Investigation of saturated ELM precursors on the KSTAR tokamak

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Introduction

Oscillations with saturated amplitude up to 10 ms prior to ELMs are observed on KSTAR with ECEi, BES and magnetic diagnostics. The frequency often changes step-wise, but gradual frequency shifts are also observed. The purpose of this work is to contribute to exploring the cause of the frequency change by analyzing the time evolution of the frequency, poloidal wavenumber and flow velocity and other parameters of the oscillations. We use two 2D diagnostics (BES[1], ECEi[2]) which are measuring poloidal segments of the plasma with 1-2 cm poloidal and radial resolution at two different toroidal locations. Unfortunately samplings of signals in the two diagnostics were not strictly synchronous. Therefore we cannot explore the full 3D structure of the modes, just limit the analysis to the 2D sections.

Hypothesis

The signals of the ECEi diagnostics are proportional to the electron temperature at the pedestal and at the inner regions of the plasma, while the signals of D BES are roughly proportional to the electron density. The precursors usually appear in the pedestal or in regions close to it. These oscillations disappear with the ELMs, therefore some connection between them and the instability is assumed.

The precursor amplitude is quasi constant during many periods. Therefore it is suggested that these are not local oscillations, but a global perturbation is frozen into the plasma and its movement is observed as an apparent wave. In a coordinate system moving with the plasma the perturbation is described as

$$p = A(t)\sin(k_\theta x_\theta + k_\varphi x_\varphi) \qquad (1)$$

Here k_φ, k_θ and x_φ, x_θ are the toroidal and poloidal wavenumbers and coordinates, respectively. A(t) describes the slow amplitude variation of the mode. We assume both poloidal and toroidal velocity so as the transformation to the laboratory coordinate system is $x_{i,0} = x_i + v_i t, \mathrm{i} = \theta, \varphi$.

$$p = A(t)\sin\left[k_\theta x_{\theta,0} + k_\varphi x_{\varphi,0} - (k_\theta v_\theta + k_\theta v_\theta)t\right] \qquad (2)$$

Both diagnostics are measuring at a given toroidal coordinate, therefore they give a poloidal section of the plasma. Hence the toroidal coordinate is constant and we choose it to be 0.

$$p = A(t)\sin\left(k_\theta x_{\theta,0} - 2\pi f t\right) \qquad (3)$$

In Eq. (3) the detected frequency can be determined using Eq. (2) and the connection between the wavenumbers and the wavelengths

$$f = \frac{v_\theta}{\lambda_\theta} + \frac{v_\varphi}{\lambda_\varphi}. \qquad (4)$$

Using Eq. (4) we can calculate the apparent poloidal velocity of the structures:

$$v_{\theta,a} = f\lambda_\theta = v_\theta + \frac{\lambda_\theta}{\lambda_\varphi} v_\varphi. \qquad (5)$$

In the 2D measurement we can determine only the apparent poloidal velocity but we have to take into mind, that it is a mixture of the poloidal and toroidal velocities.

Analysis

Three types of precursors can be found in the signals.

- Precursors with discrete frequency changes.
- Precursors with slowly decreasing frequency.
- Precursors with chaotic frequency changes.

In this work the first two types are investigated, because of the very fast frequency changes in the third type.

The several ms long time windows were split into short time windows in the order of ~100μs. In order to define the structures' time evolution, cross power spectral density (CPSD) was calculated for each short time window between the signals of the diagnostics measured from different poloidal coordinates at a fixed radial location. Hanning window was used with 50% overlapping of subsequent short time windows.

First, CPSD was calculated at every radial coordinate between the channels with different poloidal coordinates,. The channel pairs were selected with the following method. At a given radial coordinate one channel was always used and it was paired with different ones with increasing poloidal distance from the fixed one. Figure 1. shows the channel pairs of the D BES signals at a given radial coordinate. (Calculations were done purely in radial and vertical coordinates, the flux coordinates were not used.) The CPSD's absolute value is proportional to the power of the mode and if they are summed up the power spectra show a peak at frequencies with high correlation. Hence, the main frequency range was determined as the frequencies where the summed up CPSD absolute value is bigger or equal of a given percentage of its maximum.

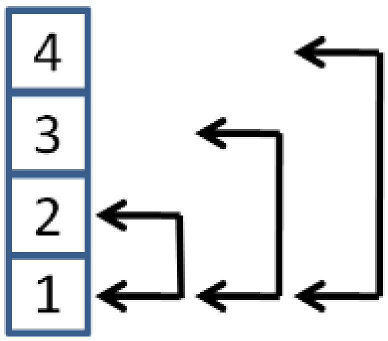


Figure 1.: Channel pairs selection at a given radial coordinate in D BES signals.

For the analysis itself CPSDs of the channel pairs were calculated again for every time window at every radial coordinate for every channel pair. To estimate the parameters of the structures power, phase and frequency were calculated for the frequency range selected with the method described above.

Hereafter, only frequencies were used with absolute value above a given percentage of the maximum one. The dominant frequency was estimated as the average of frequencies weighted with the CPSD absolute value. This way the power distribution over frequency was taken into account. The power of the structure was estimated as the sum of all absolute CPSD values at these frequencies. The phases were estimated as the mean of the phases at the frequencies, where the CPSD absolute value is higher than another given percentage of the maximum value. 2π phase jumps in the processed frequency range were corrected.

At a given radial coordinate further calculations were done using the previously estimated values belonging to the channel pairs. The frequency and the power was determined as the mean of them. At each radial location a linear curve was fitted to the phases as a function of poloidal channel separation and the steepness of it was used as the estimation of poloidal wavenumber, from which the poloidal wavelength was calculated. The apparent poloidal velocity was estimated as the product of the frequency and the poloidal wavelength.

The above numerical method was thoroughly tested using computer generated signals resembling the properties of some real measurements. Special attention was paid to realistically represent the measurement noise, mode amplitude fluctuations, flow velocity and wavenumber changes. The sensitivity of the method was explored using different length time intervals and it was found that, depending on conditions, the parameter changes can be determined with 100-200 microsecond time resolution. This is short enough to reveal changes on the ms timescale observed in the selected experimental examples.

Results

Six typical precursors were investigated up to now. The results from the analysis of one precursor with continuously decreasing frequency, and one with discrete jumps in frequency are shown on the following figures. On figure 2. the radial-temporal power distributions can be seen. A systematic drift is present between the ECEi and BES diagnostic spatial calibration which will be addressed in the future. Otherwise the two cases show a significantly different radial mode localization which is constant during the presence of one precursor event.

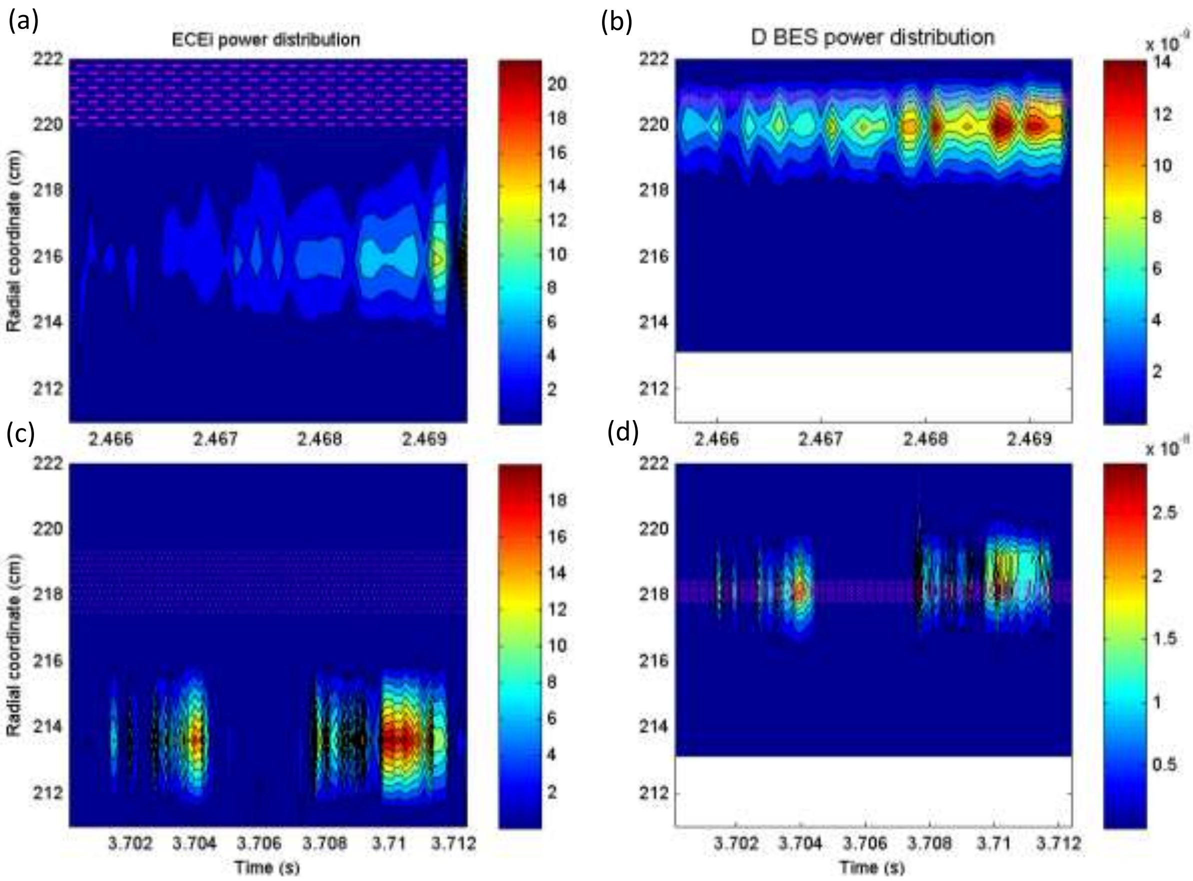
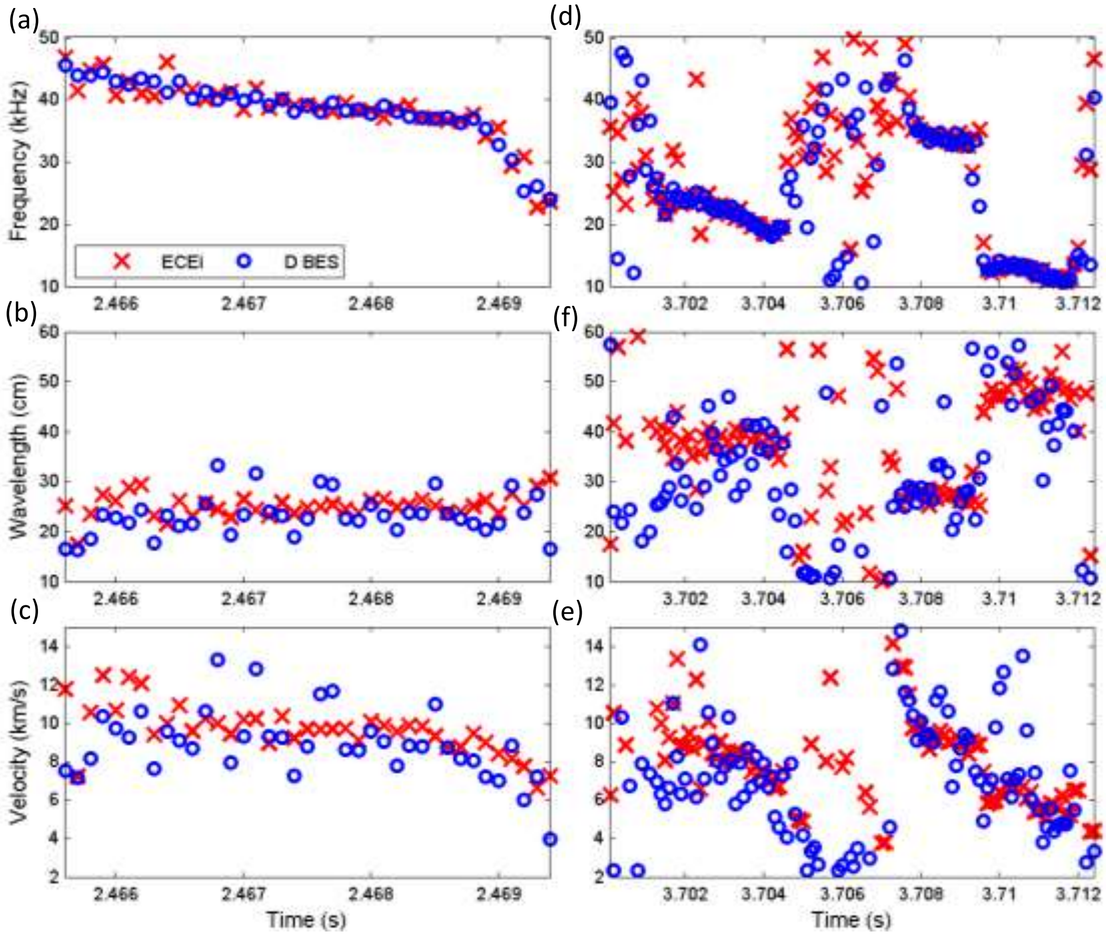


Figure 2.: (a)(b) The power distribution of a precursor with continuously decreasing frequency in the signals of (a) ECEi, (b) D BES diagnostics. (c)(d) The power distribution of a precursor with discrete frequency changes in the signals of (c) ECEi.

The frequency, wavelength and velocity time evolution for the same two events can be seen on Figure 3. The two diagnostics show excellent agreement in the determined parameters when the mode amplitude is significant. In the first case the continuous frequency change is more a response to velocity change rather than wavelength. This would indicate that either the toroidal or poloidal flow is changing during the event. The second case is more complex, it consists of three phases: 3.7015-3.704, 3.708-3.7095 and 3.71-3.712s. The significant frequency changes are clearly related to a poloidal wavelength change, while the (apparent) poloidal flow velocity changes only during the third phase. These significant poloidal wavelength changes are not reflected in the radial localization of the mode.

Summary

Up to now only a limited number of typical precursor events were investigated. The calculated frequency evolutions are consistent in the D BES and ECEi diagnostics. In most cases the wavelength error is large, but changes outside the error bars are clearly observed. The precursors appear to be highly localized radially. More cases are planned to be studied with the method described in this paper in order to obtain a more coherent view on the involved phenomena.



3. picture: The time evolution of frequency (a,d), wavelength (b,f) and velocity (c,e) of a precursor with slowly changing frequency (a,b,c) and one with discrete jumps in frequency (d,e,f).

References

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[2] G. S. Yun et al: *Phys. Rev. Lett.* **107** 045004 (2011)