

## Statistical properties of edge plasma turbulence in selected stellarator plasmas in the Large Helical Device

B Hnat<sup>1</sup>, N Ohno<sup>2,3</sup>, R O Dendy<sup>4,1</sup>, S Masuzaki<sup>3</sup>, T Morisaki<sup>3</sup>, A Komori<sup>3</sup>  
and J M Dewhurst<sup>1</sup>

<sup>1</sup>*Centre for Fusion, Space and Astrophysics, Department of Physics, Warwick University,  
Coventry CV4 7AL, U.K.*

<sup>2</sup>*EcoTopica Science Institute, Nagoya University, Nagoya 464-8603, Japan*

<sup>3</sup>*National Institute for Fusion Science, Toki 509-5292, Japan*

<sup>4</sup>*Euratom/UKAEA Fusion Association, Culham Science Centre,  
Abingdon, Oxfordshire OX14 3DB, U.K.*

**Introduction.** Recent experimental evidence suggests that turbulence in the scrape-off layer (SOL) of magnetically confined plasmas has universal and scale invariant statistical properties. These emerge in the functional forms of the probability density functions (PDFs) of the measured fluctuations and the scaling of their higher moments [1-3]. Particularly interesting is the identification of generic features that may be shared by edge plasma turbulence in conventional and spherical tokamaks and in stellarators. This requires quantitative comparison of the measured turbulence properties under different operating regimes for the full range of confinement systems using modern techniques for the statistical analysis of nonlinear time series.

Here we analyse ion saturation current ( $I_{\text{sat}}$ ) measurements in the SOL of L-mode plasmas in the Large Helical Device (LHD) stellarator, previously considered from a complementary perspective in [4] and [5]. The data is obtained from two pins in a Langmuir probe array embedded in the divertor plate [6]. The pins, numbers 16 and 17, are separated by 6mm and sample data at 250kHz. Datasets from L-mode plasmas 44190 and 44191 [4] are found to be almost identical; only 44190 is shown in this analysis. In both discharges the magnetic field strength is  $B = 2.5$  T and the central value of electron temperature is  $T_e = 2.5$  keV. The line averaged density is  $\bar{n}_e = 1.5 \times 10^{19} \text{ m}^{-3}$  in 44190 and  $\bar{n}_e = 1.4 \times 10^{19} \text{ m}^{-3}$  in 44191. The data is prepared by removing linear trends, subtracting the mean and dividing by the standard deviation; figure 1 shows the resulting time series and PDFs. The statistical techniques used here have also been applied to edge turbulence in the Mega-Amp Spherical Tokamak (MAST) [7] [8] and in astrophysics [9].

**Data analysis.** We have studied the probability density function (PDF), autocorrelation function (ACF) and power spectrum of the ion saturation current measurements. Deviations of the PDF from Gaussian are quantified by the skewness  $S = \langle x^3 \rangle / \langle x^2 \rangle^{3/2}$ , measuring asym-

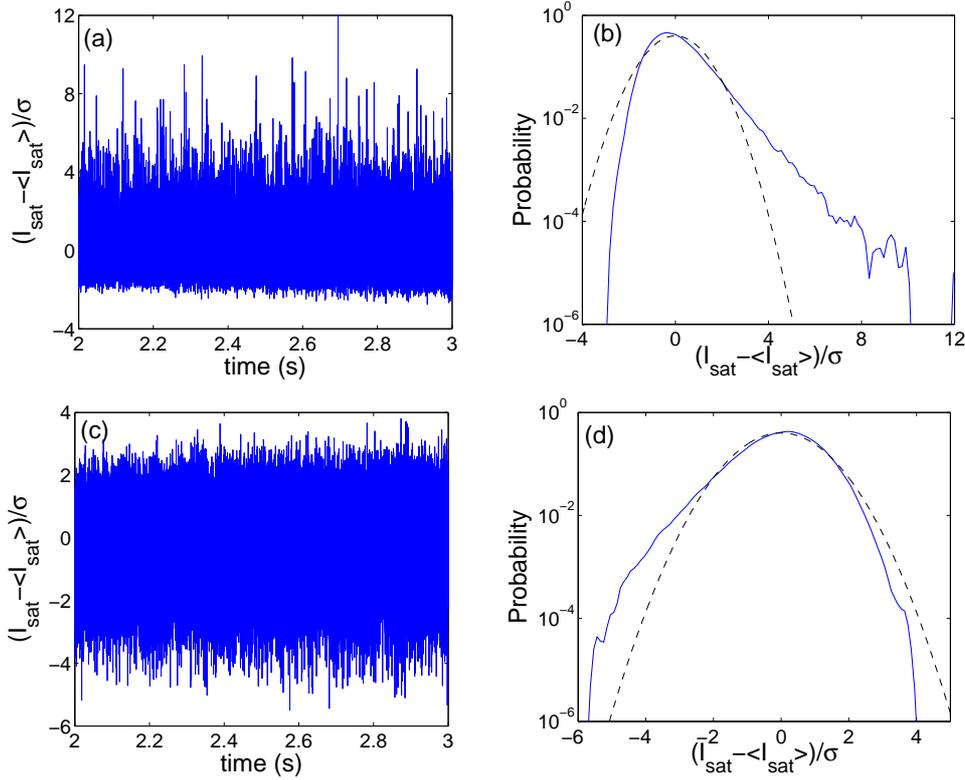


Figure 1: Time series and PDF (solid line) with Gaussian PDF for comparison (dashed line) for LHD L-mode plasma 44190 tip 16 ((a) and (b)) and tip 17 ((c) and (d)).

metry, and the kurtosis  $K = \langle x^4 \rangle / \langle x^2 \rangle^2$ , measuring ‘flatness’; the Gaussian PDF has  $S = 0$  and  $K = 3$ . The power spectrum  $P(f)$  distinguishes, for example, between uncorrelated random noise, which is constant power over all frequencies, and self-similar signals having long range correlations, for which  $P(f) \sim f^{-\beta}$ . We consider  $I_{\text{sat}}$  measurements as stochastic increments on a temporal scale  $\tau_{\text{min}} = 4\mu\text{s}$ , where  $\tau_{\text{min}}$  is the time between consecutive measurements. Fluctuations on longer time scales are obtained by summing over a window of length  $\tau$ ,  $\delta x(t, \tau) = \sum_{t'=t}^{t+\tau-\tau_{\text{min}}} (I_{\text{sat}}(t') - \langle I_{\text{sat}} \rangle_t) / \sigma$  [7], where  $\langle I_{\text{sat}} \rangle_t$  and  $\sigma$  are the mean and standard deviation of the  $I_{\text{sat}}$  signal calculated over all times. The scaling properties of the absolute moments of these fluctuations are analysed using generalised structure functions,  $S_m(\tau) \equiv \langle |\delta x(t, \tau)|^m \rangle$ . If scaling is present,  $S_m \propto \tau^{\zeta(m)}$  and a plot of  $S_m$  versus  $\tau$  on a log-log scale will yield a line for each  $m$  with gradient  $\zeta(m)$ . In general,  $\zeta(m)$  can be a nonlinear function of order  $m$ ; however, if  $\zeta(m) = \alpha m$ , where  $\alpha$  is a constant, the time series is self-similar with a single scaling exponent  $\alpha$ .

**Results.** The time series (figures 1 (a) and (c)) are bursty, intermittent and asymmetric. Significant differences between the two datasets can be seen, even though the tip separation is only 6mm. The PDFs (figures 1 (b) and (d)) clearly show a difference: for tip 16 the PDF is positively skewed, the skewness  $S = 1.1$  and kurtosis  $K = 6.0$ ; for tip 17 it is negatively skewed,

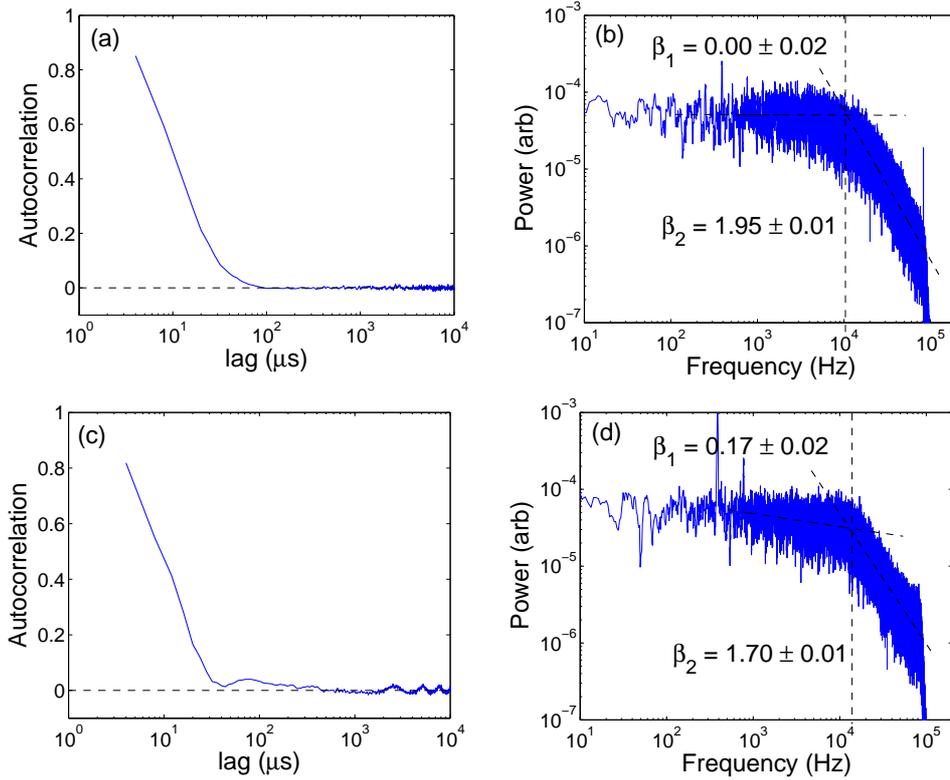


Figure 2: ACF and power spectrum for LHD L-mode plasma 44190 tip 16 ((a) and (b)) and tip 17 ((c) and (d)).

$S = -0.4$  and  $K = 3.6$ . Figure 2 shows the ACFs and power spectra. The ACF for tip 16 shows correlation up to  $100\mu\text{s}$ ; for tip 17 it is  $40\mu\text{s}$ . Both power spectra show a region close to random noise  $\beta_1 \simeq 0$  followed by a region of scaling with indices  $\beta_2 = 1.95$  for tip 16 and  $\beta_2 = 1.70$  for tip 17. The scaling region in both cases is between about 10kHz and 100kHz, corresponding to 10–100 $\mu\text{s}$ . Tip 17 shows higher power in low frequency coherent modes compared to tip 16. Figures 3 (a) and (c) show the first to fourth order structure functions for tips 16 and 17. Two distinct scaling regions can be seen, with a break at about  $40\mu\text{s}$  for tip 16 and  $30\mu\text{s}$  for tip 17. This dual scaling regime has previously been reported in MAST with the scaling break at 40–60 $\mu\text{s}$  [7] [8]. In figures 3 (b) and (d),  $\zeta(m)$  versus  $m$  is plotted for both pins and in both scaling regions; the error bars represent the errors of the linear regression. In all cases, there is a linear fit  $\zeta(m) = \alpha m$  with  $\zeta(0) = 0$ . This implies self-similar scaling, which can lead [10] to Fokker-Planck based models.

**Conclusions.** The differences between turbulence properties measured at the two pins may reflect differences in the local magnetic field at each Langmuir probe tip. It is, in principle, possible to know the stellarator magnetic field structure at each tip's location, separated by 6mm in this LHD L-mode plasma SOL. Structure function analysis shows a dual self-similar scaling regime. The transition between different scaling is found to be  $40\mu\text{s}$  for tip 16 and  $30\mu\text{s}$

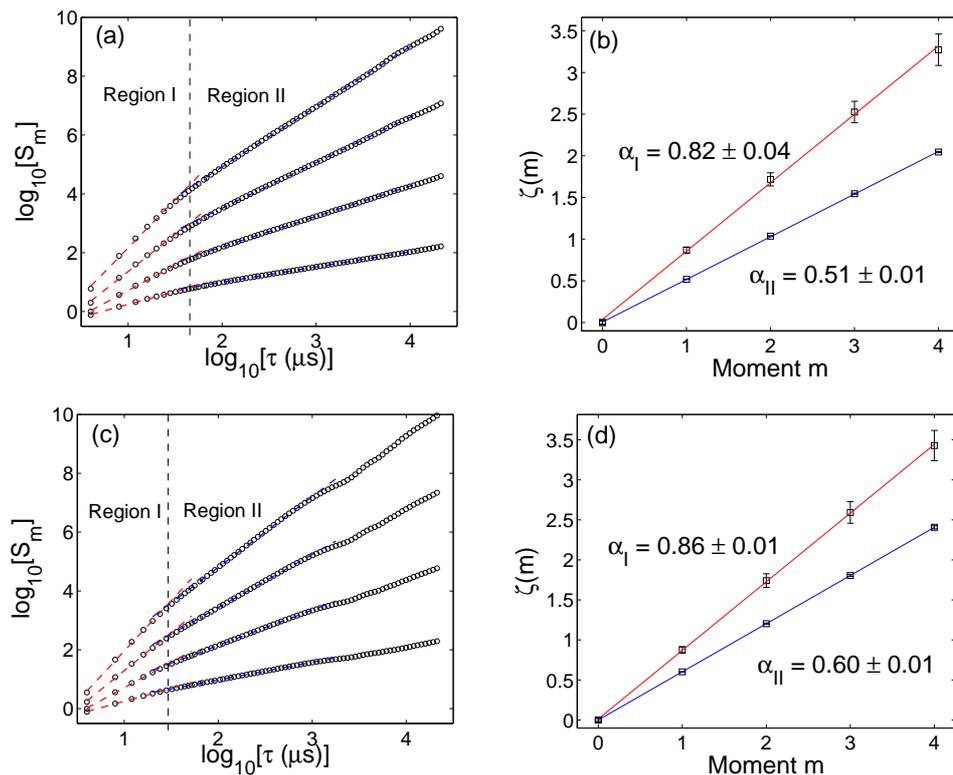


Figure 3: Structure functions of order  $1 \leq m \leq 4$  and derived scaling exponents  $\zeta(m)$  for LHD L-mode plasma 44190 tip 16 ((a) and (b)) and tip 17 ((c) and (d)).

for tip 17. This behaviour has previously been observed in MAST.

**Acknowledgements:** This work was supported in part by the U.K. Engineering and Physical Sciences Research Council and by Euratom.

## References

- [1] B Ph van Milligen, R Sánchez, B A Carreras *et al.*, Phys Plasmas **12**, 052507 (2005)
- [2] G Y Antar, G Counsell, Y Yu, B Labombard and P Devynck, Phys Plasmas **10**, 419 (2003)
- [3] R O Dendy and S C Chapman, Plasma Phys Control Fusion **48**, B313 (2006)
- [4] N Ohno, S Masuzaki, H Miyoshi, S Takamura, V P Budaev, T Morisaki, N Ohyabu and A Komori, Contrib Plasma Phys **46**, 692 (2006)
- [5] N Ohno, S Masuzaki, V P Budaev, H Miyoshi, S Takamura, T Morisaki, N Ohyabu and A Komori, 21st IAEA Fusion Energy Conference, Chengdu, China, 2006, EX/P4-20
- [6] S Masuzaki, T Morisaki, N Ohyabu, A Komori *et al.*, Nucl Fusion **42**, 750 (2002)
- [7] B D Dudson, R O Dendy, A Kirk, H Meyer and G F Counsell, Plasma Phys Control Fusion **47**, 885 (2005)
- [8] B Hnat, B D Dudson, R O Dendy, G F Counsell, A Kirk and the MAST team, this conference
- [9] J Greenhough, S C Chapman, S Chaty, R O Dendy and G Rowlands, Astron Astrophys **385**, 693 (2002)
- [10] B Hnat, S C Chapman and G Rowlands, Phys Rev E **67**, 056404 (2003)