Characterization of the electron density profile dynamic and flow velocity modulation during oscillations close to the L-H threshold at COMPASS

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Introduction

A new confinement regime is being investigated as a candidate for a limit cycle oscillation (cLCO) at the COMPASS [1] tokamak, appearing near the L-H transition, and identified by a low frequency (~3-5 kHz), divertor D_α oscillation. Similar phenomena were observed at the JET [2], ASDEX Upgrade (AUG) [3] and other tokamaks as well. This contribution aims at adding the COMPASS results to a previous study [4] which addressed the JET and AUG phenomena in terms of density pedestal dynamics and magnetic oscillation studies. The outstanding performance of the COMPASS Lithium beam emission spectroscopy (Li-BES) system enables us to resolve the phenomenon in more detail, namely the flow velocity and turbulence amplitude modulation.

Li-BES measurements

The investigation of the density profile dynamics, turbulence and flow velocity modulation became possible with the Li-BES diagnostic which is capable of density profile measurements up to the pedestal top with ~1 cm spatial and ~4 μs temporal resolution [5], beam light fluctuation measurement with 1 μs temporal resolution, and quasi 2D virtual beam measurement with 4 μs time resolution.

Density profile dynamics

Density profile modulation analysis was carried out on shot #13931 (B_T=-1.15 T, I_p=190 kA, n_e=5.5×10^{19} m^{-3}, Ohmic), which aimed at a stable cLCO scenario without transition to H-mode. Figure 1 shows the spectrogram of the HFS D-α light emission signal, the analyzed interval is indicated with a black rectangle. The Li-beam was operated in 100 kHz fast chopping mode, providing sufficient background correction on the cLCO period timescale

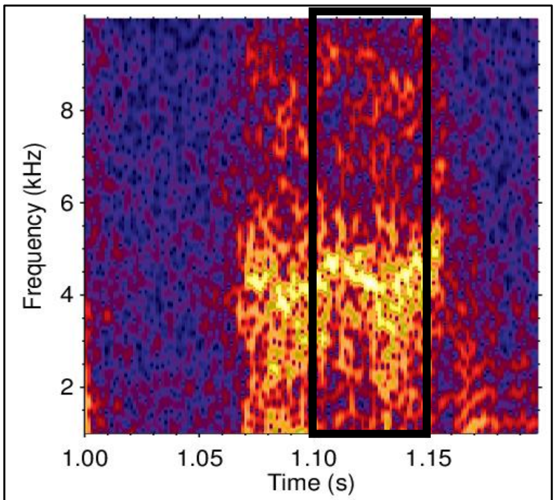

Figure 1.: Spectrogram of D-α radiation of the HFS divertor. Analyzed time range indicated with a black rectangle.

(~250µs). The density profiles were reconstructed from the relative calibrated, background corrected light signal. The density profile averaged for two phases of the cLCO is shown in Figure 2 as a function of the normalized poloidal flux coordinate (ρ_{pol}). The "cLCO on/off" profiles (red/blue) correspond to profiles averaged over increased/decreased SOL radiation levels, taking a 2-6 kHz bandpass filtered outer ($\rho_{pol}\approx 1.05$) BES channel background modulation as a reference. The estimated error of the profiles is indicated by the dashed lines. The profiles match within error between $0.6<\rho_{pol}<0.9$ and also in the far SOL, while differing significantly in the $0.9<\rho_{pol}<1.1$ range. The height of the pedestal does not change over the cLCO cycles, but the width and accordingly the gradient does. The modulation is the highest at the foot of the pedestal and in the SOL. The density profile is more flat when the SOL radiation is increased, and steeper when the SOL radiation is decreased.

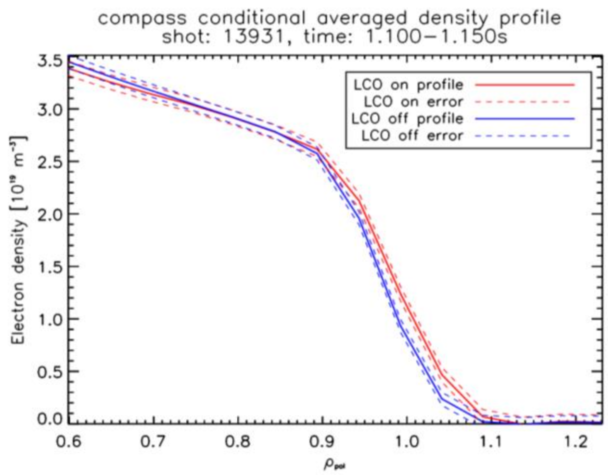

Figure 2.: Conditional averaged density profile, red is when the SOL radiation is high, blue is when the SOL radiation is low, solid line is the profile, the dashed lines are the errors.

Density profile and BES signal HFB power modulation relation

Modulation of the fluctuation power in a high frequency band (HFB) (10-250 kHz) of the BES signal is also detected, and most emphasized at the middle of the pedestal during this phenomenon. In the edge region the light fluctuations are roughly proportional to the local density fluctuations therefore we consider the beam light fluctuation as a proxy for density fluctuation.

The HFB power modulation signal is calculated by filtering the

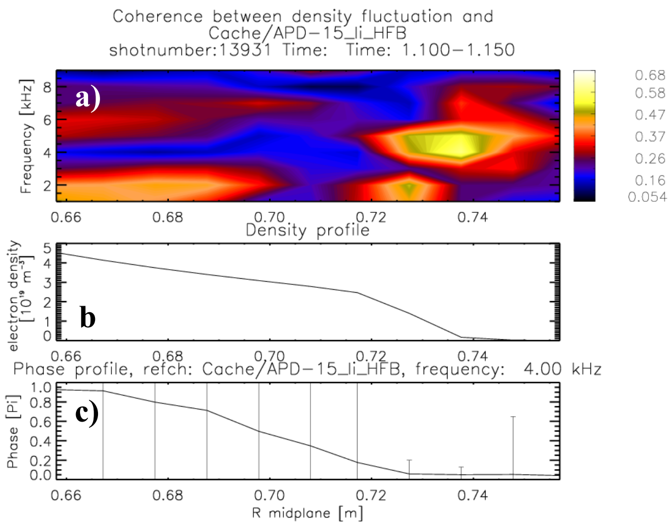

Figure 3.: (a) coherence of the HFB power modulation signal at the middle of the pedestal with the density, confidence level ~0.2; (b) averaged density profile; (c) phase between the HFB power and density at the relevant cLCO frequency.

background subtracted Lithium emission signal with a 10-50 kHz bandpass digital FIR filter, taking its square and integrating with a 1 μs time constant integrator. Figure 3 shows the coherence between the density and the HFB power modulation (a), the averaged density profile (b) and the phase profile at the cLCO frequency (c). The coherence plot shows that the density profile is influenced by the cLCO from the top of the pedestal out, the strongest modulation is seen at the pedestal bottom. The phase of the density modulation relative to the HFB modulation is close to 0 everywhere where the coherence is high. This means that the pedestal density profile is the flattest and the SOL density is the highest when the HFB activity at the middle of the pedestal is most intense.

Flow velocity modulation

The fast deflection measurement mode [6] hops the beam between two vertical positions with high frequency. This moves the intersection of the beam and the observation between two poloidal positions, therefore the poloidal flow velocity can be determined from the shift of the correlation maximum (Time Delay Estimate, TDE) between the two poloidally offset virtual beam signals. The Flow Velocity Estimate (FVE) is calculated as the poloidal displacement of the virtual beams over the TDE, however, this method overestimates the flow velocity [7]. The FVE estimation was carried out on a conditionally averaged dataset, based on the bandpass filtered outer BES signal as

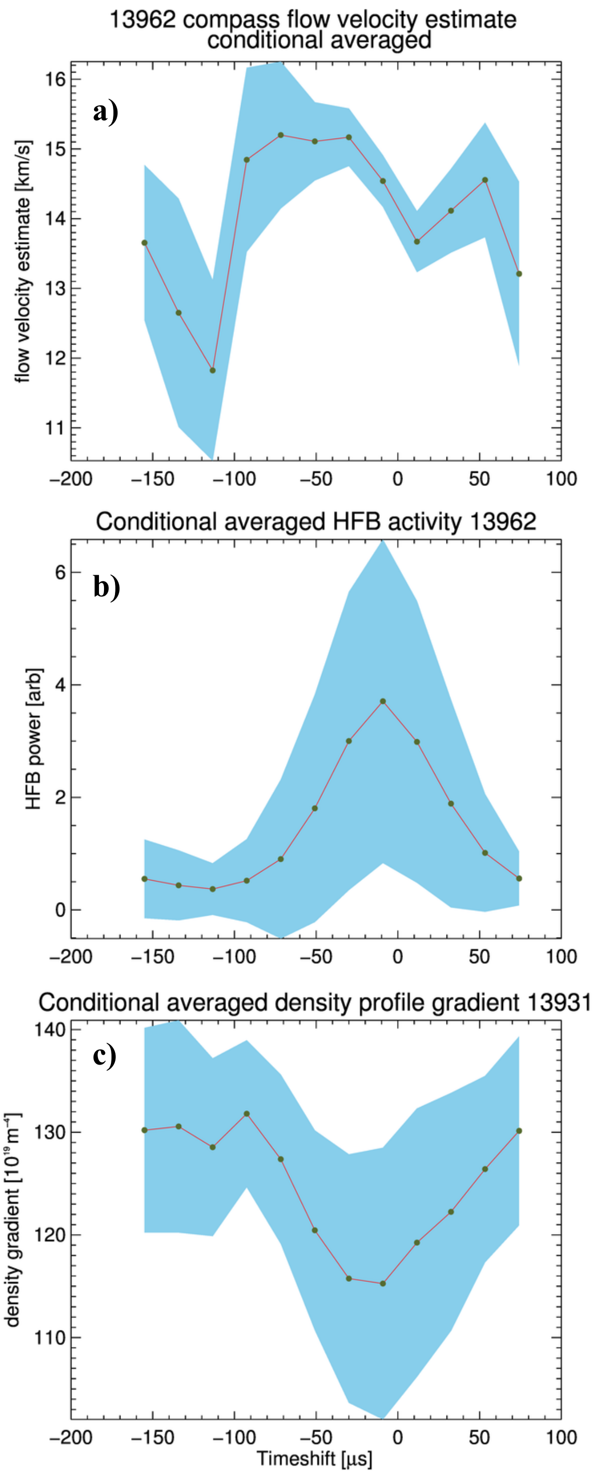

Figure 4.: Flow velocity estimate (a) HFB power in a pedestal BES signal (b) and the density gradient (c) as a function of the time shift of the conditional averaging time windows. The 1σ errors are indicated with blue.

described before. The time range of the analysis was 1.12 - 1.145 s in shot #13962 which corresponds to ~90 cycles of the cLCO. The discharge aimed at a transition to H-mode by an Ohmic heating ramp (I_p=190-250 kA ramp, B_T=-1.15 T, n_e=6*10^{19} m^{-3}, Ohmic). The ~55 µs long conditional moving average windows were shifted from -160 µs to +80 µs in 12 steps to cover the 250 µs period time of the ~4 kHz cLCO. Figure 4 (a) shows the FVE as a function of the shift of the conditional averaging time windows. One green point in this plot can be considered as the average FVE over the selected time intervals shifted by the time on the x axis. The change of the FVE indicates, that the flow velocity is modulated by the cLCO. Figure 4 (b) shows the HFB activity, while (c) the density profile gradient evolution (from shot #13931 where the cLCO had similar frequency) as a function of the time windows time shift. The 1σ standard error of the mean is indicated with blue in each plot. The FVE minima lags the HFB activity maxima in the $-50\ \mu s < \tau < 30\ \mu s$ range when the HFB activity is high. No conclusions can be drawn about the FVE when the HFB activity is low, since the sensitivity of the method is low in the absence of turbulence. The density profile evolution is close to counter phase with the HFB activity.

Summary

Our analysis revealed that the cLCO close to the L-H transition at COMPASS modulates the electron density profile at the pedestal mostly at the foot and in the SOL. The density fluctuations in the 50-200 kHz band in the pedestal are also modulated, the fluctuation amplitude is approximately in opposite phase to the density gradient. The flattening of the profile happens simultaneously with density increase in the SOL. The poloidal flow velocity of turbulence is also modulated by the cLCO, but no clear phase relation can be drawn, and further investigation of the phenomenon is needed. Also, the density pedestal dynamics similar with findings at JET M-mode and AUG I-phase. [4]

Acknowledgments

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