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Fast non-diffusive response of heat and turbulence pulse propagation to thermal perturbations

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Plasma transport cannot be explained by local models alone, and the effects of non-local transport must be taken into account. In particular, avalanche phenomena and turbulence spreading have been recognized as causes of non-local transport. However, observations of these phenomena are limited due to measurement limitations, and both experimental and theoretical understanding of these phenomena are inadequate. This study reports the new findings of turbulence and heat propagation phenomena that cannot be explained by the existing avalanche and turbulence spreading models in the Large Helical Device (LHD) experiments.

A collapse of the electron internal transport barrier (e-ITB) is targeted to induce large observable turbulence spreading phenomena. In the LHD, both turbulence and thermal pulses are generated near the foot of the e-ITB and propagate to the periphery faster than the diffusion time when thermal avalanche phenomena accompany the e-ITB collapse. The propagation velocity of the turbulence pulses is about 10 km/s, which is faster than the propagation velocity of the heat pulse of about 1.5 km/s [1]. Existing models predict that both heat and turbulence propagate at about 1 km/s, but the turbulence pulse propagates more than an order of magnitude faster than predicted. Although the simultaneous propagation of the turbulence and heat pulses has been reported in a number of experiments, it is thought that the phenomenon observed in the LHD is due to a different mechanism.

The modulated electron cyclotron heating (MECH) experiments, in which the induced time width of the heat pulse was varied by changing the time width of the ECH, were performed to systematically study the effects of the time scale of the turbulence and heat pulses on their propagation velocity[2]. The results showed that the propagation velocity of the heat and turbulence pulses is faster at shorter pulse widths. As the heating time increases, two distinct turbulence components with different propagation characteristics are observed. Figure 1 shows the electron temperature gradient and the two-component electron-scale turbulence when heated with a heating time of 40 ms and a modulation frequency of 10 Hz. The first component is excited almost simultaneously throughout the plasma by spatial coupling, while the second propagates with the temperature gradient. These two components occupy different frequency ranges: the first is in the low-frequency range (below 20 kHz), while the second is in the high-frequency range (around 100 kHz). Similar behavior has been observed for both ion-scale and electron-scale turbulence. The ion-scale, with smaller wavenumbers, contributes to the spatial coupling, and it is hypothesized that the electron-scale turbulence rides on the ion-scale turbulence acting as a mediator.

In this study, the spatial coupling component of the turbulence could be particularly observed during the collapse of the e-ITB. Conversely, in short pulse MECH experiments, both spatial coupling and gradient propagation components are observed almost simultaneously. In contrast, in long-pulse MECH experiments, these components are observed at different times, indicating that they can coexist. This study provides important insights into the physics of mediators as a possible mechanism for non-local transport.

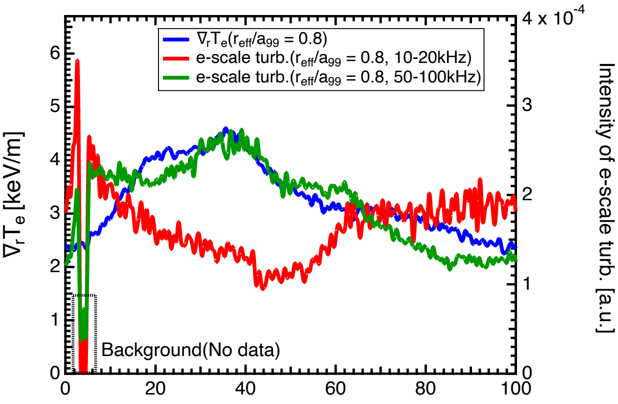

Figure 1. The time evolution of (blue) radial gradient of electron temperature, (red) low-frequency and (green) high-frequency components of electron-scale turbulence, respectively. The experimental data are conditionally averaged over a heating time of 40 ms and a modulation frequency of 10 Hz. Note that no electron-scale turbulence data were detected during the t = 2.5-5 msec because the measurement beam was not injected for background measurements.

References

[1] N. Kenmochi *et al.*, Scientific Reports **12**, 6979 (2022)

[2] N. Kenmochi *et al.*, Scientific Reports **14**, 13006 (2024)