White Paper for *Frontiers of Plasma Science Panel*

Date of Submission:	***06/16/2015***

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Title:	Physical Properties of warm compressed matter
Corresponding Author:	Philipp Sperling
• Institution:	SLAC National Accelerator Laboratory, 2575 Sand Hill Road, Menlo Park, CA 94025
• email:	ps0522@slac.stanford.edu
Co-Authors:	

Physical Properties of warm compressed matter

Philipp Sperling

SLAC National Accelerator Laboratory, 2575 Sand Hill Road, Menlo Park, CA 94025

With the advent of the Linac Coherent Light Source (LCLS) at the SLAC National Accelerator Laboratory first-principles studies of physical properties of matter at high energy densities have become possible [1, 2]. Measuring the physical properties, for example the electrical conductivity, has recently been demonstrated in proof-of-principle experiments with in situ x-ray scattering measurements using LCLS' 120 Hz capability on isochorically heated aluminum. However, to fully explore the phase space where experimental data are urgently needed to test theory will require a high-repetition rate laser driver with sufficient energy to obtain high-quality inelastic x-ray scattering spectra.

Determining the physical properties of warm compressed matter states is important to characterize conditions such as those found in the interior of planets and stars [3–5] or in the laboratory, e.g. within laser produced materials and the ignition fuel of inertial confinement fusion capsule targets [6]. Further, the investigation of such matter states are of paramount interest for the understanding of the generation of the magnetic field of planets and stars [7, 8] or the assembly of thermonuclear fuel for laser fusion [9]. The first requires the knowledge of the electrical conductivity for modeling the streams and mixing behavior of the fluid or gaseous interior which defines the generation of the magnetic fields [8, 10]. The latter uses estimates of the electrical conductivity to predict Rayleigh-Taylor instability growth and the assembly of the thermonuclear fuel [11]. These examples demonstrate the importance to deliver accurate experimental data and theories of the electrical conductivity of warm dense matter that is largely missing for compressed matter states.

The small bandwidth and high brightness of LCLS allow scattering measurements with unprecedented signal-to-noise, spectral, and wavenumber resolution [12], which enables the accurate inference of the electrical conductivity (see Figure 1). The electrical conductivity was measured by inelastic x-ray scattering [13] as function of the temperature for a density of 2.7 g/cm^3 and an ionization degree of $Z_f = 3$. The new LCLS experiments also provide electron temperatures and densities not achieved in previous studies, e.g. [14]. These new capabilities provide experimental data testing or guiding the development of theoretical models, cf. Fig. 1 in regimes where no previous data exist. For example, the first measurements in isochorically heated aluminum have tested our models for ion-ion correlations, screening, and Pauli blocking that all need to be included to arrive at reliable estimates for the conductivity.

The measurement of electrical conductivities requires uniformly heated and compressed matter. Future investigations of conditions of > 10 Mbar pressure require nanosecond laser pulses that are shaped in time, provide green or blue laser wavelength with laser focal spots that are smoothed by laser smoothing techniques, and > 100 J of energy on target. In addition, a high repetition rate in the range of 0.1 Hz to 120 Hz is important. This is necessary to 1) take full advantage of the high-repetition rate provided by LCLS, 2) to accumulate in a reasonably short time over 2000 shots that are required for one accurate data point on electrical conductivity, and 3) to deliver a sufficient number of data points to fully explore the high-density, high-temperature, high-pressure phase space.

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Figures

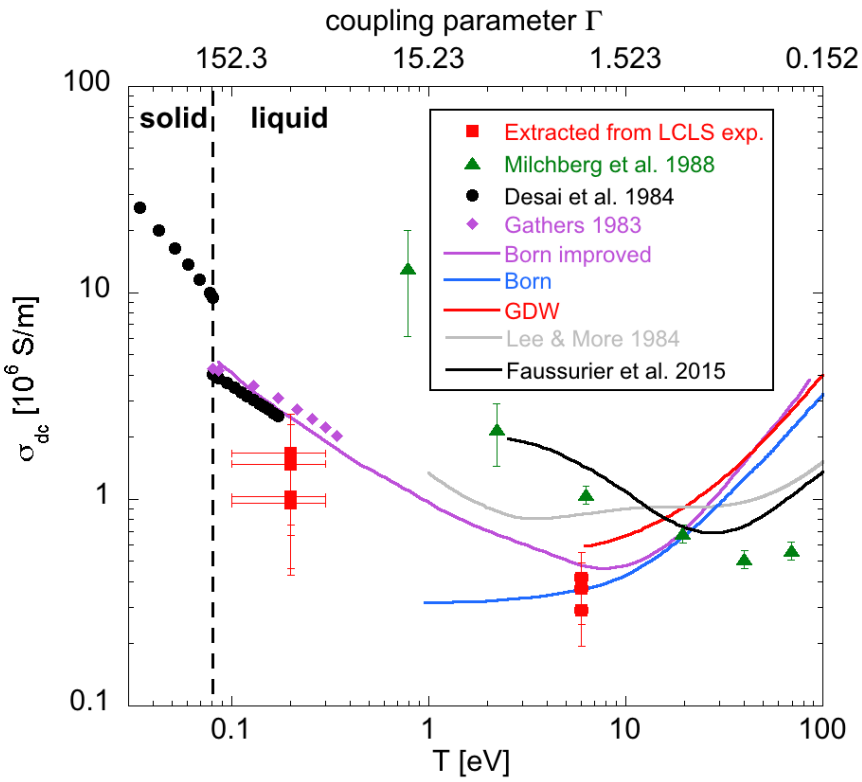

FIG. 1. The electrical conductivity of isochorically heated aluminum is shown as function of electron temperature. Experimental data from LCLS are compared to other experiments and theories. Experimental results of this work (red squares), Desai et al. (black dots), Gathers (violet rhombus), and Milchberg et al. (green triangles) as well as the theoretical models of Lee et al. (gray), Faussurier et al. (black), Gould-DeWitt (red), and Born (blue) are indicated (screened Coulomb interaction, no ion-ion correlation). To study the influence of the ion-ion structure factor and a pseudopotential, the dc conductivity with the corresponding Born collision frequency (Born improved, violet) is also shown.