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Local electromagnetic characterization of type I ELMS on ASDEX Upgrade

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Edge Localized Modes (ELMs) are short breakdowns of the high confinement regime (H-mode) which is envisaged to be used in power producing tokamaks [1]. Due to the high power fluxes associated with them, ELMs pose demands on the design of plasma facing components. Apart from the interest in thermonuclear oriented plasmas the physics of ELMs suggests fascinating analogies with all those explosive phenomena in nature accompained by rapid particles and large amounts of energies expulsion as observed for example on solar flares [2] or magnetic substorms [3]. Present theories on ELM formation and dynamics suggest that they originate from a combination of pressure gradient driven MHD modes (balloning) and edge current density gradient driven modes (peeling modes) which combine in creating intermediate mode number structures ($n \cong 10-15$) well localized in the plane perpendicular to the guiding magnetic field but extended along the field lines [4, 5]. These structures are then found to propagate in the Scrape Off Layer (SOL) where they have been measured using Langmuir probes [6, 7], magnetic pick-up coils [4] or gas puff imaging [8].

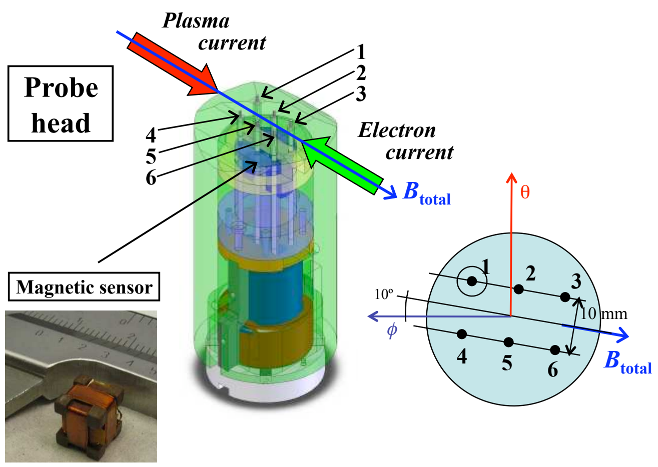

Figure 1: Schematic drawing of the probe head. The probe pins are numbered with probe 1 protruding 3 mm from the other probes. In the toroidal and poloidal directions the distance between the probe pins is 10 mm respectively. Probe head is tilted in order to align pins to the toroidal field direction

In this contribution we present results on simultaneous investigations of electric and magnetic fluctuations in ASDEX Upgrade SOL plasma by means of a probe head combining Langmuir probes and magnetic pick-up coils mounted on the mid-plane manipulator. A schematic drawing of the probe head is shown in figure 1. On the front side of a cylindrical graphite case of about 60 mm diameter and 150 mm length six graphite pins of 1 mm diameter and 2 mm length are mounted isolated from each other by boron nitride. The six pins are arranged in two rows of 3 pins each with a distance of 10 mm from each other. In poloidal direction the two rows of pins are situated above each other with a distance of 10 mm in between. The probes are arranged in order to simultaneously measure radial and poloidal electric field components (computed from floating potential gradients neglecting temperature fluctuations), plus one pin measuring the ion saturation current in order to infer the local density whereas one last pin is kept sweeping as a single probe. Inside the graphite case, 20 mm behind the front side, a magnetic sensor measuring the time derivative of the three components of the magnetic field is mounted. The sensor has a measured bandwidth of 1 MHz with -3 dB cutoff at 1.1 MHz.

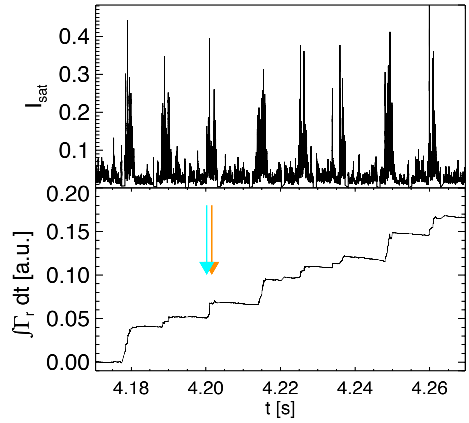

Figure 2: Top: ion saturation current during the entire probe insertion. Time integrated particle flux $\int \Gamma_r dt$. The two colored arrows correspond to the shaded time intervals shown in figure 4

During the analysis we have used the ion saturation current as collected from one of the probe's tip to infer the passage of the ELM structure in front of the probe, as done for example in [6], in order to correctly time the local passing of an ELM filament. Indeed it is a well know feature [6, 9] that during the passage of an ELM, abrupt increases of the ion saturation current are measured.

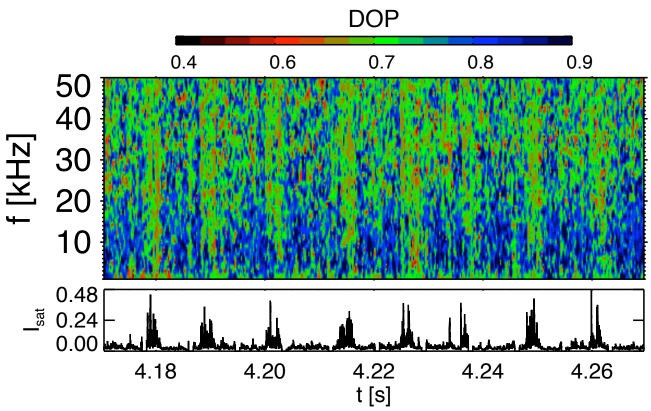

Figure 3: Top:Degree of Polarization analysis as a function of time and frequency. Bottom: Ion saturation current

This can be recognized for example from the top panel of figure 2, where the 8 sharp increases of the ion saturation current can be observed corresponding to 8 different ELM events [10].

Approximating the radial velocity by the corresponding $\mathbf{E} \times \mathbf{B}$ component, and neglecting temperature fluctuations also in the determination of the density from ion saturation current measurements, we can also compute the turbulent instantaneous particle flux $\Gamma_r = \tilde{n}\tilde{v}_r = \frac{\tilde{j}_s \tilde{E}_\theta}{e c_s B_\phi}$ and the corresponding time integral $\int_{t_0}^{t} \Gamma_r(t^{'})\mathrm{d}t^{'}$ which gives an insight into the temporal increase of the radially transported particles. The estimate of $\int \Gamma_r$ is shown in the lower panel of the same figure 2. It clearly demonstrates the sharp increase of outward fluxes corresponding to the local passage of an ELM in front of the probe. In analyzing the magnetic data associated with the ELM and the sharp increase of the particle flux, we employ the idea that the magnetic signal during the ELM can be separated into different frequency components: the high-frequency part of the spectrum (a few hundred of kHz) is expected to be generated mostly by high frequency turbulence, whereas at lower frequencies we assume that magnetic activity is mainly generated by moving currents convected with the filaments. This hypothesis can be checked using the so-called Degree of Polarization (DOP) technique [12, 13]. This technique may be interpreted as a test for plane wave ansatz. It is based on the evaluation of the spectral matrix $S = \langle B_j B_i \rangle$, calculated in the Fourier space. A high value of DOP implies that the fluctuations are correlated over several wavelengths and thus can be approximated by a plane wave. The results of this analysis, applied to the same shot and interval is shown in figure 3 where strong reductions of the DOP are observed in correspondence with the sharp increase of the ion saturation current signals, confirming that during ELMs, magnetic fluctuations are better represented as coherent structures rather than a plane wave.

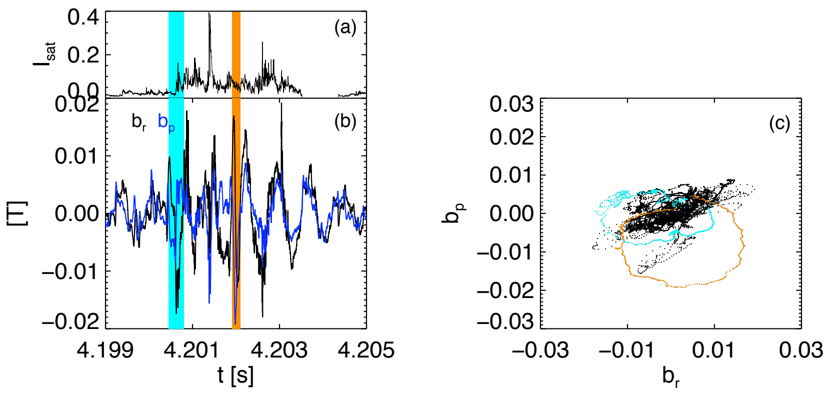

Figure 4: (a) Ion saturation current measured in zoomed window (b) Radial and poloidal component of the magnetic field (c) hodogram of the perpendicular magnetic field. The two highlighted closed loops correspond to the highlighted time windows in panel (a) and (b)

A closer zoom on one of the events previously shown is reported in figure 4. In the panel (a) a zoom on the ion saturation current is shown whereas in the panel (b) the radial and poloidal components of the magnetic field are shown. These two components correspond approximately to those perpendicular to the background magnetic field. It can be clearly observed that when the ion saturation current increases, correspondingly also the magnetic activity increases and the radial and poloidal components change their phase relation, moving from approximately in phase to approximately in quadrature, as highlighted by the two colored shaded regions.

This can be more clearly seen by looking at the hodogram of the two components, i.e. by considering the magnetic field perturbation trajectory in the $b_r - b_p$ plane. Indeed, the shaded regions correspond to close loops clearly recognizable whereas outside the ELM the magnetic field exhibits an almost linear polarization in the perpendicular plane.

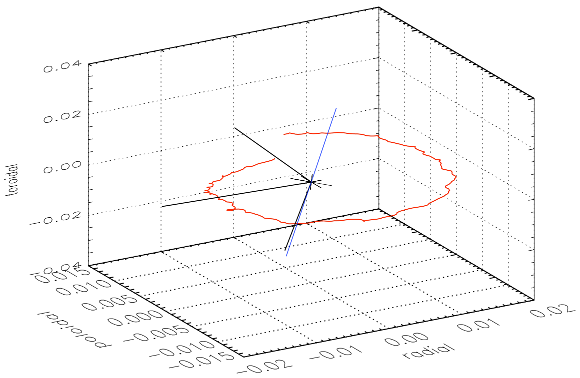

Figure 5: 3D hodogram of the magnetic perturbation associated to an ELM filaments in all the three components. The direction normal to the plane where the ellipse lies is shown together with the direction of the equilibrium magnetic field in a blue line

Closed loops in the hodograms are indeed compatible with the passage of a current filament [11], as expected from ELM theories. Using all three components of the magnetic field it is possible to reconstruct the 3D hodogram shown in figure 5 corresponding to the second shaded interval of figure 4. The trajectory spans a well defined ellipse lying in a plane slightly tilted with respect to the nominal toroidal position. It is possible to infer the direction perpendicular to this plane (shown in figure 5 by a black line), and this is found to correspond to the direction of the equilibrium magnetic field shown in the same figure by a blue line. Thus this is a further confirmation of the existence of a parallel current filament associated to an ELM.

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References

[1] Zohm H, 1996 *Plasma Phys. Control. Fusion* **38** (1996)

[2] Fundamenski W *et al.* , 2007 Plasma Phys. Contro. Fusion **49** R43

[3] Lui A, 2000, *IEEE Trans. Plasma Science* **28** 1854

[4] Kirk A *et al.* 2006 *Plasma Phys. Contr. Fusion* **48**, B433

[5] Hermann A *et al.* 2007 *Journ. Nucl. Mat.* **363-365** 528

[6] Endler M *et al.* 2005, Plasma Phys. Contro. Fusion **47** 219

[7] Leonard A.W. 2006 Plasma Phys. Contro. Fusion **48** A149

[8] Maquead R *et al.* 2009 *Phys. Plasmas* **16** 056117

[9] Schmid A *et al.* 2008 Plasma Phys. Contro. Fusion , **50** 045007

[10] Ionita C, Vianello N *et al.* 2009 *Journ. Plasma and Fus. Research Series* to be published

[11] Vianello N, Naulin V, Schrittwieser R *et al.* 2009 *Phys. Rev. Lett.* to be submitted

[12] Samson J and Olson J 1980 *Geophysical Journal International* **61** 115

[13] Santolík O 2003 *Radio Sci.* **38** 13