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 $\delta n_e$ and temperature fluctuations $\delta T_e$. 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 (Fig 1(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 $\delta T_e$ and $\delta n_e$ at the pedestal top (at $\rho \sim 0.95$). The two ECE frequencies point to cold resonances at the pedestal foot ($\rho \sim 0.97$) and scrape of Layer ($\rho \sim 1.03$), but their hot resonances are all centered at $\rho \sim 0.95$ 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 $\rho \sim 0.97$ is 5.5 times more sensitive to the $\delta T_e$ than $\delta n_e$ at the pedestal top ($\rho \sim 0.95$), while the radiation at $\rho \sim 1.03$ is equally sensitive to density and temperature fluctuations at the pedestal top ($\rho \sim 0.95$).

Combining the findings in the last paragraph and ECEI observations, the source of radiation fluctuation and cross phase between $\delta T_e$ and $\delta n_e$ 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 $\rho \sim 0.97$ and $\rho \sim 1.03$ on the midplane is $\sim 3.01 \pm 0.1$ rad. Consequently, we deduce that the radiation fluctuation is dominantly caused by $\delta T_e$ instead of $\delta n_e$. In addition, the $\delta T_e$ and $\delta n_e$ fluctuation are in-phase at the pedestal top.

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Reference

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 observed with ECEI (b) The ECE radiation profile modelled with the synthetic diagnostic.