Investigating the Thermal Conductivity of Warm Dense Magnesium Oxide

J. Sicard[1], S. Prins[1], C. Allen[2], E. Folsom[3], T. White[1]

[1]University of Nevada, Reno, [2]Los Alamos National Laboratory, [3]Lawrence Livermore National Laboratory

INTRODUCTION

Under extreme temperature and pressure conditions, matter behaves unusually. [1] Material in this unique state is referred to as warm dense matter (WDM), which is too hot to be described by solid matter physics and too dense to be accurately described by plasma physics (see Figure 1). WDM is found naturally in the cores of Earth and Earth-like planets. Understanding the thermal conductivity of warm-dense composites in Earth's core is vital to furthering our understanding of planetary evolution. [2,3]

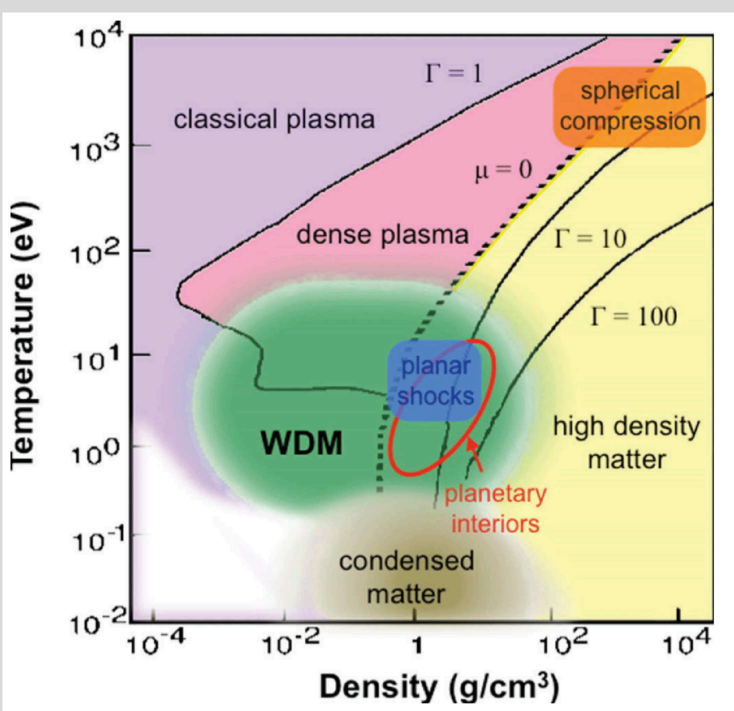


Figure 1: Warm Dense Matter Regime [1]

The mantles of Earth-like planets are abundant in magnesium and oxygen. Magnesium oxide (MgO) is an ideal material for studying planetary interiors. [4,5] Its thermal conductivity plays a crucial role in the structure and dynamics of the core-mantle boundary, heat transfer from the core to the mantle, and the generation of a planet's magnetic field [4]. Computational research on MgO has produced inconsistent results, indicating need for experimental data to validate and benchmark conflicting simulations. [6] My research group has previously developed an experimental platform that successfully analyzed the thermal conductivity of warm dense tungsten. My goal is to simulate a future experiment using this same platform for warm dense MgO, assessing the feasibility of pursuing an experiment to investigate its thermal conductivity with our proposed design.

METHODOLOGY

- My research group has previously developed an experimental platform for investigating thermal conductivity
- My simulations assume the same platform design and target geometry
- A wire of MgO is encased in plastic (CH) and heated to the warm dense state using x-ray heating

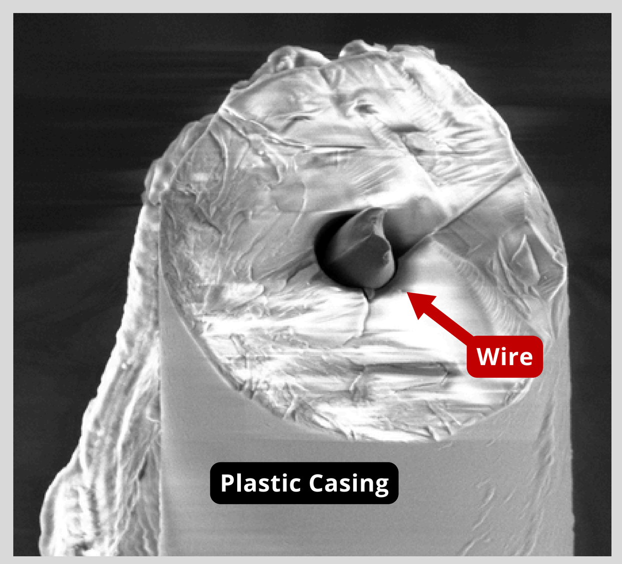


Figure 2: Iron wire encased in glass silicate from prior experiments

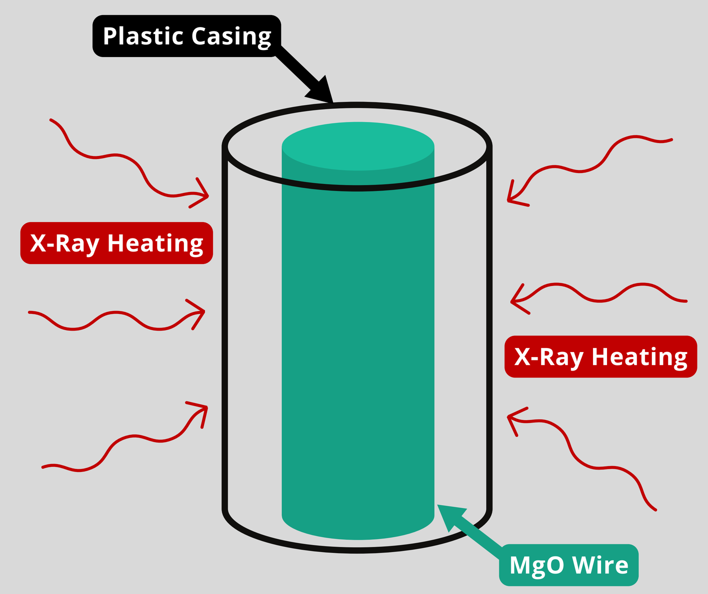


Figure 2: Demonstration of target design

- Pressure and temperature plots will inform the quality of our simulations
- Density data is the critical component for extracting thermal conductivity

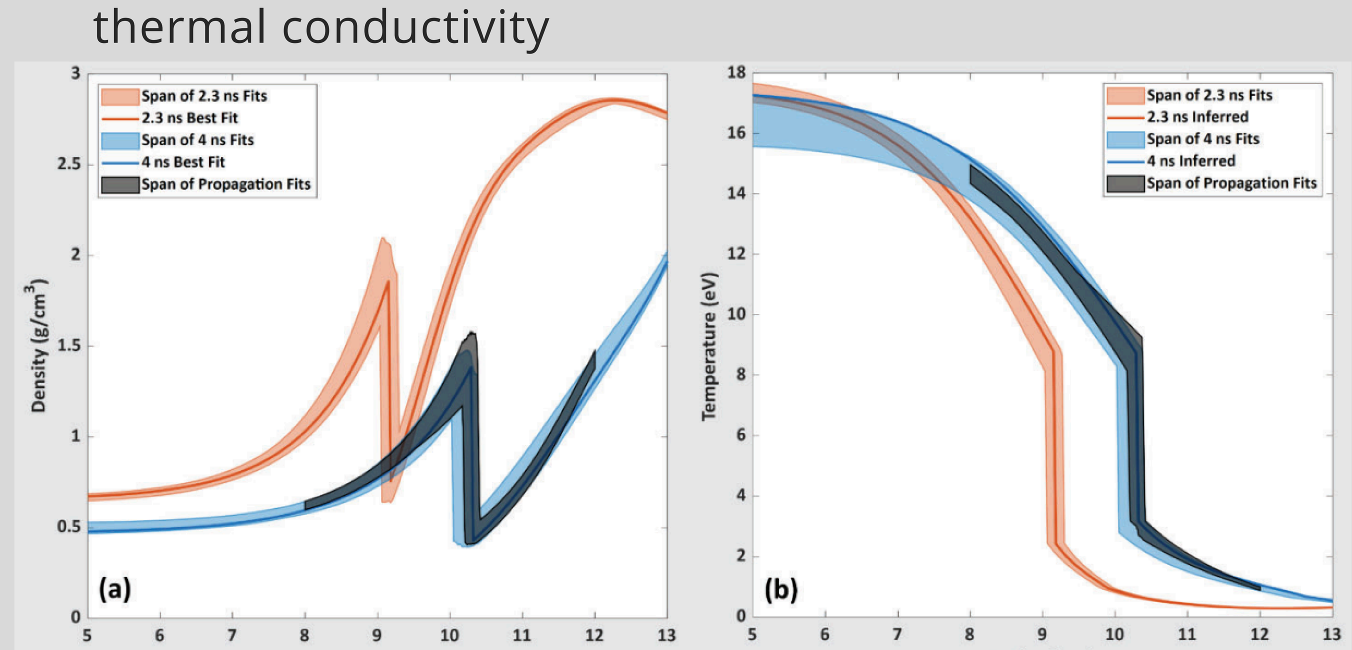


Figure 3: (a) Density profiles near the interface for the warm dense W-CH target at two times from prior thermal conductivity experiments. (b) Temperature profiles inferred from the density profiles. [7]

- The MgO and the plastic casing will heat at different rates
- Heat will then transfer from the hotter material into the cooler material
- To describe how we extract thermal conductivity, we may reference the ideal gas law for illustrative purposes. PV = nRT, or $P \propto \rho T$
  - As temperature increases, density decreases, and vice versa
  - We can use density to extract thermal conductivity
  - Actual equations of state in warm dense MgO are more complicated, but still follow this principle

RESULTS

- This work was done using FLASH, a publicly available, high-performance computing code designed for magnetohydrodynamics (MHD) simulations
- MHD combines the principles of magnetism and fluid dynamics to execute simulations relevant to astrophysics and planetary science
- Achievements of our simulations:
  - Reached necessary pressures and temperatures, mimicking planetary conditions
  - MgO's density remained constant, indicating the material does not explode at these regimes in experiment
  - Density plot indicates we successfully heated to extreme temperatures (~11,000 Kelvin) without exploding our material

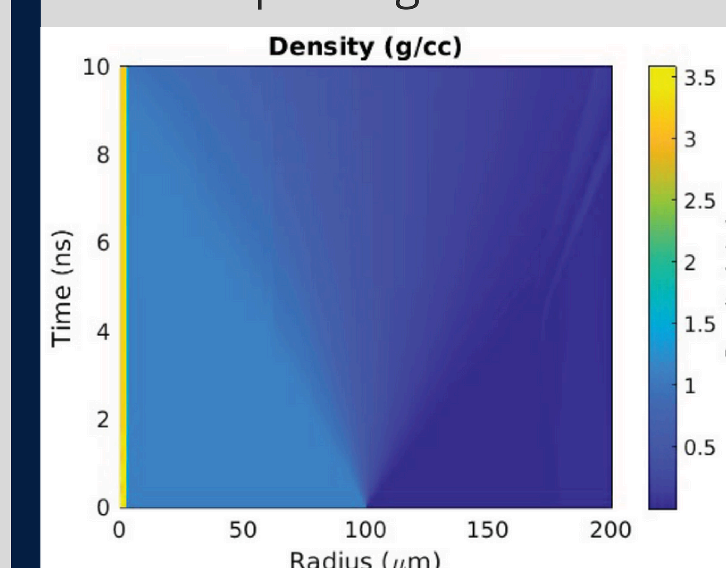


Figure 4: Temperature plot of MgO wire encased in CH plastic

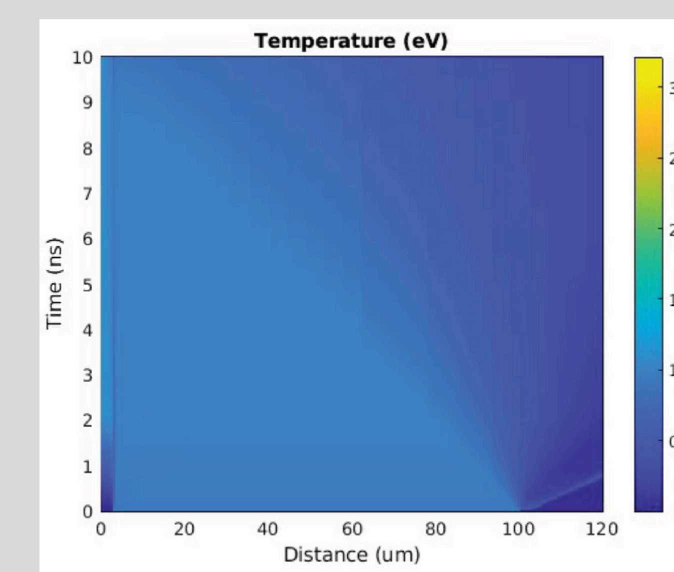
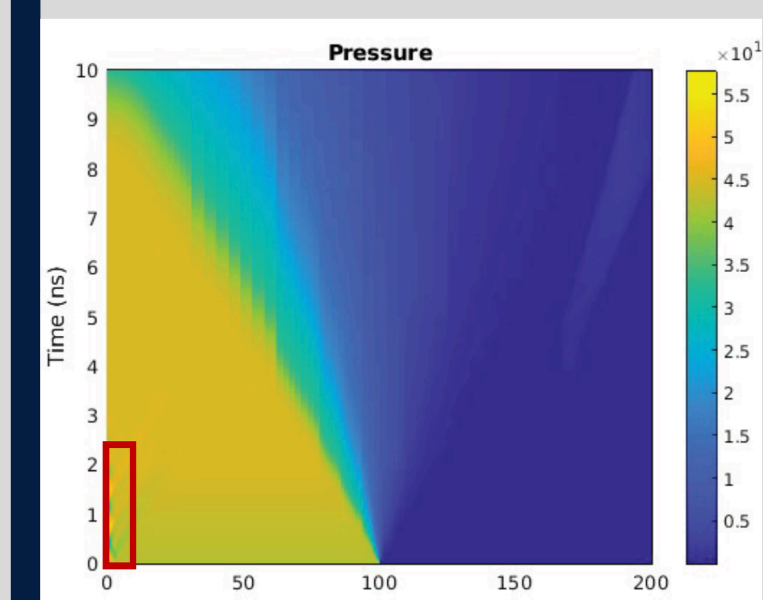
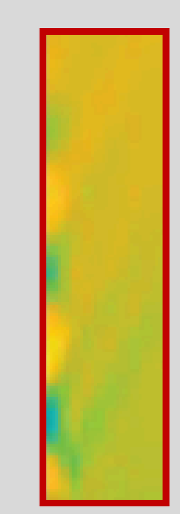


Figure 5: Density plot of MgO wire encased in CH plastic





Discoloration from t = 0 ns to t = 2.5 ns indicates a propagating shockwave due to rapid expansion in the material.

Figure 6: Pressure plot of our MgO encased in CH. Pressure units are erg/cm3.

- Obstacles of our simulations/target design:
  - Plastic casing and MgO reach the same temperature, making it impossible to assess the temperature flow between them. This is due to these materials possessing similar heat capacities
  - According to LLNL target fabricators, creating a wire of pure MgO would likely not be possible

CONCLUSION

- Simulations indicate that an experiment to analyze the thermal conductivity of warm dense MgO is feasible, with some design changes
- Simulation target design should alter the plastic casing from CH to CHCl
- Alternative forms for MgO must be explored for target fabrication

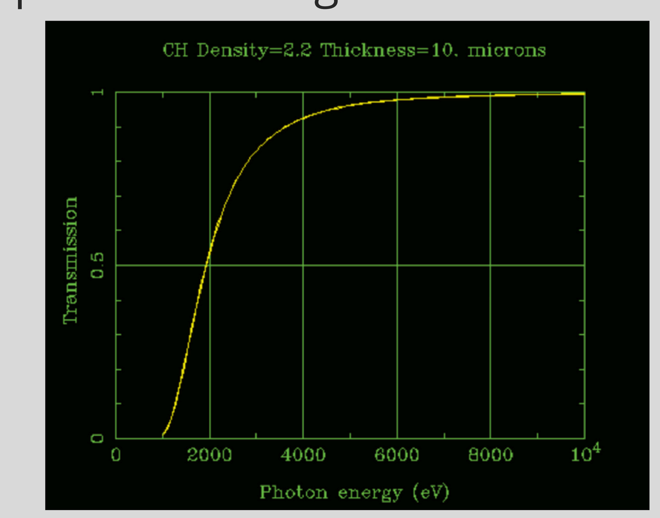


Figure 7: Filter transmission of CH, a type of plastic.

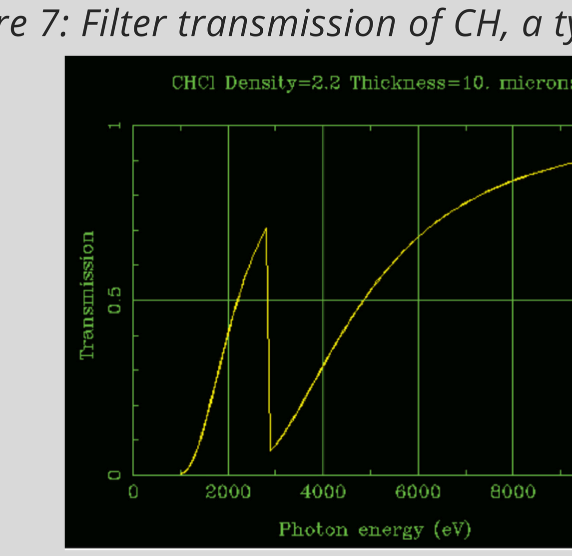


Figure 8: Filter transmission of CHCl, a type of plastic.

ACKNOWLEDGEMENTS

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