Observation of high frequency edge coherent modes in ASDEX Upgrade

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1. Introduction

The modes observed in a tokamak plasma are related to instabilities caused by different drives. The goal is to describe the mechanisms and to identify the basic properties of such instabilities, which can be measured in the experiment. High-frequency edge coherent modes (ECMs) have been detected during the experiments dedicated to the L-H transition studies on ASDEX Upgrade (AUG). Previous experiments on different devices reported the onset of high frequency edge coherent modes with $f > 40$ kHz in high confinement regimes [1, 2, 3, 4]. This contribution summarises the results obtained in a study of ECMs in AUG. They appear in different plasma confinement regimes, such as the I-phase [5, 6] or the H-mode.

2. Reflectometry methods

In AUG two systems of profile reflectometry and a poloidal correlation reflectometer are installed. The FM-CW reflectometer in O-mode provides electron density profiles by sweeping the frequency in 20 μs. It has antennas installed on the low magnetic field side (LFS) and the high field side (HFS). The same system can produce density fluctuation frequency spectra [7].

The ultra-fast swept reflectometer (UFSR) has provided electron density profile measurements with a time resolution of 1 μs [8]. Fast and repetitive sweeps provide an equivalent sampling rate of 800 kHz at a given probing frequency. The probing frequency can be expressed as a monotonic function of the radial position $F(R)$ using an averaged density profile. Due to the density profile dynamics during an FFT time window, each reflectometer frequency probes a different radial position from one sweep to the next around an average position, hence the actual shift of the profile can introduce an additional extension of the estimated mode position.

Poloidal correlation reflectometry (PCR) provides measurements of the mode's velocity and

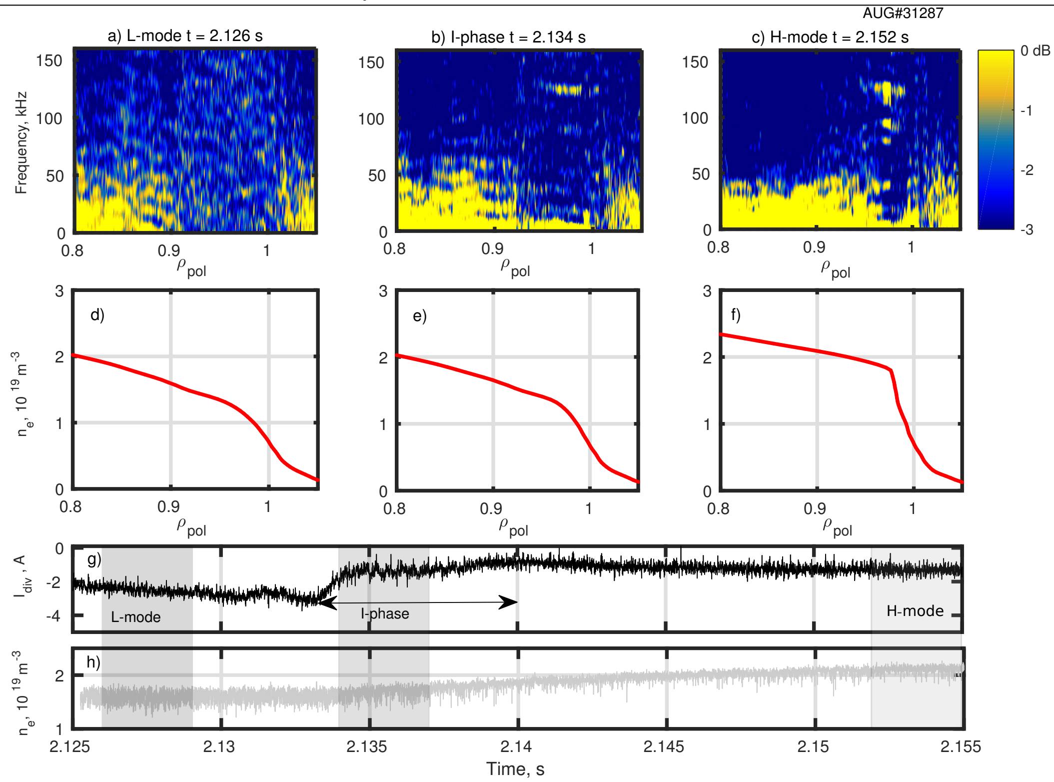

Figure 1: Density fluctuation frequency power spectra in (a) L-mode, (c) H-mode and (b) during I-phase, corresponding averaged electron density profiles (d-f), divertor current indicating the confinement transition (g) and pedestal top density (h), shaded area correspond to the time windows used for the spectra calculation.

poloidal size, which allows the identification of the mode number. In addition the temporal dynamics can be studied on a time scale of the window used in the FFT. The PCR system on AUG [9] consists of 5 antennas separated poloidally and toroidally. The mode perpendicular wavenumber $k_\perp$ is found from the ratio of the phase difference between the oscillation's maxima for a pair of antennas to the poloidal separation between the antennas. The poloidal velocity in the laboratory frame is estimated as $v_\perp = 2\pi f/k_\perp$ and the toroidal mode number can be determined as $n = R_0 k_\perp \sin(\alpha)$, where α is a pitch angle and R_0 the radial position of the mode.

3. Observation of edge coherent modes

Different edge coherent modes (ECMs) have been detected in the reflectometer signals during the experiments dedicated to L-H transition studies on AUG [10]. The mode frequency is in the range of 40–200 kHz and often several branches are observed simultaneously. ECMs were previously investigated in AUG in between ELMs [3, 11], although they were not yet identified. During the I-phase the ECMs are less pronounced than in between ELMs.

Figure 1 illustrates the development of ECMs after the L-mode (a) during the I-phase (b) and in H-mode (c) in a low density discharge #31287 with 1.6 MW of ECRH. In the pedestal region during the I-phase the density fluctuation amplitude decreases and the spectra become

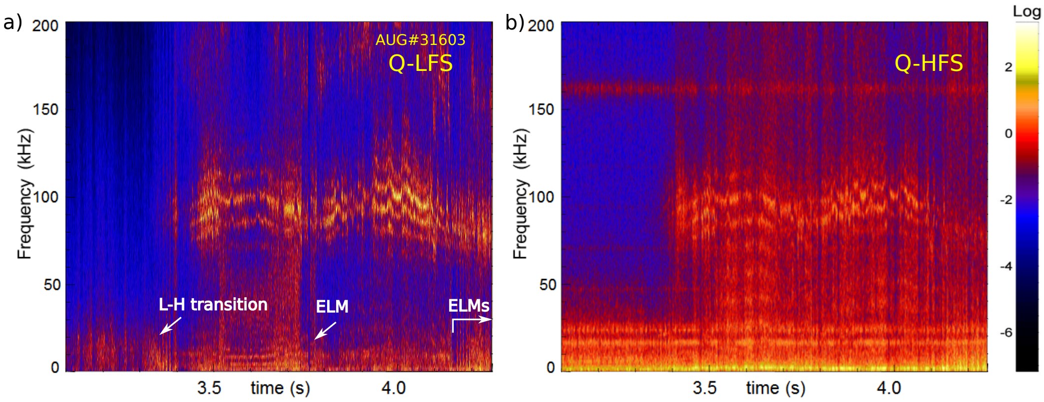

Figure 2: Spectrogram of phase fluctuations during ELM-free phase of the H-mode reconstructed from the FM-CW reflectometer signal with $F_{prob} = 39$ GHz (a) from the LFS and (b) from the HFS.

narrower compared to typical L-mode spectra (Fig. 1a) which are more broadband. Modes at about 120 kHz start to grow directly at the transition from the L-mode to the I-phase in the edge region $0.95 < \rho_{pol} < 0.99$ (Fig. 1b,e) and their amplitude saturates during the ELM-free phase of the H-mode (Fig. 1c). Due to the effect of the averaging the modes size appear to be around 2.5 cm, although from the analysis of individual profiles the size is of about 1.5 cm. From the wavenumber spectra it follows that the ECMs have a small radial wavenumber $k_r < 4\ \mathrm{cm}^{-1}$. The oscillations occur within the range of 60–80 GHz of UFSR probing frequencies, corresponding to the edge region inside the separatrix.

The magnetic pick-up coils were used to deduce the toroidal mode numbers as described in [11]. The toroidal mode numbers vary between $n = -5$ and -12 for the lowest to the uppermost branch and the modes propagate in the electron diamagnetic direction in the laboratory frame. From the same discharge the temporal evolution of the mode frequency has been compared to the density and temperature dynamics. The best fit for the density and temperature dependence is $f \propto n_e T_e$ on the top of the pedestal. Note that the microtearing mode frequency scales with the electron diamagnetic velocity also proportional to the electron pressure gradient.

In an ELM-free phase of an H-mode the ECMs were observed in the FM-CW reflectometer spectrograms at several O-mode frequencies, corresponding to the edge region $0.95 < \rho_{pol} < 1$ (Fig. 2). The amplitudes are slightly stronger at the LFS. Hence, it is possible that the ECMs do not have a strong ballooning character, which would exclude kinetic ballooning or peeling-ballooning modes (KBM and KPBM) as well as trapped electron (TEM) or electron temperature gradient (ETG) modes, although the absolute calibration of the FM-CW reflectometer channels is needed to draw a final conclusion. The modes appear after the transition to the H-mode (at $t = 3.32$ s), saturate until the first solitary ELM arrives at $t = 3.75$ s and disappear afterwards.

After the ELM the mode amplitude starts to grow again until the next type-I ELMs ($t = 4.2$ s).

Using different pairs of the PCR antennas, the toroidal mode numbers were identified between $n = -9$ and -12. The perpendicular wavenumbers are about 0.2–0.4 cm^{-1}. The perpendicular velocity is $v_\perp = 23 \pm 5$ km/s, which is higher than the diamagnetic estimate of $\mathbf{E} \times \mathbf{B}$ velocity for this discharge of about 10–15 km/s and corresponds to a phase velocity in the electron diamagnetic direction. This fact and the localisation in the pedestal region including pedestal top would be consistent with microtearing modes as source of the observed coherent fluctuations. However, if the ECMs are located substantially in the region of $\mathbf{E} \times \mathbf{B}$ velocity maximum, their phase velocity should be small and would characterize KBM or KPBM.

4. Conclusions

The observation of ECMs during L-H transitions led to a more detailed documentation of the edge modes in ASDEX Upgrade in the range of 50–200 kHz. The UFSR data locate the modes in the plasma edge $0.93 < \rho_{pol} < 0.99$ and, from the comparison between the probing frequencies and the density profiles, mostly in the gradient region. ECMs have toroidal numbers between $n = -5$ and -12 and propagate in the electron diamagnetic direction. ECMs have a small radial wavenumber $k_r < 4$ cm^{-1} and a perpendicular wavenumber of about $k_\perp$ =0.2–0.4 cm^{-1}. The impact of ECMs on plasma confinement needs to be investigated in the future.

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References

[1] Burrell K H et al., Plas. Phys. and Cont. Fusion **44** (2002)
[2] Perez C P et al., Plas. Phys. and Cont. Fusion **46** (2003)
[3] Laggner F M et al., Plas. Phys. and Cont. Fusion **58** (2016)
[4] Mink A et al., Nucl. Fusion **58** (2017)
[5] Conway G D et al., Phys. Rev. Lett. **106** (2011)
[6] Birkenmeier G et al., Nucl. Fusion **56** 2016
[7] Cupido L et al., Rev. Sci. Instr. **77** (2006)
[8] Clairet F et al., Rev. Sci. Instr. **88** (2017)
[9] Prisiazhniuk D et al., Plas. Phys. and Cont. Fusion **59** (2017)
[10] Medvedeva A et al., Plas. Phys. and Cont. Fusion **59** (2017)
[11] Mink F et al., Plas. Phys. and Cont. Fusion **58** (2016)