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Combined effects of turbulence, MHD activity and sawtooth crashes on particle transport in L-mode discharges on HL-2A tokamak

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Experiments in L-mode plasmas on HL-2A tokamak show that the electron and impurity transport is related to the normalized electron temperature gradient with opposite trends. In discharges with inner-deposited ECRH, the increase of the normalized electron temperature gradient in the confinement zone ($0.25 \leq \rho \leq 0.5$, ρ is the normalized minor radius) tends to pump out electrons and accumulate the trace Al impurity injected by laser blow-off (LBO), leading to slightly hollow electron density profiles meanwhile with an overall increase of impurity density. It is also found that the combined effects of the impurity expulsion by core magnetohydrodynamic (MHD) activity in the plasma center and the strong impurity influx driven by turbulence in the outer confinement region is responsible for the strong hollowness of impurity density profiles. By contrast, the decrease of the normalized electron temperature gradient in discharges with outer-deposited ECRH leads to centrally peaked electron density profiles and a much smaller impurity accumulation. Gyrokinetic simulation has been performed with the gKPSP code[1], confirming that the local change of the normalized electron temperature gradient affects the relative strength of the the ion temperature gradient (ITG) and trapped electron mode (TEM), eventually determining the electron particle transport in a way consistent with the experimental observations. Comparison of simulations with and without collisionallity shows that the plasma collisionality can significantly reduce the growth rate of the TEM and the associated outward particle flux.

In order to study the effect of turbulence on particle transport on HL-2A, we performed a set of experiments in which the power deposition of ECRH was modulated to locally alter electron temperature gradient as the turbulence drive [2]. According to the micro-instability analysis, the TEM will dominate over the ITG if a critical value of the normalized electron temperature gradient is reached. FIG.1 illustrates the dependence of experimental profiles of the electron temperature and its normalized gradient on the ECRH power deposition position, along with an additional profile measured in the phase without ECRH as reference. The inner-deposited ECRH increases electron temperature (from 0.7 keV to 1.8 keV) and its gradient (from 5 keV/m to 11 keV/m) around the power deposition radius of ρ=0.28, whilst the electron heating effect of the outer-deposited ECRH is less localized and lifts the electron temperature profile across the whole radius within the deposition position of ρ=0.7. In FIG.2, after the injection of Al impurity at 600 ms, the soft X-ray (SXR) reconstructed by a Bayesian tomogaphy method [3] appears to be deeply hollow in the inner-deposited ECRH case, whereas it is centrally peaked in the outer-deposited ECRH case. In particular, in discharges with inner-deposited ECRH, core MHD instabilities and sawtooth crashes are observed to have a dramatic influence on the impurity transport in the region inside the q=1 surface [4], as evidenced by the time evolution of emission profiles as shown in FIG.3. In three consecutive time points (t_3=602 ms$\longrightarrow t_5$=605.07 ms), the impurity density keeps increasing in the region outside the q=1 where an extraordinarily large density gradient has been built up, which is probably due to the turbulence characteristics of that region. Later on, this deeply hollow profile is flattened by a sawtooth crash (occurring at t_5=605.07 ms) on a time scale of approximately 0.15 ms, leading to a sharp increase of the impurity density inside the q=1 surface.

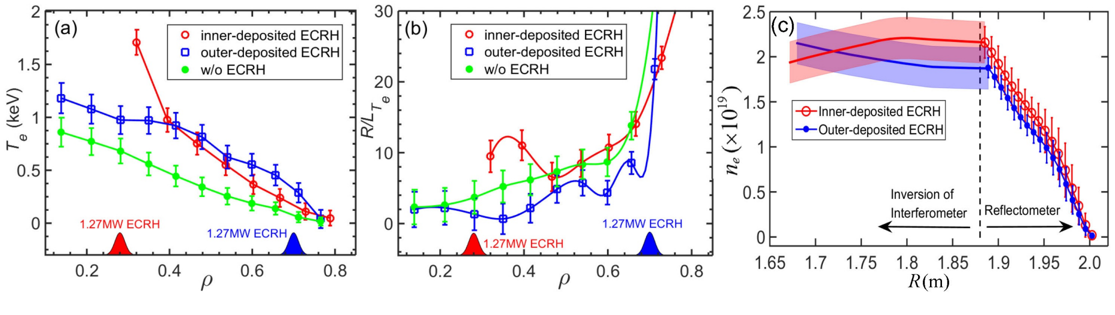

Figure 1: Experimental profiles of (a) electron temperature and (b) normalized electron temperature gradient from discharges with inner-/outer- deposited ECRH and without ECRH. Gaussian shapes indicates the ECRH deposition radii.

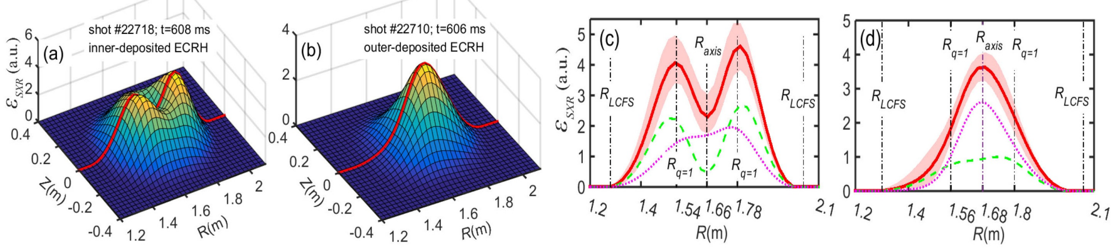

Figure 2: SXR reconstructions after the injection of trace Al impurity in discharges with (a) inner-deposited and (b) outer-deposited ECRH, and (c, d) profiles intercepted at Z=0 m. The cyan dotted lines represent the emission at the time 1 ms before the injection as background contribution; the green dashed lines represent the emission after subtracting the background contribution.

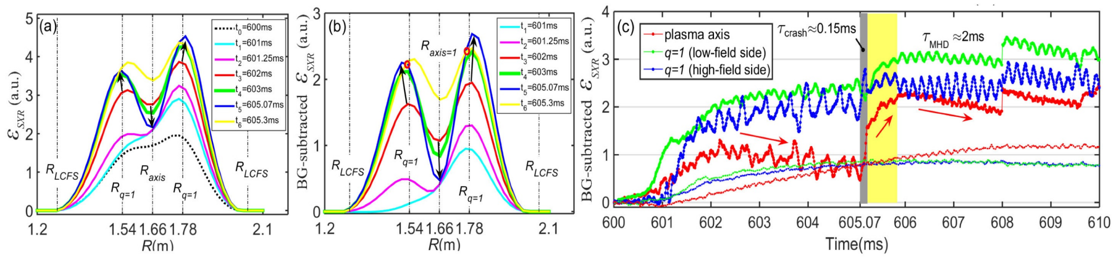

Figure 3: Profiles of the (a) total SXR emission and (b) BG-subtracted emission at several time points after the Al injection. (c) Evolution of the BG-subtracted emission at three local positions, i.e., low- and high-field sides of q=1 surface and plasma axis in the inner-deposited ECRH case. For comparison, counterpart data of the outer-deposited ECRH case are plotted by the dotted lines.

References:

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