Complex Colloidal Self-Assembly: Towards Designer Materials

19 JAN 2023 – SOFT MATTER & SELF-ASSEMBLY WORKSHOP 4TU.HTM

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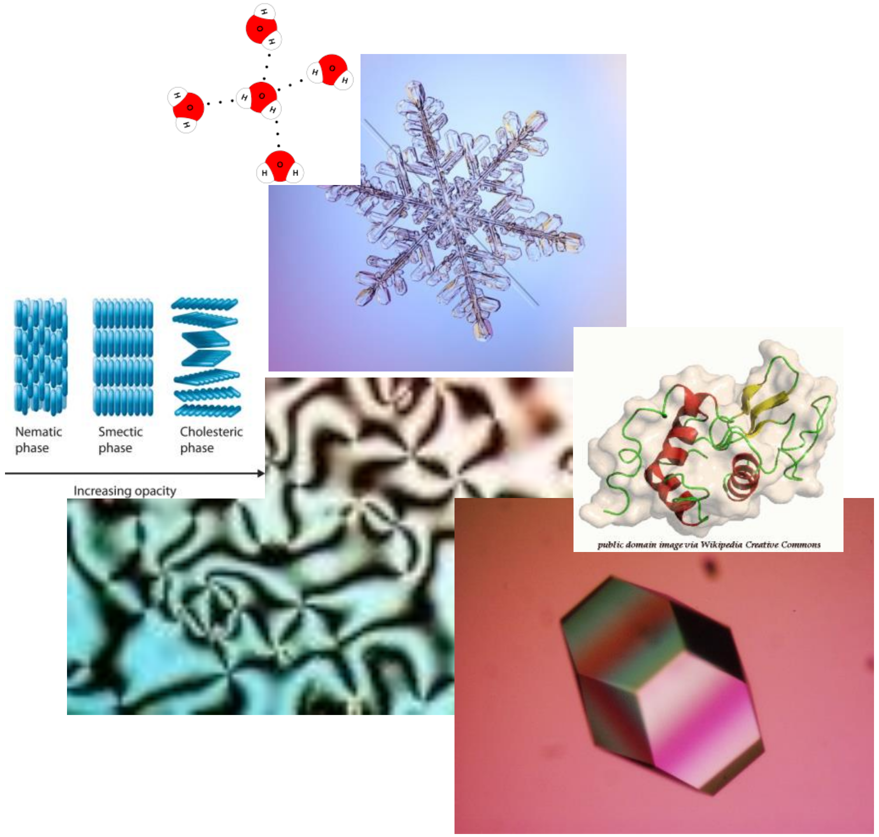
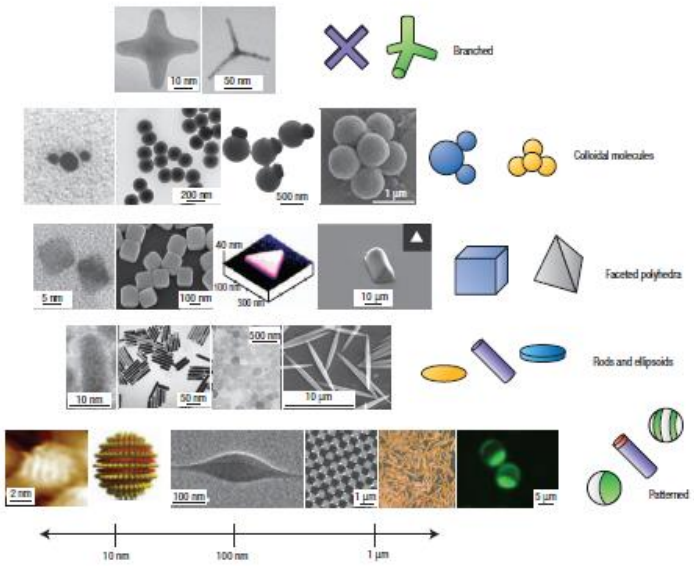
Spontaneous Self-Organization

- In nature: spontaneous organization of building blocks occurs
- Clear relationship macroscopic structure and microscopic building blocks

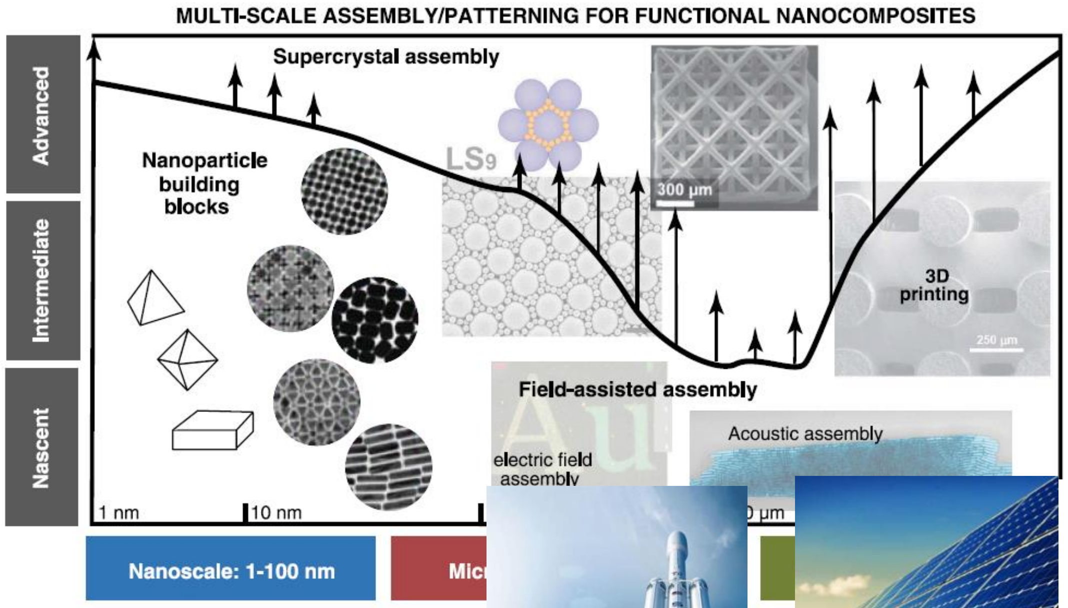


Bottom-up Assembly of Functional Materials

- Many novel building blocks: molecules, nanoparticles, colloids
- Employ spontaneous organization to make new materials



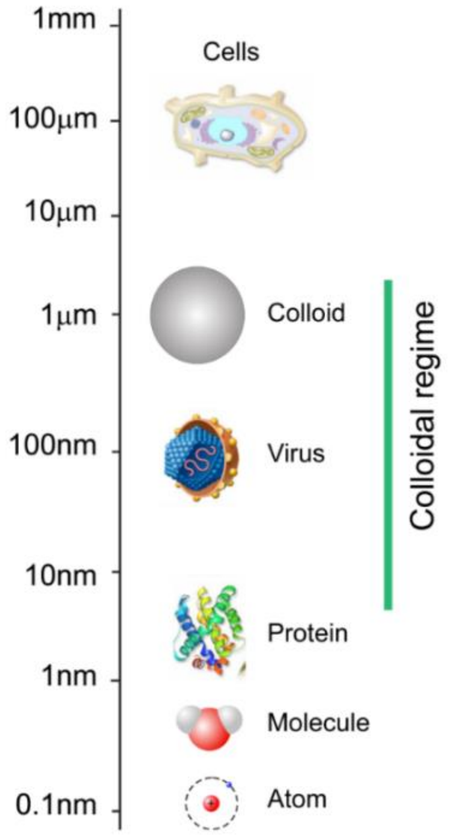
Glotzer *et al. Science* (2007)

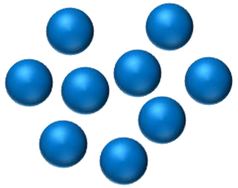


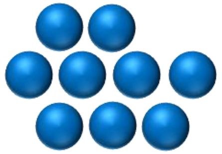
How to control the self-assembly of materials?

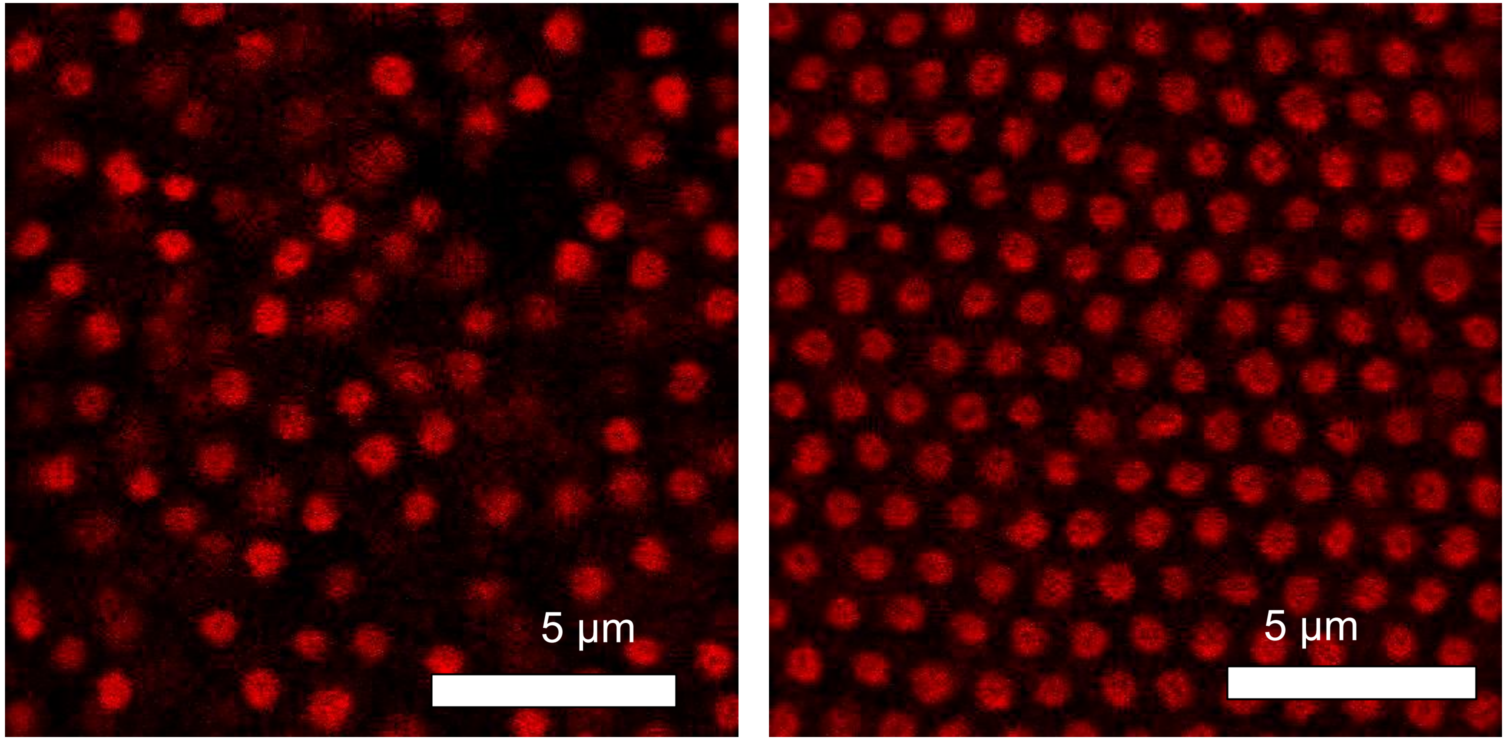
Colloids

- Size: 1-1000 nm
- “Soft, Slow & Seeable”



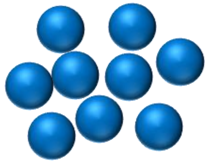






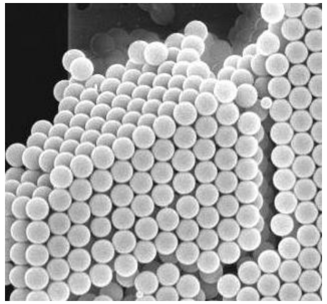
Volume fractie

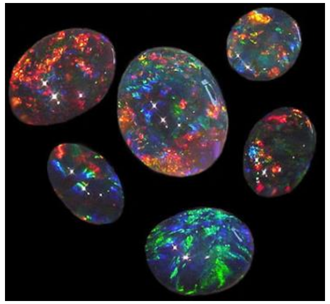
1/T



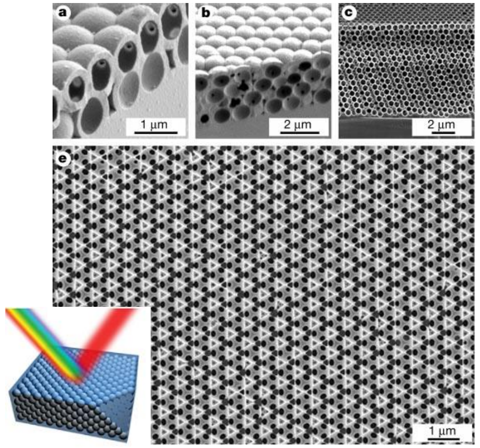
Functional Materials of Colloidal Building Blocks

Spontaneous Assembly

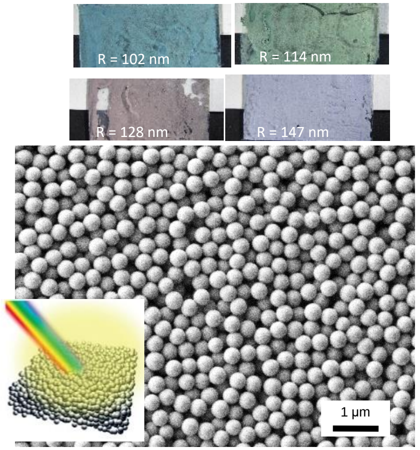




Photonic Crystals & Glasses

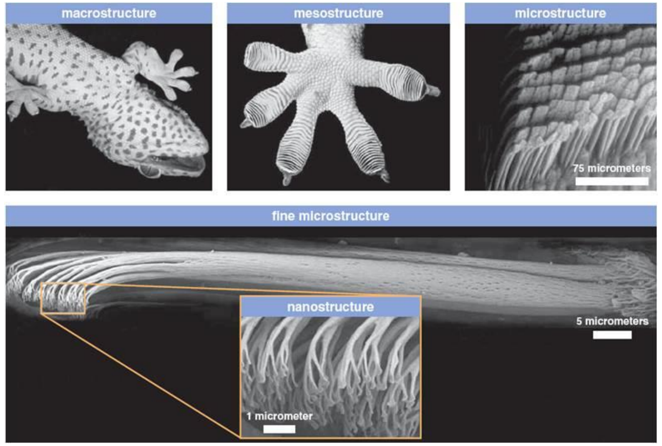


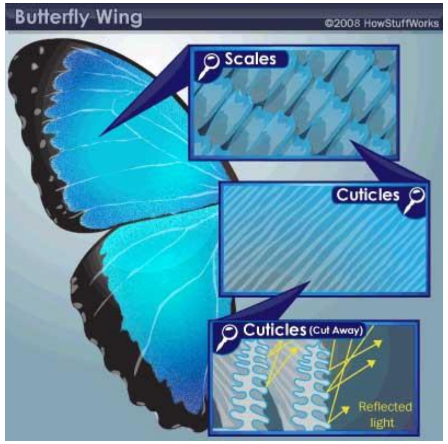
Vlaslov *et al. Nature* (2001)

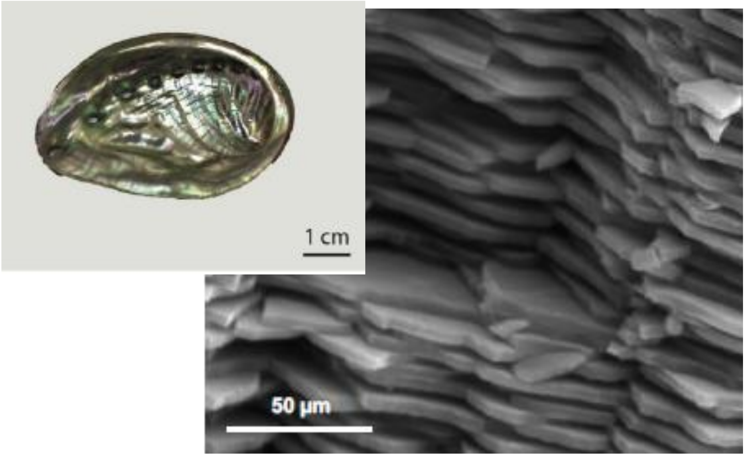


Schertel, **J.M. Meijer** *et al. Adv. Opt. Mat* (2019)

Biomimicry

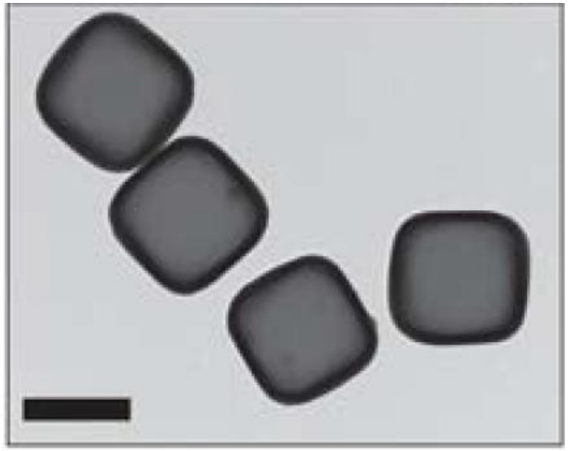




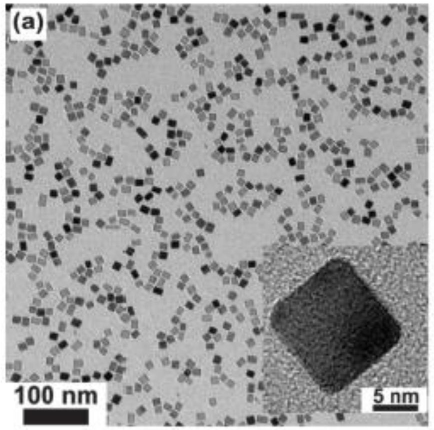


Cubes: a new frontier!

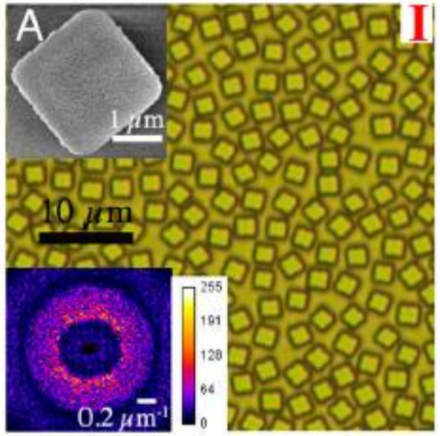
Advances in synthesis: cubic shaped (nano)particles have become available.



Rossi *et al.* (2011) Soft Matter

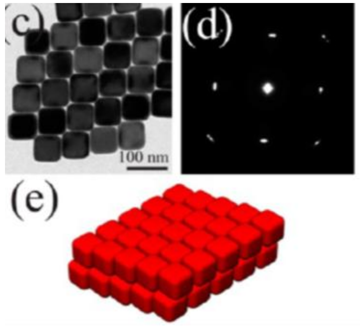


Zhang *et al*. (2011) PRL

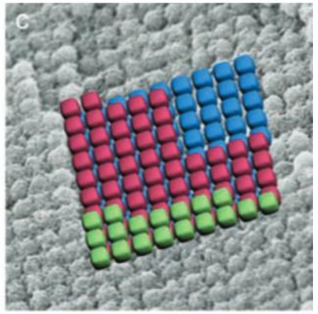


Zhou *et al.* (2011) PNAS

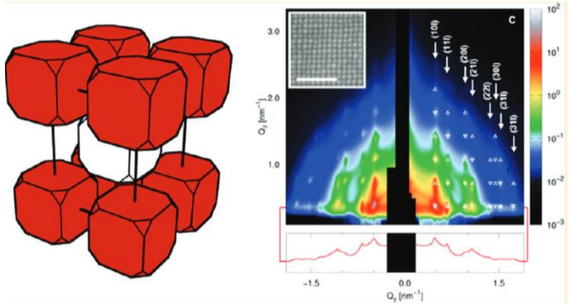
Self-Assembled Nanomaterials of Cubes



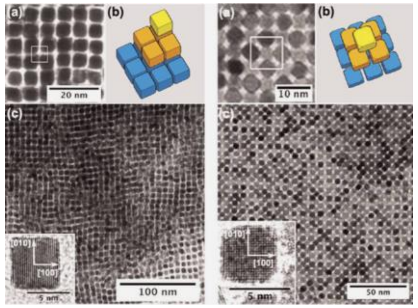
Wang et al. Chem Mater 2014



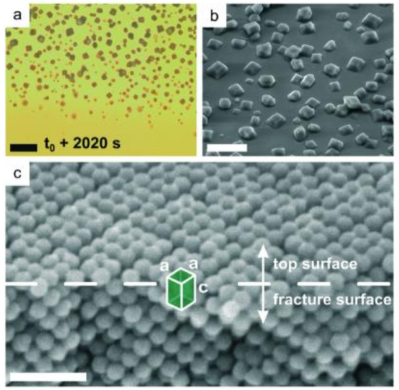
Li et al. Angew. Chem. 2007



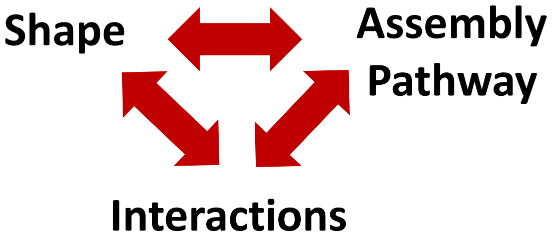
Disch *et al.* Nano Lett. 2011

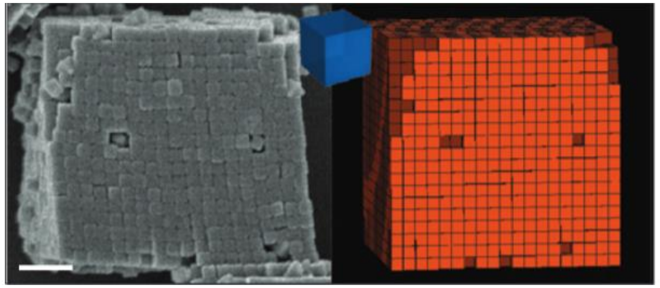


Chan *et al.* ACS Nano. 2012

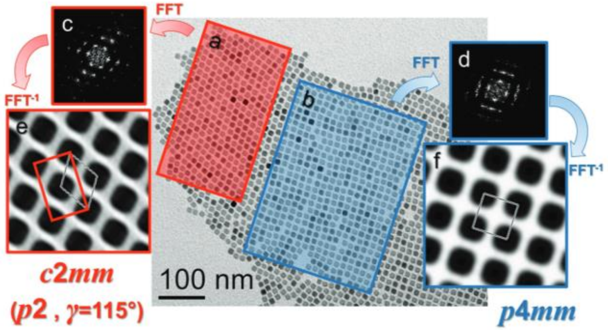


Aghte et al. CrystEng-Comm, 2014

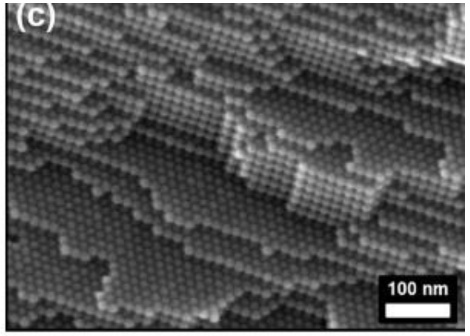




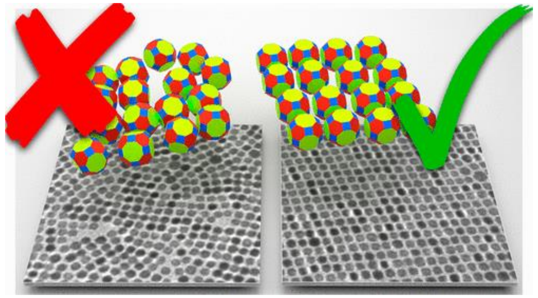
Henzie et al. Nat Mater 2012



Brunner *et al.* Adv. Mater. Int. 2017



Jenewein *et al*. Angew. Chem. 2021

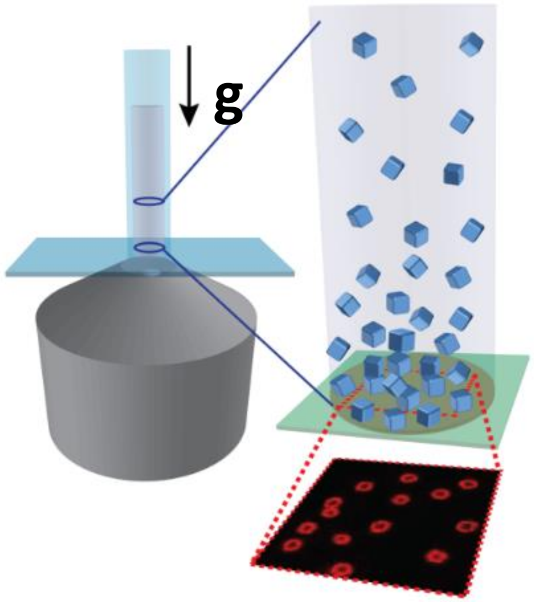


Cimada DaSilva *et al. Chem. Mater.* 2021

TU/e

Superball Self-Assembly - Shape Driven

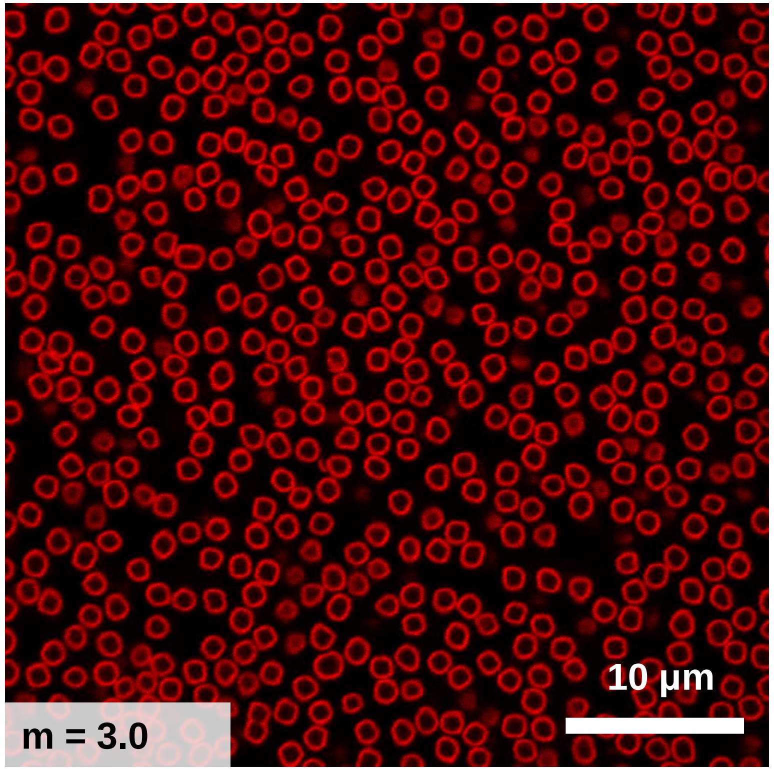
Confocal Microscopy



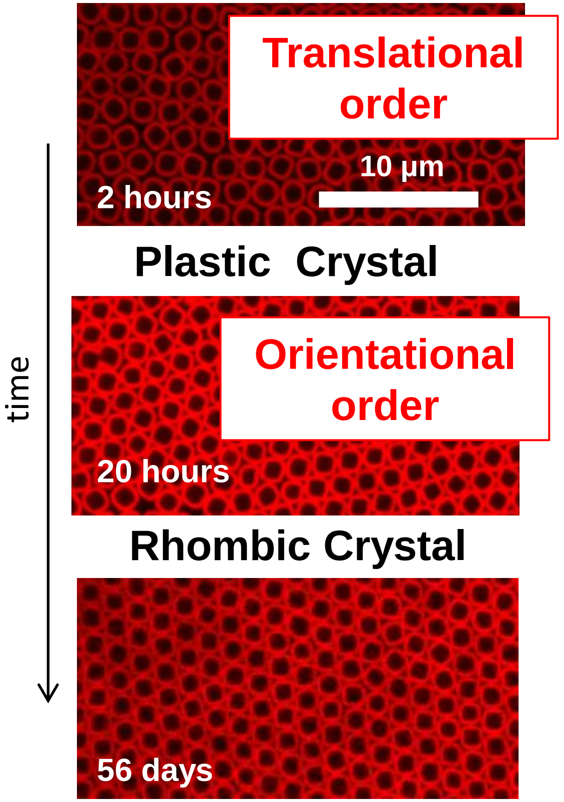
SINGLE PARTICLE

- ✓ Spatial resolution
- ✓ Dynamics
- ✓ Interactions
- ✓ Self-assembly

Low concentration
(full duration: 6 hours)

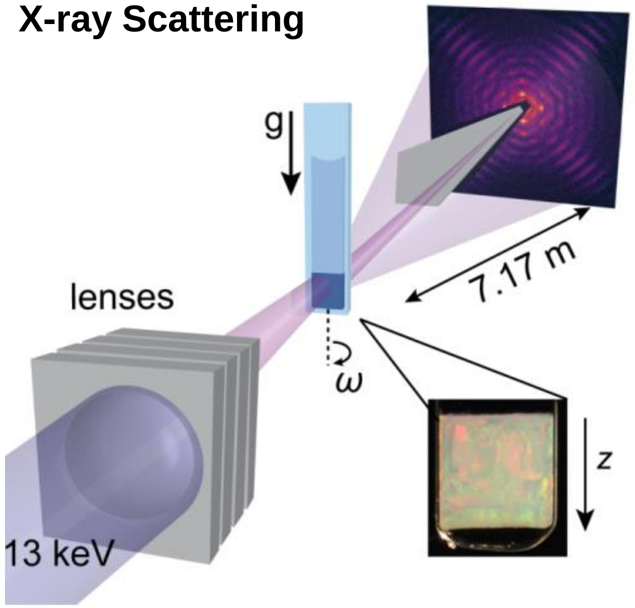


High concentration
(4.3x real time)



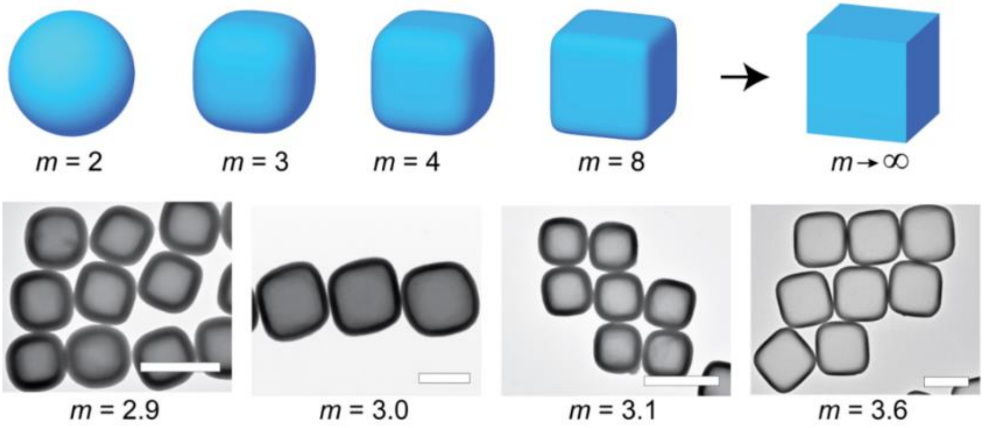
Dense Rhombic Crystals

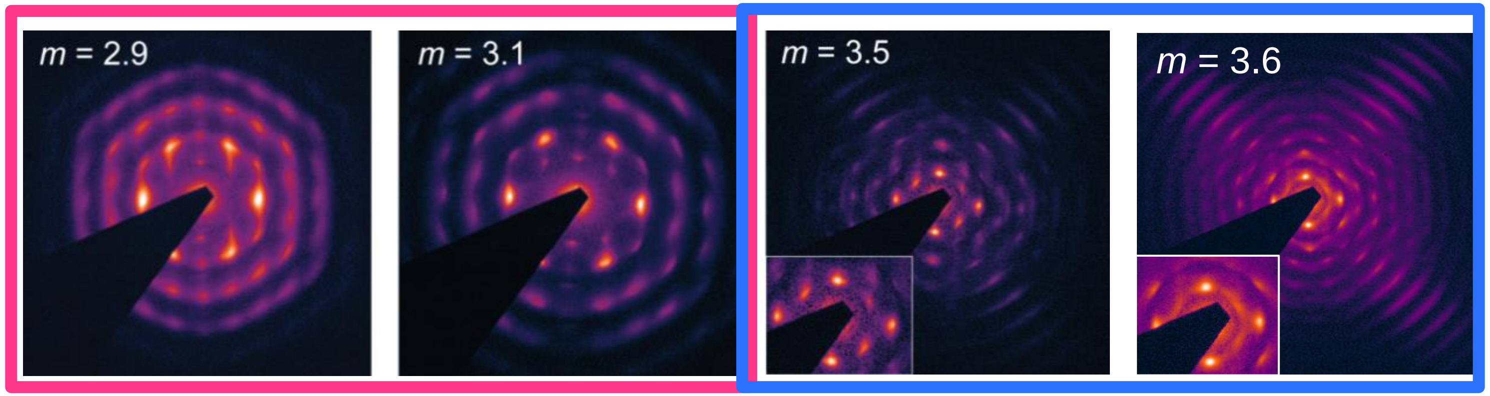
Small Angle X-ray Scattering

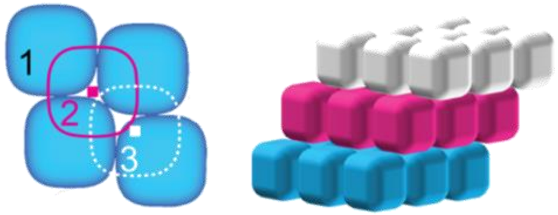


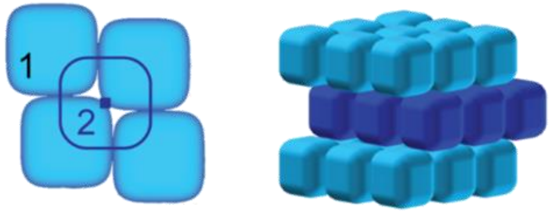
Superball:

$$\left|\frac{x}{a}\right|^m + \left|\frac{y}{a}\right|^m + \left|\frac{z}{a}\right|^m \leq 1$$









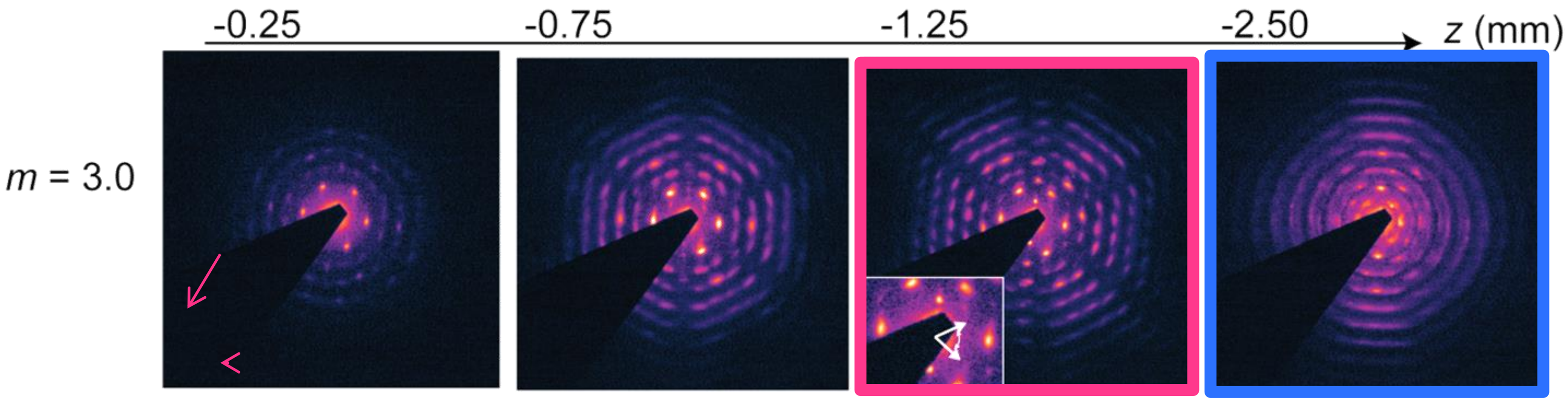
Hollow-site

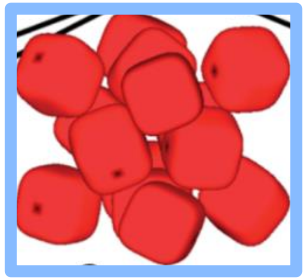
Bridge-site

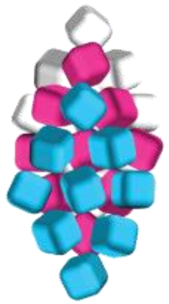
LOCAL & BULK

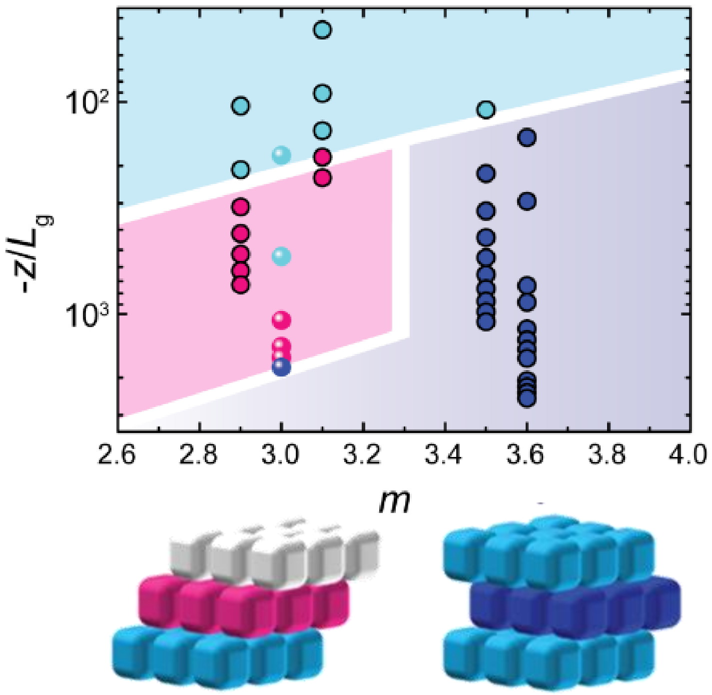
- ✓ Microscopic
- ✓ Macroscopic
- ✓ Better statistics

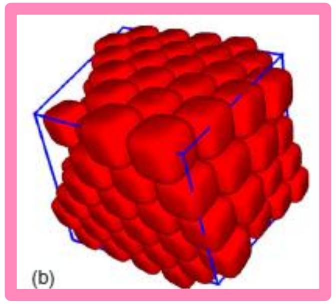
Solid-Solid Phase Transitions Induced by Shape









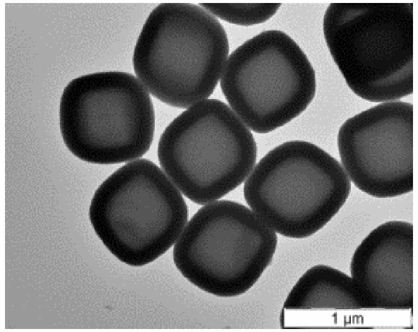


Jiao *et al*. Phys Rev E 2009,
Batten *et al*. Phys Rev E 2010, Ni *et al.* Soft Matter 2012

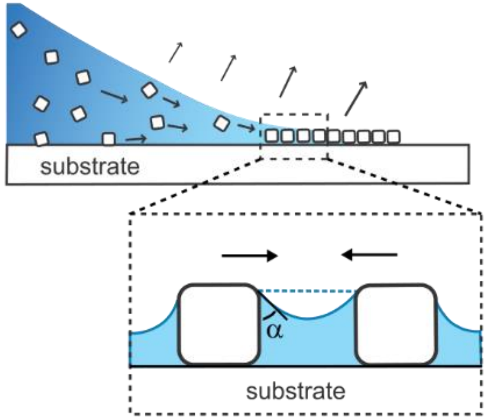
J.M. Meijer *et al. Nature Communications* (2017)

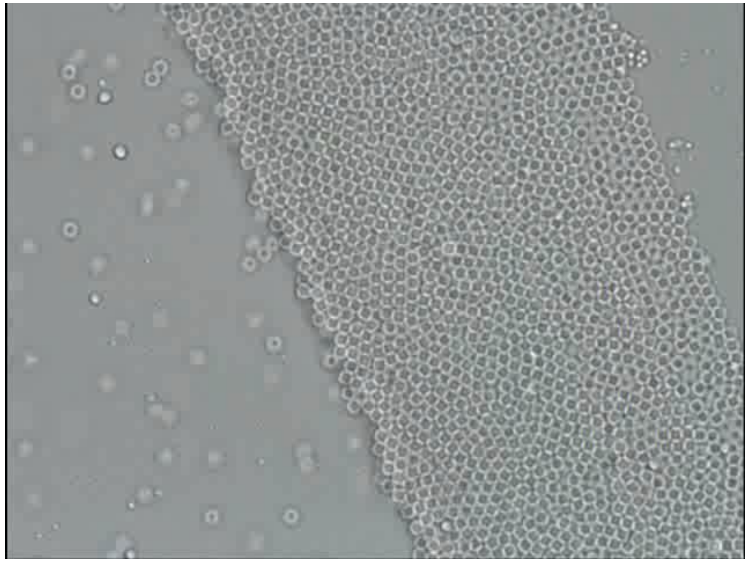
Driving Assembly with Solvent Evaporation

Convective Assembly

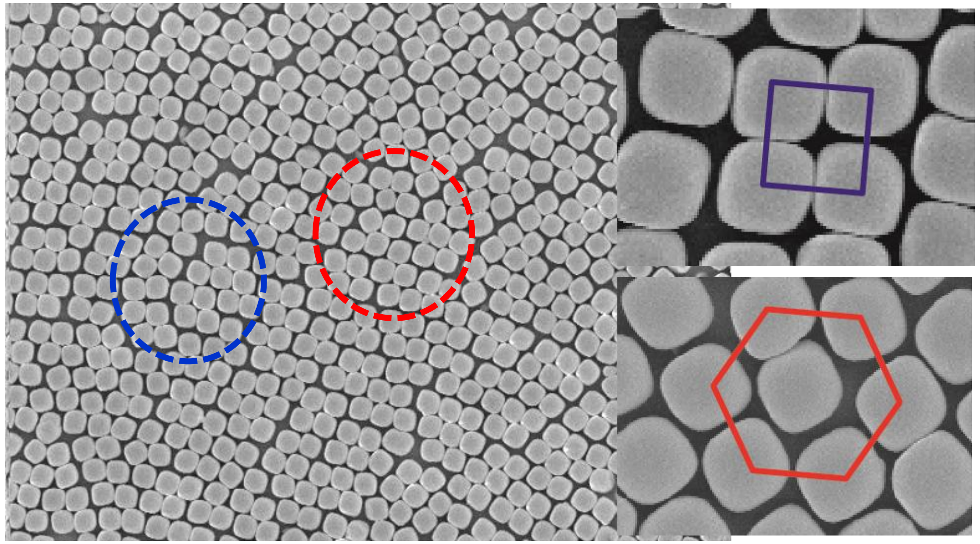


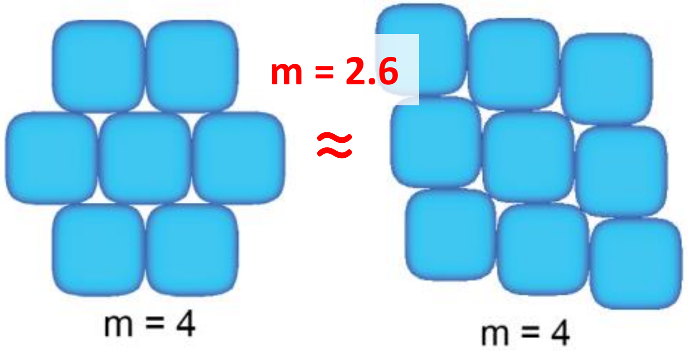
D = 774 ± 35 nm





J.M. Meijer *et al*, *Langmuir* (2012)

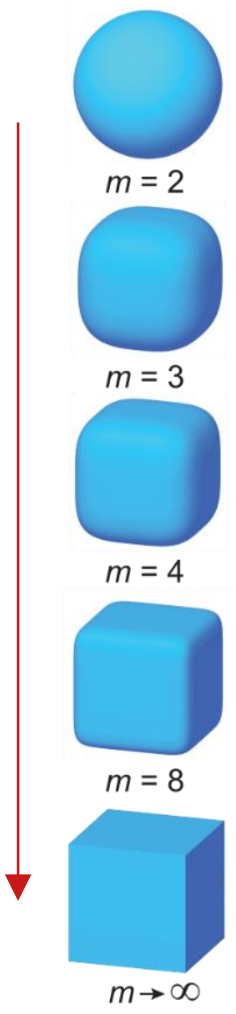


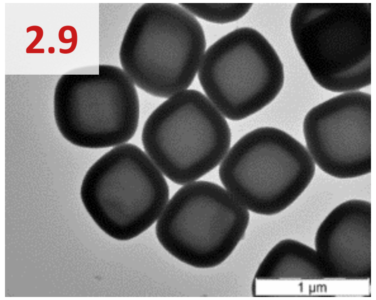


Λ_0–lattice Λ_1–lattice

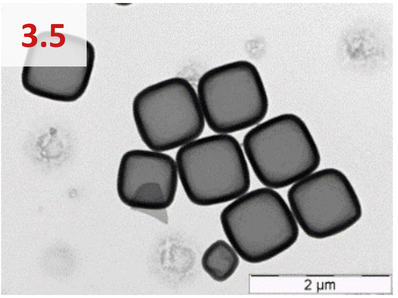
Jiao *et al.* PRL 2008

Different Structures in Dense Monolayer Structures

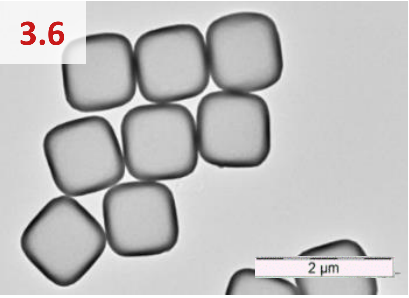




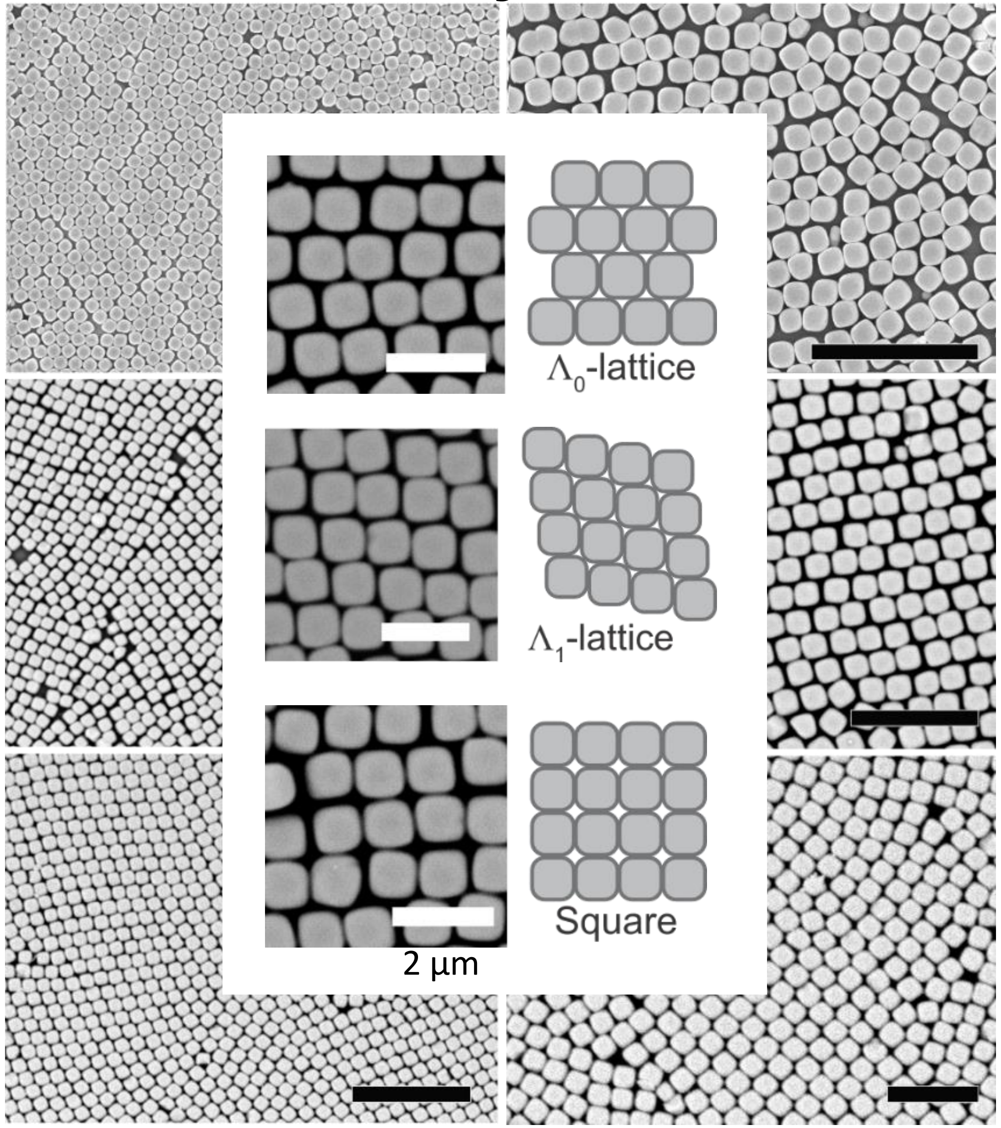
D = 774 ± 35 nm



D = 1028 ± 35 nm



D = 1266 ± 27 nm



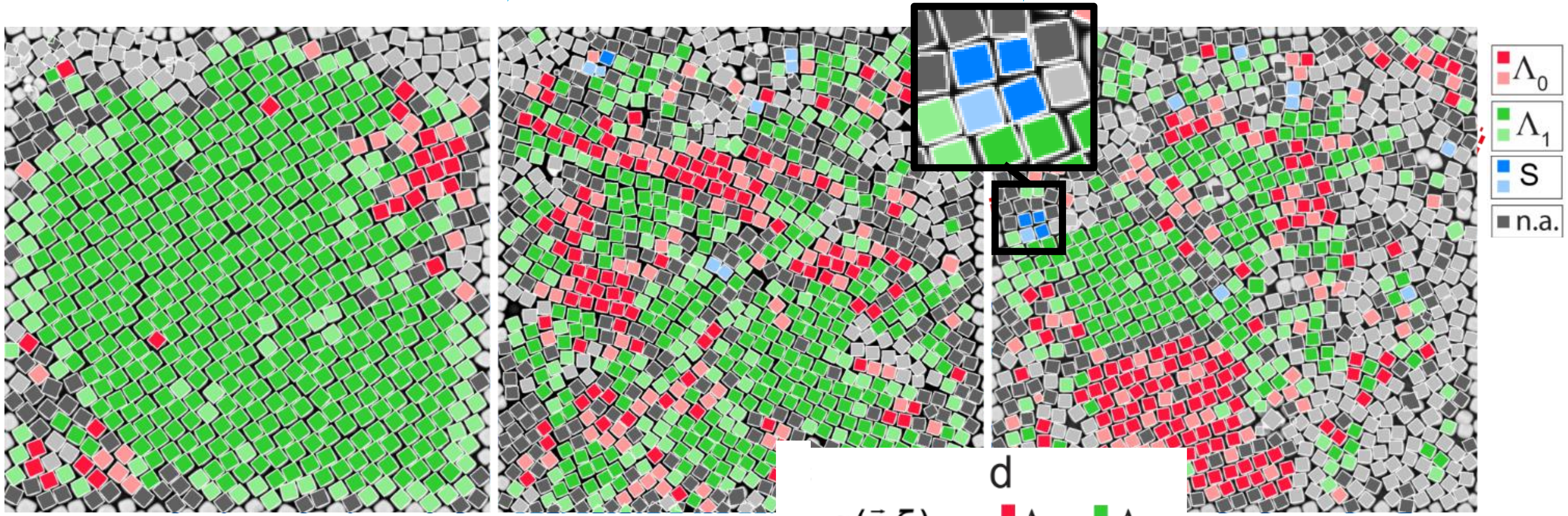
10 μm

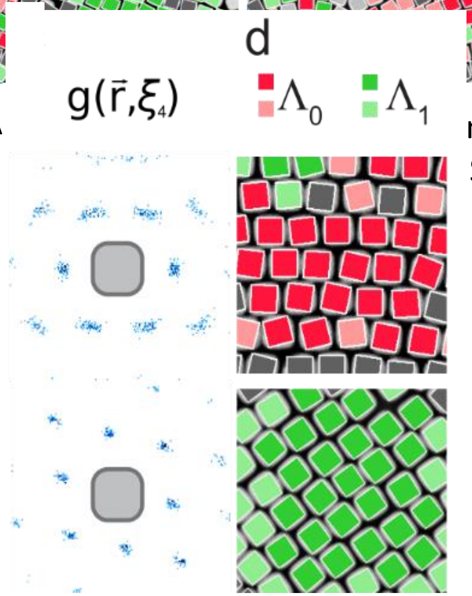
5 μm

Single-Particle Characterization of Lattices

Position & Orientation ⇨ **Orientational Order** ⇨ **Assign lattice**

3.5





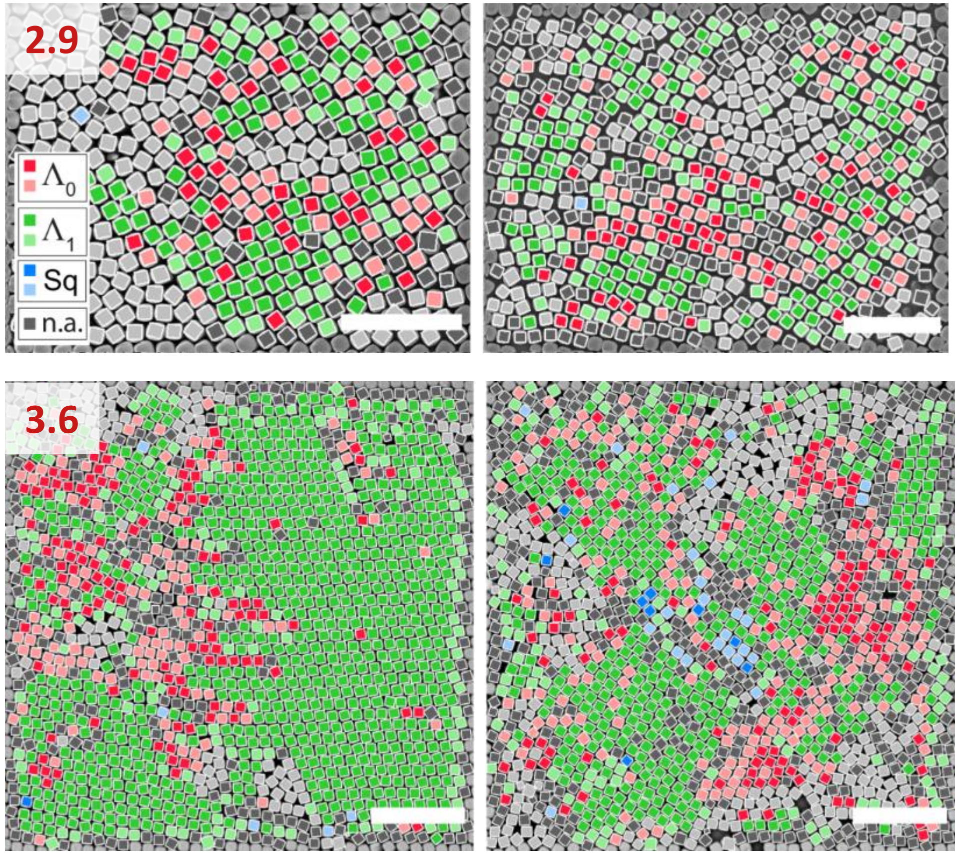
Dominant Λ_1–lattice

Mixed Λ_0 & Λ

ns of Λ_0 & Λ_1
Square

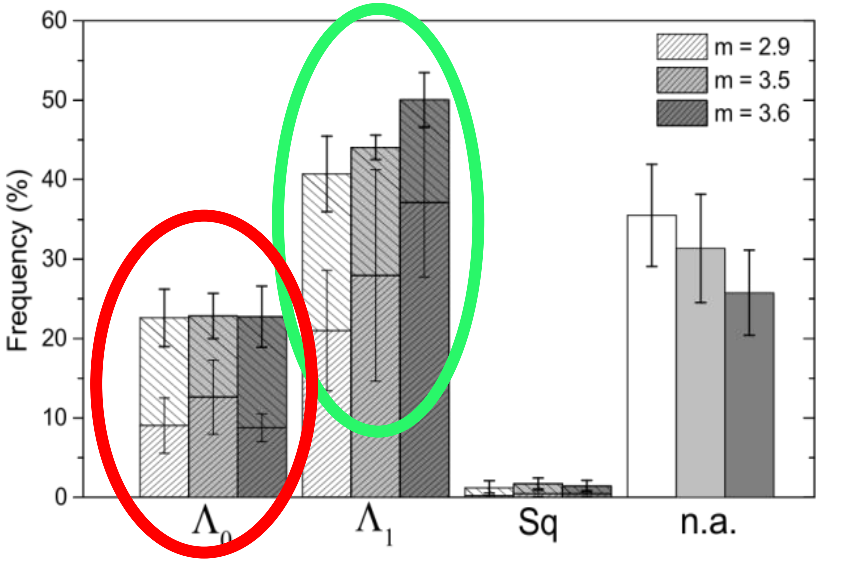
Characterization of Lattices for different *m*

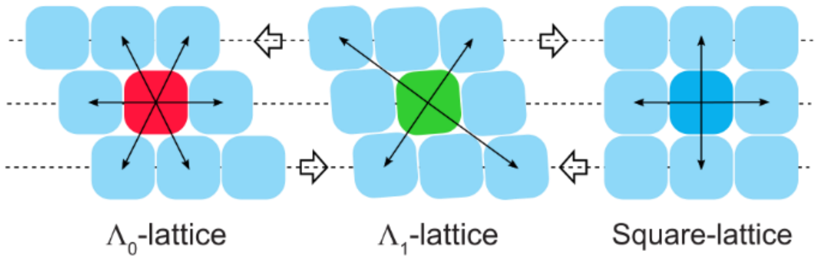
Different corner roundness



- Dominant Λ_1–lattice
- Mixed Λ_0 & Λ lattices

Lattice Frequency



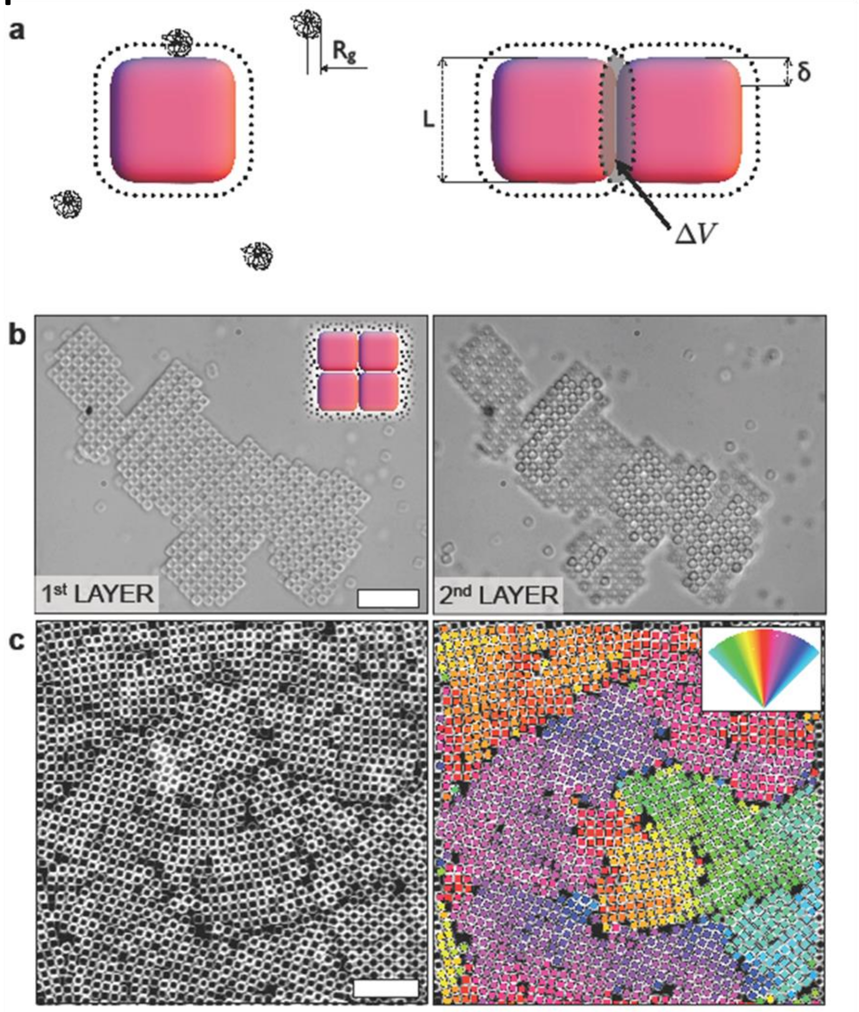


$\phi = 0.933$ $\phi = 0.940$ $\phi = 0.898$

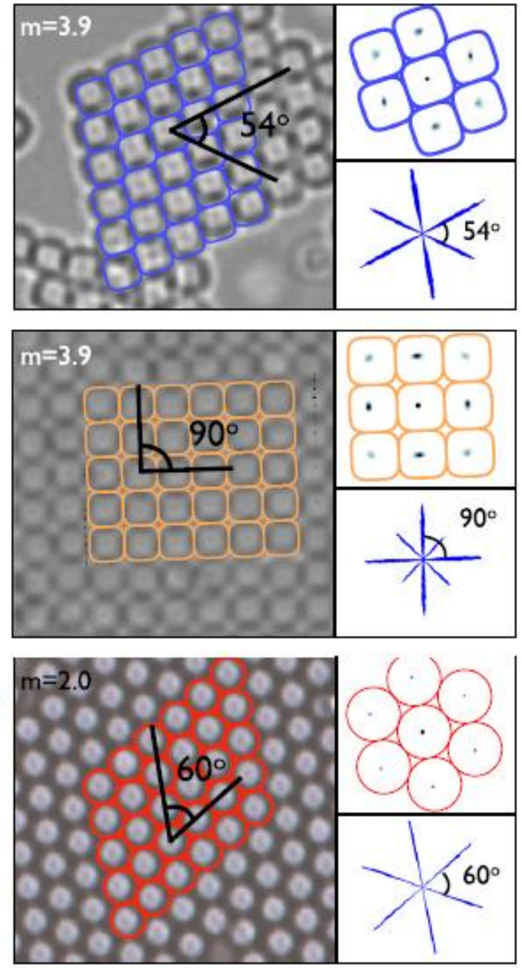
J.M. Meijer *et al*. *Langmuir* (2019)

Superstructures of Attractive Superballs

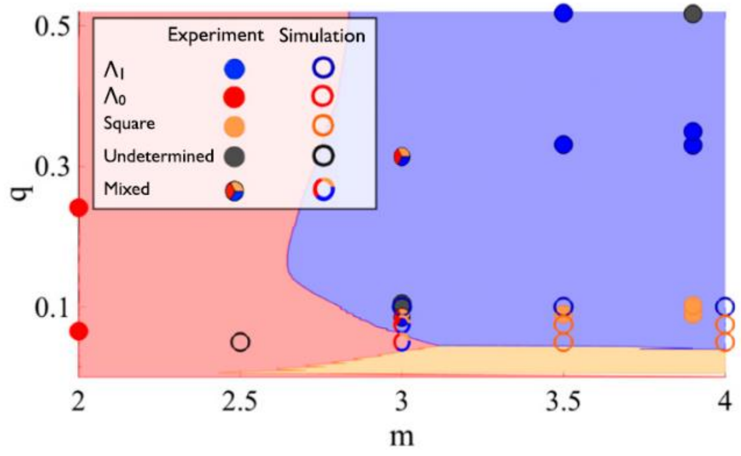
Depletion attraction



Rossi *et* al. (2011) Soft Matter



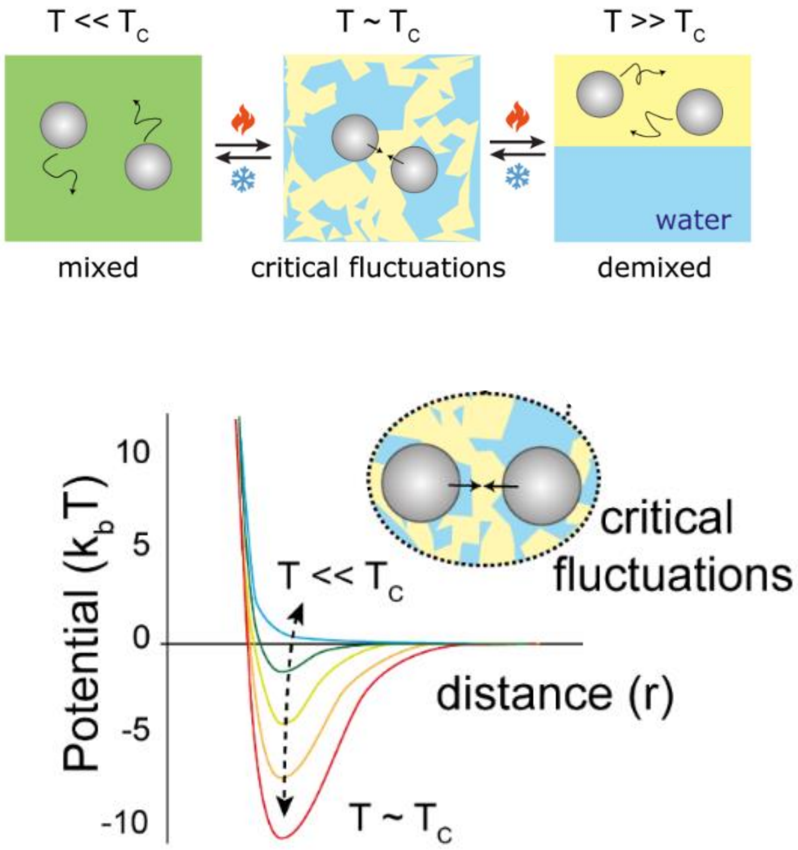
$q = 2R_g / L$

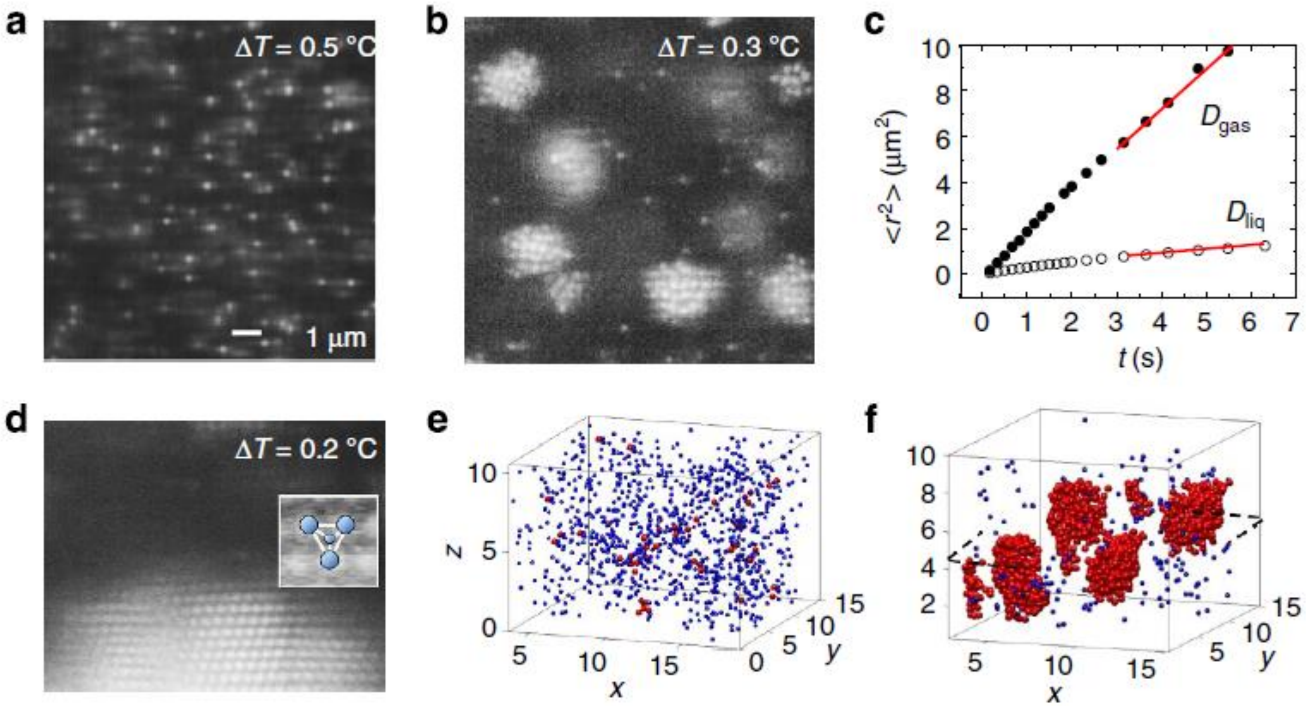


Rossi *et* al. (2015) Soft Matter

In-situ Control over Attractions

Critical Casimir force



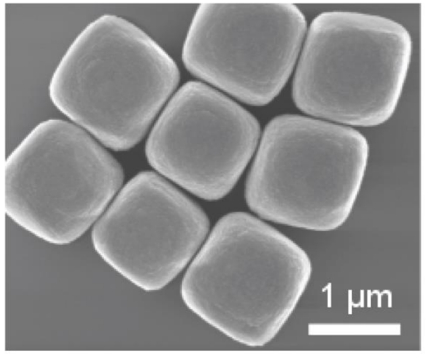


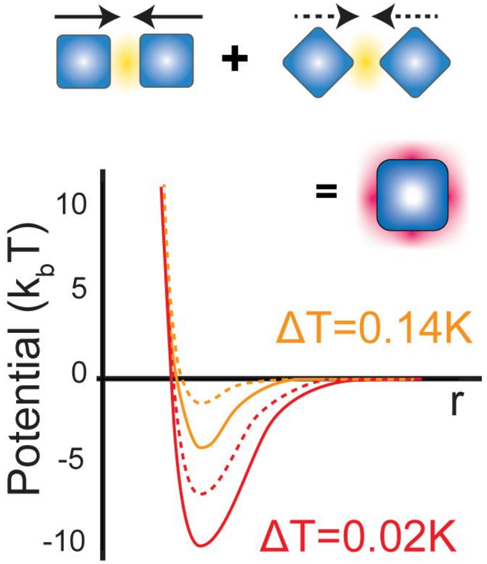
Nguyen *et al* Nat Comm 2016

Stuij, PhD Thesis, UvA, 2020

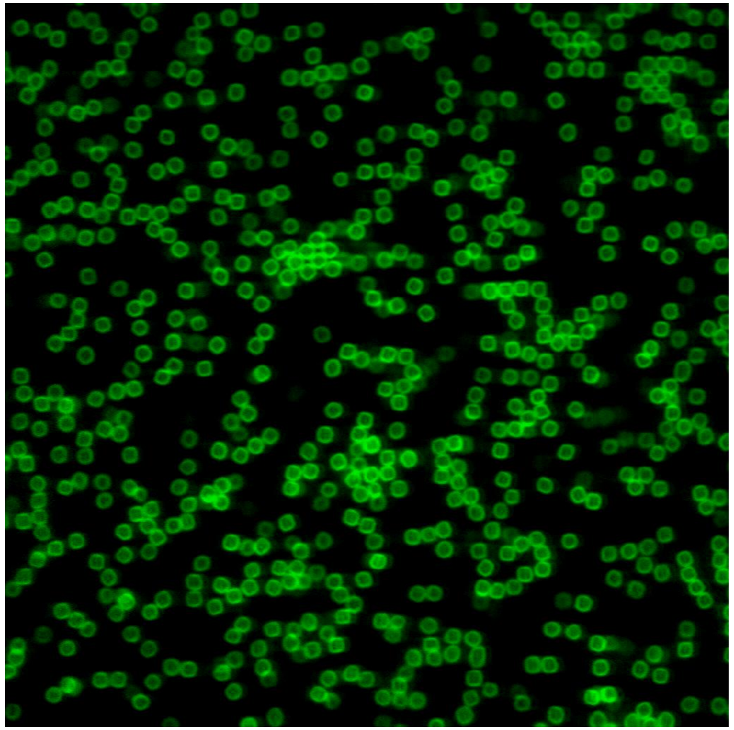
Cubes + Critical Casimir force

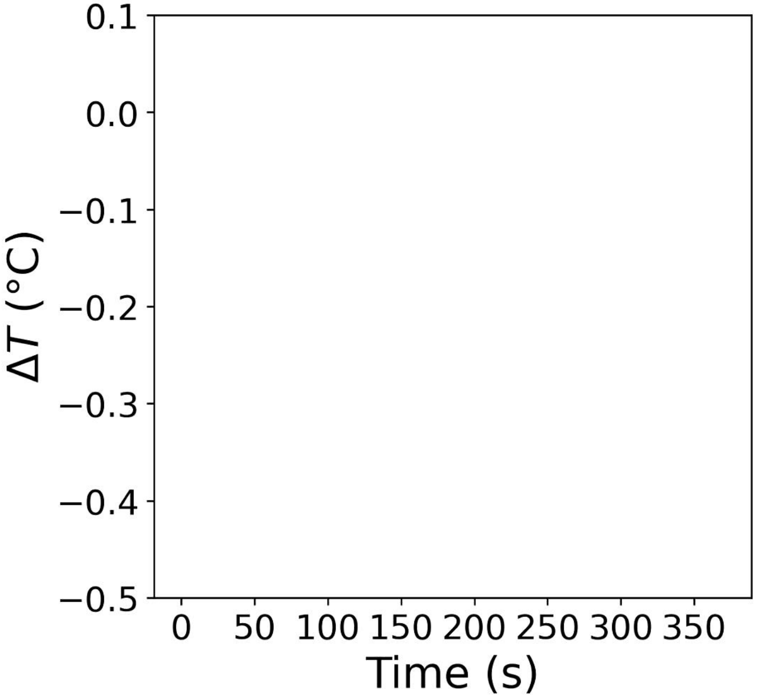
Anisotropic interactions



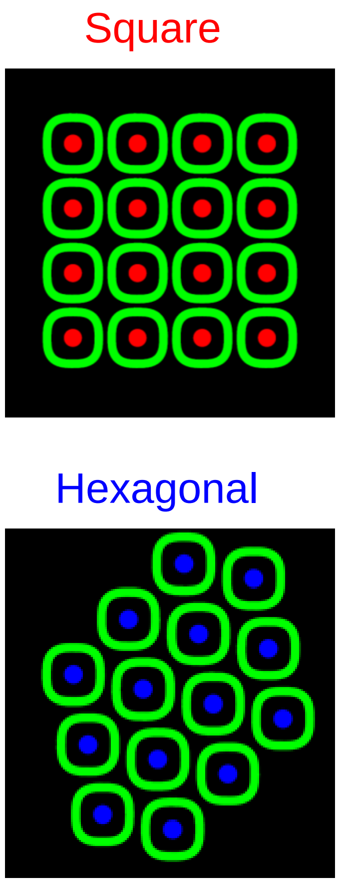


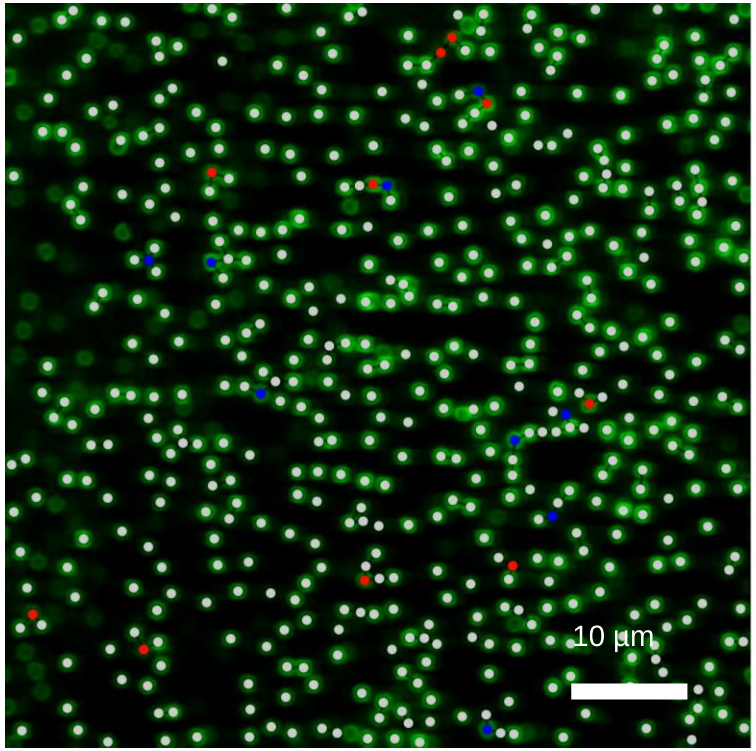
In-situ control of self-assembly process

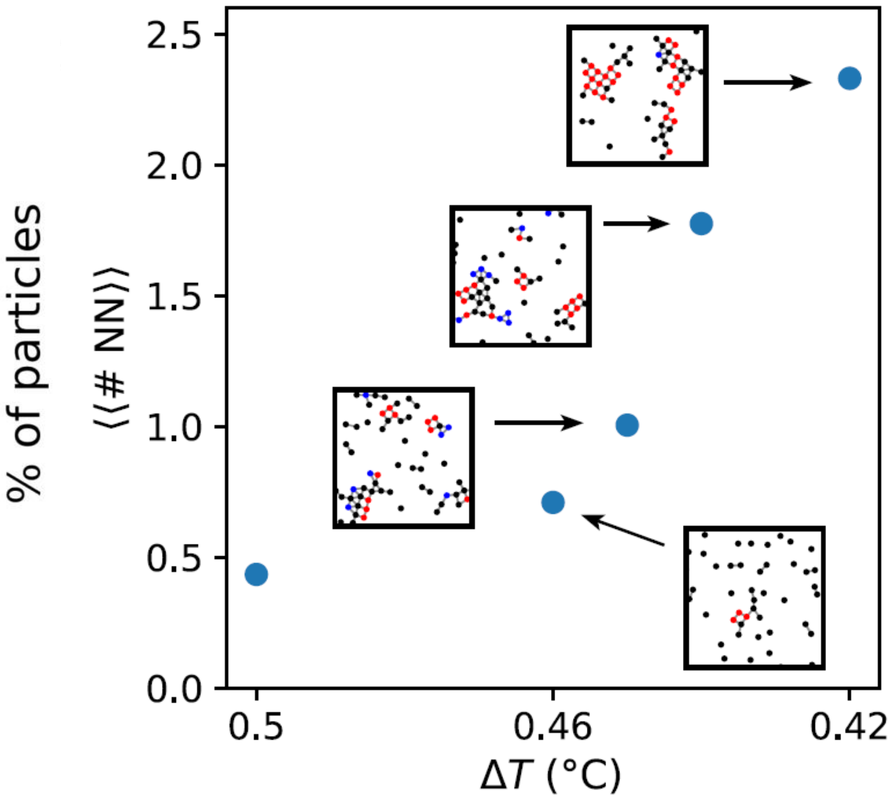




Formation of Different Superstructures

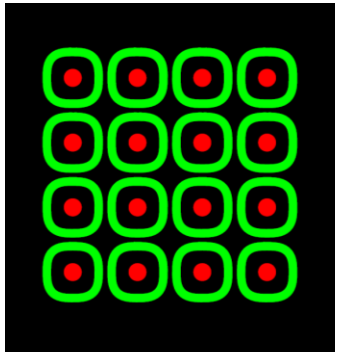




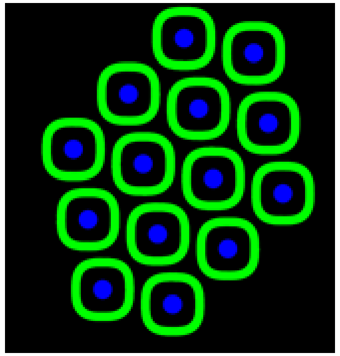


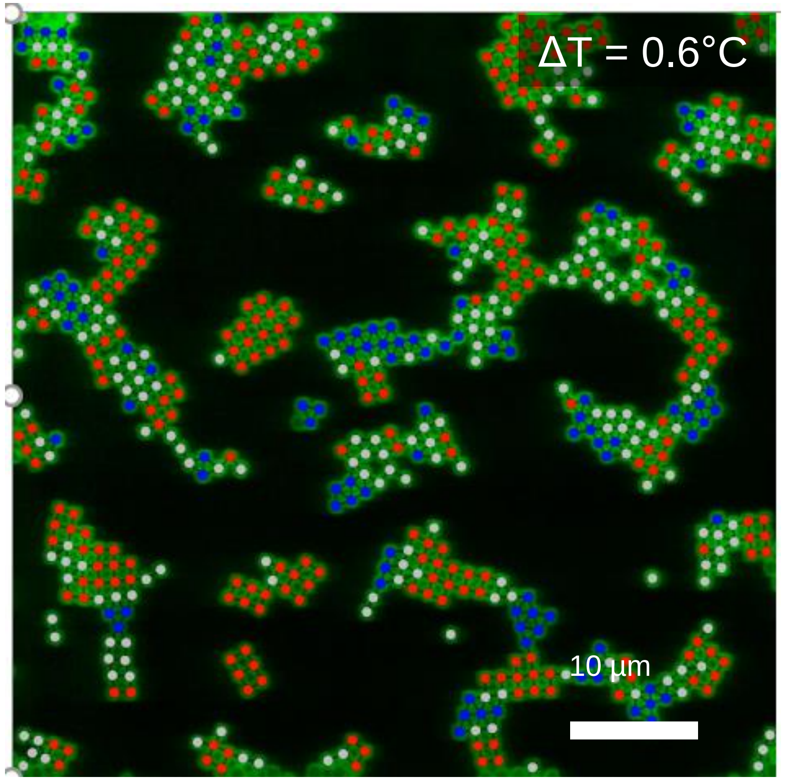
Lattice Analysis at Different Attraction Strength

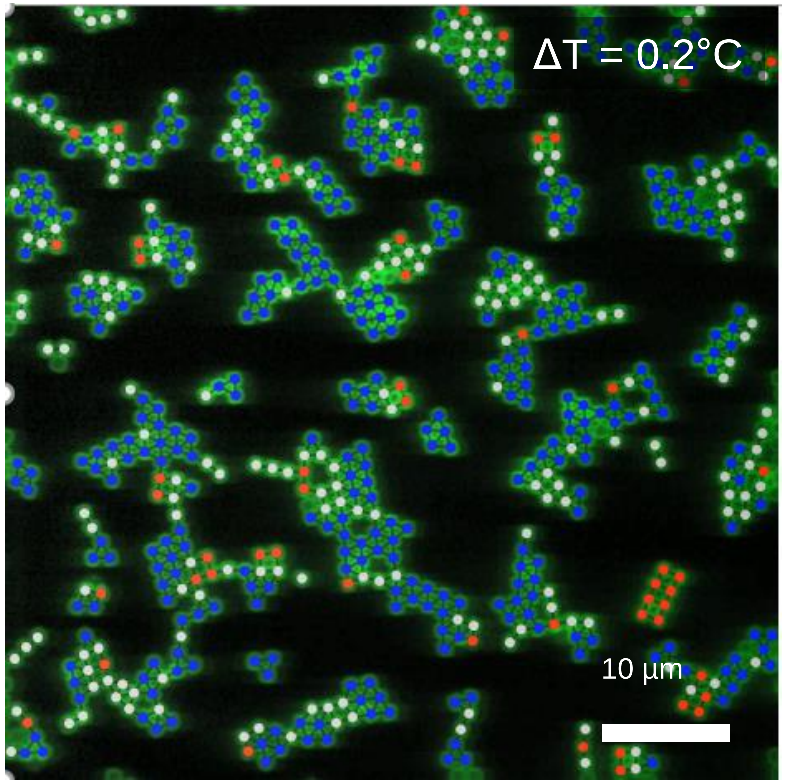
Square



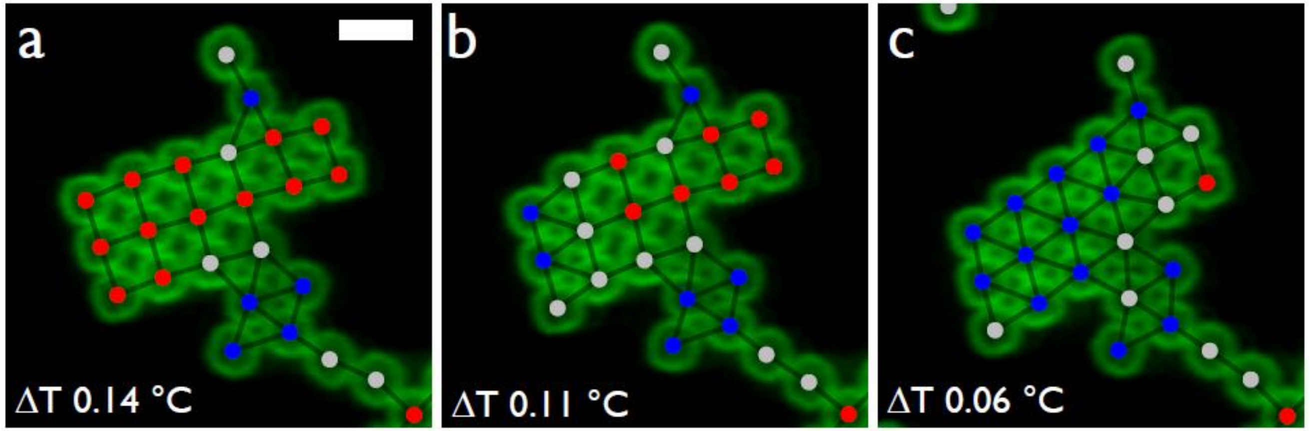
Hexagonal







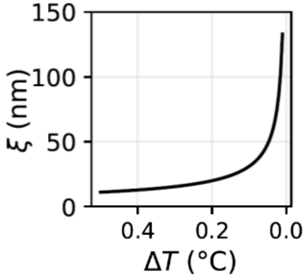
Shape Controlled Switching Structures

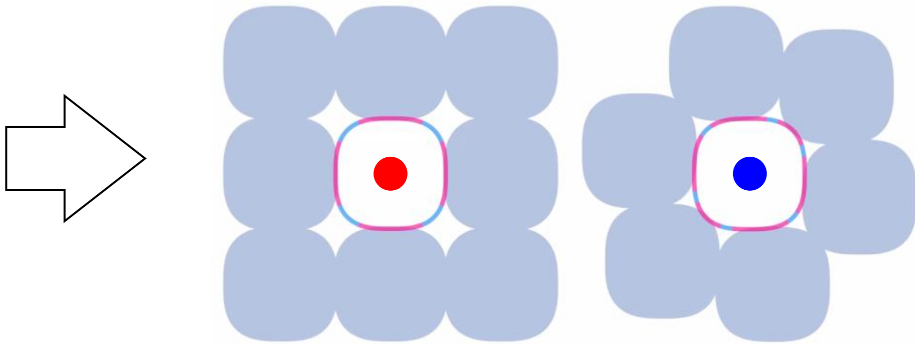


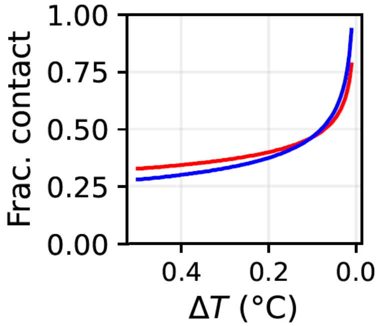
Superball:

+

Attraction range:







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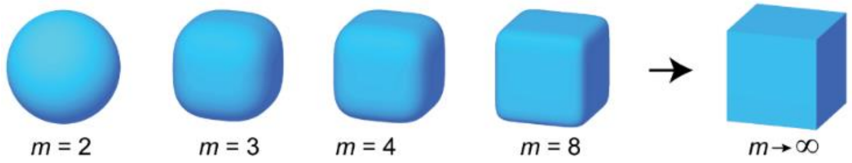
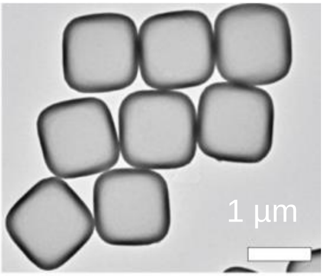
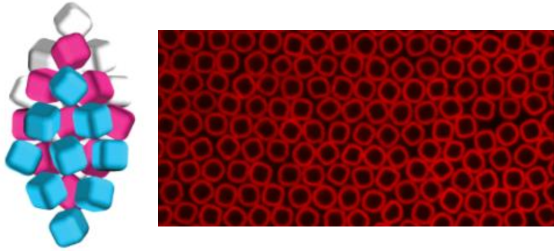
Summary: Shape, Interactions & Pathway Matters

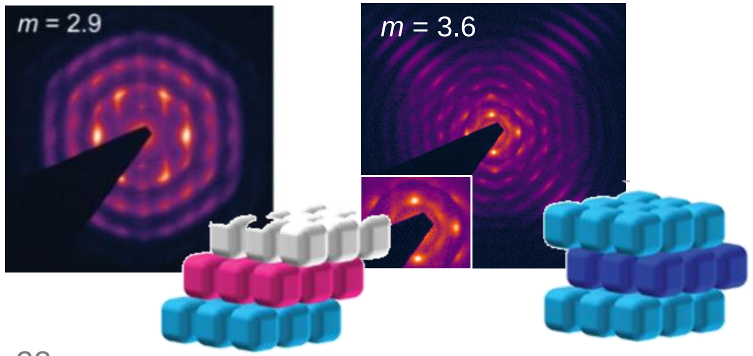
Cubic particles



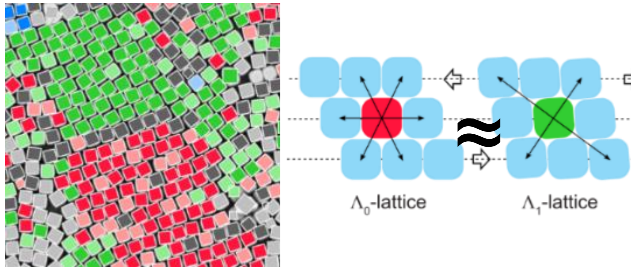


Hard body interactions

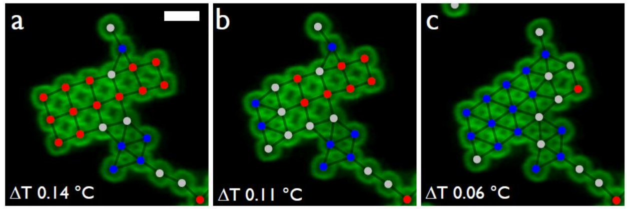


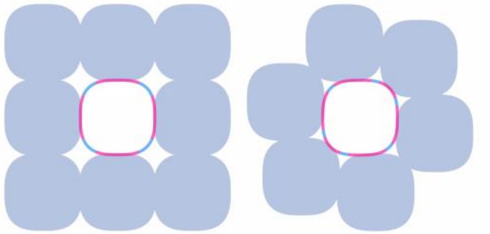


Long-range Attractions and Shear



Short-range Attractions





Acknowledgements

Van 't Hoff Laboratory Utrecht University
- Antara Pal
- Samia Ouhajji
- Fabian Hagemans
- Vera Meester
- Andrei Petukhov
- Albert Philipse
- Henk Lekkerkerker
- Laura Rossi
- Dmytro Byelov
- Jan Hilhorst
- Anke Leferink op Reinink
- Joost Wolters
- Jos van Rijssel

Hasylab, DESY
- Ivan Vartanyants
- Anatoly Shabalin
- Alexey Zozulya
- Sergey Lazarev

HHU Dusseldorf
- Astrid Rauh
- Marco Hildebrandt
- Matthias Karg

SWING, SOLEIL
- Javier Perez

Wageningen University & Research
- Joris Sprakel
- Jan Maarten van Doorn
- Ties van de Laar

ID06 & DUBBLE ESRF, Grenoble
- Anatoly Snigirev
- Irina Snigireva
- Guiseppe Portale
- Daniel Hermida Merino

Soft Matter, IoP, University of Amsterdam
- Peter Schall
- Piet Swinkels
- Daphne Sayasilpi
- Steffen Lootsma

Soft Matter and Biological Physics, TU/e
- Chris Kennedy
- Kees Storm
- Tine Stevens
- Max Schelling

Funding:

Unterstützt von / Supported by
Alexander von Humboldt Stiftung/Foundation

SFB 1214

NWO

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Thank you!

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