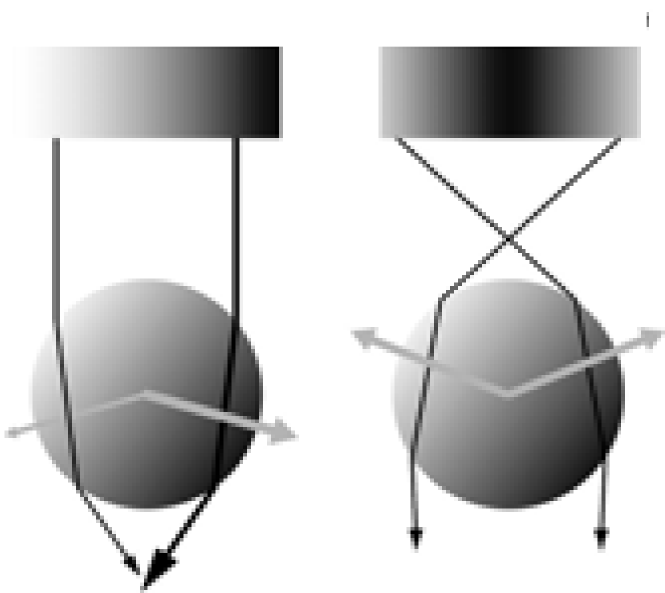
Theory of Optical Tweezers

Simple descriptions:

- Rayleigh particles (R << λ)
  (dipoles in gradient EM-field)

- Ray Optics (R >> λ)
  (refraction of light rays)

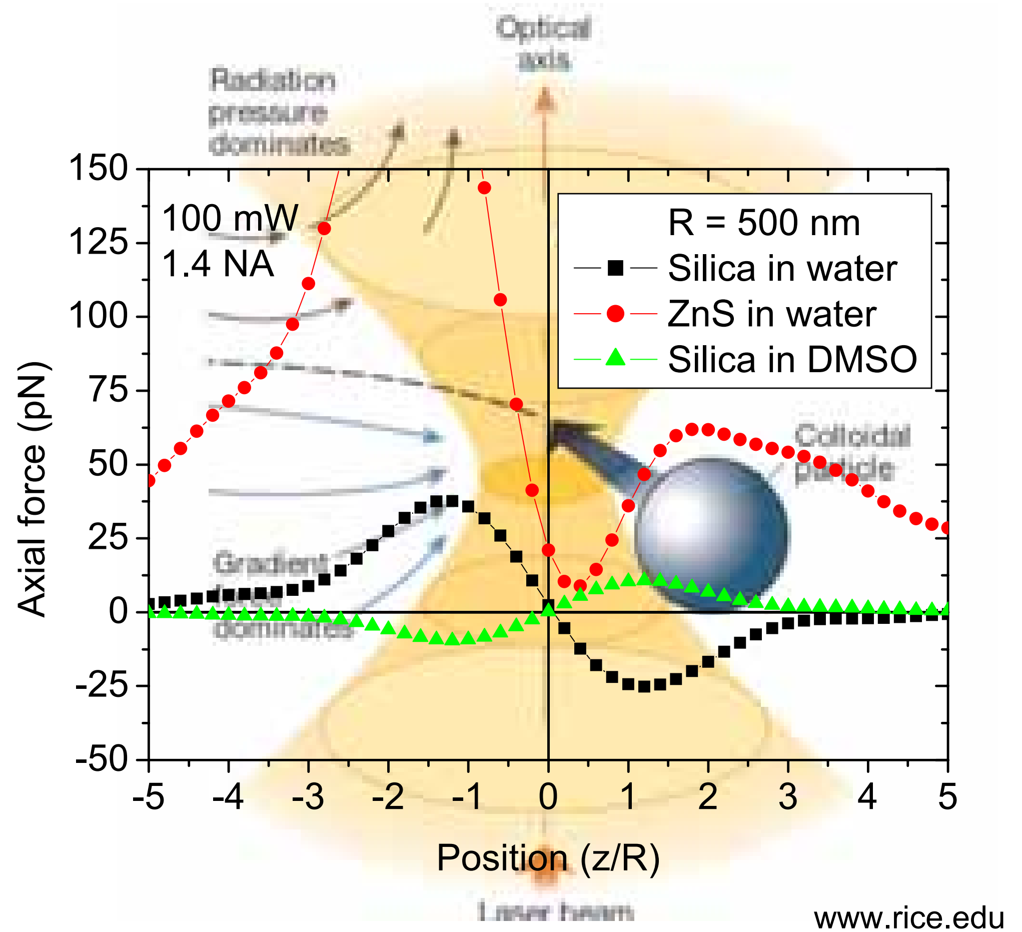


Neuman and Block
Rev. Sci. Instrum. 75, 2787 (2004)

Full calculation:

* Mie scattering in high NA focus

Neto and Nussenzveig,
Europhys. Lett. 50, 702 (2000)

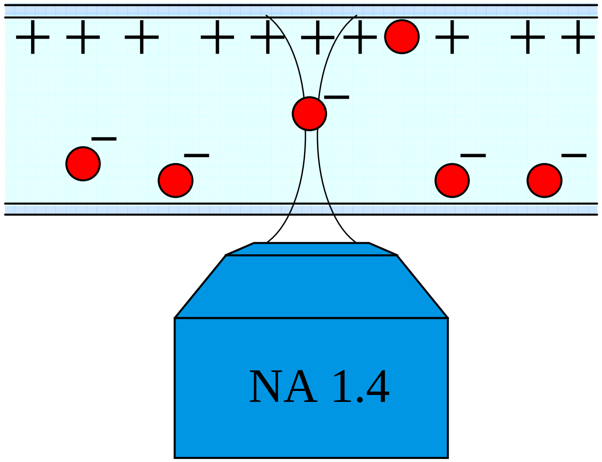


www.rice.edu

Surface Patterning using Optical Tweezers

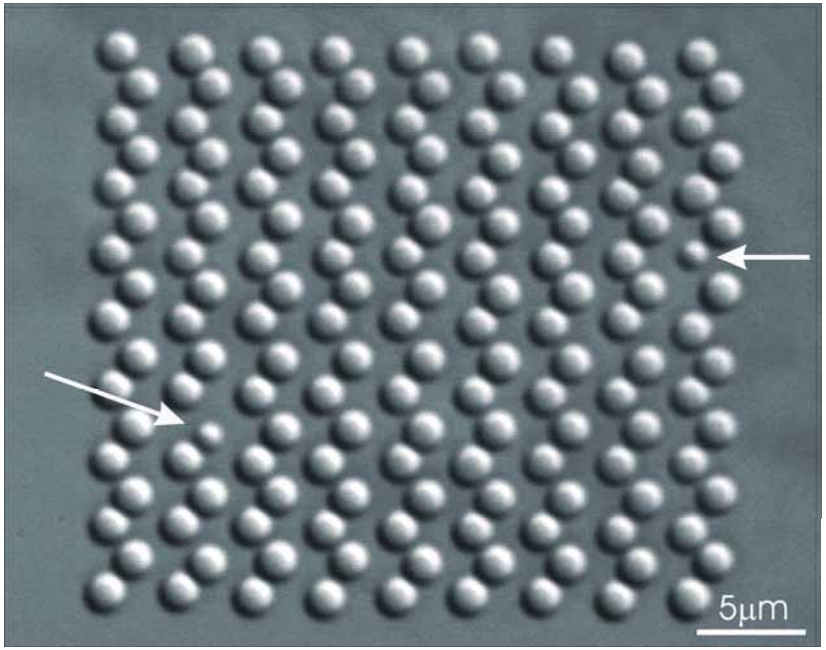
Optical Tweezers:

- 10 nm to 10 μm sized particles
- Dielectric, metal particles, and living matter



Patterning:

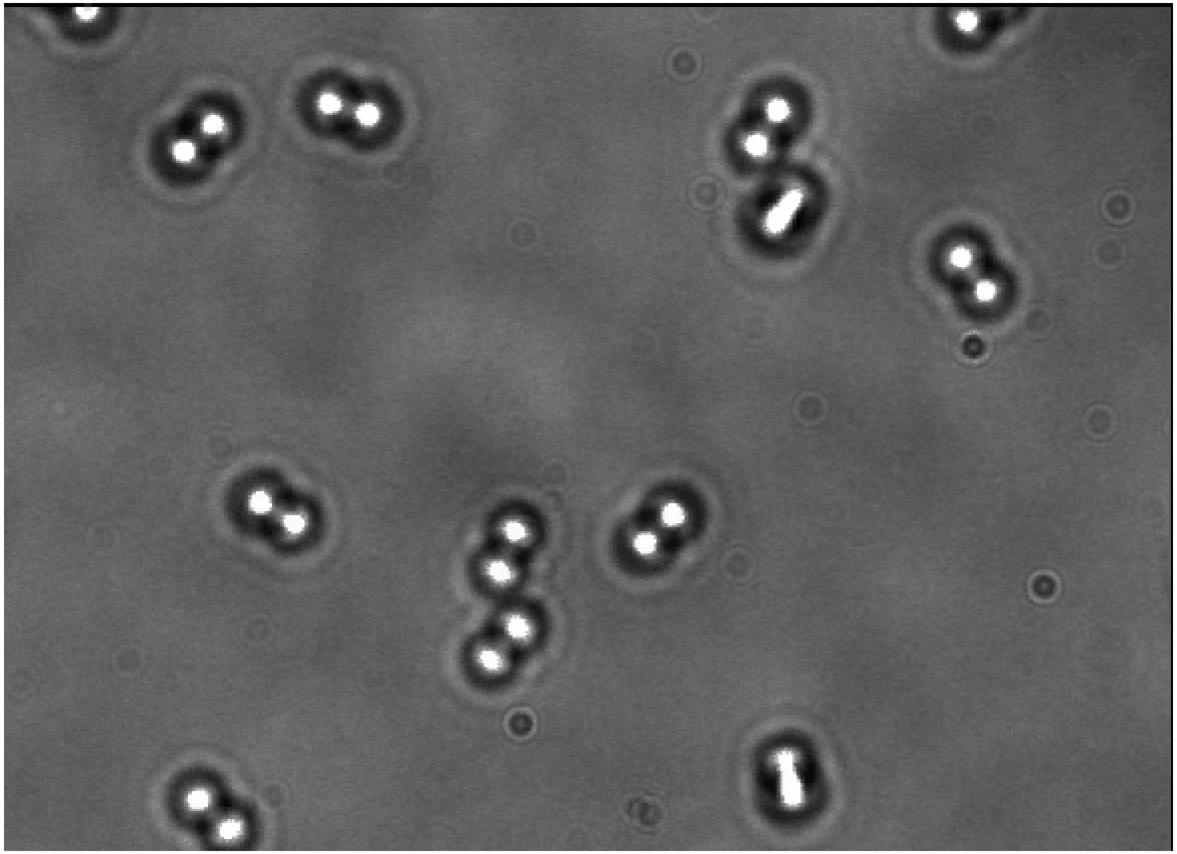
- Surface coating to create opposite charge
- Can be fully automated
    - Increased speed
    - Large patterns
    - Increased accuracy



Template for 3D HCP growth

Hoogenboom, Vossen et al. *Appl. Phys. Lett*. (2002)
Vossen, Hoogenboom et al. *MRS proc.* (2002)

2D Crystallization by Dielectrophoresis & Light



Colloidal **dumbbell** particles

Optical potential:

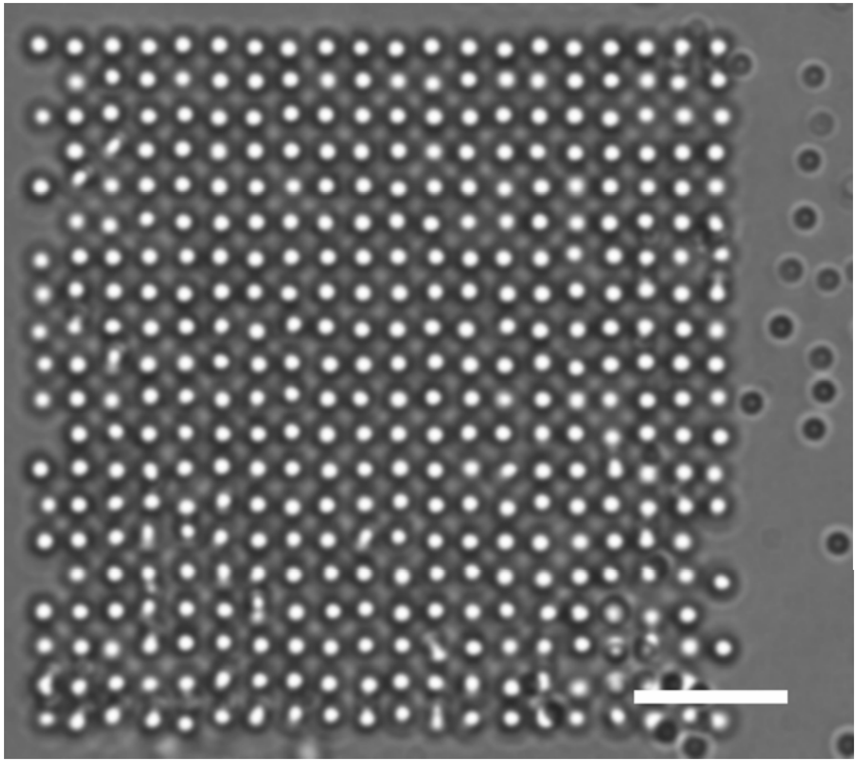
1/e ~ particle diameter

1 $k_b T$ = tens of diameters

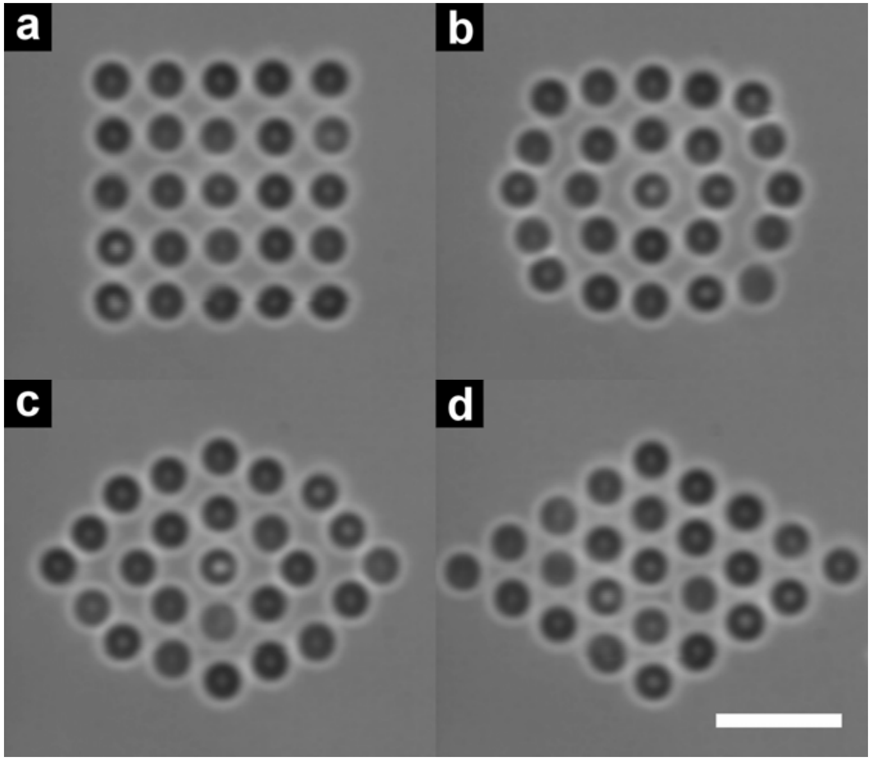
Vossen, Plaisier, and van Blaaderen
SPIE proceedings (2004)

2D-Arrays using AODs

Time-sharing at 220 kHz (point-to-point)



10 μm



5 μm

20x20 traps

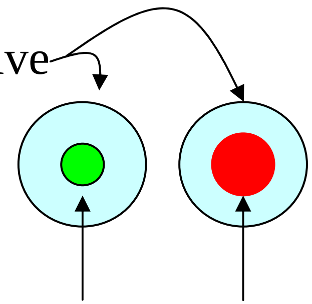
Dynamically changeable

(array scanned at 96 Hz ; 1 W BFP)

Mixtures of core-shell particles

Tracers + Hosts

Low refractive index shell



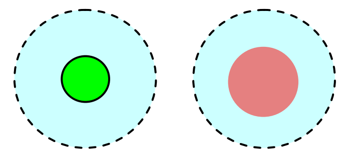
SiO_2, PMMA

High-index core

Low refractive index fluorescent core

ZnS, PS

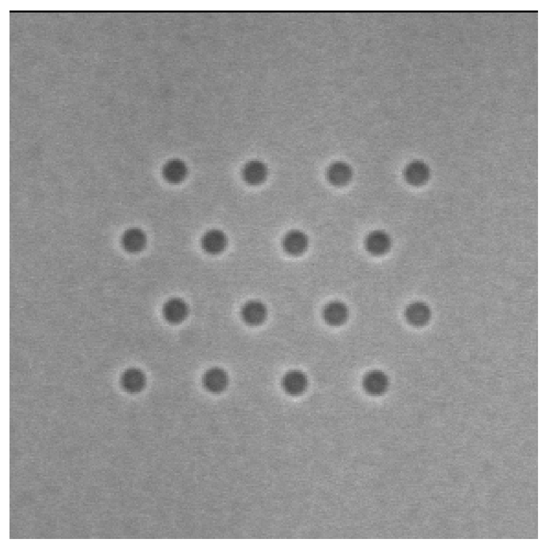
In a refractive index matching solvent (at 1064 nm)



Core-shell geometry:

- Similar surface properties
- Less distortion in 3D traps
- No optical coupling

Images 25x25 mm²



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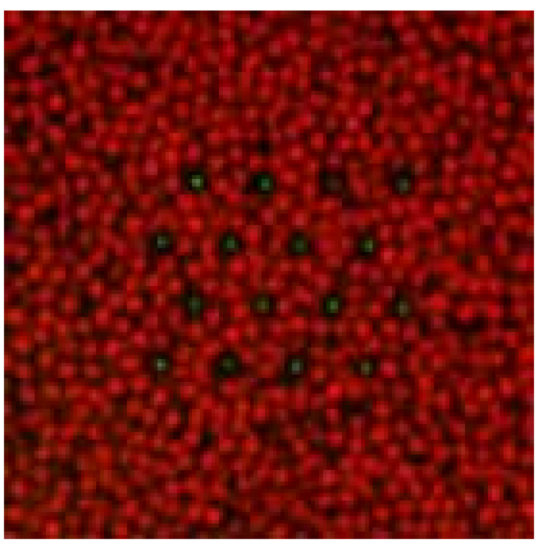
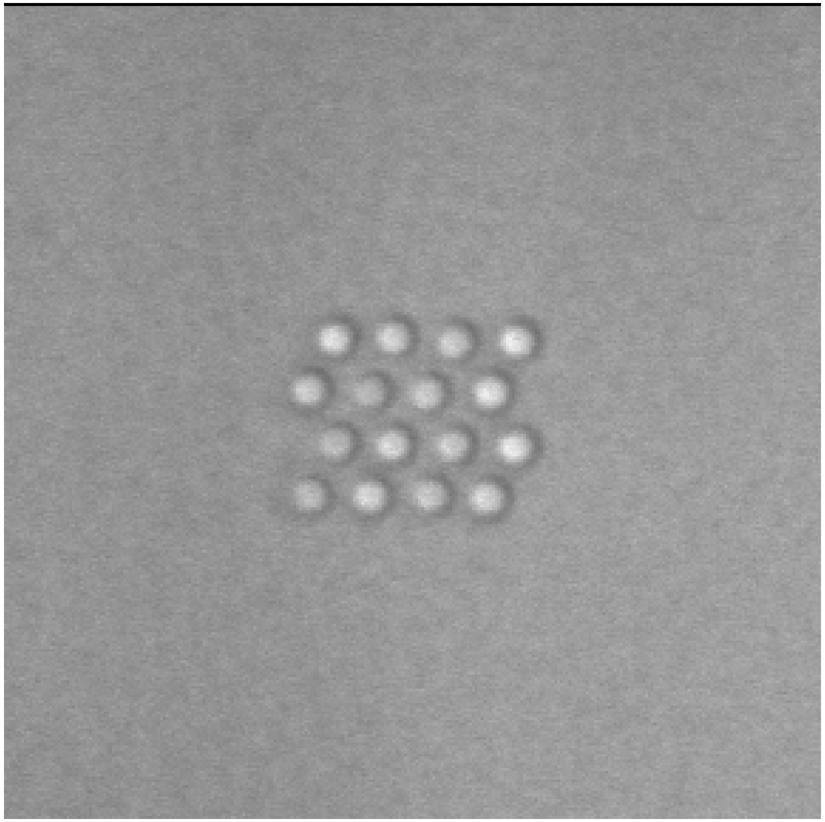


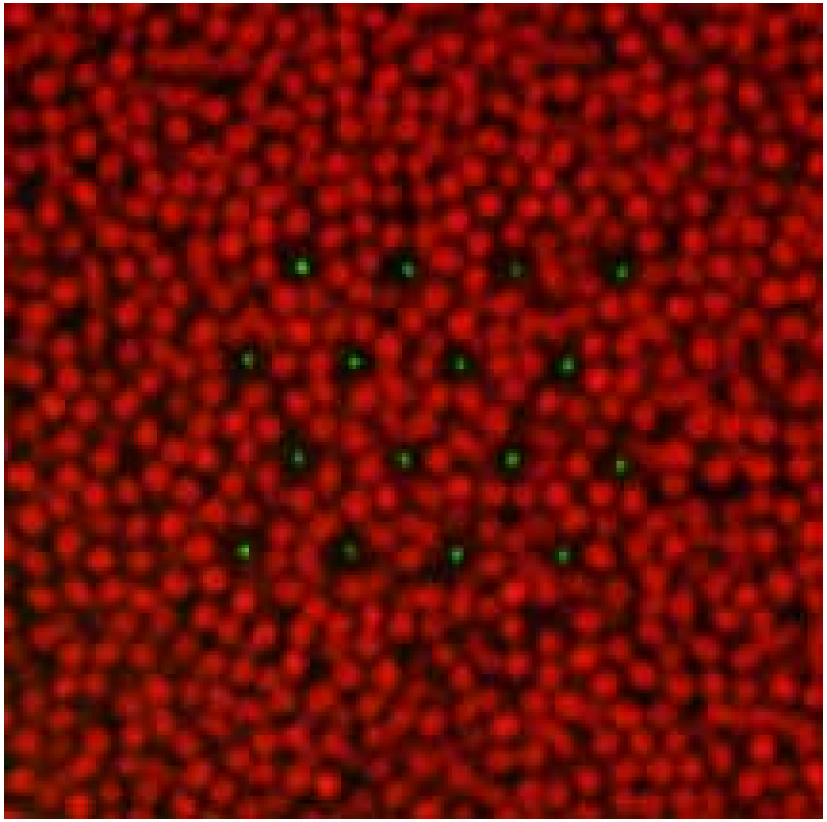
Bright field imaging **Confocal imaging**

Density-Matched Tracer-Host Mixture

(PS-SiO_2-PMMA and PMMA)



Bright field

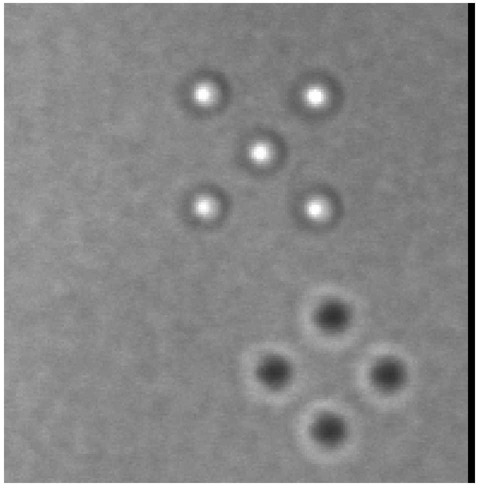


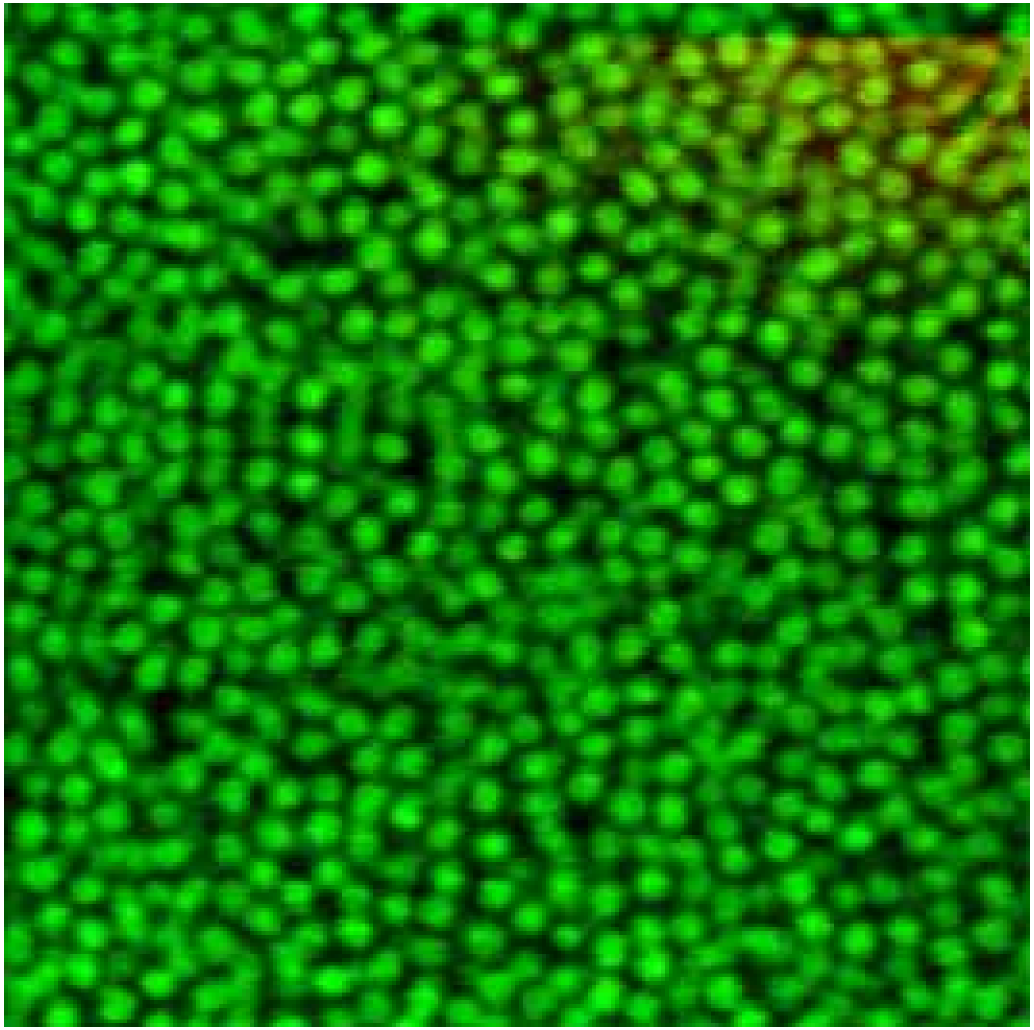
Combined fluorescence and reflection

Images
25x25 μm^2

3D Structures in a Concentrated Colloidal Dispersion

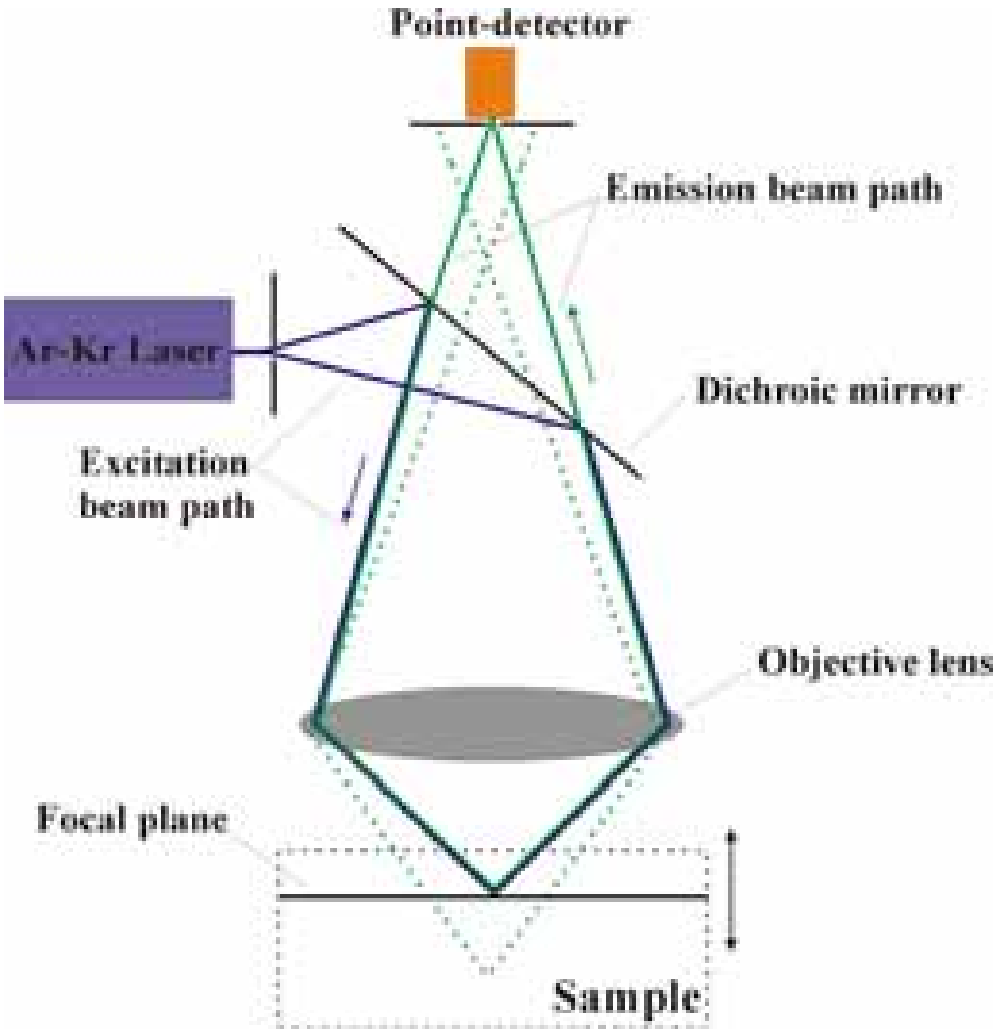
$\phi = 35\%$





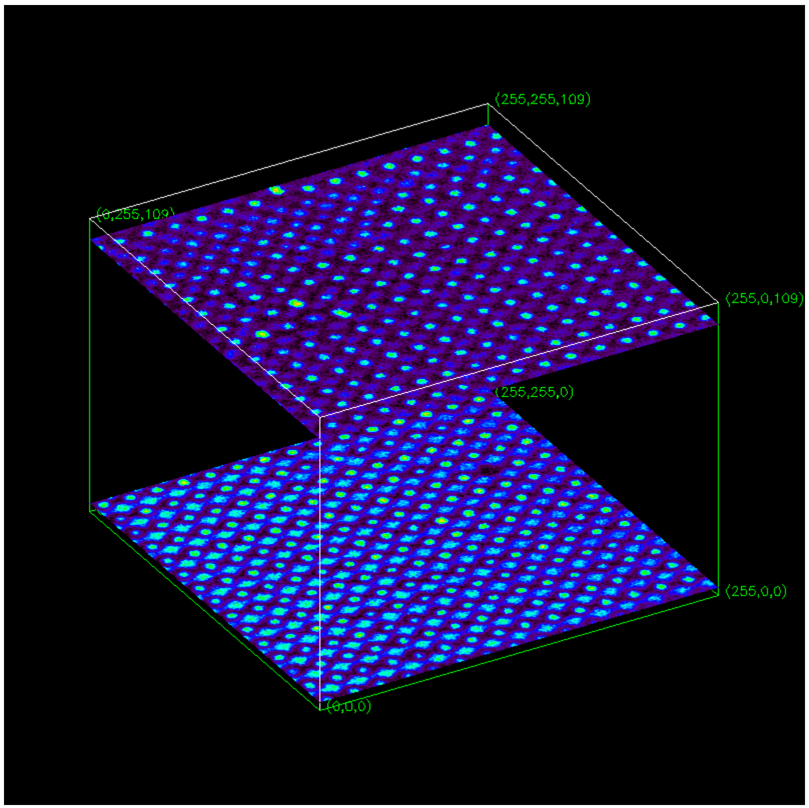
Confocal z-scan

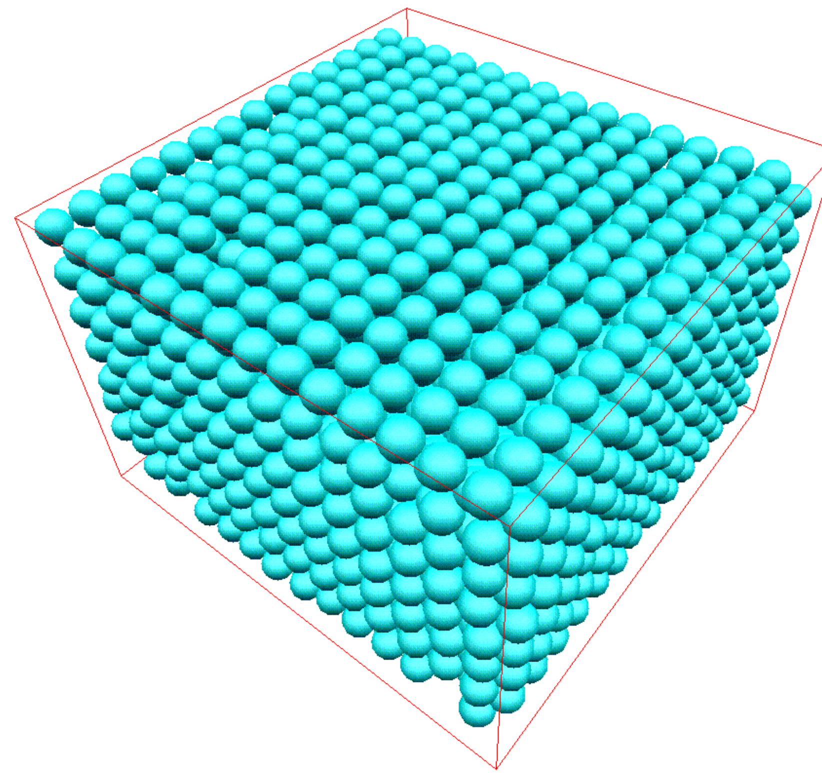
Confocal Microscopy



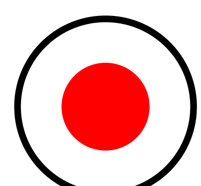
- *Increased Resolution*
  (> Rayleigh's criterion)
- *Optical Sectioning*
- *(Point)Scanning Method*

Confocal Microscopy:
3D Structure Determination





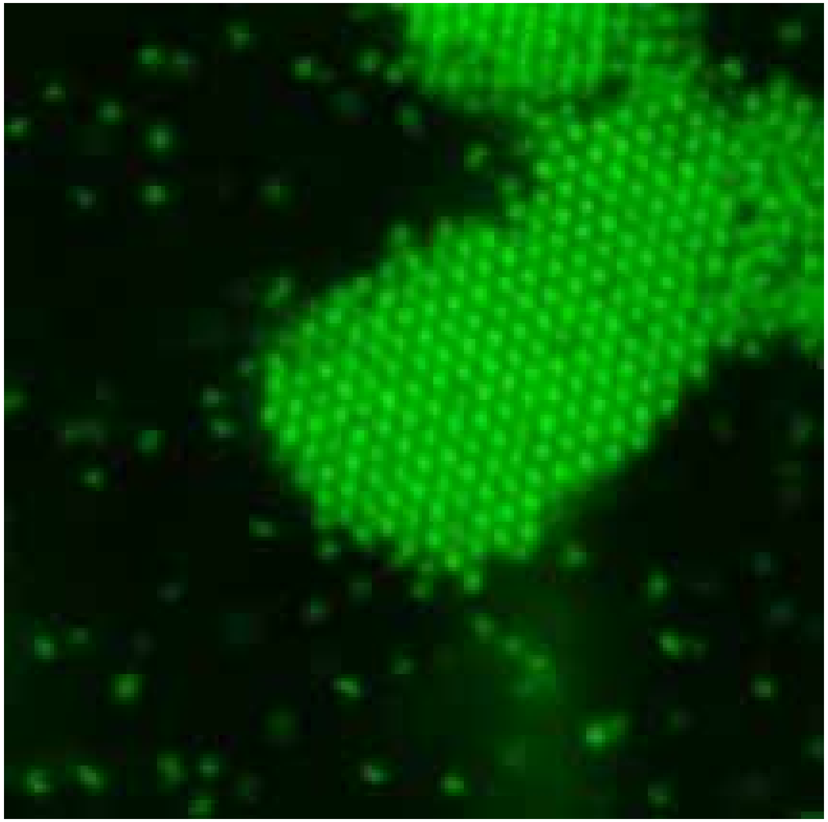
Silica Colloids (1 μm) with a fluorescent core (300 nm)

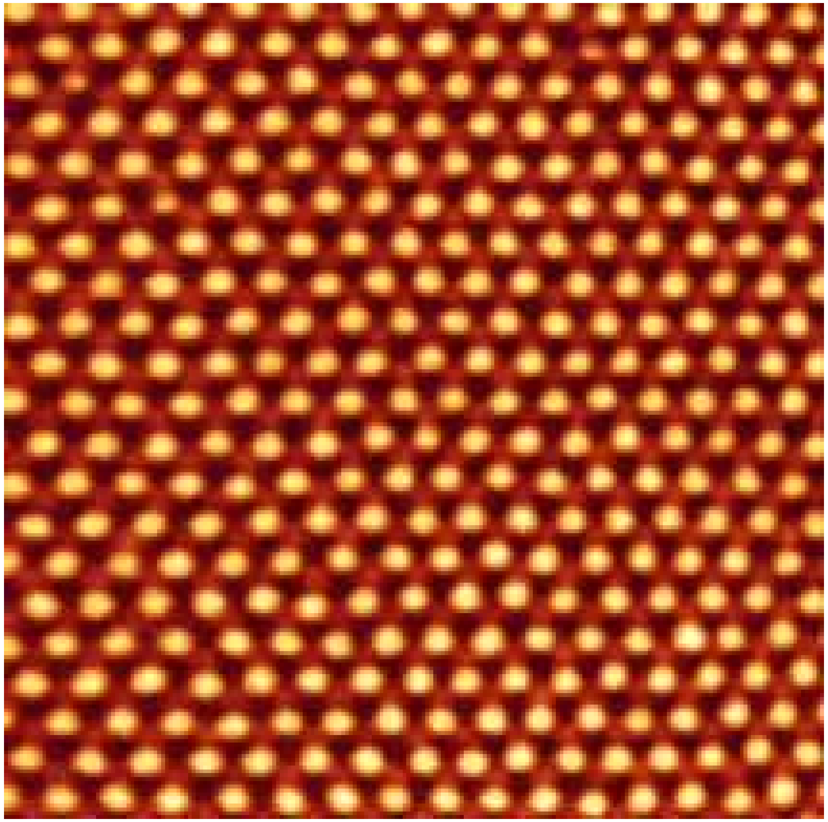


AvB, Wiltzius, *Science* (1995)

AvB, Ruel, Wiltzius, *Nature* (1997)

Confocal Microscopy: Dynamics



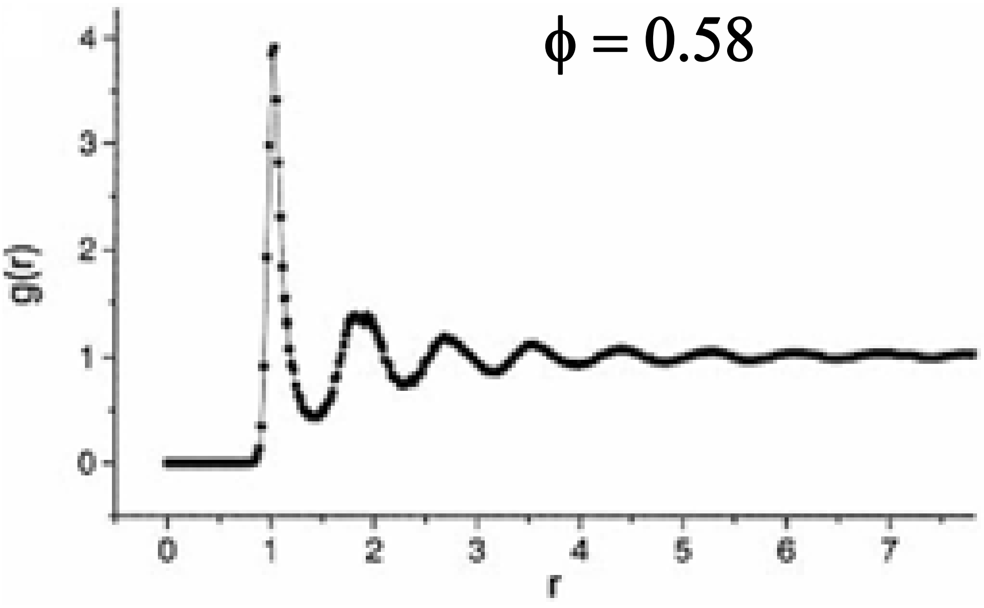


Sublimation
(control over interactions)

Phonons, Defects….

Confocal Microscopy: Dynamics
Hard Spheres near the Glass Transition

Dynamical Heterogeneities



Radial Distribution Function

Kegel, AvB, *Science* (2000)

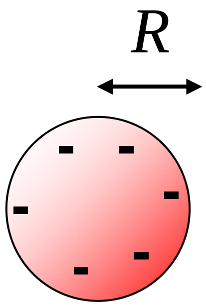
DLVO: Screened Coulomb

Solution of Poisson-Boltzmann and small DL overlap: Yukawa potential

$$V_{Yukawa} = \frac{Z_a Z_b e^2}{4\pi\varepsilon\varepsilon_0}\left(\frac{\exp[\kappa R]}{1+\kappa R}\right)^2 \frac{\exp[-\kappa r]}{r}$$

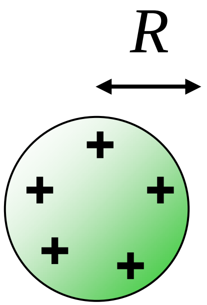
a,b = +/-

Inverse Debye Screening Length



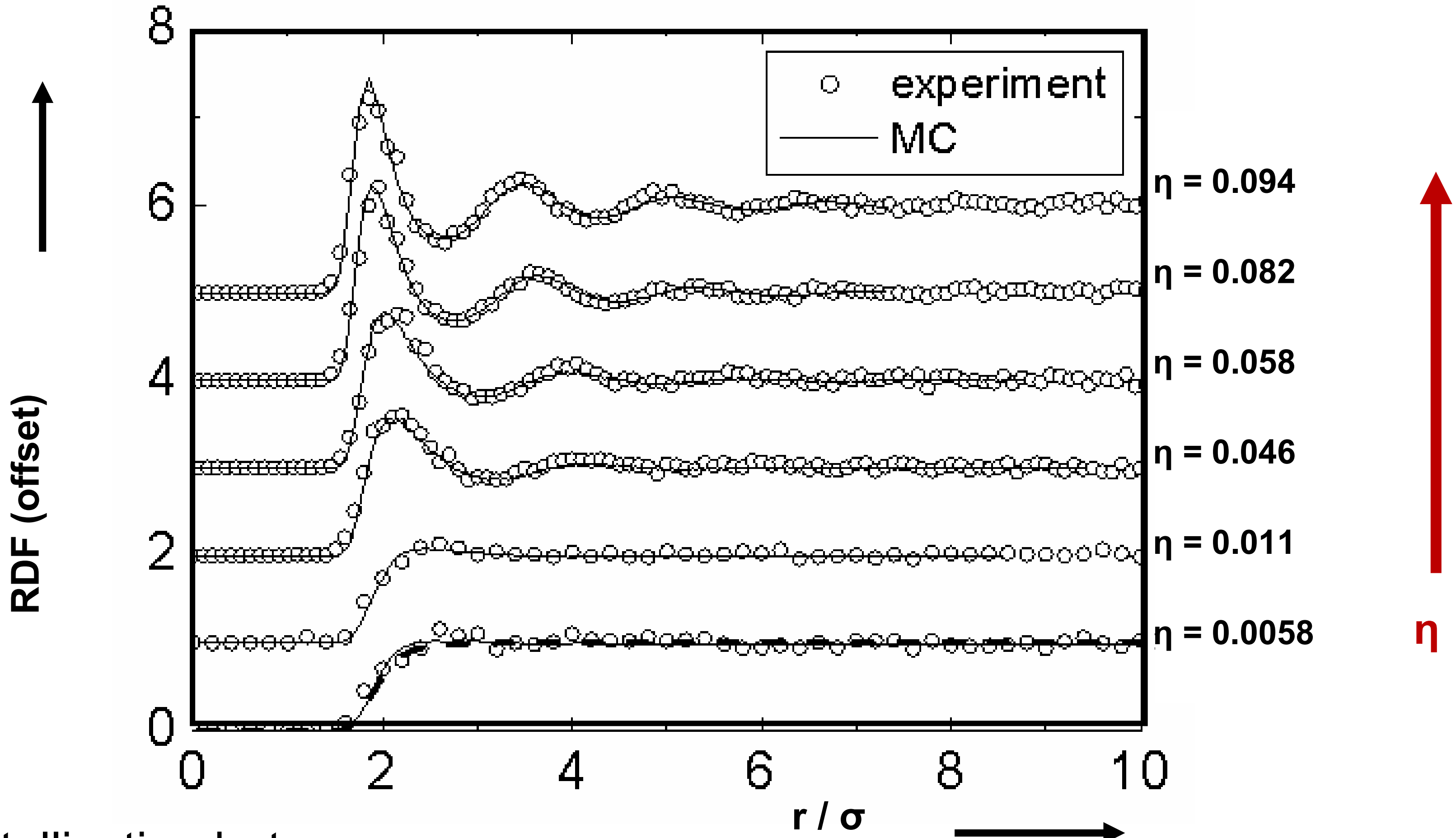
Z_a

$$\kappa = \left(\frac{\sum z_i^{\,2} e^2 n_{0i}}{\varepsilon\varepsilon_0 k_B T}\right)^{\frac{1}{2}}$$



Z_b

3D-g(r) vs Monte Carlo Simulation



Crystallization between

η = 0.094 and 0.101

C.P.Royall, et al., *J.Phys: Condens.Matter*, **2003**, *15*, 3581

Single set of parameters: $\beta\varepsilon = 140$, $\kappa R = 2.5$ (→ surface potential 36 mV)