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Probing Extreme Atomic Physics in Super-dense Plasmas

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Matter under extreme high-energy-density (HED) conditions (e.g., at superhigh pressures from billions to trillions of atmospheres) are often encountered in stars and inertial confinement fusion targets. Such extreme HED matter can now be created on energetic laser/XFEL facilities and pulsed-power machines in laboratories. Accurate knowledge of extreme HED matter is essential to better understanding planetary science and astrophysics, as well as reliably designing fusion energy targets. Over the past decade, research has revealed that traditional plasma-physics models often fail to describe the physics of matter under HED conditions since strong coupling and electron degeneracy play a crucial role in such quantum many-body systems.

Probing HED matters in an experiment mostly relies on x rays since it is one of the possible sources that can penetrate dense matters. X-ray–induced fluorescence and/or absorption are often used to infer what happens inside extreme HED matter. On the theoretical/computational side, *ab initio* methods such as density functional theory (DFT) and time-dependent DFT [1] can provide a self-consistent way to predict the properties of HED matter (with systematic improvement possible). Combining both x-ray spectroscopy experiments and *ab initio* calculations, we have investigated some new HED physics phenomena over the past few years, which include the *Fermi-surface rising* in warm dense matter [2] and *interspecies radiative transition* in super-dense matter [3]. To understand these precision x-ray spectroscopy measurements, we have derived a DFT-based kinetic model to explore the extreme atomic physics of HED matters at Gbar pressures [4], which enables us to eliminate the controversial continuum-lowering models for dense plasmas. In this talk, I will share what we have learned so far in exploring HED matter, as well as what we are still struggling to understand.

1. Y. H. Ding *et al.*, Phys. Rev. Lett. **121**, 145001 (2018).
2. S. X. Hu, Phys. Rev. Lett. **119**, 065001 (2017).
3. S. X. Hu *et al.*, Nature Communications **11**, 1989 (2020).
4. S. X. Hu *et al.*, Nature Communications **13**, 6780 (2022).

Presenting Author

Suxing Hu

Presenting Author Affiliation

Laboratory for Laser Energetics, University of Rochester

Presenting Author Gender

Male

Country

US

Presenting Author Email Address

shu@lle.rochester.edu

Primary author: HU, Suxing (Laboratory for Laser Energetics, University of Rochester)

Presenter: HU, Suxing (Laboratory for Laser Energetics, University of Rochester)

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