Characterization of intermittent turbulence in the edge of the NSTX experiment with the Gas Puff Imaging

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Motivations & Outline

✓ Turbulence commonly recognised as the dominant mechanism for *anomalous transport*

✓ Turbulent signals in all magnetic configuration exhibit *intermittent behaviour*, associated to the presence of *structures* which have a deep influence on confinement properties

✓ The optical diagnostic **G**as **P**uff **I**maging is used in NSTX† and RFX-mod* experiments to study edge turbulence and structures for all plasma conditions

✓ Comparison between NSTX and RFX-mod edge turbulence and between NBI L-mode and RF+NBI plasma in NSTX is carried out

† *M.Ono et al., Plasma Phys.Cotrolled Fusion* ***45*** *A335 (2003)*

* *R.Paccagnella et al., Phys.Rev.Lett.* ***97*** *075001 (2006)*

The GPI diagnostic: principles

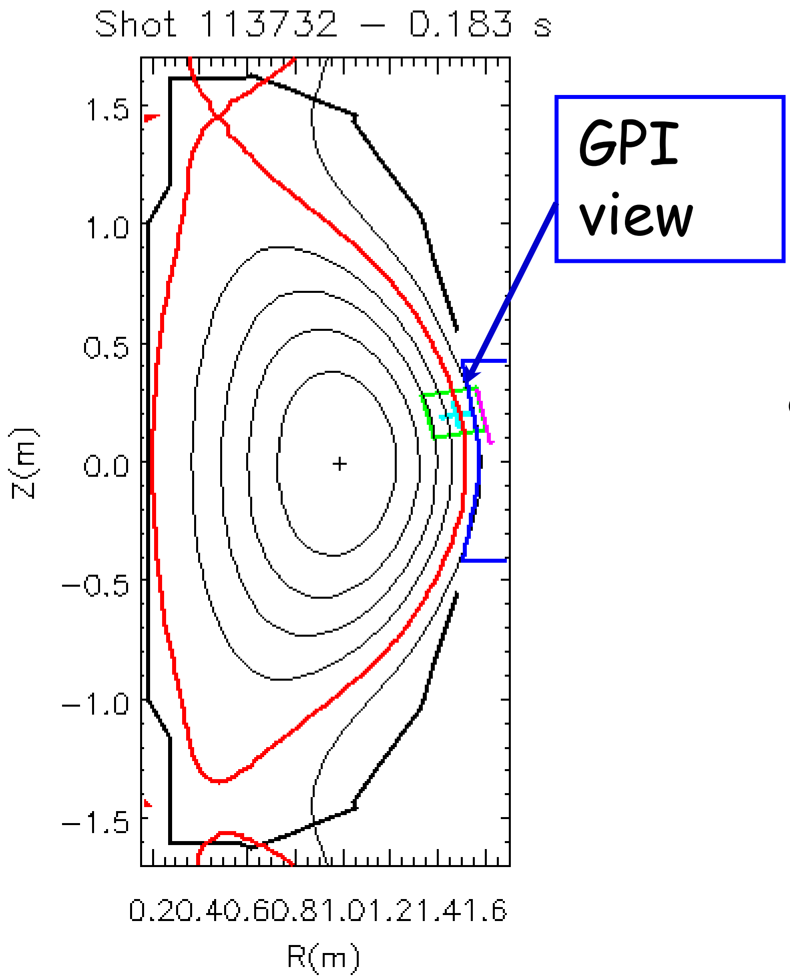
- ✓ Gas Puff Imaging: non-intrusive optical diagnostic to study the edge turbulence in fusion experiment
- ✓ Observes the excited neutral gas (D, He, H) puffed

$$I \propto n_0 \, f(n_e, T_e) = n_0 \, n_e^{\alpha} \, T_e^{\beta}$$

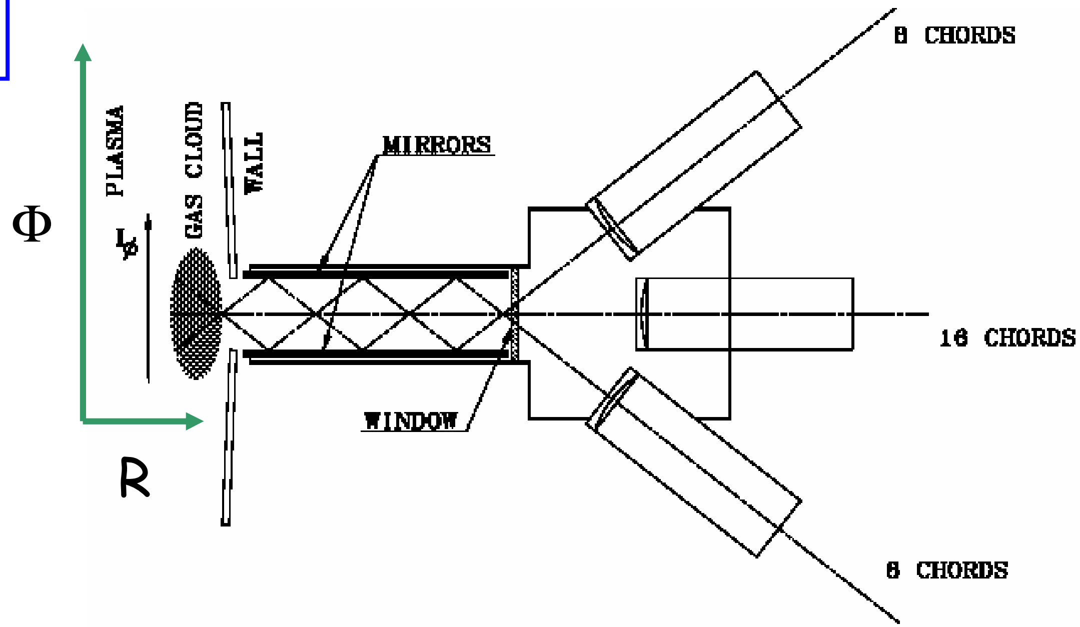
- ✓ Characterization of the turbulence in the plane perpendicular to the main magnetic field
- ✓ Study of edge structures motion and evolution

GPI geometry (1)

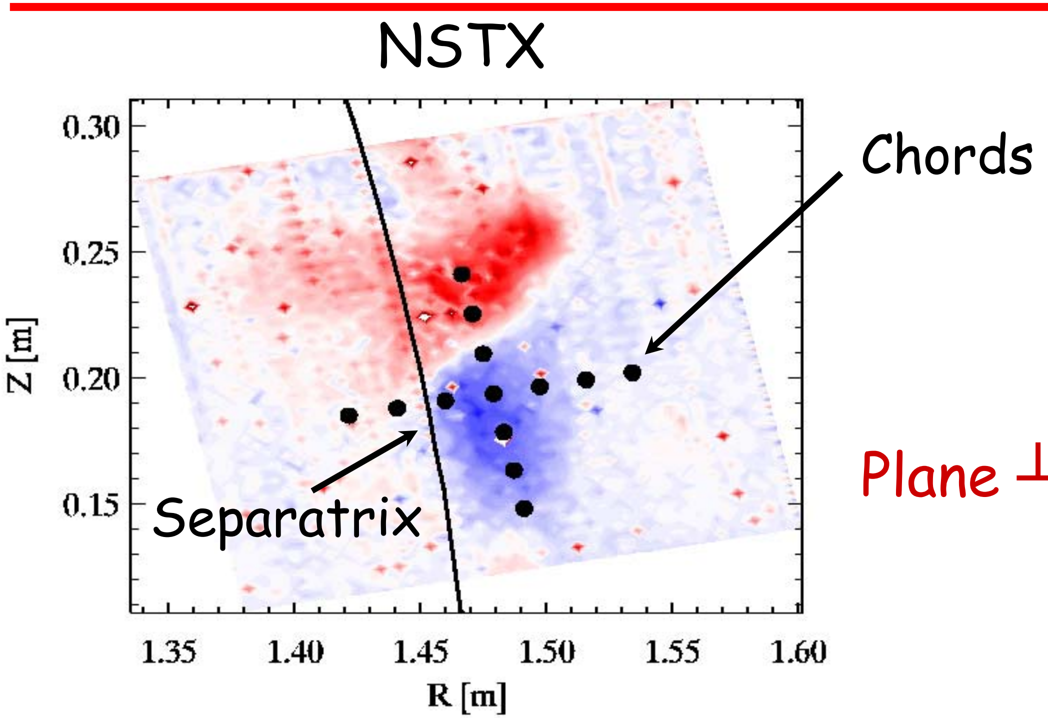
NSTX



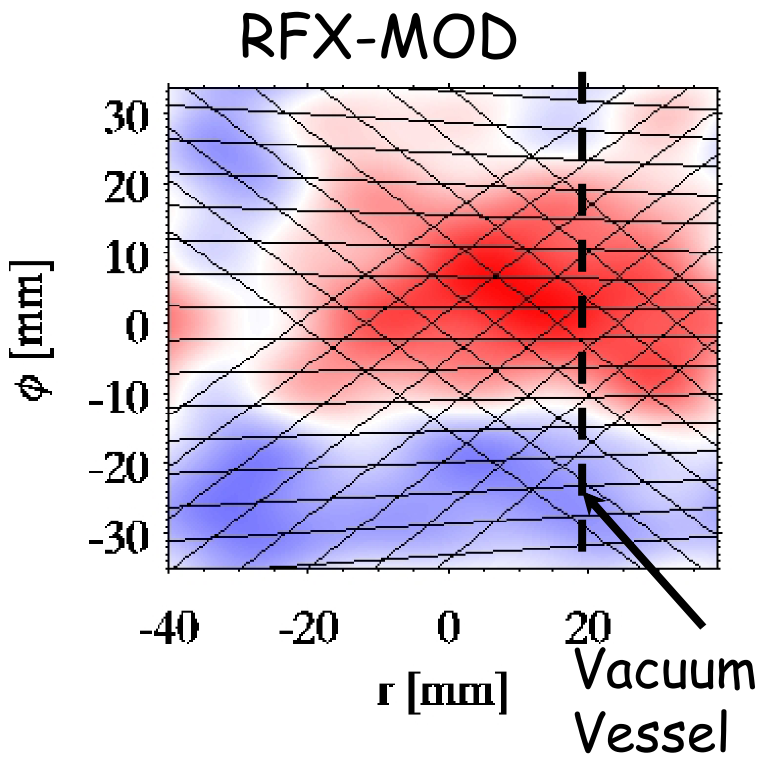
RFX-MOD



GPI geometry (2)



Plane ⊥ B



- 2D fast camera & 13 chords
- Measures the D_α line emission

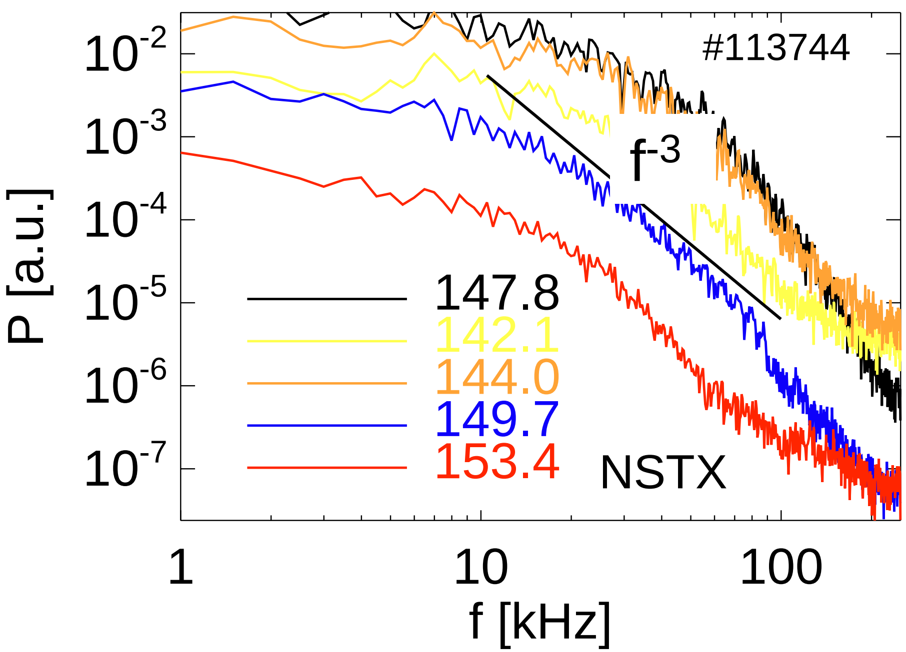
S.J.Zweben, et al., Nucl. Fusion ***44*** *132 (2004)*

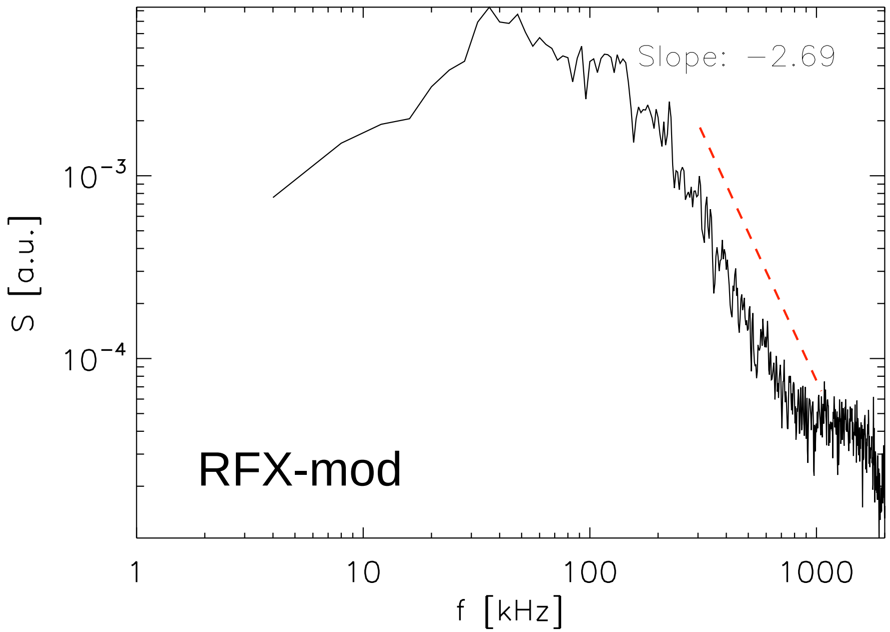
- 32 Lines of Sight
- Measures the HeI line emission

M. Agostini et al., Rev. Sci. Instrum. ***77*** *10E513 (2006)*

Serianni et al., UP1.00054, this conference

Similar power spectra in NSTX and RFX-mod





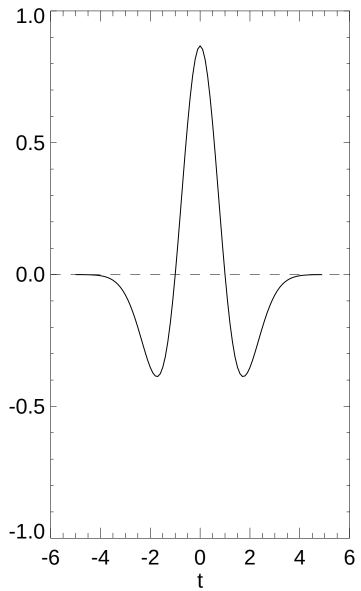
- Similar behavior between the two experiments
- Power-law decay as f^{-3}
- Different frequency ranges

The wavelet analysis

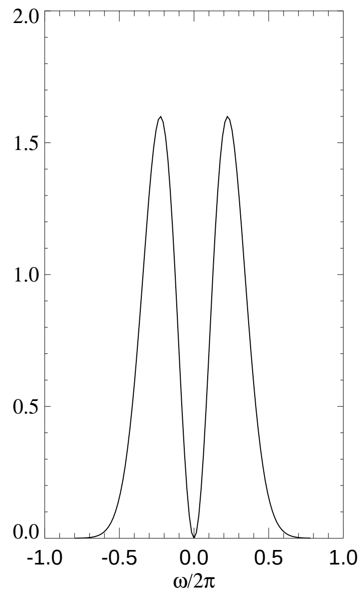
Wavelet transform of the function *f(t)* at time *s* and time-scale τ

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

Mexican Hat Wavelet



Fourier transform



Property of wavelet coefficients:

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

Fluctuation of time-scale τ at time s

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

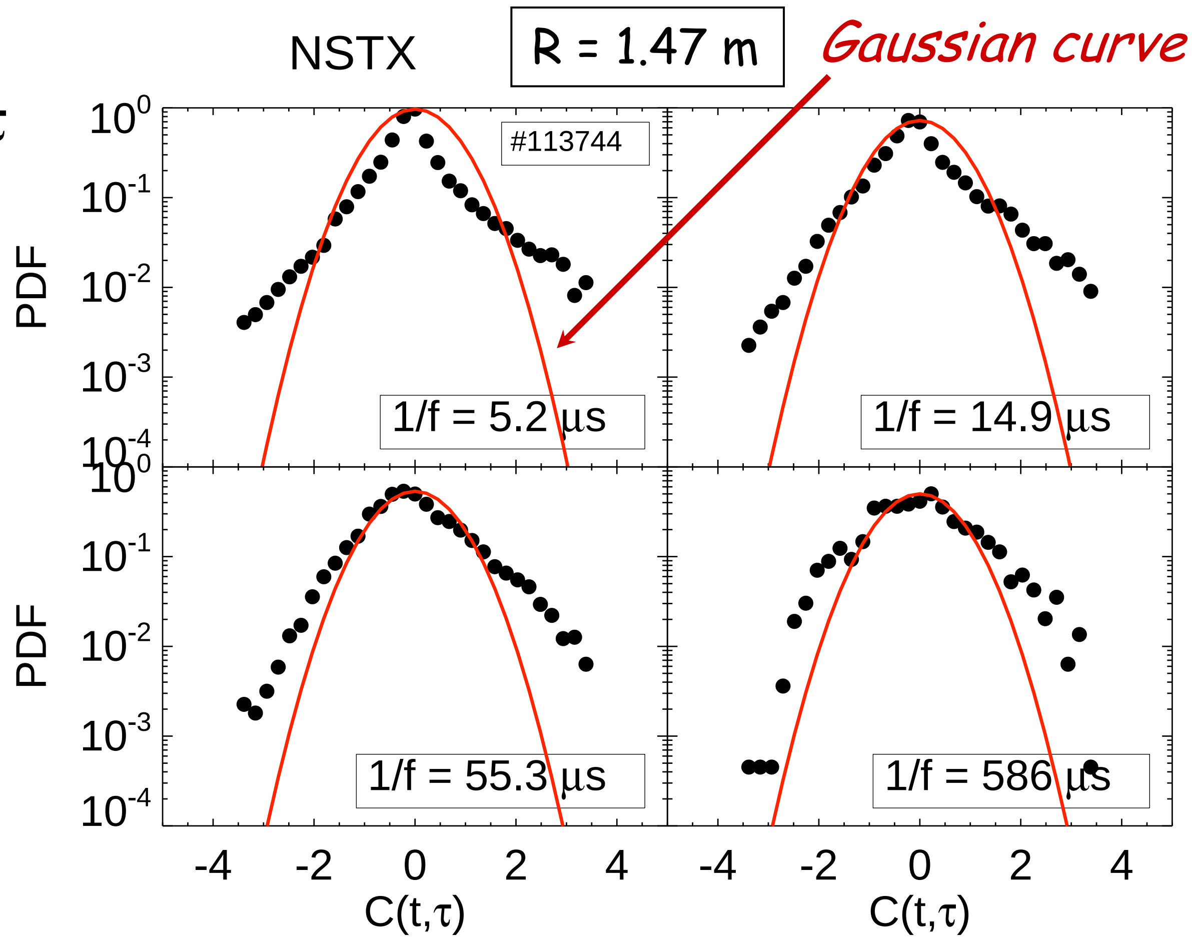
Statistical properties change with fluctuation time-scale

- ✓ **P**robability **D**ensity **F**unction of normalized GPI fluctuations for different time scales τ

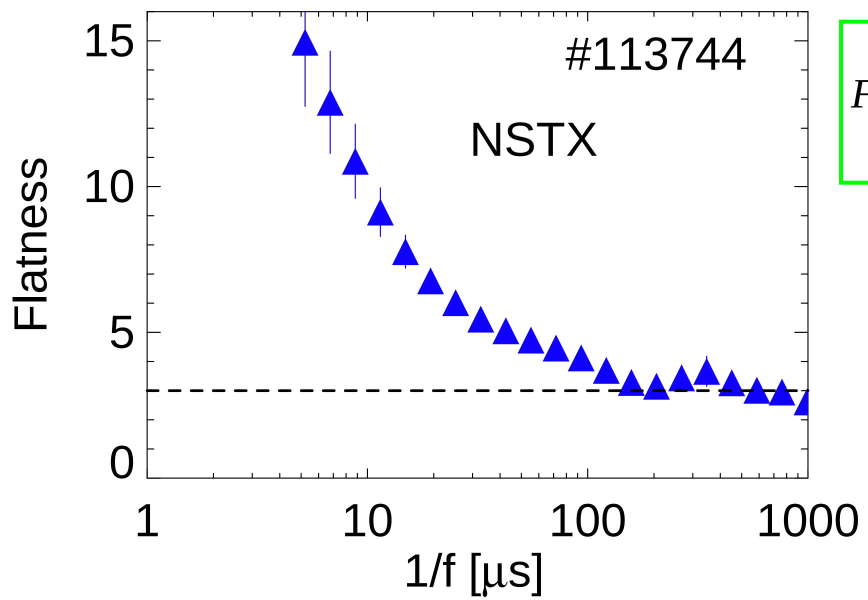
- ✓ PDFs change with the scale

Itermittency

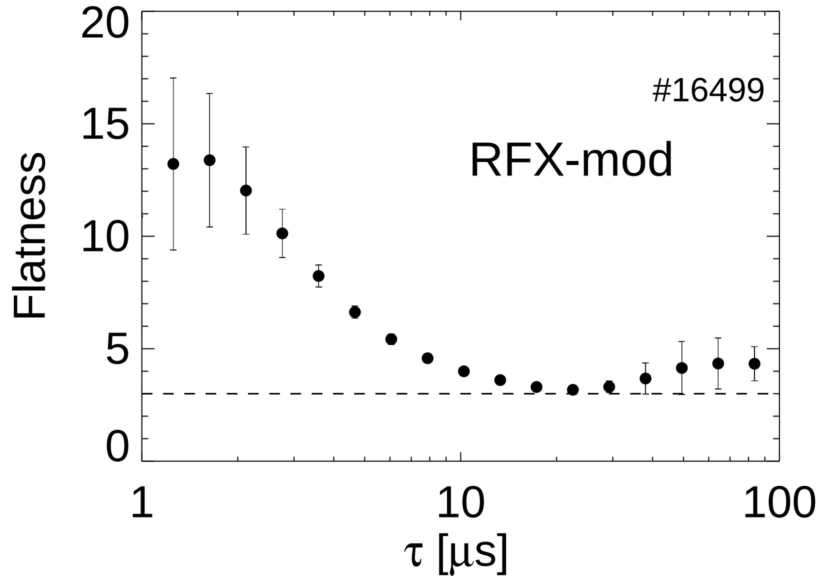
$$C(t,\tau) = \frac{w(t,\tau) - \langle w(t,\tau) \rangle}{\sigma_\tau}$$



Similar intermittent behavior in NSTX and RFX-mod

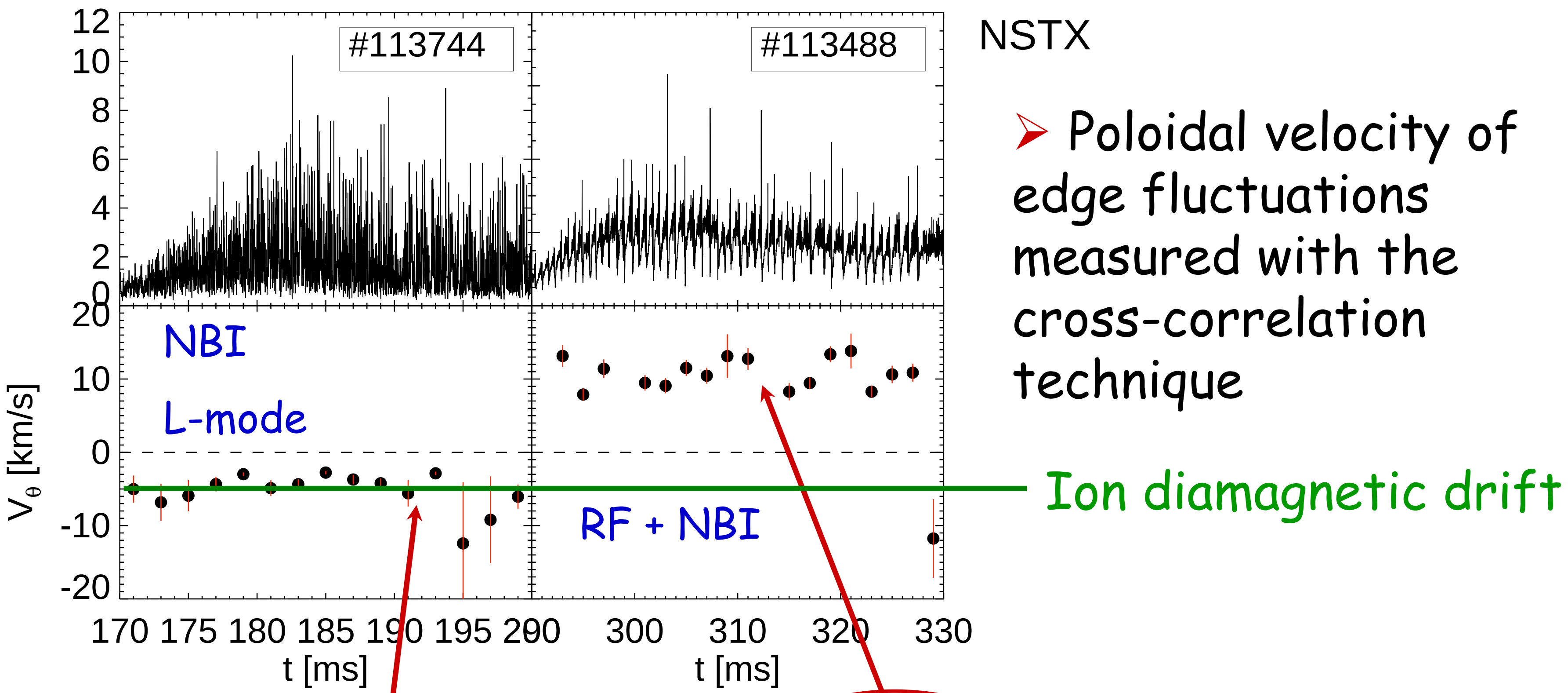


$$F = \frac{\langle x^4 \rangle}{\langle x^2 \rangle^2}$$



- Flatness changes with the fluctuations time-scale τ
- High flatness for small time-scale and Gaussian statistic for bigger ones (F = 3)
- Similar behavior between the two experiments
- Scale ranges reflects the different power spectra

Opposite poloidal velocity in RF+NBI respect to NBI L-mode

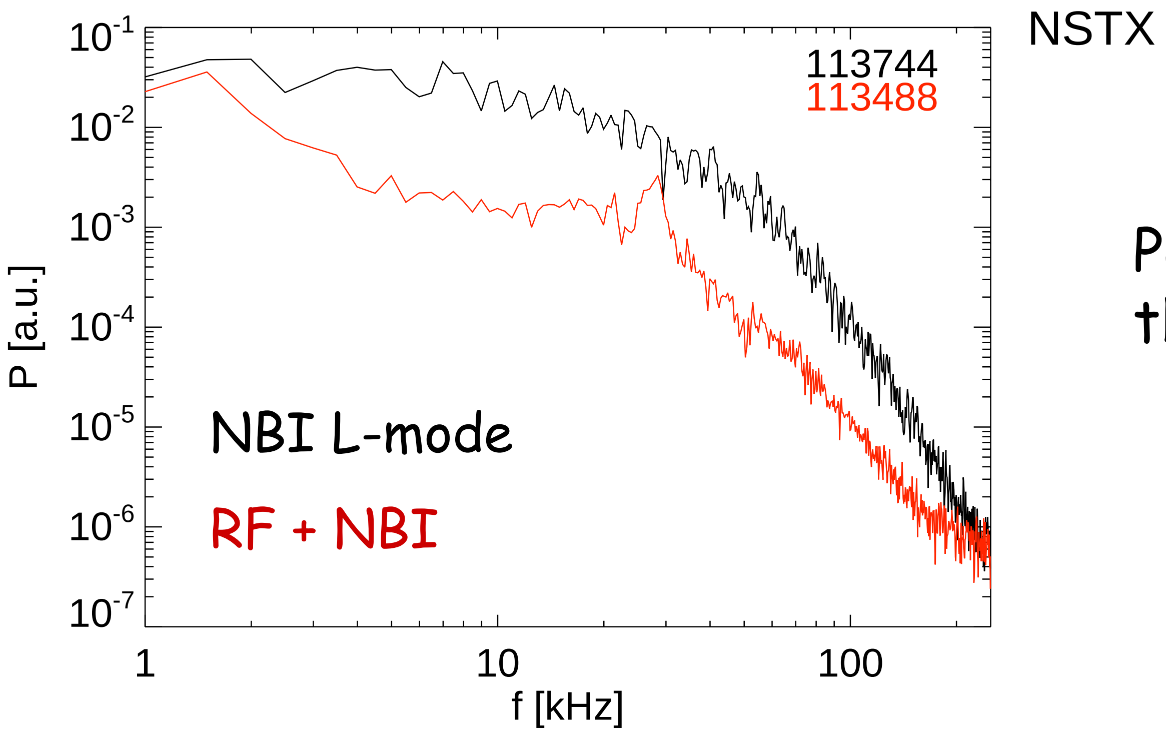


- Poloidal velocity of edge fluctuations measured with the cross-correlation technique

- Velocity along the ion diamagnetic drift
- Velocity opposite to the ion diamagnetic drift

- ✓ Positive V_{EXB}
- ✓ Inward E_R

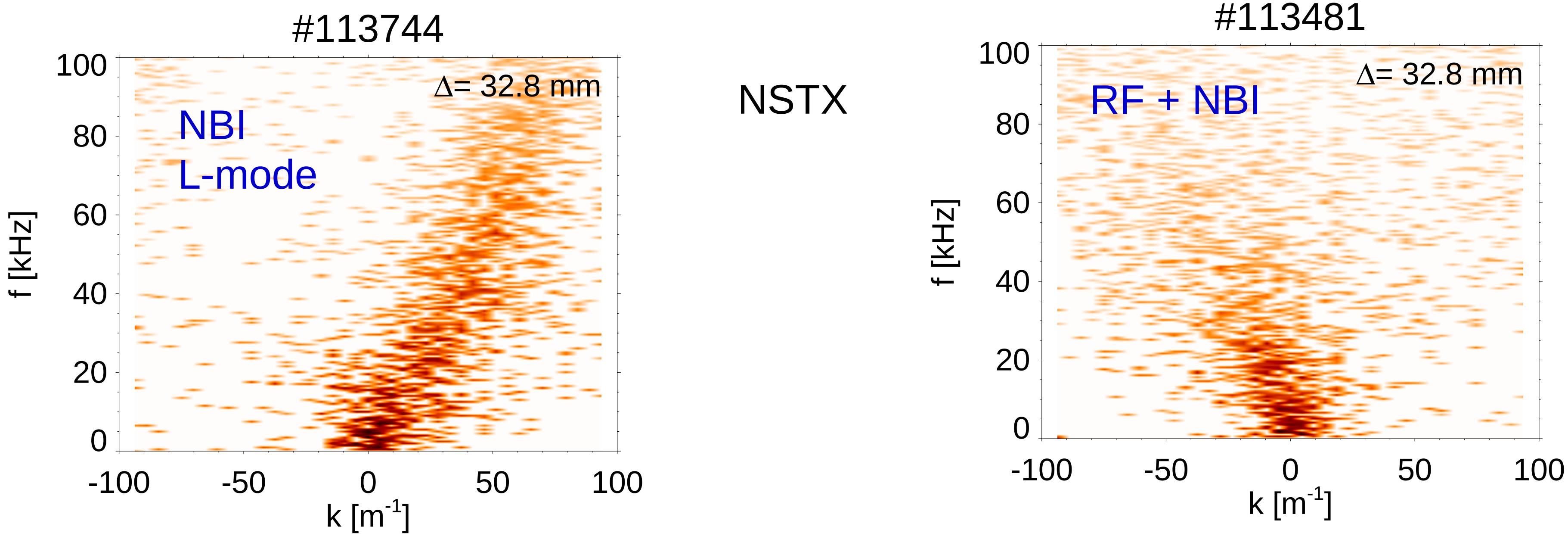
Spectra



Power spectra of the two shots

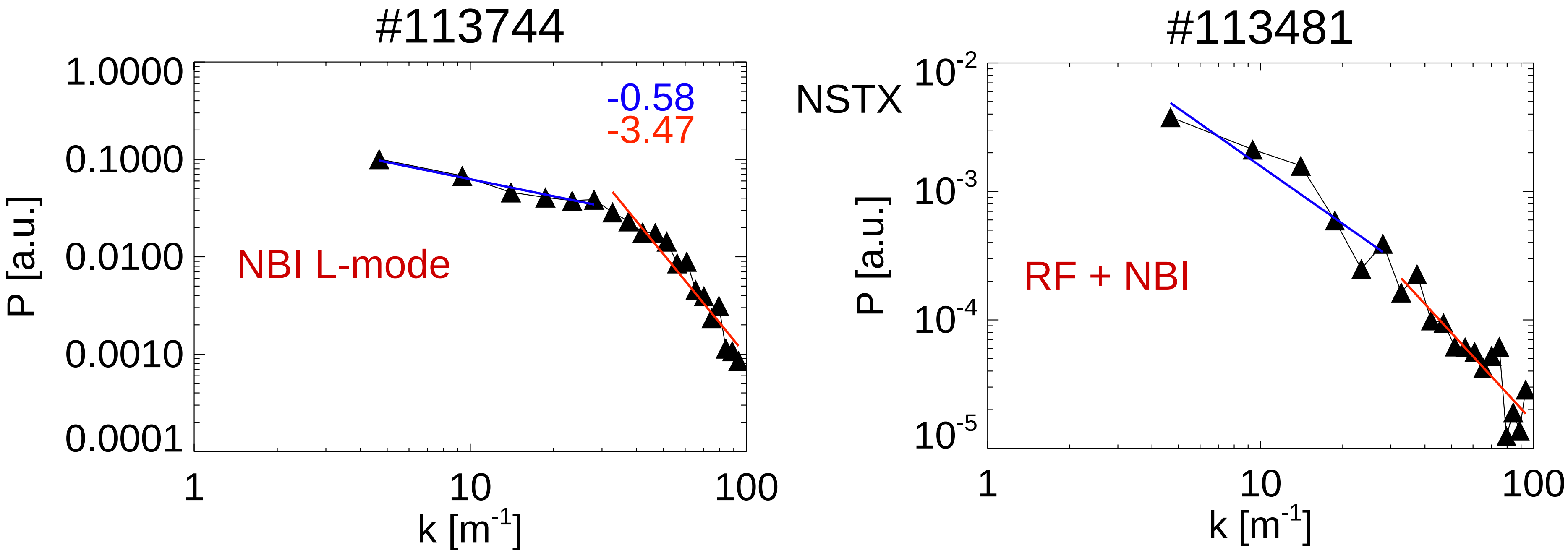
- ✓ Similar power law decay for 40 < f < 200 kHz
- ✓ RF+NBI shots exhibits a peak at low frequencies 1 < f < 3 kHz

Spectral analysis: opposite propagation of fluctuations



- Broadband fluctuations : common feature for edge plasma turbulence
- Opposite edge flow direction between L-mode and RF heated plasma

Different K Spectra in RF+NBI & NBI L-mode

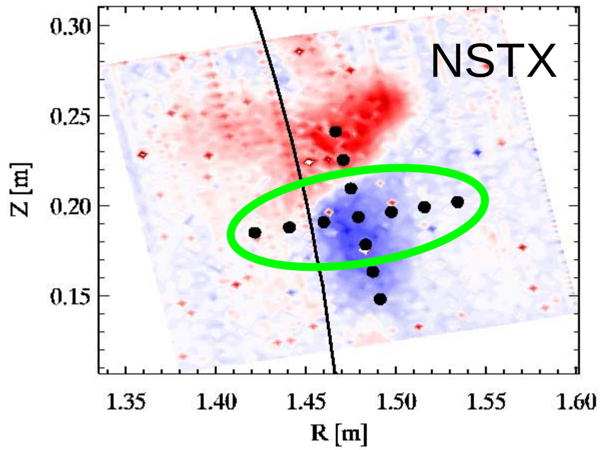


- K spectra obtained integrating the SKW spectra in frequencies
- Two different power laws decay in the L-mode shot

Changing in the K spectrum of the edge fluctuations during RF

Conditional average: technique

Technique used to study the radial extension of the structures



Intermittent structures of time scale τ identified in the central chord with a method based on the wavelet transform (LIM)**

- With this prescribed condition the conditional average is computed for all the radial chords
- Positive and negative peaks are identified

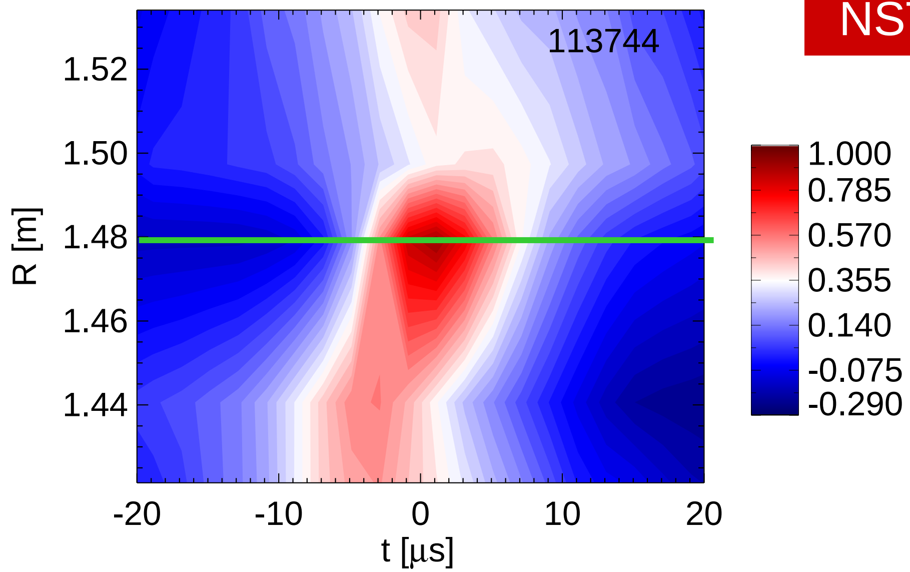
** *G.Boffetta at al., Phys.Rev.Lett.* ***83*** *4662 (1999)*

V.Antoni et al., Europhys.Lett. ***54*** *51 (2001)*

Positive peaks larger in RF+NBI

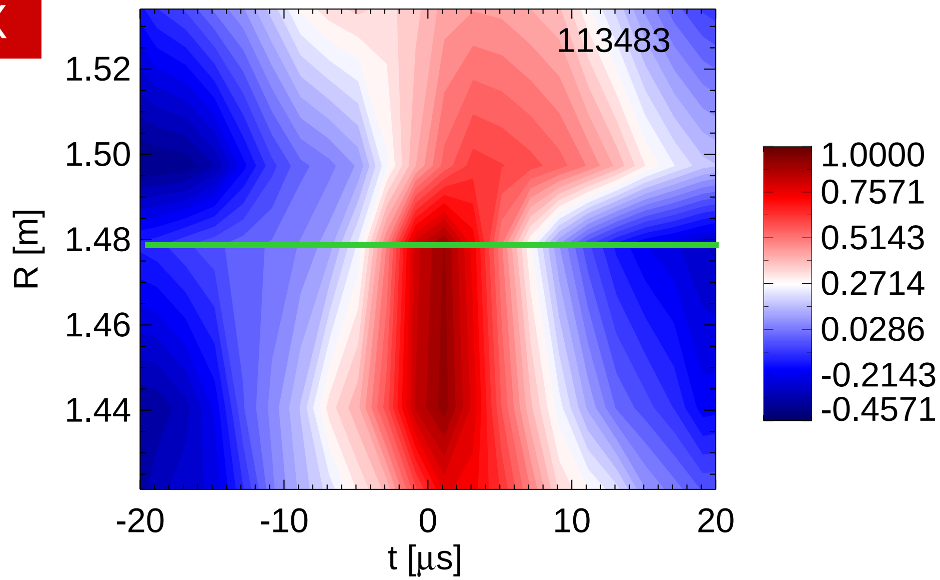
Conditional average in the radial direction

NBI L-mode



NSTX

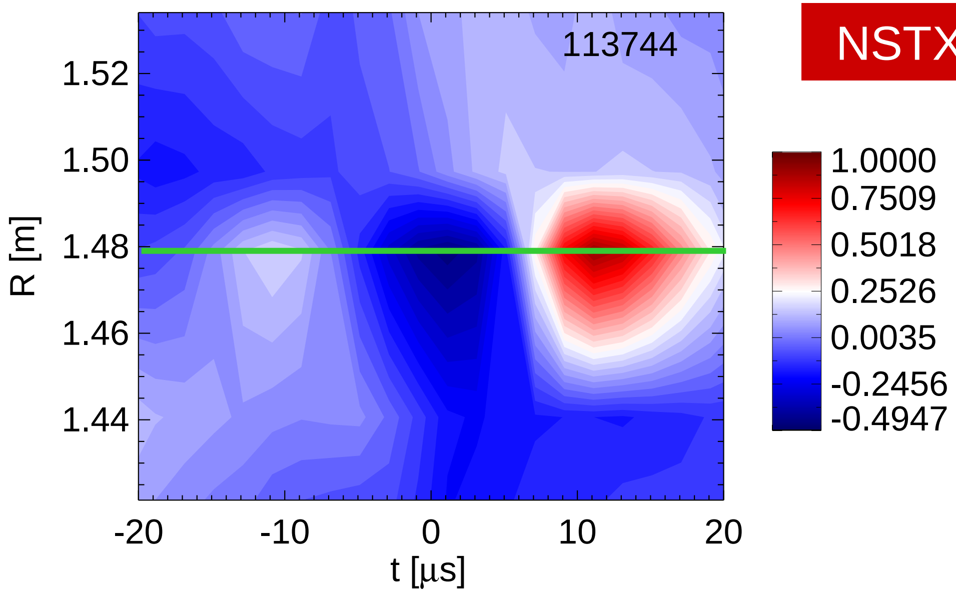
RF + NBI



- Clear positive peaks extended in the radial direction
- Peak extended mainly inward
- Structures larger radially in RF + NBI shot

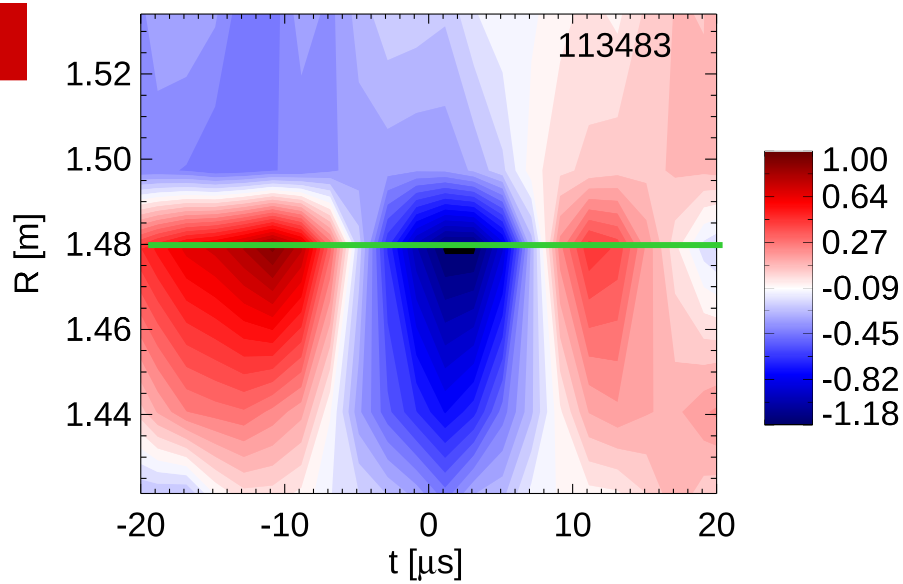
Not clear negative peaks

NBI L-mode



NSTX

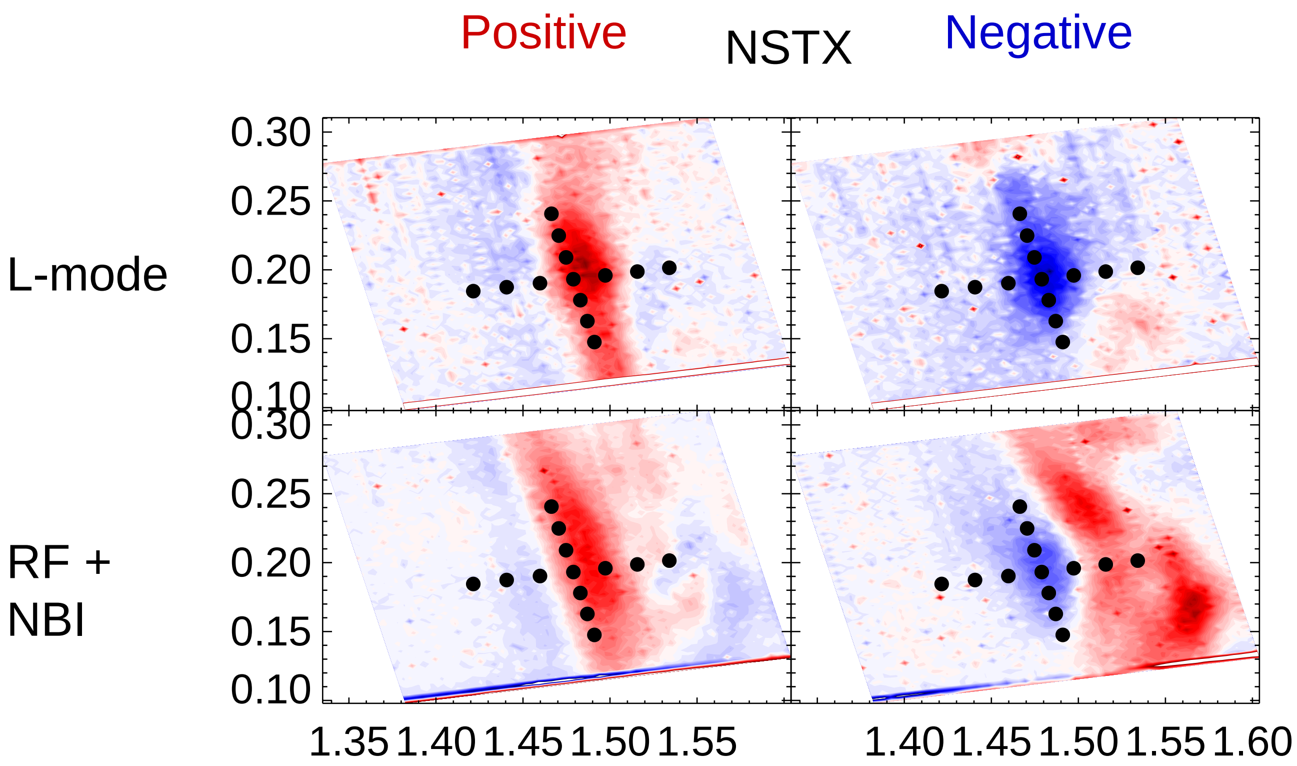
RF + NBI



- Not clear negative peaks
- Associated with a positive one

Camera data

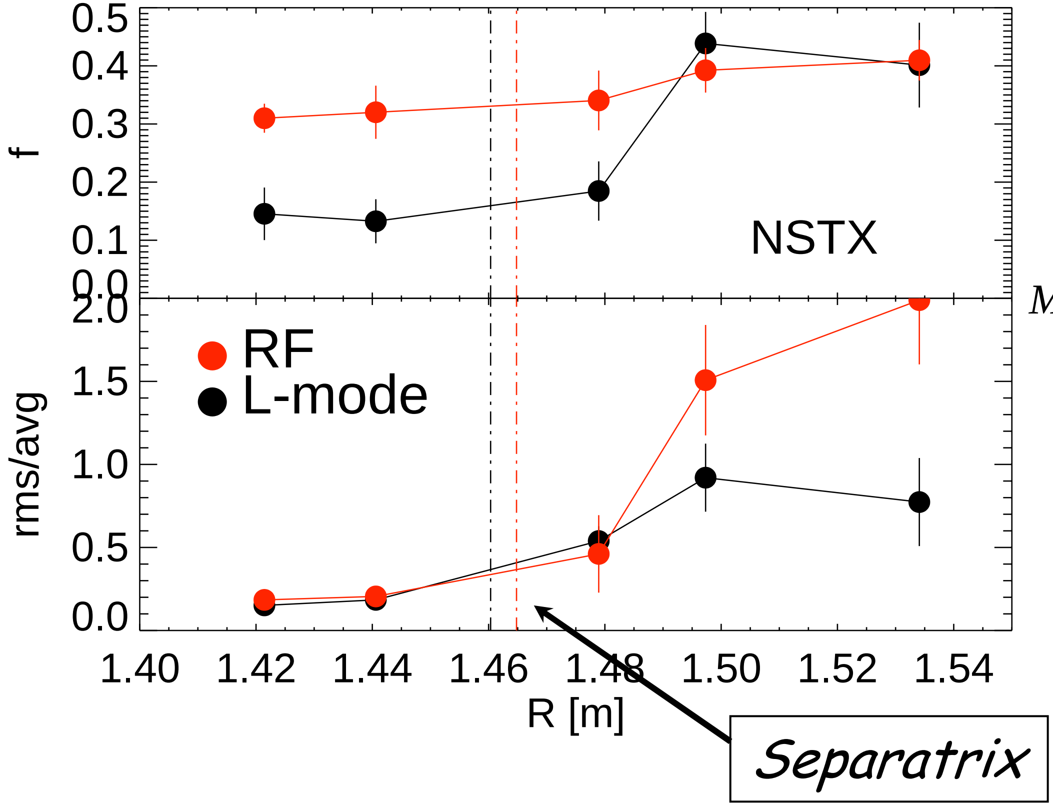
Conditional average of the camera data: “averaged” structure



Prescribed condition: detection of an intermittent event in the central chord of the GPI

Good correlation between GPI and fast camera

Different radial distribution of structures in the two cases



Packing fraction:

$$f(r) = \sum_{\tau} \tau \frac{\Delta N(r,\tau)}{\Delta t}$$

M.Spolaore et al., Phys.Rev.Lett. **93** *215003 (2004)*

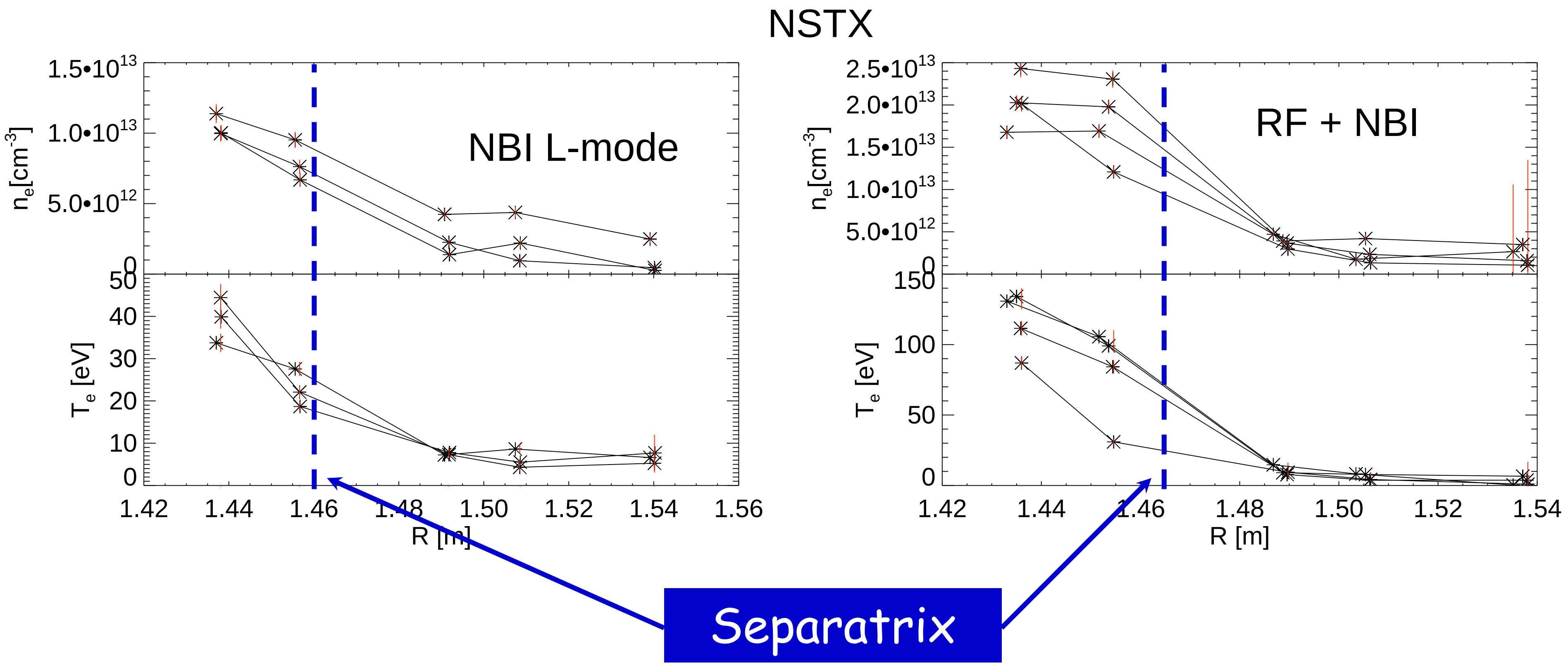
Represents the fraction of time occupied by structures

- Packing fraction increases with the radius for L-mode discharges, constant for RF plasma
- Fluctuation level increases with the radius

Radial profiles

Density and temperature profiles from Thomson scattering

Radial dependence of fluctuations and packing fraction not only due to the main profiles



Results

Statistical properties

- Similar power-law decay of power spectra for NSTX & RFX-mod
- Intermittency identified in NSTX & RFX-mod edge turbulence

Turbulence edge flow

- NSTX NBI L-mode: along the ion diamagnetic drift (~ - 5 km/s)
- NSTX RF+NBI: opposite to the ion diamagnetic drift (~ +10 km/s)
Development of strong inward E_r

Edge Structures

- NSTX : Radially more extended for RF+NBI than NBI L-mode

Conclusions

- Intermittency detected the in the edge turbulence of NSTX: statistical properties of fluctuations depend on the scale of the fluctuation itself

- Similar behavior detected in RFX-mod RFP experiment

- Negative averaged structures not clear: diagnostic limitation or real physics?

- RF heating influence the plasma edge: changing in the turbulent flow and coherent structures

Future works

- Characterize different types of discharges of NSTX

- Compare experimental results with theoretical model predictions

- Compare the evolution of 2D turbulent structures of NSTX and RFX-mod *[see G.Serianni et al., UP1.00054 this conference]*

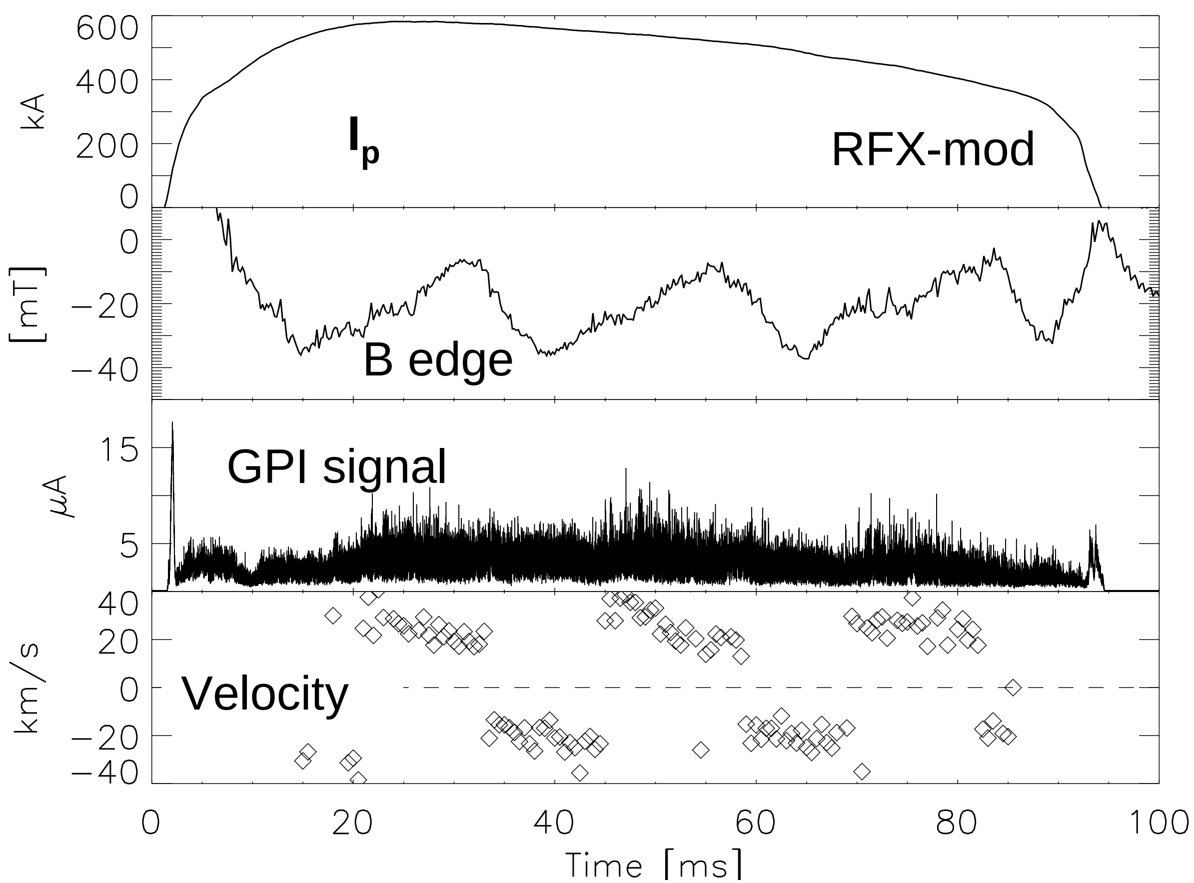
Are you interested?

email	email

Velocity in RFX-mod

➢ Velocity perpendicular to the main magnetic field is measured with GPI in RFX-mod

Rotating magnetic perturbation applied



Cavazzana et al., EPS 2005

✓ Along the ExB drift direction

✓ Comparable to the velocity measured by Langmuir probes

✓ Change in velocity sign due to opposite radial electric fields