Self-trapping and interfaces in active granular matter

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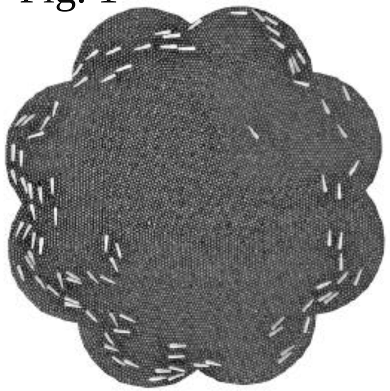
Motivation

- Active-passive mixtures: e.g. living + dead bacteria

- Nitin Kumar et al. 2014
  - Motile minority mobilizes inert majority
  - Flocking at small motile fraction
  - Can they drive other kinds of organisation?

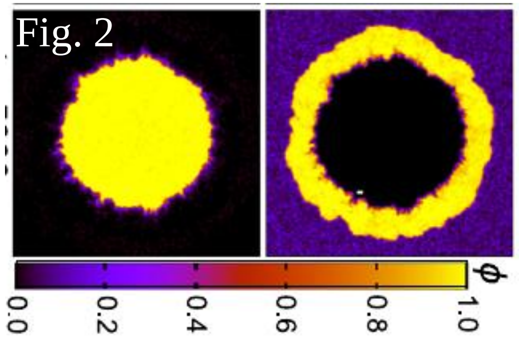
Fig. 1


Kumar et al. Nat Comm 2014

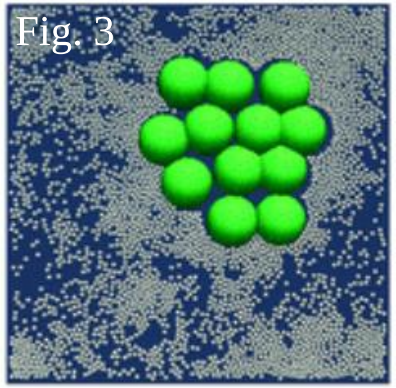
- Active-passive segregation*

No alignment: core-halo condensation

ϕ_P ϕ_A

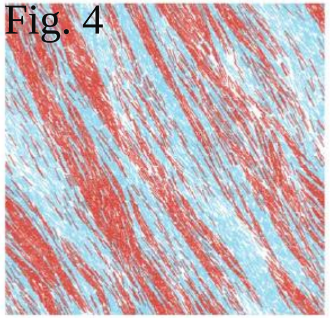
Fig. 2


Core-halo condensation
Stenhammar et al. PRL 2015

Fig. 3


Large passive particles, condensed by smaller active particles: Dolai et al. Soft Matter 2018

Aligning: lane formation

Fig. 4


Active-passive rod mixtures: transient lanes (red = active)
McCandlish et al, Soft Matter 2011

- This work: active-passive vibrated granular mixtures

Experimental set up and working principle

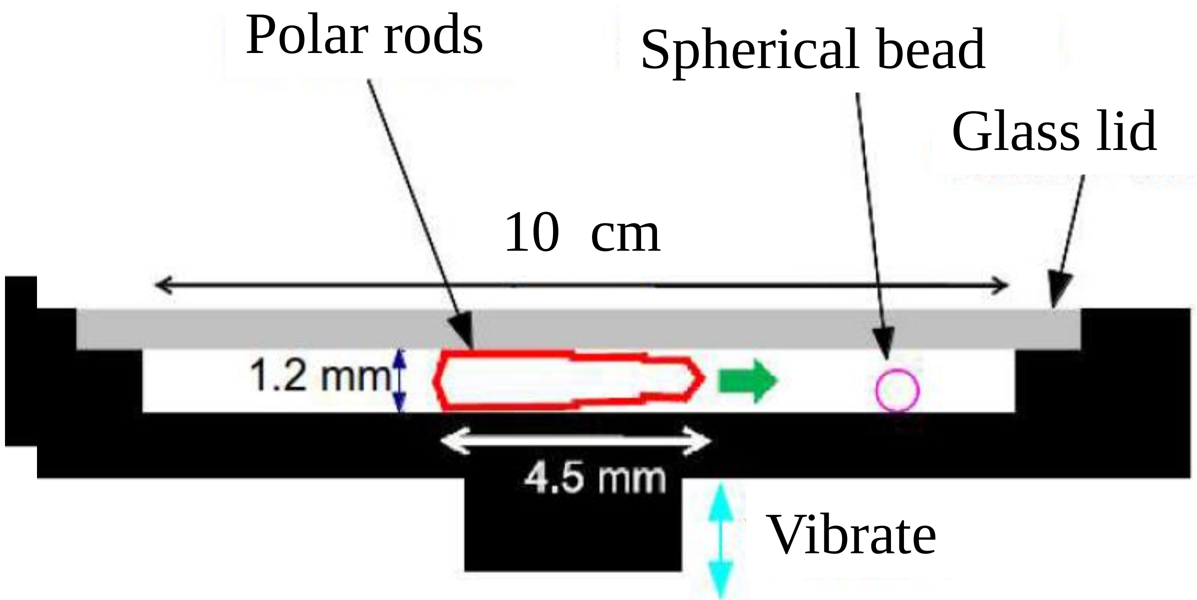


Fig 1. Experiment cell

Fig 2. Active polar particle

- Amplitude 0.04 mm
- Frequency200 Hz
- $\boldsymbol{\Gamma = A(2\Pi f)^2/g}$

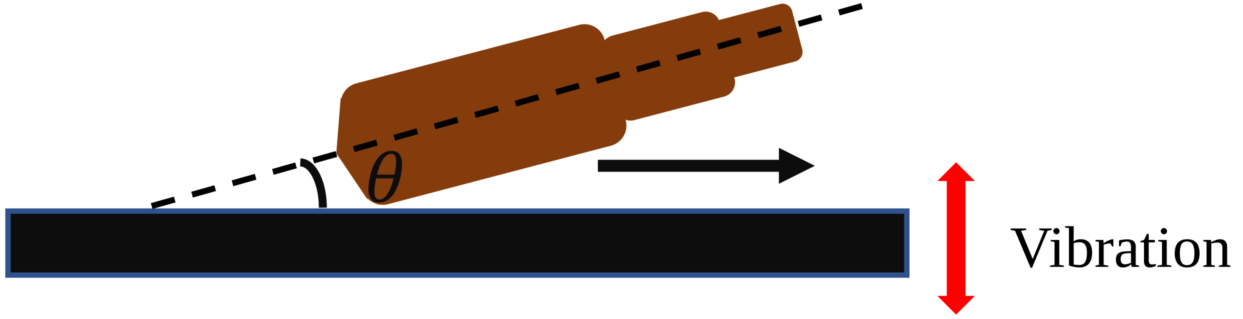


Fig 3. Motility mechanism

This Work

- Motile aligning rods + non-motile non-aligning beads
  - Experiments, simulations, simple theory

- Results:

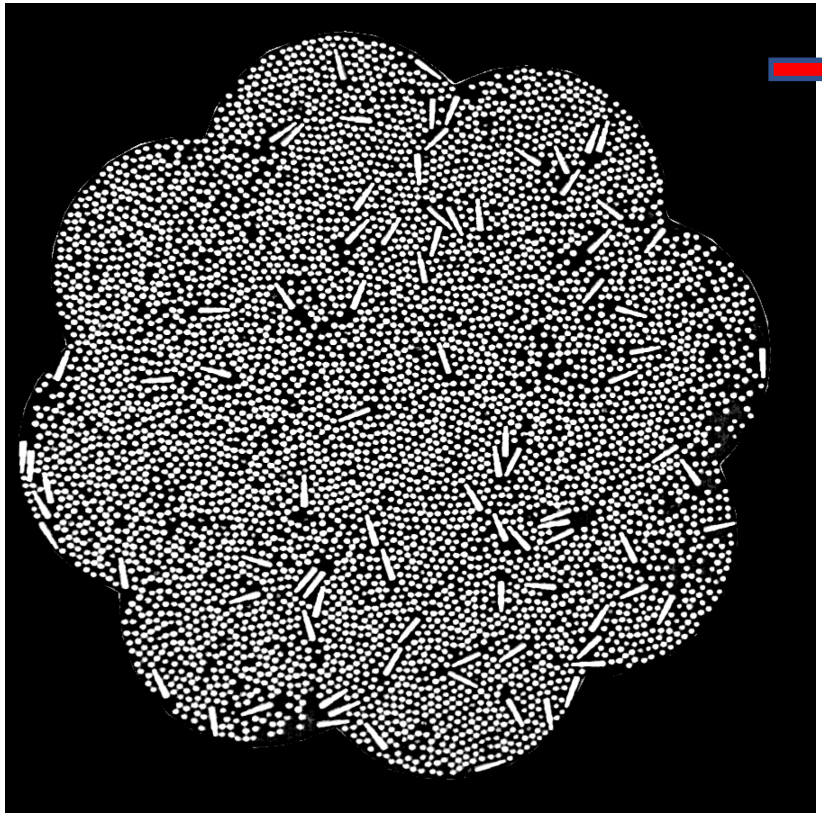
Isotropic → Flock → Segregation

  - D=2: travelling segregated bands
  - Alignment opposes core-halo in 2D
  - Quasi-1D: self-trapping segregation ~ core-halo

Results: Experiments

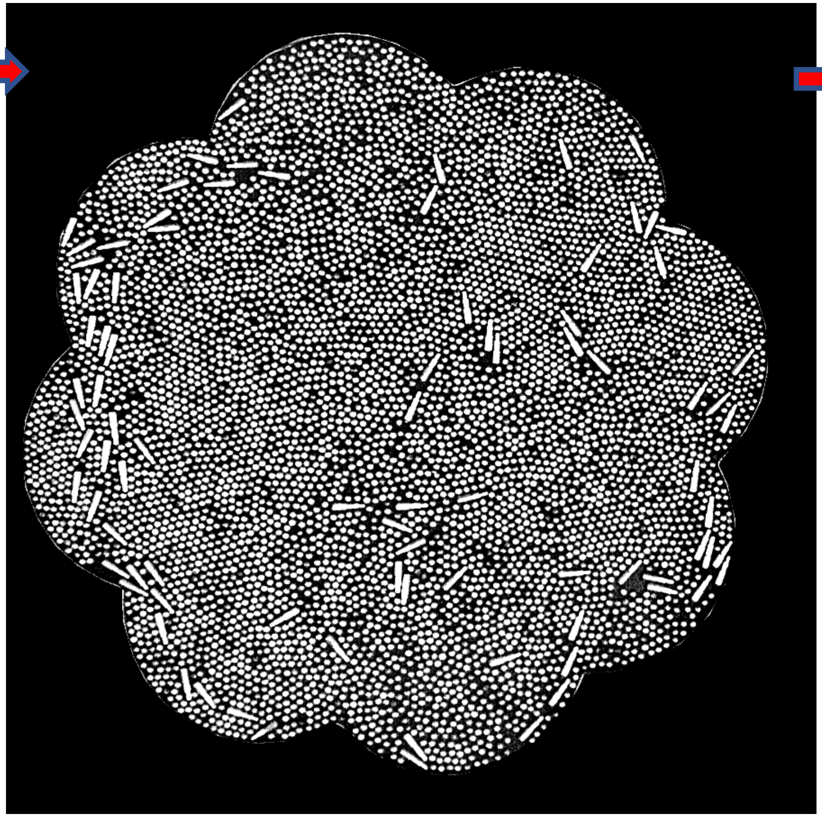
- Phase transition as function of bead fraction in 2 D.
- Very small fraction of motile rods drive such transitions.

Disordered



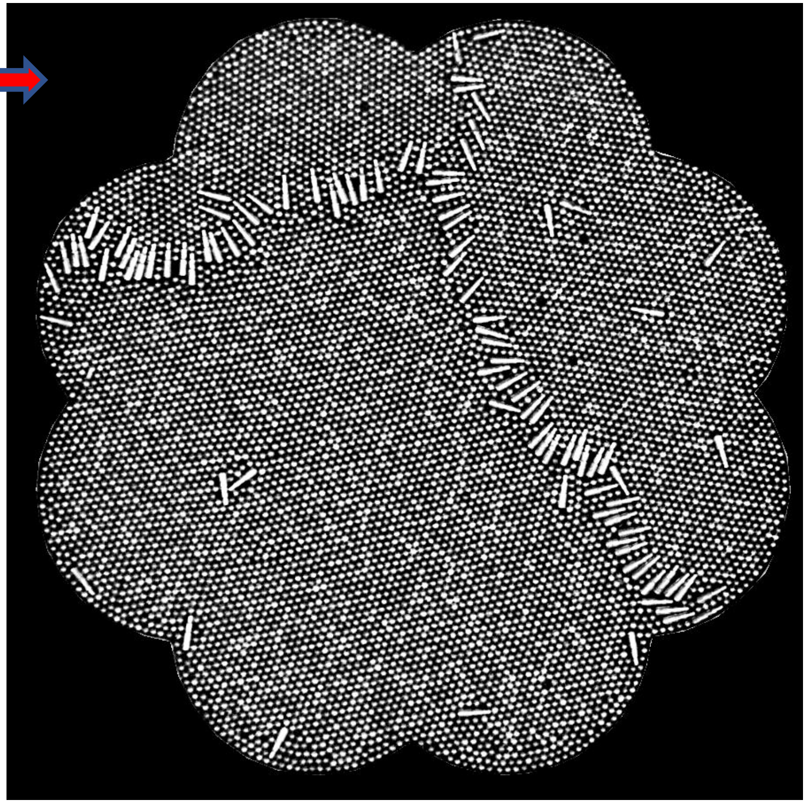
ϕ_b = 0.55, ϕ_r =0.06

Flock



ϕ_b = 0.70, ϕ_r = 0.06

Segregated



ϕ_b = 0.77, ϕ_r = 0.06

Interface state

- Rod's affinity for dense region.
- Why we are calling it interface state ?
- Related to moving segregated phase ?

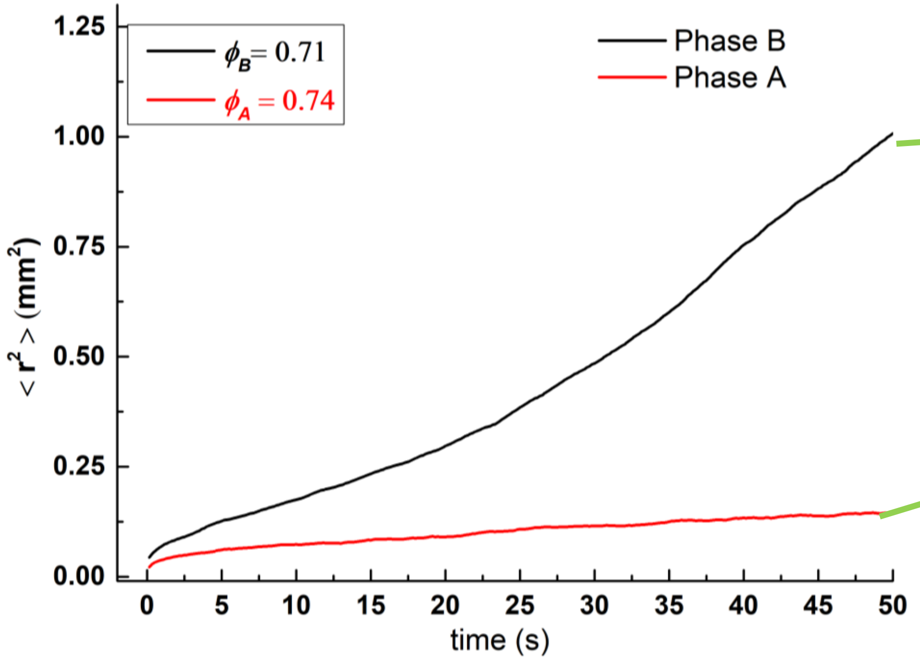
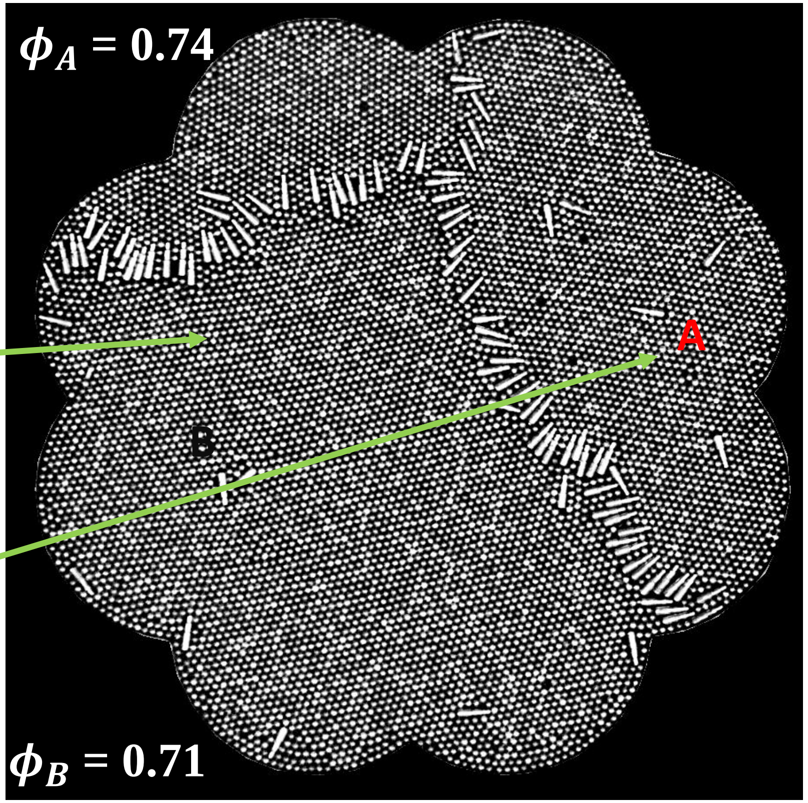


Fig. 1 Mean Square displacement of region A and region B.

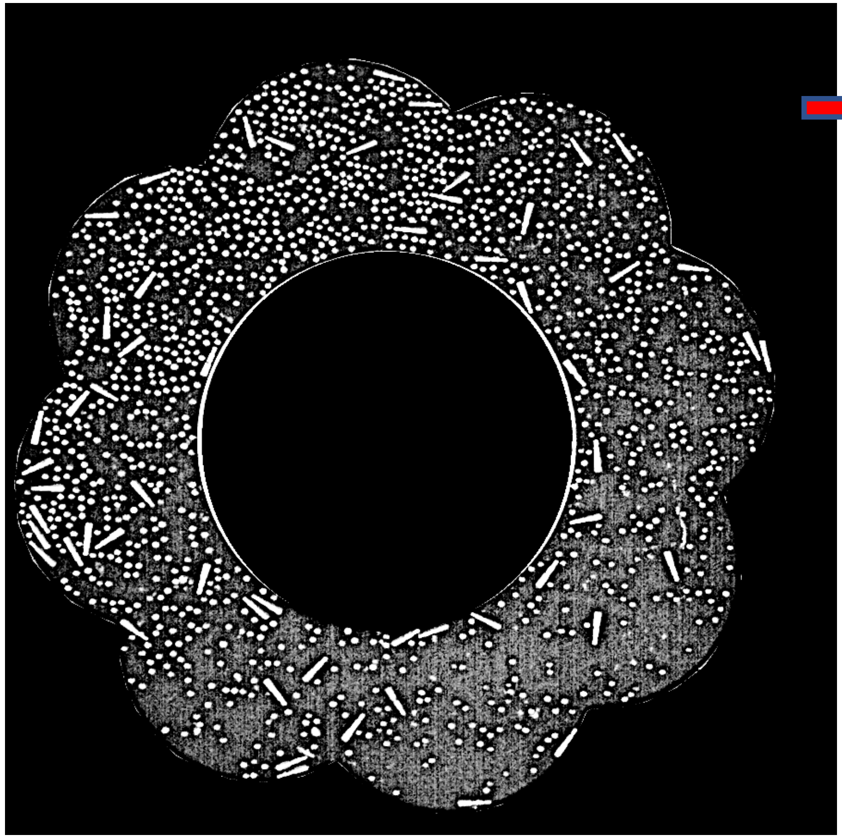


ϕ_b= 0.77, ϕ_r = 0.06

- Region A is less mobile and more denser than region B.

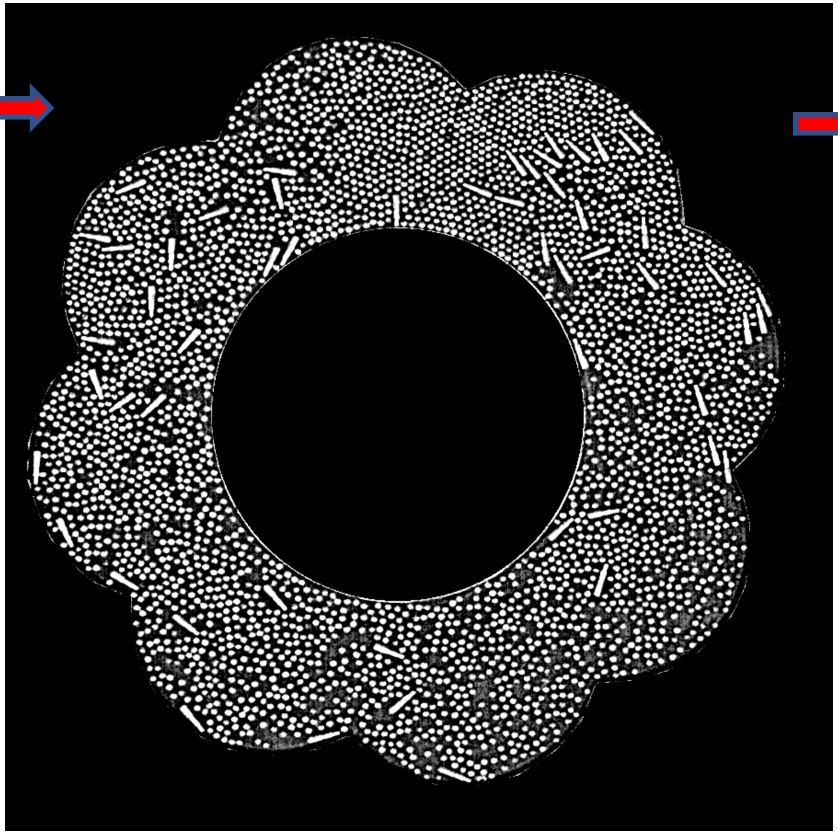
Quasi 1-D

Disordered



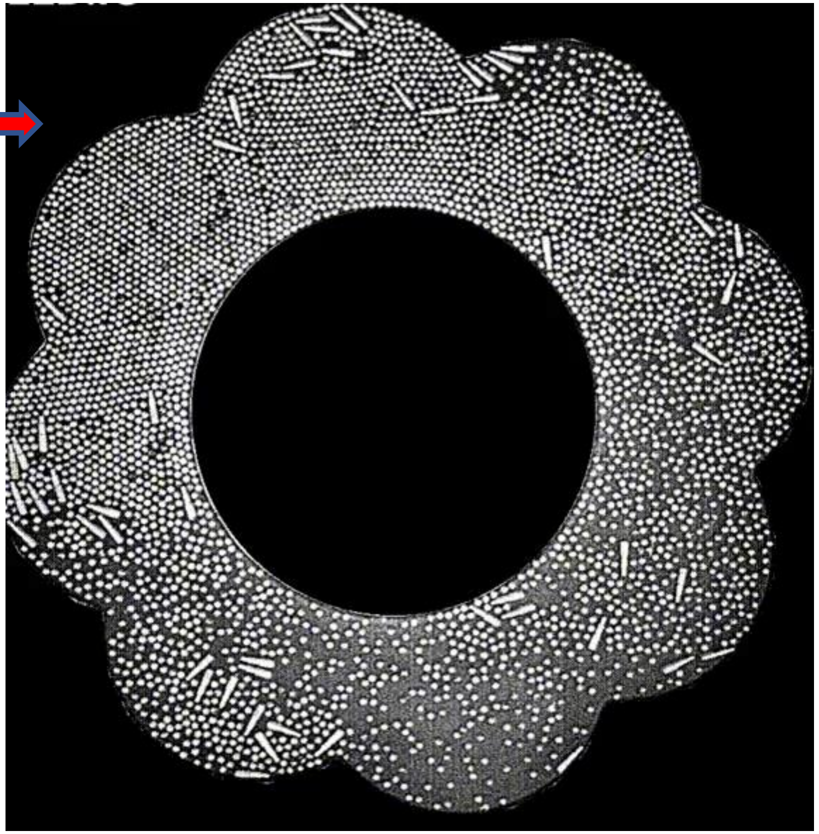
ϕ_b = 0.20, ϕ_r = 0.05

Flock



ϕ_b = 0.50, ϕ_r = 0.05

Segregated Phase (Self-trapping)

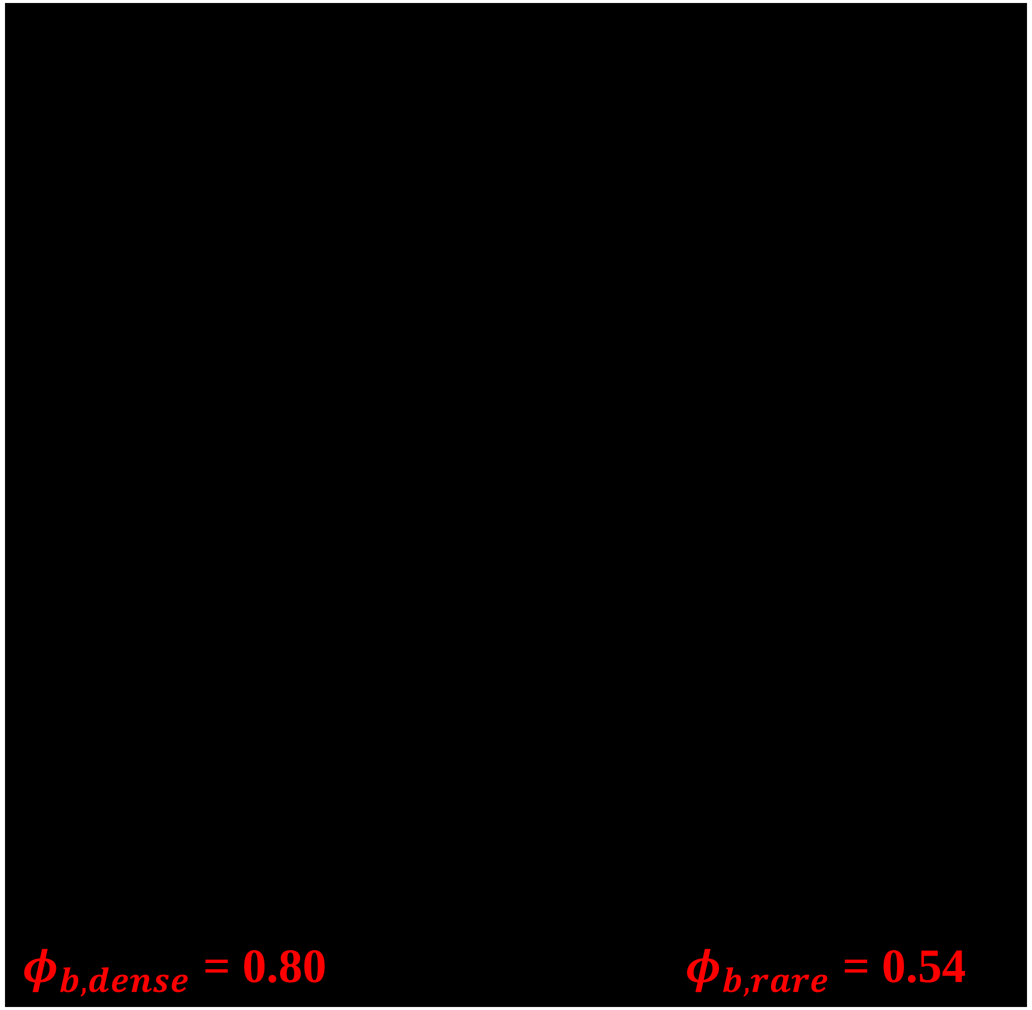


ϕ_b = 0.55, ϕ_r = 0.05

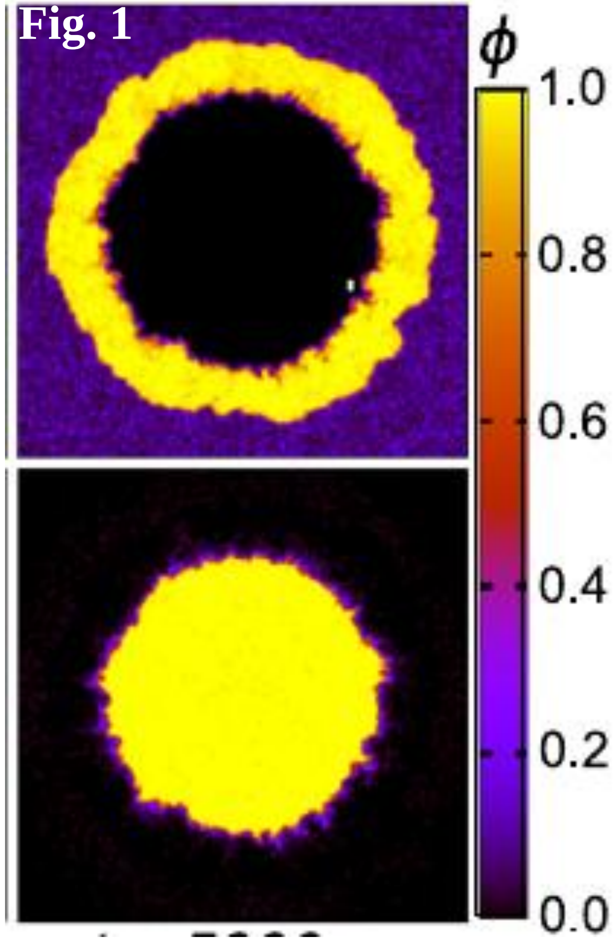
- Self-trapping in 2D ?

- Self trapping ~ **Core-halo**

- Role of alignment.



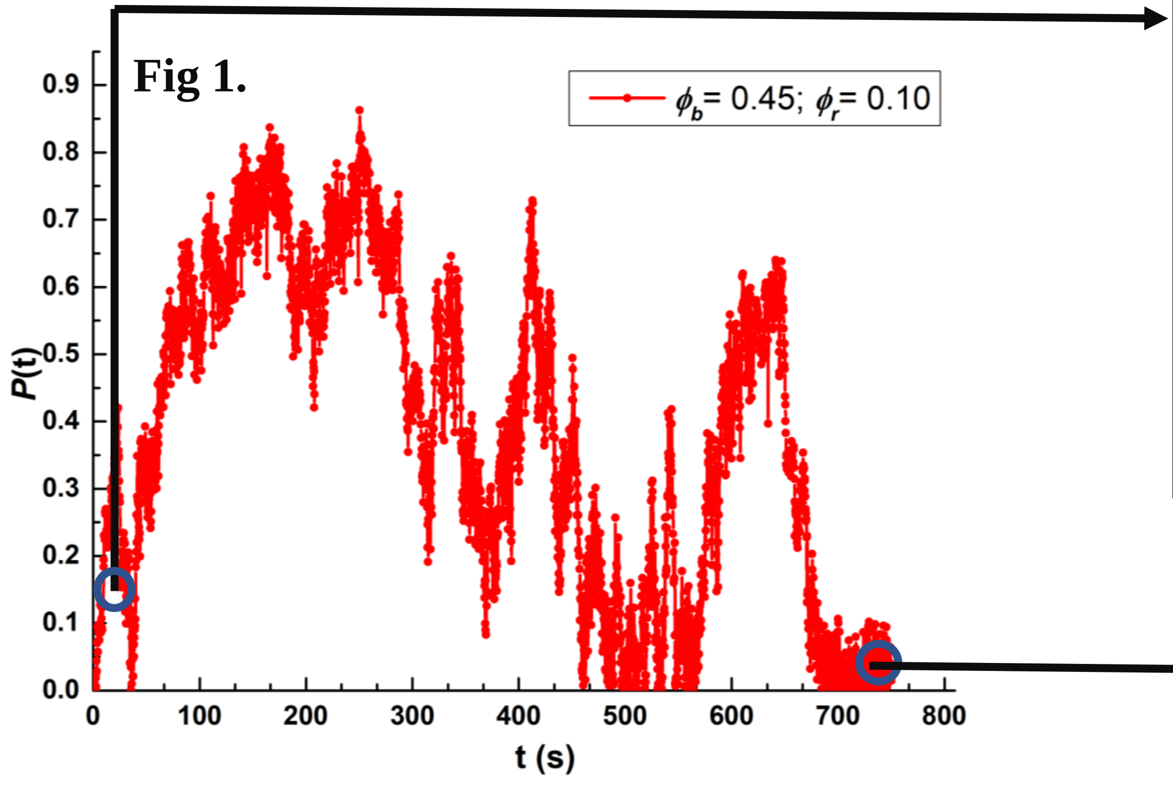
Immobile Segregated phase
ϕ_b = 0.50, ϕ_r = 0.05

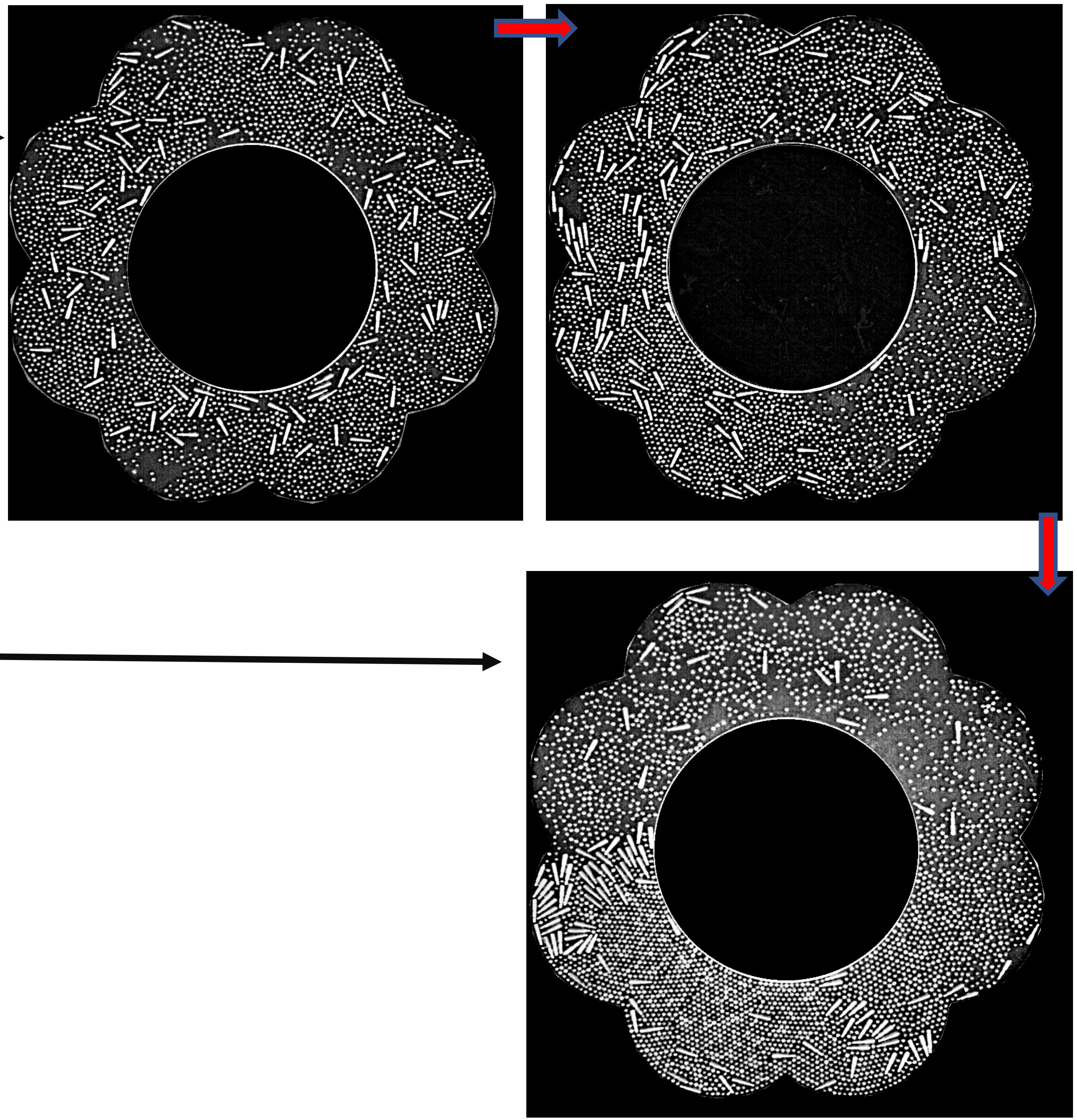


Core-halo condensation

Stenhammer et al., 2014

Kinetics of self-trapping

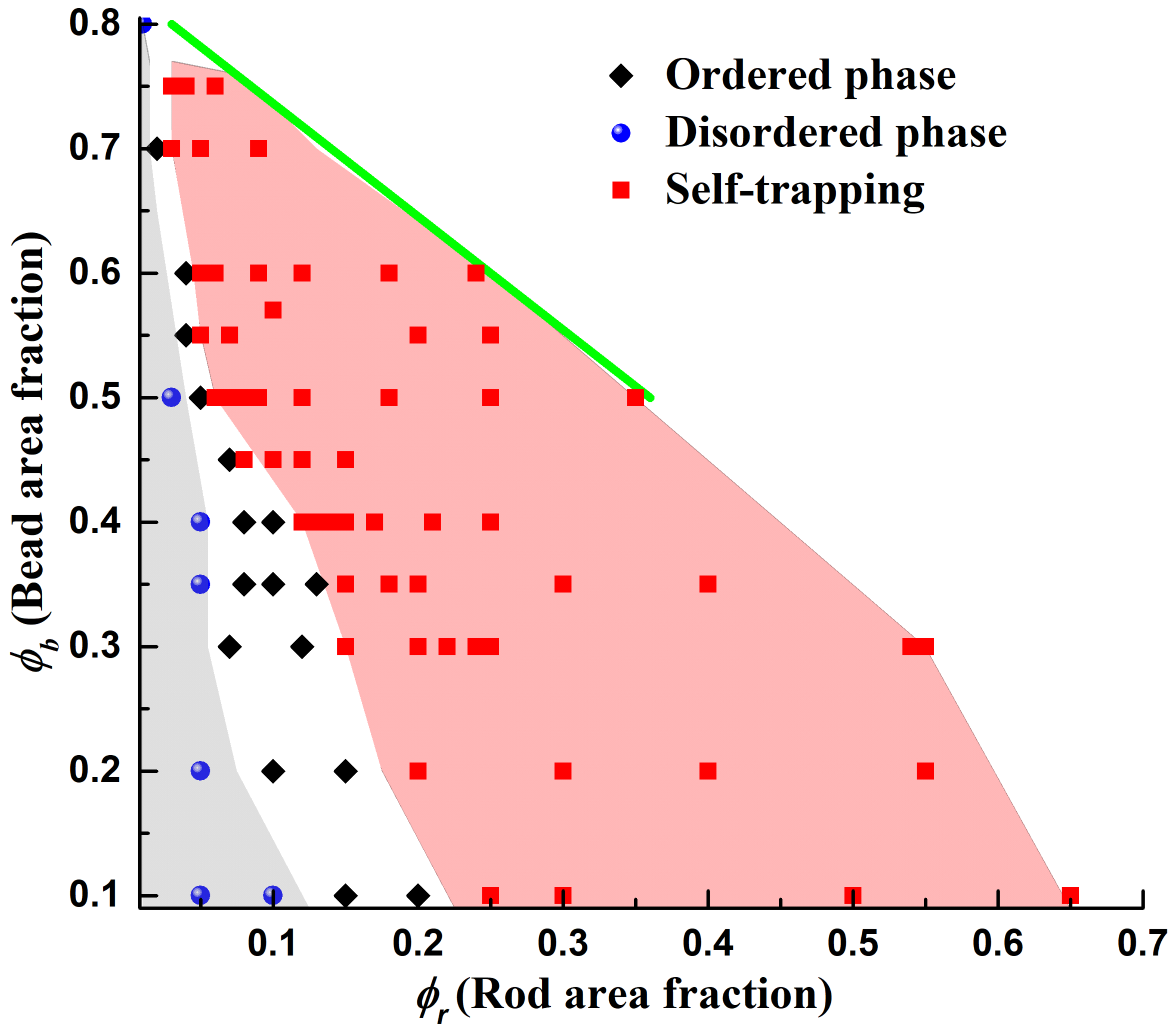




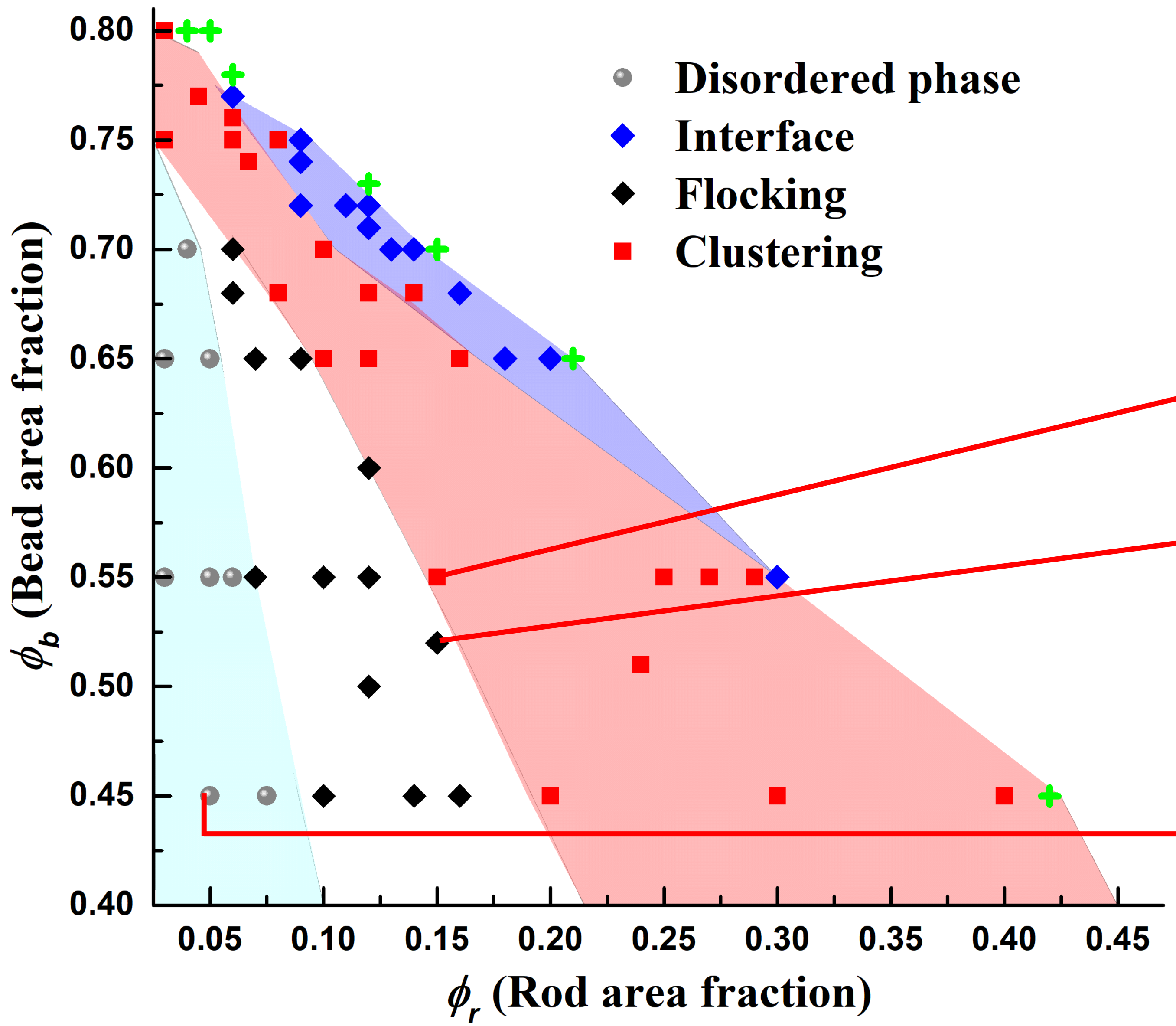
- **P = ⟨ $\boldsymbol{p_i}$ ⟩,** Order parameter
  $\boldsymbol{p_i} = \langle \widehat{\boldsymbol{n}}_i \times \hat{\boldsymbol{r}}_i \rangle$

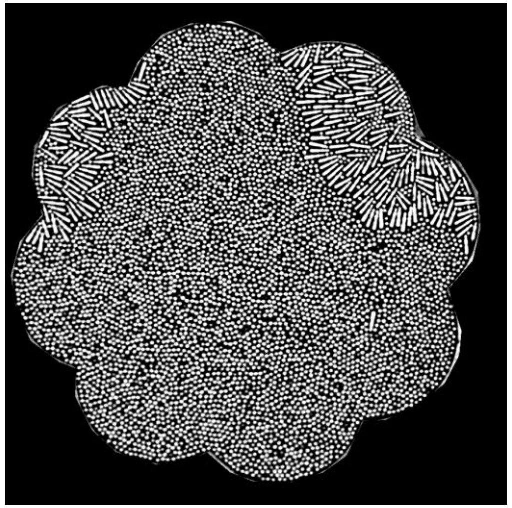
- **|P(t)|** can be used as to distinguish between ordered, disordered and self-jammed Phase

Phase diagram : Quasi 1-D

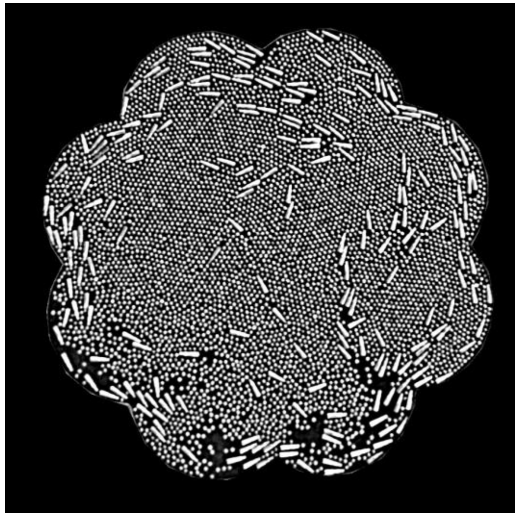


Phase diagram : 2-D

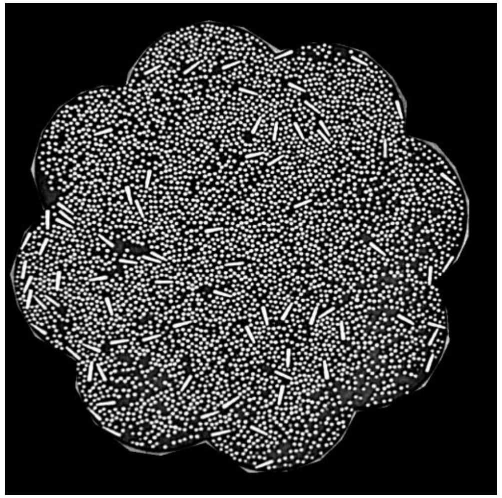




ϕ_b = 0.55, ϕ_r = 0.15



ϕ_b = 0.52, ϕ_r = 0.15



ϕ_b = 0.45, ϕ_r = 0.05

Results: Simulation

- Simulation detail

  - Random angular velocity after each collision with base and lid.

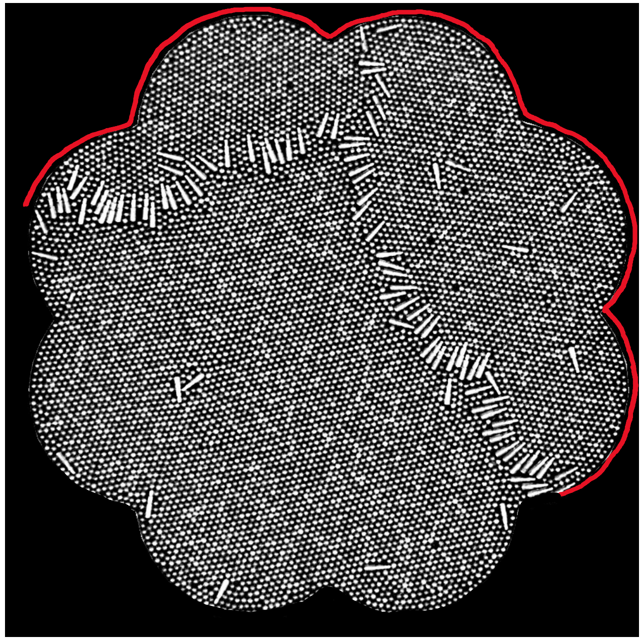
  - Impulse-Based collision model to calculate post collision velocities.

  - PBC, box size: 628 R
  (R = radius of the bead)

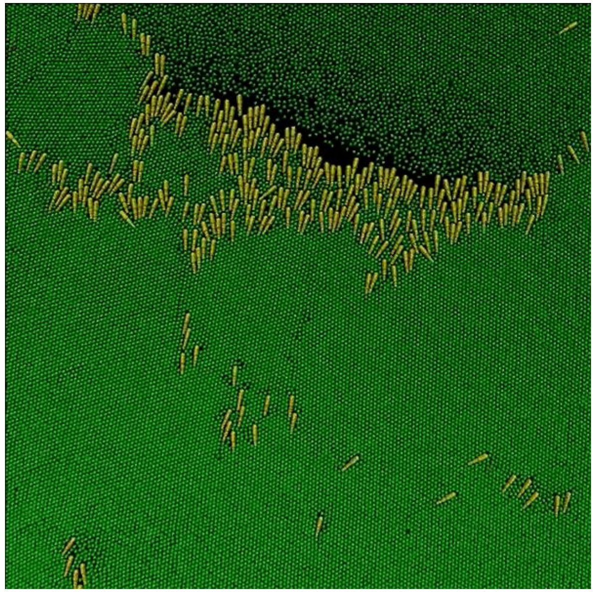
- Steady state

  - Moving segregated phase

- Core-halo ruled out in 2D
  -aligning rods enforce flat interface



ϕ_b = 0.77; ϕ_r = 0.06
(Experiment)

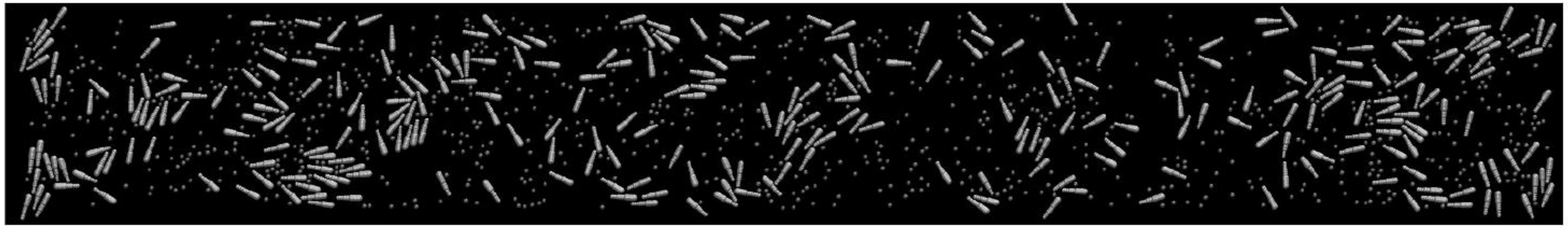


ϕ_b = 0.75 and ϕ_r = 0.07
(Simulation, periodic boundary condition)

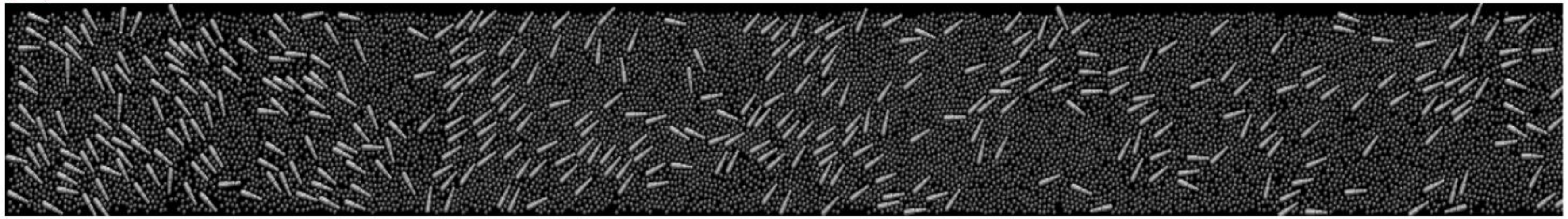
Results: Simulation

- Channel geometry

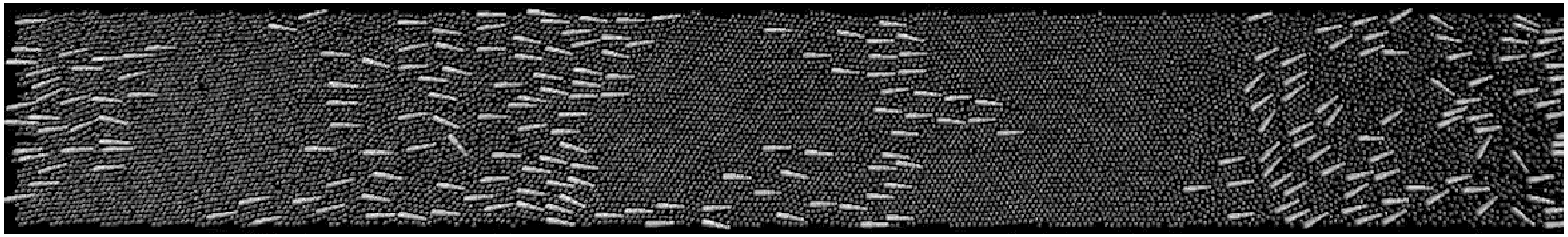
Disordered ϕ_b = 0.05, ϕ_r = 0.15



Ordered ϕ_b = 0.50, ϕ_r = 0.15



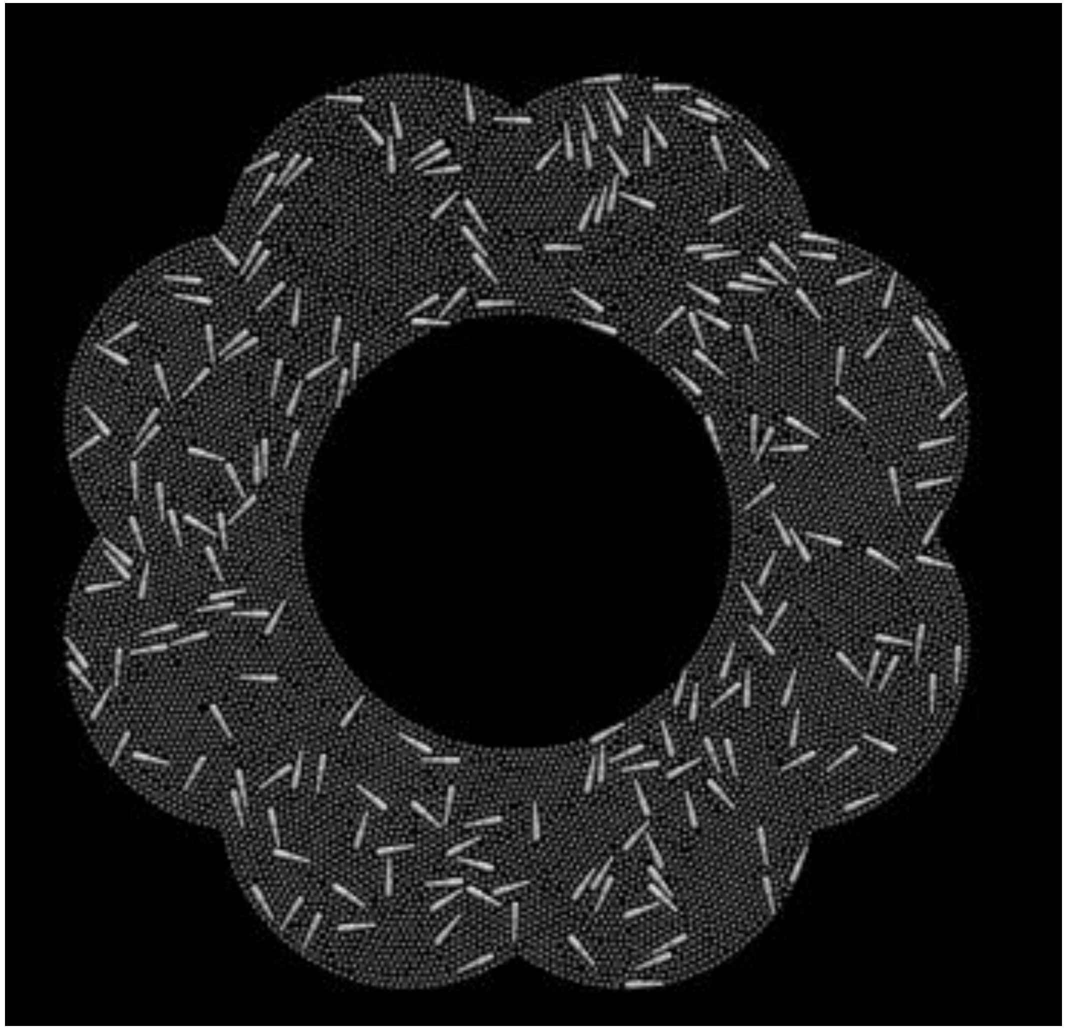
Segregated ϕ_b = 0.60, ϕ_r = 0.15



- Simulation box size
  Lx = 628 R; Ly = 78 R;
- PBC in xy-direction
- Moving segregated phase

Simulation: Quasi 1-D

ϕ_b = 0.60, ϕ_r = 0.15



Coarse-grained theory

- Rod density field and bead density field

    - Velocity of beads $\propto$ polar order parameter

- Aligning interaction of rods: work in polarised state
- Rods orientation drives bead motion
- Rods point from low to high bead density
- Results: linear instability to bead-rod segregation

Summary

- Experiment and simulation: Segregation in active rods and passive non-motile beads.

  - Very small fraction of rods can drive segregation
  - Interface state
  - Travelling segregating band in 2-D
  - Self trapping in quasi 1-D
  - Phase diagram

- Aligning interaction rules out core-halo condensation

- Coarse grained theory predicts segregation