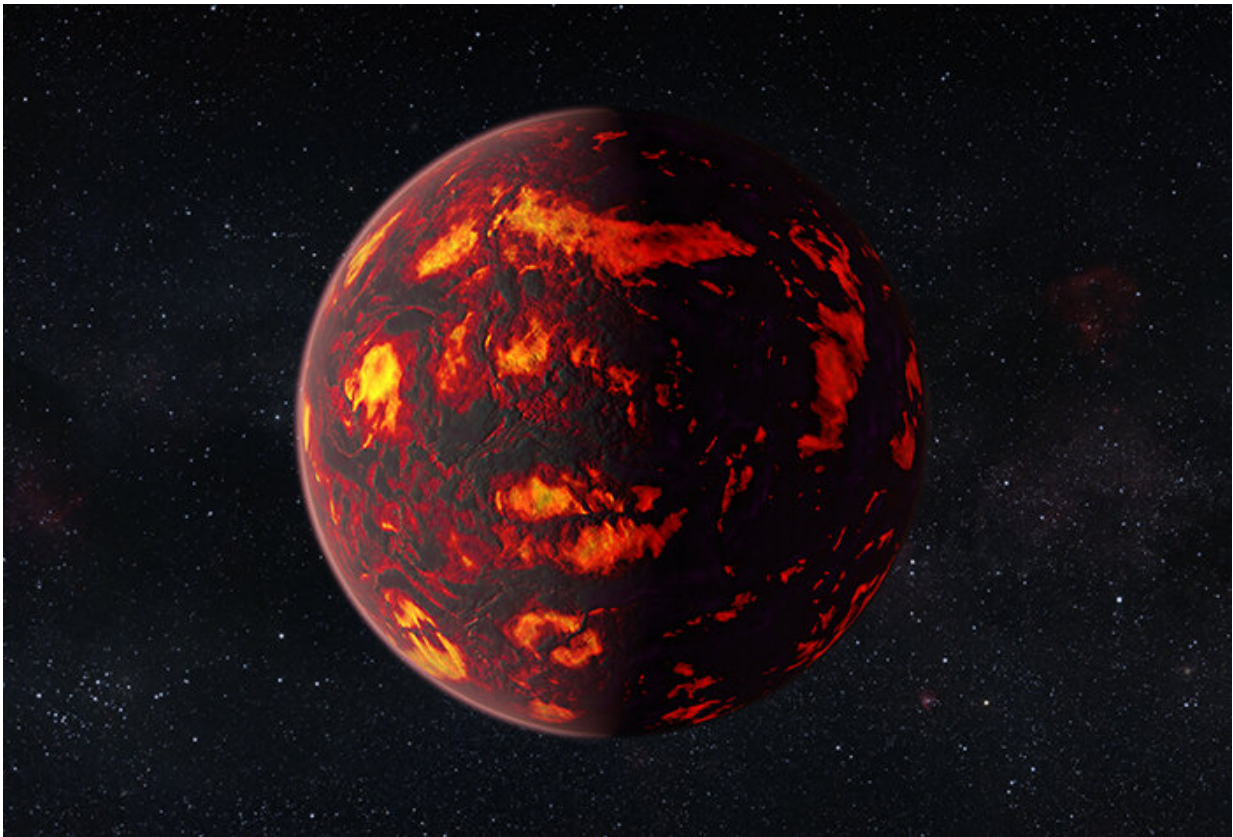


Carbon at pressures 5 times that of the Earth's core breaks crystal formation record

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An artist's rendering of 55 Cancri e, a carbon-rich exoplanet. For the first time in a laboratory setting, experiments conducted through NIF's Discovery Science program reach the extreme pressures that are relevant to understanding the structure of carbon that occupies the interior of these exoplanets. Credit: ESA/Hubble/M. Kornmesser

Carbon, the fourth most abundant element in the universe, is a building block for all known life and a material that sits in the interior of carbon-rich exoplanets.

Decades of intense investigation by scientists have shown that carbon's crystal structure has a significant impact on its properties. In addition to graphite and diamond, the most common carbon structures found at ambient pressures, scientists have predicted several new structures of carbon that could be found at pressures greater than 1,000 gigapascals (GPa). These pressures, about 2.5 times the [pressure](#) in Earth's core, are relevant for modeling exoplanet interiors but have been impossible to achieve in the laboratory.

That is, until now. Under the Discovery Science program, which allows academic scientists access to LLNL's flagship National Ignition Facility (NIF), an international team of researchers led by LLNL and the University of Oxford has successfully measured carbon at pressures reaching 2,000 GPa (5 times the pressure in Earth's core), nearly doubling the maximum pressure at which a crystal structure has ever been directly probed. The results were reported today in *Nature*.

"We discovered that, surprisingly, under these conditions carbon does not transform to any of the predicted phases but retains the diamond structure up to the highest pressure," said LLNL physicist Amy Jenei, lead author on the study. "The same ultra-strong interatomic bonds (requiring high energies to break) which are responsible for the metastable diamond structure of carbon persisting indefinitely at ambient pressure are likely also impeding its transformation above 1,000 GPa in our experiments."

The academic component of the collaboration was led by Oxford Professor Justin Wark, who praised the Lab's open-access policy.

"The NIF Discovery Science program is immensely beneficial to the academic community," he said. "It not only allows established faculty the chance to put forward proposals for experiments that would be impossible to do elsewhere, but importantly also gives graduate students, who are the senior scientists of the future, the chance to work on a completely unique facility."

The team—which also included scientists from the University of Rochester's Laboratory for Laser Energetics (LLE) and the University of York—leveraged NIF's uniquely high power and energy and accurate laser pulse-shaping to compress solid carbon to 2,000 GPa using ramp-shaped laser pulses. This allowed them to measure the crystal structure using an X-ray diffraction platform and capture a nanosecond-duration snapshot of the atomic lattice. These experiments nearly double the record high pressure at which X-ray diffraction has been recorded on any material.

The researchers found that even when subjected to these intense conditions, solid carbon retains its diamond structure far beyond its regime of predicted stability, confirming predictions that the strength of the molecular bonds in diamond persists under enormous pressure. This results in large energy barriers that hinder conversion to other carbon structures.

"Whether nature has found a way to surmount the high energy barrier to formation of the predicted phases in the interiors of exoplanets is still an open question," Jenei said. "Further measurements using an alternate compression pathway or starting from an allotrope of [carbon](#) with an atomic [structure](#) that requires less energy to rearrange will provide further insight."

More information: A. Lazicki et al. Metastability of diamond ramp-compressed to 2 terapascals, *Nature* (2021). [DOI:](#)

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