keV ion heating in solid iron via radial acoustic waves driven by nano-focused XFEL

Y. Sentoku[1], R. Royle[2], R. Mancini[3]

[1] Institute of Laser Engineering, Osaka University, Osaka, Japan
[2] Clarendon Laboratory, University of Oxford, Oxford, UK
[3] Department of Physics, University of Reno, Nevada, USA

The interiors of stars and giant planets exist in a state of high-energy-density (HED) plasma (> 0.1 MJ/cm^3 or 1 Mbar of pressure), which is divided into two broad categories. Hot dense matter (HDM) is the hot plasma found inside stars, and warm dense matter (WDM) is the strongly correlated plasma that exists deep within giant planets like Jupiter and Saturn. The study of HED matter is also of critical importance to inertial confinement fusion research. As the interiors of stars, planets, and imploding fusion capsules are inaccessible to direct measurement, we must rely on theoretical models to explain our observations. To validate our models, however, we must be able to create and diagnose sufficiently long-lived, well-characterized samples of HED matter at homogeneous temperatures and densities in the laboratory.

The hard x-ray free electron laser (XFEL) has proven to be a valuable tool for studying the properties of high energy density matter in low-Z materials as it can isochorically create plasmas at exactly solid density and temperatures up to several hundred eV. In order to drive keV plasmas in mid- or high-Z materials, it becomes necessary to focus the XFEL pulses to sub-micron spots to achieve the required fluence. The plasmas driven by such a tightly focused XFEL are non-thermal and kinetic in the sharp temperature gradients with strong electric fields that can accelerate ions radially within the target to keV energies as well as normally from the target surface to hundreds of keV in hundreds of femtoseconds. Furthermore, if the focal spot size is comparable to the collisional stopping range of the fast photoelectrons and/or Auger electrons responsible for ionizing and heating the plasma, a significant amount of the absorbed energy can be deposited well beyond the laser spot. We use the extended 2D particle-in-cell code PICLS [1,2] to model the creation and evolution of such dynamic plasmas in solid iron driven by XFEL focused to sub-micron spots. A narrow keV plasma column created in a solid iron target irradiated by a 1 mJ x-ray laser pulse focused to a 100 nm spot is demonstrated. The extent of the aforementioned non-linear effects and their dependence on experimental parameters are demonstrated, and implications for future efforts to model the spectral emissions from such plasmas are discussed.

[1] Y. Sentoku, I. Paraschiv, R. Royle et al. Phys. Rev. E 90, 051102(R) (2014).
[2] R. Royle, Y. Sentoku, R. C. Mancini et al., Phys. Rev. E 95, 063203 (2017).