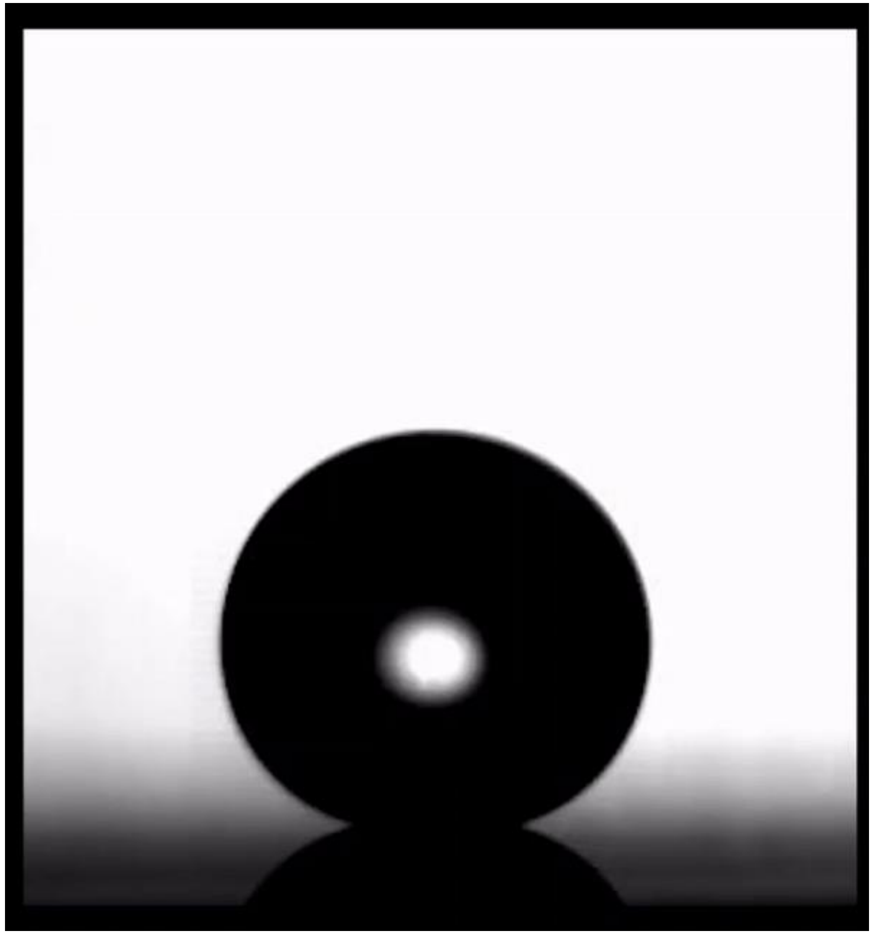


Spontaneous droplet trampolining on rigid superhydrophobic surfaces

Schutzius, T. M. et al. Nature 527, 82–85 (2015).

Team 6:

Ching Him Leung

(Zeqian) Chris Li

Kuan-Sen Lin

Gengming Liu

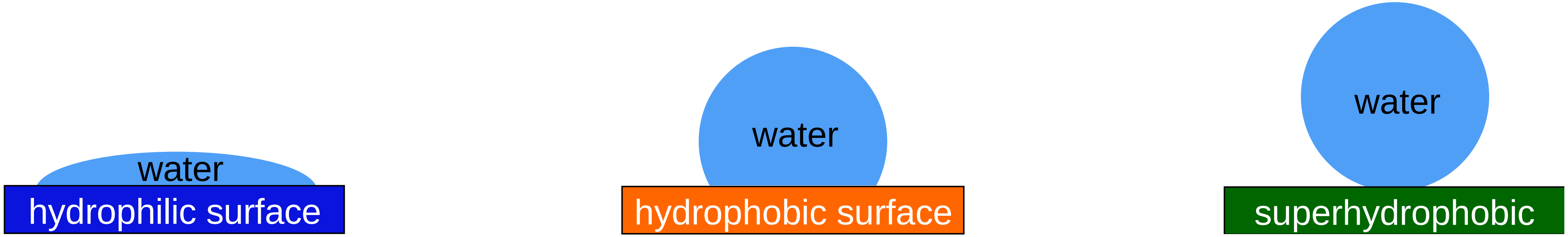
Outline

- Engineering the surface: lesson from nature
- Experimental set up and results
- Driving force for the bouncing: vaporization
- Modeling
- Droplet freezing
- Further studies
- Summary and critiques

Engineering the surface

- Surface morphology and chemistry → different surface property

- Liquid droplet behavior on the surface

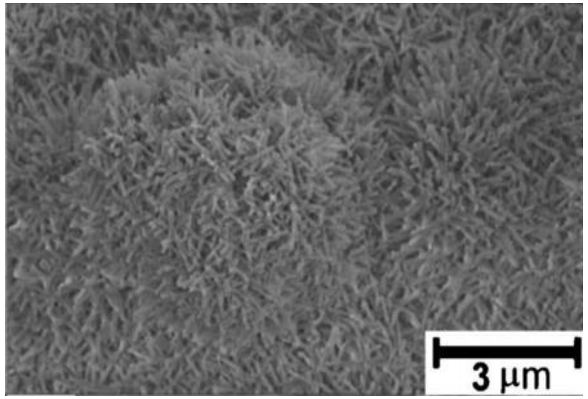


- Application: ex. Self-cleaning

Can learn from Nature

- Lotus leaf

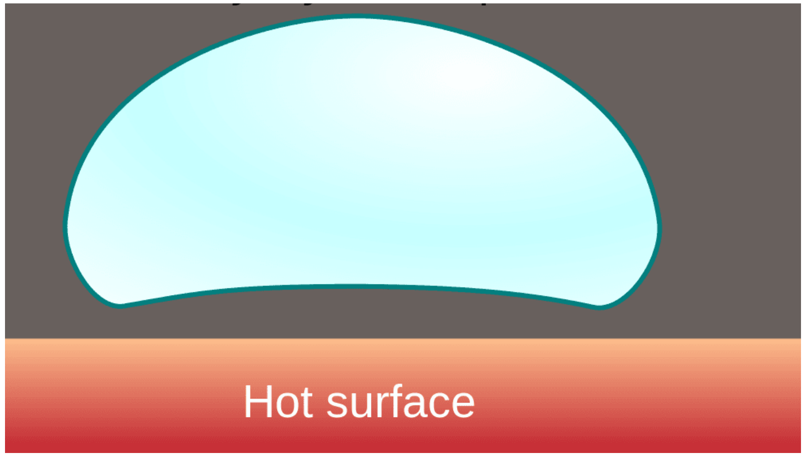
Zoom in



- When the leaf tilts a little bit the droplet will roll off.

Cheng, Y. T., et. al. Applied Physics Letters 2005, 87, 194112.

Droplets levitate due to vaporization



https://commons.wikimedia.org/wiki/File:Leidenfrost_droplet.svg

http://www.irishmanabroad.com/2015/02/science-saturday-leidenfrost-effect-explained/

In the work we are presenting…

- Combine super-hydrophobic surface + vaporization effect.
- Don’t rely on hot plate to create vapor.
- In special environment condition, single droplet can jump spontaneously.

LETTER

doi:10.1038/nature15738

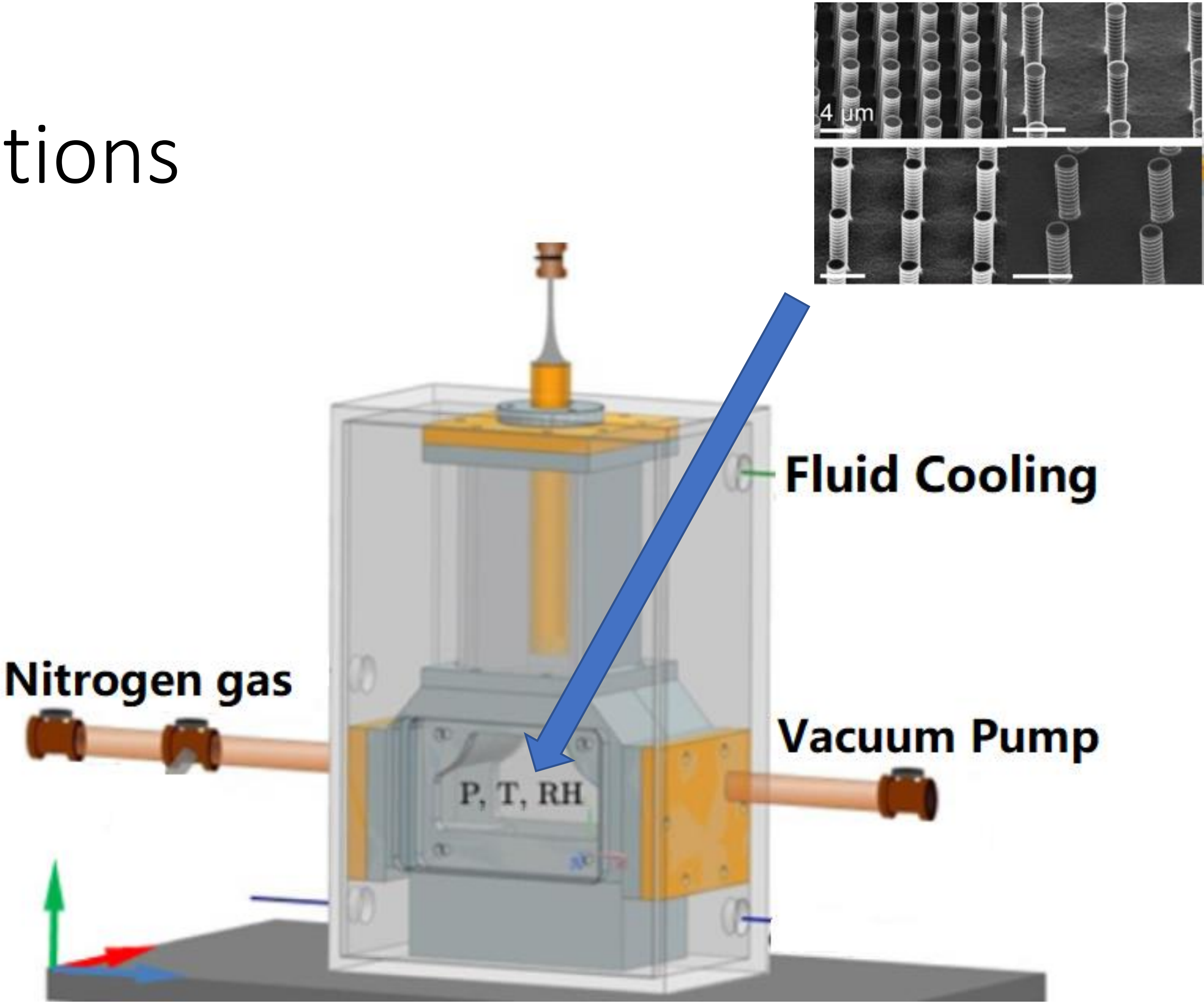
Spontaneous droplet trampolining on rigid superhydrophobic surfaces

Thomas M. Schutzius[1]*, Stefan Jung[1]*, Tanmoy Maitra[1], Gustav Graeber[1], Moritz Köhme[1] & Dimos Poulikakos[1]

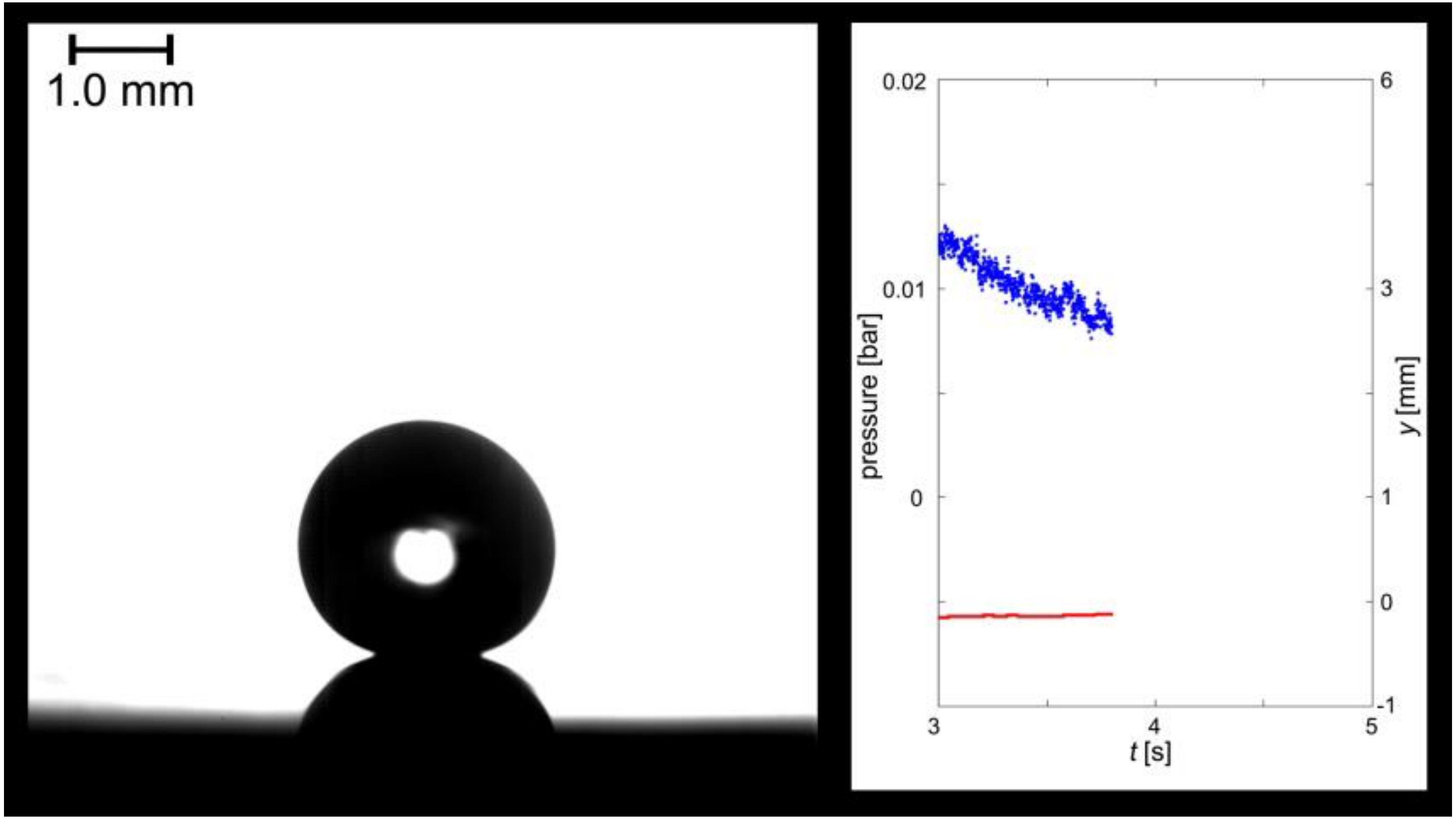
Experimental set up and results

Setups and conditions

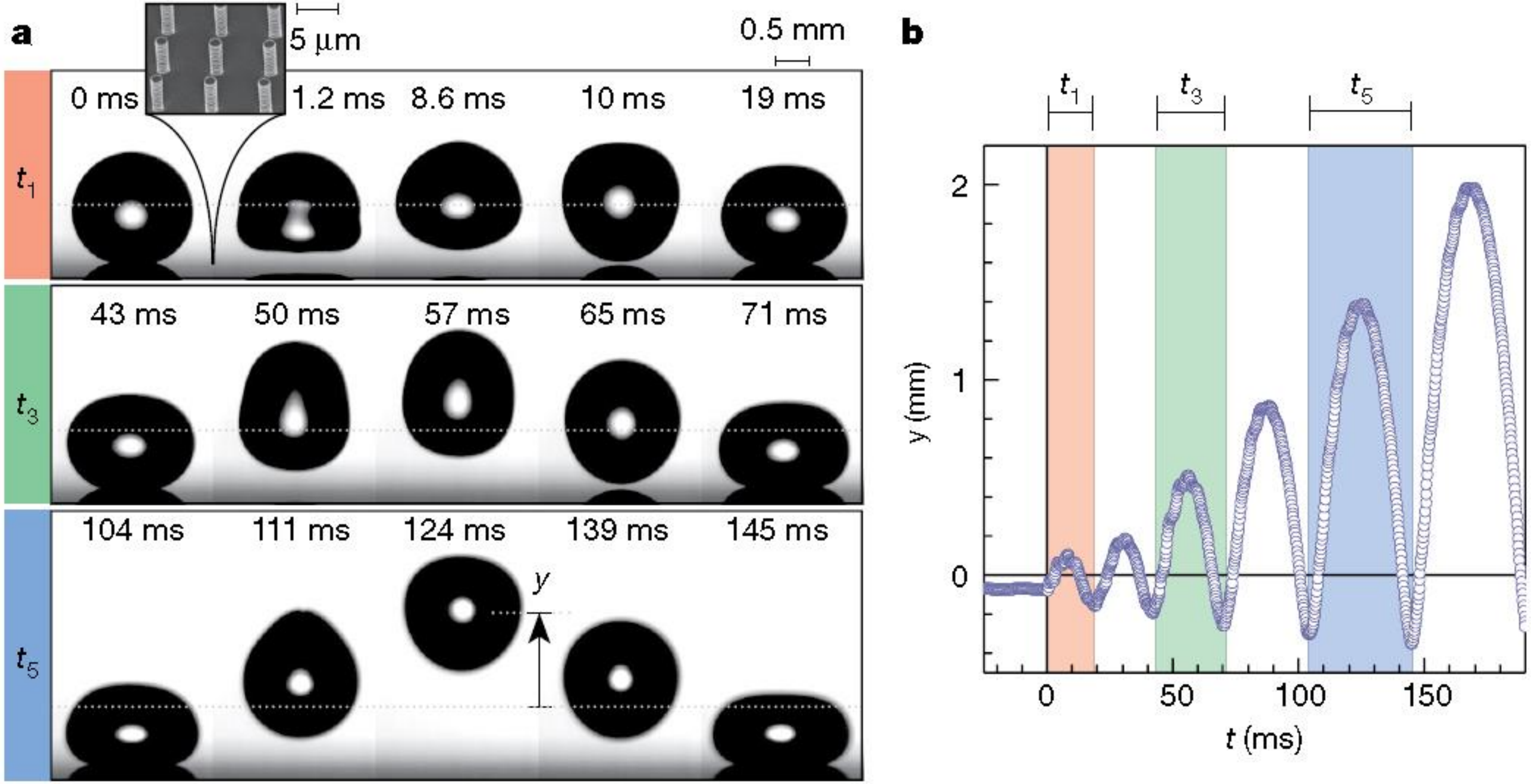
- Low ambient pressure (0.01 bar)
- Low environmental humidity
- Controllable water droplet sizes
- Silicon micropillar specifications



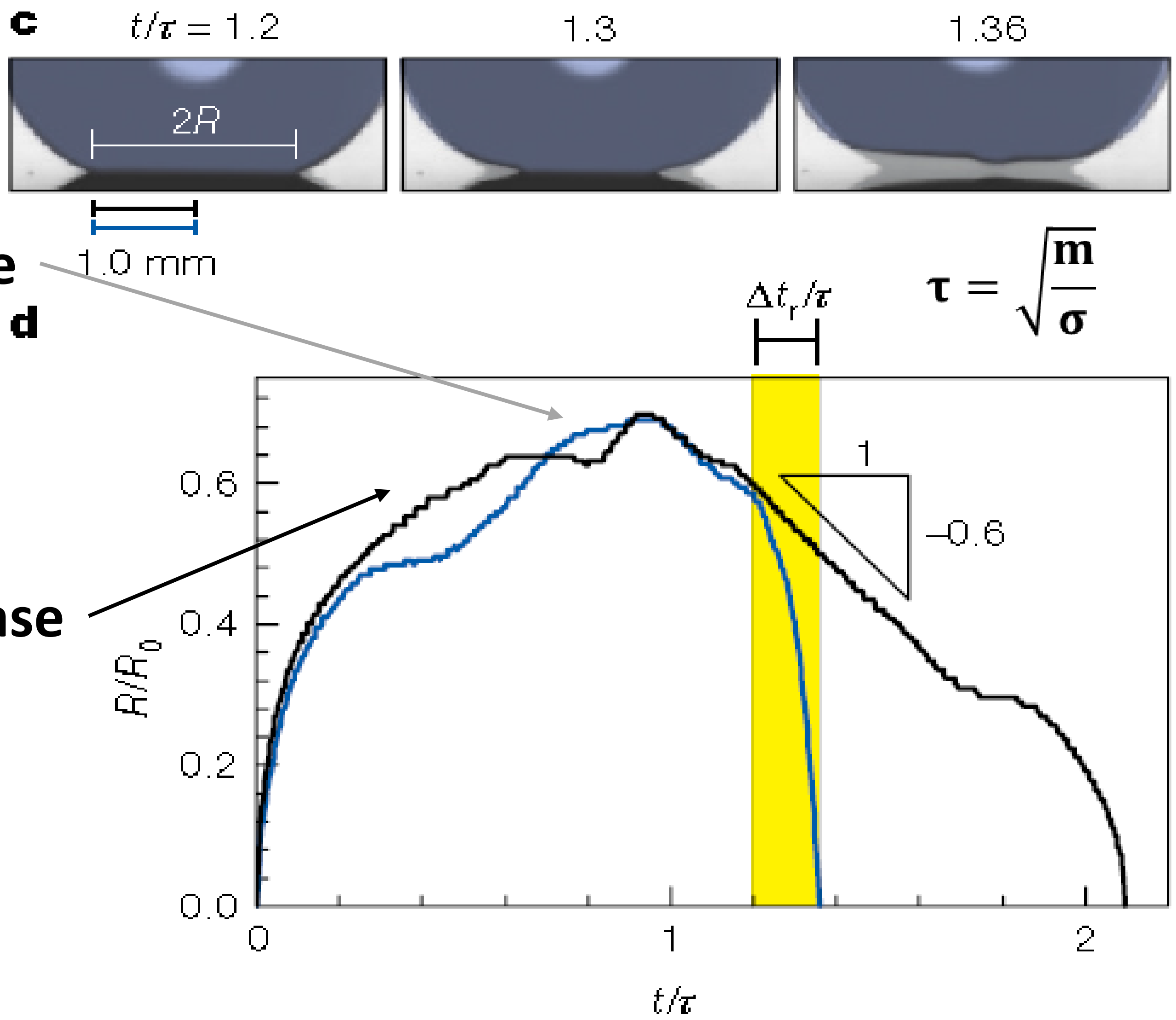
Spontaneous Trampolining



Characterizing Motion



Hunting key Forces



ase

case

$$\tau = \sqrt{\frac{m}{\sigma}}$$

Continued

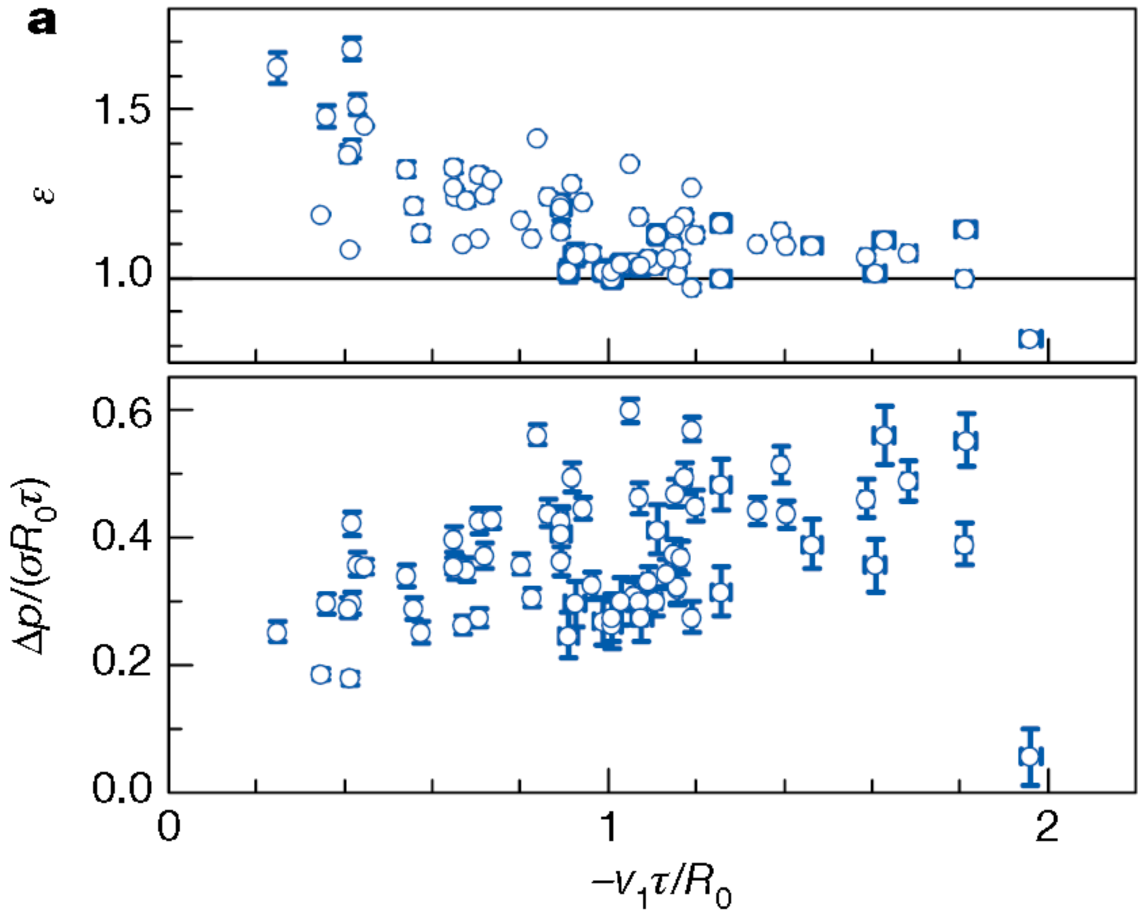
- **Measure restitution coefficient**

$$\boldsymbol{\varepsilon = \frac{v_2}{v_1}}$$

- **Assume invariant mass to estimate the momentum change**

$$\Delta P = \int_0^{\Delta t_r} f\, dt \;\approx\; \tilde{f}\Delta t_r$$

- **Then estimate average force**

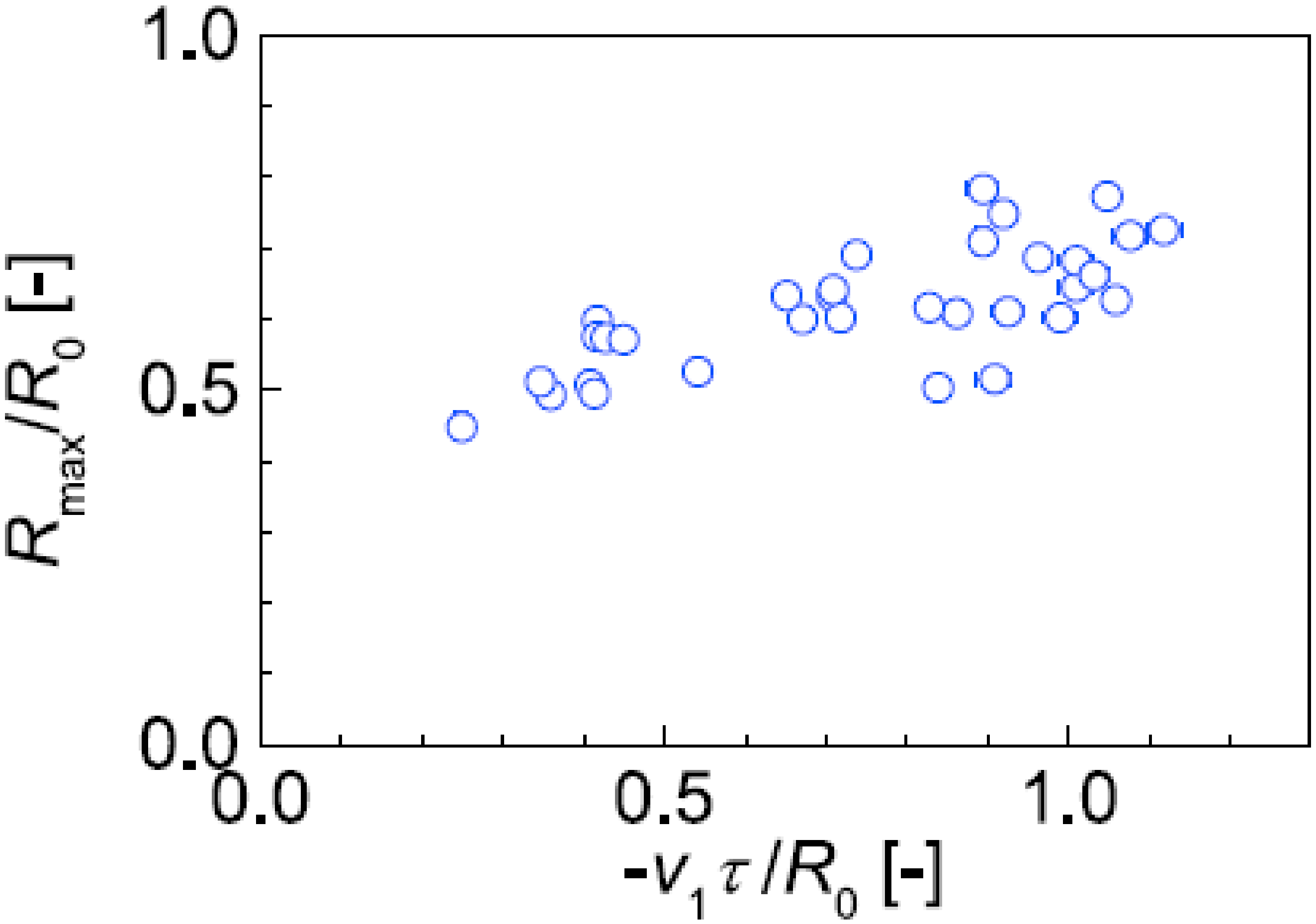


Continued

- **Then estimate average force**

$$\tilde{f} = \frac{\Delta P}{\Delta t_r} \approx 2.2\, \sigma R_0$$

- Pressure = $\frac{\tilde{f}}{Area} = 2.2 \times \frac{\sigma R_0}{\pi R_{Max}^2}$
- Pressure $\approx 0.9 \times (\frac{2\sigma}{R_0})$



Vaporization

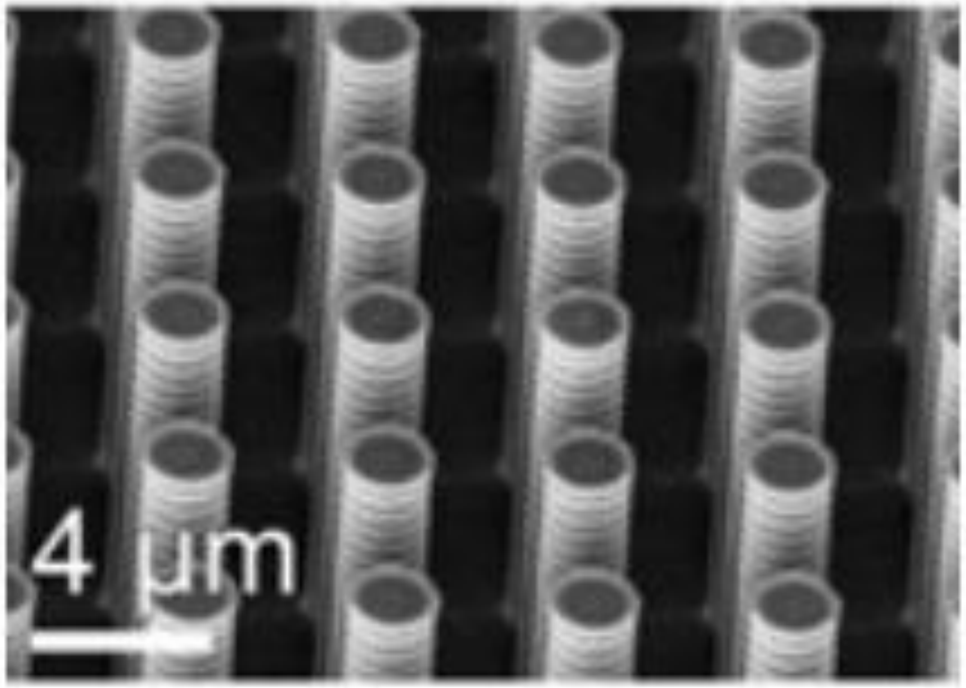
Can vaporization account for the driving force

- Vapor flow generate the force needed to accelerate the droplet
- At low pressure

high vaporization flux *J*

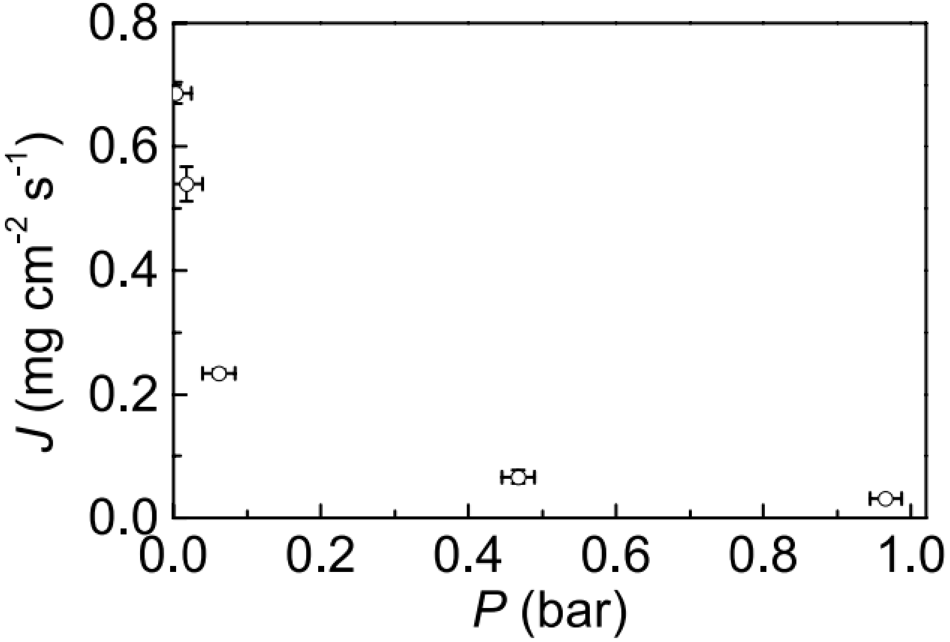
vapor can be trapped between the micropillar

Excess pressure between the droplet and the surface



Measuring vaporization flux

- At pressure lower than 0.1bar, vaporization flux increases significantly



Extended Data Figure 6 | The role of environmental pressure on the vaporization flux of a water droplet in a low-humidity environment.

Overpressure due to vaporization

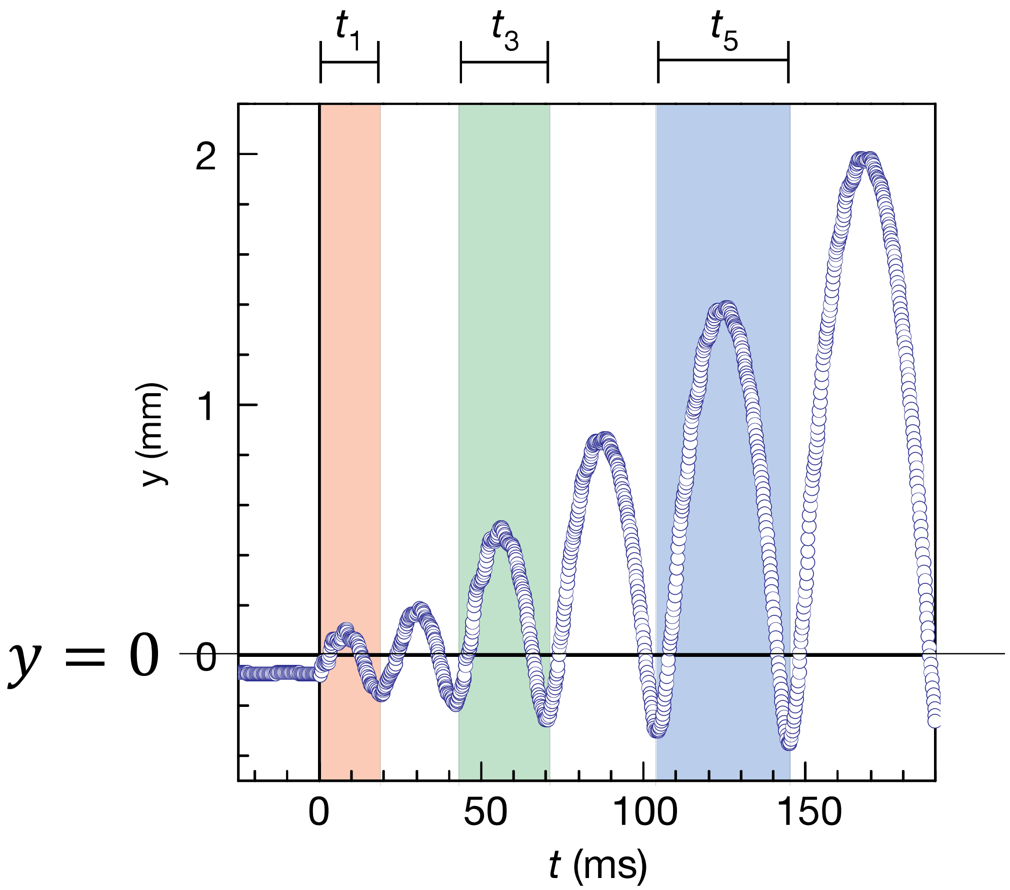
- Overpressure $\Delta P \propto J$
- Using the measured vaporization flux, the maximum overpressure $\Delta P \approx 4.7(2\sigma/R)$
- Since the pressure varies between 0 and $4.7(2\sigma/R)$, the average pressure is $\Delta\overline{\mathrm{P}} \approx 2.3(2\sigma/R)$
- From previous slides, $\Delta\overline{\mathrm{P}} \approx 0.9(2\sigma/R_0)$

R is the contact radius
R_0 is the radius of the droplet

Modeling

Modeling

- Toy model: forced, mass-spring-damper system.



$$y = y_0 + v_0 t - \frac{1}{2} g t^2 \qquad \text{(free fall)} \qquad if\ y \geq 0$$

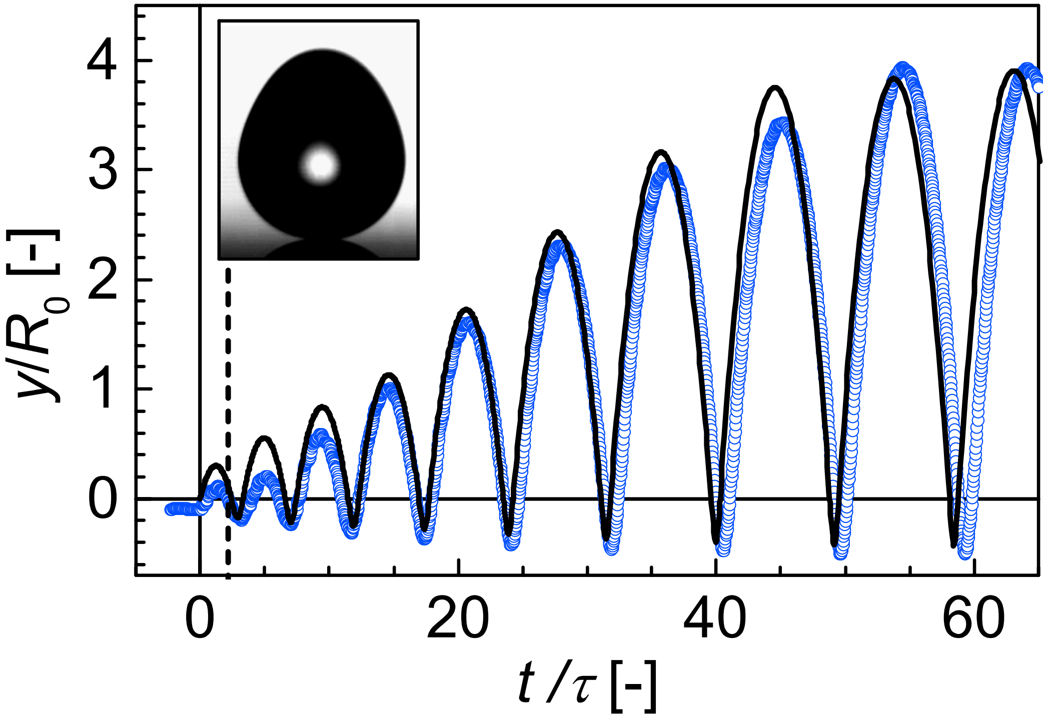
$$m \frac{d^2 y}{dt^2} + c \frac{dy}{dt} + f_k(y) = f(t) - mg \qquad if\ y < 0$$

Spring: The droplet deforms like a spring when it impacts the surface.

Modeling

- Toy model: forced, mass-spring-damper system.

Blue: experiment
Black: modeling



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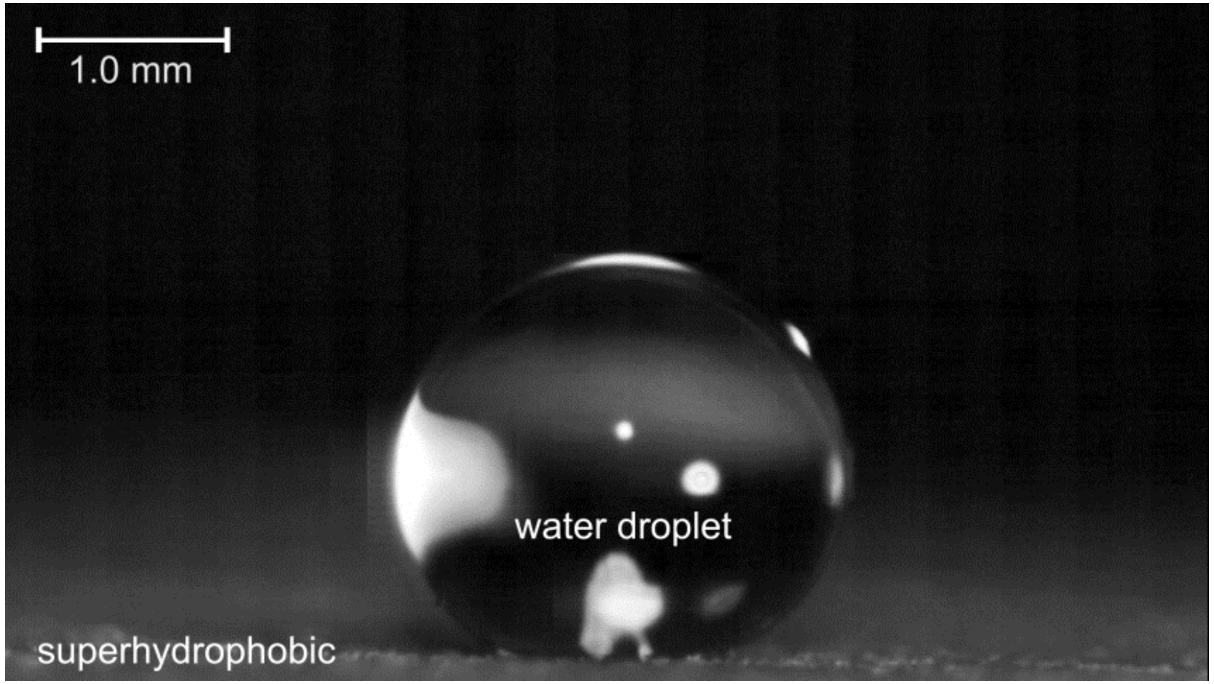
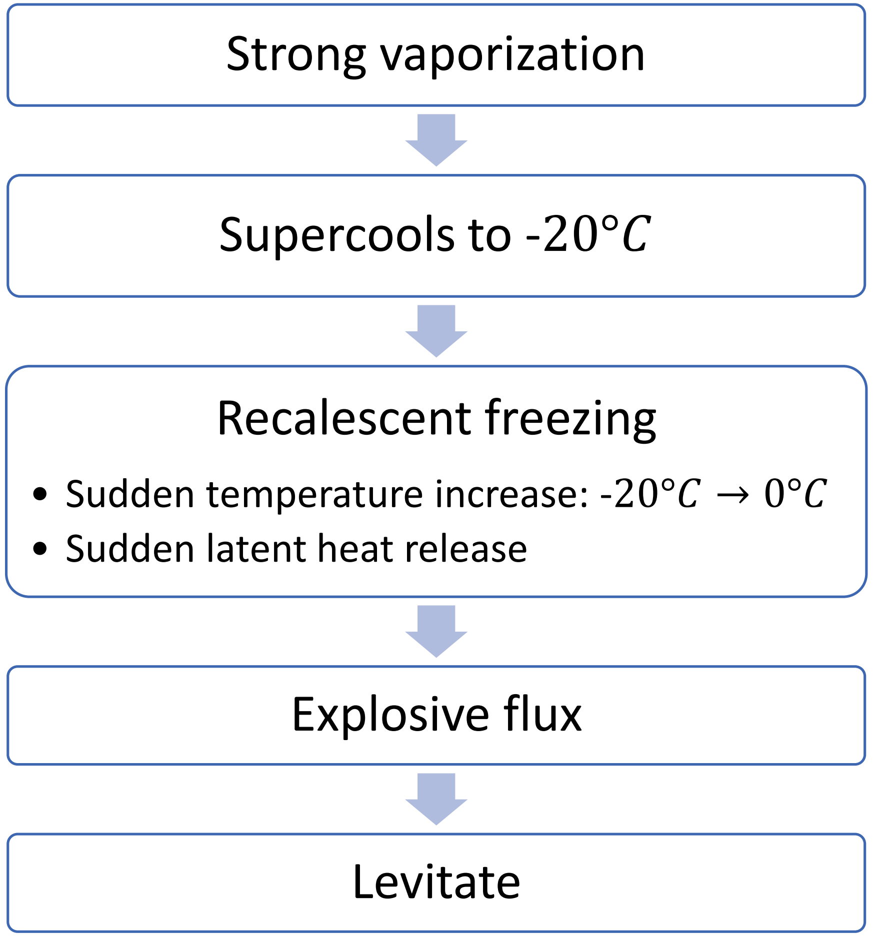
Spring: The droplet deforms like a spring when it impacts the surface.

Droplet freezing

Droplet freezing and levitation



Aluminum surface, 24°C, ~0.01bar, humidity<10%



Strong vaporization

Supercools to -20°C

Recalescent freezing

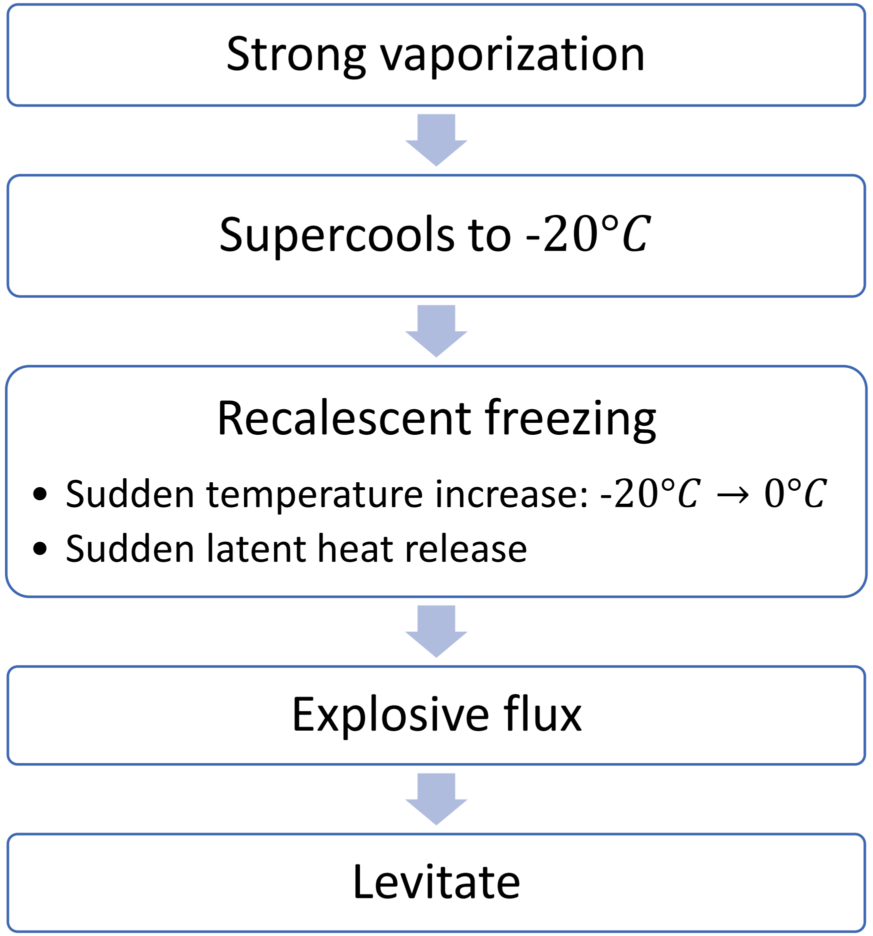
- Sudden temperature increase: -20°C → 0°C
- Sudden latent heat release

Explosive flux

Levitate

Droplet freezing and levitation

Silicon micropillar surface; 25°C, humidity<10%



Strong vaporization

Supercools to -20°C

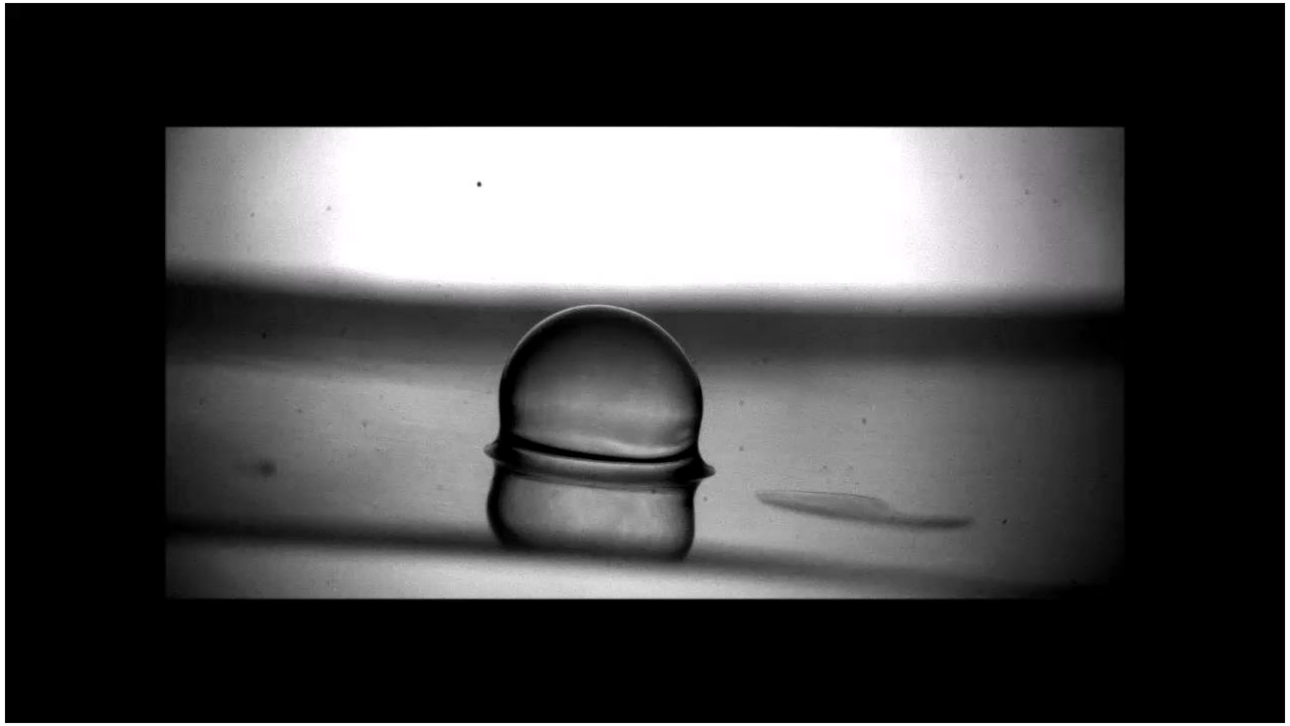
Recalescent freezing

- Sudden temperature increase: -20°C → 0°C
- Sudden latent heat release

Explosive flux

Levitate

Further studies



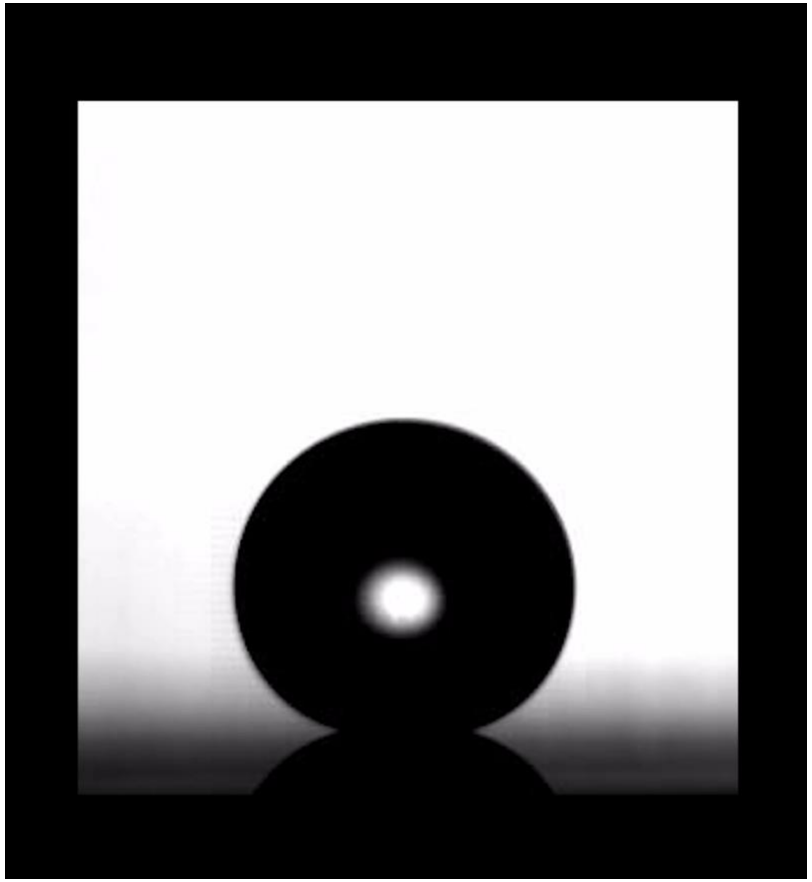
- Hydrogel
- Heated surface

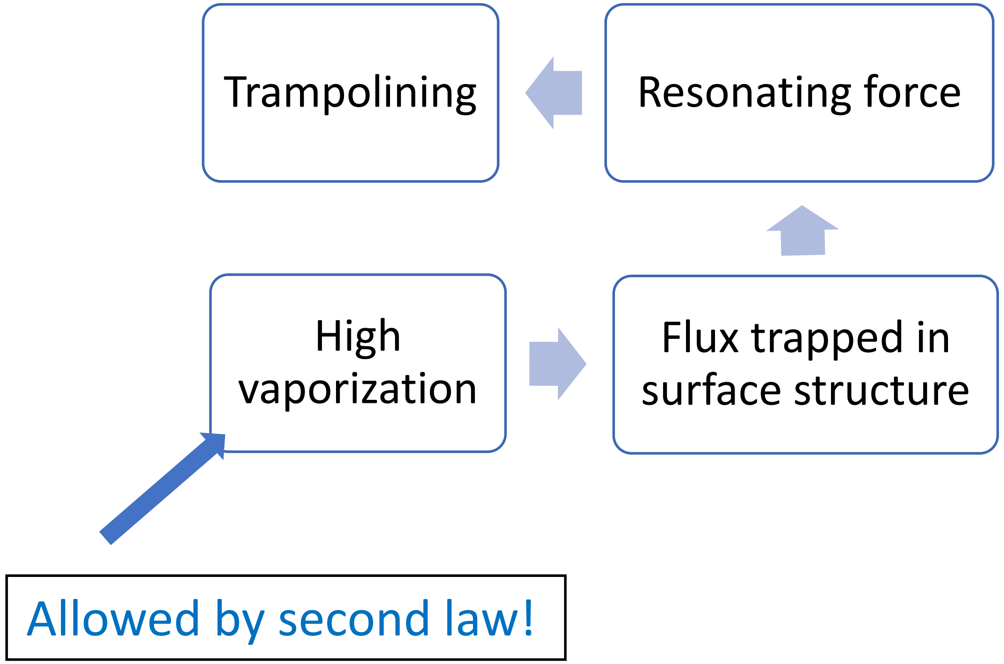
- Initial jump: massive water loss
- Trampolining after: same mechanism

Pham, J. T., Paven, M., Wooh, S., Kajiya, T., Butt, H. J., & Vollmer, D. (2017). Spontaneous jumping, bouncing and trampolining of hydrogel drops on a heated plate. *Nature communications*, *8*(1), 905.

Summary

How is this not violating the second law?





Trampolining

Resonating force

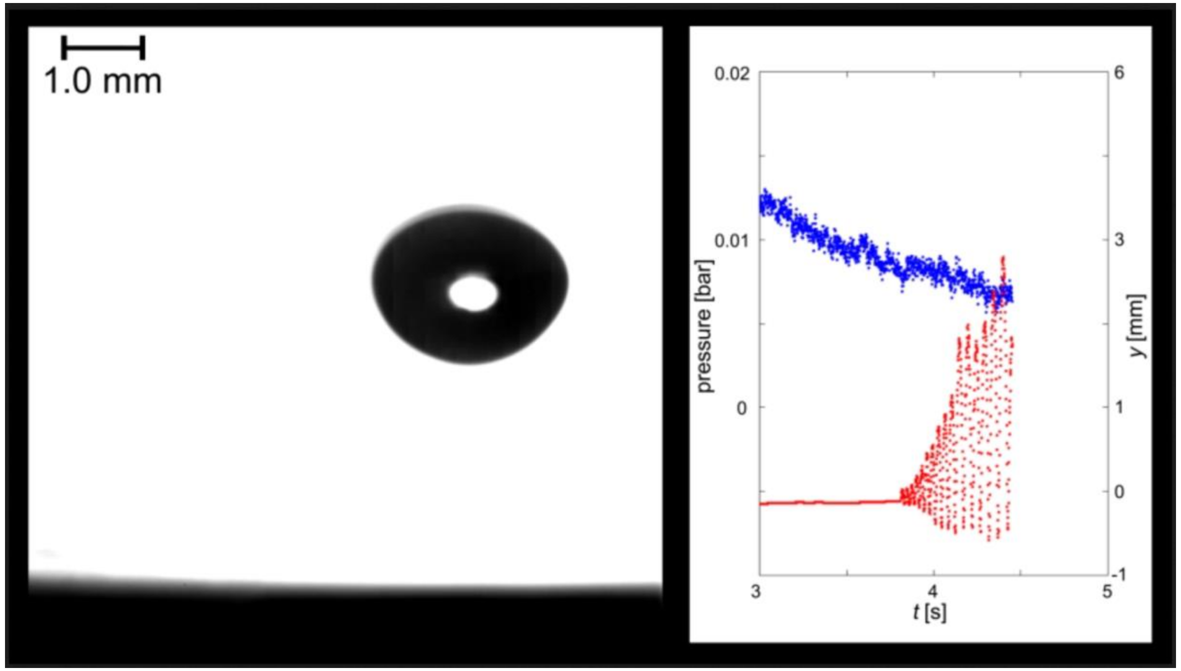
High vaporization

Flux trapped in surface structure

Allowed by second law!

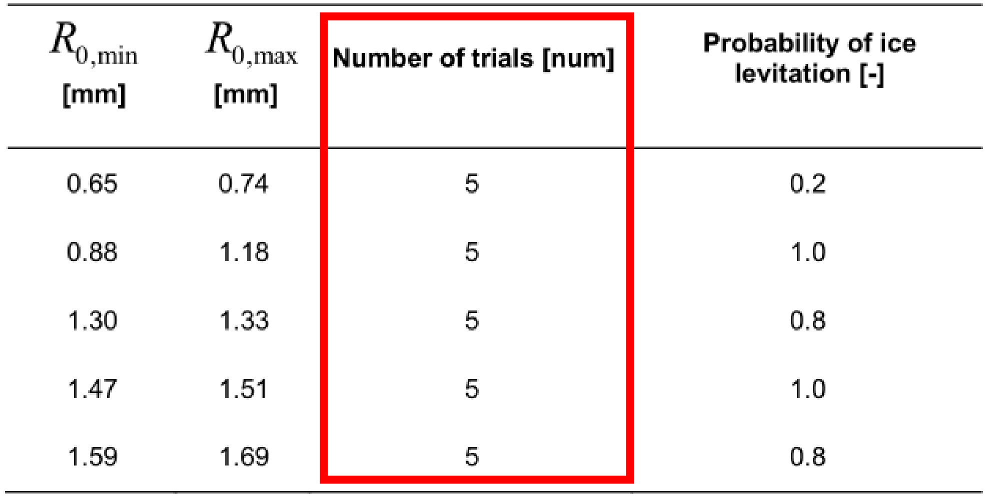
Our critiques

- Pressure control?

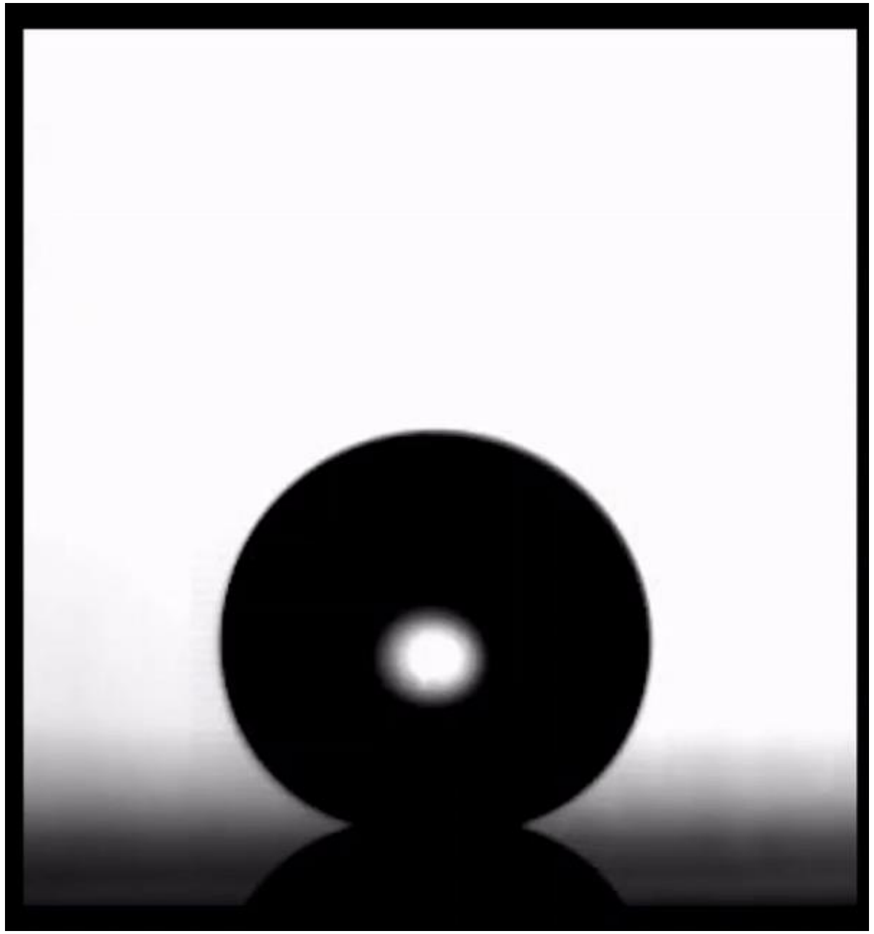


Our critiques

- Pressure control?
- The estimation of $\Delta\overline{\mathrm{P}} \approx 2.3(2\sigma/R)$ is too rough
- $0.9(2\sigma/R_0)$ and $2.3(2\sigma/R)$ are not consistent as the authors claimed.
- It does not contain enough experimental trials to convince readers that the shown contact radius dynamics is a good representation of the general trend.



$R_{0,\mathrm{min}}$ [mm]	$R_{0,\mathrm{max}}$ [mm]	**Number of trials [num]**	**Probability of ice levitation [-]**
0.65	0.74	5	0.2
0.88	1.18	5	1.0
1.30	1.33	5	0.8
1.47	1.51	5	1.0
1.59	1.69	5	0.8



Thanks!