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** See annex of F. Romanelli et al, "Overview of JET Results",*
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1, INTRODUCTION

For future ITER operations it is important to minimize the damaging effect that large amplitude ELMs may have on plasma-facing components, for example by reducing their amplitude and increasing the repetition rate. One possibility in this direction is the triggering and mitigation of ELMs by pellet injection, which was successfully achieved on ASDEX Upgrade [1]. Experiments on JET have demonstrated that ELM triggering [2] and pacing is possible also in large size tokamaks, thus encouraging further investigation of the ELM triggering mechanism by pellets. Experiments with pellet injection in JET plasmas are presented, including Ohmic, L-mode and H-mode regimes. The toroidal mode number spectrum of MHD pellet-triggered events is compared with that of spontaneous ELMs. The method, which combines wavelet spectral analysis with statistical two-point correlation techniques and is described in [3-5], allows one to extract the coherent part of fluctuations from the incoherent background and follow the evolution of the toroidal mode number spectrum with a time resolution of 0.05-0.1ms.

2. SPECTRA OF SPONTANEOUS ELMS

Both spontaneous type-I and type-III ELMs exhibit broadband magnetic perturbation spectra, from frequencies as low as a few hundreds of Hz up to the maximum measurable frequency. This range of frequencies can be ideally separated into two distinct contributions, one associated with spectral components below 4kHz and one with spectral components above this value. The two contributions also have distinct toroidal mode number spectra, as shown in Fig.1. The spectral components at lower frequencies have a toroidal mode number spectrum peaked typically at $n = 1-2$ and this value does not change in time. Conversely, higher frequency components develop a clear toroidal mode number structure. At the earlier stages of evolution, the toroidal mode number is low, then it increases approaching the ELM crash, within a time window that has a typical duration of 0.3ms. The number of modes involved also increases, suggesting the occurrence of nonlinear interactions that generate new modes. The grow the of type-I ELMs is fast, and the sampling rate is - in most cases - insufficient to resolve the evolution of the toroidal mode number. This is seen in the wavelet scalogram as a broadening of the mode at low frequencies and in the toroidal mode number spectrum as a phase jump (phase II in Fig.1).

3. SPECTRA OF MHD EVENTS TRIGGERED BY PELLETS

Figure 2 shows an example of pellets injected in Ohmic and L-mode plasmas, while the case of a pellet injected in H-mode plasma is shown in Figs.3−4. In all the plasma configurations pellets can trigger a MHD event, but only in H-mode plasma they can trigger an ELM. Magnetic perturbation spectra exhibit two distinct components, one at low and one at high frequencies. The former has a mode number spectrum peaked at $n = 1-2$, as shown in Fig.2−(f) in the case of L-mode and in Fig.4−(c) in the case of H-mode. The latter has similar features in all plasma configurations: it is observed during a time window that is comparable to the duration of the ablation phase and its amplitude - integrated over frequency - increases over longer time scales than it decays.

In H-mode plasmas an additional component at high frequency is present, with much shorter duration, as shown in Fig.3. The evolution in time of the integrated spectrum is very similar to that of spontaneous ELMs, with a fast rising and a slower decay, and it qualitatively follows the D_α emission time trace. It has been shown that the decay time of the D_α is slower in the case of triggered event with respect to spontaneous ELMs [6]. These high frequency components associated with the first, short-lived component exhibit a broad mode number structure, very similar to that measured during spontaneous type-I and type-III ELMs.

The value of n is initially low in absolute value, then it increases approaching the ELM crash, reaching a maximum value of $|n| = 6$. At the same time the number of modes involved increases suggesting nonlinear interactions among modes. Although the evolution of the toroidal mode number spectrum is similar for all the pellettriggered events analyzed so far, the maximum value of the toroidal mode number may change in different cases. Further investigation is ongoing to establish how this value is correlated with the delay after the previous, spontaneous ELM.

CONCLUSIONS

Pellets can trigger an MHD event substantially in every plasma background, including Ohmic heated plasmas and L-mode confinement regimes, although they can trigger an ELM only in H mode, where an Edge Transport Barrier is formed. The spectra of magnetic perturbations can be ideally separated into two distinct components, one at lower frequency and one at higher frequency, which exhibit distinct toroidal mode number spectra. The low frequency components of the spectrum have toroidal mode number spectra typically in the range of $n = 1$-2 and this value is comparable in L-mode and H-mode plasmas, indicating that the seed MHD triggered-event has the same nature in the different configurations. Conversely, the high frequency components of the spectrum have different temporal evolution in H-mode plasmas compared to Ohmic and L-mode plasmas. Here, an ELM component and a pellet-driven component can be identified in time. While the pellet-driven component is always present, the ELM component is observed only in H-mode plasmas. This component, which consists of the superposition of modes with $|n| = 1$-10, is very similar to spontaneous type-I and type-III ELMs. Interestingly, spontaneous type-I and type-III ELMs also exhibit the low frequency component with $n = 1$-2. This suggests that a similar mechanism for ELM triggering may be at play, possibly a global mode, with kink-like nature. The increase in the value of n measured immediately before the ELM burst suggests a coupling with ballooning instabilities, favoured by the presence of an Edge Transport Barrier, although no definite conclusions can be driven before any linear stability analysis.

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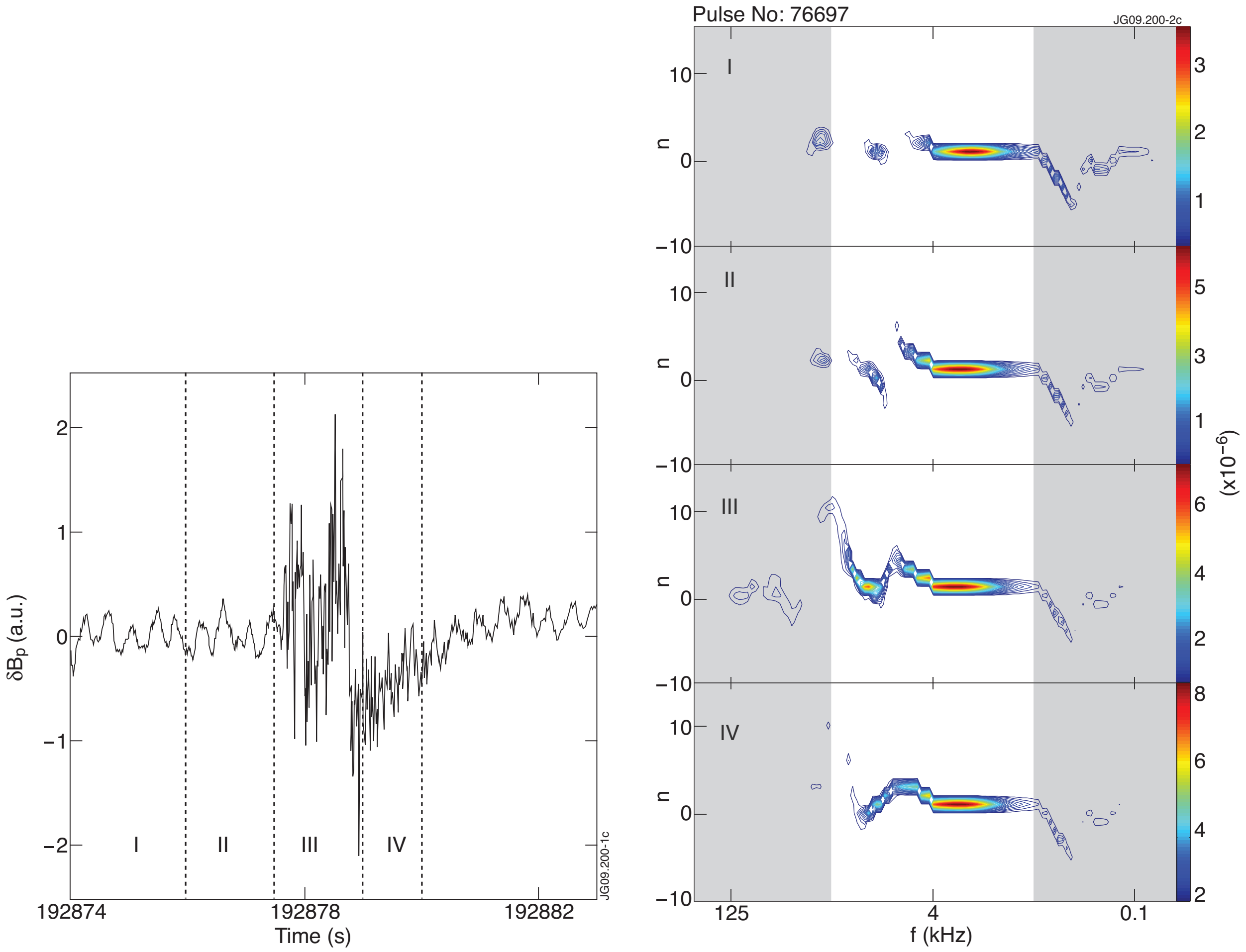

Figure 1: JET Pulse No: 76697. Spontaneous type-I ELM. Top: magnetic perturbations. Bottom: spectrum P(n,f) during phases I-IV. Shaded areas are affected by large uncertainties.

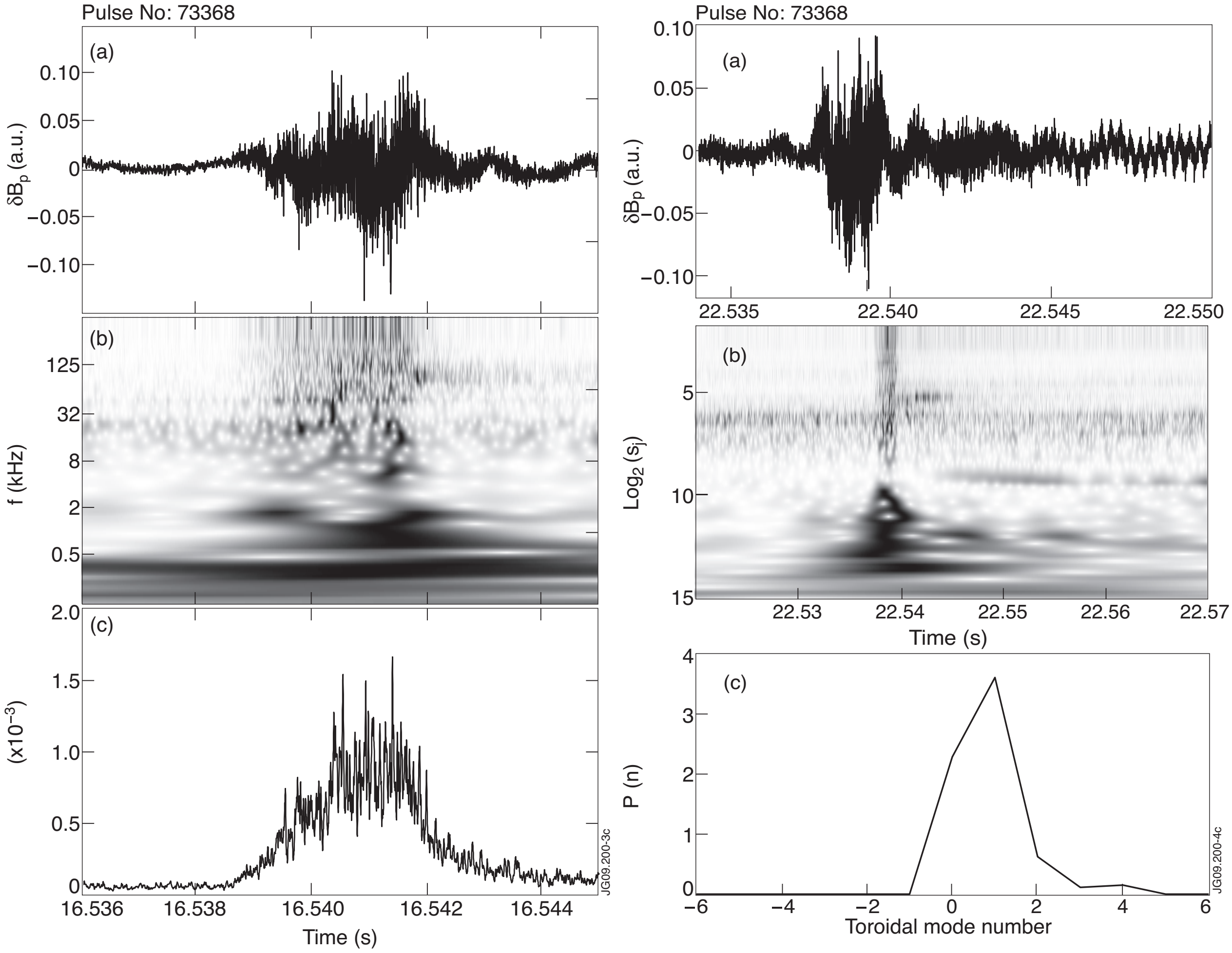

Figure 2: JET Pulse No: 73368. pellet-triggered event in Ohmic (a-c) and L-mode (d-f) plasma. (a,d) Magnetic perturbations. (b,e) wavelet coefficients. (c) integral of (b) for f>10 kHz. (f) toroidal mode number spectrum associated with f<4 kHz.

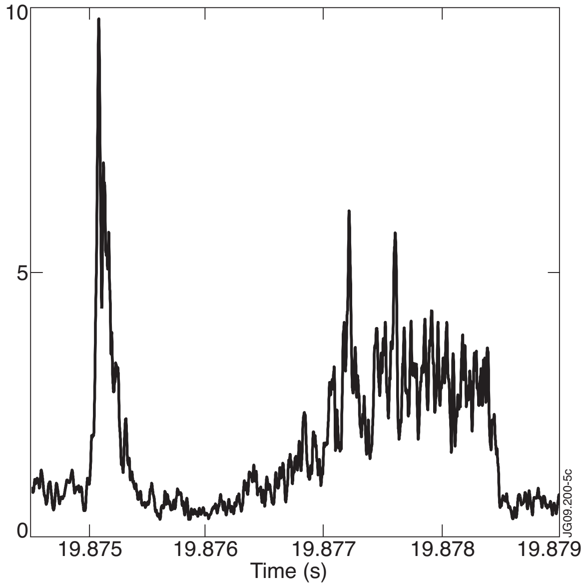

Figure 3: JET Pulse No: 59423. Pellet-triggered event in H-mode. Time evolution of wavelet coefficients integrated over frequencies f>10kHz.

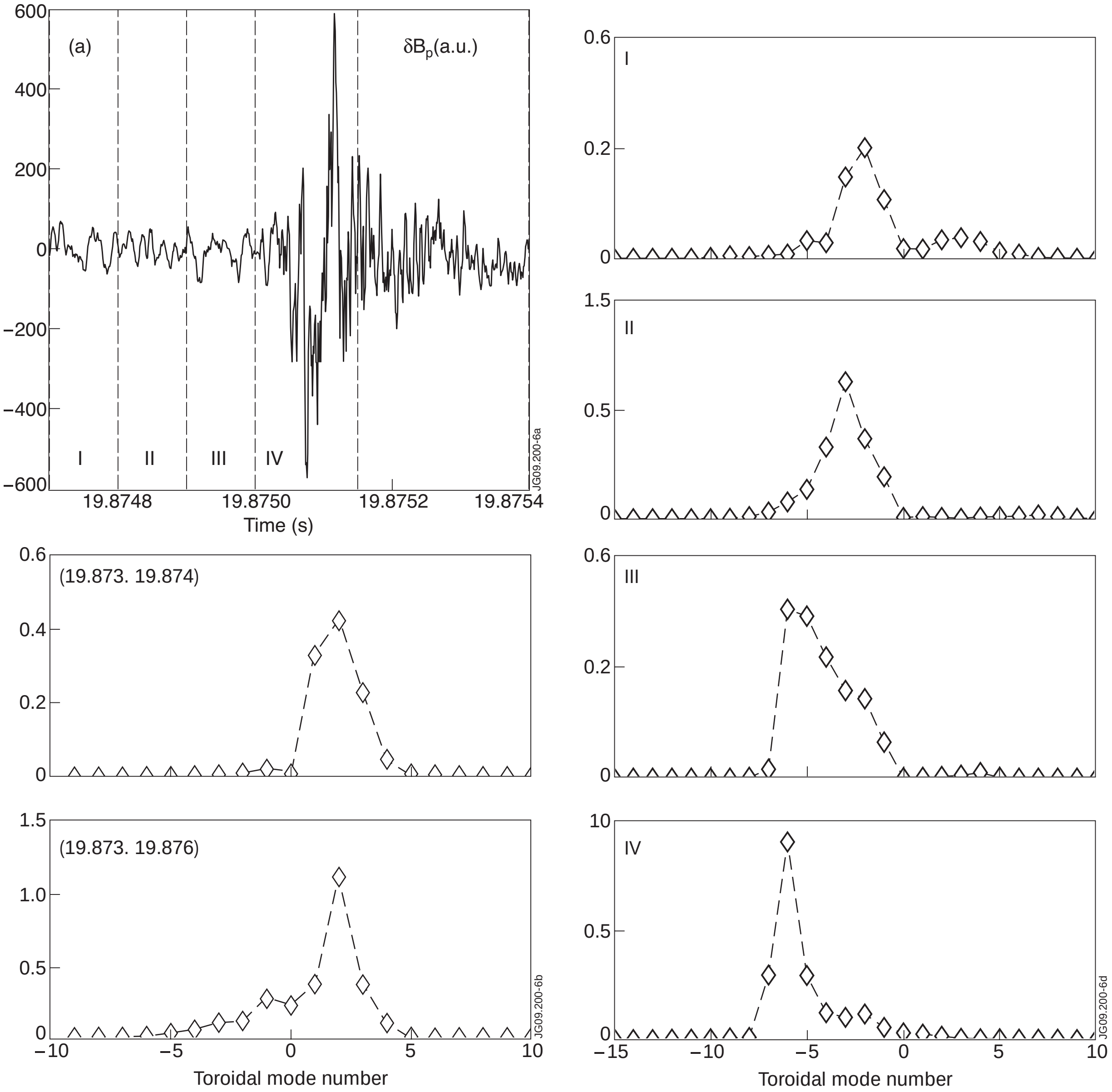

Figure 4: JET Pulse No: 59423. Pellet-triggered event in H-mode (same event shown in Fig. 3). (a) Magnetic perturbations. Toroidal mode number spectrum associated with components with frequencies f<4kHz (b) and with frequencies f>4kHz (c).