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on the origin of 'intermittency' in the scrape-off layer of (linear) magnetic confinement devices

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Intermittency in the scrape-off layer (SOL) was observed in nearly all magnetically confined plasmas. Recent investigation indicates that intermittent events have large scales, greater or about the macro-scale of turbulence, and high radial velocities as high as 1/10th of the sound speed [1]. These structures were named avaloids, and they transport about 50% of matter outside the main plasma. Because of their properties, avaloids alter the concept of the scrape-off layer (SOL) where hot and dense plasma is no longer limited to a region near the last closed flux surface but can be found far from it with intensity as high as at the plasma edge [1, 2]. Avaloids density and temperature do not decay exponentially leading to the observed flat profiles in tokamaks and linear plasma devices that cannot be described by a purely diffusive approach. They can explain the enhanced erosion and the high impurity levels recorded on different tokamaks. For devices like ITER, they could lead to a high level of erosion of the first wall.

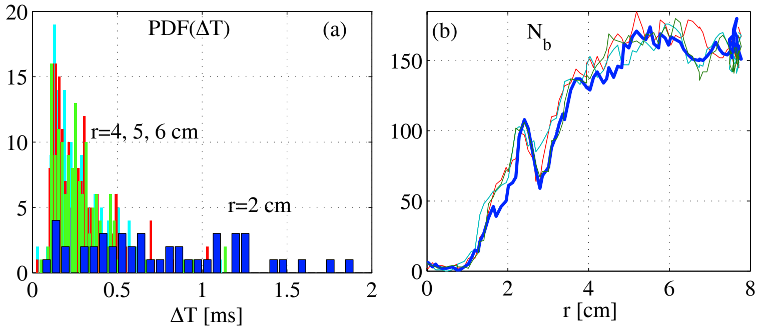

Figure 1: (a), the PDF of ΔT at $r = 4$, 5 and 6 cm, and the solid edge bars are for $r = 2$ cm. The PDF's are not normalized so the y-axis reflects the number of counts. (b), the number of bursts recorded on I_{sat} for $I_{th} = 3\sigma$ as function of r for four plunges to demonstrate the reproducibility of the result. At the main plasma column edge, the signals are non-stationary leading to the fast modulation of N_b where there is over-estimation followed by under-estimation of N_b as r increases.

The results presented here are obtained on the PISCES linear device. A baffle tube, acting like a circular limiter, reduces the radial extension of the plasma to 2.5 cm in radius while the chamber walls have a radius of $r = 10$ cm. The axial magnetic field is $B = 0.12$ Tesla. The central electron density and temperature are respectively about 1.5×10^{17} m^{-3} and 10 eV. We call SOL in PISCES the region $10 \geq r \geq 2.5$.

The conditional averaging technique consists in selecting maxima of I_{sat} above a certain threshold (I_{th}), here equal to three times the standard deviation (σ). Fig. 1(a) shows that the probability distribution function (PDF) of the time between bursts (ΔT) peaks around 5 kHz in the SOL of PISCES [1]. Should we emphasize that the same distribution is recorded in the SOL of the Tore Supra, Alcator C-MOD and MAST tokamaks as exposed in Ref. [2]. Fig. 1(a) indicates that PDF(ΔT) changes shape as the main column plasma is probed. This is merely a consequence of the lack of events selected above the threshold. Fig. 1(b) shows the number of spikes decreasing dramatically when the probe is moved inside the main plasma column. This is caused by the change in the signal properties from intermittent ($r > 2.5$) to Gaussian ($r < 2.5$) as it was shown in Ref. [1]. Next, the number of bursts, N_b, is determined as function of I_{th}. Inside the main plasma column, Fig. 2(a) shows that N_b decreases sharply just after $I_{th} = 2\sigma$, and the number of spikes nearly goes to zero. This behavior is expected for signals where the amplitude is bounded such as waves. Furthermore, for $I_{th} \sim 1.8\sigma$ the distribution of the waiting times in the SOL and inside the plasma are now similar as shown in Fig. 2(b). This strongly suggests a relationship between the average waiting time between two bursts in the SOL and the dynamics inside the main plasma column.

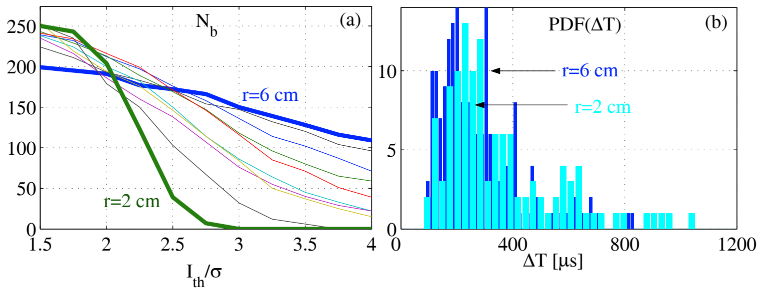

Figure 2: (a), the number of bursts N_b plotted against I_{th}/σ for $r = 2.5$ and 6 cm in thick solid lines; the thin solid lines represent intermediate values of r. (b), the PDF of ΔT at $r = 2$ and 6 cm for $I_{th} = 1.8\sigma$ showing the strong similarities in shape. The PDF's are not normalized so the y-axis reflects the number of counts.

The coherent oscillation, suggested by changing the threshold of the conditional averaging, is reflected more clearly in the power spectra plotted in Fig. 3(a). The frequency spectra of the density ($|n(f)|^2$), radial velocity ($|V_r(f)|^2$) and radial flux ($\Re(n(f)V_r^*(f))$) inside the plasma contain a coherent peak at a frequency $f \simeq 80$ kHz. According to Fig. 3(a), about 50% of the particles that are ejected radially outside the main plasma column is taking place at a this frequency.

We aim now at showing that the fluctuations in the SOL, dominated by avaloids, and the fluctuations inside the main plasma column, dominated by the

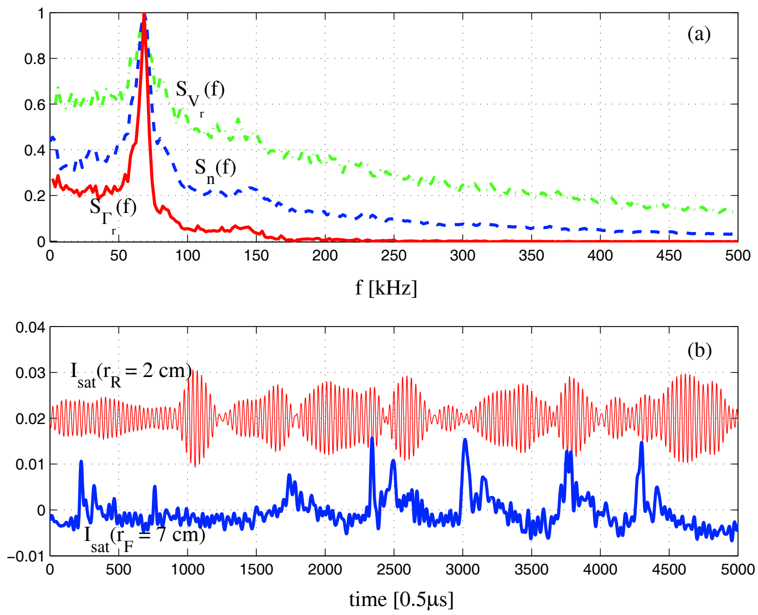

Figure 3: (a), the power spectra of the density (n), radial velocity (V_r) and radial flux (Γ_r) in arbitrary units at $r \simeq 2$ cm normalized to maximum intensity. (b), the thick solid line represents I_{sat} from the fixed probe at $r_F \simeq 7$ cm. At the same time, the solid curve is I_{sat} from the reciprocating probe filtered around 80 kHz at $r_R \simeq 2$ cm. Both I_{sat} signals are in arbitrary units.

mode at 80 kHz, are actually correlated. We use of two identical Langmuir probes positioned horizontally and vertically in PISCES to relate the density fluctuations deduced from the two ion saturation currents. The horizontal probe is fixed, and its position (r_F) is altered after each plunge of the vertical reciprocating probe. The data acquisition on the two probes is triggered at the same time and for each r_F, 2 million points are recorded.

Because we are interested in what happens to avaloids in particular, we performed cross-conditional averaging (CA_{RF}) between the signals on the two probes. Maxima above 3σ are selected on one probe (reciprocating probe) and the averaging over N_b of the $N_b \times 201$ matrix is made on the fixed probe. The number of points around each maximum is 201. The result is shown in Fig. 4(a) for $r_F = 8$ cm.

Fig. 4 shows that for $r_R > 10$ cm, the wall position, the signal is essentially white noise and no correlation exists between the signals recorded on the two probes. As the reciprocating probe moves in the SOL, the amplitude of CA_{RF} increases indicating correlation between bursts on the two probes. Moreover, only positive fluctuations are recorded. The amplitude of CA_{RF} decreases towards 0 as the probe approaches the plasma. When the probe reaches inside the plasma, CA_{RF} increases to ± 0.2. Most importantly, the temporal behavior of CA_{RF}

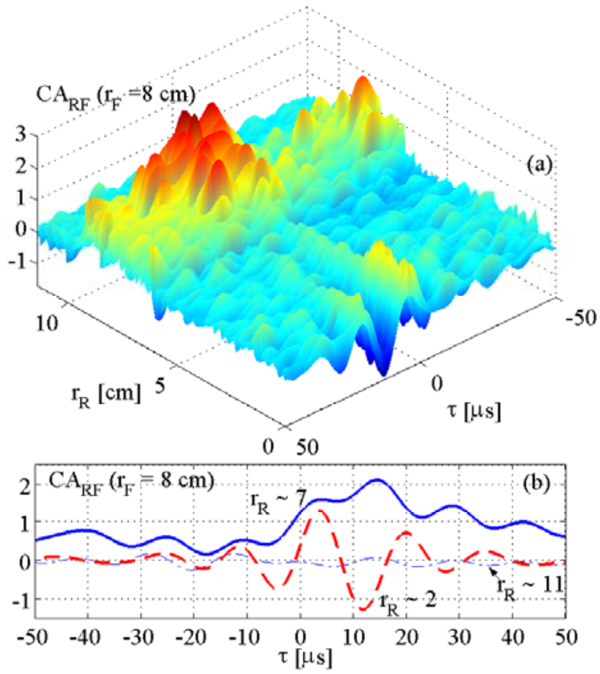

Figure 4: (a) the conditional average CA_{RF} as function of time and r_R for $r_F = 8$ cm. The two I_{sat} signals on the horizontal and vertical probes used to compute CA_{RF} and thus to produce the graph were normalized to their standard deviations. (b), CA_{RF} for $r_F = 8$ cm and $r_R \simeq 7$ (solid), 2 (dashed) and 11 (dash-dotted).

indicates that an avaloid in the SOL is correlated to a *wave-packet* occurring inside the main plasma column. The shift in time of CA_{RF} is hard to interpret because it includes the phase of the wave, the time when an avaloid is emitted and the poloidal and radial velocities.

In this article, the use of several data analyses allowed us to unveil the origin of convective transport by avaloids. They are emitted into the scrape-off layer *periodically* due to a non-linear saturation of instability inside the main plasma column. For more information, please see reference G. Y. Antar Phys. Plasmas, **10**, 3629 (2003).

References

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[2] G. Antar *et al.*, Phys. Plasmas **10**, 419 (2003).