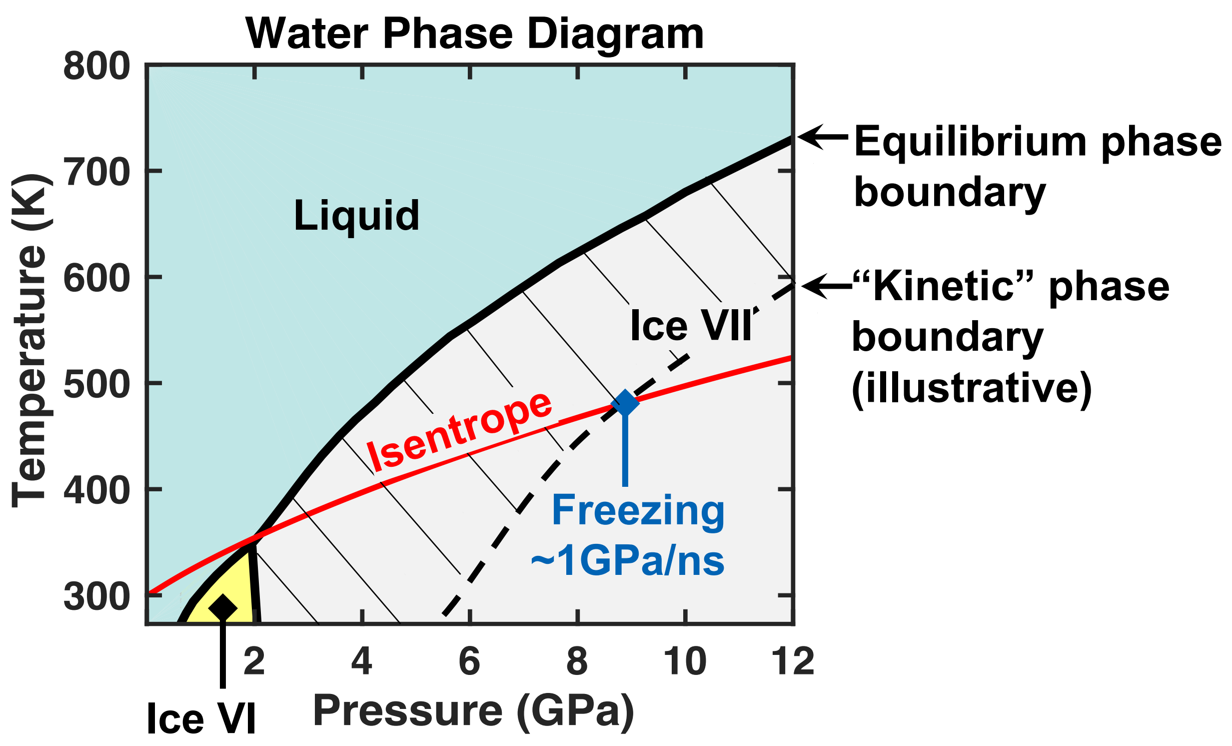
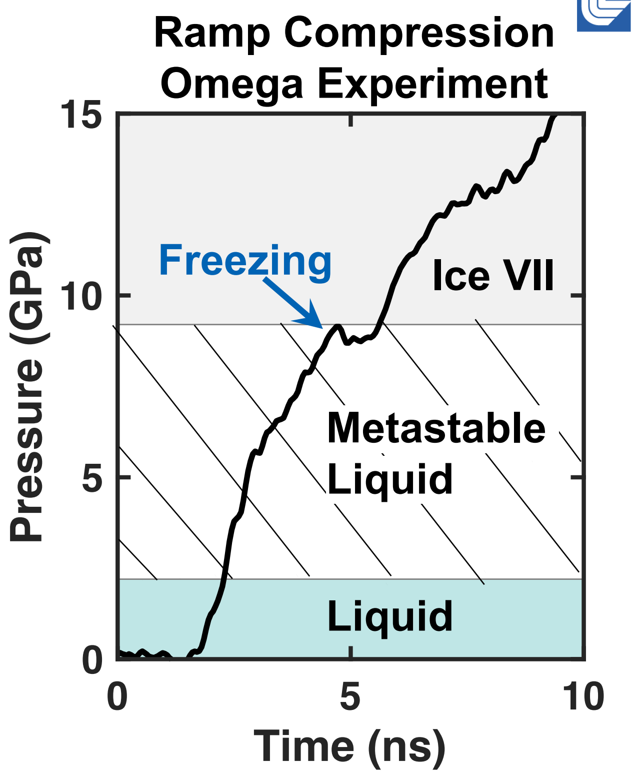
Probing the Metastability Limit of Liquid Water under Dynamic Compression





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Division of Plasma Physics
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The metastability limit of liquid water undergoing compressive freezing into ice VII is at least ~30% higher than previously reported

- Significant deviations from the equilibrium phase diagram are seen in dynamic compression experiments*
  - Water can remain liquid in a metastable state beyond the liquid-ice VII equilibrium phase boundary**
- We ramp compressed water into ice VII at rates of 0.3 – 3 GPa/ns at the Omega laser facility
- The freezing pressure increases with compression rate to 9 GPa, which is 30% higher than the freezing pressure in Z and Thor experiments at 30x lower compression rates**
- Simulations using the SAMSA kinetics code corroborate the experimental results

*R. F. Smith *et al.,* Phys. Rev. Lett. 101, 065701 (2008).
**D. H. Dolan *et al.*, Nat. Phys. 3, 339-342 (2007);
E. J. Nissen and D. H. Dolan, J. Appl. Phys. 126, 015903 (2019);
M. Bastea *et al.*, Phys. Rev. B 75, 172104 (2007).

Collaborators

M. Millot, D. E. Fratanduono, P. C. Myint, J. L. Belof, Y.-J. Kim, F. Coppari, J. H. Eggert, R. F. Smith, and J. M. McNaney
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D. M. Sterbentz
University of California, Davis

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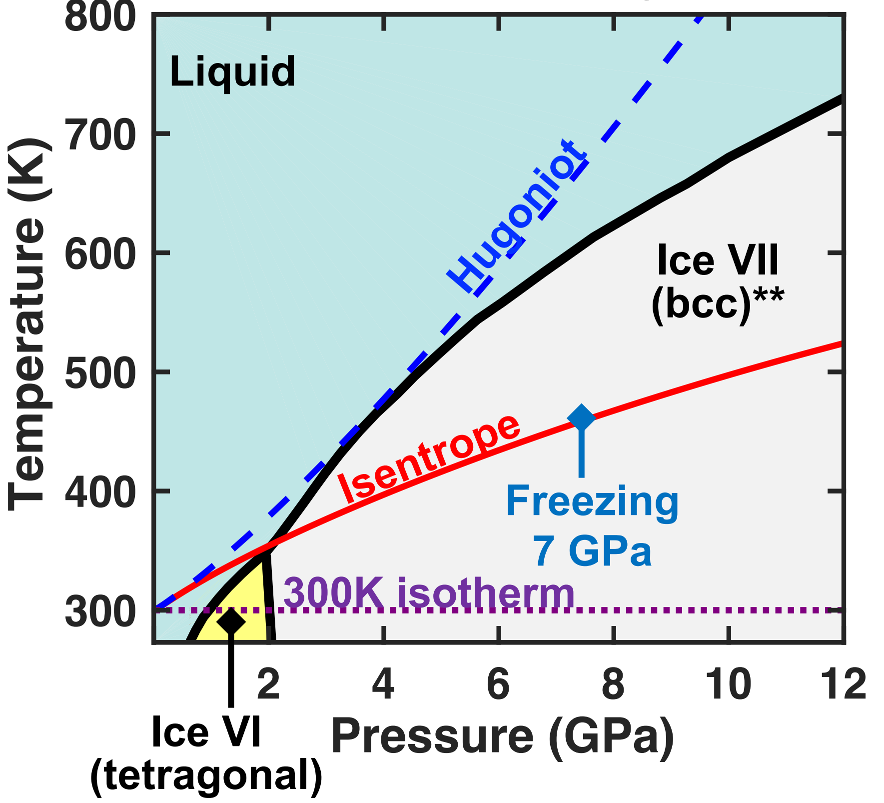
Motivation

The metastable limit of liquid water under ramp compression was previously measured to be 7 GPa at the Sandia Z facility*

Water Phase Diagram



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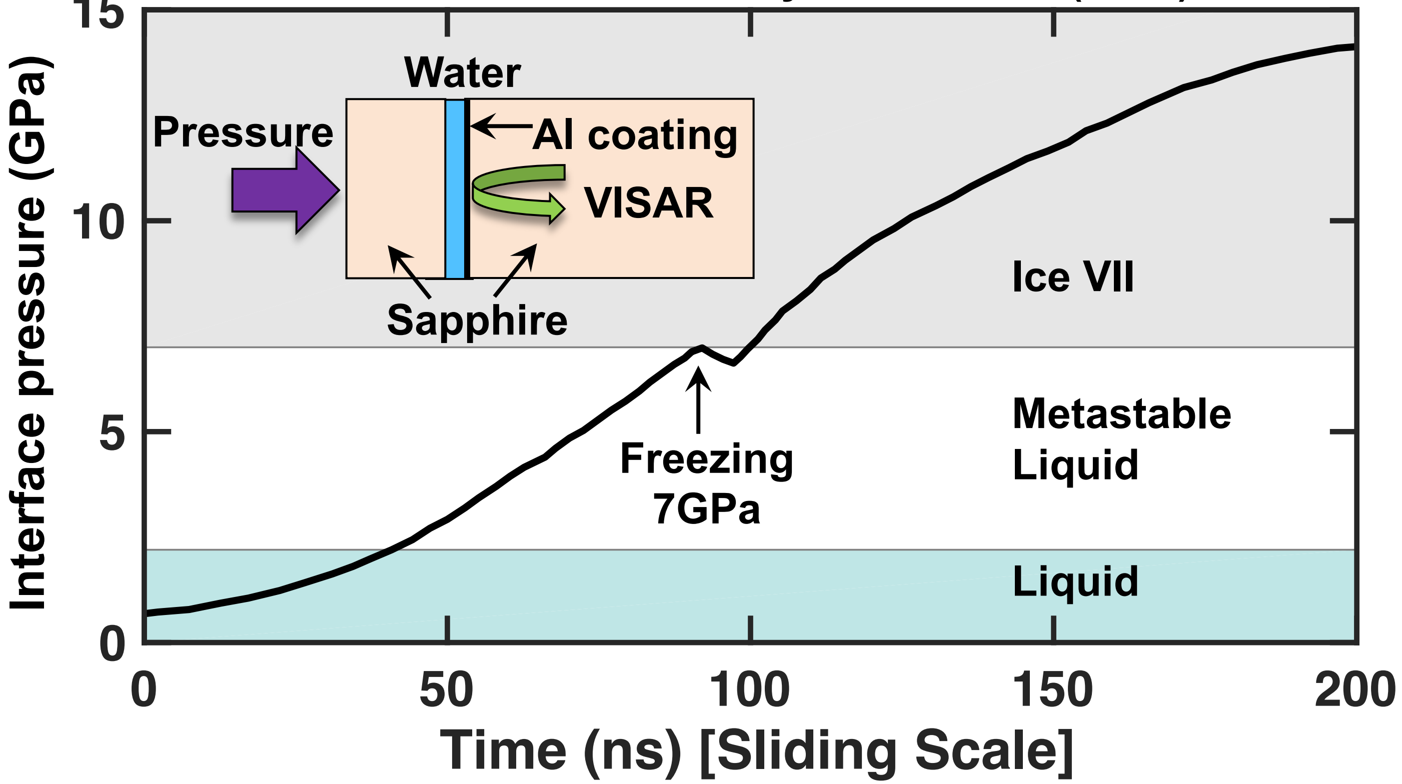

Equilibrium phase boundaries: C. W. F. T. Pistorius *et al.*, J. Chem. Phys. 48, 5509 (1968)
Thermodynamic curves: P. C. Myint *et al.*, J. Chem. Phys. 147, 084505 (2017)
**Gleason *et al.*, Phys. Rev. Lett. 119, 025701 (2017).

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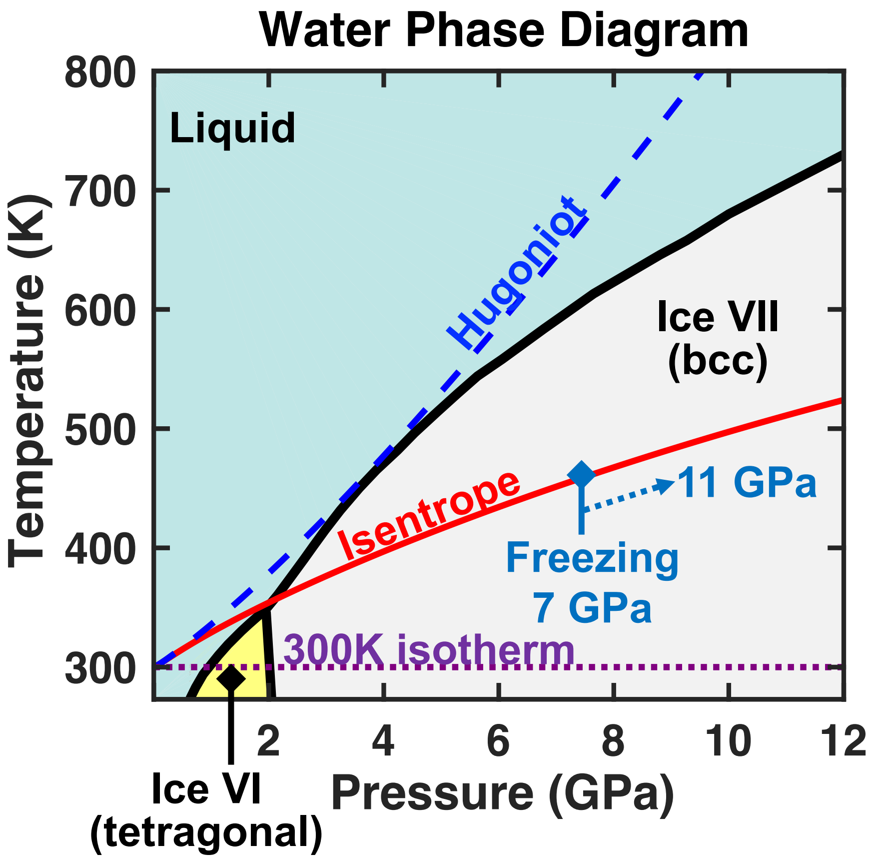

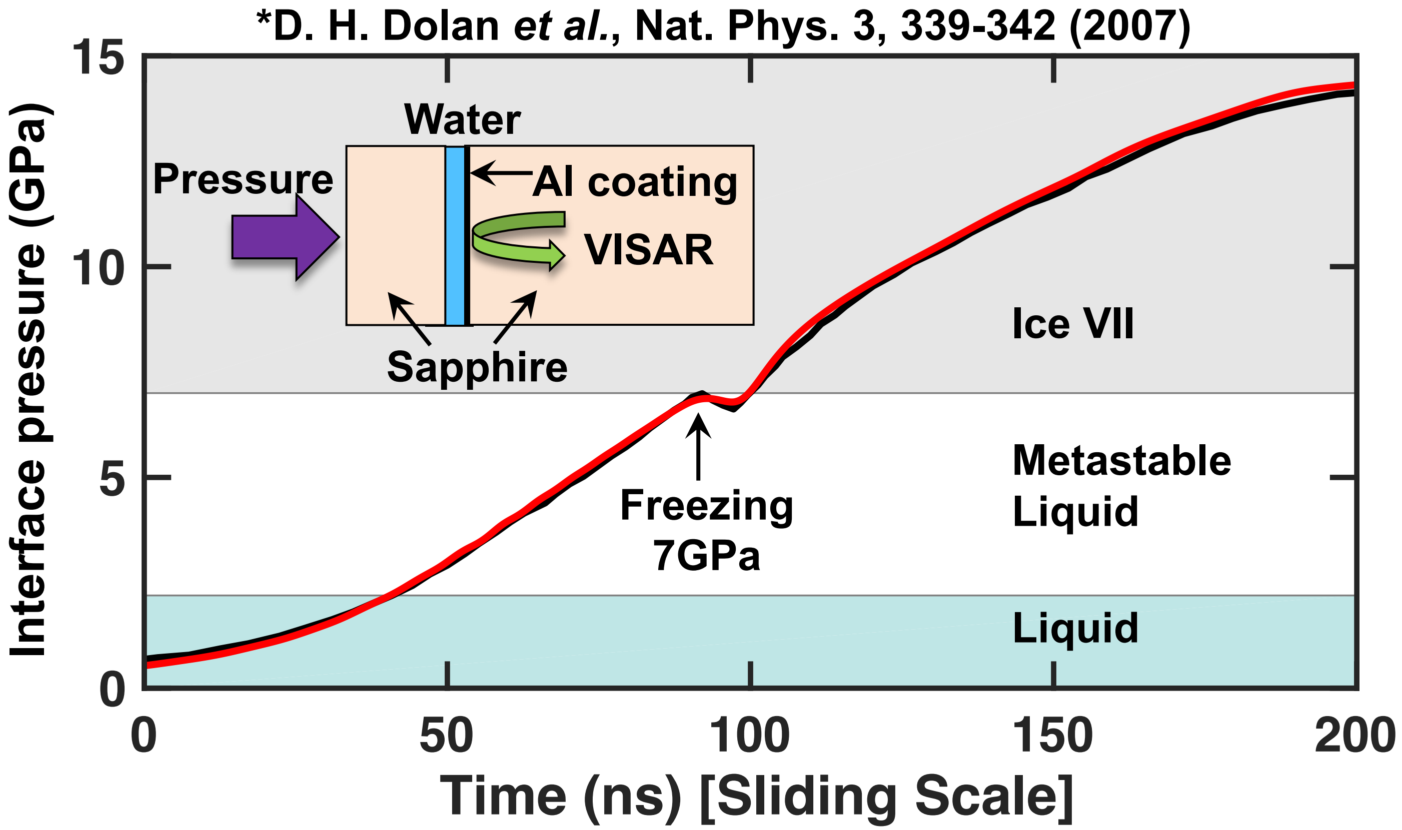

SAMSA kinetics code reproduces experimental data using classical nucleation theory when including: (1) transient nucleation and (2) separate solid and liquid temperatures**

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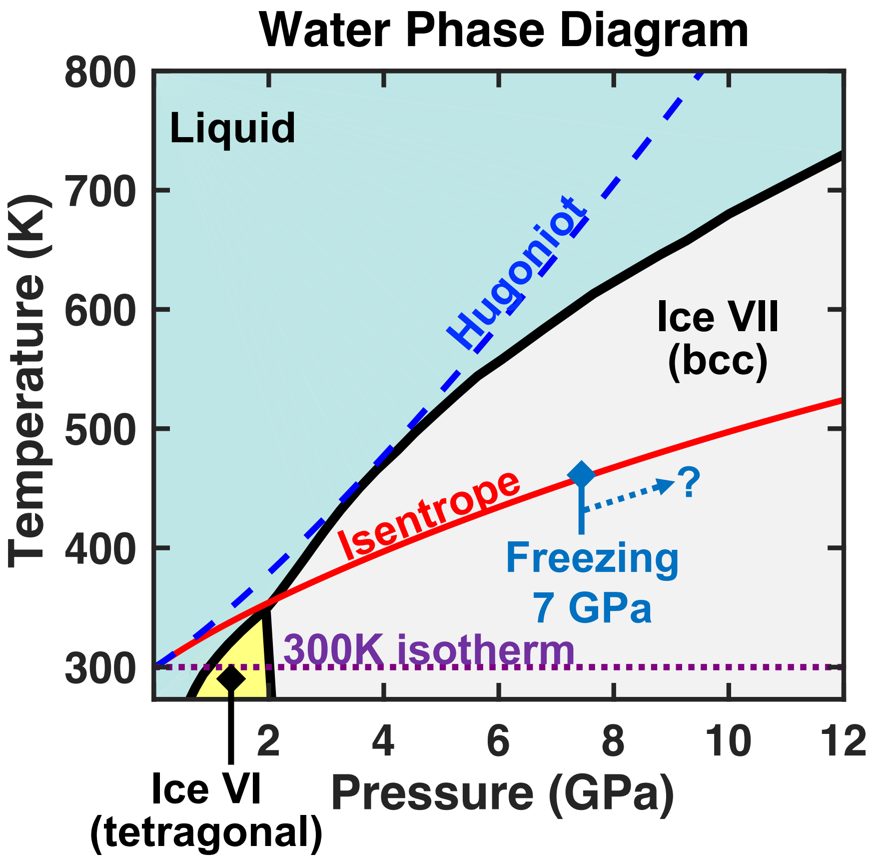
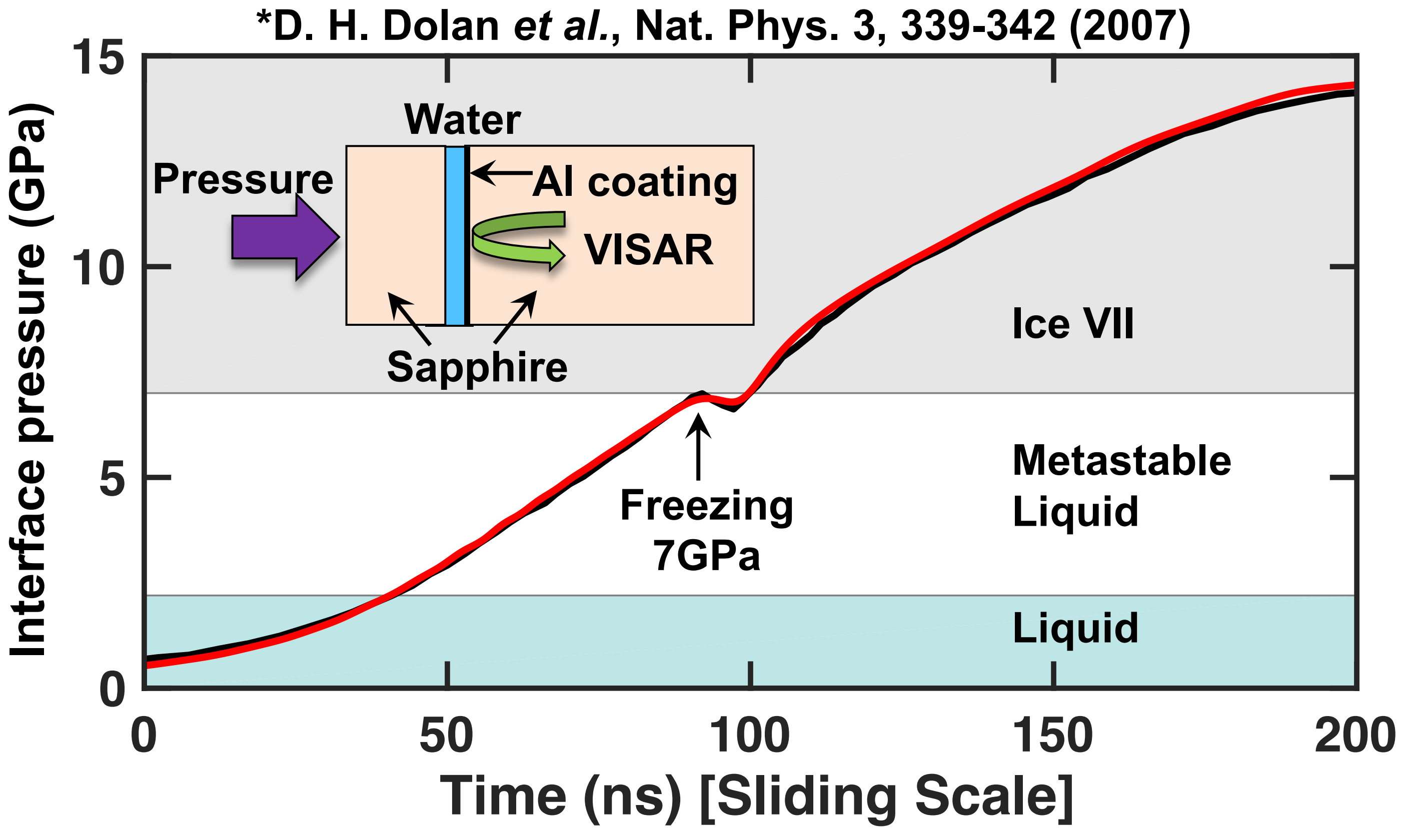
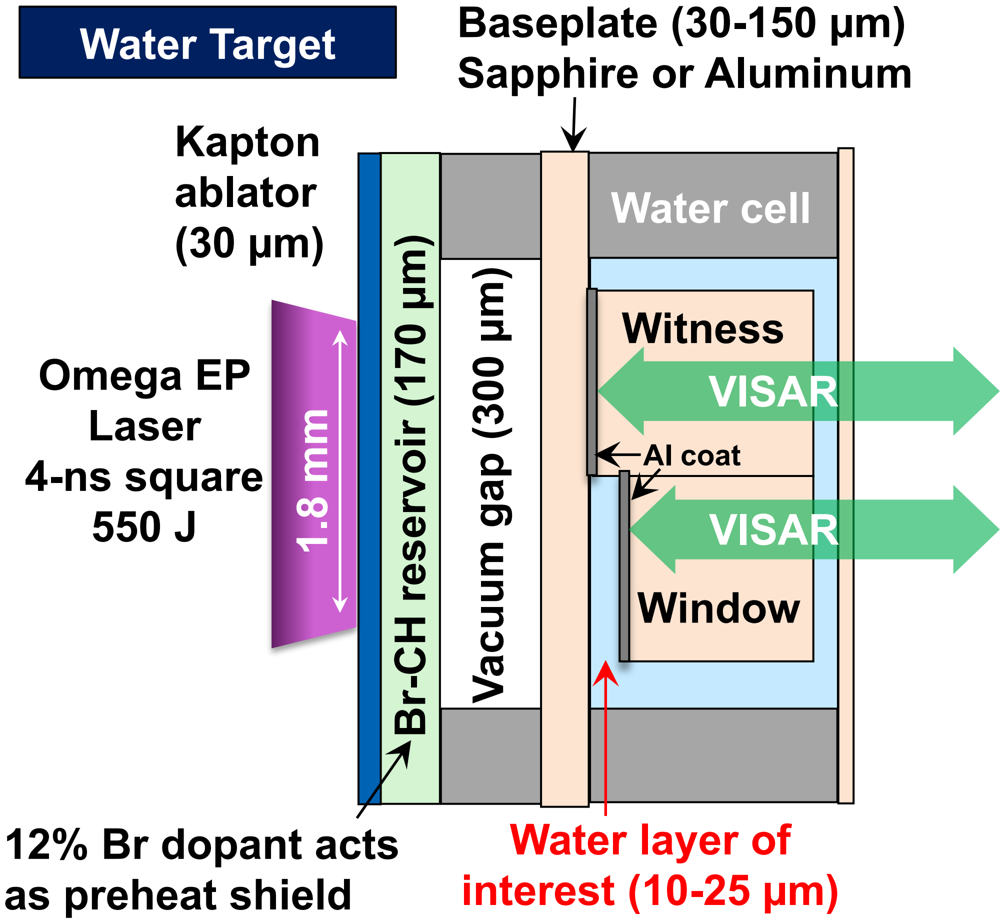




Is the metastability limit higher than 7 GPa?
We will investigate the liquid-ice VII phase transition at 10x higher compression rates

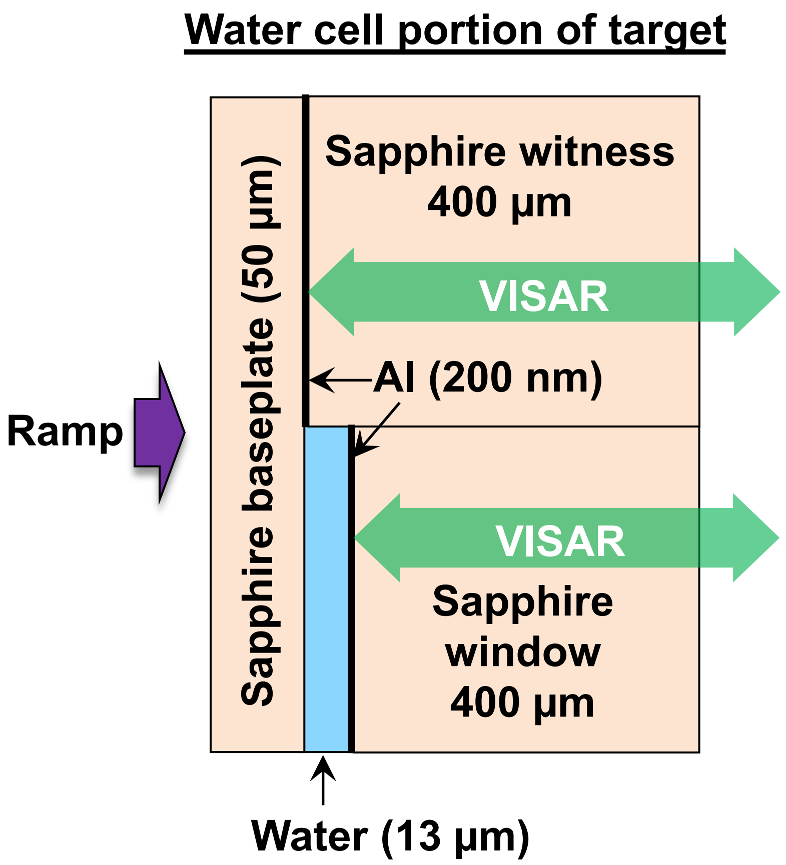
Water was ramp compressed using a reservoir release technique* at the Omega laser facility

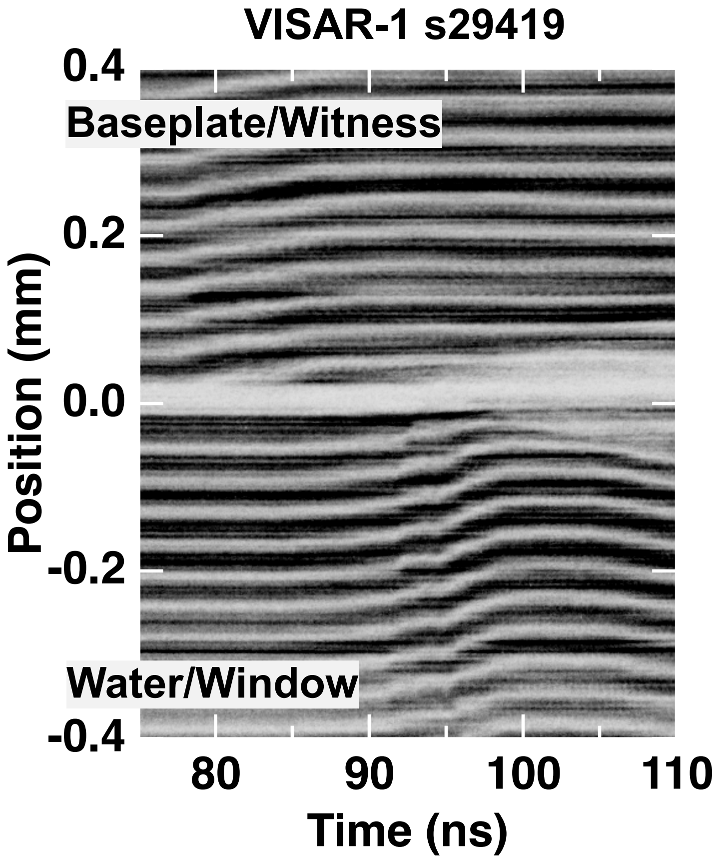


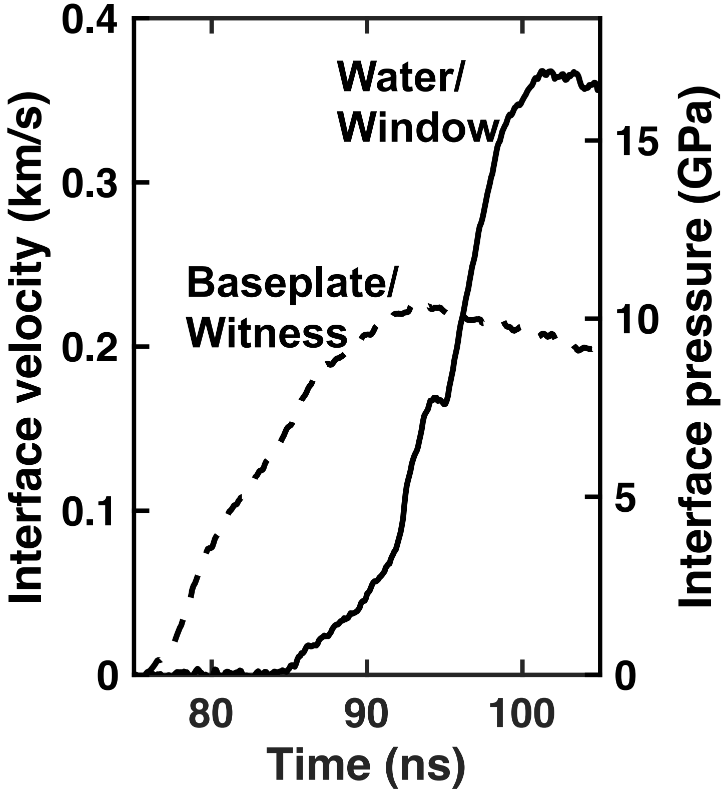
- Technique has been characterized to ramp compress solids (Al, Fe, Si)* – first time being applied to water
- Well-defined ramp to ~15 GPa over short ~10-20 ns time scales

*Reservoir release technique
J. Edwards *et al.*, Phys. Rev. Lett. 92, 075002 (2004).
K. T. Lorenz *et al.*, High Energy Dens. Phys. 2, 113 (2006).
R. F. Smith *et al.*, Phys. Plasmas 14, 057105 (2007).

The liquid-ice VII freezing pressure was detected *in situ* using VISAR







VISAR: velocity interferometer system for any reflector
Sapphire EOS: O. V. Fat'yanov *et al.*, J. Appl. Phys. 97, 123529 (2005).

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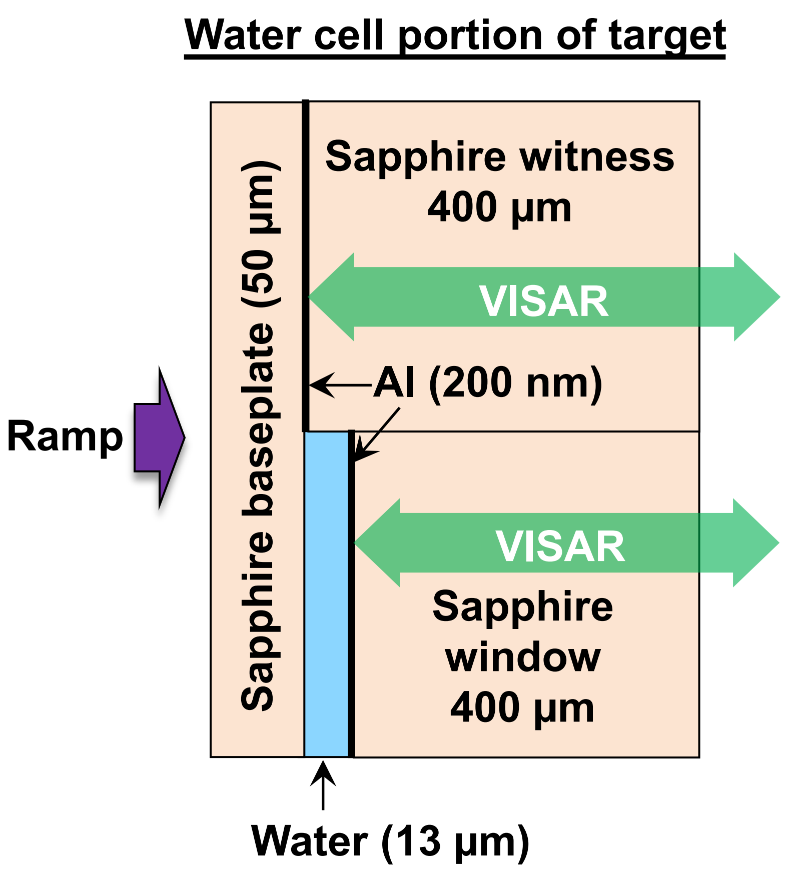

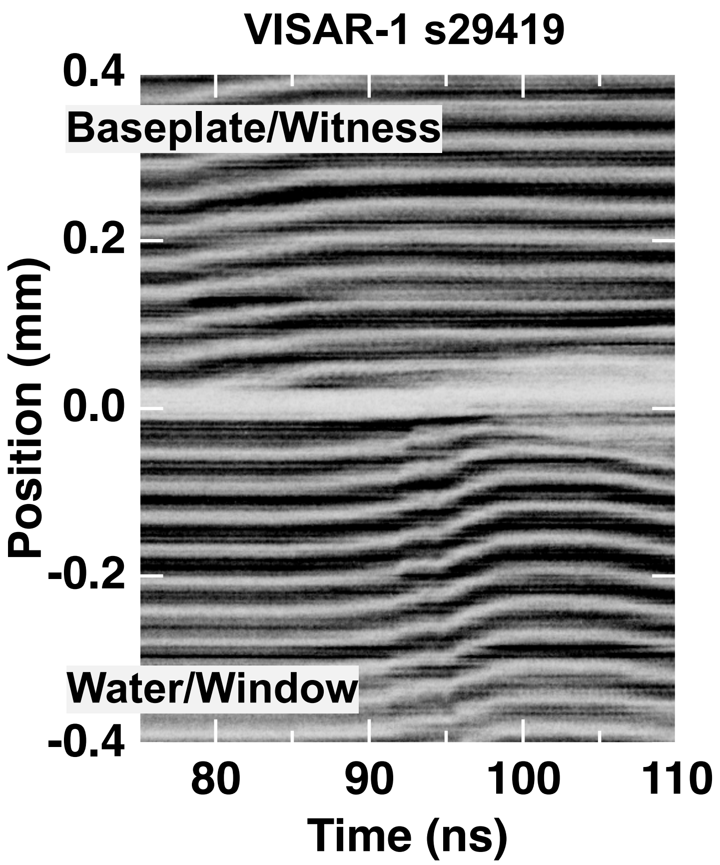

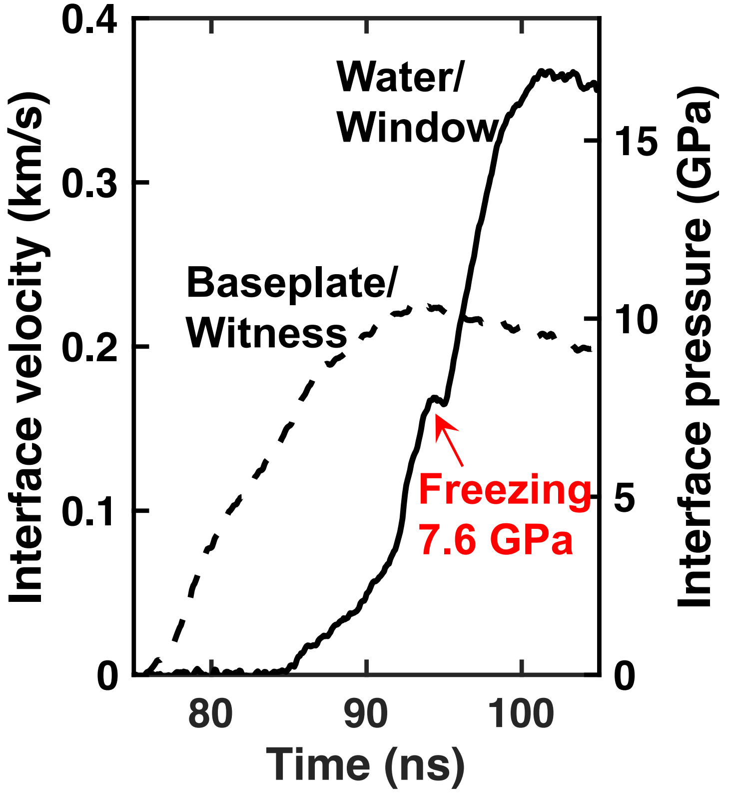

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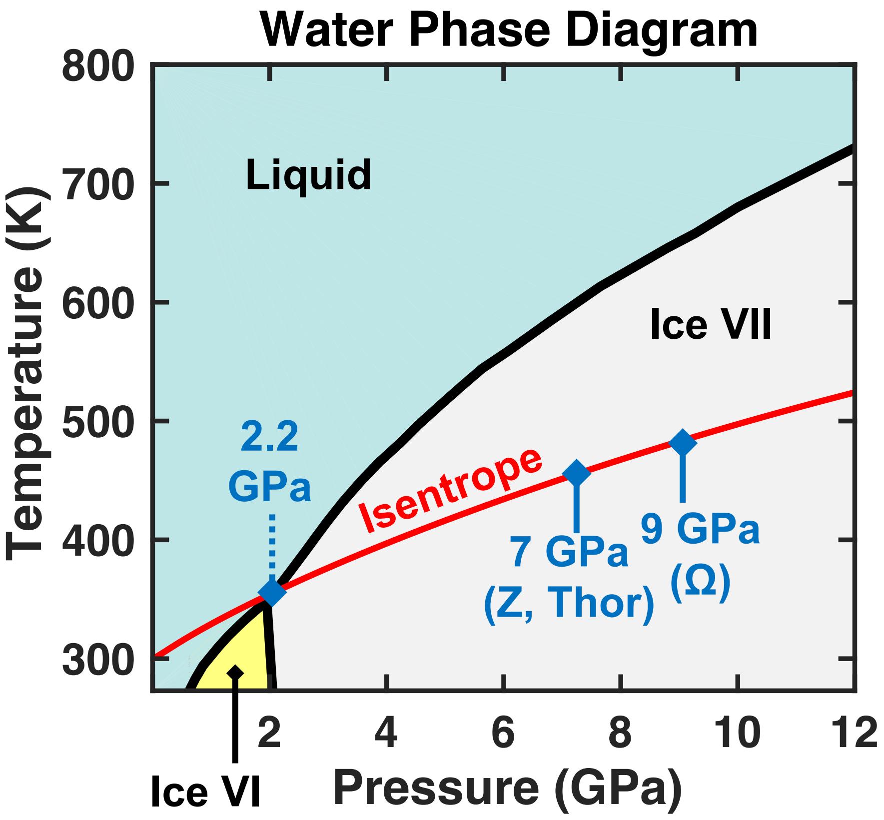
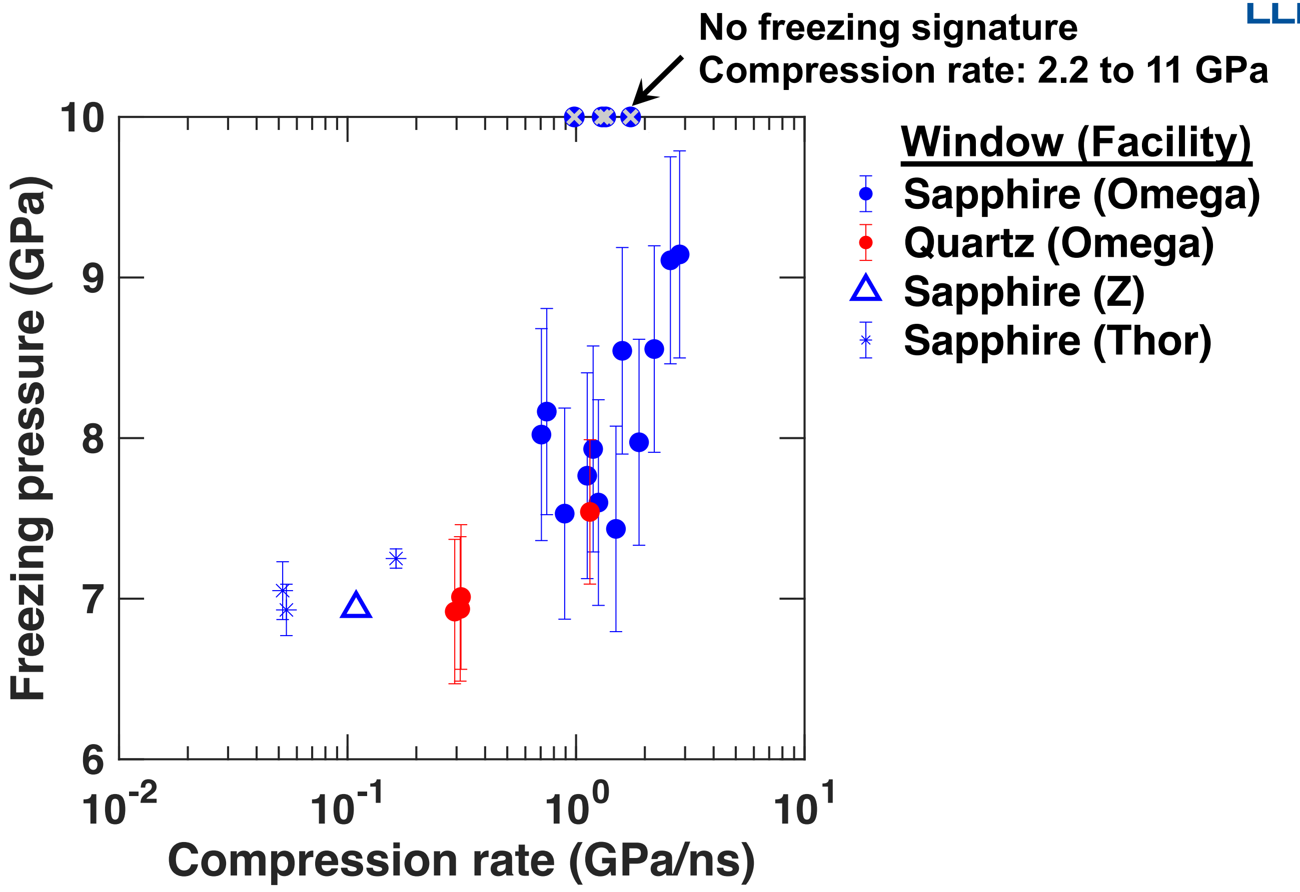
The measured freezing pressure increases with compression rate to 9 GPa





$$\eta = \frac{P_{freeze} - P_{2.2GPa}}{t_{freeze} - t_{2.2GPa}}$$

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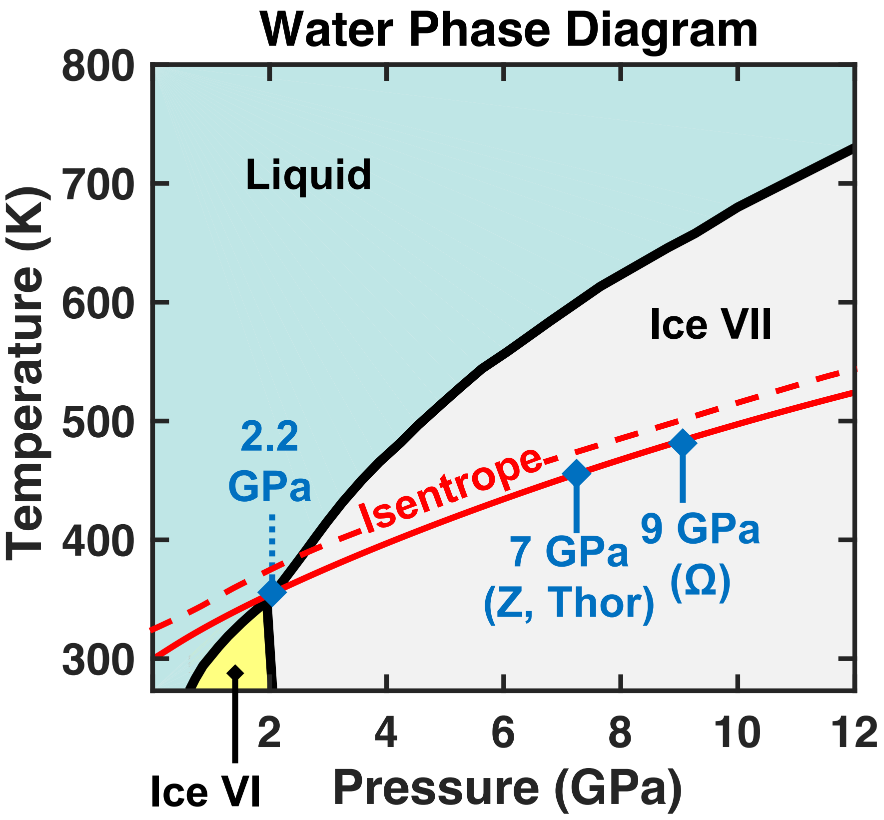

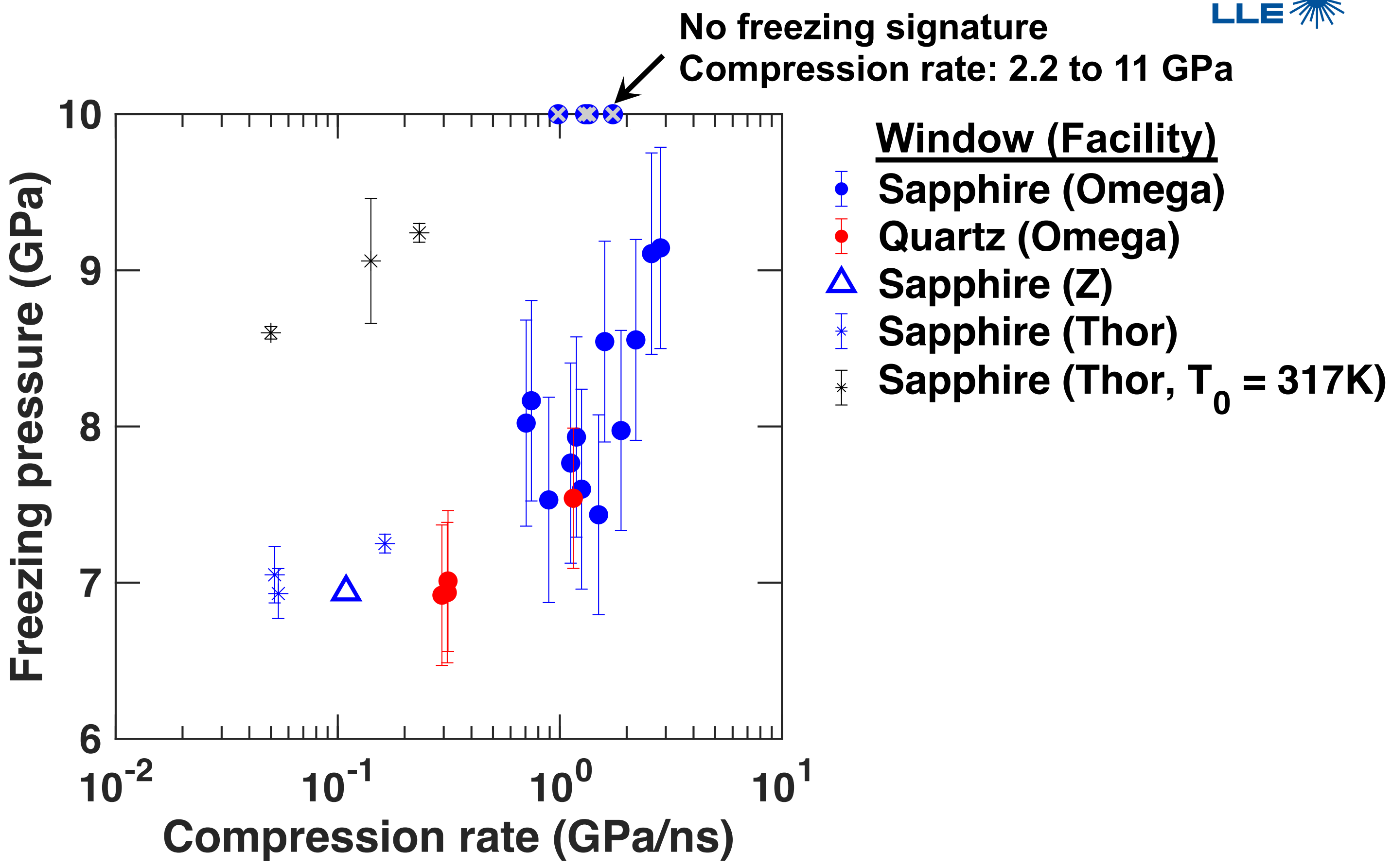

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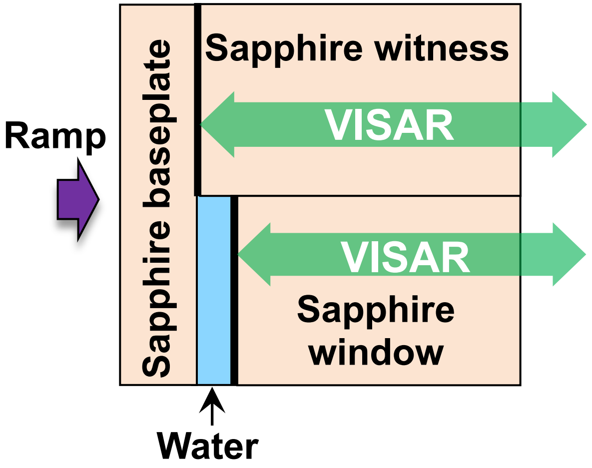
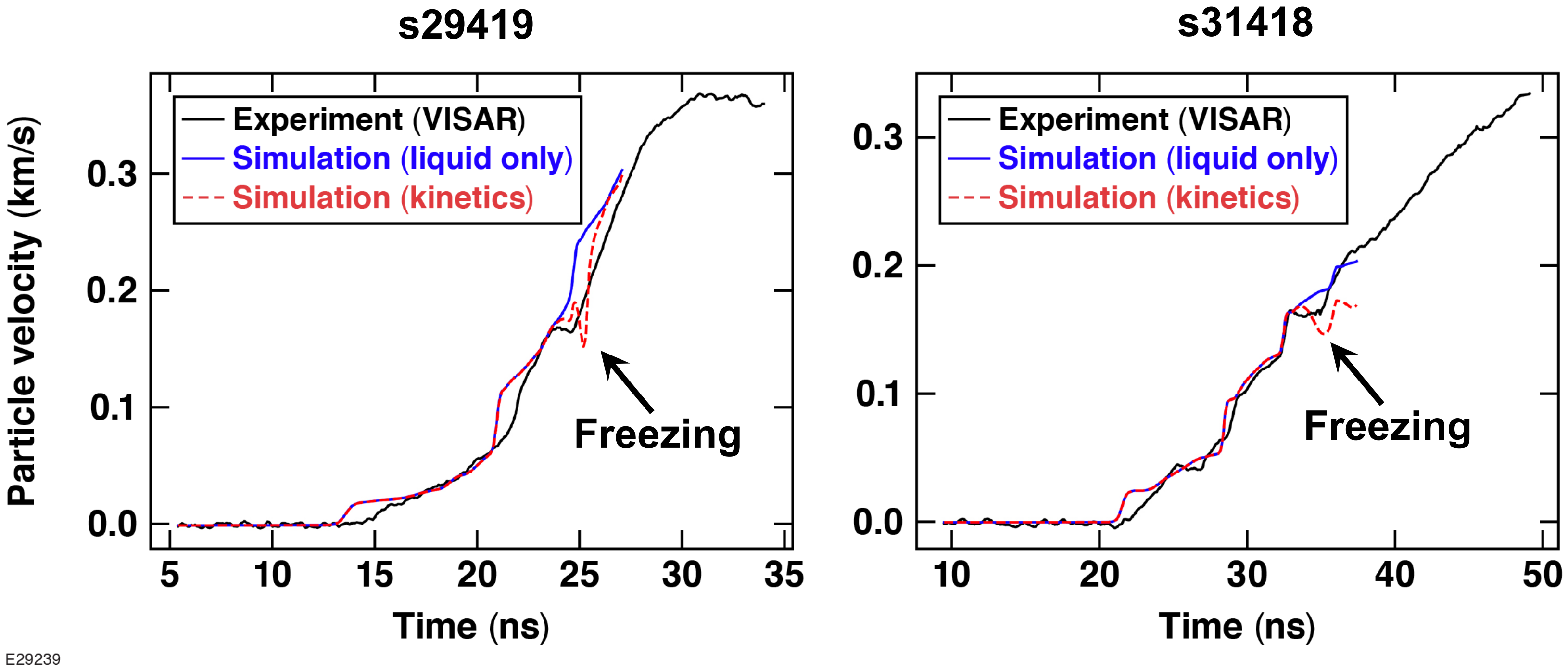
Simulations using the SAMSA kinetics code* predict the ice VII phase transition close to the experimental observation

- **The pressure drive on the baseplate was determined through an optimization technique using the measured witness velocity for the individual shot****



Shot	29419	31418
Sapphire baseplate	53 µm	146 µm
Water	13 µm	13 µm
Sapphire Window	400 µm	400 µm



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