Resolving ultra-fast heating of dense cryogenic hydrogen

U. Zastrau[1,7], P. Sperling[2], G. Gregori[3], S. Toleikis[4],
T. Tschentscher[5], T. Döppner[6], S. H. Glenzer[7], R. Redmer[2]
[1] *IOQ, Friedrich-Schiller-Universität, 07743 Jena, Germany*
[2] *Institut für Physik, Universität Rostock, D-18051 Rostock, Germany*
[3] *Department of Physics, Clarendon, University of Oxford, Oxford, UK*
[4] *Deutsches Elektronen-Synchrotron DESY, D-22607 Hamburg, Germany*
[5] *European XFEL, 22761 Hamburg, Germany*
[6] *Lawrence Livermore National Laboratory, Livermore, CA 94550, USA*
[7] *SLAC National Accelerator Laboratory, Menlo Park, CA 94025, USA*

Knowledge of thermodynamic properties of matter under extreme conditions is critical for modeling stellar and planetary interiors, as well as for inertial confinement fusion (ICF) experiments. Of central importance are the electron-ion collision and equilibration times that determine the microscopic properties of matter related to reflectivity and thermal conductivity. On a macroscopic scale, these affect the depth of mixing layers in Jovian planets, as well as the formation of a central hot spot and the assembly of a stable thermonuclear fuel layer in ICF implosions. Uncertainties in the transport properties in dense matter limit our ability to accurately model such complex systems. As a versatile diagnostic tool for warm and dense matter states, x-ray scattering was demonstrated on picosecond and nanosecond time scales. With the advent of free electron lasers (FELs) the implementation of volumetric x-ray heating and accurate x-ray scattering on the femtosecond time scale is now becoming possible due to the short FEL pulse lengths (< 300 fs), their unprecedented peak brightness, and the high repetition rate. To investigate dynamic processes of warm dense matter on such short time scales, pump-probe experiments are necessary, where a first pulse generates an excited state that is subsequently probed by a second pulse at well-defined time delays.

We have used the split and delay capability of FLASH to produce two pulses of comparable intensity to volumetrically heat dense cryogenic hydrogen and subsequently probe it by soft x-ray scattering. The total scattered fraction rises to a peak value of $4 \cdot 10^{-6}$ within 0.9 ps, remaining constant for delays up to 2 ps [1]. This dynamics is reproduced with a Saha model for ionization. In contrast, simulations using a quotidian equation of state (QEOS) show quasi-instantaneous heating within the FEL pulse duration of 300 fs.

References

[1] U. Zastrau, P. Sperling, M. Harmand et al., Phys. Rev. Lett. **112**, 105002 (2014)