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Effect of turbulence and MHD activity on impurity transport on HL-2A tokamak

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ABSTRACT

In this work, we study the effect of turbulence, magneto-hydrodynamic (MHD) instability and sawtooth crashes on the trace impurity particle transport in a series of discharges with ECRH and NBI heating. Experimental analysis shows that after the injection of trace aluminium (Al) impurity by laser blow-off (LBO) the distribution of impurity density is relatively uniform in the NBI heated plasmas. When the power is sufficiently high, both NBI and ECRH heating can produce strong MHD instability which expels the impurity from the plasma centre. In particular, inner-deposited ECRH heating has a significant influence on both electron and impurity transport. Specifically, it can induce a high electron temperature gradient which is beyond the threshold of the trapped electron mode (TEM), resulting in the pump out of electrons and accumulation of impurity. While the impurity density profile appears to be strongly hollow due to the combined effect of impurity expulsion by MHD activity and an inward impurity convection driven by thermo-diffusion. Depending on whether the initial impurity density profile prior to the sawtooth crashes is centrally peaked or hollow, the impurity can be pumped out and into the plasma centre, respectively.

BACKGROUND

Turbulent and neoclassical transport are two most important factors that determine the confinement performance of fusion plasmas, and thus a comprehensive understanding of them in both experimental and theoretical aspects is crucial for achieving improved confinement in future device like ITER. Generally, the relative role of the turbulent and neoclassical transport varies for different experimental scenarios and particle species. In comparison with neoclassical transport, the turbulence of trapped electron mode (TEM) or ion temperature gradient (ITG) type usually plays a dominant role for electrons, as evidenced in many anomalous transport phenomena. By contrast, the neoclassical transport becomes particularly important for the high Z impurities due to their high collision rate. Besides, magneto-hydrodynamic (MHD) activity and sawtooth crashes are often found to have a long-lasting or transient effect on the particle transport. Turbulence, MHD activity and sawtooth crashes drive particle transport in different spatial and temporal scales, jointly determining the shape of the particle density profiles.

EXPERIMWNT AND THEORY

In our experiments, the trace impurity injected by LBO has a very small concentration less than 0.1 percent of the main plasma, thus it does not affect background plasma parameters significantly and has negligible influence on the quasi-neutrality condition. Therefore, the trace impurity can be taken as a test particle and its transport coefficients depend only on the parameters of the main species (electrons and ions) rather than its own. In quasi-linear gyrokinetic theory, the particle flux driven by turbulence can be described by the following equation:

$$\frac{\Gamma_e^{QL}}{n} = -D_n \frac{1}{n}\frac{\partial n}{\partial r} - D_T \frac{1}{T}\frac{\partial T}{\partial r} - D_u \frac{R}{\upsilon_{th}}\frac{\partial \upsilon_\phi}{\partial r} + V_{pn}$$

where υ_{th} and υ_ϕ are the particle thermal velocity and toroidal rotation velocity. In the Pfirsch-Schlüter (PS) regime, the diffusion coefficient of neoclassical transport also depends on the plasma parameter:

$$D^{NC} \propto \frac{q^2}{B^2}\frac{m_i}{\sqrt{T_i}} n_i$$

All the transport coefficients are complex functions of the plasma parameters, temperature and rotation velocity, which will be reflected as the dependence of the impurity transport on these parameters in experiments.

IMPURITY TRANSPORT IN ECRH HEATED PLASMAS

Fig.1 illustrates the effect of the ECRH power deposition position on the electron temperature Te and its normalized gradient $R/L_{Te} = -R\nabla T_e/T_e$. After the injection of Al impurity, SXR reconstructions by a Bayesian tomography method [1] appears to be deeply hollow in the inner-deposited ECRH case, with a large amount of Al impurity accumulated in the confinement region. This result indicates that the inner-deposited ECRH creates a turbulence state which tends to produce an inward impurity convection.

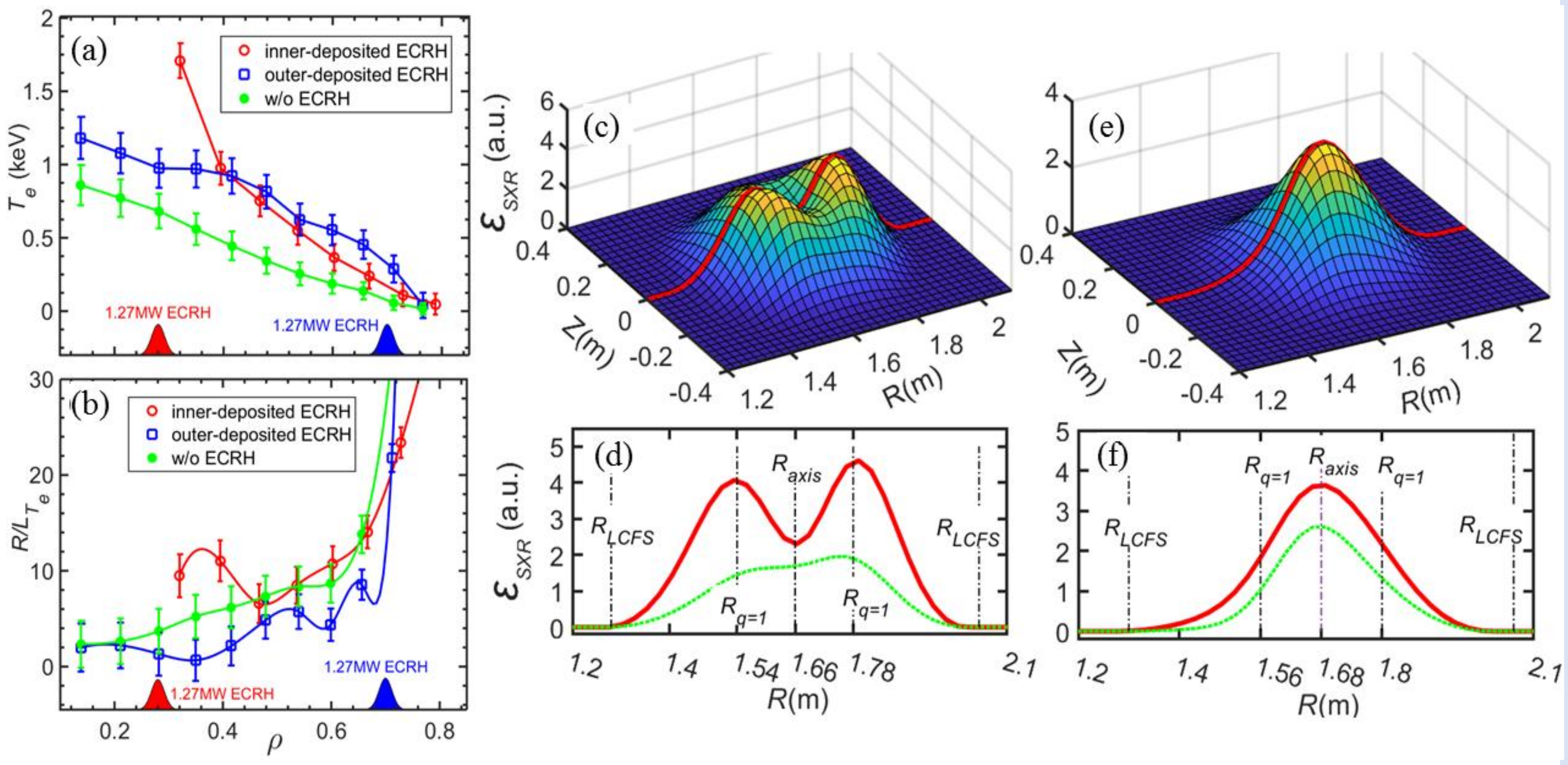

Fig. 1: Profiles of the (a, b) electron temperature Te and normalized gradient from discharges with inner- and outer-deposited ECRH; SXR reconstructions after the injection of trace Al impurity in the former (c, d) and latter (e, f) cases (green dotted lines indicate BG-emission).

EFFECT OF MHD ACTIVITY ON IMPURITY TRANSPORT

The comparison of impurity emission between two discharges with and without MHD activity in Fig. 2 suggests that after the injection the impurity density increases much more slowly in the case with core MHD instability. The sawtooth crash tends to flatten a centrally peaked impurity density profile.

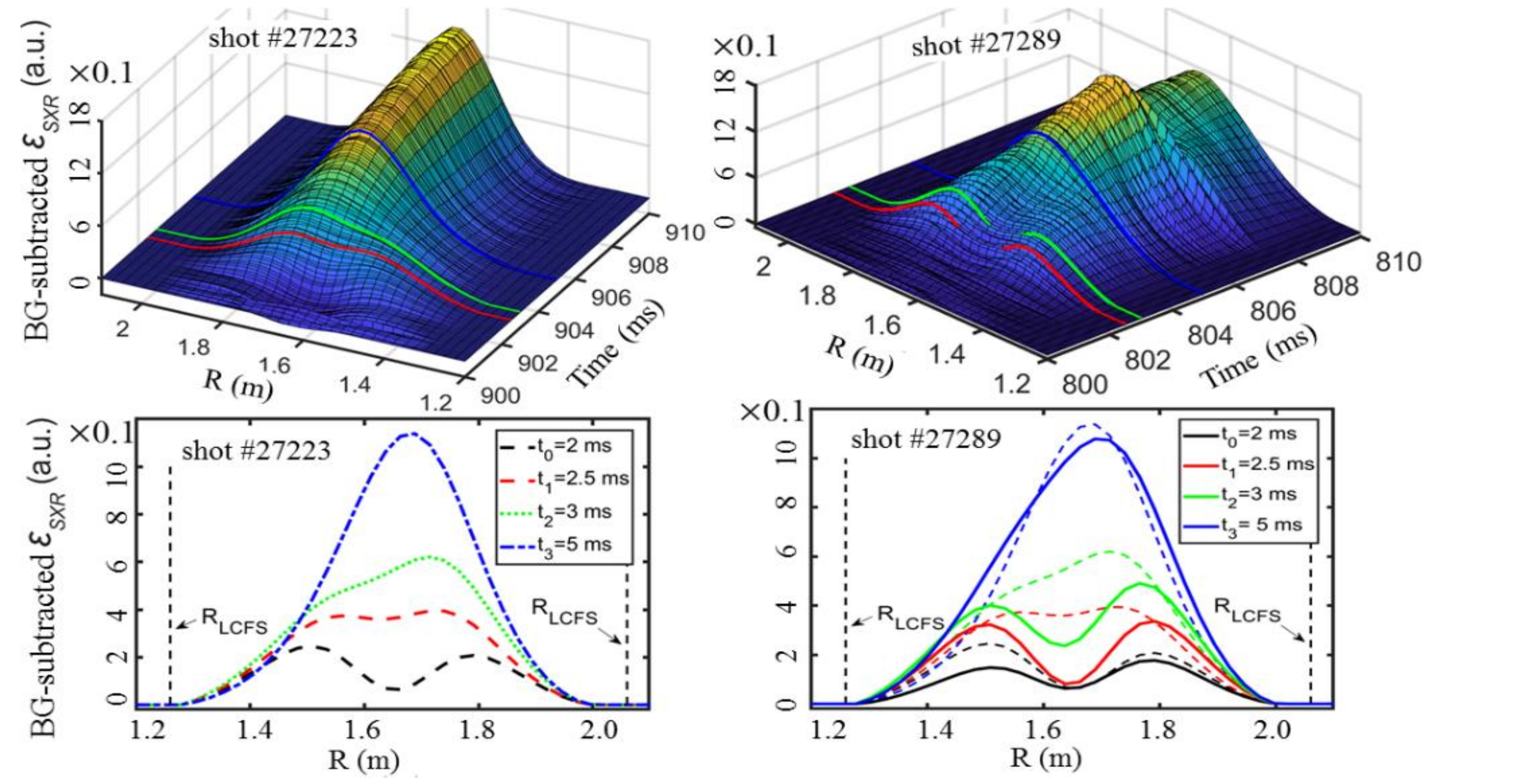

Fig. 2: Time evolution of the impurity emission profile in two similar discharges with (left column) and without (right column) MHD activity.

CONCLUSION

This study presents the effect of temperature gradient driven turbulence and core MHD activity on impurity transport in different heating scenarios of HL-2A experiments [2]. In discharges with inner-deposited ECRH, impurity density profiles are strongly hollow due to a combined effect between the expulsion of impurity by core MHD in the plasma centre and the inward impurity convection driven by turbulence in the confinement region. The effect of sawtooth crashes depends on the impurity density profile prior to the crashes.

ACKNOWLEDGEMENTS / REFERENCES

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[2] Dong Li et al, Nucl. Fusion **60**, 076005 (2020).