Emergent Structures in Active Fluids of Self-Propelled Particles

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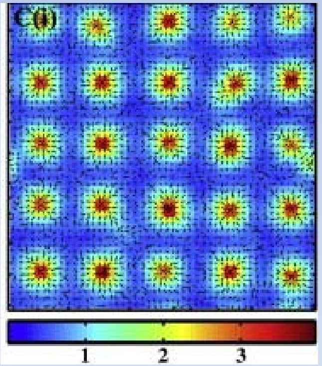
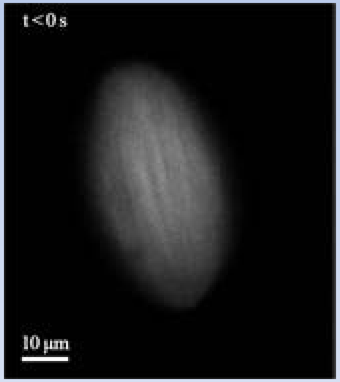
Active Processes in living and nonliving matter, KITP, Santa Barbara Feb 2014

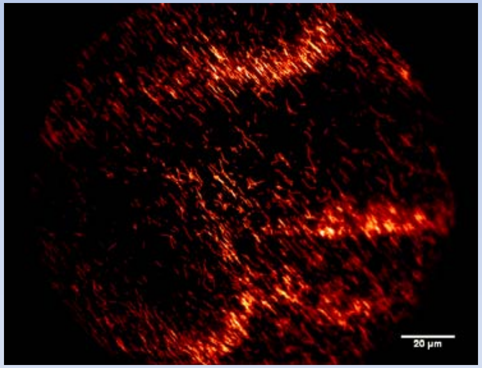
Introduction and Scope

- **Active Fluids** : Complex fluids that are driven out of equilibrium by energy input at the level of the individual units.
- Create and maintain spatial gradients at the macroscale

Examples :



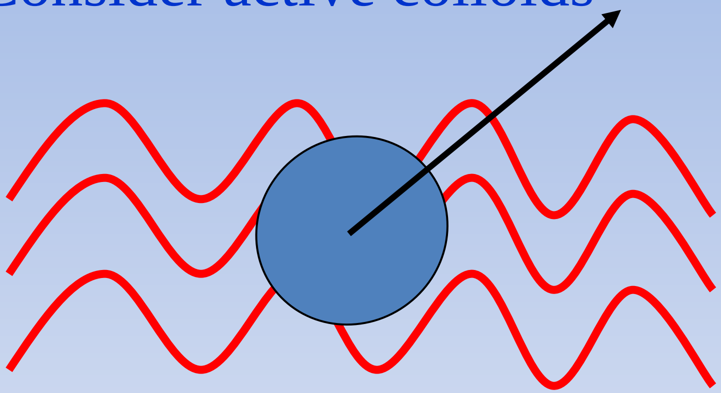




- Can we understand generic mechanisms from model systems?

Story 1: Active colloid

- Hard sphere colloids – Prototype for atoms and molecules
- Consider active colloids



$$\partial_t \mathbf{r} = v_0 \hat{\mathbf{u}} + \boldsymbol{\eta}$$

+ purely repulsive interactions

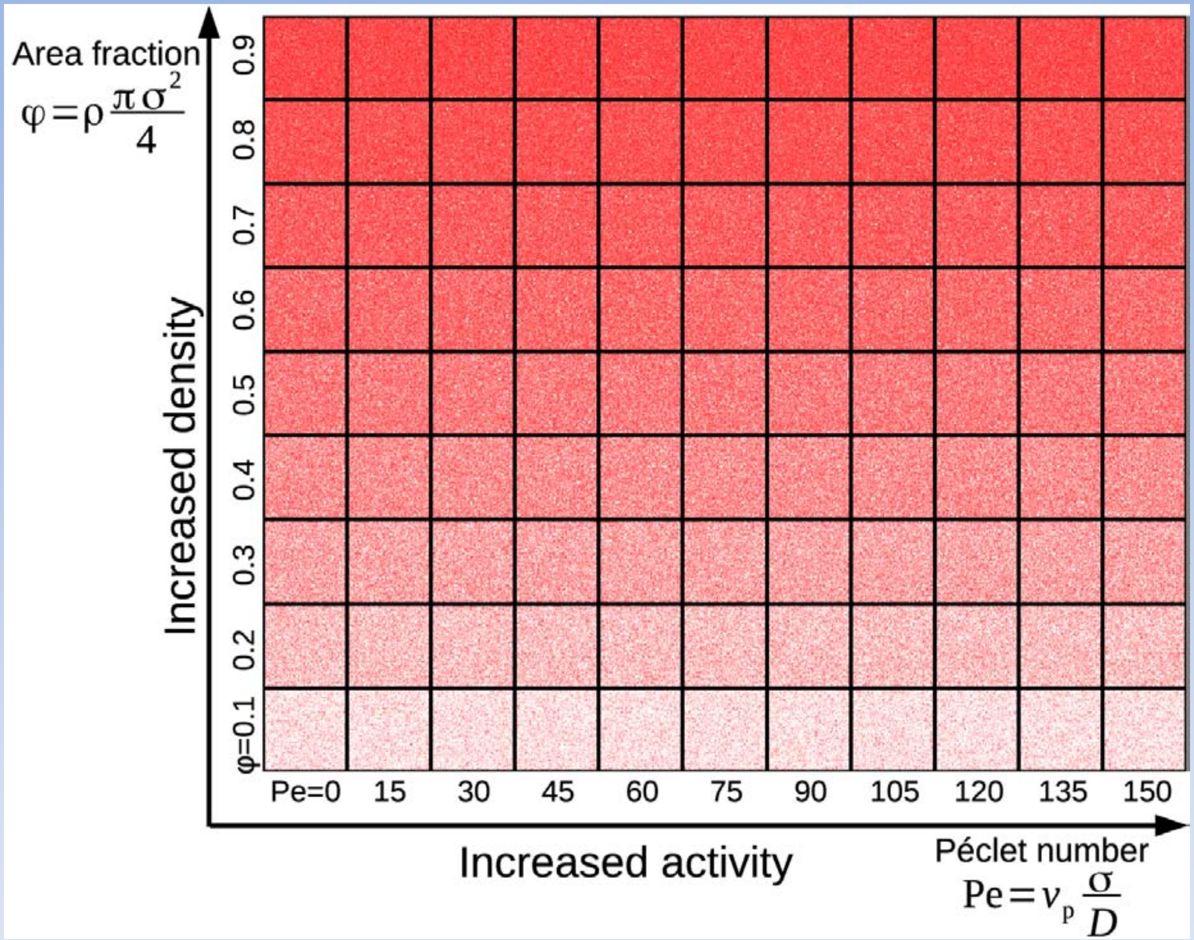
z

$$\partial_t \theta = \eta^R$$

$$\langle Z_i(t)\, Z_j(t')\rangle = \frac{v_0^2}{D_R}\delta_{ij} e^{-D_R|t-t'|} + D\delta_{ij}\delta(t-t')$$

$$\langle r^2(t)\rangle \to 2\left(D + \frac{v_0^2}{2D_R}\right)t$$

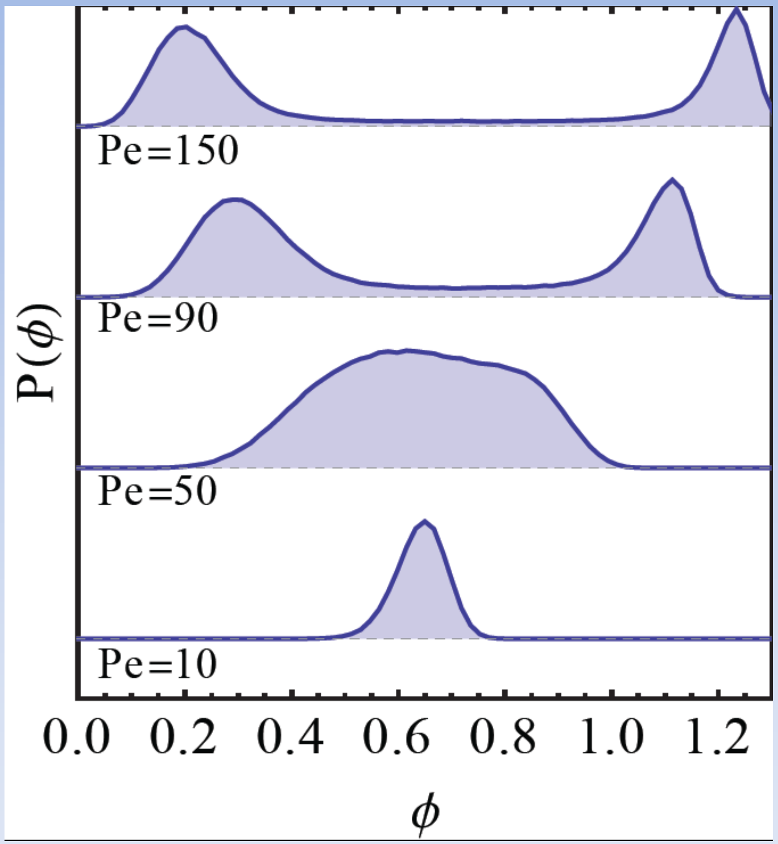
Story 1: Active colloid

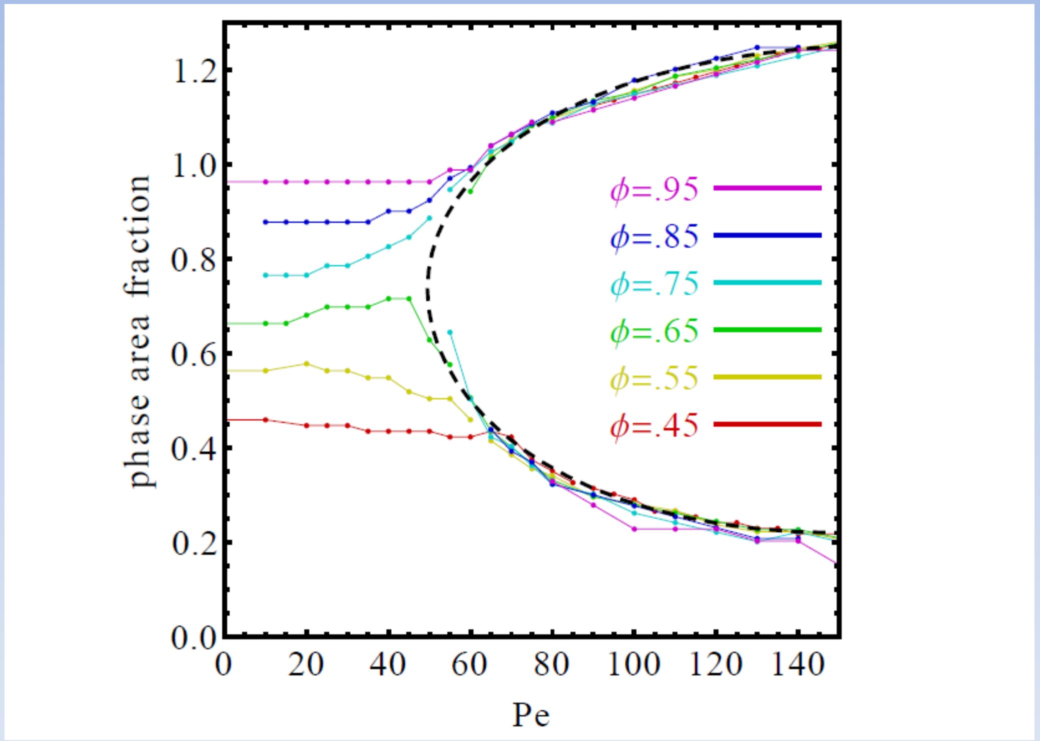


Movie

Story 1: Active colloid

Paradigm – Phase separation

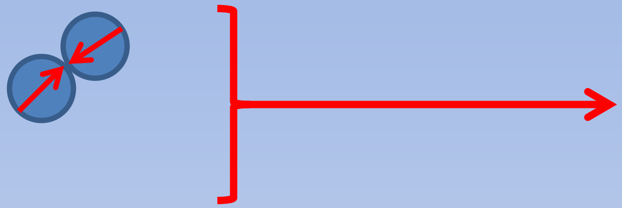




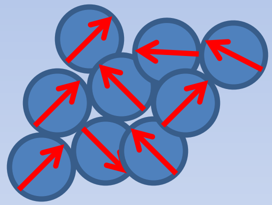
- Coarsening

Story 1: Active colloid

Mechanism – Self-propulsion acts as attraction



Duration of collision – 1/Dr



Threshold for onset of phase separation

$$\phi \sigma v_{\mathrm{p}} \sim D_{\mathrm{r}}.$$

Story 1: Active colloid

Phase separation :Tailleur and Cates “Self trapping”

$$\partial_t \rho = -\nabla \cdot \mathbf{J}$$

$$\mathbf{J} = -D(\rho)\nabla\rho - D(\rho)\nabla\mu_{ex}$$

$$D(\rho) = \frac{v^2(\rho)}{D_R}$$

$$\mu_{ex} = \log v(\rho)$$

Story 1: Active colloid

- Francesco Alarcon
- Jure Dobniker
- Yaouen Fily
- Gerhard Gompper
- Silke Henkes
- Lisa Manning
- Cristina Marchetti
- Ignacio Pagonabarraga
- Gabriel Redner
- Joakim Stenhammer
- Julien Tailleur
- Chantal Valeriani
- Xingbo Yang

Story 2: Self-propelled rods and segregation

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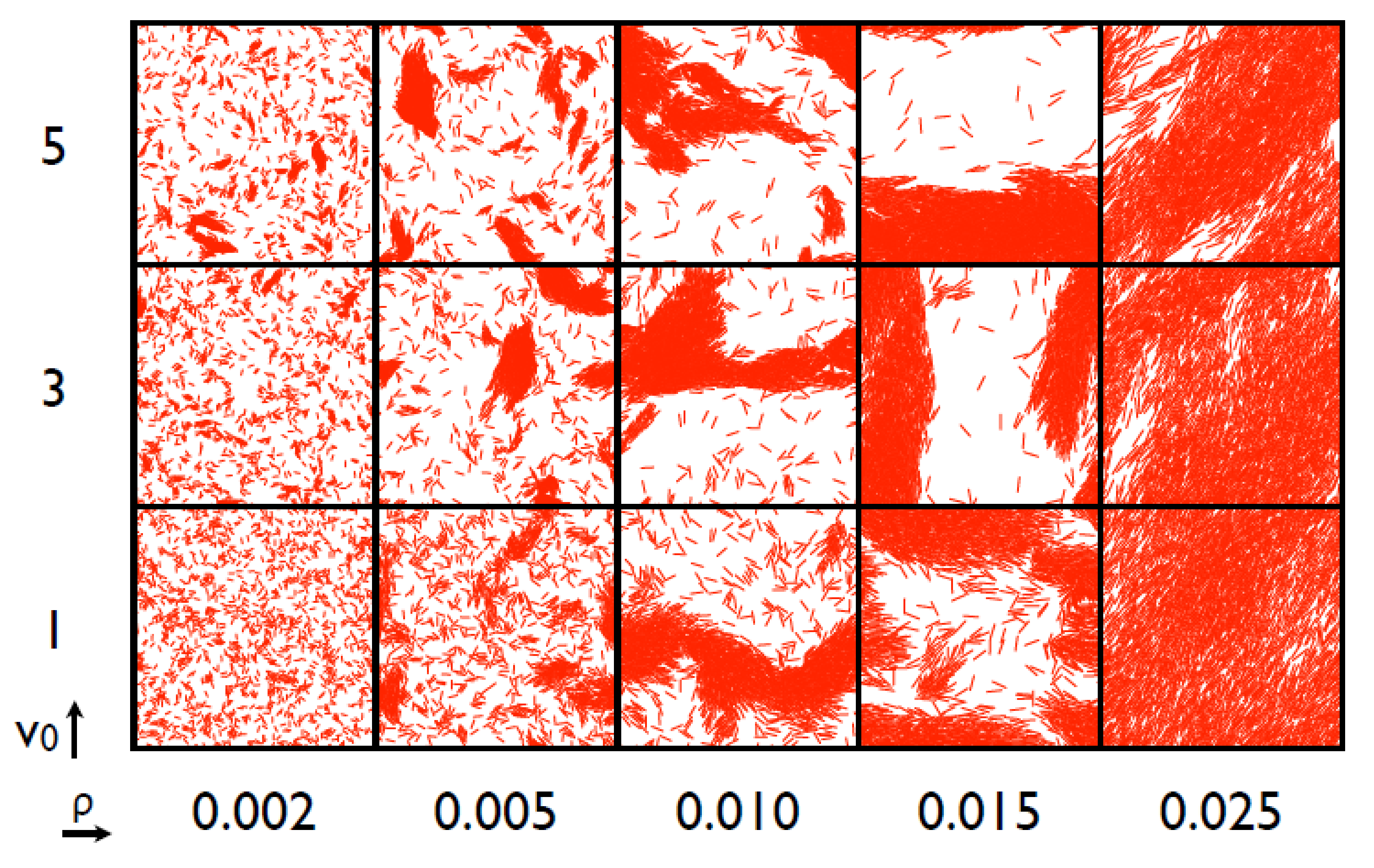
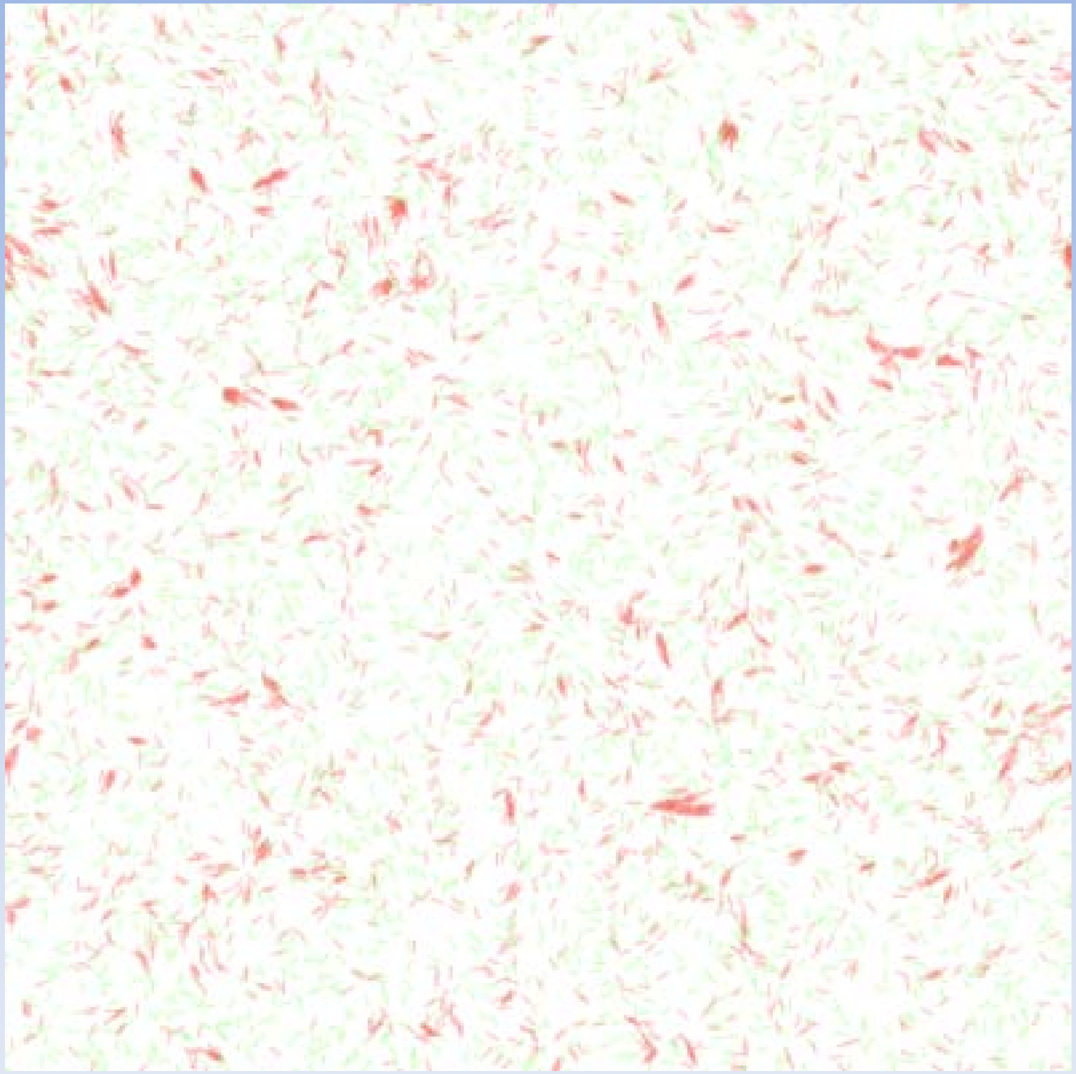
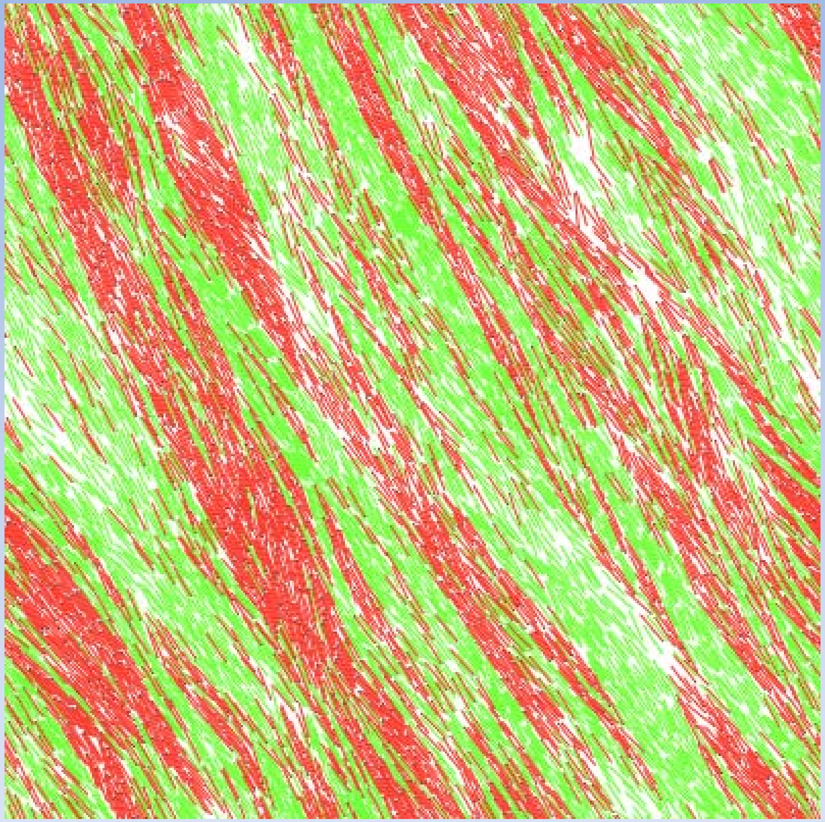
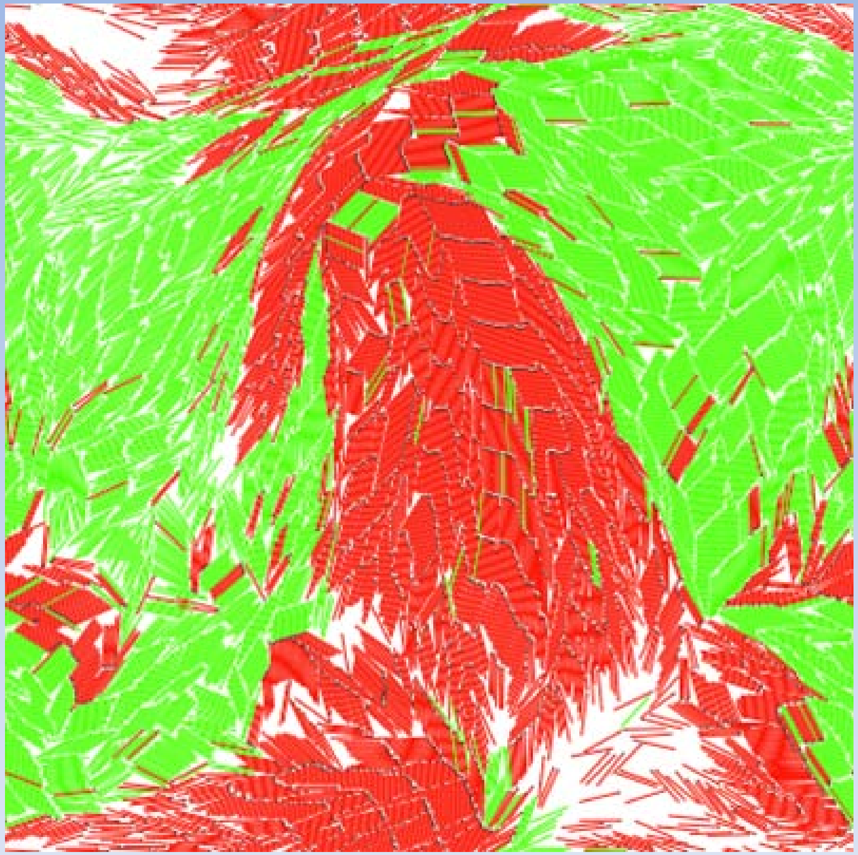


Story 2: Self-propelled rods and segregation



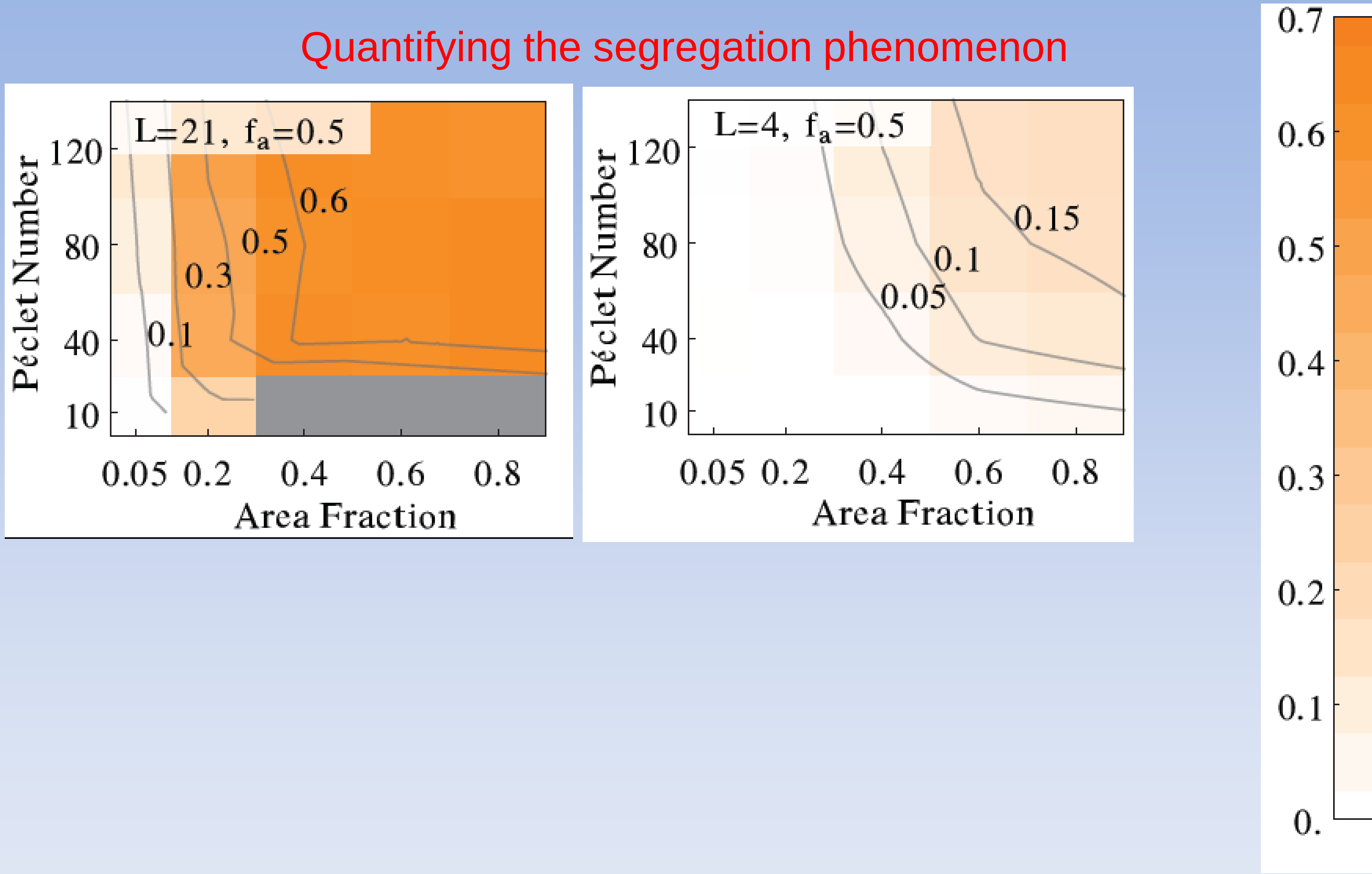
Story 2: Self-propelled rods and segregation





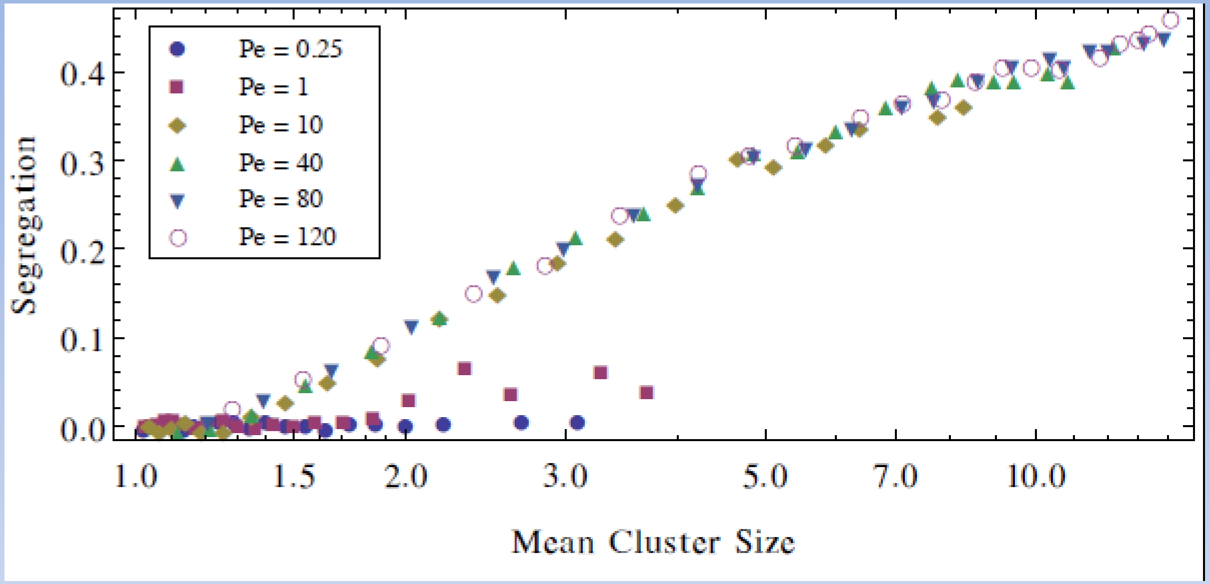
Story 2: Self-propelled rods and segregation

Quantifying the segregation phenomenon



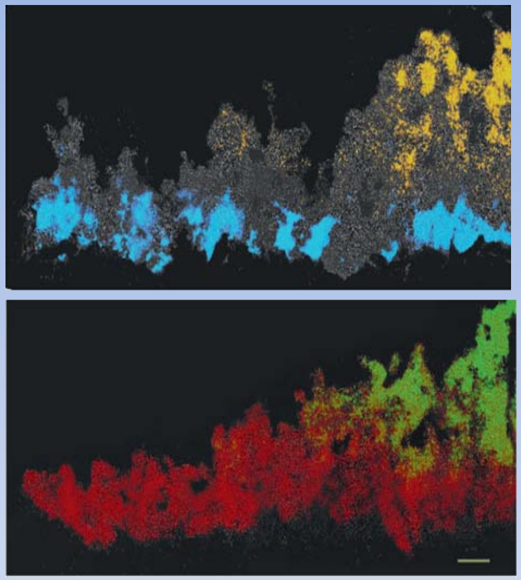
Story 2: Self-propelled rods and segregation

Quantifying the segregation phenomenon

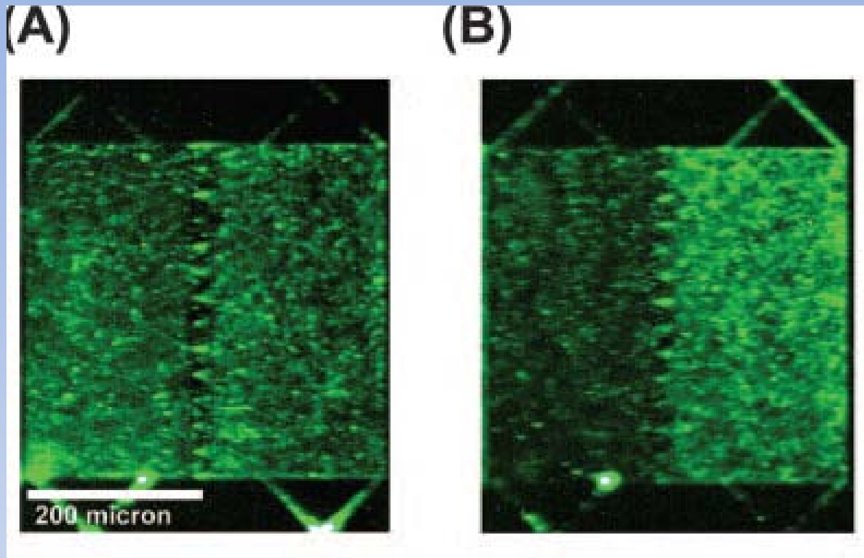


- Clustering and segregation are correlated
- In detail – positive feedback between the two processes

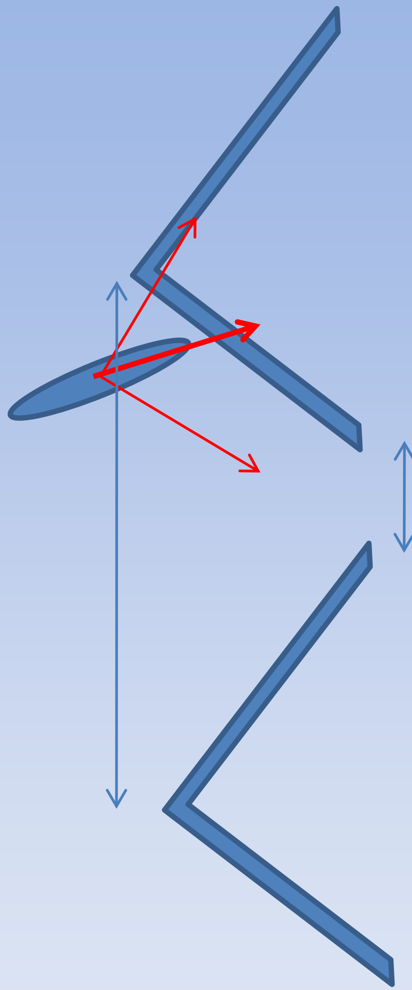
Story 2: Self-propelled rods and segregation



Story 3: Brief Remarks on Confinement



$$\frac{l}{v_0} << \frac{1}{D_R}$$



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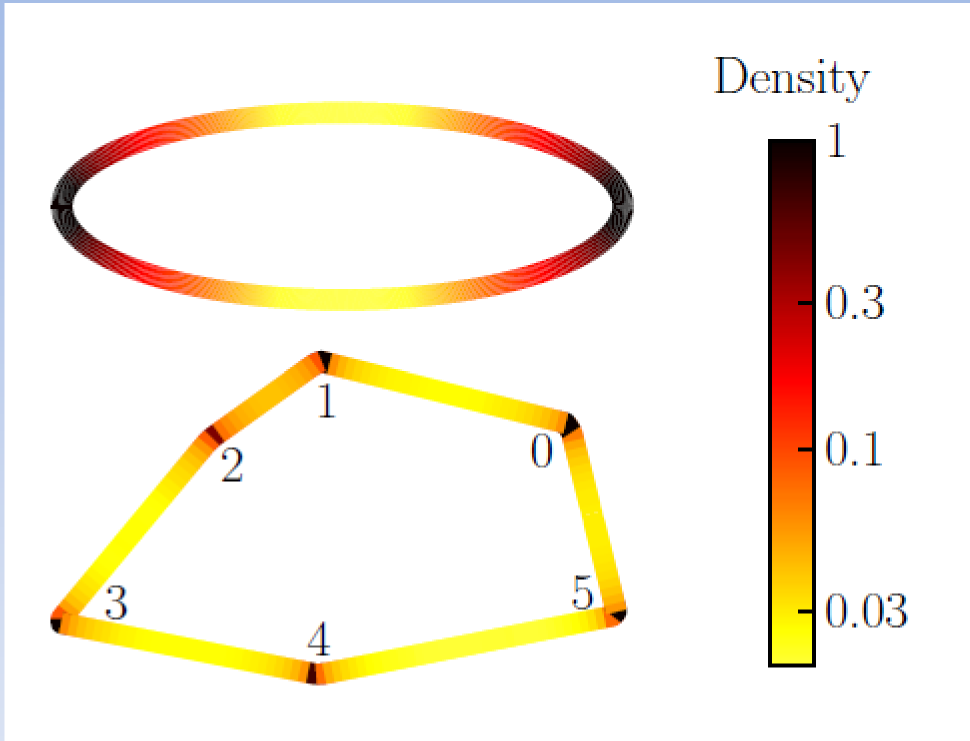


Scope of today's talk

- Self-propulsion has an intrinsic correlation time 1/Dr
- When this is probed by collision frequency – clustering, phase separation, segregation
- When probed by walls – rectification, accumulation

Students

Gabe Redner

Sam McCandlish

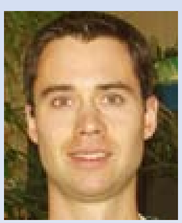
Elias Putzig

McCandlish et al Soft Matter 2012

Redner et al Phys Rev Lett 2013

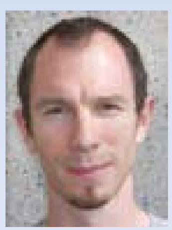
Redner et al Phys Rev E 2013

Collaborator



Mike Hagan

Post Doc



Yaouen Fily

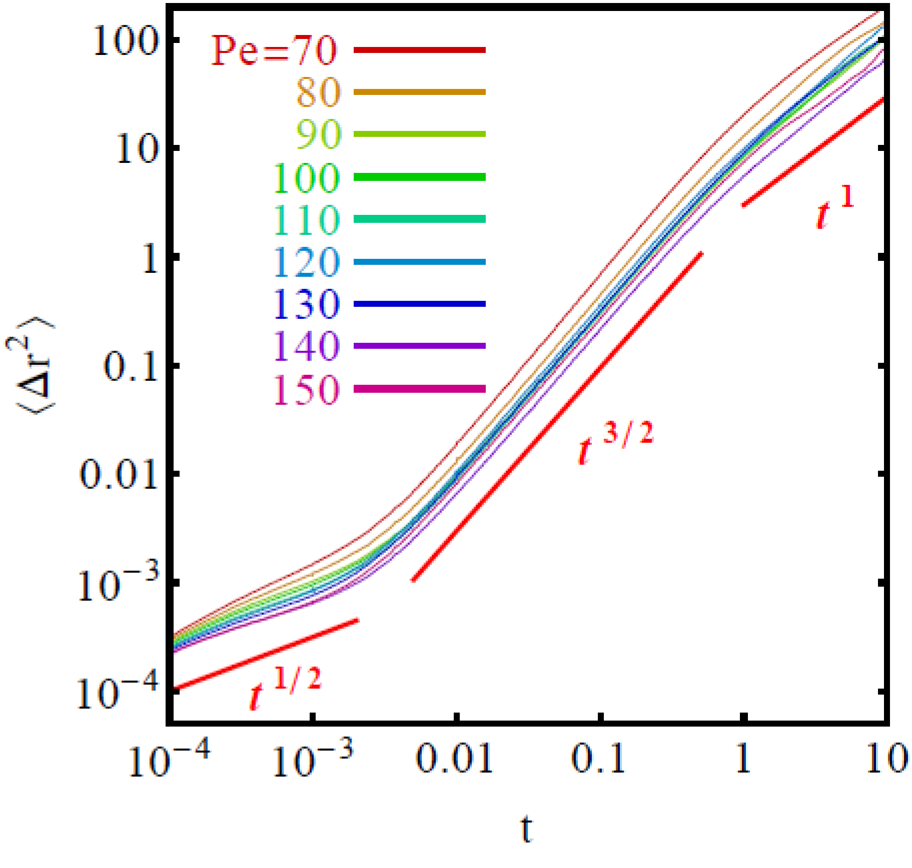
Story 1: Active colloid

Properties of the clump :

- Crystal like – defects
- Heterogeneous stresses
- Super - Diffusive transport
- Real Attractive interactions?

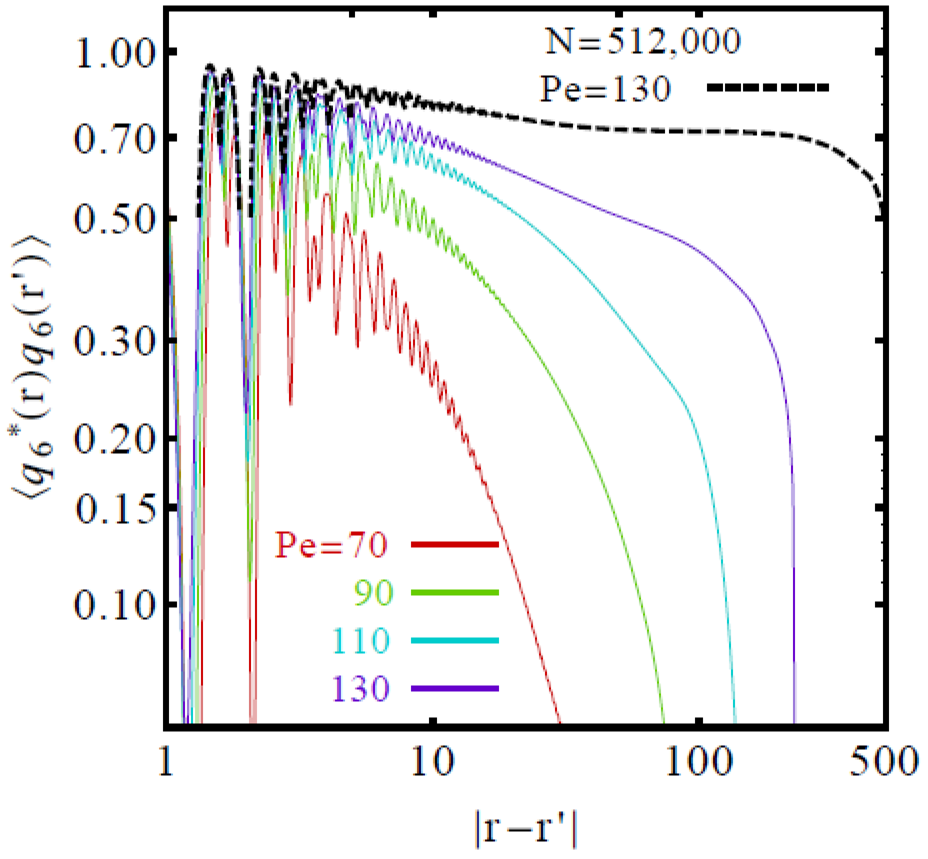
Dynamics

Mean-square displacement



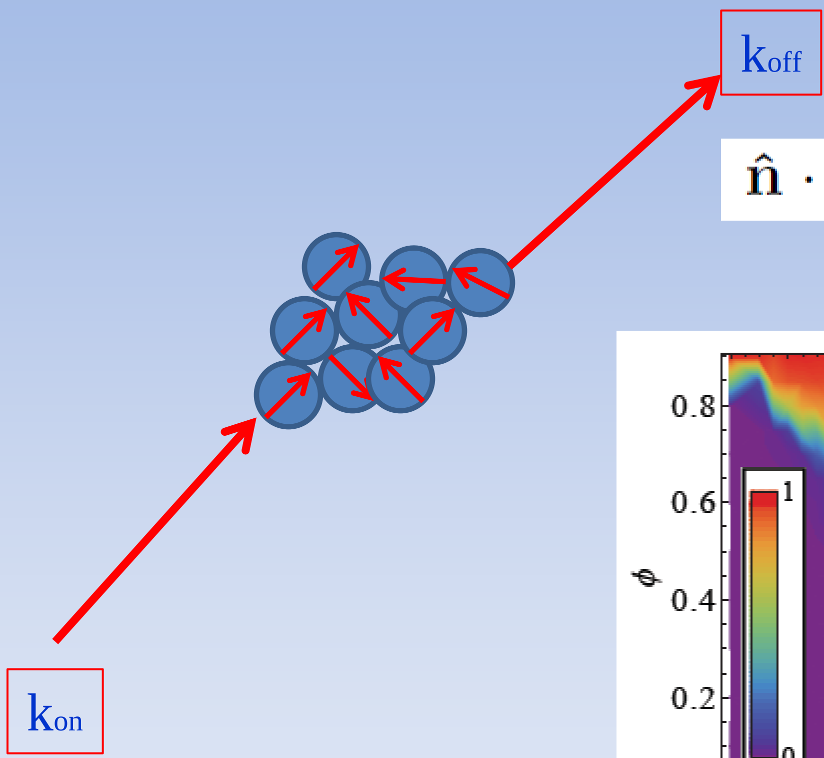
Structure

q_6 correlation function

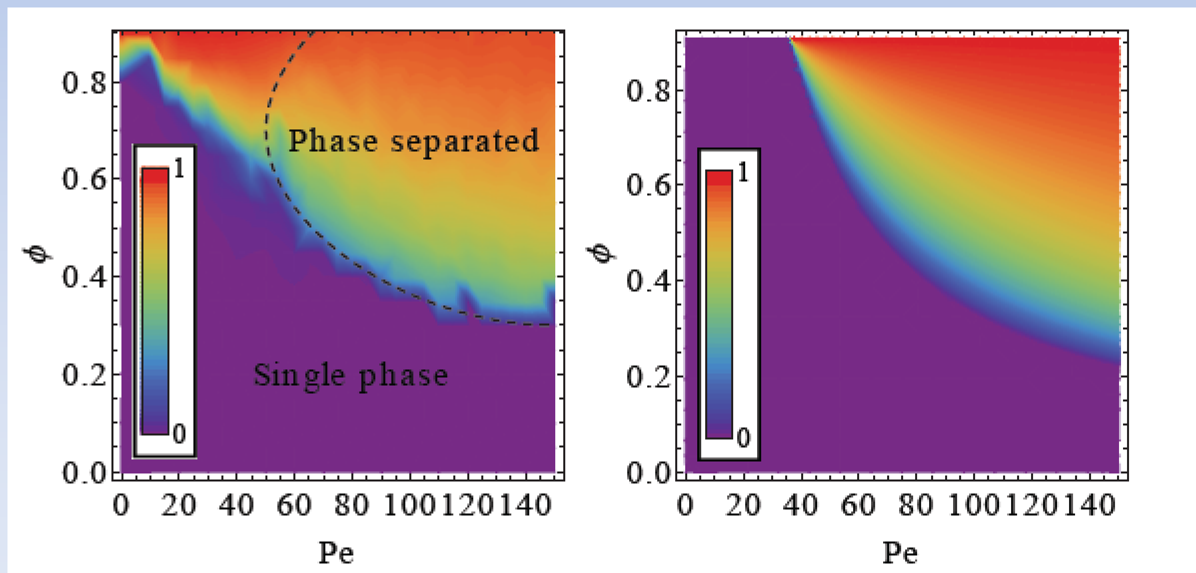


Story 1: Active colloid

Phase separated steady state : Kinetic model



$$\hat{n} \cdot \hat{\nu} < 0,$$



Part 2 - Microdynamics

Quantifying the segregation phenomenon

Define an order parameter as follows :

$$\sigma_a(b) = \frac{1}{2f_a(1-f_a)} \sum_i \left(\frac{n_i}{n_{tot}}\right) |f_i - f_a|$$