18.357: Lecture 10

Marangoni Flows III

Course Projects

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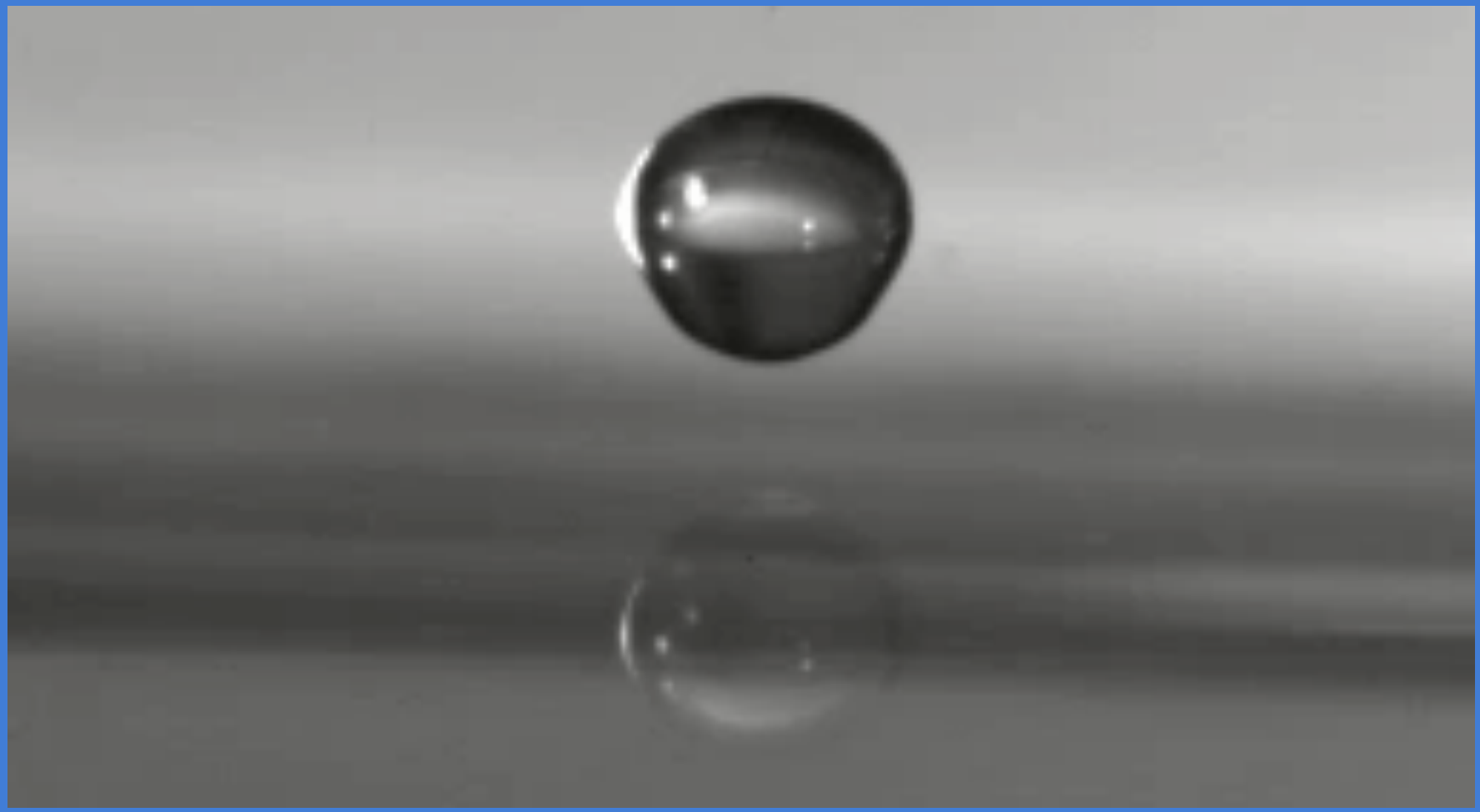
MIT

Problem Set 1, Question 2



Raindrops strike a puddle

Problem Set 1, Question 2

Water Drop Coalescing Into Methanol

A Film by: Hamarz Aryafar

All work preformed at:

UC, Los Angeles

Complex Fluids and

Interfacial Physics Labratory

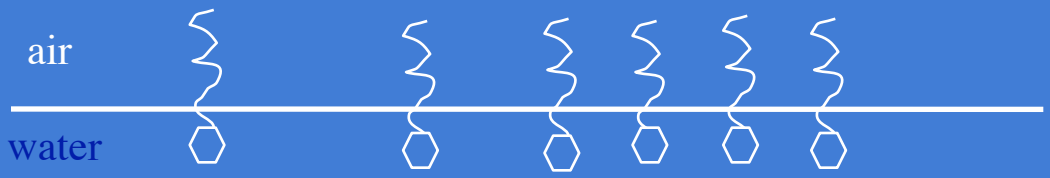
Advisor:Pirouz Kavehpour

Drinking in space: Pset 1, Q6

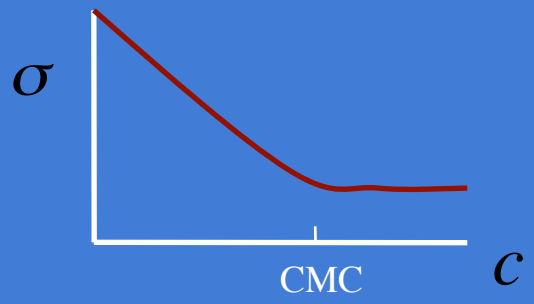
Surfactants: surface-active reagents

- molecules that find it energetically favourable to reside at an interface

e.g. commercial detergents

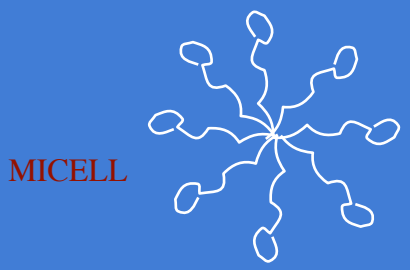


- generally act to reduce σ locally, $\frac{d\sigma}{d\Gamma} < 0$: may induce Marangoni flows



e.g. Soap boat

- beyond the CMC (critical micell concentration), there is no further dependence of σ on c

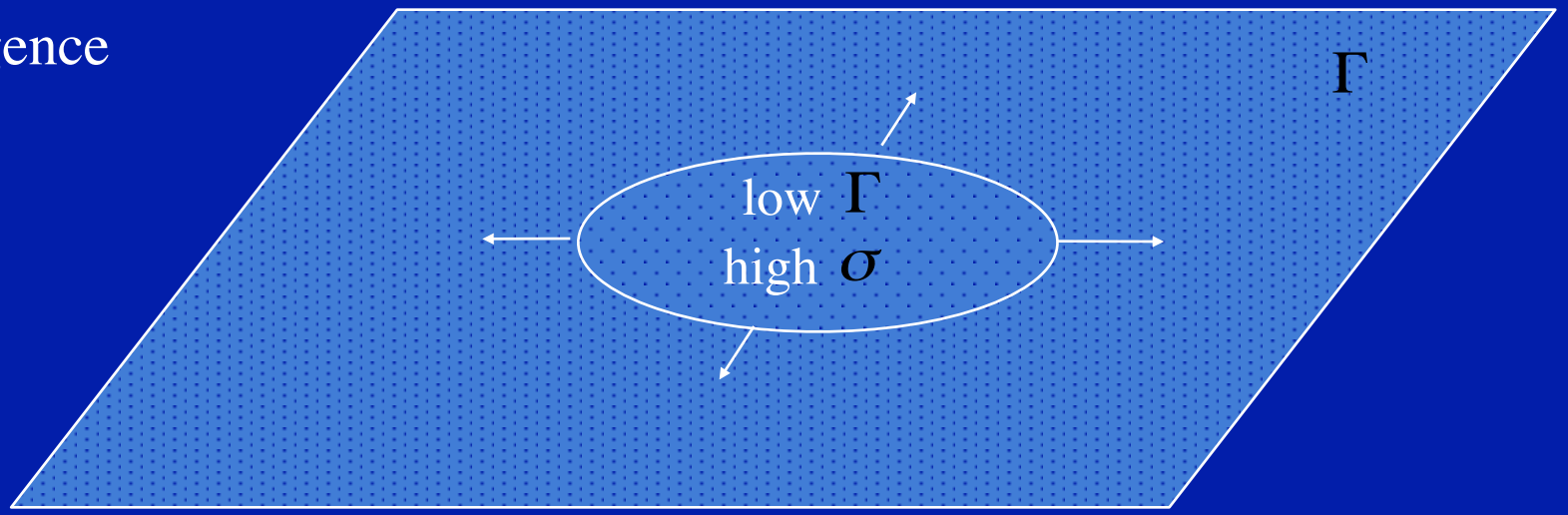


micells shed by saturated interface, desorbed into bulk

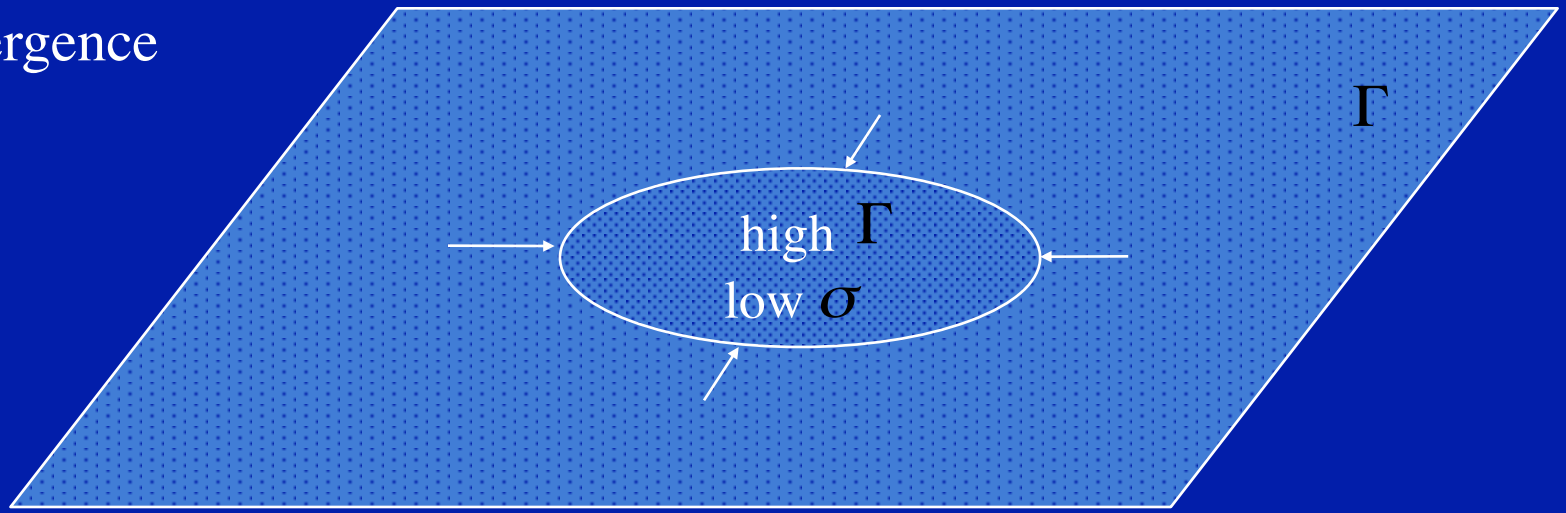
Surfactants: impart effective elasticity to contaminated interfaces

through resisting flows with non-zero surface divergence

Surface divergence



Surface convergence



Surfactants: impart effective elasticity to contaminated interfaces

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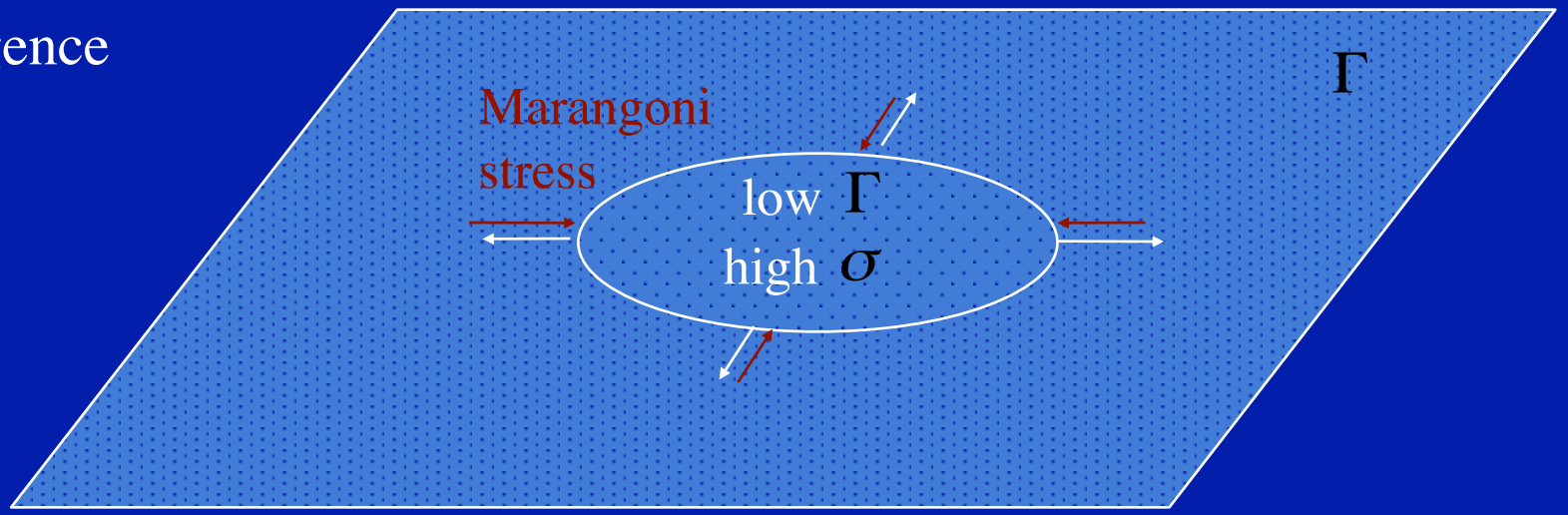
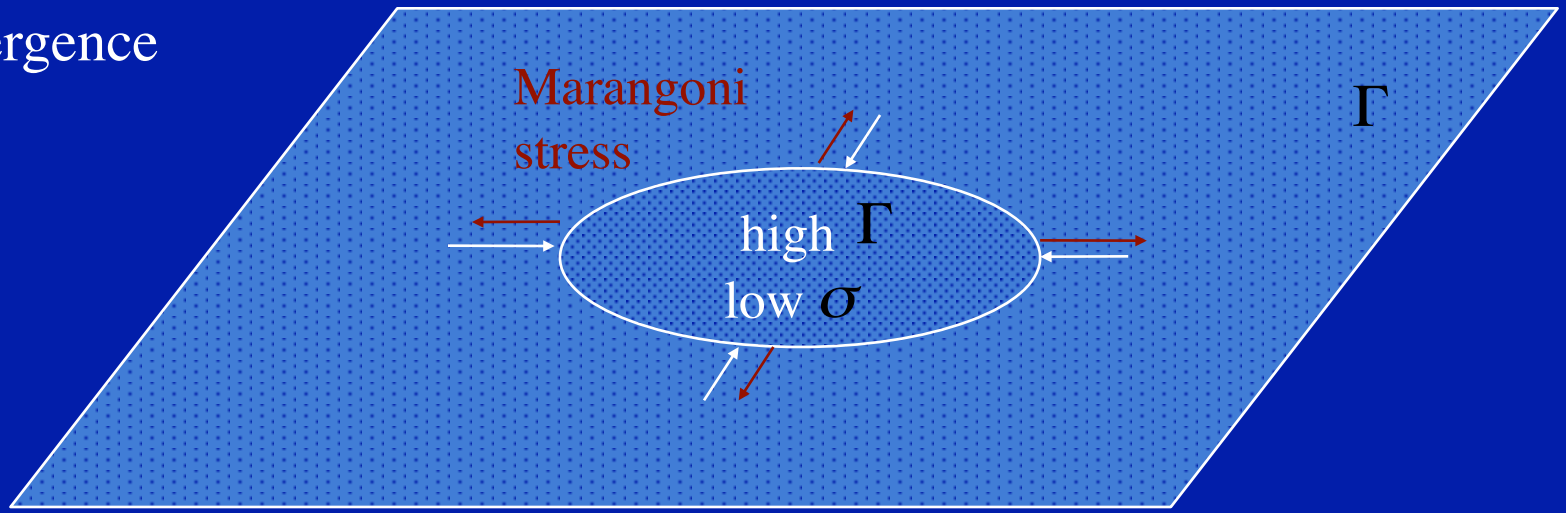
Surface divergence

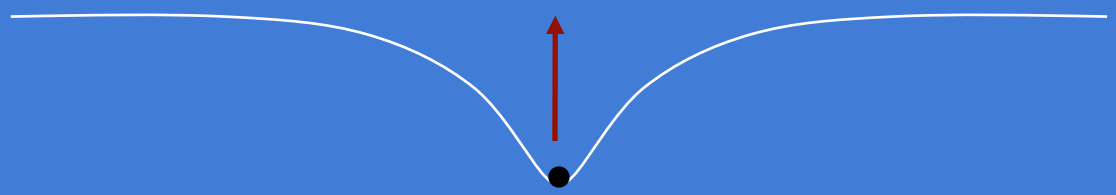


Surface convergence



Clean interface = `slippery trampoline'

- resists deformation through generation of normal curvature pressures
- cannot generate traction on the interface



Surfactant-laden interface = trampoline

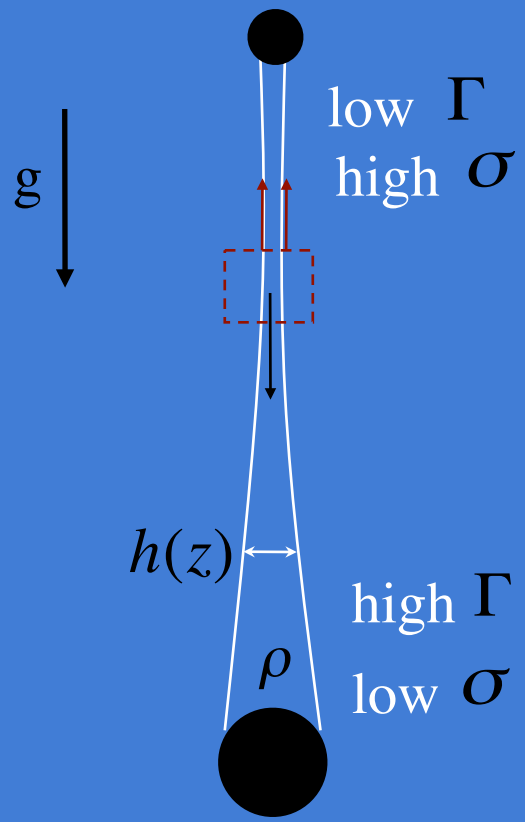
- resists surface deformation as does a clean interface
- can support tangential stresses via Marangoni elasticity

Soap films

- stabilized against rupture by presence of surfactants

Draining soap film

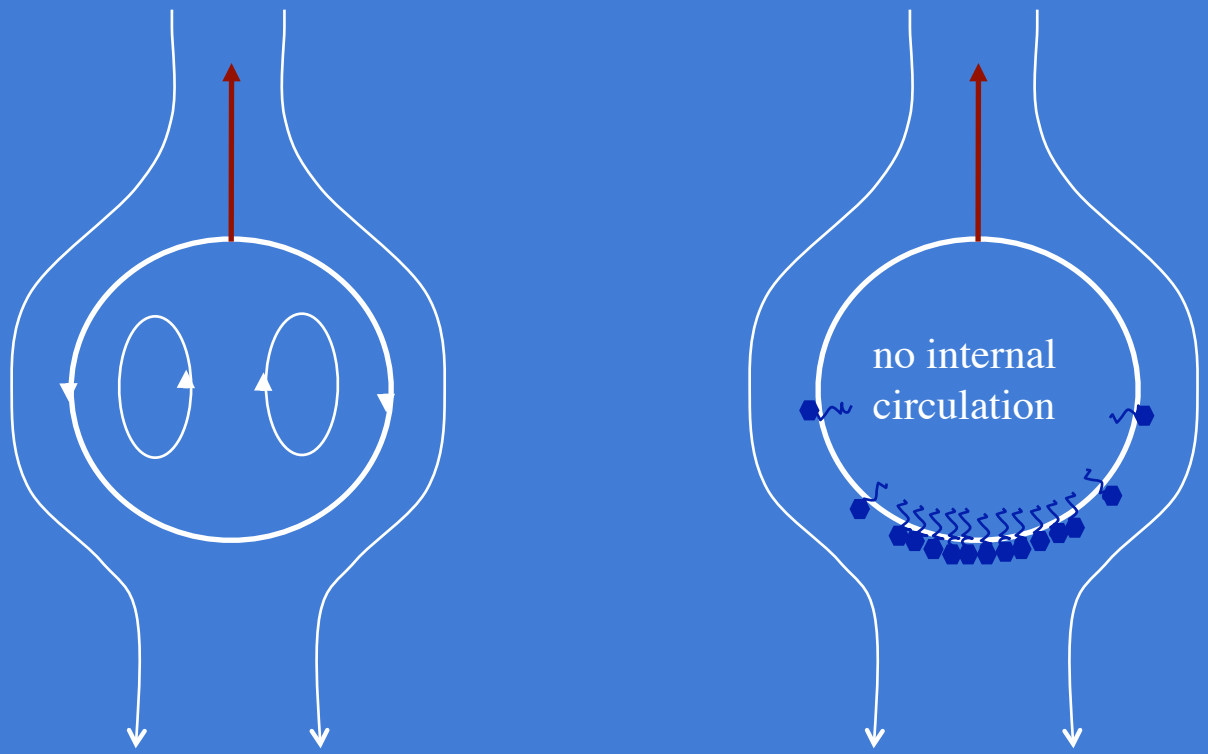
- weight of film supported by Marangoni stress



$$\rho g\, h(z) = 2\frac{d\sigma}{dz} = 2\frac{d\sigma}{d\Gamma}\frac{d\Gamma}{dz}$$

The influence of surfactant on bubbles and drops

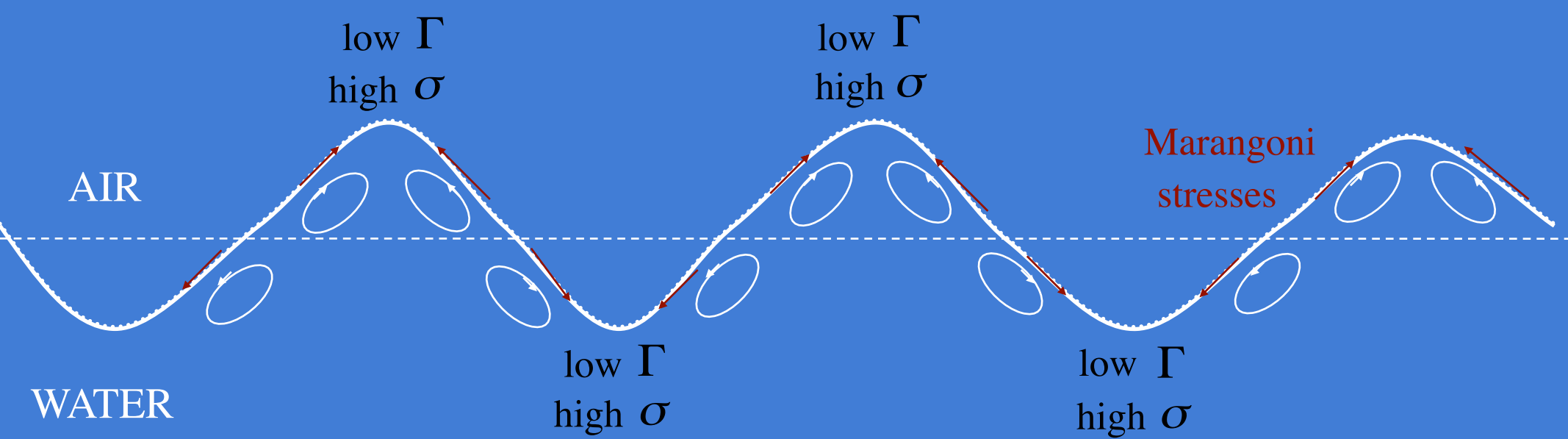
Observation: small bubbles, drops rise at speeds anticipated for RIGID particles



- rearrangement of surfactant → Marangoni, viscous stresses balance on surface
- surfactant rigidifies drop surface: internal circulation suppressed
- effect most pronounced for small drops, bubbles since $\nabla\sigma \sim \frac{\Delta\sigma}{a}$

The suppression of capillary waves by surfactant

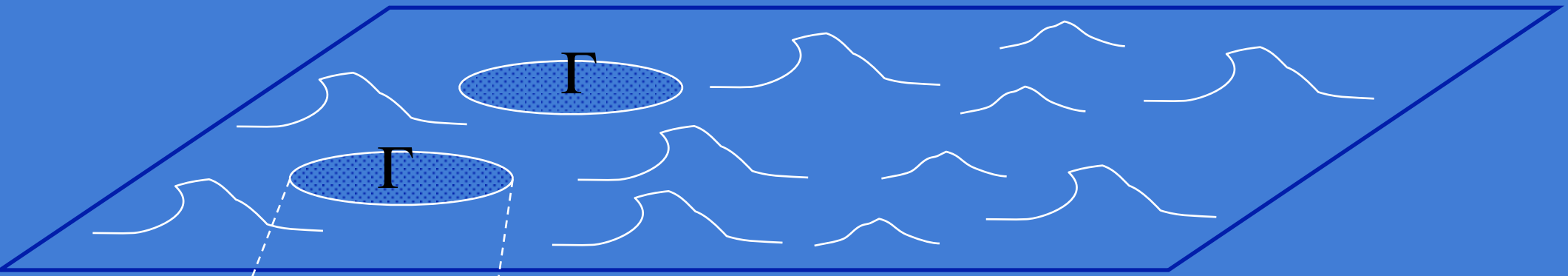
- wave motion generates regions of surface divergence
- concomitant surfactant gradients generate Marangoni stresses $\frac{d\sigma}{d\Gamma} < 0$
- resulting small scale flows extremely dissipative

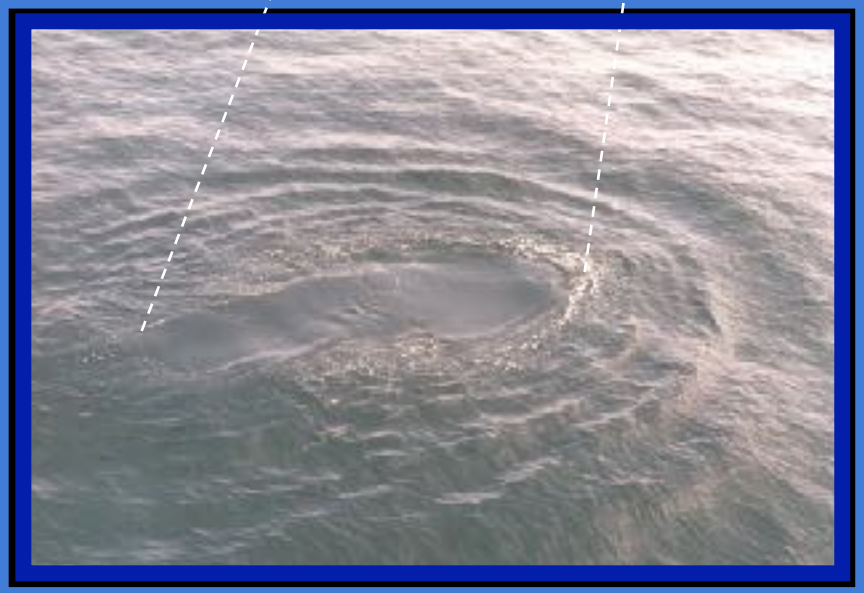


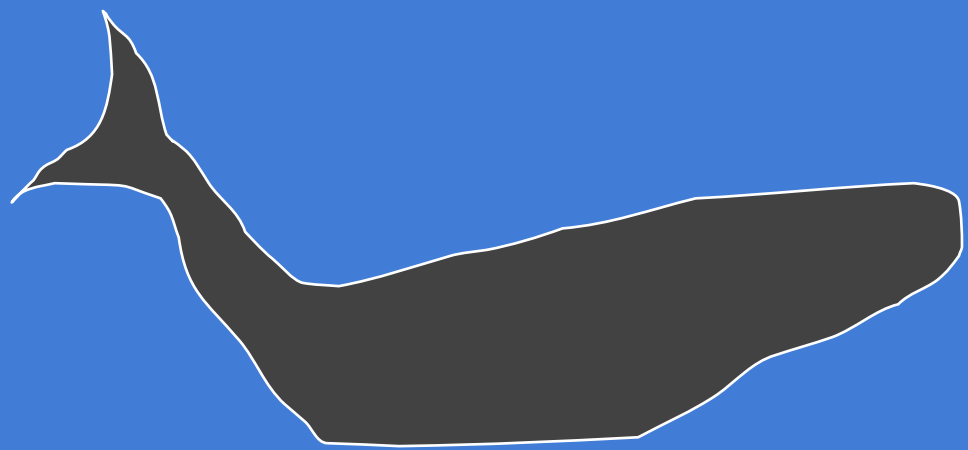
- flat ship wakes first remarked upon by Pliney the Elder
- examined by Benjamin Franklin, motivated by Bermudan spear fishermen
- now used to track submarines: flat wakes visible on satellite images

The footprints of whales

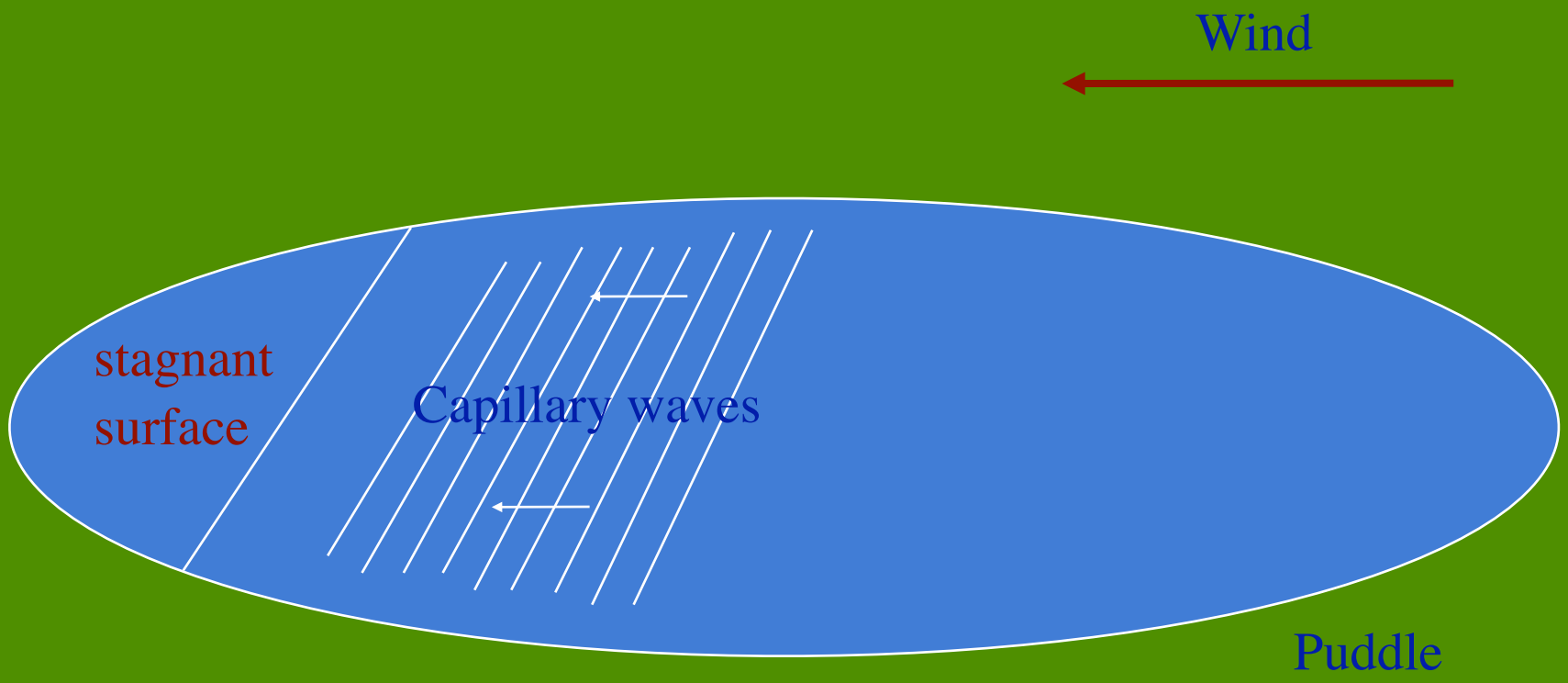
- surfactants (biomaterial in water column) swept to surface by diving whales
- suppress capillary waves and cascade to larger scale waves





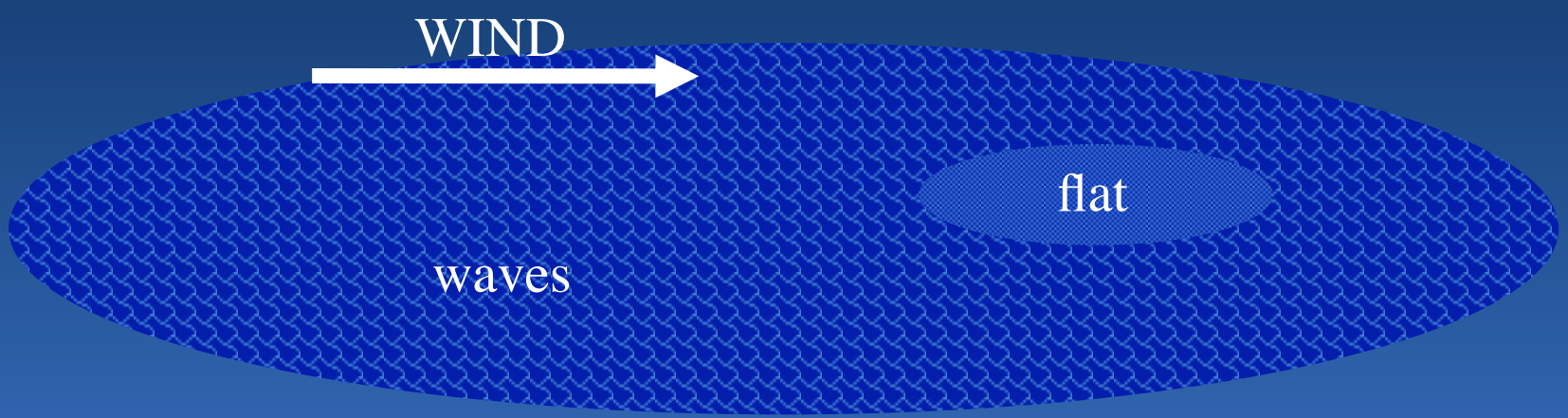


The dynamics of puddles



- surfactants swept to lee of puddle by wind stress
- Marangoni stress balances wind stress $\Rightarrow$ stagnant surface
- capillary waves suppressed by surfactant in lee of puddle

Surfactants and a murder mystery



Who dunnit?

"In the autumn of 1878 a man committed a terrible crime in Somerset, which was for some time involved in deep mystery. His wife, a handsome and decent mulatto woman, disappeared suddenly and entirely from sight, after going home from church on Sunday, October 20. Suspicion immediately fell upon the husband, a clever young fellow of about thirty, but no trace of the missing woman was left behind, and there seemed a strong probability that the crime would remain undetected. On Sunday, however, October 27, a week after the woman had disappeared, some Somerville boatmen looking out towards the sea, as is their custom, were struck by observing in the Long Bay Channel, the surface of which was ruffled by a slight breeze, a long streak of calm such as, to use their own illustration, a cask of oil usually diffuses around it when in the water. The feverish anxiety about the missing woman suggested some strange connection between this singular calm and the mode of her disappearance. Two or three days after – why not sooner I cannot tell you – her brother and three other men went out to the spot where it was observed, and from which it had not disappeared since Sunday, and with a series of fish-hooks ranged along a long line dragged the bottom of the channel, but at first without success. Shifting the position of the boat, they dragged a little further to windward, and presently the line was caught. With water glasses the men discovered that it had caught in a skeleton which was held down by some heavy weight. They pulled on the line; something suddenly gave way, and up came the skeleton of the trunk, pelvis, and legs of a human body, from which almost every vestige of flesh had disappeared, but which, from the minute fragments remaining, and the terrible stench, had evidently not lain long in the water. The husband was a fisherman, and Long Bay Channel was a favourite fishing-ground, and he calculated, truly enough, that the fish would very soon destroy all means of identification; but it never entered into his head that as they did so their ravages, combined with the process of decomposition, would set free the matter which was to write the traces of his crime on the surface of the water. The case seems to be an exceedingly interesting one; the calm is not mentioned in any book on medical jurisprudence that I have, and the doctors seem not to have had experience of such an occurrence. A diver went down and found a stone with a rope attached, by which the body had been held down, and also portions of the scalp and of the skin of the sole of the foot, and of clothing, by means of which the body was identified. The husband was found guilty and executed."

Nature, 22, 1880

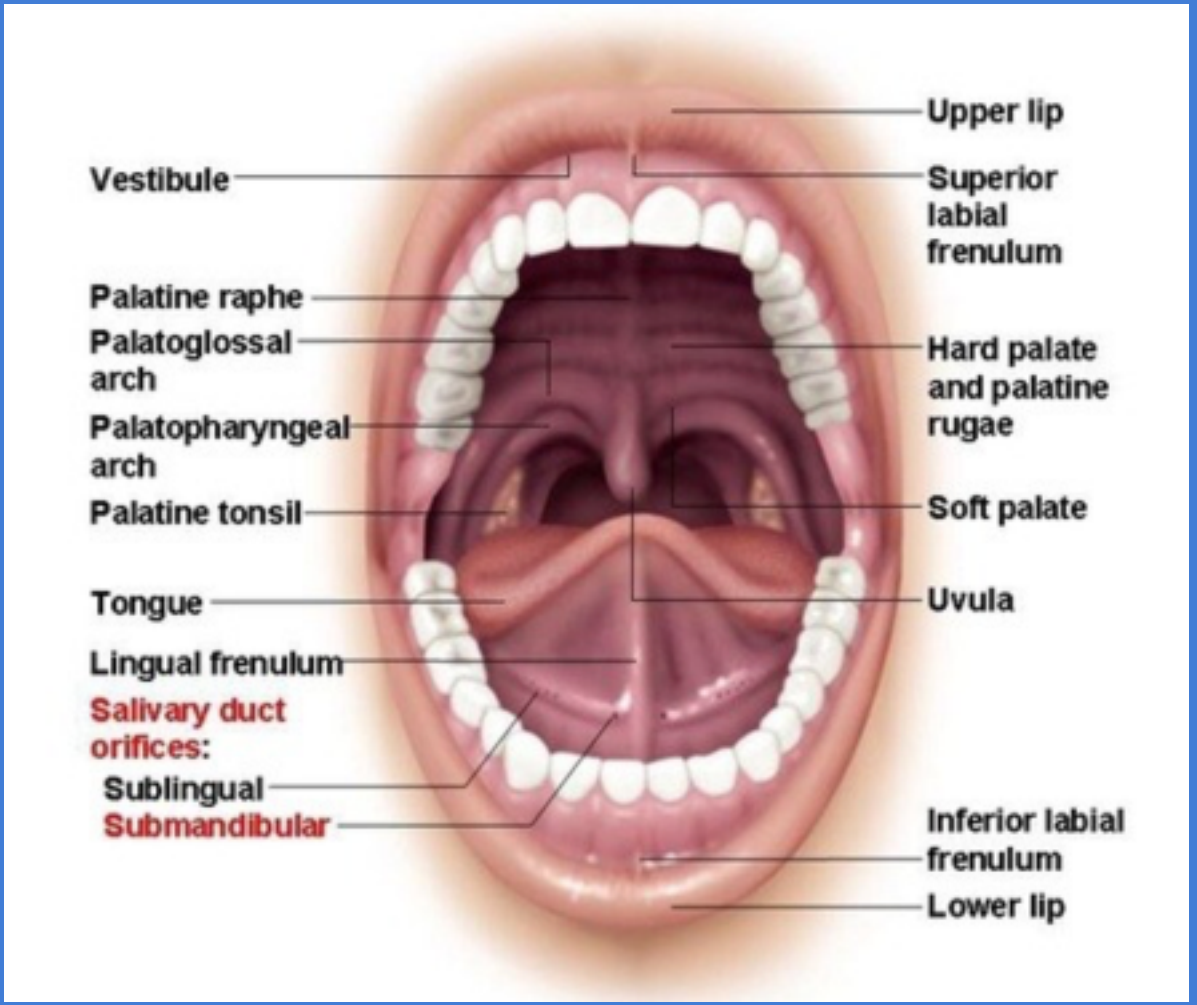
Course projects: some old favorites

#1: Michela Geri. Thermally-induced drop noncoalescence

Course projects: some old favorites

#2. Bubbles in moonshine production

#3: On gleeking: yawn-induced sprays



Some course project ideas

Solve this problem exactly…

…. and find some interesting extensions.

Can you develop it into a nice problem set problem?

Anurida maritima

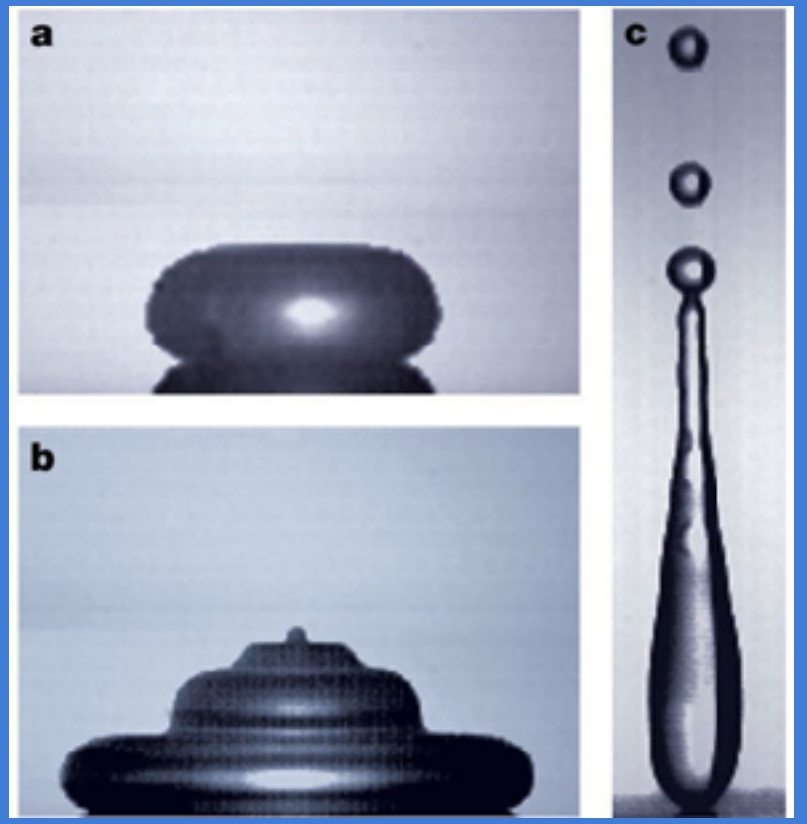
Can a floating body propel itself across a
flat interface quasi-statically?

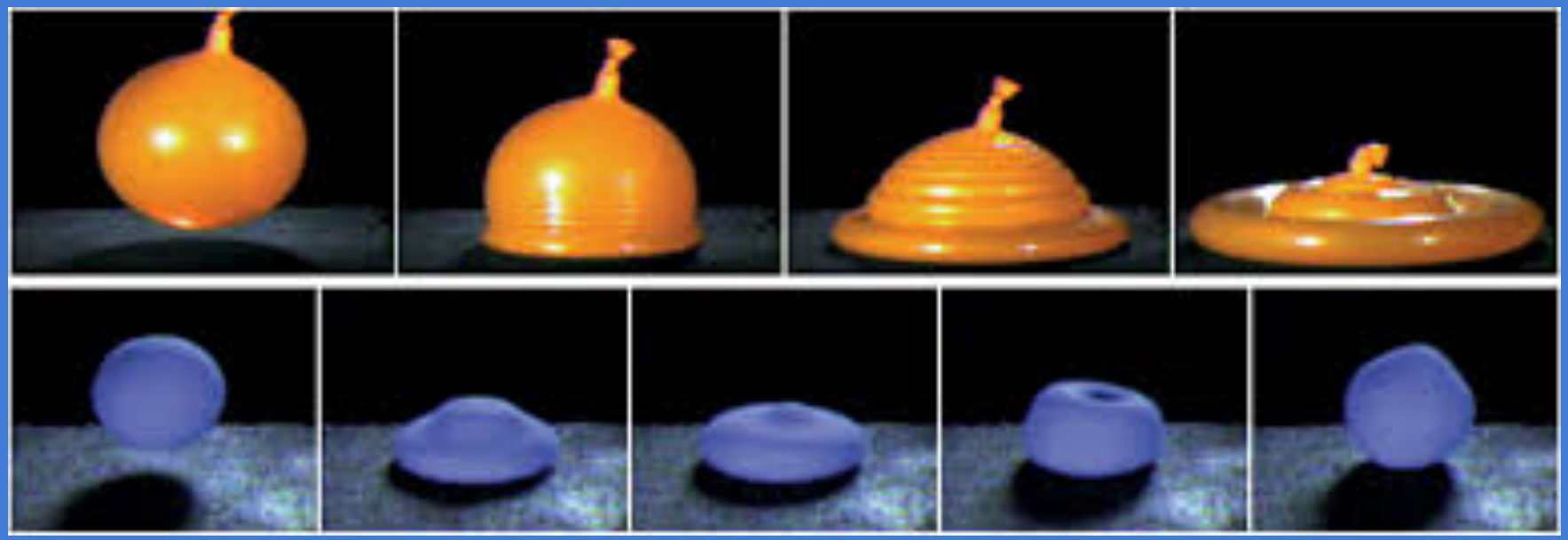
Propulsion via Faraday waves : Experiments

Produce a boat powered by Faraday waves…

Produce a boat/gear powered by a walking drop…

Wedding cake structure in impacting drops and water balloons

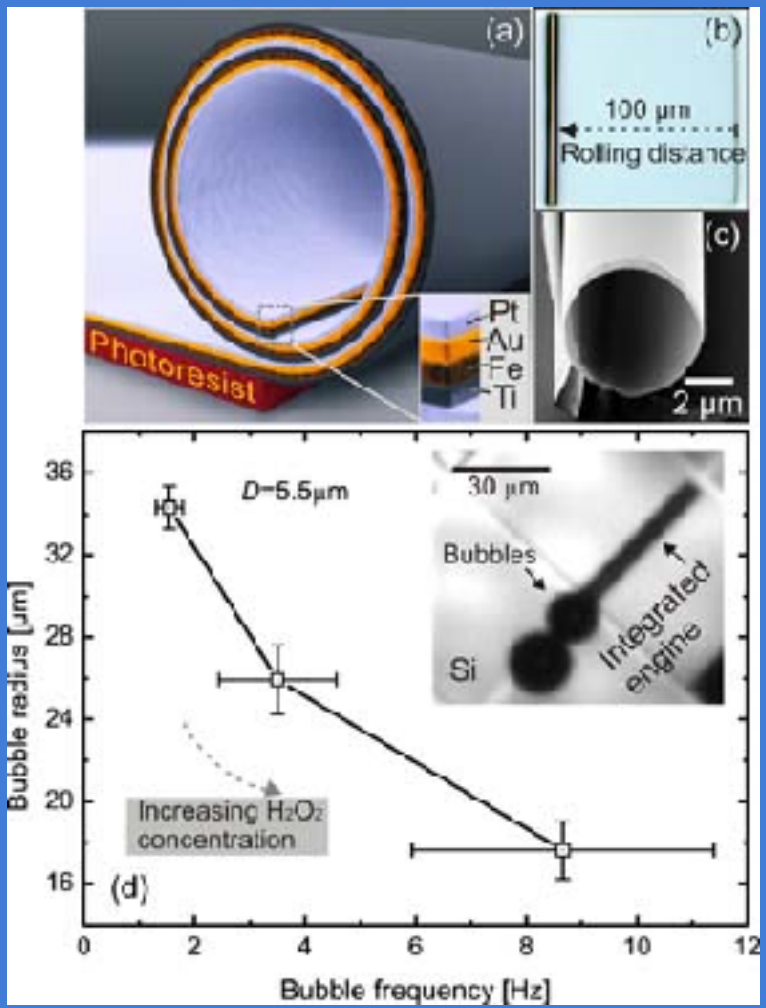


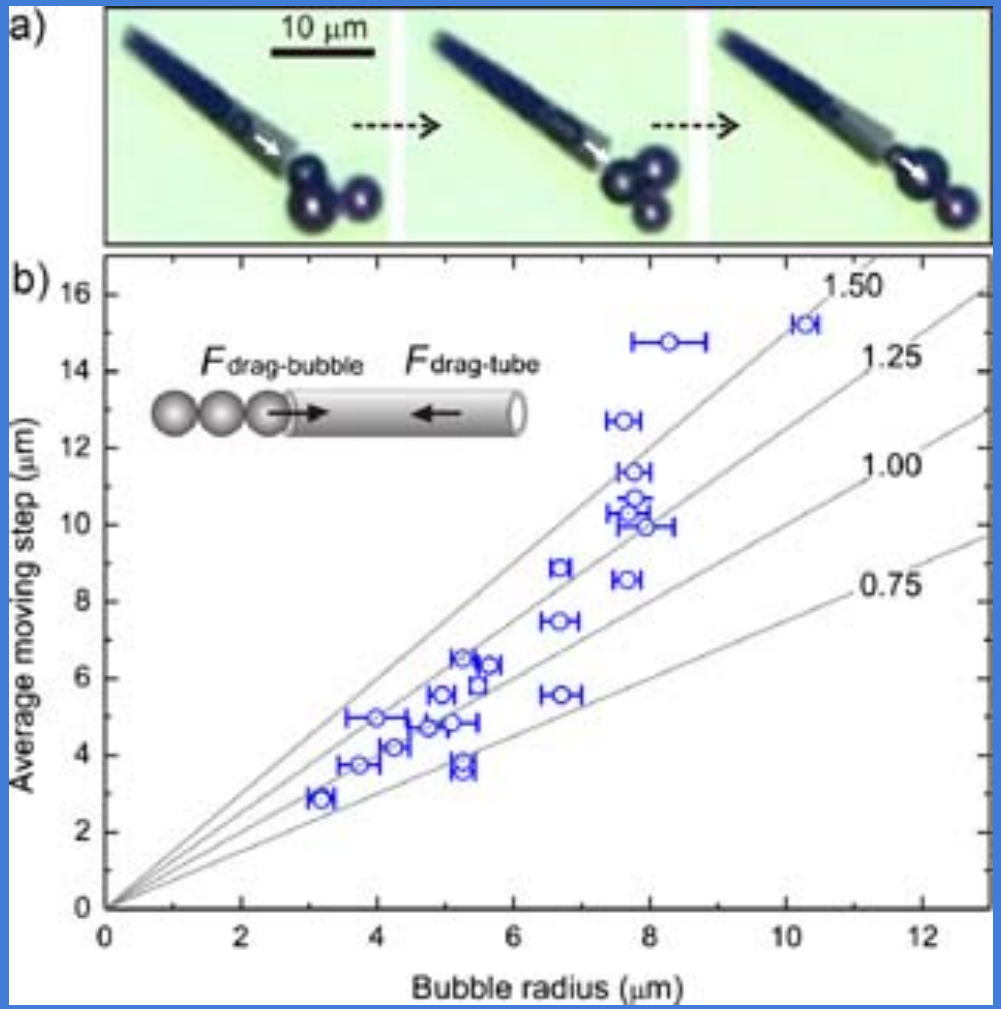


The bubble engine

Catalytic Microtubular Jet Engines Self-Propelled by Accumulated Gas Bubbles

- Solovev et al. (2009):





Fireworks

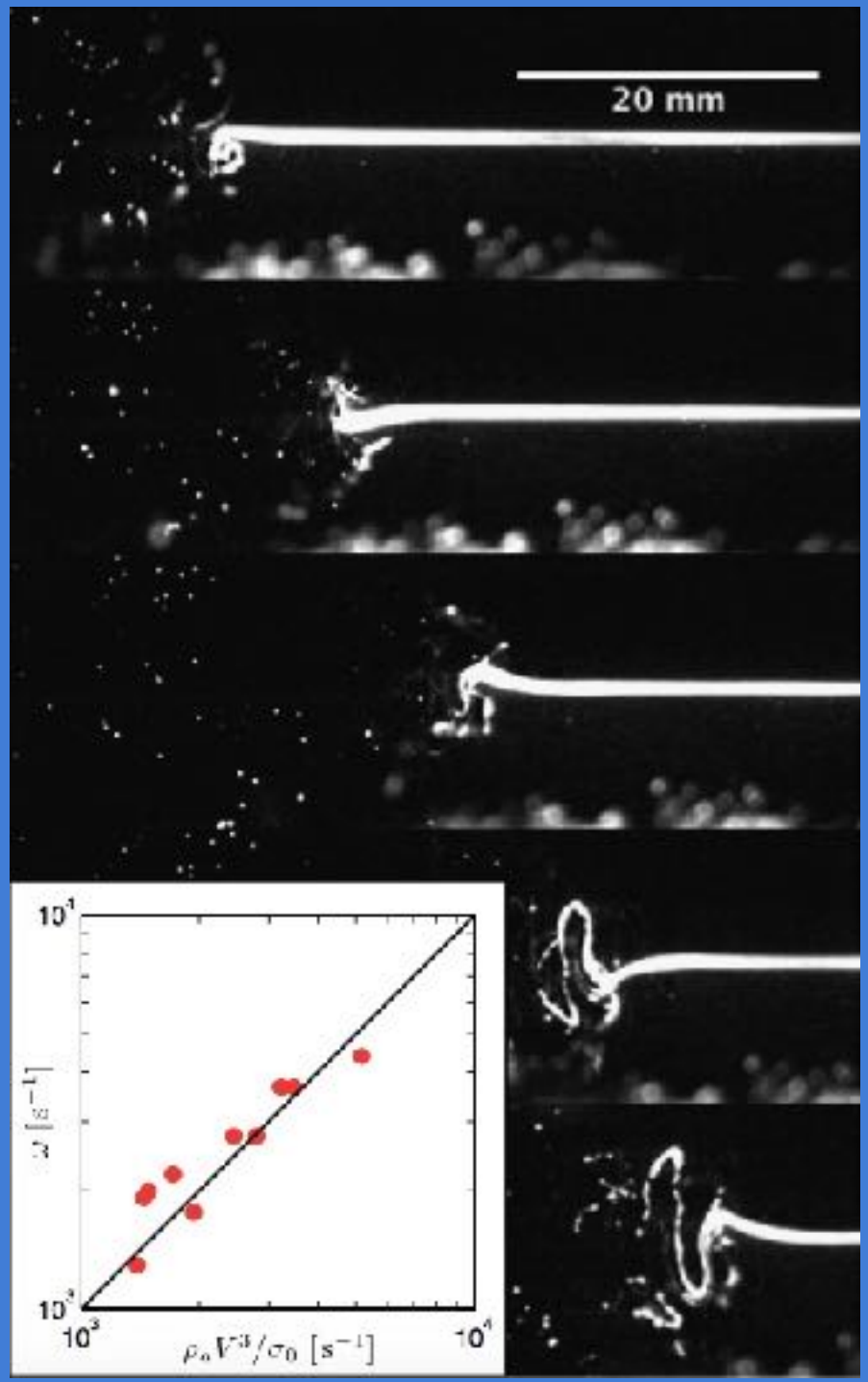
(see Inoue et al. GFM)

Sparklers

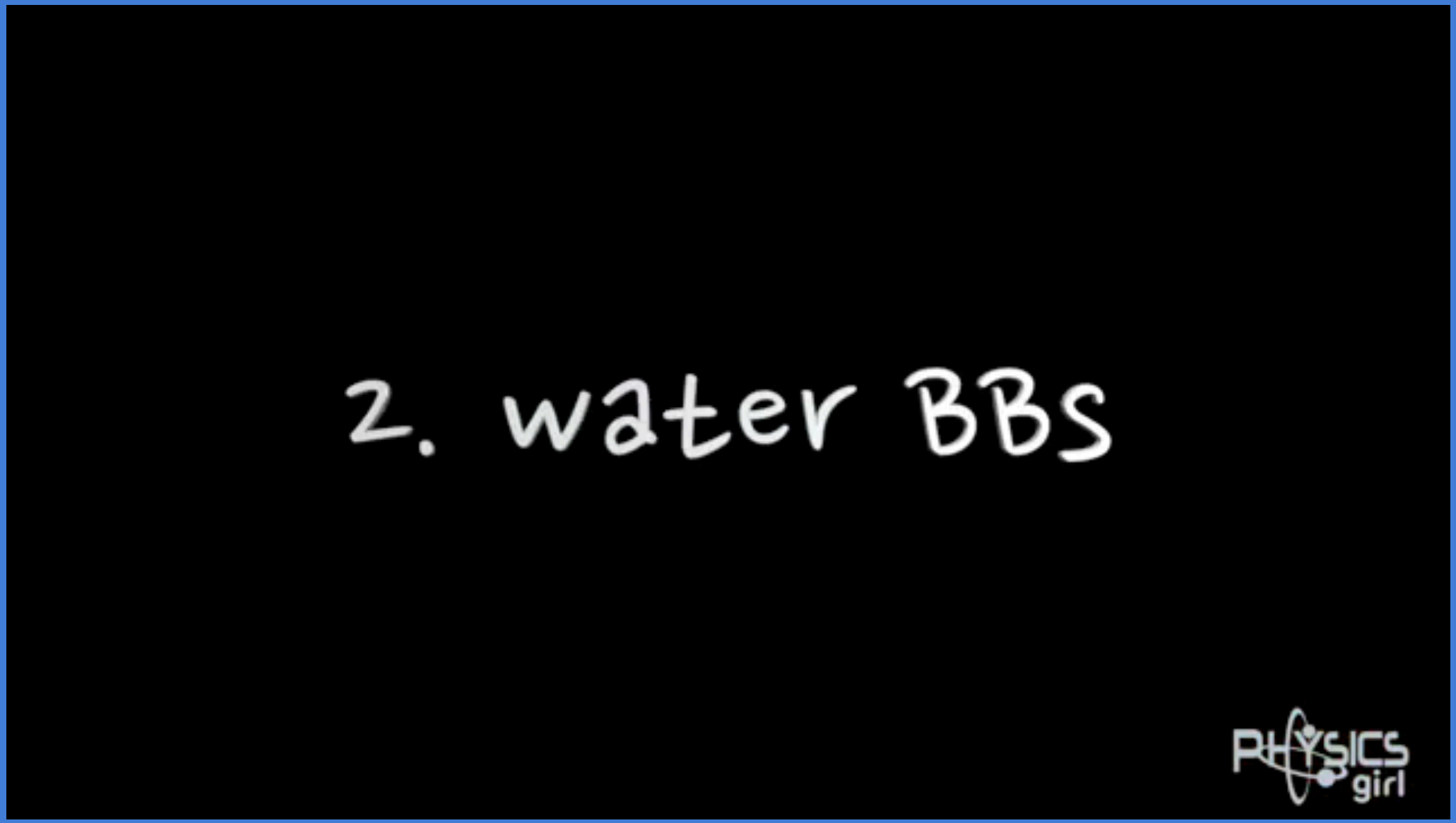
Flapping retracting soap films

(Lhuissier & Villermaux, 2009)

- results from Marangoni elasticity of soap film



Art project (with Physics Girl)



Starlings

What is the effective surface tension of the flock?

Peloton dynamics

What is the effective surface tension of the peloton?

Can inter-peloton motion be considered as a Marangoni flow?

Physics of skiing and skating

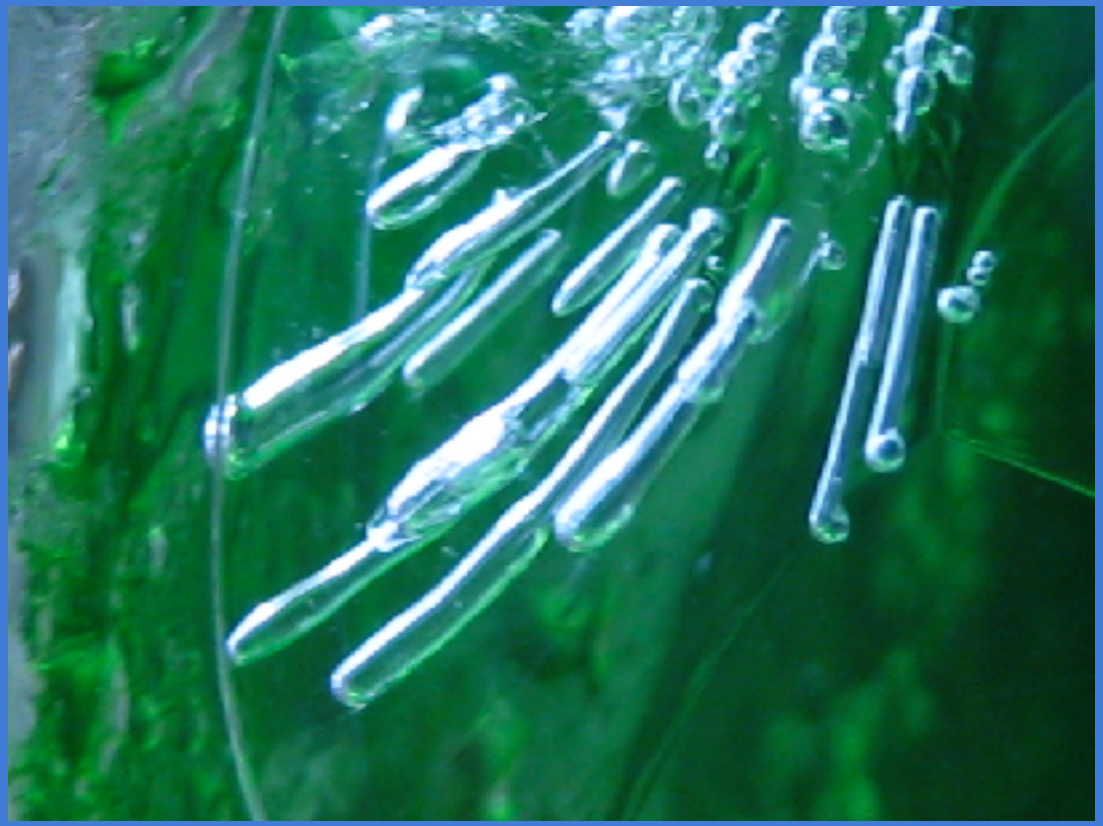
Physics of curling

What sets the wavelength of the ripples?

What sets the wavelength of the ripples?

Interfacial effects in snowflake formation

Bubbles in ice



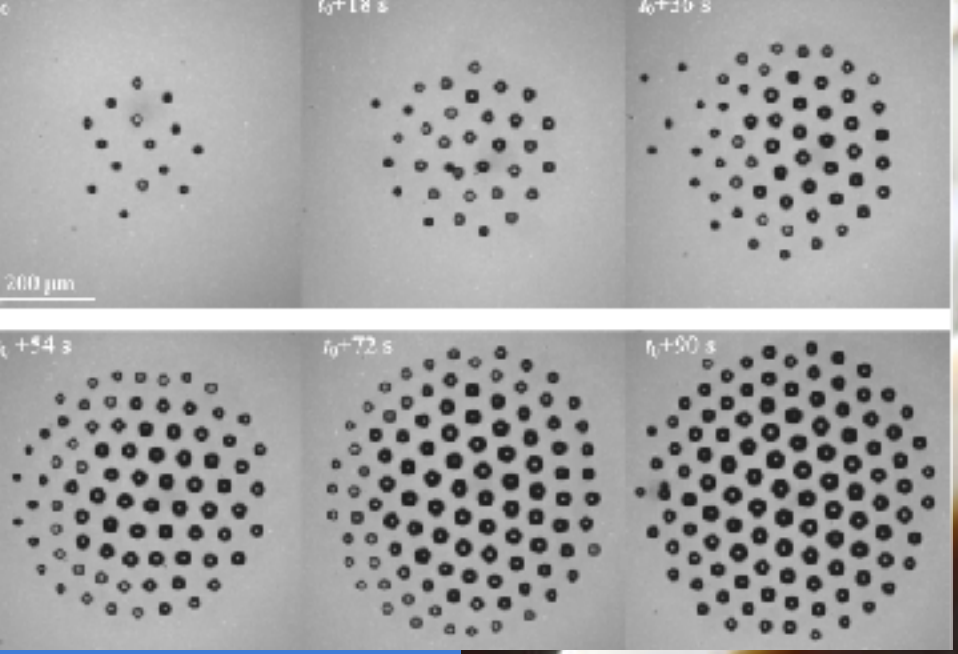
Bubbles in ice

What sets their shape?

Frost

Fire & Ice

On icicles and deep-fried turkey



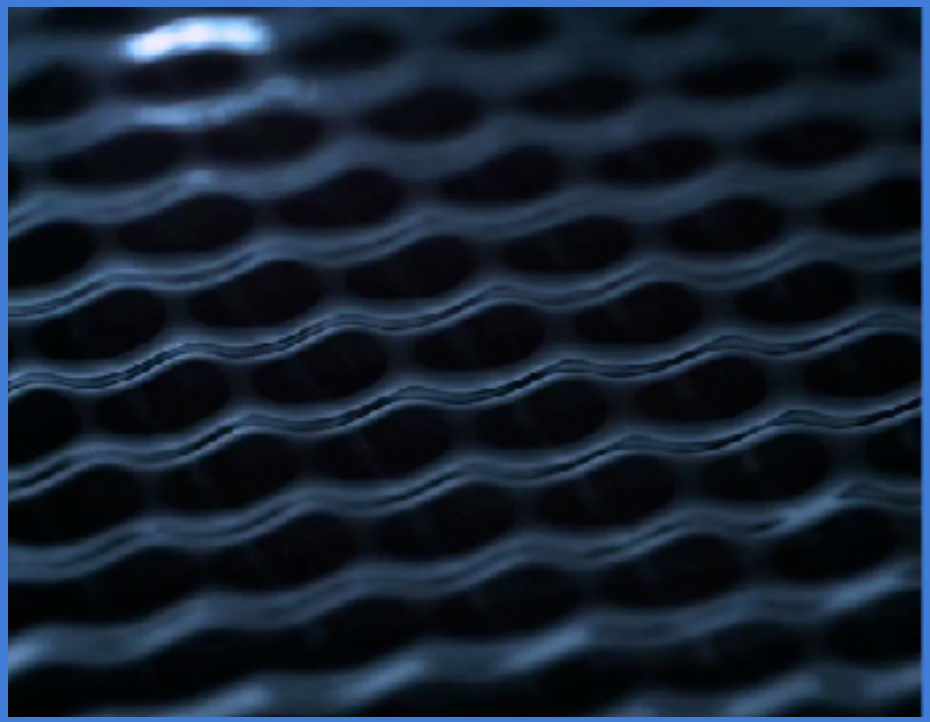
Dynamics of microdroplets over the surface of hot water (Umeki et al., Sci. Rep., 2015)

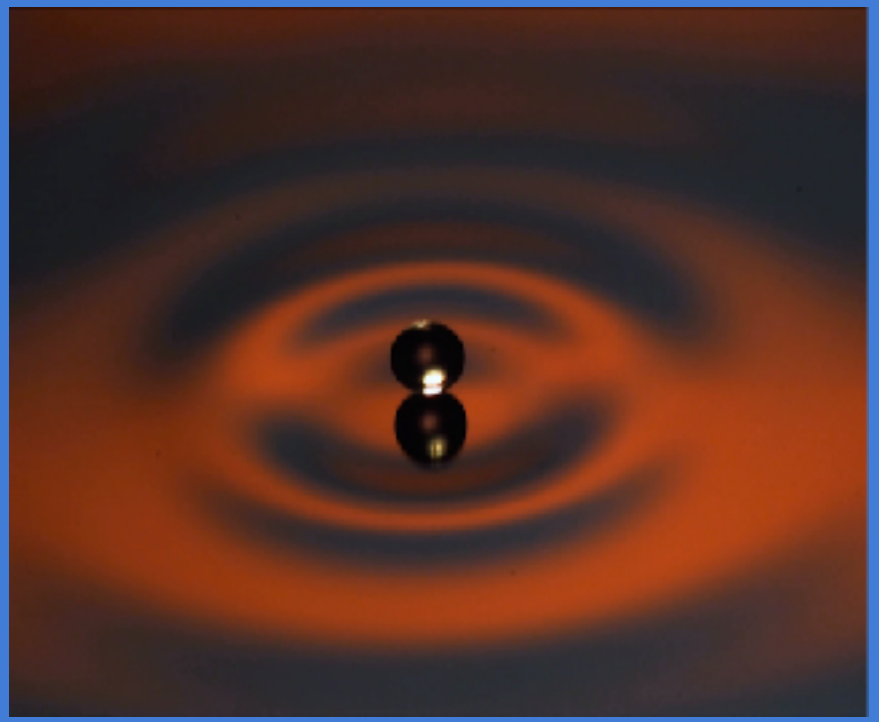
Acoustically forced jets

Harmonic Faraday Instability : Experiment

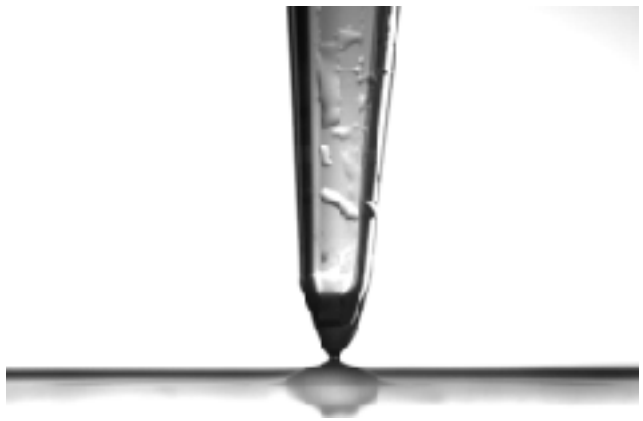
There are fluids for which the most unstable wave mode is harmonic rather than subharmonic.

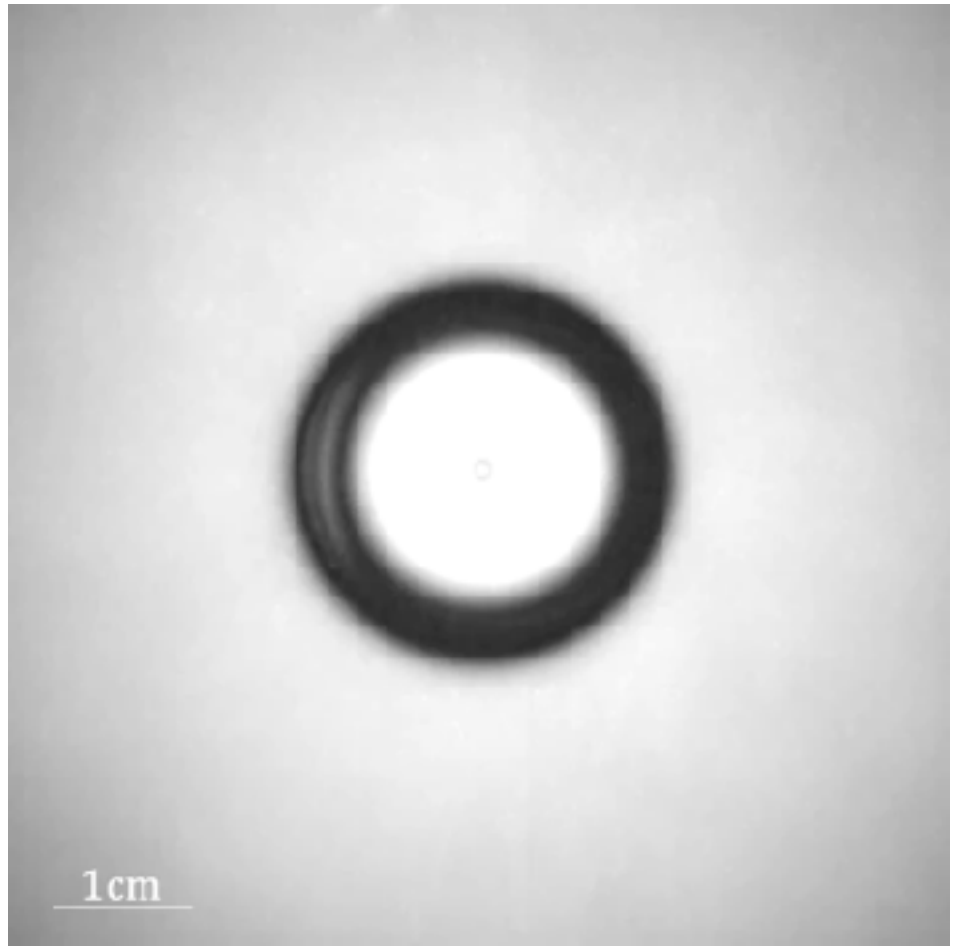
In this regime, assess whether it is possible for drops to levitate or walk.





Faraday waves in floating lenses (Pucci et al. 2012)

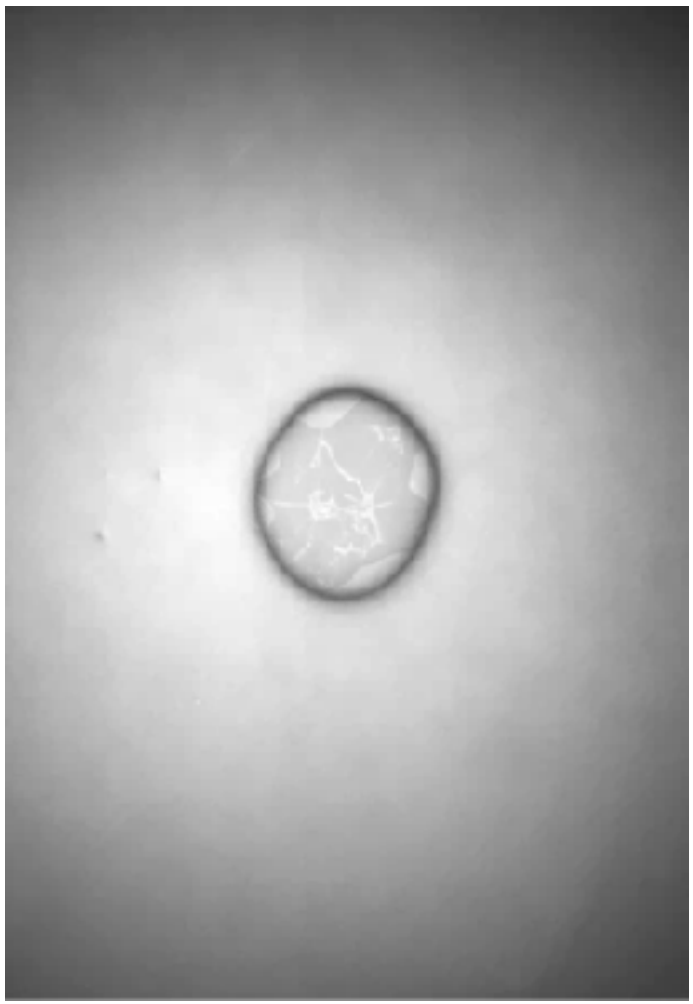


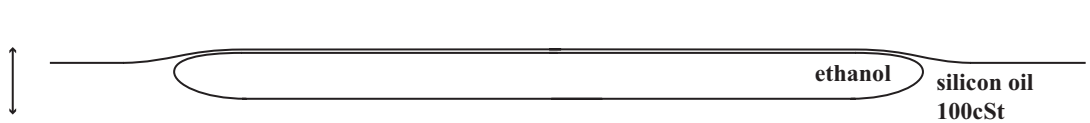


Faraday waves in floating lenses

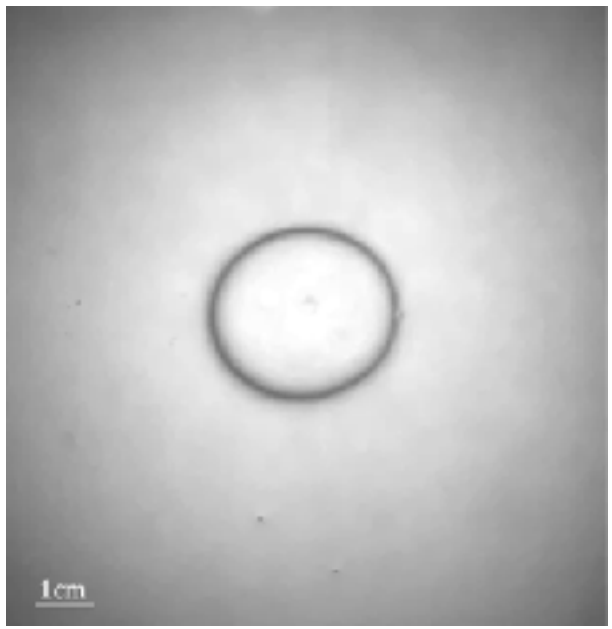
low interfacial tension

low forcing amplitude

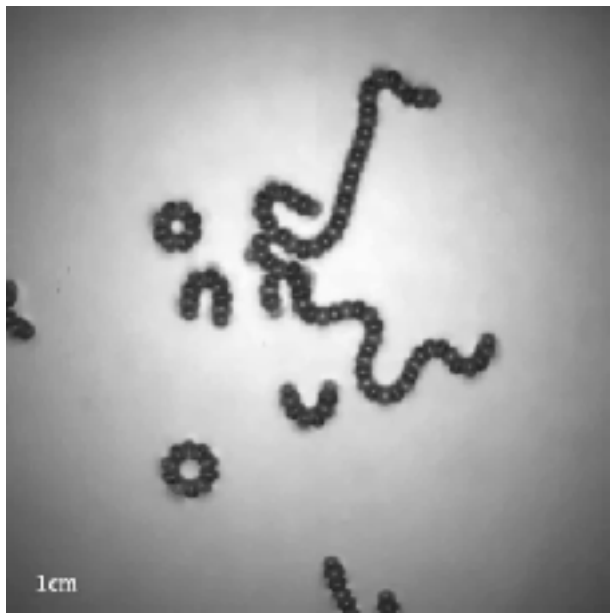




high forcing amplitude

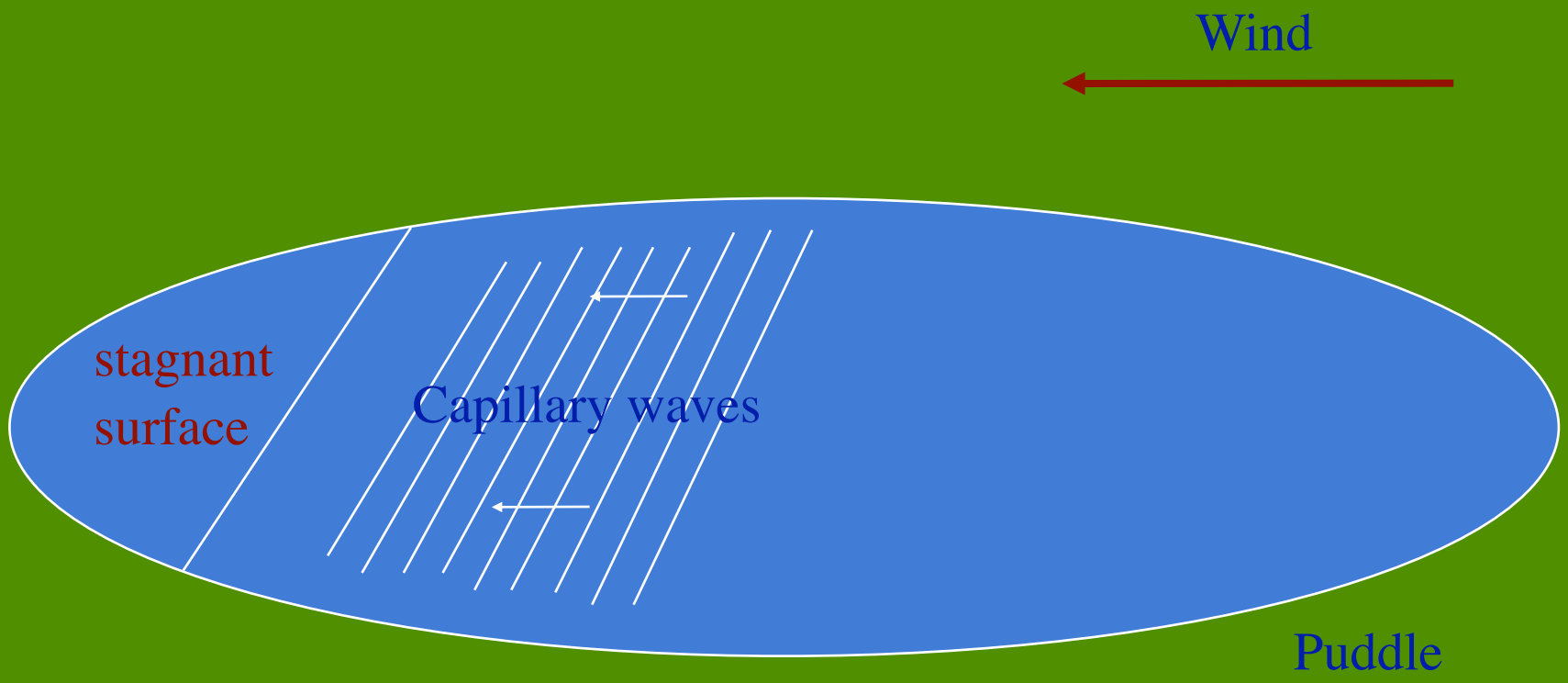


after a few minutes



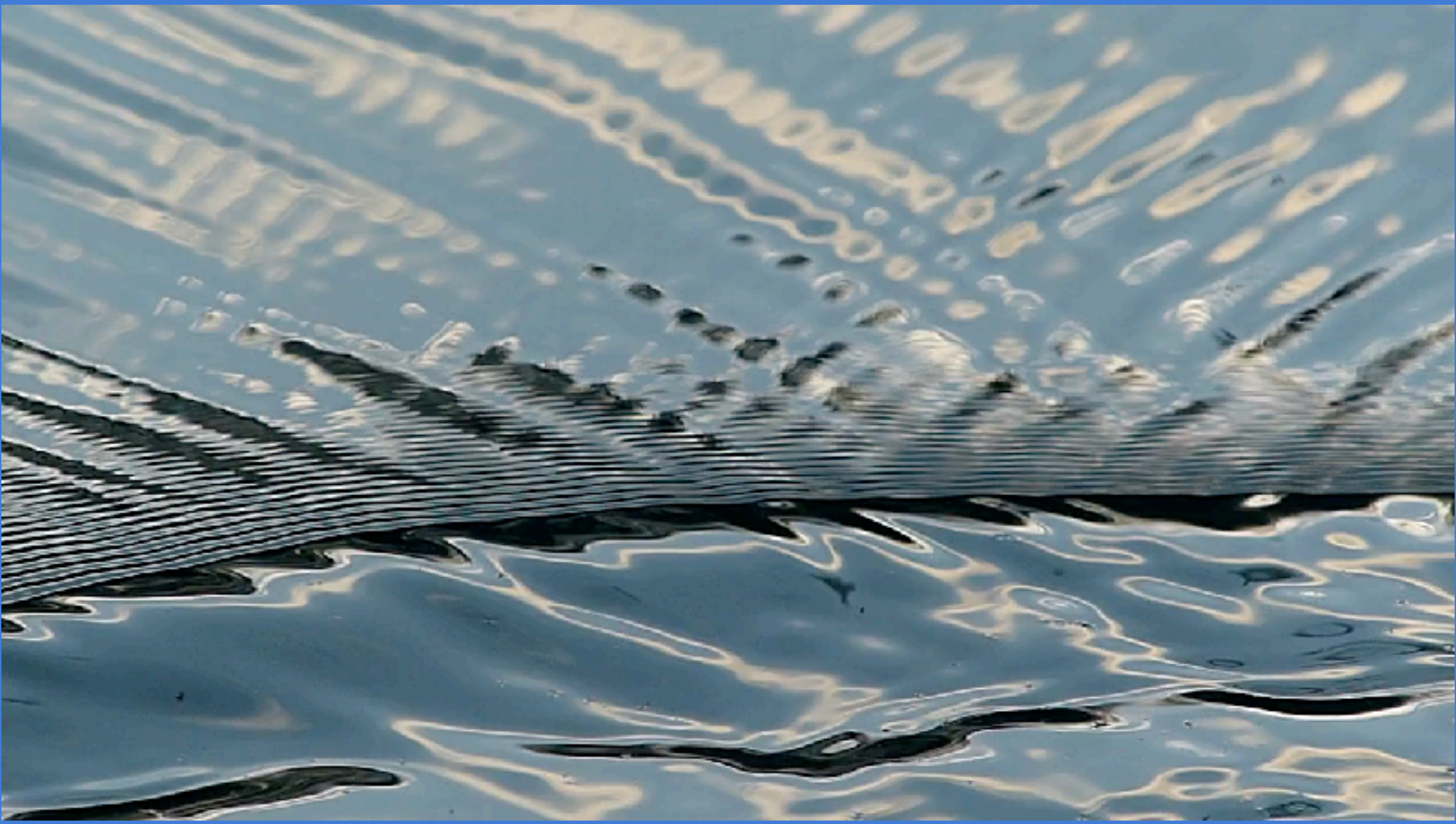
Jet-induced fracture of a free surface

The dynamics of puddles

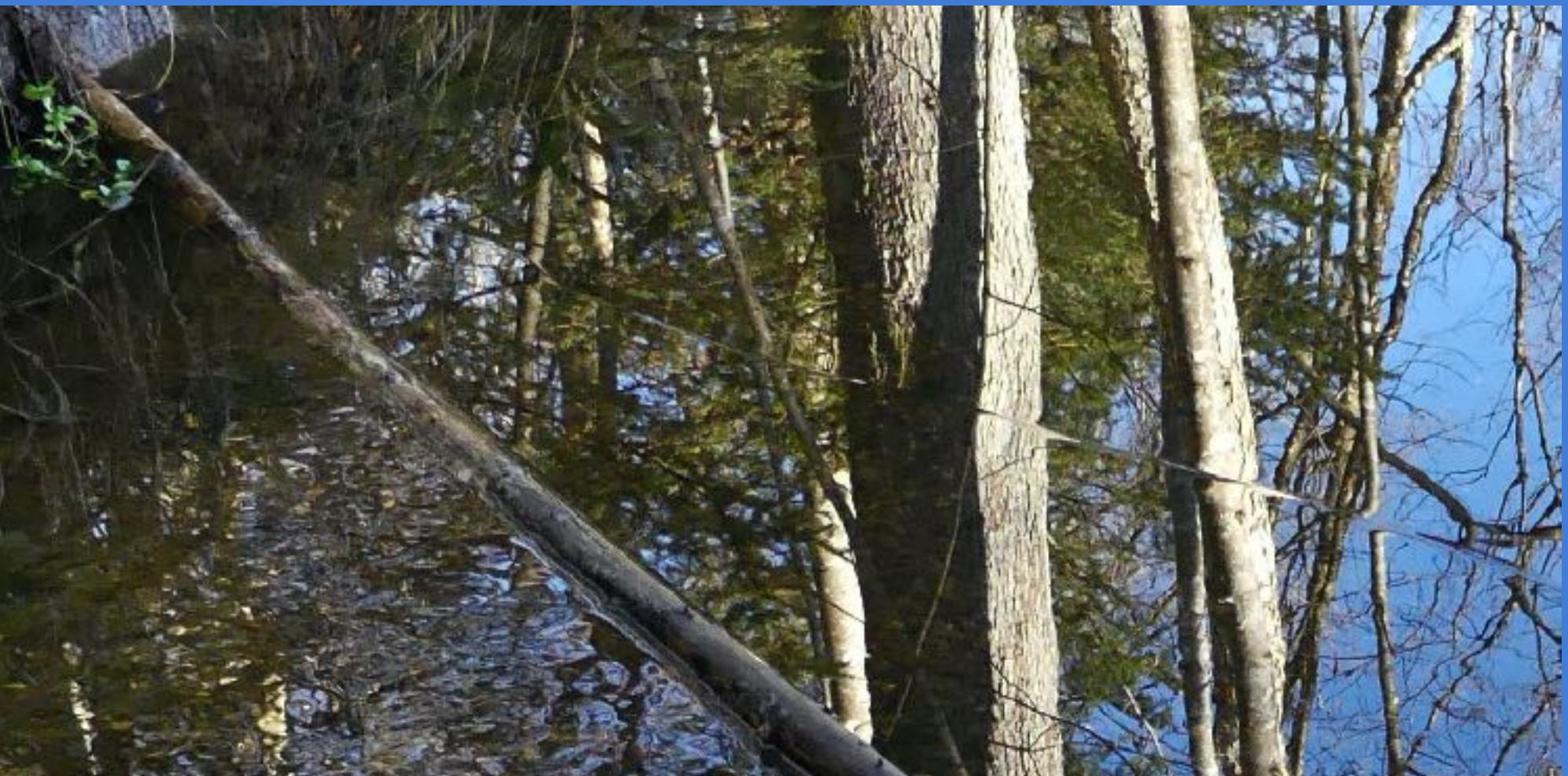


- surfactants swept to lee of puddle by wind stress
- Marangoni stress balances wind stress $\Rightarrow$ stagnant surface
- capillary waves suppressed by surfactant in lee of puddle

The Thoreau-Reynolds Ridge



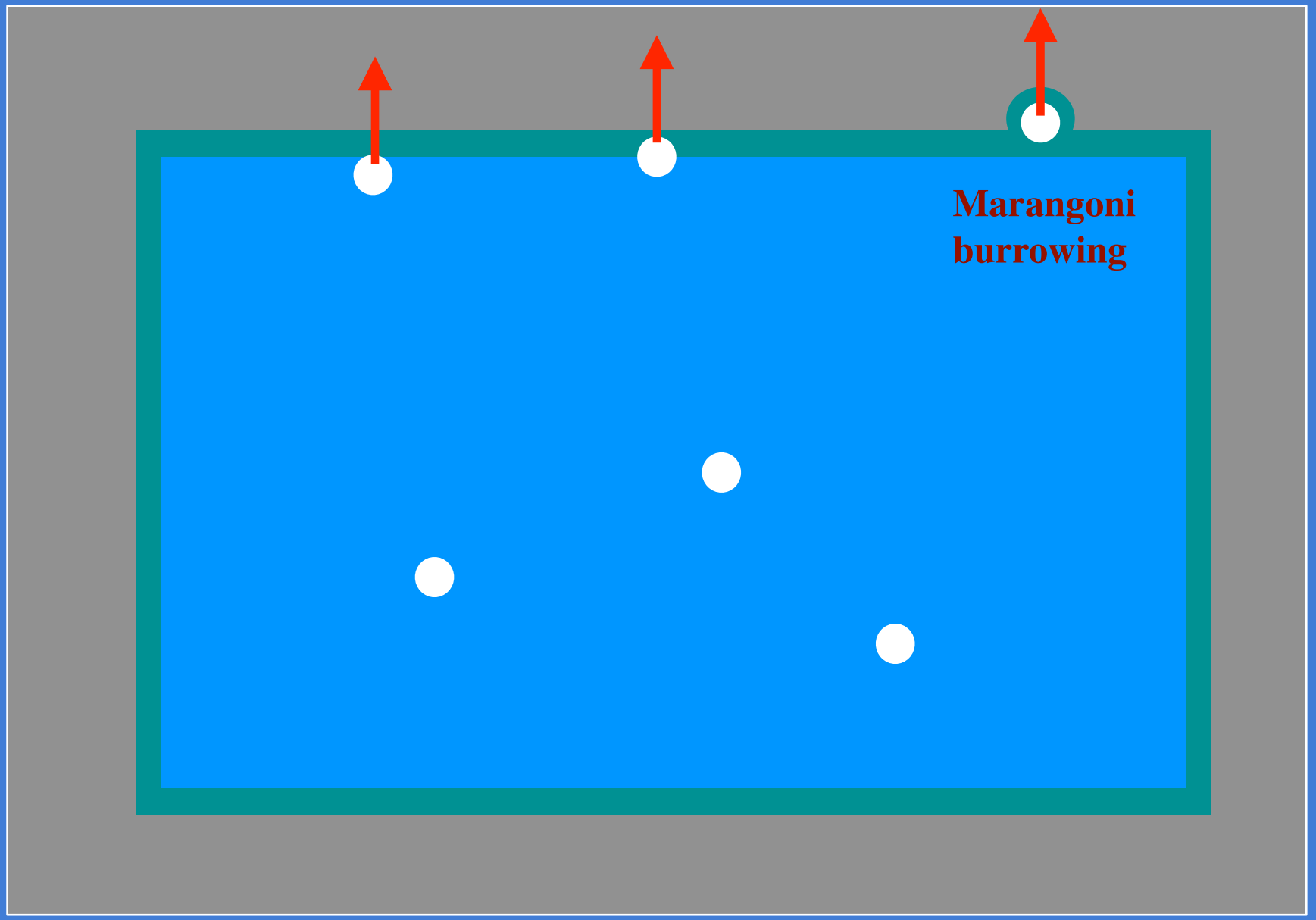
The Thoreau-Reynolds Ridge



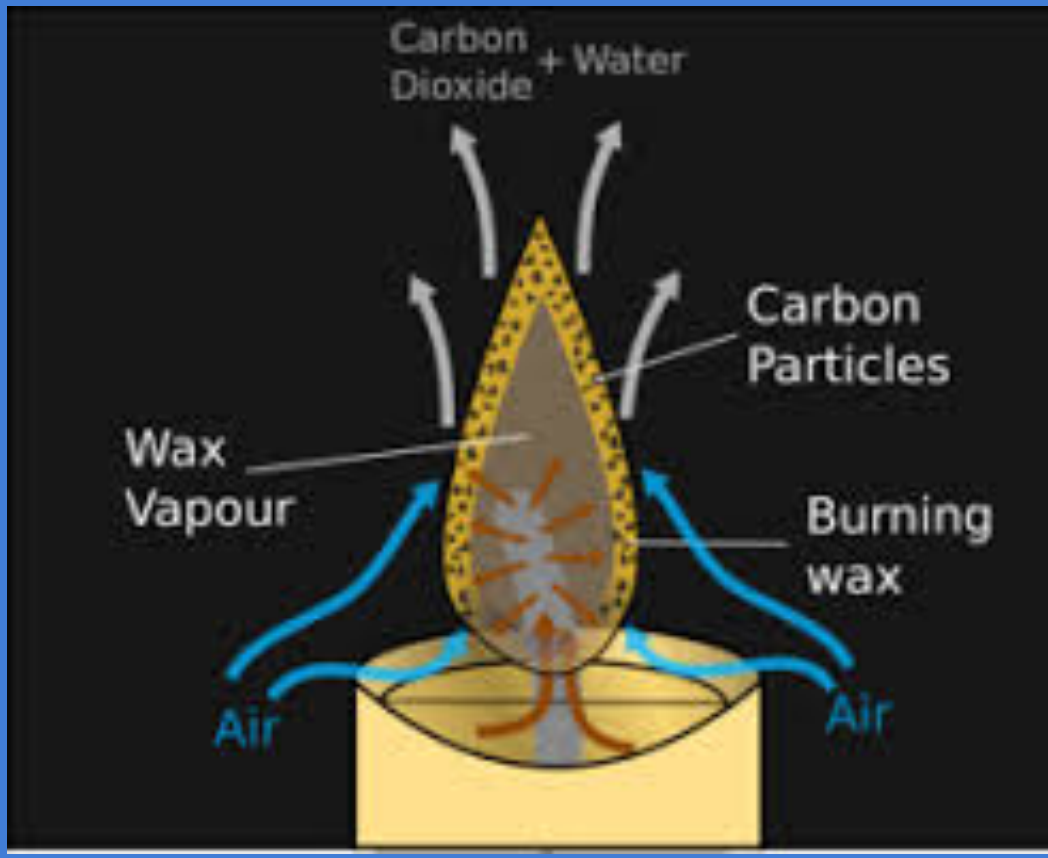
Bubbles in glass blowing

Marangoni Doomsday

The storage of radioactive liquid waste.



Capillary effects in candles

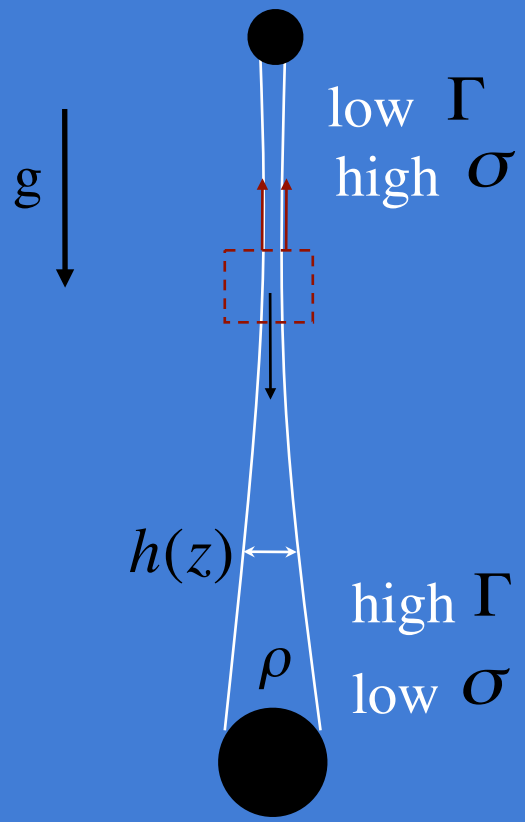


Soap films

- stabilized against rupture by presence of surfactants

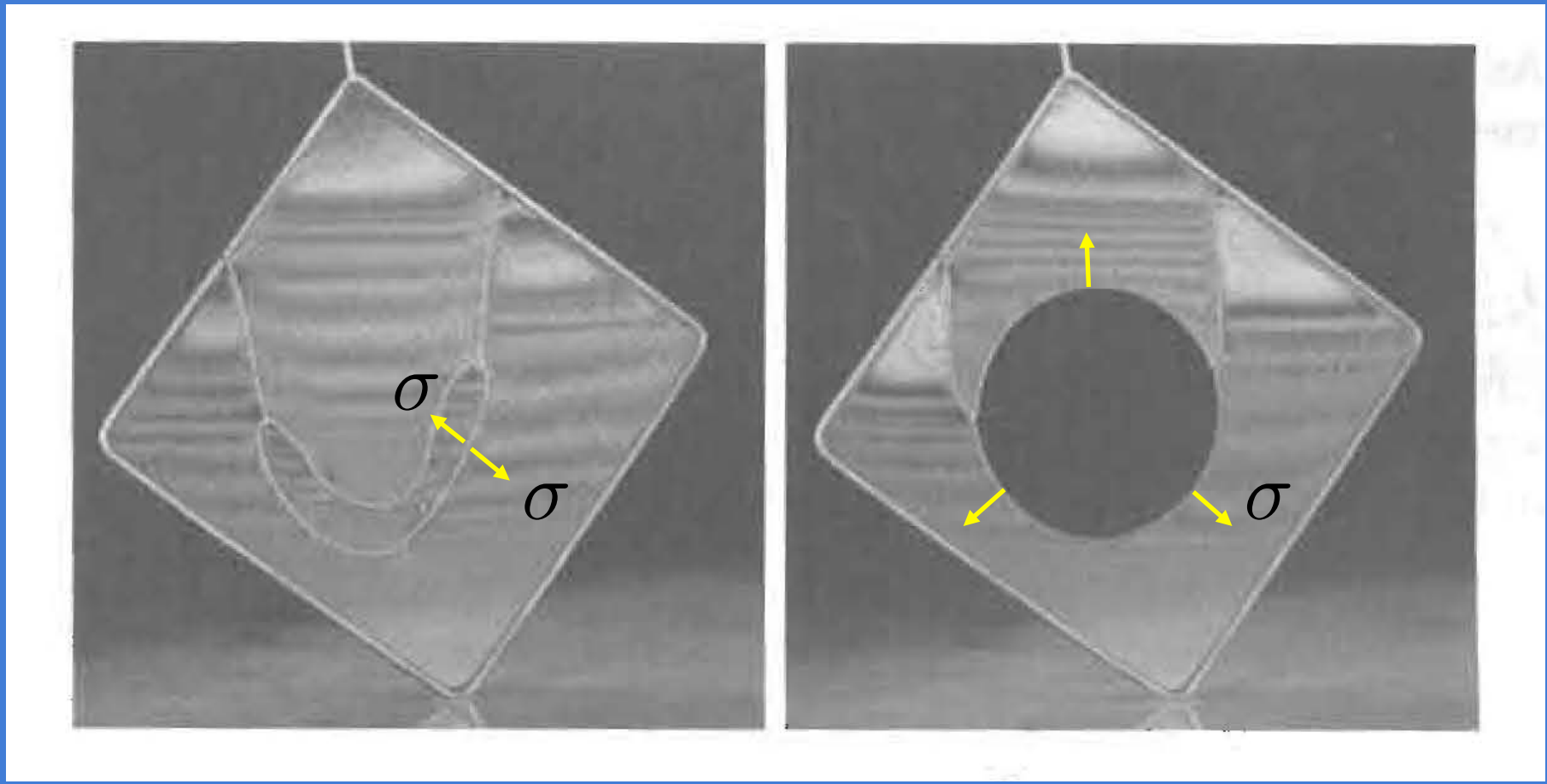
Draining soap film

- weight of film supported by Marangoni stress



$$\rho g\, h(z) = 2\frac{d\sigma}{dz} = 2\frac{d\sigma}{d\Gamma}\frac{d\Gamma}{dz}$$

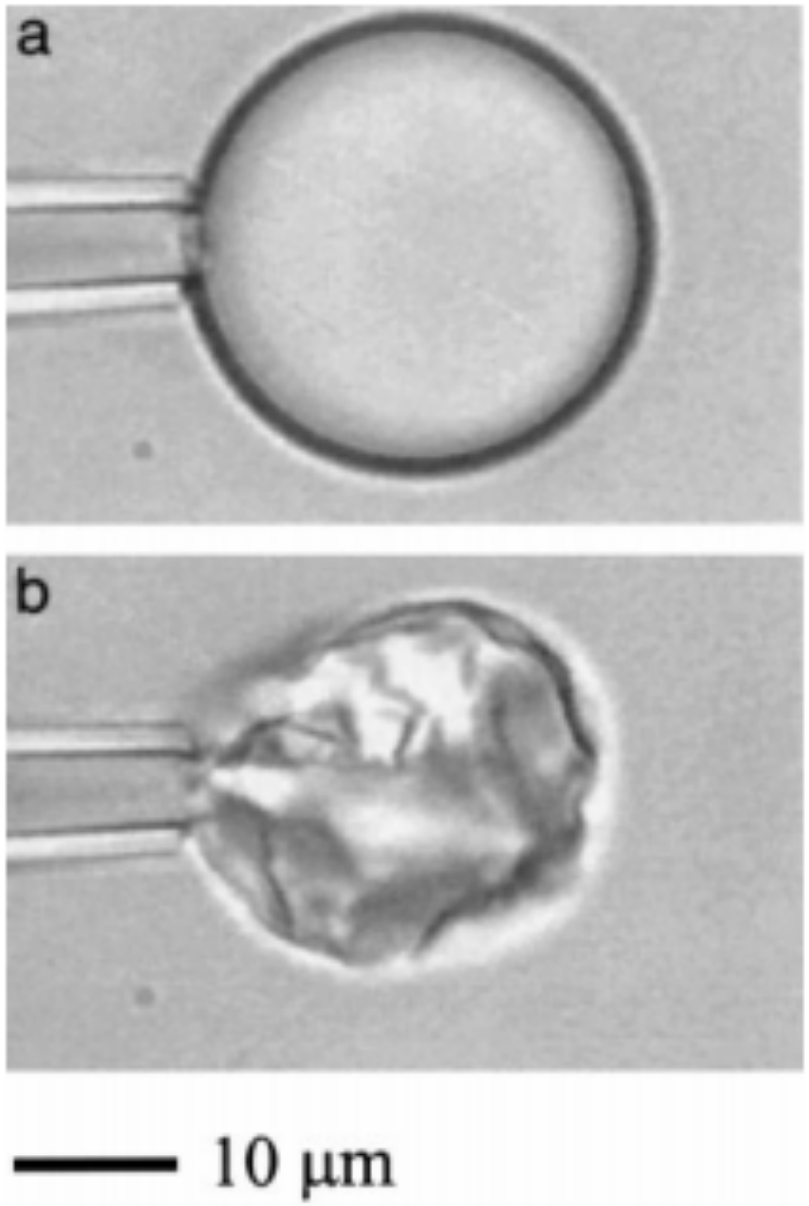
A string in a soap film



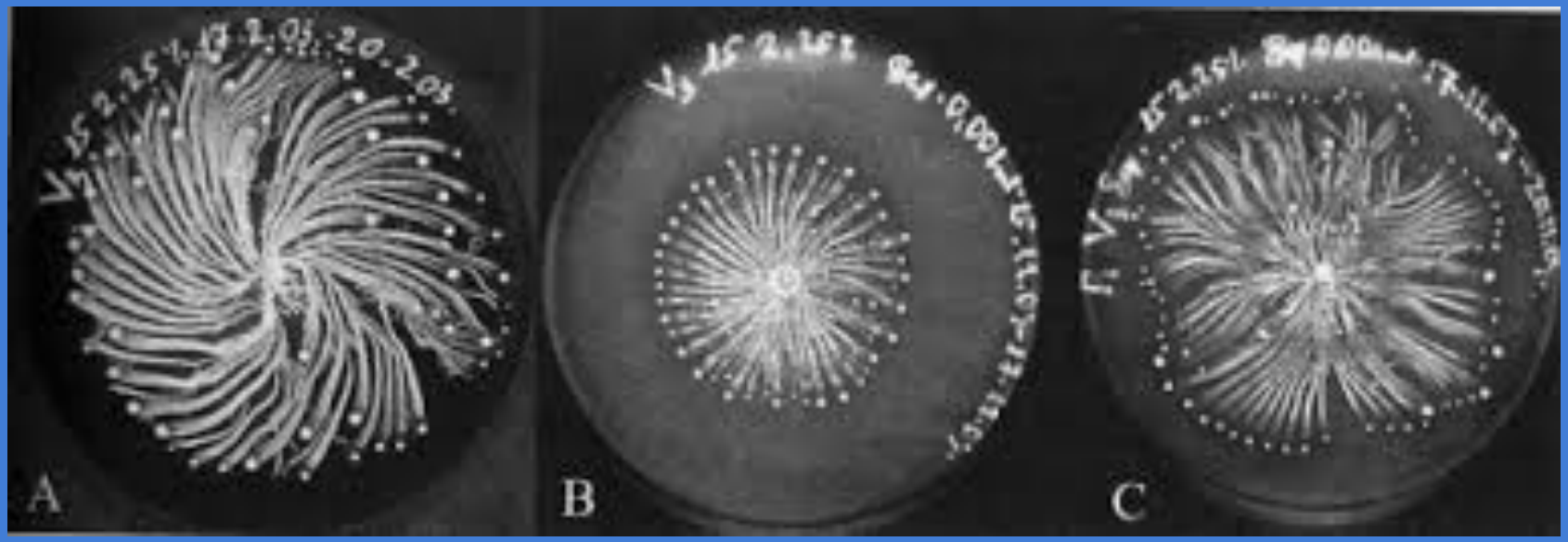
If you use a hair, you can achieve neutral buoyancy, and so have a two-dimensional model of a balloon in the atmosphere.

Marangoni buckling

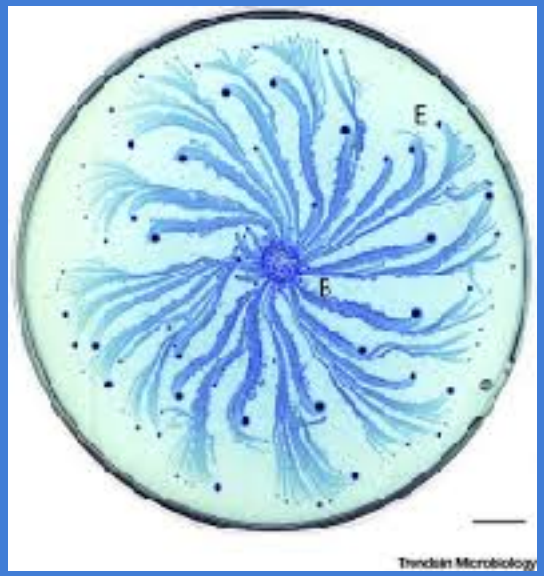
The collapse of a water drop in a surfactant-laden oil

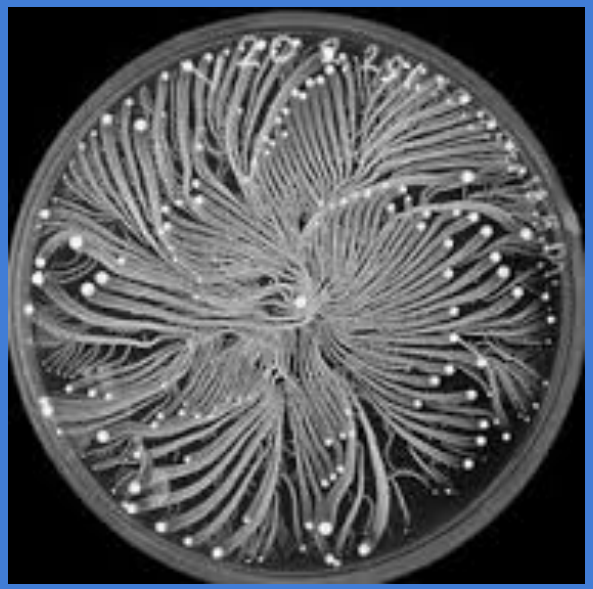


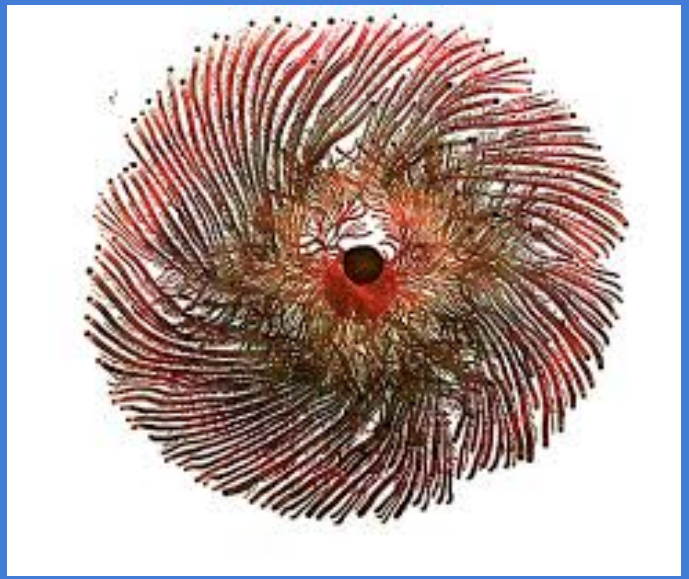
Emulsification through Area Contraction
T.Dabros A.Yeung J.Masliyah J.Czarnecki



Biofilms and Marangoni convection

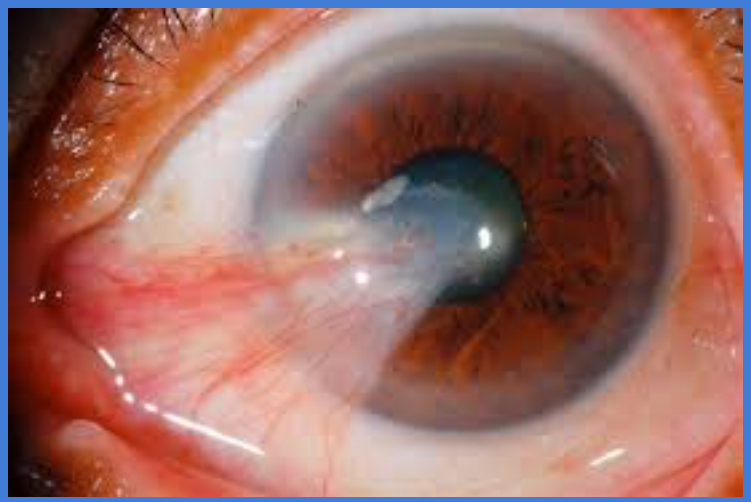


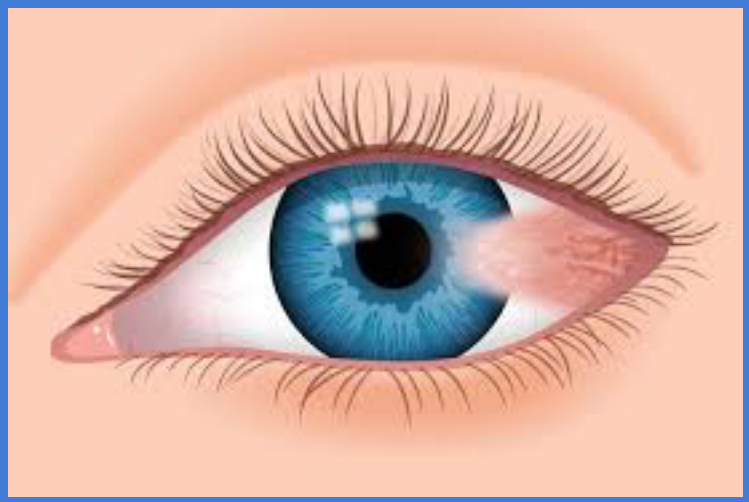




Ben-Joseph et al.

Capillary effects in the eye

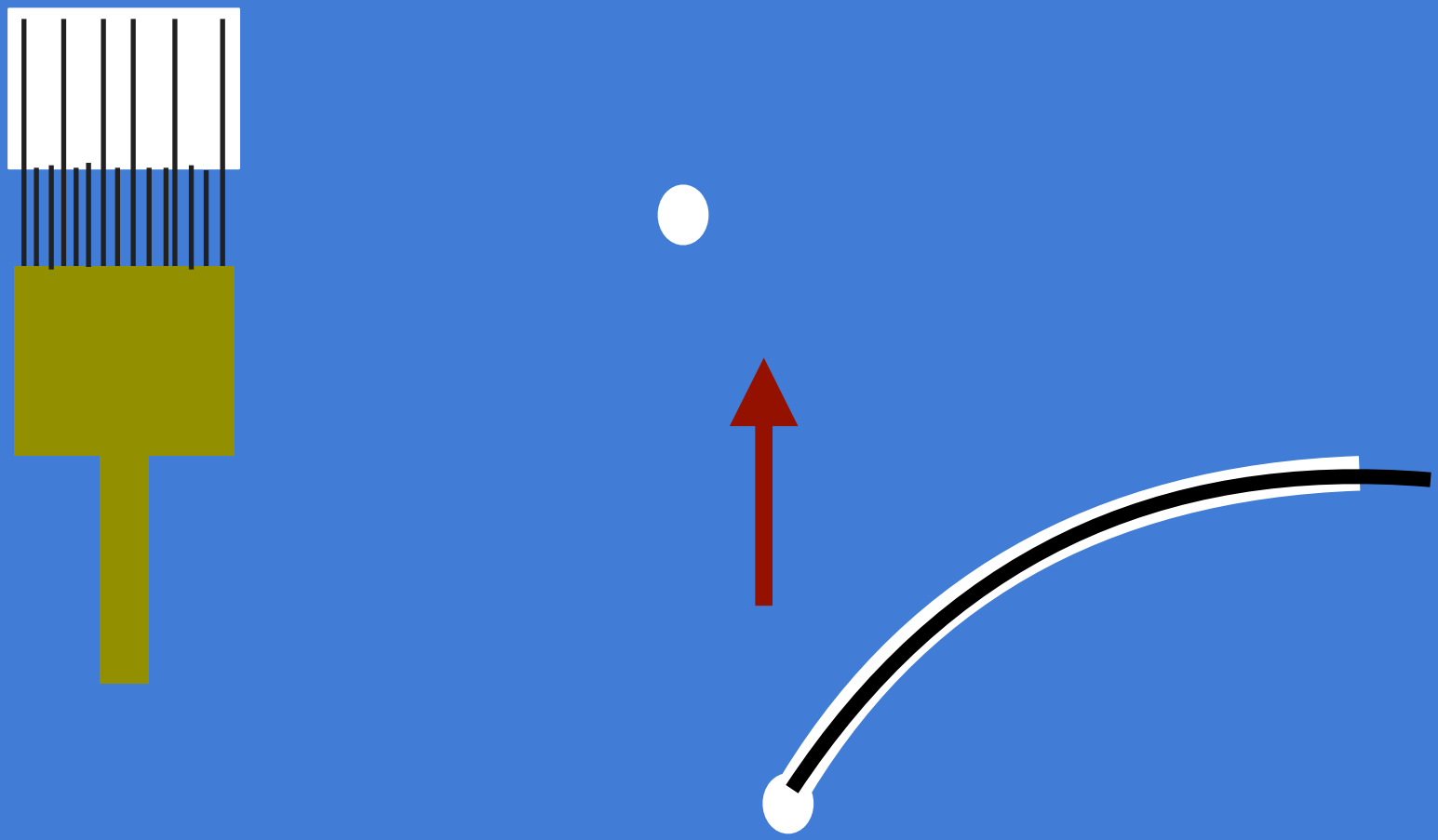




Capillary effects and spider webs


1 cm

Paint spray



Criterion for drop formation?

Toroidal bubbles

Knots? Buckling?