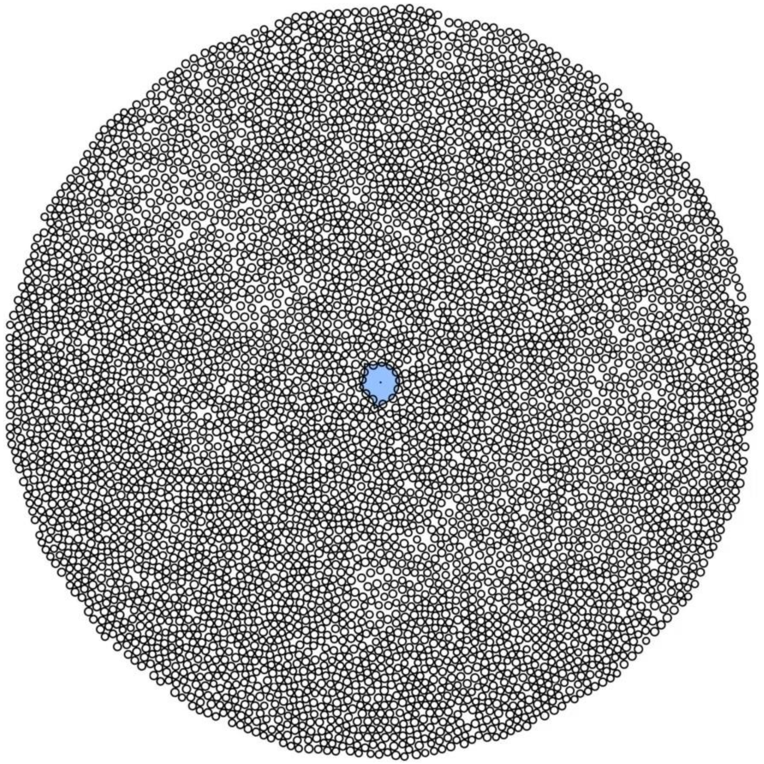
Jamming transition and emergence of fracturing

In wet granular media



ERL Annual Meeting

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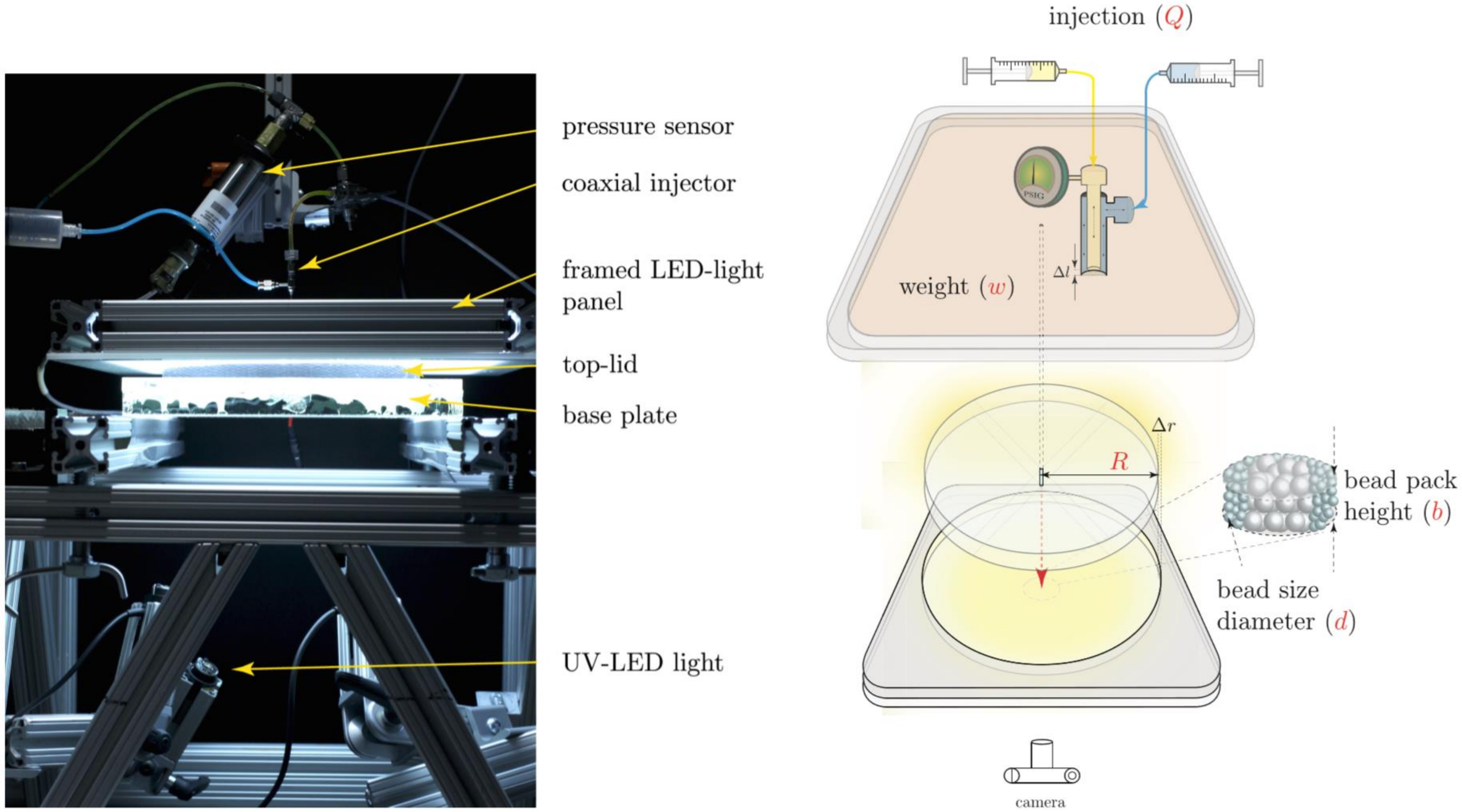
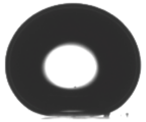
Experiments phase diagram: wettability and granular fracture



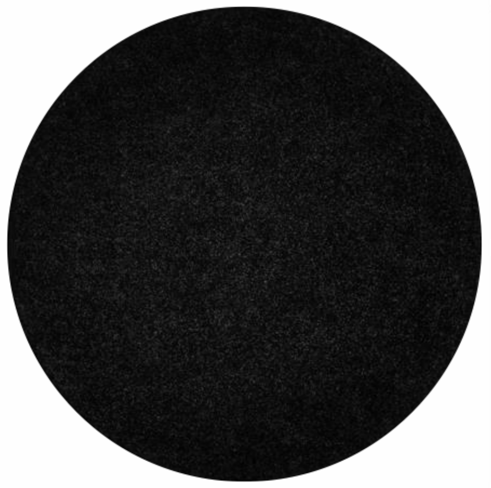
Trojer et al. (*in review*).

Experiments phase diagram: wettability and granular fracture

silicone oil – glycerol



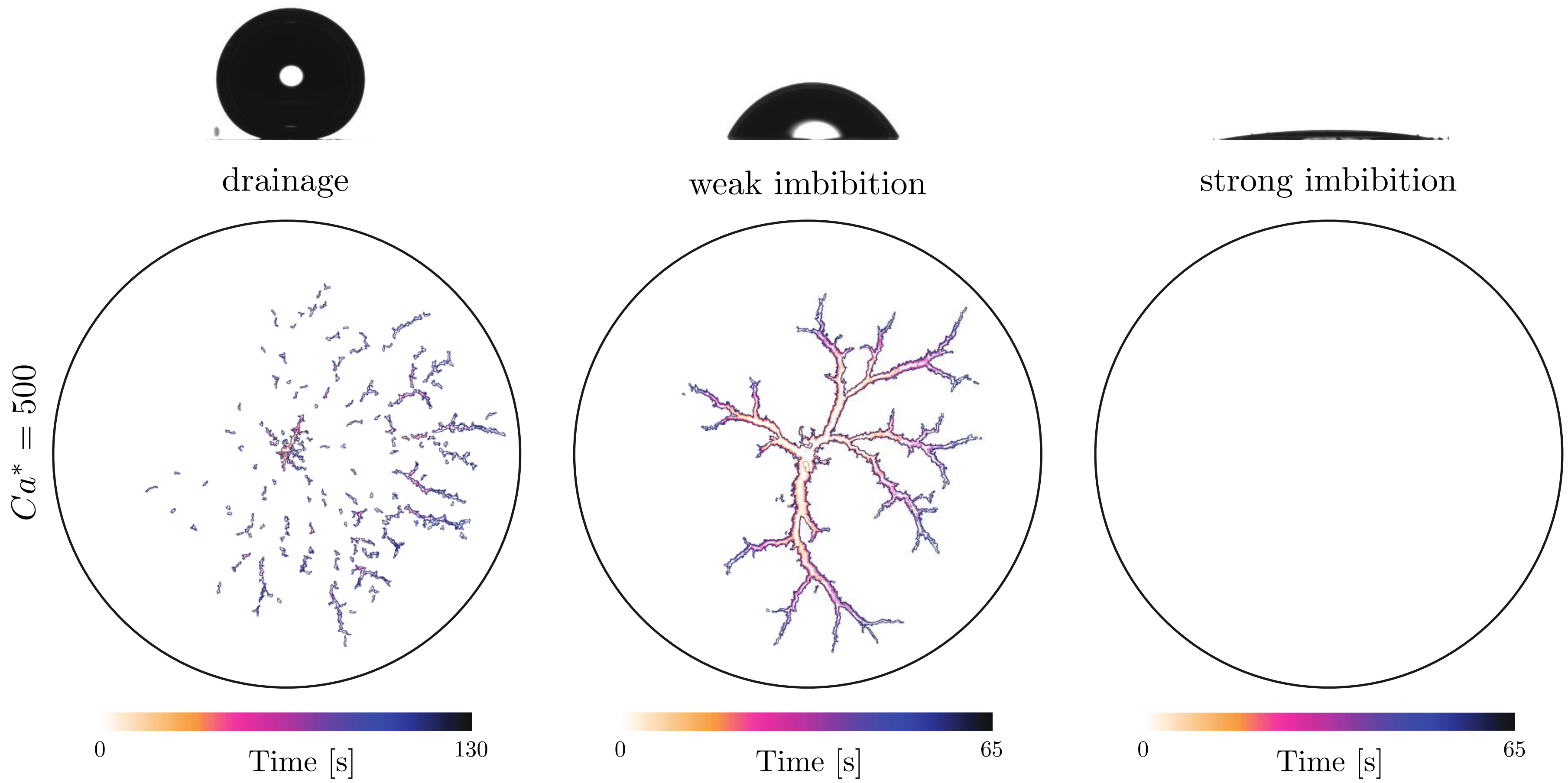
water – silicone oil



water – fluorinated oil

Trojer et al. (*in review*).

Experiments phase diagram: wettability and granular fracture



Trojer et al. (*in review*).

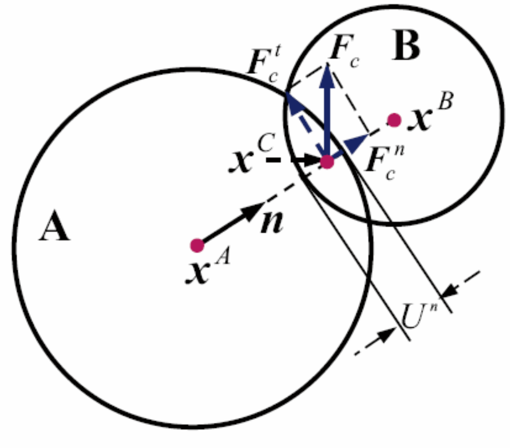
Coupling of multiphase flow and grain mechanics

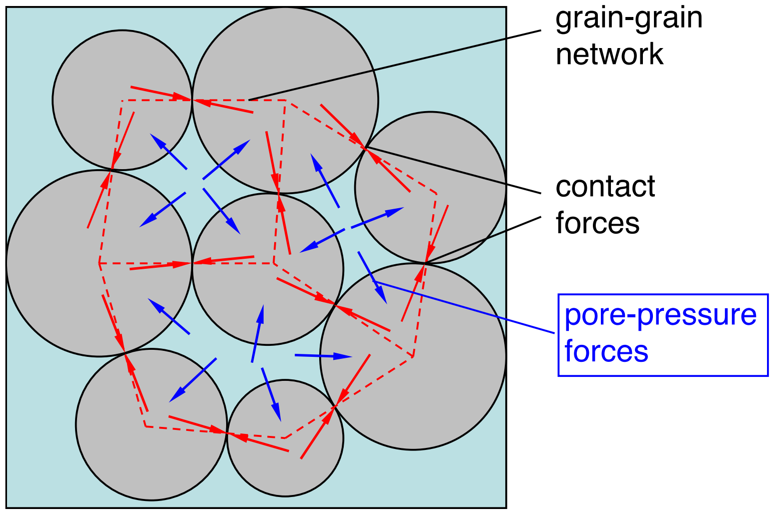
- **Discrete element modeling (DEM) framework:**
  - Simulate particle interactions solving Newton's law of motion

$$m_i\ddot{\mathbf{x}}_i = \sum_j \mathbf{F}_{ij} \qquad \mathbf{I}_i\ddot{\theta}_i = \sum_j \mathbf{M}_{ij}$$

  - Define dual networks: grain-contact network and pore network

- **Two-way coupling:**
  - Pressure (from both fluids) exert forces on particles
  - Particle rearrangement causes volume and pressure changes

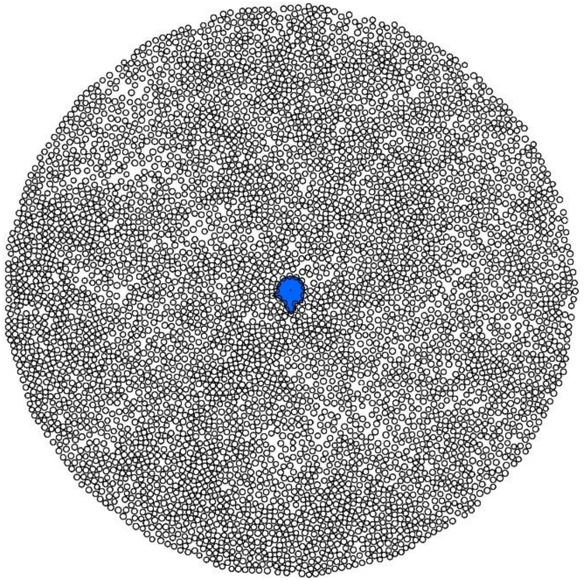




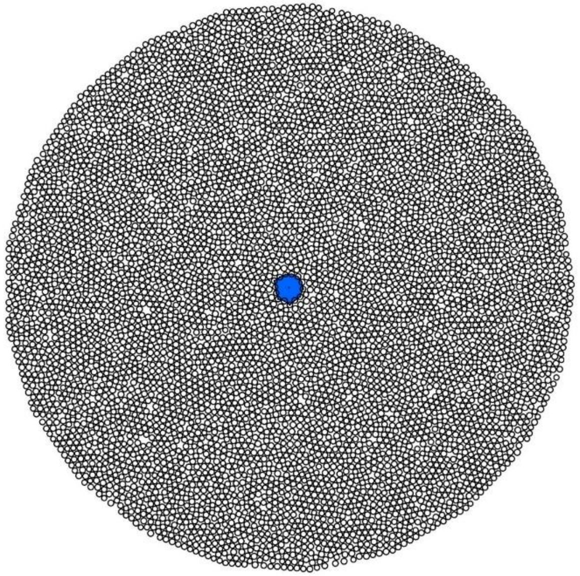
Primkulov et al. *JFM* (2019).
Primkulov et al. *PRF* (2018).

Simulation setup: frictional granular pack

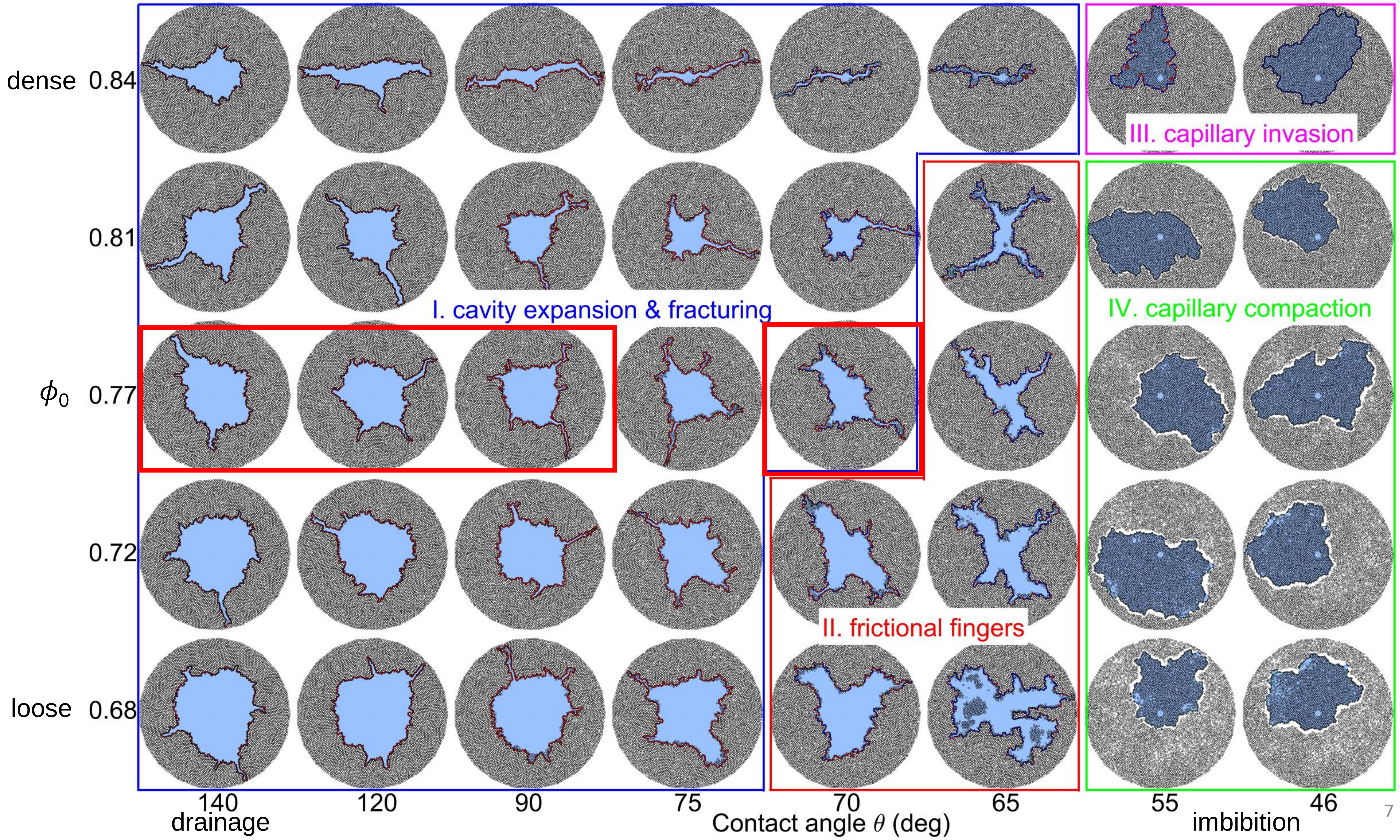
ϕ_0 = 0.68 (loose)



ϕ_0 = 0.84 (dense)



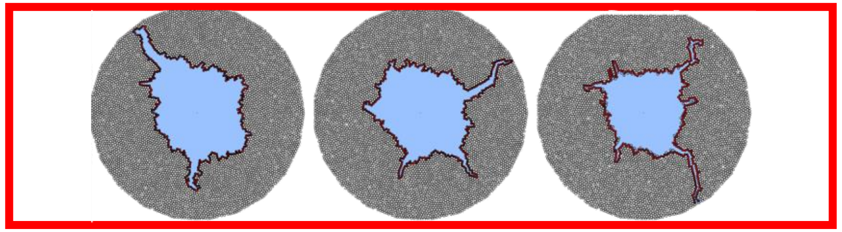
- Contact angle θ = 140° (drainage) - 90° (neutral) - 46° (imbibition)
- Initial packing density ϕ_0 = 0.68 (loose) - 0.84 (dense)
- Coefficient of friction $\boldsymbol{\mu}$ = 0.3
- Ca* = 0.5, Q = 4.29 × 10^{-11} m^3/s → $\Delta P_{viscous} \approx 0.001\ \Delta P_{capillary}$ → capillary-dominated regime

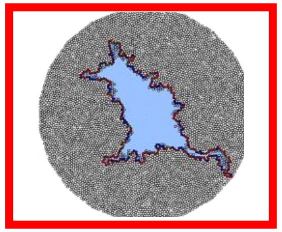


dense 0.84
0.81
ϕ_0 0.77
0.72
loose 0.68
I. cavity expansion & fracturing
II. frictional fingers
III. capillary invasion
IV. capillary compaction
140
120
90
75
70
65
55
46
drainage
Contact angle θ (deg)
imbibition

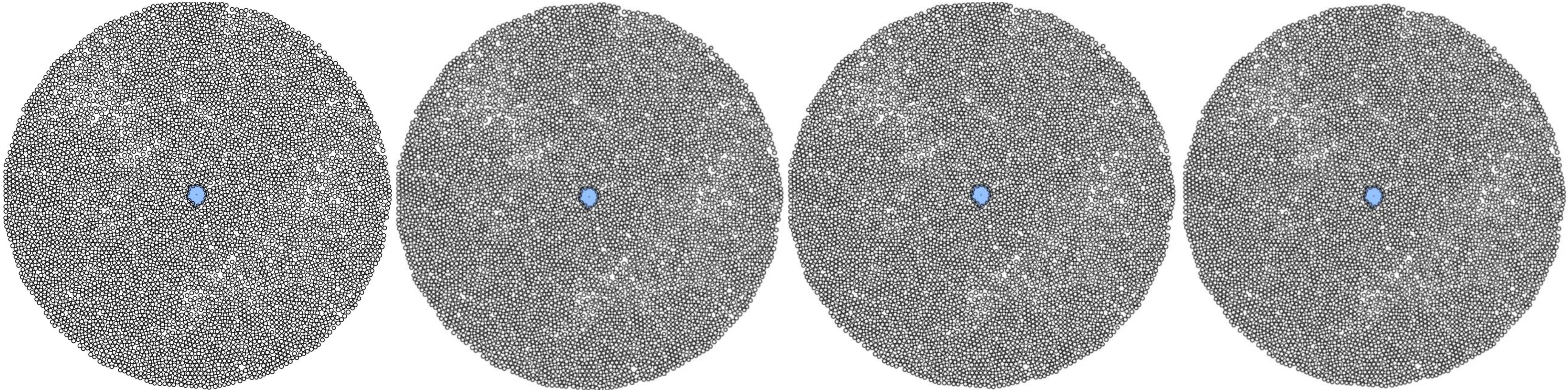
Evolution of interface morphology

ϕ_0 = 0.77





θ = 140° | θ = 120° | θ = 90° | θ = 70°

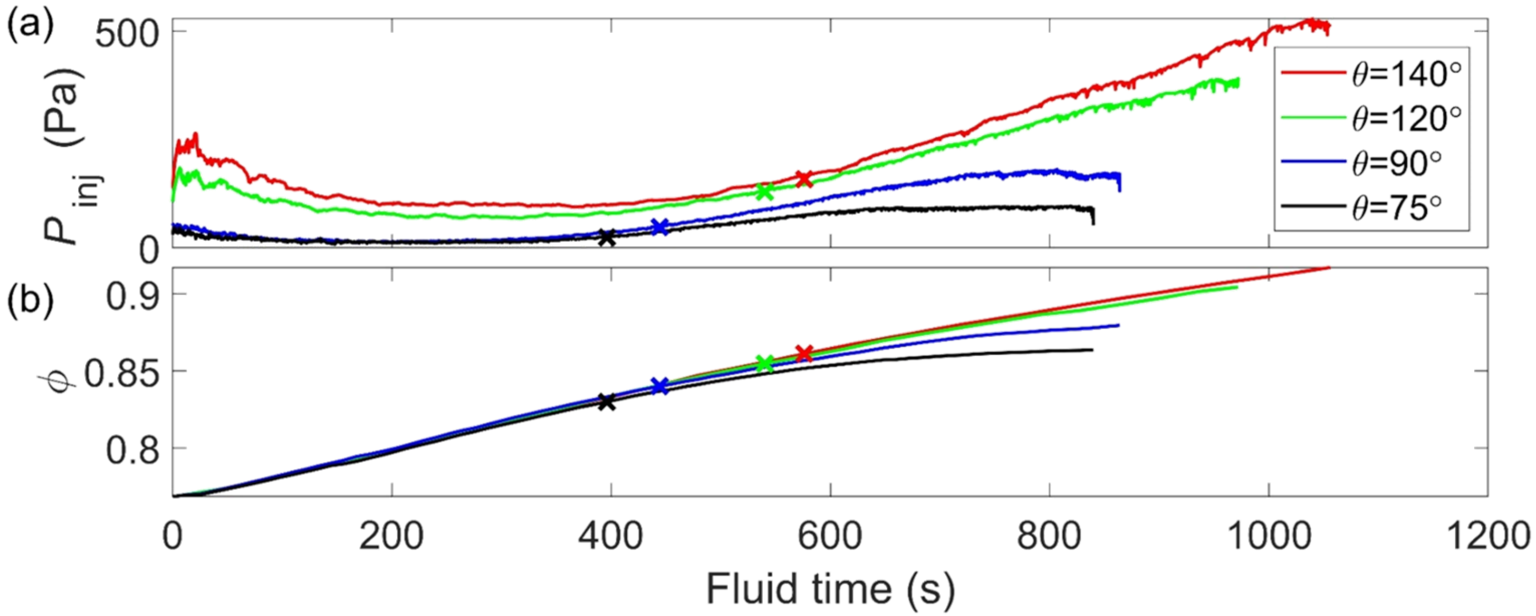


drainage | imbibition

- **Key observation:** contact angle impacts the onset of fracturing – imbibition promotes fracture

What causes the transition from cavity expansion to fracturing?

- The injection pressure by itself, or packing fraction by itself, do not explain the transition



- We hypothesize that this is akin to a phase transition from liquid-like to solid-like behavior

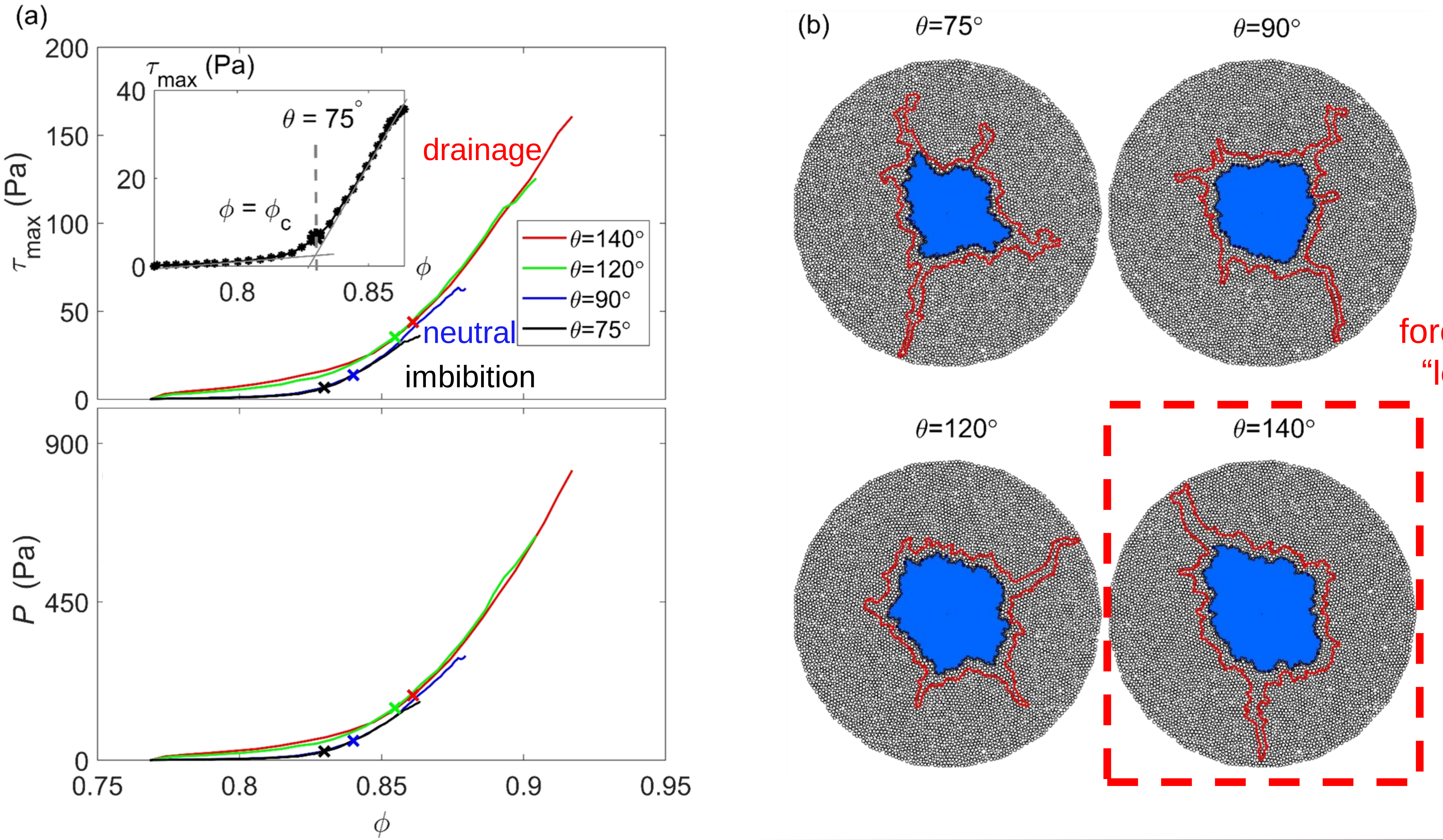
  ⟶ A jamming transition

  - Can be characterized by the mean contact number *Z* or the mean particle stress *P*

(Majmudar et al., *PRL* 2007)

Fracture initiation at the jamming transition

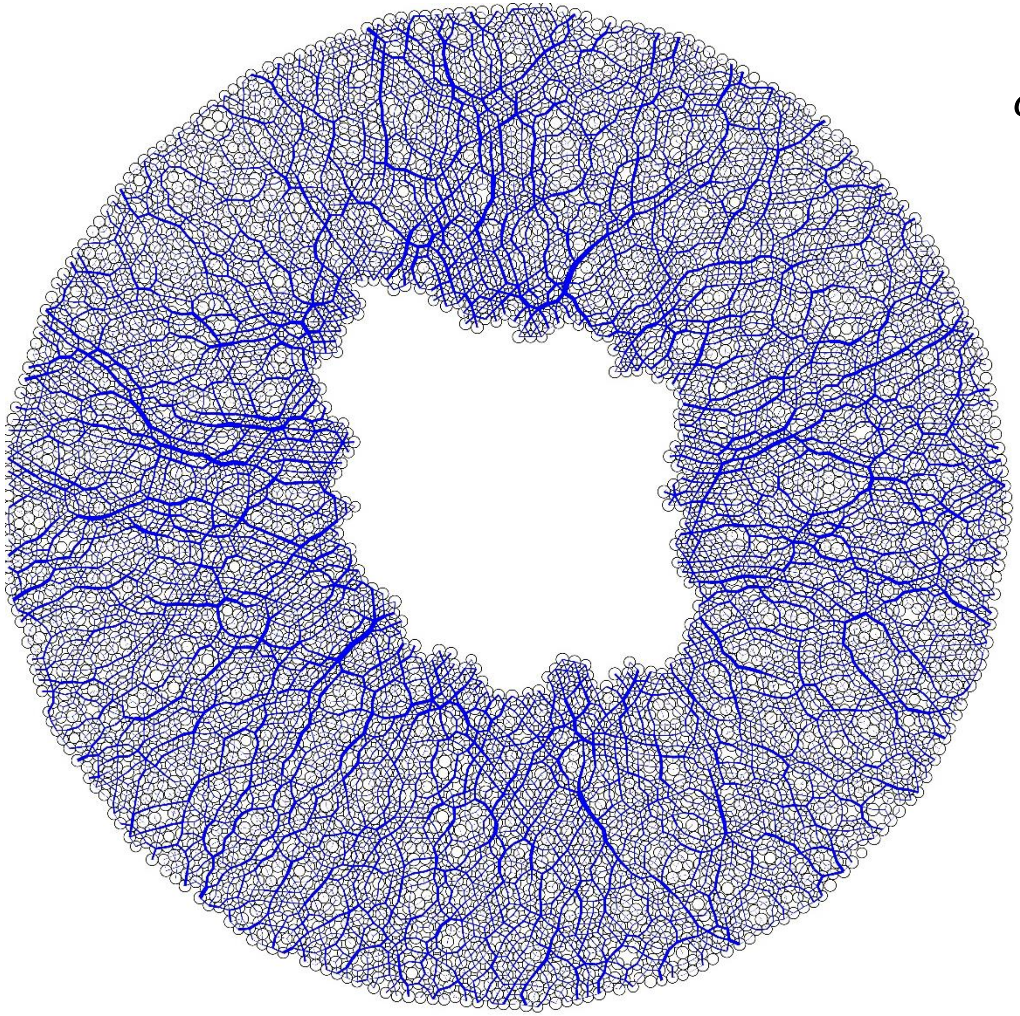
$\phi_0 = 0.77$



force chains "lock-in"?

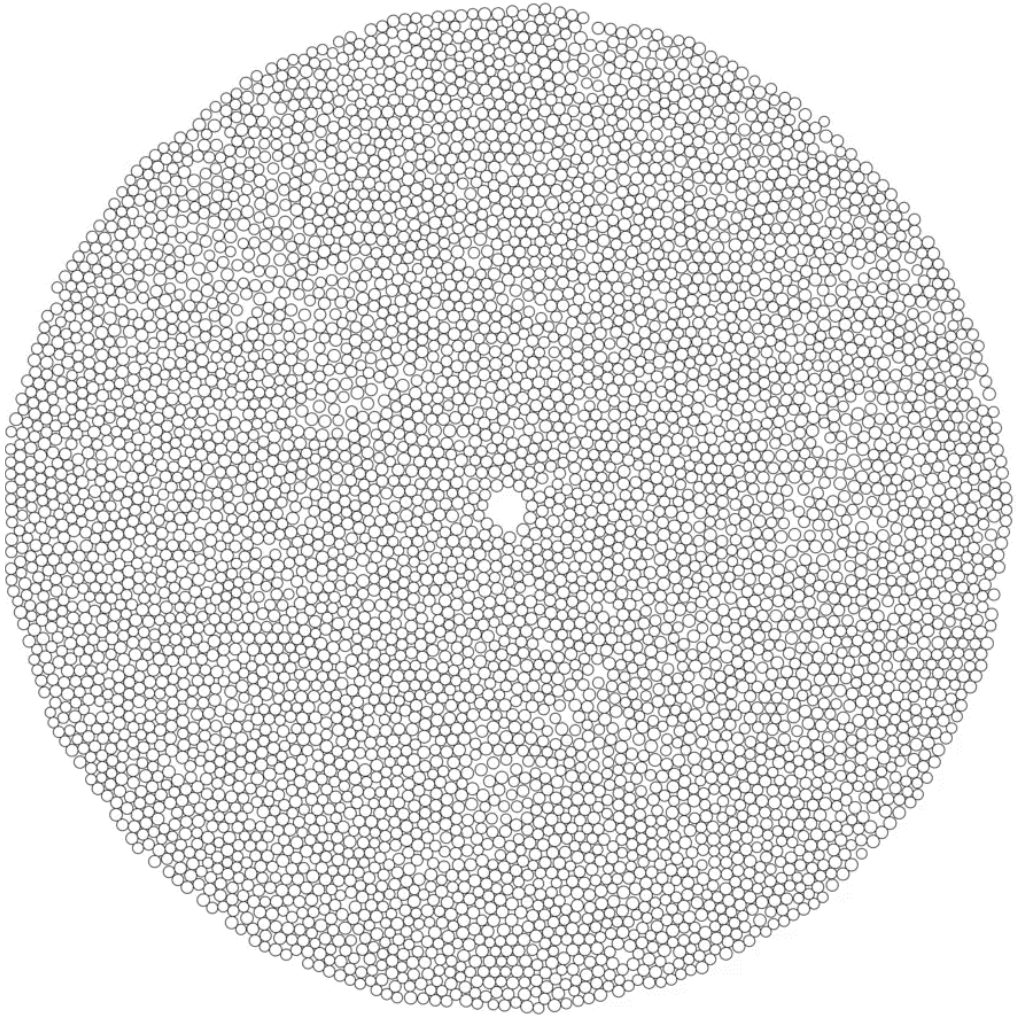
Jamming transition: force chains "lock-in" ?

force chain network at jamming transition



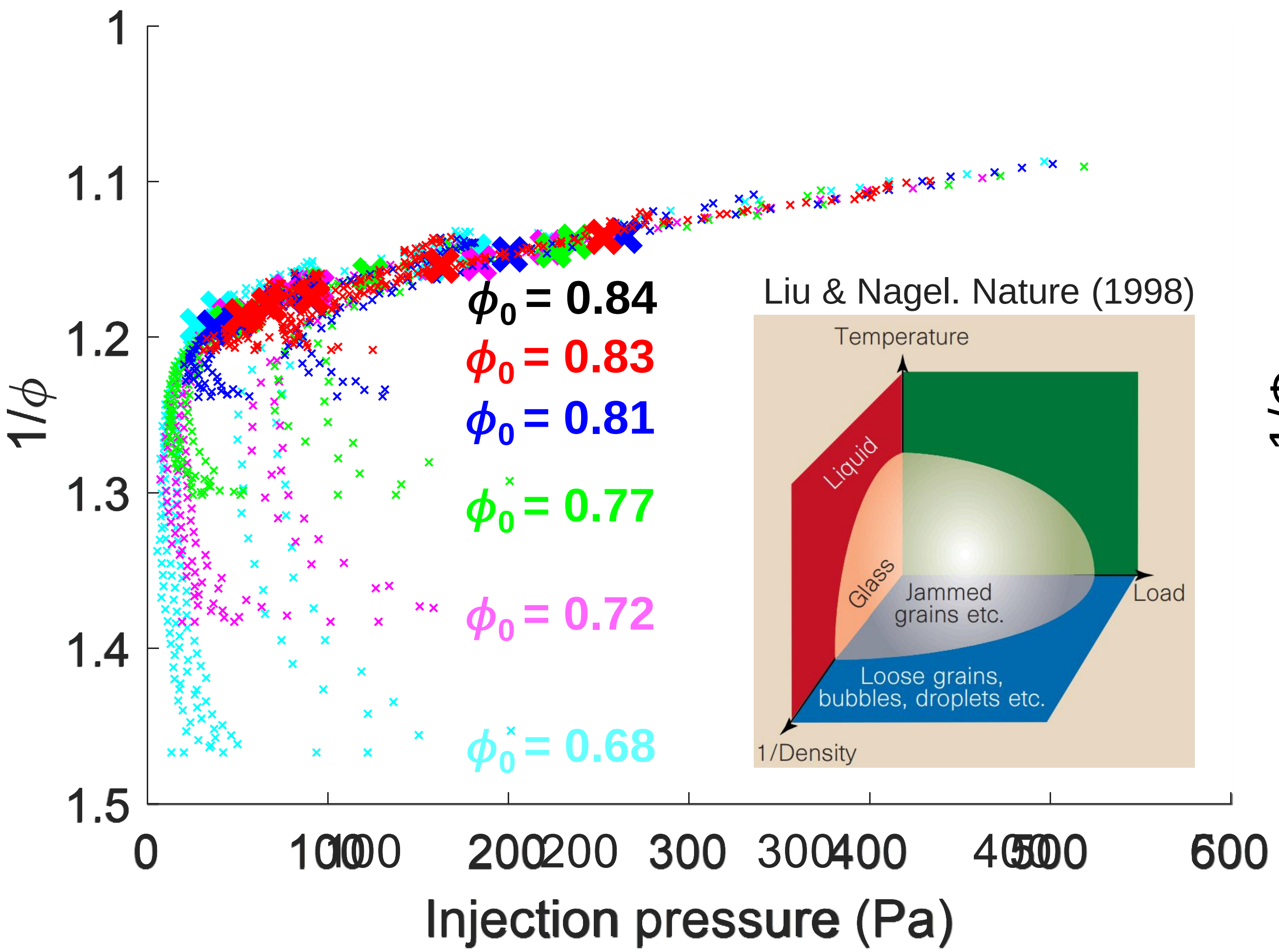
$\phi_0 = 0.77$

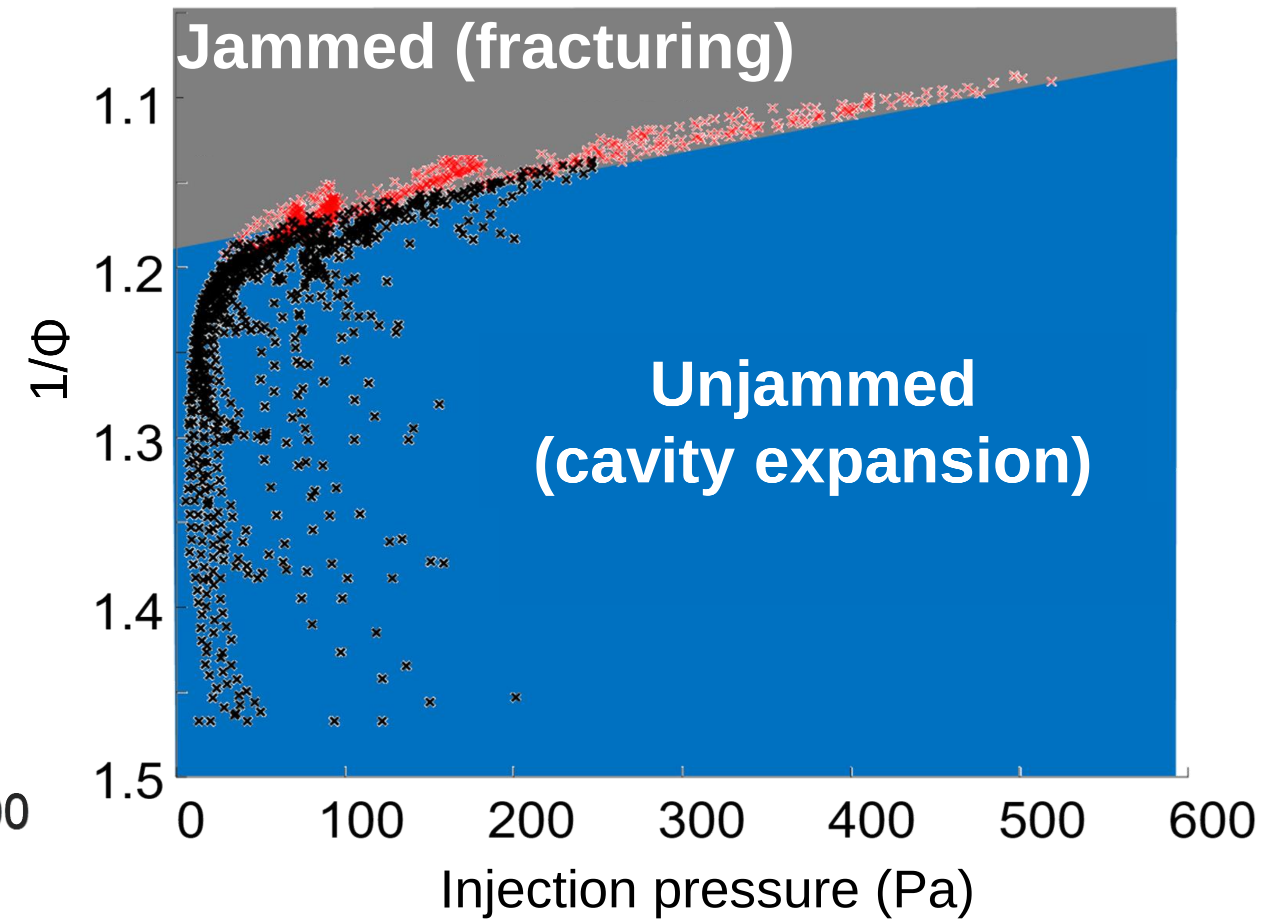
$\theta = 140°$



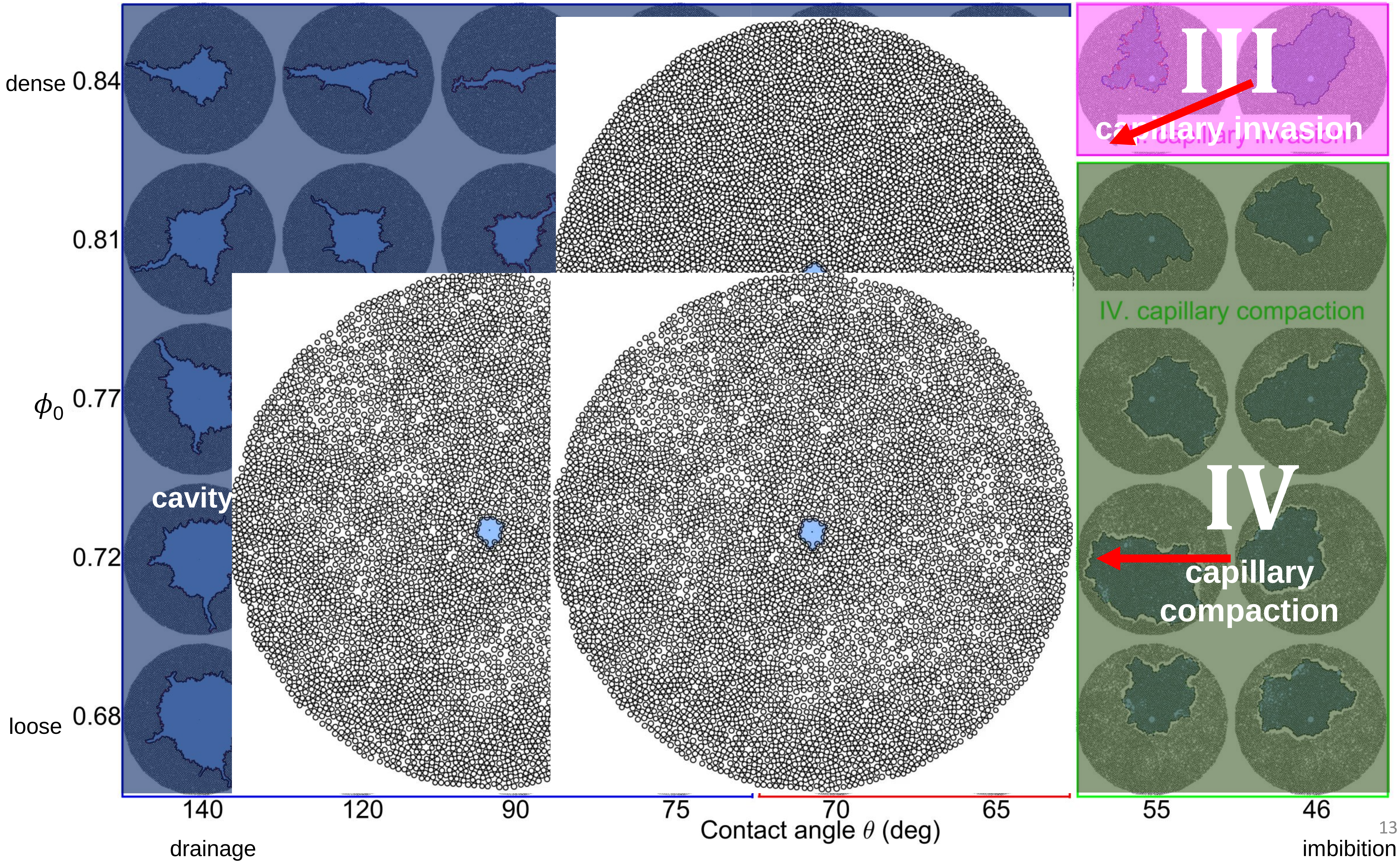
- ❑ Jamming transition: the system reaches "mechanical stability": force chains "lock-in"

Trajectories in phase space (p_{inj}, $1/\phi$): different initial packings





- **Key result:** the transitions to fracturing for all (θ,ϕ_0) collapse on a single line in (p_{inj},$1/\phi$)-space



III
capillary invasion
III. capillary invasion
IV. capillary compaction
IV
capillary
compaction
cavity
dense 0.84
0.81
ϕ_0 0.77
0.72
loose 0.68
140
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Contact angle θ (deg)
drainage
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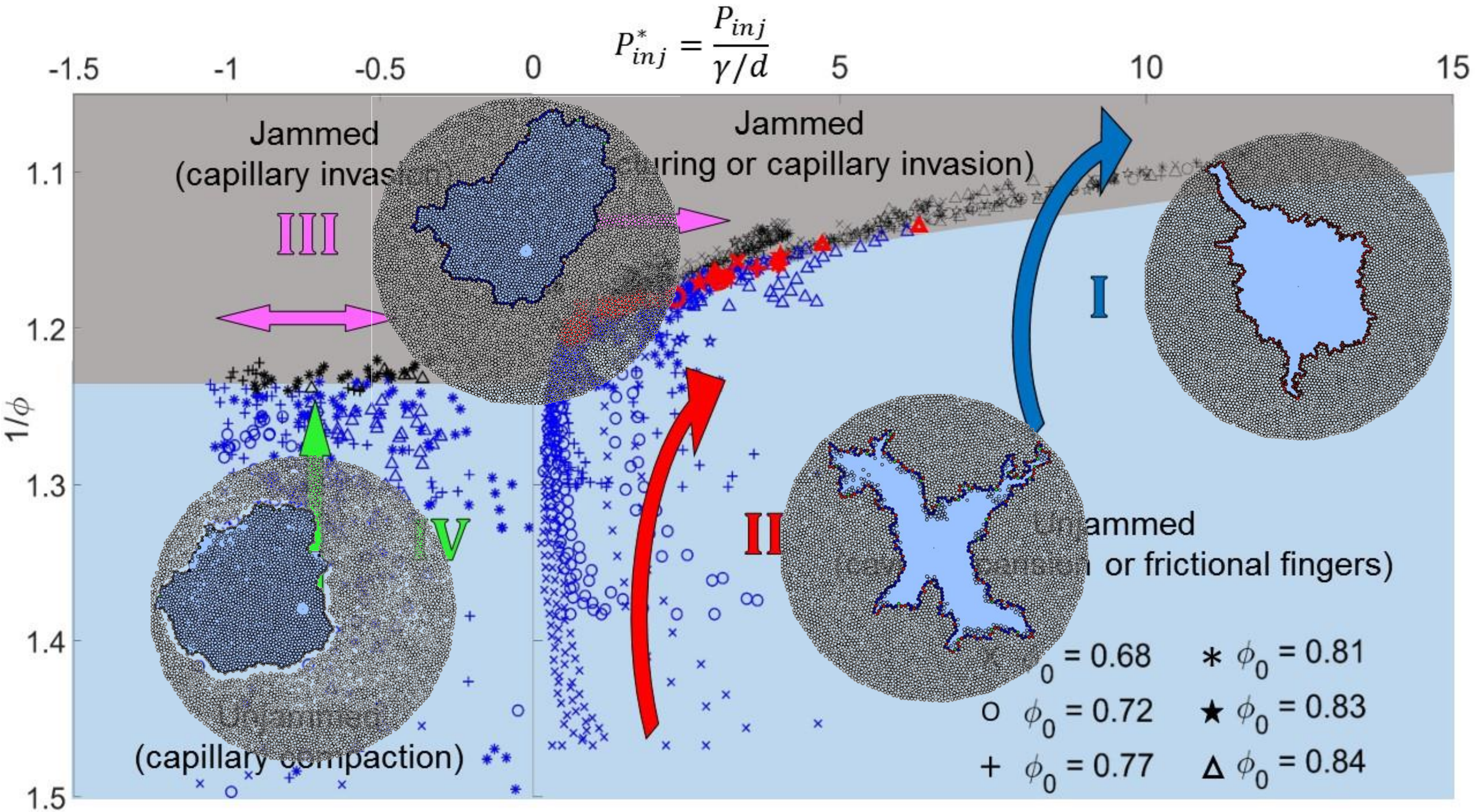
Phase diagram of jamming for wet granular media



Y. Meng et al.,
Physical Review Research (2020)