**Ionization dynamics in ultra-relativistic laser plasmas   
using X-ray free electron lasers**

Mikhail Mishchenko1, Motoaki Nakatsutsumi1, Erik Brambrink1, Toma Toncian2, Dominik Kraus2, Irene Prencipe2, Thomas Kluge2, Thomas Cowan2, Lingen Huang2, Michal Smid2, Alejandro Garcia2, Hauke Höppner2, Paul Neumayer2, Oliver Humphries1,2, Eyal Kroupp3, Evgeny Stambulchik3, Ingo Uschmann4, Robert Lötzsch4, Paul B Neumayer5, Byoung-ick Cho6 and Ulf Zastrau1,

*1European XFEL GmbH, Germany*

*2 Helmholtz-Zentrum Dresden-Rossendorf (HZDR), Germany*

*3 Weizmann Institute of Science, Israel*

*4 Friedrich-Schiller-Universität Jena, Germany*

*5 GSI Helmholtzzentrum für Schwerionenforschung, Germany*

*6 Gwangju Institute of Science and Technology, South Korea*

The dynamics of bulk heating and ionization determines the crucial plasma parameters such as plasma temperature and density in ultra-short relativistic laser-solid target interactions. We have experimentally demonstrated (resonant) time-dependent probing of radiative K-transitions in a mid-Z Cu plasma as a convenient method for the simultaneous study of spatial and temporal ionization and relaxation dynamics.

Experimental data on relaxation dynamics and recombination rates are in high demand to improve particle-in-cell simulations. We have no direct information on the actual recombination rates, as the widely applied Thomas-Fermi approximation lacks the reaction rate information and thus usually overestimates the ionization degree. [1,2,3]

Opportunities at HED instrument at the European XFEL with its 25-fs x-ray pulses, together with the demonstrated 20-30 fs timing synchronization to the sub-petawatt class ReLaX short-pulse laser, allows unprecedented studies of relativistic laser plasmas with few-fs precision. [4]

In the course of this project, we managed to measure the characteristic lifetime for oxygen-like ionization states of a copper for plasma obtained from flat foils irradiated by ultra-relativistic laser radiation, and also to demonstrate the effectiveness of resonant X-ray pumping for the simultaneous study of the temporal and spatial dynamics of ionization in laser plasma.

[1]L. G. Huang, T Kluge, and T E Cowan, “Dynamics of bulk electron heating and ionization in solid density plasmas driven by ultra-short relativistic laser pulses,” Phys. Plasmas

[2]T. G. White et al., “Electron-Ion Equilibration in Ultrafast Heated Graphite,” 2014

[3]L. Gaus et al., “Probing ultrafast laser plasma processes inside solids with resonant small-angle x-ray scattering,” Phys. Rev. Research, vol. 3, no. 4, 2021

[4]A. Laso Garcia et al., “ReLaX: the Helmholtz International Beamline for Extreme Fields high-intensity short-pulse laser driver for relativistic laser–matter interaction and strong-field science using the high energy density instrument at the European X-ray free electron laser facility,” High Pow Laser Sci Eng, vol. 9, 2021