Exploring of some of the Universe's most extreme environments through laser-plasma experiments

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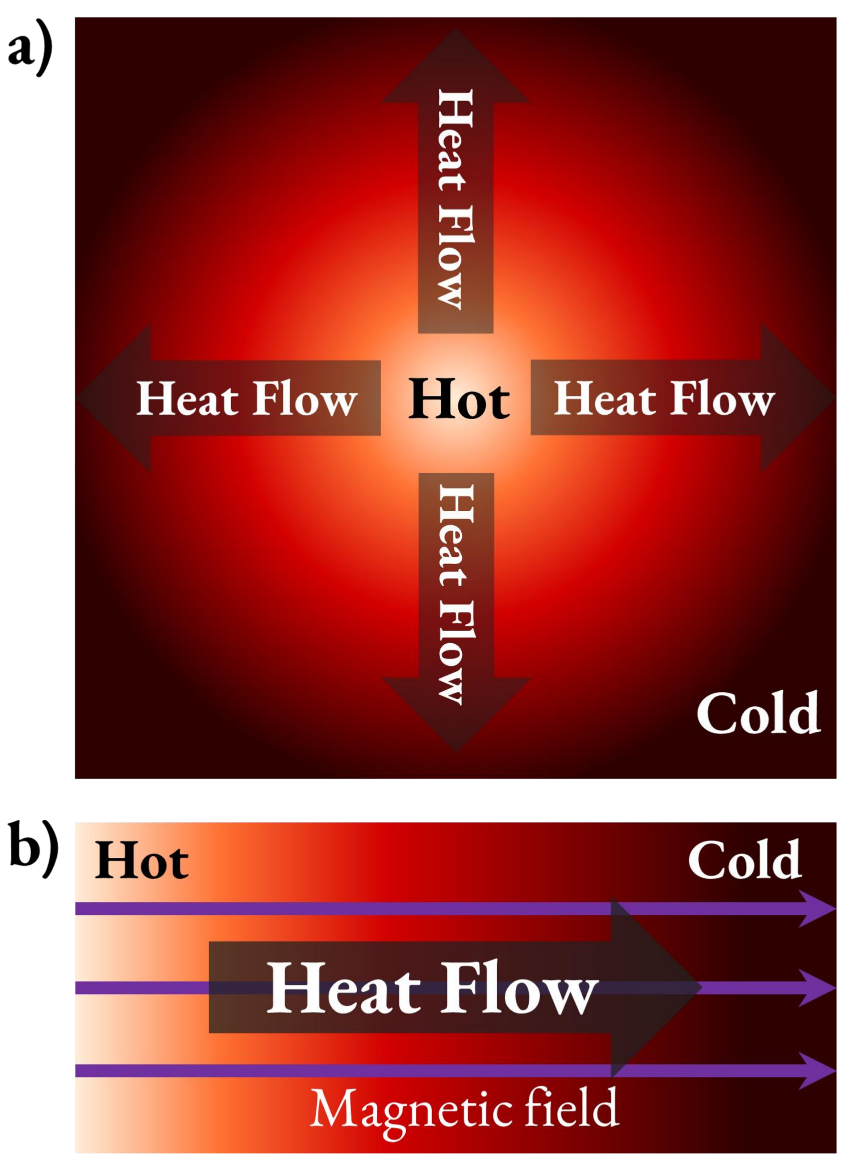
1. Motivations

Heat conduction plays a crucial role in shaping some of the most extreme environments in the Universe. For example, galaxy clusters are extremely hot – tens of millions of degrees - and classical conduction theories suggest they should cool much faster than they actually do. Similarly, in nuclear fusion experiments, keeping the fuel in the core hot enough without constant energy input is a major challenge. Both systems involve plasmas where the conduction is not well understood. We have designed and performed new laser laboratory experiments to address this shortcoming, measuring how heat is conducted through these plasmas.

2. How does heat conduct in plasma?



Heat conducts from hot to cold, and is mediated **by collisions** between heat-carrying particles. The hot, more energetic particles collide with the colder particles, impart some of their energy and heat them up. The **result is a smooth diffusion of heat** through your medium, illustrated in panel (a).

When there is a **magnetic field** present the heat carriers will travel along this field, colliding as before, resulting in **heat conduction in the direction of magnetic field**, illustrated in panel (b).

3. Evidence of anomalous conduction

Laboratory **experiments, and observations** have shown **anomalous heat conduction** compared to classical models:

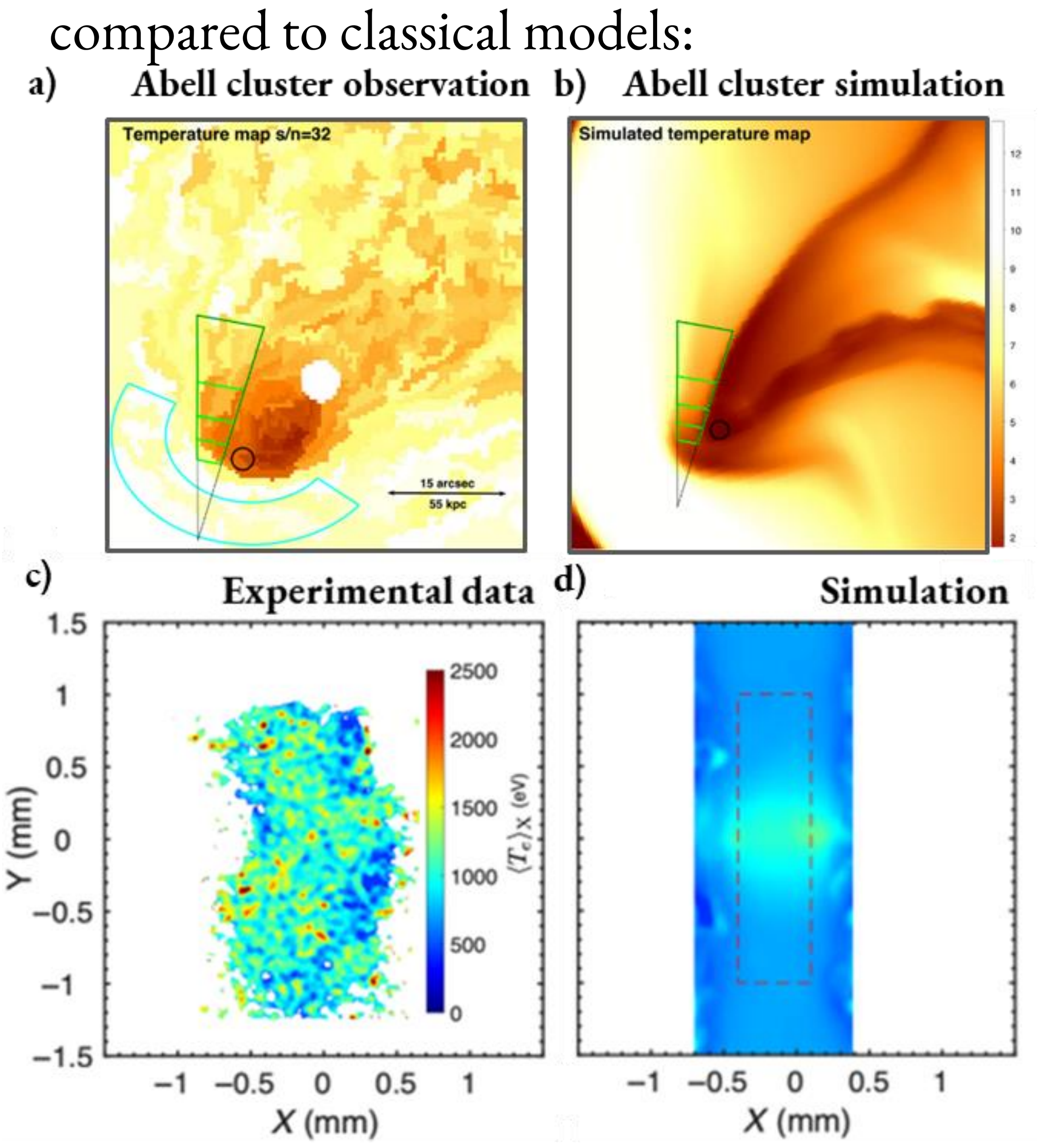
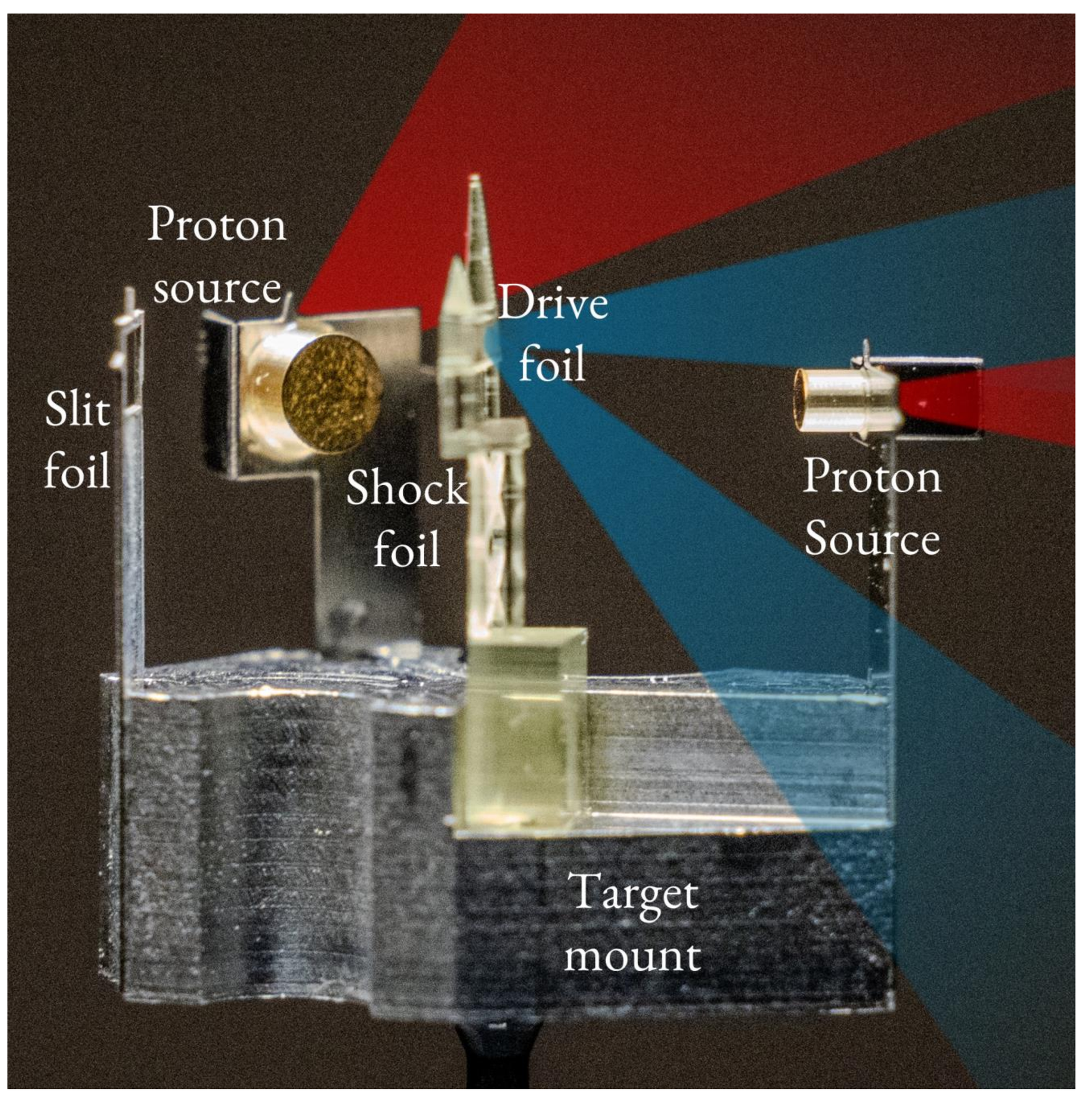


Figure edited from – Richard-Laferrière, A. et al. 2023. MNRAS. **526** & Meinecke, J. et al. 2022. *Sci. Adv.* **8**

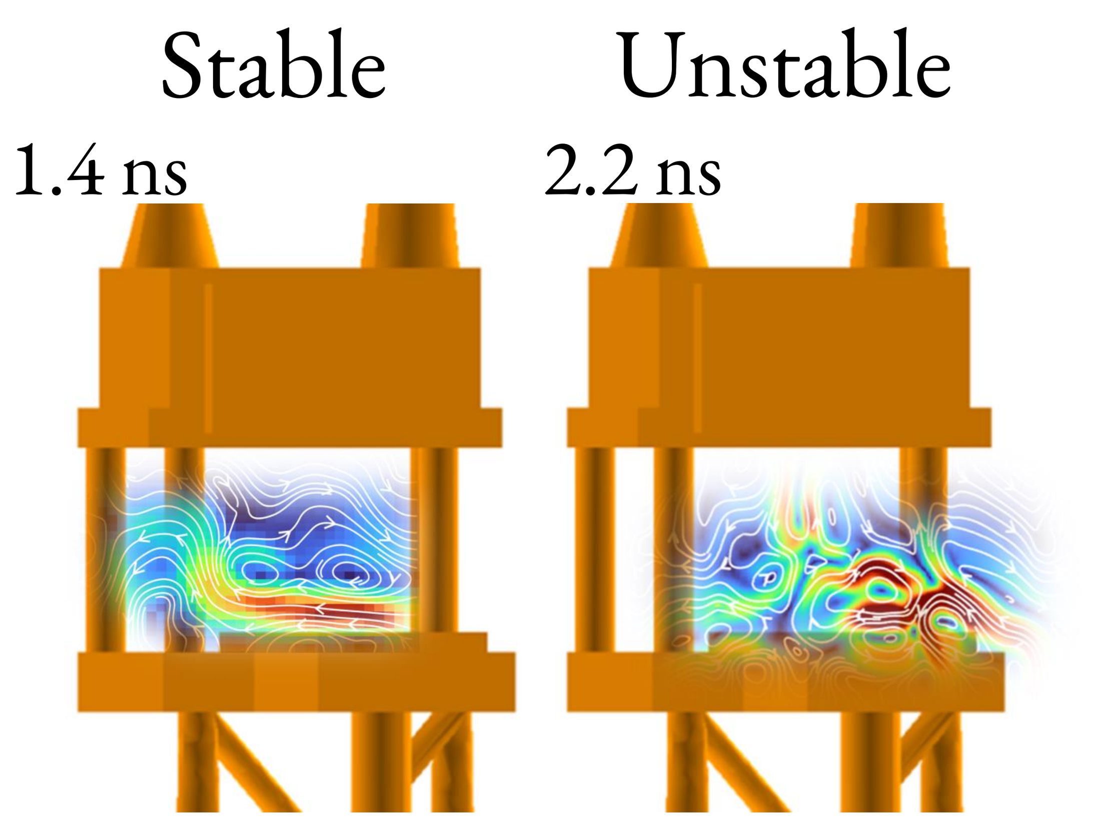
4. What is causing this peculiar behaviour?

If the magnetic field lines direct the heat flow, what happens to the flow of heat if the field lines buckle? This **instability in the magnetic field** is thought to **suppress the conduction of heat**, though has never been proven experimentally.

5. First ever experimental confirmation of heat conduction suppression due to unstable plasma

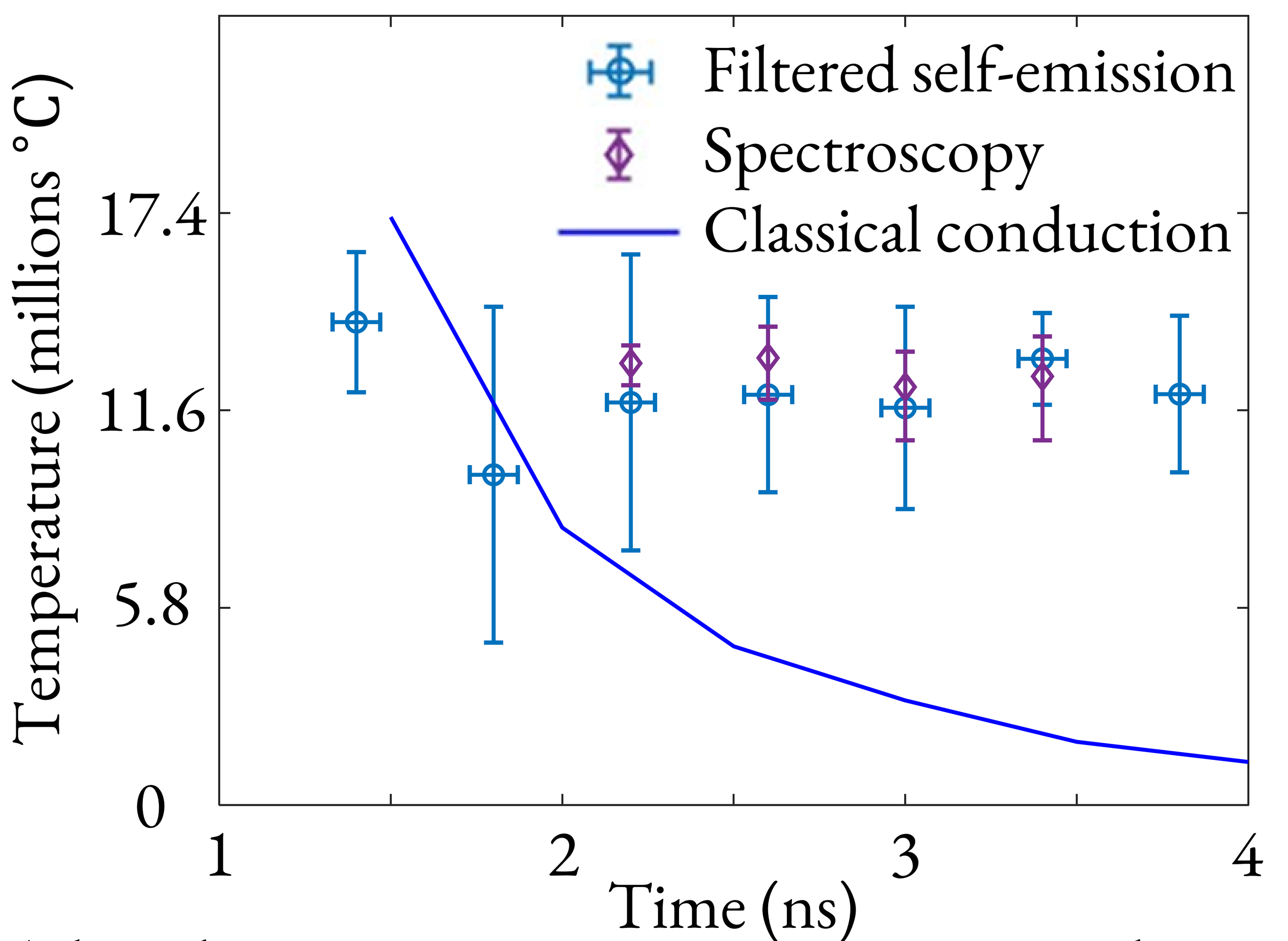


I have performed an **experiment at** the **Orion laser facility**, to measure the temperature evolution in a plasma expected to be unstable to heat conduction-suppressing instabilities.



The **generated plasma** was planar, with **laminar magnetic field** lines, and sat atop the shock foil.

Interestingly, before 2 ns the magnetic field lines are straight but **after 2 ns they become unstable** and start to buckle.



The plasma **temperature was measured** over time, with two independent techniques, filtered self-emission and x-ray spectroscopy. The results agree with classical conduction before 2 ns, when the plasma is stable. After 2 ns, when the **plasma is unstable**, the temperature remains constant indicating **significant suppression of heat conduction**.

Want more details?

Experimental design paper can be found at:
(results paper coming soon!)

Acknowledgements

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