Polymorphism of Superionic Ice at Planetary Interior

Vitali PRAKAPENKA and Stella CHARITON (The University of Chicago, USA),
Alexander GONCHAROV (Carnegie Institution of Washington, USA)

Abstract

The behavior of water under extreme pressure and temperature is crucial for modeling the internal structure, stratification, and magnetic field generation of ice giant planets. At high pressures and temperatures, ice transforms into a superionic state characterized by a solid oxygen lattice with highly mobile protons. Defining the exact pressure-temperature boundaries of the superionic phases and their ultimate melting curve is critical for accurate modeling of gas planets. Recent static and dynamic experiments [1-5] utilizing laser-heated diamond anvil cells technique have confirmed the existence of *bcc* and *fcc* superionic phases (SI), although the precise pressure-temperature boundaries and the ultimate melting curve remain subjects of intense debate.

In our work [1-3], we have reported a significant increase in the melting curve in conjunction with the superionic phase transition and an extended temperature stability field for superionic ice, suggesting that the *fcc*-SI phase remains solid at high temperatures (approaching ~3000 K near 150 GPa). However, other studies [4-5] report a significantly lower melting curve for superionic phases. Most recently, a structural signature with an anomalously large thermal expansion crossover for the superionic transition in metastable *fcc*-SI ice was observed. Their results point to much lower transition temperatures for the *fcc*-SI phase, confirming its stability at approximately 2000 K beyond 150 GPa.

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This discrepancy of up to ~1000 K at extreme pressures highlights critical challenges in high-pressure metrology, particularly concerning temperature gradients during laser heating and potential chemical effects. Resolving these controversies is very important for determining whether planetary mantles sustain solid superionic ice or transition to a fully fluid state fundamentally alters our understanding of ice giant evolution and interior dynamics.

Here, we will present results of recent measurements on superionic phase boundaries determined at different experimental conditions with extensive comparison to available static and dynamic data, including theoretical simulations. Unique properties of superionic phases will be discussed in the light of understanding the interior structure and dynamo processes in icy exoplanets.

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[4] Weck et al. Evidence and Stability Field of fcc Superionic Water Ice Using Static Compression. Phys. Rev. Lett. 2022

[5] A. Forestier et al. X-Ray Signature of the Superionic Transition in Warm Dense fcc Water Ice. Physical Review Letters 134 (7), 076102 (2025)