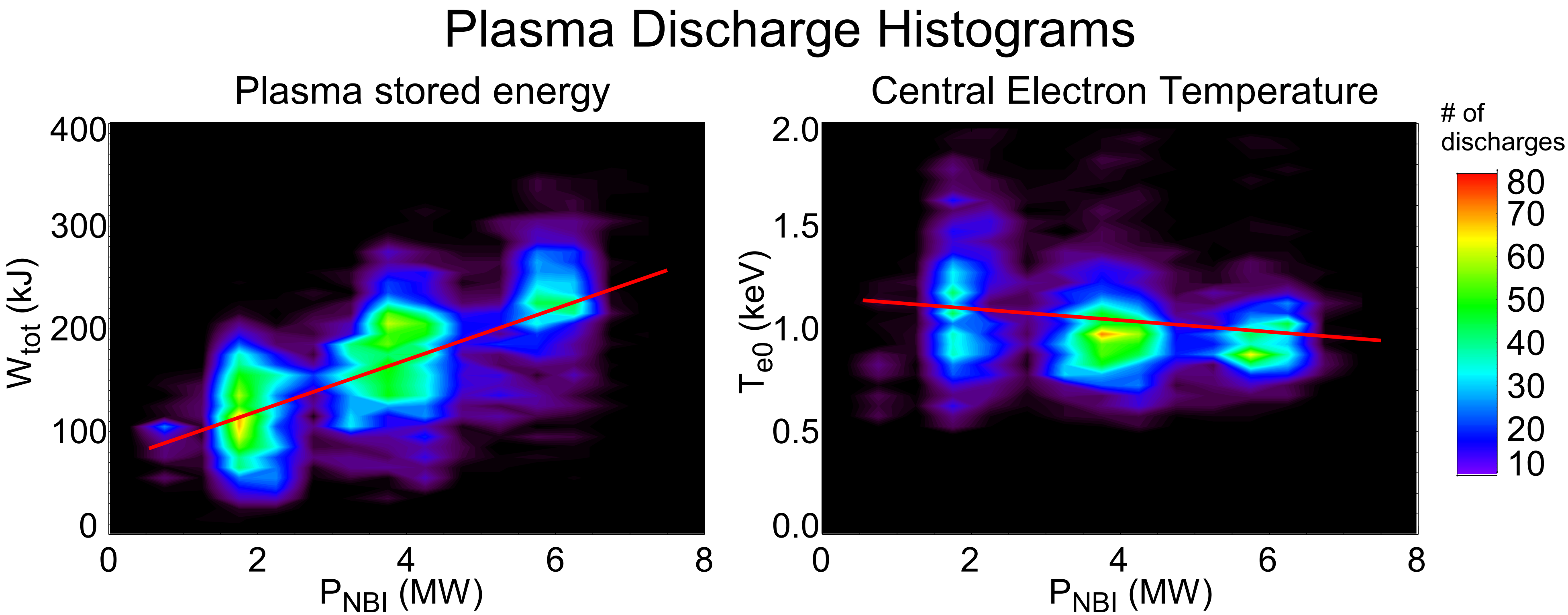
International Spherical Torus Workshop
Toki City, Japan 9/29/2011



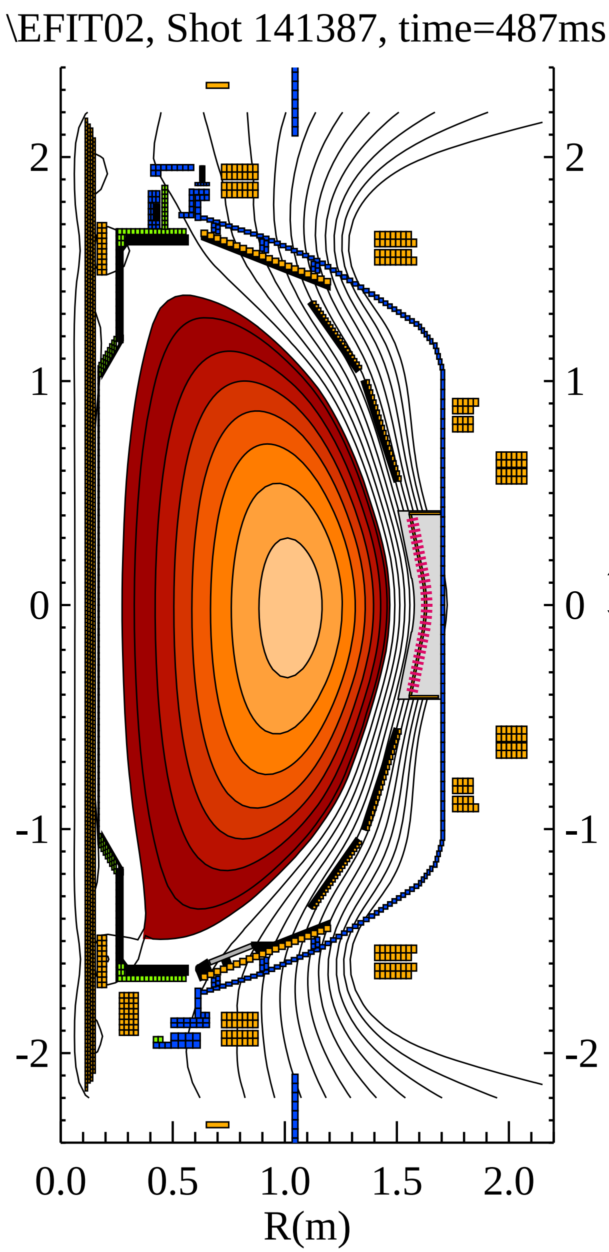
Fast ion-induced GAEs are a good candidate to explain the unusually high levels of electron thermal transport in the core of high power NBI heated H-mode NSTX plasmas.

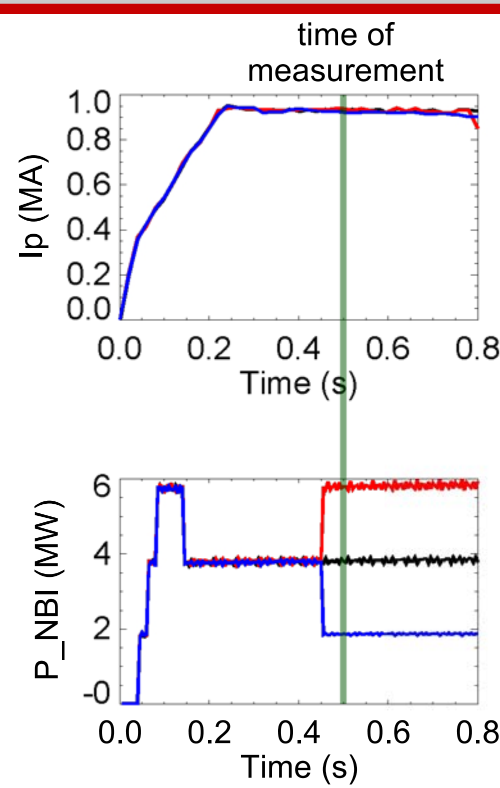
NB power has little effect on T_{e0}



- Database scan of >4000 NBI plasma discharges on NSTX
  - Identify central electron temperature at maximum stored energy
  - Analysis restricted to NBI heated plasmas, RF heating achieves T_{e0}=6keV
- Large scatter observed, wide range of plasma discharges
- Small but noticeable decrease in T_{e0} vs. P_{NBI}

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



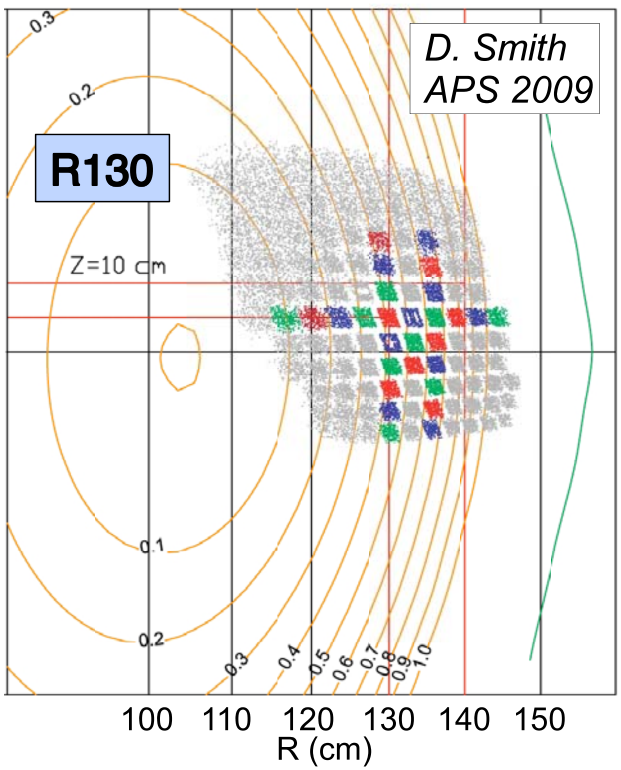


Mag. axis R_{mag}	1.03m
Aspect Ratio A	1.4
Elongation κ	2.4
Triangularity δ	~0.6
Plasma Current I_p	0.9MA
Toroidal Field B_T	0.45T
Pulse Length	~1s
P_{NB} (100keV)	2-6MW
$\beta_{T,tot}$	~15%

- 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 (32 channels at present)

~3cm resolution

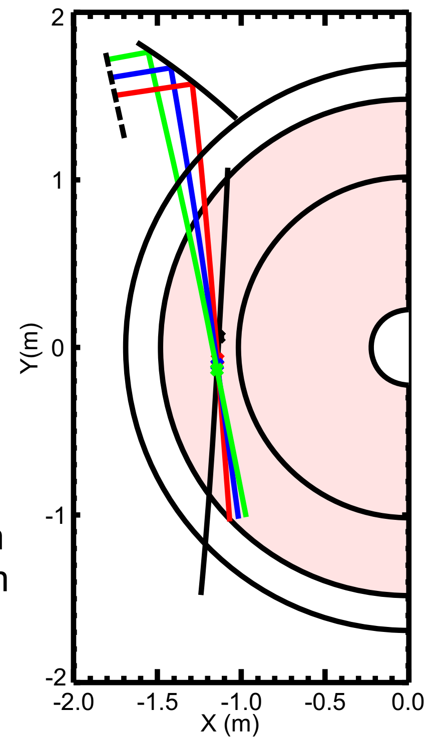
1MHz bandwidth

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

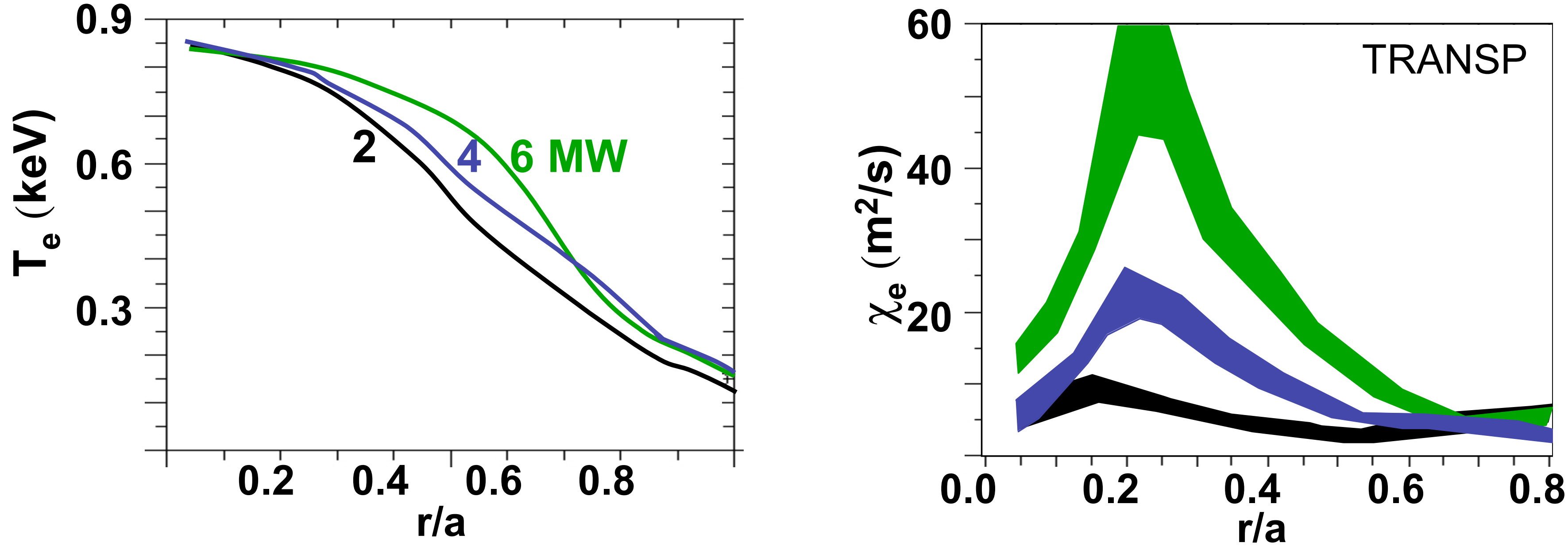
4MHz sampling

remote control over radial position

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

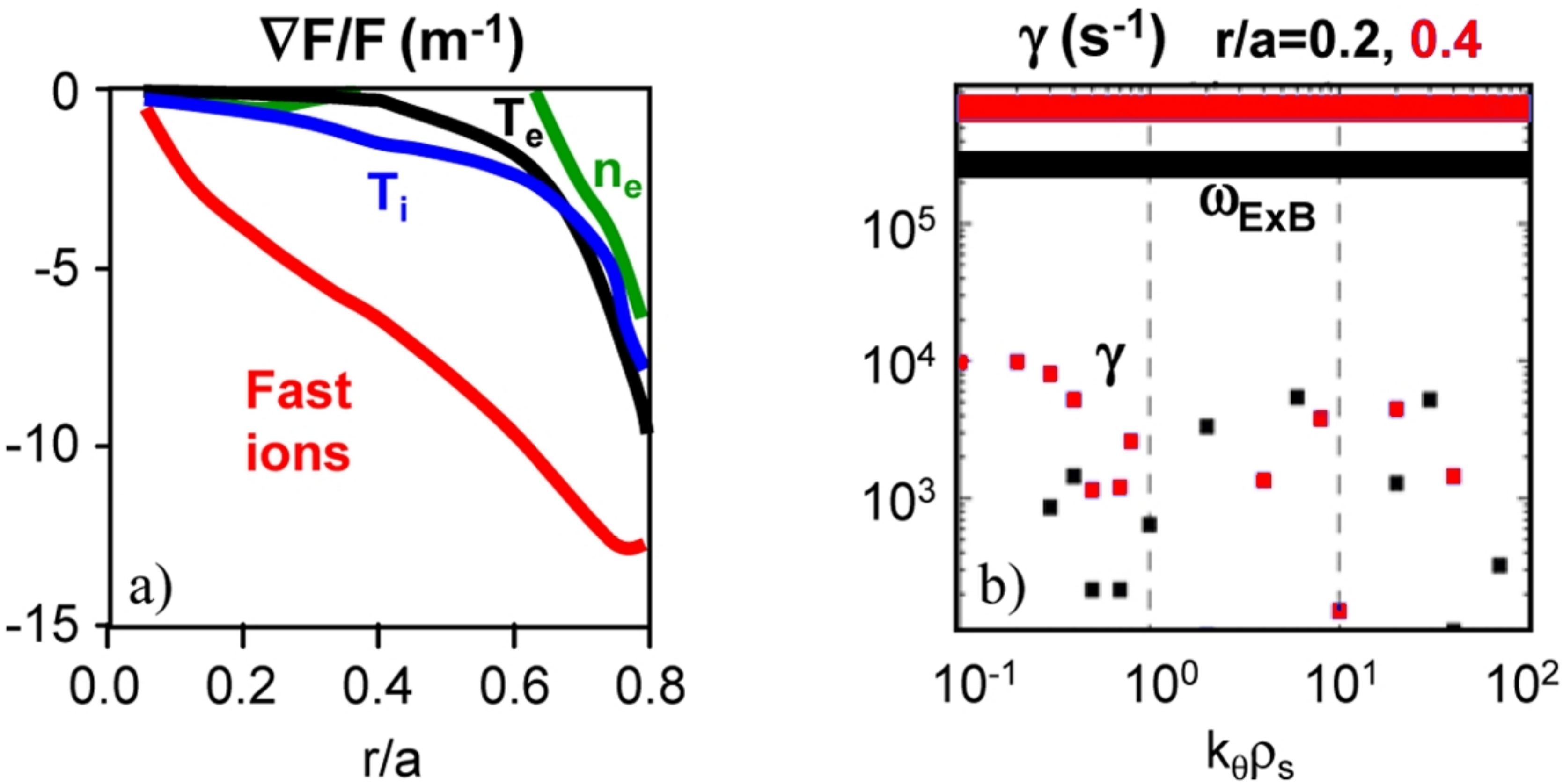
- BES provides low-k δn/n fluctuations in plasma
- μ-wave system measures line-integrated density in 'interferometric' mode and scattered high-k δn/n turbulence
- Combination of systems provides coverage of low/high k_r

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 χ_e ~ $100 m^2/s$ (*Tritz PoP 2008*)

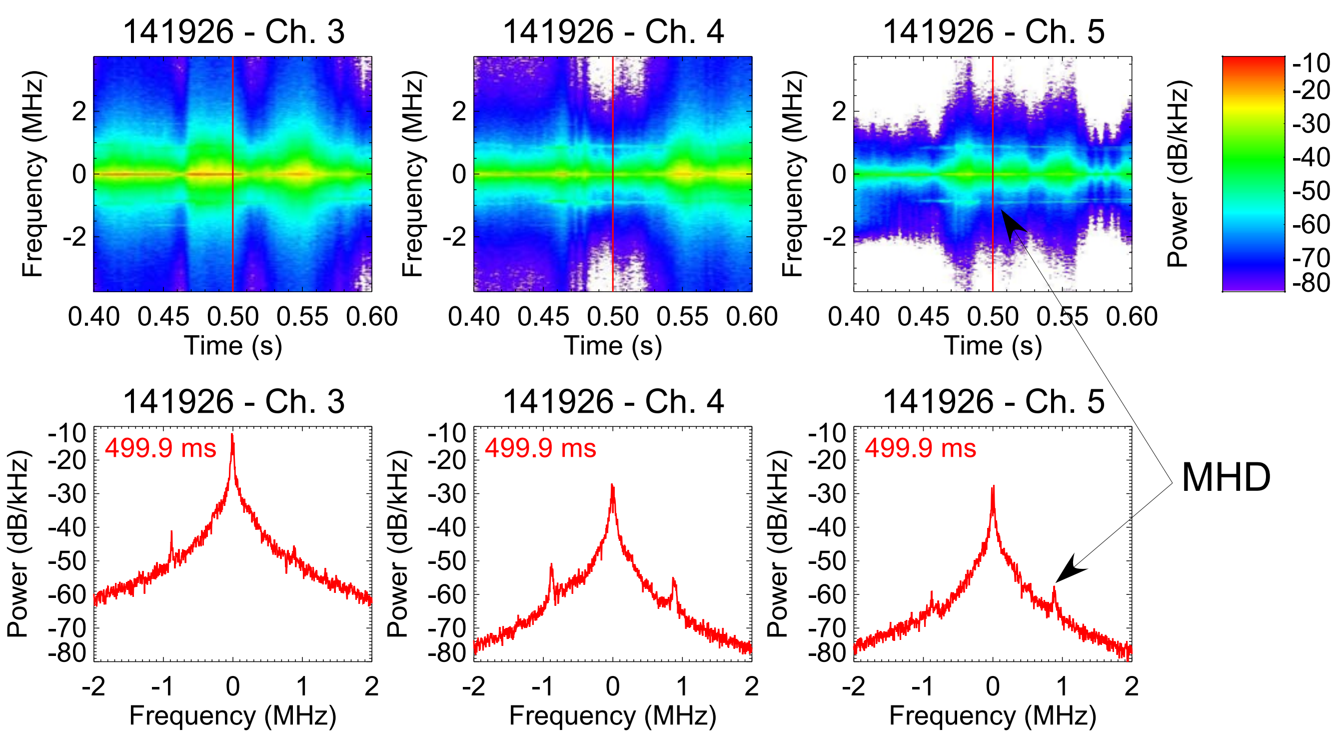
Flat plasma profiles and high rotation shear suggest suppression of electrostatic turbulence



- 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 wavelength turbulence in core of many NBI-heated discharges in NSTX

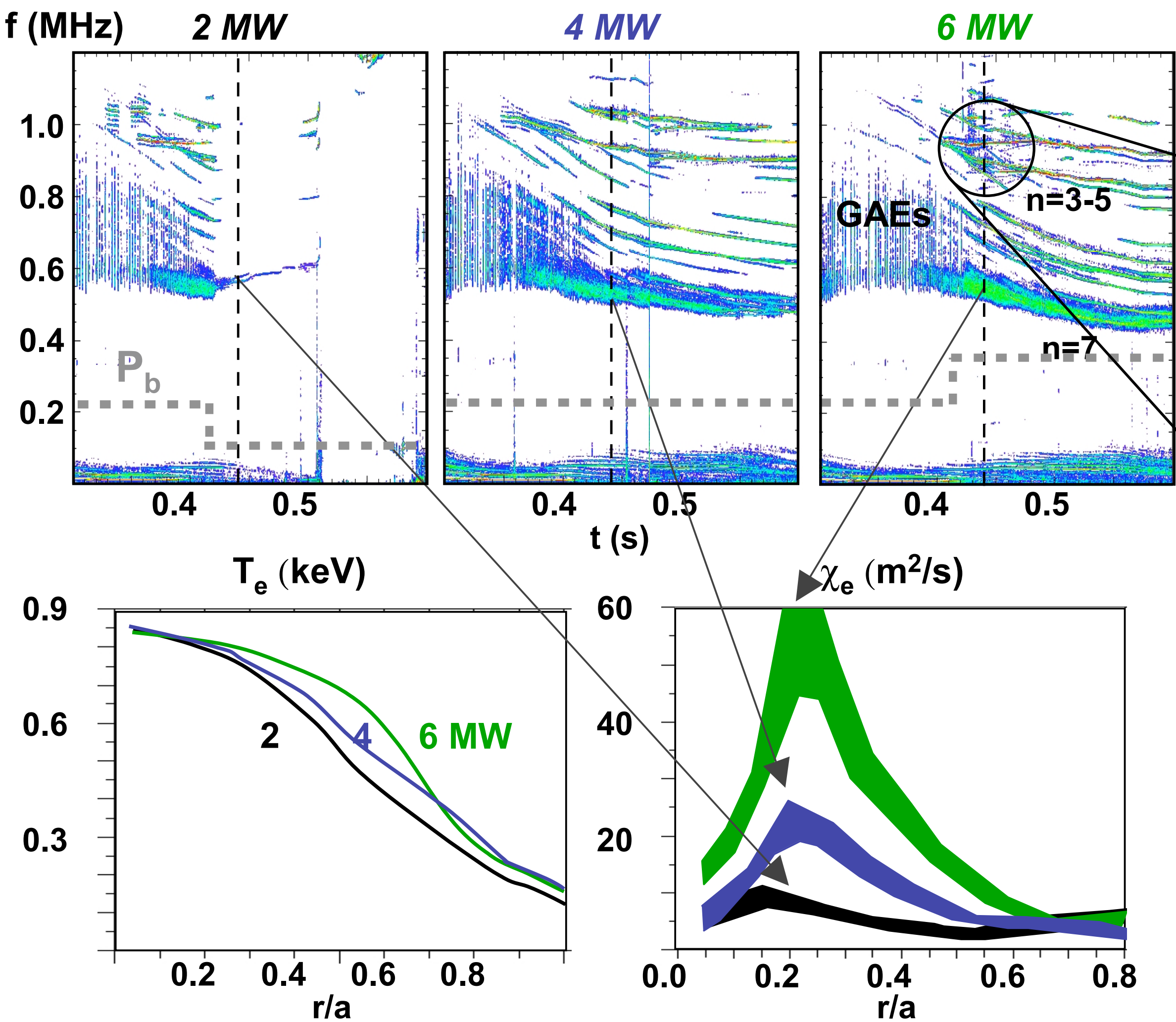
High-k fluctuation spectrum R=123cm k_r = 9-16 cm^{-1}



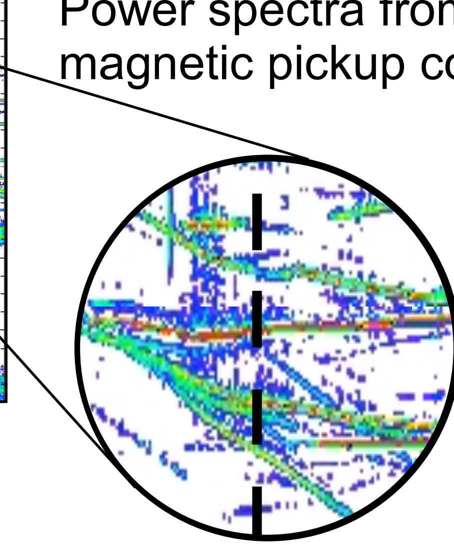
- Initial BES coherence analysis shows low-level fluctuations (<30kHz) across plasma radius, further analysis ongoing
- High-k system shows little to no broadband high-k activity in plasma (R=123cm)

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

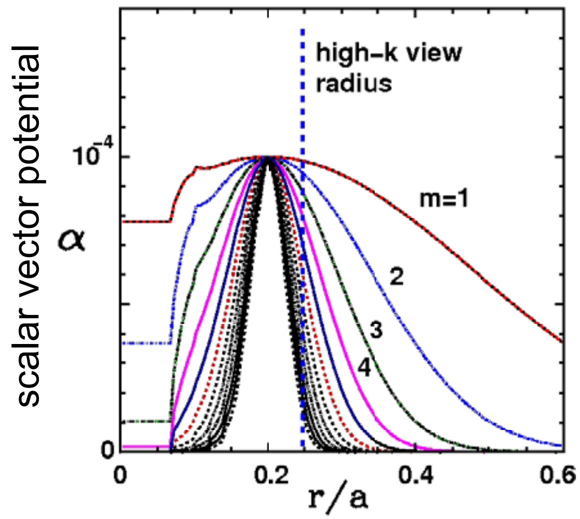
$$\omega_j = \upsilon_A k_{\|j} \approx \upsilon_A \frac{m_j - n_j q}{q R_0}$$

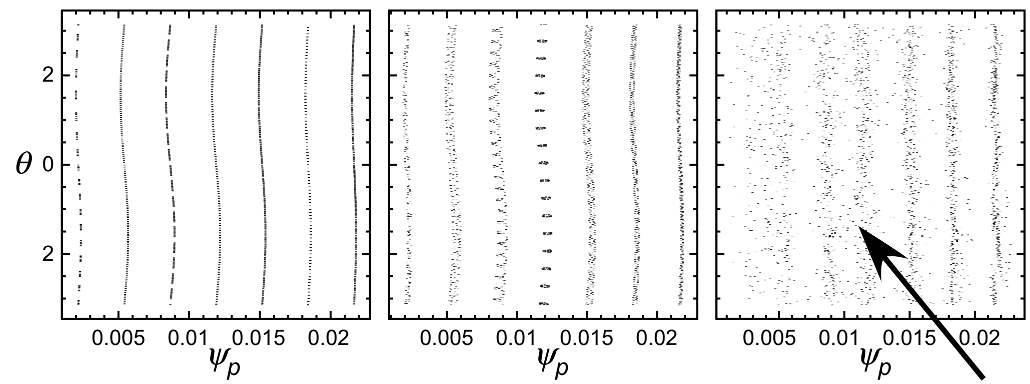
- GAE activity correlates strongly with P_{NBI} steps and enhanced core electron thermal transport

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

N. Gorelenkov Nucl. Fus. 2010

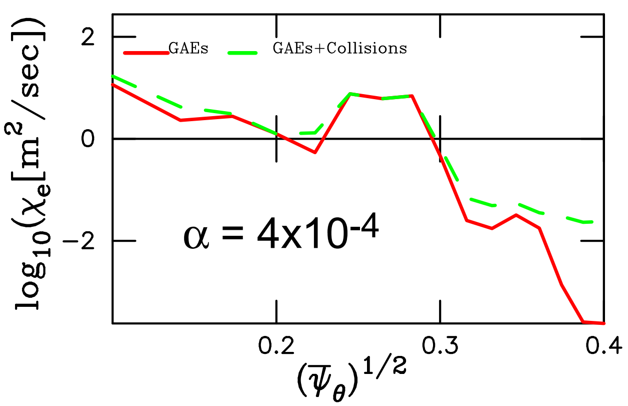
GAE Model used in ORBIT calculations





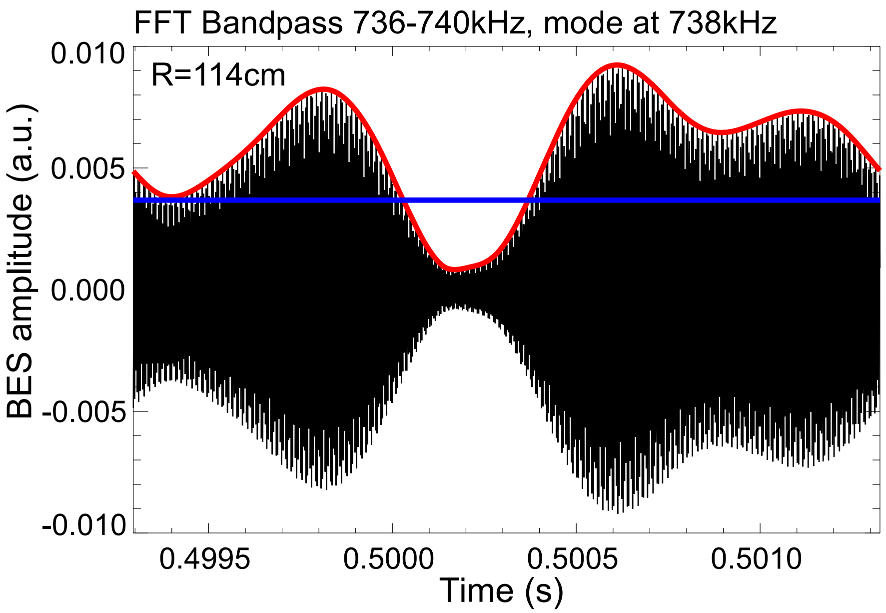
Poincaré plot of electron trajectory

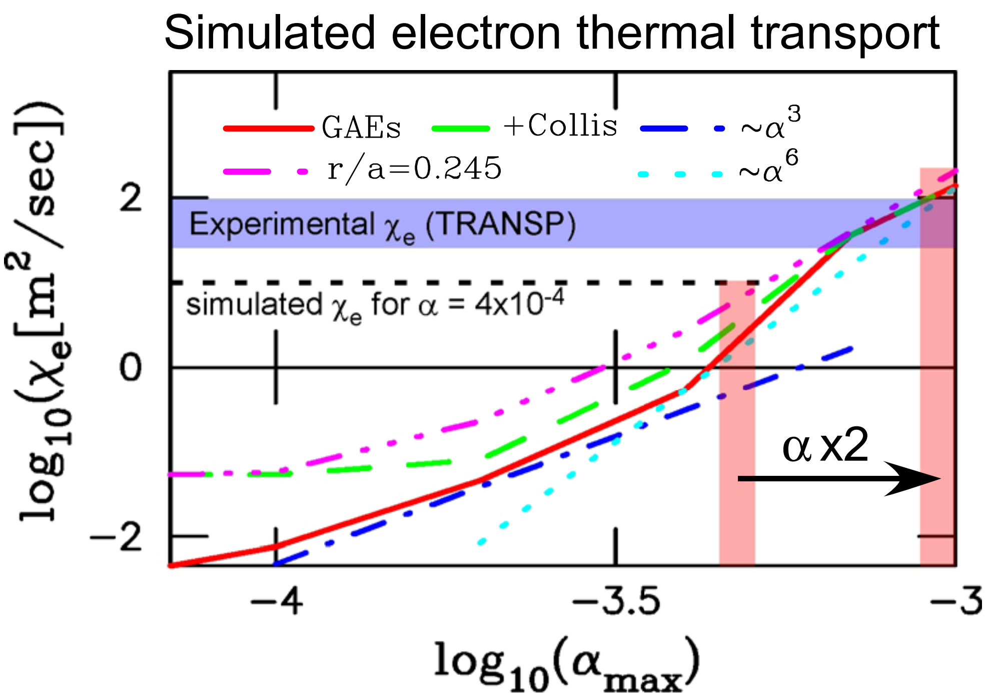
Simulated electron transport



- 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)

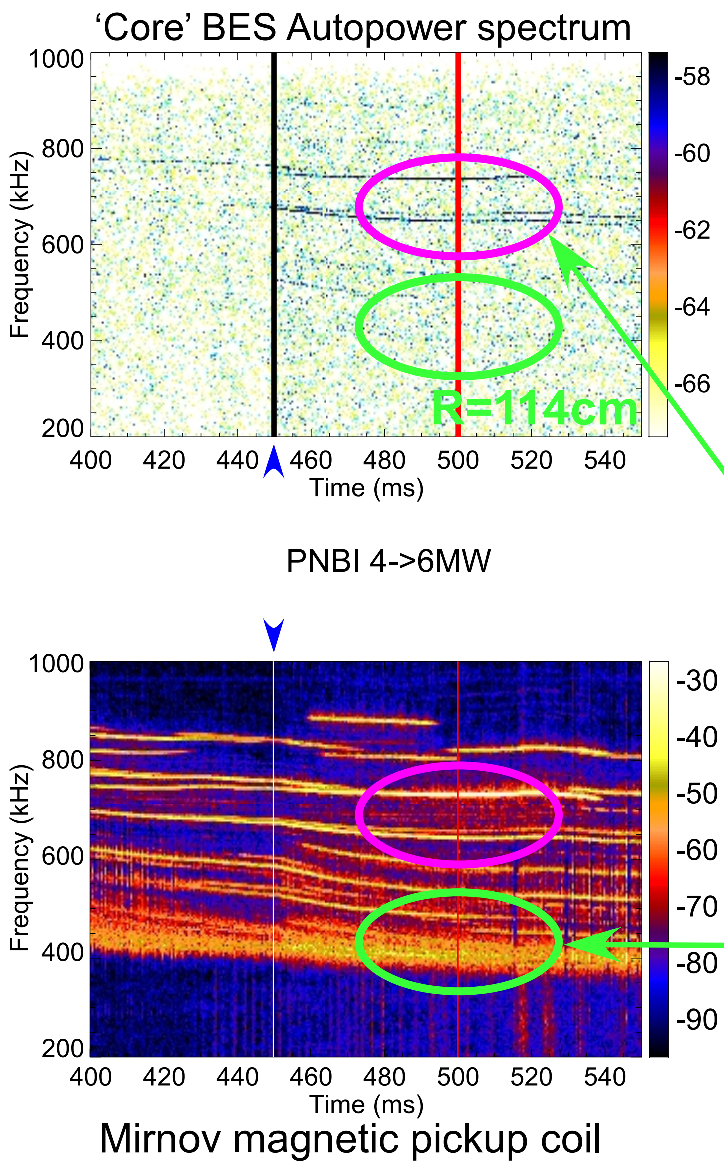
‘Time-varying’ *AE mode activity may strongly affect predicted electron thermal transport

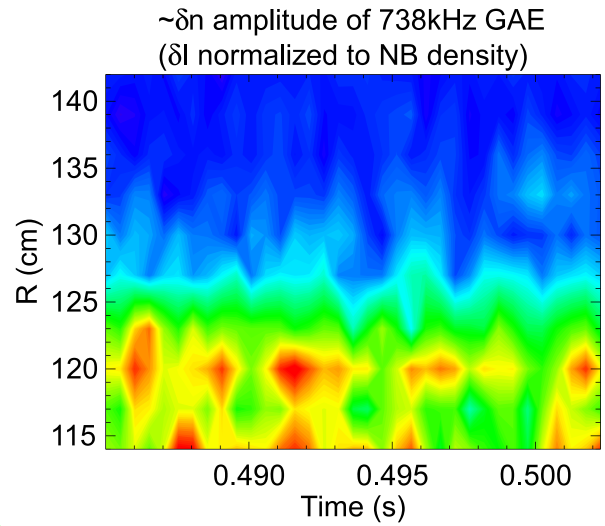


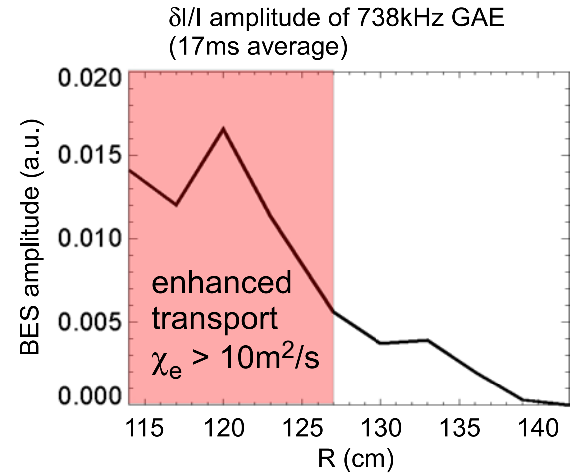


- Strong scaling of transport with α indicates mode amplitude peak values dominate χ_e
- Peak amplitudes ~ x2 to x3 higher than time-averaged, rms values from BES and magnetics
- Calculated electron thermal transport from peak *AE mode amplitudes roughly agrees with experimental TRANSP values

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

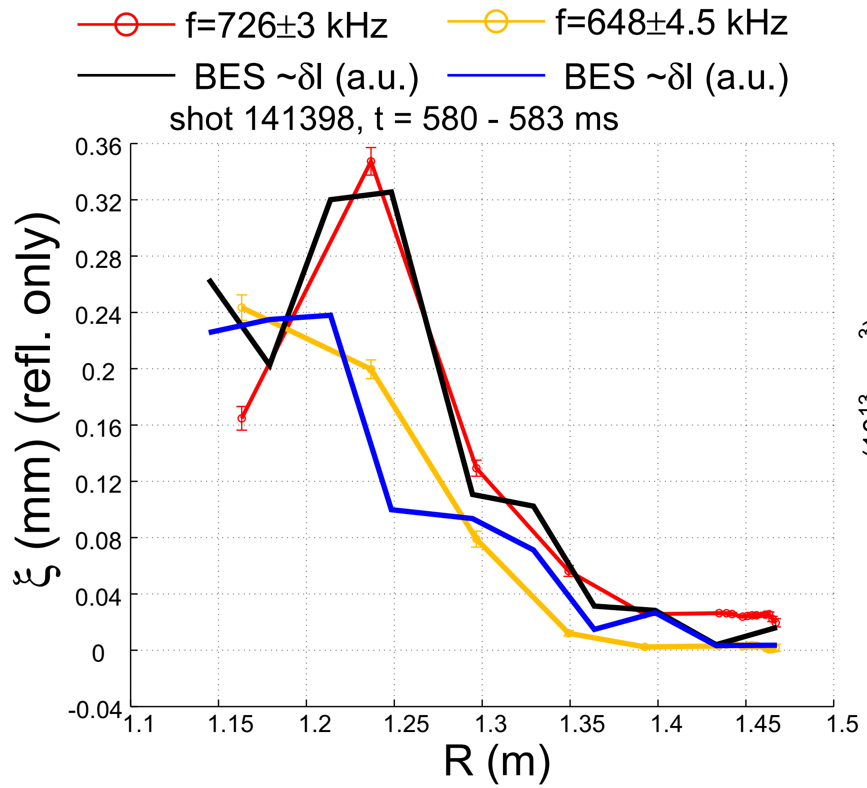


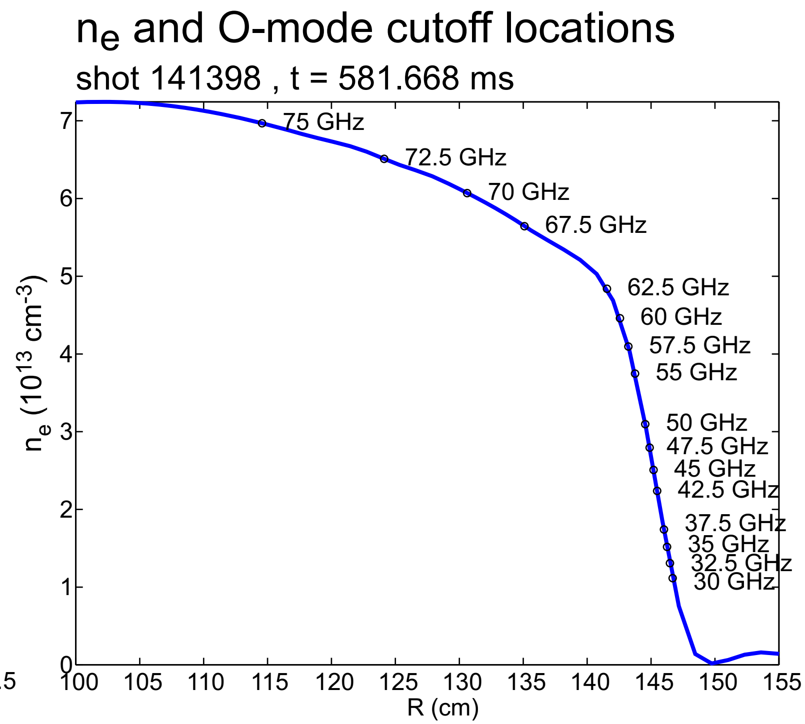




- BES spectrogram shows high-intensity *AE modes R < ~135cm ~ 5-10dB above background
- Mirnov pickup coils reveal additional, lower amplitude modes below BES detector limit

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

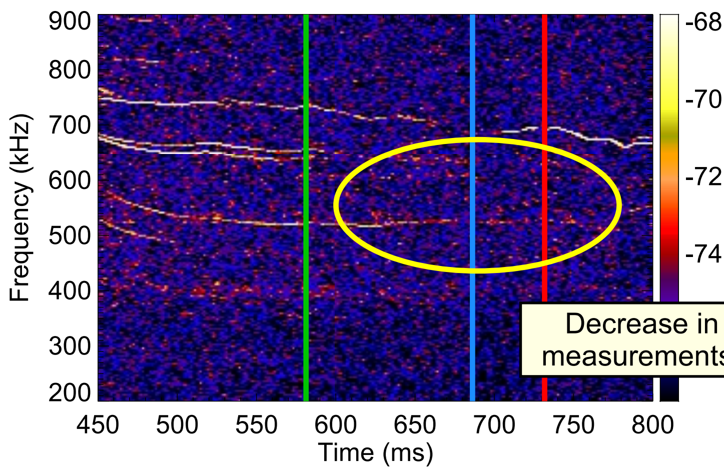




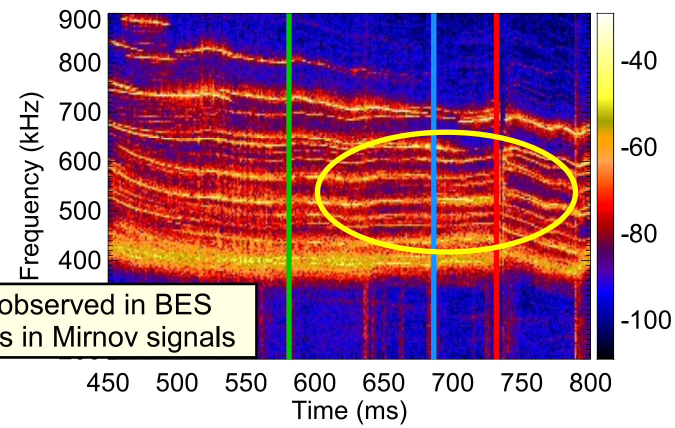
- Reflectometer measured displacement of 0.35mm rms ($\zeta/R \sim 4\times10^{-4}$) indicates $\delta n/n \sim 4.5\times10^{-4}$
- Further analysis indicates mixture of CAE/GAE modes peaking near magnetic axis, multiple locations (*Crocker, et al., PPCF 2011*)

Decrease in *AE activity corresponds with peaking of central electron temperature

BES Spectrogram, R ~ 114cm

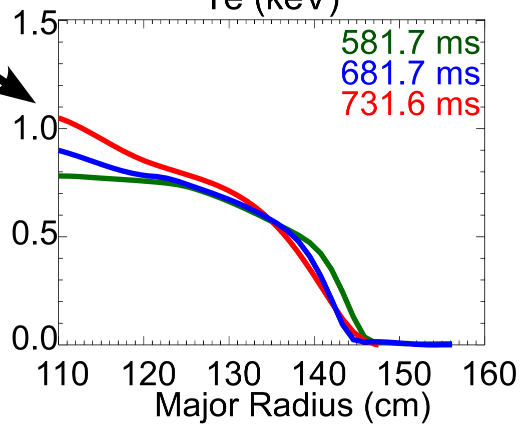


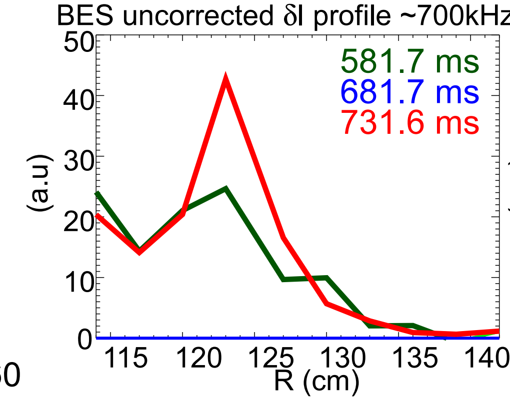
Mirnov Spectrogram

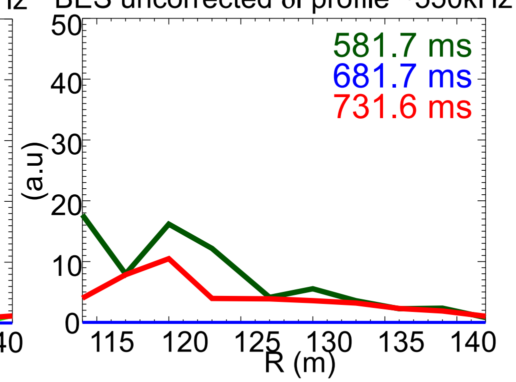


Decrease in *AE activity observed in BES measurements, not obvious in Mirnov signals

T_e Peaks

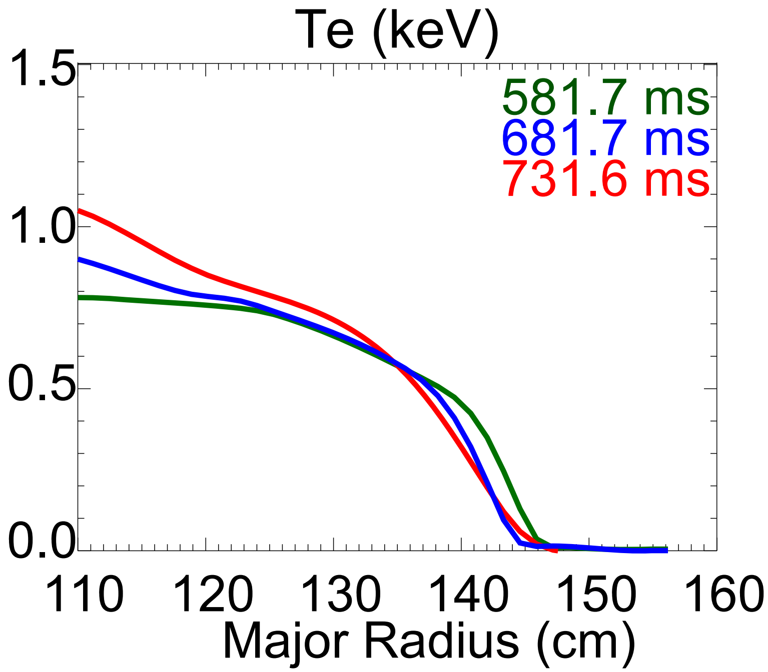


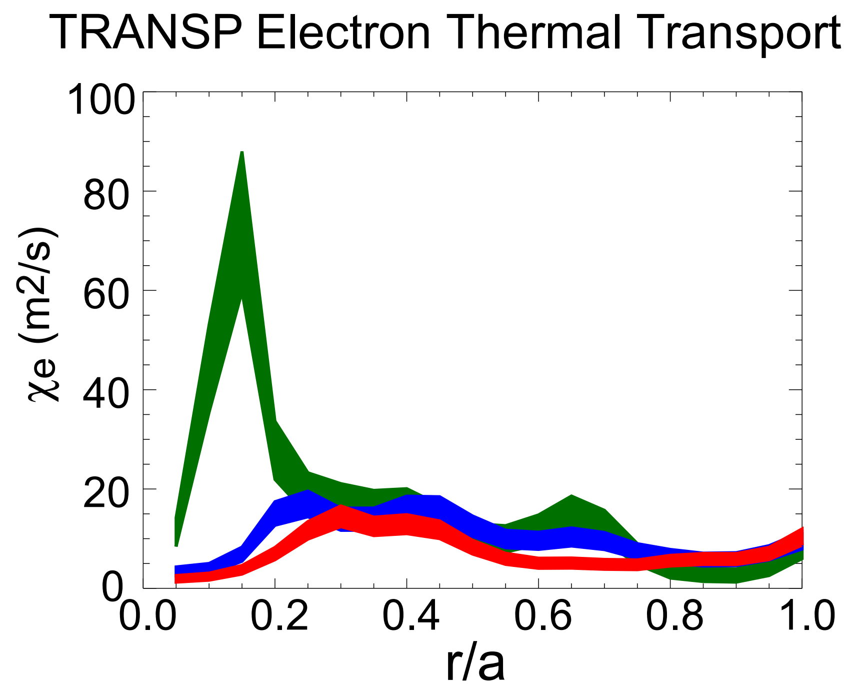




- T_e remains peaked even with large single mode (bulk *AEs still largely supressed)
- BES sensitivity to *AEs marginal at later times, density rise limits reflectometer data
- Need high-k core data to determine if high-k turbulence limits central T_e gradient

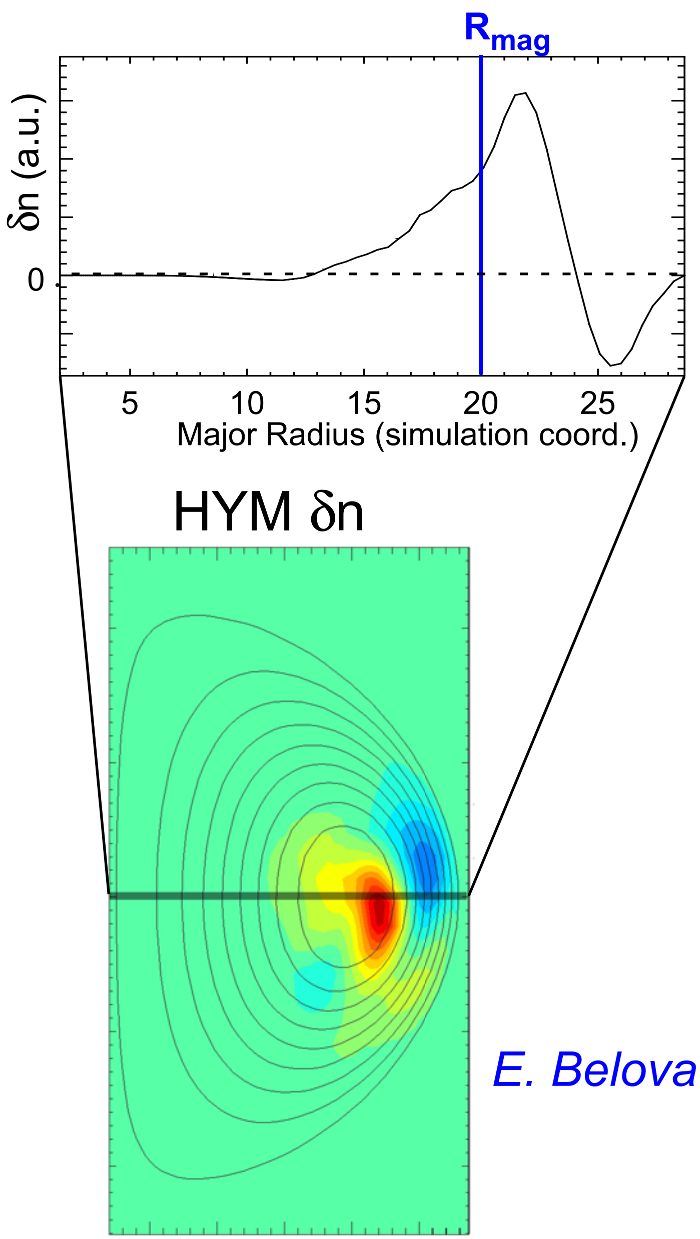
Reduced *AE drive corresponds with lowers thermal electron transport



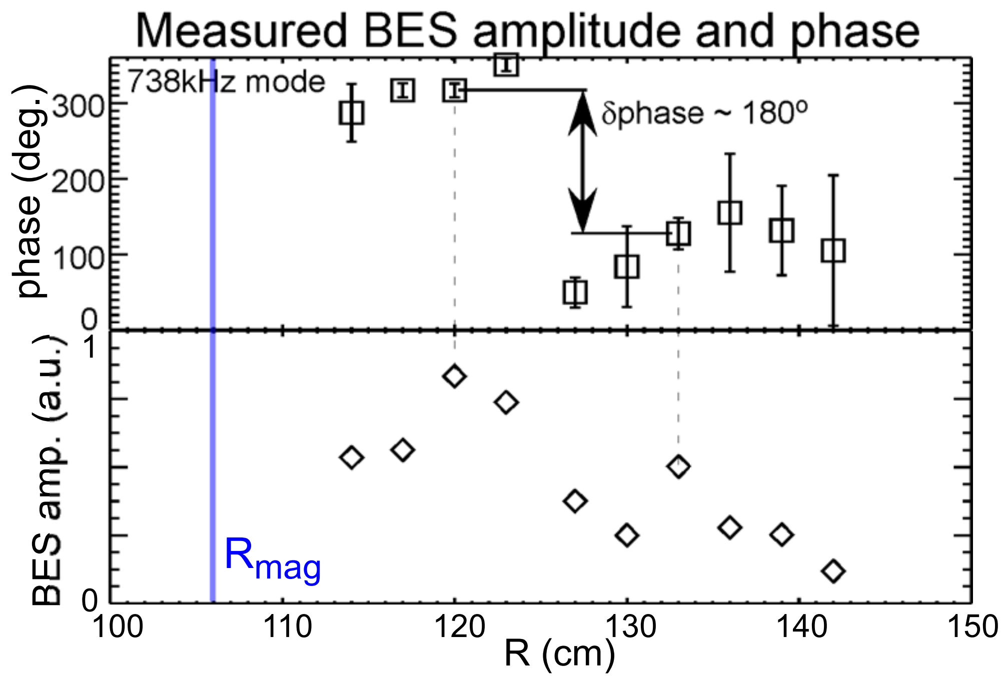


- Electron temperature likely limited by other anomalous transport mechanism
- BES fluctuations require further analysis
- Possible ETG or micro-tearing modes present
- Future experiments will include high-k scattering diagnostic, polarimetry, density control to investigate interplay between *AEs and turbulent induced transport

HYM code predicts δn inversion across plasma radius



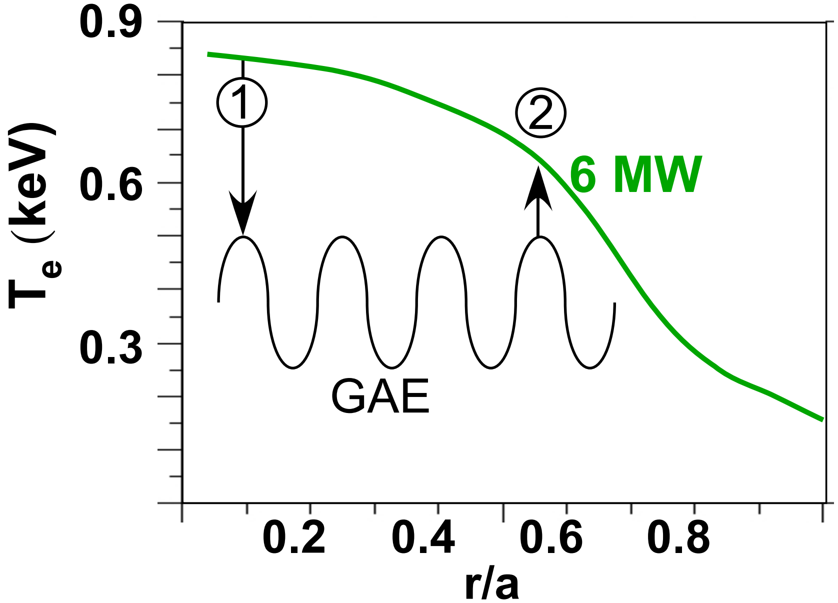
E. Belova



- BES raw data also indicates 180 degree phase shift
- Still needed: HYM CAE nonlinear simulations and ORBIT transport calculations using GAE/CAE modes spatial overlap

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 yet explained with electrostatic turbulence in high power NSTX H-modes
- Strong correlation of *AE activity with NBI power and high electron thermal transport
- Measured *AE mode structure and amplitude roughly consistent with predicted values of transport using ORBIT code

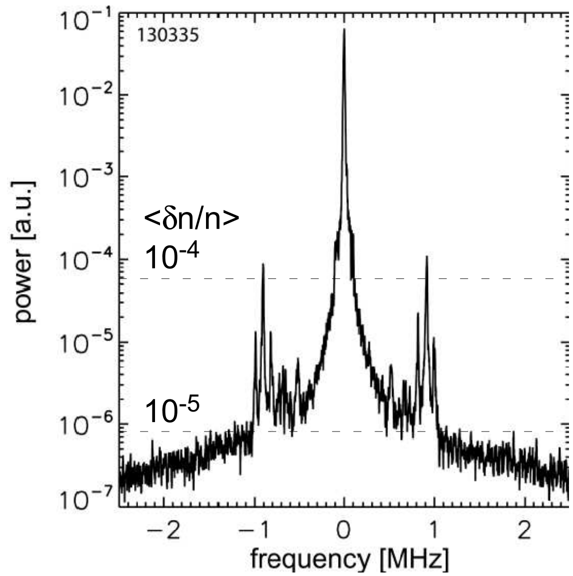
Future Work

- Validation of the HYM code using GAE/CAE mode structure and phase measurements, BES poloidal measurements
- Include both CAE/GAE modes and spatial distribution for transport calculations
- Attempt to predict CAE/GAE transport relationship for NSTX-U and future ST devices

Backup Slides

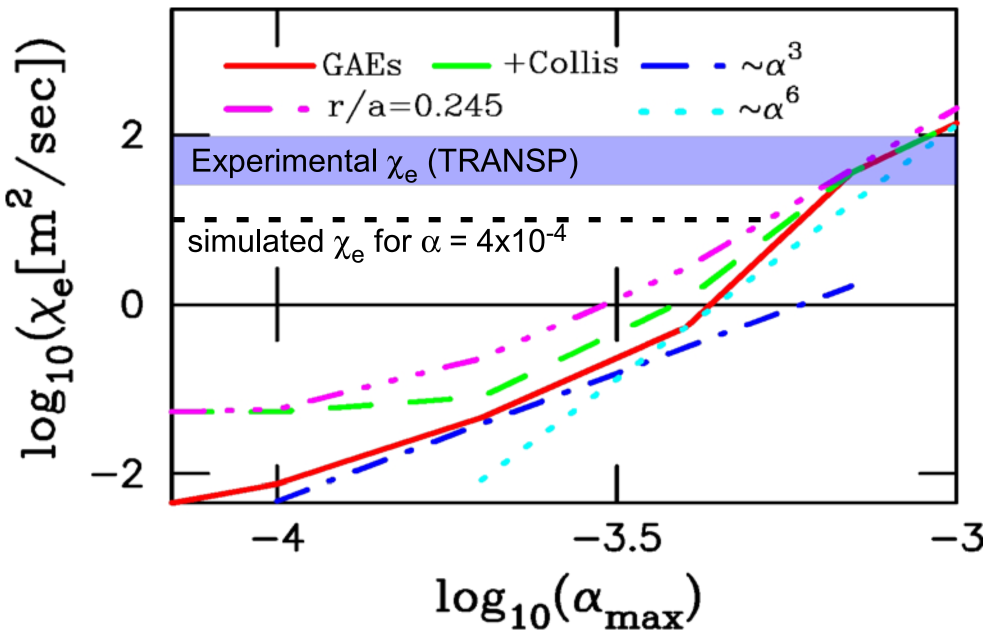
GAE ORBIT model using measured amplitudes under-predicts TRANSP χ_e by x4-10

high-k power spectrum



$<\delta n_{rms}/n> \sim 1.5x10^{-4} \rightarrow$ local $\delta n/n \sim 9x10^{-4}$

Simulated electron thermal transport



- $\alpha=4x10^{-4}$ 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