Some properties of LH-generated fast electrons in the SOL*

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1 Introduction

Recent experiments **[1, 2]** during lower hybrid (LH) operation on Tore Supra revealed two distinct groups of fast electrons, according to their temporal behavior and radial location. At all radial positions reached by a retarding field analyzer (RFA) mounted at the top of the machine on a reciprocating manipulator, the recorded signal is intermittent **[1, 2]**,.but at the LH grill mouth the fast electron signal has a steady DC component. Away from the grill mouth, only the intermittent signal survives. We have previously advanced the hypothesis **[2, 3]** that this nature of the fast electrons is associated with edge turbulence – blobs **[4]** - propagating outward from the last closed flux surface (LCFS) around low field side mid-plane.

We explain the observed fast electron features as follows. At the grill mouth, continuous Landau damping of resonant high-$n_{//}$ components of the grill spectrum is responsible for the DC signal. Landau damping on the incoming higher-temperature and higher-density blobs causes the intermittent bursts. Away from the grill mouth, the high-$n_{//}$ spectral components are filtered out, so only the intermittent signal remains.

We make use herein of recent Tore Supra edge fluctuation measurements **[5]** to understand the observed fast electron intermittency and the properties of the associated duty cycle, which is the fraction of time during which fast electron bursts are recorded at some radial position **[2].** Likewise, we show that the fluctuating electron temperature T_e can fall below 10eV about 5% of the time, a number compatible with the duty cycle near the LCFS. This is a sufficiently low-temperature background allowing access of a weakly damped spectrum to blobs away from the grill mouth.

Finally, we carry out test electron simulations with an LH antenna electric field from the ALOHA code **[6]** to determine the electron distribution function and to subsequently solve the LH dispersion relation for a T_e=10eV and supercritical n_e=3.5x10^{17} m^{-3} background plasma, with blob temperature and density assumed equal to time-averaged values measured in Tore Supra shot 39547. A typical resulting value of fast electron parallel power-flow from the grill is about 25 MW/m^2, varying slightly with radial position.

2 The LH-generated fast electron duty cycle

An important quantity characterizing the fast electron intermittency with the associated bursts is their duty cycle, defined as the fraction of the observation time during which they are detected by the probe. Equivalently, the duty cycle at a certain radial distance *d* from the grill is the probability that fast electrons are detected at a particular position. The duty cycle was observed to decrease with distance from the grill mouth **[2]**, which is easily understood on grounds that the probability of a blob located between the grill and the probe (which therefore intercepts the spectrum before it can reach the radial position of the probe) increases with increasing distance *d* of the probe from the grill. The assumption here is of course that a hot and dense blob will almost completely absorb the incoming spectrum. A quantitative understanding of this observation can be obtained using blob dynamic parameters, determined from edge turbulence measurements on Tore Supra **[5]**. Specifically, a blob enters the SOL with a certain velocity v at a repetition rate δt (or frequency $f=1/\delta t$). Both v and δt are random variables described by, respectively, probability densities $P_v(v)$ and $P_t(\delta t)$. An example of these PDFs from Tore Supra shot 44635 **[5]**) is shown in **Fig.1.** By definition, the duty cycle is the probability

$$P'(d) = 1 - P(d) = 1 - \iint d(\delta t)\, dv\, P_v(v\,\delta t < d)\, P_{\delta t}(\delta t) \qquad (1)$$

where the integral is the conditional probability of a blob to be present between the grill and the probe. In Eq. (1) we use the normalized $P_v(v)$ for $v>0$, since only such perturbations are relevant here.

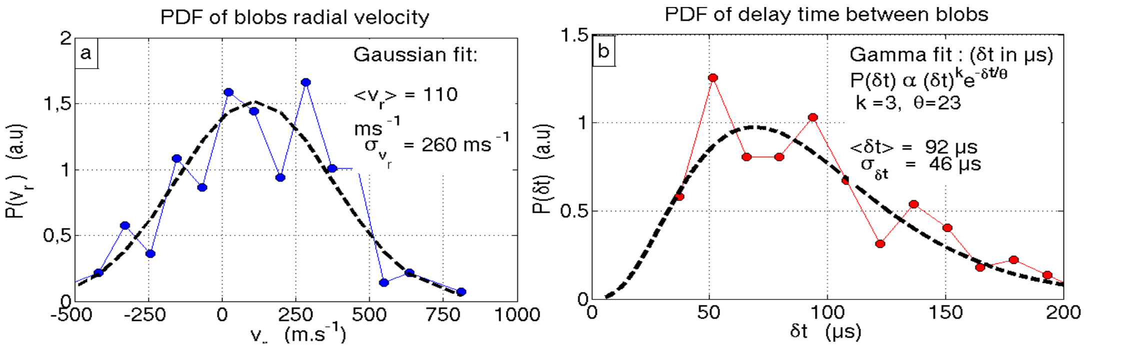

Fig. 1. *a) PDF of the ExB radial velocity v_r of blobs, fitted with a Gaussian function. b) PDF of the delay time δt between blobs (in μs), fitted with a generalized Gamma function: $\delta t_{max} = \Theta k$ is the position of the peak, $\sigma_{\delta t} = \sqrt{\Theta k+1}$, $\int P(\delta t)\, d(\delta t) \cong \Theta^{k+1} k!$*

Figure 2 shows in red the duty cycle measured in shot 39547, together with results from Eq. (1). The duty cycle clearly decreases with decreasing $<\delta t><v>$.

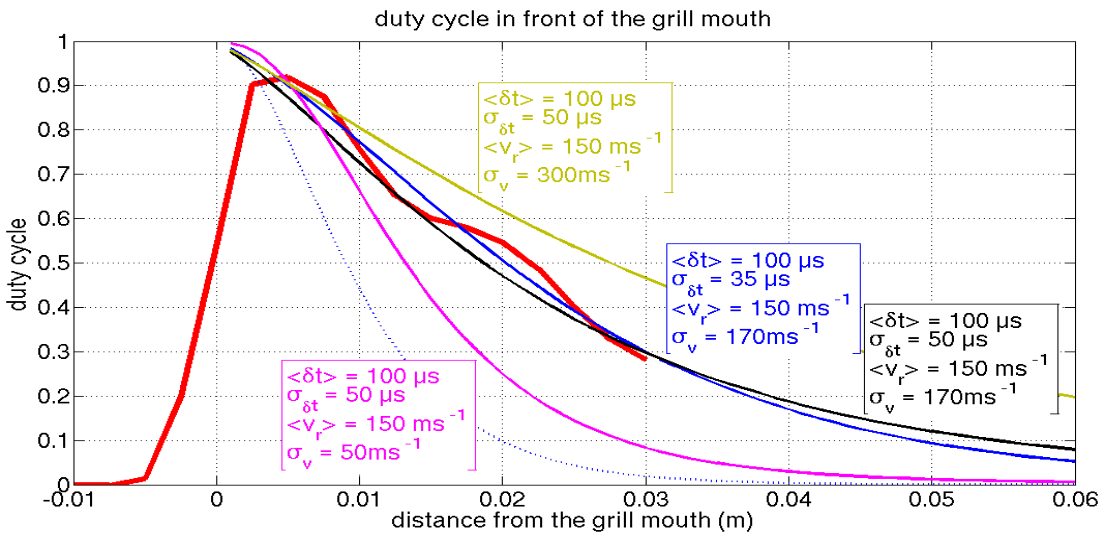

Fig. 2 *Duty cycle as function of radial distance d from the grill mouth situated at the origin. Red curve: experimental duty cycle. Also shown are results from Eq. (1) using various fits with an intermittency rate <δt>=100 μs as observed in TS shot 39547.*

3 Conditions for Landau damping of the LH spectrum on blobs

We need to demonstrate that the SOL plasma background electron temperature between blob events can fall to sufficiently low levels in order to allow the LH spectrum reaching a blob away from the grill mouth. At typical voltage bias values below -200eV, the probe records the ion saturation current $J_{sat} \approx n\, T_e^{1/2}$. Allowing a certain contribution from both density and electron temperature to J_{sat} fluctuations, with say $T_e \approx J^{\alpha}_{sat}$, $0 \le \alpha \le 2$, the electron temperature fluctuations can be extracted from the J_{sat} signal and processed with the result shown in **Fig 3**

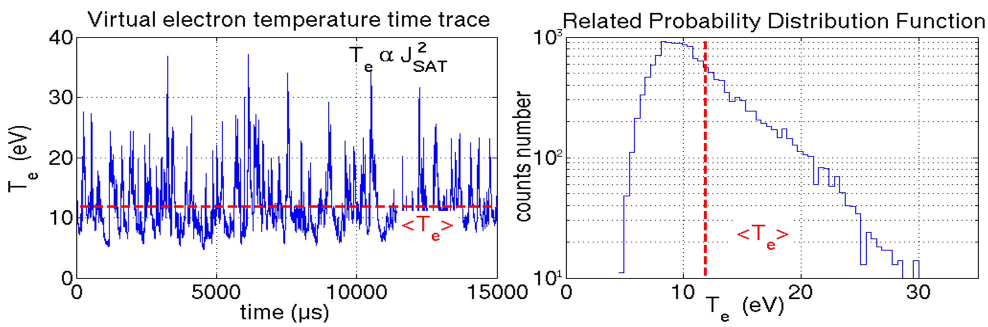

Fig 3. *a) Time trace of the temperature fluctuations in the extreme case α = 2. b) Related probability distribution function. The time averaged temperature of the time trace is shown in red. Large deviations from the mean value are noticeable.*

Assuming now an equal contribution (α=1) of density and temperature fluctuations to J_{sat} fluctuations, we see from **Fig. 4b** that there is a 0.2%-20% chance of T_e falling between 8eV-10eV. This percentage is compatible with the least probable ≈5% duty cycle near the LCFS (Fig. 2). We therefore carry out self-consistent test electron and Landau damping calculations in a 10eV background following the method of a previous study **[3].** This gives the result of Table 1:

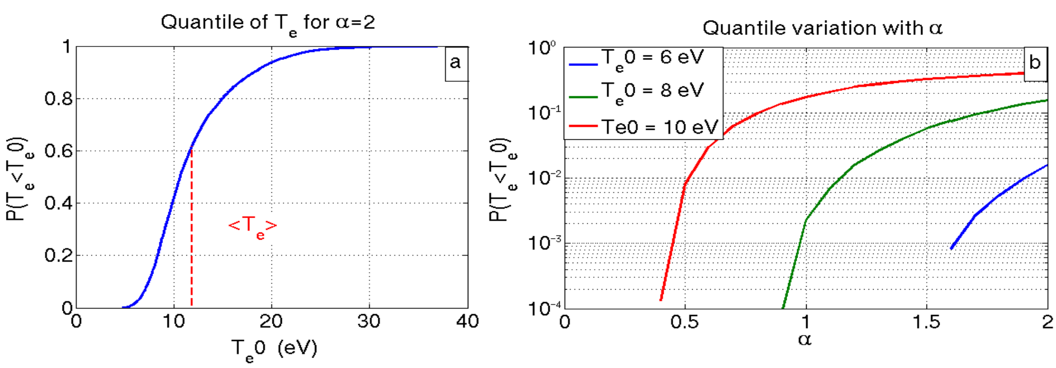

Fig 4 *Quantile of T_e in the case α=2: Probability of finding the instantaneous local temperature below a given value T_{e0}. b) Variation of the quantile as a function of the partition parameter α, for different value of T_{e0}.*

Table 1 *Result of blob interaction with lower hybrid spectrum in a 10eV, 3.5x10^{17} m^{-3} homogeneous SOL background. Blob temperatures and densities are correlated with the measured profiles of TS shot 39547. The total indicated outgoing supra-thermal power-flow $S^{(+)}$-$S^{(-)}$ naturally equals the dissipated LH power density in the grill region.*

	background suprathermals		T_e and n_e of blob		blob suprathermals		powerflow [MW/m^2]	
r [cm]	T_h[eV]	η_h	T_e [eV]	n_e [10^{17} m^{-3}]	T_h[eV]	η_h	S(-)	S(+)
0.0	1100	0.014	15.0	3.00	850	0.03	-35	34
0.10	900	0.022	15.2	3.12	800	0.045	-27	27
1.0	750	0.02	17.4	3.72	600	0.07	-28	30
2.0	600	0.016	21.0	4.78	450	0.08	-37	35
3.0	500	0.014	25.5	6.14	350	0.08	-25	20
4.0	400	0.014	30.8	7.88	350	0.10	-23	22
5.0	350	0.014	37.2	10,12	350	0.10	-40	35
6.0	300	0.014	45.0	13.0	300	0.13	-51	47

4 Conclusion

We have demonstrated that the experimentally determined duty cycle of LH-generated fast electrons is comparable with results from an equivalent definition Eq. (1) based on probability density functions, respectively, of blob radial velocity and detachment rate. Furthermore, we conclude from analysis of Tore Supra edge temperature fluctuation statistics that the SOL electron temperature between blob events can drop to levels below 10eV about 5% of the time, compatible with the duty cycle at the LCFS. We confirm by test electron simulations coupled with solutions of the LH slow wave dispersion relation that such conditions allow penetration of the spectrum to blobs anywhere between the grill and the LCFS.

References

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