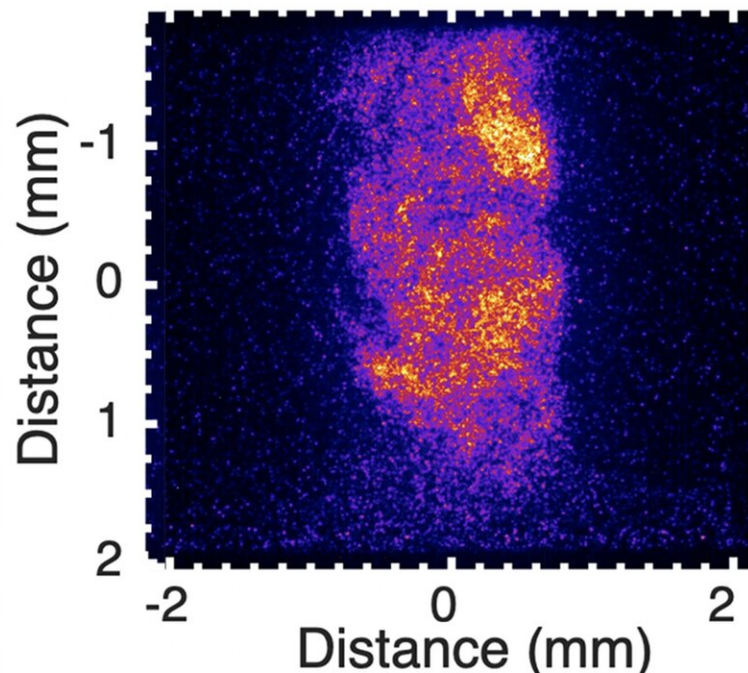
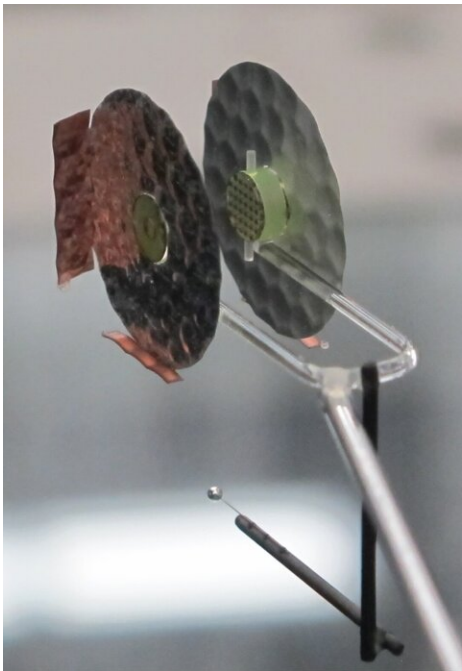


Researchers unravel the inner workings of heat conduction in galaxy clusters

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Left: Photo of the TDYNO target deployed at the National Ignition Facility through the Discovery Science program. The experimental target consists of two foils and a pair of grids, held together by cylindrical shields. Each target is about the size of a penny. Photo credit: National Ignition Facility Operations team.

Right: X-ray image of the turbulent plasma generated in the experiments, taken at 28 billionths of a second after the lasers fire. The hot plasma emits soft X-rays, which enables the researchers to characterize the properties of the turbulent flow and measure the fluctuations of electron temperature that revealed the strong suppression of heat transport. Credit: National Ignition Facility Operations team

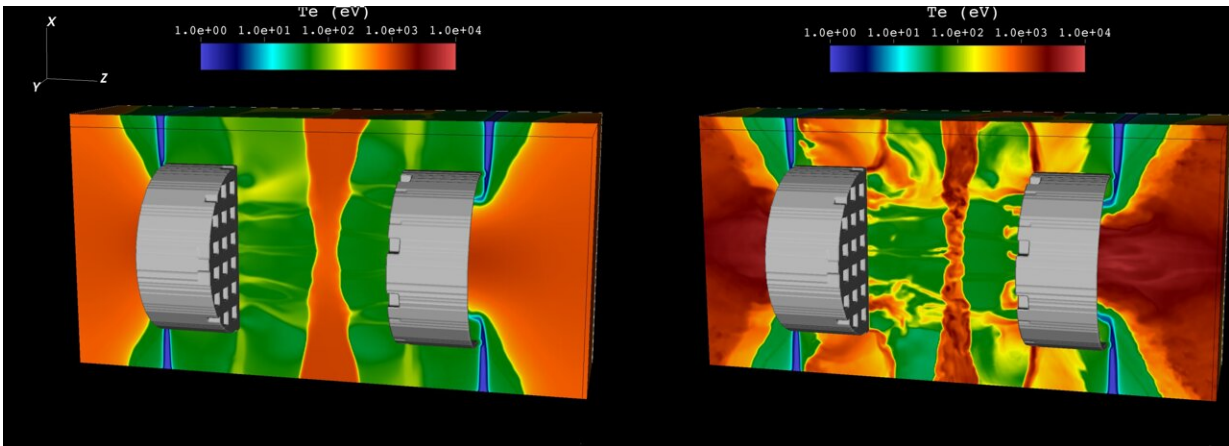
The inner workings of heat conduction in galaxy clusters have been unraveled by a collaboration of international researchers led by the University of Oxford, University of Rochester and the University of Chicago.

Most matter in galaxy clusters is in the form of tenuous ionized gas called plasma that is threaded by magnetic fields and is in a turbulent state; in observing many of these clusters of galaxies, astronomers have been facing a difficult conundrum: they all appear much hotter than expected.

Paper author Dr. Jena Meinecke and the research team used the largest laser system in the world—the National Ignition Facility (NIF) at Lawrence Livermore National Laboratory (LLNL) in California—to create a replica of the plasma conditions expected to occur in the clusters of galaxies.

Co-author Professor Alexander Schekochihin, Department of Physics at the University of Oxford says that "how energy is injected into the plasma that fills [galaxy clusters](#) by the violently active galaxies at their centers, how it is then spread around and heats up the entire enormous system, producing the X-ray glow that observatories like Chandra X-ray Observatory pick up—these are fundamental questions about the largest building blocks of our Universe. Both observations and the logic of our theoretical models suggest that heat conduction in these plasmas is strongly suppressed compared to naïve expectations. Several schemes for such suppression have been theorized about and simulated numerically, but very tentatively."

"Here suddenly we have it in a real laboratory plasma—and so experiment now has a chance to leapfrog theory in helping sort out the basic properties of an astrophysical plasma, an exciting prospect."



FLASH simulations of the TDYNO platform with Spitzer thermal conductivity turned on (left) and off (right), showing the electron temperature in electron volts, eV (1 eV corresponds to 11,333 oC or 20,431 oF). The strong magnetization of the plasma achieved at the NIF TDYNO experiments results in significant suppression of the thermal conduction, which in turn results in significant fluctuations in the electron temperature (right), which are reproduced in the FLASH simulation. Credit: Yingchao Lu, University of Rochester.

Dr. Meinecke, who was at the University of Oxford during the research and is now at Boise State University, continued: "The experiments conducted at the NIF are literally out of this world. Capable of bringing the powerful dynamics of the Universe to the laboratory, the NIF truly provides opportunities to step into the unknown."

The researchers used laser beams to vaporize plastic foils and generate a turbulent and magnetized plasma in the experiments at NIF.

Dr. Archie Bott, Department of Astrophysical Sciences at Princeton University says that "what is unique in these NIF experiments is that electrons in the plasma collide sufficiently infrequently with each other

that they end up following the tangled [magnetic field](#) lines."

"This phenomenon, which is precisely what is believed to occur in clusters of galaxies, gives rise to suppressed heat conduction," said Dr. Bott

This effect is clearly seen in the laboratory data: the measurements show pockets of hot plasma that persist in time and heat cannot escape.

The principal investigator for the experiments Professor Gianluca Gregori, Department of Physics at the University of Oxford says that "this work is an important stepping stone to understanding the microscopic processes that occur in plasmas that are both magnetized and turbulent. The experimental findings are somewhat surprising as they demonstrate that energy is transported in ways that are very different from what we would have expected from simple theories."

"This is indeed an astonishing result," confirms Professor Petros Tzeferacos, director of the Flash Center of Computational Science, who led the simulation efforts to design and help interpret the NIF experimental campaign.

"To model the NIF experiments, we brought to bear the full array of physics capabilities of FLASH, the multi-physics simulation code we develop. The FLASH simulations were key for untangling the physics at play in the turbulent, magnetized plasma, but the level of thermal transport suppression was beyond what we expected."

Although the simulations reproduce the experimental results by controlling the electron [heat](#) transport, the microscopic mechanism ultimately responsible for the observed suppression remains unclear.

Preparations are underway for further work using the NIF laser to look

at the details of these interactions.

"These experiments provide insight into complex physics processes and also raise additional questions that we hope to answer in upcoming NIF Discovery Science experiments with an optimized target design and diagnostic configuration," said Dr. James Steven Ross, the project's liaison scientist at the LLNL.

These experiments demonstrate how laboratory explorations can help the understanding of astrophysical systems in a way that is complementary to observations.

The research was published in *Science Advances*.

More information: J. Meinecke et al, Strong suppression of heat conduction in a laboratory replica of galaxy-cluster turbulent plasmas, *Science Advances* (2022). [DOI: 10.1126/sciadv.abj6799](https://doi.org/10.1126/sciadv.abj6799).
www.science.org/doi/10.1126/sciadv.abj6799

Provided by University of Oxford

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