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** See annex of J. Pamela et al, "Overview of Recent JET Results and Future Perspectives", Fusion Energy 2000 (Proc. 18th Int. Conf. Sorrento, 2000), IAEA, Vienna (2001).*

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INTRODUCTION

Type-I ELMs [1–3] are regarded as a possible method to control the plasma density and impurity content of H-Mode discharges. The transient heat losses caused by them are of particular concern for ITER due to the large transient power loads expected on the divertor tiles. Although their existence is known since many years, their physics is not well understood yet, and search for ELM precursor activity which could bring light into its mechanism and control possibilities has been performed in many devices. Type-I ELM precursor modes were observed in JET through multiple diagnostics and studied in detail.

MAGNETIC MEASUREMENTS

Compared to other MHD activity like internal kinks or NTMs, the precursors are much weaker and often hard to observe directly on the Mirnov signals. The time by which the mode startup precedes the ELM crash scat-ters greatly: Usually, the precursors appear ~0.2-1ms before the ELM, but there are many cases where they become desta-bilized several tens of ms in advance of it. In the time win-dow of Fig.1 three Type-I ELMs and a sawtooth crash occur. The first ELM is preceded by a shorter precursor (~2ms), shown in the zoom view, while the second and third ELMs have much longer ones (~30ms), but are difficult to see here. Fig.2(a) shows the corresponding spectrogram where the pre-cursors (f~18 kHz) are marked by arrows. The first pre-cursor can be hardly seen on it due to its shortness. With the used sampling rate of 250 kHz precursors shorter than 1 ms are difficult to impossible to discern on the spectrograms. The toroidal mode numbers can be inferred from mode number spectra as shown in Fig. 2(b). By making a Fourier decomposition of a toroidal set of Mirnov coils and analysing the phase shift of the fluctuations the n-numbers can be obtained. For the analysis a high resolution array of 5 coils, with toroidal angles $\Delta\phi$ gradually increasing from 1.7 to 15.9 degrees, was used, adequate for modes with $n \leq 11$.A subset of these coils was employed if higher mode numbers should be resolved or simply to check the correctness of previous calculations. The coils are positioned close to the plasma boundary, with r_{sep}/r_{coil} being roughly 0.8, depending on the plasma shape. It proves very useful for finding hidden activity to plot the mode numbers in a spectrogram-like way due to its twofold filtering: in frequency- and in phase-space. This increases the contrast and makes it possible to observe modes faintly visible on the spectrograms. To reduce the noise level of the plots, points are discarded when the amplitudes are below a user defined threshold or the fitting error of the mode number exceeds a certain amount. The color in the plot denotes n. Modes with negative n-numbers rotate in the opposite direction than modes with positive ones. The convention used here is that modes with negative n rotate in the di-coils rection of the electron diamagnetic drift for co-injected pre-discharges. For the 3 ELMs shown the precursors have n = +8. In general, a whole spectrum of toroidal mode numbers in the range 1-14 has been observed, with n around 7-10 being the most commonly observed in conventional ELMy H-Mode scenarios. Comparison of Mirnov signals of low and high field side coils revealed that while precursors with low n =1 or 2 show no ballooning or even slight antiballooning character, with increasing n-numbers the ballooning character of the modes becomes gradually more and more accentuated. Fig. 3 shows the Fourier spectra of one of the n = 8 precursors shown. Although the two coils used have comparable distance to the separatrix in this discharge (~22 cm), the ratio of amplitudes on the low/high field side is very high, approximately 30.

MODE LOCATION AND STRUCTURE

The radial location of the coherent precursors can be most easily seen on the ECE diagnostic, which turned out to be to be very sen-sitive to these modes. JET's ECE system consists of 48 heterodyne radiometers sampled with 250kHz, mea-suring near the vessel midplane. The spacing between resonant measurement radii is typically only 1 or 2 cm. The precursors always occur close to the separatrix, in the pedestal region. Figure 4 shows a set of edge ECE signals for our example. Figure 5 shows the ECE tem-perature profile and the location of the separatrix as cal-culated by the EFIT equilibrium code. The channels at 3.78m and 3.79m measure at the top of the pedestal, where the precursors are weak but still visible through spectrograms. The oscillations are most clearly seen at 3.81m, supported by the stronger temperature gradients in the pedestal. Concerning the channels from 3.82m outwards one has to be cautious. The density is too low and the plasma does not radiate as a black body anymore. Radiation picked up by this channels can have contributions from other plasma regions (shine-through effect), corrupting the signal. This shows up in the ECE emission profile, where the "temperature" appears to rise again. While it is difficult to locate the origin of the shine through radiation picked up (it is in general a com-bination of several sources), it is probable that the amount of shine-through itself is additionally modu-lated by the local density oscillations caused by the mode (which are present, as confirmed by reflectom-etry). In all discharges analysed the phase of the oscillations shows π-shifts between channels when the slope of the ECE emission profile changes sign (in our case between the channels at 3.81m and 3.82m and also around 3.87/3.88 m, already outside the separa-trix), but not in channels measuring between these radii. Although this observation suggests a mode with twisting parity, for the reasons above the interpretation of shine-through dominated channels is quite problematic. The precursor is also detected through the edge reflectometer again confirming its location at the plasma edge. JET's O-mode edge reflectometer system consists of 10 channels with cut-off densities ranging from 0.4 up to 6.0×10^{19} m^{-3} . Depending on how high the discharge dentsity is, the modes are seen on all channels or a subset with lower cutoff densities. Due to the lack of a fast diagnostic for measuring the edge density profiles, which continuosly evolve in-between ELMs, it is not always easy to ascertain whether the channels with higher cutoff-densities are still measuring at pedestal radii or further in the plasma. However, the fact that the modes are always seen on the channels with lowest cutoff densities, clearly measuring at the pedestal, normally including radii where the ECE suffers from shine-through, indicates that the precursors indeed extend from about the pedestal shoulder, as seen from ECE measurements, at least until fairly close to the separatrix or further out. Figure 6 shows the fringe-jump corrected traces of an n = 8-precursor in an older discharge (in the present reflectometer setup fringe-jumps are not corrected) showing no phase inversions between channels, confirming that the mode has most probably twisting parity. Furthermore, the precursor occurrence is accompanied by a moderate D_α-rise mainly in the outer divertor (Fig.7).

SUMMARY

Type-I ELM precursors in standard H-Mode charges have been studied in considerable detail. The modes have low frequency (<40 kHz), propagate in the direction of the ion diamagnetic drift and show a wide spectrum of n-numbers (1-14). The ballooning character of the modes in-0.2creases gradually with increasing n-numbers. They are found to be localised near the plasma edge with no evident radial phase inversion, and their occurrence is accompanied by a rise of the D_α-signal, mainly in the outer divertor. Further interesting properties of these modes can be found in [4].

REFERENCES

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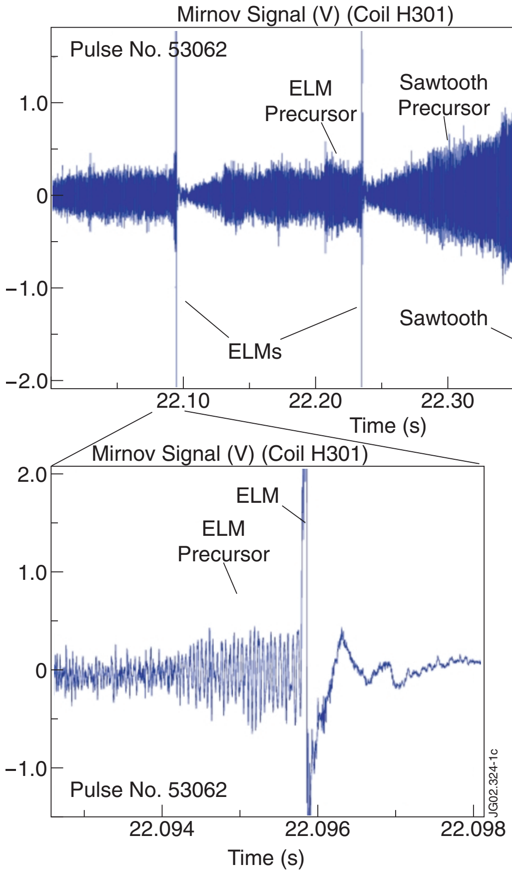

Figure 1: Mirnov signals of a low field side coil.

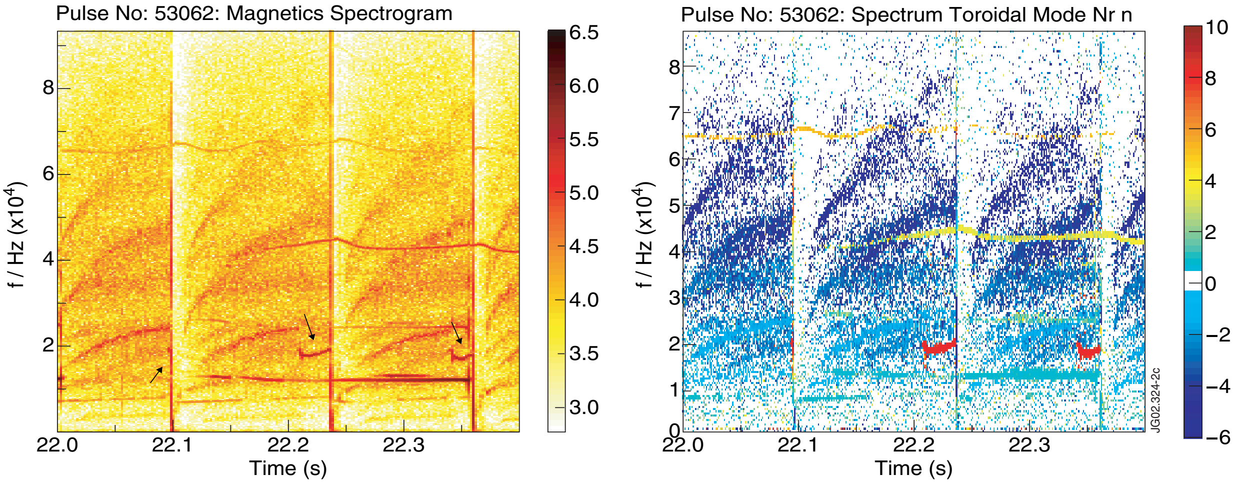

Figure 2: Magnetics spectrogram of a coil located on the low field side with the precursors being marked by the arrows, and spectrum of toroidal mode numbers showing the modes to have n=8 (red).

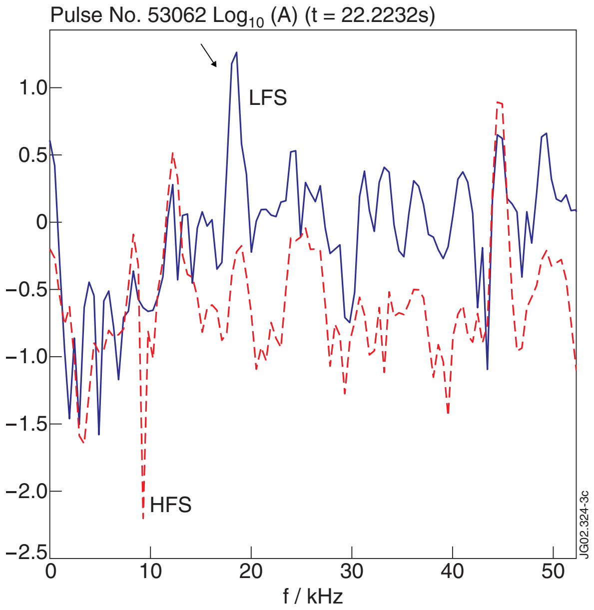

Figure 3: Logarithmic Fourier spectra of Mirnov signals of low/high field side with comparable distance to the separatrix. The arrow points at the cursor contribution. The ratio of plitudes on the low/high field side is roughly 30.

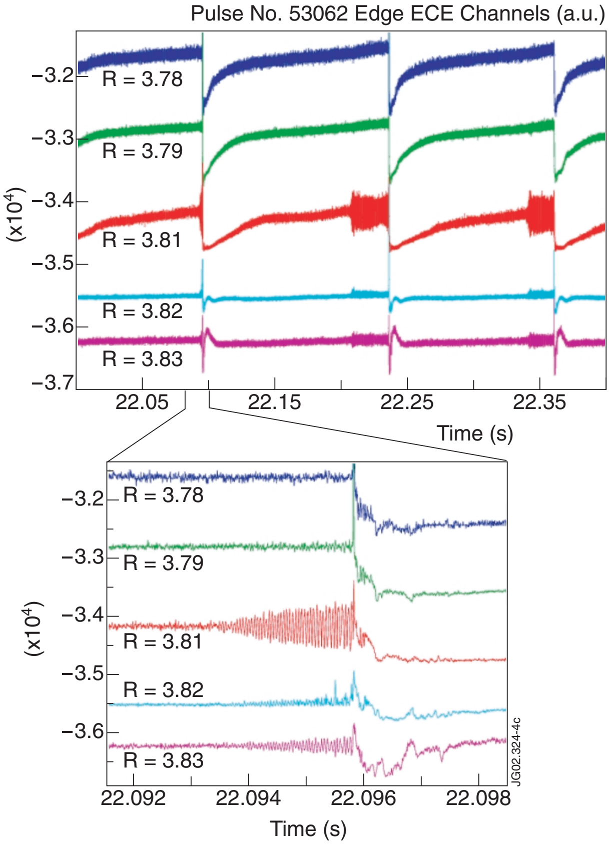

Figure 4: Edge ECE signals showing the coherent precursors.

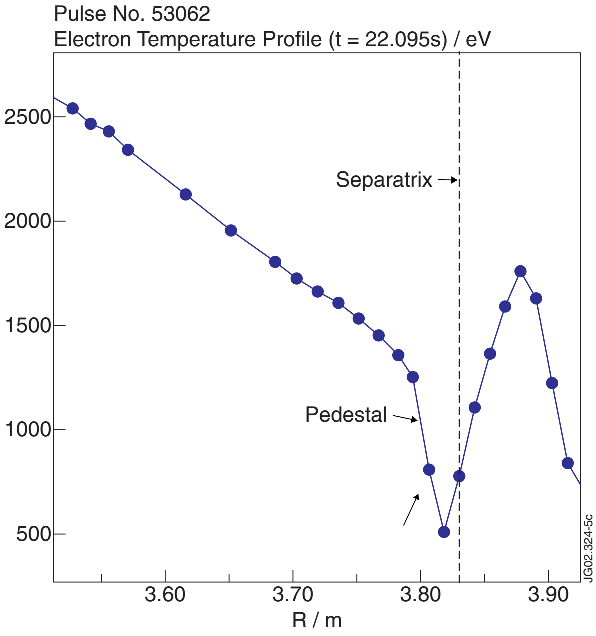

Figure 5: Electron temperature profile as measured by the ECE. The arrow marks the channel at 3.81 m were the signal oscillations are most prominent on Fig. 4.

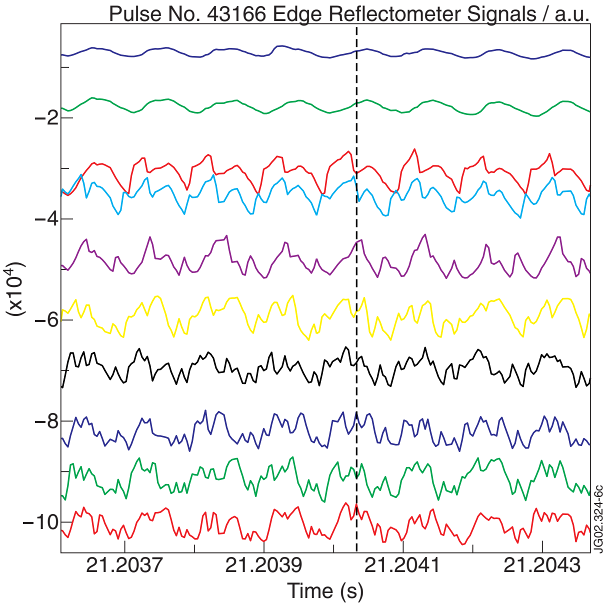

Figure 6: Edge reflectometer traces

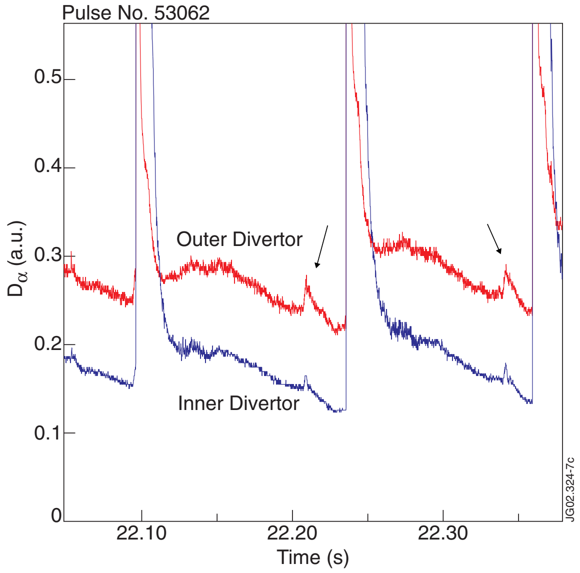

Figure 7: D_α-signals for the of Fig.2.