Spontaneous Intrinsic Rotation and Changes in Turbulence in Ohmic H-modes on NSTX

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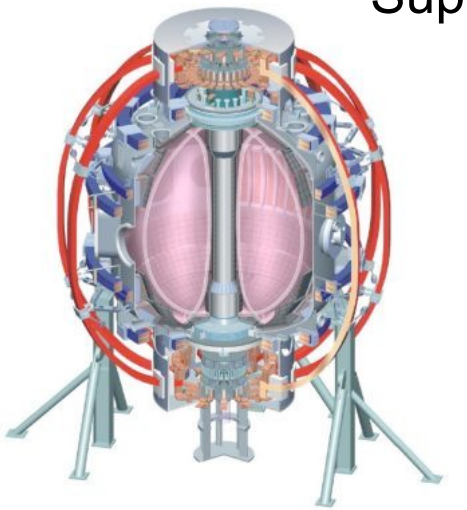


Abstract

Spontaneous spin-up in intrinsic toroidal and poloidal rotation of impurity ions (mainly carbon and helium) was observed at the edge of ohmic plasmas during L-H mode transitions in NSTX. The rotation was usually reduced again after the H-L back transition. The changes in rotation were accompanied by changes in plasma fluctuations and turbulence observed over a wide extent of the plasma minor radius from the far SOL to relatively deep in the core using a variety of diagnostics including fast reflectometry and Langmuir probes near the chamber walls, gas puff imaging (GPI), and microwave reflectometry and high-k scattering in the plasma core. Intrinsic rotation increases of 10s of km/s were observed using an edge rotation diagnostic (ERD) and correlation reflectometry showed the long wavelength correlation length in the plasma core to drop sharply at the L-H transition. GPI and a fast radial (midplane) scanning probe showed a strong decrease in plasma turbulence (blob activity and $\tilde{n}/n$) at the plasma edge. The intrinsic velocities were found to be consistent with scalings for a wide variety of toroidal devices. Discussions of these observations relative to understanding of the L-H mode transition and H-mode physics in general is also presented.

Goal:

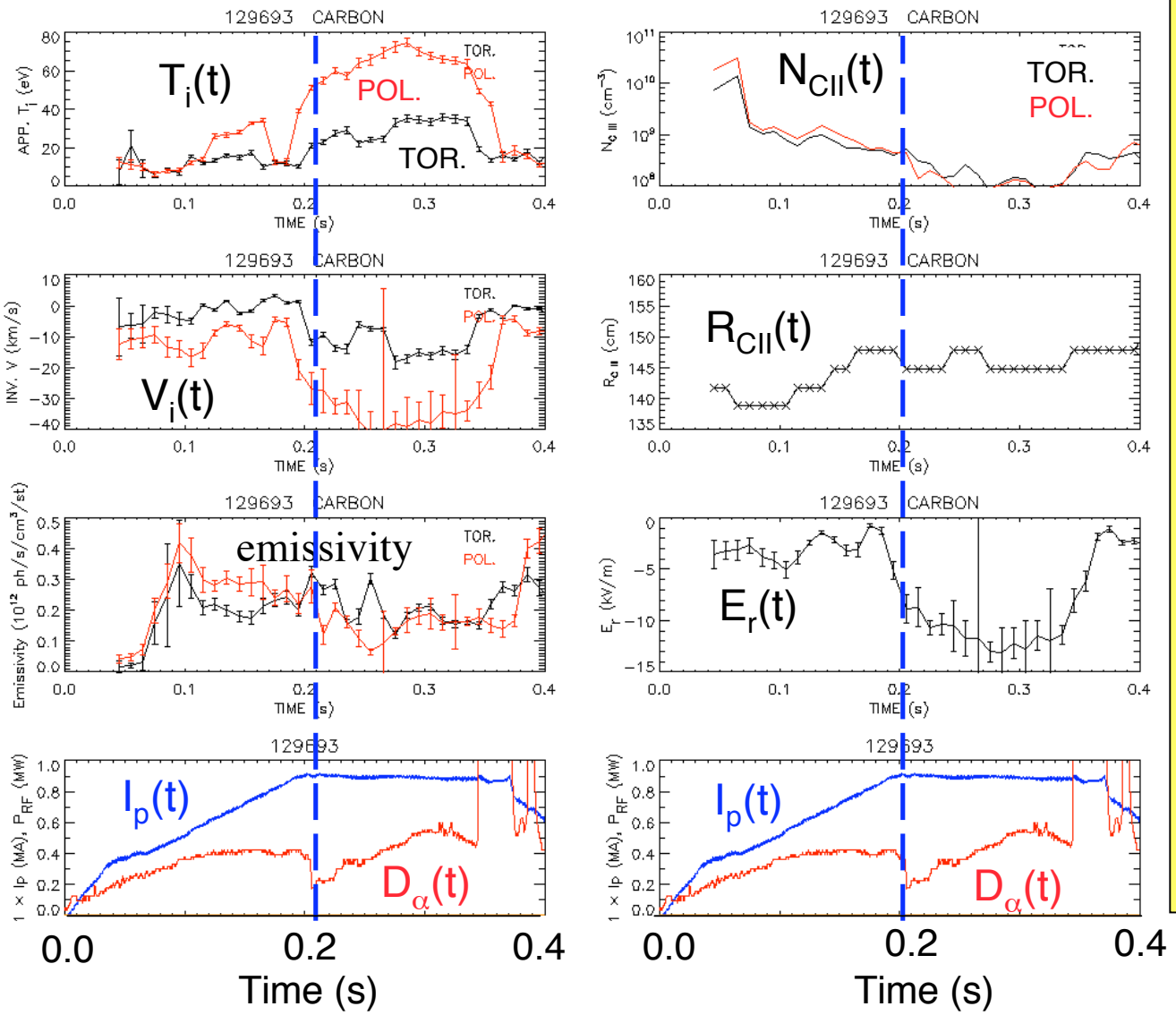
- To study H-modes created without use of external fast particle or momentum input in order to understand the fundamental physics of the L-H transition and the H-mode in general. Requires H-modes in which core and edge turbulence can be measured (preferably simultaneously).

Main Results from 2008 Run

- Simultaneous measurements of fluctuations and turbulence from the plasma core to the Far SOL
- New! Solid measurement of correlation length. Verification that correlation length in core does indeed drop by ~ 4x across L-H transition (S. Kubota, **Poster NP6.00090**, Weds Nov. 19, 2008, Marsalis A/B 9:45am)
- Edge Rotation Diagnostic (ERD) analysis improvements (R. Bell)
- Additional MPTS edge channels for T_e and n_e (B. LeBlanc)
- Simultaneous Fast Probe measurements (J-W. Ahn)
- BEaP probes - decrease in n_e and turbulence in Far SOL at L-H transition (S. Zweben, C. Bush)
- First measurements by high-k diagnostic in core of OHHmode (E. Mazzucato)
- New outer FIRe TIP channel views through edge barrier region (KC Lee)
- MHD mode velocity decrease to zero at H-L back-transition (E. Fredrickson)

V_t, V_p, T_t, and T_p change at L-H Transition

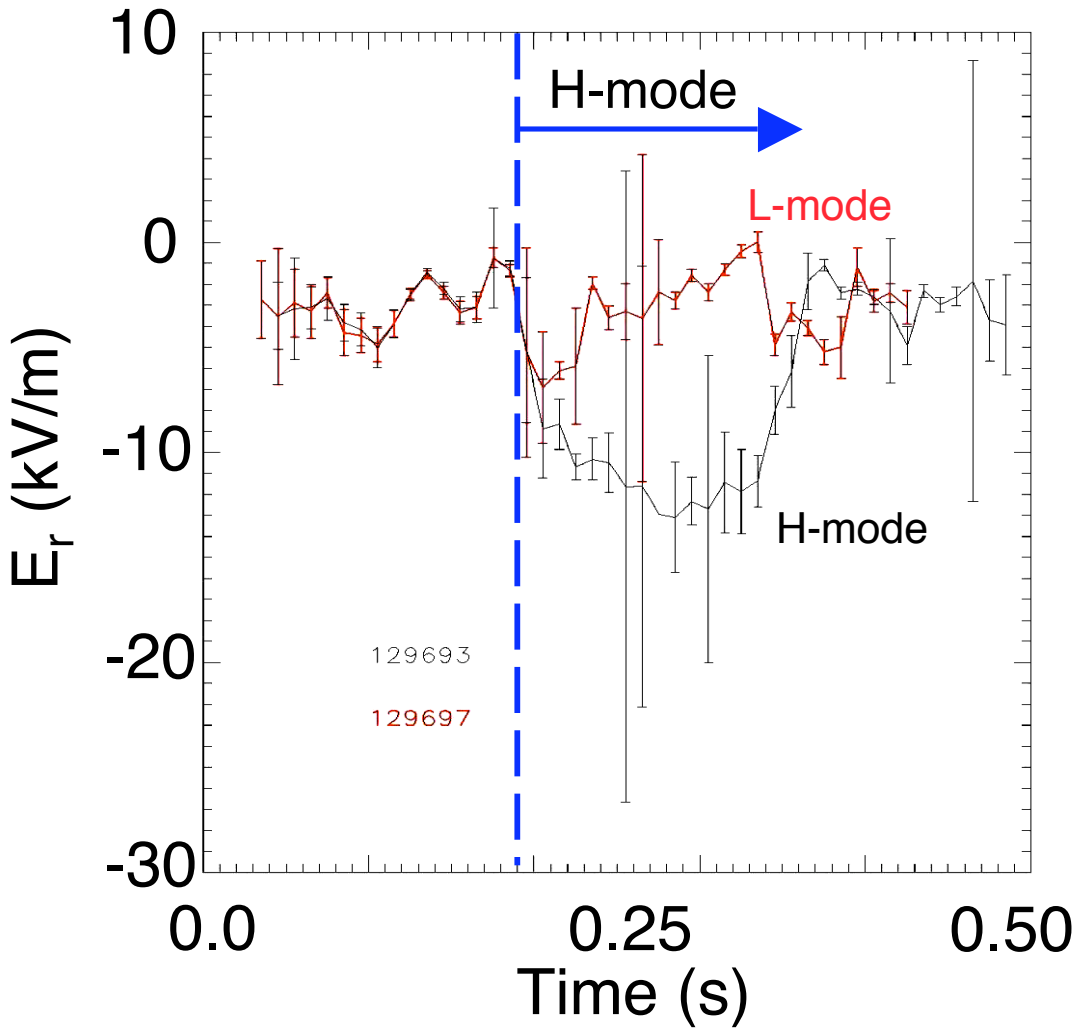
– Parameters determined using the Edge Rotation Diagnostic (ERD)



- **Begin H-mode at 0.20 s. Velocity gradients increase**
- **Intrinsic Vpol increases from -10 to - 40 km/s -(velocity of carbon impurity)**
- **H-mode phase terminates as Vpol spins down and MHD mode frequency spins down and passes thru zero.**
- **Edge Rotation Diagnostic (ERD)**

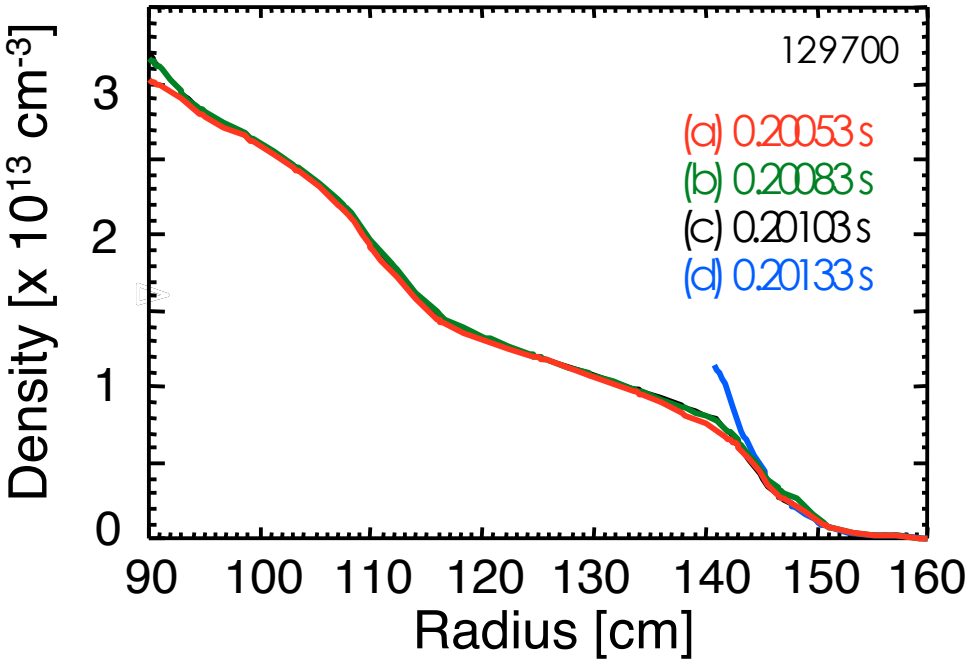
R. Bell

Er Increases by > 12 kV/m after L-H-mode Transition



- Vpol increases by 30 km/s after L-H transition *R. Bell*
- Ti and Te increase after transition

Density Profiles from FMCW Reflectometry



S. Kubota

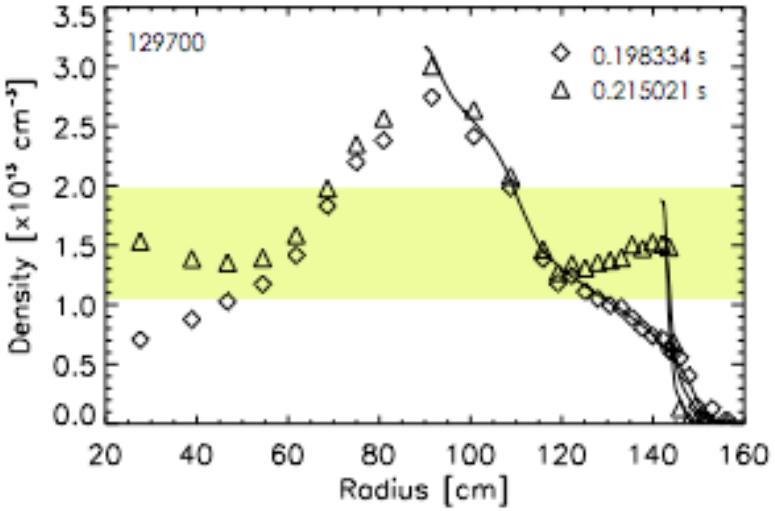
- FMCW reflectometry is a radar-like diagnostic that measures time-of flight.
- Time-of-flight, t_{tof}, is Abel-inverted to recover density profile ($n_e(f)$ vs $r_c(f)$).

$$r_c(f) = r_{ref} - \frac{c}{\pi}\int_0^f \tau_{tof}(f')\frac{df'}{\sqrt{f^2 - f'^2}}.$$

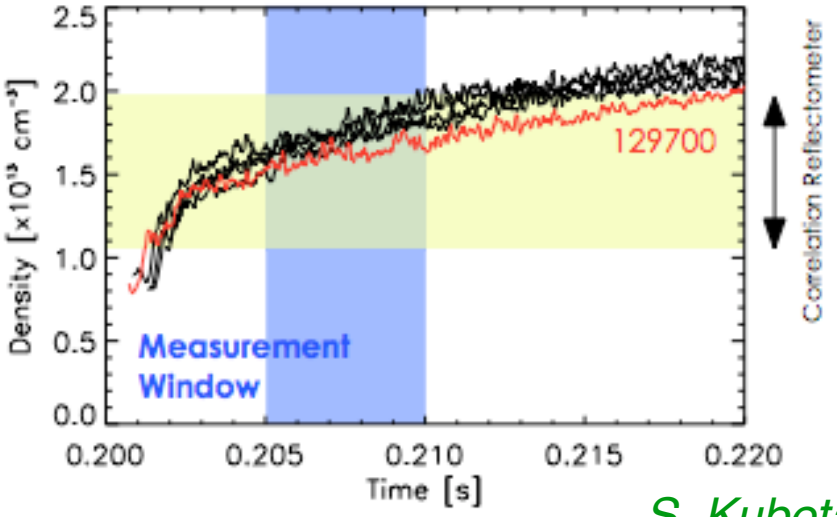
Reflectometer Results from XP-506: Ohmic H-Modes

- **Goals:**
  - Turbulence properties across the L-H transition.
  - Changes in the correlation length (requires plasma is stationary~few ms). If edge is measurement is not possible -> infer from core.
  - Evolution of edge pedestal/ear (prevents core accessibility).
- **Tools:**
  - Reflectometers (profile, fixed frequency, correlation).
- **Previous results reinforced:**
  - Core signal characteristics change little ***except for correlation***. (reduction in turbulence correlation length).

Electron Density Profile Evolution



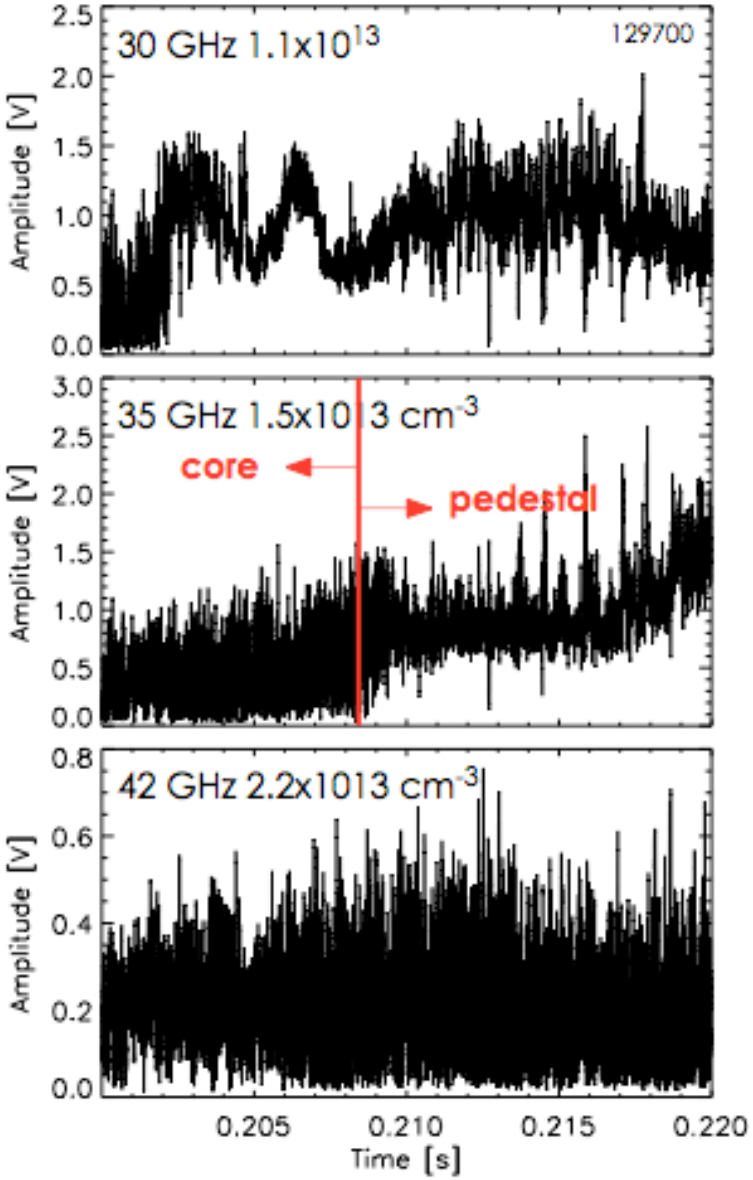
Pedestal Height from tanh fit



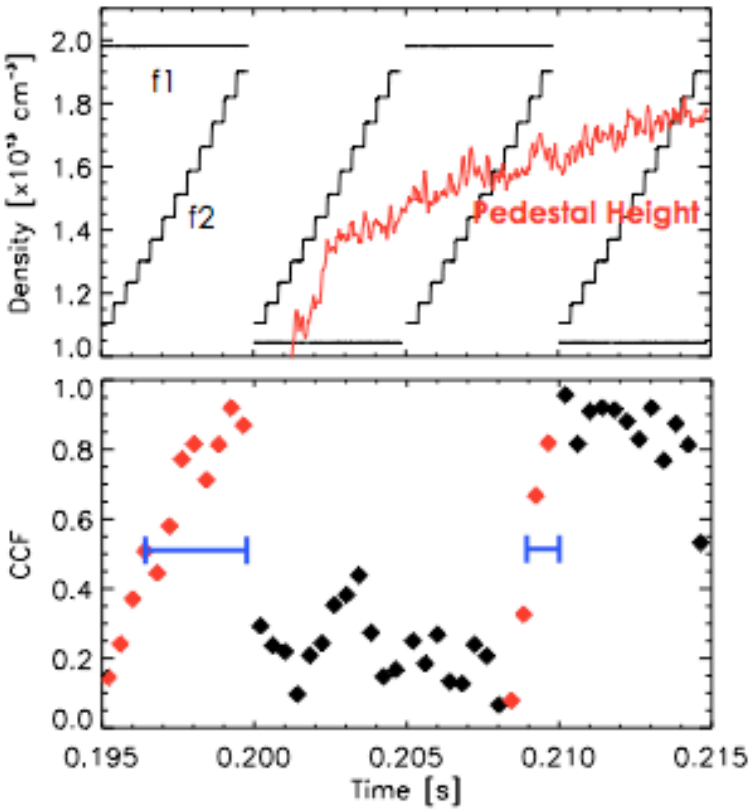
S. Kubota

Evolution of n_e and Turbulence at the L-H Transition

Fixed Frequency Reflectometer Data Consistent with Profile Measurements



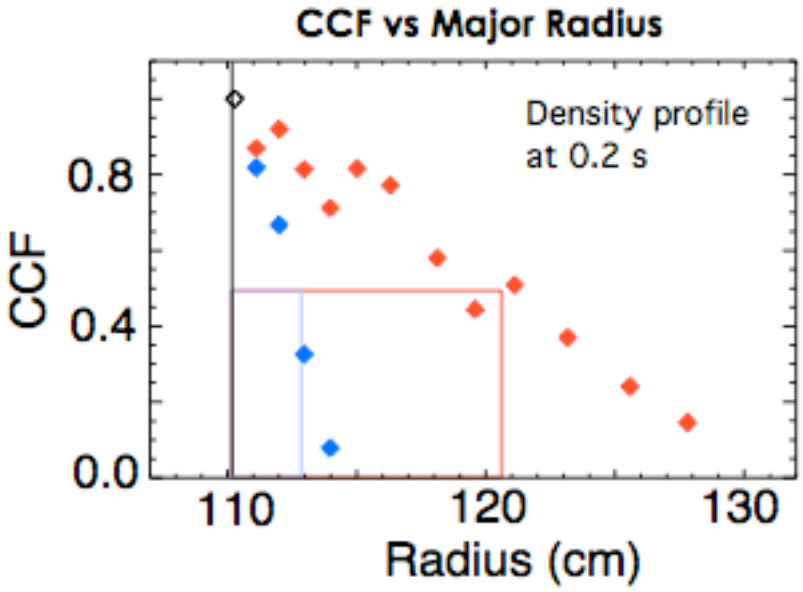
One channel of correlation reflectometer stepping in frequency (or density/radius).



CCF Width Decreases by a Factor of >3

S. Kubota

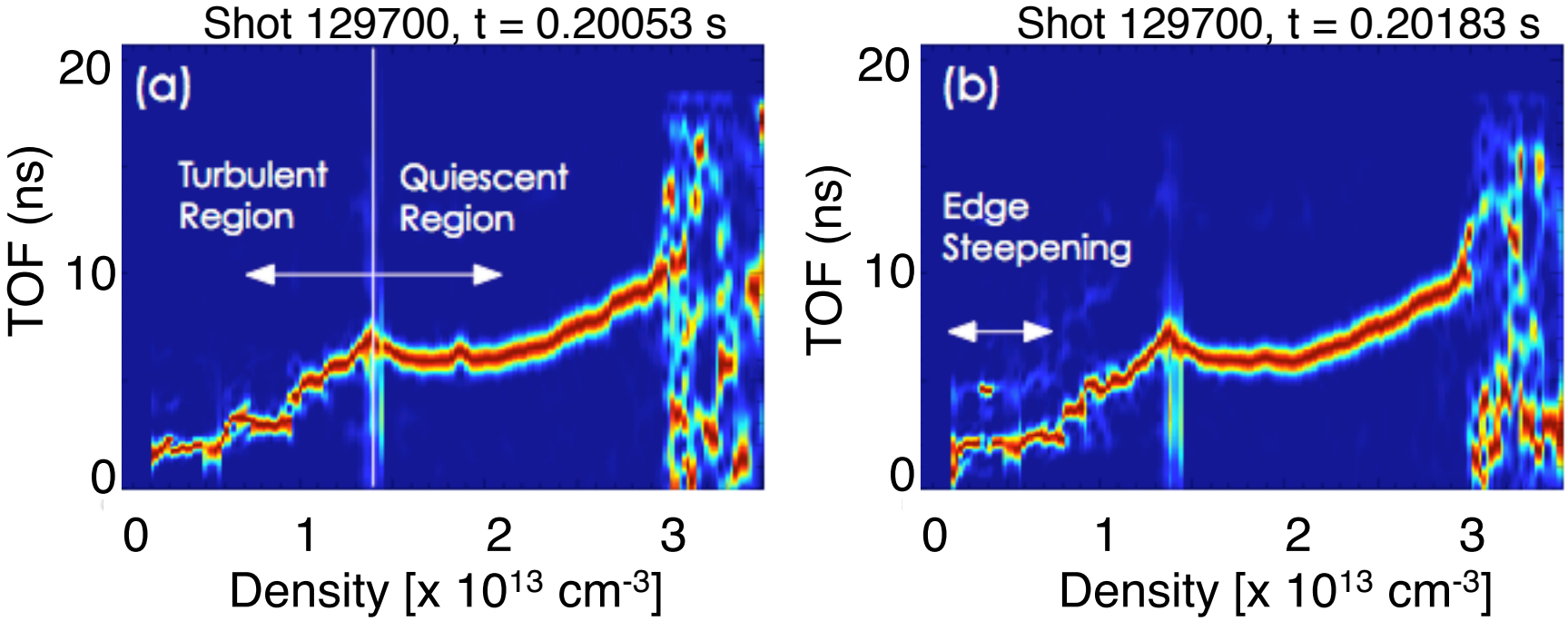
Radial Correlation Length Decreases By Factor of 4



S. Kubota

- **Summary**
  - XP-506 finally finished after 3 year wait.
  - Uncertainty of pedestal height eliminated from correlation length measurements.
  - Correlation length decreases by a factor of 4 after L-H trans.
- **Follow Up**
  - 2D/3D simulations with full-wave codes for quantitative estimate of correlation length (fluctuation levels, spectra, etc.).
- **Can we make better measurements at the edge?**
  - Use profile reflectometer (10 μs sweep) as a radial correlation reflectometer. Pinpoint correlation measurements in time and space.

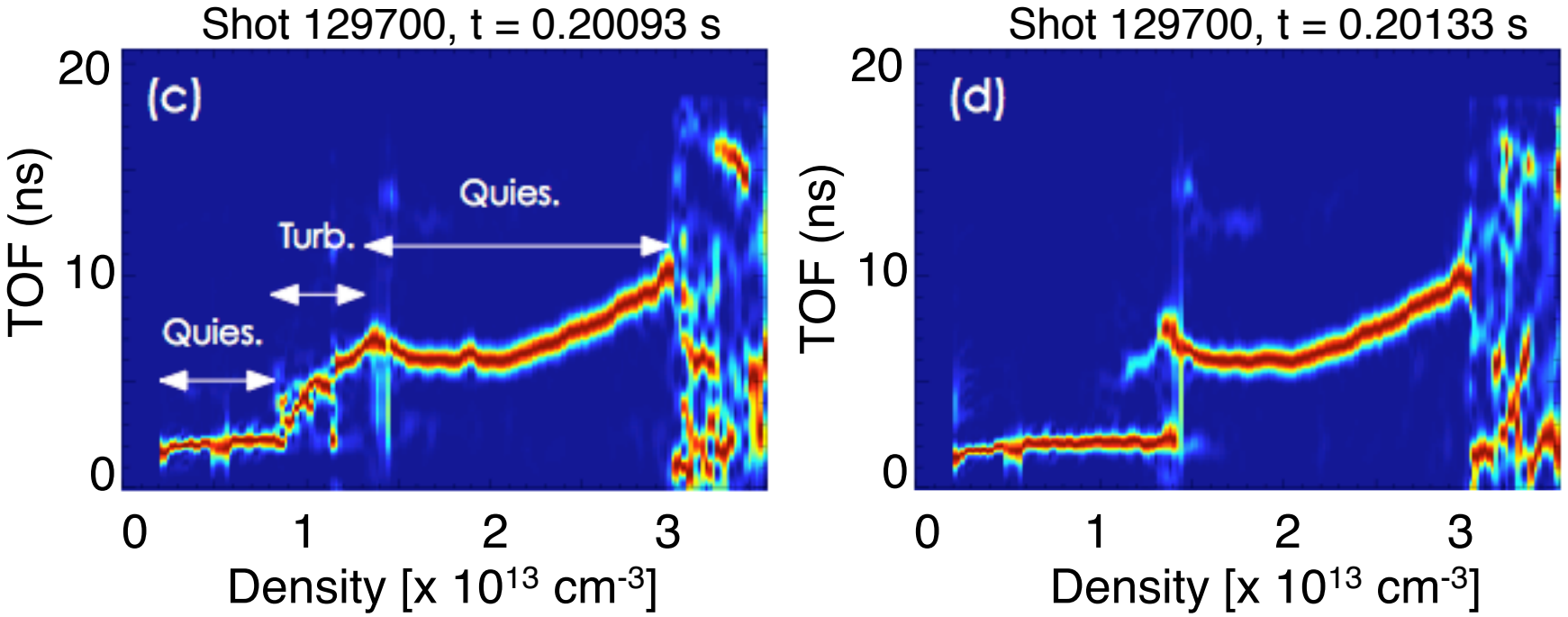
Density Turbulence during L-mode Phase



- **FMCW reflectometry time-of-flight versus launch frequency (cutoff density).**

- **(a) L-mode phase:**
  - Typical L-mode discharge has core quiescent zone and edge turbulent region.
- **(b) Immediately before L-H transition:**
  - Edge density profile begins to steepen, but still turbulent.

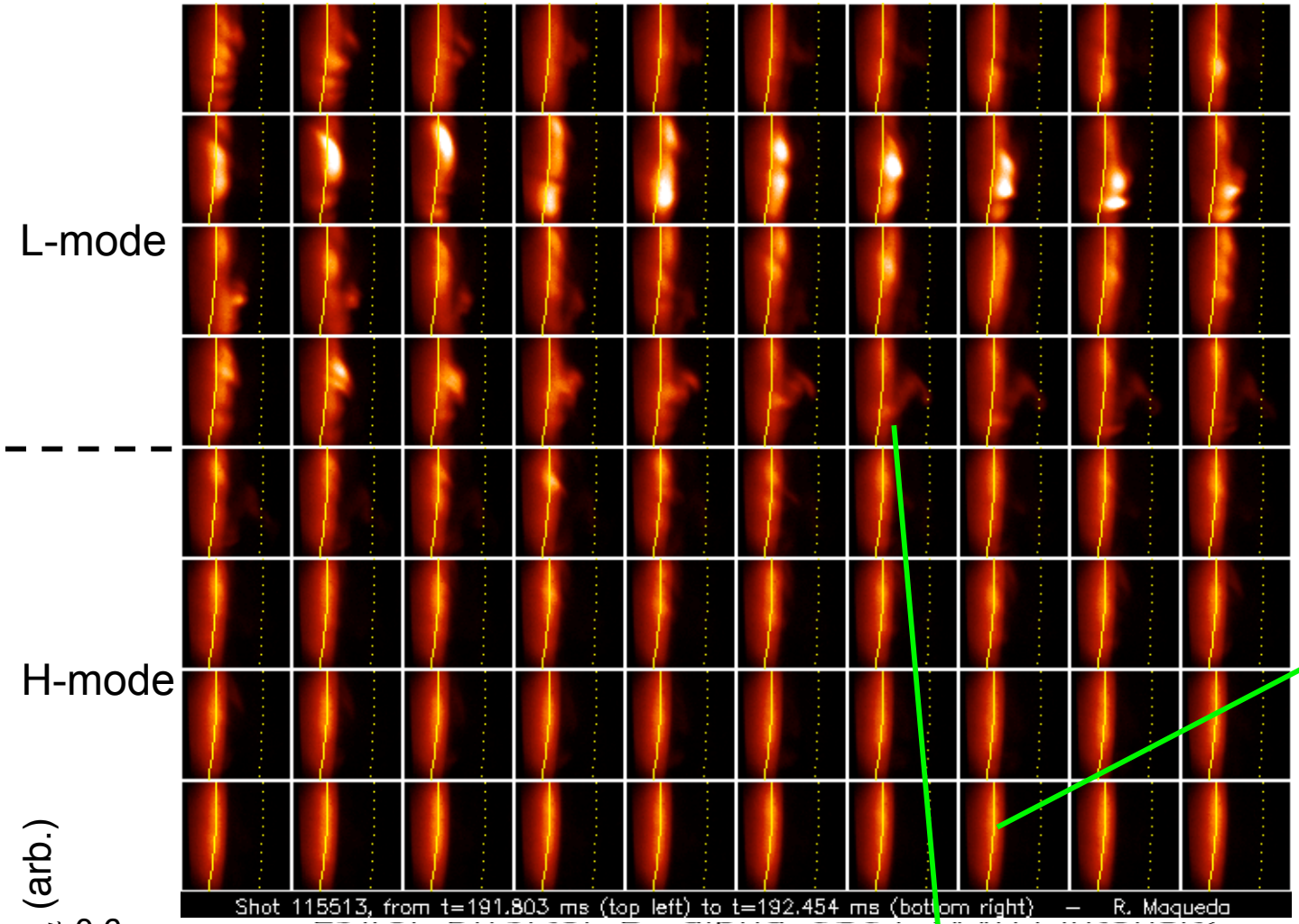
Evolution of Density and Turbulence at the L-H Transition



- **(c) At the L-H transition:**
  - Edge profile steepens further and becomes quiescent. Turbulent region sandwiched by two quiescent regions.
- **(d) H-mode phase:**
  - Height of edge density "ear" grows with time.

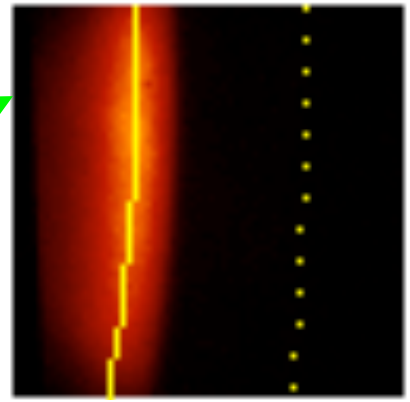
S. Kubota

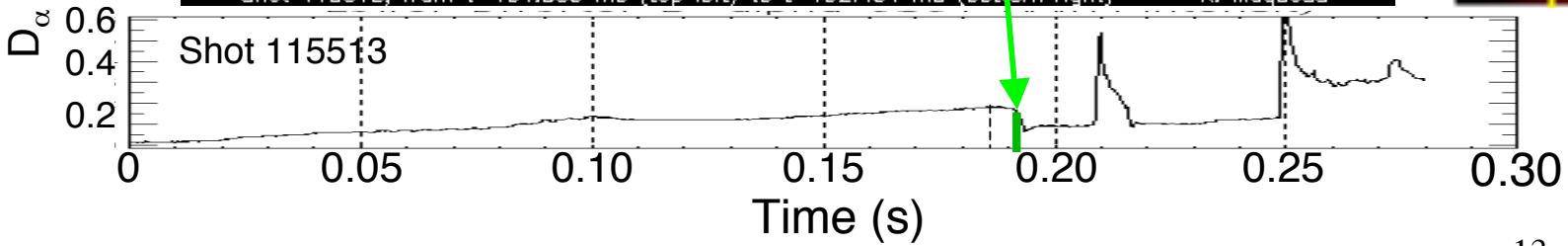
Gas Puff Imaging (GPI): L-H transition



- **Turbulence during L-mode (blobs)**
- **L-H Transition takes place at ~192.1 ms (blobs go away)**

"Quiescent" H-mode edge



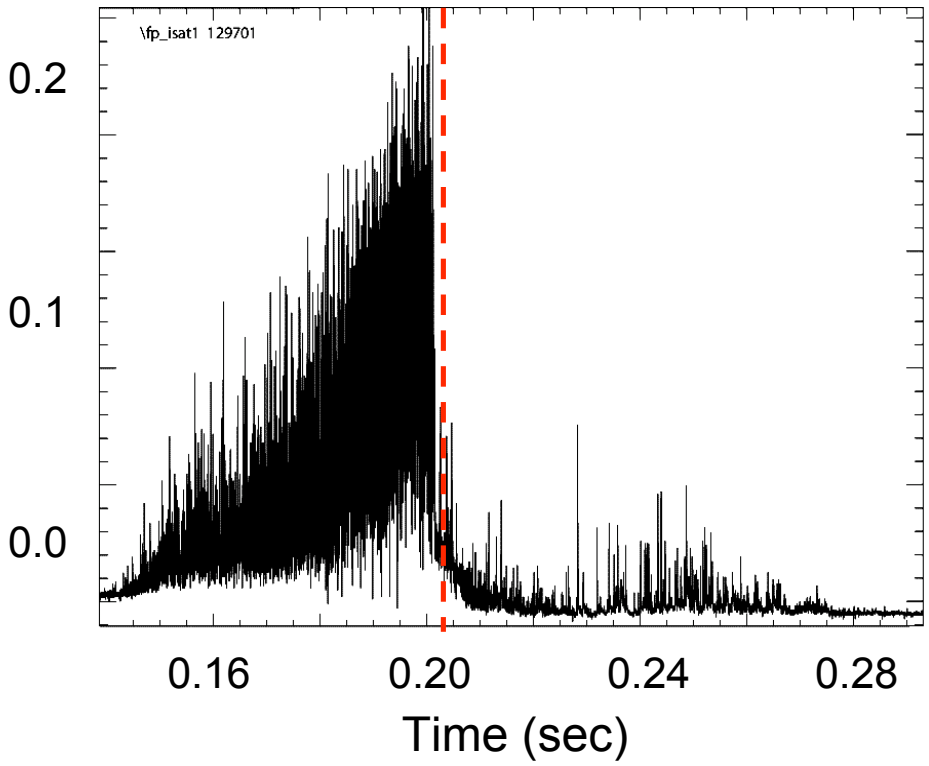


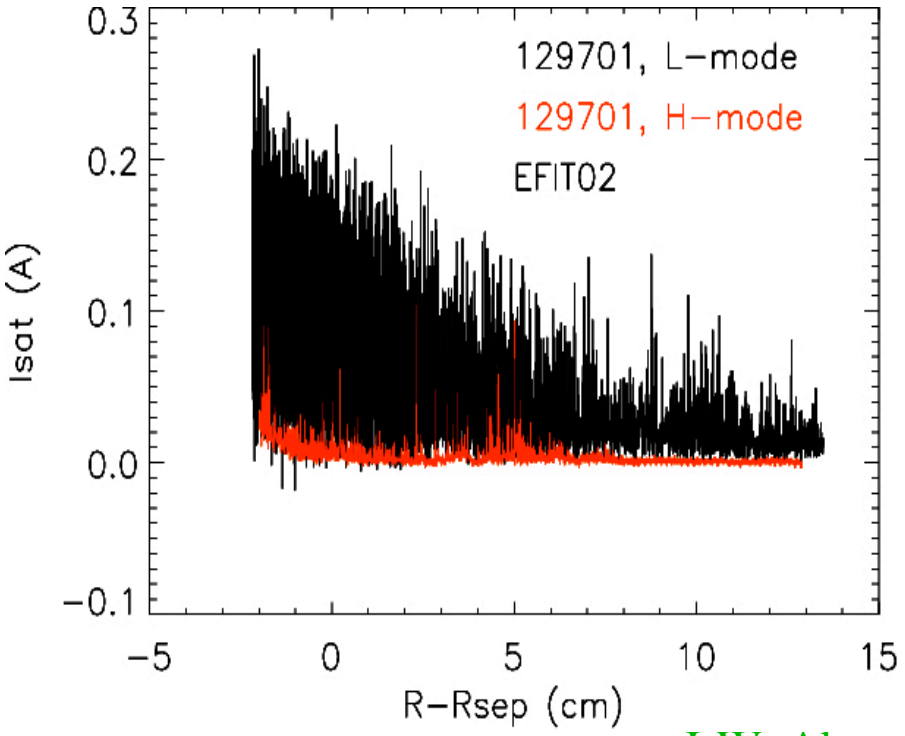
R. Maqueda

Isat Fluctuations Dramatically Reduced in H-mode

– Fast reciprocating probe data

L → H transition

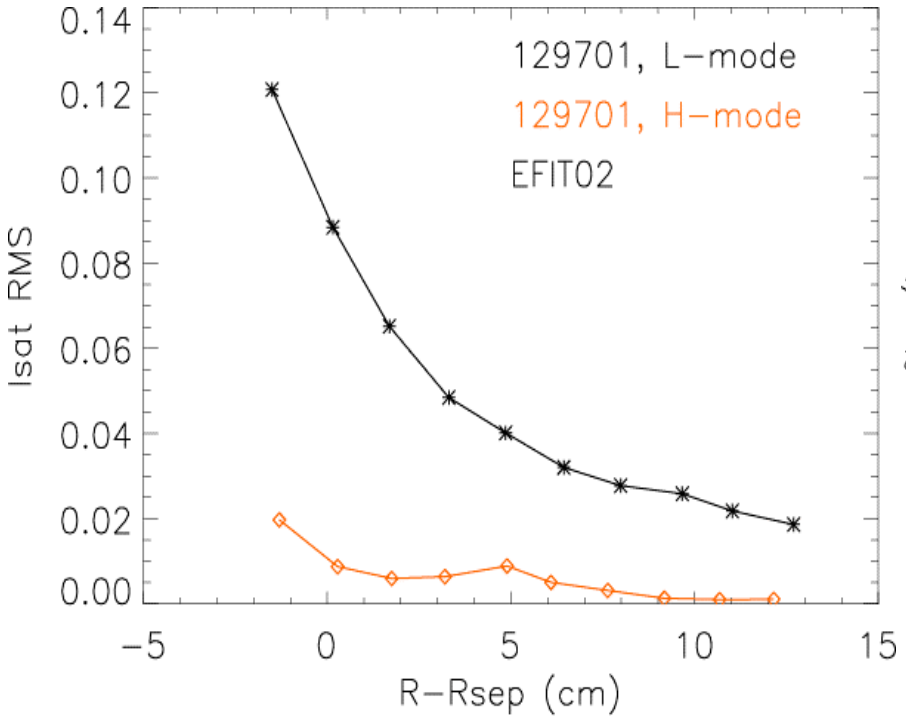


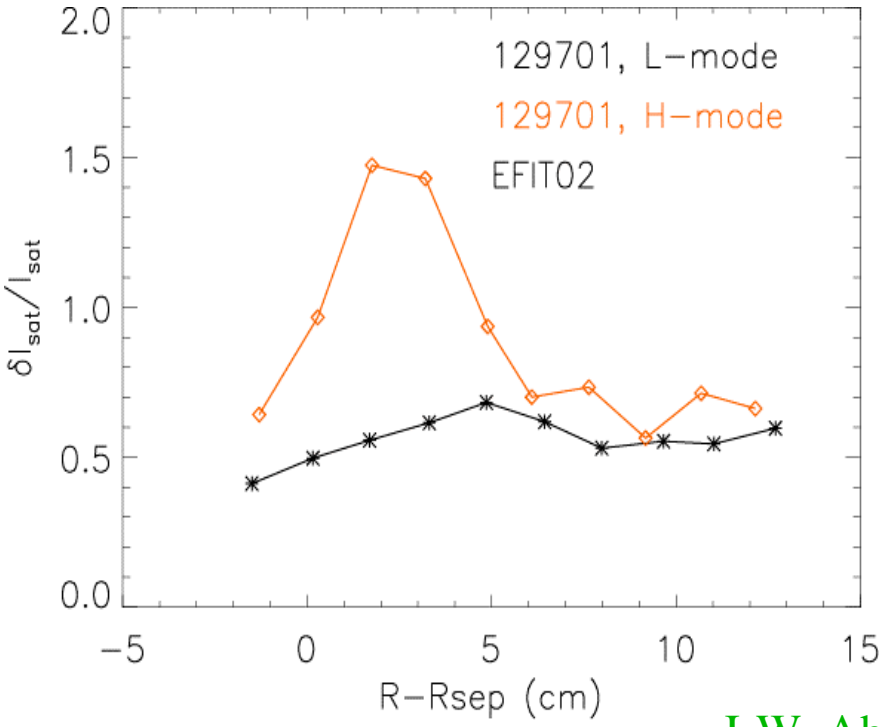


J-W. Ahn

- Probe plunge reached maximum distance at L-H transition time
- Isat amplitude dramatically reduced in H-mode compared to L-mode

RMS fluctuation level shows different trend in L- and H-mode





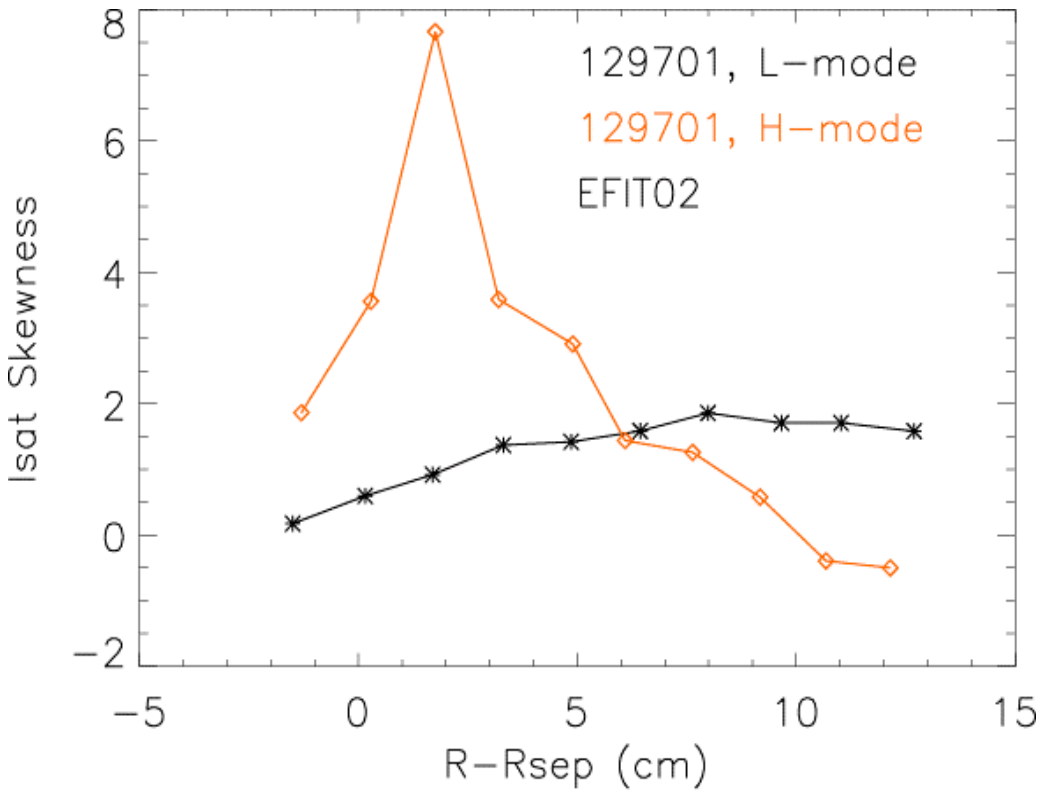
J-W. Ahn

- Isat RMS level peaked near separatrix in both L- and H-mode
- Isat RMS fluctuation level is indicated by $\delta I_{sat}/I_{sat}$

  L-Mode: Increases from separatrix into the SOL, then slightly decreases or saturates in the far SOL

  H-mode: Rapidly increases in the near SOL (R-Rsep up to 2-3cm), then drops and becomes saturated in the far SOL (R-Rsep ≥ 6-7cm)

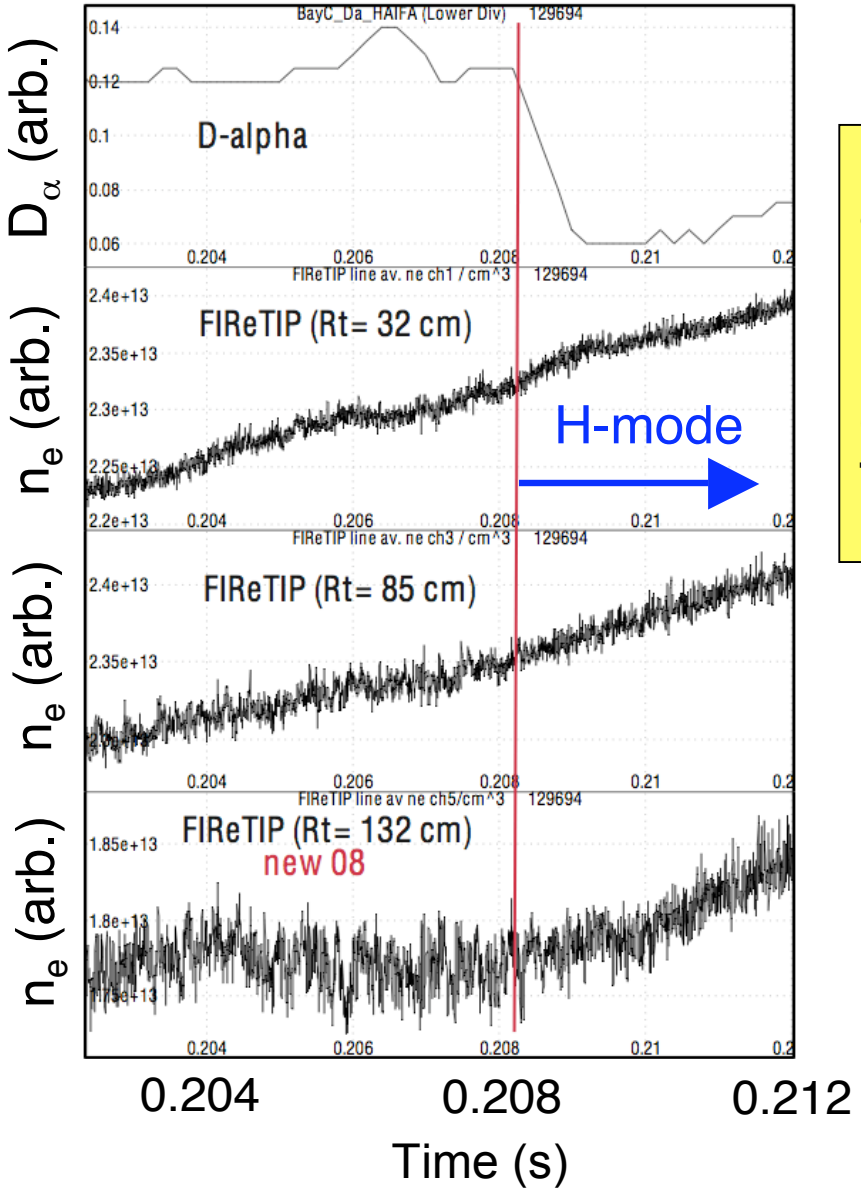
Isat Skewness Trend Similar to RMS Fluctuation Level



J-W. Ahn

- Skewness is indicative of fluctuations deviation from Gaussian
- L-Mode: Increases from separatrix into the SOL, slightly decreases in the very far SOL
  Positive over the whole SOL region
- H-mode: Rapidly increases in the near SOL and then drops in the rest of SOL
  Becomes negative in the very far SOL (R-Rsep~10cm)

FIReTIP density fluctuation change near plasma edge at the L/H transition (red line) of Shot 129694

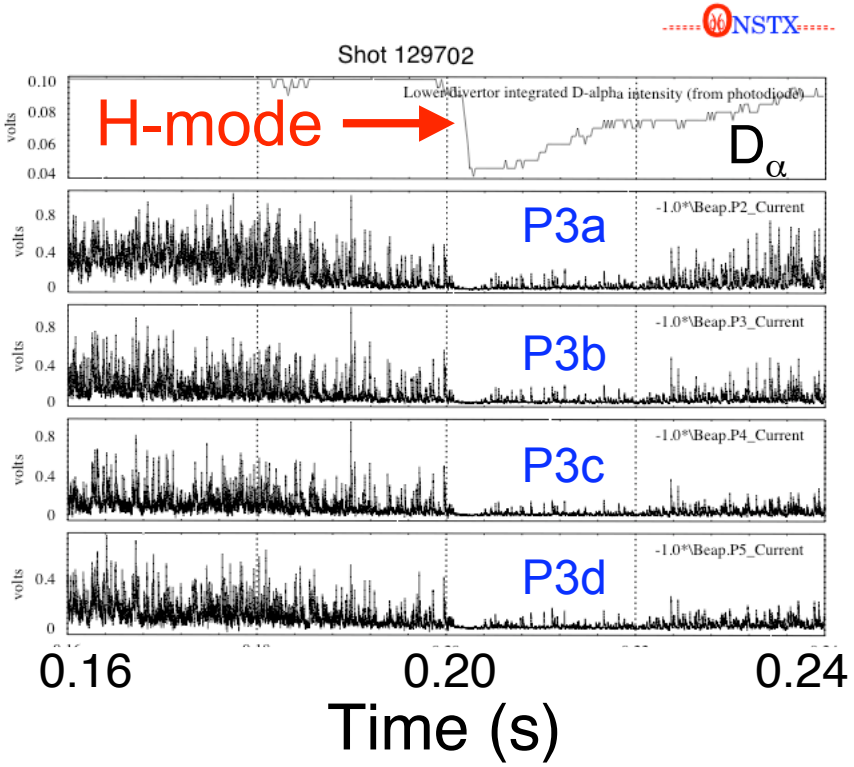


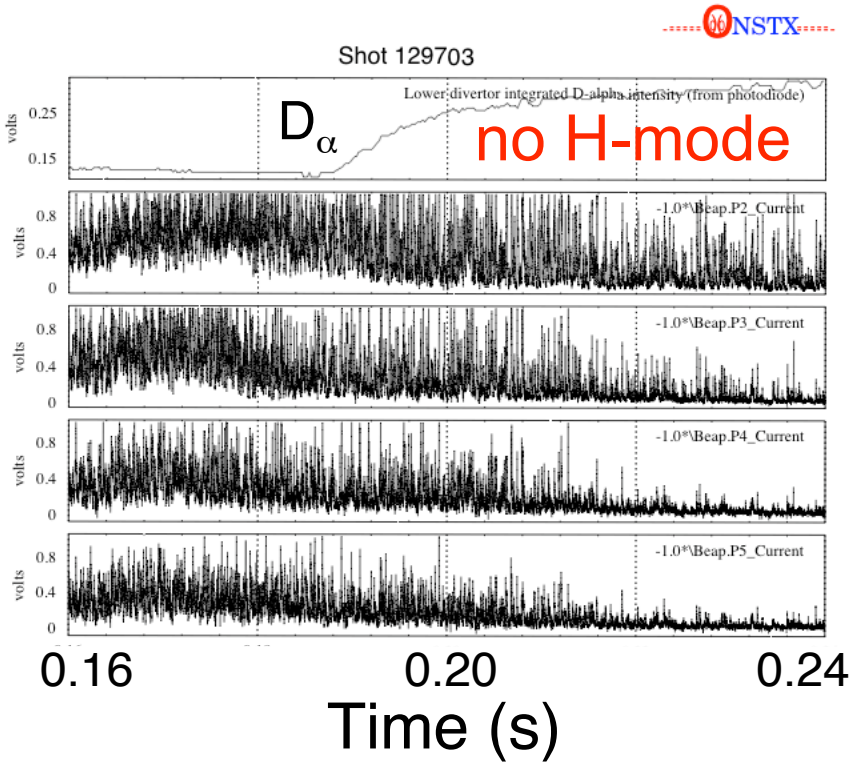
- **H-mode transition at 0.2082 s**
- **New channel at R_{tan} = 132 cm shows decrease in density fluctuations at the L-H transition**

KC Lee

Ohmic H-modes and BEaP Probes

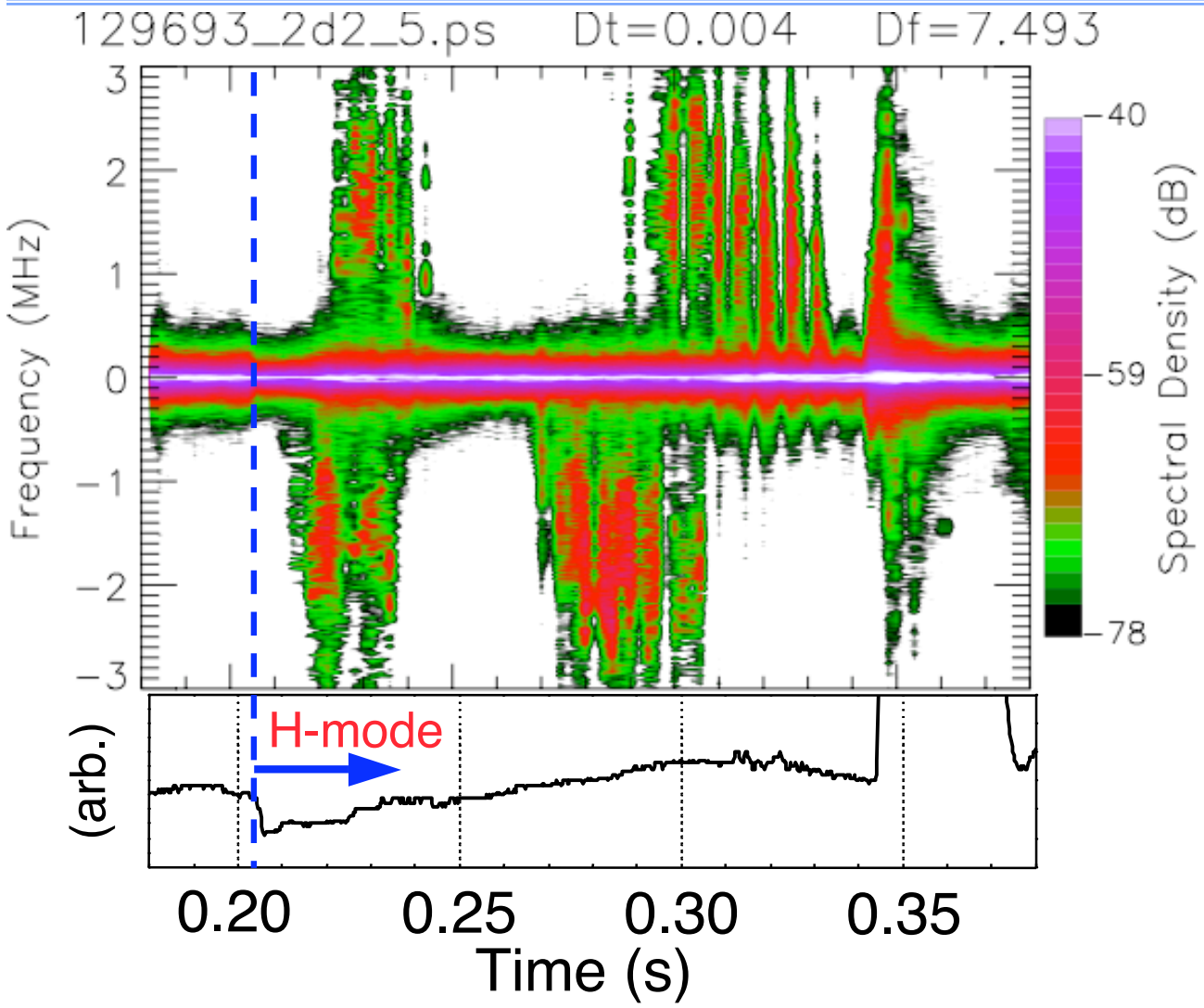
- *Far-SOL midplane density goes down suddenly at H-mode*
- *Far-SOL density (and turbulence) can return during H-mode*
- *Far-SOL density was dropping slowly even without H-mode*





S. Zweben

High-k result for H-mode shot 129693

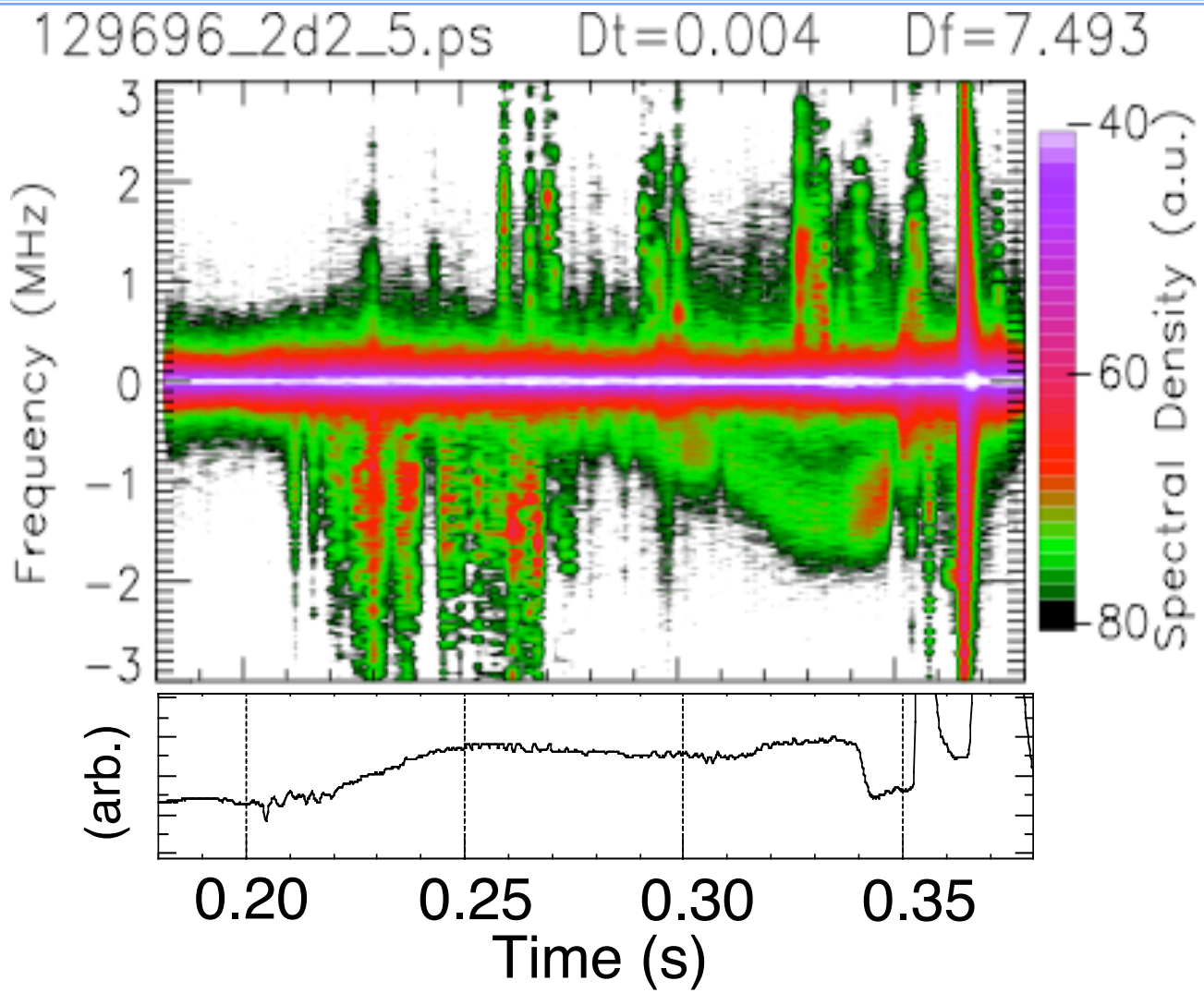


- **H-mode discharge**
- **L-H Transition takes place at ~203 ms**
- **k = 14/cm**
- **Periods of reduced fluctuations during H-mode, but there is still bursting.**
- **Additional studies are needed.**

E. Mazzucato

Spectra of fluctuations at R=1.20 m (H-mode, t = 0.203 - 0.344 s)

High-k result for no-H-mode shot 129696



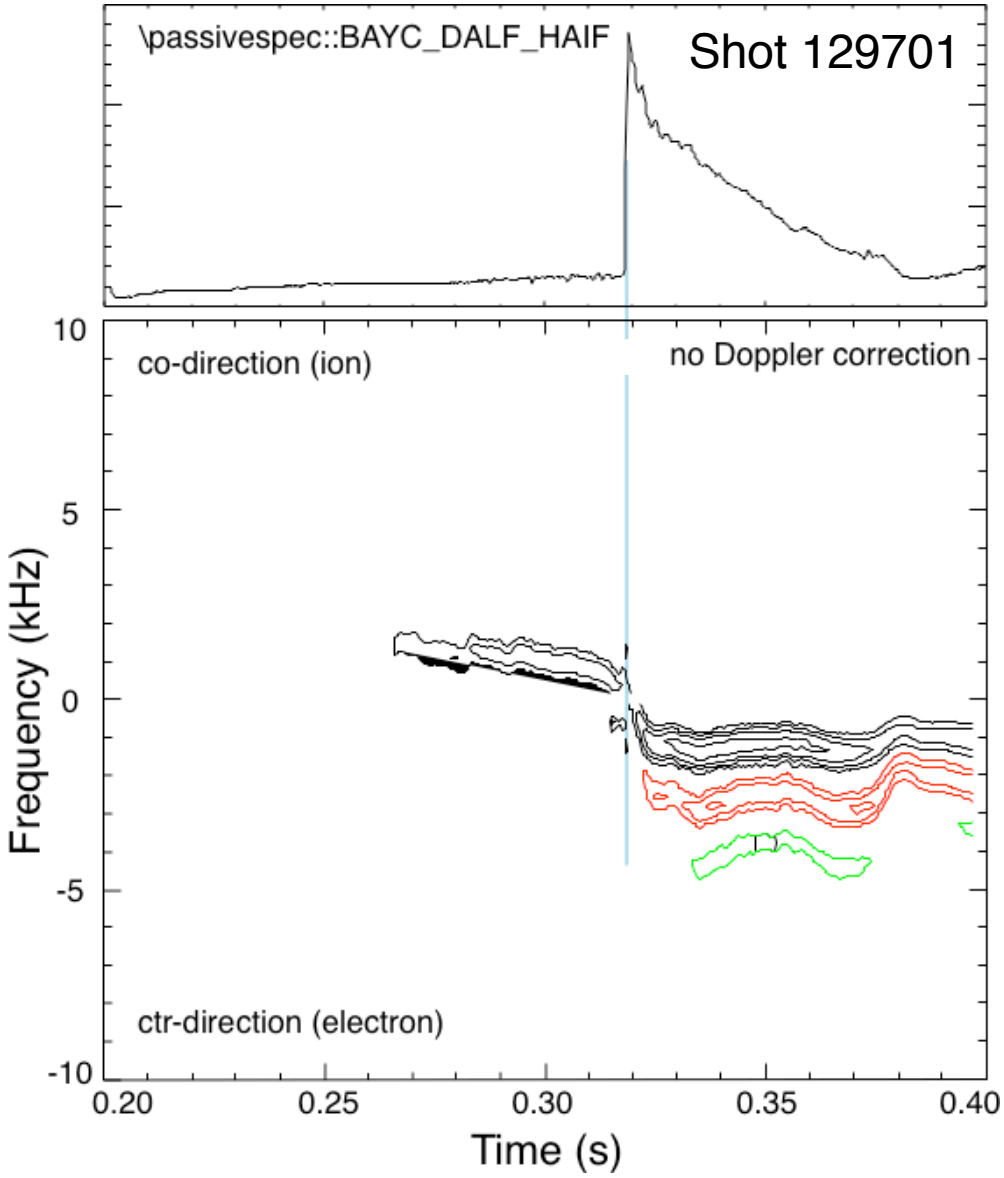
- **no-H-mode shot**
- **k = 14/cm**
- **Bursting is not as pronounced.**
- **More study needed**

E. Mazzucato

Spectra of fluctuations at R=1.20 (no H-mode)

MHD mode slows and reverses at H to L

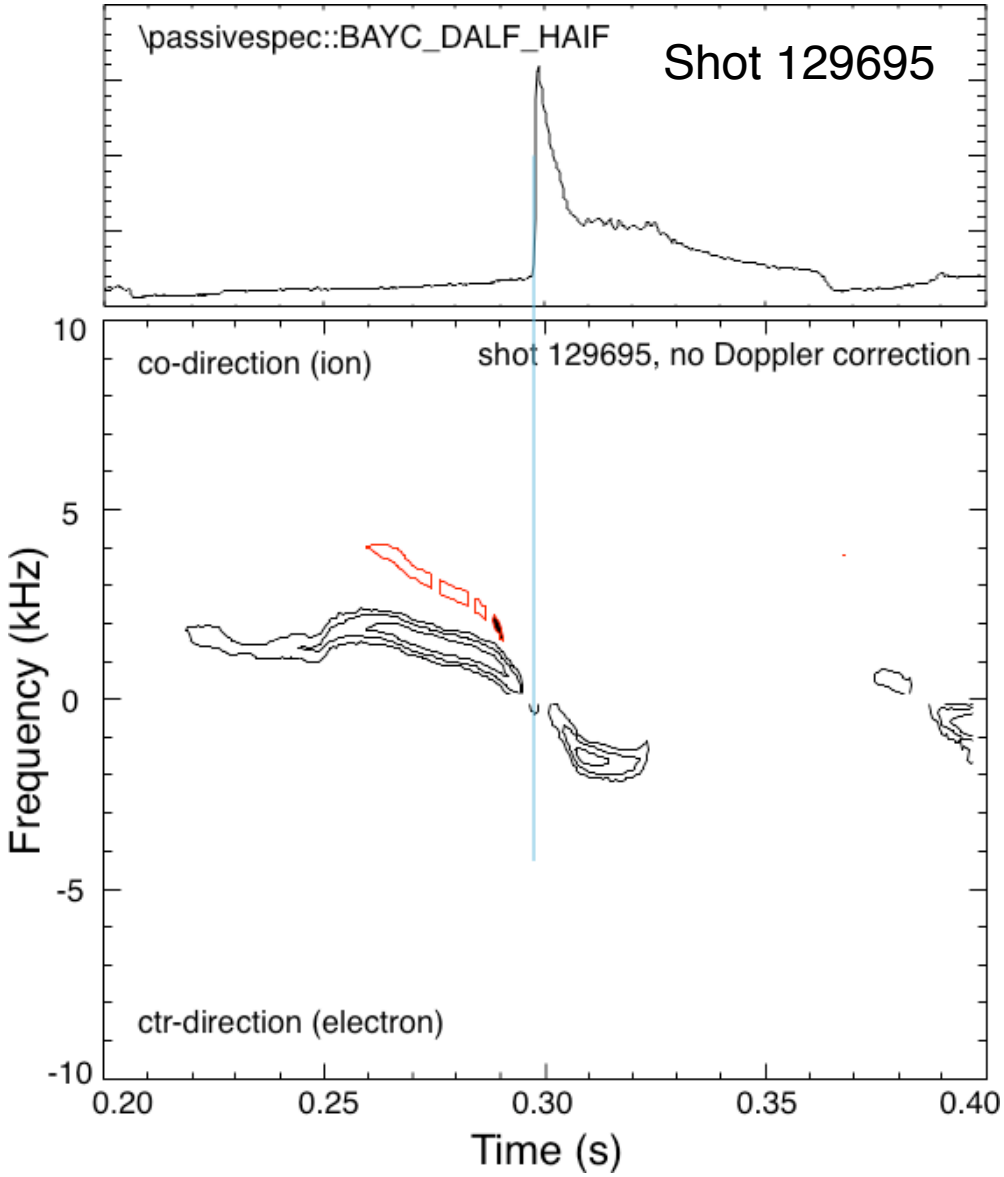
- Mode rotating in co direction during H-mode; typically without beams, MHD rotates in ctr (electron) direction.
- Mode doesn't lock when passing through zero-frequency - error fields apparently are not an important factor.
- Spin down in frequency correlates with that in intrinsic edge velocity from ERD measurement.



E. Fredrickson

Similar behavior on other shots

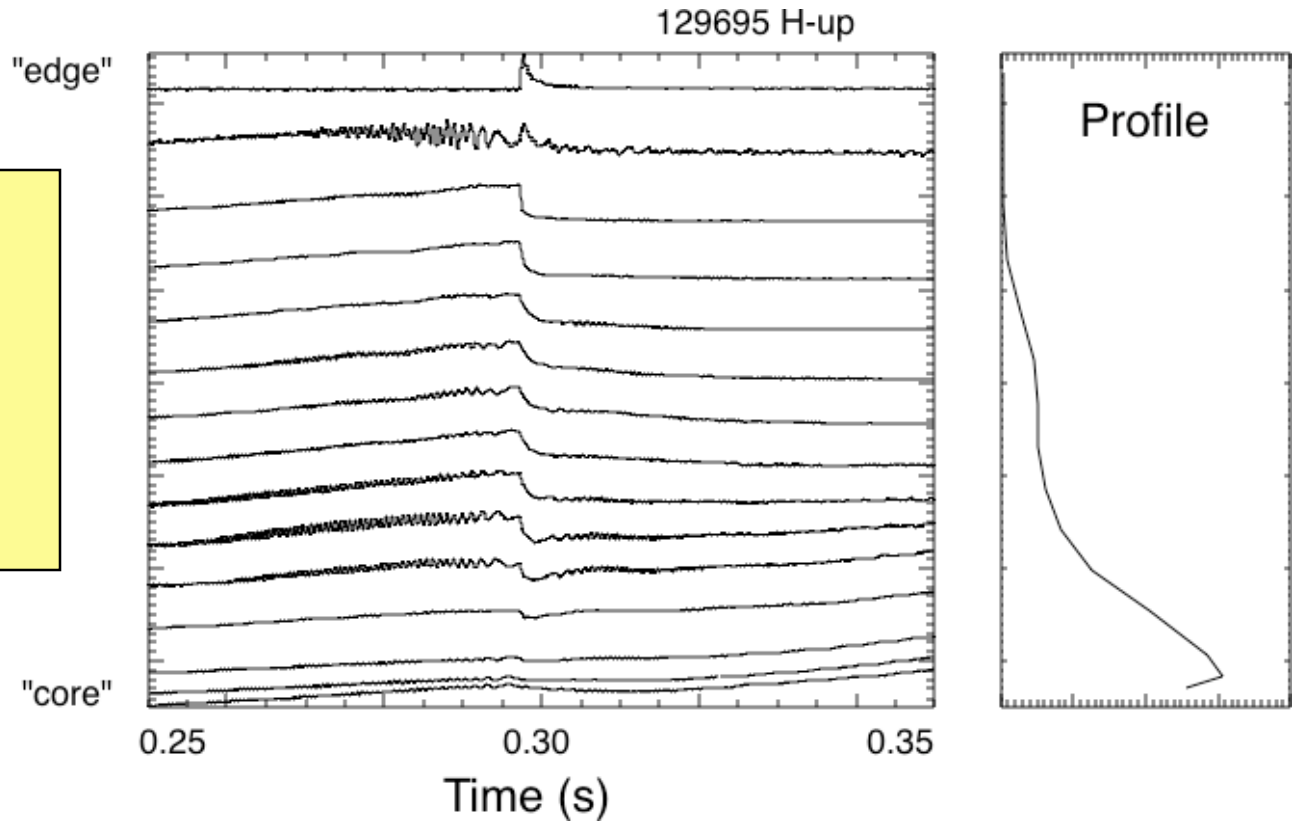
- Rate of frequency chirp increases as mode slows
- D-alpha suggests fairly violent event when freq = 0, but why?



E. Fredrickson

Soft x-rays show global reconnection occurs at the time frequency passes through zero

- Possibly core and edge mode coupled together?



E. Fredrickson

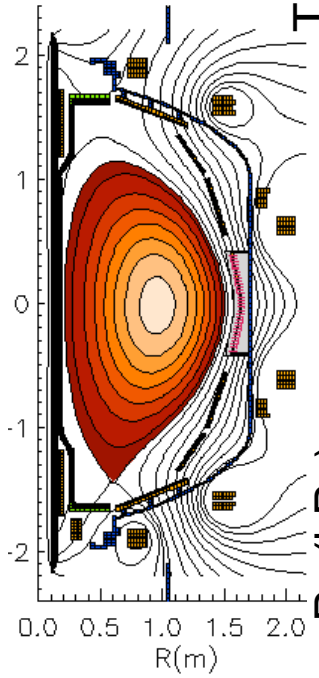
Summary

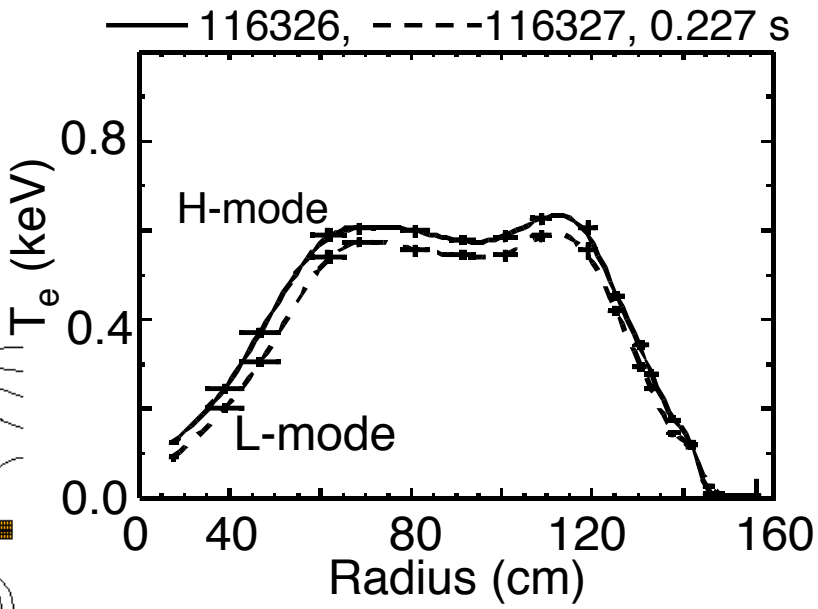
- H-mode physics and phenomena are studied reliably and reproducibly in NSTX Ohmic H-modes.
- Spontaneous intrinsic rotation increases of $\geq$ 30 km/s were observed during these H-modes.
- Reflectometry shows the correlation length for long wave length fluctuations in the core to decrease by a factor of 4 across the L-H transition.
- Changes in turbulence accompany the changes in spontaneous intrinsic rotation and they are studied in several successive radial regions from the core to beyond the Far SOL simultaneously using a variety of diagnostics.
- The H-mode phase usually terminates when several MHD modes rotating poloidally in the co-direction spin down and pass through zero frequency. After a strong perturbation and termination of the H-mode the mode spins up again but in the opposite (counter) direction.

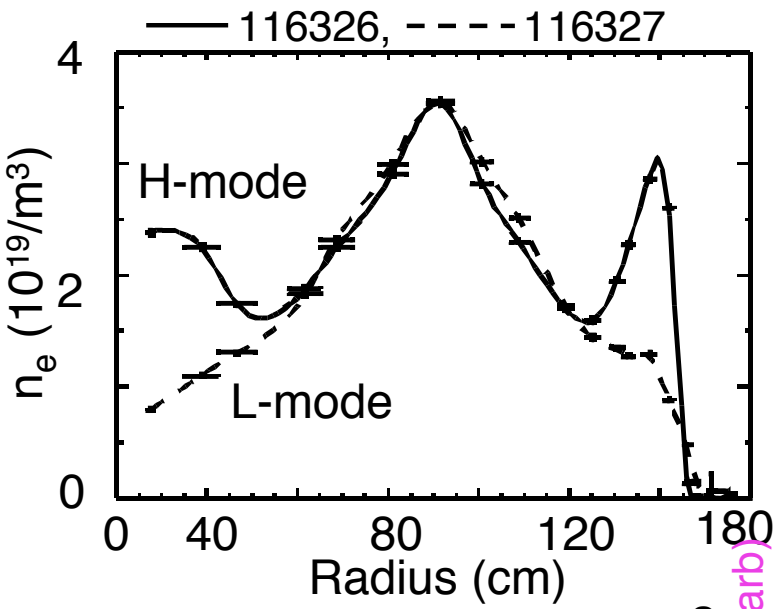
END

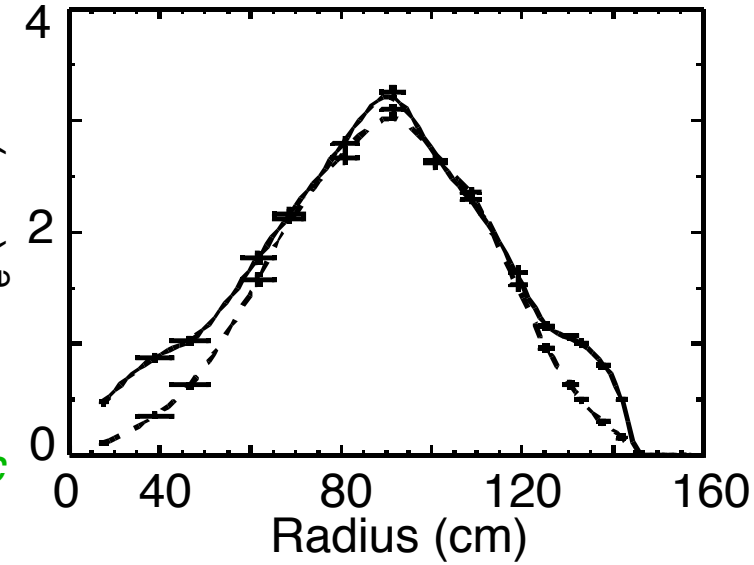
Name, Institution, and E-mail address

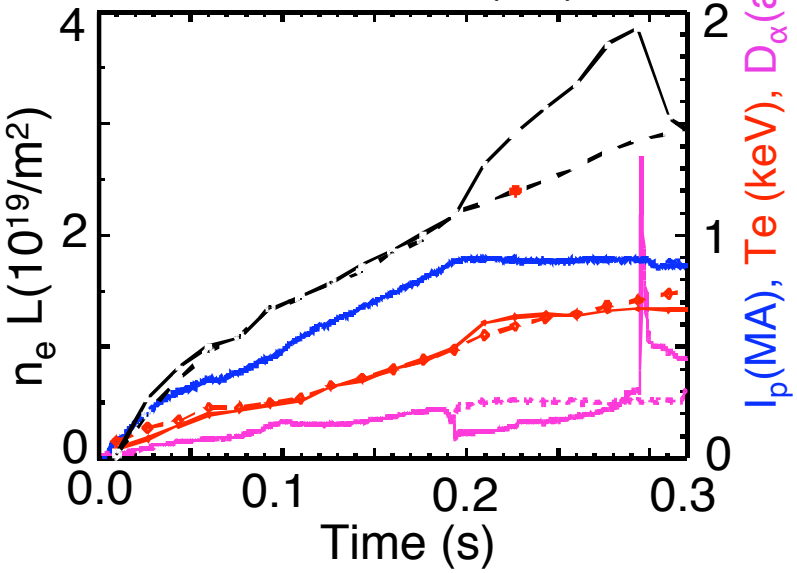
ELM-Free OHH-mode Obtained with LSN





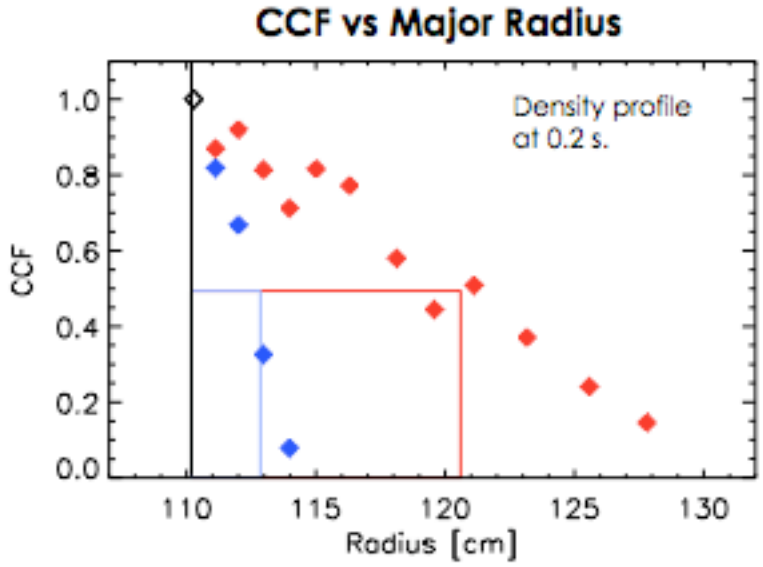






B. LeBlanc

Radial Correlation Length Decreases By Factor of 4



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  - 2D/3D simulations with full-wave codes for quantitative estimate of correlation length (fluctuation levels, spectra, etc.).
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