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Detailed measurements of momentum balance during the periodic collapse of a transport barrier

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In this paper, we present results of edge plasma biasing experiments [1] performed in the CASTOR tokamak (R=0.4 m, a = 85 mm, B_T= 1.3 T, $I_p \approx 10$ kA, $n_e \approx 10^{19} m^{-3}$) with an enlarged set of edge plasma probes offering high temporal and spatial resolution.

Experimental set-up

A poloidal array of 96 Langmuir probes, 16 magnetic coils, and 16 Hall sensors surrounding the full poloidal circumference monitors poloidal profiles of electric field, density, and magnetic field. A radial array of Langmuir probes measures the radial profiles of floating potential, poloidal electric field, and ion saturation current. A Gundestrup probe [2] measures the parallel and perpendicular flows while a segmented tunnel probe measures the electron and ion temperatures. All data are acquired with up to 1 MHz sampling rate. This complex diagnostic set offers new insight into the observed phenomena.

Introduction

A biasing voltage of +200 V is applied to a graphite electrode immersed in the edge plasma of the tokamak [3]. During the biasing a clear and reproducible transition to improved confinement is routinely observed along with the formation of an edge transport barrier which is characterized by (i) a steepening of the time-averaged density gradient (ii) a reduction in recycling (iii) a substantial improvement of the global particle confinement. For biasing voltages above ~200 V, the creation of a strongly sheared radial electric field within the transport barrier is followed by an abrupt collapse of the potential and density gradients. The observed radial propagation of dense structures and fast spikes of electron temperature immediately following the collapse indicate the ejection of hot dense plasma towards the wall. This process is repetitive with a frequency of about 10 kHz throughout the full biasing phase of the discharge.

Results

Figure 1 shows a detail of the creation and collapse of the transport barrier together with the corresponding evolution of the H_α line radiation. First, a strong transport barrier of width ~ 4-5 mm is periodically formed in the proximity of the Last Closed Flux Surface (LCFS), in the range of radii 55-67 mm. Then, it propagates radially towards the wall with a velocity of ~ 220 m/s. Finally, the barrier collapses, when approaching the Last Closed Flux Surface, which is located at r = 67.2 mm in this particular case.

The H_α line starts to decrease, when the strong barrier is formed at 55-60 mm. This can be interpreted as a reduction of convective transport towards the wall and consequently the reduction of recycling. When the barrier collapses, the plasma burst interacts with the walls (or limiter) and the recycling and H_α intensity increases.

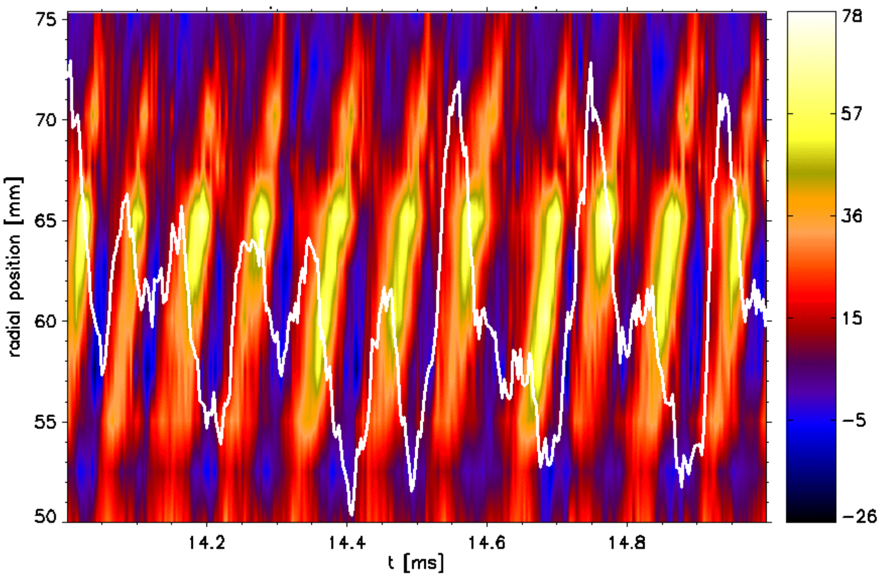

Fig. 1: Comparison of the temporal evaluation of the radial electric field with the time trace of the H_α line radiation

Figure 2 presents the temporal evolution of the parallel and perpendicular flows [4]. The periodic redistribution of the plasma flow between the parallel and perpendicular directions is observed with characteristic frequency of ~10 kHz. The breakdown of transport barrier is followed by an increase of the parallel flow, along with an increase of the H_α radiation due to enhanced influx of neutrals into the plasma, appearing shortly after.

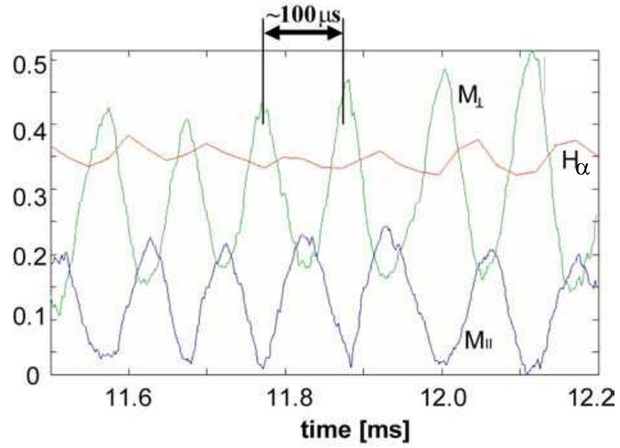

Fig. 2: Temporal evolution of the parallel $M_{||}$ and perpendicular $M_\perp$ Mach numbers and of the H_α line radiation.

The temporal evolution of the poloidal profile of the floating potential on the upper part of the torus is shown in Figure 3. An evidence of relaxations is apparent, the relaxations are poloidally symmetric with poloidal mode number m ~ 0.

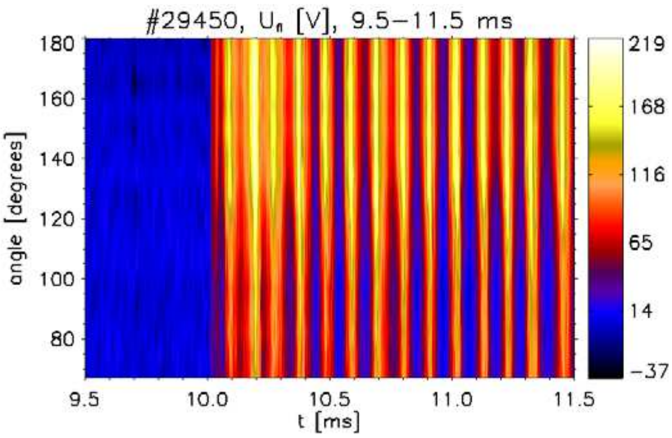

Fig. 3: Temporal evolution of the poloidal profile of the floating potential.
The biasing starts at t = 10 ms.

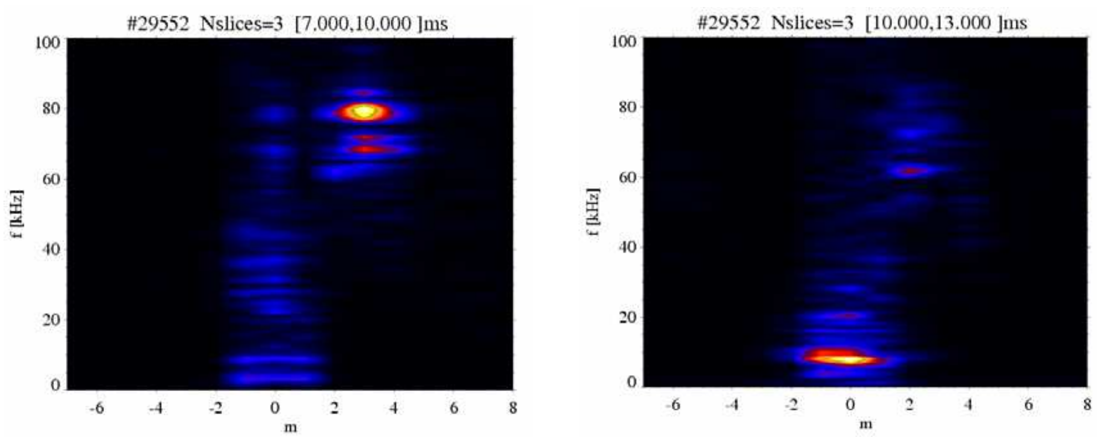

Fig. 4: S(m,f) spectra of magnetic perturbations measured using a poloidal array of Mirnov coils before (left) and during (right) the biasing phase of the discharge.

Figure 4 presents the spectra of magnetic perturbations measured using the poloidal array of Mirnov coils. In the ohmic phase of the discharge, the coils observe a magnetic island m=3 at f=80kHz. During the relaxations, magnetic activity is observed at f ~ 10 kHz with the poloidal mode number m = 0-1, while the m = 3 magnetic island is fully suppressed. This indicates a significant redistribution of current density profile during the relaxations.

Summary

The onset of relaxation events is observed at the plasma edge of the CASTOR tokamak during the biasing experiments at high enough electrode voltages. These relaxations were studied with high spatial and temporal resolution by using several probe arrays.

The transport barrier is periodically created and relaxes with frequency ~10 kHz. The maximum radial electric field within the transport barrier is up to 70 kV/m, which causes strong ExB rotation in the poloidal direction. The resulting poloidal velocity (up to 50 km/s) is comparable with the ion sound velocity.

The observation of plasma flows confirms their periodic redistribution between the parallel and perpendicular directions. The measurements of Mach numbers confirm that the $M_{||}$ and $M_{\perp}$ are in anti-phase. The radial transport of the plasma towards the wall during the relaxations causes an enhancement of the influx of the neutrals into the plasma, which is in good agreement with the observed increase of the H_{α} line radiation.

The poloidally resolved measurements have also demonstrated that the relaxation events are poloidally symmetric (both in their electric and magnetic components).

References

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