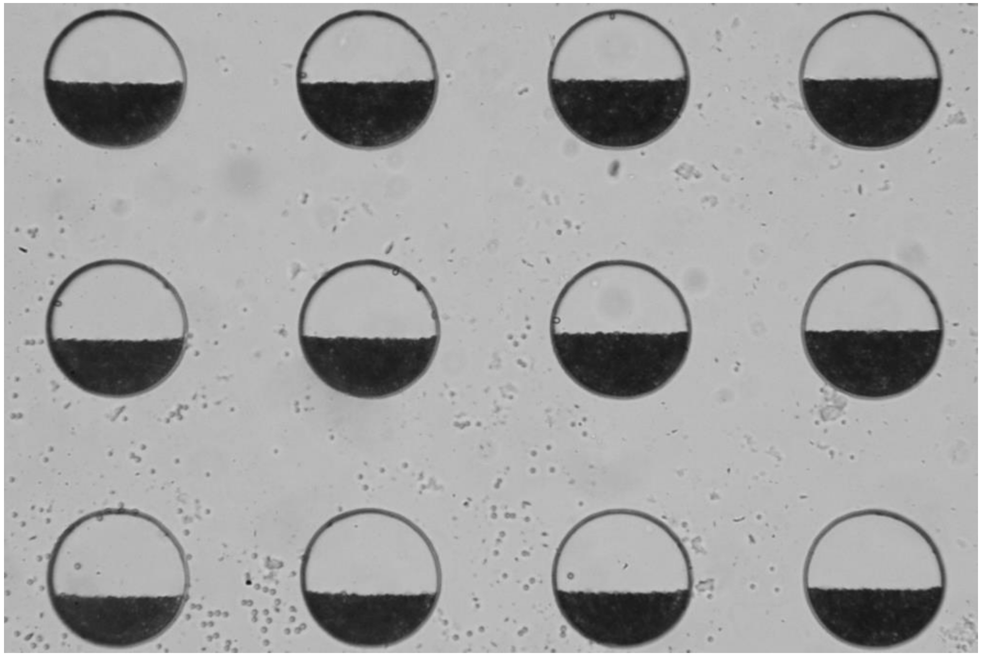
Creep behavior in piles of dense colloids confined by gravity

TPCE 2019



Antoine Bérut[ab], Olivier Pouliquen[b], Yoël Forterre[b]

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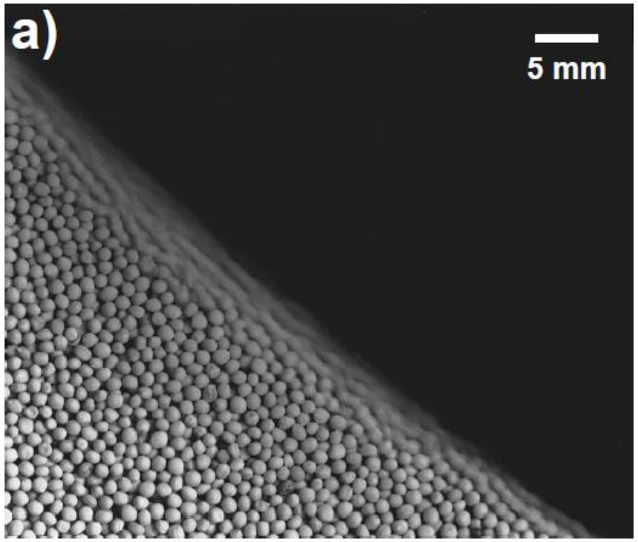
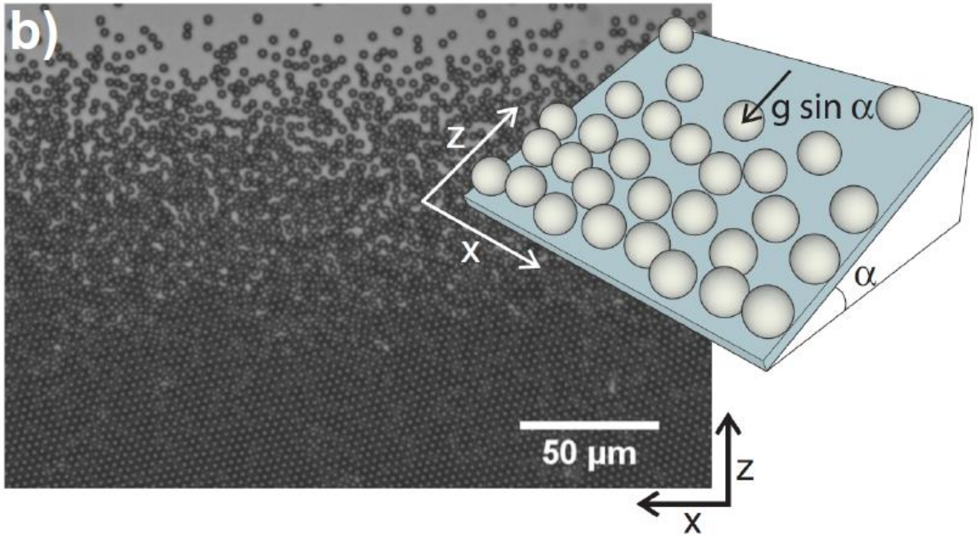
Granular materials VS Colloids

Similarities: both made of an ensemble of independent grains



Mustard grains avalanche, from Jaegger et al, Rev. Mod. Phys. **68**, 1259-1273 (1996)



2.79 µm melamine particles sedimenting, from Thorneywork et al. Phys. Rev. Lett. **118**, 158001 (2017)

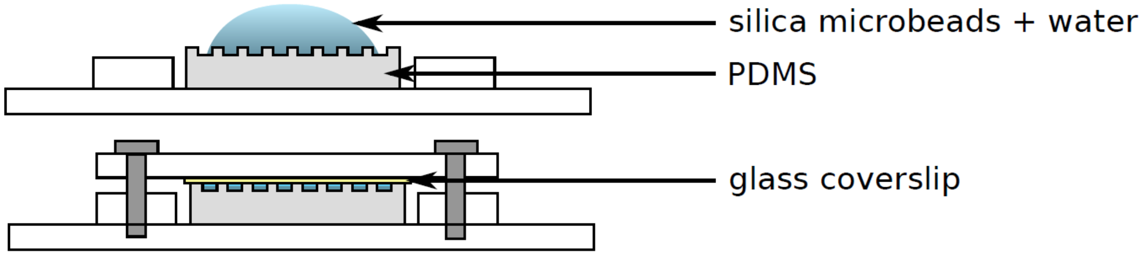
Differences:

- Granular materials: always in the athermal regime
- Colloids suspensions: always in the limit where thermal forces are dominant

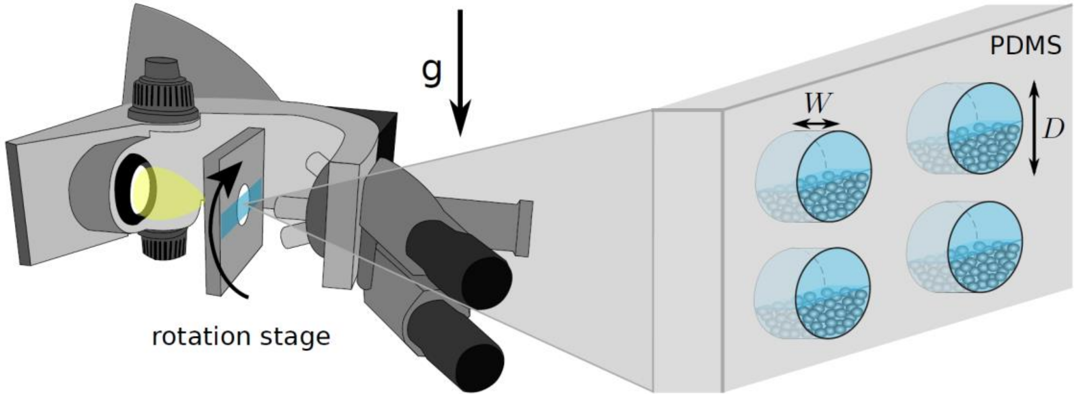
➔ **What happens in between?**

Brownian granular material

Microfluidic cells

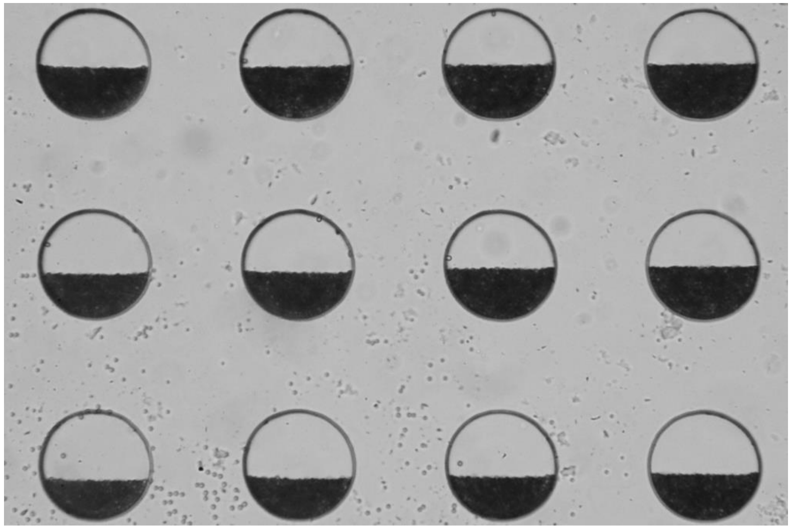


on an inclined microscope



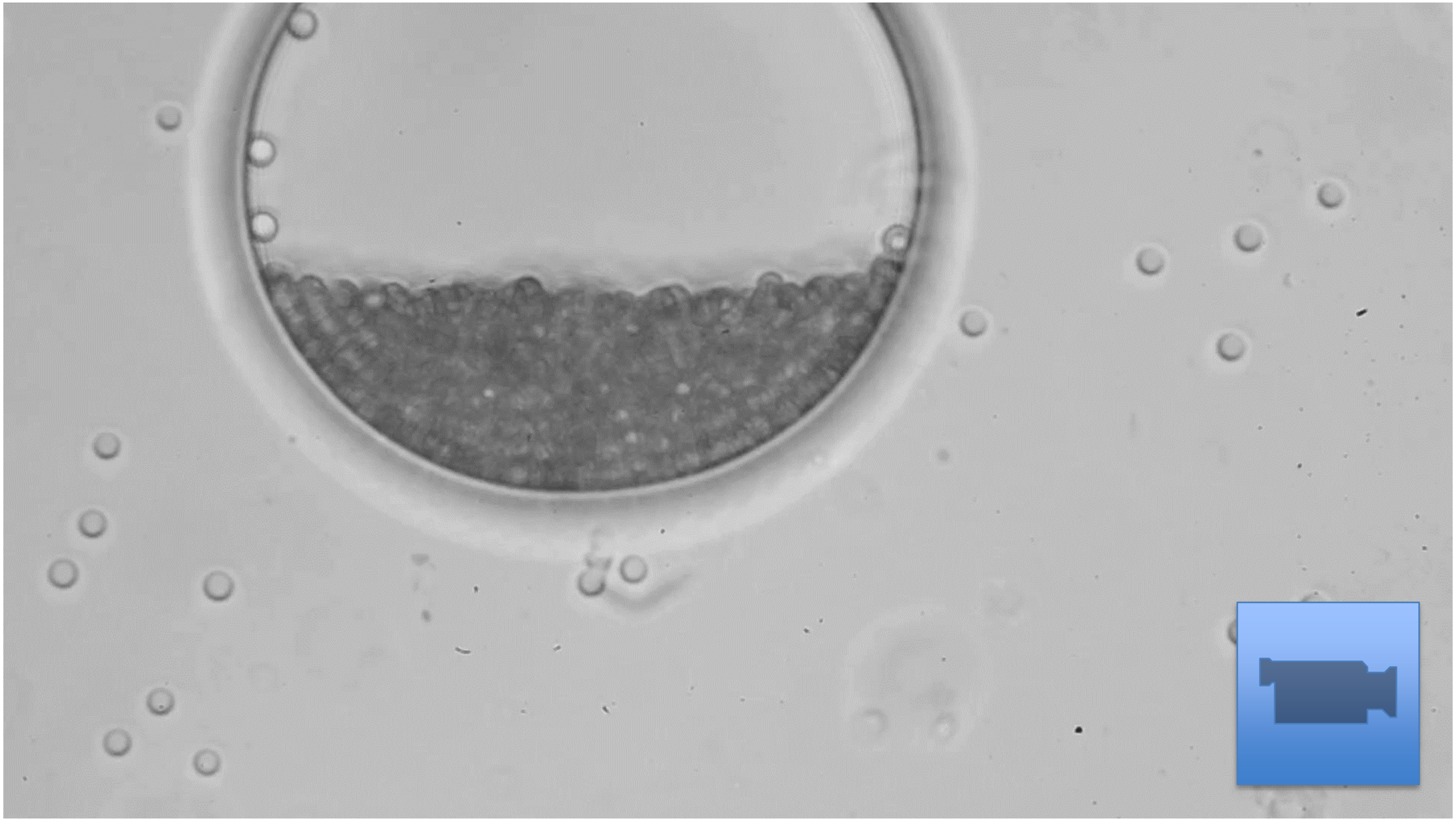
↓

100 microns drums filled with silica microparticles (different sizes)



What does it look like?

4.4 µm silica particles in 100 µm filled with water
(speed x10)



Relevant parameter(s)?

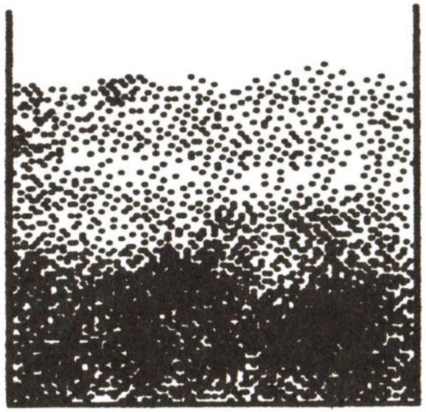
- Free Brownian diffusion:

Mean standard deviation: $\langle [x(t) - x(0)]^2 \rangle = D\, t$

with: $D = \dfrac{k_B T}{6\pi R \eta}$

→ Temperature/Viscosity competition

- When there's gravity (Perrin's law)



$$\rho(z) \sim e^{-mgz/k_B T}$$

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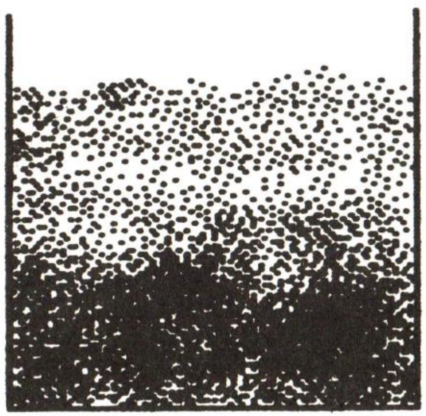

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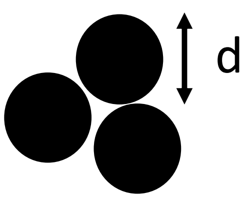
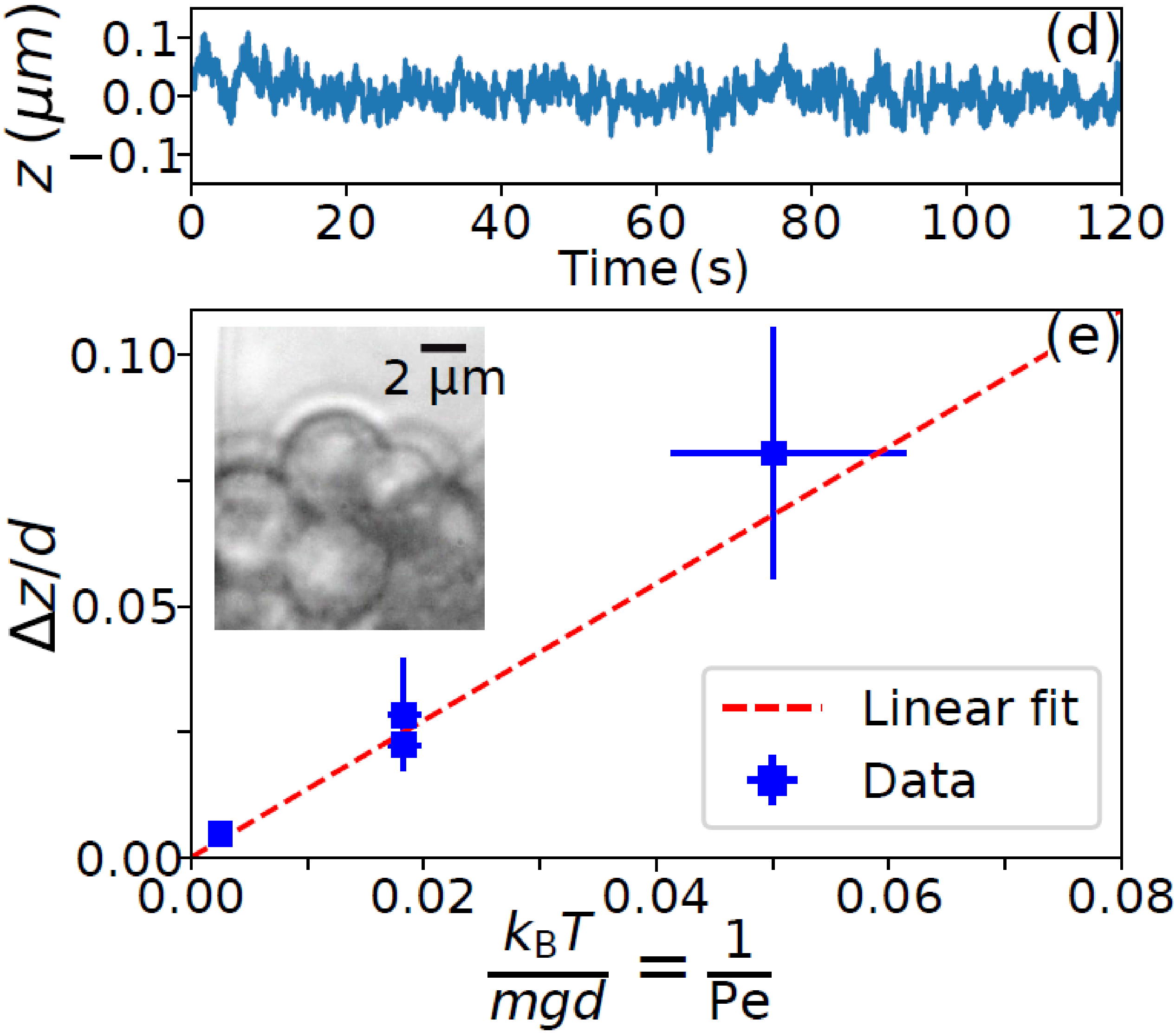


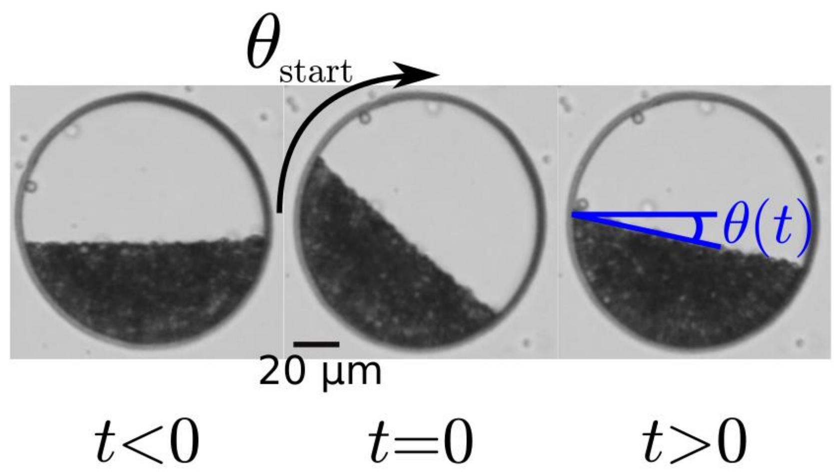
- Péclet number: $$\frac{mgd}{k_{\mathrm{B}} T}$$

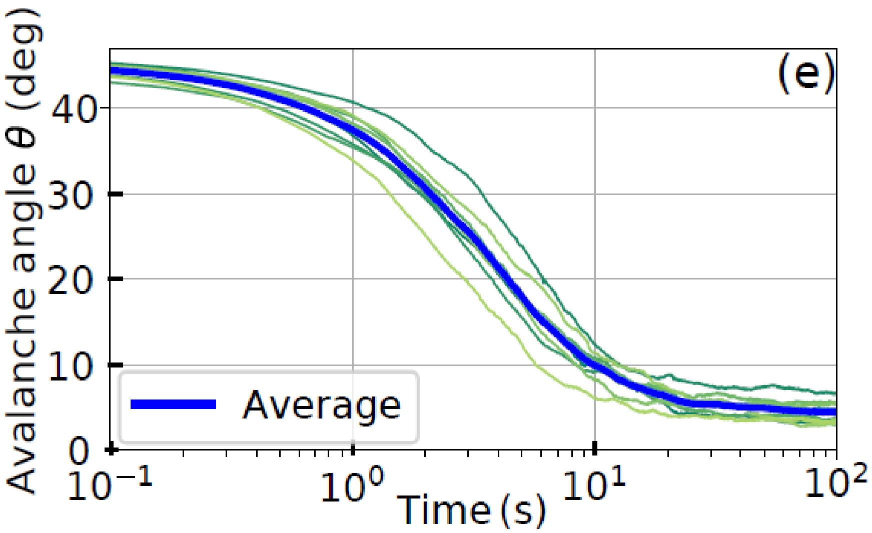
→ scales as d^4
→ for 2 µm beads : Pe ~ 20
→ for 4.4 µm beads : Pe ~ 400

Vertical fluctuations of particles on top of the pile



Rotation experiment





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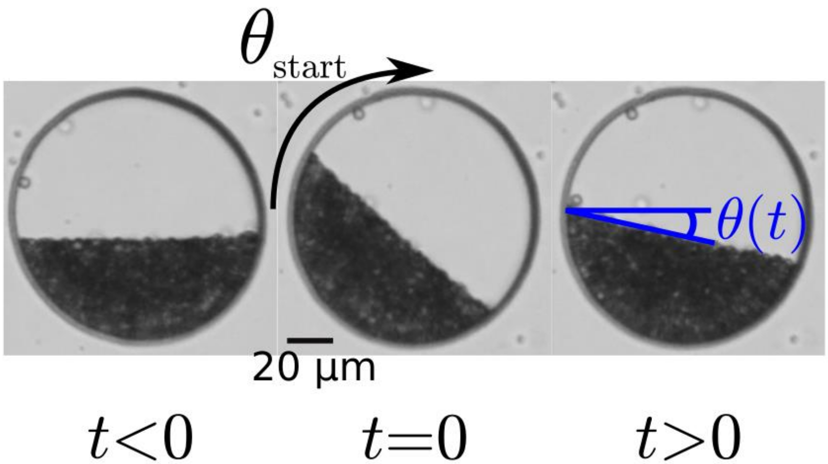

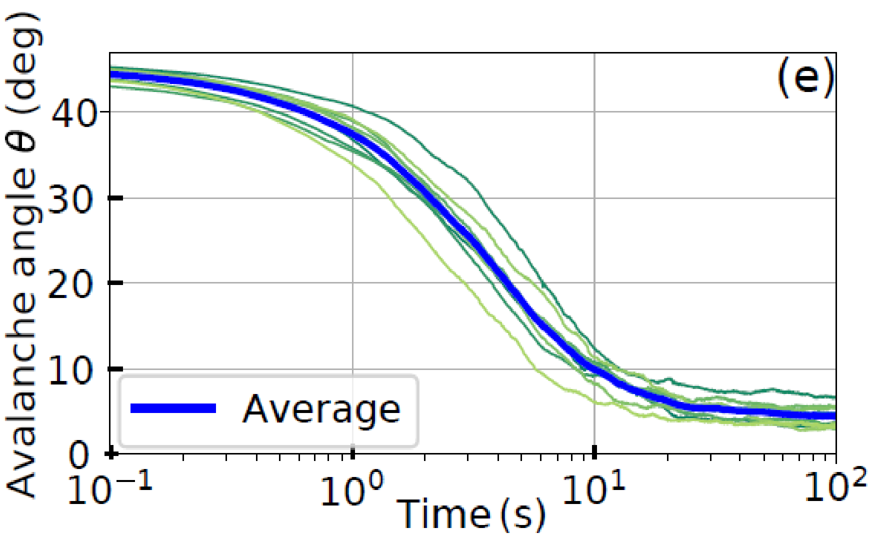

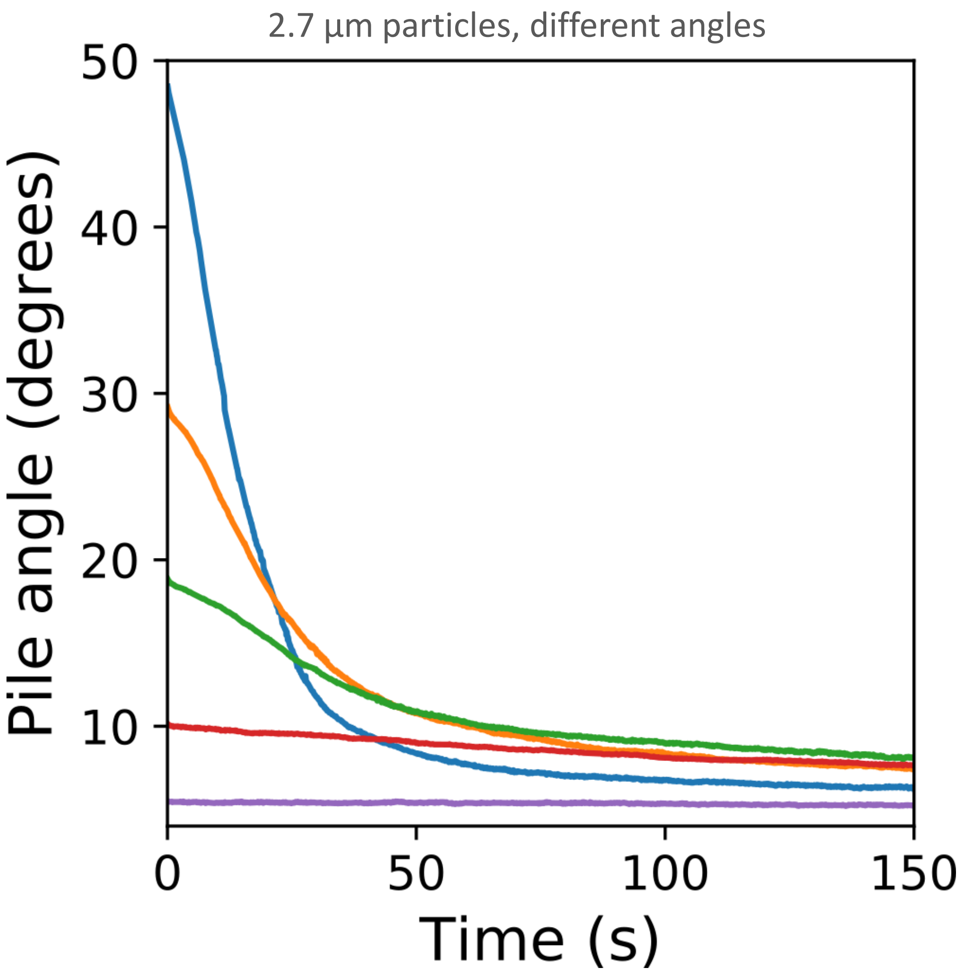

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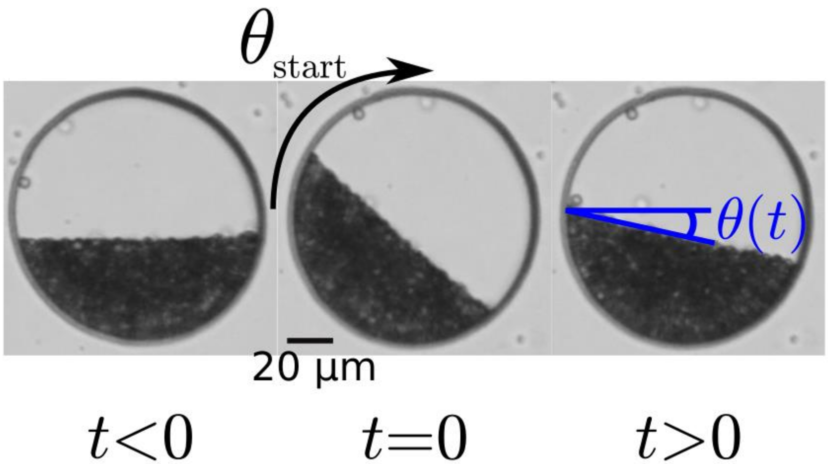
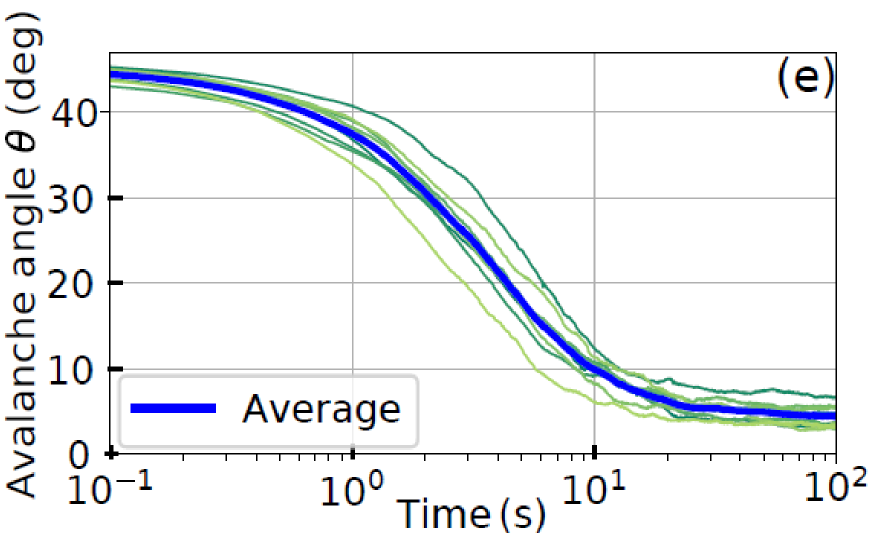
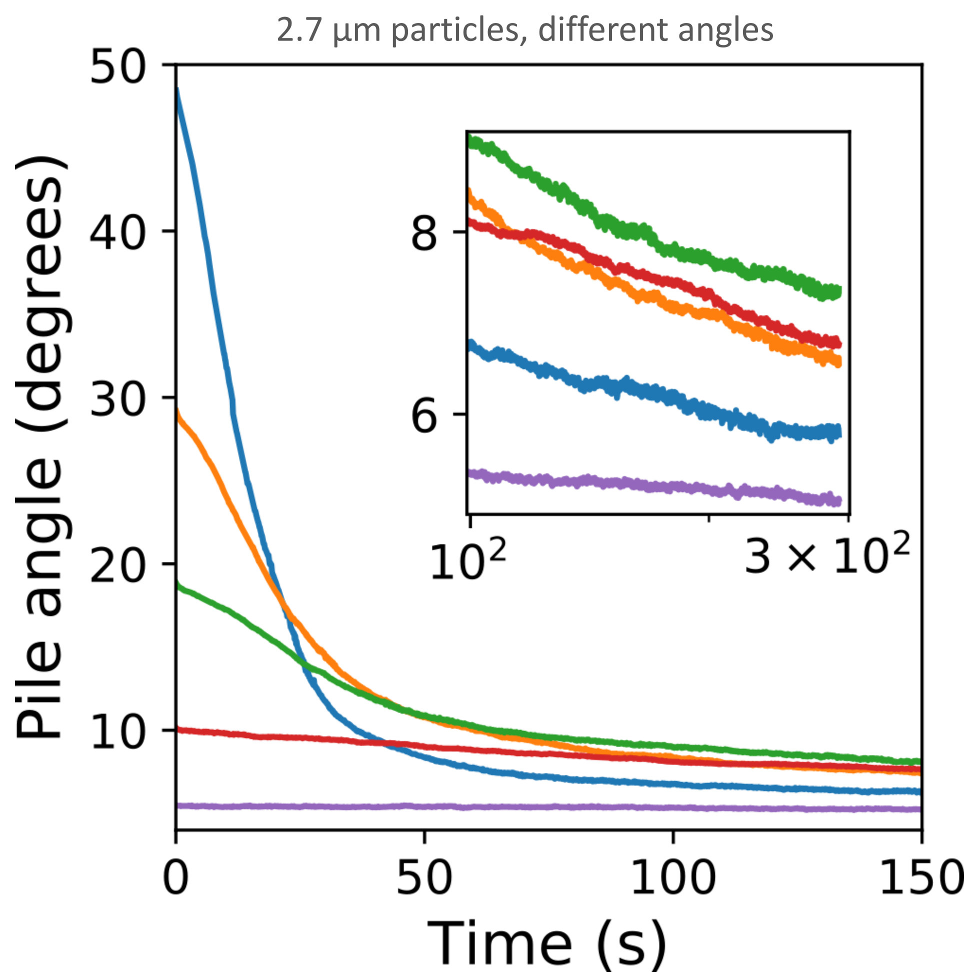
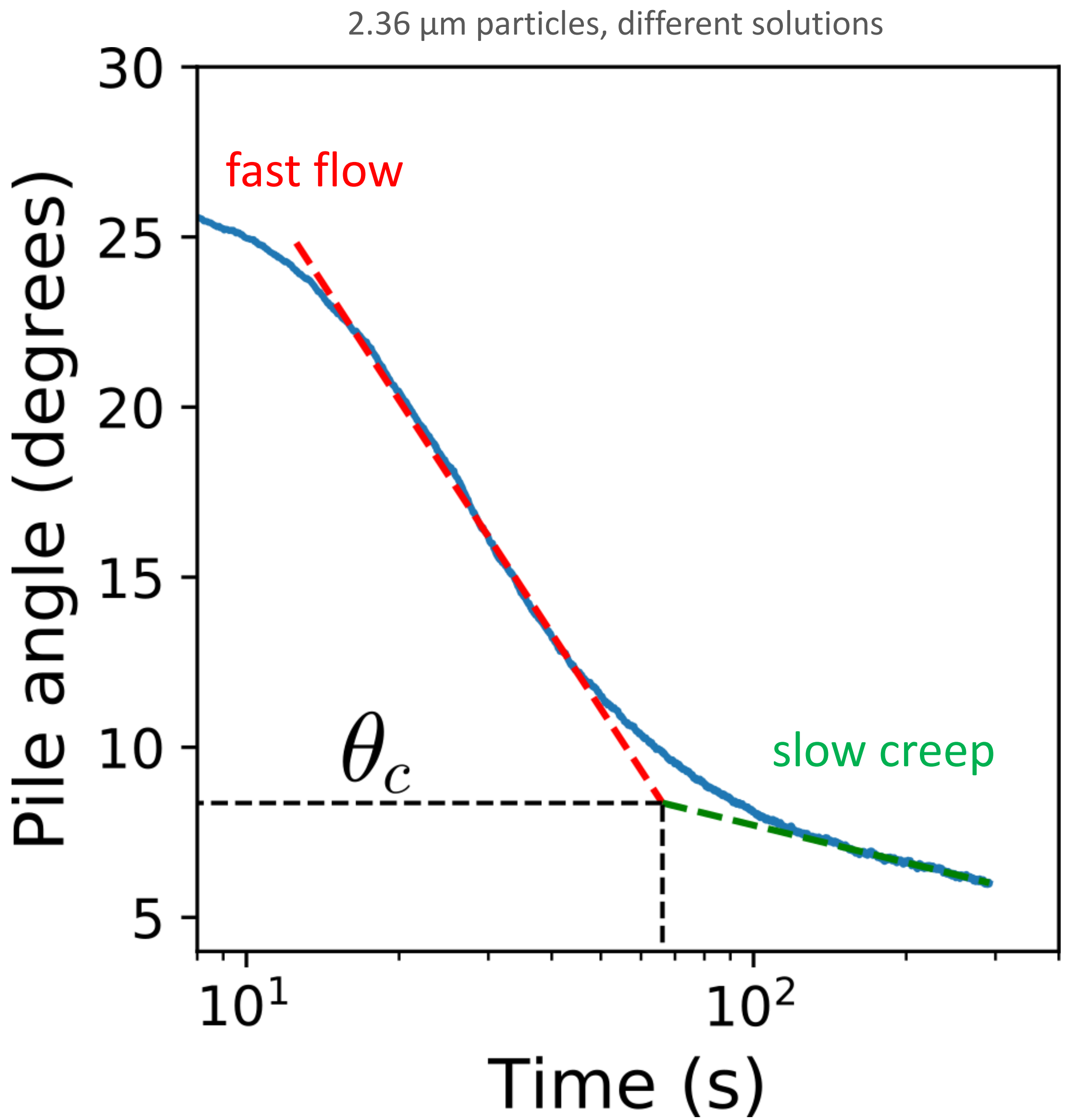






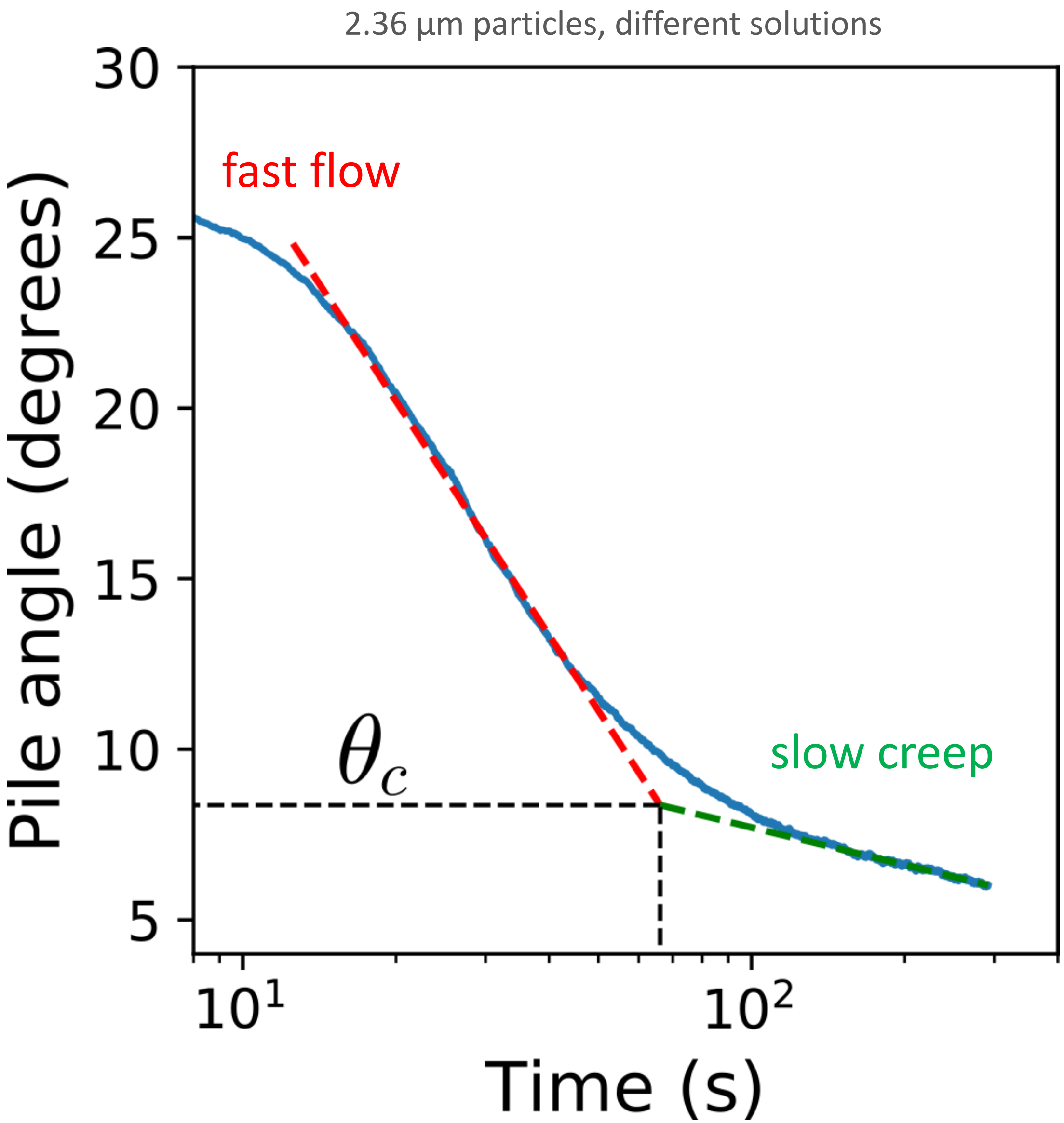
➔ Flow at any angle

Two flowing regimes



θ_c= angle of repose of the macroscopic material

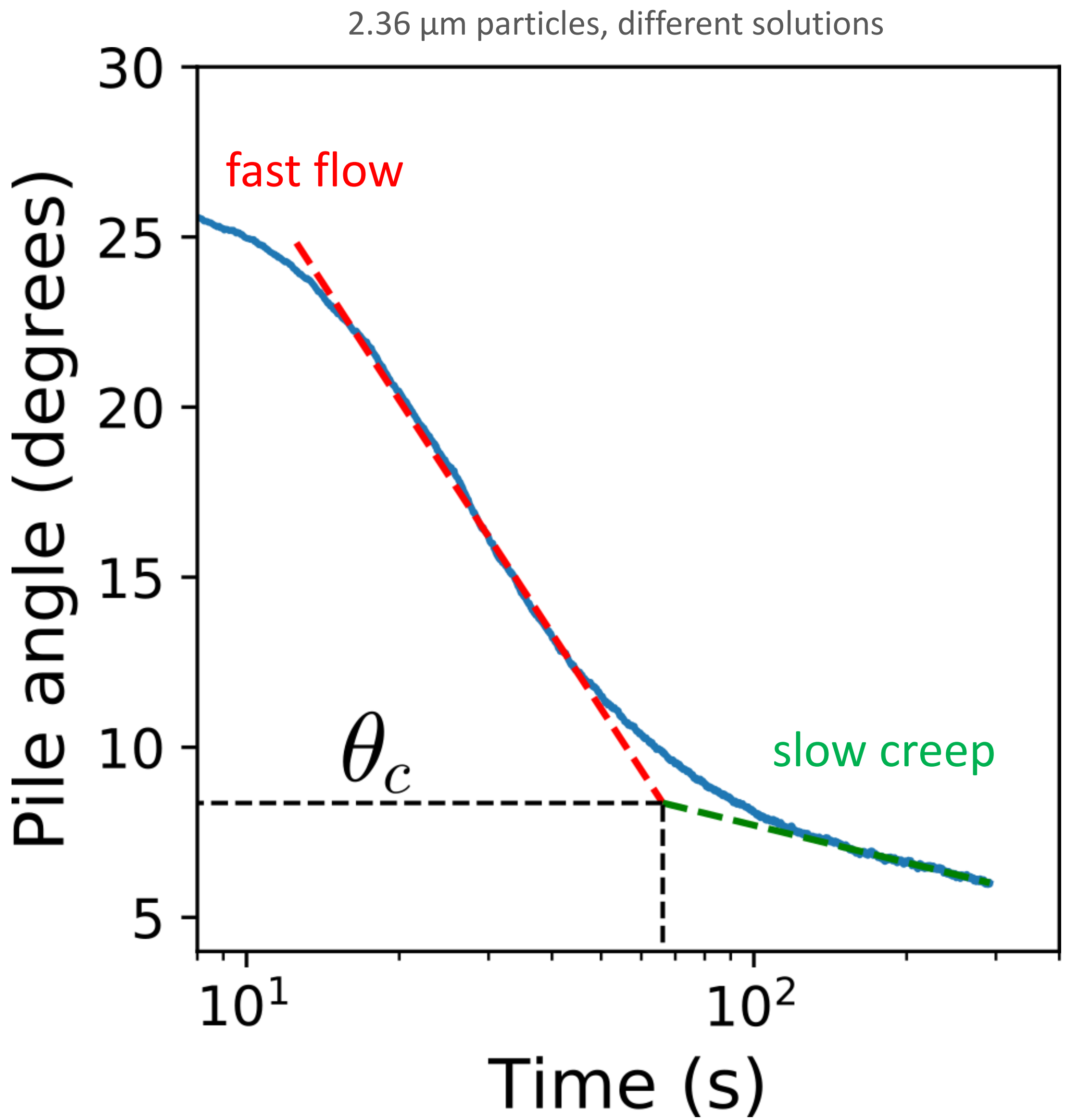
Two flowing regimes



θ_c = angle of repose of the macroscopic material

Metallic bead (2 mm) in viscous fluid, initial angle 15°

Two flowing regimes



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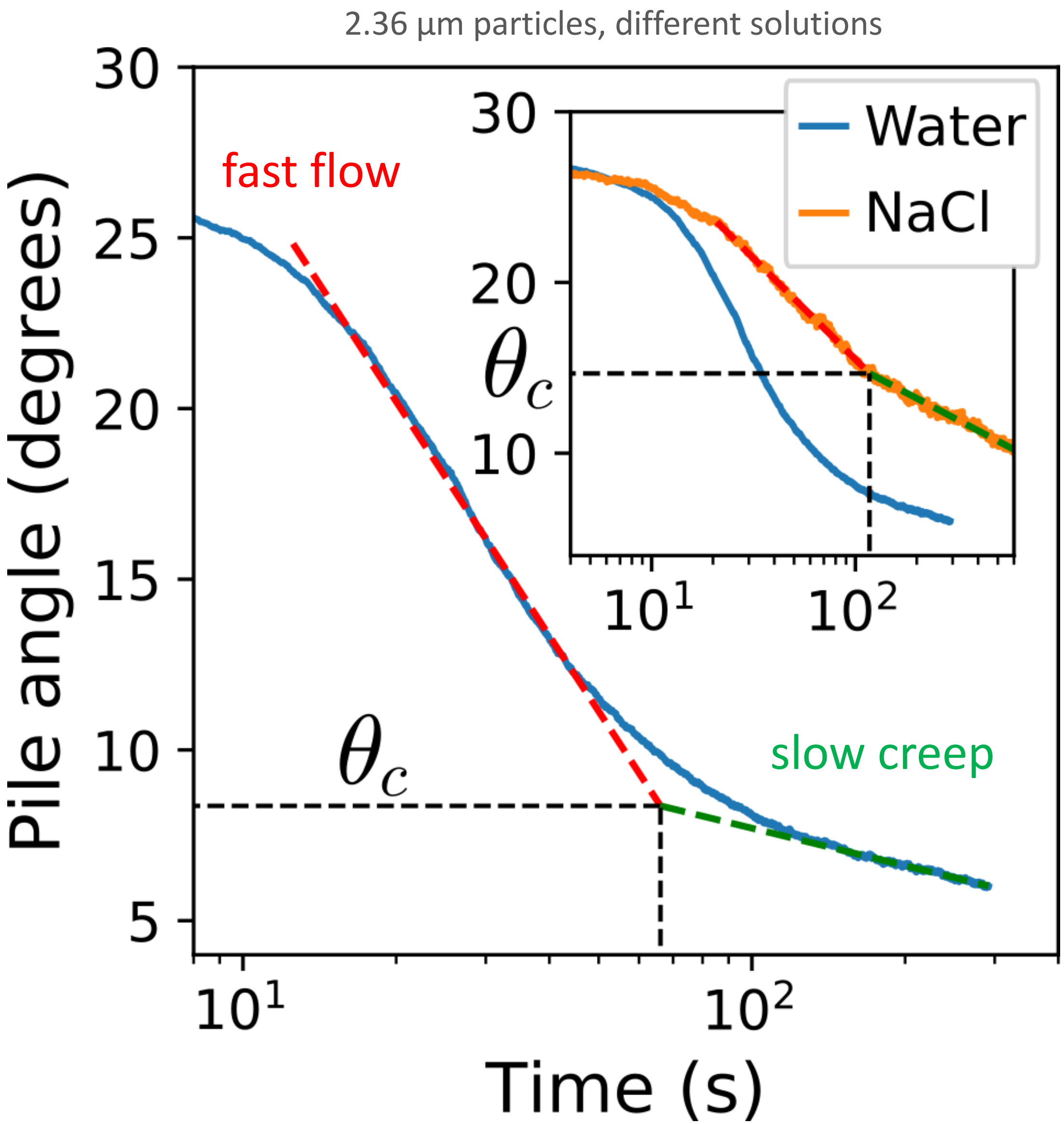
Silica particles are nearly frictionless due to negatively charged surface

Adding salt ➔ charge screening

➔ Possible to change inter particles friction

Two flowing regimes



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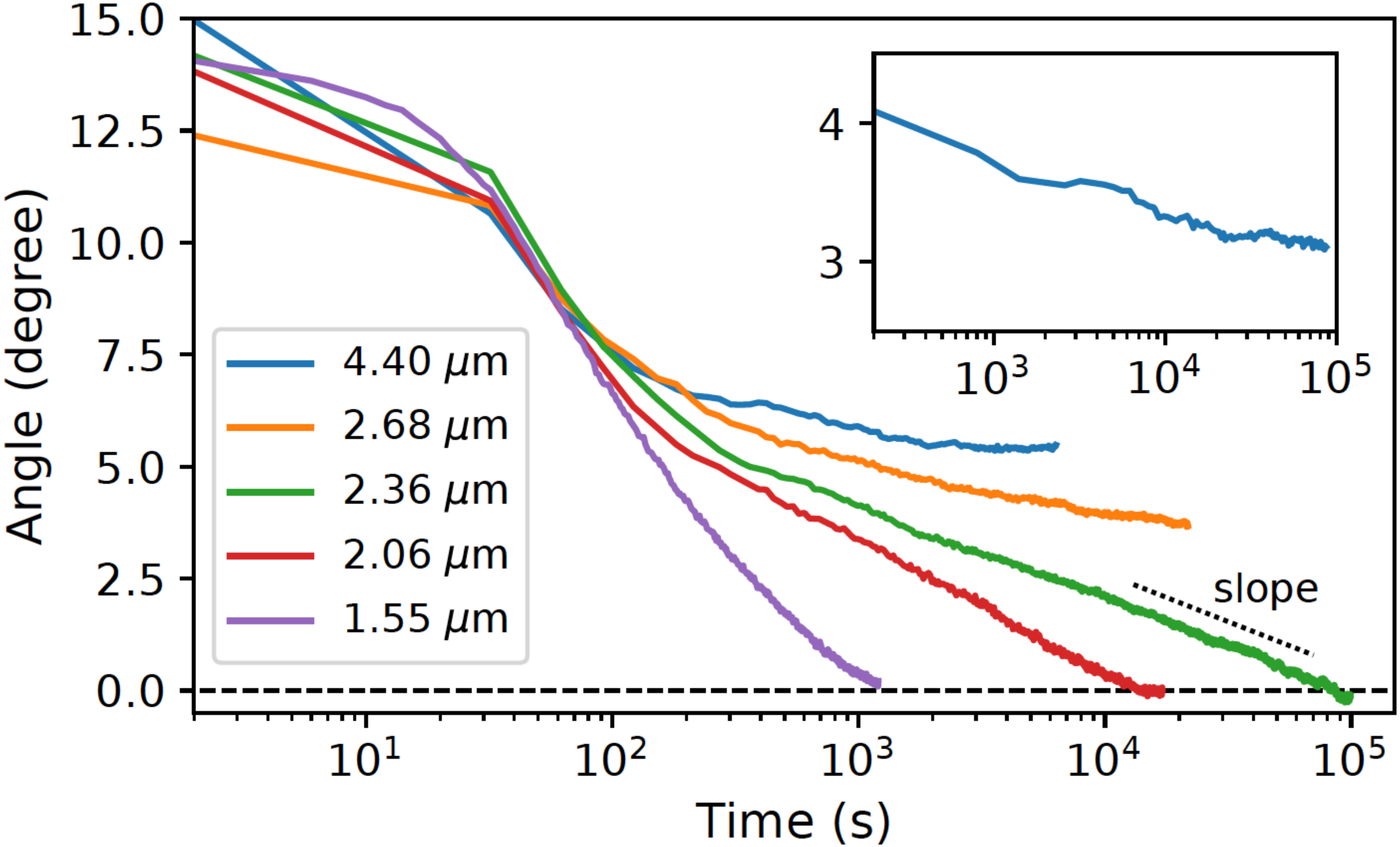
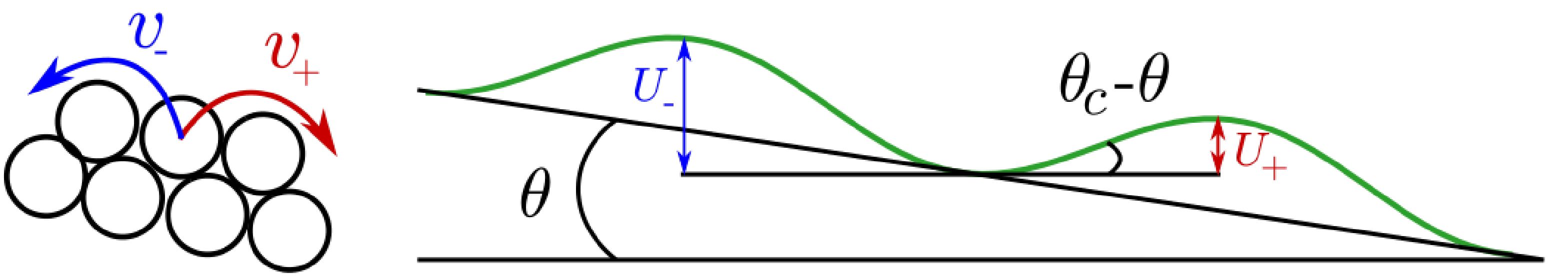
Effect of Péclet number

$$\mathrm{Pe} = \frac{mgd}{k_\mathrm{B}T}$$

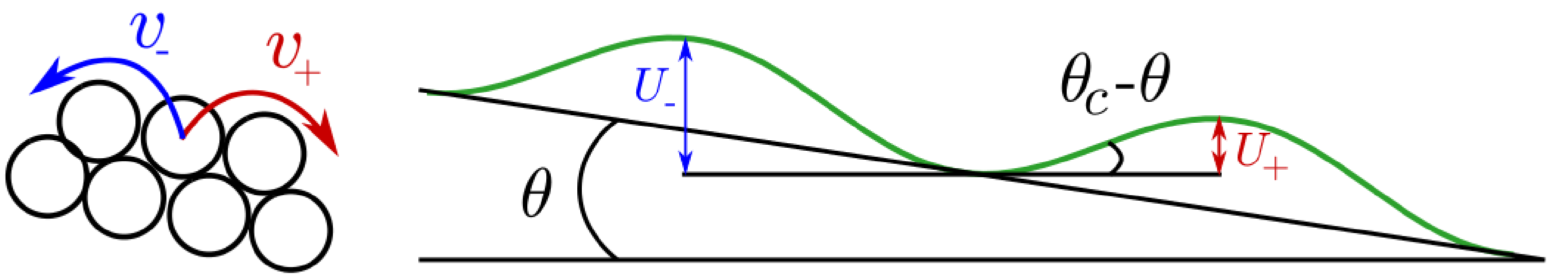


Toy model



Kramer's probability : $p \propto \exp(-U/k_{\mathrm{B}}T)$

Toy model



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Velocity down the pile: $v_+ \propto \exp\left(-\alpha \mathrm{Pe}(\tan\theta_c - \tan\theta)\right)$

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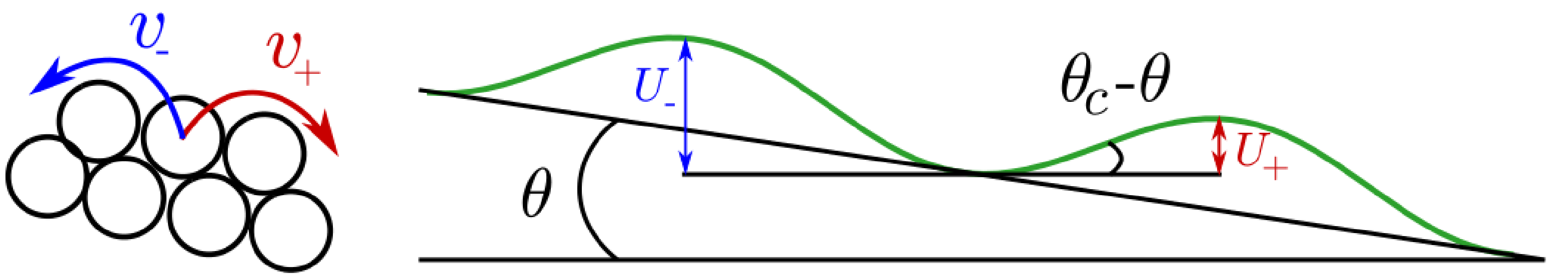

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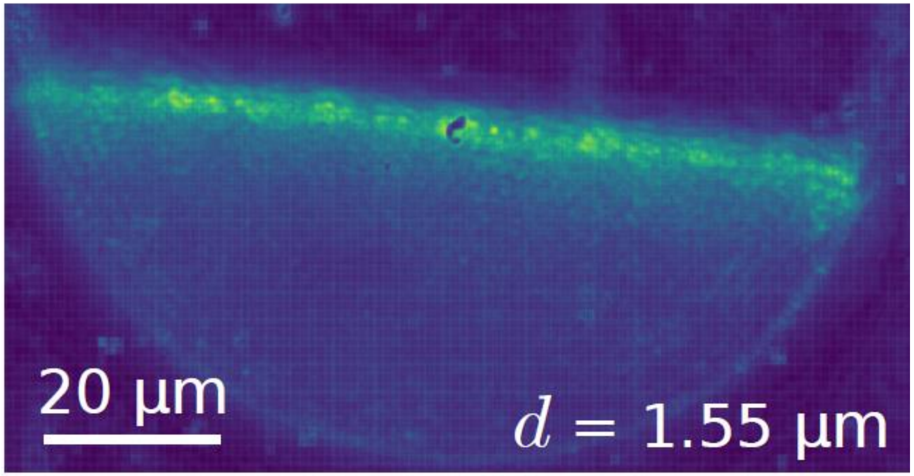

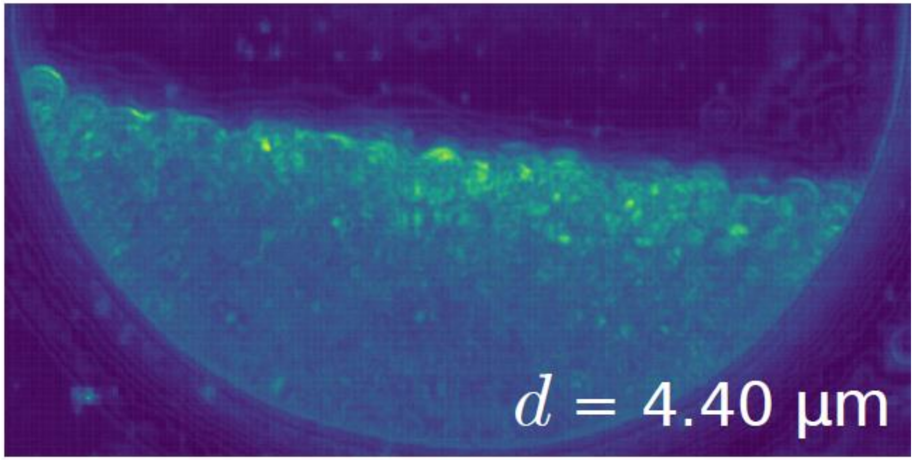

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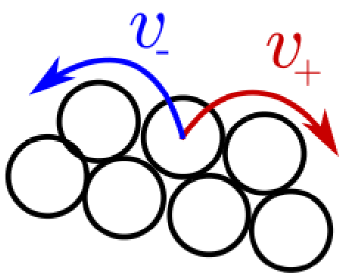

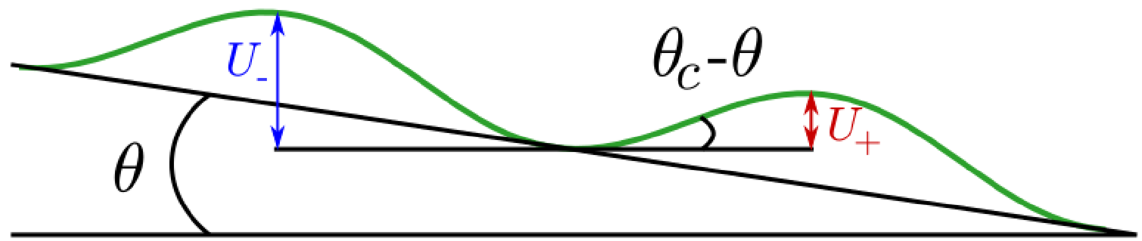

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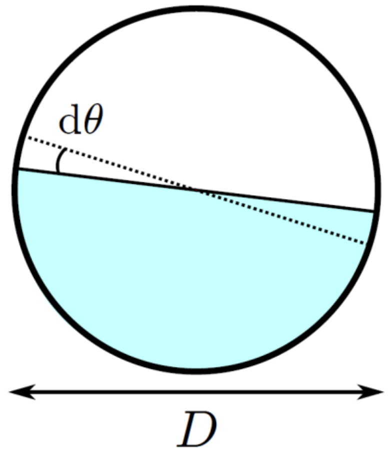
Volume conservation:



$$\frac{D^2}{8} \times \frac{\mathrm{d}\theta}{\mathrm{d}t} = h(v_+ - v_-)$$

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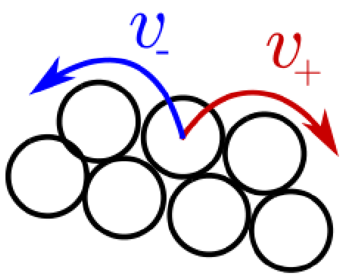

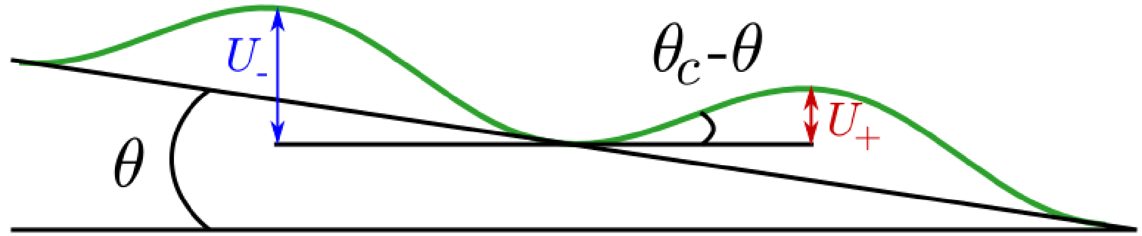

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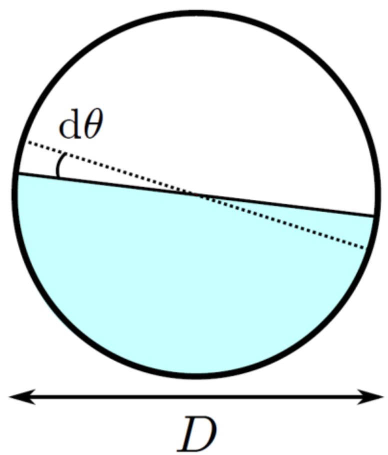


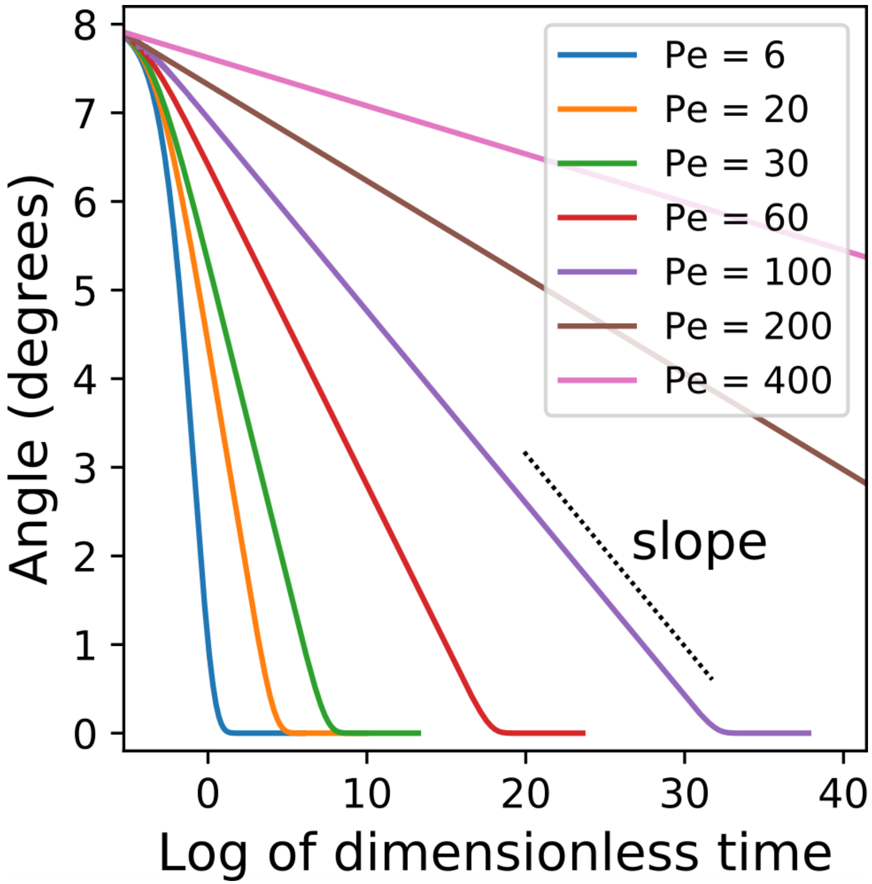
$$\frac{D^2}{8} \times \frac{\mathrm{d}\theta}{\mathrm{d}t} = h(v_+ - v_-)$$

➔ $$\frac{\mathrm{d}\theta}{\mathrm{d}t} = -\frac{1}{\tau}\,\mathrm{e}^{-\alpha \mathrm{Pe}\tan\theta_c} \sinh\left(\alpha \mathrm{Pe}\tan\theta\right)$$

with: $\tau \propto D^2\eta/(\Delta\rho g d^3)$

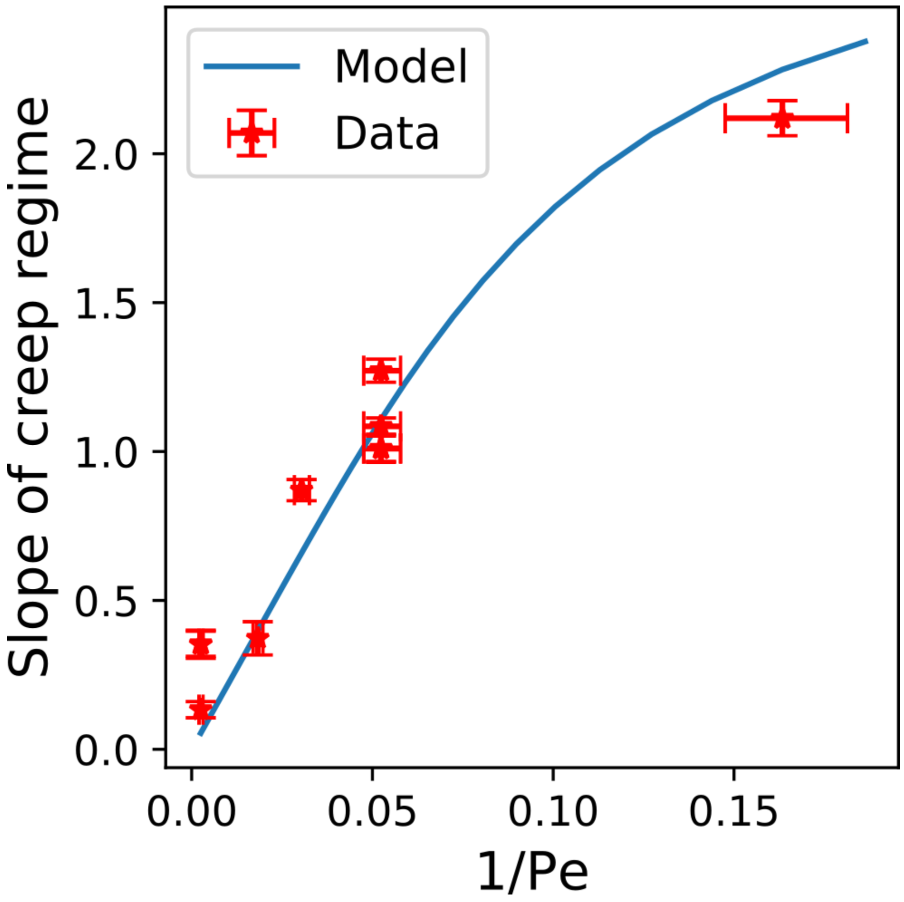
Exact solution of the model

$$\theta(t) = \frac{2}{\alpha \mathrm{Pe}} \operatorname{arcoth}\left[\exp\left(\frac{t}{\tau}\alpha \mathrm{Pe}\, e^{-\alpha \mathrm{Pe}\theta_c}\right) \coth(\alpha \mathrm{Pe}\theta_c/2)\right]$$



Approximation: $$\theta(t) \approx \theta_c - \frac{1}{\alpha \mathrm{Pe}} \log\left(\frac{1}{2}\alpha \mathrm{Pe}\frac{t}{\tau}\right)$$

Does it agrees with data?



$\alpha = 2.64$

→ Model a bit too simple, but still a good agreement!

Take home message

- Small « Brownian » granular material flow at any inclination angle, there’s no angle of repose
- The slow creep regime depends heavily on the Péclet number
- A very simple toy-model can predict the correct time dependency (logarithmic relaxation) and Pe dependency

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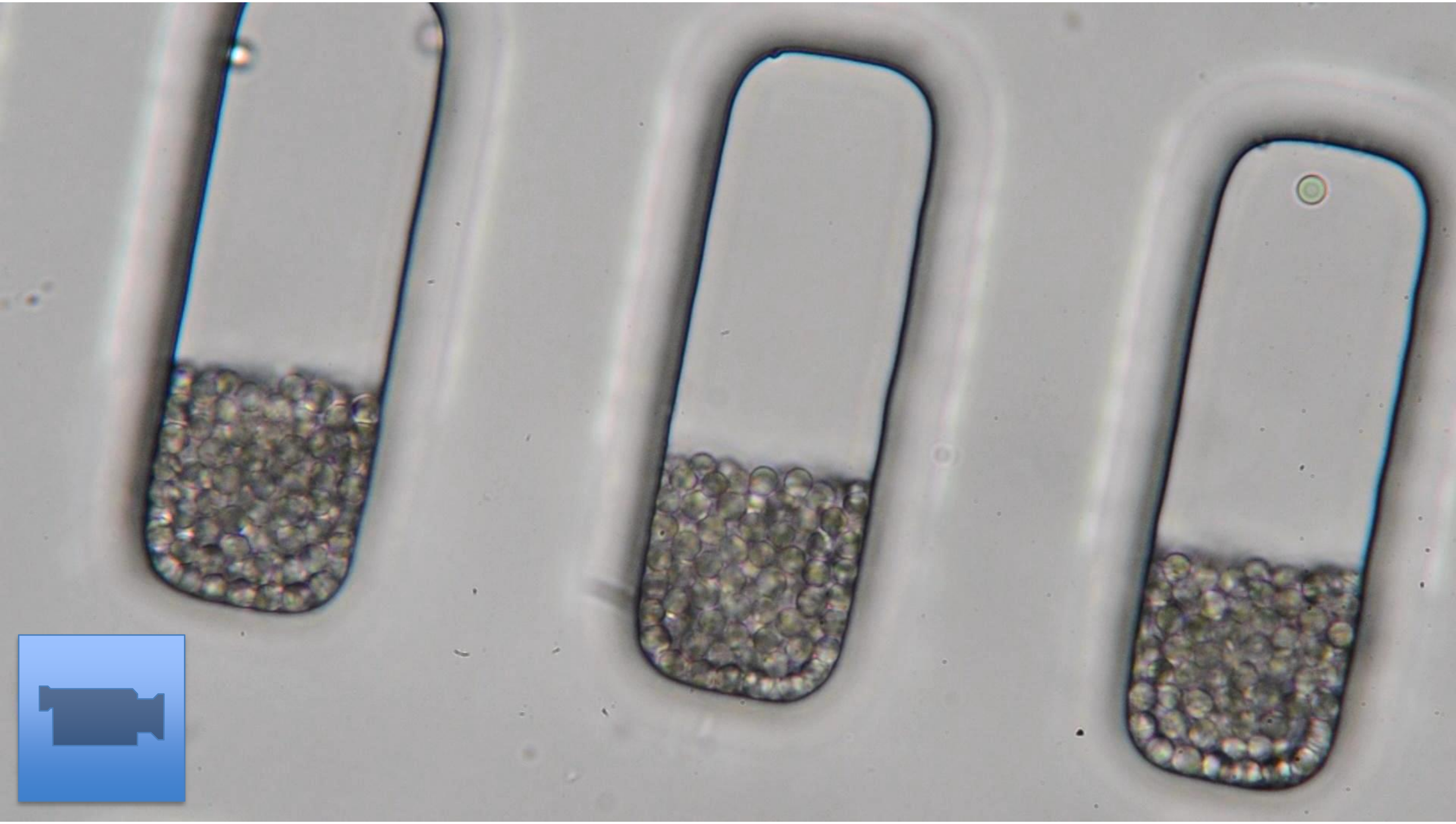
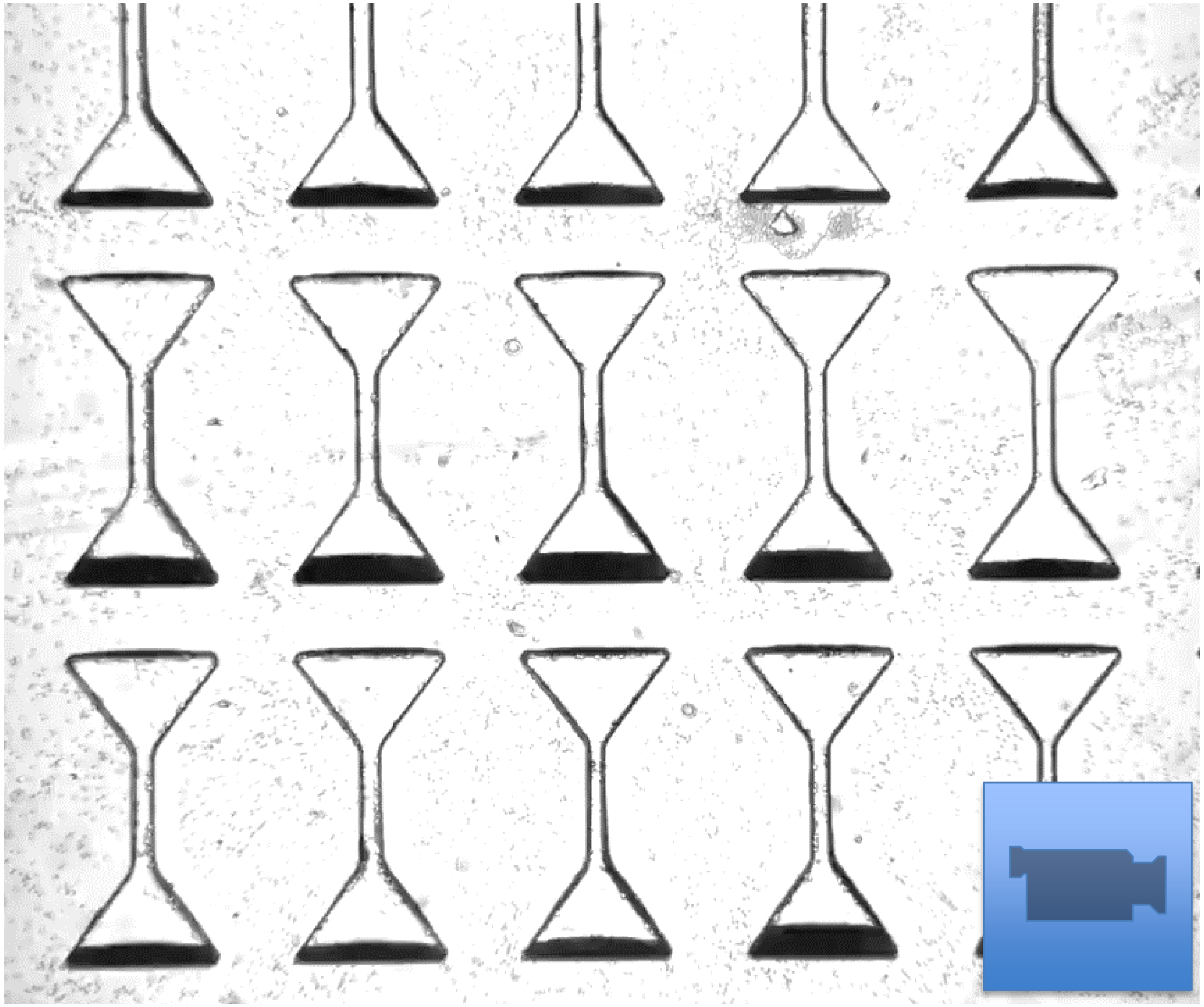
Bérut A., Pouliquen O., Forterre Y. : arXiv:1908.10762

Intermittency?



Other geometries?

2.4 μm silica particles in hourglasses (central gap = 10 μm) filled with water (speed x4)



Fin