Spectroscopic and x-ray diagnostics for warm dense matter and applications

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Interaction between charges at high densities forms the basis of solid-state physics and high energy density states in planets, stars, and laser-solid interactions. At the transition between cold solid and classical, under-dense, hot plasmas, Warm Dense Matter is a state in which temperature is comparable to its Fermi energy, and density is sufficiently high for the Coulomb potential to exceed ion kinetic energy. Challenging to describe accurately with reduced theoretical frameworks, this last frontier of plasma physics is now being explored thanks to recent developments in numerical and experimental capabilities.

Following the idealized slab plasma approach for the study of warm dense matter proposed by Ng [1], our group has been pursuing the diagnostic of isochorically heated WDM for the past decade. Such states can be achieved transiently, by interaction with femtosecond pulses, via X-ray laser heating of bulk, solid density targets, or IR heating of nm-scale, skin depth thin foils. First experiments at the novel X-ray lasers showed that X-ray self-emission reveals the correlated nature of the plasma [2], but with intrinsically limited temporal resolution. Probes capable of penetrating solid density plasmas and with femtosecond resolution are required, and our team has led the use of High Harmonic Generation from noble gases to probe WDM. We have shown that time resolved XUV absorption measurements separate the timescales of electron and ion populations, revealing their interplay [3]. After first experiments starting at XFELs, we have since built a platform for creating and probing WDM by isochoric heating of free-standing nano-foils in Lisbon. Leveraging on our expertise in manipulating these coherent x-ray sources [3], we have performed the first temporally and spatially resolved measurements of XUV opacity of solid density Titanium up to 10 eV.

Here, we give an overview of the spectroscopic and x-ray imaging diagnostics we developed for Warm Dense Matter, and propose novel opportunities for WDM studies from small-scale to large-scale facilities.

[1] Ng, A., et al., Laser and particle beams 23.4 (2005): 527-537.

[2] G Williams et al, Physical Review Research 1 (3), 033216, 2019

[3] G Williams et al, Physical Review A 97 (2), 023414, 2018

[4] J Duarte et al, Nature Photonics 13 (7), 449-453, 2019