

## STUDIES OF EDA H-MODE IN ALCATOR C-MOD

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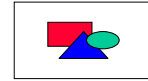
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<sup>1</sup>Princeton Plasma Physics Laboratory.

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and Transport Barrier Physics

Oxford, October 1999

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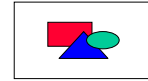


## TYPE I ELMy DISCHARGES ARE NOT SEEN IN C-MOD INSTEAD, A REGIME THAT WE HAVE CALLED EDA (ENHANCED $D\alpha$ ) IS OBSERVED

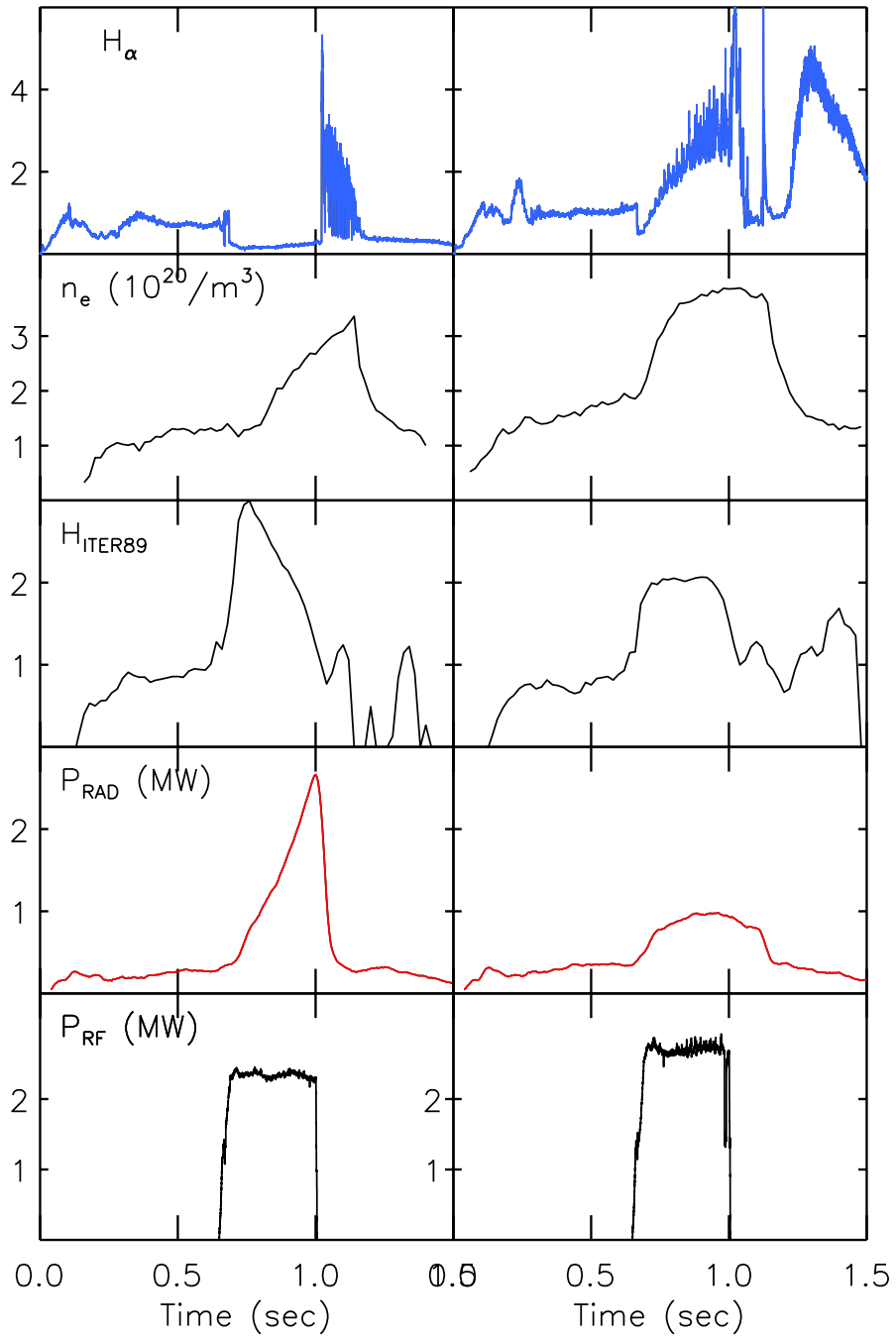
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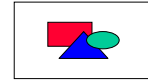
- First signature - enhanced level of light from neutral deuterium
- Particle confinement much lower than ELM-free
- **No strong accumulation of impurities**
- Energy confinement slightly lower than ELM-free (10-20%)
- **No large discrete ELMs**
- So far, we don't see type I ELMs, though pressure gradient challenges MHD ballooning stability limit
- $T_e$  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  
Shares many characteristics with type II or other "small"  
ELM regimes (DIII-D, JT60-U).



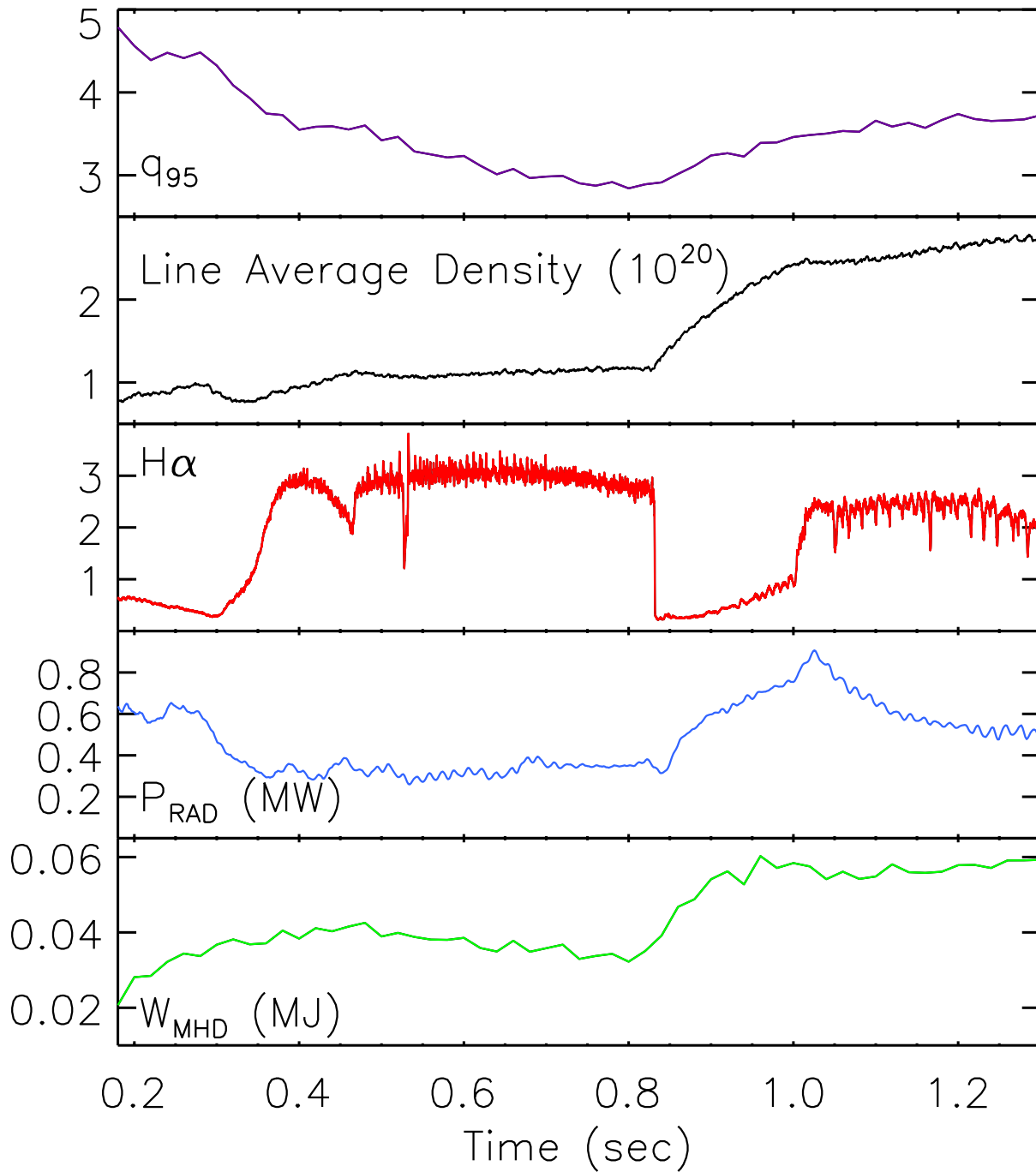
# EDA H-MODES DO NOT SHOW IMPURITY ACCUMULATION

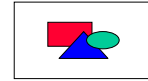




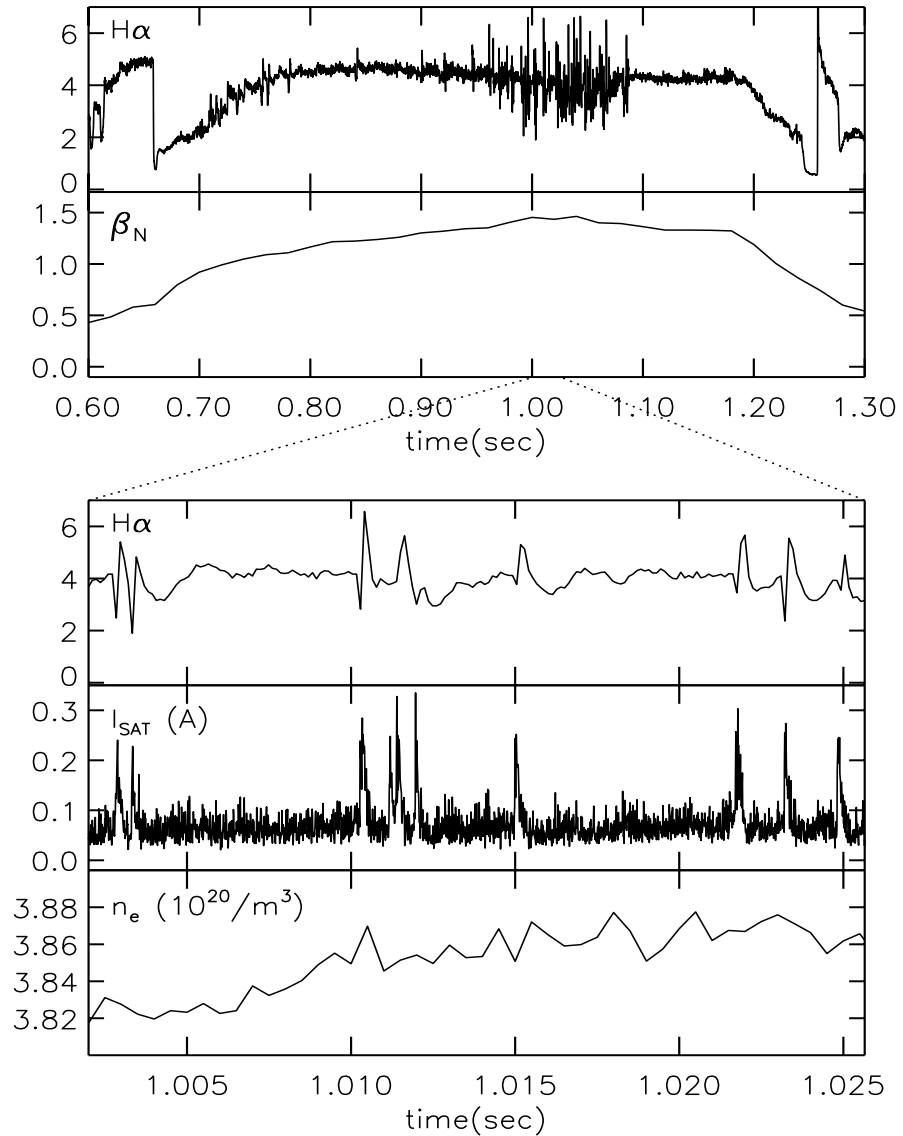
# EDA H-MODES ARE READILY OBTAINED WITH OHMIC HEATING ALONE

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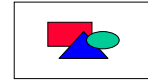




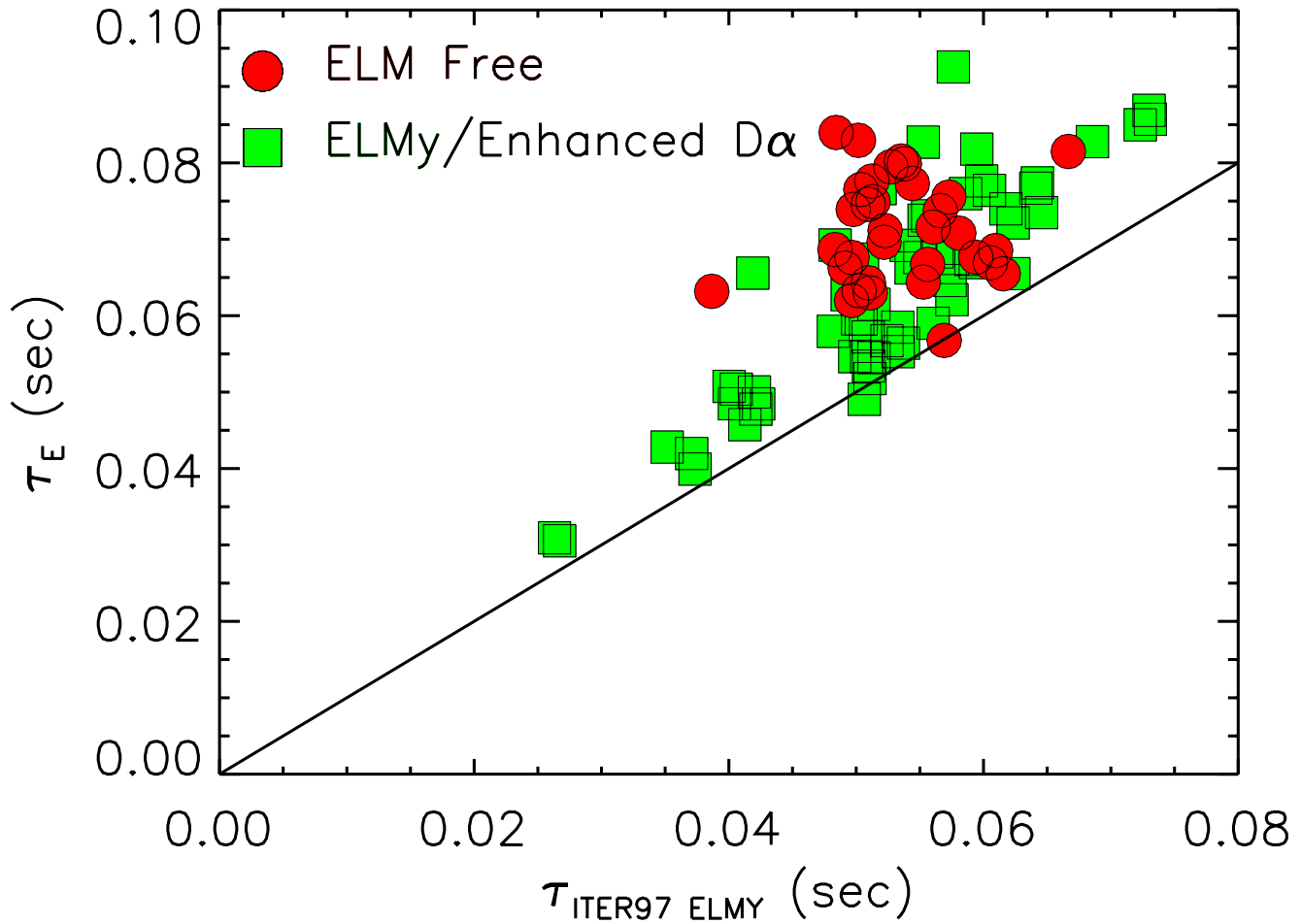
## SMALL ELMS ARE OFTEN SEEN ON TOP OF EDA



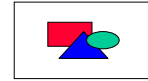
- Seen when  $\beta_N > 1.2 - 1.3$
- Negligible net loss of energy or particles detected by core diagnostics



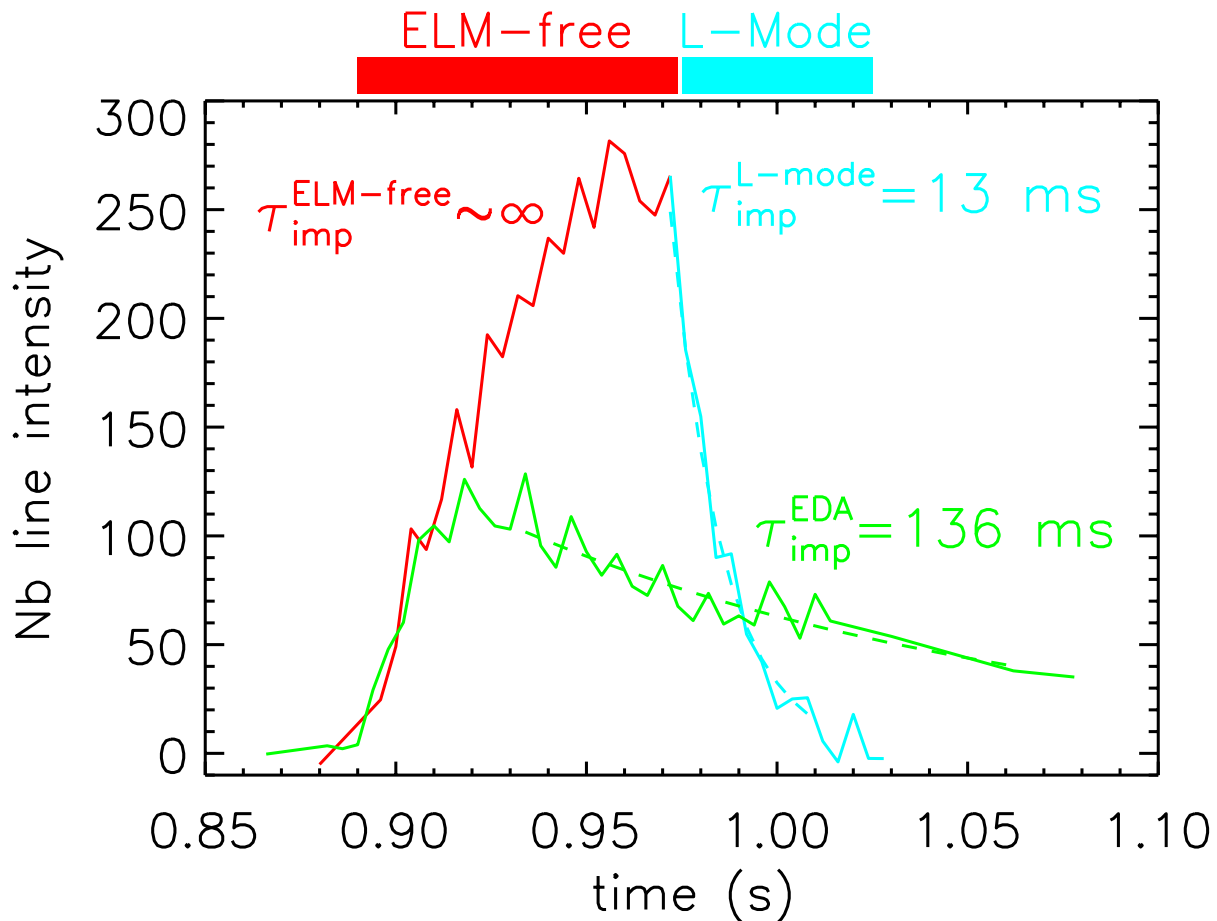
## EDA DISCHARGES HAVE ENERGY CONFINEMENT ONLY SLIGHTLY LESS THAN ELM-FREE



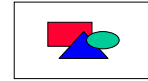
- C-Mod data are in rough agreement with latest ITER H-mode scaling laws (though about 15% higher)
- for ELM-free:  $H_{ITER89} = 2.1$
- for EDA:  $H_{ITER89} = 1.9$



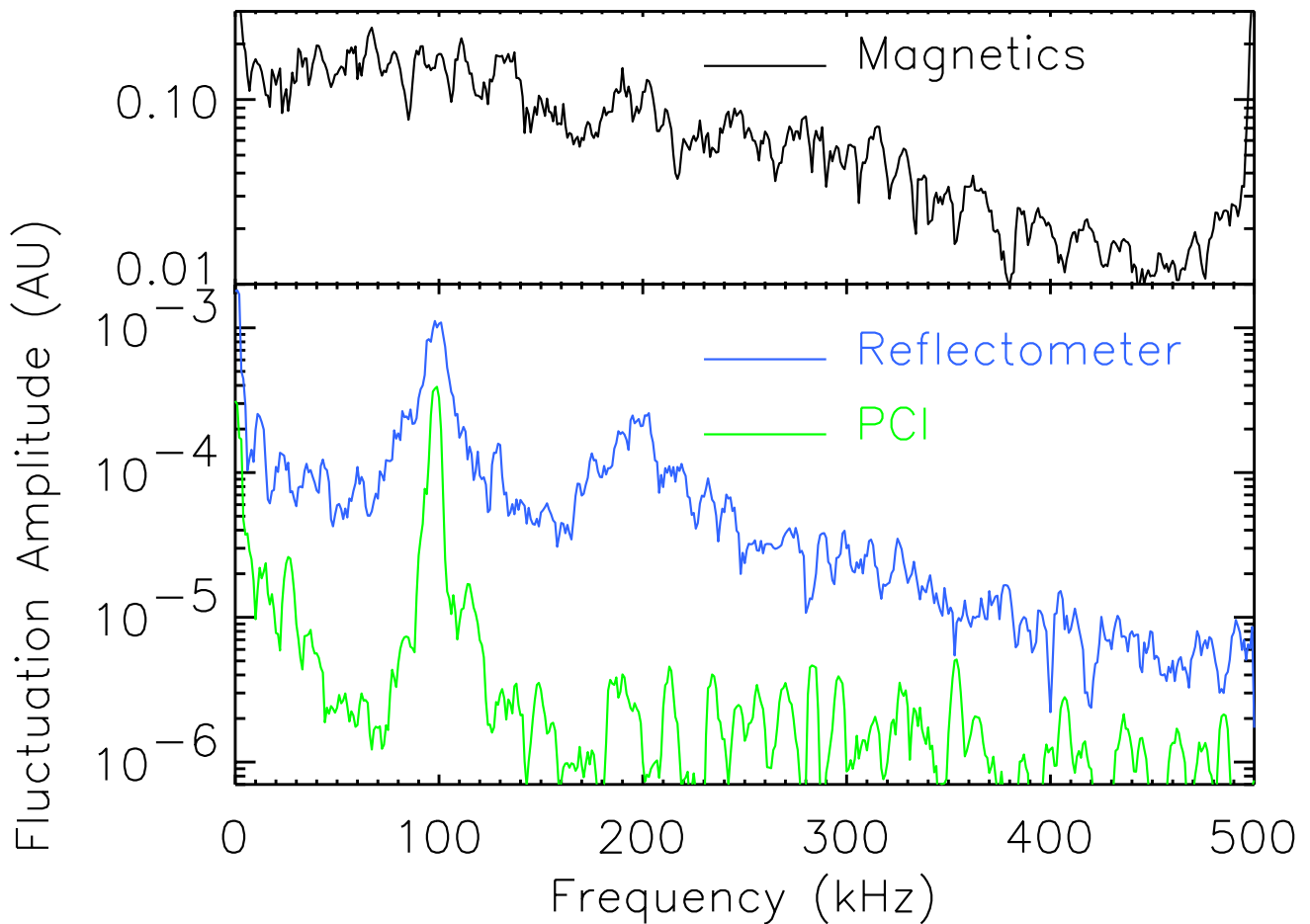
## THE BEHAVIOR OF INJECTED IMPURITIES IS CONSISTENT WITH THAT OF INTRINSIC IMPURITIES



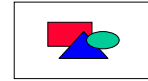
- In ELM-free H-modes,  $\tau_I$  is too long to measure.  $\tau_I \gg \tau_E$
- For EDA,  $\tau_I \sim 2-3 \times \tau_E$
- For L-Mode,  $\tau_I < \tau_E$



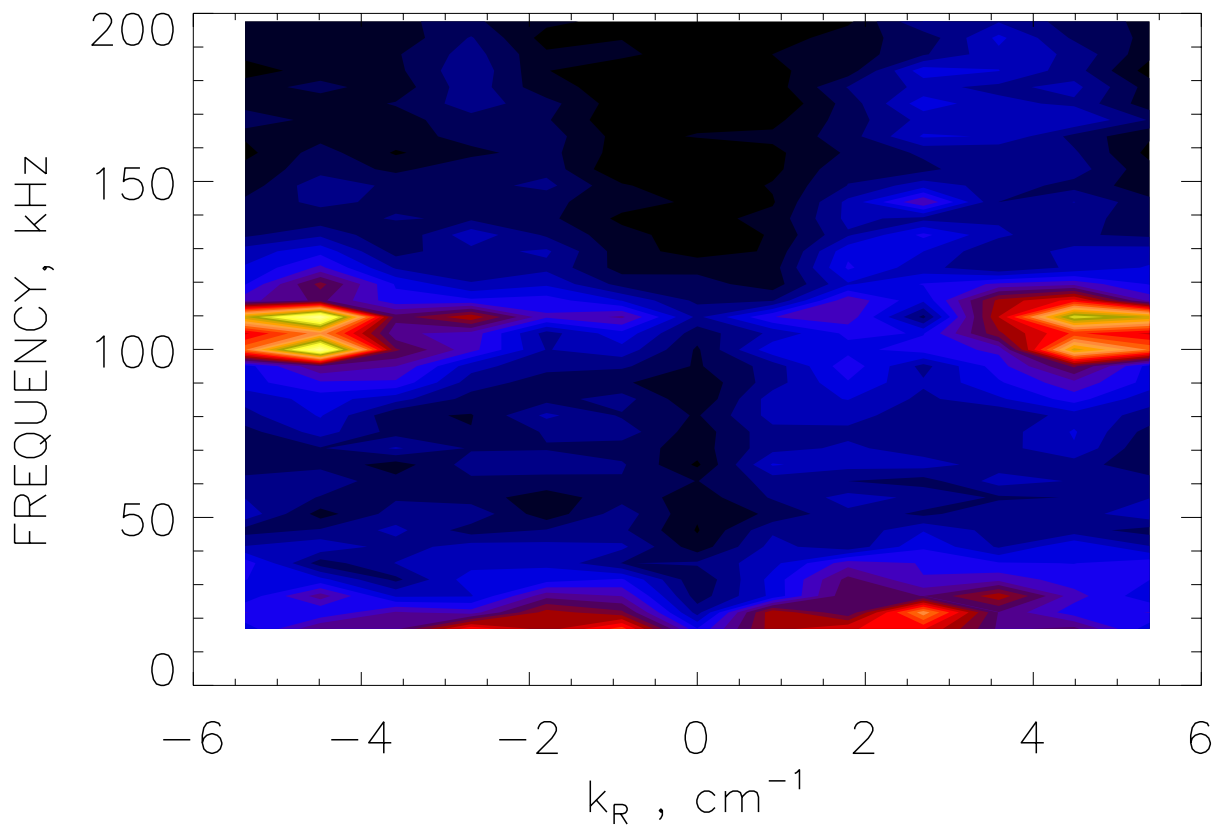
## SIMILAR FLUCTUATIONS ARE SEEN WITH PCI (Phase Contrast Imaging)



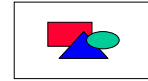
- Power spectra from both diagnostics see quasi-coherent feature.
- Broadband feature shows up on reflectometer and magnetics
- Diagnostics view different parts of the plasma and have different  $k$  sensitivities (see posters by Lin, Mazurenko, Hutchinson – Wed. afternoon)



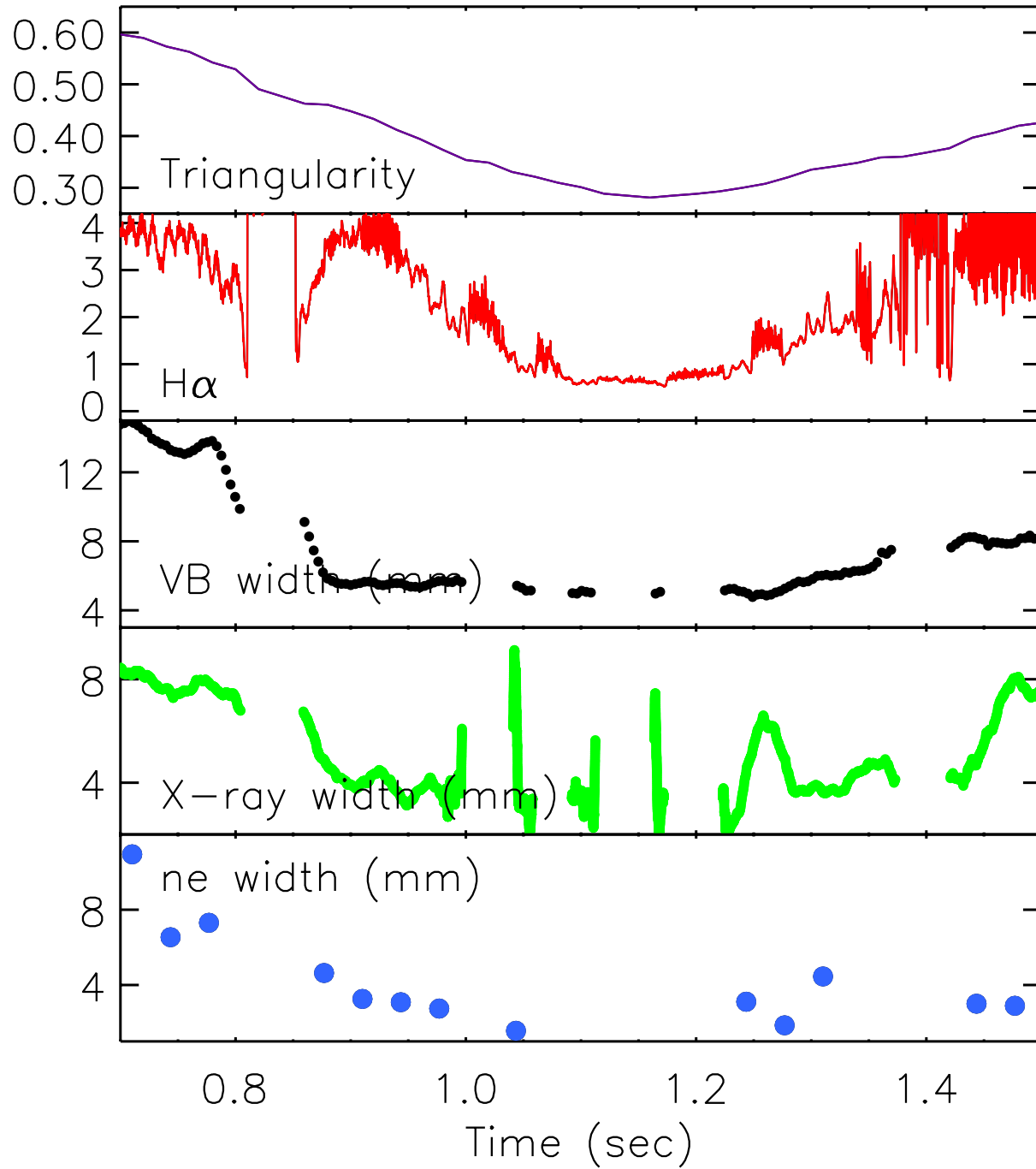
## PCI SHOWS A SIGNAL WITH A WELL DEFINED $\omega$ AND $k$ STRUCTURE

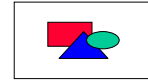


- Data taken from a short interval of time during EDA H-mode
- $\omega$  and  $k$  vary with the strength of the  $H\alpha$  signal and are modulated by sawteeth



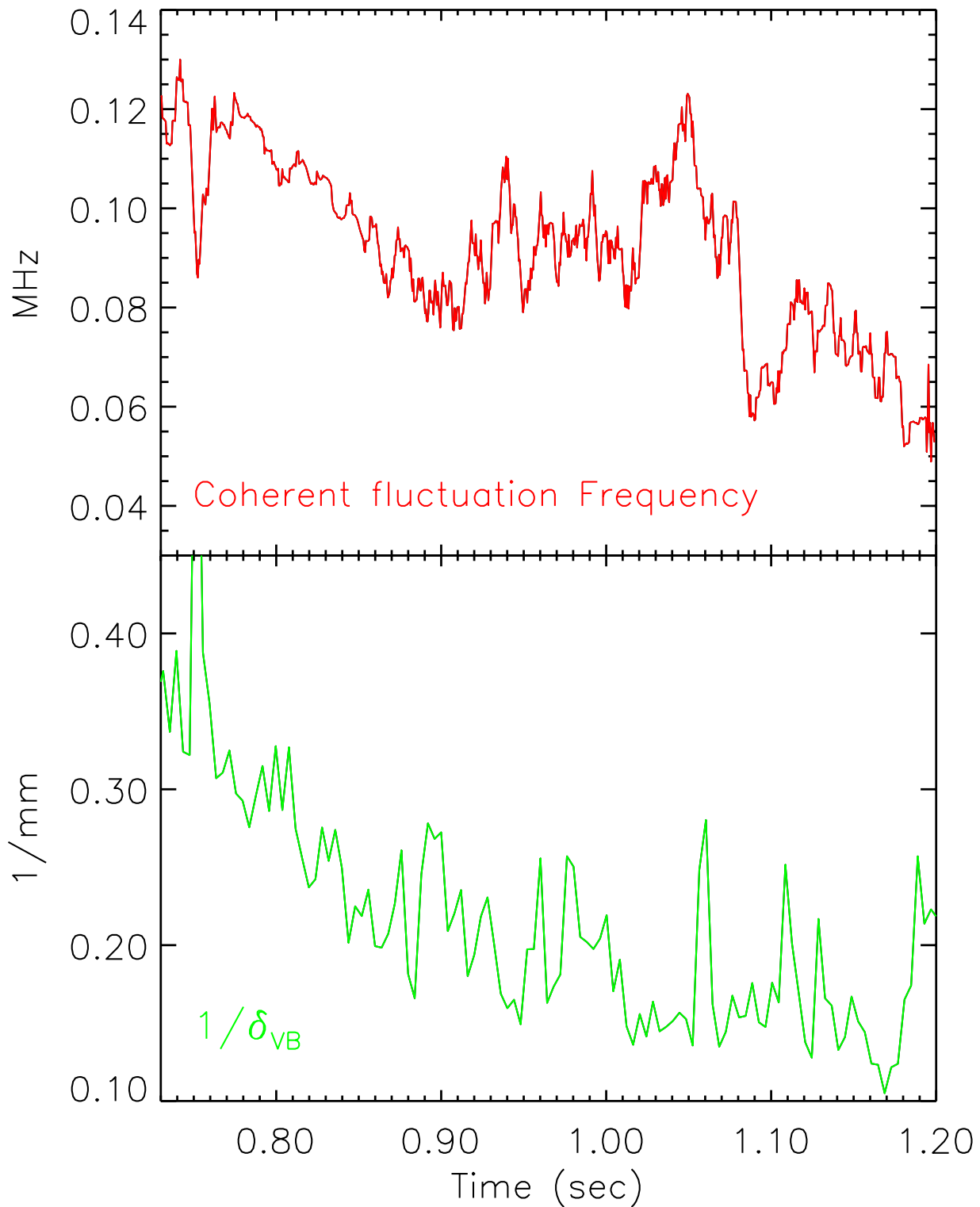
# WIDTH OF EDGE PROFILES SCALES WITH $\delta$

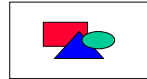




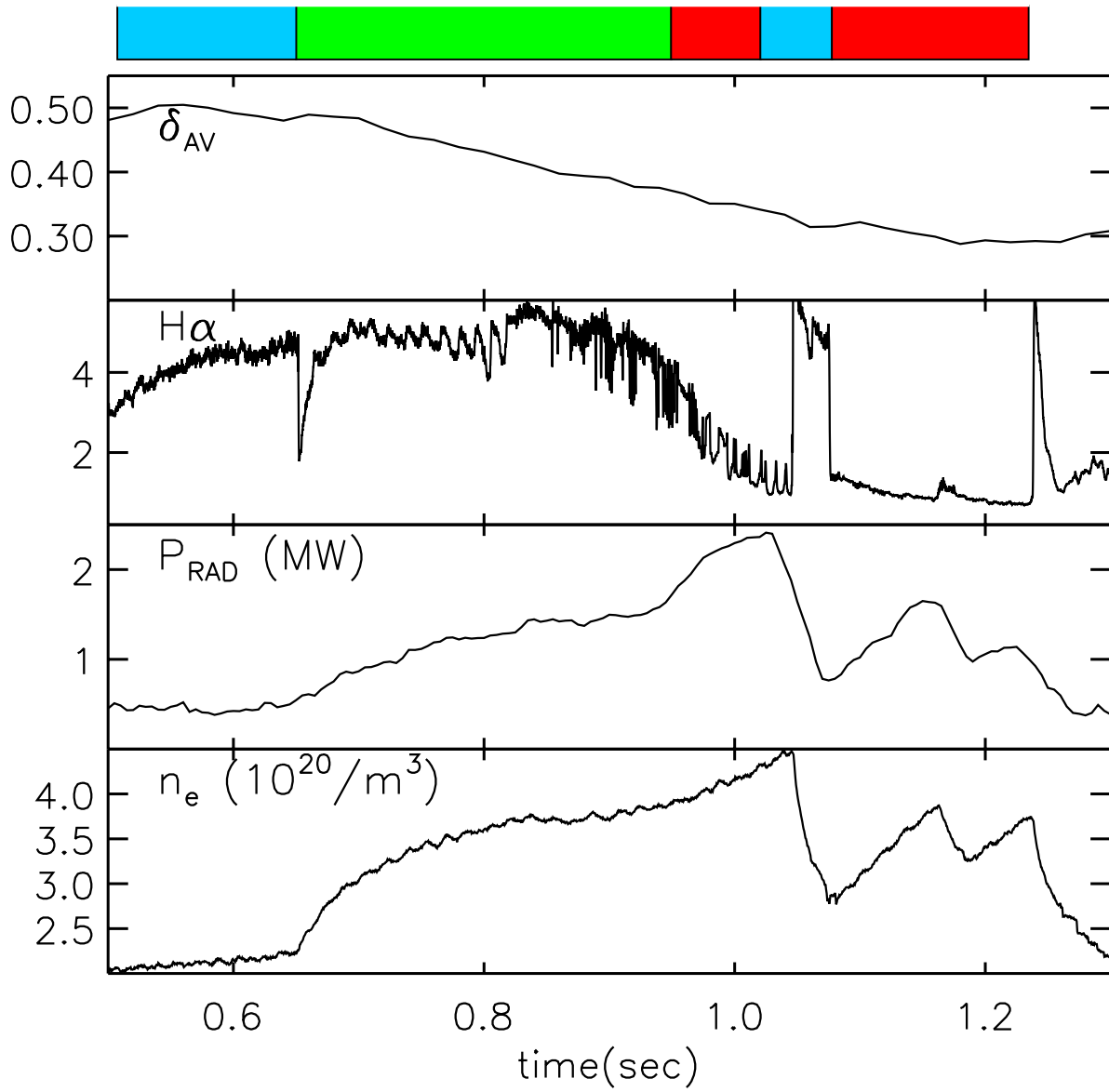
# QUASI-COHERENT FLUCTUATION FREQUENCY SCALES INVERSELY WITH PEDESTAL WIDTH

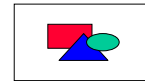
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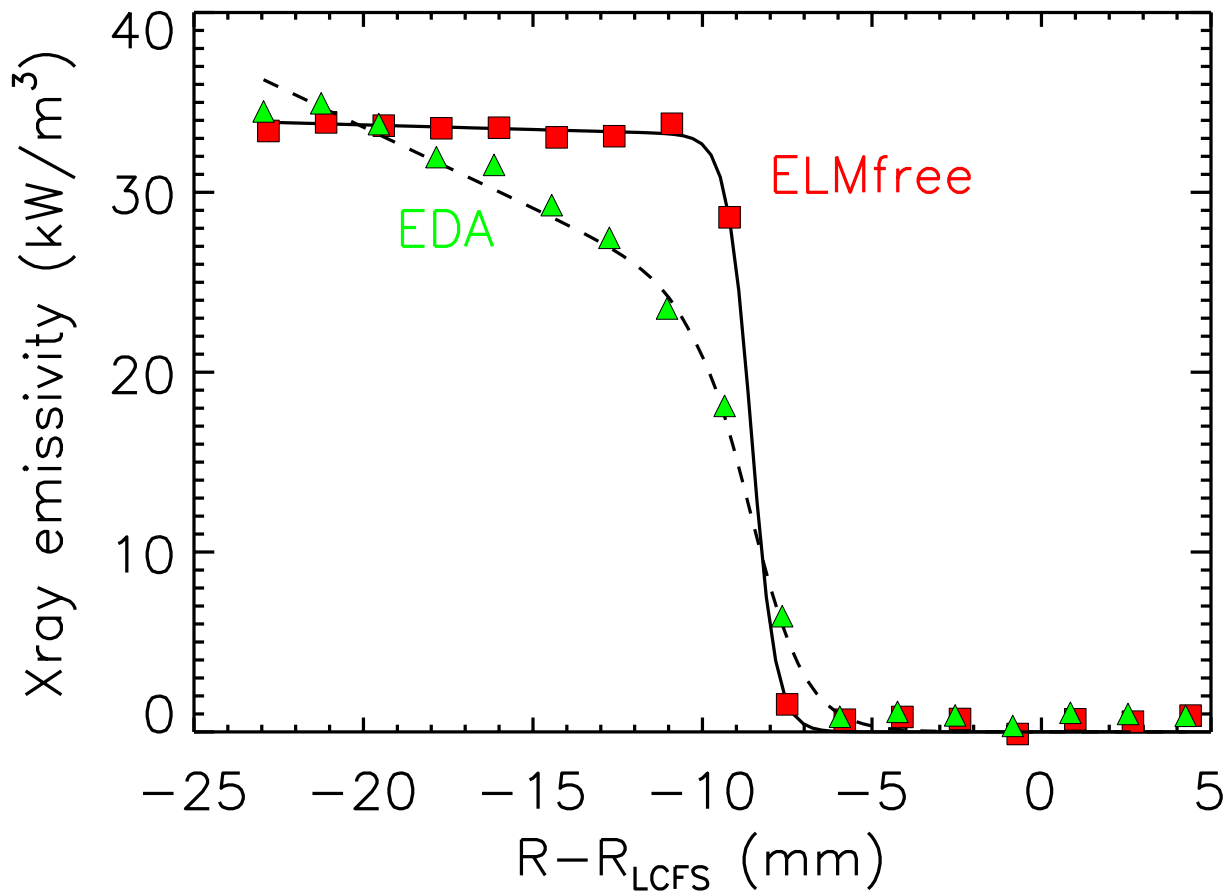


# EDA-ELM-free BOUNDARY IS A FUNCTION OF $\delta$

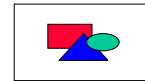




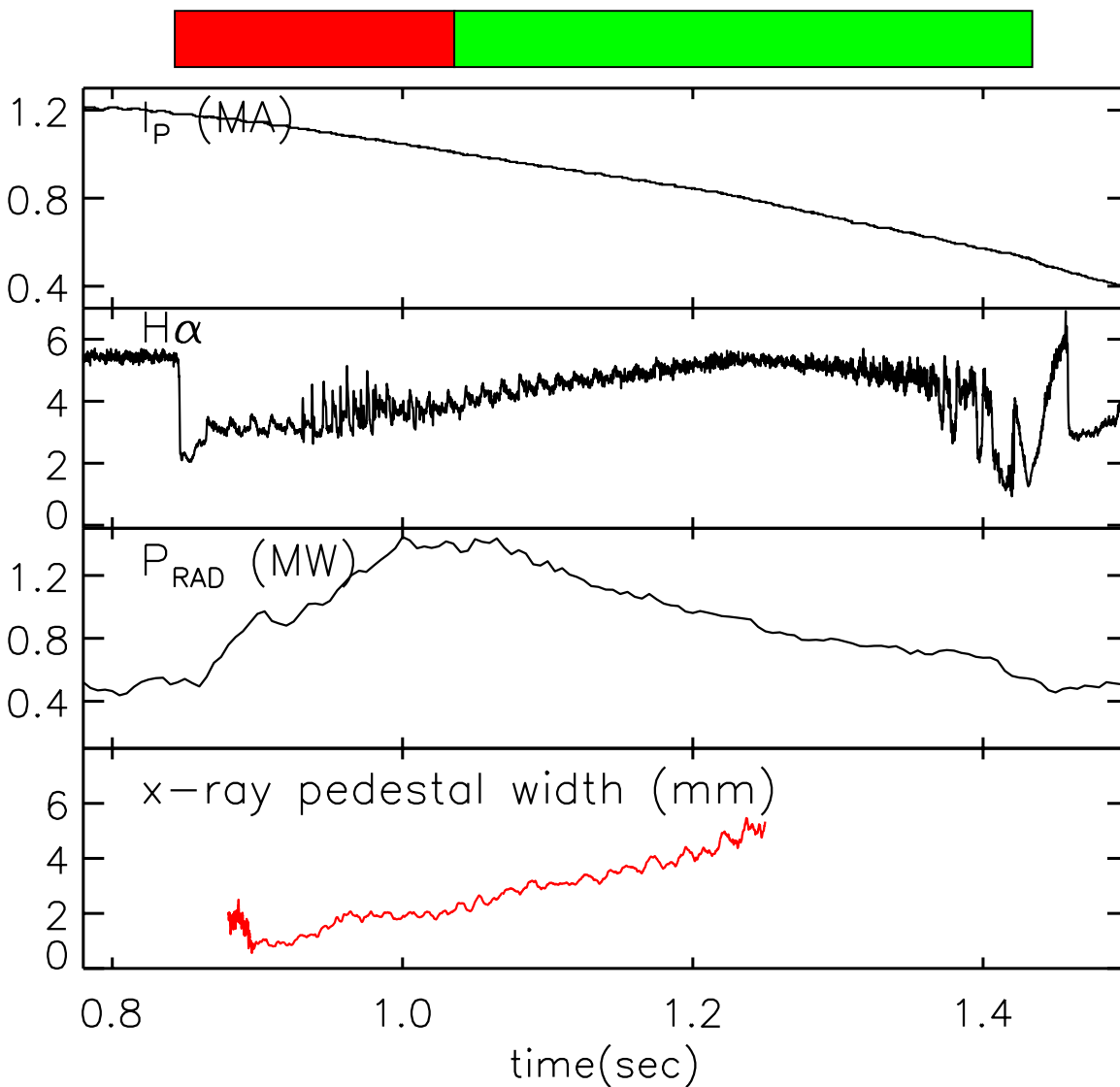
## HIGH RESOLUTION X-RAY MEASUREMENT PROVIDES DETAIL ON EDGE DENSITY PROFILES

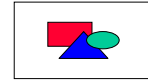


- H-Mode pedestal scale lengths in C-Mod are typically < 1 cm.
- To begin studies of pedestal scaling, a very high resolution soft x-ray array was installed.
- X-ray signal intensity  $\sim n_e n_i$  (profile width a measure of particle transport)

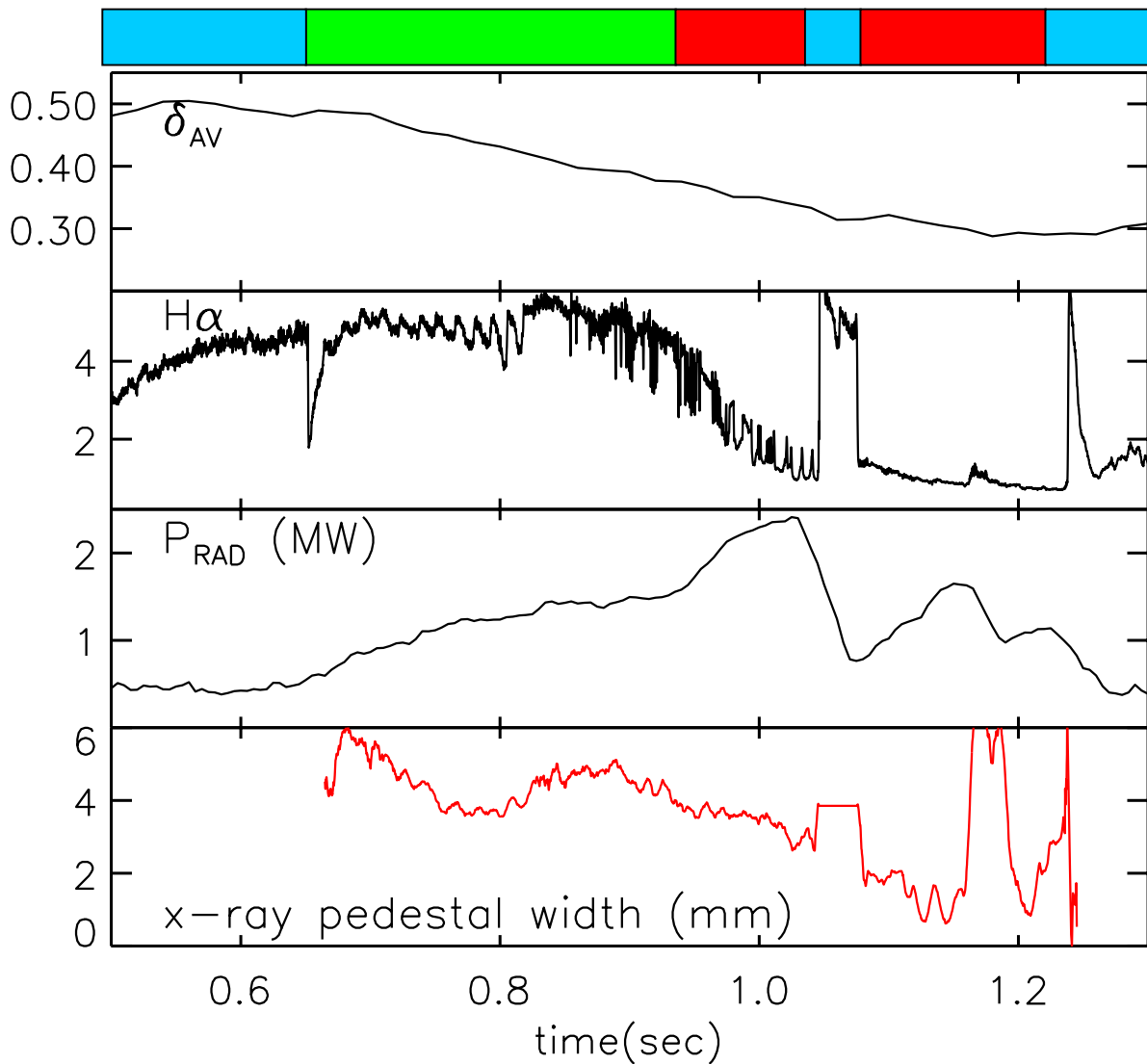


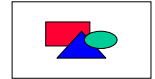
# X-RAY PEDESTAL WIDTH SCALES WITH $I_p$ IN THE SAME MANNER AS THE EDA/ELM-FREE BOUNDARY



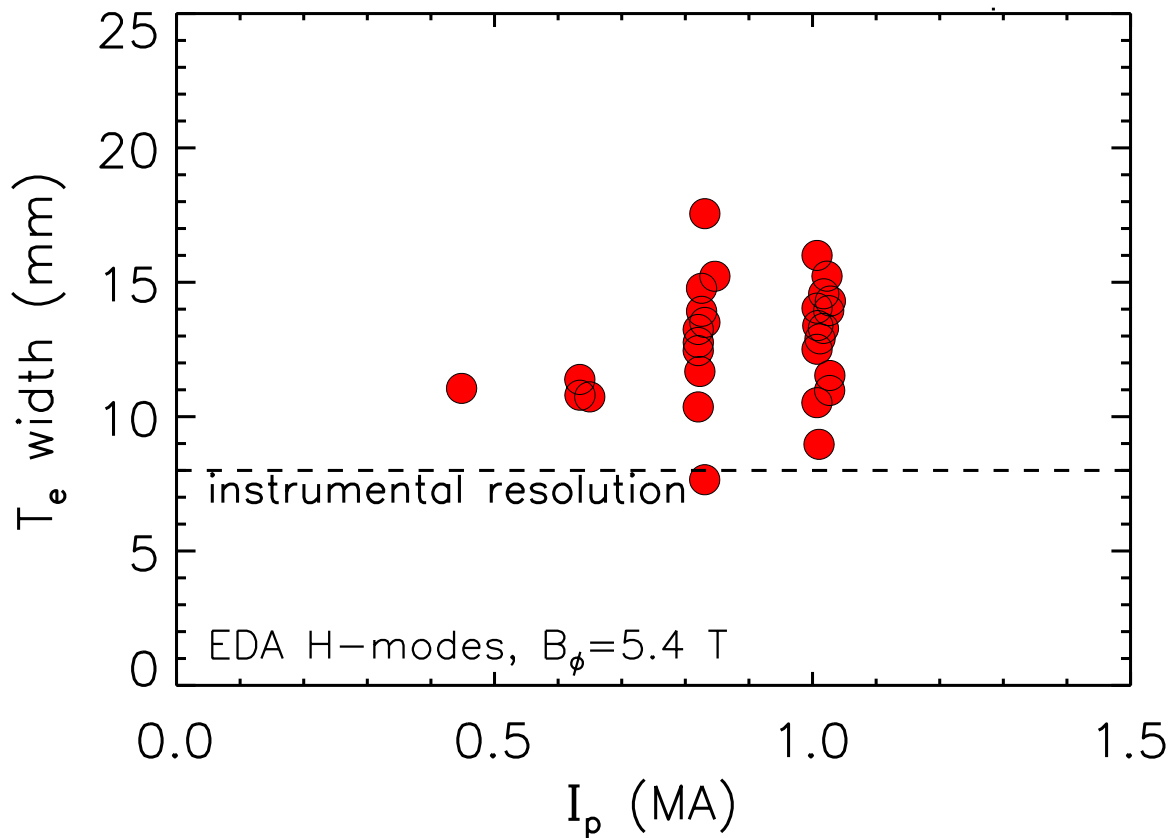


# X-RAY PEDESTAL WIDTH SCALES WITH $\delta$ IN THE SAME MANNER AS THE EDA/ELM-FREE BOUNDARY

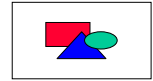




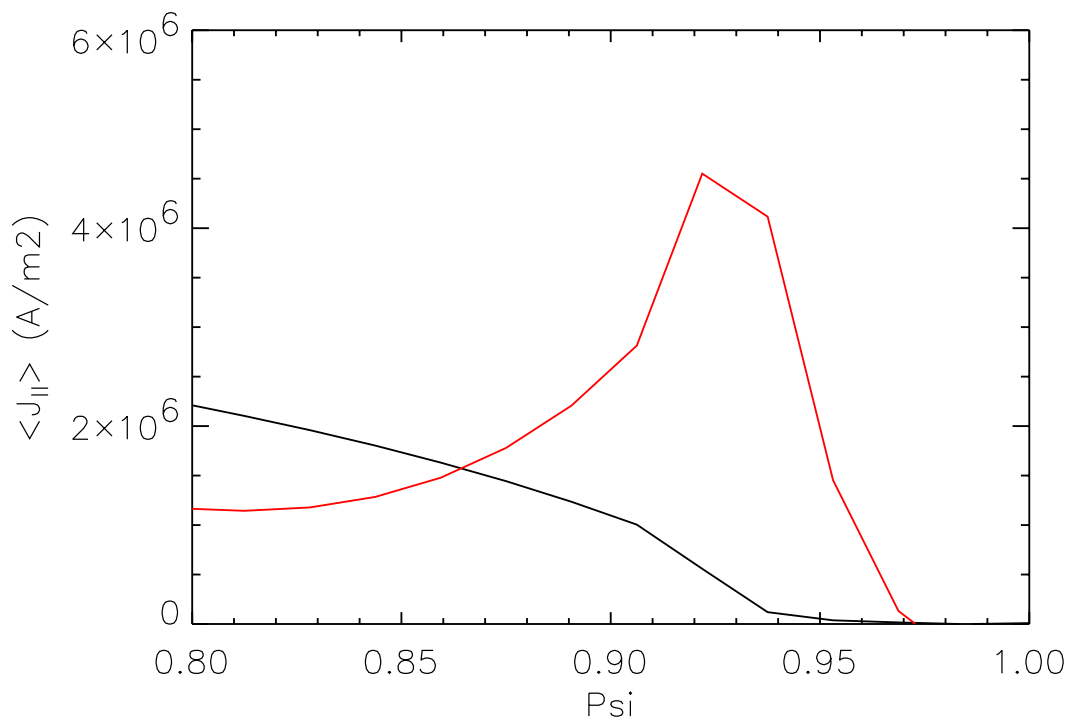
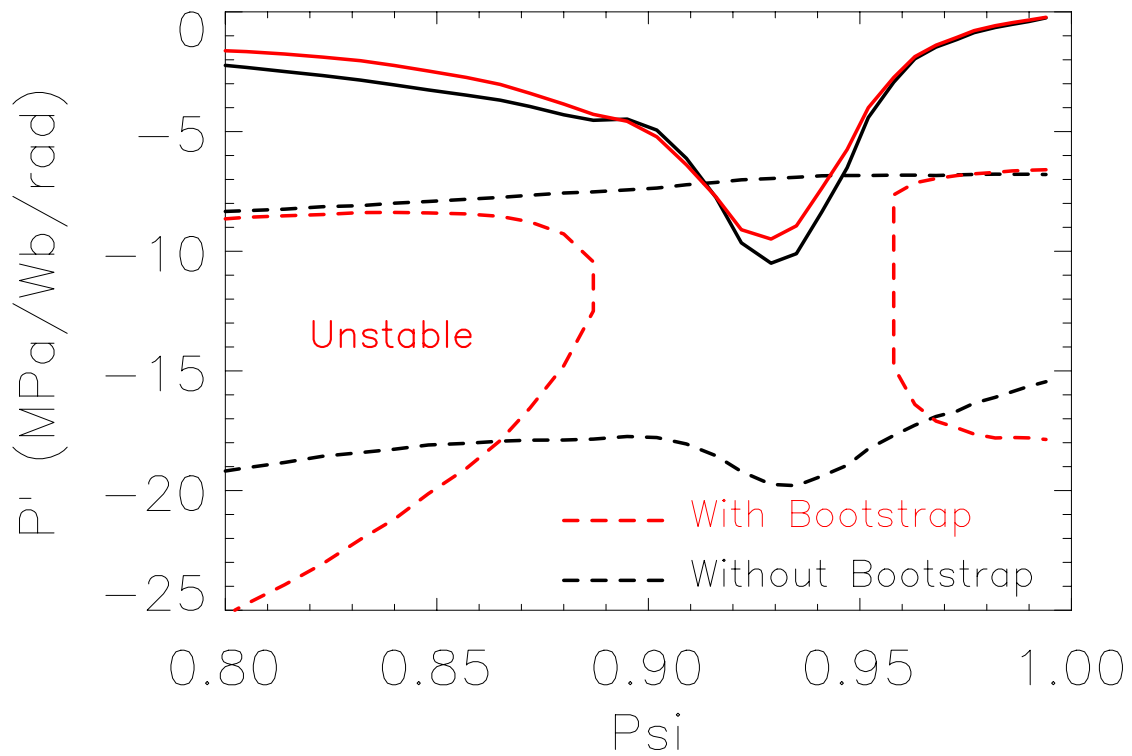
# Te PEDESTAL PROFILE DOES NOT SHOW STRONG SCALING

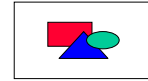


The difference between the scaling of  $T_e$  and the x-rays may reflect the difference in the effect of EDA on energy and particle confinement



# THE PEDESTAL IS FOUND TO BE MHD STABLE ONLY WITH THE INCLUSION OF EDGE CURRENT

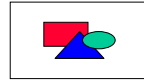




## STABILITY OF THE H-MODE EDGE

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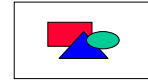
- The dependence of the EDA/ELM-free boundary on  $\delta$  and  $q$  are reminiscent of the MHD stability calculations done by Miller et al. (Bootstrap current and access to 2<sup>nd</sup> stability).
- However, to interpret our results in that light, it would be necessary to identify EDA as the **more** stable state
- Due to its high density, the edge plasma in C-Mod is quite collisional ( $v^* \sim 1-5$ ), so bootstrap current will be reduced.
- In this light, we may be able to understand the absence of type I ELMs through the stability of the peeling modes (see Connor and Wilson)
- The fluctuations seen in EDA have the character of turbulence rather than ideal MHD.
- We are beginning to investigate whether EDA is a manifestation of Drift Alfvén turbulence



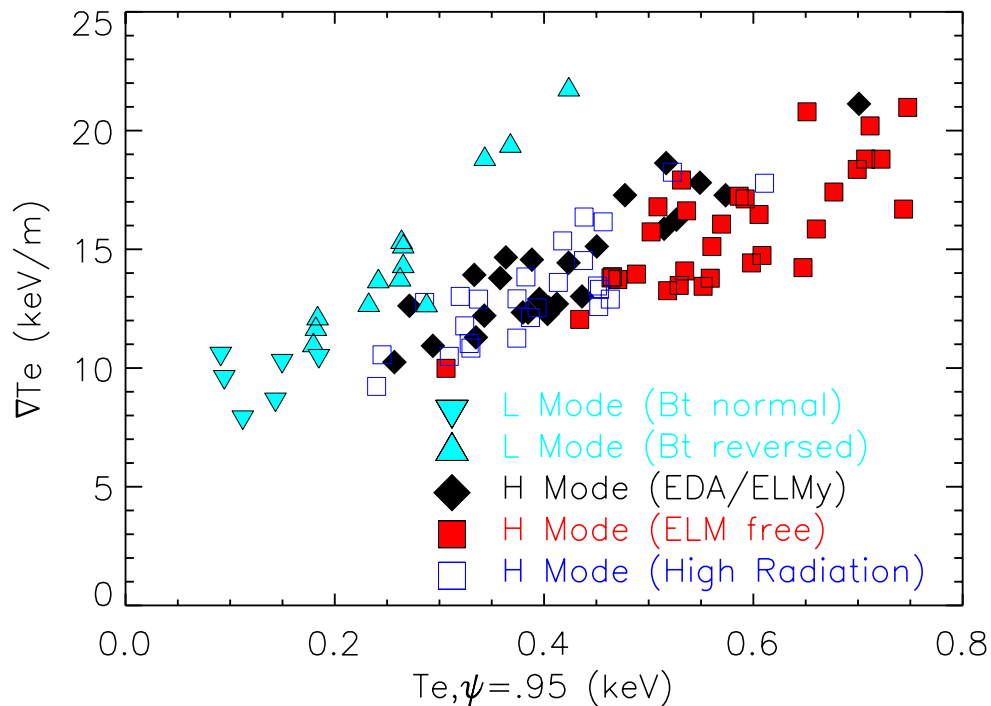
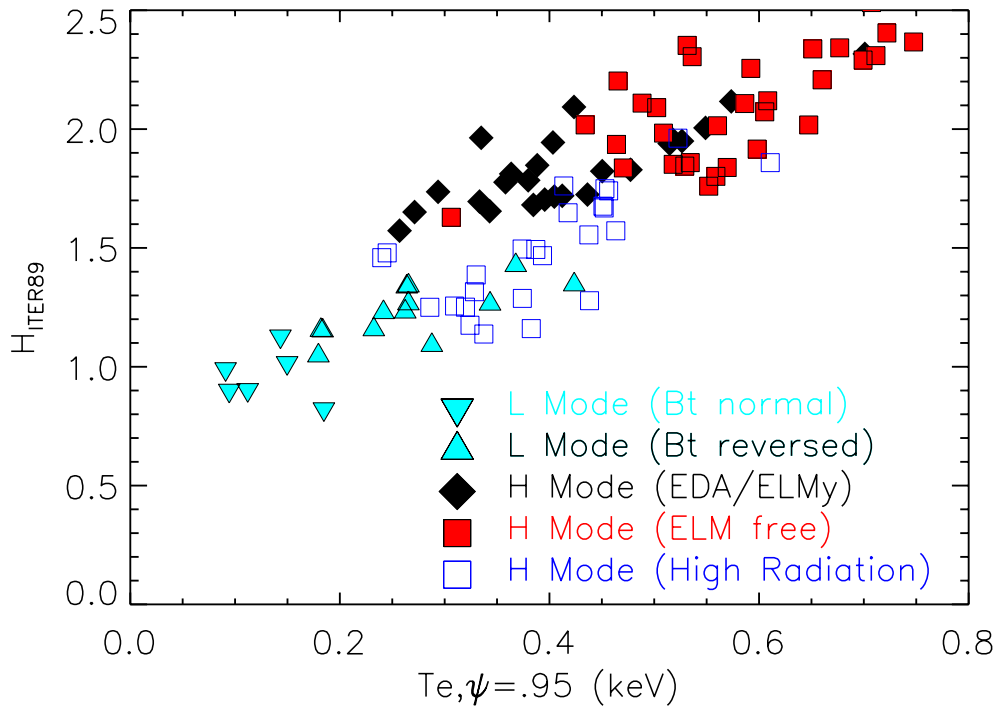
## SUMMARY

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- The EDA regime combines good energy confinement, moderate particle confinement and no energy impulses to the first wall.
- The pedestal is limited by a continuous rather than intermittent process, probably related to density and magnetic fluctuations which are observed.
- EDA is most easily accessed at  $q_{95} > 3.5$ ,  $\delta > 0.35$
- EDA is easily obtained with ohmic heating alone - rules out fast particles or RF/Edge interactions as cause.
- Pedestals scale in the same manner as EDA/ELM-free boundary



# CORE CONFINEMENT AND GRADIENTS DEPEND ON EDGE TEMPERATURE



# ALCATOR C-MOD FLUCTUATION DIAGNOSTICS

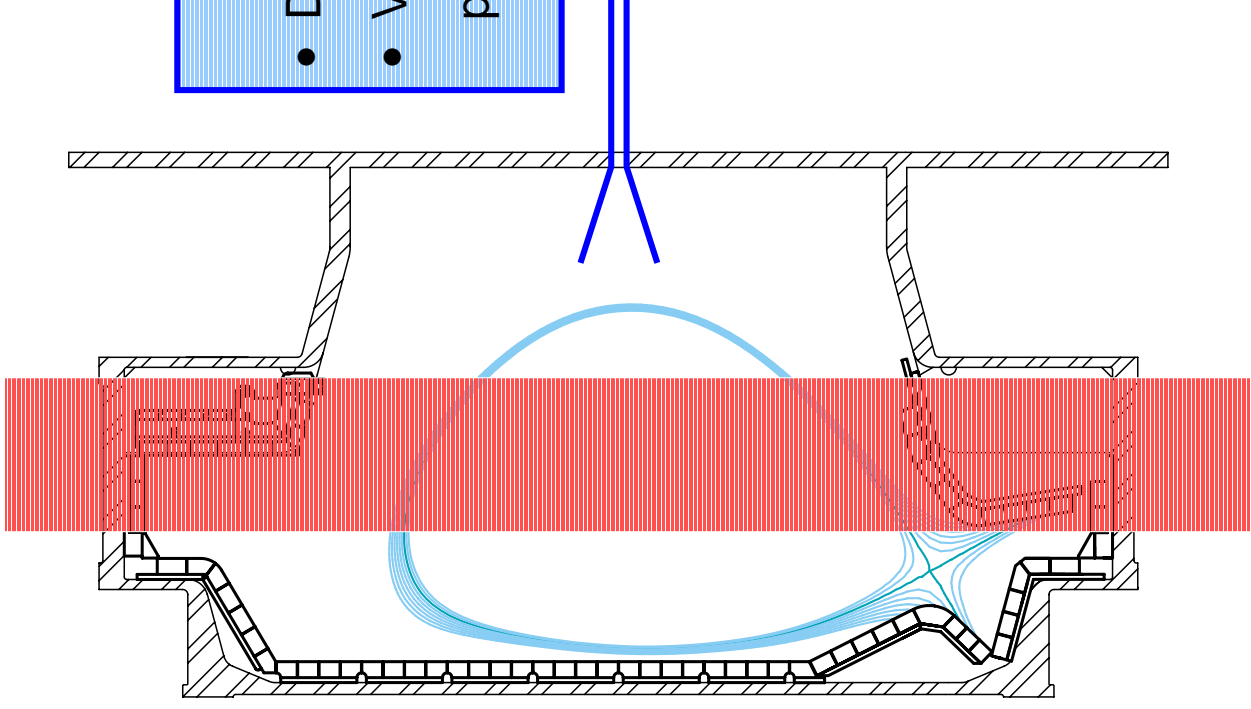


## Phase Contrast Imaging

- Density fluctuations
- Line integral through core

## Reflectometry

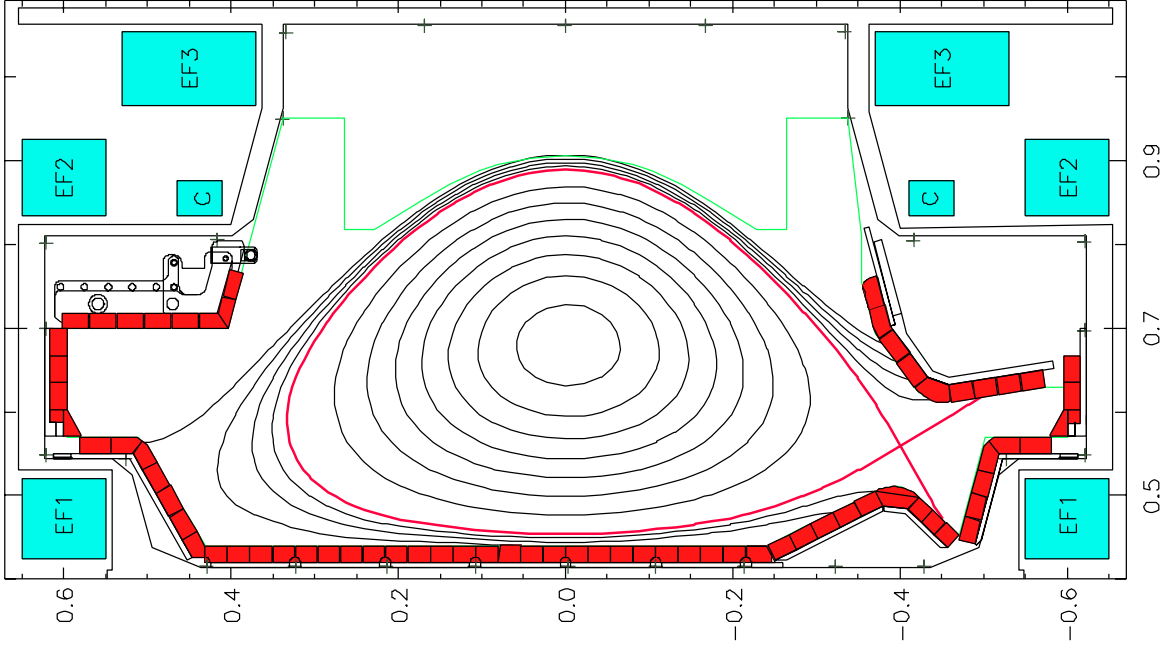
- Density Fluctuations
- Views foot of pedestal in H-Mode



## Magnetic Probes

- BP fluctuations
- Poloidal and toroidal arrays





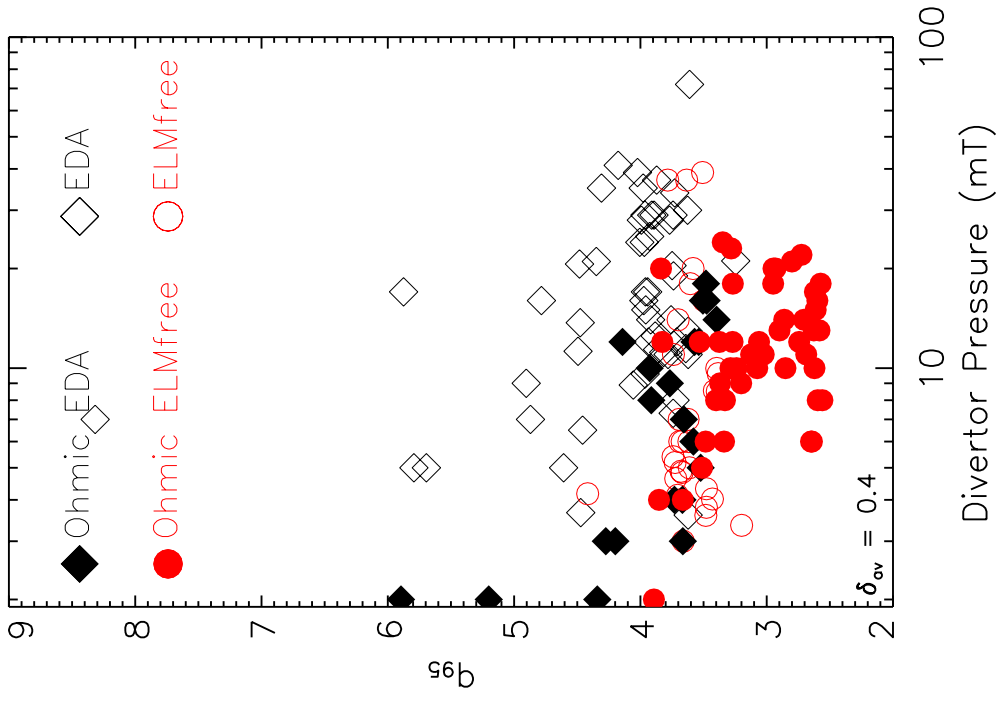
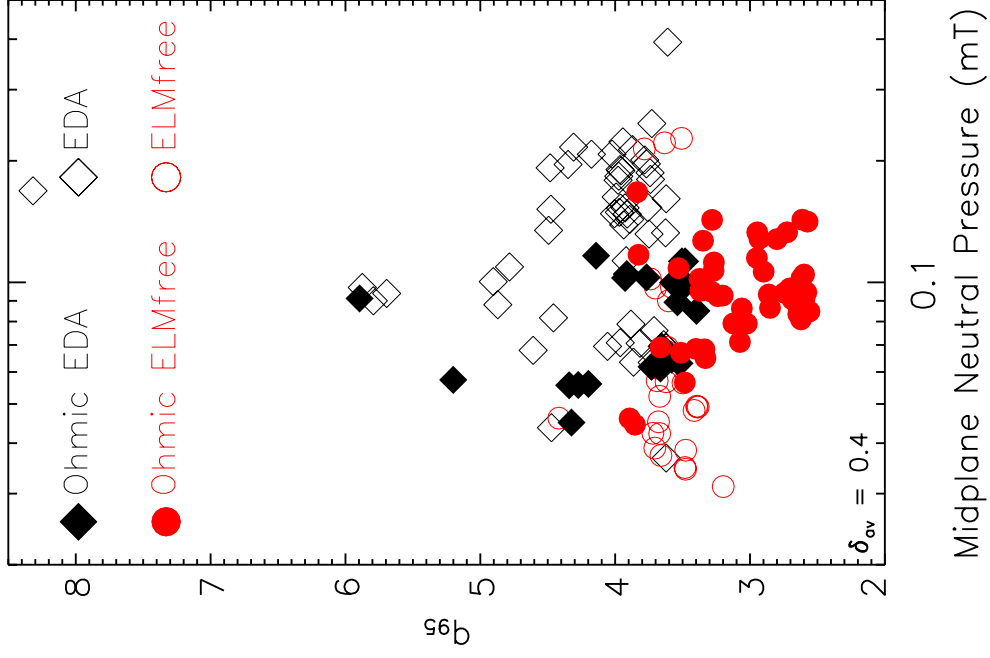
## Characteristics of Alcator C-Mod

### Tokamak

- High  $B/R$ ,  $n_e$ , neutral pressure
  - ▶  $T_e \sim T_i$
  - ▶ Minimal fast ion content
- Strong ICRF heating
  - ▶ No central particle source
  - ▶ No external torque
- Closed Divertor
- Molybdenum walls - boronized



# EDA SEEN AT $Q > 3.5$ WITH SIMILAR BOUNDARY FOR OHMIC AND ICRF PLASMAS



# NO STRONG DEPENDENCE IS SEEN ON TOTAL OR NET POWER

