

Science Highlight

Exploring ‘Warm Dense Matter’ at Cores of Giant Planets

A shock wave experiment at SLAC’s X-ray laser tracked the formation of a mysterious type of matter believed to exist at the cores of giant planets. The results could help scientists understand this “warm dense matter” and could aid studies of nuclear fusion as a new source of energy.

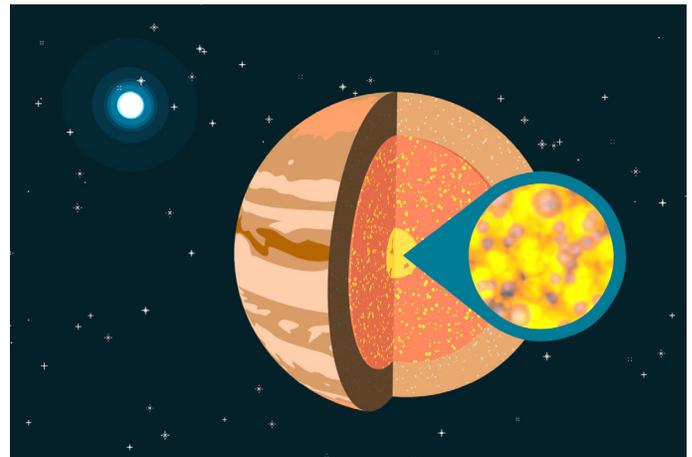
Best Look Yet at Exotic State of Matter

In the experiment, scientists precisely measured the temperature and structure of aluminum as it transitions into a superhot, highly compressed concoction known as “warm dense matter.” This exotic state of matter is believed to be at the cores of giant gas planets in our solar system, as well as in some “exoplanets” that orbit distant suns.

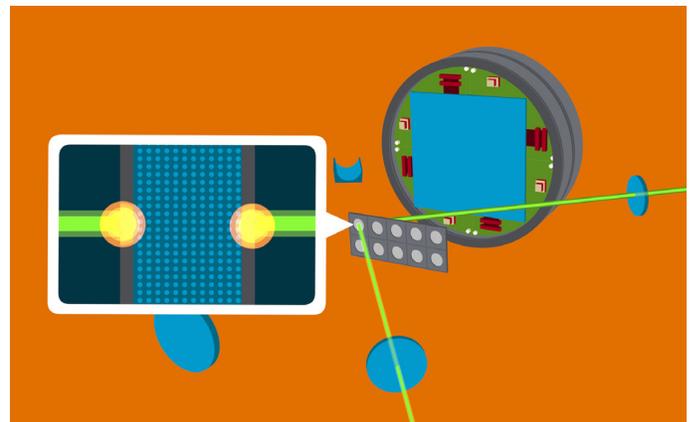
The results of the SLAC research, published in *Nature Photonics*, could help scientists figure out what’s going on in the hearts of planets and also lead to a greater understanding of how to produce and control nuclear fusion, which scientists hope to harness as a new source of energy.

“The heating and compression of warm dense matter has never been measured before in a laboratory with such precise timing,” says Siegfried Glenzer, a distinguished staff scientist who is part of the Stanford Institute for Materials and Energy Sciences (SIMES) at SLAC. “We have shown the detailed steps of how a solid hit by powerful lasers becomes a compressed solid and a dense plasma at the same time. This is a step on the path toward creating fusion in the lab.”

Glenzer’s team used laser light to compress ultrathin aluminum foil samples to a pressure more than 4,500 times higher than the deepest ocean depths and superheat it to 20,000 kelvins – about four times hotter than the surface of the sun. SLAC’s Linac Coherent Light Source (LCLS) X-ray laser precisely tracked and measured the foil’s properties as it transformed into warm dense matter and then into a plasma – a very hot gas of electrons and supercharged atoms.



This illustration shows a cutaway view of Jupiter, which is believed to contain warm dense matter at its core. A study at SLAC’s LCLS X-ray laser has provided the most detailed measurements yet of a material’s temperature and compression as it transitions into this exotic state of matter.



Researchers shocked ultrathin pieces of coated aluminum foil from both sides at once with beams of green light from a high-power optical laser (center left). Billionths of a second later, they struck the samples with X-ray laser pulses to make a series of snapshots of warm dense matter formation, recorded on detectors (upper right).

Speed Captures Fleeting Phenomena

Warm dense matter remains largely mysterious. Because it's difficult to create and lasts just billionths of a second in the lab, scientists have mostly relied on a combination of theory and computer simulations to help explain how a solid transforms into a plasma.

LCLS is uniquely suited to probing the creation of these extreme forms of matter. Like an ultra-high-speed camera, its intense X-ray laser pulses can record changes in the atomic structure of a sample at quadrillionths-of-a-second intervals.

In this case, researchers shocked ultrathin pieces of coated aluminum foil from both sides at once with beams of green light from a high-power optical laser. Each piece of foil was just half as thick as an average human hair. Shock waves from the laser blasts spread from the surfaces of the foil and converged in the middle, creating extreme temperatures and pressures.

Billionths of a second later, researchers struck the samples with X-ray laser pulses to make a series of snapshots of warm dense matter formation.

Next Up: Hydrogen

"This early work with aluminum is a first stepping stone toward other problems we really need to solve," Glenzer says, such as how hydrogen behaves under similar conditions. Hydrogen, which makes up about 75 percent of the visible mass of the universe, plays a central role in fusion, the process that powers stars. A better understanding of how hydrogen transitions into warm dense matter could help resolve conflicting theories on this transition and help unlock the secrets of fusion energy.

Participants in the research included scientists at SLAC, University of California, Berkeley, Lawrence Livermore National Laboratory and General Atomics; QuantumWise A/S in Denmark; AWE plc, University of Warwick and University of Oxford in the U.K.; and the Max Planck Institute for the Physics of Complex Systems, Institute for Optics and Quantum Electronics, Friedrich-Schiller-University and GSI Helmholtz Center for Heavy Ion Research in Germany.

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For More Information

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Scientists prepare for an experiment at SLAC's Matter in Extreme Conditions (MEC) station, part of the LCLS X-ray laser. They used this MEC station to create and measure the properties of ultrathin sheets of superheated aluminum as it transitioned into warm dense matter.