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

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**2023 APS March Meeting**

**March 7th, 2023**

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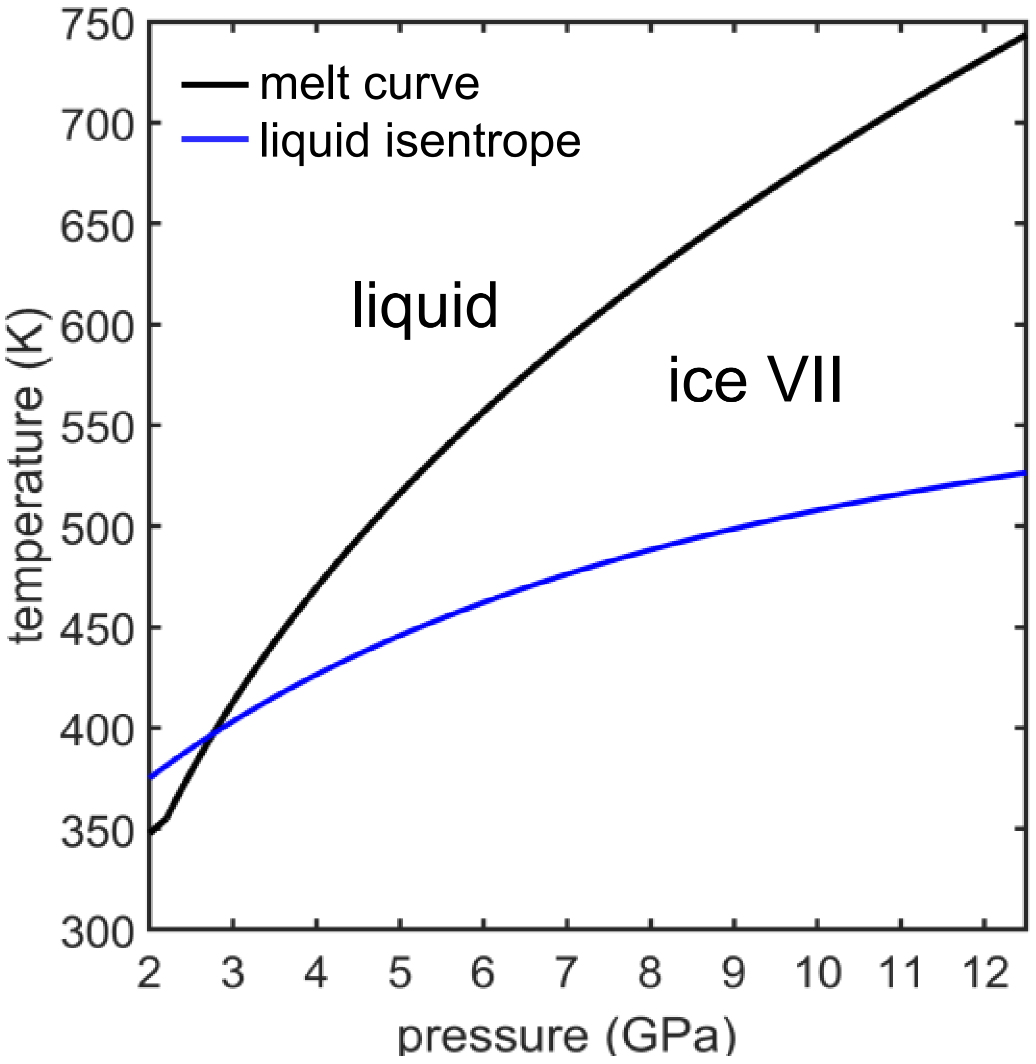
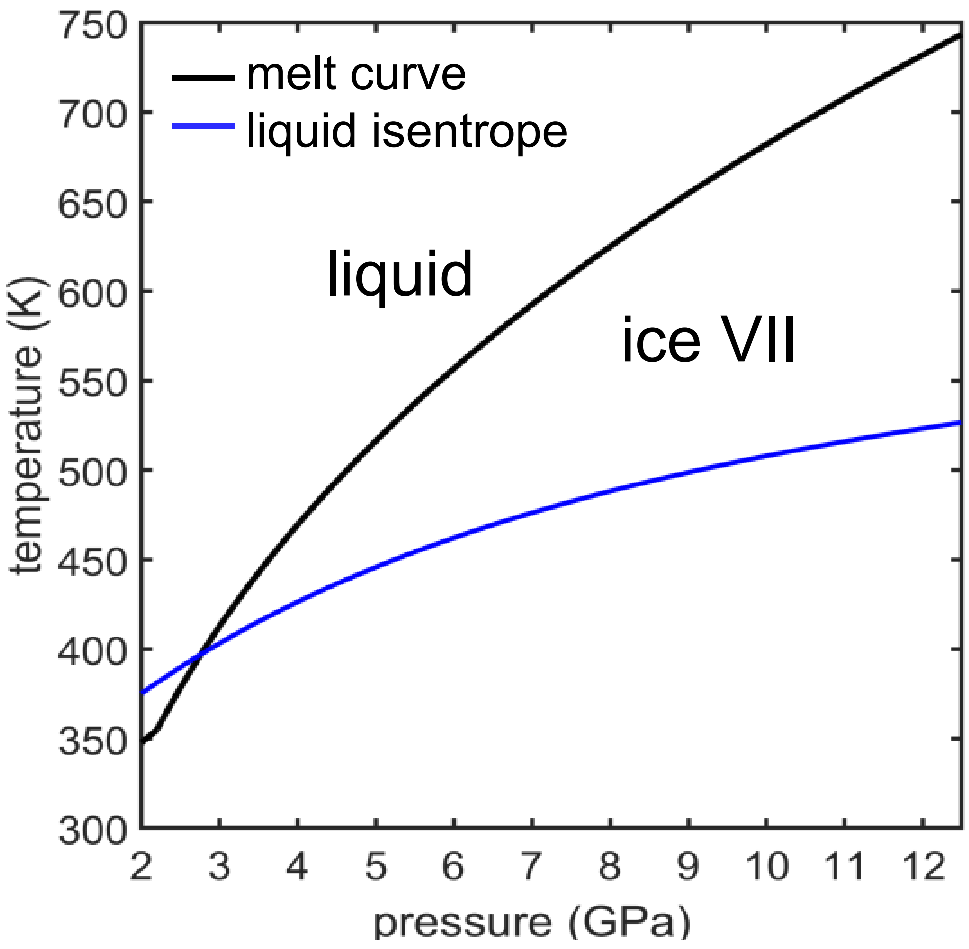
# Motivation

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

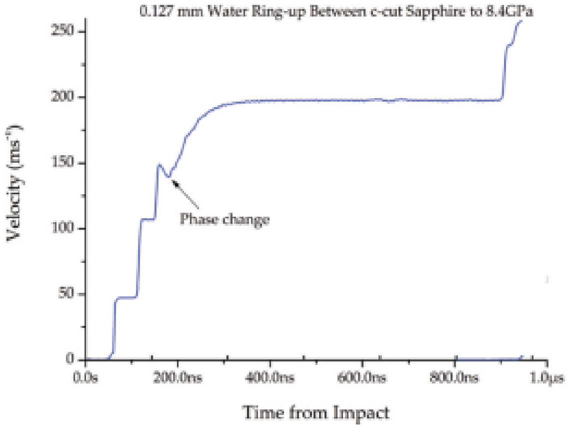
Water is one of the few materials known to freeze on nanosecond timescales

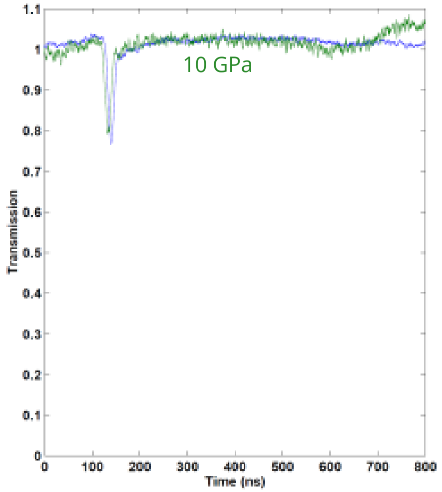


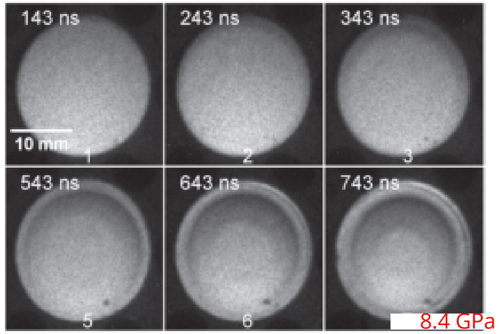



# Homogeneous Nucleation

Sapphire Windows
6-7 GPa
~ tens of nanoseconds




D. H. Dolan, Time dependent freezing of water under multiple shock wave compression(Washington State University, 2003).
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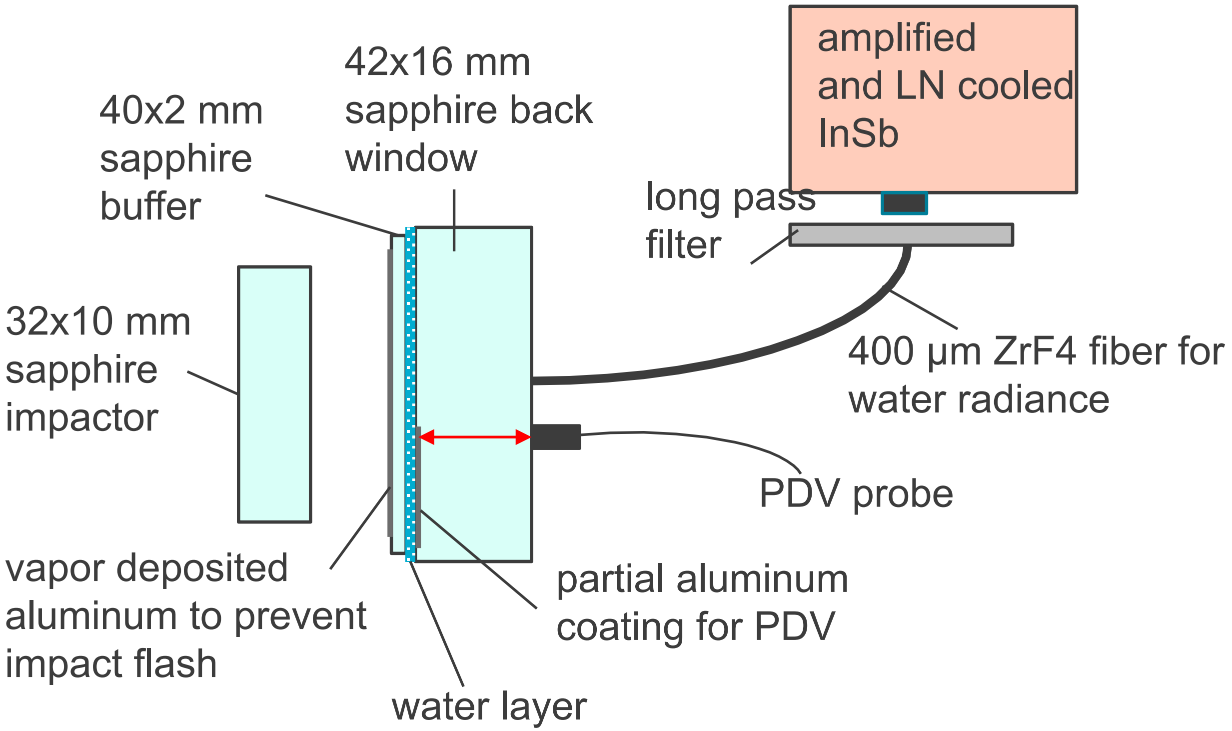
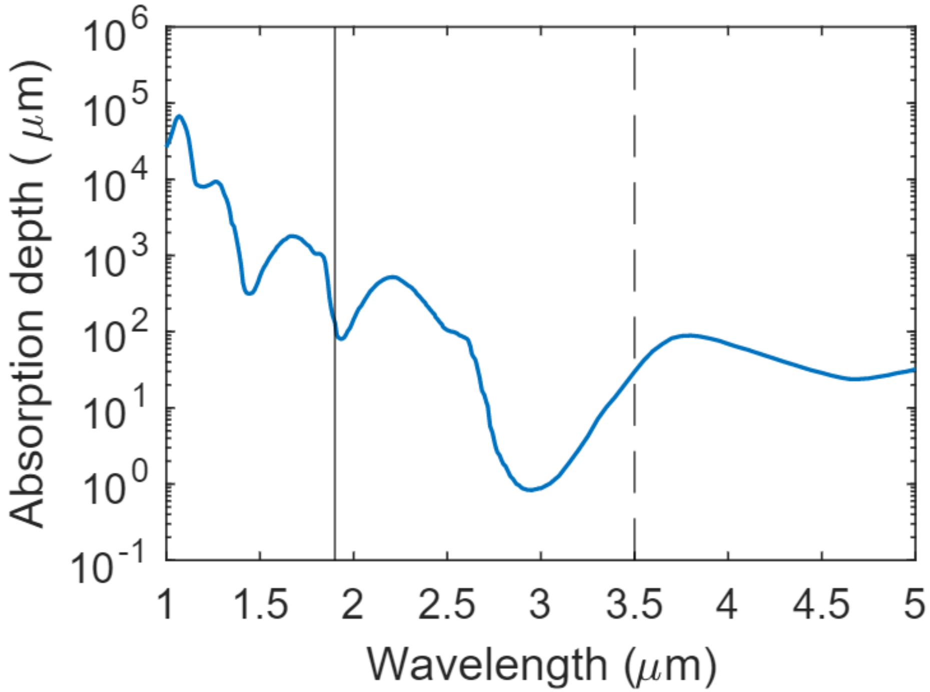
# Experimental Design




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

*calibrated temperature using a blackbody source

*10 ns resolution

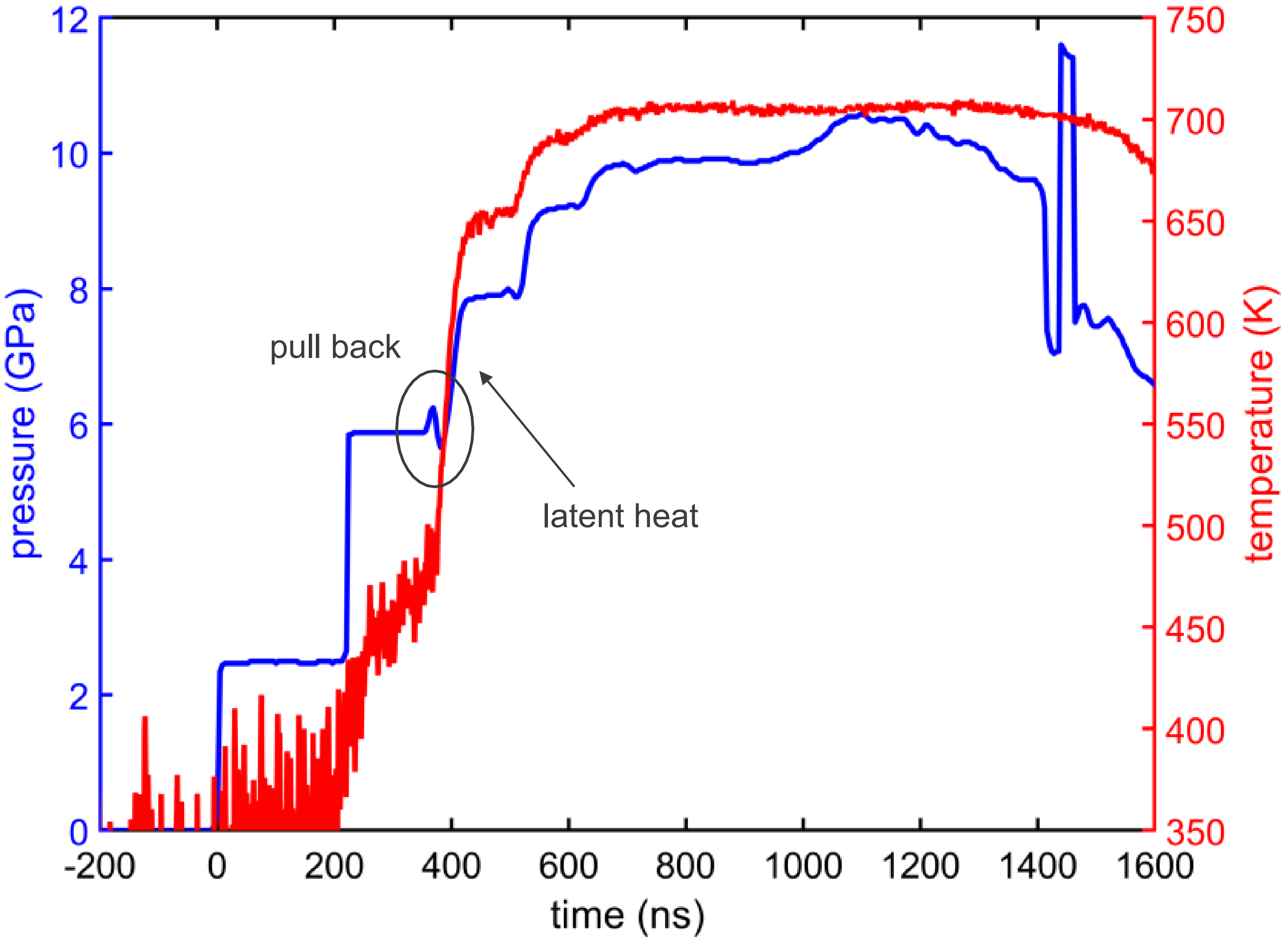
E. J. Nissen, D. H. Dolan, B. M. La Lone, J. G. Mance, and E. Larson, Physical Review Letters, (Under Review).

# Pressure and Temperature vs. Time

Peak
Pressure: 10.5 GPa

500 µm
thick sample

3.5 µm filter

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# Pressure and Temperature vs. Time

Peak Pressure

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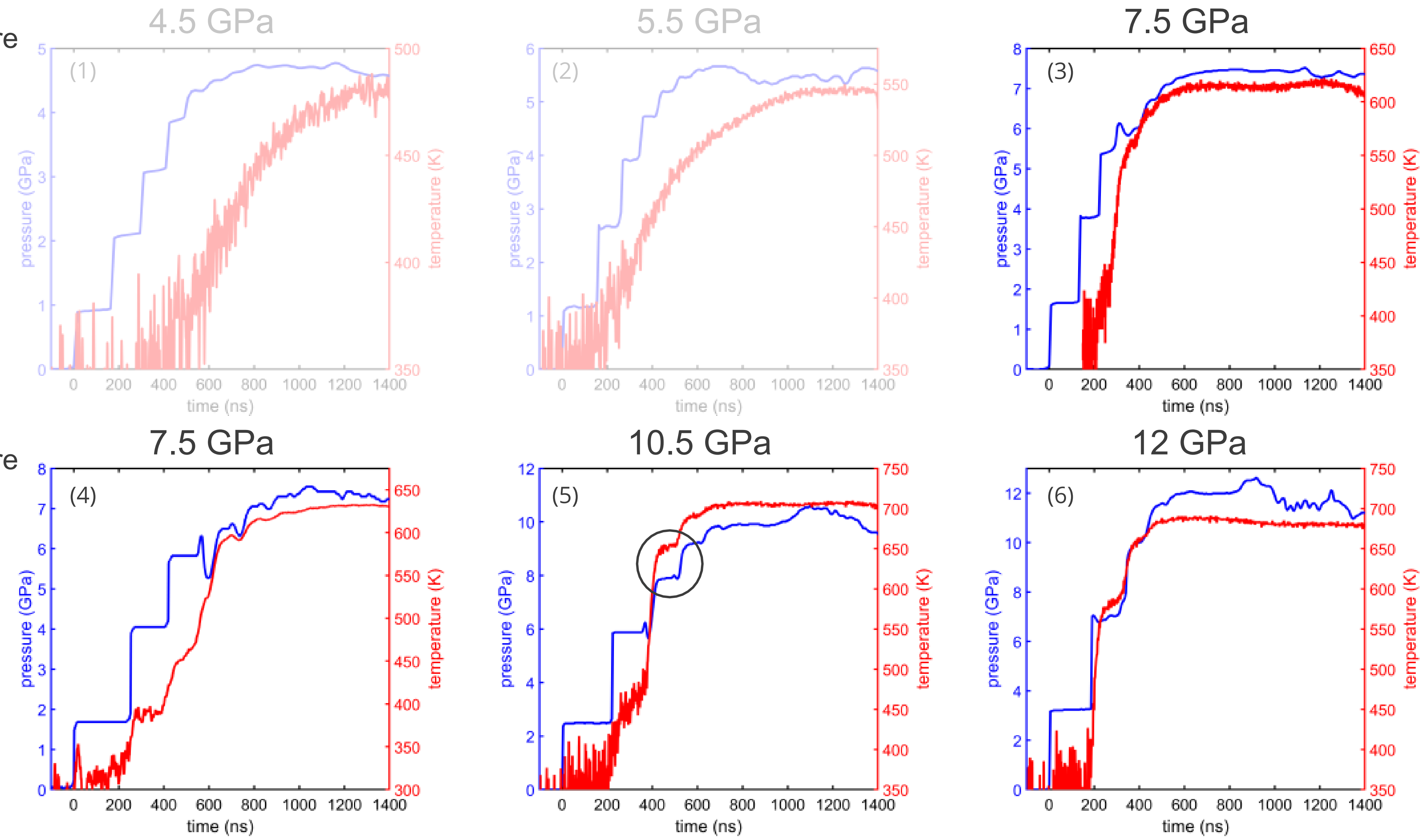
250 µm thick
1.9 µm filter

Peak Pressure

4-6
500 µm thick
3.5 µm filter

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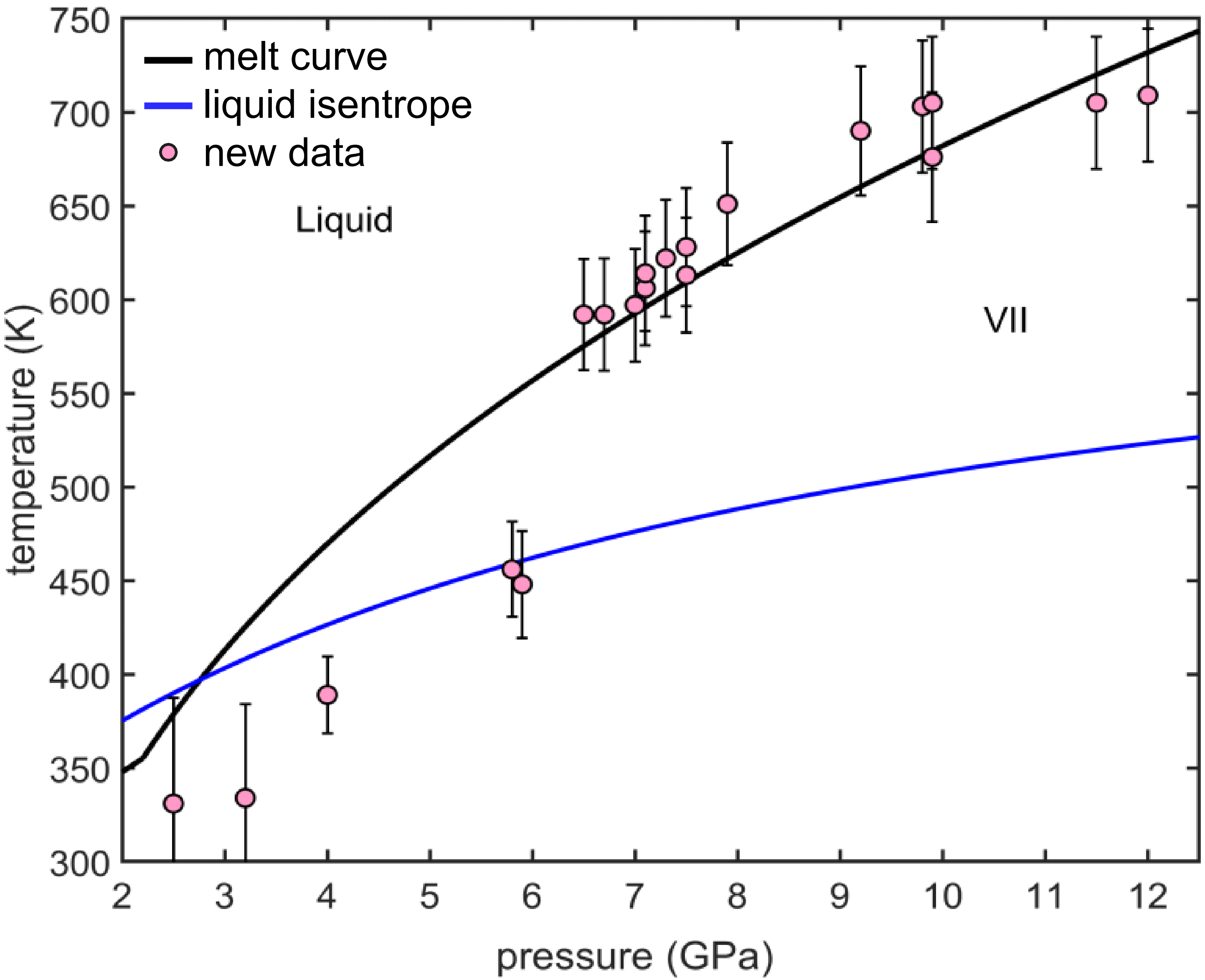
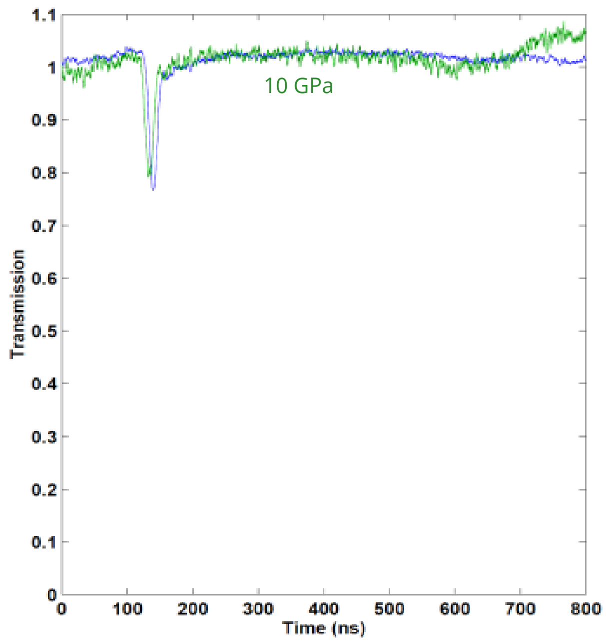
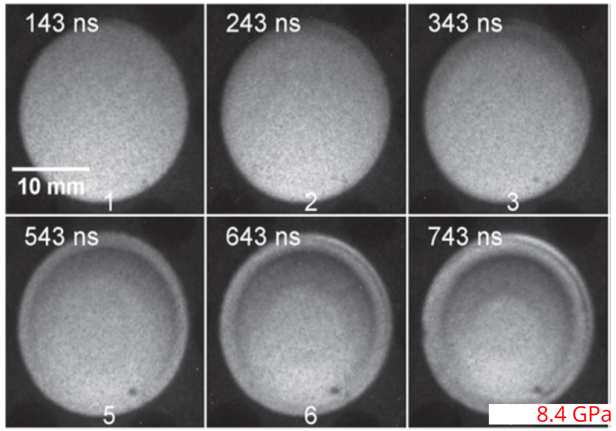
# Pressure vs. Temperature

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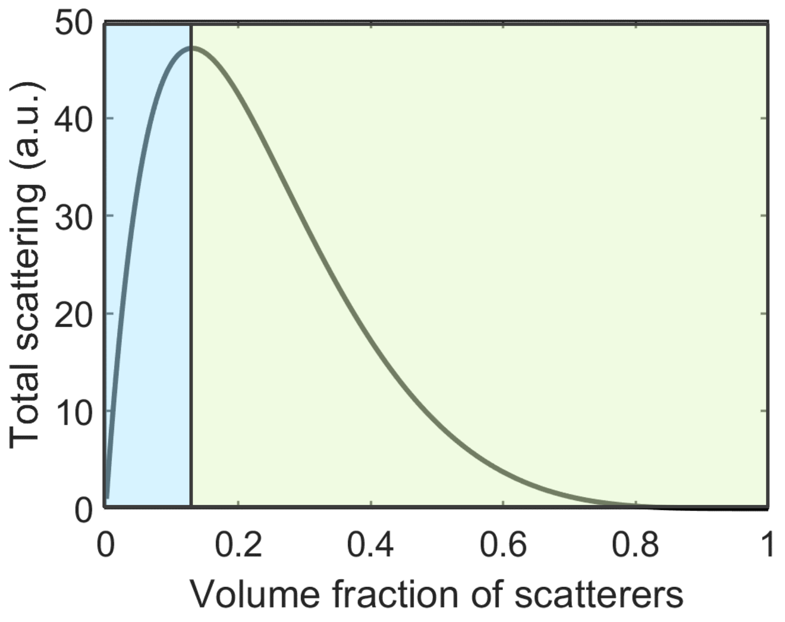
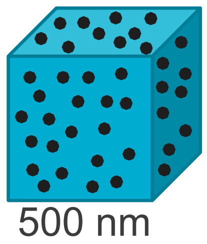
# Dynamically compressed water does not have to be completely frozen to be optically transparent

*A similar argument explains transparency of the mammalian cornea and lens and zoo plankton tissue transparency*



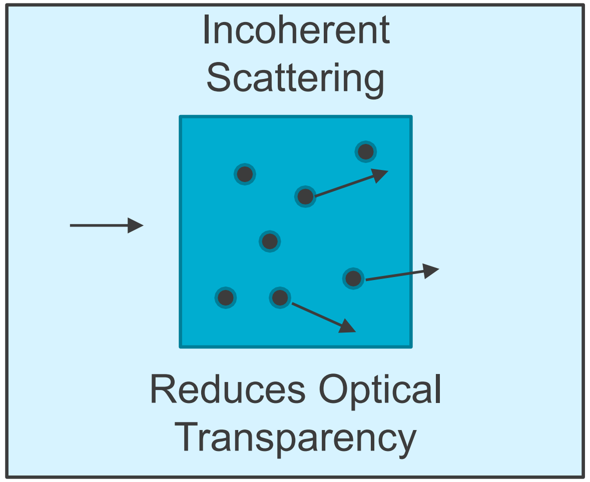

$$C_{total} = NC_{sca}S(\phi)$$

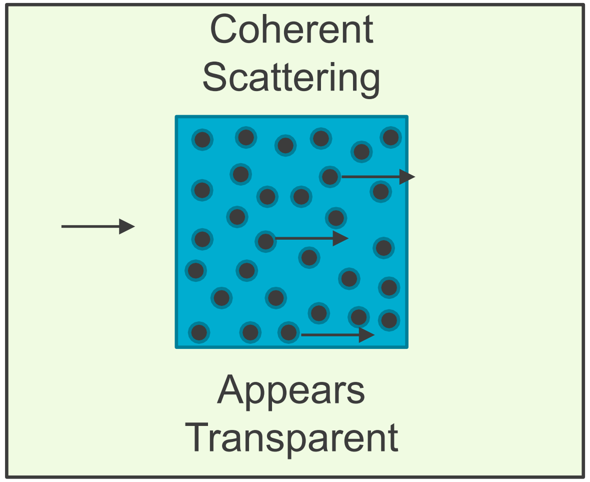
$$S(\phi) = (1-\phi)^4/(1+4\phi+4\phi^2-4\phi^3+\phi^4)$$




1% volume ice

> 2000 scatters

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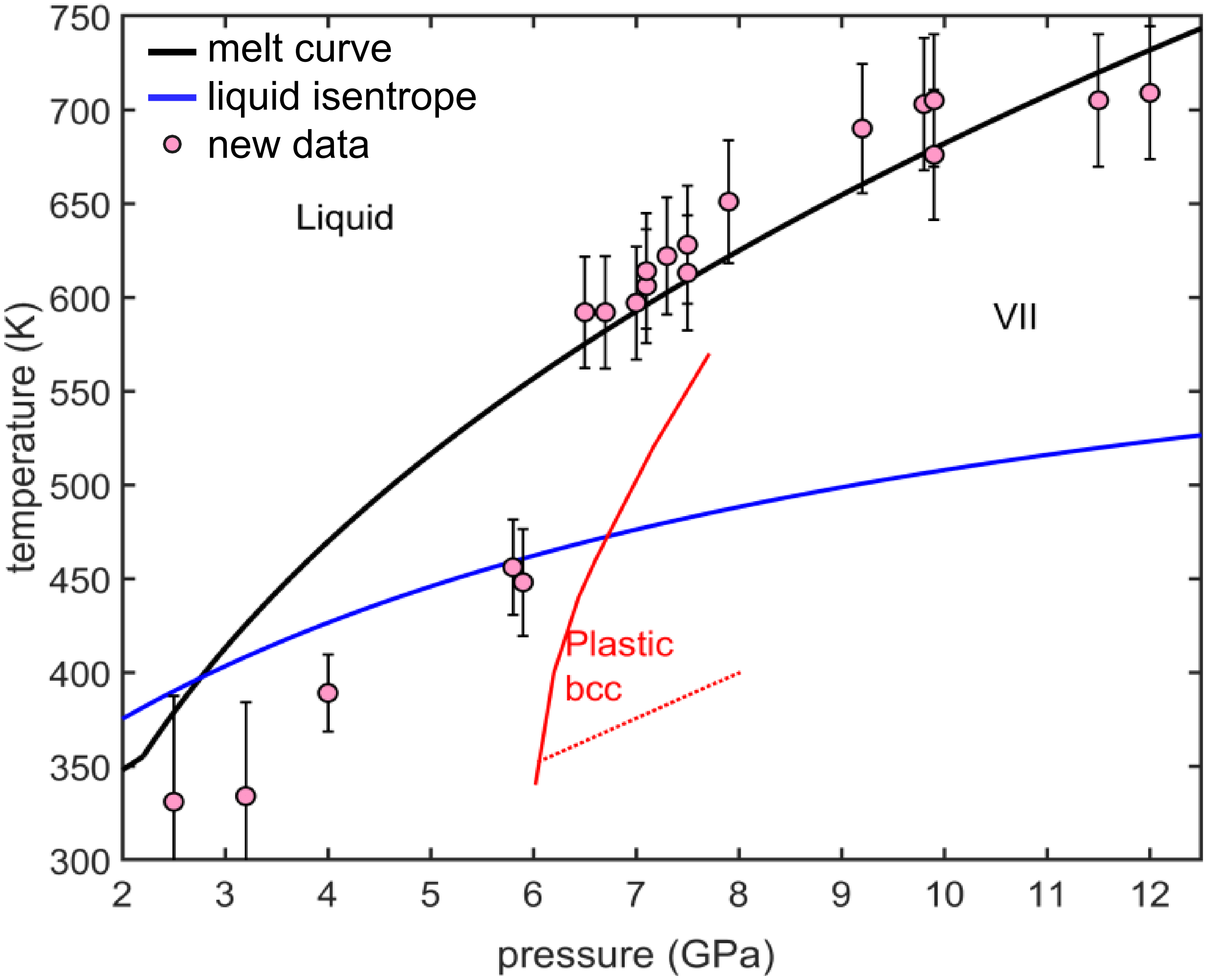
A. Tardieu and M. Delaye, Annual Review of Biophysics and Biophysical Chemistry 17, 47 (1988).
S. Johnsen and E. A. Widder, Journal of Theoretical Biology 199, 181 (1999).

# Ice VII or a Plastic Crystal Phase?

*time resolved x-ray diffraction on dynamically compressed water could not distinguish between ice VII and a plastic bcc phase*

*plastic ice (bcc) predicted using the TIP4P/2005 model*

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J. L. Aragones and C. Vega, The Journal of Chemical Physics 130, 244504 (2009).
Gleason et al., Physical Review Letters 119, 025701 (2017).

# How does the New Data Compare with Theory?

*Dolan EOS – continuum model

$(C_v = 3 \frac{J}{g \cdot K})$

* Myint EOS – free energy model

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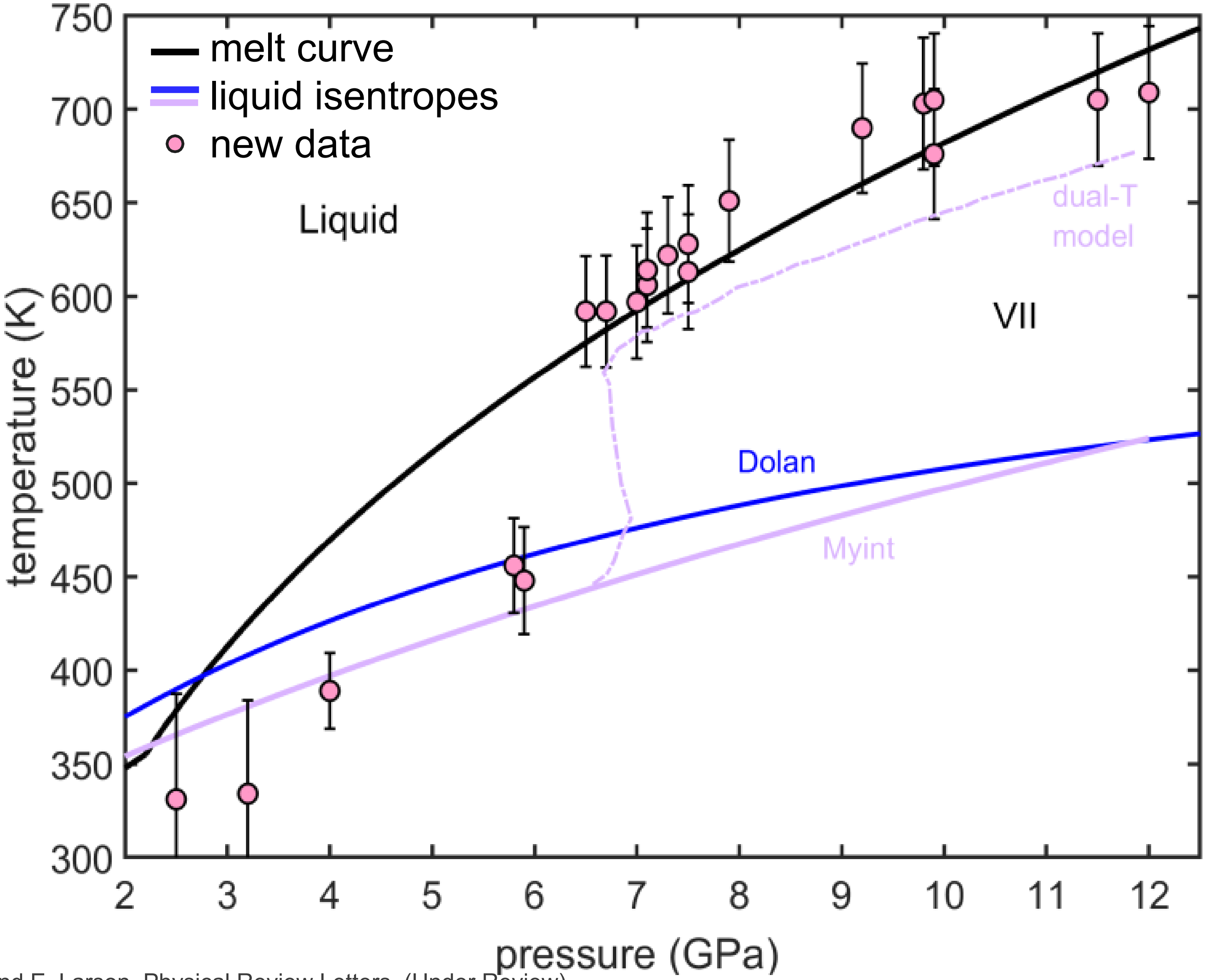
*The dual-temperature model is derived from coupling classic nucleation theory and growth with hydrodynamic simulations to reproduce observed transition kinetics*

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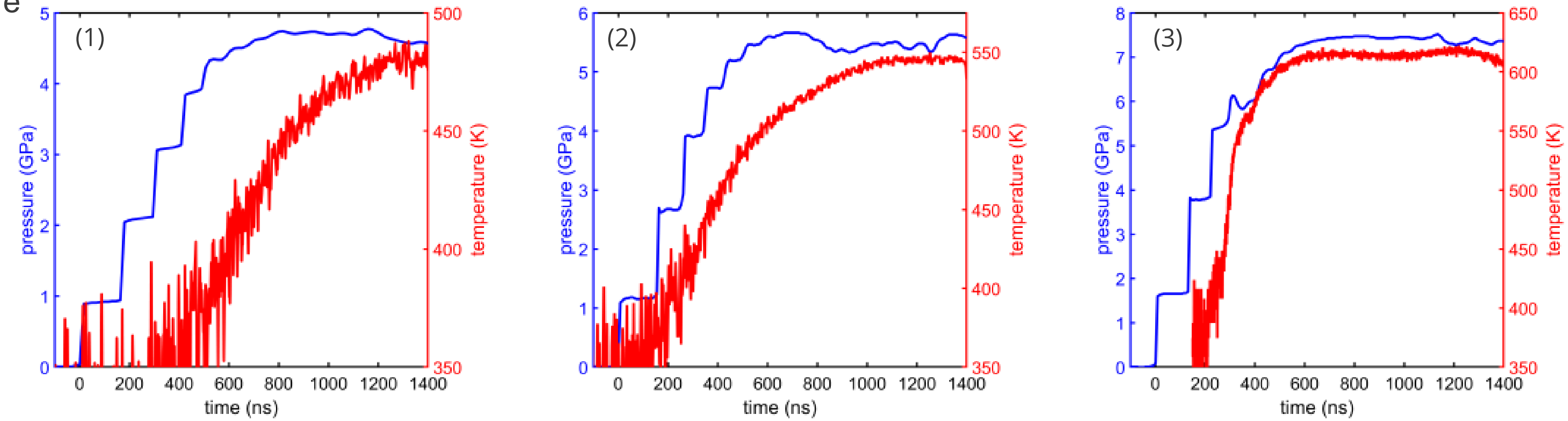
D. H. Dolan, J. N. Johnson, and Y. M. Gupta, The Journal of Chemical Physics 123, 064702 (2005).
P. C. Myint, A. A. Chernov, B. Sadigh, L. X. Benedict, B. M. Hall, S. Hamel, and J. L. Belof, Physical Review Letters 121, 155701 (2018).
P. C. Myint, L. X. Benedict, and J. L. Belof, The Journal of Chemical Physics 147, 084505 (2017).

# What Happens Below the Metastable limit ?

Peak Pressure

4.5 GPa | 5.5 GPa | 7.5 GPa

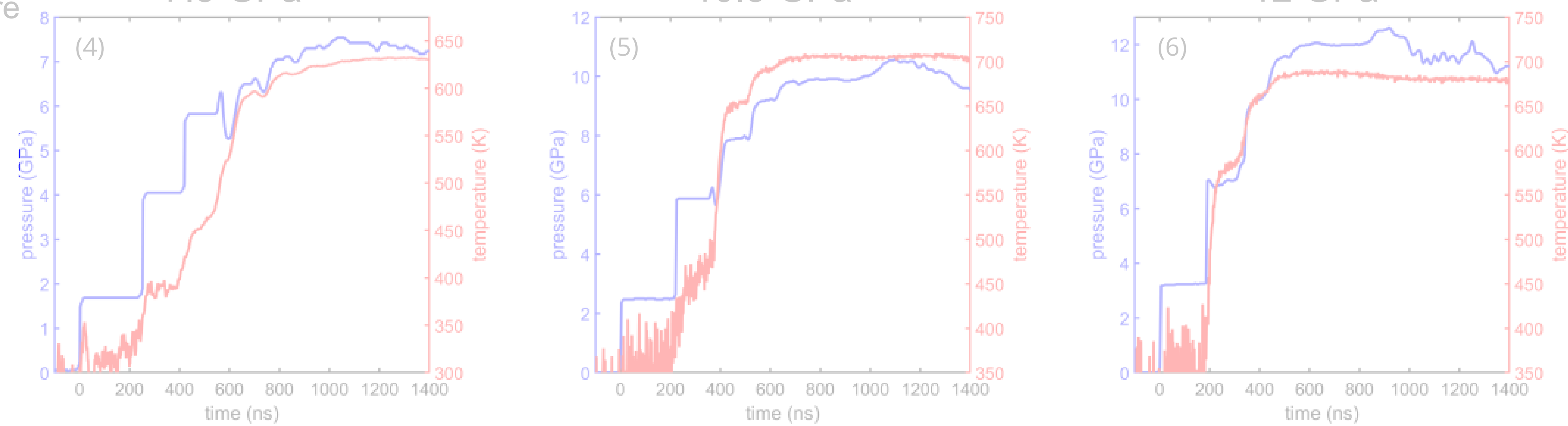
1-3
250 μm thick
1.9 μm filter




Peak Pressure

7.5 GPa | 10.5 GPa | 12 GPa

4-6
500 μm thick
3.5 μm filter

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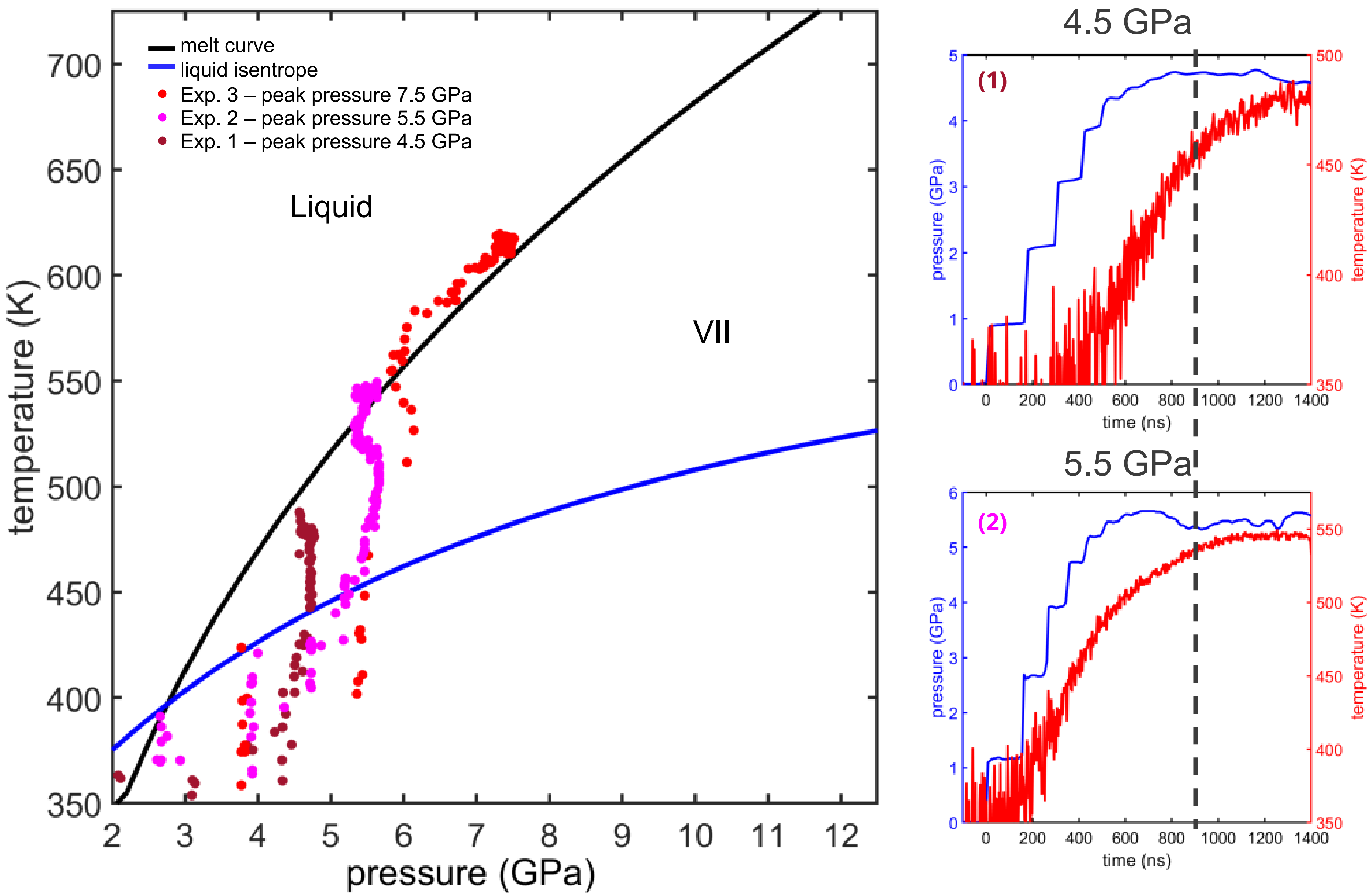


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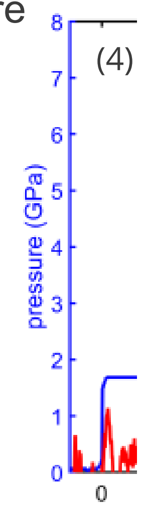
# Did the Filter Switch make a Difference?

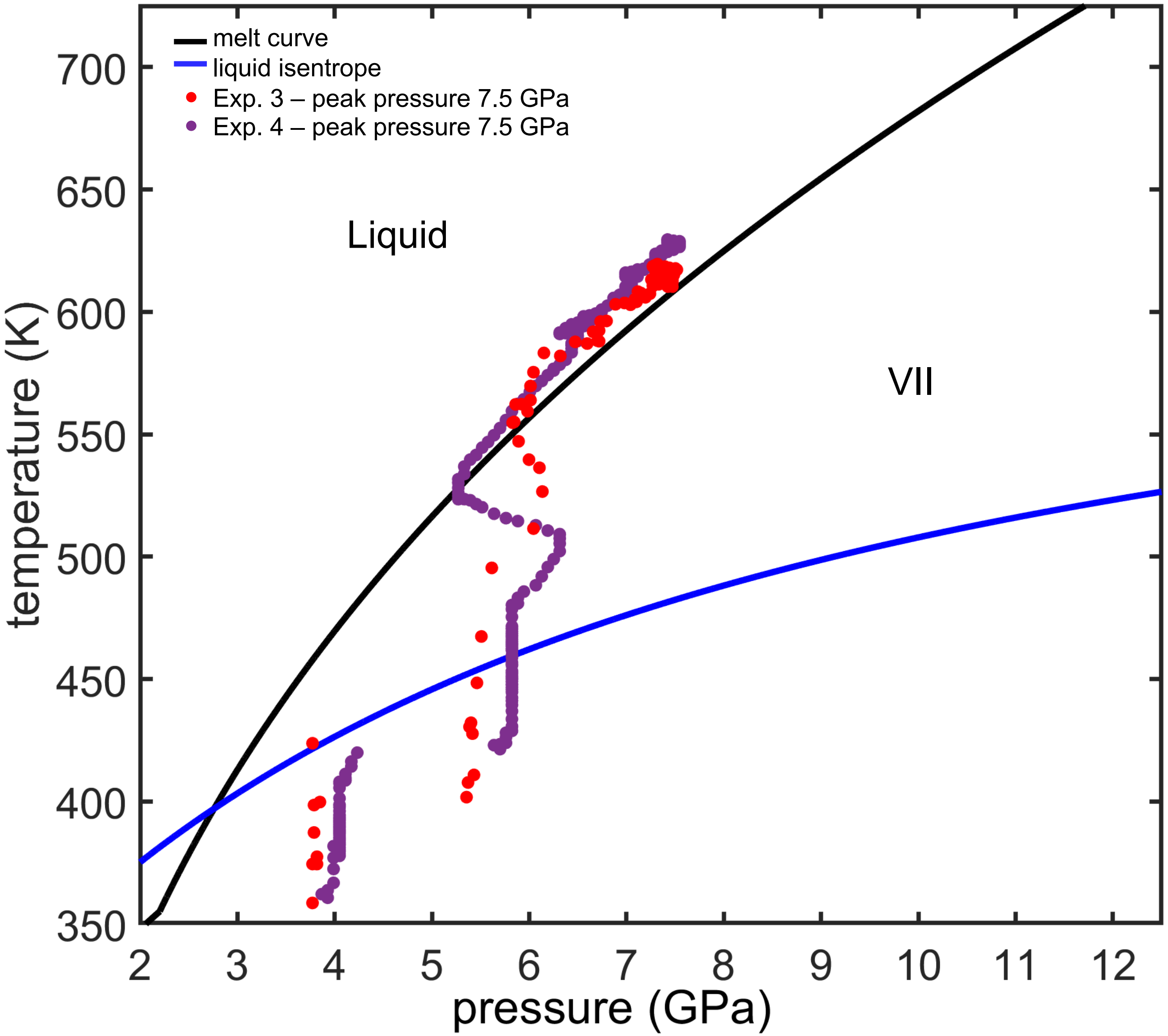
Peak Pressure

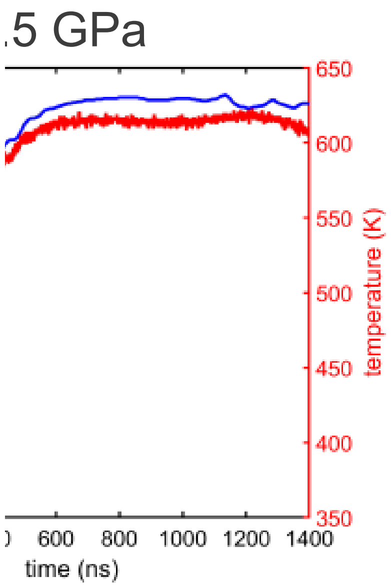
1-3
250 μm thick
1.9 μm filter


Peak Pressure

4-6
500 μm thick
3.5 μm filter







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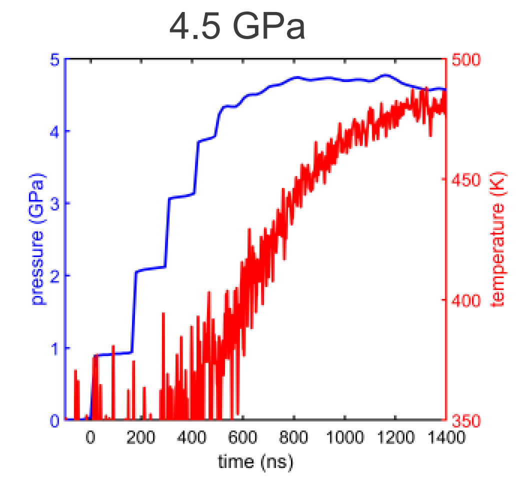
# Conclusion

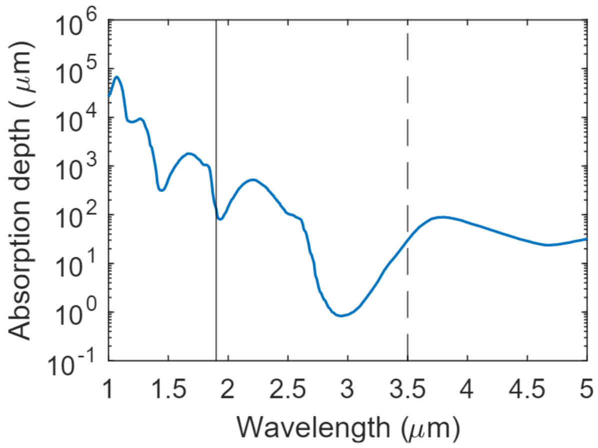
* latent heat and ice are formed even if you can't see it in the PDV/VISAR

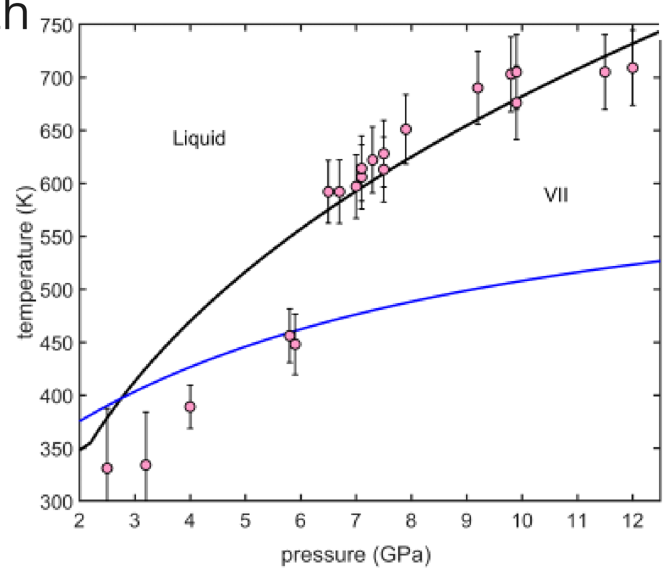
* dynamically compressed water does not have to be completely frozen to be optically transparent

* future studies with water or other materials with absorption bands between 2-5 μm

* does water ever come off the meltline?



# Thank You!

# Questions?

**Erin Nissen**, Dan Dolan, Brandon La Lone, Jason Mance, and Eric Larson

Matt Staska, Reuben Valencia and Rick Allison for their contributions in designing and machining all of the parts

March 7th, 2023

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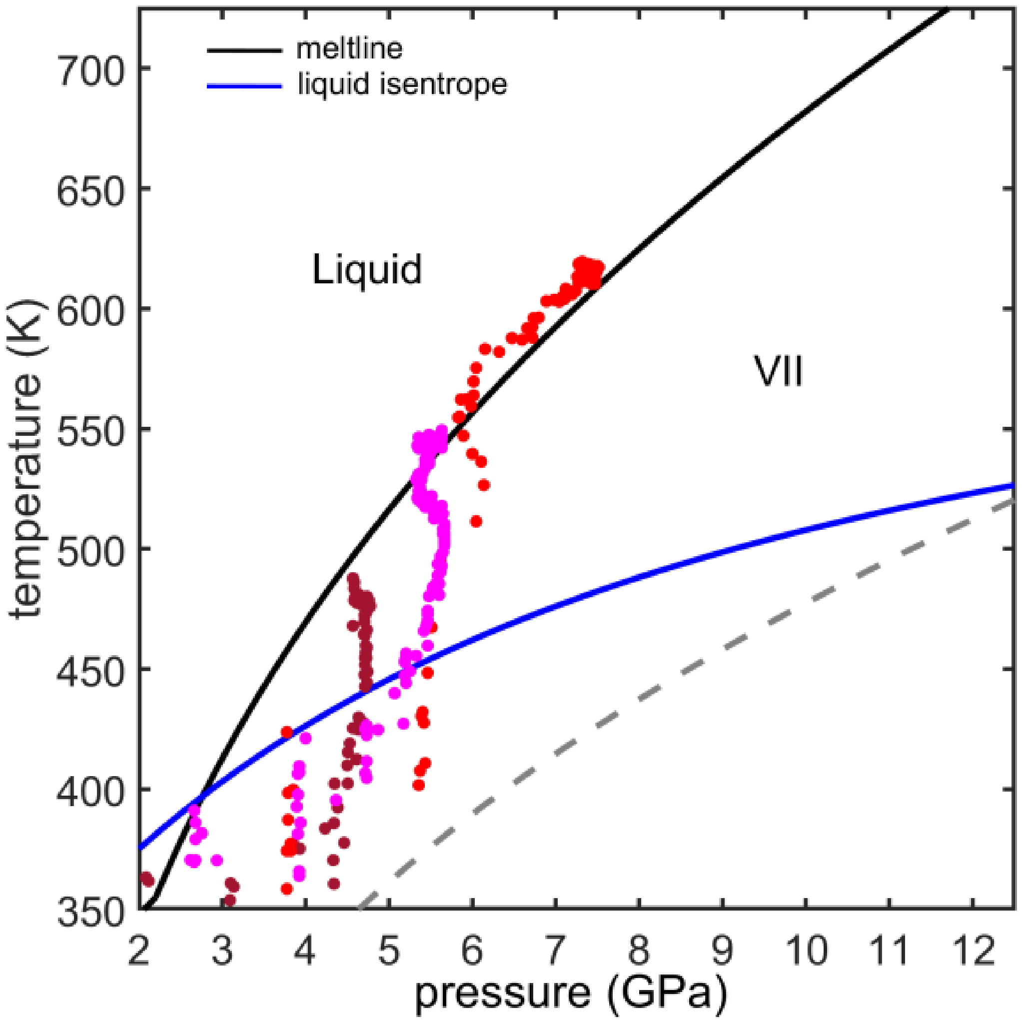
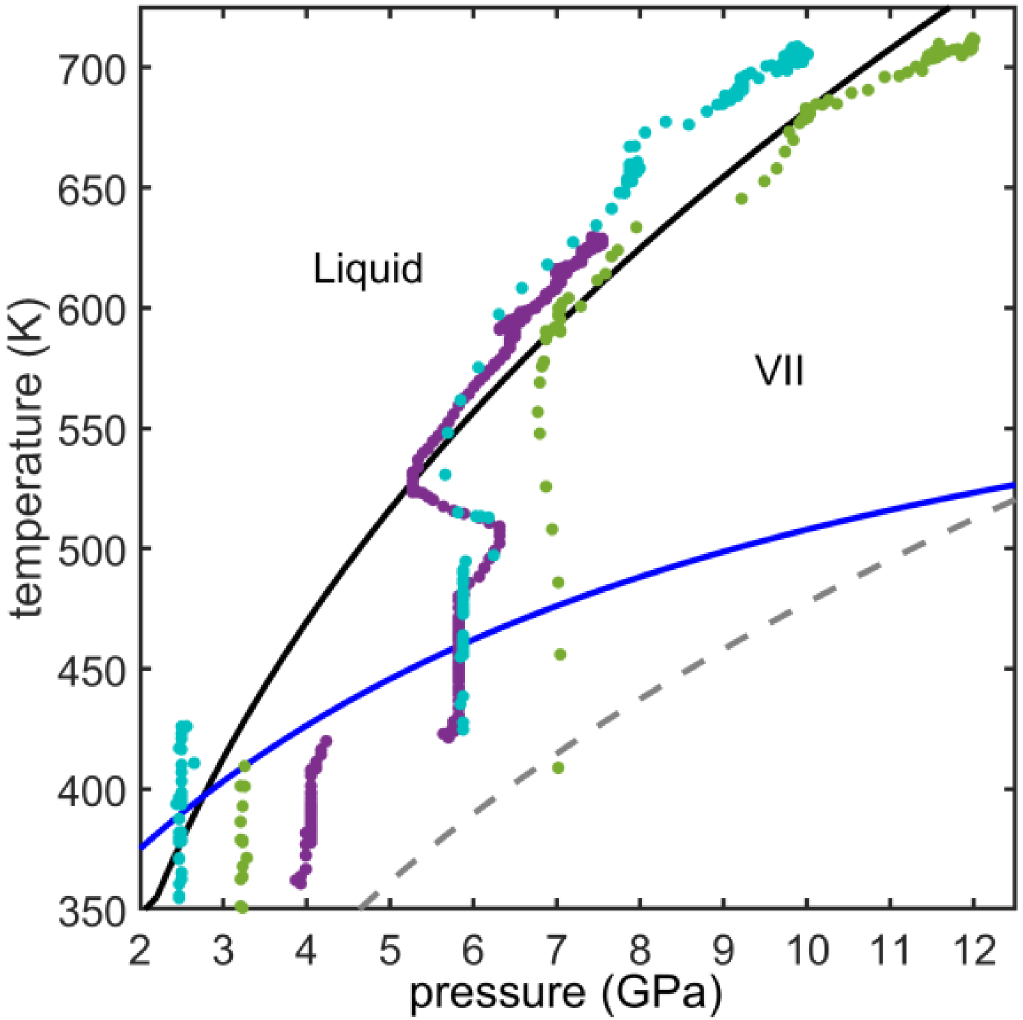
# THANK YOU

# Pressure vs. Temperature Profiles

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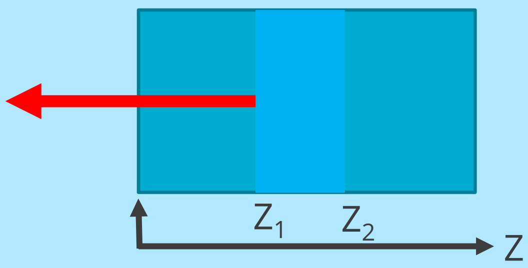
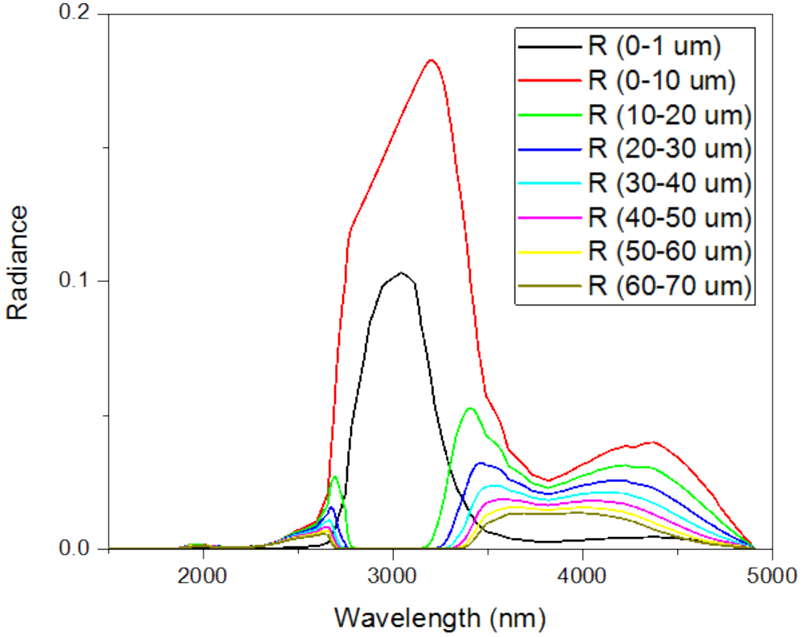
# Radiation comes from different depths within the Water cell




The radiance exiting the water sample from a slice of material between position $Z_2$ and $Z_1$ is

$$R = B(\lambda, T)[\exp(-\alpha z_1) - \exp(-\alpha z_2)]$$

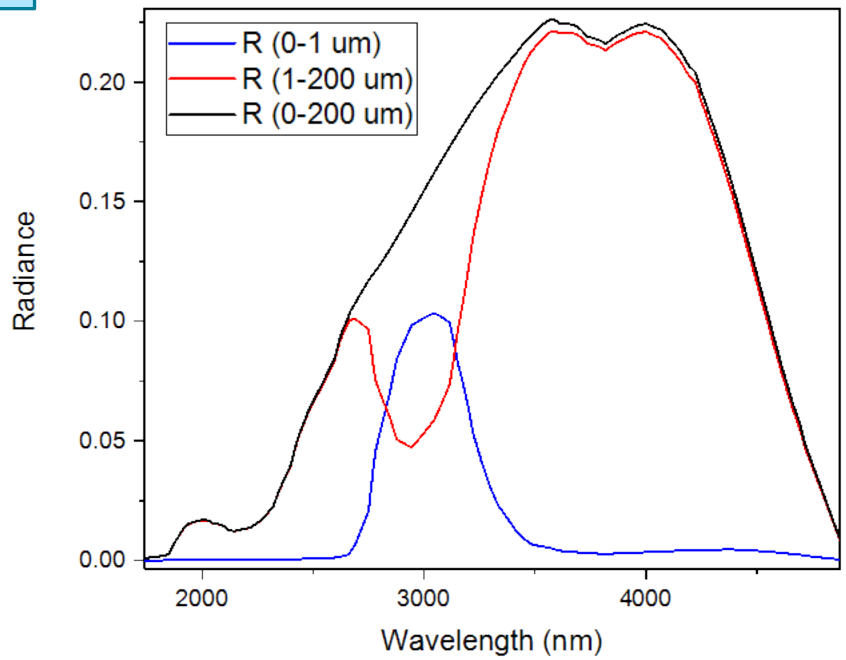
Where $B(\lambda,T)$ is the blackbody function




This plot calculates the radiance spectra exiting the water for layers at various depths into the water. The absorption spectrum of water and $ZrF_4$ fiber were used (InSb response not included).

Spectra at the surface emits more near the 3 micron absorption peak of water.

0-1 um acccounts for 13% of integrated radiance

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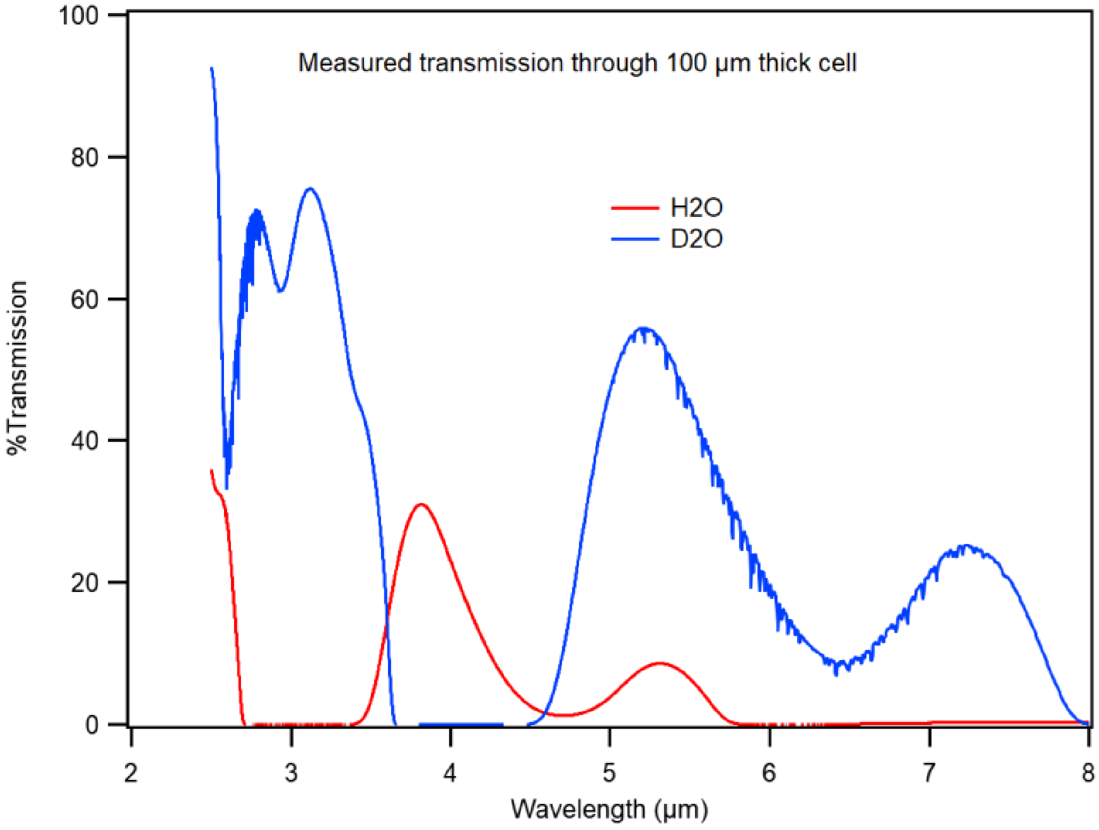
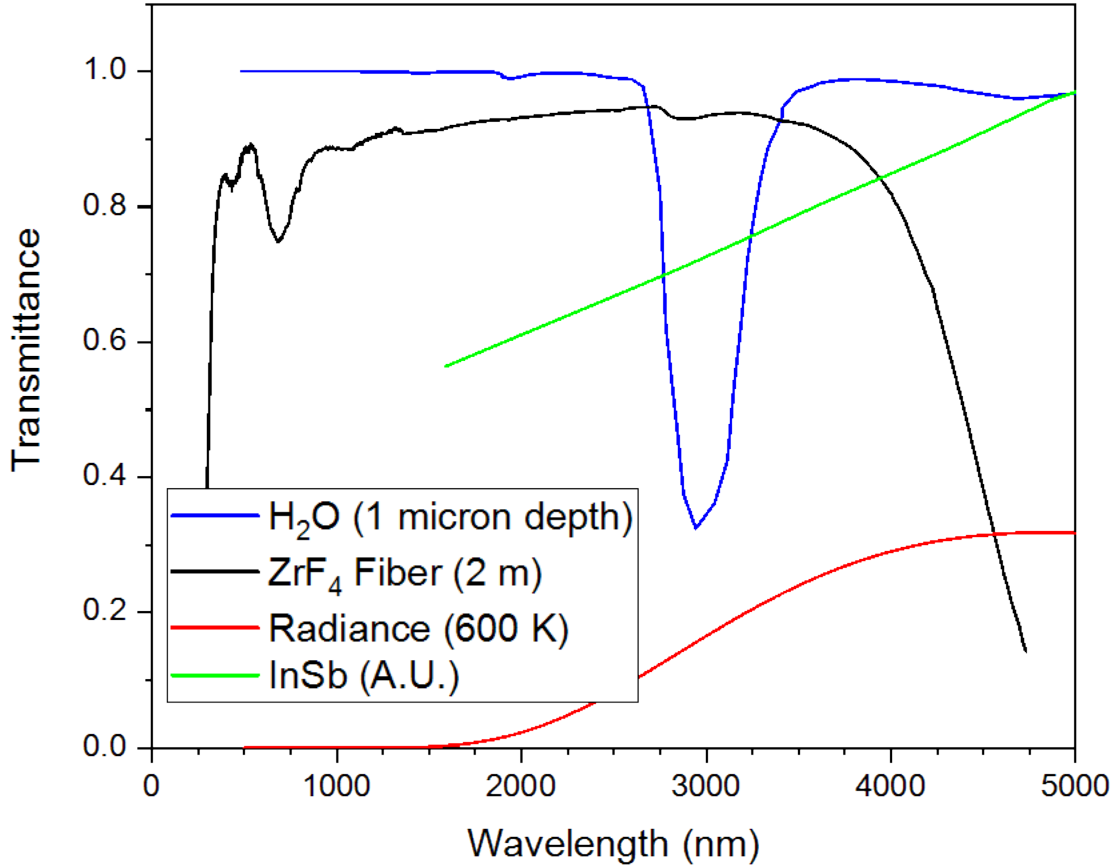
# Transmission Profiles

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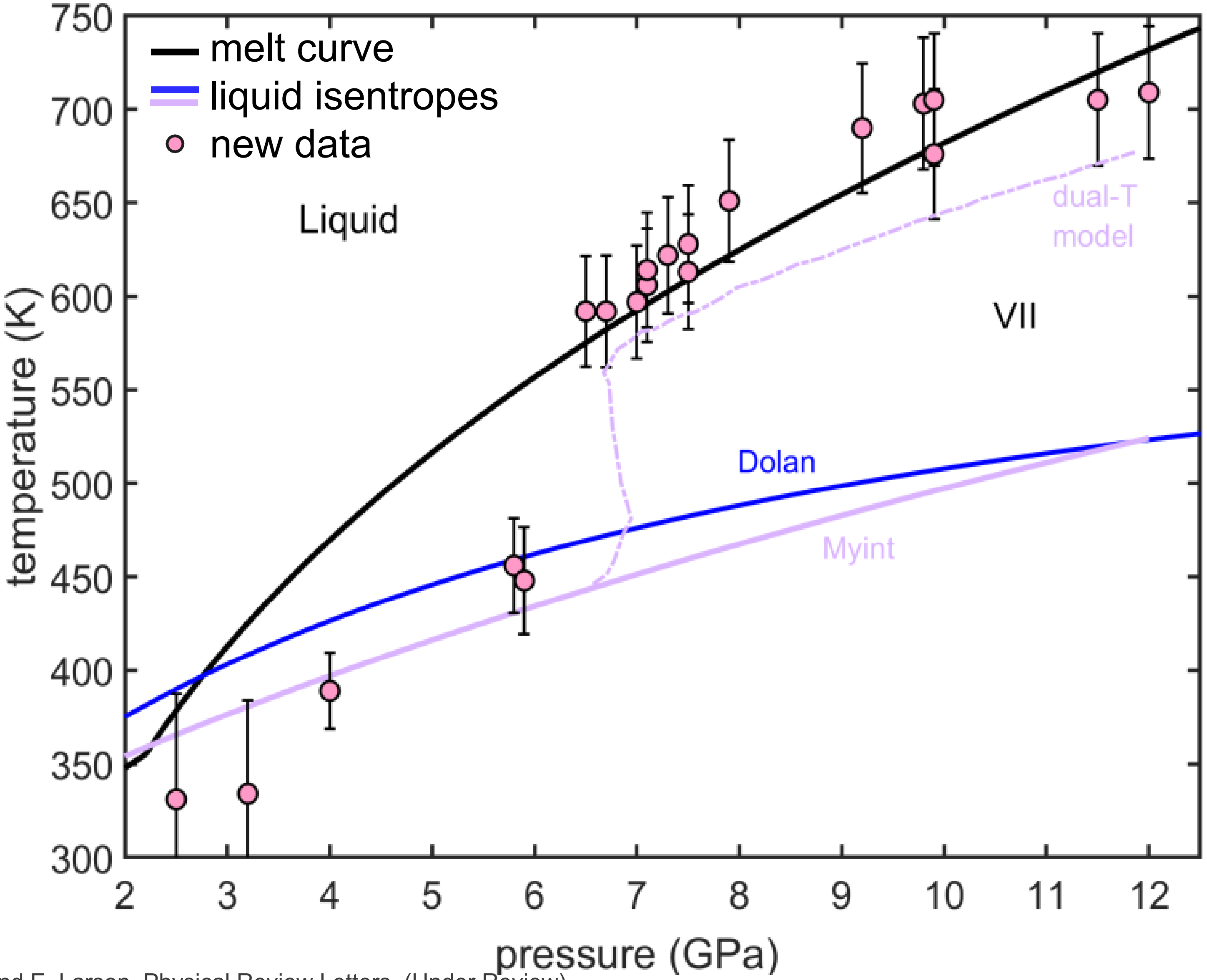


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