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Pedestal ECE data interpretation for turbulence characterization with a synthetic diagnostic

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Although a powerful local electron temperature fluctuation diagnostic, ECE (Electron Cyclotron Emission) data interpretation is complicated by insufficient optical depth and non-local radiation effect when being used for pedestal turbulence characterization. Consequently, the diagnostic data are a mixture of density fluctuations δn_e and temperature fluctuations δT_e. Forward modeling of the ECE radiation at the pedestal is thus essential in interpreting the measurements. Here, synthetic ECE [1] is applied to enhance the capability of ECEI (ECE-Imaging [2]) in characterizing an ion scale turbulence, which occurs during ELM (Edge Localized Modes) suppression with RMP (Resonant Magnetic Perturbation) in the DIII-D tokamak.

The synthetic ECE is first benchmarked to prove its capability in simulating radiation near the separatrix. The anomalous radiation is robustly observed with ECEI in the presence of a strong core MHD, as shown in Fig 1(a). Assuming the core MHD perturbs the plasma edge with a periodic rigid displacement, the ECE radiation temperature $T_{e,rad}$ profile is then modelled by a rigid shift of the temperature and density profiles. Due to the nonlocal radiation effect, the radiation profile shows an anomalous increase outside the separatrix. This anomalous radiation results in a phase inverted structure in the radial profile of the radiated power near the separatrix (Fig1(b)). This benchmark using core MHD is crucial as it shows that our synthetic diagnostic is in quantitative agreement with the radiation profile at the pedestal foot or even outside the separatrix [3].

Fundamental and quantitative understanding are achieved with the synthetic modeling of radiation at two ECE frequencies in response to analytical δT_e and δn_e at the pedestal top (at rho~0.95). The two ECE frequencies point to cold resonances at the pedestal foot (rho~0.97) and Scrape of Layer (rho~1.03), but their hot resonances are all centered at rho~0.95 due to the nonlocal radiation effect in the pedestal. The density and temperature have opposite effects on the radiated power as the electron temperature enhances the local emission, while electron density produces radiation absorption. Quantitatively, we found the ECE radiation from the location rho~0.97 is 5.5 times more sensitive to the δT_e than δn_e at the pedestal top (rho≈0. 95), while the radiation at rho~1.03 is equally sensitive to density and temperature fluctuations at the pedestal top (rho≈0.95).

Combining the findings in the last paragraph and ECEI observations, the source of radiation fluctuation and cross phase between δT_e and δn_e are inferred. Experimentally in shot 179328, we found the pedestal top turbulence during RMP ELM suppression displays $1.55 \pm 0.08\%$ $\delta T_{e,rad}/T_{e,rad}$, and the cross phase between the two ECEI channels at rho~0.97 and rho~1.03 on the midplane is $\sim 3.01 \pm 0.1\, rad$. Consequently, we deduce that the radiation fluctuation is dominantly caused by δT_e instead of δn_e. In addition, the δT_e and δn_e fluctuation are ~ in-phase at the pedestal top.

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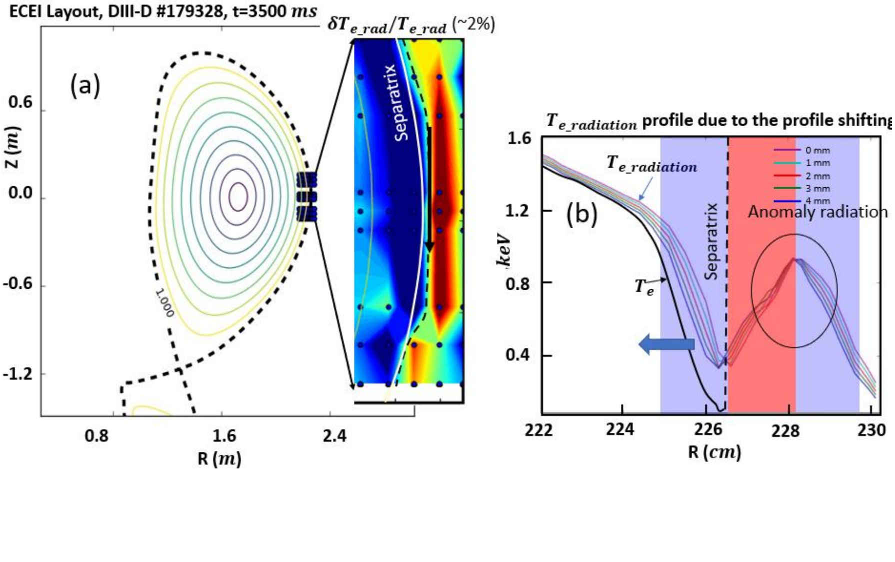

Fig. 1: The ECE radiation profile due to the inward shift of the n_e and T_e profile is consistent with the phase inverted structure that often appears on ECEI in presence of strong rotating core MHD. (a) Phase inverted structure observed with ECEI (b) The ECE radiation profile modelled with the synthetic diagnostic