Colloidal Superstructures in Space

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Science Team

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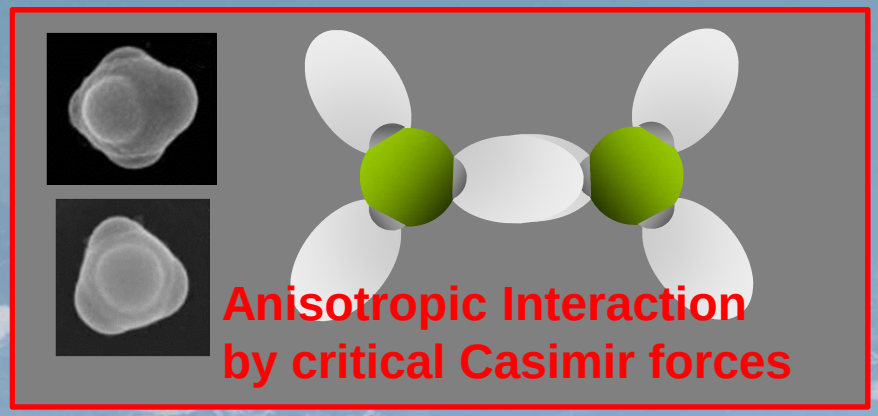
Colloidal Superstructures in Space

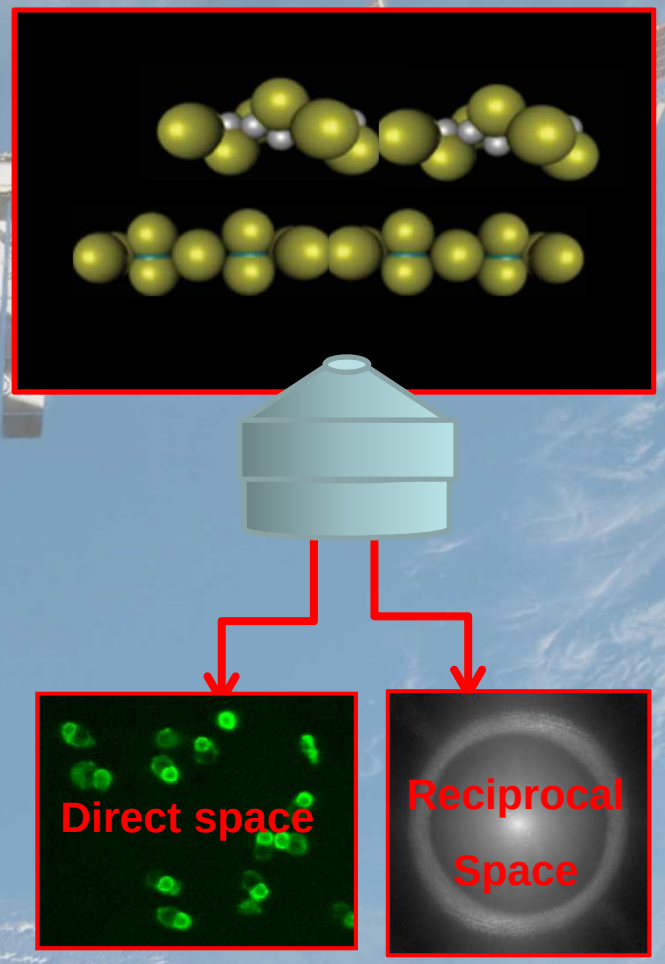
- Anisotropic interactions

- *T* control of interactions

- Superstructures:
Formation + Growth

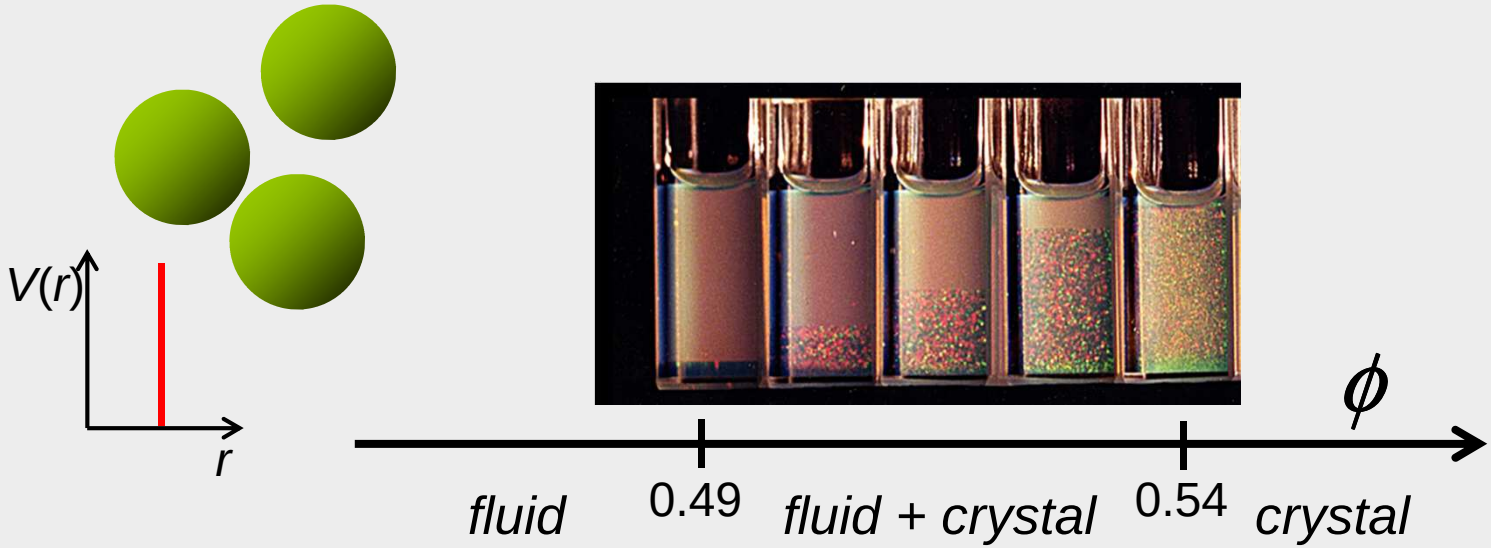
- Direct + reciprocal imaging





Science Overview

Colloids - Hard Spheres



Science Overview

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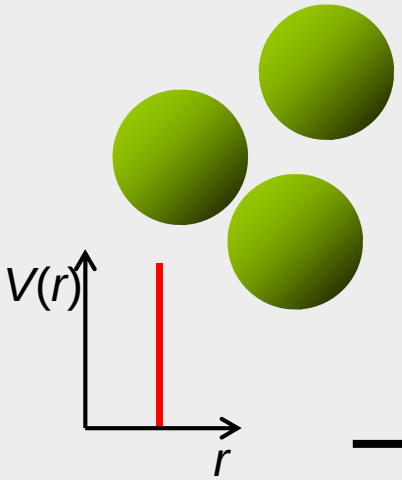
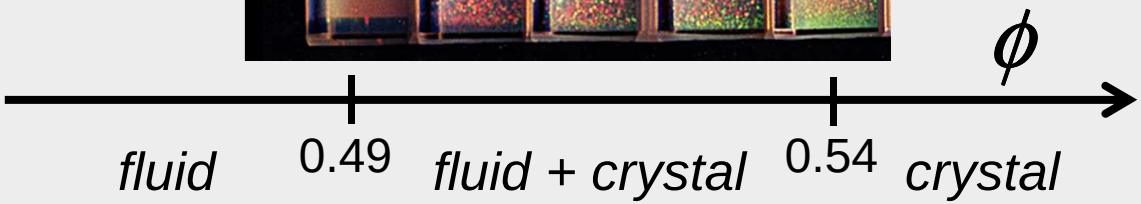
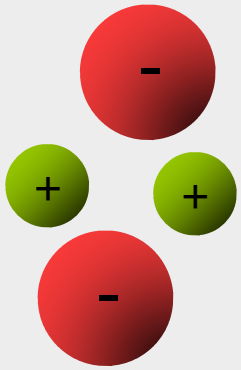


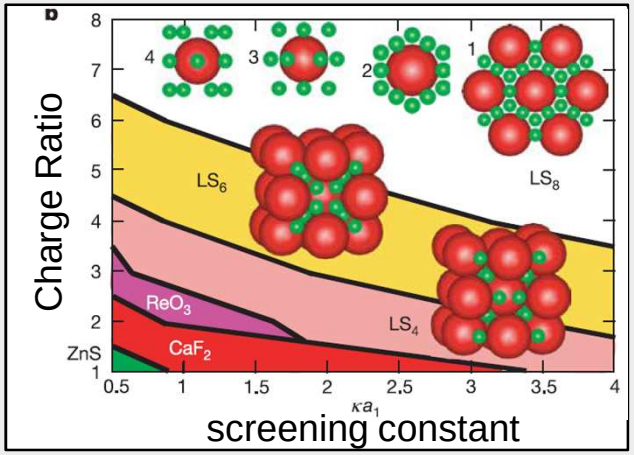


Chaikin, Russel et al.

Science Overview

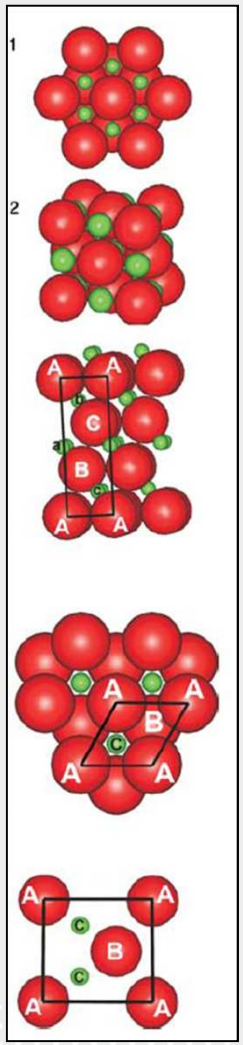
Colloids - Charged Spheres





Leunissen *et al.* (*Nature* 2005)

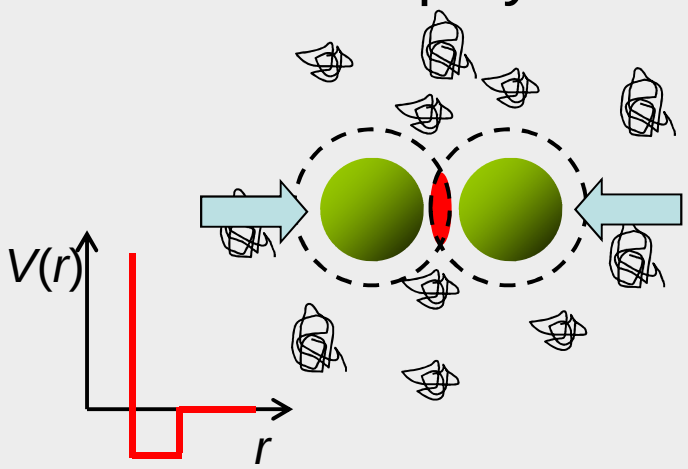
Ionic crystals

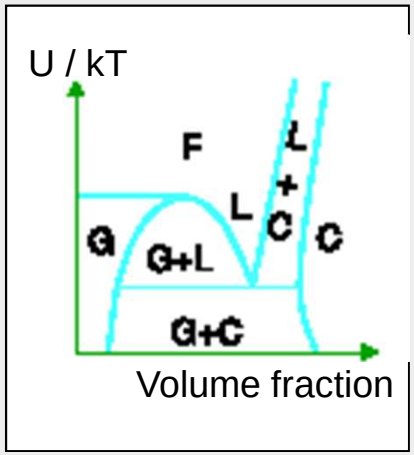


Science Overview

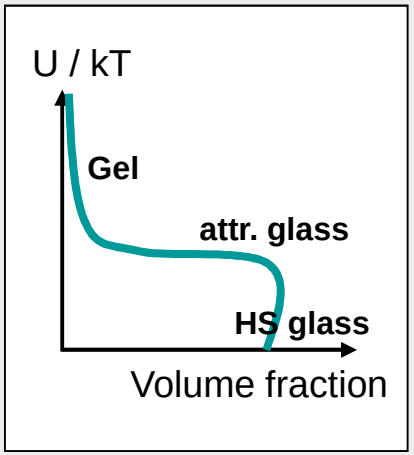
Colloidal Phase behavior - Depletion

Colloid-polymer



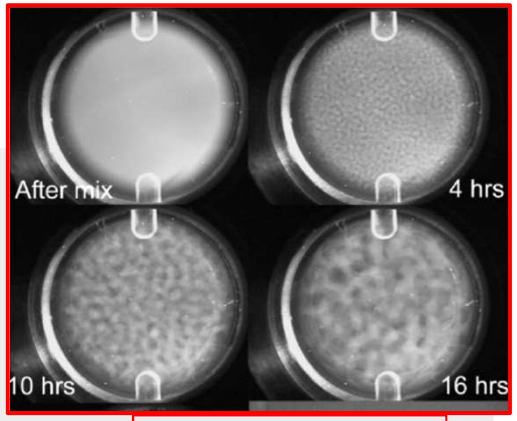


equilibrium



out of equilibrium

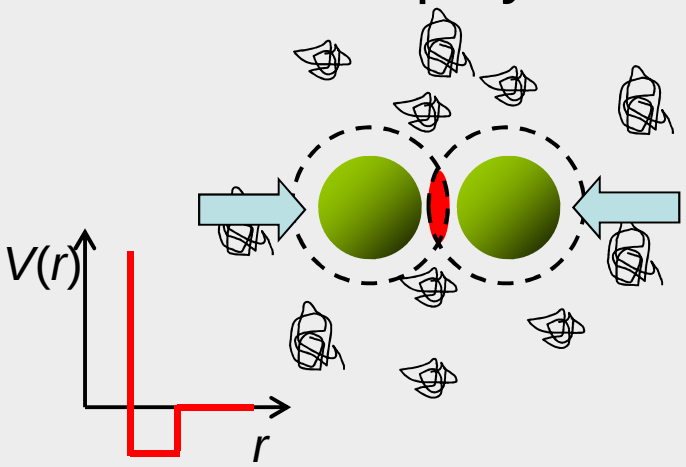
Science Overview

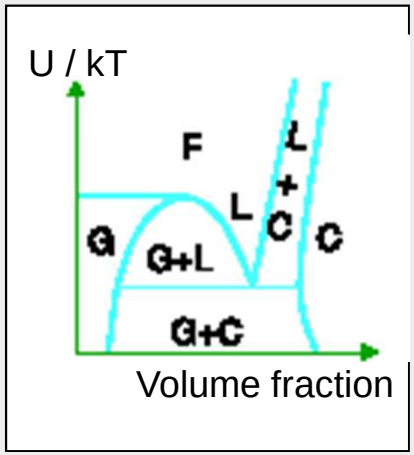


Chaikin, Weitz

Colloidal Phase behavior - Depletion

Colloid-polymer





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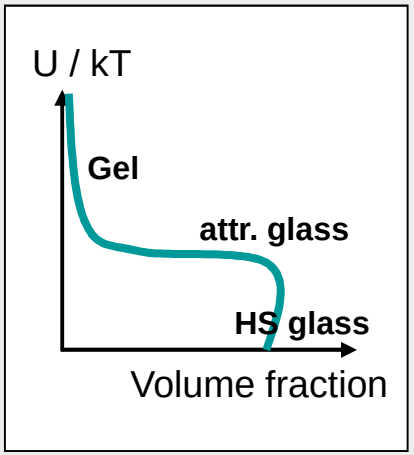
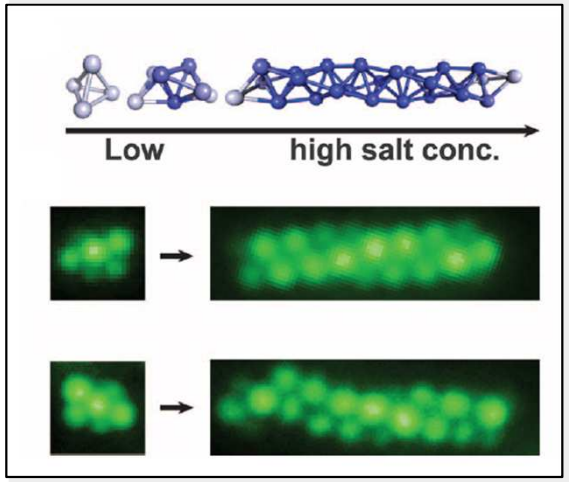


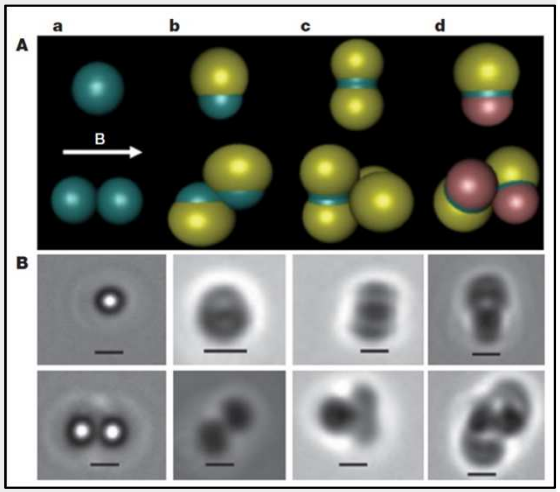
out of equilibrium

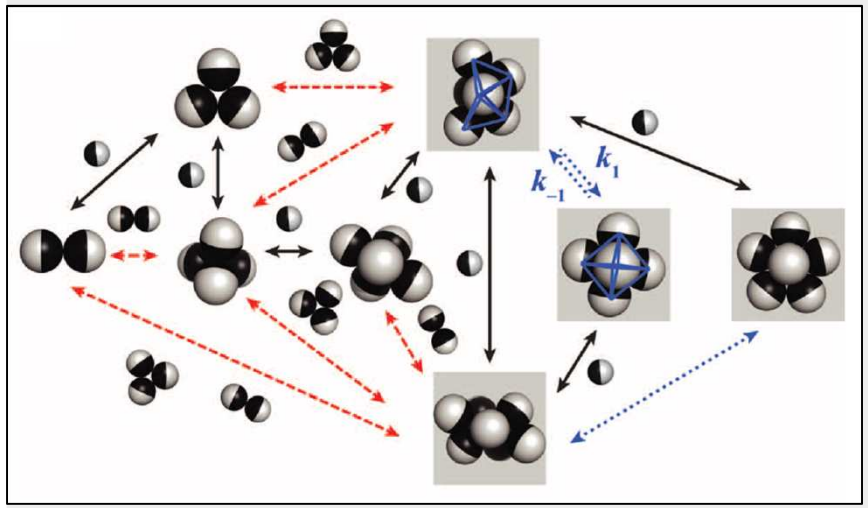
Science Overview

Anisotropic Interactions

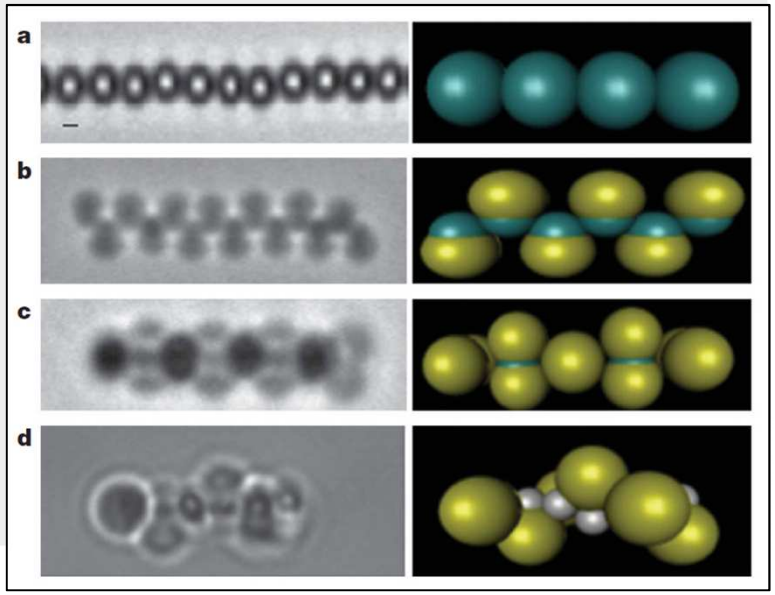


D. Zerrouki, J Baudry, D. Pine, P. Chaikin, J. Bibette, *Science*, 455 (2008) , 380-382



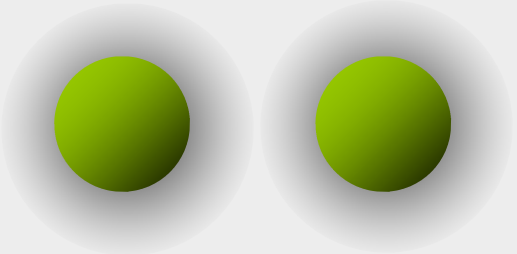


Q. Chen, J.K. Whitmer, S. Jiang, S.C. Bae, E. Luijten, S. Granick ,*Science*, 331 (2011) 199-202



Science Overview

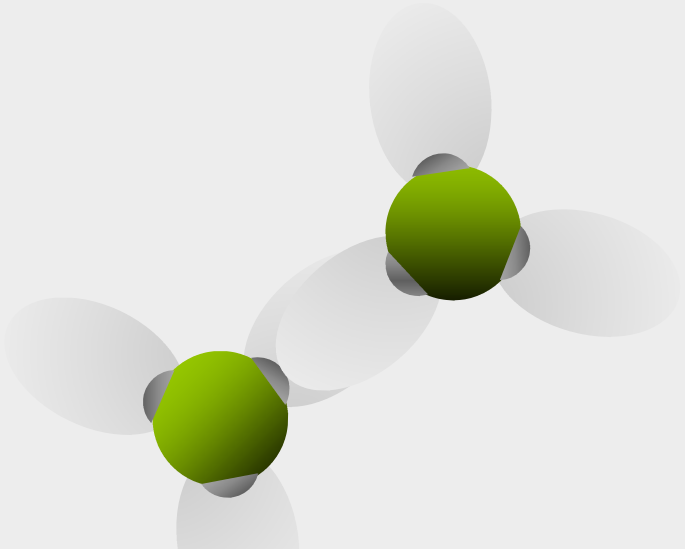
Control Interactions - Critical Casimir effect



T

1. Active Potential Control

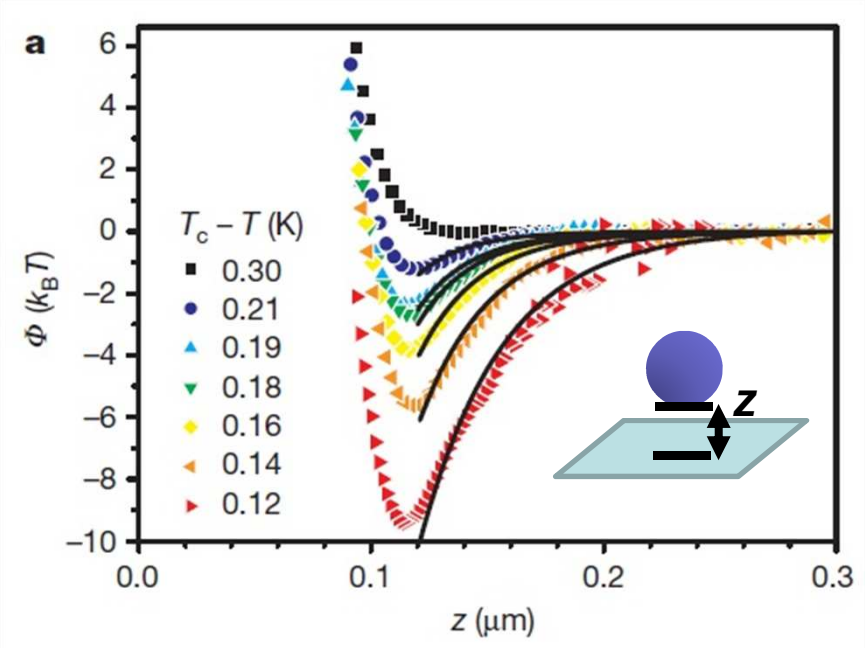
+



2. Anisotropic Interaction

Science Overview

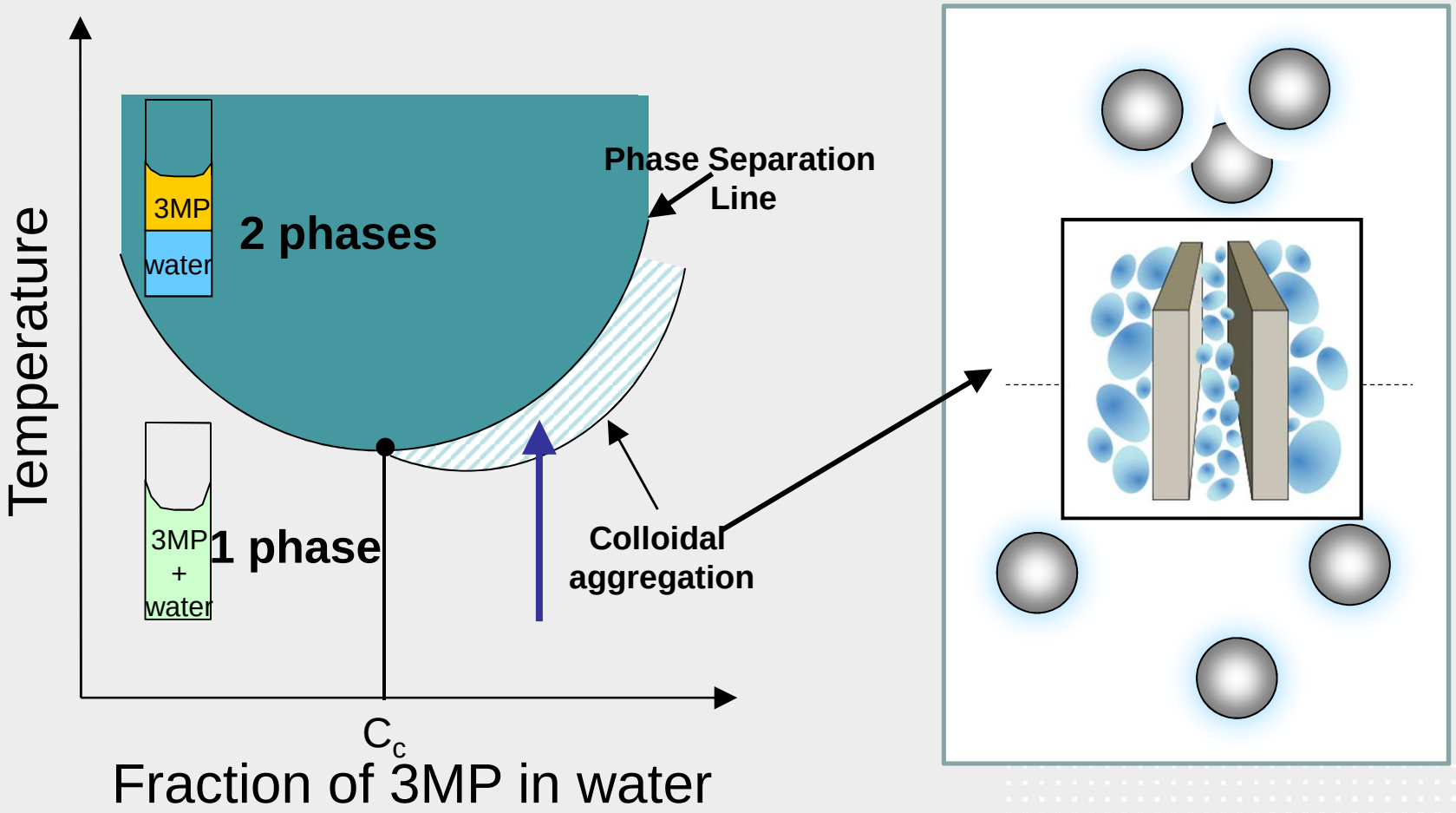
Control Interactions - Critical Casimir effect



Bechinger et al. (*Nature* 2008)

Science Overview

The Critical Casimir effect



Science Overview

Particle interactions

Coulomb repulsion

$$V_{el}(a) \propto \lambda_d^2 e^{-a/\lambda_d}$$

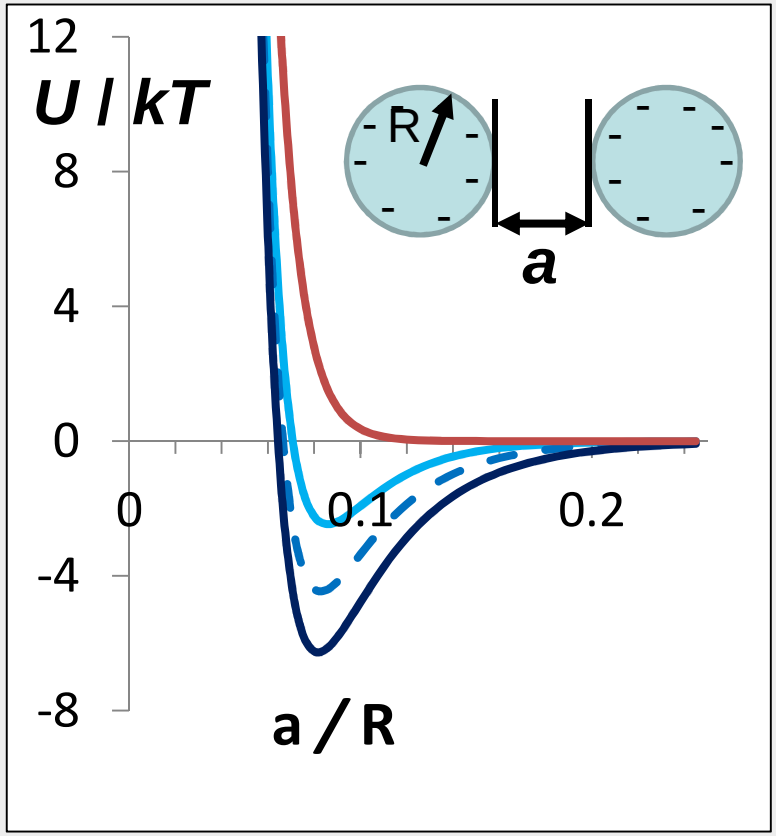
λ_d → Salt concentration

+

Casimir attraction

$$V_{casimir}(a) \propto -\frac{1}{\xi} e^{-a/\xi}$$

ξ → Temperature



Fisher, de Gennes, C.R. Acad. Sc. Paris, t287 (1978), 207 Schall et al. PRL **103**, 156101 (2009)

Science Overview

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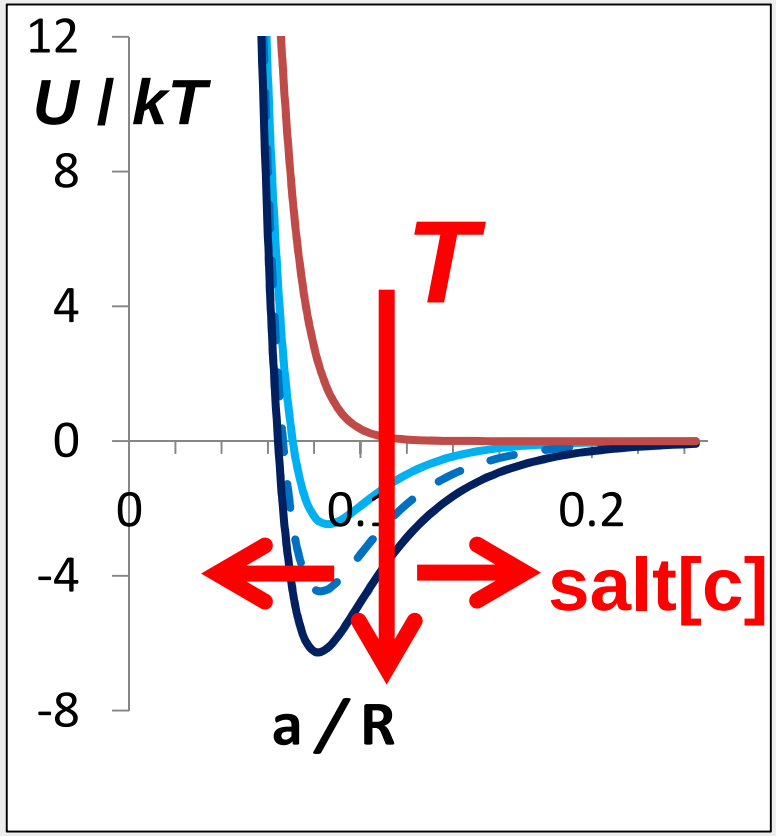
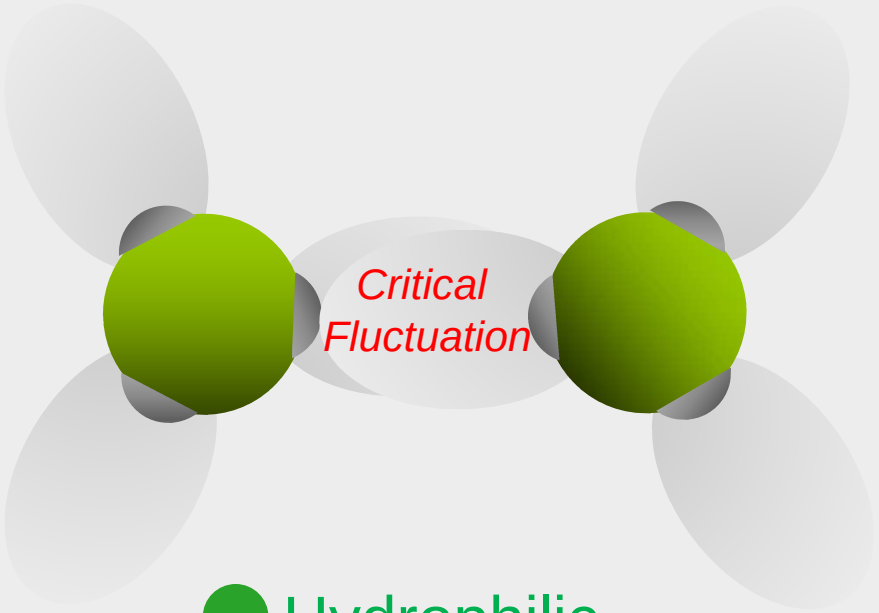


Fisher, de Gennes, C.R. Acad. Sc. Paris, t287 (1978), 207 Schall et al. PRL **103**, 156101 (2009)

Scientific Merit

Control Anisotropic Interactions



Hydrophilic
Hydrophobic

Scientific Merit

Control Anisotropic Interactions

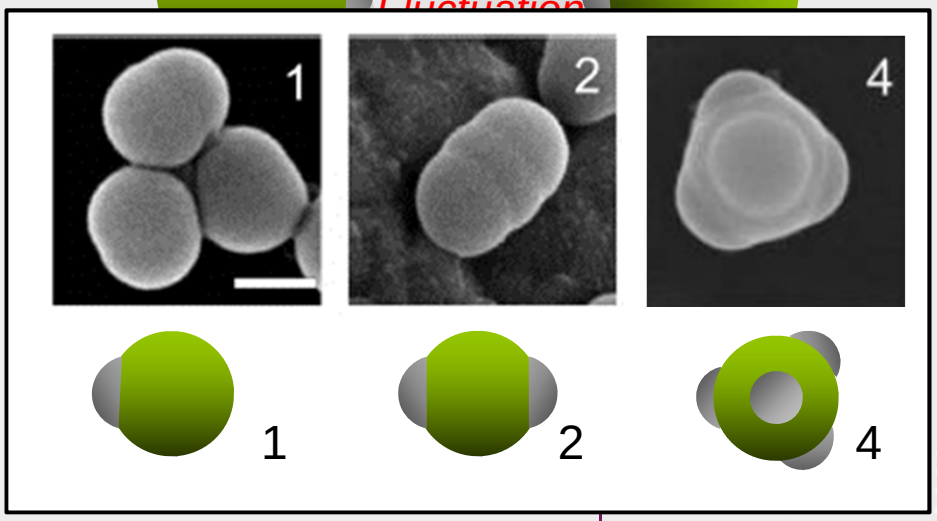
Living polymer chains
(Particles 2)

Diamond structure
(Particles 4)

Colloidal Micelles
Helices
(Particles 1)

Molecules
(Particle Mixtures)

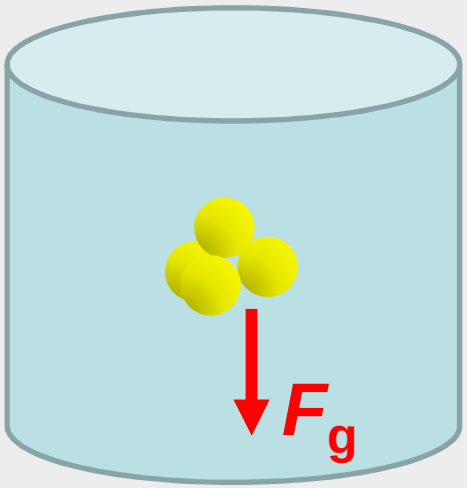
Critical



D.J. Kraft et al, *JACS*, 131, (2009) 1182-1186

Need for ISS environment

1. Follow the growth of structures



$$F_g = \Delta\rho g V$$

$$\Delta\rho = \rho_{Colloid} - \rho_{Solvent}$$

Need for ISS environment

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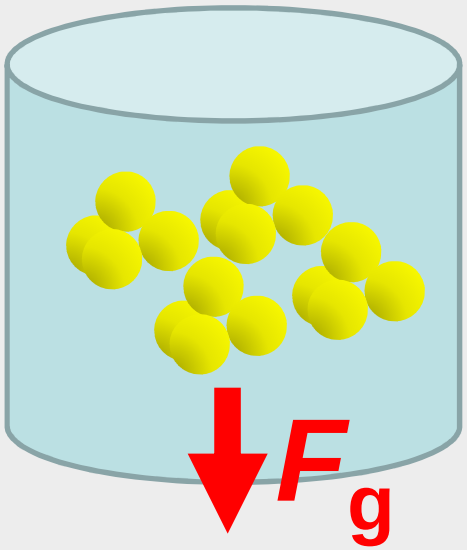
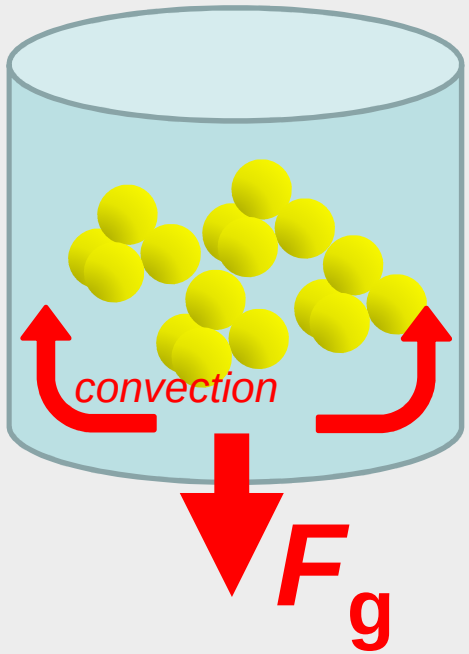


$$F_g = \Delta\rho g V$$

$$\Delta\rho = \rho_{Colloid} - \rho_{Solvent}$$

Need for ISS environment

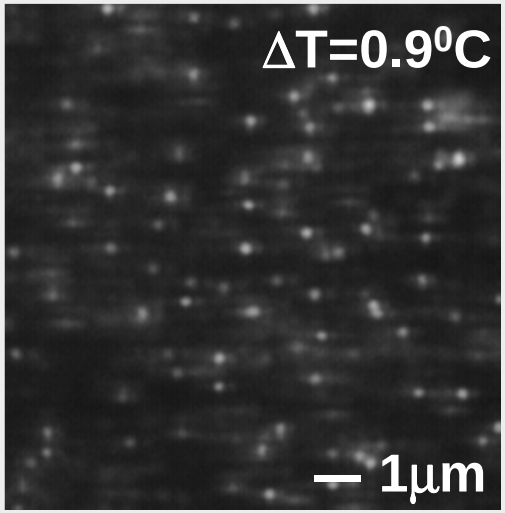
2. Temperature is control parameter



- Change Temperature
  $\Delta\rho$ changes
- Temperature → Convection disrupts growth

Ground-based work

Microscopy



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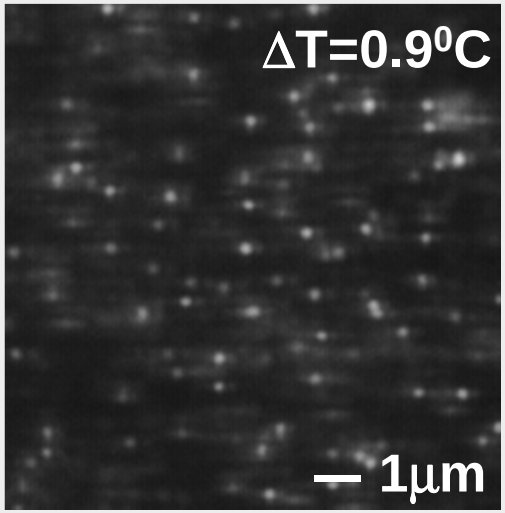
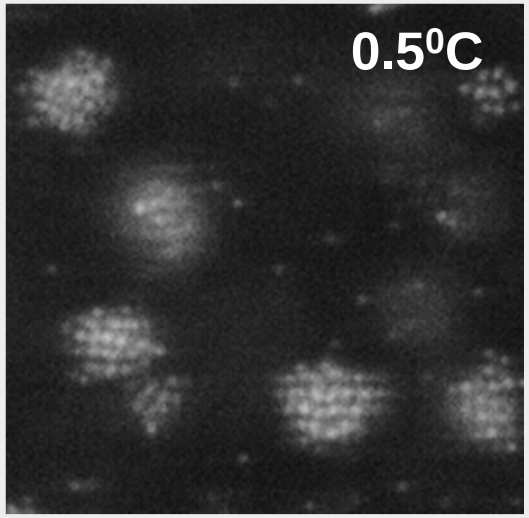
Ground-based work

Microscopy





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Ground-based work

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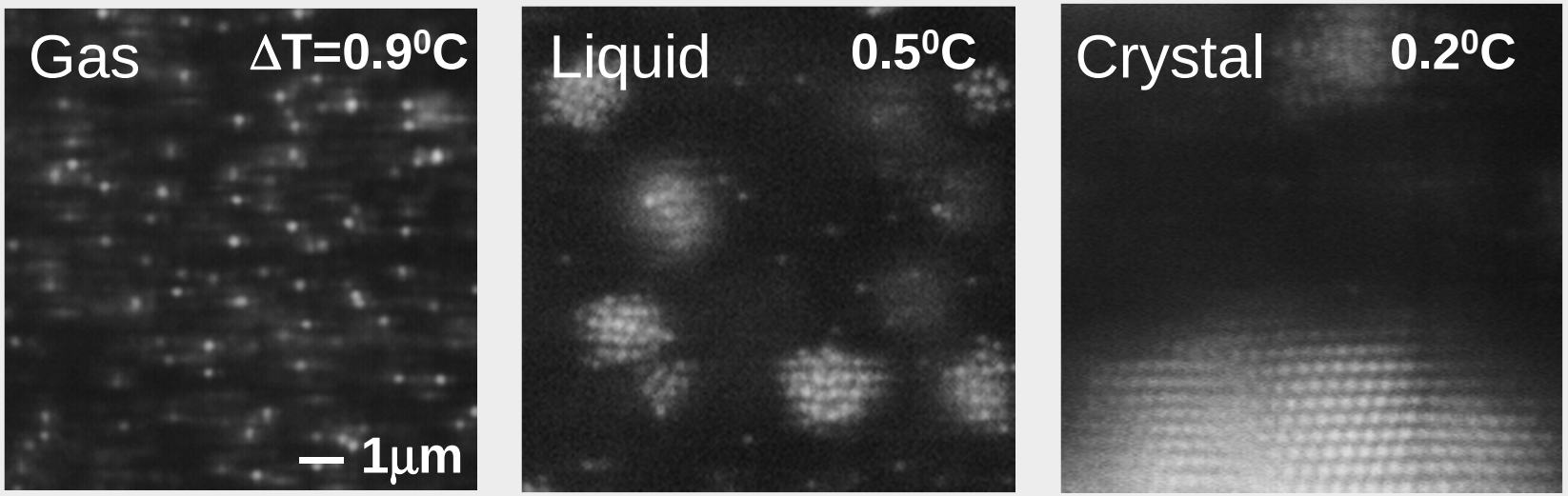

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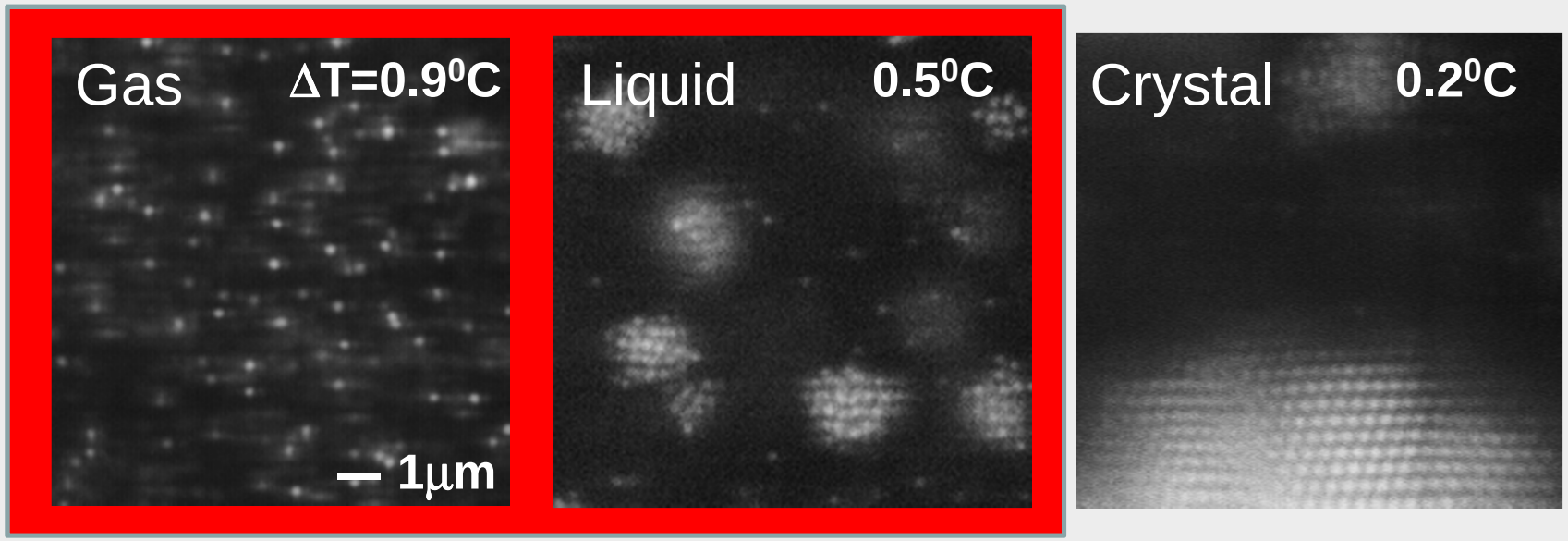

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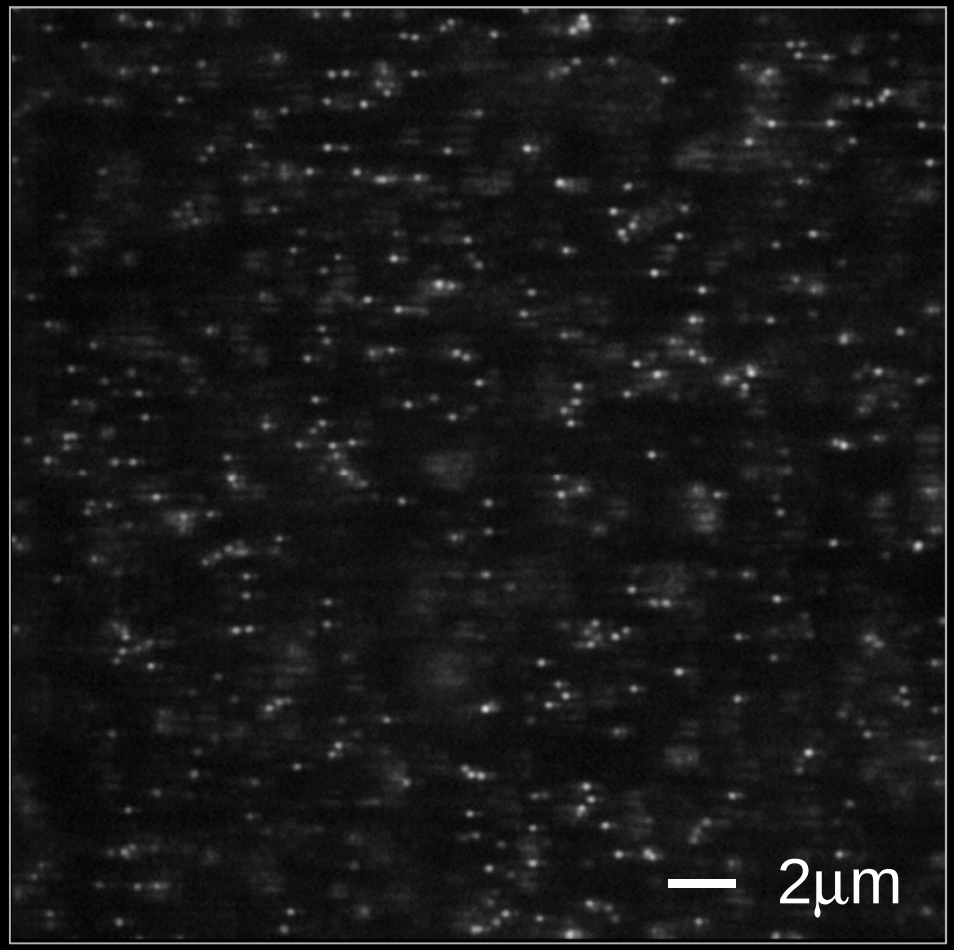

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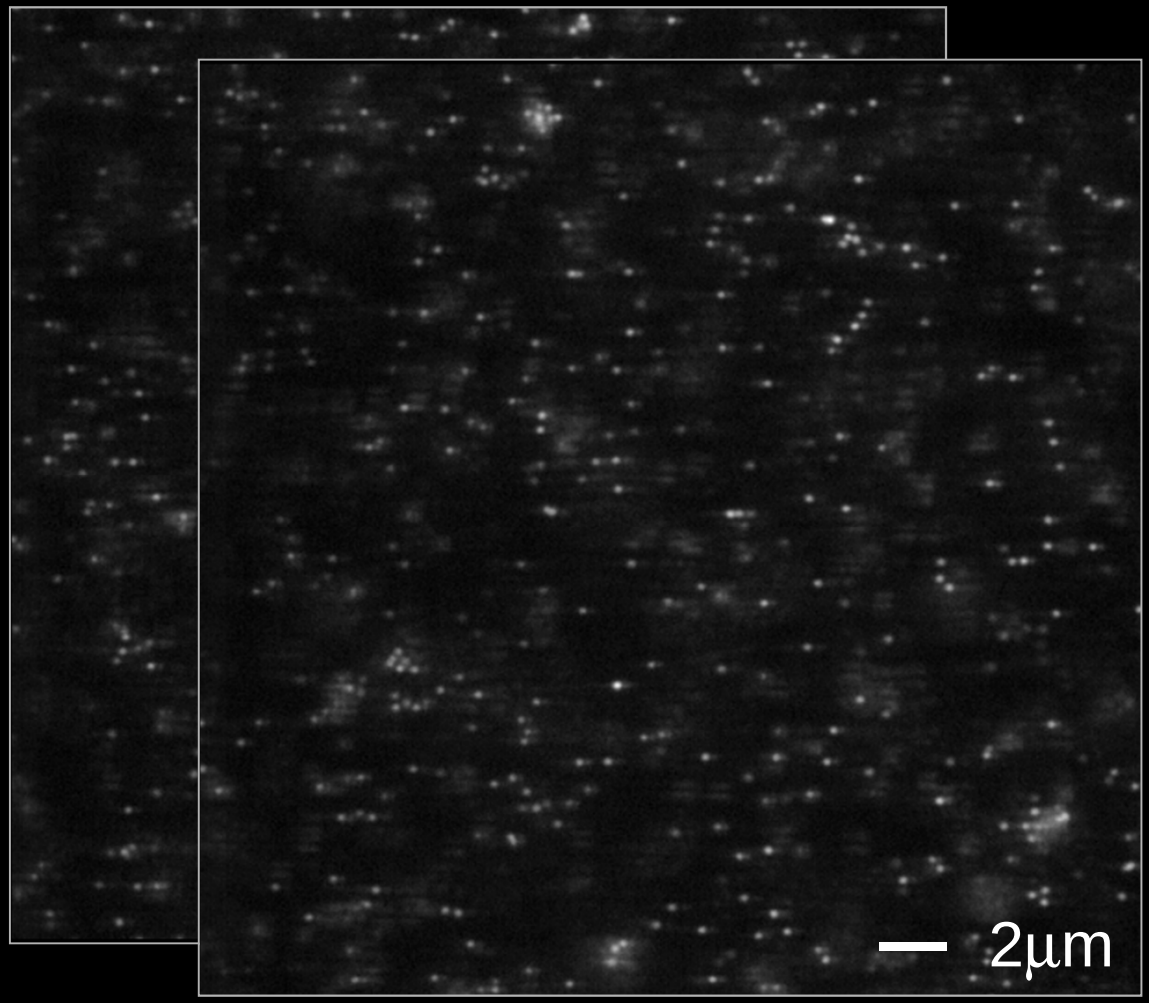

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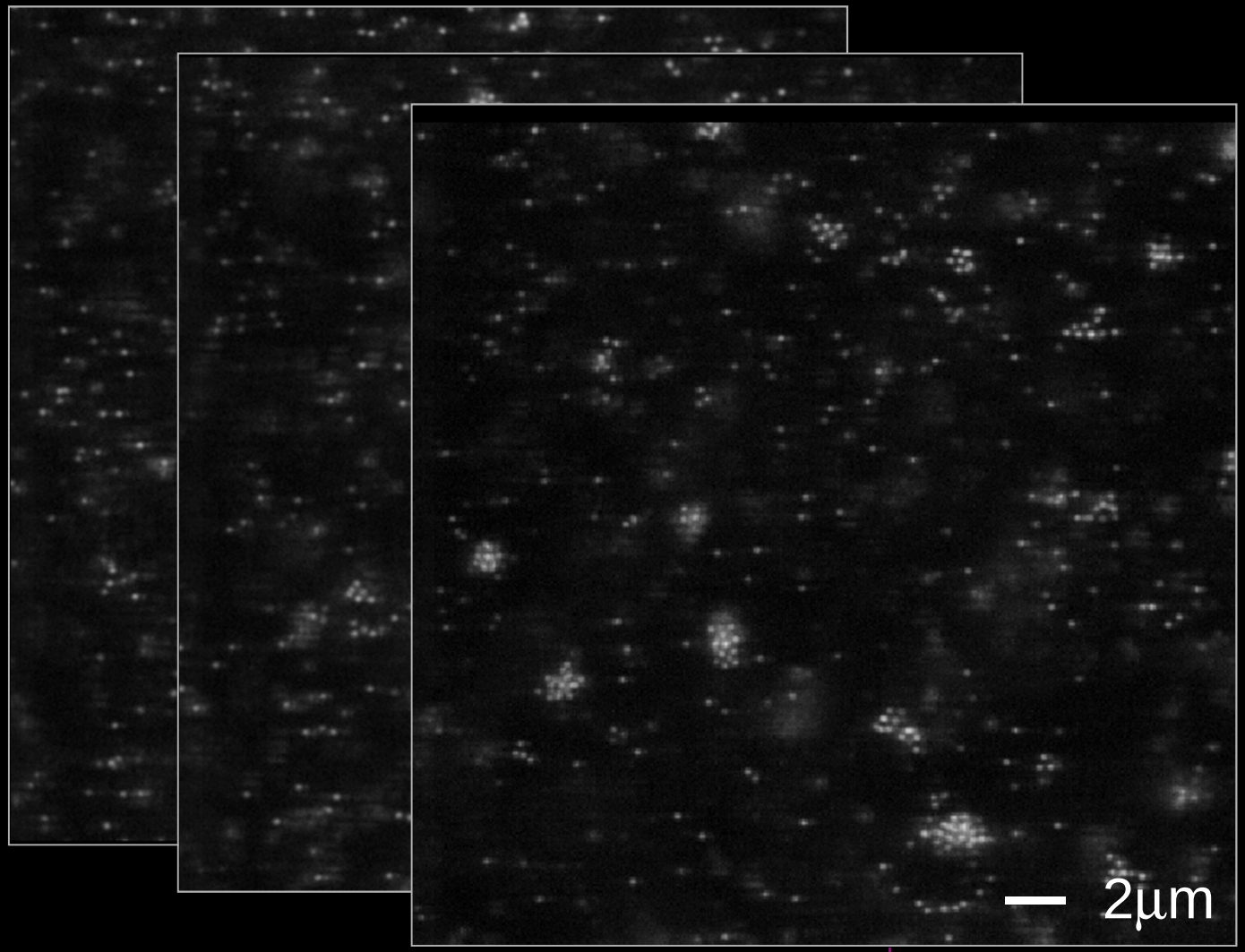

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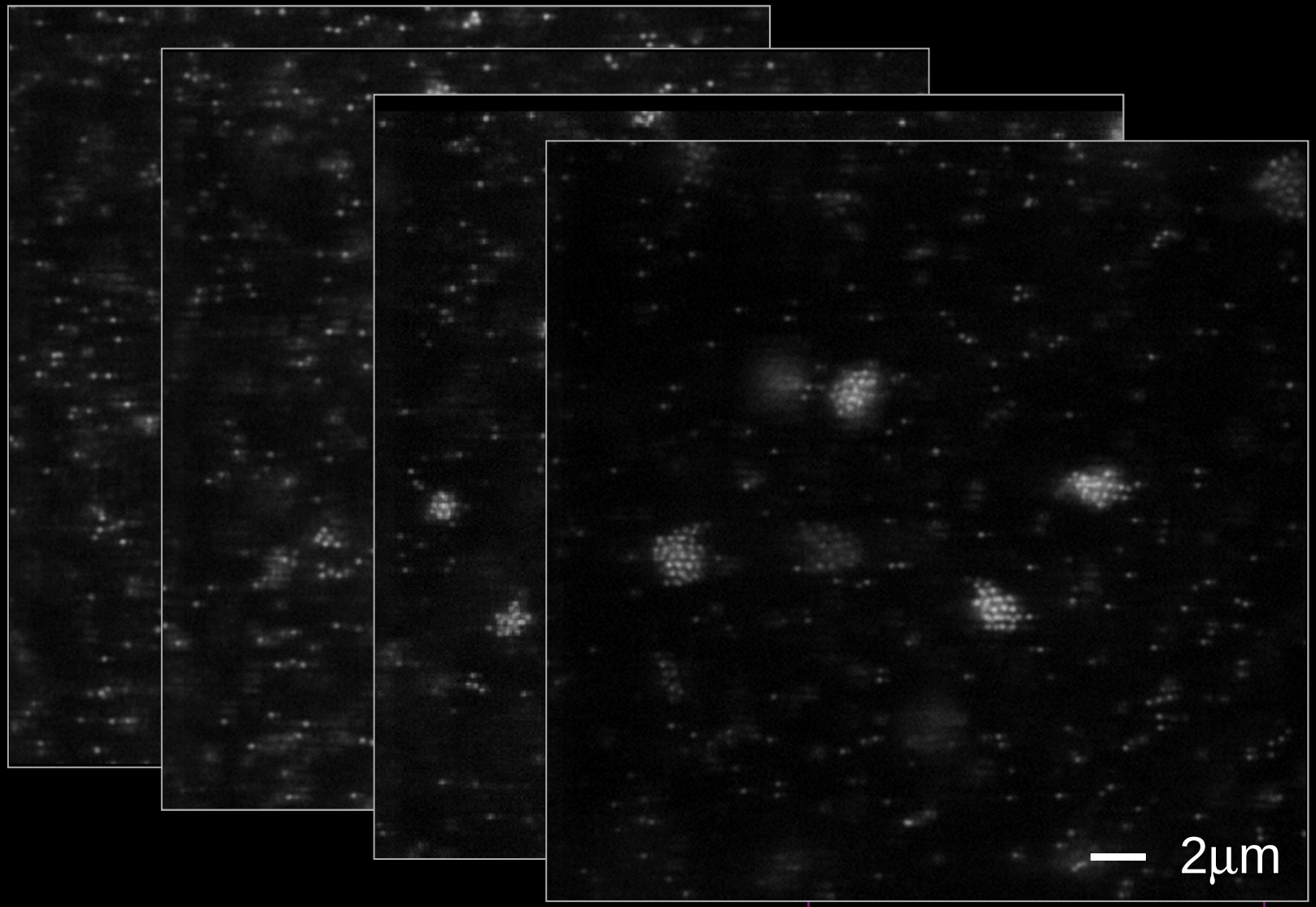
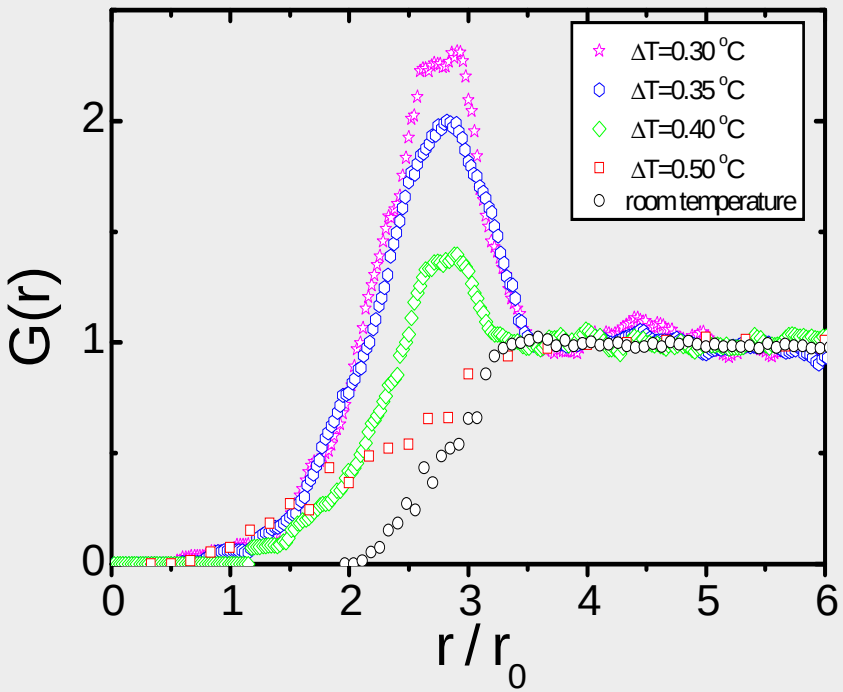


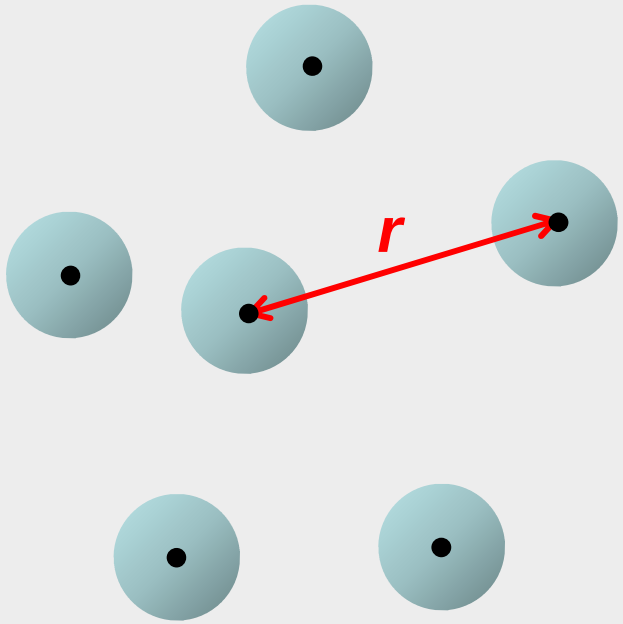
Ground-based work

Potential measurement

Pair distribution function



Particle distribution



Ground-based work

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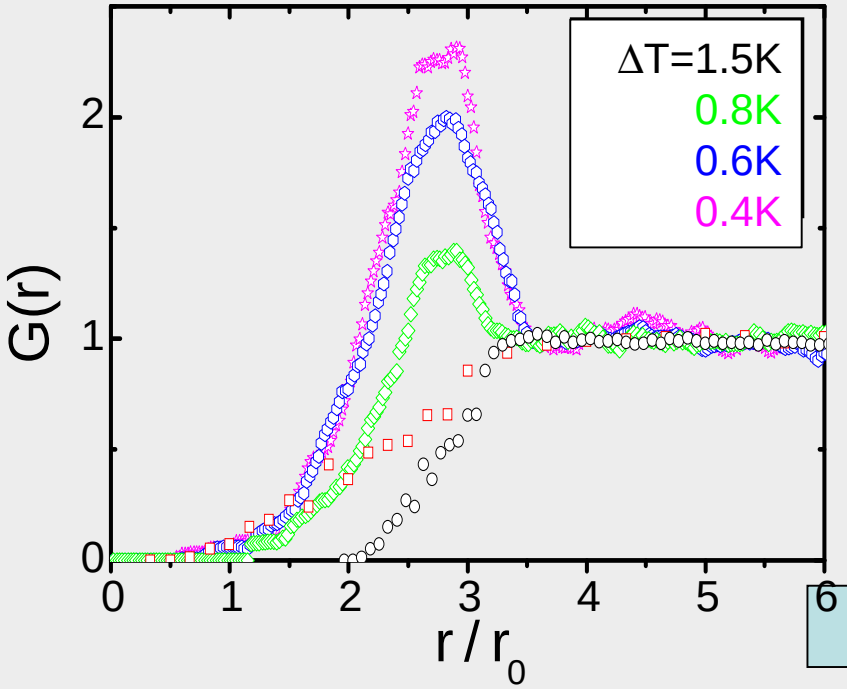
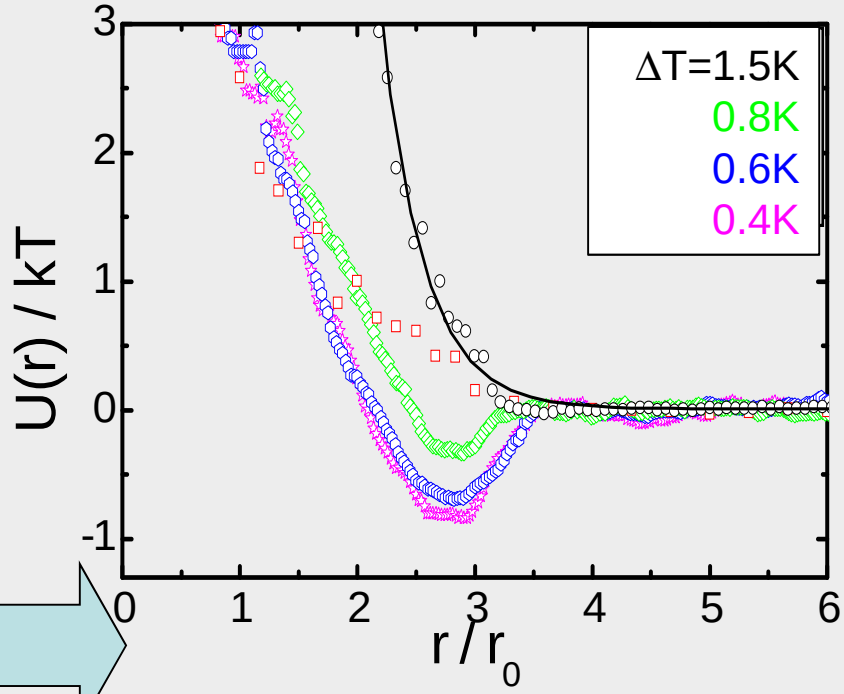


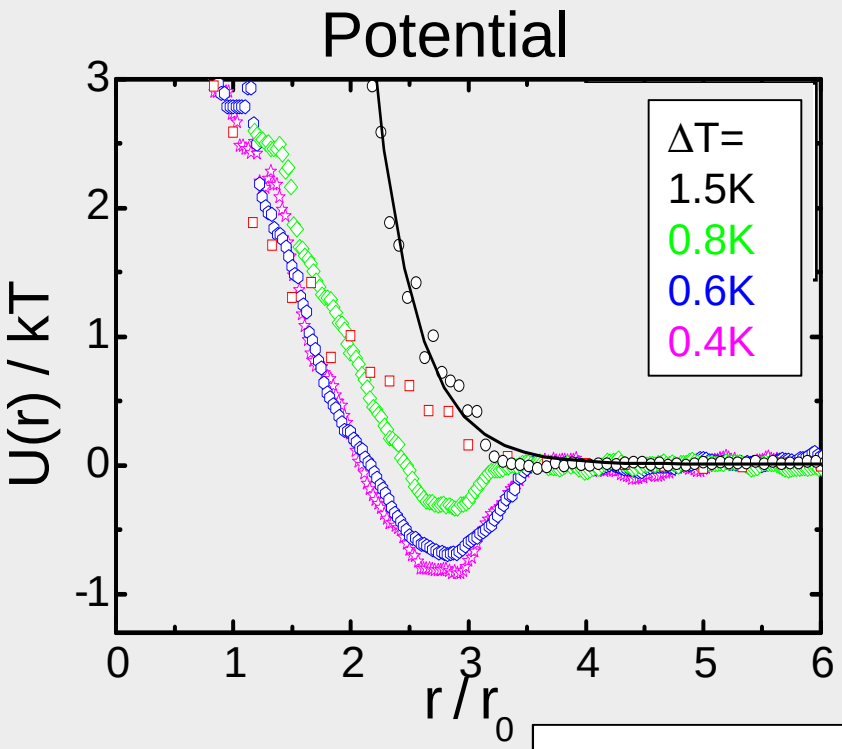
Potential



$$G(r) = \exp(-U(r) / k_B T)$$

Ground-based work

Potential measurement

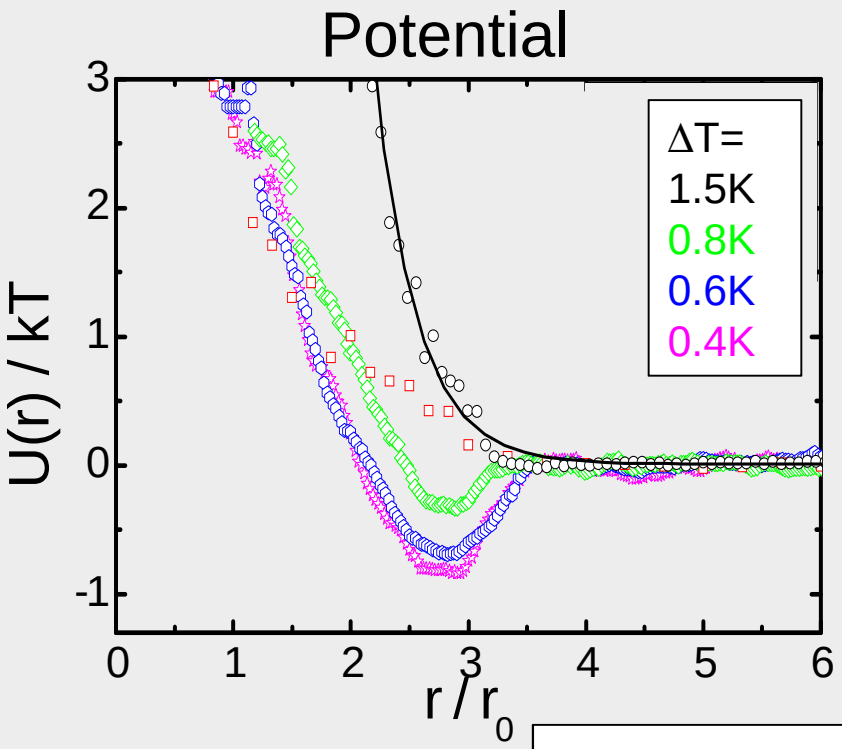


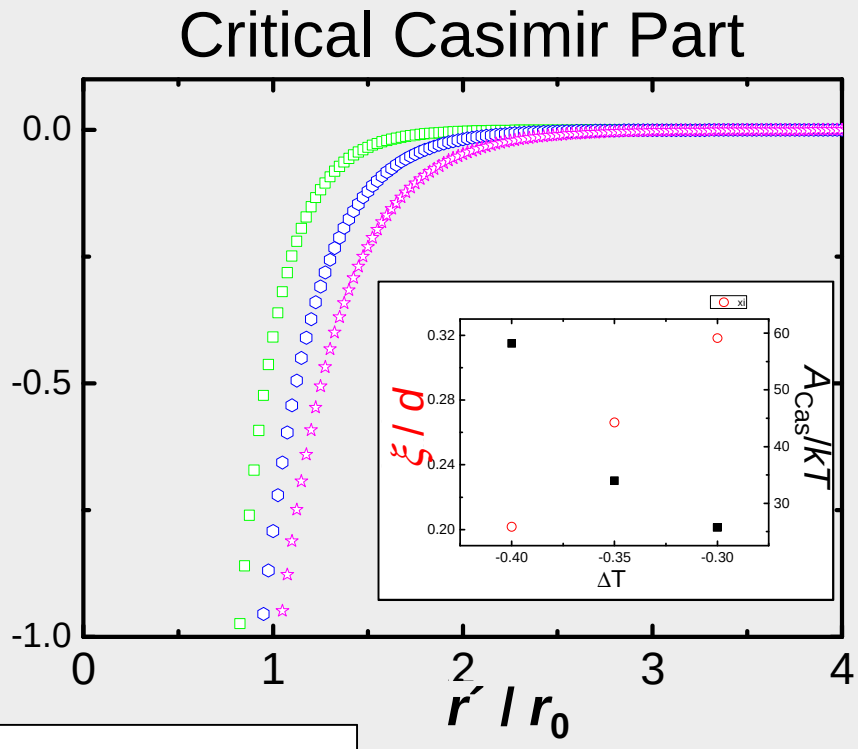
$$U_{total} = U_{el} + U_{Casimir}$$

$$A_{el}\, e^{-(r'/\lambda_d)} \qquad A_{Cas}\, e^{-(r'/\xi)}$$

Ground-based work

Potential measurement





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$$A_{el}\, e^{-(r'/\lambda_d)} \qquad A_{Cas}\, e^{-(r'/\xi)}$$

Ground-based work

Van der Waals model

$$(v-b)\left(p+\frac{a}{v^2}\right)=k_BT$$

Excluded volume $b=\frac{16}{3}\pi\, {r_0}^3$

Effect. attraction $a=-2\pi\int_{r_1}^{\infty}U(r)r^2dr$

Israelachvilli, Intermolecular and surface forces

Ground-based work

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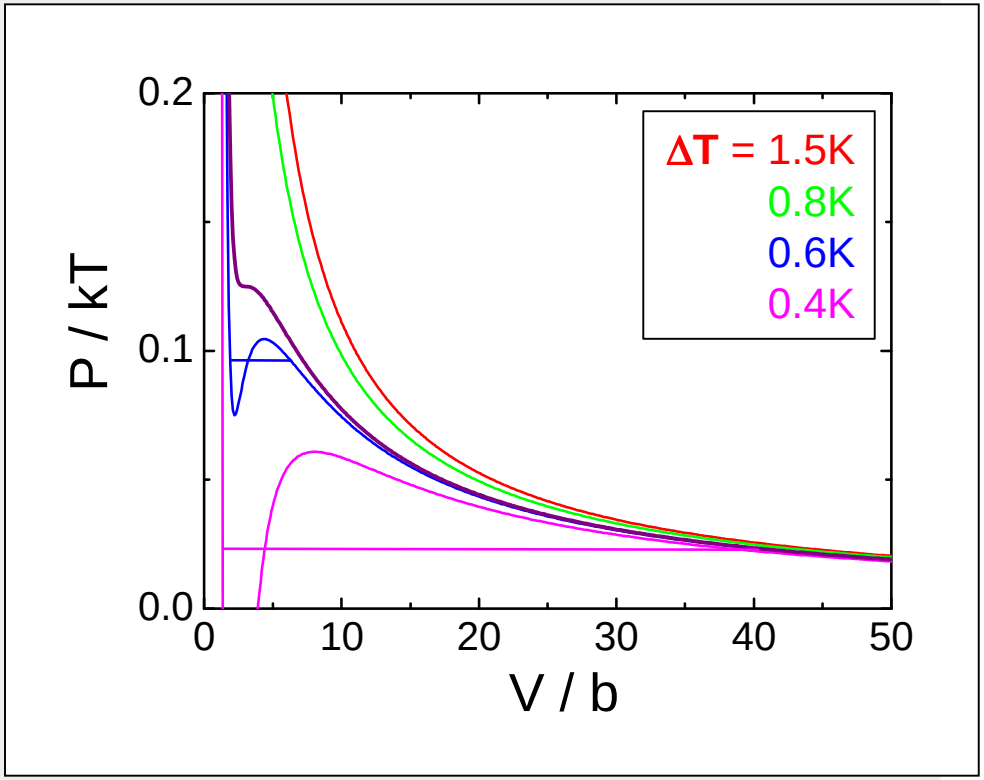

D. Nguyen, S. Faber and P. Schall, in preparation

Ground-based work

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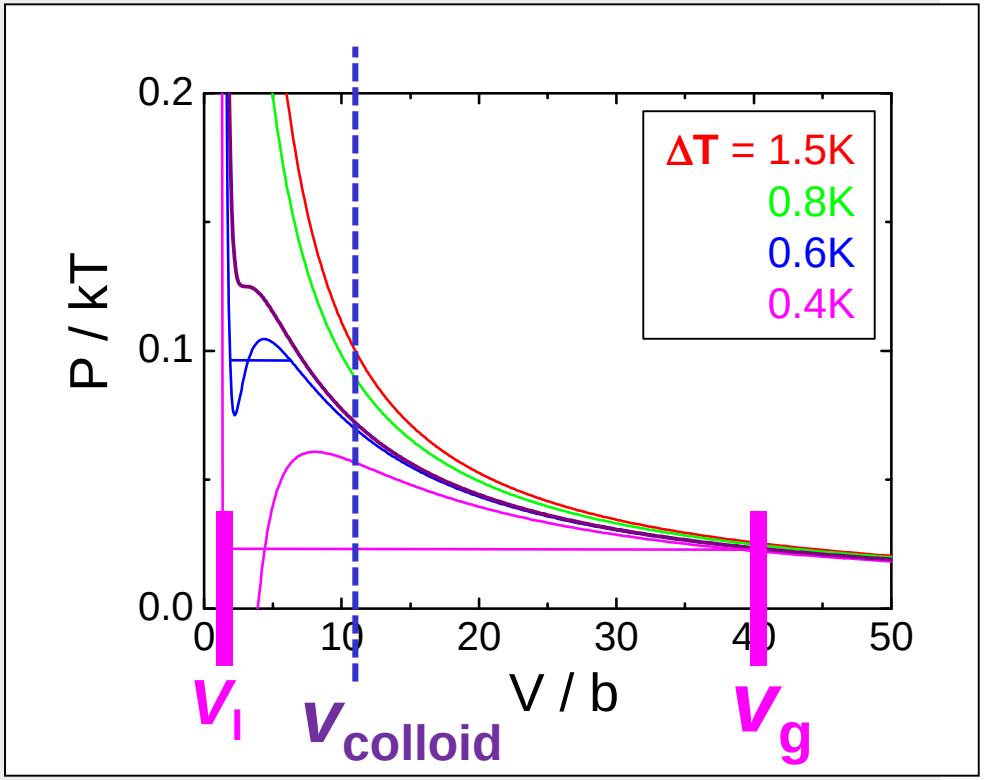
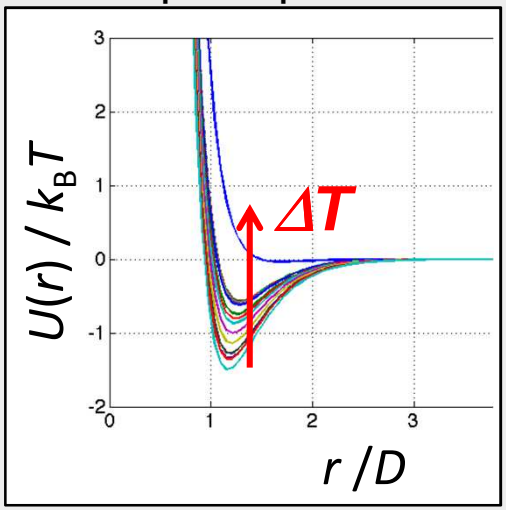


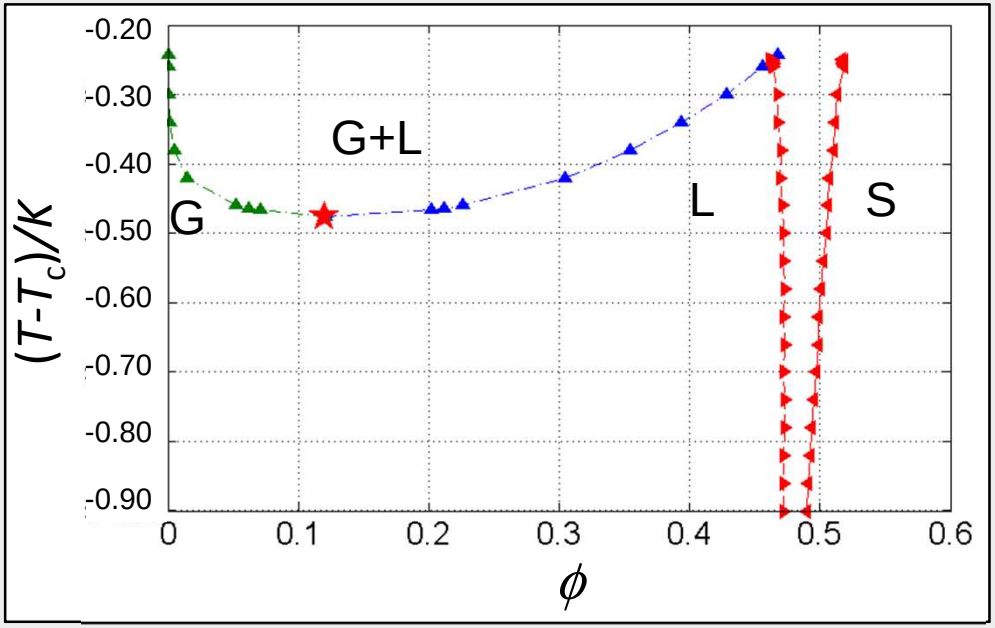
Ground-based work

Monte Carlo Simulations

Extrapolte potential



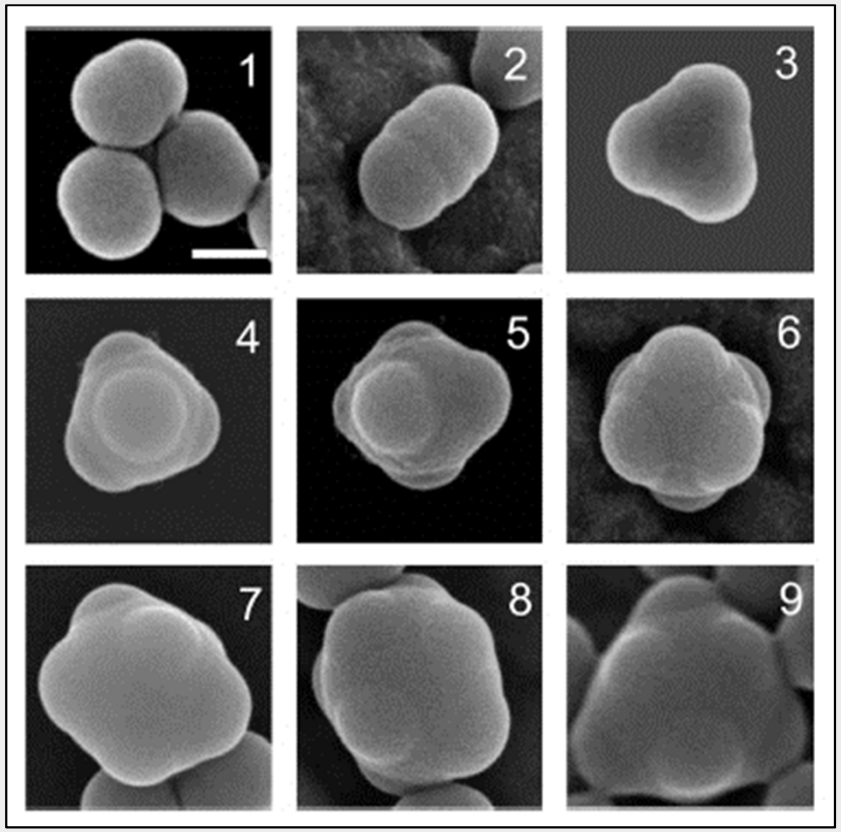
Equilibrium phase diagram



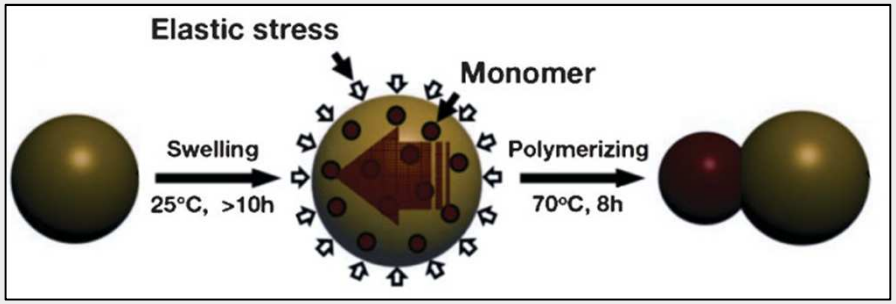
D. Triet, D. Nguyen, P. Bolhuis and P. Schall, in preparation

Ground-based work

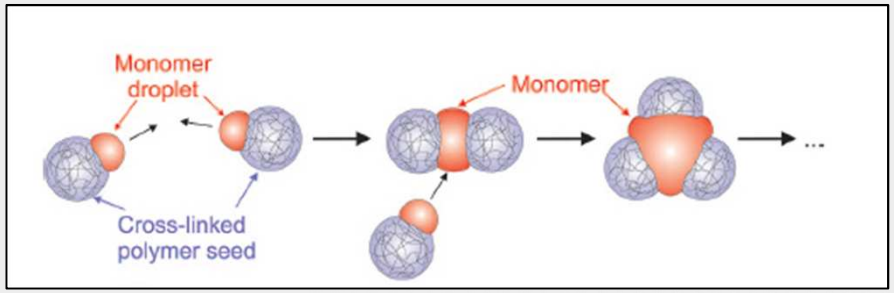
Colloidal Molecules



Single protrusion



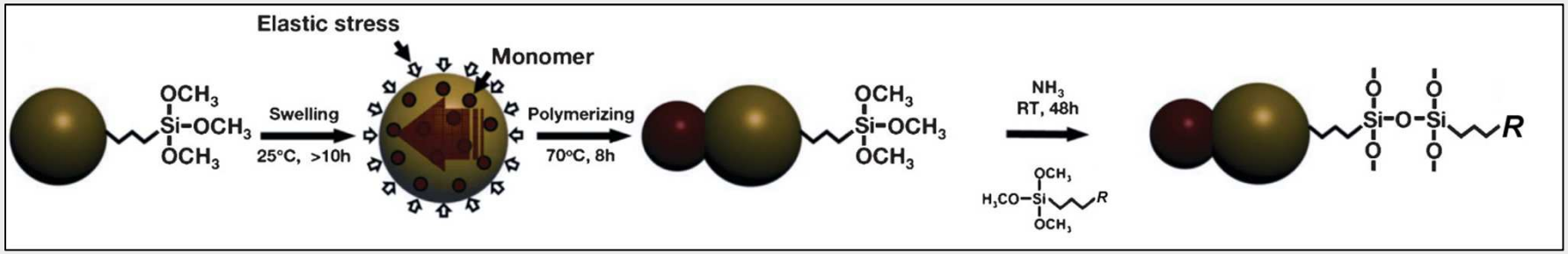
Making molecules

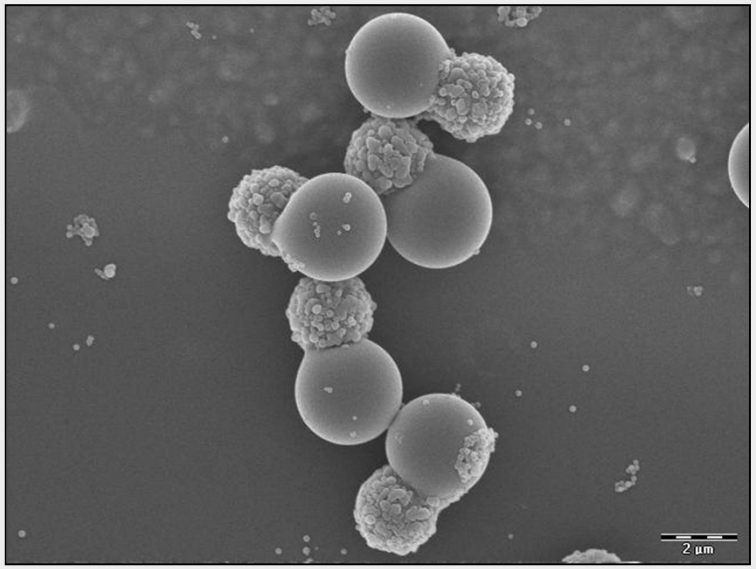


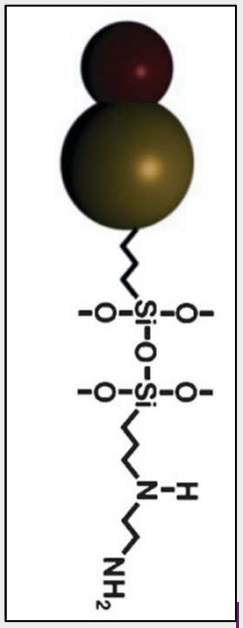
D.J. Kraft et al, *JACS*, 131, (2009) 1182-1186

Ground-based work

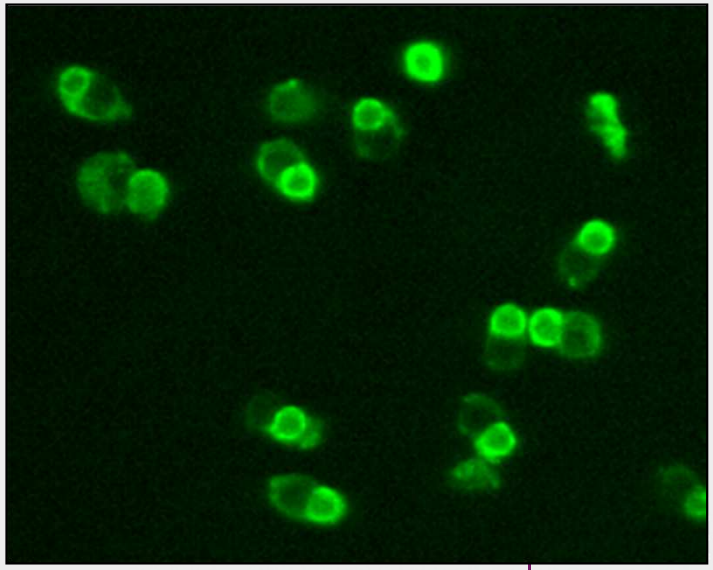
Adjusting the surface properties







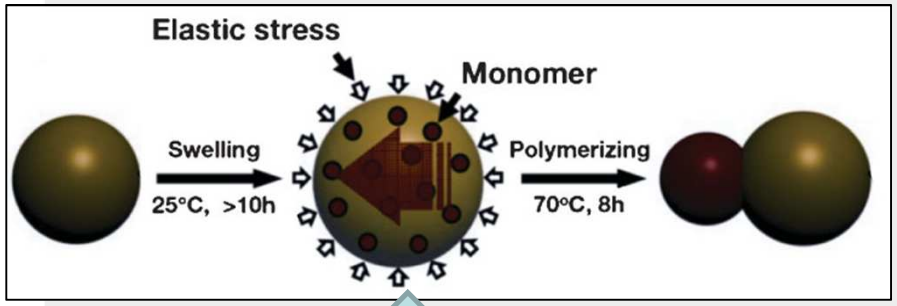
Add Fluorecein



J.W. Kim, D. Lee, H.C. Shum, D.A. Weitz, *Advanced Matt.* 20 (2008) 3239-3243

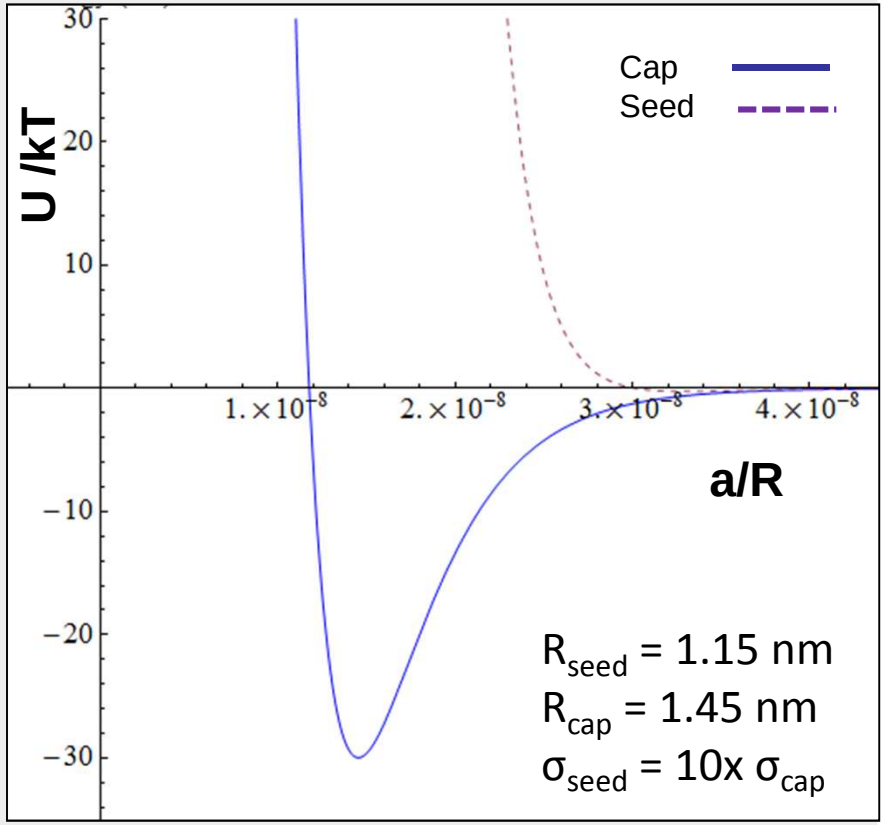
Ground-based work

Adjusting the surface properties



Creating differences:
- Different monomer (PS/PMMA)
- Charged/uncharged initiator

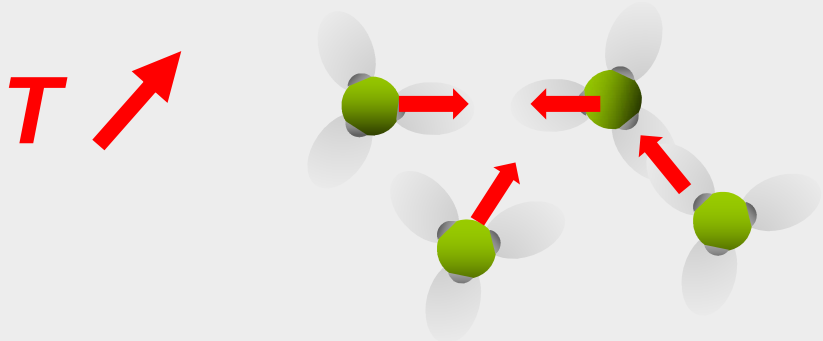
Current system:
- Charged protrusion
- PolyStyreen/PS particles
- Readily suspendable in water/3MP
- Promising ground-based measurement



Simple calculation
Charge density difference only
Same temperature

Proposed Experiment

Temperature control
→ Attraction on/off
→ Follow structure formation
→ "Reaction kinetics"



Vary Temperature → Vary attraction strength

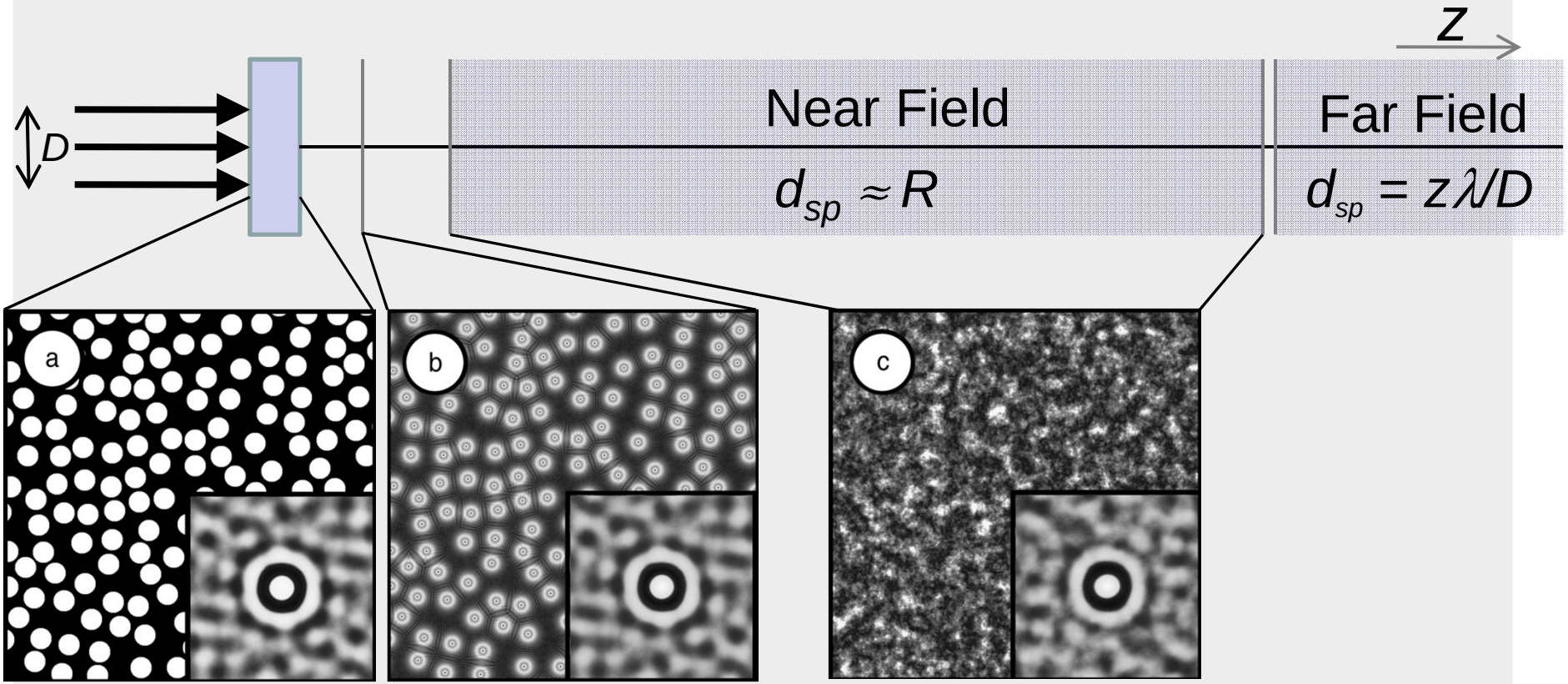
Vary Rate of change → Eqilibrium vs. out-of equilibrium

Reverse Temperature → Repeat Experiment

Image in real + reciprocal space

Proposed Experiment

Direct imaging + Near Field Scattering



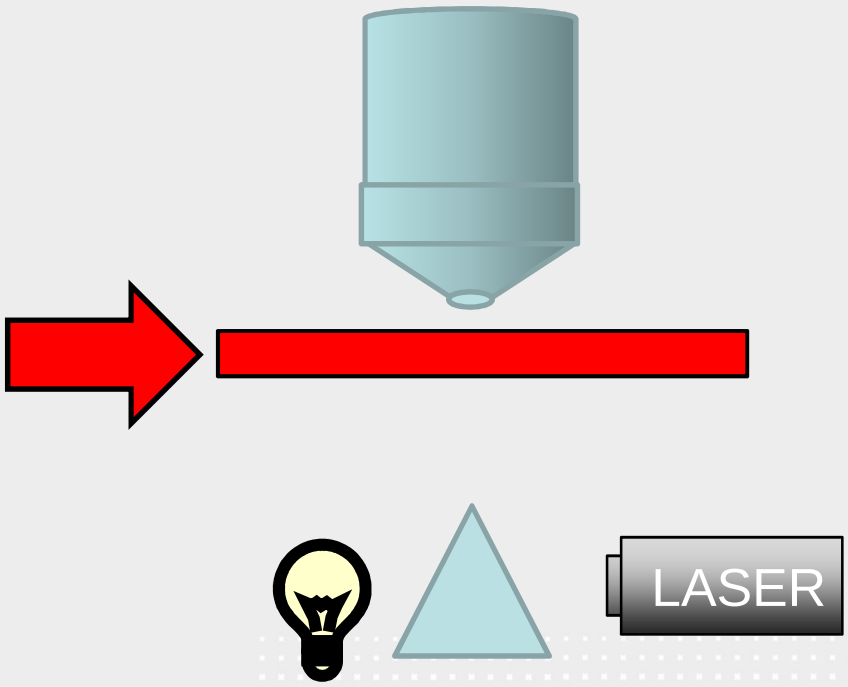
R. Cerbino, A. Vailati, Curr. Op. Coll. Int. Sc. ***14****, (2009), 416-425*

Proposed Experiment

1. Sample Cells

- Stirrer
- No bubbles in field of view
- Quartz cells
- Max 3 mm thick

ACE microscope



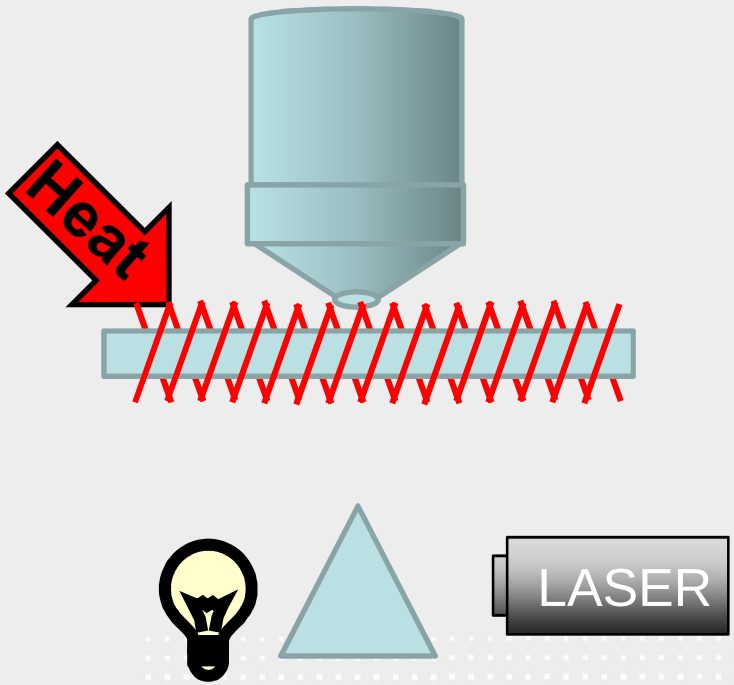
Proposed Experiment

2. Temperature control

- 0.5 ℃ steps, better 0.2℃

- Possible to heat samples individually

ACE microscope



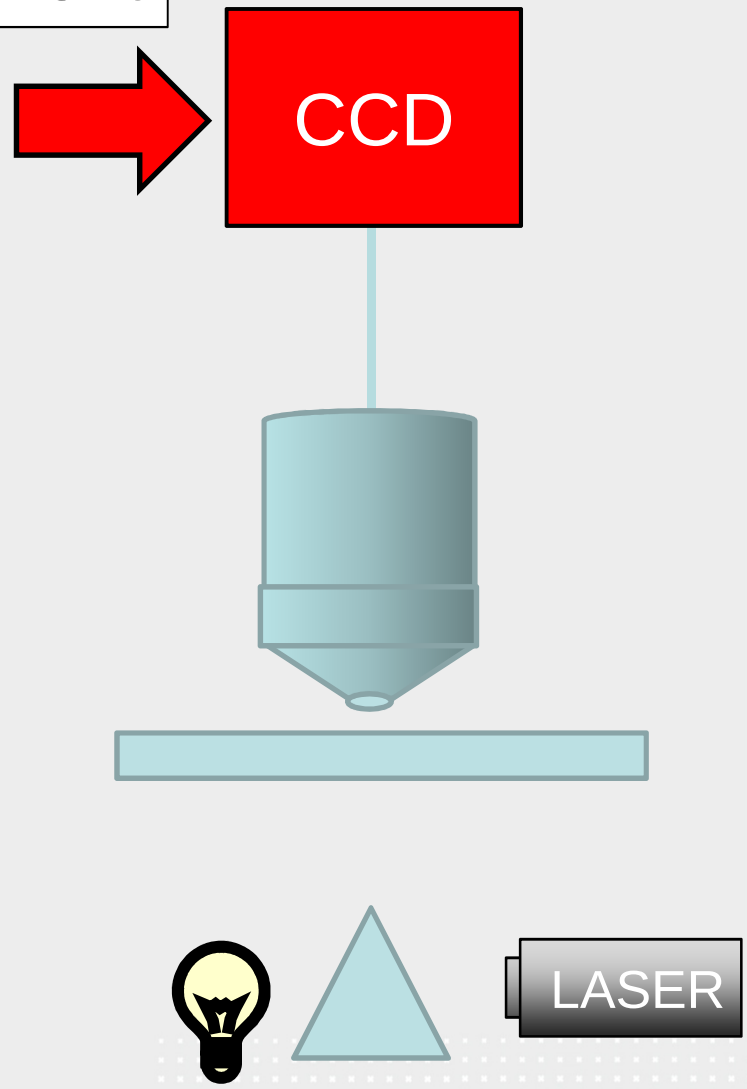
Proposed Experiment

3. Camera

- 1024x1280 pixels

- Dynamic range: 12 bit

- Low signal to noise ratio



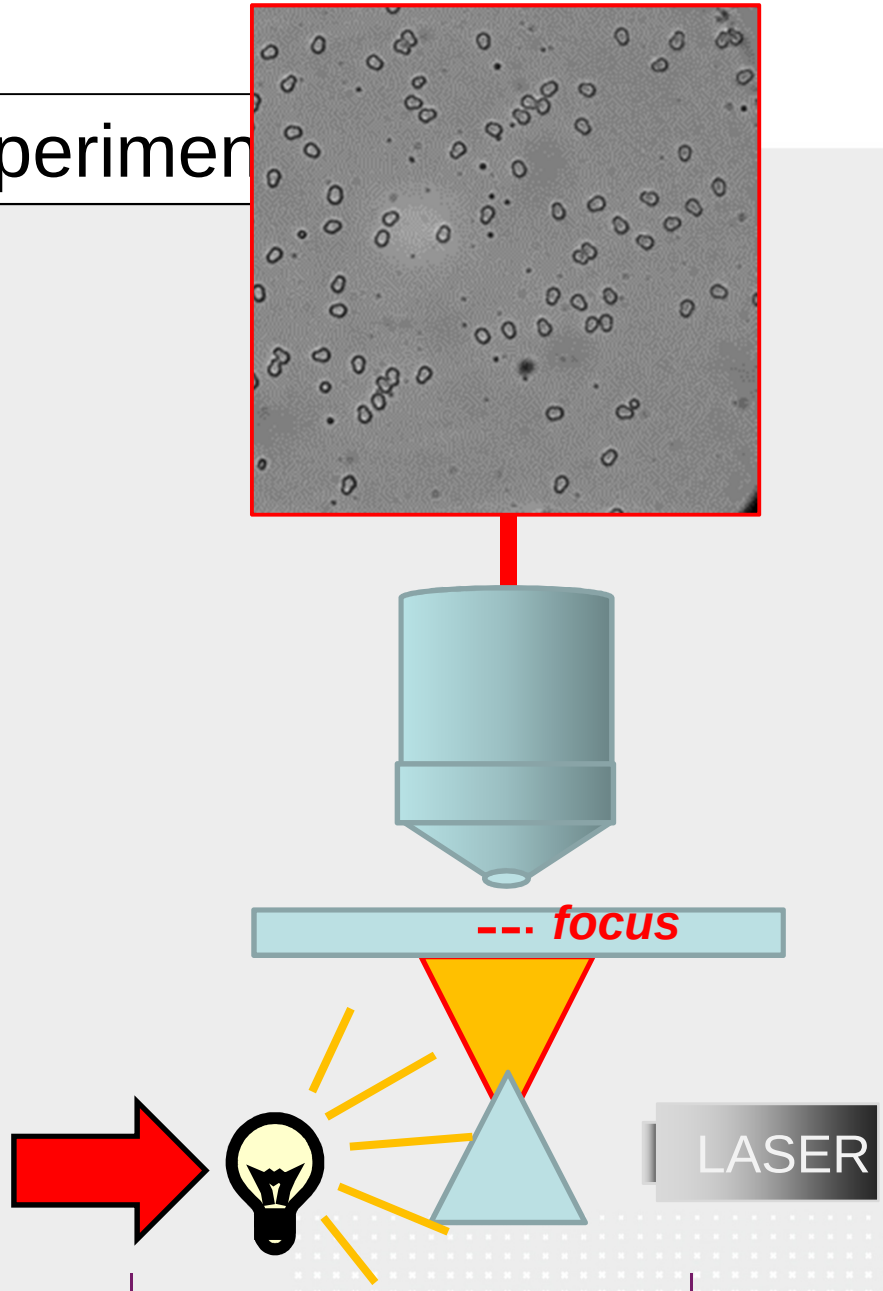
Proposed Experimen

4. Direct Imaging Mode

- White light illumination on

- Laser off

- Focus in sample



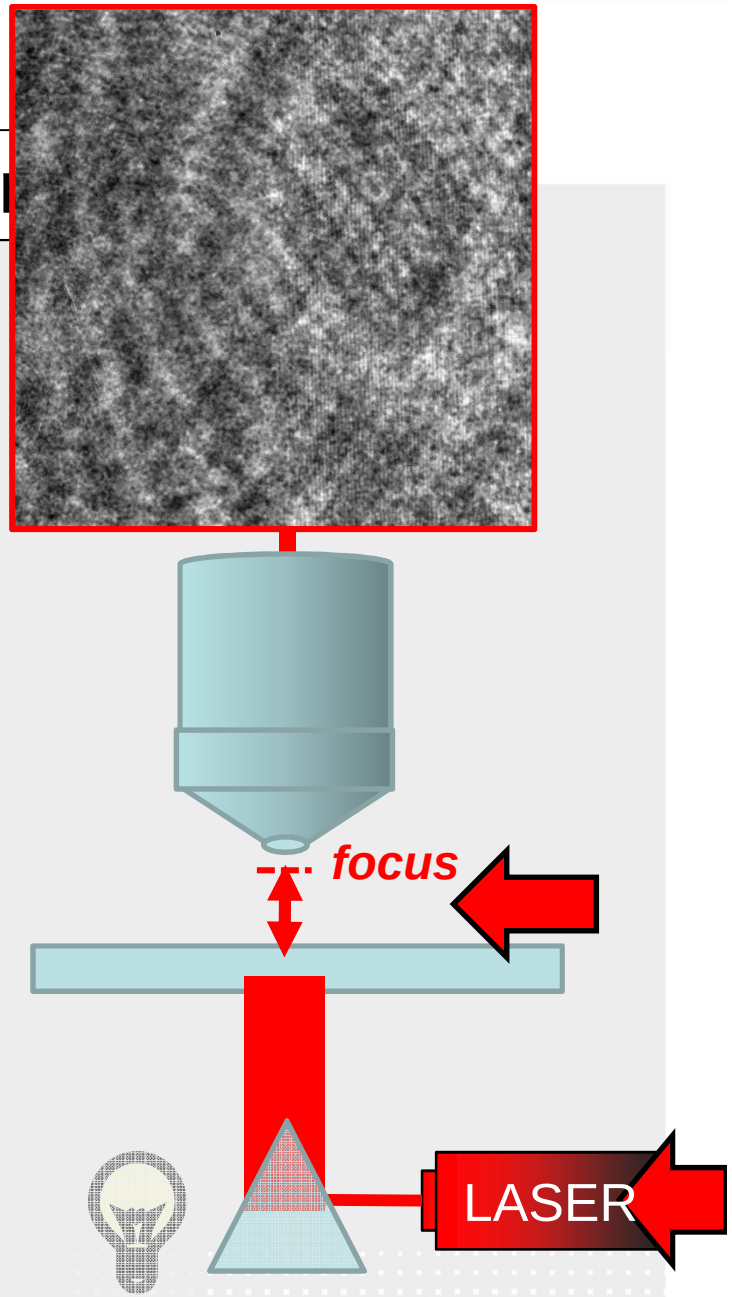
Proposed Experimen

5. Near field scattering Mode

- White light off

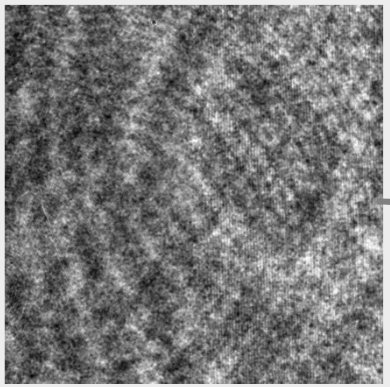
- Laser on:
  Beam Collimated
  Coherence length ~ 3mm

- Focus above sample



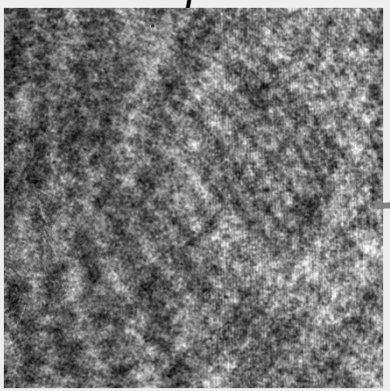
Proposed Experiment

Raw image at t_i

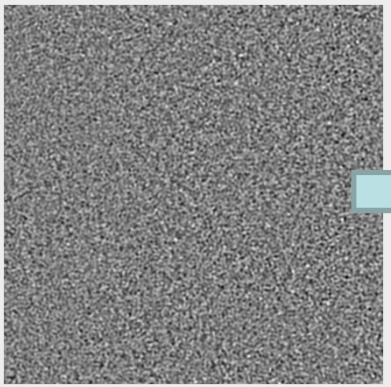


Raw Image at

$t = t_i + \Delta t$

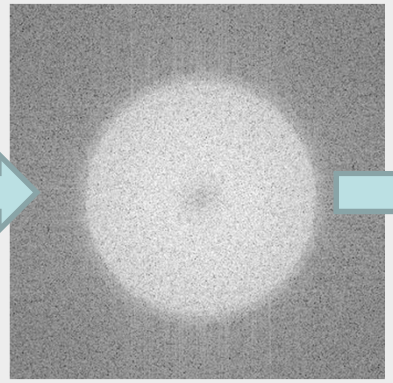


Subtracted Image



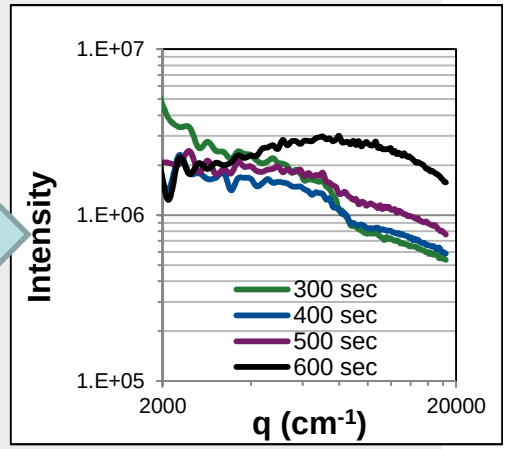
$$D_i(x, y)$$

Power Spectrum



$$S(q_x, q_y) = \left| FFT[D_i(x, y)] \right|^2$$

Azimuthal averaging



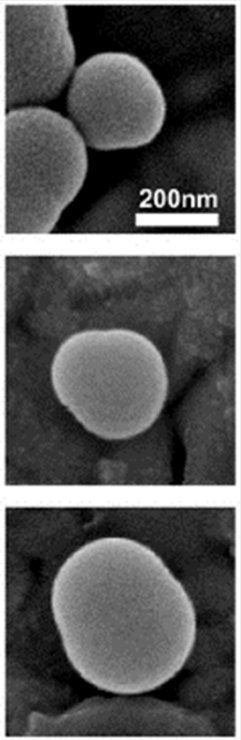
$$I(q)$$

*F. Ferri, D. Magatti, D. Pescini, M.A.C. Potenza, M. Giglio, Phys. Rev. E, **70**, (2004), 041405*

Proposed Experiment - Samples

1. Mono Patch

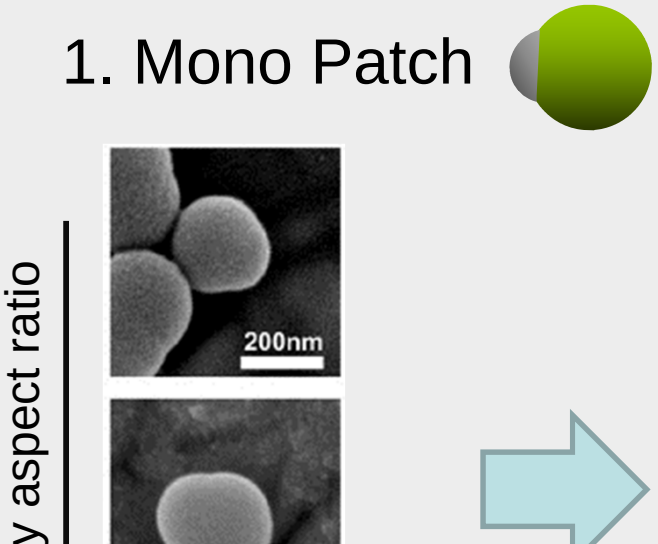
vary aspect ratio



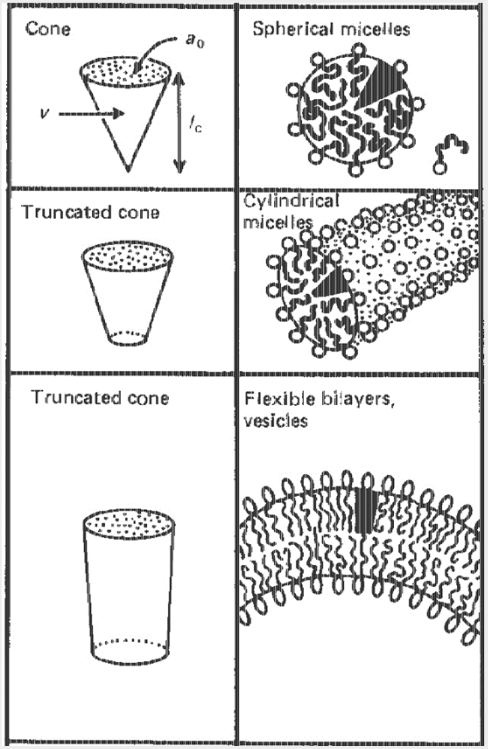
D.J. Kraft et al, *JACS*, 131, (2009) 1182-1186

Proposed Experiment - Samples

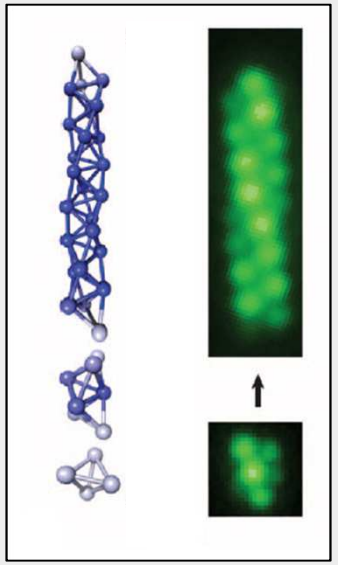
1. Mono Patch



Colloidal Micelles



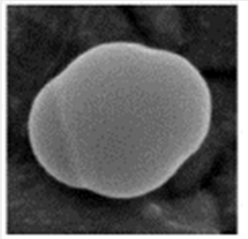
Helices



D.J. Kraft et al, *JACS*, 131, (2009) 1182-1186

Proposed Experiment - Samples

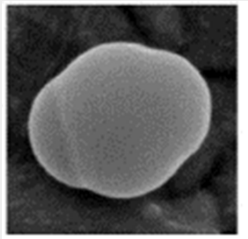
2. Di-Patch



Colloidal Polymers

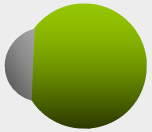
Proposed Experiment - Samples

2. Di-Patch

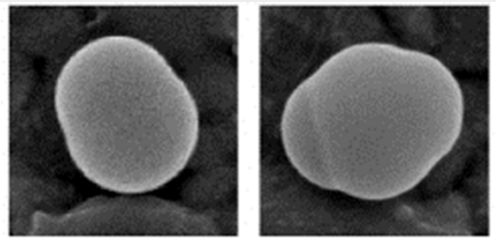


Colloidal Polymers

3. Mixtures
Mono Patch



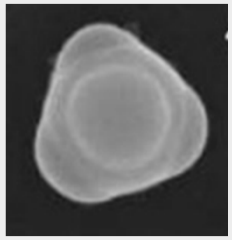
+ Di-Patch



Molecules
Superstructures

Proposed Experiment - Samples

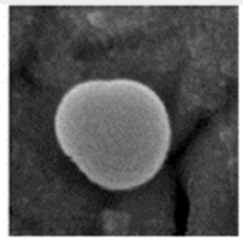
4. Tetra-Patch

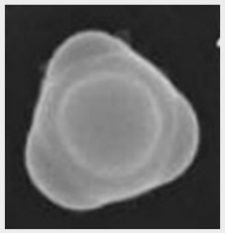


Diamond structure

3. Mixtures
Tetra Patch

+ Di-Patch





CH_4, organic molecules

Succes Criteria

- What do we want to see?
  - Temperature - controlled assembly + Imaging
  - Novel structures from anisotropic potential
  - Control structure with attraction strength
  - Follow Dynamics of ‘molecular reactions’

Summary

- Growth of colloidal superstructures
- Direct T control of anisotropic potential

→New equilibrium + out-of-equilibrium structures

- Real+reciprocal space imaging
- Colloidal Micelles, Helices, Polymer chains, Diamond structure, complex molecules

Collaborators

- Willem Kegel, Daniela Kraft (Utrecht)
- Peter Bolhuis (Simulations, Amsterdam)
- T. Narayanan (ESRF Grenoble)
- D. Nguyen, D. Triet, J. Moons (PhD, Amsterdam)