Understanding warm dense matter: from theory to experiment

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Over the last decades, there has been a remarkable surge of interest in the properties of matter at extreme densities, temperatures and pressures. Such warm dense matter (WDM) naturally occurs in a host of compact astrophysical objects such as giant planet interiors, brown and white dwarfs, and the outer layer of neutron stars. In addition, WDM plays an important role in cutting-edge technological applications such as material science and inertial confinement fusion.

From a theoretical perspective, WDM is characterized by the complex interplay of effects such as Coulomb coupling between the electrons and nuclei, quantum degeneracy and delocalization, strong thermal excitation, and partial ionization. This makes its description challenging even for ab-initio methods [1]. An additional challenge is given by the diagnostics of experiments with WDM as corresponding measurements are often being interpreted based on a number of model assumptions and approximations.

Here, I give an overview of a number of recent developments that promise to overcome these limitations. Very recently, a new framework for the interpretation of x-ray Thomson scattering (XRTS) experiments has been suggested that gives one direct access to important parameters such as the temperature [2] and absolute intensity [3] without the need for any model calculations. The combination of this idea with novel approximation-free ab-initio path integral Monte Carlo (PIMC) simulation capabilities [4] allows for the rigorous interpretation of XRTS measurements of WDM states; this is demonstrated on the example of a dataset for spherically compressed beryllium [5] that has been taken at the National Ignition Facility (NIF) in Livermore, USA. Interestingly, the utilization of state-of-the-art ab-initio methods such as PIMC or density functional theory (DFT) leads to a substantially lower mass density compared to the original analysis that was based on the widely assumed Chihara decomposition [see Fig. 1]. This has important implications for the diagnostics of future experiments with WDM, and for the modeling of inertial confinement fusion applications.

Beyond their value for XRTS diagnostics, these new PIMC capabilities open up avenues for a number of research directions. Recently, first results have been presented for the density response of warm dense hydrogen [6,7], which is of key importance for the modeling of laserfusion applications and astrophysical objects alike. In addition to being interesting in their own right, such datasets are also useful for the benchmarking of other simulation methods such as static [8] and time-dependent density functional theory (TD-DFT) [9] and the ubiquitous Chihara models [10], and for the construction of improved equation-of-state tables.

The talk is concluded by a summary of current capabilities and of future challenges for the improved description of extreme states of matter on a true ab-initio level [1].

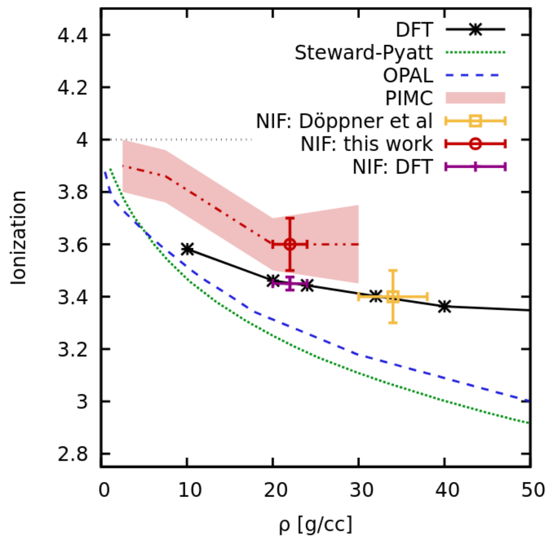

Figure 1: Ionization degree of warm dense beryllium; the solid red cross shows novel PIMC results. Taken from [4].

References
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