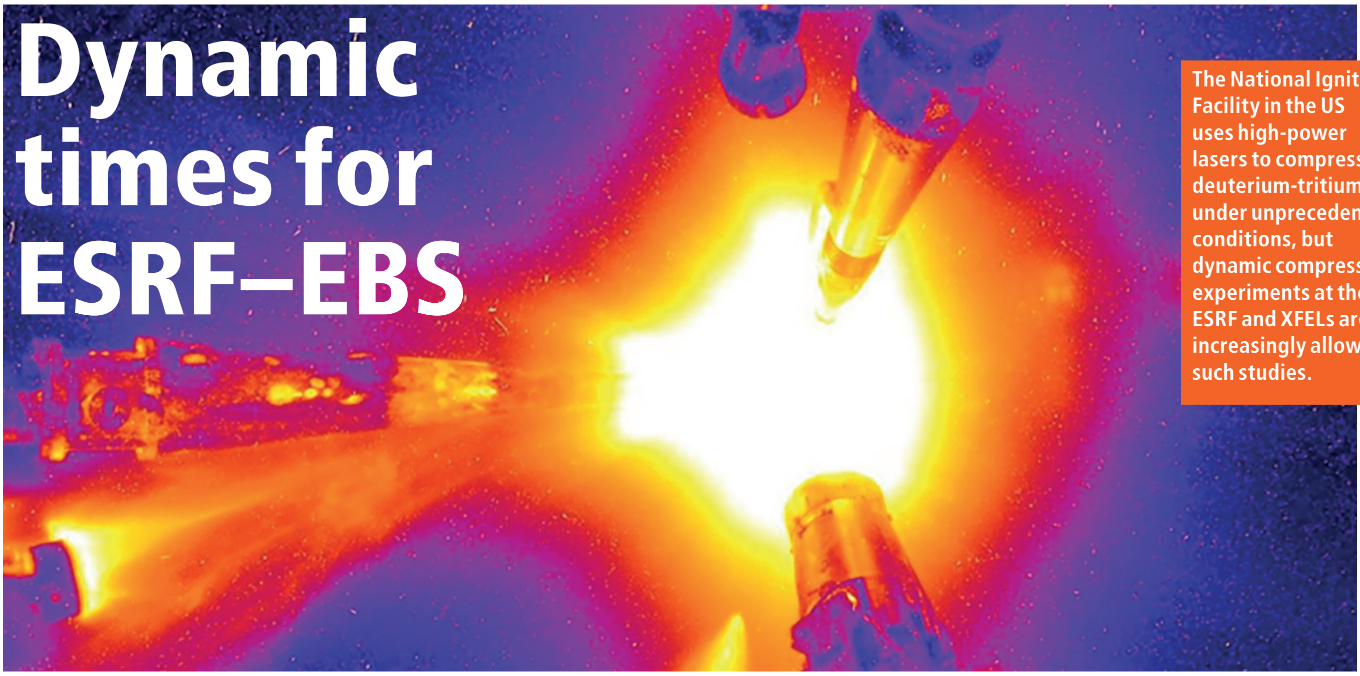
Dynamic times for ESRF–EBS



The National Ignition Facility in the US uses high-power lasers to compress deuterium-tritium under unprecedented conditions, but dynamic compression experiments at the ESRF and XFELs are increasingly allowing such studies.

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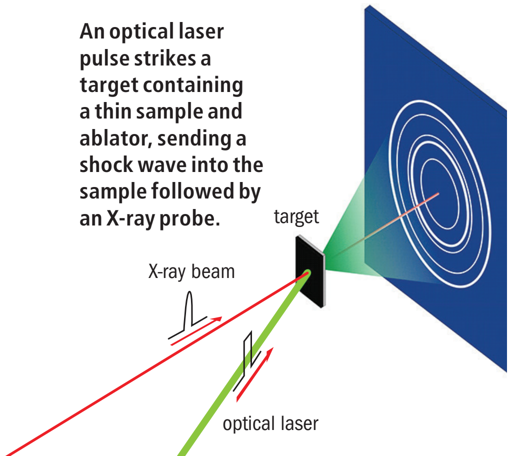
In conjunction with the European-XFEL, ESRF–EBS will provide European researchers with two world-leading facilities for the study of dynamically compressed matter.

The dynamic compression of matter, whereby pressure is rapidly applied to substances by impact, explosion or illumination, plays a central role in many natural and technological systems. Impact cratering by asteroids is a well-known example, but it also occurs in medical therapies such as the removal of kidney stones, inertial confinement fusion energy and even the strike of a mantis shrimp's claw.

Dynamic compression is also a primary technique to study the properties of matter under extreme pressure, density and temperature. In dynamic compression, changes in pressure travel through matter in the form of a shock wave. Although similar to a sound wave, shock waves have a very high pressure such that the highest-pressure part of the wave overruns any lower pressure part of the wave in front of it, producing a sudden jump in pressure. The conditions obtained in shocked samples can be much more extreme that those obtainable in a static compression experiment, but they last only for a period of a few nanoseconds – about the time it takes for a sound wave to travel across a tiny sample.

Modern shock-compression science began 60 years ago, when researchers found that solid iron undergoes a structural phase transition from the familiar body-centred-cubic structure to a hexagonal-close-packed structure when shock pressures exceeded 10 GPa. Studying such phenomena at the lattice level, however, has long been limited by the lack of X-ray sources with sufficient brightness.



An optical laser pulse strikes a target containing a thin sample and ablator, sending a shock wave into the sample followed by an X-ray probe.

Synchrotron studies over the last 25 years show that the structural behaviour observed in even simple metals at high pressures is extremely complex, and this complexity is believed to continue to multi-TPa pressures. Dynamic compression alone can obtain the extreme pressures and temperatures of interest, but if we are to truly probe the behaviour of materials at extreme conditions we also need improved structural diagnostics.

Complementing XFELs

X-ray free electron lasers (XFELs) have recently offered dynamic compression science an almost ideal X-ray source: monochromatic, micro-focussed, high-energy X-ray pulses as short as one ten-thousandth of a nanosecond. With a peak brightness one billion times higher than a synchrotron, XFELs are perfectly suited for pump–probe experiments whereby an optical laser compresses a sample followed by interrogation by the XFEL beam. This allows extremely high-quality diffraction and scattering measurements that are unaffected by any smearing from atomic motion.

While some studies of shock-compressed matter have recently been performed at synchrotrons, the signal obtained is generally poorer than is obtainable at an XFEL. That situation is about to change, however, thanks to the lattice upgrades planned on third-generation synchrotrons such as the ESRF. In particular, an anticipated 100-fold increase in flux on beamline ID27 following ESRF–EBS will make single X-ray pulse experiments much more feasible.

The first ultra-fast synchrotron spectroscopy experiments on laser-shocked iron were recently performed at ESRF beamline ID24 by a team from France and the UK (*Scientific Reports* **6** 26402). This summer will see five experiments performed at ID24 to investigate the behaviour of a wide range of materials compressed with a high-energy optical laser provided by the CEA. A particular aim is to determine whether the quality of the spectroscopic data obtainable from a synchrotron, for which the X-ray bandwidth can be chosen, is better than that from an inherently monochromatic XFEL.

The start-up of the European-XFEL in Germany in 2018, in conjunction with ESRF–EBS in 2020, will provide European researchers with two world-leading facilities for the study of both statically and dynamically compressed matter. With fortuitous timing, high-power, high-repetition-rate diode-pumped solid-state lasers are also becoming available that will deliver 100 J, 10 ns pulses at a rate of 10 Hz. When combined with the ability to shape the laser pulse, such lasers will enable exotic compression paths that are perfectly suited for dynamic compression studies at both the European-XFEL and the ESRF.

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