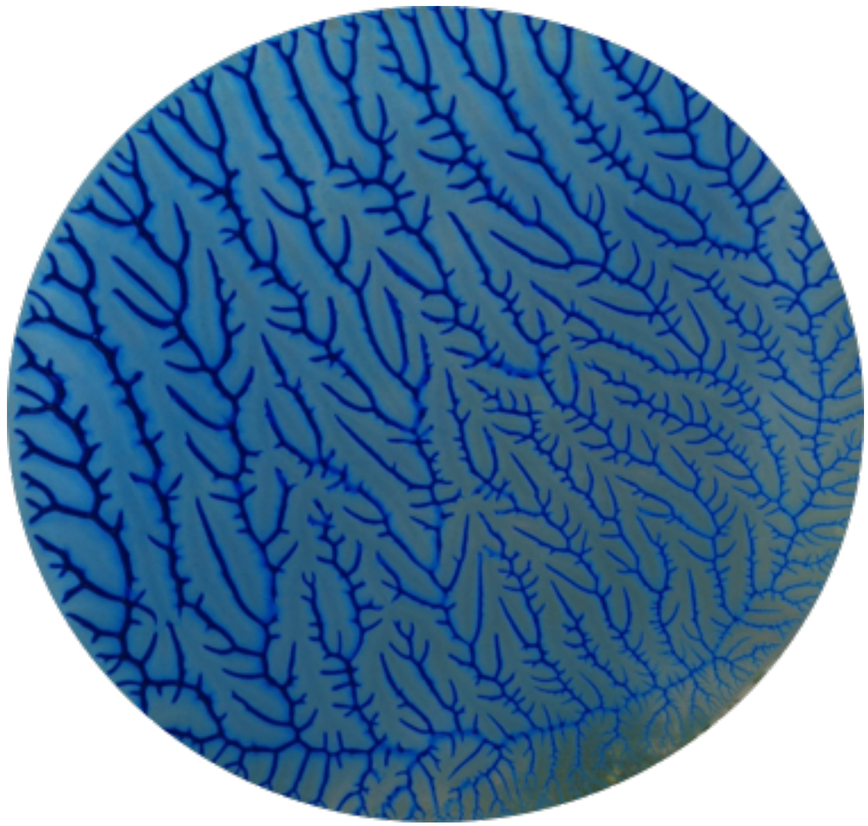
Impact and Intrusion

Hoxton Lecture; University of Virginia; April 14, 2016

“Philosophy begins in wonder.” *Plato*



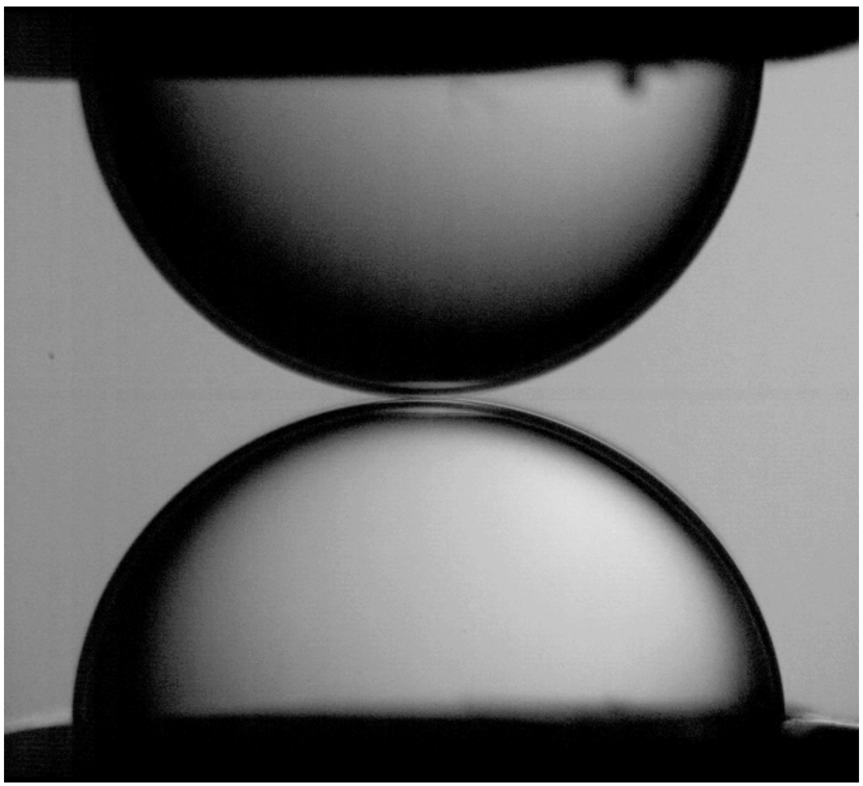
Emergence of structure:
symmetries and instabilities

Instabilities

Smooth evolution punctuated by catastrophic events

⇒ instabilities

⇒ singularities



1 mm Drop merger

Bubble breakup

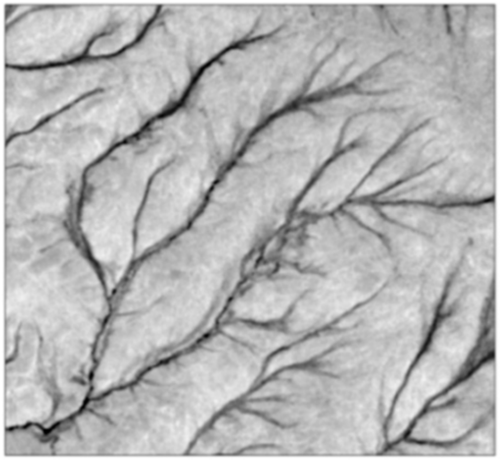
Conform to symmetries ⇒ form & structure

Joseph Paulsen, Nathan Keim

Dilation symmetry and penetration of space

Tree branches

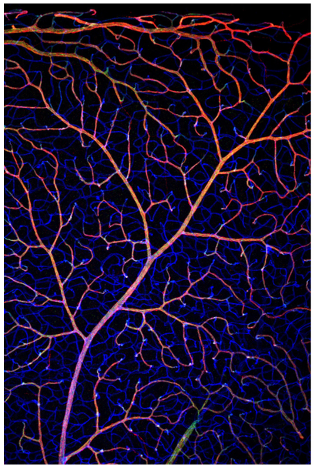
River network



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

Discharge

Blood vessel



www.mpg.de/9846568/
transcription-factors-blood-
vessel-growth1

Aggregation

en.wikipedia.org/wiki/Diffusion-limited_aggregation

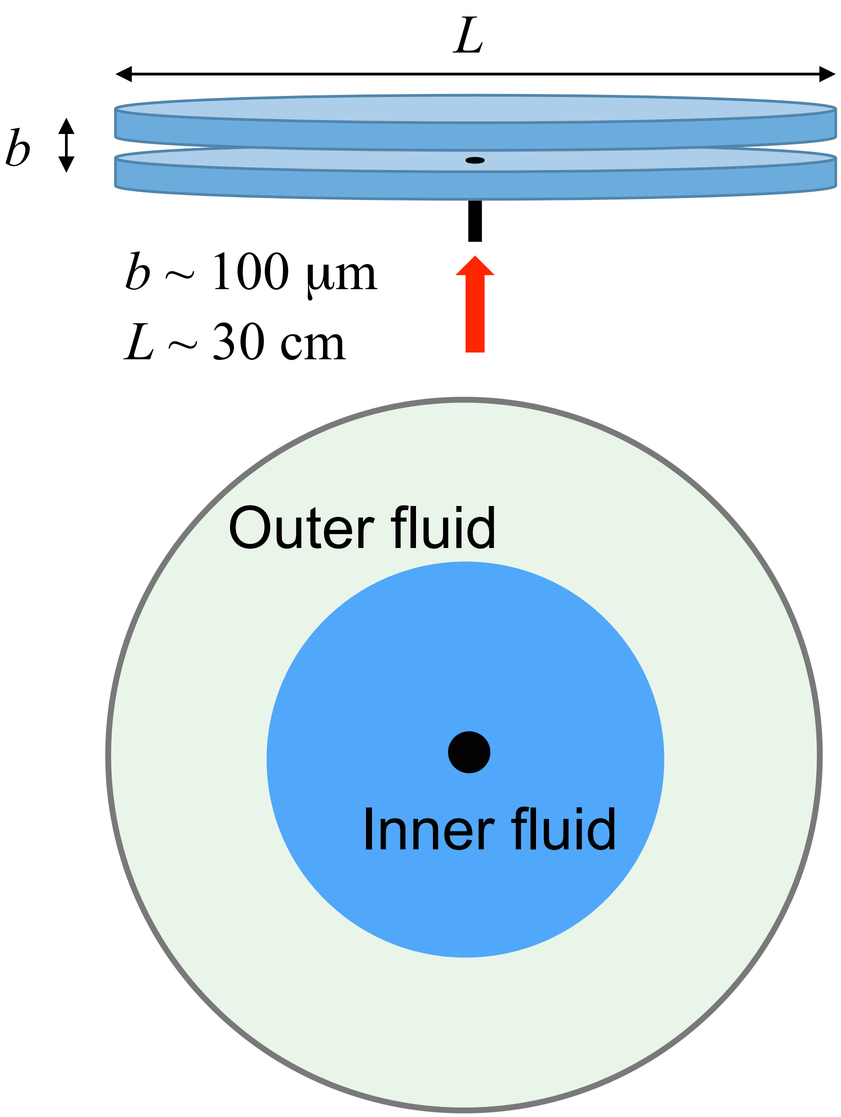
Lightening

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

Dilation symmetry: expand ⇒ same shape

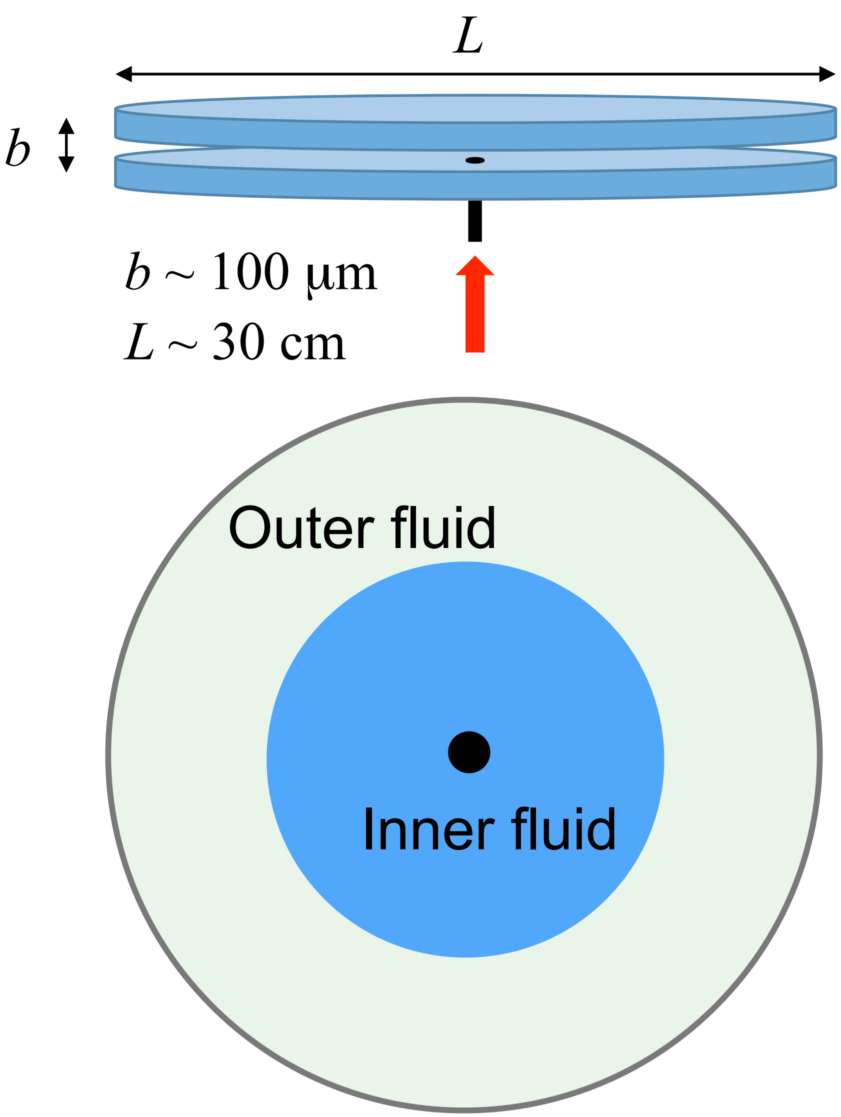
Viscous-fingering instability

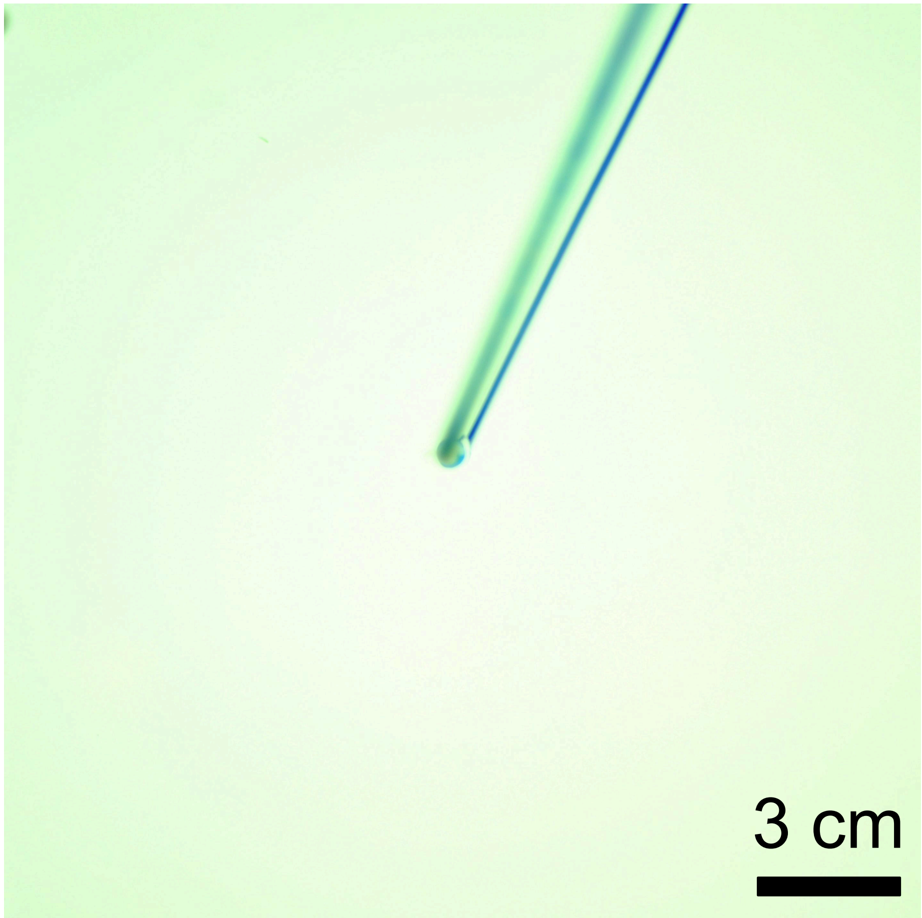
Displace one fluid by another



Viscous-fingering instability

Displace one fluid by another





Unstable if inner fluid
less viscous than outer fluid

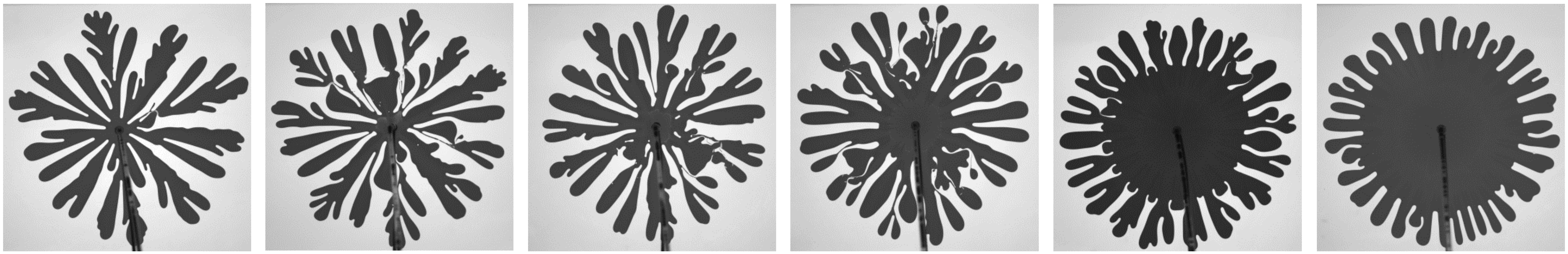
Surface tension - stabilizing force

Irmgard Bischofberger

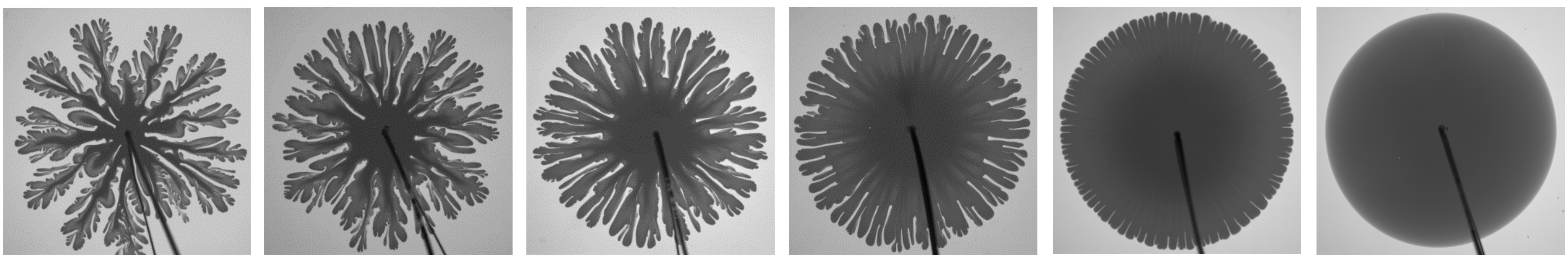
Removing surface tension stabilizes patterns!

Everything *except* surface tension is same

Immiscible fluids: surface tension



Miscible fluids: no surface tension



Viscosity ratio

New length scale emerges ⇒ global patterns

Irmgard Bischofberger

New regime: toes

miscible fluids

Viscosity ratio = 280

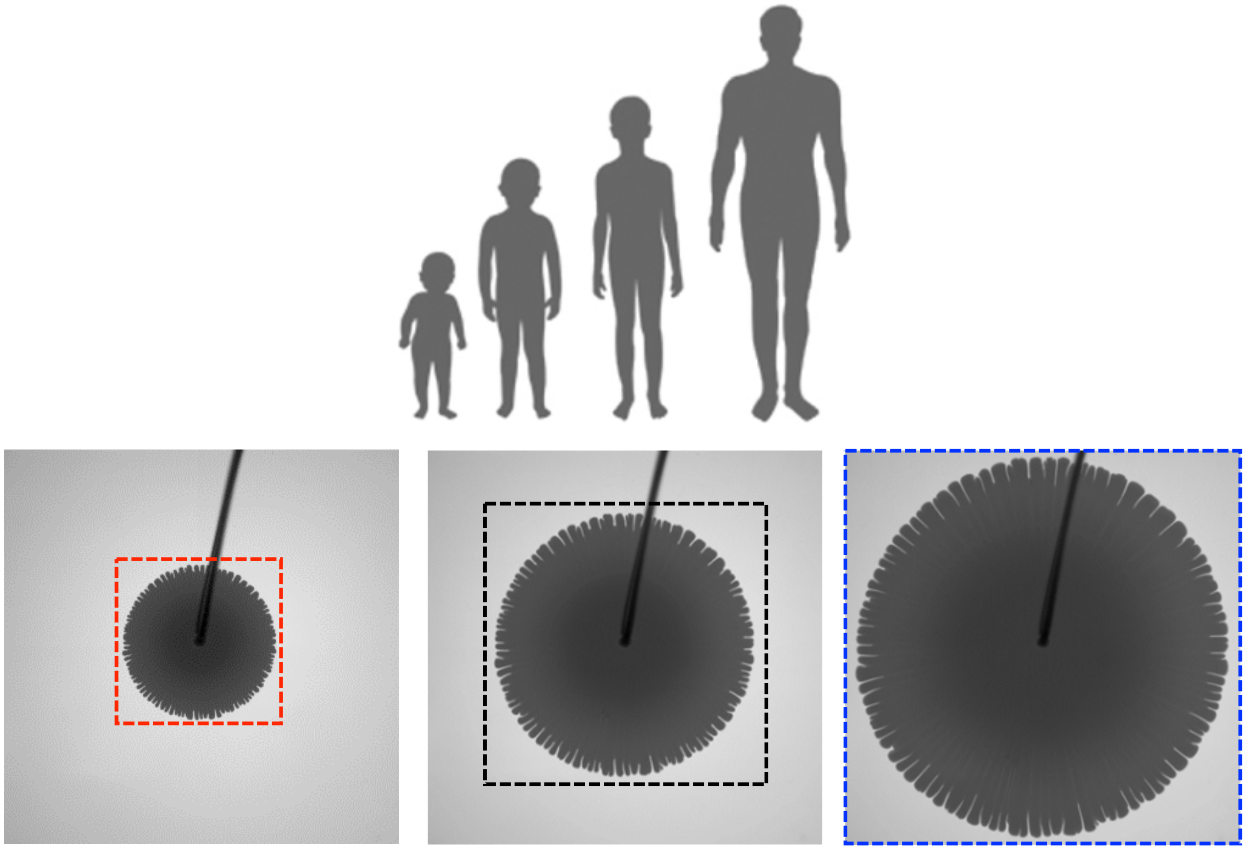
Viscosity ratio = 5.4

Once toe forms it no longer splits

Instability turns itself off

Irmgard Bischofberger

Proportionate growth - how mammals grow



Only physical (as distinct from biological) example known

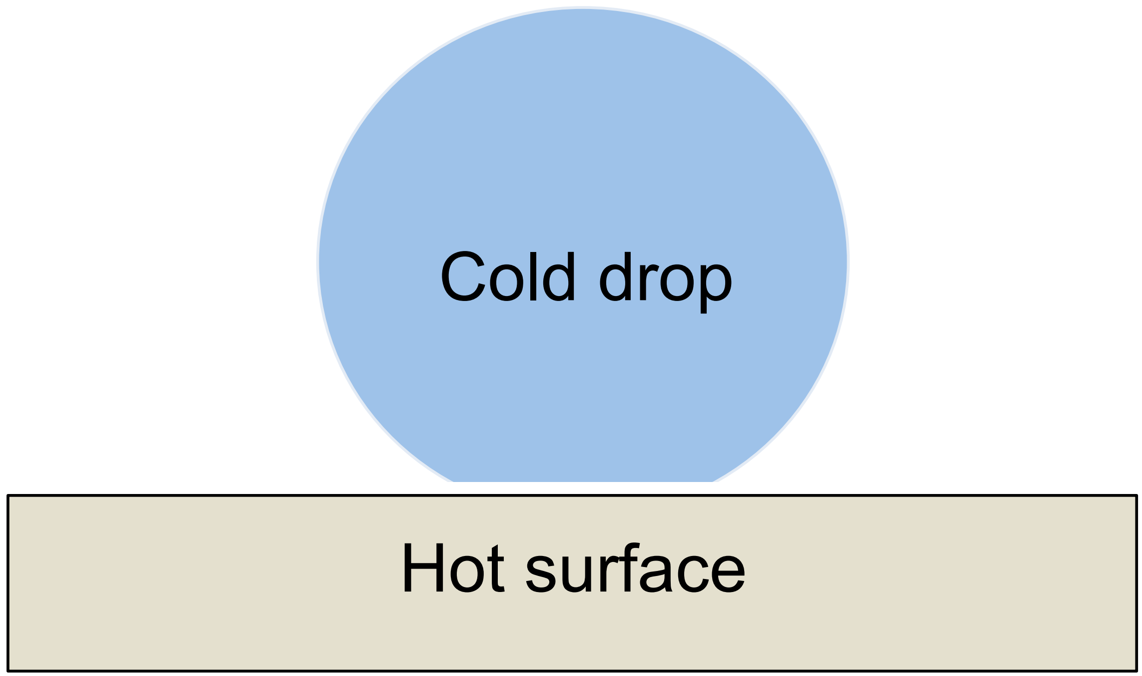
Irmgard Bischofberger

Drop lands on hard surface

Splashes?   Spreads?   Floats?

Drop lands on hard surface

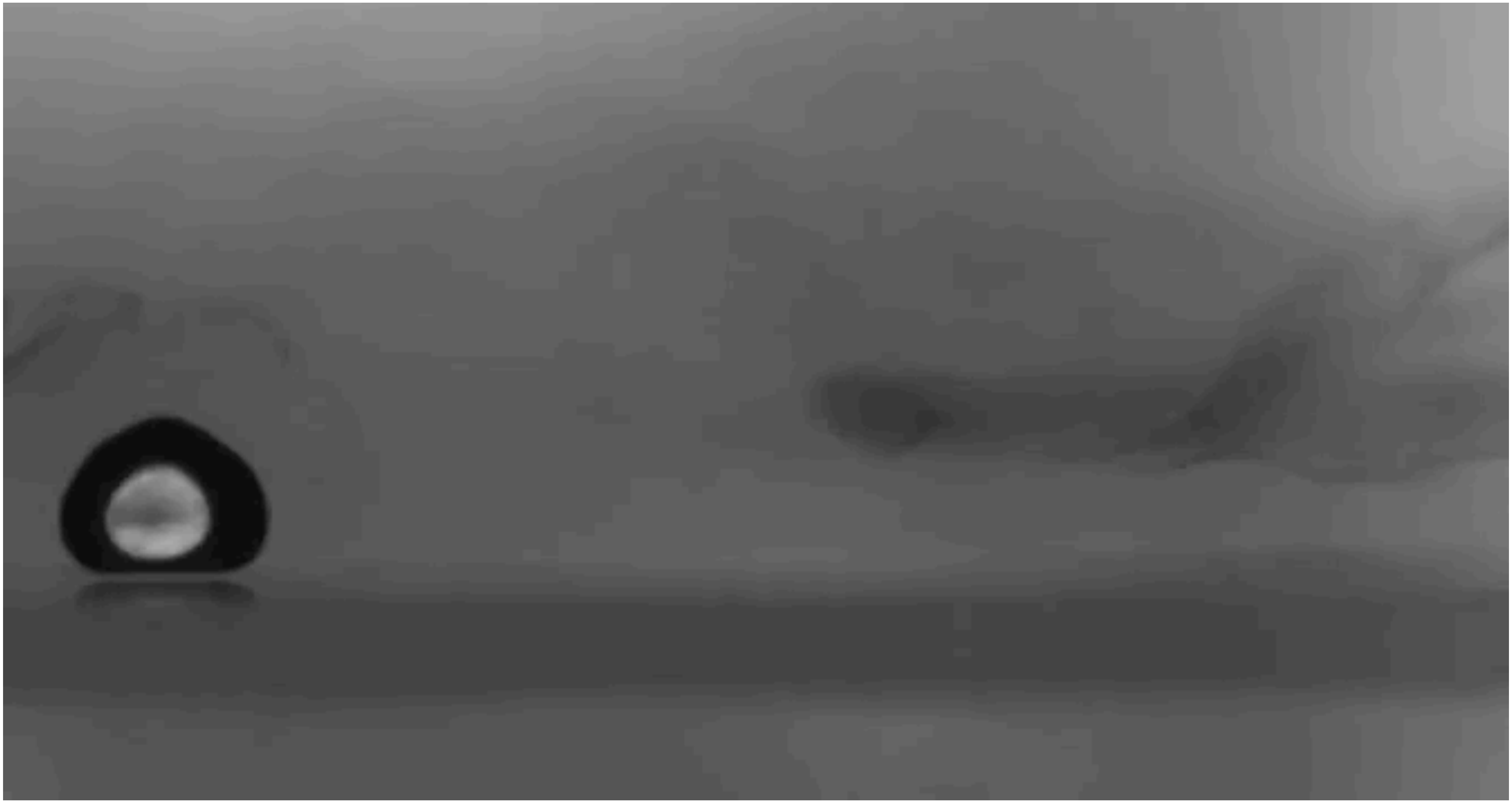
Splashes? Spreads? Floats?



Transition: Liquid evaporates (boils)
As T raised, boiling suddenly drops!

Drop lifetime suddenly increases!

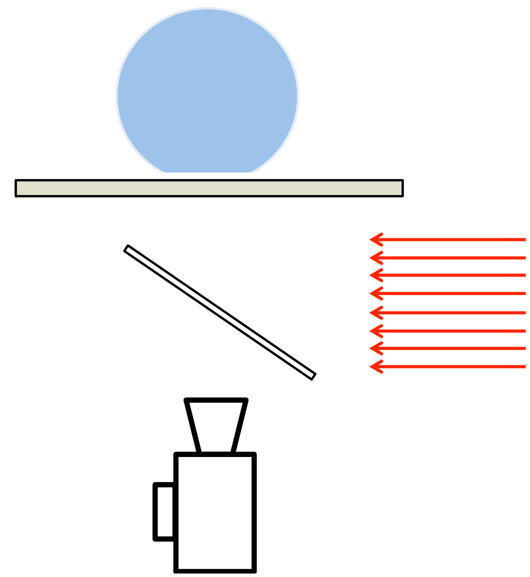
Leidenfrost drops



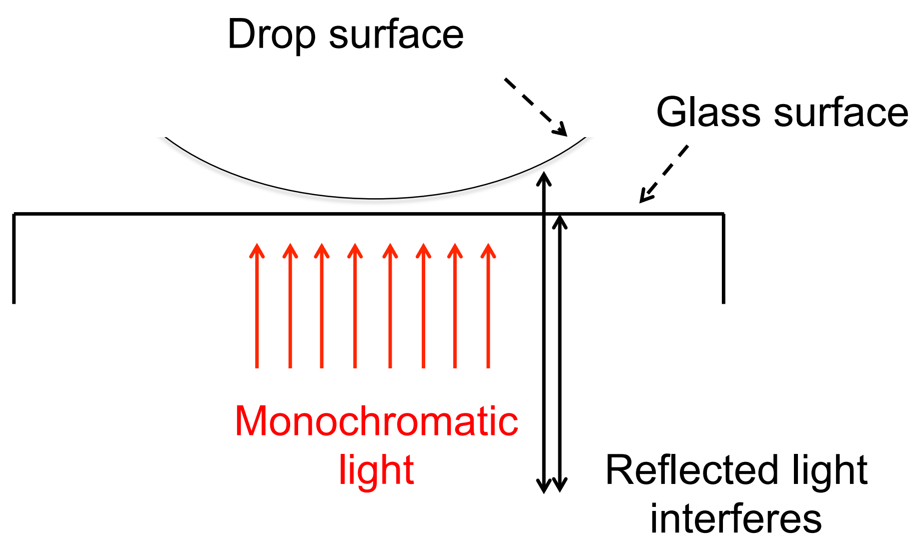
Justin Burton, Thomas Casewell

Beneath Leidenfrost drop

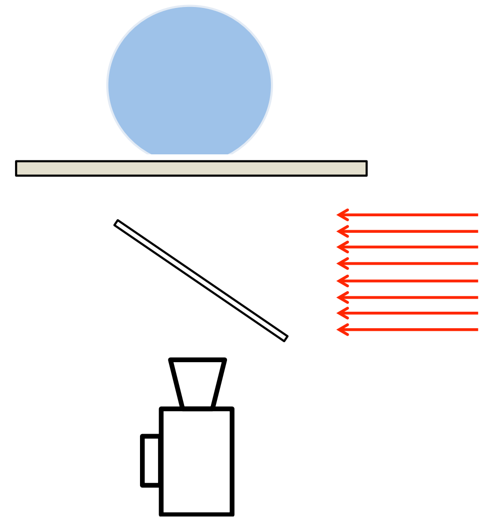
Reflections from liquid surface and from substrate interfere.



Fringes measure shape of hidden surface.



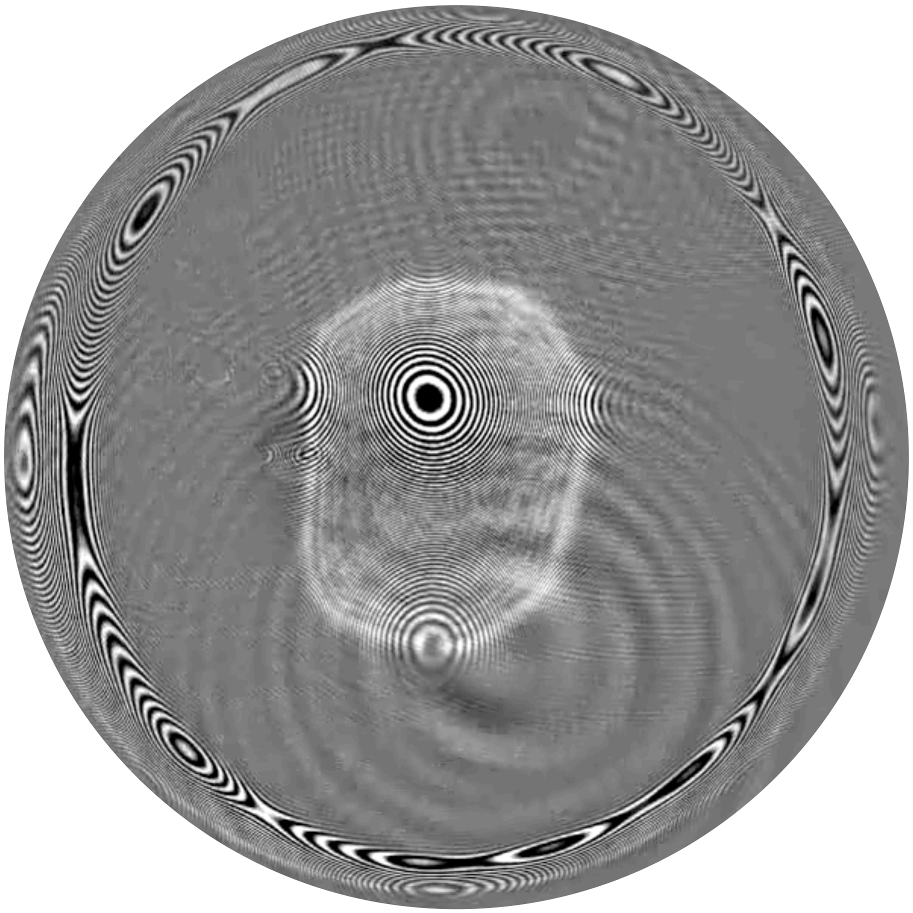
Beneath Leidenfrost drop

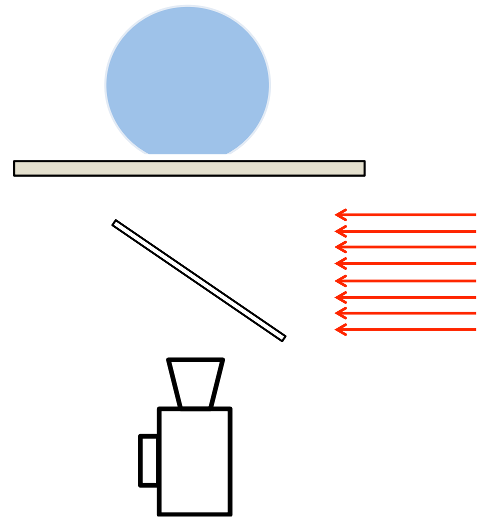


Vapor layer forms dome - supports drop

Justin Burton, Thomas Casewell

Dynamics beneath Leidenfrost drop

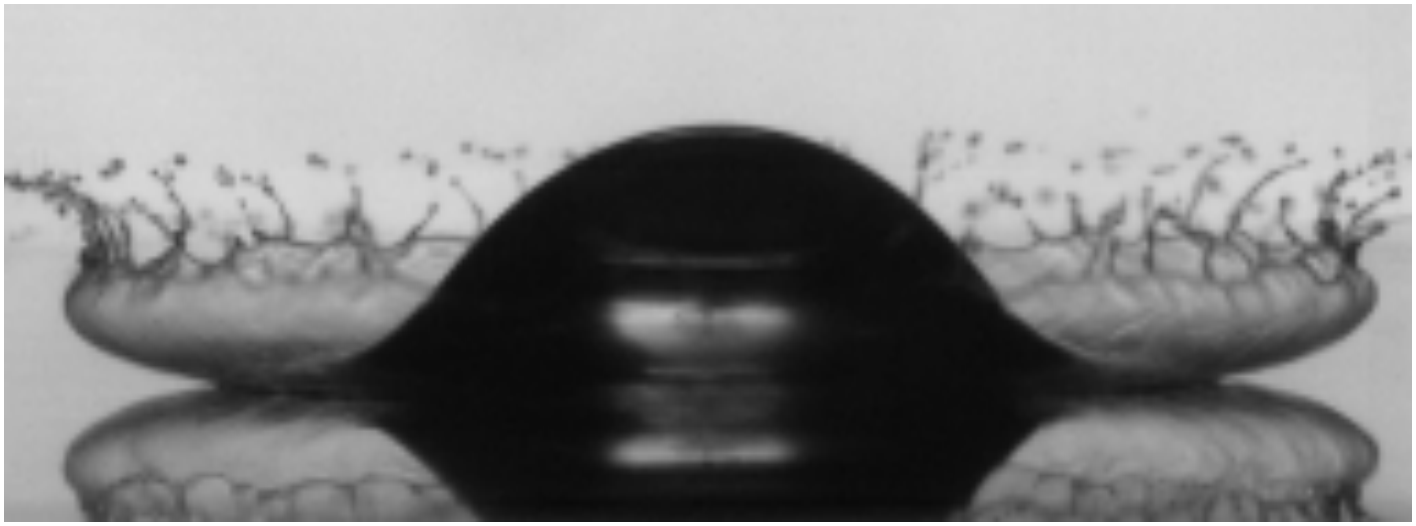




Vapor layer forms dome - supports drop
Dome held up by fluctuating ridge

Justin Burton, Thomas Casewell

Spashing



Drop splashes

Drop of alcohol hitting smooth, dry slide

Lei Xu, Wendy Zhang

Drop splashes

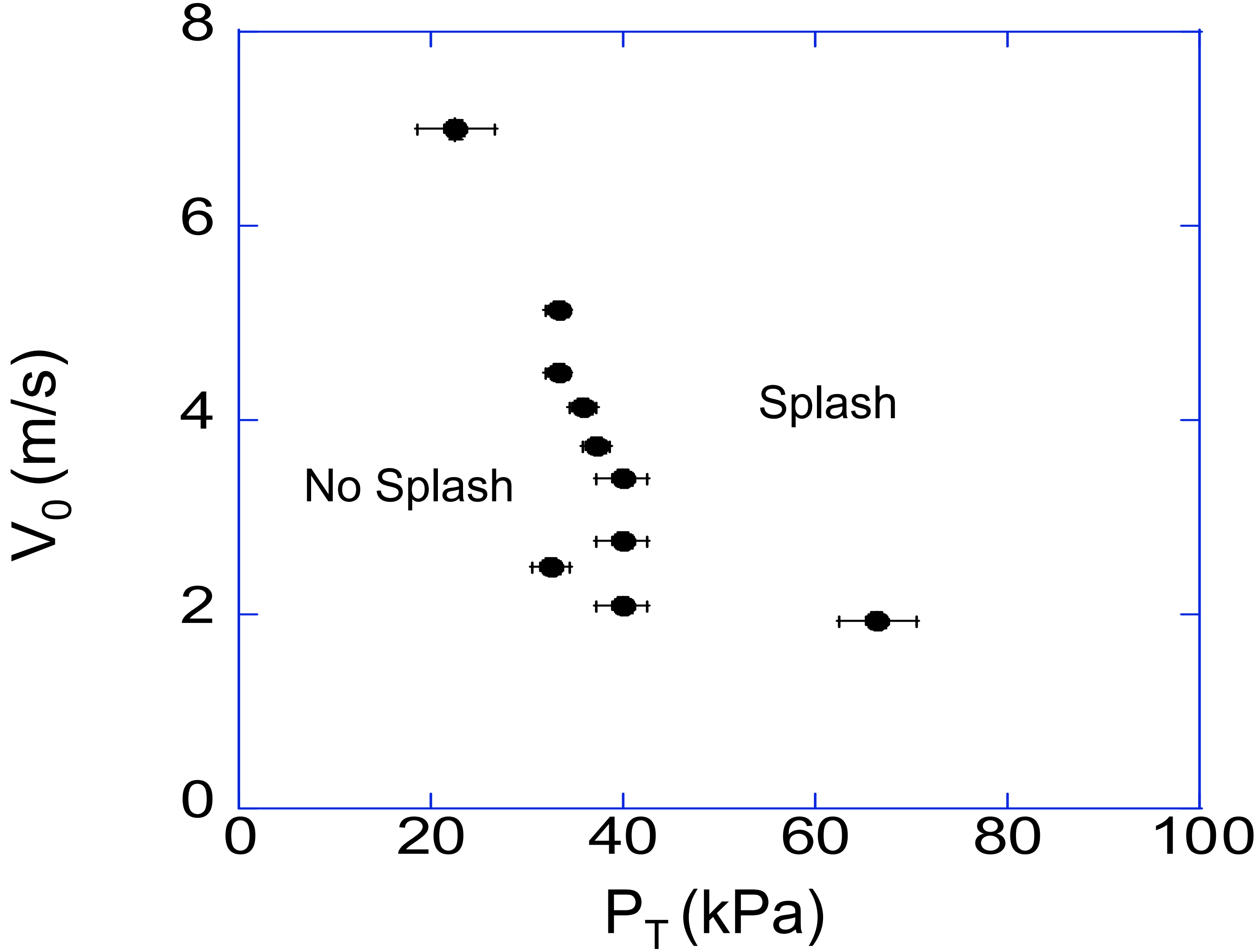
atmospheric pressure

1/3 atmospheric pressure

(Mt. Everest)

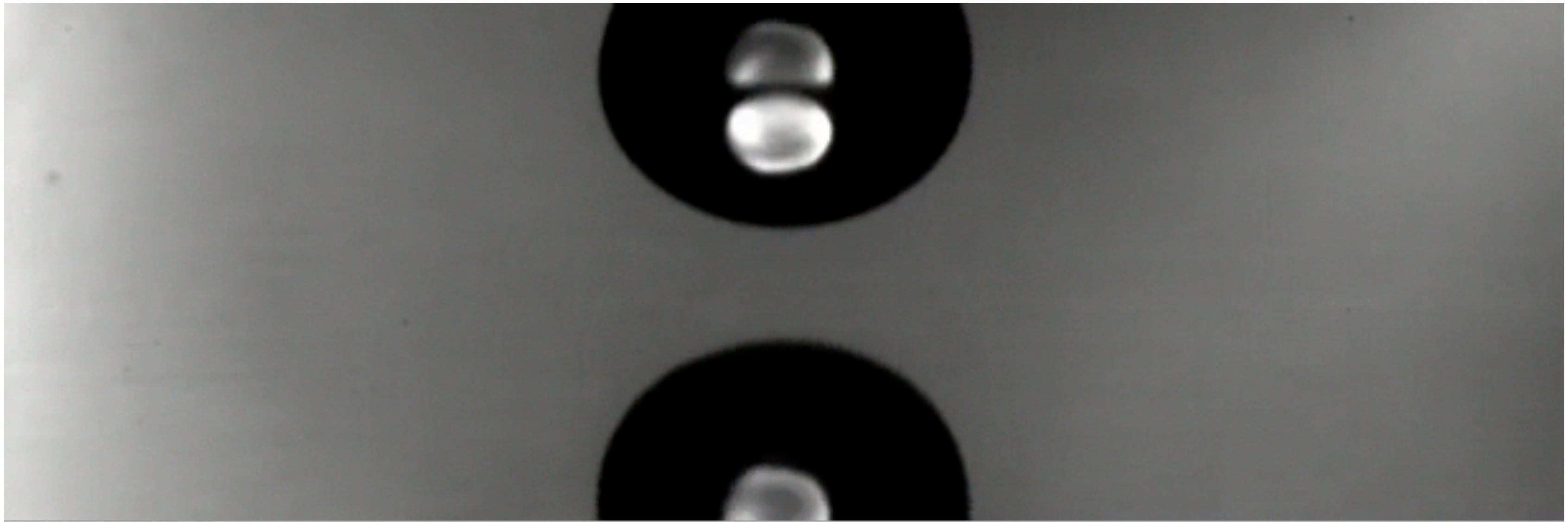
Lei Xu, Wendy Zhang

Impact velocity *vs.* threshold pressure



Lei Xu, Wendy Zhang

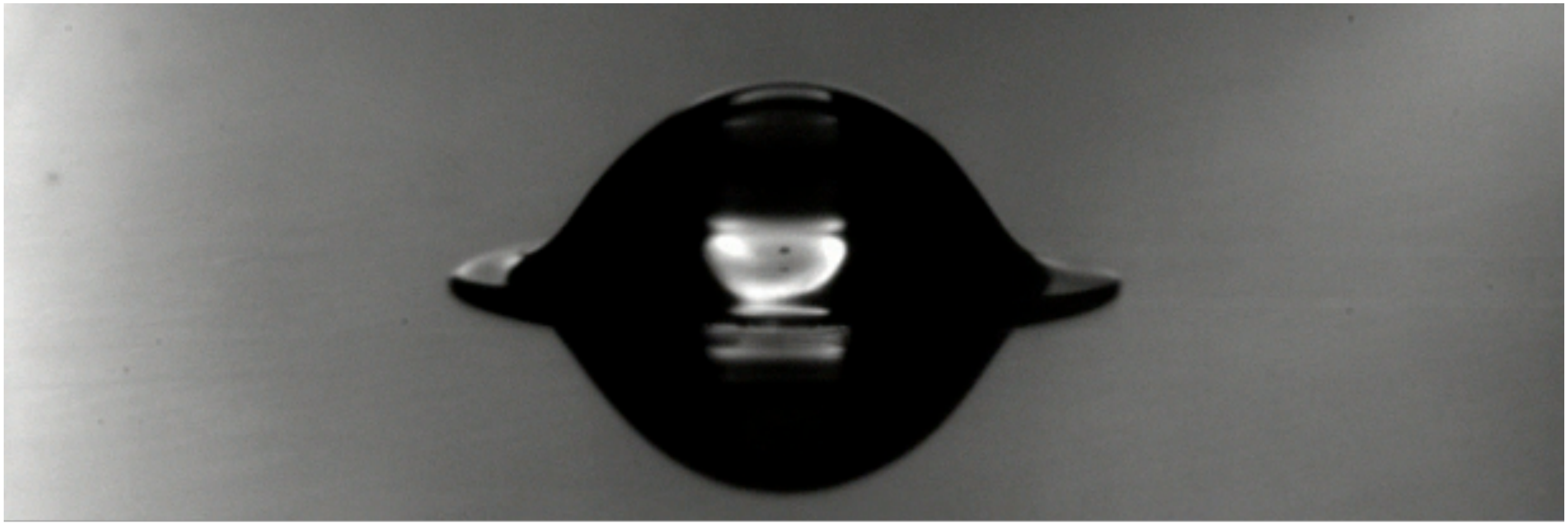
10 x higher viscosity



101 kPa

Michelle Driscoll, Cacey Stevens, Lei Xu

10 x higher viscosity



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Michelle Driscoll, Cacey Stevens, Lei Xu

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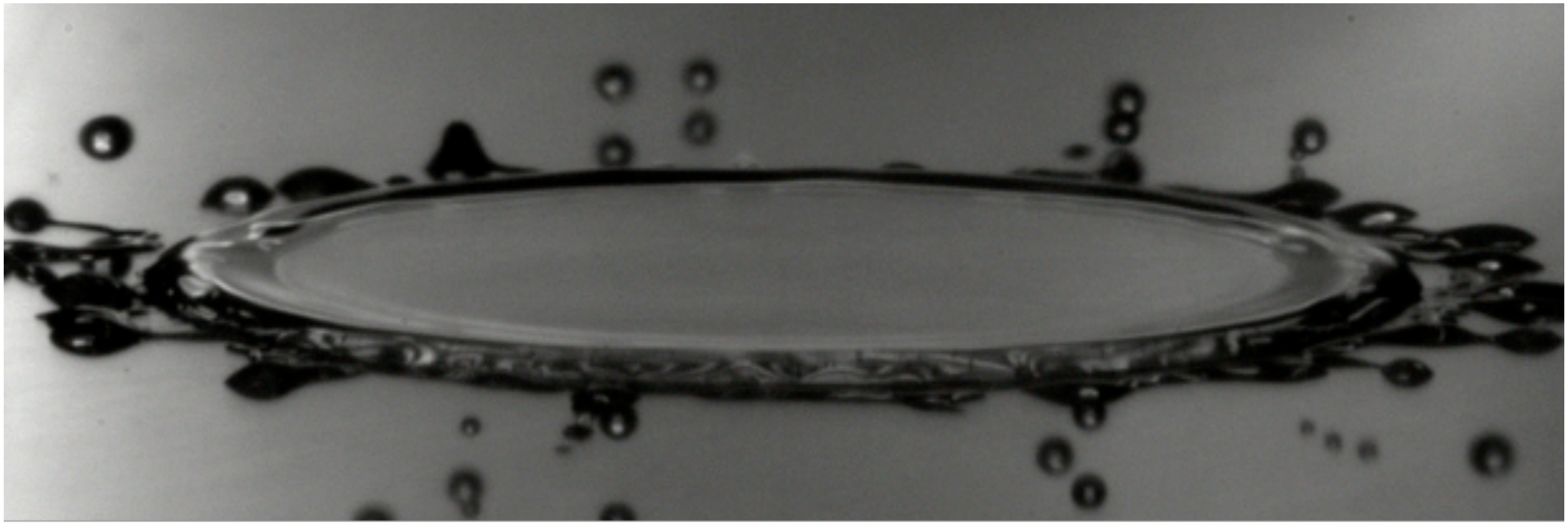
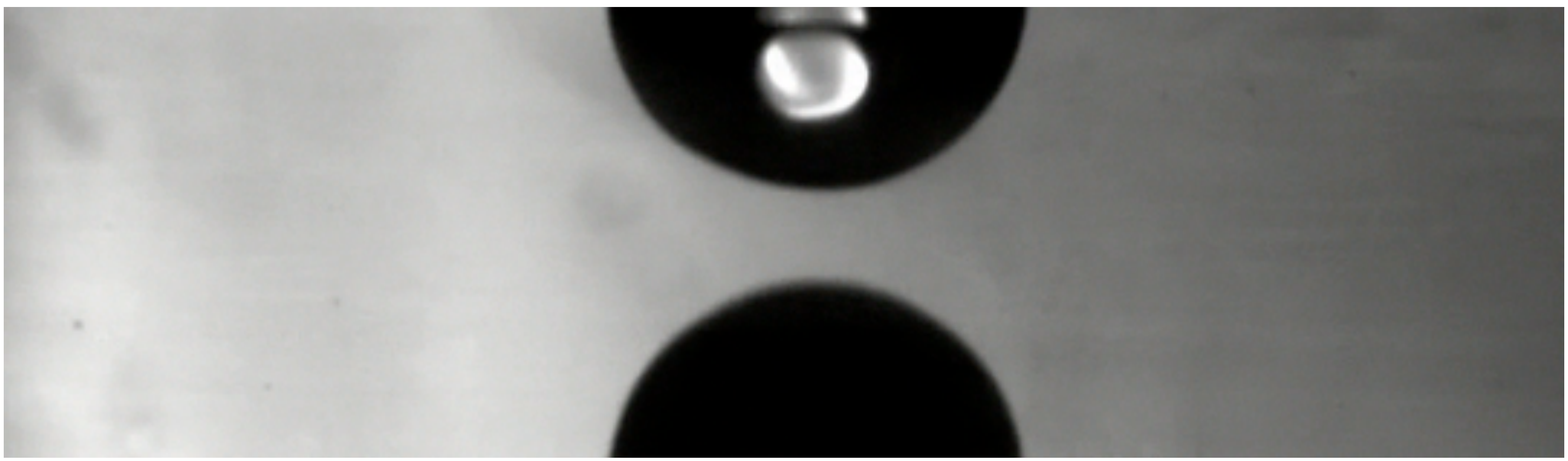


101 kPa



20 kPa

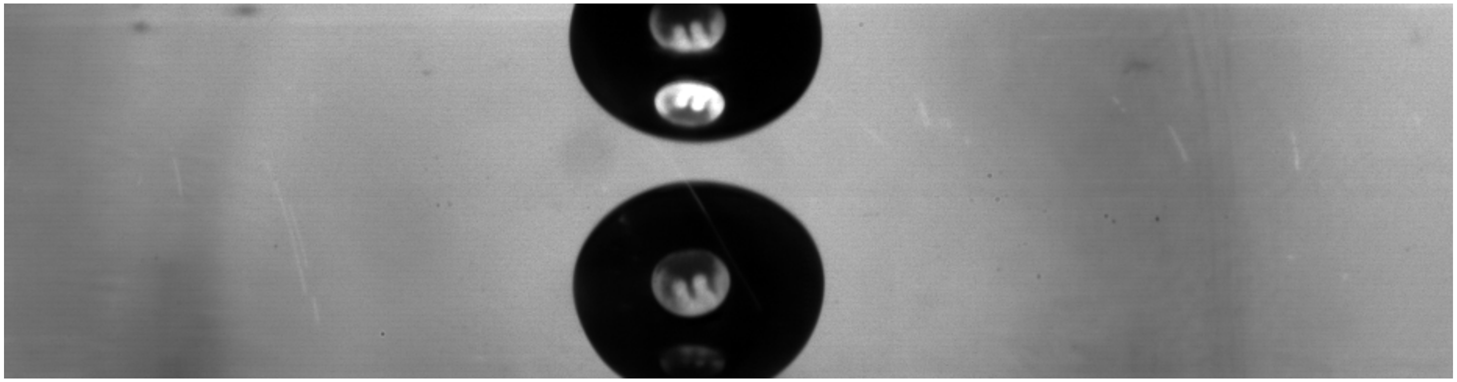
Late-time sheet ejection; low velocity

Air still matters!

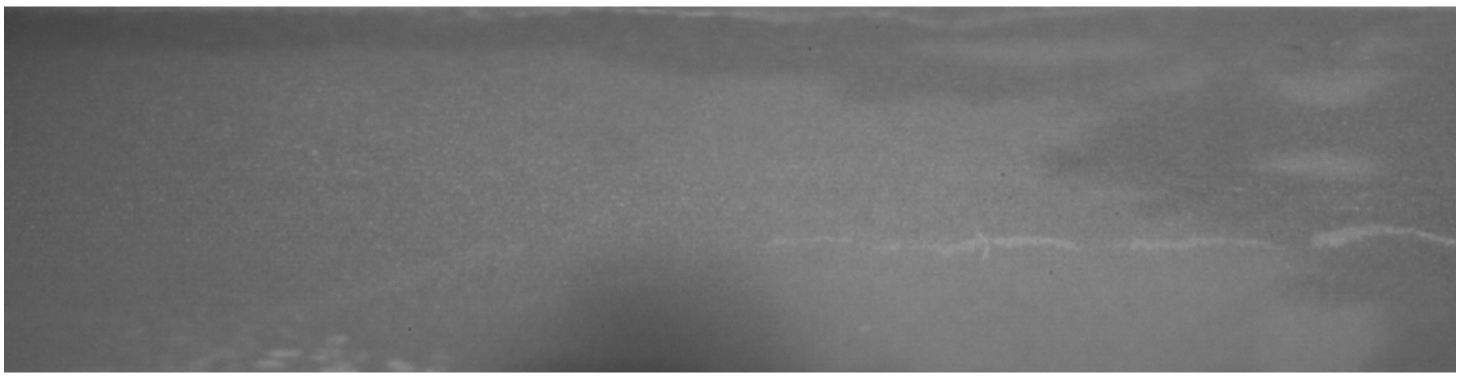
Michelle Driscoll, Cacey Stevens, Lei Xu

What does roughness do?

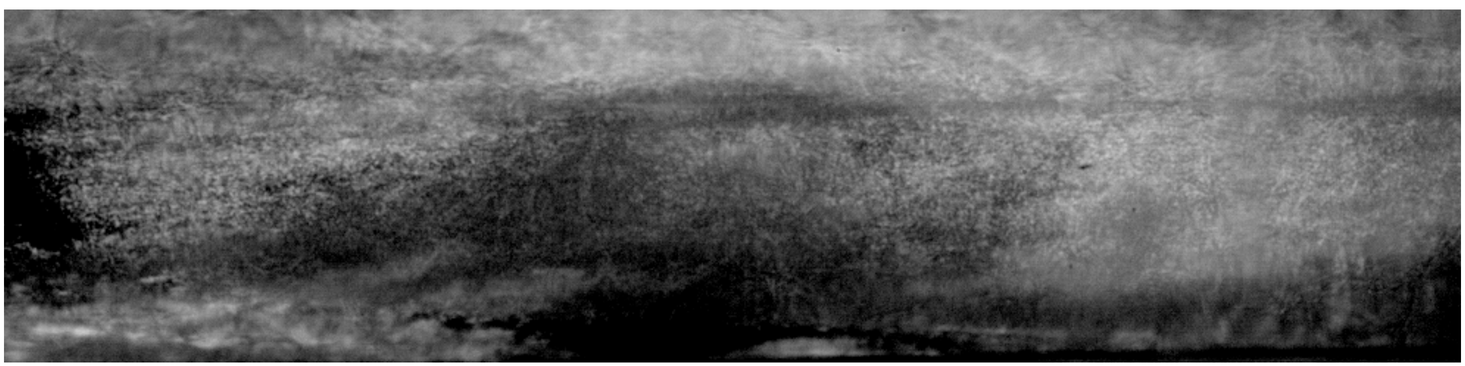
Of course it makes drop splash…or does it?



smooth glass



rough etched glass



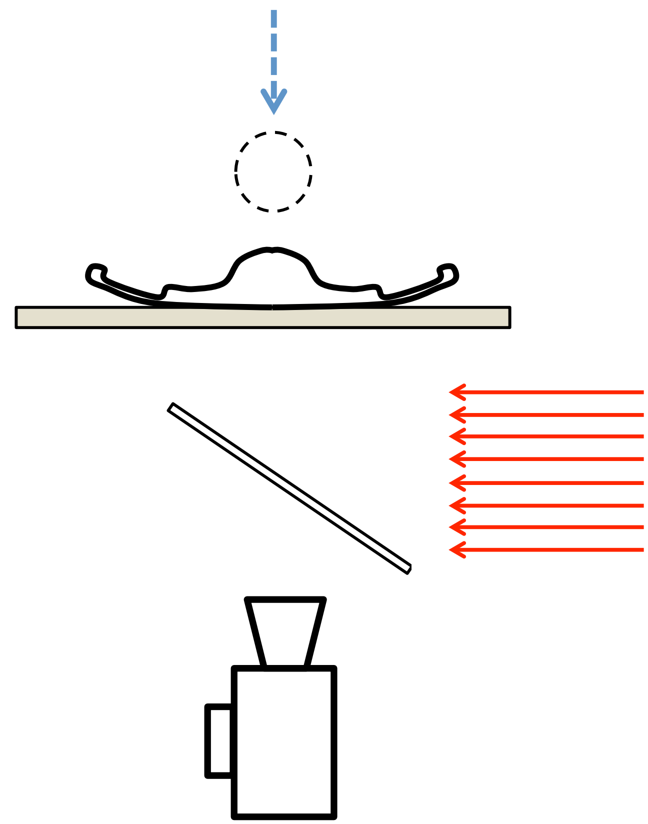
very rough etched glass

Roughness can eliminate splashing

Michelle Driscoll, Andrzej Latka, Cacey Stevens, Ari Strandburg-Peshkin

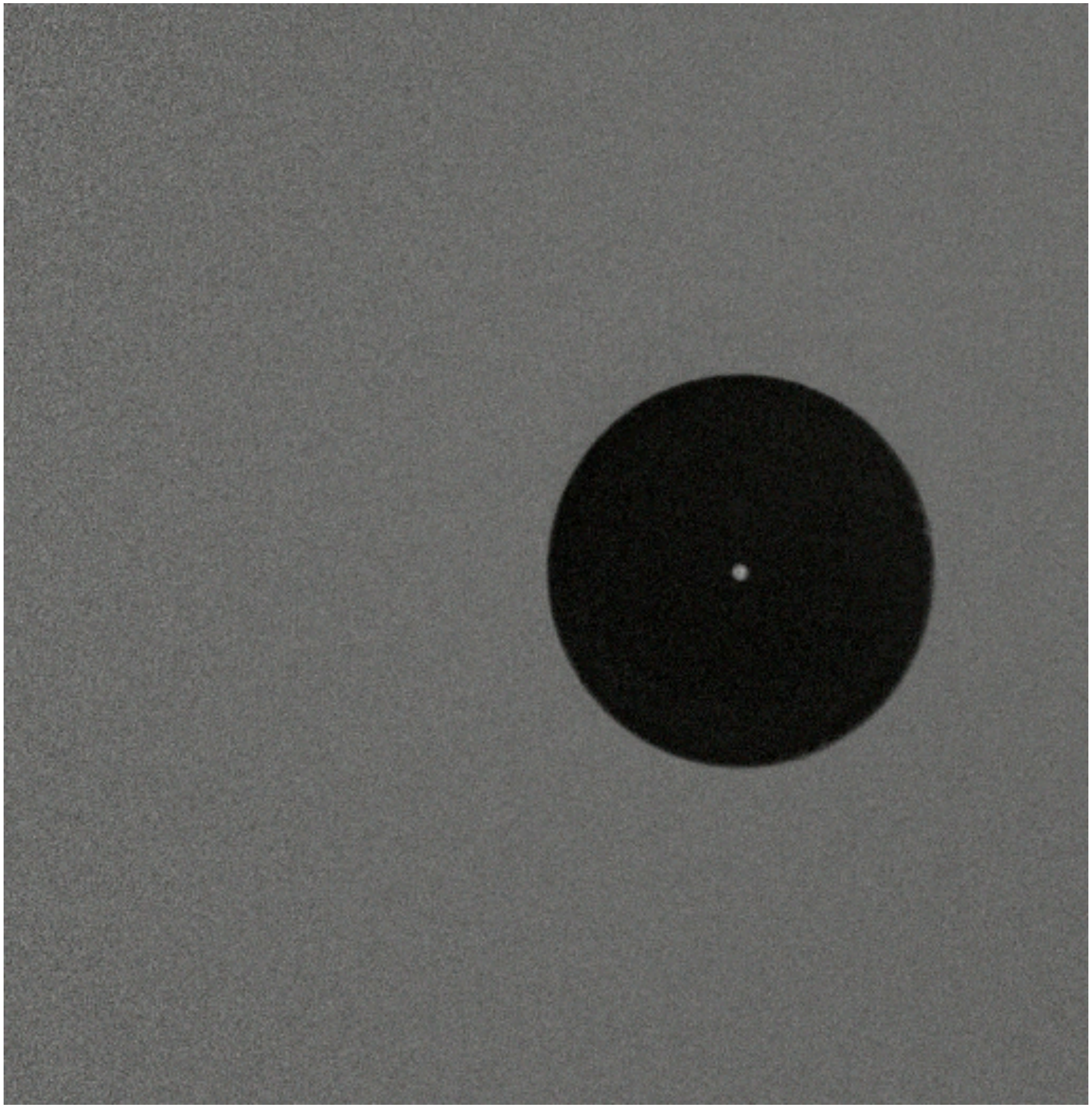
Where is air important? Below drop?

Interference imaging:
How thick is air gap?

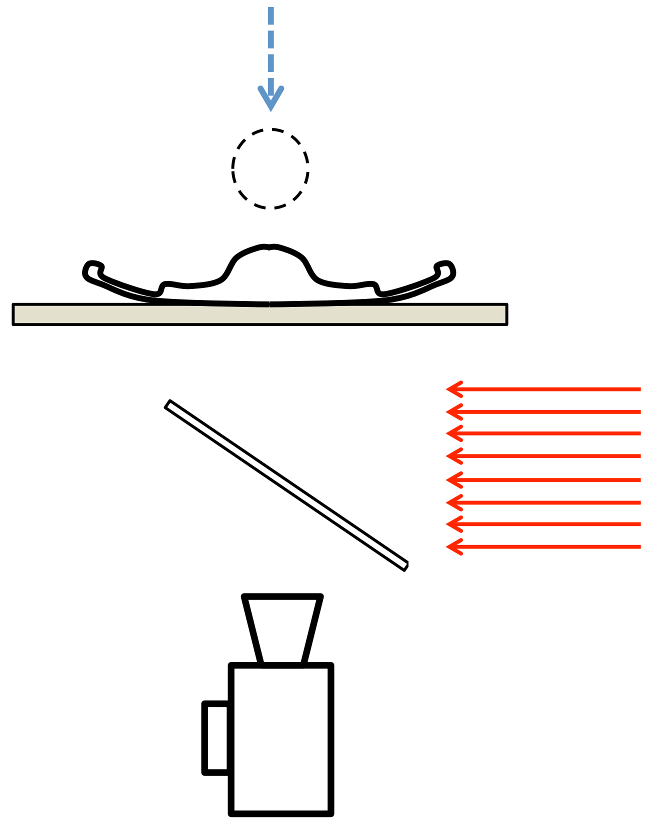


Michelle Driscoll

Where is air important?   Below drop?

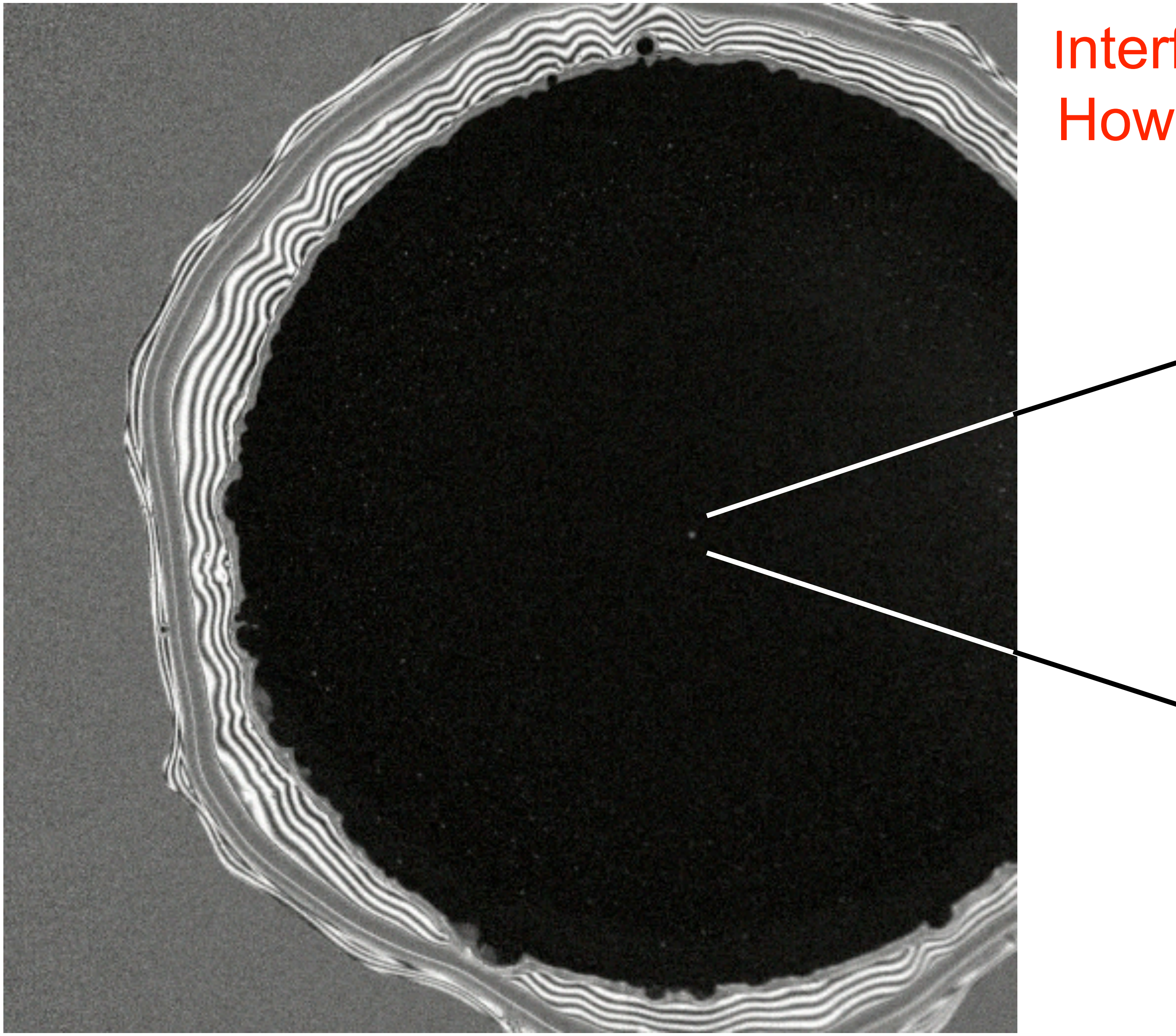


Interference imaging:
How thick is air gap?



Michelle Driscoll

Where is air important? Below drop?



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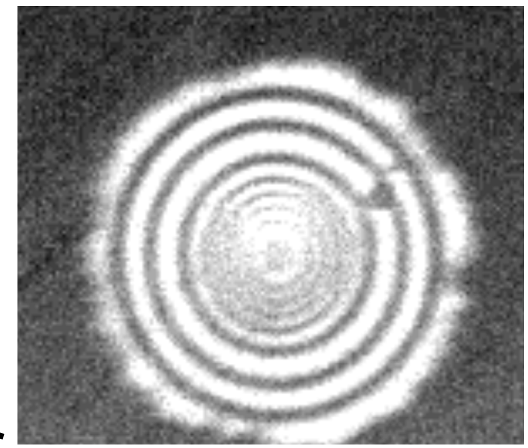
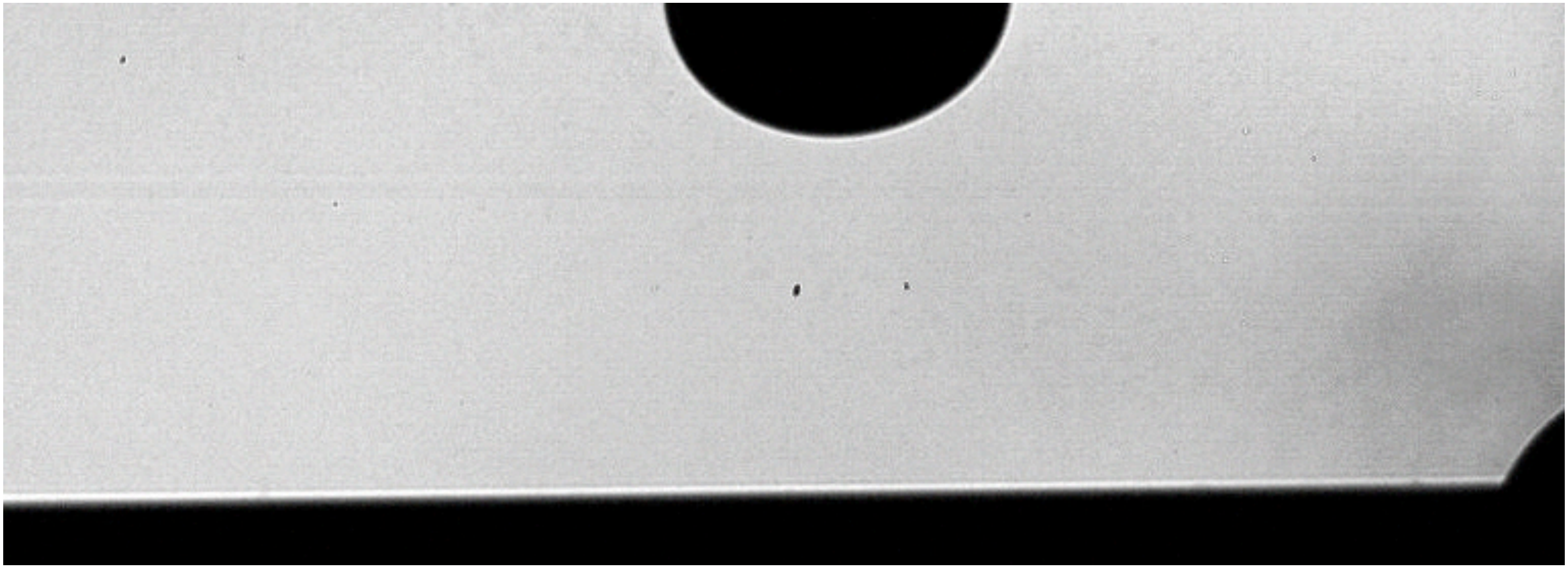


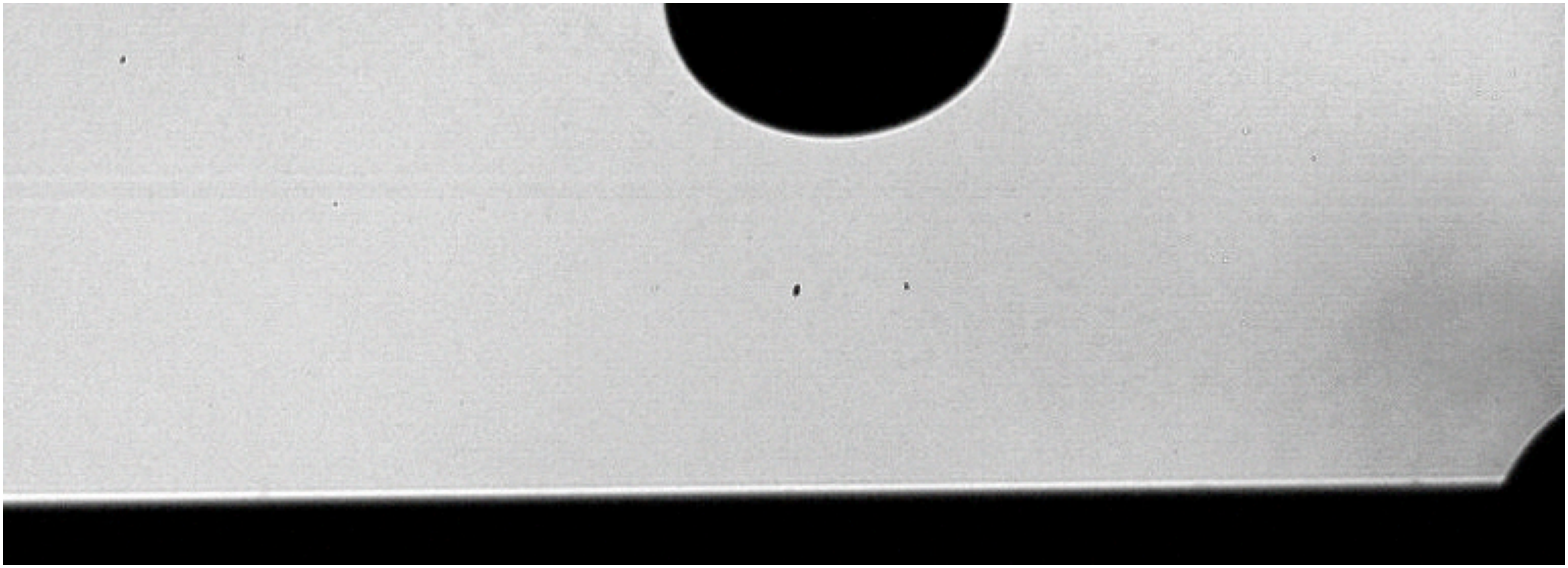
Michelle Driscoll

Visualize air above drop



Irmgard Bischofberger, Kelly Mauser

Visualize air above drop



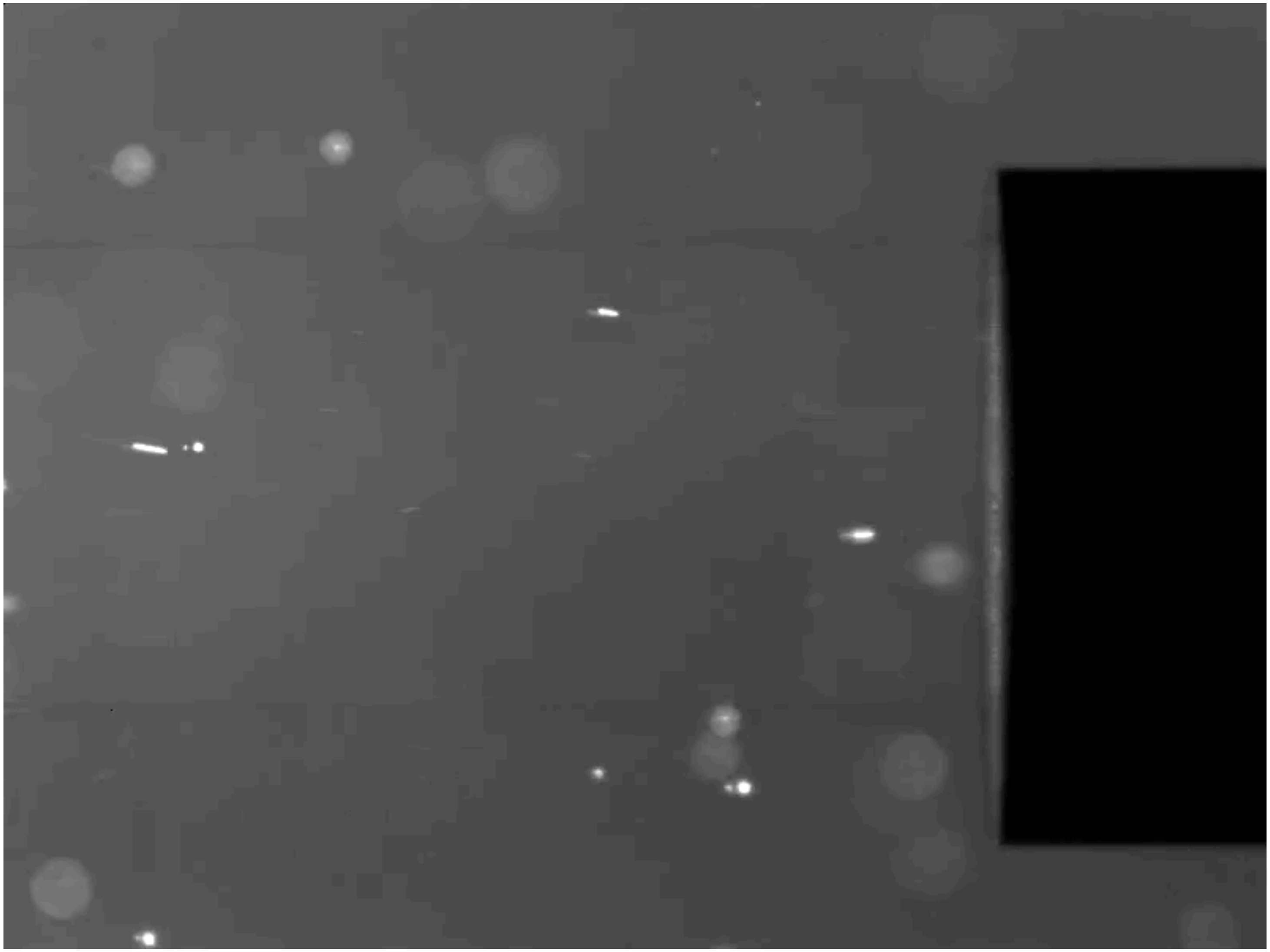
Irmgard Bischofberger, Kelly Mauser

Jet impact - continuous splashing

Liquid jet hitting target: “water bells”

How general is “bell” formation?

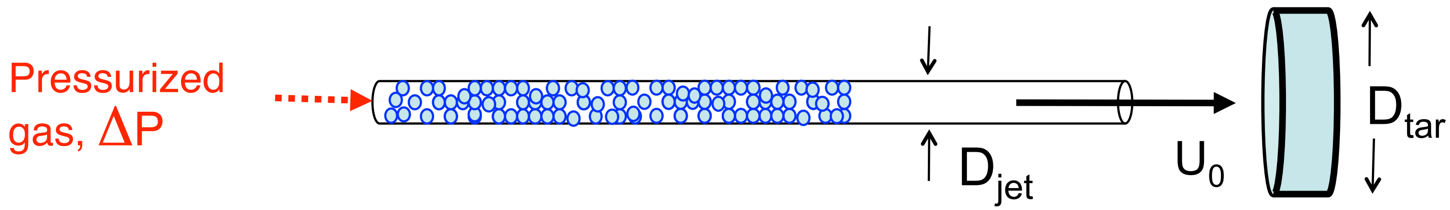
Individual particle collisions with target



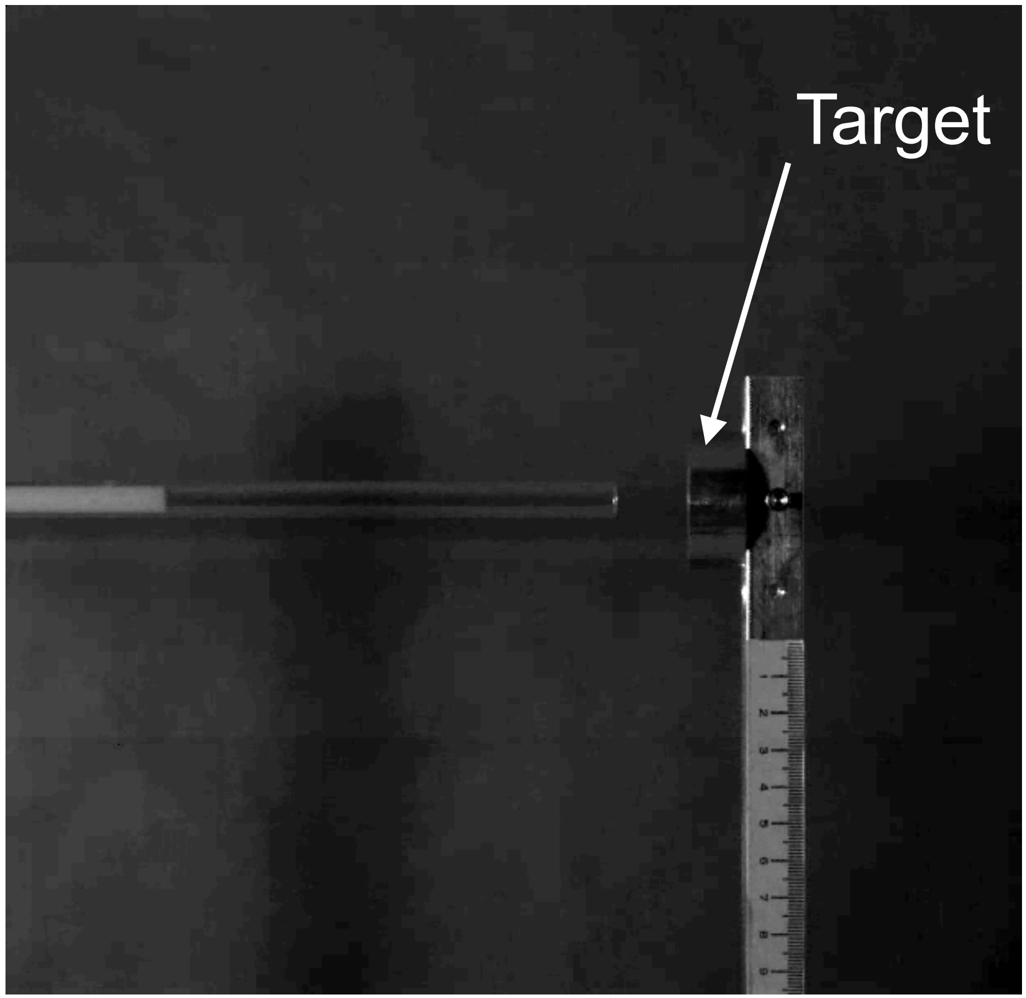
500μm glass beads hitting aluminum target

How about jet of granular material?

Granular jet hitting target



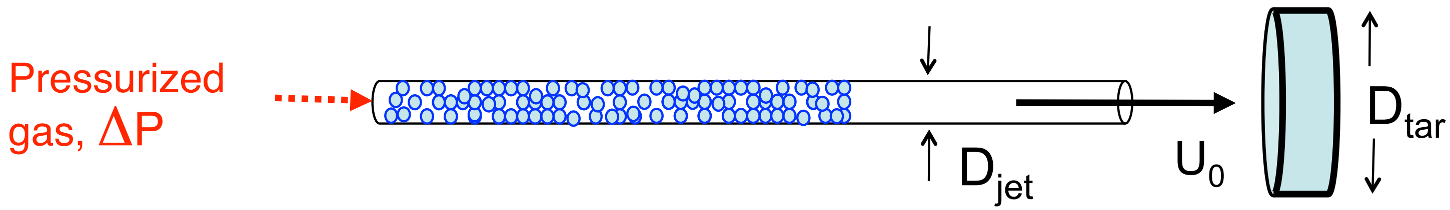
100 µm
glass beads
D_{tar}/D_{jet} = 4.5



Side view

Xiang Cheng, German Varas, Daniel Citron, Heinrich Jaeger

Granular jet hitting target



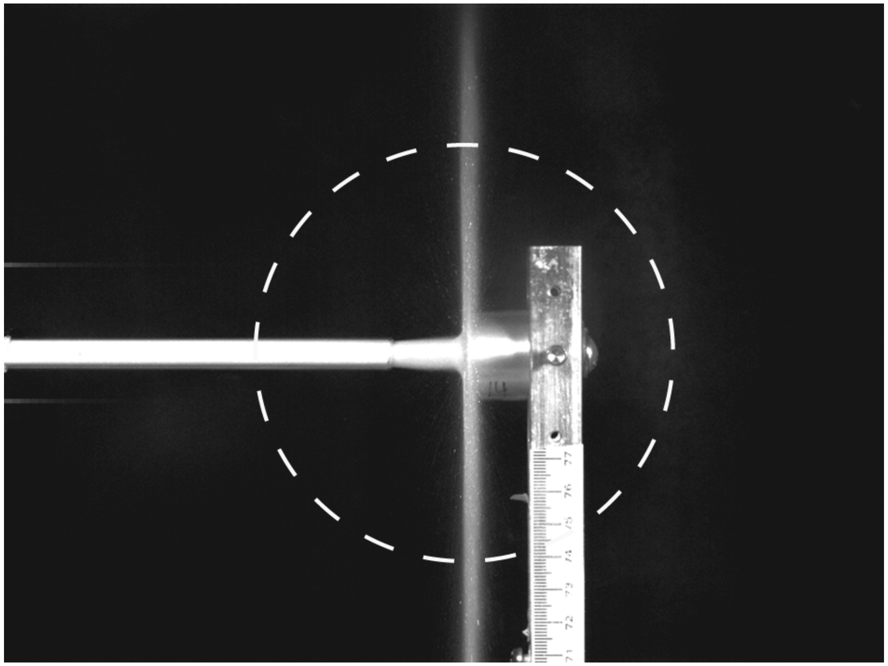
100 μm
glass beads
$D_{tar}/D_{jet} = 4.5$

Front view

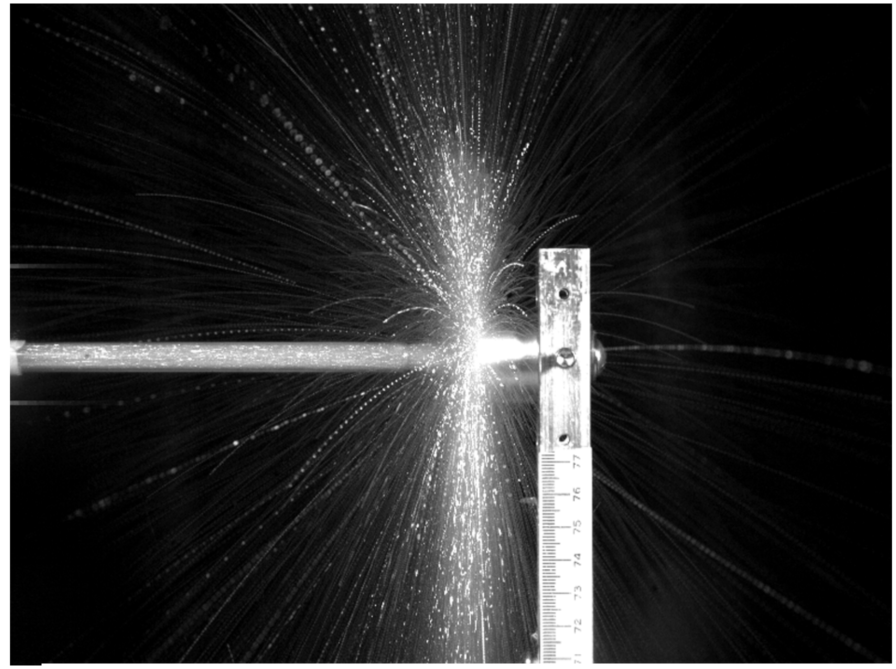
Xiang Cheng, German Varas, Daniel Citron, Heinrich Jaeger

From fluid to particle

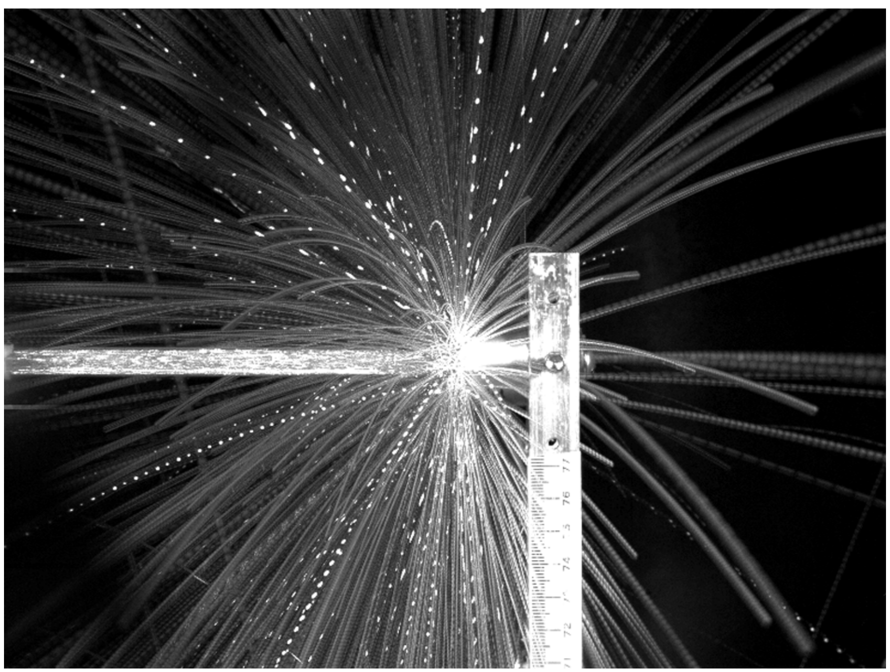
100 μm

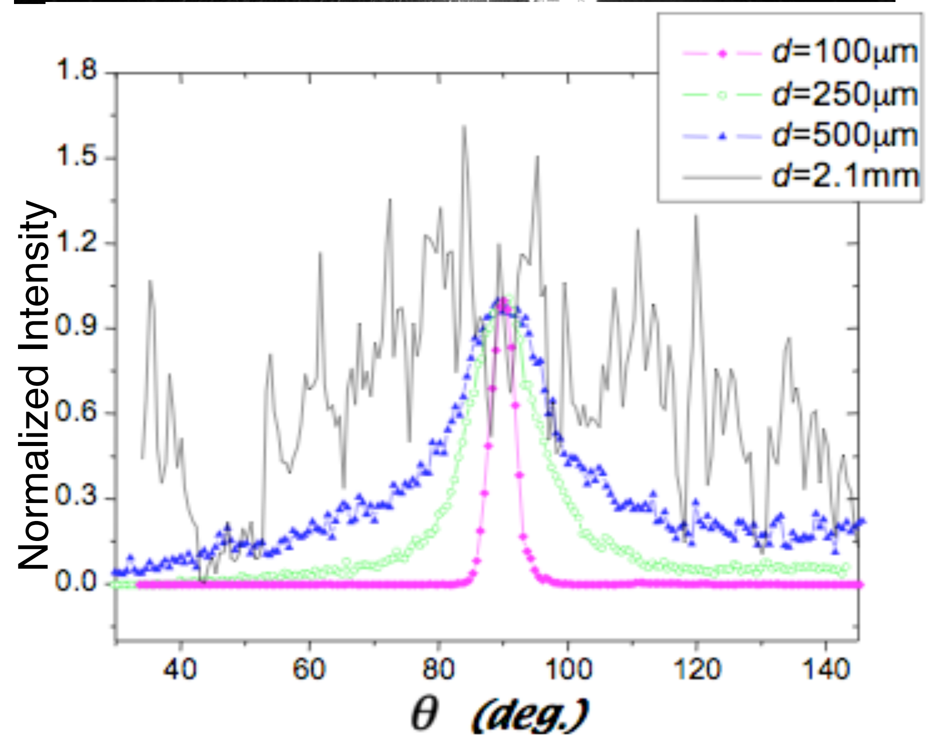


500 μm



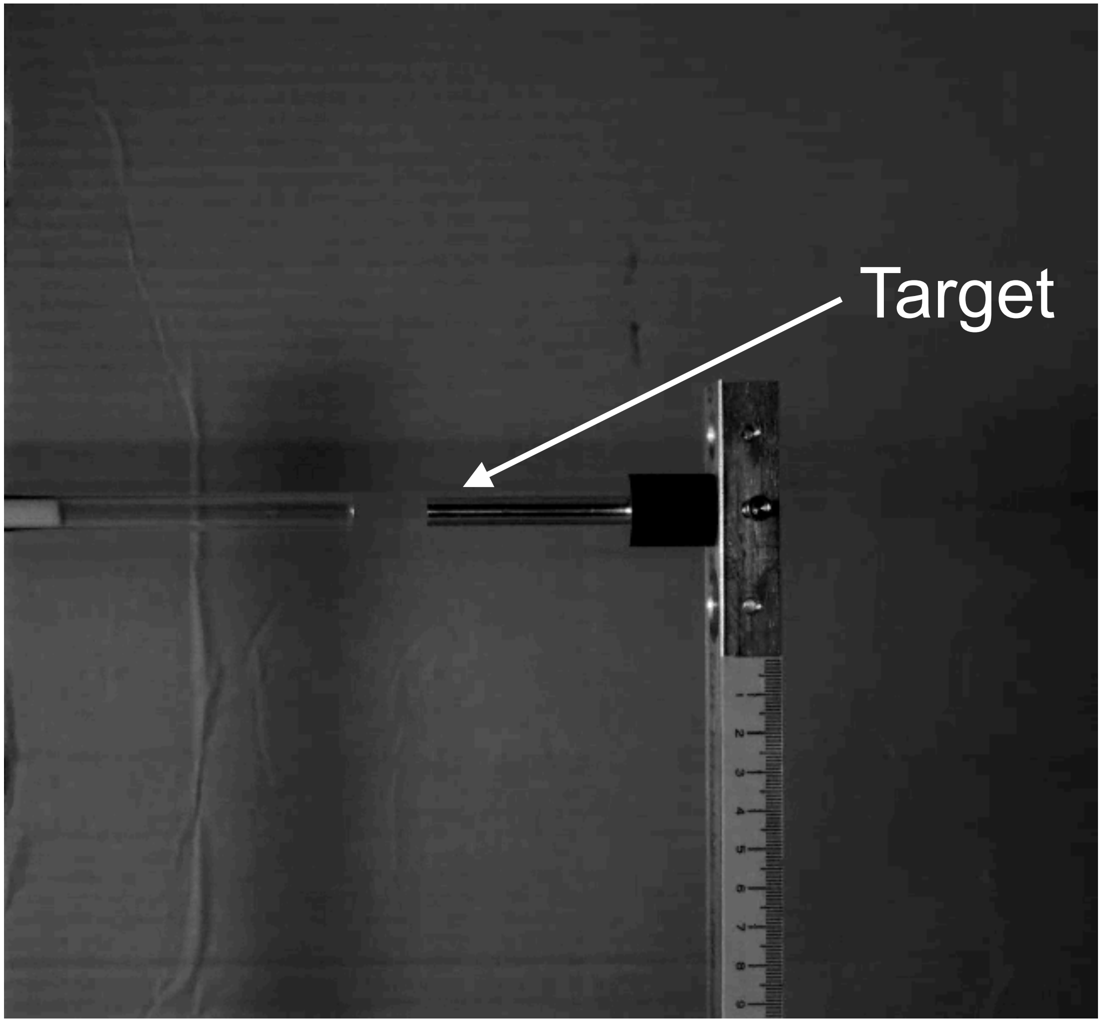
2.1 mm





Formation of granular cone

100 μm
glass beads
$D_{target}/D_{jet} = 1$



Xiang Cheng, German Varas, Daniel Citron, Heinrich Jaeger

Liquid formed from discrete particles

Classical analog to heavy-ion collider physics

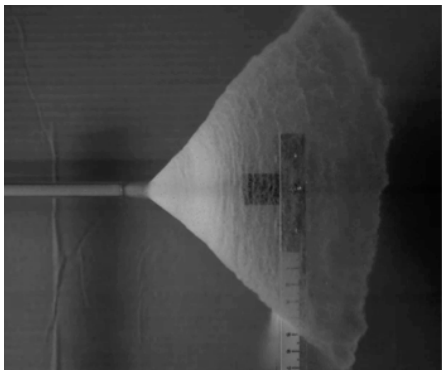
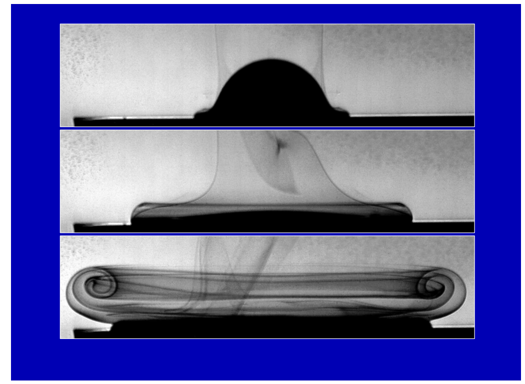
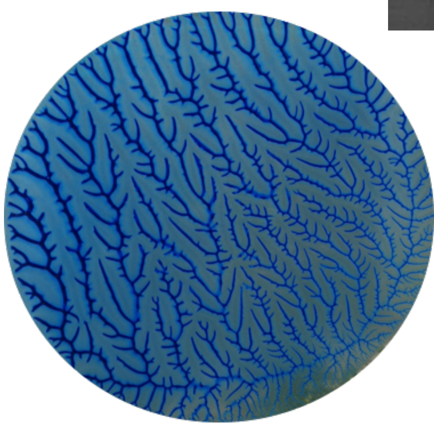
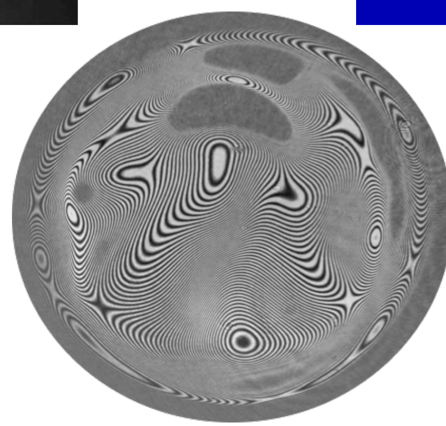
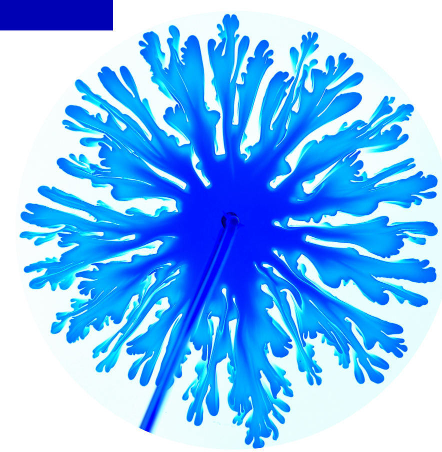
At RHIC (Brookhaven) & LHC (CERN)
collide heavy ions (gold nuclei) $\Rightarrow$ quark-gluon plasma

Also liquid!
not due to attraction
not due to confinement
just kinematics (same reason granular gas was liquid)

Raises issue of what it means to be a liquid

Emergence of structure ⇒ texture to our world

Nature is subtle, surprising
Symmetries and instabilities arouse wonder

Examples use similar tools & concepts (*e.g.*, scaling)

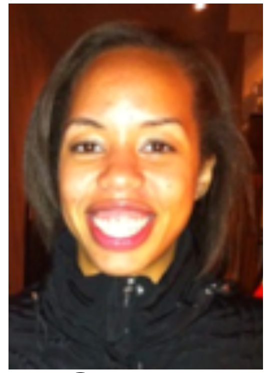
A great idea *"is like a phantom ocean beating upon the shores of human life in successive waves of specialization."*

A. N. Whitehead


Wendy Zhang


Lei Xu


Michelle Driscoll


Cacey Stevens


Andrzej Latka


Kelly Mauser


Ariana Strandburg-Peshkin


Samantha Jones


Loretto Barcos


Irmgard Bischofberger


Radha Ramachandran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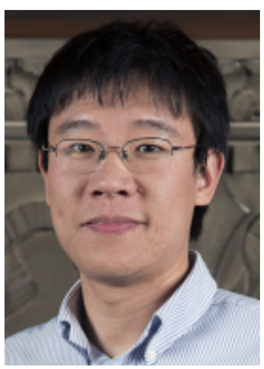
Xiang Cheng


Hervé Turlier


Daniel Citron


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Leonardo Gordillo