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Real-time latent heat emission during dynamic-compression freezing of water

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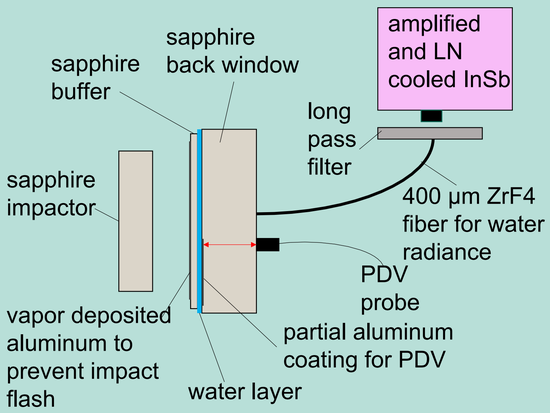
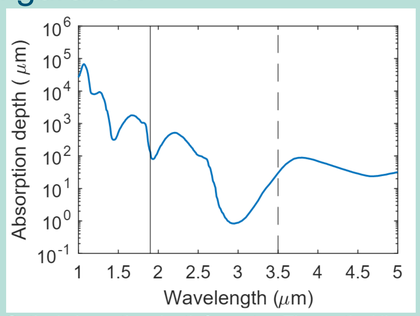
Motivation

Understanding the structural and thermal properties of high pressure ices has implications for understanding water-rich expo planets and icy moons, where environments are promising for the development of life.

Water is one of the few materials known to freeze on nanosecond timescales.

Experimental Configuration

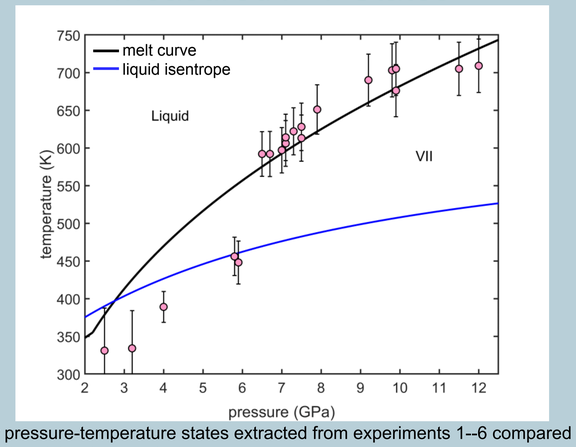




Optical absorption depth for water. The vertical lines indicate long-pass filter edges used in the experiments.

Experiments:	1-3	4-6
Sample Thickness:	250 μm	500 μm
Filter:	1.9 μm	3.5 μm

Phase Diagram for Water with Measured *P-T* States



Steady pressure-temperature states extracted from experiments 1--6 compared to the melt line (black) and calculated isentrope. Error bars were determined from the combination of the standard deviation at each plateau and the 5% systematic uncertainty diagnosed from experiment-to-experiment (fiber bends, feed through coupling, and calibrating outside the chamber). Since the detector limit was roughly 375~K, it was difficult to accurately detect temperatures during the first pressure jumps.

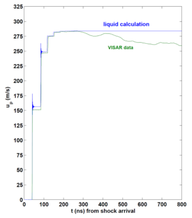
Heterogeneous Nucleation

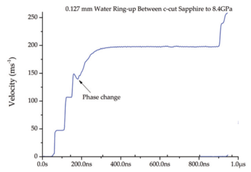
Silica Windows
< 5 GPa
~ hundreds of nanoseconds

Homogeneous Nucleation

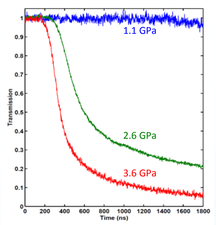
Sapphire Windows
6-7 GPa
~ tens of nanoseconds

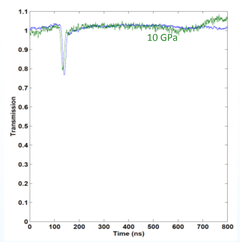
Velocimetry



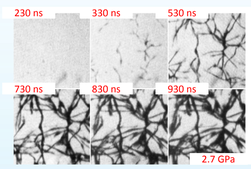


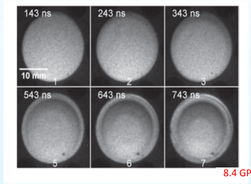
Transmission Loss



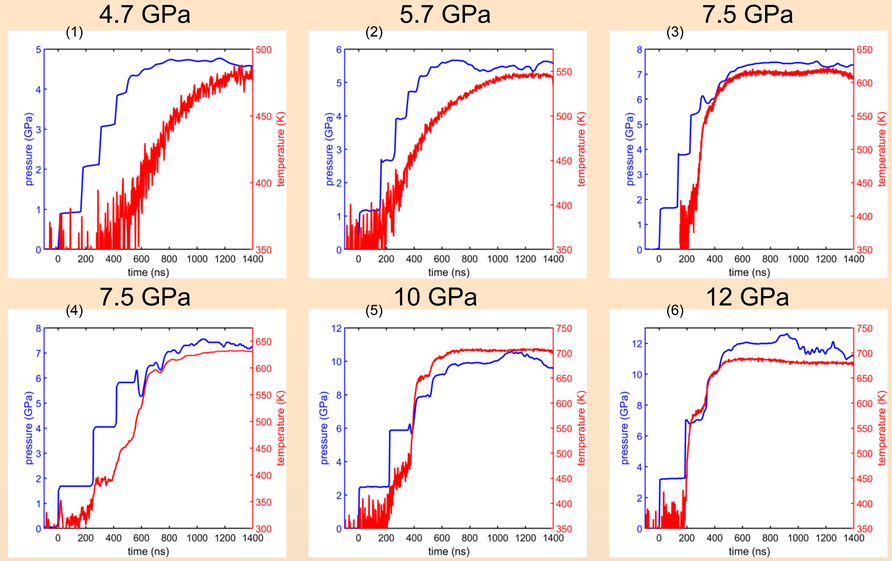


Imaging

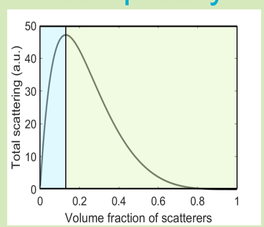




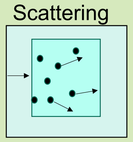
Pressure and Temperature vs. Time Profiles for Shock Compressed Water



Dynamically compressed water doesn't have to be completely frozen to be optically transparent

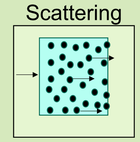


Incoherent Scattering



Reduces Optical Transparency

Coherent Scattering



Appears Transparent

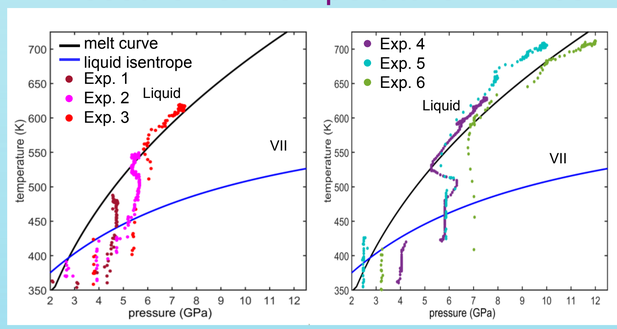
1% volume ice
> 2000 scatters
in a 500 nm cube

As the concentration of scatters increases, there are more scattering events, but also more destructive interference. The maximum total scattering occurs around 13% and decreases beyond this concentration.

$C_{total} = NC_{sca}\,S(\phi)$ *A similar argument explains transparency of the mammalian cornea and lens*

$S(\phi) = (1-\phi)^4/(1+4\phi+4\phi^2-4\phi^3+\phi^4)$

Pressure vs. Temperature Profiles



Steep temperature increases indicate latent heat emission from the formation of ice. Note there is no indication of time in these plots - the rapid increase in temperature during the lower pressure shots (1-2) takes place once the peak pressure state has been held for tens-hundreds of nanoseconds.

References & Acknowledgements

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