Acoustic-like modes driven by fast electrons in TJ-II ECR plasmas

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Abstract. Intense harmonic oscillations in radiation signals are commonly observed during ECR heating in TJ-II stellarator plasmas with low line-averaged electron density ($0.15 < n_e < 0.6 \times 10^{19}$ m^{-3}). Their nature is mostly electrostatic (rarely detected with Mirnov coils or ECE detectors) and their frequencies scale with acoustic speed. The poloidal modal structure is compatible with Geodesic Acoustic Modes (GAM) [1] but an n≠0 toroidal structure is detected. The modes are localized in the proximity of low order rational values of the rotational transform (such as $1/q$ = 8/5, 5/3) and seem to be excited by fast electron populations. The presented observations might contribute to energetic-particle-induced GAM [2] phenomenology.

Experimental observations and mode characterization.

The TJ-II is a four-period flexible Heliac with low magnetic shear and major and averaged minor radii of 1.5 m and ≤ 0.22 m, respectively. Plasmas of interest here ($0.15 < n_e < 0.6 \times 10^{19}$ m^{-3}) are started with ECR heating ($P_{in} \leq 600$ kW, 2 gyrotrons, at 53.2 GHz, 2nd harmonic, X-mode polarization). The main diagnostic used in this investigation is the bolometer system, consisting in fast AXUV photodiodes arranged in three 16-channel arrays with identical viewing geometry and three 20-channel arrays for tomography [3].

Thousands of discharges produced under different magnetic configurations of the TJ-II operational space (i. e., $2.2 \geq \iota(0) \geq 1.2$), different wall conditions (all metal, metal/C, Be and Li coating) and different gases have been examined. It has been found that low frequency modes appear very frequently and, although a more extended study is necessary, several characteristics can be stated at this moment.

1) Magnetic configuration dependence.

We have compared discharges with a) similar plasma parameters but different magnetic configurations and b) similar configurations but different plasma parameters.

As an example, figure 1 shows in the upper row the power spectra of one bolometer signal with impact parameter $\rho = r/a \approx 0.5$; averaged electron density and diamagnetic energy are plotted in the central row, and the lower row contains the corresponding rotational transform profiles in vacuum of the three magnetic configurations. Comparison a) is made between left and central columns, and comparison b) between left and right columns. It is apparent that the ~ 20 kHz mode is excited only in configurations whose rotational transform profile contains a low-order rational value close to the periphery.

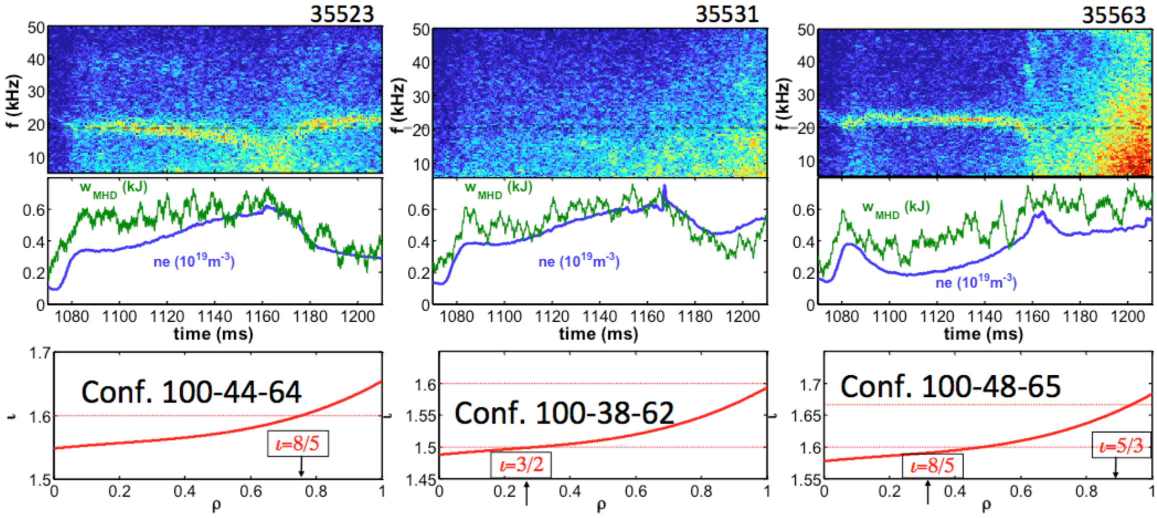

Figure 1. Mode excitation dependence on magnetic configuration (see text).

2) Electron temperature and ion mass dependence: frequency scaling.

Now, keeping fixed the magnetic configuration, we have compared discharges with a) same gas but different plasma parameters and b) similar plasma parameters but different gas.

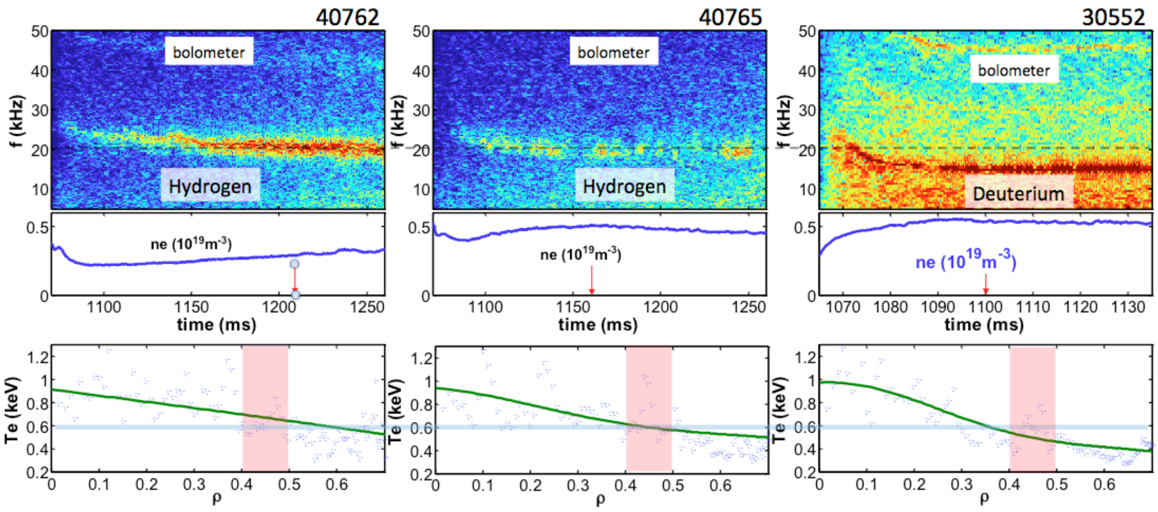

Figure 2. Mode excitation relation with plasma parameters and ion mass. Configuration 100-44-64. See text.

Figure 2 shows in the upper row the power spectra of one bolometer signal with impact parameter $\rho \approx 0.5$; averaged electron density is presented in the central row, and the lower row contains the corresponding electron temperature profiles at the time instants marked with the short red arrows. Comparison a) is made between left and central columns, and comparison b) between central and right columns. It is apparent that the mode frequency is not (much) dependent on n_e, but on m_i and/or T_e.

As the mode is not detected with magnetic coils, we have assumed that it has electrostatic nature. Then, using the typical ion temperature value in ECRH plasmas of ~ 80 eV and the measured values of electron temperature in the region where the mode shows the maximum amplitude, we have computed the expected frequency for two acoustic waves: the ion sound wave (ISW) and the geodesic acoustic wave (GAM). This is represented in figure 3.

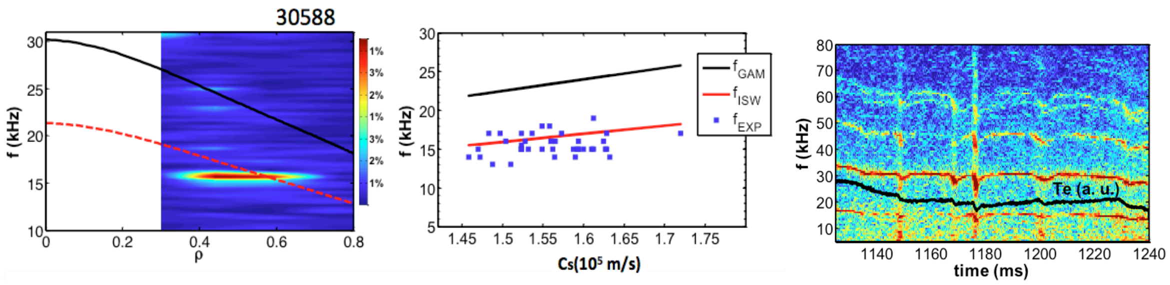

Figure 3. left: Maximum intensity location of the fundamental mode and calculated frequencies $f_{\rm ISW} = C_s / 2\pi R$ and $f_{\rm GAM} = \sqrt{2}\, C_s / 2\pi R$ for the experimental T_e profile; centre: Experimental mode frequency versus the sound speed for around 40 deuterium discharges in configuration 100-44-64. For comparison, the expected GAM and ISW frequencies at $\rho \approx 0.5$-0.6 are also plotted; right: Fast effect on mode frequency of a sudden decrease of T_e / m_i provoked by impurity entrances. $T_e (\rho = 0.45)$ is over plotted to compare with frequency evolution.

3) Localization.

Although we have used the line integrals, i. e., not the local values of emissivity, it is still possible to determine at least the external limit of the mode. Typically, the signals of the outermost detectors do not reveal any coherent 'electrostatic' fluctuation of the considered frequencies. From left to right, figure 4, shows the toroidal distribution of bolometer arrays in TJ-II; the lines of sight of one 16-channel array; the correlation of detector signal #8 (central chord) with the all the array signals in one poloidal sector, and the toroidal correlation of the signals from detectors D3, A3 and B3 ($\rho = 0.45$). We have over plotted a sort of m=2 structure compatible with the 'poloidal' correlation pattern shown below. Correlation is performed for a narrow band around the frequency of the first harmonic.

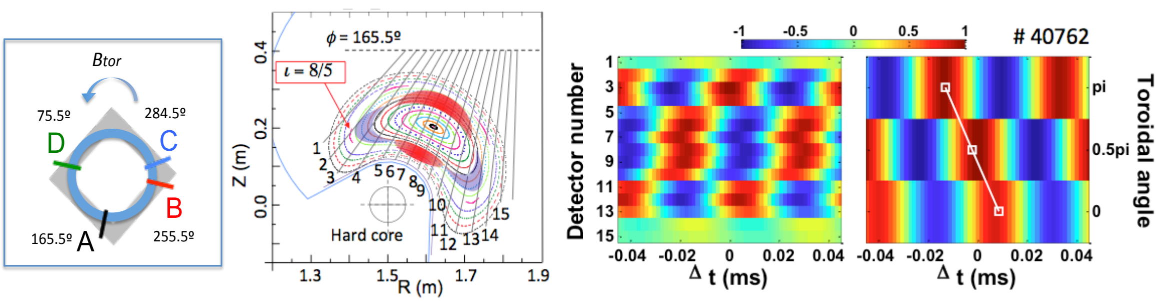

Figure 4. Sketch of the bolometer system and poloidal and toroidal correlation patterns for the first harmonic.

In toroidal direction, a phase-shift $\Delta\phi = \phi/2\pi$ (being ϕ the toroidal angle) in the emissivity oscillations is seen. As 'propagation' is opposite to the toroidal magnetic field direction, the deduced mode number is n=-1.

4) Relation with fast electrons.

The electron distribution function plasmas heated with ECR usually departs from maxwellian and it is known that, in TJ-II, fast electrons survive for rather long times (~50 ms) in the vicinity of rational surfaces [4]. In figure 5 the relation between the loss of fast electrons with frequency and intensity of the mode can be seen (see caption).

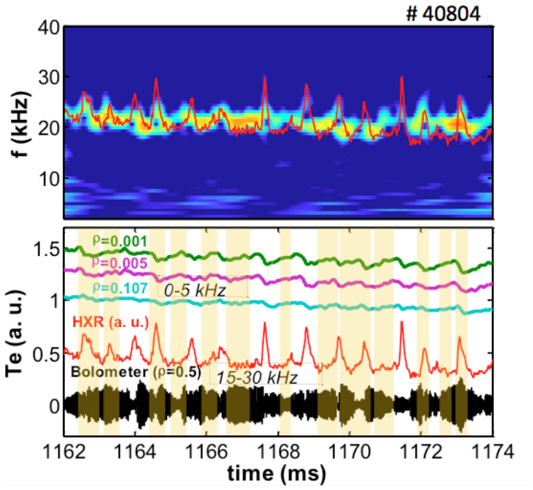

Figure 5. Mode behaviour in relation with fast electrons. When pulses of fast (E_{sth} ≥ 80 keV) electrons are released, mode frequency chirps down. The time evolution of the central electron temperature signal is sawtoothing, in coincidence with the spiky hard x-ray (HXR) signal. The mode amplitude recovers right after the spikes, during the fast electrons well confinement periods. Configuration 100-44-64.

Summary.

Acoustic-like modes have been detected in low collisionality TJ-II plasmas using fast bolometer arrays toroidally distributed.

The frequency of the modes is generally below that of standard GAM and seems to scale with acoustic speed. Commonly, several harmonics are detected with variable intensities.

The modes are linked to low-order rational surfaces located near the plasma periphery.

In the few occasions that a magnetic component is also detected, the deduced poloidal mode number of the fundamental harmonic is m ≈ 2. Toroidal phase shift analysis of signal spectra from detectors with equivalent lines of sight yields a toroidal mode number n ≈ -1.

Excitation and mode characteristics appear to be related to fast electrons transport.

Acknowledgement

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