Quasi-Coherent Fluctuations Limiting the Pedestal Growth on Alcator C–Mod: Experiment and Modeling

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Alcator C-Mod

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PRINCETON PLASMA PHYSICS LABORATORY

Objective: Understanding the pedestal structure is crucial for performance prediction of fusion devices

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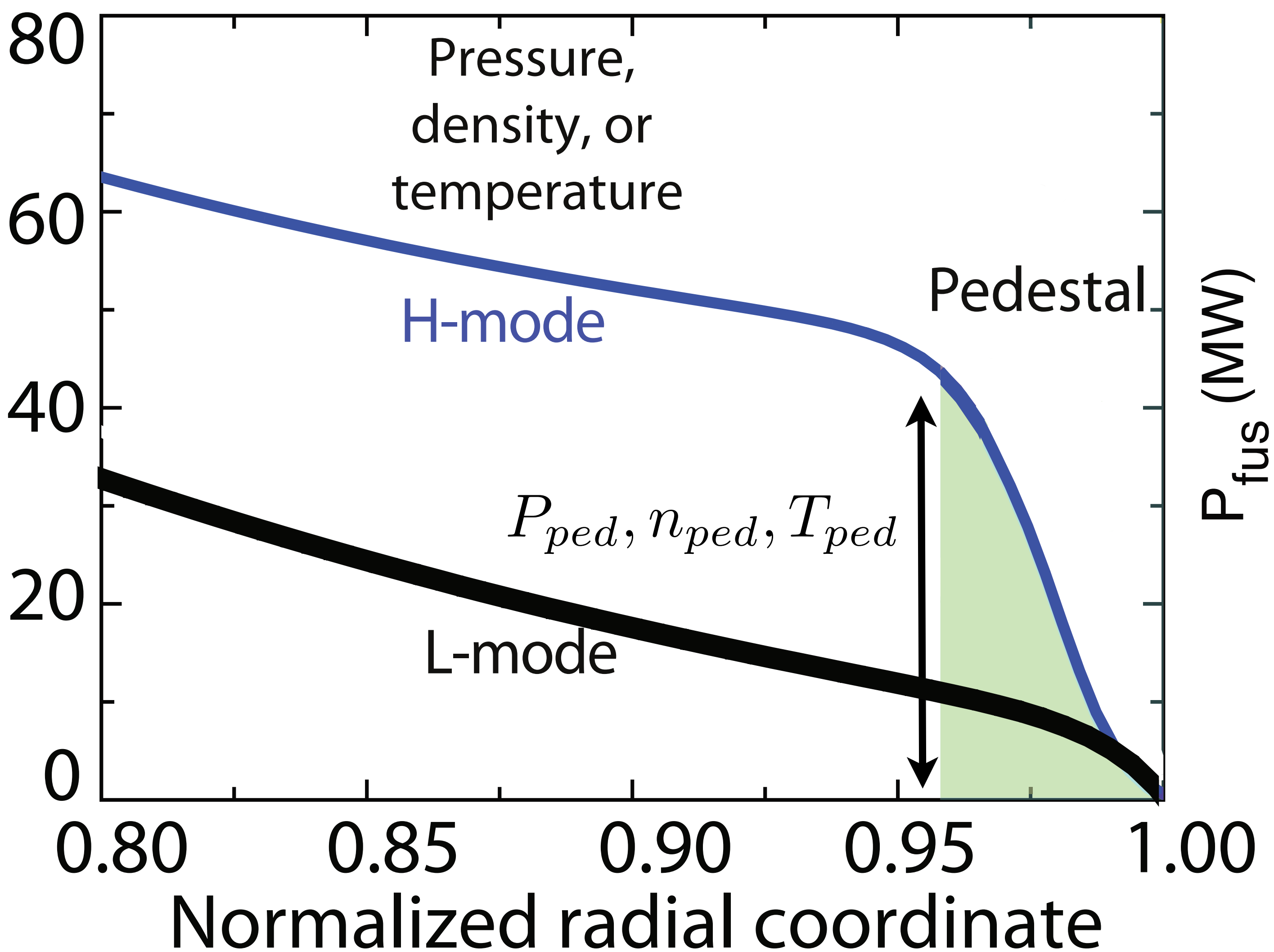
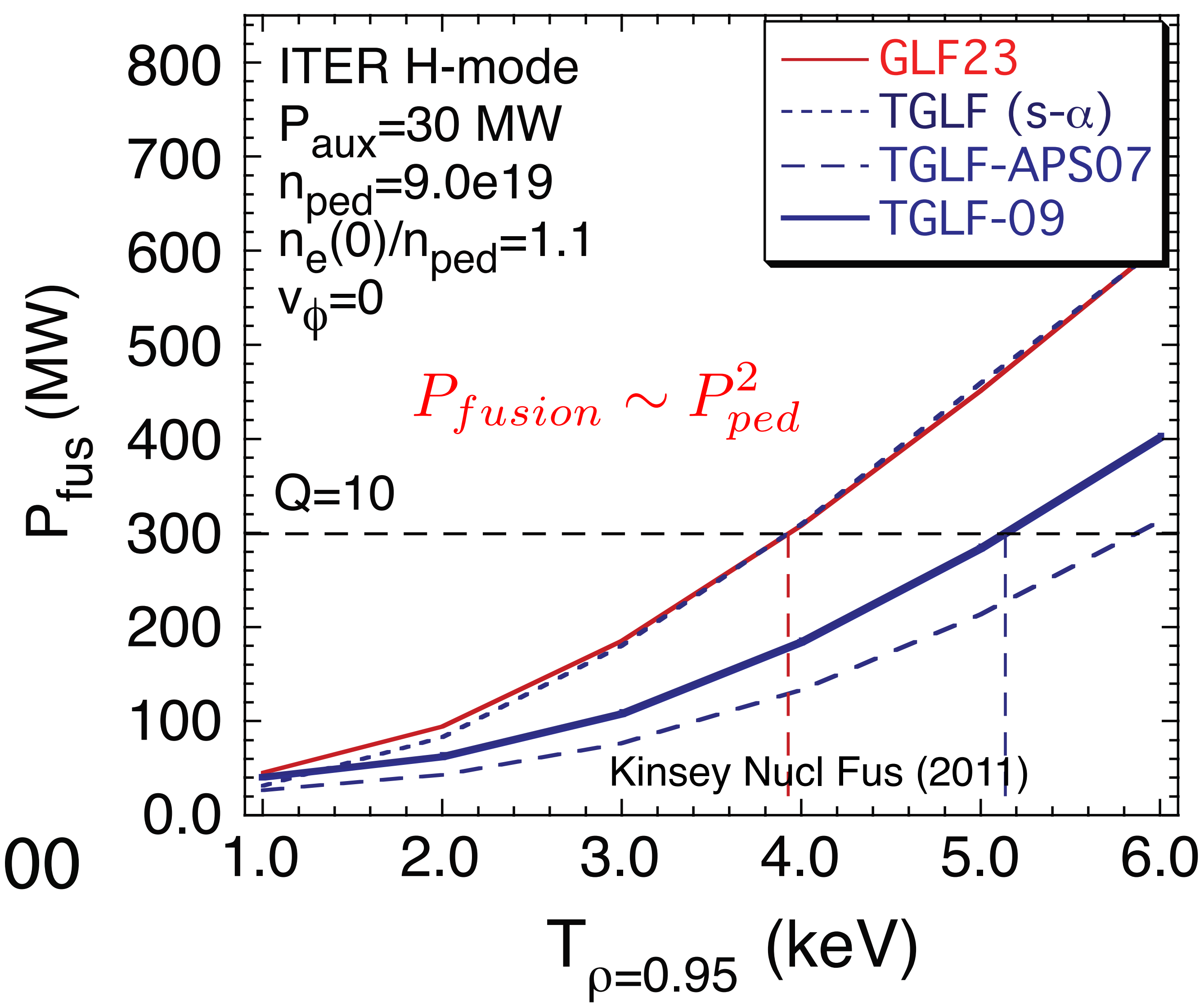
- Substantial pedestal heights are critical for achieving high fusion power in ITER

- Link between pedestal height and global confinement well established by current experiments, transport modeling



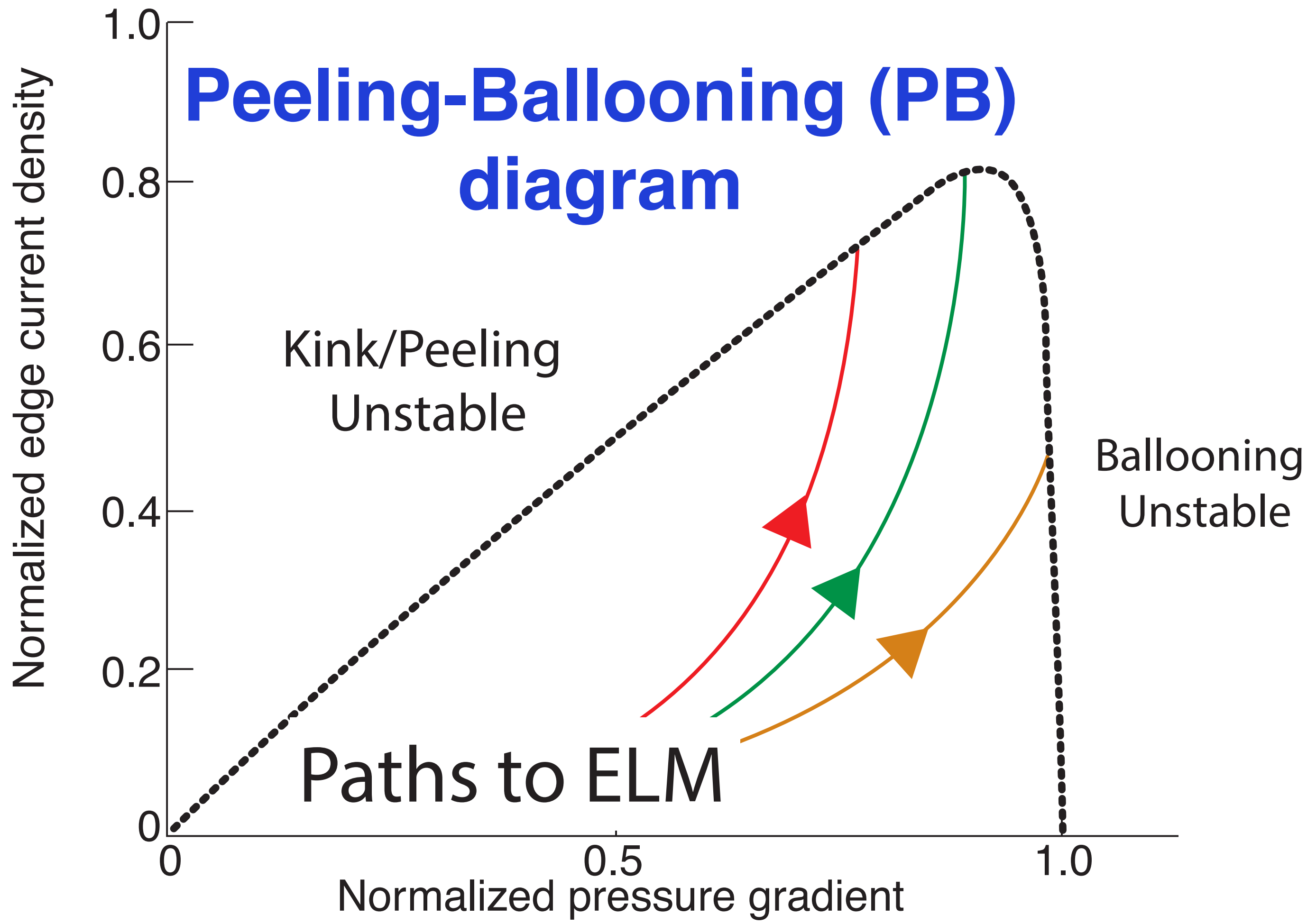
Predicted fusion power vs pedestal temperature at fixed pedestal density

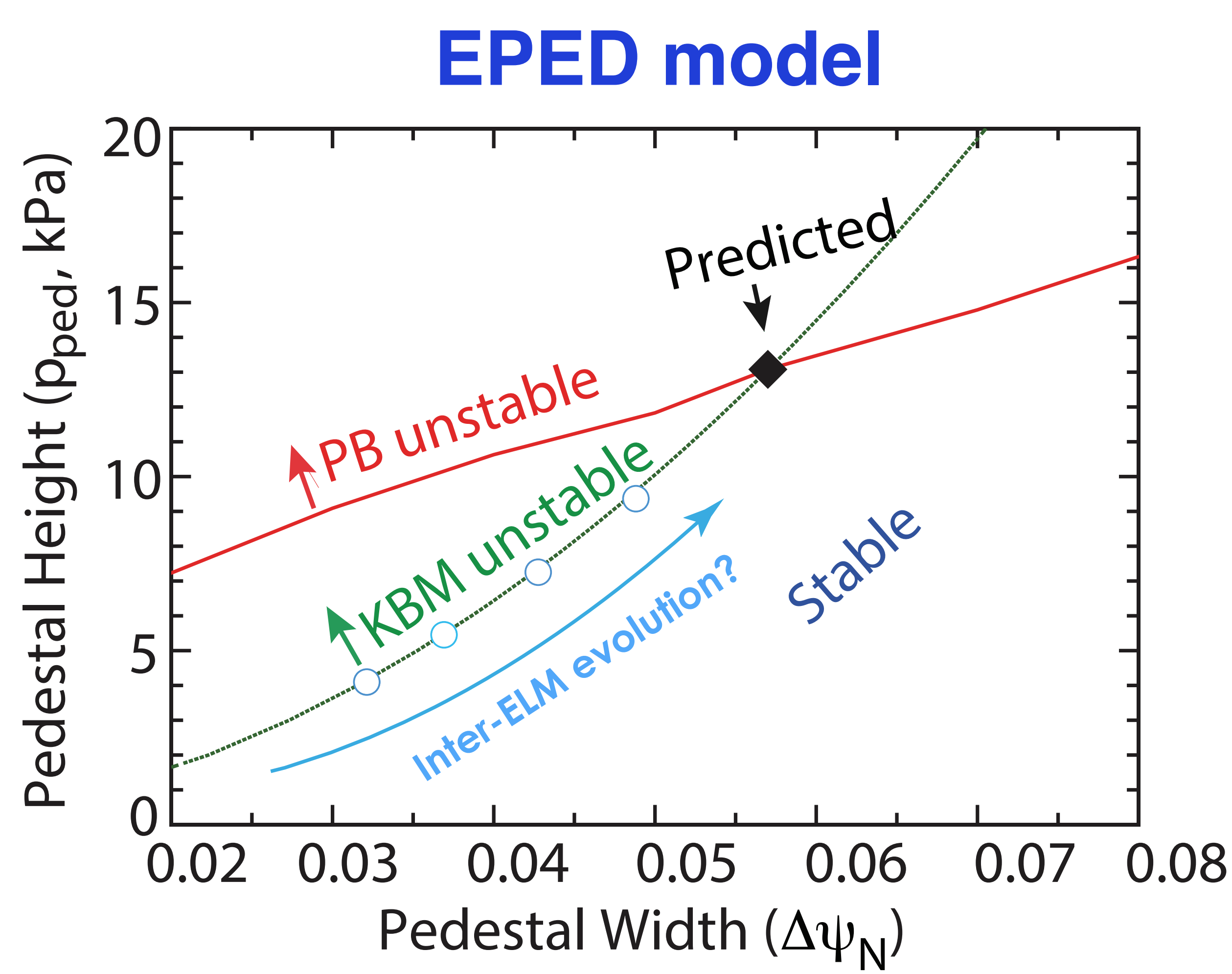


EPED predictive model provides a candidate mechanism for pedestal formation

- EPED: pedestal structure set by two key limiting instabilities:
  - non-local peeling–ballooning modes (PBM) — trigger for edge-localized mode (ELM)
  - nearly local kinetic ballooning modes (KBM) — regulates transport between ELMs
  - – Combining these two constraints allows prediction of two unknowns, the pedestal height and width.

Connor, PoP (1998); Wilson, PoP (2002); Snyder, PoP (2001); Snyder, NF (2011)





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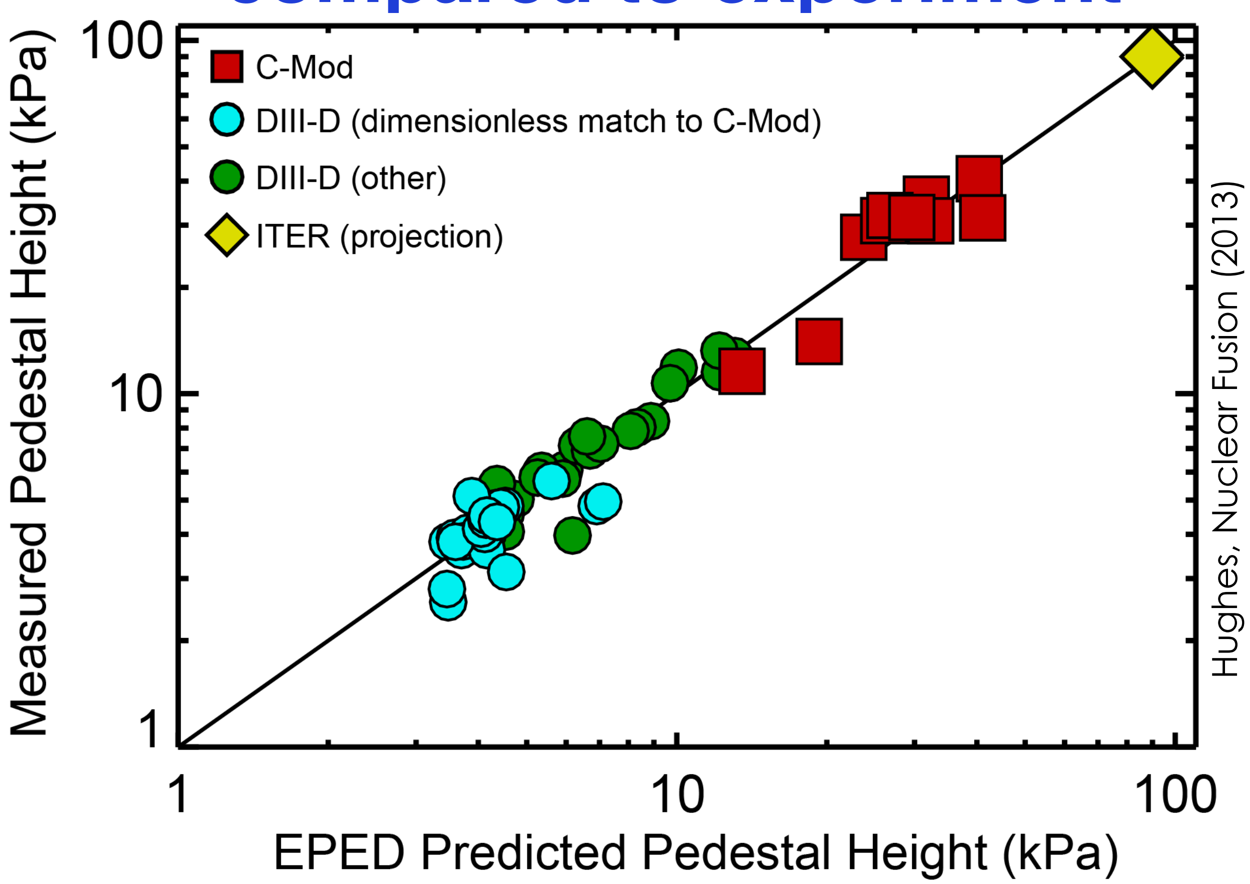
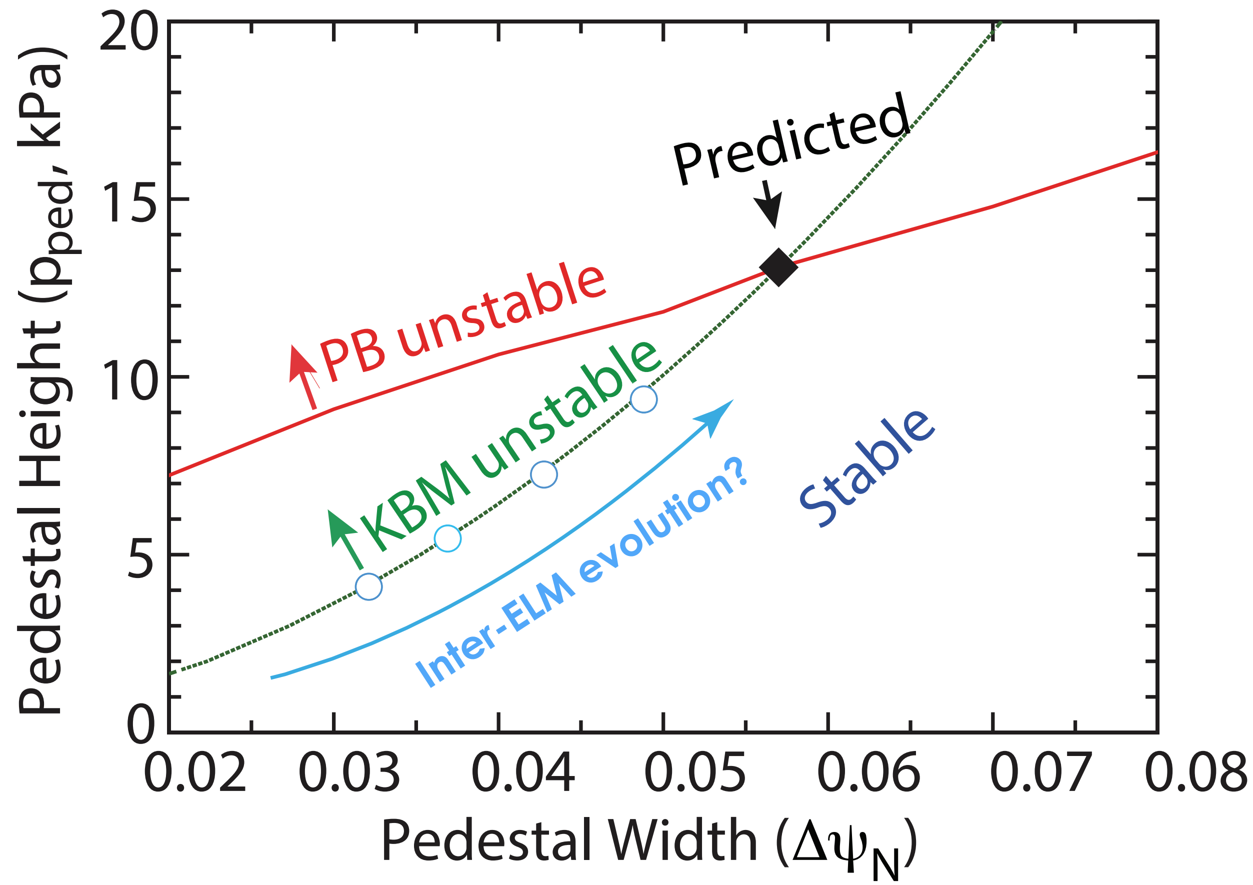
EPED predictions compared to experiment



EPED model



Can we find signatures of pedestal-limiting mechanisms between ELMs?

Theory predicts a sensitivity of KBM growth rate to β — observable between ELMs?

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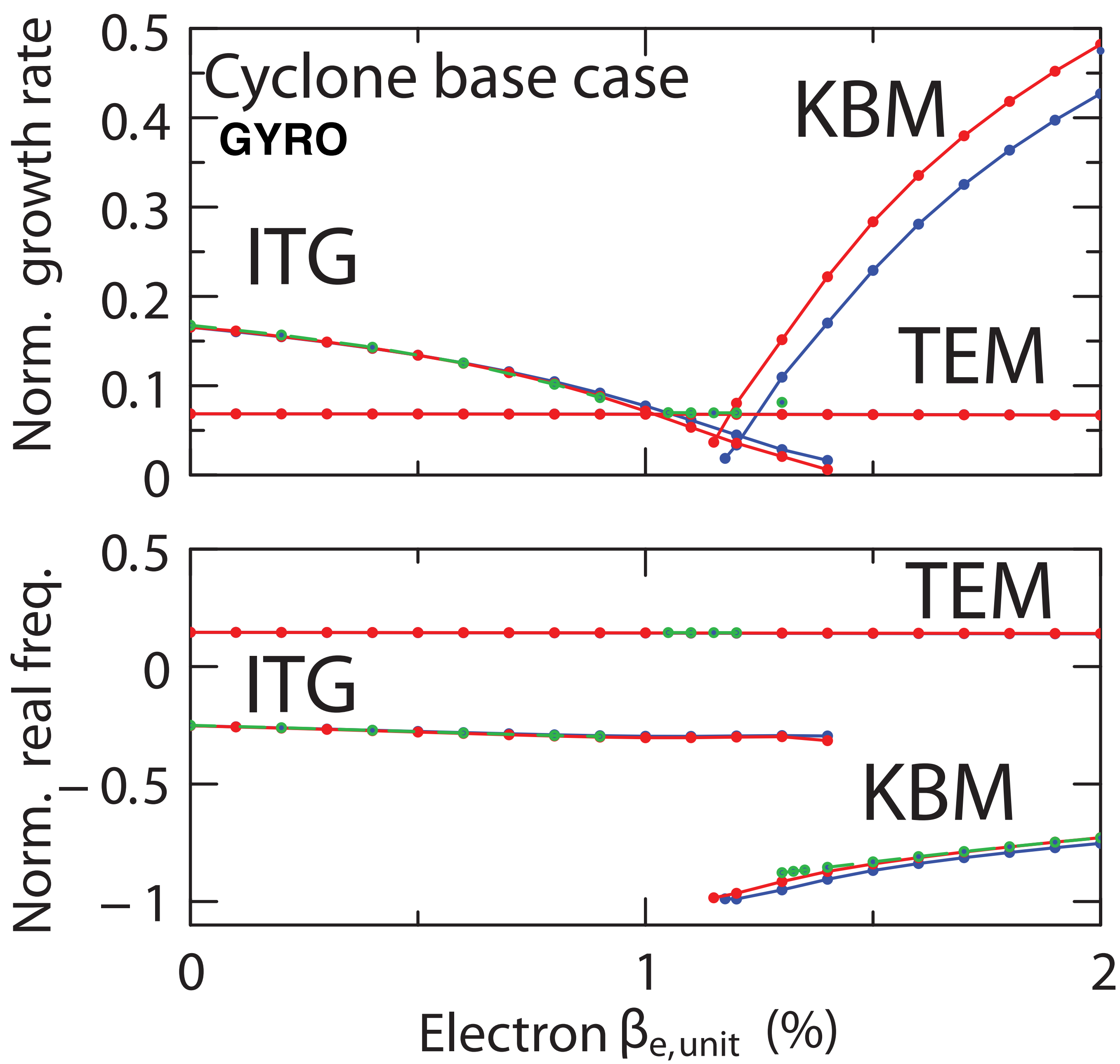
Belli and Candy Phys. Plasmas 17, 112314 (2010)



Variations can be captured between ELM cycle

- Experimental goal: Identify and characterize *turbulent fluctuations* during the ELM cycle
- Expected measurable characteristics
  - Pedestal localized
  - Intermediate-n and electromagnetic mode
  - Sudden change in growth rate
  - Ion spatial scale ($k\rho_s$< 1)
  - Propagates in ion diamagnetic direction.

Experimental collisionality scans are used to access Type I ELMy H-mode

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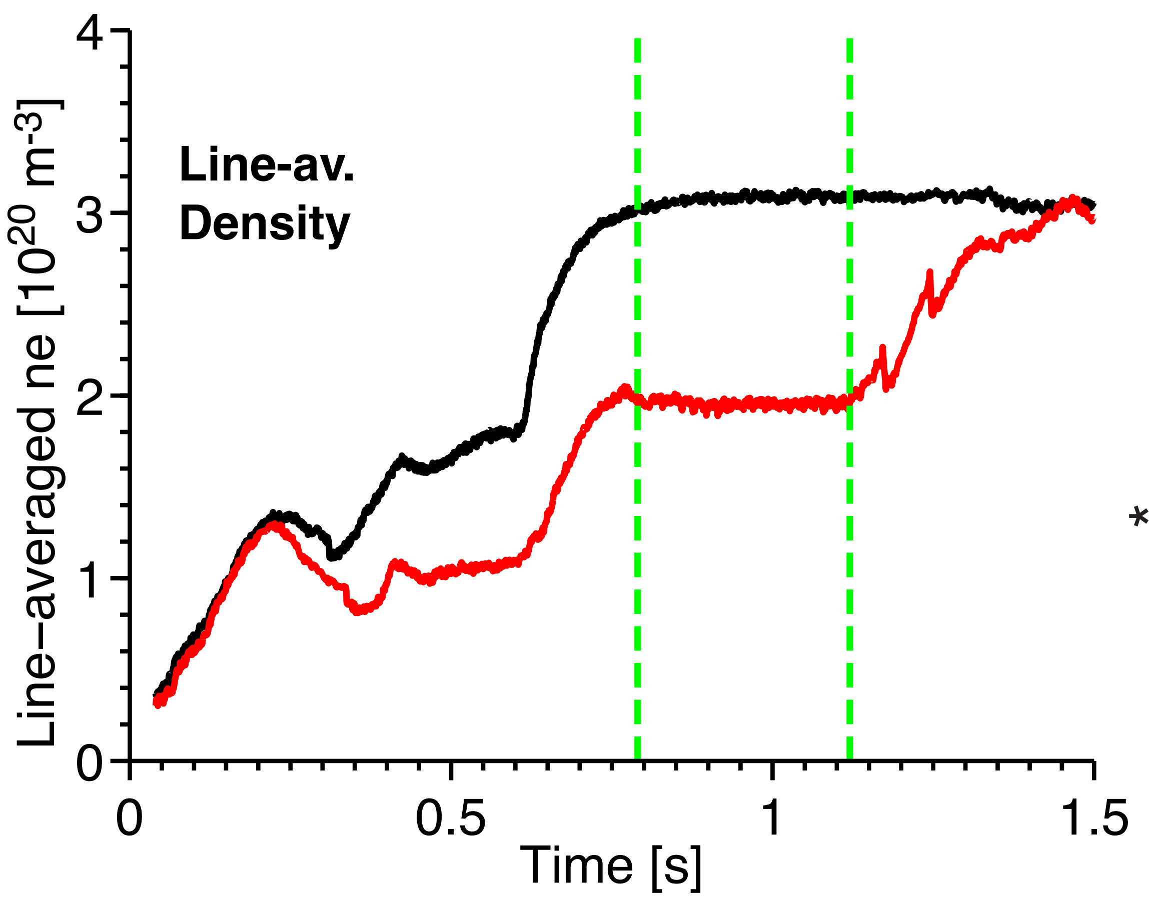

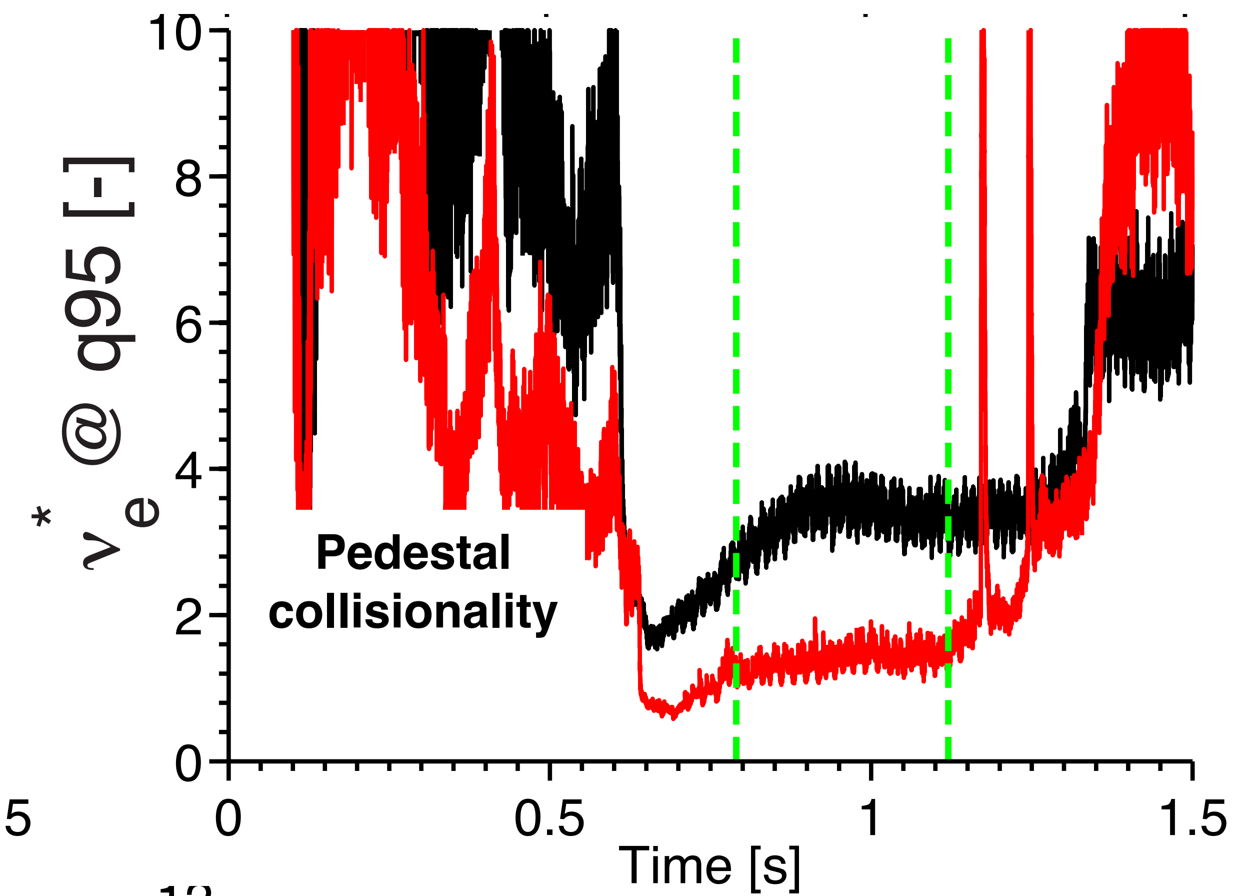

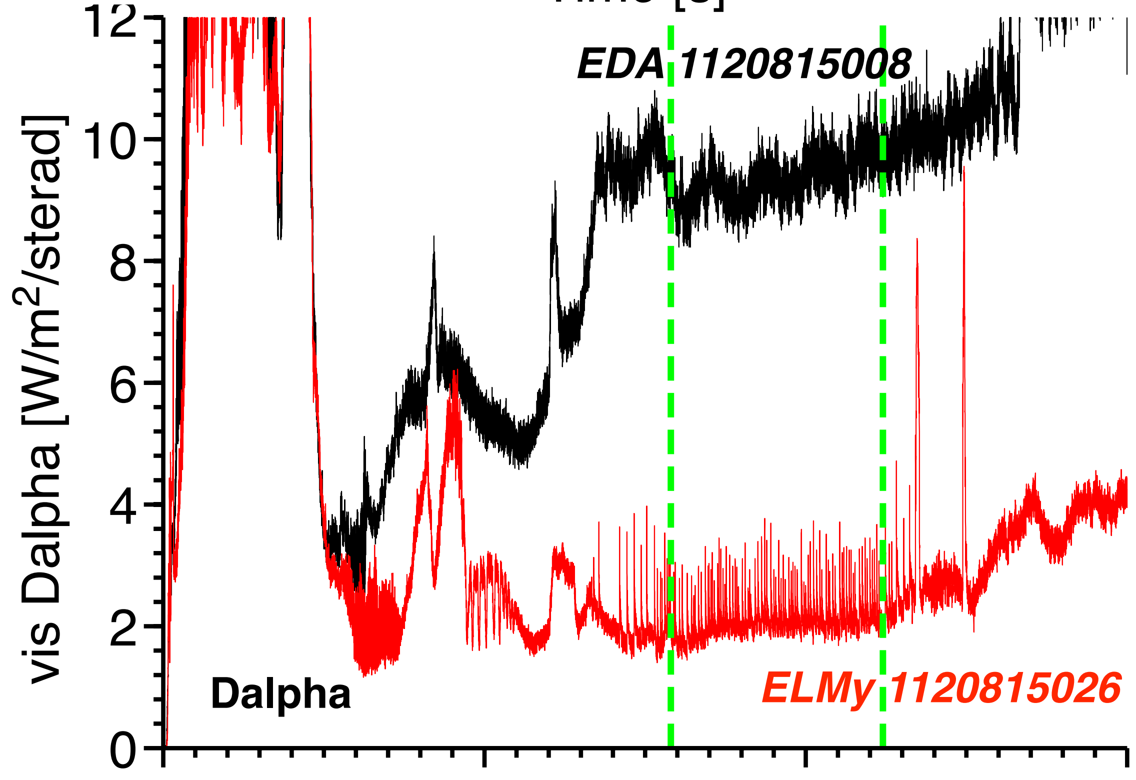

Transition from enhanced D$_\alpha$ (EDA) H-mode to ELMy H-mode occurs around ν^*~1

Radially resolved profiles may be either averaged over ELMs or binned by phase of ELM cycle

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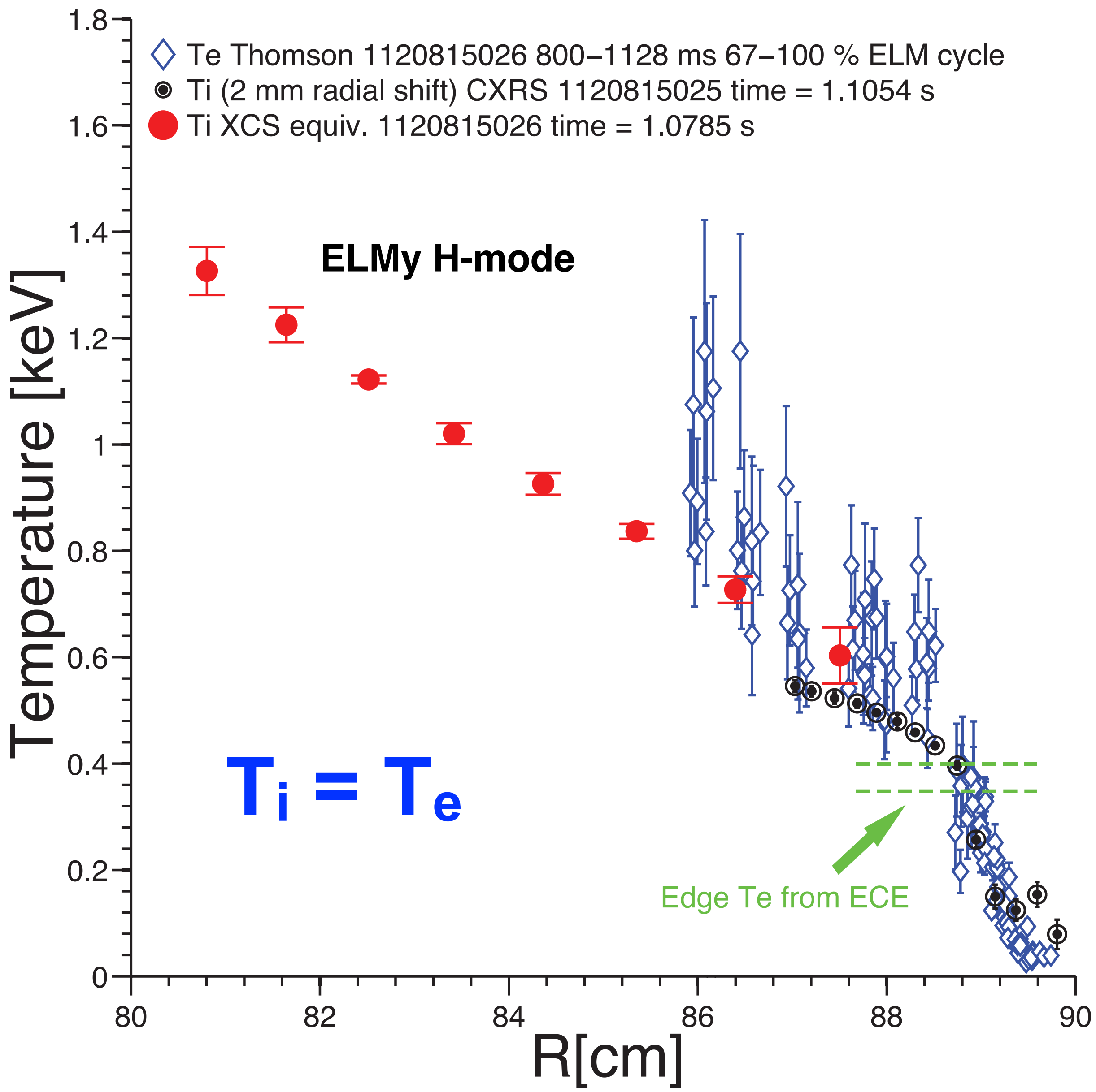

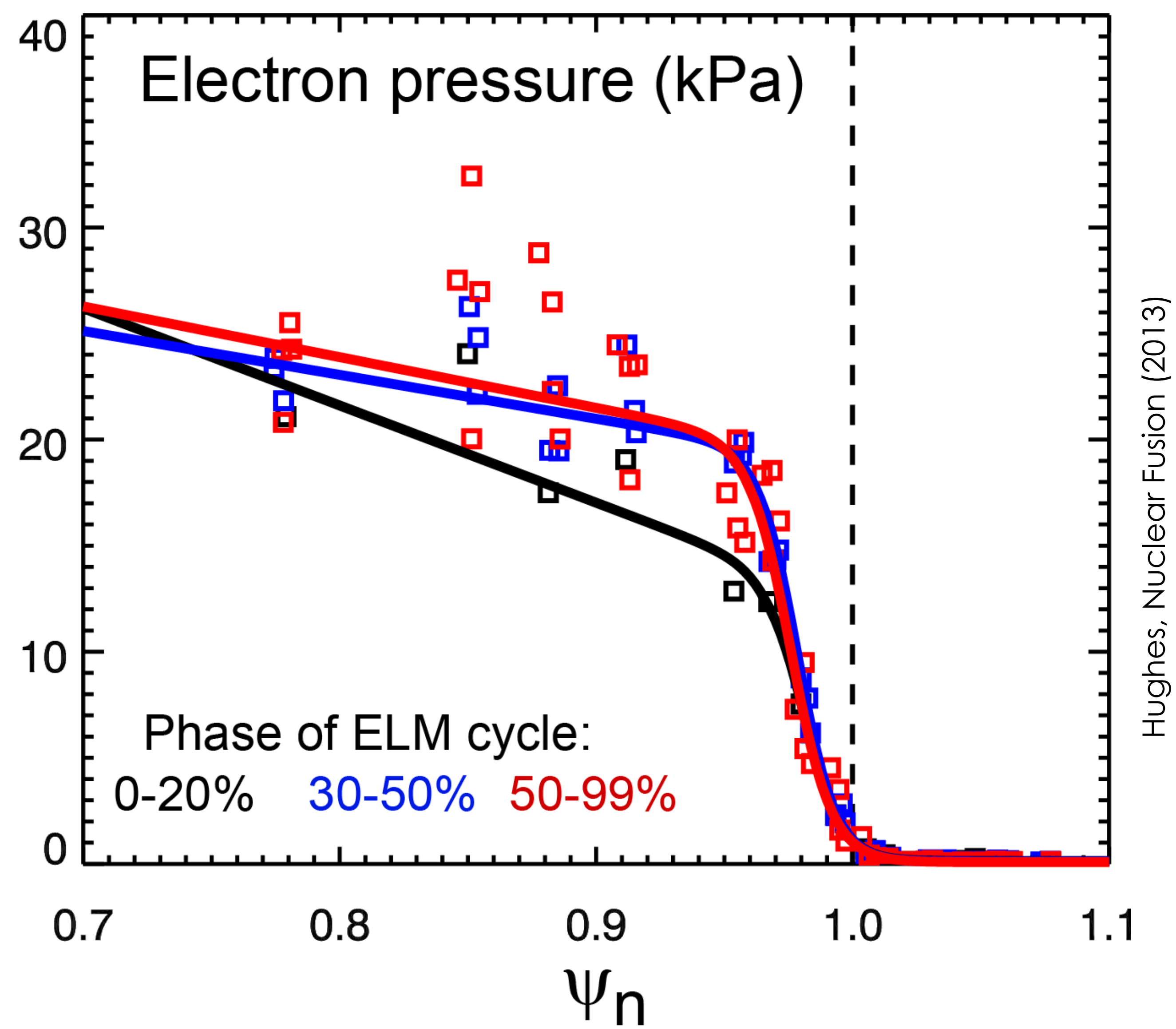

- ELM crash induces fast drop in Te and measurable rebuild time
- ELM perturbation to density is weaker

Pressure evolution is a test bed for KBM onset

Various poloidally separated diagnostics provide edge fluctuation measurements between ELMs

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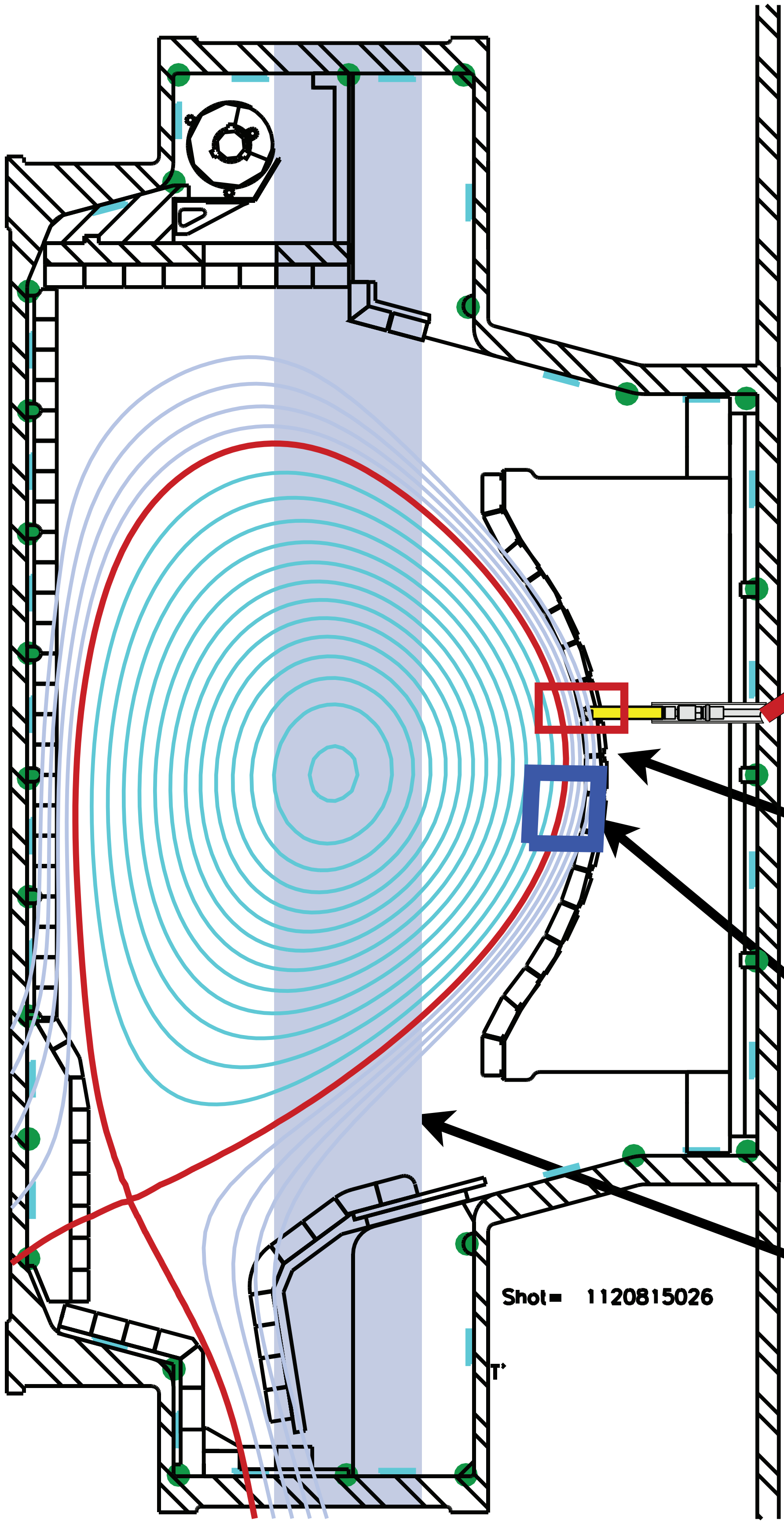
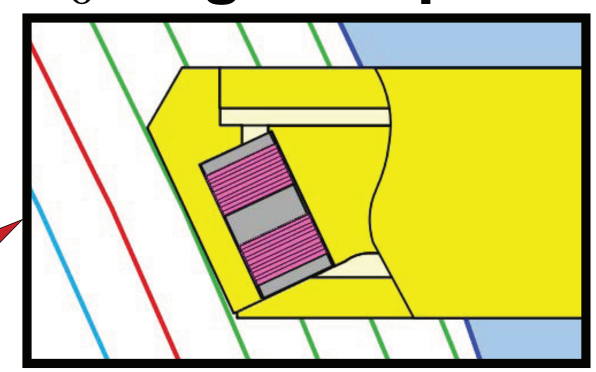


LSN - 2MW ICRF heated ELMy discharges

$\tilde{B}_\theta$ magnetic probe



magnetic fluctuations

O-mode Reflectometer

Local electron density fluctuations

Gas-Puff Imaging (GPI)

Proxy local density fluctuations

Phase-Contrast Imaging (PCI)

Line-integrated electron density fluctuations

Quasi-coherent fluctuations (QCF) are observed on phase contrast imaging (PCI) spectrogram

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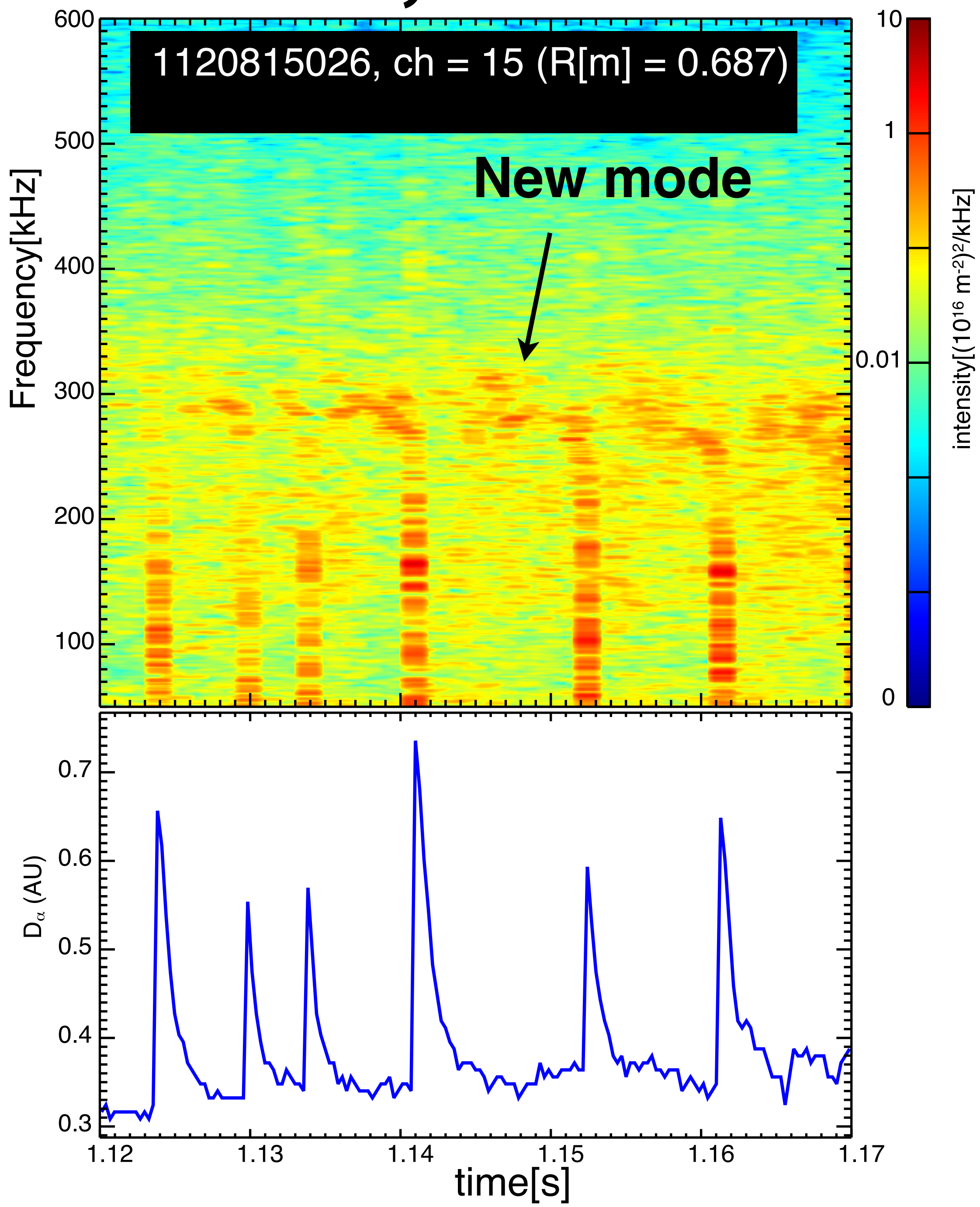
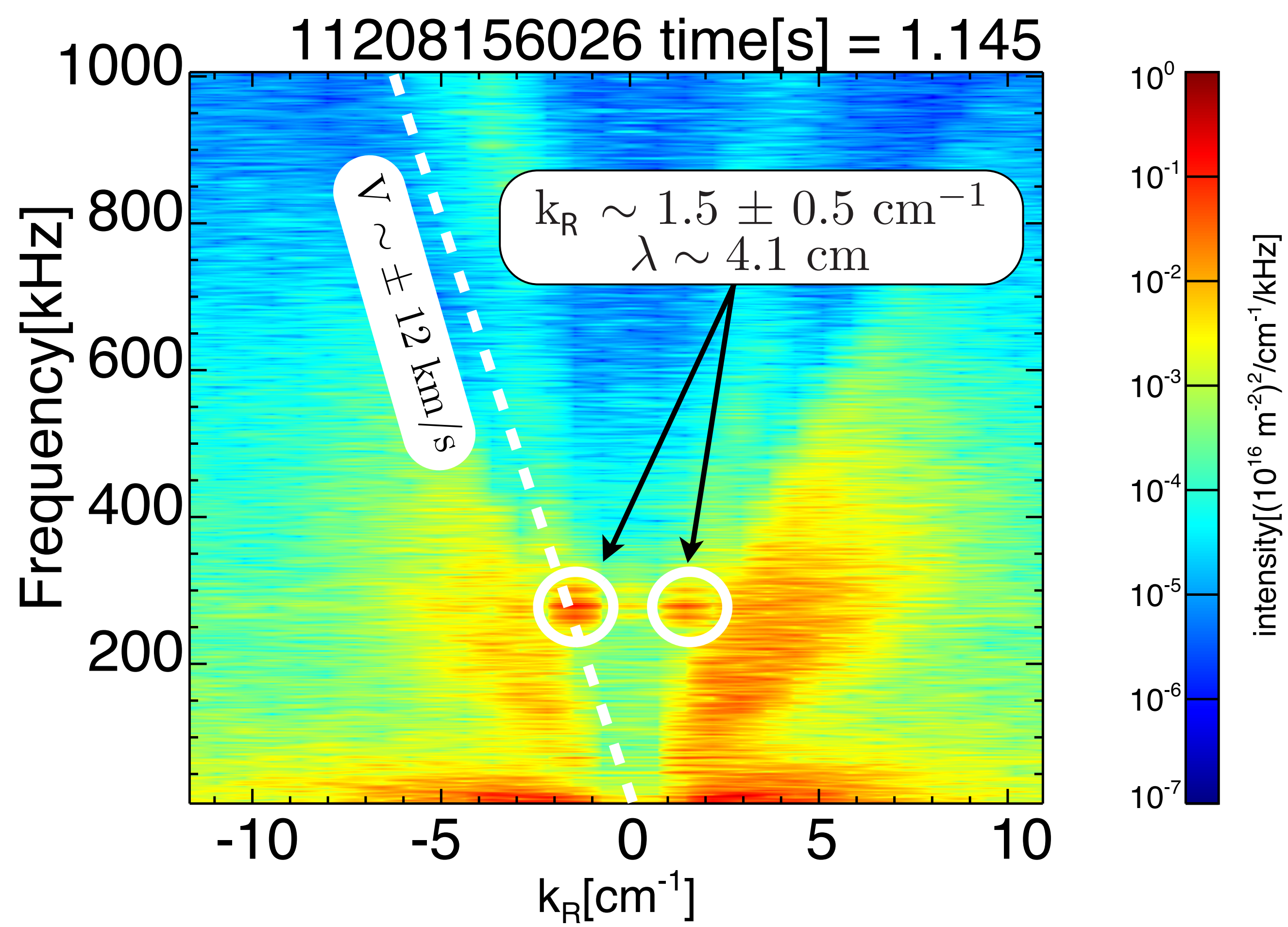
ELMy H-mode

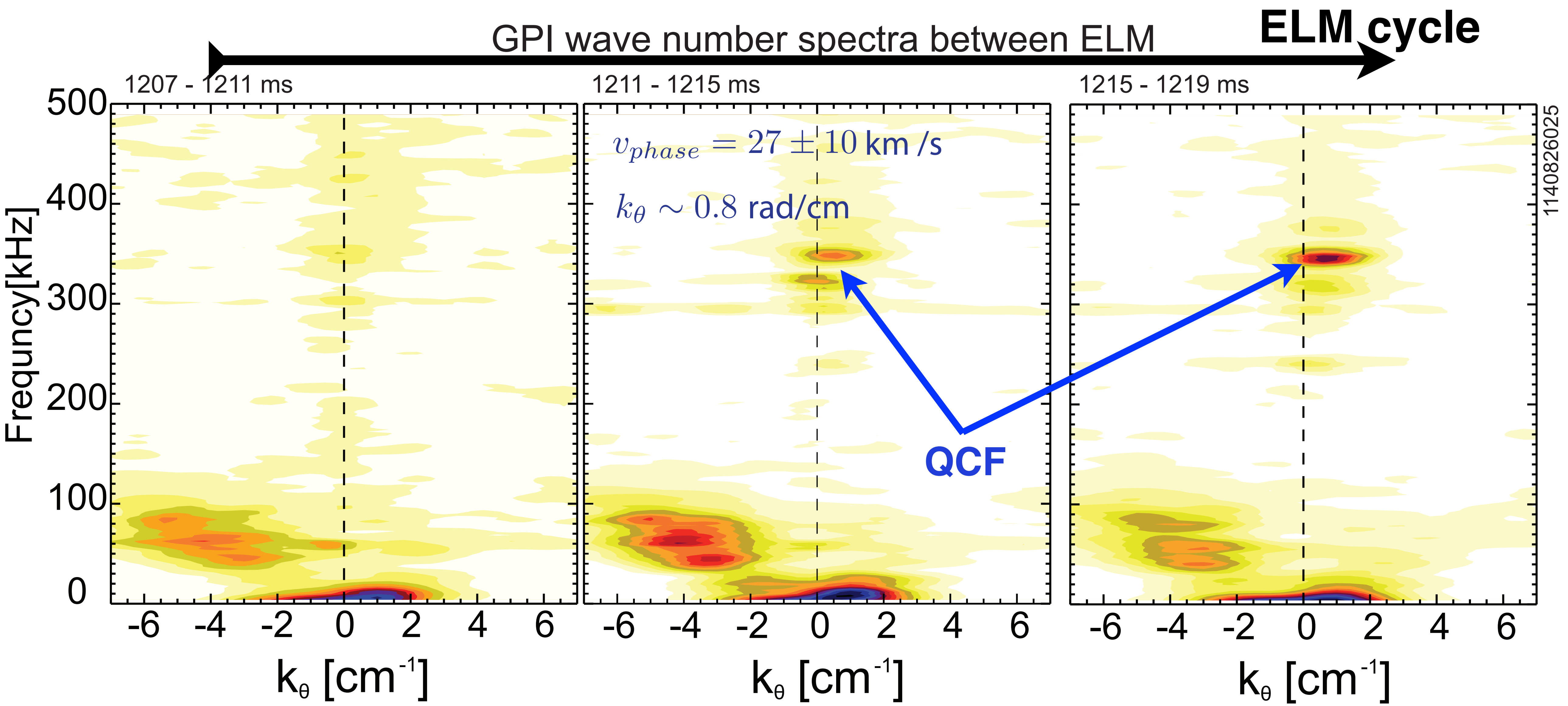




PCI provides an estimate the radial component wavevector

k_R ➠ k_θ when mode is edge localized

Signatures of the QCF have been observed on gas puff imaging (GPI) between ELMs



- QCF is coherent in frequency and wavenumber
- Propagates in the electron direction in the lab frame

GPI indicates strong radial localization of QCF

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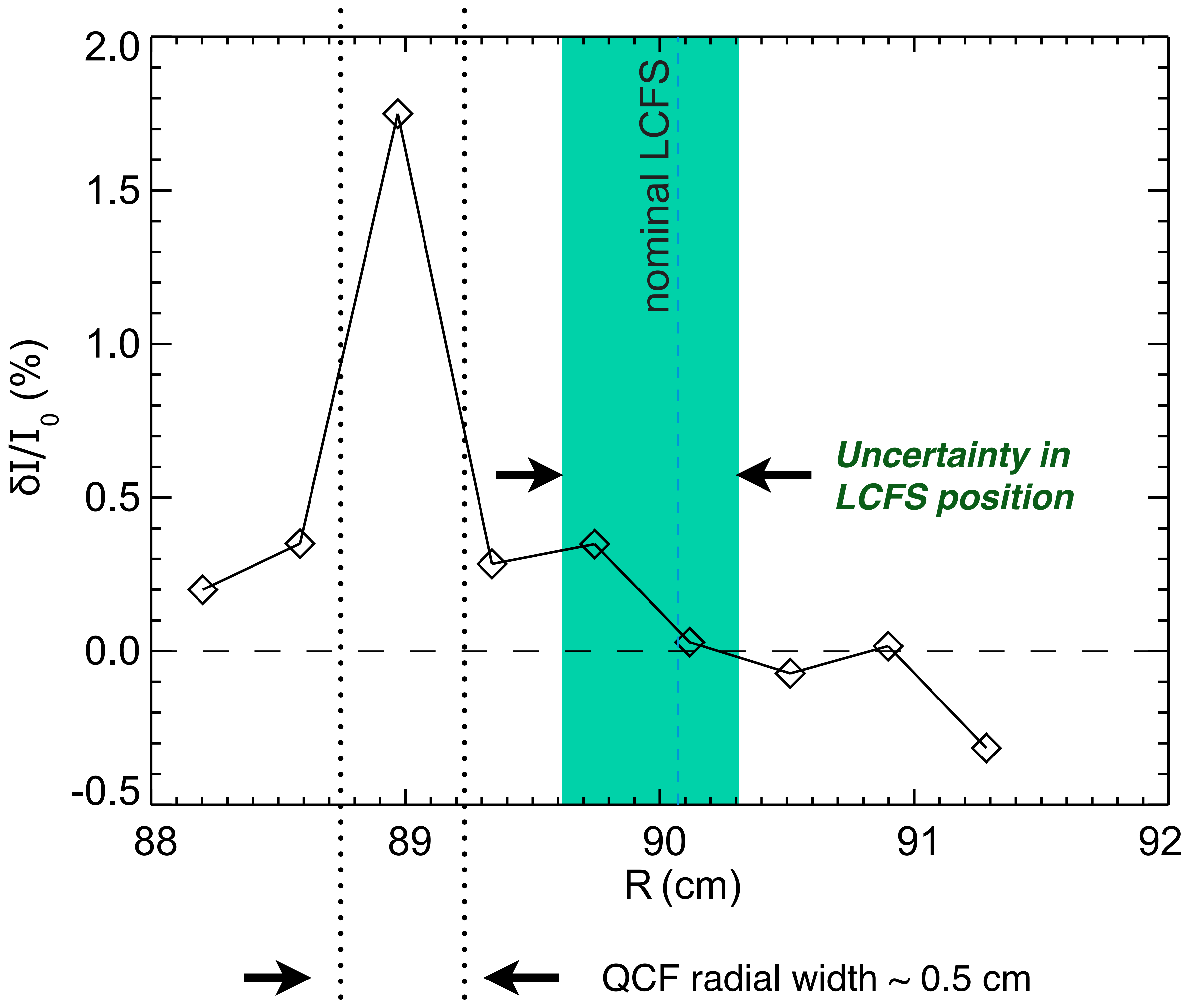
Fluctuations in measured intensity (proportional to δn/n) vs. radius



O-mode reflectometry localizes the QCFs to the sub-centimeter scale density pedestal

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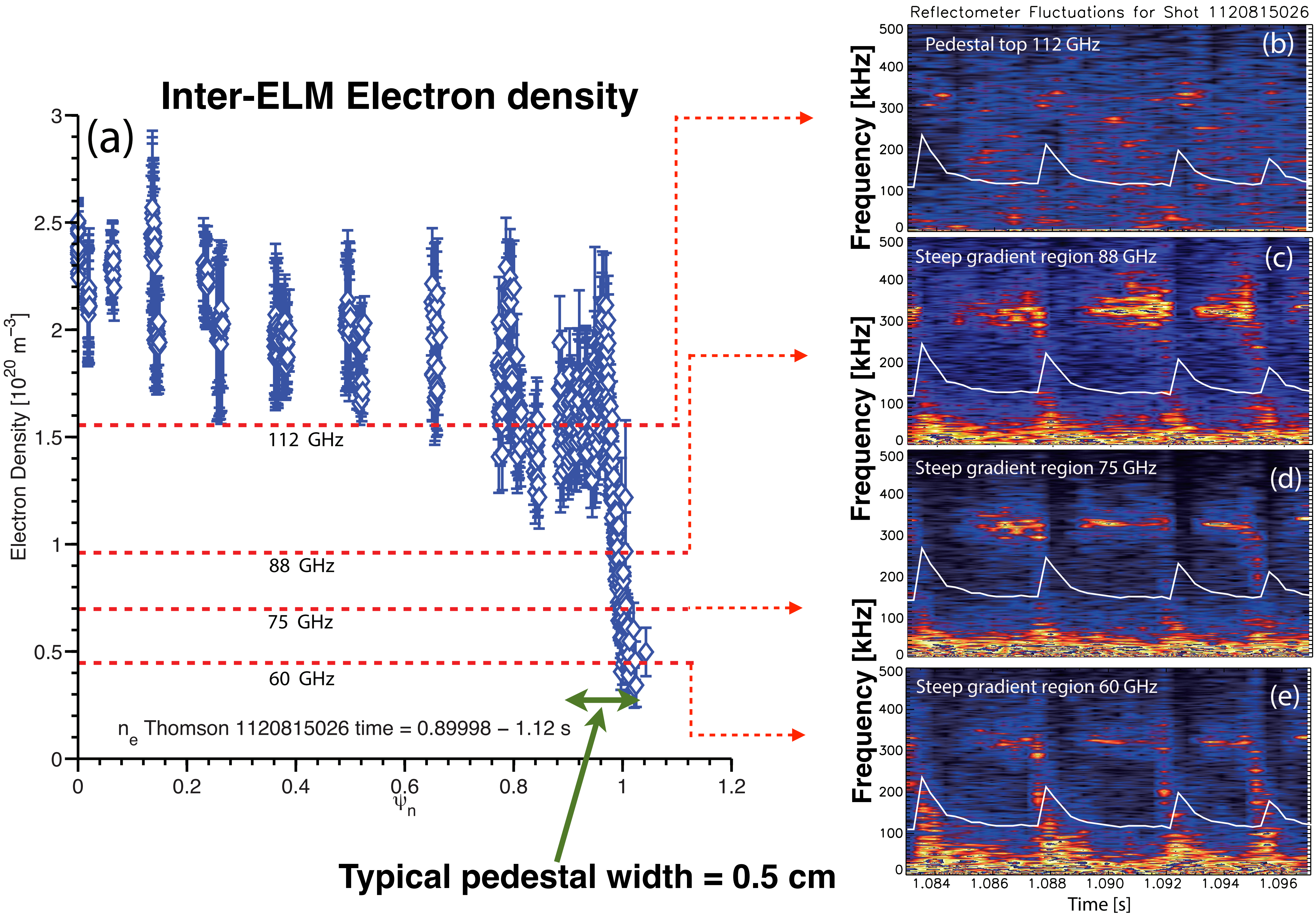

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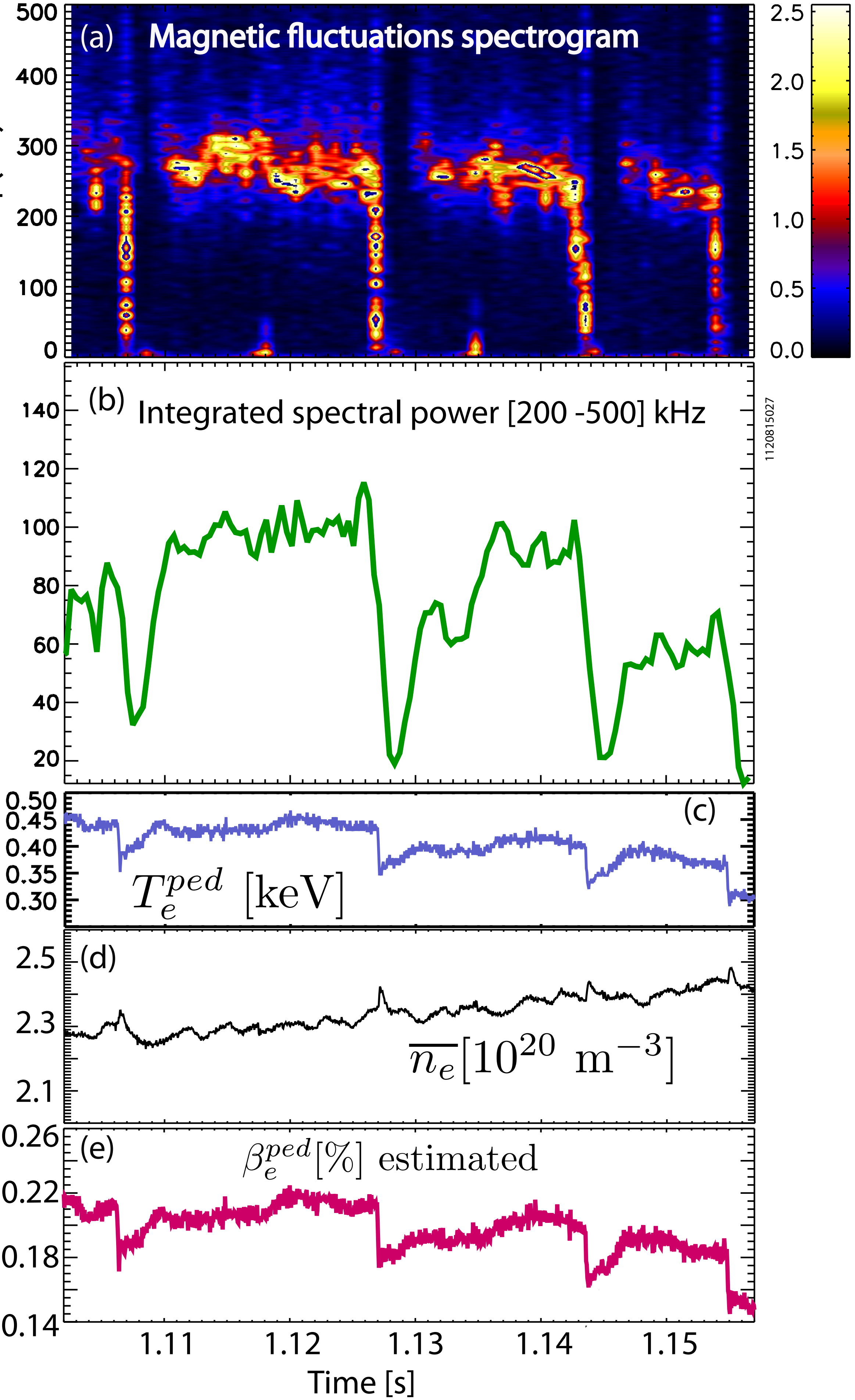
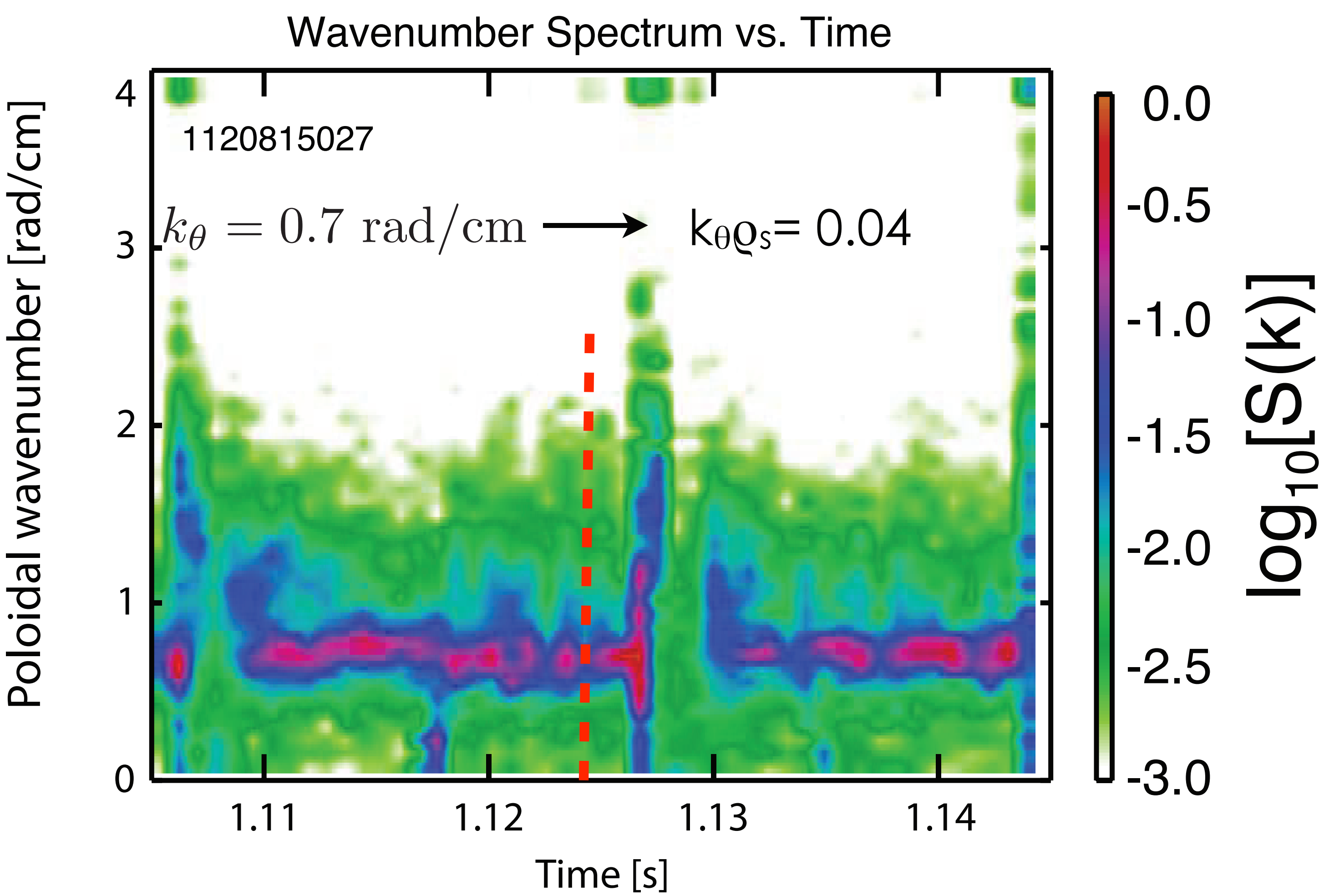
Inter-ELM magnetic fluctuations track the edge electron temperature

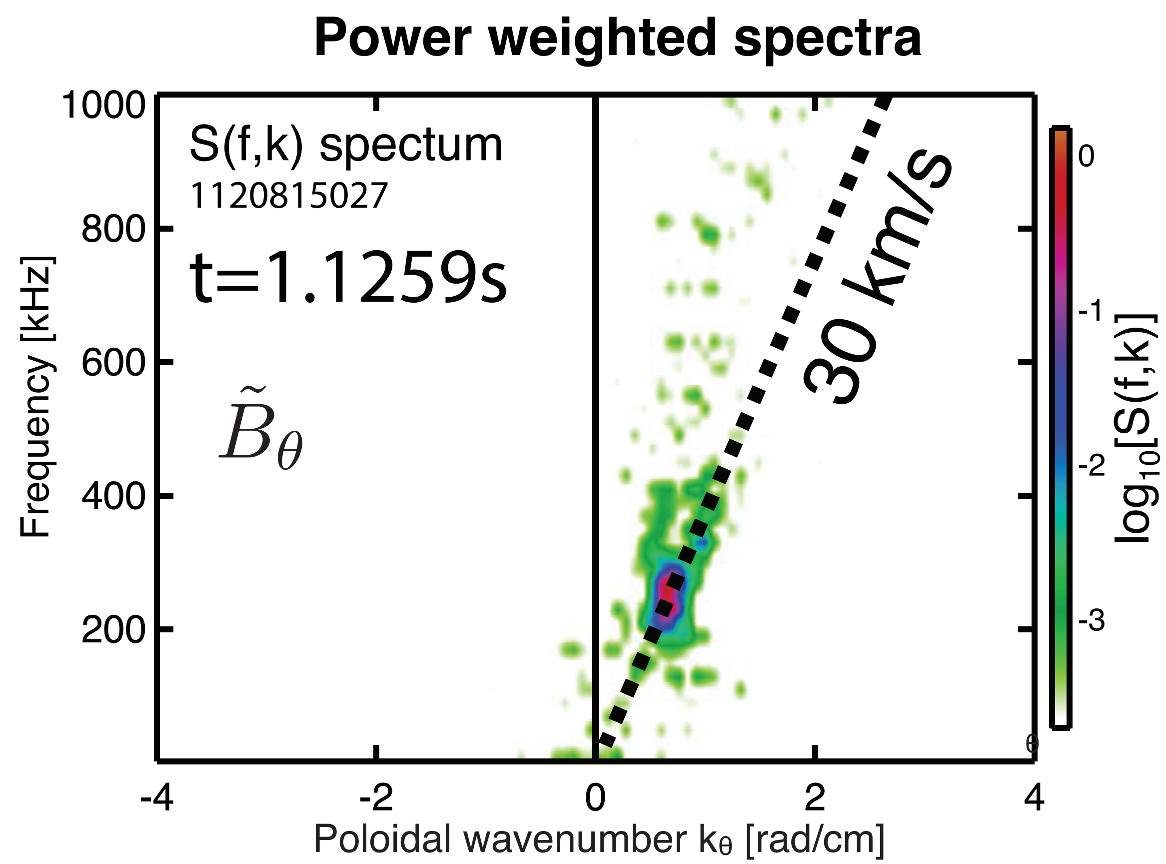


- ECE shows prompt drop in Te.
- Each ELM event is followed by period of the pedestal-T_e increase and then saturation
  - Similar T_e dependence with washboard modes on JET **Perez, PPCF 2004**
- Mode *turn on* is correlated with the pedestal saturation
- β-limit is consistent with the expected *KBM or microtearing* growth rate dependencies

Diallo, PRL (2014)

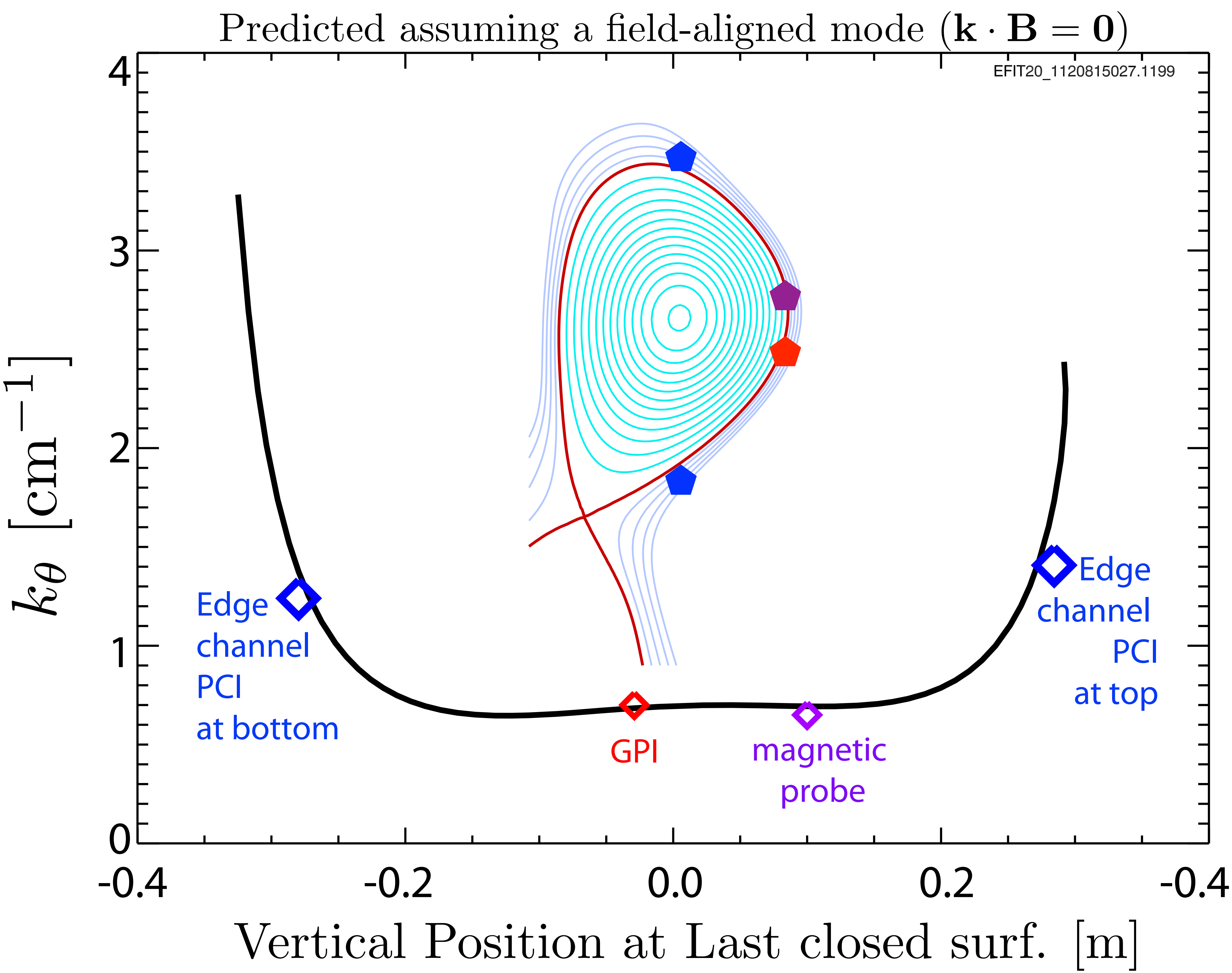
Quasi-coherent fluctuations are low k_θ and propagate in electron diamagnetic direction (lab frame)



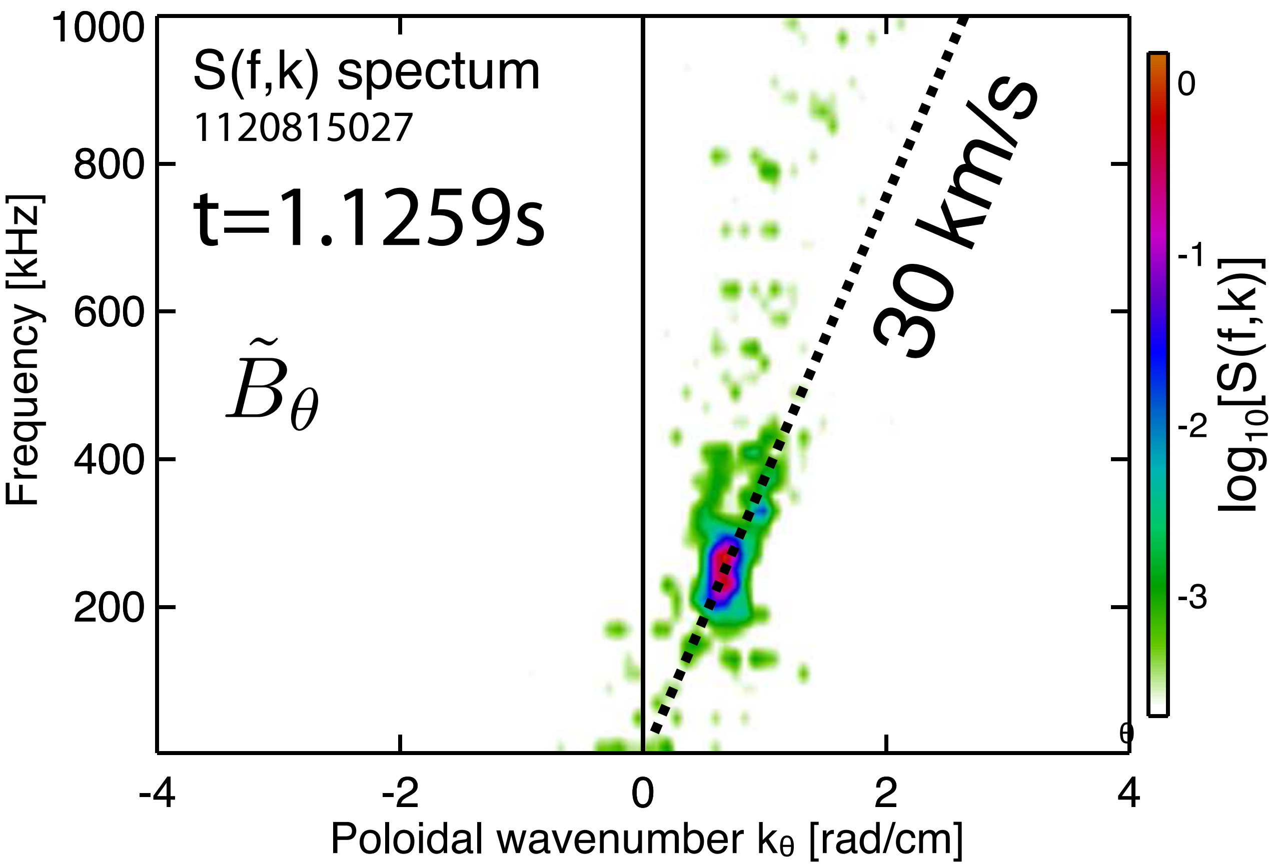


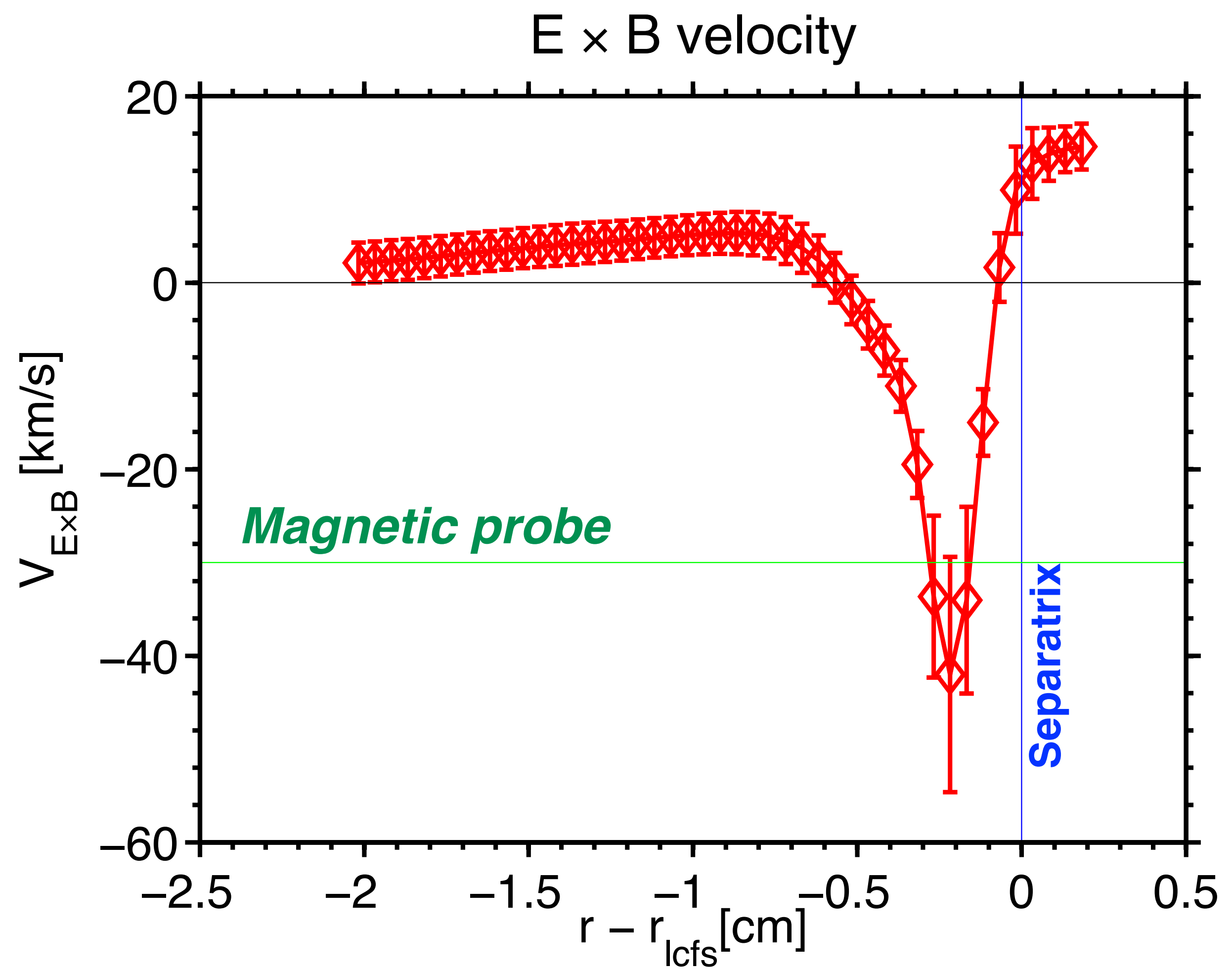
- $k_\theta \rho_s$= 0.04 , n=10
- Two-point correlation using a double-head magnetic provides the wavenumber and propagation direction

Wavenumbers from various diagnostics consistent with field-aligned perturbation



Pedestal-localized fluctuations are consistent with an ion mode, localized to E_r well





- Width of pedestal, width of well in radial electric field ~ millimeters
- Uncertainty in flux surface mappings between poloidally separated diagnostics is of similar scale!
- Ongoing work to obtain accurate mapping of fluctuation radial location onto plasma flow profile
- *Localization in the deepest part of the E_r well would imply fluctuations propagating in the ion direction*

ELITE calculations indicate that the experimental point is near both the nominal PBM and KBM thresholds

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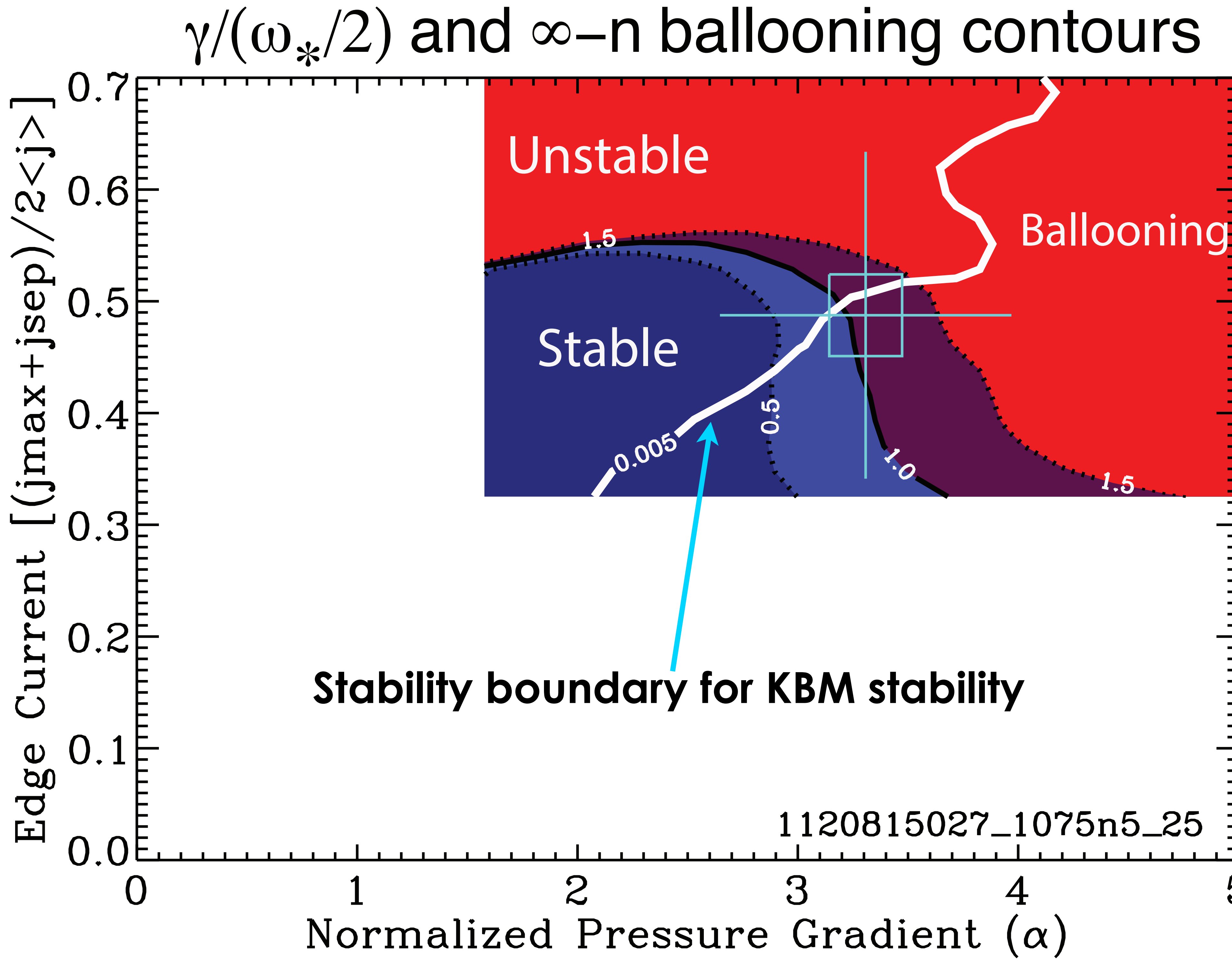
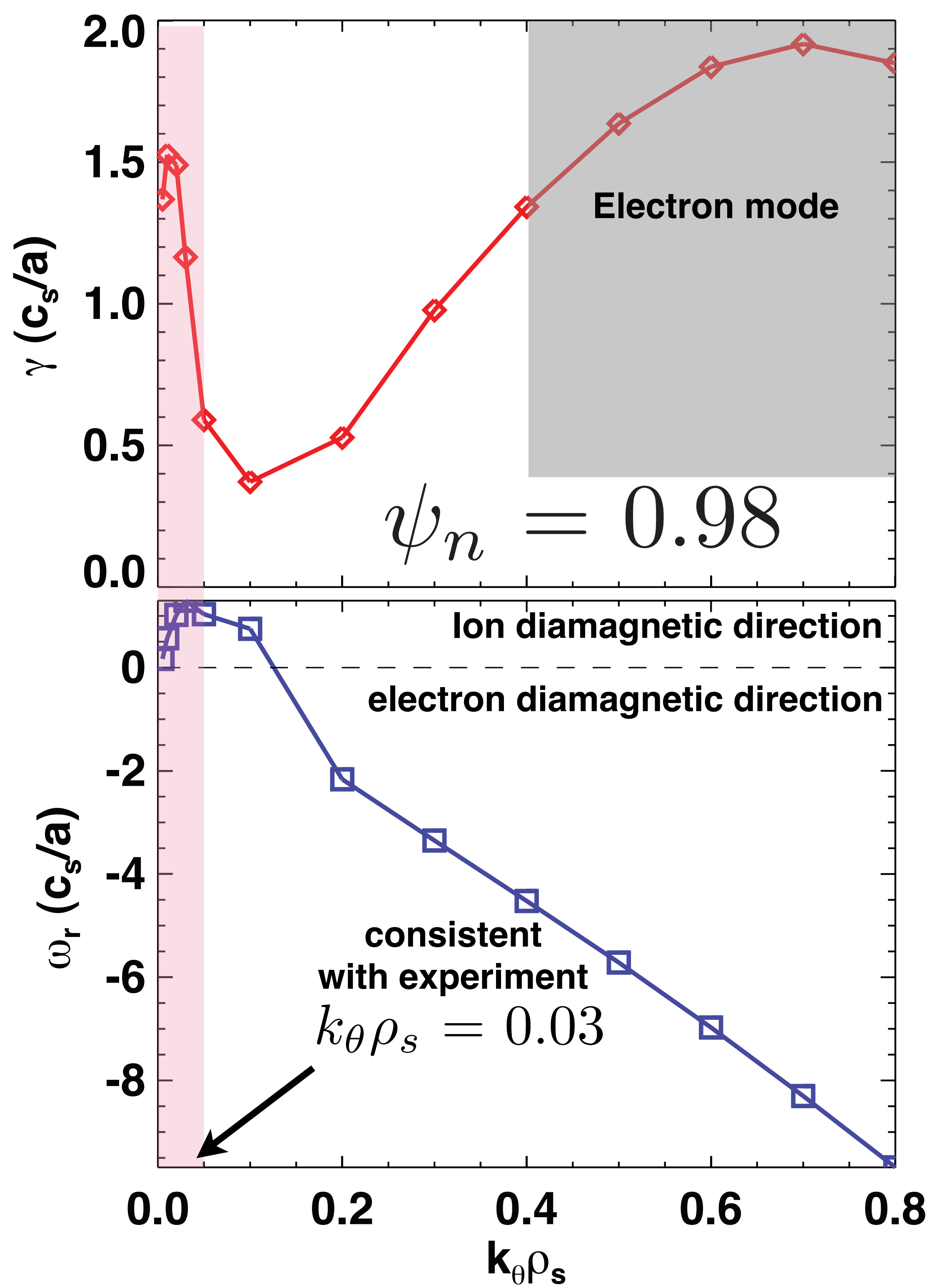
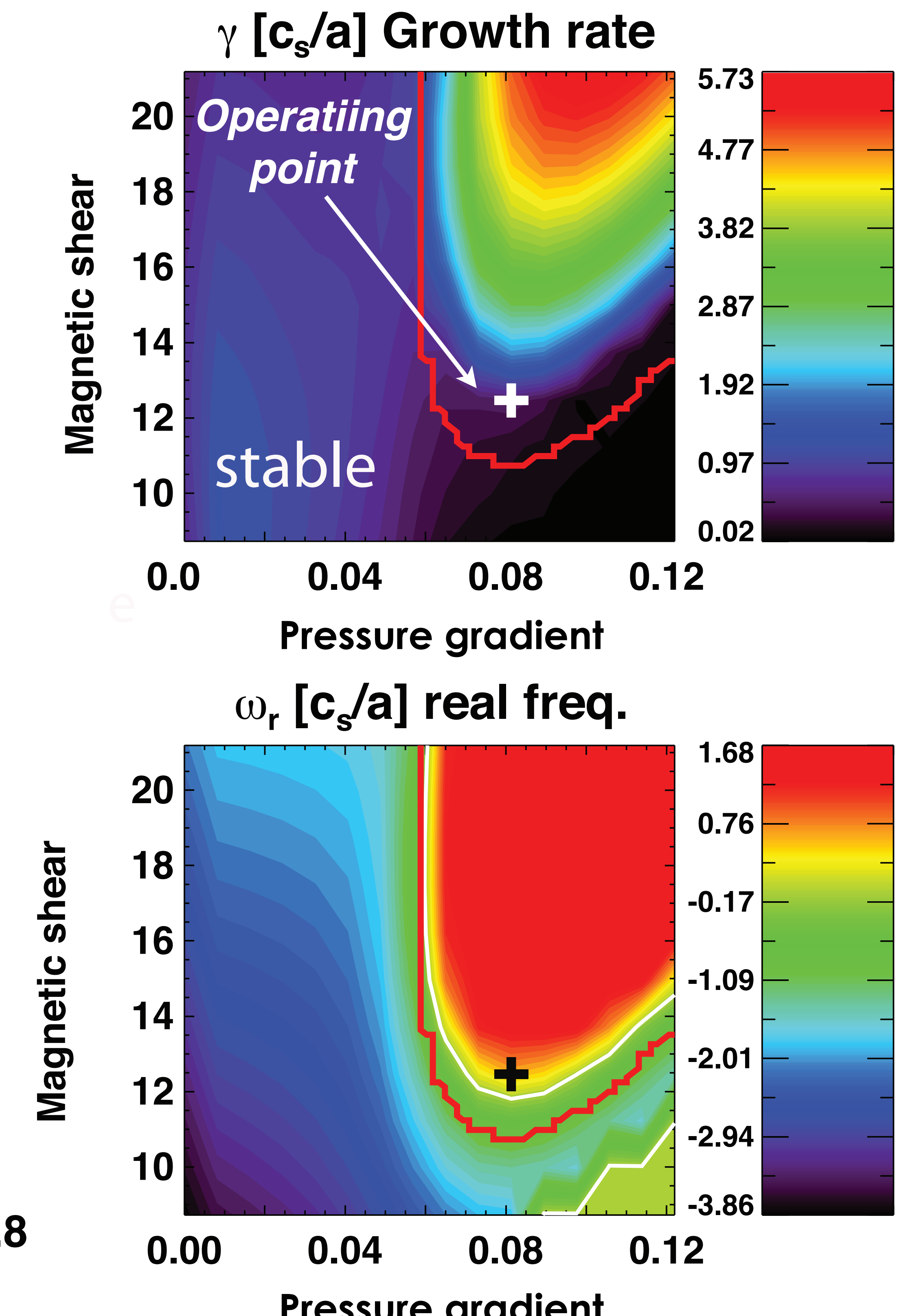


GS2 linear stability predicts low $k_\theta \rho_s < 0.2$ mode propagating in the ion diamagnetic direction (plasma frame)

Alcator C-Mod





Experiments on C-Mod show evidence of QCF contributing to the pedestal dynamics between ELMs, suggestive of KBM

- Inter-ELM fluctuation measurements on C-Mod show onset of quasi-coherent density and magnetic fluctuations, *localized to pedestal*
  - frequency of approximately 300 kHz and spatial poloidal scale $k_\theta \rho_s \sim 0.04$
  - electron diamagnetic propagation in lab frame; possibly ion-directed in plasma frame

- Results clearly show that the QCF is pedestal localized; its ***onset*** at a critical edge pressure (or ∇p) is suggestive of the kinetic ballooning mode (KBM)
  - onset and saturation of this mode simultaneous with plateau in pedestal T_e

- Linear GS2 calculations indicate the most unstable mode is edge localized with $k_\theta \rho_s = 0.03$ and has KBM characteristics, consistent with experiment

- Open questions and further investigations
  - Why the relative coherence of the fluctuations?
  - Can we get at the transport driven by these fluctuations?
  - Can we improve our understanding with time-resolved profile evolution?