

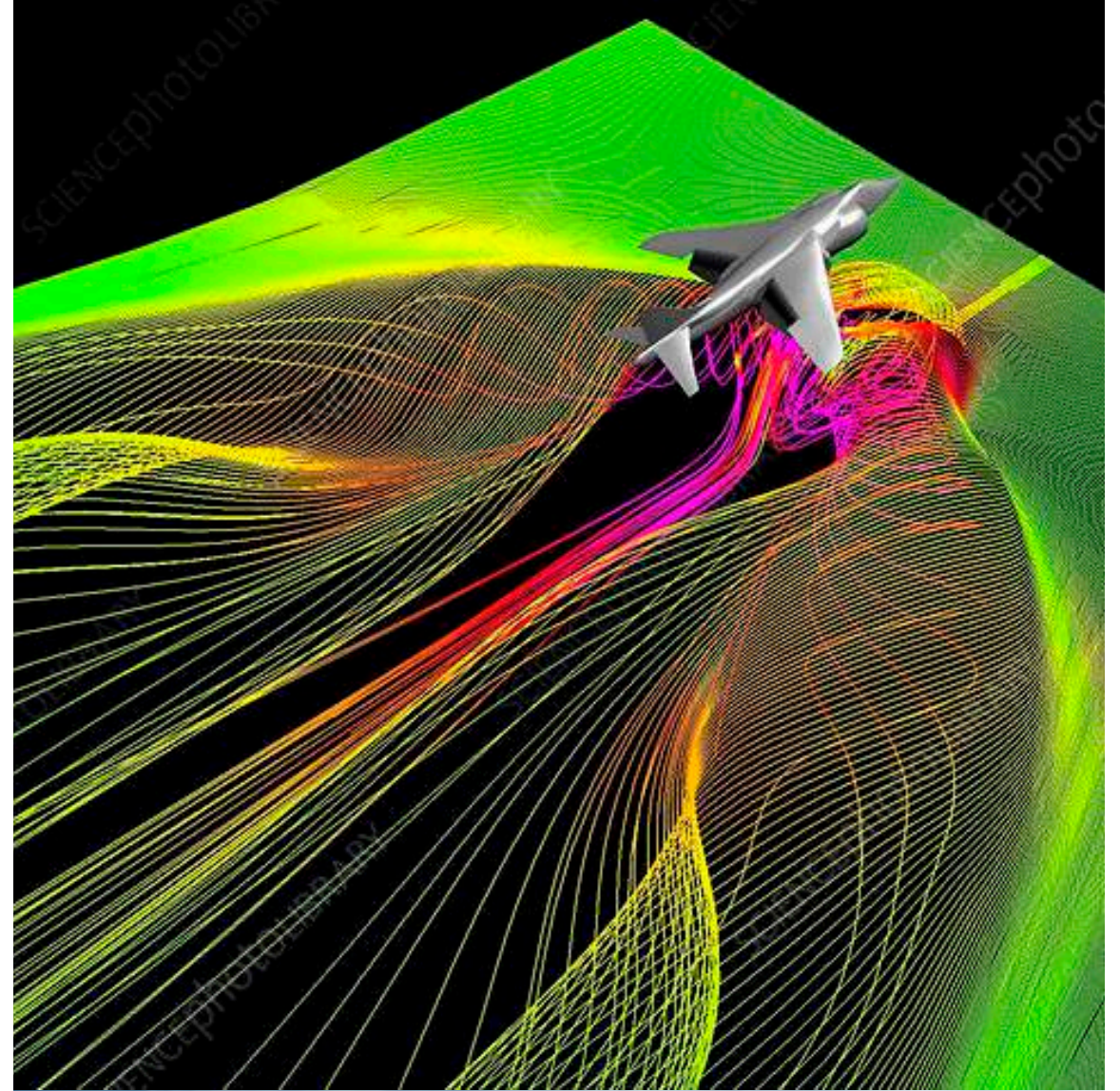
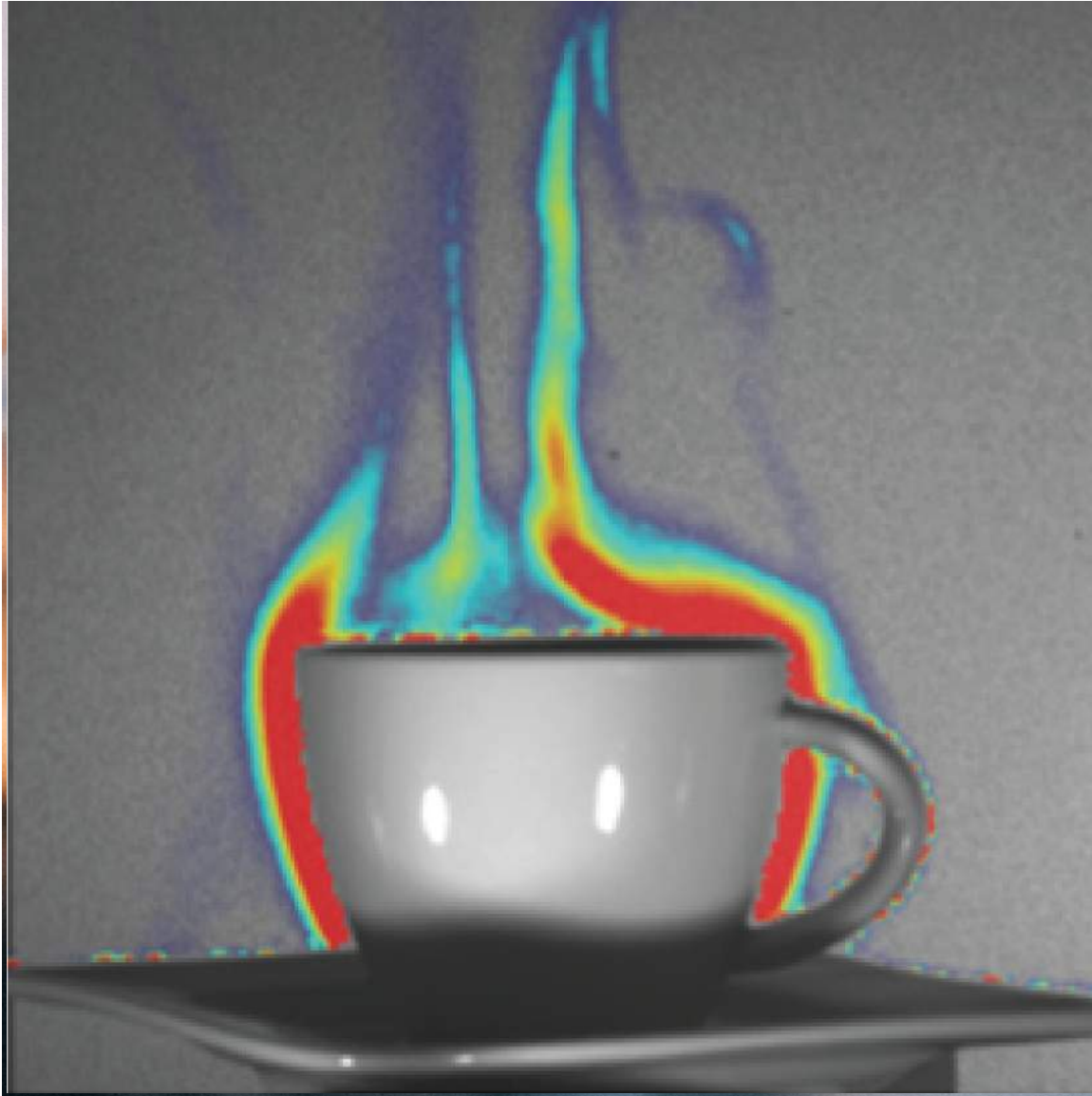
Culinary Fluids Mechanics

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



**FOOD
MANUFACTURING**



OIL AND GAS



**SIMULATION
AND MODELLING**



**RENEWABLE
POWER**



**PERFORMANCE
SPORTS**



**METEOROLOGY
AND CLIMATE**



AGRICULTURE



HEALTHCARE



**HIGH-TECH
MANUFACTURING**



**LIQUID
CONTROL**



**SHIPPING /
MARINE**



**POWER
GENERATION**



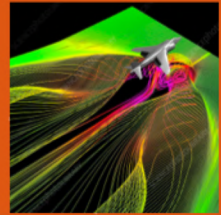
**CHEMICAL
INDUSTRY**



**BUILT
ENVIRONMENT**



**WATER
MANAGEMENT**



**AEROSPACE
AND DEFENCE**

Why study “Culinary Fluid Mechanics”?



Creative
(just like chefs)



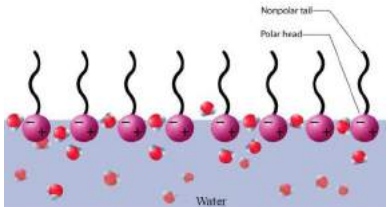
Accessible
(affordable and observable)



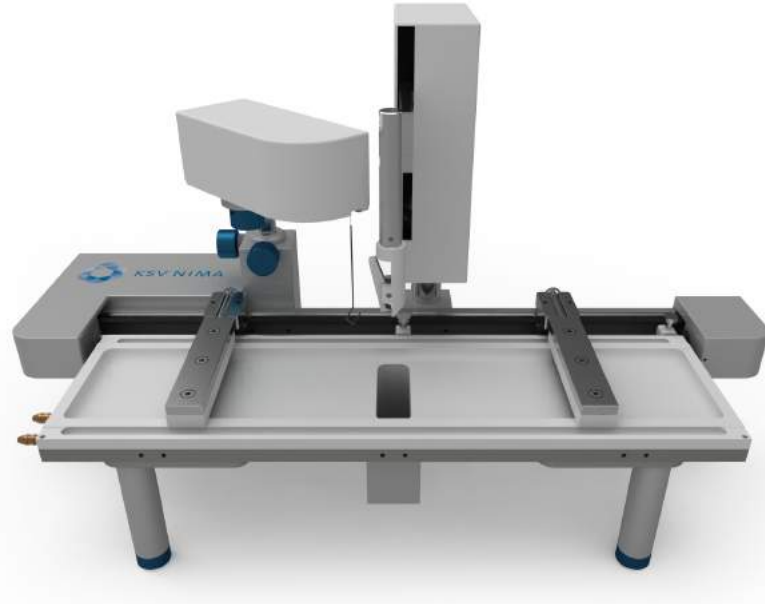
Equitable
(support minorities in STEM)



Agnes Pockels
(1862 - 1935)



The legacy of Agnes Pockels



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"*

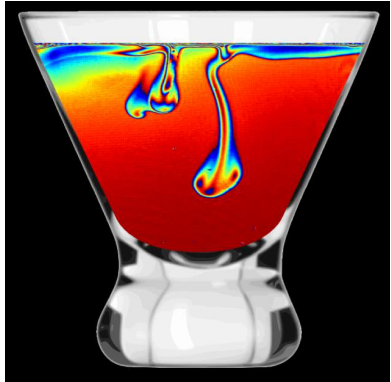
Rayleigh helped to publish
her work in the journal **Nature**

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.

**So, she established the modern
discipline known as surface science**

Overview of this Presentation (Menu of the Day)



Drinks



Starter



Main course

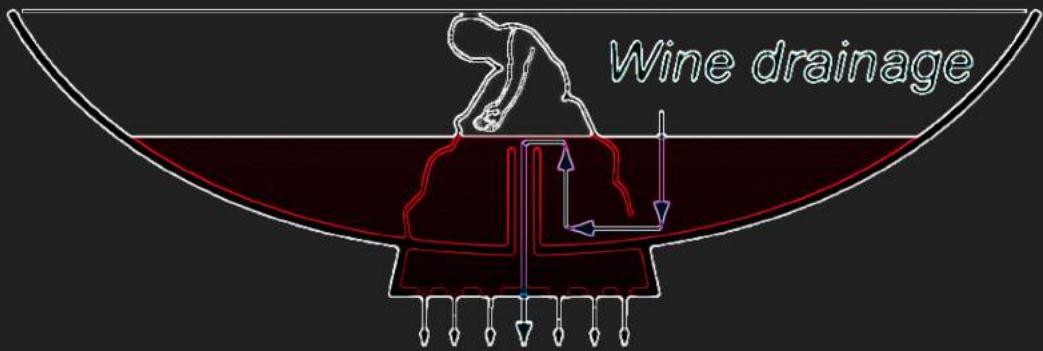


Dessert



Coffee

Tantalus bowl: an ancient practical joke



WHERE IS MY WINE??



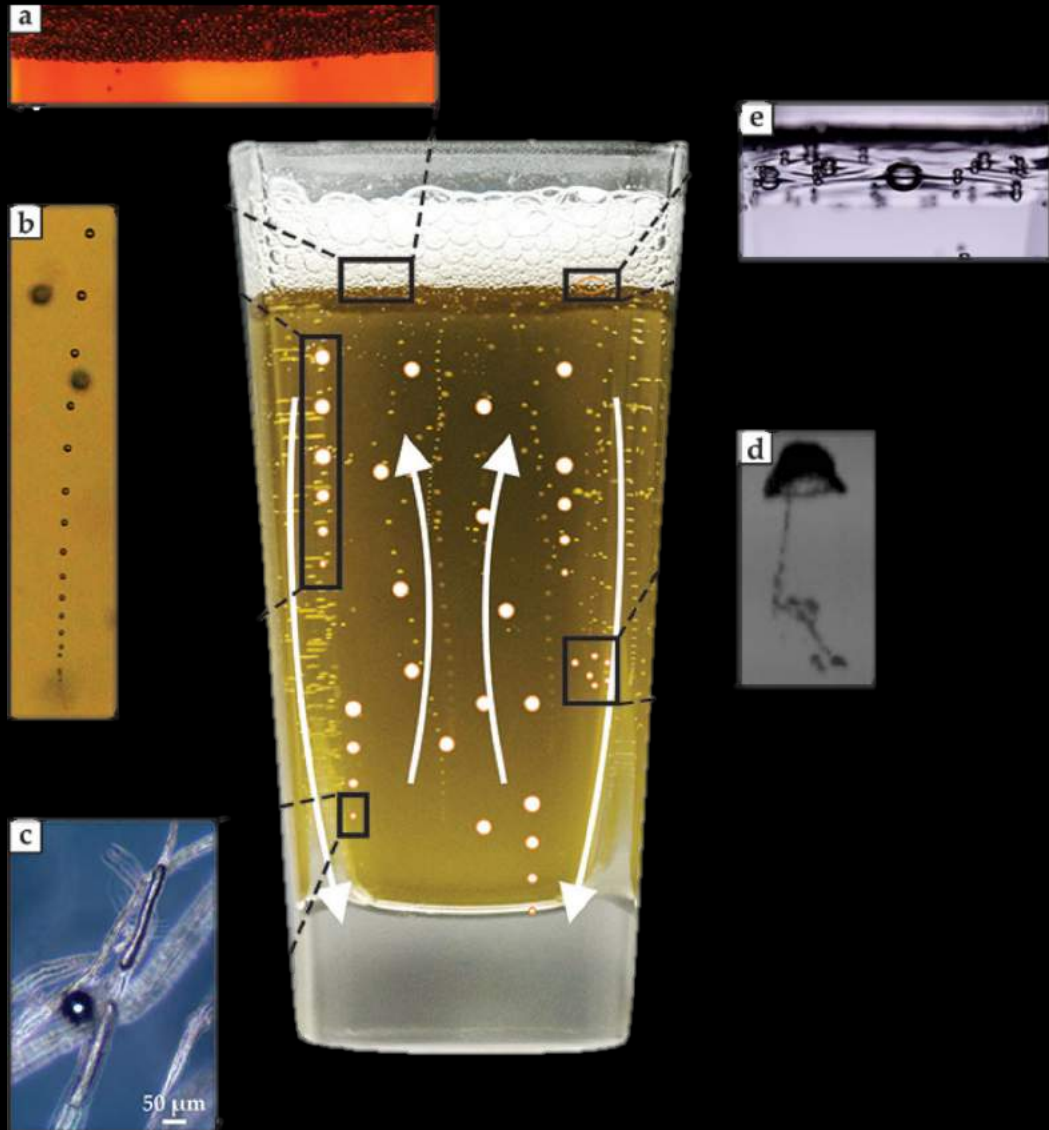
The bowl replies: You already had too much!



Vinkovci treasure of late Roman silver plate
Vulic et al. (2017), J. Roman Archaeol. 30, 127

Ewoldt research group

Physics of bubbly drinks

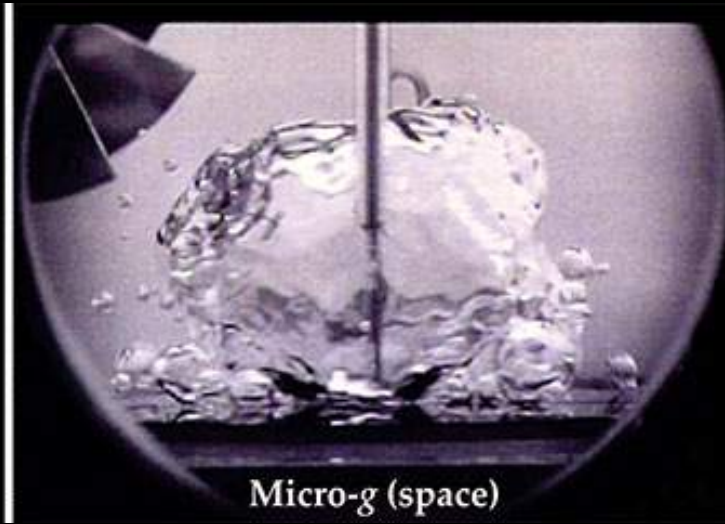
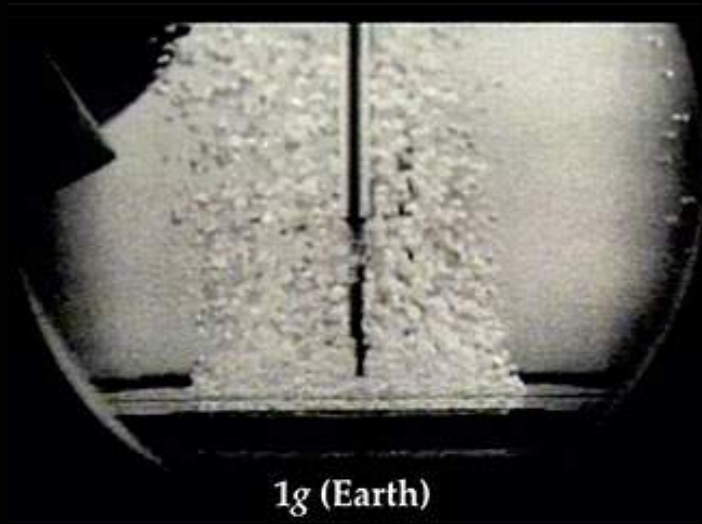


- a) Foam
 - Creamy taste (yield stress rheometry)
 - Temperature insulation (heat transfer)
- b) Bubble train
 - Size increases (supersaturated CO_2)
 - Velocity increases (drag hydrodynamics)
- c) Nucleation
 - Creation of bubbles (thermodynamics)
- d) Bubble implosion
 - Plume formation (multiphase flows)
- e) Foam stability
 - Drainage dynamics (interfacial flows)

Bubbles in space

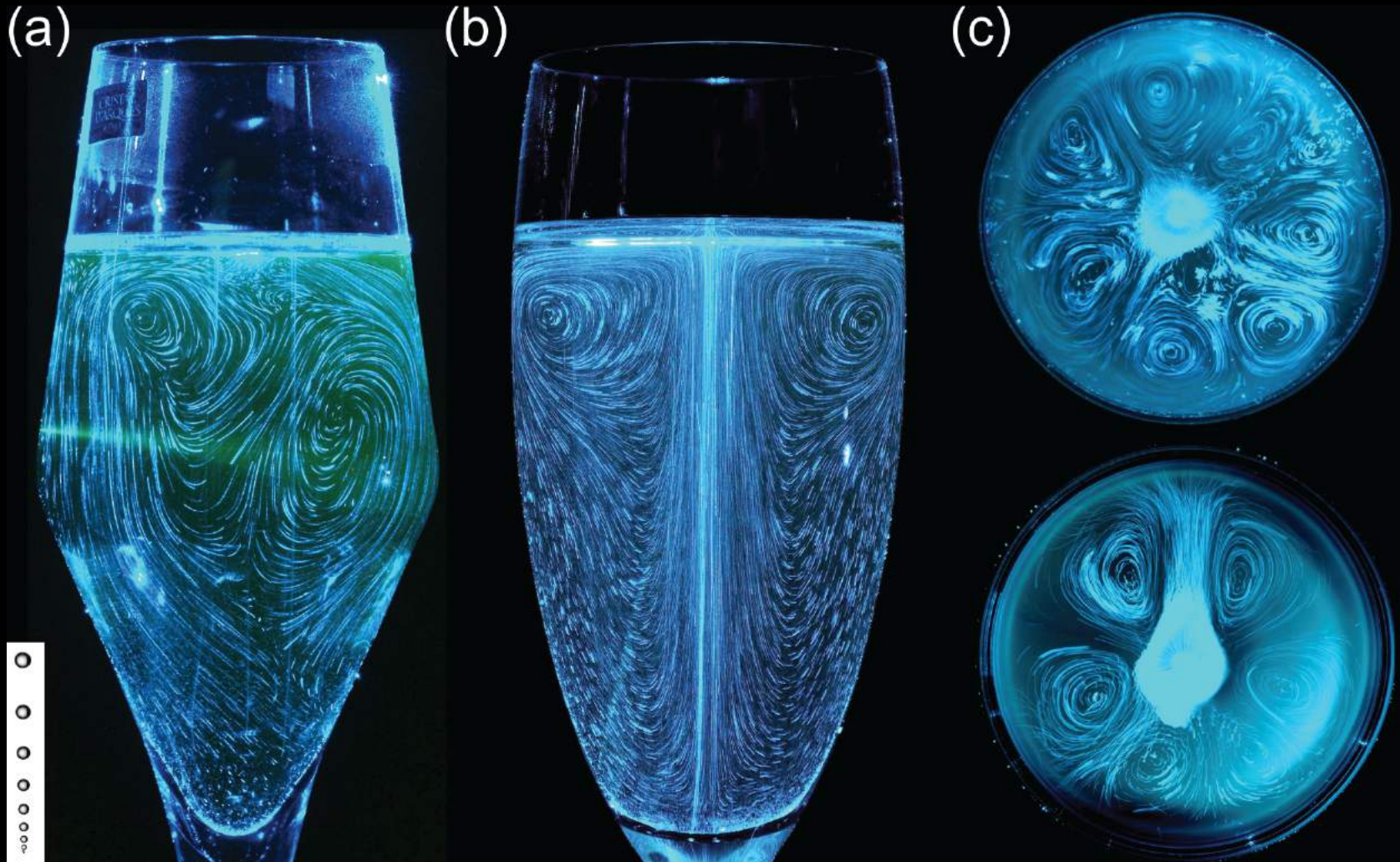


What happens if an astronaut drinks sparkling water?



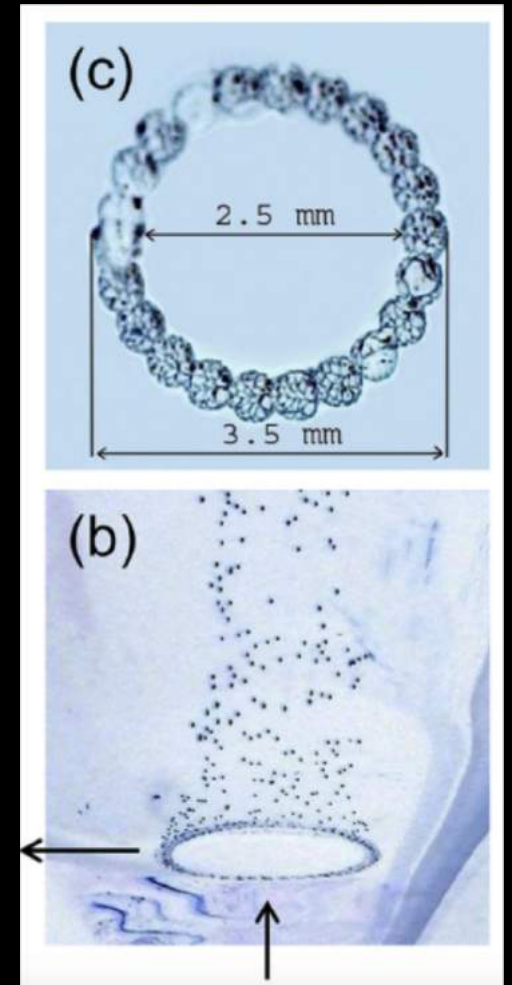
Hard to burp... extremely uncomfortable!!

Champagne effervescence



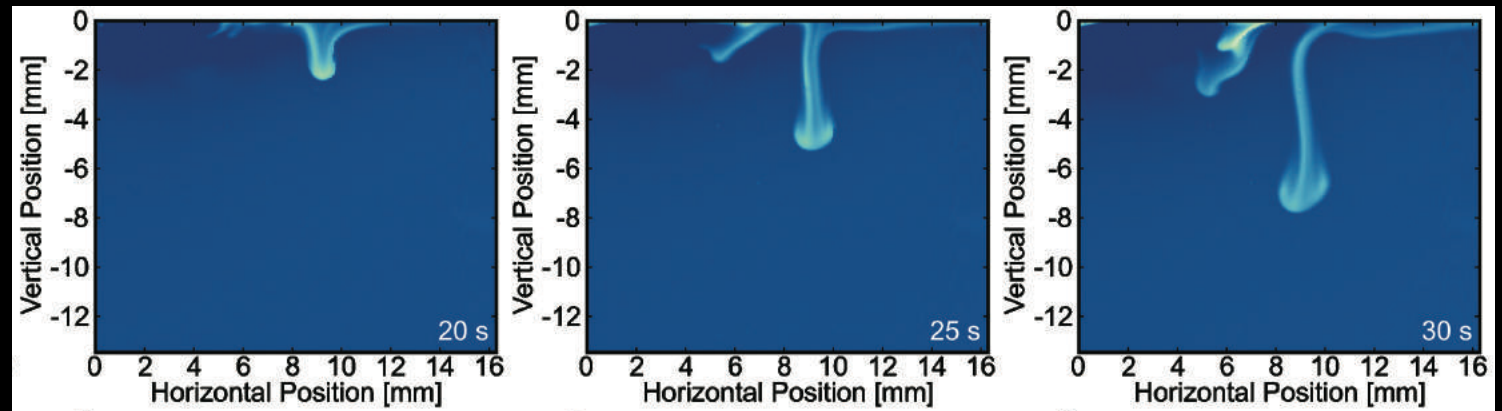
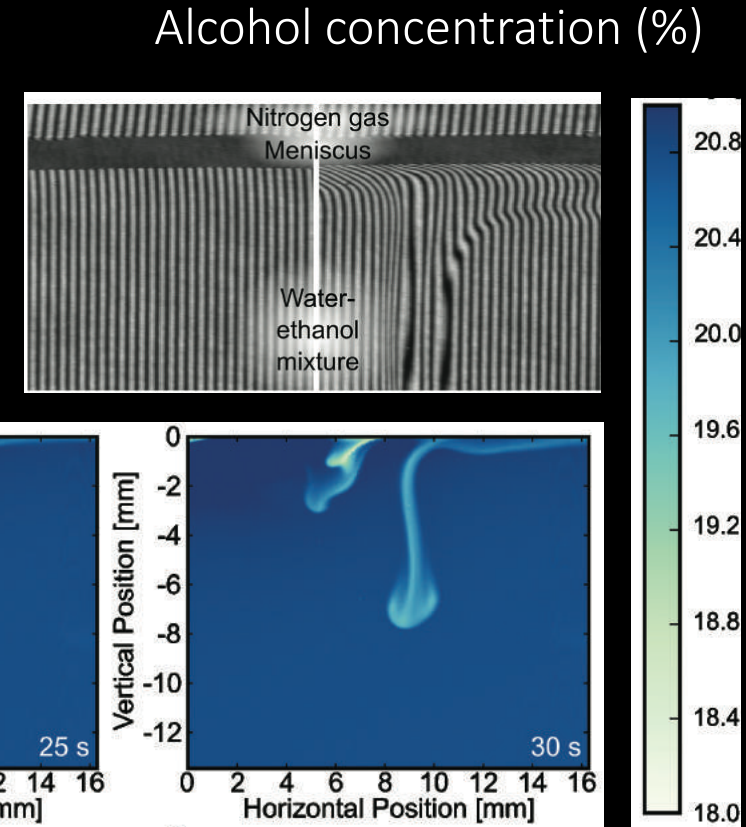
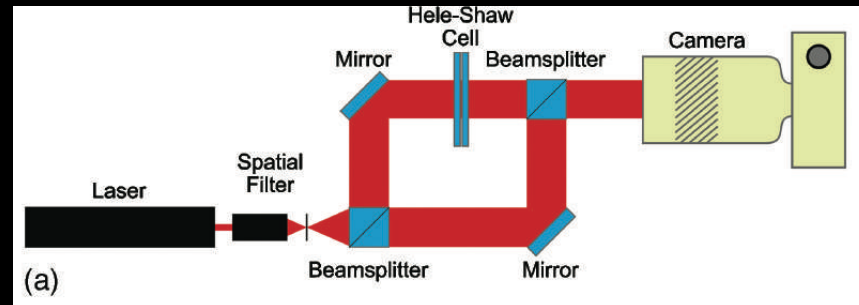
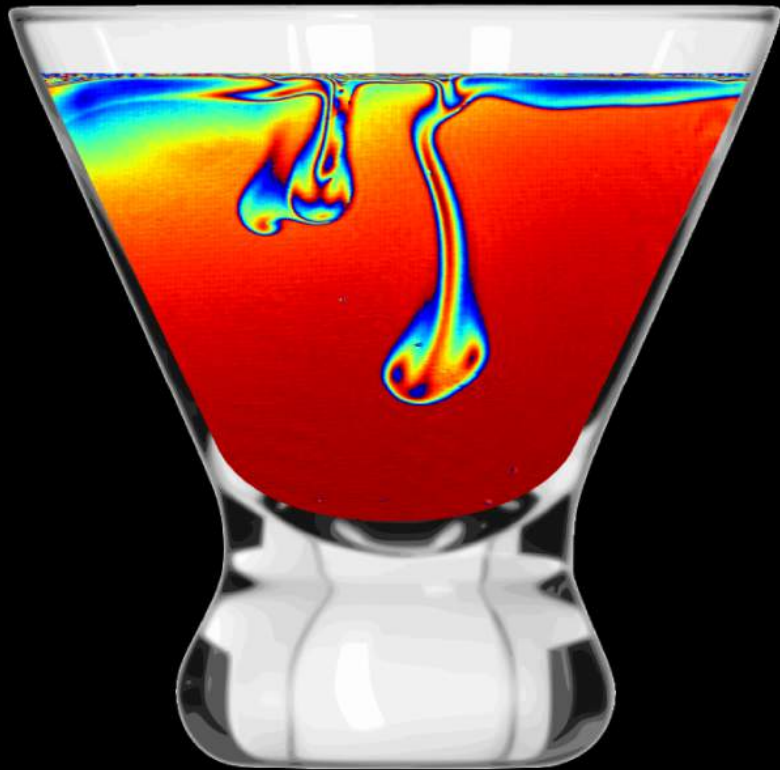
Normal glass

Treated glass



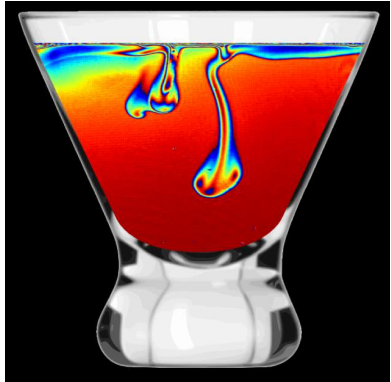
Evaporating cocktails – Rayleigh Taylor instability

Alcohol evaporates,
heavier water remains,
Top layer becomes unstable



Breakthrough experiment for Rayleigh-Taylor instabilities in miscible fluids

Overview of this Presentation (Menu of the Day)



Drinks



Starter



Main course



Dessert

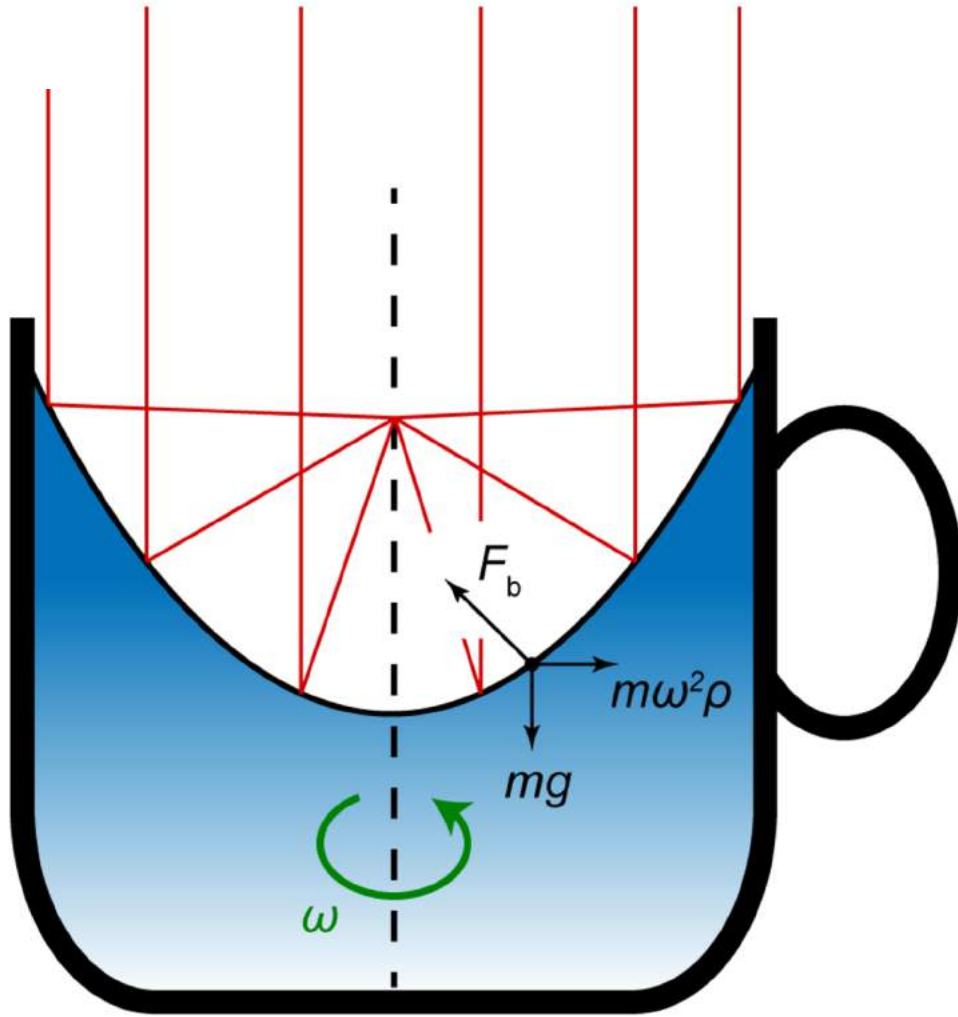


Coffee

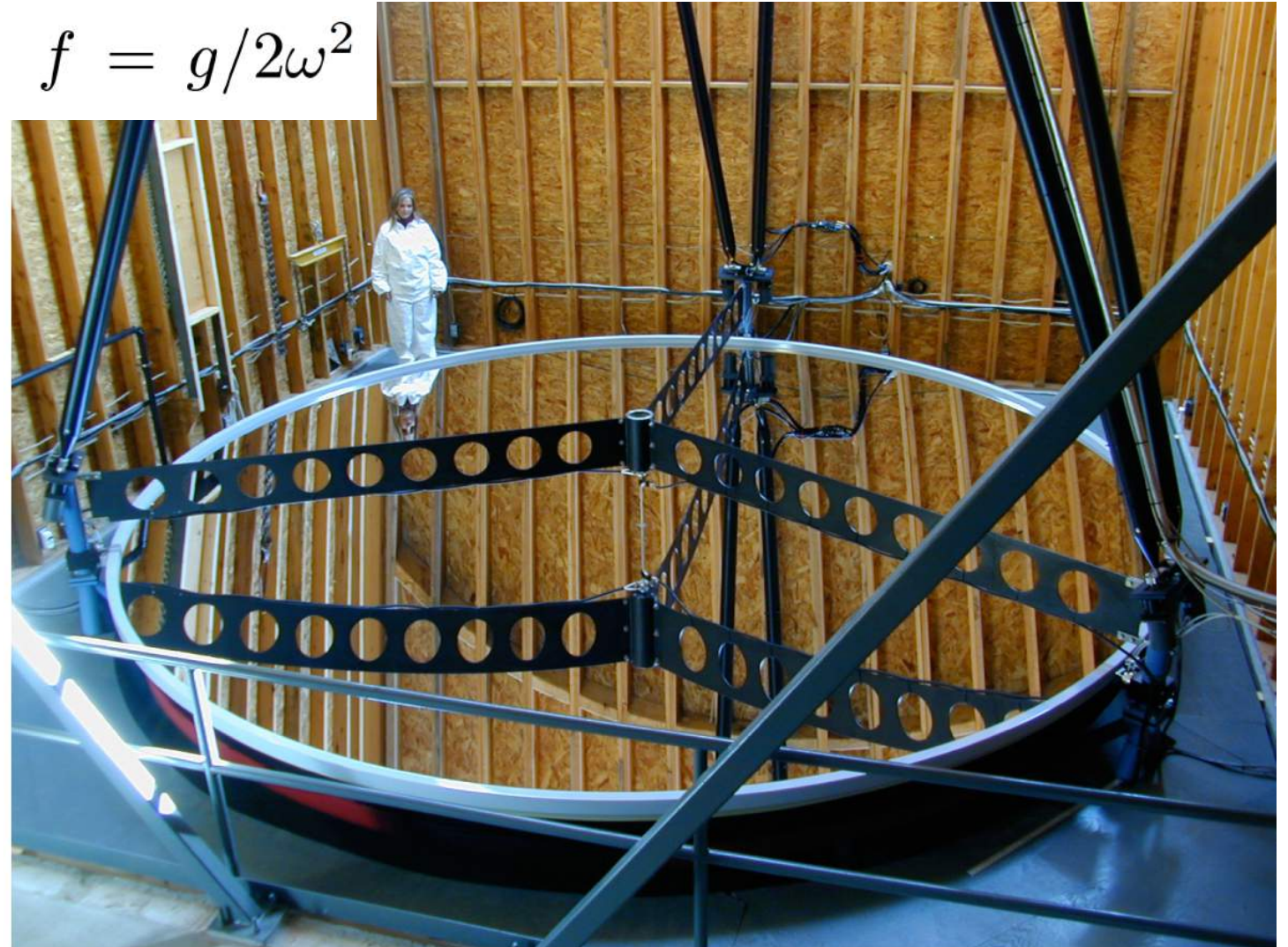


Stirring soup - Parabolic mirror

Large Zenith Telescope

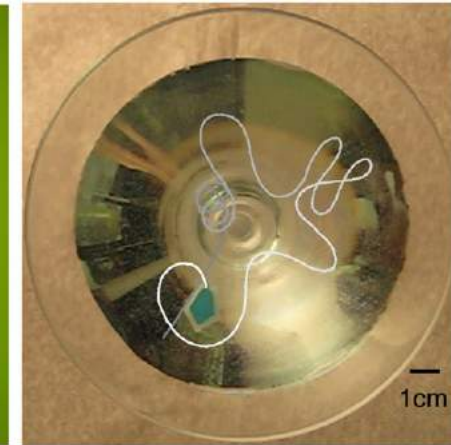
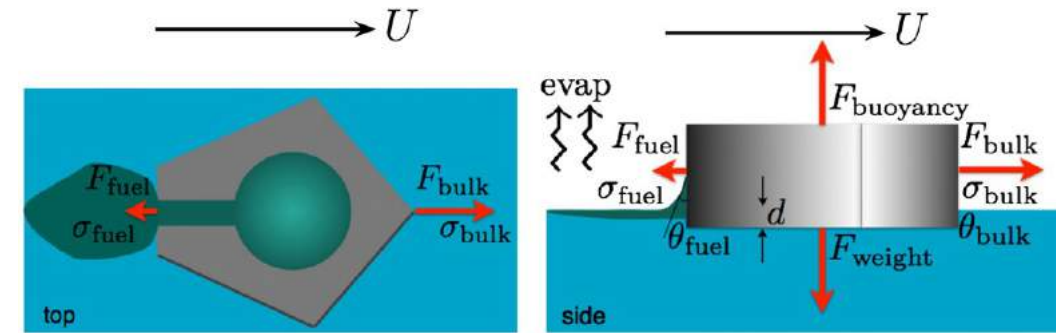
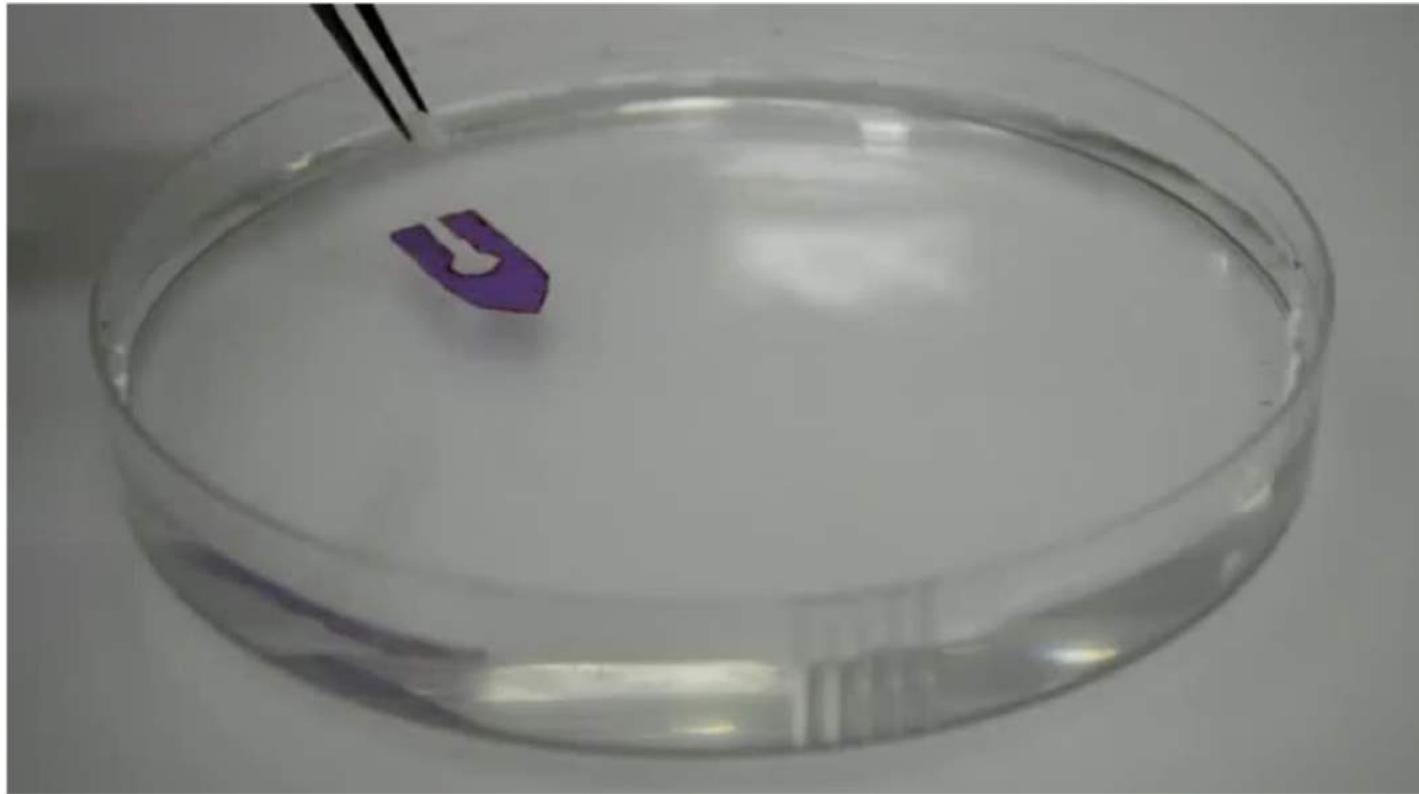


$$f = g/2\omega^2$$



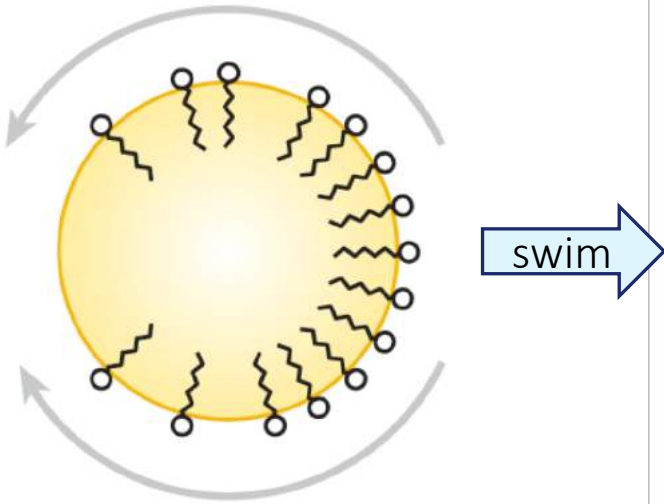
Self-propelled boats

Camphor boat

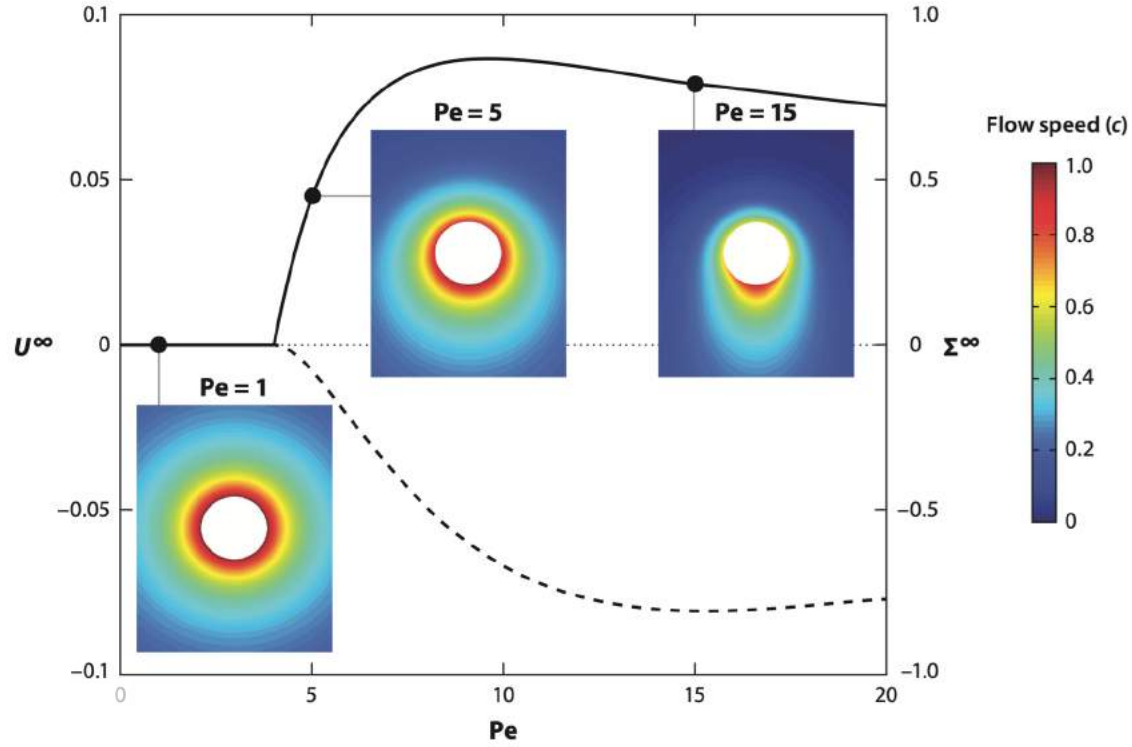


Swimming micro-droplets (50 μm)

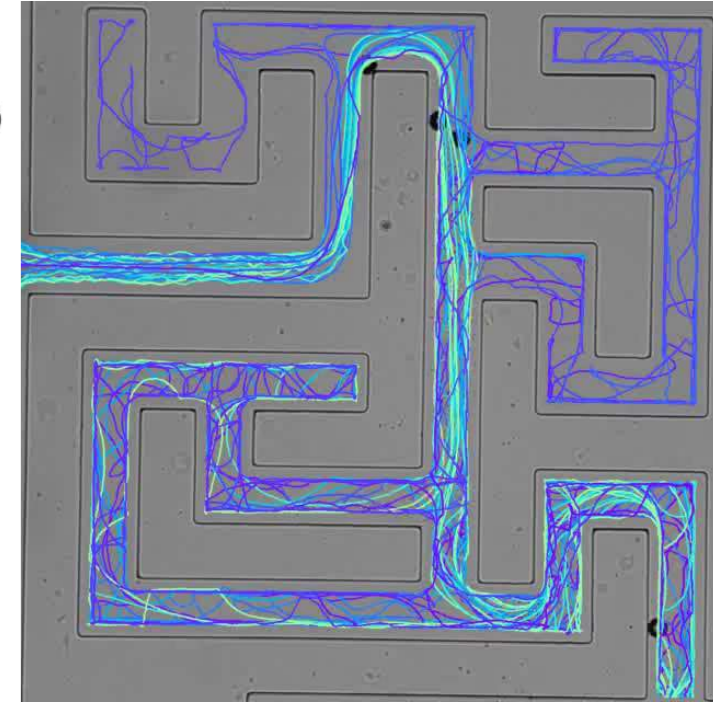
Marangoni stresses propel droplet



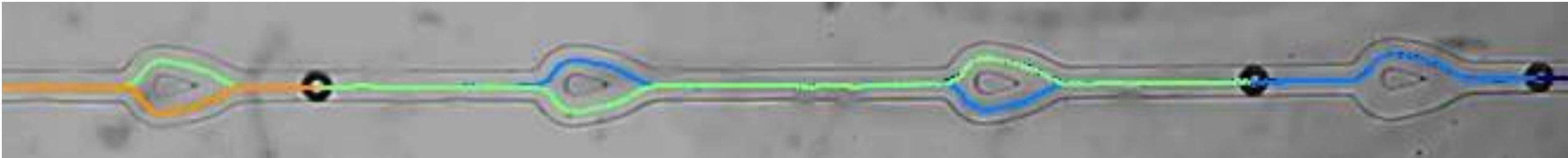
Maass et al. (Annu Rev Cond Matt Phys, 2016)



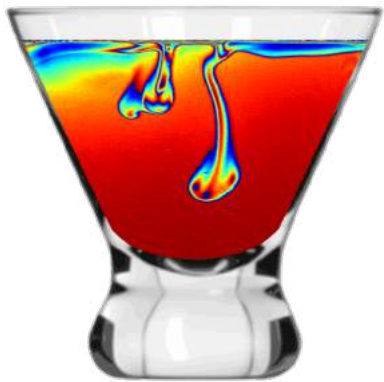
Droplets solving a maze



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



Overview of this Presentation (Menu of the Day)



Drinks



Starter



Main course

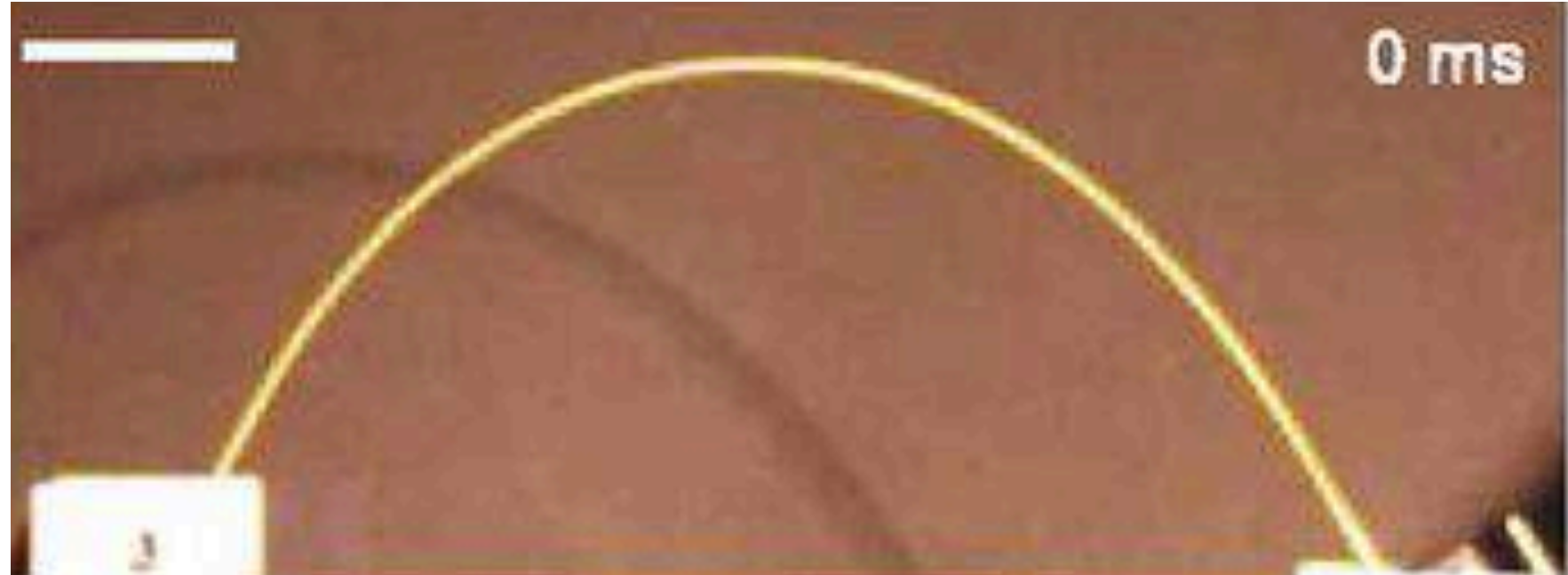


Dessert



Coffee

Spaghetti experiment

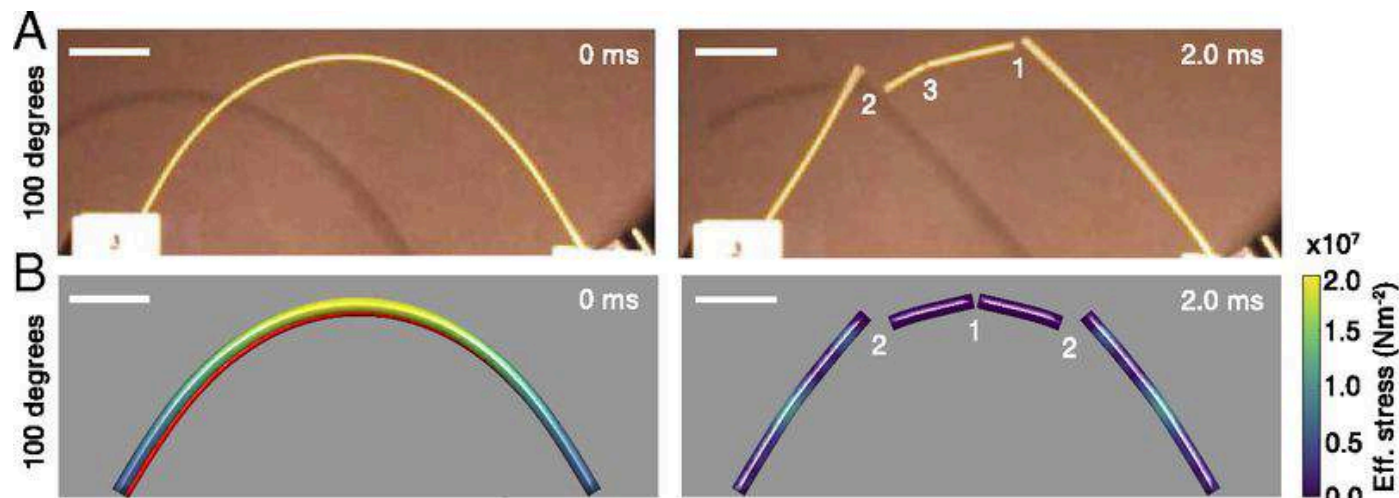


Experiment Time!

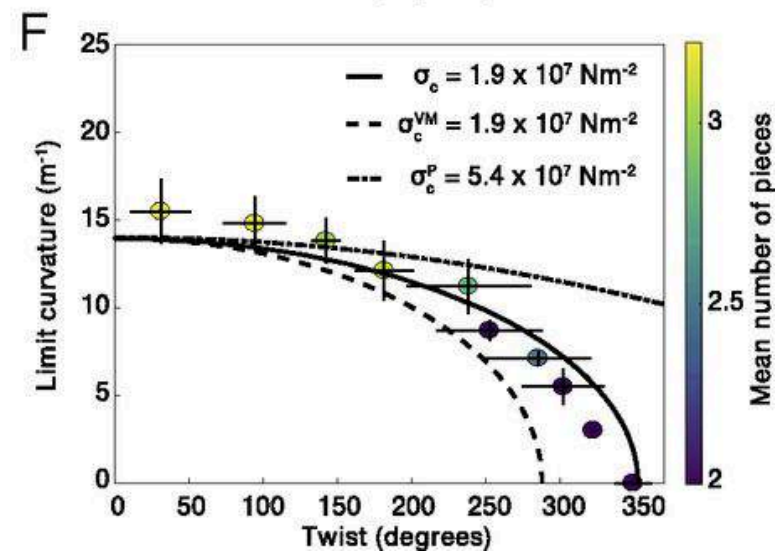
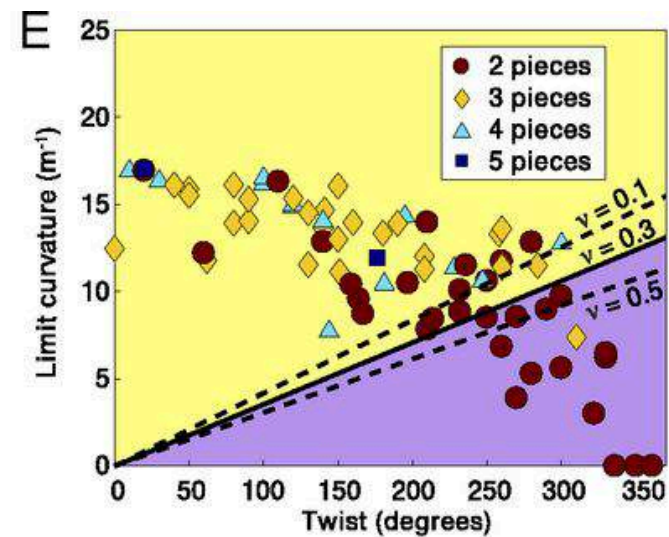
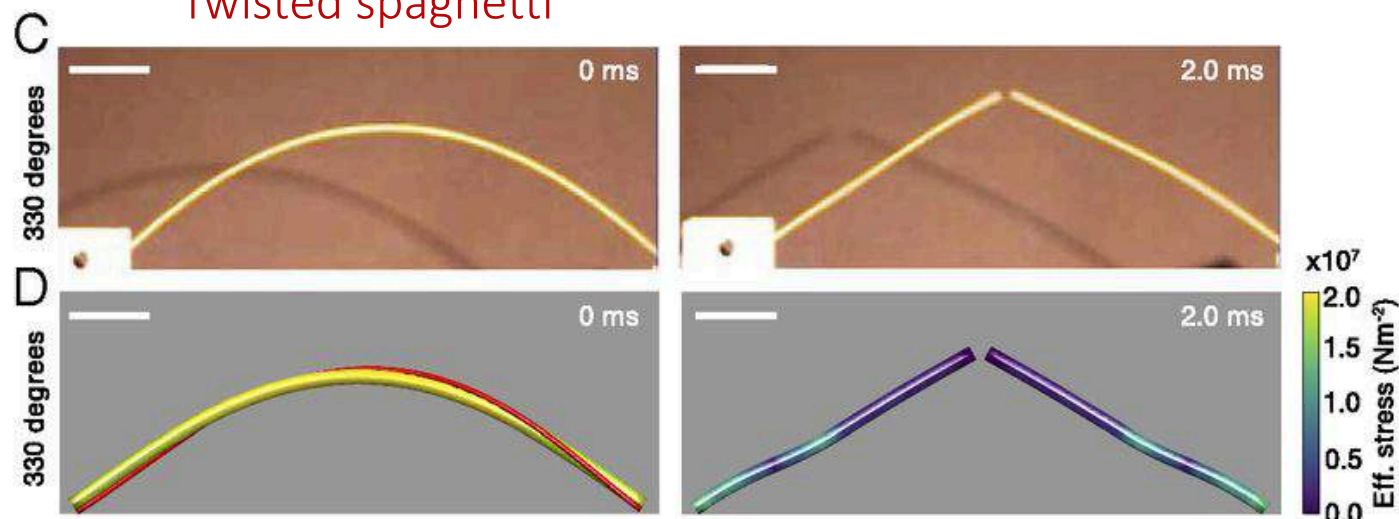
Bend the pasta – in how many pieces does it break?

Breaking spaghetti

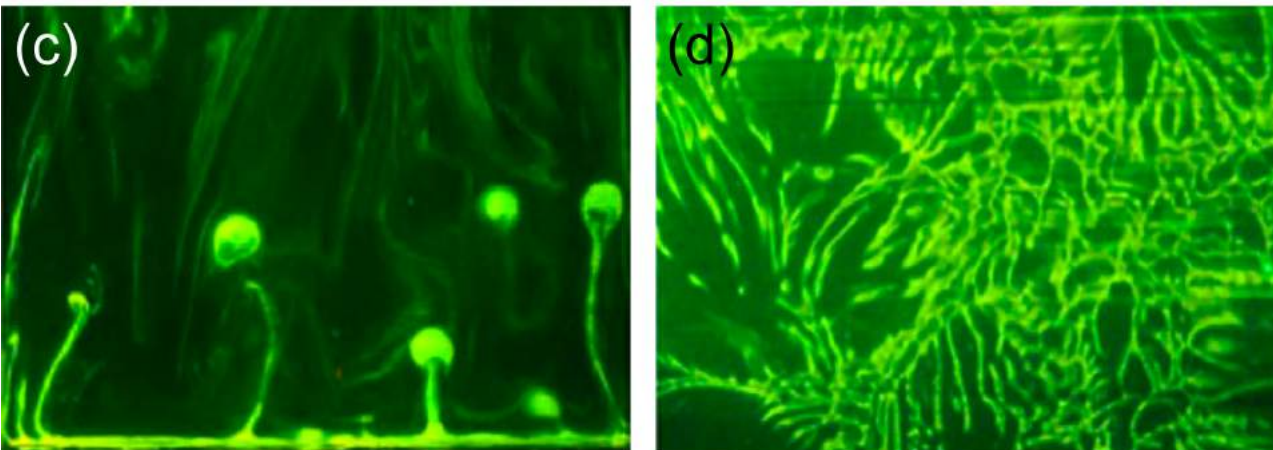
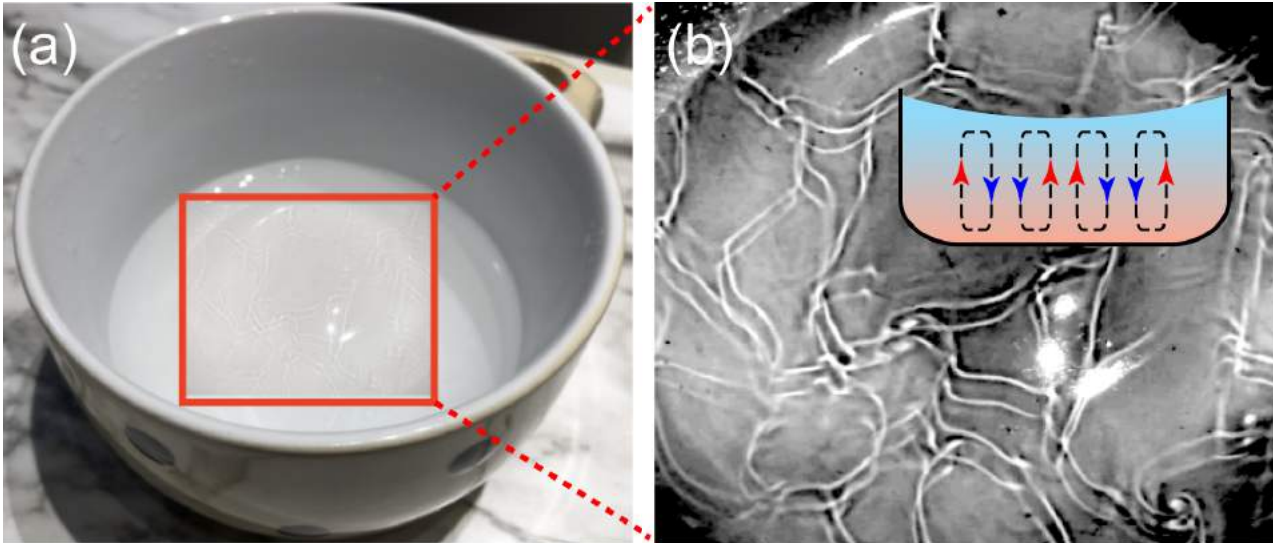
Normal spaghetti



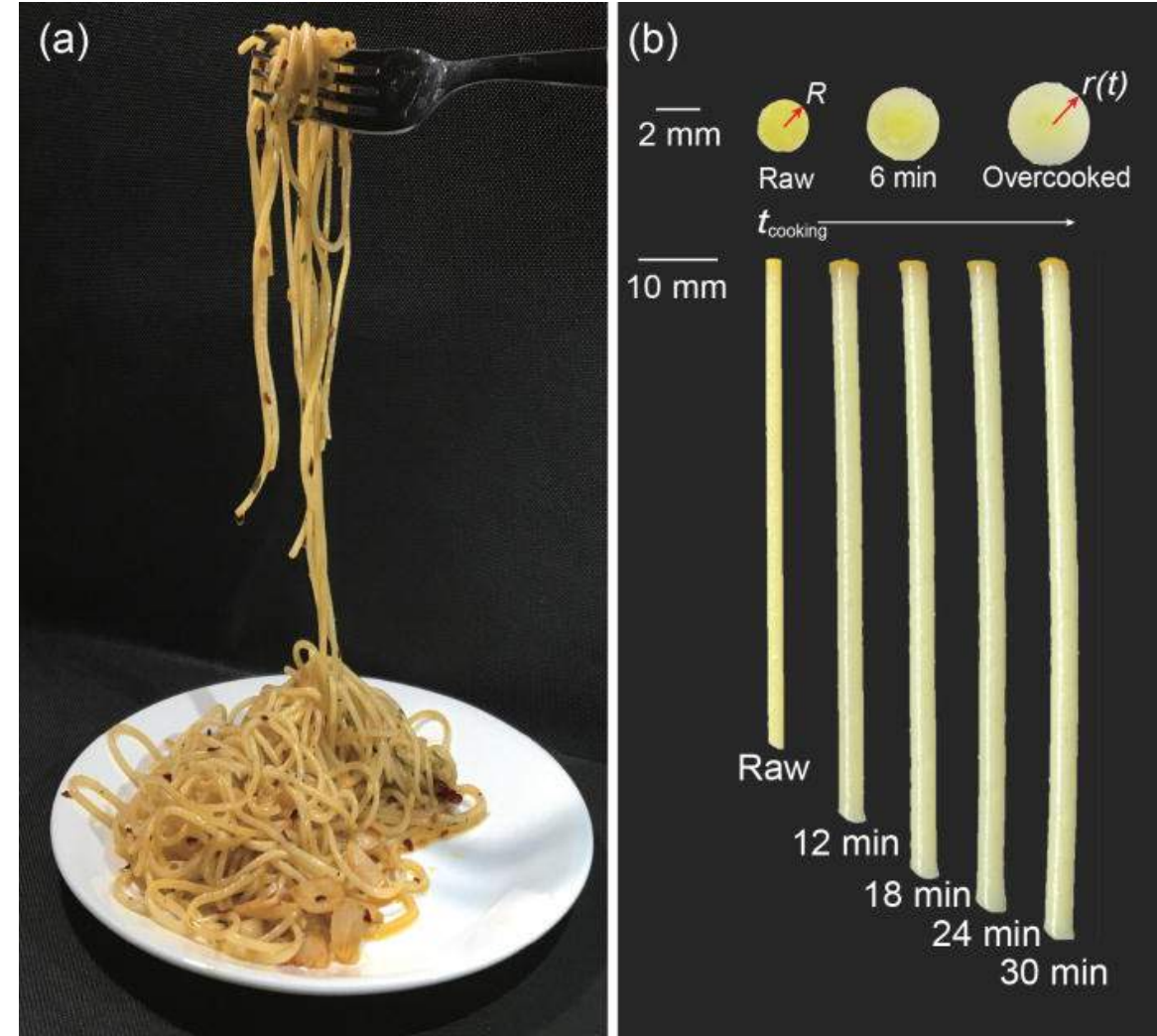
Twisted spaghetti



Cooking pasta



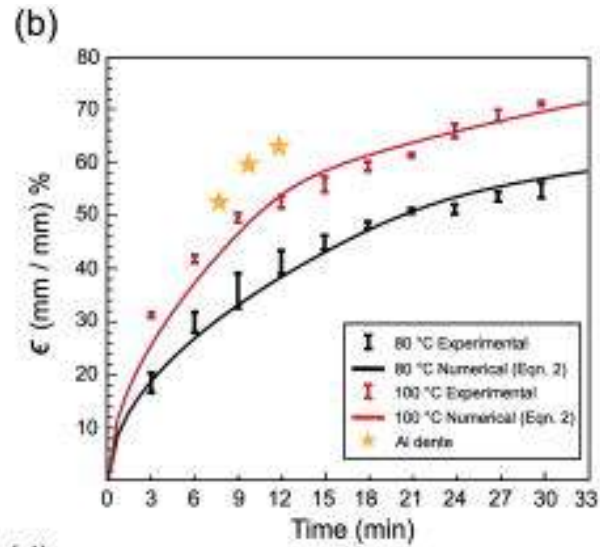
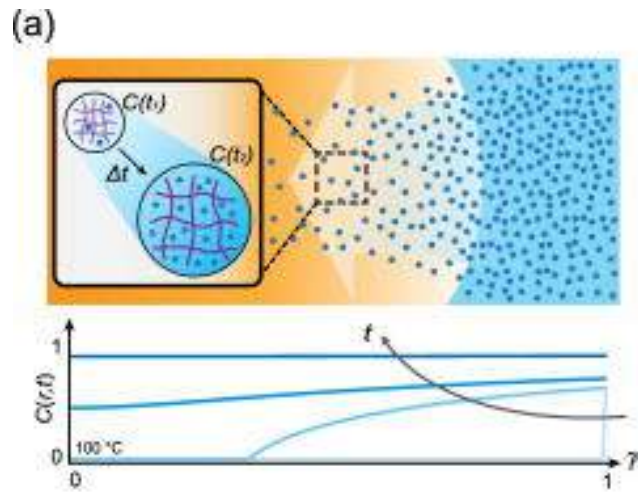
Prakash et al. (Chem Eng Sci, 2017)



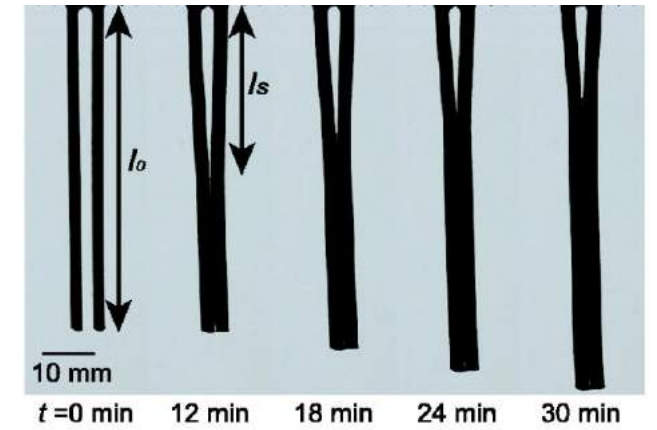
Hwang et al. (Physics of Fluids, 2021)

Cooking pasta

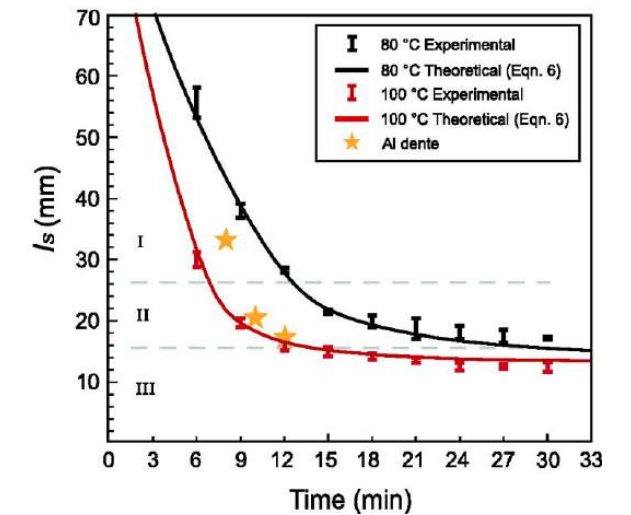
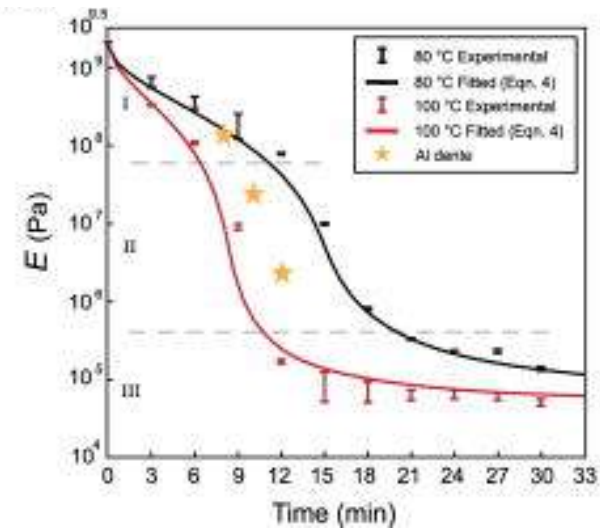
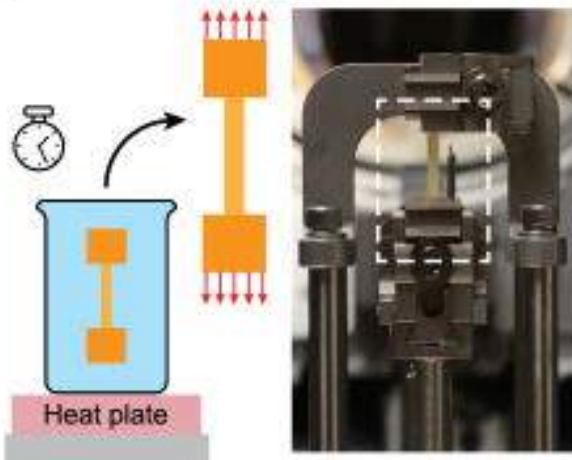
Swelling



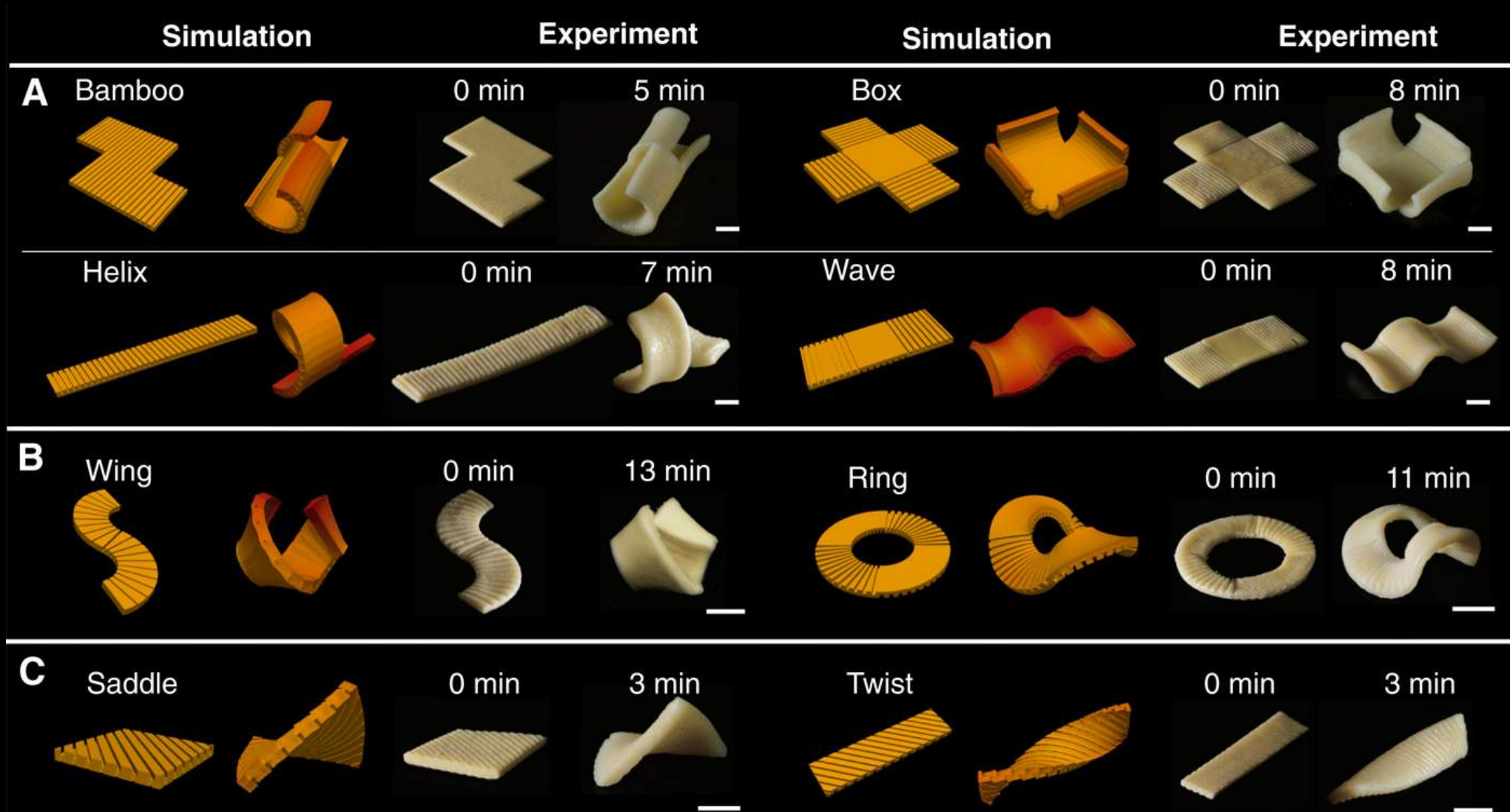
Stickiness



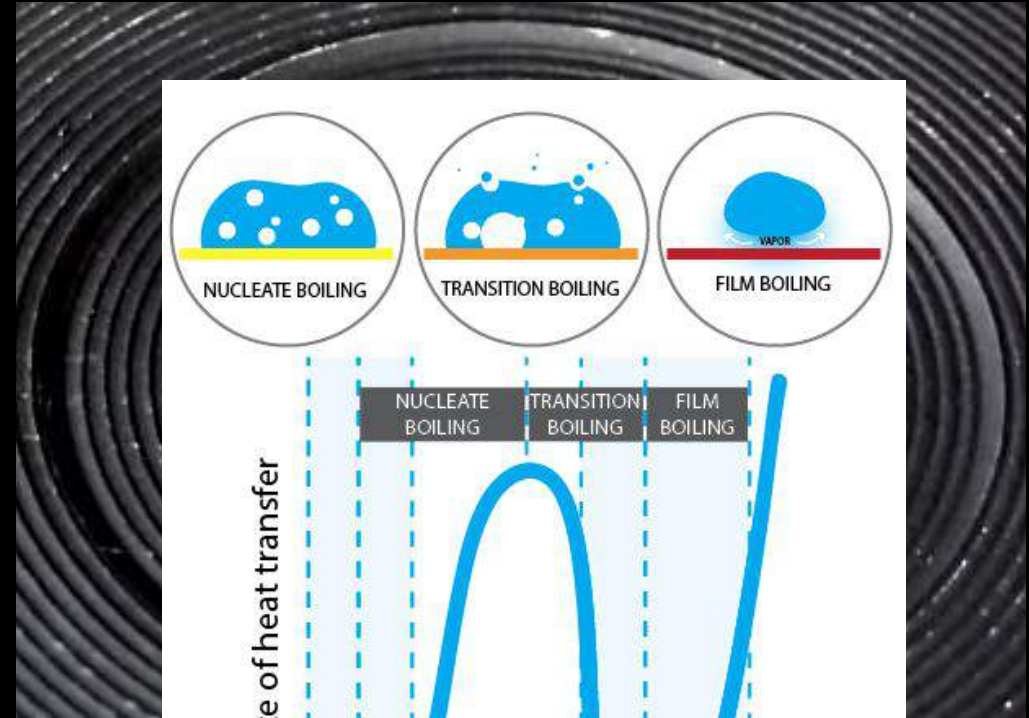
Softness



Morphing pasta into 3D shapes



Grilling with the Leidenfrost effect



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

More fun with the Leidenfrost effect

EARTH
UNPLUGGED

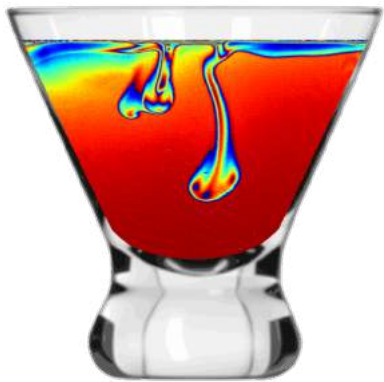


More fun with the Leidenfrost effect



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

Overview of this Presentation (Menu of the Day)



Drinks



Starter



Main course

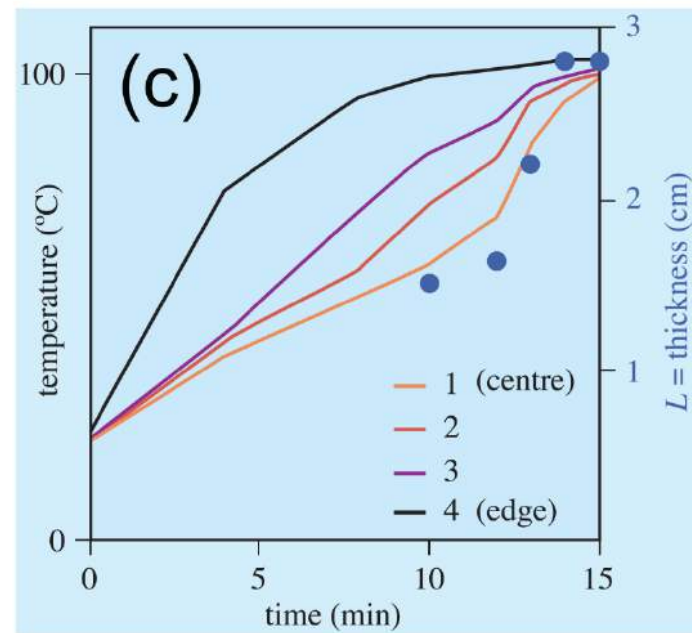
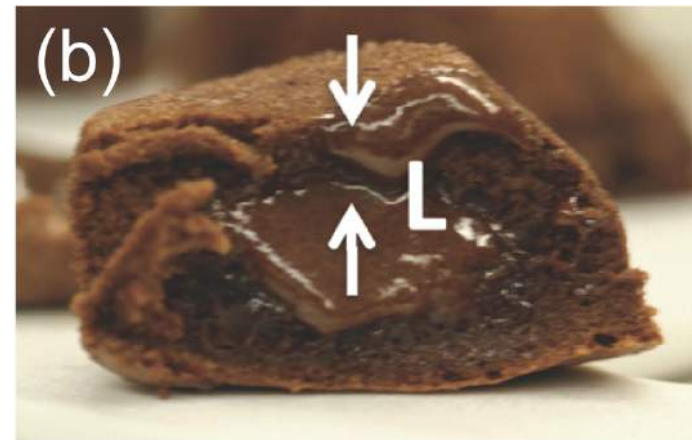
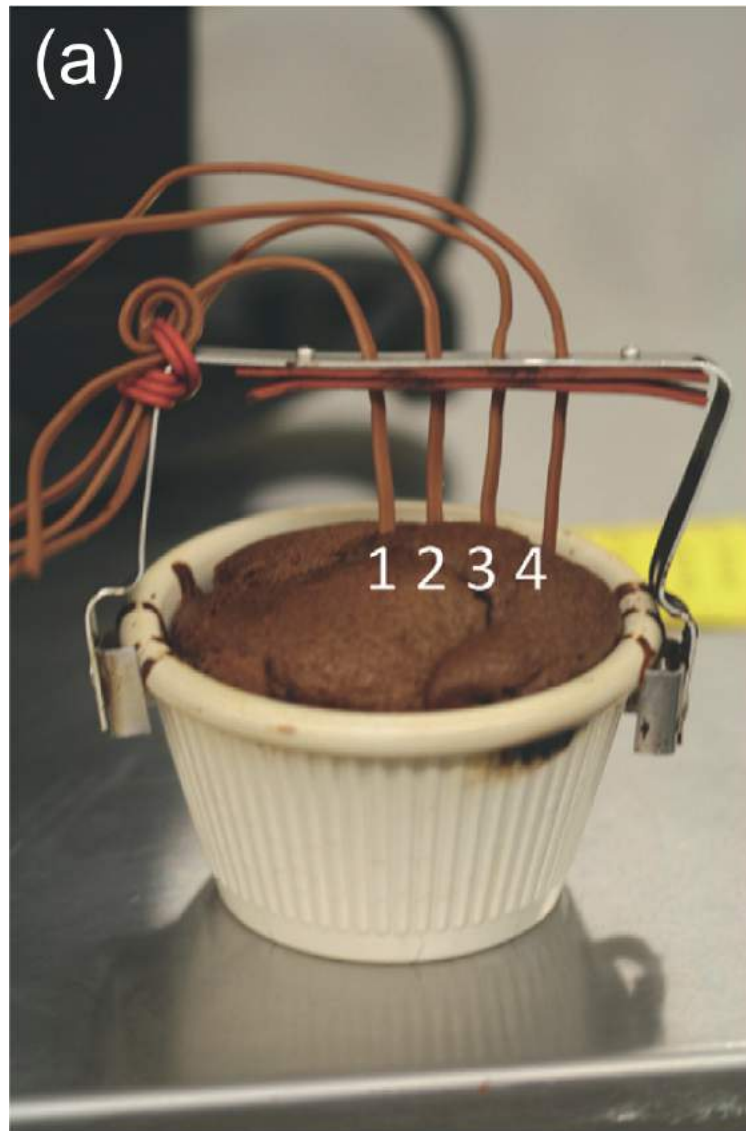


Dessert



Coffee

Baking a cake properly

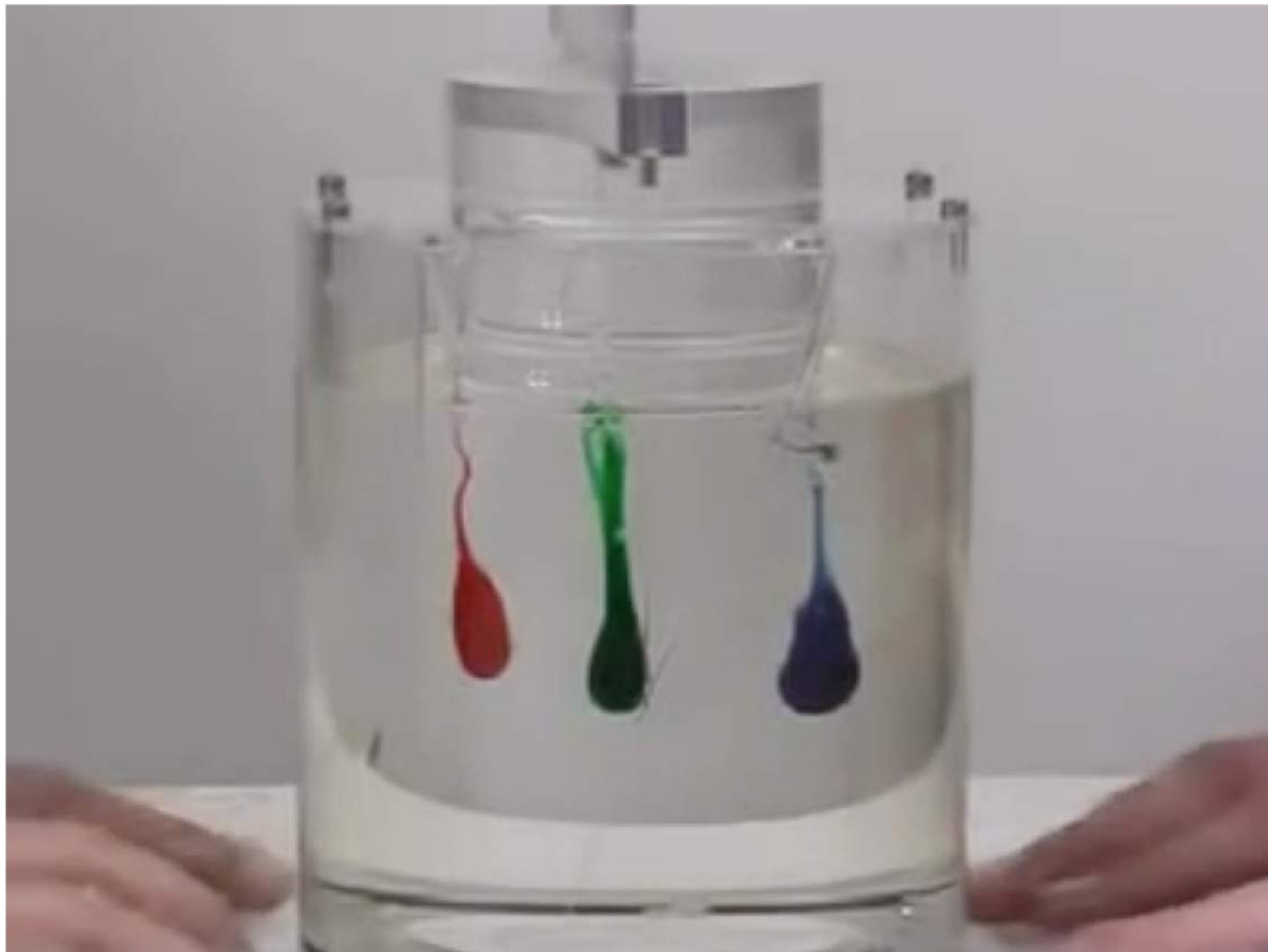




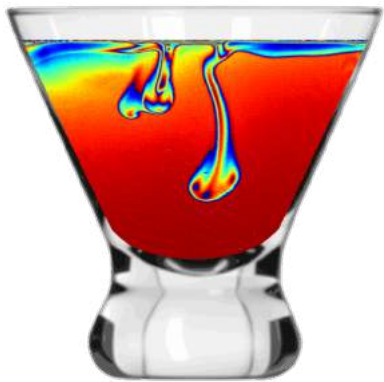
asc-csa.gc.ca



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

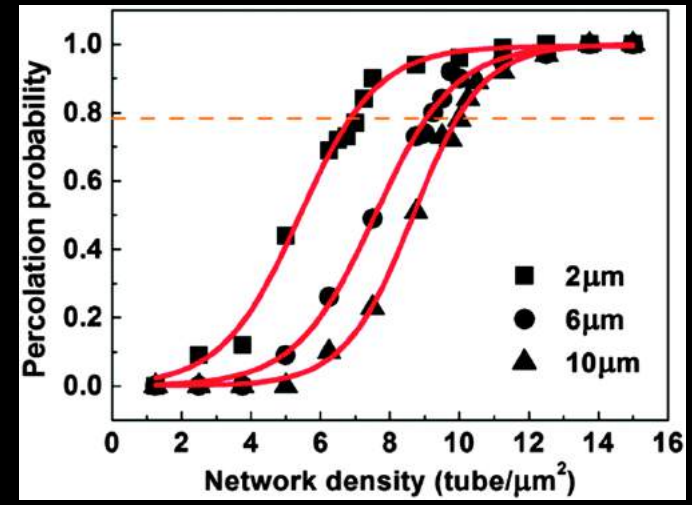


perfect cup

$p=0.8$
percolation



Too weak coffee



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

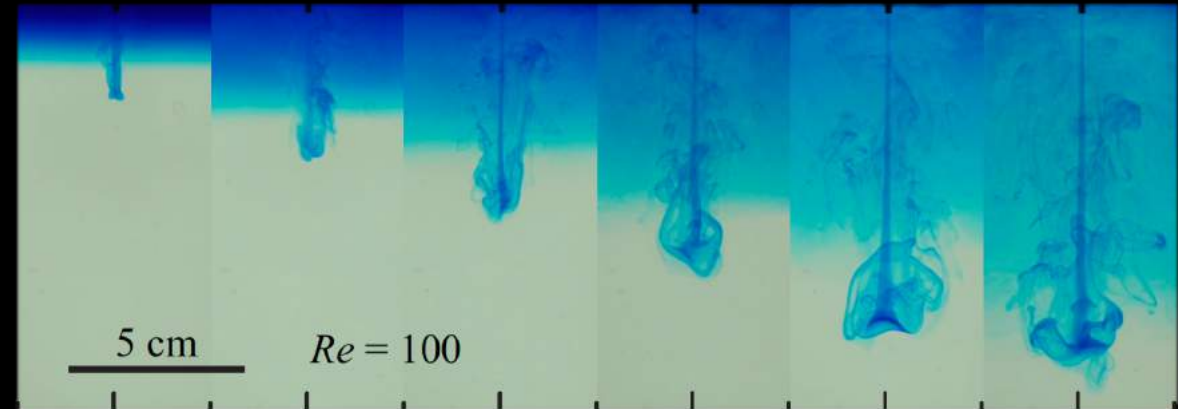
Latte art = inverted fountain



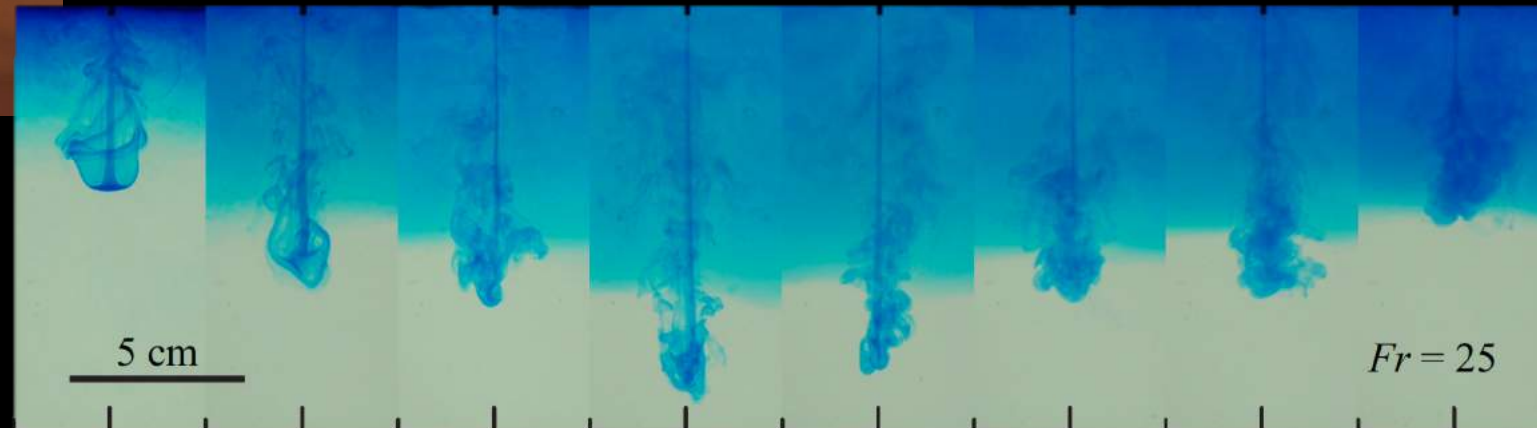
Key variables:

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

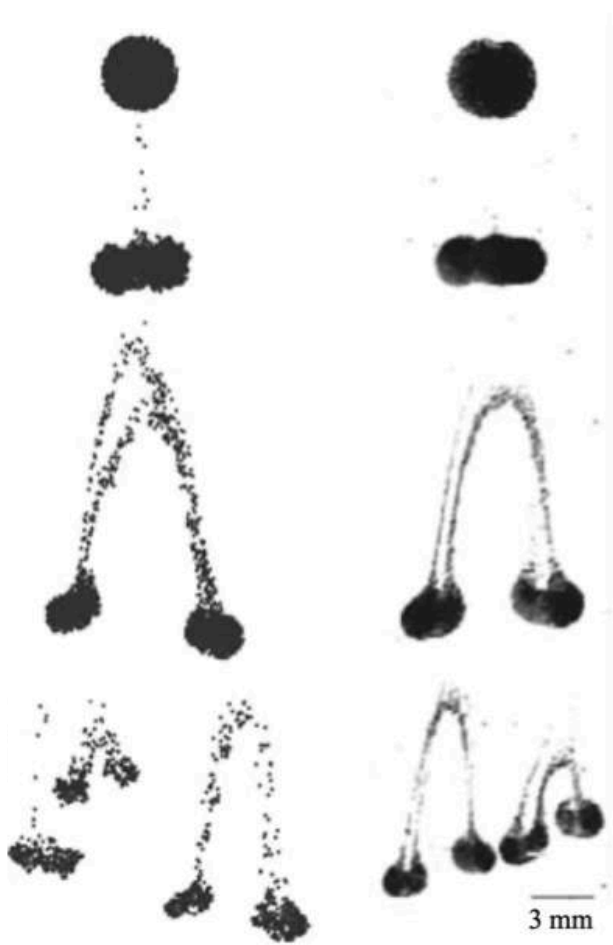
Increasing Froude number →



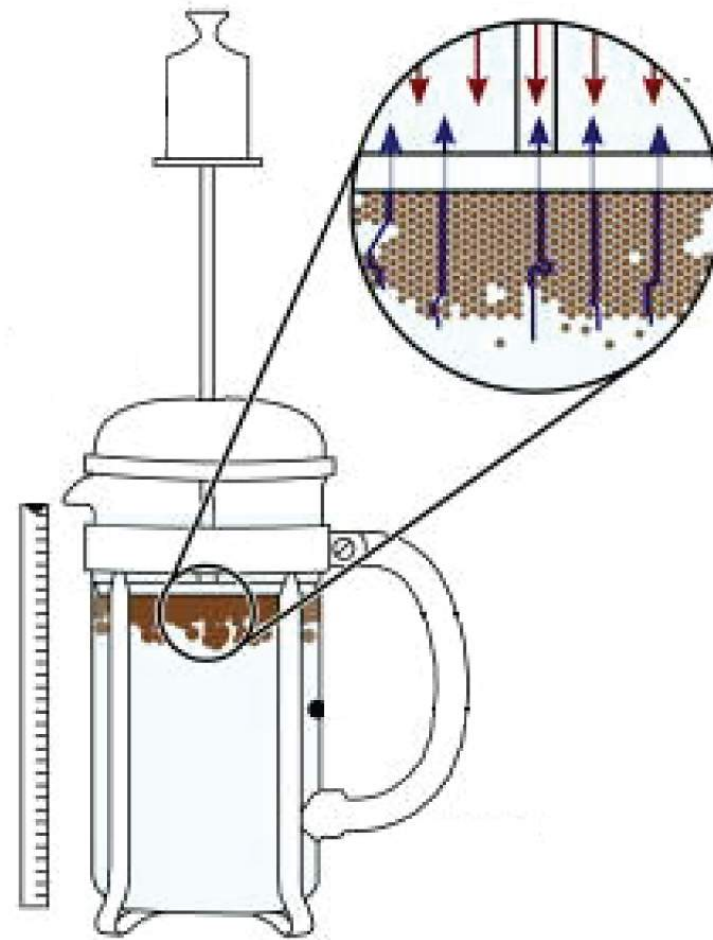
Increasing Reynolds number →



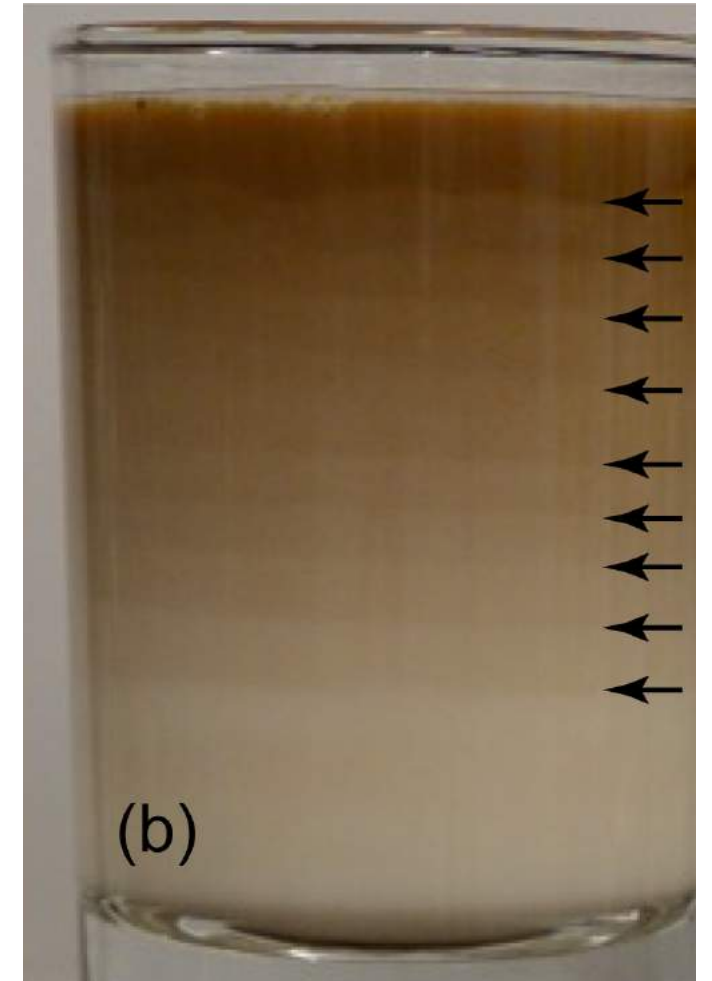
More coffee preparation methods



Metzger et al. (J Fluid Mech 2007)



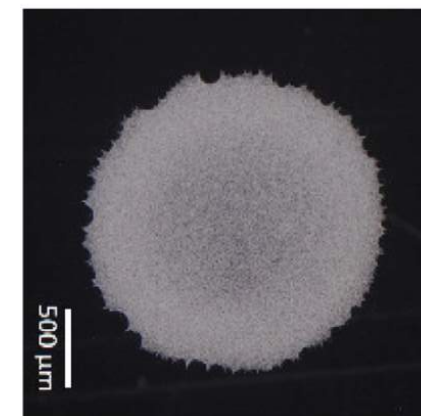
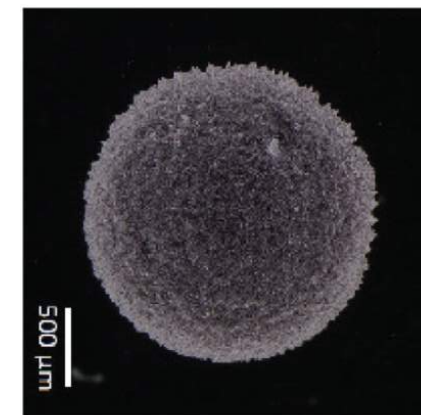
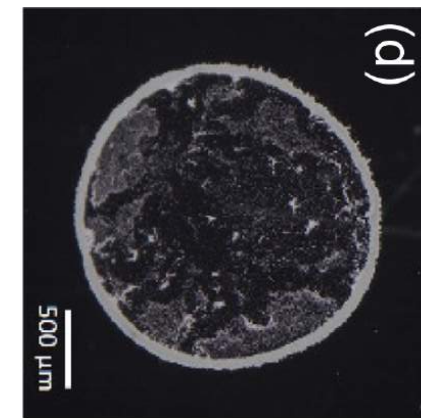
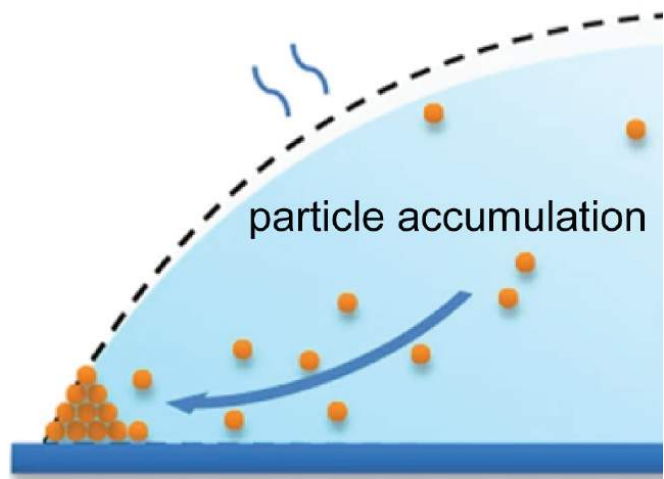
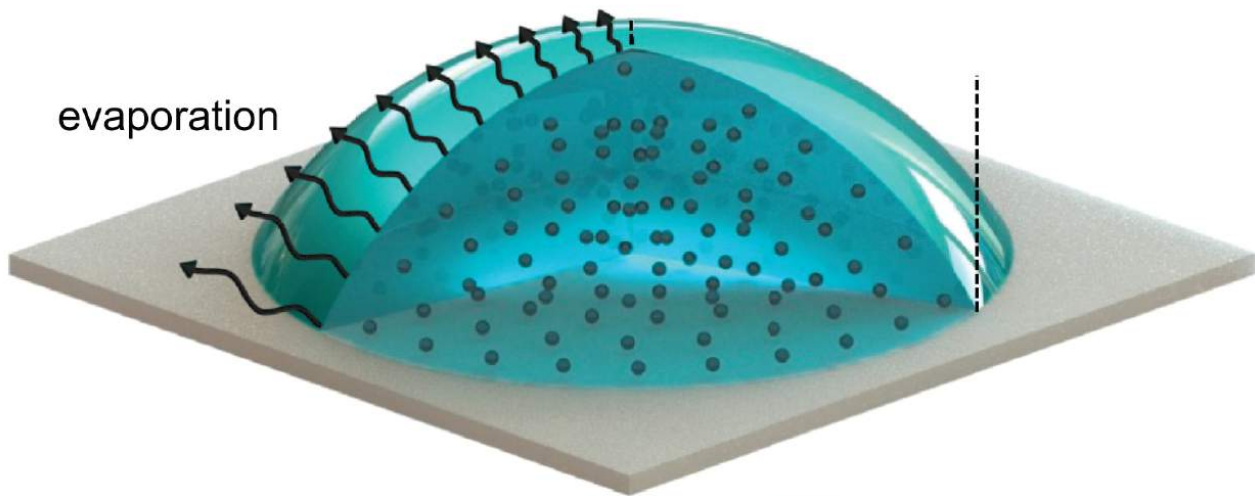
Wadsworth et al. (Am J Phys 2021)



Xue et al. (Nat Commun, 2017)

Coffee ring effect

...and preventing it for coating materials



Add cellulose nanofibers

Culinary Fluid Mechanics



Arnold Mathijssen, Maciej Lisicki, Vivek Prakash, Endre Mossige

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

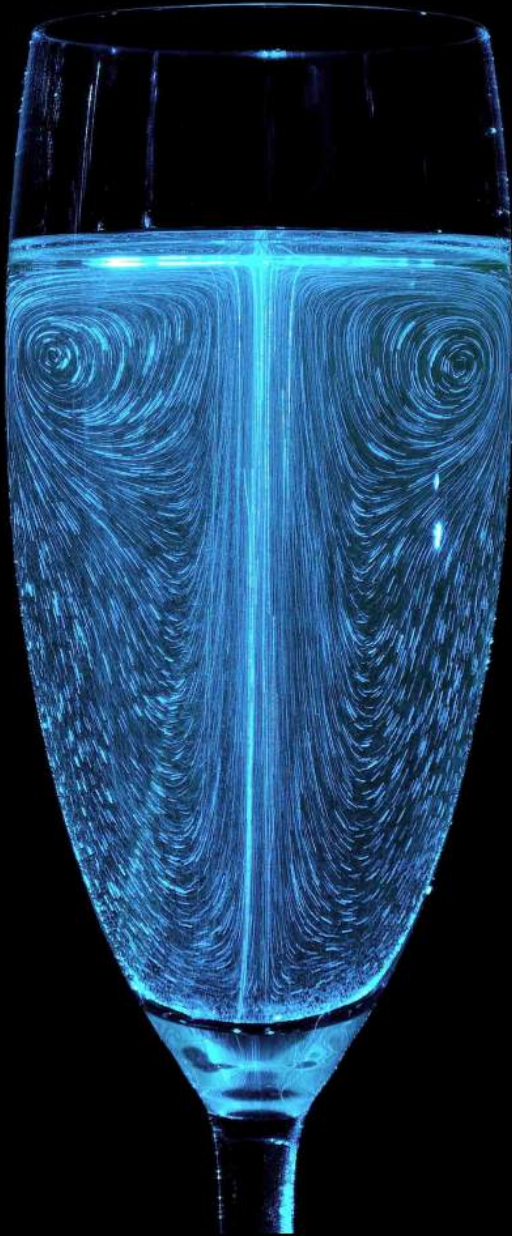


Image courtesy of
Gerard Liger-Belair

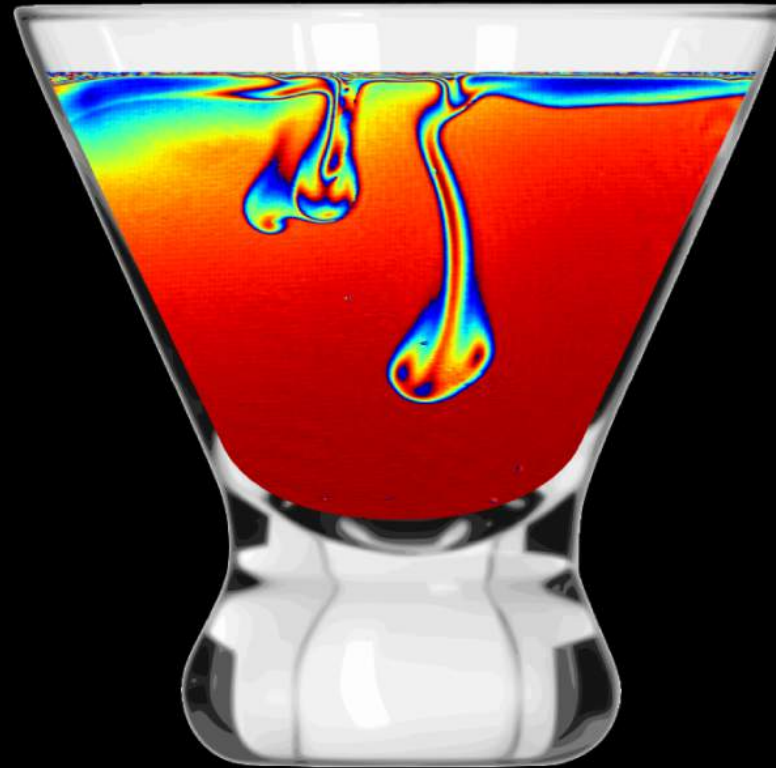


Image courtesy of
Sam Dehaeck



Image courtesy of
photographer "Burst"

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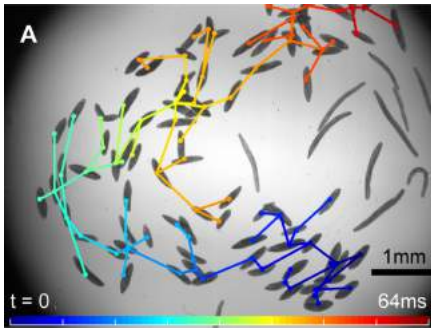
Thank you for your attention!!

amaths@upenn.edu



Intelligent active matter

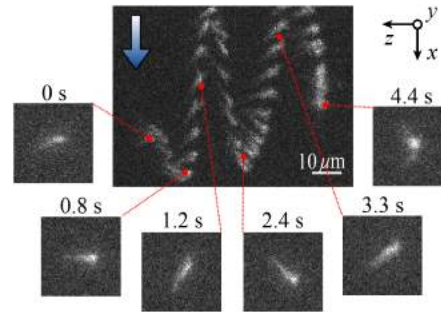
Ultra-fast motion in cell biology



Nature (2019)

Physics of Pathogens

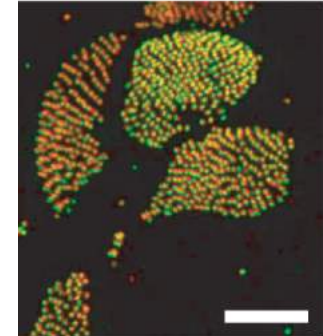
Bacterial contamination dynamics



PRL (2016), Nature Communications (2019)

Respiratory flows

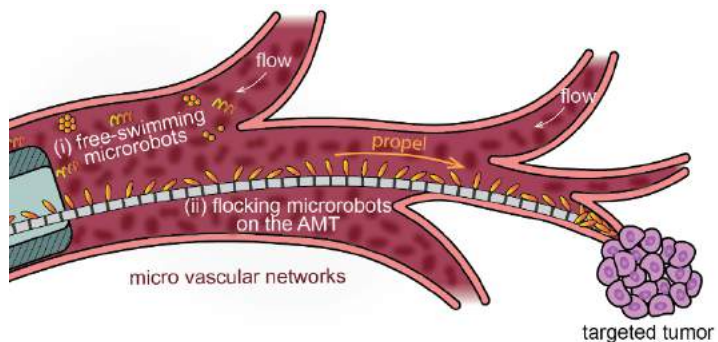
Pathogen clearance in the mouse airway



Nature Physics (2020), JFM (2016)

Microbiological fluid mechanics

Cargo transport in cardiovascular flows



PRL (2021, 2019), JFM (2015)

Food science

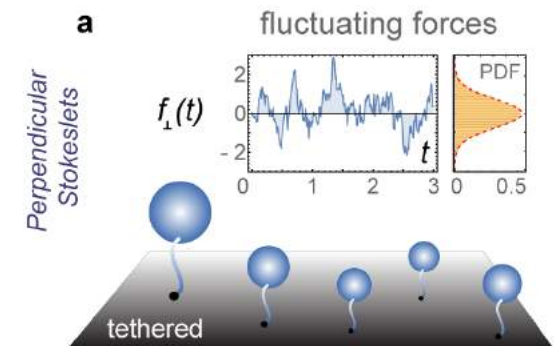
Culinary physics and edible materials



arxiv.org/abs/2201.12128 (RMP 2023)

Non-equilibrium stat. mech.

Actively driven diffusion in biology



Nature Communications (2021)