CHARACTERISTICS OF EDGE QUASI-COHERENT MODE IN THE EDA H-MODE ON HL-3

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High confinement mode (H-mode) [1] in magnetic fusion devices is considered as the optimal plasma scenarios for ITER and future fusion reactors, due to its high energy and particle confinement. However, the steep edge plasma pressure gradient in H-mode usually leads to the edge localized modes (ELMs) [2-4]. The collapse of the pedestal by ELM causes rapid burst of energy and particles from the confined plasma onto the divertor target plates, which can induce severe erosion of plasma facing components, posing significant risks to the fusion devices. Thus, Effective control of ELMs is crucial for maintaining plasma stability and improving fusion device performance [5]. One of a promising approach is to utilize naturally ELM-free high-confinement regimes, which operate without the disruptive effects of ELMs, offering significant potential to enhance plasma performance and ensure the stable operation of future fusion reactors. The EDA H-mode [6] exhibits several desirable features, including excellent energy confinement, no impurity accumulation, and natural ELM-free operation, making it a promising candidate for future fusion reactors. Recently, EDA H-mode has been achieved in the HL-3 tokamak. This work reports the characteristics of edge quasi-coherent mode (QCM) in the EDA H-mode on HL-3.

Figure 1 illustrates the waveform of a typical EDA H-mode discharge on HL-3. In this scenario, auxiliary heating is provided by Neutral Beam Injection (NBI) with a power of 1.5 MW [Figure 1(a)]. The plasma undergoes a transition from low to high confinement mode (L-H transition) at approximately 1.08 s, as indicated by a decrease in divertor D_α intensity [Figure 1(b)]. Following the L-H transition, the plasma density [Figure 1(c)] and stored energy [Figure 1(d)] increases dramatically, with an energy confinement factor $H_{98,y2}$~1 [Figure 1(d)], indicating the improved plasma confinement. The divertor D_α intensity decreases initially at the L-H transition, and then rises subsequently. No ELMs are observed during the H-mode. A QCM is observed in the edge density fluctuation spectrogram measured by Doppler reflectometry, as shown in Figure 1(e). The QCM initially appears at a higher frequency of approximately 60 kHz shortly after the L-H transition and gradually decreases to about 20 kHz. However, the frequency of QCM increases later to about 40~50 kHz. This ELM-free H-mode, characterized by an enhanced D_α level, exhibits high energy confinement and is accompanied by a QCM in the edge region, consistent with the typical characteristics of the EDA H-mode. A comparison of the plasma profiles in L-mode at 1.04 s and H-mode at 1.28 s of discharge #6269 is presented in Figure 1(f) and 1(g). Inside the last closed flux surface (LCFS), a steep gradient can be observed in the H-mode for both density and temperature profiles, indicating the formation of edge transport barrier in density and temperature. This edge transport barrier contributes to the enhanced confinement in the EDA H-mode. The ability to sustain a stationary edge pedestal in the EDA H-mode, without the relaxation typically induced by ELMs, is likely attributed to the QCM.

Figure 2(a) and (b) shows the poloidal and radial wavenumber spectrum of the QCM, respectively. The QCM exhibits a frequency range between 20 and 60 kHz, with a radial wavenumber of k_r = 0~0.5 cm^{-1} and a poloidal wavenumber of k_θ = 0.4~0.8 cm^{-1}, propagating in the electron diamagnetic drift direction. Moreover, it has been found that the QCM is localized in the edge pedestal region, with its peak observed near the top of the pedestal, indicating that the mode is driven by the edge steep plasma pressure gradient. The nonlinear interaction between the QCM and the background turbulence could have important implications for understanding the dynamics of the edge region, particularly in relation to edge particle transport and confinement in the absence of ELMs.

References

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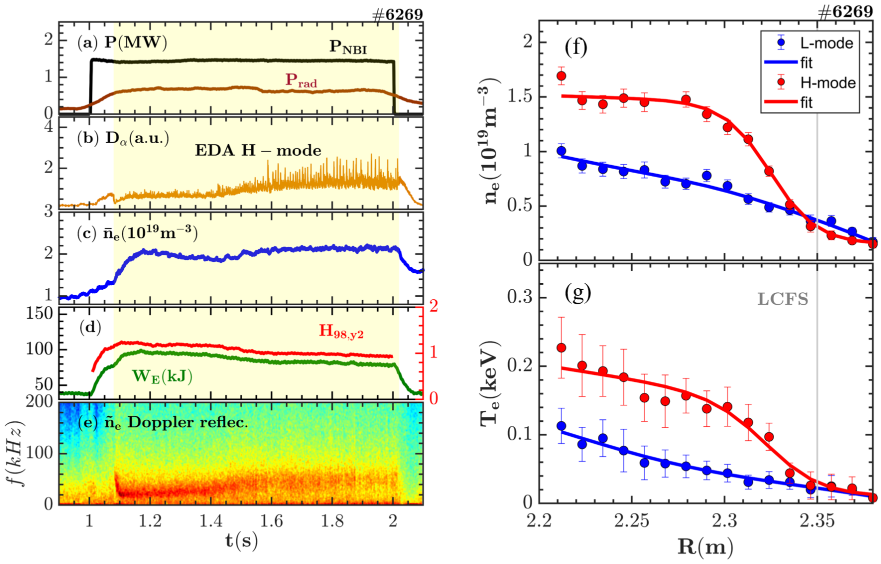

Figure-1. A typical waveform of EDA H-mode on HL-3: (a) NBI heating power (black) and radiation power (brown), (b) divertor D_α intensity, (c) central line averaged electron density, (d) plasma stored energy (green) and energy confinement factor $H_{98,y2}$, (e) spectrogram of edge density fluctuation measured by Doppler reflectometry, Comparison of plasma profiles in L-mode (t = 1.04 s) and EDA H-mode (t = 1.28 s): (f) Edge density profiles, (g) edge electron temperature profiles.

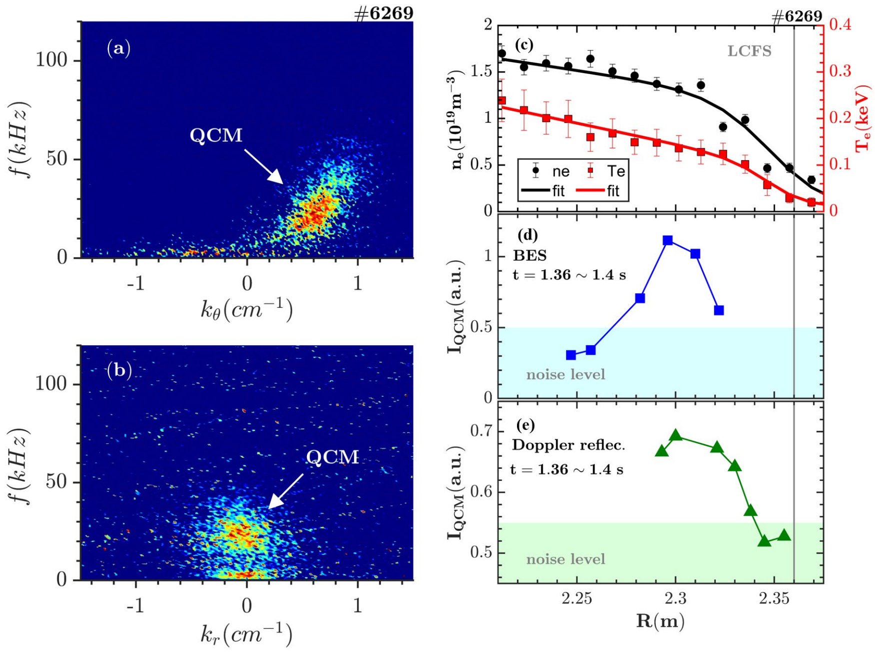

Figure-2. (a) poloidal wavenumber spectrum of the QCM, positive value indicates electron diamagnetic drift direction, (b) radial wavenumber spectrum of the QCM, positive value indicates outward propagation, (c) density and temperature profiles in H-mode, (d) radial distribution of QCM amplitude measured by BES, and (e) radial distribution of QCM amplitude measured by doppler reflectometry.