Study of Electron Temperature Fluctuations in DIII-D using a Correlation ECE Diagnostic

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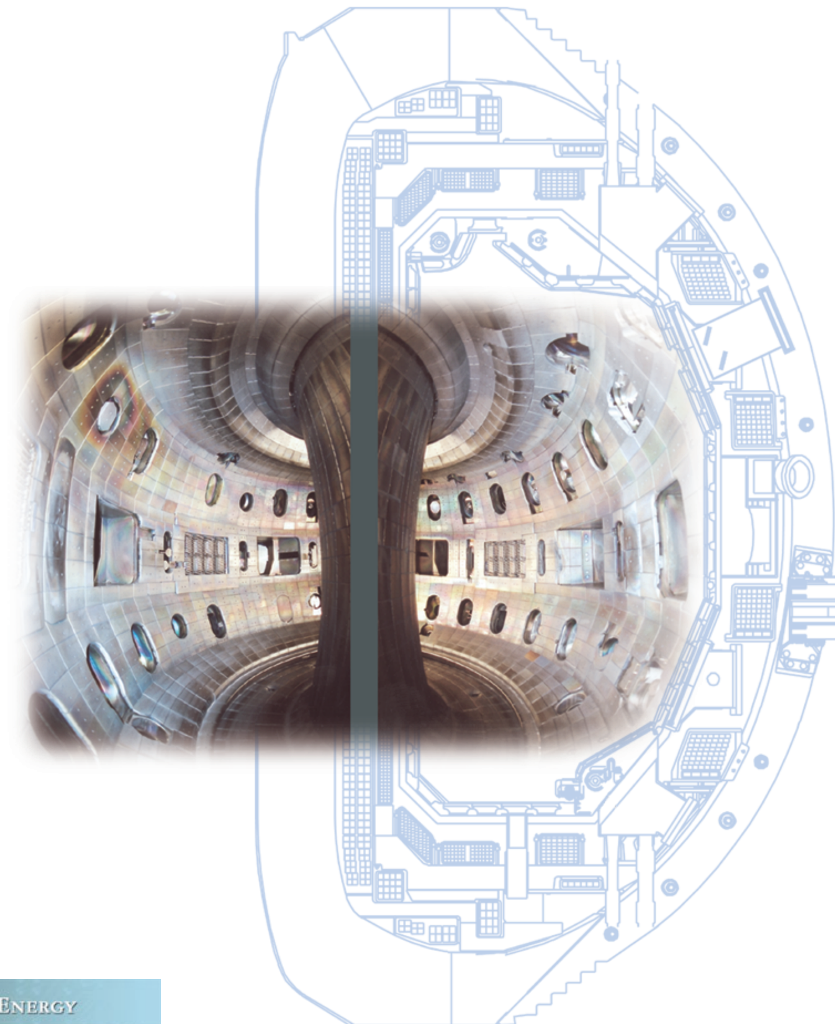

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Poster Outline

INTRODUCTION:

The UCLA correlation electron cyclotron emission (ECE) diagnostic has been used to measure broadband electron temperature fluctuations in the core of DIII-D tokamak plasmas. Ohmic, Co and Counter NBI L-mode and H-mode plasmas have been investigated.

- Background and Diagnostic description
- Outer half-radius results ($r/a > 0.5$)
- Core and high-field results ($-0.1 < r/a < 0.5$)
- Summary
- Future Work

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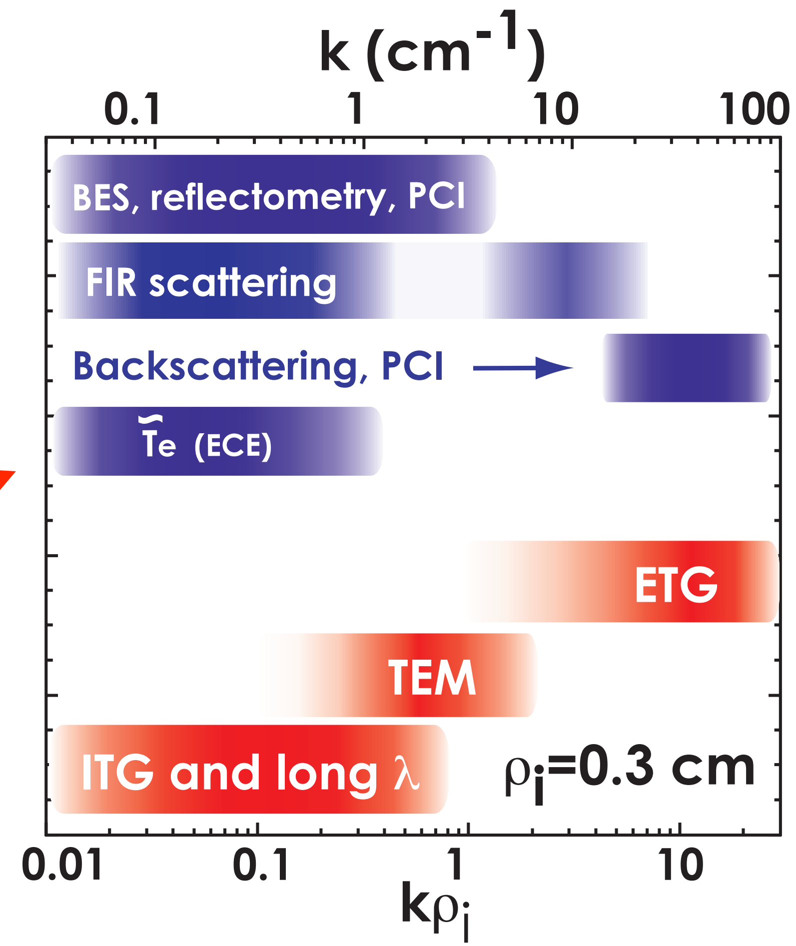
Motivation:
Anomalous Transport and Turbulence

Measurements of density fluctuations have been made in the core of DIII-D with far infrared scattering (FIR), back scattering, beam emission spectroscopy (BES), Phase Contrast Imaging (PCI) and reflectometry

A measurement of electron temperature fluctuations in the core with a correlation electron cyclotron emission (ECE) diagnostic will help identify the nature of the turbulence



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Background:

Correlating two ECE radiometer signals for $\tilde{T}_e$ / T_e Measurements

- W7-AS measured temperature fluctuations in ECRH plasmas, rms amplitude between 0.5 - 1.0 % **[Sattler (1994)]**
- TEXT-U measured temperature fluctuations in Ohmic plasmas, rms amplitude between 0.5 - 1.5 % **[Cima (1995)]**
- C-MOD did not observe temperature fluctuations in RF plasmas, but reported that line-of sight may have been in a poloidal region of very low fluctuation levels **[Watts (2004)]**
- TORE SUPRA **[Udintsev (2006)]** measured temperature fluctuations in ECRH plasmas, and temperature fluctuations have also been observed in RTP and TEXTOR **[Deng (2001)]**
- Thermal noise (wave noise, statistical noise) from two distinct radial emission layers (i.e. at distinct cyclotron frequencies), will be uncorrelated
- Cross-correlate two signals that are disjoint in frequency space, but are within a correlation length of the turbulence
- *Technique requires large number of samples 'N', this limits time resolution*
- *Can obtain spectrum and rms fluctuation amplitude, radial correlation length, Δr*

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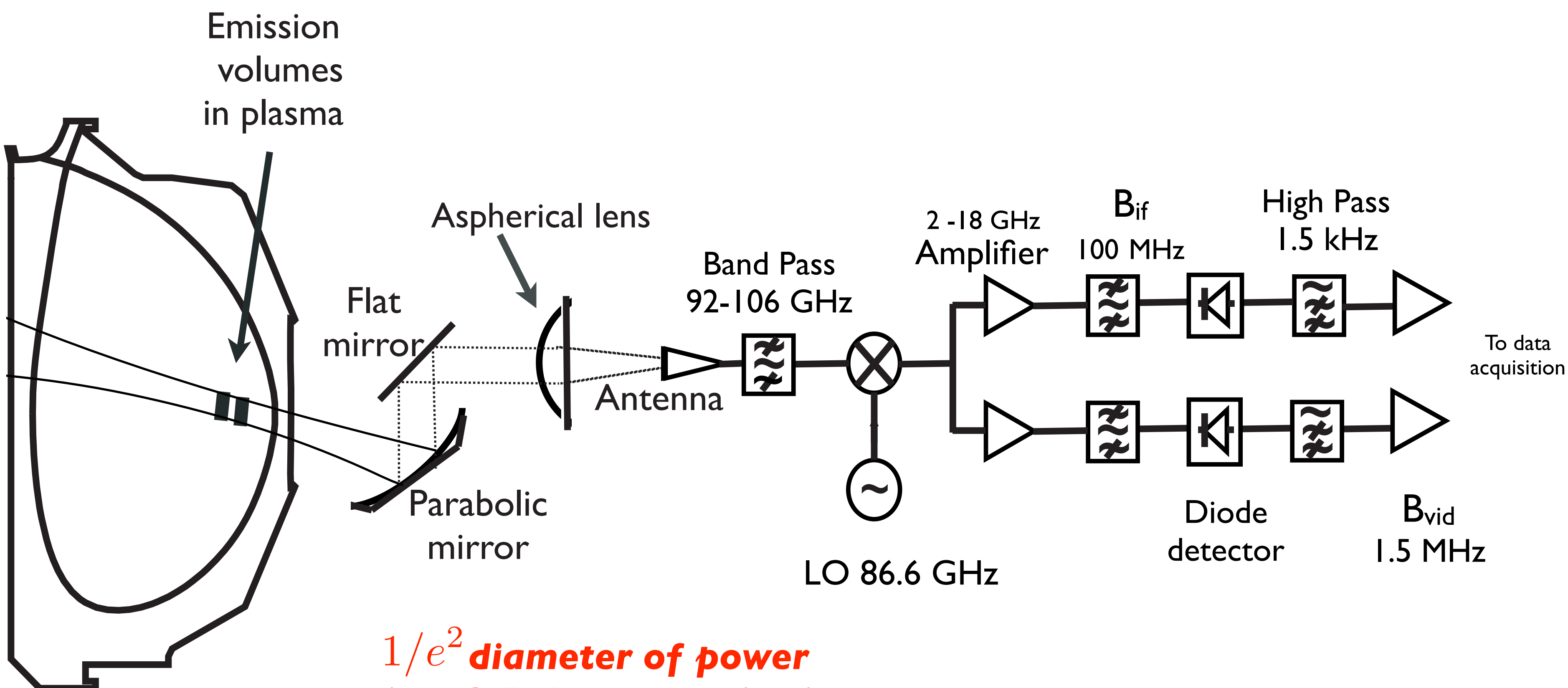
Diagnostic:
Diagram of UCLA Correlation ECE System on DIII-D



$1/e^2$ diameter of power gives 3.5-4 cm spot size in region of interest

$k_\theta \leq 1.25 cm^{-1}$

Radial resolution

B_{if} = 100 MHz ~ 3 mm

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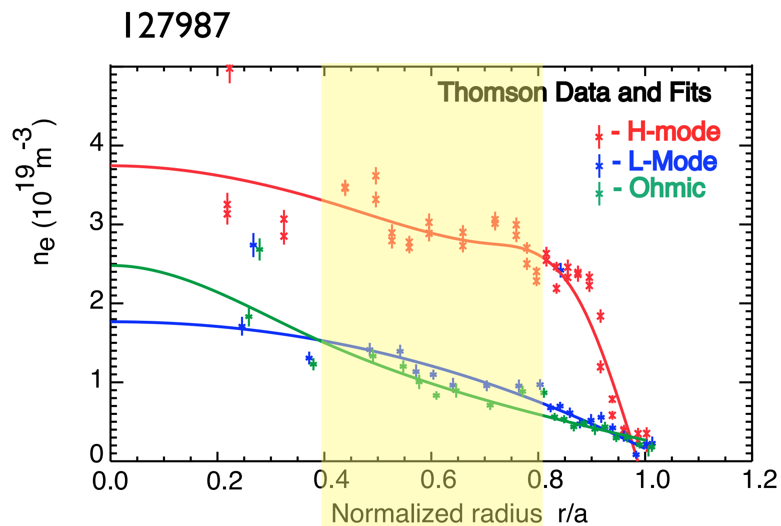
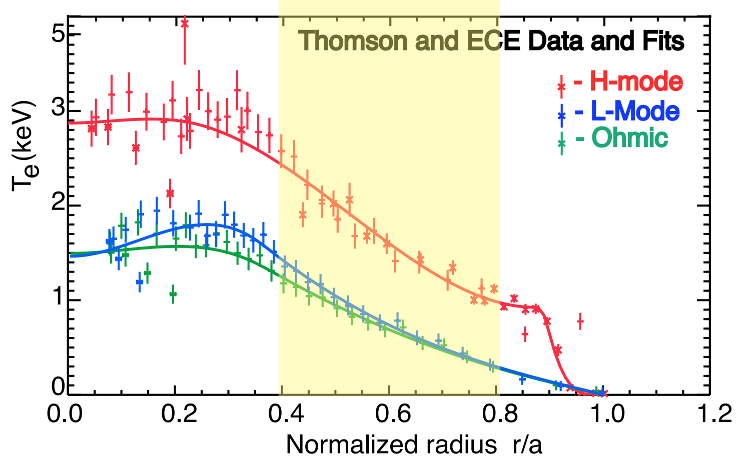
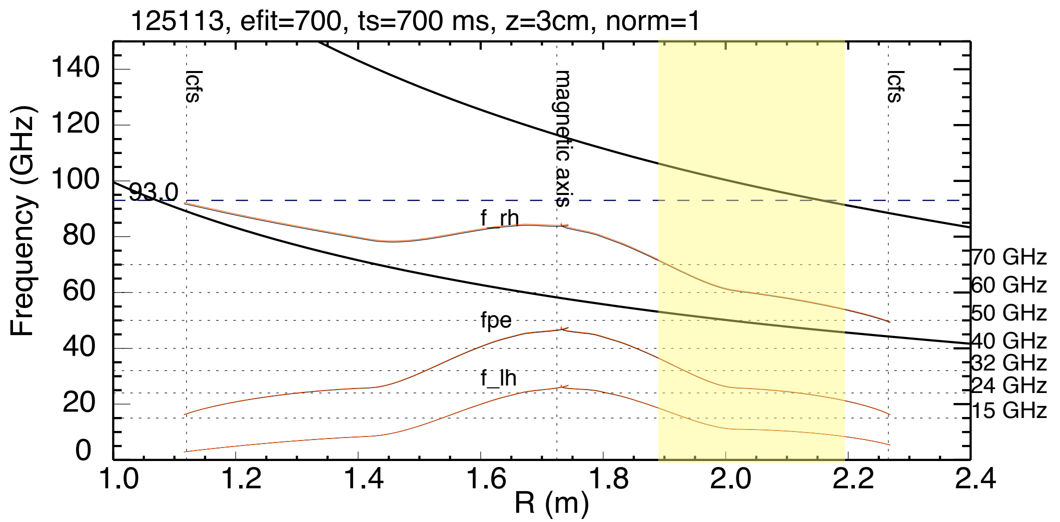
Results from outer half radius r/a > 0.5 :

Differences between OH, L and H mode plasmas





- 0.4 < *r/a* < 0.8, 600-800 ms (L-mode)
- PNBI ~ 2.5 MW co beam
- density (line averaged) ~$0.8 \times 10^{13} cm^{-3}$
- *Te* (*r/a* = 0.7) ~ 0.77 keV
- $0.4 < \beta_N < 0.5$ over 200 ms average time



Results from outer half radius r/a > 0.5 :

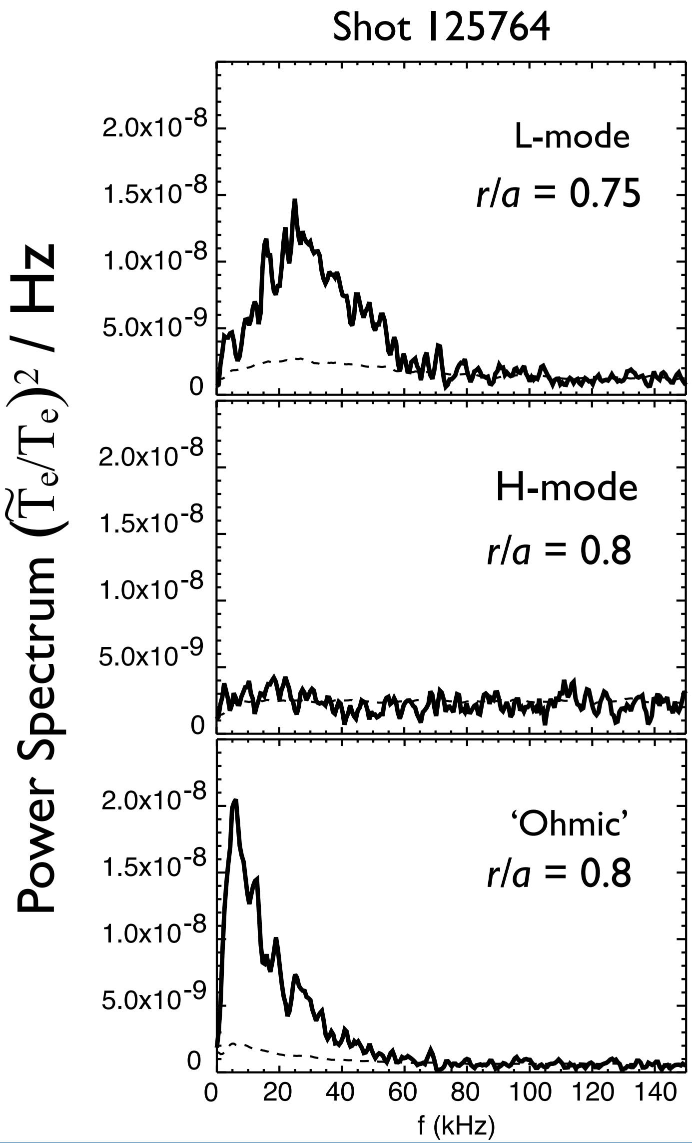
Differences between OH, L and H mode plasmas

Data has been obtained in many different plasma regimes during "piggybacking" experiments from June 2006 - March 2007.

Relative fluctuation levels are between 0.5 and 2 % in the radial region 0.6 ≤ r/a ≤ 0.8 in L-mode and 'Ohmic' plasmas.

During ELM-free H-modes no fluctuations above the minimum detectable level are observed.

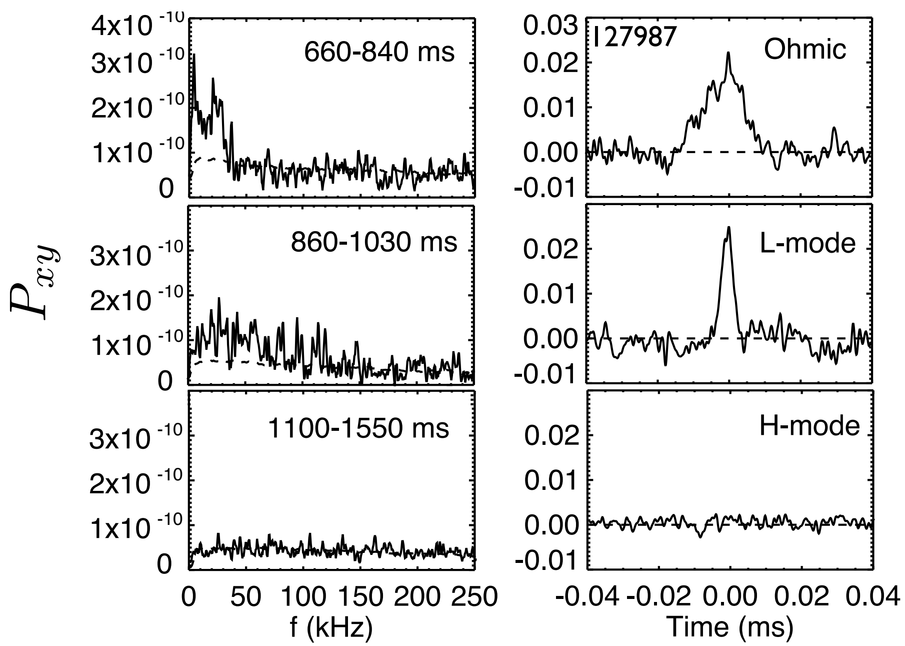
Data is obtained in Ohmic/ L-mode plasmas early in the discharge (with and without ramping Ip) and also late in the discharge > 200 ms after the NB heating has ended.

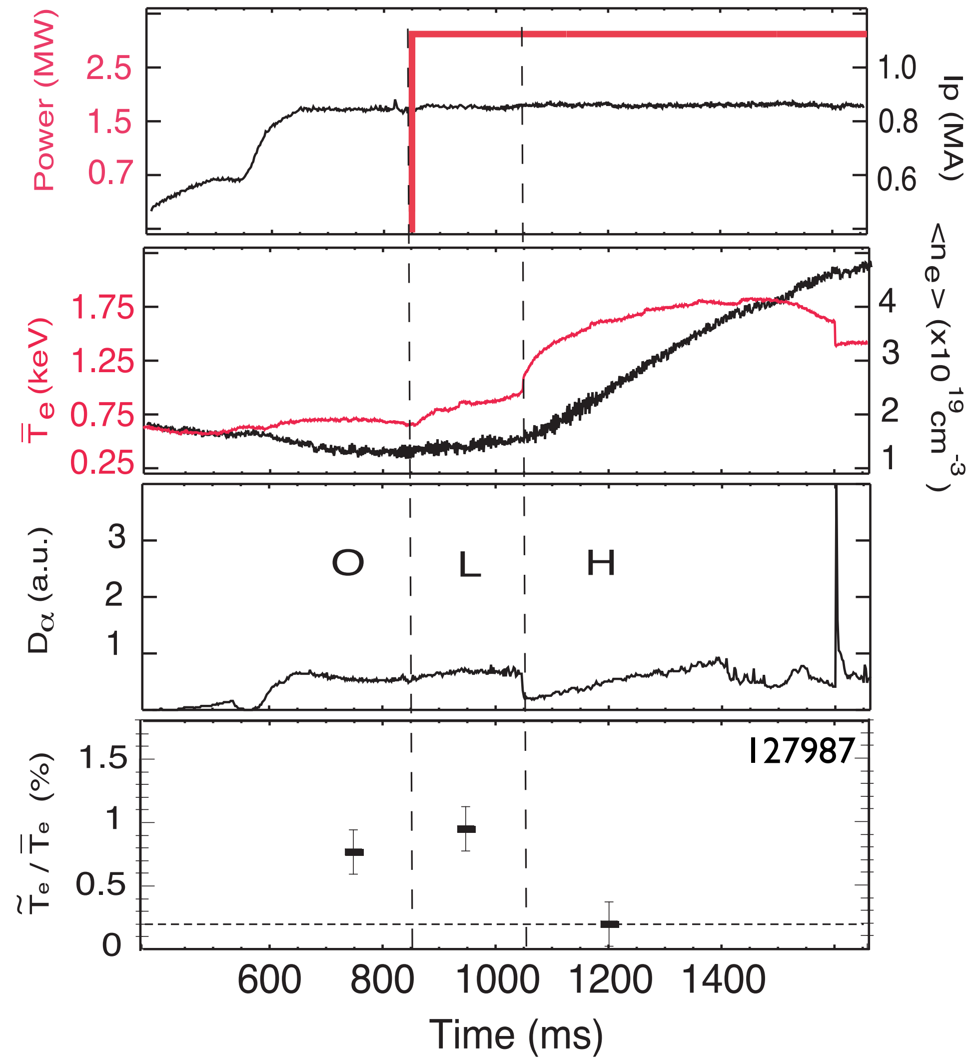


Results from outer half radius r/a > 0.5 :
Differences between OH, L and H mode plasmas

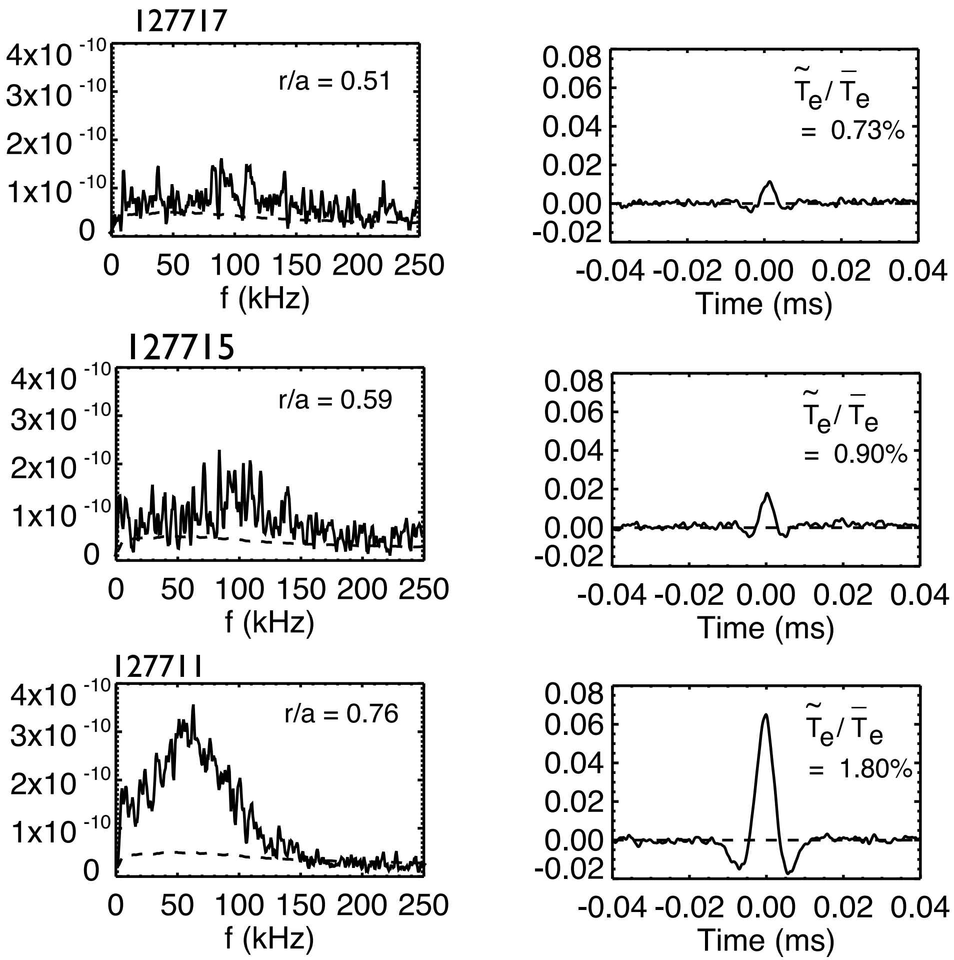
Relative fluctuation levels are slightly higher in L-mode plasmas compared to Ohmic plasmas at the same radial locations, *r/a* ~ **0.7**

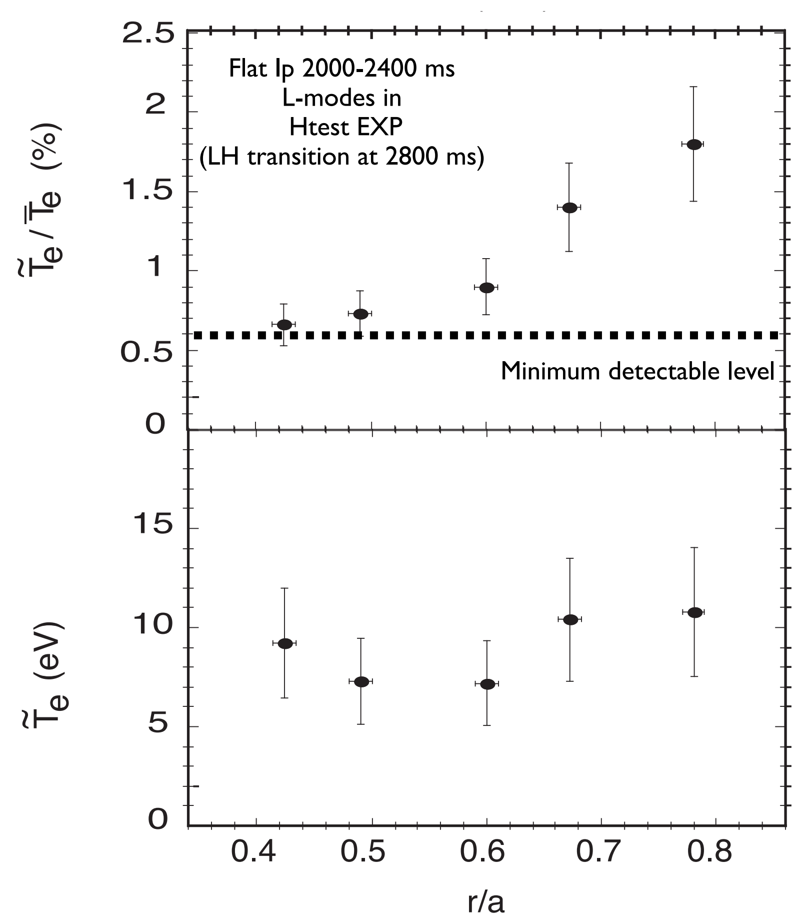
During ELM-free H-modes no fluctuations above the minimum detectable level are observed.





Results from outer half radius r/a > 0.5 :
L-mode fluctuation levels are largest at outer radii and spectral features move to higher frequency at inner radii





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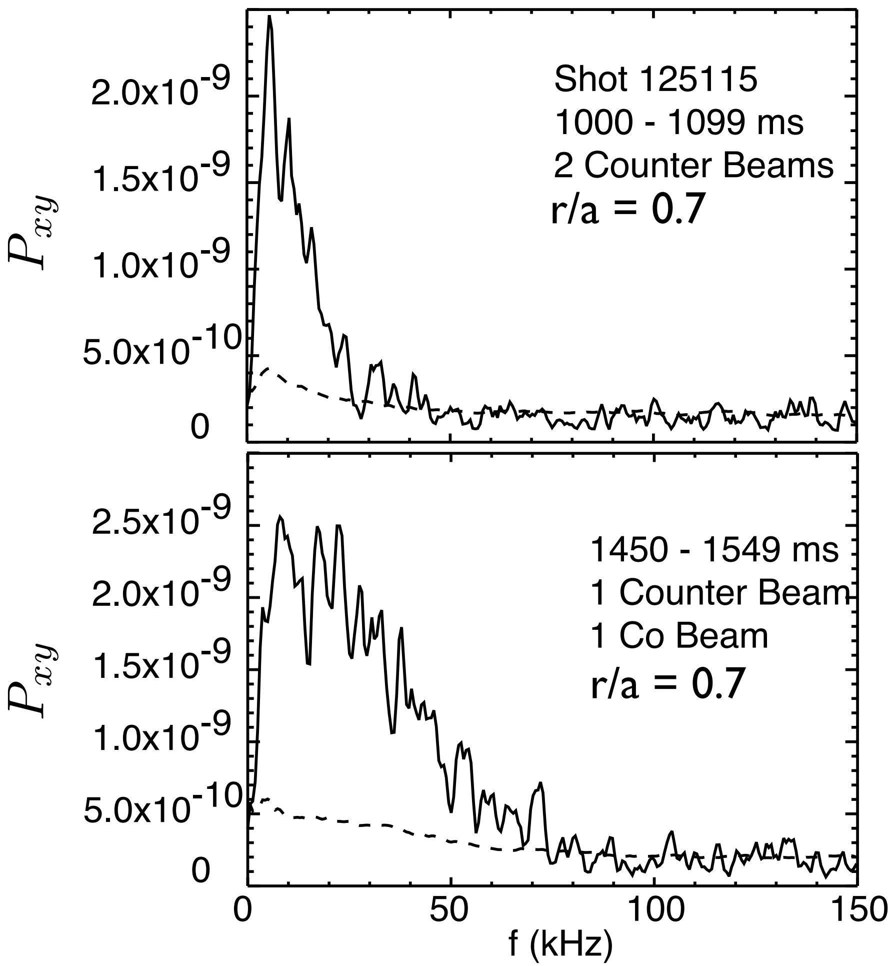
Results from outer half radius r/a > 0.5 :
Counter injected neutral beams reduce plasma rotation and observed spectral width narrows



The spectral features of the temperature turbulence respond to changes in the plasma rotation

The ExB velocity is obtained from CERFIT analysis of Charge Exchange Recombination Spectroscopy (CER) data.

The measured center frequency of the temperature turbulence is consistent with the prediction for a Doppler shifted frequency given as

$$f_{Dopp} = \frac{1}{2\pi} k_\theta v_{E\times B}$$

With a mean wavenumber assumed:

$$\langle k_\theta \rangle \sim 1cm^{-1}$$

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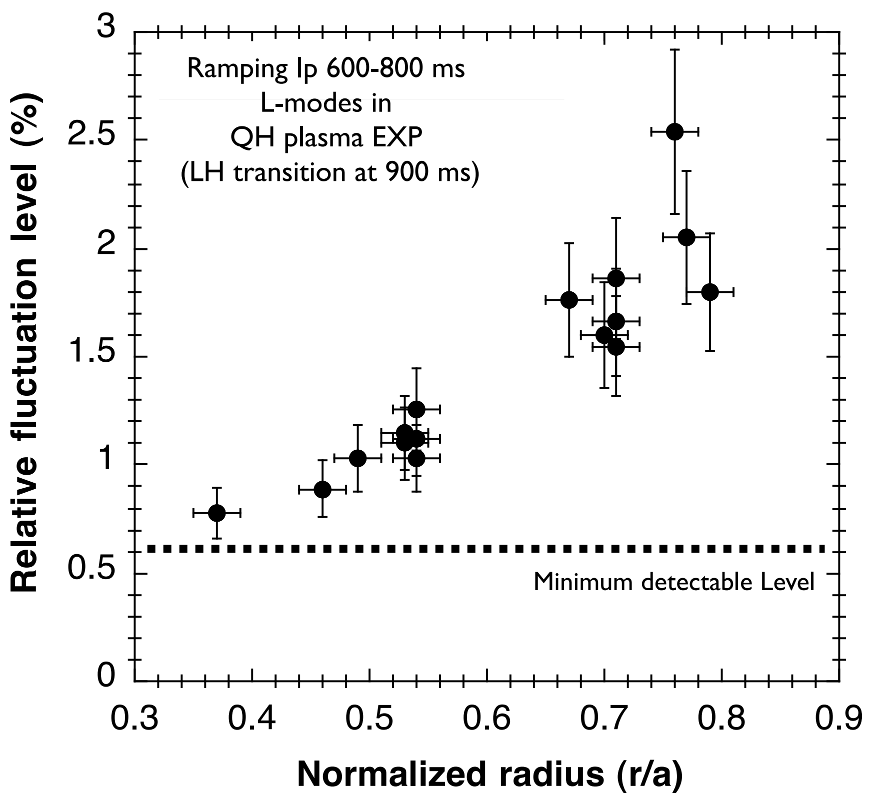
Results from outer half radius r/a > 0.5:

Profiles obtained from ramp Ip and flat Ip L-mode plasmas show same levels and scaling with radius



Relative fluctuation levels are between 0.5 and 2 % in the radial region $0.6 \leq r/a \leq 0.8$ in L-mode plasmas

Data is obtained at different radii by moving measurement location on shot-by-shot basis

Data obtained during many different experiments indicates that temperature fluctuations are very similar in long, stationary L-mode plasmas and start-up Ip ramp plasmas

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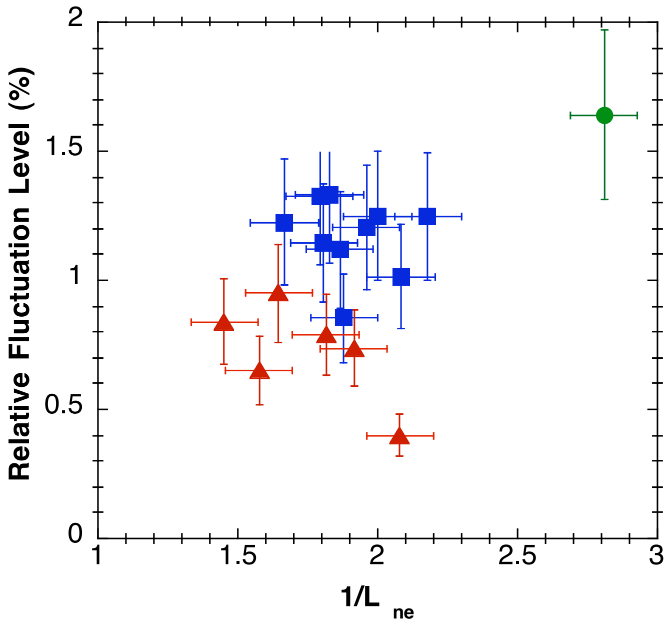
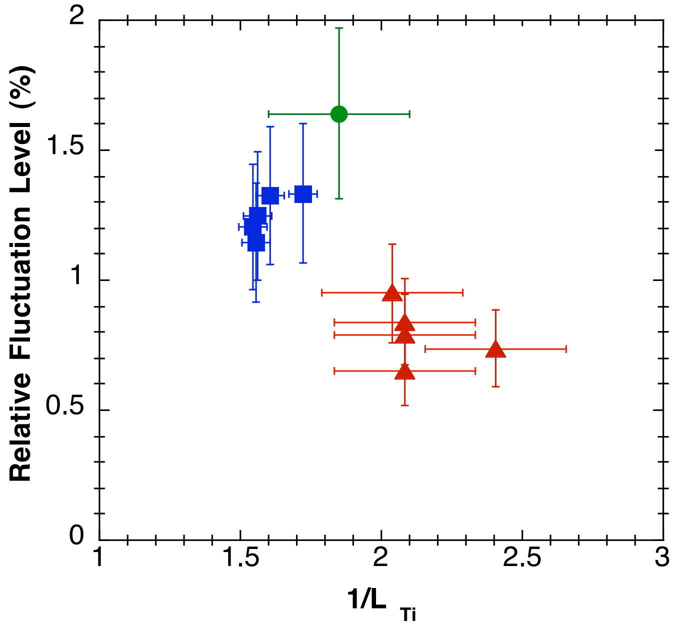
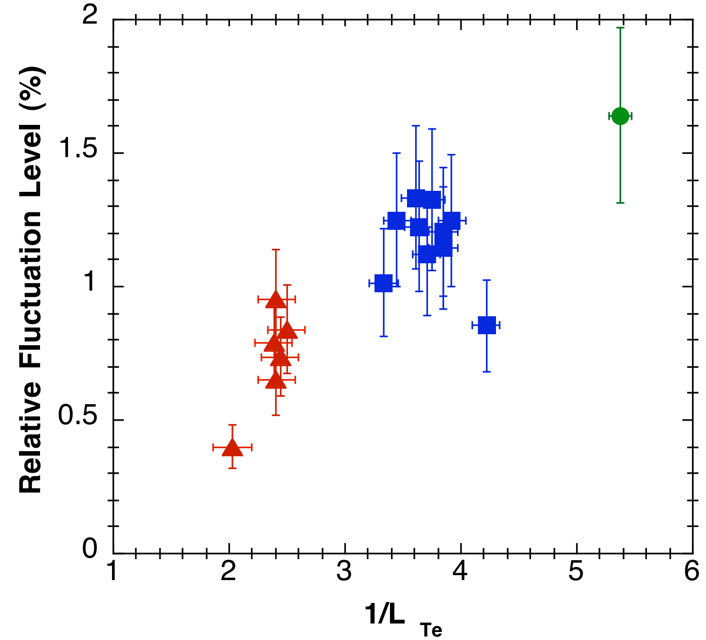
Results from outer half radius r/a > 0.5:
Investigation of possible drive for low-k electron temperature fluctuations







Fluctuations do not scale with electron density gradient

Fluctuations show possible scaling with ion temperature gradient and electron temperature gradient

Data from the Ip ramp L-mode plasmas investigated between 600-800 ms from QH mode EXPs days on DIII-D

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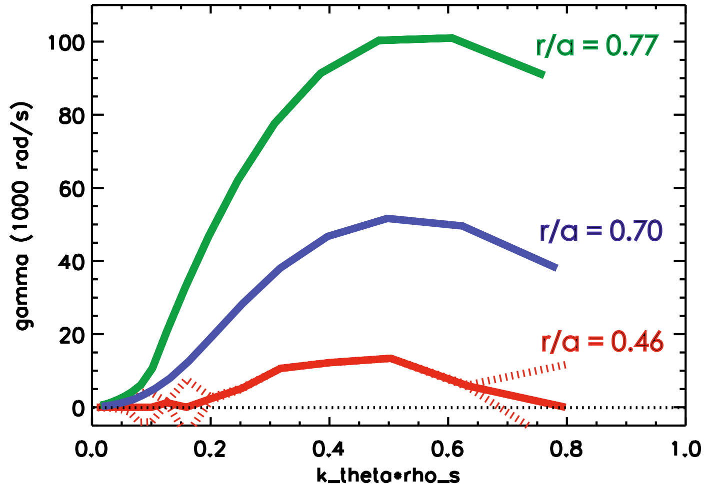
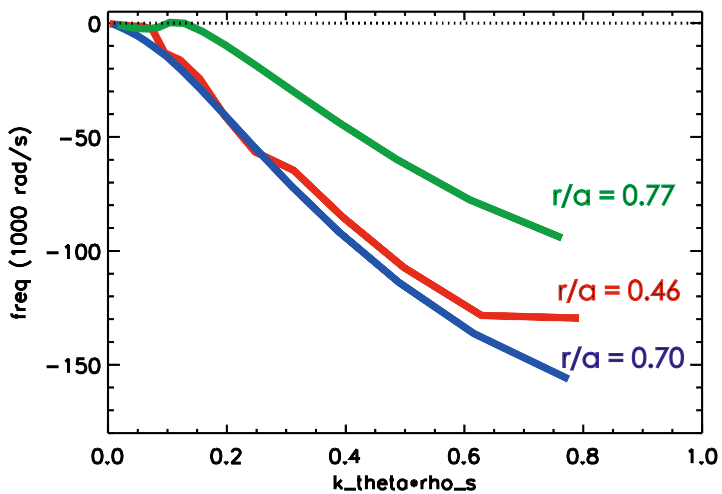
Results from outer half radius r/a > 0.5:

Investigation of possible drive for low-k electron temperature fluctuations





L-mode parameters and spot-size give

$$k_\theta \rho_s < 0.5$$

for measured electron temperature turbulence

Linear GKS results indicate that the ITG mode is most unstable mode during the Ip ramp L-mode plasmas investigated between 600-800 ms from QH mode EXPs days on DIII-D

Future work with TGLF model and nonlinear GYRO calculations are needed to help understand the possible drive for observed temperature fluctuations

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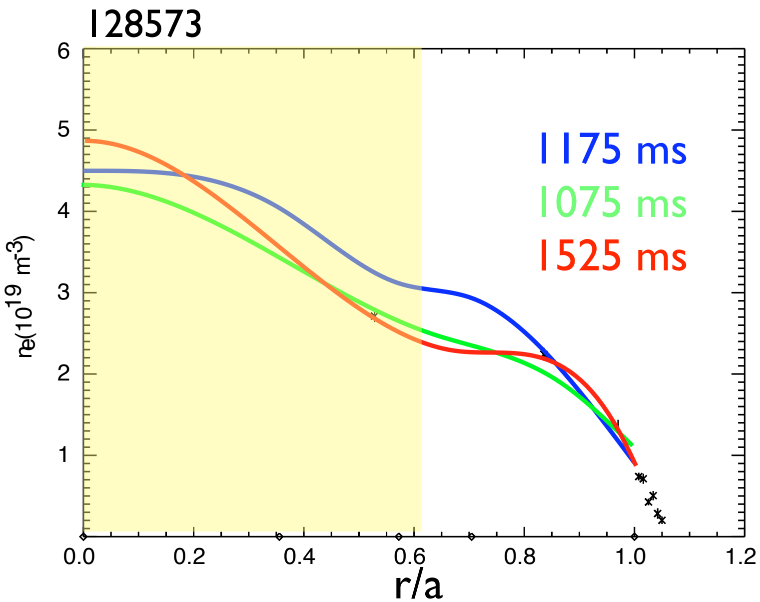
Results from outer half radius r/a > 0.5: Future work

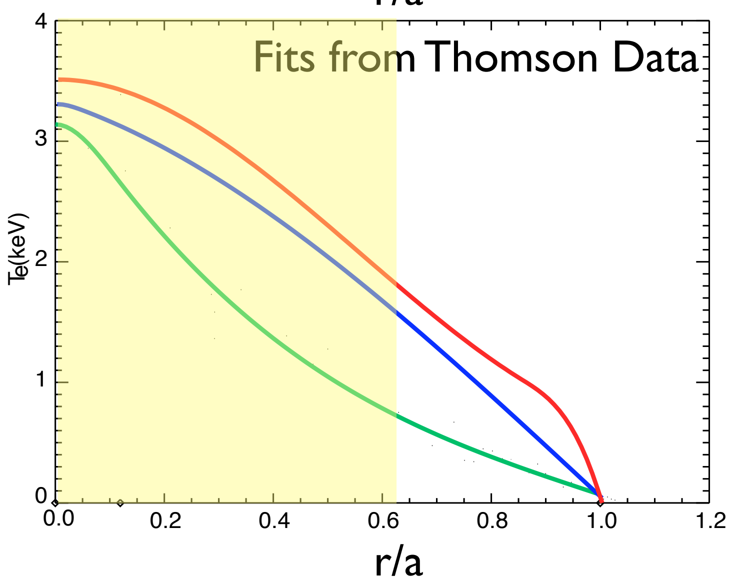
- Planned run-day to investigate temperature fluctuations in L-Mode and Ohmic plasmas across the entire accessible radial region, $-0.2 < r/a < 0.9$
- Compare with density fluctuation data from other diagnostics (e.g. BES, collective scattering, reflectometry)
- Theory Comparison Possibility: Collaborate with Center for Multiscale Plasma Dynamics (CMPD) and DIII-D/General Atomics theory group for theory and simulation comparisons
- TGLF and GYRO linear/nonlinear simulation work will help to elucidate the possible roles of ITG/TEM modes in the typical L mode plasmas studied here.

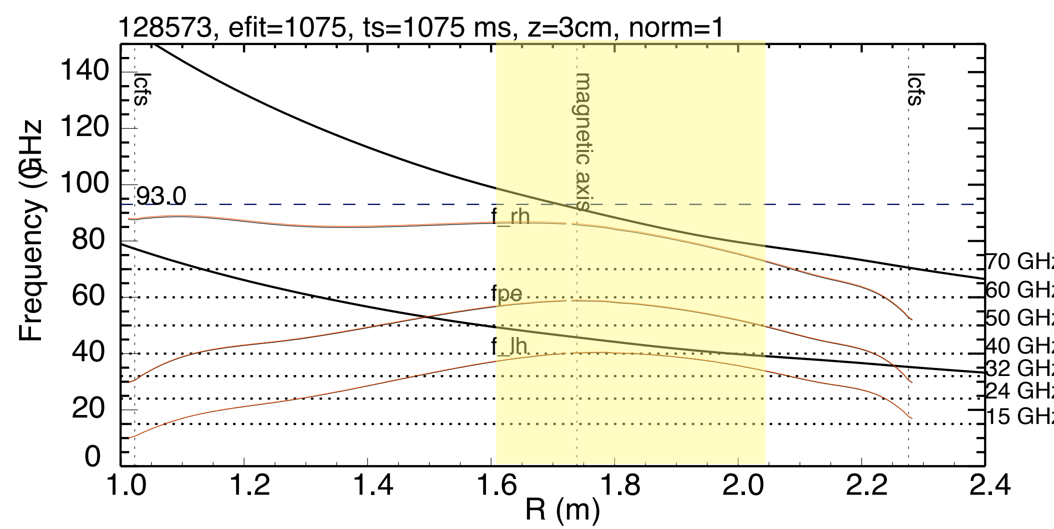
Results from inner half radius -0.1 < r/a < 0.6:

Hybrid plasma experiments are run using a 1.7 T field -- allows access to core and high field region



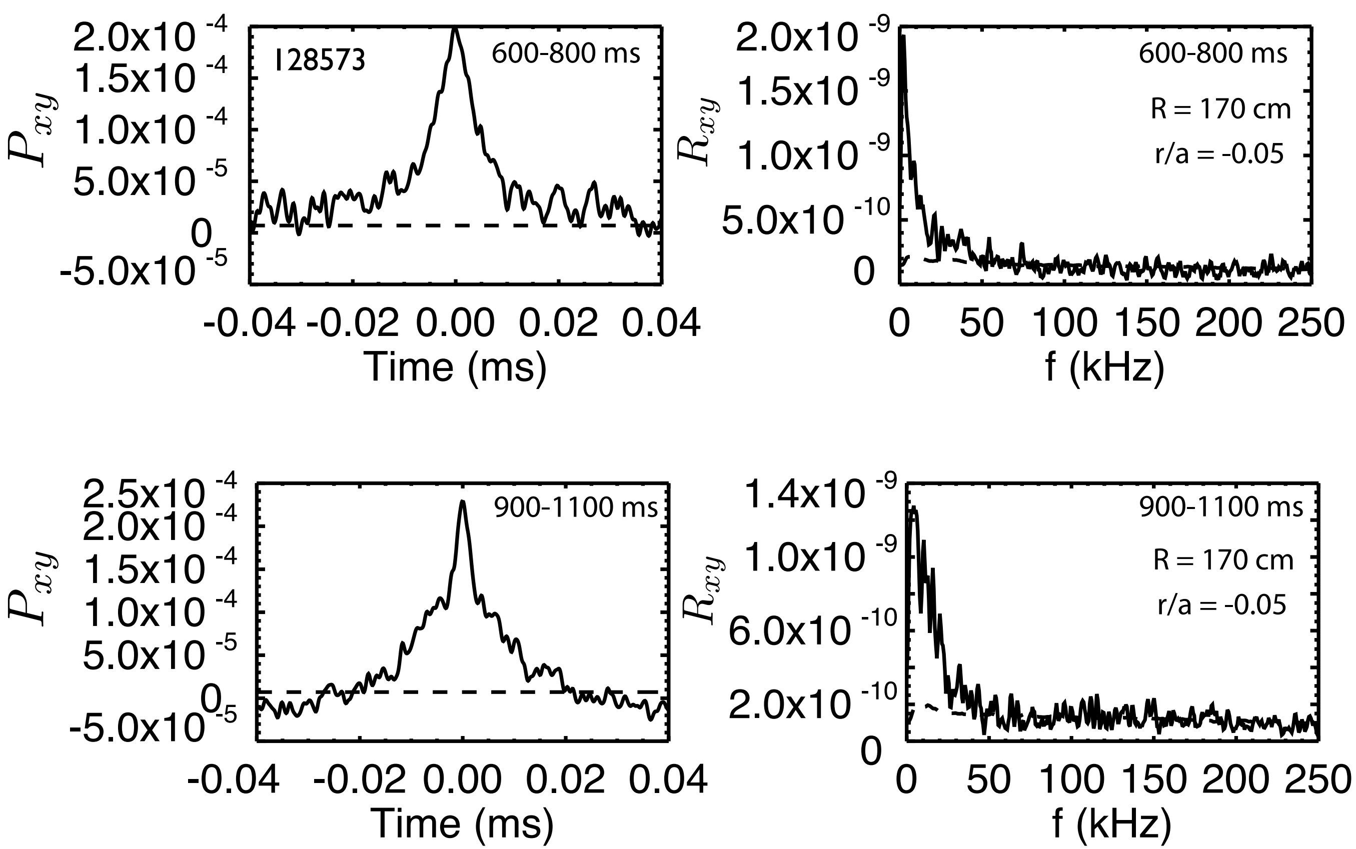
- -0.1 < *r/a* < 0.6, 1000-1100 ms (L-mode)
- PNBI ~ 5.5 MW co beams
- density (line averaged) ~ $3.0 \times 10^{13} cm^{-3}$
- *Te* (*r/a* = 0.1) ~ 2 keV
- $1.0 < \beta_N < 1.5$ over 100 ms average time





Results from inner half radius -0.1 < r/a < 0.5:

L-mode power spectrum in the core is very narrow



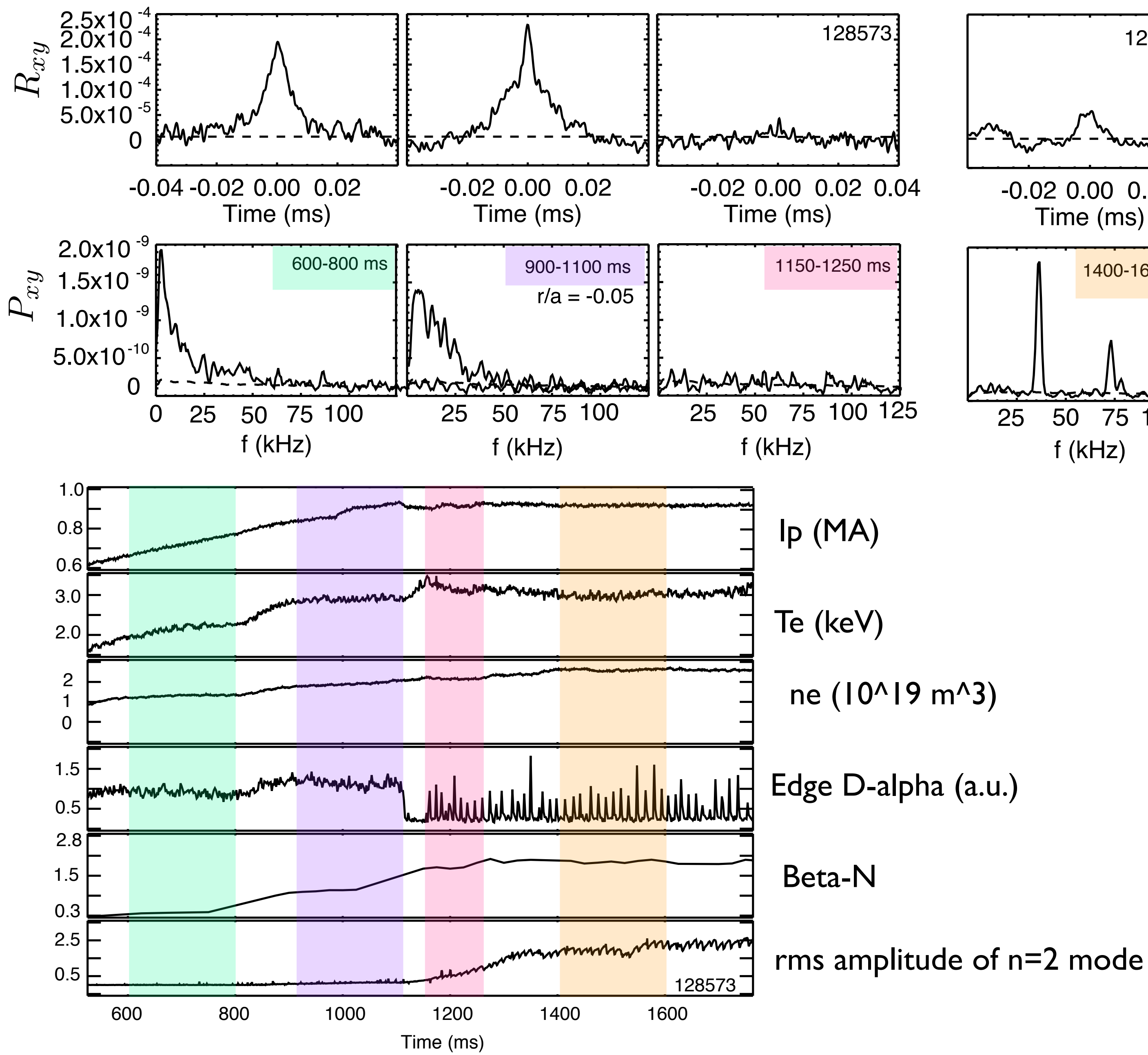
Power spectrum of fluctuations in the core is very narrow -- ExB velocity expected to be low leading to less Doppler shift and broadening

There is no sawteeth activity or MHD mode present on the ECE signals

Fluctuation amplitude decreases with radius between
-0.1 < r/a < 0.6
for "higher" beta
$0.5 < \beta_N < 1.5$
L-mode plasmas in Hybrid beta scaling experiment

Results from inner half radius -0.1 < r/a < 0.5:

Evolution of temperature fluctuations shows decrease in fluctuation level at LH transition near the magnetic axis



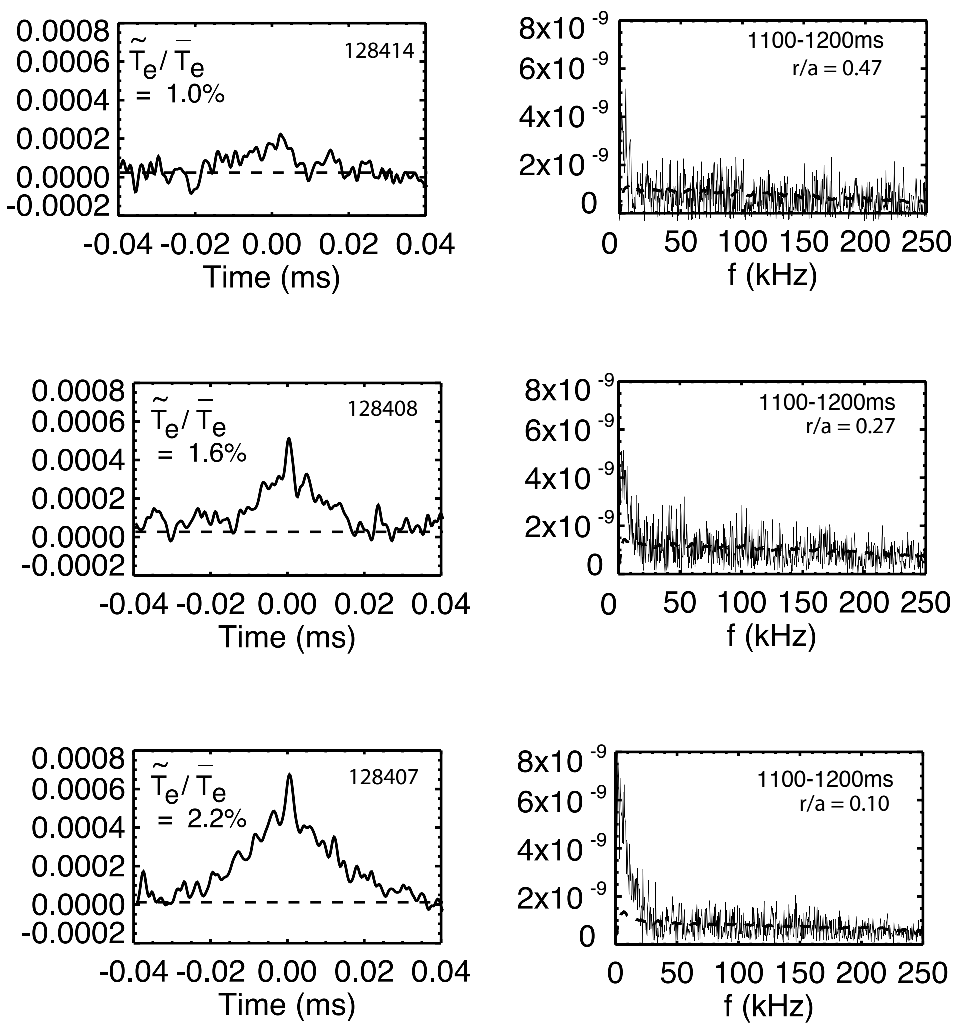
L-mode Power spectrum of fluctuations in the core is very narrow -- ExB velocity expected to be low leading to smaller doppler shift and broadening

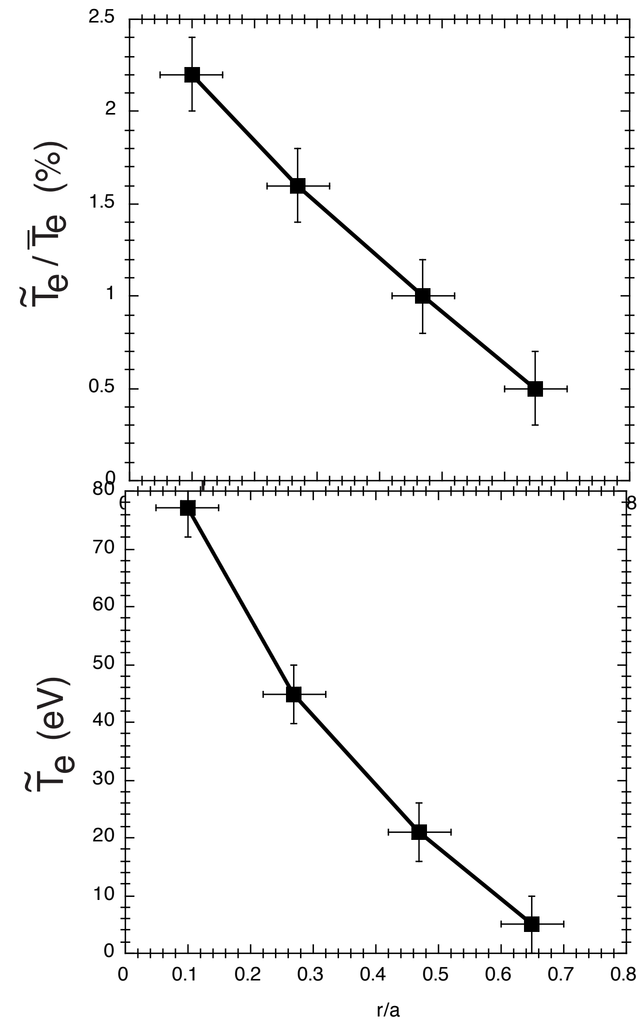
In H-mode before amplitude of n=2 tearing mode is large the temperature fluctuations remain below the detection limit

After growth of n=2 mode, perturbations associated with that MHD activity are seen in the ECE cross-correlation

Results from inner half radius -0.1 < r/a < 0.5:

Radial profile of temperature fluctuations shows opposite radial trend for these L-mode plasmas





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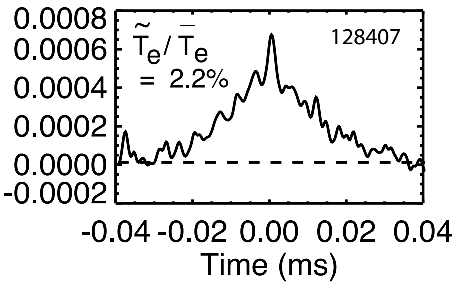
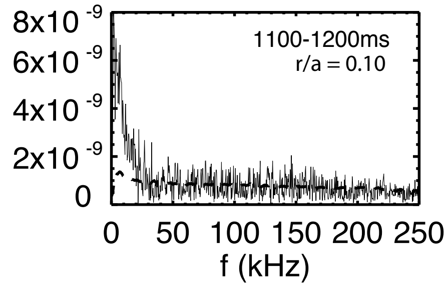
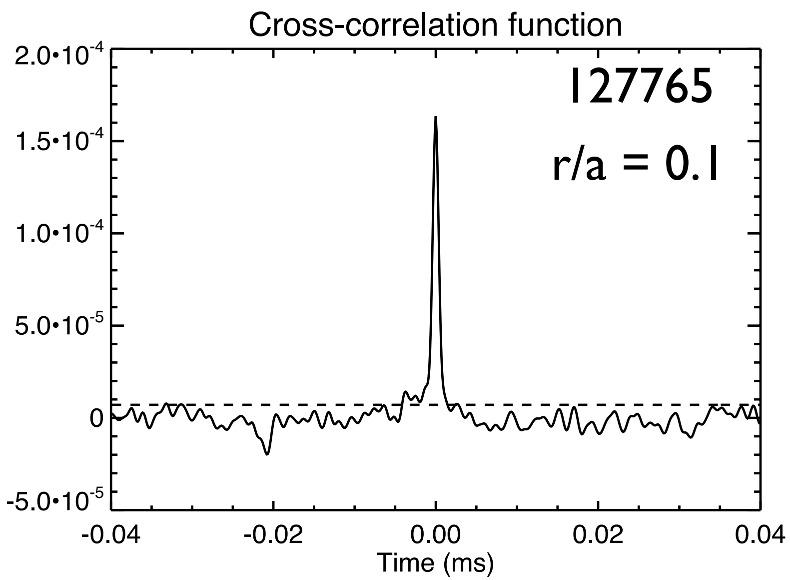
Results from inner half radius -0.1 < r/a < 0.5:

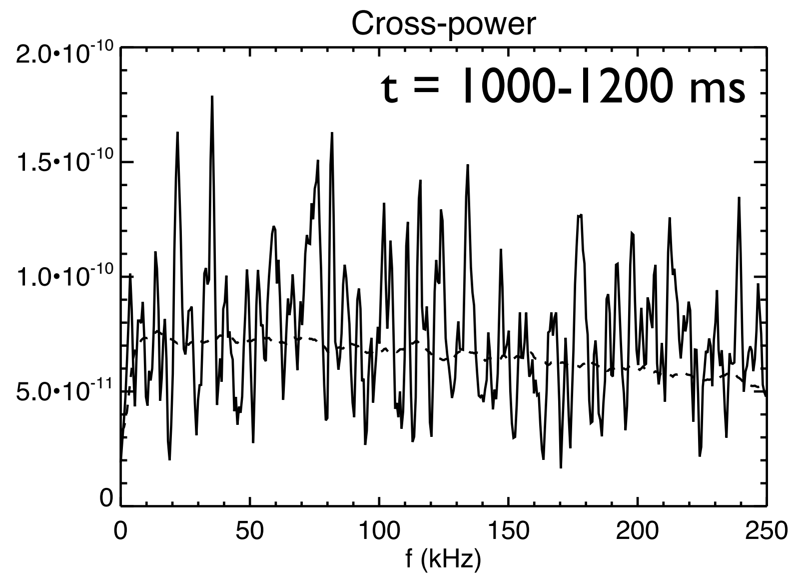
Similar L-mode plasmas do not reveal detectable temperature fluctuations at same radius





No fluctuations observed





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Results from inner half radius -0.1 < r/a < 0.5:

Summary and Future Work

- Fluctuations with large amplitude (2 %) observed near the magnetic axis during L-mode plasmas (128406-128573) from Hybrid experiment.
- Fluctuations found to decrease in amplitude with increasing radius (-0.1< r/a < 0.6).
- No direct scaling with beta or toroidal rotation is observed in cases where the core fluctuations are observed.
- No fluctuations are observed at these locations in similar L-mode plasmas from an earlier Hybrid experiment (127765-127775).
- Need to fully exploit DIII-D suite of diagnostics to further compare the shots with and without observable core fluctuations to determine parameter(s) that might be varied in an experiment.
- Need series of repeatable shots to fully investigate the characteristics of the temperature fluctuations in the core plasma, r/a = 0

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