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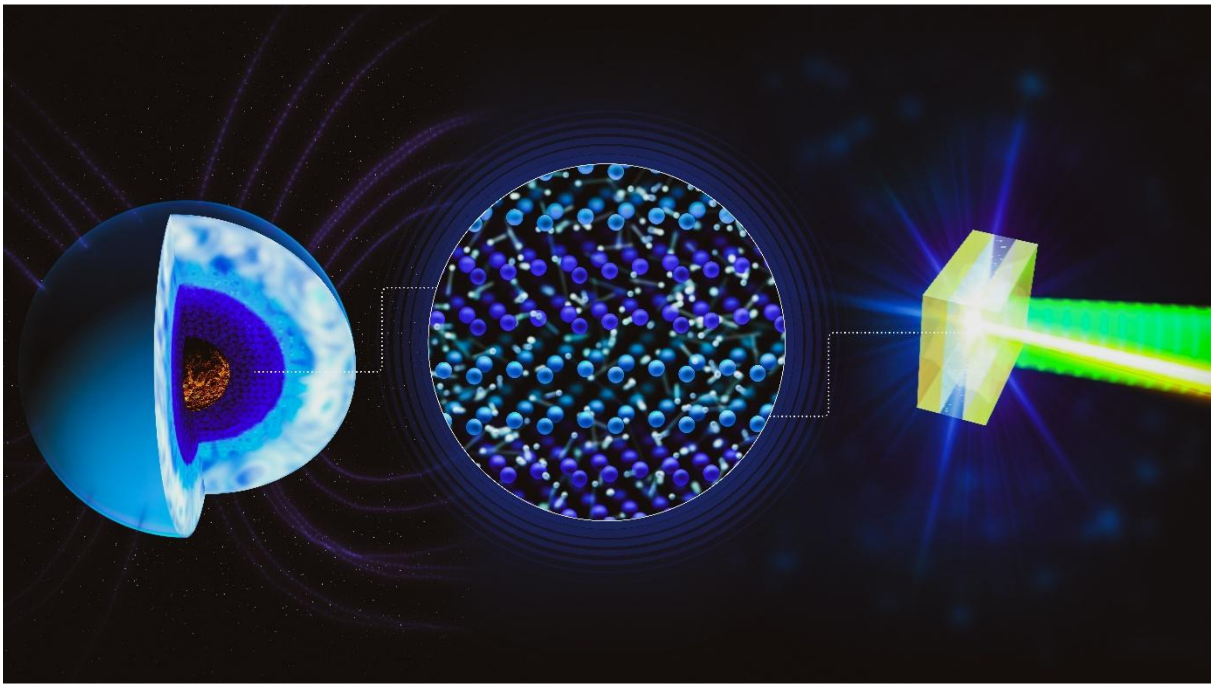
Key to researching large planets: Research team discovers novel form of water



Schematic representation of the microscopic structure of superionic water, in which the oxygen atoms form a solid crystal lattice, while hydrogen ions are virtually free to move within it. With the aid of powerful lasers, this extreme state, which otherwise only occurs inside large planets, could be measured experimentally. (© Greg Stewart / SLAC National Accelerator Laboratory)

An international research team led by scientists from the University of Rostock, CNRS-École Polytechnique in France, and Helmholtz-Zentrum Dresden-Rossendorf has discovered a previously unknown form of superionic water for the first time: The researchers have succeeded in experimentally discovering an exotic, highly electrically conductive phase at the European XFEL X-ray laser near Hamburg and the Linac Coherent Light Source (LCLS) at SLAC in the USA. It may occur inside ice giants such as Uranus and Neptune.

Temperatures of several thousand degrees Celsius and pressures of millions of atmospheres: superionic water only forms under extreme conditions. These conditions transform water into an unusual state in which hydrogen ions move freely through a solid lattice of oxygen atoms.

Milestone in planetary research

Since this so-called phase conducts electrical current particularly well, it is associated with the formation of the unusual magnetic fields of ice giants. Due to the large amounts of water inside Uranus and Neptune, superionic water could even be the most common form of water in our solar system.

New study reveals complex details about water

Although superionic water has already been produced in previous experiments, its detailed structure remained unclear until now. Previous studies suggested that the oxygen atoms in superionic ice arrange themselves in either a body-centered cubic or a face-centered cubic structure, i.e., in two variants of a cube lattice: in the former, an additional atom sits in the center of the cube, in the latter, on each cube face.
However, the new study paints a much more complex picture. The researchers found that superionic water forms a structure that combines both face-centered cubic and hexagonal close-packed stacking. The latter corresponds to a layering of closely packed atoms in hexagonal patterns and, together with the cubic areas, leads to significant stacking errors. Instead of arranging themselves in a single regular configuration, the oxygen atoms form a hybrid, misstructured sequence – a pattern that can only be made visible by high-precision measurements using state-of-the-art X-ray lasers.

Researchers create extreme conditions

To gain these insights, the team conducted two experiments: one on the Matter in Extreme Conditions (MEC) instrument at LCLS in the US and another on the HED-HIBEF instrument at European XFEL. These facilities enable researchers to compress water to pressures of more than 1.5 million atmospheres and heat it to temperatures of several thousand degrees Celsius – while simultaneously recording its atomic structure within trillionths of a second.
Insight into the structure of water creates new possibilities

The results, which are consistent with the most advanced simulations, show that superionic water can exhibit structural diversity similar to that of solid ice, which forms a variety of different crystal structures depending on pressure and temperature. The work underscores that water—despite its apparent simplicity—continually reveals new and remarkable properties under extreme conditions. In addition, the findings provide valuable constraints for improved models of the interiors and evolution of ice giants, which are also very common outside our solar system.

The project was supported as part of a joint initiative between the German Research Foundation (DFG) and the French research funding agency ANR. More than 60 scientists from Europe and the US were involved in the experiments and evaluation.

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