Fluctuation statistics in the scrape-off layer of Alcator C-Mod

R. Kube[1,2], O.E. Garcia[2], B. LaBombard[3], and J.L. Terry[3]

[1] *Institute for Applied Physics and Ion Physics, University of Innsbruck, Austrian*

[2] *Department of Physics and Technology, UiT - The Arctic University of Norway, Tromsø, Norway*

[3] *MIT Plasma Science and Fusion Center, Cambridge, MA, 02139, USA*

Introduction

The scrape-off layer (SOL) of magnetically confined plasmas is dominated by order unity fluctuations of the particle density and large, concomitant transport events. A large body of research links these phenomena to the radial propagation of plasma filaments which are elongated along the magnetic field and highly localized in the radial poloidal plane, called *blobs* [1]. The observed characteristics of the turbulence in the far SOL plasma is further believed to be universal. For one, the conditionally averaged waveform of large amplitude events in the particle density time series presents a steep rise and a slow decay [2]. On the other hand, feature time series with frequent large amplitude events larger than zero coefficients of sample skewness and excess kurtosis. When sampled at a single radial position, it was shown that the histograms coincide upon normalization [3]. A novel stochastic model for fluctuations in the SOL predicts that, given independent arrival of plasma blobs with exponentially distributed amplitudes, particle density time series are Gamma distributed. This model was successfully used to describe intensity fluctuations, measured by gas-puff imaging in the SOL of Alcator C-Mod [4].

In this contribution, we present analysis of ion saturation current time series, sampled at the outboard mid-plane far SOL (ASP) and at the outer divertor in the Alcator C-Mod tokamak for a series of ohmically heated discharges, where the line-averaged density was between 0.15 and $0.42\overline{n}_{\mathrm{e}}/n_{\mathrm{G}}$. All discharges where performed in a lower single-null magnetic geometry with a plasma current of $I_{\mathrm{p}} = 0.55$MA and an on-axis magnetic field of $B_{\mathrm{T}} = 5.4$T. The parameters of the discharges, along with the length of the time series and the position of the probe at outboard mid-plane are listed in tab. 1. For all discharges are the two outermost divertor probes at $\rho \approx 8$mm and ≈ 10mm, where ρ denotes to the distance to the last closed flux surface, as mapped to outboard midplane by the magnetic field.

Fluctuation statistics

In Fig. 1 we present the time series sampled at outboard midplane in discharge 2. The length of the time series is approx. 0.85s and the histogram spans 4 decades in normalized probability.

Shot	$\overline{n}_e/n_G$	T_e/eV	ASP position	t_{start}/s	t_{end}/s	Plot marker
1	0.15	35	near SOL	0.75(0.75)	1.10(1.10)	▼
2	0.28	25	far SOL	0.65(0.65)	1.50(1.50)	◆
3	0.32	25	far SOL	0.80(–)	1.10(–)	■
4	0.31	20	far SOL	0.80(0.80)	1.10(1.10)	⬟
5	0.42	20	far SOL	0.50(0.50)	0.70(0.70)	▲

Table 1: List of the plasma parameters and the time interval used for time series analysis. The numbers in parenthesis give the interval on which data from the divertor probe is used. A dash indicates that no data is available.

The best fit of a Gamma distribution on the sample yields a shape parameter of $\gamma = \overline{I}/I_{rms} = 9.77$ and a scale parameter of $\overline{I}/\gamma = 4.14 \times 10^{-3}$A. Here $\bar{\cdot}$ denotes the sample mean and $\cdot_{rms}$ the sample root mean square. This distribution gives a good description of the histogram over the entire range. Coefficients of sample skewness, S, and excess kurtosis, F, indicate a discernible deviation from normality. Fig. 2 presents histograms of the ion saturation current time series sampled by the two outermost divertor probes in discharge 1. We find that while at $\rho \approx 8$mm the fluctuations rarely exceed twice the mean of the time series, this threshold is exceeded at $\rho \approx 10$mm. From the mean and the variance of the time series we find $\gamma = 8.64(10.1)$ $\rho \approx 8(10)$mm. While a Gamma distribution over estimates the tails of the histogram in the upper panel, it gives a good description of the histogram in the lower panel.

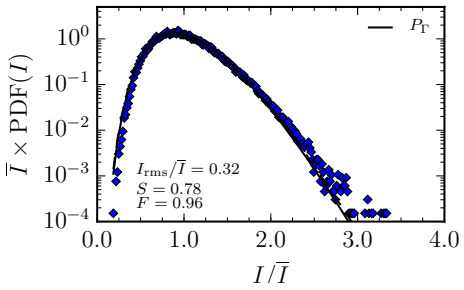

Figure 1: Histogram of the ion saturation current sampled in the far scrape-off layer during discharge 2.

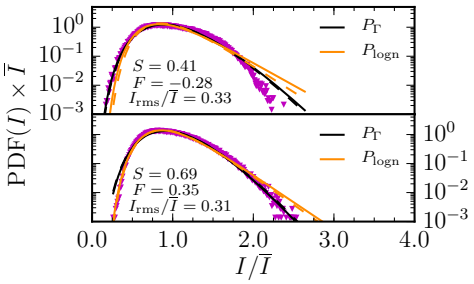

Figure 2: Histogram of the ion saturation current sampled by divertor probes at $\rho \approx 8$mm (upper panel) and at $\rho \approx 10$mm (lower panel) during discharge 1.

We continue by employing conditional averaging [5] to study the ion saturation current time series. In the following, time series are normalized according to $\widetilde{I} = \left(I - \overline{I}\right)/I_{rms}$ and $\widetilde{V} = e\left(V - \overline{V}\right)/T_e$. The waiting times between the arrival of bursts whose amplitude exceeds

2.5 times the root mean square of the time series is shown in Figs. 3 and 4. Compared to the histograms is a maximum likelihood estimate of an exponential distribution, which approximates the histogram well over more than one decade in normalized probability, for all discharges. This implies that large amplitude burst events occur independent. The time scales of the distribution vary between $\sim 120\mu$s and $\sim 260\mu$s in the far scrape-off layer and between $\sim 280\mu$s and $\sim 440\mu$s at the divertor. No systematic variation with the line-averaged plasma density is discernible.

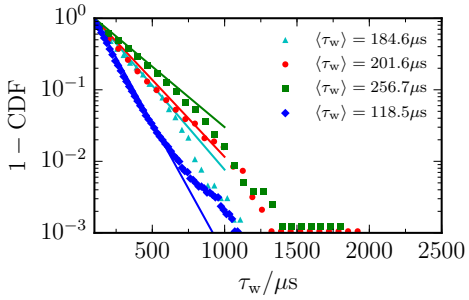

Figure 3: Histogram of waiting times between large amplitude bursts for the time series sampled at outboard mid plane.

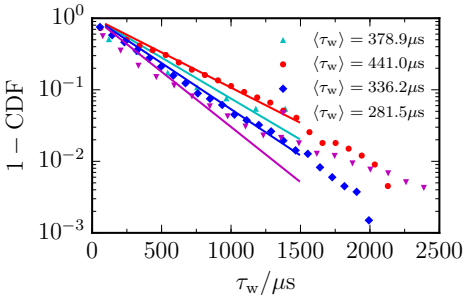

Figure 4: Histogram of waiting times between large amplitude bursts for the time series sampled by the divertor probes.

The dynamics of all time series is governed by the intermittent arrival of large amplitude bursts. This universal dynamics of the time series is reflected in Figs. 5 and 6, which presents histograms of the normalized time series. Within the same normalization, all histogram ms collide. In these figures denotes a triangle up data sampled at outboard mid plane and triangle down data sampled by the divertor probes.

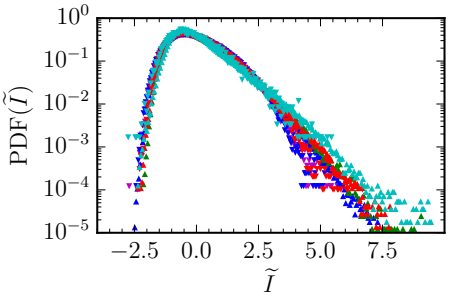

Figure 5: Histogram of all normalized I time series

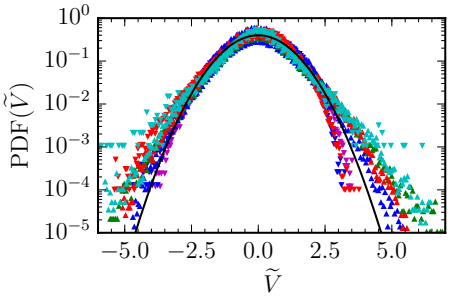

Figure 6: Histogram of all normalized V time series

Blob detection at the divertor probes

Fig. 7 shows the conditionally averaged waveform of large amplitude bursts in time series of the ion saturation current as well as the floating potential, as sampled by the Langmuir probes embedded in the divertor. The conditional variance is shown in Fig. 8, where a value of $1-\mathrm{CV} =$

0 denotes a random waveform while $1-\mathrm{CV}=1$ indicates perfect reproducibility. For discharges 1 and 2 we find that the ion saturation current signal shows a steep front and a slow decay. This is accompanied by a dipolar waveform of the floating potential. Discharge 5 features a similar conditionally averaged waveform for $\widetilde{I}$ and a random waveform in the floating potential. This indicates that the plasma blobs are electrically disconnected from the sheaths at this line-averaged plasma density.

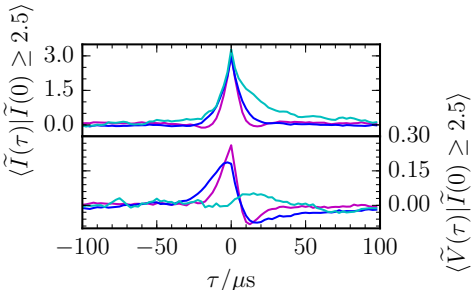

Figure 7: Conditionally averaged waveform of the ion saturation current (upper panel) and floating potential(lower panel), sampled by the outermost divertor probe.

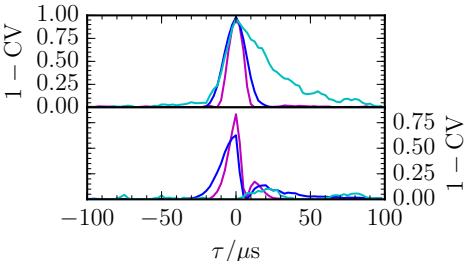

Figure 8: Conditional variance of the wave forms in fig. 7.

References

[1] D.A. D'Ippolito, J. R. Myra and S. J. Zweben, Phys. Plasmas **11** 060501(2011)

[2] J.A. Boedo, D.L. Rudakov. R.A. Moyer, et al. Phys. Plasmas **10**, 1670 (2001), D.L. Rudakov, J.A. Boedo, R.A. Moyer, et al. Plasma Phys. Control, Fusion **44** 717 (2002), G.S. Kirnev, V.P. Budaev, S.A. Grashin, et al. Plasma Phys. Control. Fusion **46** (2004) O.E. Garcia, J. Horacek, R.A. Pitts et al. Nucl. Fus. **47** 667 (2007)

[3] J.P. Graves, J. Horacek, R.A. Pitts and K.I. Hopcraft, Plasma Phys. and Control. Fusion **47** L1 (2005), B.P. van Milligen, R. Sanchez, B.A. Carreras, et al. Phys. Plasmas **12**, 052507 (2005), O.E. Garcia, J. Horacek, R.A. Pitts, et al. Nucl. Fus. **47** 667 (2007)

[4] O.E. Garcia, Phys. Rev. Lett. **108** 265001 (2012), O.E. Garcia, S.M Fritzner, R. Kube, et al. Phys. Plasmas **20**, 055901 (2013)

[5] F.J. Oynes, H.L. Pecseli and K. Rypdal Phys. Rev. Lett. **75** 81 (1997)