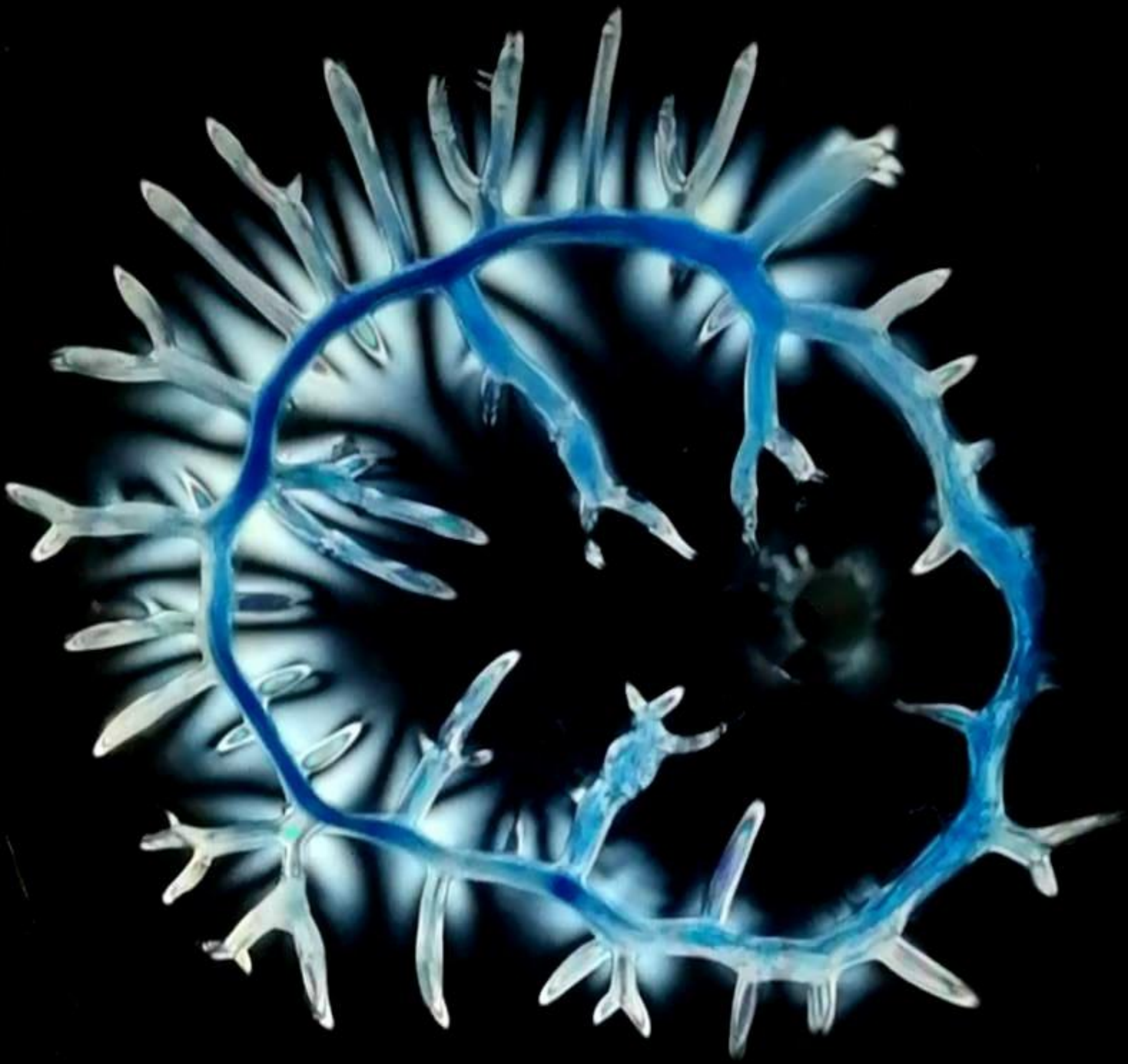
Flowing through a world of patterns

Irmgard Bischofberger

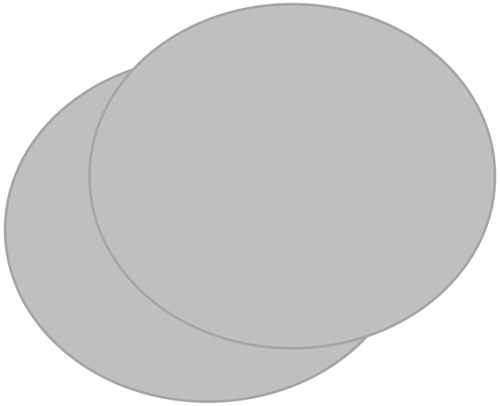


Demo materials

3D fabric paint
(Michaels, Amazon, …)

Drying time ~ 15 minutes

Acrylic plates
(McMaster-Carr, Amazon, …)



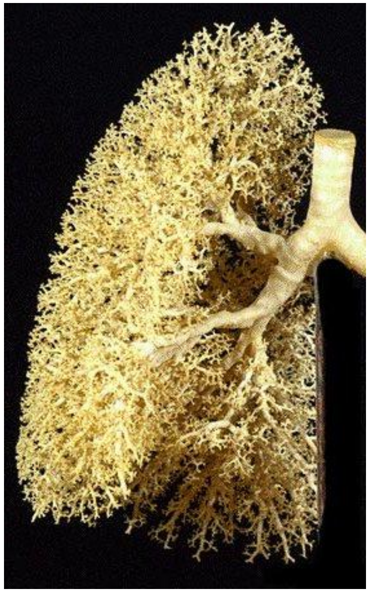
Duco Cement glue + powdered food color
(Hardware store, Walmart, Amazon, …)

Drying time ~ 2 seconds

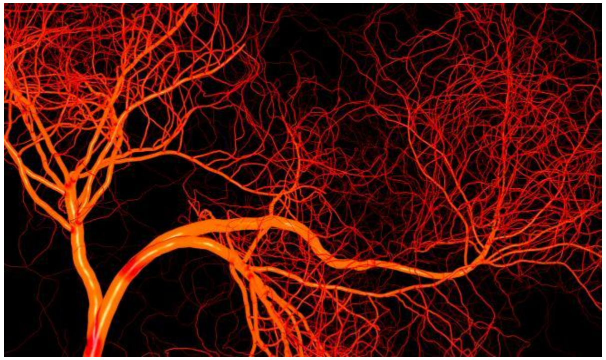
Branching patterns in nature

Trees

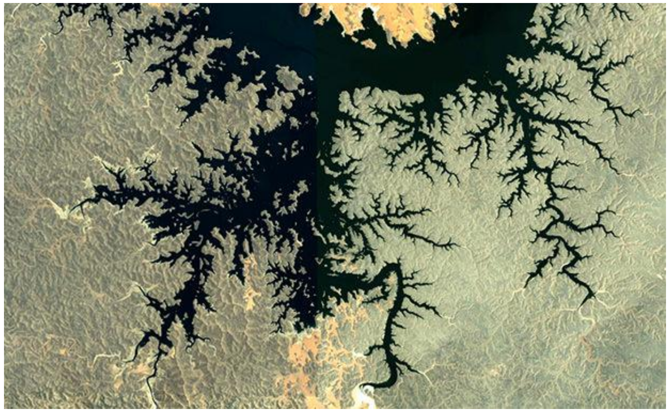
Lightning



Bronchial trees in lungs



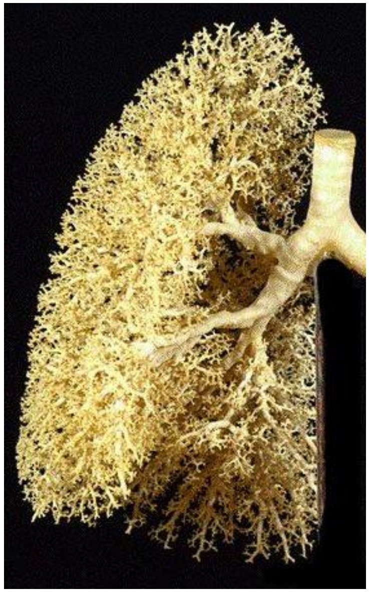
Blood vessels



River networks

Branching patterns in nature

Trees



Bronchial trees in lungs

Patterns grow by branching/tip-splitting

Large surface area at small volume

Volume of pair of human lungs ~1 gal,

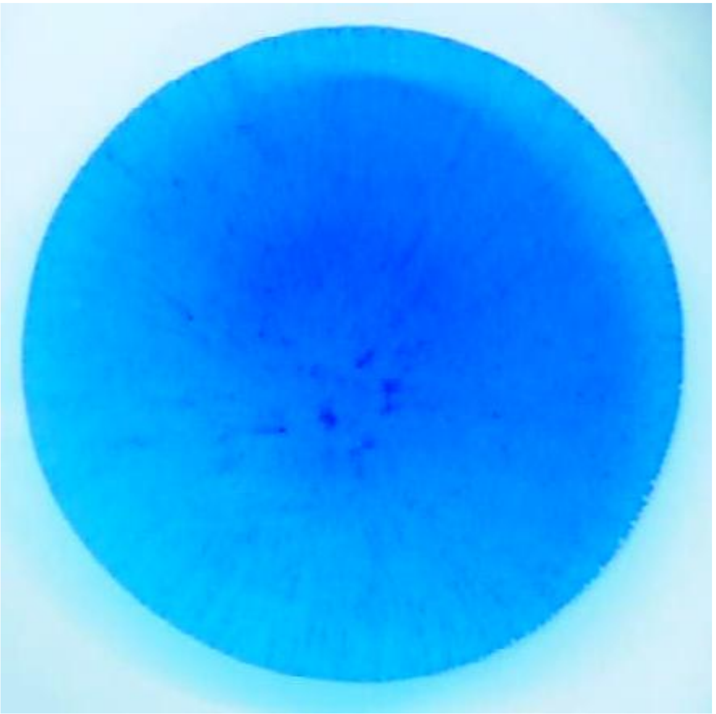
surface area ~500-1000 ft^2 (~ tennis court!)

How do these patterns spontaneously grow?

We use model systems to study growth

Many surprises → deep science

Let’s do it again!



Two fluids of different viscosities: drop of paint and air

Viscosity: a fluid’s resistance to flow

Viscous fingering instability

More viscous fluid → ***less viscous*** fluid

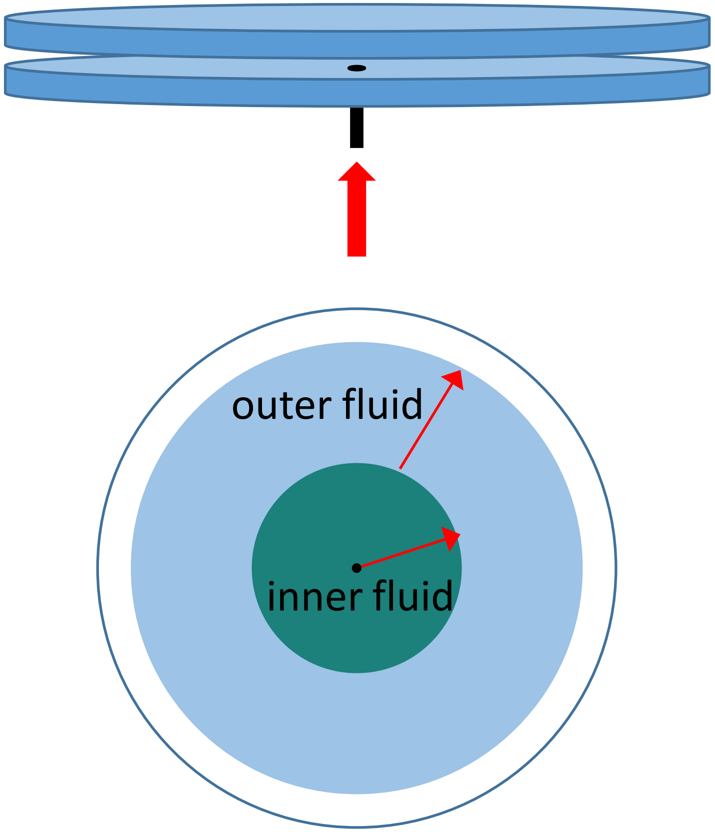
Stable: small perturbations get stabilized

Less viscous fluid → ***more viscous*** fluid

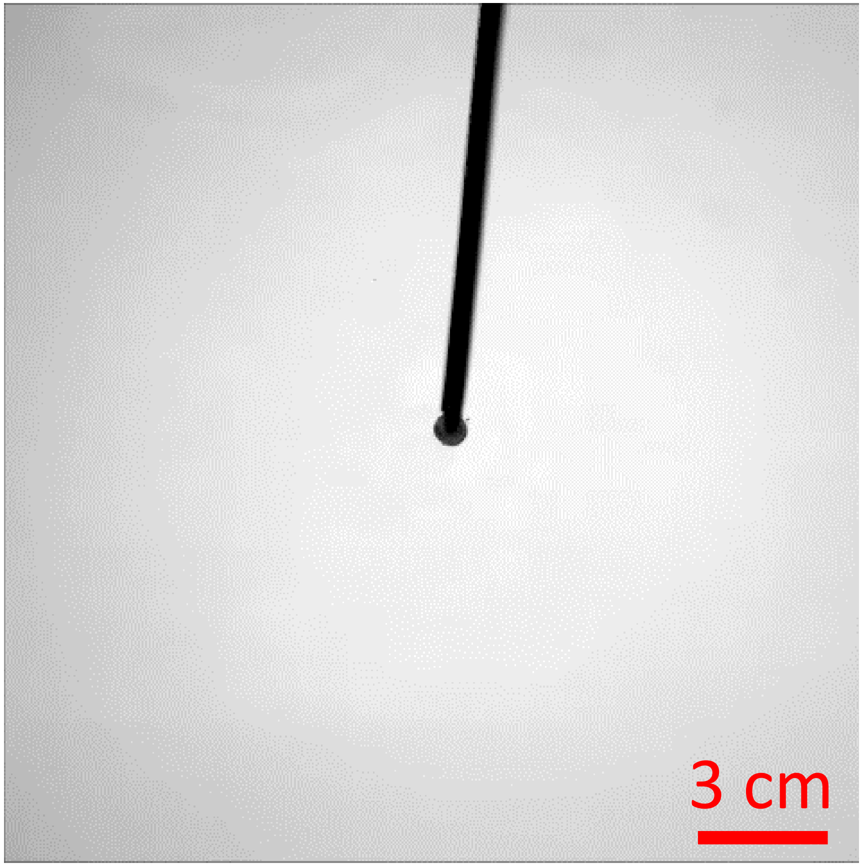
Unstable: small perturbations grow

Repeated branching

Viscous fingering instability



Less viscous fluid displaces ***more viscous*** fluid



Total time ~ 1 min

Viscous fingering instability

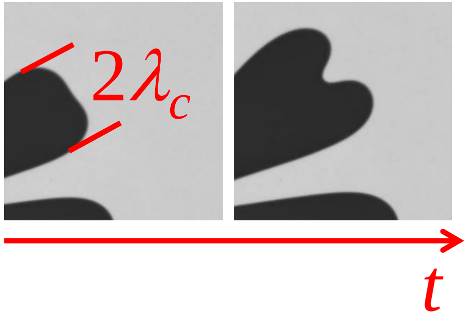
Width of fingers λ_c

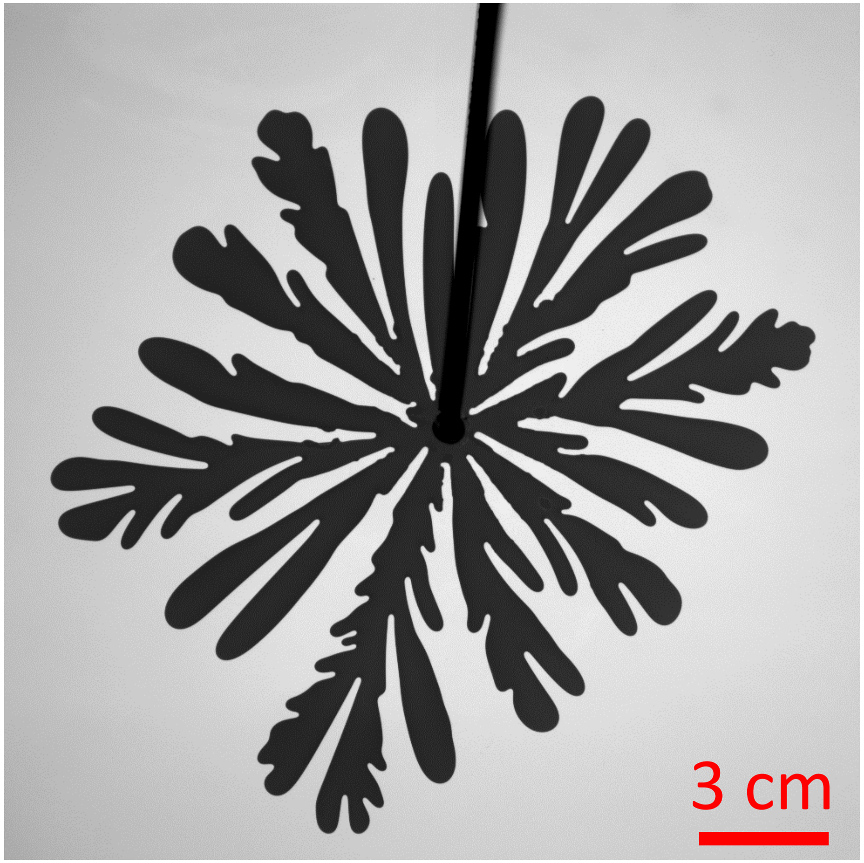
$$\boxed{\lambda_c \propto \sqrt{\frac{\sigma}{\Delta\eta V}}}$$

σ : surface tension

$\Delta\eta$: viscosity difference

V : velocity





Patterns at different $\lambda_c \propto \sqrt{\dfrac{\sigma}{\Delta\eta V}}$

Same σ, $\Delta\eta$

V = 0.1 ml/min

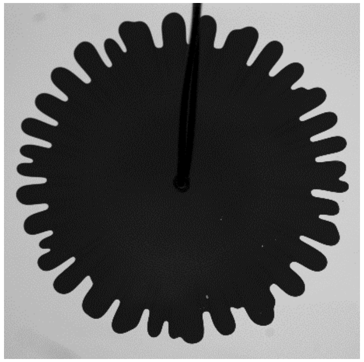
V = 1 ml/min

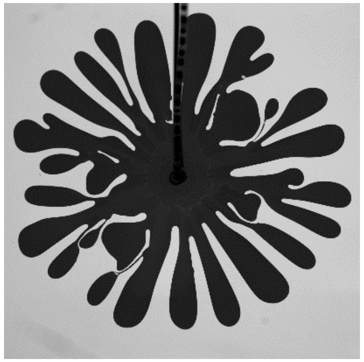
Against expectations!

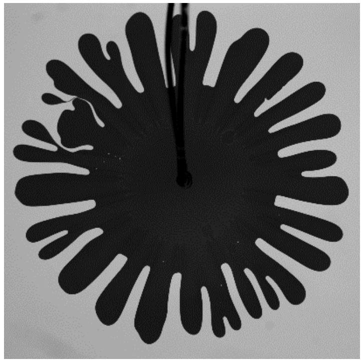
What are we missing?

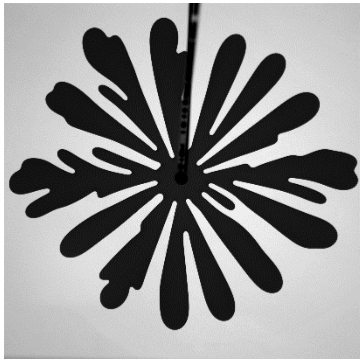
Fully developed patterns

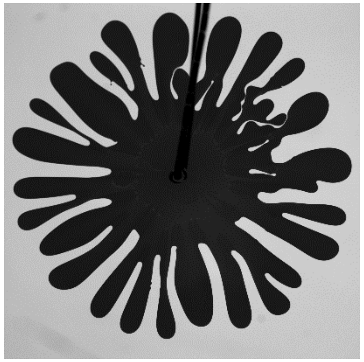
Fixed finger width λ_c







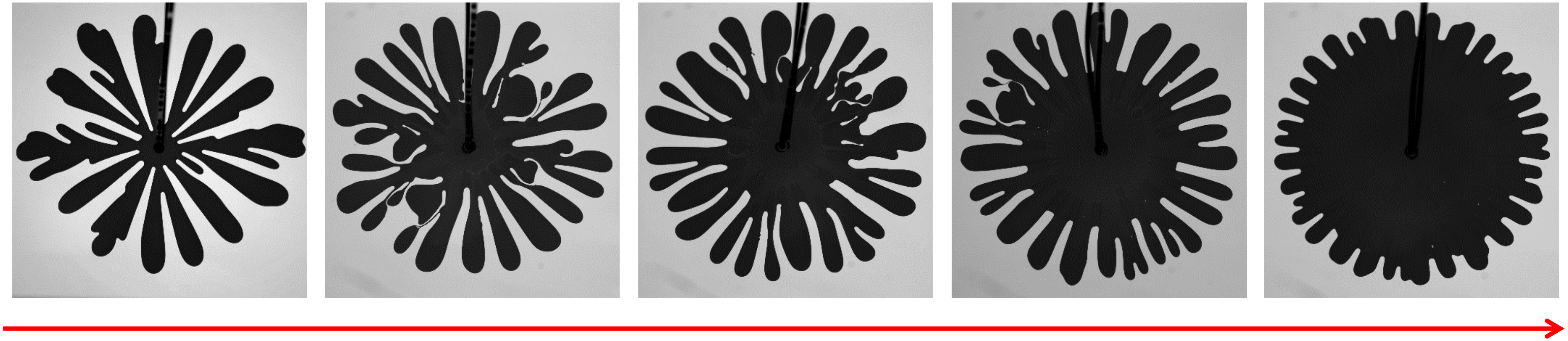




Different η_{in}/η_{out}

Fully developed patterns

Fixed finger width λ_c



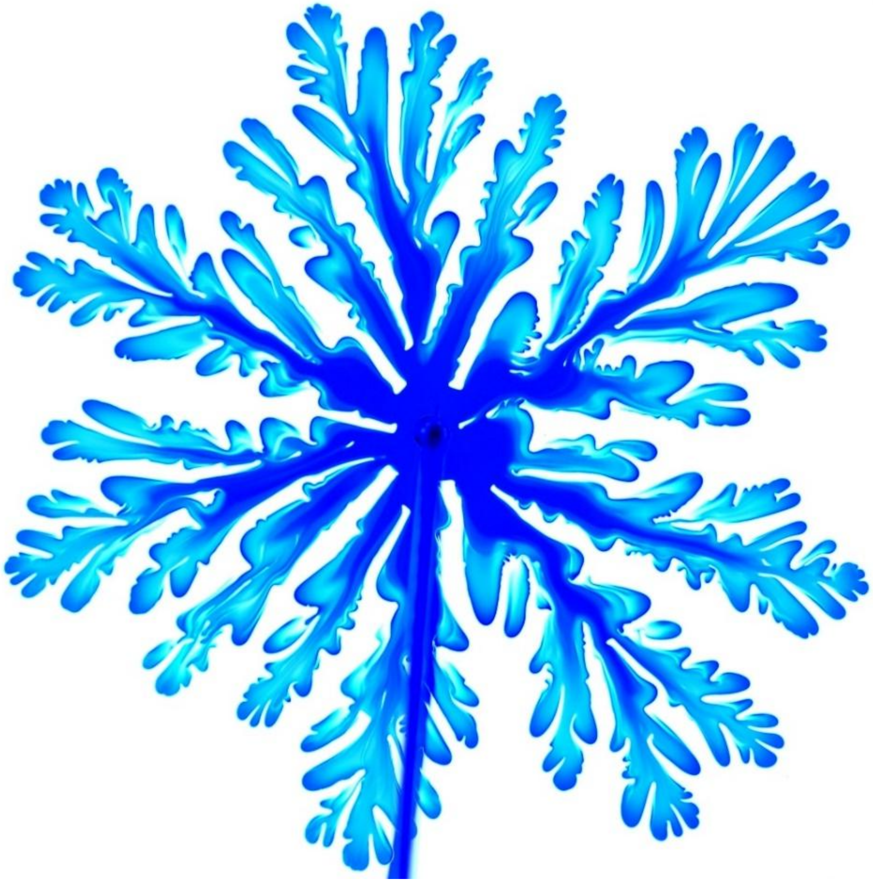
η_{in} / η_{out}

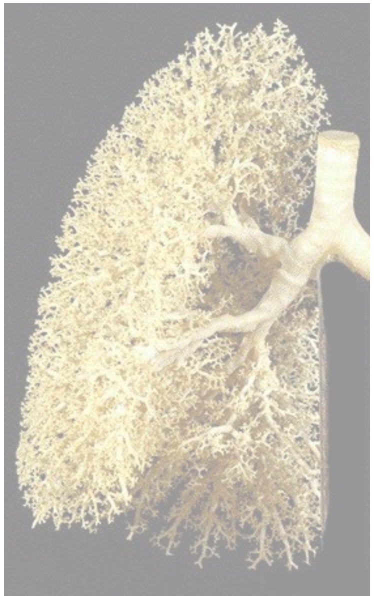
Second control parameter !

Sets *relative length* of finger

TWO length scales in patterns: finger width and finger length

Branching patterns: Random disordered growth

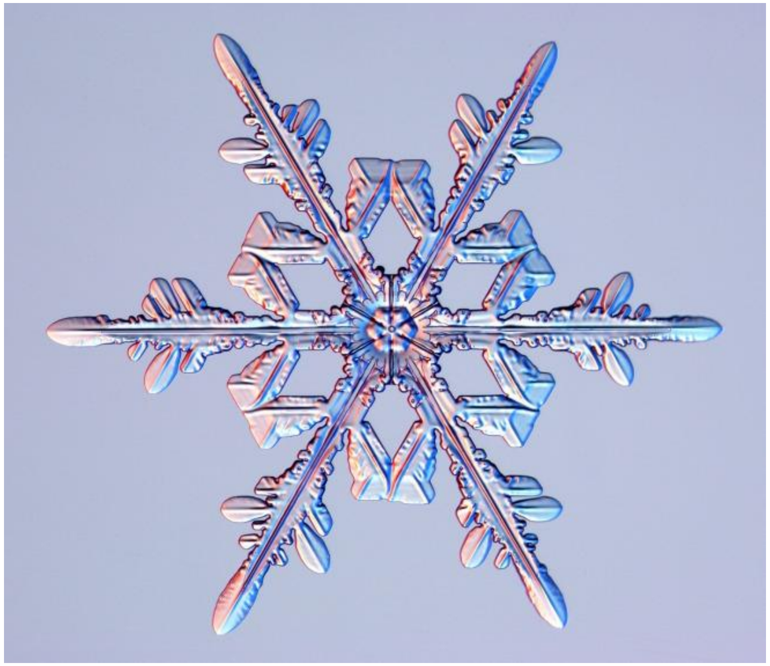




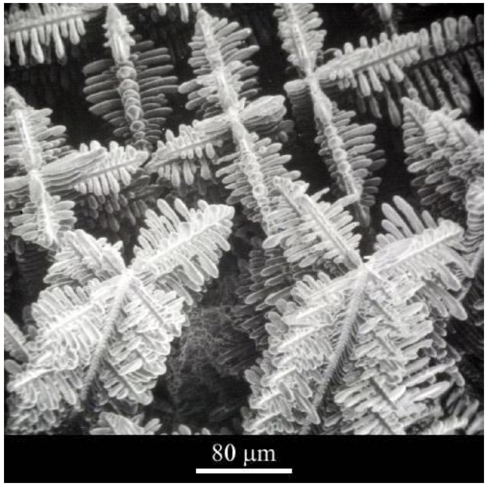
Nature has many more tricks!

Dendritic patterns: Ordered growth

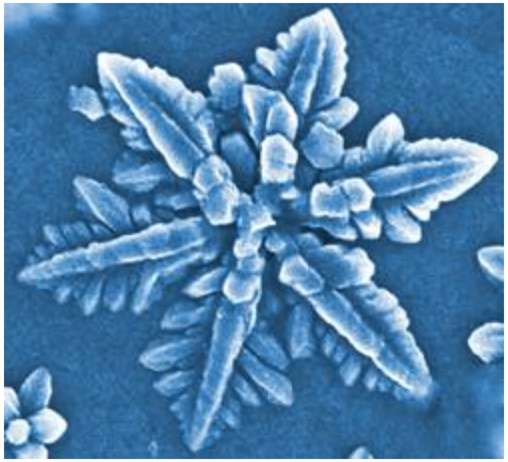
Dendritic patterns: Ordered growth



Snowflake



Solidified alloy



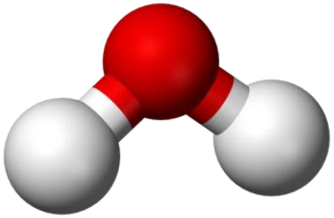
Copper oxide

Dendritic patterns: Ordered growth

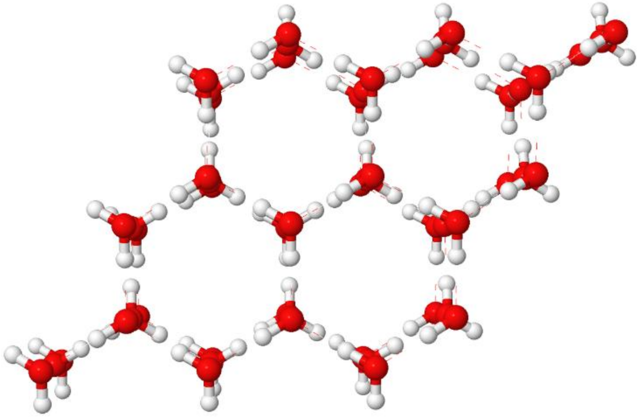
Dendritic growth requires **anisotropy** in interfacial dynamics

Anisotropy: property of being directionally dependent

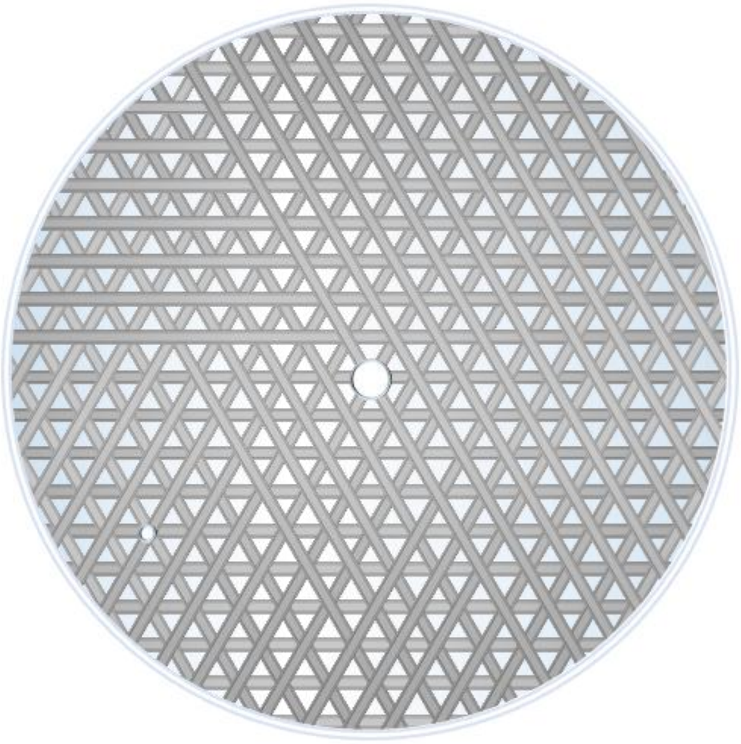
Water molecule
H_2O



Ice structure
Six-fold symmetry



Dendritic growth in anisotropic systems



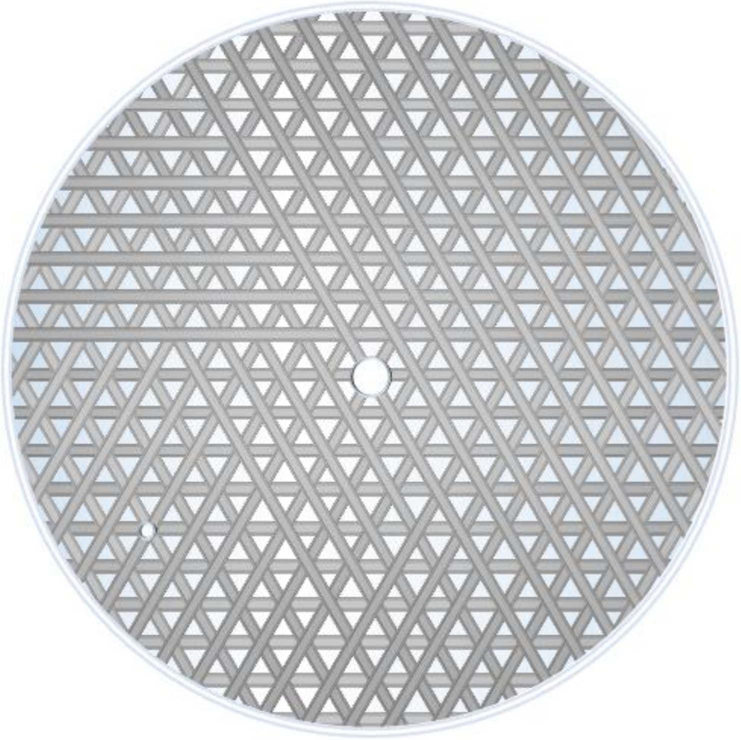
Six-fold symmetric lattice

Introduce anisotropy in growth environment

Engraved ordered channels

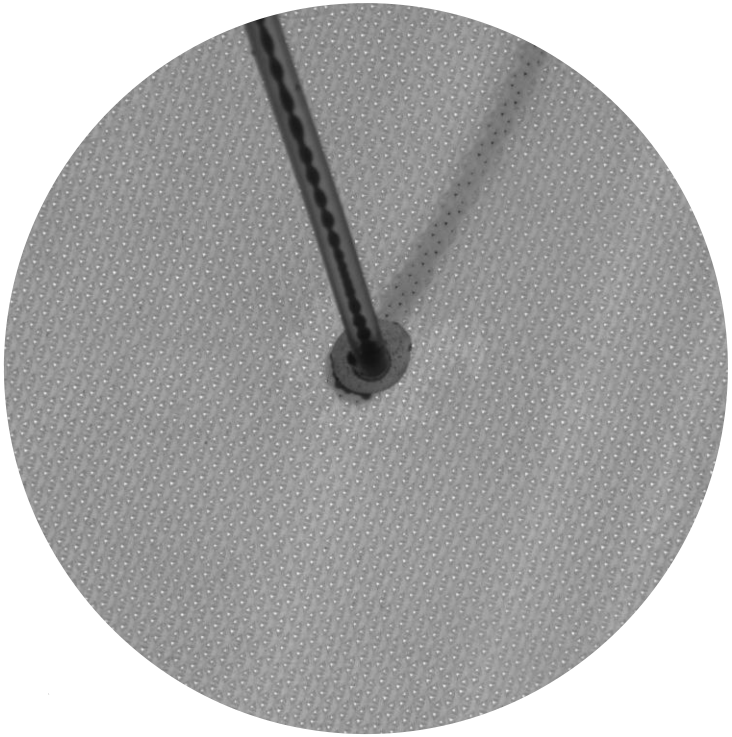
Channels modulate gap spacing,
become preferred growth direction

Dendritic growth in anisotropic systems



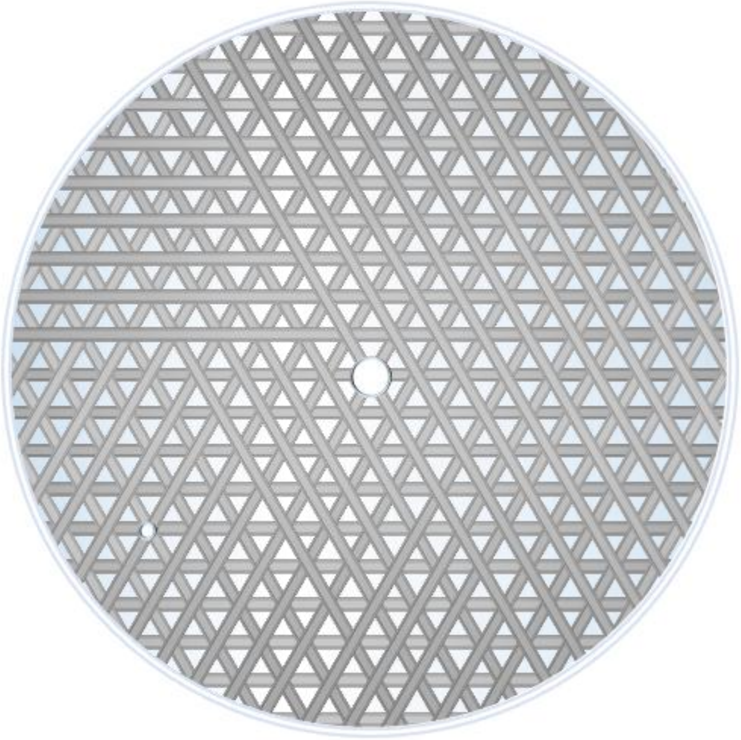
Six-fold symmetric lattice

low η_{in}/η_{out}



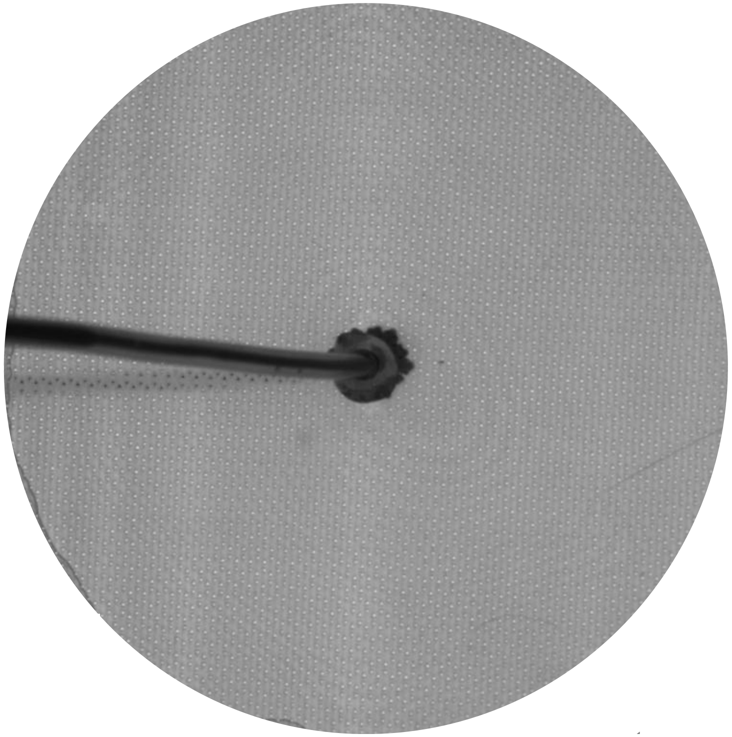
Six-fold symmetric pattern

Dendritic growth in anisotropic systems



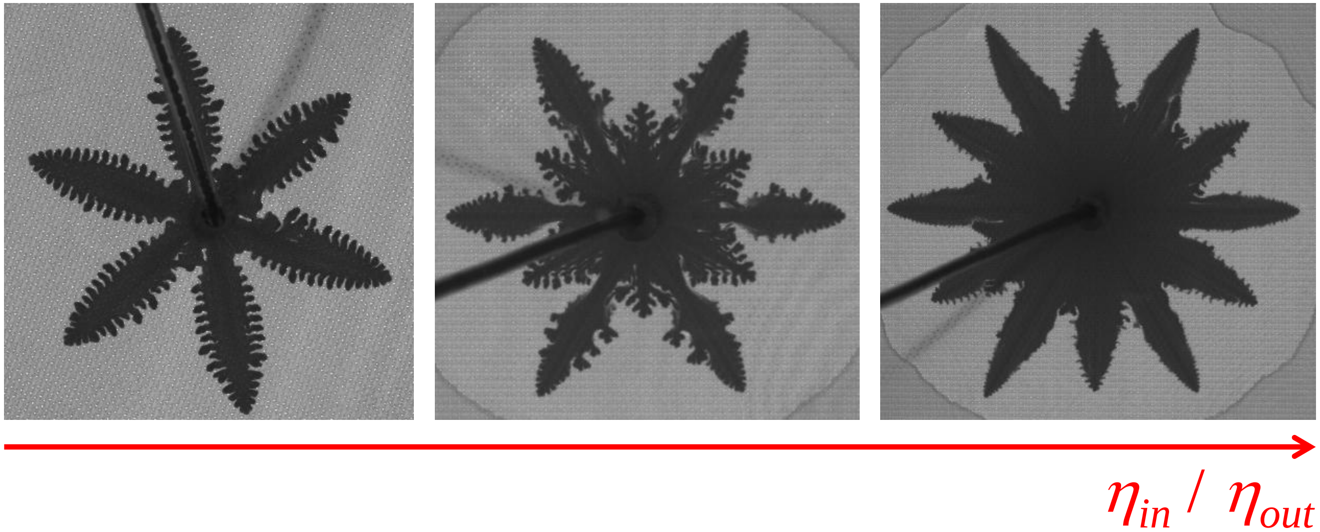
Six-fold symmetric lattice

higher η_{in}/η_{out}



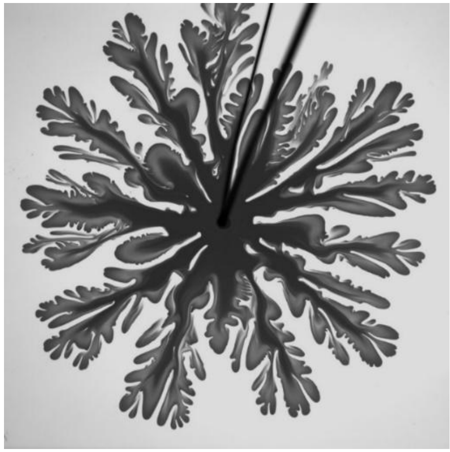
TWELVE-fold symmetric pattern!!!

Symmetry depends on viscosity ratio

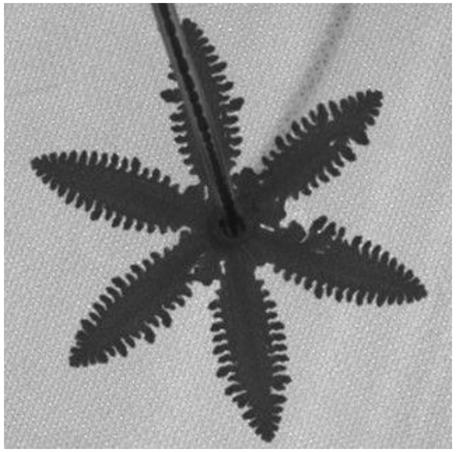


Randomness versus Order

Branching growth



Dendritic growth



Morphology selection depends on

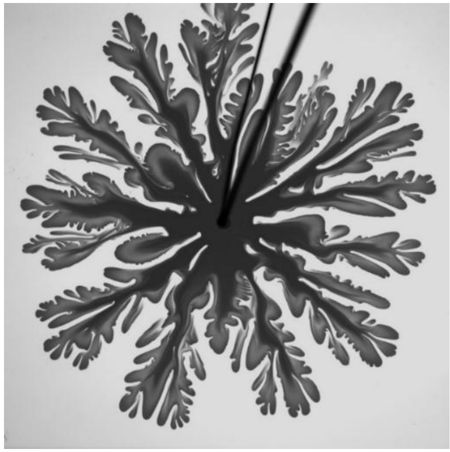
intrinsic symmetries

growth environment

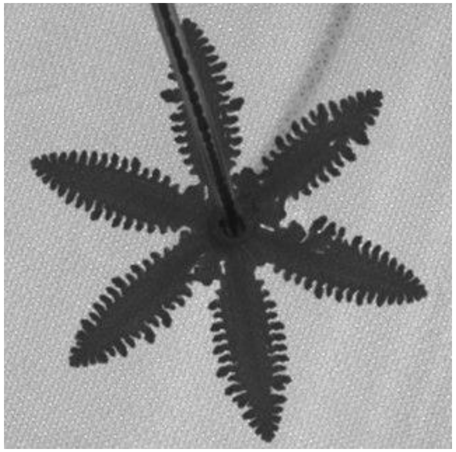
desired function

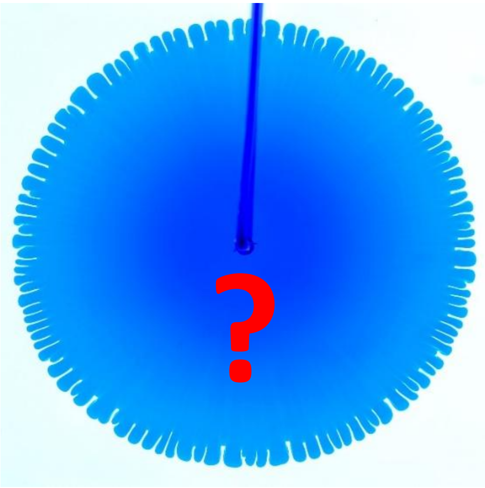
Life is neither random nor ordered

Branching growth



Dendritic growth



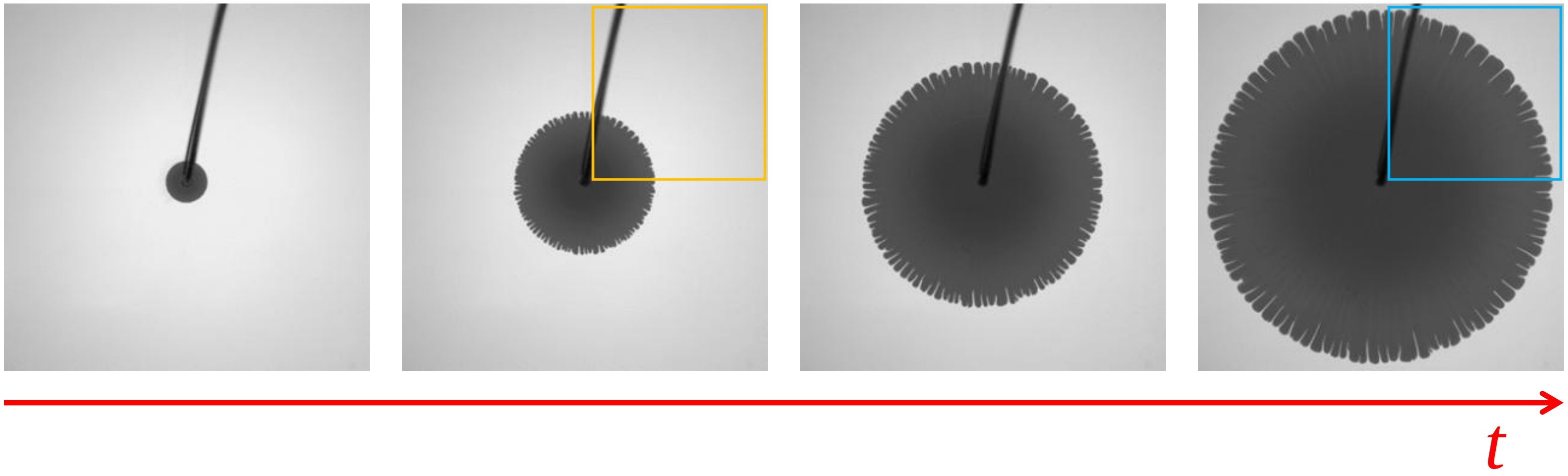


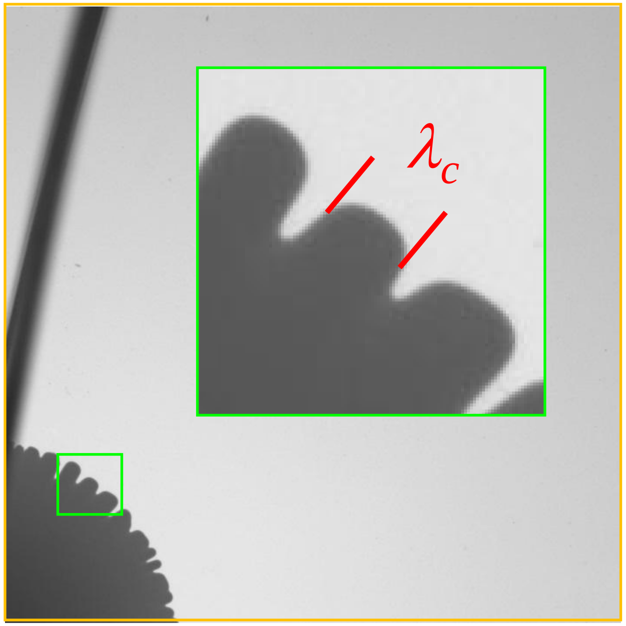
A new class of patterns

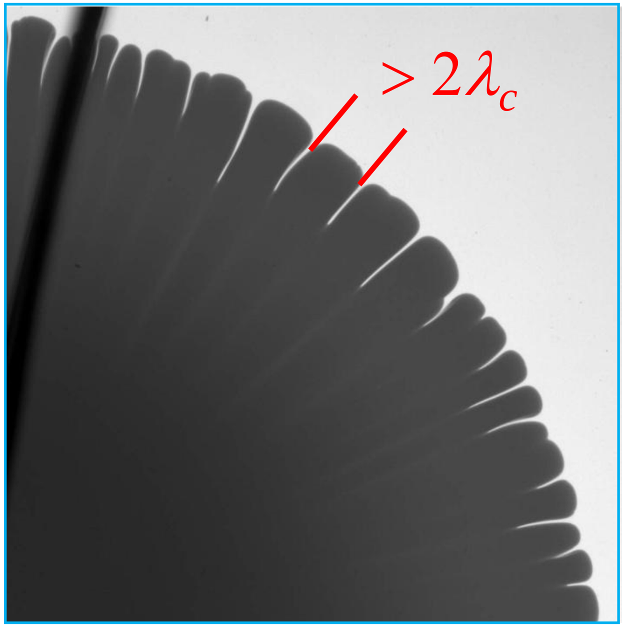
$3\text{-}10\,\eta_{in} \approx \eta_{out}$

Toes !

No tip-splitting: no new toes!

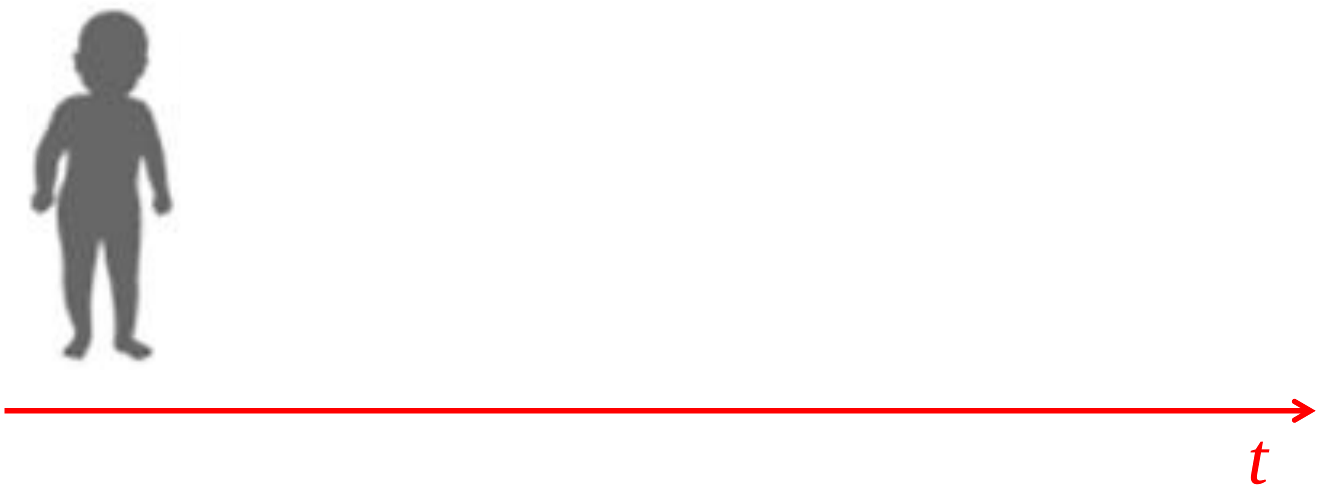




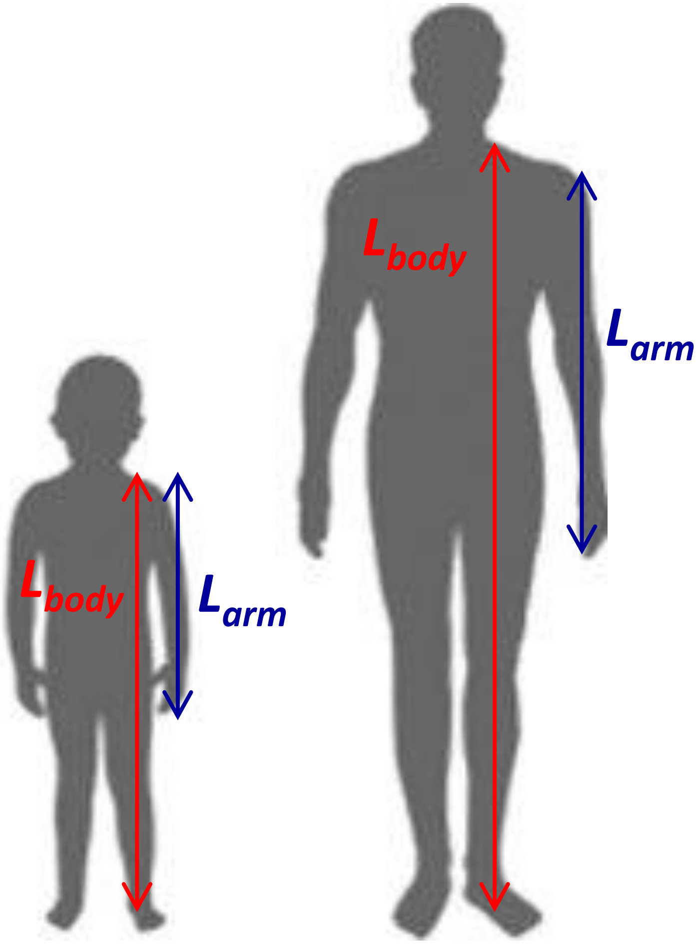


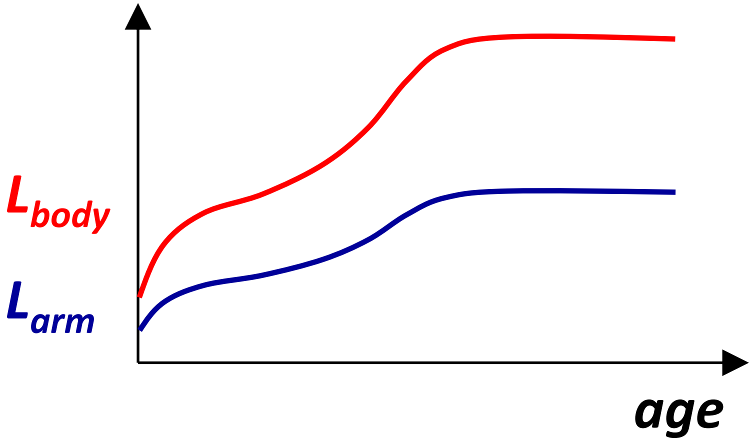
Proportionate growth

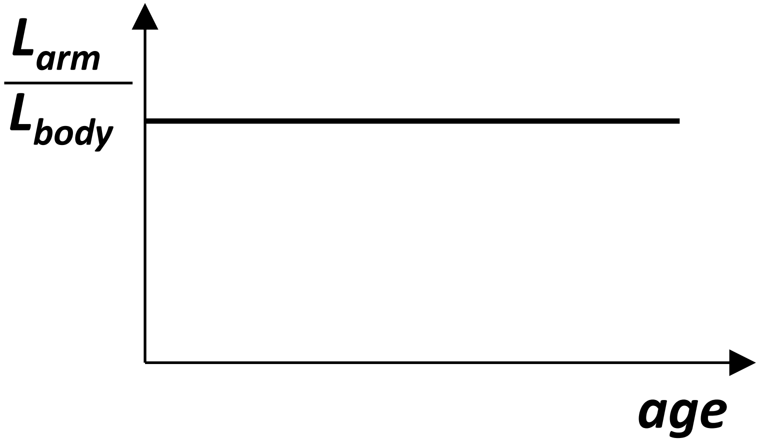
Toes exhibit features of proportionate growth



Proportionate growth



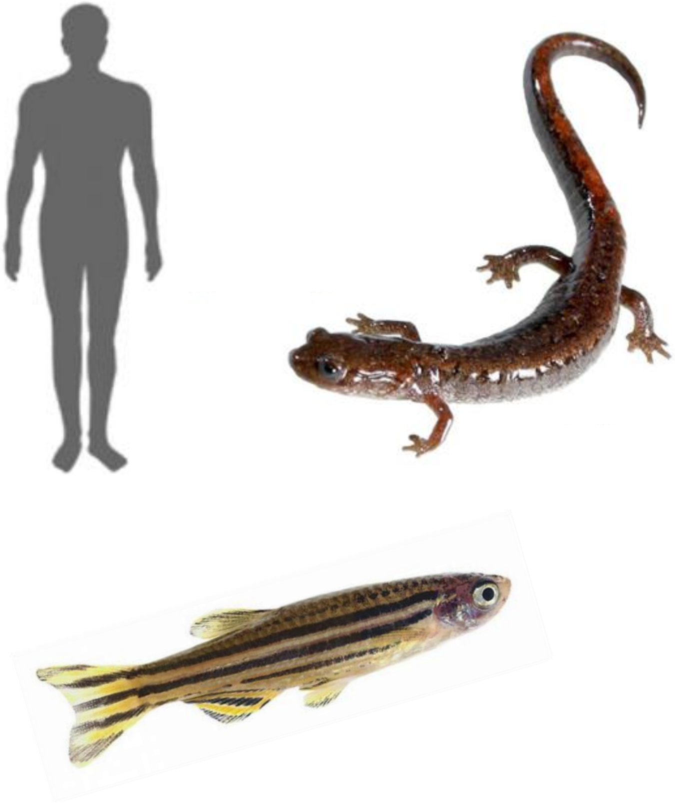




Proportionate growth

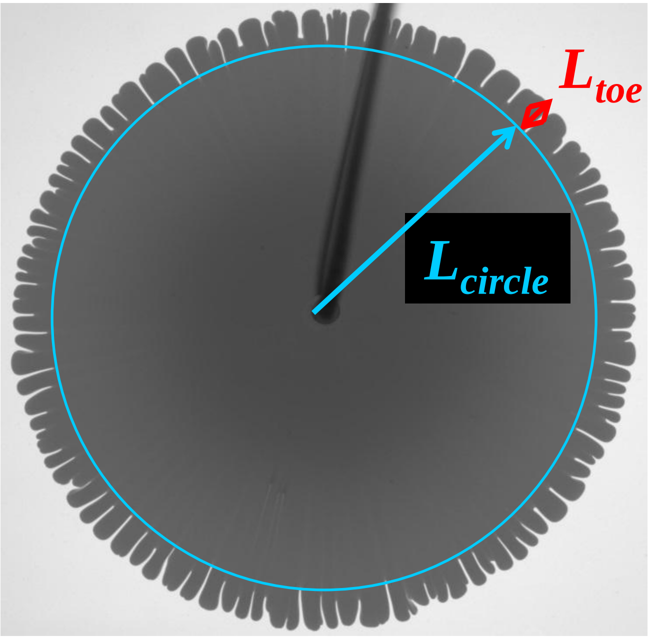
common in biological world…

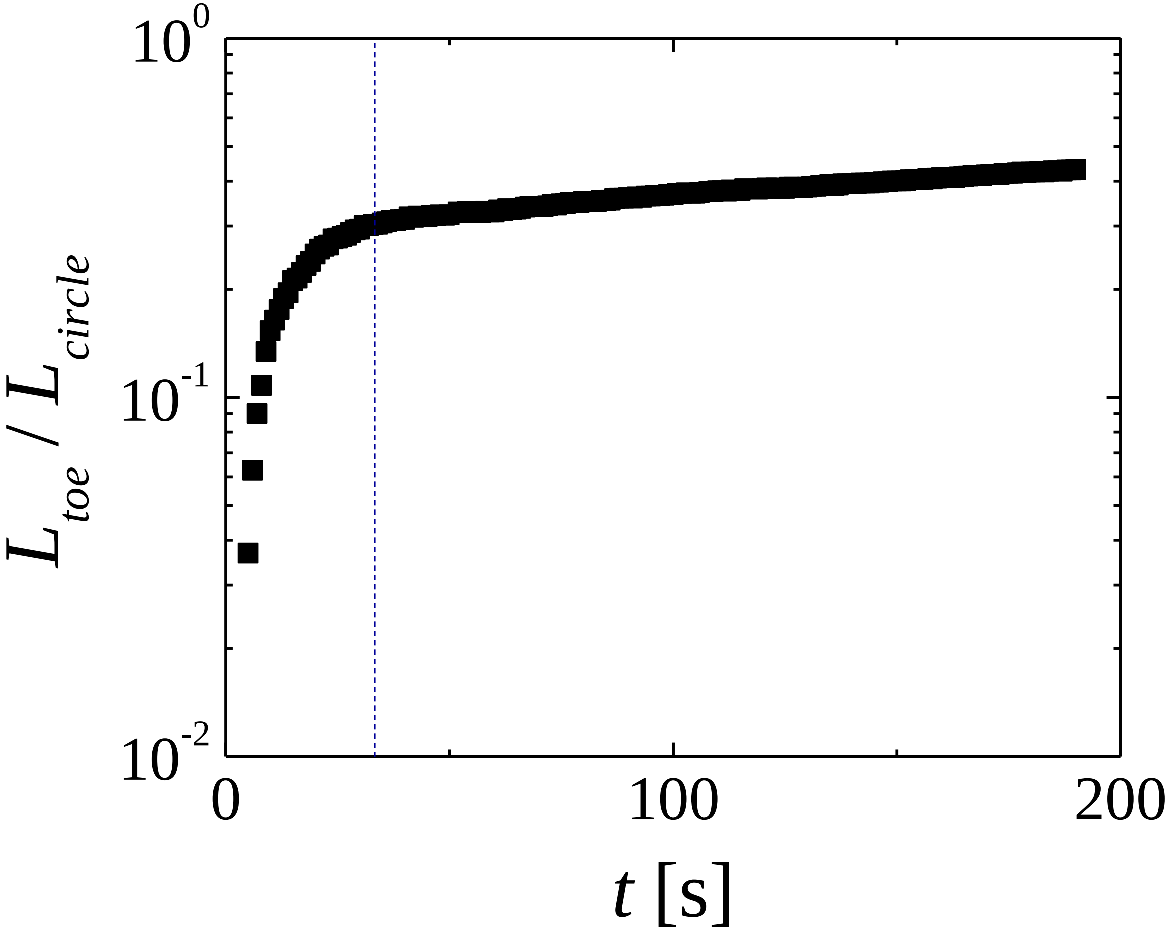
… but rare otherwise



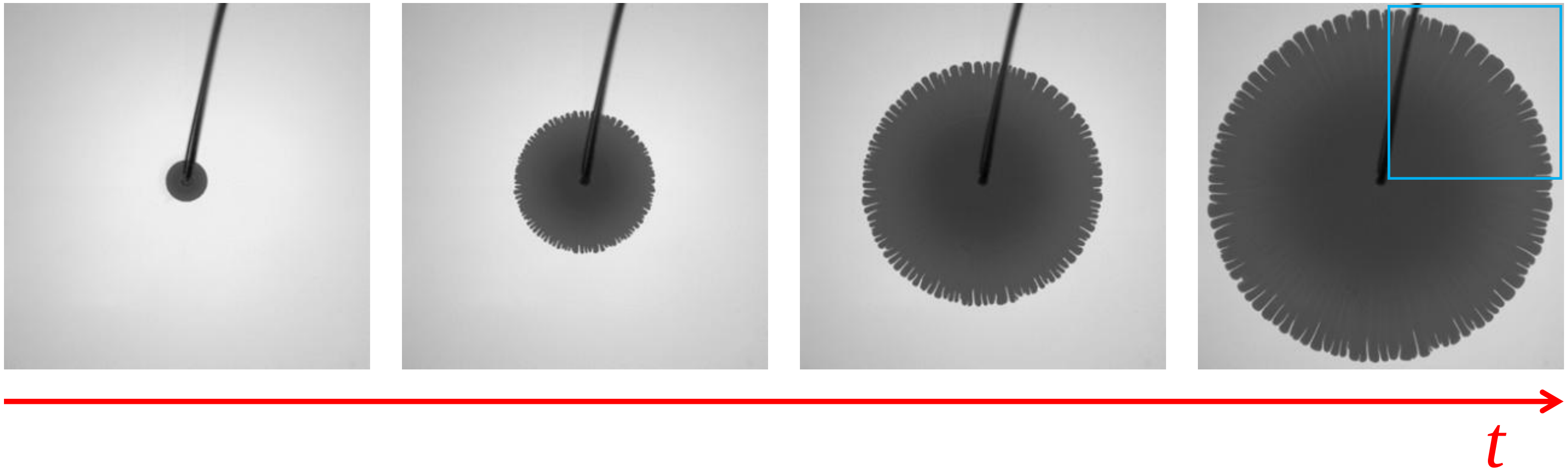
Growth in the toe regime

Toes grow proportional to inner circle

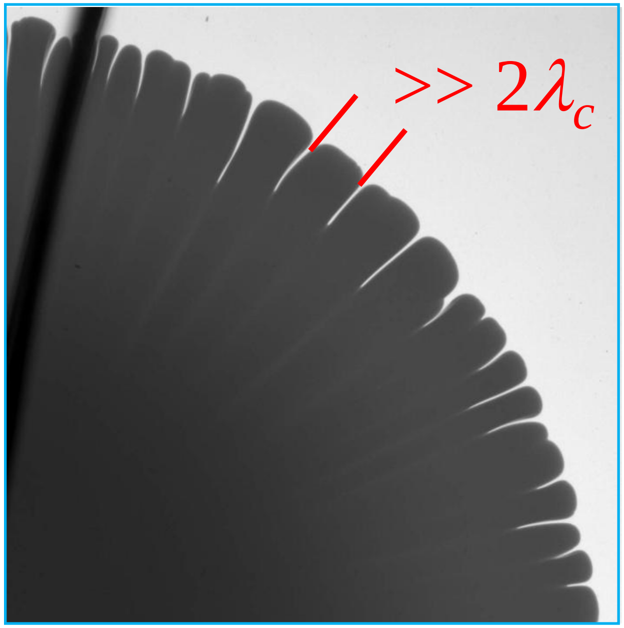




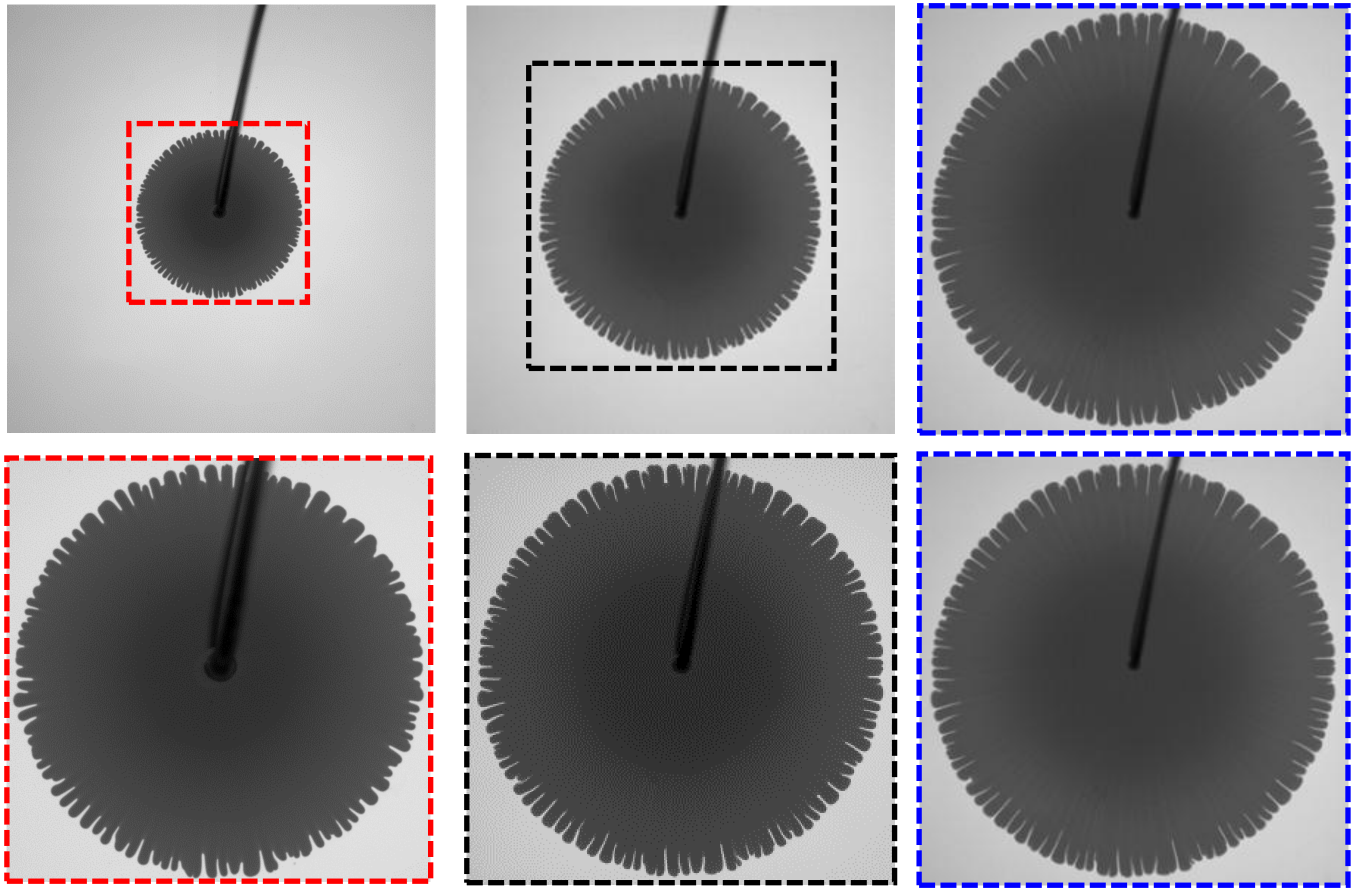
No tip-splitting: no new toes!



$2\lambda_c$

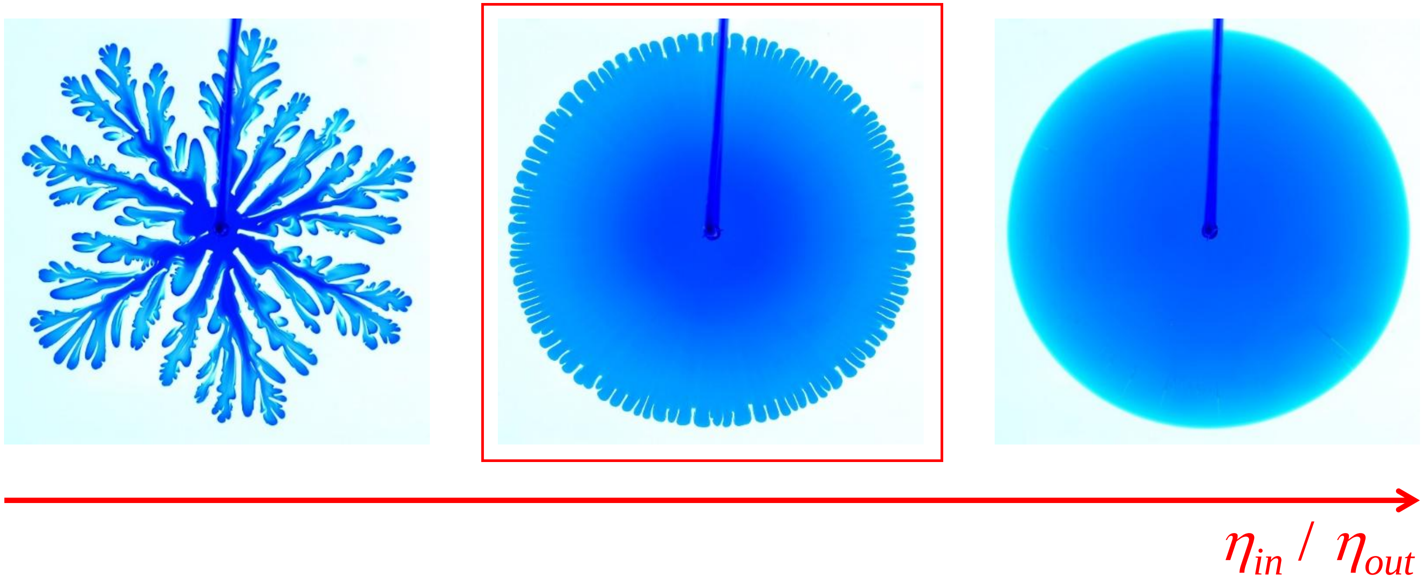


Proportionate growth in the toe regime



Proportionate growth in the toe regime

An example of memory formation

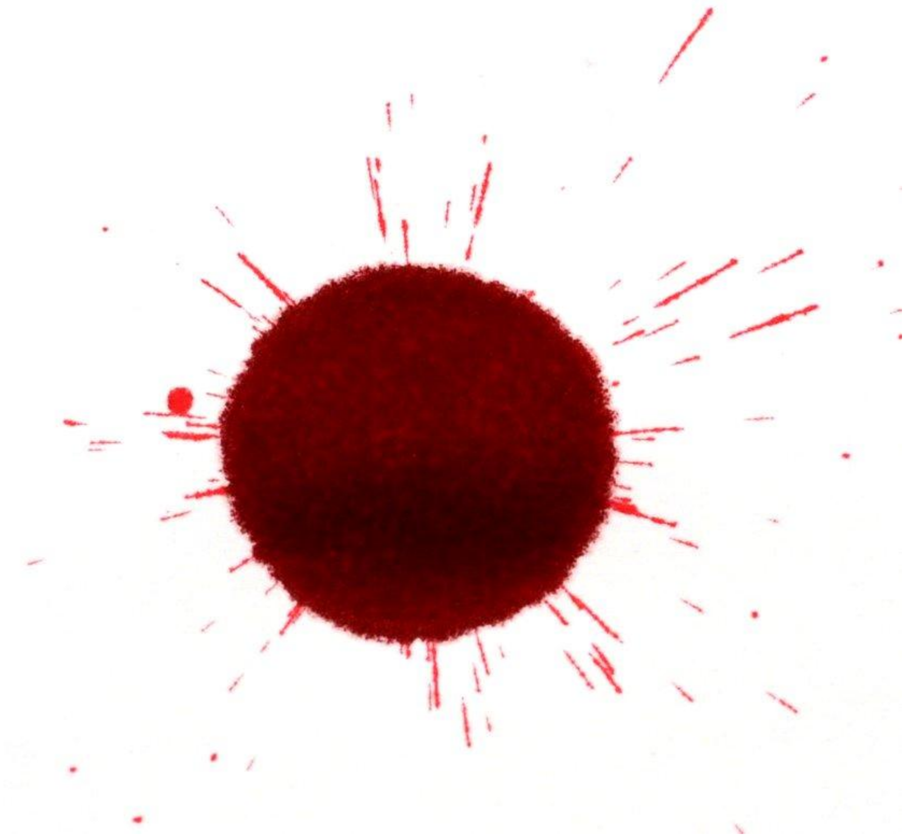


System remembers initial state

Instability needed once,
but further instabilities prevent memory formation

Pattern growth from fluid instabilities

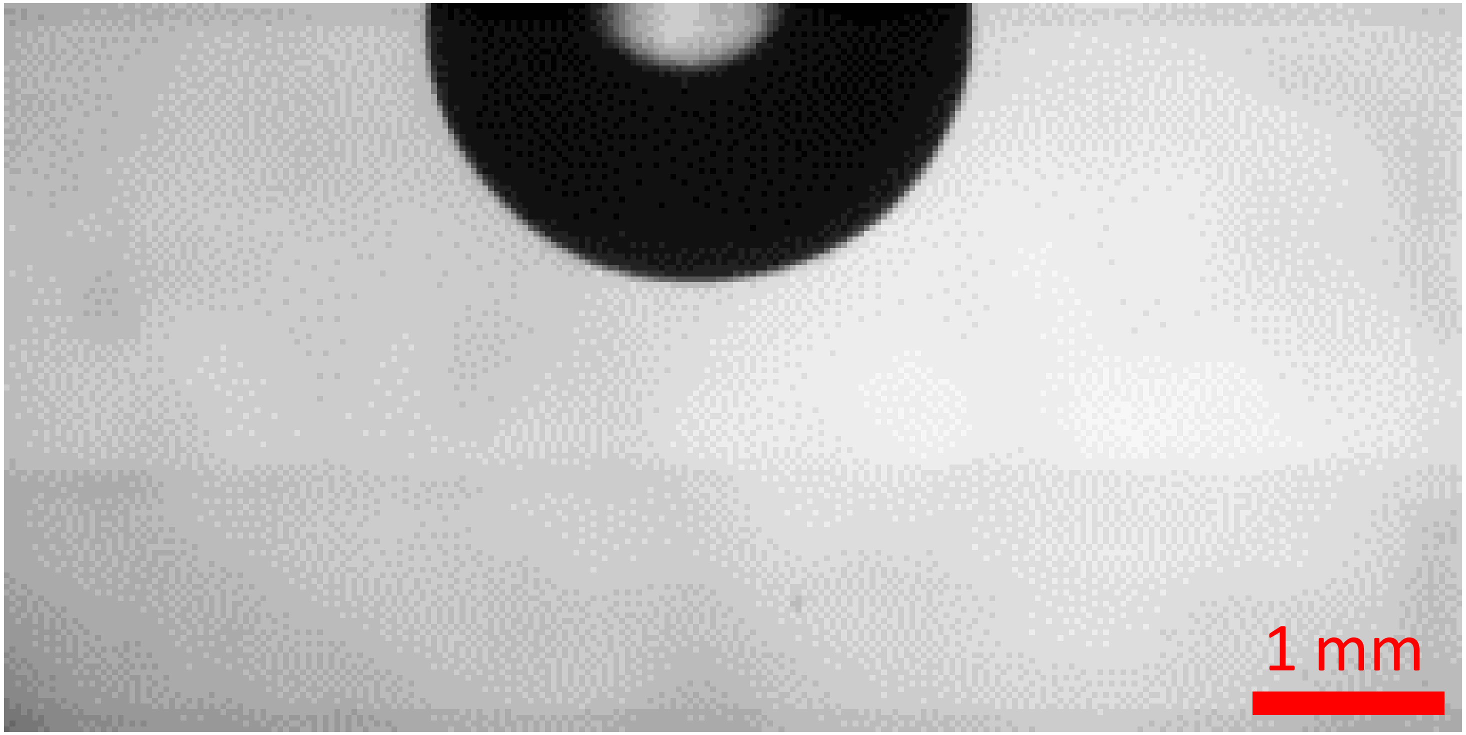
Sometimes we can only see the memory



A story about a most familiar phenomenon
that completely defies our normal intuition

A splash

Filmed at ~50’000 fps

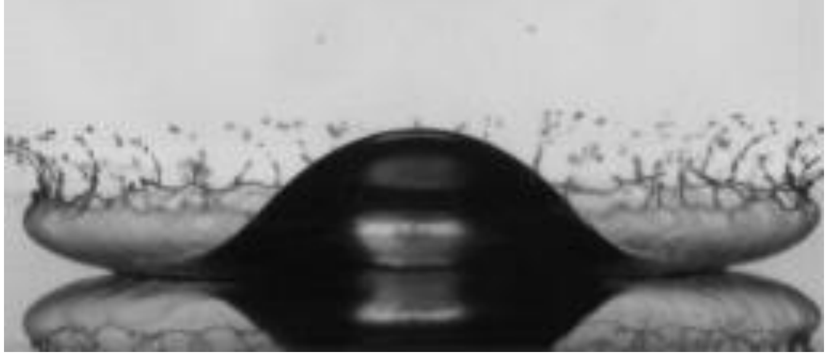


Ethanol impacting dry glass

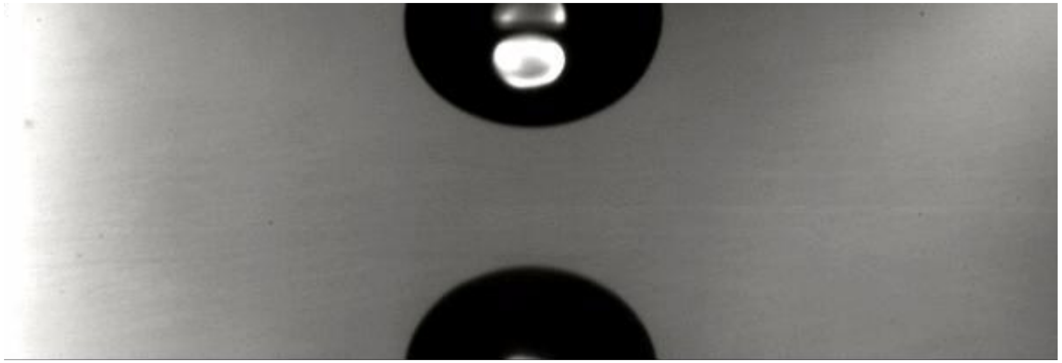
$u_0 \approx 3$ m/s

A variety of splashes

Viscosity matters



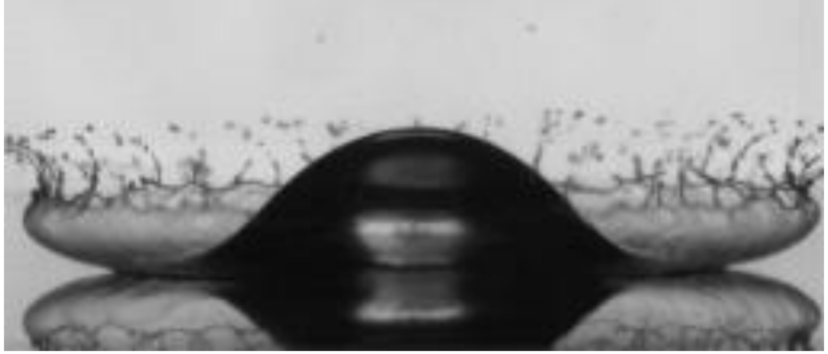
η = 1.4 mPa s



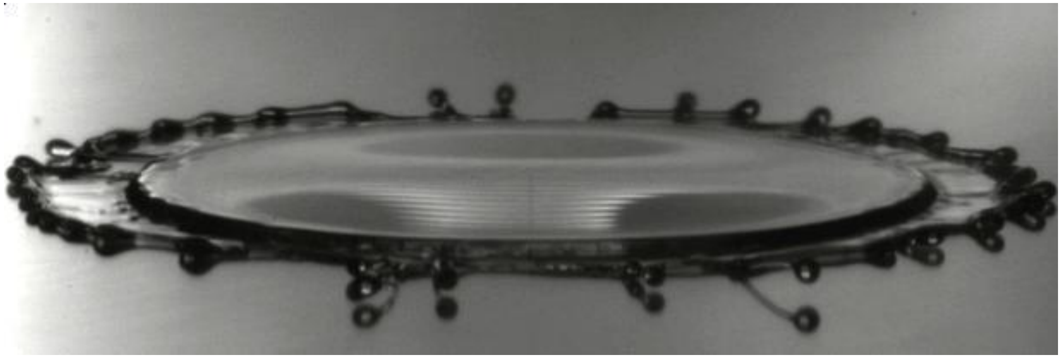
η = 10 mPa s

A variety of splashes

Viscosity matters



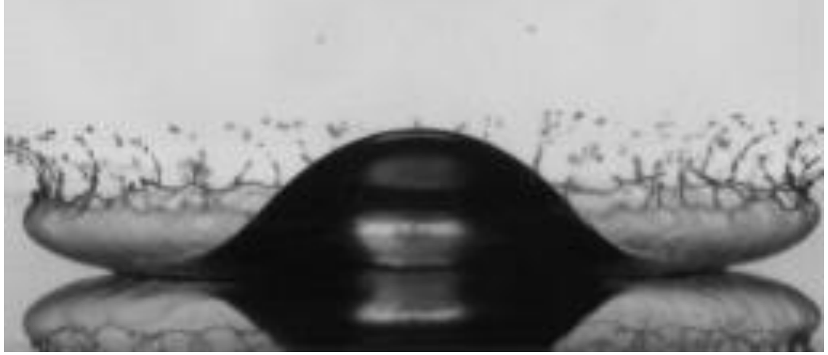
η = 1.4 mPa s



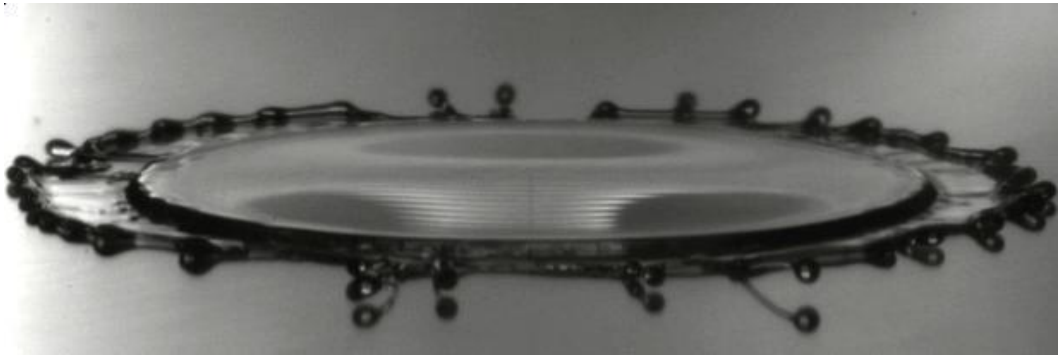
η = 10 mPa s

A variety of splashes

Viscosity matters

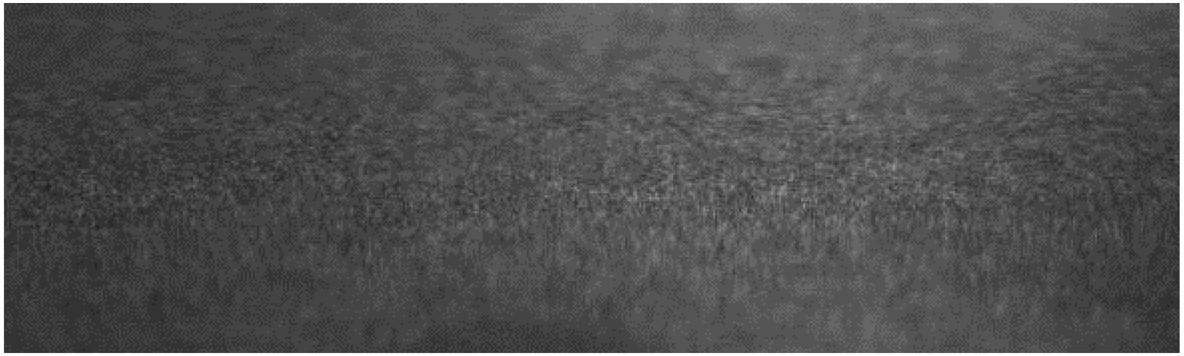


η = 1.4 mPa s



η = 10 mPa s

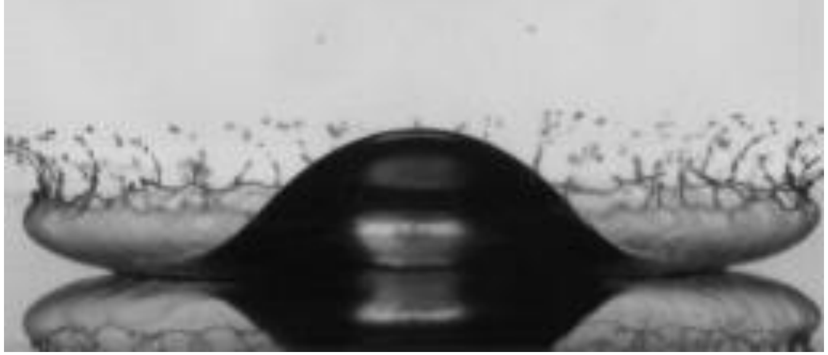
Substrate roughness matters



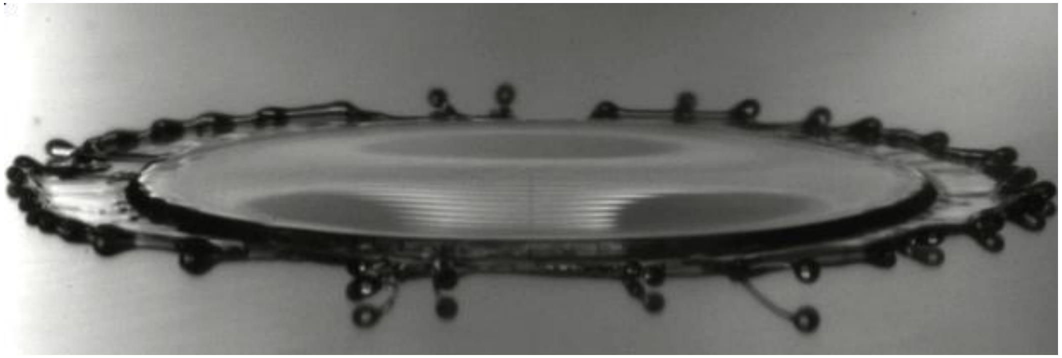
η = 10 mPa s

A variety of splashes

Viscosity matters

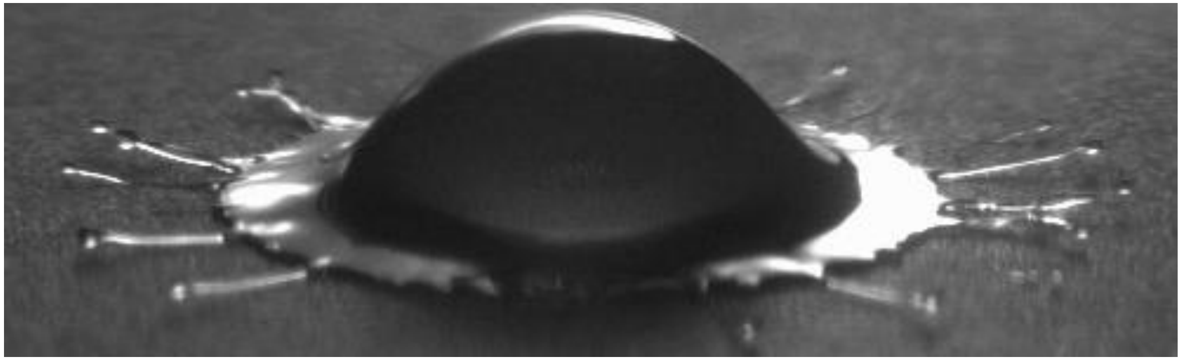


η = 1.4 mPa s



η = 10 mPa s

Substrate roughness matters



η = 10 mPa s

What else matters?

Drop size

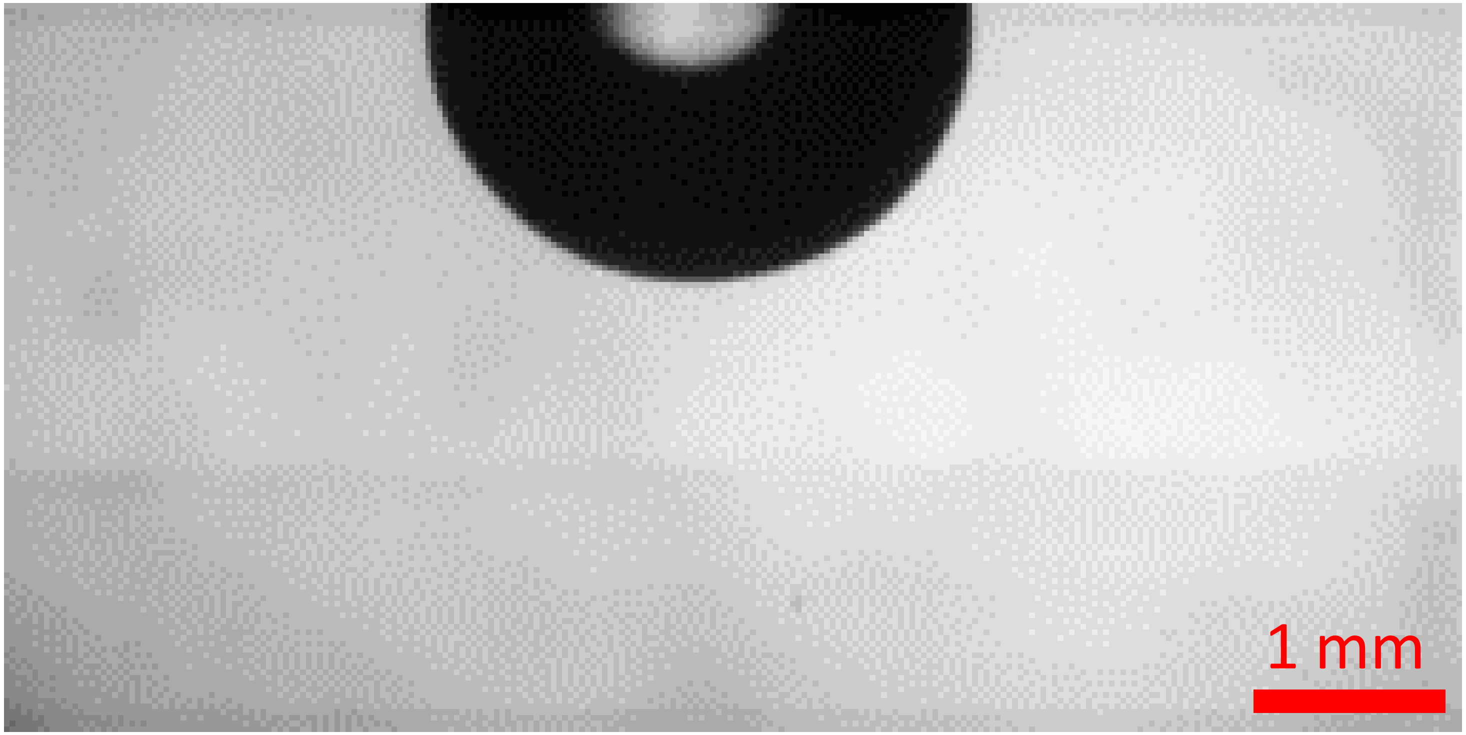
Viscosity

Substrate roughness

Surface tension

Impact velocity

A splash

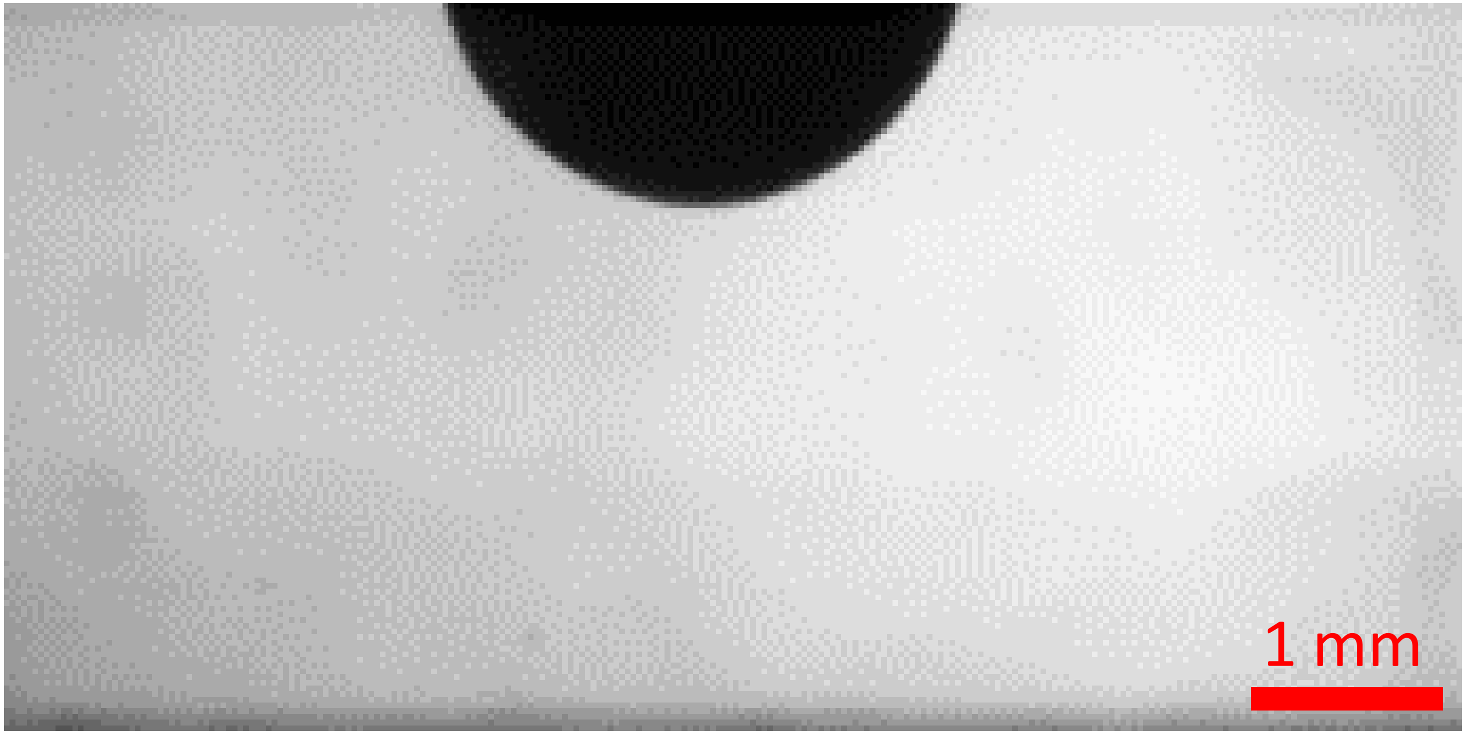


Ethanol impacting dry glass

$u_0 \approx 3$ m/s

atmospheric pressure

Lowering pressure suppresses splashing

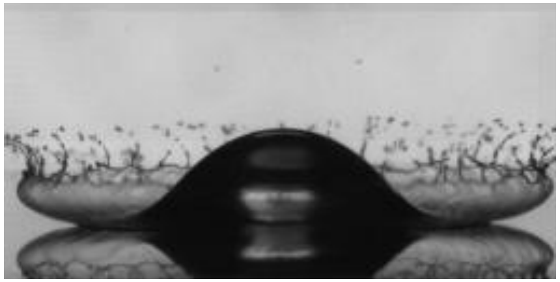


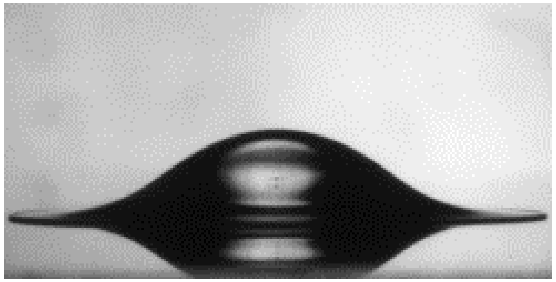
Ethanol impacting dry glass

$u_0 \approx 3$ m/s

1/3 of atmospheric pressure

No splash on Mount Everest





atmospheric pressure

1/3 of atmospheric pressure

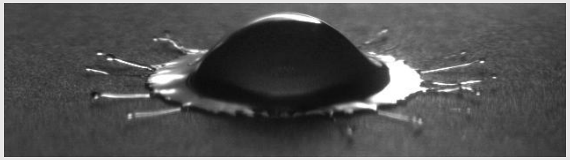
Pressure controls splashing in all regimes

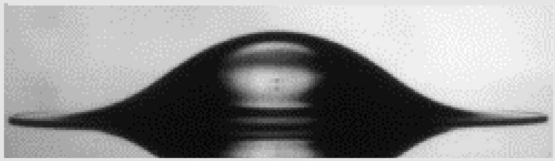
atmospheric pressure

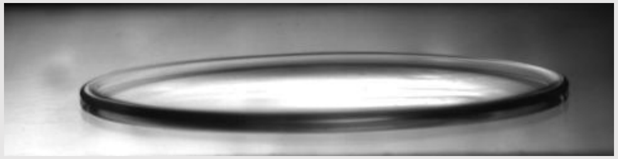
low viscosity

high viscosity

rough surface







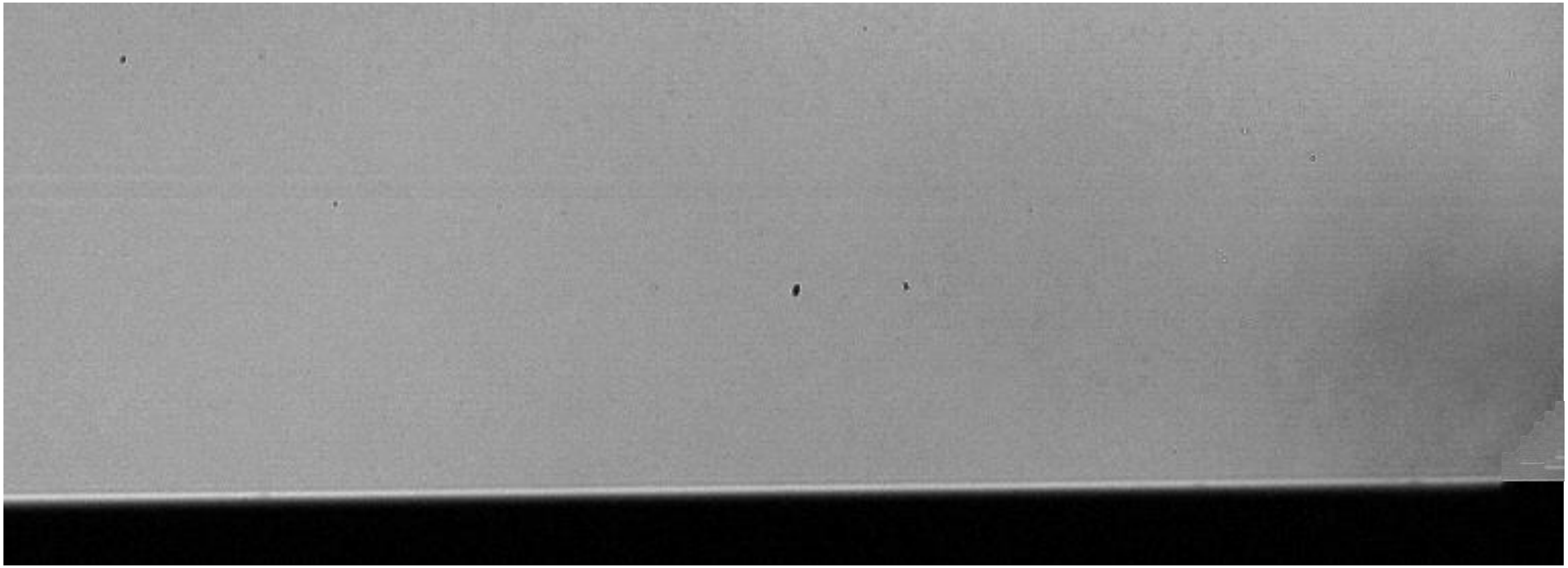
1/3 of atmospheric pressure

lowering pressure always suppresses splashing → **common cause?**

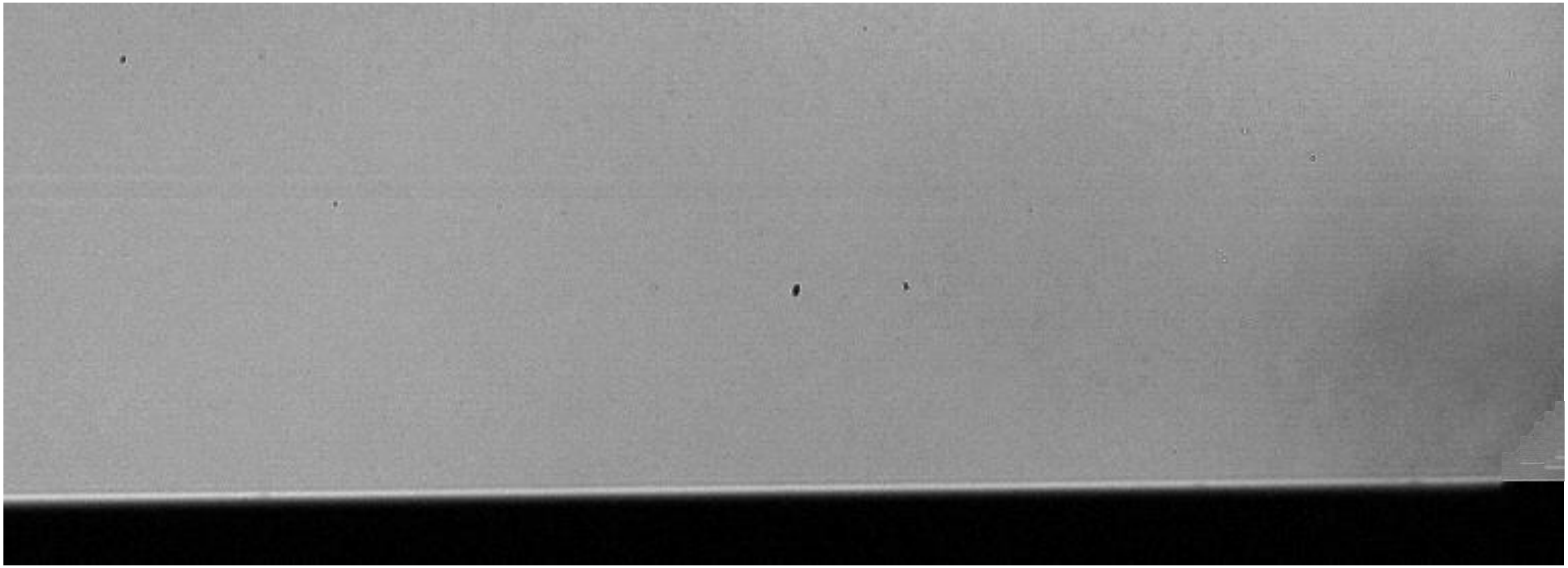
Why is the air so important?

What is the air doing?

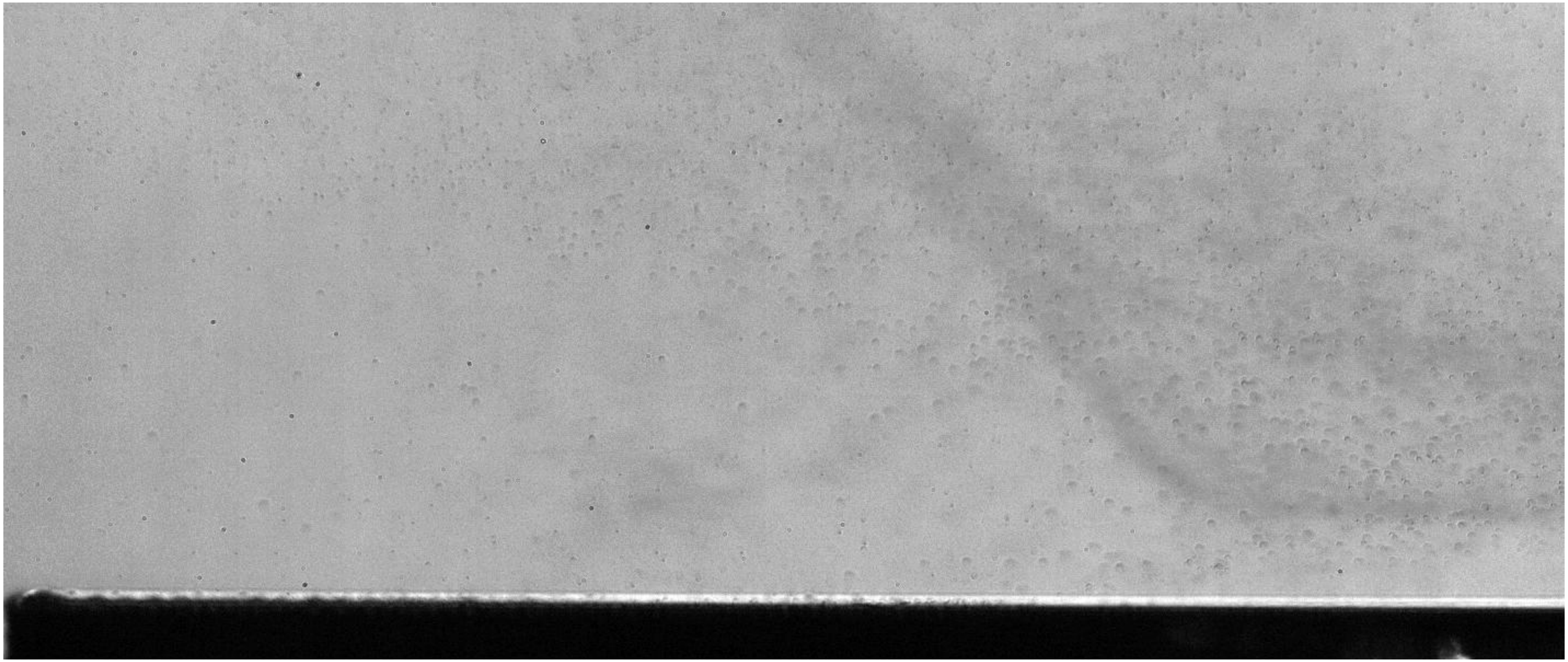
Seeing the invisible



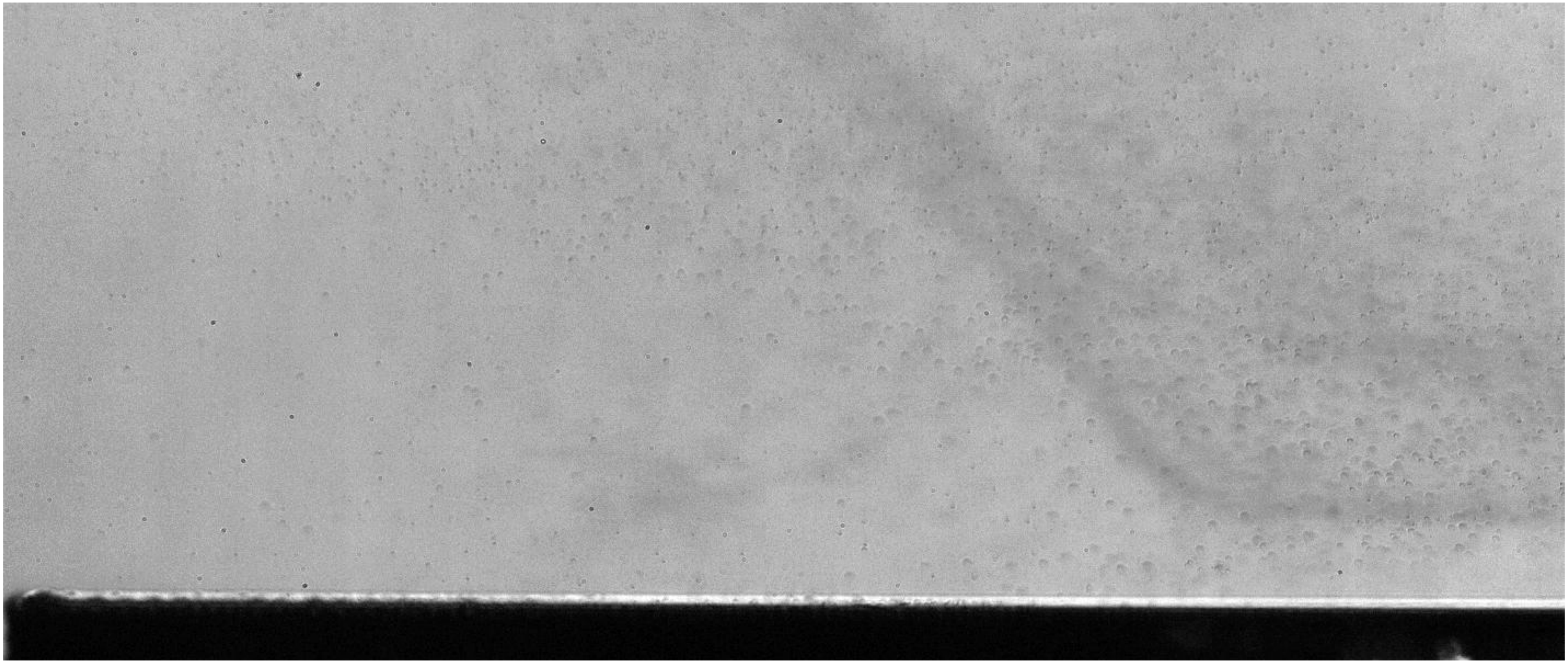
Seeing the invisible



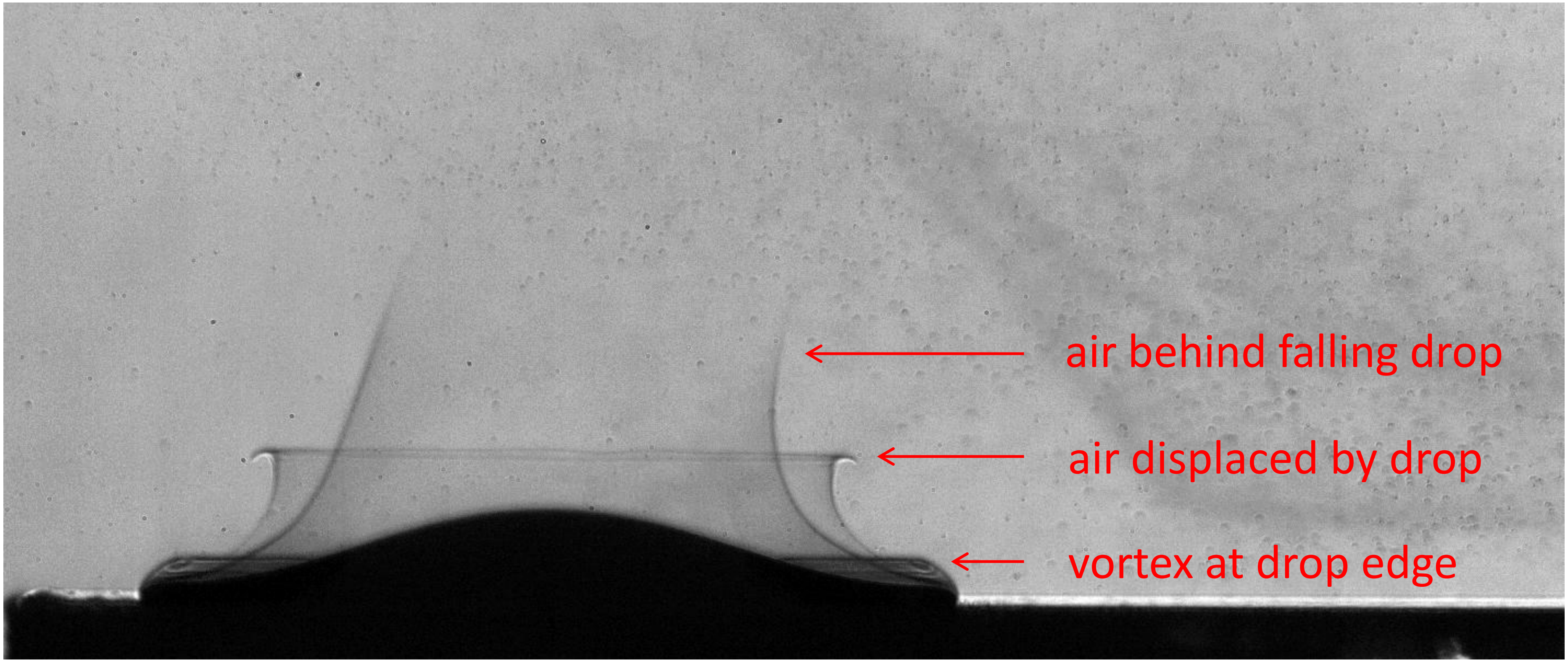
Seeing the invisible



Seeing the invisible



Seeing the invisible



Air flows are not governing splashing

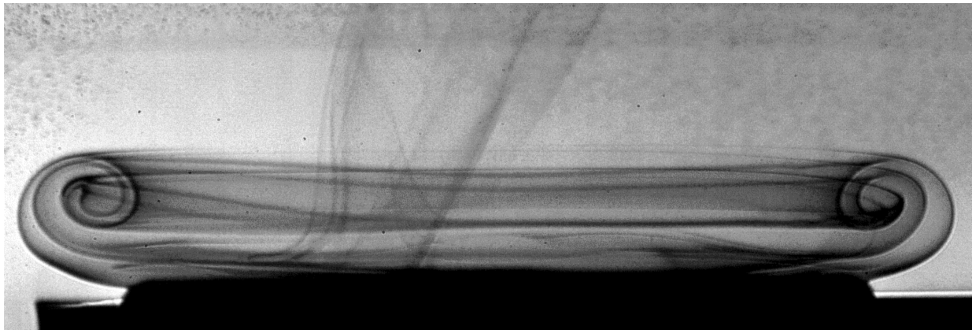
Find control parameters

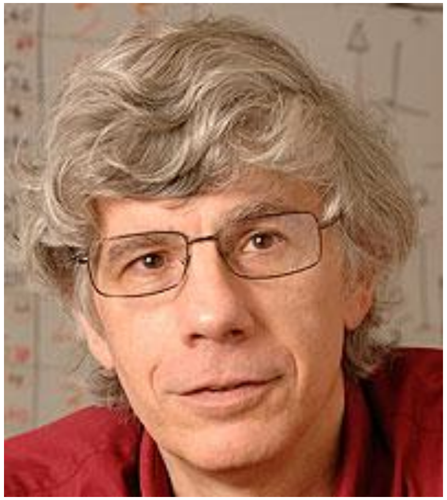
Air flows:
Impact velocity
Air viscosity
Drop size

≠

Splashing threshold:
Liquid viscosity
Drop size
Surface tension
Impact velocity
Weight of gas
Air viscosity

Many discoveries awaiting




Sidney Nagel


Cacey Bester-Stevens


Michelle Driscoll


Andrzej Latka

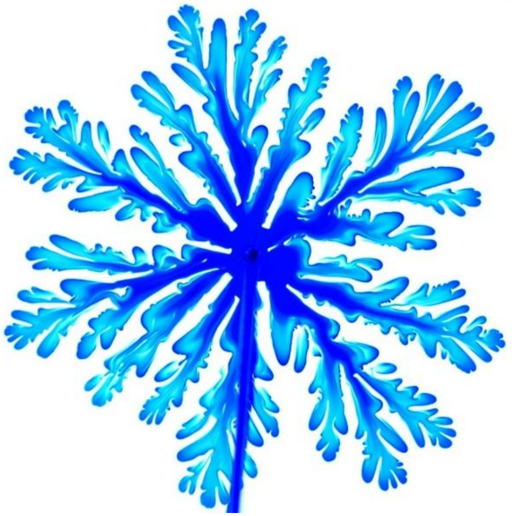

Radha Ramachandran


Qing Zhang

A great resource

http://fyfluiddynamics.com/

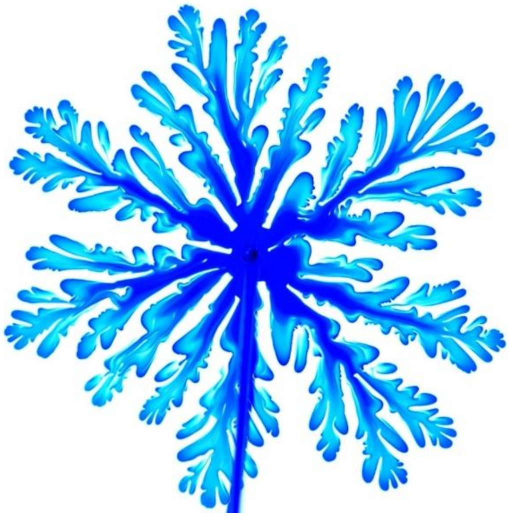
Flowing through a world of patterns



Pattern growth is full of surprises

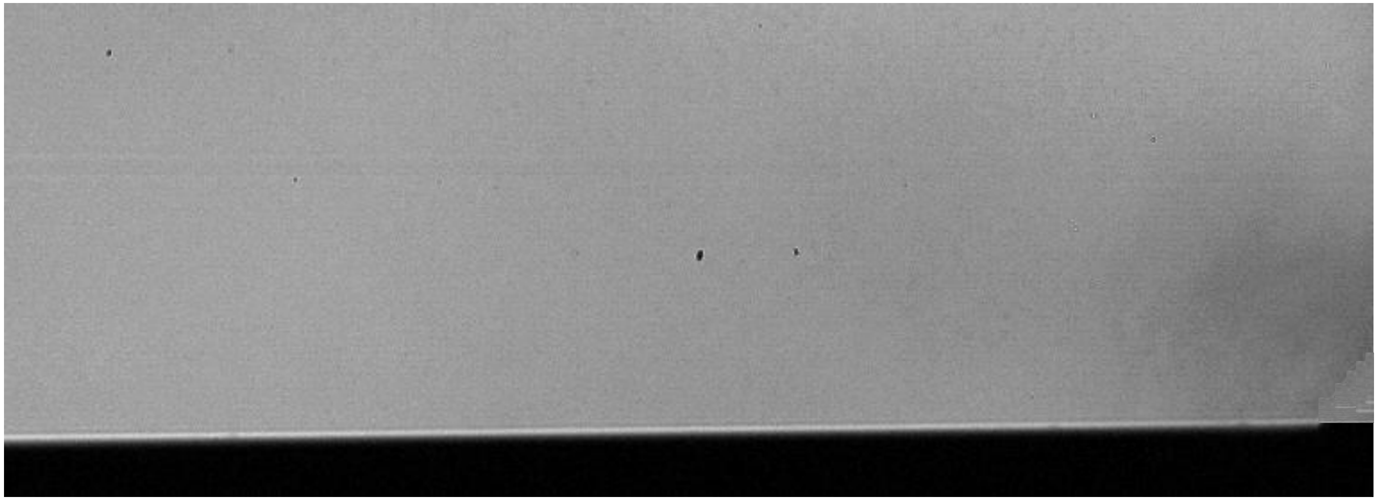
we are only starting to understand
the deep and complex science behind

Flowing through a world of patterns



Pattern growth is full of surprises

we are only starting to understand
the deep and complex science behind



Thank you for your attention !