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Study of the universality of the probability density function of turbulent fluctuations and fluxes in a linear plasma machine

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Introduction

The cross-field transport in the scrape-off layer (SOL) of tokamaks and stellarators is known to be dominated by large radial transport events (called blobs, avaloids, or intermittent plasma objects) that have been observed by different plasma diagnostic techniques. However, the dynamics underlying the radial transport of these blobs is not well understood. In recent years the importance of the statistical description of transport processes in fusion plasmas, has been emphasized. Furthermore, evidence for the universality of the probability density functions (pdfs) of turbulent transport has been reported for different fusion devices[1,2,3]. Recent results[1] show that pdfs of turbulent fluxes tend to adopt a canonical shape very close to the Bramwell, Holdsworth and Pinton (BHP) distribution[4]. In this context, it is useful to analyse and compare the statistical properties of pdfs of turbulent fluctuations in non-confined plasmas[5,6]. Statistical properties of turbulent fluctuations and turbulent induced fluxes and its universality have been investigated in a linear plasma machine (SPLM)[7].

Experimental Setup and Data

The plasma is performed in a cylindrical glass vessel with an internal diameter of 0.07 m and a length of 1m.The vessel is located inside a circular waveguide of 0.08 m in diameter. A longitudinally magnetized plasma is produced by launching longitudinally (LMG) electromagnetic waves (f = 2.45 GHz). The incident power (P_{LMG}) is in the range 0.6 kW < P_{LMG} < 1.2 kW and the system can operate in a continuous regime. The stationary longitudinal magnetic field (0.05 T < B < 0.15 T) is generated by six water-cooled coils, which are concentric with the waveguide[7]. Measurements reported in this paper were performed for Helium plasmas. The mean electron density is determined by an 8 mm interferometer and typically ranges from 10^{15} m^{-3} to 10^{18} m^{-3}. Two radially movable array of Langmuir probes provide local value of electron density, floating potential, electron temperature and its fluctuations along the whole plasma radial column. One of them, using a double probe configuration, provides averaged plasma profile measurements (T_e(r) and n_e(r)). The second array of probes provides electron density and potential fluctuations and

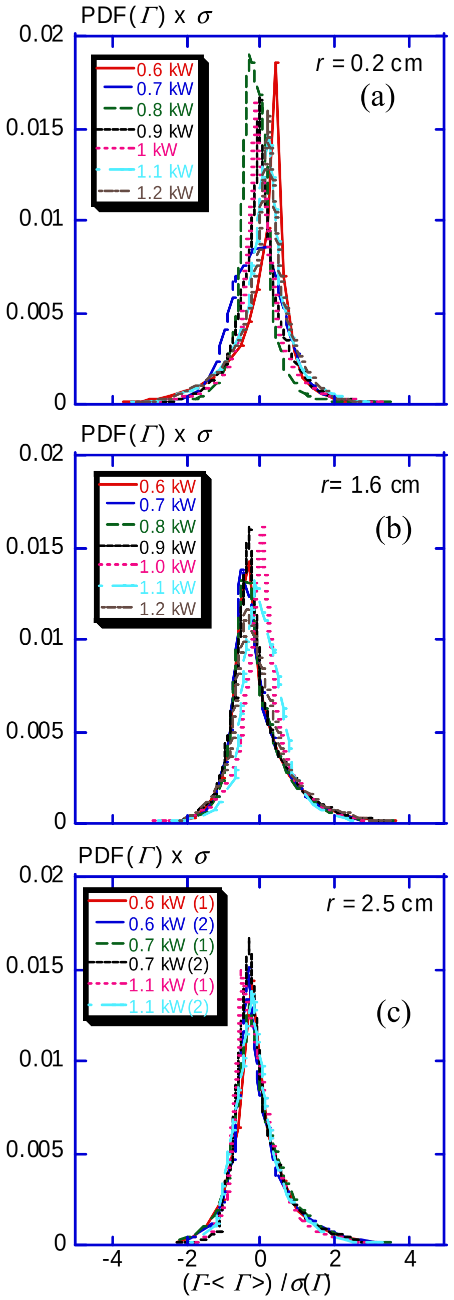

Fig. 1 Rescaled turbulent flux pdfs for different values of P_{LMG} (a) $r = 0.2$ cm; (b) $r = 1.6$ cm; (c) $r = 2.4$ cm

consists in a set with 4 tips (cylindrical tips 2 mm long, 0,5 mm in diameter) aligned perpendicular to the magnetic field.

The turbulence induced particle flux can be inferred from the simultaneous measurement of the density and potential fluctuations: $\Gamma(t) = \tilde{n}\tilde{E}_\theta / B$ where $\tilde{E}_\theta \approx (\Phi_1 - \Phi_2)/d_\theta$. Here Φ_1 and Φ_2 are the floating potentials provided by two probes poloidally separated $d_\theta = 2$ mm. The electron temperature fluctuations are neglected. Our data sets consist of time-series of $N_{data} = 2\times10^5$, taking over a total time $T = N_{data}/\nu_s$, where $\nu_s = 1$ MHz is the sampling frequency.

Empirical similarity in turbulent fluxes

The distribution function of Γ has been estimated (PDF(Γ)) under different experimental conditions and at different scales of time (coarse-graining)[3,5]. To test this pdfs for universal properties, we first subtract the mean and divide by the variance. Universality in the shape of the pdf will be claimed whenever a similar function is obtained for different experimental conditions. In all cases, turbulent fluxes have a non-gaussian behavior. Typically, skewness (S) and kurtosis (K) have a radial dependence with mean values around 1 and 6 respectively. In Figure 1, the measured pdfs are shown (without coarse-graining), after being rescaled, at three radial positions and for different values of P_{LMG}. Typically, no similarity on pdfs, around $r \approx 0$, has been found. However, it should be noted that the fitting of positive part improves as we move to the edge of the plasma. As it is found in ref. 3, the fitting improves, as the time scale decreases.

Self-similarity of flux turbulent distributions

In order to determine the self-similarity of PDF(Γ) we have analyzed experimental data over a wide range of time scale. We start off with a time-series $\Gamma(t_i)$ of i =1,....N_{data}. Then, we construct a whole sequence of coarse-grained time series Γ_m (t_i) (i = 1,...N_m=N_{data}/m). Notice that as m increases, the time scale is m times longer than the original one. In figure 2 we have plotted the standard deviation σ(m) / σ(1) for each Γ_m obtained from the induced particle flux data. Qualitatively, the behaviour of σ(m) seems similar to what is reported in other devices[5,8].

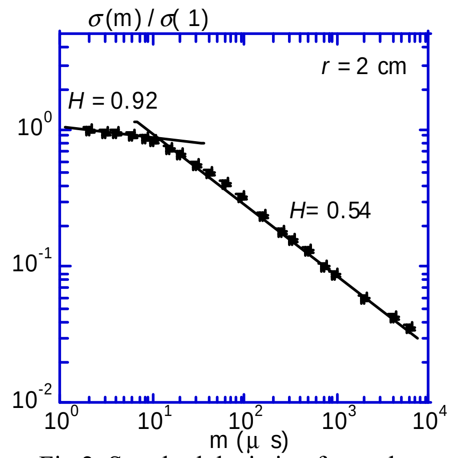

Fig.2 Standard deviation for each series Γ_m as a function of m

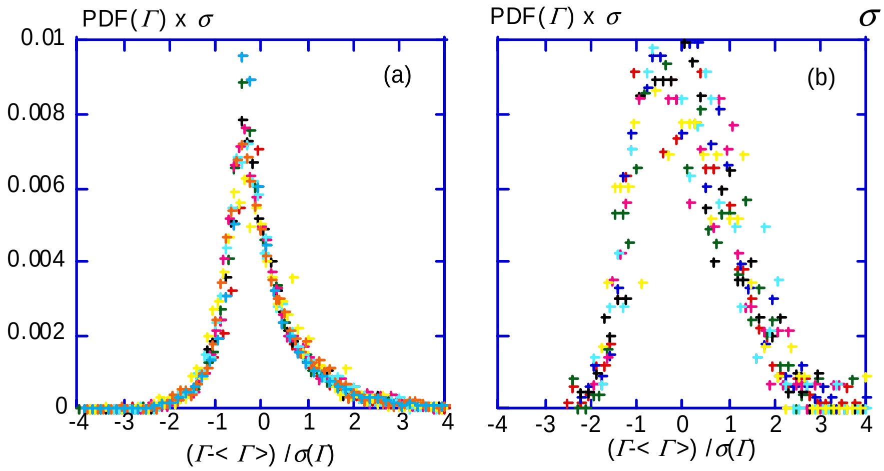

Figure 3. Probability distribution function of the turbulence induced fluxes for time scales in the range: (a) 1< m <32; (b) 128 ≤ m ≤ 1024

Two distinct regimes, a "fluctuation range" for t < 20-30 μs and a "mesoscale range" for t > 40 μs have been found. For short time scales σ(m) displays an approximate power-law behaviour of σ(m) ~ m^{H-1}, with an effective Hurst exponent $H \approx 0.90$. In the mesocale range, $H \approx 0.55$, and the self-similarity range is well defined over three decades. However, under different experimental conditions, we have found a similar behaviour on the mesocale range, but with different values of H (0.55 < H < 0.75). In the figure 3, we separate both time scales in two ranges: 1<m<32 (figure3 (a)) and 128 ≤ m ≤ 1024 (figure3 (b)). It is clear the change in the functional form of the pdfs for the two time scales.

PDFs in the mesocale range

In general, the turbulent flux carries information of at least two processes: fast and small turbulent fluctuations and slow and large transport events[8]. We have analyzed pdfs for m > 40 μs (mesocale range). Concerning the mesocale range, the BHP distribution has been suggested[1] as a canonical shape that fluctuations of density and flux tend to adopt in the SOL of tokamaks and stellarators.

In figure 4, the rescaled electron density pdfs (fig.4 (a)) and the flux pdfs (fig. 4(b)) has been plotted for different values of P_{LMG}. For comparison, we show the standard gaussian distribution, the BHP distribution, and a Gumbel distribution. Unlike fusion devices, the experimental pdfs in the SPLM don't tend to any particular shape. In particular, a BHP distribution fitting is not found.

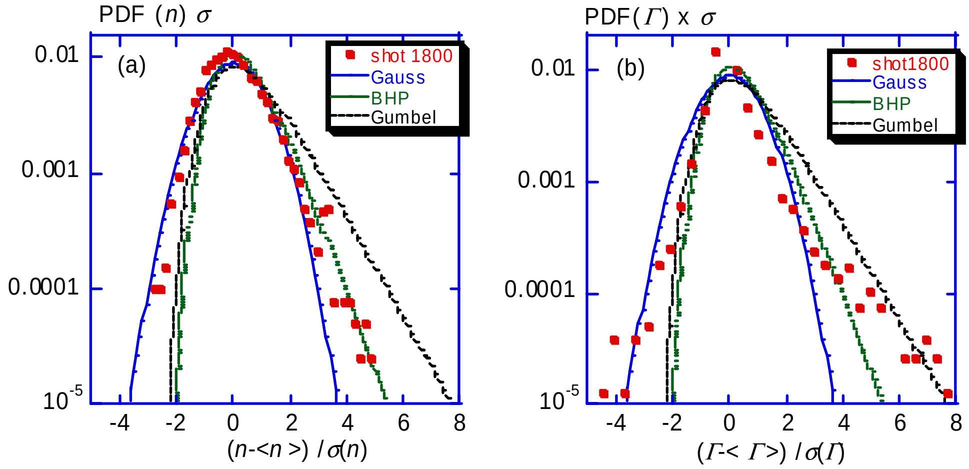

Figure 4. Rescaled density fluctuation pdf (a) and flux fluctuation pdf (b) for the shot 1800 (r = 0.1 cm; P_{LMG} = 0.6 kW, B = 0.12 T). For comparison we show the standard Gauss distribution, the BHP distribution and a Gumbel distribution

Conclusions

We have reported experimental evidence on a linear plasma device of non- similarity of PDF (Γ). As we move to the edge of the plasma, the positive part of the pdf tend to a adopt a similar shape. This fact suggests a different behaviour between the plasma core and the plasma edge. Like in other devices, two different scales of time for induced turbulent fluxes, have been found. The Hurst coefficient changes with the radial position. Finally, no canonical shape of turbulent fluxes and electron density fluctuations pdfs has been found.

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