Pourquoi la glace est si glissante ?
nouvelles perspectives grâce à la nanorhéologie

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and C. Cohen, C. Clanet (LadHyX)

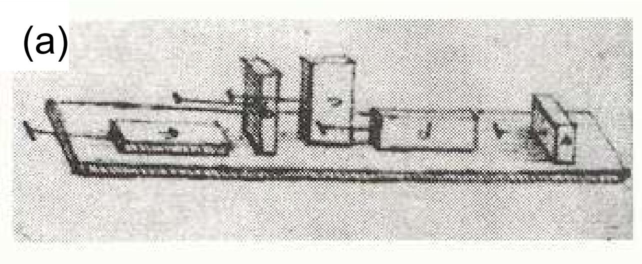
WINTER SPORTS

all these games exist because of slipperiness of snow and ice

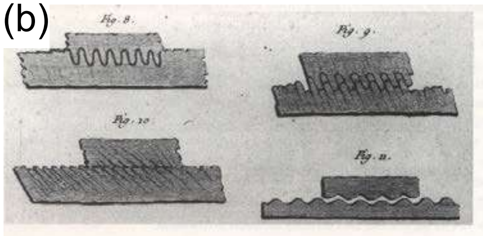
SNOW AND ICE FRICTION ?

ultra-low friction coefficient

(a)



(b)



Leonard de Vinci

solid-on-solid friction

$$F_T = \mu \times F_N$$

$$\mu \approx 0.5$$

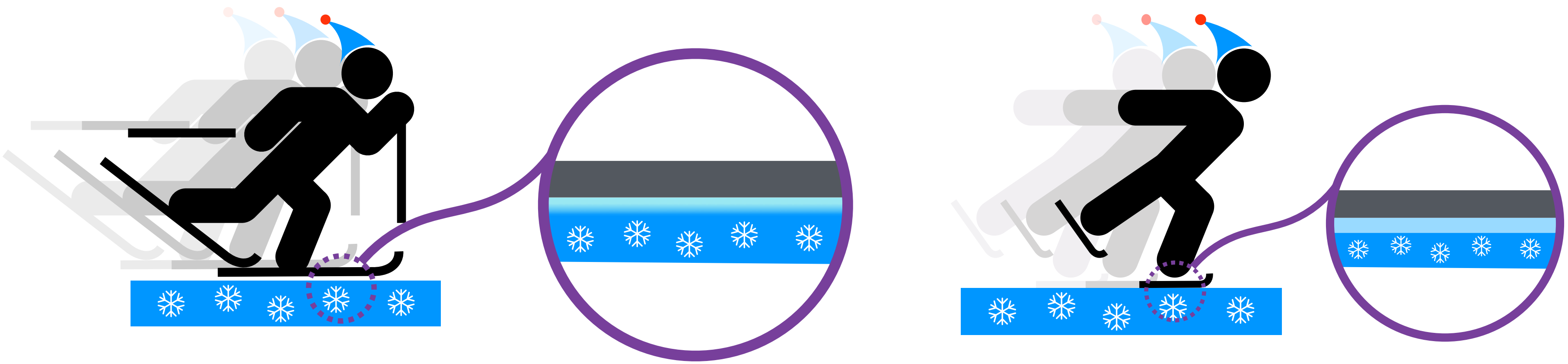
… but for ice and snow

$\mu \approx 0.01$ (ice)

$\mu \approx 0.01 - 0.2$ (snow)

?

ORIGIN OF LOW ICE/SNOW FRICTION ?



« skiing/sliding on a liquid film leads to low friction »

?

ON THE SPORT SIDE

can scientists be of any help to competitors ?

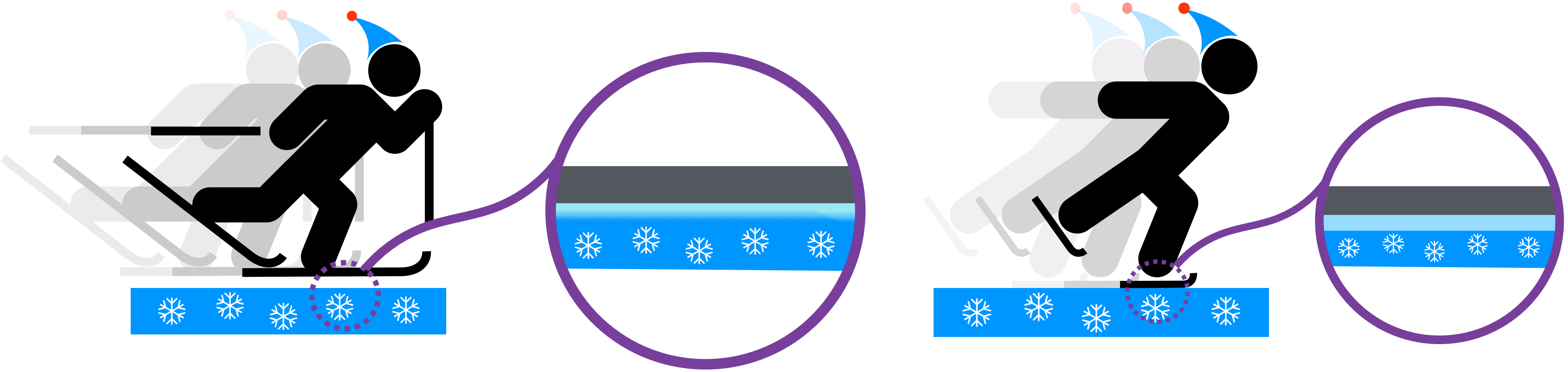


Martin Fourcade, Biathlon

project in collab with *Martin Fourcade* and Gregory Deschamp (FFS Biathlon)

NEED FOR MORE SCIENCE

what do we know about snow and ice friction ?

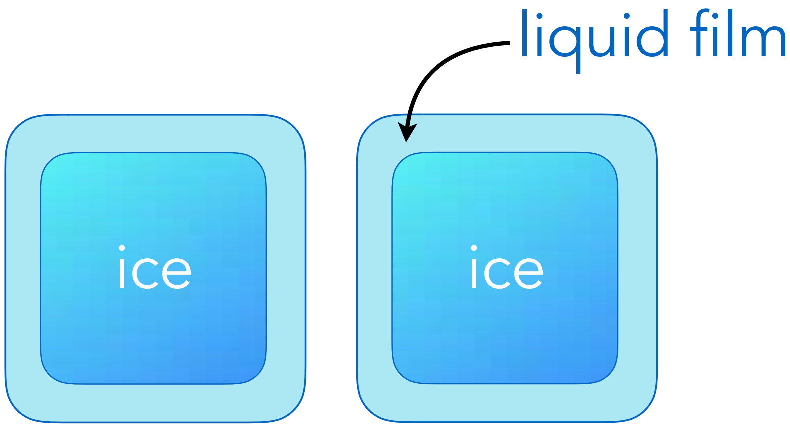


« skiing on a liquid film leads to low friction »

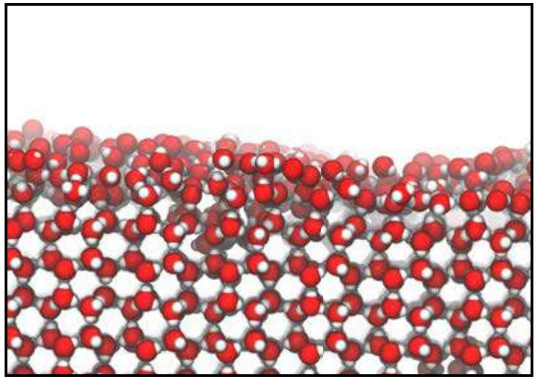
« wax (a hydrophobic material) helps sliding »

SLIPPERY ICE: PREEXISTING LIQUID FILM

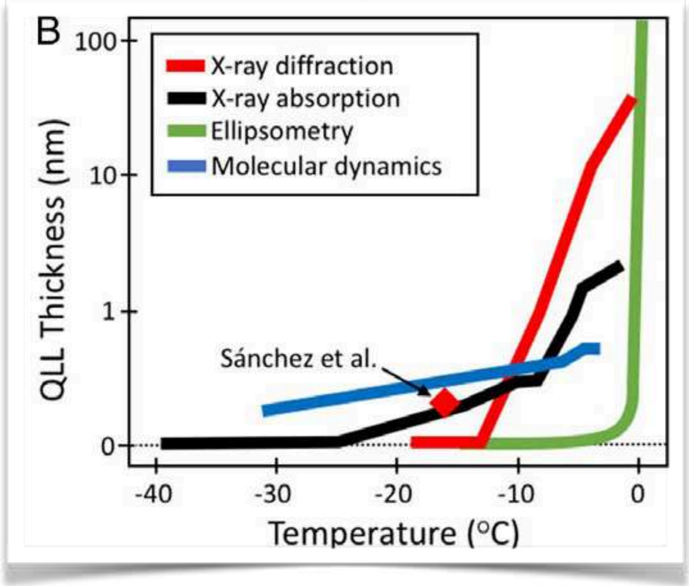
surface melting: back to Faraday and Thomson debates (1850-…)



Faraday (1859)
against Thomson



Limmer PNAS (2016)



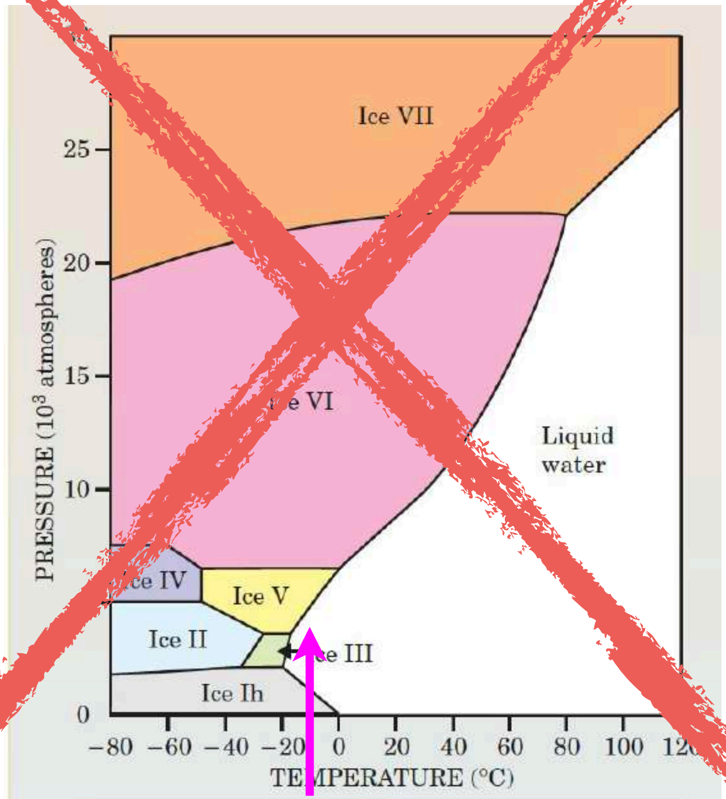
Michaelides PNAS (2017)

surface premelting of ice: slippy (but adhesive)

ICE FRICTION AND SURFACE WATER FILM

Two competing views

Joly (1886), Reynolds (1899), …
(inspired by Thomson)



Physics Today (2005)

pressure melting

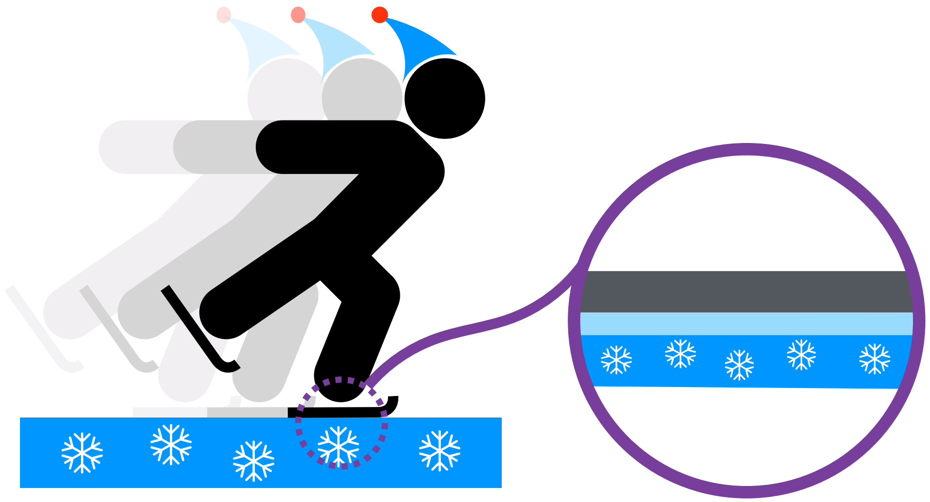
Bowden (1939), Colbeck (70's), …

P. Trouvé

frictional heating

« WATER SKIING » ?

some theory, very few experiments…

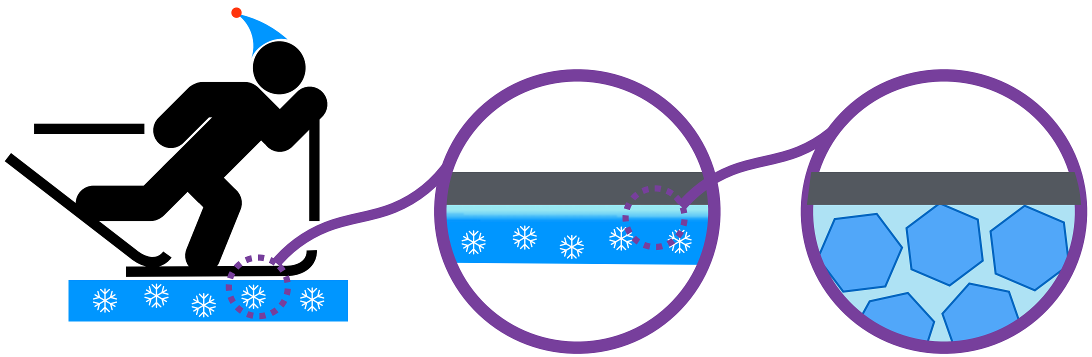


how to investigate the properties of the interfacial liquid film ?

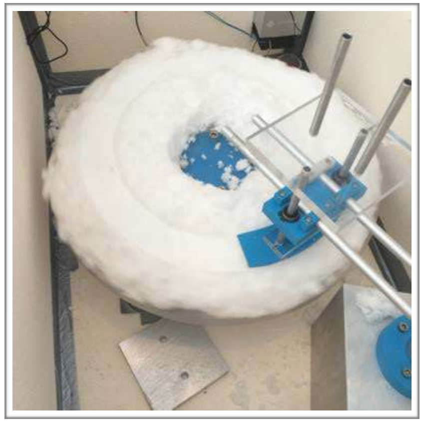
THE SNOW-ICE PROJECT

with C. Clanet (LadHyX)

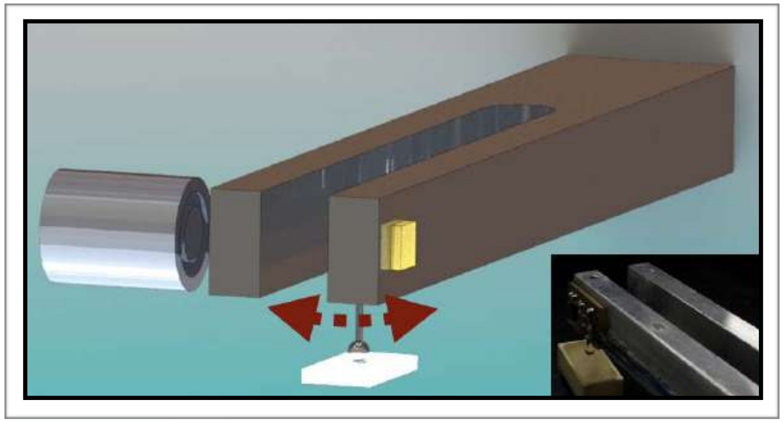
propose a ***multi scale perspective*** to disentangle phenomena at stake



from ski…



to tribometer…



to AFM…

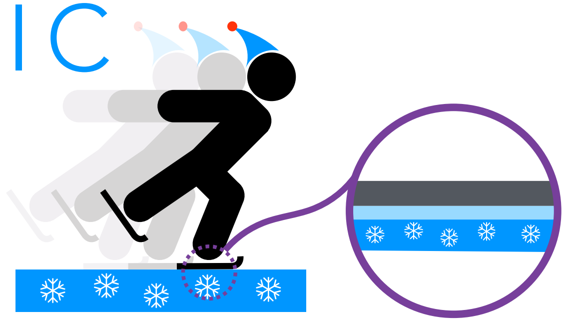
A SKI RESORT (LadHyX)

SKI/ICE FRICTION AT LARGE SCALE: MACRO EXPERIMENTS

Many results…

but not sufficient to disentangle various mechanisms

MORE INTO MICROSCOPIC



in a few words:

macroscopic experiments on snow and ice are interesting but do not provide much information on the intimate mechanisms

we miss information about the film, how to probe it ?

dig further downscale,
an experimental challenge at small scales …

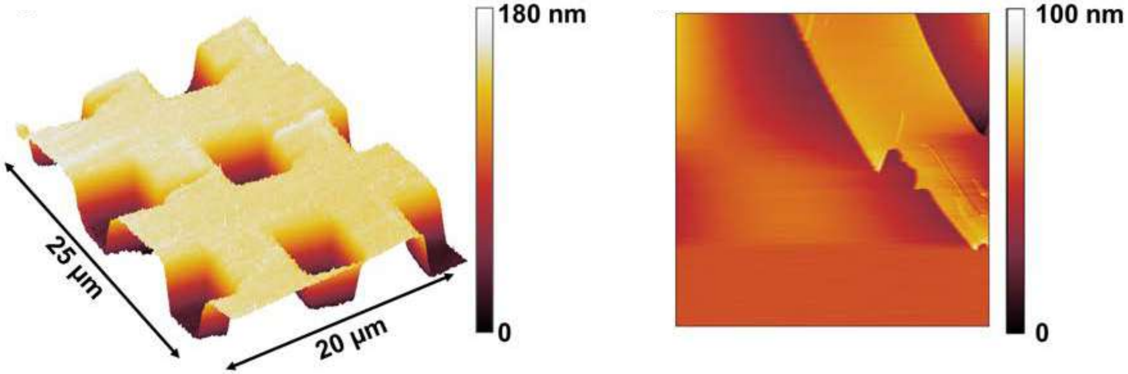
A NEW ATOMIC FORCE MICROSCOPE

« hearing forces »

- frequency shift tells about the **elasticity** of the probed material
- attenuation (quality factor) tells about the **dissipation**: friction & rheology

A NEW ATOMIC FORCE MICROSCOPE

with exceptional performance…

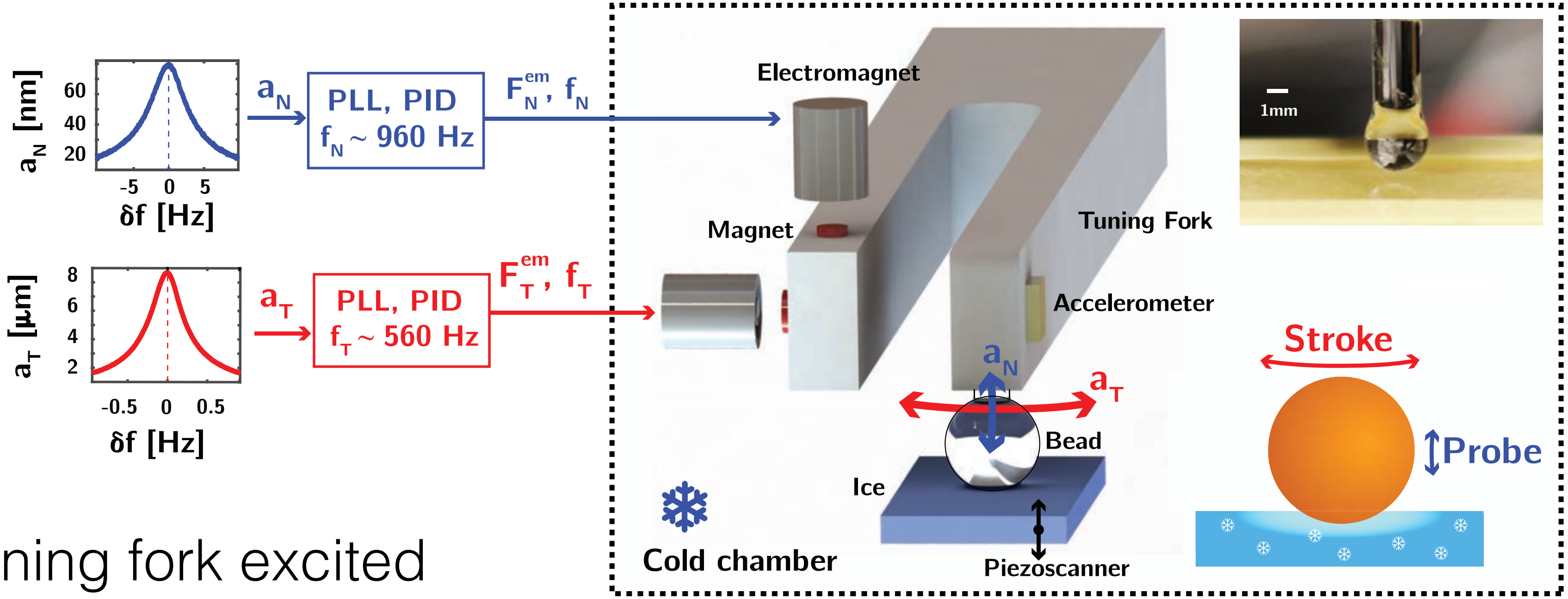


Scan of a calibration grating + mica

- Nanometric resolution
- Versatility
- Easy application in liquids

(patented)

A NEW ATOMIC FORCE MICROSCOPE



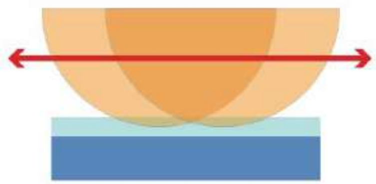
Tuning fork excited
at
its **resonant frequencies**

Glass bead, R~1.5mm
V~10^{-2} - 10^{-1} m.s^{-1}

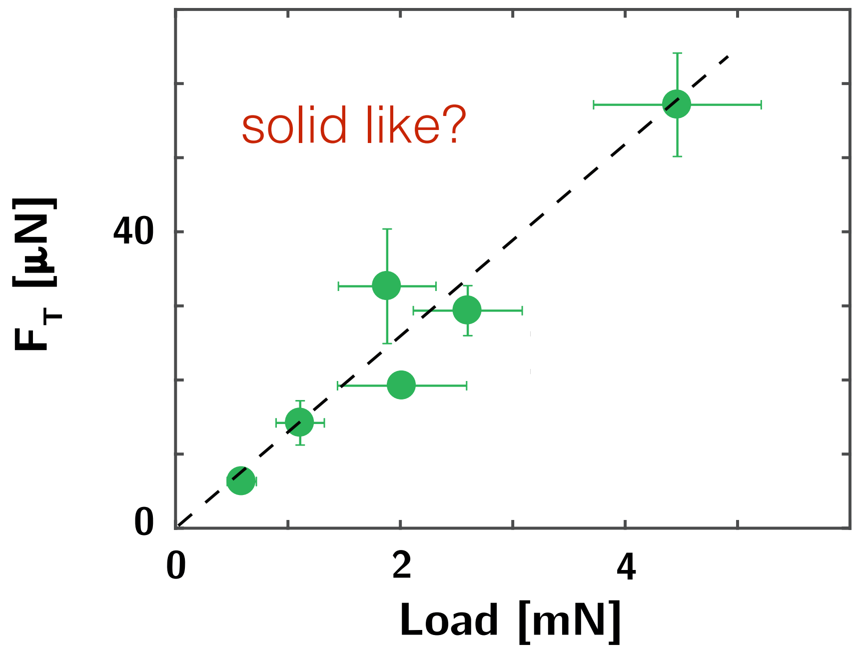
to probe friction on ice (-15°C-0°C)

TWO MAIN FOCUS

(1) the friction force



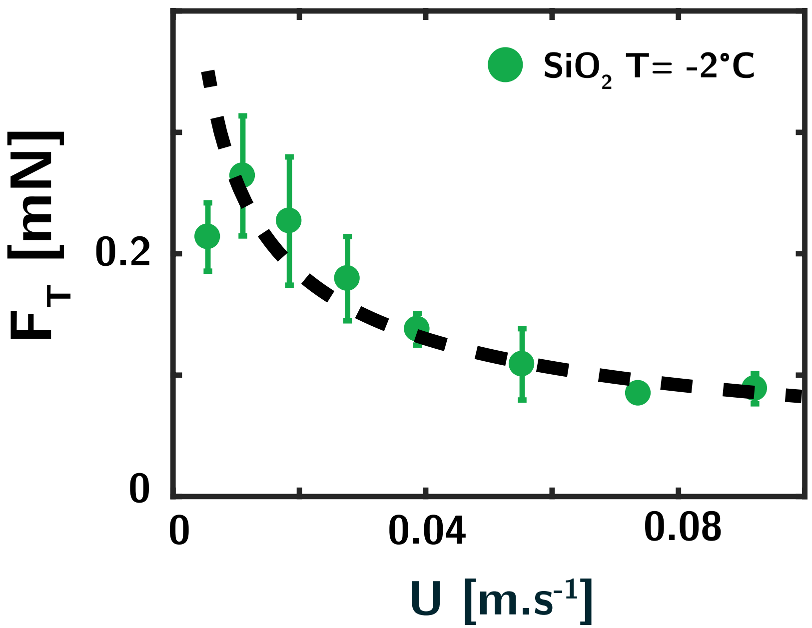
Stroke
frictional sliding
$a_T \approx$ 1-10 µm



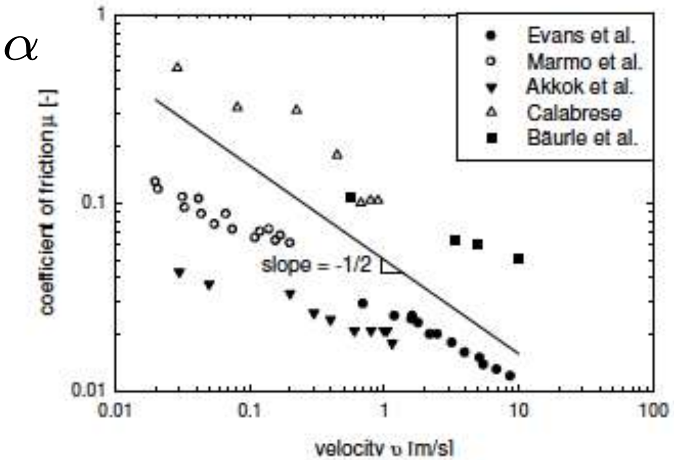
$$\mu \sim 0.01 - 0.1$$

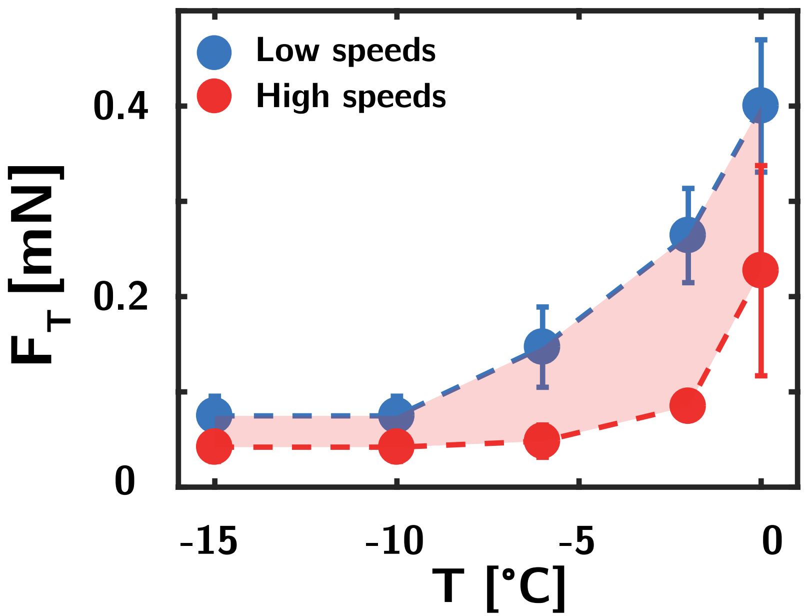
(depending on velocity, temperature ...)

DETAILED FRICTIONAL BEHAVIOUR



- $U \rightarrow 0 : F_T \neq 0$
- $F_T \propto U^{-\alpha}$

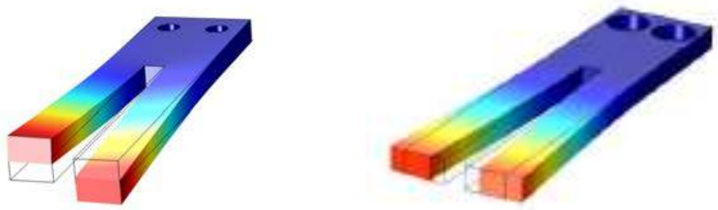




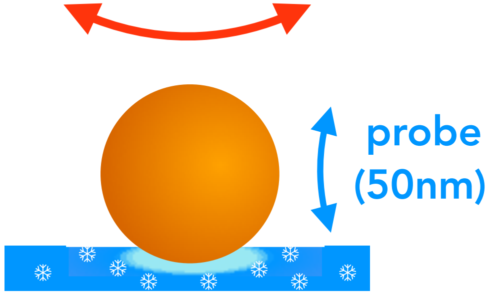
NOW, INVESTIGATE THE FILM

(2) thickness and properties of the interstitial liquid

a « stroke-probe » approach with the AFM



stroke
(1-10 µm)



probe the interstitial film
⇒ it is liquid ! (but special)

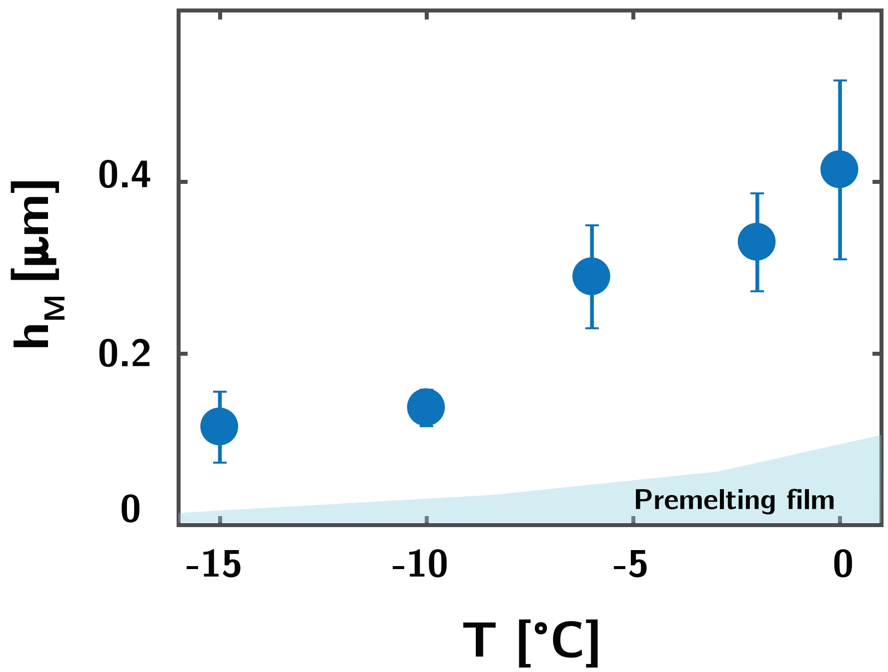
$$Z''_N = \frac{6\pi\eta R^2\omega}{h}$$

Reynolds formula

⇒ extract film thickness from measured dissipation

FILM THICKNESS

so thin !!



Mean thickness increases as intuitively expected with temperature!

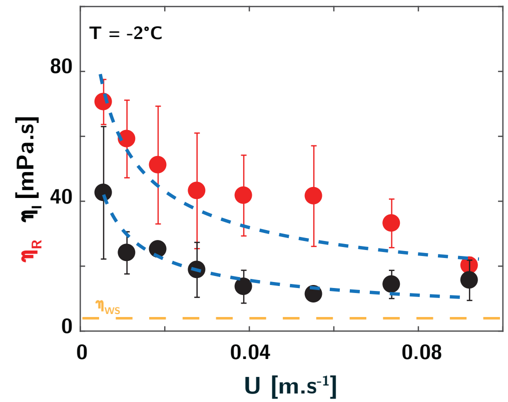
Range in the hundreds of nanometers, below what was usually believed/predicted (rather microns and more)

WATER BUT HIGHLY COMPLEX

probe the interfacial rheology (how it flows)

$$\tilde{\eta} = \eta_R - i\eta_i$$

dissipation   elasticity



- $\eta_R \sim \eta_I$: strong viscoelasticity
- $\eta_R \gg \eta_{w\ supercooled}$ « as viscous as an oil ! »
- $\eta_{I,R} \propto U^{-\gamma} \longrightarrow \gamma \sim 0.5$

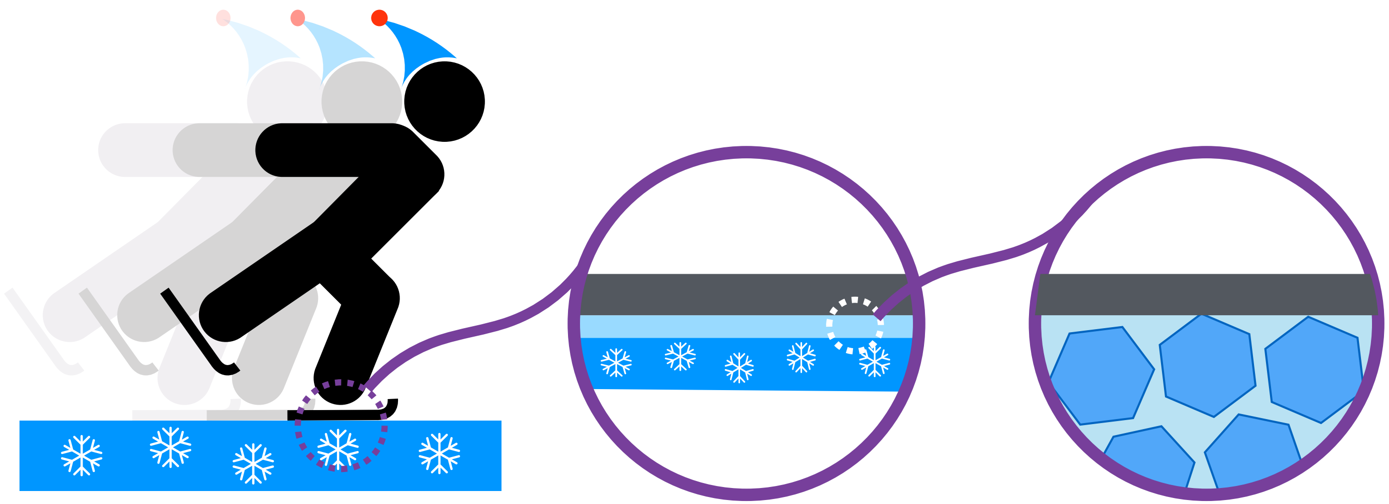
a complex (yielding) fluid

ALTOGETHER, A NEW PERSPECTIVE

- highly viscous & visco-elastic water

  = becomes a **very good lubricant**

- rather suggests a mixture of water and ice debris (partial melting)



ice debris surrounded by water, not full melting

complex rheology of a suspension

NEW TOOLS, NEW INSIGHTS

a multi scale approach is efficient:

- ice is an incredibly complex material as a lubricant

- new materials to improve wax effects

- consequences/advices for sports: revisit strategies, materials, how to promote/suppress melting, fluidisation of the water debris, etc.

BACK TO OUR CHAMPION

Pyeong Chang: ***he won ! (three times)***

THANKS TO THE SKI TEAM

at ENS: Luca Canale (PhD), Jean Comtet (PhD)
& Alessandro Siria, Antoine Niguès

at LadHyX: C. Cohen & C. Clanet

also Martin Fourcade and Gregory Deschamp (FFS Biathlon)






Canale et al., Phys. Rev. X (2019)