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DENSITY FLUCTUATIONS DURING CONFINEMENT CHANGES IN THE WENDELSTEIN 7-AS STELLARATOR

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1.Introduction

The CO_2 laser based LOTUS (**lo**calised **tu**rbulence **s**cattering) dual volume electron density fluctuation diagnostic installed on the W7-AS stellarator has been used to investigate changes in density fluctuations during confinement transitions. In this paper we discuss two examples, slow transitions due to slight changes of the edge rotational transform ι_a and fast L-H*-mode transitions, H* being the ELM-free H-mode.

The optical setup has been described in detail elsewhere [1]; the two vertical measurement volumes passing close to the plasma center were separated by 29 mm (center-to-center), had a waist w of 4 mm and measured density fluctuations with a k_θ of 15 cm^{-1} (section 2) and 31 cm^{-1} (section 3). The measurement volumes extend along the entire plasma column, providing line integrated density fluctuation measurements.

2.Slow Transitions

At certain values of ι_a substantial (about a factor of two) differences can be observed in the confinement time of W7-AS plasmas [2]. As ι_a can be changed by an externally induced ohmic plasma current, confinement transitions can be created during one discharge in a controlled fashion.

To some extent these confinement transitions are comparable to the L-H* transition; the edge temperature and density profiles steepen, the poloidal flow velocity increases and the edge H_α radiation decreases in the good confinement phase. However, these transitions are completely reproducible and occur gradually in time. Phenomenological model calculations [2] indicate that anomalous transport at rational surfaces might play a decisive role in these phenomena, so it is worthwhile analysing the electron density fluctuation behaviour during a slow current ramp induced iota-edge transition. For this purpose high-density ECRH heated discharges were initiated under good confinement conditions and a 700 ms long ohmic plasma current ramp was applied from 0-2 kA. The line averaged electron density was kept constant by a feedback regulation of the gas inlet rate. In response to the current ramp induced ι_a change both the stored energy and the plasma temperature dropped gradually by more than a factor of two.

Electron density fluctuations were analysed in a series of identical discharges where the alignment of the two measurement volumes of the LOTUS diagnostic was changed from shot to shot. The crosspower spectrum of the two scattered signals enables one to measure changes in the frequency and power of the fluctuations from the top to the bottom of the device [1]. Figure 1 shows the time dependent normalised crosspower amplitude spectrum in identical discharges with different measurement volume alignments. Also shown are 2D comparisons between the good and bad confinement phases. Positive frequencies are fluctuations travelling inward parallel to the major radius, negative frequencies are fluctuations travelling outward. At 400 ms the plasma is at good confinement while at 900 ms it reaches the final bad confinement condition.

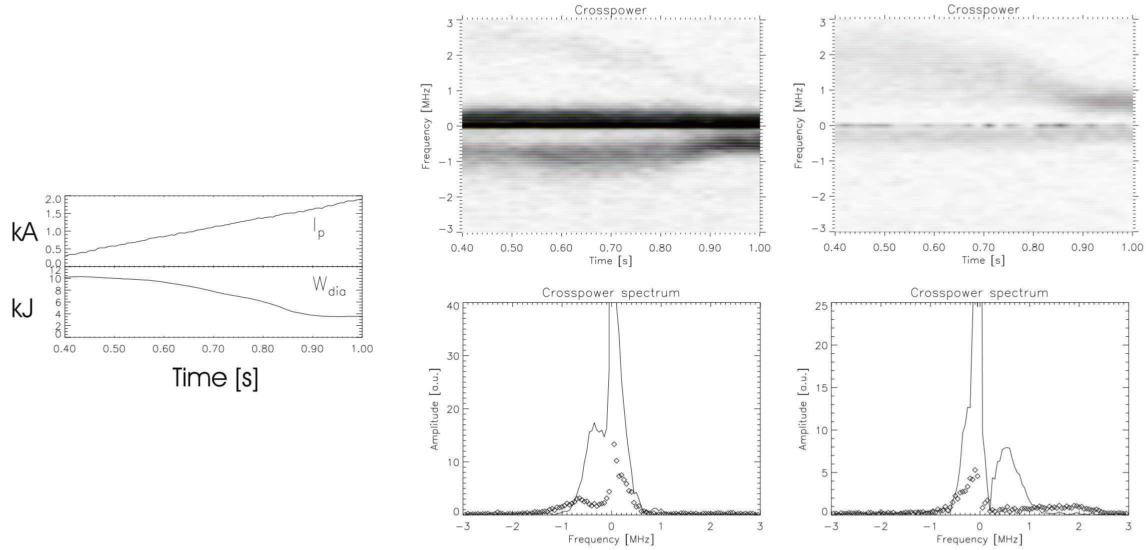

Figure 1: *Far left: Plasma current and stored energy vs. time, upper center/right column: Normalised crosspower amplitude spectra at the top/bottom of the plasma, lower center/right column: Non-normalised crosspower amplitude spectra at the top/bottom of the plasma. The solid lines in the lower plots are at bad confinement, diamonds at good confinement*

The fluctuations can clearly be separated into low-frequency (LF; $<$ 500 kHz) and high-frequency (HF; $>$ 500 kHz) parts. For both features the frequency changes sign when moving from the bottom to the top of the plasma. The frequency of the two features at a given alignment is opposite, that is they are counterpropagating fluctuations in the laboratory frame. The LF fluctuations travel in the ion diamagnetic, while the HF ones move in the electron diamagnetic drift direction.

During the transition to bad confinement the frequency of the HF feature decreases considerably. This observation is in agreement with poloidal plasma rotation measurements which generally indicate higher velocities on the good confinement side of the iota edge. In contrast to this the LF feature shows no change in frequency. The amplitude of both features is considerably larger in the bad confinement case.

Finally it has to be emphasised that in contrast to the L-H* transition the current ramp induced transitions analysed above show no bifurcation. The time evolution of both the plasma parameters and the fluctuation characteristics are determined by the speed of the current ramp and not by the intrinsic dynamics of the transition.

3.Fast Transitions

We continue with an investigation of L-H*-mode transitions. The discharge singled out (47061) was heated by 400 kW ECRH power; ι_a was 0.5227 and the line density was ramped up from 0.5 to 4.1 $\times$ 10^{19} m^{-2}. The first L-H* transition took place at 480 ms into the discharge. A large 'dither' back into L-mode followed from 520 to 545 ms (a bunch of 9 ELMs) and the plasma finally entered a 500 ms H* phase.

Figure 2 shows the autopower spectrum of volume 1 vs. time and frequency up to $\pm$ 700 kHz; the L-H* transitions are clearly seen as sudden drops in the scattered power at 480 and 545 ms. The signal around 0 Hz is instrumental. The volume 2 signal is similar, although smaller in magnitude because of path differences on the optical tables.

It would seem that the density fluctuations increase during the long H*-mode, but that is not the case. The signal increase is due to the density ramping, as the scattered signal theoretically scales as density squared. If we apply this scaling to the data they stay at a constant level during the H*-mode, see Figure 3. We show the power scattered in the [100,200] kHz interval (denoted the 'bandpower') divided by the line density squared.

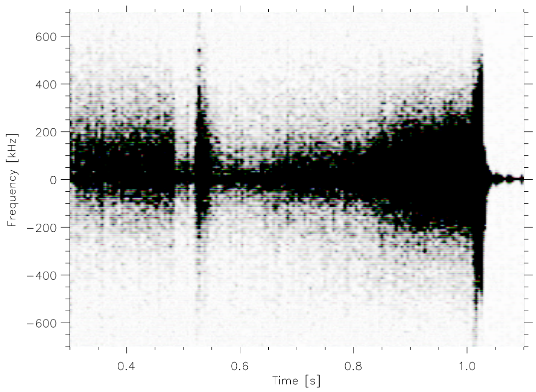

Figure 2: *Autopower spectrum, volume 1*

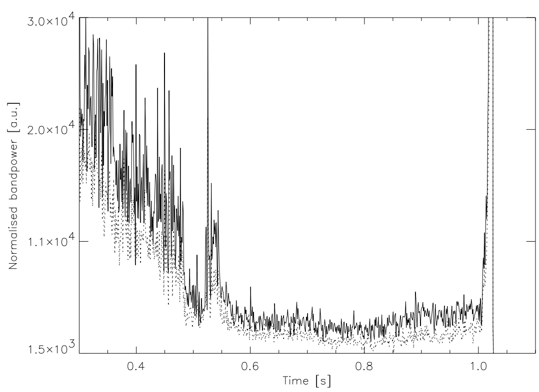

Figure 3: *Density normalised bandpower, volumes 1 (solid line) and 2 (dotted line)*

Figure 4 left shows overlayed autopower spectra just before and after the second transition, again for volume 1. The L-mode autopower is the solid line, the H*-mode is marked by triangles. Figure 4 right shows the H*-autopower divided by the L-autopower; we observe that the power drops a factor of 2 for all frequencies. The left-hand Figure shows that the autopower for positive frequencies dominate, both before and after the transition. We believe this to be due to an up-down asymmetry; fluctuations in the ion diamagnetic drift direction have a larger amplitude at the top of the plasma than at the bottom. The same feature can be observed in Figure 1 for the LF fluctuations.

A measure of the asymmetry with respect to frequency sign is shown in Figure 5. The solid line shows scattered autopower from volume 1 in the [100,200] kHz interval divided by the [-200,-100] kHz signal. A signal larger than 1 indicates that positive frequencies are dominating. The dotted line shows the same quantity calculated for volume 2. The trend is clear: In L-mode positive frequencies are dominating; this tendency almost disappears at the beginning of the H*-modes, only to resurface in the final H*-mode. The frequency asymmetry peaks between 100 and 200 kHz and disappears above 600 kHz.

We can now use the fact that our 2 measurement volumes are displaced to localise structures connecting these. The alignment of the volumes was toroidal; the 'horizontal'

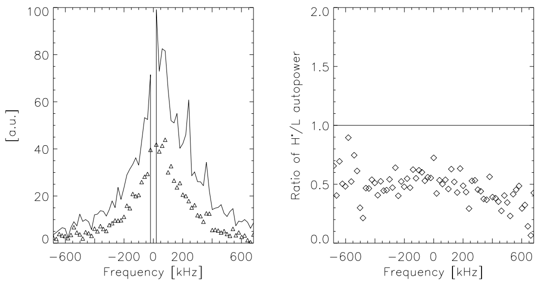

Figure 4: *Left: Autopower spectra just before and after the second L-H* transition for volume 1, right: Ratio of H*/L autopower*

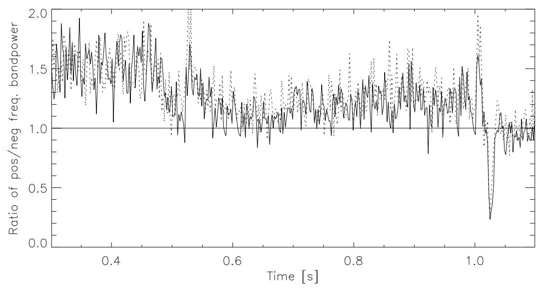

Figure 5: *Bandpower (± [100,200] kHz) ratio, volumes 1 (solid line) and 2 (dotted line)*

pitch angle was close to 0° at the top of the plasma. Therefore the crosspower amplitude between the two volumes will show the correlated signal at the extreme top of the plasma [1]. Figure 6 shows the normalised crosspower amplitude spectrum vs. time and frequency. We immediately observe that the volumes are exclusively correlated for positive frequencies; here this means fluctuations travelling in the ion diamagnetic drift direction. The transitions are visible as drops in the crosspower. However, the crosspower recovers in the H*-mode, centered around 150 kHz. This corresponds to a phase velocity of 300 m/s in poloidal direction. As was the case for the slow transition discharges, the LF feature peak does not change frequency during the discharge.

We believe the correlated fluctuations in the ion diamagnetic drift direction are outside (but close to) the LCFS and are associated with the small positive E_r observed there. The E_r inversion radius roughly coincides with the LCFS; E_r becomes large (negative) inside.

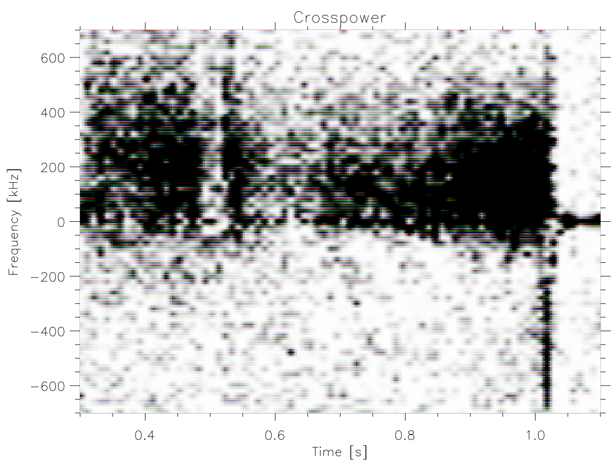

Figure 6: *Normalised crosspower amplitude spectrum*

References

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