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Statistical features of edge turbulence in RFX-mod and TPE-RX from Gas Puffing Imaging

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The physics of plasma transport in the edge region of fusion devices is of considerable interest for its implications in plasma-wall interactions and, ultimately, confinement performances of the devices themselves. Particle edge transport is known to be intermittent, i.e., much-larger-than-average events occur sporadically but more often than predicted from a Gaussian statistical distribution. Since these bursts, although rare, do contribute for a relevant fraction of the total flux, an understanding of the physics lying behind the generation and dynamics of the intermittent events is deemed necessary. Nowadays, it is commonly acknowledged that bursts are associated to coherent plasma structures moving within the plasma. Many statistical properties of these objects appear to be universal, i.e., common to all plasma devices, regardless of their magnetic or geometrical configuration (Tokamaks, Stellarators, Reversed Field Pinches, toroidal or linear devices) [1]: an evidence of a common physical mechanism driving this turbulence. The experimental and theoretical investigation is rapidly progressing in the study of the properties of the individual coherent structures. However, statistical analysis of the signal is essential in order to gain information about the underlying physics. The most informative statistical quantity related to any plasma parameter is its Probability Distribution Function (PDF). Several investigations of edge quantities' PDFs have appeared in literature, most of them devoted to measuring saturation current by Langmuir probes. A common finding, and clue of the intermittency, is that fluctuations of these quantities depart from a normal distribution: Graves *et al* [2] performed recently a radial scan of ion saturation current's PDF in the Scrape-Off Layer (SOL) of TCV tokamak. Their PDFs were interpreted in terms of a Gamma distribution, featuring an exponential tail:

$$P(x) = C\, x^{N-1} \exp(-\beta N x) \qquad (1)$$

In general, all devices feature an exponential decay of the PDF at high values of the signal while at the same time the PDF acquires more and more of a Gaussian character while going from the wall to the plasma (perhaps crossing the source region of the coherent structures) [2,3].

An inspection of the literature shows that phenomenology may also be fairly more complicated: measurements from the devices PISCES [4], and TORPEX [5], show rather clear evidence for a double structure in the density PDF; that is, a single curve like (1) is not able to account for the whole structure of the data. A recent experimental and theoretical analysis on Tore Supra data identified the two peaks, respectively related to background uncorrelated turbulence and coherent structures [6].

In order to address this issue, we present in this work results from an extensive study of edge density fluctuations carried on RFX-mod [7] and TPE-RX [8] Reversed Field Pinches,

using the Gas Puffing Imaging Diagnostics [9]. RFX-mod and TPE-RX are two geometrically similar devices (R = 2, 1.75 m respectively; a = 0.46, 0.45 m) but working into two widely different current- and density-regimes: RFX-mod discharges used here are taken mostly at currents I_p between 400 and 600 kA, and electron densities n_e around $(3\div4)\times10^{19}$ m^{-3}, while TPE-RX discharges feature $I_p \approx 180\div350$ kA, and $4\times10^{18} < n_e < 1\times10^{19}$ m^{-3}. The PDFs are built from the signal time series, taken during the flat-top phase of each pulse (about 10 ms for TPE-RX, 30 ms or longer RFX-mod).

Our results are unambiguous in supporting the existence of a complex shape of the PDF, although not as much evident as in [4,5], and suggest that the PDFs may be interpolated by a linear combination of two Gamma distributions: a few samples are shown in Figs. 1,2.

$$P(n) = C_< \frac{(\beta_< N_<)^{N_<}}{\Gamma(N_<)} n^{N_<-1} \exp(-\beta_< N_< n) + C_> \frac{(\beta_> N_>)^{N_>}}{\Gamma(N_>)} n^{N_>-1} \exp(-\beta_> N_> n) \qquad (2)$$

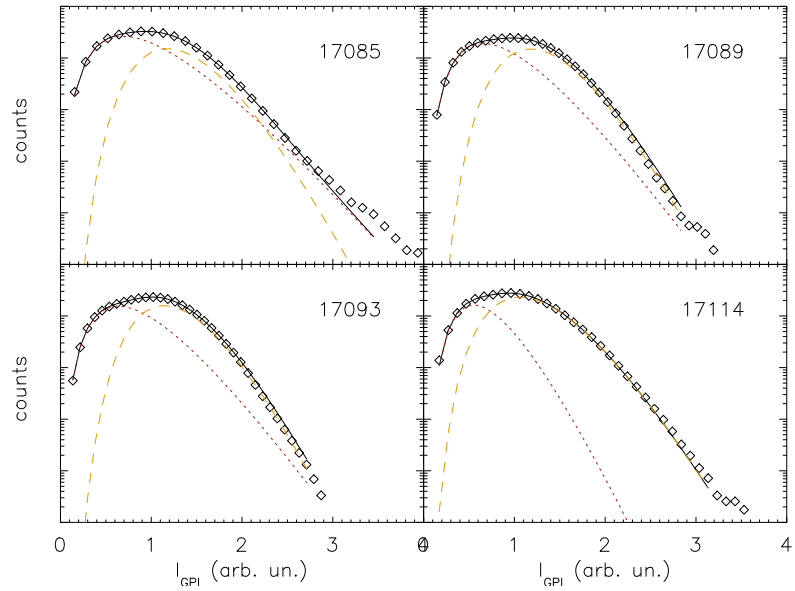

Fig. 1. Symbols, GPI data for a few RFX-mod discharges; solid curve, best fit from a linear combination of two Gamma functions (Eq. 2). The two individual Gamma components are shown as dashed and dotted curves.

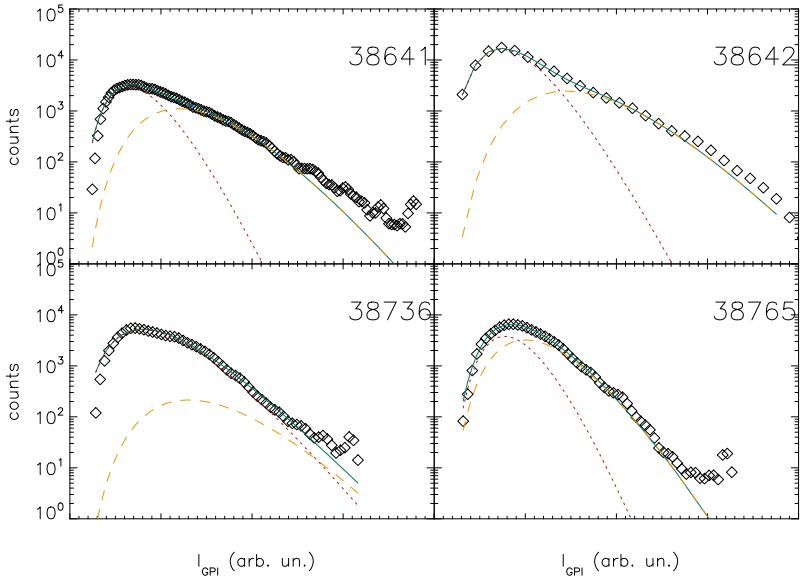

Fig.2 Symbols, GPI data for a few TPE-RX discharges; solid solid curve, best fit from a linear combination of two Gamma functions (Eq. 2). The two individual Gamma components are shown as dashed and dotted curves.

The physical meaning of parameters in Eq. (2) is still to be assessed. The models developed by Graves *et al* [2] and Sattin *et al* [10] (this latter paper includes a more extensive account

of the investigation carried on in RFX-mod) suggest that the parameter N in Eq. (1) might be identified with the effective dimensionality of an abstract phase space where the system is evolving in. Therefore, in Eq. (2) each Gamma component may be related to an independent source of fluctuations with $N_>$, $N_<$ degrees of freedom respectively. Since the Gamma distribution becomes a Gaussian one for $N \to \infty$, the fitting (2) may account also for the case of a PDF made of (Gamma) + (Gaussian) curves, thus recovering the same situation dealt with in [6]. Actually, if we let the lowerscript ">" label the contribution with the higher N, we find that in all cases $N_> > 10$, thereby providing a rather good approximation to a Gaussian curve, while in most cases $4 < N_< < 10$. An intriguing hypothesis, therefore, is postulating the $N_>$ contribution as due to the uncorrelated fluctuations that drive turbulent diffusion, while the $N_<$ one is related to the coherent part of the fluctuations. In order to provide a test of this conjecture, we plot in Fig. (3) the fraction of the PDF with $N_<$ (< 10) versus the local displacement of the plasma column, Δ, for several RFX-mod discharges. Negative values of Δ mean that the plasma is, locally, shifted inwards. Hence, the diagnostics, whose spatial position is fixed, is sampling the outermost part of the plasma (roughly equivalent to "far SOL" in tokamak's language[1]). Conversely, smaller absolute values of Δ are equivalent to probing the "near SOL" region[2]. Our results are in agreement with those of Graves *et al* [2]: the $N_<$-fraction diminishes, i.e., the overall PDF becomes closer and closer to a Gaussian, while going from "far SOL" to "near SOL".

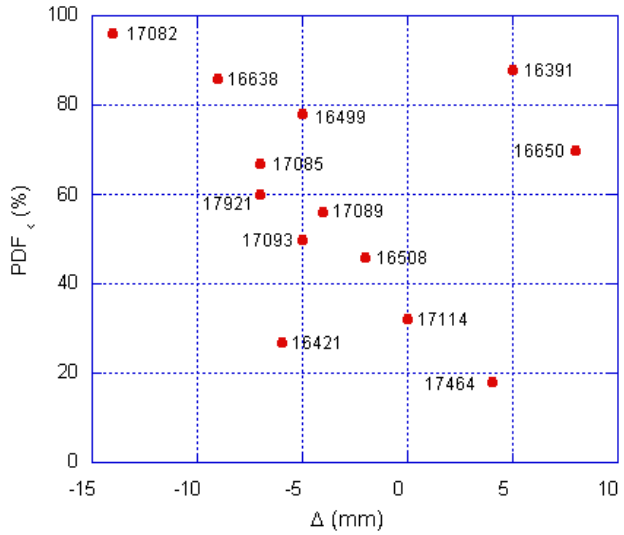

Fig. 3. It is shown the fraction of the PDF due to the low-N Gamma contribution for a few discharges of RFX-mod *versus* the shift of the plasma column at the GPI location.

Another convincing test comes from the explicit comparison with the number of intermittent events counted from the original timeseries through a wavelet technique described elsewhere [11] (Fig. 4). There appears a fairly good correlation between the "coherent" fraction of the signal measured through the PDF analysis and the spatial density of bursts standing out of the background turbulence. In the figure, we have conventionally

[1] But note that RFX-mod has not physical limiters. An "effective limiter" (and, hence, an "effective SOL") is instead produced by the field lines intercepting the walls due to non-axisymmetric magnetic perturbations that are intrinsic to RFP configuration. The discharges shown in Fig. (3) do not adopt the "Virtual Shell" (VS) mode control, which is by now becoming standard on RFX-mod. When the VS is turned on, magnetic perturbations are much smaller at the edge and a plot like Fig. (3) cannot be reproduced.

[2] Positive values of Δ correspond to plasma flowing onto the walls, hence an highly perturbed situation whose interpretation is difficult.

set to zero the "coherent" fraction when both exponents $N_<$, $N_>$ were larger than 10, meaning that a true low-dimensional fraction of the PDF could not be recovered.

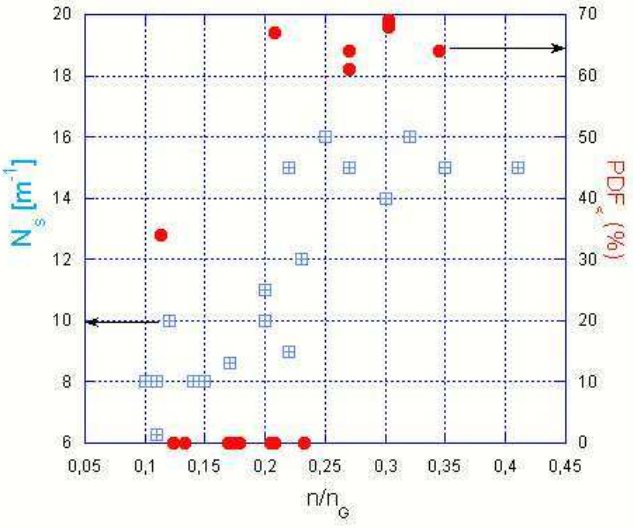

Fig. 4. Low-N fraction of the PDF (red circles) and linear density of bursts (filled squares) *versus* normalized density, for RFX-mod. Discharges are selected on the basis of the reversal parameter, $F = B_\phi(\text{wall})/\langle B_\phi \rangle \approx -0.1 \pm 0.03$

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[1] G.Y. Antar, *et al*, Phys. Plasmas **10**, 419 (2003); B.Ph. van Milligen, *et al*, Phys. Plasmas **12**, 052507 (2005)

[2] J.P. Graves, J. Horacek, R.A. Pitts, and K.I. Hopcraft, Plasma Phys. Control. Fusion **47**, L1 (2005)

[3] Y.H. Xu, *et al*, Plasma Phys. Control. Fusion **47**, 1841 (2005); G.Y. Antar, *et al*, Phys. Rev. Lett. **87**, 065001 (2001); G.Y. Antar, G. Counsell and J.-W. Ahn, Phys. Plasmas **12**, 082503 (2005); J.A. Boedo, *et al*, Phys. Plasmas **8**, 4826 (2001); B. LaBombard, *et al*, Nucl. Fusion **45**, 1658 (2005); F. Sattin, N. Vianello, Phys. Rev. E **72**, 016407 (2005)

[4] T.A. Carter, Phys. Plasmas **13**, 010701 (2006)

[5] A. Fasoli, *et al*, Phys. Plasmas **13**, 055902 (2006)

[6] M. Farge, K. Schneider, and P. Devynck, Phys. Plasmas **13**, 042304 (2006)

[7] W. Baker, *et al*, Fus. Eng. Design **63-64**, 461 (2002); P. Sonato, *et al*, Fus. Eng. Design **66-68**, 161 (2003)

[8] Y.Yagi, *et al*, Fus. Eng. Design **45**, 409 (1999)

[9] R. Cavazzana, *et al*, Rev. Sci. Instrum. **75**, 4152 (2004)

[10] F. Sattin, *et al*, "*Statistical features of edge turbulence in RFX-mod from Gas Puffing Imaging*", Plasma Phys. Contr. Fusion (to appear)

[11] P. Scarin, *et al*, "*Edge turbulence in RFX-mod virtual-shell discharges*", poster P3-28 presented at the 17th International Conference on Plasma Surface Interactions (Hefei, China, 2006); M. Agostini, *et al*, poster P5.094, this conference