The High-Power Laser Facility at ESRF: local and electronic structure of matter up to Mbar range

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Abstract

The High Power Laser Facility (HPLF) is a new platform at the ESRF that performs laser-driven dynamic compression probed by ultra-fast (<100 ps) X-ray Absorption Spectroscopy (XAS) at the energy dispersive beamline ID24-ED.

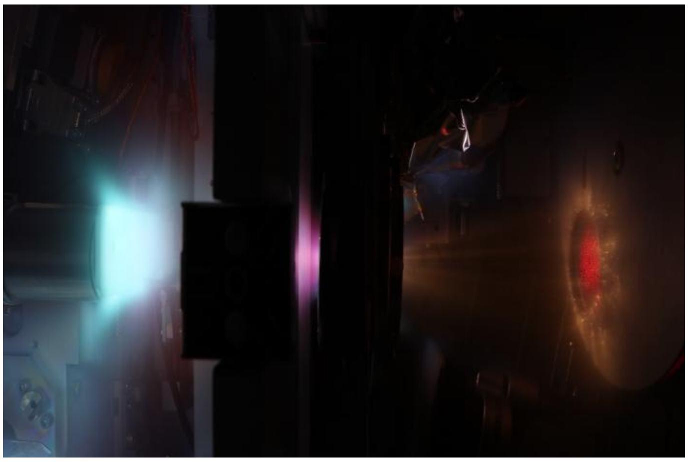
Dynamic compression provides a unique way to explore matter under extreme conditions of pressure and temperature up to several hundreds of GPa and tens of kK (for 100 J-class lasers), it also allows to explore the response of materials under high strain rates, and to generate over-liquidus states with non-eutectic composition, as the fast time scale (ns) allows to prevent chemical reaction and diffusion.

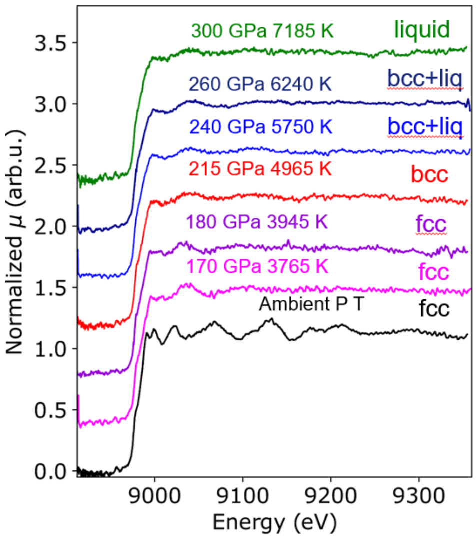
XAS provides local electronic and structural information around specific atoms whose core electrons are excited by the incident X-ray radiation. This technique is increasingly used in dynamic compression experiments [2, 3, 4] and offers complementary information to X-ray diffraction measurements. The element selectivity of XAS makes it well adapted to determine oxidation states and local ionic environment of both order and disordered systems.

ID24-ED offers time-resolved high-resolution X-ray Absorption Near Edge Spectroscopy (XANES) and Extended X-ray Absorption Fine Structure (EXAFS) measurements for materials with absorption edges between 5 and 28 keV.

The HPLF drive laser operates at 1053 nm wavelength and delivers 50 J in 4 to15 ns square pulses, producing ablation pressures up to 140 GPa in black Kapton, corresponding to around 300 GPa in 3d metals and 400 GPa in 4d metals. The facility is equipped with two line-imaging VISAR, one line-imaging streak optical pyrometry system for shot-to-shot characterization of the hydrodynamic conditions.

The science cases encompass fundamental science, Earth and planetary science and materials/industrial science. In this presentation I will provide an overview of the facility and focus on a selection of scientific results obtained during the first years of operation.





Left: photo of the shock event (curtesy of J-A Hernandez); right: XAS data of copper under shock compression up to 300 GPa [5]

[1] Hernandez et al., High-Pressure Research (2024)
[2] Sio et al., Nature Communications (2023)
[3] Turneaure et al., PRB (2022)
[4] Balugani et al., PRL (2024)
[5] Balugani et al. arXiv:2503.01939v1