Avalanche statistics of fluctuation-induced fluxes in SLPM and W7-AS

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1. Introduction. The study of anomalous transport in fusion plasmas has traditionally been limited to confinement devices such as tokamaks and stellarators where hot, fully-ionized plasmas are generated. Experimental data show that transport dynamics is ruled by intermittency in the form of avalanches or bursts of activity. We study radial flux burst events (i.e., avalanches) in a linear plasma inside the Santander Linear Plasma Machine (SLPM), a non-confining device [1,2], and in a toroidal plasma inside the W7-AS, a confining device [3,4]. Fluxes are obtained by means of Langmuir probes. The statistical properties of avalanche-like events (i.e., avalanche sizes/durations and inter-avalanche quiet times) derived from flux time series are analyzed.

Avalanching processes have been postulated as a possible explanation for the observation of non-diffusive propagation in real plasmas. Results for the dynamics of transport in SLPM point to a rather diffusive dynamics, except at the outermost radial locations in the plasma column. On the other hand, the dynamics in W7-AS at the single radial location where experimental data is available is markedly non-diffusive, consistent with previous work [5].

2. Experimental arrangements and plasma parameters. The SLPM is schematically shown in Fig. 1(a). The plasma is generated by launching electromagnetic waves with a frequency $f = 2.45$ GHz along the static magnetic field B_0 by means of a circular waveguide. The magnetic field is generated by a set of six water cooled coils, concentric with the waveguide, arranged in Helmholtz configuration. The power given by the generator (P_{LMG}) is in the range 0.6 kW $< P_{\mathrm{LMG}} < 6$ kW, operating the whole system in a continuous regime. The source of electromagnetic oscillations is a magnetron and the power coming from the microwaves is sent to the polarizer. The plasma is placed in a cylindrical glass vessel with an internal diameter of 7 cm and 100 cm length. Measurements were carried out for Helium plasmas. An array of Langmuir probes provides the local value of the electron density and floating potential across the whole plasma radial column.

The W7-AS device was a flexible system composed of 45 modular coils, equivalent to 5 toroidally connected mirrors, each one composed of 2 planar and 9 non-planar coils. The scheme of the coil system for this device is illustrated in Fig. 1(b). Table 1 shows typical plasma parameters for both SLPM and W7-AS.

Measurements of the ion saturation current (I_s) and the floating potential (ϕ_f) via Langmuir probes allow to derive the corresponding fluctuation-induced fluxes. Any measure can be digitized at sampling frequencies $f_s^{\mathrm{SLPM}} = 1$ MHz, for SLPM, and $f_s^{\mathrm{W7\text{-}AS}} = 0.5$ MHz, for W7-AS. Time series last 200 miliseconds for SLPM data and 100 miliseconds for W7-AS data.

The $\mathbf{E} \times \mathbf{B}$ radial particle flux is computed as $\Gamma = \tilde{n}\tilde{V}_r = \tilde{n}\tilde{E}_\theta/B = \tilde{n}(\tilde{\phi}_2 - \tilde{\phi}_1)/(r\varepsilon B)$. The density fluctuations, $\tilde{n}(r,\theta,t)$, are estimated through the measured values of the ion saturation current, $I_s \propto n\sqrt{T_e}$. Fluctuating poloidal electric fields, $\tilde{E}_\theta$, are estimated through the measured values of the electrostatic potential plasma fluctuations at two nearby positions, $\tilde{\phi}_1(r,\theta,t)$ and

Figure 1: Scheme of (a) the SLPM and (b) the magnet system of W7-AS (Fig. taken from Ref. [4]).

	R_0/m	a/m	B_0/T	T_e/eV	n_e/m^{-3}	T_i/eV	NC	HP/MW	V/m^3
SLPM	∞	0.03	0.12	20	10^{17}	0.05	6	0.005	0.03
W7-AS	2	0.15	2	1000	10^{19}	1500	45+10	5	1

Table 1: Typical plasma parameters and operating conditions in SLPM and W7-AS. R_0: major radius, a: minor radius, B_0: magnetic field, T_e: electron temperature, n_e: electron density, T_i: ion temperature, NC: number of external coils, HP: heating power and V: Plasma volume.

$\tilde{\phi}_2(r, \theta + \varepsilon, t)$, poloidally displaced ε radians, with θ the poloidal angle, r the radial coordinate and B_0 the axial magnetic field.

Figure 2 shows the time trace of the fluctuating $\mathbf{E} \times \mathbf{B}$ radial flux at $r = 2.2$ cm measured in SLPM for a lapse of time of 2 miliseconds. In Fig. 2(b), the same signal is zoomed in a time window of 0.2 miliseconds to better show the abrupt fluctuations of the flux. Avalanches can be considered as the evolution of an initial perturbation followed by successive relaxations. These kind of events should be longer in time than local fluctuations. An overview of the main concepts are depicted in Fig. 2(b). The "duration" can be defined as the lapse of time where the signal remains above (below) some prescribed threshold Γ_t^+ (Γ_t^-). The "size" can be defined as the area enclosed between the signal and the threshold. The inter-avalanche "quiet-time" can be defined as the period of time between two consecutive events.

Figure 2: (a) Time record of the turbulent particle flux in SLPM flux at r = 2.2 cm. (b) Same trace as in (a), during a 0.2 milisecond interval [i.e., shaded region in (a)]. Dashed lines stand for amplitude thresholds. Relevant definitions associated with avalanches are sketched.

3. Avalanche-like events statistics. The number of experimental data for the fluctuation-induced flux series is scarce, being insufficient for the calculation of well-defined avalanche size/duration probability distribution functions (pdfs), as well as inter-avalanche quiet-time