Low frequency intra ELM pedestal MHD activity observed in low collisionality peeling limited scenario on JET

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Introduction

In the last few years JET made experiments to reach peeling limited pedestals [1]. This work investigates properties of pre-ELM MHD instabilities in these peeling limited pedestals. A pre-ELM mode appears at a frequency below 15 kHz, with a toroidal mode number in the range 3-7 and can be observed on the fast ECE, an example is shown in figure 1. The modes are located on the pedestal and are visible also in the shine-through region with an opposite phase as expected for modes living on the pedestal. An analysis of an intra ELM mode behaviour in balloning limited and coupled peeling-balloning limited pedestals has already being presented in [2], we extend further the characterization of the peeling modes in a scenario relevant to ITER.

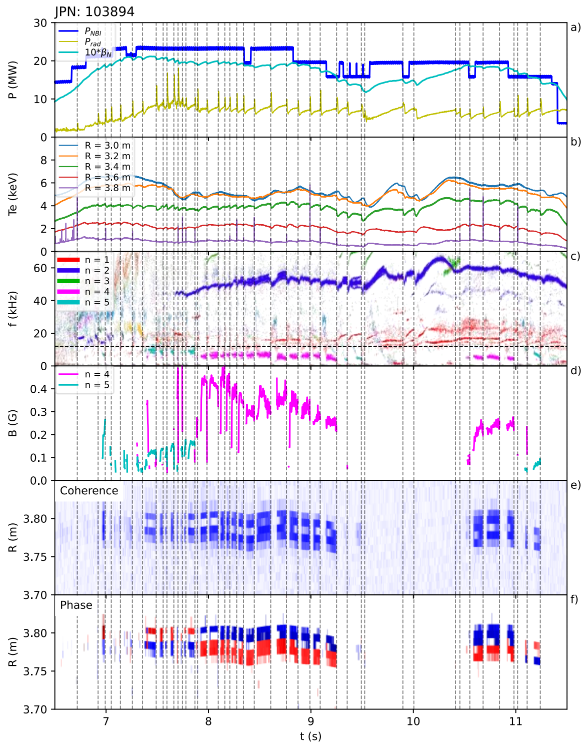

Fig. 1. For the JET pulse: 103894: a) NBI and radiated power, β_N; b) electron temperature; c) spectrum of the modes; d) amplitude of the inter ELM modes; e) coherence of the fast ECE; f) phase of the fast ECE signals where one can sees the change of phase in the shine through region.

A toroidal set of coils at the same poloidal position has been used to determine the toroidal mode number, while fast ECE data can be used to determine their position and amplitude.

Data analysis

Analysis has been done with a specialized python code. First, the coil signals were short Fourier transformed with an appropriate normalization such that the amplitude of monochromatic signal will be recovered by summing the square of the of the transformed spectrum, and then taking their square root. At each time and frequency, and each coil we get a complex number $\hat{S}_{tf,c}$. The code finds the mode number n that maximize:

$$R_{tf}(\mathrm{n}) = \left|\sum_c \hat{S}_{tf,c} \exp(-i\phi_c n)\right|^2$$

Where ϕ_c are the coil toroidal positions. The amplitude and the spatial coherence are defined (N_c being the number of coils) as:

$$\dot{B}_t(n) = \sum_{c,f} \hat{S}^2_{tf,c} I_{tf}(n)\,, \qquad F_t(n) = \frac{\sum_{c,f} F_f\, \hat{S}^2_{tf,c} I_{tf}(n)}{\dot{B}_t(n)}, \qquad C_{tf}(n) = \frac{R_{tf}(n)}{\sum_c \left|\hat{S}_{tf,c}\right|^2 N_c}$$

Where $I_{tf}(n)$ is an index function that is 1 for the n that maximize $R(n)$ and zero otherwise, while F_f is the frequency corresponding to the frequency index "f". Only value of n from 0 to 12 have been considered. The frequency sum is for $0.5\,\mathrm{kHz} < f < 12\,\mathrm{kHz}$. This spatial coherence is mainly used as a check that only one value of N is really fitting the data. A limit of 0.1 T/s is assumed for the mode amplitude $\dot{B}_t(n)$. From $\dot{B}_t(n)$ and $F_t(n)$ one can easily get $B_t(n)$.

Correlation with fast ECE can be used to determine its radial position and associated temperature fluctuations. An MHD coil is used as a reference. As before the signals are short Fourier transformed and one get at each time and frequency a complex amplitude $\hat{S}_{tf}$ for the reference coil and a complex temperature fluctuation $\hat{T}_{tf}(R)$ for the ECE signals, where R is an index for the ECE channel that is measuring the electron temperature at position R. Integrating over a range of frequencies one can get the temperature fluctuation $\bar{T}_t(R)$ and a coherence between the ECE signal and the magnetic one $C_t(R)$:

$$\bar{T}_t(R) = \frac{\sum_f \hat{S}^*_{tf} \hat{T}_{tf}(R)}{\sqrt{\sum_f \left|\hat{S}_{tf}\right|^2}}, \quad C_t(R) = \frac{\left(\sum_f \hat{S}^*_{tf} \hat{T}_{tf}(R)\right)^2}{\sum_f \left|\hat{S}_{tf}\right|^2 \sum_f \left|\hat{T}_{tf}(R)\right|^2}$$

As before the frequency sum is between 0.5 kHz and 12 kHz. This coherence is used to determine the radial position of the mode and check that it is really located on the pedestal.

The dataset

The same dataset considered in [1] has been used. To reach peeling limited plasmas in JET-ILW, high q_{95} operation is necessary. All the pulses are at a plasma current of 1.4 MA a target external power of 25 MW and high triangularity. The dataset is composed of a B_T scan from 1.7 T to 3.8 T (to reach the peeling limited scenario), a deuterium gas scan at 3.8 T (to investigate the pedestal behavior in peeling limited scenario), an effective mass scan at 3.8 T and constant gas from pure D to T-reach plasma (A_{eff} = 2.0-2.8).

At $B_T = 1.7$ T no ECE data is available, while, at $B_T = 2.2$ T, ECE data at the edge is of suboptimal quality, and their data should be taken with care. Moreover, even magnetic data gives spurious result at low magnetic field as core modes are quite external and can be triggered by ELMs. Different figures of merit have been used to characterize the mode like the average toroidal mode number, the average mode amplitude, the average duration of the inter ELM period, and the percentual of the discharge time when a mode is present, and others. The presence of inter ELM modes seems correlated with the ELM period and consequently with the gas injection. Longer ELM period gives higher presence of inter ELM modes. The average toroidal mode number (fig. 2) is correlated with the toroidal magnetic field. The trend is the same as that calculated by the EUROPED code [3], even though the experimental toroidal mode number are smaller.

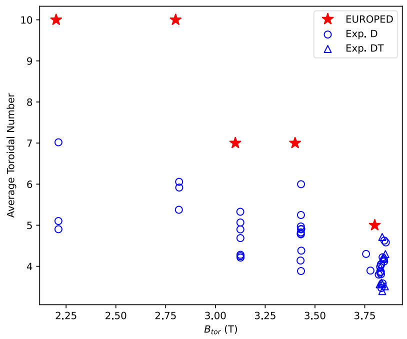

Fig. 2. The average toroidal mode number and that from the EUROPED code for inter ELM peeling modes.

Profile shift

As discussed before, the square root of the sum of the absolute square of the short Fourier transform is equal to the amplitude of a sinusoidal signal. As shown before the temperature fluctuations in the different channels have all the same phase, except in the shine through region where they have the opposite one, as it is expected in a simple radial shift of the pedestal. We can add the temperature fluctuation $\bar{T}(R)$ to the average temperature and get its profile during the evolution of the mode, the angle θ being a phase angle.

$$T_e(R,\theta) = T_{e,0}(R) + \mathrm{Re}[\bar{T}(R) \exp i\theta]$$

In general, we look at the phases corresponding to the extreme of the oscillation. A suitable θ_0 and a $\theta_1 = \theta_0 + \pi$ has been chosen so to maximize the pedestal shift. These profiles are shown in fig. 3. A further provision should be used to decide if a particular point is or is not inside the shine through region. Signal from channels close to the bottom of the pedestal may be considered inside or outside the shine through depending on their phase. Points inside the shine through region are discarded, and then a tanh fit has been done on the remaining points:

$$T_f(R) = [\alpha_1(R - R_0) + \alpha_0]\,\frac{e_m^2}{1 + e_m^2}, \qquad e_m = e^{-\frac{R-R_0}{\tau}}$$

The data are compatible with a radial shift of the profile of about 1 cm in this case. Further analysis that takes in to account the effect of the shine through on the temperature are needed to better characterize the structure of the mode and avoid a somewhat arbitrary discarding of the data.

Conclusion

Inter ELM modes have been observed in low collisionality peeling limited scenario on JET-ILW. The modes have an n = 3 – 7 and are in the pedestal. Their presence seems to be related to the ELM frequency, with no mode observed at high ELM frequency. The main toroidal mode number instead is linked mainly to the magnetic field (or q_{95}) with n decreasing with increasing q95 in qualitative agreement with EUROPED prediction. The effect of the mode on T_e is to shift the T_e profile in the pedestal region inwards and outwards by about of 1 cm in the considered case. The vicinity of the shine-through in some way limits the possible analysis as only one or two ECE channel can be seen on the pedestal. The size of the detected pedestal from the ECE measurement is close to the diagnostic resolution.

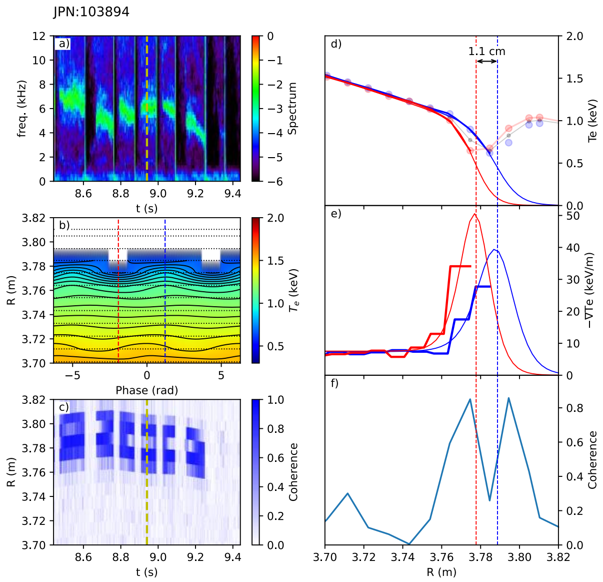

Fig. 3. For the discharge #103894: a) The spectrum of the inter ELM modes; b) a pseudo-colour plot of the function $T_e(R,\theta)$; c) the coherence close to the selected time; d) plot of the two profiles corresponding to the maximal shift of the pedestal the points assigned to the shine through are in light colour, the thin line is a tanh fit; e) the gradient of the temperature for the same profiles; f) the coherence associated with the observed data. The vertical lines on the time plots correspond to the analysed time point.

References:

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