Study of the statistical properties of edge turbulence in NSTX with the GPI diagnostic

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MOTIVATIONS & OUTLINE

✓ Turbulence is commonly recognized as the dominant mechanism for *anomalous transport*

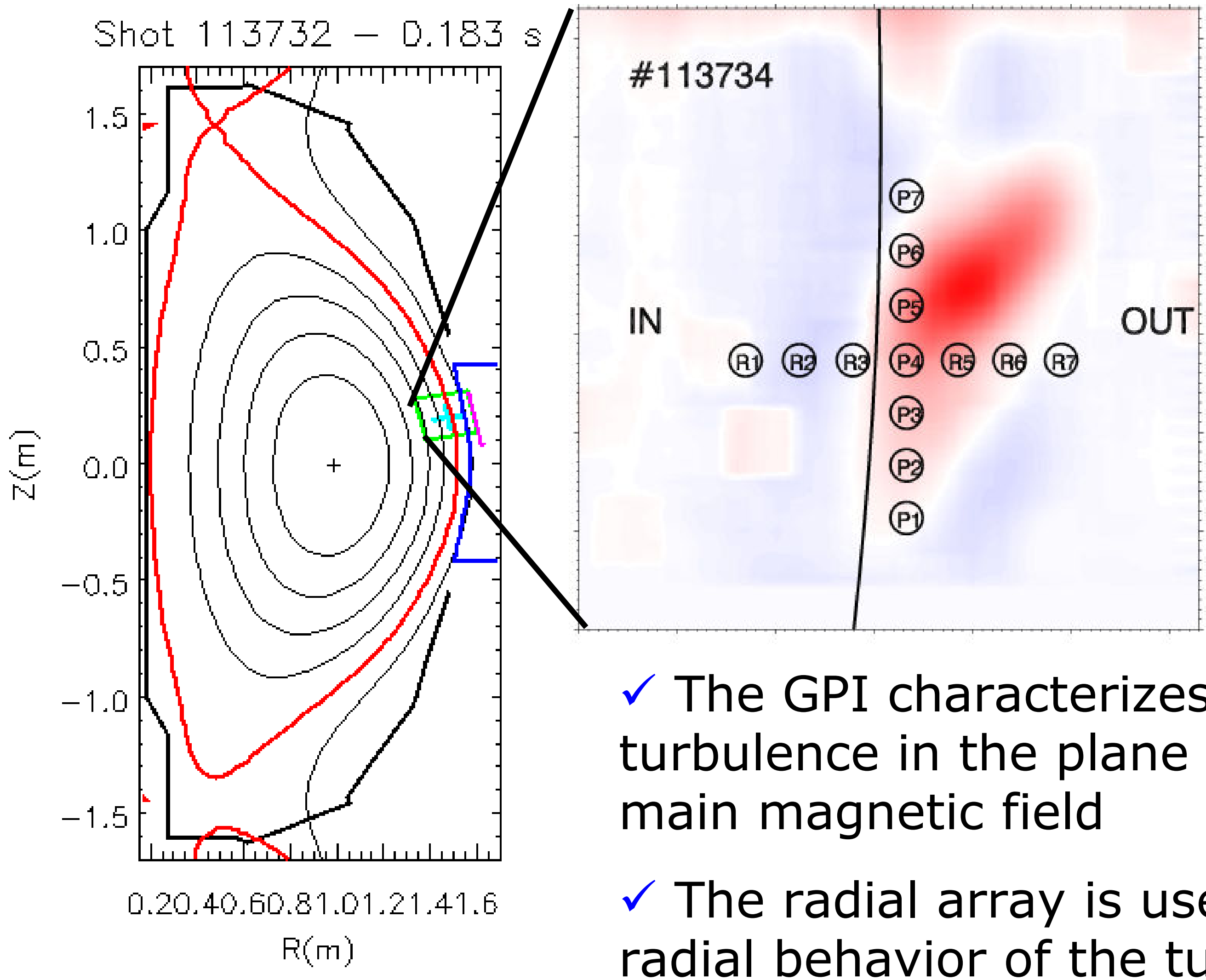
✓ The edge particle transport is caused mainly by intense bursts with non-Gaussian statistics in all the magnetic configurations

✓ The statistical properties of the edge turbulence of **NSTX** tokamak are studied with the **GPI** diagnostic

✓ The link between the electron pressure and edge structures is shown

✓ A decrease in the number of intermittent events between H-mode and L-mode is detected

EXPERIMENTAL SET UP



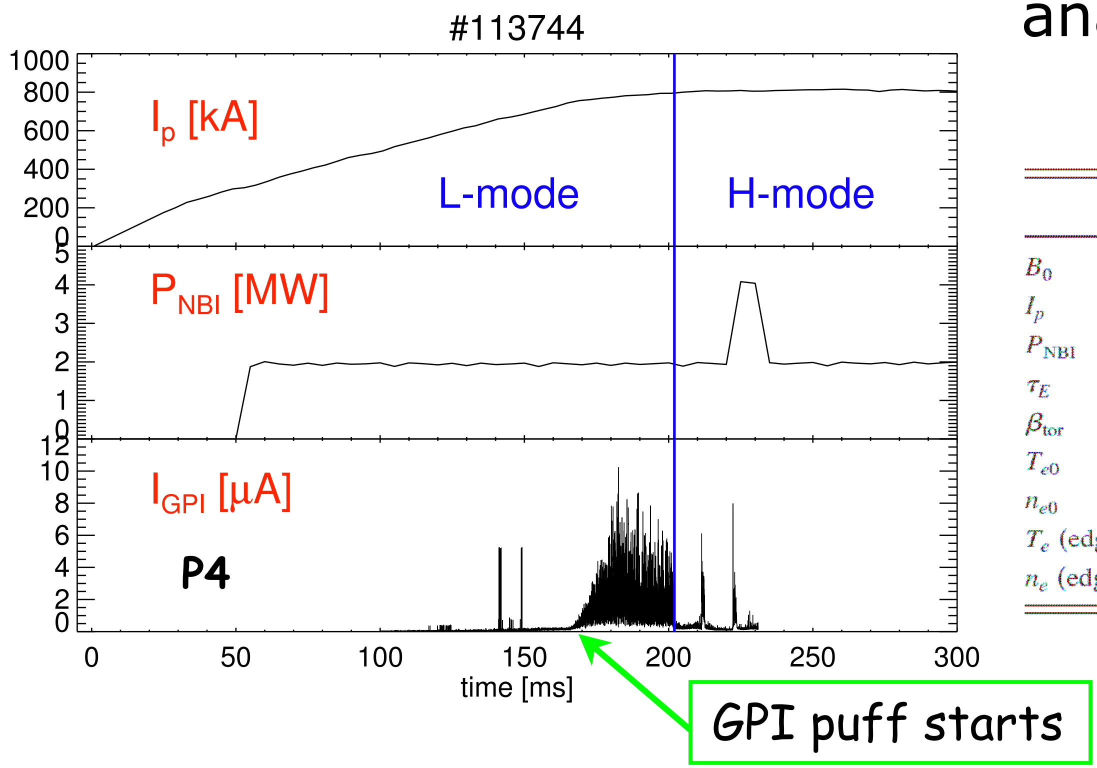
- The GPI measures the D_α fluctuations at the plasma edge with two arrays of *PMTs*: radial and poloidal
- Sampling rate of the *PMTs*: *500 kHz*

✓ The GPI characterizes the edge turbulence in the plane perpendicular to the main magnetic field

✓ The radial array is used to study the radial behavior of the turbulence

SIGNALS ANALYZED

Example of one plasma shot



✓ 13 plasma discharges analyzed

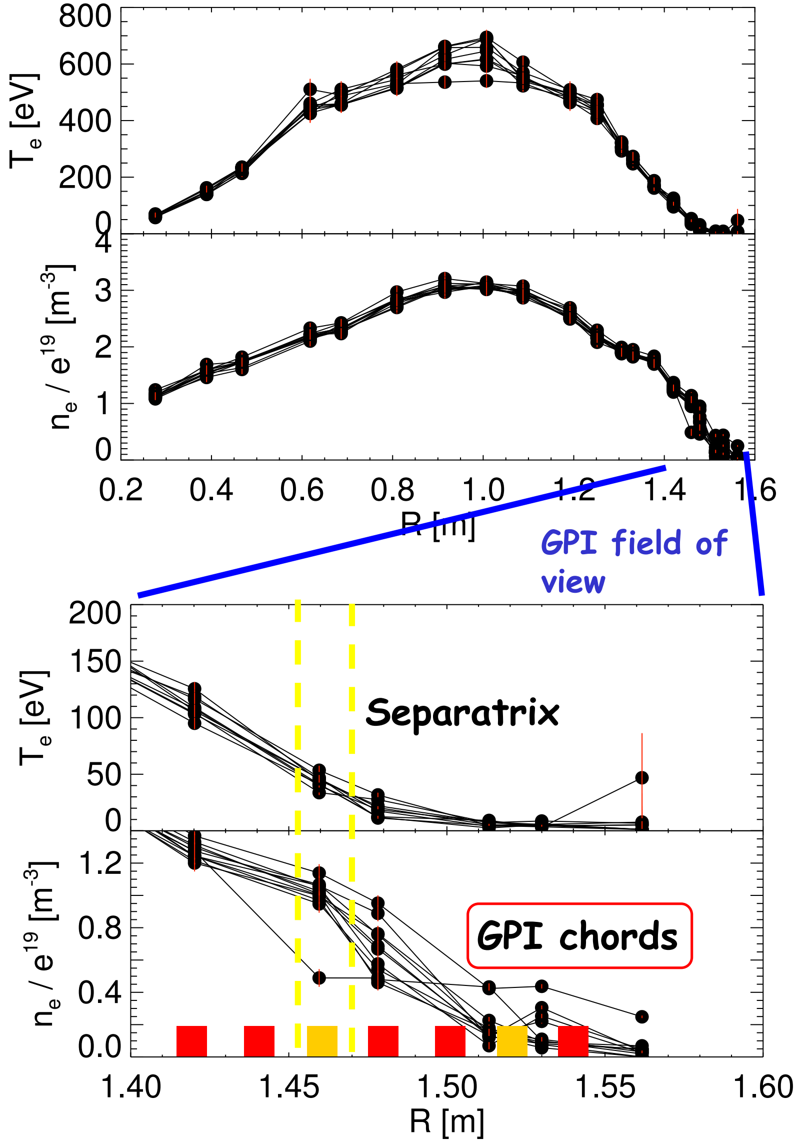
Main parameters:

	L-mode	H-mode
B_0	0.3 T	0.3 T
I_p	0.8 MA	0.8 MA
P_{NBI}	2–4 MW	2–4 MW
τ_E	20 ms	30 ms
β_{tor}	8%	10%
T_{e0}	600 eV	800 eV
n_{e0}	3×10^{19}	3×10^{19}
T_e (edge)	20 eV	50 eV
n_e (edge)	0.7×10^{19} m^{-3}	1.5×10^{19} m^{-3}

$n/n_G \sim 0.4$

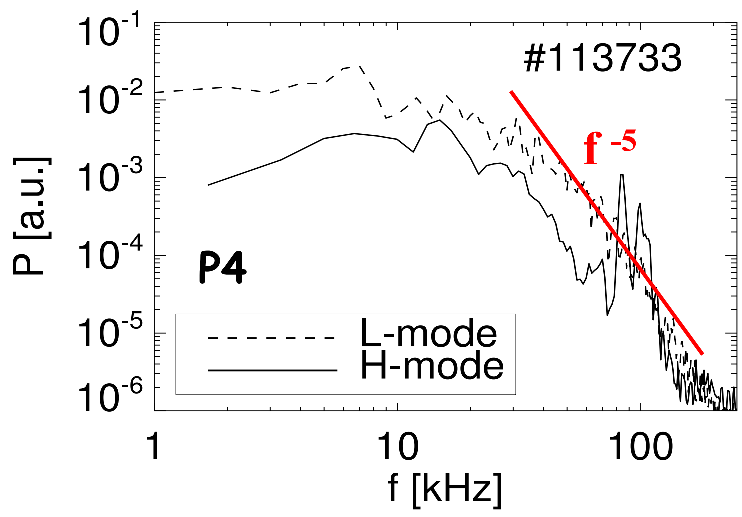
- Every discharge has a L-H transition detected with the GPI
- The 13 discharges are well reproducible

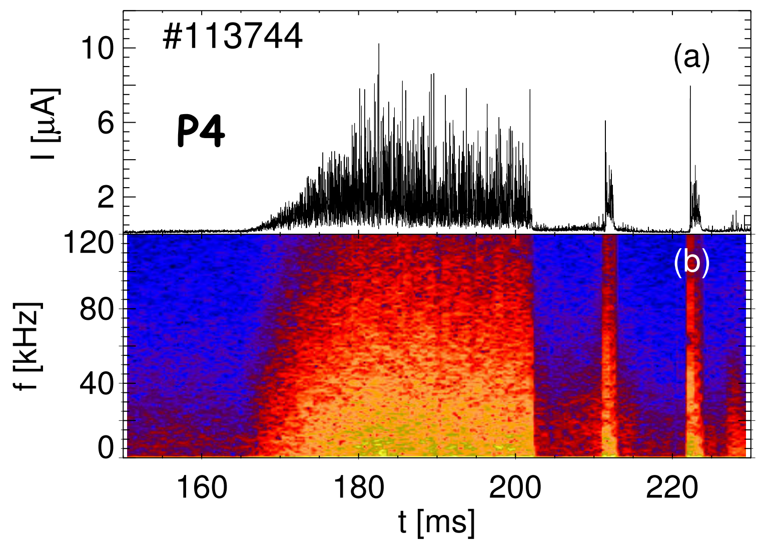
EDGE PROFILES



- The 13 discharges have reproducible temperature and density radial profiles *[Measured with the Thomson scattering]*
- Also the edge profiles are reproducible
- The separatrix is about in the same position respect to the GPI chords
- 5 chords are used to characterize radial profiles of the edge turbulence

SPECTRAL PROPERTIES





✓ Power spectra in L- and H-mode have a power-law decay for frequencies *30 kHz< f < 200 kHz*

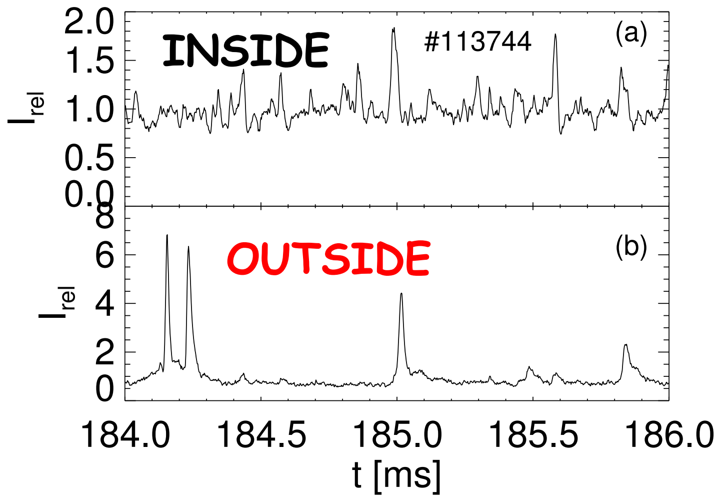
✓ Universally detected in many plasma devices

✓ Indication of energy exchange processes between fluctuations at different scales *[B.Carreas et al., PoP **6**, 4615 (1999)]*

✓ During the H-mode the fluctuation level decreases

✓ Bursts are detected during all the time window analyzed

STATISTICAL ANALYSIS

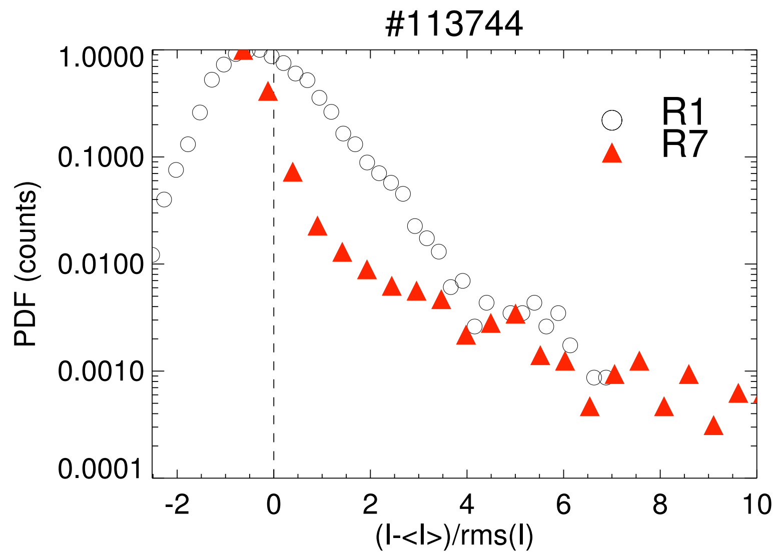


- The dependence of the edge turbulence with the radius is clear also in the raw data
- *Inside* : small but many bursts
- *Outside*: few but intense bursts

➢The normalized **P**robability **D**ensity **F**unctions of the normalized fluctuations are evaluated

➢Both the signals have a **non-Gaussian** statistics

➢The departure from Normal distribution is greater for the most external chord

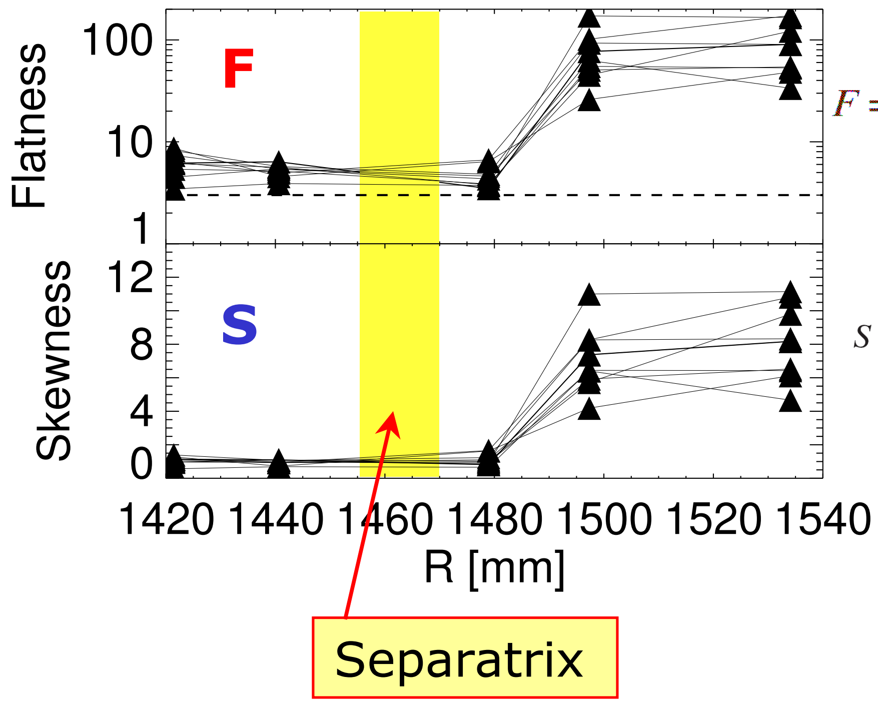


FLATNESS & SKEWNESS

✓ Flatness and Skewness of GPI fluctuations are evaluated for the different discharges as a function of the radius

✓ **F** measures the weight of the tail of the distribution

✓ **S** measures the asymmetry of the distribution



$$F = \frac{\langle (I - \langle I \rangle)^4 \rangle}{\langle (I - \langle I \rangle)^2 \rangle^2}$$

$$S = \frac{\langle (I - \langle I \rangle)^3 \rangle}{\langle (I - \langle I \rangle)^2 \rangle^{3/2}}$$

➢ For the most internal chords **F**~5 and **S**~1 and increase in the outermost ones

➢ Edge fluctuations are more and more dominated by positive (**S**>0) bursts with high amplitude (great **F** values) relative to the mean as we move outward

WAVELET ANALYSIS

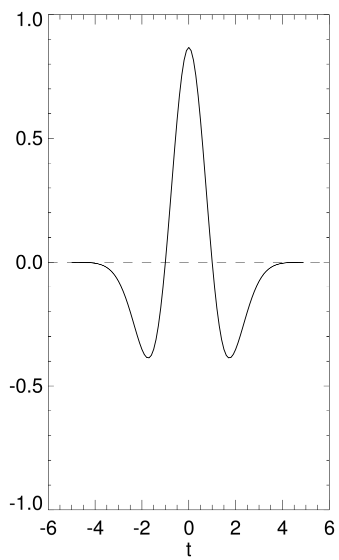
- Continuous wavelet analysis is applied to the GPI data to study the fluctuations at different time-scales τ *[M. Agostini et al.,PoP* ***14*** *102305 (2007)]*

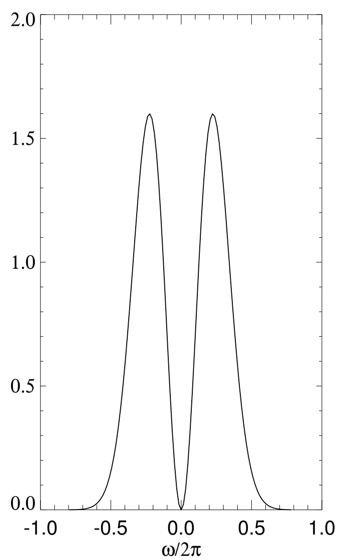
Wavelet transform:

$$w(s,\tau)=\frac{1}{\sqrt{\tau}}\int_{-\infty}^{+\infty} f(t)\psi^{*}\left(\frac{t-s}{\tau}\right)dt$$

M.Farge, Annu.Rev.Fluid Mech. ***44*** *395 (1992)*

Mexican Hat and its Fourier Transform:





- Wavelet coefficients represent the time behavior of the characteristic fluctuations at each scale τ

$$w(s,\tau)\propto f(s+\tau)-f(s)=\delta_{\tau} f(s)$$

- The statistical properties of fluctuations at different time scales can be studied

INTERMITTENCY

- The **P**robability **D**istribution **F**unction of the normalized wavelet coefficients **$C(t,\tau)$** reflects the PDF of the fluctuations at different scales
- The PDF of the fluctuations depends on the time scale

The statistical properties depend on the scale itself: this is the **Intermittency**

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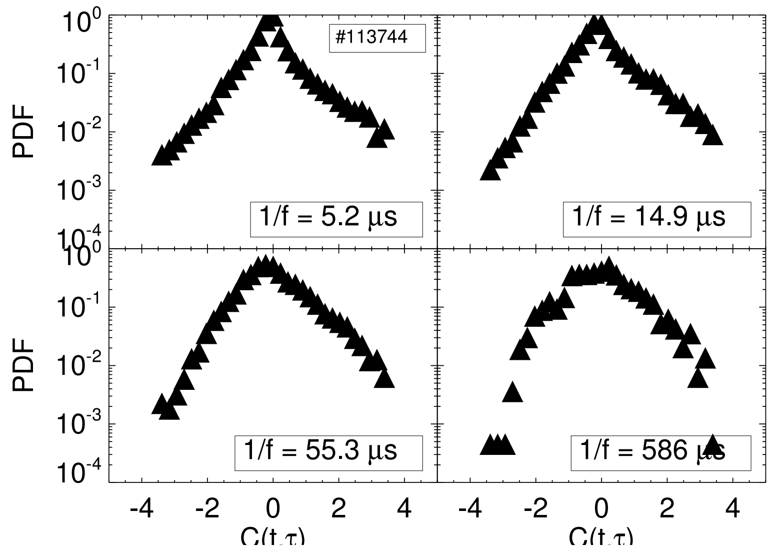
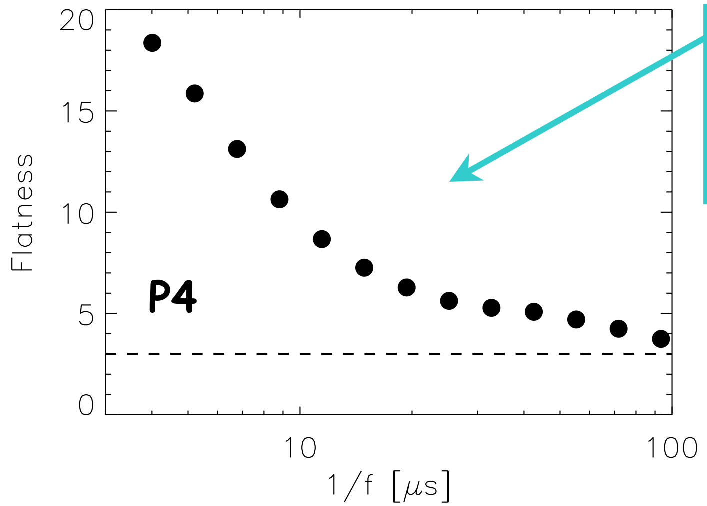




Intermittency is reflected on $F(\tau)$

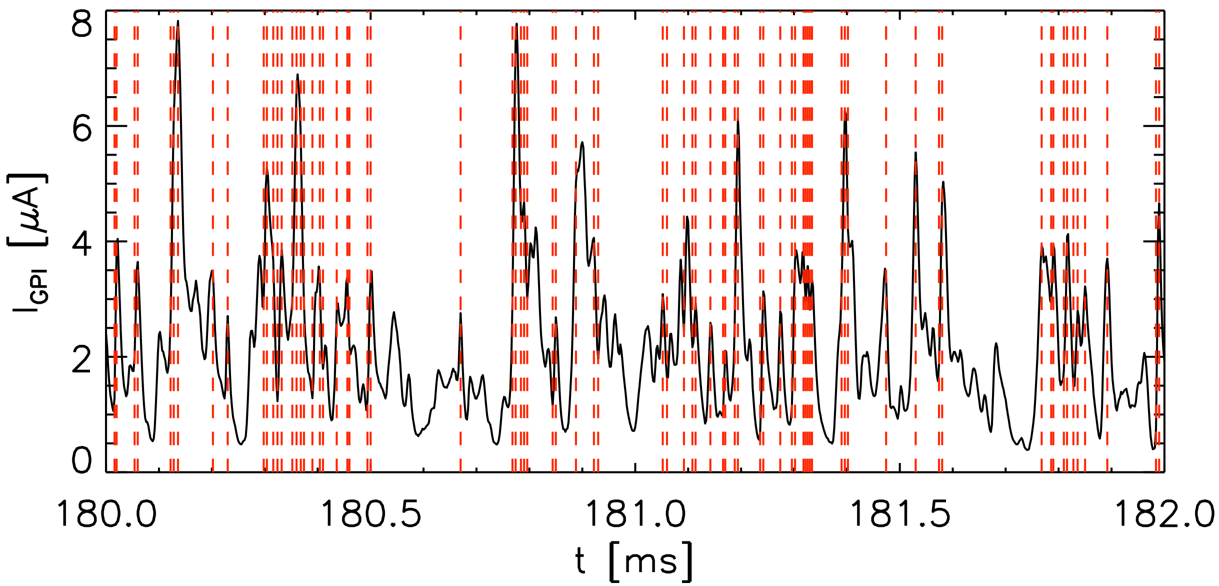
U.Frish, Turbulence, Cambridge University Press, 1995

*M. Farge et al., PoP **13** 042304 (2006)*

BURSTS DETECTION

Bursts detected in the GPI signal with the Local Intermittency Measure (LIM) *[Onorato et al., PRE, 61, 1447, (2000)]*

$$\text{LIM: } l(t,\tau) = \frac{w(t,\tau)^2}{\langle w(t,\tau)^2 \rangle}$$



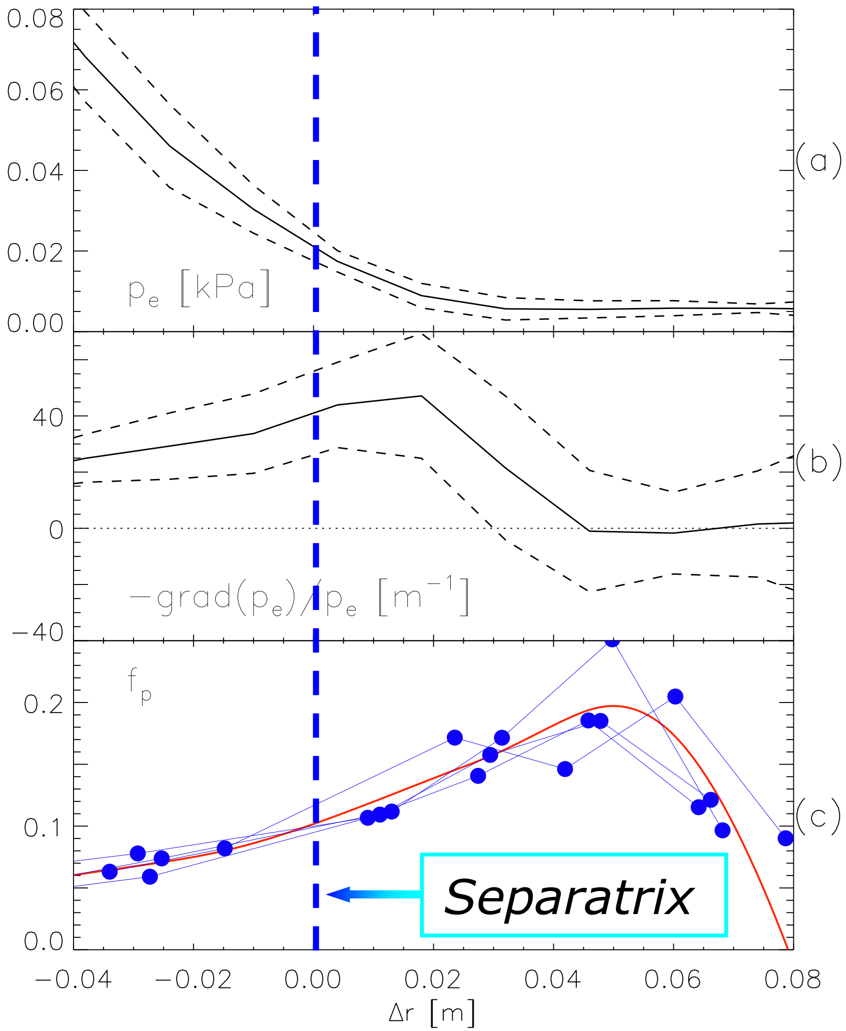
✓ For each time scale τ a threshold $S(\tau)$ in the LIM signal is chosen that divides the wavelet coefficients in two orthogonal sets:

$$\boxed{w(t,\tau) = w_e(t,\tau) \oplus w_g(t,\tau)}$$

assuring $Flatness[w_g(t,\tau)] = 3$

✓ An intermittent event is identified in the signal when $l(t,\tau) > S(\tau)$ and simultaneously $l(t,\tau)$ has a local maximum

PACKING FRACTION



- ✓ Packing fraction of edge turbulence as a function of the radius is evaluated: *[M.Spolaore et al., PRL **93** 215003 (2004)]*

$$f_p = \sum_{\tau} \tau N_\tau / \Delta t$$

- ✓ Sum over all the structures of scale τ detected with the LIM method

- ✓ It measures the percentage of the signal occupied by structures

- ✓ f_p has its maximum where the logarithmic derivative of p_e is minimum: blobs born near the separatrix evolve outward

*[J.R.Myra et al. PoP **13** 092509 (2006)]*

SUMMARY L-MODE

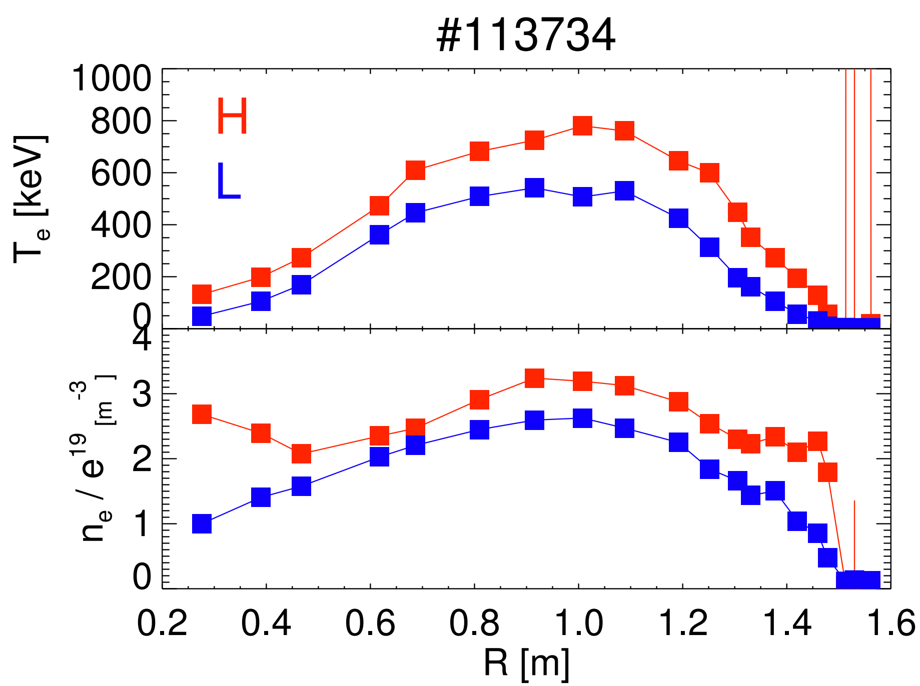
- Non-Gaussian statistics detected in all the radial position for the L-mode
- Power-law decay of the spectrum detected for all the signals of the GPI
- Intermittency increases for the most external chords
- The packing fraction increases outward, where $\nabla p_e / p_e$ has its minimum

- The intermittent behavior of the signals is related to the presence of intense bursts, responsible for the non-Gaussian tails of the PDF
- Outside the separatrix there are more and more intense events (**F**, **S** increase) with respect to the inside: these structures occupy a larger area (f_p increases)

L-MODE Vs H-MODE

- The difference between the edge turbulence during **L-mode** and **H-mode** is carried out

- The improved confinement is normally observed with a reduction of edge turbulence and with a reduction of edge transport



✓ Typical radial profiles of electron temperature and density for the analyzed shots in L and H mode

✓ Steep edge gradient in electron density is observed

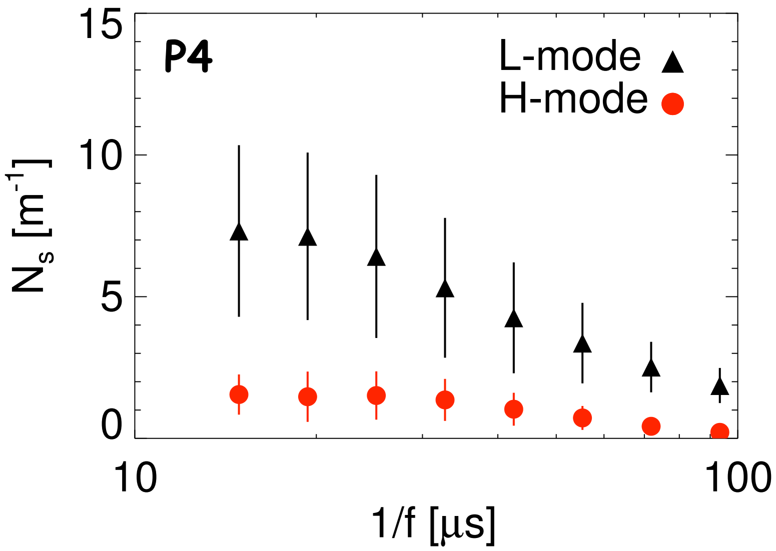
✓ Good reproducibility of the radial profiles also in the edge

INTERMITTENT EVENTS

✓ The intermittent events are detected with the LIM method in the poloidal array of the GPI and then counted

✓ Their linear density is defined as: $N_s = \Delta N_\tau / (v_\theta \Delta t)$

Poloidal velocity



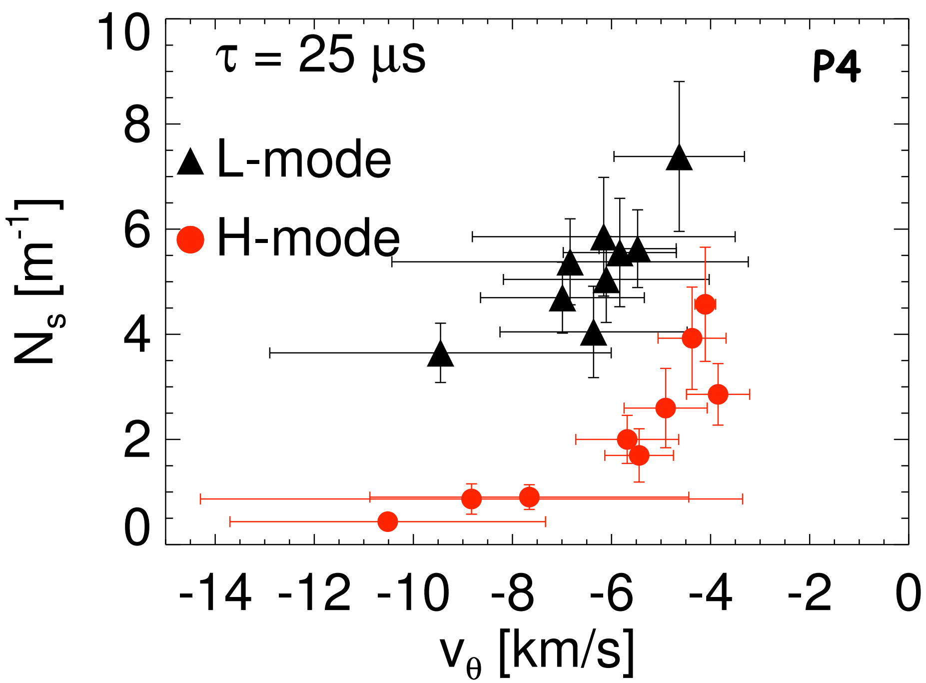
➢ Near the separatrix, there is a drastic decrease in the linear density of edge structures in H-mode respect to the L-mode

➢ Structures at all scales are reduced

The decrease of edge fluctuations is reflected in a decrease of intermittent events and with the presence of the high confinement phase of the discharge

LINEAR DENSITY OF BURSTS

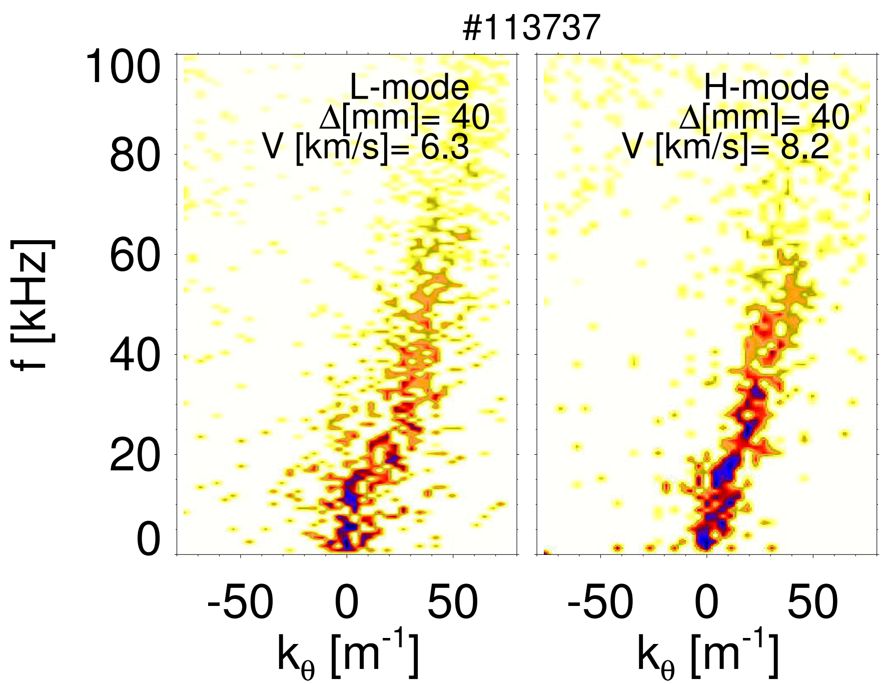
N_s as a function of the average poloidal velocity of propagation of fluctuations for structures with τ = 25μs

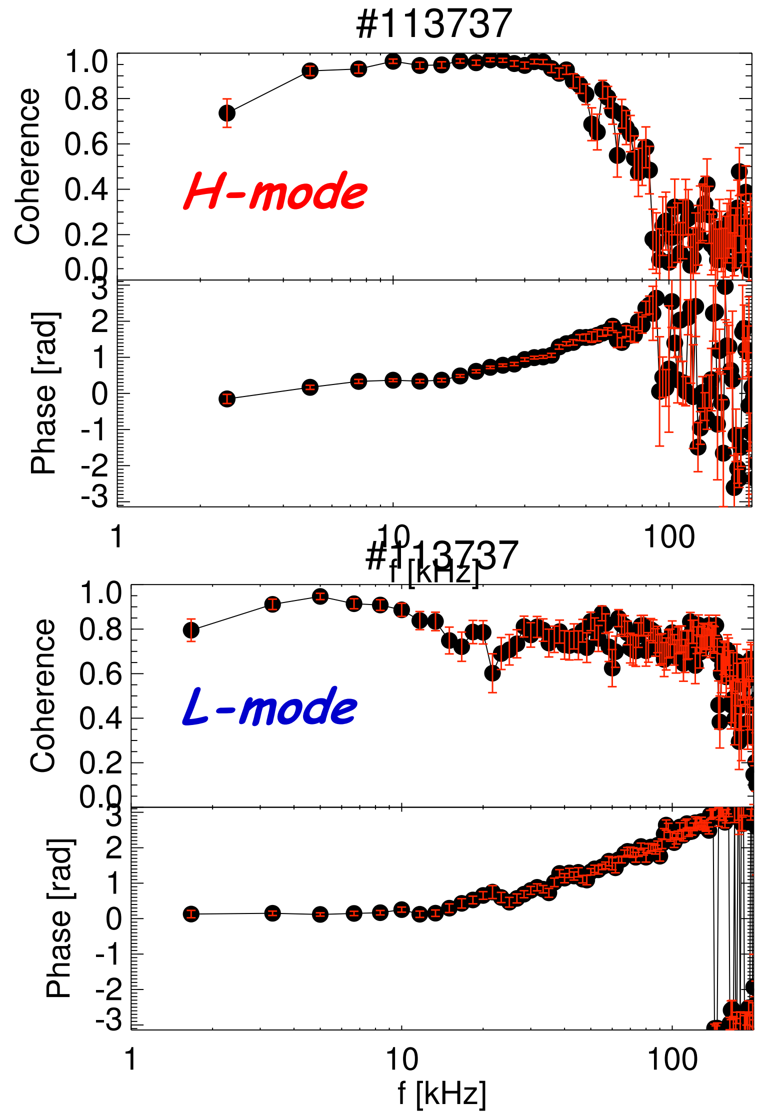


- The poloidal velocity does not vary between L- and H-mode
- If the edge structures are considered to be responsible for the most of the anomalous transport in the edge this measurement correlates the better confinement with their reduction

POWER SPECTRAL ANALISYS

- *SKW* spectra are evaluated for L and H-mode with two poloidal chords with Δ=40 mm



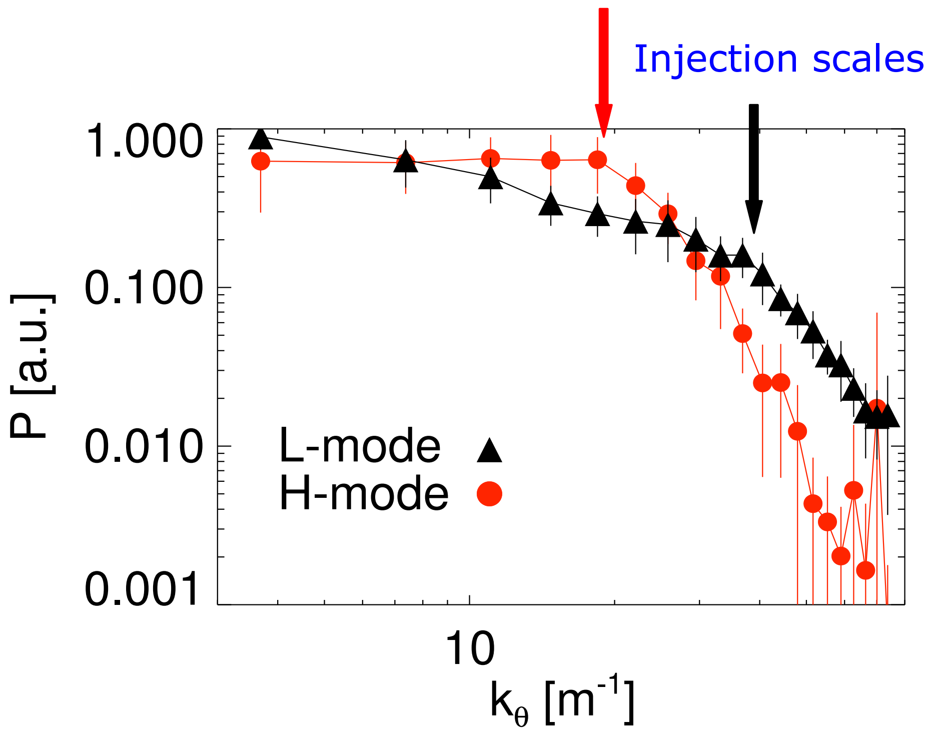


High coherence and quasi-linear dispersion relation between f and k_θ

POLOIDAL K-SPECTRA

- ✓ Integrating *SKW* in frequency the power spectrum of the **poloidal wavenumber** ***k_θ*** is obtained
- ✓ The two **normalized spectra** are different
- ✓ Different **power law decay** in high k_θ
- ✓ No power slope decay in low k_θ for the H-mode
- ✓ **Different injection** scales in the two regimes
- ✓ **Different cascade** processes in the two regimes

[M.G.Shats et al.,PRE ***71*** *046409 (2005)]*



	L-mode	H-mode
k_θ^*	$40\,m^{-1}$	$20\,m^{-1}$
Decay $k_\theta < k_\theta^*$	$k_\theta^{-0.7\pm0.1}$	$k_\theta^{0.1\pm0.3}$
Decay $k_\theta > k_\theta^*$	$k_\theta^{-3.7\pm0.4}$	$k_\theta^{-5.5\pm0.6}$

[M. Agostini et al.,PoP ***14*** *102305 (2007)]*

CONCLUSIONS

L-mode

- Intermittency is higher for the external GPI chords respect to the inside ones
- Radial profile of packing fraction of edge structures well correlated with the electron pressure gradient
- Blobs probably born near the separatrix develop moving outward and increasing amplitude and dimension

L *Vs* H-mode

- Clear relation between the transition and the edge fluctuations
- Near the separatrix the poloidal velocity does not change but the linear density of burst has a clear decrease
- Different poloidal *k* spectrum between the L and H-modes: probably different cascade processes

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