Measuring the physical properties of matter in extreme conditions with a seeded x-ray laser

Siegfried H. Glenzer

SLAC National Accelerator Laboratory, 2575 Sand Hill Rd, Menlo Park, CA 94025
glenzer@slac.stanford.edu

Abstract: One of the great challenges of this century is to determine if nuclear fusion of hydrogen isotopes can be demonstrated in the laboratory and developed into an unlimited carbon-free energy source. Recent experiments have led to the important finding that the demonstration of a fully burning plasma state will require much improved understanding of the microscopic physics of dense plasmas. In particular, the physical properties of dense matter determine the hydrodynamic instability growth that it is presently the limiting factor for the successful demonstration of ignition fusion targets. To provide first-principles experimental validation of modeling of compressed matter we have therefore begun developing novel experiments at the recently commissioned Matter in Extreme Conditions (MEC) instrument at the Linac Coherent Light Source (LCLS). Here, we use seeded x-ray laser pulses with the highest peak brightness available today of $2.7 \times 10^{34}$ photons s$^{-1}$ mm$^{-2}$ mrad$^{-2}$ 0.1% BW. This capability allows us to measure plasmons in shock-compressed matter. In applications to compressed aluminum experiments, the plasmon data determine the mass density of 7 g cm$^{-3}$ with a free electron density of $n_e = 4.7 \times 10^{23}$ cm$^{-3}$ and a temperature of 35,000 K. In these extreme matter conditions, wavenumber resolved scattering visualizes the density and pressure evolution by resolving correlations up to distances comparable to atomic scales. These data allow accurate determination of pressure that is approaching 5 megabar validating theoretical models for the thermodynamics of dense matter.

The figure shows x-ray scattering data from aluminum using forward (plasmon) scattering and back-scattering spectrometers for seeded and self-amplified spontaneous emission (SASE) x-ray laser beams. A 1 eV bandwidth obtained in seeded mode resolves the collective plasmon oscillations.