

TRANSPORT IN EDA H-MODE AND ITS RELATION TO FLUCTUATIONS AND THE MICRO-STABILITY OF THE PEDESTAL



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

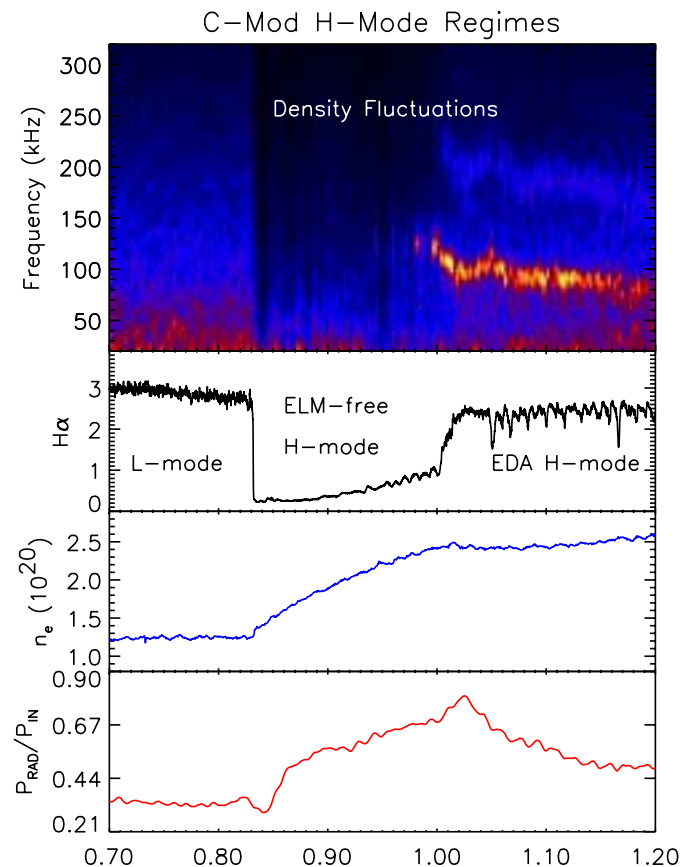


- First signature - enhanced level of light from neutral deuterium
- Energy confinement slightly lower than ELM-free (10-20%)

Impurity particle confinement
much lower than ELM-free

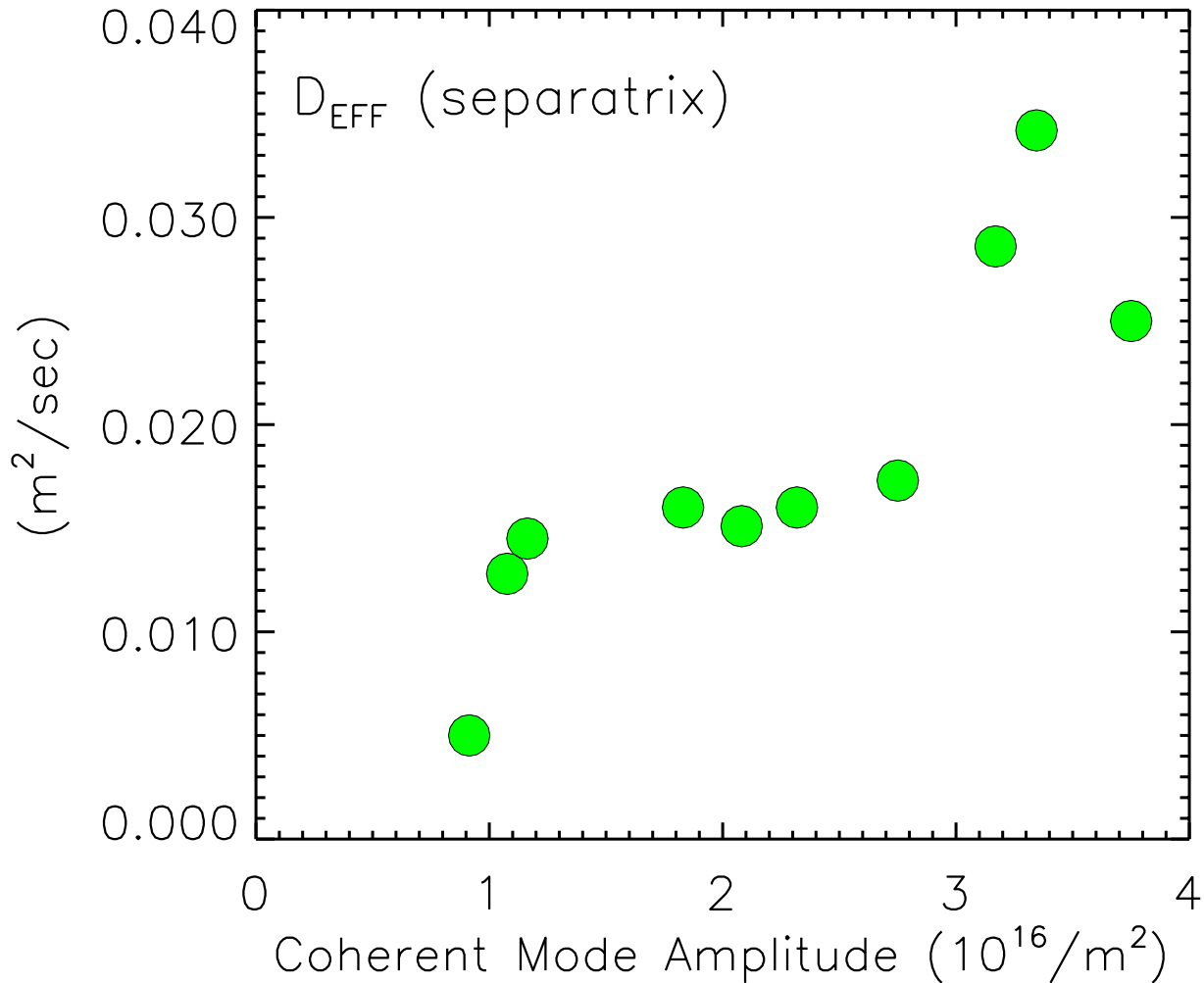
- **No strong accumulation of impurities**
- **No large discrete ELMs**
- No type I ELMs*
- EDA regime shows **continuous** degradation of pedestal transport

*See Mossessian UP1.096



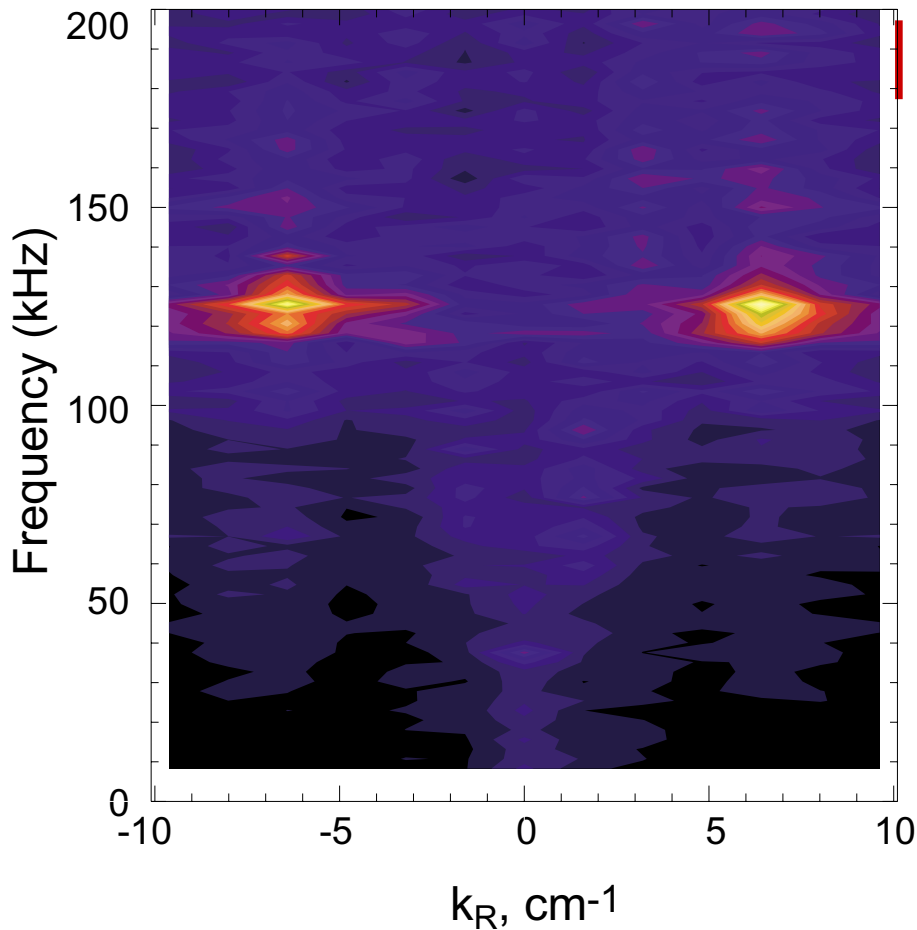
INCREASED PARTICLE TRANSPORT IS CORRELATED WITH THE STRENGTH OF THE QUASICOHERENT MODE

Alcator
C-Mod



- Particle source calculated with Lyman- α emission, $n_e(r)$, and $T_e(r)$
- $D_{\text{EFF}} = (\text{Integrated Source} - dN/dt) / \nabla n$

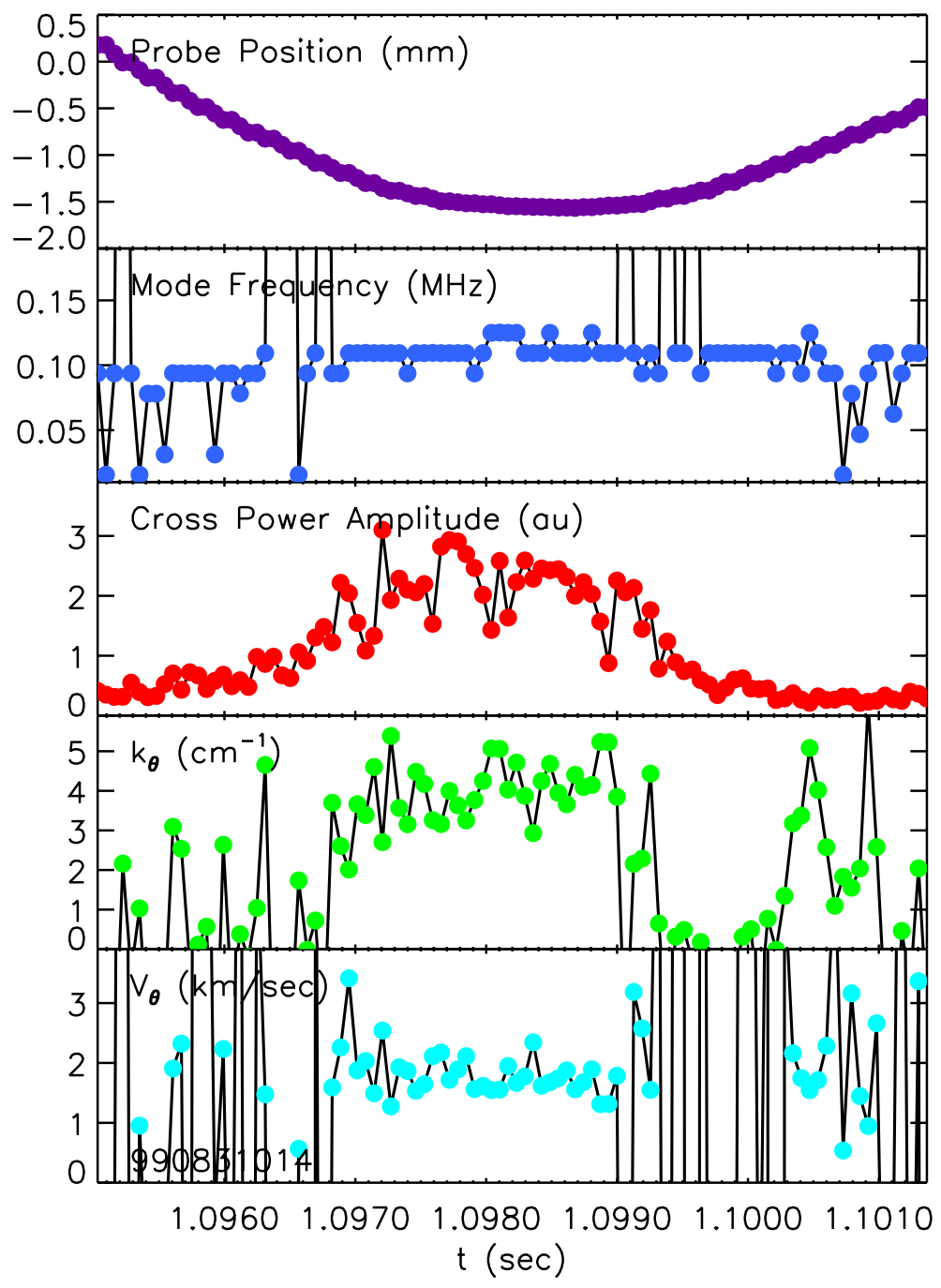
PCI AND PROBES SHOW A WELL DEFINED ω AND k STRUCTURE



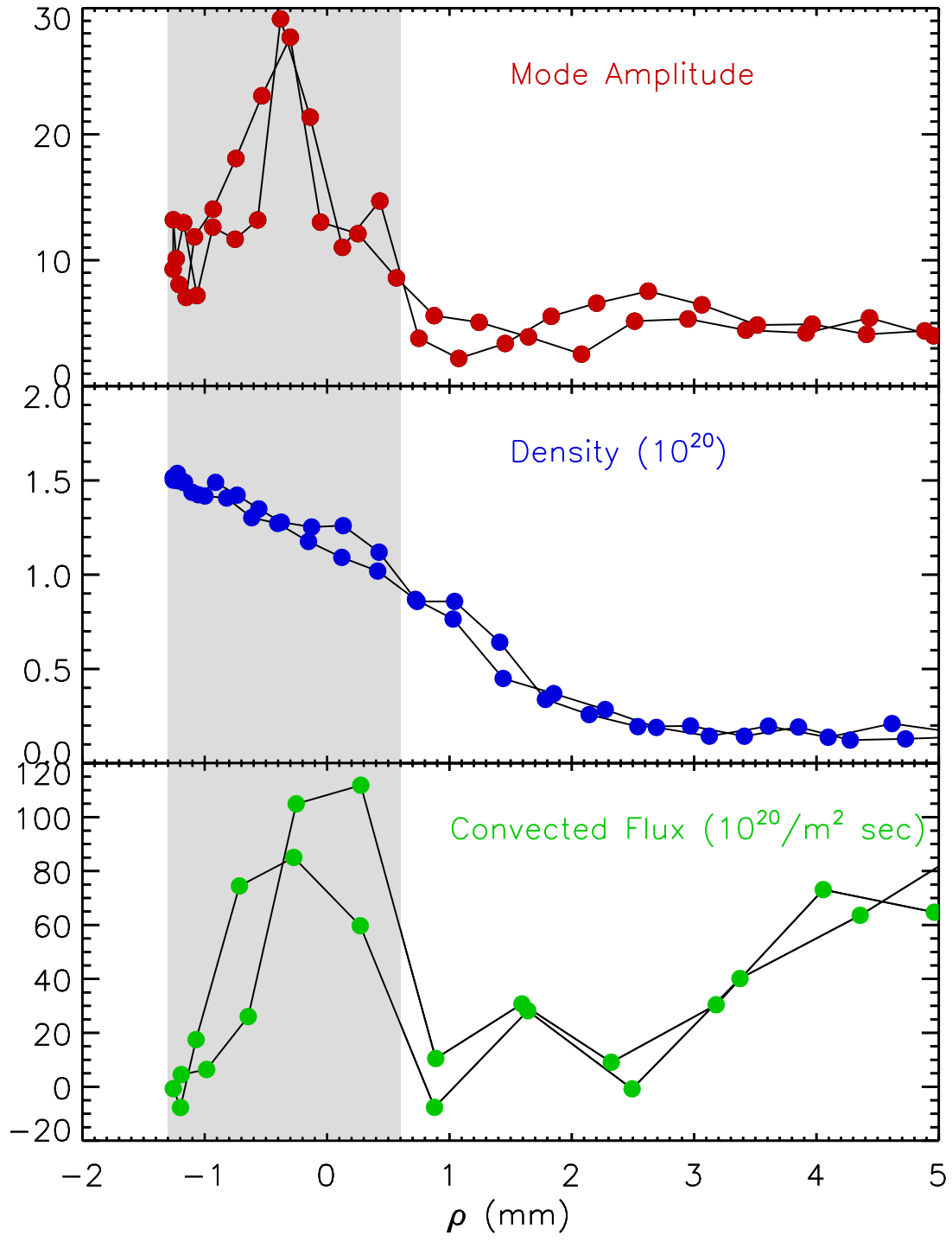
- \tilde{n} , $\tilde{\phi}$, \tilde{B} observed with reflectometry, PCI, probes with $f \sim 100\text{-}140$ kHz, $\frac{\delta f}{f} \sim 0.1$
- $k_\theta \sim 5$ cm⁻¹, propagates (slowly) in the electron diamagnetic direction.
- Fluctuations are localized in the density pedestal

See Mazurenko UP1.105, Lin UP1.094

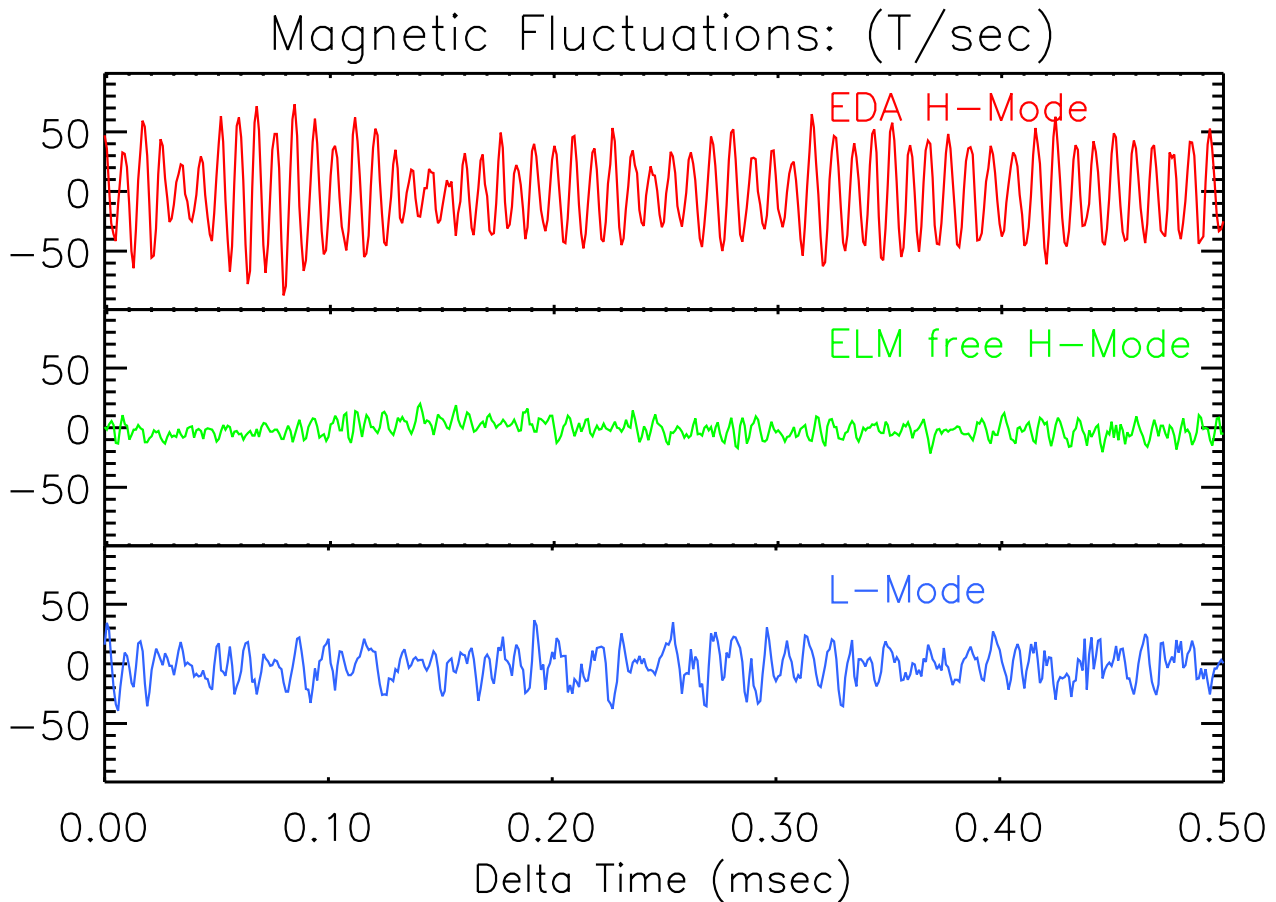
PROBE SIGNALS CAN BE ANALYZED TO DETERMINE WAVELENGTH OF COHERENT MODE



ANALYSIS OF $\langle \tilde{n}\tilde{E} \rangle$ SHOWS THAT THE OSCILLATIONS DRIVE SIGNIFICANT PARTICLE TRANSPORT



THE QUASI-COHERENT FLUCTUATION HAS AN IMPORTANT MAGNETIC COMPONENT

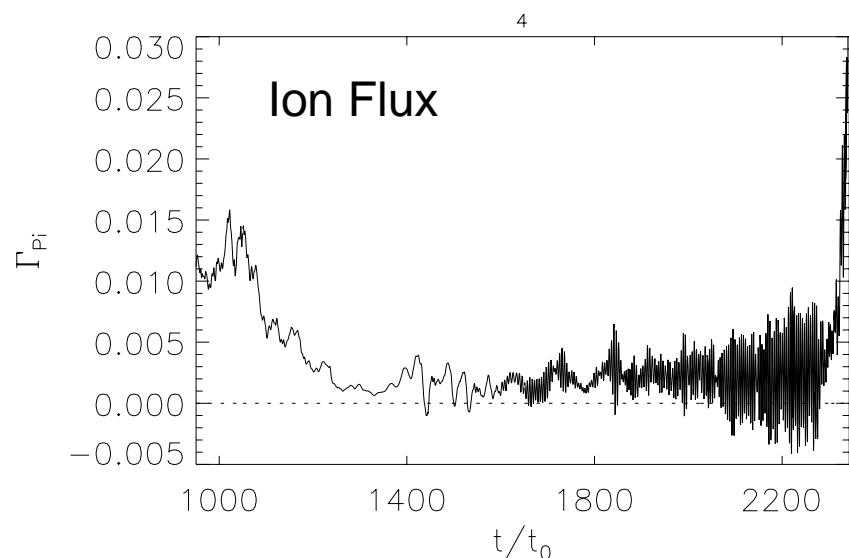
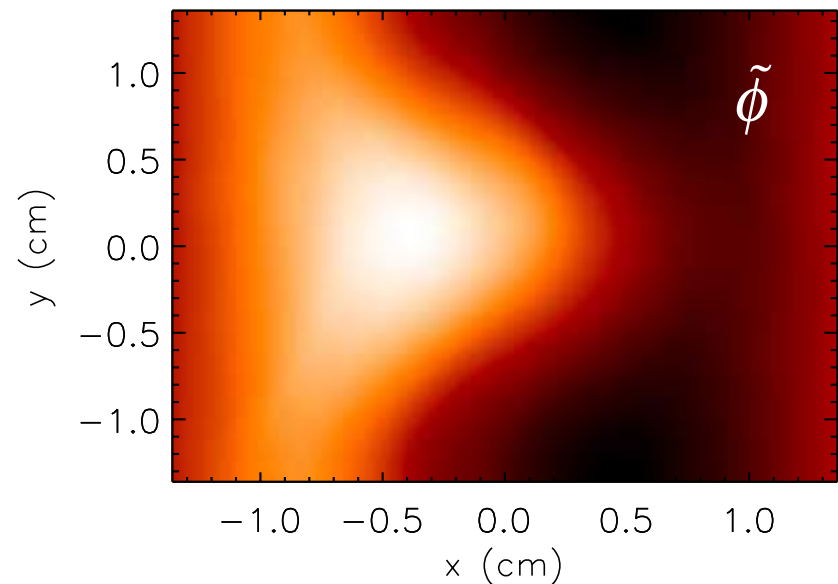


- Recently observed with a fast scanning magnetic probe (**Not** seen with standard set of fast magnetic pickups: m, k too large)
- $\tilde{j} \approx 20 \text{ A/cm}^2$ with $j_{\text{Ohmic}+\text{Bootstrap}} \approx 100 \text{ A/cm}^2$
- These are **not** ELM precursors (which are also seen, but at much lower m (10-20))

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



The calculated k
($3-6 \text{ cm}^{-1}$) and
frequency (50-
200 kHz) of this
mode¹ are in
rough
agreement with
our
measurements



¹Rogers and Drake, *Phys. Plasmas*, **6**, 2797 (1999)

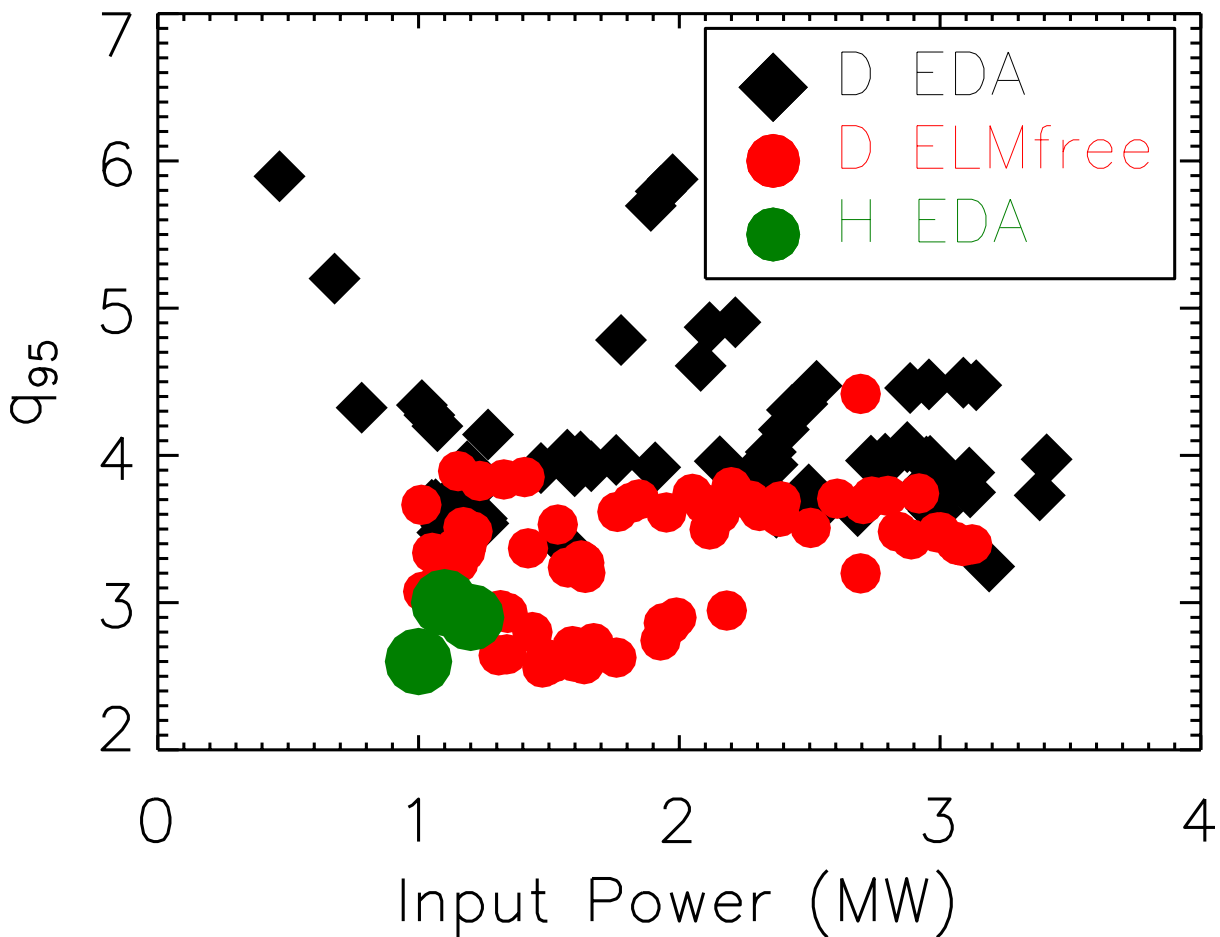
SCALING OF EDA/ELMFREE BOUNDARY WITH Q AND ION MASS IS CONSISTENT WITH STABILITY OF COLLISIONLESS BALLOONING MODES



Diamagnetic stabilization is significant for:

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

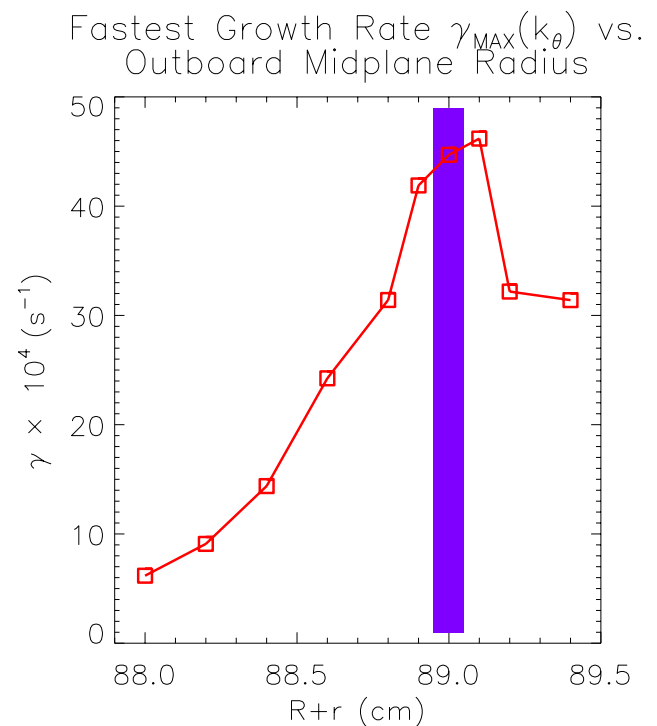
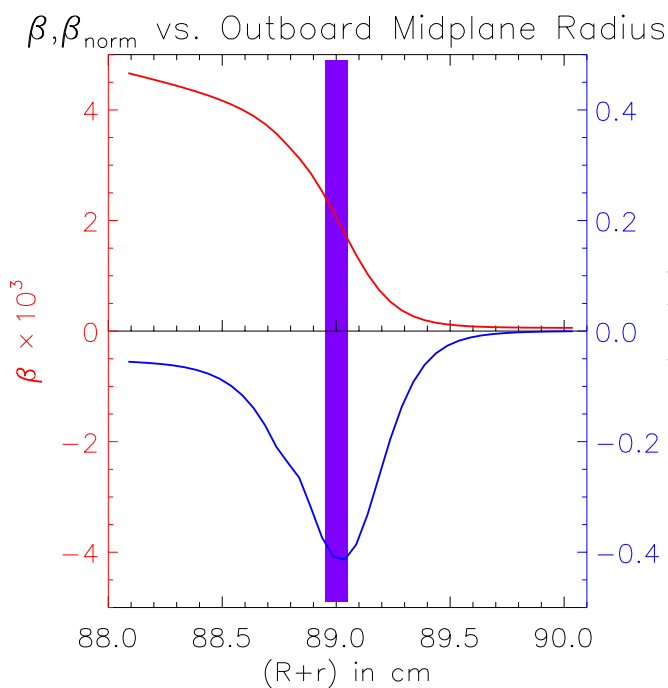
So, for $qR \propto L_{\parallel}$, $T_e \sim T_i$, critical $q \propto m_i^{0.5}$



GYROKINETIC STABILITY CODE (GS2²) FINDS UNSTABLE WITH CHARACTERISTICS SIMILAR TO EXPERIMENT



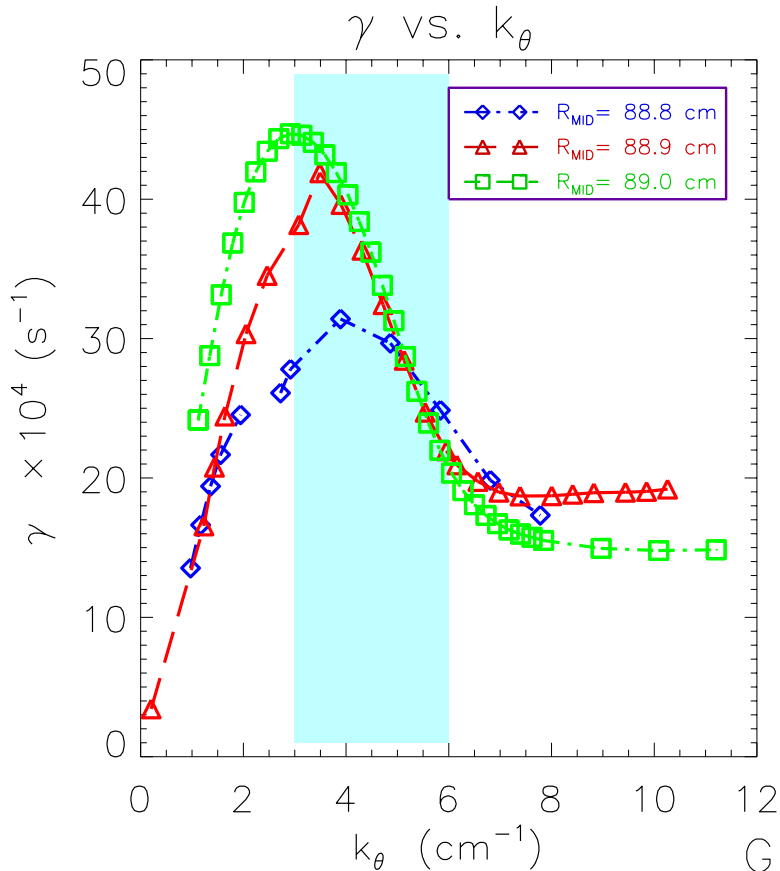
- GS2 solves 5-D gyrokinetic equations in the flux-tube limit as initial value problem - includes electrons dynamics and electromagnetic effects.



- Strongly growing unstable mode found in pedestal
- Tentatively identified as resistive ballooning mode

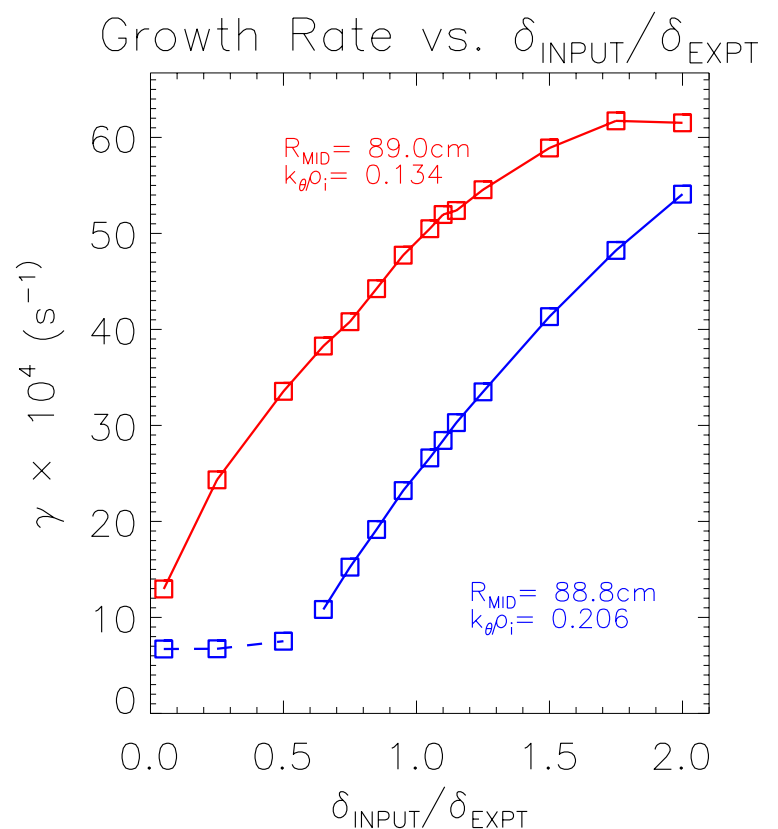
²Kotchenreuther, Rewoldt, Tang,
Comp. Phys. Comm., **88**, 128, (1995)

GROWTH RATES FOUND BY GS2 SHOW DEPENDENCIES CONSISTENT WITH EXPERIMENTS

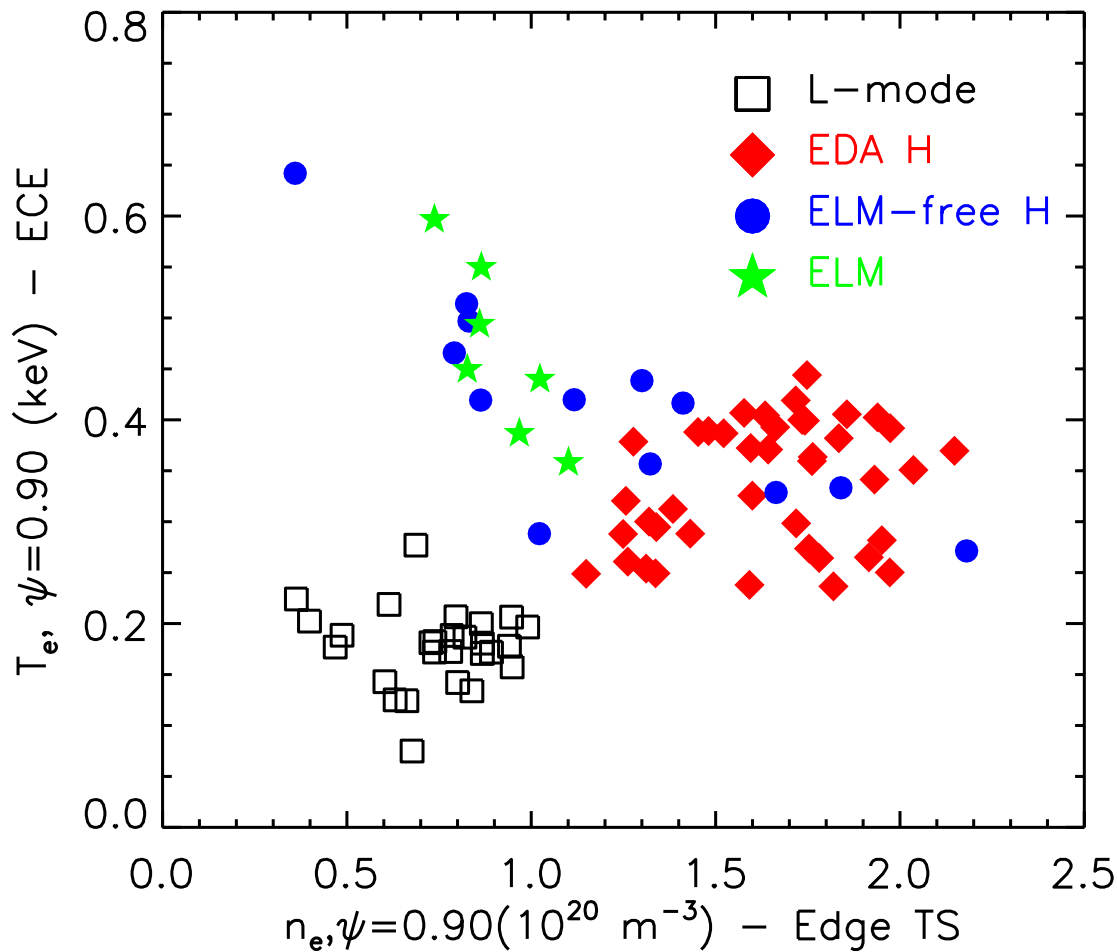


- Most unstable modes have k and ω in the range found in the experiment
- $D \sim \gamma/k^2 \sim 1 \text{ m}^2/\text{sec}$ is significant

- Growth rate increases with shaping (δ)
- May correspond to threshold seen in experiment



COLLISIONALITY MAY ALSO BE A KEY PARAMETER IN EXPERIMENTS

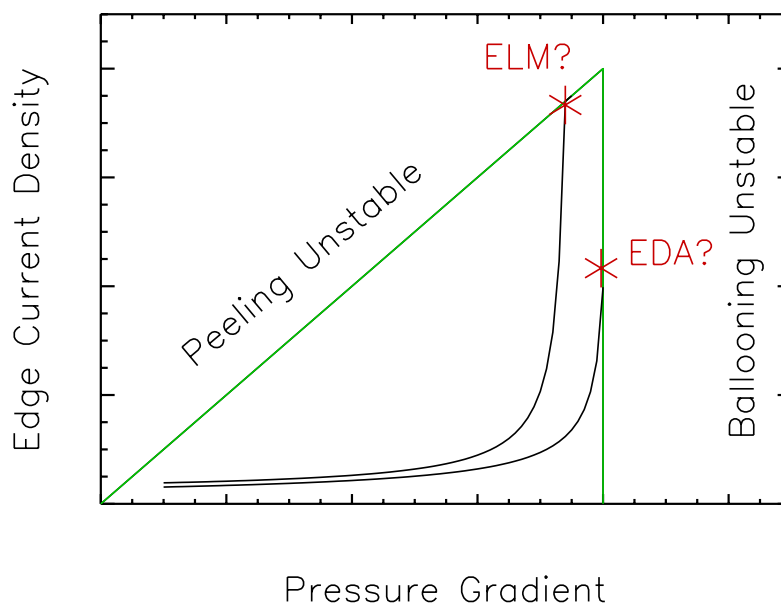


- At very low density (for C-Mod), isolated ELMs are seen rather than EDA
- If ELMs are current driven, higher edge collisionality might be stabilizing by reducing bootstrap current.

EDA AND EDGE STABILITY OF THE H-MODE

Alcator
C-Mod

- 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 ($\nu^* \sim 1-5$), 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.



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. ($f \sim 100$ kHz, $k \sim 5$ 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).
- These modes are tentatively identified as **resistive ballooning**
- We are also investigating the role of collisionality in suppressing edge current/ peeling modes.

OUTSTANDING QUESTIONS



- What is origin of quasi-coherent mode?
- What determines its wavelength and frequency?
- Why is it a single mode - no mixing/turbulence?
- What determines stability/growth rate?
- Why doesn't it cause more transport on other machines?