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MHD Phenomena and their Influence on Confinement in JET Hot-ion H-mode D-D and D-T Discharges

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INTRODUCTION

Hot -Ion H-modes (H-I) are the discharges which produce the highest fusion performance on JET. The main MHD features observed during such discharges are small ELMs at the L-to-H transition, a sawtooth usually within the first 300ms, low 'n' core modes rotating with the bulk plasma ions, outer modes (OM) ~0.9-1.3 s. into the H-I discharge and a Giant ELM at the end of the high performance phase after ~1.3-1.8 s. The performance of a H-I discharge for the same current and power is primarily determined by the timing and amplitude of the **outer modes** and **giant ELM**. These two modes are regarded as edge phenomena, yet a global loss in performance occurs. Little change in MHD was observed when going from D-D to D-T plasmas.

OUTER MODES

The OM in H-I discharges which has been identified as an external kink mode[1], is clearly seen at frequencies ~8kHz (n=1), or multiples thereof, and is found to be localised close to the plasma edge (near the q=3 surface) by the SXR, ECE and reflectometer diagnostics. The mode is associated with a rise in the D_α and outer SXR emission and a flattening or fall in fusion yield. Although from SXR analysis the mode is observed to be localised in a narrow edge region (only ~1 cm wide on the out-board side) a global fall in temperature and fusion performance results within a few ms. Figure 1 shows time traces during an OM. Although the mode occurs between times (a)&(c), the fall in T_e and flattening in neutron rate (R_{nt}) is restricted to the period (b)-(c). Figure 2 shows frequency vs time for a 1MHz sampled pickup coil. An increase in broad-band magnetic activity up to ~200kHz is present throughout the time (a-c) of the OM and is associated with high (m,n) activity. This activity is always present throughout an OM. A strong broad-band enhancement above 300kHz is clearly seen but only over the time (b)-(c). This period corresponds to the major loss in confinement clearly seen in Figure 1 by the fall in T_e and flattening of R_{nt}.

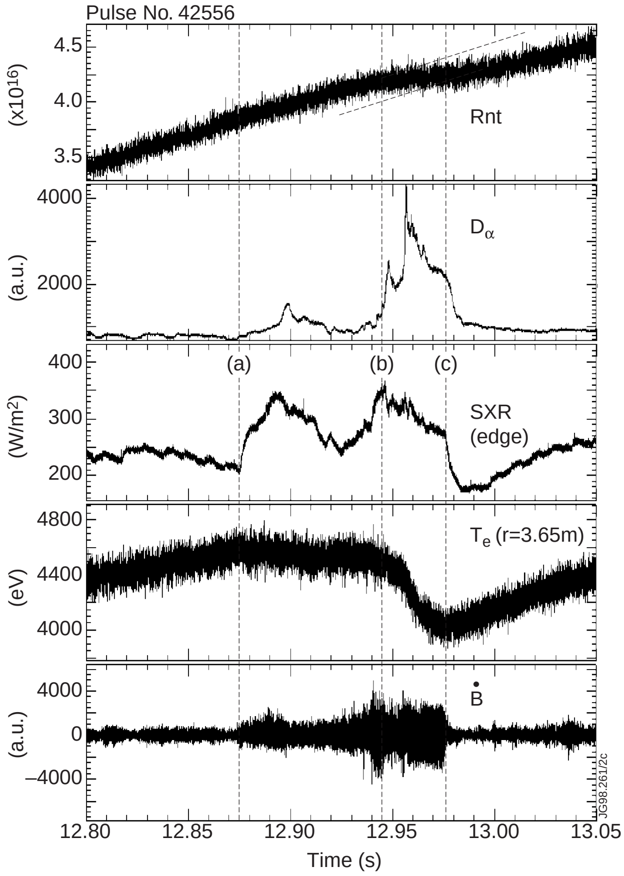

Fig.1. The OM is present throughout the period (a)-(c) but the fall in T_e and flattening of Rnt only occurs over (b)-(c).

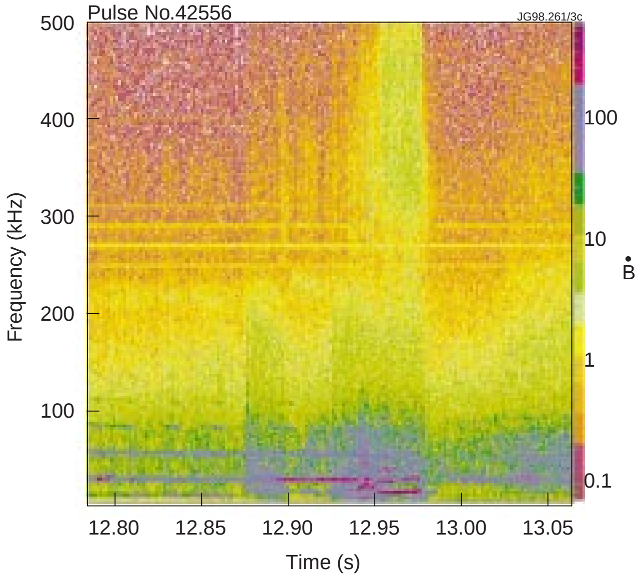

Fig.2. Enhanced activity above 300kHz is clearly present only during the period (b)-(c) of Fig.1.

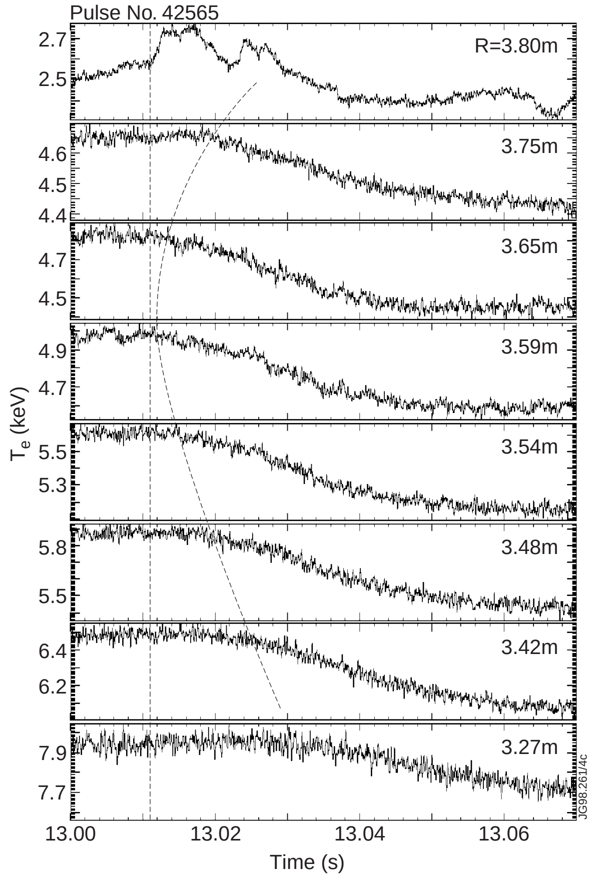

Fig.3. The fall in T_e commences with the onset of high frequency activity (vertical line) at R~3.6m and propagates both to the core and edge.

Figure 3 shows T_e time traces during an OM for a H-I discharge. A local rise in T_e (as well as SXR emission) at the location of the OM near the plasma edge is seen. A rapid fall in T_e occurs with the onset of the high frequency activity emanating from further into the plasma at R~3.6m, (q~1.5) rapidly expanding both outwards and into the core. A similar fall in T_i but determined with poorer time resolution is usually observed. The OM, when seen as a precursor to the giant ELM, displays a rapid growth in amplitude over the 2-10ms preceding the ELM together with short bursts at discrete frequencies of high n components (15<n<25).

THE GIANT ELM

The giant ELM generally leads to an abrupt and permanent fall in fusion yield over and above any reduction in Neutral Beam (NBI) heating - see Figure 4. The rate of fall-off in R_{nt} is much greater than the removal of 8MW of NBI power before the ELM and virtually independent of the subsequent total removal of NBI power. Z_{eff} rises from ~1.5 before the ELM to over 3.0 afterwards. A strong increase in SXR emission follows the ELM - it can double within the first 20ms. The rate of fall-off in R_{nt} is strongly correlated with the absolute increase in SXR emission - see Figure 5 -suggesting impurity influx leading to **dilution** may be the dominant cause of the fall in fusion yield. Using tomography, it is apparent that this increase in SXR emission is not

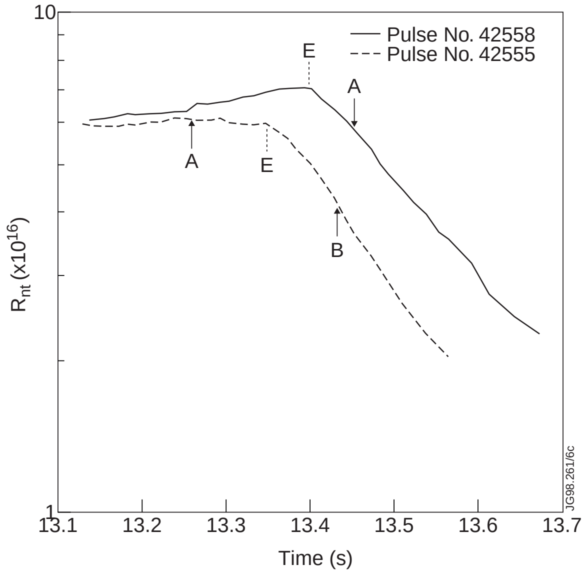

Fig.4. The change in slope of R_{nt} is dominated by the timing of the ELM (E) compared to the loss of 8MW (A), or even total loss (B), of NBI power

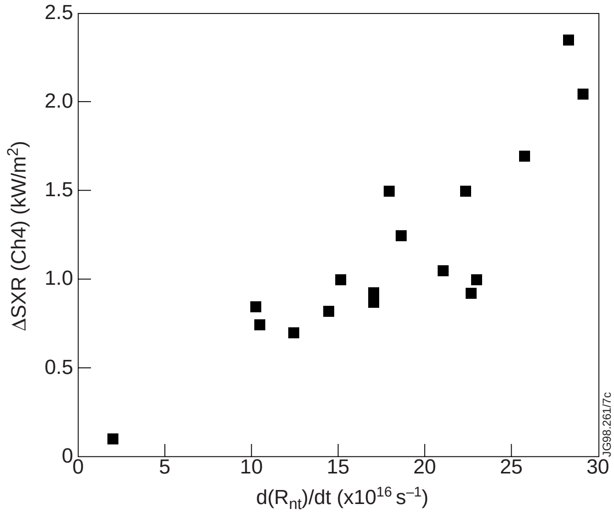

Fig.5. Absolute change in SXR emission 10ms following the ELM compared to rate of fall of R_{nt}

global but is localised to a crescent shaped region on the outboard (low-field) side of the plasma[2]. This impurity localisation is believed to be due to the effects of a combination of the centrifugal force from the rapid plasma rotation and neo-classical diffusion associated with the hollow ion density profile[3]. This asymmetric impurity emission is greatly enhanced in intensity following the ELM, though the asymmetry reduces slightly as the rotation rate falls and light ions are sputtered into the plasma.

The equatorial ion density asymmetry (out/in) is given by

$$\frac{\rho_o}{\rho_i} = exp\left\{ f\,\frac{\omega^2 (R_o^2 - R_i^2)}{2{v_{th}}^2} \right\} \text{ with } f = \left(1 - \frac{T_e}{T_i + T_e}\frac{m_i}{m_Z} Z \right)$$

For H-I discharges, the in/out asymmetry (R_o=3.6m / R_i=2.3m) is ~1.45 for carbon and ~1.3 for beryllium; (typical parameters: T_i~6 keV, T_e~5 keV, ω~70krad./s). Impurity levels following a Giant ELM are ~4-8% for both carbon and beryllium at these radii. This leads, assuming n_e remains constant on a flux surface, to a D/T dilution asymmetry of ~10-20%. The thermonuclear yield asymmetry would be proportional to the square of this dilution, giving -: **R_{nt}(outer)/R_{nt}(inner) = 1.2 - 1.4**.

This is confirmed in the neutron profiles from a D-T discharge following a Giant ELM. The fall in neutron emission soon after the ELM, Figure 6, is almost entirely on the low field side and the asymmetry change, 25ms after the ELM at 3.6m (points (a),(b) in Figure 7.), is ~30%, consistent with the above estimates. A further enhancement in the in-out asymmetry occurs with NBI turn-off at time t_3, indicating a possible contribution from fast trapped ions.

In addition to dilution, global energy confinement rapidly falls following the giant ELM[4]. Stored energy drops by ~10% within few 100μs of the ELM and then continues to fall with a time constant of ~1.2 s^{-1} compared to a time constant of ~3.5 s^{-1} for R_{nt}. Broad-band magnetic activity, which rises prior to the ELM, is found to fall to low levels subsequently. The plasma remains in H-mode following the ELM with the pedestal pressure restored to ~80-90% of its original height within ~30ms.

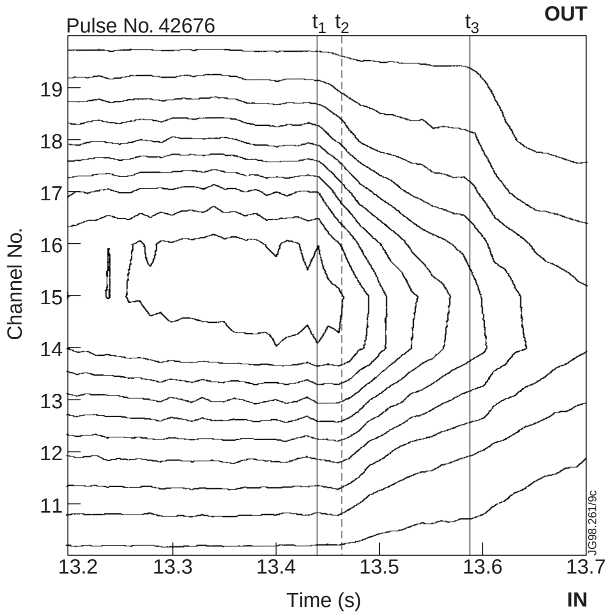

Fig.6. The erosion in vertical neutron emission profile is almost entirely on the outboard side over 25ms following a giant ELM (t_1 to t_2). The effect of NBI turnoff can be seen at t_3 .

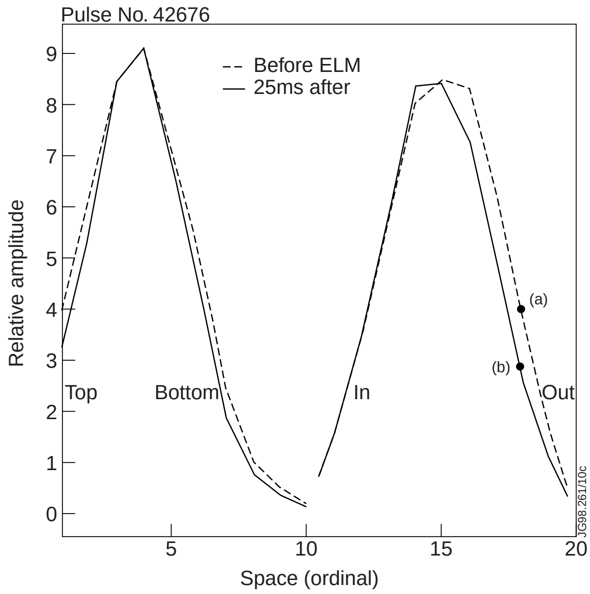

Fig.7. The relative fall in R_{nt} at R~3.6m ((a)-(b)) is~30% consistent with in/out dilution asymmetry estimates.

SUMMARY

Outer modes and **Giant ELMs** are two MHD modes which clearly correlate with a fall in fusion performance in H-I discharges. Both modes are 'edge-localised', yet a global loss in performance results. The OM is often correlated with high frequency broadband magnetic activity (300-500 kHz). The fall in confinement (especially T_e) begins ~15cm in from the plasma edge and propagates rapidly both out to the edge and inwards to the core. It is correlated in time with the high frequency magnetic activity. The rapid fall in fusion yield following a giant ELM dominates over any loss in NBI heating and is probably due to dilution. The in-out asymmetry of the neutron emission profile following the ELM can be explained by the effect of centrifugal force on the impurity ions. The cause of the global loss in confinement following the ELM, however, has not been identified.

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