

# MHD PHENOMENA AND THEIR INFLUENCE ON CONFINEMENT IN JET HOT-ION H-MODE D-D AND D-T DISCHARGES

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## 1. Introduction

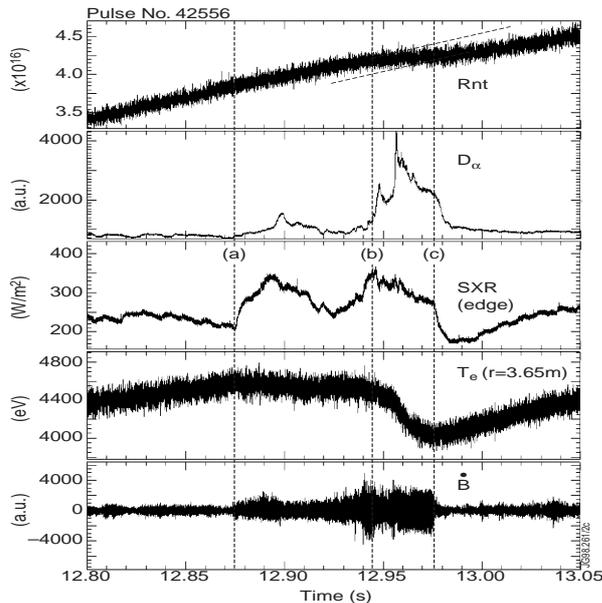
Hot -Ion H-modes (H-I) are the discharges which produce the highest fusion performance on JET. The main MHD features observed during such discharges are small ELMs at the L-to-H transition, a sawtooth usually within the first 300ms, low 'n' core modes rotating with the bulk plasma ions, outer modes (OM)  $\sim 0.9$ - $1.3$  s. into the H-I discharge and a Giant ELM at the end of the high performance phase after  $\sim 1.3$ - $1.8$  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.

## 2. Outer modes

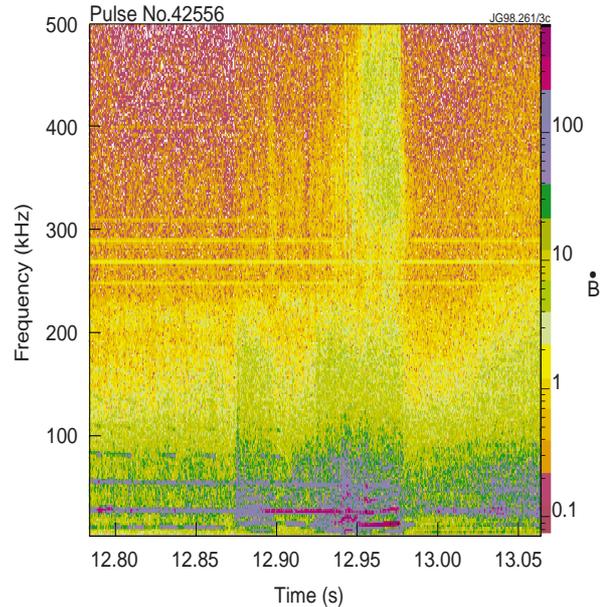
The OM in H-I discharges which has been identified as an external kink mode[1], is clearly seen at frequencies  $\sim 8$ kHz ( $n=1$ ), or multiples thereof, and is found to be localised close to the plasma edge (near the  $q=3$  surface) by the SXR, ECE and reflectometer diagnostics. The mode is associated with a rise in the  $D_\alpha$  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  $\sim 1$  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  $\sim 200$ kHz 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  $R_{nt}$ .

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  $R \sim 3.6$ m, ( $q \sim 1.5$ ) 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 ( $15 < n < 25$ ).



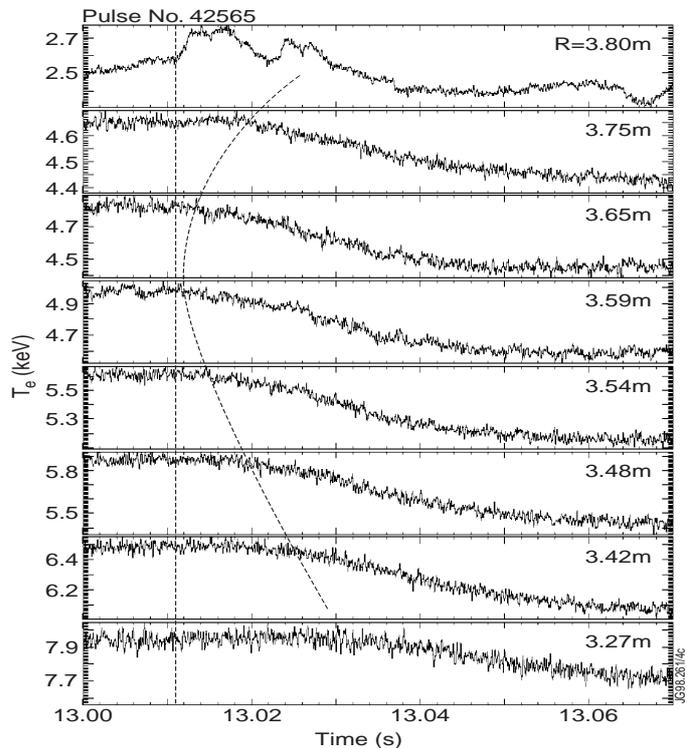
**Fig. 1.** The OM is present throughout the period (a)-(c) but the fall in  $T_e$  and flattening of  $R_{nt}$  only occurs over (b)-(c).



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

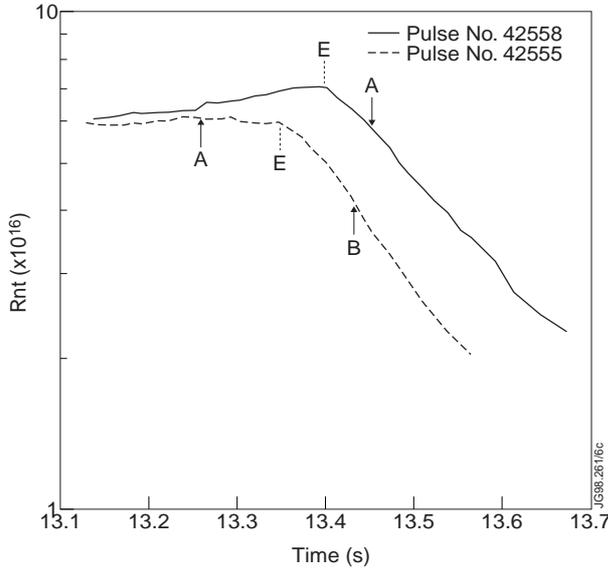
### 3. The Giant ELM

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  $\sim 1.5$  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 global but is localised to a

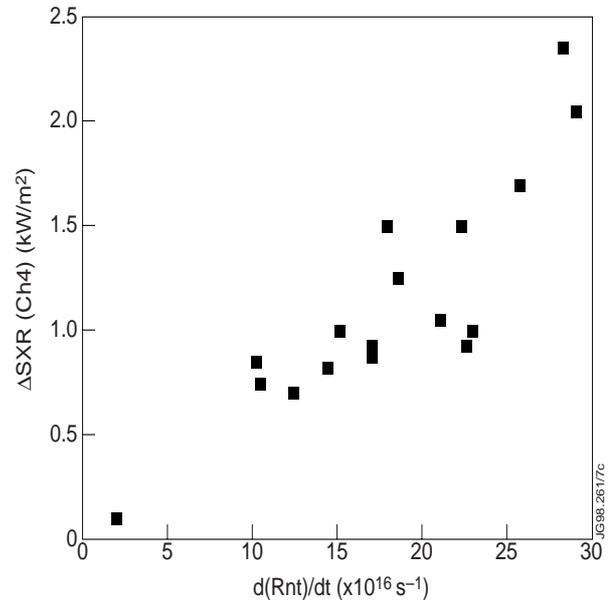


**Fig. 3.** The fall in  $T_e$  commences with the onset of high frequency activity (vertical line) at  $R \sim 3.6m$  and propagates both to the core and edge.

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.



**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  $R_{nt}$

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

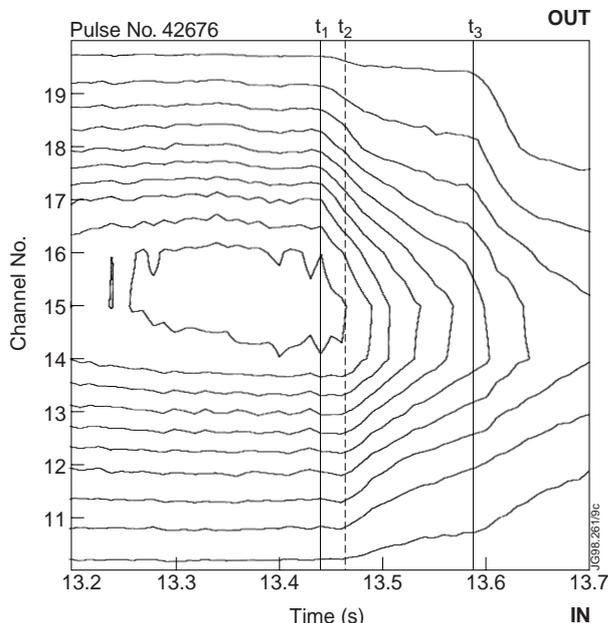
$$\frac{\rho_o}{\rho_i} = \exp \left\{ f \frac{\omega^2 (R_o^2 - R_i^2)}{2 v_{th}^2} \right\} \quad \text{with } f = \left( 1 - \frac{T_e}{T_i + T_e} \frac{m_i}{m_z} Z \right)$$

For H-I discharges, the in/out asymmetry ( $R_o=3.6\text{m} / R_i=2.3\text{m}$ ) is  $\sim 1.45$  for carbon and  $\sim 1.3$  for beryllium; (typical parameters:  $T_i \sim 6 \text{ keV}$ ,  $T_e \sim 5 \text{ keV}$ ,  $\omega \sim 70 \text{ krad./s}$ ). Impurity levels following a Giant ELM are  $\sim 4\text{-}8\%$  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  $\sim 10\text{-}20\%$ . The thermonuclear yield asymmetry would be proportional to the square of this dilution, giving  $\therefore R_{nt}(\text{outer})/R_{nt}(\text{inner}) = 1.2 - 1.4$ .

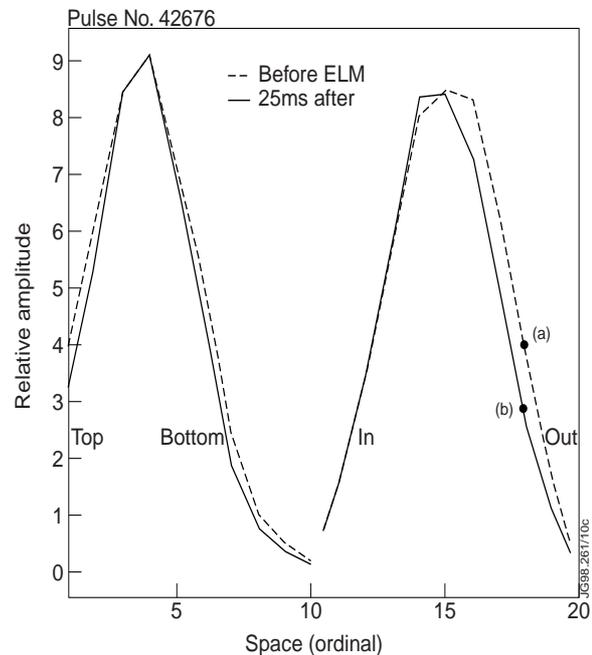
This is confirmed in the neutron profiles from a D-T discharge following a Giant ELM. The fall in neutron emission soon after the ELM, Figure 6, is almost entirely on the low field side and the asymmetry change, 25ms after the ELM at 3.6m (points (a),(b) in Figure 7.), is  $\sim 30\%$ , consistent with 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  $\sim 10\%$  within few  $100\mu\text{s}$  of the ELM and then continues to

fall with a time constant of  $\sim 1.2 \text{ s}^{-1}$  compared to a time constant of  $\sim 3.5 \text{ s}^{-1}$  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  $\sim 80\text{-}90\%$  of its original height within  $\sim 30\text{ms}$ .



**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  $R\sim 3.6\text{m}$  ((a)-(b)) is  $\sim 30\%$  consistent with in/out dilution asymmetry estimates.

#### 4. 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  $\sim 15\text{cm}$  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.

#### References

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- [3] M. Romanelli et al.: *24th EPS Conference*, Berchtesgaden, Vol. **21A**, Part 1, p. 5 (1997)
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