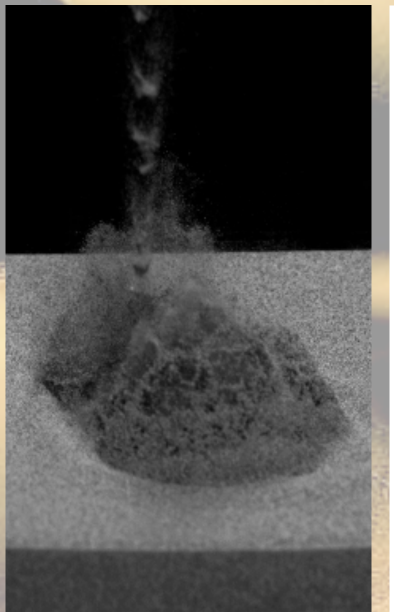
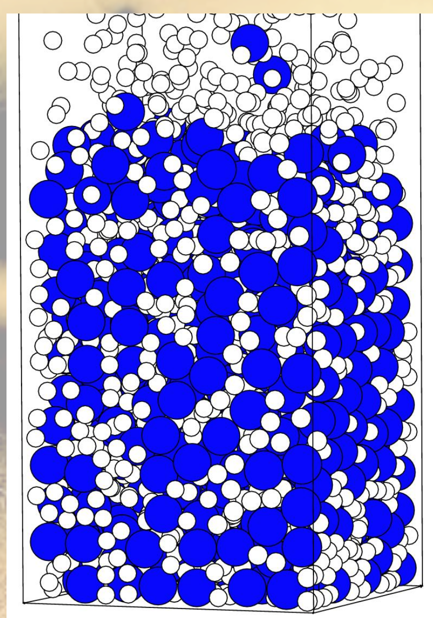
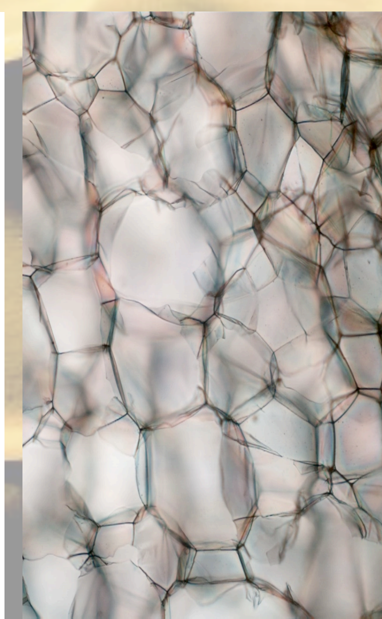
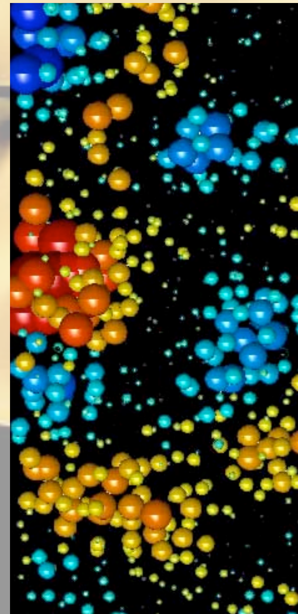
JMBC Workshop
“Statics and dynamics of soft and granular materials”
Drienerburght, University of Twente, February 25 - March 1, 2013

Speakers: Dirk van der Ende - Nico Gray - Detlef Lohse - Stefan Luding - Martin van Hecke
Martin van der Hoef - Devaraj van der Meer - Peter Schall - Vicenzo Vitelli

Many materials, often grouped together using the term ‘soft matter’, share common characteristics and behavior: For example, the materials consist of macroscopic particles, larger than the molecules that build up the world around us. They jam when flow is about to stop, and unjam just before flow starts. The static (‘solid’) situation is often characterized by a high degree of disorder, inhomogeneity and anisotropy, while the dynamic (‘fluid’) situation is frequently dominated by dissipative interaction forces leading to a dissipation time scale that interacts with other time scales in the system. Finally, there is the role of the interstitial fluid that resides between the particles and may mediate thermal (Brownian) motion, in the case of colloids, or hydrodynamic interactions (drag) in the case of macro-scopic grains. This course, aimed at graduate students, will provide an introduction to this type of materials and discuss many of the phenomena mentioned above both as an overview and in the context of actual research.

PROGRAM JMBC Workshop "Statics and dynamics of soft and granular materials"
(Drienerburght, University of Twente, February 25, 2013 - March 1, 2013)

	MONDAY February 25, 2013	TUESDAY February 26, 2013	WEDNESDAY February 27, 2013	THURSDAY February 28, 2013	FRIDAY March 1, 2013
09:00 - 10:45		**Granular avalanches (Nico Gray)** **Student talks**	**Simulation of granular two-phase flows 1 (Martin v/d Hoef)**	**Rheology and microstructure of dispersions (Dirk v/d Ende)**	**Granular matter and interstitial fluids (v/d Meer/Luding)**
10:45 - 11:15	**Welcome**	coffee & tea	coffee & tea	coffee & tea	coffee & tea
11:15 - 12:15	**Introduction (Devaraj v/d Meer)**	**Particle segregation in granular free-surface flows (Nico Gray)**	**Simulation of granular two-phase flows 2 (Martin v/d Hoef)**	**Student talks**	**Impact on granular solids (Detlef Lohse)**
12:15 - 13:30	lunch	lunch	lunch	lunch	
13:30 - 15:15	**Mechanical metamaterials 1 (Martin v Hecke)**	**From particle description to continuum rheology (Stefan Luding)**	**Shocks in fragile matter 1 (Vicenzo Vitelli)**	**Jamming and glassy behavior in colloids and grains 1 (Peter Schall)**	
15:15 - 15:45	coffee & tea	coffee & tea	coffee & tea	coffee & tea	
15:45 - 17:30	**Mechanical metamaterials 2 (Martin v Hecke)**	**What is rheology about? (Dirk v/d Ende)**	**Shocks in fragile matter 2 (Vicenzo Vitelli)**	**Jamming and glassy behavior in colloids and grains 2 (Peter Schall)**	
18:30 - 21:00				**Conference dinner**	

Registration: http://www.jmburgerscentrum.nl/formulier/6/JMBC-PhD-Course.htm

Tuition fee: University PhDs/postdocs/staff Netherlands: €250; idem other countries: €400; others: €1,000

More information: d.vandermeer@utwente.nl


What is Soft Matter ?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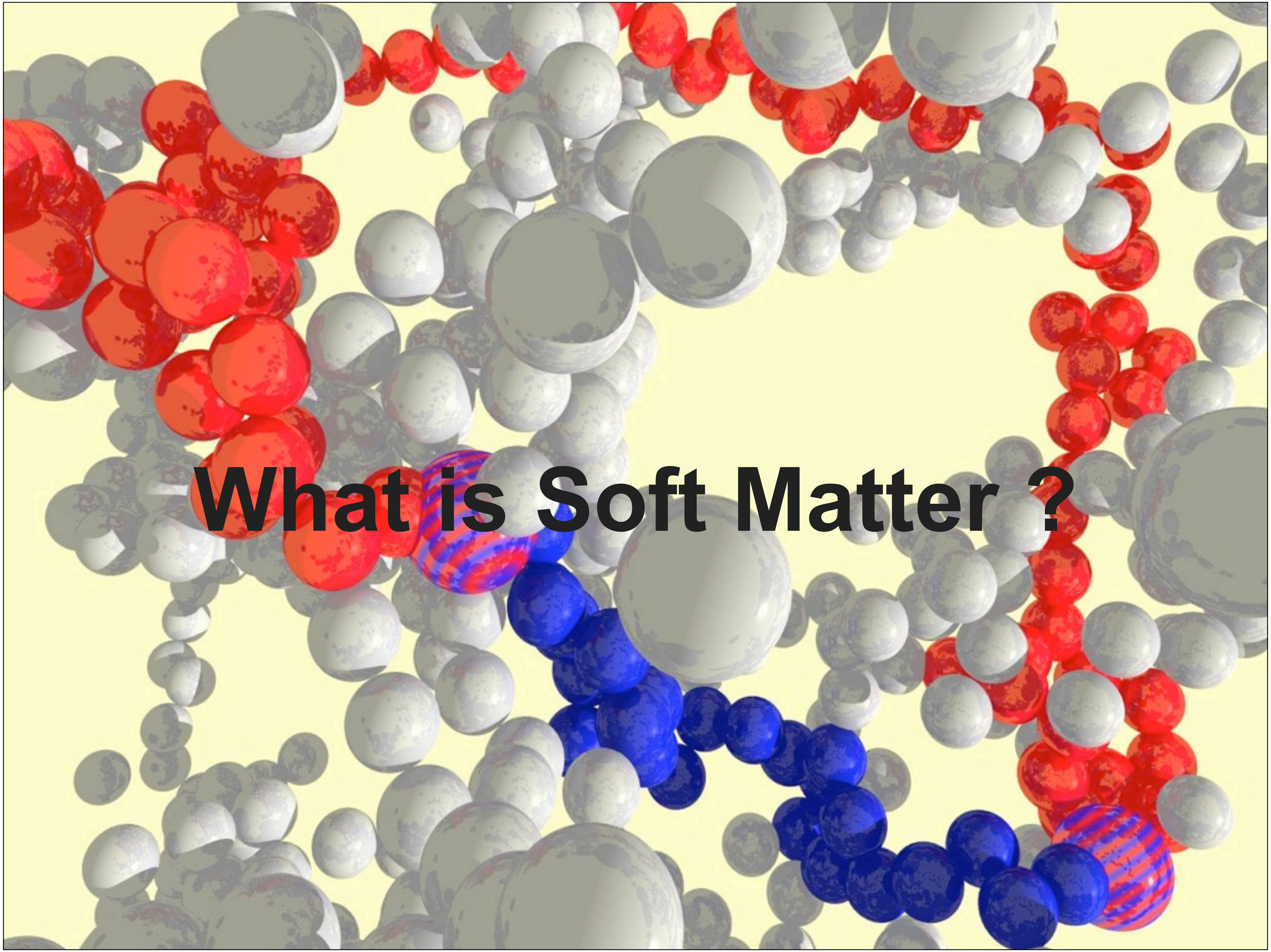
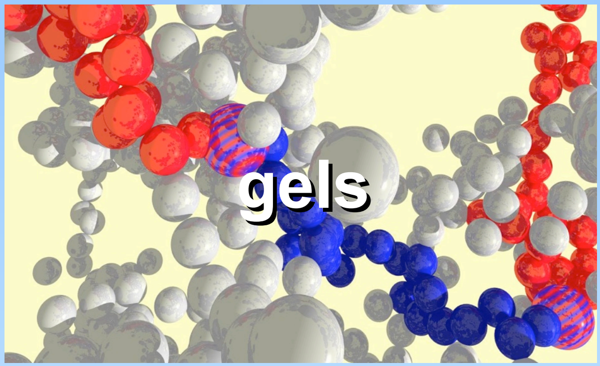
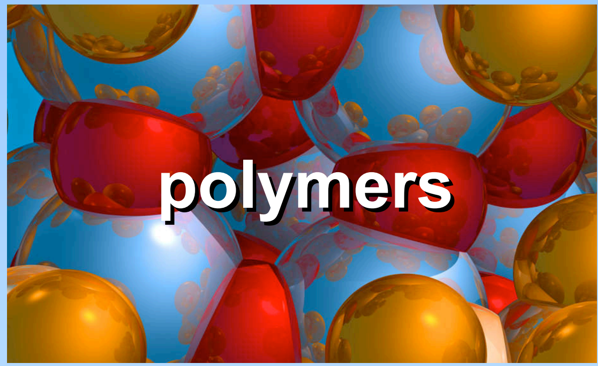


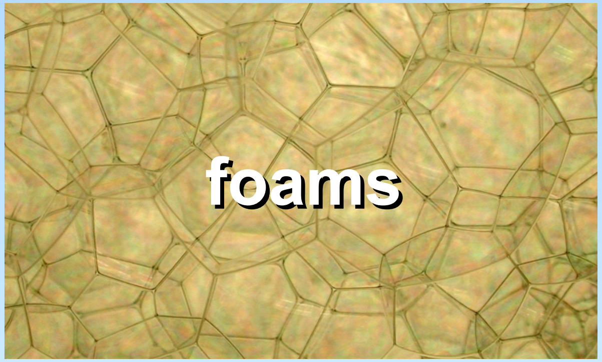
Soft Matter physics is:

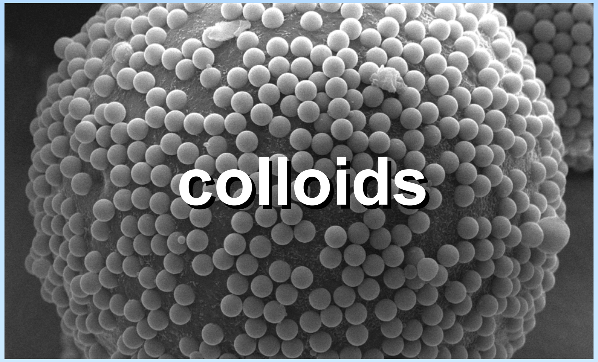
the physics (statics/dynamics) of a system consisting of many particles at a scale on which quantum effects are not important.

Soft Matter includes:

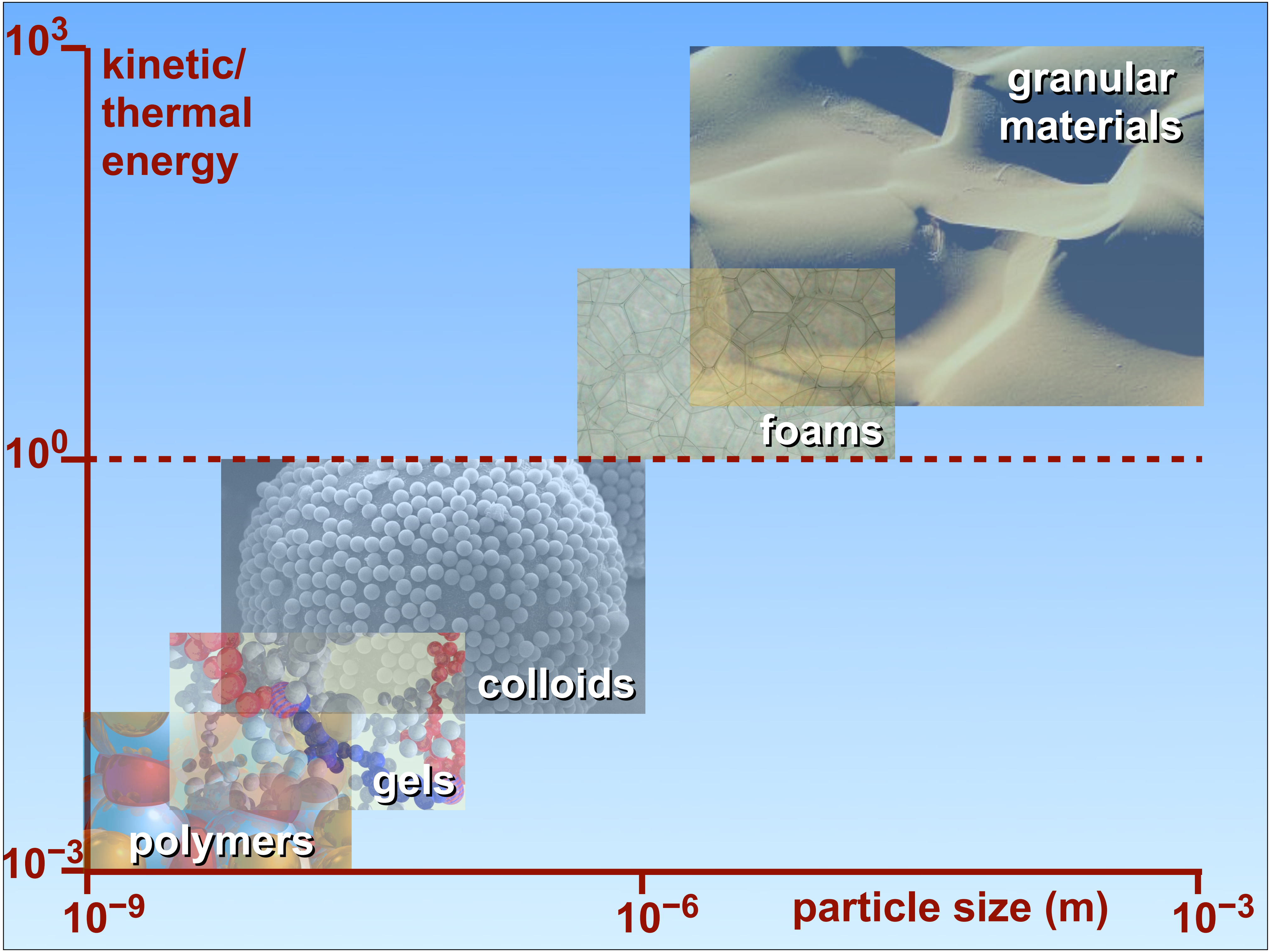




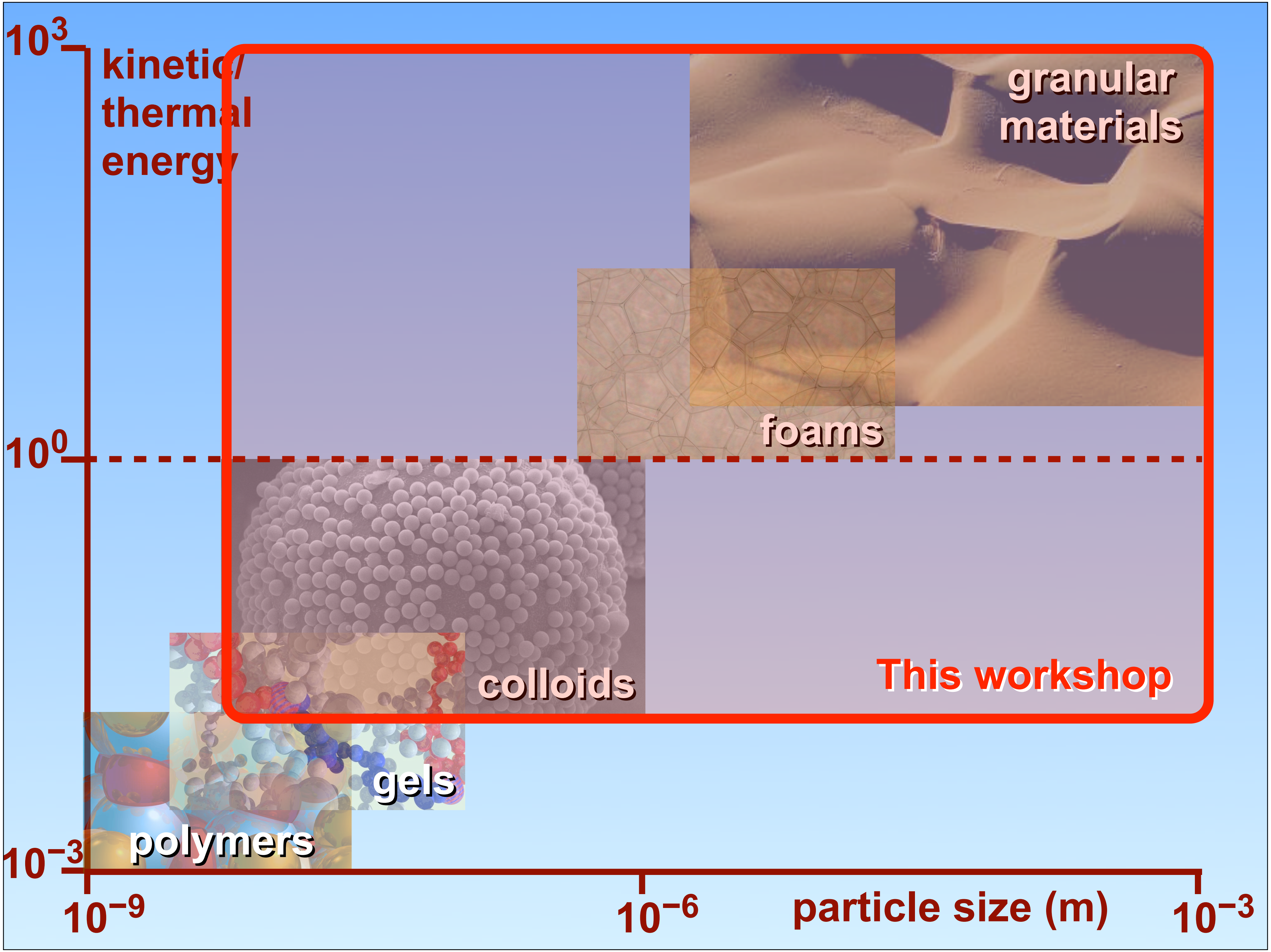




and many biological materials.



kinetic/
thermal
energy
10^3
10^0
10^{-3}
10^{-9}
10^{-6}
10^{-3}
particle size (m)
granular
materials
foams
colloids
gels
polymers

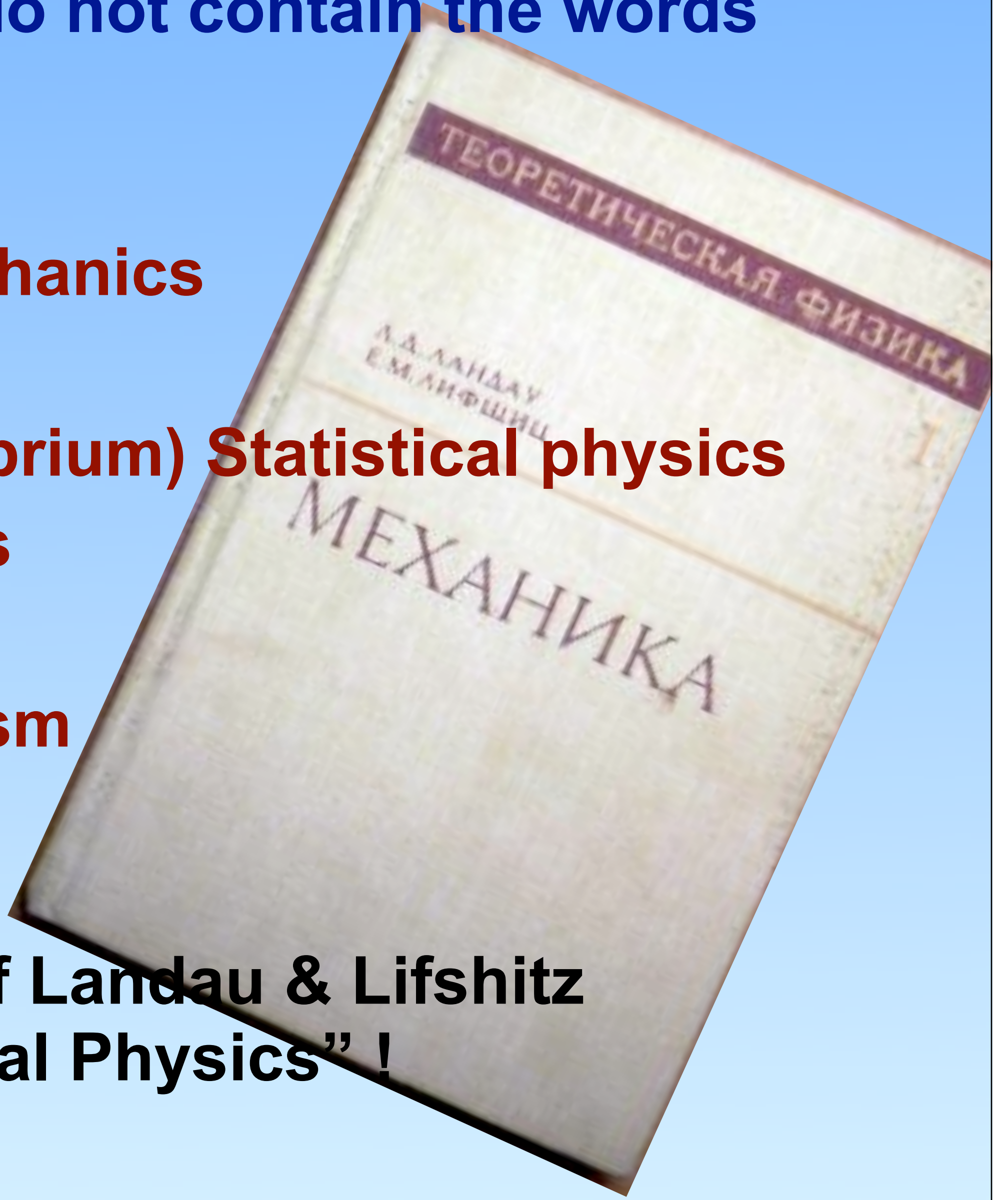


10^3
kinetic/ thermal energy
granular materials
foams
10^0
colloids
This workshop
gels
polymers
10^{-3}
10^{-9}
10^{-6}
particle size (m)
10^{-3}

The tools of Soft Matter physics

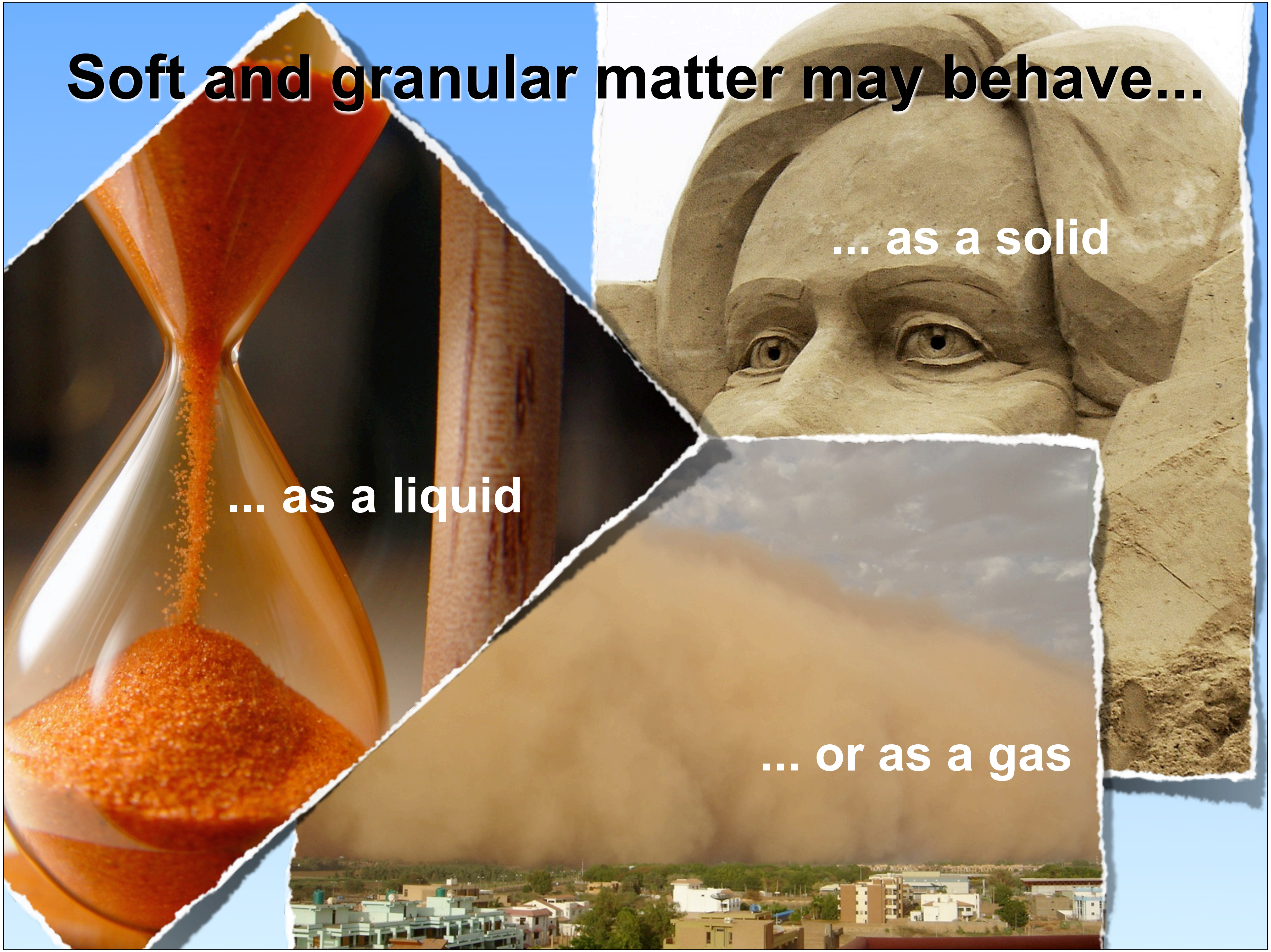
All the tools of physics that do not contain the words "quantum" or "high energy":

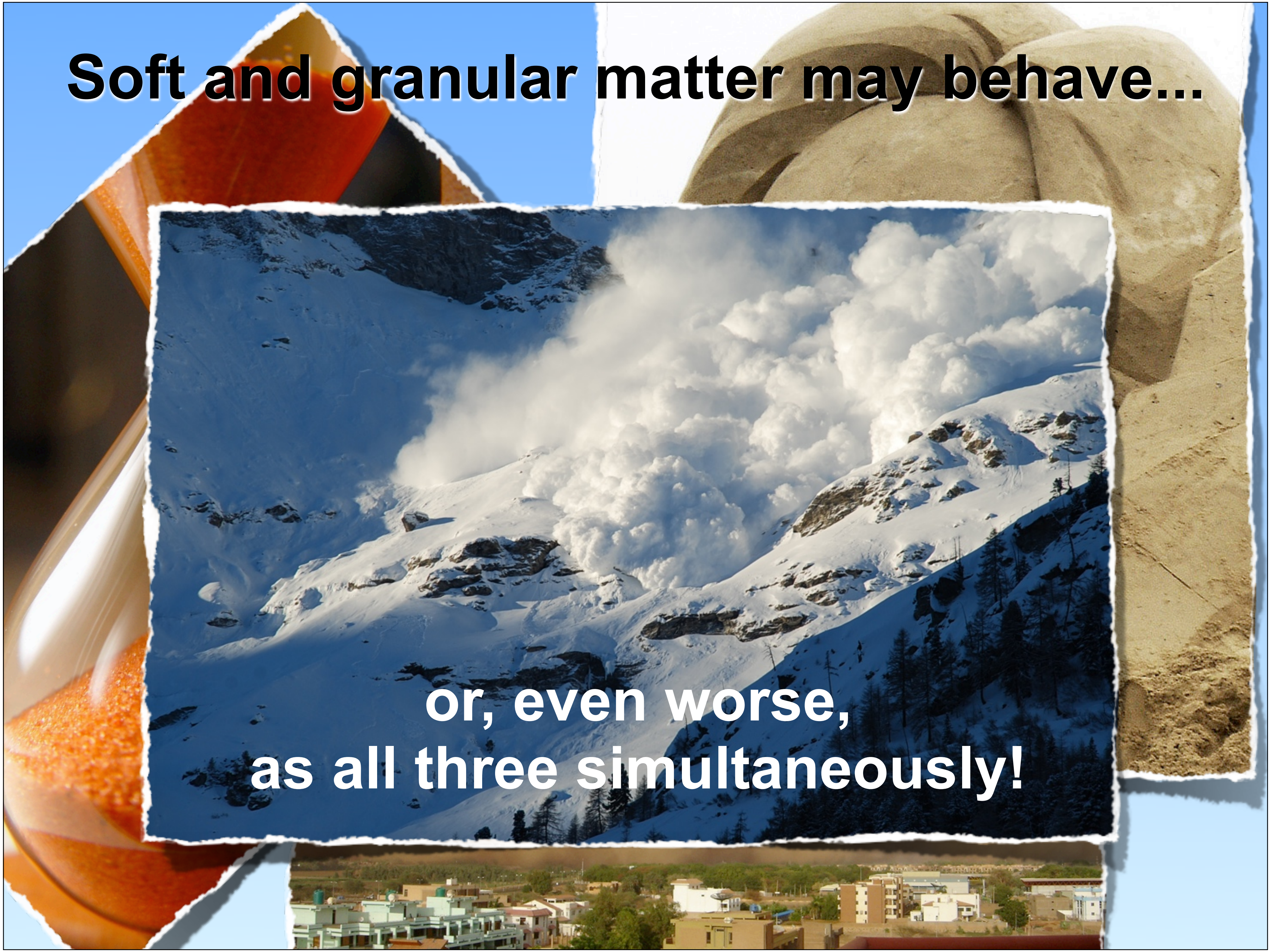
V1	**(Nonlinear) Mechanics**
V2	**Classical fields**
V5 & V9	**(Far from equilibrium) Statistical physics**
V6	**Fluid Mechanics**
V7	**Elasticity**
V8	**Electromagnetism**
V10	**Kinetic Theory**



This is 8 out of 10 volumes of Landau & Lifshitz famous "Course of Theoretical Physics" !

Soft and granular matter may behave...



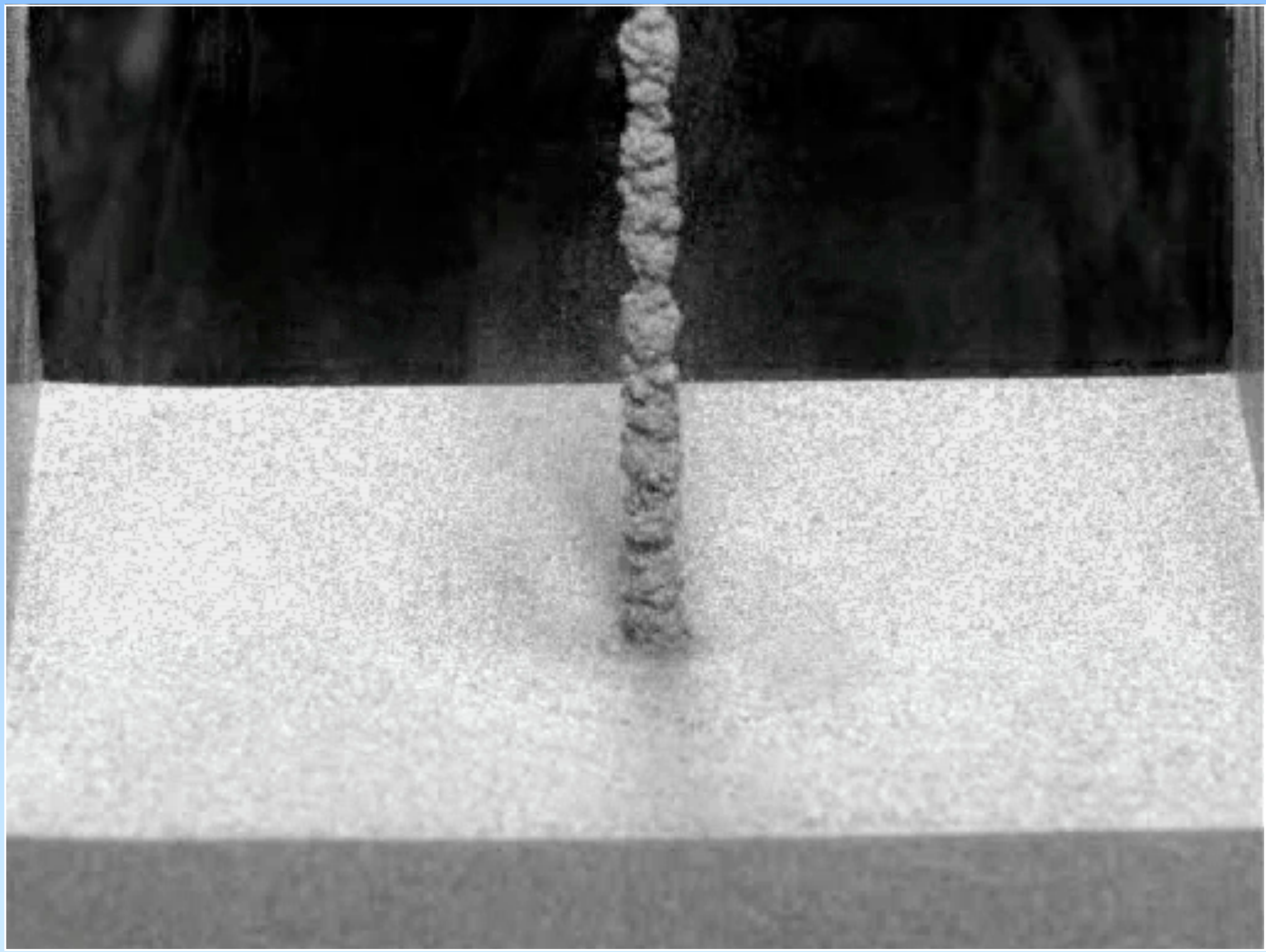

Soft and granular matter may behave...
or, even worse,
as all three simultaneously!

Impact on a granular solid

Ball dropped onto loose, very fine sand

Impact on a granular solid

Ball dropped onto loose, very fine sand



Impact on a granular solid

Ball dropped onto loose, very fine sand

Friday morning:

Detlef Lohse

Impact on granular solids

What sets these materials apart from their molecular counterparts ?

To some or large extent, they:

1. are *athermal*
2. interact through *contact forces*
3. have *dissipative* interactions
4. are *inhomogeneous*

1. Granular matter is *athermal*

Definition:

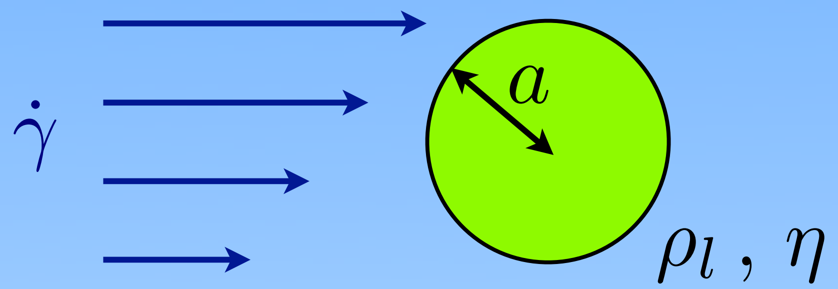
Granular matter =
many body system in which the typical particle size > 10 μm

$$\frac{1}{2}mv_{\text{thermal}}^2 = \frac{3}{2}k_B T \quad \Rightarrow$$ (at room temperature)

$$v_{\text{thermal}} = \sqrt{\frac{3k_B T}{\frac{4}{3}\pi r^3 \rho}} \approx \sqrt{\frac{10^{-20}}{10^{-11}}} \approx 3 \cdot 10^{-5} \text{ m/s}$$

Thermal energy is negligible for such particles !

When does thermal motion matter?



Droplet (radius *a*) in liquid with viscosity *η* and density *ρ*$_l$. Flow with shear rate $\dot{\gamma}$.

Péclet number:

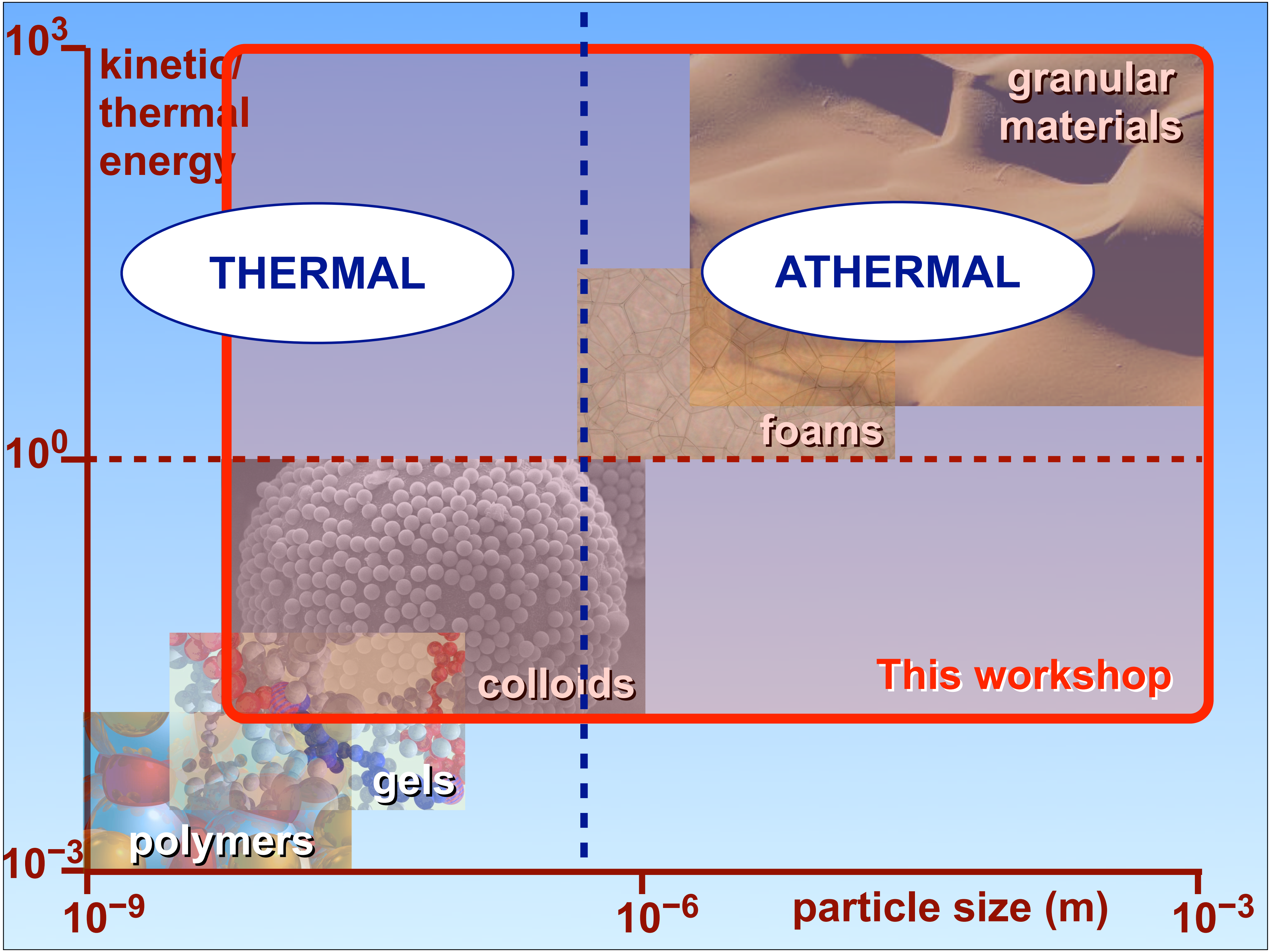
$$\mathrm{Pe} = \frac{\tau_{\mathrm{thermal}}}{\tau_{\mathrm{shear}}} = \dot{\gamma}\,\frac{a^2}{D_0} = 6\pi\,\frac{\eta\dot{\gamma}a^3}{k_B T} = 6\pi\,\frac{\tau a^3}{k_B T}$$

$$D_0 = \frac{k_B T}{6\pi\eta a}$$ **(Stokes-Einstein FDR)**

Péclet number (sedimentation):

$$\mathrm{Pe_s} = \tfrac{4}{3}\pi\,\frac{\Delta\rho\, g\, a^4}{k_B\, T}$$

$$\mathrm{Pe_s} \approx 1 \quad \Rightarrow \quad a \approx 500\,\mathrm{nm}$$



kinetic/
thermal
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10^3
10^0
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THERMAL
ATHERMAL
granular
materials
foams
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This workshop
10^{-9}
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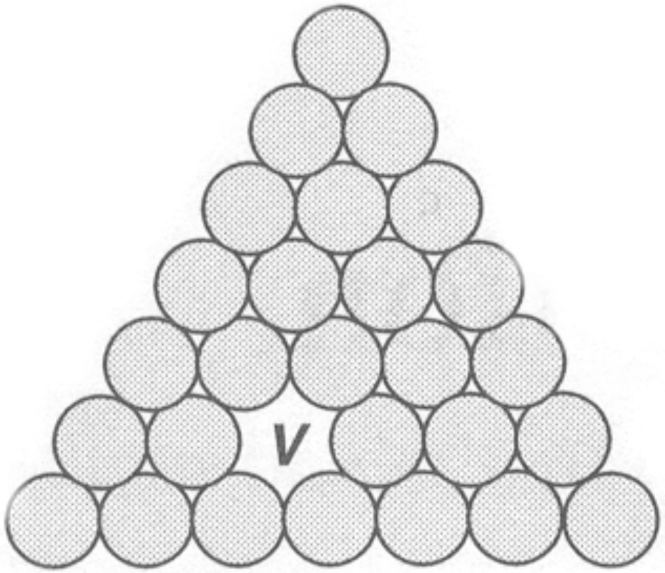
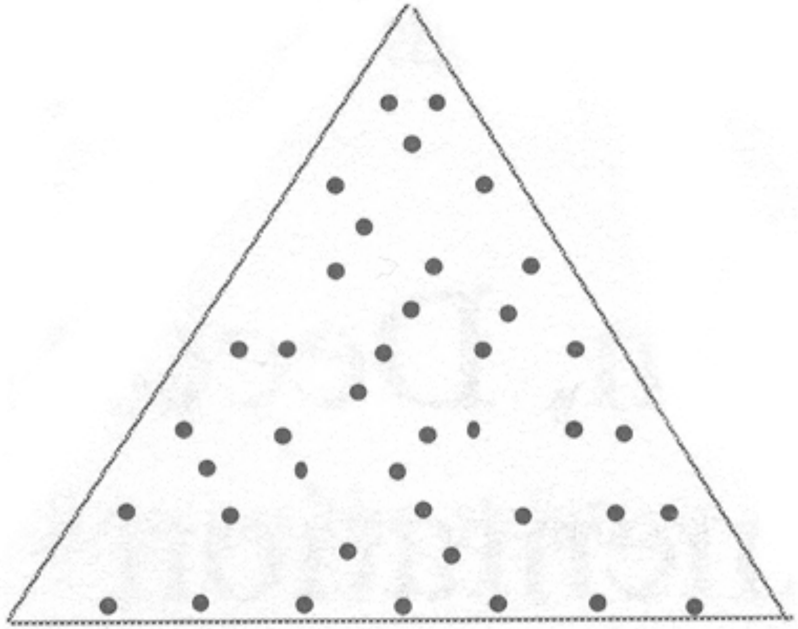
particle size (m)
10^{-3}

2. Contact forces

Dominant for granular materials at rest



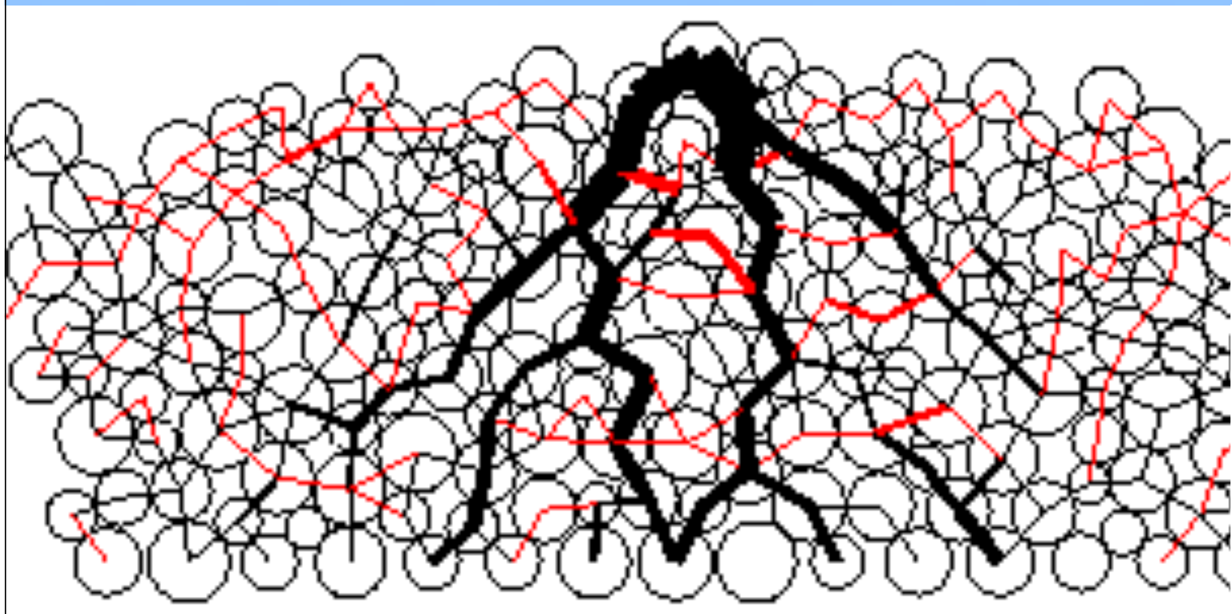
Cannon Ball Stack

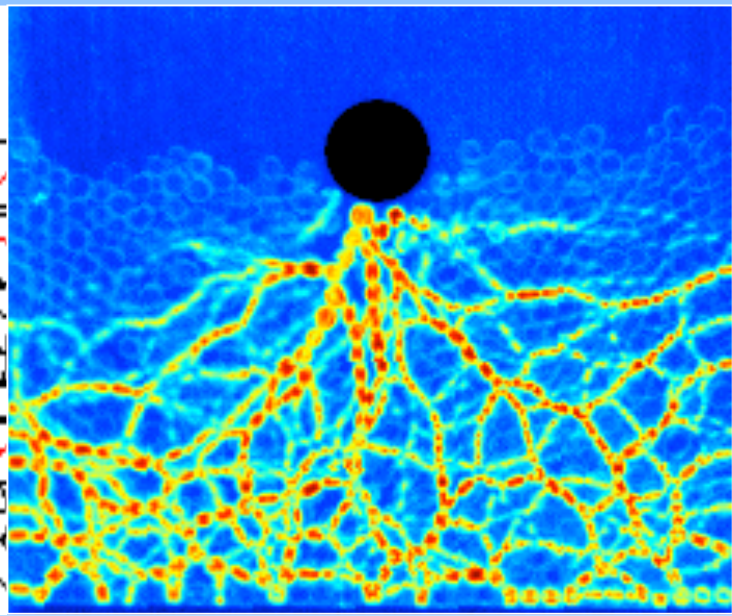


Contact Points

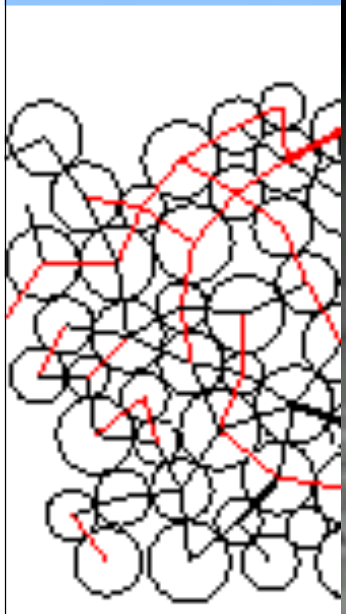
“Chaotic” network of contact points and forces !

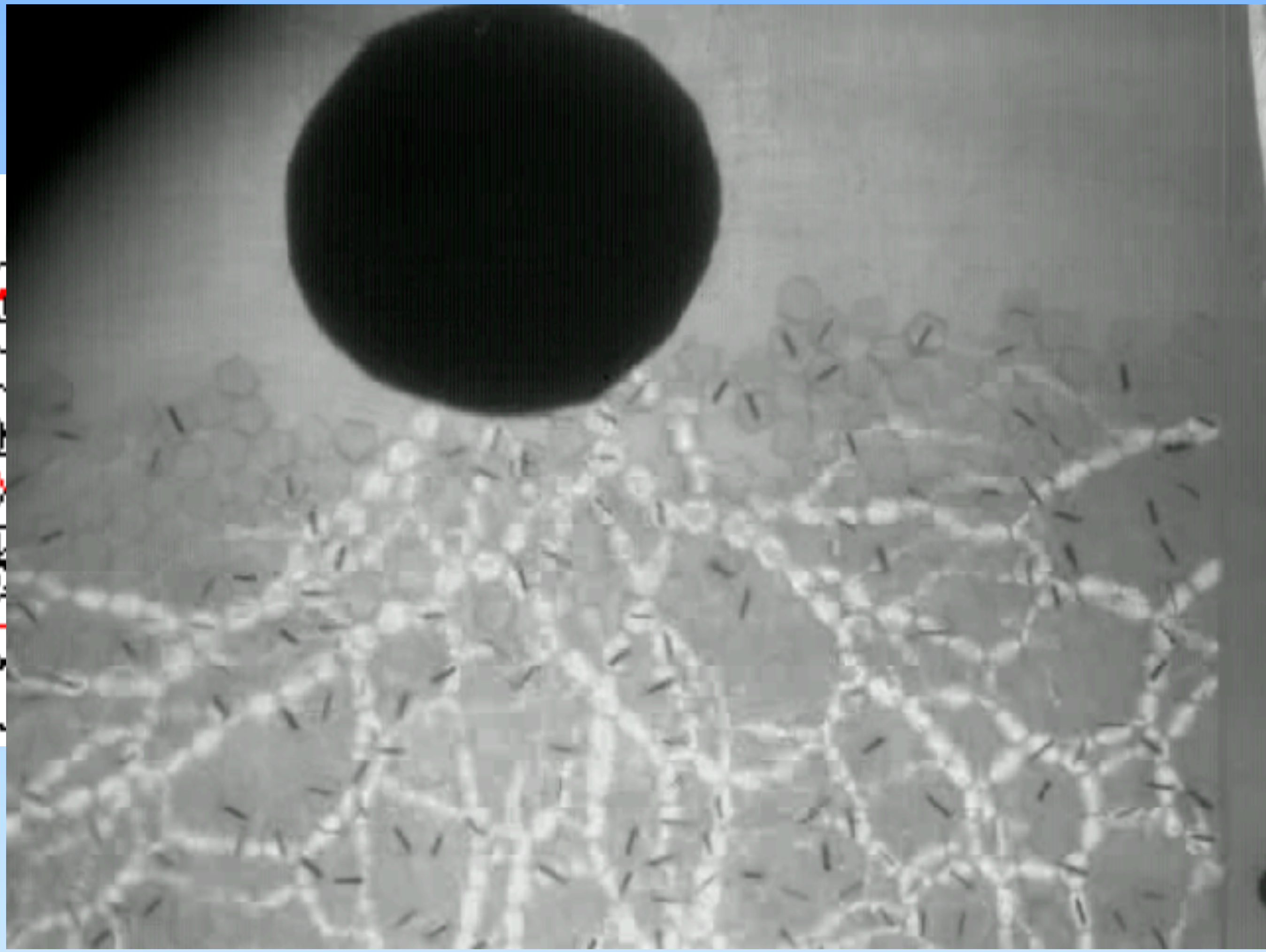
Static granular matter: Force Chains

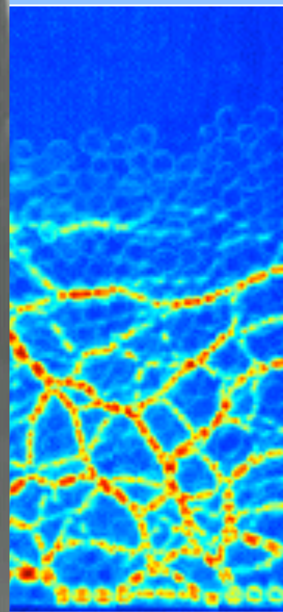




Static granular matter: Force Chains



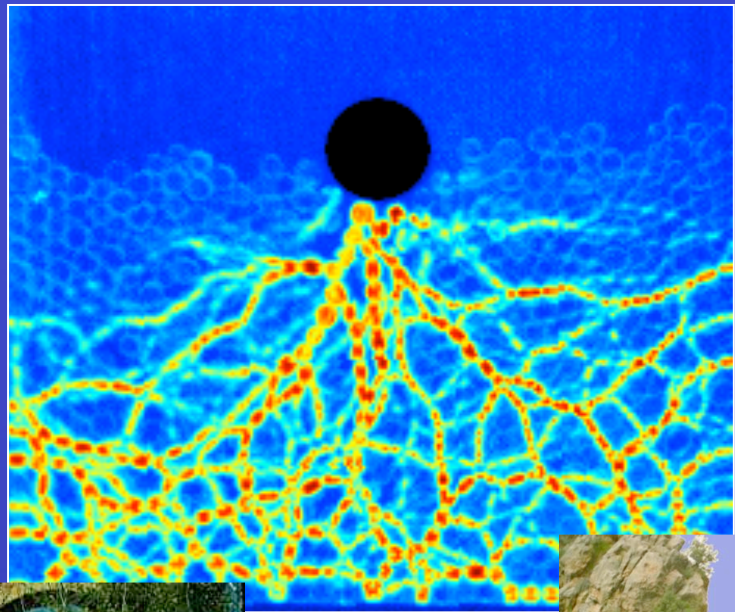


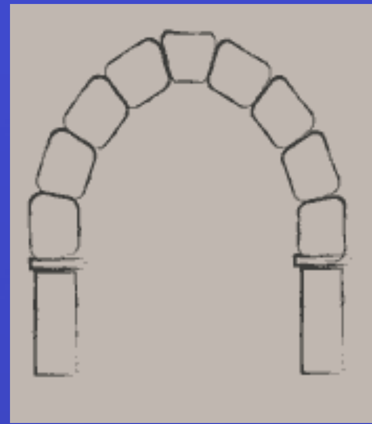


(Bob Behringer, Duke)

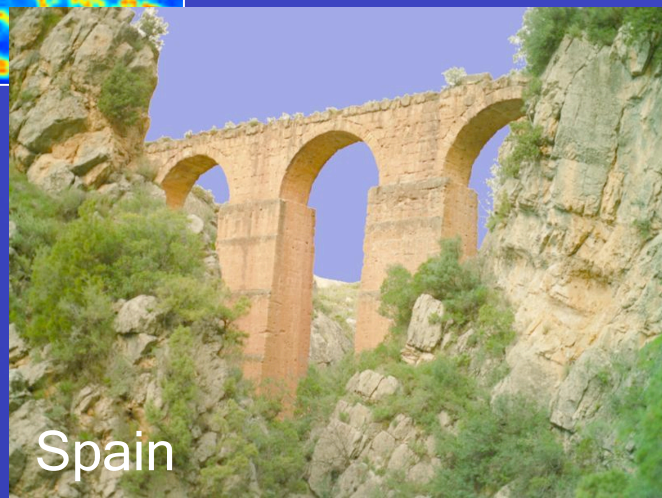
In stalling flow, force chains manifest themselves as arches

Segovia, Spain



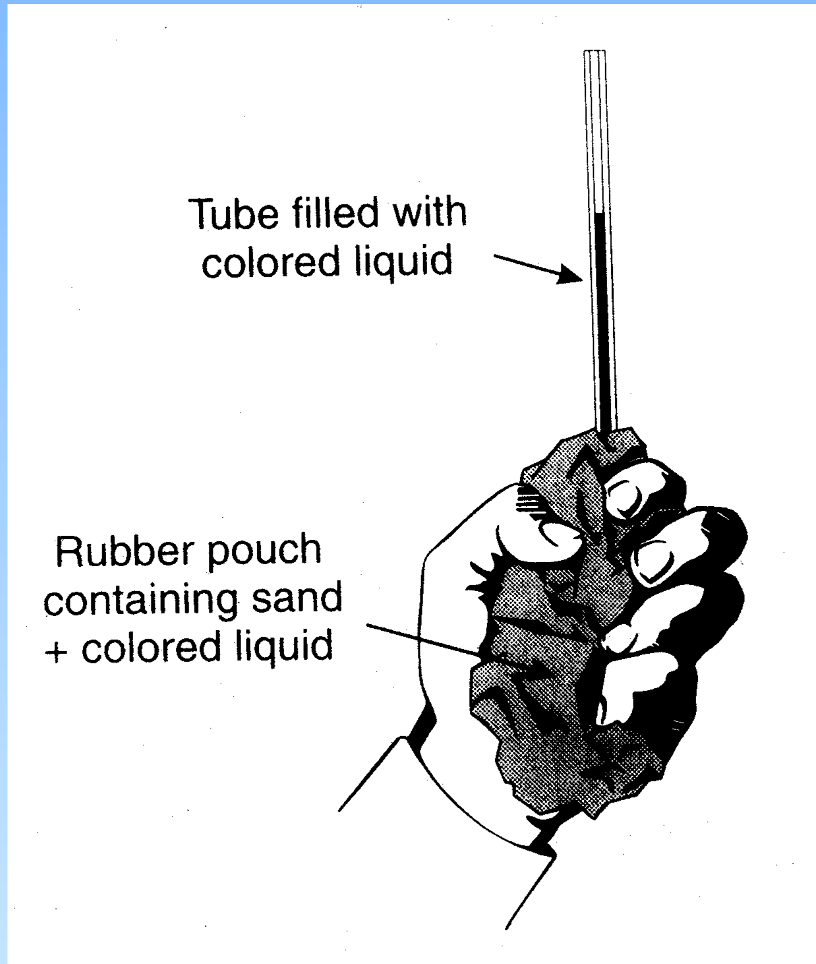


Pont du Gard, France



Spain

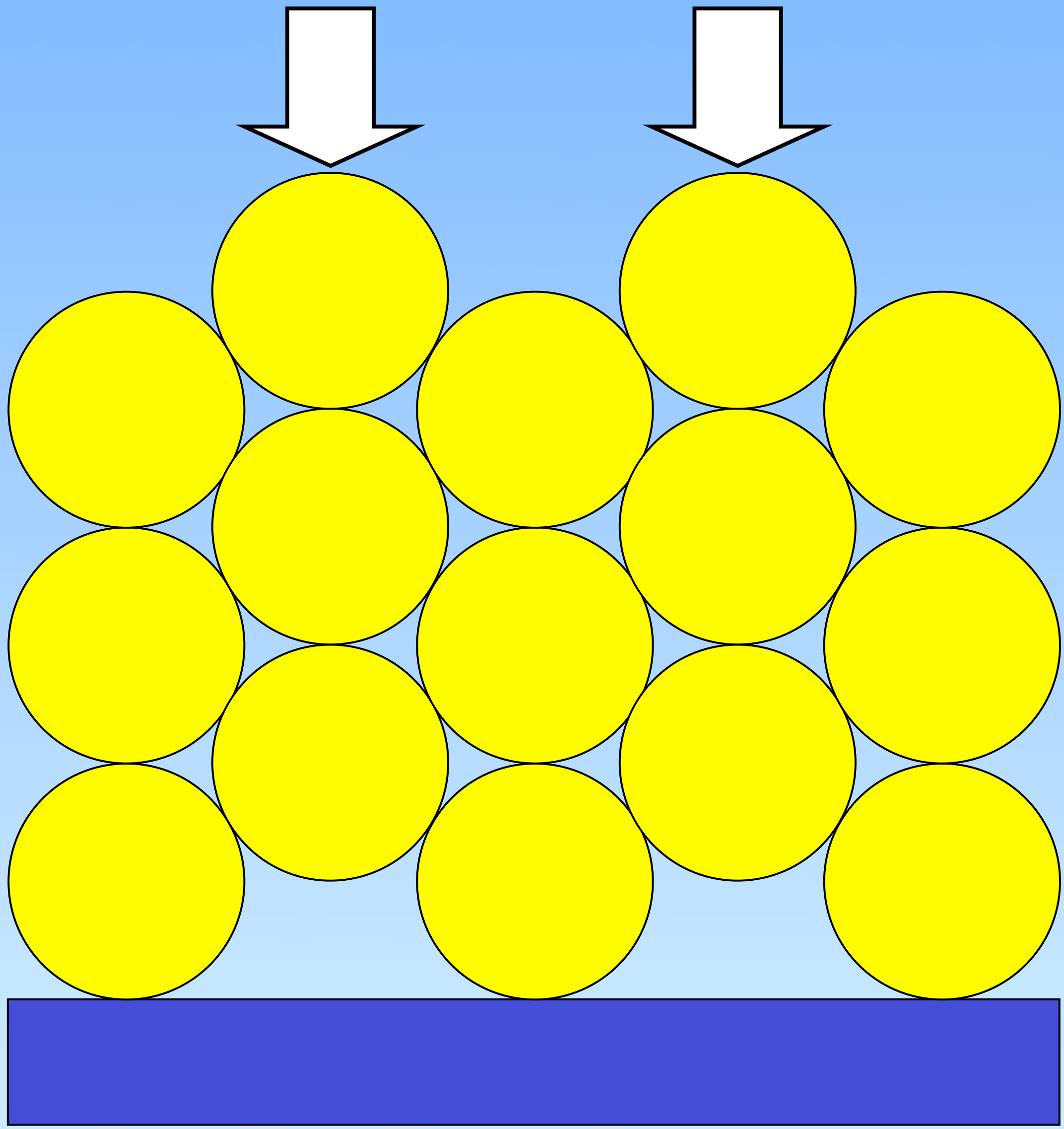
Reynolds dilatancy



Osborne Reynolds (1885):

"A strongly compacted granular medium dilates under pressure".

What causes the dilatancy ?

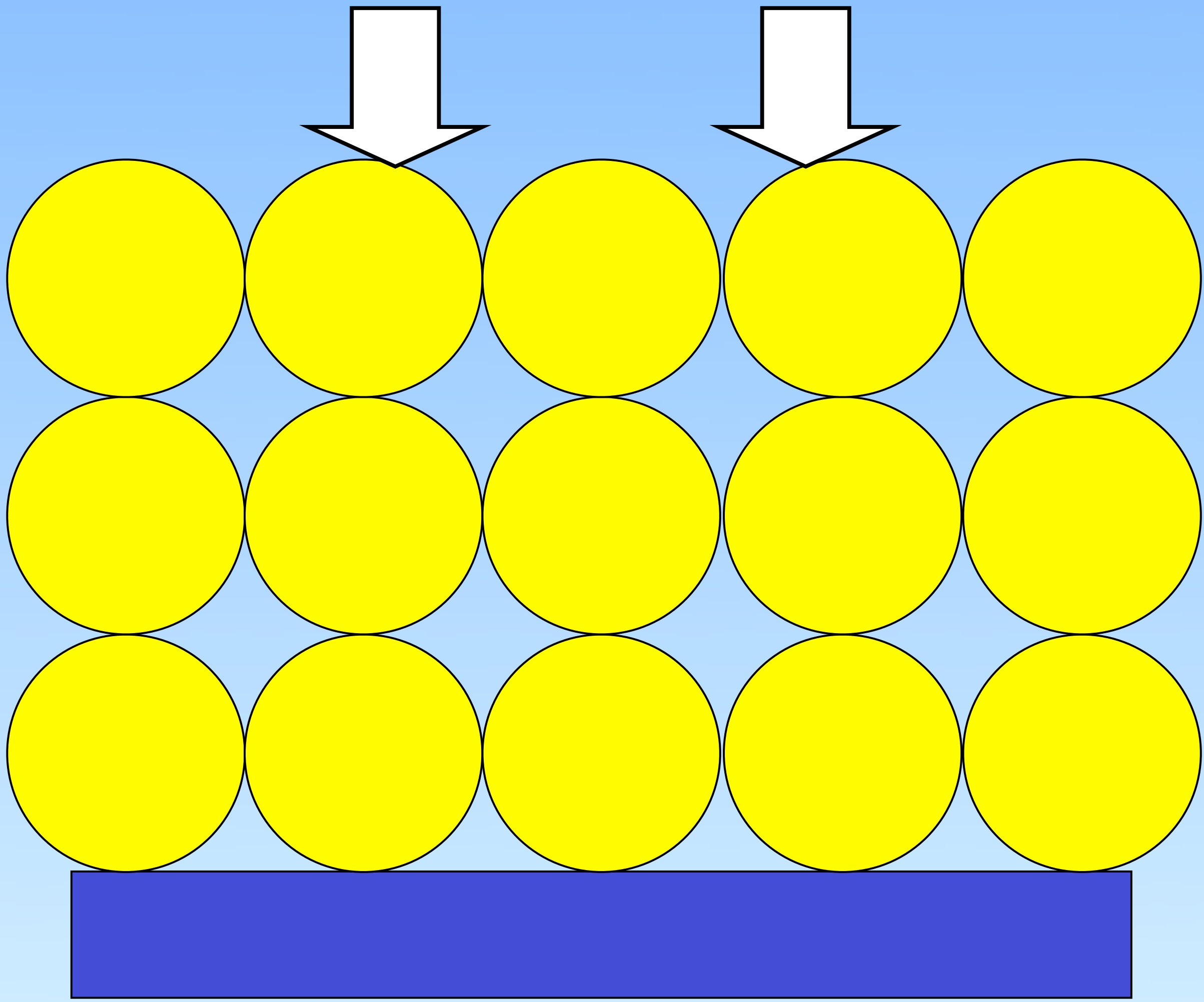


$\varphi = 0.907$

φ = packing fraction

$= V_{solids}/V_{total}$

What causes the dilatancy ?



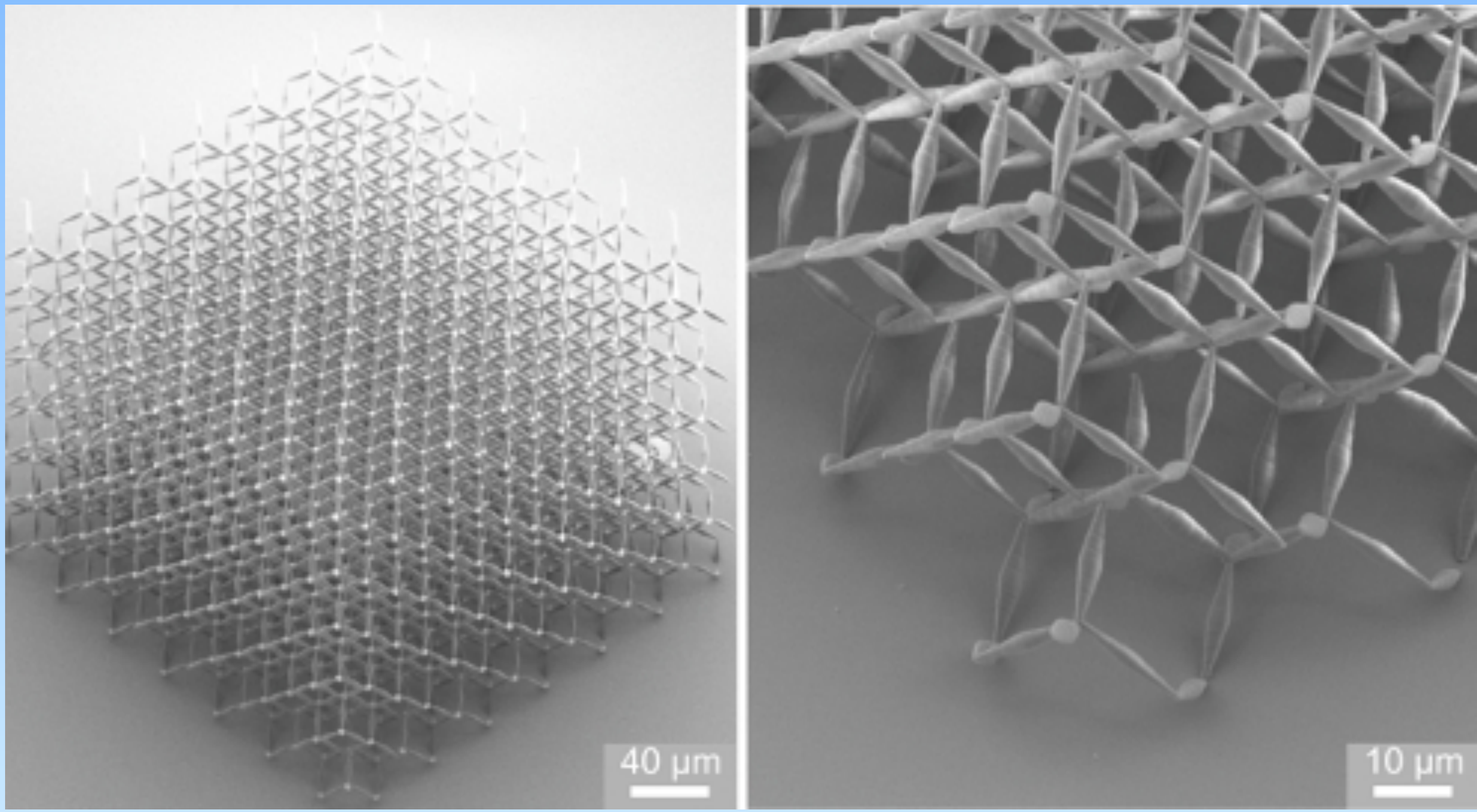
$\varphi = 0.907$

$\varphi = 0.785$

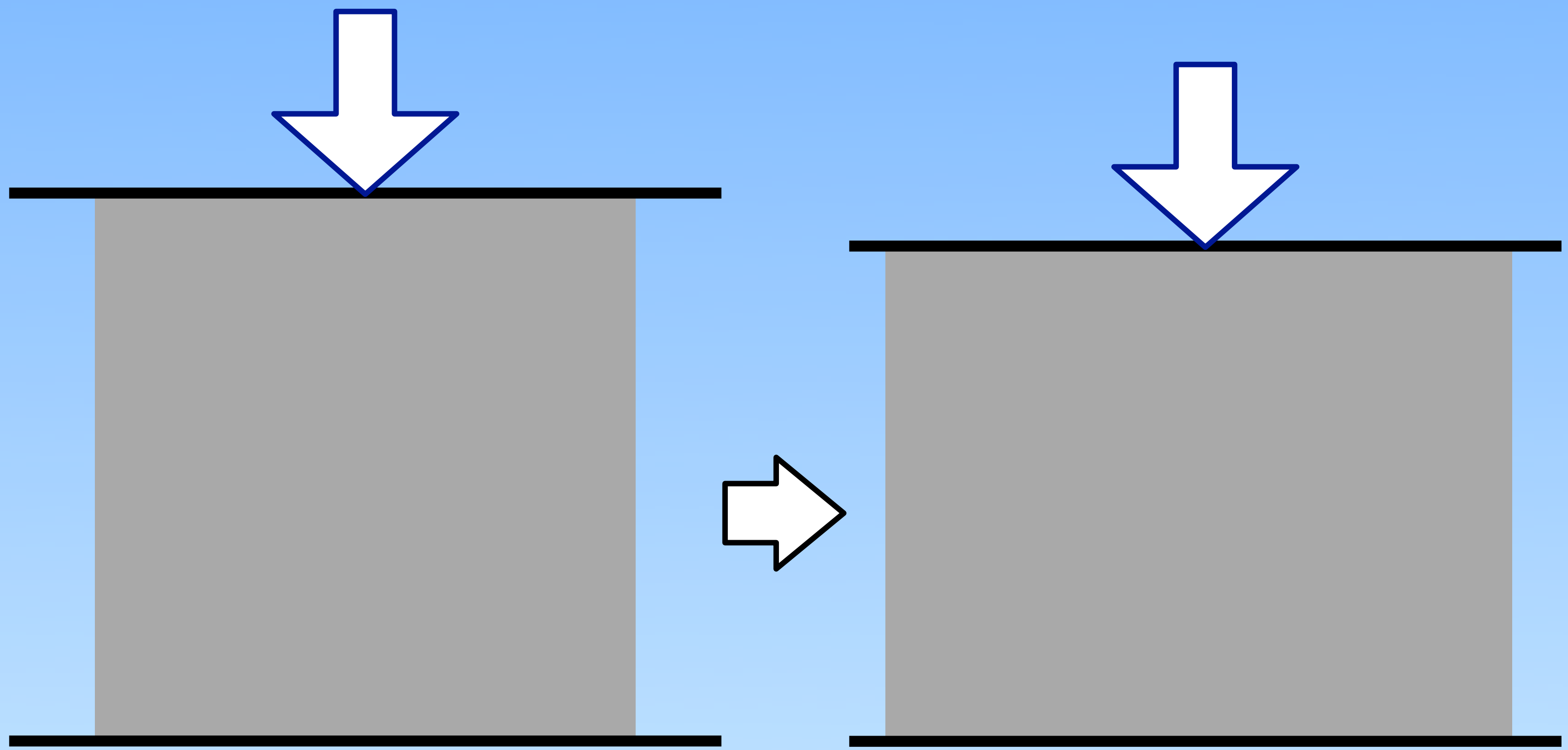
φ = packing fraction

$= V_{solids}/V_{total}$

Metamaterials



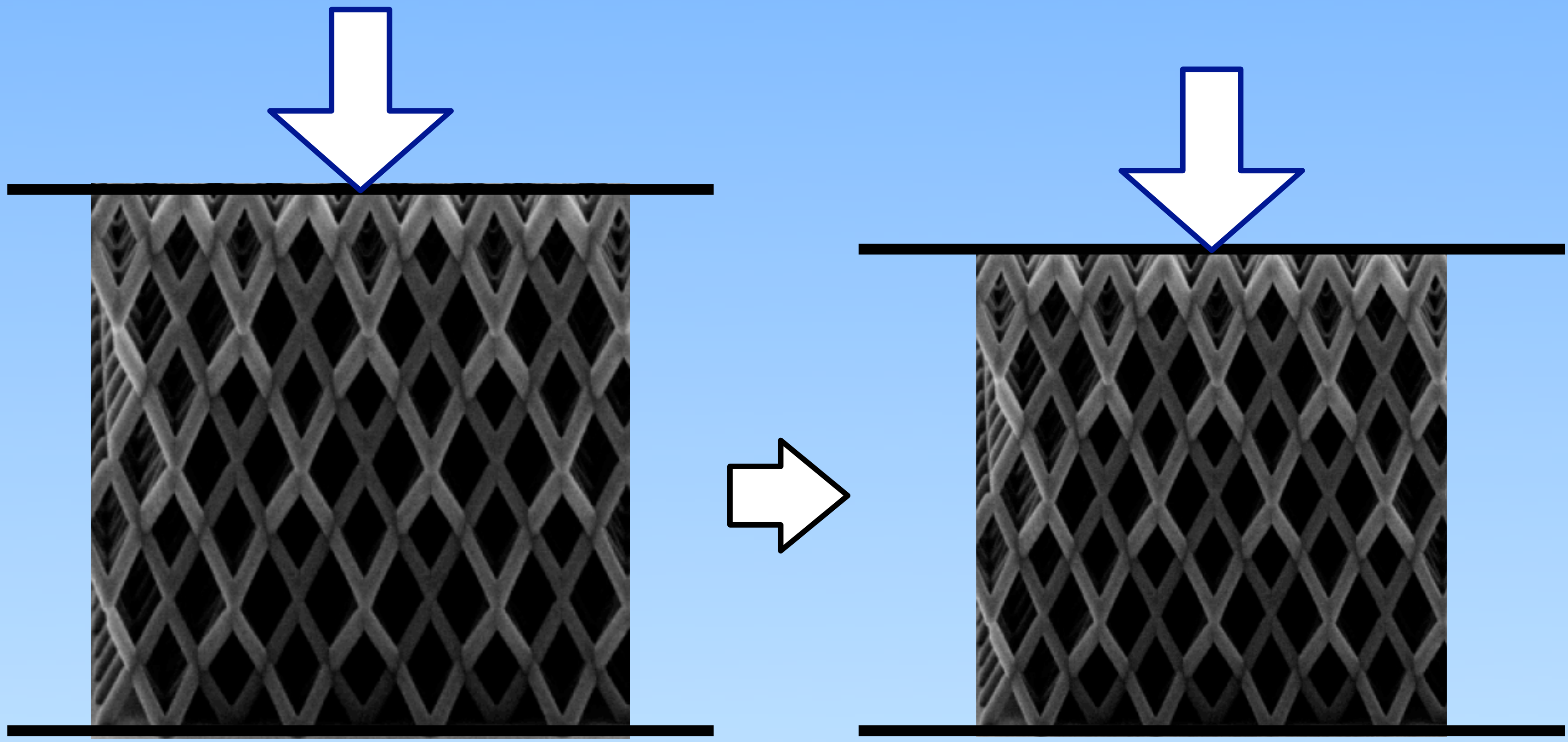
Negative Poisson ratio ν



When compressed vertically, ordinary materials expand horizontally.

$\nu > 0$

Negative Poisson ratio ν



When compressed vertically, tailored metamaterials compress horizontally.

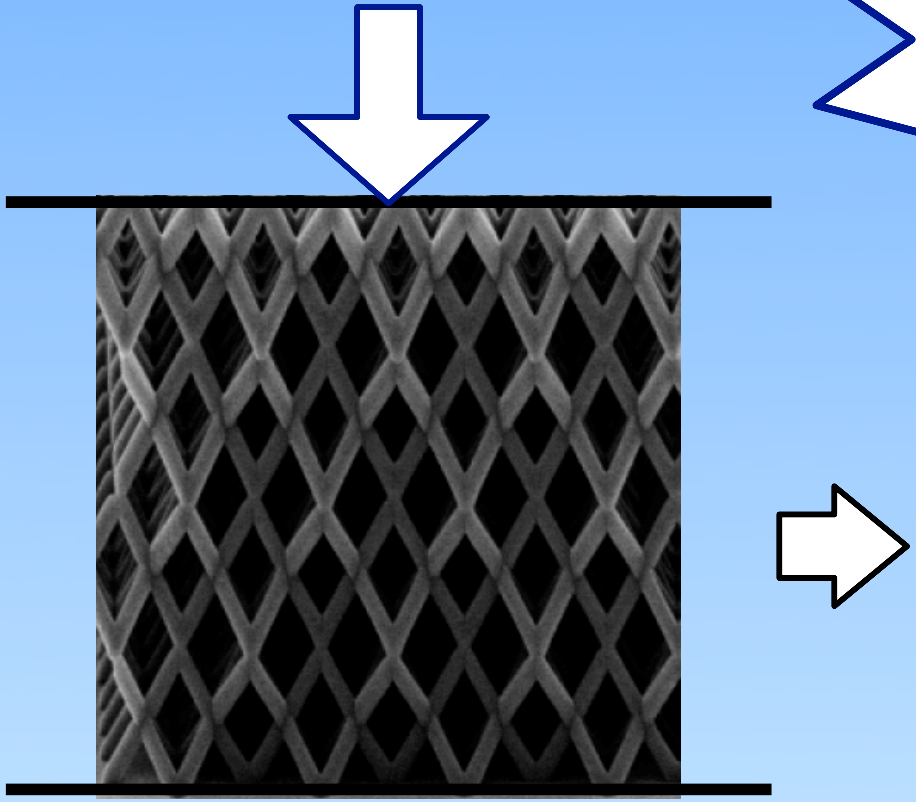
$\nu < 0$

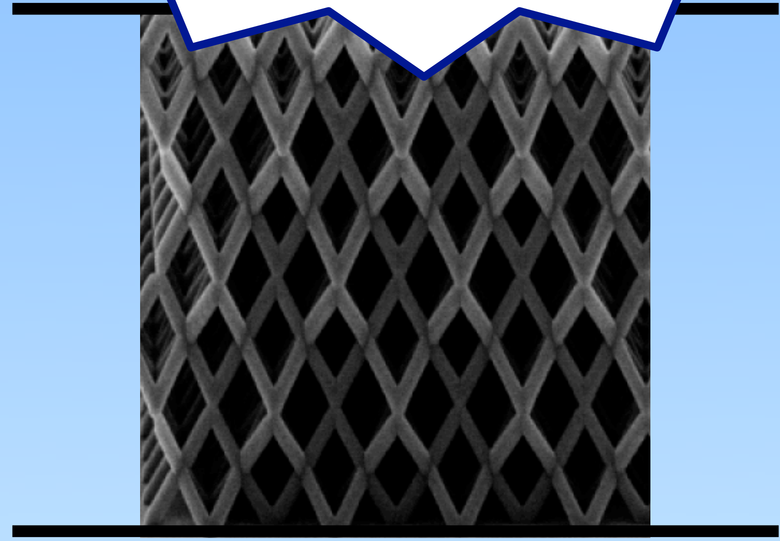
Negative Pois

Monday afternoon:

Martin van Hecke

Mechanical metamaterials

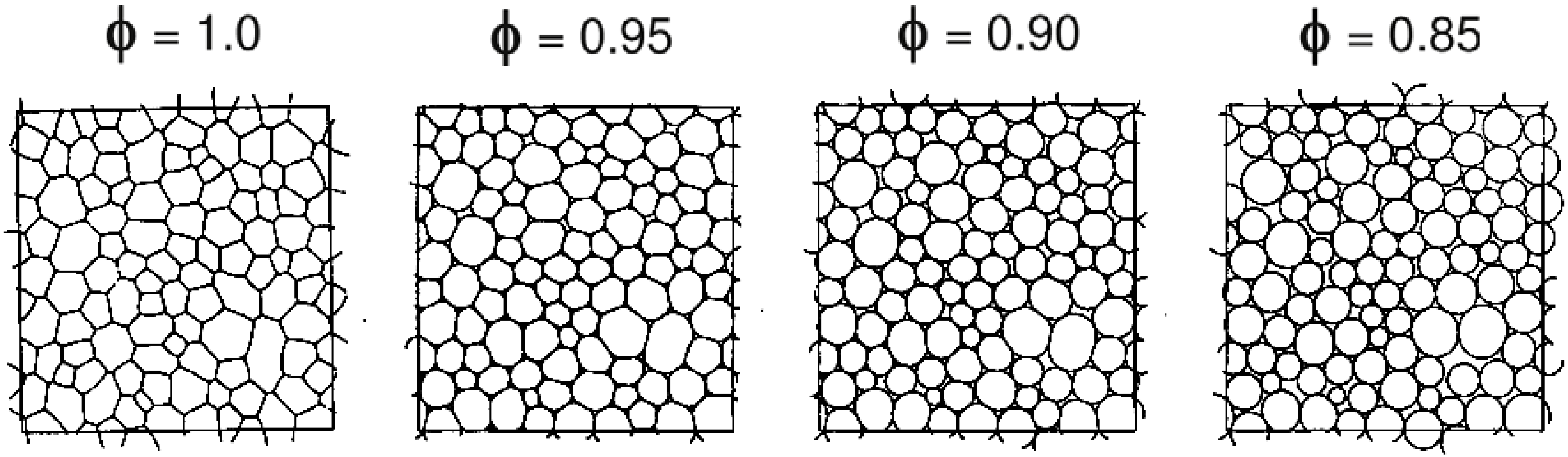




When compressed vertically, tailored metamaterials compress horizontally.

$\nu < 0$

Stability of foams

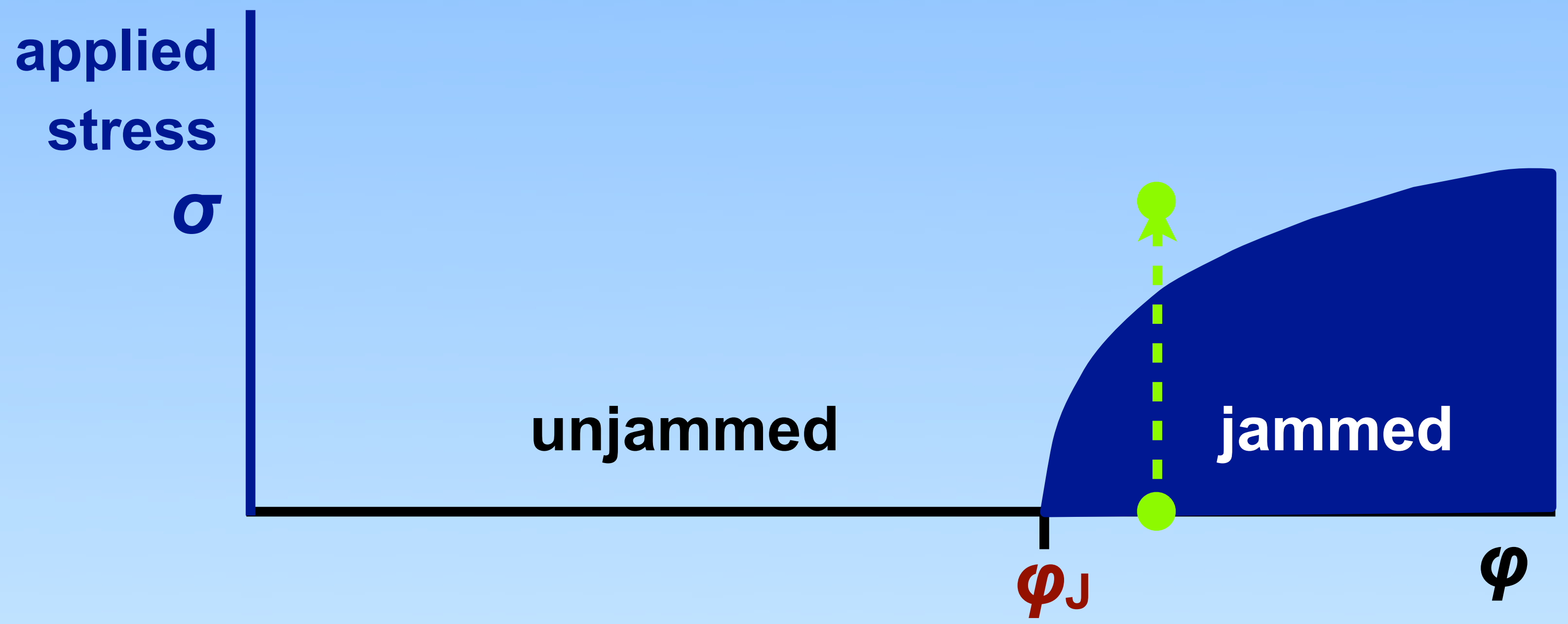


Bolton, Weaire, PRL (1990)

The foam looses stability at $\varphi \approx 0.84$

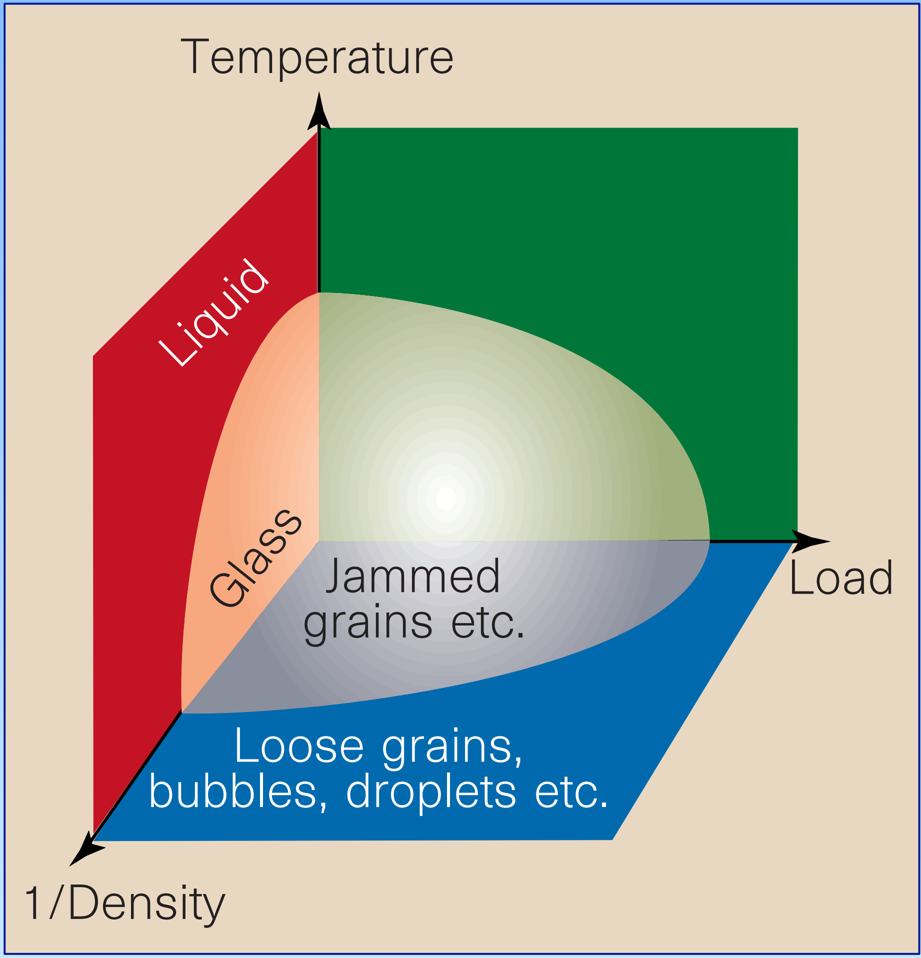
Jamming

A granular material with a packing fraction above a critical value φ_J is stable.

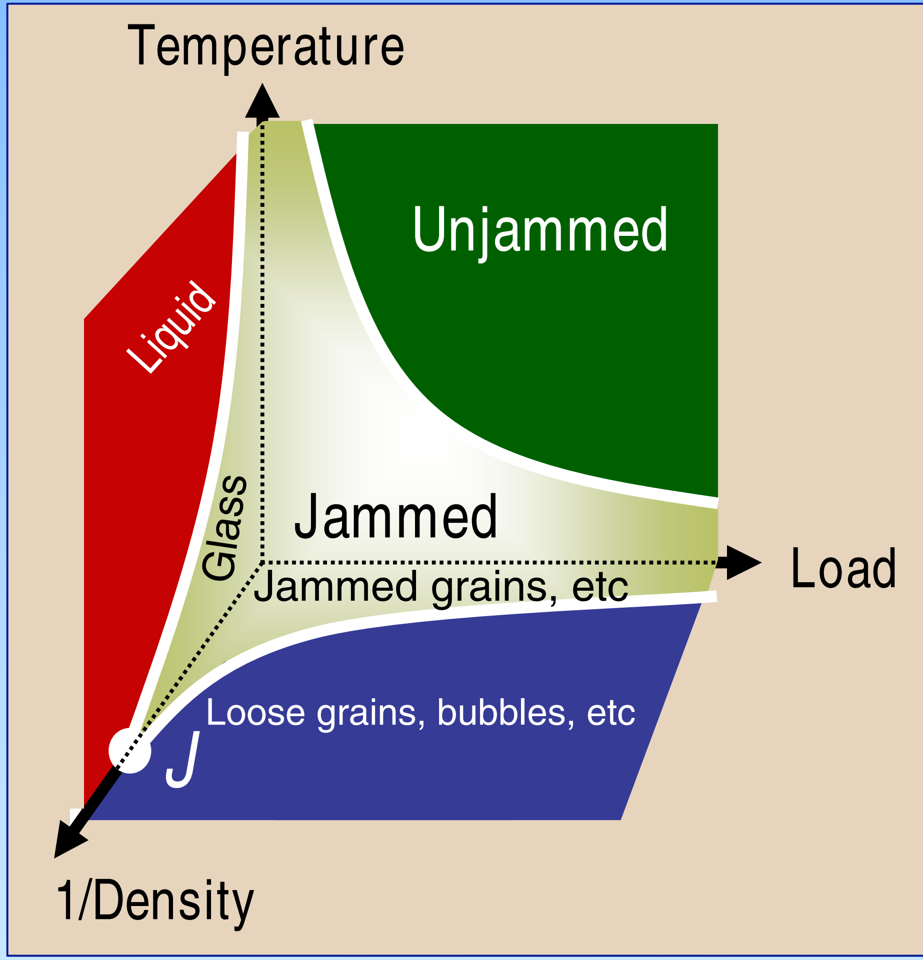


At φ_J the packing is marginally stable: any stress will destroy the packing

Jamming diagrams



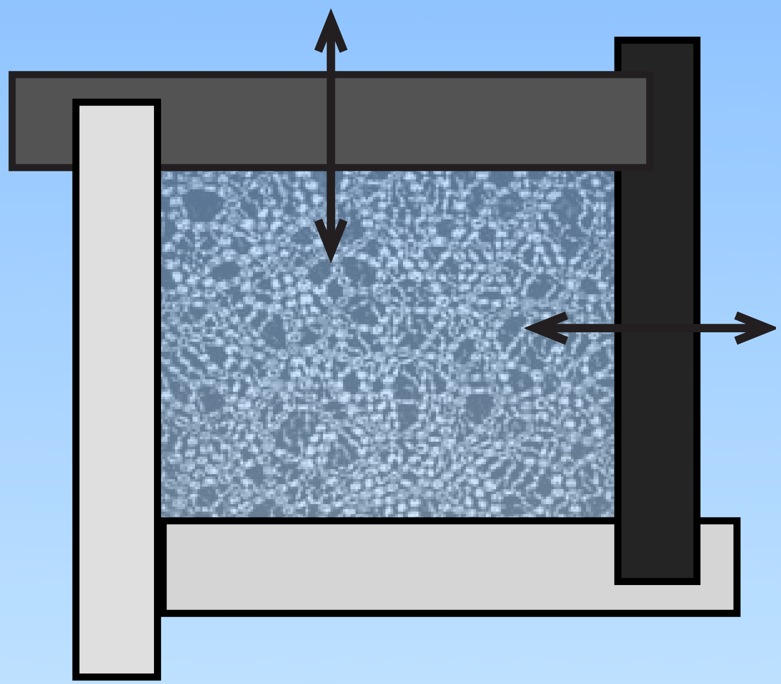
Andrea Liu, Sid Nagel
Nature (1998)

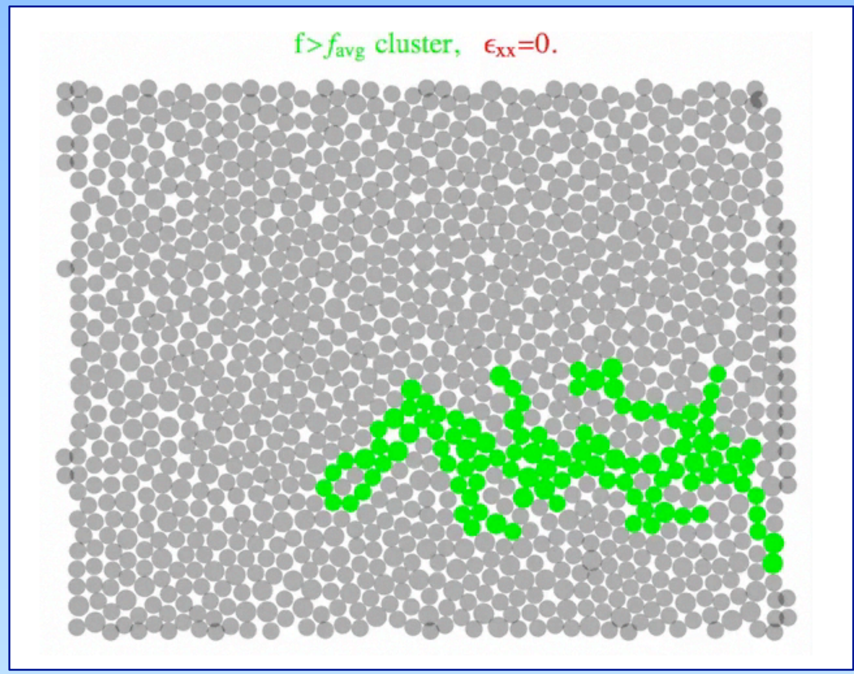


Martin van Hecke,
J. Phys.: Cond. Matt. (2010)

The controversy continues...

Jamming by shear

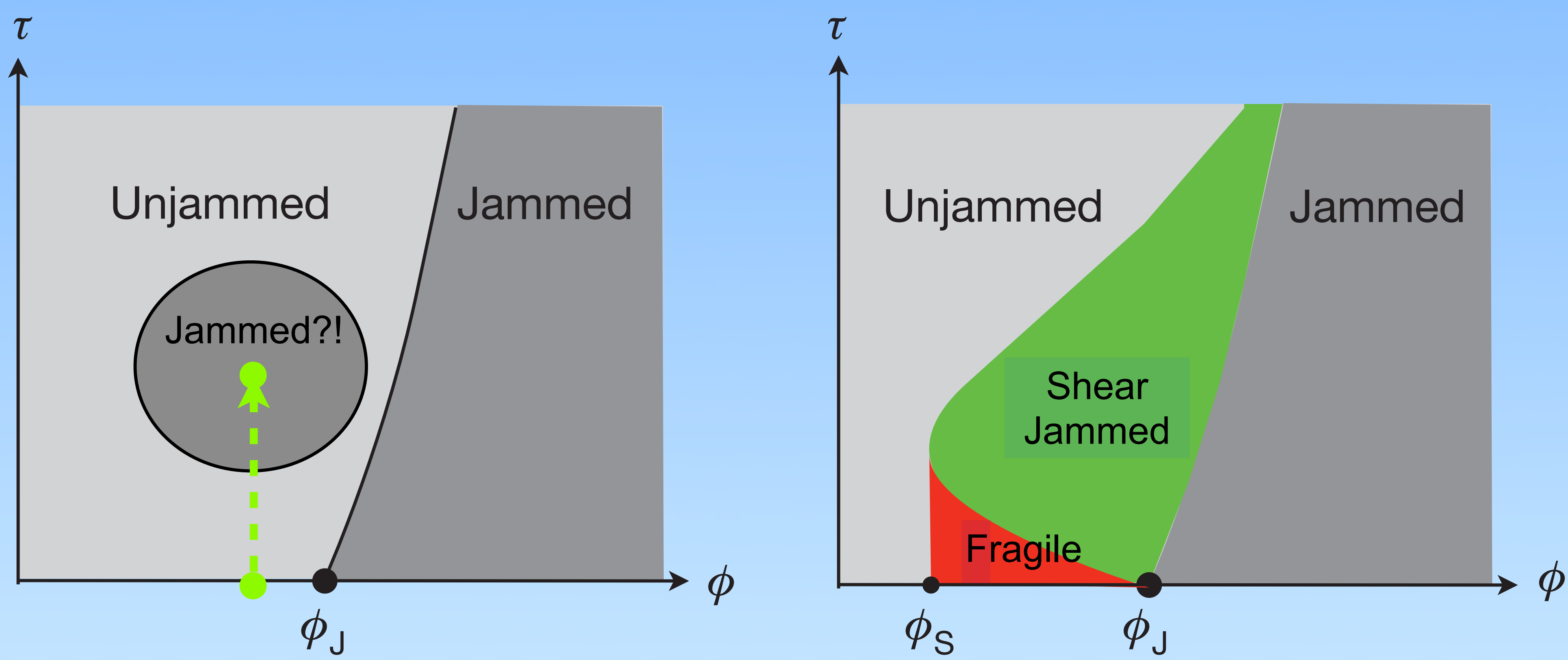




Dapeng Bi, Jie Zhang, Bulbul Chakraborty, Bob Behringer, Nature (2011)

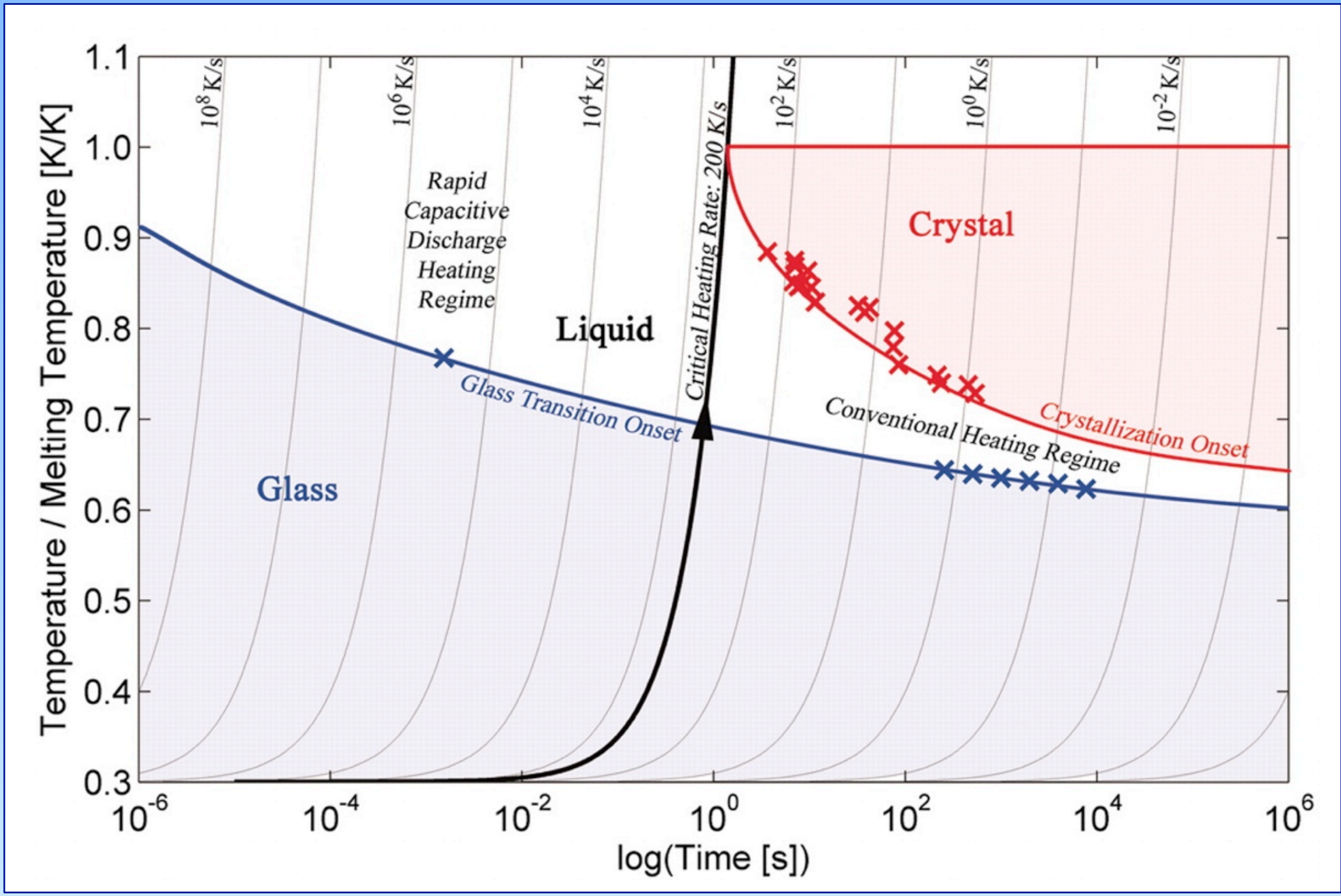
The controversy continues...

Jamming by shear



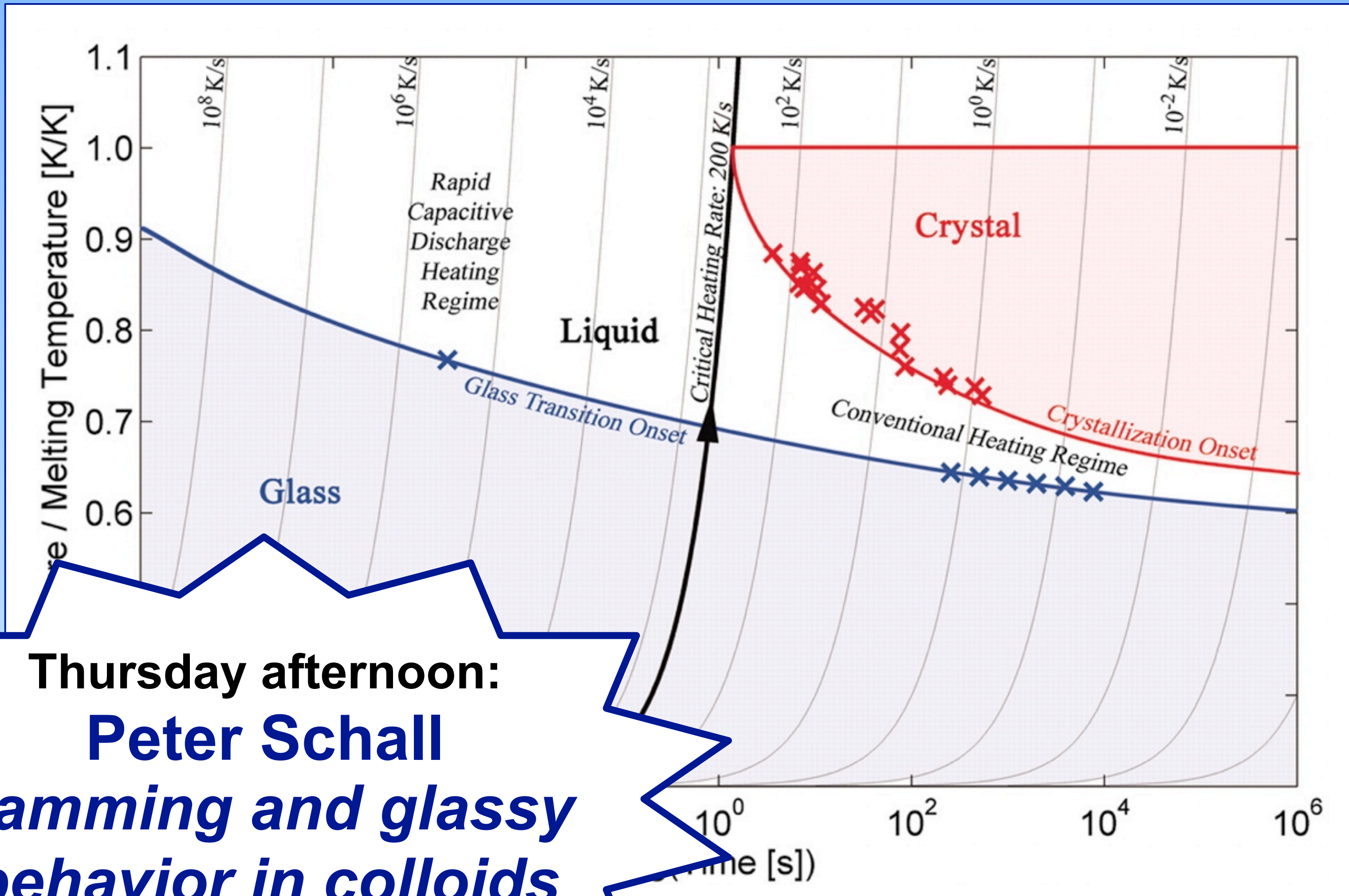
Dapeng Bi, Jie Zhang, Bulbul Chakraborty, Bob Behringer,
Nature (2011)

Finite temperature: glassy behavior



System quenched in a jammed or glass state

Finite temperature: glassy behavior



Thursday afternoon:

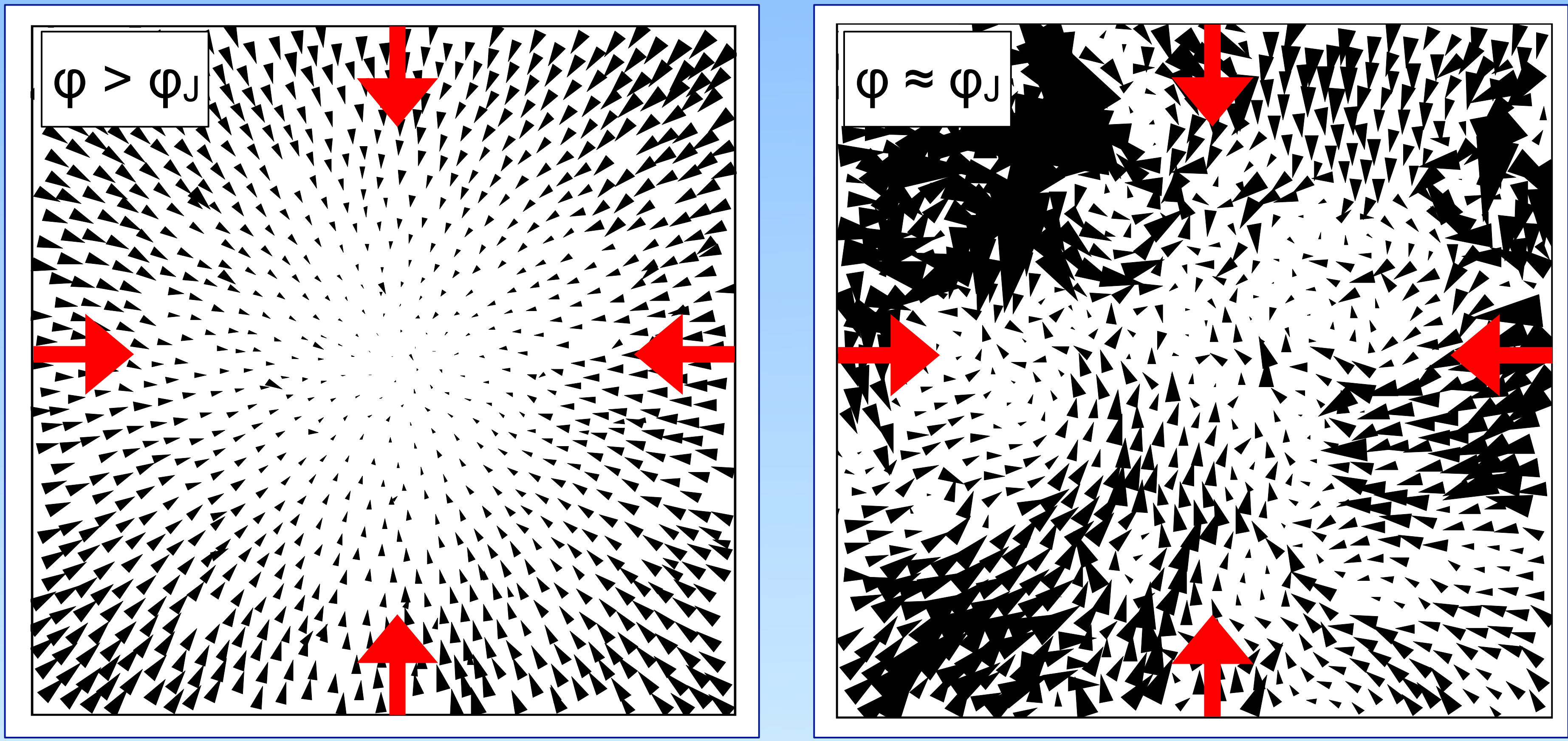
Peter Schall

Jamming and glassy behavior in colloids and grains

Sy… …d in a jammed or glass state

Close to point J:
Very loose contact networks

response to uniform compression

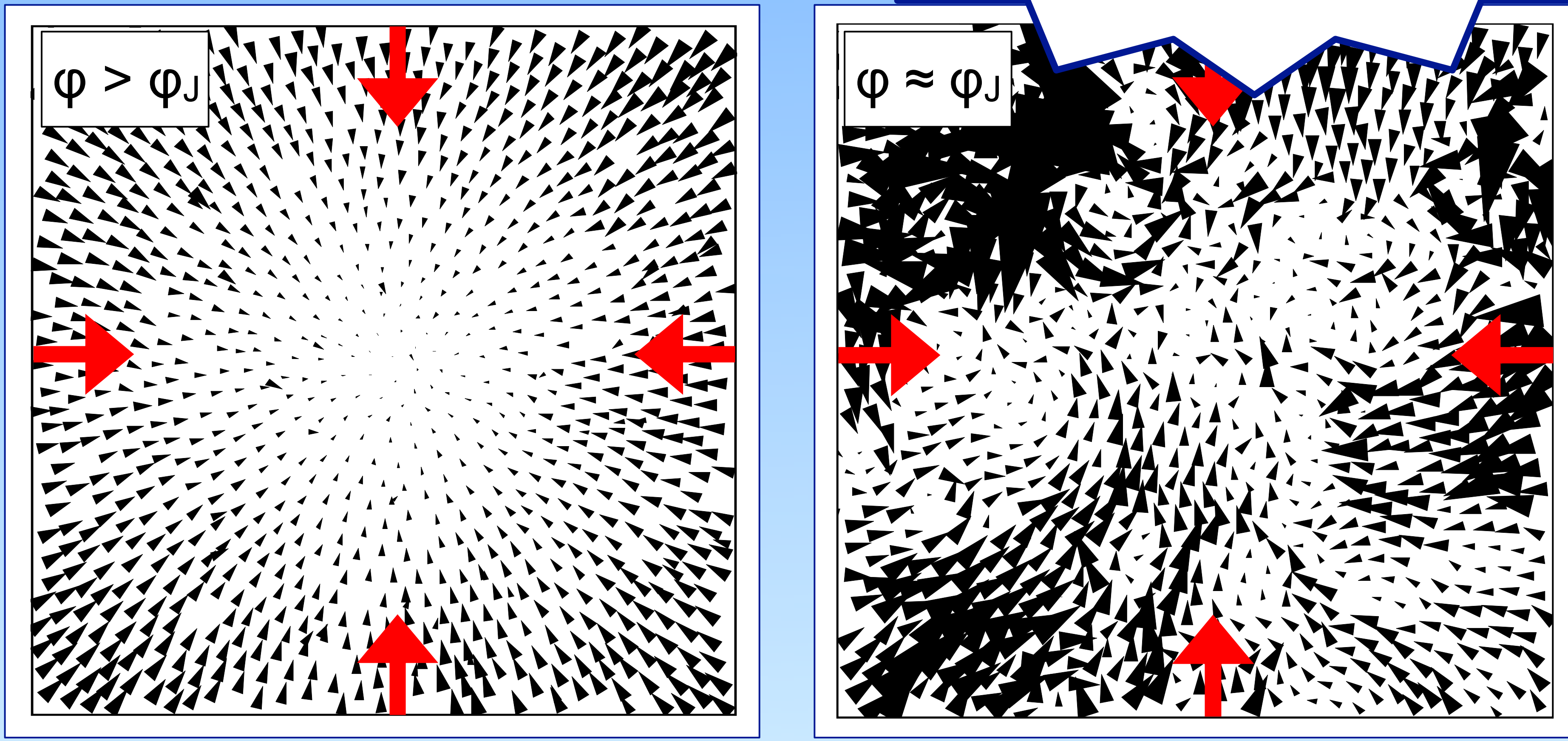


close to φ_J: displacement field has non-affine response

Close to po…
Very loose cont…

response to uniform c…

Wednesday afternoon:
Vicenzo Vitelli
Shocks in fragile matter



close to φ_J: displacement field has non-affine response

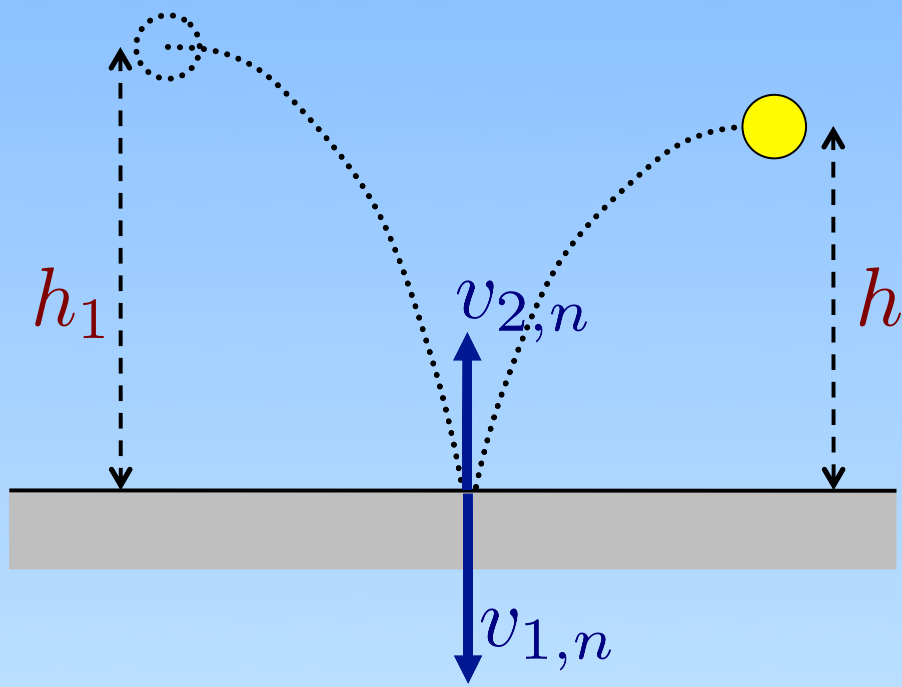
3. Dissipative interactions

Dissipative interactions may arise:

- as a result of motion through another medium (see 4)
  - Brownian motion (fluctuation-dissipation)
  - dissipation in medium (viscosity, turbulence)
- as a result of contact forces:
  - friction
  - inelastic collisions

transfer of kinetic energy into other degrees of freedom.

Dissipative collisions



coefficient of normal restitution:

$$e = \frac{v_{2,n}}{v_{1,n}} \left(= \sqrt{\frac{h_2}{h_1}} \right)$$

Grains have many internal degrees of freedom through which kinetic energy is dissipated.

(sound, heat, deformation)

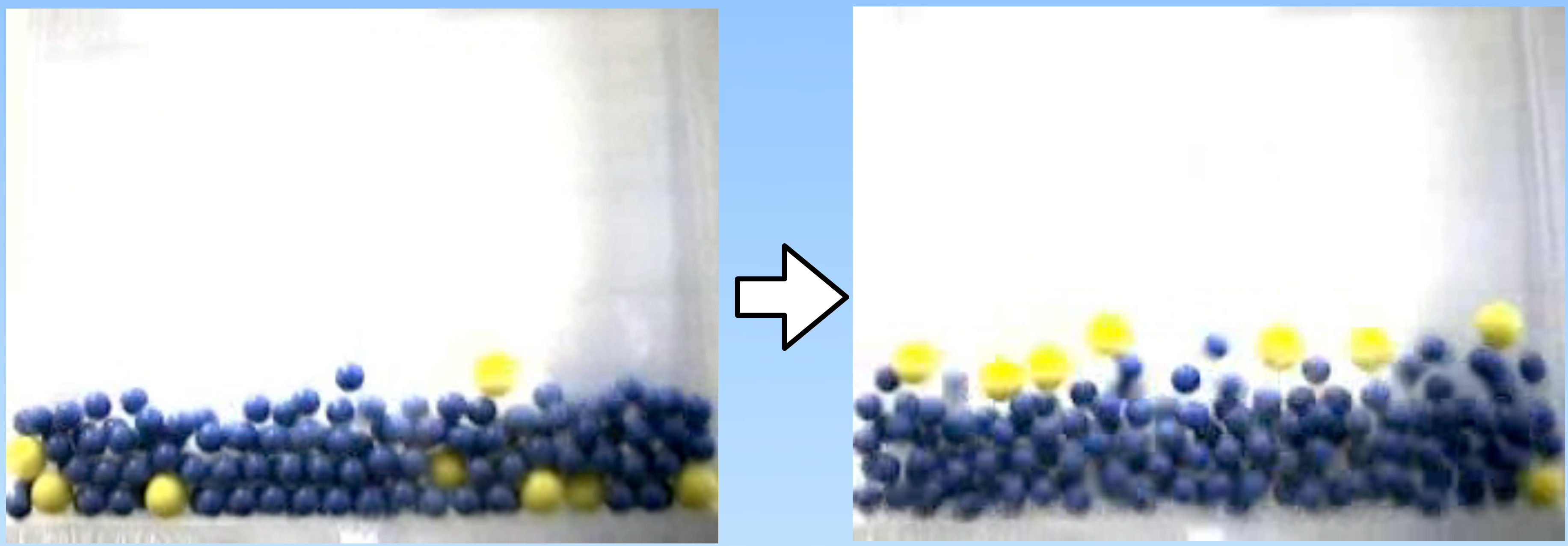
4. Inhomogeneous

Soft Matter is usually inhomogeneous. There are two main causes:

1. **The inhomogeneity is caused by the (unavoidable) presence of an interstitial fluid (*intrinsic*).**
   - **colloids are particles subject to Brownian motion and hydrodynamic interactions with the embedding fluid.**
   - **polymers are modeled as Brownian particle-springs**

2. **The inhomogeneity is due to inhomogeneity of the material (*external).***
   - **granular materials can be bidisperse or polydisperse**
   - **clay is a material made up of clay (nanoscale) and silica particles**

Vibrated bidisperse mixture



Segregation !

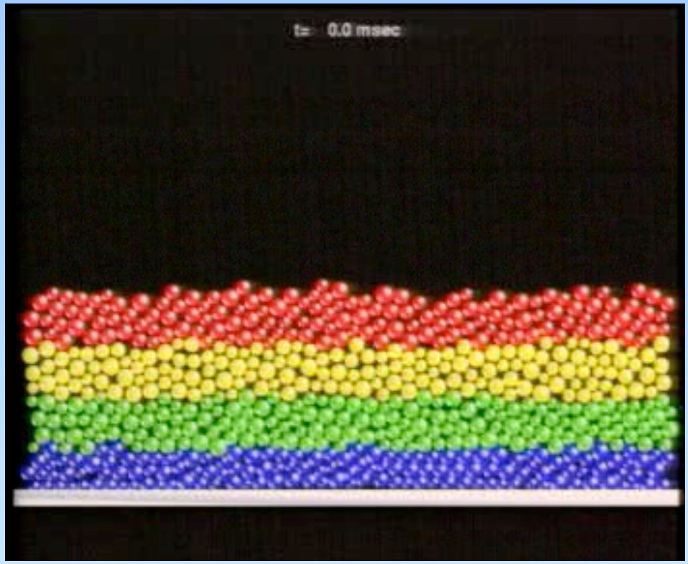
“Brazil Nut Effect”

Three explanations BNE

1. percolation: small grains percolate the empty spots between the large ones.

2. exclusion: while vibrating small grains fill space below the large ones, not vice versa.

3. convection: interaction with walls trigger convection rolls.



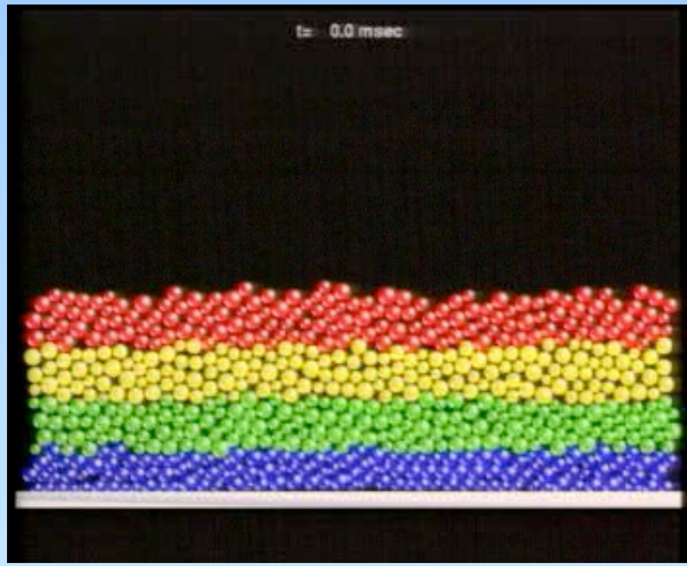
large grains can follow the upward, but not the downward flow.

Three explanations BNE

1. percolation: small grains percolate the empty spots between the large ones.

2. exclusion: while vibrating small grains fill space below the large ones, not vice versa.

3. convection: interaction with walls trigger convection rolls.



Large grains can follow the upward, but not the downward flow.

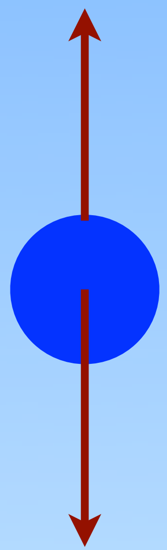
Tuesday morning:

Nico Gray

Granular avalanches & particle segregation

Role of intersitial air: single particle

$$F_{drag} = 3\pi\eta dV$$



$$F_g = \frac{1}{6}\pi d^3 \rho_p g$$

d = particle diameter
V = typical particle velocity
η = air viscosity ($2\cdot10^{-5}$ Pa·s)
ρ_p = part. density ($2.5\cdot10^3$ kg/m^3)
g = grav. acceleration (10 m/s^2)

$$B \equiv \frac{F_{drag}}{F_g} = \frac{18\eta V}{\rho_p g d^2}$$

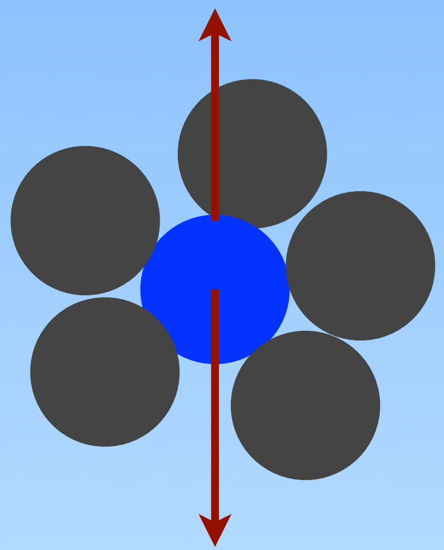
$$B \approx 1 \rightarrow d \approx \sqrt{\frac{18\eta V}{\rho_p g}}$$

$$V \approx 1 \text{ m/s} \rightarrow d \approx 120\ \mu\text{m}$$

$$V \approx \sqrt{2gd} \rightarrow d \approx 16\ \mu\text{m}$$

Role of interstitial air: packed particle

$$F_{f\to s} = 2k\frac{1-\varepsilon}{\varepsilon^3}F_{drag}$$



$$F_g = \tfrac{1}{6}\pi d^3 \rho_p g$$

$\varepsilon = 1 - \varphi =$ porosity (≈ 0.5)
$k =$ Kozeny constant (≈ 5)

$$B_p \equiv \frac{F_{f\to s}}{F_g} \approx 40\frac{18\eta V}{\rho_p g d^2}$$

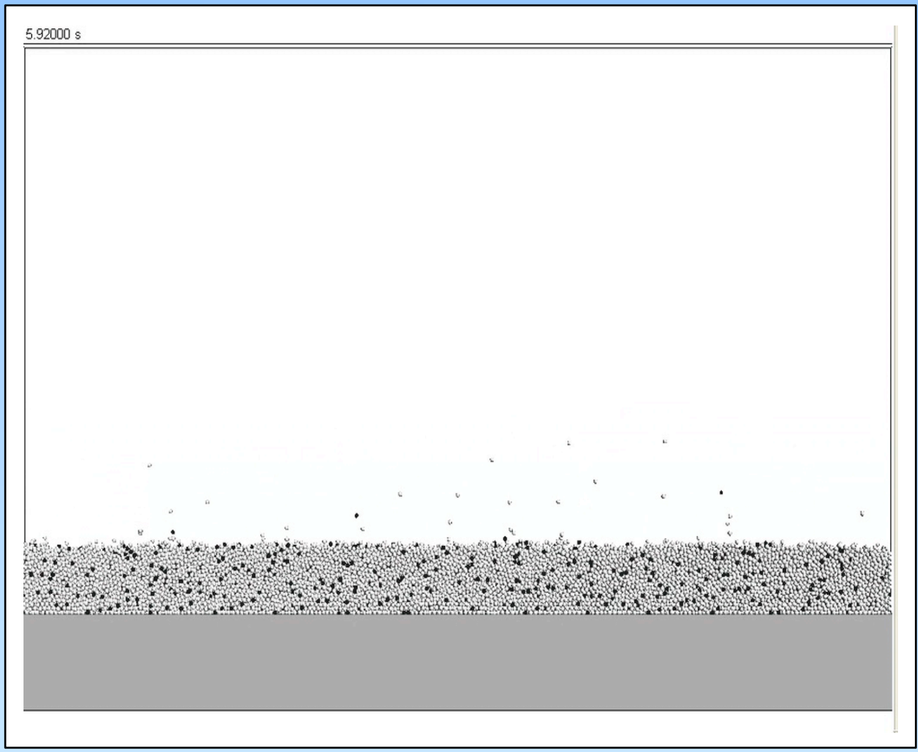
$$B_p \approx 1 \to d \approx \sqrt{40}\sqrt{\frac{18\eta V}{\rho_p g}}$$

$$V \approx 1\ \mathrm{m/s} \to d \approx 760\ \mu\mathrm{m}$$

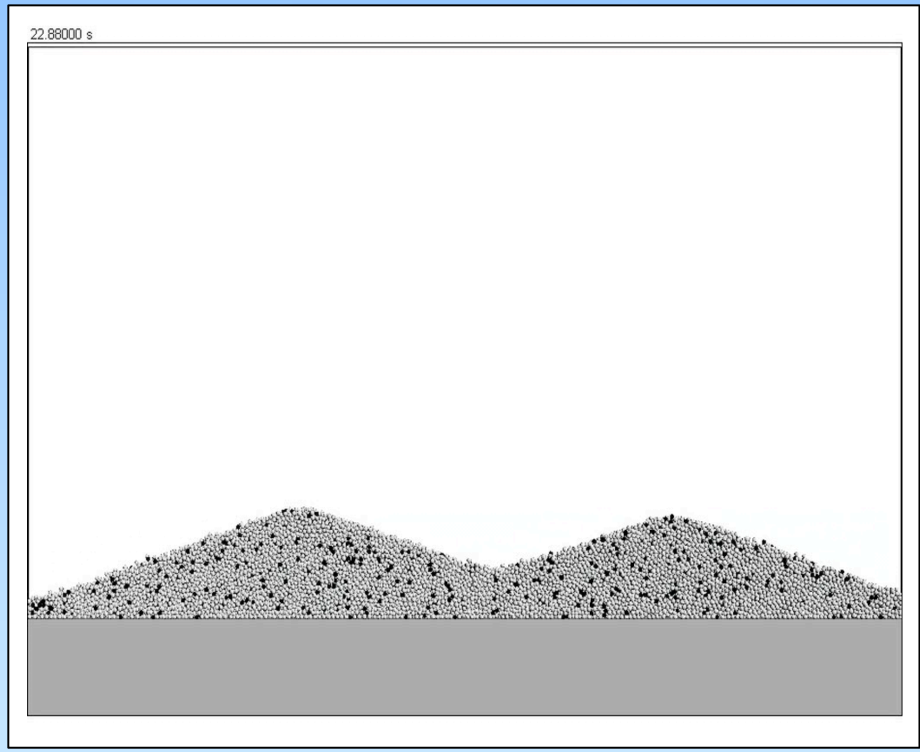
$$V \approx \sqrt{2gd} \to d \approx 190\ \mu\mathrm{m}$$

Faraday heaping

Vertically vibrated granular layer:
Numerical simulation of heaping with a hybrid GD-CFD code



without air



with air

Faraday he

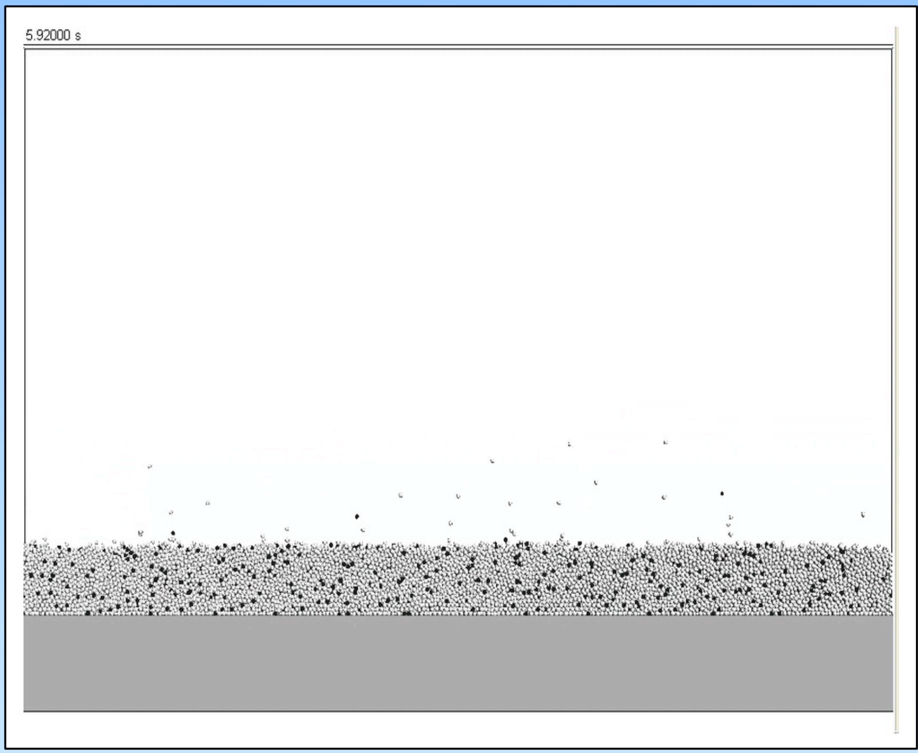
Wednesday morning:

Martin van der Hoef

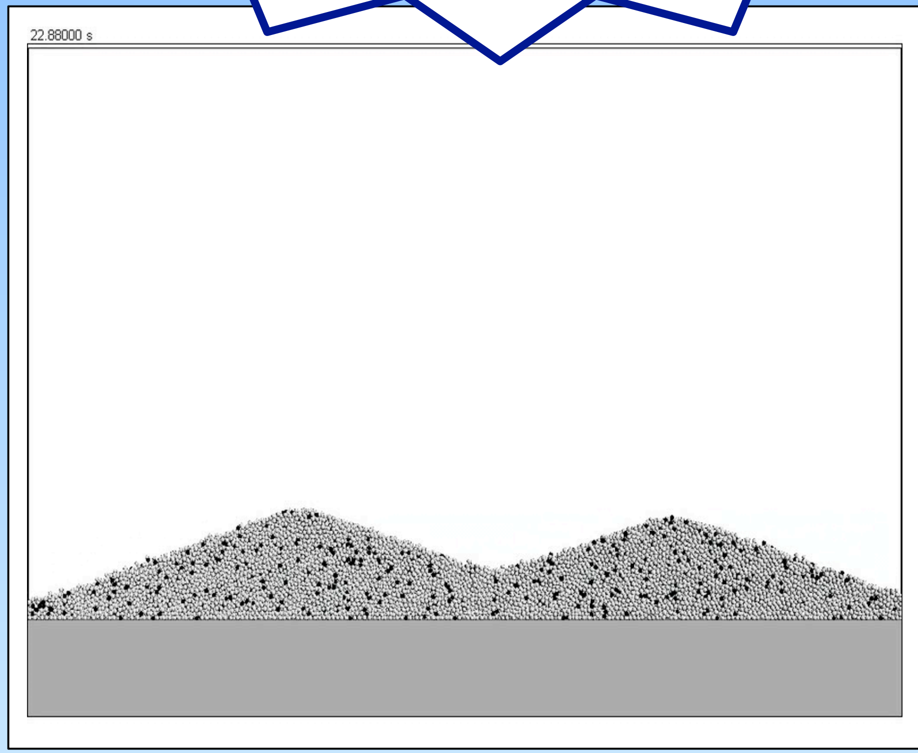
Simulation of granular two-phase flows

Vertically vibrated

Numerical simulation of heaping w



without air



with air

Interstitial liquids: suspensions

a granular suspension: cornstarch on a shaker

Walking on cornstarch

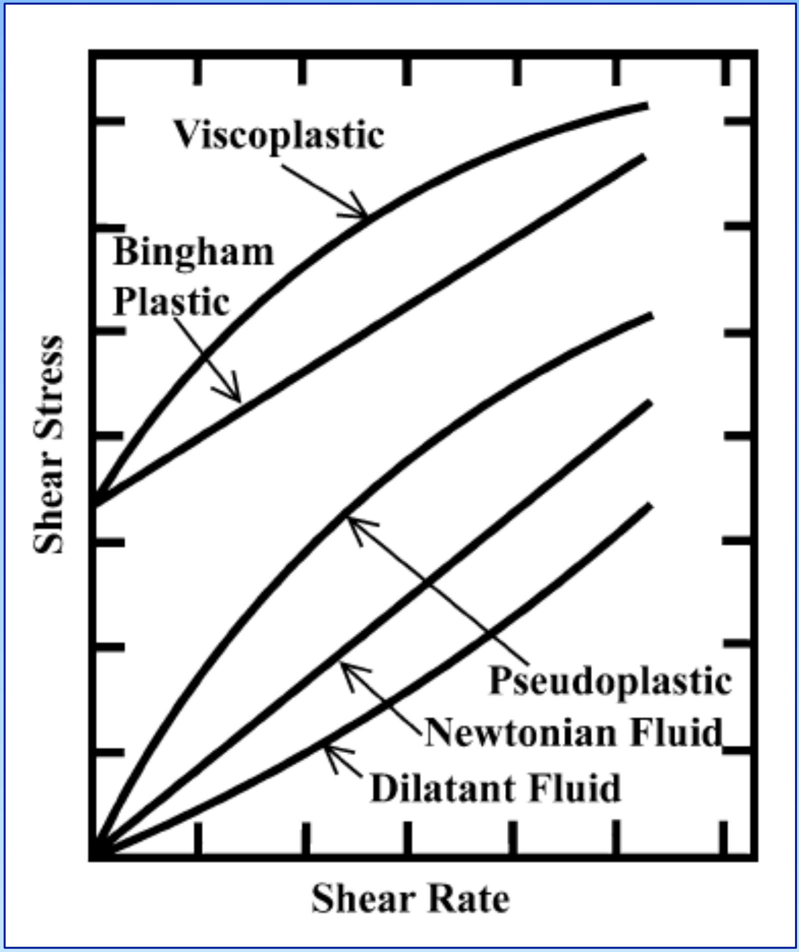
Walking on cornstarch

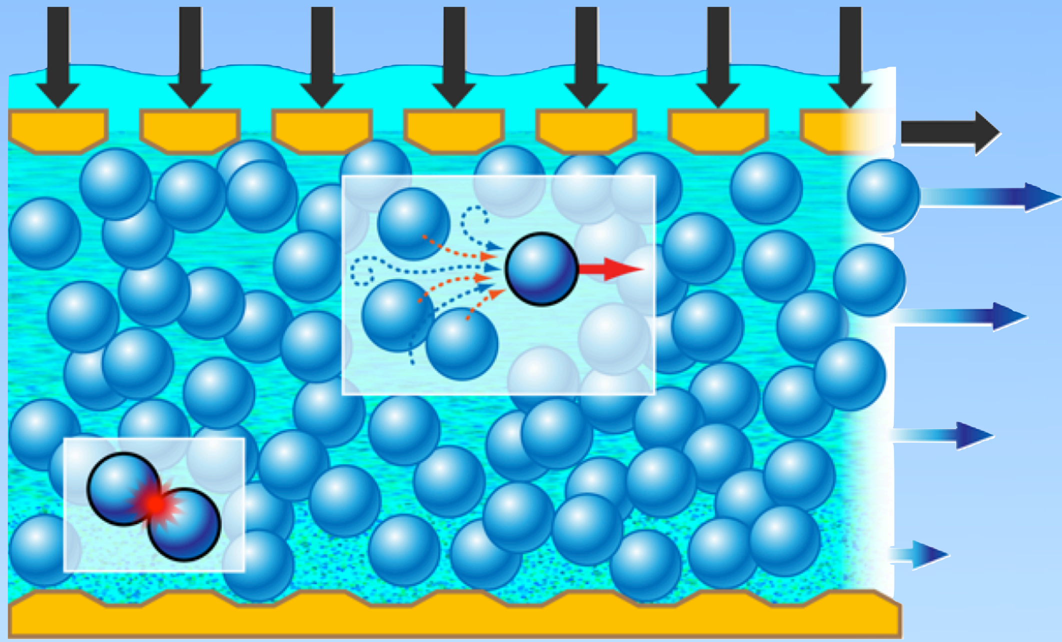
Friday morning:

Stefan Luding / Devaraj van der Meer

Granular matter and interstitial fluids

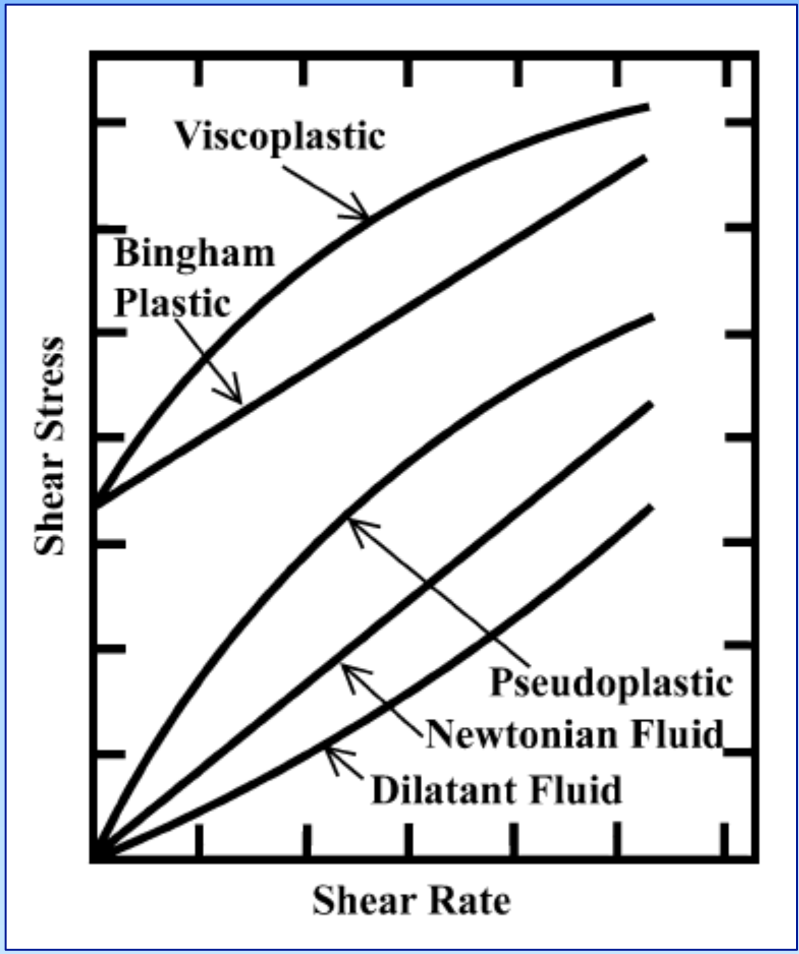
Macroscopic vs microscopic

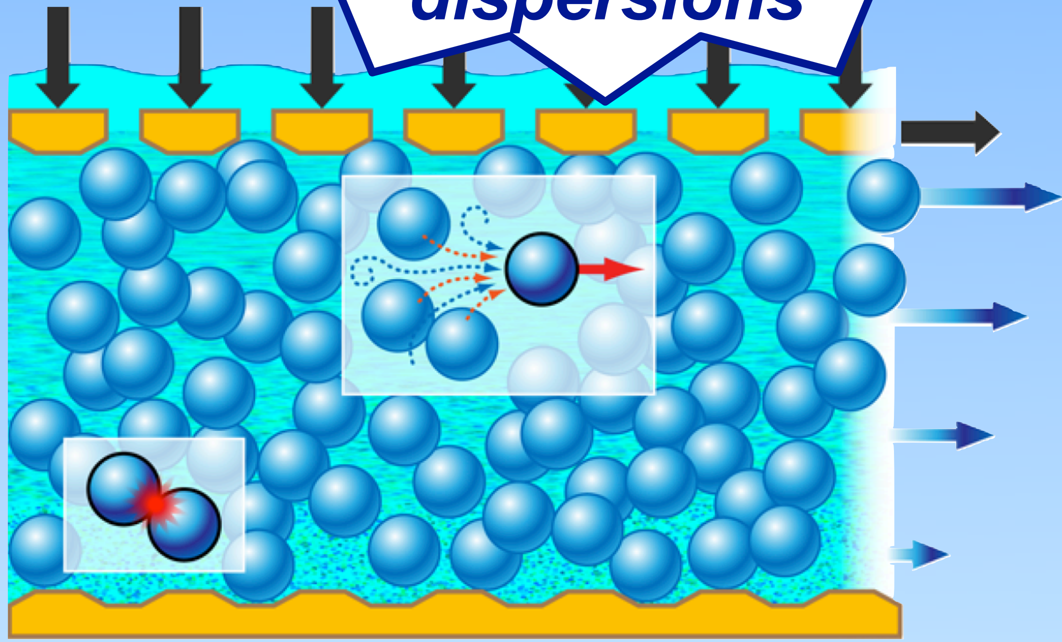




Macroscopic vs

Tuesday afternoon,
Thursday morning:
Dirk van den Ende
What is rheology about ? / Rheology of dispersions





Why is Soft Matter a booming subject in physics ?

There are many reasons, but one has been absolutely crucial:

NUMERICS

Some numerical techniques

- Brownian dynamics
- Monte Carlo
- molecular dynamics
- lattice Boltzmann
- Event driven hard sphere dynamics
- Hard sphere dynamics
- Soft sphere dynamics
- Two or multiple fluid models
- Multi-particle collision dynamics
- Hybrid MD lattice Boltzmann
- Stochastic rotation dynamics
- Hybrid granular dynamics computational fluid dynamics

Some numerical techniques

- Brownian dynamics
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Tuesday afternoon:
Stefan Luding
From particle description to continuum rheology


Thank you!