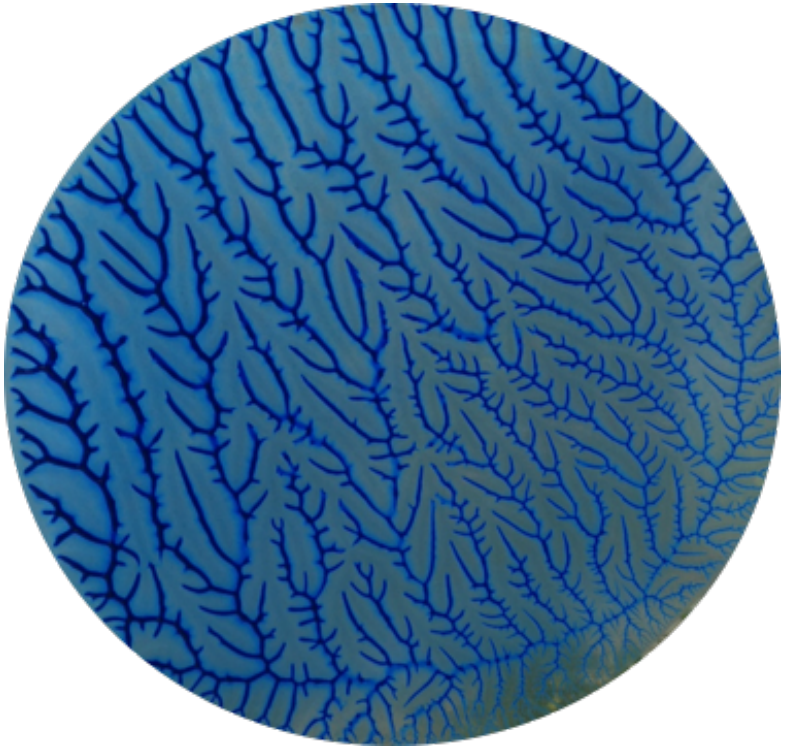
Impact and intrusion:
patterns, structure and the texture of our world

KITP; February 28, 2018



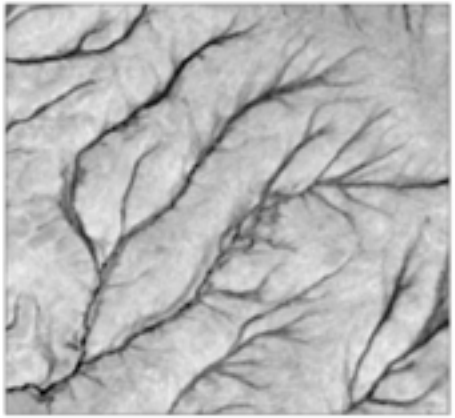
"Philosophy begins in wonder." *Plato*

Dilation symmetry and penetration of space

emergence of structure

Tree branches

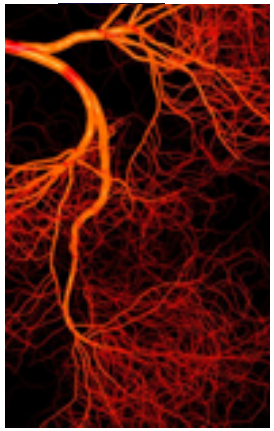
River network



www.mdpi.com/2072-4292/7/7/8779/htm

Discharge

Blood vessel



www.fi.edu/heart/blood-vessels

Aggregation

en.wikipedia.org/wiki/Diffusion-limited_aggregation

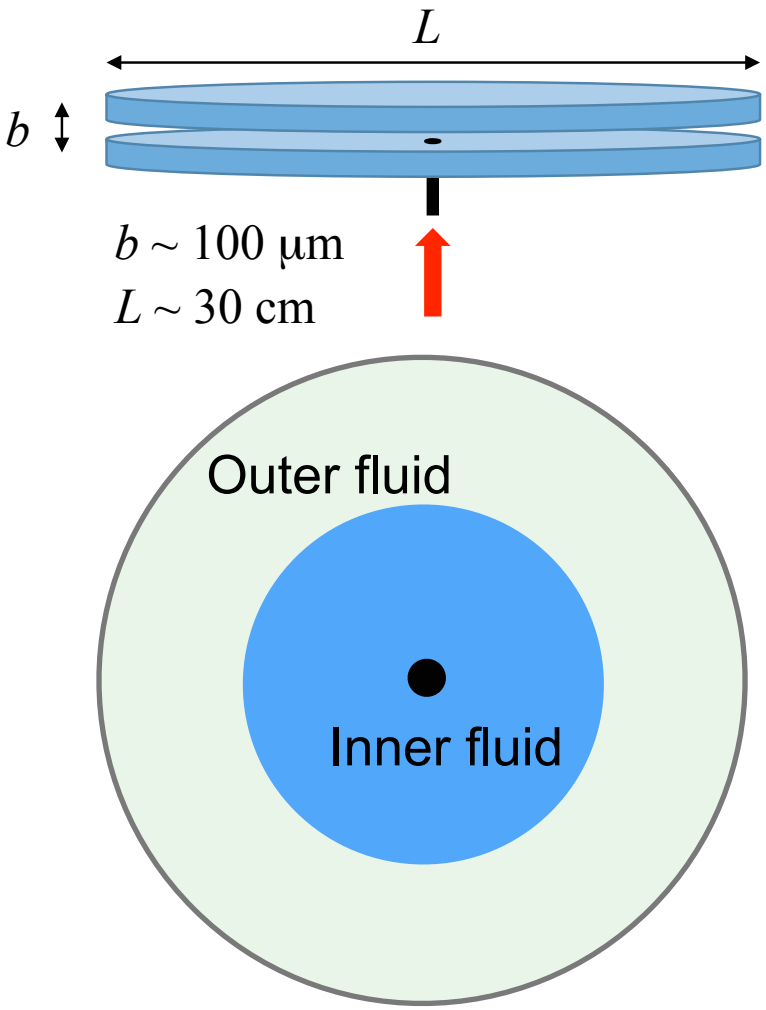
Lightning

www.grahamisd.com/page.cfm?p=938

Spans many scales and many branches of science

Viscous-fingering instability

One fluid displaces another



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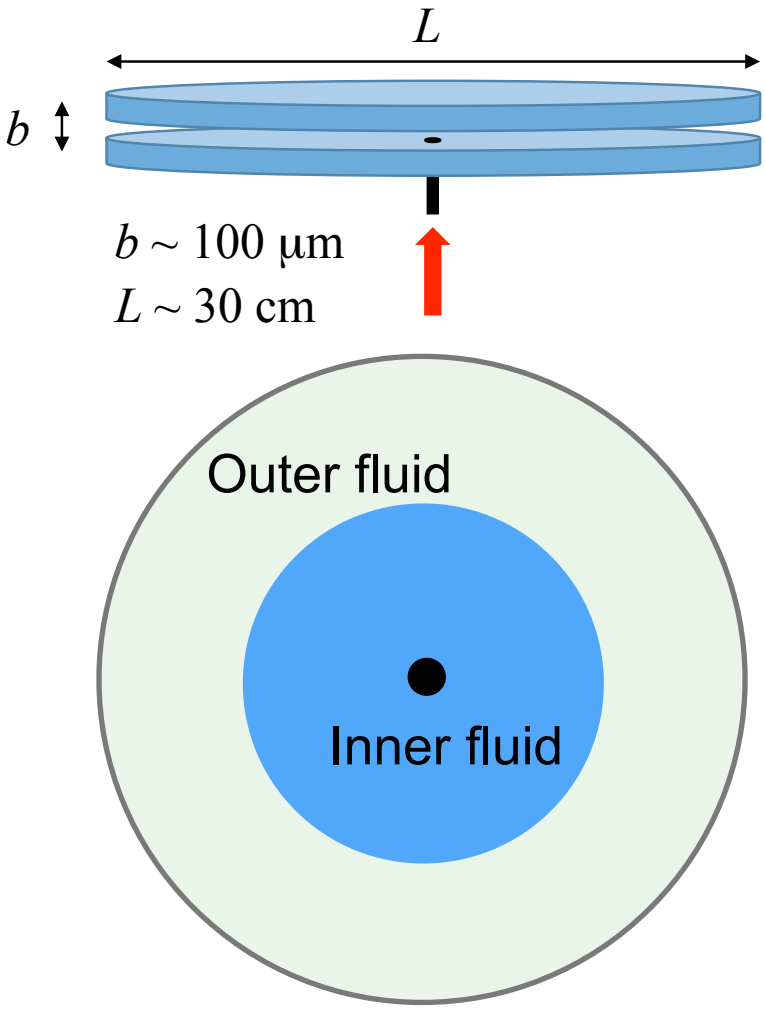

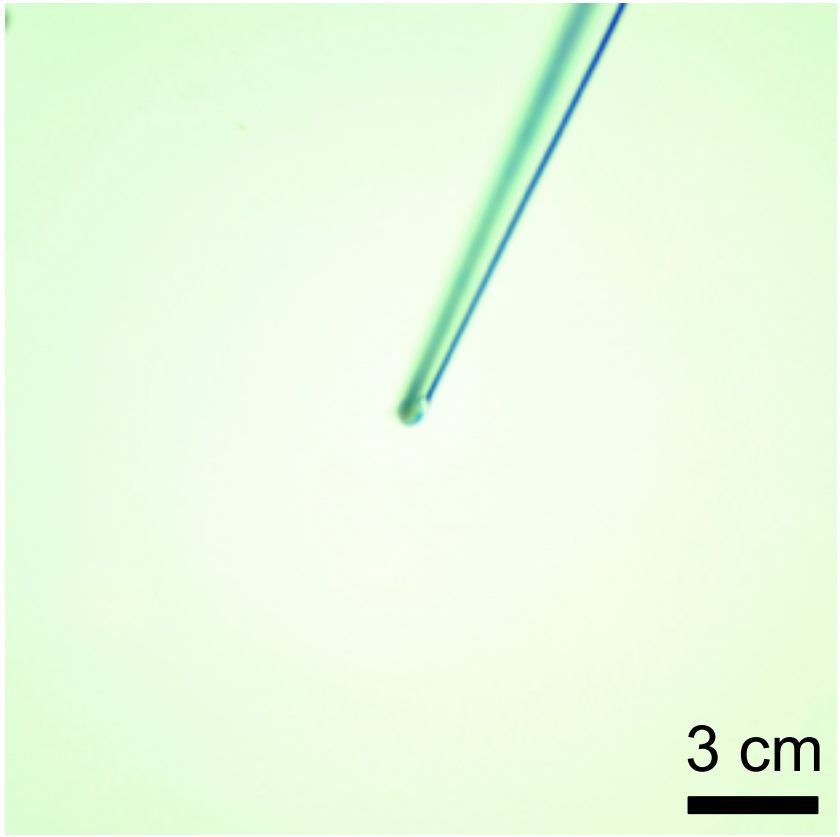

Unstable if inner fluid
less viscous than outer fluid

Irmgard Bischofberger

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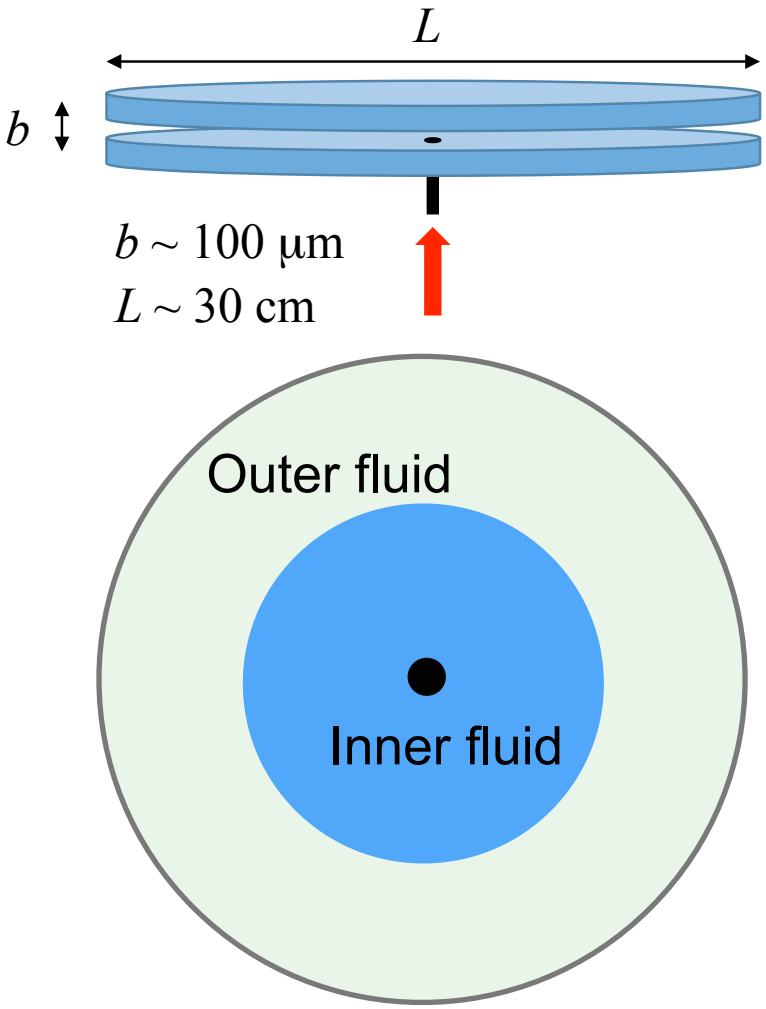

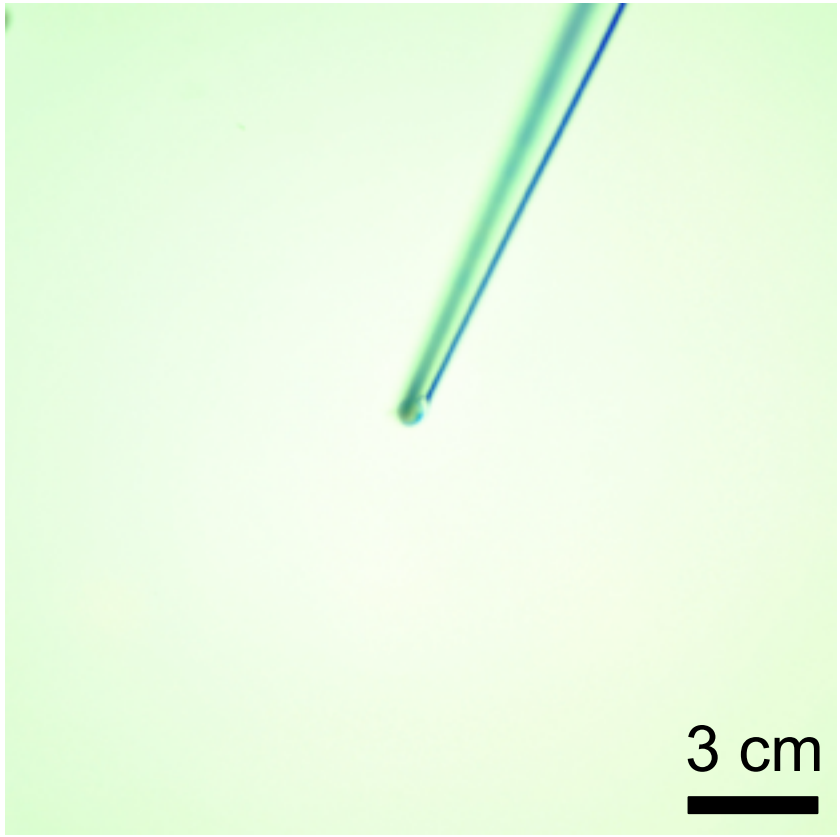

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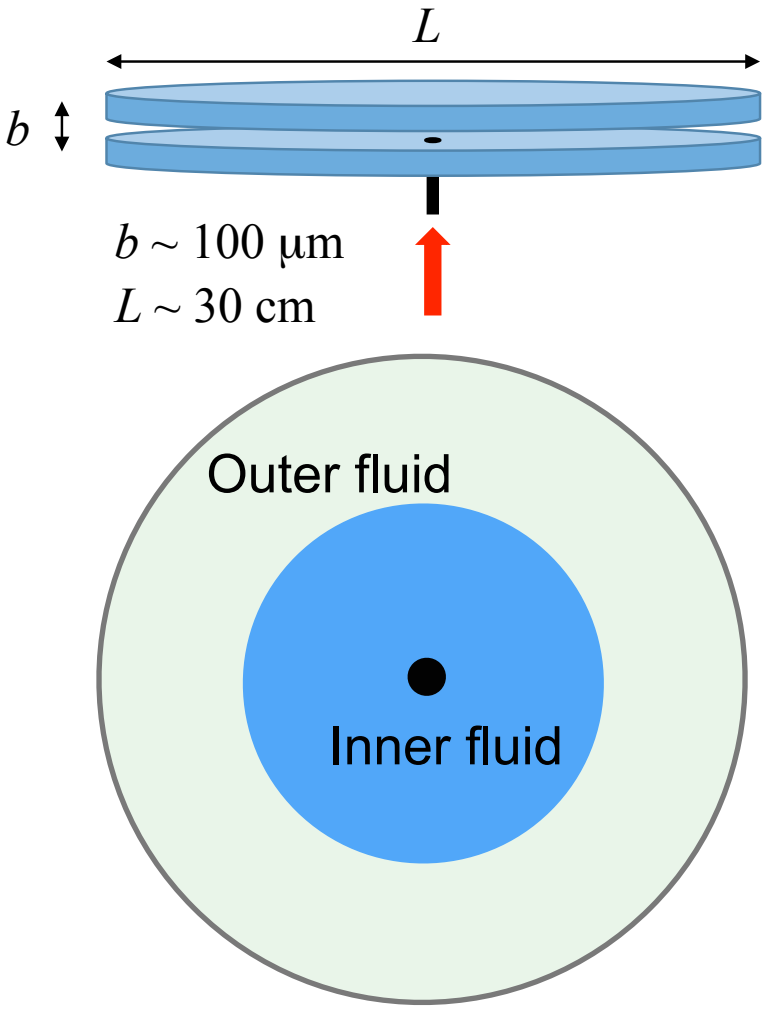
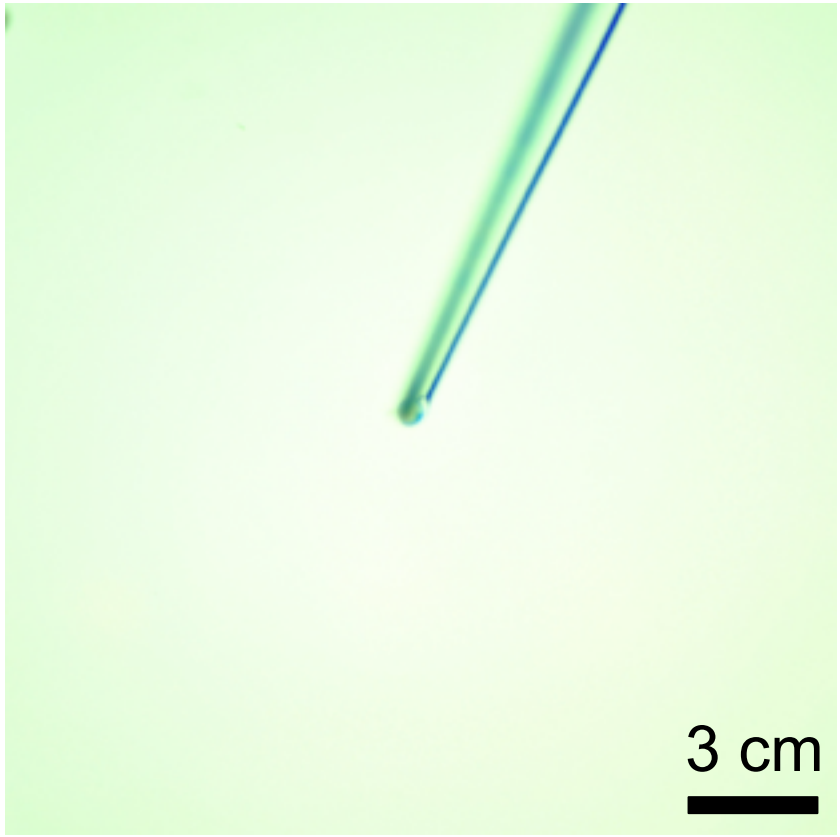


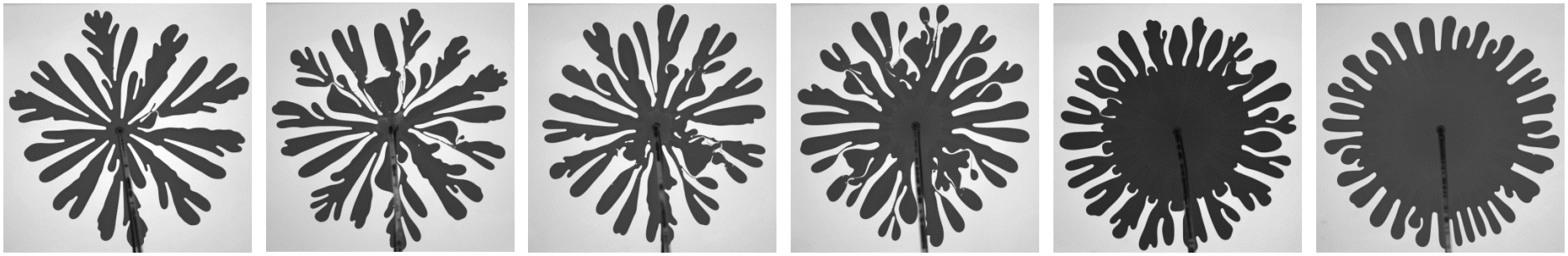


Unstable if inner fluid
less viscous than outer fluid

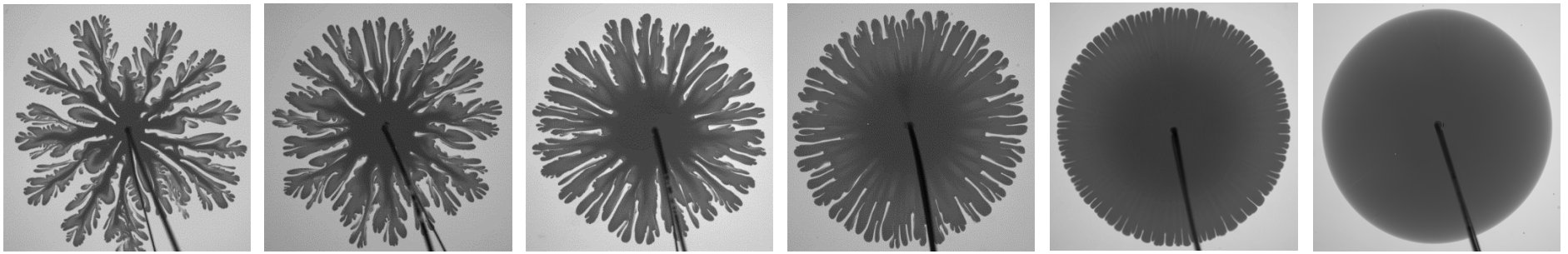
Surface tension - stabilizing force

Keep everything same *except* surface tension

Immiscible fluids: surface tension



Miscible fluids: no surface tension



Viscosity ratio

Removing surface tension stabilizes patterns!

New length scale ⟹ global patterns

Irmgard Bischofberger

New regime: toes

miscible fluids

Viscosity ratio ≃ 0.004

Viscosity ratio ≃ 0.2

New regime: toes

miscible fluids

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New regime: toes

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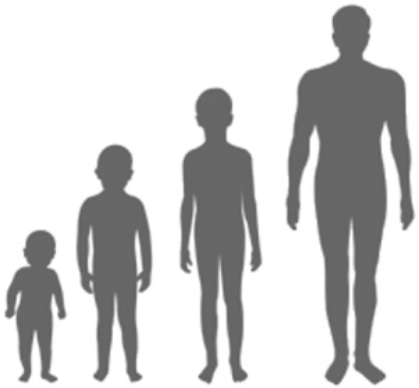
Viscosity ratio ≃ 0.004

Viscosity ratio ≃ 0.2

Once toe forms it no longer splits

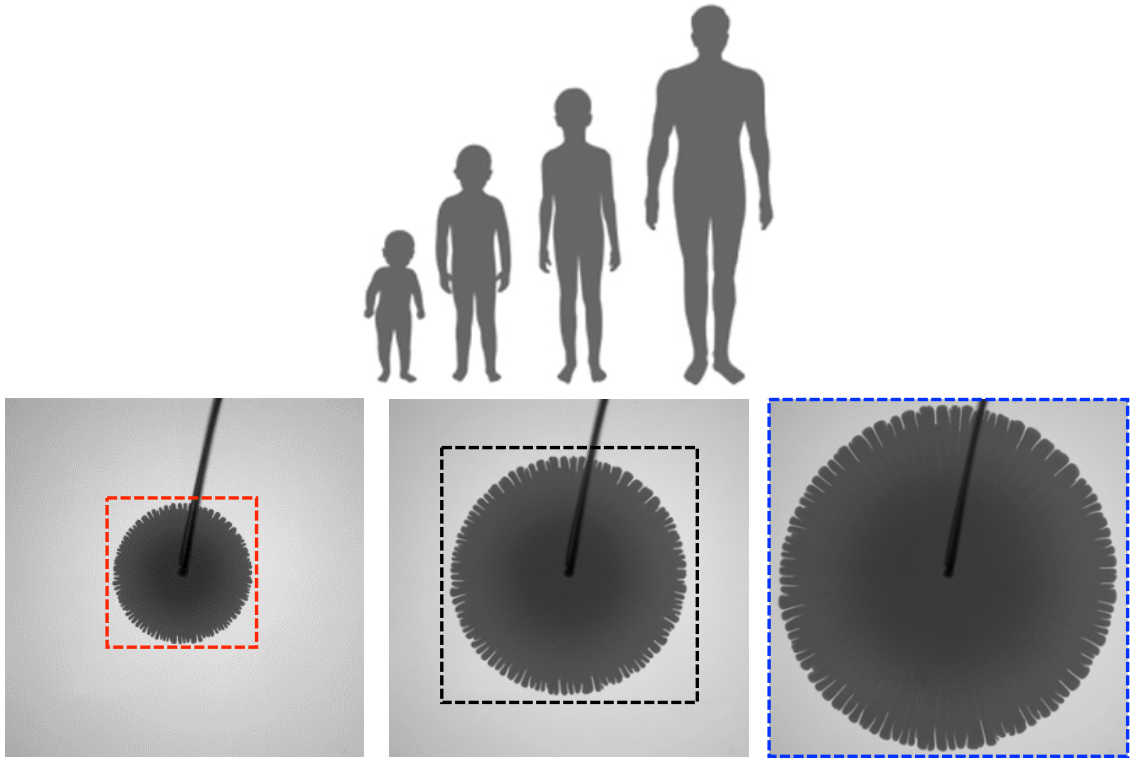
Instability turns itself off

Proportionate growth - how mammals grow



Irmgard Bischofberger

Proportionate growth - how mammals grow



Irmgard Bischofberger

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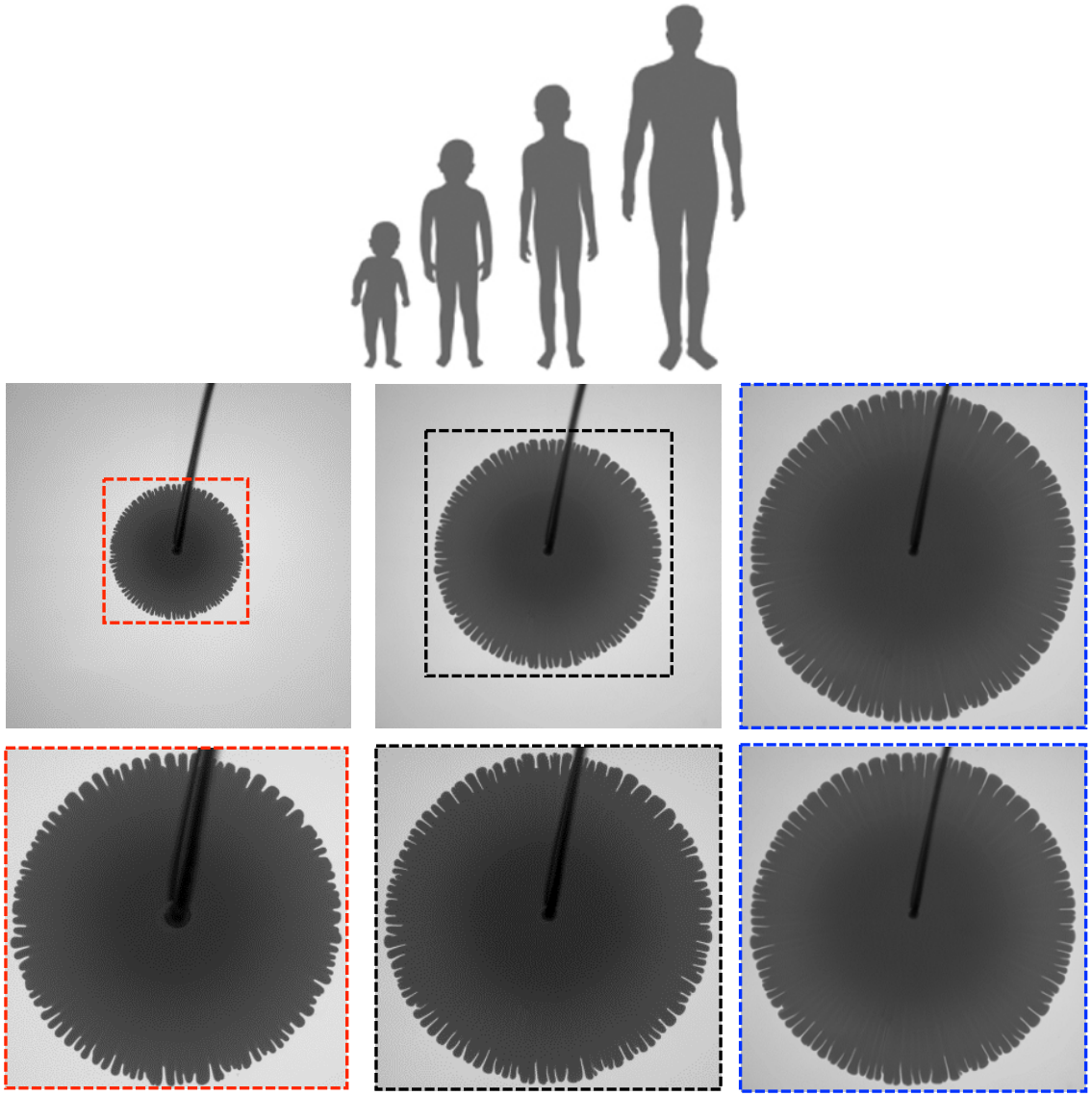
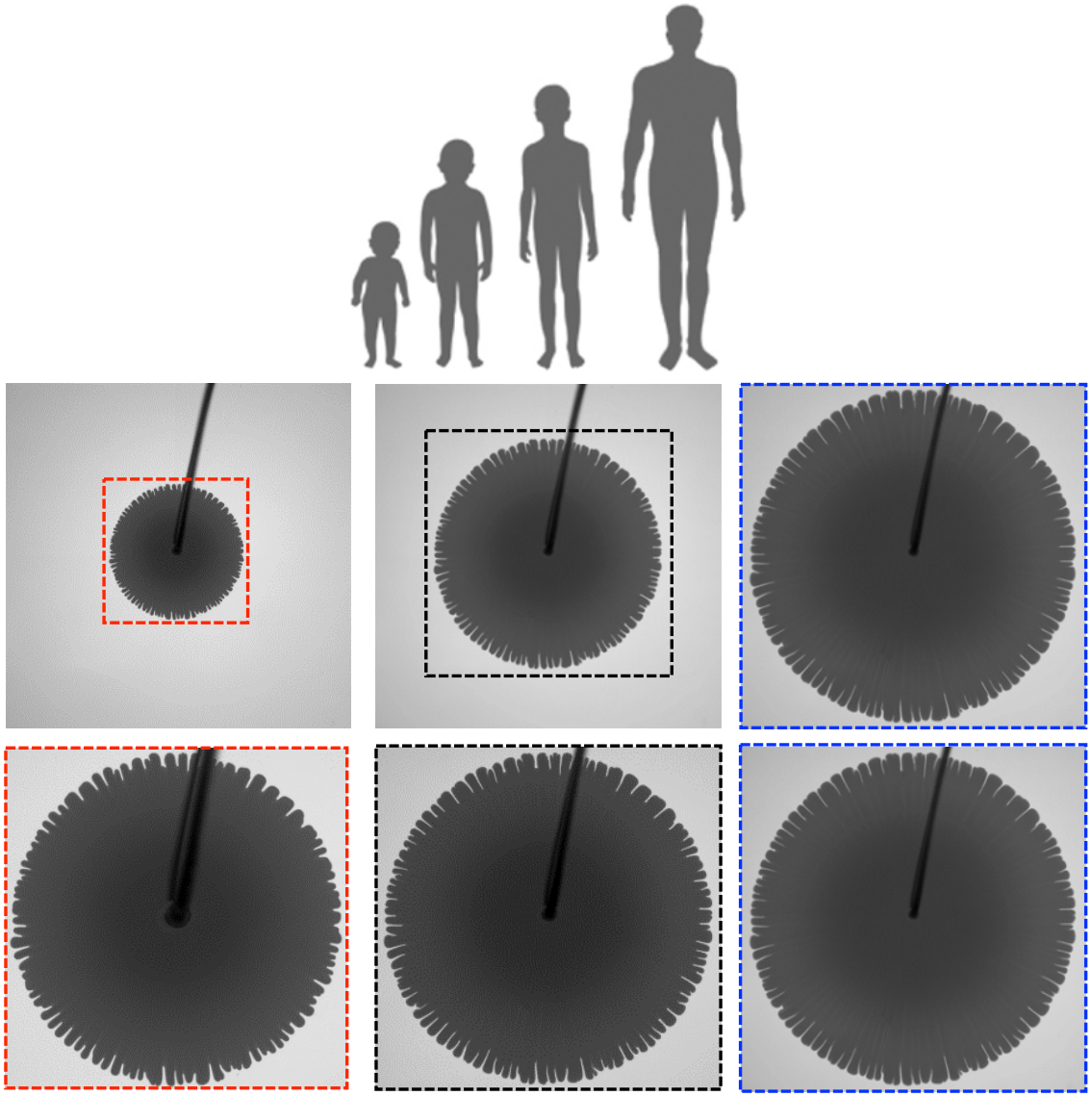


Irmgard Bischofberger

Proportionate growth - how mammals grow



Only physical (as distinct from biological) example known

Irmgard Bischofberger

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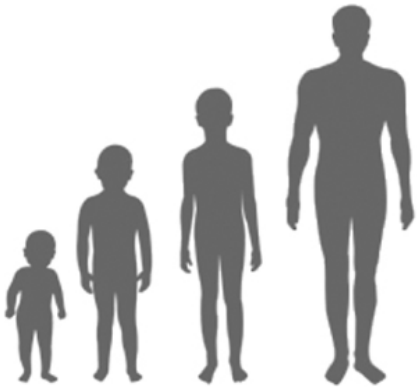
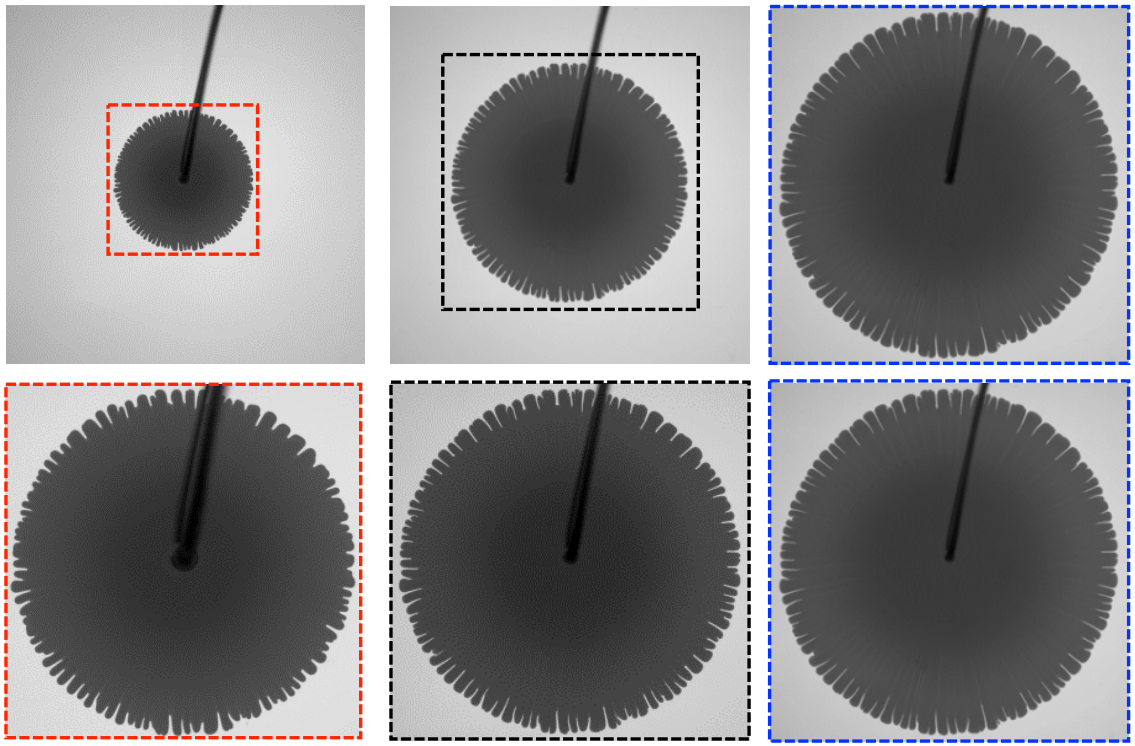




Only physical (as distinct from biological) example known

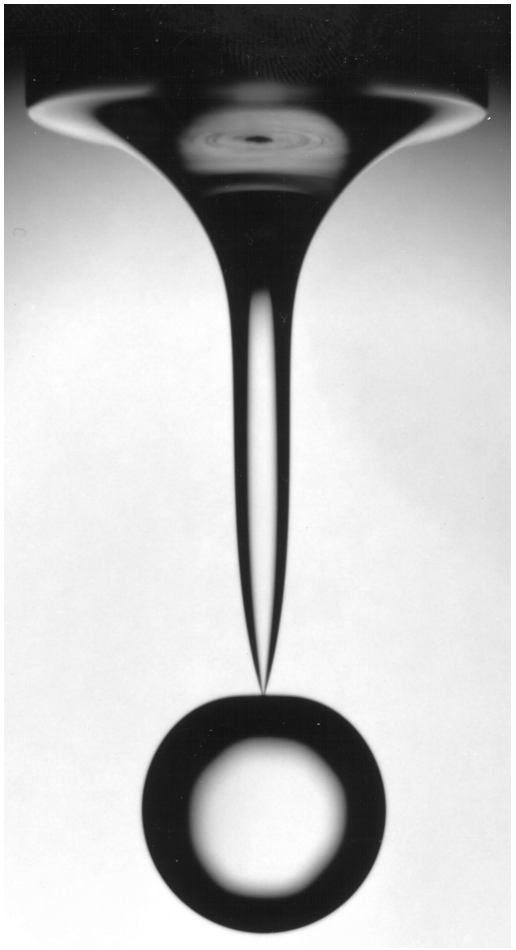
Memory of structure

Irmgard Bischofberger

How do drops break apart?
example of transition

Topology change $\Longrightarrow$ transition

Neck radius $\longrightarrow 0$ Pressure $\longrightarrow \infty$



Cannot simulate to get past snapoff

Similar behavior: Star formation

PILLARS OF CREATION
IN STAR-FORMING REGION

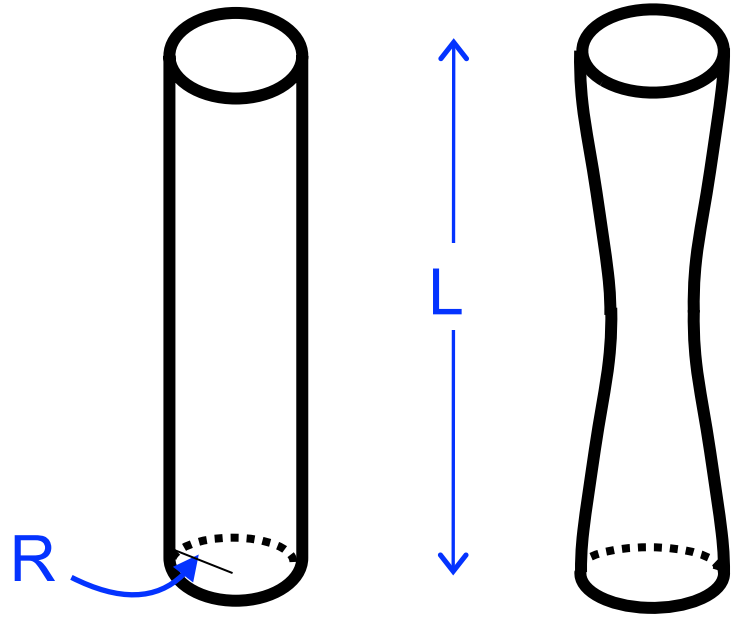
Gas Pillars - Eagle Nebula
Hubble Space Telescope

Similar behavior everywhere

celestial ⟹ microscopic ⟹ nuclear fission…

Cylinder of fluid

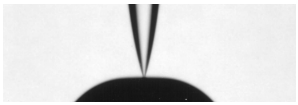
"Rayleigh-Plateau Instability"

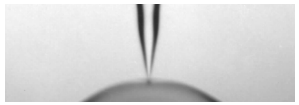


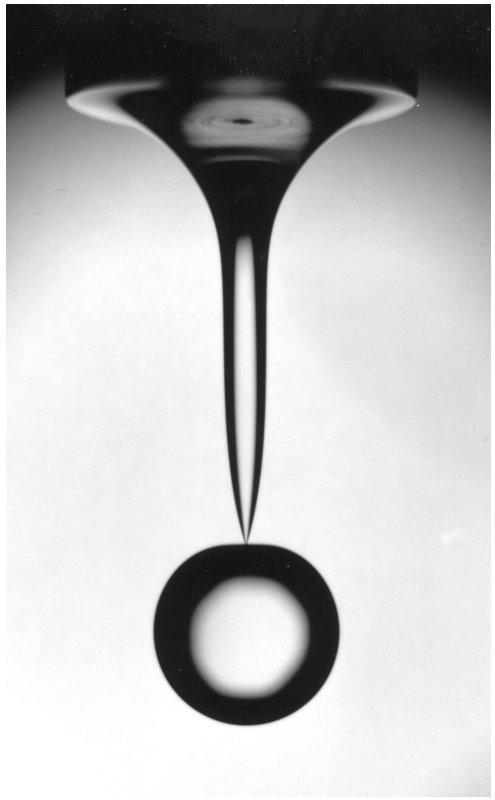
Surface area <u>decreases</u> if $L > 2\pi R$
$\Rightarrow$ unstable

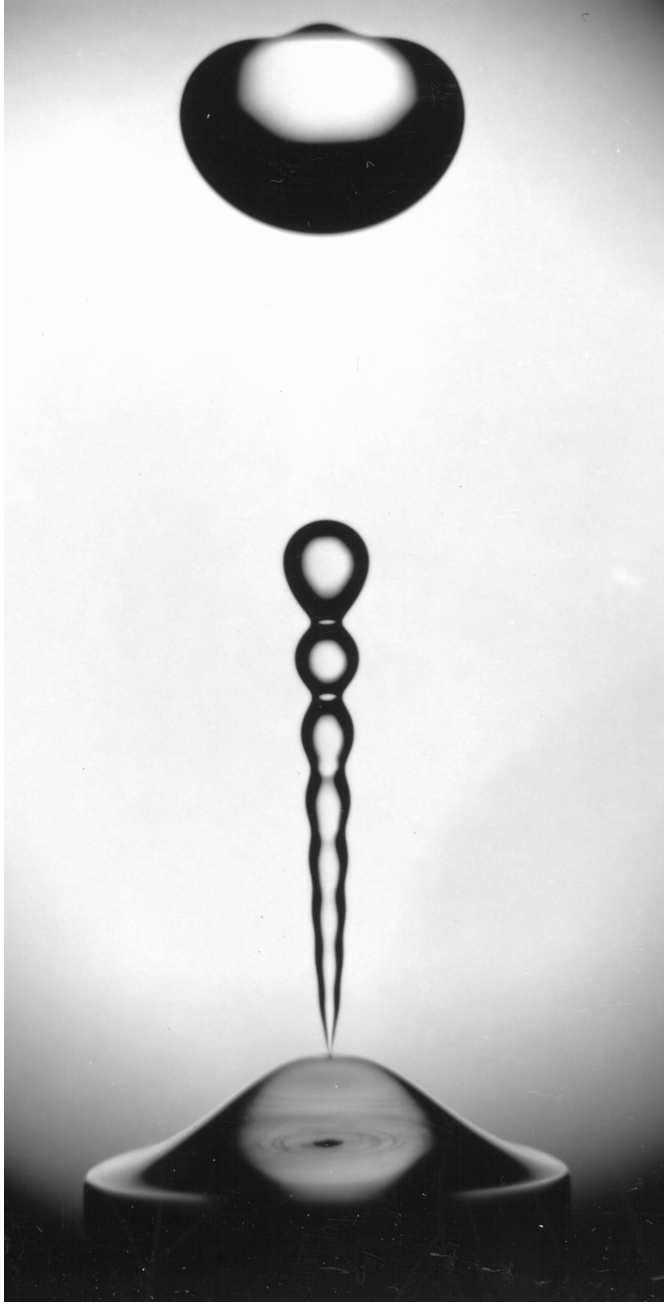
Bolas Spider

Singularity









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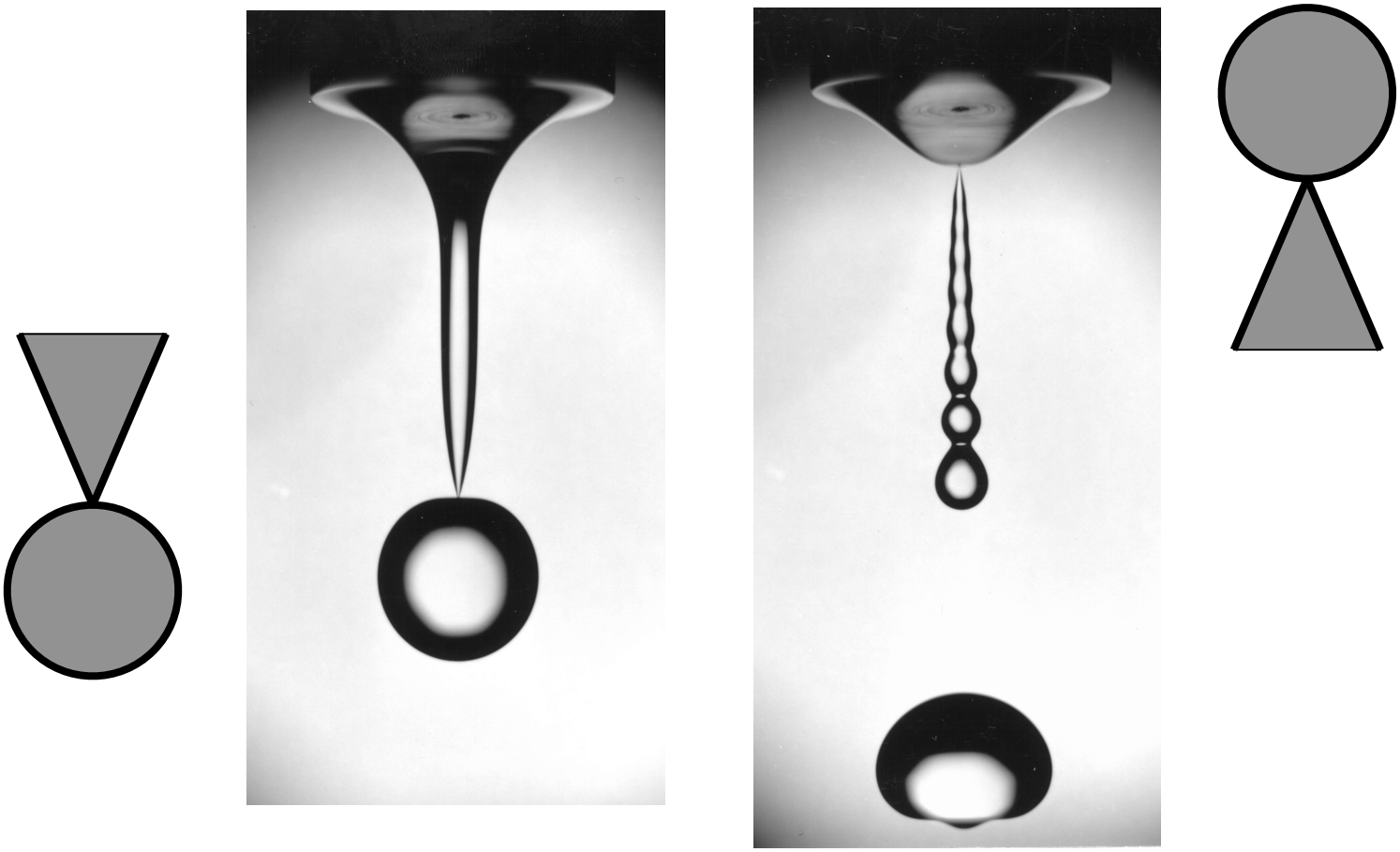
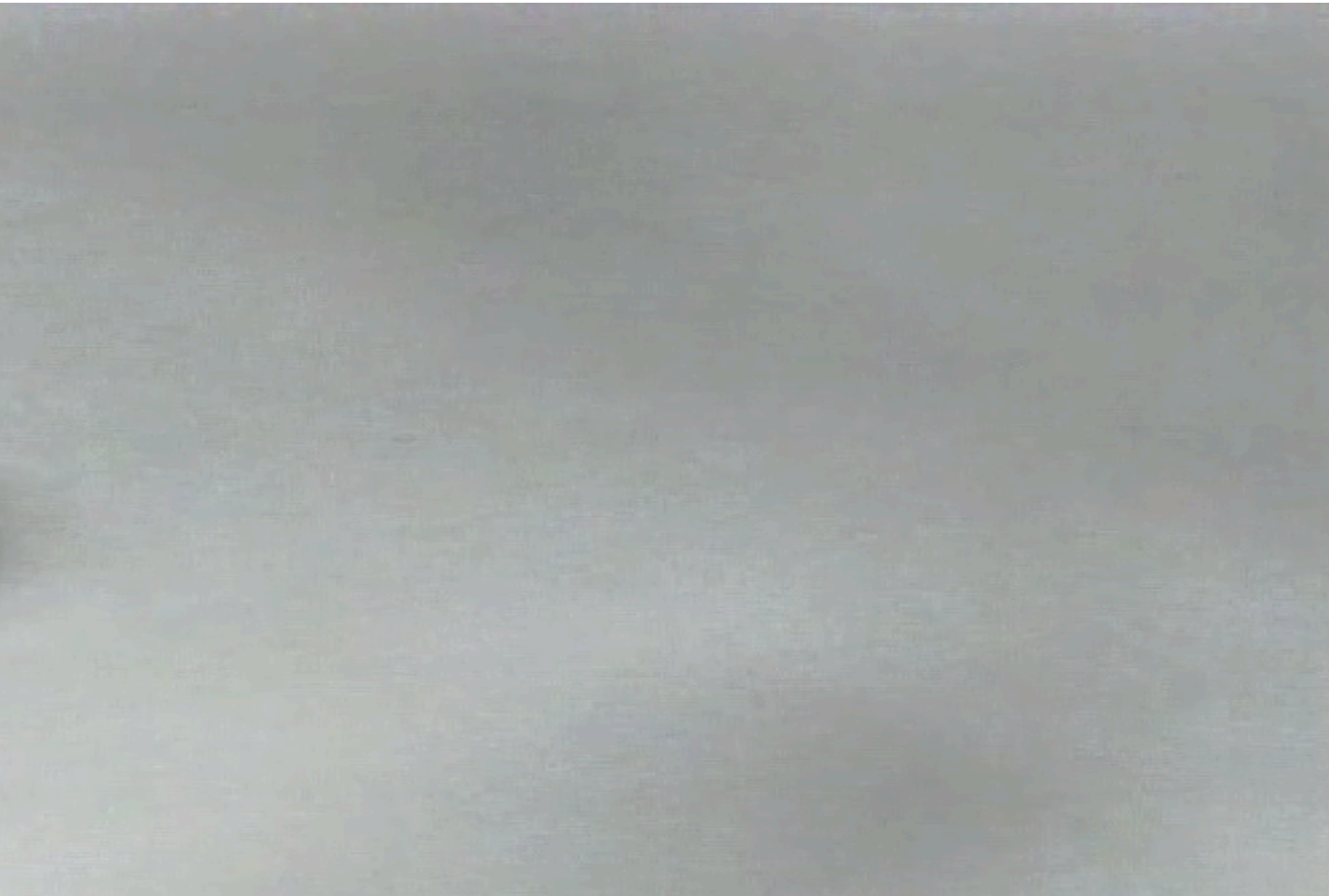


Pinch-off same even though gravity in opposite direction

Something is universal

Xiangdong Shi, Michael Brenner

Water drops



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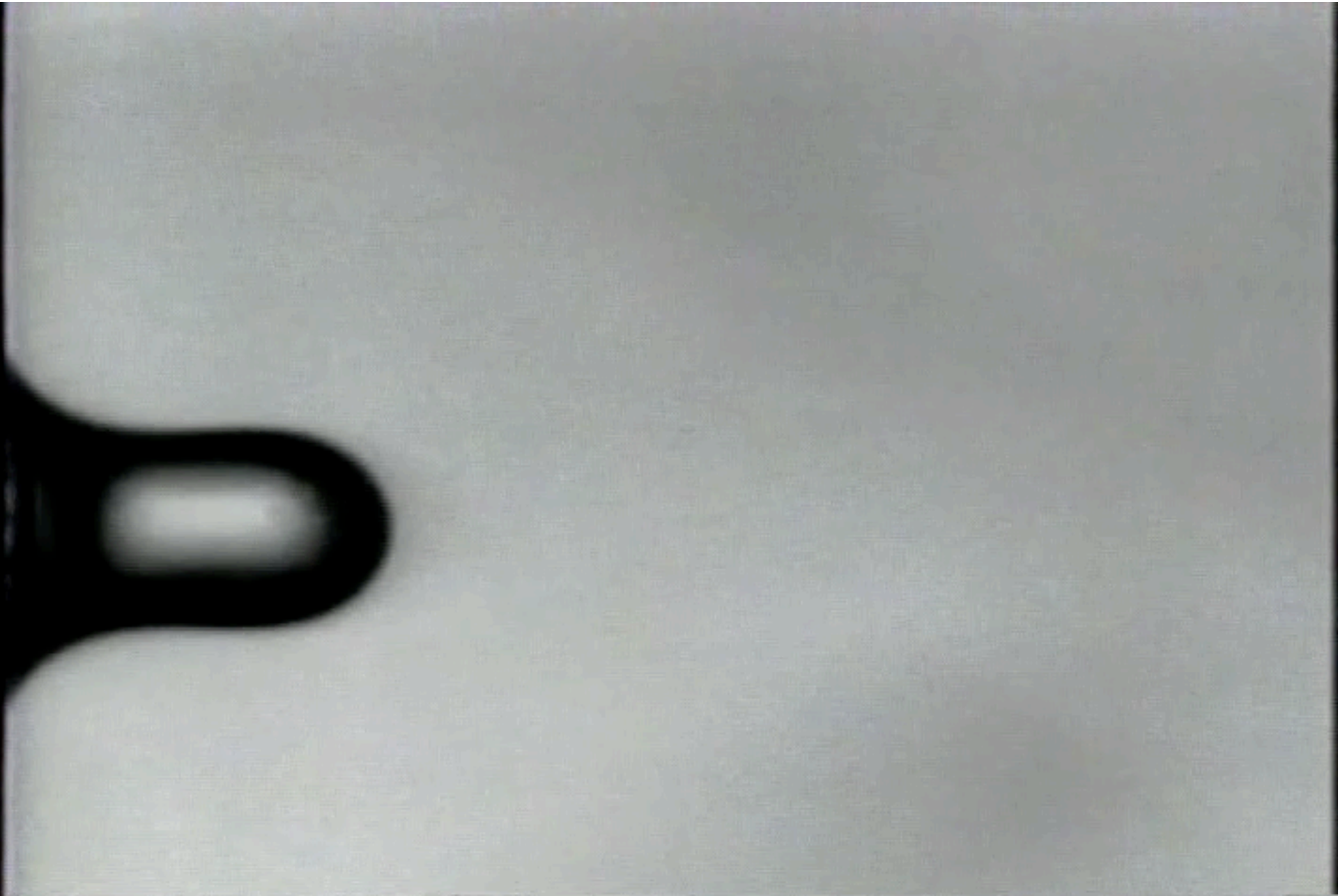

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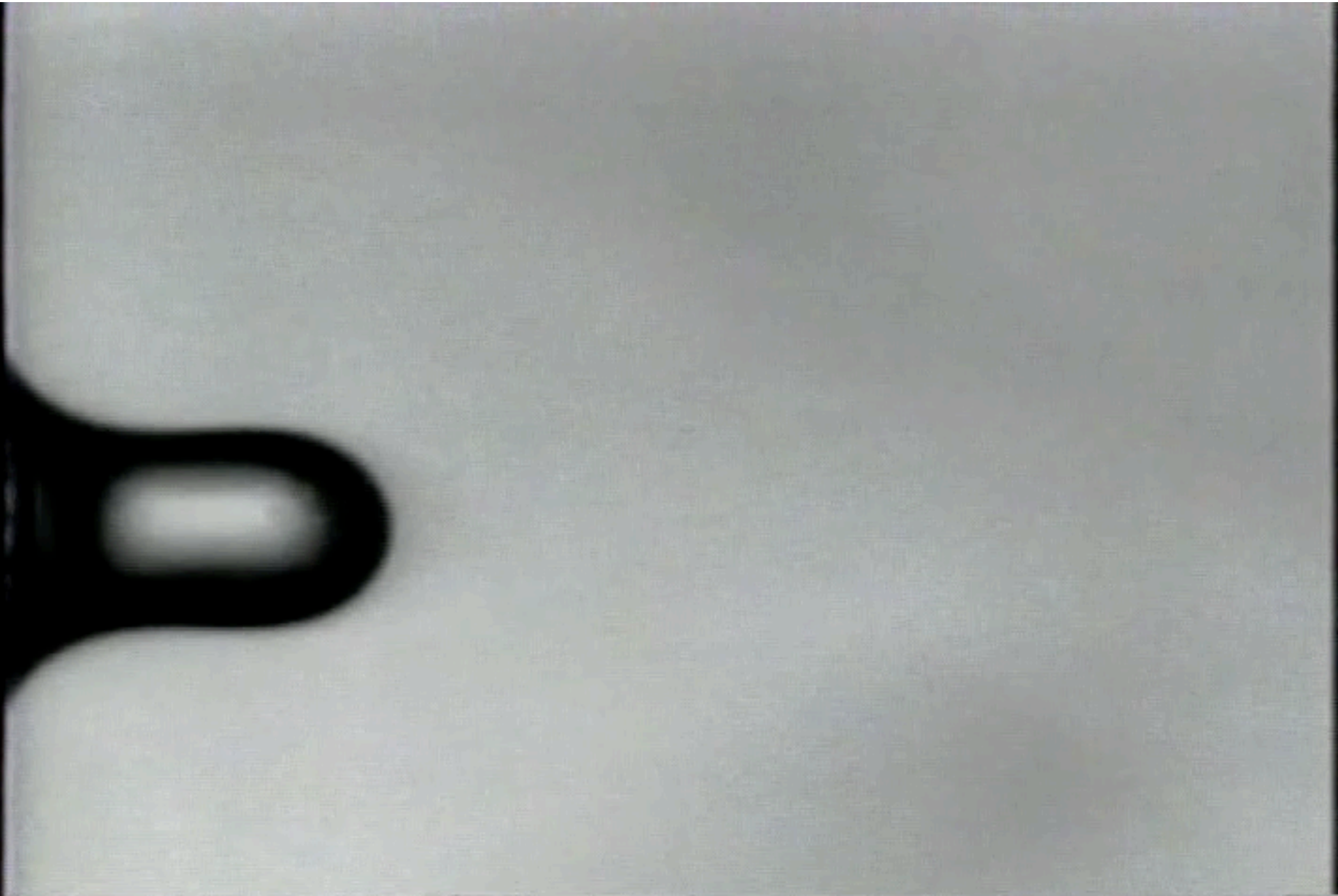
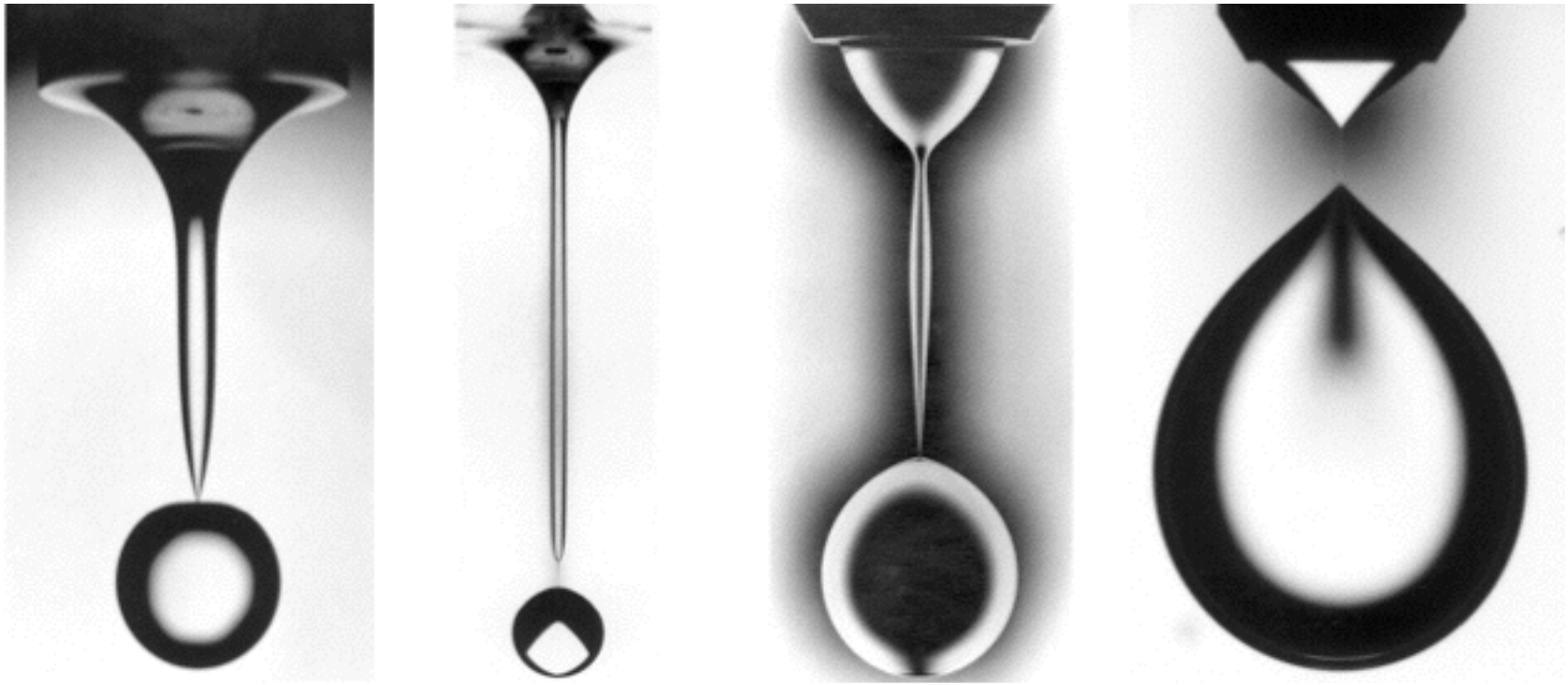


Each unhappy drop is unhappy in its own way



Different regimes depend on:

viscosity inner fluid
viscosity outer fluid
density inner fluid
density outer fluid
surface tension
nozzle diameter

How to think about shapes: scale invariance

Breakup ⇒ radius smaller than any other length.

Dynamics insensitive to all other lengths.

Flow depends only on shrinking radius.

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But: Radius depends on flow

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Self-similar structure*

Blow up any part ⇒ regain original

Universal shapes

* Keller & Miksis *SIAM* (1983)
* Eggers & Dupont *JFM* (1993)

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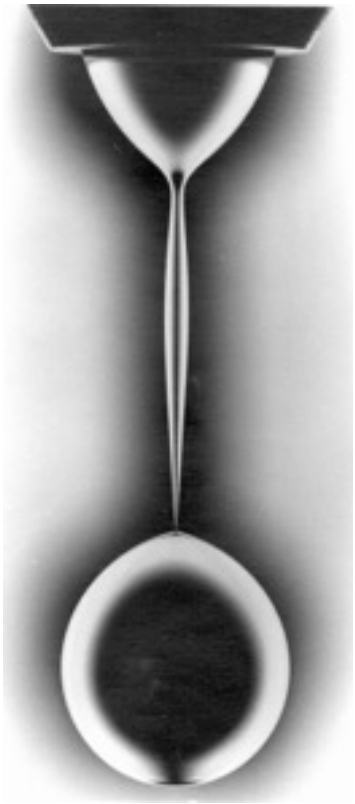
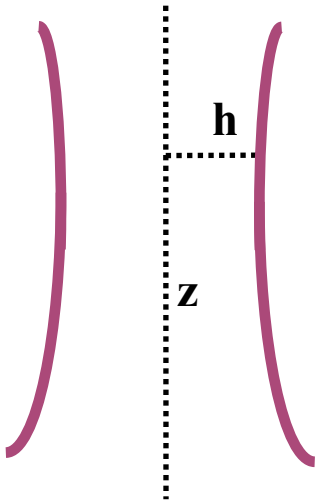
Implication

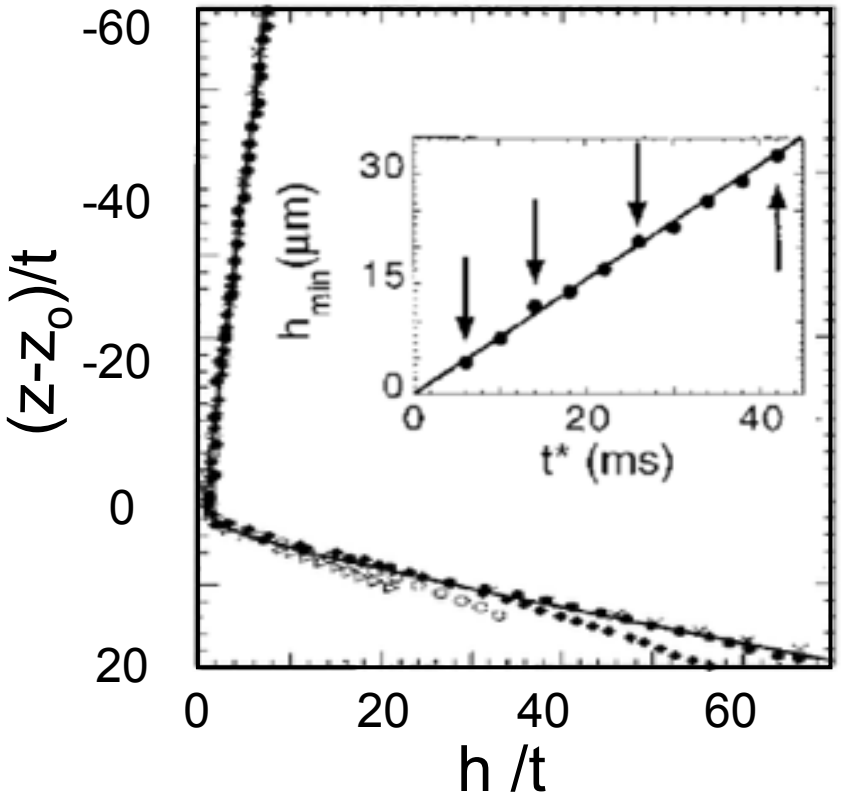
stretch axes ⇒ curves overlap

$$h(z,t) = f(t)\, H[(z-z_o)/f(t)^{\beta}]$$





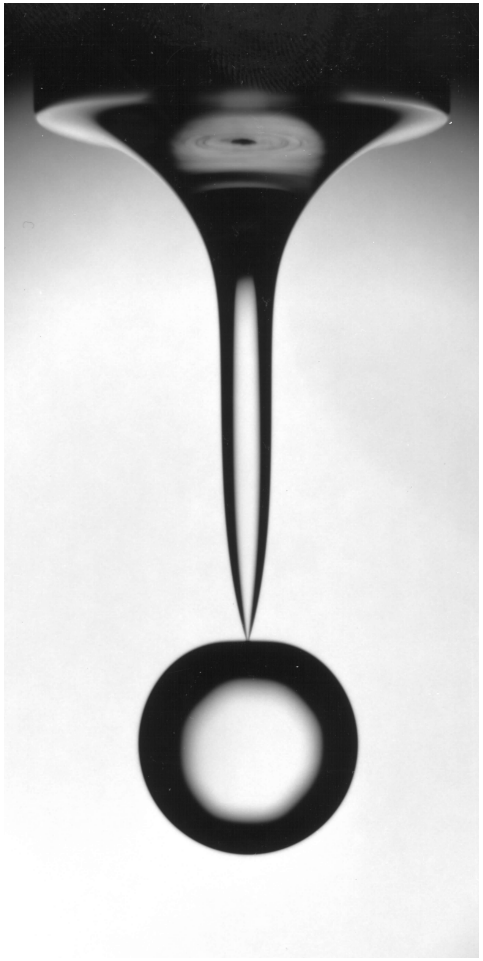
Example: glycerol into oil



Emphasizes what is universal

Itai Cohen, Michael Brenner, Jens Eggers

BUT …
Remember water drop in air?



What about air bubble in water?

Nathan Keim, Laura Schmidt, Wendy Zhang

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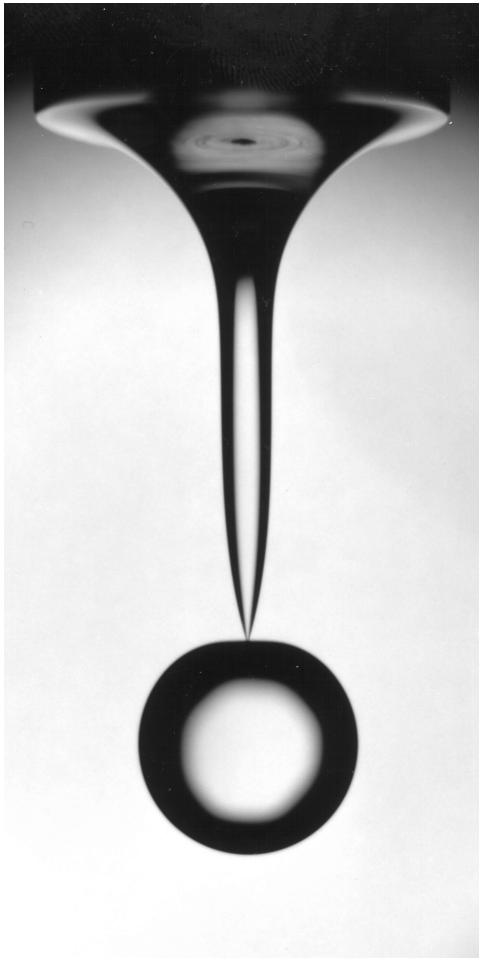

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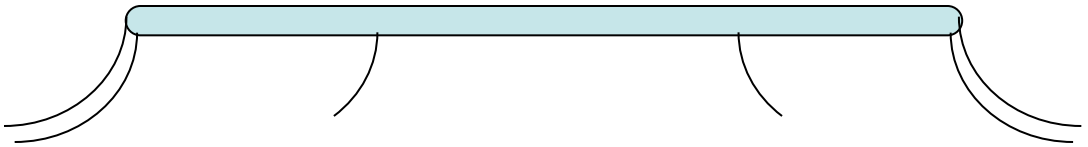
Different response to perturbations

change nozzle shape

slot nozzle



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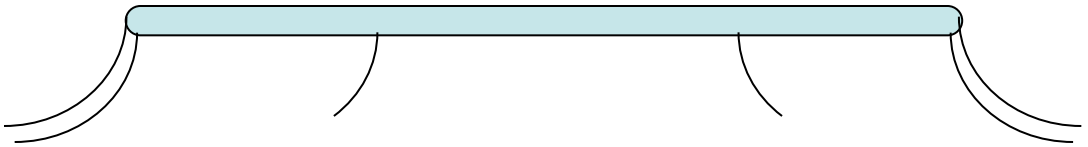

Nathan Keim, Laura Schmidt, Wendy Zhang

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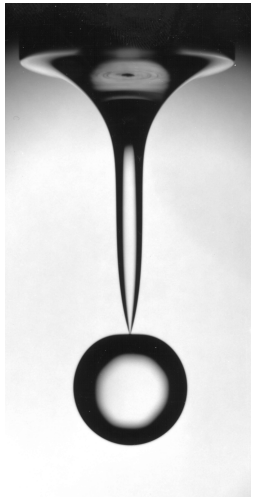
Different kind of singularity

Nathan Keim, Laura Schmidt, Wendy Zhang

Two possibilities:
Nature *vs.* Nurture



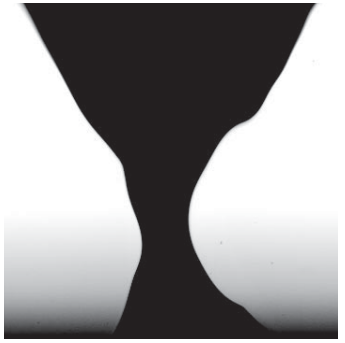
Nature

Lose identity:

Evolution to singularity depends only on material

⇒ no memory

or



Nurture

Retains identity:

Early life determines evolution

⇒ nearly complete memory

Liquid jet impact on target

"water bells"

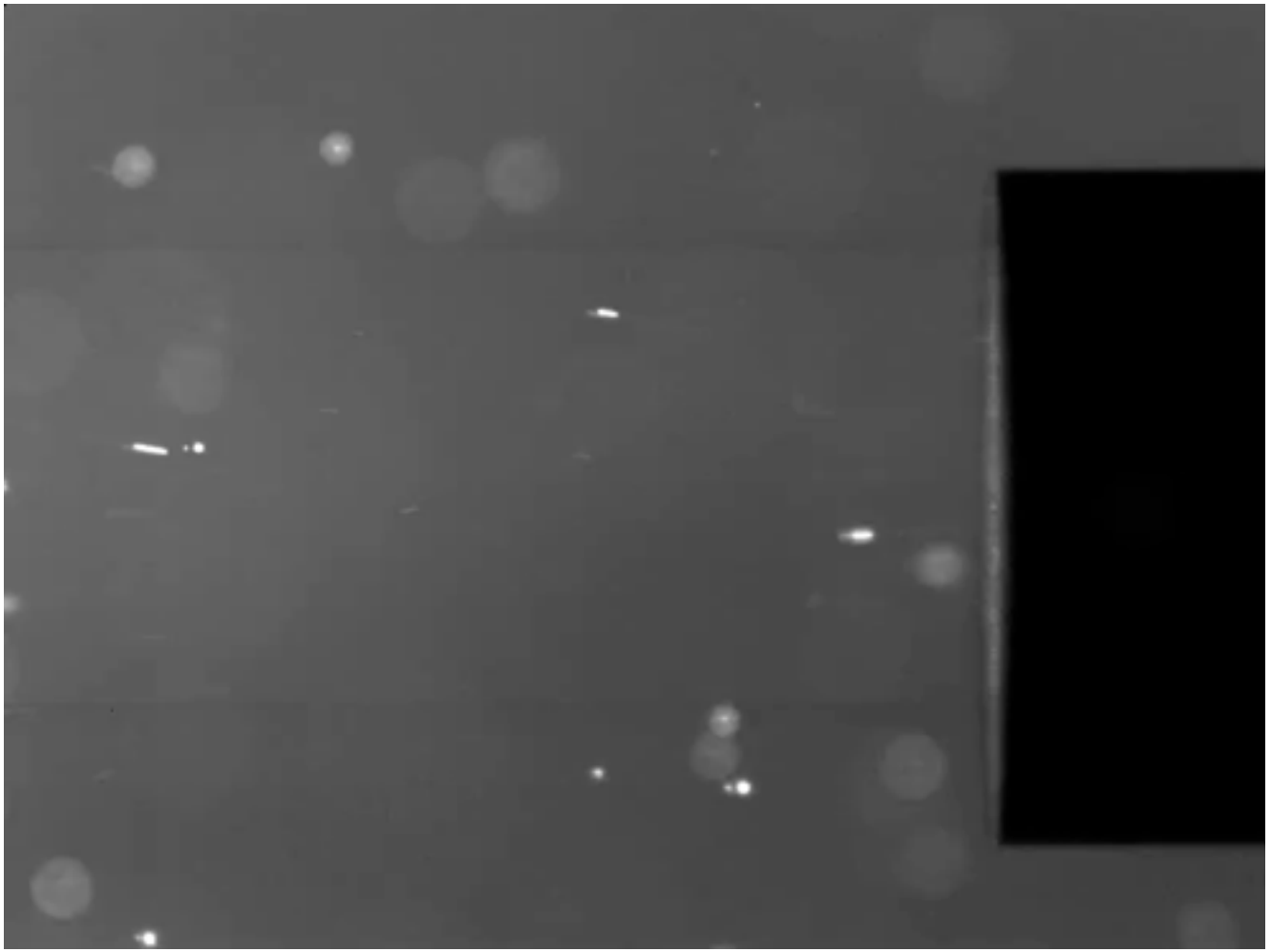
How general is "bell" formation?

Liquid jet impact on target

"water bells"

How general is "bell" formation?

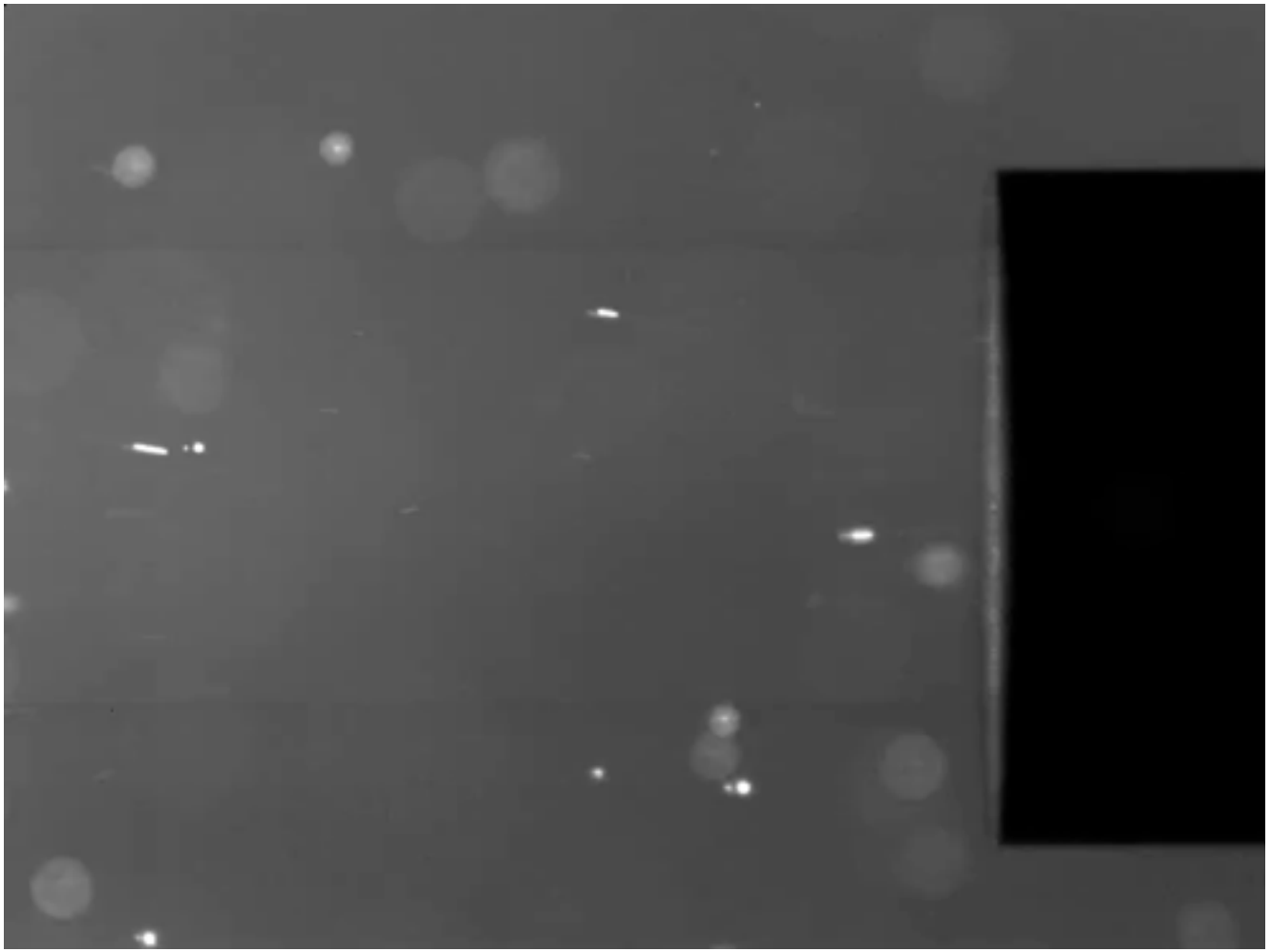
Individual particle collisions with target



500μm glass beads hitting aluminum target

How about jet of granular material?

Individual particle collisions with target



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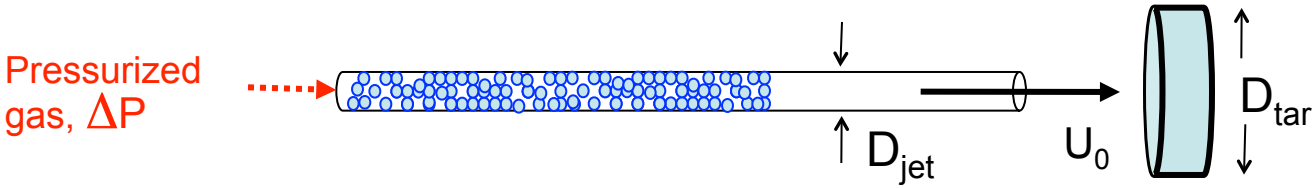
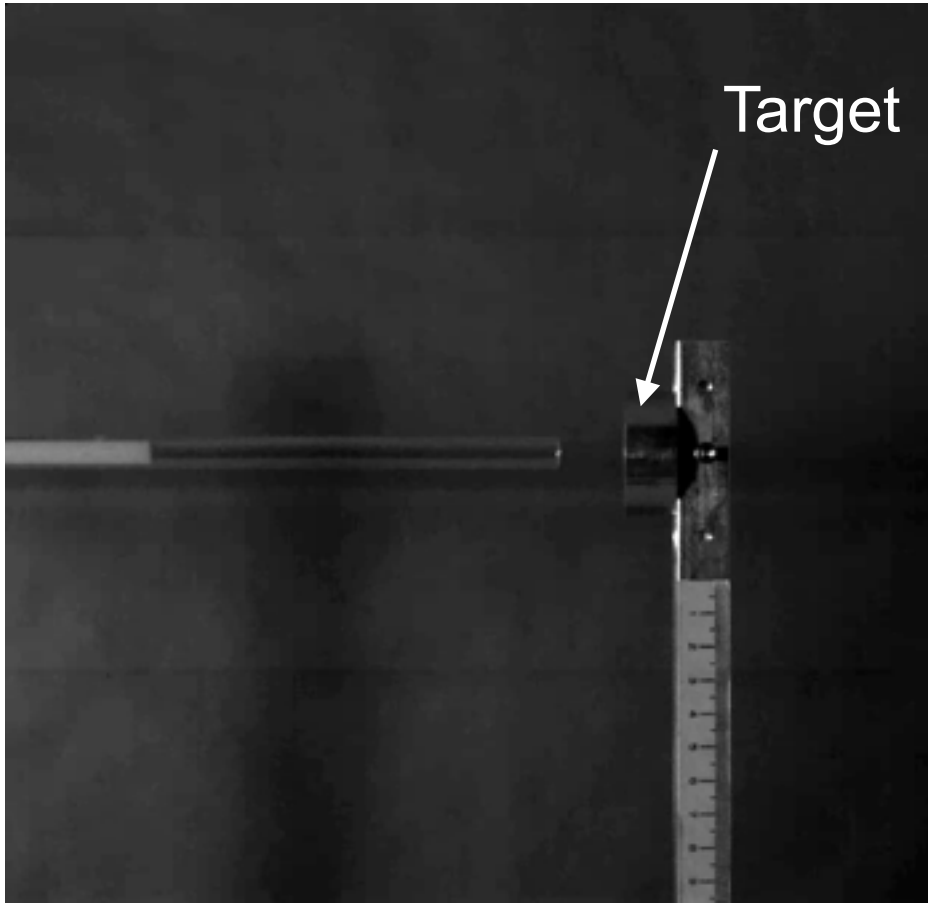


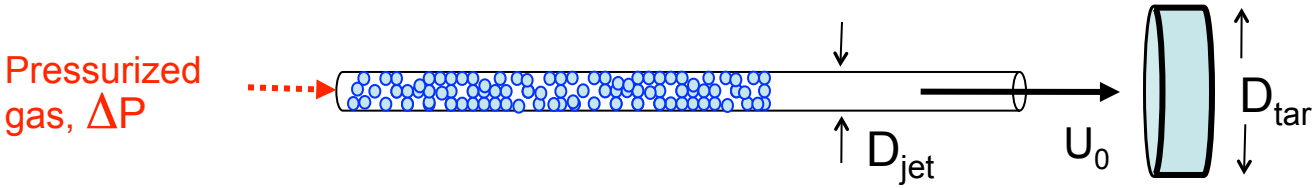
100 μm
glass beads
$D_{tar}/D_{jet} = 4.5$



Side view

Xiang Cheng, German Varas, Daniel Citron, Heinrich Jaeger

Granular jet hitting target



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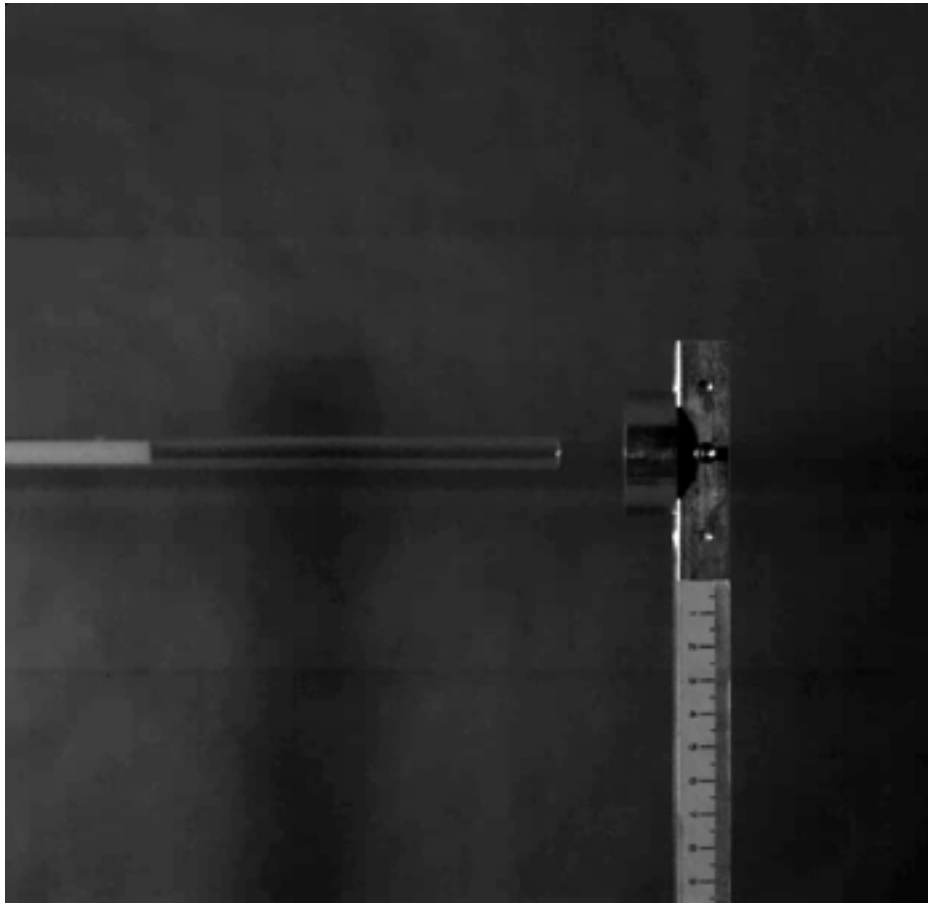

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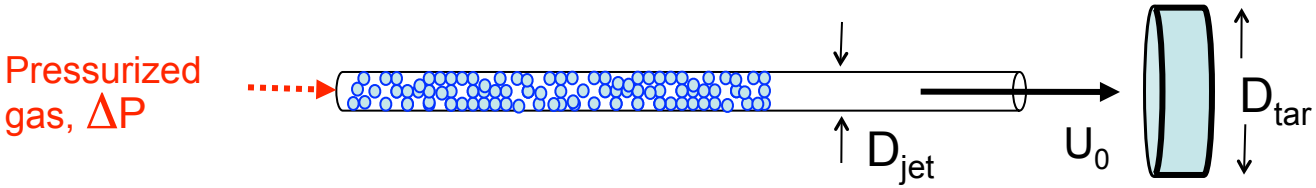

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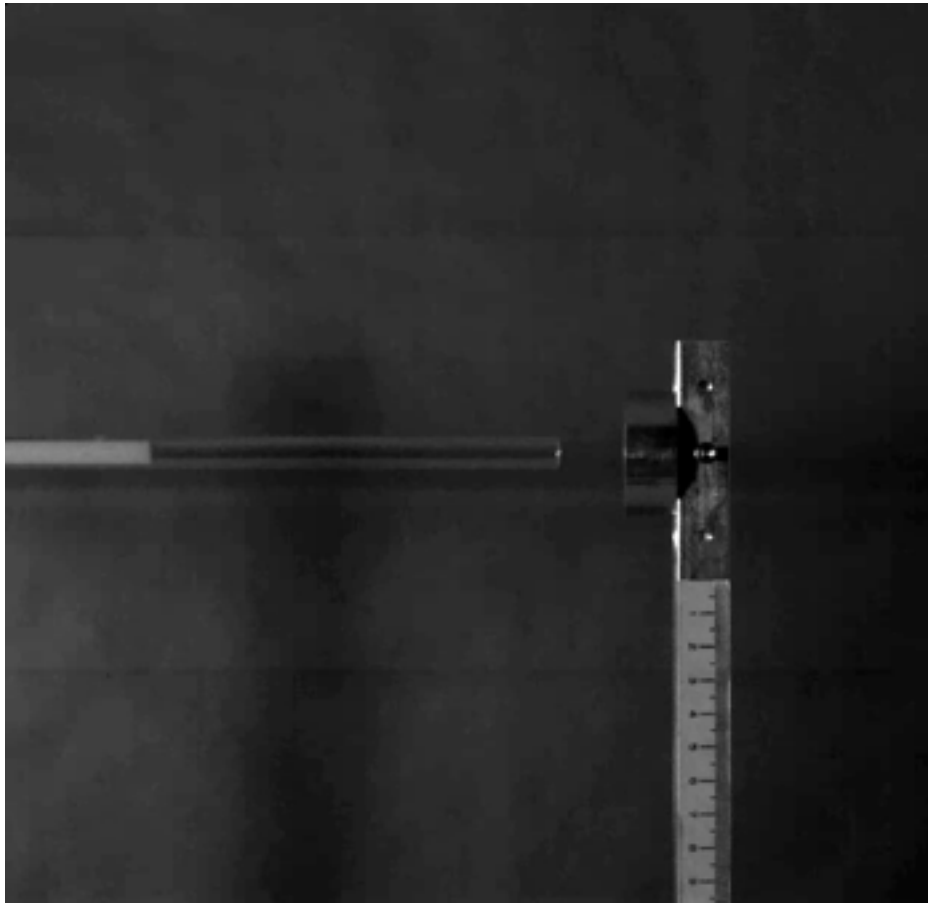

Side view

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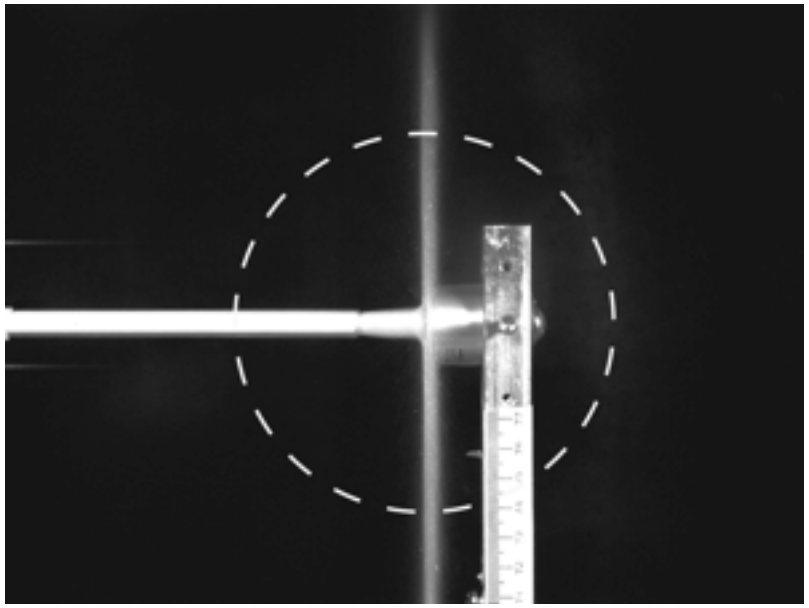
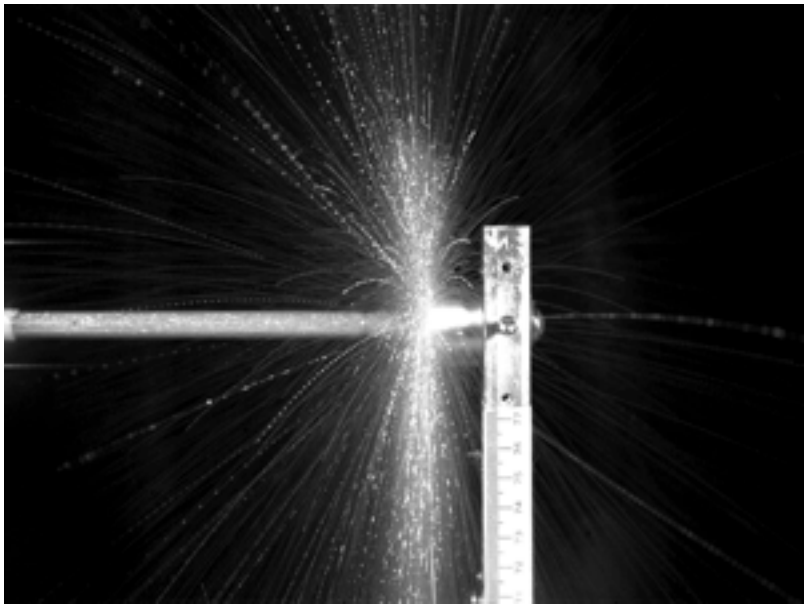
From fluid to particle

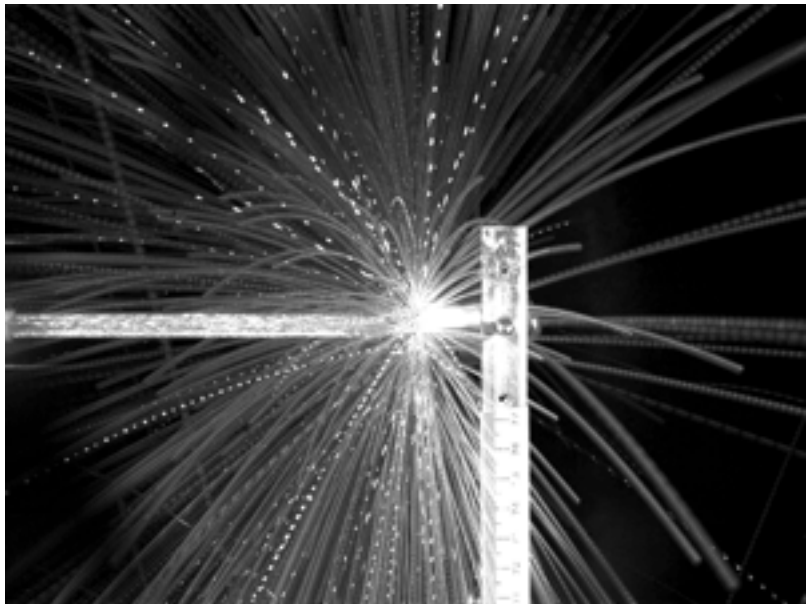
100 µm



500 µm



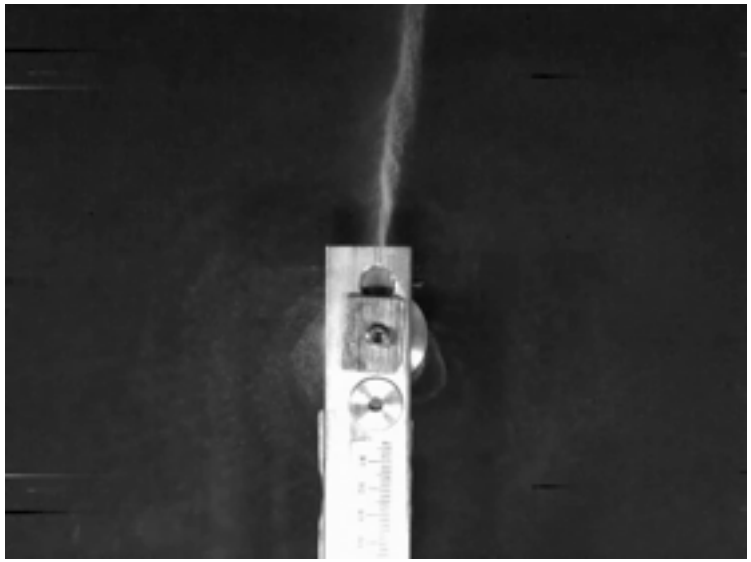
2.1 mm



Liquid formation from discrete particles

Not due to attraction
Not due to confinement
Just kinematics

Classical analog to heavy-ion collider physics: RHIC, CERN
collide gold nuclei $\Longrightarrow$ quark-gluon plasma $\Longrightarrow$ liquid !!!



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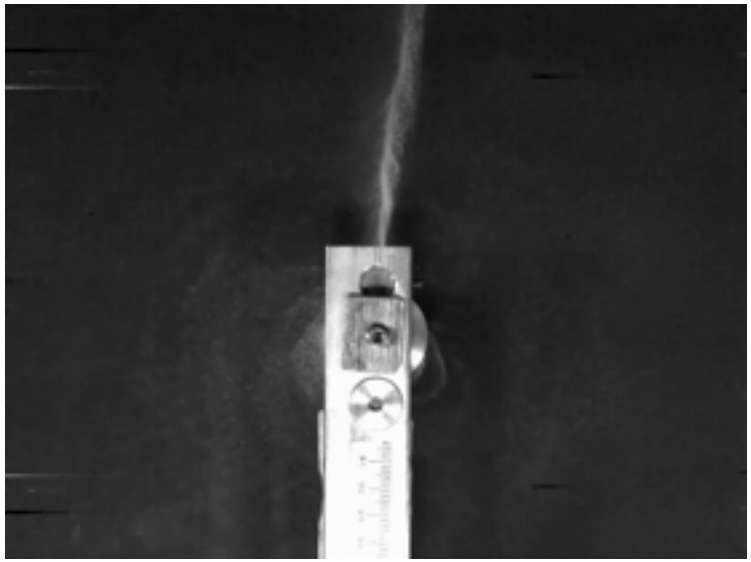

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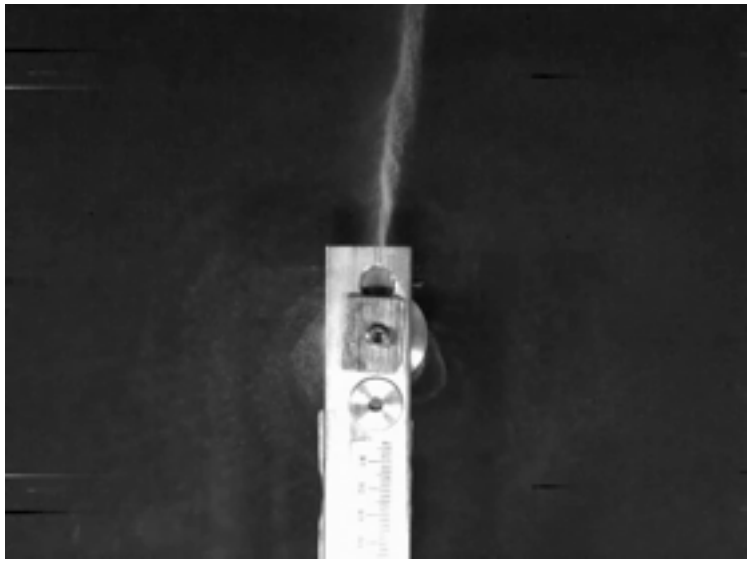
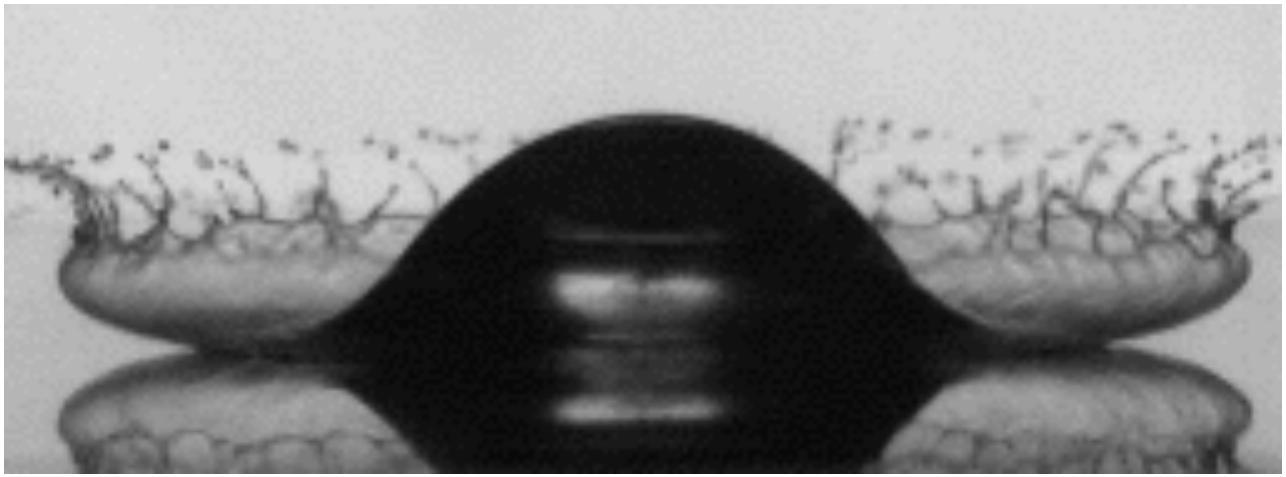


same reason granular gas was liquid

Raises issue of what it means to be a liquid

Splashing



Drop splashes

Drop of alcohol hitting smooth, dry slide

Lei Xu, Wendy Zhang

Drop splashes

Drop of alcohol hitting smooth, dry slide

Lei Xu, Wendy Zhang

Drop splashes

atmospheric pressure

1/3 atmospheric pressure

(Mt. Everest)

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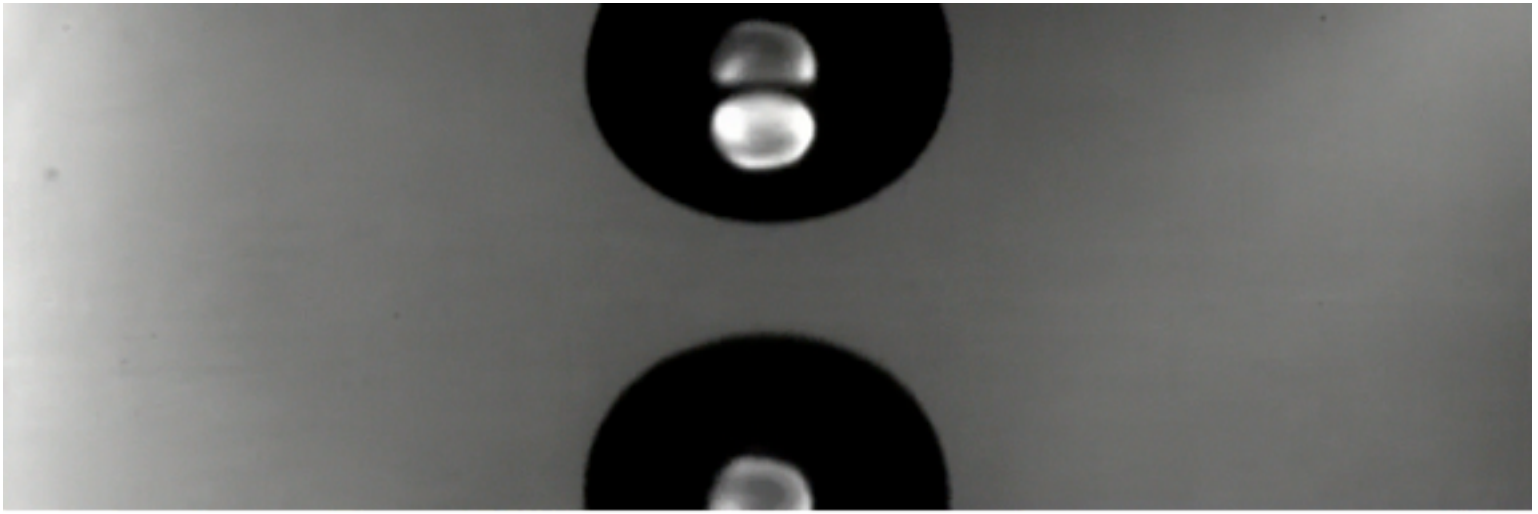
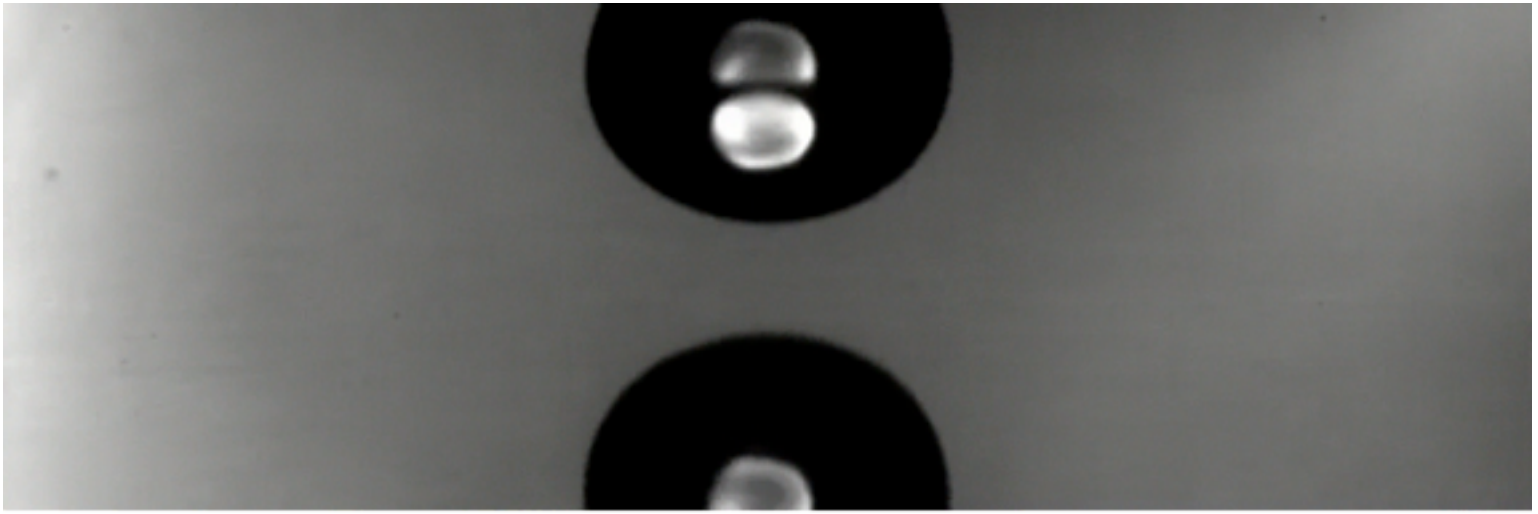
10 x higher viscosity



101 kPa

Michelle Driscoll, Cacey Stevens, Lei Xu

10 x higher viscosity



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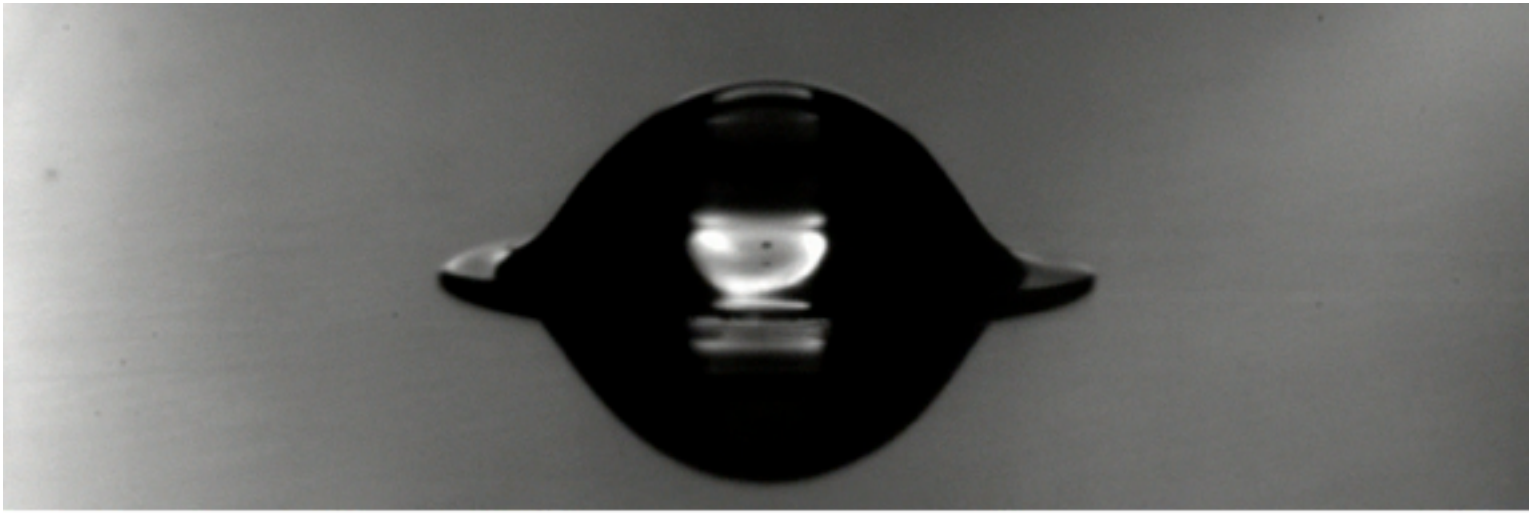

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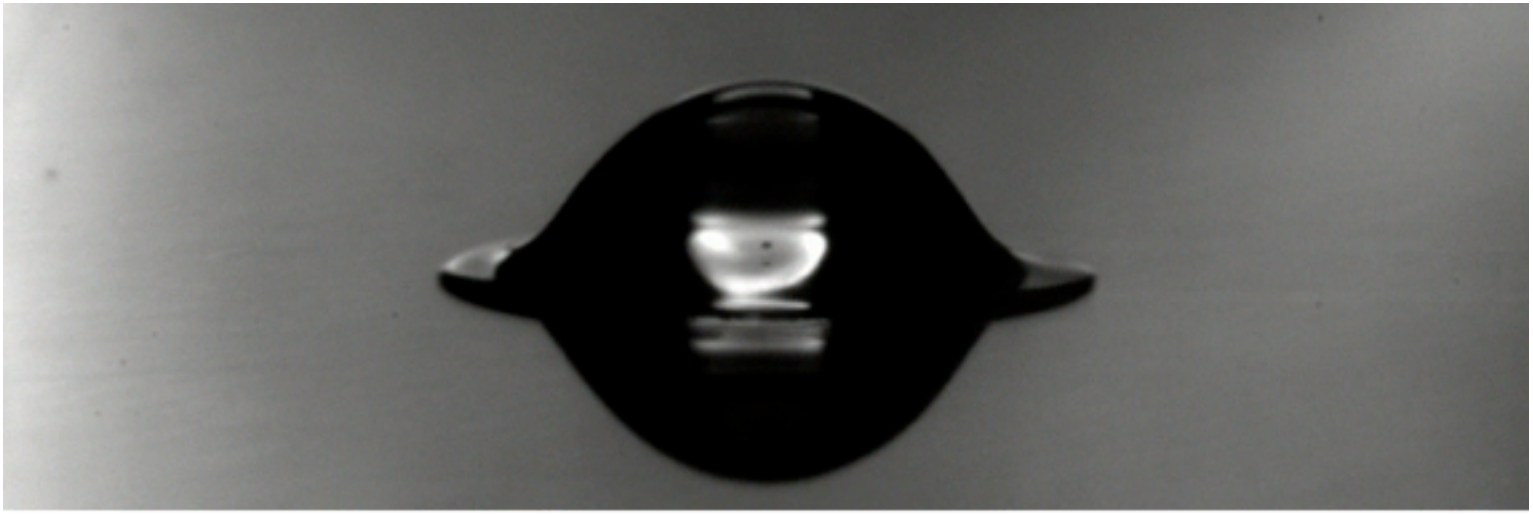

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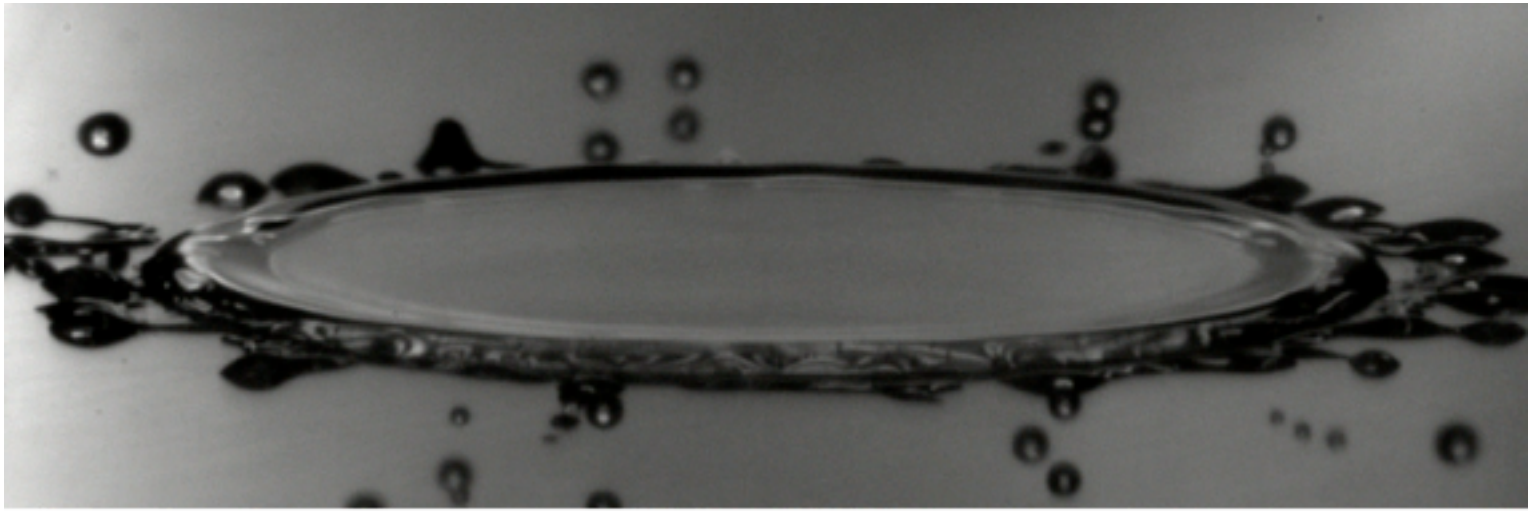
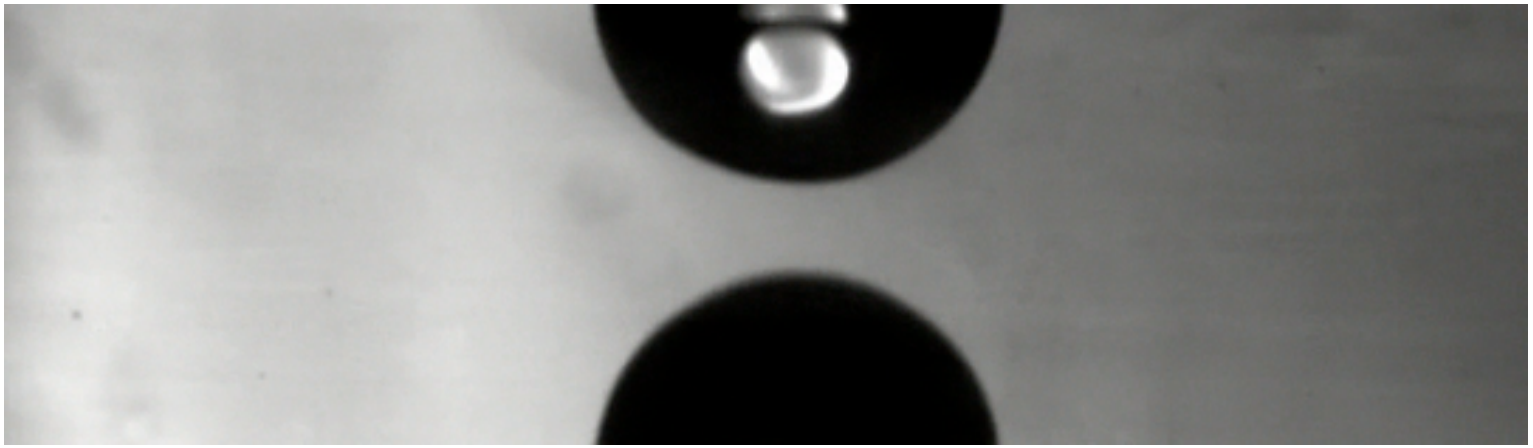


101 kPa



20 kPa

Late-time sheet ejection; low velocity

Air still matters!

Michelle Driscoll, Cacey Stevens, Lei Xu

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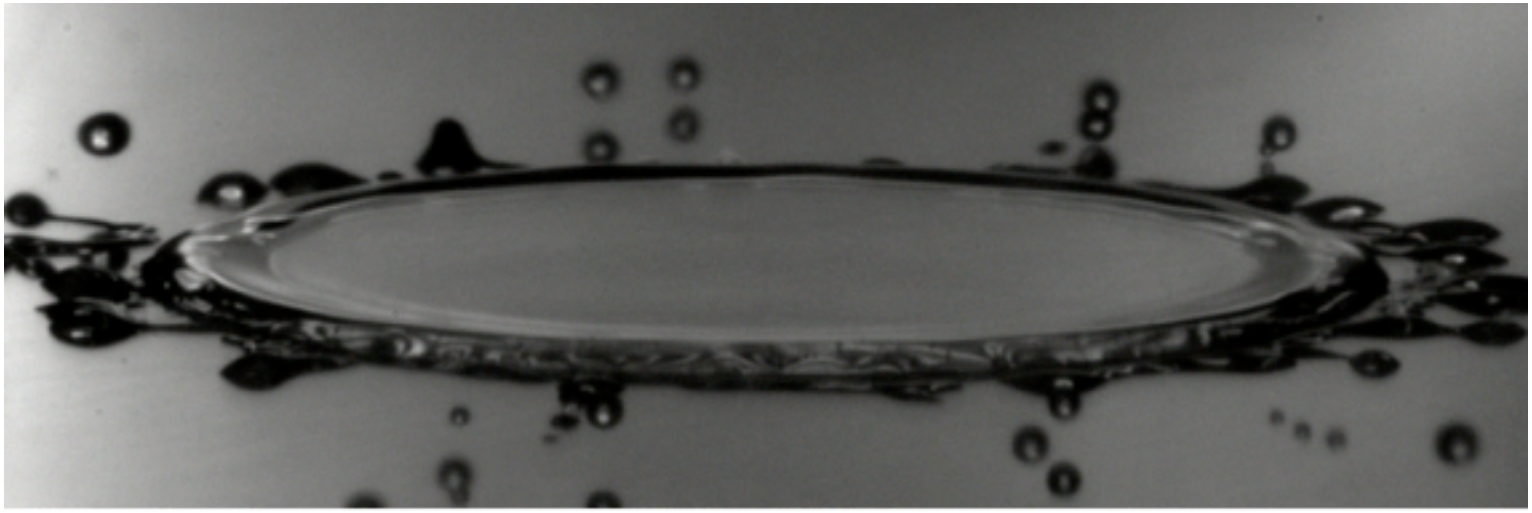

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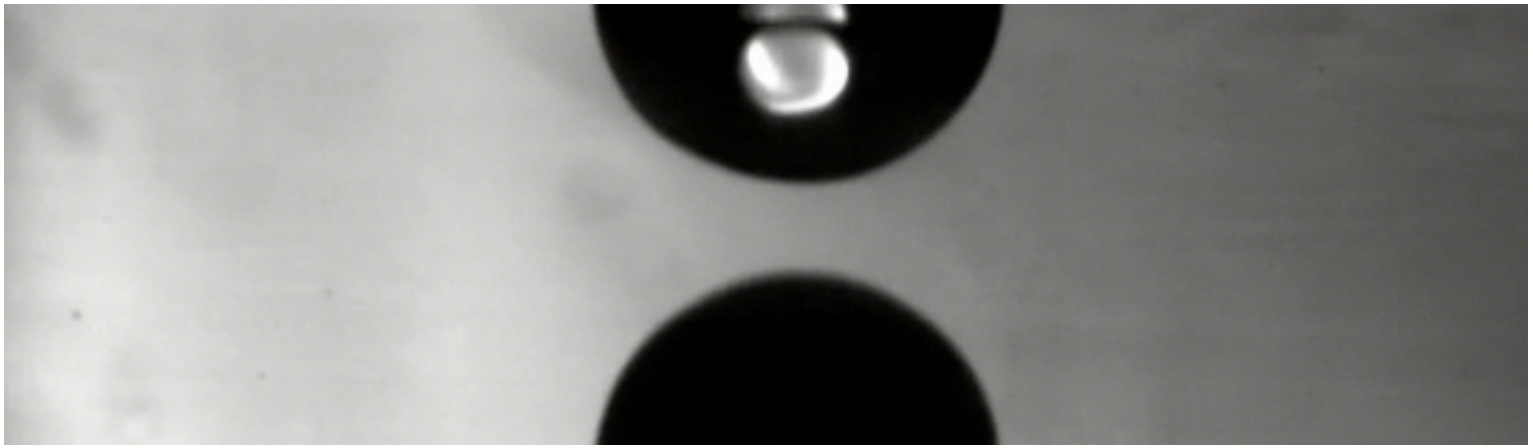

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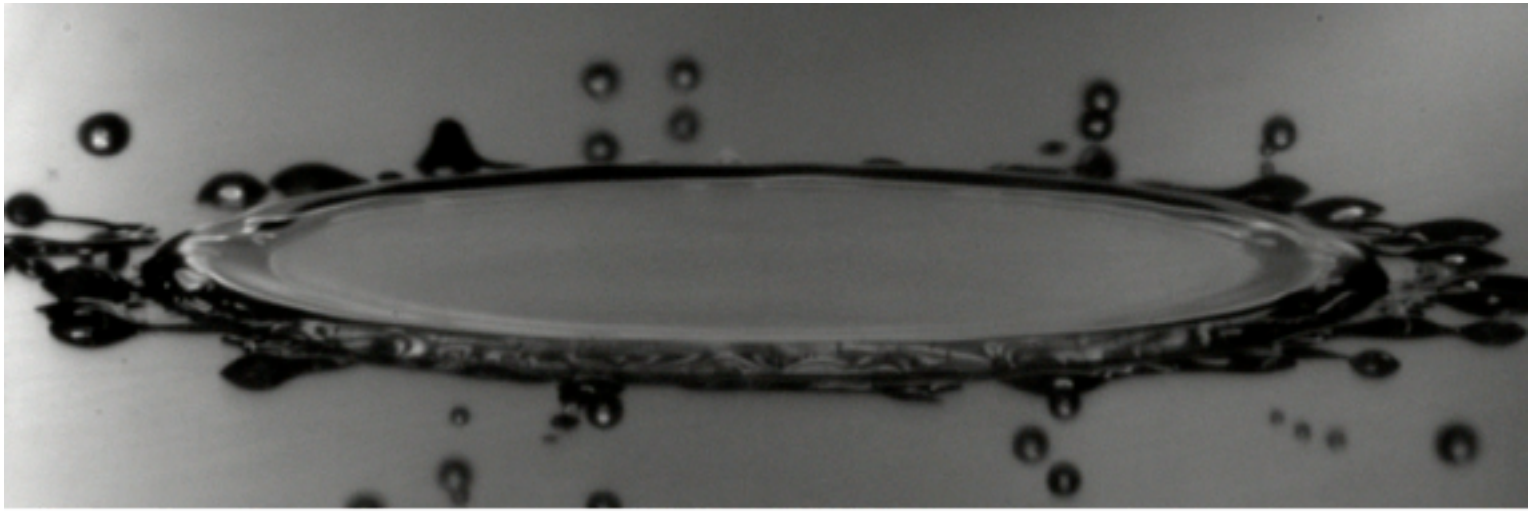

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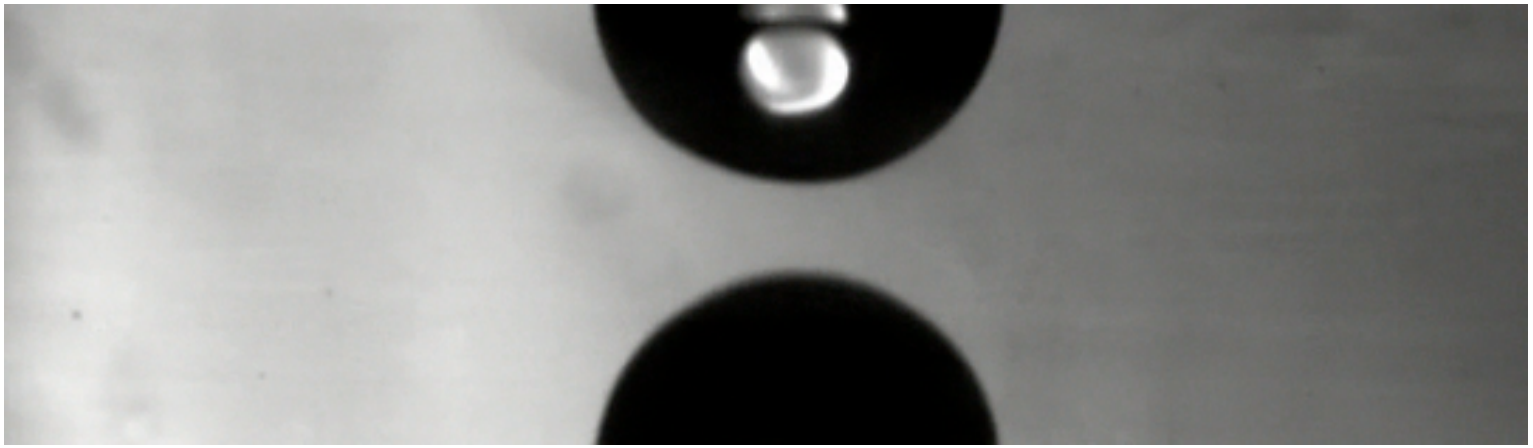

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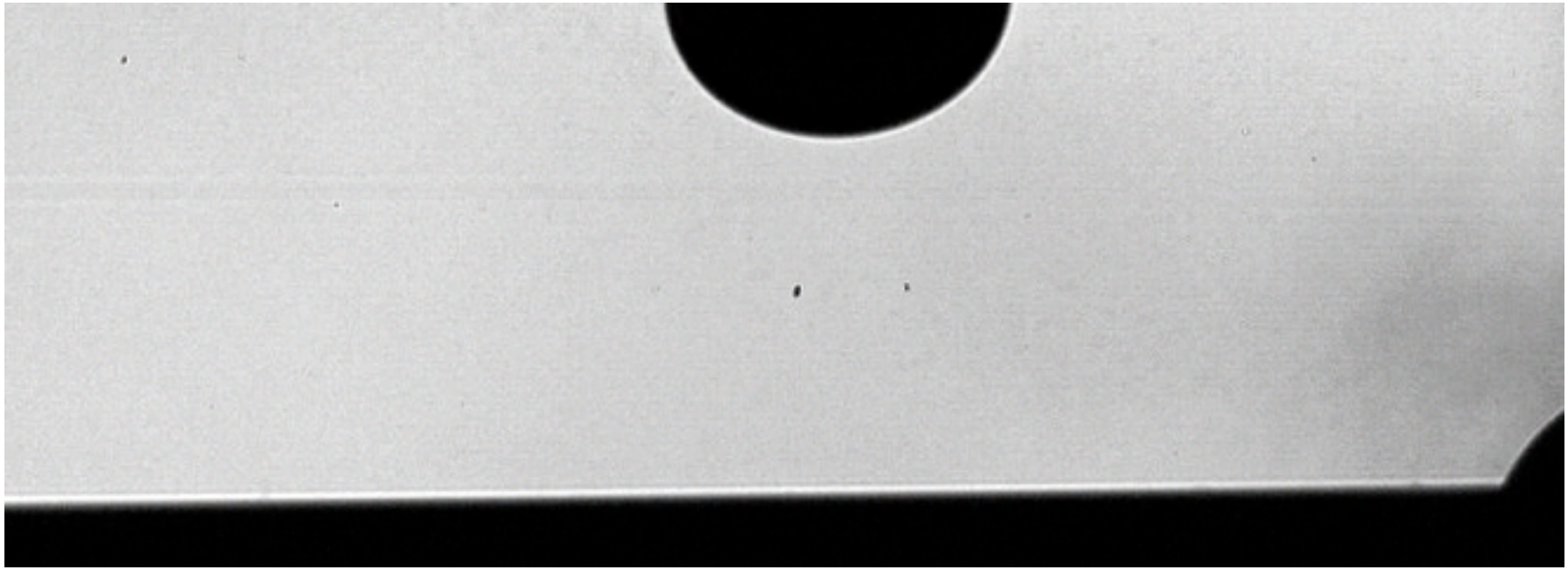
Visualize air above drop



Irmgard Bischofberger, Kelly Mauser

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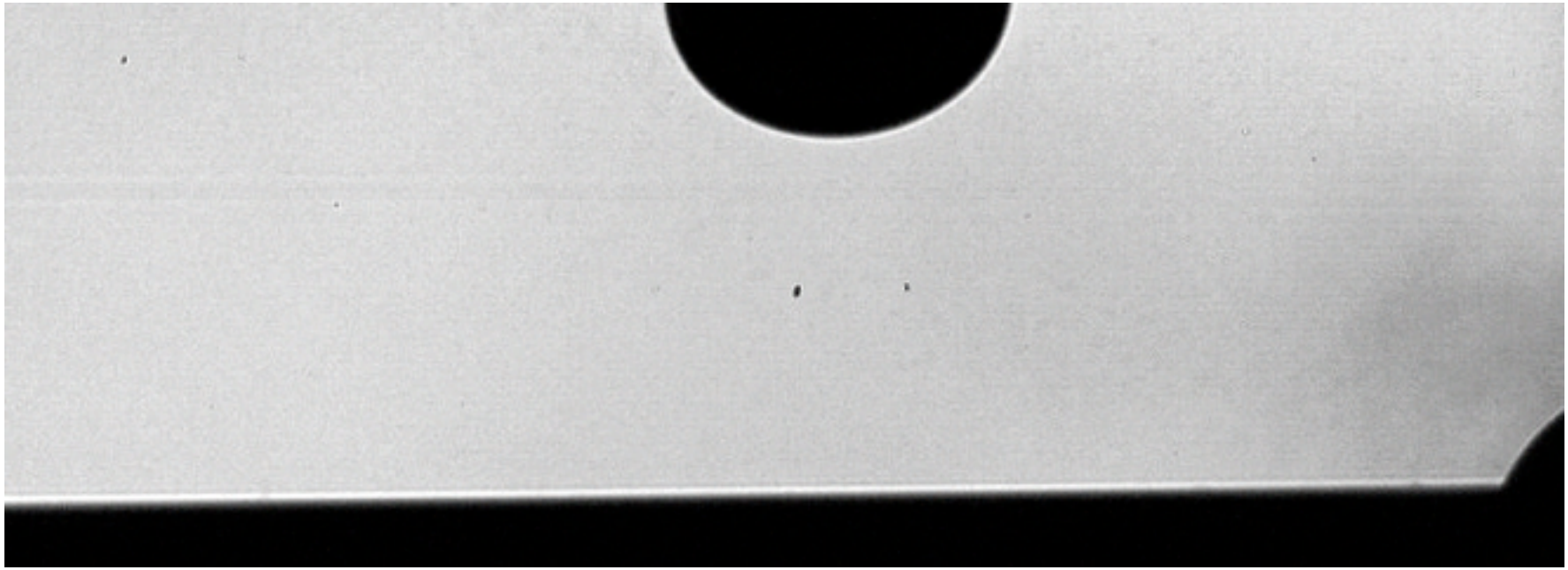

Irmgard Bischofberger, Kelly Mauser

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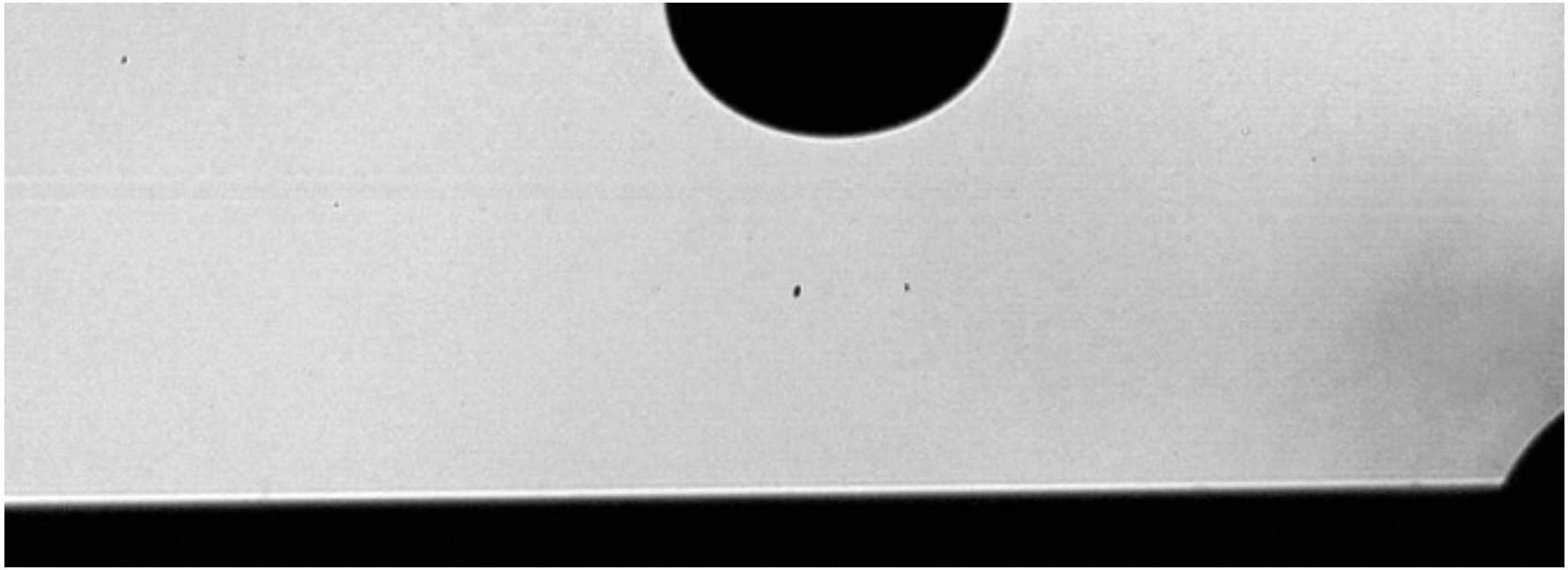

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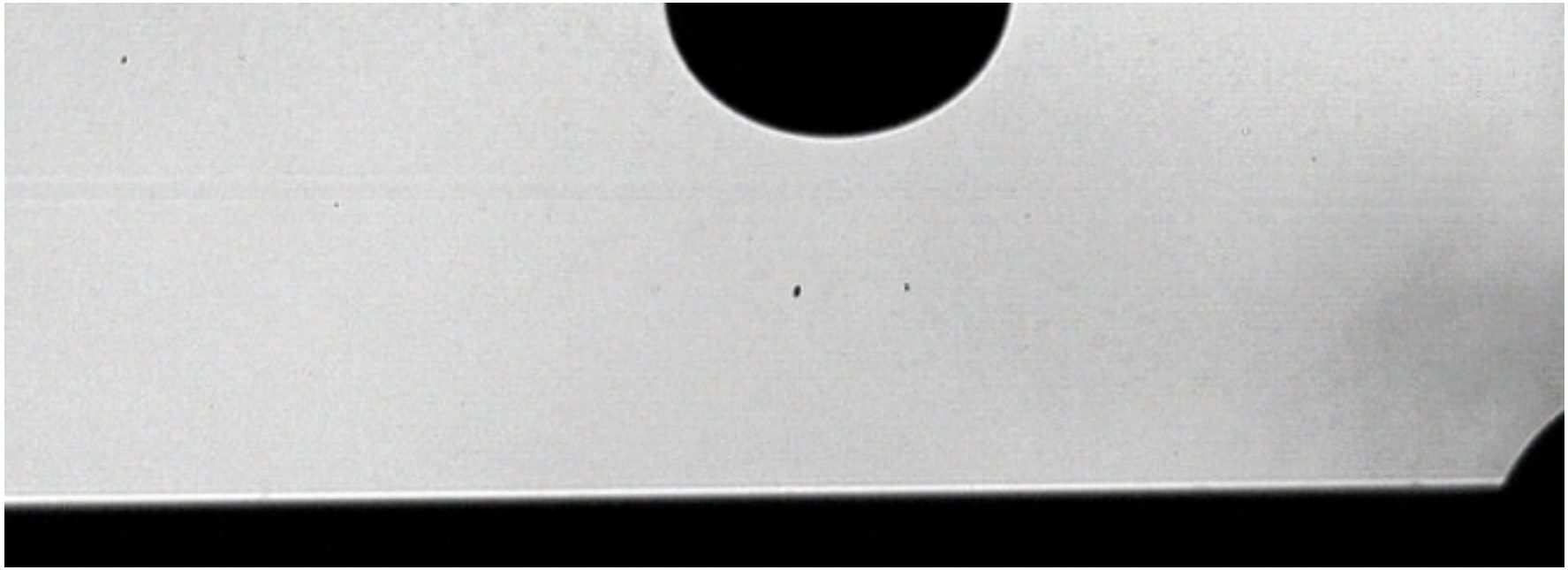

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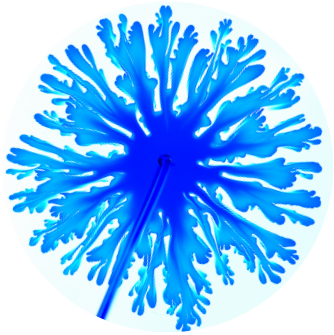
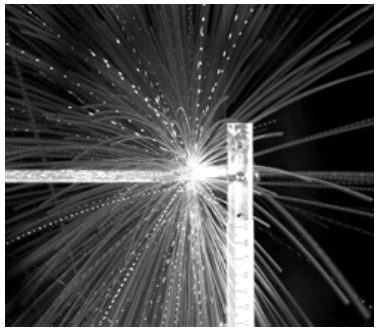
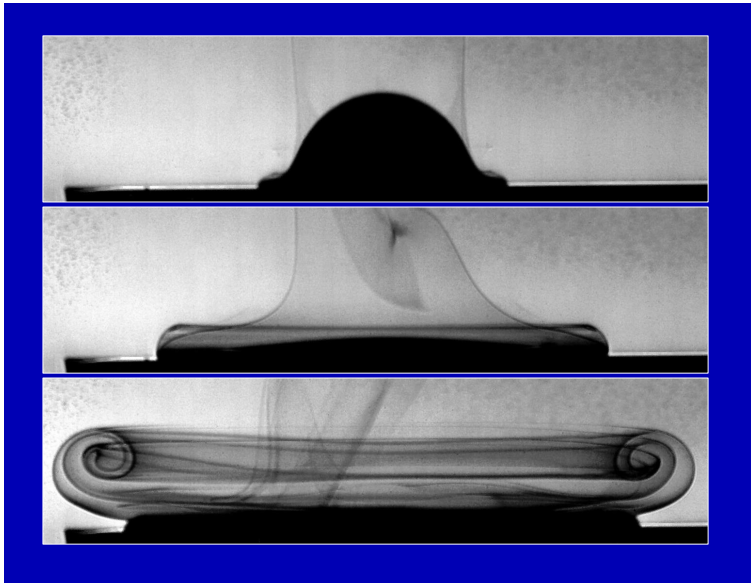
Emergence of structure ⟹ nature's texture

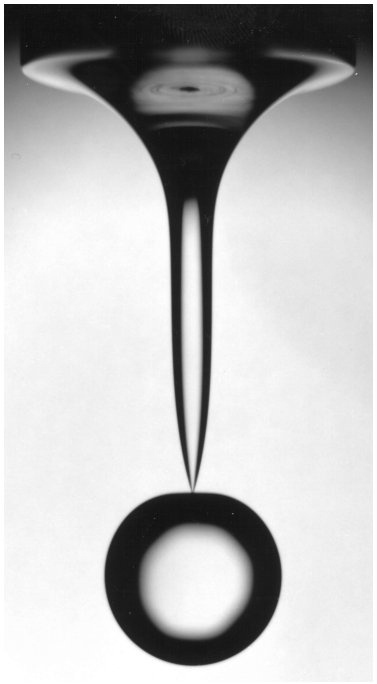
Renewed appreciation of world around us

Connections ⟹ biology, memory, quark-gluon plasma









Nature reuses same ideas in different phenomena

Scientists reuse same ideas to explain them…

A great idea *"is like a phantom ocean beating upon the shores of human life in successive waves of specialization."*

A. N. Whitehead


Irmgard Bischofberger


Radha Ramachandran

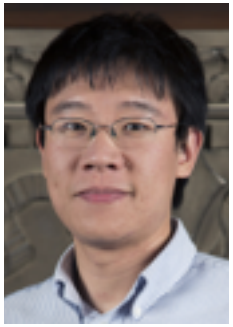

Michael Brenner


Itai Cohen


Wendy Zhang


Nathan Keim

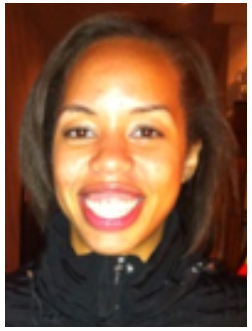

Laura Schmidt


Xiang Cheng


Heinrich Jaeger


Michelle Driscoll


Lei Xu


Cacey Stevens


Kelly Mauser


Andrzej Latka


Ariana Strandburg-Peshkin


Loretto Barcos


Samantha Jones