(9) IN/34

D100

This talk will present recent results from ground-based research to support the "Physics of Colloids in Space" project which is scheduled to fly in the ISS approximately one year from now. In addition, results supporting future planned flights will be discussed.

PCS

PHYSICS OF COLLOIDS IN SPACE

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COLLOIDAL CRYSTALS → BINARY ALLOYS

COLLOIDAL GELS

COLLOID/POLYMER MIXTURES

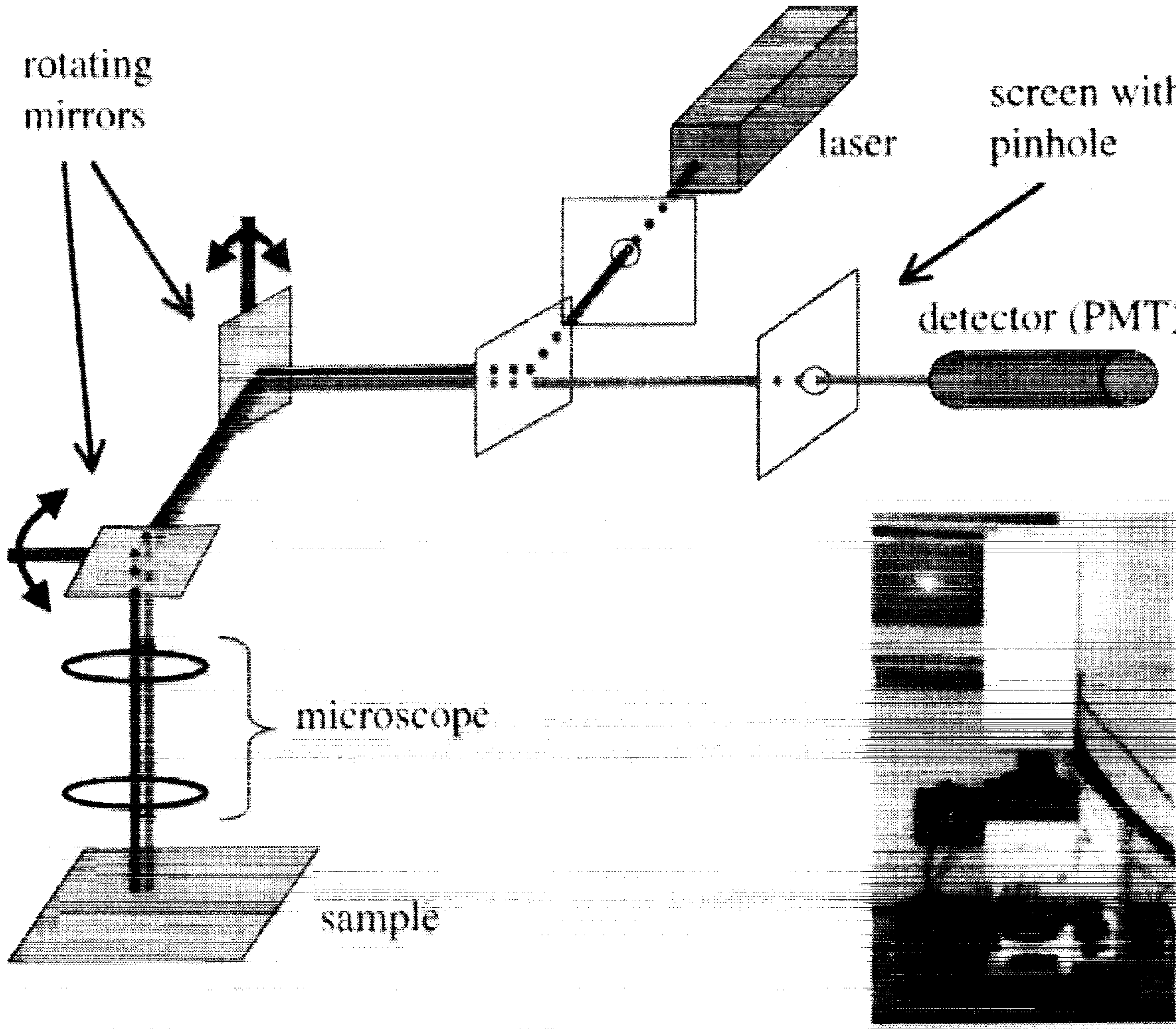
SCATTERING

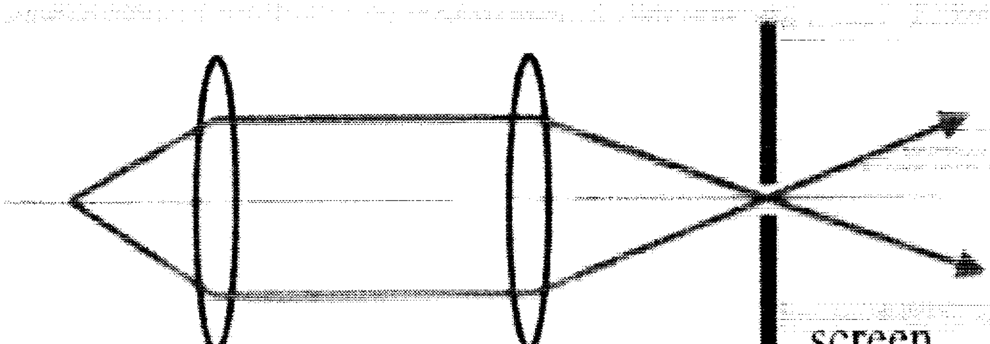
MICROSCOPY

PCS

PAUL CHAIKIN SCIENCE

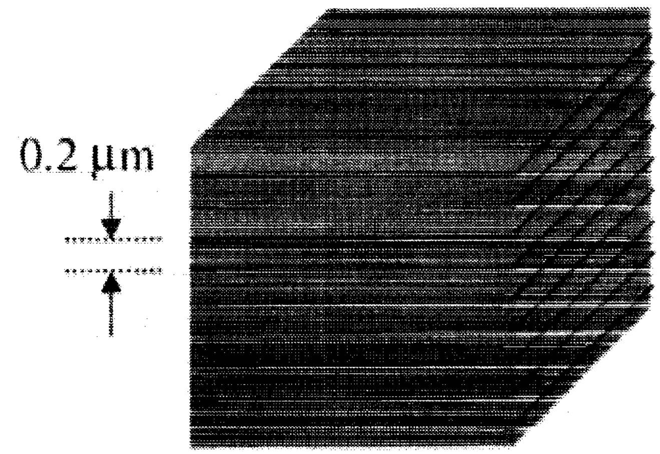
Confocal Microscopy

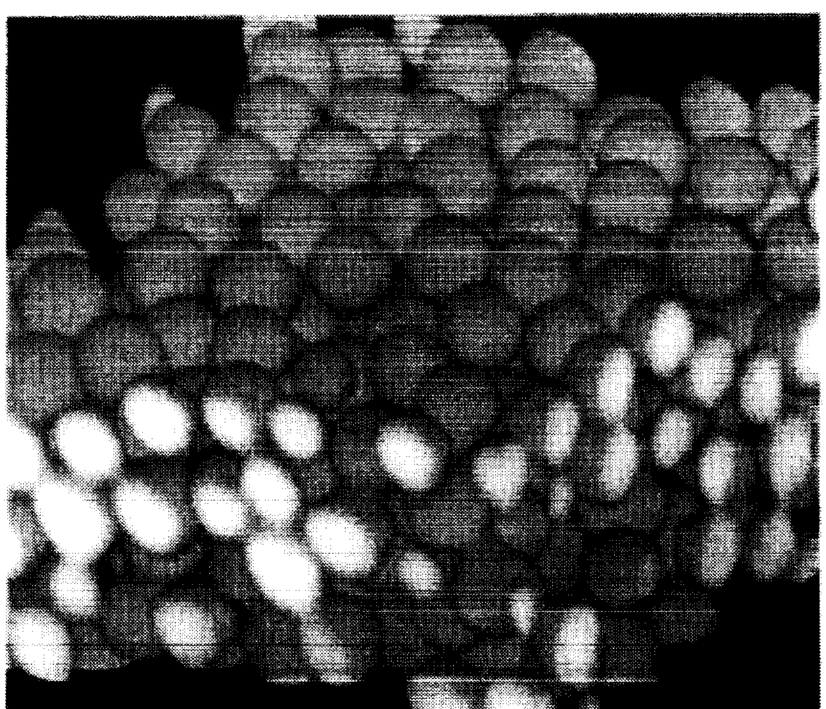




Confocal microscopy for 3D pictures

Scan many slices, reconstruct 3D image





2.3 µm diameter PMMA particles

Microscopy and Tracking

Microscopy:

- 30 images/s (512×480 pixels, 2D)
- one 3D "cube" per 6 s
- 67 × 63 ×14 μm^3
- 100× oil / 1.4 N.A. objective
- Identify particles within 0.03 μm (*xy*)
  0.05 μm (*z*)

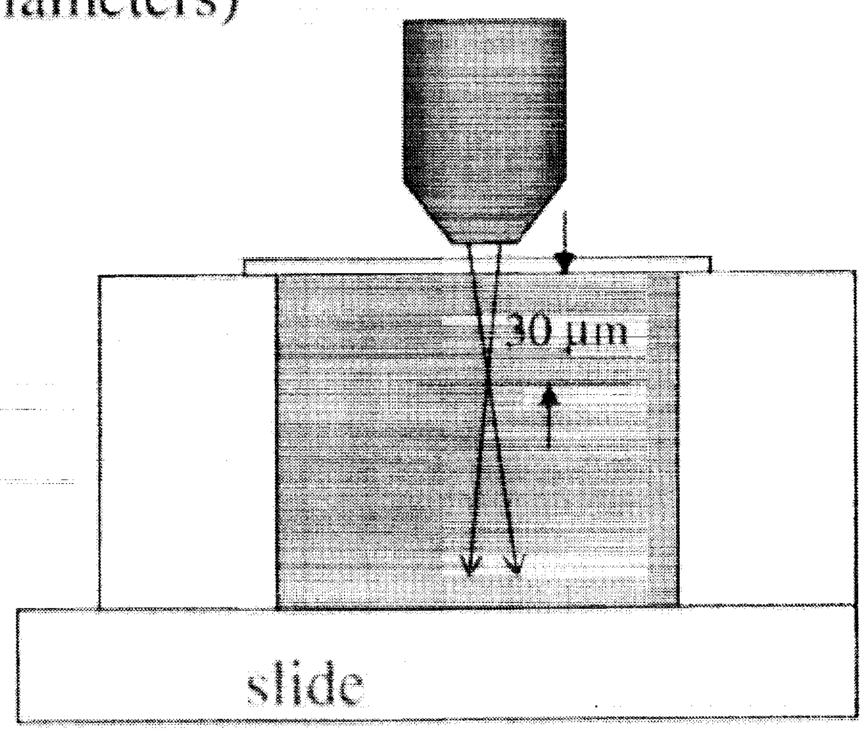
Particle tracking:

- Follow 3000-5000 particles, in 3D
- 200-1000 time steps = hours to days
- ≈ 4 GB of images per experiment

PMMA particles:

- made by Andrew Schofield (Edinburgh)
- fluorescent (Andrew Levitt, U. Penn)
- monodisperse, can crystallize
- density matching solvent
- 3D samples: look >30 μm from wall (>10 diameters)

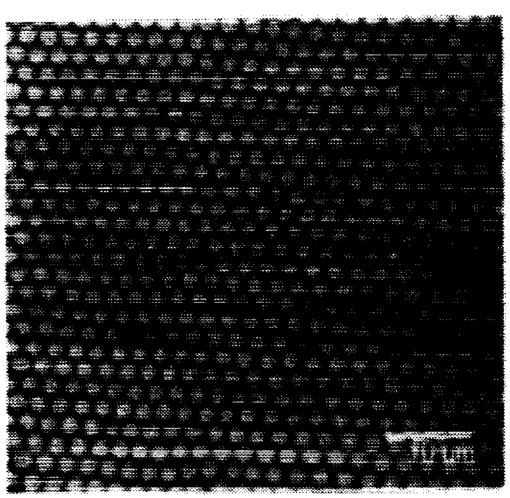
(not to scale)



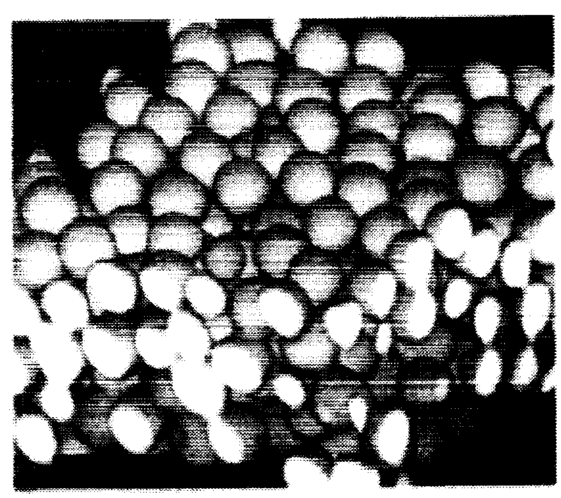
Experimental Details

- •2.3 μm diameter PMMA colloids
- •density matched solvent
- •act like hard spheres
- •equilibrium is random HCP

- •confocal microscopy to take 3D pictures
- •look 30 μm in from cover slip



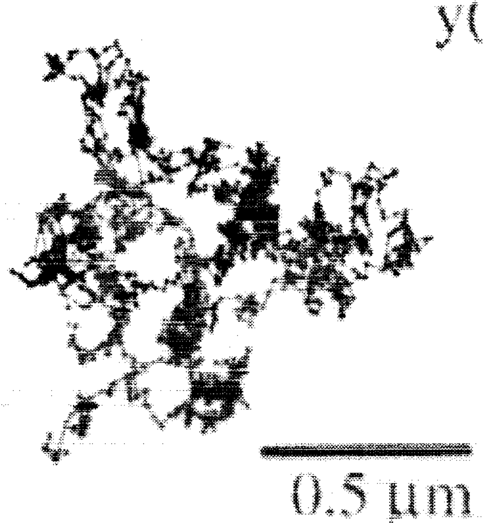
single 2D image

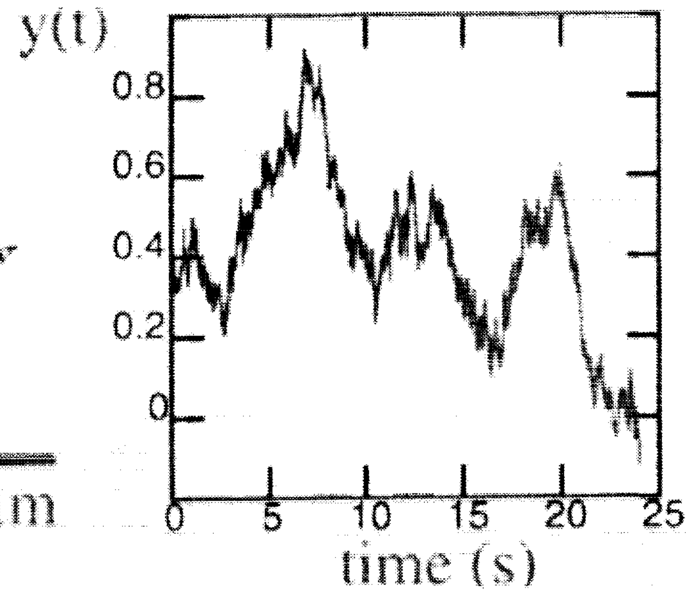


3D reconstruction from many 2D slices

Brownian Motion

(2 μm particles, **dilute** sample)





Leads to normal diffusion:

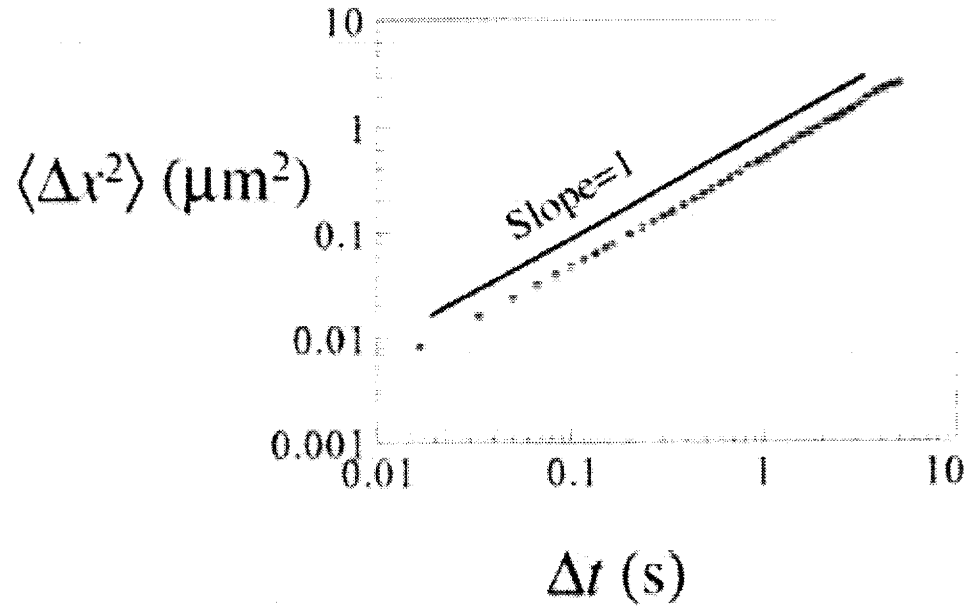
$$\langle \Delta x^2 \rangle = 2Dt$$

$$D = \frac{k_B T}{6\pi\eta a}$$

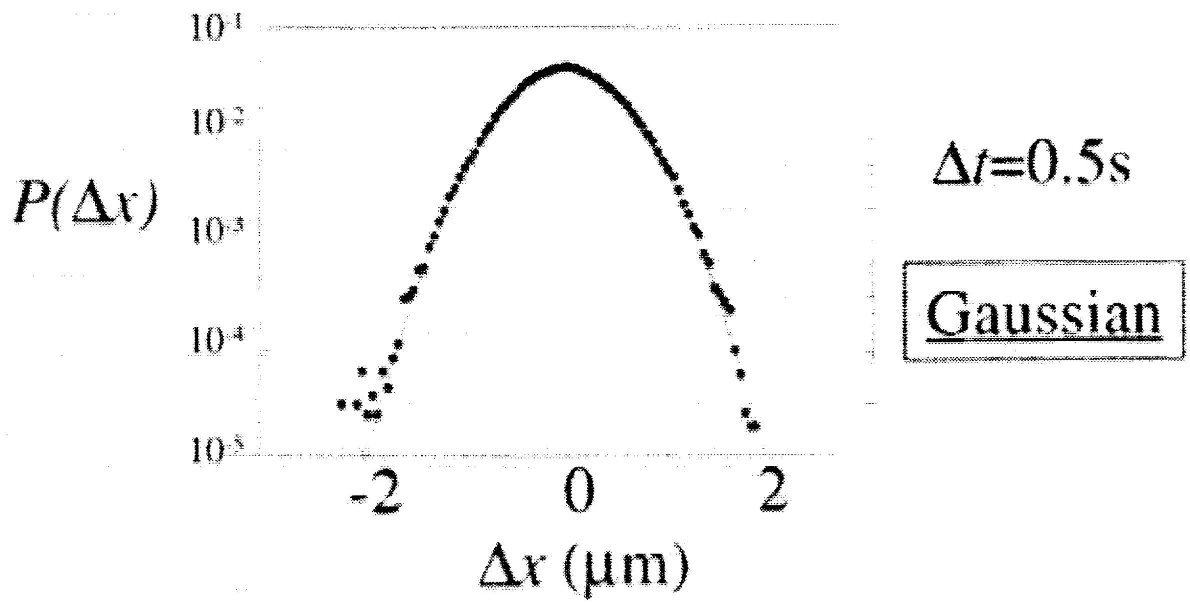
viscosity η particle size a

Diffusion: **dilute** samples

Mean square displacement:

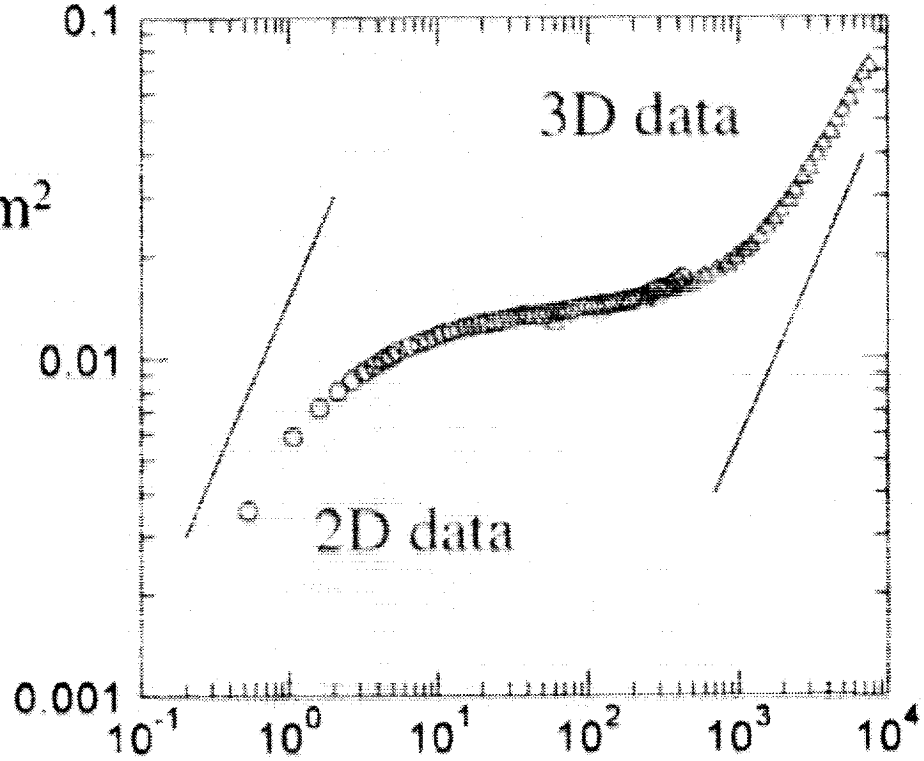


Displacement distribution function:



Mean square displacement

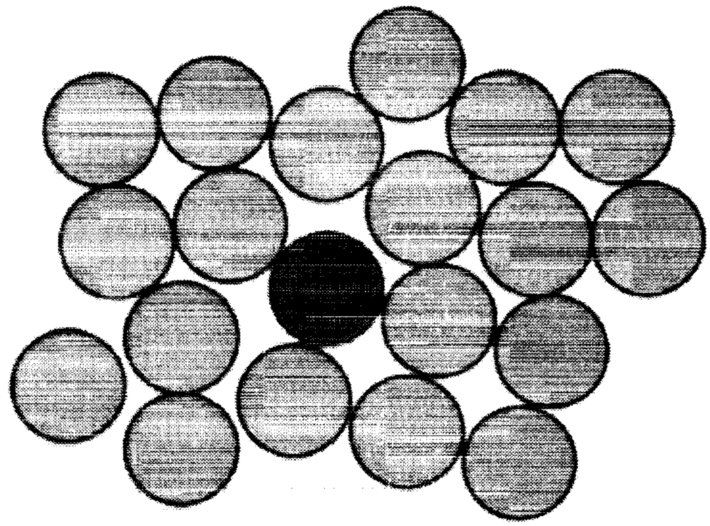
Volume fraction ϕ=0.53,
"supercooled fluid"



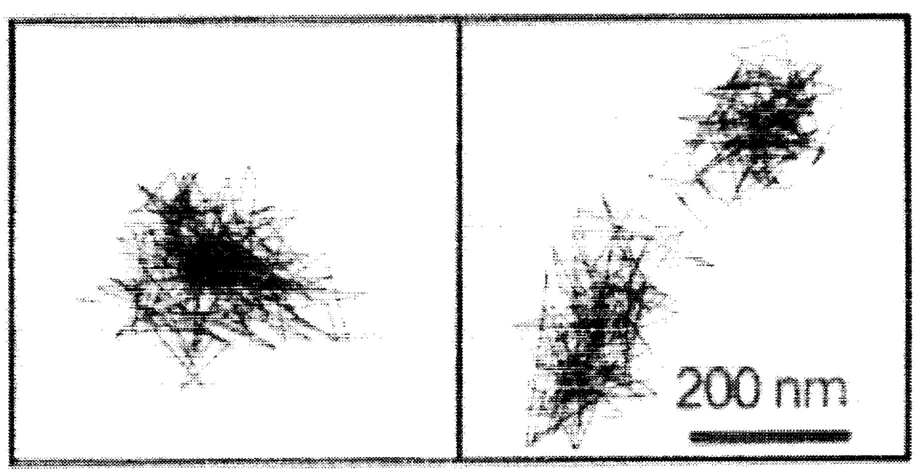
$\langle x^2 \rangle$ μm²

lag time Δt (s)

Cage trapping:



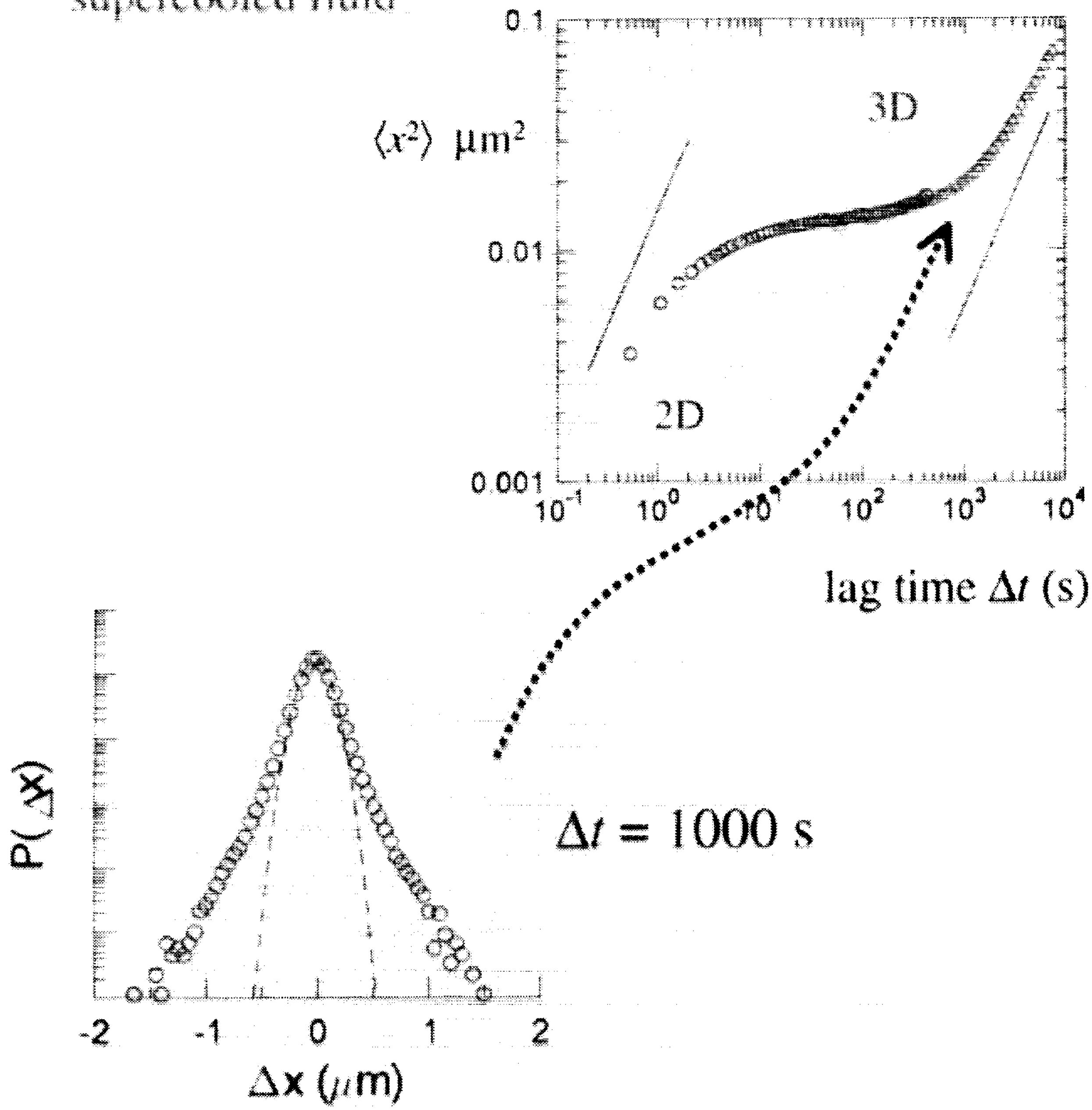
•Short times: particles stuck in "cages"
•Long times: cages rearrange

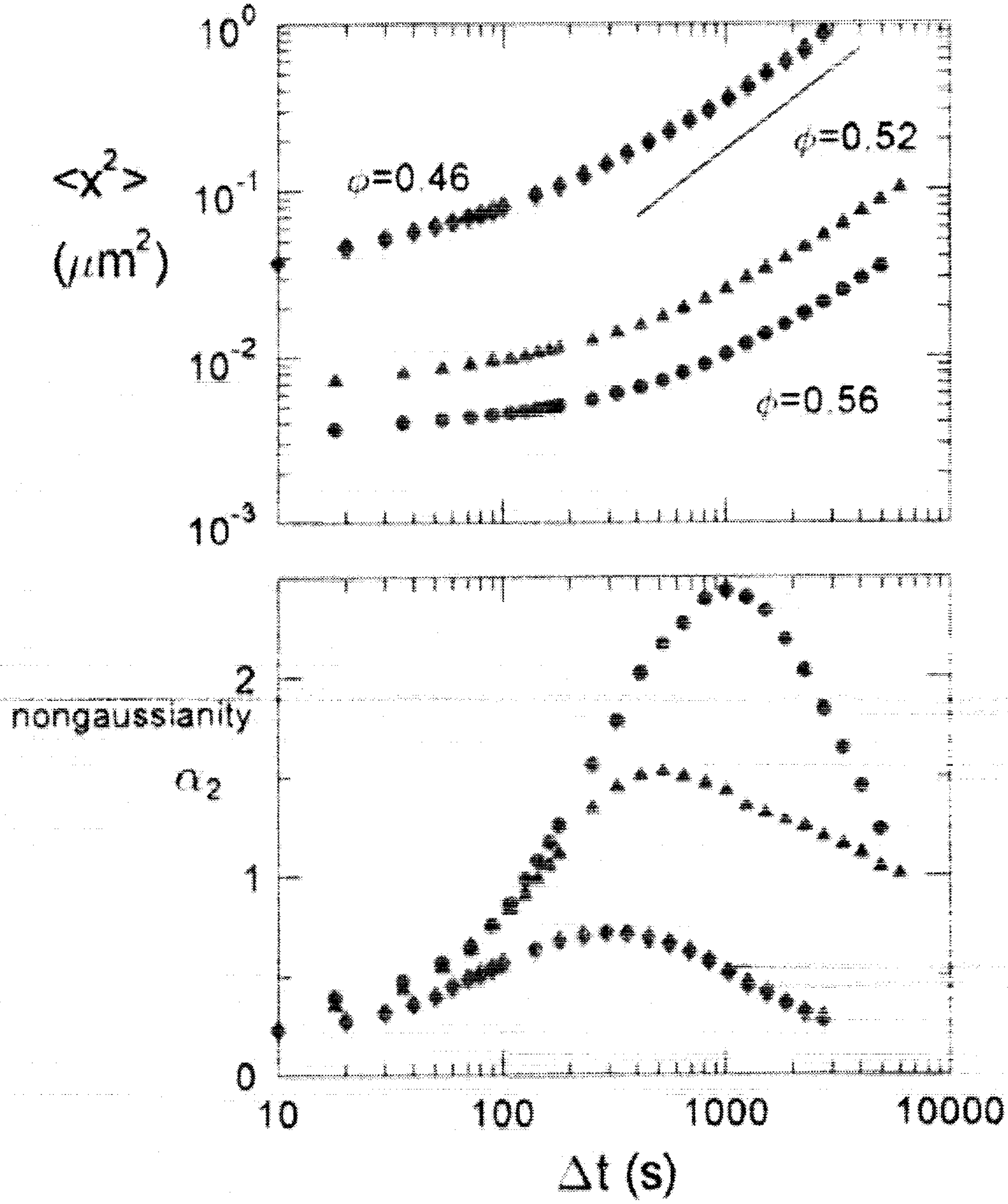


ϕ=0.56, 100 min (supercooled fluid)

Displacement distribution function

Volume fraction ϕ=0.53,
"supercooled fluid"




10^0
10^{-1}
10^{-2}
10^{-3}
$<x^2>$
(μm^2)
ϕ=0.46
ϕ=0.52
ϕ=0.56
nongaussianity
α_2
0
1
2
10
100
1000
10000
Δt (s)

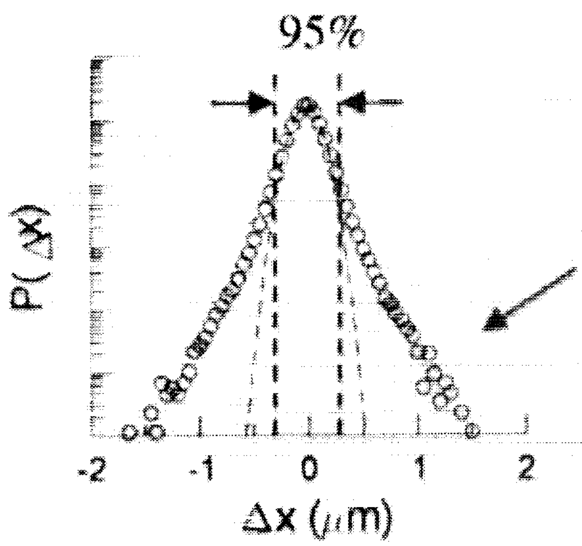
Time scale:

Δt^* when nongaussian parameter α_2 largest

Length scale:

Δr^* on average, 5% of particles have $\Delta r(\Delta t^*) > \Delta r^*$

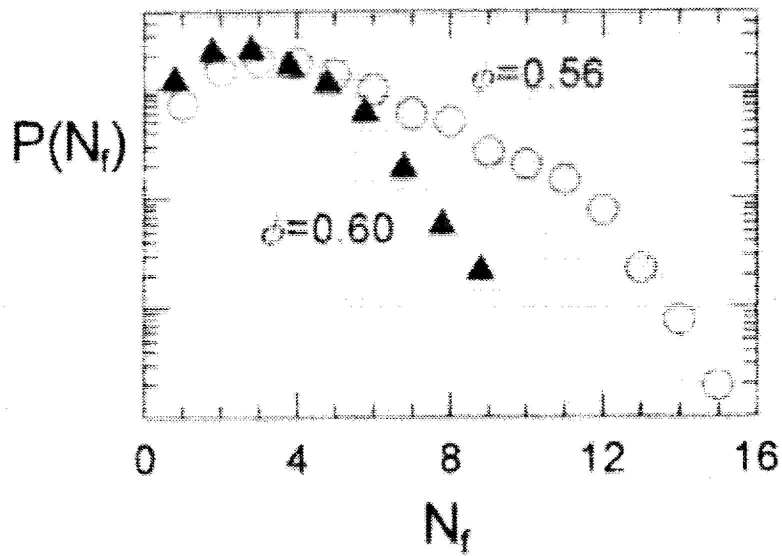
$\boxed{\approx \text{cage rearrangements}}$



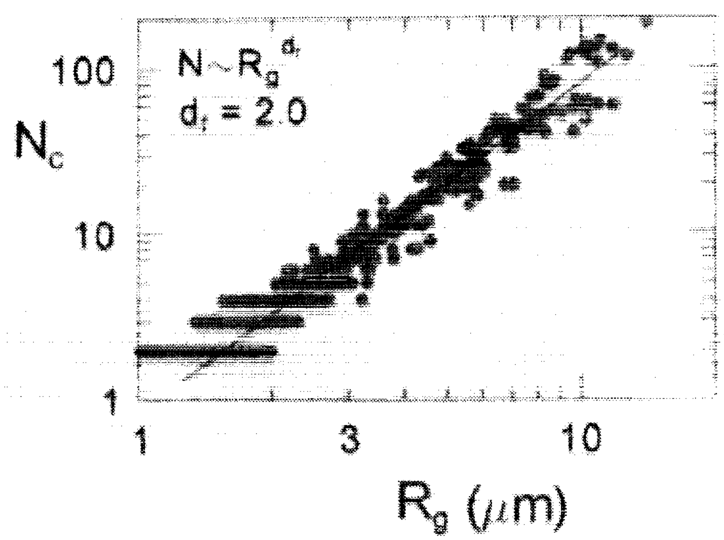
top 5% = tails of Δx distribution

(ϕ=0.53, supercooled fluid)

Number N_f of fast neighbors to a fast particle:



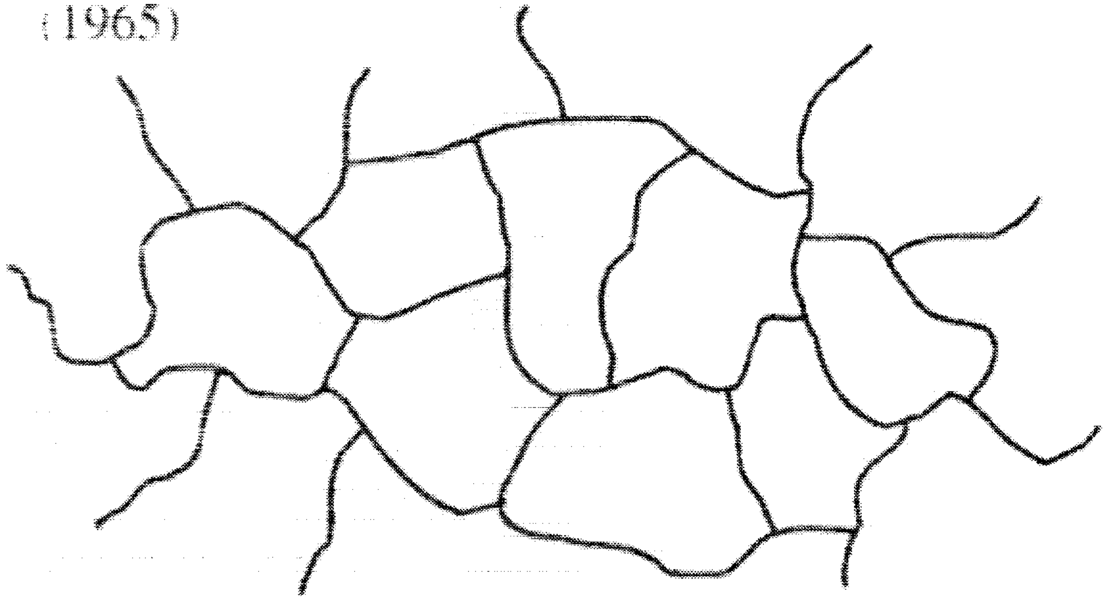
Fractal dimension:



Φ=0.56
supercooled fluid

Dynamical Heterogeneity: possible *dynamic* length scale

Adam & Gibbs: "**cooperatively rearranging regions**" (1965)



NMR experiments:

- •Schmidt-Rohr & Spiess (1991, polymers)
- •Tang, Johnson, et al (1998, metallic glasses)
- •Sillescu et al (1992, o-terphenyl)

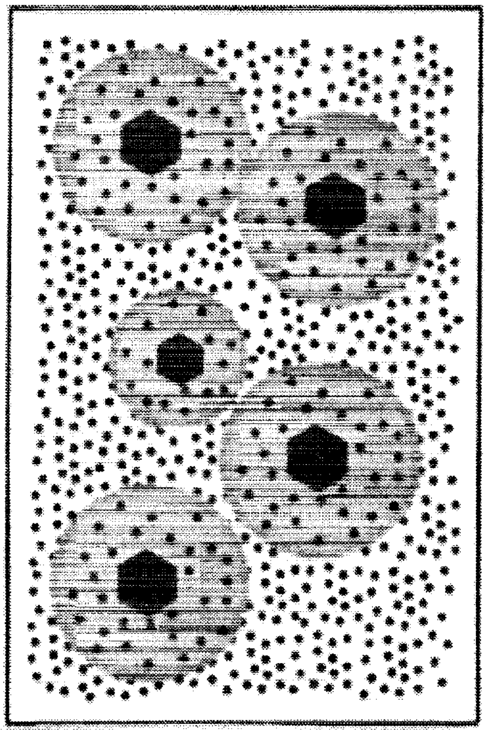
Photobleaching:

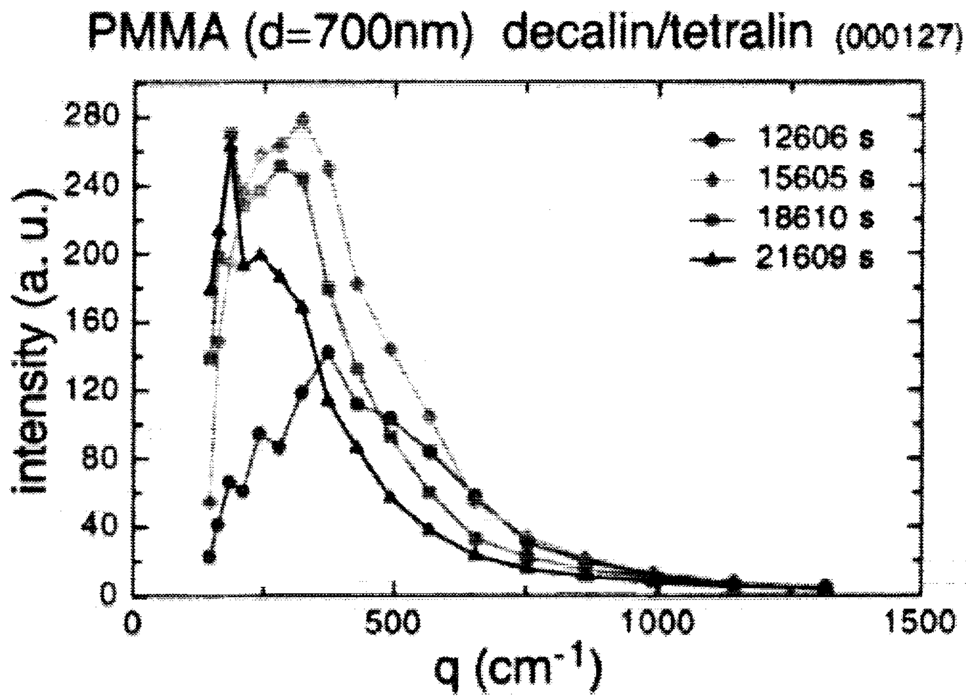
- •Cicerone & Ediger (1995, o-terphenyl)

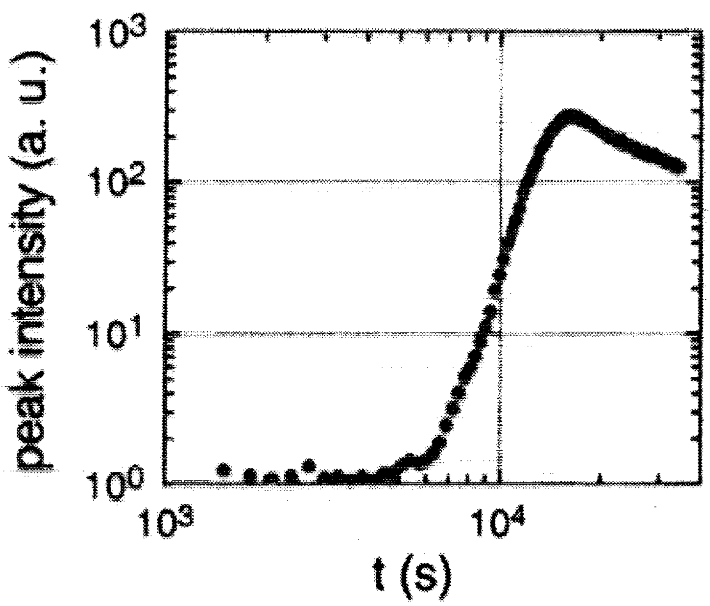
Simulations:

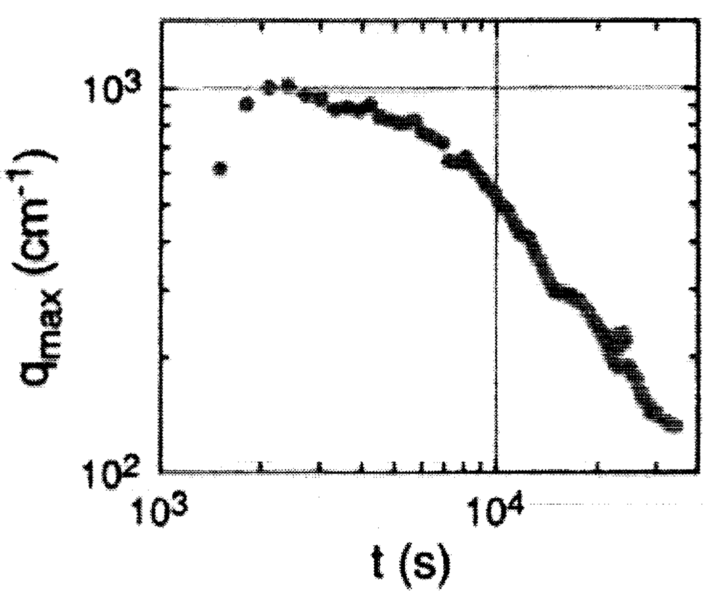
- •Glotzer, Kob, Donati, et al (1997, Lennard-Jones)

Nucleation and Growth of Colloidal Crystals
by Small Angle Light Scattering







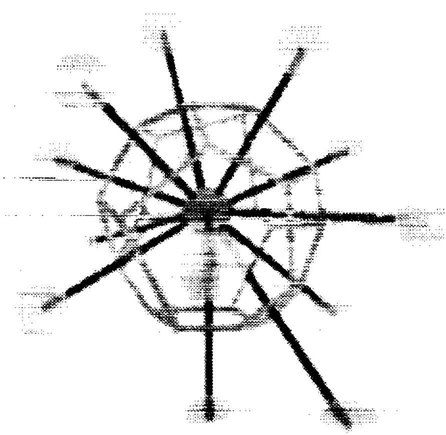


Local crystallization order parameter:

P. R. ten Wolde, M. J. Ruiz-Montero, D. Frenkel: *J. Chem. Phys.* **104**, 9932 (1996)

•Lennard-Jones simulation

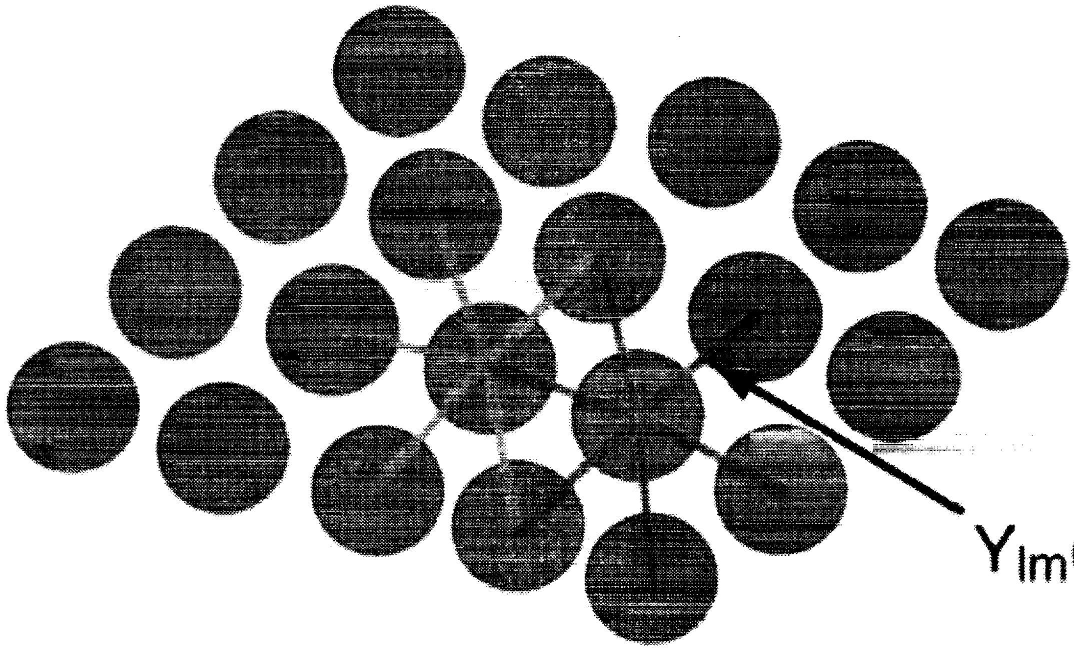
•Find nearest neighbor connections r_{ij}



•Resolve connections in spherical harmonics:

$$q_{lm}(i)=\langle Y_{lm}(r_{ij})\rangle_j$$

•Examine $l=6$



local bond order parameters:

$q_{lm}(i) = 1/N_i \sum_{j(n.n.)} Y_{lm}(r_{ij})$

rotationally invariant form:

$q_l(i) = [\ 4\pi/(2l+1) \sum_m |q_{lm}(i)|^2\ ]^{1/2}$

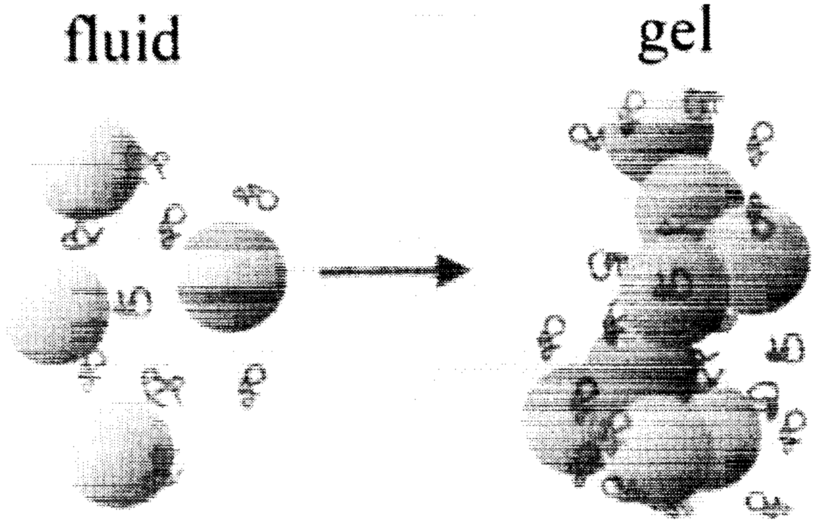
crystal-like bonds:

$\overrightarrow{q_6}(i)\cdot\overrightarrow{q_6}(j) = \sum_m q_{6m}(i)\ q^*_{6m}(j) > 0.5$

Gelation:

Non-Equilibrium States

Aggregation in colloid-polymer mixtures



Polystyrene polymer, r_g=37 nm

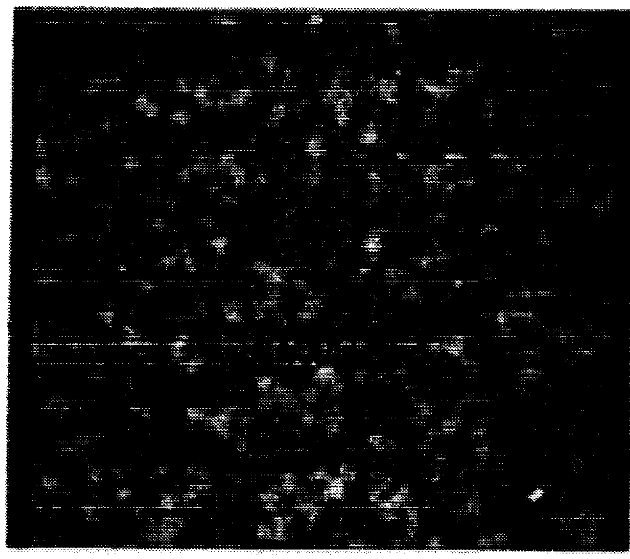
+

PMMA spheres, r_c=350 nm

↓

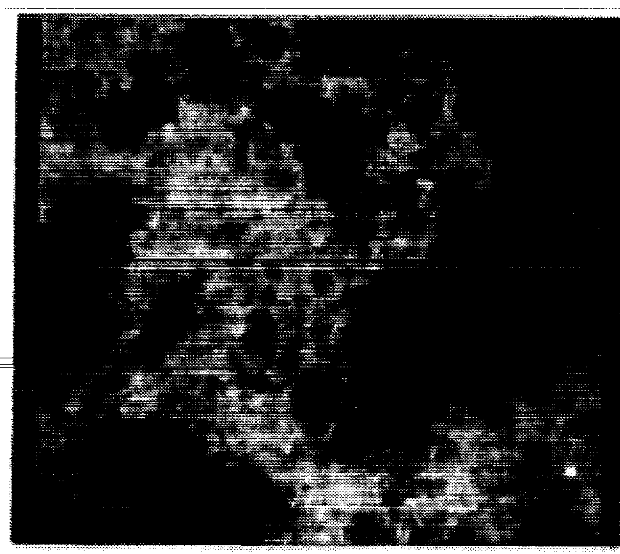
Depletion attraction

c_p=5.0



(image is 20 diameters thick)

c_p=8.8 (gel)

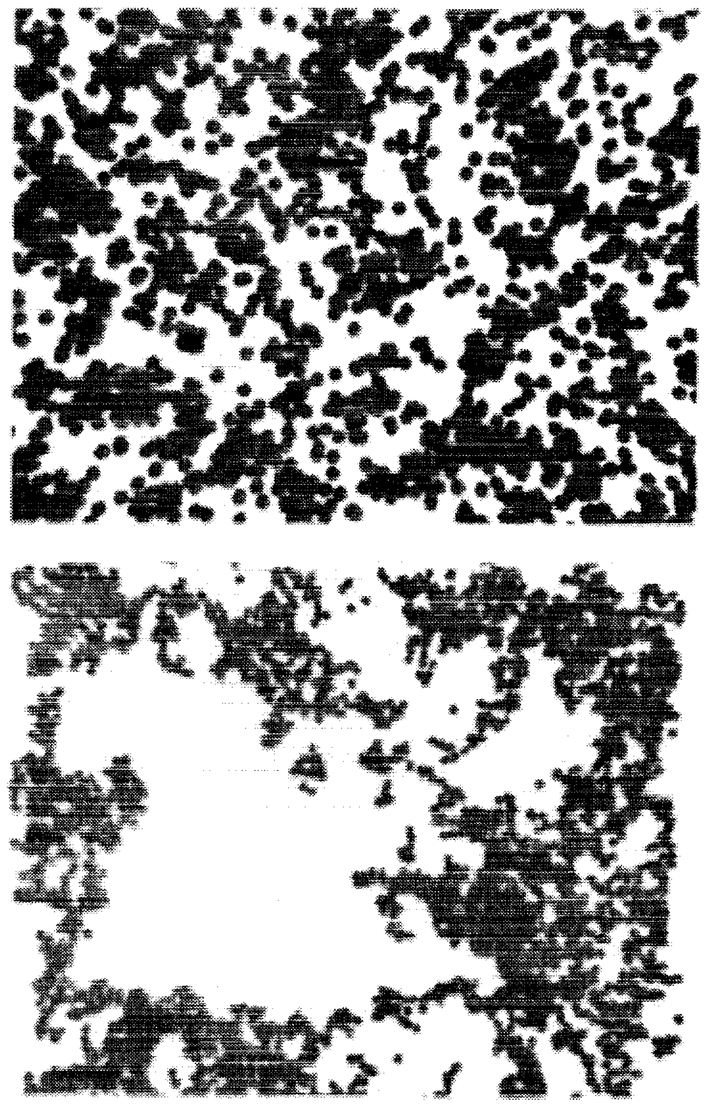


(image is 40 diameters thick)

Reconstructions of 3D images

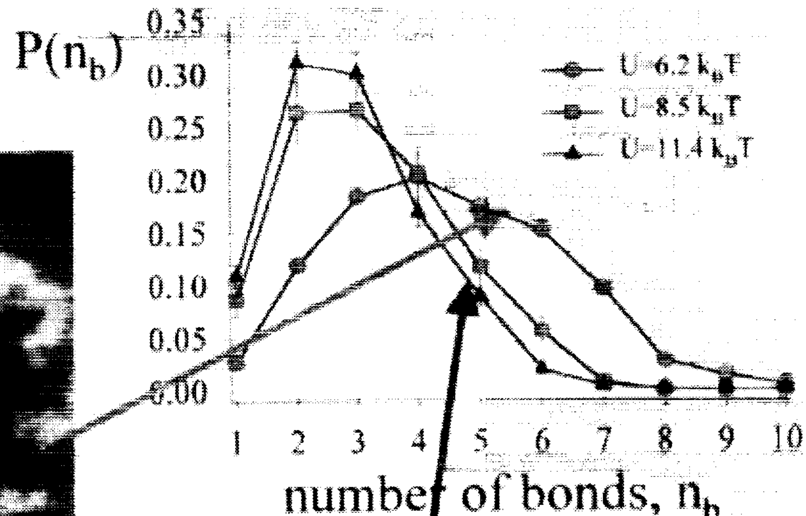
c_p=5.0
('fluid-
cluster')

c_p=11.8
(gel)



ϕ=0.03

Gel morphology



$U=5.1\ k_BT$

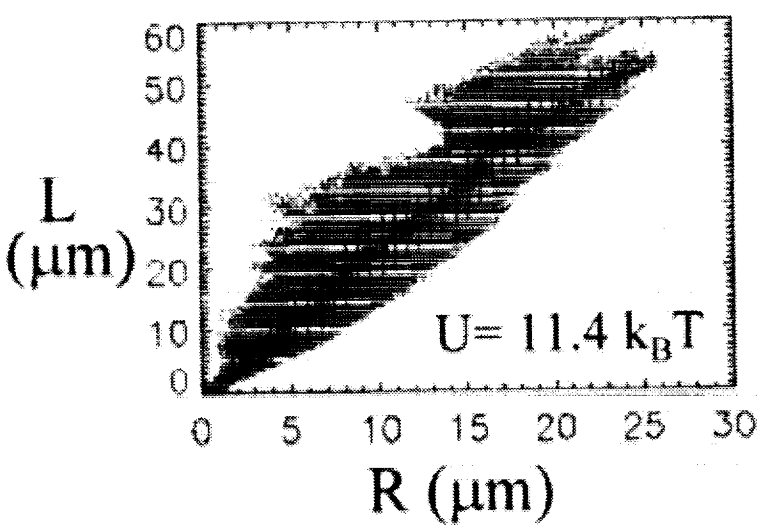
$U=11.4\ k_BT$

$\phi = 0.03$
$R_c = 0.35\ \mu m$
images are 2 μm thick

~12h old

Gel morphology - chains

- Define chain, determine its length
- Find particles in chain (red)



- Shortest-path length, L
  - $L=2.3 \times R$ (for all samples, $U=5\text{-}11\ k_BT$)

- Chemical dimension, $N_{ch} \propto R^{d_{chem}}$
  - measured $d_{chem} = 1.0 \pm .1$
- Chain cross section $= N_{ch}/(L \times \text{sphere diameter})$
  - 1.5 particles ($U= 5.6\ k_BT$)
  - 1.0 particles ($U= 11.4\ k_BT$)