Final MOTIMO workshop, Collective dynamics of active particles, swimmers, motile cells,
September 22-23, 2015, Institut de Mecanique des Fluides de Toulouse (IMFT).

Floaters on Faraday waves: Clustering and heterogeneous flow

@CeydaSanli

September 23, 2015, Toulouse.

CompleXity Networks

UNamur

naxys

Namur Center for Complex Systems

Physics of Fluids

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Greetings, …

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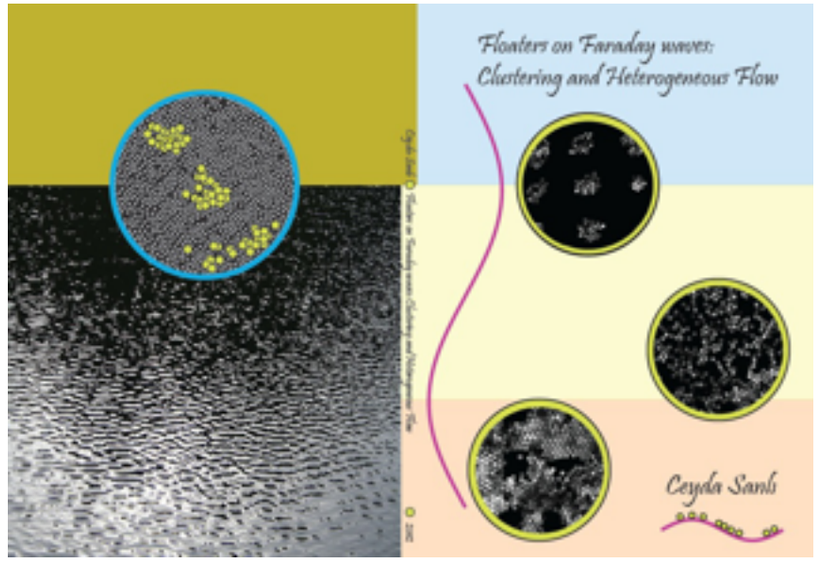

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Two Directions of my PhD Thesis:

- Clustering on **standing** Faraday waves

- C. Sanlı *et al*,
  Phys. Rev. E **89**, 053011 (2014).

- Heterogeneous flow on **capillary** Faraday waves

- C. Sanlı *et al*,
  Phys. Rev. E **90**, 033018 (2014).

Observation

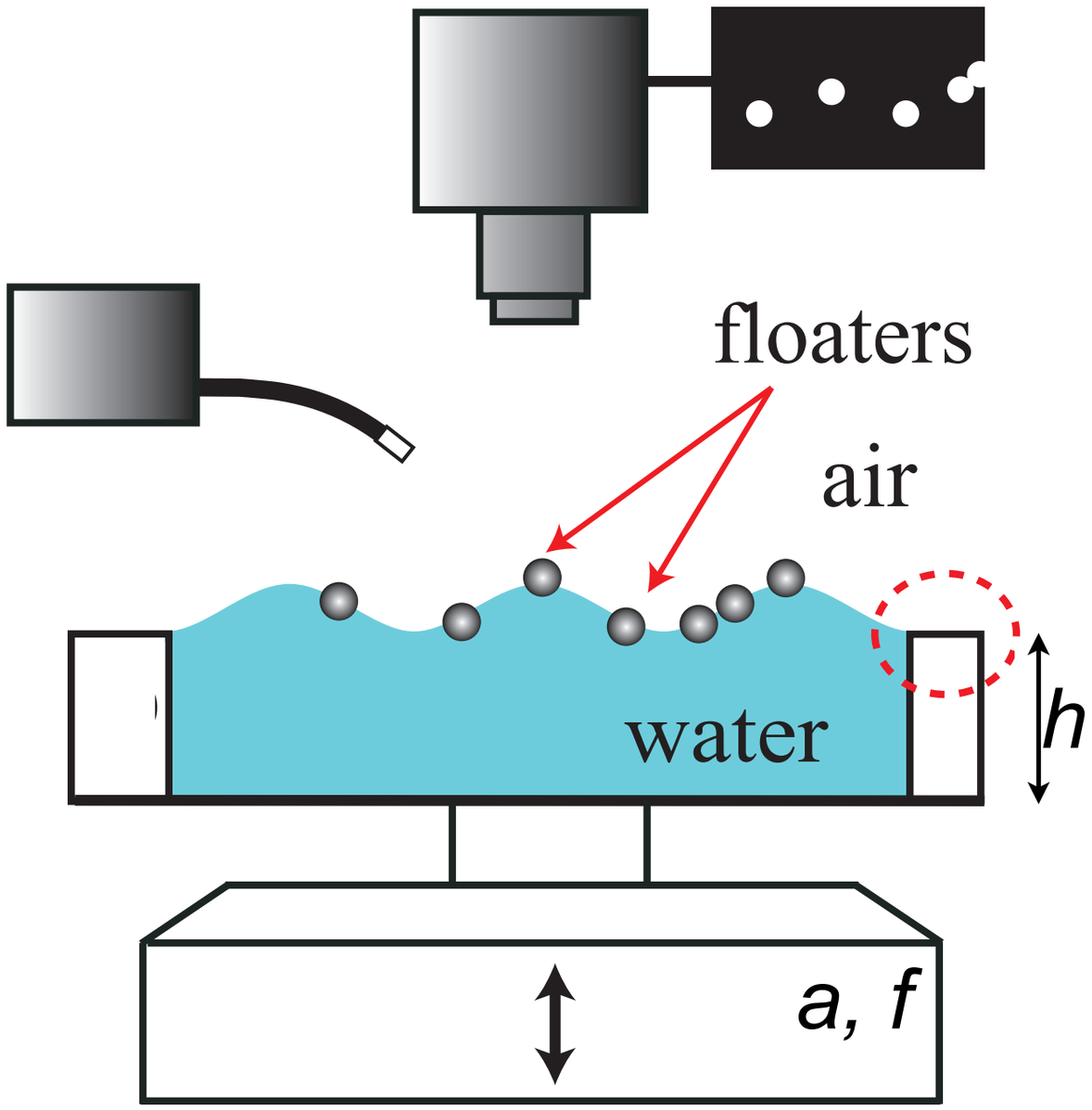
- low ϕ:

- a ~ 0.8 mm
- f = 19 Hz

- high ϕ:

- a ~ 1.2 mm
- f = 20 Hz

Experimental set-up

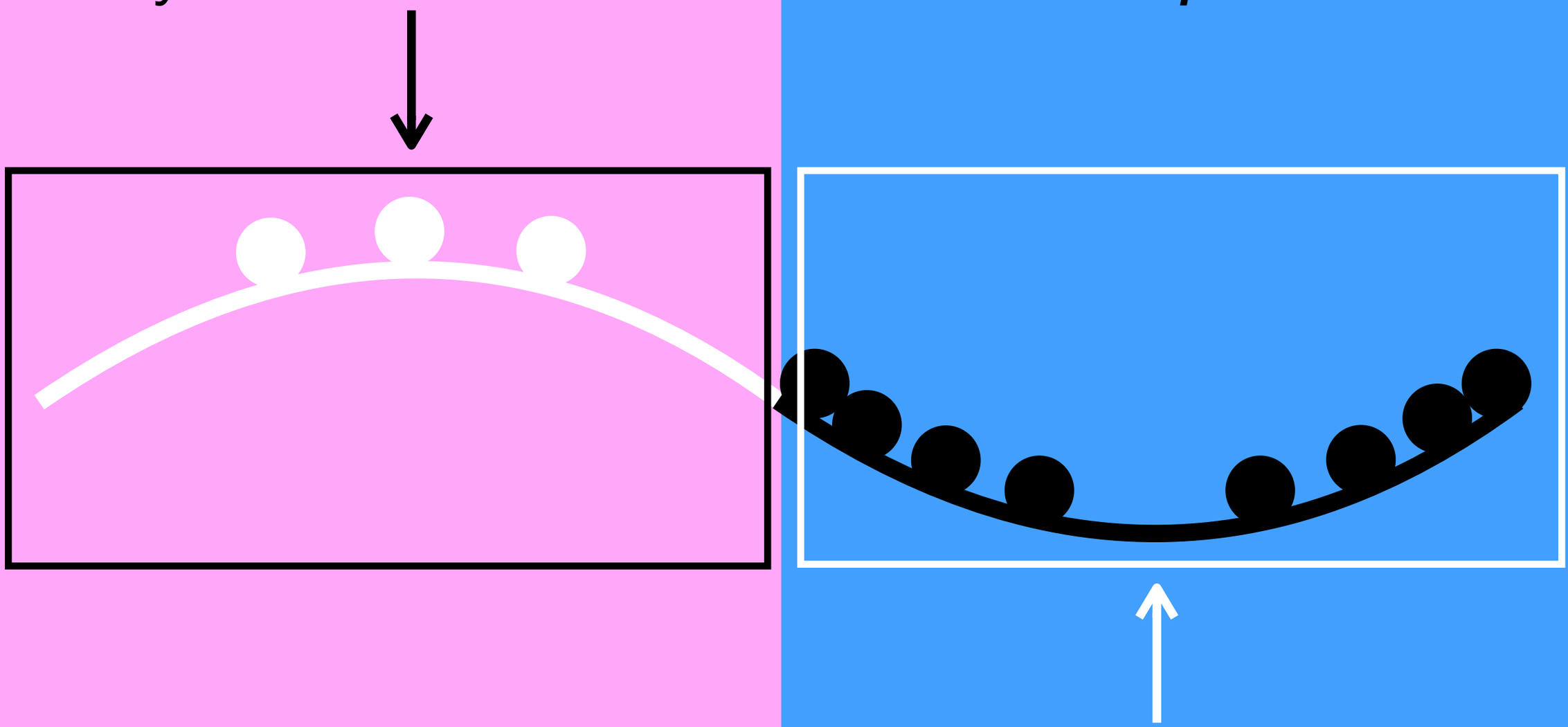


- Control parameters
  - θ: contact angle of spheres
  - R: radius of spheres
  - a: shaking amplitude
  - f: shaking frequency
  - h: depth of water layer
  - ϕ: area fraction

ϕ =bead area/total area

Part-1:

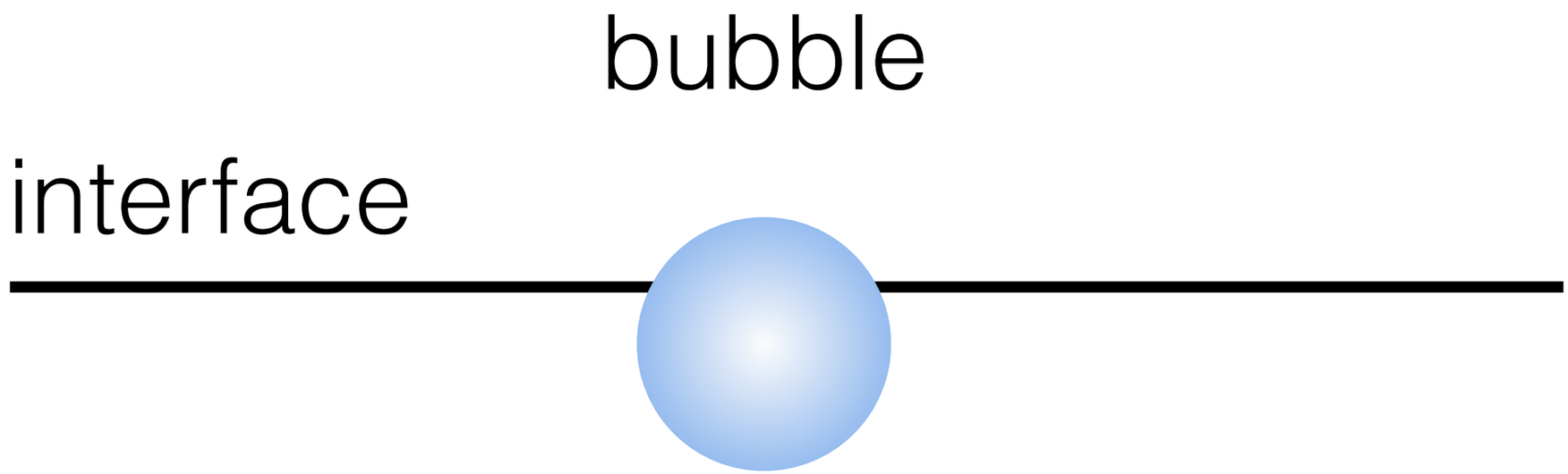
- Why the antinode clusters at low ϕ ?



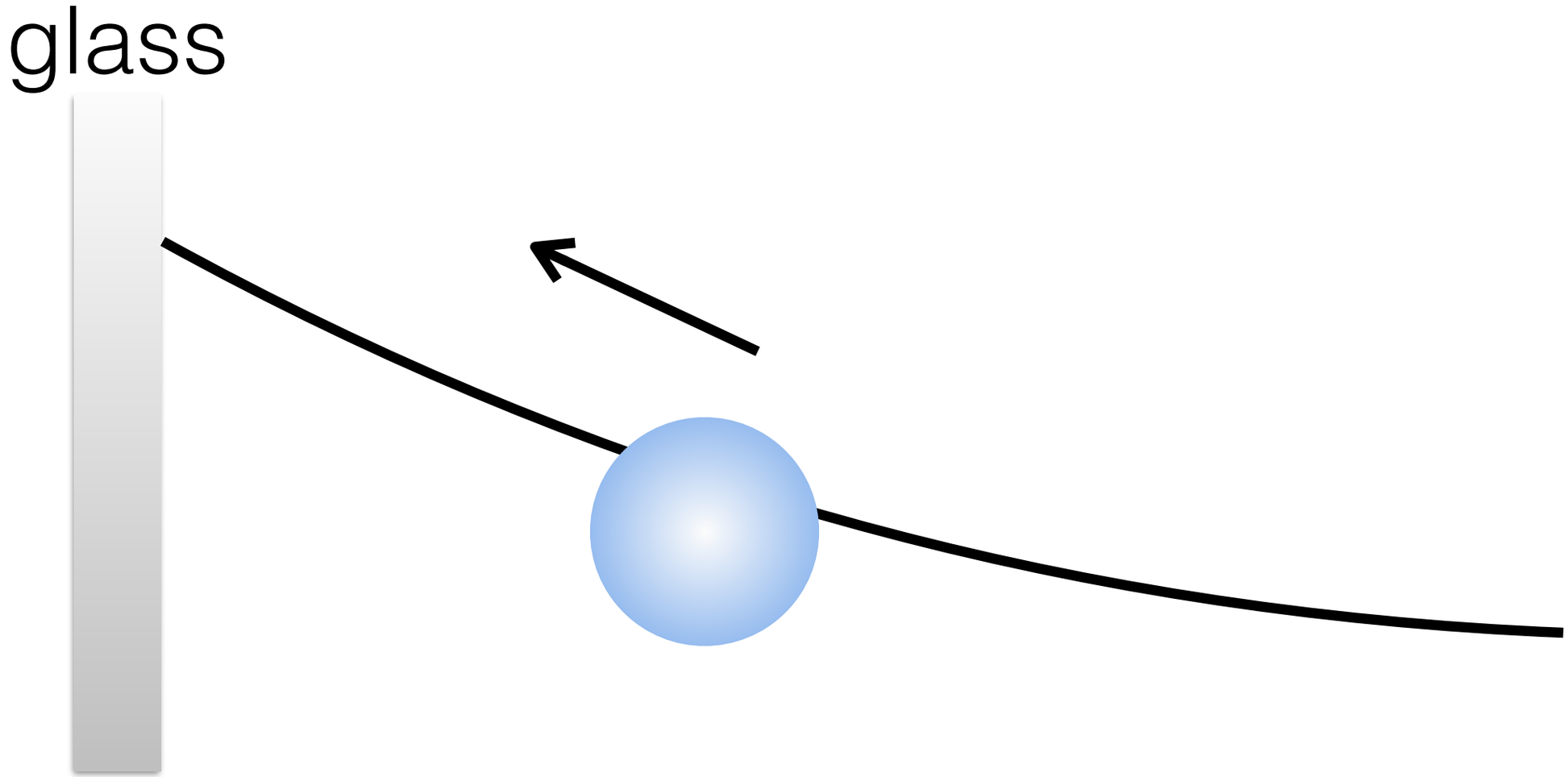
- Why the node clusters at high ϕ ?

Floaters on a static surface

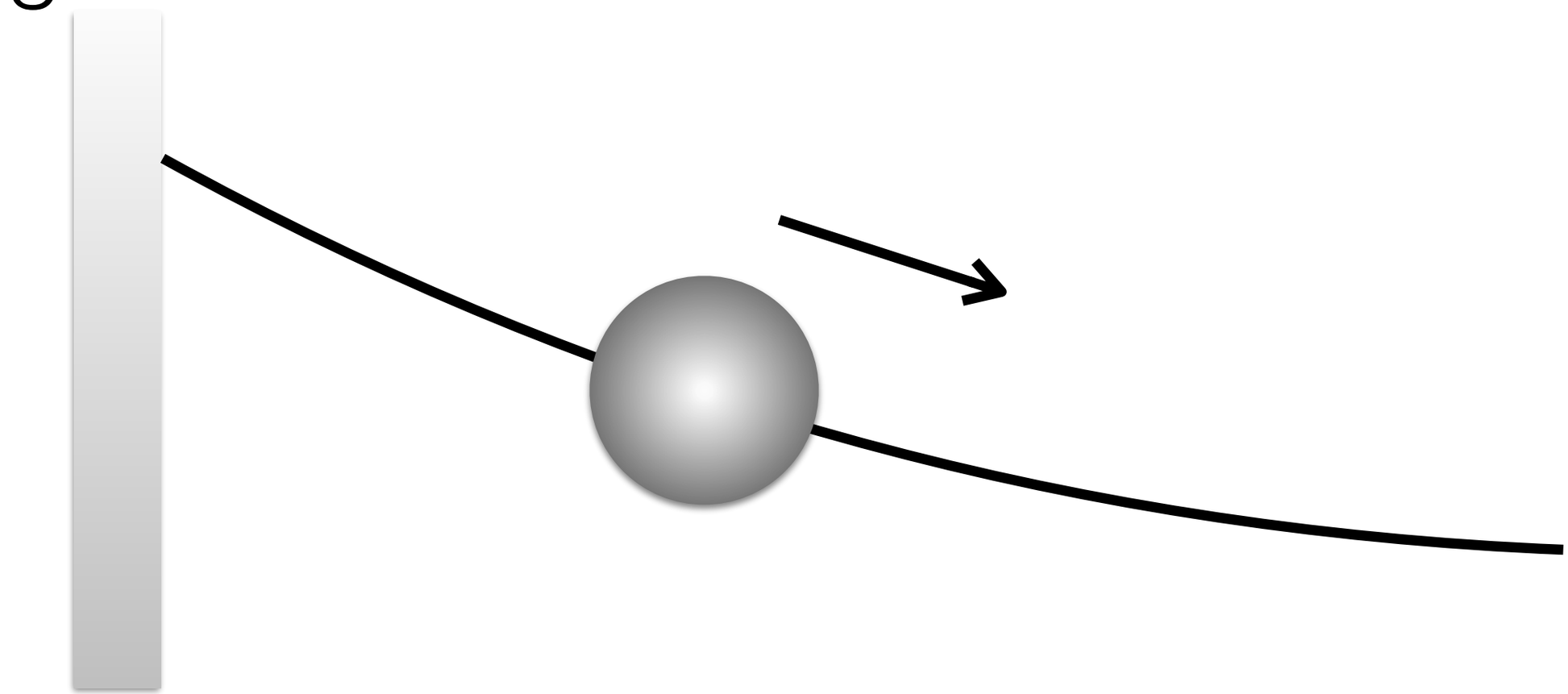
Bubble in an equilibrium



Bubble in a curved interface

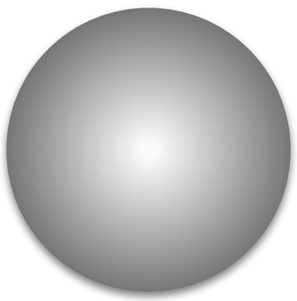


Heavy particle in a curved interface



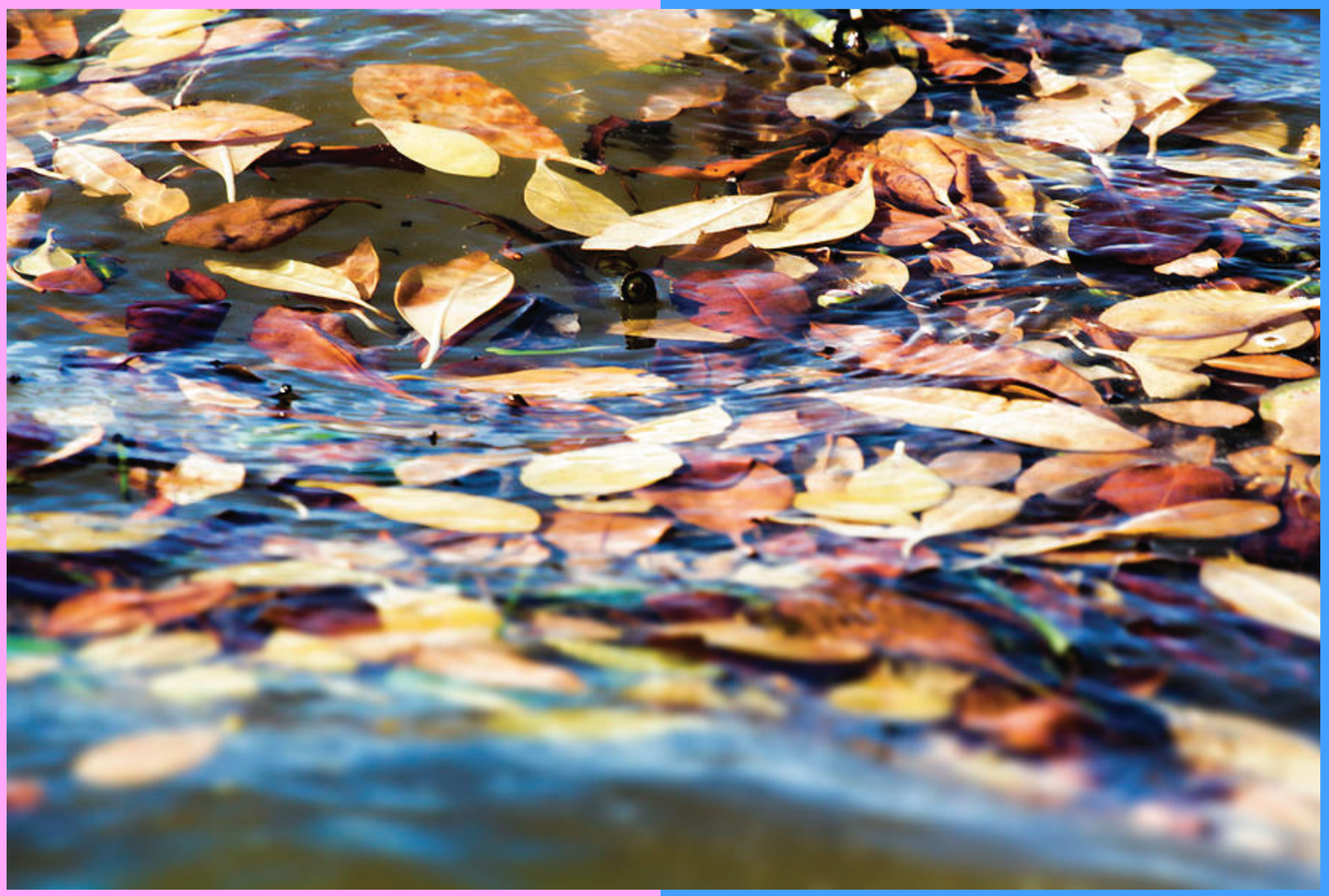
Phenomenological conclusion

- bubbles (**light** particles) drift to a local surface **maximum**

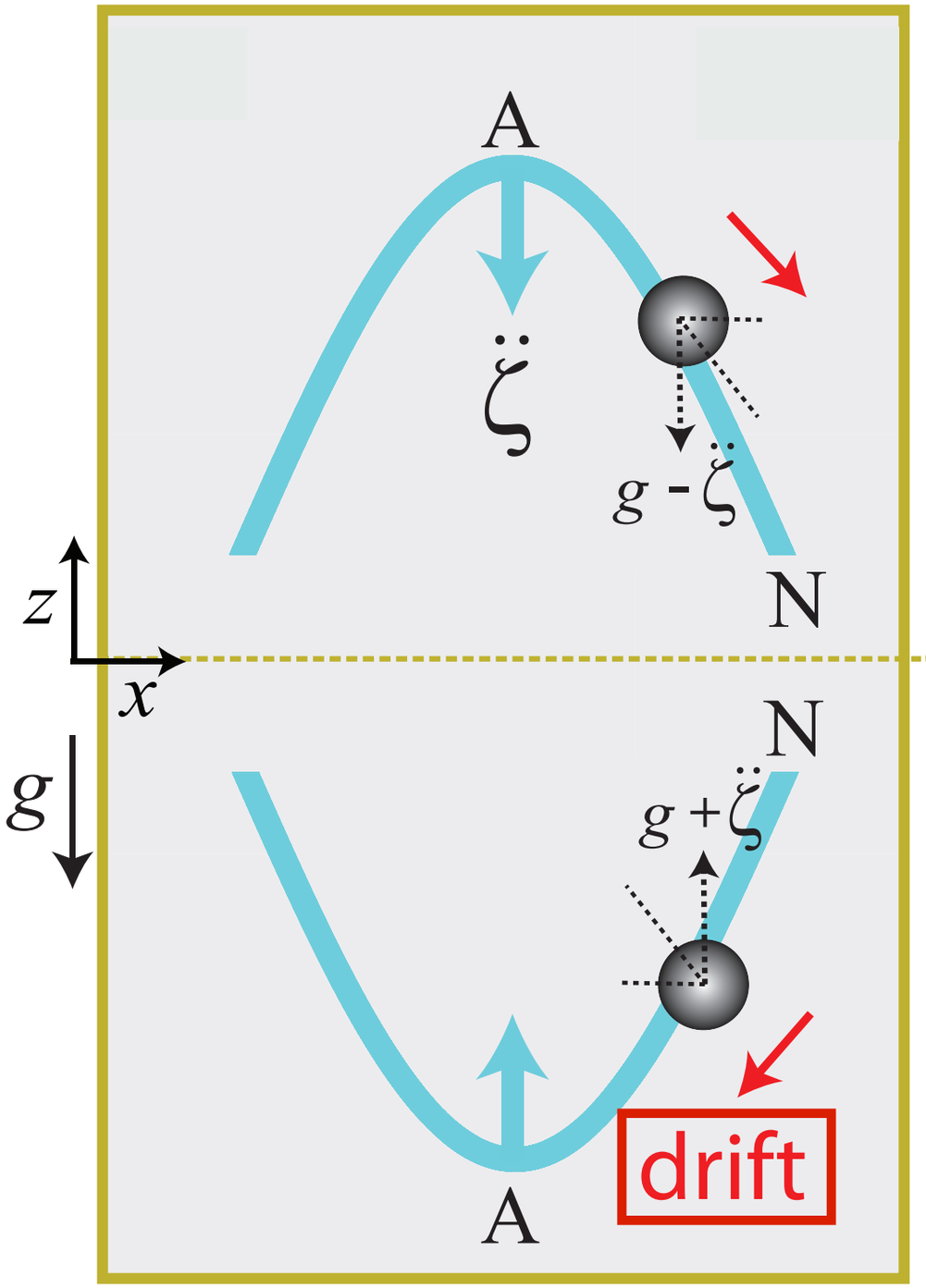


- **heavy** particles drift to a local surface **minimum**

Floaters on a dynamic surface



Heavy particle on a standing wave



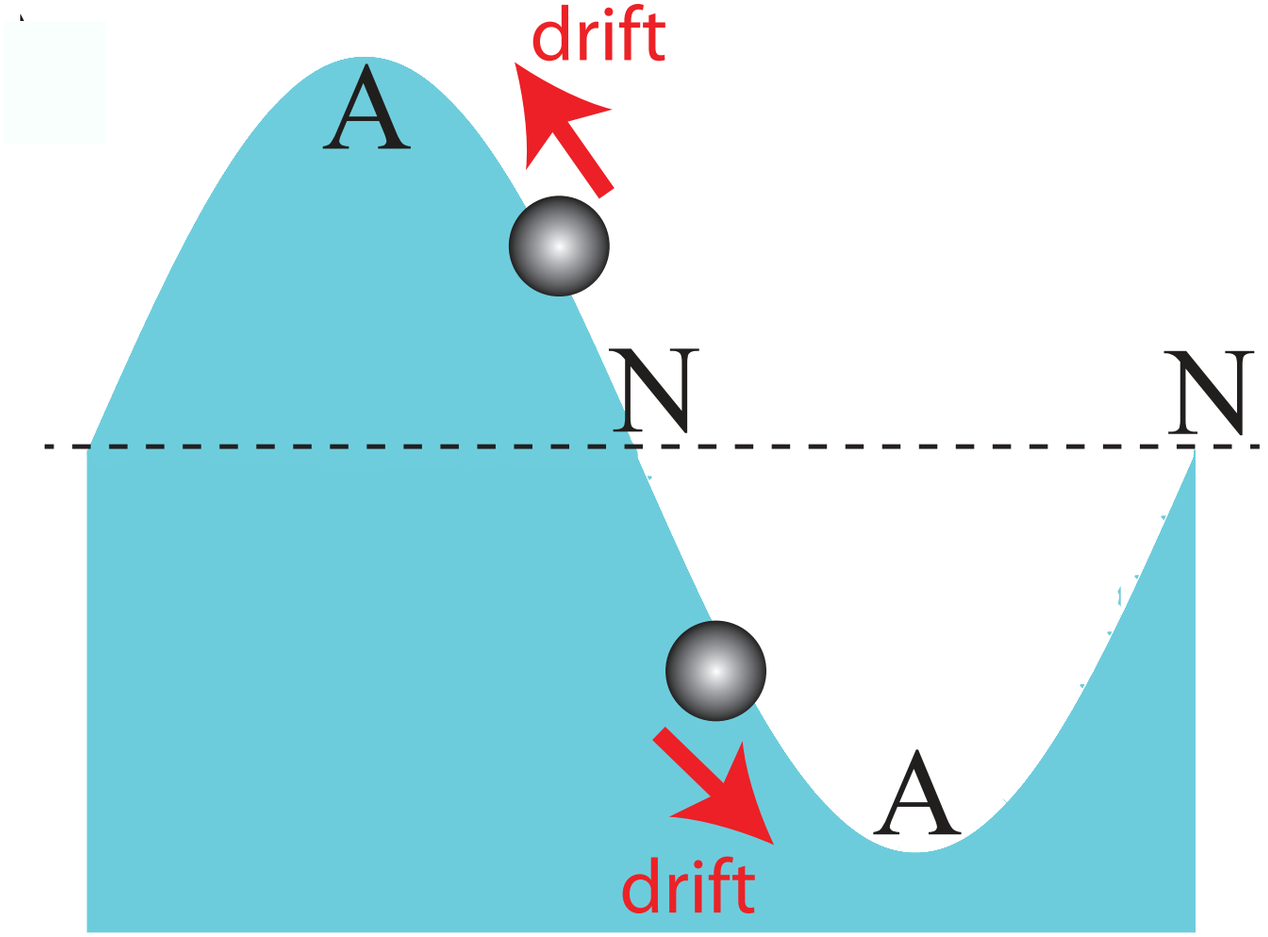
- T: the wave period

$t < T/2$

wave elevator!

$t > T/2$

Antinode clusters at low ϕ

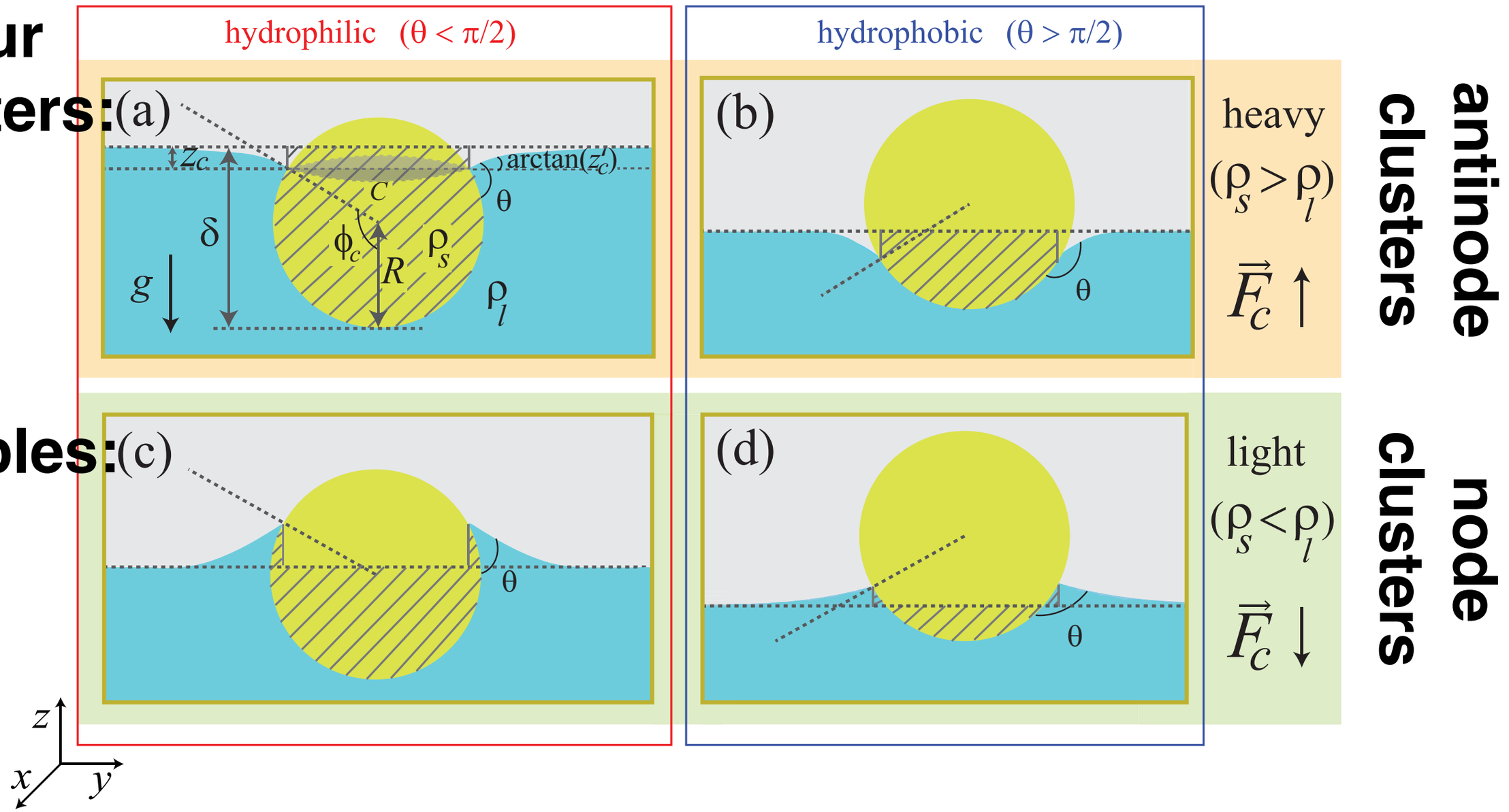


- The drift force is always towards the **antinodes** for our floaters.

- The drift force is a **single** floater force.

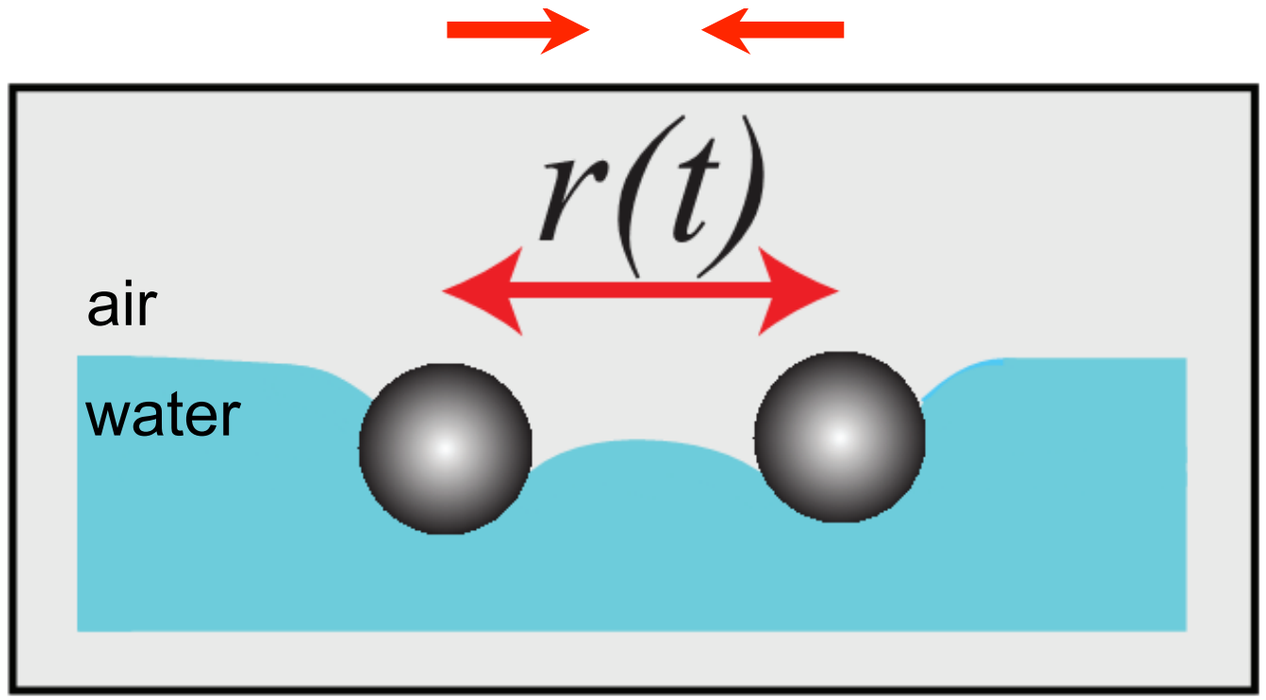
- G. Falkovich, A. Weinberg, P. Denissenko, and S. Lukaschuk, "Floater clustering in a standing wave", Nature (London) **435**, 1045–1046 (2005).

Full story at low ϕ



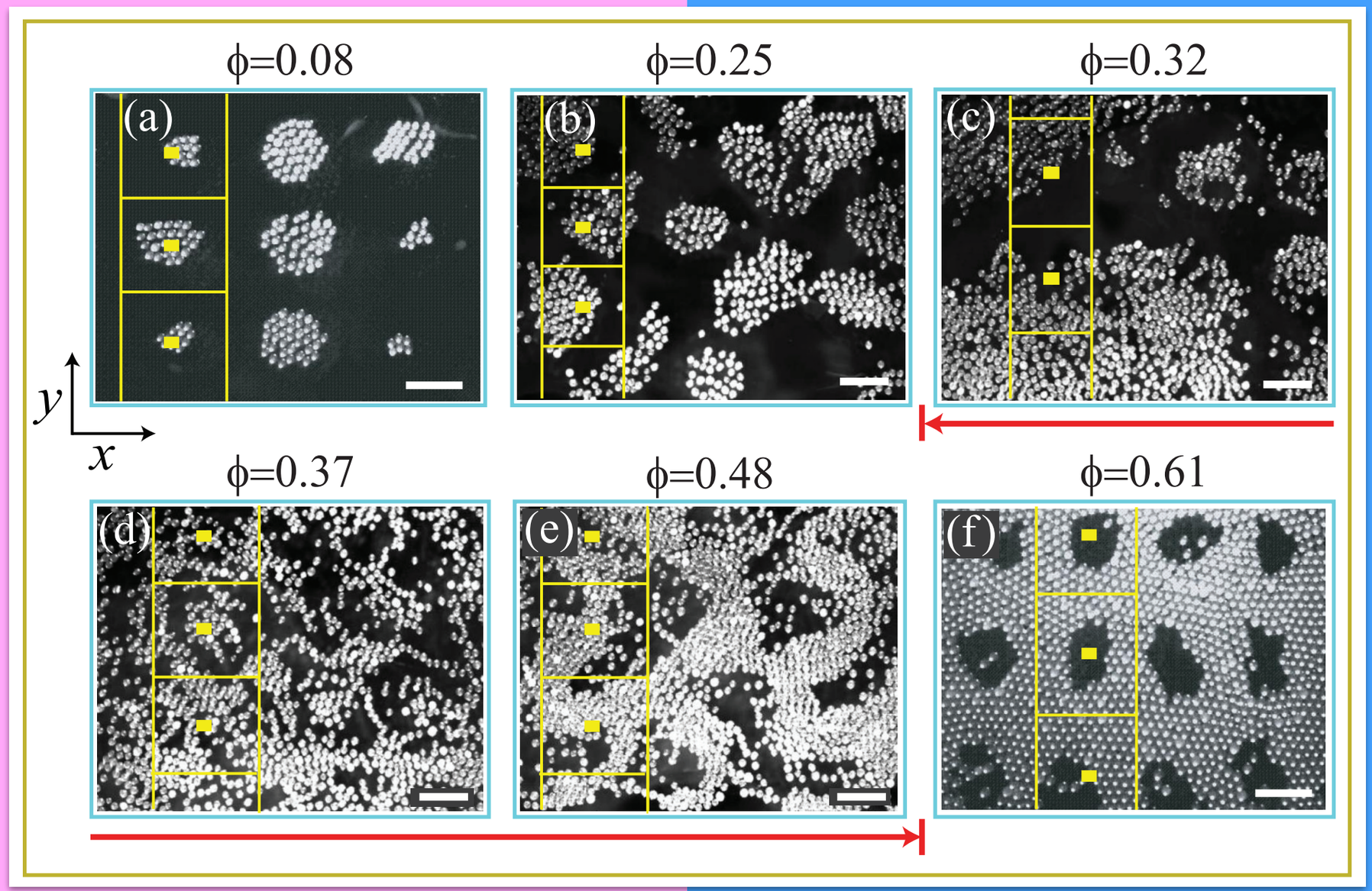
- J. B. Keller, "Surface tension force on a partly submerged body", Phys. Fluids **10**, 3009–3010 (1998).

Attractive capillary interaction



- D. Vella and L. Mahadevan, “The Cheerios effect”, Am. J. Phys. **73**, 817–825 (2005).
- D. Y. C. Chan, J. D. Henry, Jr., and L. R. White, “The interaction of colloidal particles collected at fluid interfaces”, J. Colloid Interface Sci. **79**, 410–418 (1981).
- N. D. Vassileva, D. van den Ende, F. Mugele, and J. Mellema, “Capillary forces between spherical particles floating at a liquid-liquid interface”, Langmuir **21**, 11190–11200 (2005). (PhD Thesis, UTwente)

Experiment: Clusters



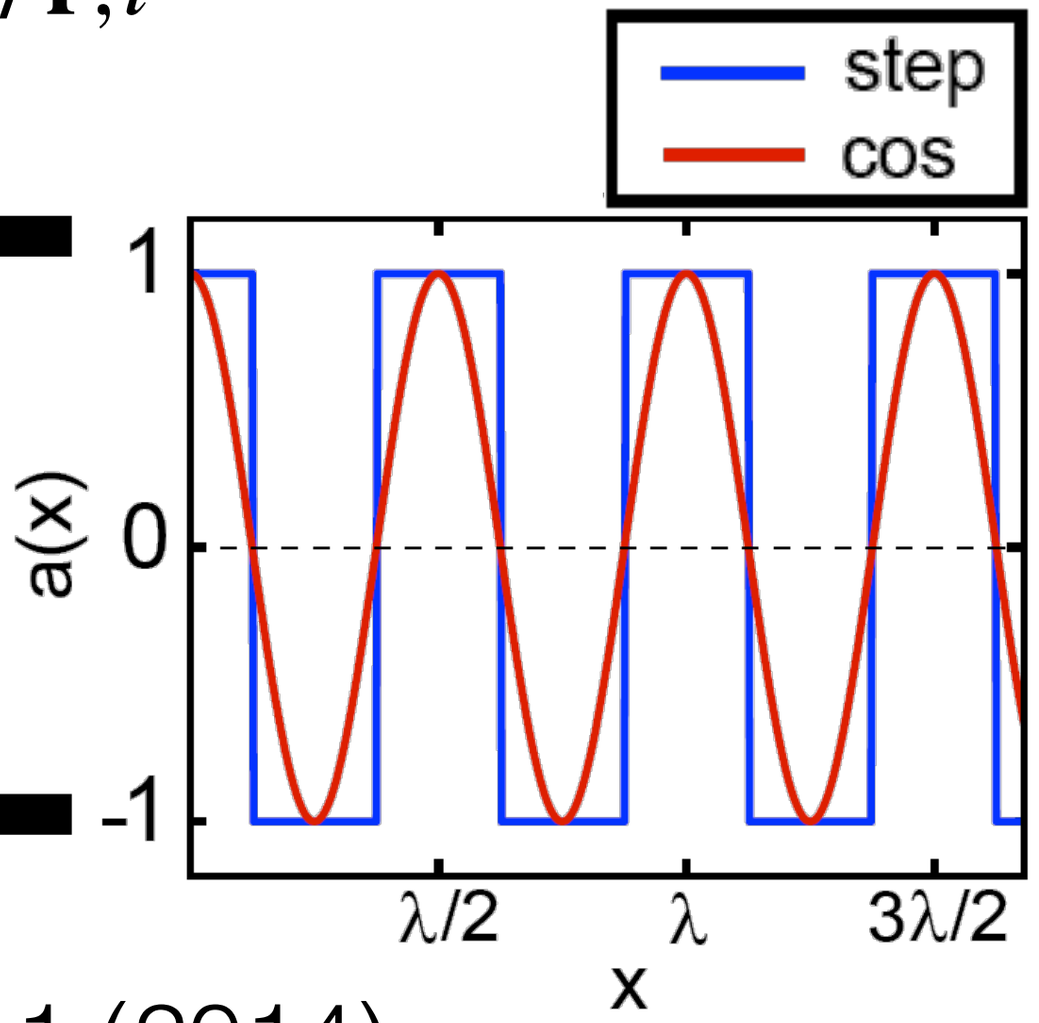
arXiv:1405.2027

Correlation number c

- $$c \equiv \frac{\langle \phi(\mathbf{r},t)a(\mathbf{r})\rangle_{\mathbf{r},t}}{\langle \phi(\mathbf{r},t)\rangle_{\mathbf{r},t}}$$

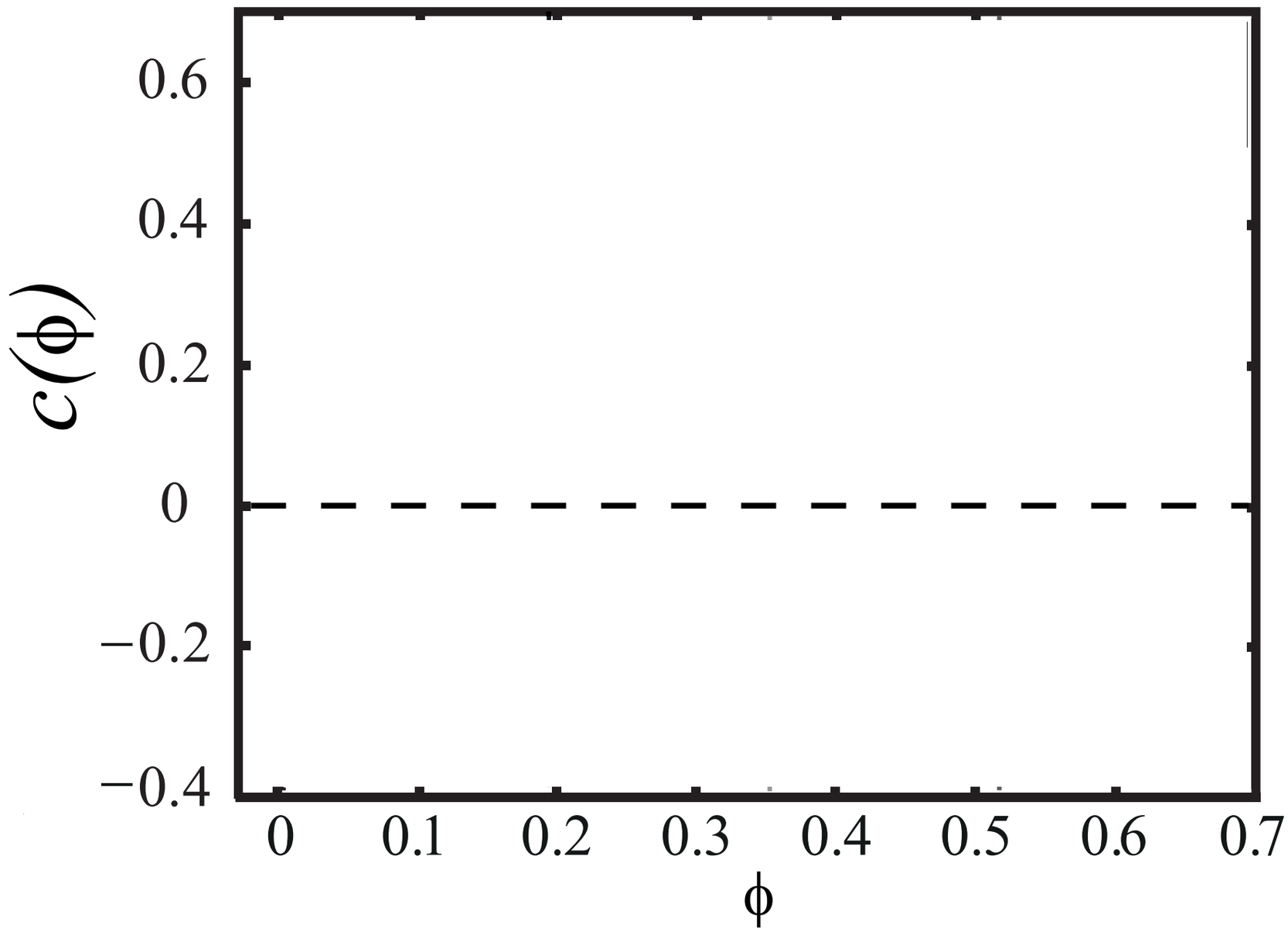
- $\mathbf{r} = (x, y)$ antinodes ⬅
- t is time
- λ is the wavelength

nodes ⬅

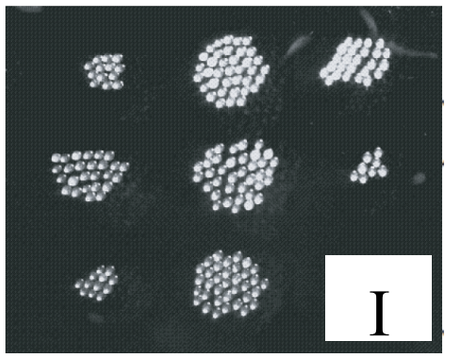


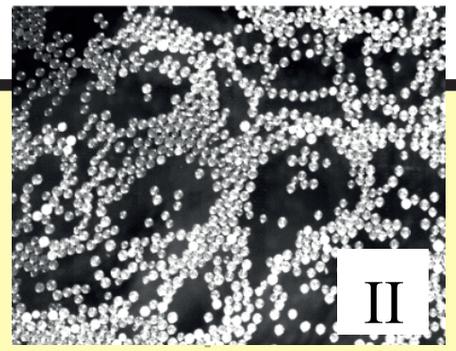
- C. Sanlı *et al.* PRE **89**, 053011 (2014).

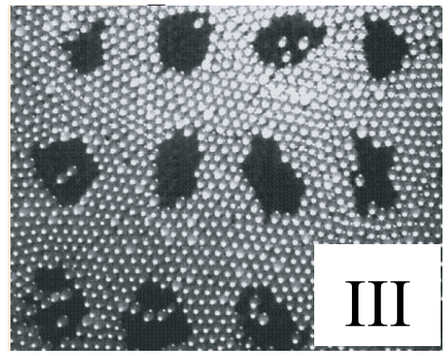
Correlation number c



Correlation number c



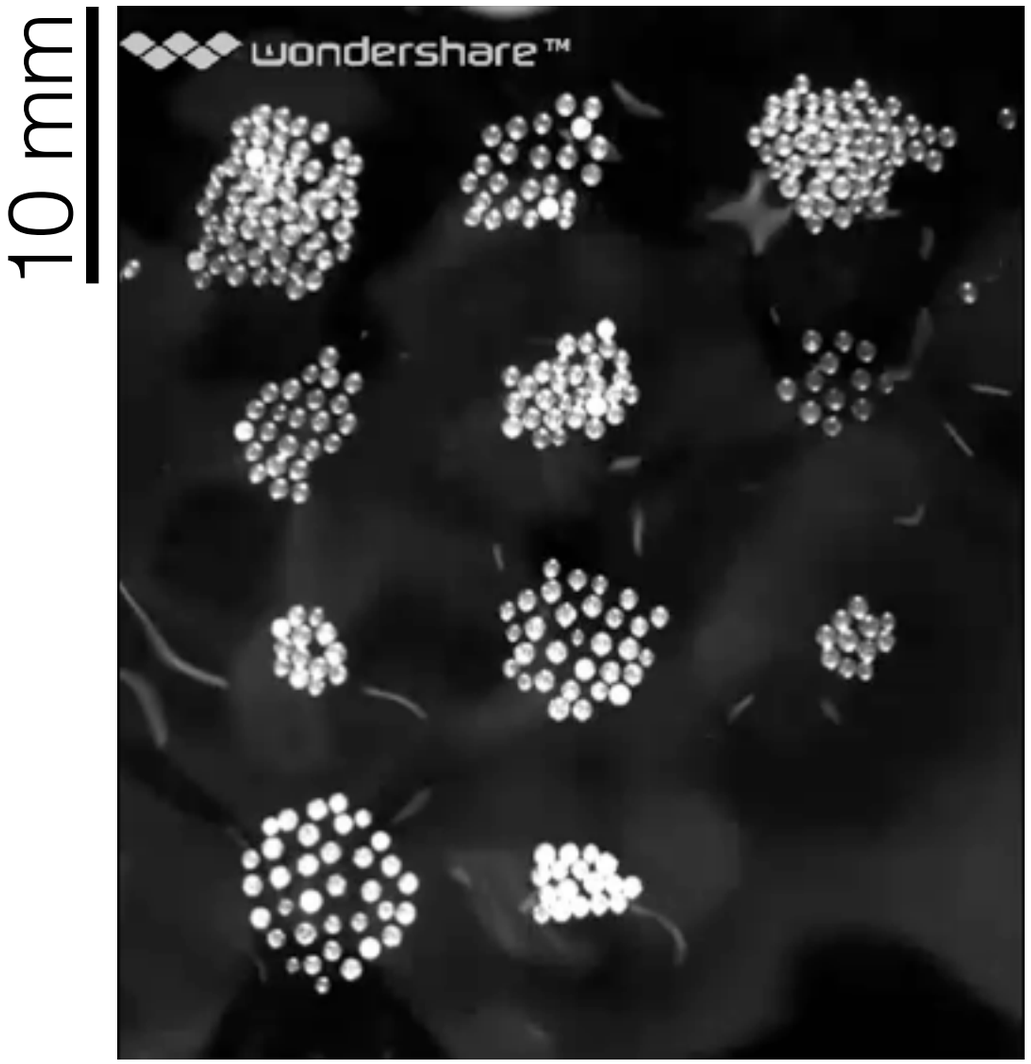




Why the node clusters at high ϕ?

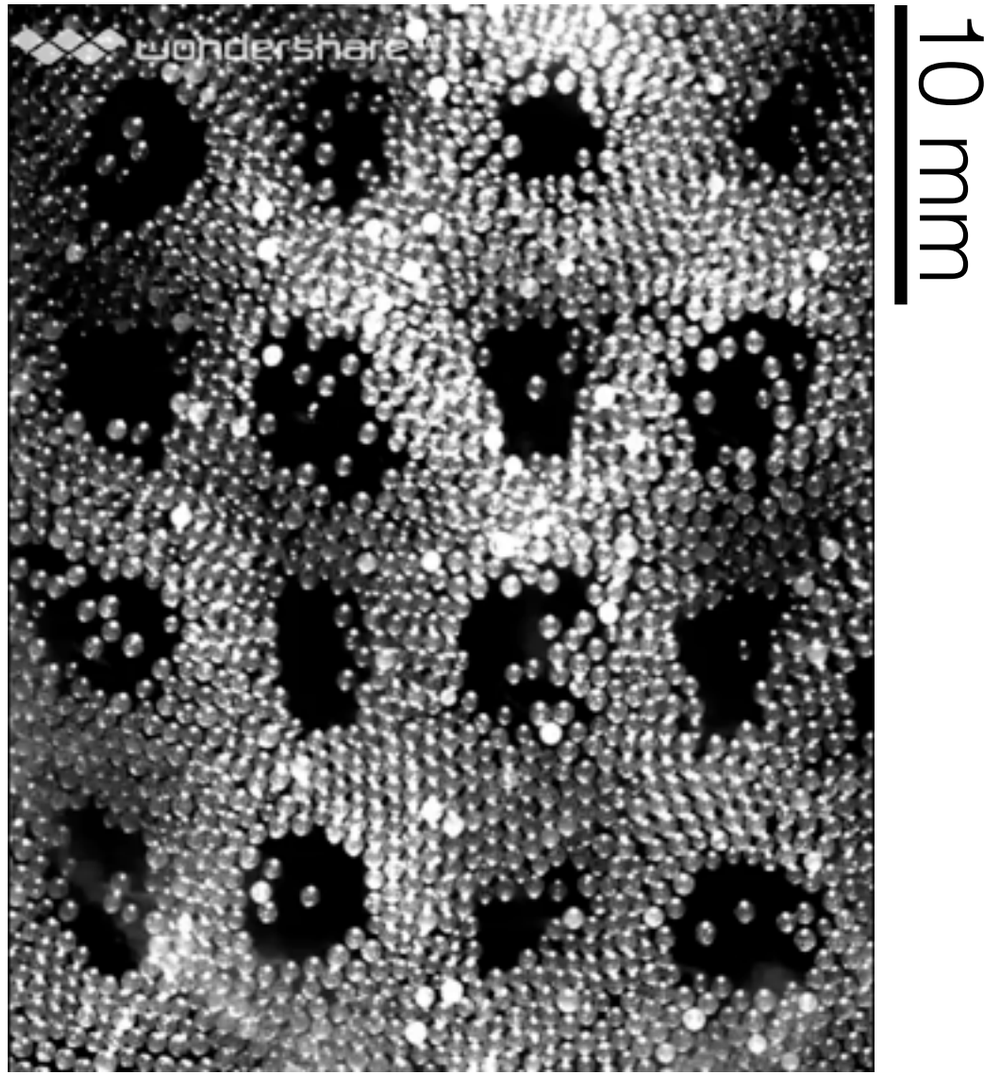
- Let's look at the experiment more carefully!

breathing



antinode clusters

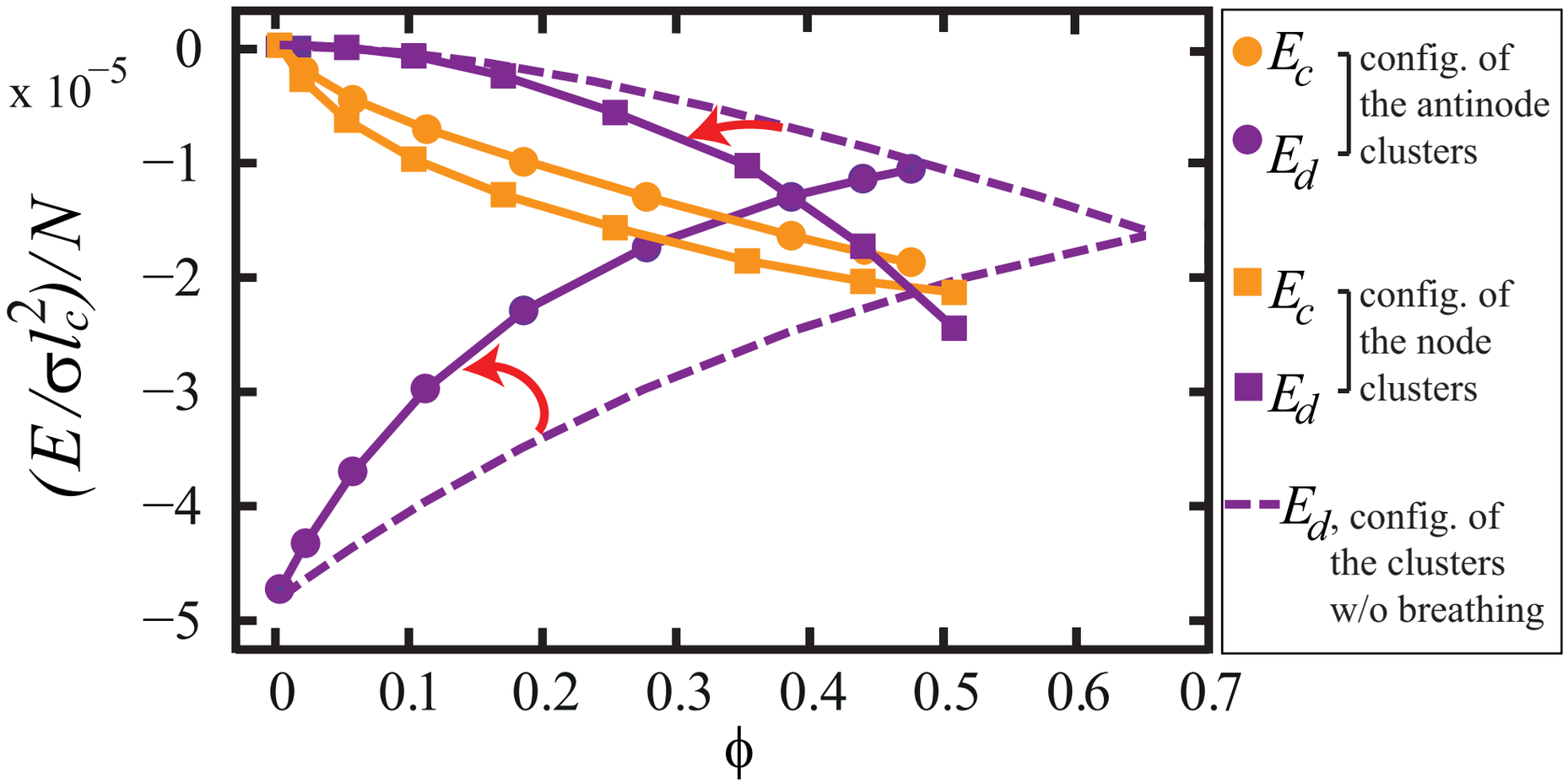
non-breathing

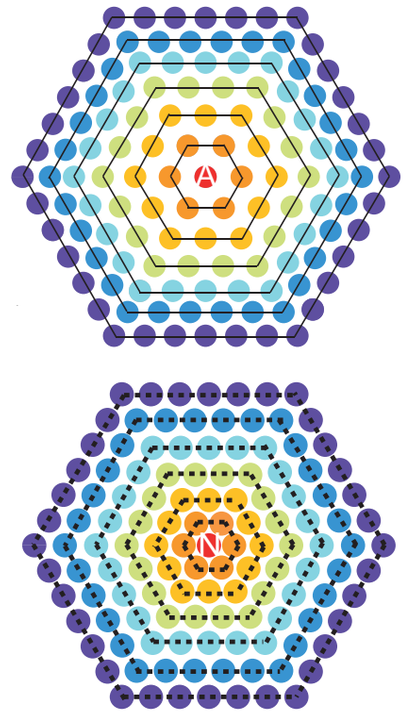


node clusters

Potential energy approach

drift to the antinodes + capillary attraction + breathing

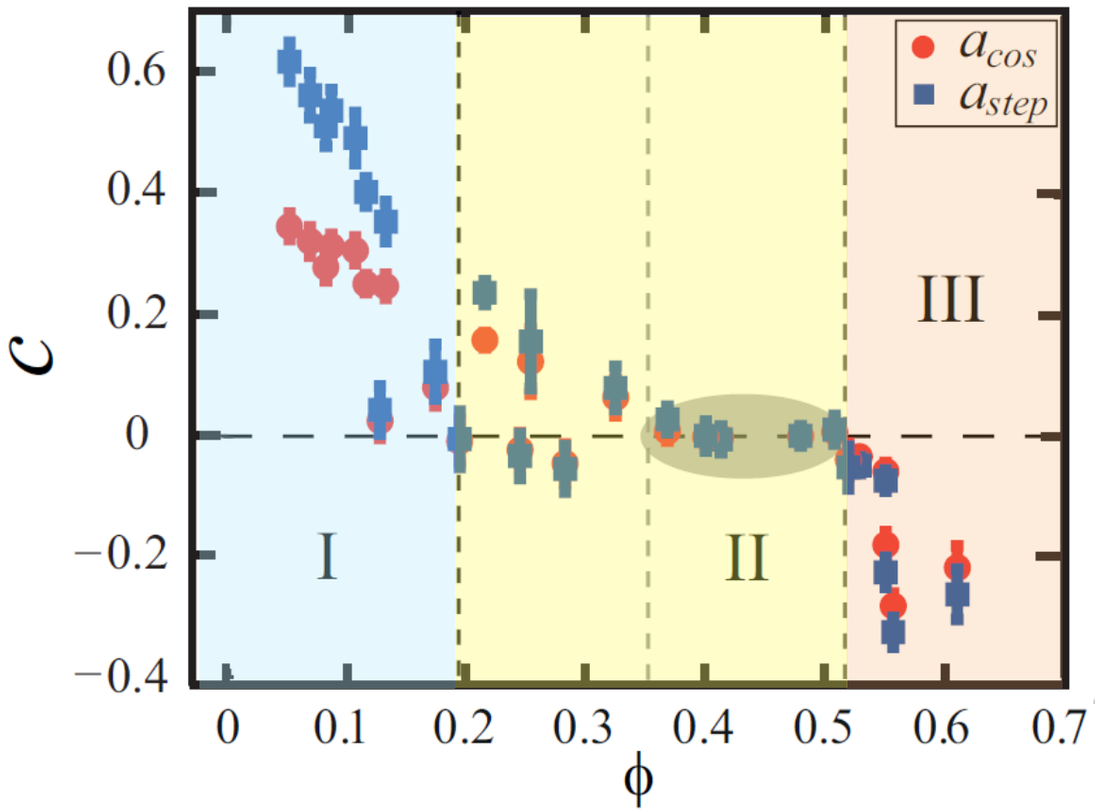




- E_c: **capillary energy**
- E_d: **drift energy**

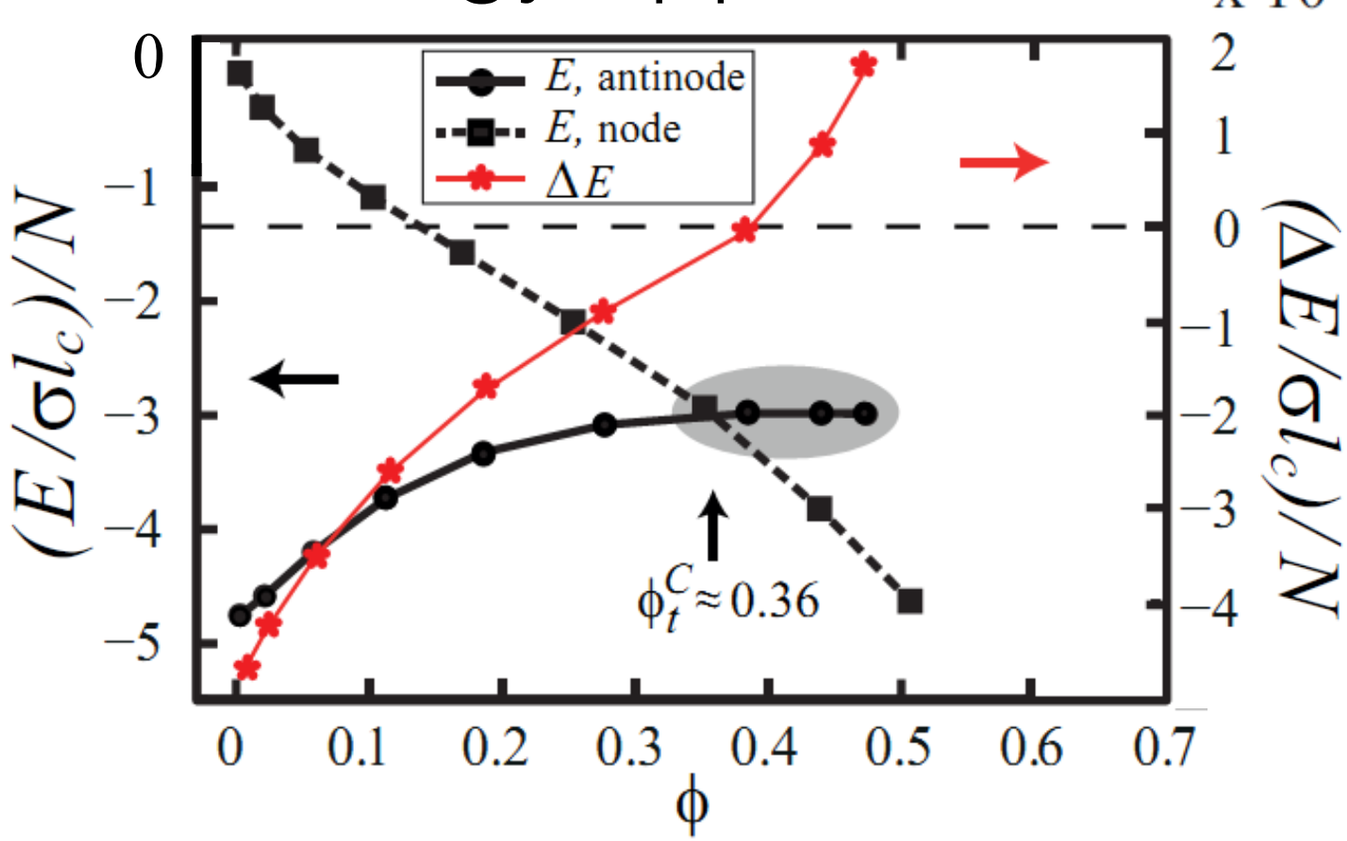
- σ : surface tension
- l_c : capillary length
- N : number of floaters

Comparison with experiment



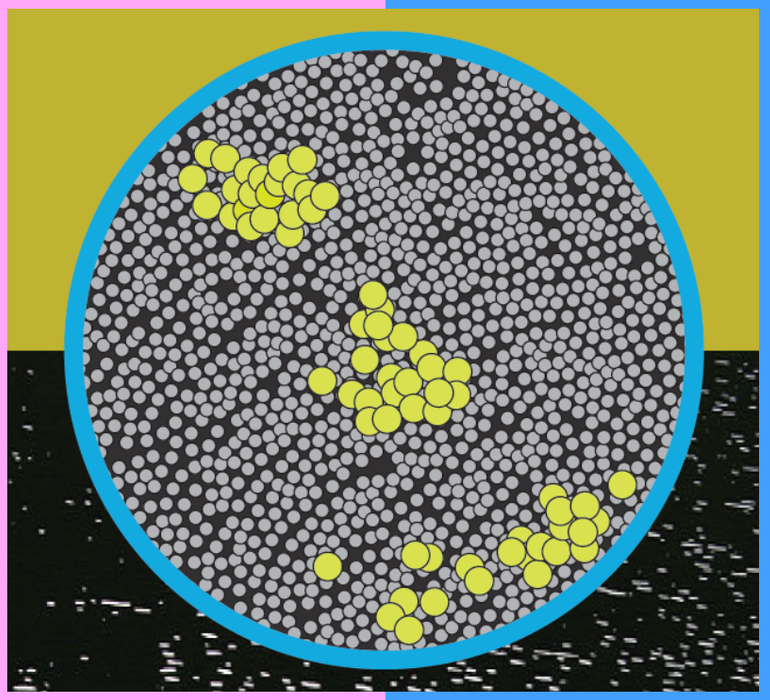
- experiment

- energy approach



Part-2: capillary Heterogeneous flows and group formations

Floaters on a Faraday wave:



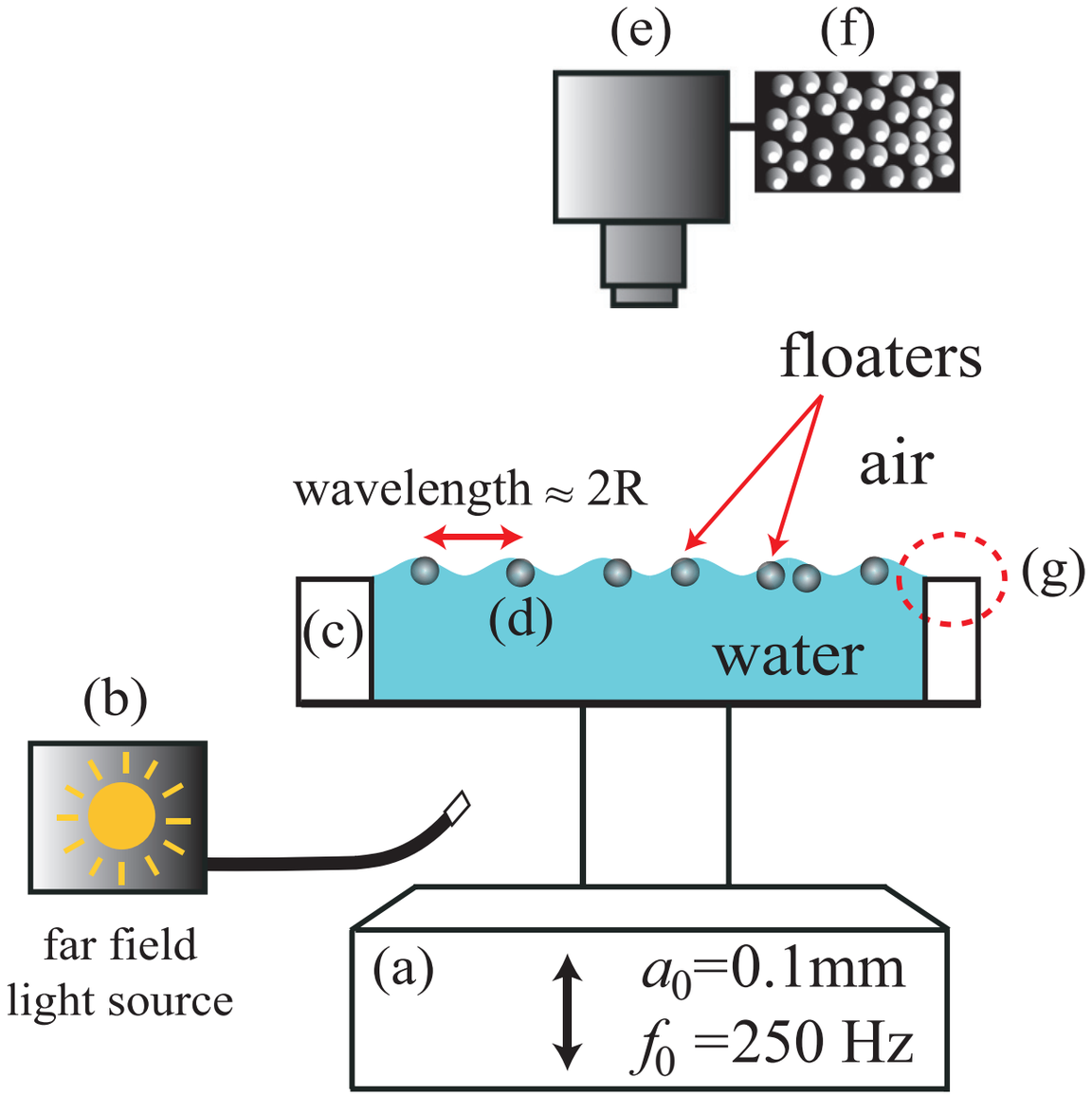
Observation

- ϕ = 0.63

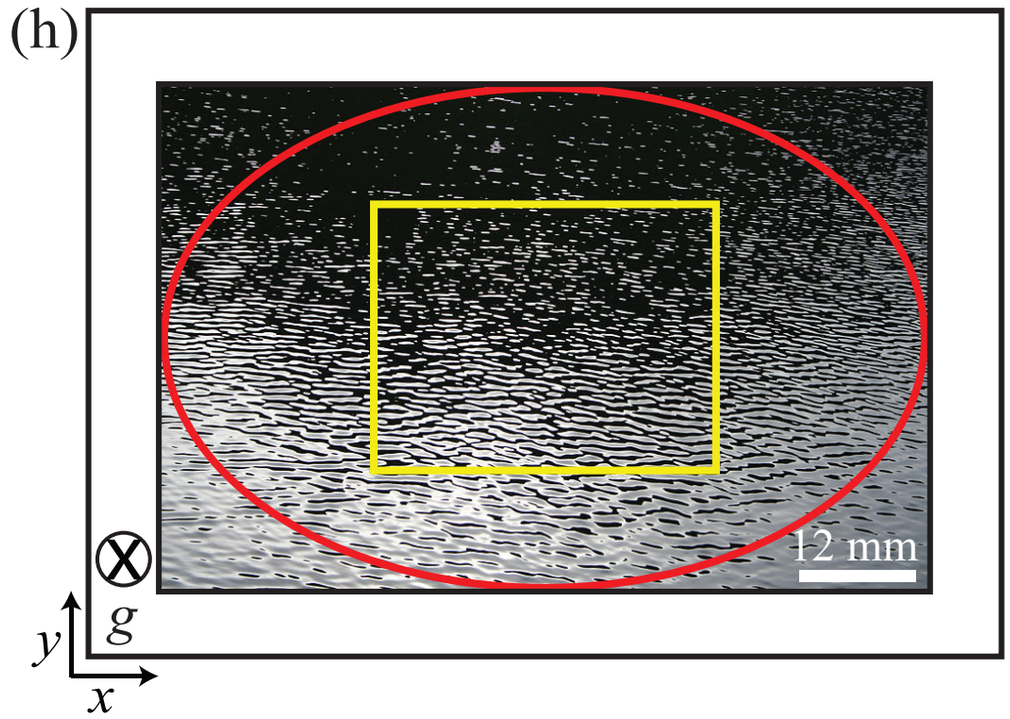
- a = 1 mm
- f = 250 Hz

- 4 times slower than real time

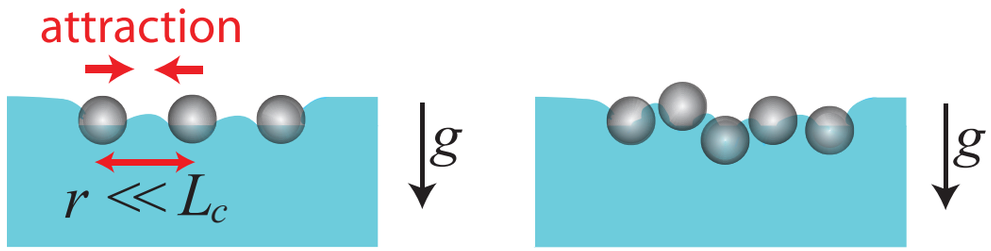
Experimental set-up



- capillary Faraday waves



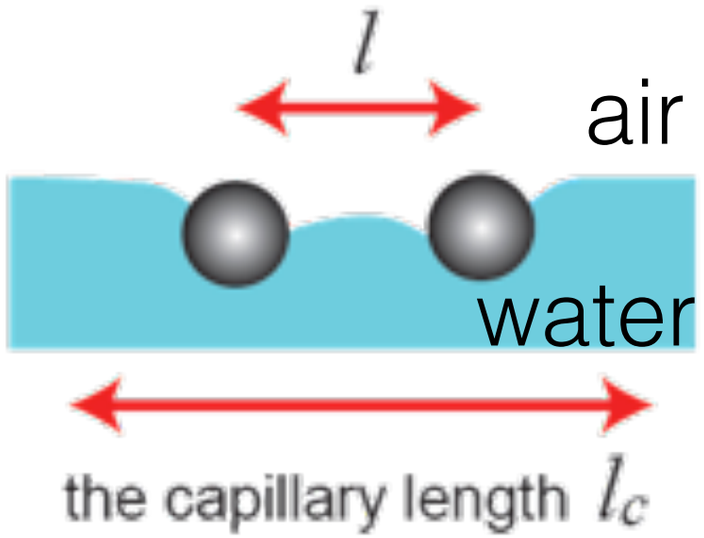
(i) moderate regime (j) dense regime



ϕ = bead area/total area

Driving interactions and forces

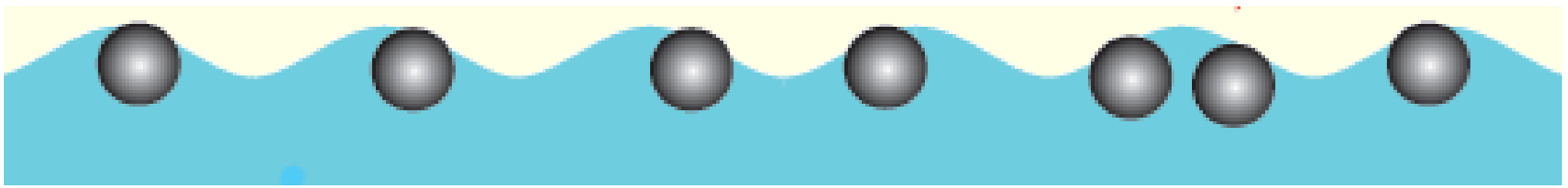
- attractive capillary interactions



the capillary length l_c

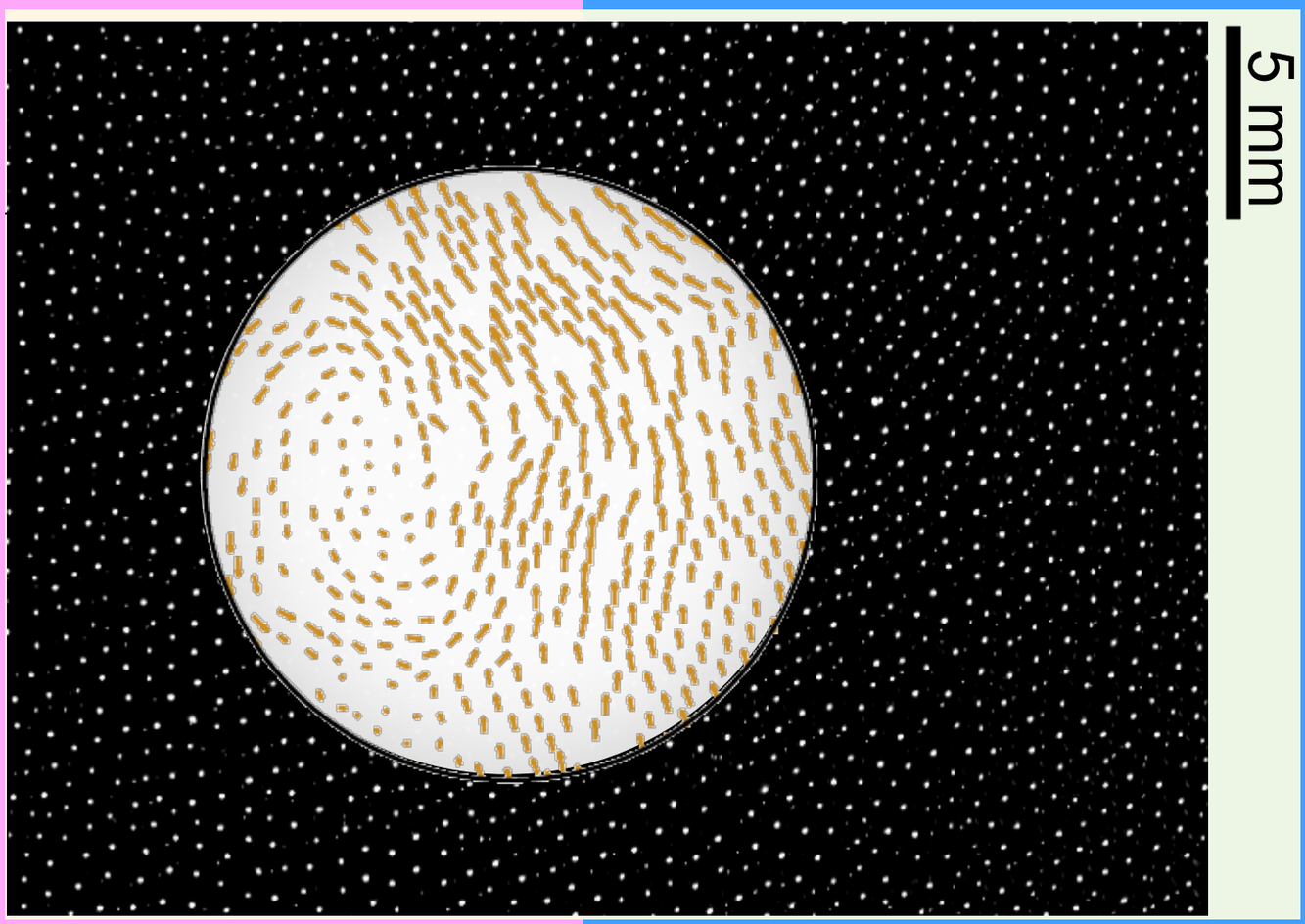
$$l << l_c$$

- erratic capillary (Faraday) waves



Four-point dynamic susceptibility:

To quantify the heterogeneous dynamics



Self-overlap order parameter

time

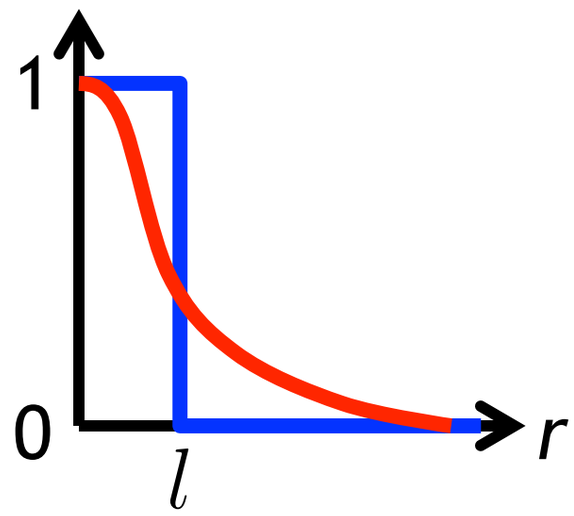
$$Q_t(l,\tau) = \frac{1}{N}\sum_{i=1}^{N}\omega_l(r_i)$$

a cutoff function

number of spheres

sphere index

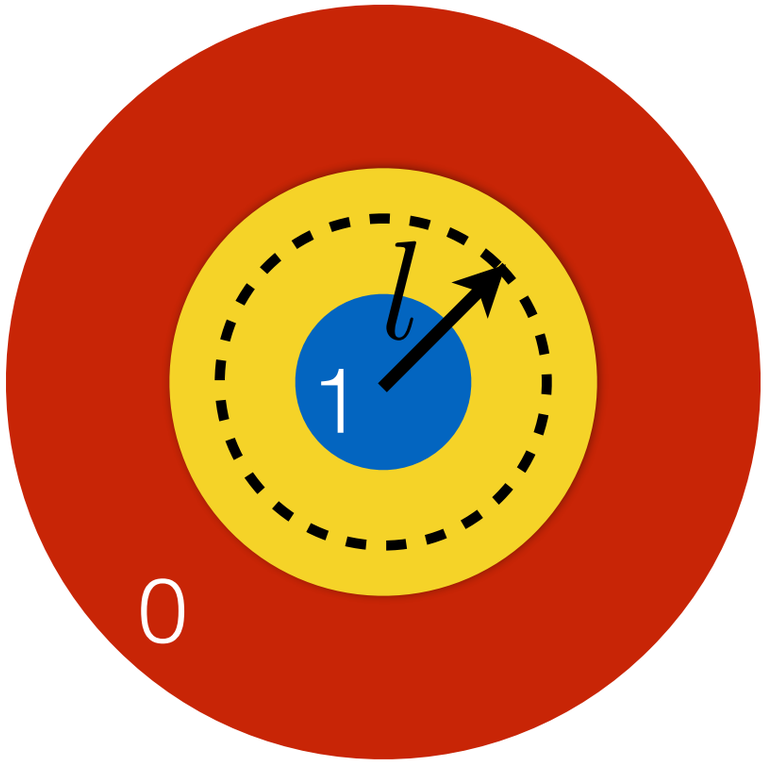
- $\omega_l(r_i) = e^{-r_i^2/(2l)^2}$
- $r_i = |\mathbf{r}_i(t+\tau) - \mathbf{r}_i(t)|$

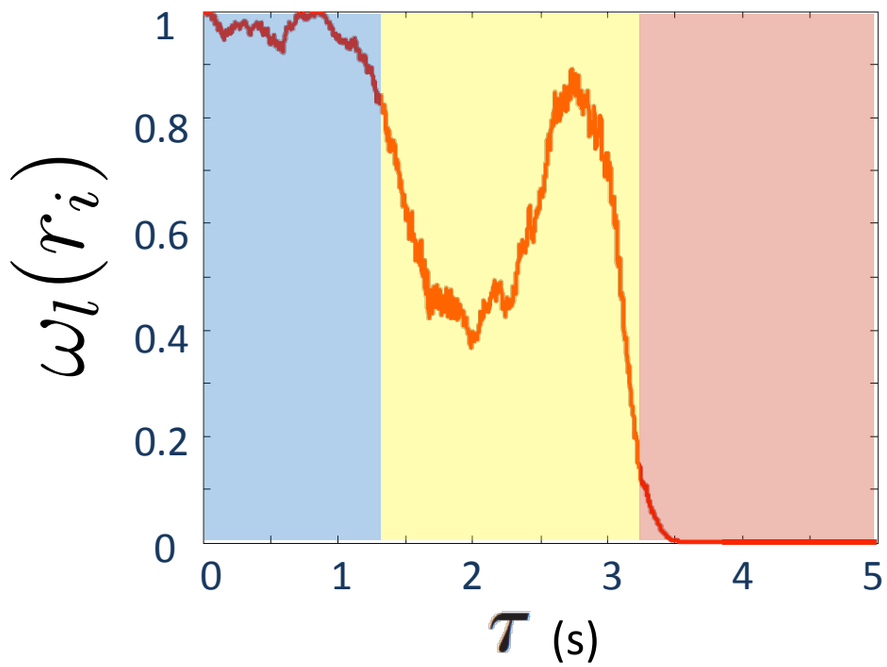


- A. R. Abate and D. J. Durian, "Topological persistence and dynamical heterogeneities near jamming", Phys. Rev. E **76**, 021306-1–9 (2007).

A measure of mobility

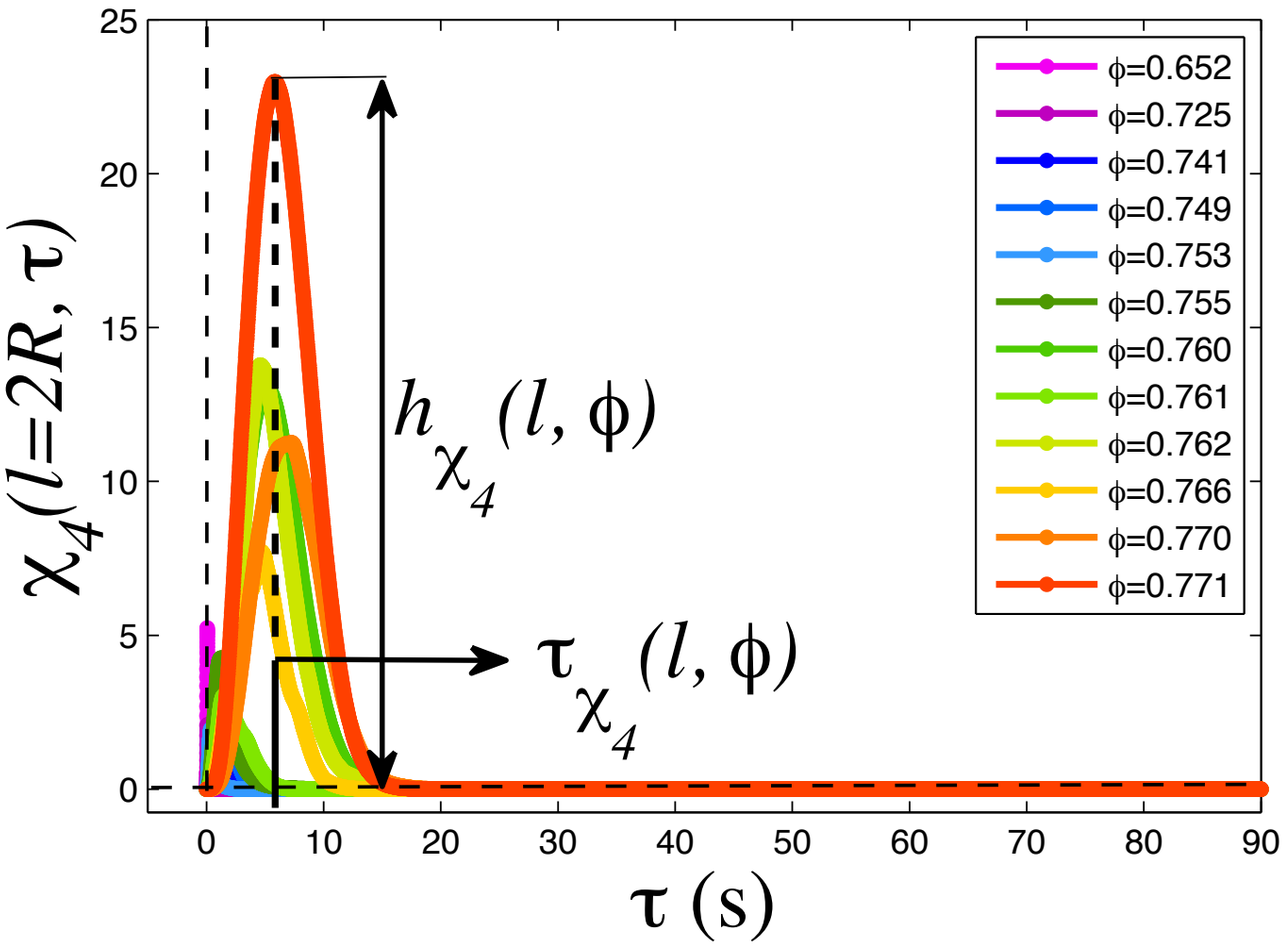
- $$\omega_l(r_i) = \begin{cases} 1, \text{ if a sphere } i \text{ travels } << l \text{ within } \tau \\ 0, \text{ if a sphere } i \text{ travels } >> l \text{ within } \tau \end{cases}$$





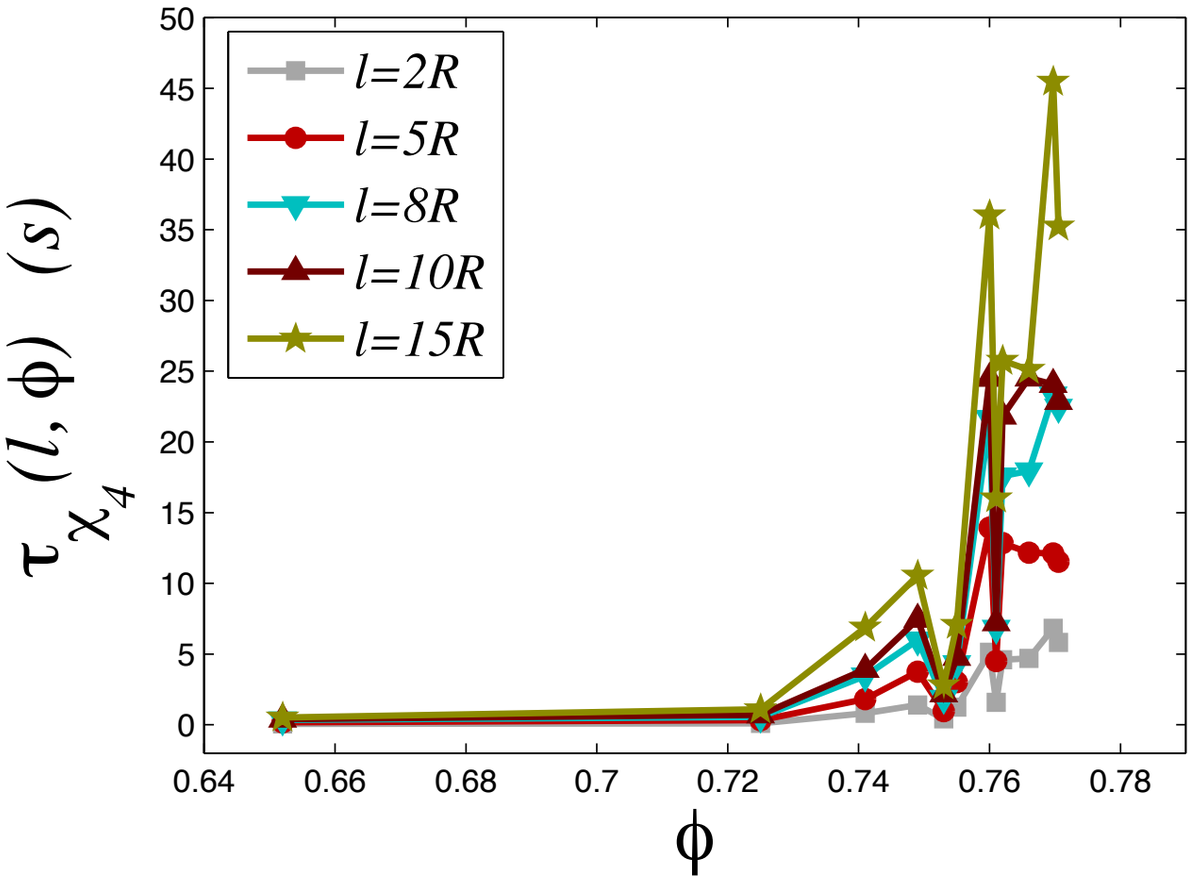
Four-point dynamic susceptibility

- To quantify the heterogeneous dynamics by the mobility (self-overlap order parameter):
  - $\chi_4(l,\tau) = N\left[\langle Q_t^2(l,\tau)\rangle_t - \langle Q_t(l,\tau)\rangle_t^2\right]$

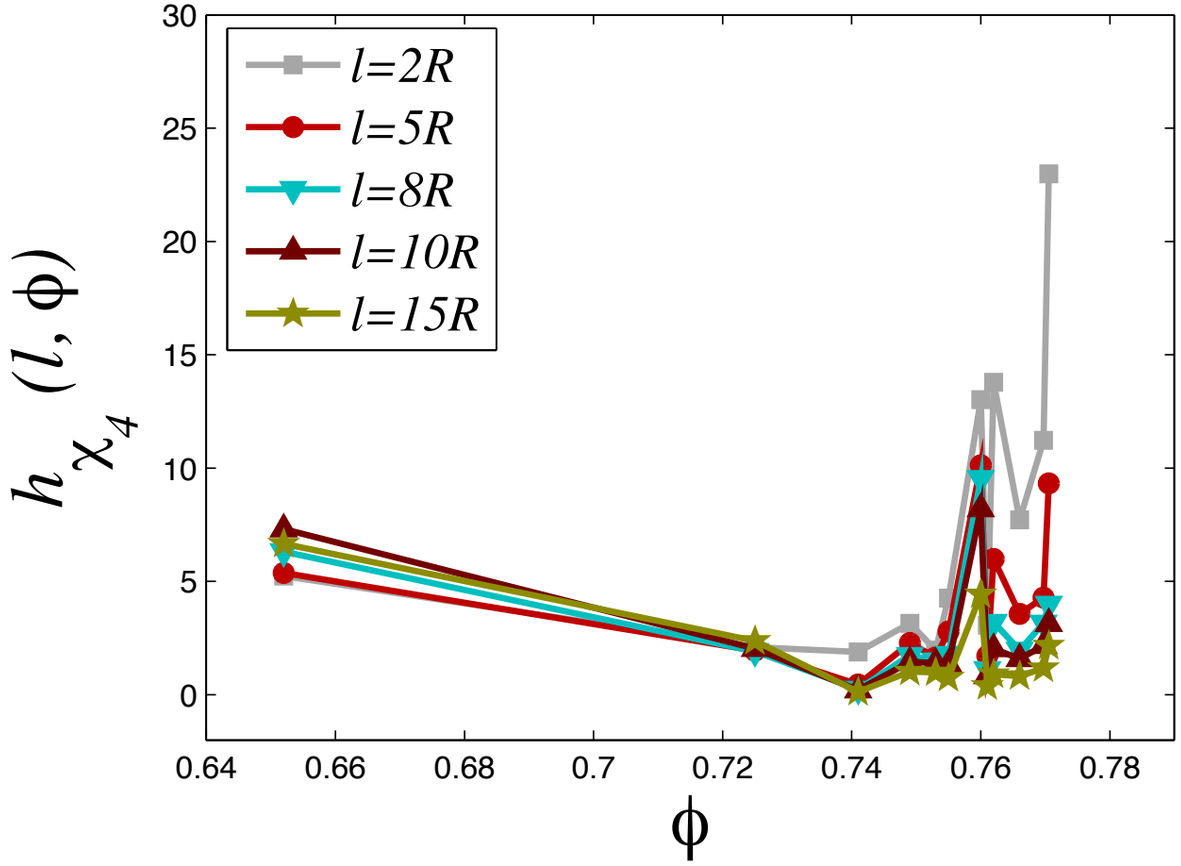


Quantifying the heterogeneous flow

- time-scale of the heterogeneity



- amount of the heterogeneity



Greetings, …

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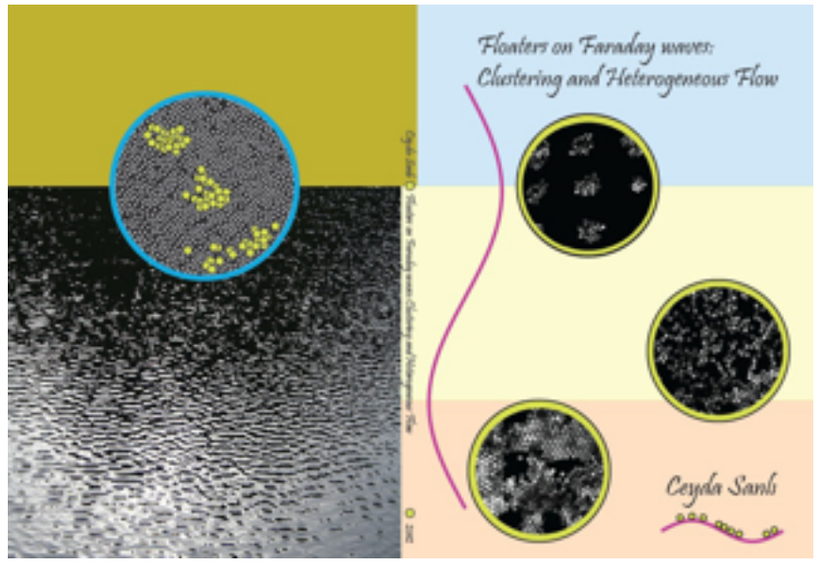

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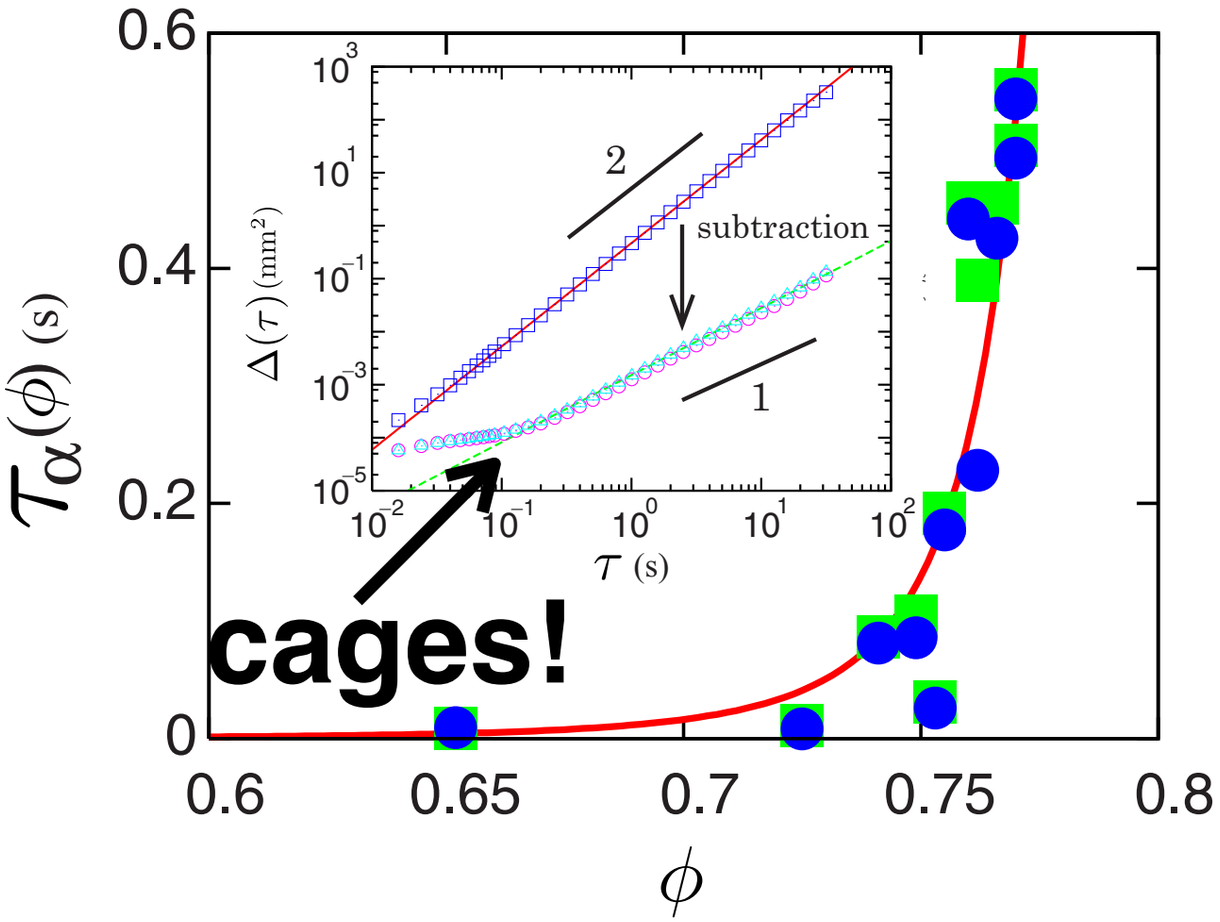
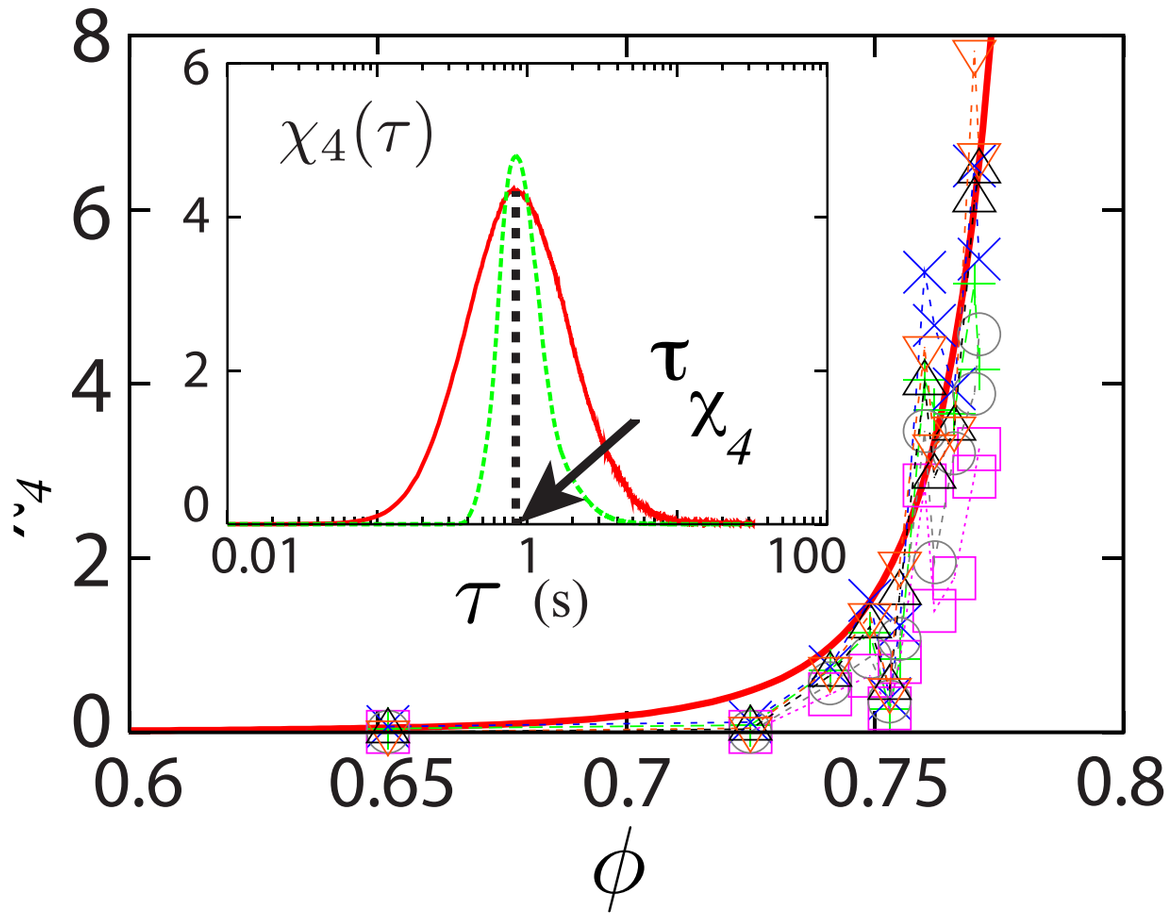
What does $\chi_4(l,\tau)$ measure?

- time-scale of the flow by the diffusion



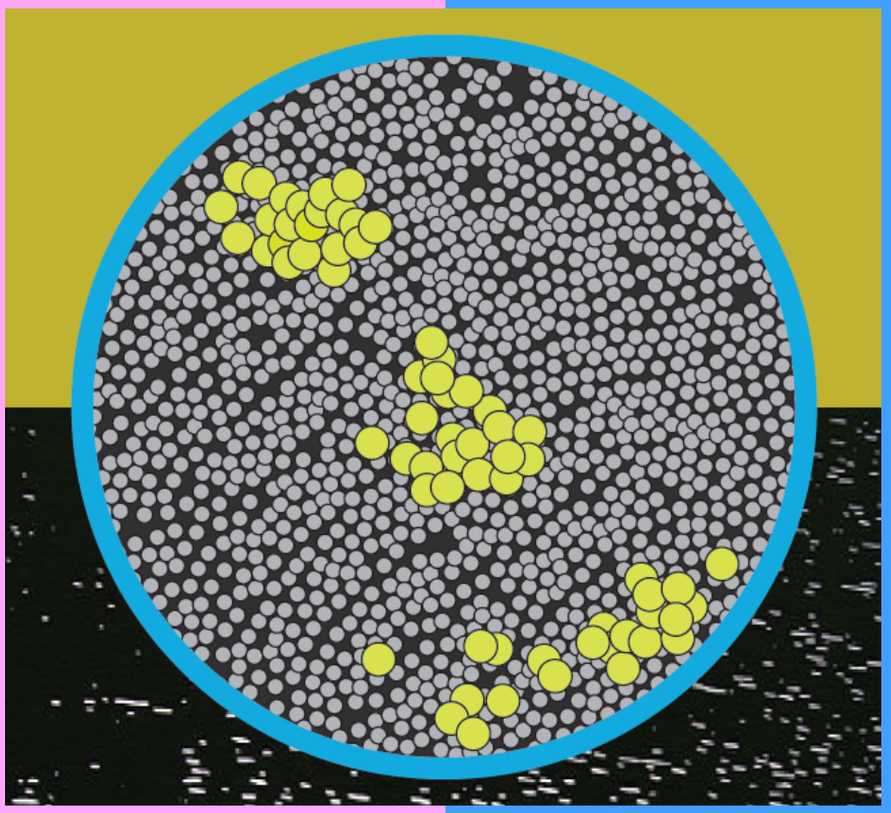
- time-scale of the heterogeneous flow



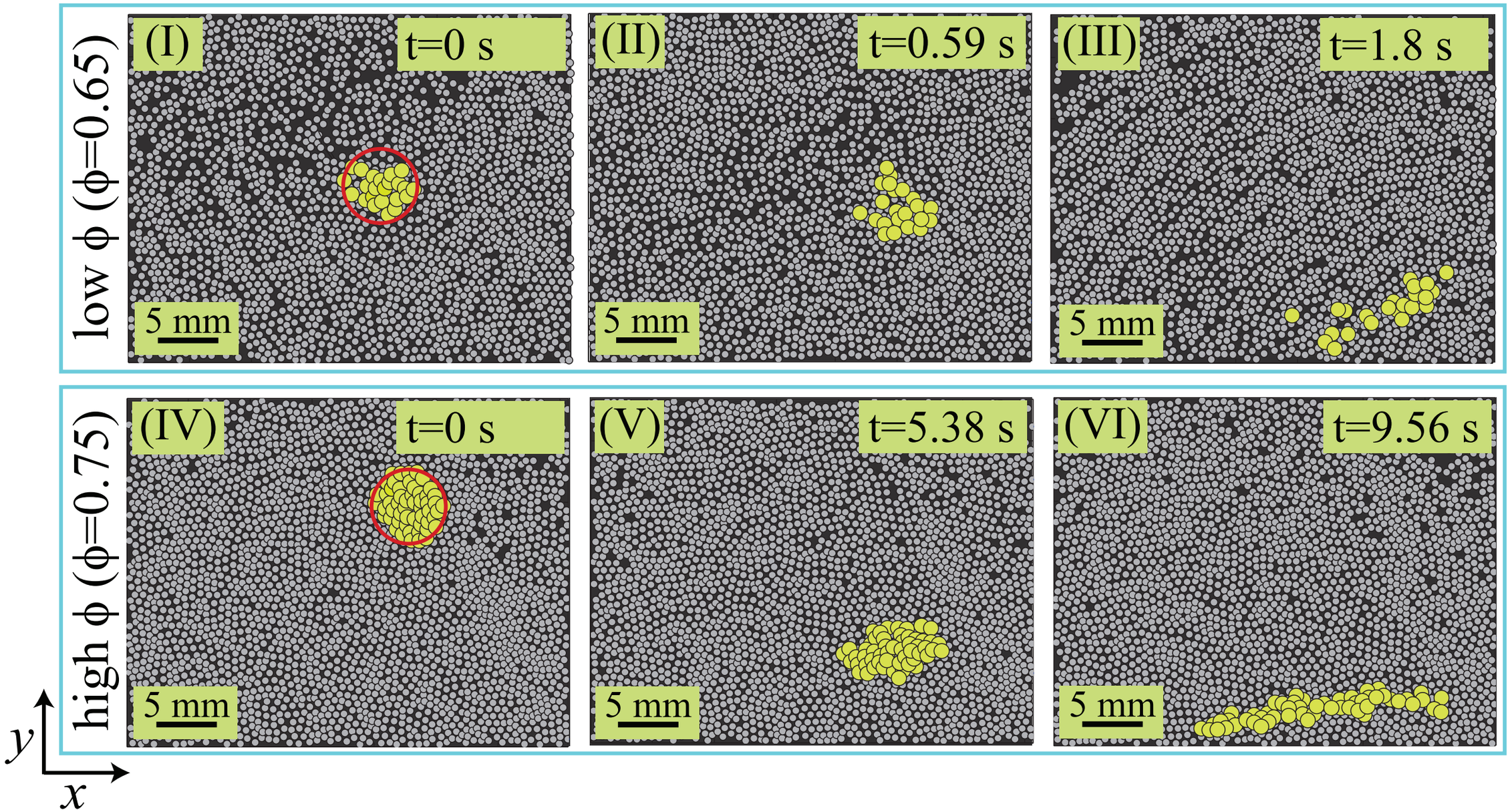
- C. Sanlı, Kuniyasu Saitoh *et al.* PRE **90**, 033018 (2014).

Morphological analysis:

Quantifying dynamics of the group deformation

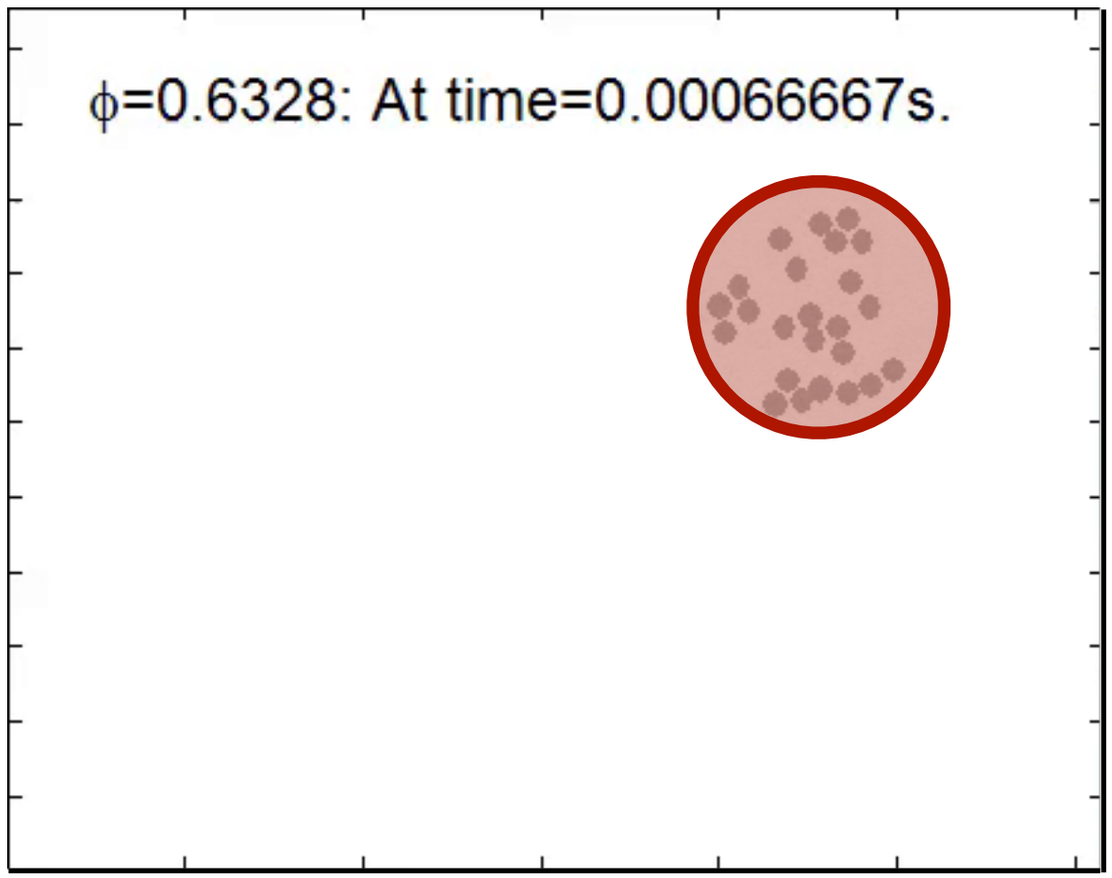


Observation: Detail looking

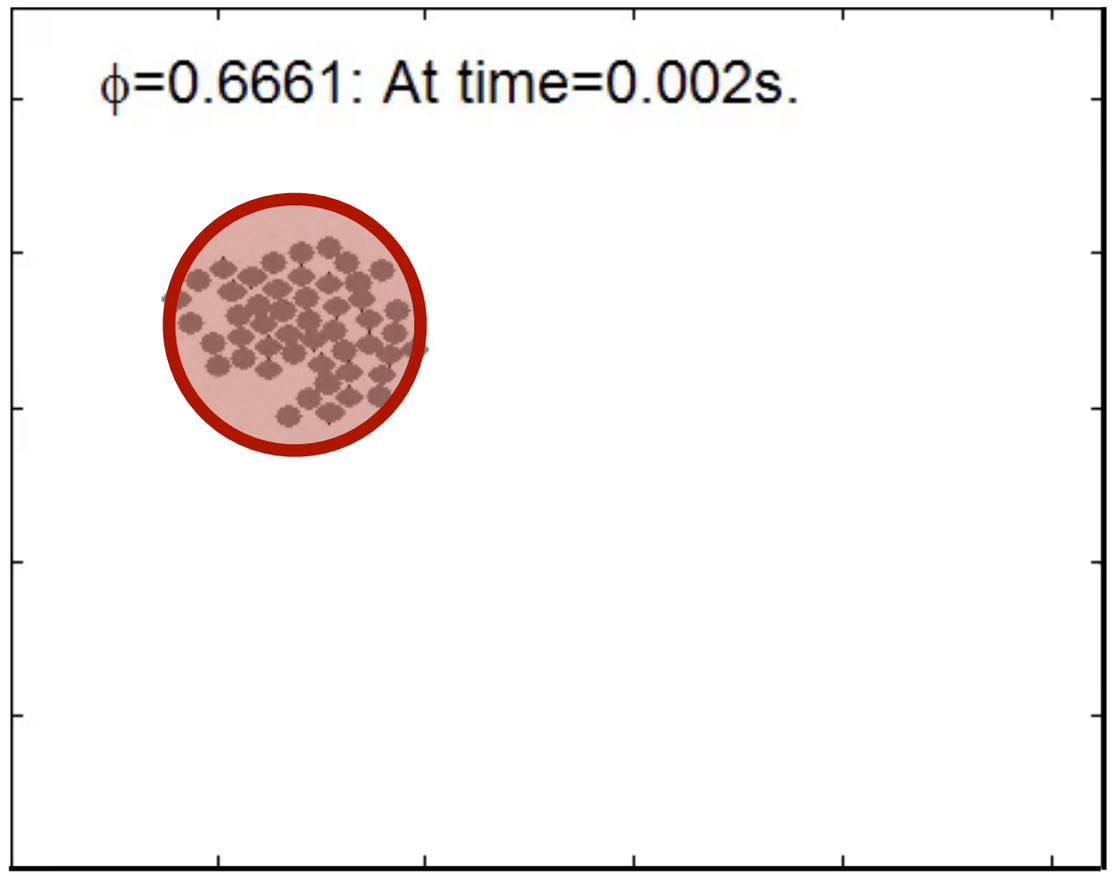


Construction of a subgroup

low ϕ



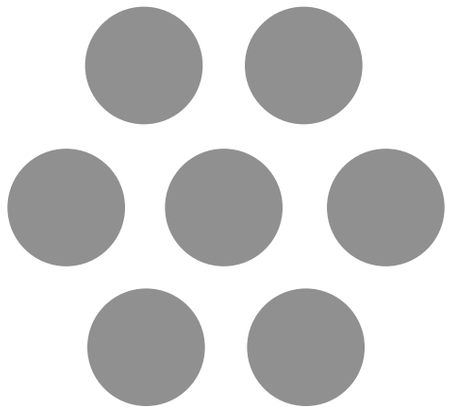
high ϕ



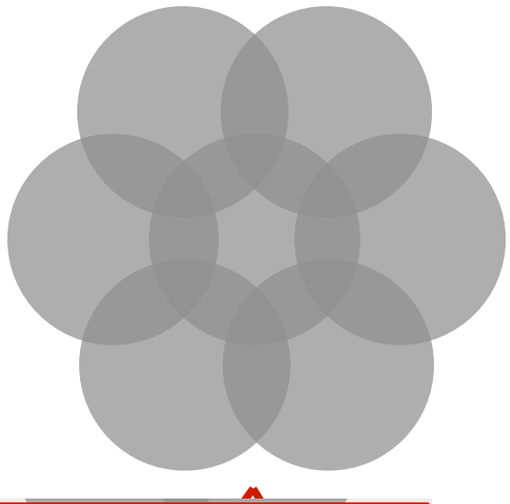
- At a certain ϕ, we construct a subgroup of beads which
- For high ϕ, the subgroup deforms at a later time.
  the initial positions are inside the shaded region.
- For low ϕ, the subgroup breaks into more pieces.
- Then, we track these beads as a function of time.

Morphological parameter when $r=2R$

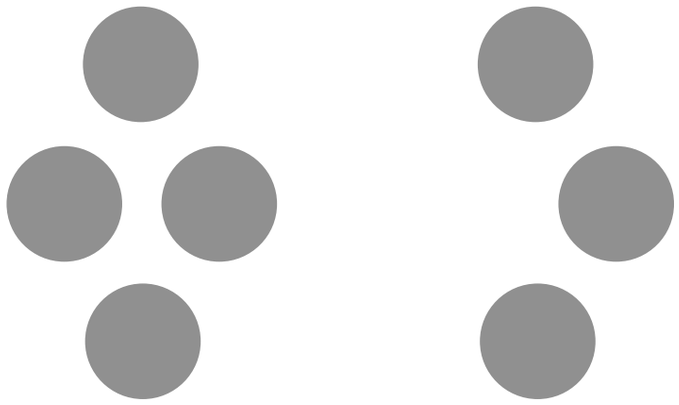
- When $r=1R$:

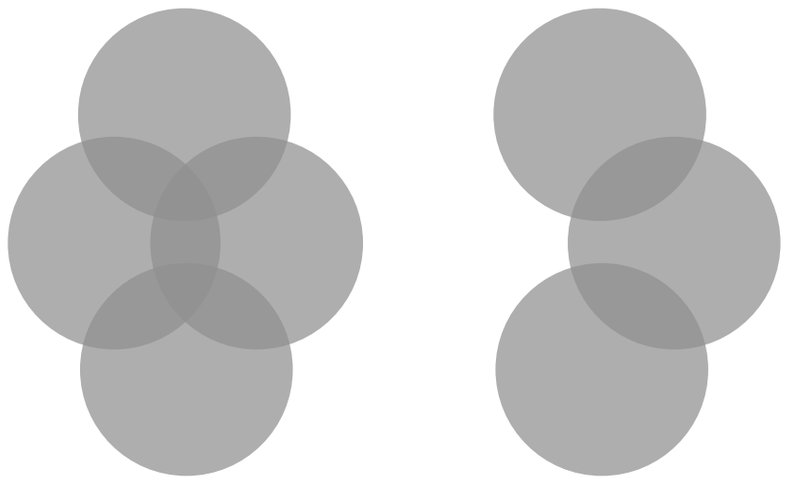


- When $r=2R$:



➢ a morphological parameter = $\dfrac{\text{total area of the connected region}}{\text{\# of connected regions}}$

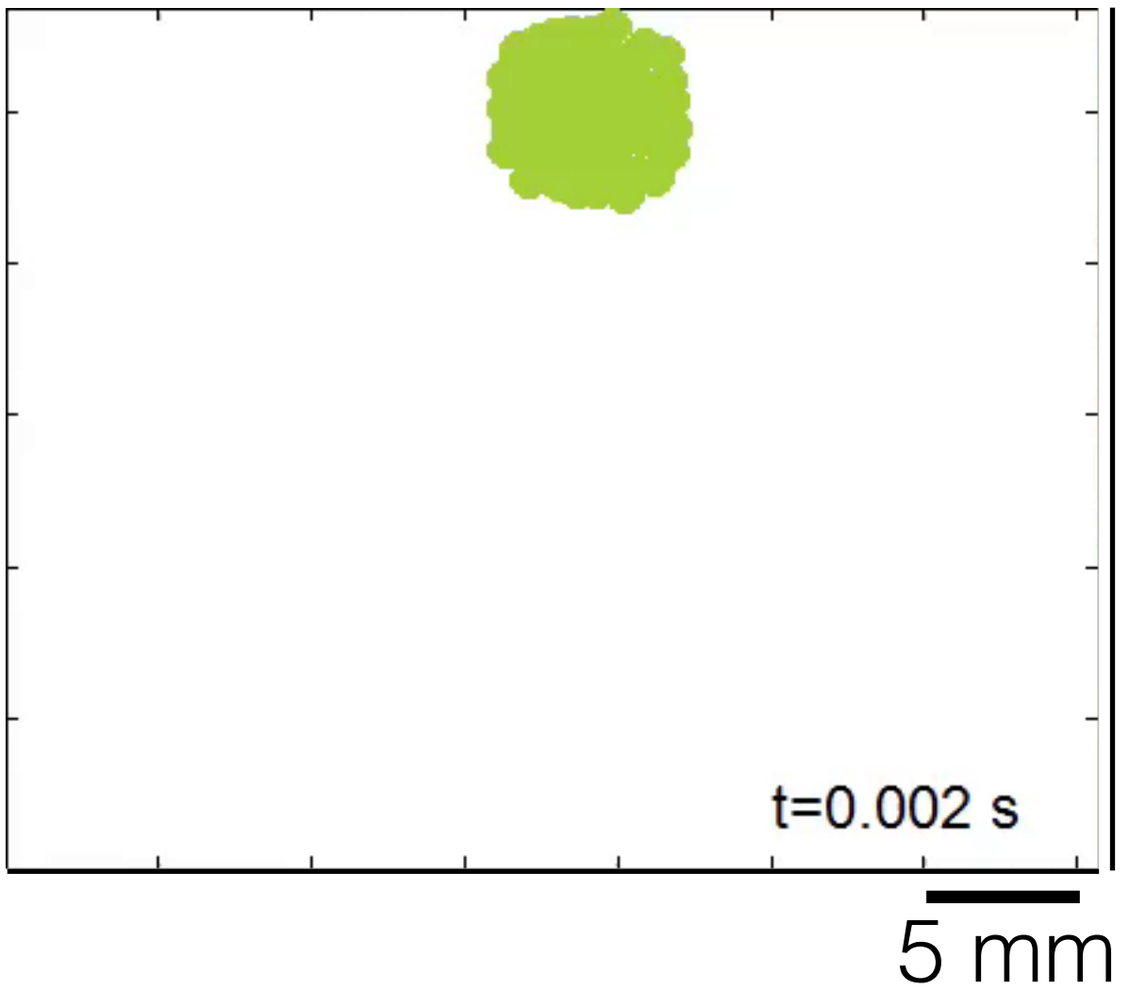




Morphological analysis of subgroups

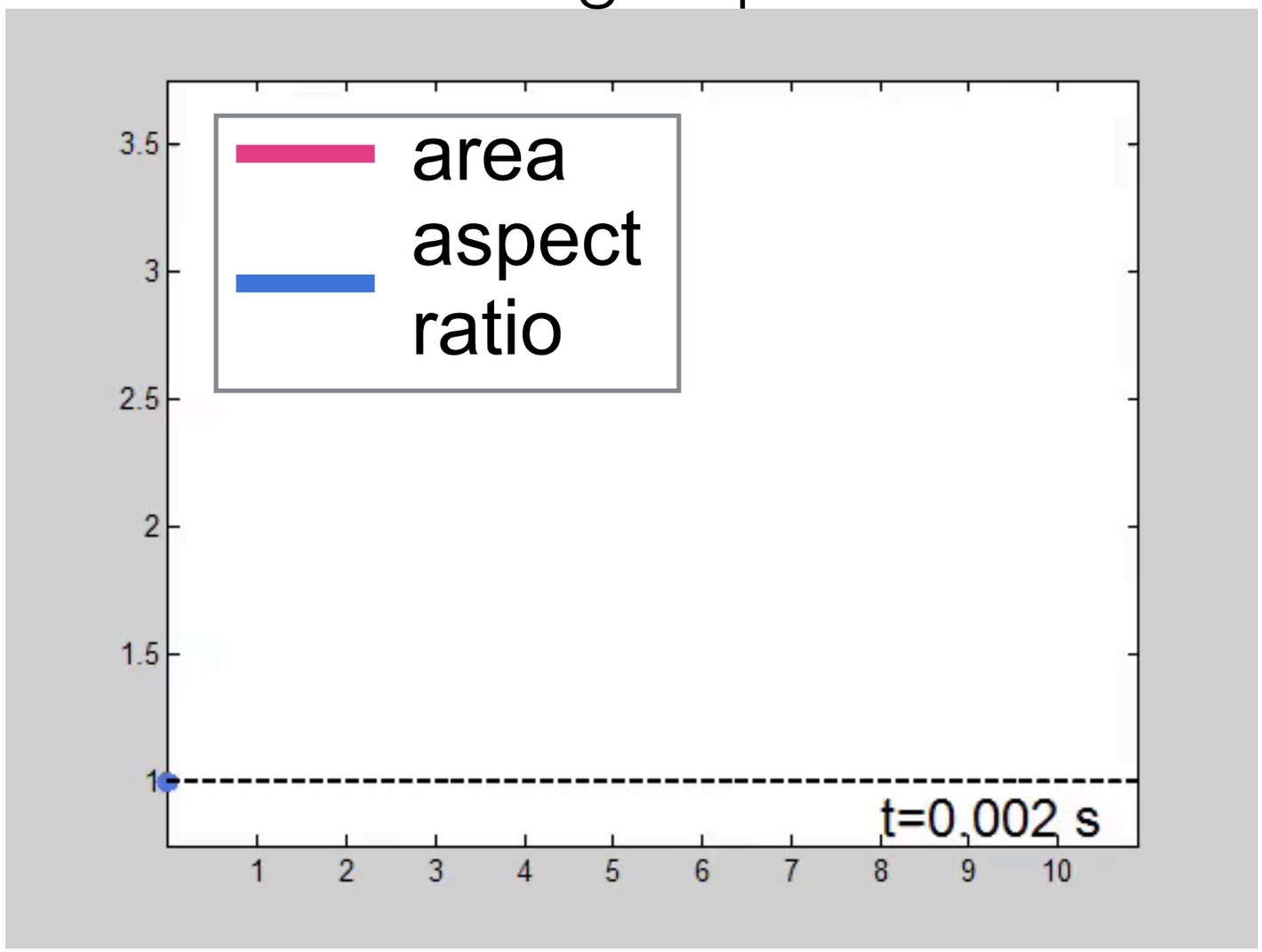
ϕ = 0.76

- time evaluation of a subgroup:



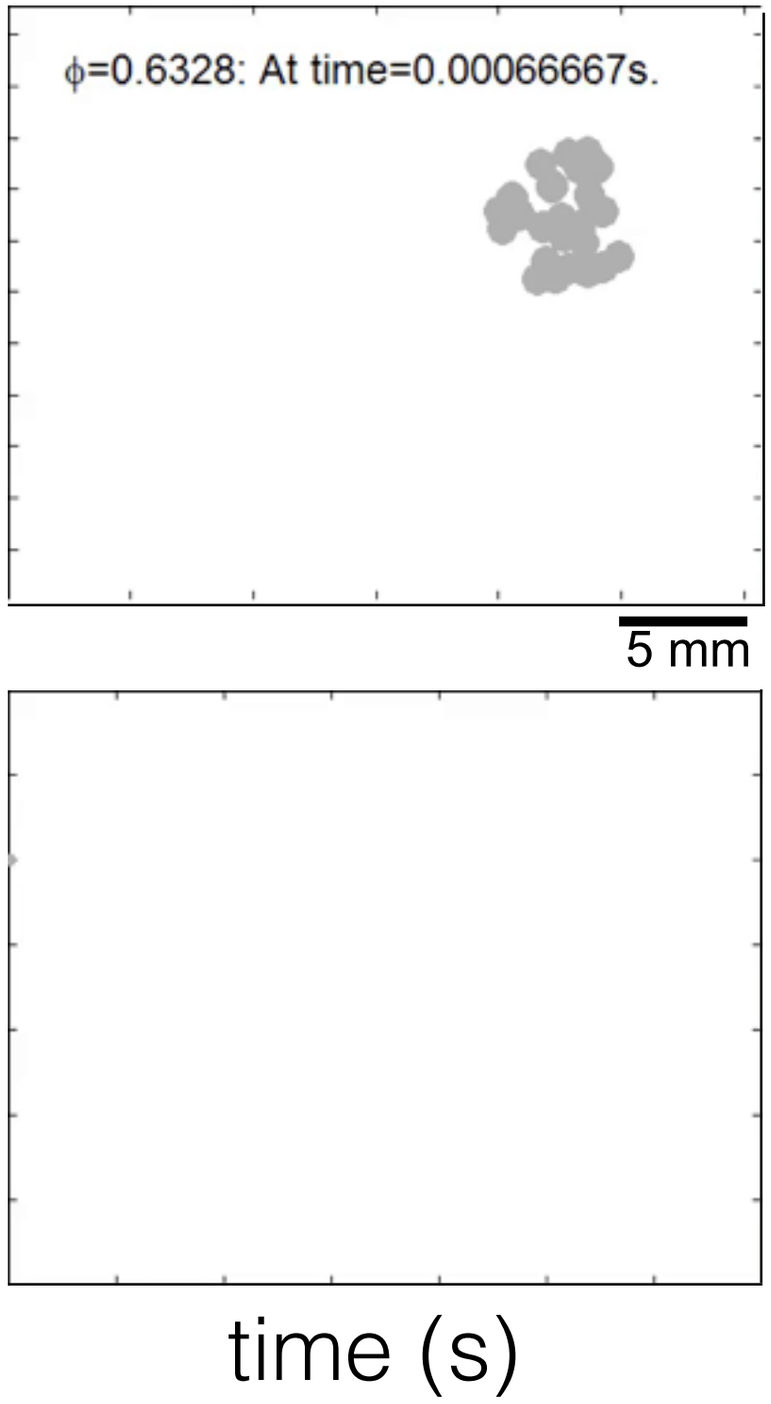
ϕ = 0.76

- morphological deformation of the subgroup:

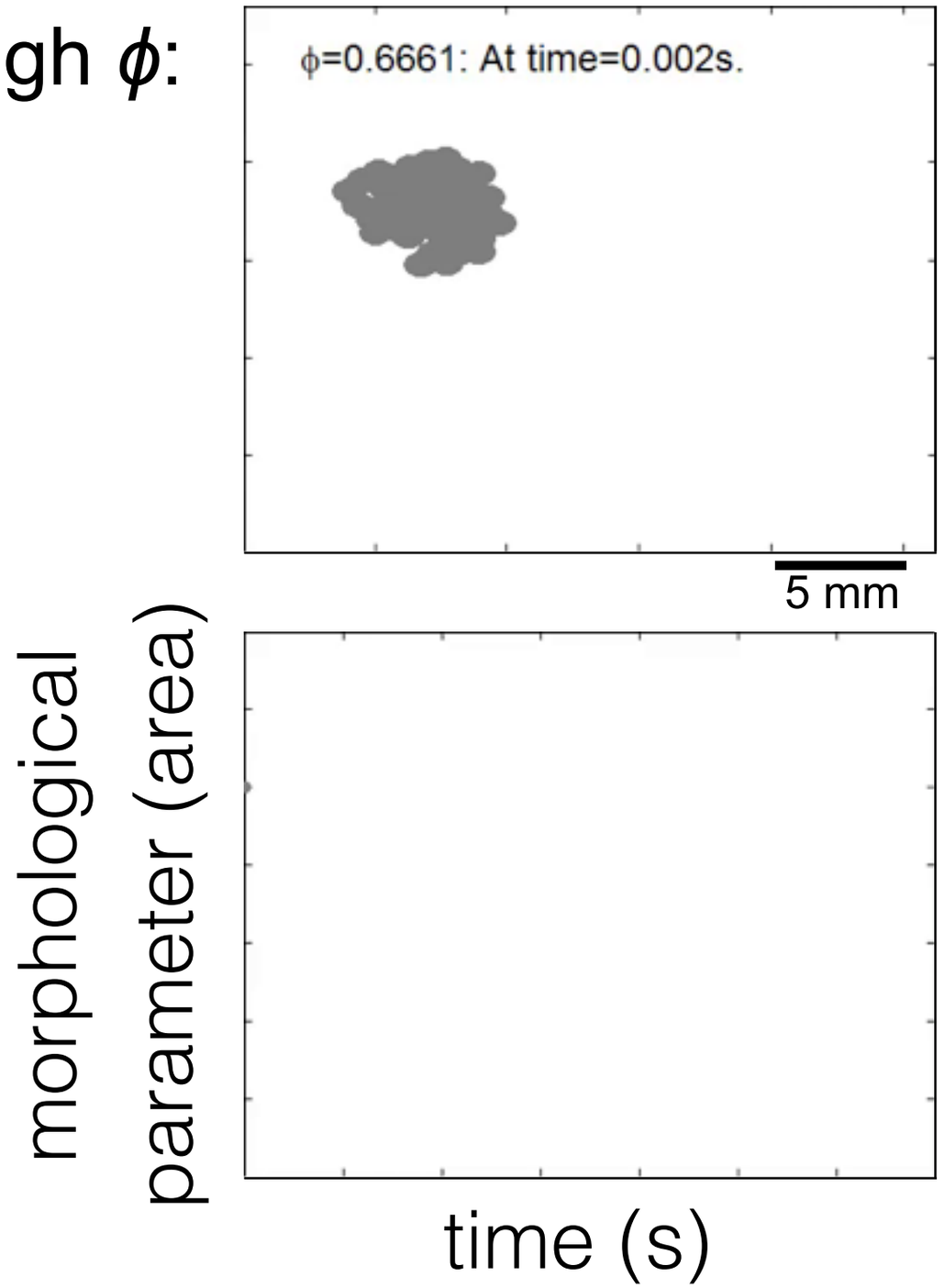


Comparative analysis of subgroups

- low ϕ:

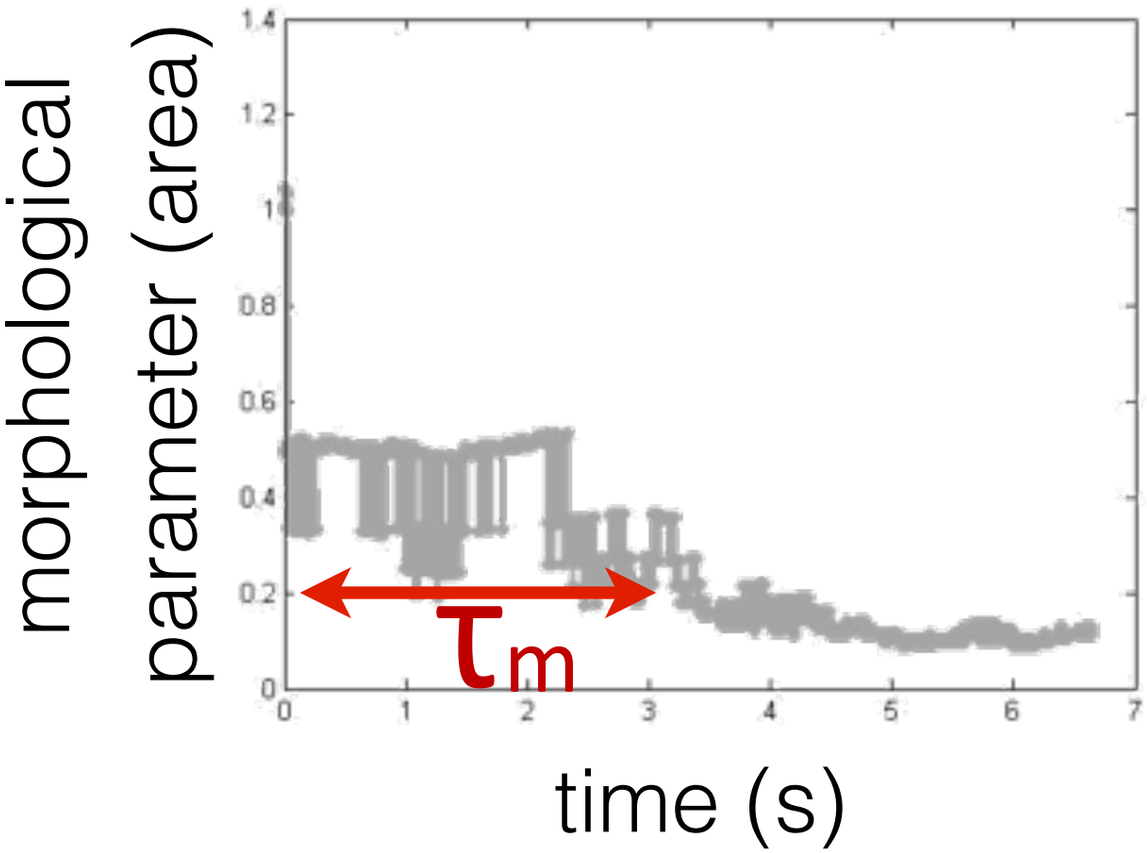


- high ϕ:

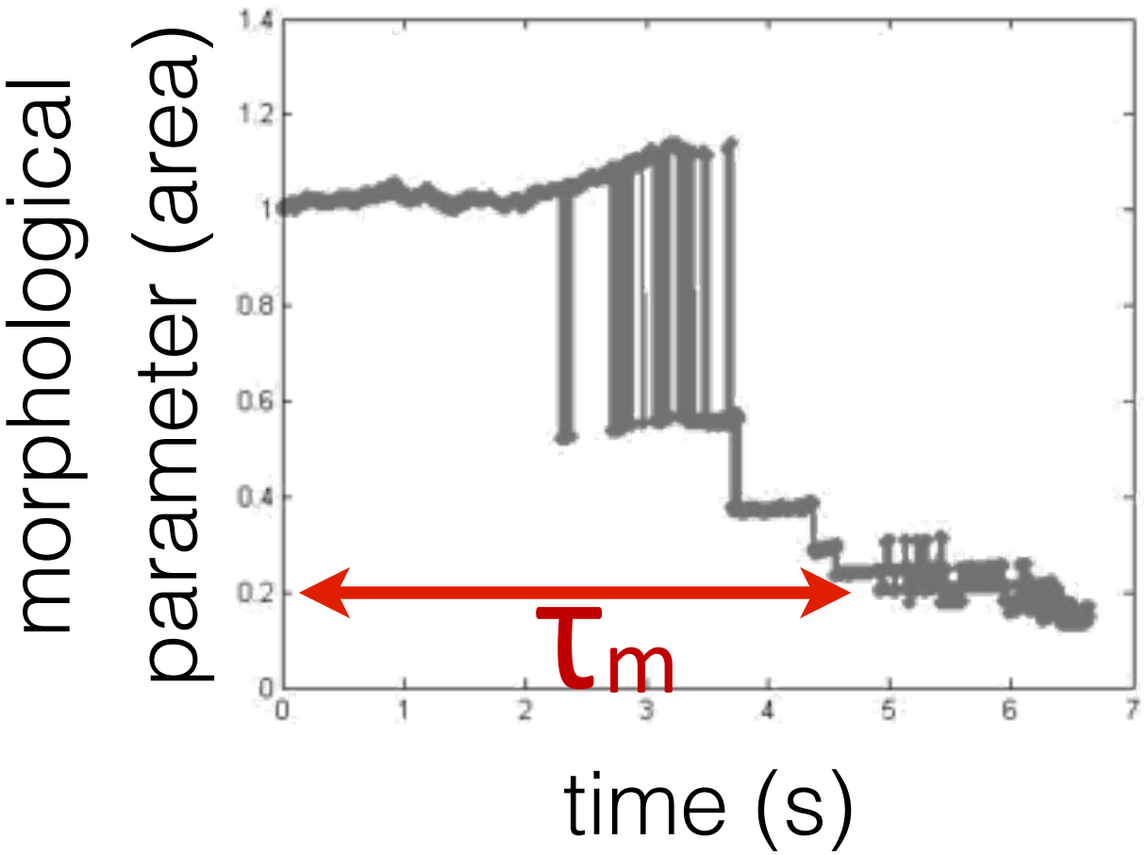


Quantifying break-up time

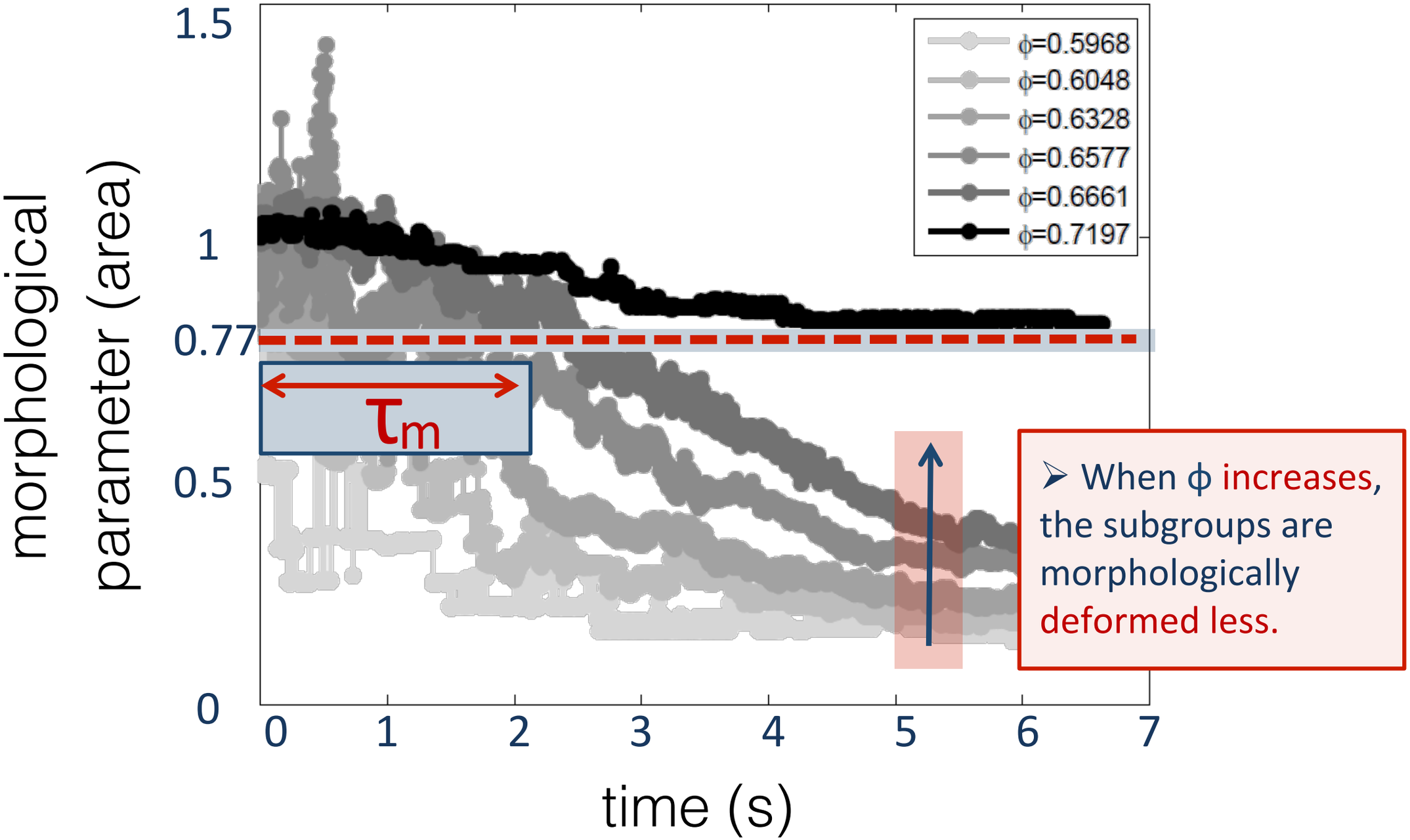
- low ϕ:



- high ϕ:

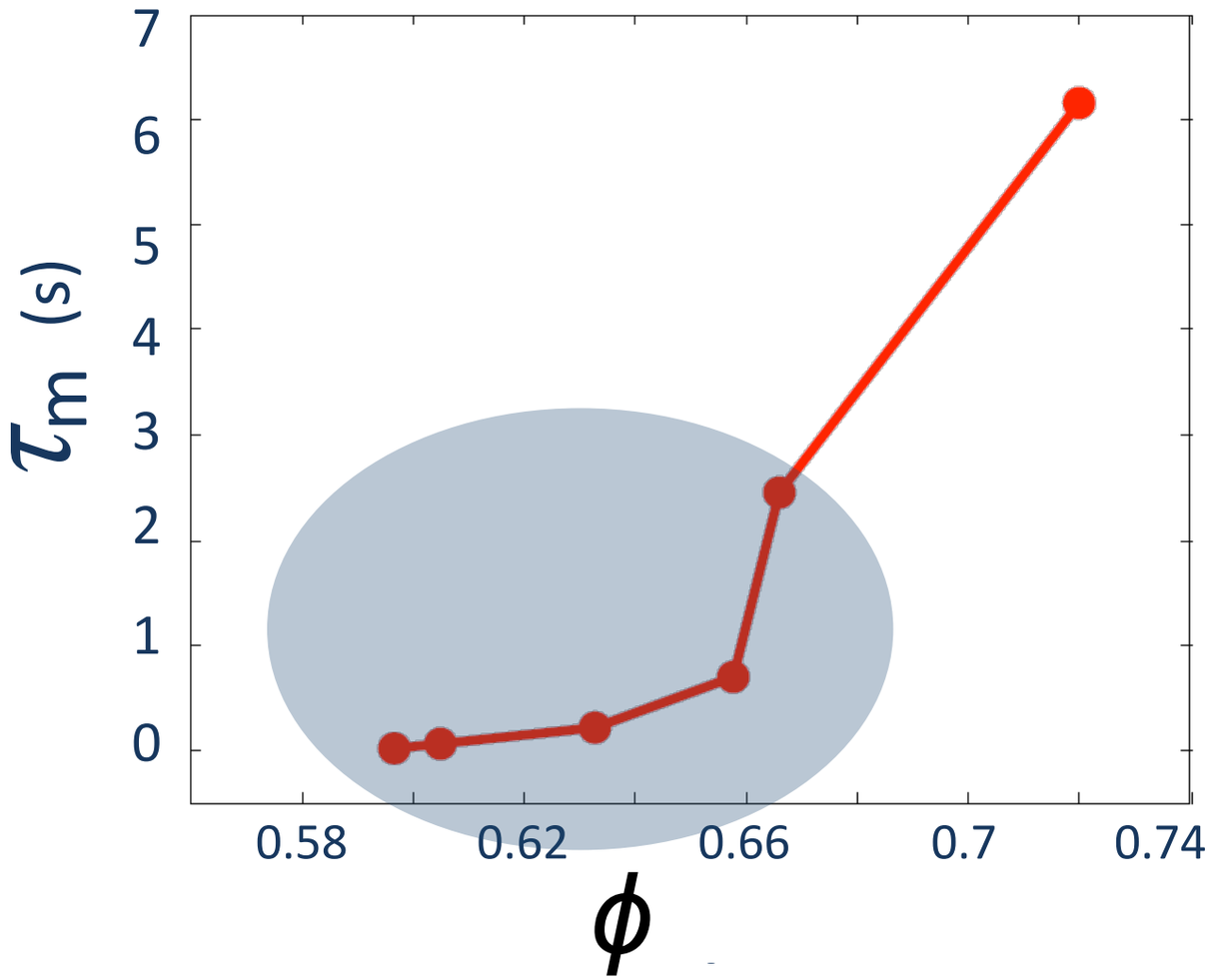


Morphological parameter

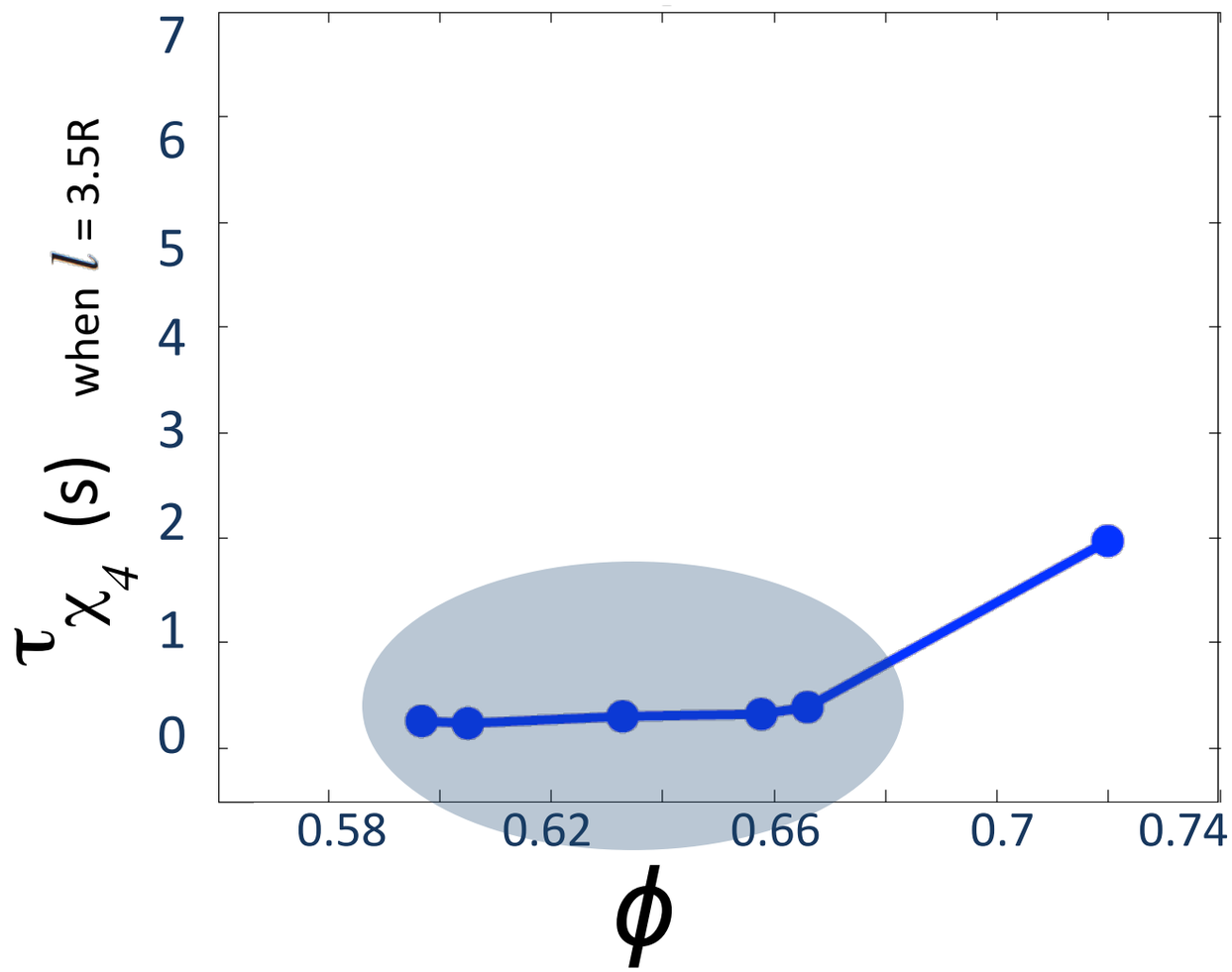


Comparison: In progress

- Morphological analysis

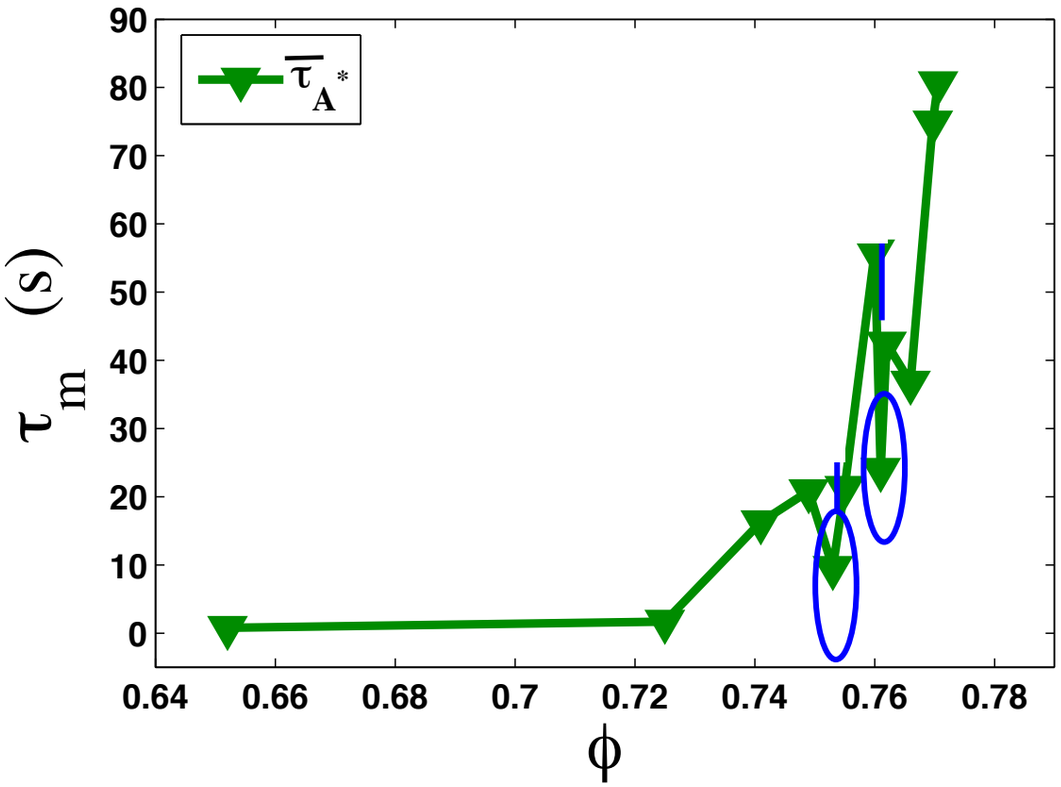


- Four-point dynamic susceptibility

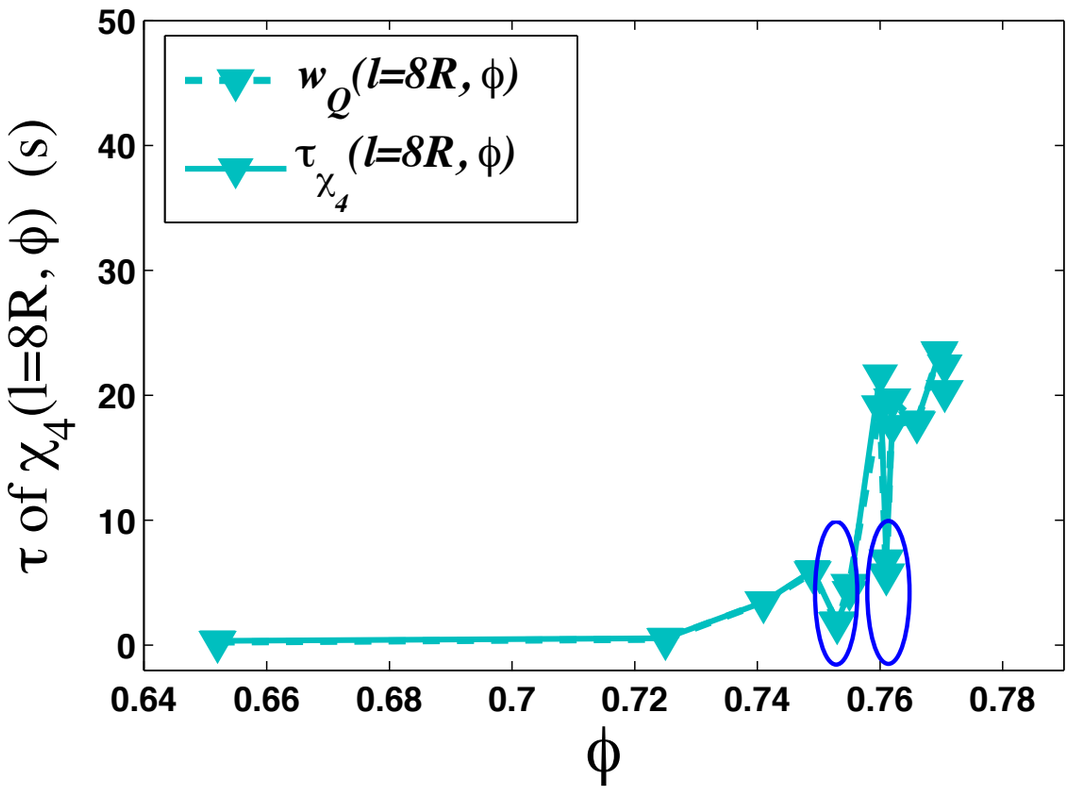


Comparison: In progress

- Morphological analysis

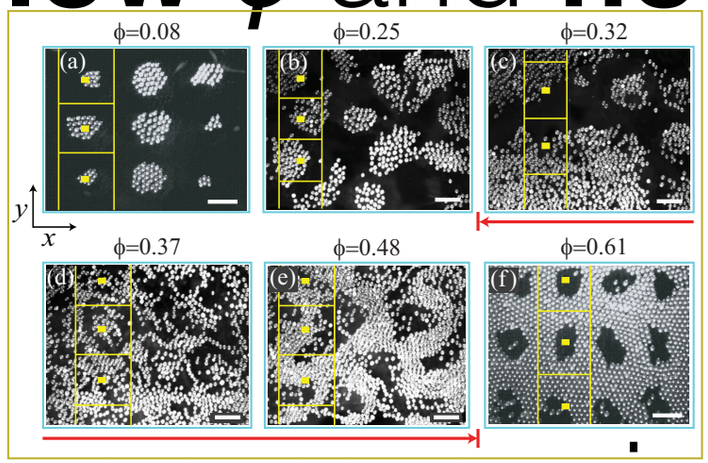


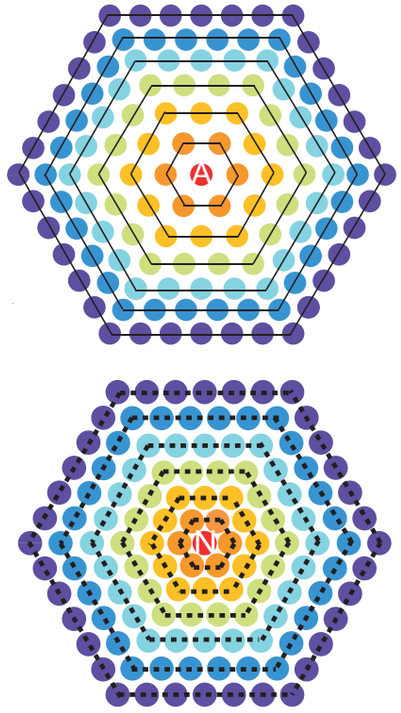
- Four-point dynamic susceptibility



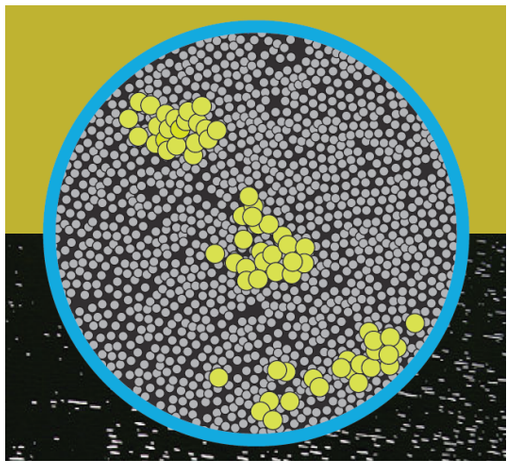
Summary

- On a **standing** Faraday wave regime. **Antinode** clusters at **low ϕ** and **node** clusters at **high ϕ**.



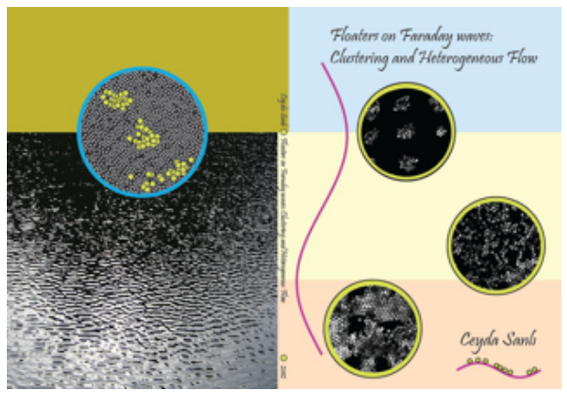


- On a **capillary** Faraday wave regime: We investigate an alternative approach to quantify **heterogeneous** flow by **group deformation**, usually done by the four-point dynamic susceptibility.

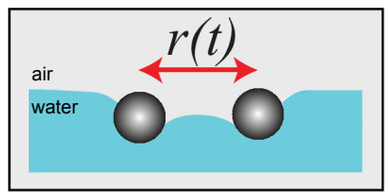


Take home messages

- Dynamics of floaters is too complicated ~ further **4** years project is indeed necessary.



- The deep **theory** behind and there is no exact solution, even for just **two floating spheres on a static surface**



- Currently, our **numerical simulation** cannot reach the experimental limits at **high ϕ.**