PARTICLE TRANSPORT DRIVEN BY QUASI-COHERENT FLUCTUATIONS IN EDA H-MODES ON ALCATOR C-MOD

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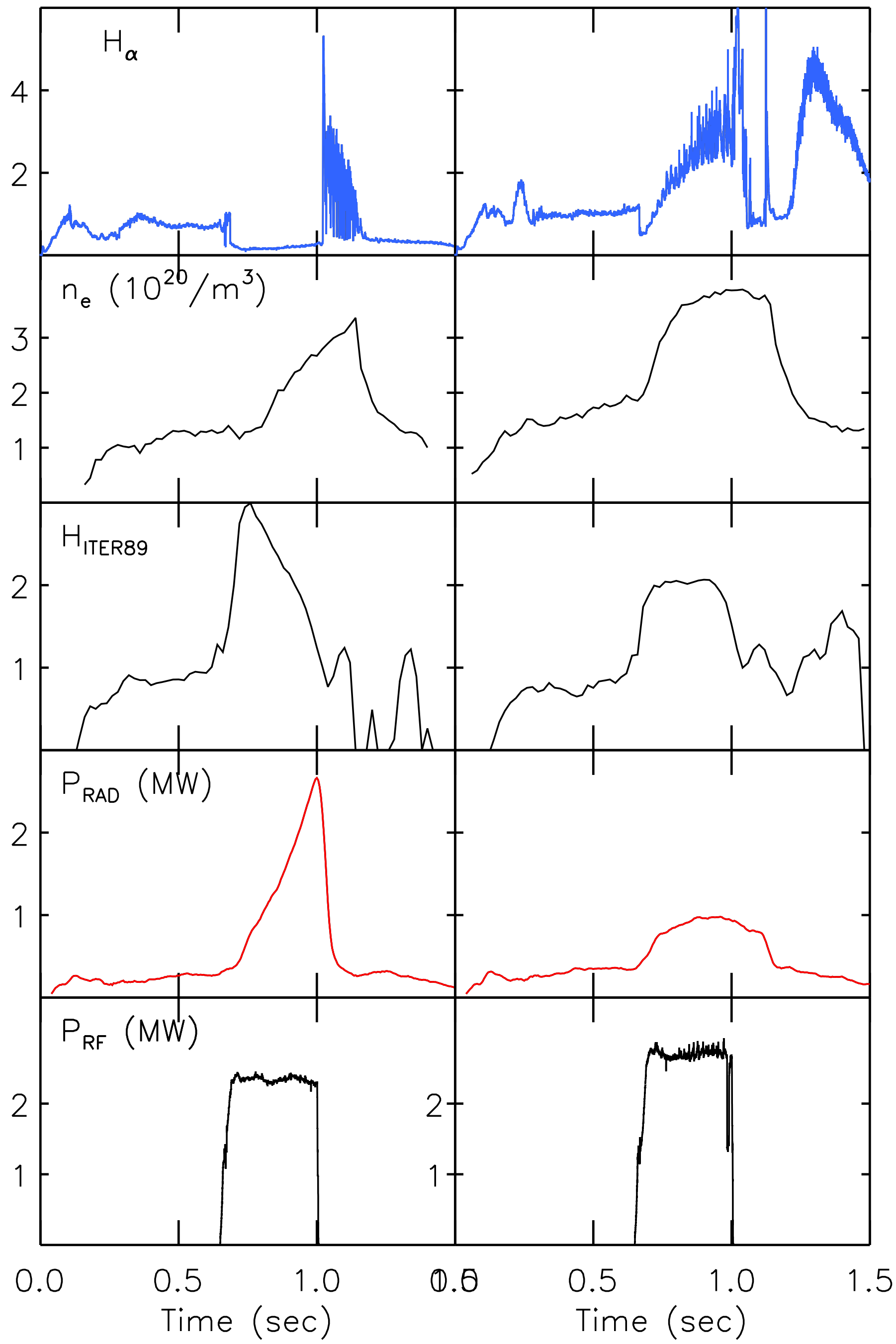
TYPE I ELMy DISCHARGES ARE NOT SEEN IN C-MOD INSTEAD, A REGIME THAT WE HAVE CALLED EDA (ENHANCED Dα) IS OBSERVED

- First signature - enhanced level of light from neutral deuterium
- Impurity particle confinement much lower than ELM-free
- **No strong accumulation of impurities**
- Energy confinement slightly lower than ELM-free (10-20%)
- **No large discrete ELMs**
- Typically don't see type I ELMs, though pressure gradient is at or above ideal MHD ballooning stability limit
- T_e well above type III boundary
- EDA regime shows **continuous** degradation of pedestal rather than relaxation oscillation

EDA may be closely related to JET LPC H-mode, DIII-D QH? Shares many characteristics with type II or other "small" ELM regimes (DIII-D, JT60-U, JFT-2M).

EDA H-MODES HAVE GOOD ENERGY CONFINEMENT BUT DO NOT SHOW IMPURITY ACCUMULATION



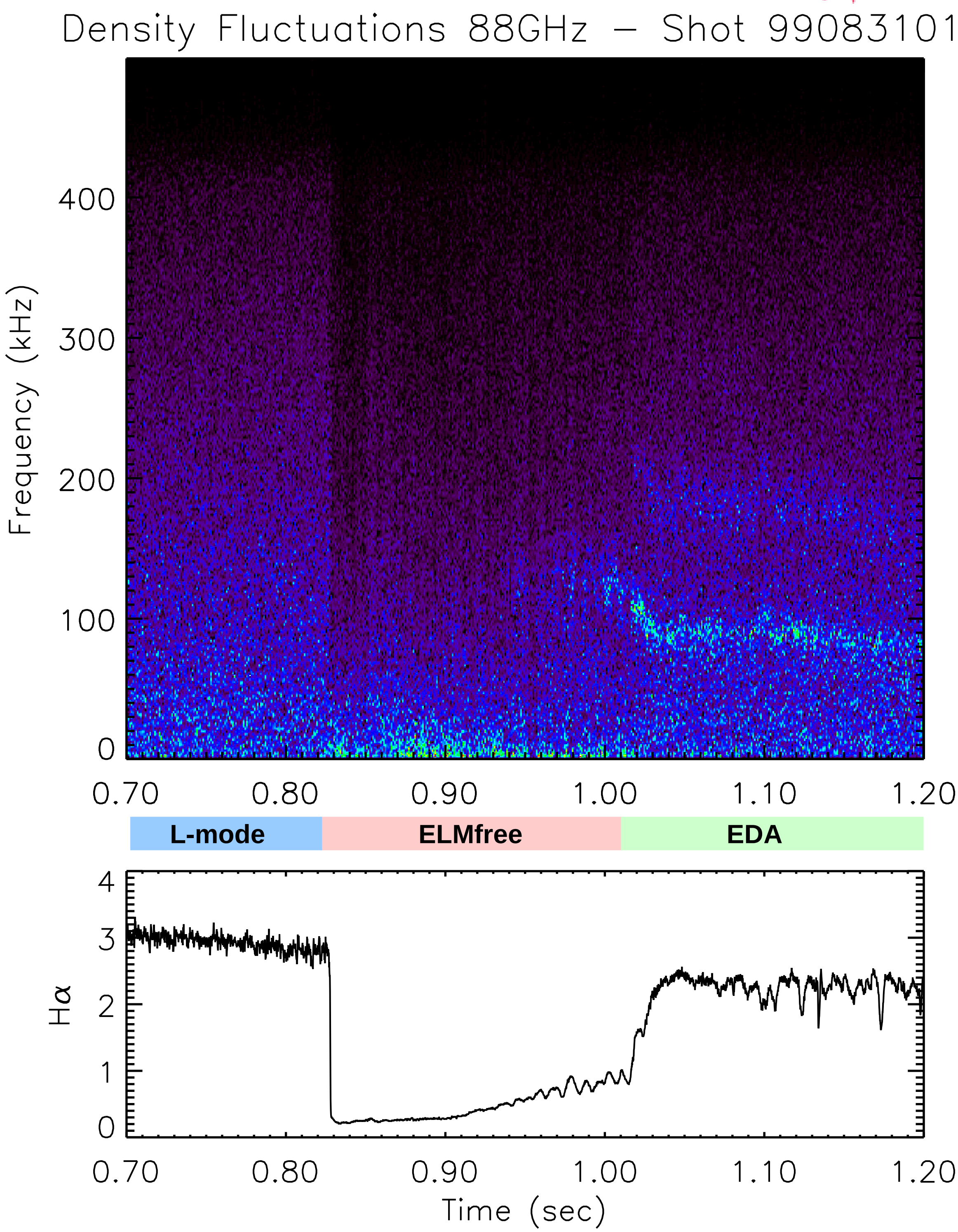
ELM-free **EDA**

A KEY SIGNATURE OF EDA IS QUASI-COHERENT FLUCTUATIONS LOCATED IN PEDESTAL

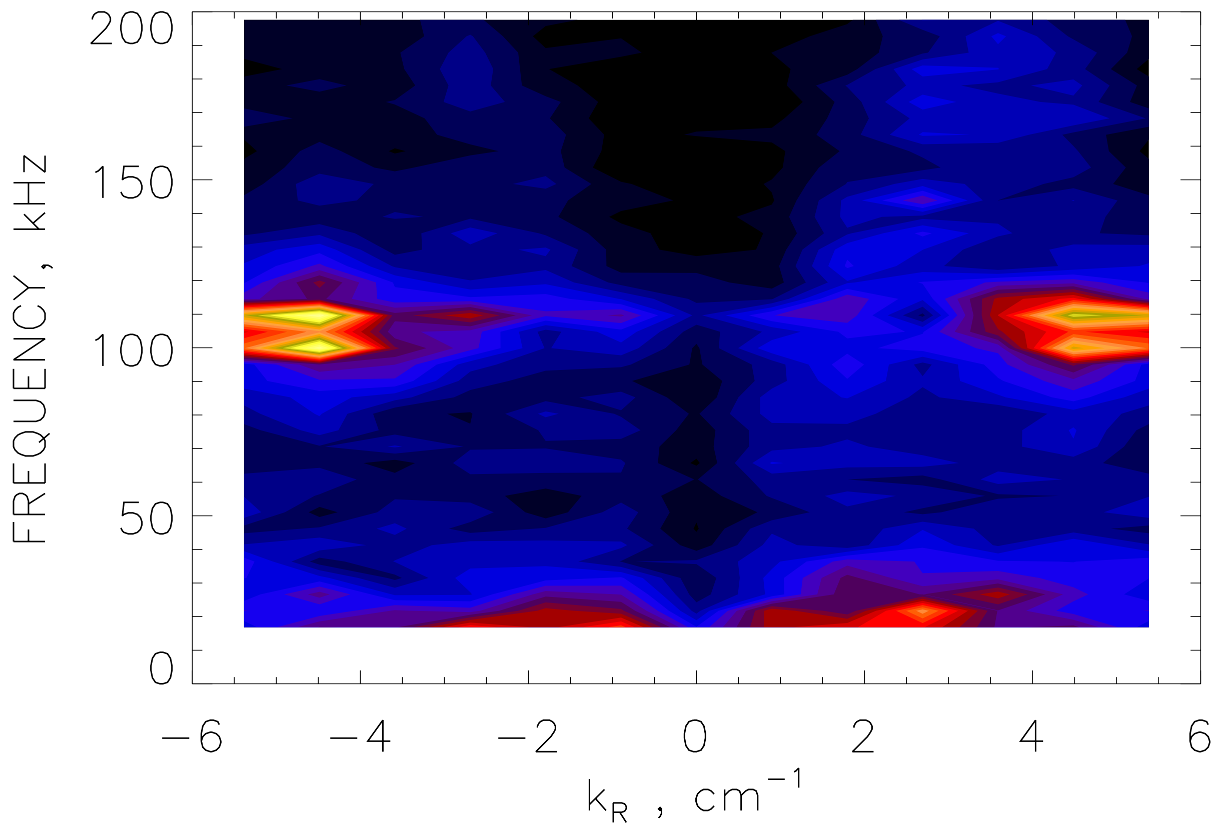
Alcator C-Mod

- $\tilde{n}, \tilde{\phi}$ observed with reflectometry, PCI, probes.
- Frequency on the order of 100-140 kHz, $\frac{\delta f}{f} \sim 0.1$
- k_θ ~ 5 cm-1 (m ~ 100-150)
- Fluctuations propagate (slowly) in the electron diamagnetic direction.
- Fluctuations are localized in the density pedestal, frequency scales inversely with pedestal width.
- **Analysis of probe signals demonstrates that significant particle transport is caused by these modes.**
- An increase in background turbulence is seen as well.
- Is there a magnetic component to the fluctuations?.

THE QUASI-COHERENT FLUCTUATIONS ARE SEEN WITH REFLECTOMETRY

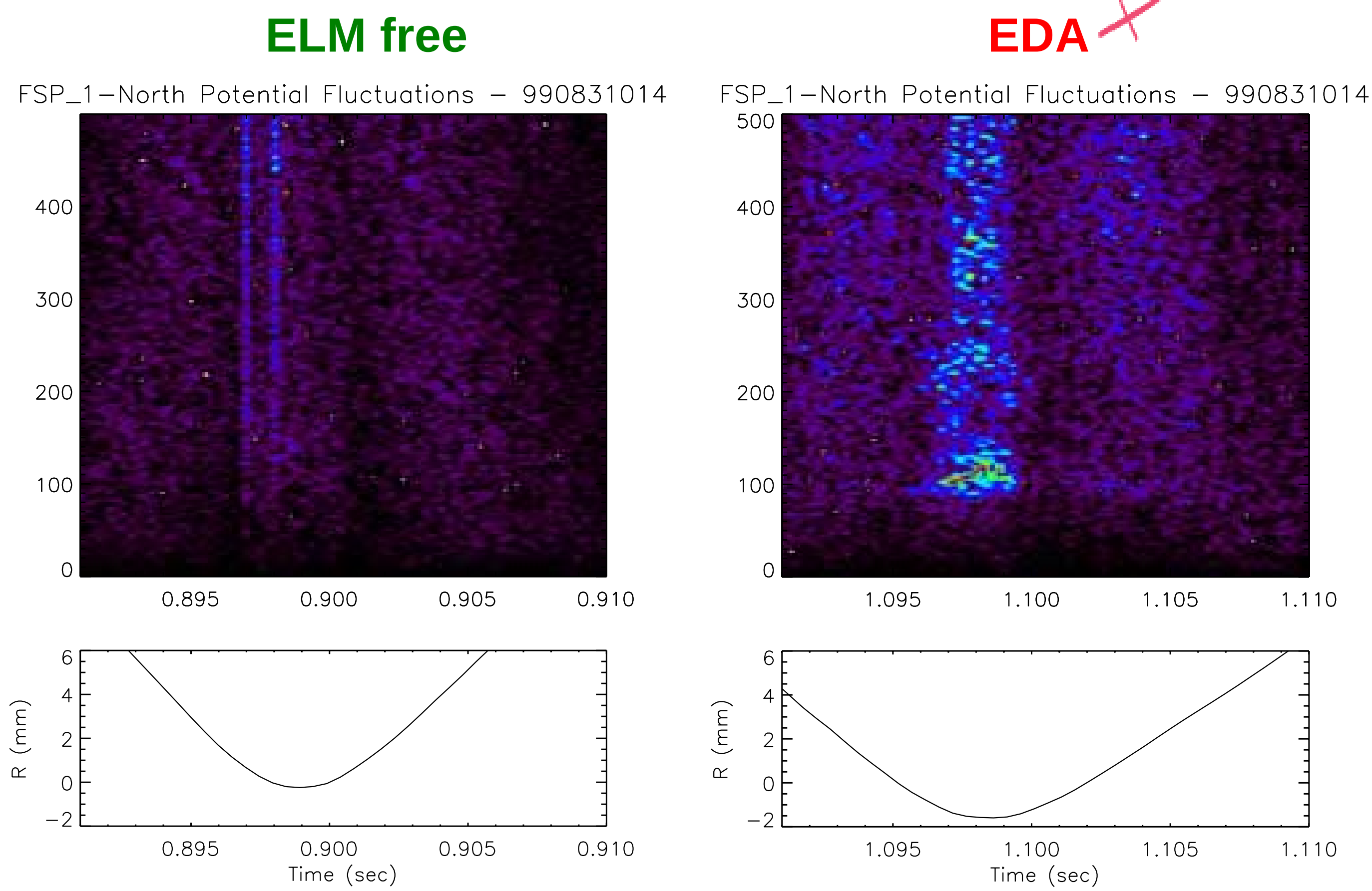


PCI SHOWS A SIGNAL WITH A WELL DEFINED ω AND k STRUCTURE



- Data taken from a short interval of time during EDA H-mode
- For edge fluctuations, PCI view implies k_θ ~ 5-6 cm^{-1}; m ~ 100-150

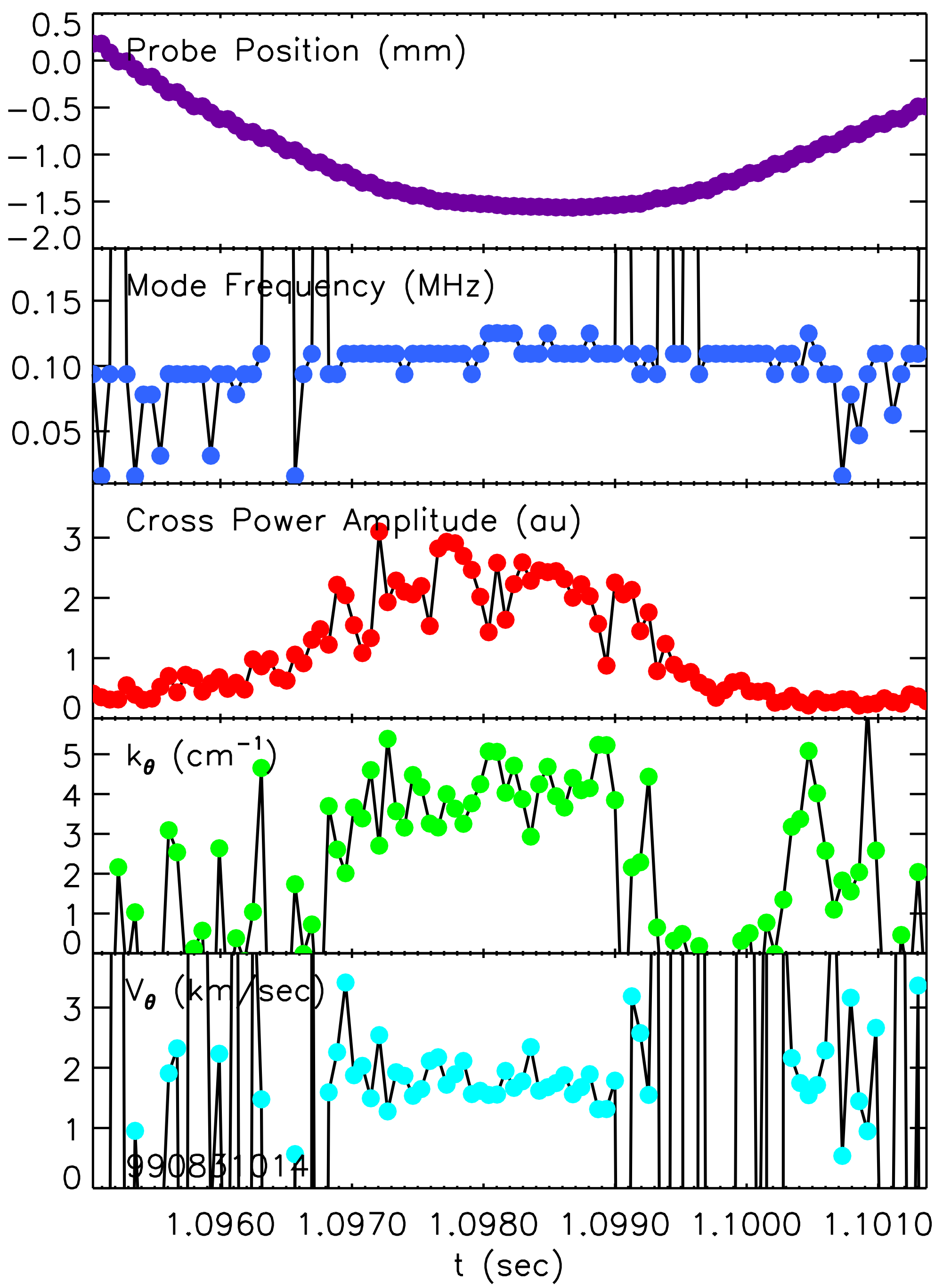
A SET OF SCANNING LANGMUIR PROBES HELPS LOCALIZE THE MODE



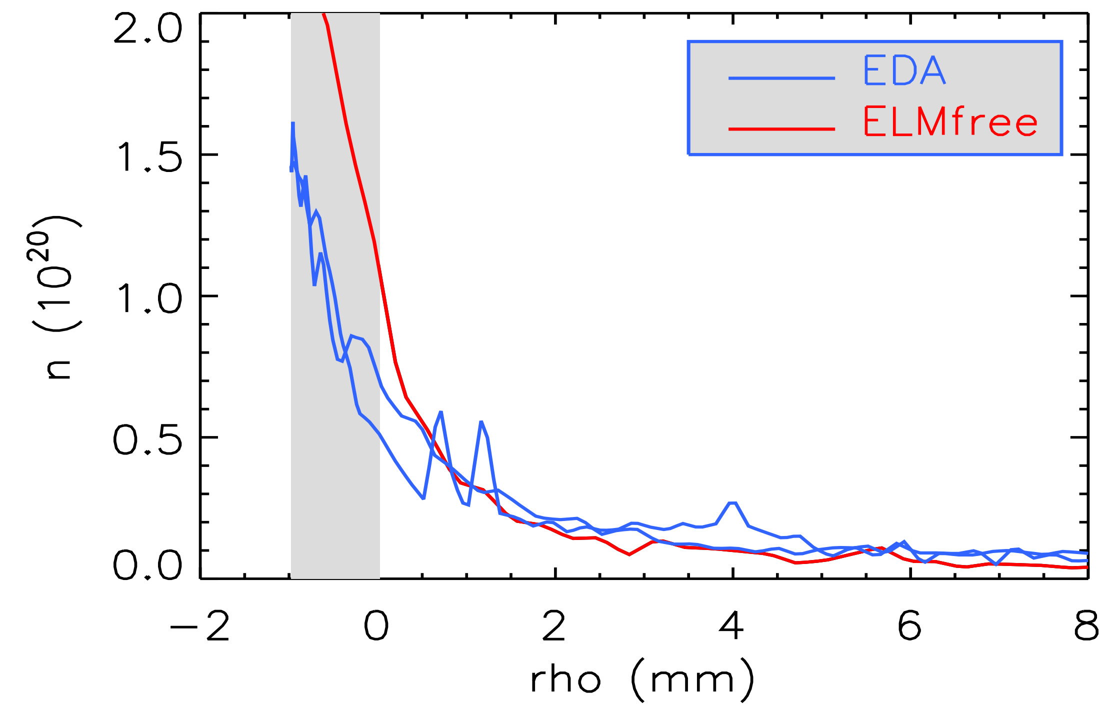
- Two arrays are available, each with multiple probes.
- Measure local temperature, density and floating potential.
- Q-C fluctuations in ion saturation current and floating potential and their relative phase are measured
- Fluctuations are seen only in EDA and only when the probe crosses/approaches the separatrix.

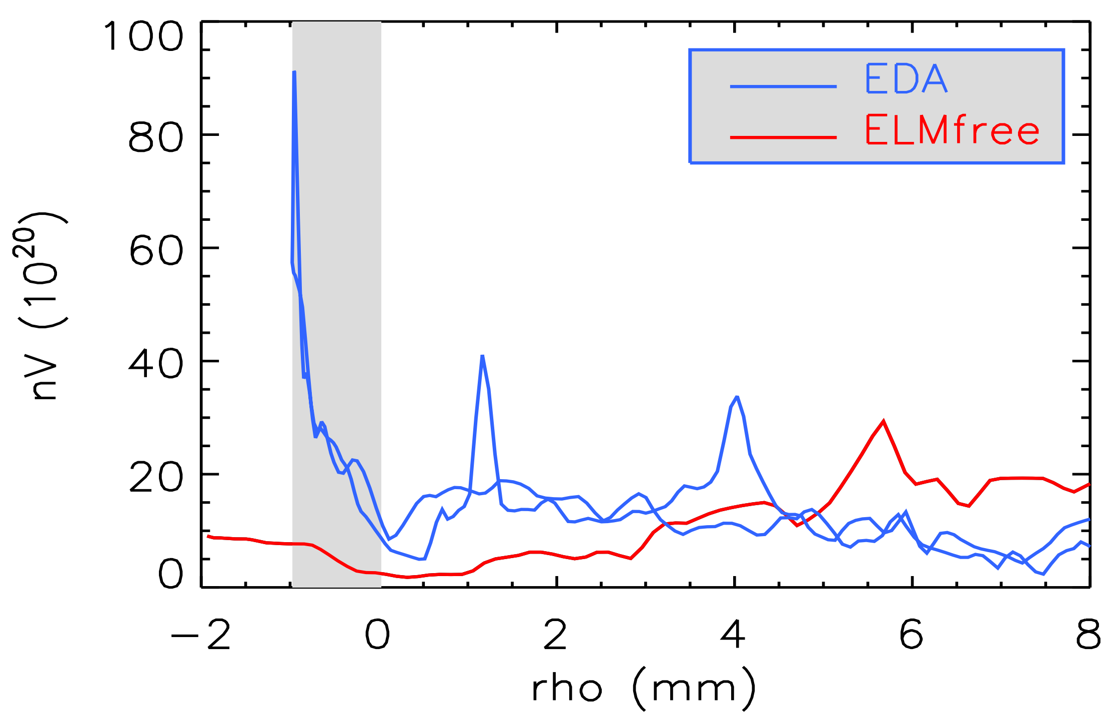
PROBE SIGNALS CAN BE ANALYZED TO DETERMINE WAVELENGTH OF COHERENT MODE

Alcator C-Mod

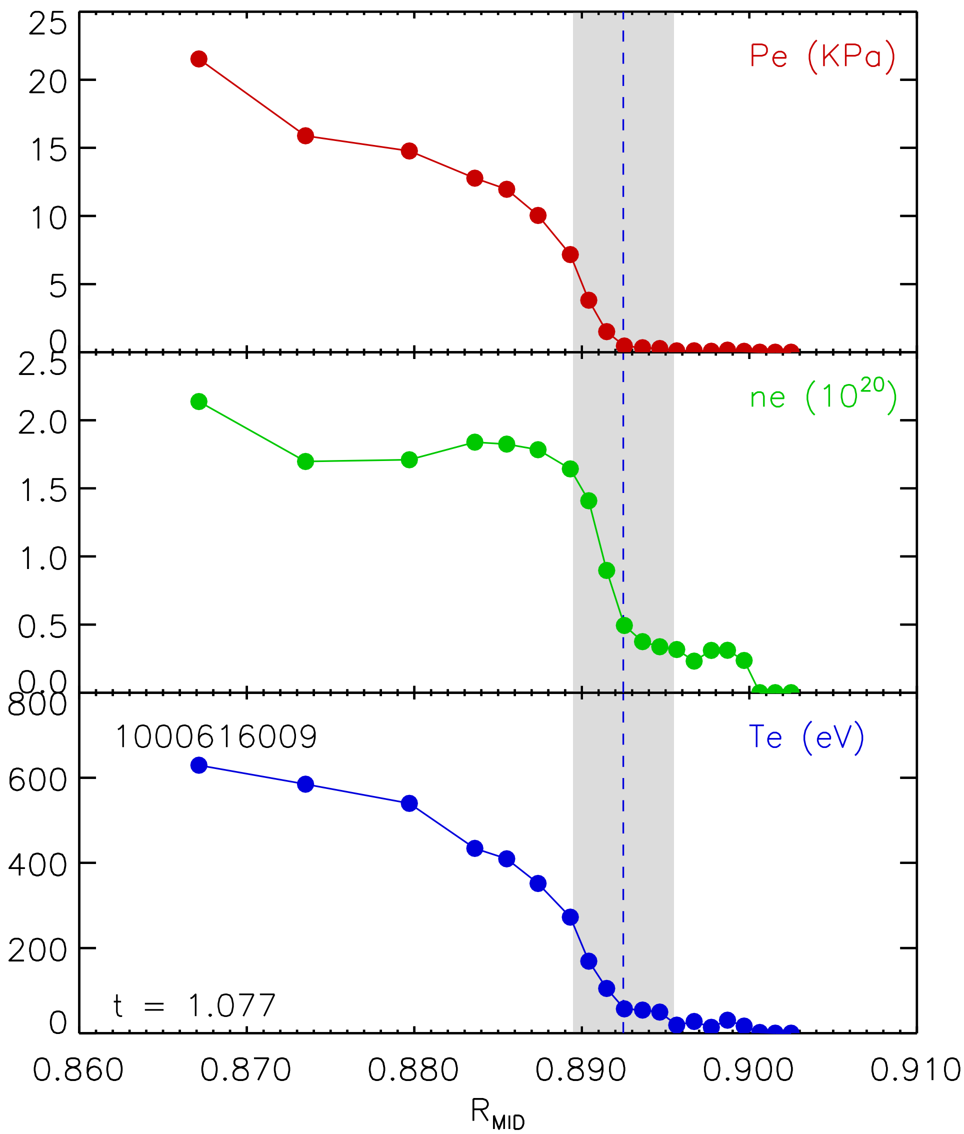


ANALYSIS OF <ñẼ> SHOWS THAT THE OSCILLATIONS DRIVE SIGNIFICANT PARTICLE TRANSPORT



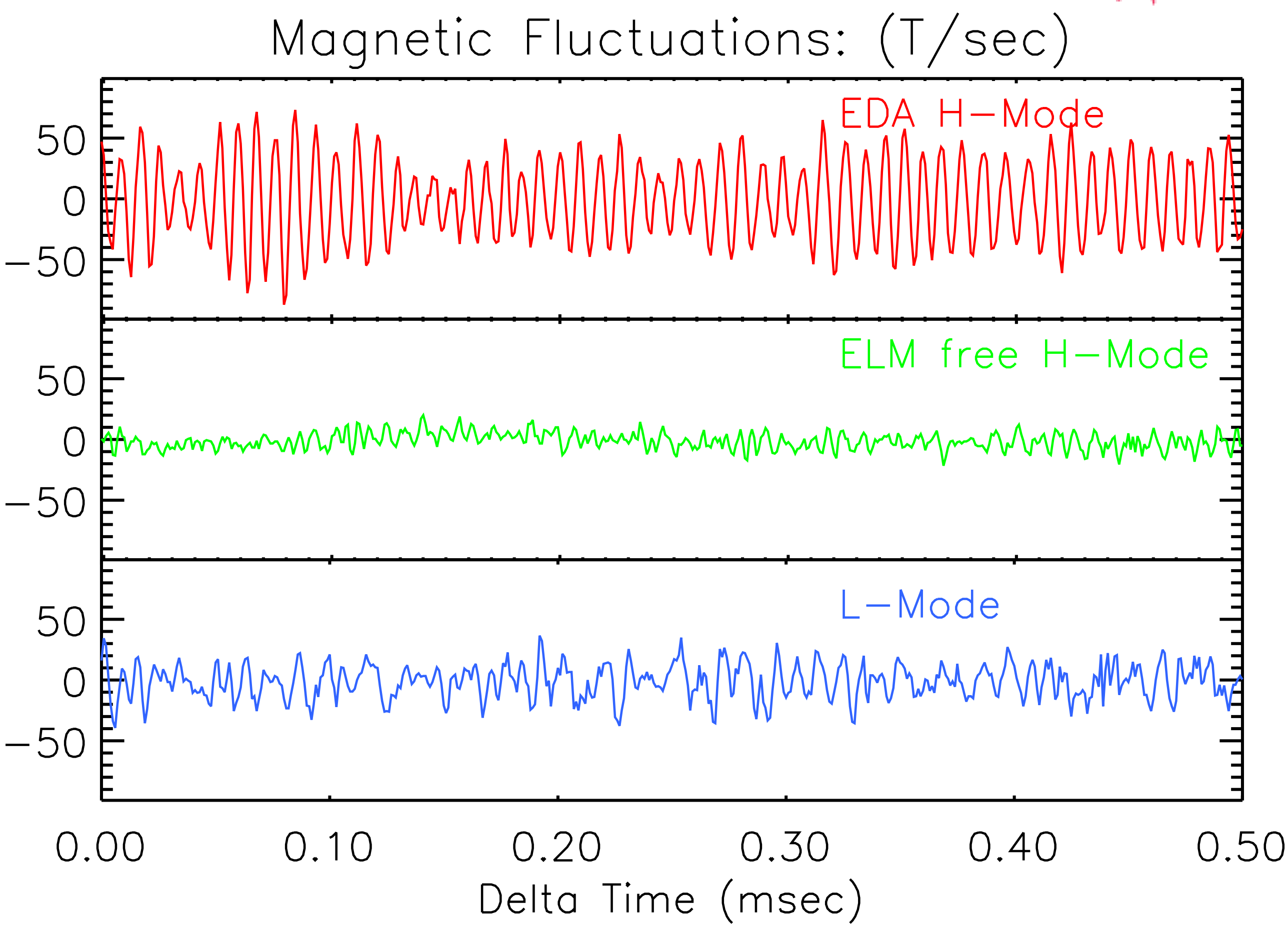


TYPICALLY, DENSITY PEDESTAL IS STEEPER, WITH SHARP GRADIENTS IN REGION OF LOWER PRESSURE



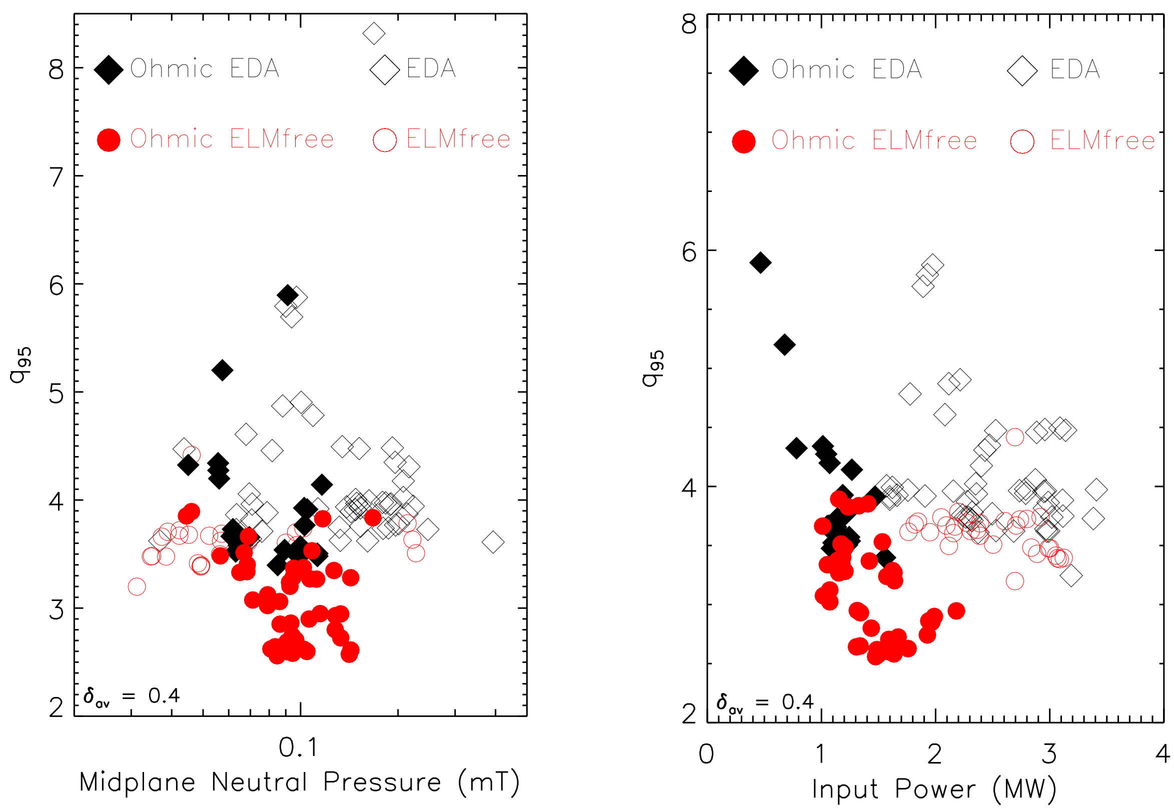
- Little difference between Te, ne pedestal profiles in EDA and ELMfree
- Impurity density profiles are much sharper in ELMfree

THE QUASI-COHERENT FLUCTUATION HAS AN IMPORTANT MAGNETIC COMPONENT



- Recently observed with a fast scanning magnetic probe (**Not** seen with standard set of fast magnetic pickups: m, k too large)
- $\tilde{j} \approx j_{Ohmic+Bootstrap} \approx 100 A/cm^2$
- These are **not** ELM precursors (which are also seen, but at much lower m (20-30)

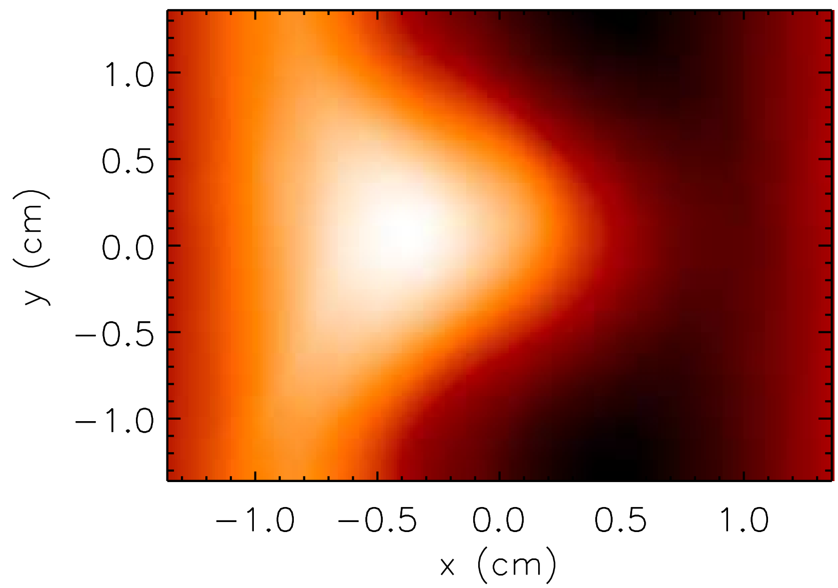
EDA SEEN AT q > 3.5 AND HIGHER δ (> 0.35) WITH SIMILAR BOUNDARY FOR OHMIC AND ICRF PLASMAS

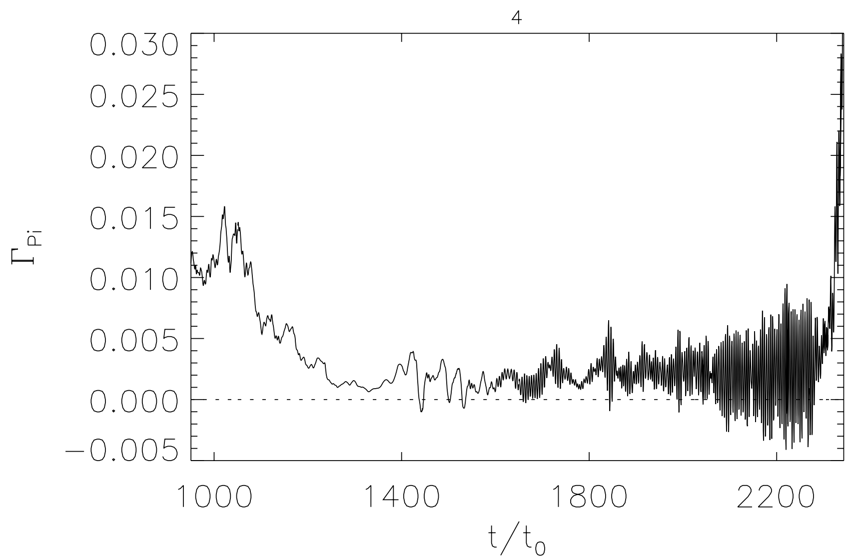


- Dependence on input power, plasma density, and neutral density is apparently weak at best.
- EDA is essentially the same in OH and RF plasmas.
- **Would seem to rule out mechanisms based on direct RF interaction or through the influence of fast particles.**

SIMULATIONS OF DRIFT-ALFVEN TURBULENCE SHOW AN MHD-LIKE MODE ARISE AT HIGH EDGE PRESSURE GRADIENTS

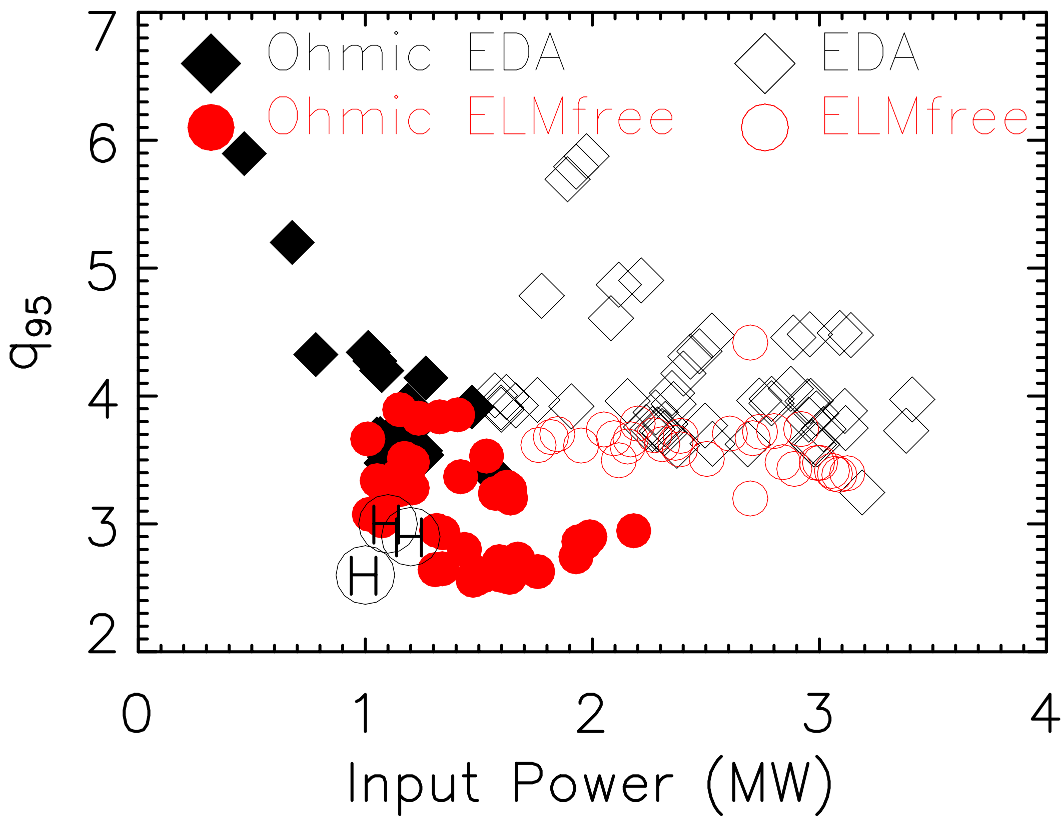
The calculated k ($3\text{-}6\ cm^{-1}$) and frequency (50-200 kHz) of this mode[1] are in rough agreement with our measurements





*Rogers and Drake, Phys. Plasmas, **6**, 2797*

SCALING OF EDA/ELMFREE BOUNDARY WITH q AND ION MASS IS CONSISTENT WITH RESISTIVE BALLOONING



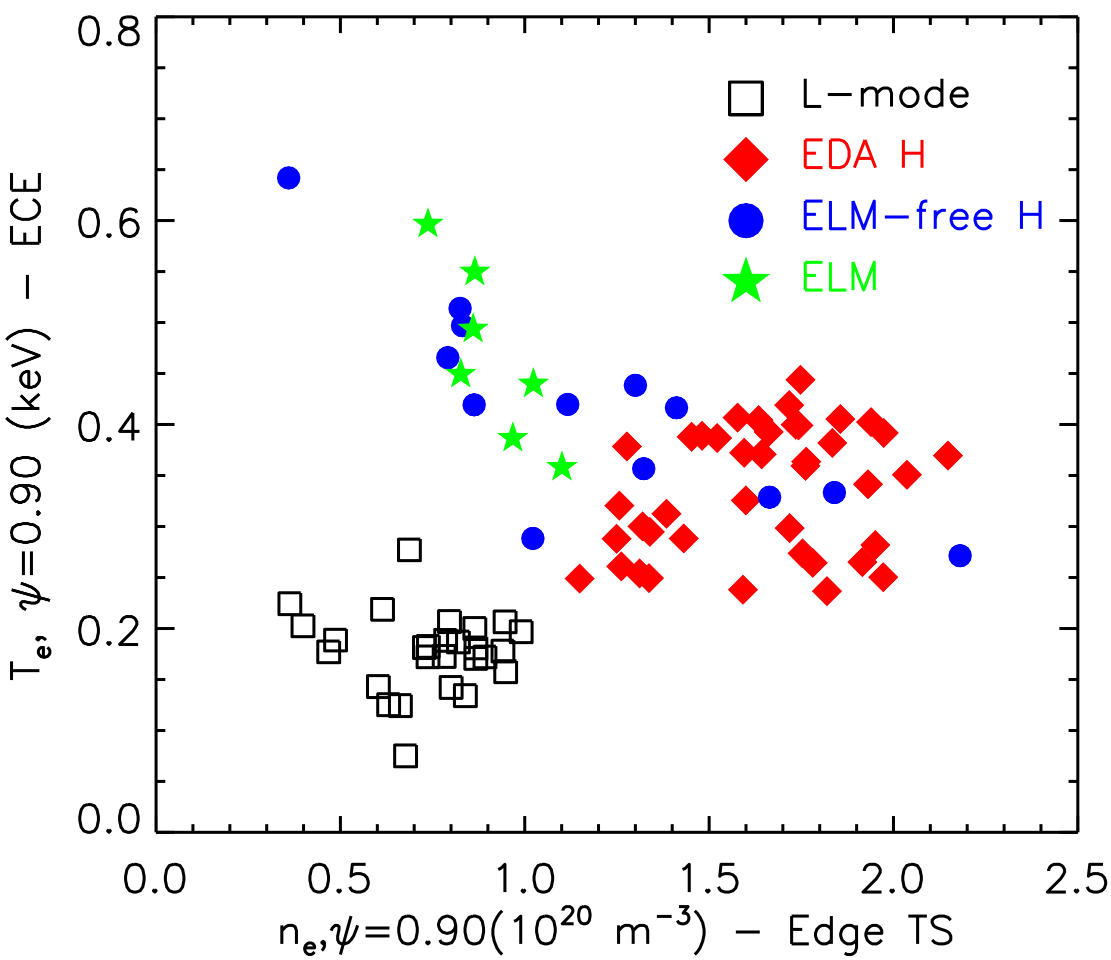
Diamagnetic stabilization is significant for:

$$\left(\frac{qR}{L_{||}}\right)\frac{\sqrt{m_i/m_e}}{2q(1+T_i/Te)} \approx 1$$

So, for $qR \sim L_{||}$, $T_e \sim T_i$, critical q ~ m_I

COLLISIONALITY MAY BE A KEY PARAMETER

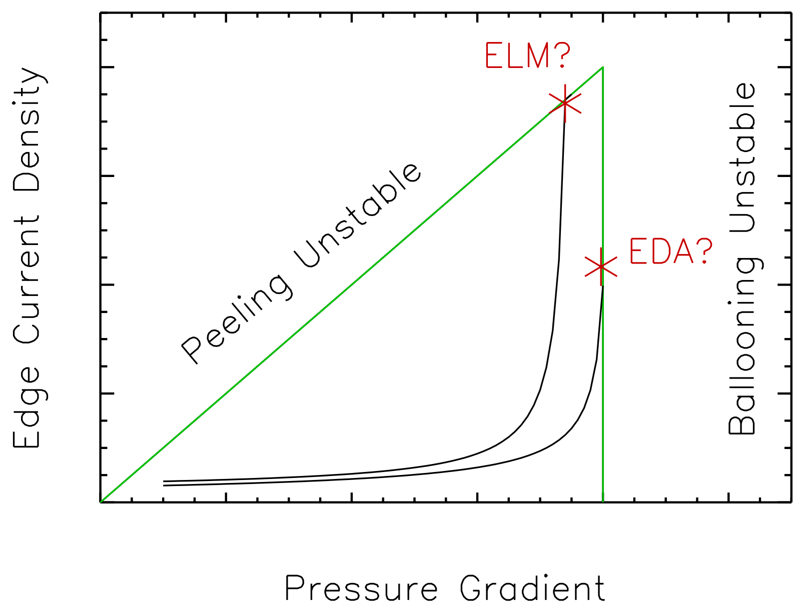
Alcator C-Mod



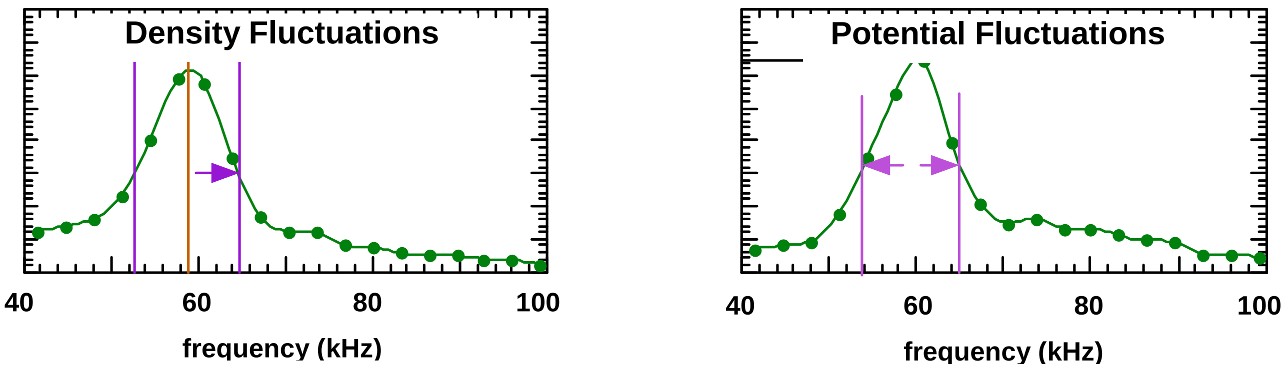
- At very low density (for C-Mod), isolated ELMs are seen rather than EDA
- If ELMs are current driven, higher edge collisionality might be stabilizing by reducing bootstrap current.

EDA AND EDGE STABILITY OF THE H-MODE

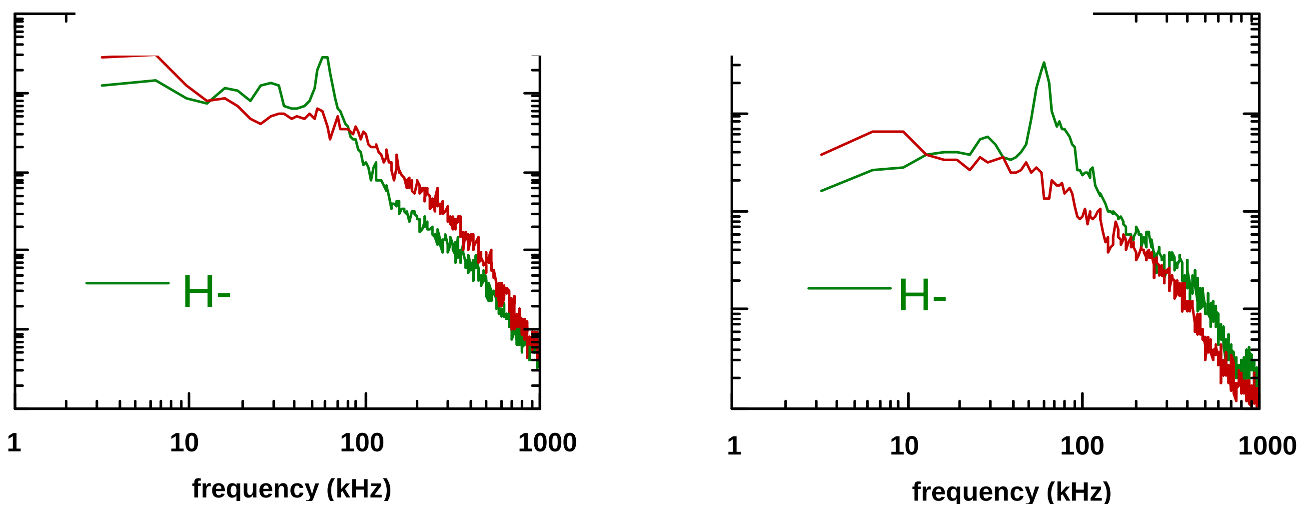
- ELMs are thought to be "peeling modes" driven by edge current (See Connor and Wilson for example)
- However, due to its high density, the edge plasma in C-Mod is somewhat collisional ($\nu^* \sim 1\text{-}5$), so bootstrap current will be reduced.
- Pressure driven ballooning modes are enhanced, current driven peeling modes suppressed.
- **Perhaps** the EDA is a manifestation of ballooning modes in a regime that doesn't proceed on to become peeling unstable.



IF THIS PICTURE IS CORRECT, THE QUASI-COHERENT MODE SHOULD BE OBSERVED BETWEEN ELMS



coherent mode appears only in H-mode phase:



- Observed on DIII-D by Moyer et al. APS 1997
- Also seen on PDX? Slusher et al, PRL 1984 pg 667
- PBX? Tynan Phys. Plasmas 1994, 3301

SUMMARY

- The EDA H-mode regime combines good energy confinement, moderate particle confinement and no ELMS
- EDA is easily obtained with ohmic heating alone - rules out fast particles or RF/Edge interactions as cause.
- The pedestal gradient is limited by a continuous rather than intermittent process, related to **electromagnetic** fluctuations which are observed. (f ~ 100 kHz, k ~ 5 cm^{-1})
- The observed fluctuations drive significant particle flux.
- A coherent mode with similar properties was seen in non-linear simulations of edge plasmas. This same mode has been identified with gs2 (gyrokinetic stability) detailed studies are underway
- EDA is most easily accessed at q95 > 3.5, δ > 0.35, hydrogen, consistent with diamagnetic stabilization of ballooning modes
- We are investigating the role of collisionality in suppressing edge current/ peeling modes.