White Paper for *Frontiers of Plasma Science Panel*

Date of Submission:	***7/17/2015***

Indicate the primary area this white paper addresses by placing "P" in right column.
Indicate secondary area or areas by placing "S" in right column

	"P", "S"
• Plasma Atomic physics and the interface with chemistry and biology	
• Turbulence and transport	P
• Interactions of plasmas and waves	S
• Plasma self-organization	
• Statistical mechanics of plasmas	S

Indicate type of presentation desired at Town Hall Meeting.

	"X"
Oral	
Poster	
Either Oral or Poster	

Title:	Energy transport in HED matter
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(Limit text to 3-pages including this form. Font Times Roman size 11.
1 page of references and 1 page of figures may also be included. *Submit in PDF format*.)

- ***Describe the research frontier* and importance of the scientific challenge.**

As the ignition campaign on NIF approaches the conditions for hot-spot ignition, the demand for benchmarking data and more sophisticated models under these extreme conditions has never been so urgent. Even after demonstration of ignition, optimization for high gain will also require next-generation physics models and simulation tools in areas such as equation of state (EOS), non-local thermodynamic equilibrium (NLTE) opacity and transport properties. These models and simulation codes will remain untested and unvalidated unless there are experimental data under well-defined conditions to benchmark them.

At present, the high-foot approach has boosted neutron yield by an order of magnitude, reaching a milestone for ICF. The hot-spot conditions are inferred from a few observables with assumptions about energy transport coefficients. Based on the current level of understanding, the results do not match the predicted yields without making ad-hoc adjustments to the parameters of the calculations. Using accurate transport models that are validated by experimental data is a key step toward understanding and control of the capsule performance to reach ignition.

Energy-transport processes, including thermal/electrical conduction, radiation, viscosity, electron-ion equilibration, particle stopping, etc, determine the mechanisms and rates of how energy is transferred and redistributed in the imploded core. These energy partition pathways must be understood and properly controlled to guide the energy toward desired paths for nuclear combustion.

In addition to their traditional definition in the fluid regime, recent evidences of kinetic effects necessitate re-examining these transport processes under strong fields and/or with non-Maxwellian distributions, opening a wealth of research opportunities at this frontier of the HED science.

- ***Describe the approach to advancing the frontier and indicate if new research tools or capabilities are required.***

A number of experimental platforms and diagnostics for measurements of transport properties have been or are being developed including but not limited to:

- Differential heating for thermal conductivity (optical heating, proton heating, x-ray heating, shock heating)
- Resonant phase contrast imaging (PCI) for shock front structure and diffusivity
- Broadband proton radiography for fields and kinetic effects
- Ultrafast isochoric heating for e-ion equilibration rate
- New diagnostics or old techniques adopted for HED matter: EXAFS, XANES, PCI, Chirped pulse interferometry (CPI), x-ray fluorescence….

The measurements themselves are difficult: data interpretation is often reliant on modeling of experimental conditions hence not completely model-independent. Therefore, it is important to perform these measurements under various conditions and using different facilities in order to obtain self-consistent results. Systematic discrepancy between data and models will be convincing evidence that some physics is missing in the models.

The development effort as well as high-accuracy measurements will require access to state-of-the-art facilities. Over the past decades the advancement in laser technologies and world-wide growth of laser facilities have been impressive. It is time to combine lasers with other kinds of mature facilities, such as synchrotrons, XFELs, and particle accelerators, to create new platforms and new research capabilities. The MEC station at LCLS and the DCS station at APS are good examples of progress in this direction. High-power and stable-performance lasers are needed in order to reach ICF-relevant conditions.

- ***Describe the impact of this research on plasma science and related disciplines and any potential for societal benefit***.

The transport properties of HED matter affect capsule performance not only in hot-spot ignition but also in other schemes such as fast ignition and shock ignition. The database created by well-designed measurements will provide not only benchmark data, but also guidance for next-generation transport models which should be implemented in hydrodynamic codes for ignition design. Although modeled as many kinds of processes, the energy transport problem in HED matter is basically how to treat collisions in a proper statistical way, taking into account quantum effects, field effects, collective effects, time-dependent effects, etc. New data under different conditions will promote theoretical efforts and yield insight into this grand challenge.

The data will also have an impact on many fields where HED science plays a critical role, such as the study of geophysical phenomena, planetary formation, and astrophysical objects. For example, thermal

conductivity of iron under Earth core conditions, a key parameter for Earth core formation and dynamo energetics, has recently been re-visited and measurements are still lacking.

Universities and young scientists will be heavily involved in these projects. Energy transport includes various processes and data are scarce in HED regime, providing ample opportunities for students and postdocs to pursue as thesis topics and advance their career paths.

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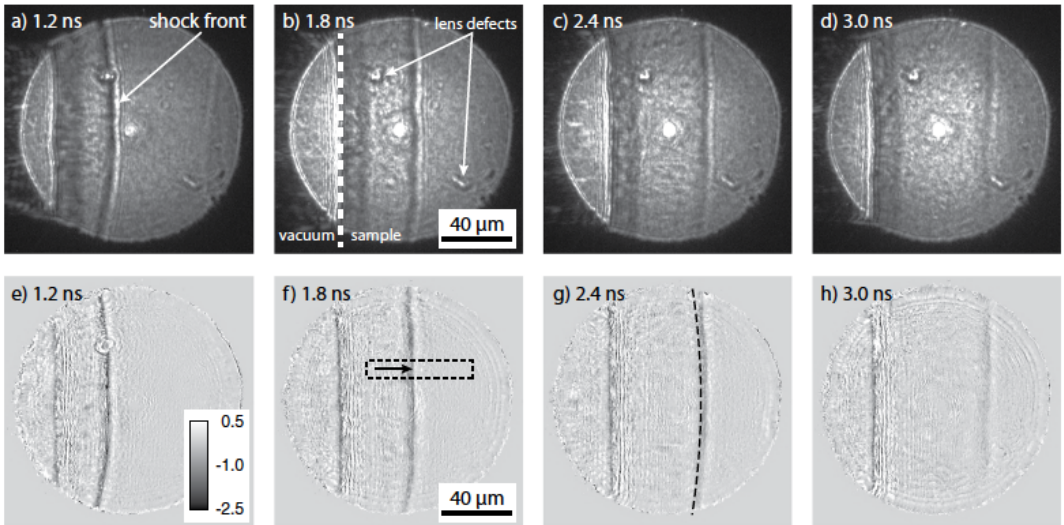

Fig.1 Coherent phase contrast imaging of shock propagation in diamond (from an LCLS experiment by A. Shropp et al).

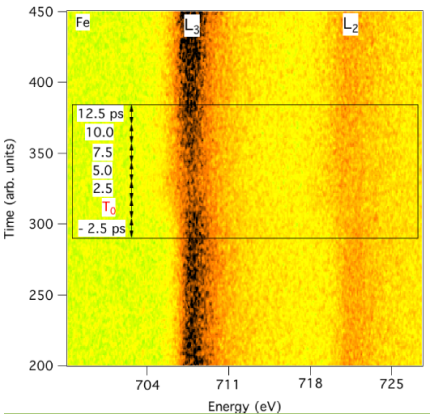

Fig. 2 X-ray absorption near edge structure (XANES) spectra of iron heated by fs laser pulses. The temporal blurring of the edge provides time history of electron temperature and e-ion coupling rate (from an ALS experiment by A. Fernandez, et al.)

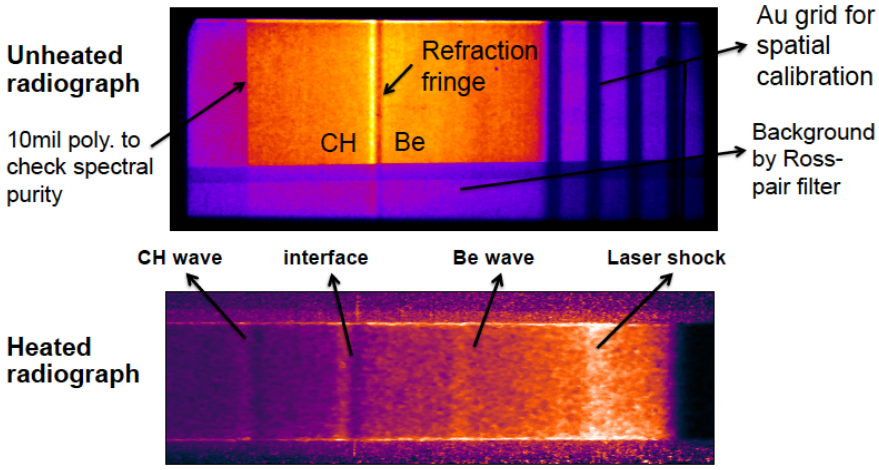

Fig. 3 X-ray radiographs of a differentially heated CH/Be interface for thermal conductivity measurements (from an OMEGA experiment by Y. Ping et al).