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B. Alper, R.O. Dendy, R.D. Gill, C.G. Gowers, T.C. Hender
and T.T.C. Jones
and contributors to the EFDA-JET workprogramme*

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EURATOM/UKAEA Fusion Association, Culham Science Centre, Abingdon, OX14 3DB, UK
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INTRODUCTION:

Type I or giant ELMs, along with sawteeth and disruptions, belong to a class of fast crash or collapse events which occur in JET plasmas. When studied using fast data acquisition, these events are seen to display many features in common. Most noteworthy is their abrupt onset, which can be as fast as 10μs, and their apparent unpredictability. These features are discussed below together with an experiment on ELM control using pellets.

ELM OCCURRENCE CAN BE BOTH PREDICTABLE AND UNPREDICTABLE

A striking feature of ELMs is the variation of their probabilistic character. Just above H-mode threshold, Type III ELMs appear at a very regular frequency: see Figure 1 (early times), where the ELMing rate can be represented by an almost constant frequency in a Fourier spectrum. Higher harmonics are also weakly present due to the non-sinusoidal shape of the signal. This frequency can change in a potentially predictable way as the height of the edge pressure pedestal increases, for example on the arrival of the heat pulse from a sawtooth crash indicated by the increase in edge temperature in Fig.1. As the input power is increased, the discharge moves away from the H-mode threshold. Examples exist of the height of the ELMs (as seen in H-alpha emission) becoming more variable and unpredictable in time, even though the underlying frequency remains unchanged [Fig.2]. Compound ELMs can also arise where Type III ELMs follow Type I ELMs in an apparently unpredictable (random or chaotic) fashion. Plasma shaping, gas puffing and divertor geometry affect the frequency of ELMs with varying degrees of correlation and sometimes hysteresis occurs. Major changes in ELM behaviour between the various JET divertor geometries have also occurred in optimised shear discharges, but have not been fully explained.

SANDPILE CRITICAL GRADIENT MODELS

Features such as the correlation of ELM frequency with plasma confinement can be replicated by sandpile models governed by a critical gradient. The transition from compound ELMs to Type I ELMs, for example, can be produced by the sandpile modes simply by changing the single control parameter L_f which is a proxy for the dominant length scale of non-diffusive transport [1]. This implies that a simple paradigm can capture important aspects of ELM physics.

THE ROLE OF MHD MODES IN ELM EVENTS

Considerable attention has been given to the role of MHD modes, especially precursors or triggers, in the understanding of these phenomena. Here we define a precursor mode as a slowly growing mode which precedes the event whilst a trigger mode has a large growth rate just prior to the event. The "outer mode", an ideal external kink mode seen in hot-ion H-modes [2], can show trigger-like features in relation to giant ELMs, often growing rapidly just before ELM onset (Fig.3). However, it could also appear transiently without provoking an ELM. Successful experiments have been performed to delay the onset of this mode by ramping down the edge plasma current; paradoxically this advanced the onset of Giant ELMs! [3]. Whilst this mode has toroidal mode number n = 1, other cases of MHD modes preceding Type I ELMs are found with n in the range 3 to 12 [4]. Postcursor modes are sometimes seen - for example the "Palm Tree" mode [5] has a (3,1) structure and lasts for a few ms following the ELM. However, it is argued here that whilst a study of associated MHD modes may lead to an understanding of the relevant stability issues (edge q values, ballooning limits, etc.), the exact trigger mechanism remains to be identified. In many cases the modes associated with the ELM appear to be purely incidental. Most ELMs have MHD activity preceding the event. In some cases MHD modes are present near the edge of an H-mode plasma, and are subsequently terminated by an ELM. As the pressure gradient is gradually restored following the ELM the mode reappears - initially growing then saturating - only to be terminated by the next ELM. In these cases it is doubtful that the mode has any direct link to the structure or timing of the ELM. Broadband activity can also appear prior to a giant ELM probably driven by the high edge pedestal pressure. There are examples, particularly in Optimised or Reversed Shear plasmas with ITBs, of giant ELMs occurring with no apparent precursor activity until as little as 10 ms before the event [Fig 4]. In the figure even a (windowless) X-UV diagnostic edge channel sees no change in radiation just prior to the ELM onset. The ECE measurement is dominated by non-thermal emission during the ELM. In contrast to the above, the presence of large MHD activity at the plasma edge can change local plasma conditions to such an extent as to suppress ELMs altogether. Such examples include the "Picket Fence" mode on JET, which is believed, keeps the Optimised Shear plasma in L-mode even when the plasma is well above the H-mode threshold [6] and the "Quiescent Double Barrier" mode on DIII-D maintained by the edge harmonic oscillation [7]

RELATION TO OTHER COLLAPSE EVENTS

Type I ELMs can be regarded as part of a class of fast crash or collapse events [8] which include disruptions, sawteeth and Internal Reconnection Events (IRE). The following features are common to most (or all) of these: -

- Timescales: Onset ~10μs, collapse 50μs-200μs
- Rapid radial transport of energy and particles: $v_r \sim 10^3 - 10^4\ \mu.s^{-1}$ as seen with ELMs[9], Sawteeth[10] and Disruptions[11]
- Generation of large electric fields as evidenced by edge SXR emission and by spikes in the ECE emission in Giant ELMs [9], hard X-ray emission following the sawtooth crash [12], and the generation of energetic ion tails in IREs on MAST [13].
- Absence, in general, of clear evidence for trigger modes.

EXTERNAL ELM CONTROL

Being able to control the frequency and size of ELMs is important for ITER operation. Management by means of global parameters (shaping, gas puffing, etc.) is under development. In addition techniques must be developed, akin to disruption mitigation, to prevent a long ELM-free period occurring following, for example, the loss of an Internal Transport Barrier. An experiment was carried out on JET, which aimed at achieving this objective by pre-empting ELM occurrence. Small (2mm) slow (140 m / s) deuterium pellets were injected into the low-field side of a Hot-Ion H-mode plasma during the initial ELM-free period. Pellets were fired from one second into the ELM-free phase initially at 10Hz then at 5Hz. A comparison of the pellet shot 49762 (blue) with reference Pulse No: 49755 (red- no pellets) is shown in Fig.5. Each pellet triggered an ELM of smaller size, with < 20% the loss in energy, than the "spontaneous" Giant ELM. By lowering the "violence" of the initial ELM, the transition to a state of lower confinement was mitigated, as indicated by the higher stored energy two seconds later. Increased edge density is perhaps an unfortunate side effect of this technique. Small C or Be pellets could be an improved alternative.

SUMMARY

- ELMs belong to a class of fast collapse events, which include sawteeth and disruptions with many features in common. These include: rapid onset, fast radial transport of particles and energy and production of non-thermal distributions.
- Although their general properties are predictable their precise timing, is often apparently

unpredictable.

- The role that MHD modes play in determining the ELM structure and timing has yet to be clearly identified.
- The frequency and size of Type I ELMs can be controlled by external means and their effect on plasma confinement mitigated to some extent in the Hot-Ion H-mode.

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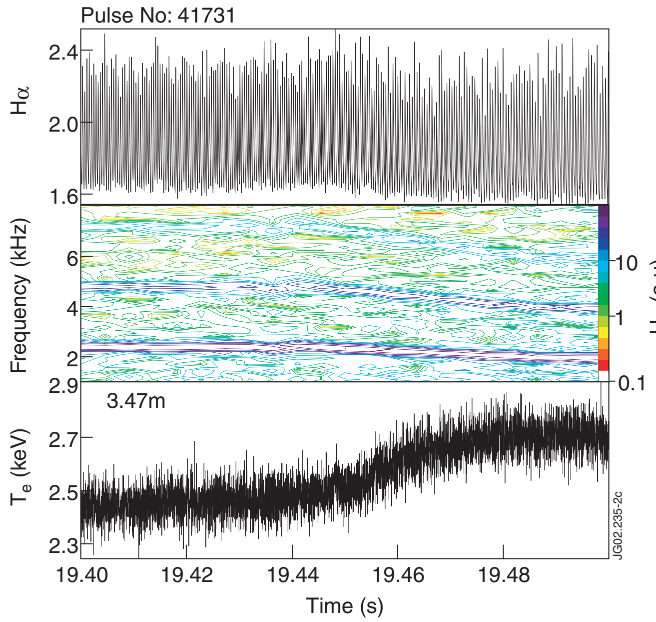

Fig. 1. Showing fall in ELM frequency with arrival of heat pulse from sawtooth

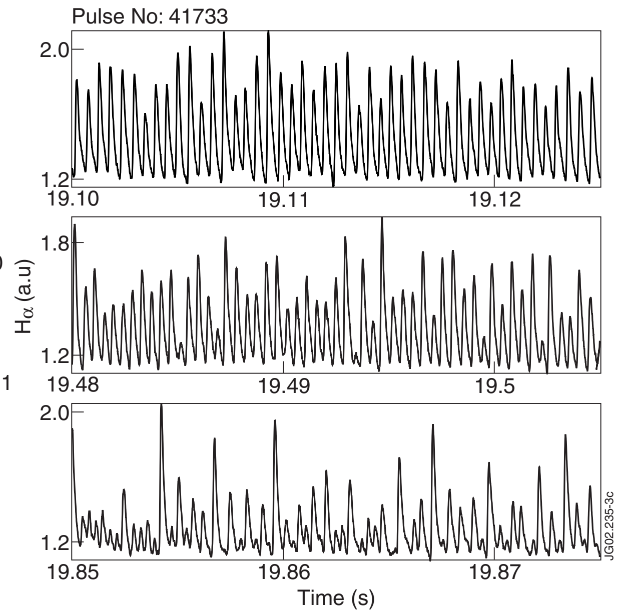

Fig. 2. ELM amplitude becomes more random or chaotic with increasing input power

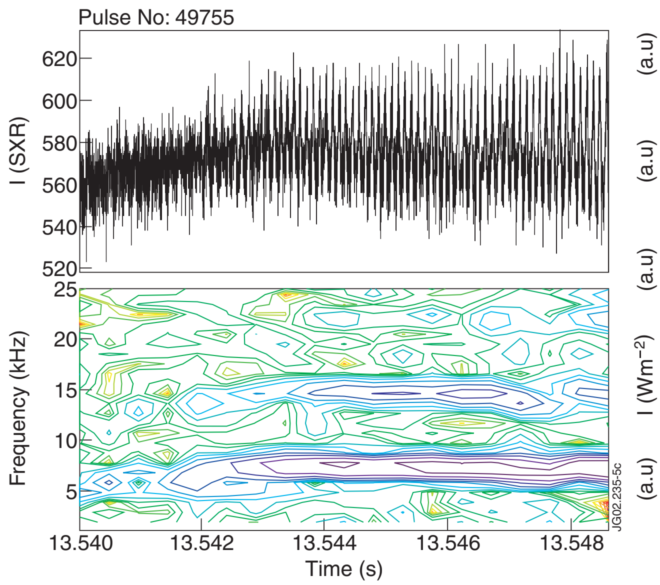

Fig. 3. Outermode as an ELM trigger. ELM onset occurs within 10µs of last data

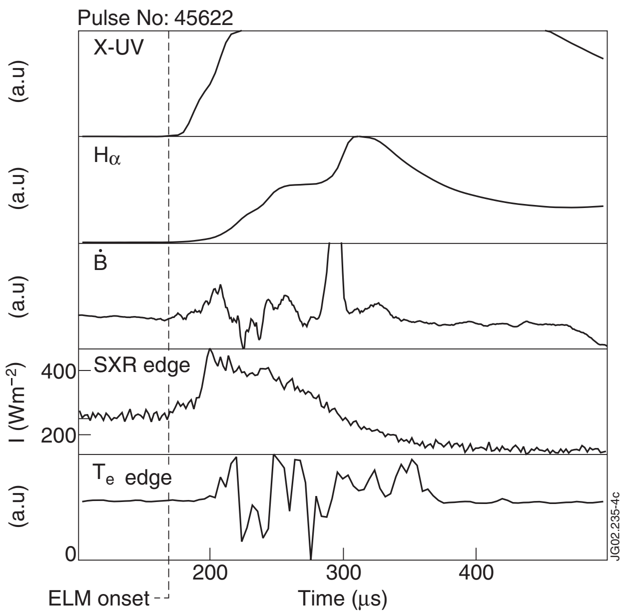

Fig. 4. Giant ELM with no detectable precursor

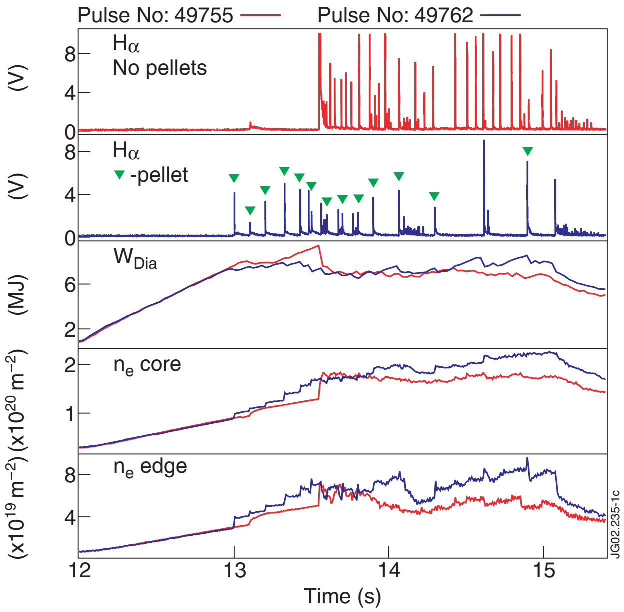

Fig. 5. Control of ELM frequency with pellets in Hot-Ion H-mode