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ABSTRACT

Confinement transitions with the characteristics of H-mode are observed in JET inner wall limited plasmas in experiments performed at a magnetic field of 0.8T and at a current of 0.9 MA, using up to 7MW of auxiliary heating power. These confinement transitions are short lived, with durations of up to 20ms, but the overall stored energy increases by up to 5% and edge density by up to 20%. The termination of the period of good confinement correlates with the observation of a burst of magnetic fluctuations, similar to those associated with Edge Localised Modes (ELMs).

These transitions in confinement also correlate with a significant decrease in the density fluctuations measured by the microwave reflectometer and a small decrease in the magnetic fluctuations measured using "Mirnov" probes, accompanied by a reduction of the D(alpha) emission. The comparison of the fluctuations in the transitions to limiter H-mode in JET with the divertor H-modes shows a similar behaviour, in particular, the reduction of the fluctuation levels at high frequencies (f>10 kHz) and an increase in the fluctuation levels at lower frequencies (f<10 kHz). The strong electrostatic nature of the plasma edge turbulence is confirmed, where a reduction of up to ~50% in the density fluctuation levels correlates with an increase of up to 50% in the confinement time during the transition to H-mode. However, the importance of instabilities with a dominant magnetic component (such as ELMs) is also highlighted, which cause significant increase in transport, including the loss of the good confinement phase in limiter H-modes.

INTRODUCTION

It is foreseen that the next step tokamak fusion experiment (ITER) will operate in improved confinement regimes such as the H-mode [1]. H-mode is characterised by a spontaneous confinement transition that leads to an increase in plasma density and temperature [2], when the plasma heating power exceeds a given threshold [3]. H-mode confinement is obtained mostly in divertor plasmas [4], i.e. in configurations with the magnetic separatrix inside the vacuum vessel, either two ("double null configuration") or one ("single null configuration") poloidal field nulls [5]. Transitions to H-mode have also been observed in limiter plasma configurations. These observations have been reported in several tokamaks, such as JFT-2M [6], JT60 [7], JIPP T-IIU [8], TFTR [9], TEXT-U [10], T10 [11], STOR-M Tokamak [12], TUMAN-3 and TUMAN-3M [13], ISTOK [14]. The objectives of these experiments were mainly two fold; improve and optimise the confinement plasma properties and study the plasma turbulence and transport in improved confinement regimes.

This operational regime has been first observed in JFT-2M [6] neutral beam heated limiter discharges, in 1987. This regime was characterized by confinement times close to those of Ohmic and divertor H-mode discharges. Later on, in JT60 [7], H-mode was achieved in limiter discharges with lower-hybrid current drive for the first time. The simultaneous application of radio frequency power at two different frequencies such as 1.74 and 2.23 GHz or 1.74 and 2.0 GHz appeared to be effective in the attainment of the H-mode. Valuable information regarding the nature of the transitions was then obtained in the JIPP T-IIU [8] tokamak, with a circular cross-section plasma bounded by a limiter. The H-mode transition in JIPP T-IIU was triggered by a rapid rampdown in plasma current during auxiliary heating, even in the case when the edge electron temperature was gradually decreasing prior to the transition. This result suggested that the transition is governed by the enhancement of the magnetic shear near the plasma edge, associated with the radial modification of the edge current-density profile. At the same time, circular-limiter H-modes were obtained on the TFTR tokamak during high-power neutral-beam heating. The transition was usually obtained from the supershot to the H-mode rather than the usual L to H transition [15]. In TFTR, the magnetic fluctuation levels in the frequency range 15-25kHz increased while the high frequency fluctuation (150-250kHz) decreased and the density fluctuation levels were reduced by a factor of 1 to 1.5 over a 5 cm region at the plasma edge across the transition. Later on, circular limiter H-mode configuration has been also obtained with Deuterium-Tritium mix, following a programmed rapid decrease of the plasma current [16], also emphasising the importance of the edge current density profile during the confinement transitions. Further information on the turbulence behaviour in limiter H-modes was obtained in TUMAN-3 and TUMAN-3M [13], where the transition from an ordinary Ohmic regime into improved confinement mode has been found in circular limiter configuration in a vessel with all-metallic walls and limiters. Suppression of the high frequency fluctuations in Ohmic H-mode was measured in TUMAN-3M by a low field side reflectometer adjusted to boundary density, high field side interferometer showed a moderate increase in the high frequency part of the spectrum, indicating strong poloidal asymmetry of the turbulence. In TEXT-U [10], H-mode transitions in limiter plasmas have been observed with central Electron Cyclotron Heating (ECH). These are dithering transitions which are induced by sawtooth crashes and display the typical signatures of H-modes (D(alpha) drop, spontaneous density increase, evidence of a transport barrier). In TEXT-U, density fluctuations levels measurements with the 2 MeV Heavy-Ion Beam Probe (HIBP) (in the core) and Langmuir probes (in the edge) shows no change within the q=1 radius after the transition and a small increase outside the q=1 radius.

More recently, improved confinement regimes were observed on T-10 [11] in limiter configurations with circular cross-section. A reduction in the density fluctuations (turbulence amplitude) was observed in T-10 in the frequency range f>100 kHz, measured using reflectometry in the region near the limiter at the plasma periphery (r/a>0.65). No turbulence reduction was observed in the core in T-10.

The knowledge gathered regarding the nature of the confinement transitions and associated turbulence lead to new techniques for improving edge plasma confinement. In ISTOK [14], negative limiter bias leads to better particle and energy confinement, and improved stability. H-mode like discharges were induced by tangential compact torus injection in the STOR-M tokamak [12] as well as the other techniques, such as by a short current pulse and electrode/limiter biasing.

H-mode confinement transitions have also recently been observed in JET inner wall limiter plasmas. However, limiter H-modes in JET are short lived (with the duration of up to 20ms), when compared with the H-mode regime in JET divertor plasmas and other devices (lasting up to several seconds). The confinement properties of these plasmas are analysed in this paper. The density and magnetic fluctuation measurements, obtained in both limiter and divertor configurations allows a detailed study of the turbulence behaviour in this regime, complementing the studies carried out in other tokamak experiments. The correlation between the turbulence levels and confinement are particularly clear, enabling the analysis of the nature of the mechanisms behind the transitions. In particular, the strong electrostatic nature of the plasma edge turbulence is confirmed, where a reduction in the density fluctuation levels correlates with an increase in the confinement time during the transition to H-mode. The importance of instabilities with a dominant magnetic component in the termination of the improved confinement phase is also highlighted.

The paper is organised as follows. In section I the characteristics of limiter H-mode observed in JET inner wall limited plasmas are described. In section II, the confinement improvement of the limiter H-mode is analysed. In section III, the spectrum of density fluctuations is studied by comparing confinement transitions in limiter and X-point configurations. Section IV is devoted to the termination of the confinement transitions. Discussion and summary of the conclusions is the subject to the last two sections of the paper.

1. LIMITER H-MODE IN JET

Confinement transitions with the characteristics of H-mode are observed in JET inner wall limited plasmas in experiments performed at a magnetic field of 0.8T and at a current of 0.9MA, using 5MW of auxiliary heating power. JET can operate with magnetic fields of up to 4.0T, but in these particular experiments the choice of magnetic field was such the NBI ions were injected at super-Alfvénic velocities in order to destabilise Alfvén Eigenmodes [17, 18]. The Alfvén Eigenmode studies carried out during these experiments will be the subject a subsequent publication and will not be covered here. The NBI heating is switched on for a period of 3 seconds as shown in Figure 1, which is sufficient to achieve quasi-steady-state, given that both the overall energy confinement time and the beam slowing down time in these discharges are less than 200ms. Figure 1 shows the time evolution of the NBI power and the central soft X-ray emission, where sawtooth crashes with a period of tsawtooth~100-150ms are clearly visible. During this period several abrupt transitions in confinement are observed which are characterised by a significant decrease, over 50%, in the D(alpha) emission as shown in Figure 2. Figure 2 shows the time evolution of the D(alpha) light emission and the edge density measured by the microwave interferometer diagnostic during the H-mode transitions. The start of high (H) and low (L) confinement phases are marked in the figure 2. These confinement transitions are short lived, with a duration of up to 20ms, but the line integrated edge density increases by up to 20% as can be seen in Figure 2. These transitions in confinement are observed in a narrow range of NBI input power of around of P_{NBI}=5MW. Experiments performed in the same configuration, plasma current (0.9MA) and magnetic field (0.8T), but with either less input power P_{NBI}=3MW or more input power P_{NBI}=7MW fail to produce similar confinement transitions.

These transitions in confinement also correlate with a significant decrease in the density fluctuations measured by the microwave reflectometer probing the plasma edge, discussed in detail in section III and a small decrease in the broad band magnetic fluctuations measured by “mirnov” sensors shown in Figure 4, accompanied by the reductions of the D(alpha) emission seen in Figure 2. Figure 3 shows the comparison between the time evolution of the D(alpha) light emission and the magnetic fluctuations measured by the “Mirnov” probes. Figure 4 shows the spectrogram of magnetic fluctuations measured by one of the fast Mirnov probes installed at the outer midplane. In the spectrum of magnetic fluctuations (figure 4) sawteeth, fishbones and Alfvén instabilities are observed. Each sawtooth crash causes a short lived t<1ms broad band of fluctuations seen at t=23.22s and t = 23.25s. Bursts of magnetic fluctuations caused by the fishbone instability are observed with a frequency around f~10kHz and a duration of around 10ms. Alfvén instabilities are observed in the frequency range of f = 80-100kHz, consistent with the magnetic field and density used in the experiments. Sawtooth, fishbone and Alfvén instabilities are instabilities of the plasma core while the transitions in confinement are triggered at the plasma periphery. Therefore, no correlation between the H-mode transitions and such core instabilities has been found as shown in detail in figure 3.

2. CONFINEMENT IMPROVEMENT IN THE LIMITER H-MODE

In this section the confinement properties of the limiter H-mode transitions observed at JET are discussed. In the Ohmic phase of the discharge, the L-mode confinement time is around τ_E~300ms, as measured by the diamagnetic loop stored energy and calculated Ohmic heating power. The confinement time in the L-mode phase with 5MW of NBI auxiliary power is significantly less, around τ_E~100-150ms, due to the degradation of confinement with increasing auxiliary heating power. The value of the stored energy measured by the diamagnetic loop under these conditions is 0.8 MJ and it is modulated by the sawtooth activity clearly observed in the central soft X-ray emission, shown in Figure 1. In order to correctly assess the effect of the improved confinement during the short lived confinement transitions, the effect of the sawteeth on the overall stored energy has to be taken into account. The plasma stored energy for shot 60908 can be accurately fitted using an Ohmic confinement time of τ_E(Ohmic) = 315ms and L-mode with 5MW of NBI auxiliary power phase τ_E(NBI) = 125ms. The NBI ions slowing down time is assumed to be τ_S = 200ms. The modulation of the stored energy caused by the sawtooth instability can be fitted assuming a confinement time modulation between τ_E(NBI) = 90ms and τ_E(NBI) = 140ms by the sawtooth instability as shown in figure 5. Figure 5 shows the evolution of the plasma stored energy and the simulated stored energy ($W \sim P_{IN} \times \tau_E$) assuming τ_E~125ms modulated by sawtooth with very good agreement. The good agreement shown (figure 5) during the rise of the store energy immediately after the NBI power is switch on confirms the assumed value for the NBI ions slowing down time (τ_S = 200ms). Figure 6 shows in more detail the evolution of the plasma stored energy and the simulated stored energy, illustrating the effect of the H-mode transitions. The increase in plasma stored energy during the H-mode transitions can be clearly seen superimposed on the trend caused by the sawtooth oscillations. This increase is around 30-40kJ (5%) in approximately 10-15ms. It should be noted that the sawtooth period is significantly longer ($\tau_{sawtooth}$~100-150 ms) than the timescale of the duration and repetition of the transitions to H-mode, which is around 10-20ms. 4 confinement transitions are shown in figure 6 during one single sawtooth period. This transient increase in the plasma stored energy can be explained by a 50% reduction of the power loss, which corresponds to a transient increase of up to 100% in the confinement time, i.e. to around τ_E~300ms. Although, the transitions are very short lived the effect in the local edge confinement is significant, comparable with the overall confinement improvement of the usual JET H-mode regimes observed in plasma X-point configurations.

3. SPECTRUM OF DENSITY FLUCTUATIONS

A) EDGE FLUCTUATION MEASUREMENTS

The plasma edge fluctuation measurements performed using fixed frequency O-mode reflectometry [19] are discussed in this section. Due to the nature of the measurements, only qualitative information on the fluctuation levels before and after the confinement transitions is obtained. The density measurements obtained using the Thompson scattering diagnostic shows a very flat density profile, with a maximum value of $n_e = (2\text{-}3)\times10^{19}\,m^{-3}$ as shown in figure 8. Therefore, the two fixed frequency (18, 29GHz) O-mode reflectometer channels, probing densities in the range of $n_e = (0.5\text{-}1.0)\times10^{19}\,m^{-3}$, give detailed information on the density fluctuation levels in the plasma edge corresponding to major radius around R_0~3.8m.

Figure 7 shows the time evolution of the overall spectrum of density fluctuations measured by the microwave reflectometer for two fixed frequency (18, 29GHz) O-mode reflectometer channels (Pulse No:60908), probing the plasma edge. It is clear that the transitions in confinement correlate with a significant overall decrease, of more than 50%, in the fluctuations measured by the microwave reflectometer probing the plasma edge as shown in figure 7. The start of high (H) and low (L) confinement phases are marked in figure 7. This reduction in fluctuations correlates perfectly with the reduction of the D(alpha) emission [20] seen in figure 2. A small reduction of the magnetic fluctuations can also be seen in the spectrum of magnetic fluctuations shown in figure 4. Figure 9 shows the spectrum of density fluctuations from the 18GHz reflectometer channels, before the H-mode transition (solid line) and after the transition (dashed line) limiter configuration. A reduction of the fluctuation levels at high frequencies (f>30kHz) accompanied by an increase in the fluctuation levels at lower frequencies (f<30kHz) is clearly visible in both channels. Figures 11 and 12 show the density fluctuation spectrogram for the 18GHz and 29GHz reflectometer channels, where the periodic transitions in confinement are clearly visible due to the reduction in the fluctuation levels.

A more detailed analysis of the time evolution of the fluctuation levels and the time evolution of the edge density profile shows that fluctuation levels are of similar value just before the beginning and just after the end of the good confinement phases as seen in figure 7. In contrast, the density evolution has its minimum just before the beginning of the good confinement phases and the maximum at just after the end of the good confinement phases as seen in figure 2. Furthermore, the changes in the levels of the fluctuations are large ~50% while the overall change in the edge density is relatively small ~15% and the edge density gradient is very steep as shown in figure 8. Since the edge density gradient is so steep, the change in the pedestal density across the transition will not affect the local density gradient at the reflectometer cutoff layer, so the signal is propotional to $\delta n_e / n_e$. Therefore, the changes in the fluctuation levels can not be attributed to changes in the density profile evolution and are clearly due to changes in the local turbulence levels. This is confirmed by the consistency of the data obtained from both reflectometer channels analysed, which look at slightly different edge plasma positions as show in figure 8.

The fluctuation levels in the transitions to limiter H-mode in JET are also compared with similar discharges; same current, magnetic field and auxiliary heating power, but with divertor X-point configuration. Figure 10 shows the spectrum of density fluctuations from the 18GHz reflectometer before the H-mode transition (solid line) and after the transition (dashed line) in X-point plasma configuration. It shows the reduction of the fluctuation levels at high frequencies ($f>10$ kHz) and an increase in the fluctuation levels at lower frequencies ($f<10$ kHz). The fluctuation measurements are performed just before (10ms) and just after the L-H transition (10ms). Thus, the density, temperature and rotation profiles have not evolved significantly during 20ms and can be assumed to be the same. Therefore, the behaviour of the fluctuations measured by the reflectometer can also be attributed to changes in the local turbulence levels.

These turbulence measurements are consistent with the results obtained in other Tokamaks such as TFTR, TEXT-U, T-10 and TUMAN-3M, where a decrease in the high frequency ($f>50$ KHz) density and magnetic fluctuations was generally observed close to the plasma edge during the limiter H-mode and no significant effect was observed in the core fluctuation levels. In particular, in TFTR where the magnetic fluctuation levels in the frequency range 15-25kHz increase during the H-mode transition, while the high frequency fluctuations (150-250kHz) decreases and the density fluctuation levels are reduced by a factor of 1 to 1.5 over a 5 cm region at the plasma edge across the transition.

The comparison between the fluctuations during the transitions to H-mode in the limiter and X-point configuration shows a qualitatively very similar behaviour. Therefore, it can be concluded that the processes that trigger the transitions in both configuration are essentially the same. The difference is that in the limiter configuration the period of good confinement is short lived (20ms) and it is terminated abruptly by instabilities with a strong magnetic component, while in the X-point configuration the period of good confinement can last for a much longer period.

B) CORE FLUCTUATION MEASUREMENTS

The fact that the core density is around $n_e = 2.5\times10^{19}m^{-3}$ and very flat, makes it difficult to determine the exact location of the cut off layer for the 45GHz reflectometer channel, probing the plasma core. If the core density is lower than $n_e < 2.54\times10^{19}m^{-3}$ there is not a cut off layer inside the plasma and this channel shines through the plasma. However, there is some variation in the core density and there is evidence that the core density is usually larger than ne>2.5 x1019m-3 from the detailed observation of the density evolution and the spectrum of fluctuations measured by the 45GHz reflectometer channel. This is confirmed by the observed correlation between the spectrum of fluctuations and the sawtooth instability. However, no correlation with the confinement transitions is observed, indicating that the changes in the fluctuation levels during the confinement transition are located at the plasma edge.

4. TERMINATION OF THE GOOD CONFINEMENT PERIOD

The termination of the good confinement period in the limiter configuration will be the subject of this section. Figure 13 shows the time evolution of the D(alpha) emission and magnetic fluctuations showing a burst of magnetic activity before the termination of the period of good confinement in the limiter configuration for Pulse No: 60908. Similar to figure 13, figure 14 shows the time evolution of the D(alpha) emission and magnetic fluctuations during an Edge Localised Mode (ELM) [21,22] event in X-point configuration Pulse No: 60900. It can be seen from this analysis that the termination of the period of good confinement correlates with the observation of a burst of magnetic fluctuations, similar to those associated with ELMs, shown in Figure 14. It should be noted that both experiments were performed with the same plasma current $I_p = 0.9$MA, magnetic field $B_T = 0.8$ T and auxiliary heating power $P_{NBI} = 5$MW. A 500 microseconds delay between the maximum in the magnetic activity and the sudden increase in the D(alpha) light is observed in both cases. The difference between the two scenarios is that the D(alpha) light emission from the plasma recovers to values similar to the ones preceding the ELM in the X-point configuration within ~1ms. In the limiter configuration, D(alpha) light emission from the plasma stays at a relatively high level for a longer period >10ms until the next transition to H-mode is triggered. From this information, it can be concluded that the termination of the good confinement periods (H-mode), i.e. transition back to L-mode in the limiter configuration is caused by instabilities with a strong magnetic signature, such as MagnetoHydroDynamic (MHD) instabilities. This contrasts with the process that triggers the transition to H-mode, which is dominated by a change in the density fluctuations, with a small effect in the level of magnetic fluctuations.

Analysis of the evolution of the impurity levels during the confinement transitions, as seen from the total radiation measured by the bolometers and visible spectroscopy is inconclusive due to the short lived nature of the period of good confinement. However, the soft X-ray emission shows no evidence that impurity levels play a role in the confinement transitions in the limiter H-modes at JET. Therefore, Carbon sputtering is not the reason for the short duration of the limiter H-modes.

DISCUSSION

Limiter H-modes in JET are short lived (<20ms) when compared with the Sawtooth period $\tau_{sawtooth}$~100-150ms and the energy confinement time τ_E~100-150ms. They occur in a very narrow parameter regime such as low magnetic field $B_T = 0.8$ T and auxiliary heating power $P_{NBI} = 5$MW.

Therefore, this regime does not look very attractive for further development in view of an operating regime for a tokamak reactor. Nevertheless, the local changes of around 50% in levels of turbulence are significant and consistent with the 50% reduction in the measured power loss. This is confirmed by the rise in the edge density and overall stored energy. Thus, the results of this analysis can be used to try to understand the processes behind the H-mode transition in more detail.

It is clear that the H-mode onset is triggered by a change in electrostatic turbulence [23,24] levels, as measured by the reflectometer diagnostic through the density fluctuations. The increase in confinement leads to an increase in the edge density. However, the limiter configuration does not allow the profiles to evolve significantly ($\Delta n_e/n_e<15\%$) before an edge localised MHD instability is triggered within 10-20ms of entering the H-mode. This instability could be triggered by the increased edge pressure and increased edge current due to the bootstrap effect and there is no evidence that impurity influxes play a role in the confinement transitions.

The good confinement phase is then lost and the edge density starts to decline back to values similar to the ones before the transition to H-mode occur. At that point a new transition to H-mode is triggered and the cycle is repeated.

In the X-point configuration, the profiles are allowed to evolve to a much higher degree leading to an over 100 % overall increase in density, before an edge localised MHD instability is triggered. This could be due to the stabilising effect of the plasma boundary shape and higher edge shear on the MHD instabilities [25,26] in the X-point configuration.

Therefore, in order to obtain a transition to H-mode a bifurcation [27,28] in the edge plasma transport driven by electrostatic turbulence must occur, leading to the so called edge transport barrier [29]. However, this may not be sufficient. In addition, significant magnetic shear might be required to delay the onset of edge MHD instabilities and allow the profiles to evolve significantly, leading to an overall better confinement and higher plasma stored energy.

In summary, this analysis complements previous studies by the detailed comparison of the turbulence spectrum during H-mode transitions in limiter and divertor configurations with similar plasma conditions and by expanding the configuration range where confinement transitions have been observed in JET. The study benefits from the choice of scenario, where the confinement is generally poor, enhancing the detailed turbulence measurements. This fact combined with the frequent nature of the transitions cycle allows the collection of a large set of data during a single discharge, which include both density and magnetic fluctuation measurements.

CONCLUSIONS

JET inner wall limiter configurations at low field and current show confinement transitions with the same characteristics of H-modes, i.e. increase in density and stored energy, accompanied with a decrease in D(alpha) and density fluctuations. The turbulence spectrum measured by the reflectometer diagnostic in limiter H-modes have similar spectral characteristics of those measured in X-point H-modes, for similar plasma parameters. However, limiter H-modes in JET are short lived (<20ms) and they are terminated by a burst of magnetic fluctuations with characteristics similar to those of ELMs. The onset of the good confinement period is caused by a reduction in micro-turbulent transport very close to the plasma edge. On the other hand the termination of the period of good confinement has a clear magnetic signature, most likely caused by an edge instability driven by the pressure or current gradients.

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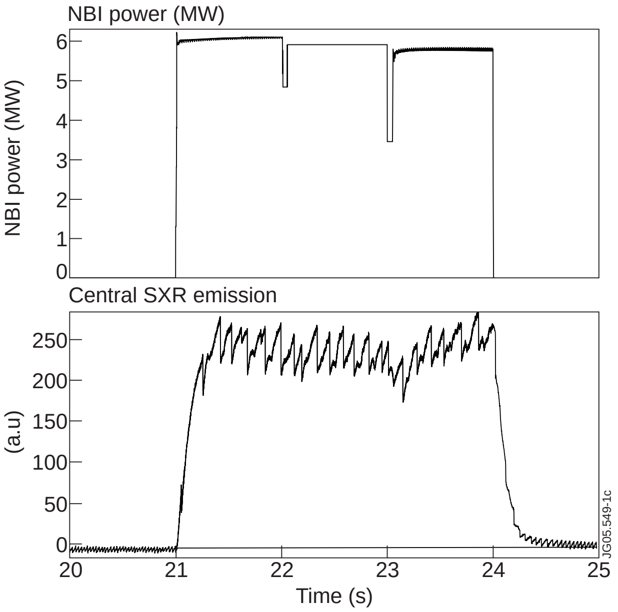

Figure 1: Time evolution of NBI power for the limiter Pulse No: 60908 and the central soft X-ray emission showing the sawteeth activity.

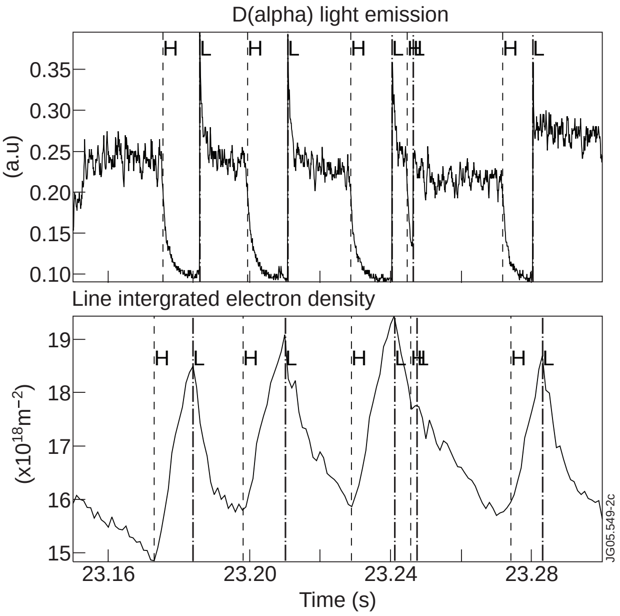

Figure 2: D(alpha) light emission and edge density (microwave interferometer) evolution during the H-mode transitions. The start of high (H) and low (L) confinement phases are marked in the figure.

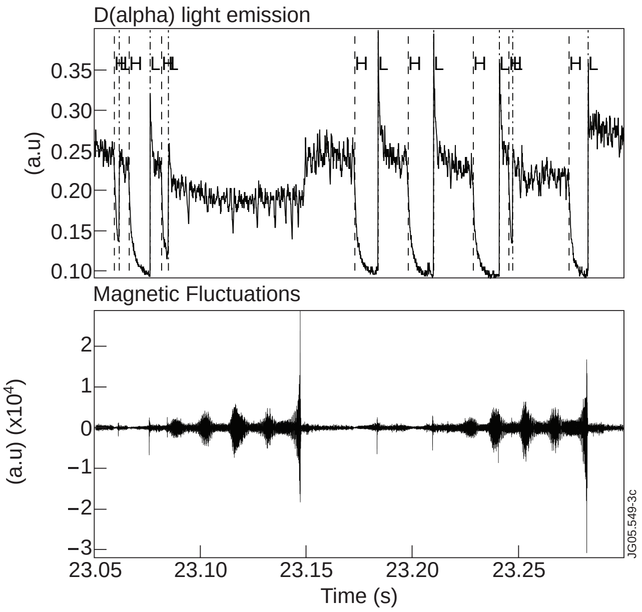

Figure 3: Comparison between the time evolution of the D(alpha) light emission and the magnetic fluctuations measured by the "Mirnov" probes.

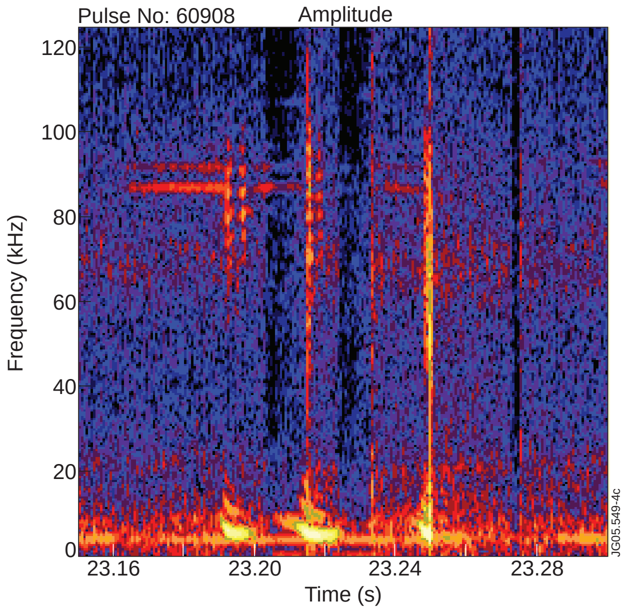

Figure 4: Spectrogram of magnetic fluctuations (Mirnov coils), shows no correlation between h-mode transitions and (sawtooth, fishbones or TAE) in Pulse No: 60908.

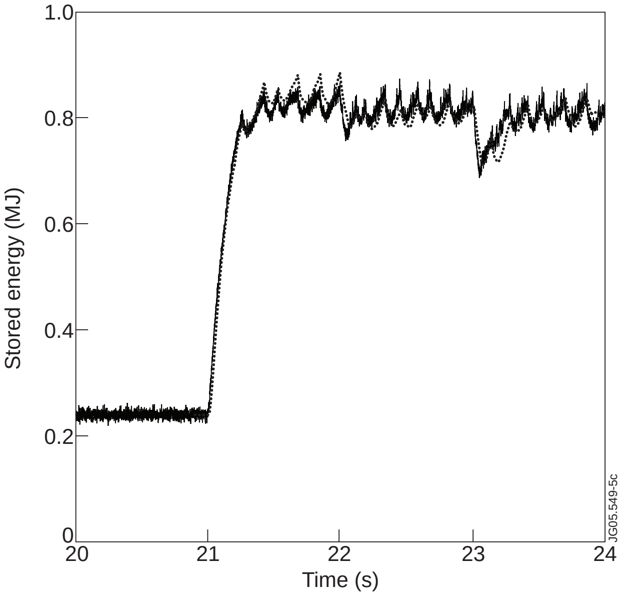

Figure 5: Evolution of the measured plasma stored energy (solid line) and the simulated stored energy (dashed line) assuming τ_E~125ms (modulated by sawtooth).

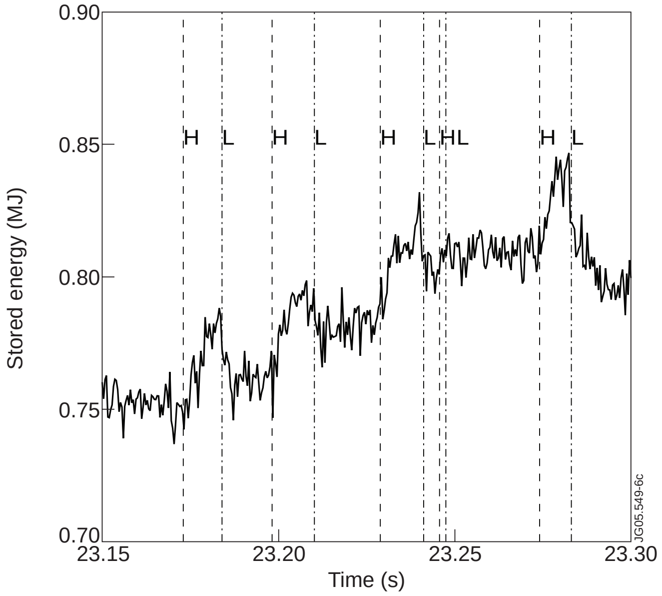

Figure 6: Evolution of the measured plasma stored energy and the simulated stored energy (dashed line) showing the effect of the H-mode transitions.

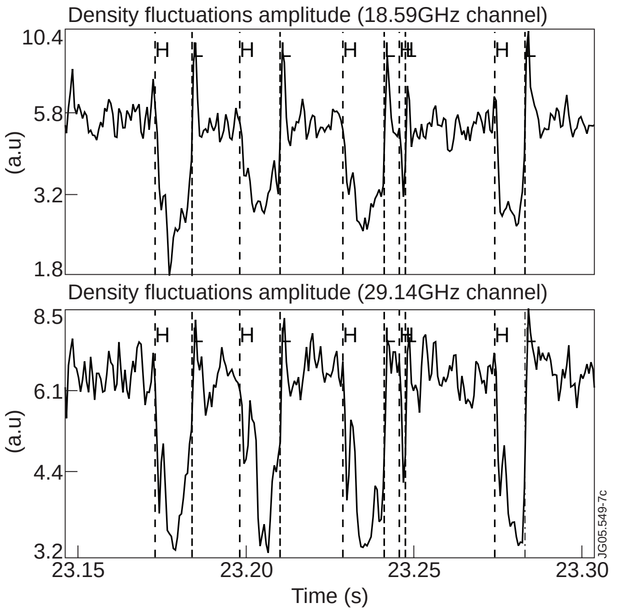

Figure 7: Time evolution of the overall spectrum of density fluctuations measured by the microwave reflectometer. The start of high (H) and low (L) confinement phases are marked in the figure.

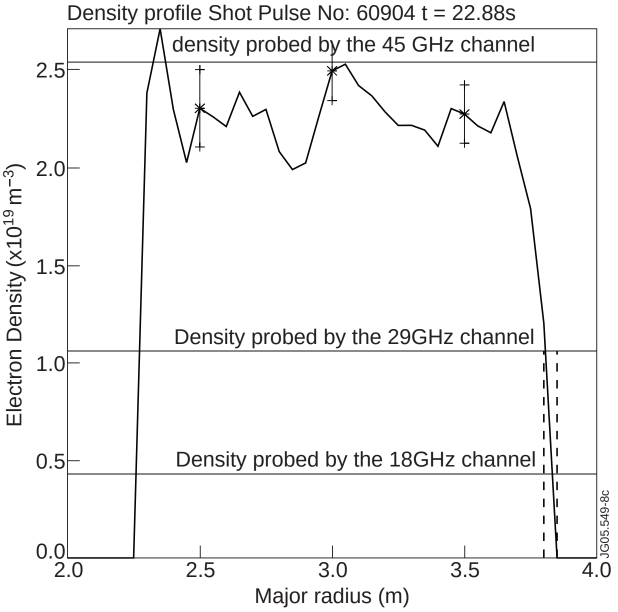

Figure 8. Radial profile of the plasma electron density as measured by the Thompson Scattering (LIDAR) diagnostic showing the two fixed frequency (18, 29GHz) O-mode reflectometer channels probing densities in the range of $n_e = (0.5\text{-}1.0)\times10^{19}m^{-3}$, corresponding to the plasma edge (major radius around R0~3.8m).

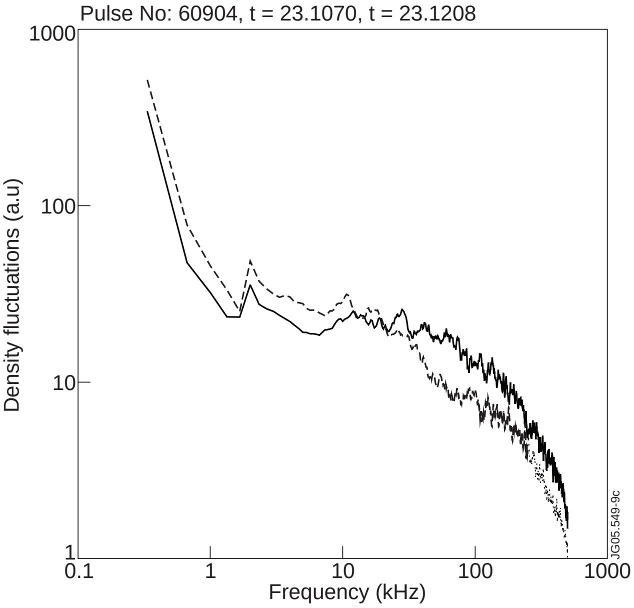

Figure 9: Spectrum of density fluctuations from 18GHz reflectometer just before(10ms) the H-mode transition (solid line) and just (10ms) after the transition (dashed line) in limiter configuration.

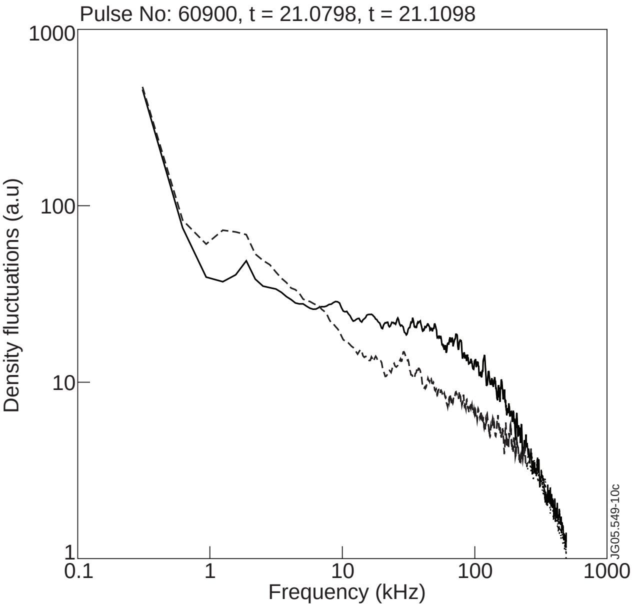

Figure 10: Spectrum of density fluctuations from 18GHz reflectometer before the H-mode transition (solid line) and after the transition (dashed line) in X-point configuration.

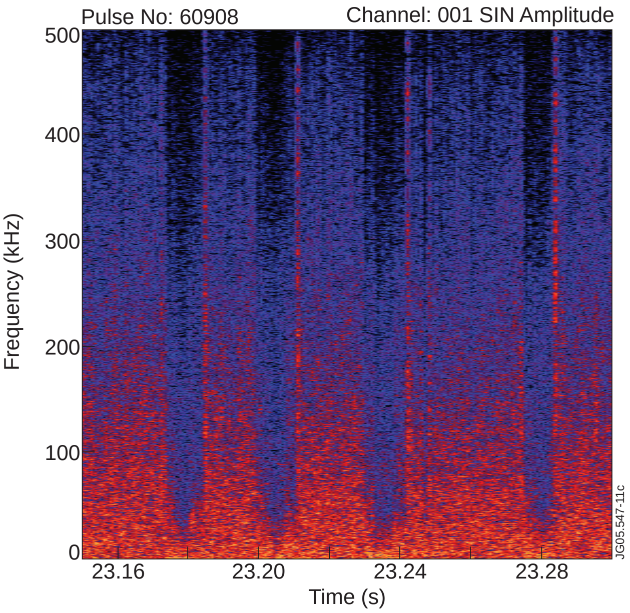

Figure 11: Density fluctuation spectrogram (18GHz) showing the periodic transitions in confinement with a reduction in the fluctuatios levels.

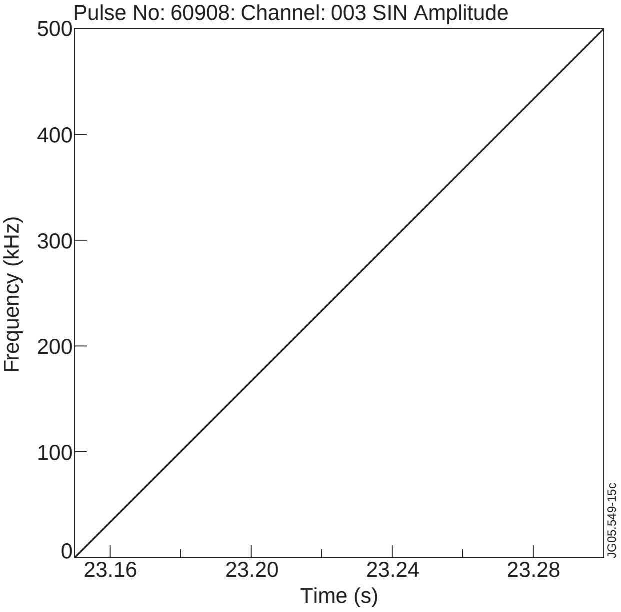

Figure 12: Density fluctuation spectrogram (29GHz) showing the periodic transitions in confinement with a reduction in the fluctuation levels.

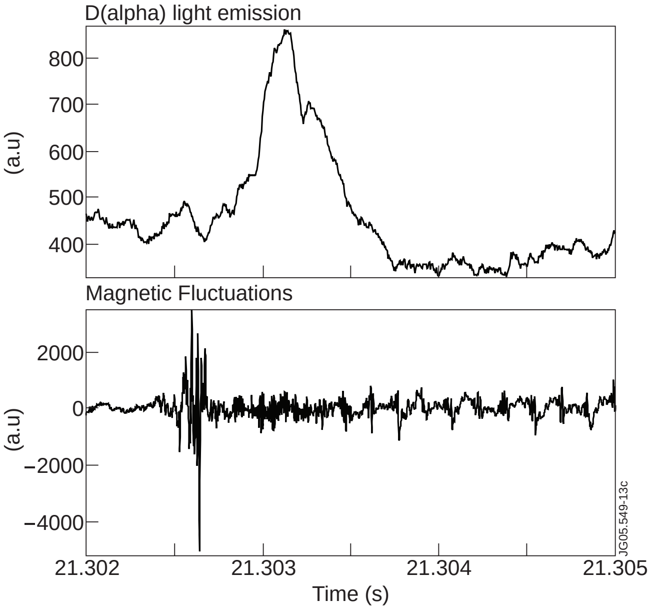

Figure 13: D(alpha) emission and magnetic fluctuations showing a burst of magnetic activity before the termination of the period of good confinement (limiter configuration Pulse No: 60908)

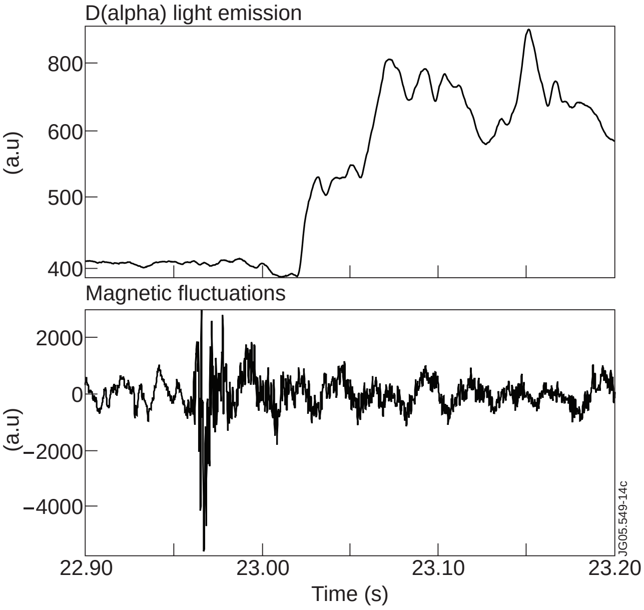

Figure 14. D(alpha) emission and magnetic fluctuations showing a burst of magnetic activity and an increase in the D(alpha) during a Edge Localised Mode (ELM) event (X-point configuration Pulse No: 60900)