Effect of ECRH and LHW on pedestal instabilities in Type-I ELMy H-mode of the HL-2A tokamak

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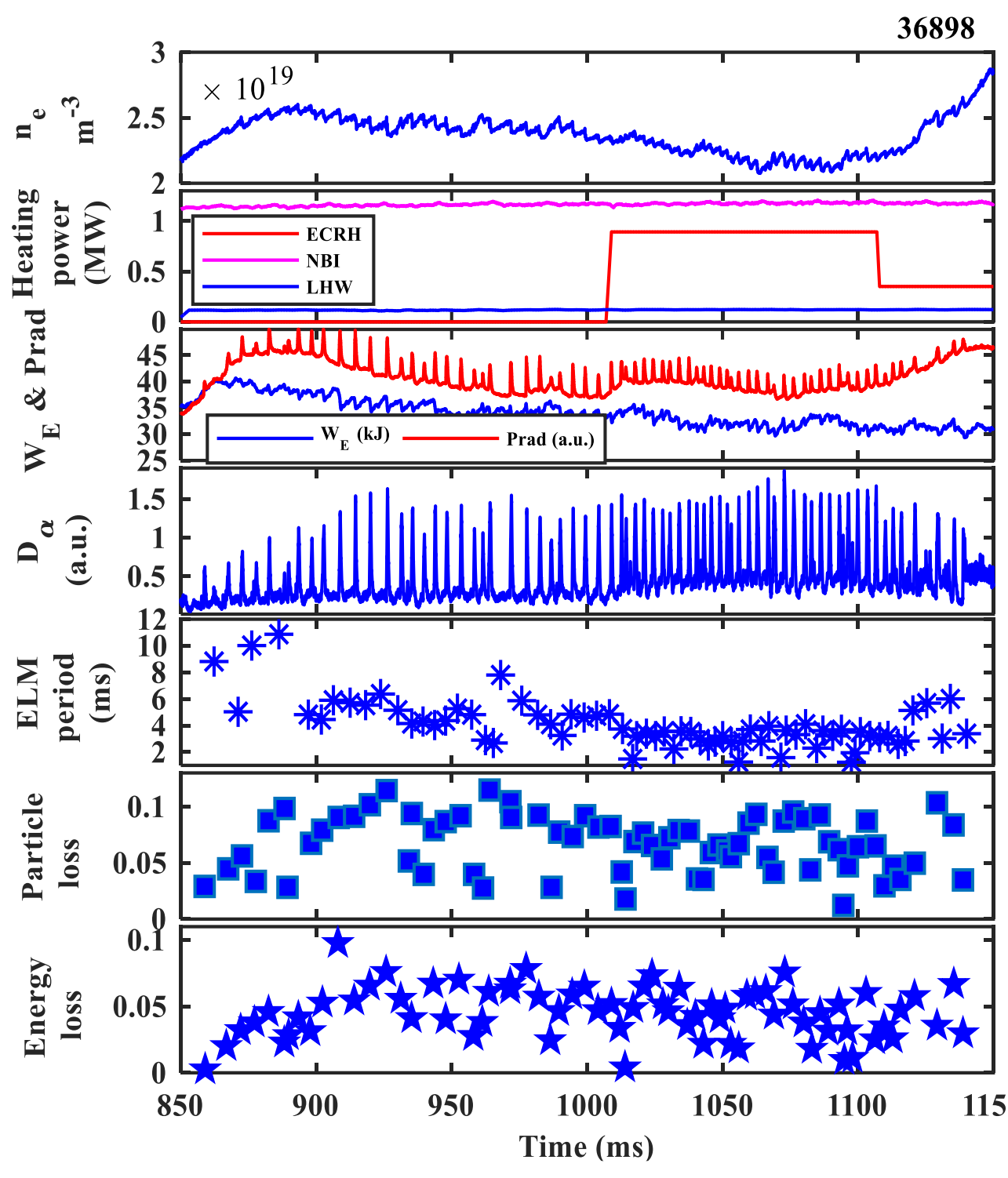
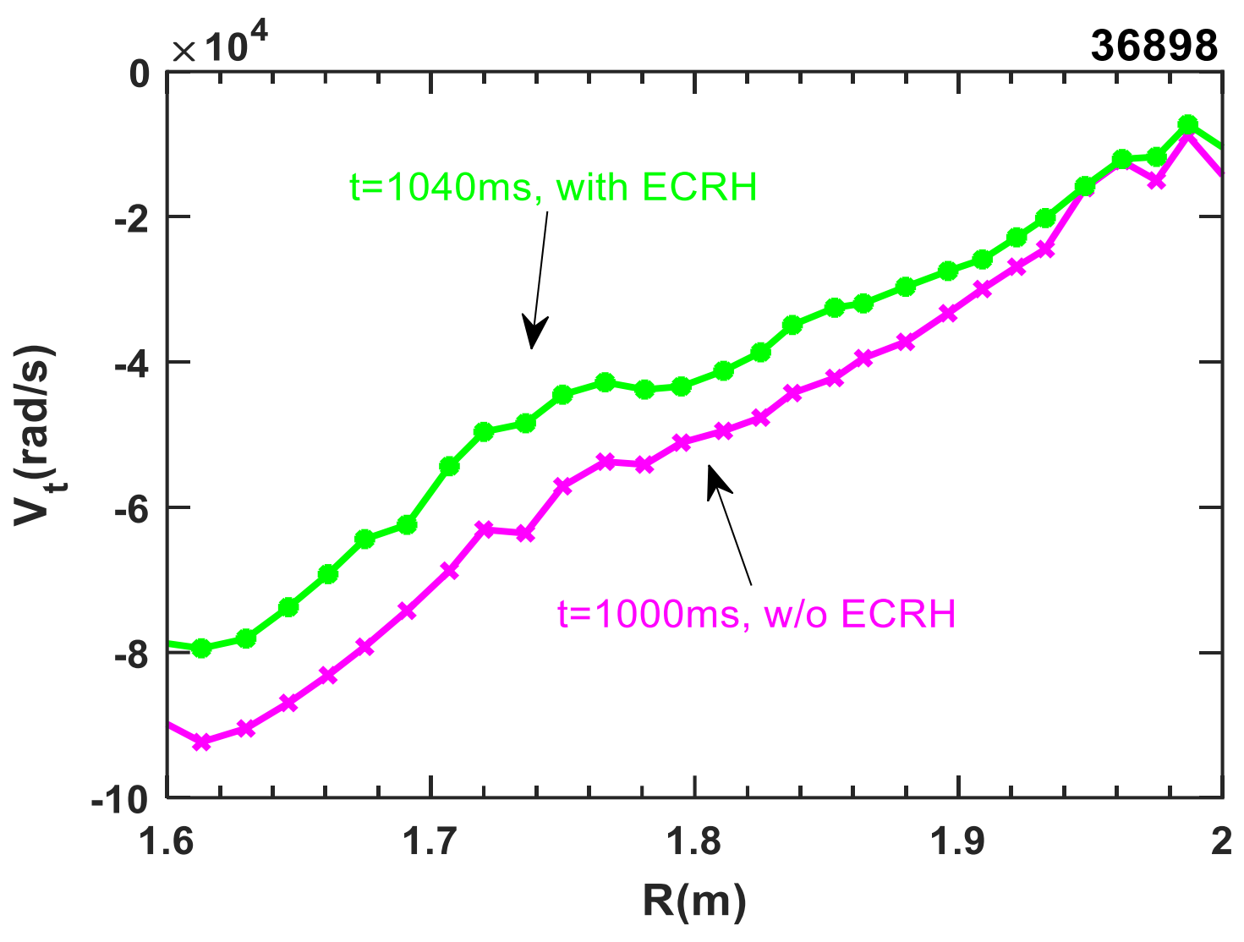
Part I Impact of off-axis ECRH on Type-I ELMs

- For the H-mode plasmas with ECRH, the ELM behaviors change accordingly. Fig. 1. illustrates the typical characteristic of Type-I ELMs, where the frequency increases with the heating power. In this shot, the power of ECRH is deposited around r = 25 cm. The ECW was perpendicularly injected into the plasma from low field side (LFS). Plasma radiation power increases lightly in the front part of ECW injection. The particle loss and energy loss keep almost constant for the periods with and without ECRH. To study the impact of ECRH on ELMs, the power deposition location has been scanned by changing the toroidal filed (B_T). The ECRH heating powers are almost identical (0.5~0.6 MW) and the ELM periods are about 6 ms without ECRH. However, it decreases from 4.5 ms to 2.7 ms with ECRH power deposition location moving from plasma core region (r/a = 0.35) to edge region (r/a = 0.8). The result suggests that edge ECRH makes it easier to ELM burst earlier, and the toroidal rotation can be affected by ECRH. ECRH decreases the plasma rotation not only in the central region but also in the edge region. The theoretical work predicted that the sheared toroidal rotation can reduce the growth rate of the high n modes.
- The results in HL-2A indicate that the reduction of co-current toroidal rotation increases the ELM frequency. As the shear of the plasma rotation has a stabilizing effect on MHD modes, the reduced V_t and softened rotation shear might have destabilized effect on ELM.



ECRH increases the ELM frequency

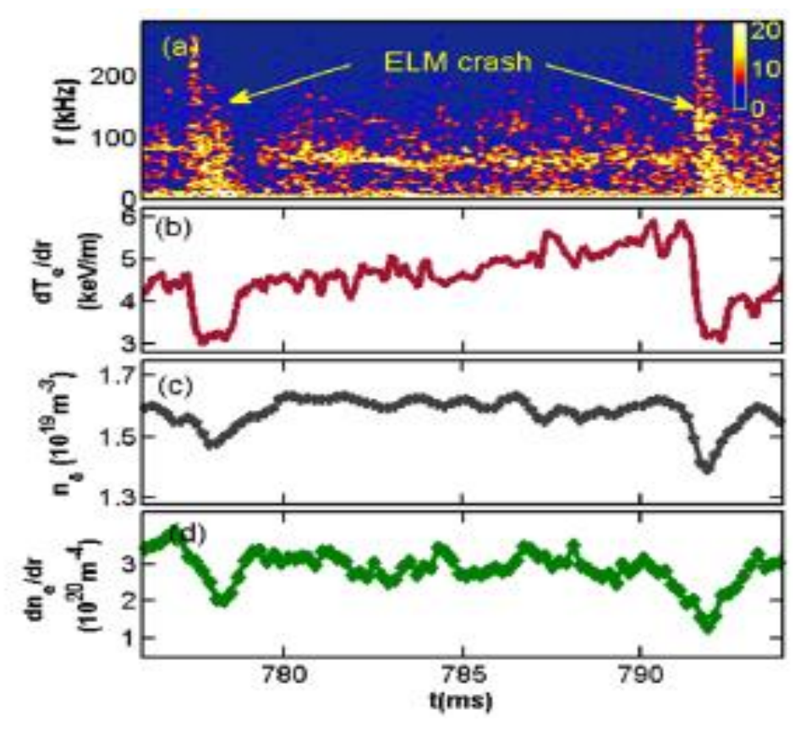


Profiles of V_t in the cases of without and with ECRH, reduced V_t and softened rotation shear might have destabilized effect on ELM

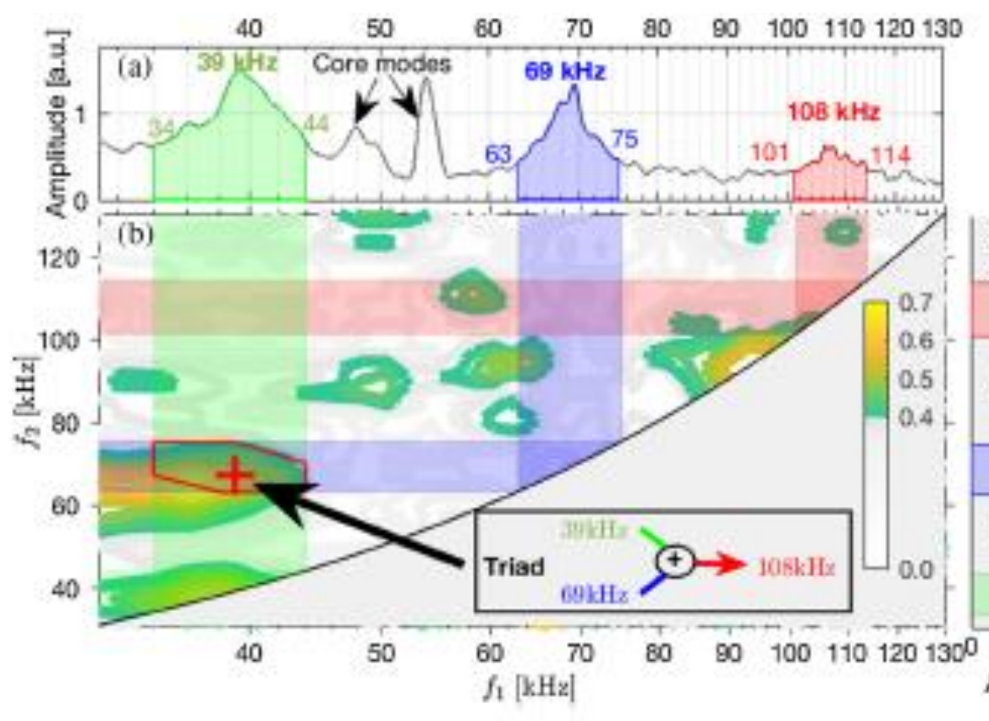
Part II Observation of a pedestal quasi-coherent mode in type-I ELMs

BACKGROUND

- Pedestal instability research is important and necessary. (1) The high pressure gradient and high current density of pedestal could provide free energy for exciting instabilities, like ELMs. (2) ELMs will lead to the rapid collapse of pedestal structure, and simultaneously lots of particles and energy will be erupted to the first wall and divertor targets in a short time. (3) It is very meaningful to understand and control the pedestal dynamics and the evolution process of ELM burst.
- Quasi-coherent mode (QCM) is a phenomenon between coherent modes and broadband turbulence. It plays an important role in regulating pedestal dynamics. (1) QCM driven by the pedestal density gradient can in return affects the pedestal density evolution. (2) Nonlinear coupling between QCMs during inter-ELM phases can lead to the ELM onset. (3) Edge coherent mode drives a significant outflow of particles and heat, thus greatly facilitating long pulse H-mode.
- This poster continues the research of pedestal QCM, and its role in the interactions on pedestal dynamics and transport, contributing to explore the general physical laws in different tokamaks, especially in type-I ELM plasmas



W.L. Zhong, PPCF 2016 (HL-2A)



A. Diallo, PRL 2018 (DIII-D)

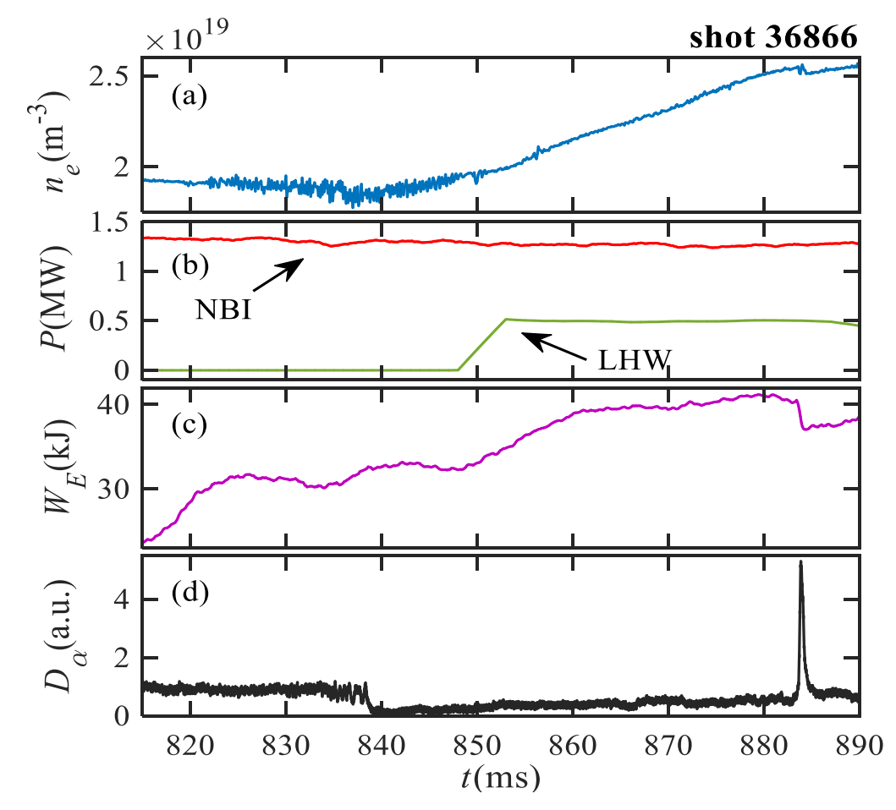
Experimental setup

HL-2A tokamak

HL-2A is a medium-size tokamak with the double null and full closed divertor configuration [35]. Its major/minor radius are R/a = 1.65/0.4 m. HL-2A has achieved the following operational parameters, the toroidal magnetic field B_T = 2.7 T, the plasma current I_P = 430 kA, the line-averaged electron density $n_e = 6 \times 10^{19}$ m-3, respectively.

Discharge parameters

HL-2A tokamak has carried out H mode discharges with Type-I ELMs, a QCM has been observed in such discharges. This poster mainly aims at shot 36866. Its toroidal magnetic field and plasma current are B_T = 1.31T and I_P = 165 kA respectively, and the main discharge parameters during the 815 – 890. The available auxiliary heating power includes 1.3 MW neutral beam injection (NBI) contributed by two tangential beamlines, and 0.5 MW lower hybrid current drive (LHCD) at 3.7 GHz. The ELM-free stage lasts about 46 ms long in Type-I ELMy H-mode, after L-H transition at 838 ms but before the first ELM burst at 884 ms. The NBI heating begins at 800 ms while the LHCD starts around the 850 ms. After the L-H transition, the core line-average electron density continues to increase.



Discharge parameters

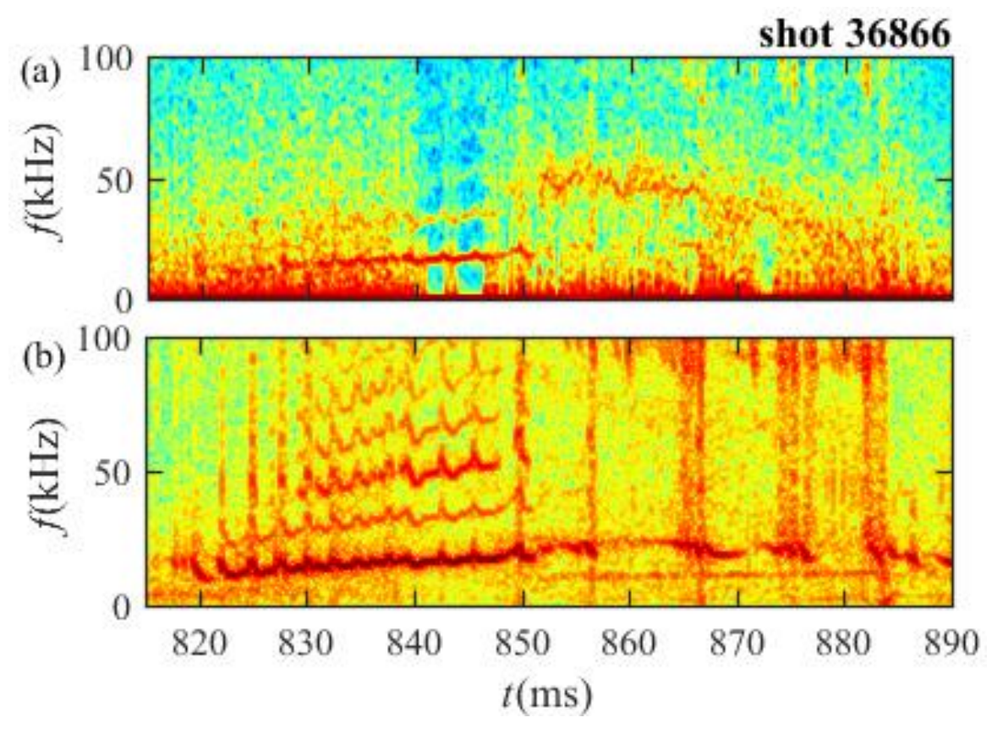
CONCLUSION

- In summary, a pedestal QCM has been experimentally observed in HL-2A Type-I ELM H mode plasmas. It exists during the ELM-free stage till the first ELM burst. Its characteristic frequency gradually changes from 50 kHz to 20 kHz. This QCM shows strong electrostatic fluctuations in turbulent measurements. The QCM is located at pedestal region, its radial wavenumber is $k_r \sim 0.8\ cm^{-1}$ and propagates radially outward, while its poloidal wavenumber is $k_\theta \sim 1.4\ cm^{-1}$ which rotates the electron diamagnetic direction. The QCM's characteristic frequency variation is linearly related to edge toroidal velocity. Experimental results show that this QCM is driven by pedestal density gradient during its rising phase, which reveals a critical density gradient value. The QCM could limit the further increase of pedestal density gradient in H mode plasmas.

- In discussion, previous results show when the QCM disappeared, the first ELM burst at the same time. But QCM has no obvious modulation on the ion saturation current density of divertor probes. The nonlinear interaction may exist between this QCM and pedestal dynamics. And more theory and simulation work combining the experiments also needed in order to unveil the mystery.

Characteristics of QCM

The QCM is electrostatic fluctuation dominated

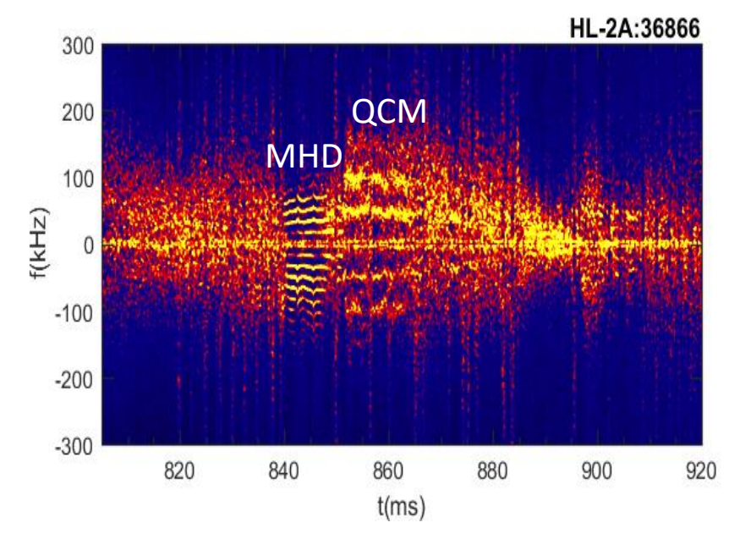


(a) turbulent density fluctuation is measured by DBS, (b) the magnetic fluctuation is measured by Mirnov coils.

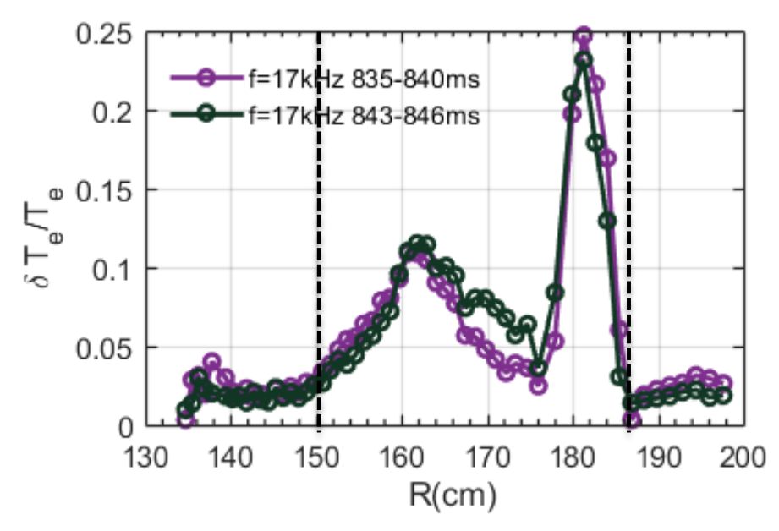
The QCM has been found mainly in turbulent density fluctuations and was firstly observed with a multi-channel Doppler backward scattering reflectometer (DBS) with 31 GHz channel in ordinary mode (O-mode) detection. During the auxiliary heating, a QCM around 50 kHz has been excited close to the MHD disappearance. At 850ms, the QCM is excited at 50 kHz with second harmonic at 100 kHz, even the weak third harmonics at 150 kHz. Its characteristic frequency gradually decreases from 50 kHz to nearly 20 kHz till the first Type-I ELM burst at 884 ms. The ELM-free state lasts long for 46 ms till the first ELM burst and the QCM disappeared at the same time. However, the 50 kHz QCM has not been found in any magnetic fluctuation measurements. So, the QCM is an electrostatic dominated instability, which has been simultaneously observed in DBS and beam emission spectroscopy (BES) diagnostics.

The fishbone MHD

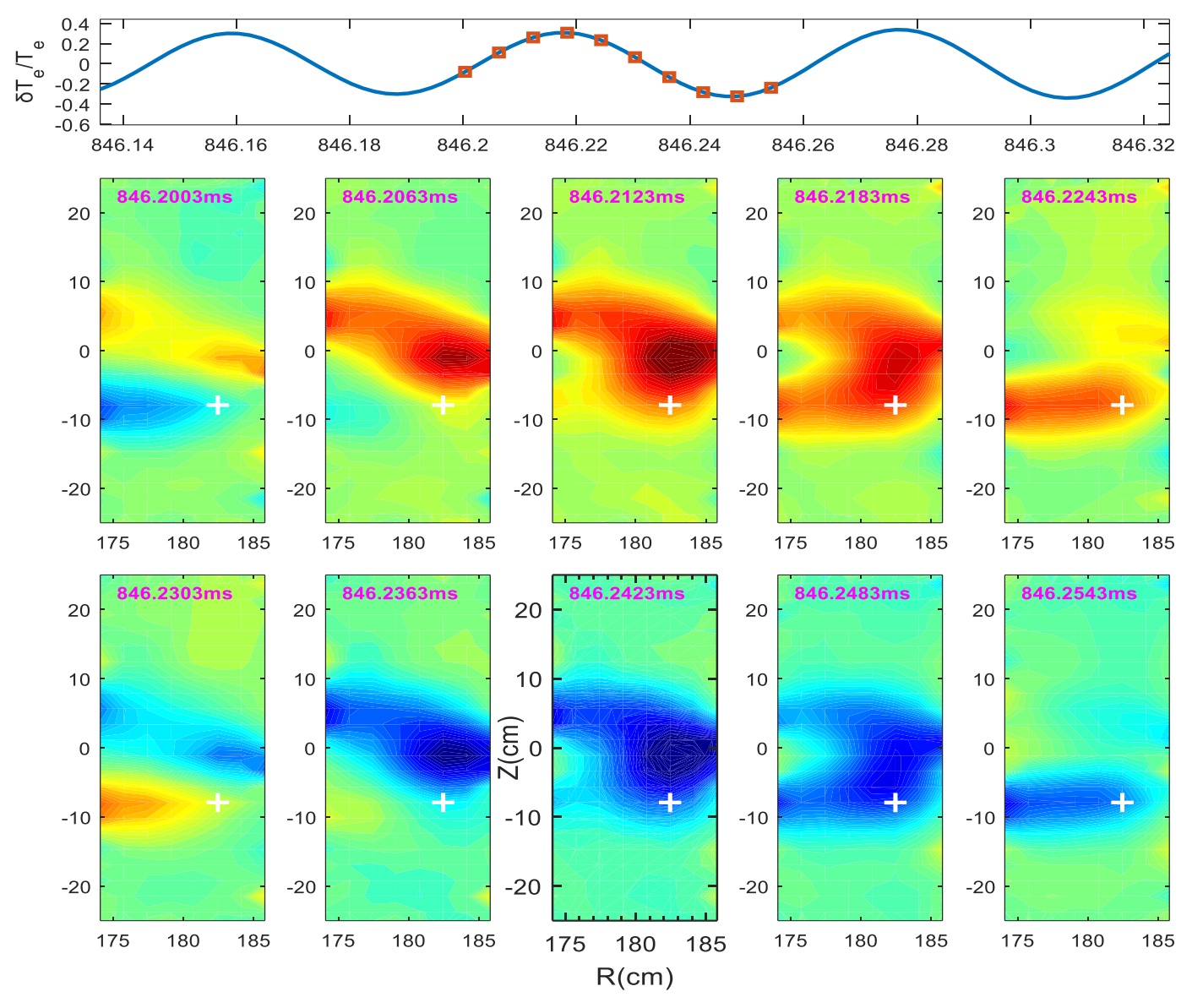
A strong MHD coherent mode has been shown with frequency at around 17 kHz and several strong harmonics. The MHD begins at 818 ms and becomes weak when the LHCD starts. The QCM is excited at 850 ms. The electron cyclotron emission imaging (ECEI) and electron cyclotron emission diagnostic results show the above MHD is m/n = 1/1 continuous fishbone instability which located around q=1 surface



Compare MHD and QCM

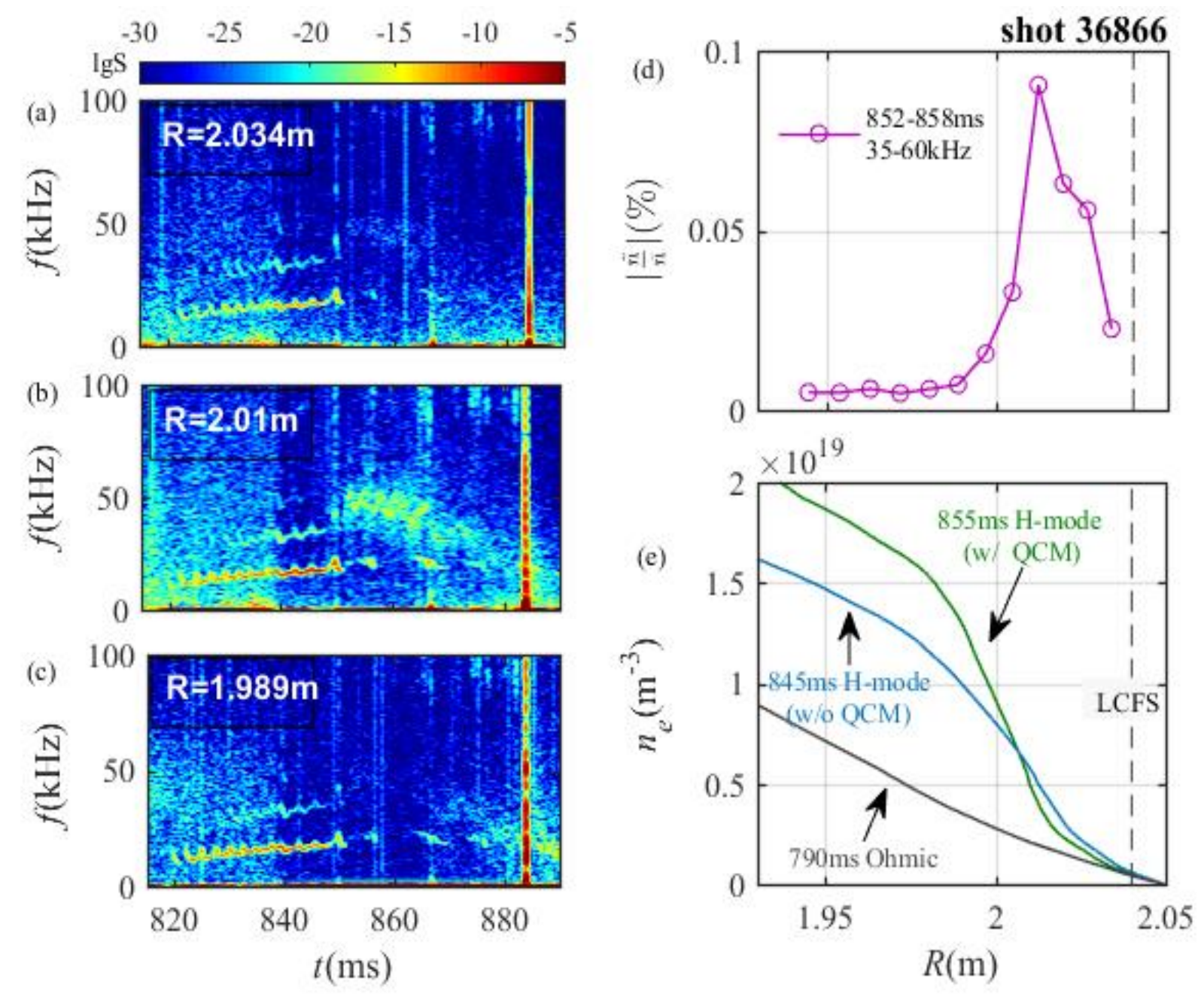


MHD near q=1 surface



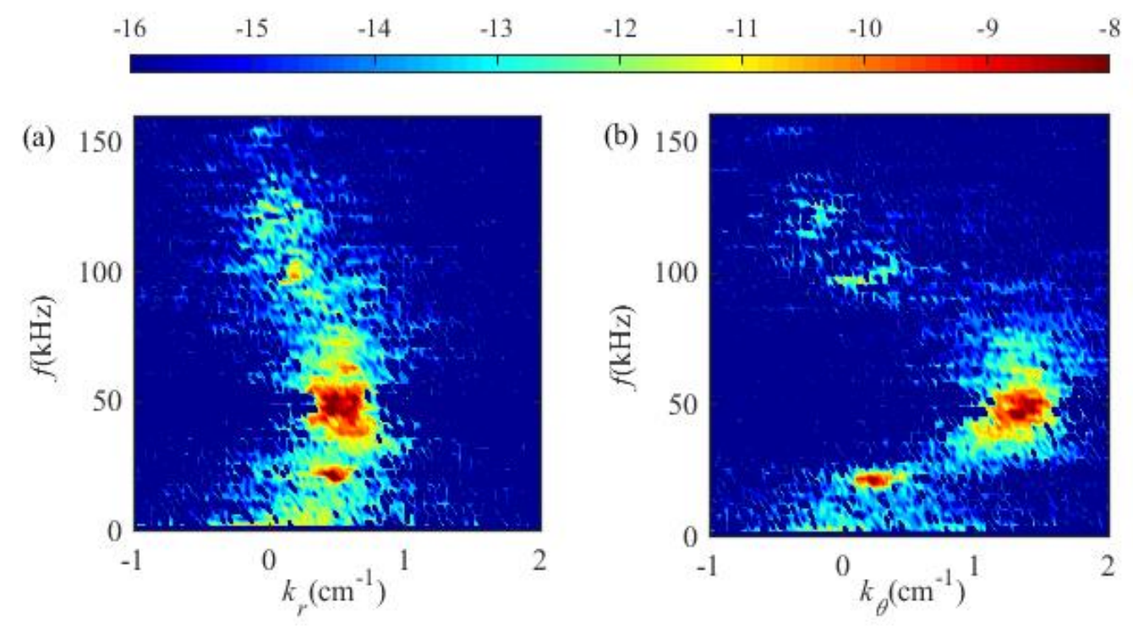
ECE imaging of MHD

QCM mode structure

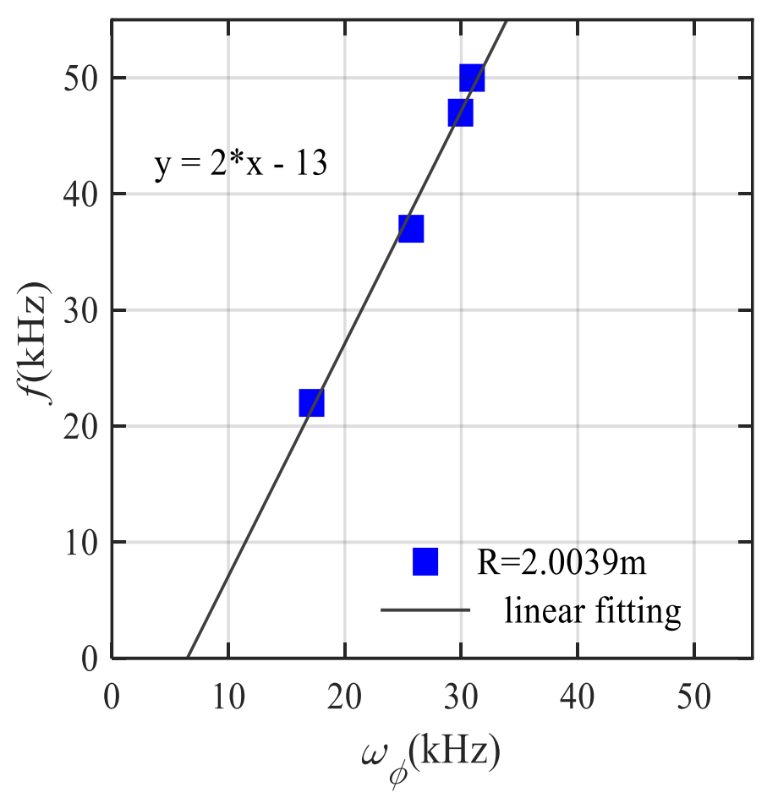


QCM located at pedestal

- Partial channels of BES diagnostic at R = 2.034 m, R = 2.01 m, and R = 1.989 m have been. 35 kHz to 60 kHz of turbulent density fluctuations are accumulated and normalized during 852 – 858 ms.
- Multi-channel BES and FMCW measurements indicate that QCM located at pedestal region.
- The wavenumber spectra were obtained by cross-correlation analysis from two neighboring radial/poloidal BES channels. The radial wave number of the QCM is $k_r \sim 0.8\ cm^{-1}$ and it is radially propagating outward. While the poloidal wave number is $k_\theta \sim 1.4\ cm^{-1}$ and it propagates in electron diamagnetic direction.



Wavenumber of QCM

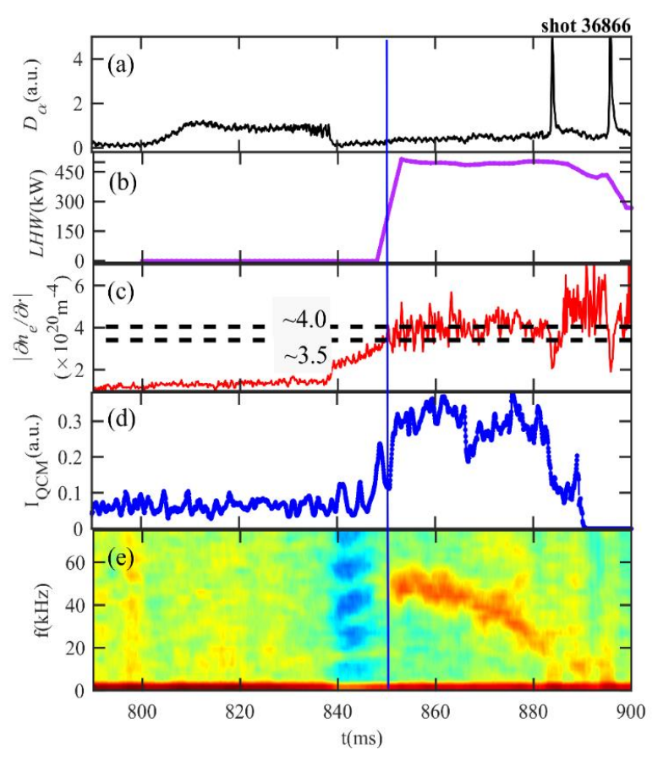


- According to the charge exchange recombination spectrum (CXRS) diagnostic, toroidal velocity has been calculated of the whole radial range during the NBI heating. It shows that the QCM frequency variation is linearly related to the edge toroidal velocity tendency.

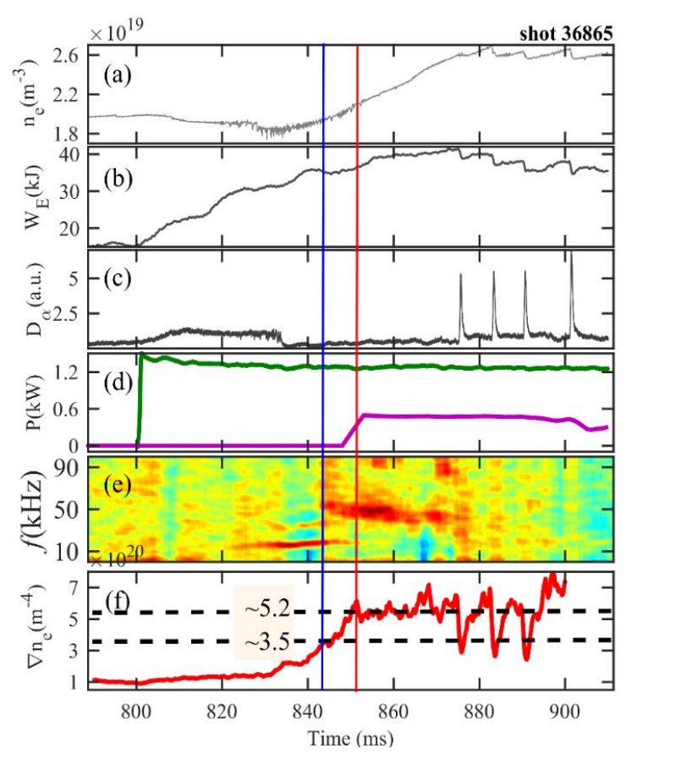
Edge toroidal velocity and QCM frequency

QCM is driven by pedestal density gradient

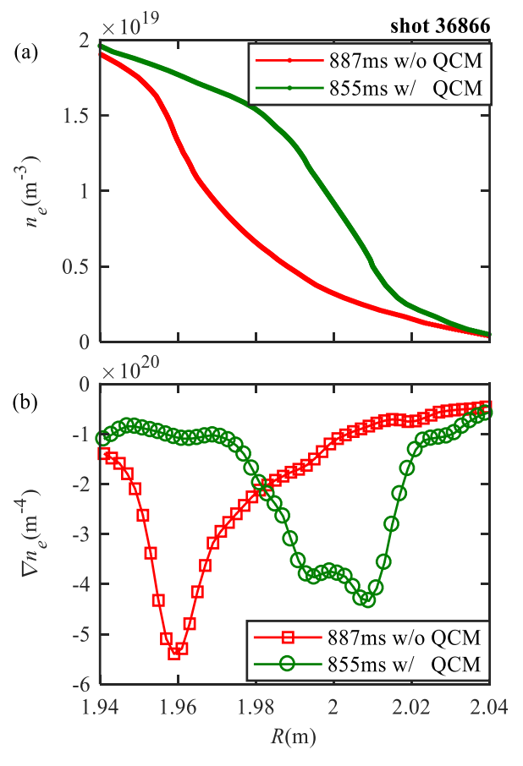
- The discharge parameters of shot 36865 are similar to the shot 36866.
- The maximum electron density gradient at pedestal region has been calculated from FMCW diagnostic. The QCM strength has been accumulated along its center frequency variation with 20 kHz band-pass filter.
- This QCM has limited the pedestal density gradient to increase and it may be a good advantage in delaying the ELM burst, thus sustaining the ELM-free state.
- Both the two shots show QCM is excited during pedestal density gradient rise and is driven only by the pedestal electron density gradient when it exceeds a threshold value at about $\nabla n_e = 3.5 \times 10^{20}\ m^{-4}$.



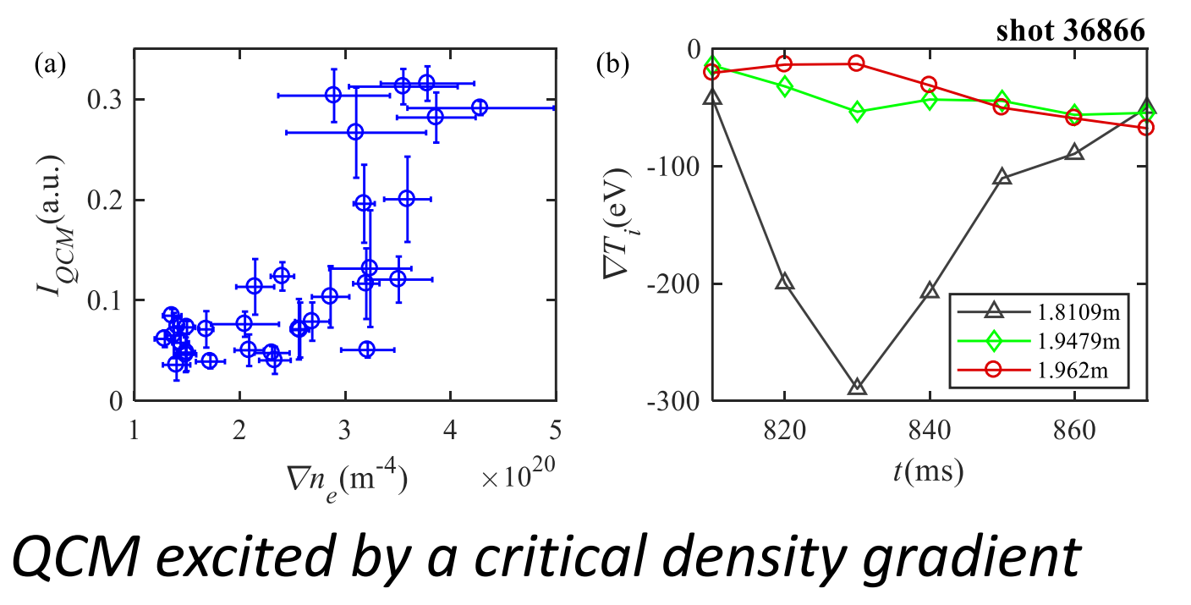
QCM intensity



QCM excited before LHCD



Effect on pedestal



QCM excited by a critical density gradient

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