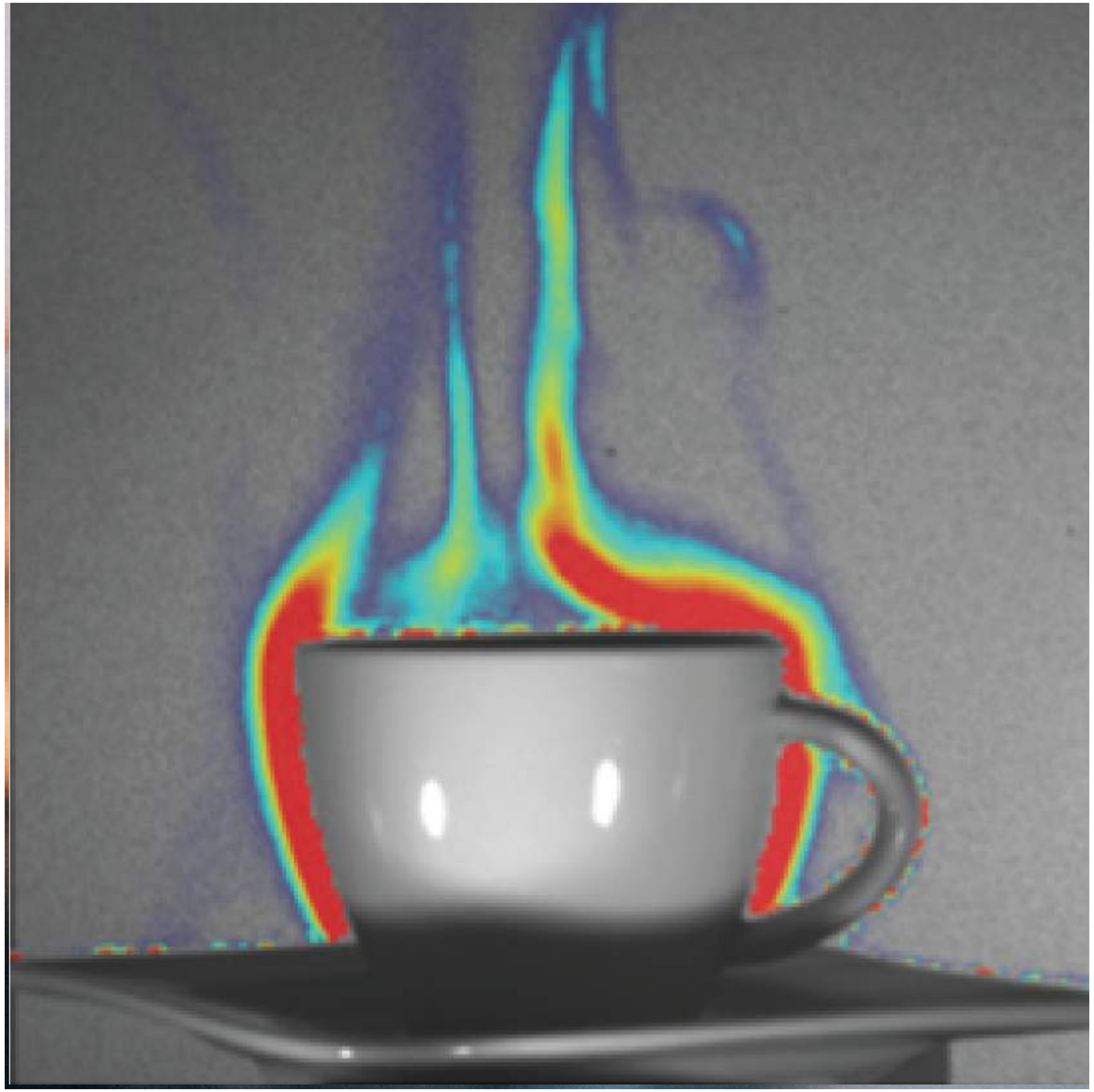
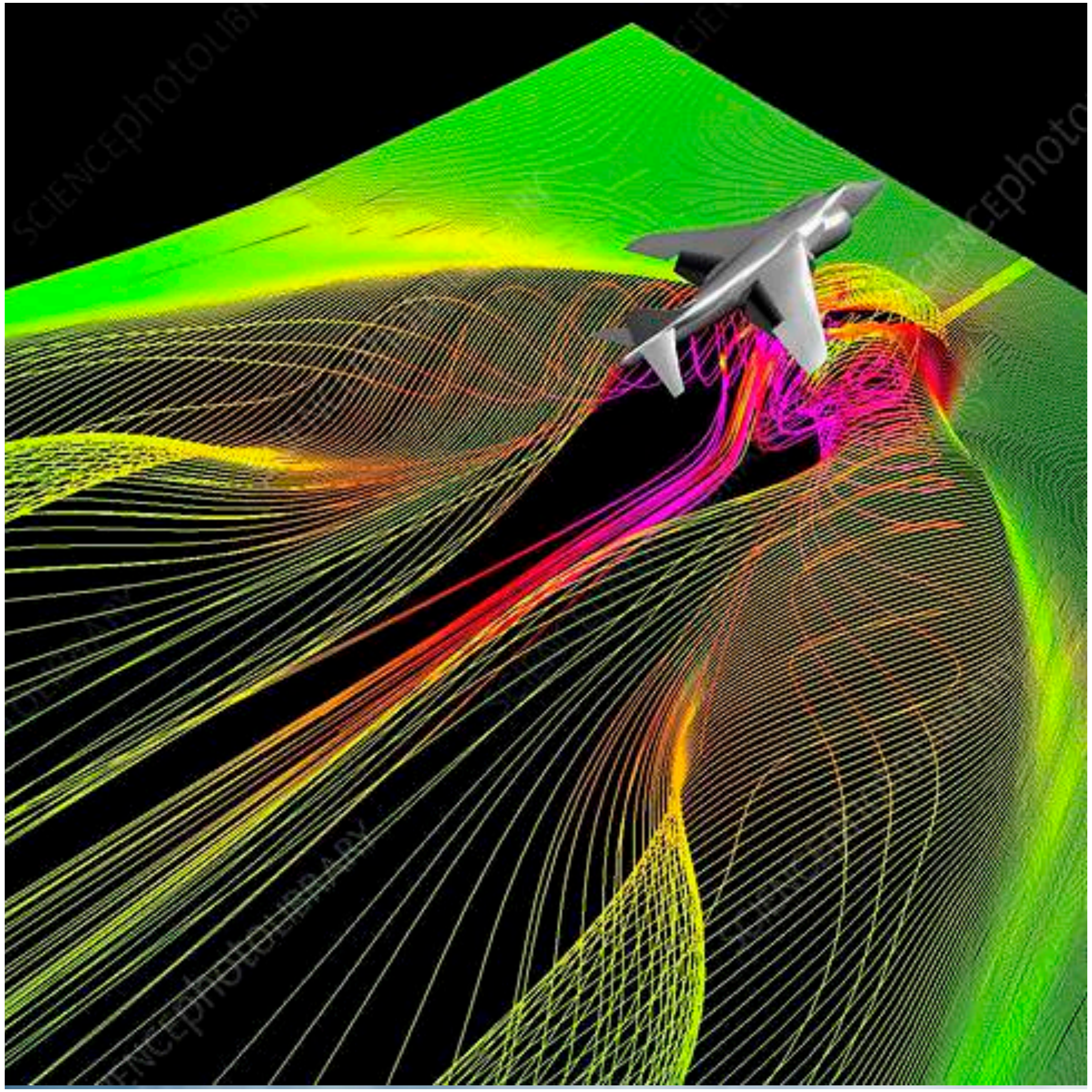
Culinary Fluids Mechanics

Arnold Mathijssen, Maciej Lisicki, Vivek Prakash, Endre Mossige

13 June 2023

Flows are everywhere... but they are often hidden





Fluid mechanics is used in many industries

Why study “Culinary Fluid Mechanics”?

Creative
(just like chefs)

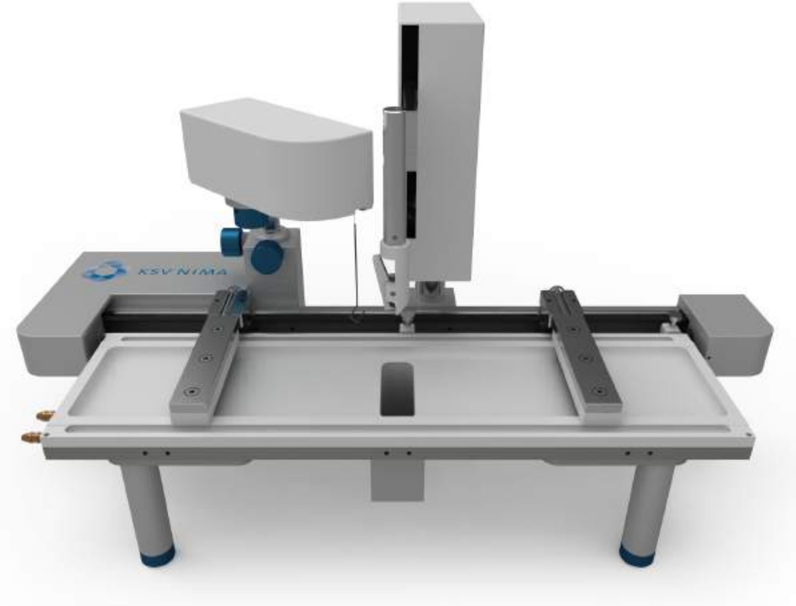
Accessible
(affordable and observable)

Equitable
(support minorities in STEM)

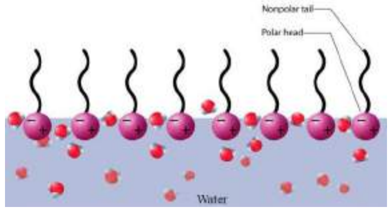
GG Fuller *et al.*, “Kitchen flows: Making science more accessible, affordable, and curiosity driven”, Phys. Fluids 34:11 (2022)

The legacy of Agnes Pockels

Agnes Pockels
(1862 - 1935)



Modern Langmuir-Blodgett Trough,
based on Pockels' sliding trough invention.



Letter to Lord Rayleigh (1891):

"My Lord,

Will you kindly excuse my venturing to trouble you ….

… I thought I ought not to withhold from you these facts which I have observed, although I am not a professional physicist; and again begging you to excuse my boldness, I remain, with sincere respect,

Yours faithfully,
Agnes Pockels"

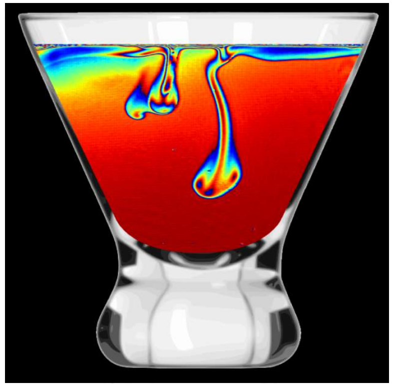
Rayleigh helped to publish her work in the journal **Nature**

Selected publications…

- "Surface Tension", (1891) **Nature**, 46, 437.
- "On the relative contamination of the water-surface by equal quantities of different substances", (1892) **Nature** 47, 418.
- "Relations between the surface tension and relative contamination of water surfaces", (1893) **Nature**, 48, 152.
- "On the spreading of oil upon water", (1894) **Nature** 50, 223.
- "The measurement of surface tension with the balance" (1926) **Science** 64, 304.

<u>So, she established the modern discipline known as surface science</u>

Overview of this Presentation
(Menu of the Day)



Drinks

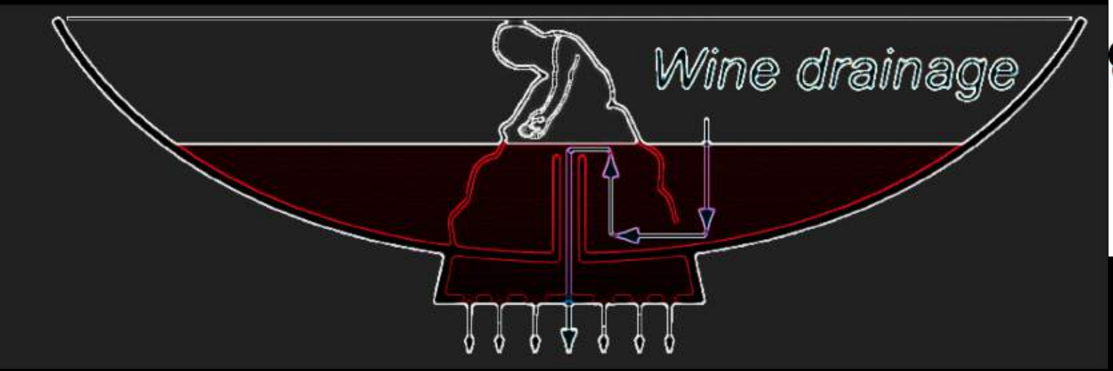
Starter

Main course

Dessert

Coffee

Tantalus bowl: an ancient practical joke



Vinkovci treasure of late Roman silver plate

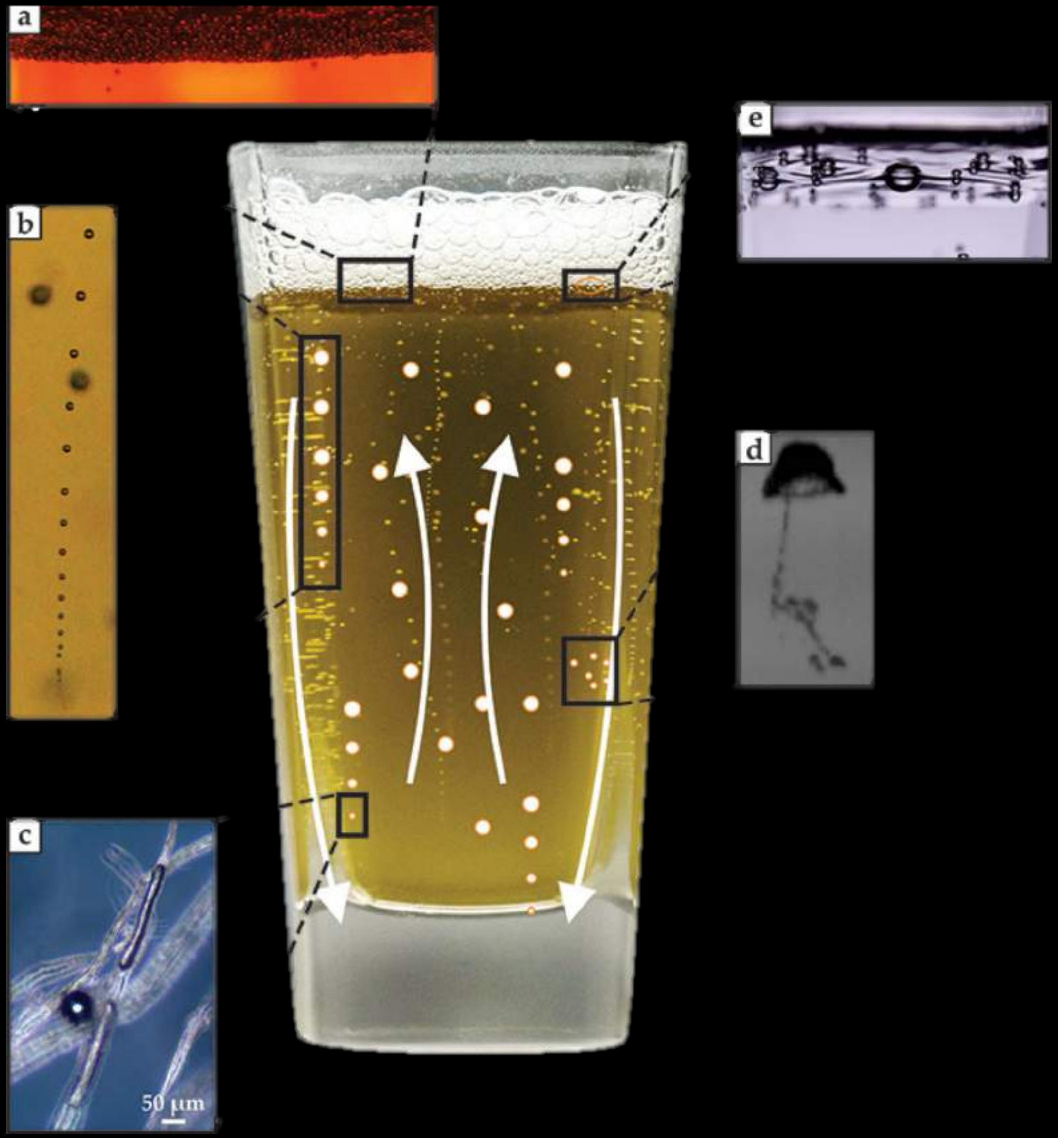
Vulic et al. (2017), J. Roman Archaeol. 30, 127

WHERE IS MY WINE??

The bowl replies: You already had too much!

Ewoldt research group

Physics of bubbly drinks



a) Foam
- Creamy taste (yield stress rheometry)
- Temperature insulation (heat transfer)

b) Bubble train
- Size increases (supersaturated CO_2)
- Velocity increases (drag hydrodynamics)

c) Nucleation
- Creation of bubbles (thermodynamics)

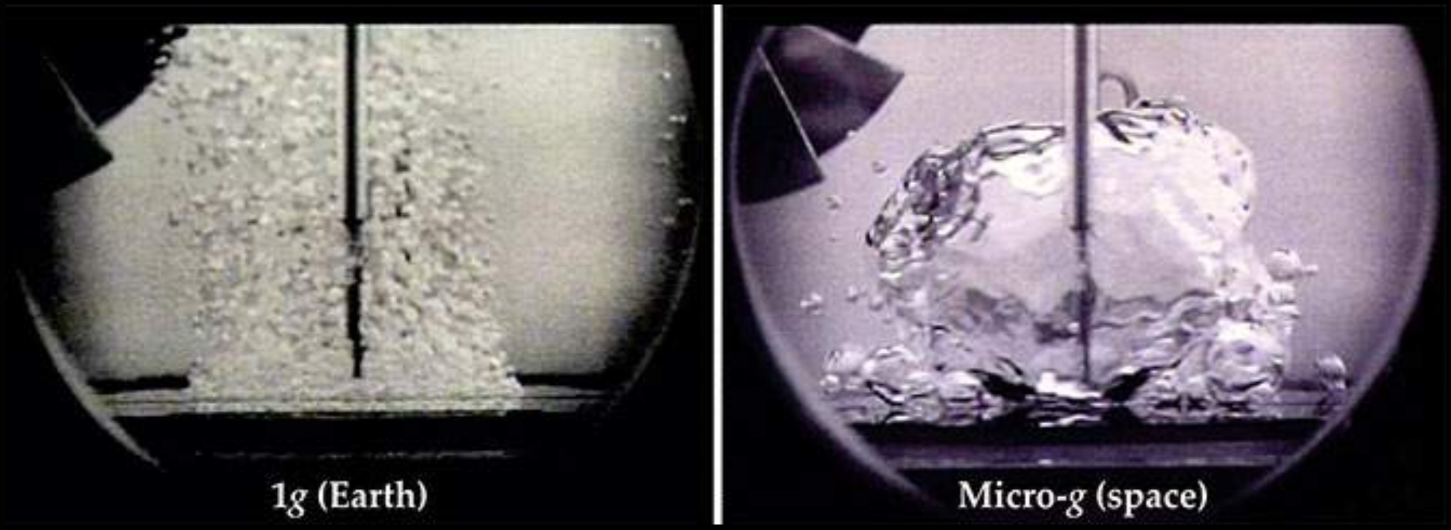
d) Bubble implosion
- Plume formation (multiphase flows)

e) Foam stability
- Drainage dynamics (interfacial flows)

Zenit et al., Physics Today 71 (11), 44–50 (2018)

Bubbles in space

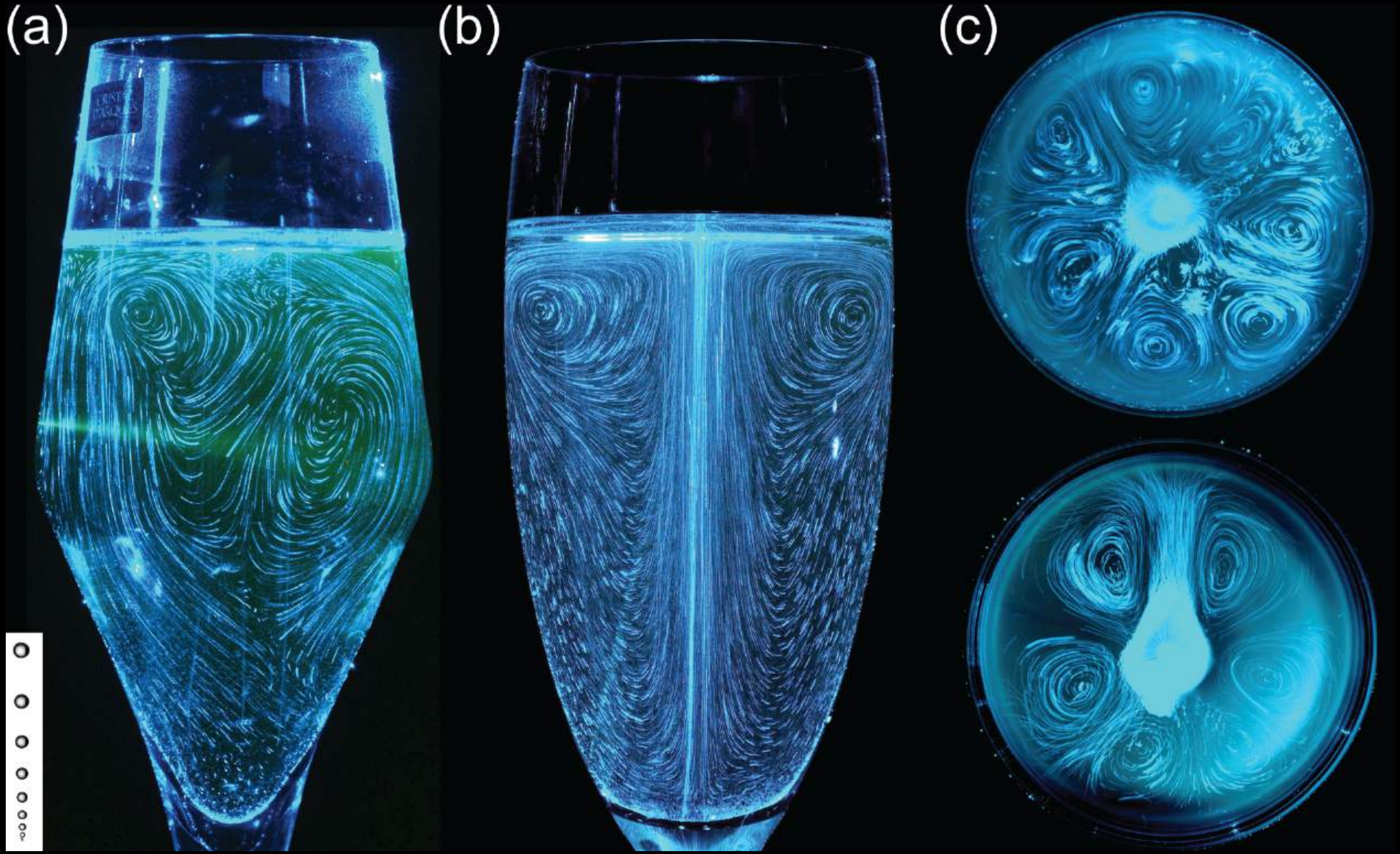
What happens if an astronaut drinks sparkling water?

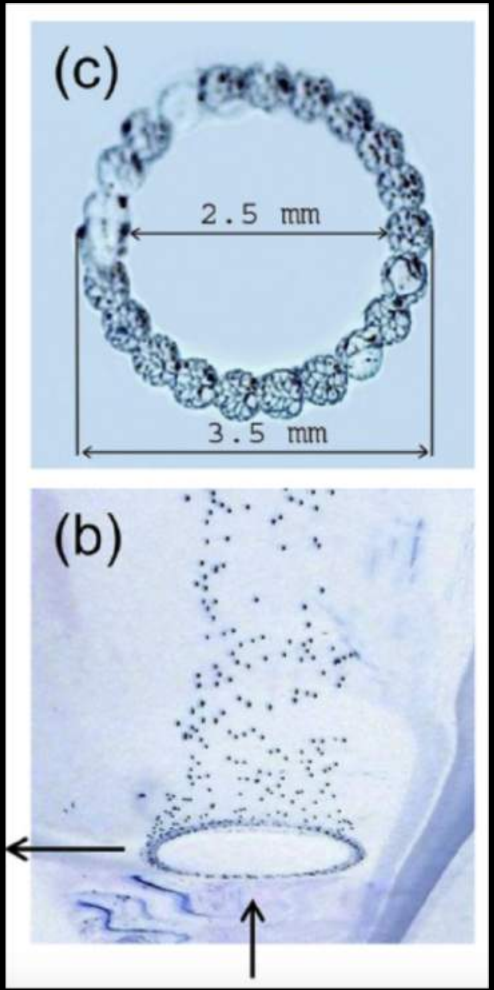


Hard to burp… extremely uncomfortable!!

Zenit et al., Physics Today 71 (11), 44–50 (2018)

Champagne effervescence





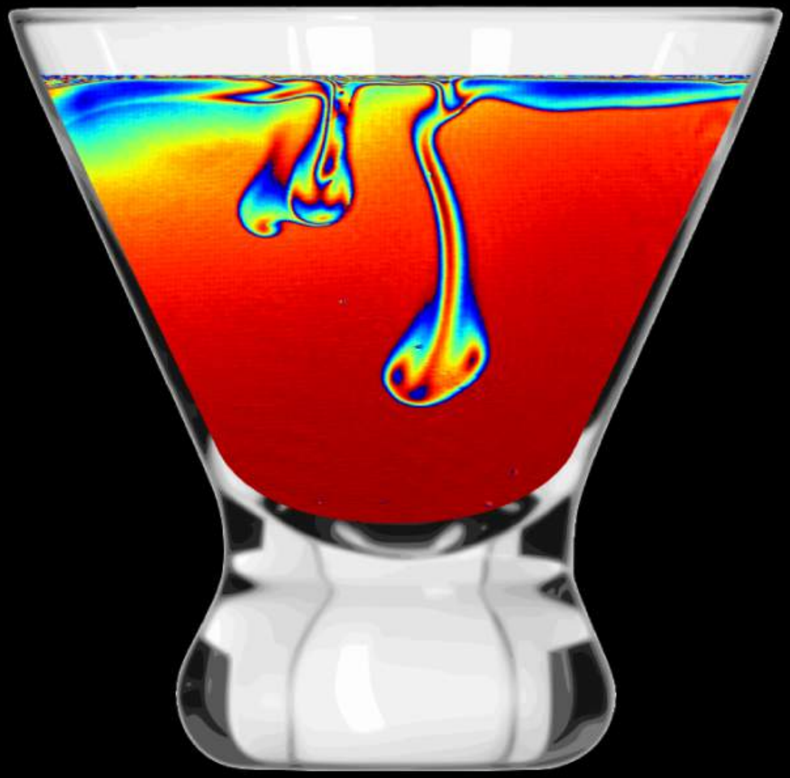
Normal glass

Treated glass

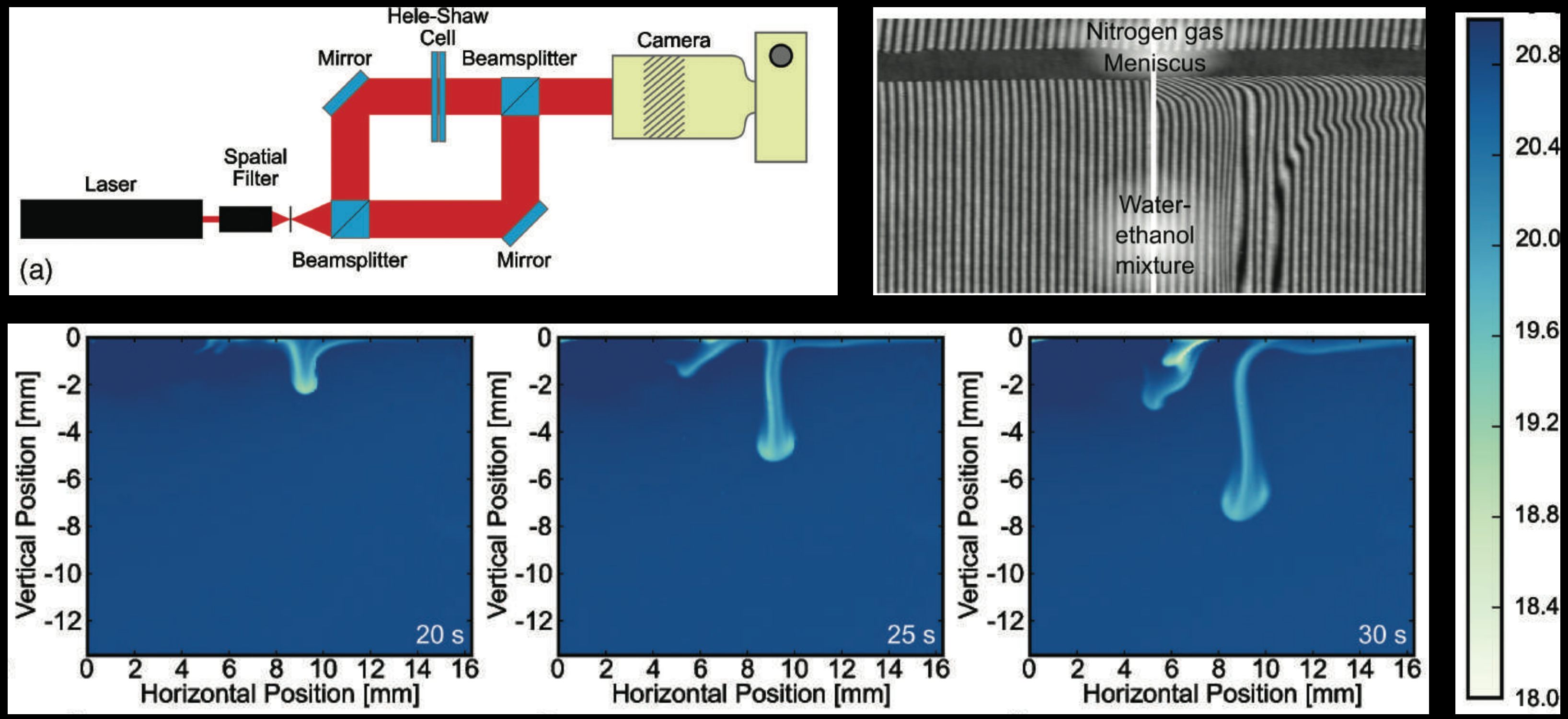
Beaumont et al. (2016) J. Food Eng. 188: 58

Evaporating cocktails – Rayleigh Taylor instability

Alcohol evaporates,
heavier water remains,
Top layer becomes unstable



Alcohol concentration (%)



Breakthrough experiment for Rayleigh-Taylor instabilities in miscible fluids

De Haeck et al. (2009) Phys. Fluids 21: 091108

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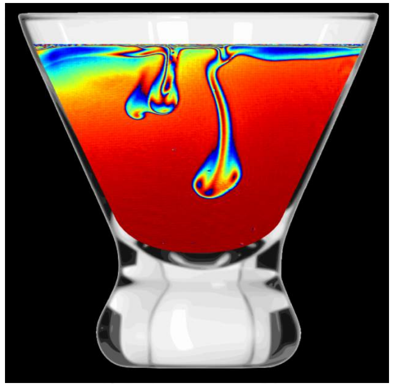


Drinks

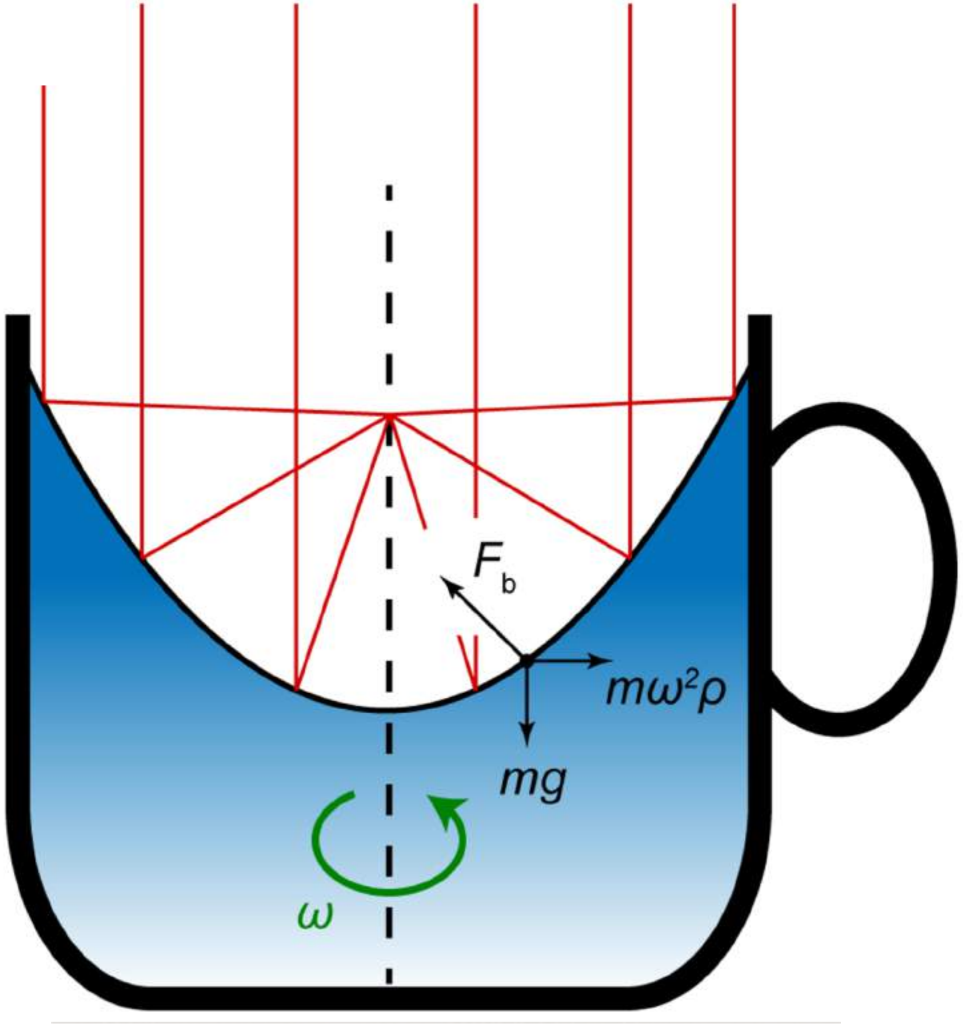
Starter

Main course

Dessert

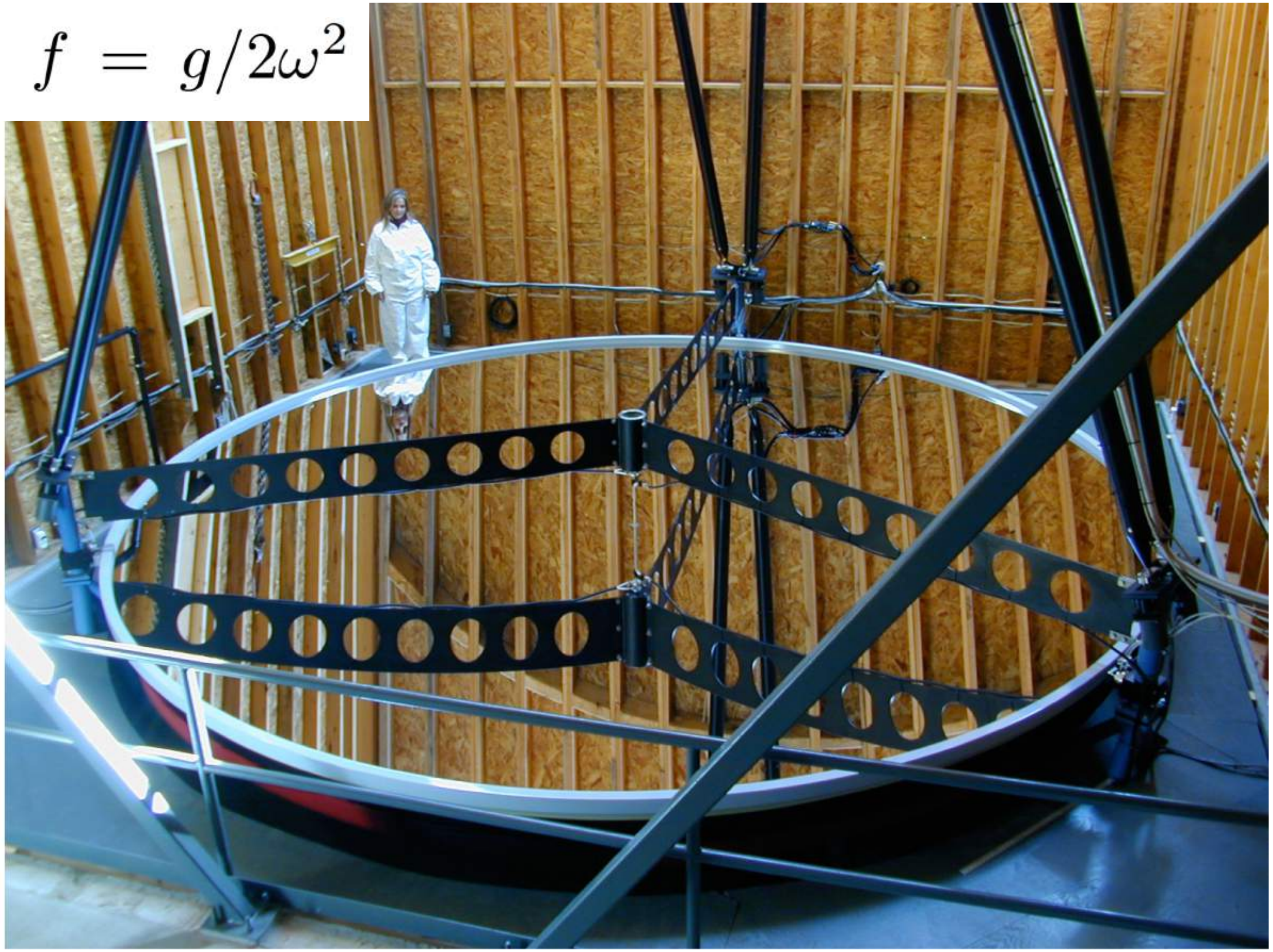
Coffee

Stirring soup - Parabolic mirror



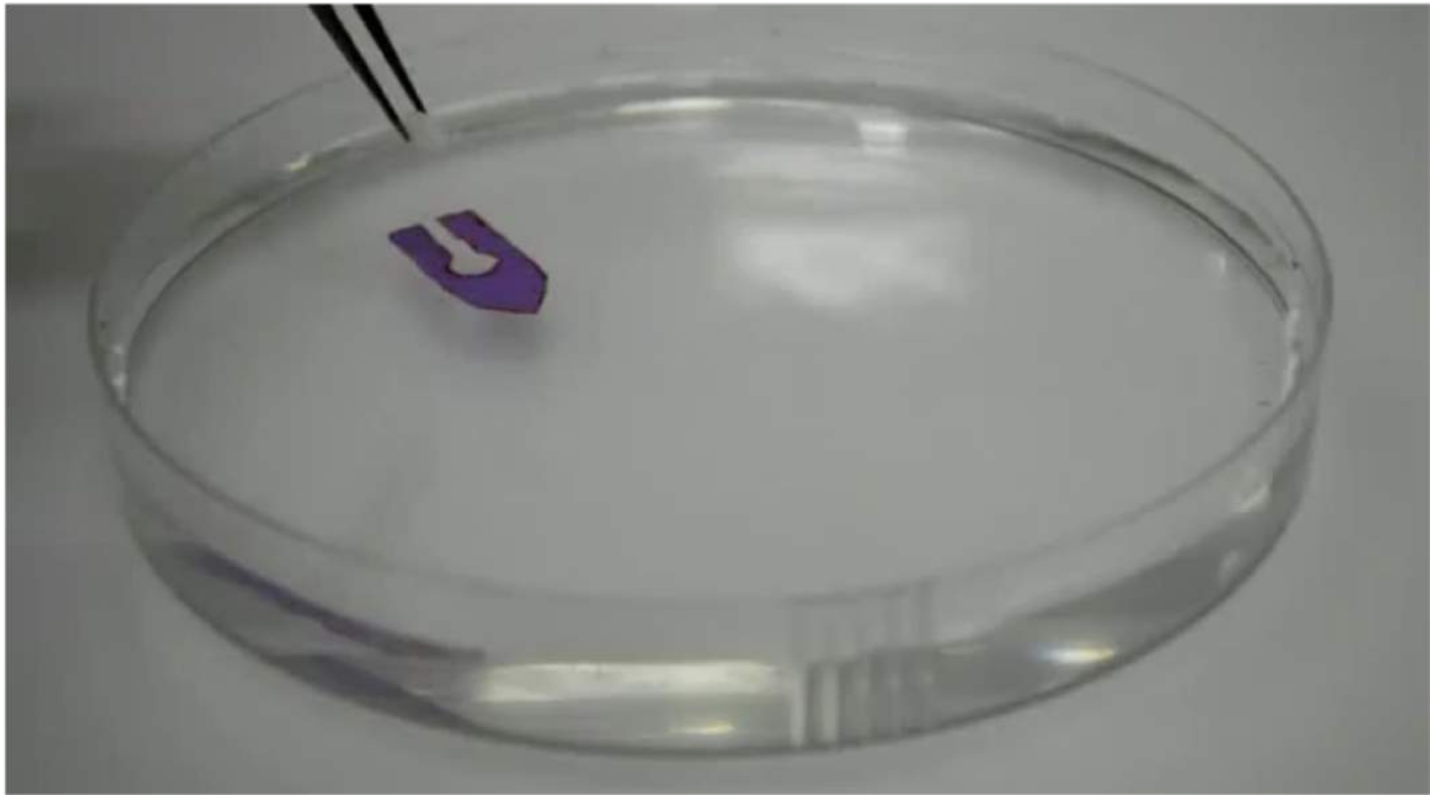
Large Zenith Telescope

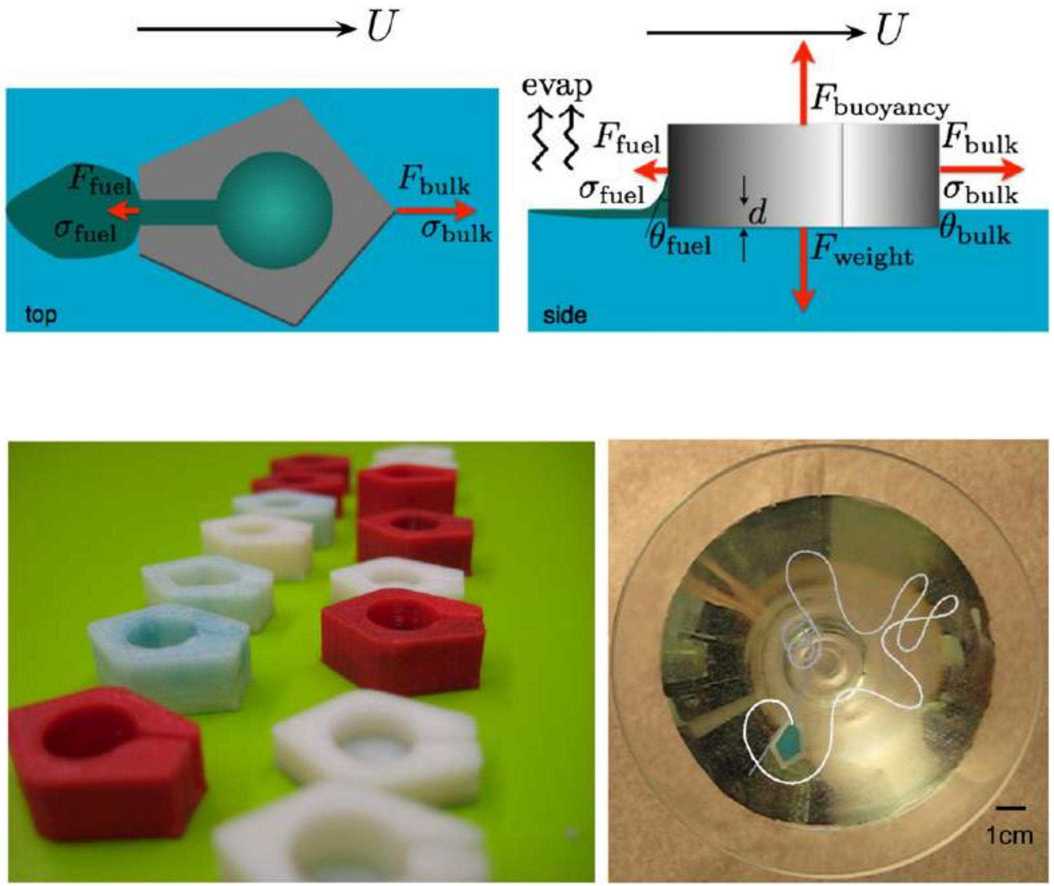
$$f = g/2\omega^2$$



Self-propelled boats

Camphor boat

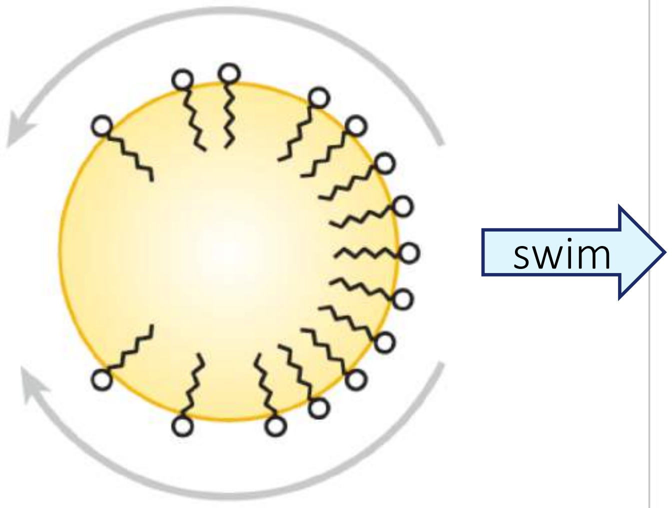


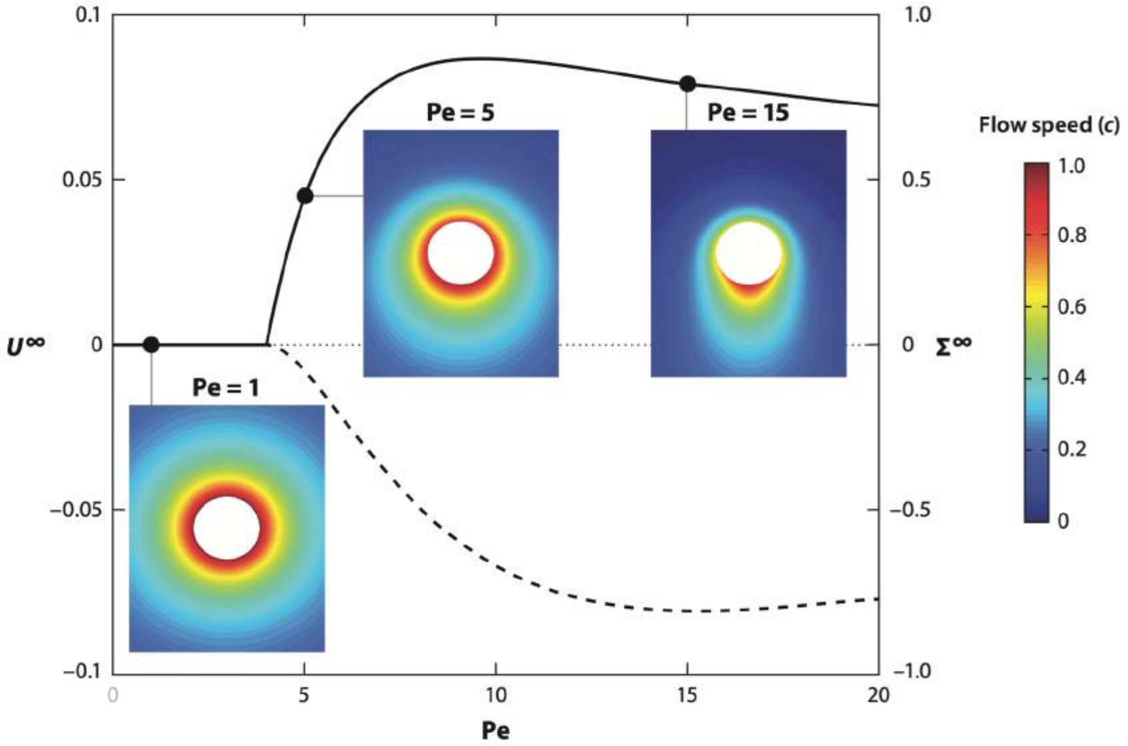


Lisa J Burton et al. (2013) Bioinspir. Biomim. 8 044003

Swimming micro-droplets
(50 µm)

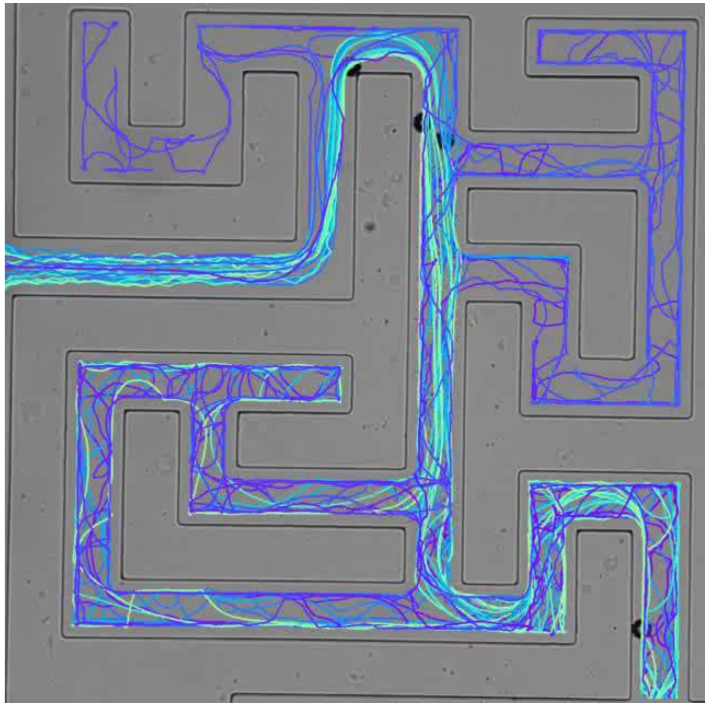
Marangoni stresses propel droplet

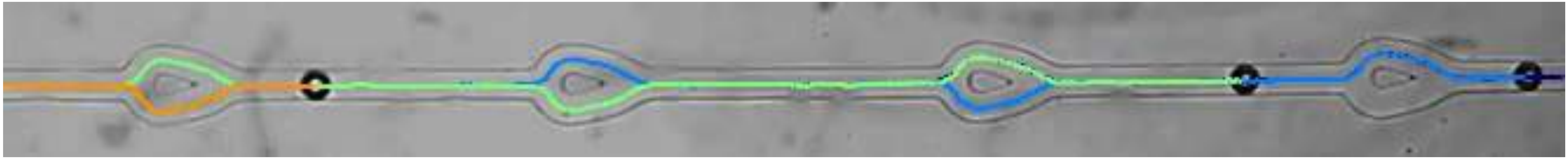




Maass et al. (Annu Rev Cond Matt Phys, 2016)

Droplets solving a maze





Jin et al. (PNAS 114: 5089, 2017)

Overview of this Presentation
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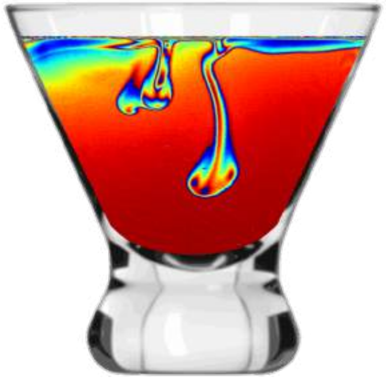


Drinks

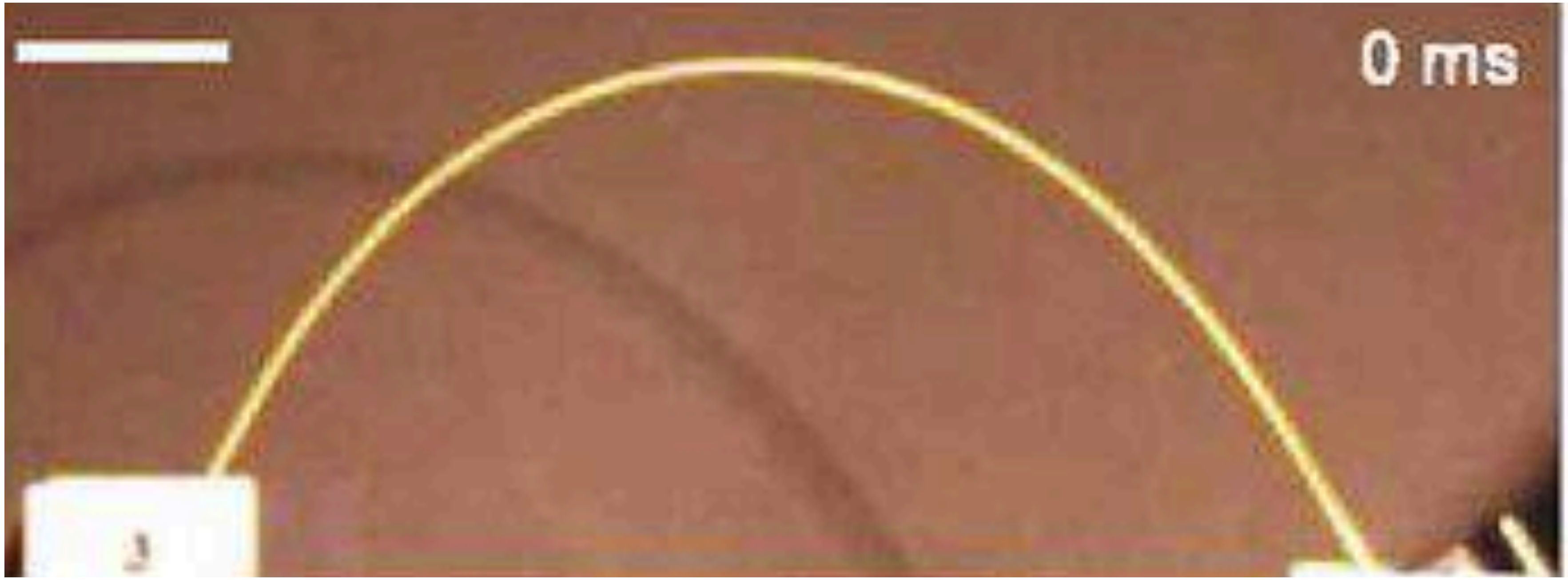
Starter

Main course

Dessert

Coffee

Spaghetti experiment

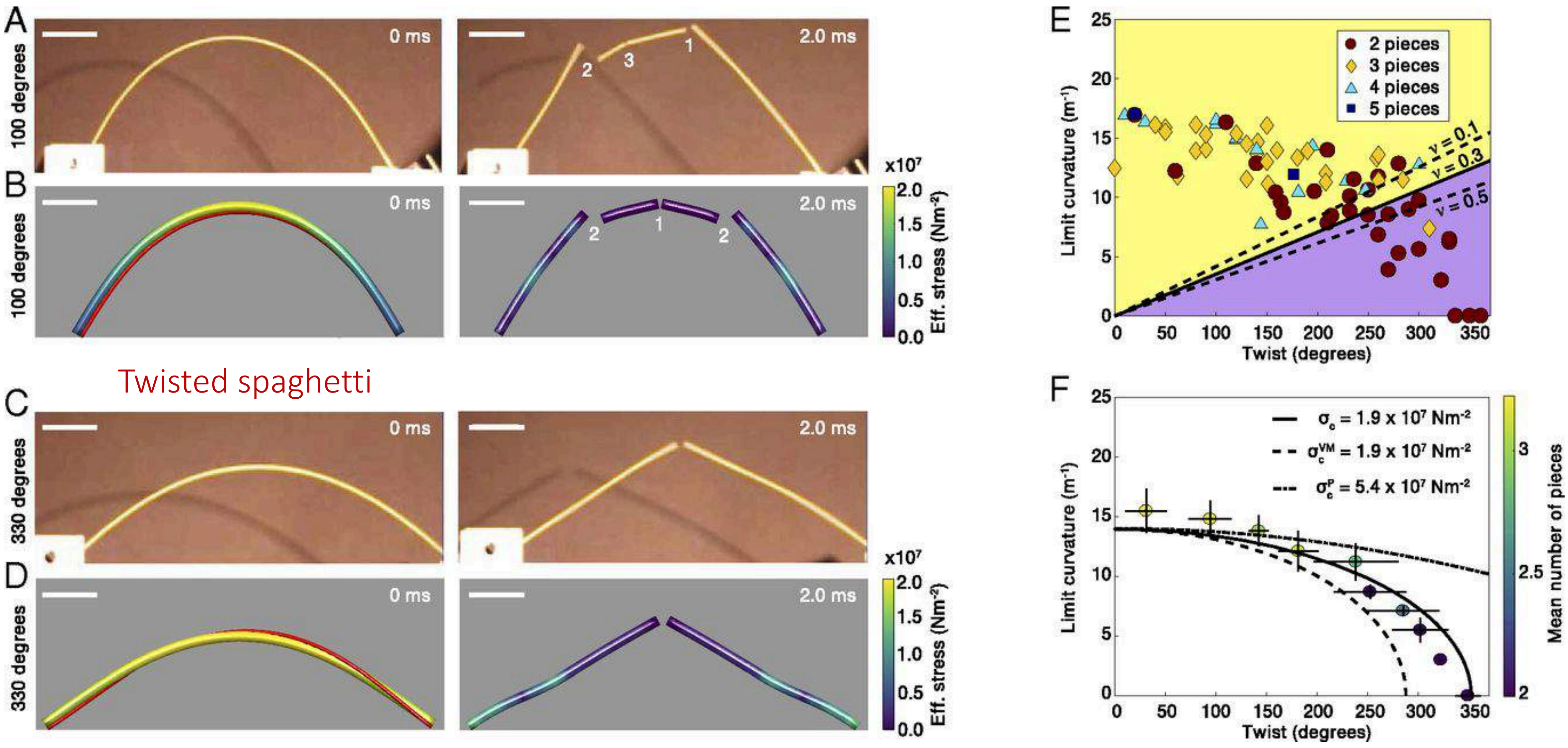


Experiment Time!

<u>Bend the pasta – in how many pieces does it break?</u>

Breaking spaghetti

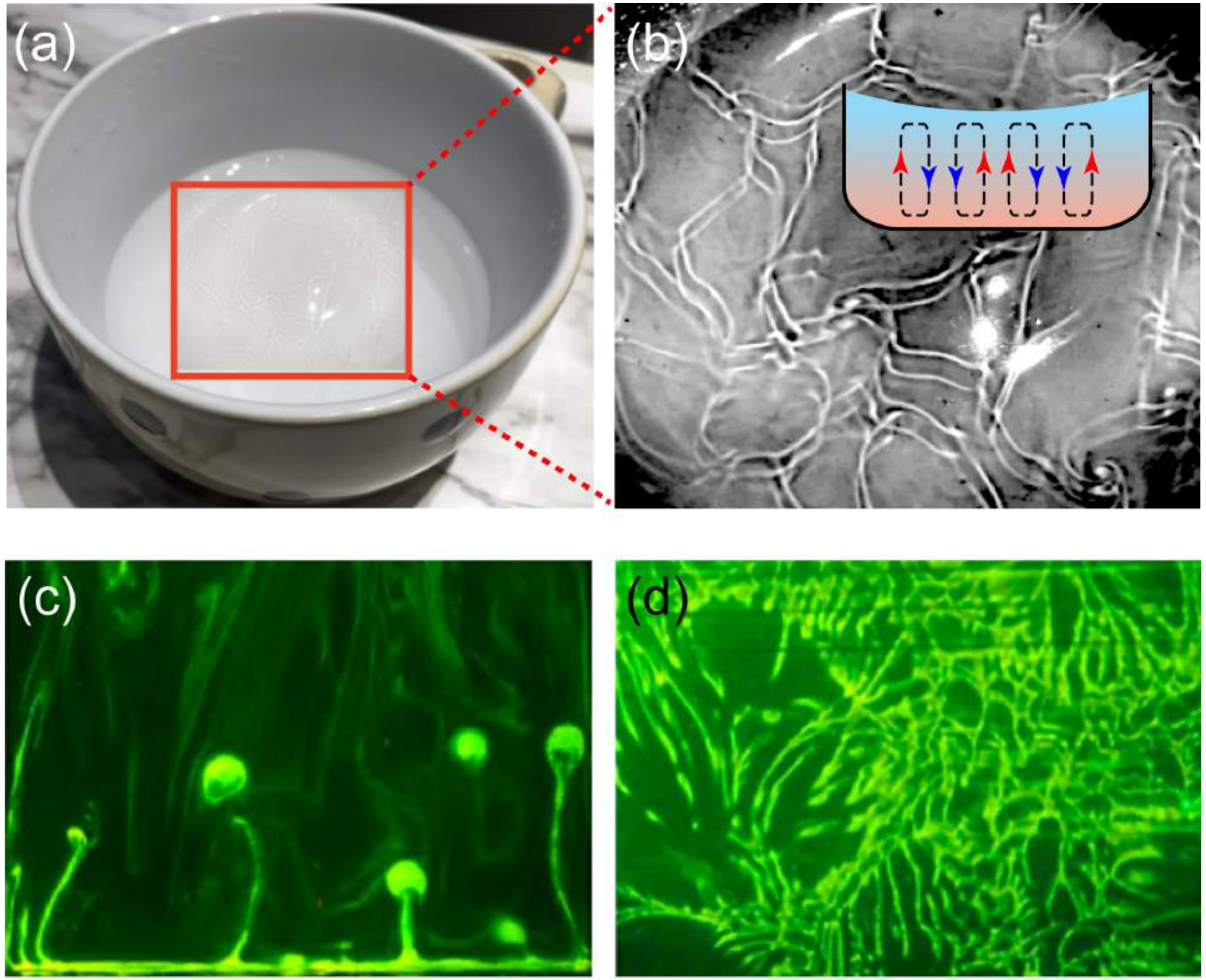
Normal spaghetti



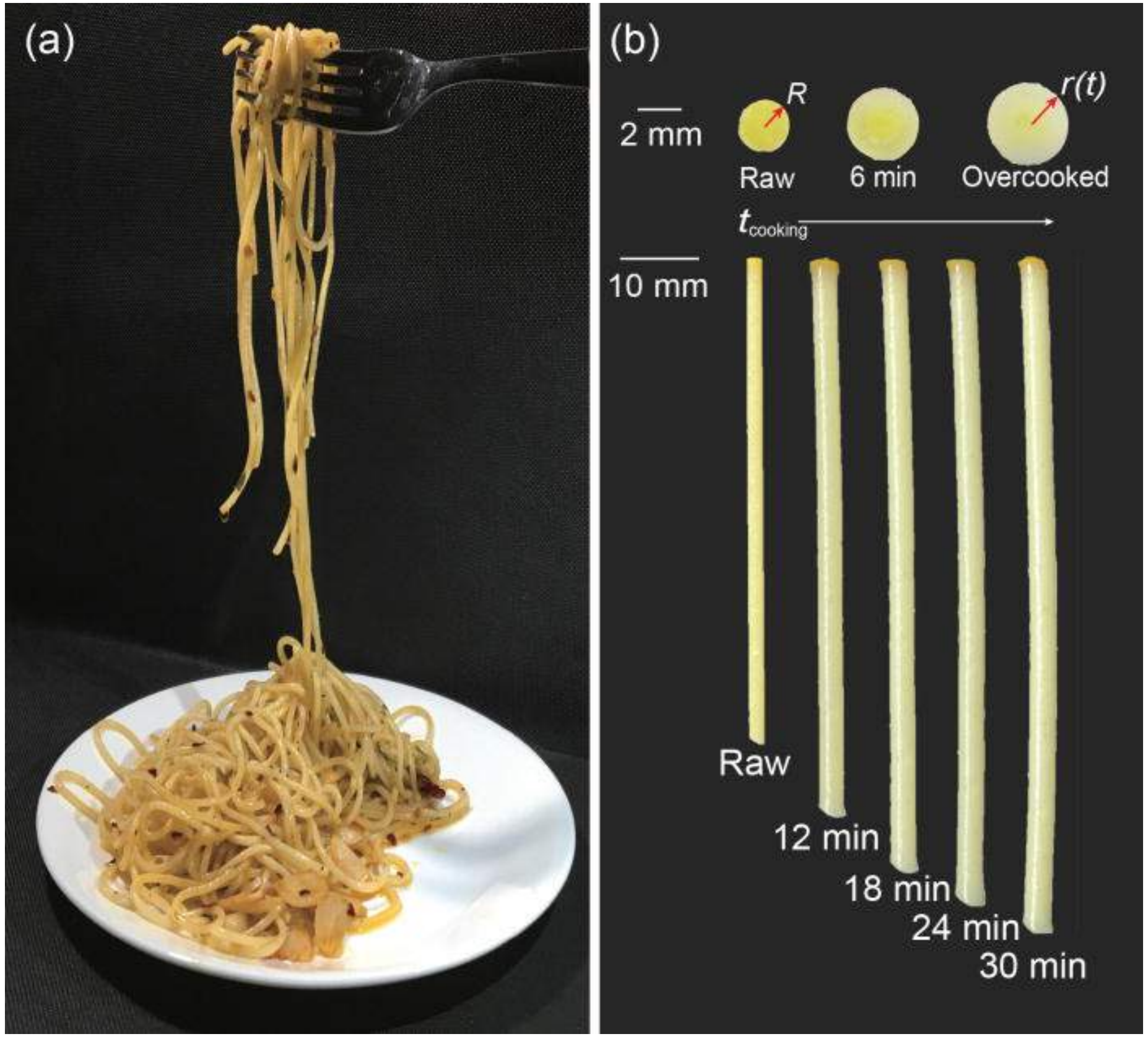
Twisted spaghetti

Heisser et al. (PNAS, 2018)

Cooking pasta



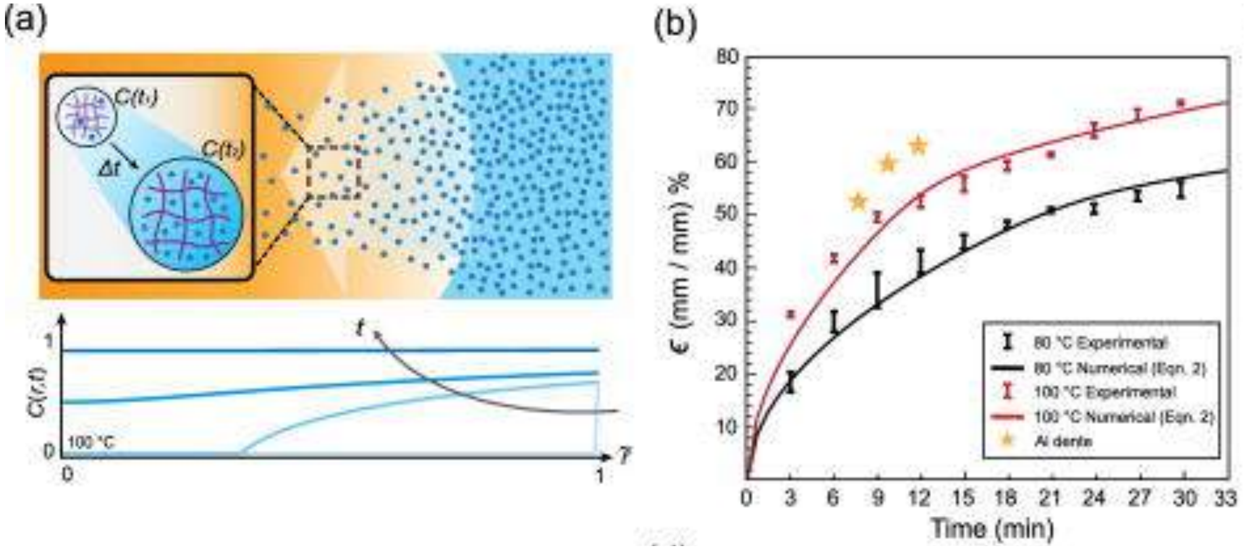
Prakash et al. (Chem Eng Sci, 2017)



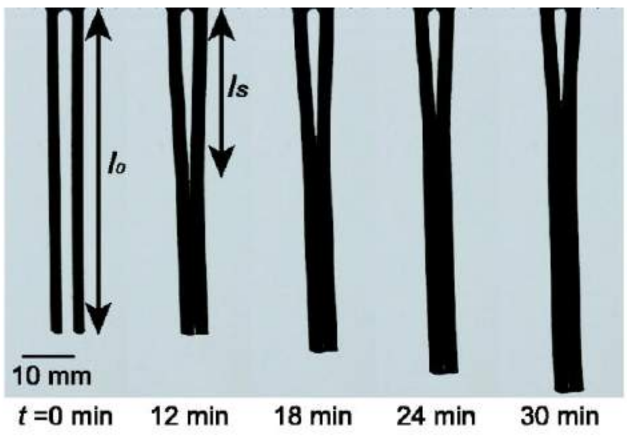
Hwang et al. (Physics of Fluids, 2021)

Cooking pasta

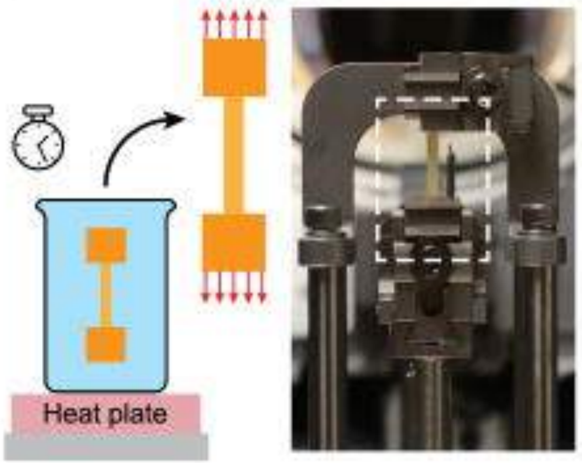
Swelling

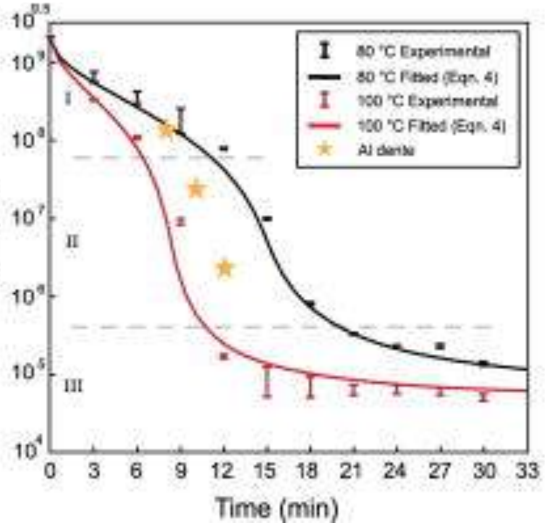


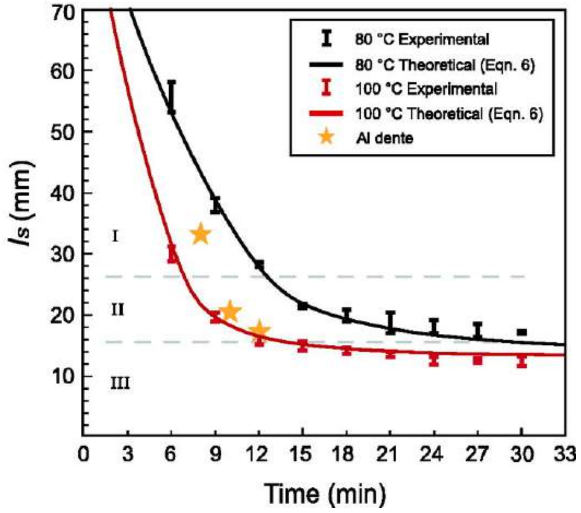
Stickiness



Softness

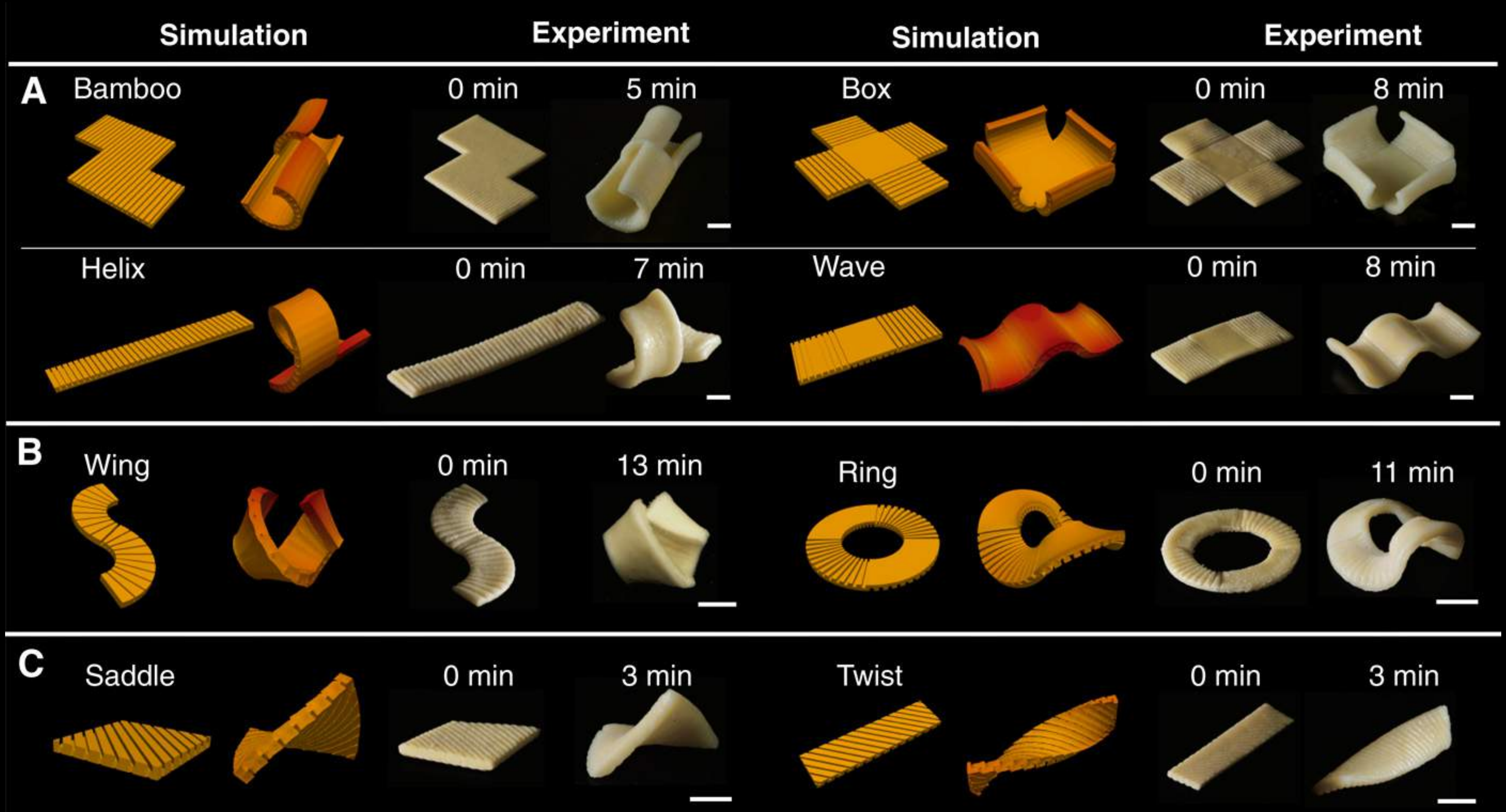






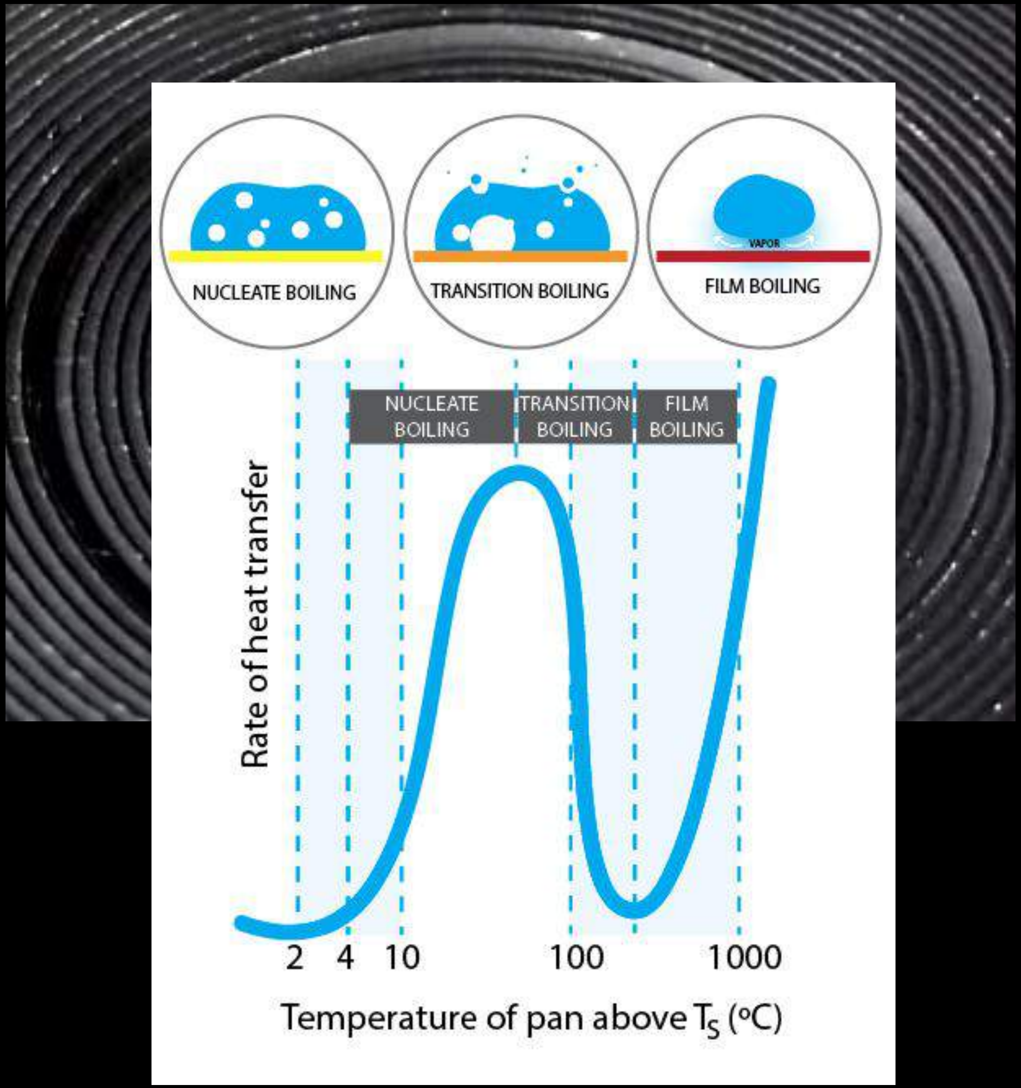
Hwang et al. (Physics of Fluids, 2021)

Morphing pasta into 3D shapes



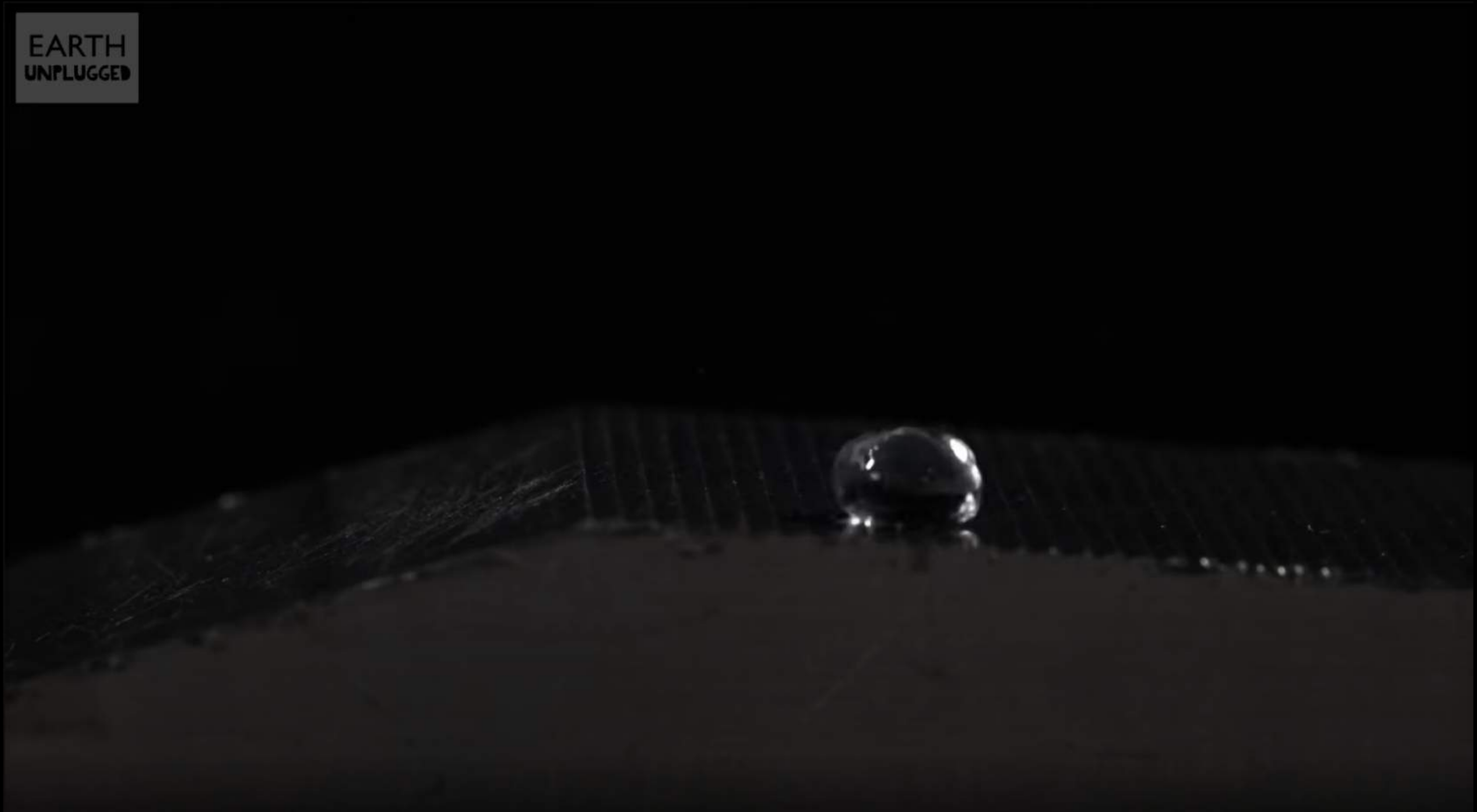
Tao et al. (Science Advances, 2021)

Grilling with the Leidenfrost effect



Bouillant et al. (Nature Physics, 2018),
Kurz Instruments

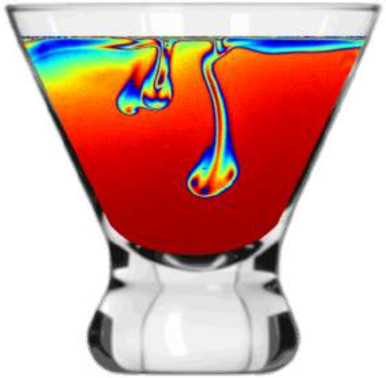
More fun with the Leidenfrost effect



More fun with the Leidenfrost effect

Singla and Rivera (PRF 2019), Bouillant et al. (Nature Physics, 2018)

Overview of this Presentation
(Menu of the Day)



Drinks

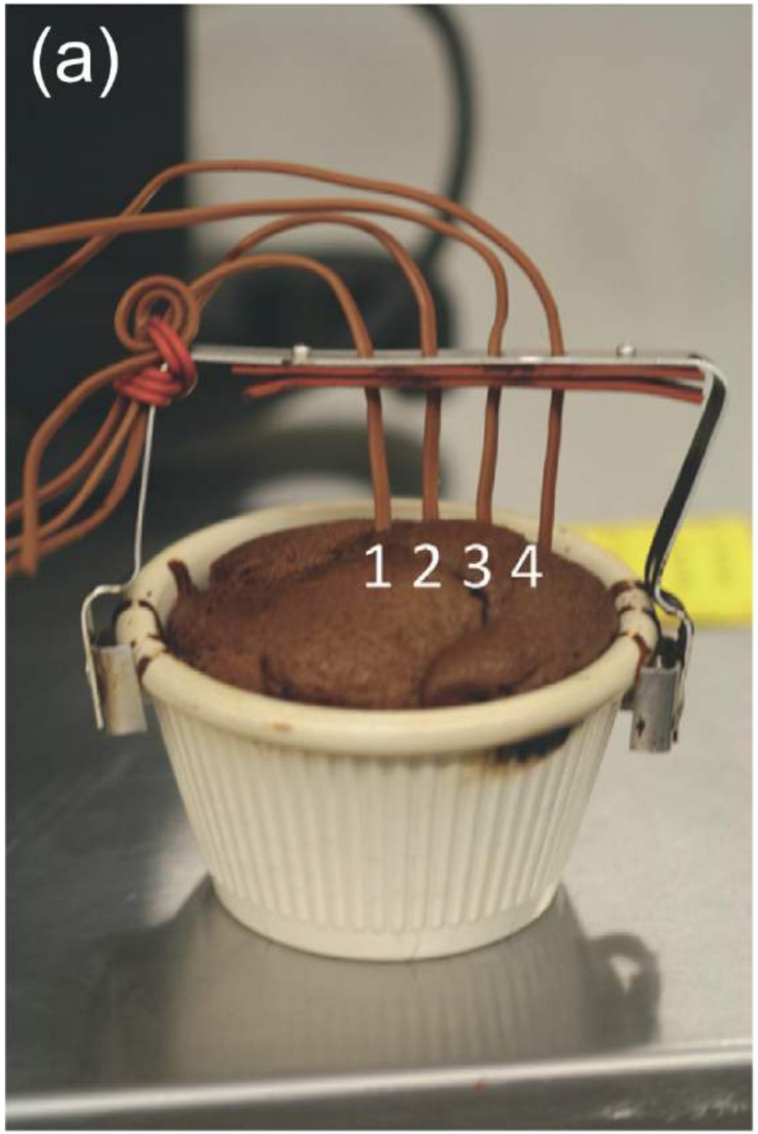
Starter

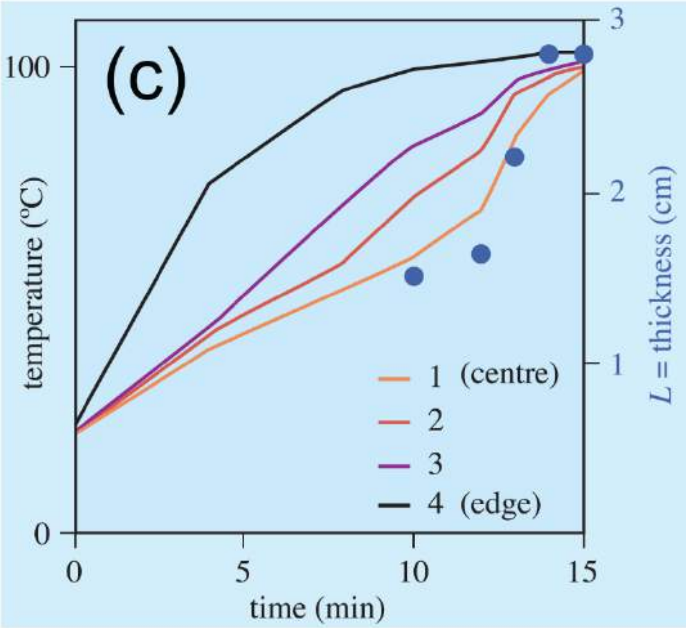
Main course

Dessert

Coffee

Baking a cake properly

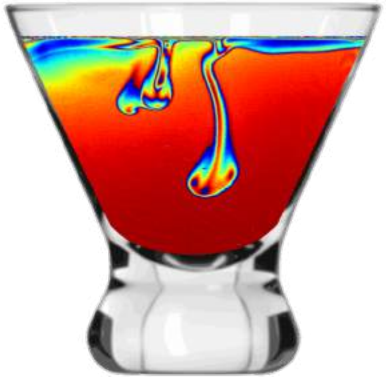





CSA ASC
asc-csa.gc.ca
GALLEY

Mixing at low Reynolds number

Overview of this Presentation
(Menu of the Day)



Drinks

Starter

Main course

Dessert

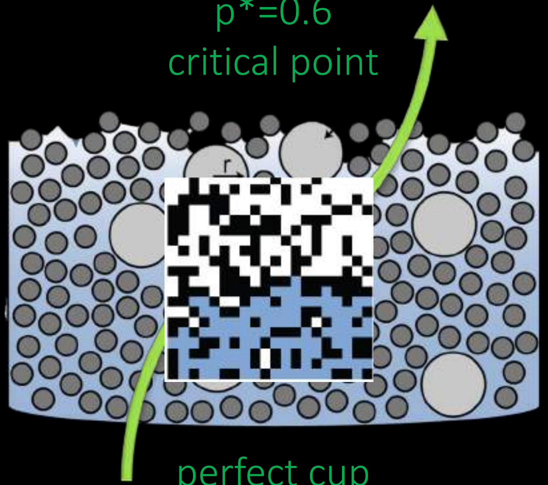
Coffee

Coffee percolation

p=0.4
no percolation

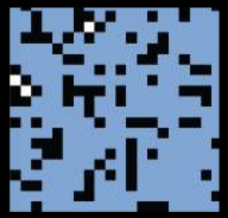
Too much coffee

p*=0.6
critical point

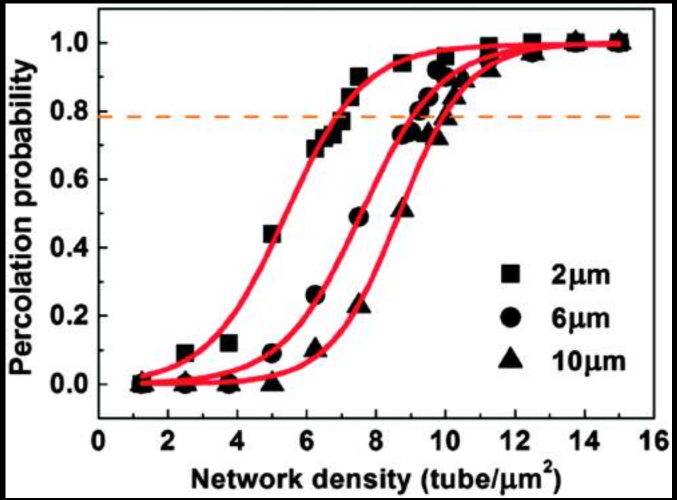


perfect cup

p=0.8
percolation



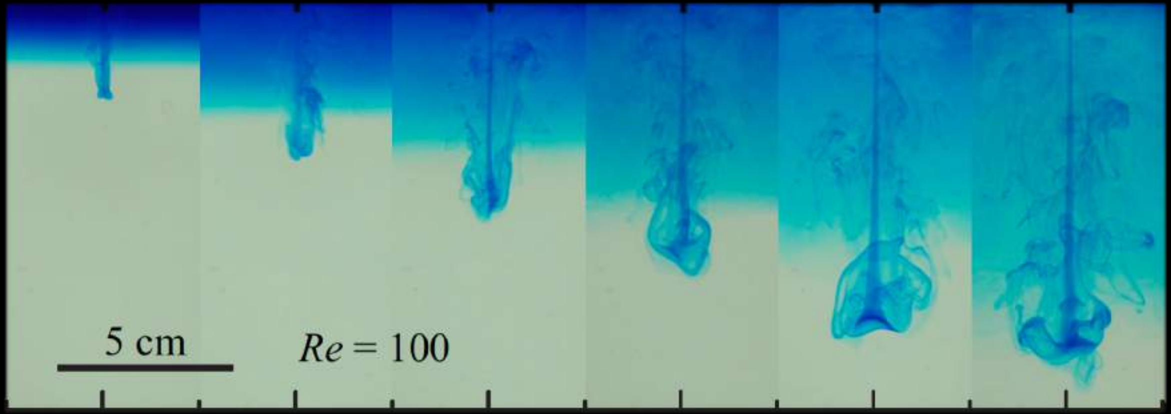
Too weak coffee



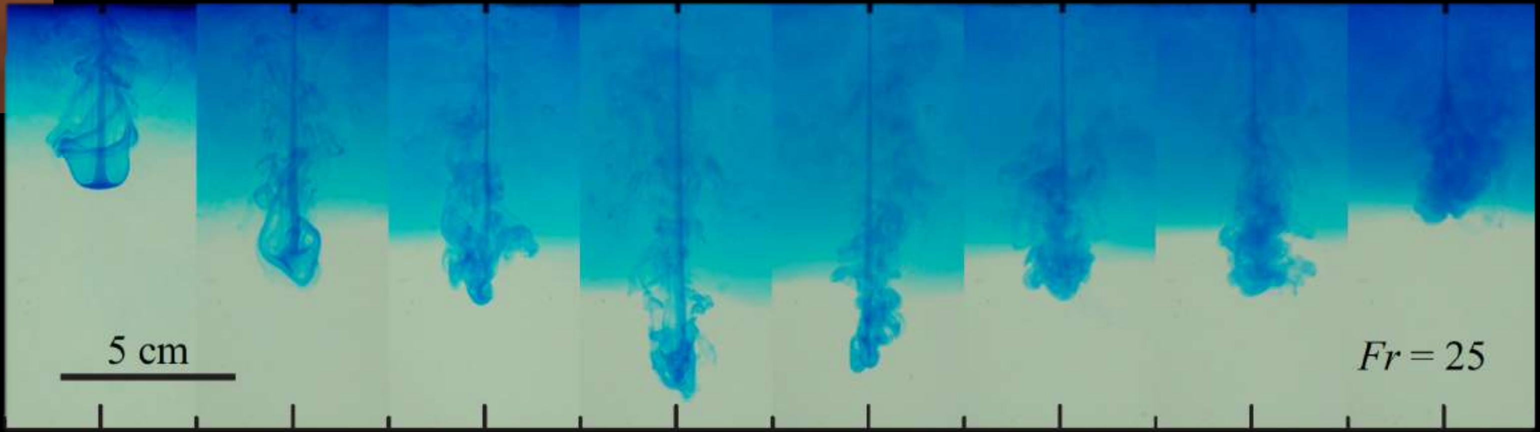
Xia & Thorpe, PRA (1988), Stauffer & Aharoni (1993), Ersi Ni (2015)

Latte art = inverted fountain

Increasing Froude number →



Increasing Reynolds number →

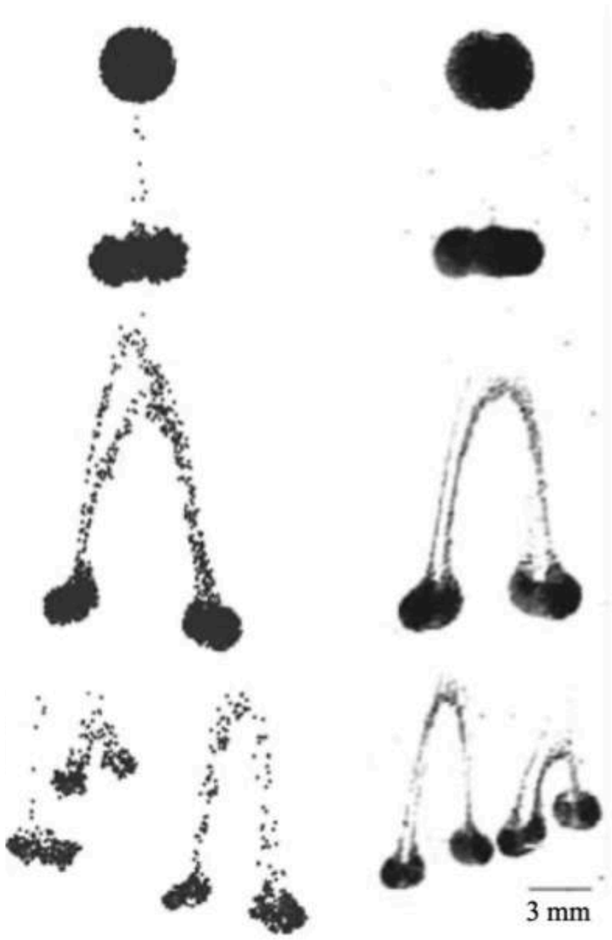


Key variables:

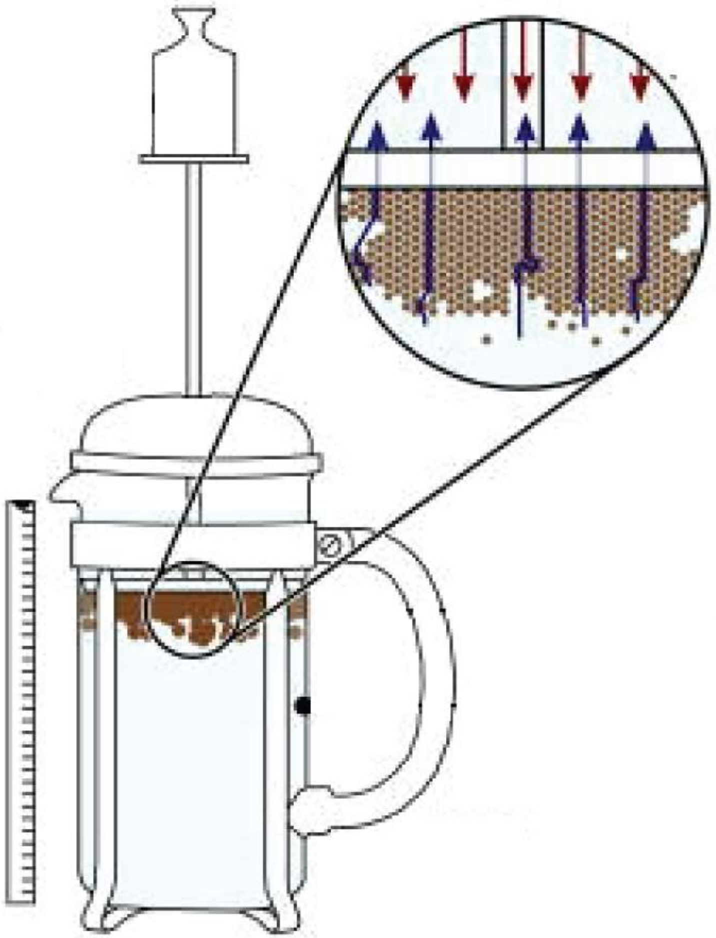
- Velocity of pouring
- Height of milk jug
- Radius of the milk jet

Xue et al. (2019) Phys Rev Fluids 4: 024501

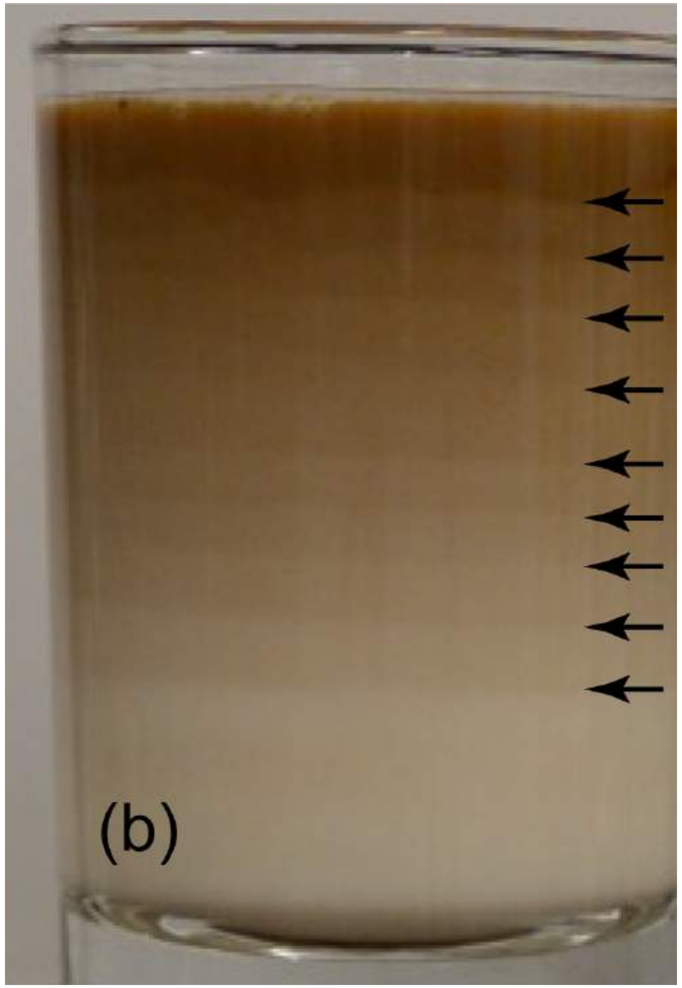
More coffee preparation methods



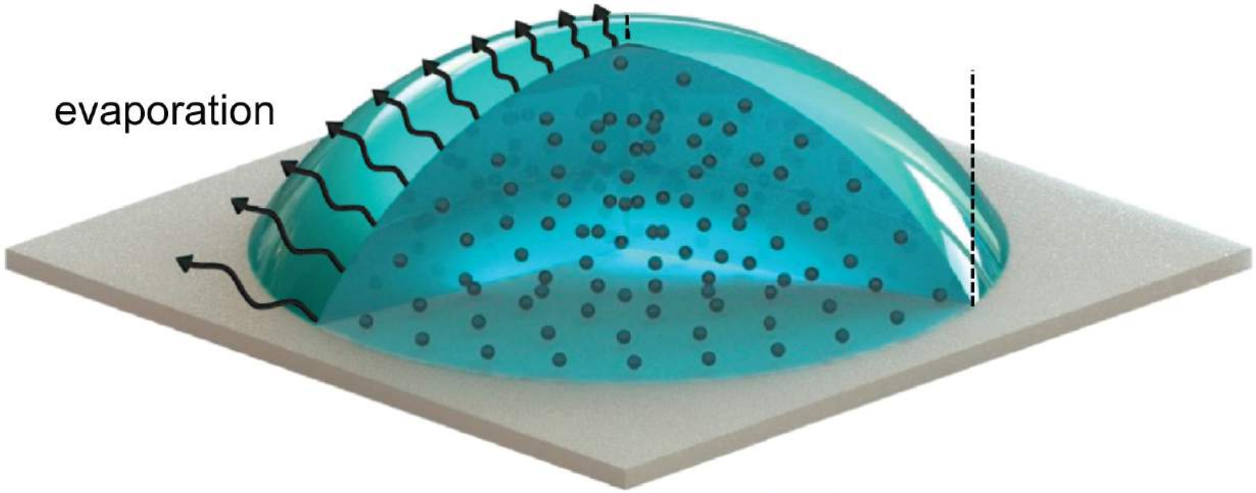
Metzger et al. (J Fluid Mech 2007)



Wadsworth et al. (Am J Phys 2021)

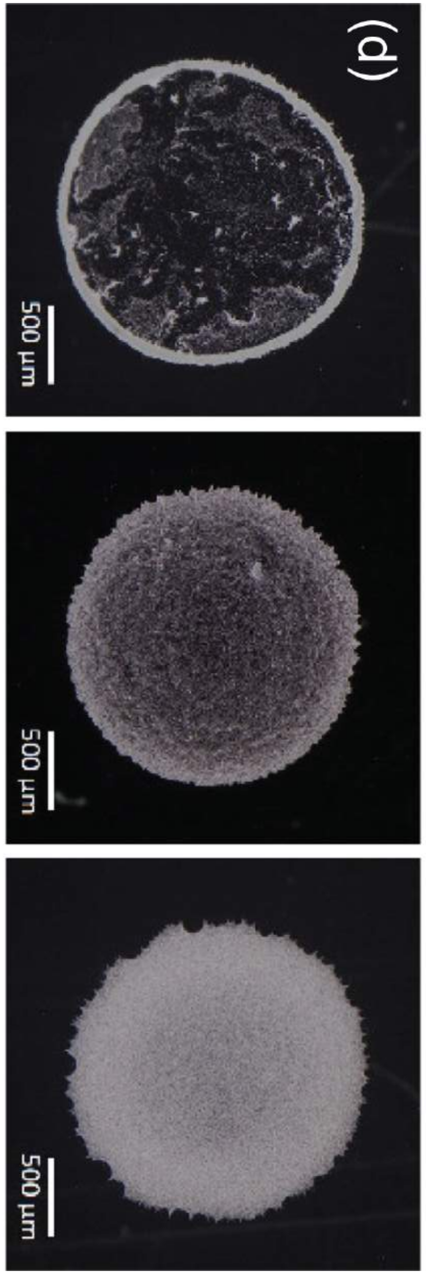


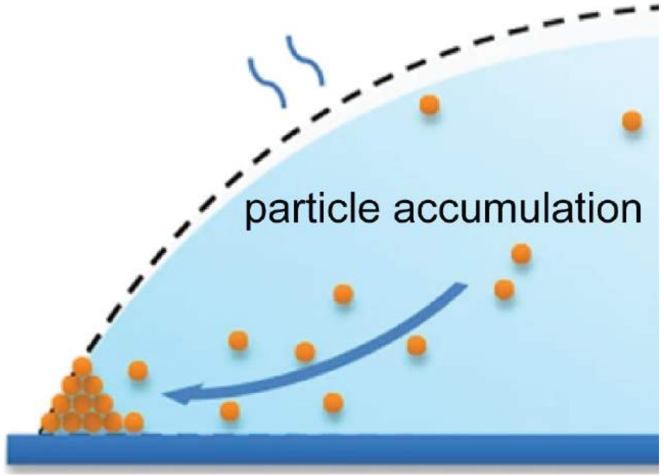
Xue et al. (Nat Commun, 2017)



Coffee ring effect

...and preventing it for coating materials





Add cellulose nanofibers

Jafari Kang et al. (2016), Li et al. (2016), Ooi et al. (2017)

Culinary Fluid Mechanics

Arnold Mathijssen, Maciej Lisicki, Vivek Prakash, Endre Mossige

In press, Reviews of Modern Physics (RMP)
Preprint: arXiv 2201.12128

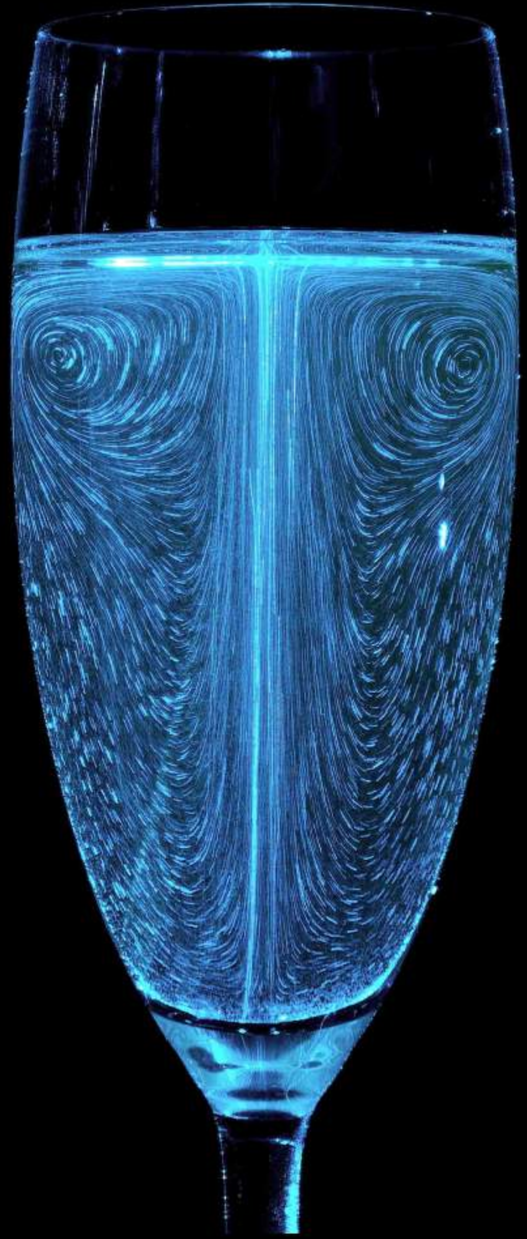


Image courtesy of
Gerard Liger-Belair

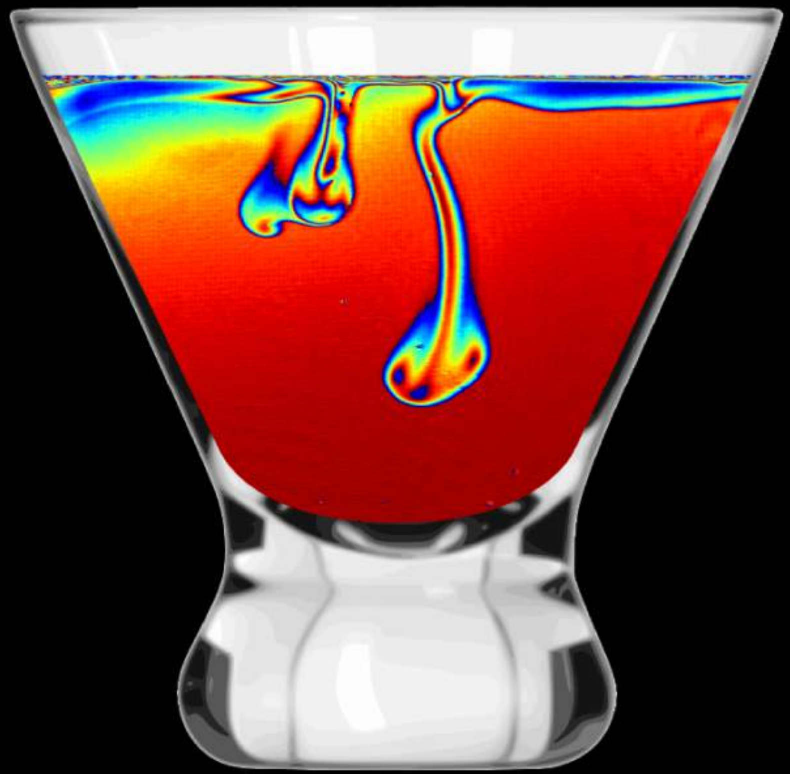


Image courtesy of
Sam Dehaeck

Image courtesy of
photographer “Burst”

CONTENTS

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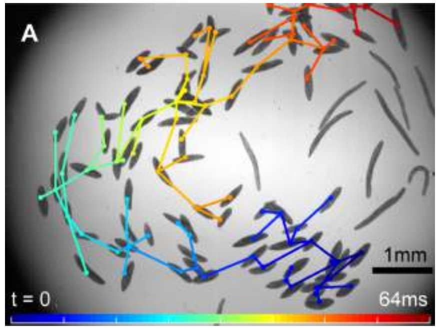
Thank you for your attention!!

amaths@upenn.edu

Intelligent active matter

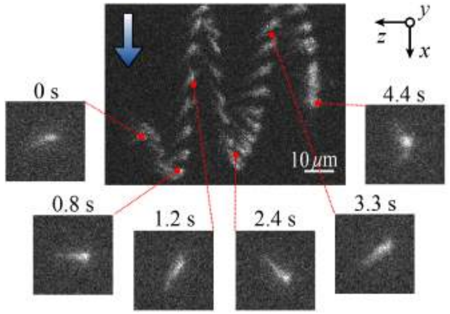
Ultra-fast motion in cell biology



Nature (2019)

Physics of Pathogens

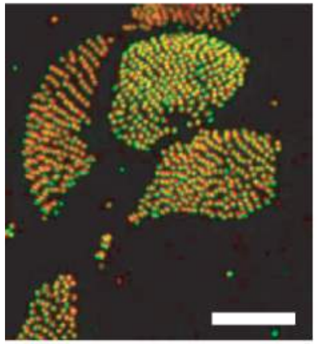
Bacterial contamination dynamics



PRL (2016), Nature Communications (2019)

Respiratory flows

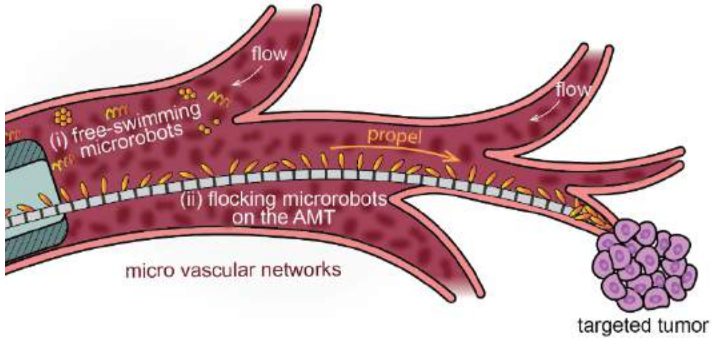
Pathogen clearance in the mouse airway



Nature Physics (2020), JFM (2016)

Microbiological fluid mechanics

Cargo transport in cardiovascular flows



PRL (2021, 2019), JFM (2015)

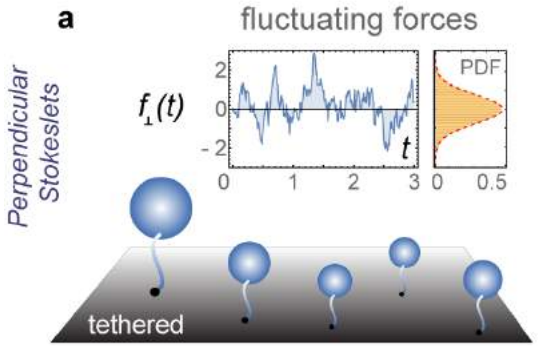
Food science

Culinary physics and edible materials

arxiv.org/abs/2201.12128 (RMP 2023)

Non-equilibrium stat. mech.

Actively driven diffusion in biology



Nature Communications (2021)