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Edge plasma dynamics during thermal quench in BOUT++ electromatic turbulence simulations

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Damage of plasma facing components during tokamak disruption is a major concern for ITER and other future fusion devices; and yet the underlying physics of disruption hasn't been fully understood. In this study, recently upgraded BOUT++ six-field drift-reduced Landau fluid turbulence model with flux-driven capability [1] is applied to investigate plasma turbulence and transport dynamics at the tokamak edge region, as well as the divertor power loads during the thermal quench phase of disruption. Excessive particle and power are applied at the pedestal region for a short period of time (about 10 – 20% of the stored thermal energy within 0.1 – 1ms) to mimic the intensive particle and energy outflow from the core during the onset of thermal quench.

Our thermal quench simulations reproduce several key signatures that agree with experimental observations. For instance, a surge of maximum divertor heat load (about 50 times larger than normal), broadening of heat flux width (about 4 times wider), and prolonged energy deposition time are observed, for both simulated DIII-D and ITER-like H-mode plasmas (e.g., **Figure 1**).

Analysis shows that the dramatic increase of divertor heat load and width are due to enhanced turbulent activity inside the separatrix. In other words, divertor heat flux is dominated by turbulence transport [2] during the thermal quench phase. As the thermal quench onsets, energy influx from core heats edge plasma. The resulting steepen temperature/pressure profile not only increases fluctuation level, but also shift the dominant modes to lower k, i.e., larger eddies that are more resilient to shear. As a result, edge turbulence becomes a much more efficient radial transport channel to rapidly move particle and energy from core to SOL across through the E × B convection that eventually are deposited at the divertor plates.

Meanwhile, magnetic perturbation, accompanying with the enhanced turbulence, amplifies at least one order of magnitude up to $|\delta B/B_0| \sim O(10^{-3})$, particularly near the separatrix and X-point. Instead of distorting localized magnetic flux surfaces, such a strong magnetic perturbation completely breaks magnetic flux surfaces by forming stochastic magnetic field-lines that directly connects pedestal top plasma to the first wall or divertor target plates and reduces the magnetic connection lengths to 10^{2-3} meters. Our study suggests that in the late stage of thermal quench, stochastic field transport is accounted for roughly 30% of the total electron heat flux across the separatrix. Therefore, in addition to the turbulent cross-field advection, stochastic electron parallel thermal transport may also play an important role in the thermal quench edge plasma evolution [3].

References

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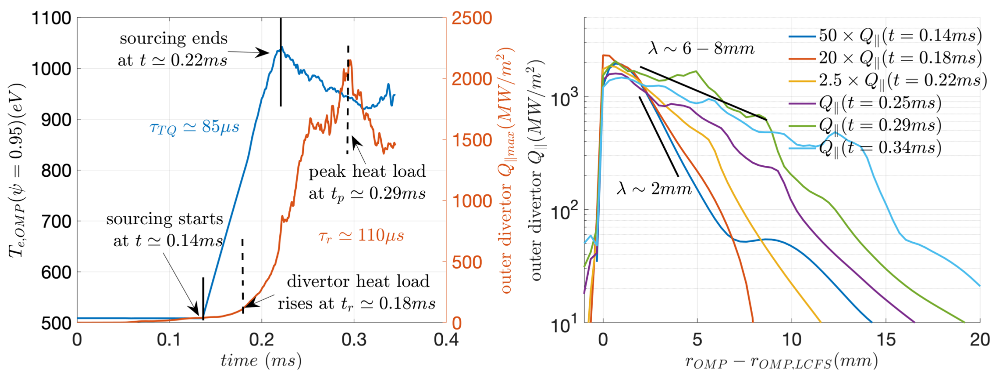

Figure 1. (Left) Outer divertor peak heat flux and pedestal top Te evolution, and (right) outer divertor heat flux profiles of DIII-D thermal quench simulation.