BIOACTER-related topics

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KITP, UC Santa Barbara, January 17th 2014

Modeling bacterial motility

- Fluctuation-induced superdiffusive behaviour in E. Coli chemotaxis *(BiophysJ 2009, PLoS One 2011)*
- Sensing vs communicating: pattern formation *(PLoS One 2013)*
- Twitching motility in P. Aeruginosa: effect of pili microscopic properties (e.g. elasticity) on macroscopic trajectories *(preprint)*

Modeling active colloids

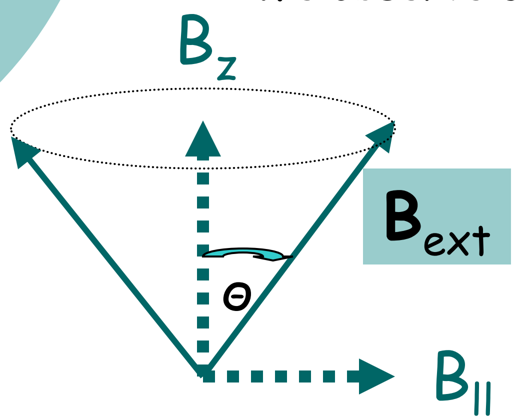
- Walking DNA-coated colloids *(submitted)*
- Phase separation in hard colloids with density-dependent propulsion *(in progress)*
- Interactions between passive colloids induced by active medium *(in progress)*

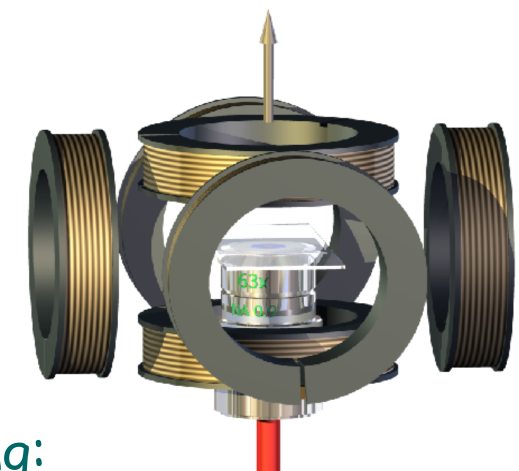
"Almost active" magnetic colloids

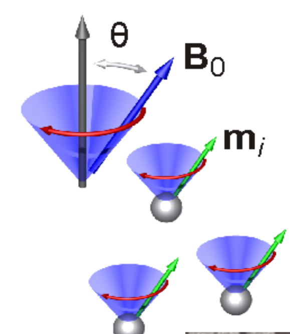
EXPERIMENTS: **Natan Osterman, Gašper Kokot, Dušan Babič**
University of Ljubljana, Slovenia

Superparamagnetic colloids in external time-dependent fields

- Interactions are externally induced
- Driving is the same for all the particles → not active
- **Many-body effects**: interactions depend strongly on local structure
- We observe **chains** and **membrane** formation as well as **dynamic vortices**

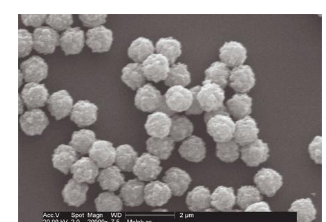






precessing field cone opening:
$tg(\Theta) = B_{||}/B_z$

Dynabeads MyOne, 1 μm



Magnetic interaction: SCFI

Superparamagnetic colloids in external magnetic field:

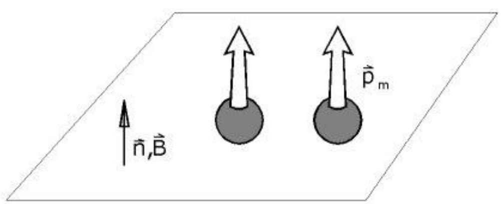
$$\mathbf{m}_i = \chi V \left[\mathbf{B}_0 + \sum_j \mathbf{B}_j(\mathbf{r}_i) \right] \Big/ \mu_0$$

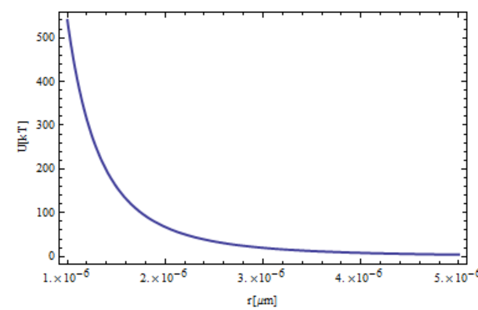
~1/r³ induced interactions

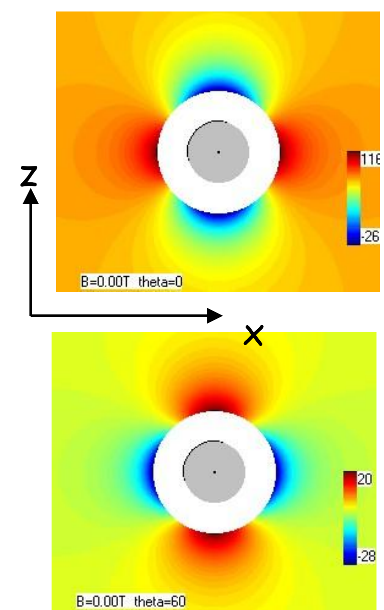
[redacted]

movies

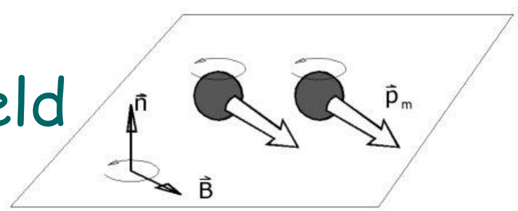
static field

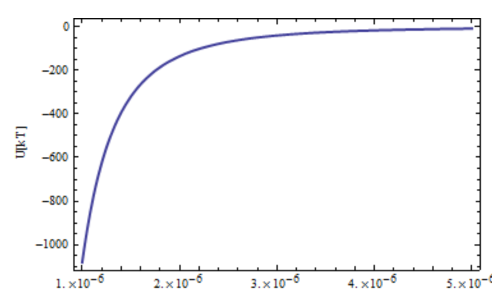






rotating field





Martin et al. *J. Chem. Phys.* **118**, 1557 (2003)

Magic Angle Geometry (bulk system)

magic angle:

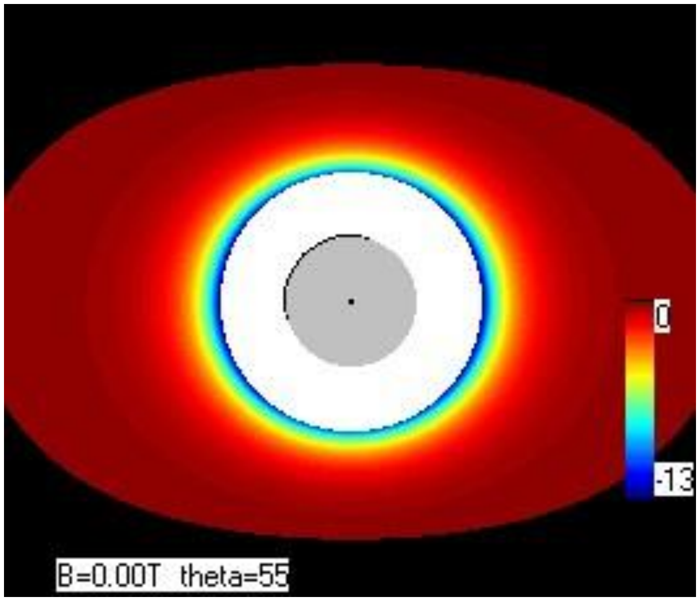
$\Theta_m = arccos\ (1/\sqrt{3}) \approx 54.7°$

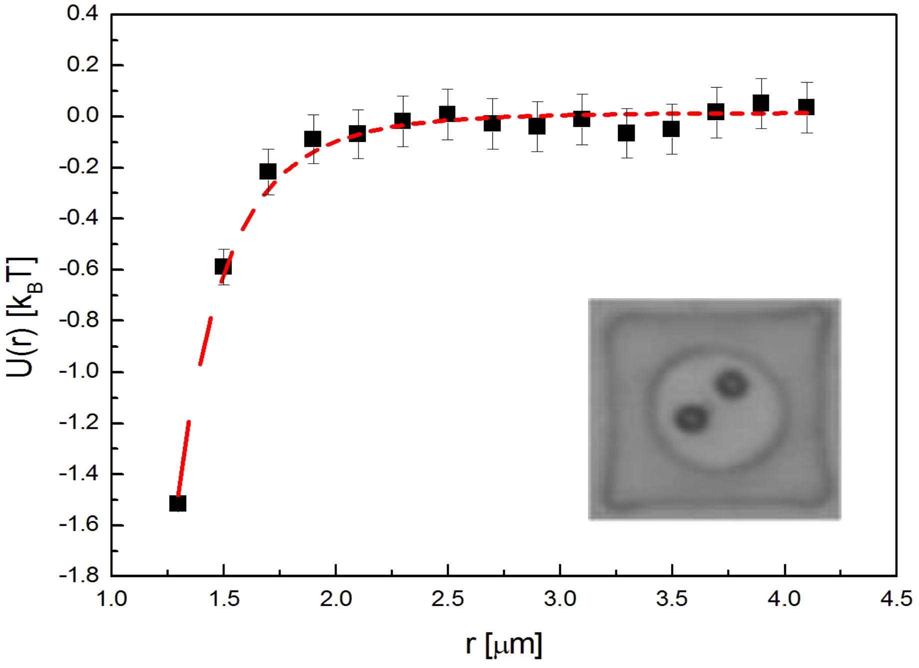
r^{-3} terms vanish

isotropic r^{-6} attraction in 3D!

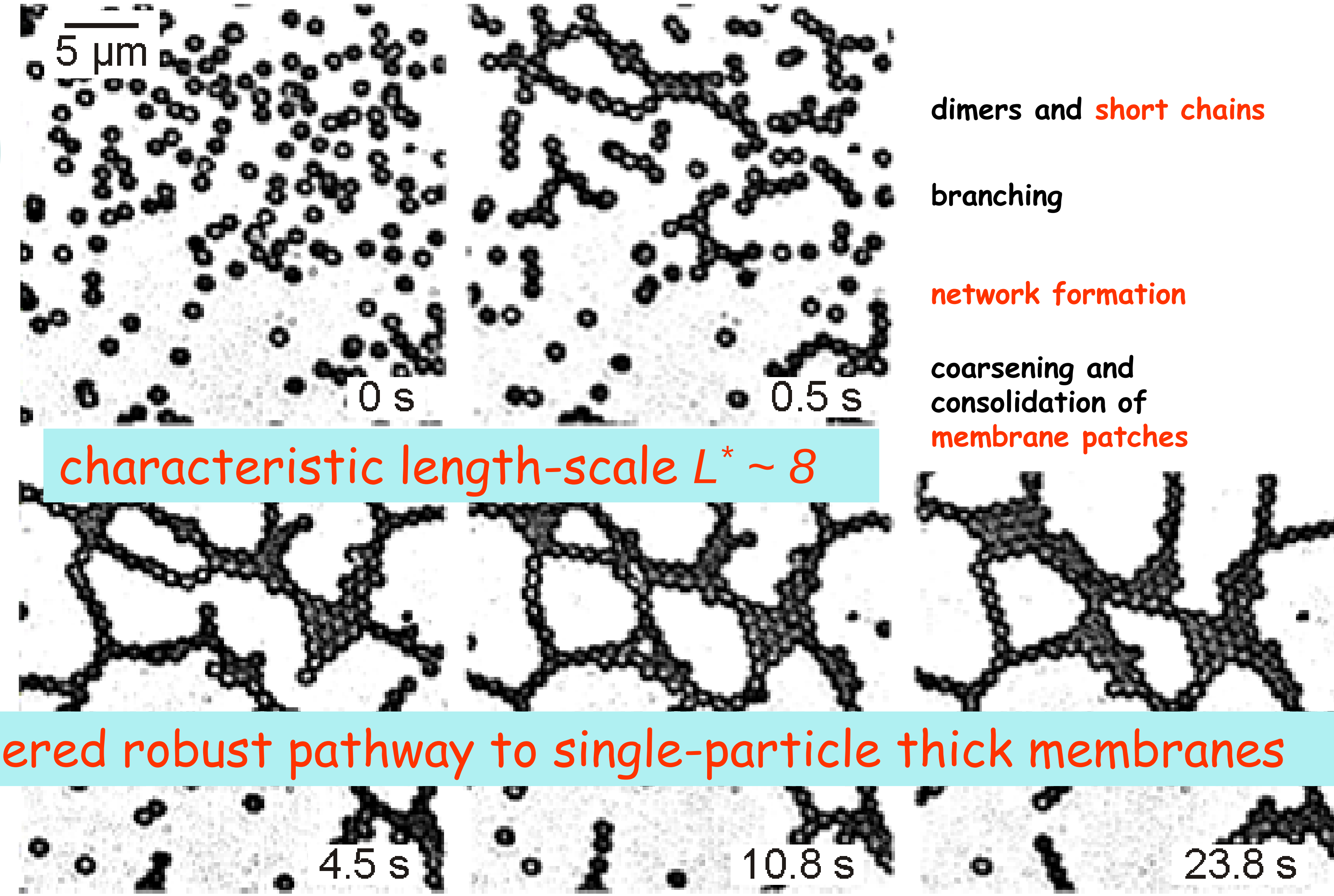
(SCFI: van der Waals-like)

$$U_2(r) = -3\chi^3 V^3 B_0^2 / 8\pi^2 \mu_0 r^6$$





Experiment: aggregation in 3D at magic-angle



dimers and short chains

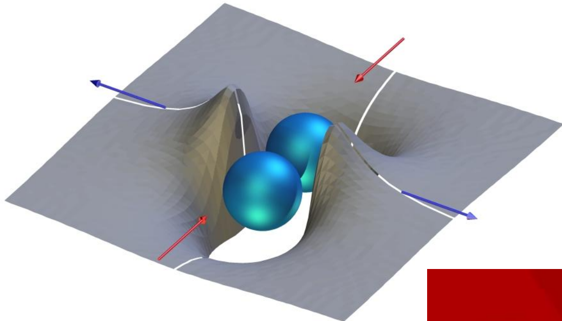
branching

network formation

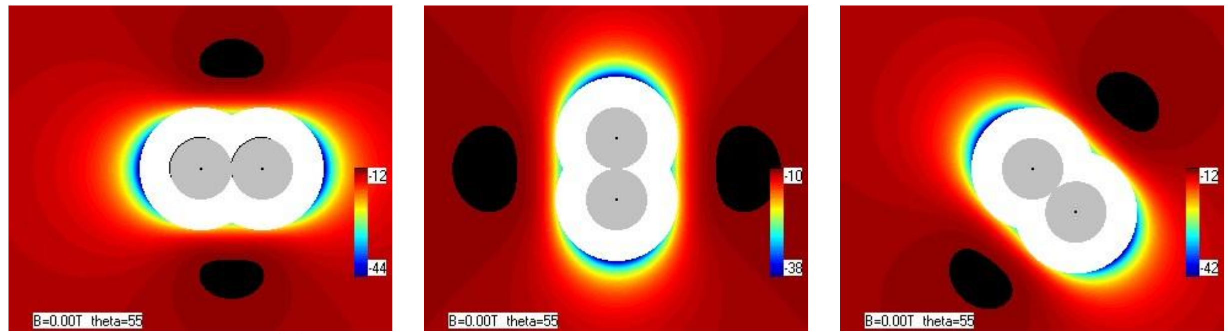
coarsening and consolidation of membrane patches

characteristic length-scale $L^* \sim 8$

ordered robust pathway to single-particle thick membranes

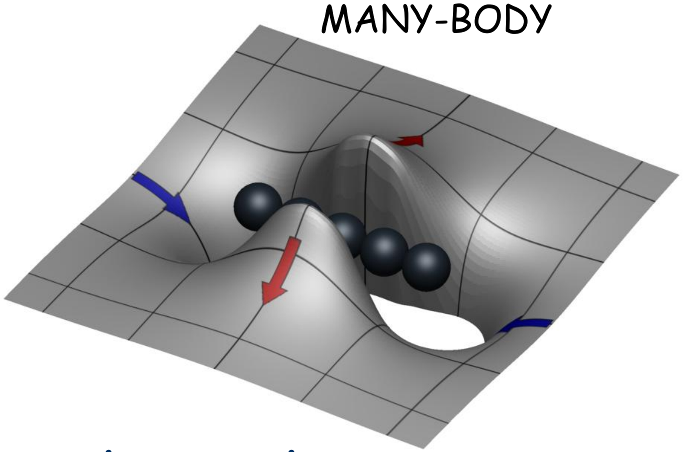


Interaction potential

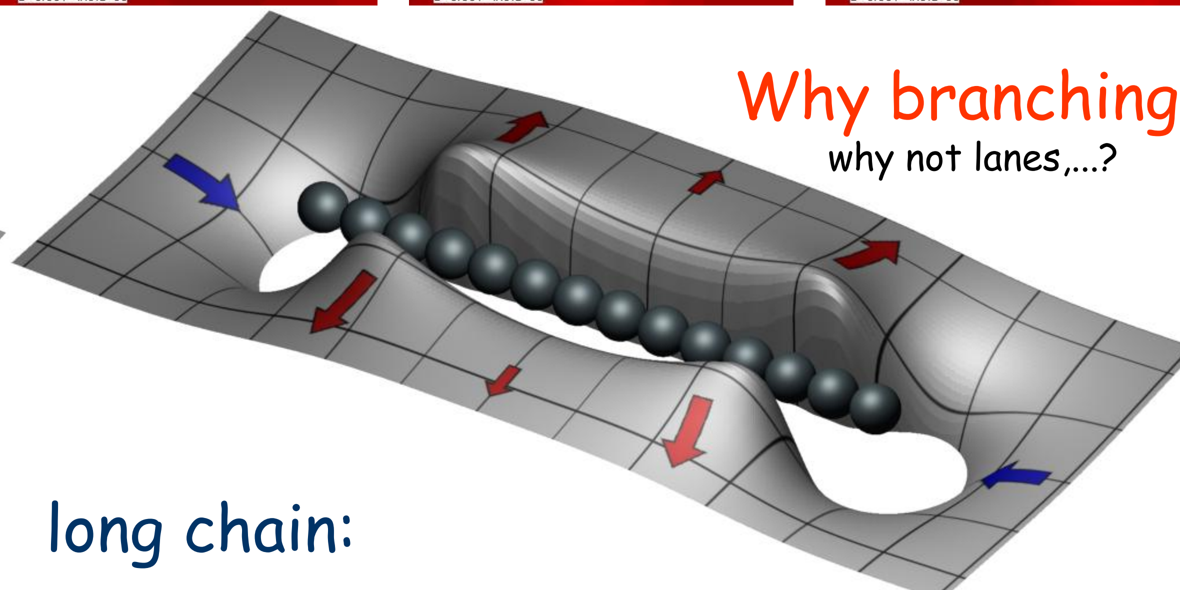


test particle
around dimer

Why chains?
MANY-BODY



Why branching?
why not lanes,...?



short chain:
lateral barrier
~ 1.6 $k_B T$

long chain:

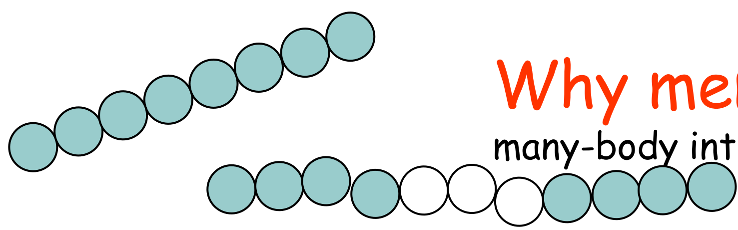
saddle-shaped barrier « 1 $k_B T$
→lateral attachment likely for $L \geq 8$ ($=L^*$)

Membranes

phenomenological model

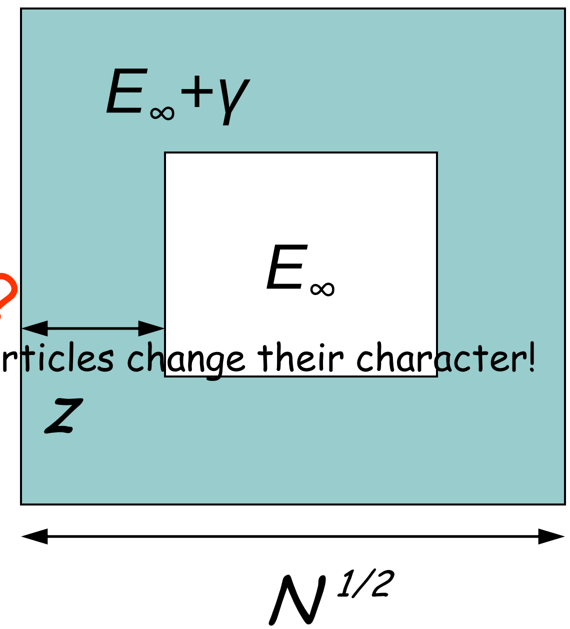
membranes are stable

chains: core and caps



Why membranes?

many-body interactions → particles change their character!

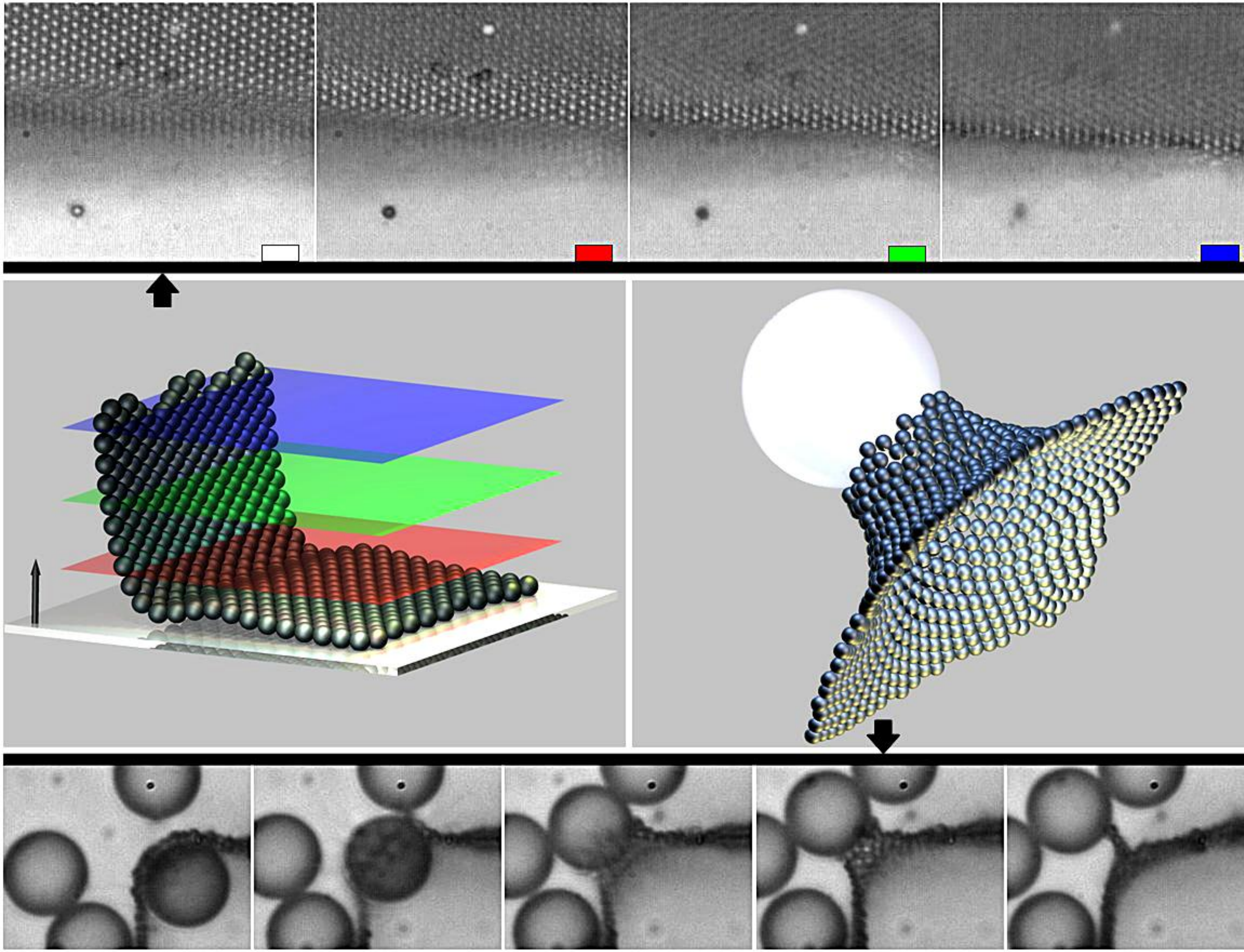


$L^* = 2\, z^* = 8$ consistent result

$$E(N) = E_\infty + 4z\gamma N^{-1/2}\left(1 - zN^{-1/2}\right)$$

$$E_\infty = -119 k_B T \qquad z^* = 4 \qquad \gamma^* = 52 k_B T$$

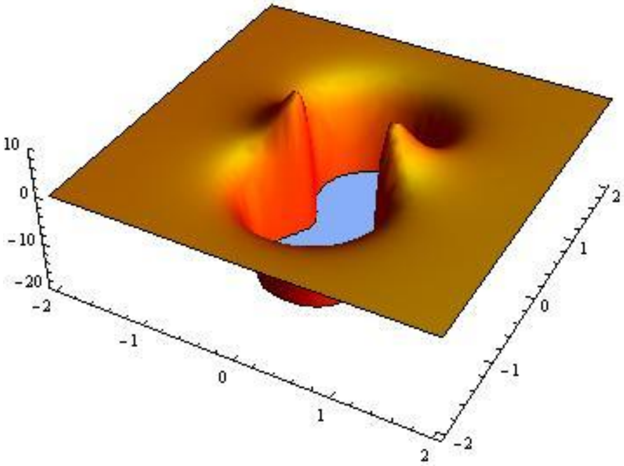
Phys.Rev. Lett. ***103*** *228301 (2009)*



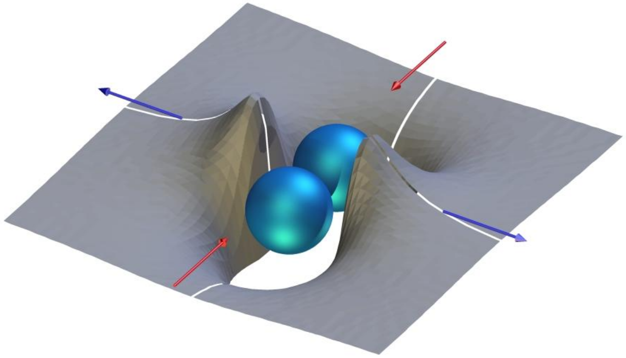
Phys.Rev. Lett. **103** 228301 (2009)

VdW vs SCFI

AT 3-body term in VdW



van der Waals:
decoherent dipole fluctuations
→ weaker many-body effects
→ bulk aggregates, ...



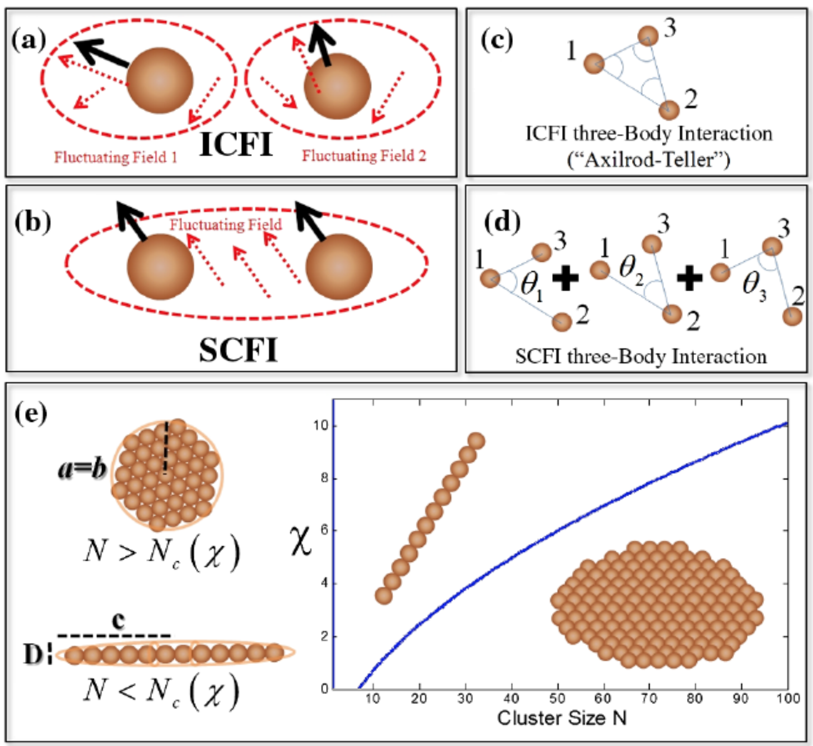
Coherently varying fields:
→ enhanced many-body terms
→ low-dimensional structures

VdW (ICFI) vs SCFI

PRL 111, 198301 (2013) PHYSICAL REVIEW LETTERS week ending 8 NOVEMBER 2013

Self-Assembly of Colloidal Superstructures in Coherently Fluctuating Fields

Igor M. Kulić[1,*] and Miodrag L. Kulić[2,†]



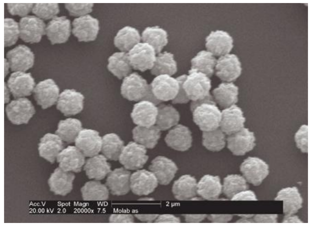
2-body:

$$\sim \chi_b^2 R^{-6}$$

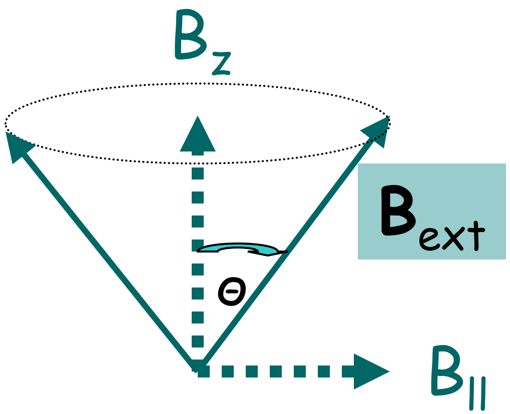
3-body:

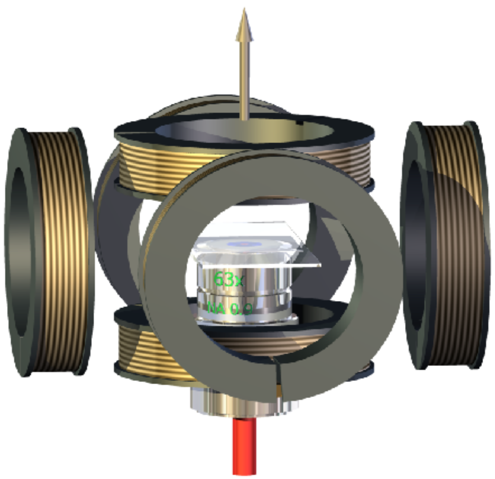
$$\sim \chi_b^3 R^{-9} \quad \text{ICFI}$$

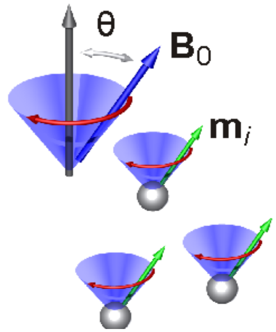
$$-\chi_b^3 |\mathbf{R}_{ij}|^{-6} \quad \text{SCFI}$$



Physical rotation of colloids







Flipping the direction → suppressing rotation → no HD

What happens if we let them rotate?

Hydrodynamics

I. Pagonabarraga: rotators in liquid

Eur. Phys. J. E **26**, 103–113 (2008)

- hexagonal array of rotators is unstable
- inertia (high Re) can stabilize it

Possible scenario:

- single colloid membrane unstable

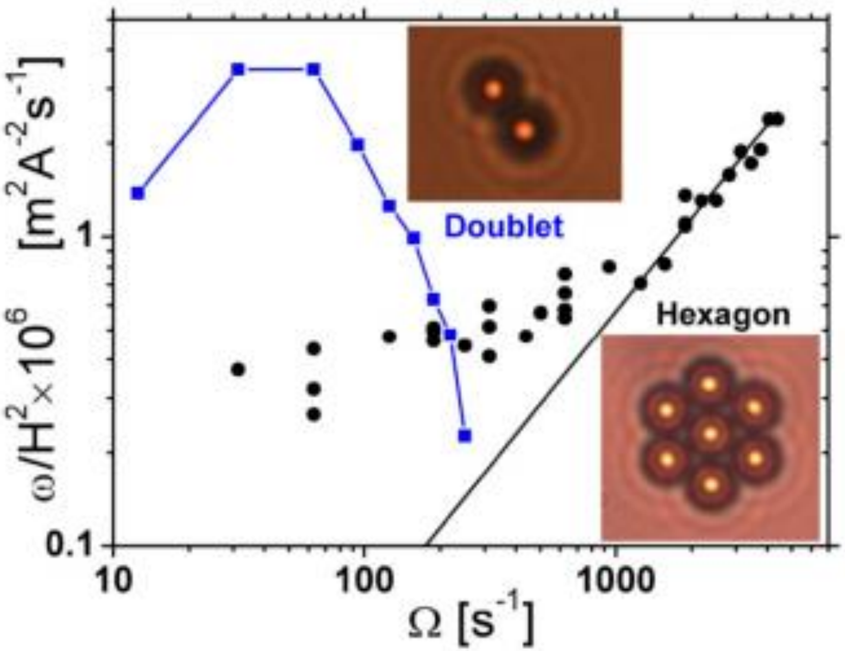
(viscous hydrodynamics vs magnetic) → vortices (?)

- inertial terms stabilize **hexagonal array of vortices** (?)

Work in progress...

Rotating clusters *(Fischer et al.)*

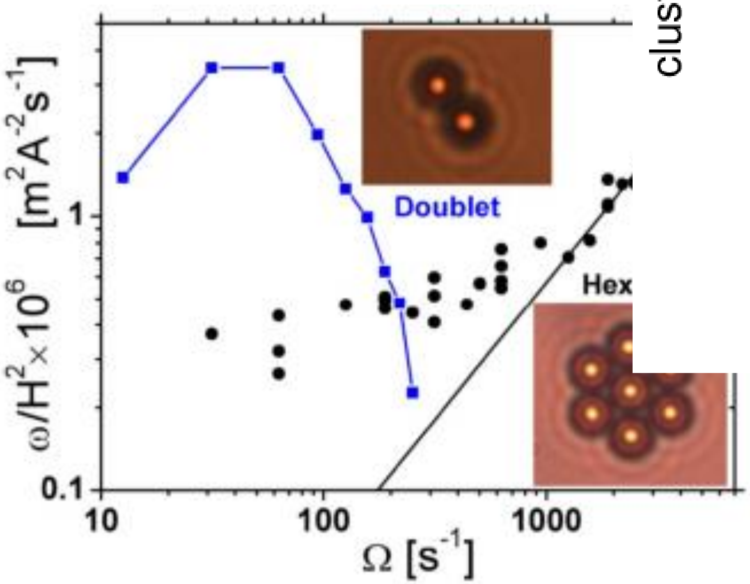
- Chains rotate due to anisotropic susceptibility
- Hexagons rotate due to tidal locking of the shear deformation *(P. Tierno, R. Muruganathan and T.M. Fischer, PRL 2007)*

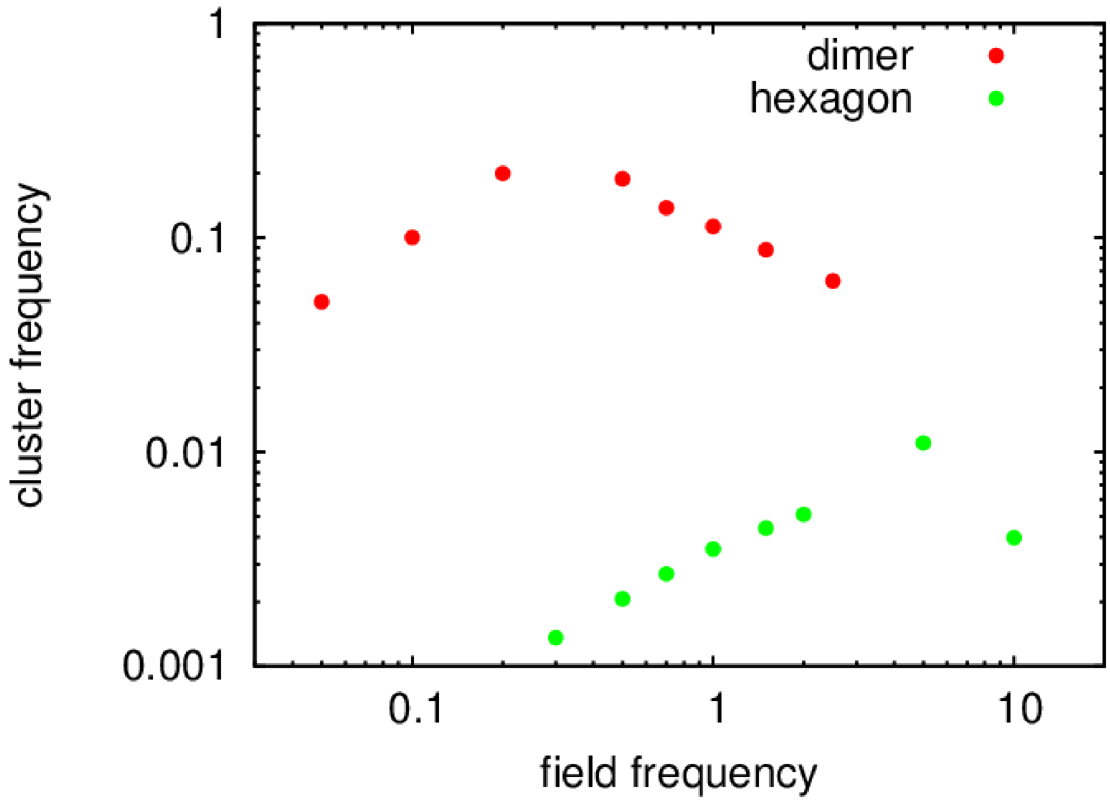


Synchronization-induced structural transition in magnetic Jamus colloids:

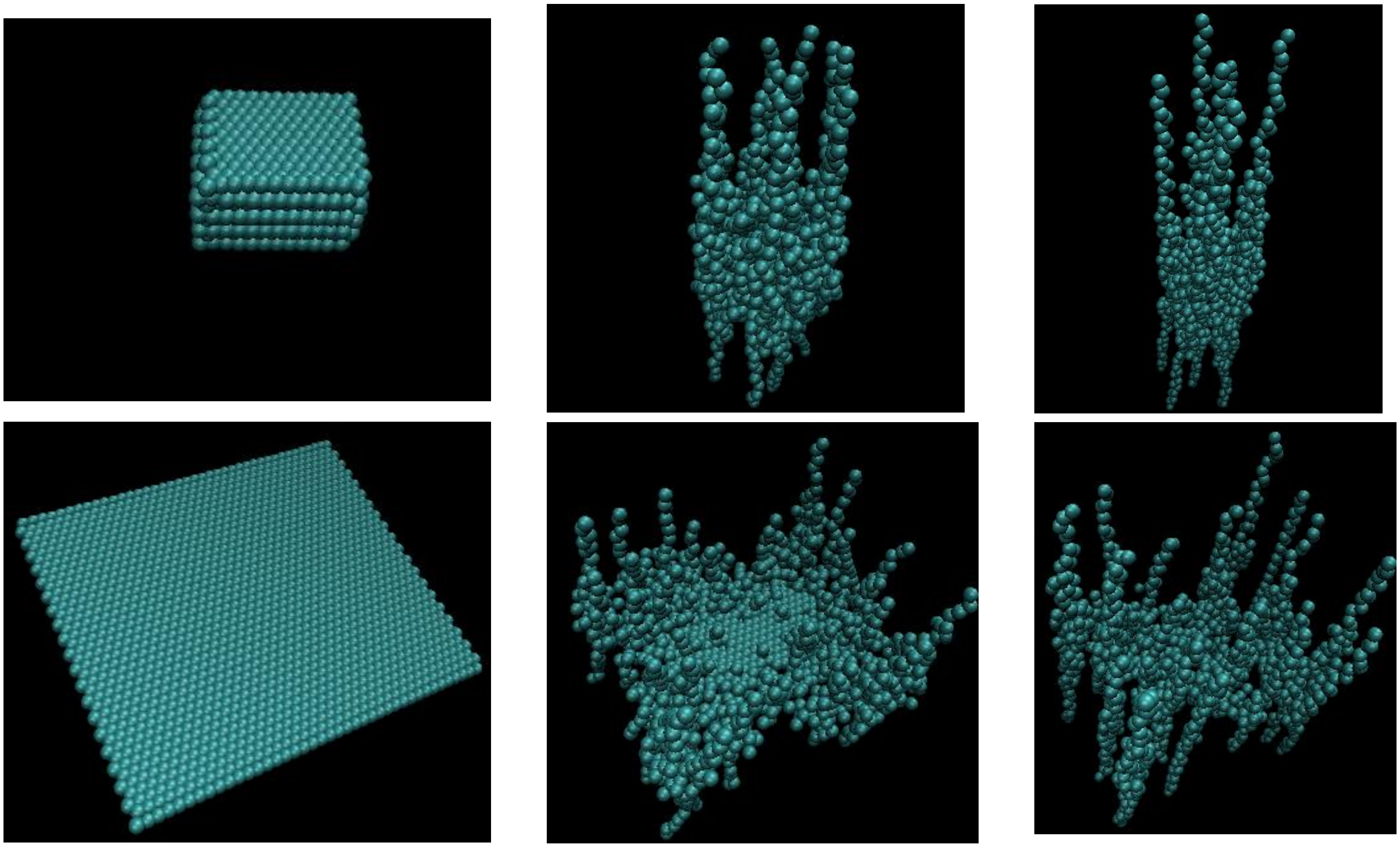
Jing Yan, Moses Bloom, Sung Chul Bae, Erik Luijten & Steve Granick, Nature **491**, 578 (2012)

SIMULATIONS (in progress)



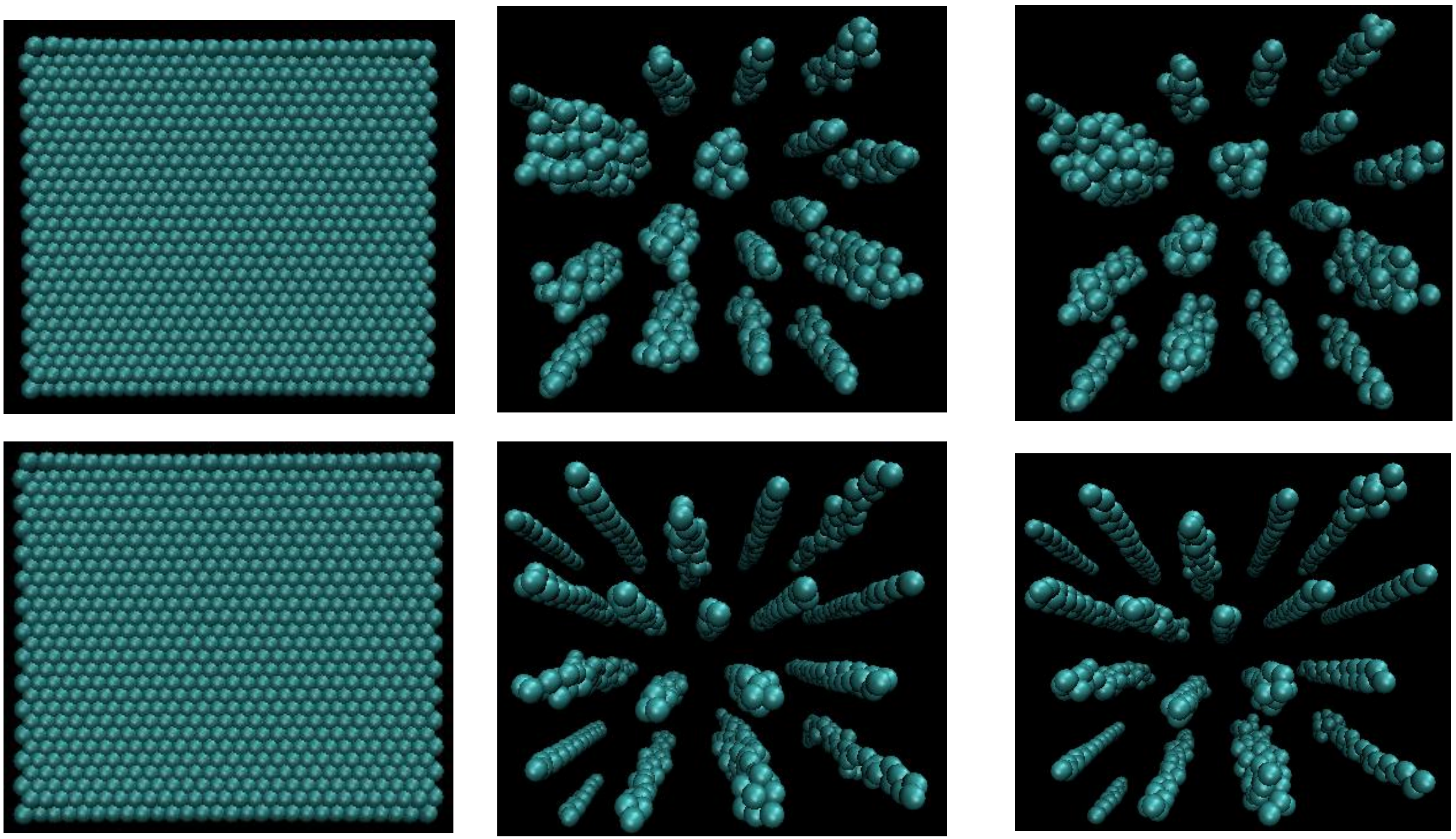


SIMULATIONS (very preliminary)



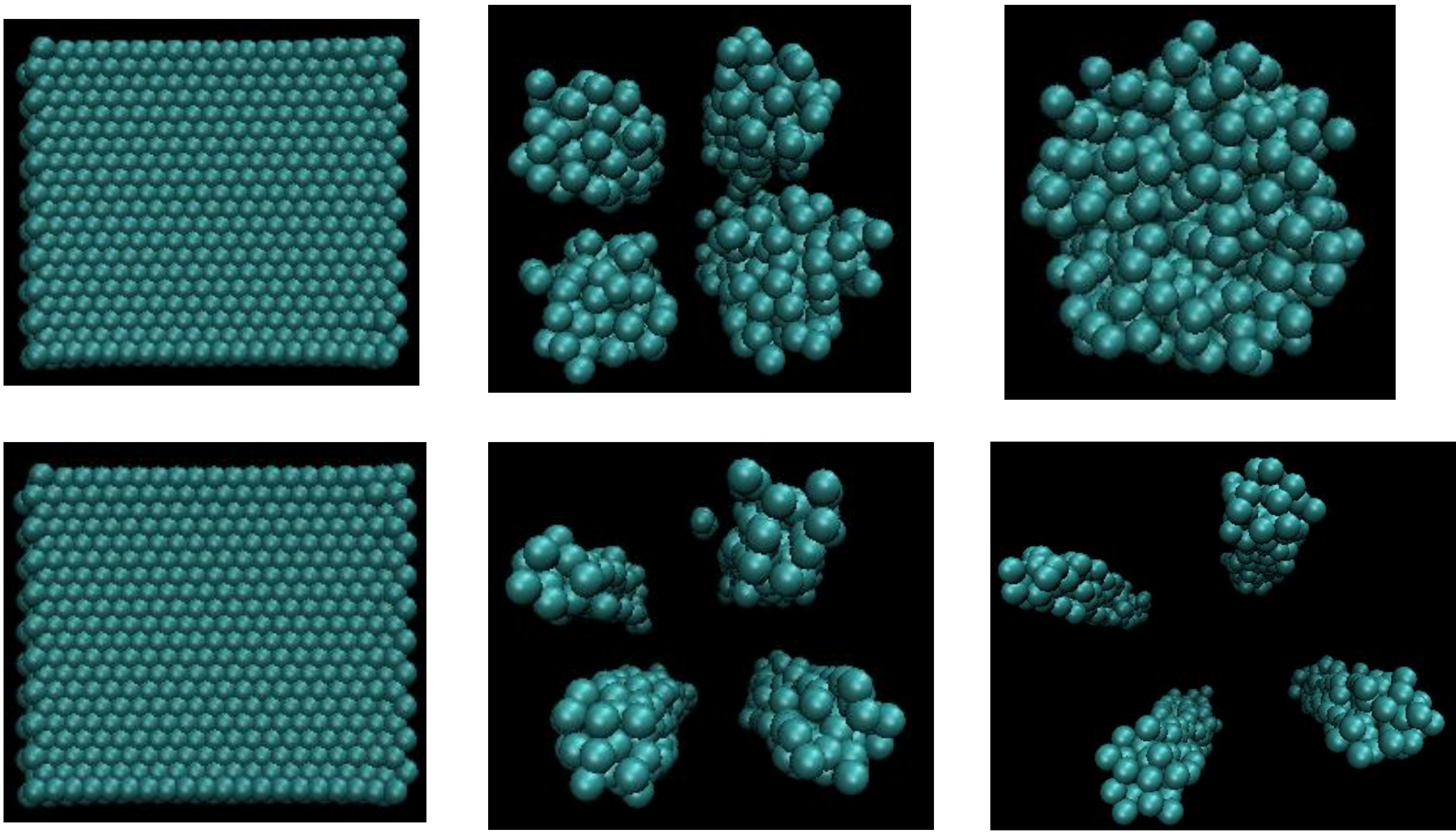
Initial state | 10^6 steps | 2×10^6 steps

Dependence on initial conditions



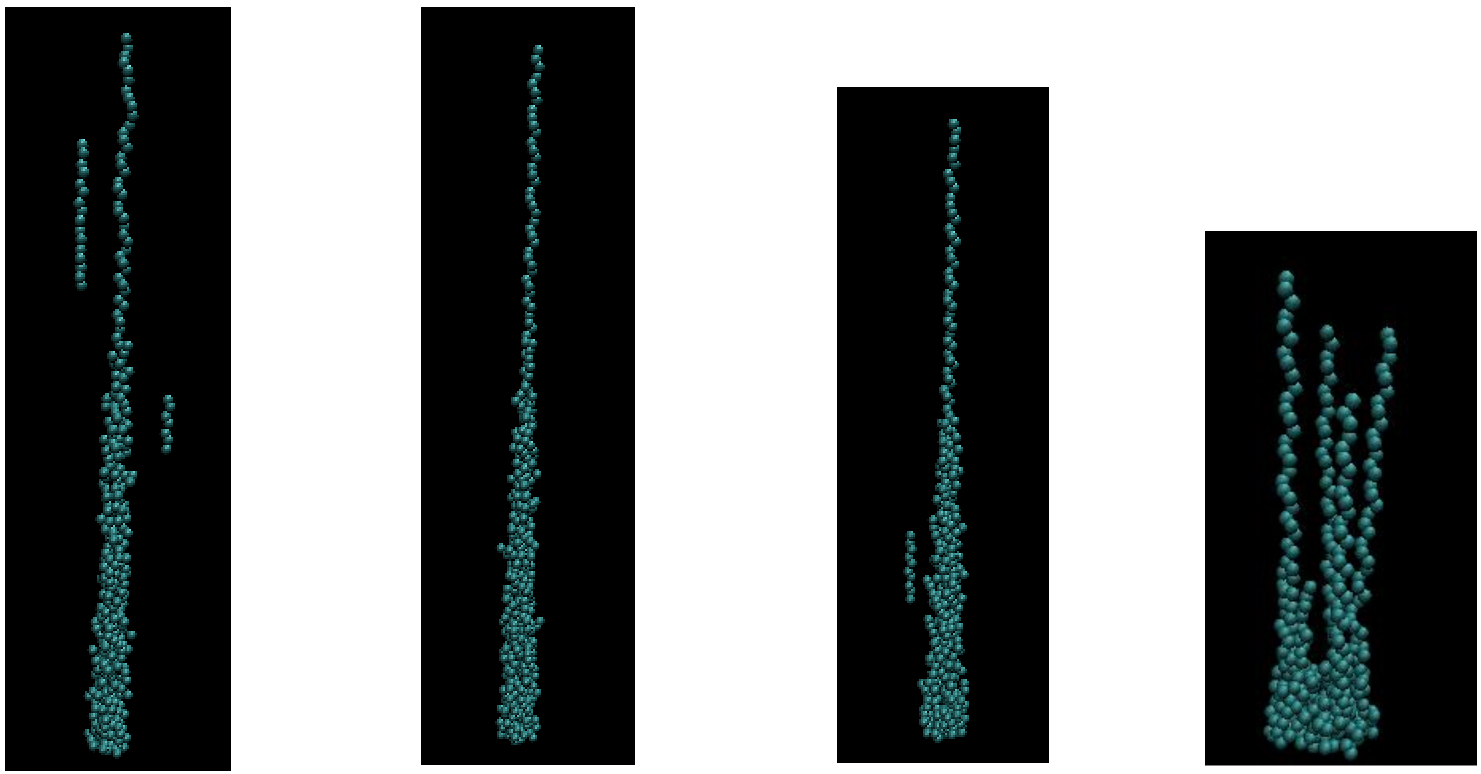
Initial state | 10^6 steps | 2×10^6 steps

Dependence on initial conditions



Initial state | 10^6 steps | 2×10^6 steps

Effect of gravity …



16 mT | 10 mT | 5 mT | 2.5 mT

in progress …

Conclusions

Rich emergent behaviour

Equilibrium self-assembly:
Low-dimensional structures, closed-shell objects?

Dynamic self-assembly:
we need to understand better what is going on...

Thank you.