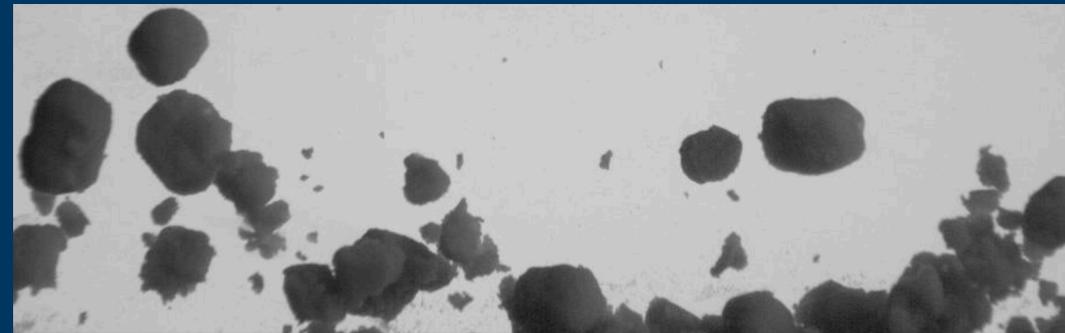
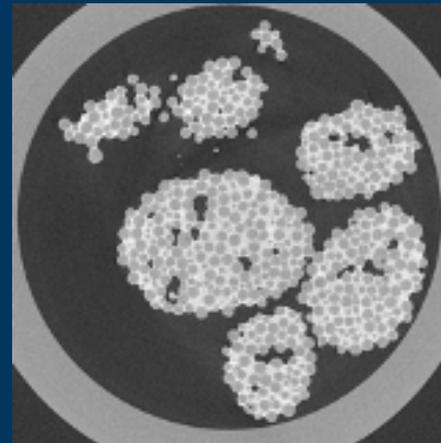


# DRYING WET POWDERS WITH SHEAR TO PREVENT AGGLOMERATE FORMATION

Ram Sudhir Sharma, Jackie Li, Alban Sauret

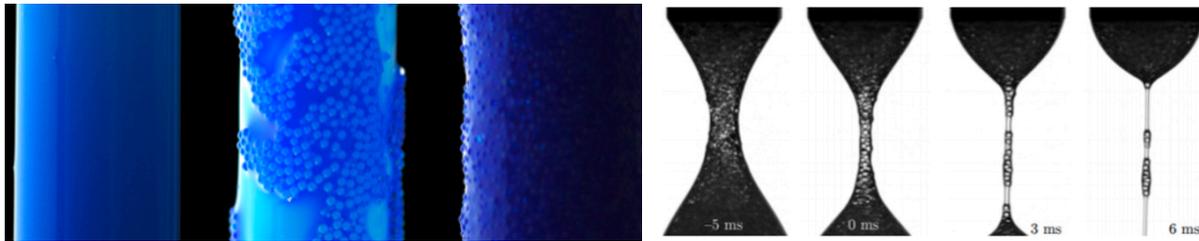
Jack Kingdon, Ryan Chambers, Kirk Fields



UC SANTA BARBARA

# MULTIPHASE & MULTISCALE FLOW LAB @ UCSB

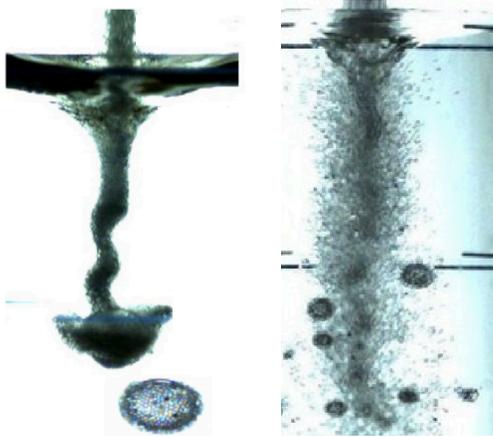
Interfacial dynamics & additive manufacturing



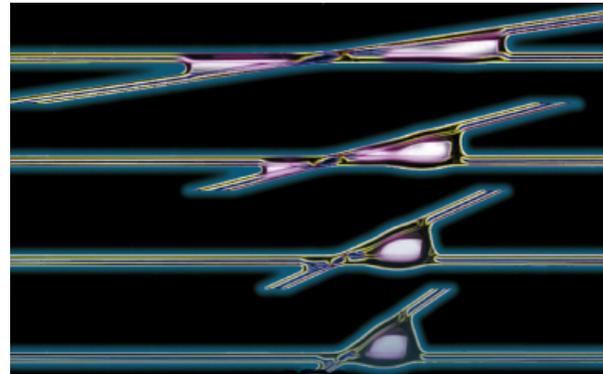
Clogging



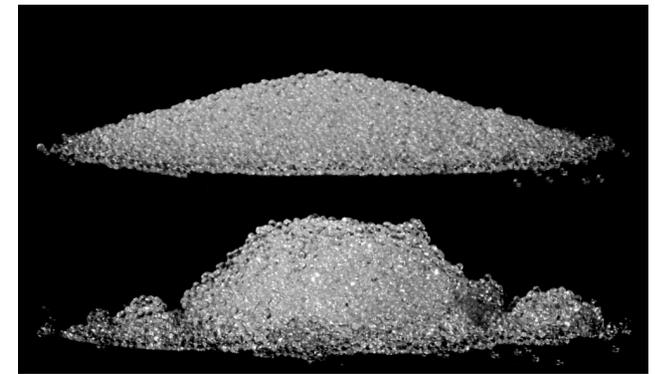
Blending liquid and grains



Heat transfer and phase change



Cohesive granular material



# COHESION OF WET GRAINS: FROM THE HOURGLASS TO THE SANDCASTLE



+ wetting liquid



Mitarai and Nori,  
Adv. Phys. (2006)

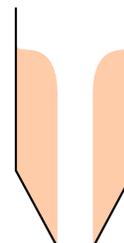
## Arching and "rat-hole" formation



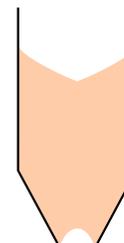
fine powders or  
exposure to  
humidity



rat-hole



arching



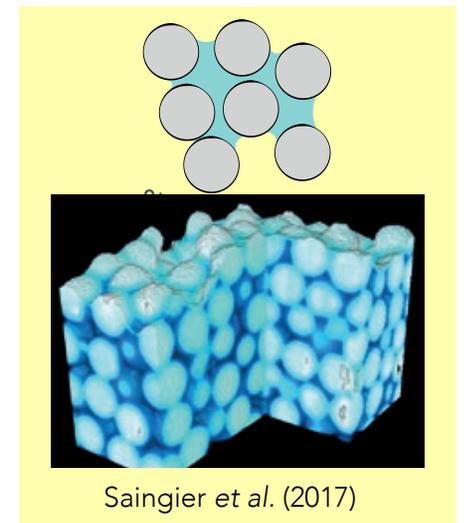
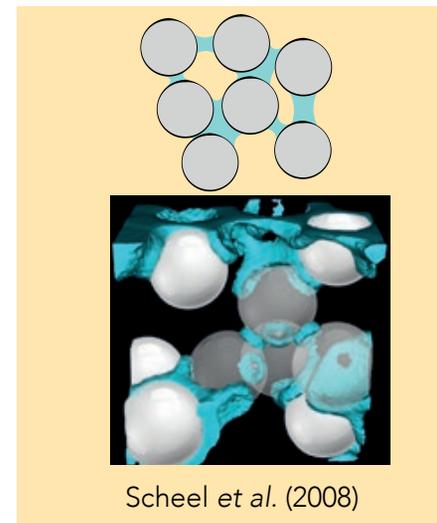
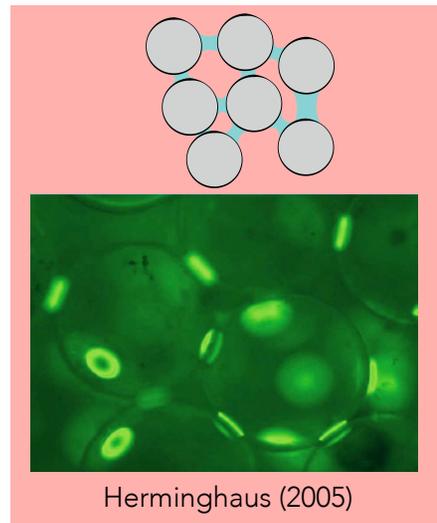
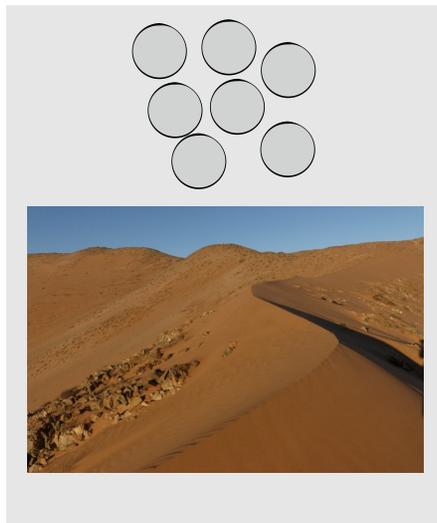
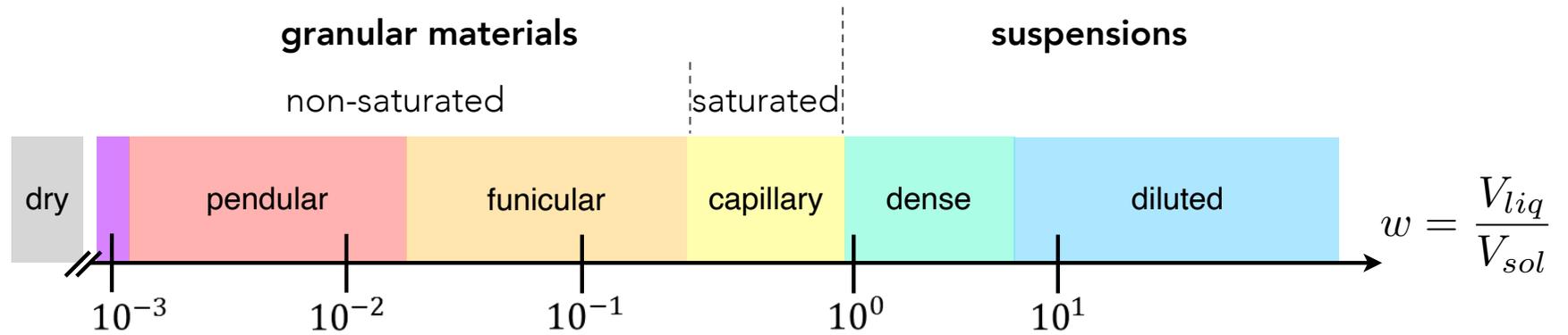
## Granulation processes



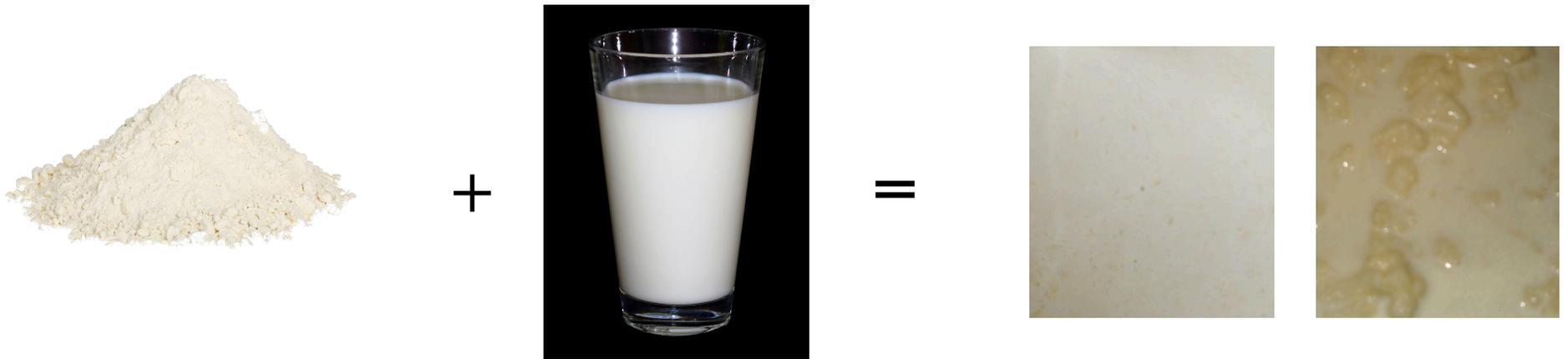
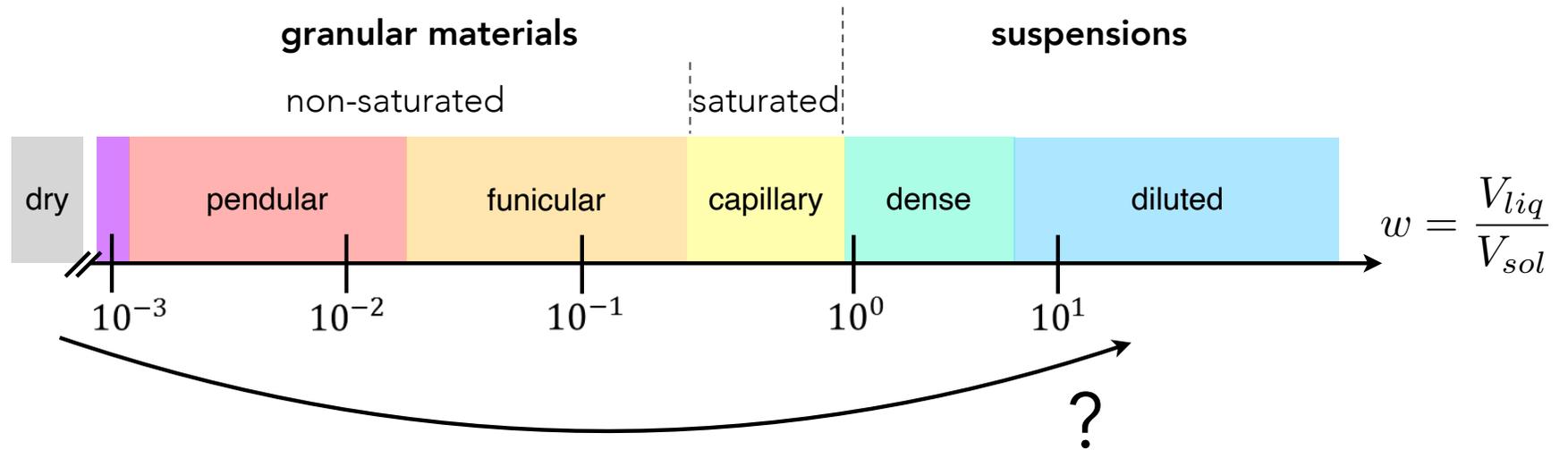
+ liquid binder



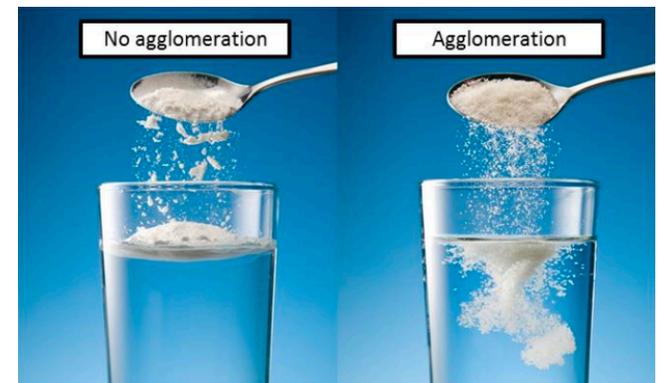
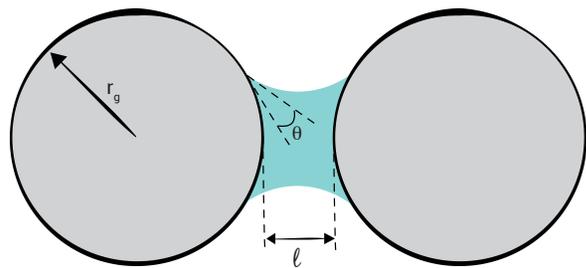
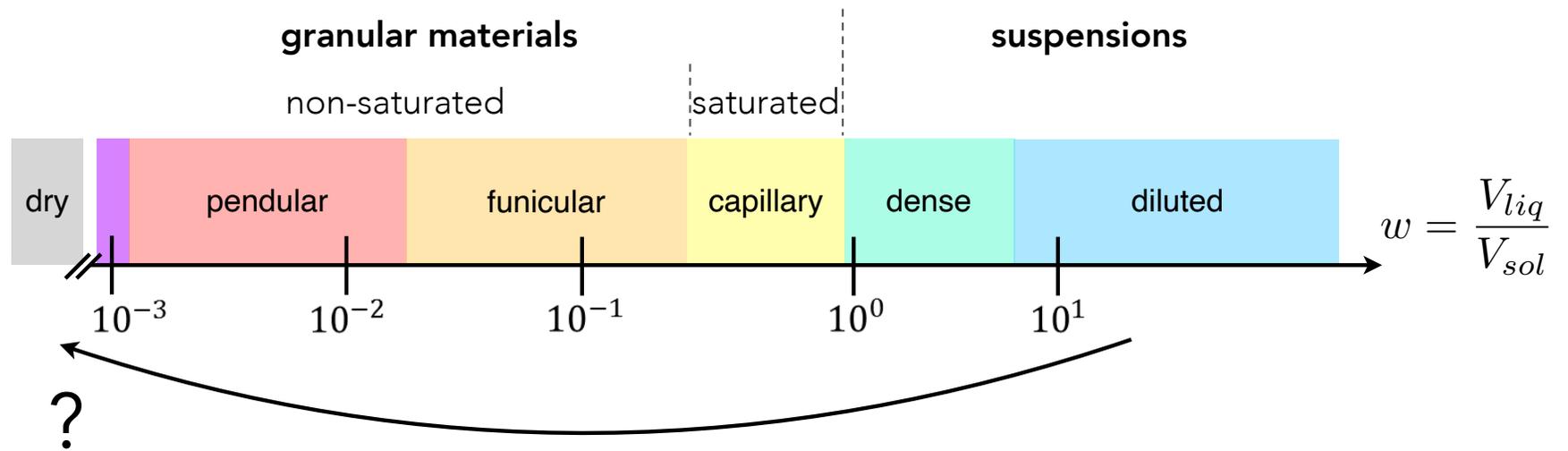
# WET GRAINS: LIQUID CONTENT AND REGIMES



# WET GRAINS: HOW TO BLEND LIQUID AND GRAINS ?



# DRYING OF POWDERS: FORMATION OF AGGLOMERATES



© Chalta Farm

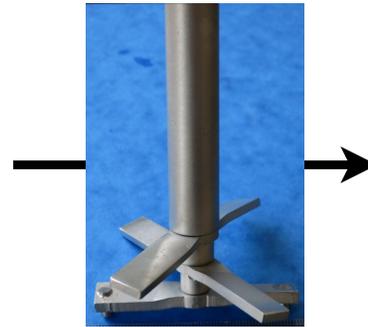
# DRYING OF POWDERS AND FORMATION OF AGGLOMERATES

Granulation process versus drying under shear

## High shear granulation



+ liquid binder



- suspension of agglomerates, dominated by impacts
- empirical control of the agglomerates properties
- complex flow and geometry

Can we model this process with a simpler system?

# OBJECTIVE AND APPROACH

## Objective

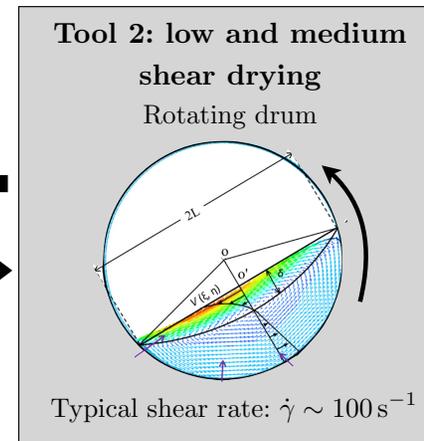
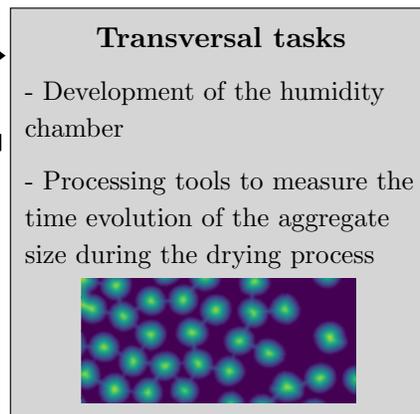
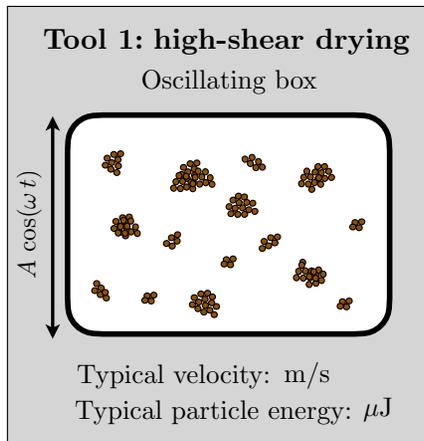
Characterize how the methods of drying a mixture of particles and liquid affect the state of agglomeration of the final dried product, particularly through the influence of shear.

## Approach

Experimental approach - Develop new small-scale tools for studying the drying of wet powders with controlled shear and allowing to characterize the time evolution of the agglomerates during the drying process.

# OBJECTIVE OF THE PROJECT

Development of the best proxy for the testing of the drying of wet powders with shear



Characterizing the formation of agglomerates during drying with different model powders and shear conditions

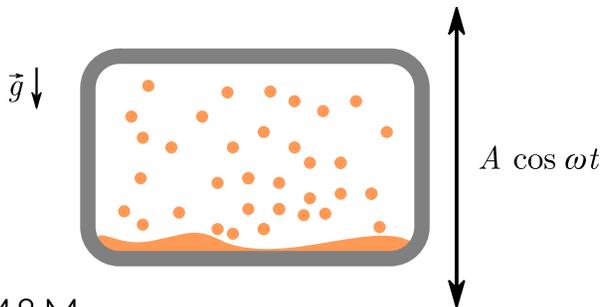
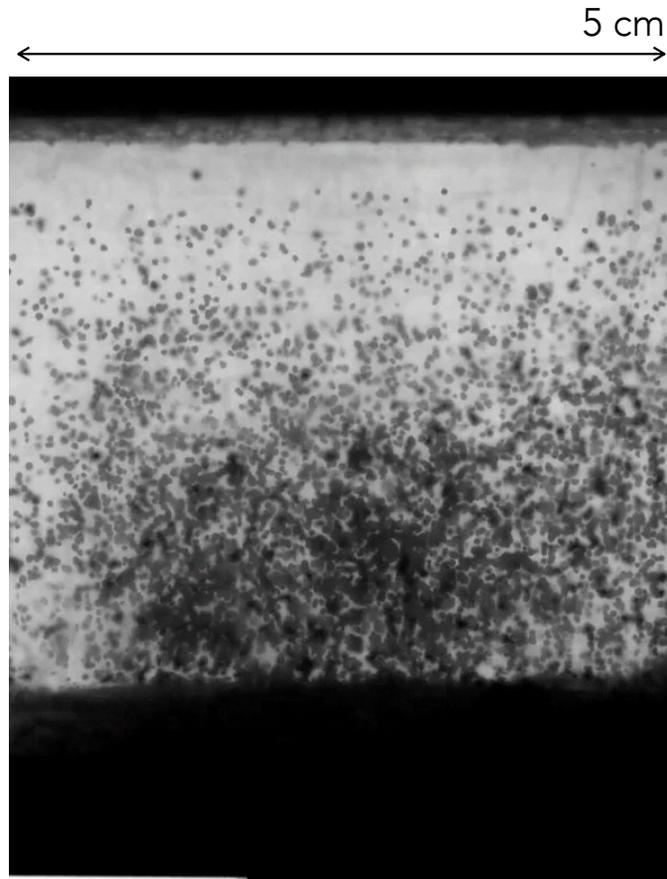
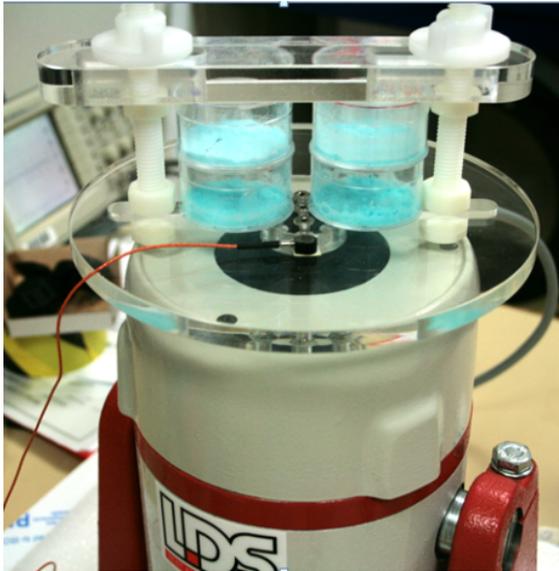
Practical results

- Experiments performed with model powders (e.g. calcium carbonate, quartz, cornstarch, etc.)
- Experiments with model material (glass beads) and liquid phase that solidifies upon drying
  - Time-resolved regime map varying the temperature, relative humidity and energy input
  - Key results: agglomerates size distribution

Input from IFPRI members with powders of interests

# TOOL 1 : OSCILLATING BOX

with Pascal Raux and Pierre Jop (SVI - CNRS/Saint-Gobain, 2018)



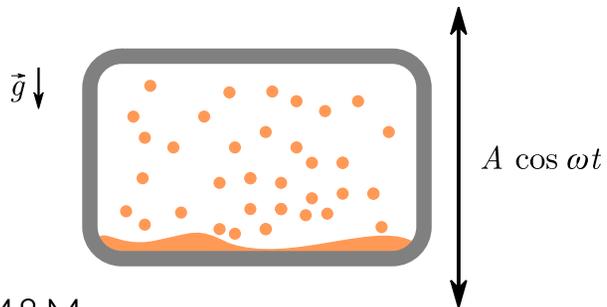
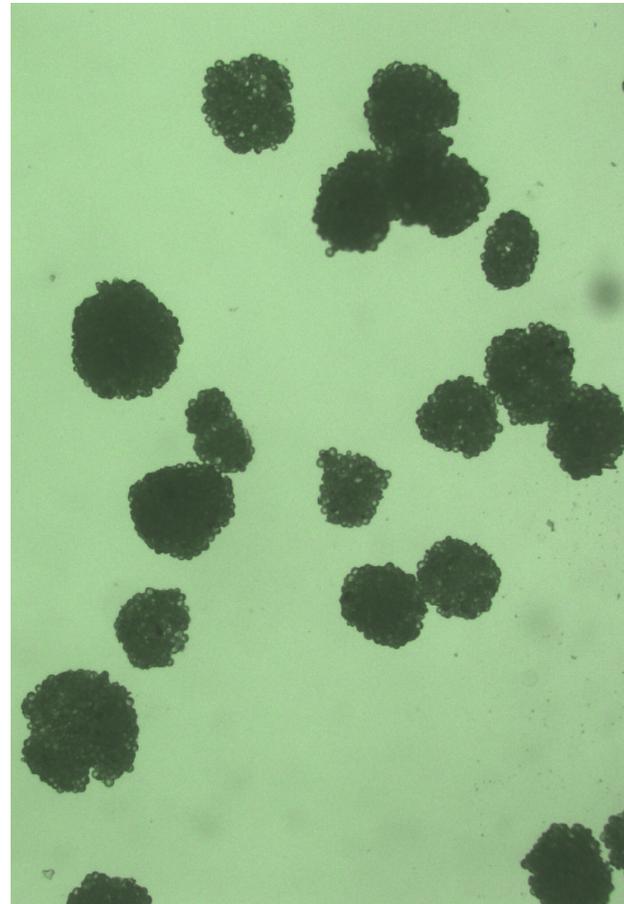
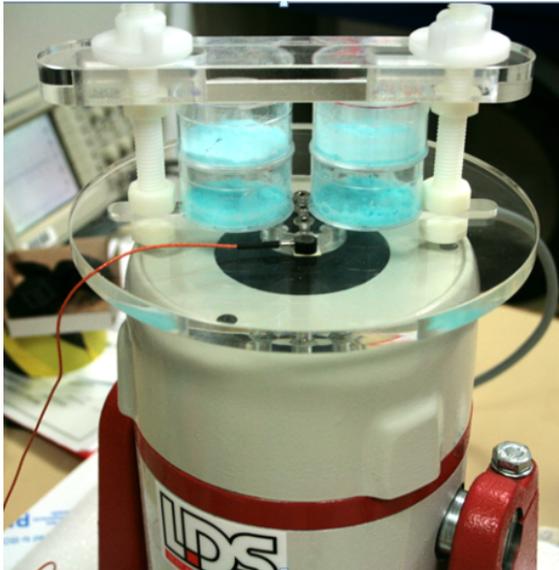
Raux et al., Phys. Rev. Fluids (2018)

slowed down 50x

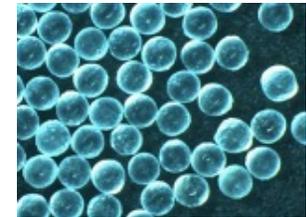
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# TOOL 1 : OSCILLATING BOX

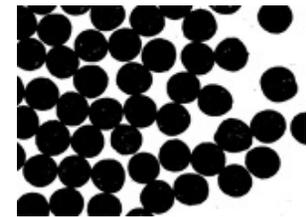
with Pascal Raux and Pierre Jop (SVI - CNRS/Saint-Gobain, 2018)



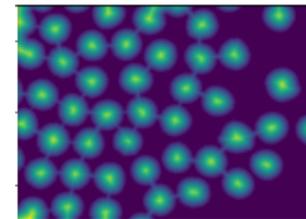
Raux et al., Phys. Rev. Fluids (2018)



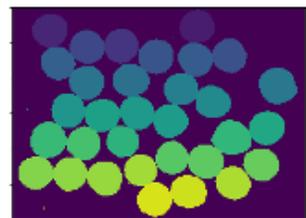
↓ Threshold



↓ Segmentation



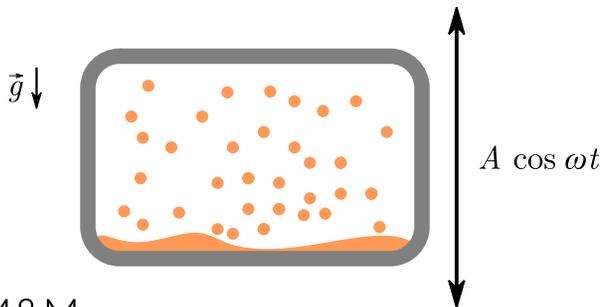
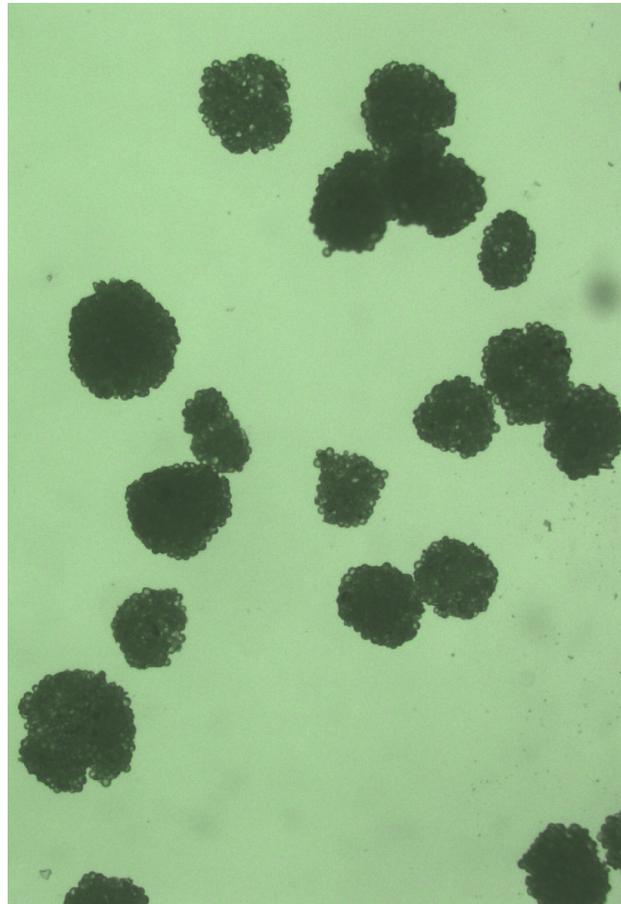
↓ Label



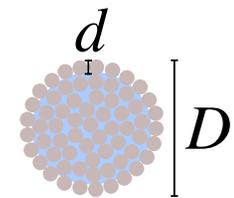
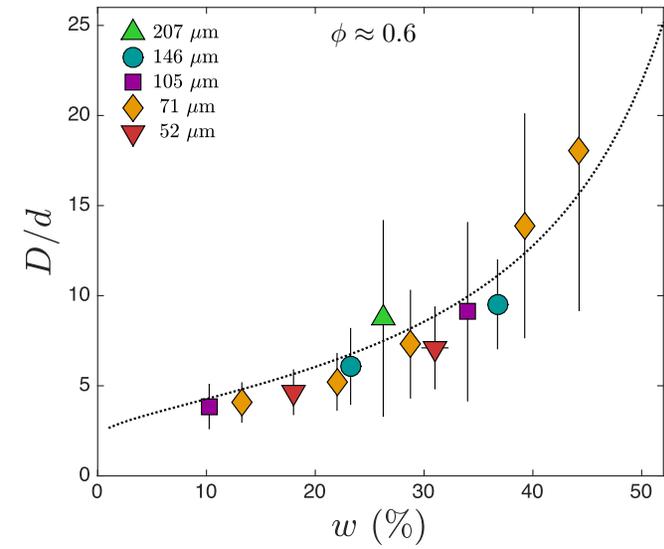
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# TOOL 1 : OSCILLATING BOX

with Pascal Raux and Pierre Jop (SVI - CNRS/Saint-Gobain, 2018)



Raux et al., Phys. Rev. Fluids (2018)



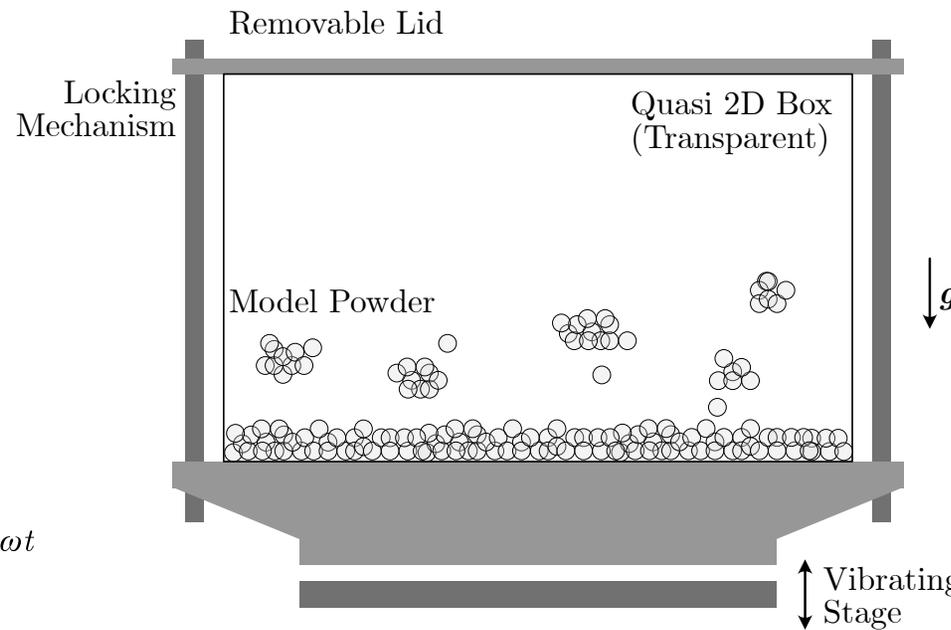
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# TOOL 1 : OSCILLATING BOX

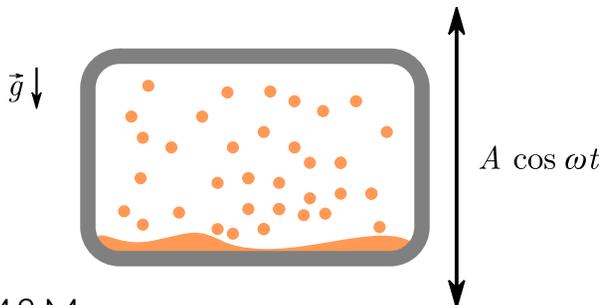
with Pascal Raux and Pierre Jop (SVI - CNRS/Saint-Gobain, 2018)



Previous version → **Issue:** real-time visualization of individual agglomerates impossible

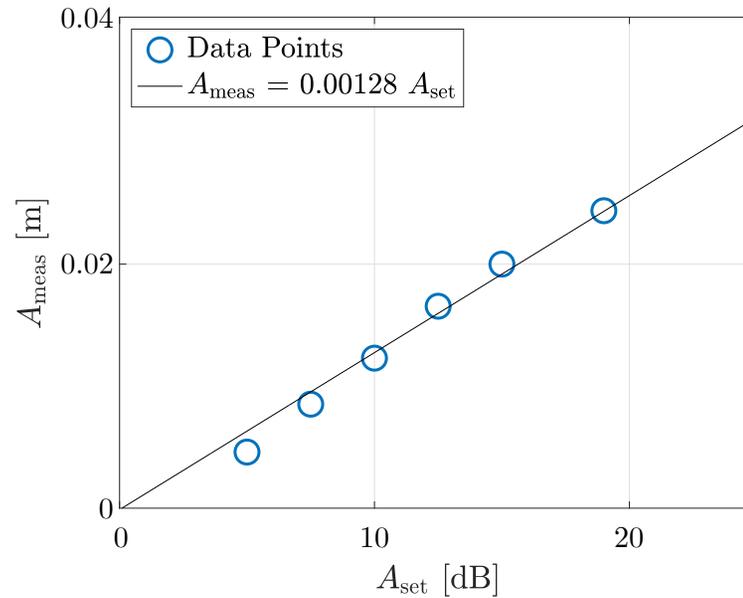
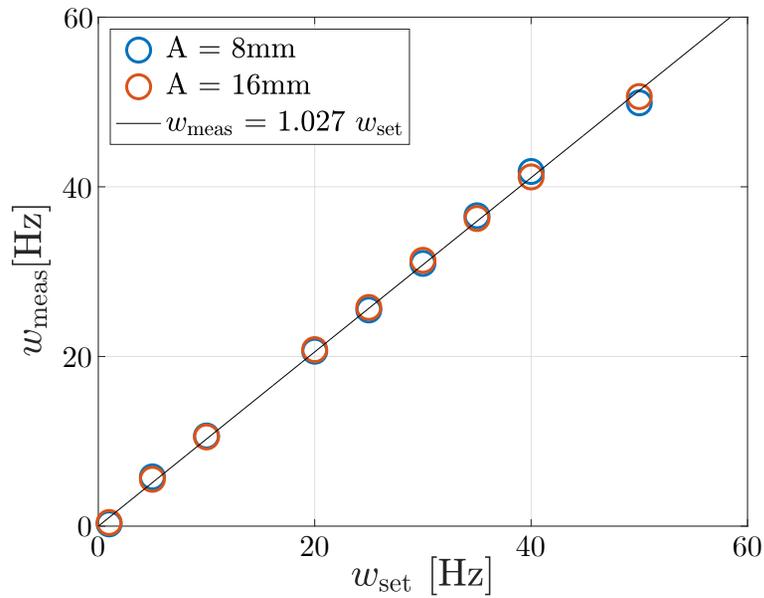


2D analogue  
Rapid prototyping



Raux et al., Phys. Rev. Fluids (2018)

# OSCILLATING BOX : CALIBRATION



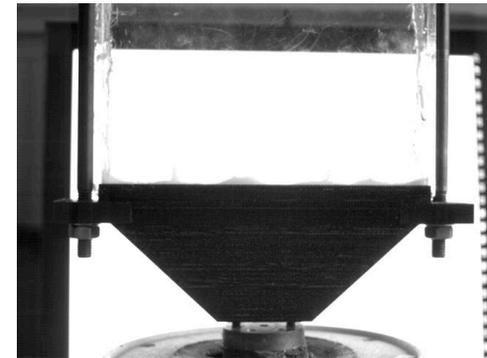
$$a \sim A \omega^2$$

$A$  : Amplitude [up to 4 cm]

$\omega$  : Frequency [up to 150Hz]

$$a_{\text{max}} \approx 70\vec{g}$$

Dry Grains:  $d \sim 0.3\text{mm}$   
 Slowed down 10x  
 $a \approx 3\vec{g}$



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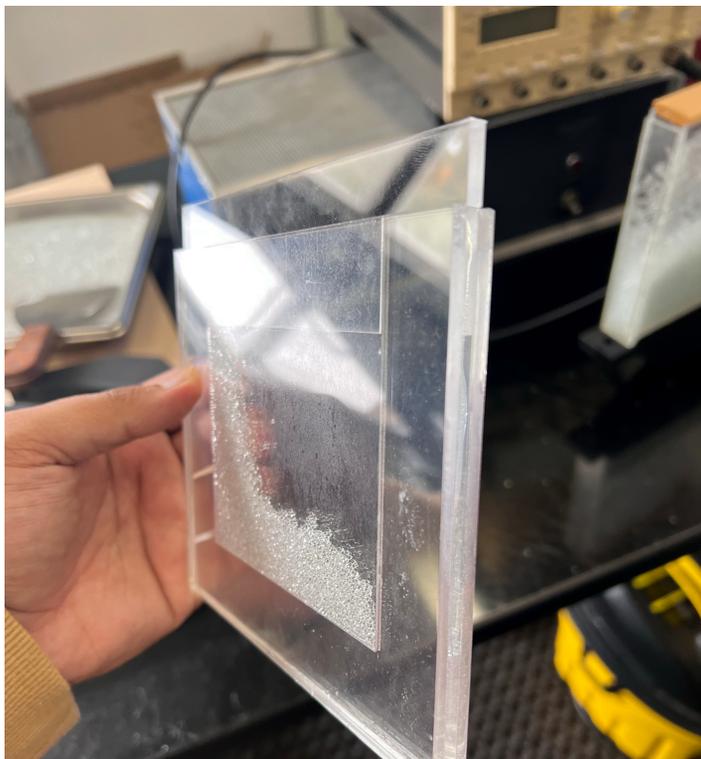
$a \approx 40g$

System mass: 0.5 grams



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## OSCILLATING BOX : PROTOTYPING & EARLY ISSUES



Adhesion causes coating of a grain layer, making visualization of agglomerates challenging

### **Solutions:**

Make system wider

Hydrophobic coating (worked!)

# OSCILLATING BOX : AGGLOMERATE PHENOMENOLOGY

Once grains have been prepared, the shaker is started - causing rapid initial agglomeration

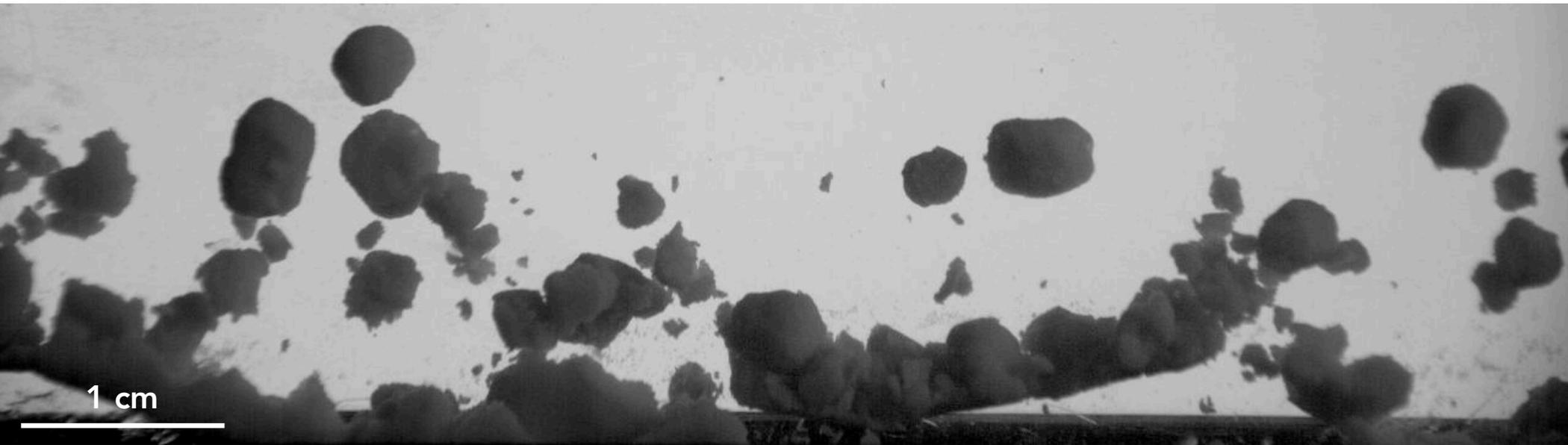
Visualized here:  $d = 65\mu\text{m}$

$W = 30\%[\text{/v}]$

Acceleration  $\sim 1g$

Parabolic trajectories

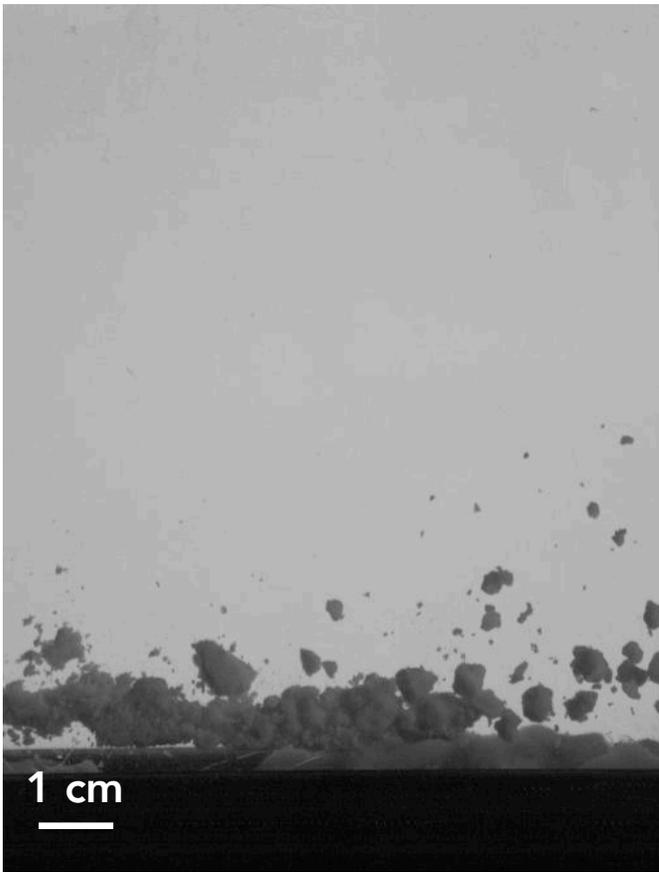
Agglomerate break-up/ collisions



$t = 1\text{min}$

$t = 3\text{min}$

$t = 8\text{min}$

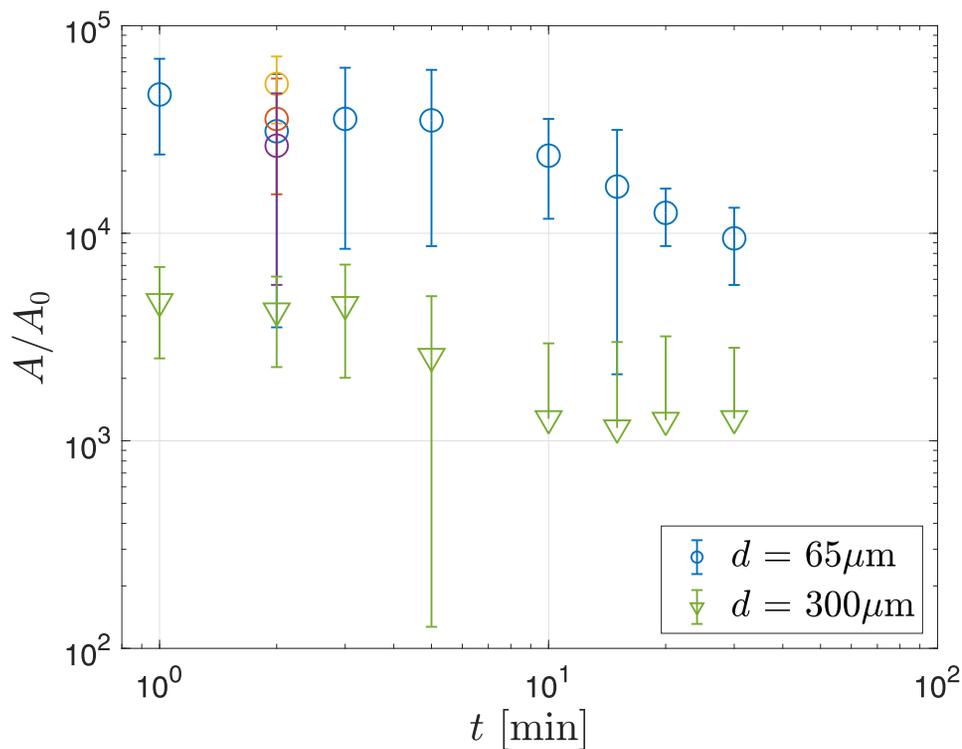


$a \approx 40g$

# INITIAL TESTS: NO MOISTURE EXCHANGE

## Agglomerate Size

$$A_0 = \pi(d/2)^2$$



Preliminary analysis using thresholding and area estimation of agglomerates using imageJ

Normalized by the projected area of a single grain  
 $\implies$  Estimate of agglomerate size

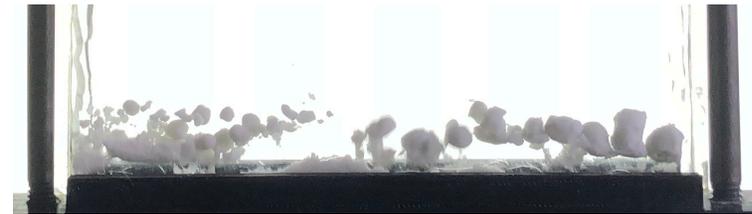
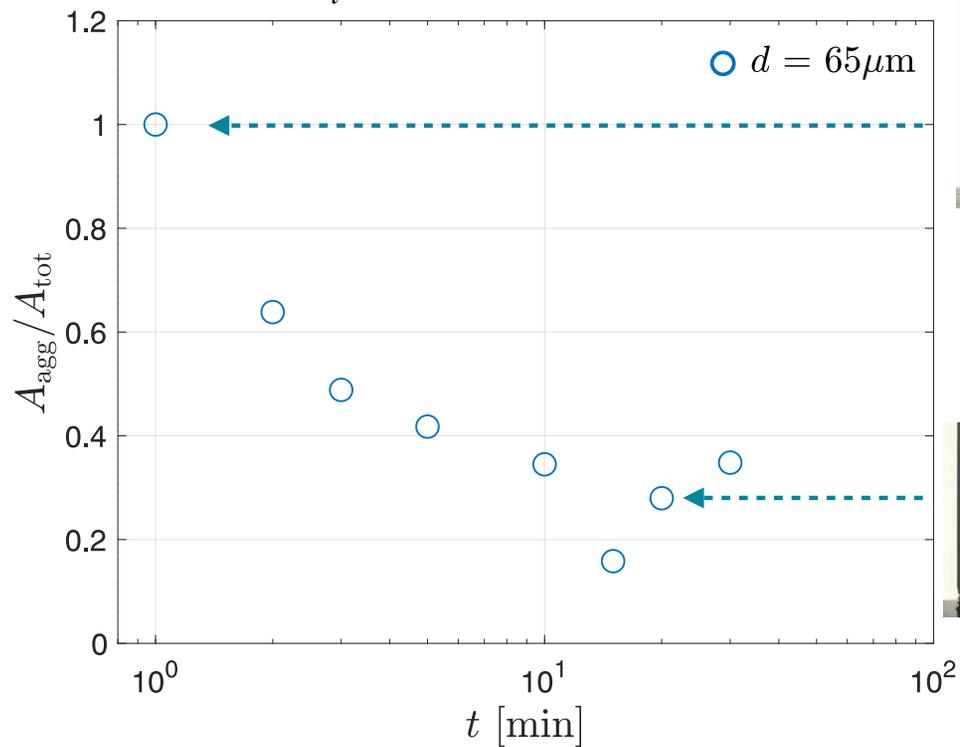
Smaller grains  $\implies$  more grains per agglomerate

Over time agglomerates becoming smaller

# INITIAL TESTS: NO MOISTURE EXCHANGE

## Agglomerate Concentration

$$A_{\text{agg}}(t) = \sum_i A_i(t)$$

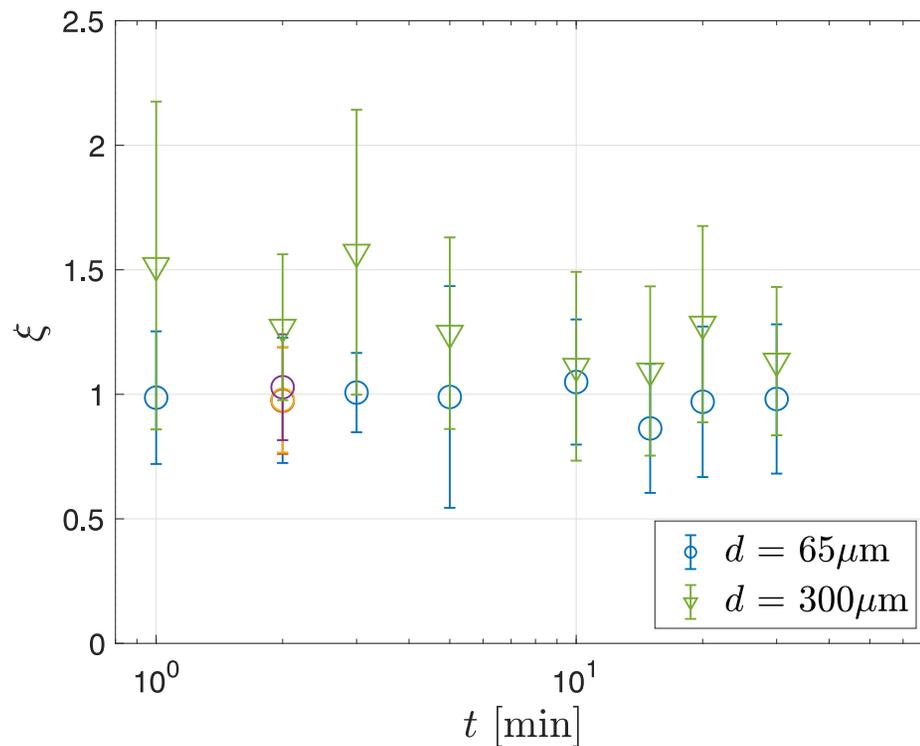
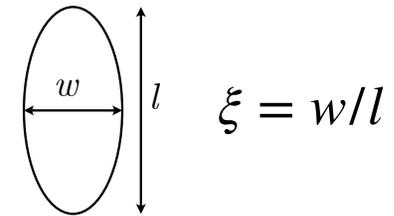


Agglomerates breakup over time, as the system approaches a cohesive layer at the bottom of box



# INITIAL TESTS: NO MOISTURE EXCHANGE

## Agglomerate Shape



Estimate agglomerate shape using length and width

Agglomerates roughly circular in shape for all times for smaller grains

To be tested with non-spherical grains

## OSCILLATING BOX : NEXT STEPS

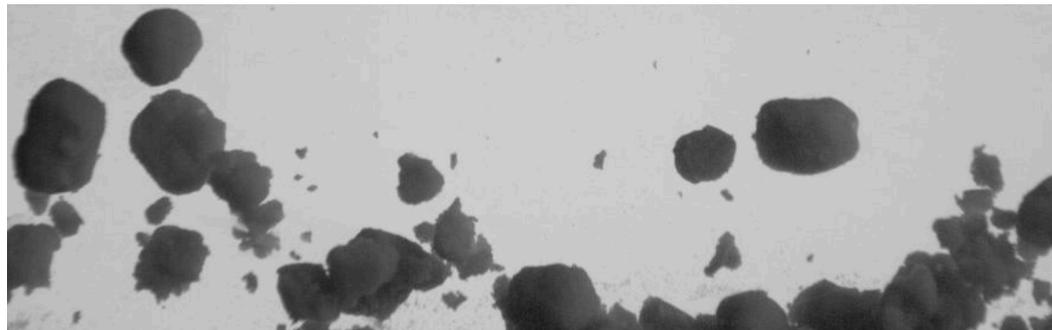
Reach higher acceleration of the oscillating box (higher shear)

Air Exchange: Design updates to allow air without leaking powder

Humidity and temperature control

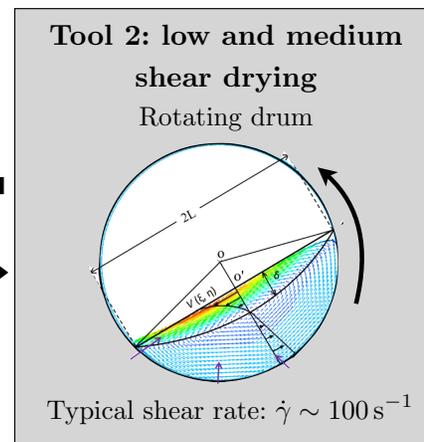
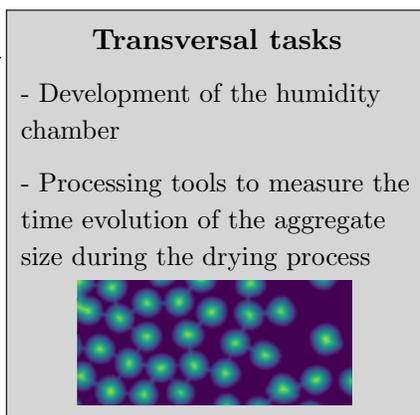
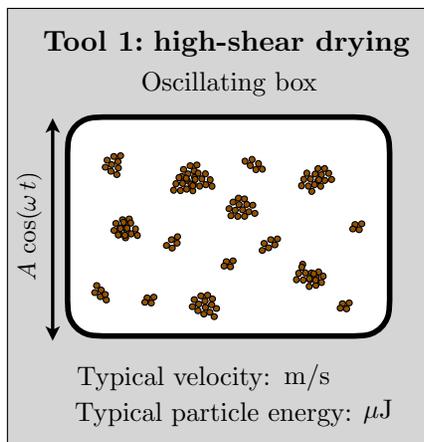
Parameter space sweep and first tests with small glass beads

Powders (input from IFPRI members)



# OBJECTIVE OF THE PROJECT

Development of the best proxy for the testing of the drying of wet powders with shear



Characterizing the formation of agglomerates during drying with different model powders and shear conditions

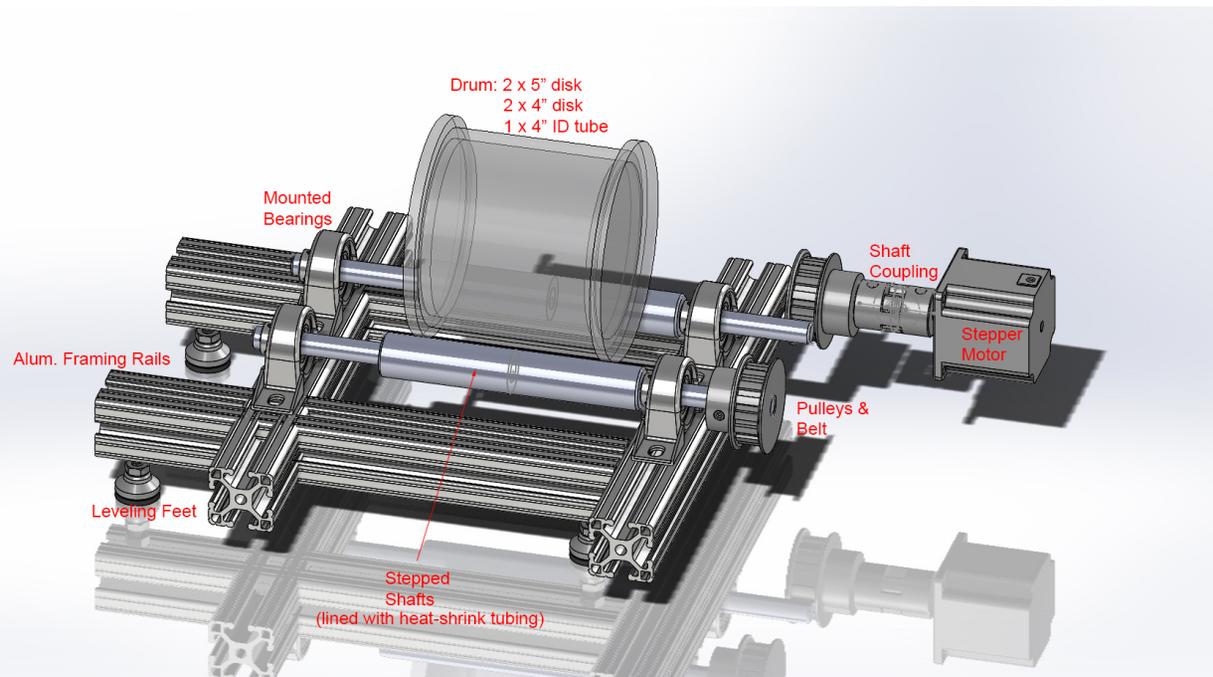


Practical results

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- Experiments with model material (glass beads) and liquid phase that solidifies upon drying
  - Time-resolved regime map varying the temperature, relative humidity and energy input
  - Key results: agglomerates size distribution

Input from IFPRI members with powders of interests

## TOOL 2 : ROTATING DRUM



### Experimental system:

- Built and operational
- Ability to tune the drum size and the rotation speed
- Visualization through the side
- Experiments with glass beads

### Next steps:

- IFPRI: shear of interest in industrial systems + powder

## TOOL 2 : ROTATING DRUM

### Prototype cylinder



1mm glass beads: dry



1mm glass beads: 1% wet

### Further work

- Faster motors
- Larger drum
- Measure and vary humidity exchange
- Characterize aggregate size - image processing

# PERSPECTIVES

Design an air exchange mechanism (humidity and temperature control)

Automize the processing of the experimental pictures

Start considering real powders (input welcome!)

## Thanks to:

### UC Santa Barbara



Ram Sharma



Jackie Li

### SVI (CNRS/Saint-Gobain)



Pierre Jop



Pascal Raux

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