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Dynamic compression of water to 700 GPa: single- and double shock experiments on Sandia's Z machine, first principles simulations, and structure of water planets

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Significant progress has over the last few years been made in high energy density physics (HEDP) by executing high-precision multi-Mbar experiments and performing first-principles simulations for elements ranging from carbon [1] to xenon [2]. The properties of water under HEDP conditions are of particular importance in planetary science due to the existence of ice-giants like Neptune and Uranus. Modeling the two planets, as well as water-rich exoplanets, requires knowing the equation of state (EOS), the pressure as a function of density and temperature, of water with high accuracy. Although extensive density functional theory (DFT) simulations have been performed for water under planetary conditions [3] experimental validation has been lacking. Accessing thermodynamic states along planetary isentropes in dynamic compression experiments is challenging because the principal Hugoniot follows a significantly different path in the phase diagram. In this talk, we present experimental data for dynamic compression of water up to 700 GPa, including in a regime of the phase-diagram intersected by the Neptune isentrope and water-rich models for the exoplanet GJ436b. The data was obtained on the Z-accelerator at Sandia National Laboratories by performing magnetically accelerated flyer plate impact experiments measuring both the shock and re-shock in the sample. The high accuracy makes it possible for the data to be used for detailed model validation: the results validate first principles based thermodynamics as a reliable foundation for planetary modeling and confirm the fine effect of including nuclear quantum effects on the shock pressure. Sandia National Laboratories is a multiprogram laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under Contract No. DE-AC04-94AL85000.

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