29th EPS Conference on Plasma Phys. and Contr. Fusion Montreux, 17-21 June 2002 ECA Vol. ***26B****, P-1.023 (2002)*

Type-I ELM Precursor Modes in JET

C. Perez[1], H. R. Koslowski[1], G. T. A. Huysmans[2], P. Smeulders[3], B. Alper[4], T. C. Hender[4], L. Meneses[5], M. Zerbini[4] and contributors to the EFDA-JET workprogramme*

[1] Forschungszentrum Jülich GmbH, Institut für Plasmaphysik, EURATOM Association, Trilateral Euregio Cluster, 52425 Jülich, Germany

[2]Association Euratom-CEA, Cadarache, F-13108 St. Paul-lez-Durance, France

[3]Associaziano Euratom-ENEA, Centro Ricerche Frascati, Italy

[4]Euratom-UKAEA Fusion Association, Culham Science Centre, Abingdon, UK

[5]Euratom/IST, Instituto Superior Tecnico, Lisbon, Portugal

Introduction Type-I ELMs [1, 2] are compatible with good confinement at high density but the transient heat losses associated with them are a concern for ITER, due to the expected large transient power loads 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 varies greatly: Usually, the precursors appear ∼0.2-1 ms before the ELM, but there are many cases where they become destabilized several tens of ms in advance of it. In the time window of Fig. 1 three type-I ELMs and a sawtooth crash occur. The first ELM is preceded by a shorter precursor (∼2 ms), shown in the zoom view, while the second and third ELMs have much longer ones (∼30 ms), but are difficult to see here. Fig. 2a shows the corresponding spectrogram, where the precursors ($f \sim 18$ kHz) are marked by arrows. The first precursor can be hardly seen on it due to its shortness (with 250 kHz sampling rate precursors shorter than 1 ms are difficult, or impossible, to discern on spectrograms). The toroidal mode numbers can be inferred from mode number spectra as shown in Fig. 2b, where the colors denote

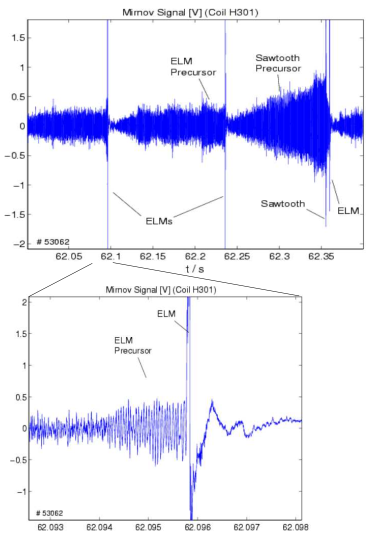

Figure 1: Mirnov signals of a low field side coil.

*see appendix of the paper by J. Pamela *Overview of recent JET results*, Proceedings IAEA Conference on Fusion Energy, Sorrento, 2000

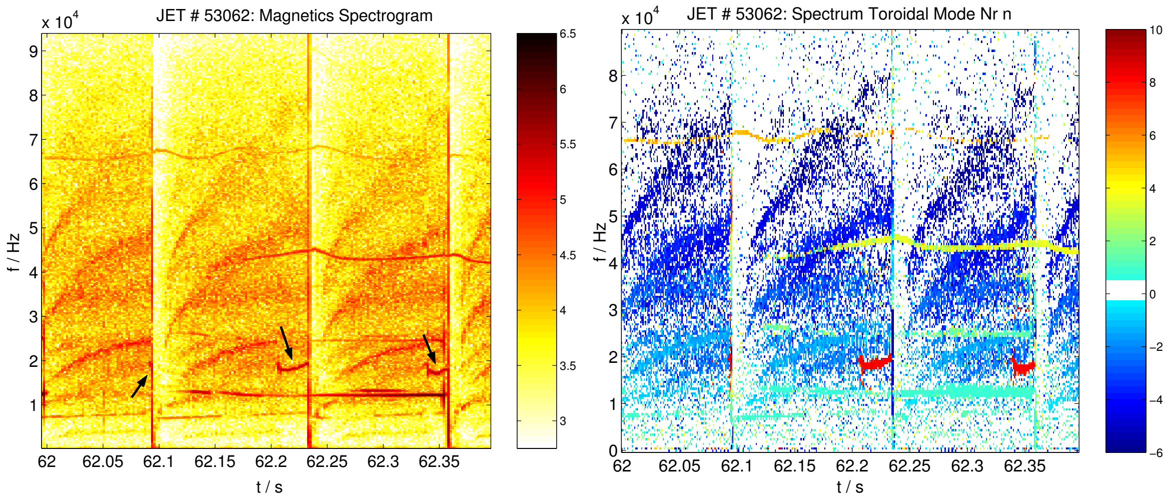

Figure 2: Magnetics spectrogram of a coil located on the low field side with the precursors being marked by the arrows, and spectrum of toroidal mode numbers showing the modes to have n=8 (red).

the toroidal mode numbers n. 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, adequate for mode numbers $n \leq 11$, was used. A subset of these coils was employed if modes with higher n 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 otherwise hidden MHD 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 only faintly visible on 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. Positive and negative mode numbers are detected. 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 direction of the electron diamagnetic drift for co-injected discharges. For the three ELMs shown the precursors have $n = +8$. In addition, one observes several broader bands of magnetic fluctuation with higher frequency ($\sim$ 20-80 kHz) propagating in the direction of the electron diamagnetic drift (negative n), with n typically ranging from -1 to -12. These bands were already studied in [3] and named washboard modes.

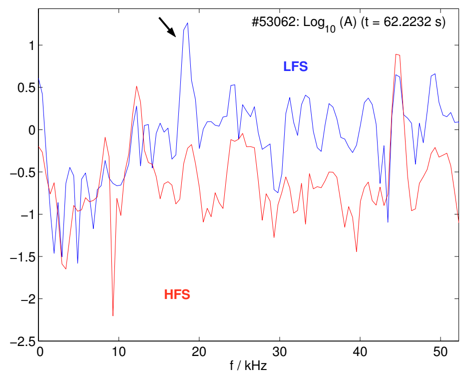

Figure 3: Logarithmic Fourier spectra of Mirnov signals of low/high field side coils with comparable distance to the separatrix. The arrow points at the precursor contribution.

In general, a whole spectrum of precursor 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 sensitive to these modes. JET's ECE system consists of 48 heterodyne radiometers sampled with 250 kHz, measuring 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. Fig. 4 shows a set of edge ECE signals for our example. Fig. 5 shows the ECE temperature profile and the location of the separatrix as calculated by the EFIT equilibrium code. The arrow marks the channel at 3.81 m were the signal oscillations are most prominent on Fig. 4. The channels at 3.78 and 3.79 m measure at the top of the pedestal, where the precursors are weak but still visible through spectrograms. The oscillations are most clearly seen at 3.81 m, supported by the stronger temperature gradients in the pedestal. Concerning the channels from 3.82 m 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. The ECE channels in the optically thick region show no phase inversion indicating a twisting parity mode. This is further verified by information on the radial structure of the precursors from edge reflectometer measurements. These measurements confirm the precursor location as being 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 $\times 10^{19}$ m^{-3}. Depending on how high the discharge density is, the modes are seen on all

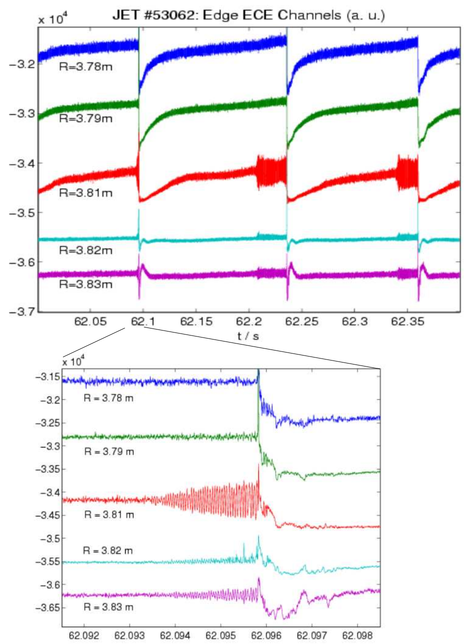

Figure 4: Edge ECE signals showing the coherent precursors.

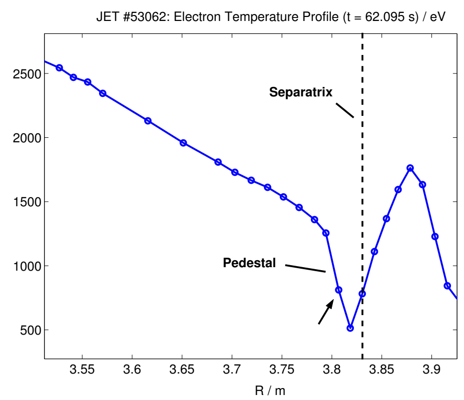

Figure 5: Electron temperature profile as measured by the ECE.

channels or a subset with lower cutoff densities. Due to the lack of a fast diagnostic for measuring the edge density profi les, which continuously evolve inbetween 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, normally including outer pedestal 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. Fig. 6 shows the fringe-jump corrected traces of an $n = 8$-precursor showing no phase inversions between channels, confi rming that the mode has a kink-like structure.

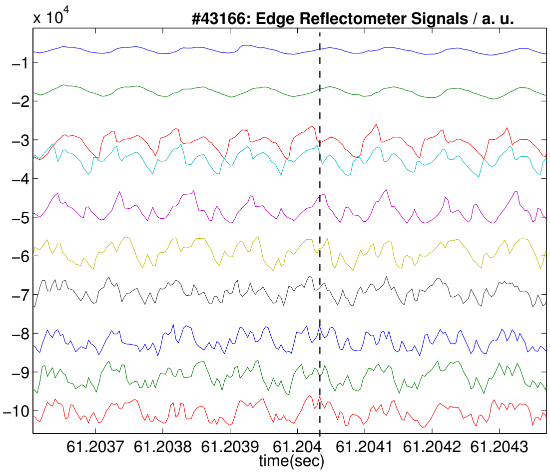

Figure 6: Edge reflectometer traces

Furthermore, the precursor occurrence is normally accompanied by a moderate D_α-rise mainly in the outer divertor (Fig. 7).

Summary Type-I ELM precursors in standard H-Mode discharges 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 increases 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. A more detailed description of these modes can be found in [4].

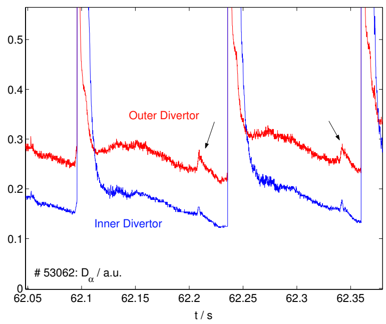

Figure 7: D_α-signals for the example of Fig. 2.

[1] Zohm, H., Plasma Phys. Control. Fusion **38** (1996) 105.
[2] Connor, J.W., Plasma Phys. Control. Fusion **40** (1998) 191; **40** (1998) 531.
[3] Smeulders, P., et al, Plasma Phys. Control. Fusion **41** (1999) 1303.
[4] Perez, C., to be submitted to Nucl. Fusion.

This work has been conducted under the European Fusion Development Agreement.