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TDYNO: FLASH simulations and NIF experiments to study thermal conduction suppression in galaxy clusters

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Understanding heat transport is important in astrophysical plasmas such as those in galaxy cluster cores. Spitzer's theory for thermal conduction can break down in magnetized, turbulent, weakly collisional plasmas, although modifications are difficult to predict from first principles due to the complex, multiscale nature of the problem. The advent of high-power laser systems, along with the scaling of the equations of magneto-hydrodynamics (MHD), has made it possible to recreate astrophysical conditions and processes in terrestrial laboratories. In our recent experiments at the National Ignition Facility (NIF) at Lawrence Livermore National Laboratory (LLNL), we created turbulent plasmas with large magnetic Reynolds numbers and above-unity magnetic Prandtl numbers [1]. The generated magnetic fields are significantly stronger than what was achieved in previous experiments [2-4] at the Omega Laser Facility at the Laboratory for Laser Energetics (LLE) at the University of Rochester. In the NIF experiments, we demonstrated that magnetized turbulence can strongly suppress local heat transport by two orders of magnitude or more [1].

To design, execute, and interpret the NIF laser-driven plasma experiments of fluctuation dynamo, we executed several campaigns of three-dimensional radiation-MHD simulations with FLASH [5, 6], which resulted in the platform shown in Figure 1 (top). Here we present an overview of these campaigns and discuss how they enabled the interpretation of the experiments. We have validated and compared the numerical results with experimental data using synthetic diagnostics such as proton radiography, Thomson scattering, and X-ray self-emission imaging. The results obtained open a new way of studying the role of stochastic magnetic fields in astrophysical heat transport.

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References

[1] Meinecke *et al,* Sci. Adv. 8, eabj6799 (2022)
[2] Tzeferacos *et al*, Phys. Plasmas 24, 041404 (2017)
[3] Tzeferacos *et al*, Nat. Commun. 9, 591 (2018)
[4] Bott *et al*, PNAS 118, e2015729118 (2021)
[5] Fryxell *et al*, ApJS 131, 273 (2000)
[6] Tzeferacos *et al*, HEDP 17, 24 (2015)

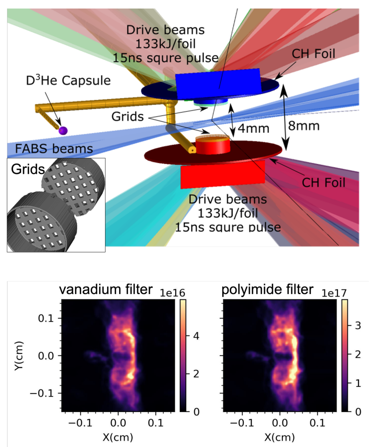

Figure 1. Top: Experimental configuration of the NIF TDYNO experiment, where the inset shows the two grids of the target set to be parallel but with holes offset laterally, which helps create the desired turbulence. Bottom: Synthetic X-ray self-emission images at 23 ns with vanadium filter and polyimide filter to measure temperature fluctuations.