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Fluid and kinetic modeling of runaway electron seed generation during disruptions

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Since the RE generation during tokamak disruption is exponentially sensitive to initial plasma current, highly energetic RE beams pose a critical challenge for future tokamaks. Accurate simulations of tokamak disruptions are therefore essential for the development of successful mitigation strategies and safe operation. However, when simulating such disruptions, fluid plasma models are often preferred due to their low numerical cost, even though they generally are less accurate than kinetic models.

We have compared simulations using both fluid and kinetic modeling of the RE seed generation for a diverse set of disruption cases in ITER and SPARC. The kinetic model is simplified by assuming that pitch angle scattering dominates the electron dynamics, enabling the distribution function to be analytically averaged over pitch angle. Furthermore, the distribution function has only been evolved for electrons within the mildly superthermal energy range, while ions, thermal electrons and REs are evolved as fluids. We have considered both non-activated and activated scenarios; for the latter we have derived and implemented kinetic sources for the Compton scattering and tritium beta decay RE generation mechanisms [1] in the simulation tool DREAM [2].

We find that fluid and kinetic disruption simulations of non-activated scenarios can have significantly different RE dynamics, due to an overestimation of the RE seed generation by the fluid model. The primary cause of this is that the fluid hot-tail generation model neglects superthermal electron transport losses during the thermal quench. In the activated scenarios the fluid and kinetic models give more similar predictions, which can be explained by the activated sources' significant influence on the RE dynamics and the seed.

[1] J.R. Martín-Solís et al., Nucl. Fusion. 57 066025 (2017).
[2] M. Hoppe et al., Comp. Phys. Comm. 268 108098 (2021).

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