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INTERSECTION OF PHYSICS AND CHEMISTRY

*Why Is Ice Slippery?*





# The Physics behind ice skating

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Bart Weber

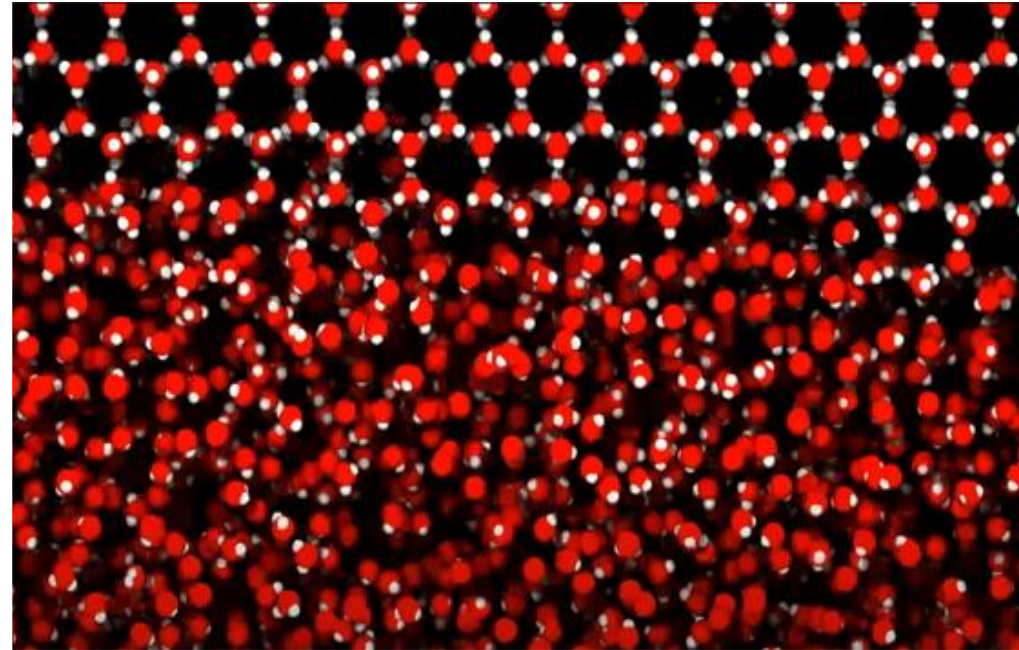
Daniel Bonn



# Water expands while freezing



\*



$$N_{\text{H-Bond}} \approx 4$$

$$N_{\text{H-Bond}} \approx 3$$

I.e., density of ice < density of liquid water

Water expands 9.2 % while freezing

So, ice floats on water, but why is it slippery?



# The “explanations” of ice skating



Three camps



Pressure melting



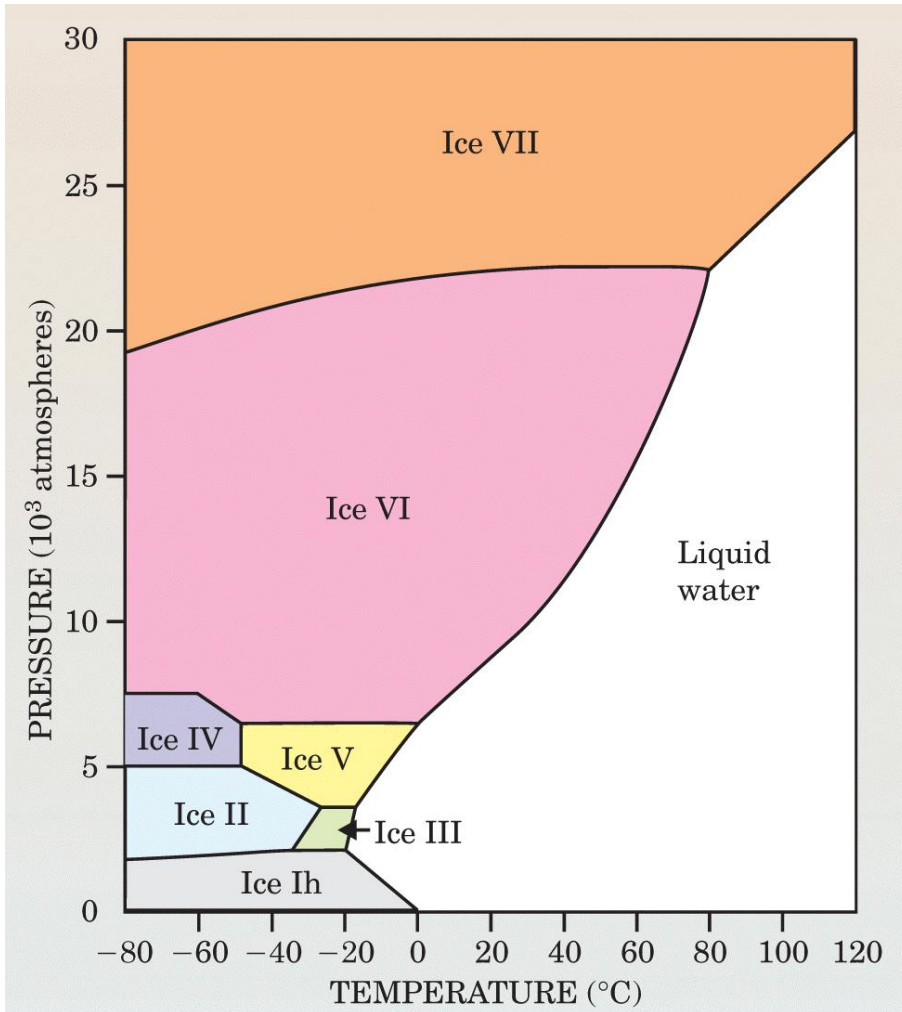
Premelting



Frictional heating



# Pressure melting

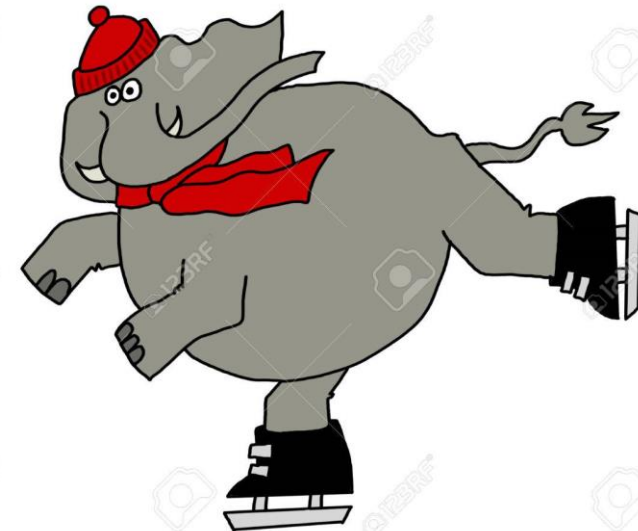


Every 100 atmospheres the melting temperature drops about 1 °C

Let's do a calculation: how much mass do you need to melt ice at -10 °C?

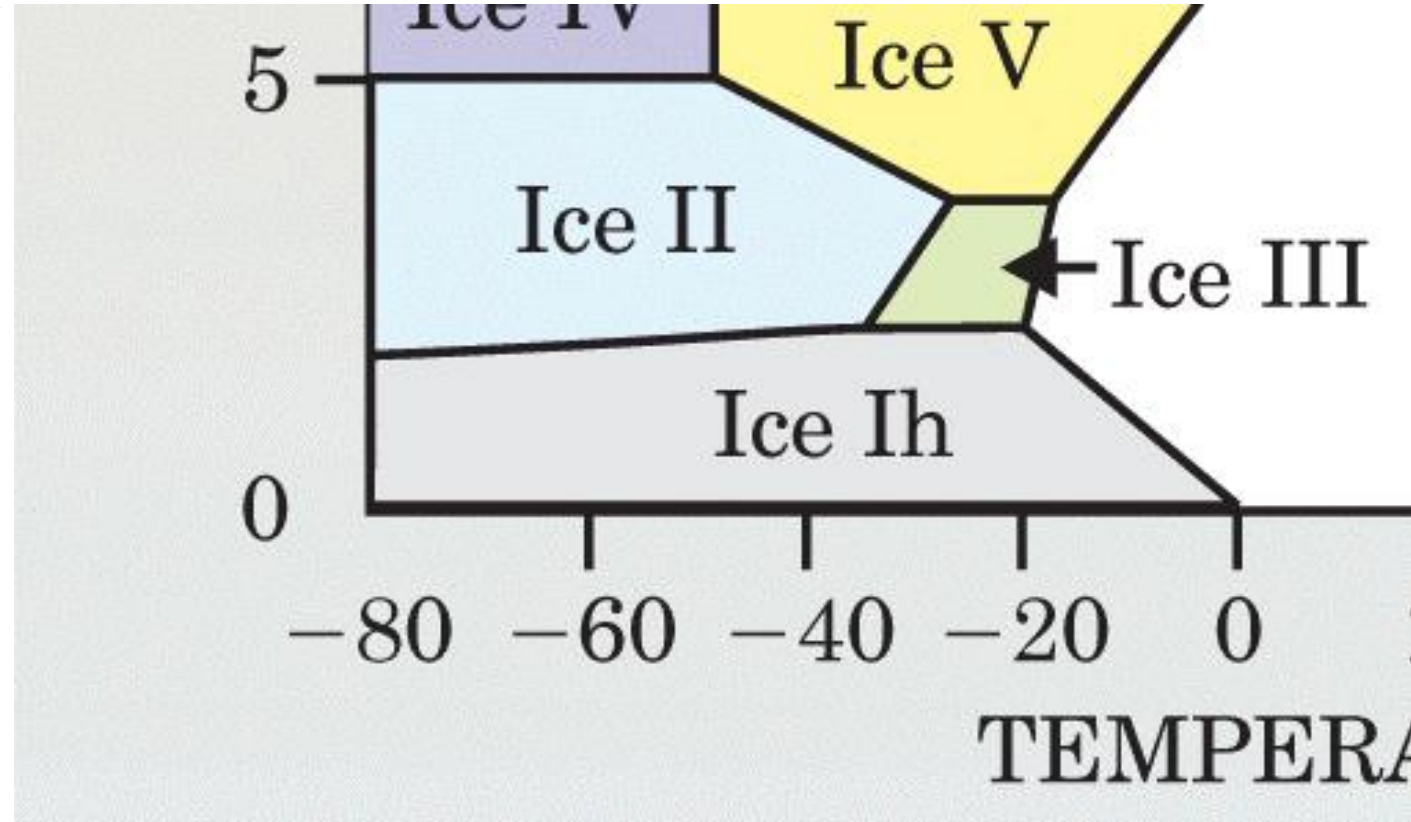
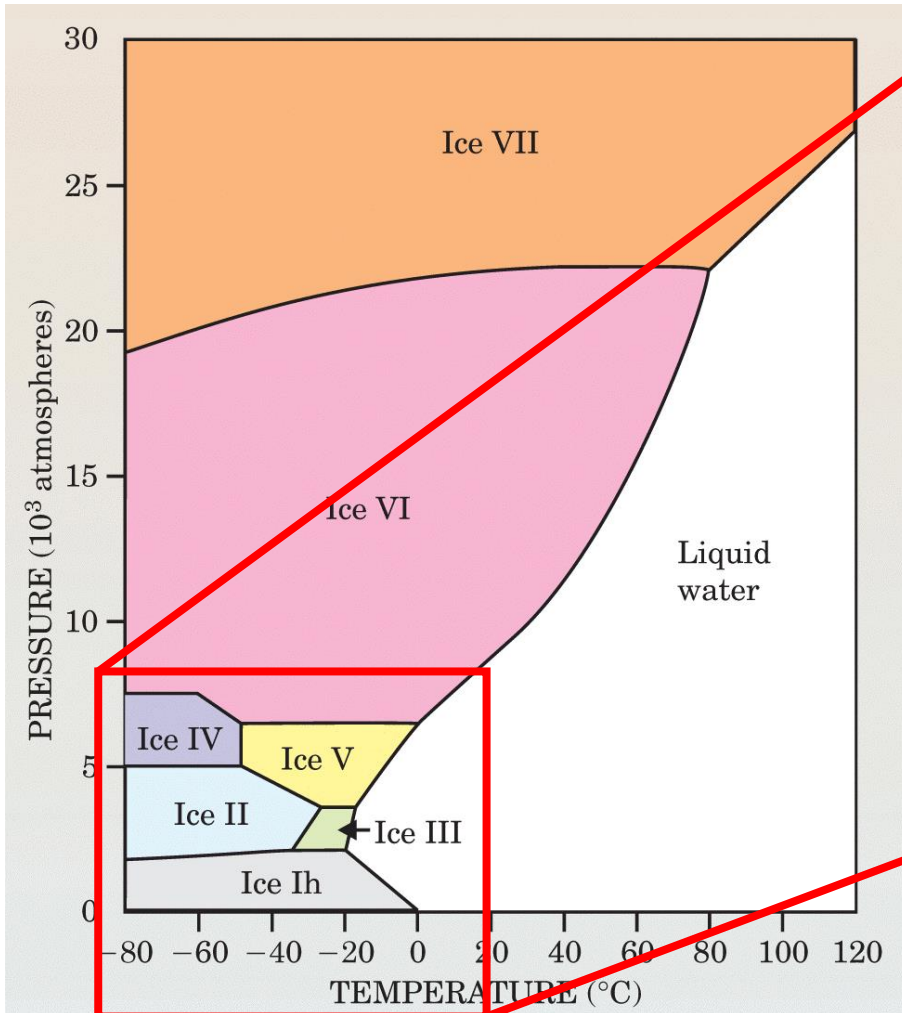
1000 atmospheres  
= 100 million Pa

1 square cm





# Pressure melting



We can skate at -10 °C and also below -22 °C!

# The explanations of ice skating



Three camps



Premelting



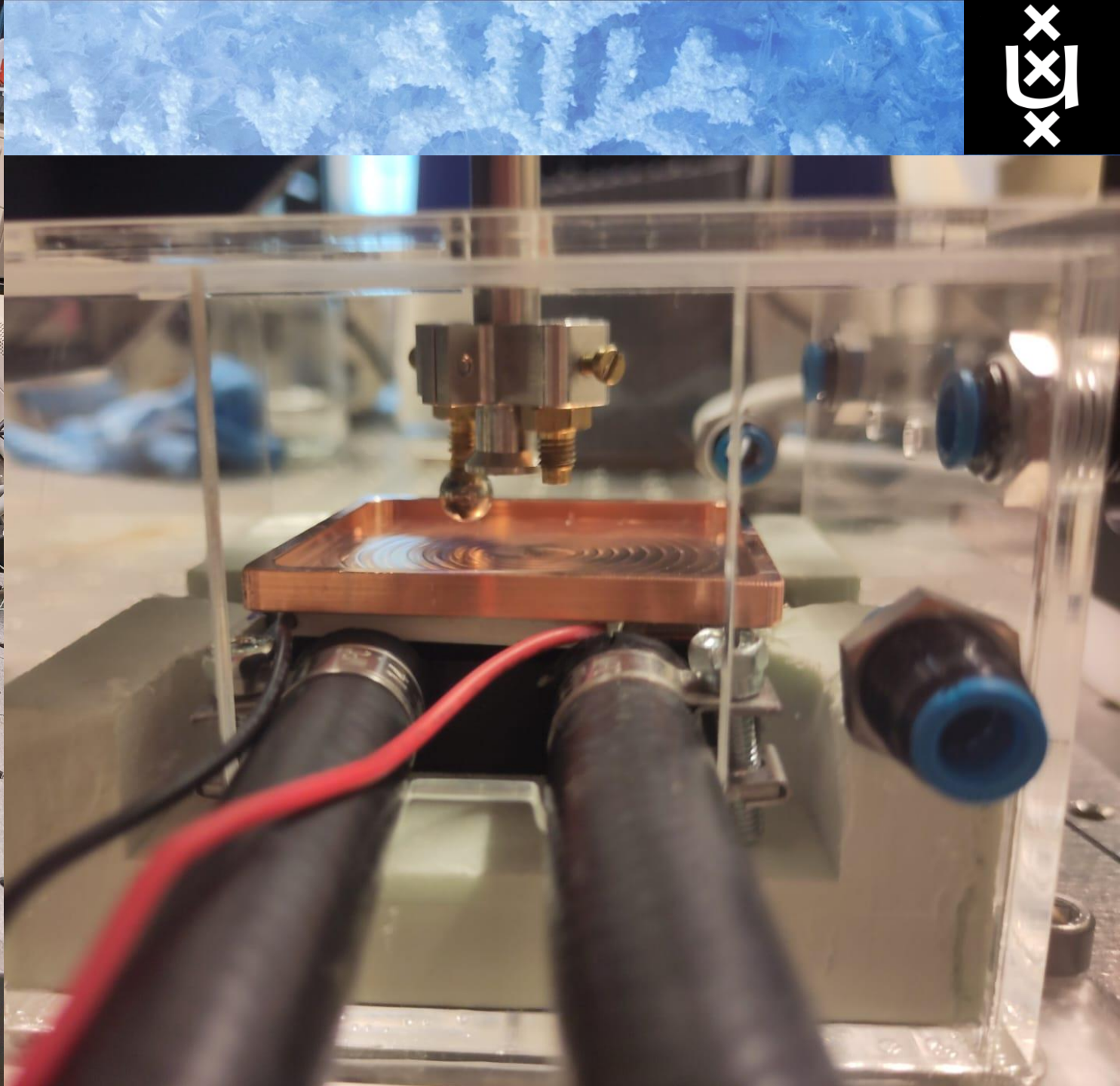
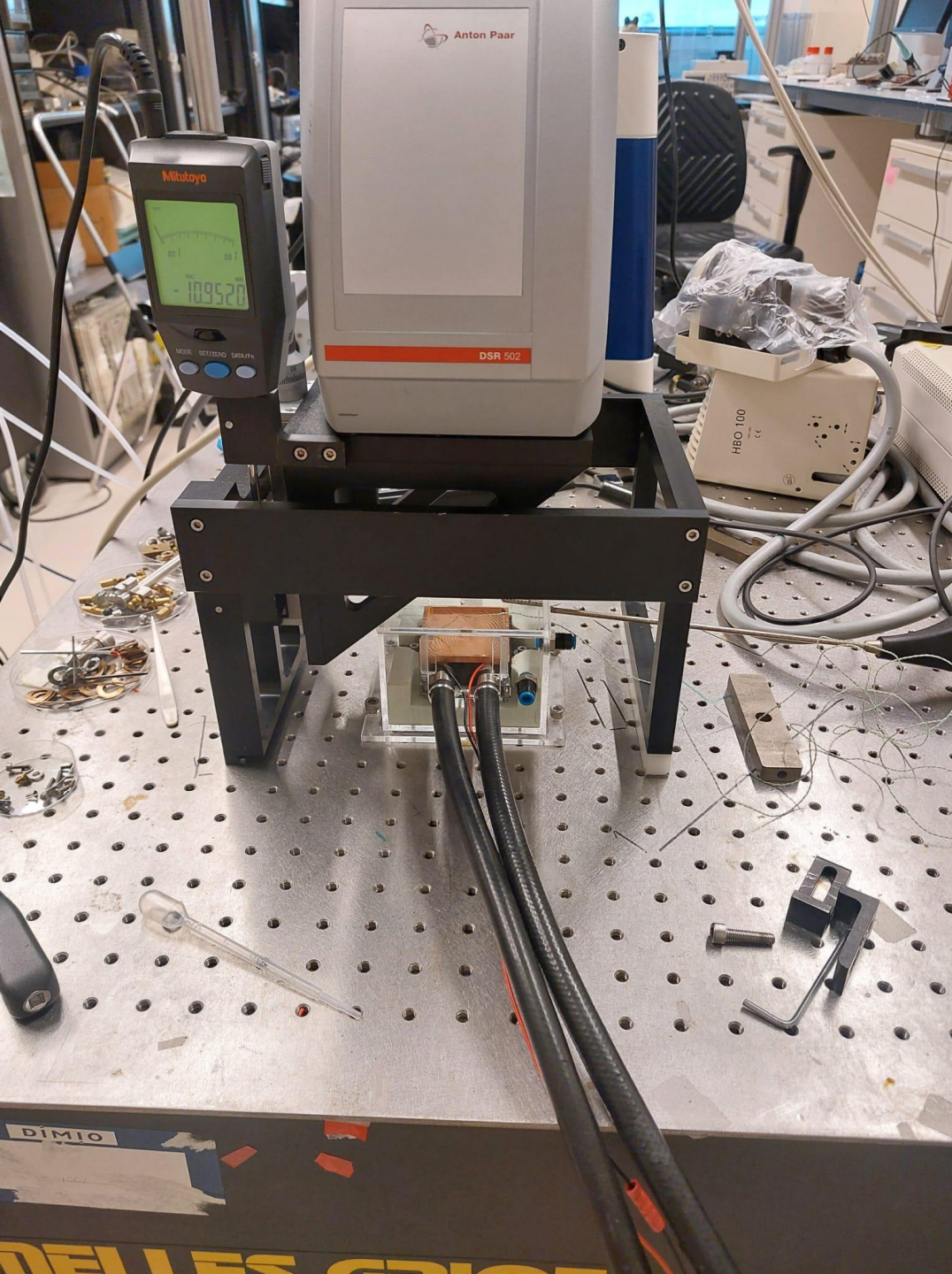
Frictional heating



Pressure melting









# Premelting



PNAS

## Experimental and theoretical evidence for bilayer-by-bilayer surface melting of crystalline ice

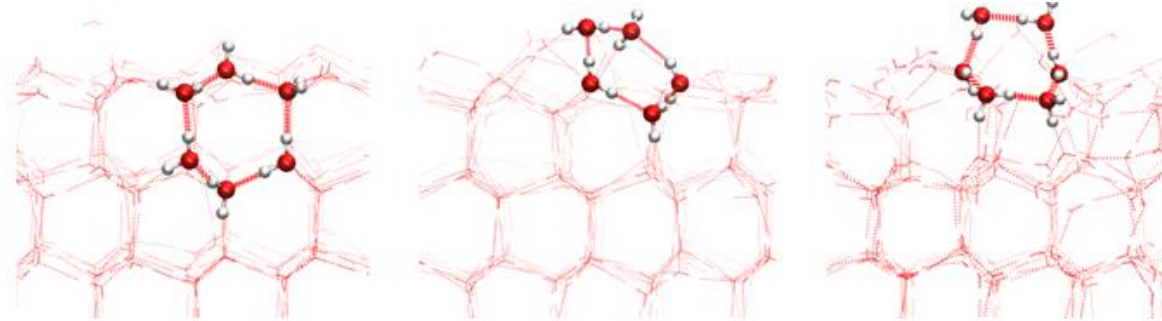
M. Alejandra Sánchez<sup>a</sup>, Tanja Kling<sup>a</sup>, Tatsuya Ishiyama<sup>b</sup>, Marc-Jan van Zadel<sup>a</sup>, Patrick J. Bisson<sup>c</sup>, Markus Mezger<sup>a,d</sup>, Mara N. Jochum<sup>a,e</sup>, Jenée D. Cyran<sup>a</sup>, Wilbert J. Smit<sup>f</sup>, Huib J. Bakker<sup>f</sup>, Mary Jane Shultz<sup>c</sup>, Akihiro Morita<sup>g,h</sup>, Davide Donadio<sup>a,i</sup>, Yuki Nagata<sup>a</sup>, Mischa Bonn<sup>a,1</sup>, and Ellen H. G. Backus<sup>a,1</sup>

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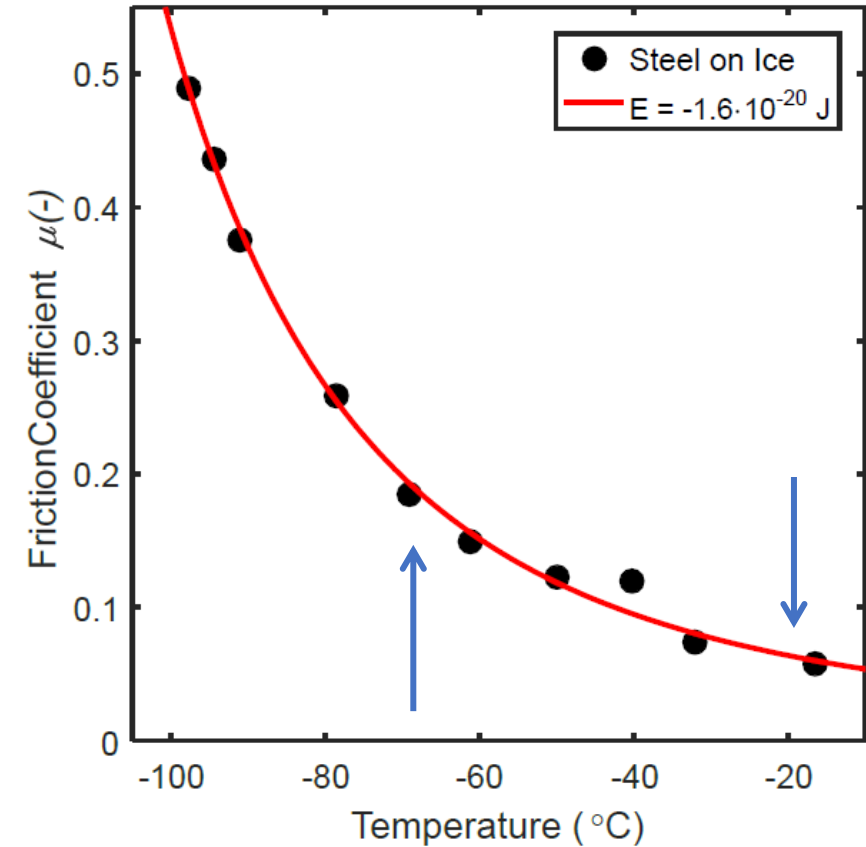
$T < -70\text{ }^{\circ}\text{C}$

$-70\text{ }^{\circ}\text{C}$

$-20\text{ }^{\circ}\text{C}$



Floors get slippery when soap is used



$$\mu = \frac{F_f}{F_n}$$

No evidence of bi-layer premelting in friction coef.,  
Water is a bad lubricant!

# The explanations of ice skating



Three camps



Pressure melting



Premelting

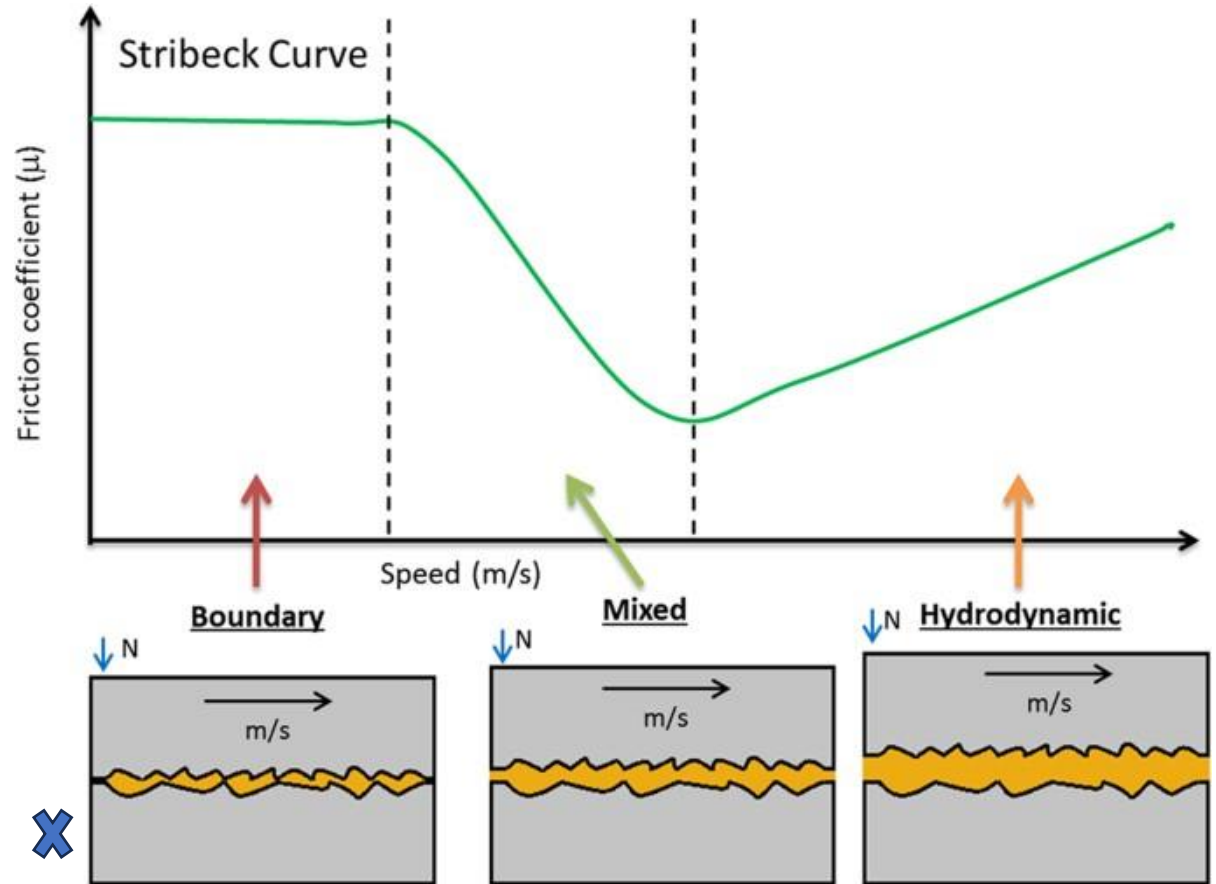
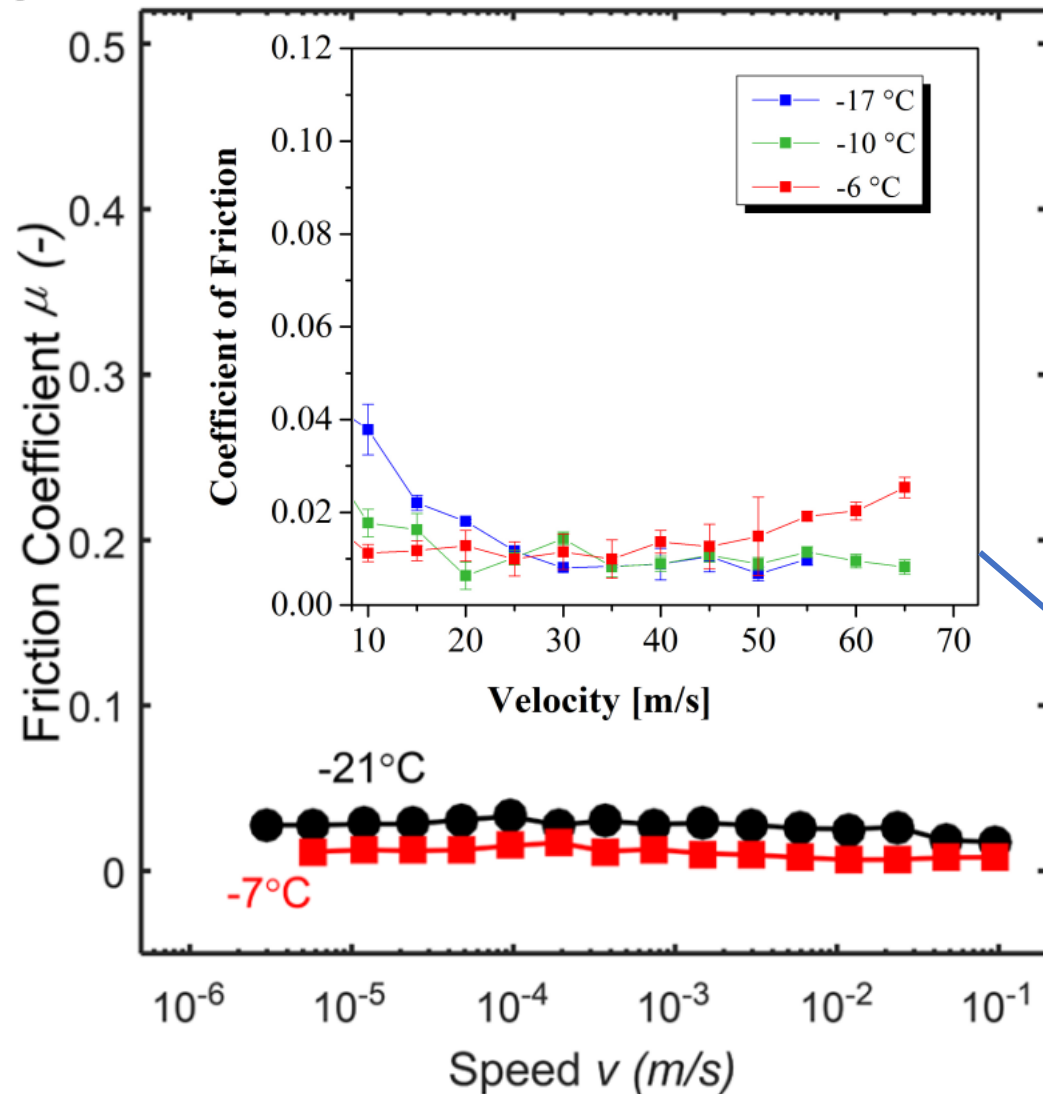


Frictional heating





# Frictional heating



Friction does not depend on sliding velocity, no evidence of “Stribeck” behavior.

# The explanations of ice skating



Three camps



Pressure melting



Premelting



Frictional heating





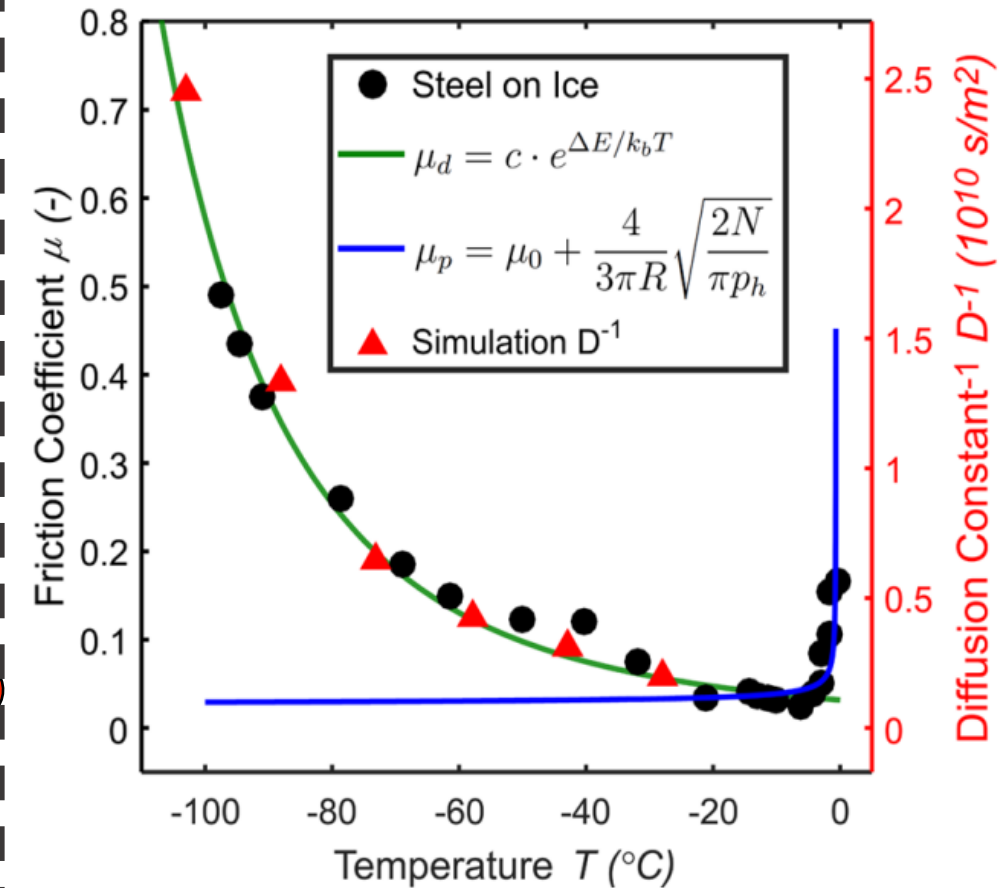
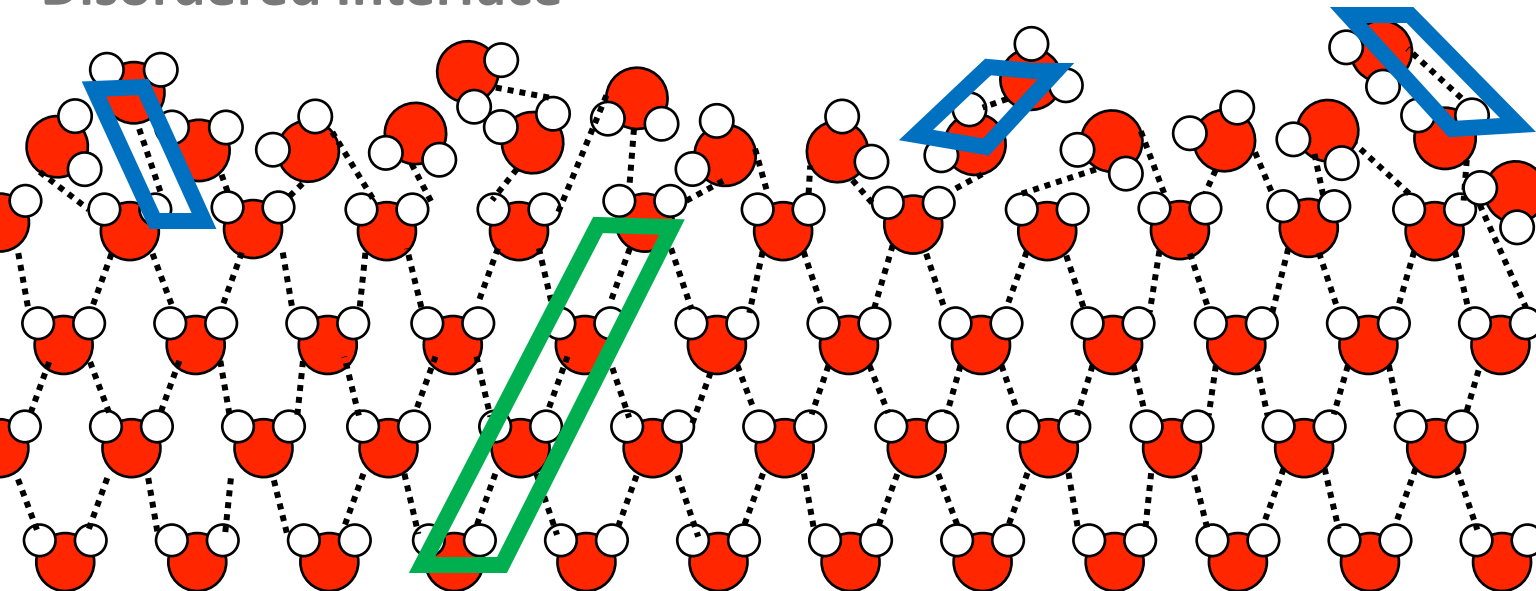
# So why can we skate?

Surface  
Diffusion

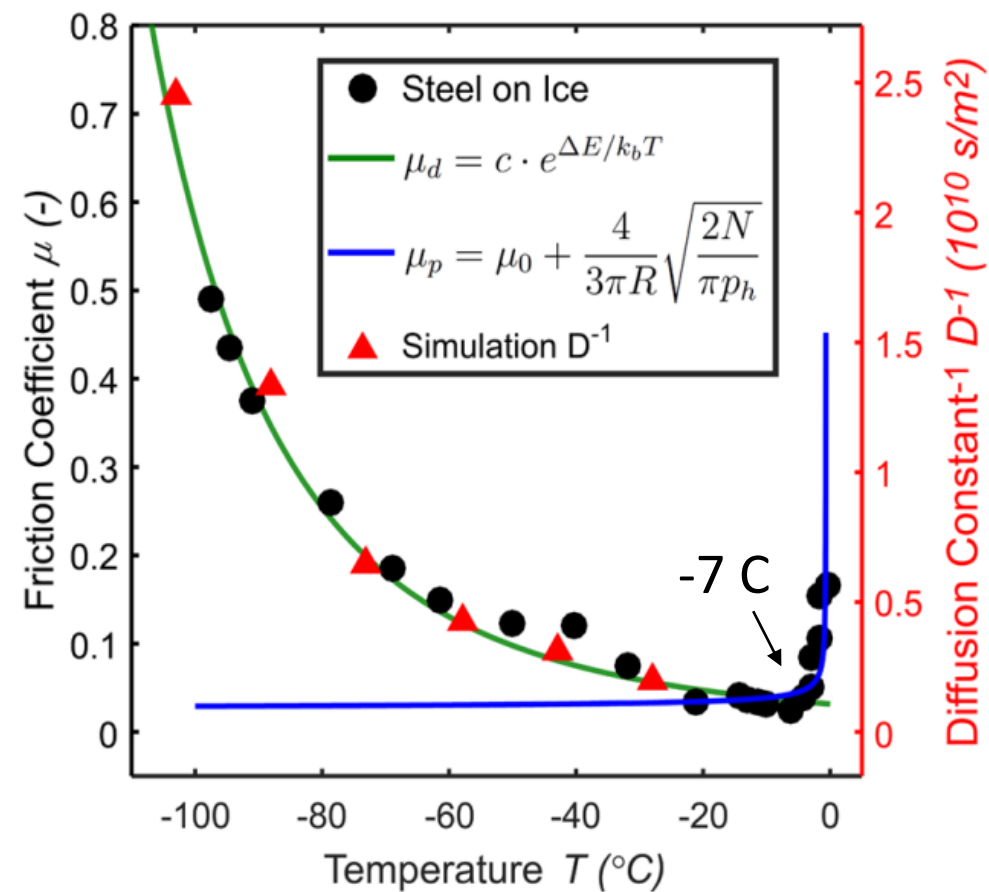
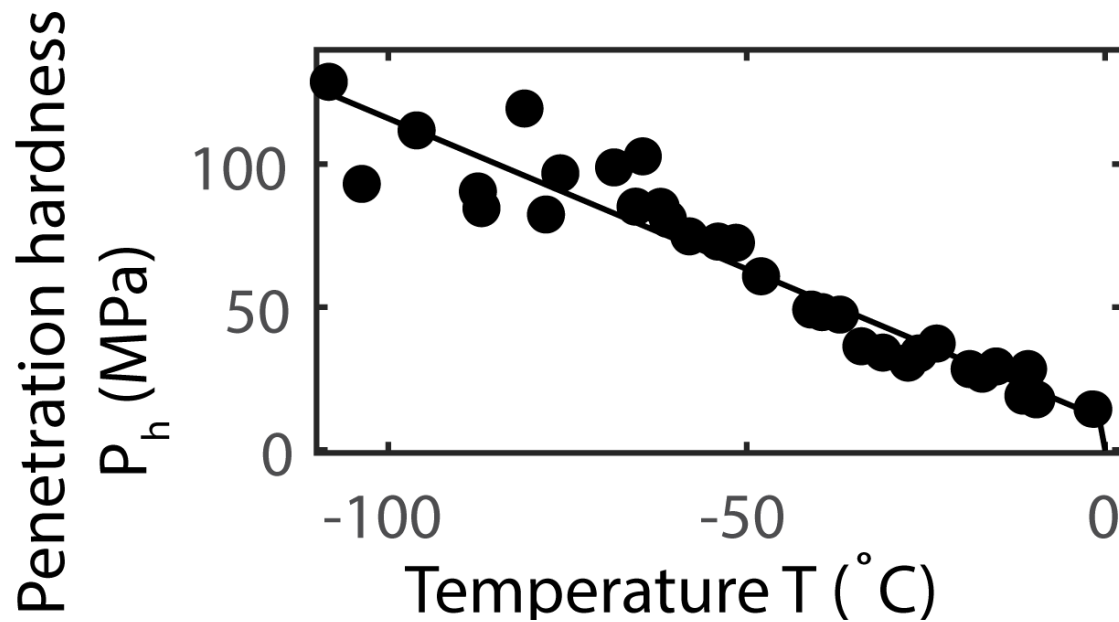


Hydrogen bonding is highly cooperative:  
3 H-B in a row  $\gg$  3 times an isolated H-B

Disordered Interface



# So why can we skate?





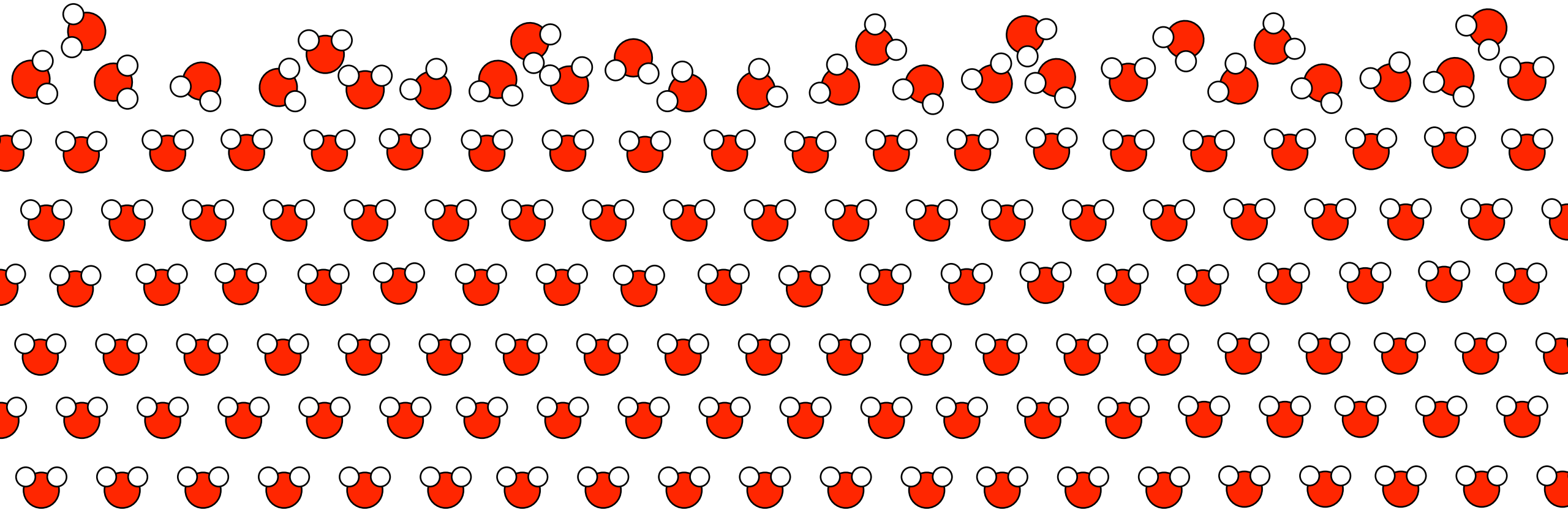
# So why can we skate?



Water molecules have high mobility at the surface, but bulk ice has an exceptionally high hardness

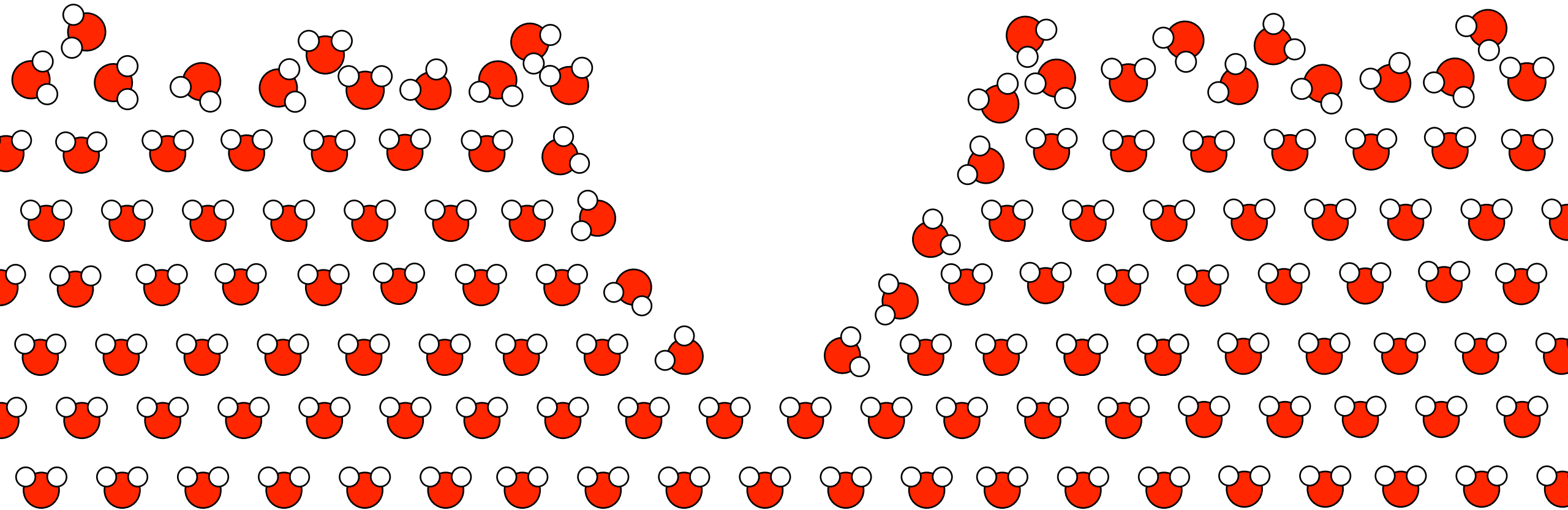


# How to investigate the dynamics?

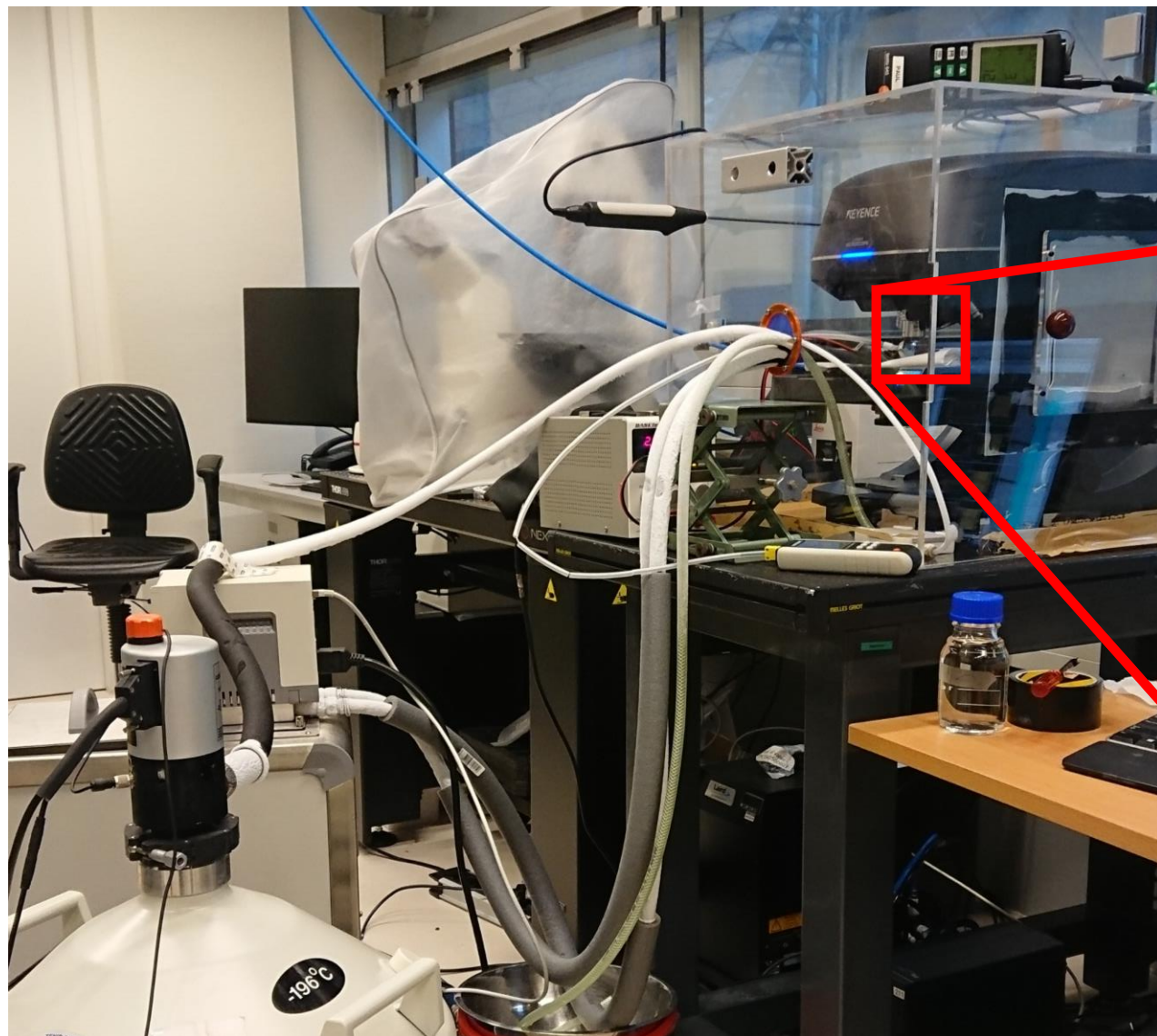




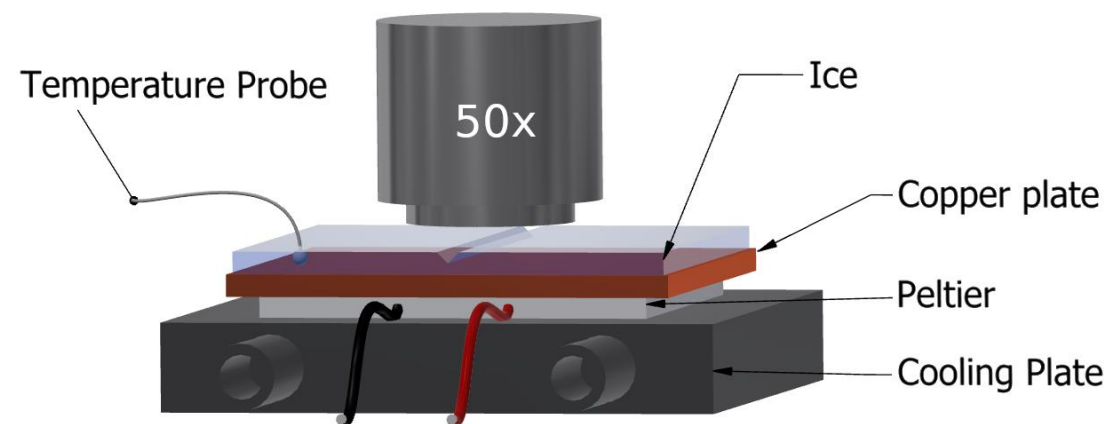
# Let's cut it!



# Set up



← Humidity control

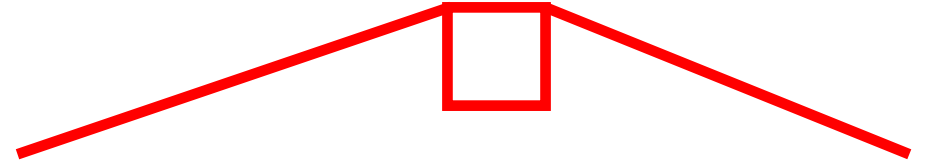
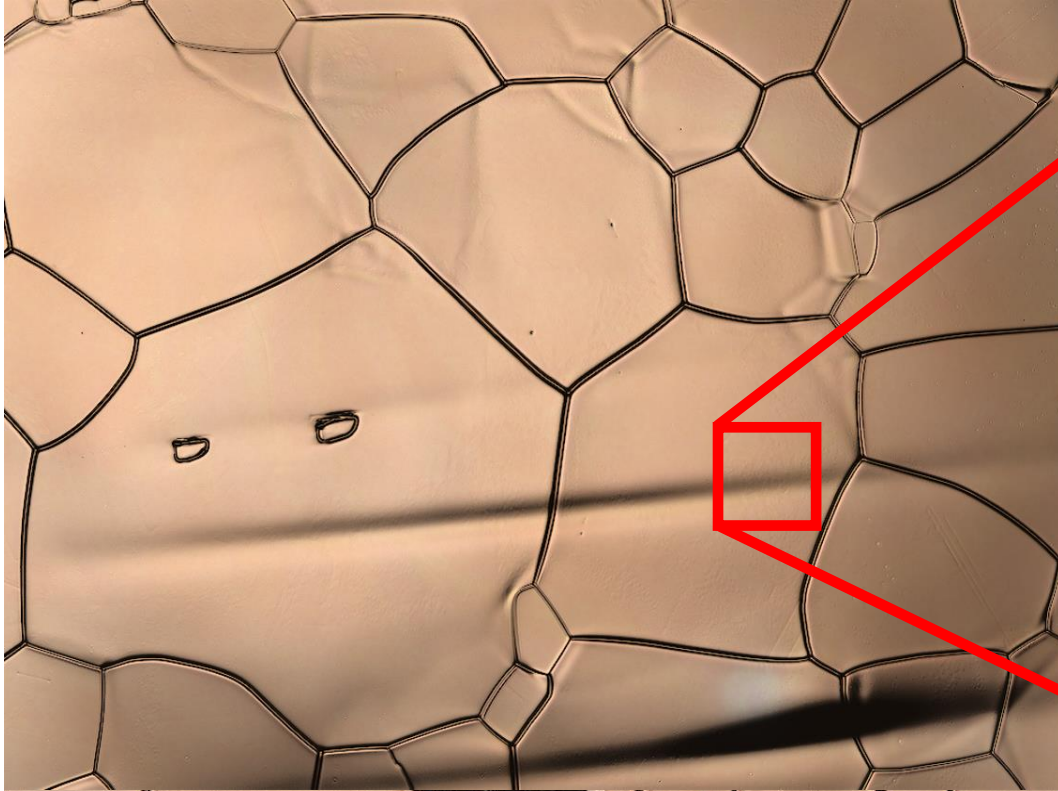




# Scratch disappears



$T = 247 \text{ K}$



# Self-healing quite unique for ice





# Sublimation of snow is actually very well known!

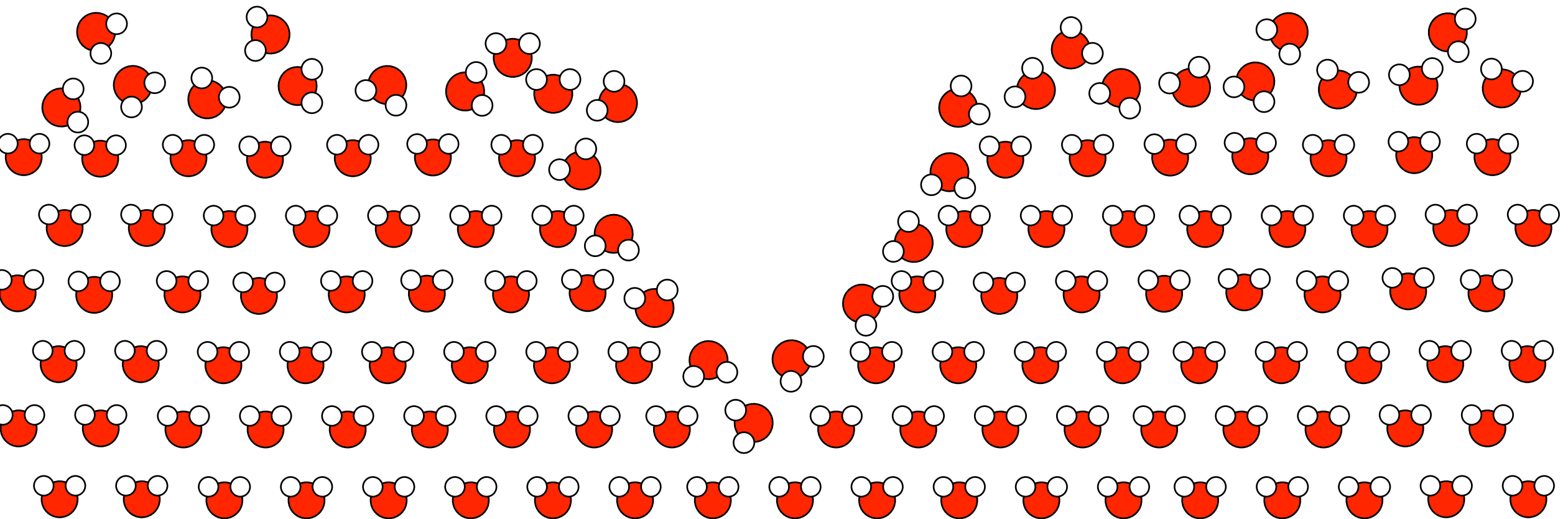


# Self-healing by local sublimation and condensation



To conclude: top molecules of ice are loosely bound (it is volatile):

- Causes slipperiness by surface diffusion
- Scratches disappear spontaneously and make the ice surface extremely flat





# If you have enough time ice resurfaces itself



Demmenie, Menno, et al. "Scratch-healing behavior of ice by local sublimation and condensation."  
*The Journal of Physical Chemistry C* 126.4 (2022): 2179-2183.

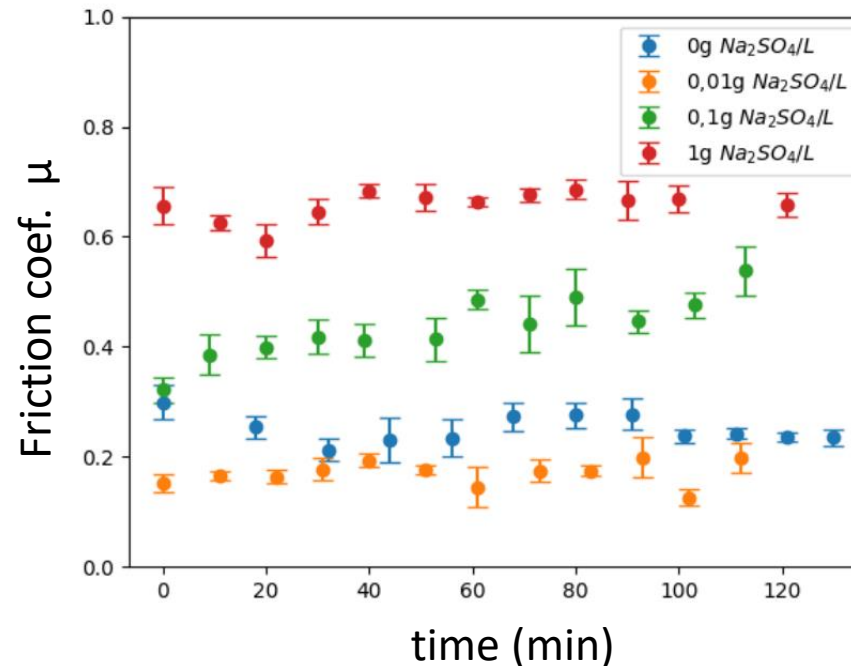
# Energy consumption



Unfortunately, thermodynamics is acting against us:

- Water has a high specific heat capacity: it costs a lot of energy to decrease T
- Upon freezing, even more latent heat is released

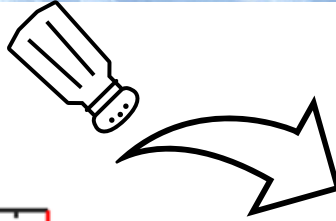
## What if we use additives? $\text{Na}_2\text{SO}_4$



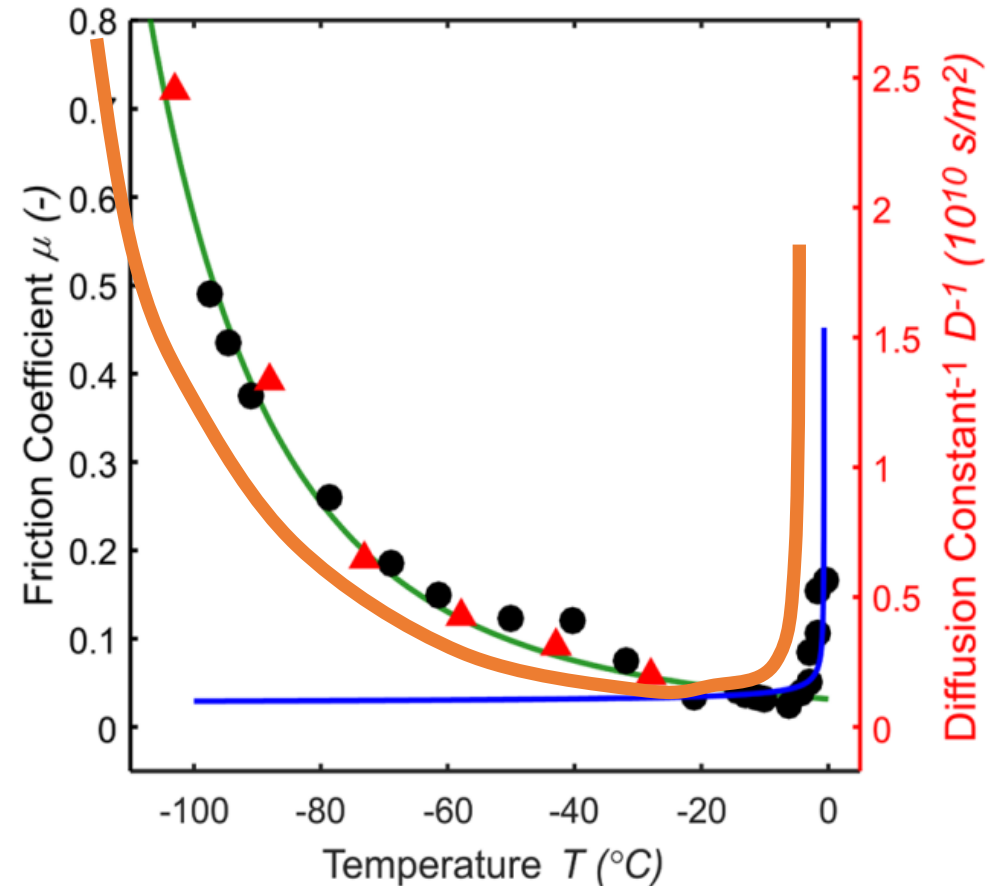
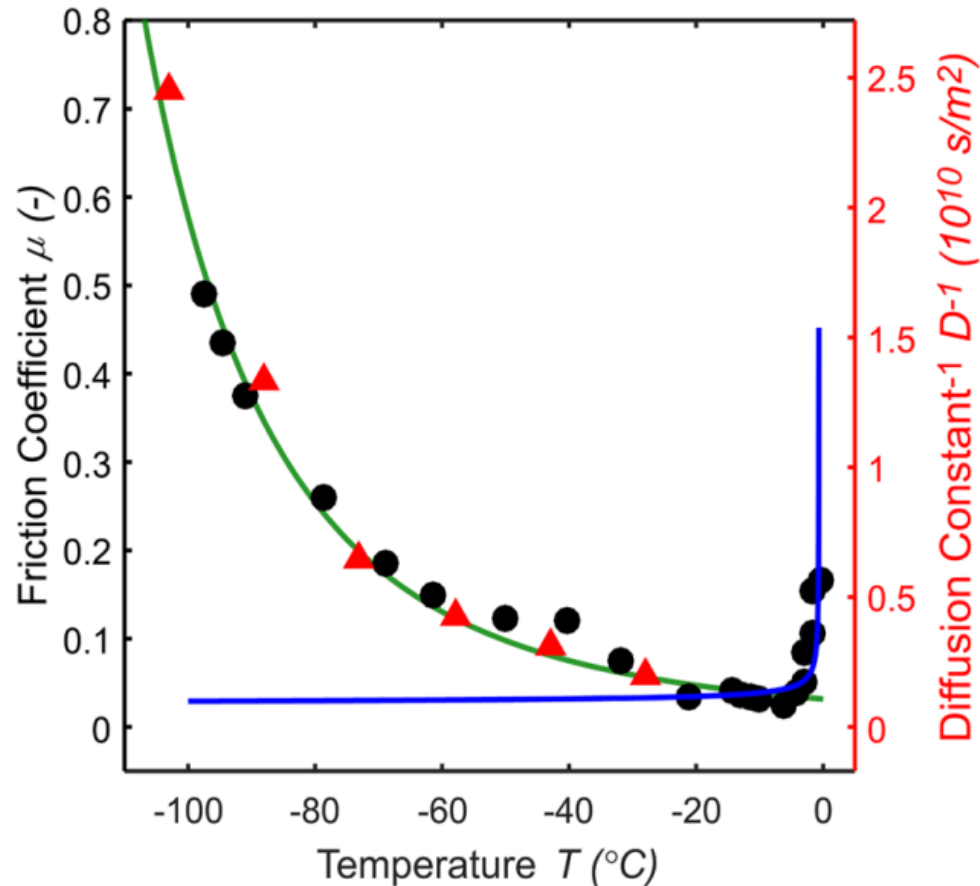
All done at -7 C, as it is the lowest friction coefficient



# What does salt do to the friction curve?



The friction curve shifts to the left,  
at minus 7 C the friction is higher (more grip)



I.e.: having the rink on a higher  $T$ , has the same effect!

# Questions?

