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Understanding electron dynamics in dense plasmas through ultrafast X-ray heating and probing

Dense plasmas, in which the electronic structure is shaped by the density, are ubiquitous in compact objects in space, and in laboratories where solids driven to plasma state by short pulses. In these plasmas, electron collisions determine the plasma properties such as ionisation state, energy transport, and relaxation rates. In recent years, x-ray free electron lasers (XFEL's) have heralded a new paradigm in creating and diagnosing plasmas at solid densities and above [1].

Here, we present data and analysis of XFEL heating of solids and the induced k-alpha emission. We highlight the role of degeneracy, cross-sections and double ionisation shake-off, and how these experiments have improved our understanding of electron dynamics in dense plasmas [2-4]. We further highlight experiments and future prospects of probing the outer electronic structure of solid plasmas using high-order-harmonics, and how this can improve our understanding of ultrafast changes to the electronic structure during femtosecond laser heating of solids [5].

[1] S. M. Vinko et al., "Creation and diagnosis of a solid-density plasma with an X-ray free-electron laser", *Nature* 482, 59–62 (2012)

[2] G. O. Williams et al., "Collisional ionization and recombination in degenerate plasmas beyond the free-electron-gas approximation", *Phys. Rev. E* 102, 063204 (2020)

[3] G. O. Williams et al., "Impact of free electron degeneracy on collisional rates in plasmas", *Phys. Rev. Research* 1, 033216 (2019)

[4] G. O. Williams et al., "Shake-off in XFEL heated solid density plasma", *arXiv:2501.16970* (2025)

[5] G. O. Williams et al., "Tracking the ultrafast XUV optical properties of x-ray free-electron-laser heated matter with high-order harmonics", *Phys. Rev. A* 97, 023414 (2018)

Hosts: Beata Ziaja-Motyka & Ruslan Kurta



Virtual participation (via Zoom):

<https://xfel.zoom.us/j/69226950869?pwd=DW81EikPcT0iWXZ6Vhf801oGfCt3mD.1>

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