

Wicked membrane

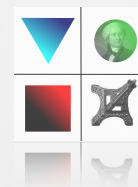
elasto-capillary buckling of a thin fibrous membrane for the design of stretchable fabrics

Paul Grandgeorge¹, Natacha Krins², Aurélie Hourlier-Fargette¹, Sébastien Neukirch¹ and Arnaud Antkowiak¹

¹ Institut Jean le Rond d'Alembert, Sorbonne Université, Paris, France

² Chimie de la Matière Condensée, Sorbonne Université, Paris, France

July 5th, 2018 - Bologna



wicked

/ˈwɪkɪd/ 🔊

3. *informal*
excellent; wonderful.

wick¹

/wɪk/ 🔊

1. absorb or draw off (liquid) by capillary action.
"garments that **wick** moisture **away** from the skin"

Wicked membrane

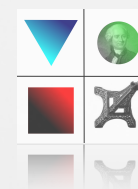
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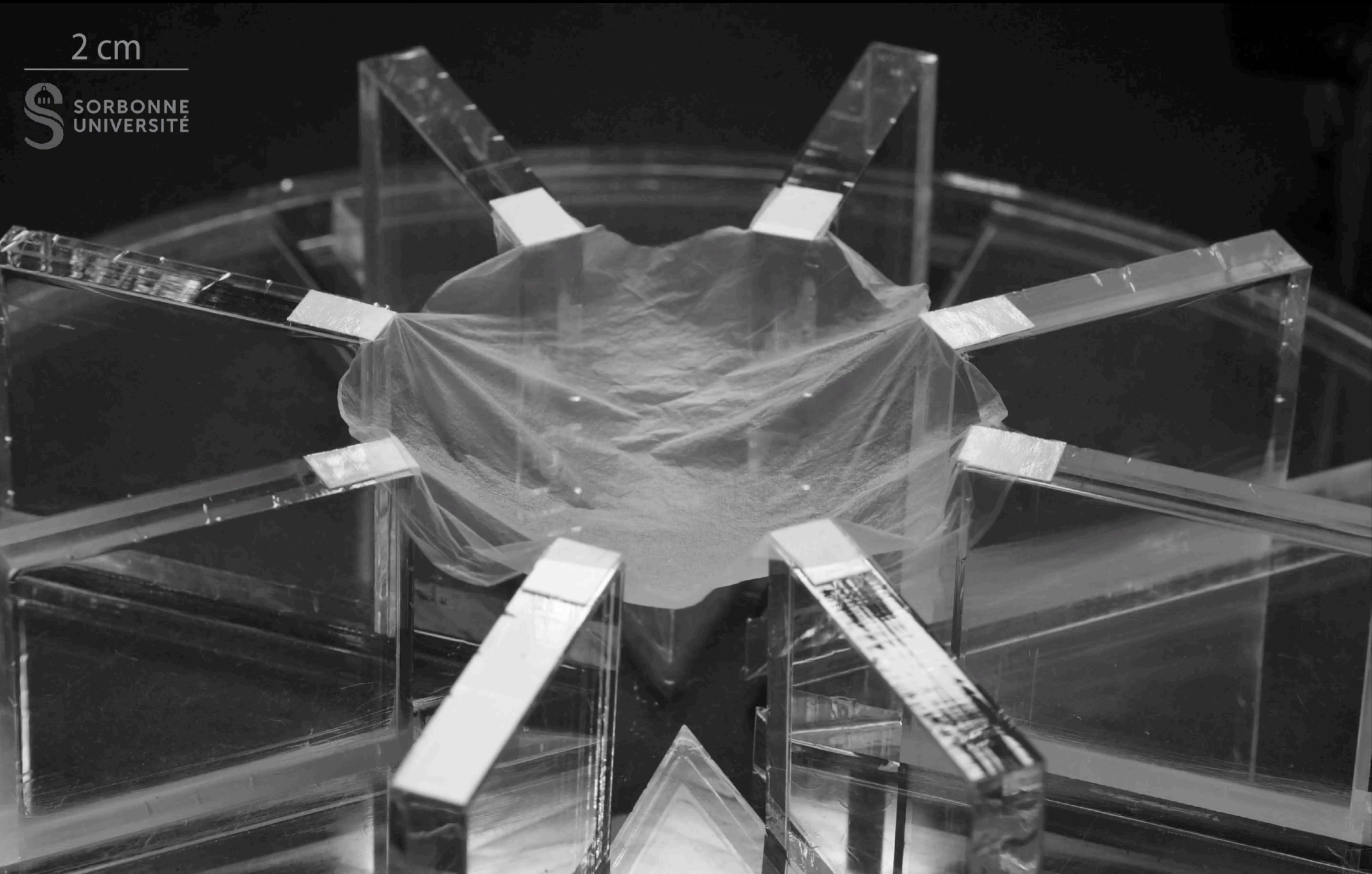
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Wicked membrane

2 cm



Wicked membrane

2 cm



Non-woven fabric

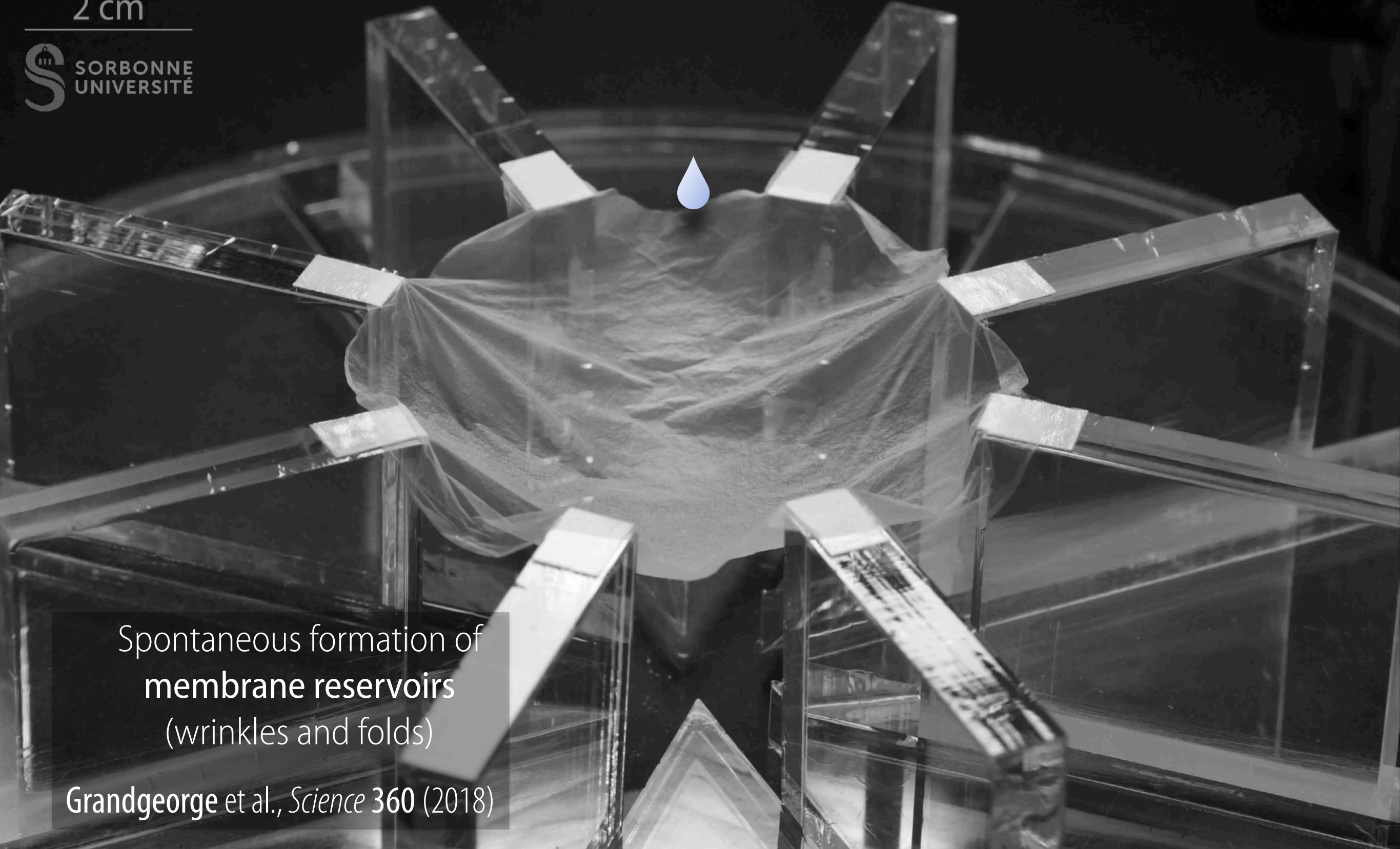
Diameter of the fibers ~ 100 nm

Thickness of the fabric ~ 1 μ m

50 μ m

Wicked membrane

2 cm

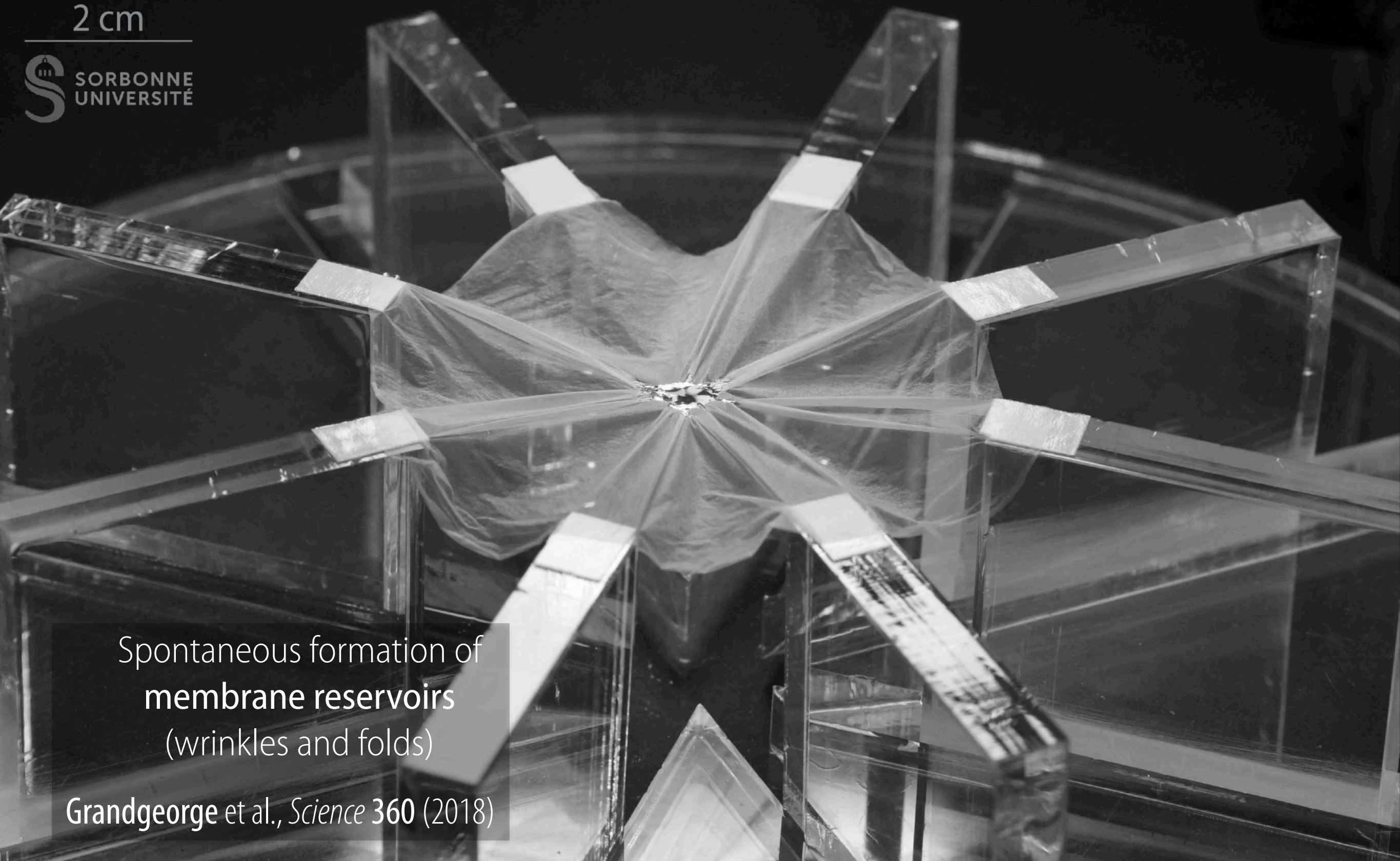


Spontaneous formation of
membrane reservoirs
(wrinkles and folds)

Grandgeorge et al., *Science* 360 (2018)

Wicked membrane

2 cm

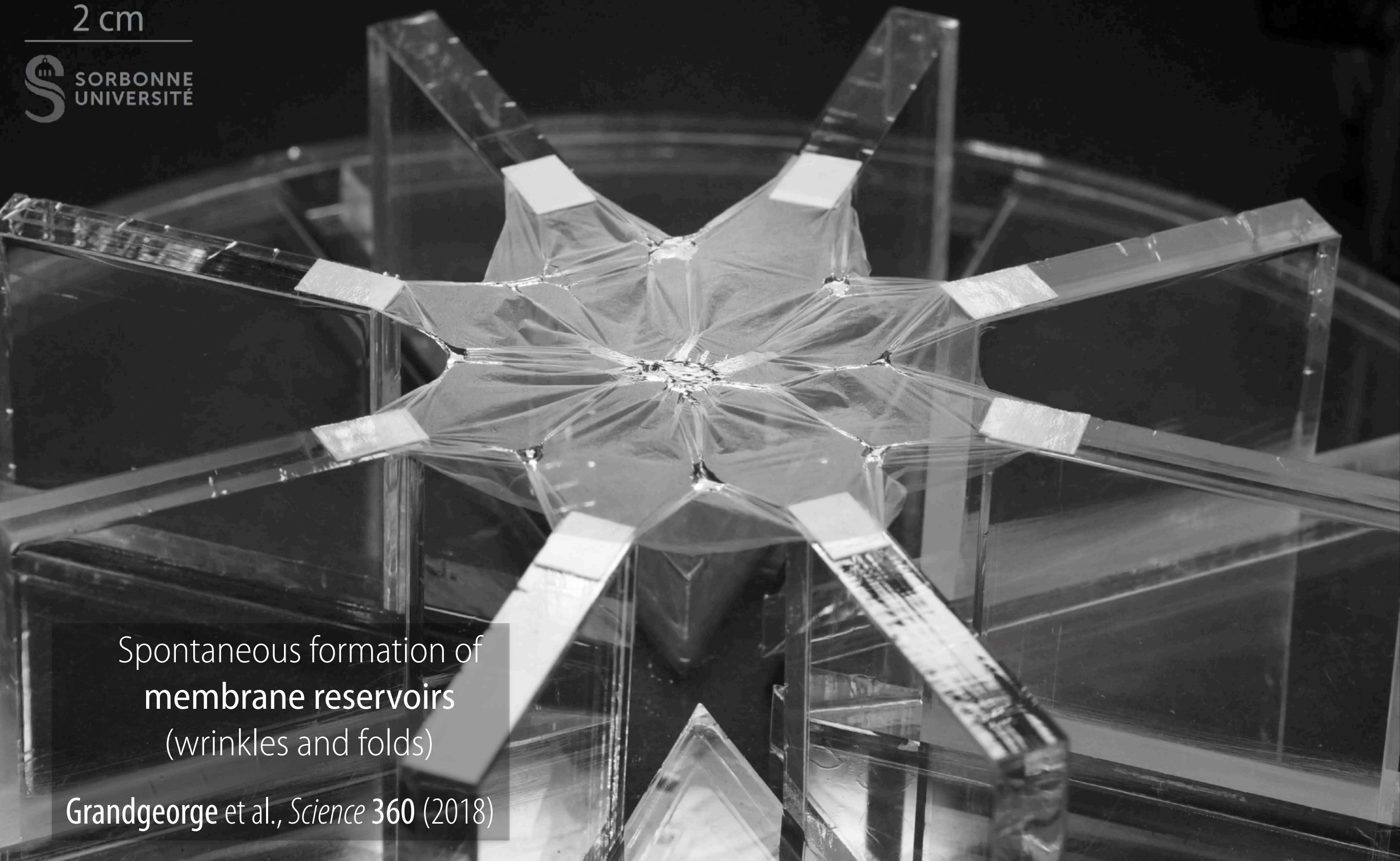


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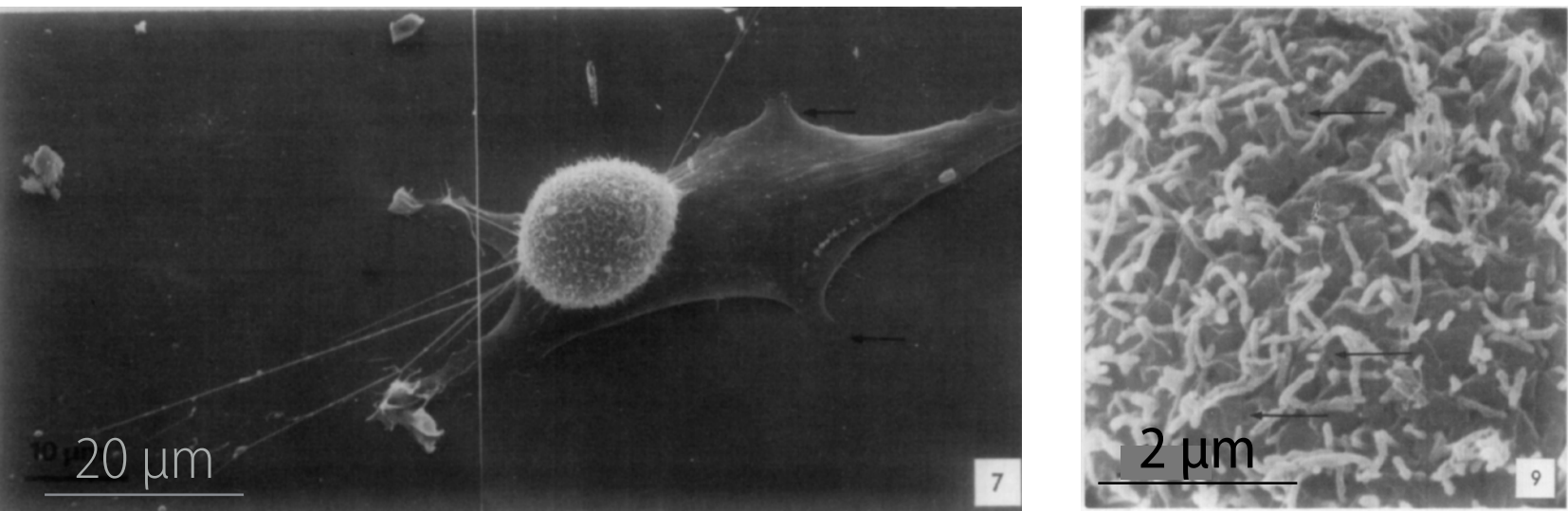


Spontaneous formation of
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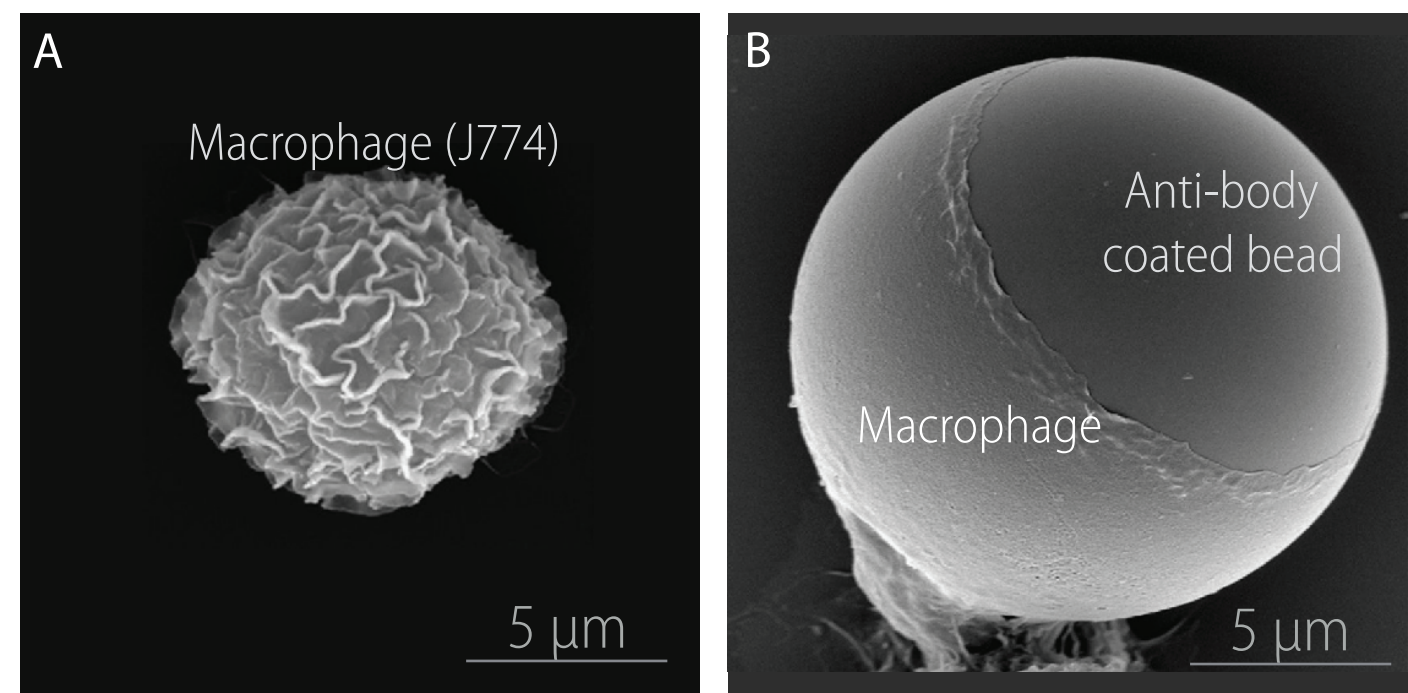
Cells

membrane reservoirs in biology

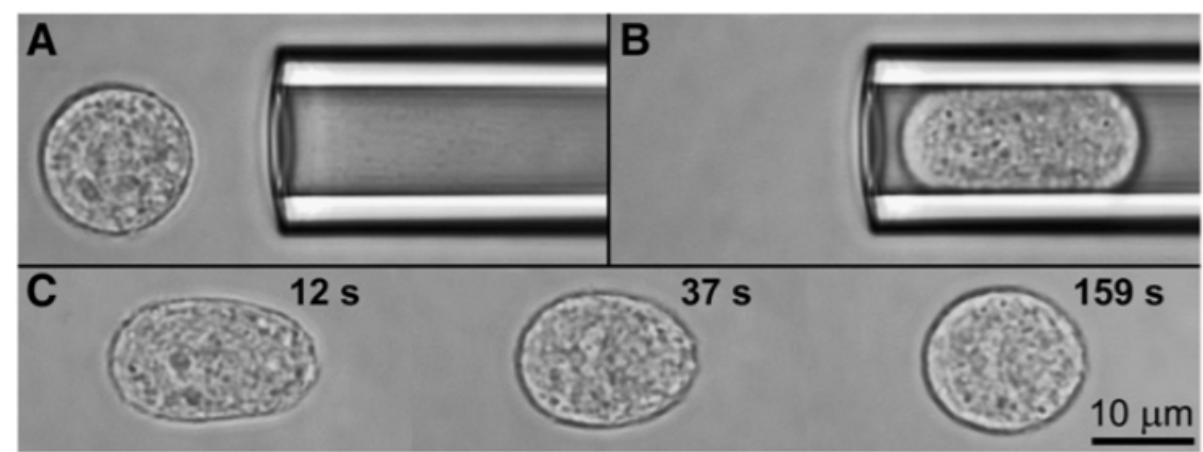


Two BHK (adherent) cells.
One **expands** on the substrate by **smoothing** out **surface reserves**.

Erickson & Trinkaus,
Microvilli and blebs as sources of reserve surface membrane during cell spreading,
Experimental Cell Research **99** (1976)



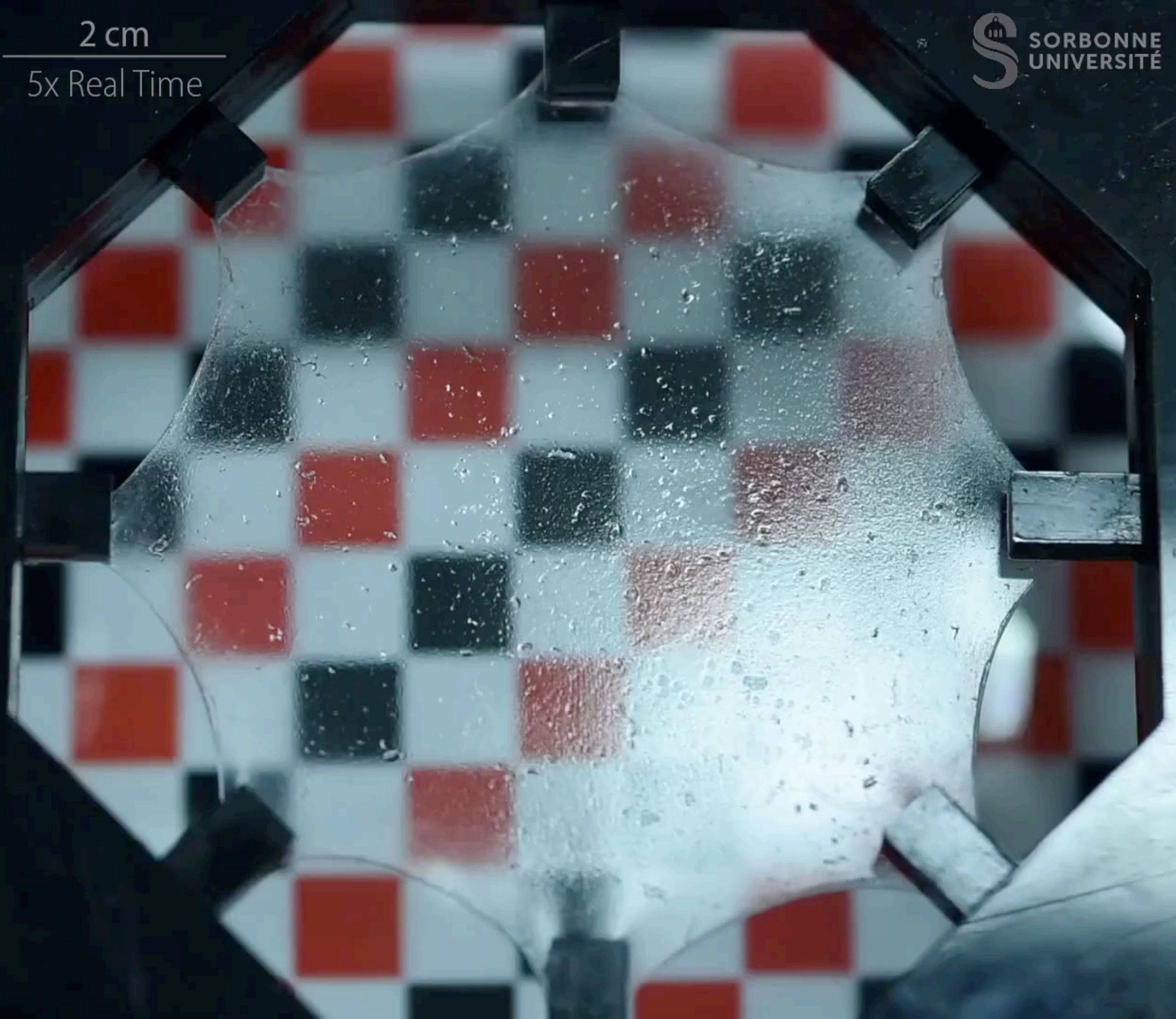
Lam et al., *Biophysical journal* **96** (2009)



Cortex tension $\left\{ \begin{array}{ll} T = \gamma & \text{for } S \leq S_0 \\ T = \gamma + k \frac{S}{S_0} & \text{for } S > S_0 \end{array} \right.$

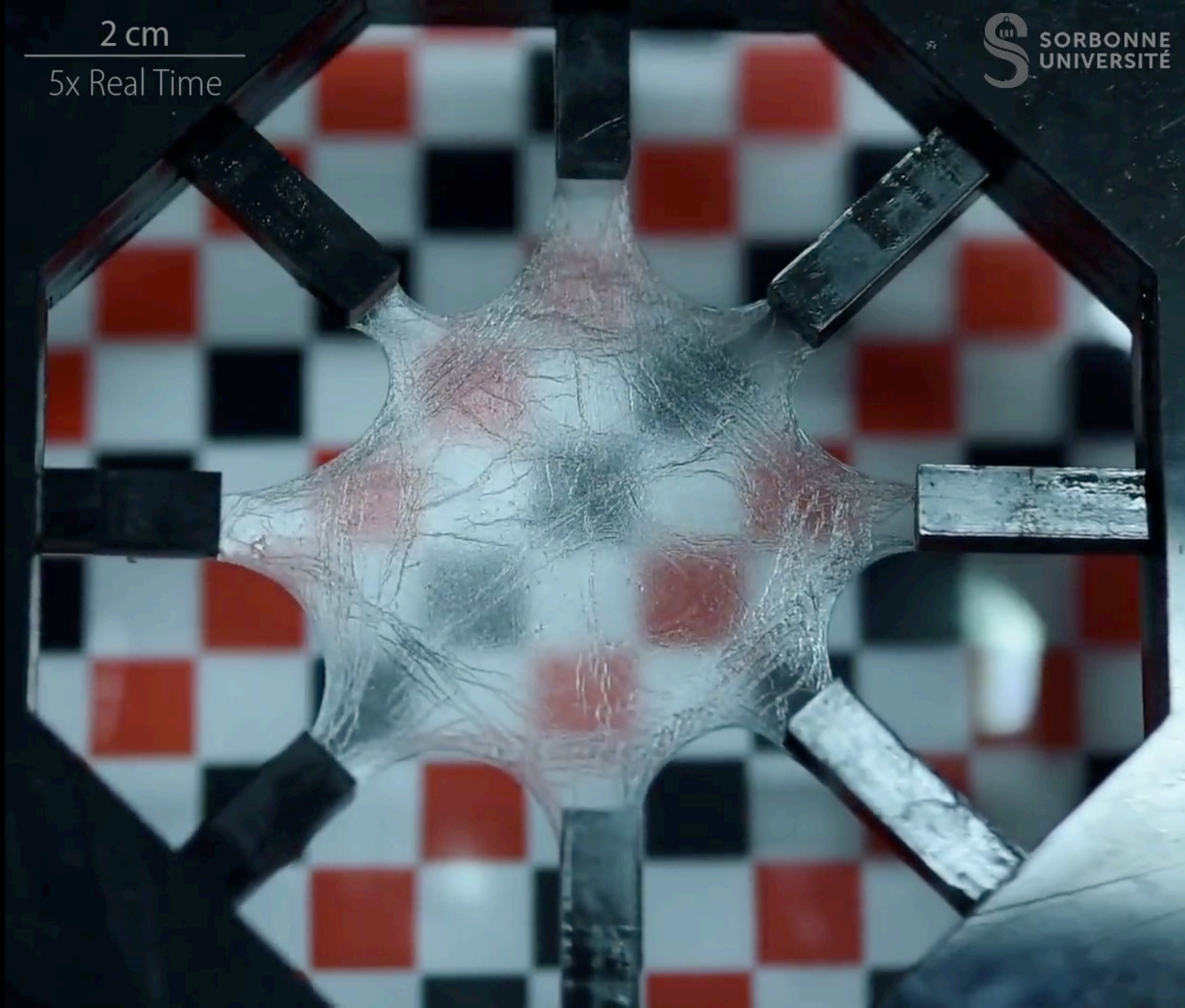
2 cm

5x Real Time



2 cm

5x Real Time

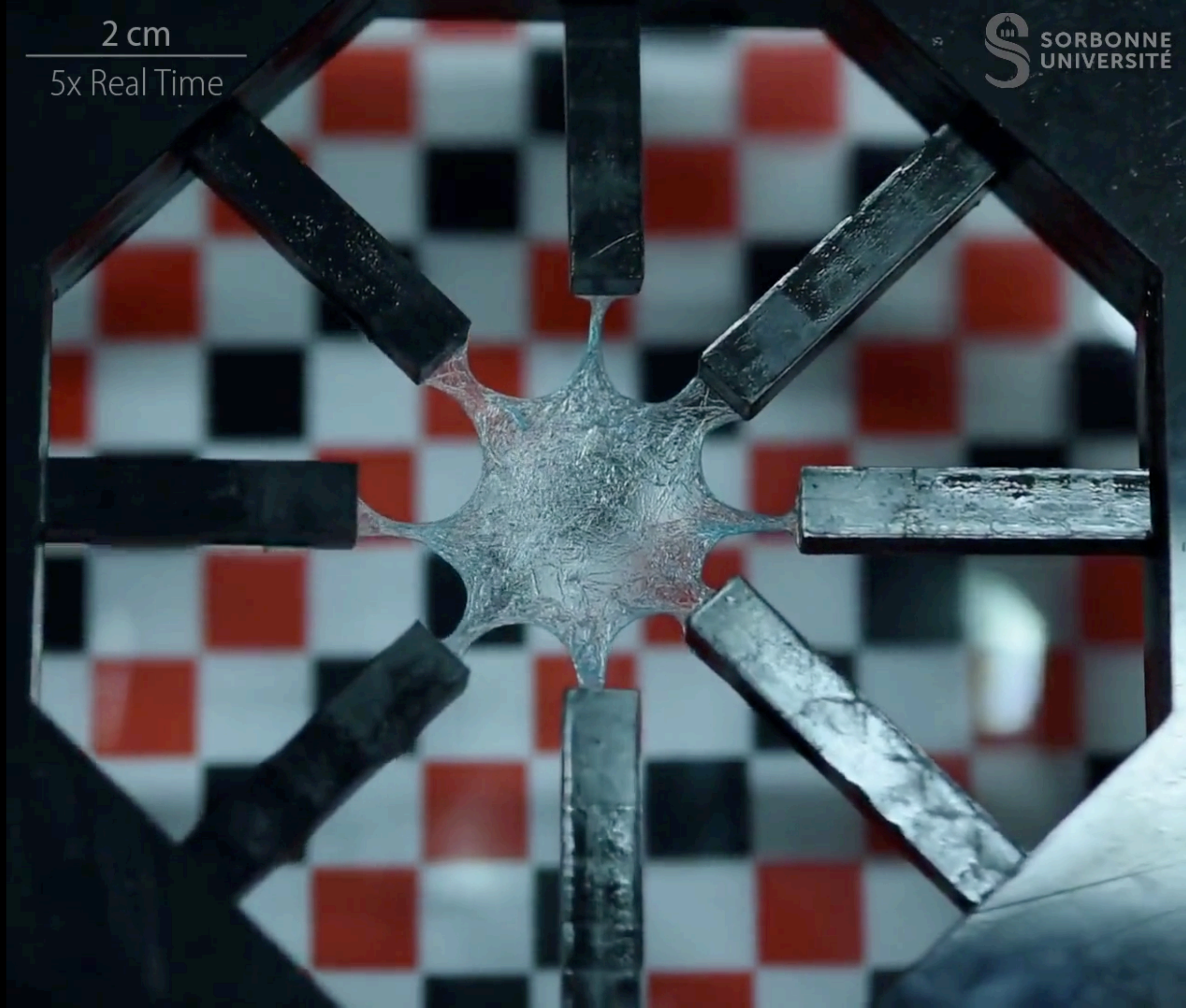


2 cm

5x Real Time

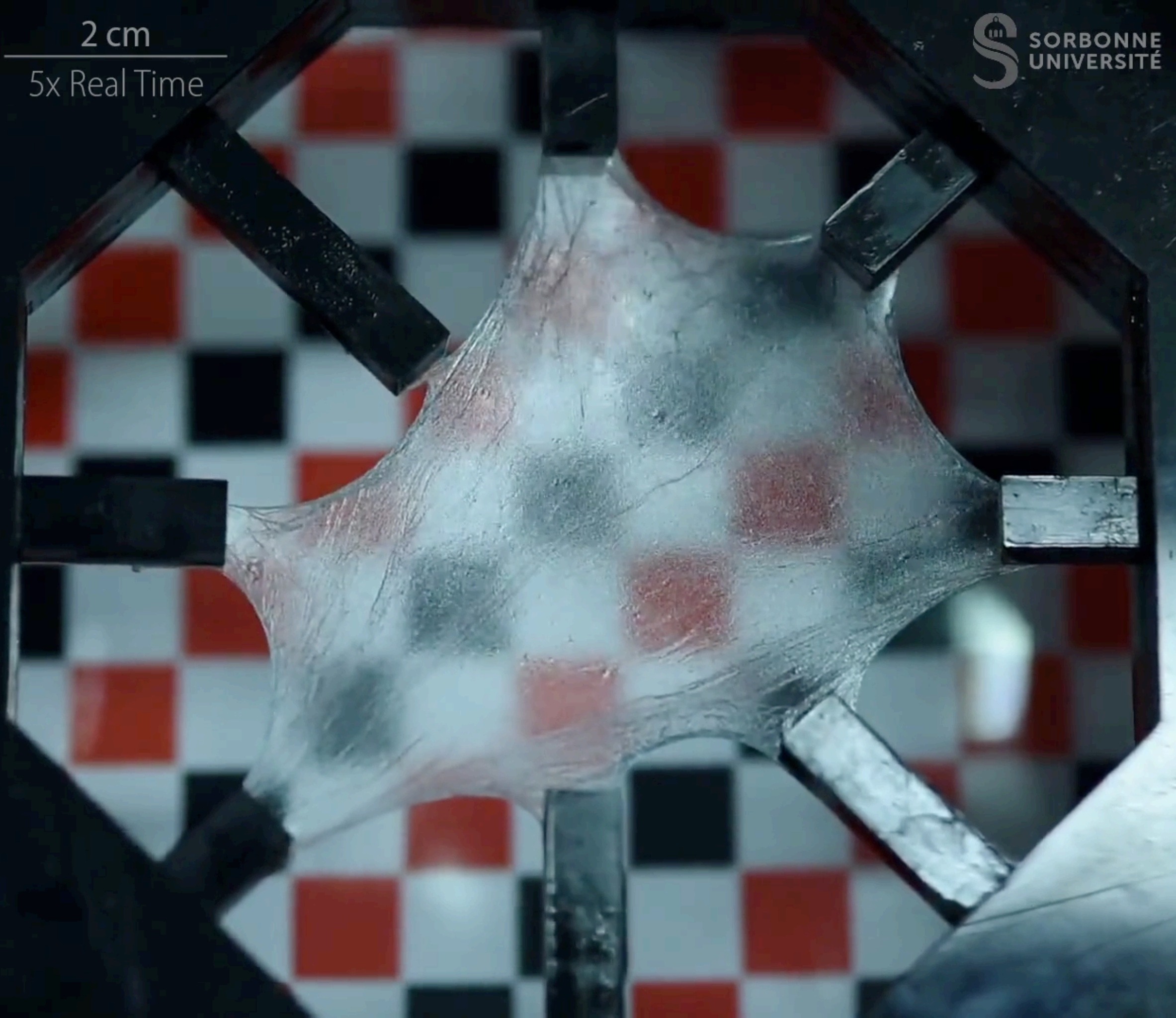


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2 cm

5x Real Time

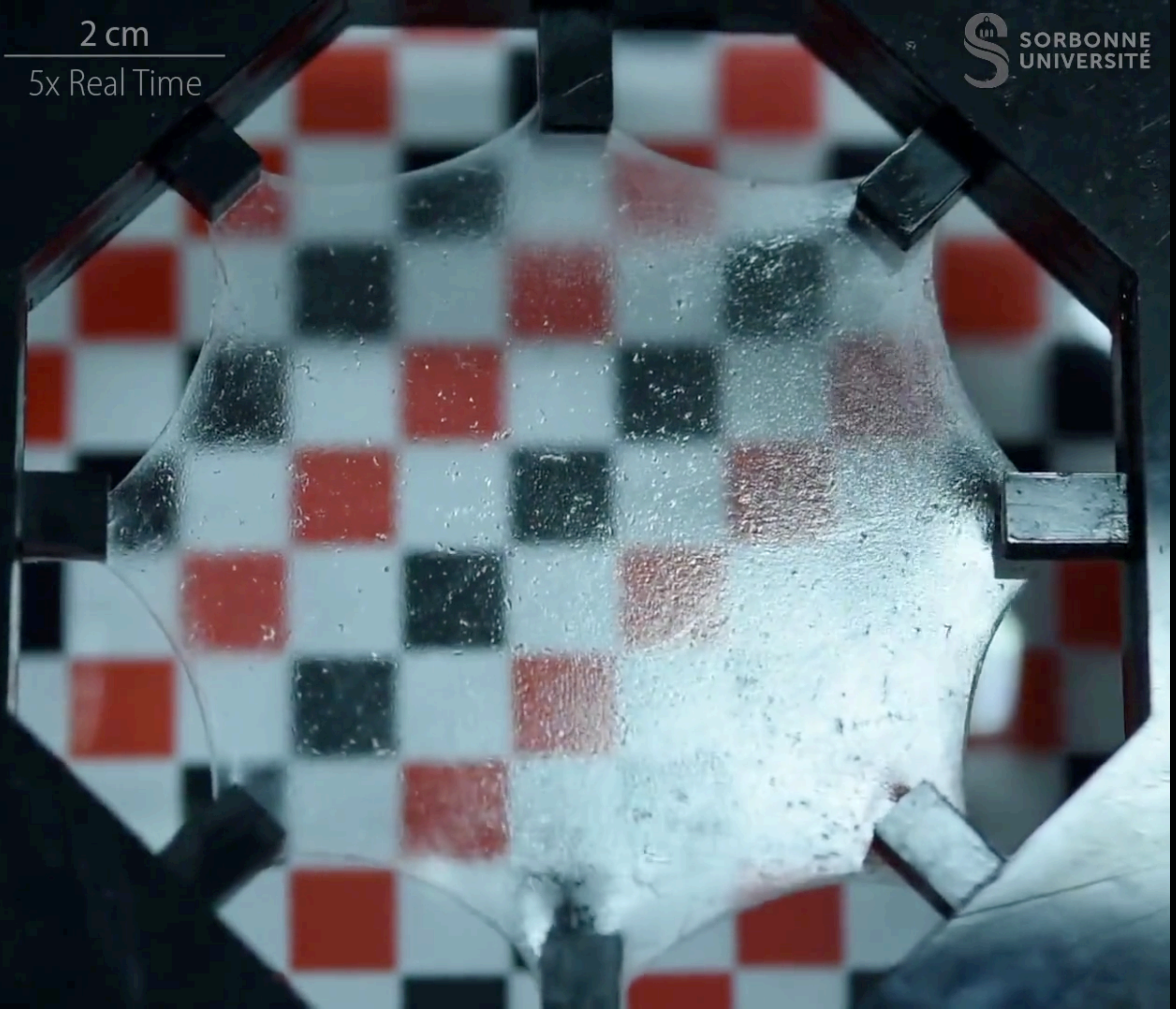


2 cm

5x Real Time



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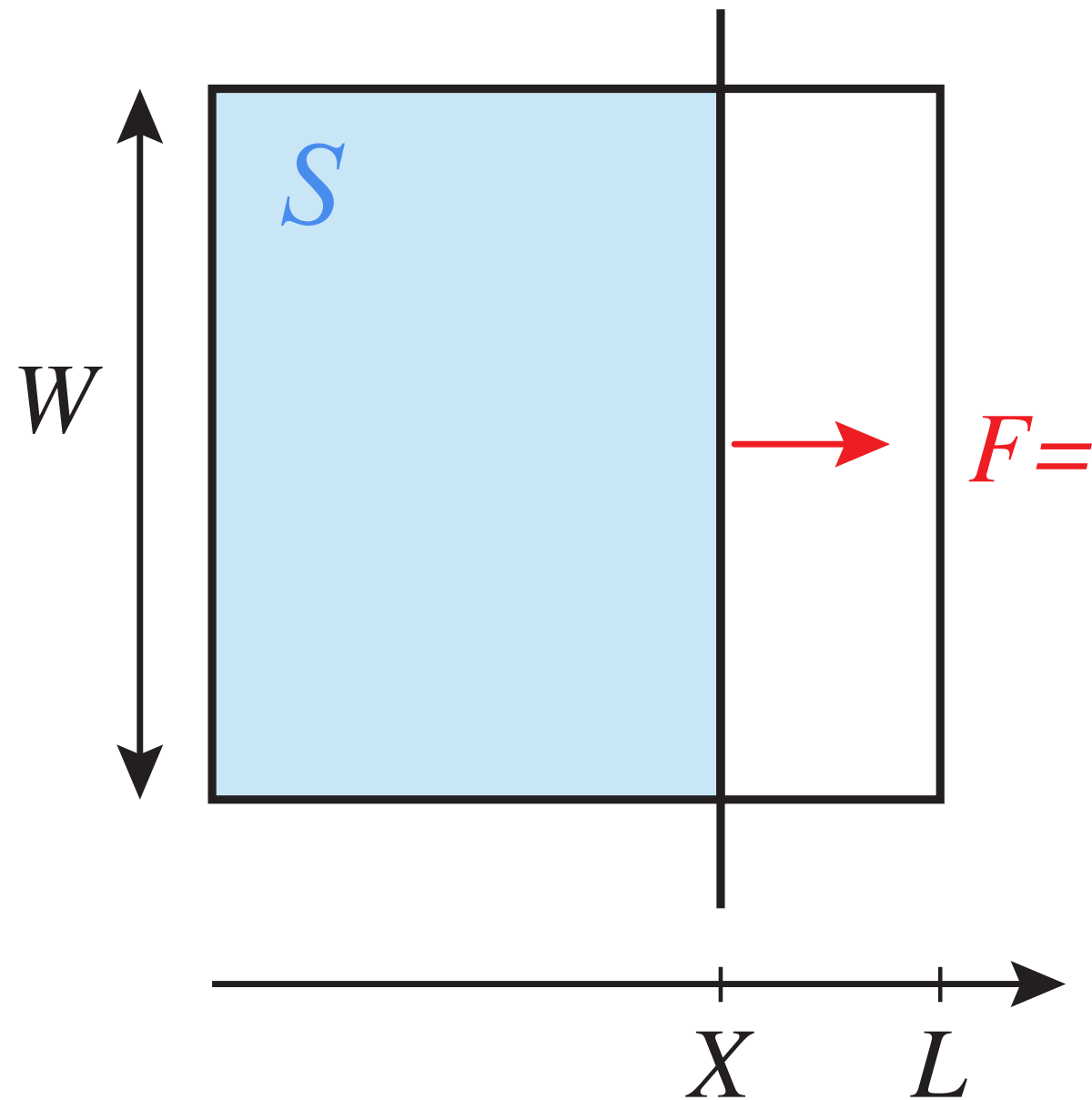
Wicked membrane

Mechanical characterization



Liquid soap film

A simple model



$$F = \frac{\partial E}{\partial X}$$

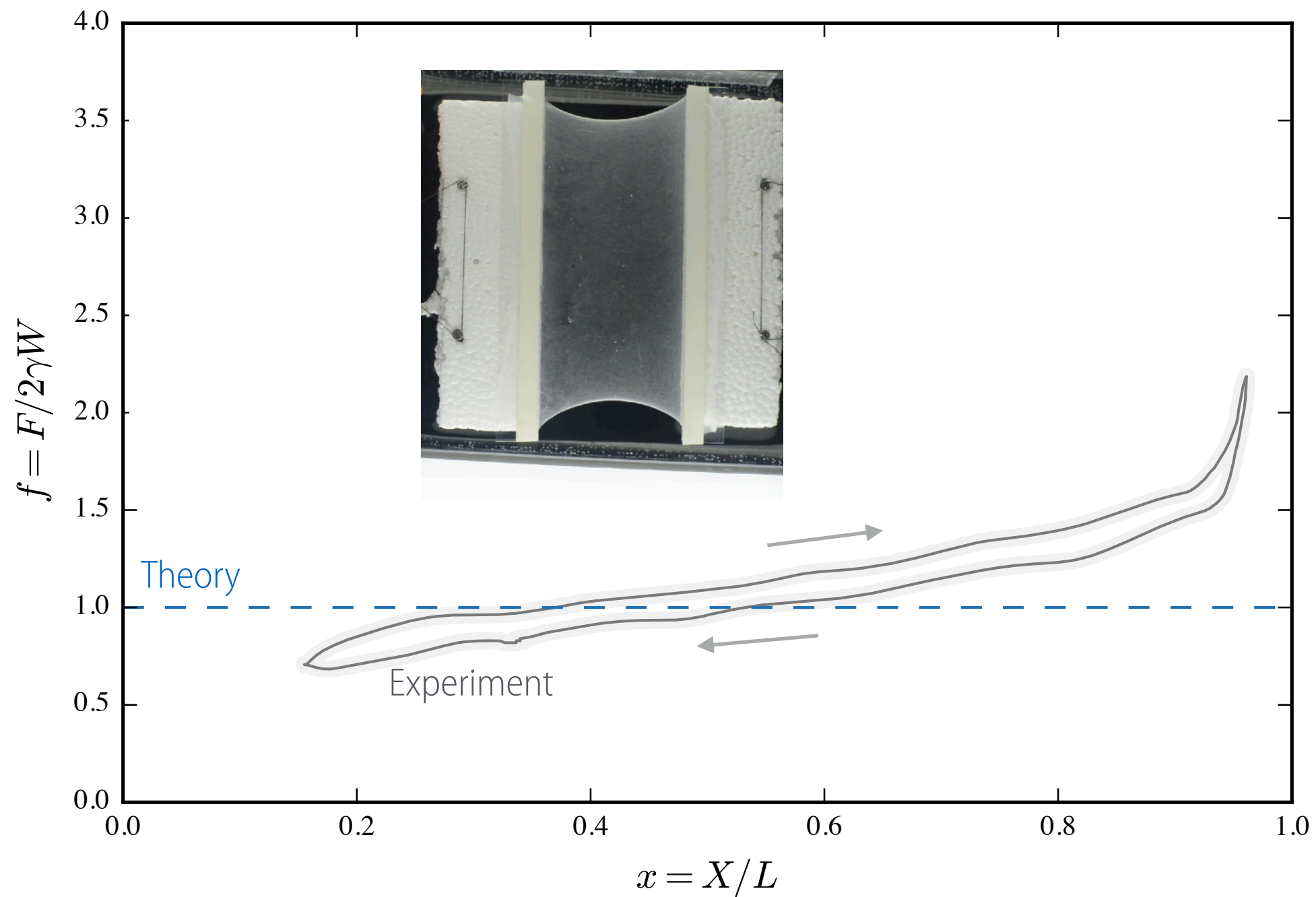
$$E = 2\gamma S$$

$$S = WX$$

$$F = 2W\gamma$$

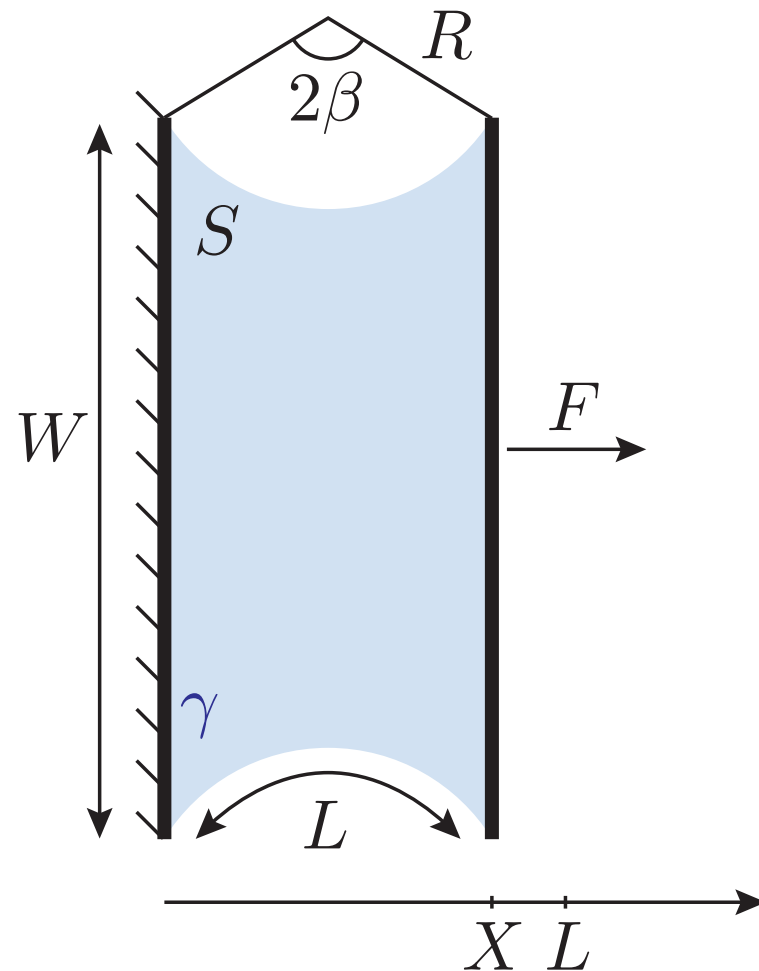
Liquid soap film

A simple model



Liquid-solid: inextensibility constraint

A better model



$$F = \frac{\partial E}{\partial X}$$

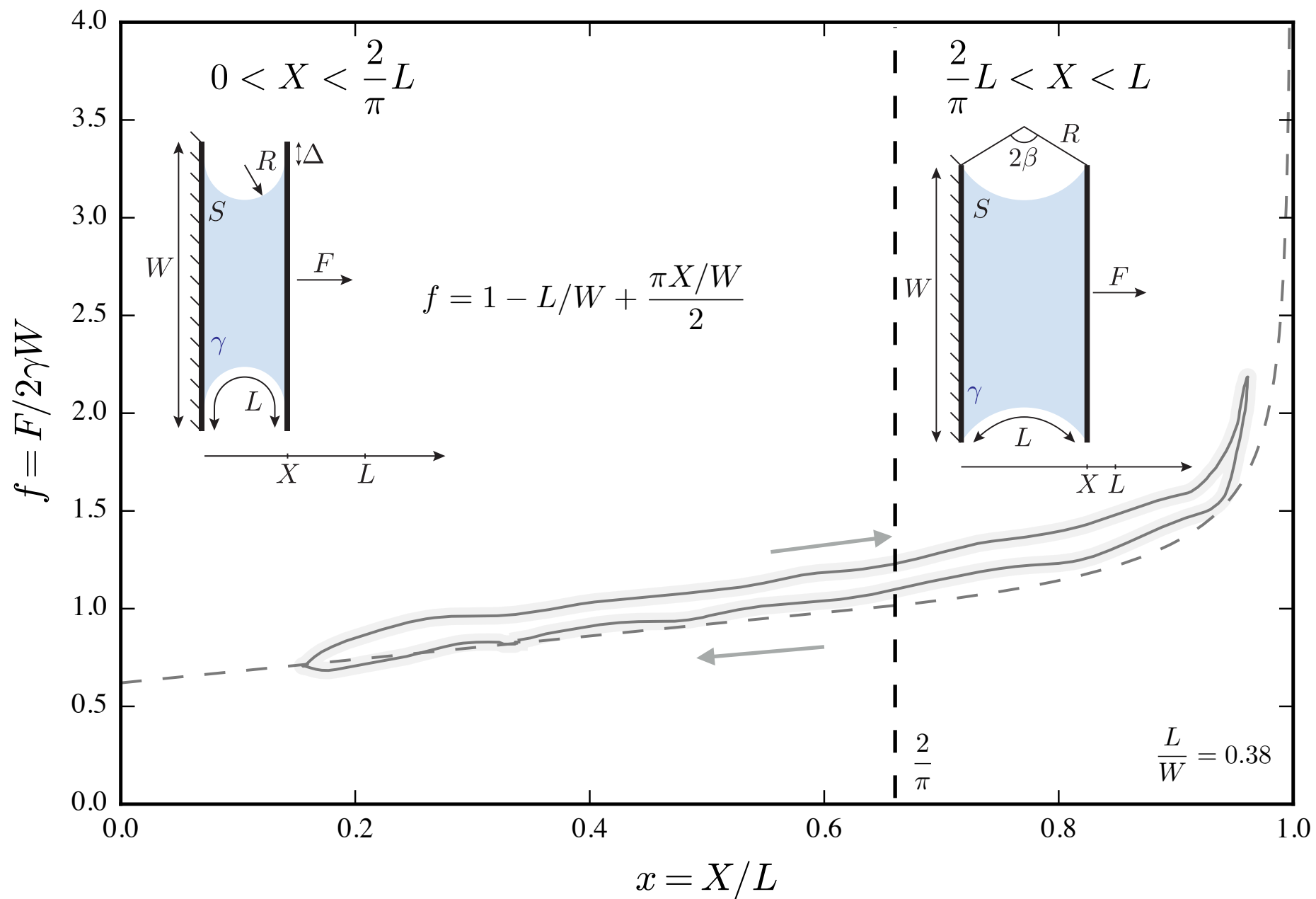
$$E = 2\gamma S$$

L is fixed

(Inextensibility of the membrane)

Liquid-solid: inextensibility constraint

A better model



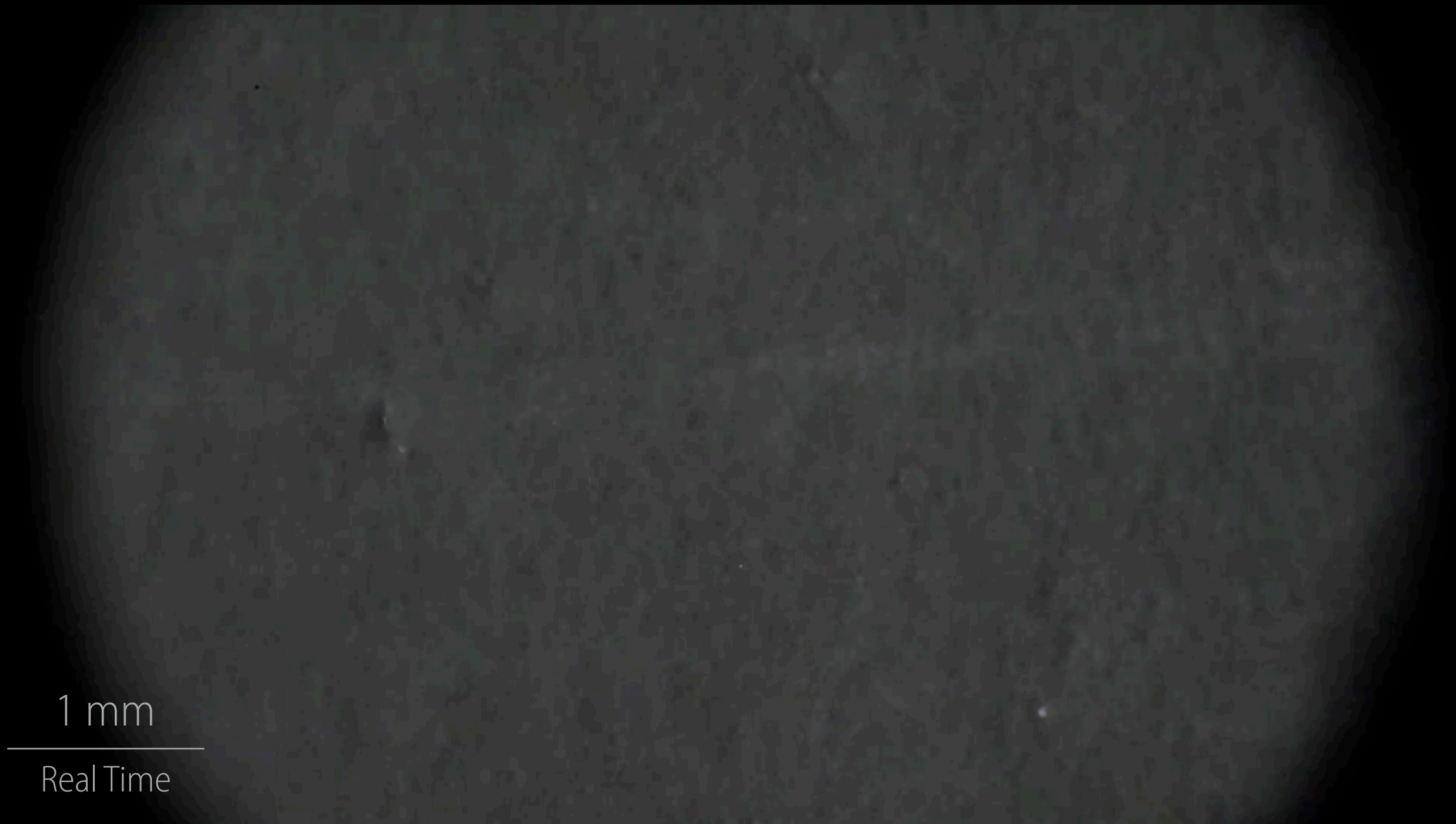
Buckling pattern of the wicked membrane



PAN membrane **wicked** with water.
Upon **compression**, the wicked membrane
exhibits a **wrinkling pattern**.

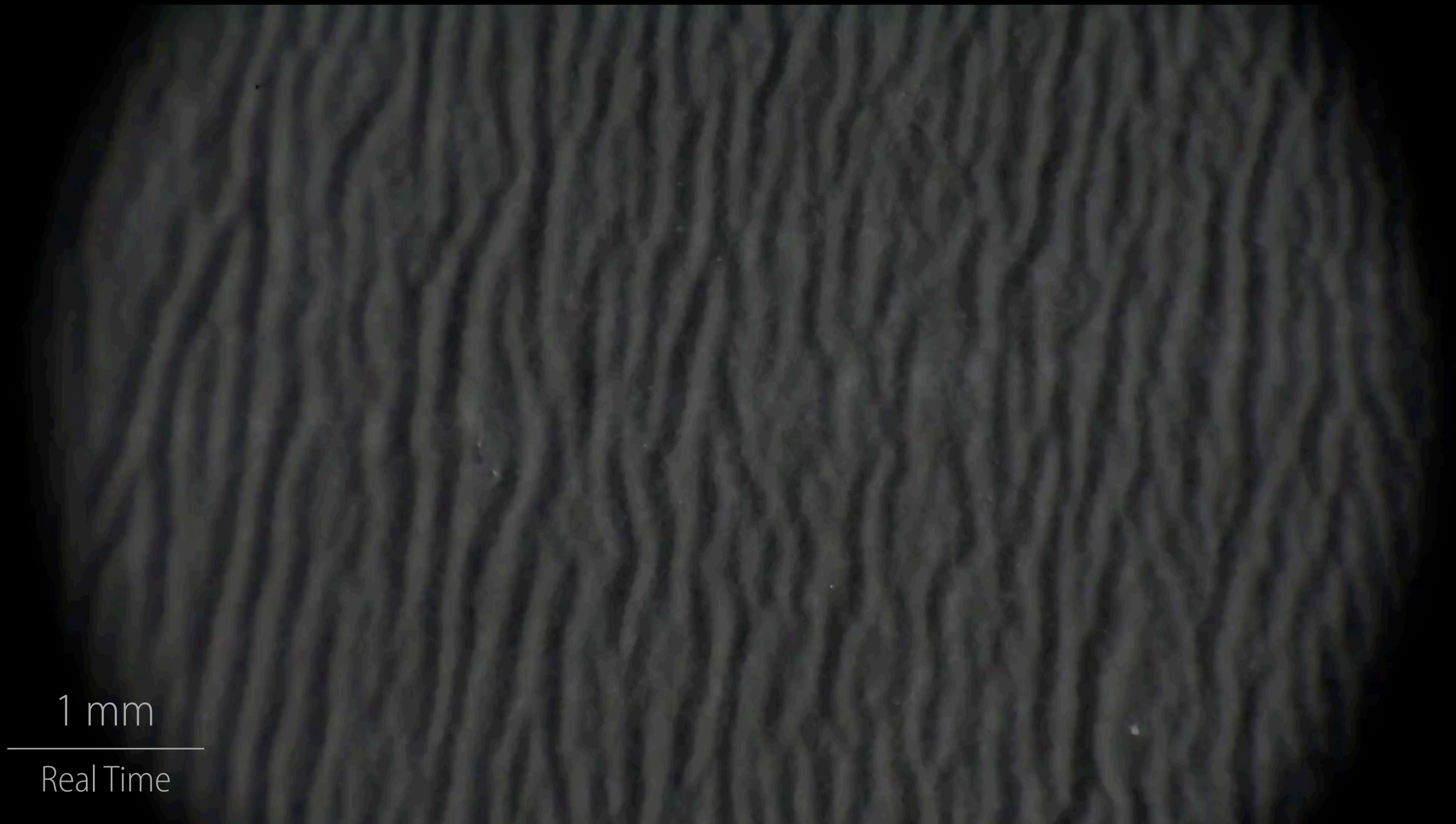
Buckling pattern

of the wicked membrane



Planar PAN **membrane** wicked with **water** under uni-axial **compression**.

Buckling pattern of the wicked membrane



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Buckling pattern

of the wicked membrane



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Buckling pattern of the wicked membrane



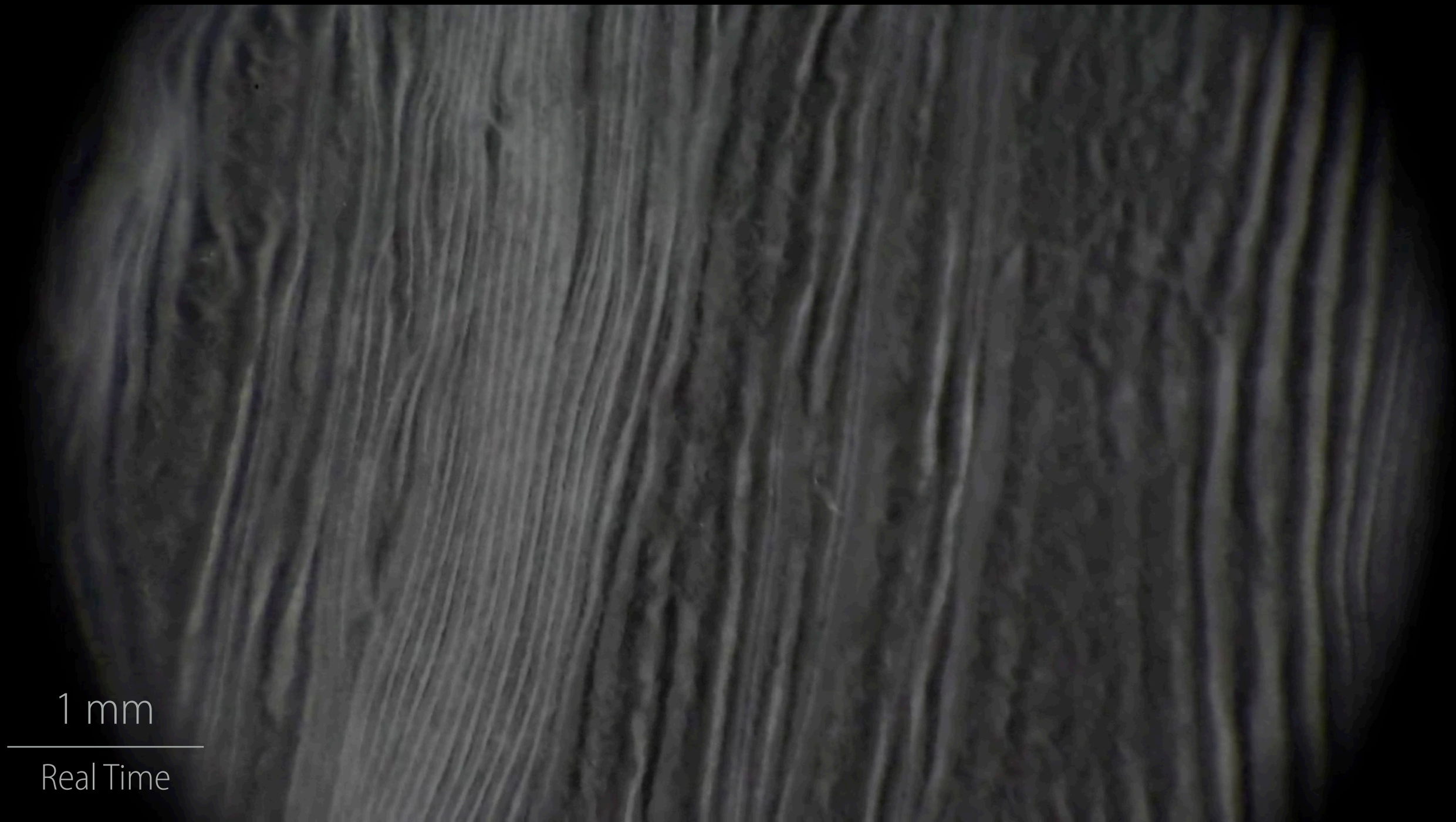
Planar PAN **membrane** wicked with **water** under uni-axial **compression**.

Buckling pattern of the wicked membrane



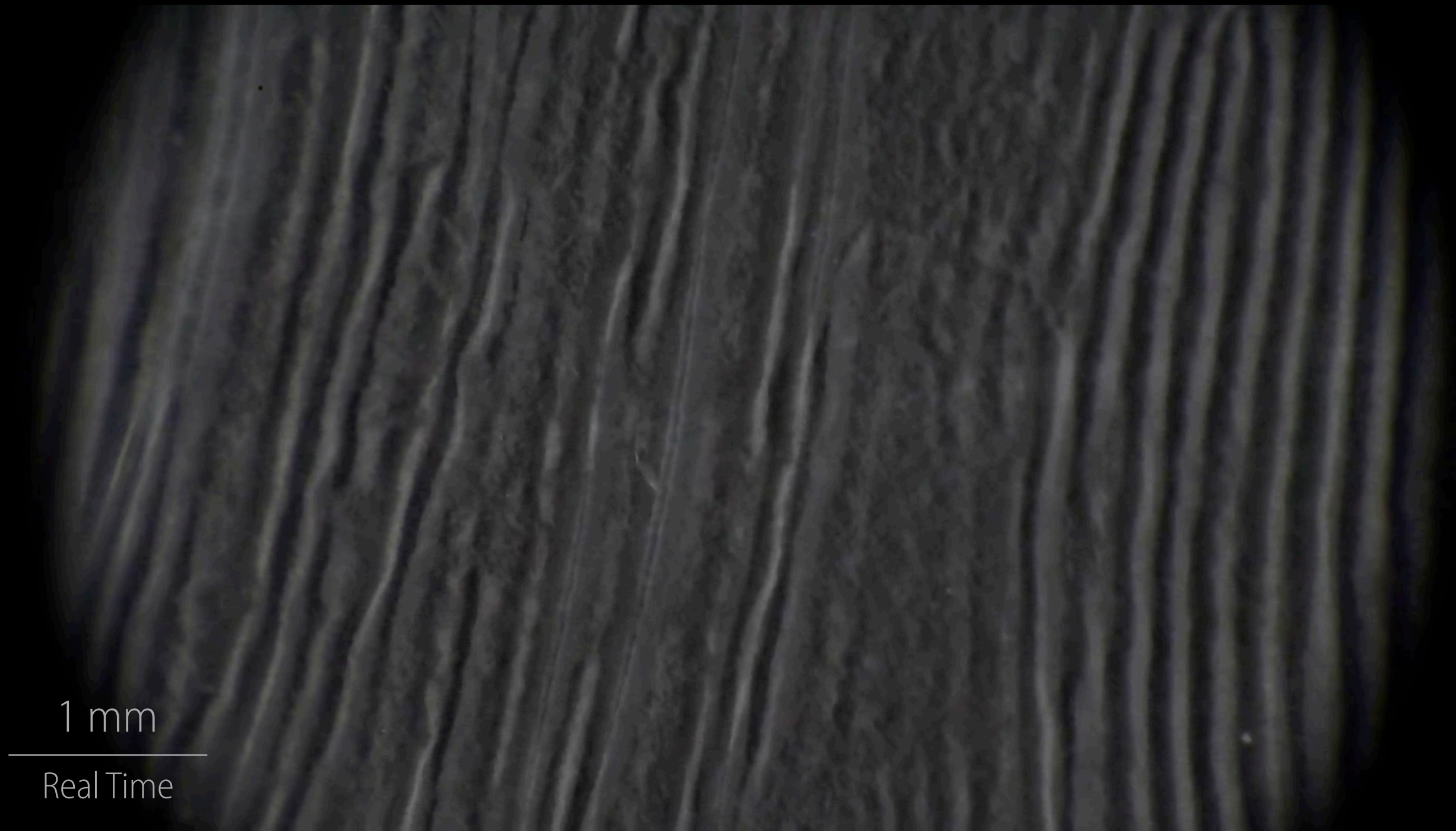
Planar PAN **membrane** wicked with **water** under uni-axial **compression**.

Buckling pattern of the wicked membrane



Planar PAN **membrane** wicked with **water** under uni-axial **compression**.

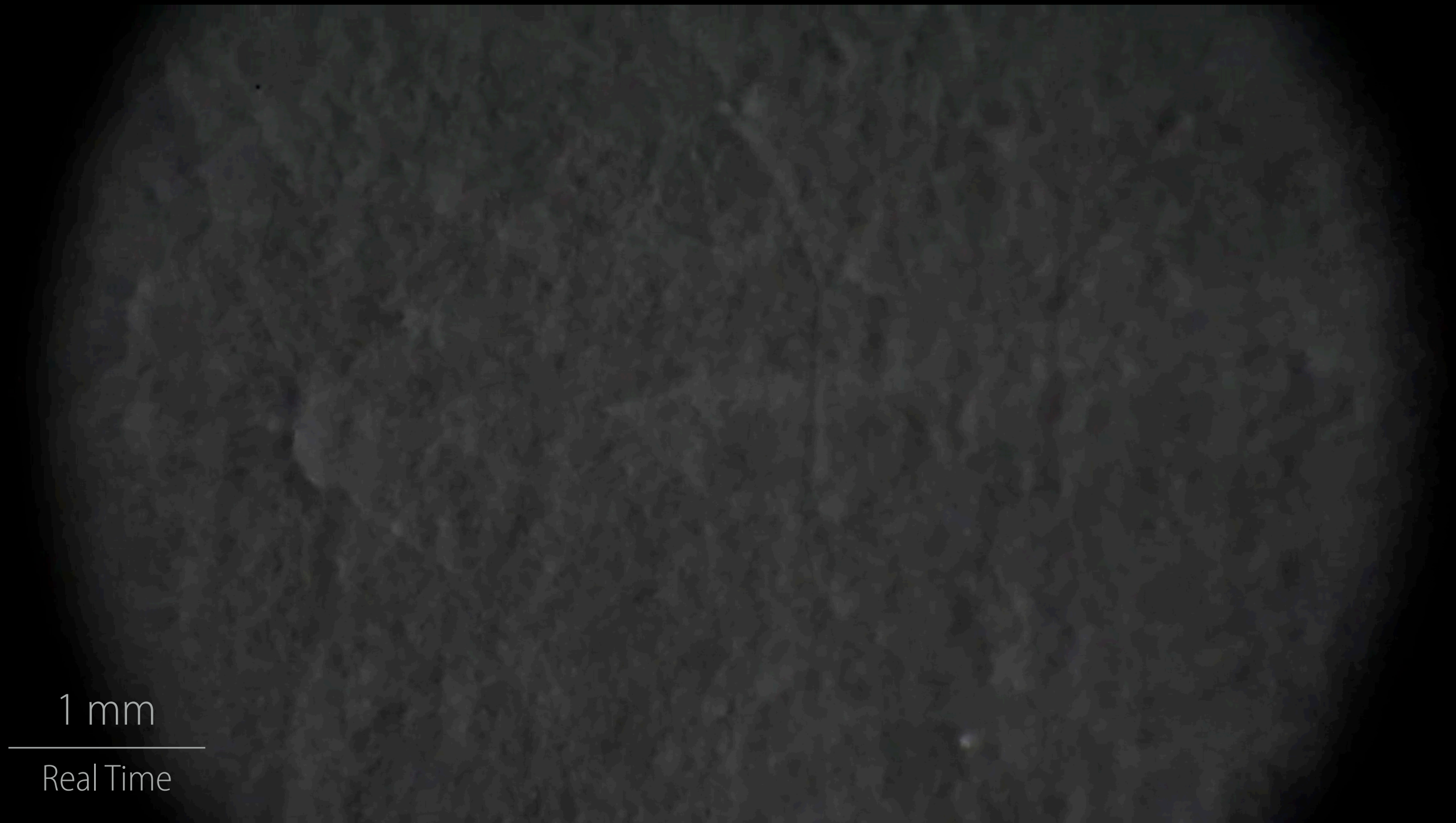
Buckling pattern of the wicked membrane



Planar PAN **membrane** wicked with **water** under uni-axial **compression**.

Buckling pattern

of the wicked membrane



Planar PAN **membrane** wicked with **water** under uni-axial **compression**.

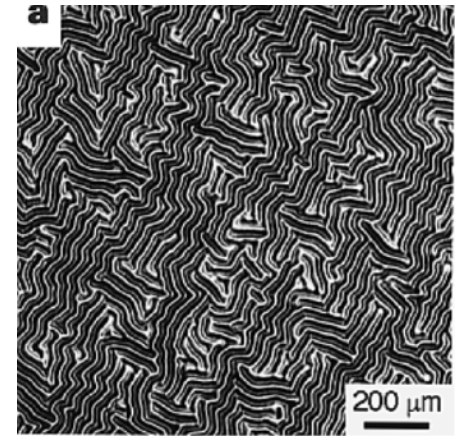
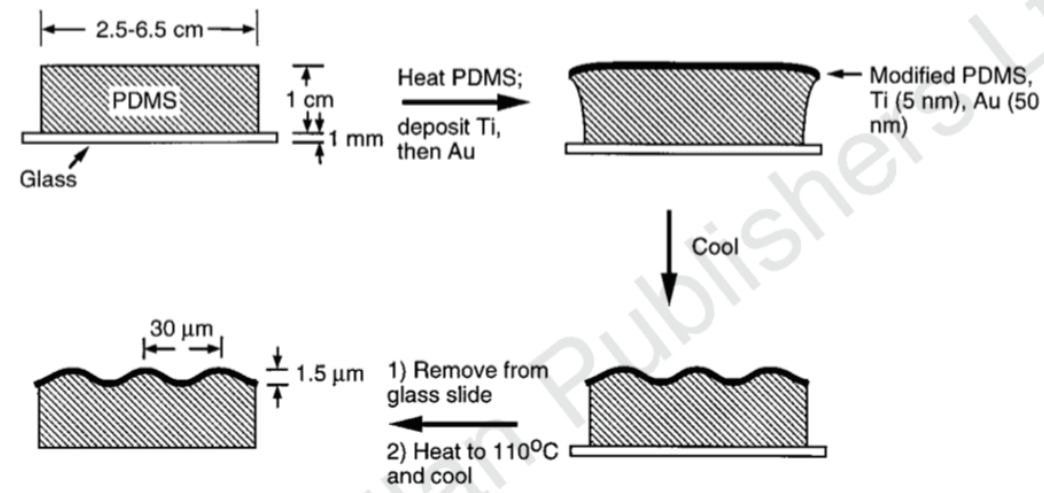
Wrinkling

Buckling on foundation

Buckling on a **soft elastic** foundation

$$\lambda \sim t \left(\frac{E_{\text{stiff}}}{E_{\text{soft}}} \right)^{1/3}$$

Bowden et al., *Nature* **393** (1998)

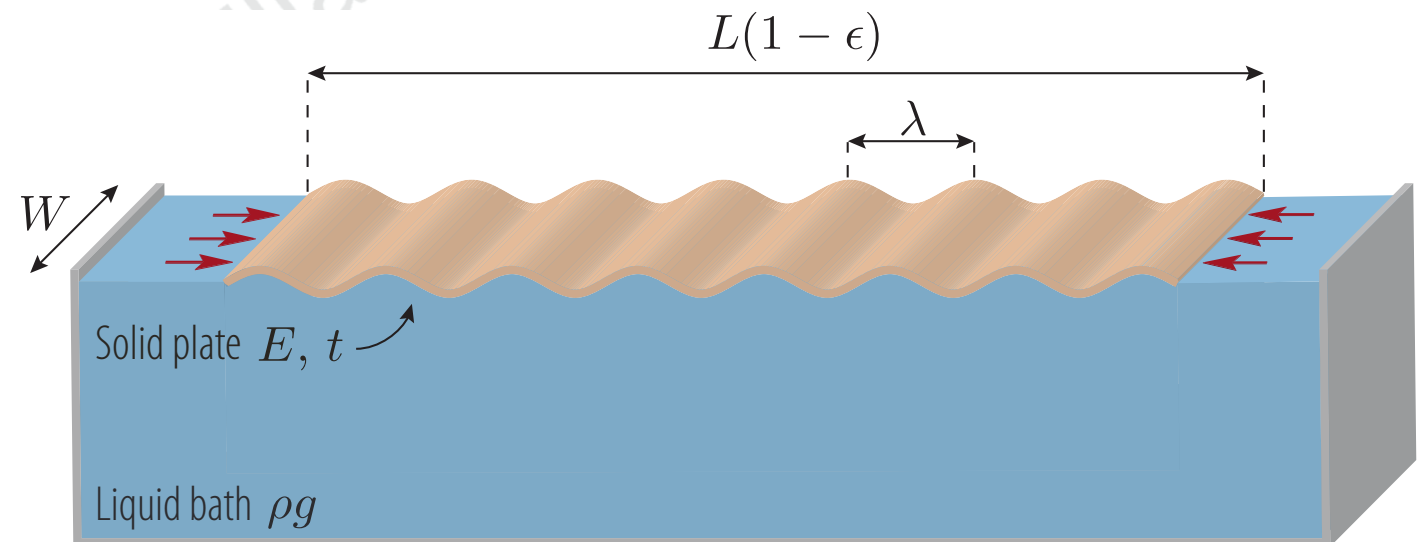


Buckling on a **hydro-static** foundation

$$\lambda \sim \left(\frac{EI}{\rho g} \right)^{1/4}$$

Hertz et al., *Annalen der Physik* **258** (1884)

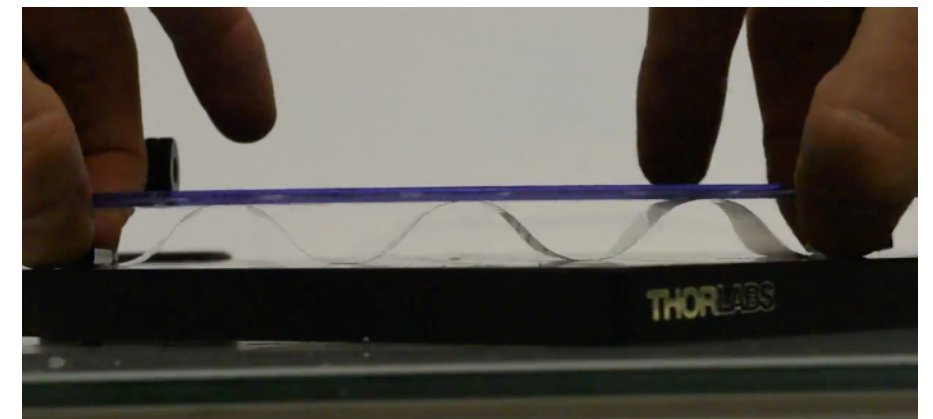
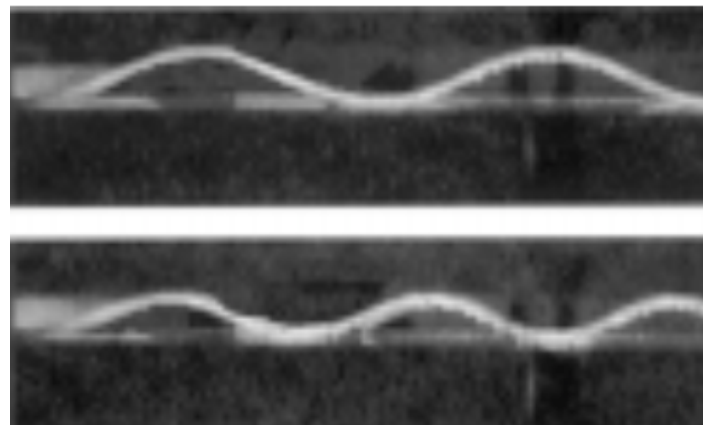
Brau et al., *Soft matter* **9** (2013)



Confined buckling

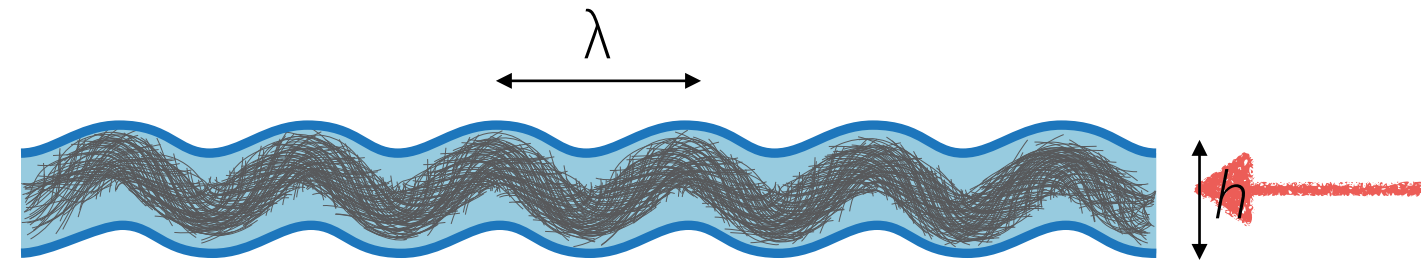
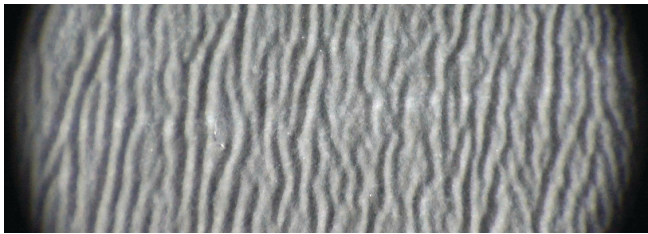
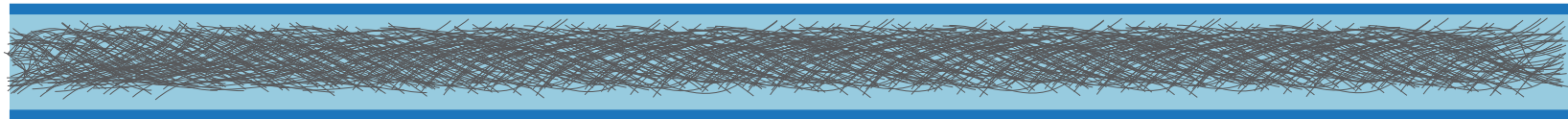
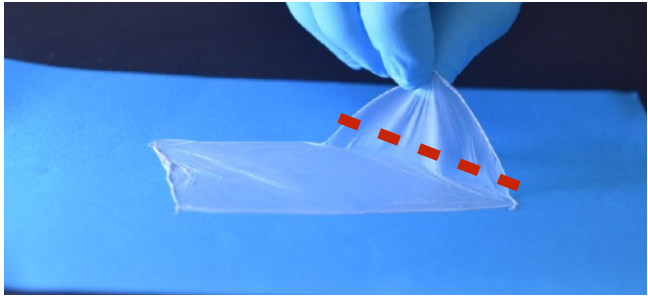
$$\lambda \sim \frac{h}{\sqrt{\epsilon}}$$

Roman & Pocheau et al., *Europhys. letters* **46** (1999)

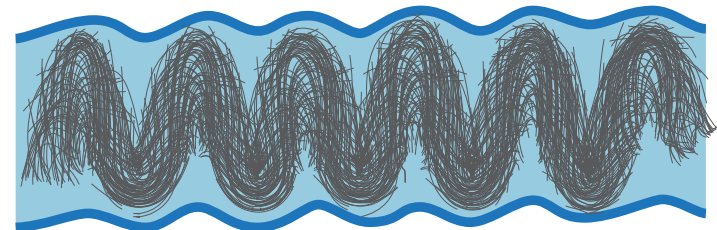
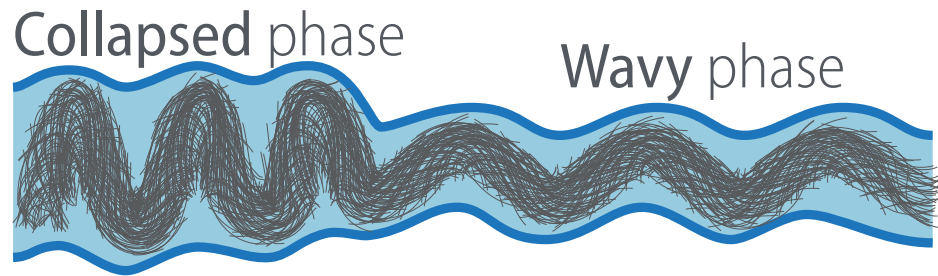
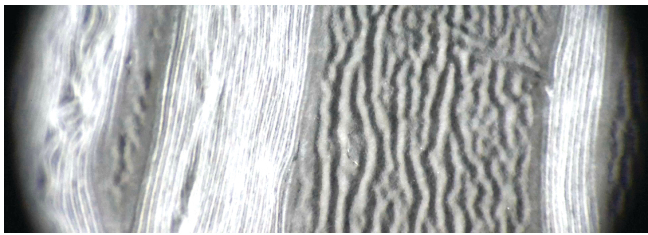


Physics of elasto-capillary wrinkling

Buckling on foundation?

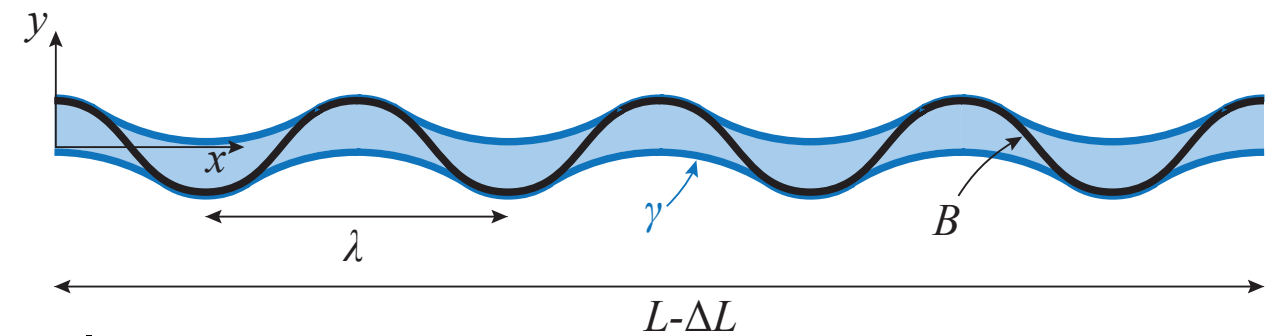
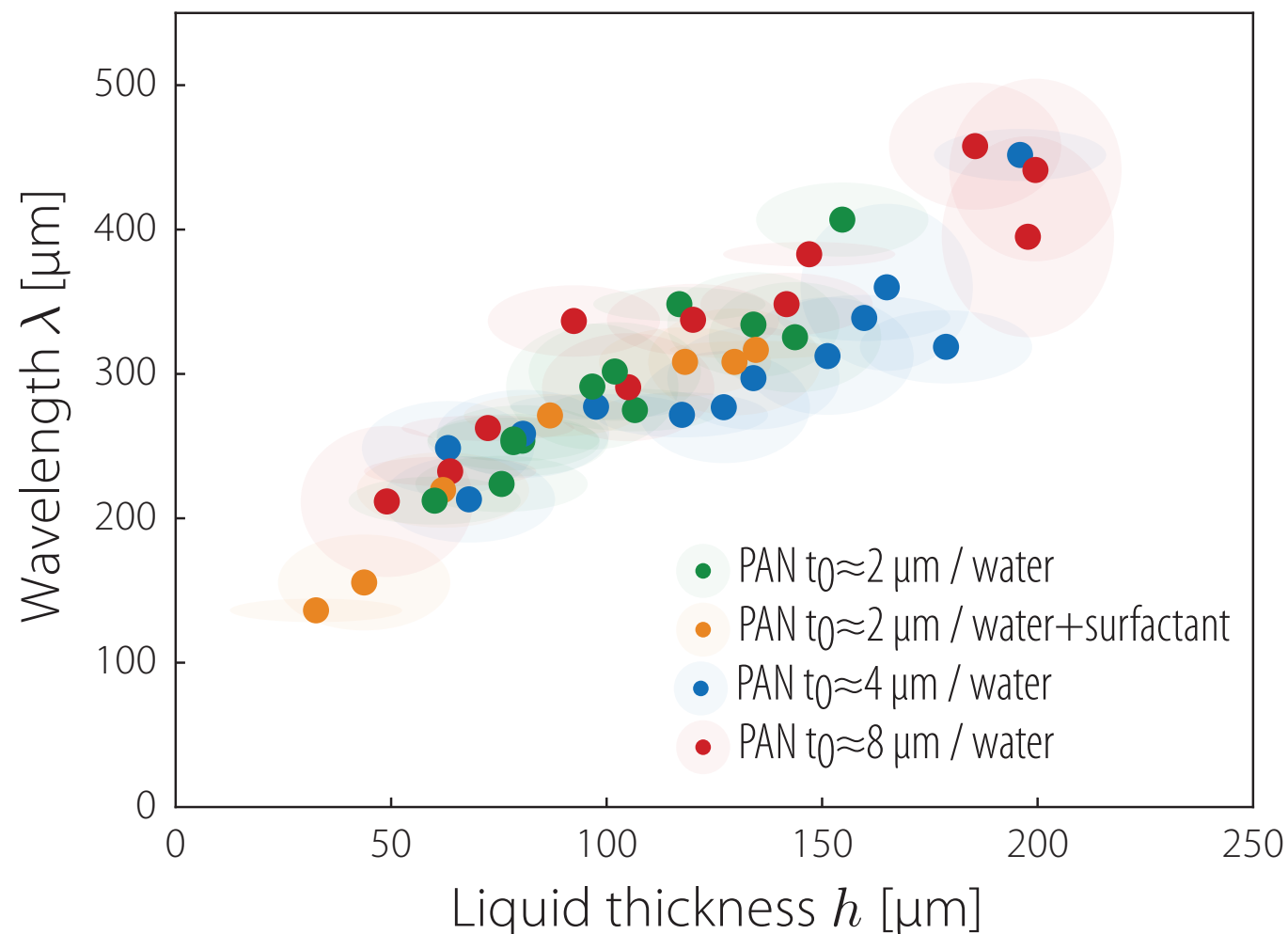
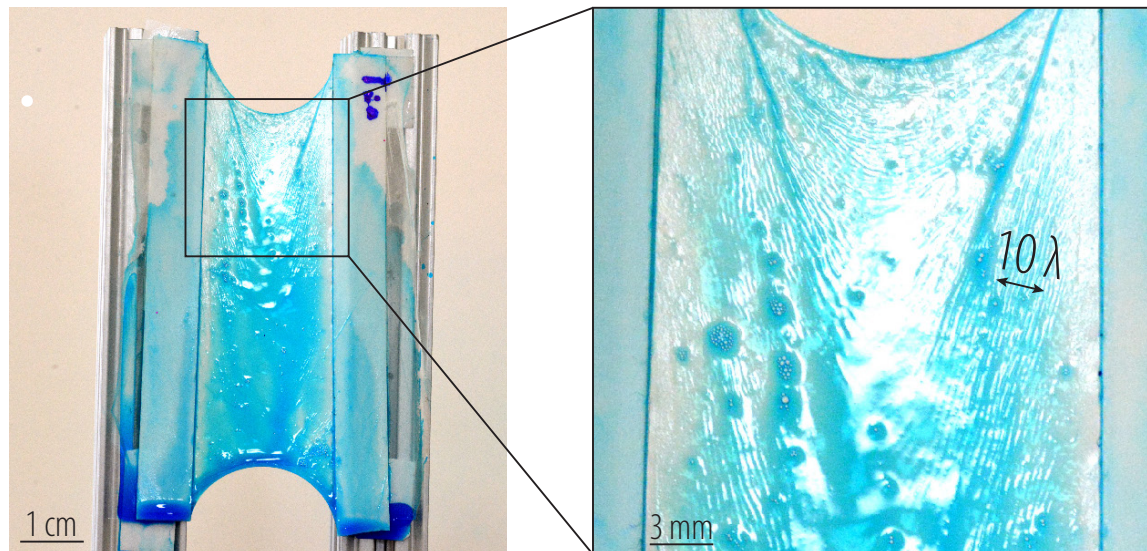


Minimizing **global** energy: **elastic bending** energy + **capillary** interface energy



Wrinkling wavelength of the wicked membrane

and liquid film thickness



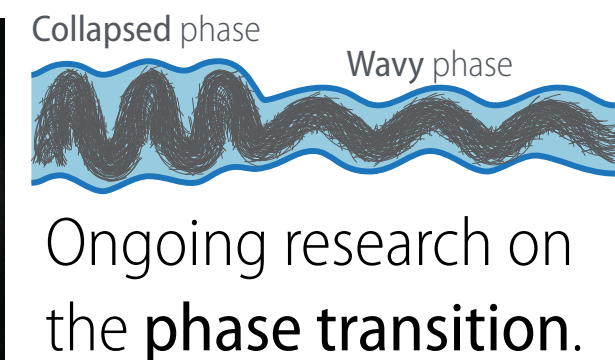
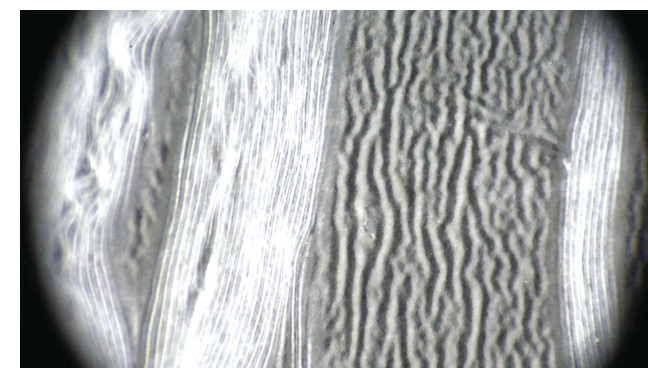
Elastic energy

$$E_e = \frac{1}{2} B \int_0^{L-\Delta L} \kappa^2(x) dx$$

Interface energy

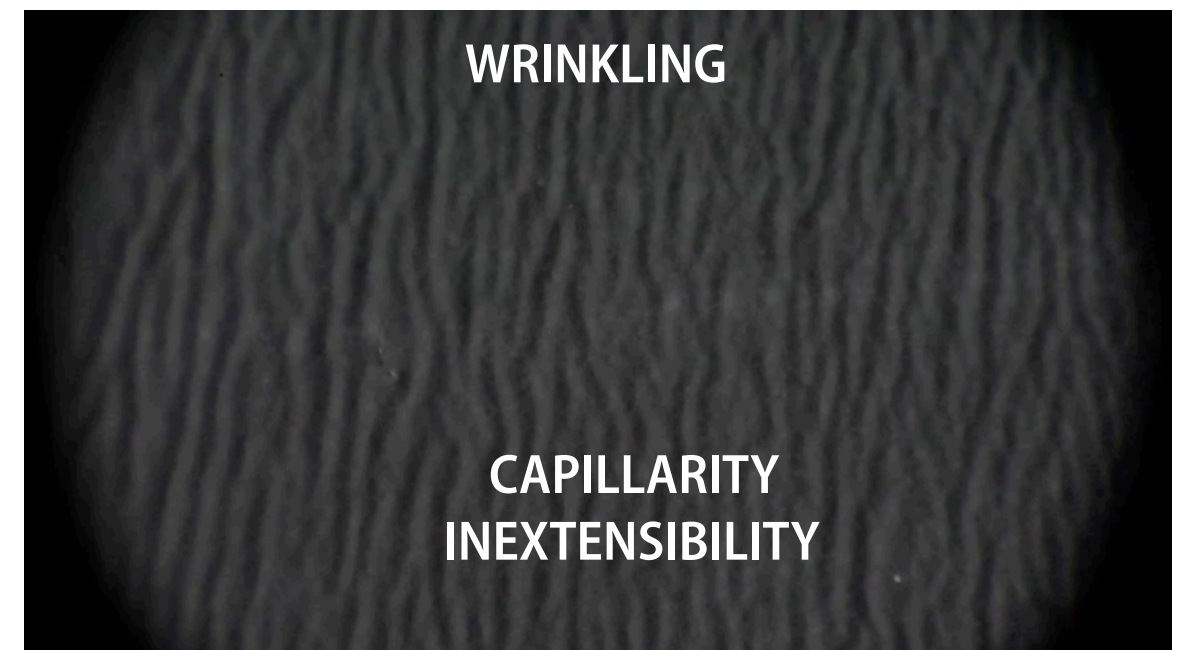
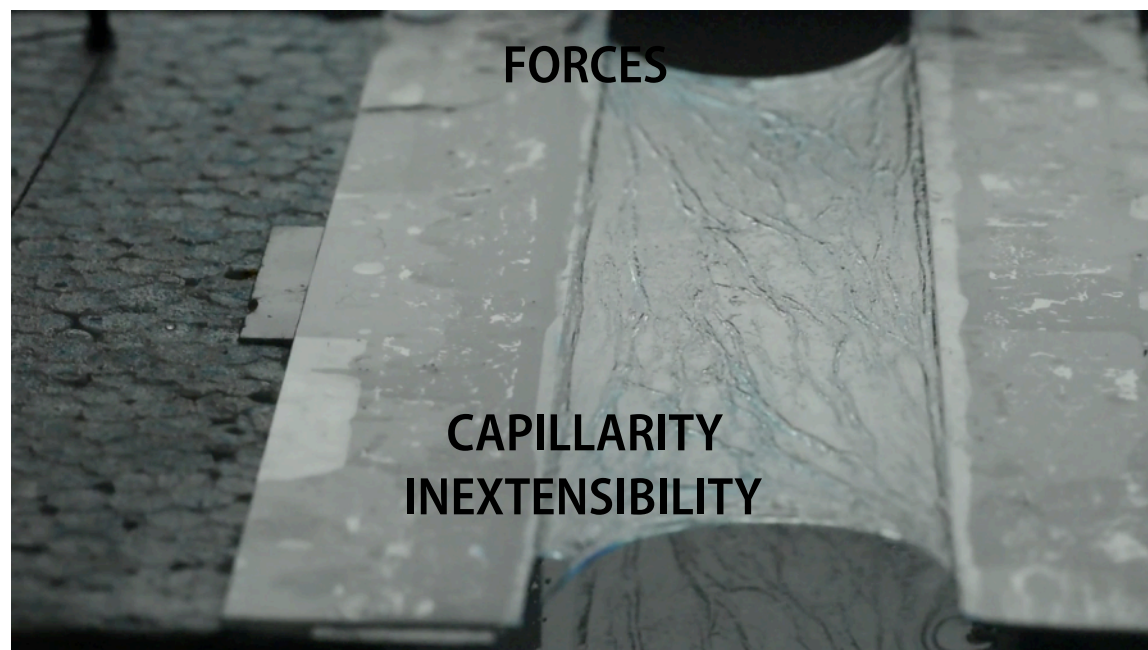
$$E_\gamma = 2\gamma \int_0^{L-\Delta L} \sqrt{1 + y_\gamma'^2(x)} dx$$

Theoretical wavelength λ
depends on compression ϵ
This is not the case **experimentally**.



Wicked membrane

for the design of stretchable fabrics

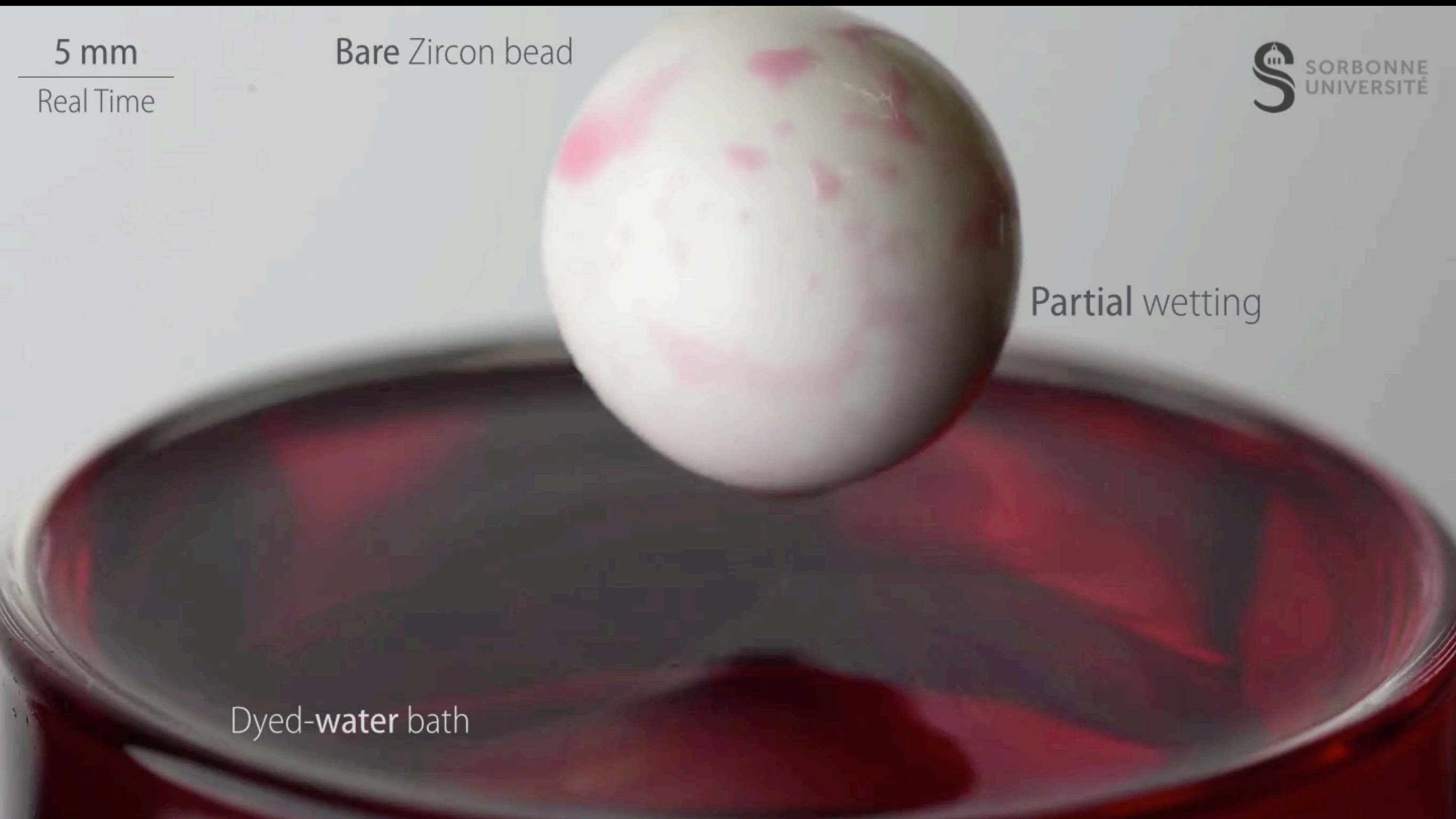


5 mm
Real Time

Bare Zircon bead

Partial wetting

Dyed-water bath

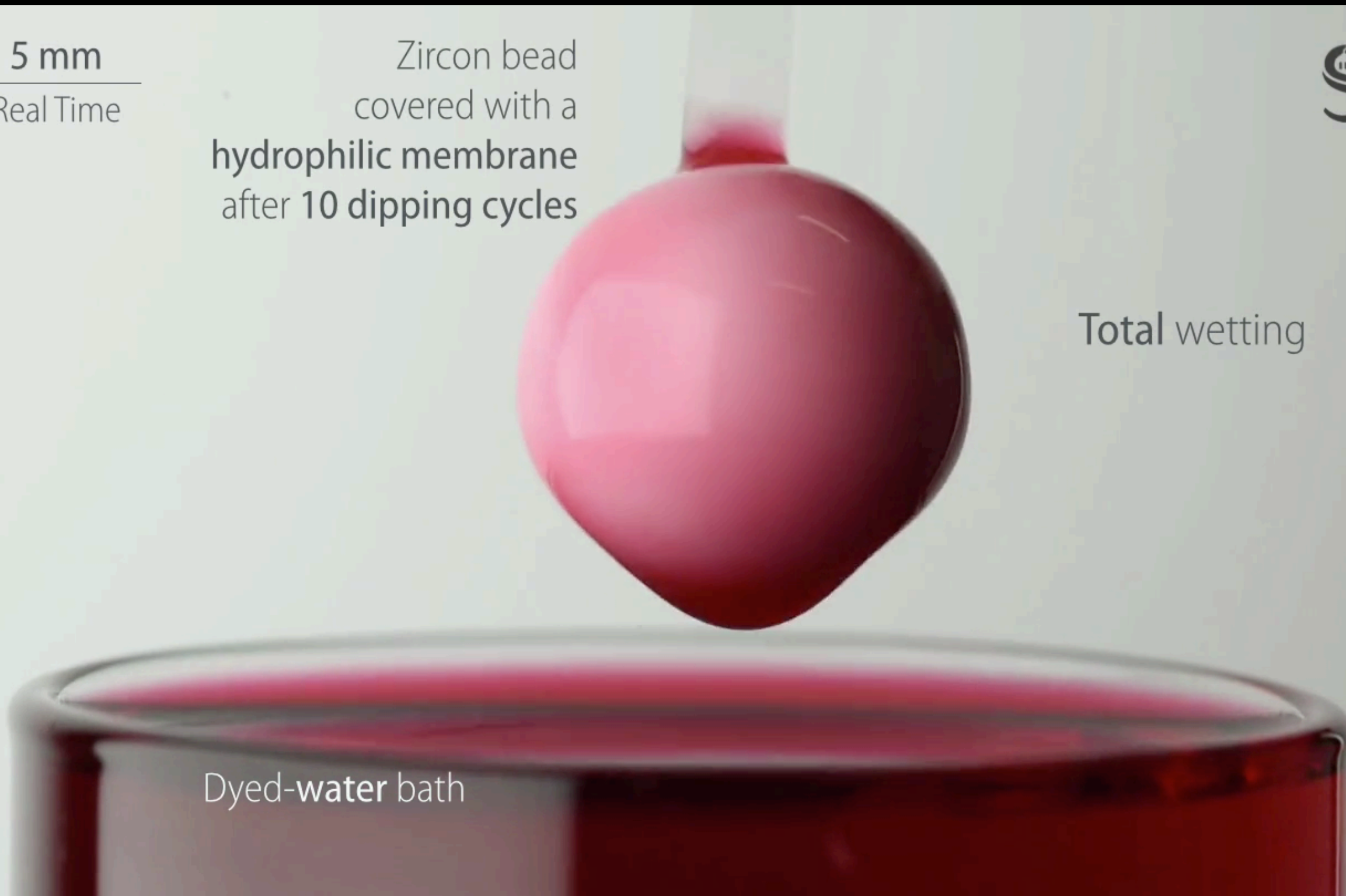


5 mm
Real Time

Zircon bead
covered with a
hydrophilic membrane
after 10 dipping cycles

Total wetting

Dyed-water bath

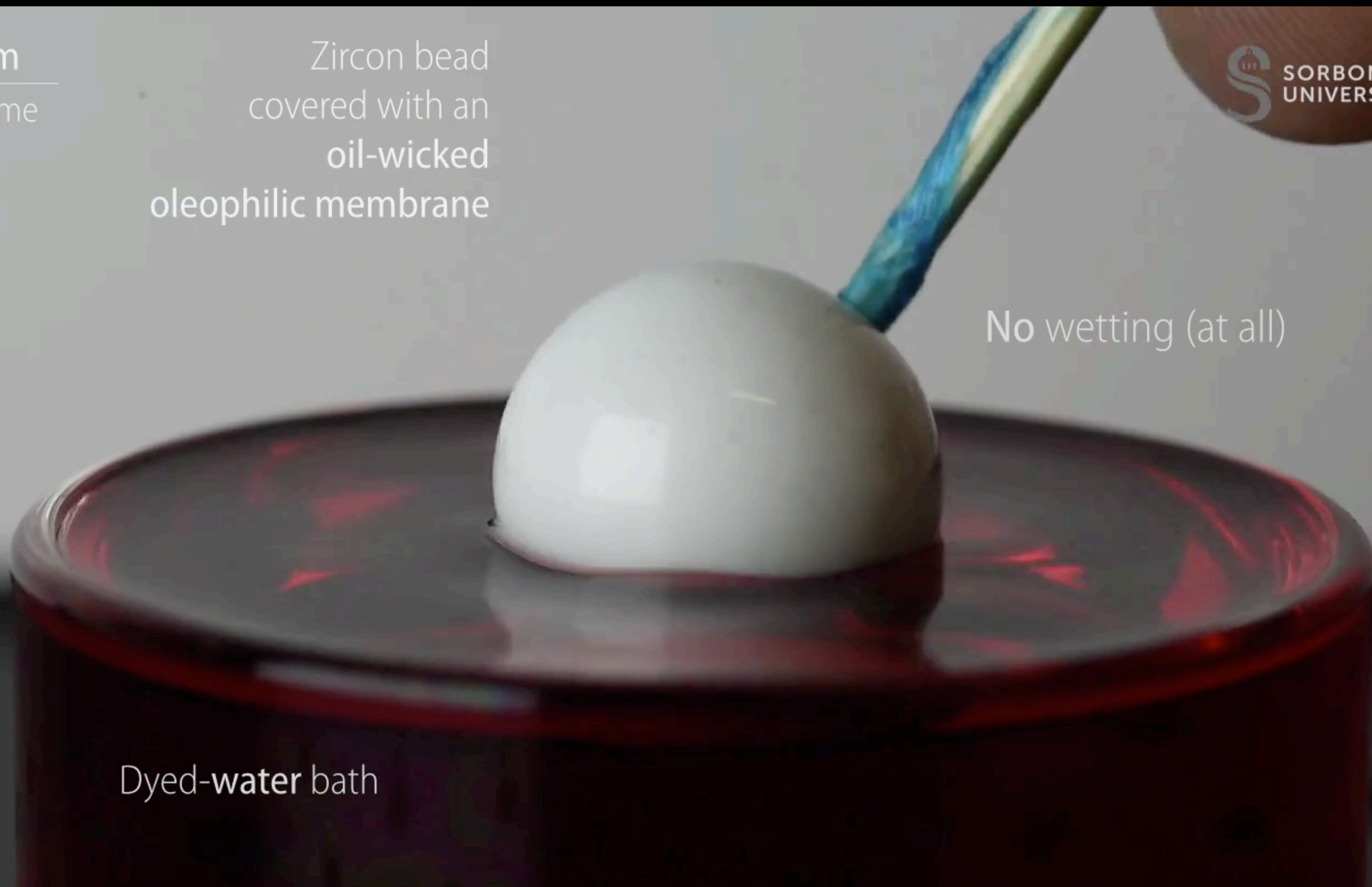


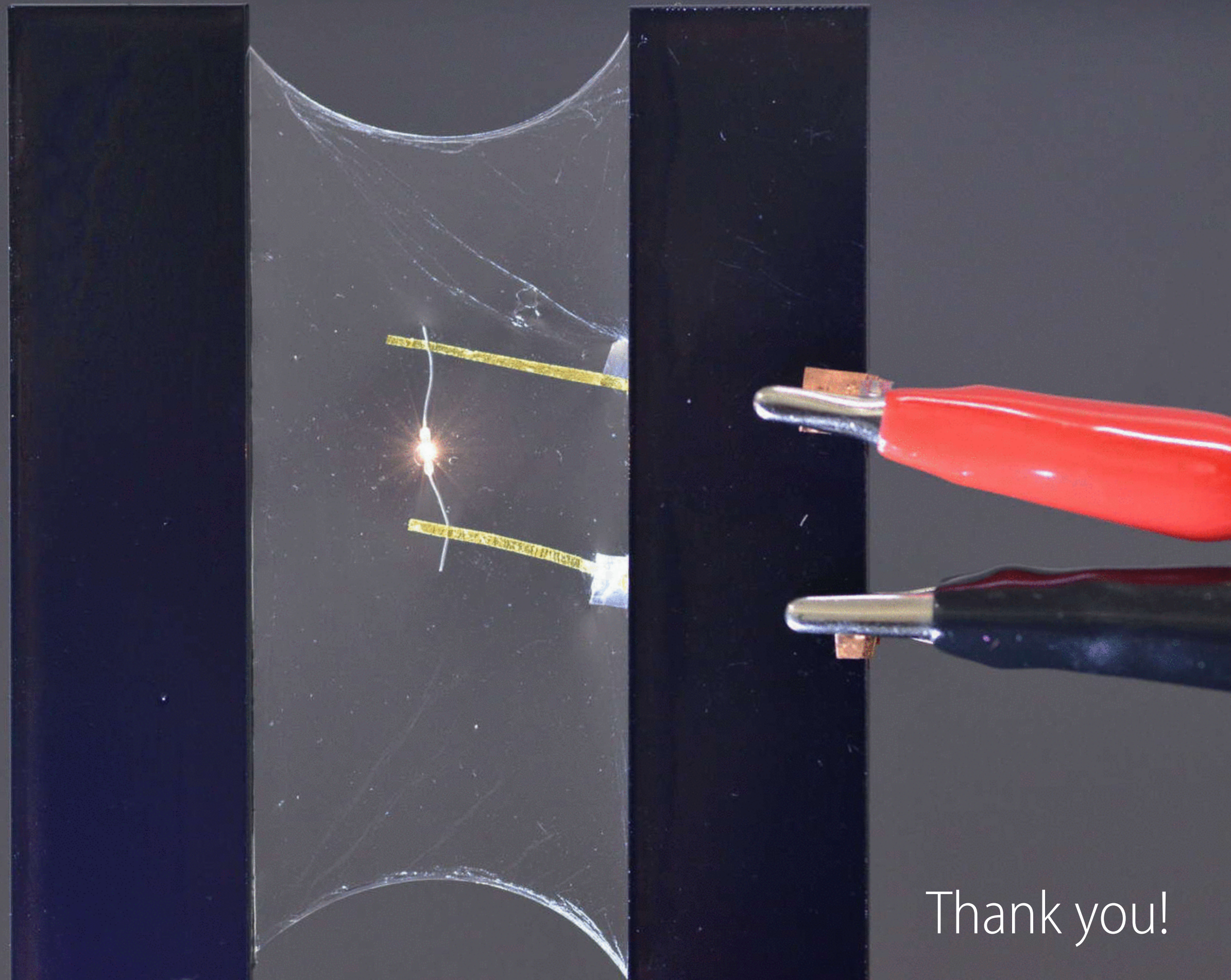
5 mm
Real Time

Zircon bead
covered with an
oil-wicked
oleophilic membrane

No wetting (at all)

Dyed-water bath





1 cm

Thank you!