Labyrinthine phase and slow dynamics in a driven magnetic granular medium

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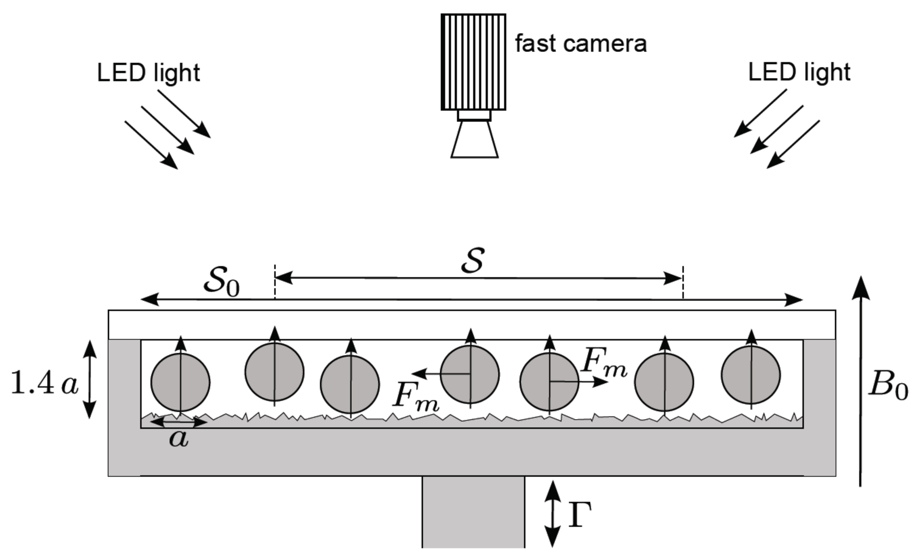
Labyrinthine patterns arise in two-dimensional physical systems submitted to competing interactions, ranging from the fields of solid-state physics to hydrodynamics. Here we report the observation of a labyrinthine phase in an out-of-equilibrium system constituted of magnetized macroscopic particles. We characterize the appearance of the labyrinthine phase as the interaction strength is increased, and we show that the large-scale disordered labyrinthine phase exhibits slow dynamics.

Experimental setup & protocol



Setup

- 2D cell: rough bottom, plexiglas lid, gap = 1.4*a*.
- *N* ferromagnetic particles: diam. *a*, area fraction $\Phi = \frac{N\pi a^2}{4S_0}$
- Shaker: acceleration Γ → granular gas
- Coils: orthogonal magnetic field B_0 → induced magnetic dipoles

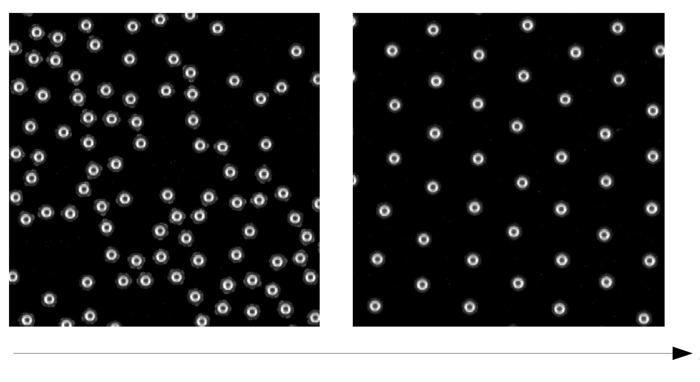
Repulsive interactions in 2D: $E_{m,ij} = \frac{\pi}{16\mu_0} B_0^2 \frac{a^6}{r_{ij}^3}$

Protocol:
1) Establish granular gas state by vibrating (Γ) ;
2) Increase linearly B_0 ;
3) Perform recordings after a given waiting time τ_w.

Recordings: fast camera (780 Hz) → single particle tracking
→ Magnetic and kinetic energy per particle: E_m and E_c

Phase transitions depending on parameters Φ and $\varepsilon = E_m / E_c$

Transition to a crystalline phase (Φ=0.2)



Particles can be considered as effective elastic disks with tunable diameter.

Tunable degree of elasticity

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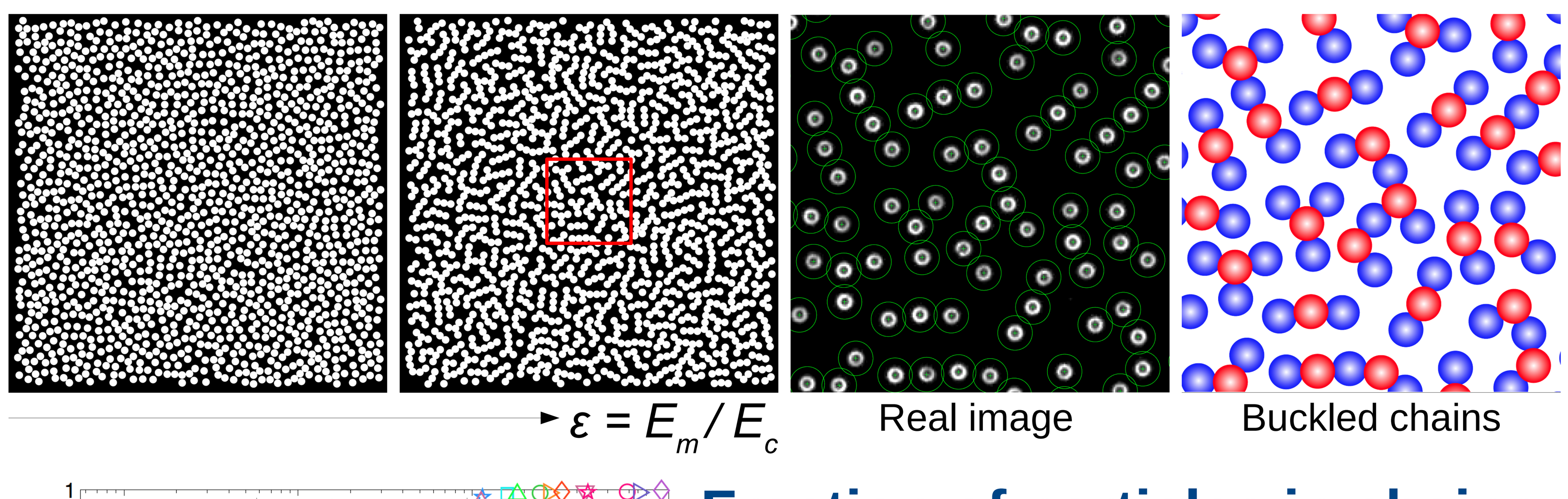
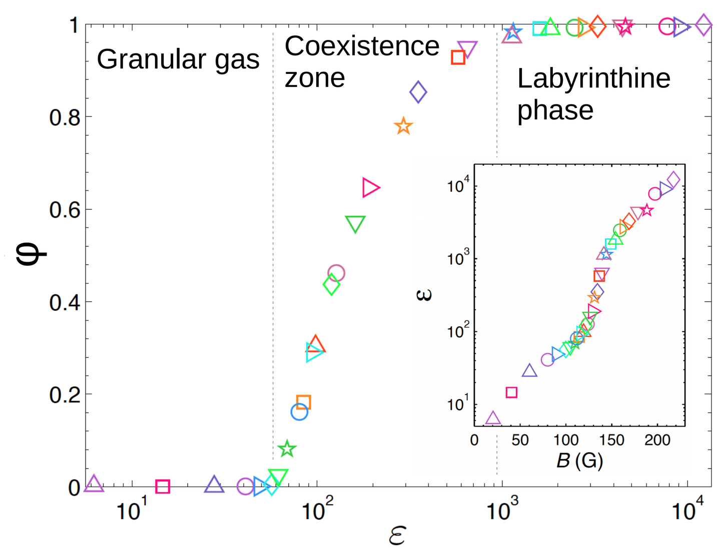
Transition to a labyrinthine phase (Φ=0.5)



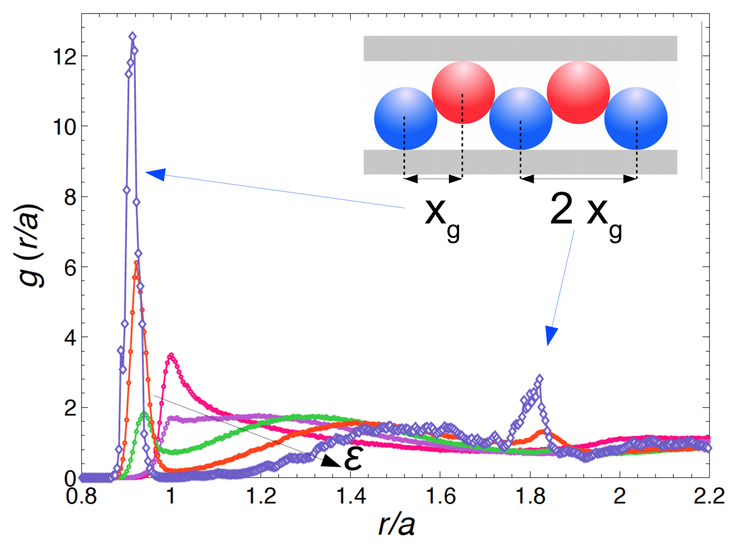


Fraction of particles in chains

Aggregation of pairs, then triplets, until solidification at the full-cell scale.

Pair correlation function

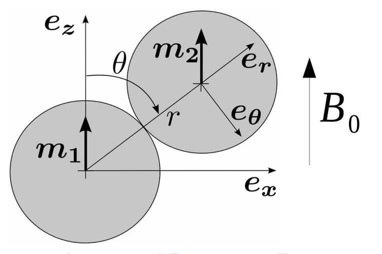
Partial overlapping limited by the cell gap size (3D effect).



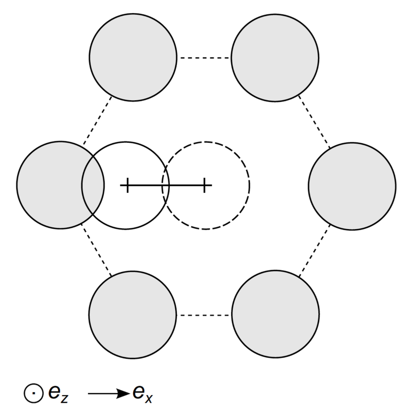
Potential energy model

Magnetic potential energy in 3D

$$U_m(r,\theta) = -\frac{\pi}{16\mu_0} B_0^2 \frac{a^6}{r^3}\left(2\cos^2\theta - \sin^2\theta\right)$$

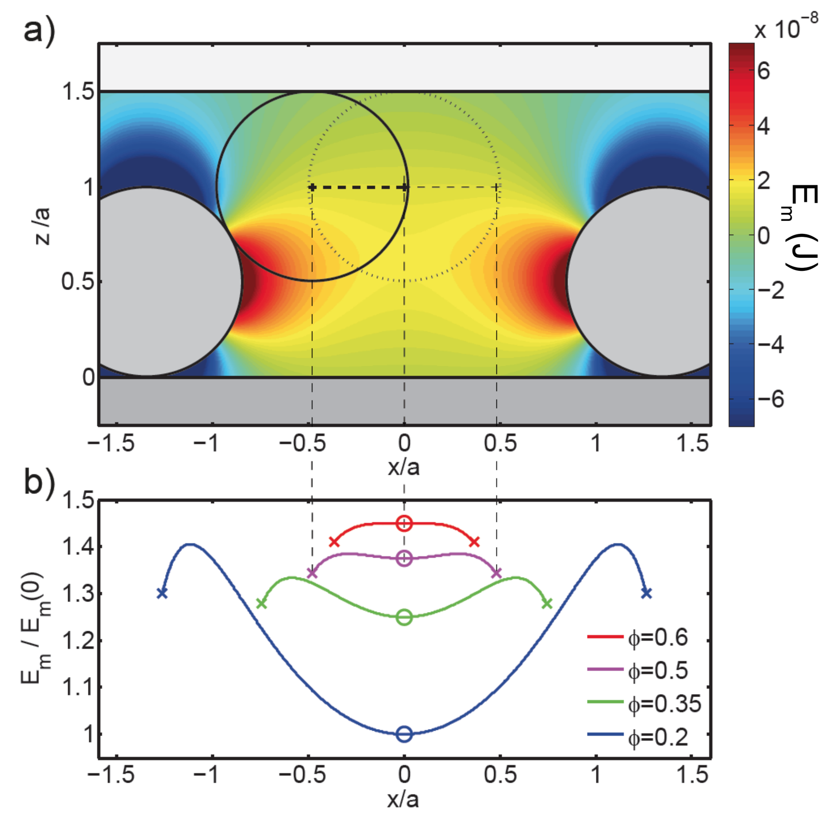


One moving *up* particle inside a hexagon of 6 fixed *down* particles



$$E_m = \frac{1}{6}\sum_{i=1}^{6} E_{m,ij}$$

$E_{m,ij}$: magnetic potential energy per particle of a given pair {neighbor *i* ; central particle *j*} (computed from U_m).



- Low Φ: *central* position is global min. → crystalline
- High Φ: *contact* position is global min. → labyrinthine

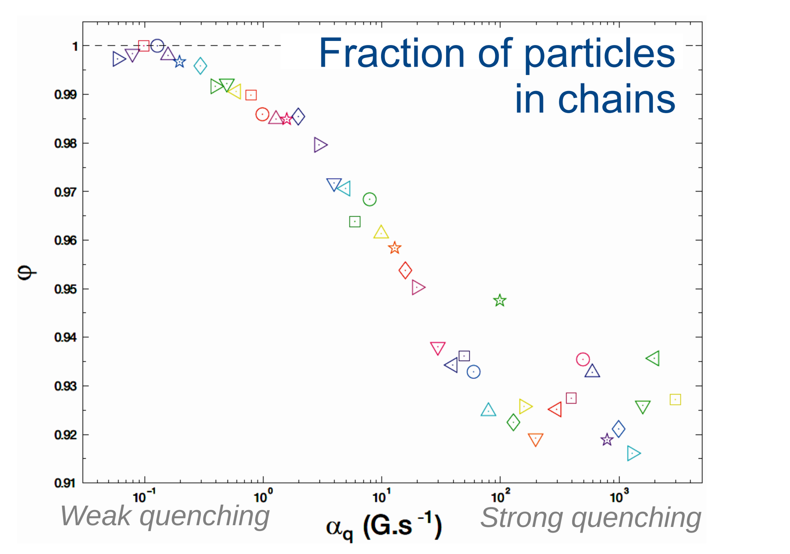
The preference for crystalline *vs.* labyrinthine phases can be explained by comparing potential energies.

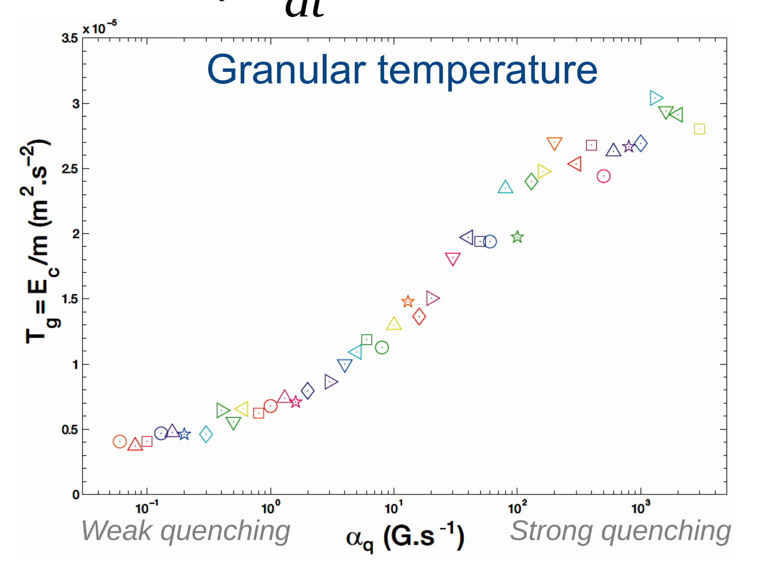
Slow dynamics

Initially very far from a steady state, the system undergoes slow relaxation, during which measured quantities depend on time.

Magnetic quenching

→ parameter $\alpha_q = \frac{dB}{dt}$

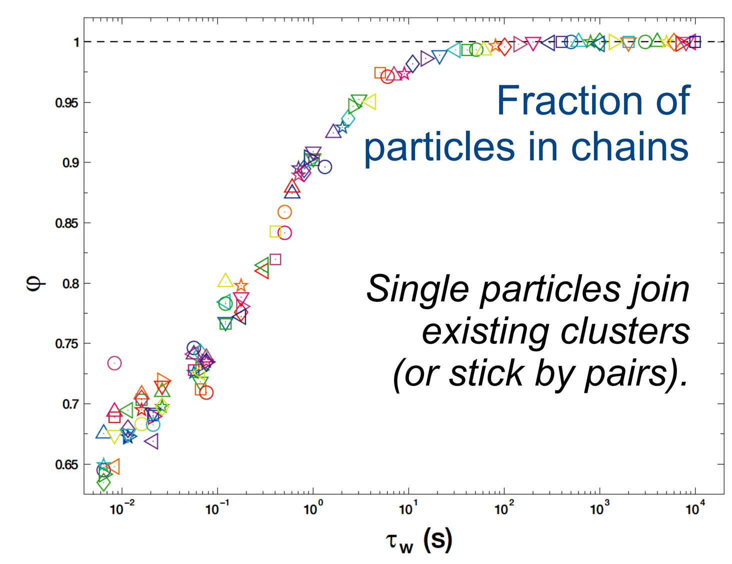


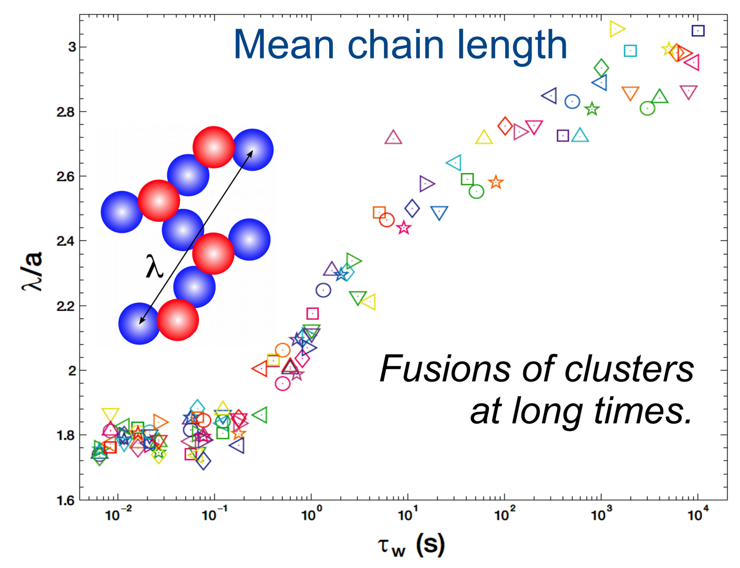


Strong magnetic quenching generates a disordered state which is ideal for studying the aging of the labyrinthine phase.

Aging

→ parameter τ_w : waiting time after B_0 reaches its max. value.





Aging implies a coarsening of the labyrinthine phase.

- By tuning the gap *h*, can we prevent the formation of the chains even at high density (Φ=0.5)? Frustrated contactless state?
- Can we experimentally check the validity of the 7-particle model presented here for other gap values?
- What are the characteristics of the system during the transient state? What can we say from the critical exponents?
  → *A model system for studying the transition from a fluctuating state to an absorbing state?*

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