

# ELM Activity in “Dithering” L-H Transitions on JET

A.V.Chankin<sup>1</sup>, S.A.Arshad, B.Alper, D.Bartlett, G.Conway,  
S.Davies, N.Deliyanakis, M.Endler, J.Lingertat, G.F.Matthews,  
R.D.Monk, E.Righi, G.Saibene and M.F.Stamp

JET Joint Undertaking, Abingdon, Oxfordshire, OX14 3EA,

<sup>1</sup>RSC “Kurchatov Institute”, Moscow, Russia.

To be submitted to Nuclear Fusion letters

August 1997

"This document is intended for publication in the open literature. It is made available on the understanding that it may not be further circulated and extracts may not be published prior to publication of the original, without the consent of the Publications Officer, JET Joint Undertaking, Abingdon, Oxon, OX14 3EA, UK".

"Enquiries about Copyright and reproduction should be addressed to the Publications Officer, JET Joint Undertaking, Abingdon, Oxon, OX14 3EA".

## ***Abstract***

*Toroidally symmetric, narrow band low frequency (<2 kHz) MHD activity at the plasma edge has been identified during initial phases of “dithering” L-H transitions in JET. It manifests itself as regular bursts on the divertor  $D_\alpha$  emission, and is also observed on magnetic and target Langmuir probes and on edge channels of the reflectometer. The oscillations appear simultaneously with the transition from L- to the “dithering” H-mode phase and disappear with the transition to the type III ELMy H-mode phase of the discharge. In spite of being regular and in many respects similar to “dithering cycles” previously observed in ASDEX Upgrade and attributed to repetitive series of L-H-L transitions, these oscillations show clear signatures of ELMs and can be gradually converted into irregular type III ELMs with the increase in edge electron temperature.*

The L-H transition is usually identified by a sharp drop in the  $D_\alpha$  emission, followed by an improvement in the plasma particle and energy confinement [1]. In most cases, however, immediately after the L-H transition the plasma enters a “dithering” H-mode phase, with large fluctuations in the  $D_\alpha$  signal and only slightly improved confinement. Before these fluctuations disappear, giving way to the high confinement phase of the H-mode, individual irregular bursts of the  $D_\alpha$  signal of variable size, caused by type III ELMs (for the definition of types of ELMs see [2]) can often be resolved.

The whole “dithering” phase is sometimes associated with the presence of type III ELMs. Type III ELM activity is known to be irregular, with distinct ELMs of variable amplitude occurring at random, with average frequency decreasing with the heating power. The systematic study of the initial phase of the dithering L-H transition in JET, however, reveals an almost periodic oscillations with narrow frequency band. Similar oscillations have previously been observed in ASDEX Upgrade [3] and were explained as “dithering cycles” of alternating L- and H-periods, by relating phases of  $D_\alpha$  rise with L-, and phases of  $D_\alpha$  fall-off - with the H-mode. The present data, however, indicate that, at least in the JET case, “dithering” should be related to MHD activity of small amplitude type III ELMs rather than to multiple L-H-L transitions.

There are examples of real dithering onset of the H-mode in JET, when a clear two-level structure of the  $D_\alpha$  emission is established, with alternating periods of the low level H-mode phase with ELMs and high level L-mode phase without ELMs. These  $D_\alpha$  fluctuations look different from the ones described in [3] and are a relatively rare phenomenon in JET. They are not discussed in the present paper, which deals with typical “dithering” (this term is apparently a misnomer if/when it is implied that the H-mode phase has not been established following the transition into this state) transitions.

Fig. 1 illustrates the typical behaviour of the outer divertor Balmer-alpha emission of all hydrogen isotopes ( $H_\alpha + D_\alpha + T_\alpha$ ) during the initial phase of an NBI heated discharge. For simplicity, the combined  $H_\alpha + D_\alpha + T_\alpha$  emission will be referred to in future as  $D_\alpha$  emission both in the text and in figures. The H-mode was obtained in a low triangularity, standard flux expansion discharge heated by NBI (D beams into T target plasma) in a roughly 25:75% D-T mixture with strike points on the horizontal target. This discharge was part of the ITER Physics experiment aimed at establishing the influence of plasma isotope composition on the H-mode power threshold. Discharges with tritium were found to have significantly lower H-mode thresholds compared to discharges in pure deuterium [4], but “dithering” is similar in plasmas with different isotope mixture. A dithering L-H transition occurs at 19.19 s, and the ELM-free H-mode phase starts at 20.5s, interrupted by the first type I ELM at 21.7 s. Also shown in Fig.1 is the edge electron temperature (at about 3.5 cm inside the separatrix) measured with ECE heterodyne radiometer.

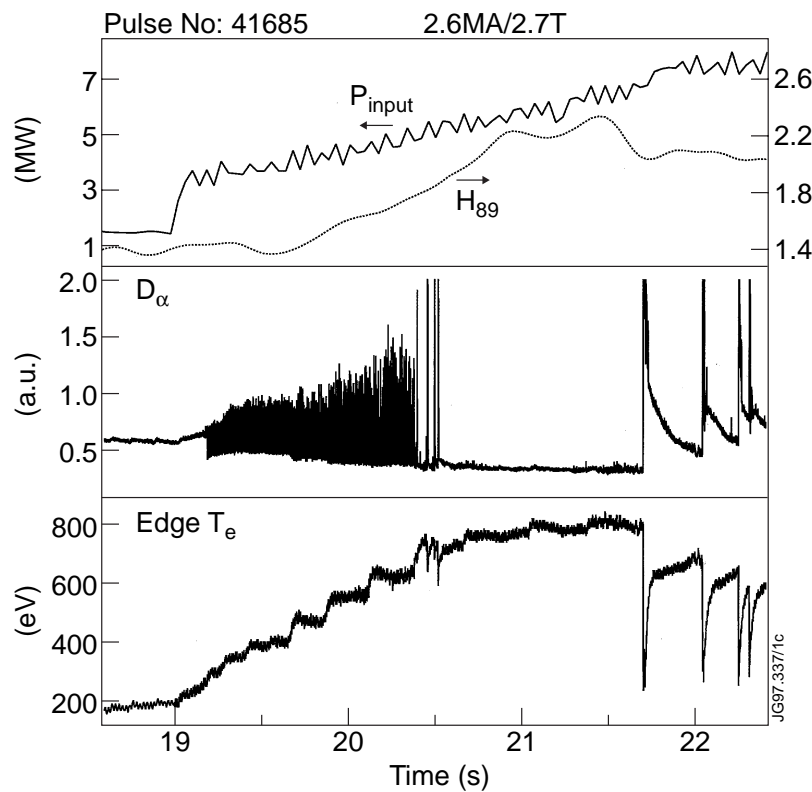


Figure 1. Typical behaviour of the outer divertor  $D_\alpha$  emission during the initial phase of an NBI heated discharge. Edge electron temperature is measured with ECE heterodyne radiometer.

An expanded view of the  $D_\alpha$  signal near the L-H transition is shown in Fig. 2a, together with the ion saturation current from a Langmuir probe. The probe is embedded in the outer part of the horizontal divertor target at about 3 cm outside the outer strike point position. The L-H transition is manifested by the appearance of regular oscillations on both the  $D_\alpha$  and Langmuir probe signals. Such clear regular oscillations can only be seen on outer divertor channels of the  $D_\alpha$

emission and, to a lesser extent, on the inner divertor channels (see Fig. 4), but not on the main chamber  $D_\alpha$  emission, which usually serves as a monitor for fast events in JET. The mode, however, can be identified on the power spectrum of its fluctuations.

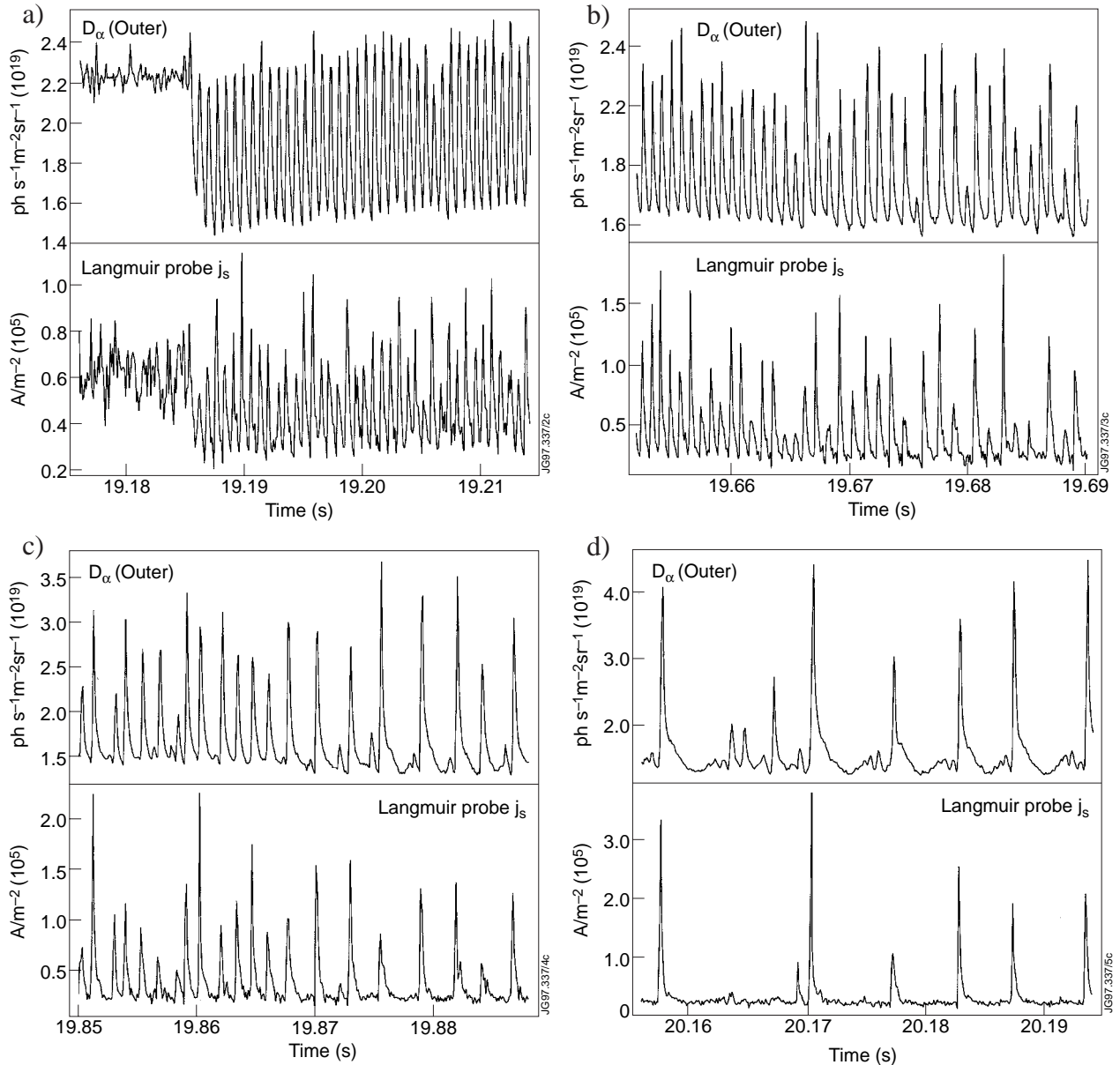


Figure 2. An expanded view of the  $D_\alpha$  signal and the ion saturation current from a Langmuir probe around the L-H transition (a), during a gradual replacement of the well-correlated oscillations by spikes of variable height characteristic of type III ELMs (b,c), and during the type III ELM phase (d).

The well-correlated oscillations characteristic of the dithering phase, are gradually replaced by spikes of variable height, as shown in Figs. 2b,c. Finally, distinct low frequency, high amplitude ELMs become the dominant feature of the fluctuations (Fig. 2d). The evolution of the power spectrum of the  $D_\alpha$  fluctuations is presented in Fig. 3. A mode with the frequency of about 1.25

kHz (around 19.5 s) and its second harmonic can be clearly identified. They are also seen on power spectra of Langmuir and magnetic probe fluctuations. The frequency of the mode decreases in two steps until, after 20.1s, it can hardly be distinguished against the background of the broad band turbulence with a maximum at the repetition rate of type III ELMs. Downward steps in the frequency coincide with the rise in the edge  $T_e$  induced by sawteeth [5] which are seen on the edge temperature signal in Fig. 1. The sequence of events repeats itself in the reverse order during the ramp down of the input power.

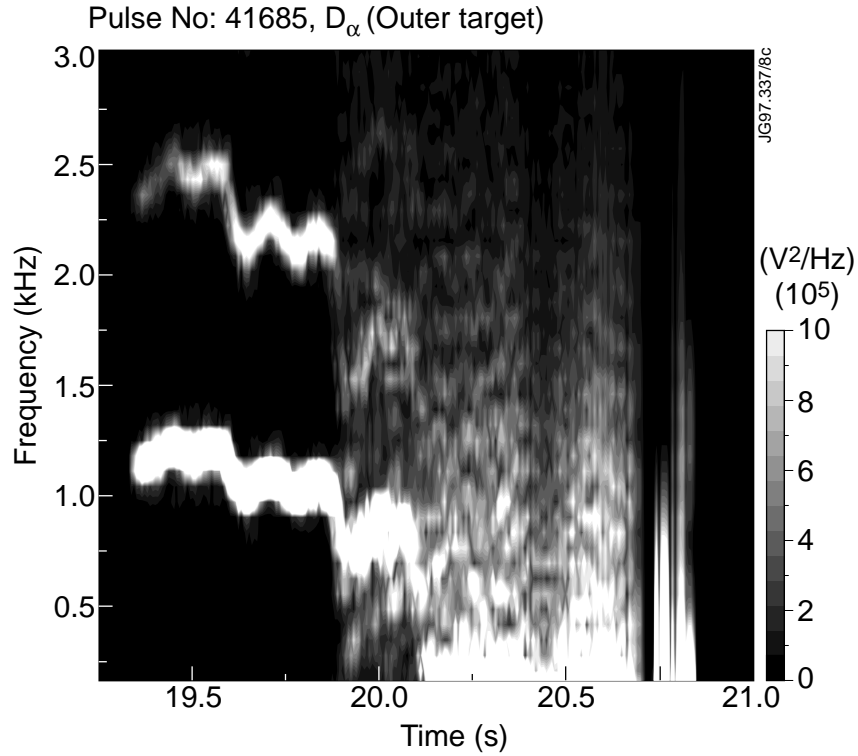


Figure 3. Power spectrum of outer divertor  $D_\alpha$  fluctuations. Downward steps in the frequency coincide with the rise in the edge  $T_e$  caused by sawtooth pulses (see Fig. 1).

The decrease in the frequency of oscillations with the rise in the edge temperature contrasts with a constant frequency of about 2 kHz observed in ASDEX Upgrade [3]. In this case, only the duration of the dithering phase decreased with increasing input power in excess of the H-mode threshold power.

The edge electron temperature has been found to be a critical parameter for the L-H transition in JET [6]. However, its role in the onset of the dithering H-mode and the transition to the type III ELMy H-mode phase is different. The former is a sharp phenomenon occurring after the edge  $T_e$  has reached some critical value. This transition is often preceded by a sawtooth crash, but the role of sawteeth is mainly in discretising the rise of the edge  $T_e$ , so that it appears as a number of steps (ratchets up) rather than steadily increasing. In this sense, an L-H transition, even if it is

only a transition to the dithering H-mode, should be regarded as a bifurcation in the plasma state. In contrast, the transition from regular oscillations characteristic of the initial phase of the dithering H-mode to the type III ELMy phase seems to be more gradual, with one type of fluctuations being converted into another as the temperature increases.

To analyse the structure of the fluctuations, the target Langmuir probes were connected to a fast acquisition system, recording with 250 kHz sampling rate during the dithering phase. Fast ECE, reflectometer, magnetics,  $D_\alpha$  and soft x-ray (SXR) data were also recorded by the same system. An example of fast fluctuations during a 4.2 ms period well inside the dithering phase of a 6.9 MW ICRH and 1.3 MW NBI combined heating discharge is presented in Fig. 4. The D-T isotope mixture was roughly 35:65% in this discharge. Note that, although the ICRH heating in JET is known to cause higher frequency, lower amplitude, less periodic type I ELMs than the NBI heating [7], dithering L-H transitions are similar for the two methods of heating.

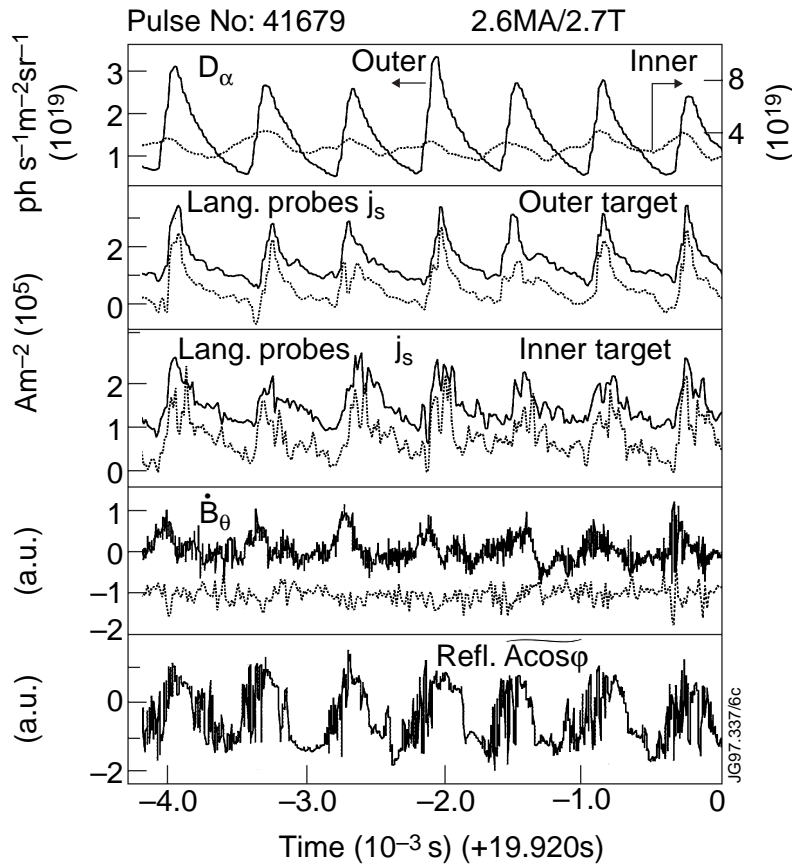


Figure 4. Fast oscillations during the dithering L-H transition: outer divertor  $D_\alpha$  (solid line) and inner divertor  $D_\alpha$  (dotted line) (top box); ion saturation currents from a toroidally separated pair of Langmuir probes on the outer (2<sup>nd</sup> box; dotted line signal has an offset of  $-1 \times 10^5 \text{ A/m}^2$ ) and inner target (3<sup>rd</sup> box; dotted line signal has an offset of  $-1 \times 10^5 \text{ A/m}^2$ ); signals from two Mirnov coils (4<sup>th</sup> box; dotted line signal has an offset of  $-1$ ) and fluctuations of signal in the coherent detector of a near separatrix channel of the O-mode reflectometer (bottom box).

As can be seen in Fig. 4, the outer divertor  $D_\alpha$  signal shows clear spikes with a slow fall-off, in contrast to the inner  $D_\alpha$  which is more sinusoidal. The overall asymmetry between the two  $D_\alpha$  signals, however, is in favour of the inner side (note a factor of 3.5 difference in vertical scales between the two signals). Fluctuations of ion saturation currents from the two pairs of the target Langmuir probes separated toroidally by 0.7 m ( $15^\circ$ ) are shown in the second (outer target pair) and third (inner target pair) boxes, with offsets of  $-1 \times 10^5$  A/m<sup>2</sup> for the probe signals shown by dotted lines, to distinguish them from the solid line curves. The position of the probes was about 2 cm inside the separatrix in the private region. These fluctuations exhibit a high degree of toroidal symmetry with the absence of any significant phase shift (larger than  $3\pi$ , according to correlation analysis). Fast changes in the currents from the whole set of target probes (in the SOL and in the private region on both targets) during the  $D_\alpha$  spikes and slow fall-offs, have also been analysed. They were found to be consistent with the assumption that the plasma as a whole moves downward in the  $D_\alpha$  rise phase, and then upward during the  $D_\alpha$  fall-offs. This behaviour is similar to the previously observed plasma movements during large type I ELMs in JET [8].

Signals from two Mirnov coils are shown in the fourth box of Fig.4 (an offset of -1 a.u. was applied to the signal shown by the dotted line). The larger signal is measured by a probe positioned at the top of the plasma, while the smaller is measured by the outer midplane probe. Poloidal variation of the probes' fluctuation levels indicates an up-down motion of the plasma edge, again similar to the previous observations on the type I ELMs behaviour [8]. Correlation analysis applied to the toroidally separated pairs of Langmuir probes and the set of Mirnov coils, confirmed the  $n=0$  (toroidally symmetric),  $m=1$  structure of the oscillations. These oscillations have also been observed on the outer midplane edge channel of the O-mode reflectometer (bottom box on Fig. 4). So far, they have not been detected on the SXR and ECE signals, indicating that it is mainly particle and not the heat losses from the plasma edge which are accompanied by the oscillations. However, at a later stage, drops in the edge  $T_e$  can be observed following each type III ELM.

In summary, the available experimental evidence suggests that “dithering” in JET is associated with ELM-like small amplitude MHD activity. The  $n=0$ ,  $m=1$  mode structure of magnetic oscillations is likely to be the result of the pressure loss from the plasma periphery due to ELMs. Initial regular oscillations can be gradually converted into irregular type III ELMs towards the end of the dithering phase, which seems to be the strongest argument for considering them small amplitude ELMs rather than short periods of L-mode imbedded into the H-mode.



## References

1. Wagner F., Becker G., Behringer K. et al., Phys. Rev. Lett. 49 (1982) 1408.
2. Hill D.N., J. Nucl. Mater., 241-243 (1977) 182.
3. Zohm H., Suttrop W., Büchl K. et al., Plasma Phys. Control. Fusion 37 (1995) 437.
4. Jacquinot J. and the JET Team, "ITER Physics Experiments in JET D/T Plasmas", presented at 24<sup>th</sup> EPS Conference on Control. Fusion and Plasma Phys., (Berchtesgaden, 1997); in JET-P(97)16.
5. Colton A.L. and Porte L., in Proceeding of the 20<sup>th</sup> EPS Conference on Contr. Fusion and Plasma Phys., Lisboa, 26-30 July 1993, V.17C, part 1, p. 11.
6. Righi E., Bartlett D., Conway G.D. et al., "The Role of Edge Parameters in the H-mode Transition on JET", presented at 24<sup>th</sup> EPS Conference on Control. Fusion and Plasma Phys., (Berchtesgaden, 1997); in JET-P(97)16.
7. Bhatnagar V.P., Bartlett D., Clement S et al., "A Comparison of ELMs Characteristics between ICRH and NBI Heated H-mode Discharges in JET", presented at 24<sup>th</sup> EPS Conference on Control. Fusion and Plasma Phys., (Berchtesgaden, 1997); in JET-P(97)16.
8. Ali-Arshad S., Edwards A., Lingertat. L., Puppin S., Wesson J., in Proceeding of the 23<sup>rd</sup> EPS Conference on Contr. Fusion and Plasma Phys., Kiev, 24-28 June 1996, V.20C, part 1, p. 179.