White Paper for *Frontiers of Plasma Science Panel*

Date of Submission:	***June 19, 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	S
• Turbulence and transport	S
• Interactions of plasmas and waves	
• Plasma self-organization	
• Statistical mechanics of plasmas	P

Indicate type of presentation desired at Town Hall Meeting.

	"X"
Oral	X
Poster	
Either Oral or Poster	
Will not attend	

Title:	Transport in Warm Dense 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.**

Warm dense matter (WDM) is one of the forefront research areas in high-energy density physics. It is defined as matter with both a Coulomb coupling parameter and degeneracy parameter of order unity, between ideal plasma physics and cold condensed matter. It has wide-ranging applications including the astrophysics of giant planets and white dwarf atmospheres [1– 24], cheap and ultra-compact particle accelerators and radiation sources [25–27], the eventual production of clean, abundant energy via inertial confinement fusion [28, 29], and national and global security.

Transport properties are particularly important for WDM. Its creation in the laboratory is a highly dynamic process. A large amount of energy is delivered to a target in a short period of time. Several different methods for delivering this energy have been developed, including exploding wire, laser foil, inertial confinement fusion, ion beam, Z machine, free electron laser, and laser induced shock experiments. Understanding energy exchange and transport processes is crucial to the proper interpretation of these experiments. For example, thermal conduction is important in inertial confinement fusion for three completely different reasons [30]: its impact on x-ray conversion in the hohlraum, its impact on Rayleigh-Taylor instability growth during implosion, and as the dominant energy loss mechanism as the fuel tries to light.

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

Warm dense matter remains an immature field and requires several different thrusts to increase fundamental understanding and prediction capabilities:

- *Improved experimental measurements of transport properties, including the diagnostic capability of measuring the state of the system, and the use of such experiments to discriminate between and constrain models* – While precision optical data from x-ray free electron laser facilities such as LCLS are constraining opacity models for WDM, there are very few [31] precision experiments involving charged-particle transport.
- *A unified description of theoretical models for WDM, connecting condensed matter theory, ideal plasma physics, atomic physics, the classical limit, the degenerate limit, and reduced descriptions used in hydrodynamic codes* – Most researchers focus on extending one of these fields to WDM, but it is likely that tools from multiple fields are needed to adequately describe WDM. Cross fertilization should be encouraged.
- *Multiscale capability, bridging the gap between fundamental particle interactions and hydrodynamic length and time scales* – Particle transport can only be calculated by taking into account individual particle interactions and correlations. Accurate methods tend to be computationally expensive and limited to one plasma steady state while simulations and experiments encompass a large number of states over their domain and evolution. There is a critical need for fits and tables of detailed calculations for use in hydrodynamic codes.
- *Improved density functionals, not only for the free energy but also for transport (i.e. What functional of the density gives accurate transport coefficients?)* – Finite temperature density functional theory is the current state-of-the-art method for determining the electronic structure of WDM systems. Research has focused on the development of better orbital-free and exchange-correlation energy functionals. While such work remains important, little is known about the accuracy of transport calculations using density functional theory for WDM. Fundamental development and validation of transport functionals is needed.
- *Resolving the attosecond timescale for electron dynamics* - Recent efforts at XFEL [32–34] to measure electron and ion dynamics at attosecond and picosecond timescales reinforce the need for a short-timescale simulation capability. Electron-electron scattering and equilibration plays a direct role in thermal conductivity and nonlinear electrical conductivity.

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

Understanding transport in WDM is a strong test of finite-temperature many-body response theory, which has implications not just for nonideal plasma science, but also the larger research world of condensed matter. Direct applications include the understanding of heat transport and diffusion in white dwarfs and giant planets, thermal equilibration in free electron laser experiments, diagnostic support for next generation particle accelerators, as well as the inertial fusion program.

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