The advent of femtosecond lasers has shed new light on non-equilibrium high energy density physics. The ultrafast energy absorption by electrons and the finite rate of their energy transfer to the lattice creates non-equilibrium states of matter, triggering a new class of non-thermal processes in solids of primordial importance in material science, as well as resulting in warm dense matter (WDM) which finds implication in astrophysics and fusion.

We have developed an original approach to study the dynamical interplay between electron and ion at the atomic scale. It is based on time-resolved x-ray absorption near-edge spectroscopy (TR-XANES) measurements, giving access to the short-range disordering together with the electronic structure modification.

Two experiments are presented. The first one has been performed on a full-optical-laser device at CELIA, and reveals the ultrafast short-range disordering in warm dense aluminum. The second one has been performed on the x-ray free electron laser (XFEL) at LCLS. Besides the demonstration of TR-XANES on XFEL within few x-ray pulses, this last provides new insight on evolution of the electron density of state (DOS) of molybdenum during its transition from solid to WDM.

The sample expansion is controlled by Fourier Domain Interferometry (FDI) optical measurements, coupled with hydrodynamic simulations of the femtosecond-laser-heated samples. XANES spectra, and related electron and ion structures, are supported by ab initio Quantum Molecular Dynamic (QMD) calculations.