33rd EPS Conference on Plasma Phys. Rome, 19 - 23 June 2006 ECA Vol.**30I**, P-5.162 (2006)

Intermittent radial transport on the ULS linear device

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Introduction

There has been increasing interest in characterising intermittent fluctuations in the scrape off layer (SOL) of fusion devices, and the role that such events may play in determining cross field transport in SOL plasmas. Examples of convective coherent structures have been observed at the edge of a range of devices, including tokamaks [1] and stellarators [2], as well as on a number of linear plasma machines [3,4]. Here we report on measurements of fluctuations on the ULS divertor simulator which have demonstrated, in certain regimes, the presence of intermittent bursts of plasma (typically of order 100µs duration) at radii well beyond the main confined plasma beam.

Experimental set-up

The ULS [5] is a linear plasma device, designed to study physics relevant to tokamak divertors. It is divided into two sections (see Figure 1): an upstream chamber into which plasma is injected from a DC arc source and a gas target chamber in which the pressure of the background gas may be controlled. For much of this work, no additional gas was introduced and the pressure in the gas target chamber was kept below 1×10^{-5} Torr. For a typical magnetic field strength of 0.1 Tesla, the device can produce hydrogenic plasmas with densities and temperatures in the range 2×10^{16} to 5×10^{19} m^{-3} and 4-15eV respectively, although in practice these studies were focussed on plasmas with densities at the lower end of this range.

The diagnostics that were used were based on electrical probes and visible light imaging using a high speed camera. A Langmuir probe, mounted on a reciprocating holder so as to minimise the effects of probe heating by the plasma beam, allows the acquisition of radial profiles of electron density and temperature at a single position within the target chamber (see Figure 1). In addition to this, a triple probe array (comprising of a central probe biased to ion saturation and two other, vertically displaced, probes providing floating potential measurements) has been installed which allows the radial particle flux due to electrostatic fluctuations to be evaluated. As well as these electrical probe diagnostics, high speed visible light imaging has been used to identify the spatial extent of the plasma structures at the edge of the confined beam. The camera used for these studies (Photron ultima APX-RS) is capable of imaging at rates of 10000 frames per second (fps) at a resolution of 512x512 pixels. In practice, the fastest frame rate is limited by the plasma light emission levels and typically it was necessary to operate at a frame rate of 50000 fps to obtain a satisfactory signal. The camera viewed the plasma through a port mounted at the end plate of the target chamber at an oblique angle along the beam (see figure 1). The use of low f-number camera optics meant that only a short (~1cm) region of the plasma was in focus, providing some degree of spatial resolution along the beam.

Results

Figure 2(a) shows a time history of the ion saturation current measured at the centre of the plasma beam, in a regime where the fluctuations are dominated by intermittent events. Experimentally, it is found that the onset of this regime corresponds to a critical value of the applied magnetic field, with a weaker dependence on background neutral density. In an attempt to correlate the observation of these intermittent events to background instabilities, we have compared the threshold for intermittency with the appearance of particular modes of plasma instability in the confined plasma (ascribed to flute, drift-wave and Kelvin-Helmholtz instabilities): interestingly, results to date indicate that the appearance of “blobs” at the edge of the confined plasma seems to be quite independent of the onset of such modes, although further work is required to explore this finding.

A statistical analysis of the time series of both the saturation current and potential in this regime reveal strongly non-Gaussian probability density functions (PDFs), as shown in figure 2(b), broadly similar to those reported elsewhere on both tokamaks and linear devices. At the core of the confined plasma (up to r/a = 0.6), the intermittent events are dominated by “holes”, characterised by sharp reductions in ion saturation current ($\delta I_{sat}/I_{sat} \sim 0.5$- 0.7), whereas at radii towards the edge of the confined plasma ($r/a > 0.8$) the events are dominated by coherent density enhancements (“blobs”) with $\delta I_{sat}/I_{sat} \sim 1$. This is indicated in figure 3 which shows the radial profile of the *skewness* of the ion saturation PDF. It is found that the boundary between these two PDF regimes corresponds roughly to a region in which the radial electric field (and hence the azimuthal plasma rotation) is changing rapidly.

The spatial structure of the plasma associated with these intermittent events has been investigated using the high speed camera system described in the previous section. To enable imaging of the hydrogenic plasmas investigated in these studies, neutral hydrogen gas was introduced into the gas target chamber, raising the pressure to approximately 5mTorr. Although the external (source and applied field) conditions needed to be adjusted slightly to obtain the intermittent regime, the properties of the fluctuations were similar to those described above. Figure 4 shows a single frame image of the plasma obtained at an integration time of 20μs. Analysis of time series of images reveals a rotating, outward propagating spiral structure, consistent with the expected ExB rotation associated with the radial electric field. These observations are superficially very similar to those reported by Barni et al [6] where conditional averaging of a large number of probe measurements has revealed a similar spiral structure.

Finally, we have attempted to evaluate the radial particle flux associated with these intermittent fluctuations. To do this, triple probe data was acquired for a large number (approximately 100) of events. Figure 5 shows the conditionally averaged product of fluctuations in the ion saturation current density and the azimuthal electric field at a radius of 7.5mm. During the intermittent events there is clearly a strong contribution to the radial transport of particles, and future work will focus on the significance of this flux to overall particle balance in the ULS.

Conclusions

Measurements of the time history of ion saturation current and floating potential have shown that for certain operating parameters, the ULS plasma enters a regime in which intermittent events dominate the observed fluctuations. At the centre of the plasma beam, these events correspond to the appearance of “holes” (density deficits), whereas towards the edge of the plasma, there are significant density enhancements (“blobs”), which are associated with significant fluctuation induced transport. Future work will focus on characterising these events for a range of operating parameters, using probe arrays to assess the structure and time evolution of the plasma blobs and an assessment of the relevance of this phenomena to detachment on linear divertor simulators.

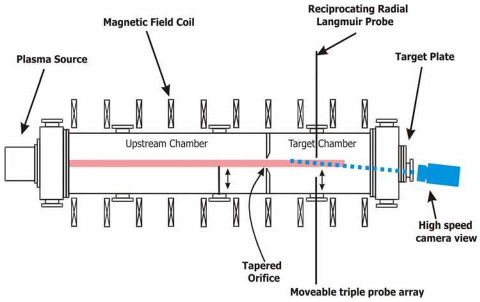

Fig 1: Schematic diagram of ULS linear plasma device showing location of main diagnostics used in this study.

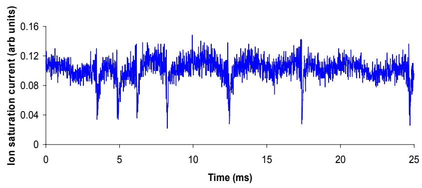

Figure 2a (above): Time history of Isat measured at the plasma centre.

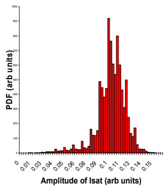

Figure 2b (left): PDF of Isat measurements

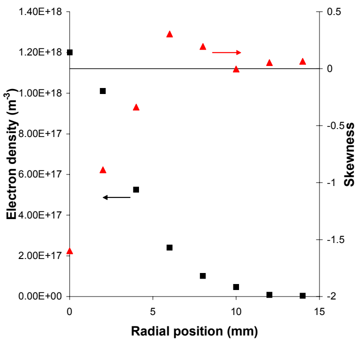

Figure 3: Radial Langmuir probe measurements of density, together with the skewness of the ion saturation PDFs, showing evidence for density deficits at the core plasma and blobs at the plasma edge.

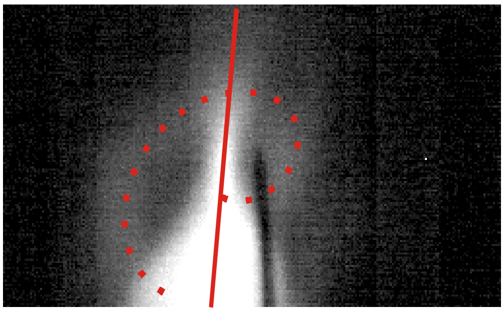

Figure 4: Image of plasma showing centreline of beam and spiral plasma structure. The dark object on the right of the beam is a Langmuir probe.

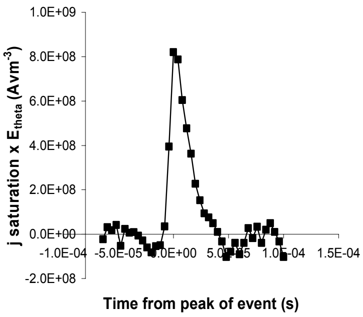

Figure 5: Product of ion saturation current density and azimuthal electric field at r=7.5mm, averaged over many intermittent events.

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