13

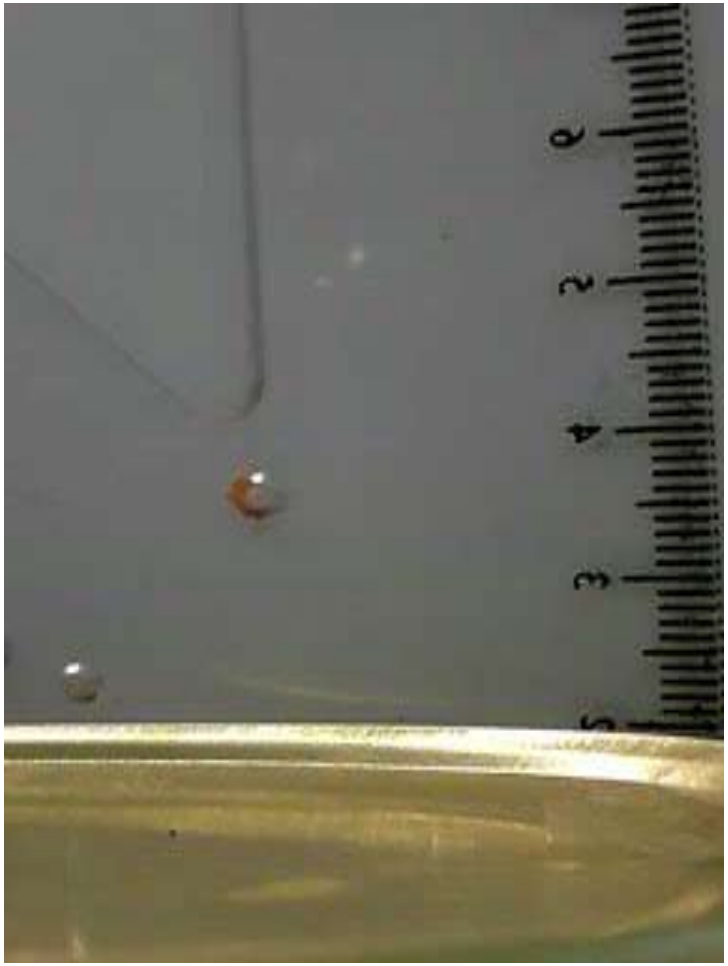
Honey Coils

Kamila Součková

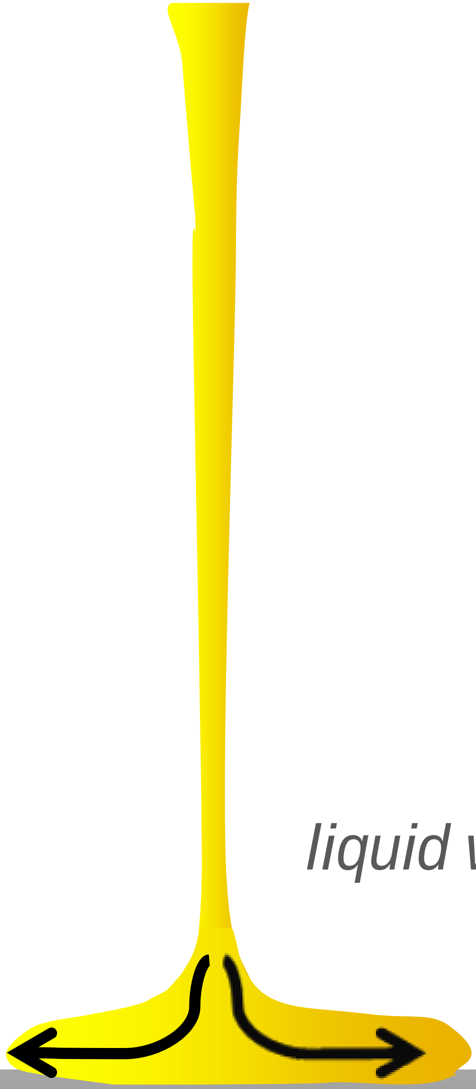
13 Honey Coils

A thin, downward flow of viscous liquid, such as honey, often turns itself into circular coils.

Study and explain this phenomenon.

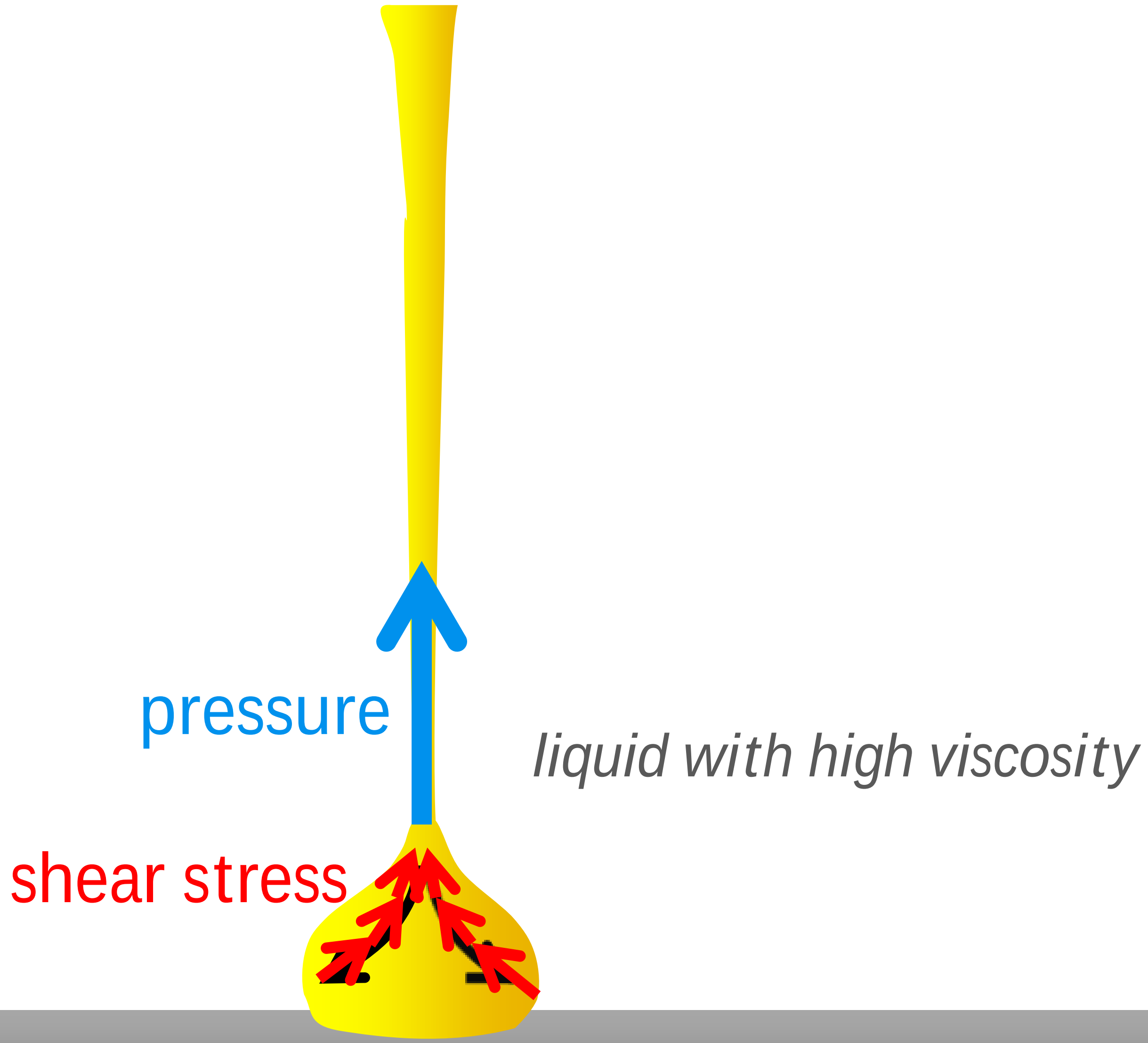


Inception Dynamics

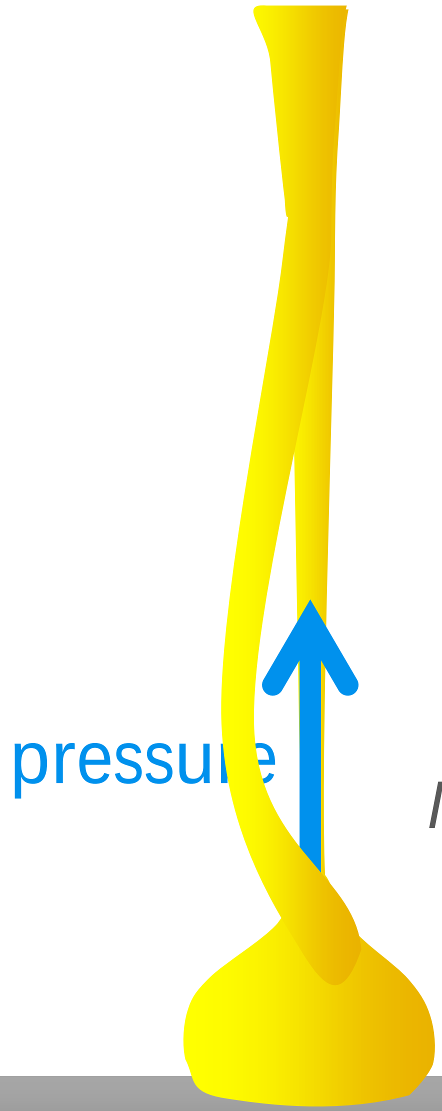


liquid with low viscosity

Inception Dynamics



Inception Dynamics



thin stream

\+

small disruption

↓

flow bending

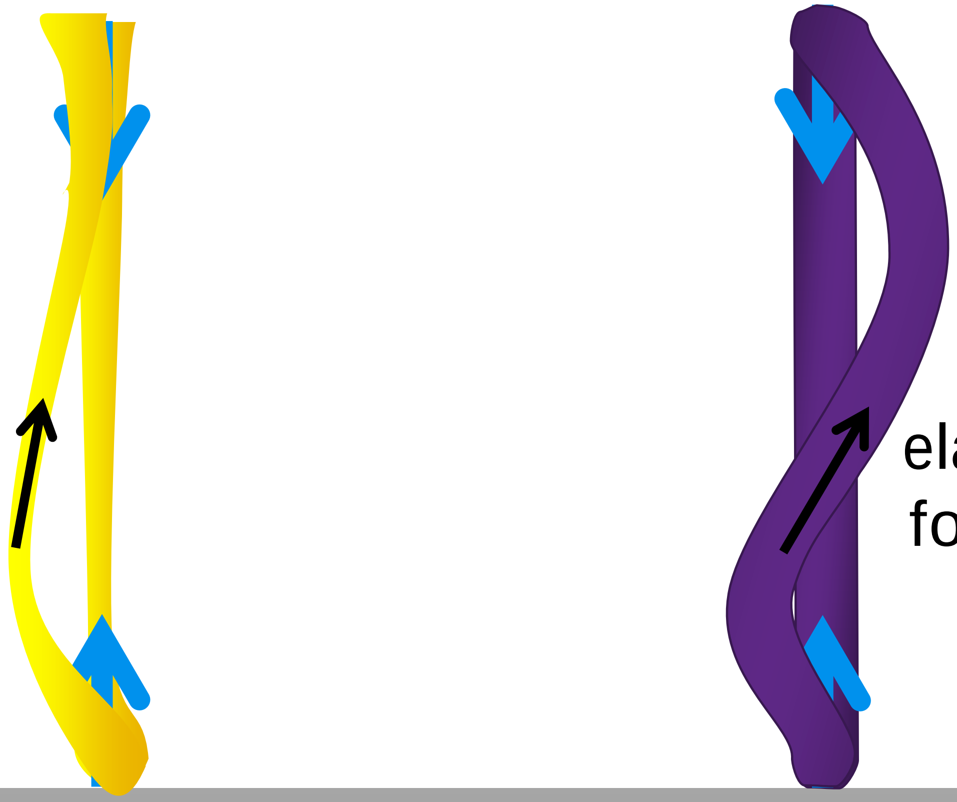
liquid with high viscosity

Partial Analogy

honey

elastic rope

viscous forces
(inner friction)



elastic
forces

High Viscosity is Necessary

glycerine soap

$\eta = 0.085$ Pa s
($100 \times$ that of water)

glycerol

$\eta = 1.2$ Pa s

shampoo

$\eta \leq 19$ Pa s
non-newtonian liquid

acacia honey

$\eta = 17.6$ Pa s
newtonian liquid

values at 22°C

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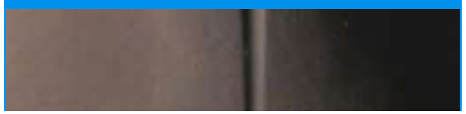

doesn‘t work

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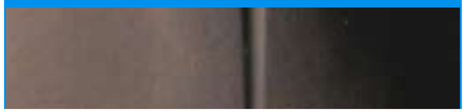

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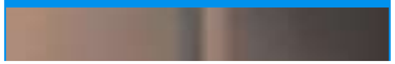

linear oscillation

$\eta = 1.2$ Pa s

shampoo

$\eta \leq 19$ Pa s
non-newtonian liquid

acacia honey

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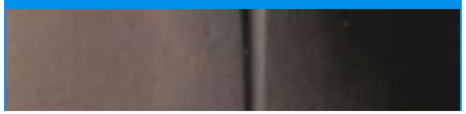
values at $22^{\circ}\mathrm{C}$

High Viscosity is Necessary

glycerine soap



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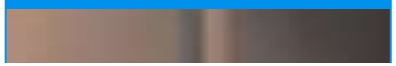
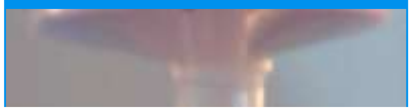


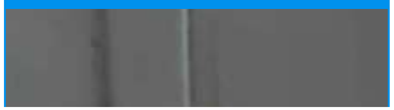
linear oscillation

$\eta = 1.2\ \mathrm{Pa\ s}$

shampoo



acacia honey



circular spirals

shampoo: $\eta \leq 19\ \mathrm{Pa\ s}$

non-newtonian liquid

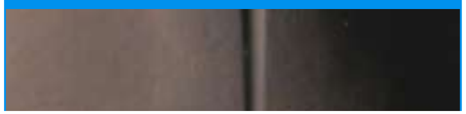
acacia honey: $\eta = 17.6\ \mathrm{Pa\ s}$

newtonian liquid

values at $22^{\circ}\mathrm{C}$

High Viscosity is Necessary

glycerine soap



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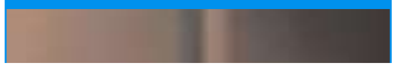
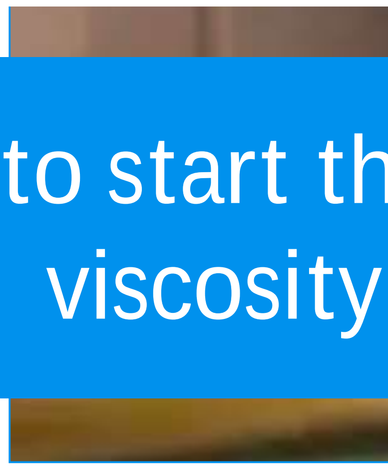
glycerol

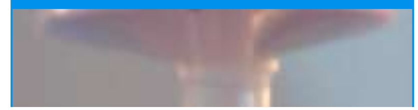


linear oscillation

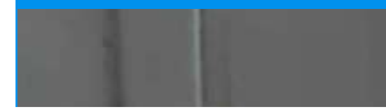


$\eta = 1.2$ Pa s

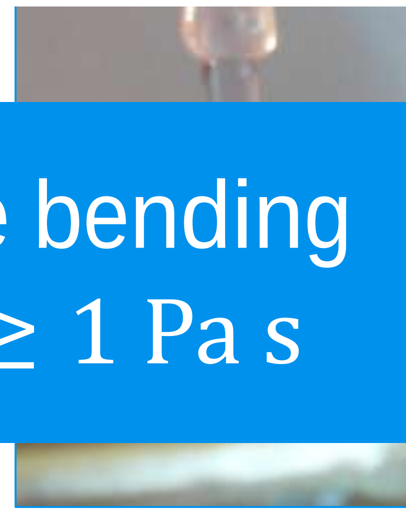
shampoo



acacia honey



circular spirals



$\eta \leq 19$ Pa s
non-newtonian liquid

$\eta = 17.6$ Pa s
newtonian liquid

to start the bending viscosity ≥ 1 Pa s

values at 22°C

Why Did the Other Liquids Fail?

- viscosity problem
  - low viscosity = low shear stress

    water, glycerin soap, olive oil, motor oils, syrup
  - could be solved by greater fall height – but surface tension issue

    (Plateau-Raileygh instability:
    stream turns into drops)

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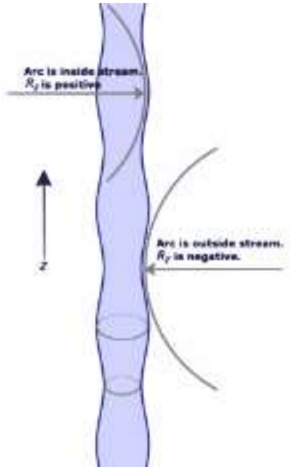
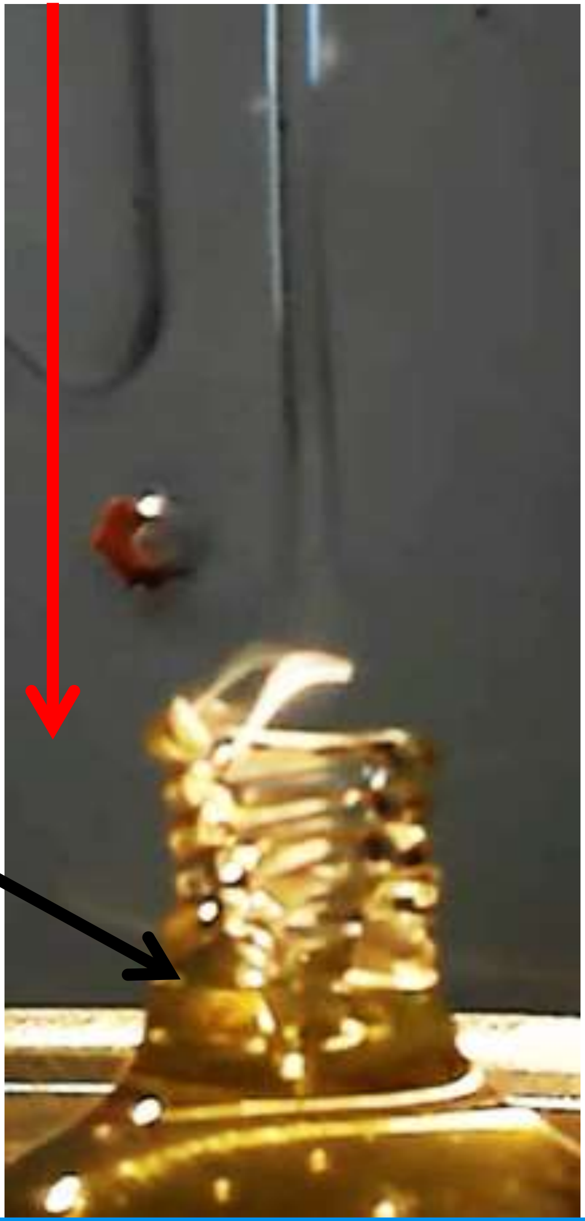


EXPERIMENTS

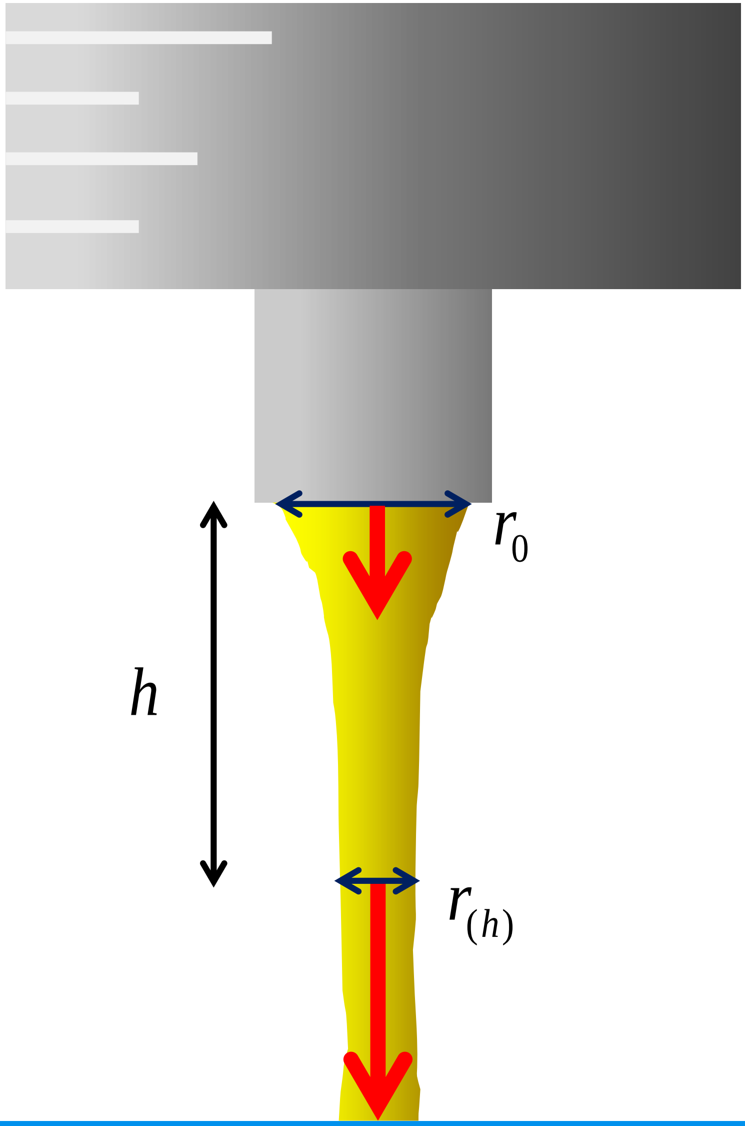
Parameters

height of fall

viscosity



Height



gravity

↓

flow velocity rises

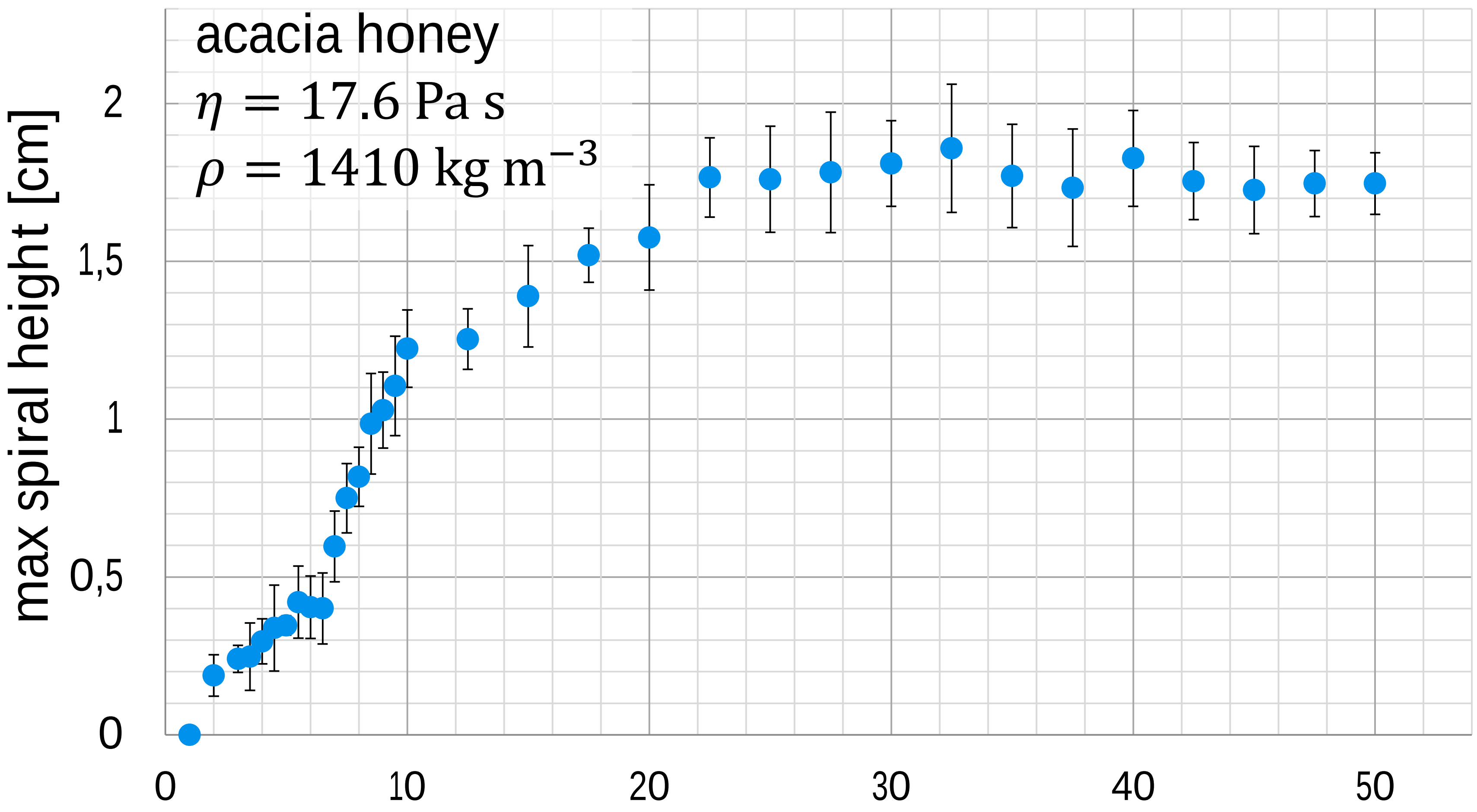
continuity

$$Sv = \text{const.}$$

↓

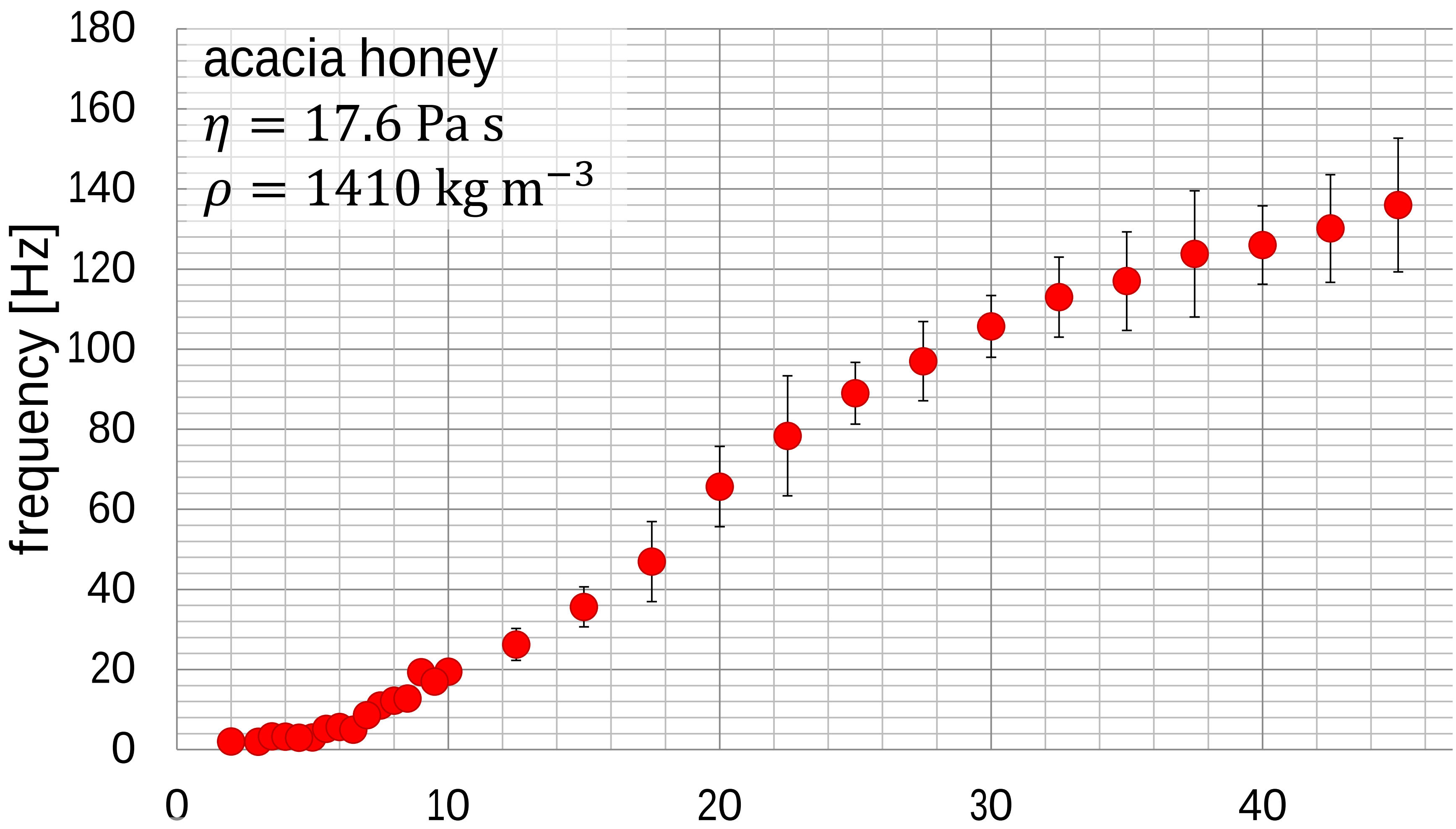
flow becomes thinner

Coil Height vs. Height of Fall



$Q = 0.045$ ml s^{-1}
$r_0 = 1$ ml

Coiling Frequency vs. Height of Fall

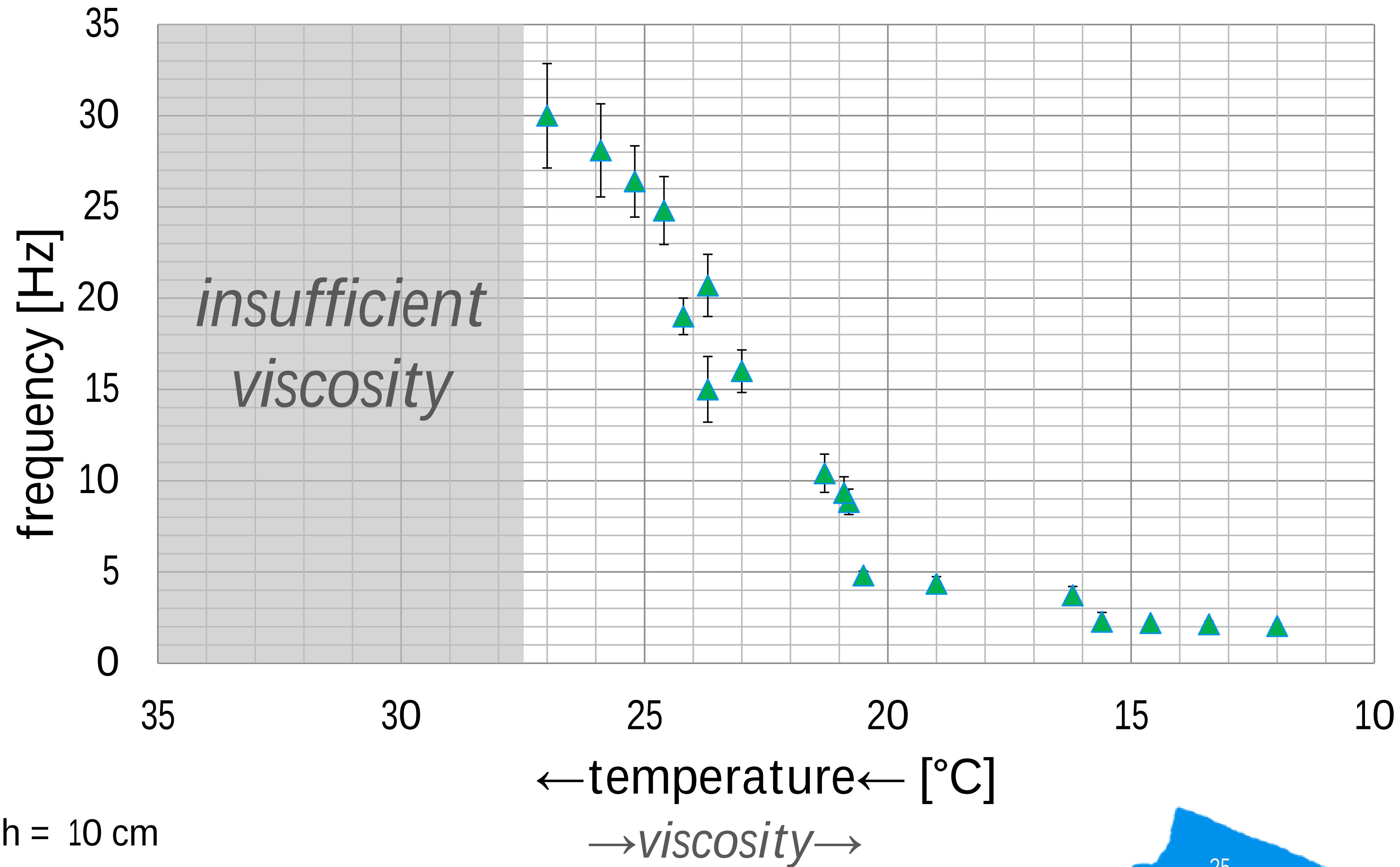


$Q = 0.045$ ml s^{-1}
$r_0 = 1$ ml

Viscosity

- must be high enough (> 1 Pa s)
- greater viscosity → more “solid-like” behavior
- coiling frequency decreases with increasing viscosity

Coiling Frequency vs. Viscosity



h = 10 cm

NOT ALL COILING IS THE SAME

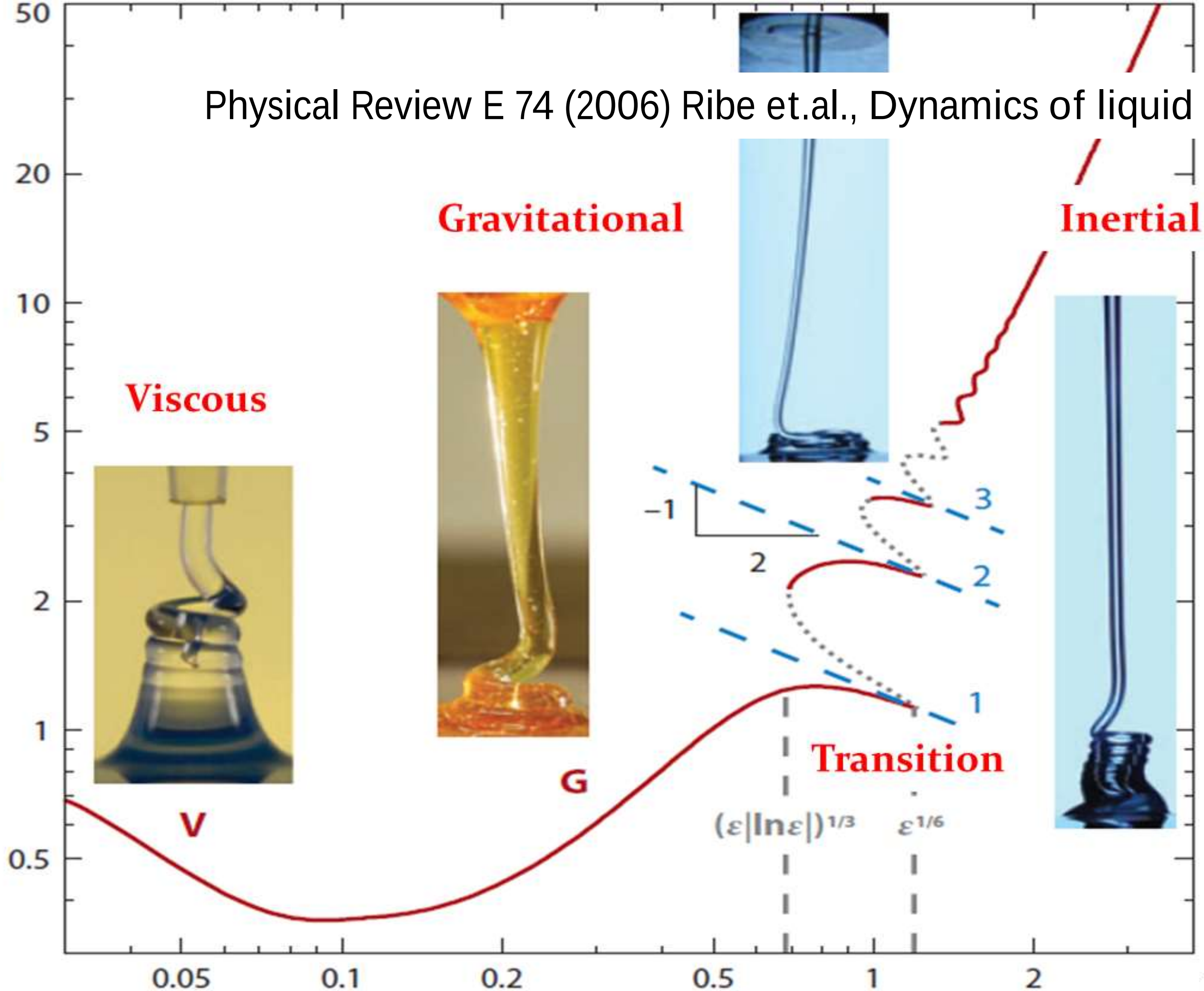
different regimes of coiling

Regimes – Results of Ribe et.al.

[Ribe et.al., 2006, *Dynamics of liquid rope coiling*, Physical Review E 74]

- different regimes found
- affected by height of fall (velocity)
- determined by relative importance of forces
  1. viscous
  2. gravitational
  - gravitational-inertial (transition)
  3. inertial

Physical Review E 74 (2006) Ribe et.al., Dynamics of liquid rope coiling

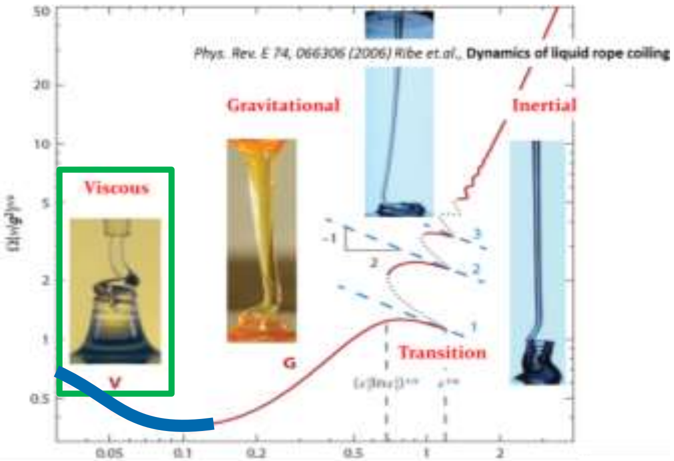


dimensionless frequency

dimensionless height of fall

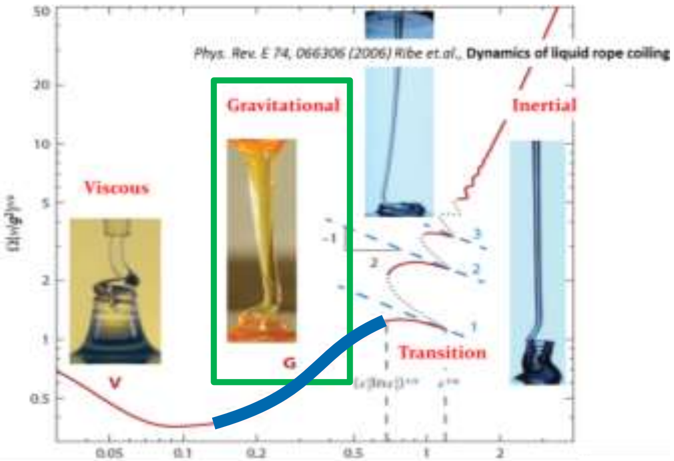
Viscous Regime

- very low height of fall
- viscous force dominant
- coiling driven by fluid extrusion
- very hard to observe



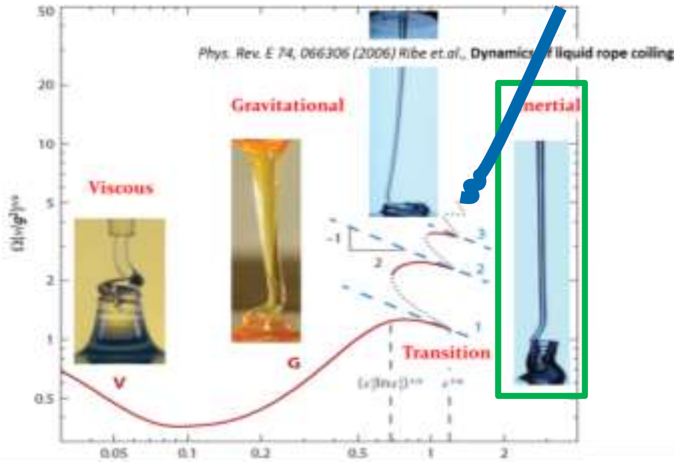
Gravitational Regime

- height of fall up to 9 cm
- gravitational force dominant
- slow & stable coiling
- very predictable



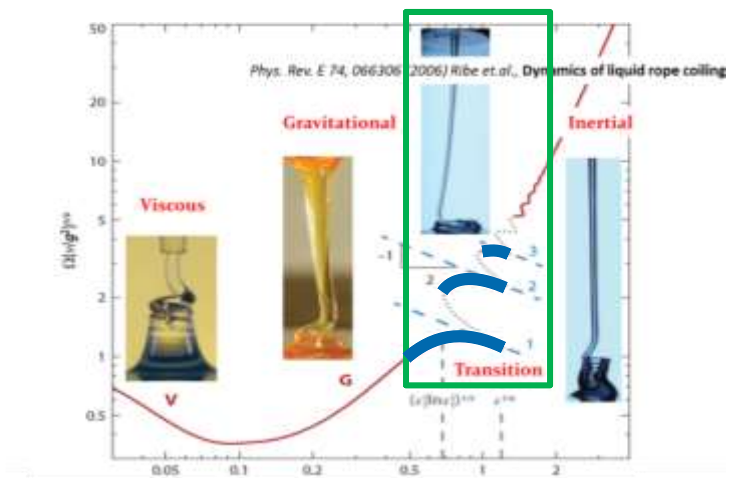
Inertial Regime

- heights $\gg 10\ \mathrm{cm}$
- inertial forces dominant
- highest coiling frequencies, unstable



Gravitational-Inertial Regime

- *transition* - between gravitational and inertial regime (height 9 to 10 cm in our case)
- both forces are relevant
- frequency: discrete multiples of “rope” (i.e. mathematic pendulum) resonant frequency



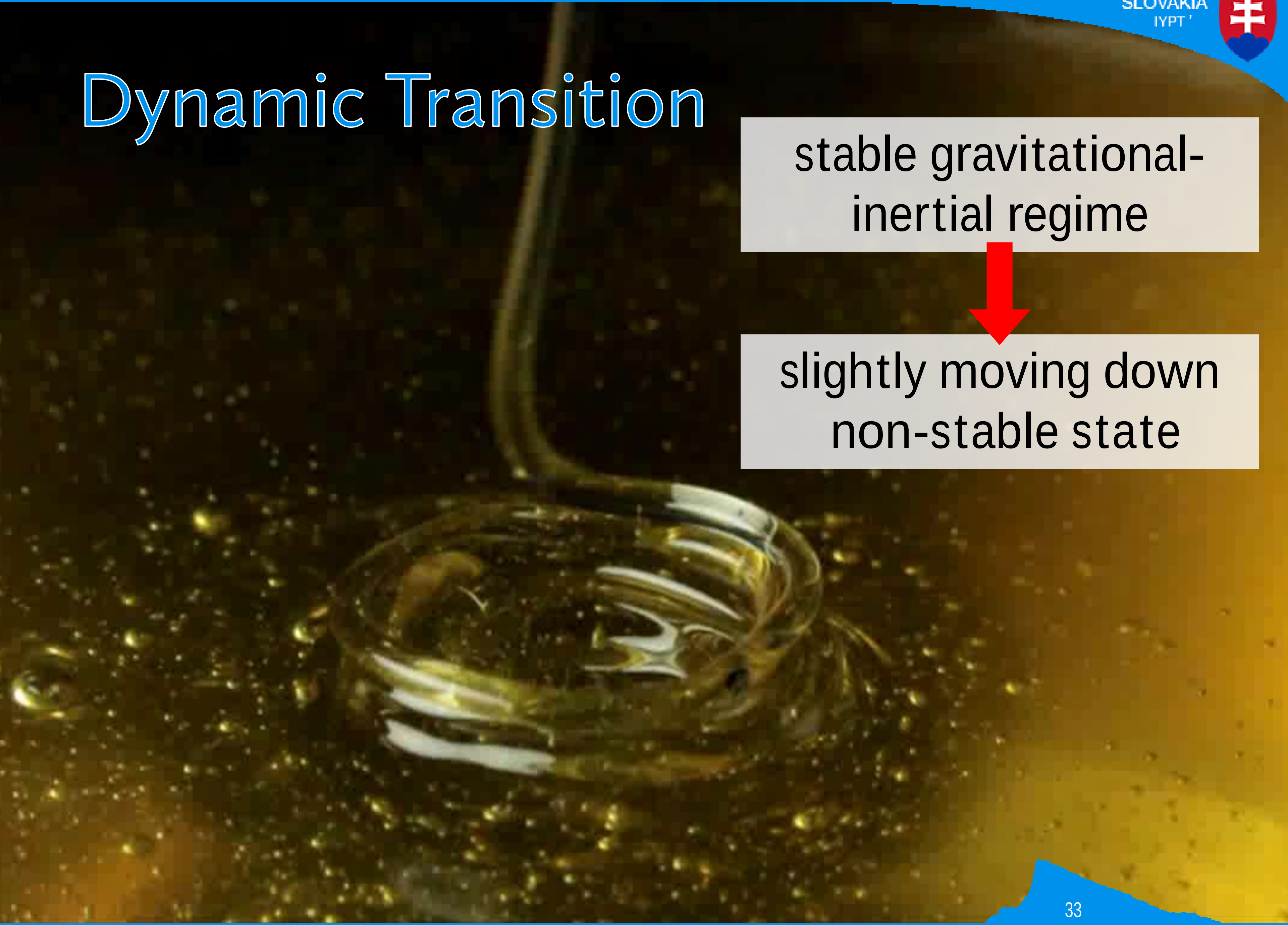
- 8-like pattern
- “history” is important (hysteresis)

Dynamic Transition

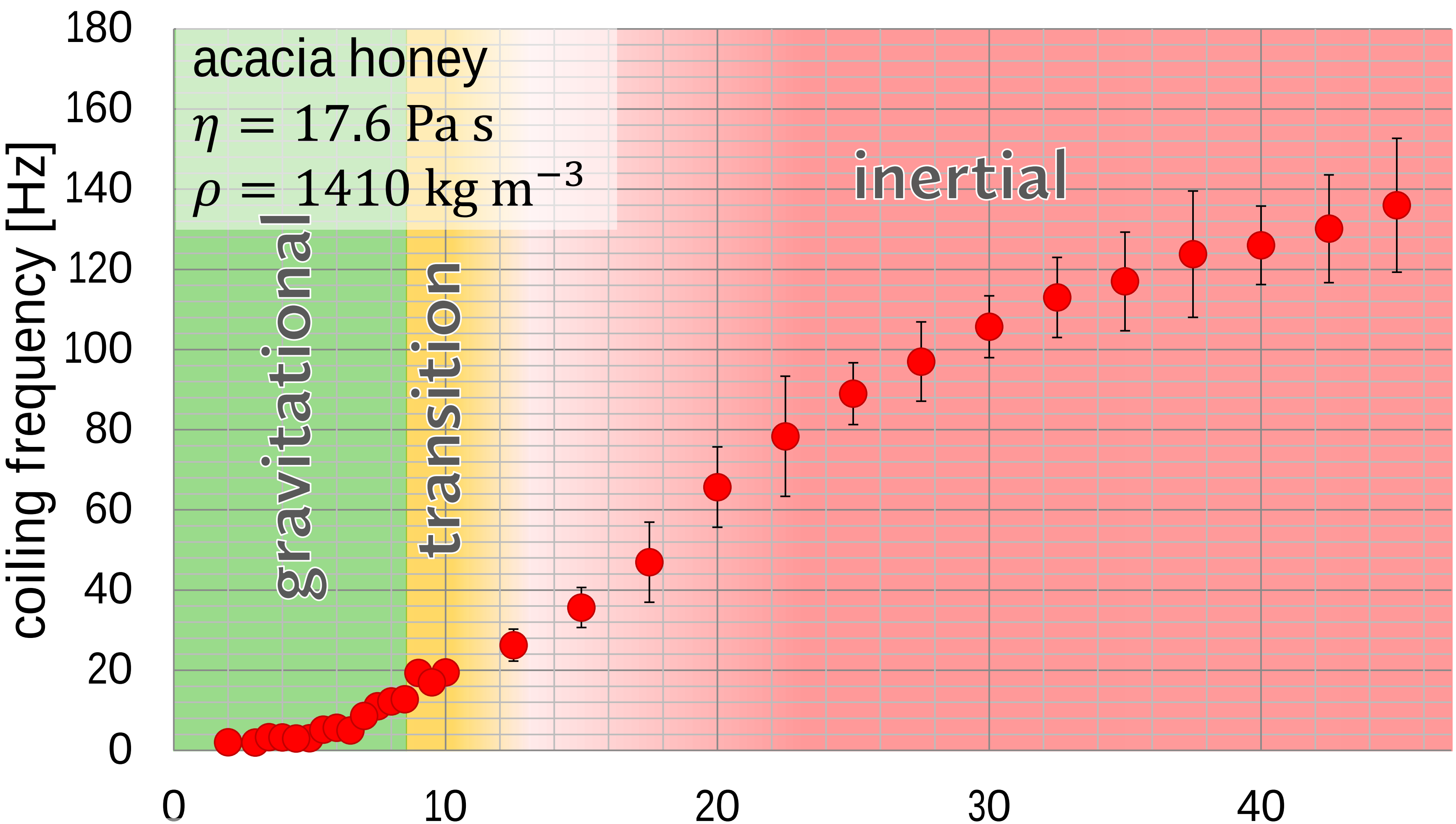
stable gravitational-inertial regime

↓

slightly moving down non-stable state



Coiling Frequency vs. Height of Fall



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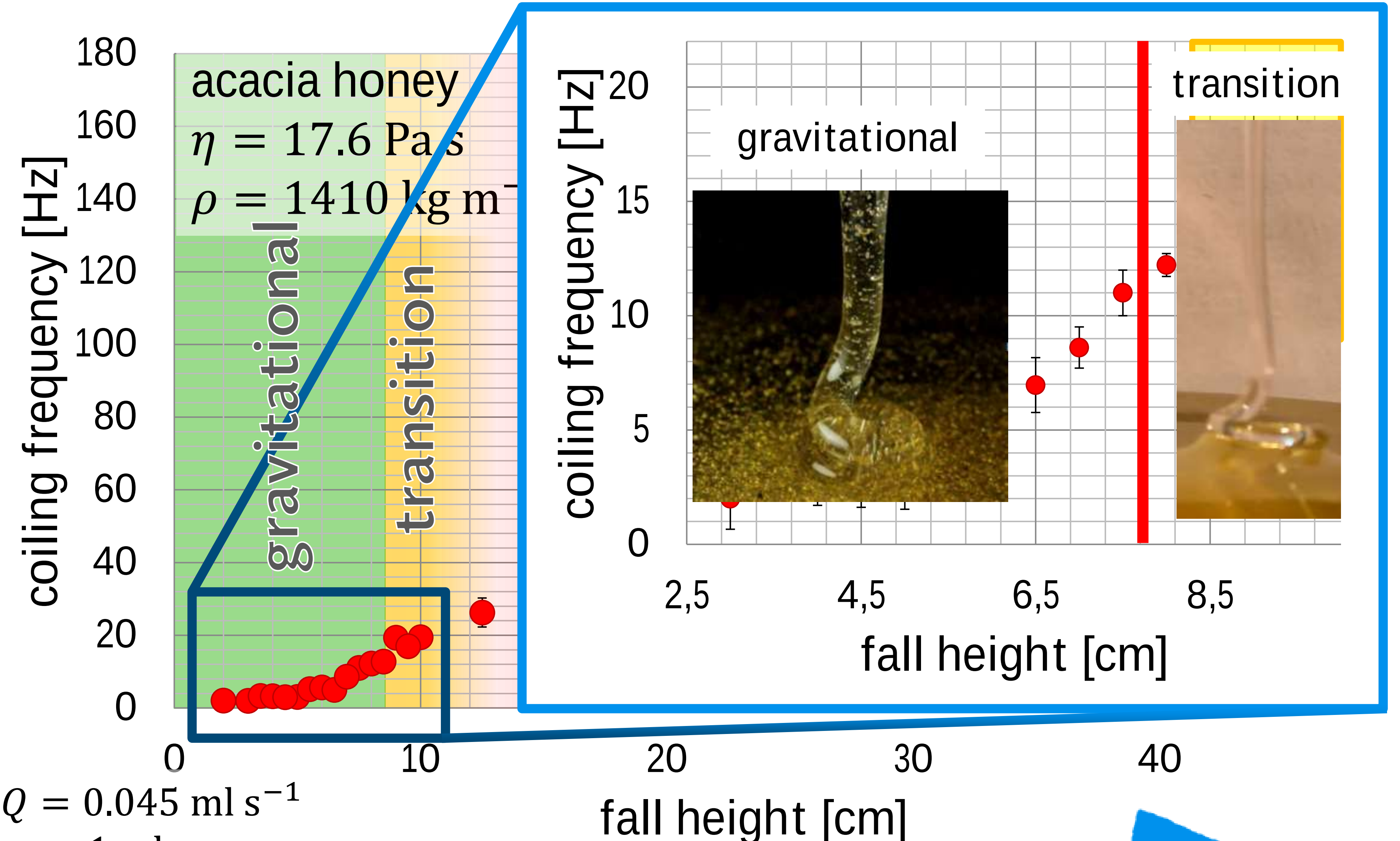

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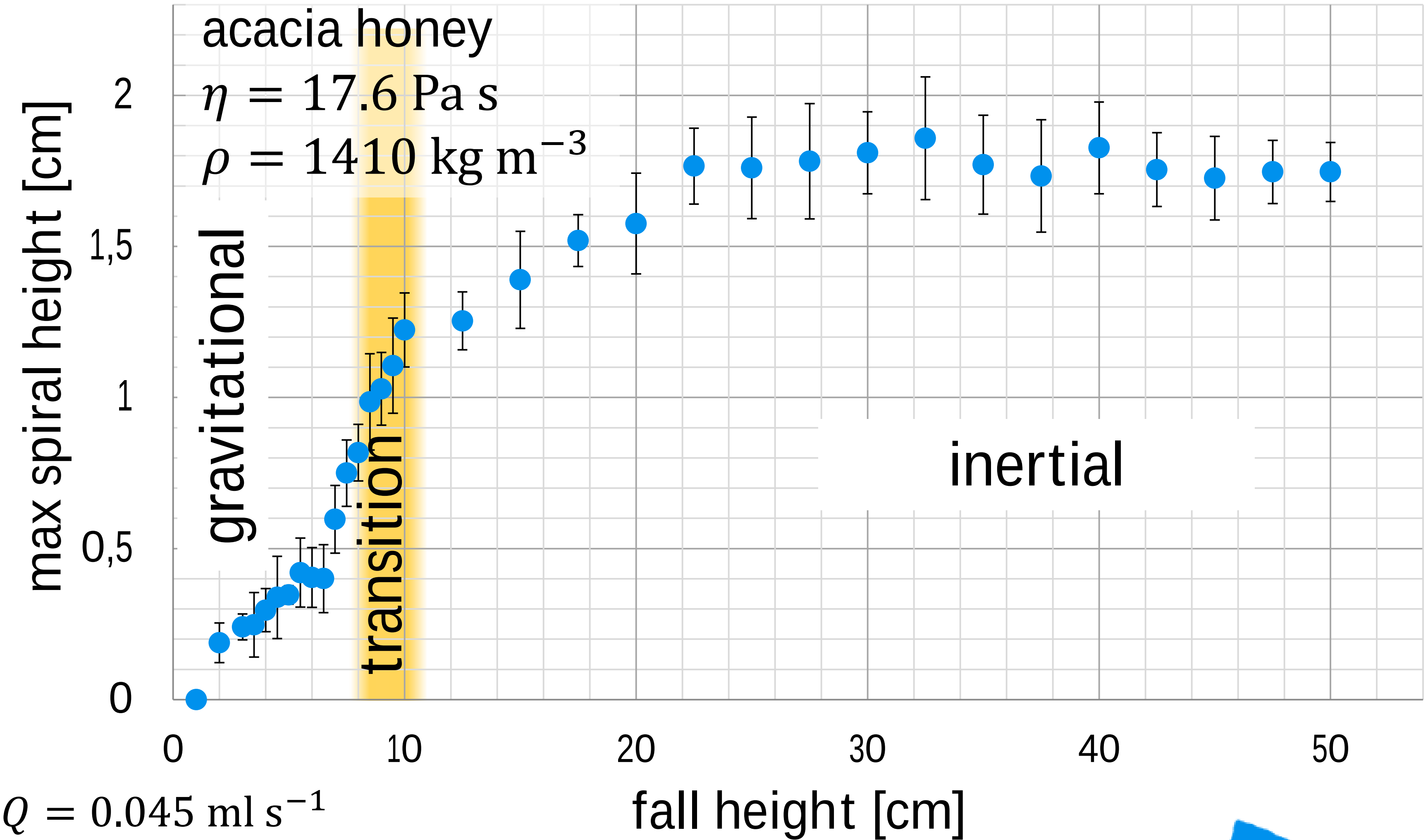

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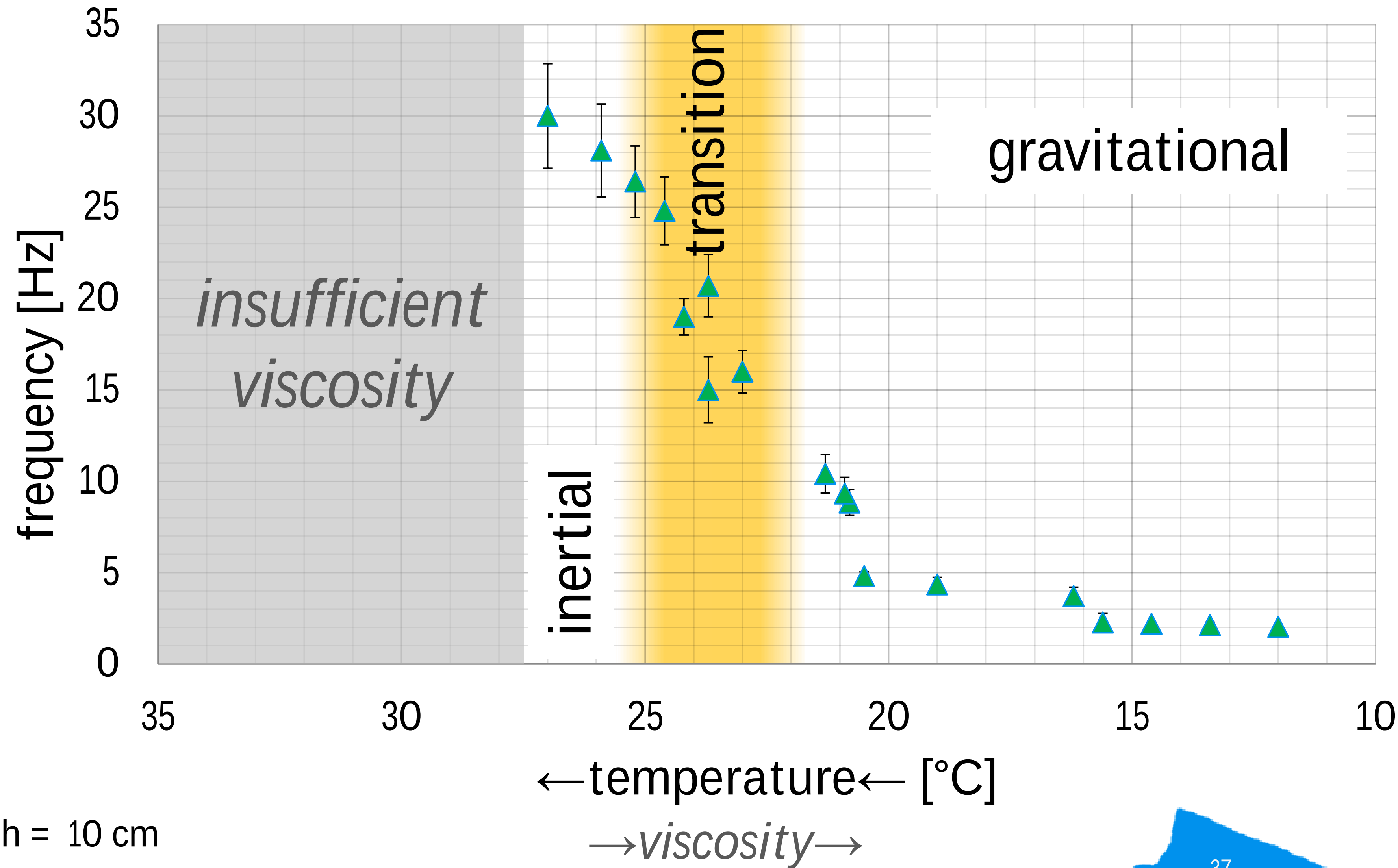
Coiling Frequency vs. Viscosity



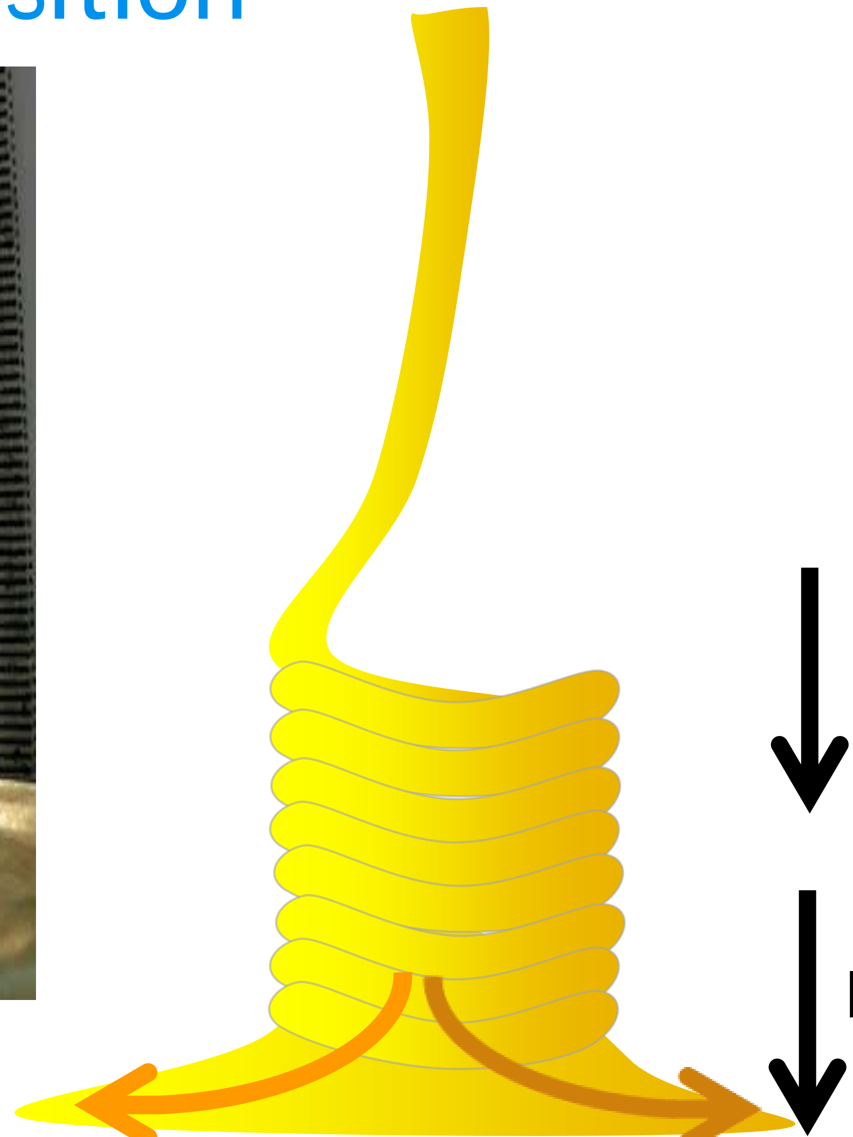
h = 10 cm

FURTHER OBSERVATIONS

Inertial Regime:

Stable Position

$$h \approx 10 \text{ cm}$$



Inertial Regime:

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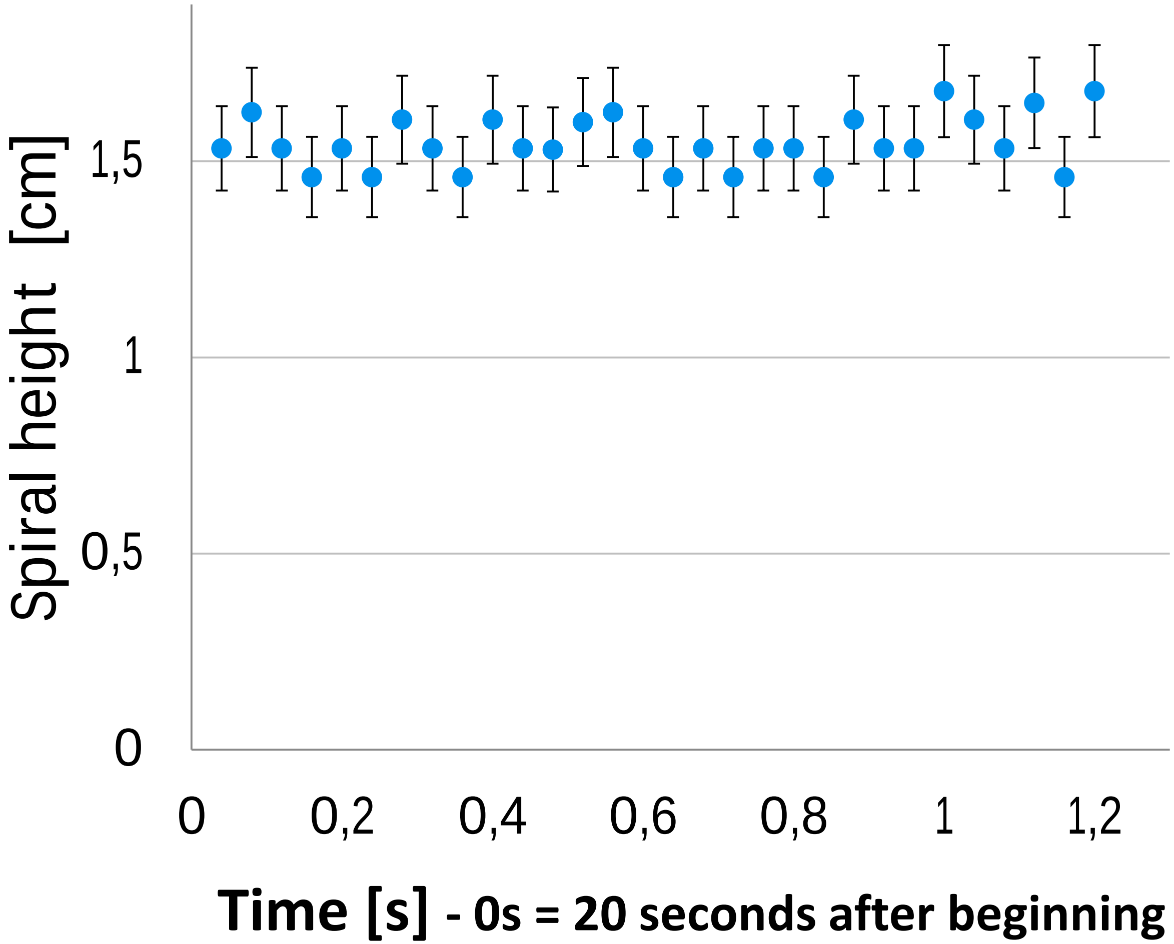
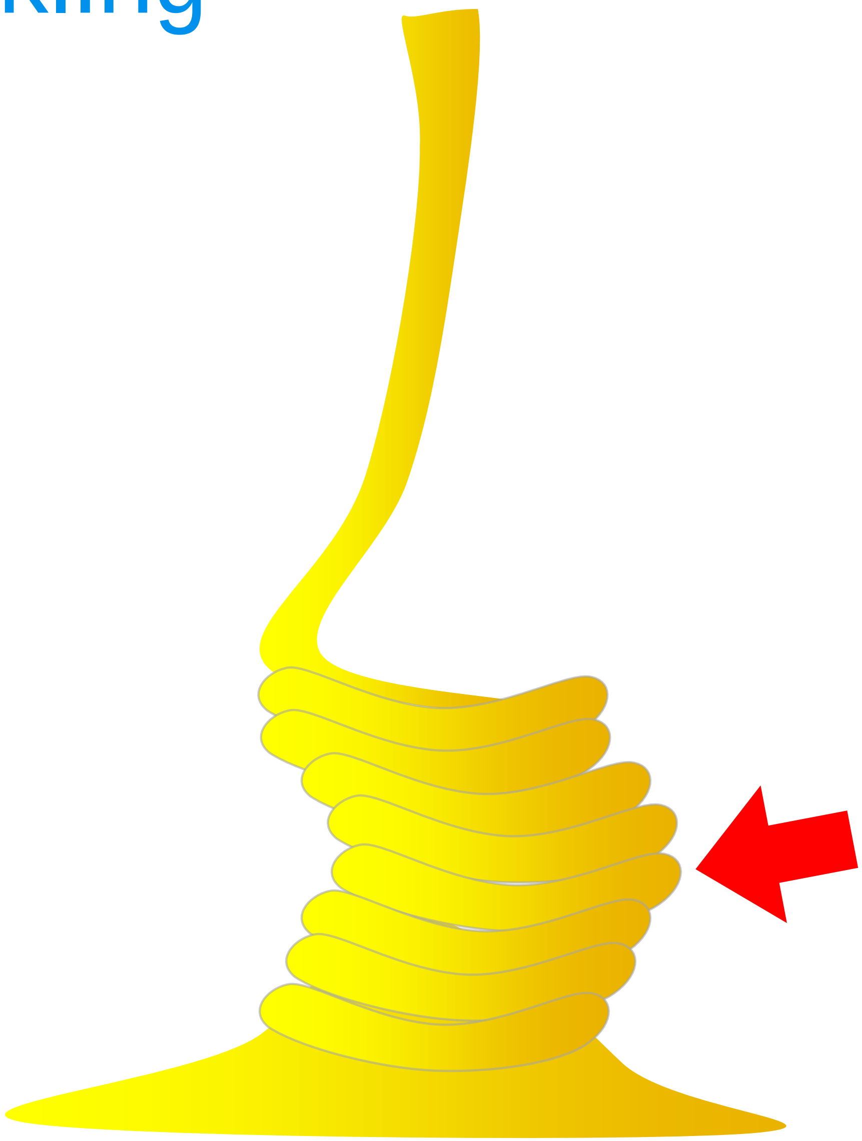


Inertial Regime:

Buckling

$h \approx 12$ cm



disturbance

instability

Inertial Regime:
Buckling

$$h \approx 12 \text{ cm}$$

low fall heights

stable

disruption
→ ***no effect***

bigger fall height

unstable

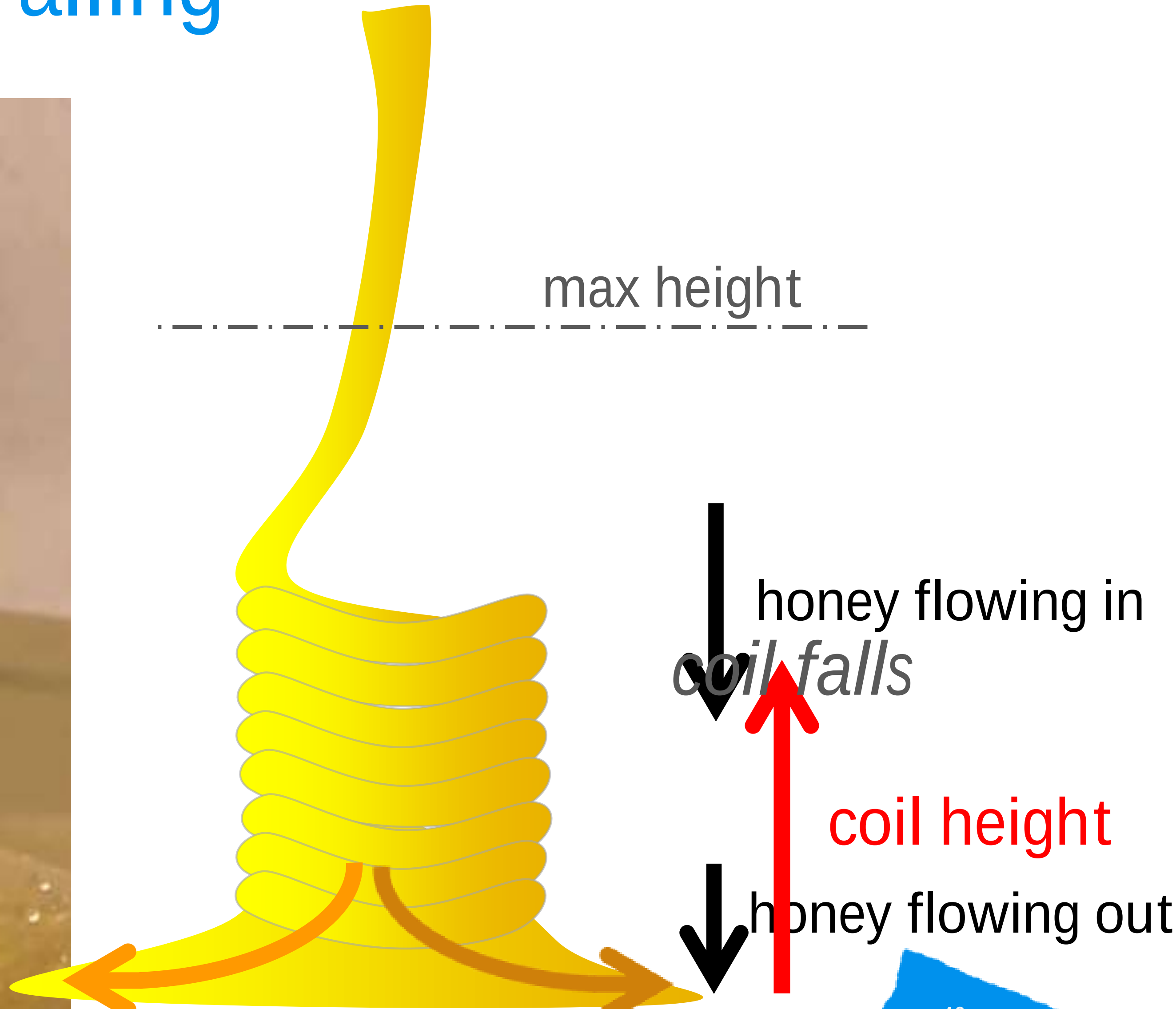
$t = 0$ s | $t = 0.1$ s | $t = 0.2$ s | $t = 0.3$ s

disruption
→ ***causes fall***

Inertial Regime:

Periodic Falling

$h > 20\ \text{cm}$



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Periodic Falling

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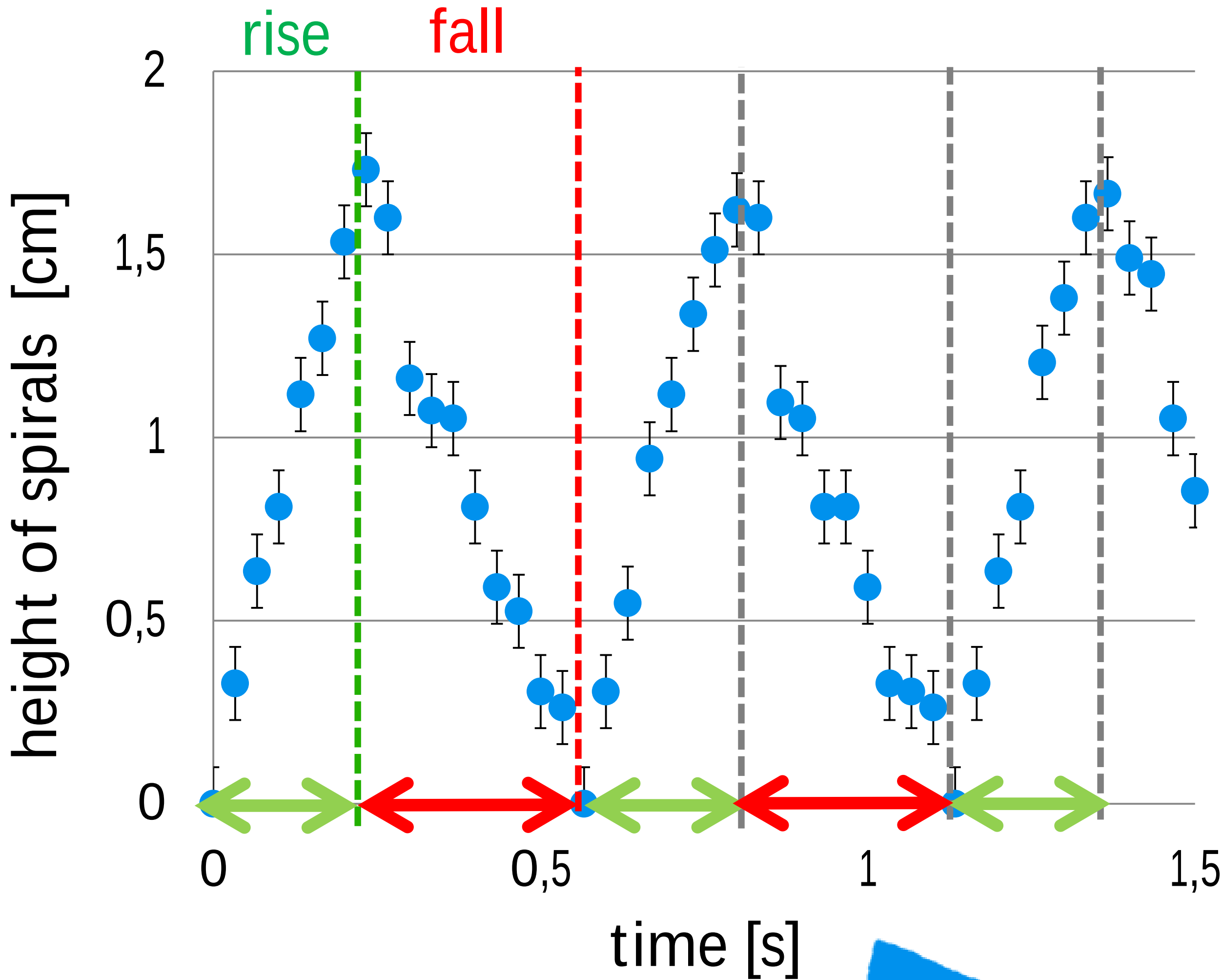

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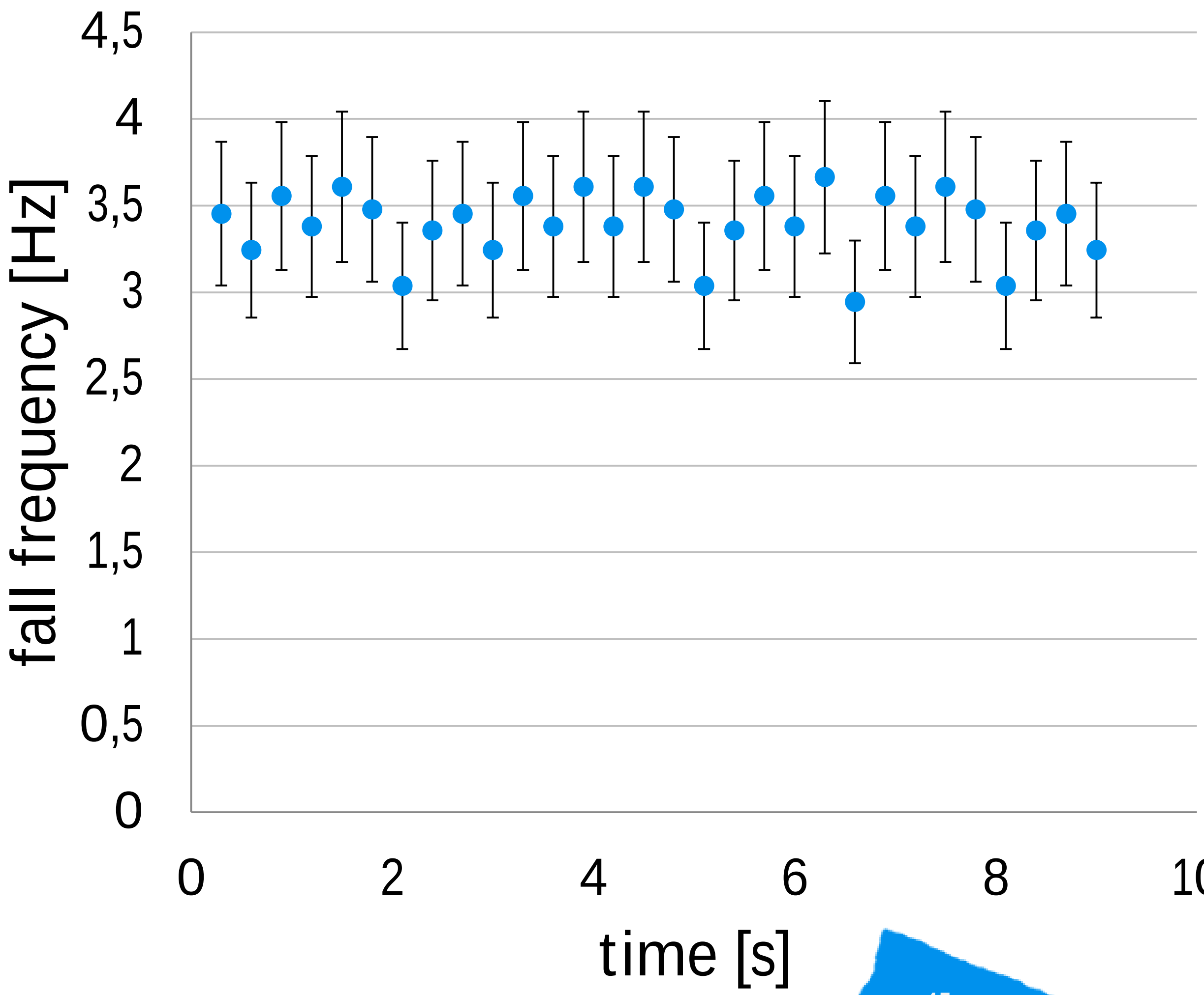
Periodic Falling

$h > 20\ \text{cm}$



Inertial Regime:
"Coilception"

$h \gg 20\text{ cm}$

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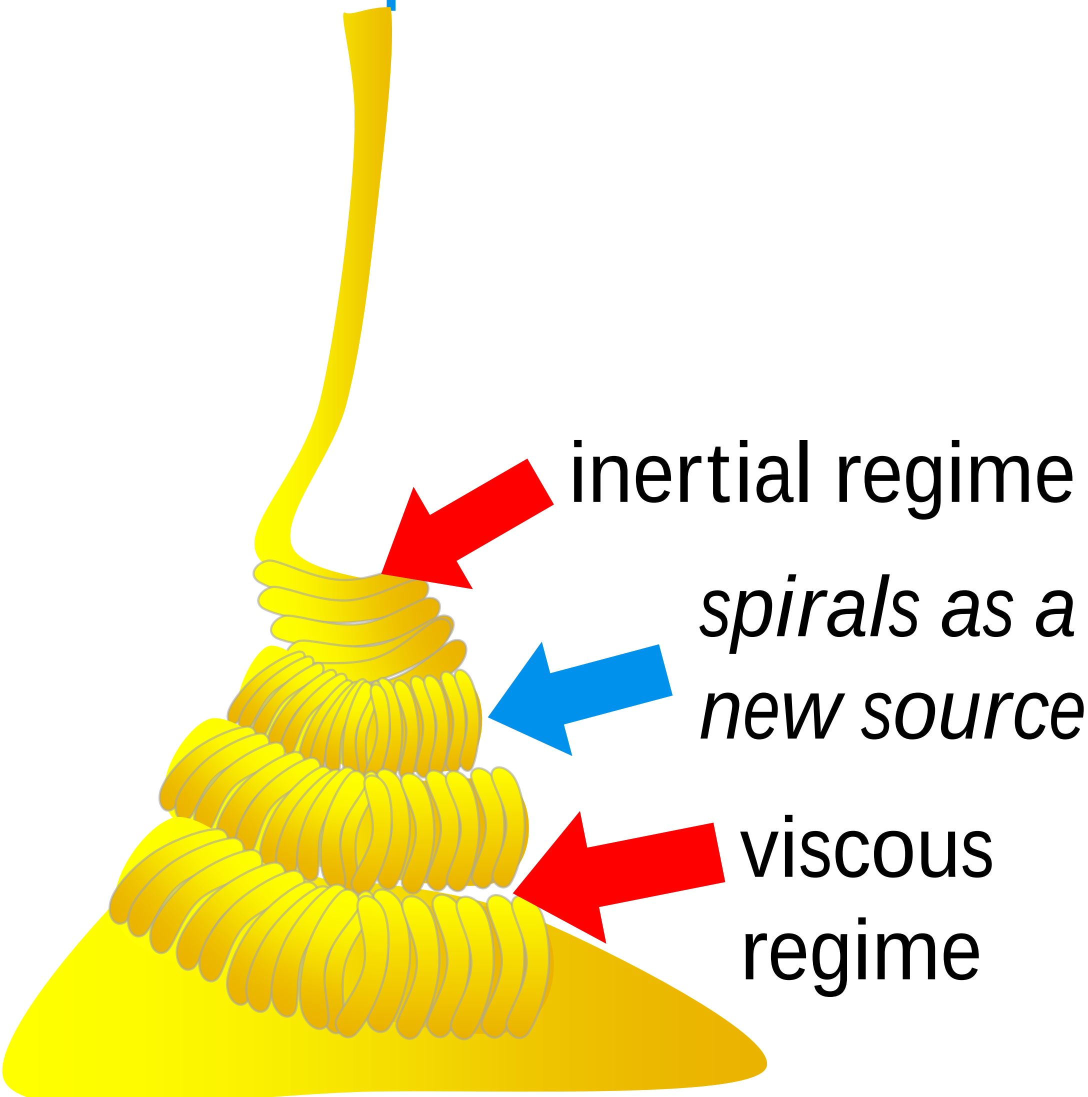
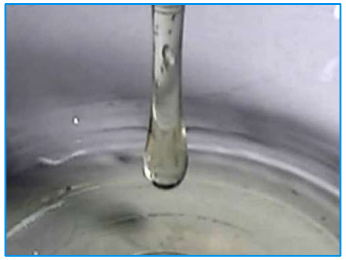
"Coilception"

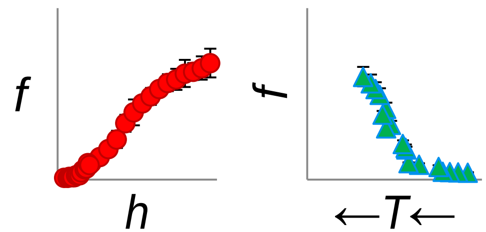
$h \gg 20\ \mathrm{cm}$



Conclusion

Thank you for your attention!



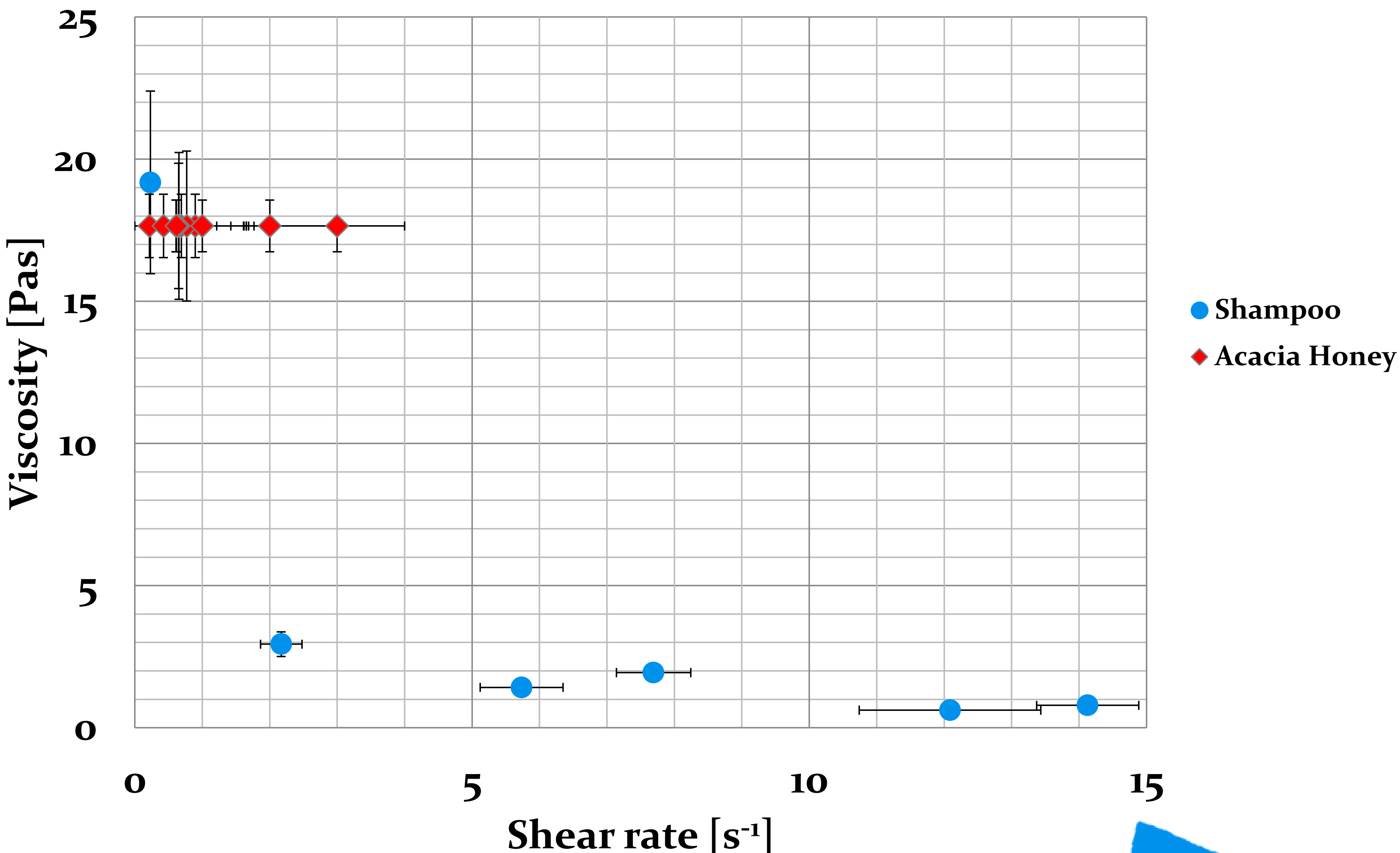


- dynamics of creation shown
- *viscous forces qualitatively equivalent to elasticity*
- influence of relevant parameters:
  - height
  - viscosity
- different regimes
  1. viscous
  2. gravitational
  - gravitational-inertial (transition)
  3. inertial

+ additional effects shown

APPENDICES

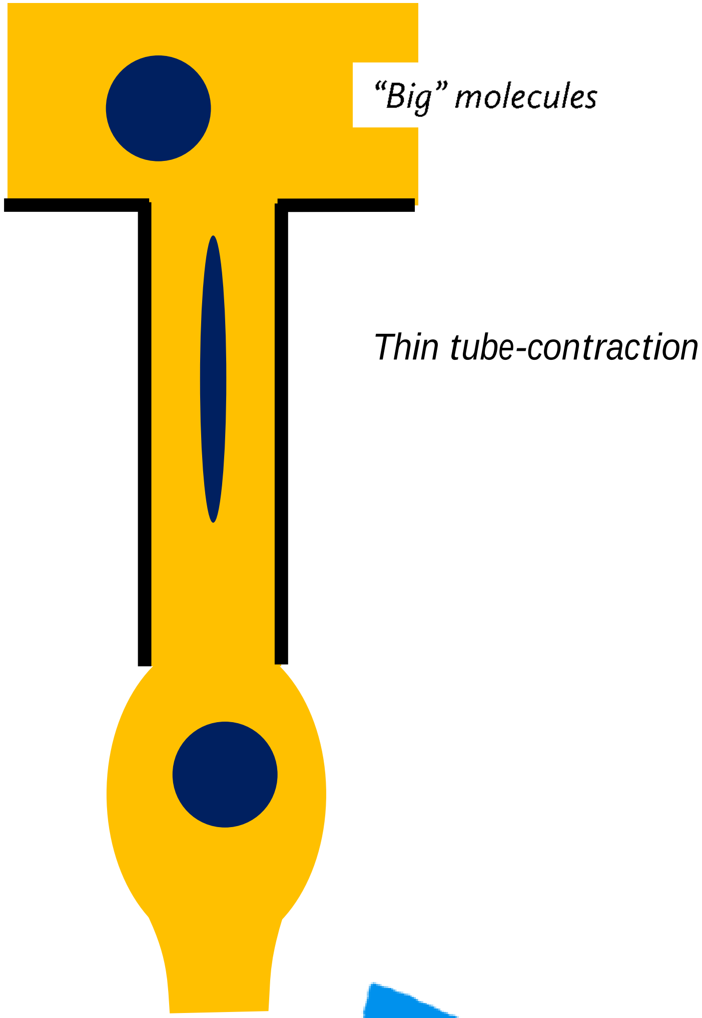
What does the viscosity look like?



Viscoelasticity

The fluid can have „**memory**“

„Die Swell“ effect



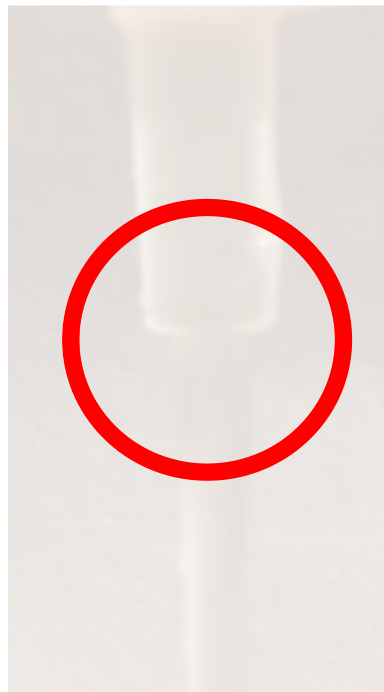
Die Swell?

Shampoo

Agate honey

Glycerol

Circular spirals

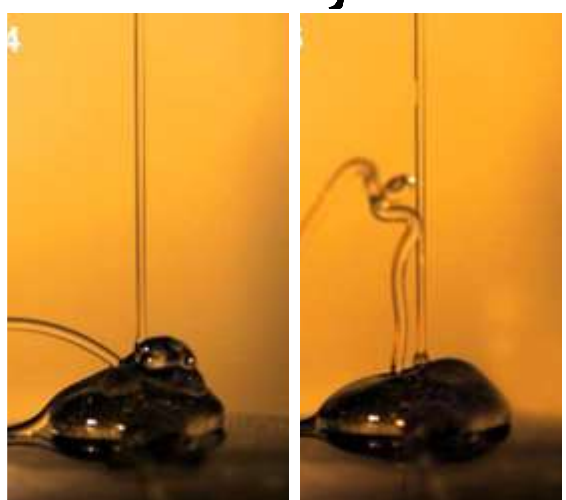


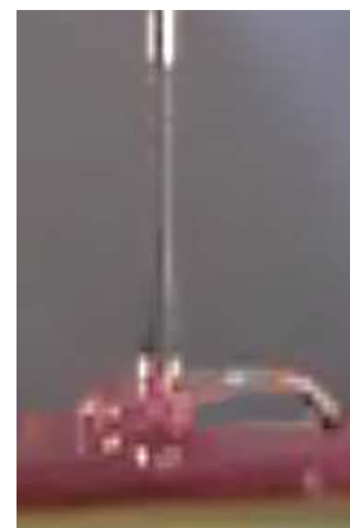
Just bending

Shampoo

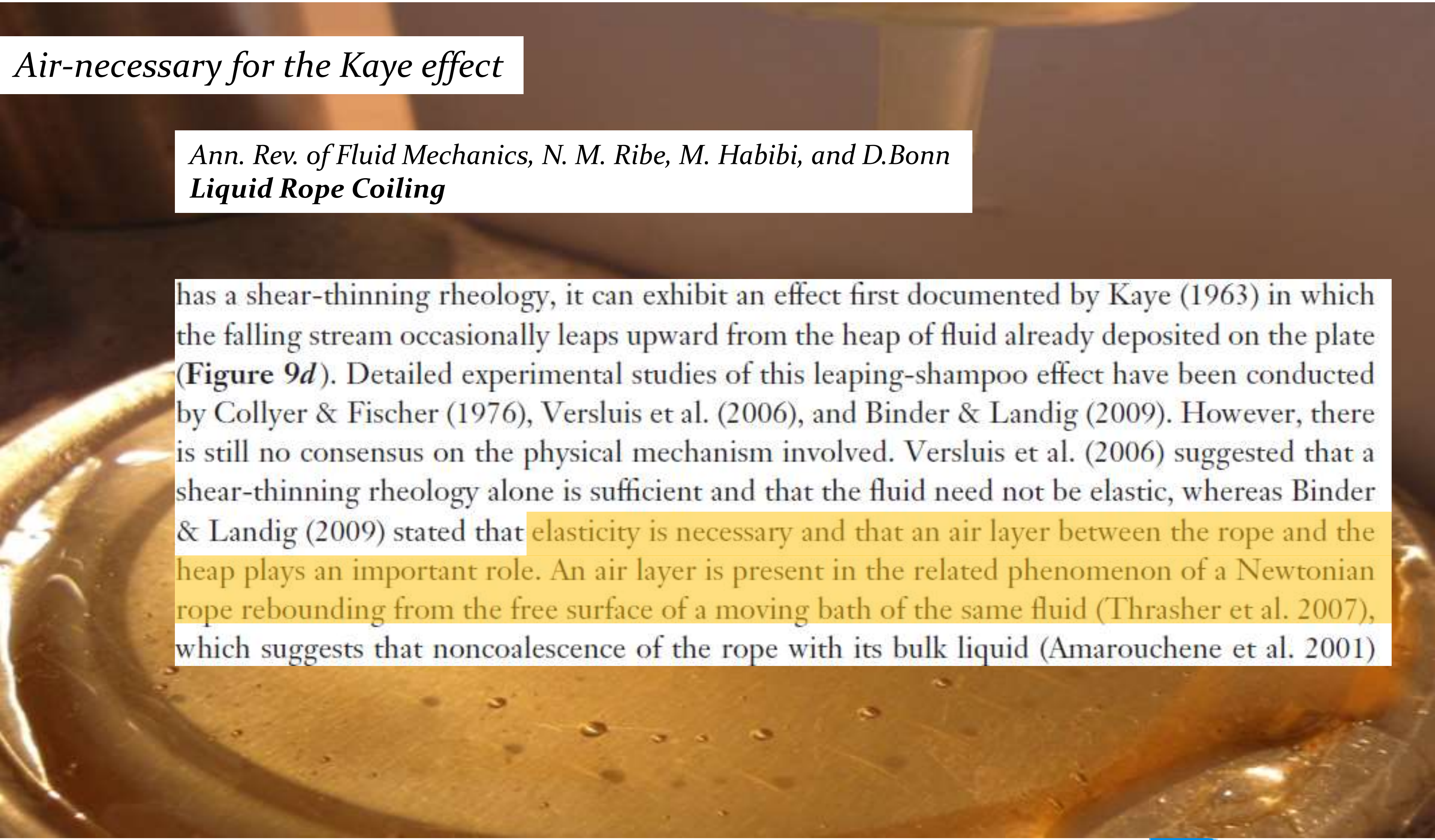
- No observed viscous regime
- Similar behavior
- **Without inertial regimes**

Kaye effect





Bubbles-on the way to the Kaye effect



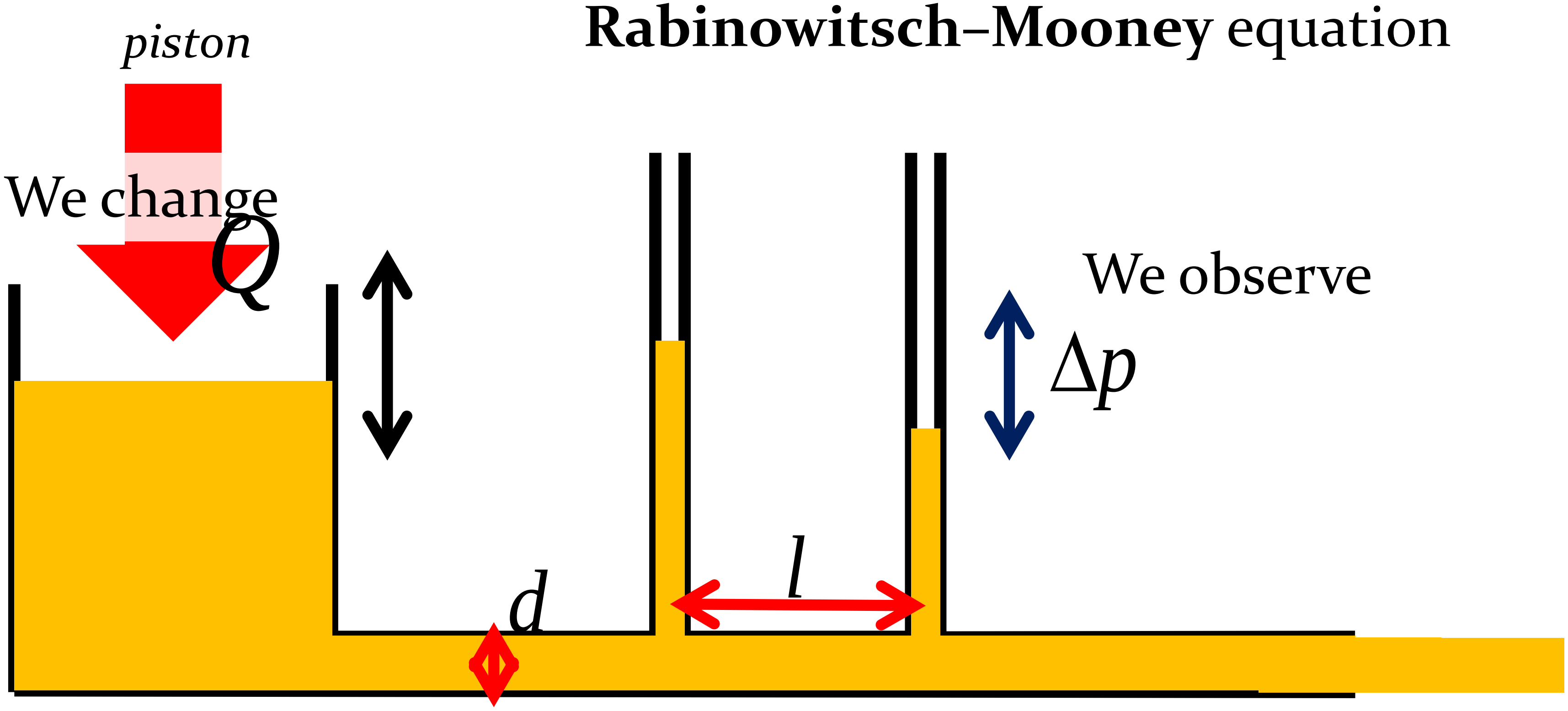
Air-necessary for the Kaye effect

Ann. Rev. of Fluid Mechanics, N. M. Ribe, M. Habibi, and D.Bonn
Liquid Rope Coiling

has a shear-thinning rheology, it can exhibit an effect first documented by Kaye (1963) in which the falling stream occasionally leaps upward from the heap of fluid already deposited on the plate (**Figure 9*d***). Detailed experimental studies of this leaping-shampoo effect have been conducted by Collyer & Fischer (1976), Versluis et al. (2006), and Binder & Landig (2009). However, there is still no consensus on the physical mechanism involved. Versluis et al. (2006) suggested that a shear-thinning rheology alone is sufficient and that the fluid need not be elastic, whereas Binder & Landig (2009) stated that elasticity is necessary and that an air layer between the rope and the heap plays an important role. An air layer is present in the related phenomenon of a Newtonian rope rebounding from the free surface of a moving bath of the same fluid (Thrasher et al. 2007), which suggests that noncoalescence of the rope with its bulk liquid (Amarouchene et al. 2001)

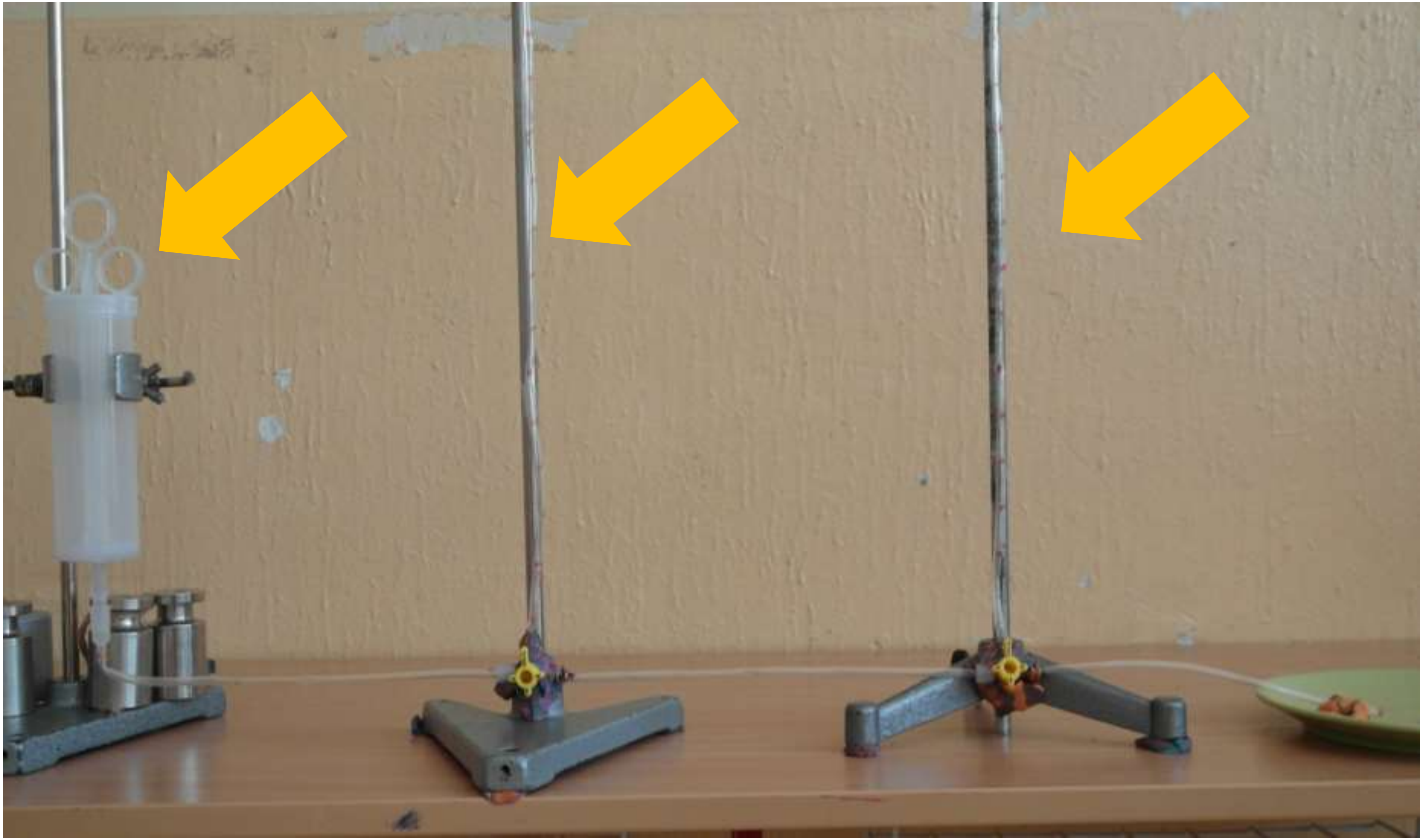
Tube viscometer

Rabinowitsch–Mooney equation

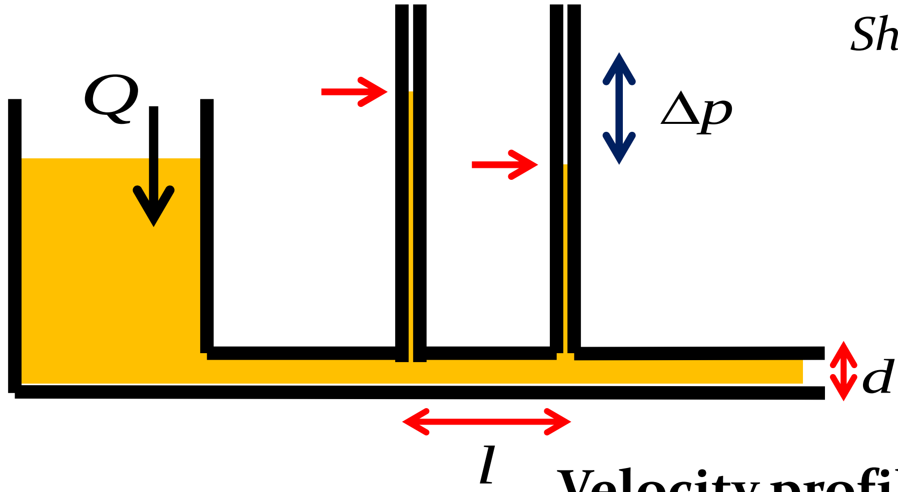


Method from : "*R. Bragg, F. A. Holland; Fluid Flow for Chemical Engineers*"

Measuring viscosity



Measuring rheology-theory



Shear stress on the wall– stabilized flow

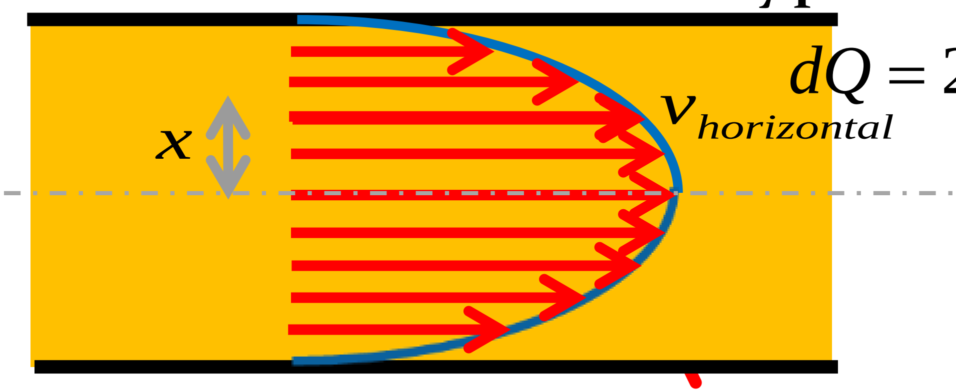
$$\tau_{wall} = \frac{d}{4}\left(\frac{\Delta p}{l}\right)$$

Pressure change

Volumetric flow rate

$$Q = \int dQ = \int_0^{\frac{d}{2}} 2\pi x v_h dx$$

Velocity profile



$$dQ = 2\pi x v_h dx$$

Integrating per partes

$$\int_0^{\frac{d}{2}} 2\pi x v_h dx = 2\pi\left[\frac{x^2 v_h}{2}\right]_0^{\frac{d}{2}} + 2\pi\int_0^{\frac{d}{2}} \frac{x^2}{2}\left(-\frac{dv_h}{dx}\right)dx$$

Velocity gradient

0 – Stabilized flow– No „Slipping“)

Method from : “*R. Bragg, F. A. Holland; Fluid Flow for Chemical Engineers*”

Measuring rheology

Volumetric flow rate

$$Q = \pi \int_0^{\frac{d}{2}} x^2 \left(-\dot{\gamma}\right) dx$$

Gradually editing

$$Q = \pi \frac{d^3}{8\tau_{wall}^3} \int_0^{\frac{d}{2}} \tau^2 \left(-\dot{\gamma}\right) d\tau$$

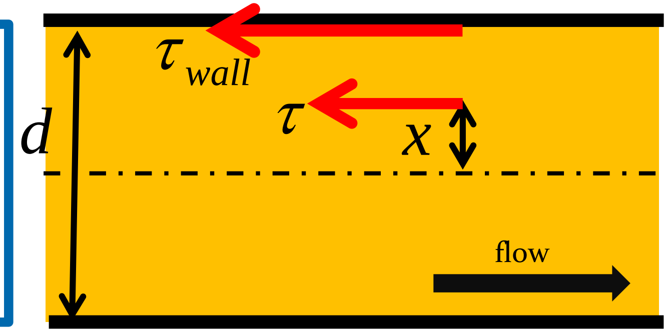
Differentiating relative to τ *and editing*

$$\dot{\gamma}_{wall} = -\frac{32Q}{\pi d^3} \left(\frac{3}{4} + \frac{1}{4} \frac{d \ln\left(\frac{32Q}{\pi d^3}\right)}{d \ln \tau_{wall}} \right)$$

Rabinowitsch–Mooney equation

For the flow in the tube

$$\frac{\tau_x}{\tau_{wall}} = \frac{2x}{d}$$



Z "R. Bragg, F. A. Holland; Fluid Flow for Chemical Engineers"

$$\tau_{wall} = \frac{d}{4}\left(\frac{\Delta p}{l}\right)$$

Measuring rheology-Agate honey

Rabinowitsch–Mooney equation

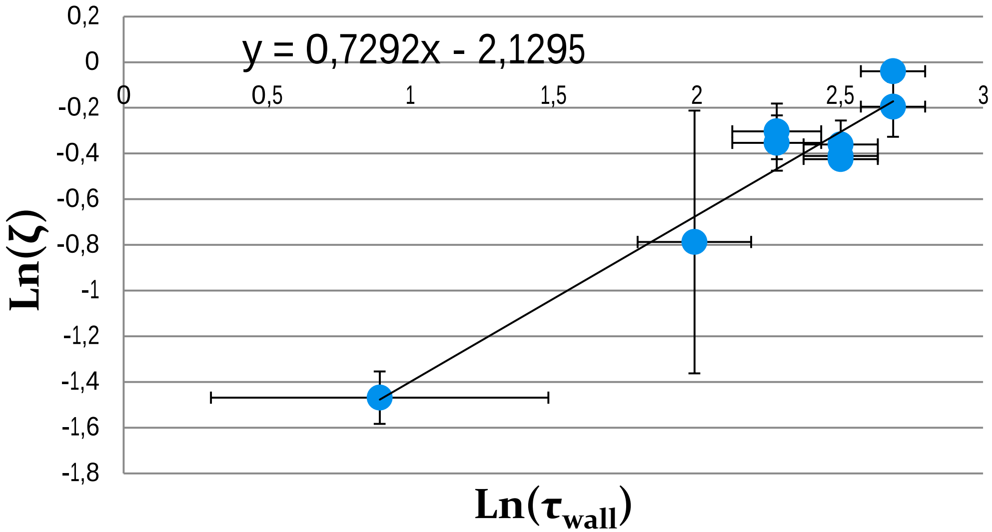
$$\dot{\gamma}_{wall} = -\underbrace{\frac{32Q}{\pi d^3}}_{\zeta}\left(\frac{3}{4} + \frac{1}{4}\frac{d\ln\left(\frac{32Q}{\pi d^3}\right)}{d\ln\tau_{wall}}\right)$$

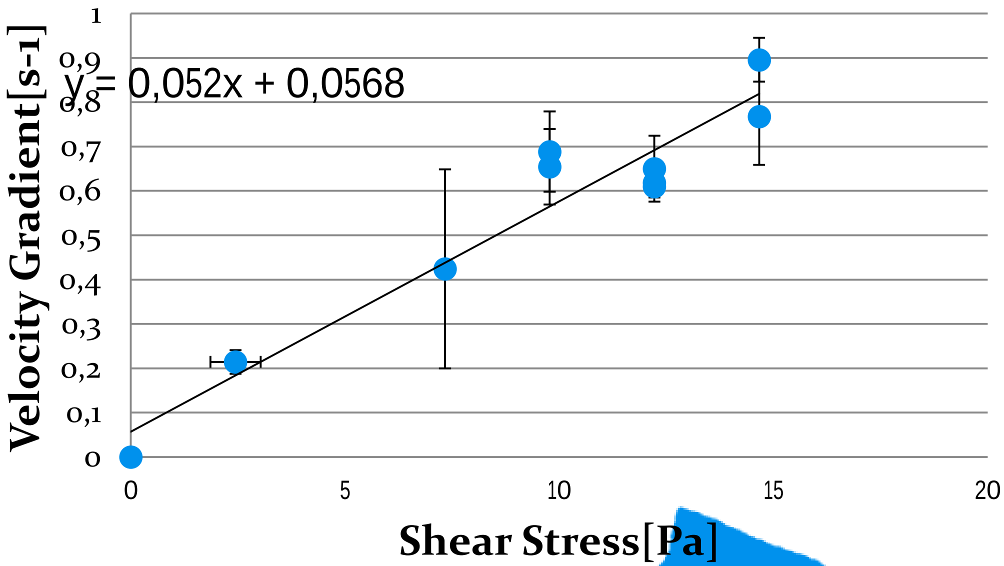
Steady flow

$$\tau_{wall} = \frac{d}{4}\left(\frac{\Delta p}{l}\right)$$

$$\frac{d\ln\left(\frac{32Q}{\pi d^3}\right)}{d\ln\tau_{wall}} \doteq 0{,}7292$$

$$\eta = \frac{\tau_{wall}}{\dot{\gamma}_{wall}} \doteq \frac{1}{0{,}052} \doteq 17{,}6 Pas$$





Measuring rheology-Shampoo

Rabinowitsch–Mooney equation

$$\dot{\gamma}_{wall} = -\underbrace{\frac{32Q}{\pi d^3}}_{\zeta}\left(\frac{3}{4}+\frac{1}{4}\frac{d\ln\left(\frac{32Q}{\pi d^3}\right)}{d\ln\tau_{wall}}\right)$$

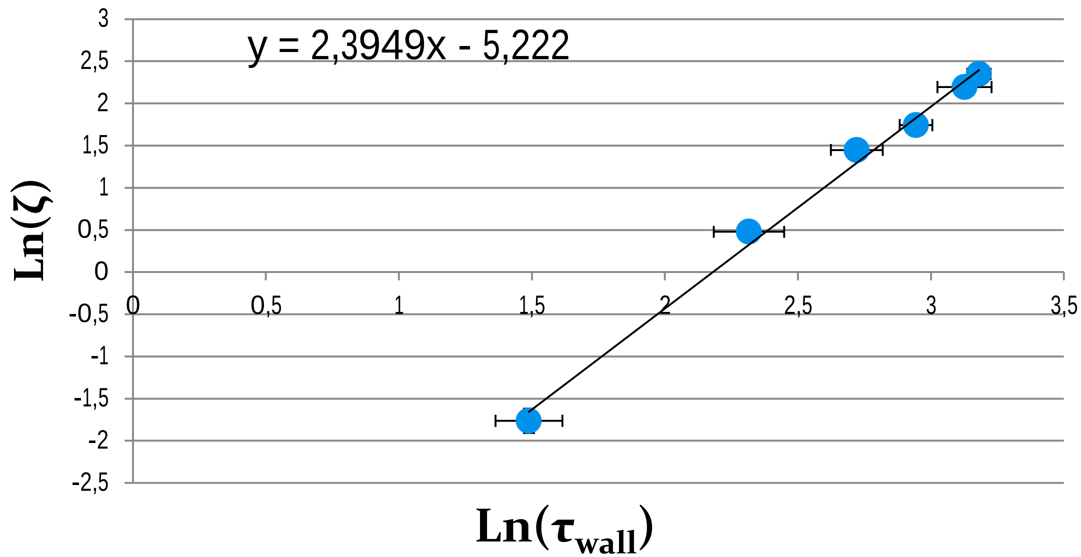
Stabilized flow

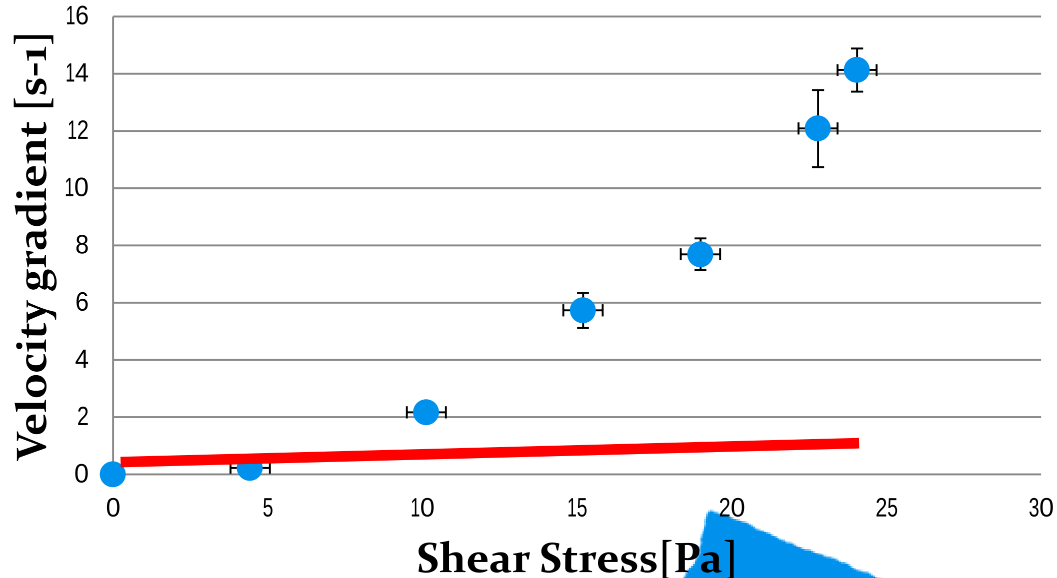
$$\tau_{wall} = \frac{d}{4}\left(\frac{\Delta p}{l}\right)$$

$$\frac{d\ln\left(\frac{32Q}{\pi d^3}\right)}{d\ln\tau_{wall}} \doteq 2{,}39$$

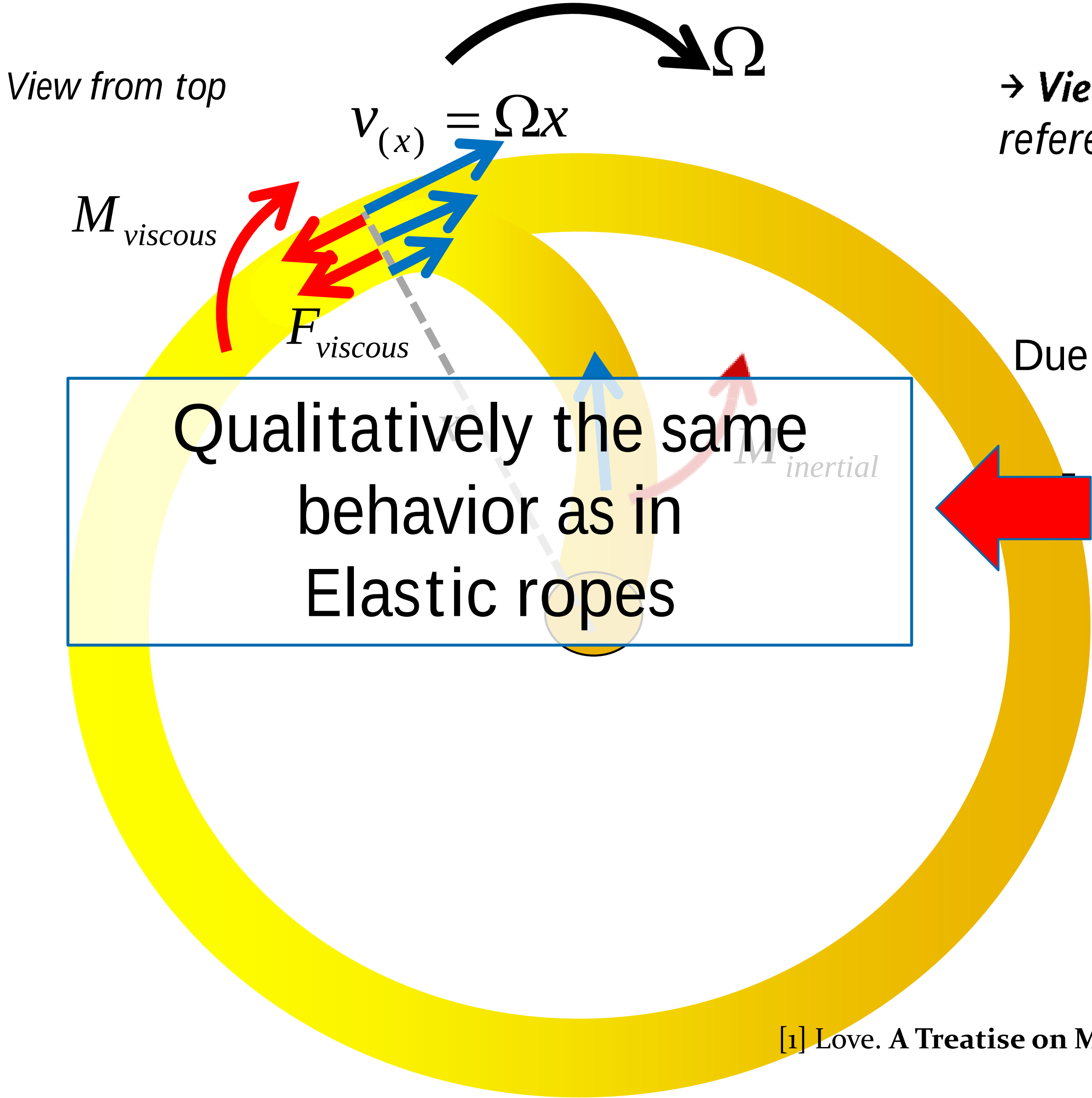
Viscosity largest in the beginning

$$\eta_{biggest} = \frac{\tau_{wall}}{\dot{\gamma}_{wall}} \doteq 19{,}6\,Pas$$





Why is it the shape stable?



Qualitatively the same behavior as in Elastic ropes

→ ***View from*** *corotating frame of reference*

$$F_{viscous} \longrightarrow \sigma_{longitudal}$$

Due to Rayleigh-Stokes analogy[1]

$$\int \sigma dA = 0 = F_{net}$$

$$\int \sigma r dA \neq 0 = M_{viscous}$$

Equilibrium implies

$$\sum \vec{M} = 0$$

Torques of (Centrifugal, Coriolis) → ***Stable shape***

Proved in L. Mahadevan, William S. Ryu and Aravinthan D.T. Samuel *Fluid rope trick investigated.* Nature, *Volume 392 Number 6672.*1998

[1] Love. **A Treatise on Mathematical Theory of Elasticity**. *Dover 1944*