Isotope Effects on High-Pressure Water

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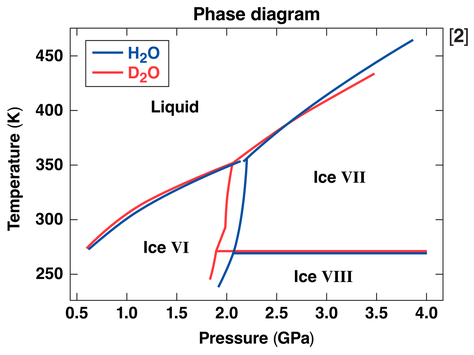
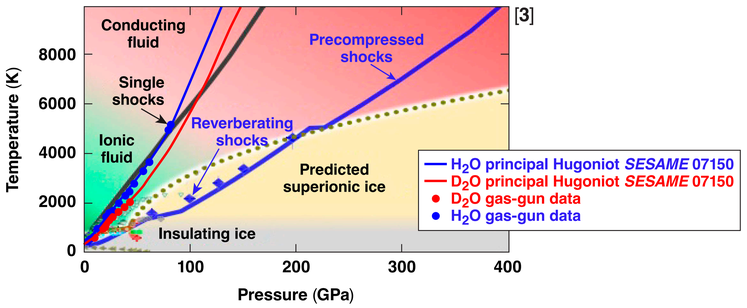
Motivation

Deuterium and hydrogen have different quantum and chemical behavior. For example, the phase boundaries between ice VI and VII are shifted in D_2O when compared to H_2O as shown on the plot below. These EOS differences between H_2O and D_2O are found within the phases as well [1].



We expect these phase differences to continue at higher pressure–temperature conditions, particularly in the superionic ice phase. Here, the H_2O dissociates, leaving a solid oxygen lattice and a permeating hydrogen fluid.

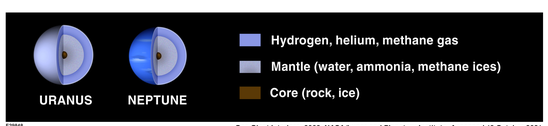
The permeating fluid in superionic D_2O will be D instead of H. How will this effect the behavior of the superionic ice and the location of phase boundaries?



EOS: equation of state

Secondary Motivation

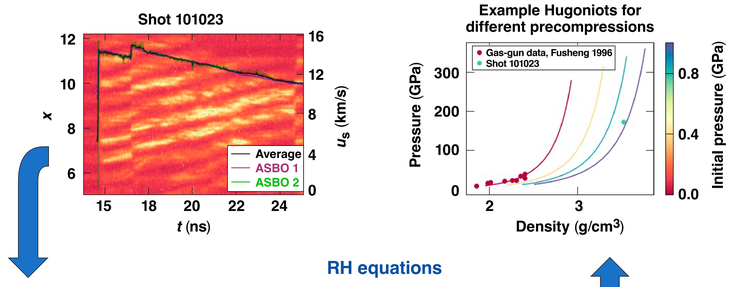
The interiors of the giant ice planets in our solar system contain water at pressures much higher than what is naturally found on Earth. It's been predicted that at these pressures, water is in the superionic phase.



Gas Giant Interiors: 2003, NASA/Lunar and Planetary Institute, Accessed 12 October 2021, https://solarsystem.nasa.gov/resources/677/gas-giant-interiors-2003/.

Sample Data: Example Analysis

VISAR [4]



Measures shock velocity (u_s)

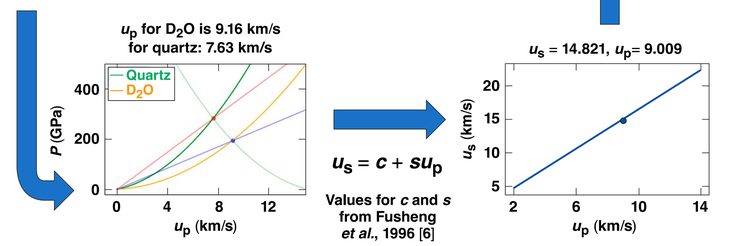
u_s and u_p (particle velocity) have a linear relationship and will likely look like this

RH equations

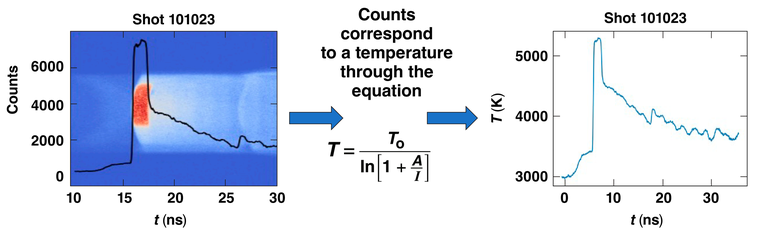
$$\rho = \frac{\rho_o u_s}{u_s - u_p}$$

$$P = \rho_o u_s u_p + P_o$$

$$E - E_o = \frac{1}{2}(P + P_o)(V_o - V)$$



SOP [5]



*RH: Rankine–Hugoniot

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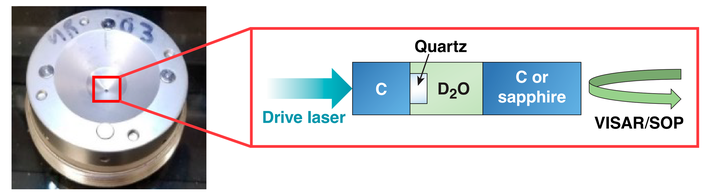
Targets

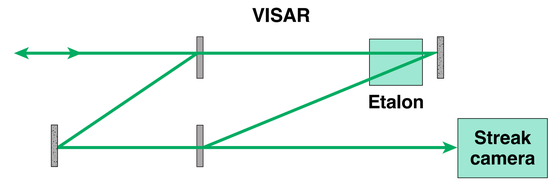
Diamond-anvil cell (DAC) filled with D_2O: these DAC's compressed the D_2O to a range of pressures from 0 to 1 GPa before dynamically compressing the sample on the OMEGA-60 laser. Planned follow-up experiments will precompress the D_2O up to 2.5 GPa.



Diagnostics

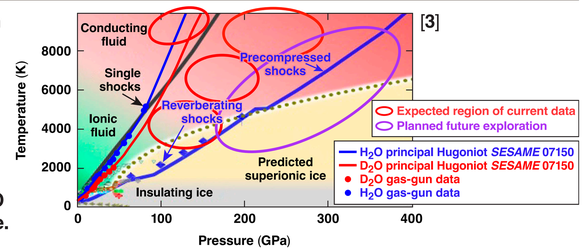
VISAR [4]: Velocity sensing interferometer
Measures the velocity of the shock front as it moves through the target; impedance matching between quartz and D_2O is used to obtain the velocity in D_2O

SOP [5]: Streaked optical pyrometer
Measures the temperature of the shocked material



Future Work

As we work through the data we have, along with data we plan to take in May 2022, the phase space below will be populated with D_2O data, and comparisons to H_2O data will be possible.



Acknowledgments

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References

[1] P. W. Bridgman, J. Chem. Phys. 3, 597 (1935).
[2] C. W. F. T. Pistorius, E. Rapoport, and J. B. Clark, J. Chem. Phys. 48, 5509 (1968).
[3] M. Millot *et al.*, Nat. Phys. 14, 297 (2018).
[4] P. M. Celliers *et al.*, Rev. Sci. Instrum. 75, 4916 (2004).
[5] M. C. Gregor *et al.*, Rev. Sci. Instrum. 87, 114903 (2016).
[6] L. Fusheng *et al.*, AIP Conf. Proc. 370, 57 (1996).

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