Landslide and snow rheology

How does it flow?

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Introduction

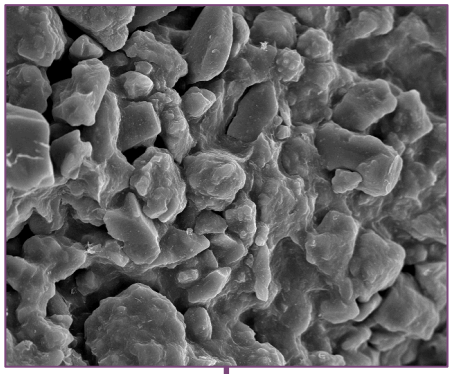
How does it flow?

- Constitutive law
  - Deformation - stresses
  - Viscosity
  - Yield stress

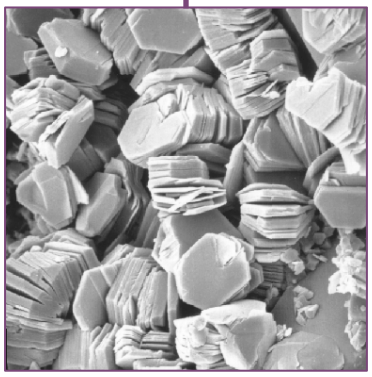



Introduction

Landslide microstructure

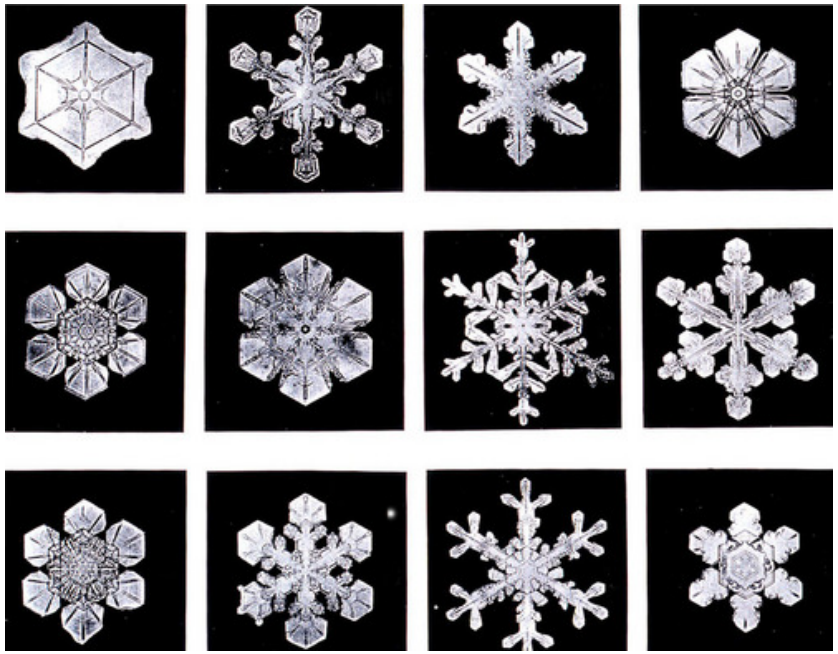


Clay (1µm) — Silt (10µm) — Sand (0.1-1mm) — Debris (0.01-10m) → Grain size



Introduction

Snow microstructure



Fresh snowflakes

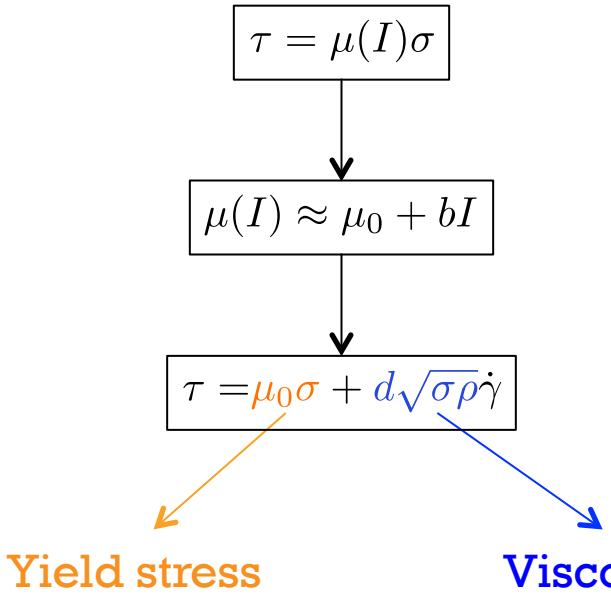
Snow grain in snow pack

- d~0.1 mm
- Cohesion

Introduction

Rheology of granular flows: frictional constitutive law

- Grain
  - Size d
  - Density ρ
  - No cohesion
- Flow
  - Normal stress σ
  - Shear stress τ
  - Shear strain-rate $\dot{\gamma}$



$$I = \dot{\gamma} d \sqrt{\frac{\rho}{\sigma}}$$

Inertial number

GDR Midi (2004); da Cruz & al. (2005); Jop &al. (2006)

Landslide and snow rheology

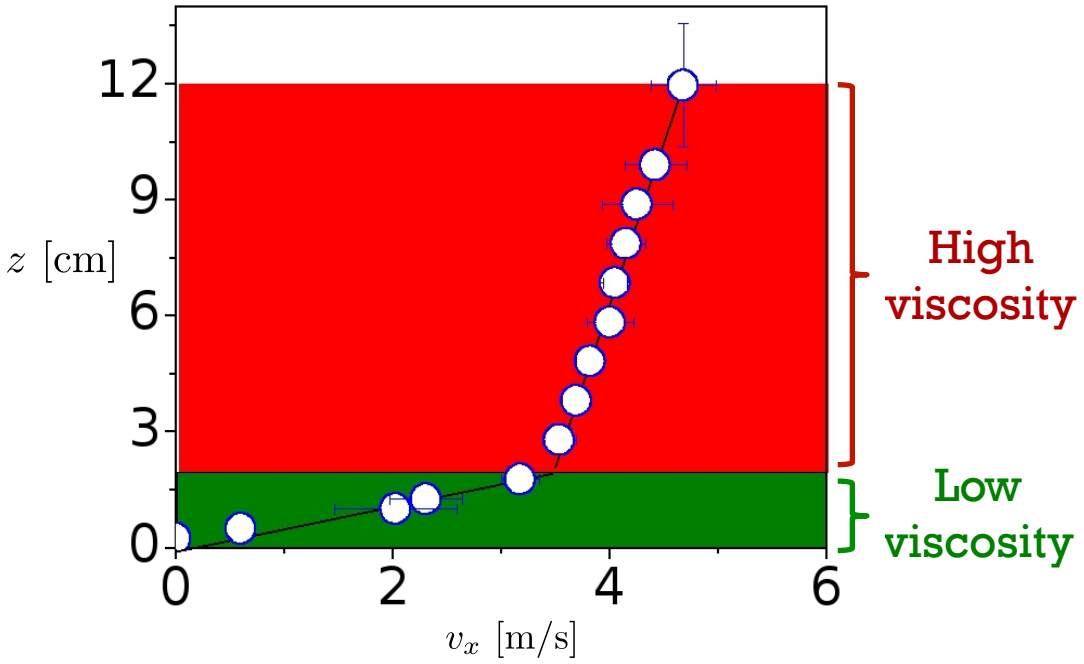
How does it flow?

- Outline
  - Snow avalanches
  - Granular flow near walls

Snow avalanches

Field experiments

Alpe d'Huez (2870m)

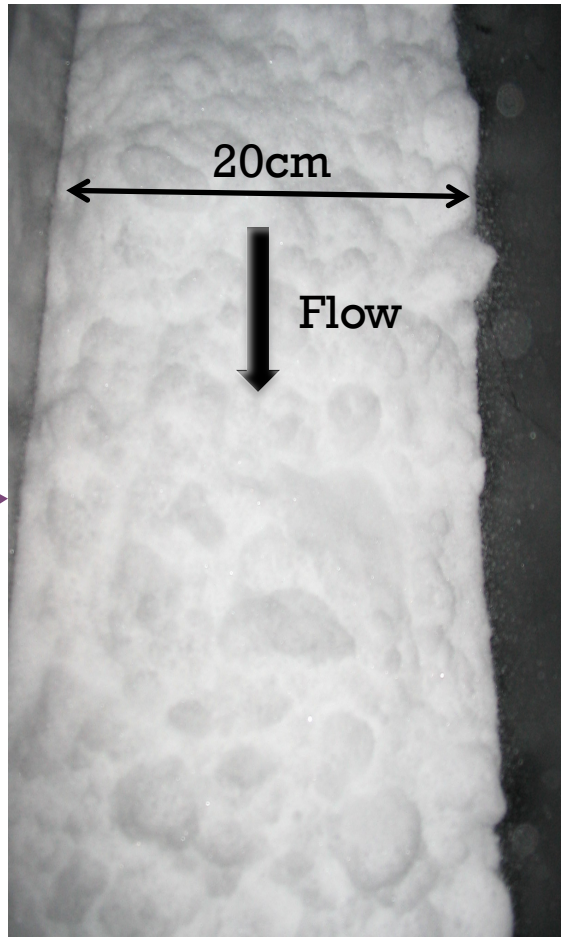


Rognon & al *J. of Rheology* (2008)

Snow avalanches

Field experiments

Alpe d'Huez (2870m)



Snow aggregates

Grain cohesion

↓

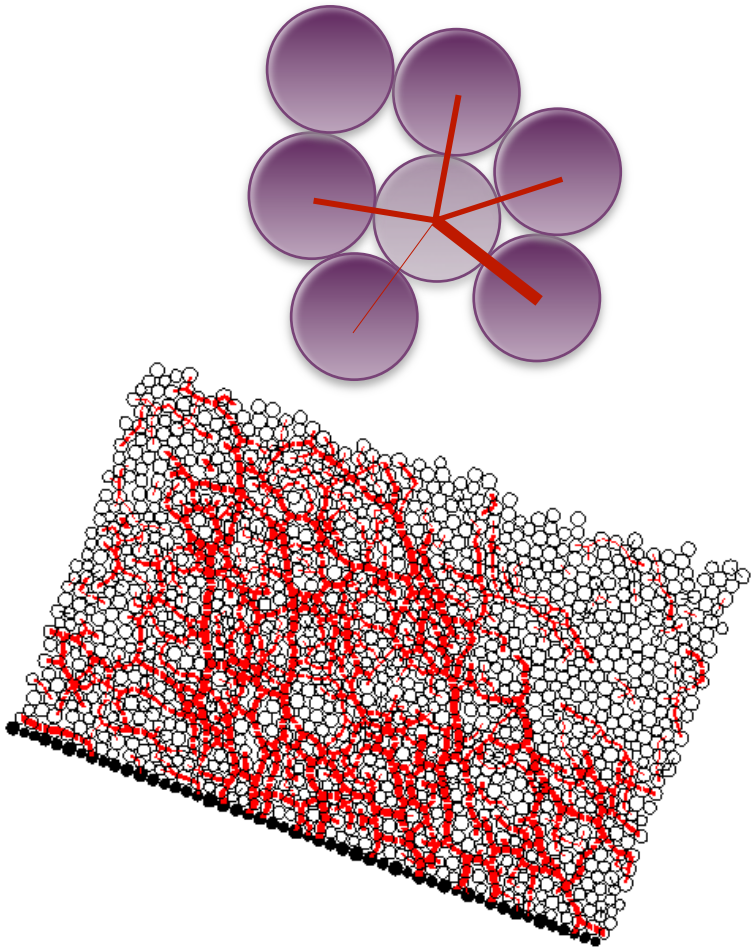
Aggregates (Snow balls)

↓

Velocity profiles

Snow avalanches

Discrete Element Method simulations

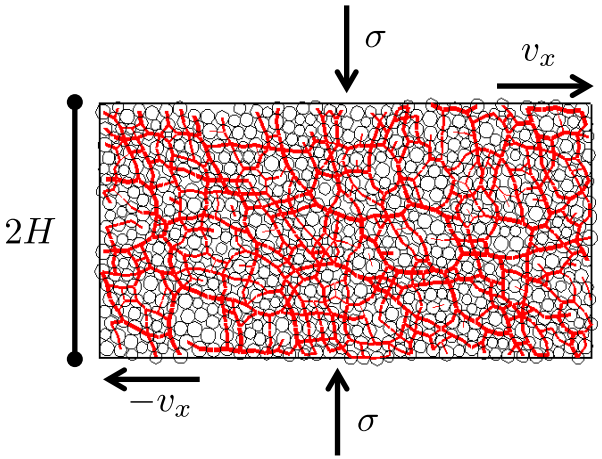


- Contact force
  - Elastic repulsion (Hertz)
  - Energy dissipation
  - Friction (Coulomb)
  - Adhesion: contact strength F_0
- Grain motion
  - Newton's law

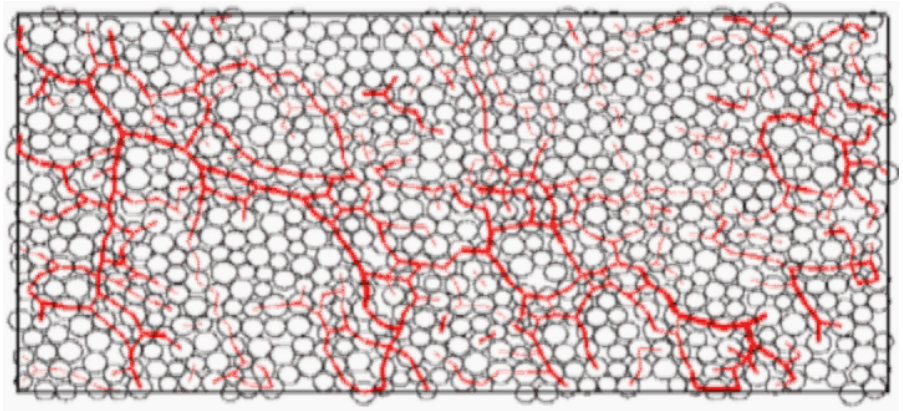
Snow avalanches

Discrete Element Method simulations

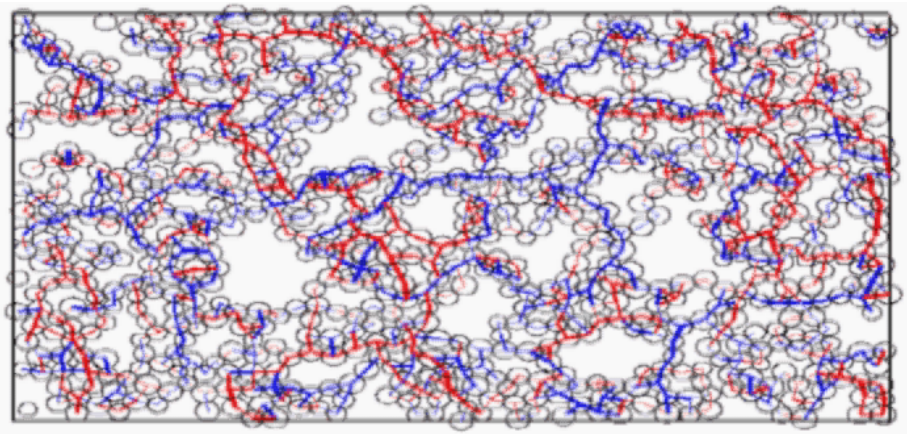
- Plane shear flow
  - Shear rate $\dot{\gamma} = \frac{v_x}{H}$
  - Normal stress σ
  - Contact strength F_0



Without cohesion



With cohesion



Snow avalanches

Discrete Element Method simulations

- Plane shear flow
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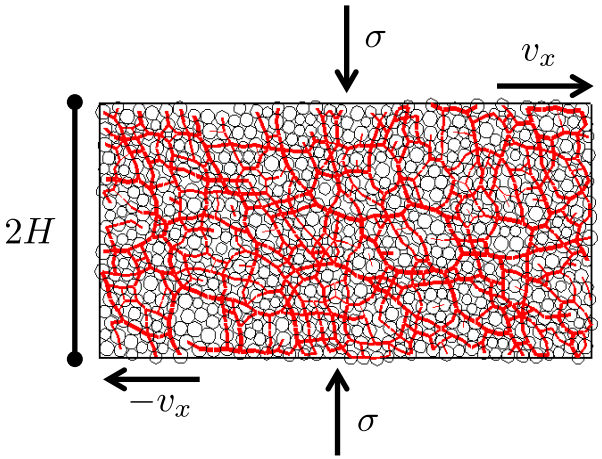
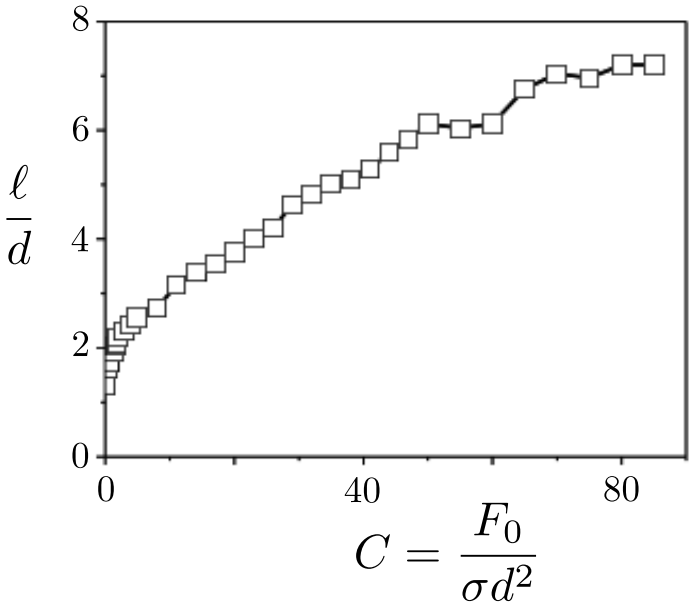




Grain cohesion

↓

Aggregates (Snow balls)

↓

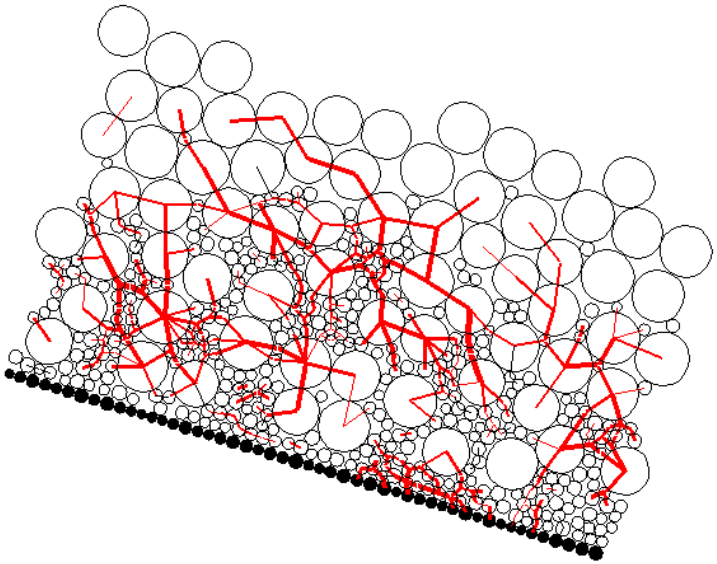
Velocity profiles

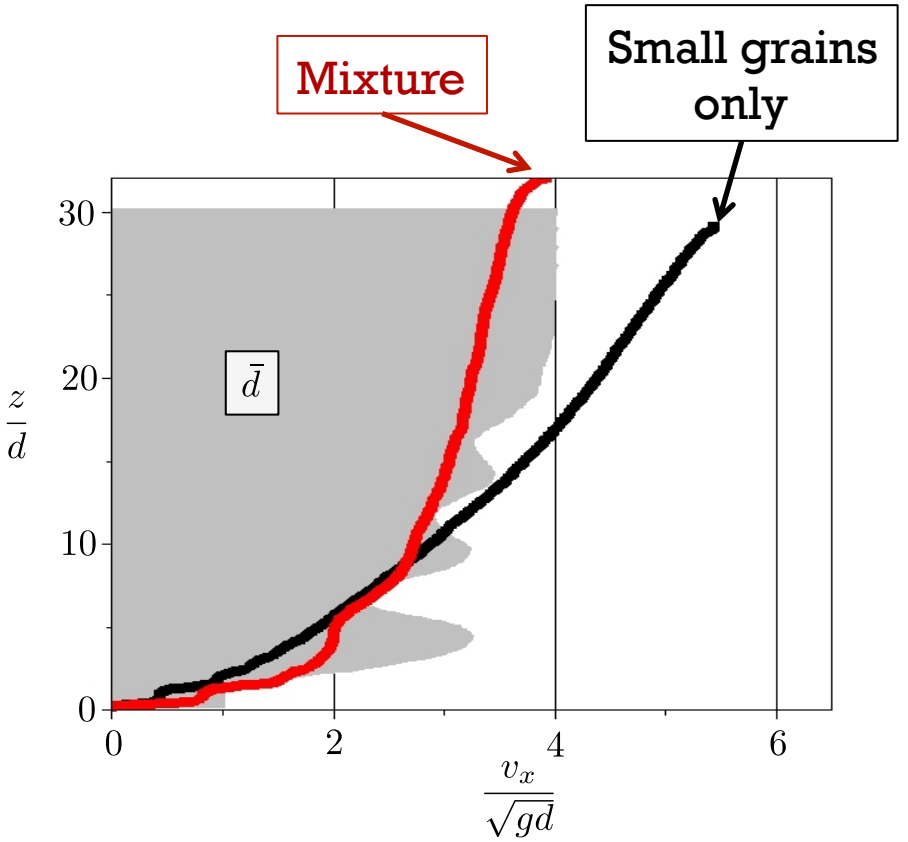
Rognon & al *J. Fluid Mechanics* (2007)

Snow avalanches

Discrete Element Method simulations

- Mixture
  - Small grains: d =1
  - Large grains D = 4d
  - No cohesion



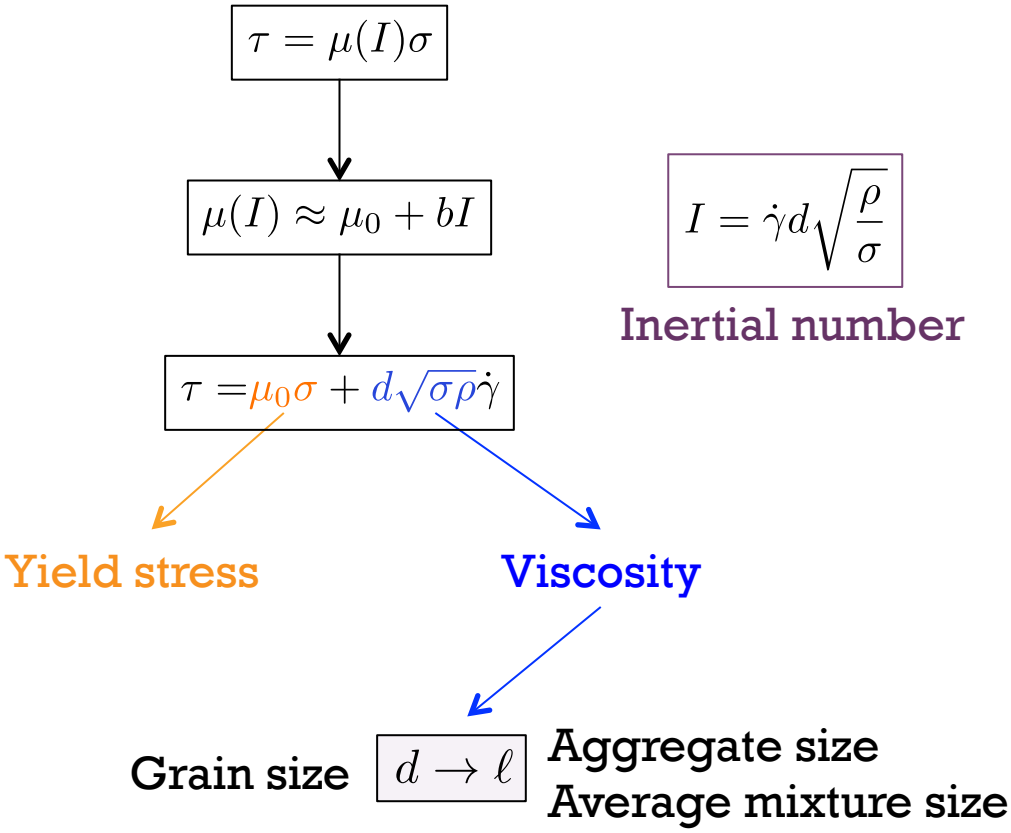


Rognon & al *Phys. Fluids* (2007)

Snow avalanches

Conclusions

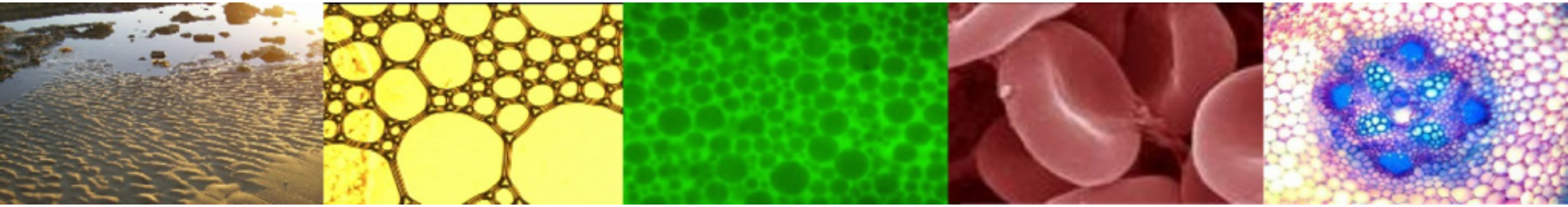
- Constitutive laws
  - Cohesion
  - Different grain size



Snow avalanches

A step further

- Constitutive laws
  - Soft grains
  - Fully saturated

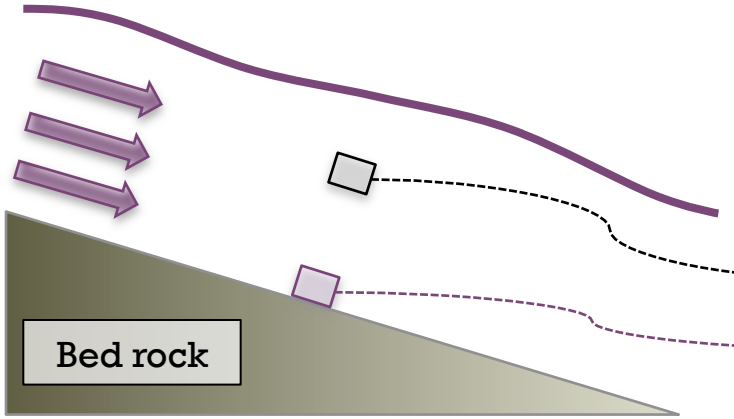


Saturated soils | Foams | Emulsions | Blood | Tissues

Soil on the move

flow properties and microstructure

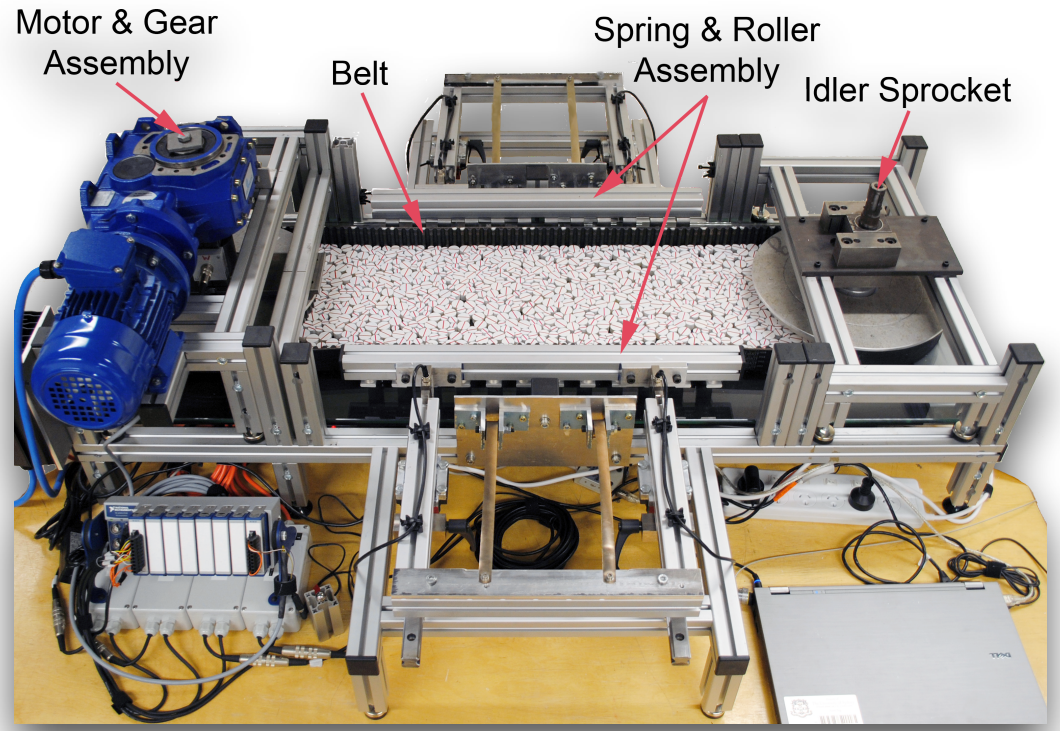
- Outline
  - Snow Avalanches
  - Granular flow near walls

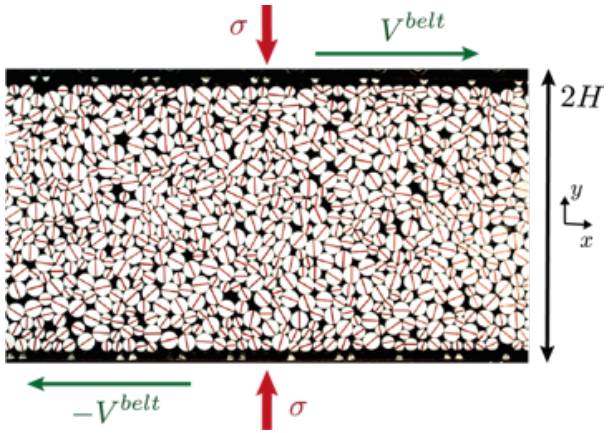


- Constitutive law
  - Far from walls/bottom $\tau = \mu_0 \sigma + d\sqrt{\sigma\rho}\dot{\gamma}$
  - Near wall/bottom?

Granular flow near walls

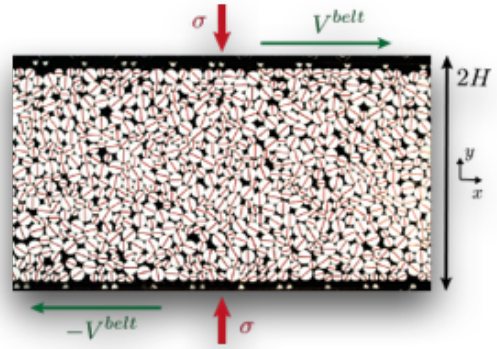
Stadium shear experiments

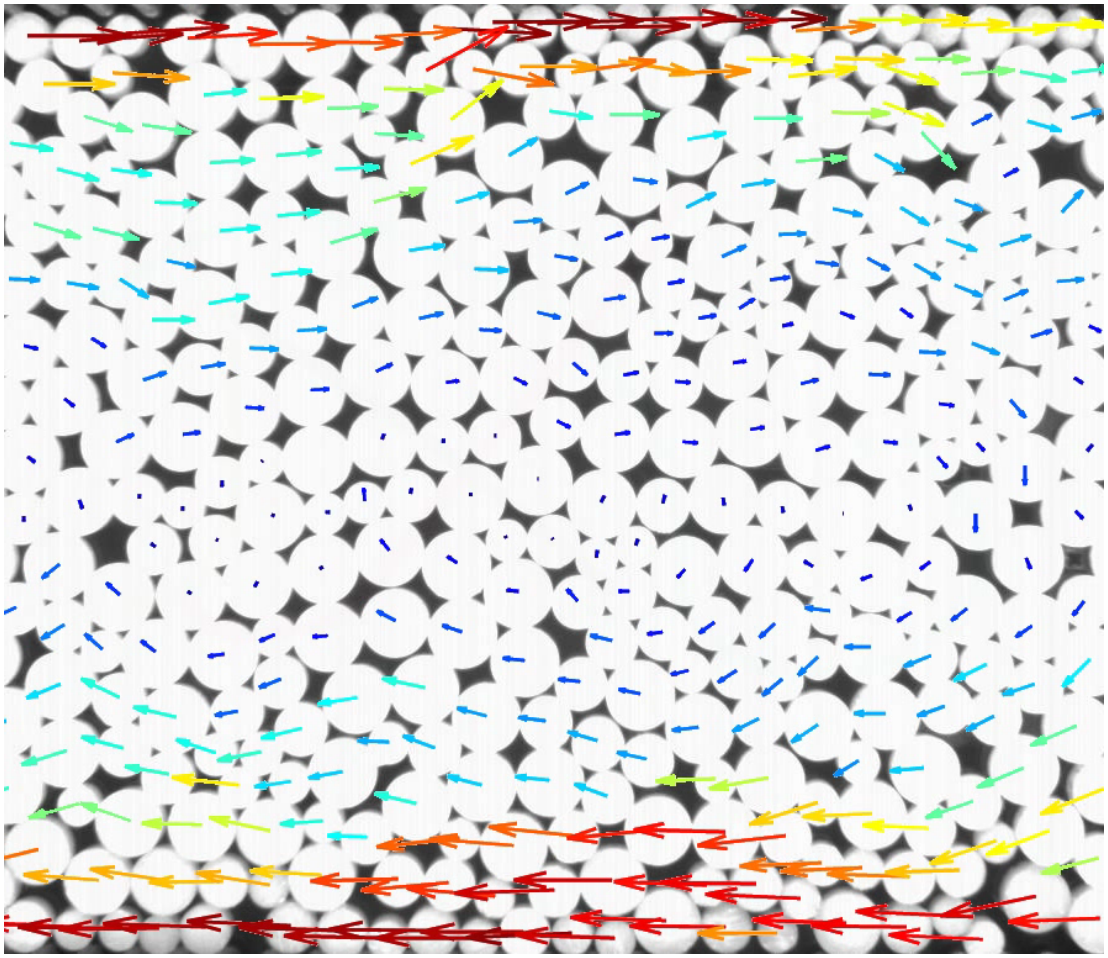




Granular flow near walls

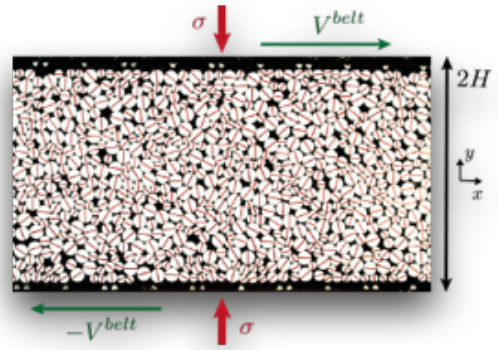
Stadium shear experiments



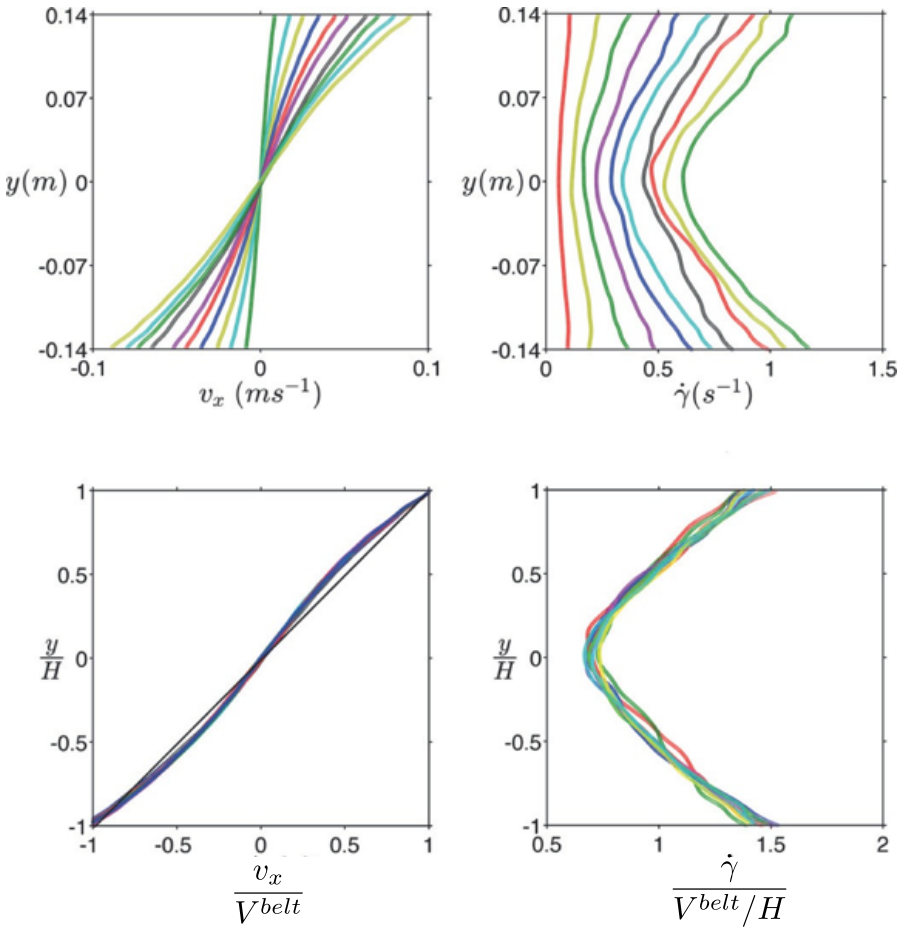


Granular flow near walls

Stadium shear experiments



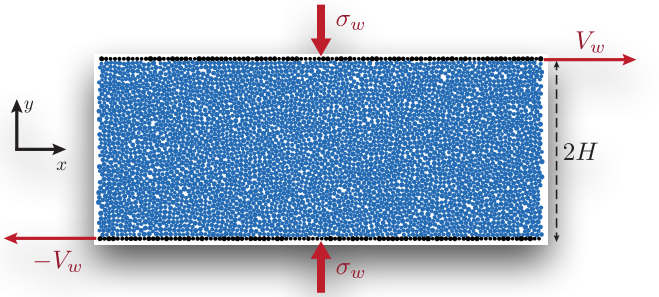
- Far from wall
  - High viscosity
- Close to wall
  - Low viscosity

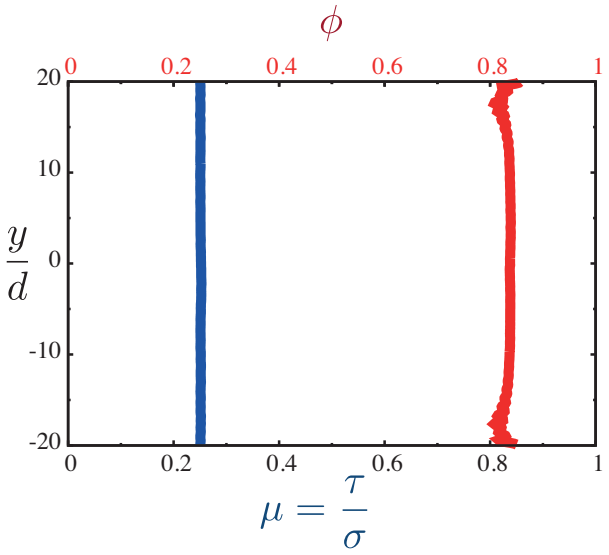


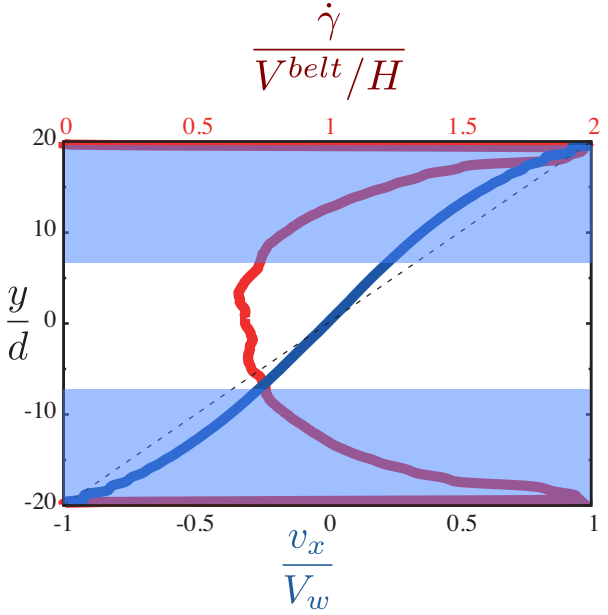
Miller, Rognon & Einav *Phys. Rev. Lett.* (2013)

Granular flow near walls

Discrete Elements Method simulation



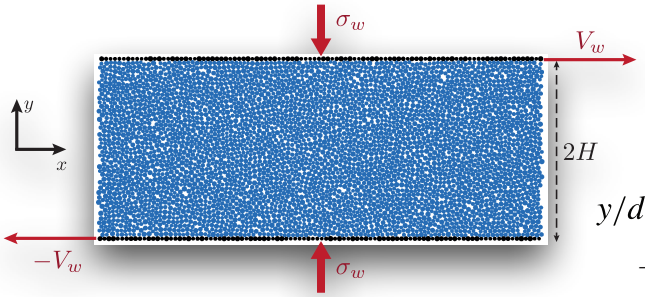


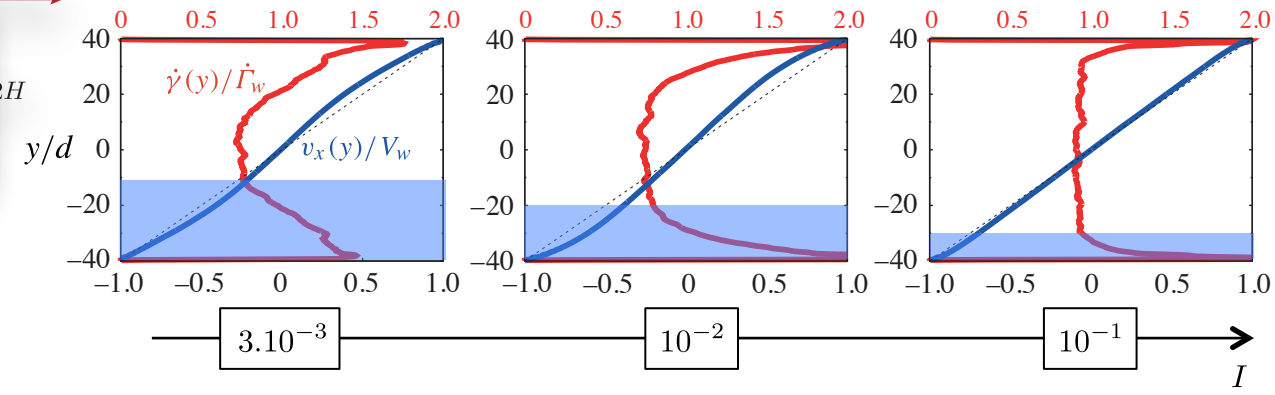


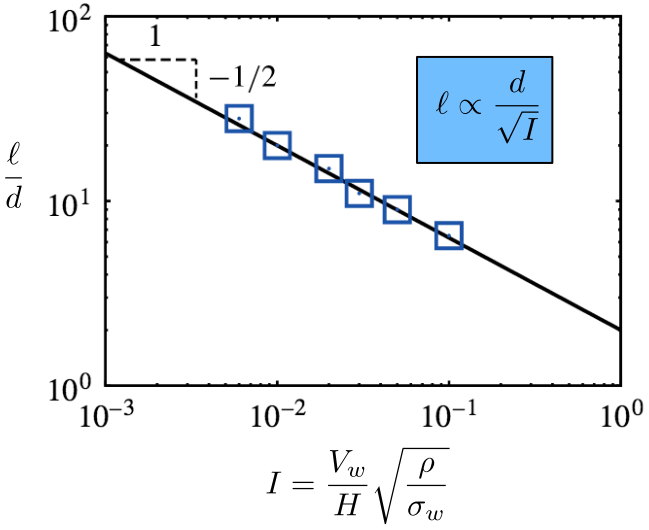
Rognon & al. *J. Fluid Mechanics* (2015)

Granular flow near walls

Discrete Elements Method simulation



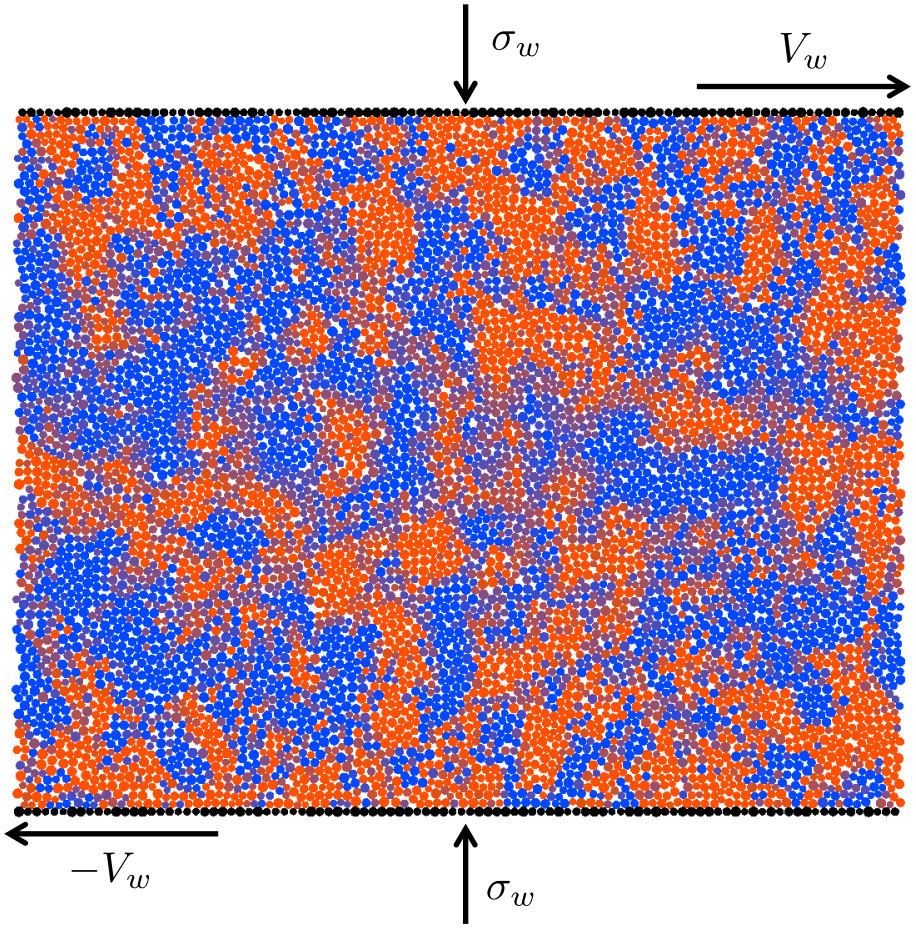




Rognon & al. *J. of Fluid Mechanics* (2015)

Granular flow near walls

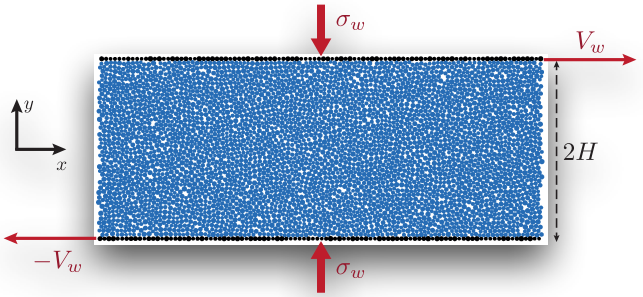
Discrete Elements Method simulation

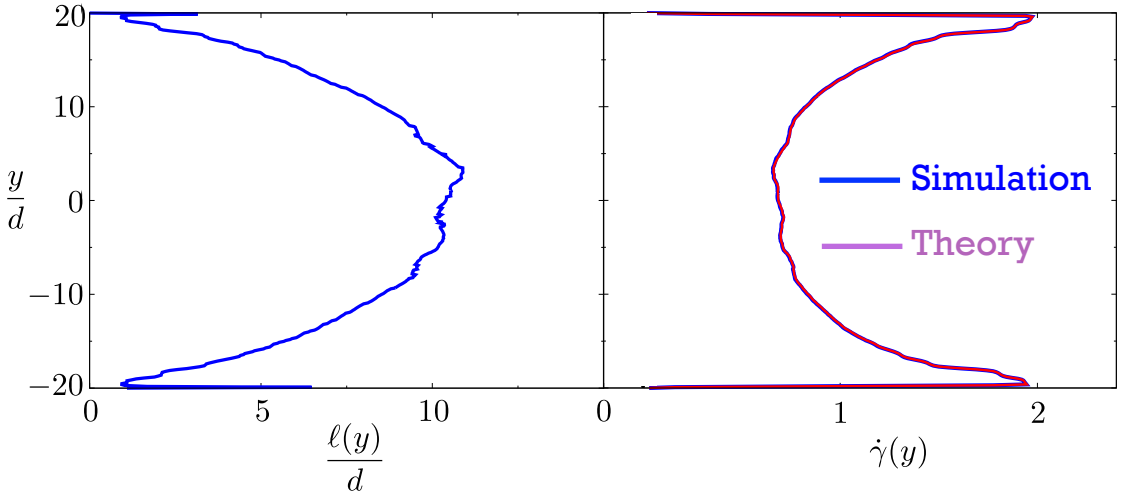


Rognon & al. *J. of Fluid Mechanics* (2015)

Granular flow near walls

Discrete Elements Method simulation





- Far from wall
  - High viscosity – large vortices
- Close to wall
  - Low viscosity – small vortices

$$\tau = \mu_0 \sigma + d\sqrt{\sigma \rho}\dot{\gamma}$$

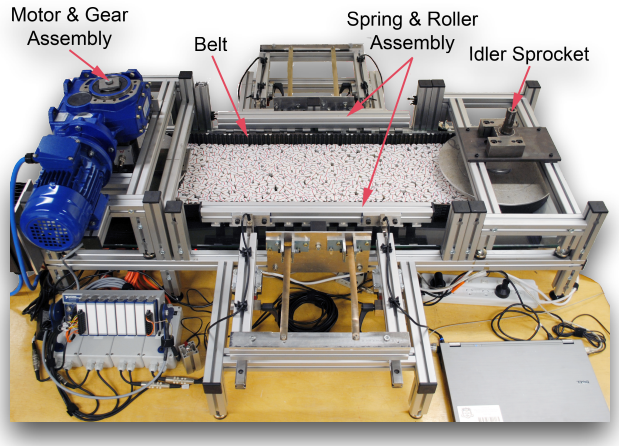
Viscosity

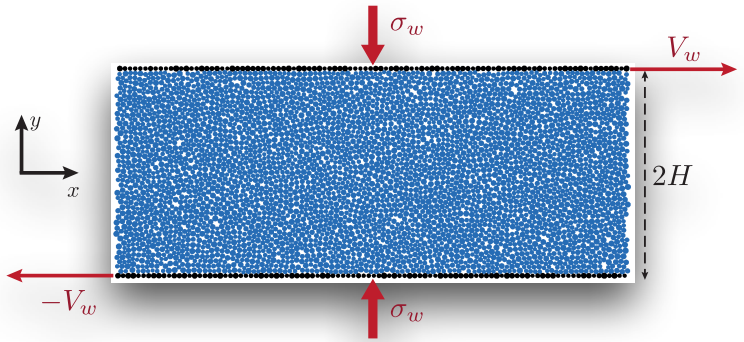
Grain size $d \to \ell$ **Vortex size**

Rognon & al. *J. of Fluid Mechanics* (2015)

Granular flow near walls

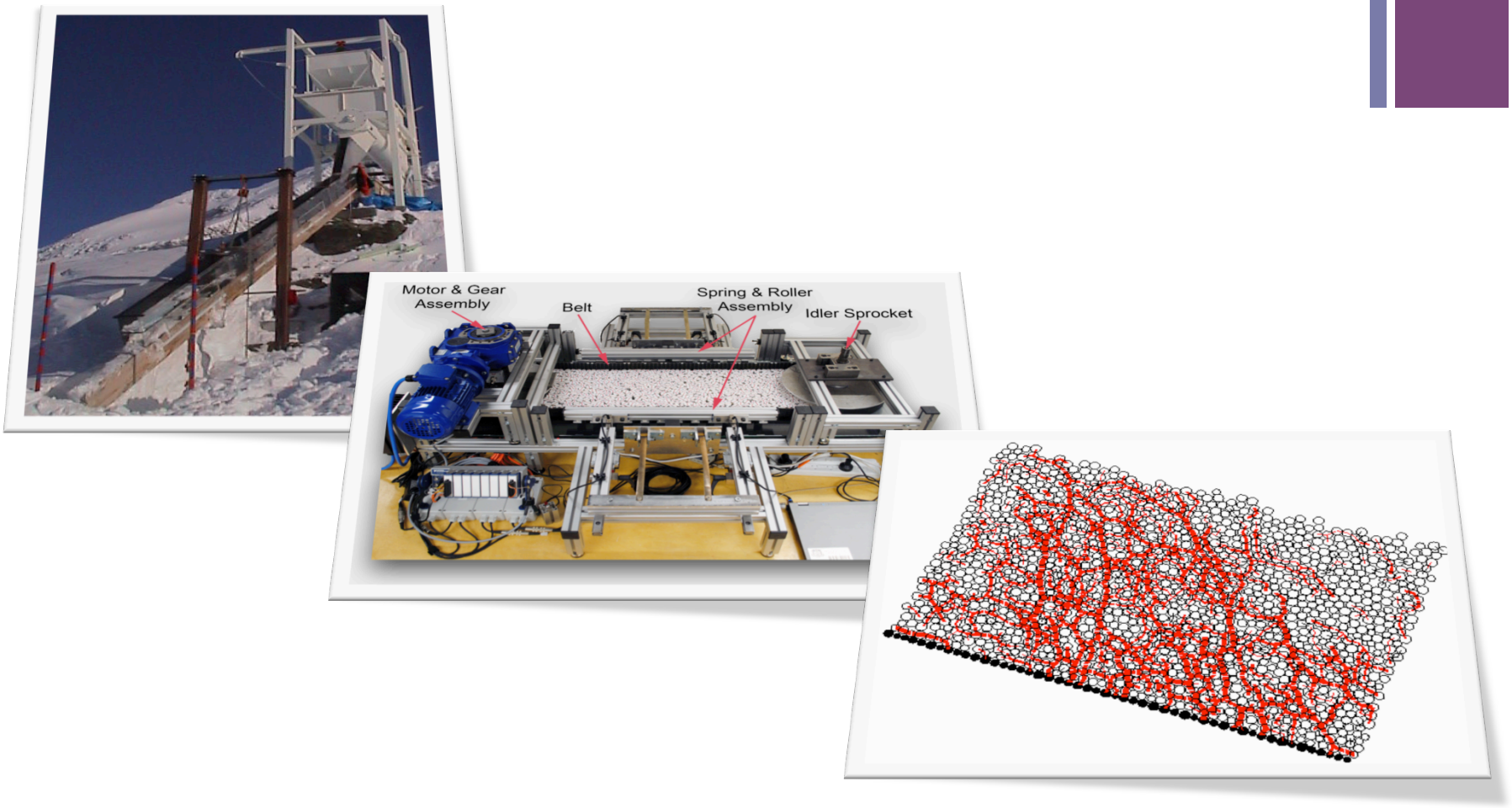
Conclusions





- Granular boundary layer/vortices
  - Long range wall perturbations
  - Low viscosity near walls
  - Due to granular vortices

Thank You!



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