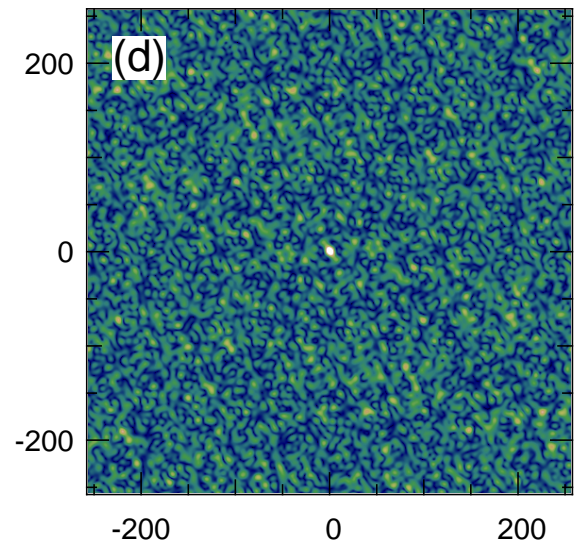
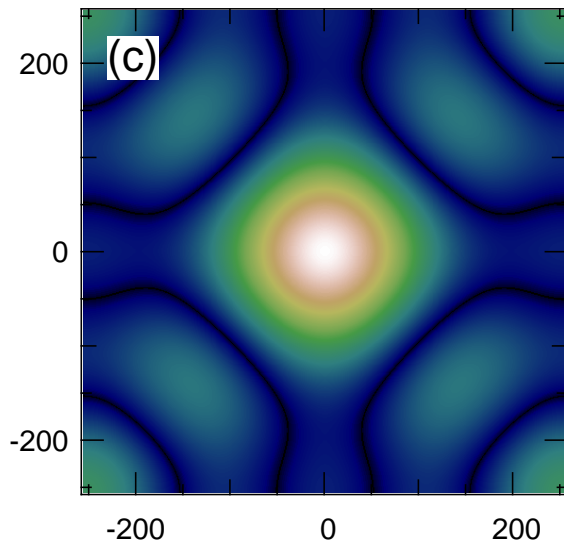
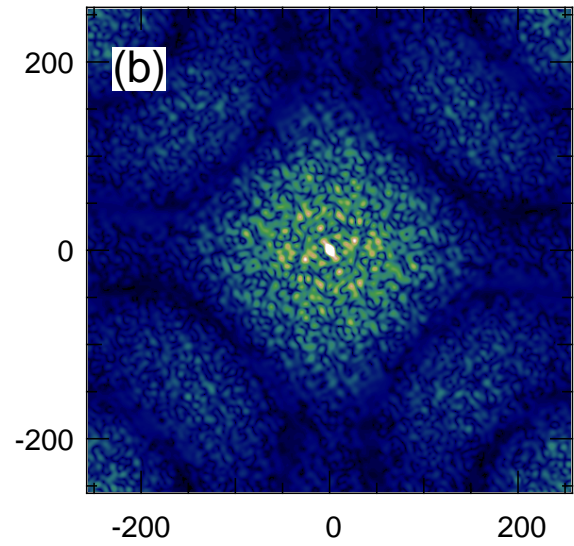
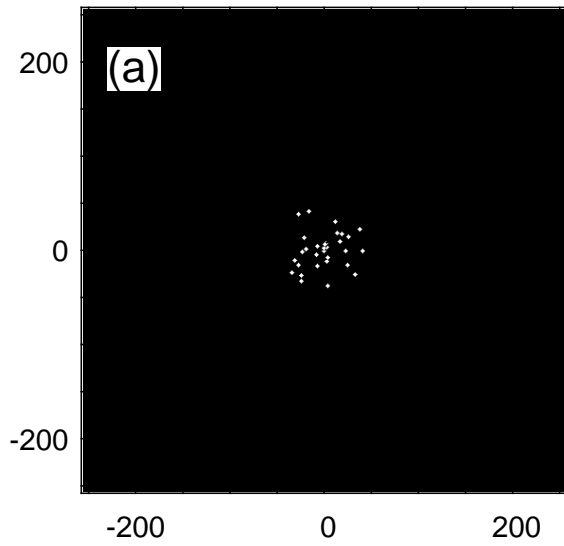


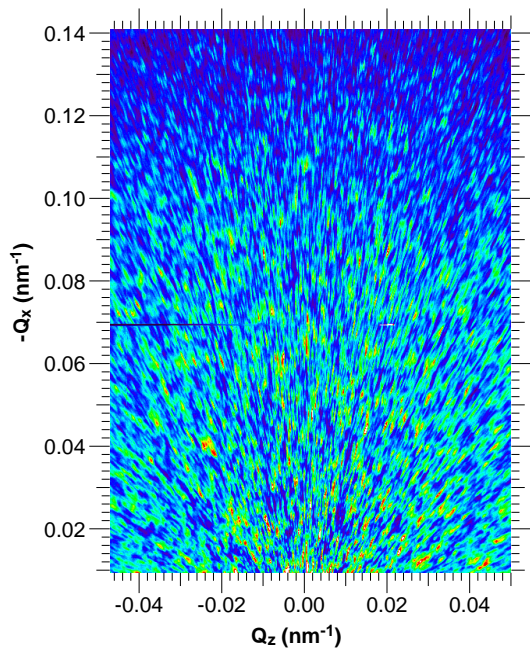
X-ray
Intensity Fluctuation
Spectroscopy

Mark Sutton
McGill University

Pinholes in Tinfoil

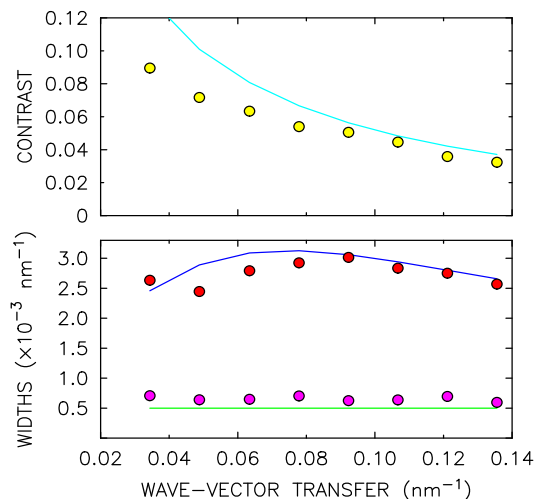
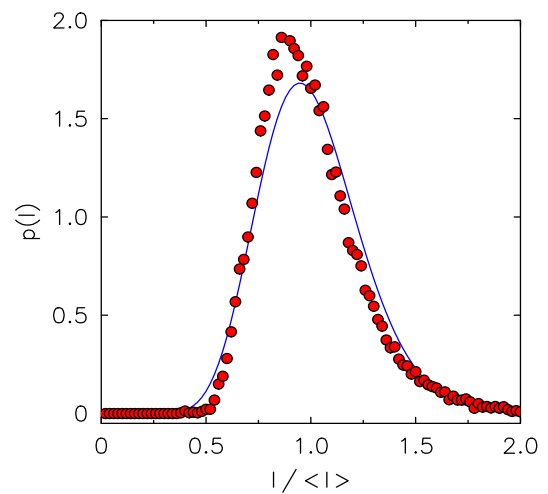


Coherent X-Rays and X-Ray Speckle



Scattering from an aerogel under partially-coherent x-ray illumination at 8-ID-E. The intensity fluctuations constitute x-ray speckle.

Speckle intensity distribution in a ring of scattering at $Q = 0.08 \text{ nm}^{-1}$ (\circ = data, $—$ = theory). The speckle contrast is $\text{var}(I)/\langle I \rangle$.



Comparison between data obtained at 8-ID (\circ) and theory ($—$) for the speckle contrast and speckle widths, as measured by the spatial autocorrelation of the speckle pattern.

Langevin Dynamics

$$\frac{\partial \Psi(\vec{x}, t)}{\partial t} = M \nabla^2 \frac{\partial F}{\partial \Psi} + \eta(\vec{x}, t)$$

where thermal noise is:

$$\langle \eta(\vec{x}, t) \rangle = 0$$

and forcing a generalized Einstein-Stokes or fluctuation

dissipation relation requires:

$$\langle \eta(\vec{x}, t) \eta(\vec{x}', t') \rangle = -2M \nabla^2 k_b T \delta(\vec{x} - \vec{x}') \delta(t - t')$$

Which is linear using the free energy:

$$F = \int \left(\frac{\kappa |\nabla \psi(\vec{x}, t)|^2}{2} + \frac{r \psi^2}{2} \right) d\vec{x}$$

Time Dependent Scattering

Structure factor is:

$$S(\vec{Q}, t) = \langle \Psi^\dagger(\vec{x}, t) \Psi(\vec{x}, t) \rangle$$

giving equation of motion in linear case:

$$\frac{\partial S(\vec{Q}, t)}{\partial t} = -MQ^2(r + \kappa Q^2)S(\vec{Q}, t) + MQ^2 k_b T$$

In equilibrium the solution is:

$$S_{eq}(Q, t) = \frac{k_b T}{r + \kappa Q^2}$$

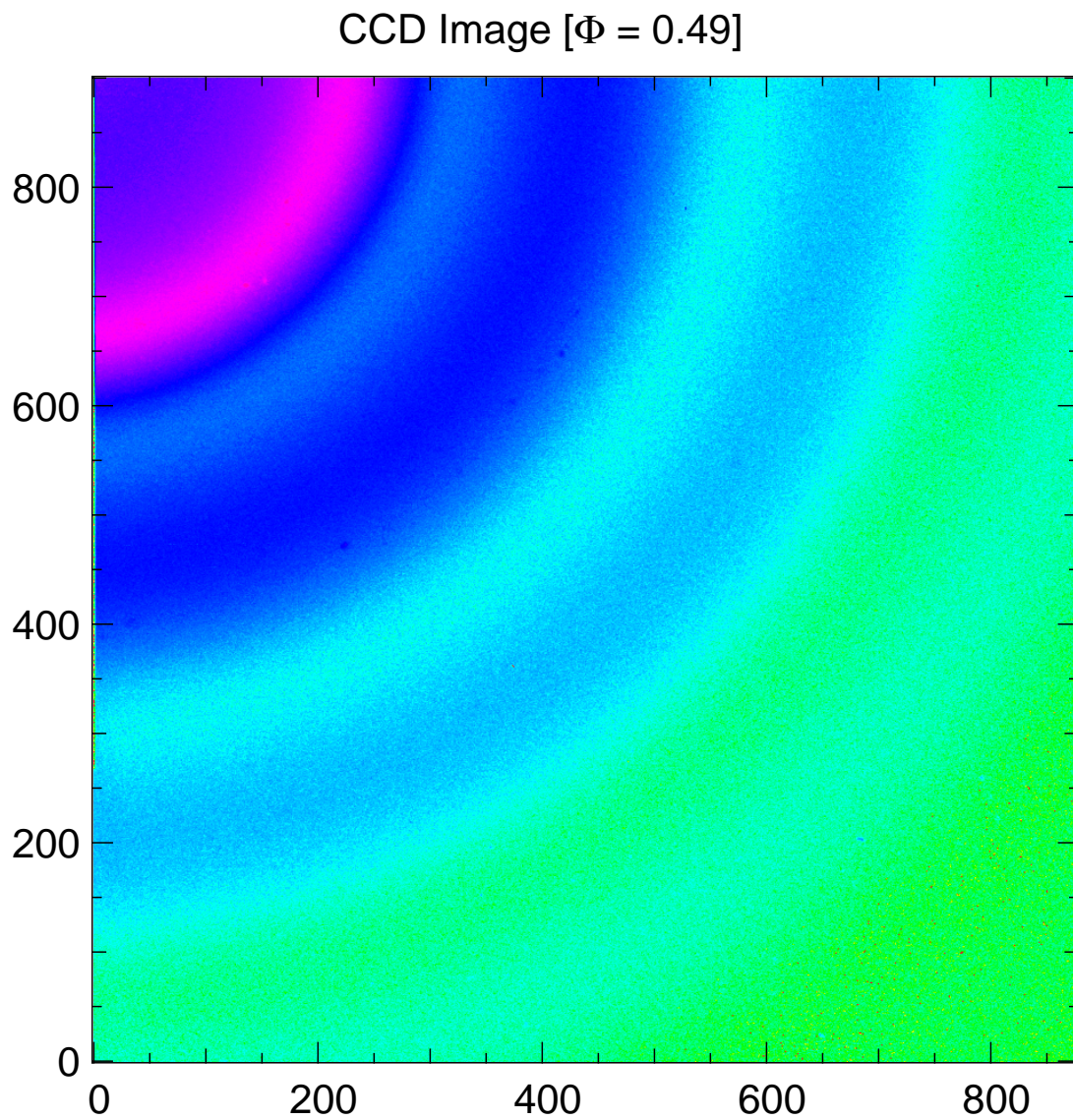
and for a transient is:

$$S(Q, t) = S_0(Q, t)e^{-t/\tau} + S_{eq}(Q, t)(1 - e^{-t/\tau})$$

with time constant τ defined as:

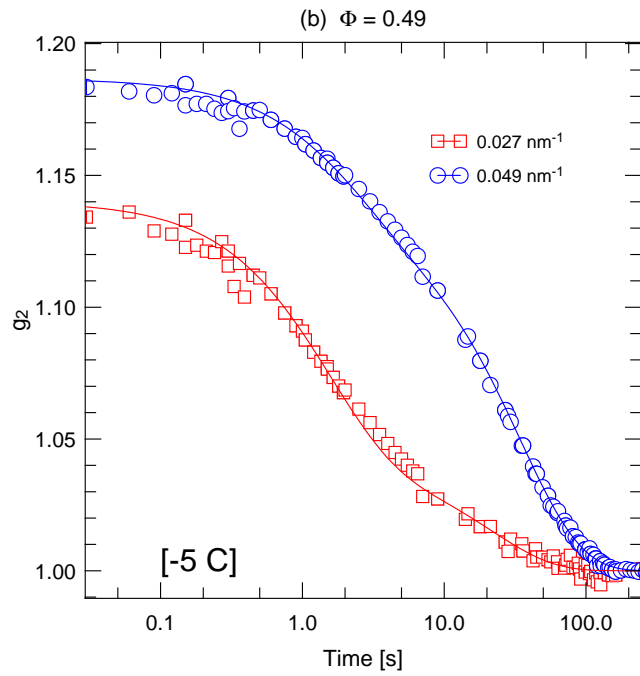
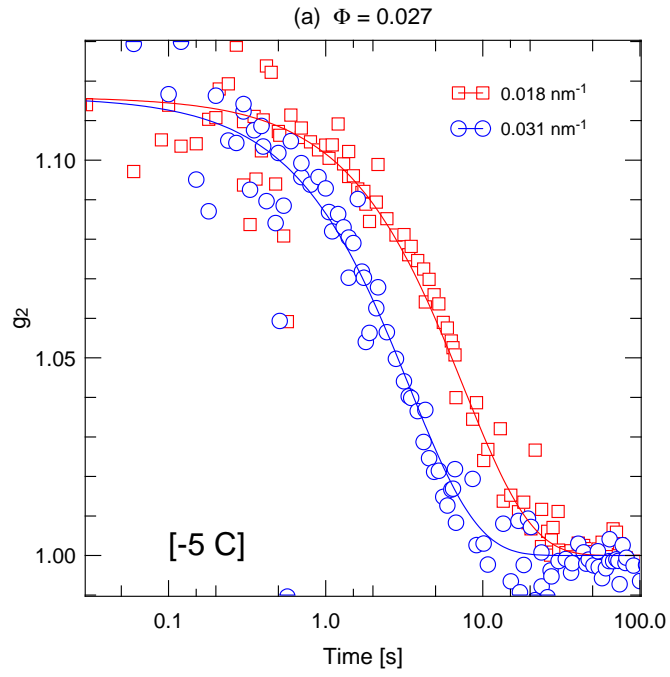
$$\tau = \frac{1}{MQ^2(r + \kappa Q^2)} = \frac{S_{eq}(Q)}{MQ^2 k_b T}$$

Polystyrene latex spheres
(710 Å diameter) in glycerol

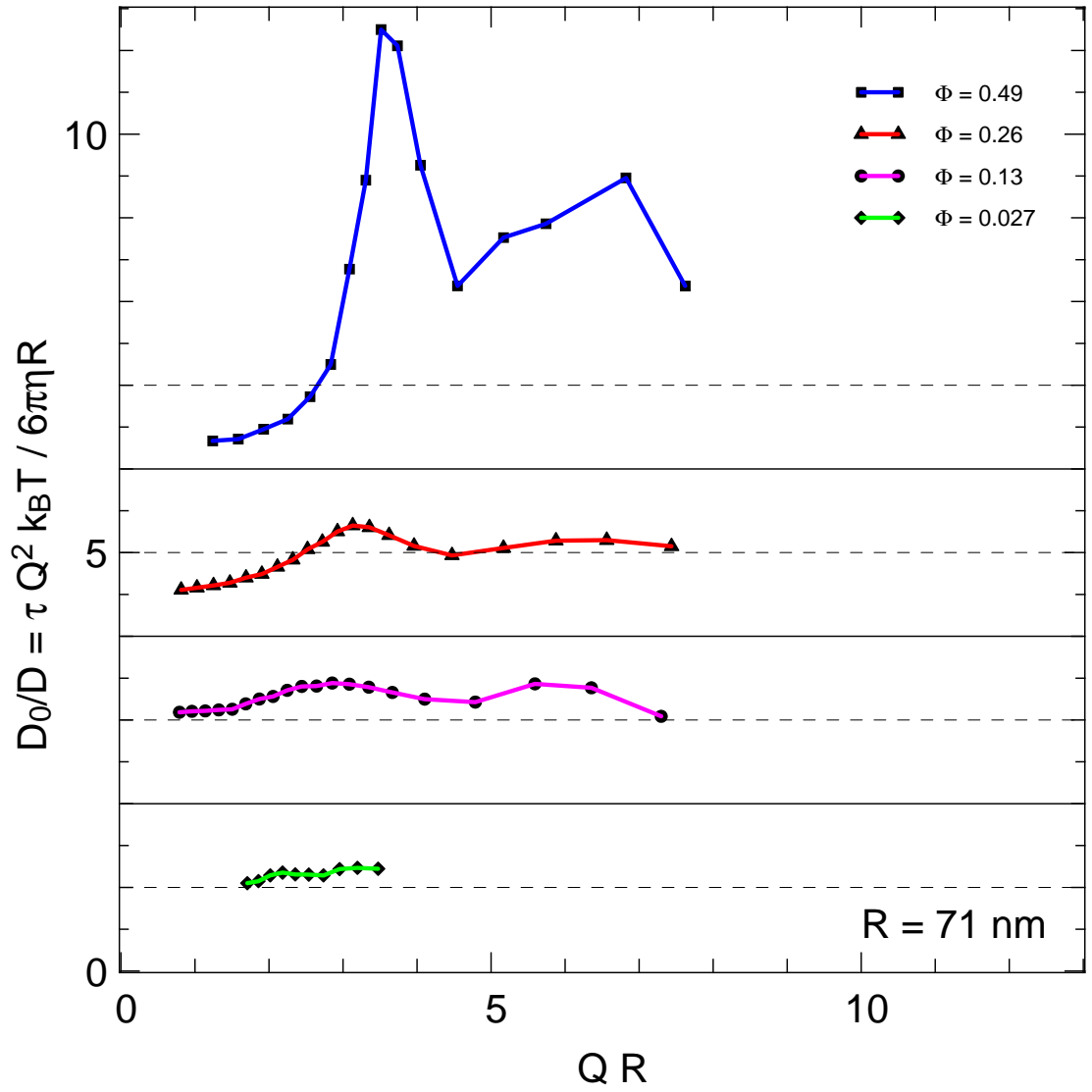


Lurio et al, PRL **84**, 785 (2000).

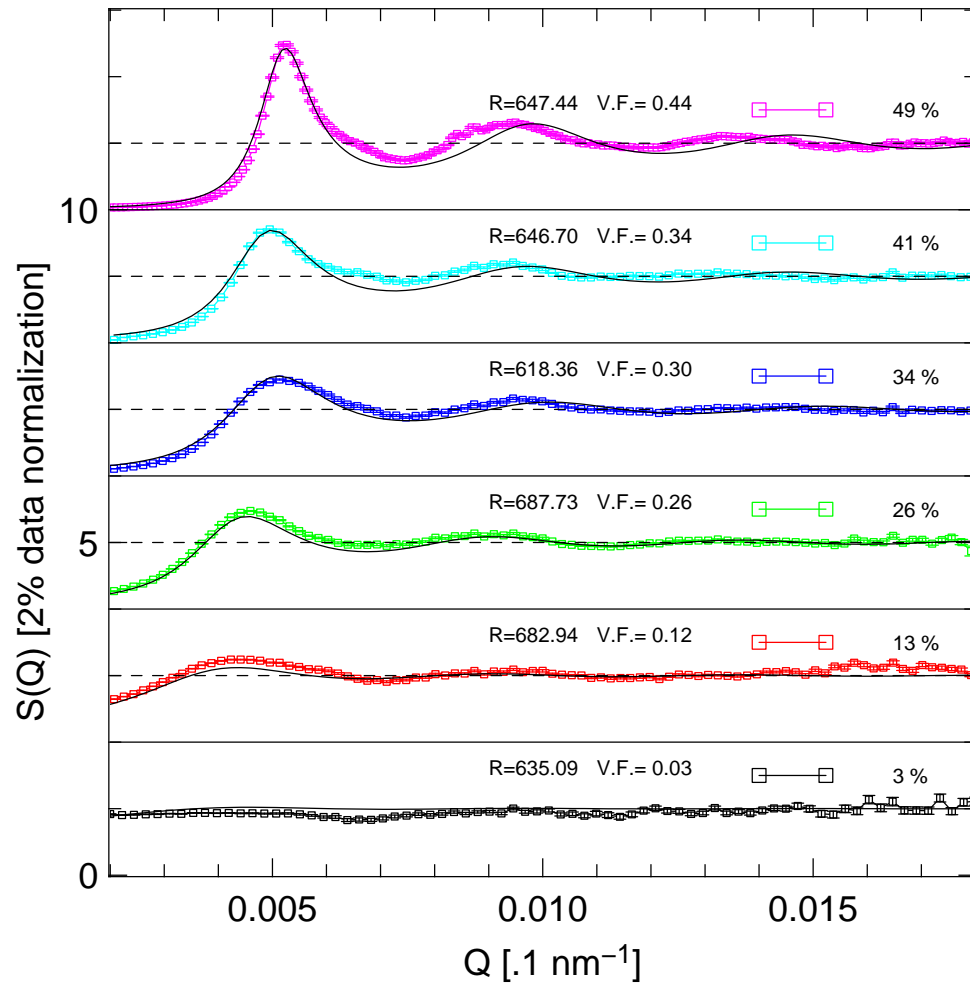
PS Latex in Glycerol: Time-Correlation Function g_2



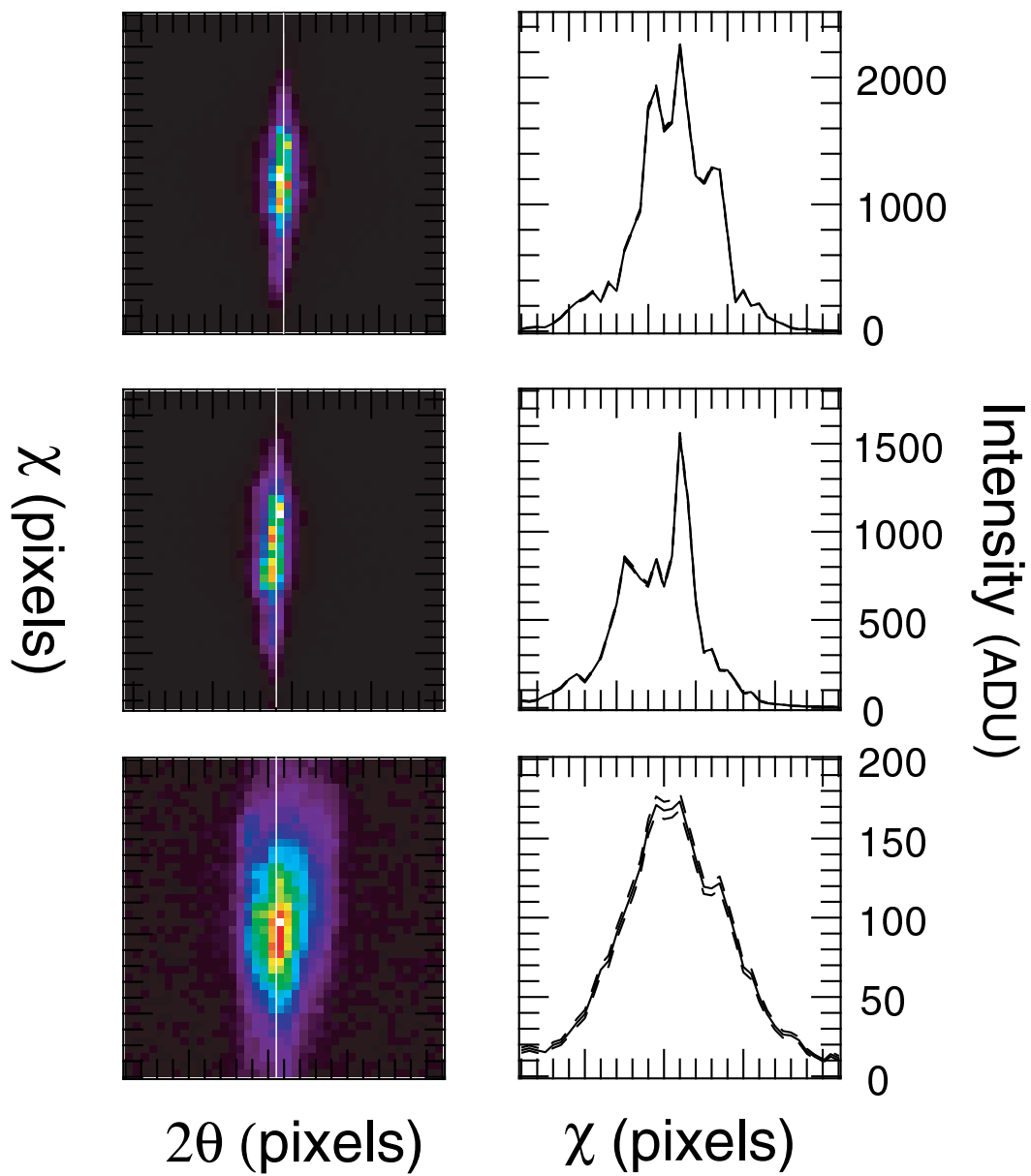
Suspension of PS Latex in Glycerol: Short-Time Diffusion



710 nm latex in glycerol

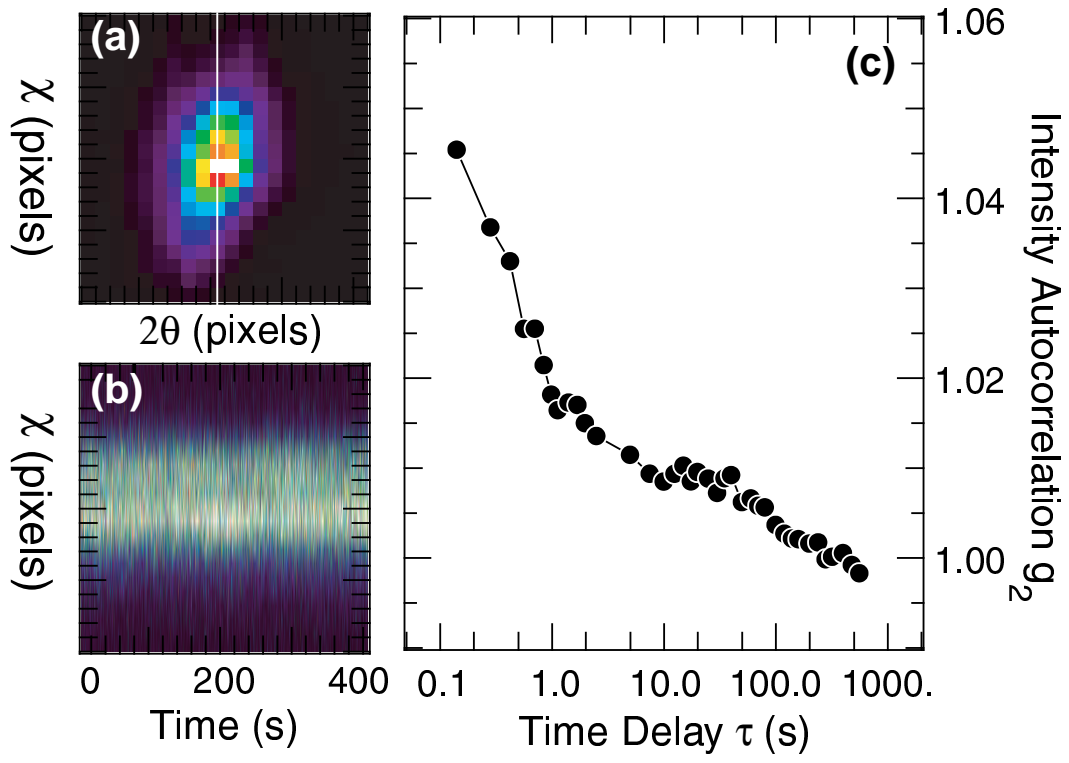


Charge density wave NbSe_3

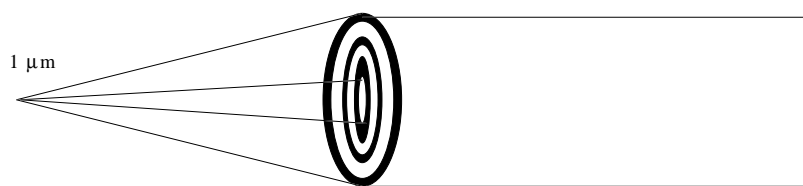
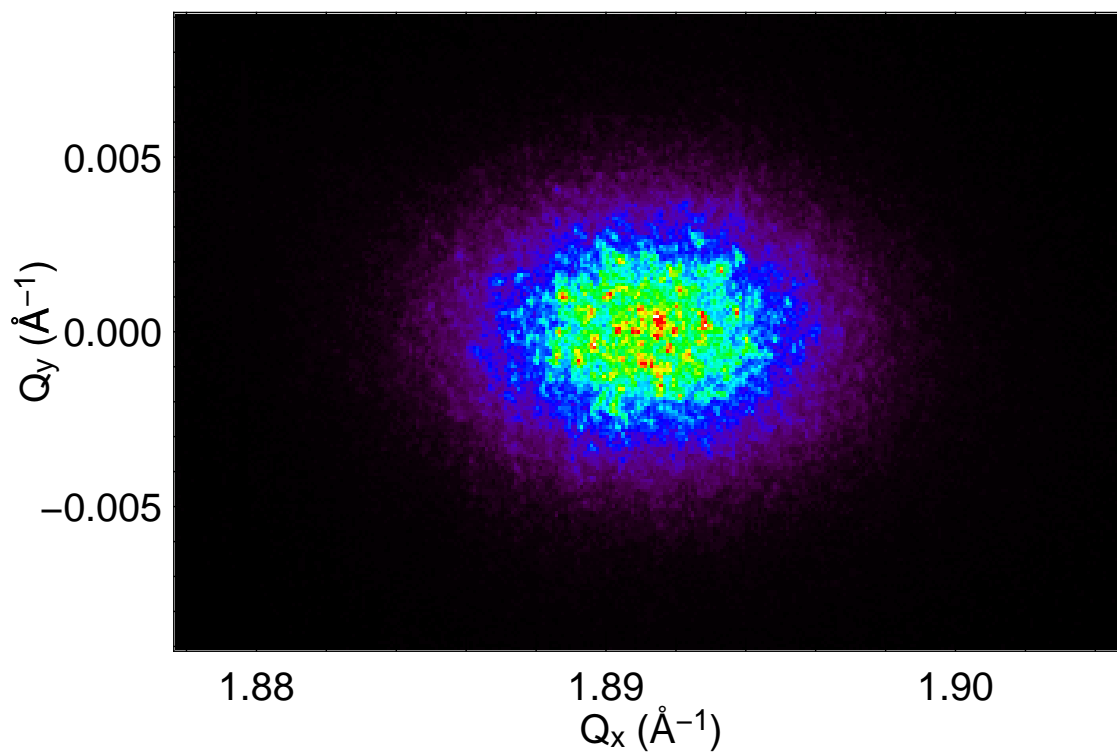


With Joel Brock and Rob Thorne, Cornell University

Charge density wave NbSe₃

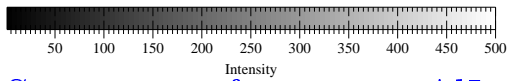
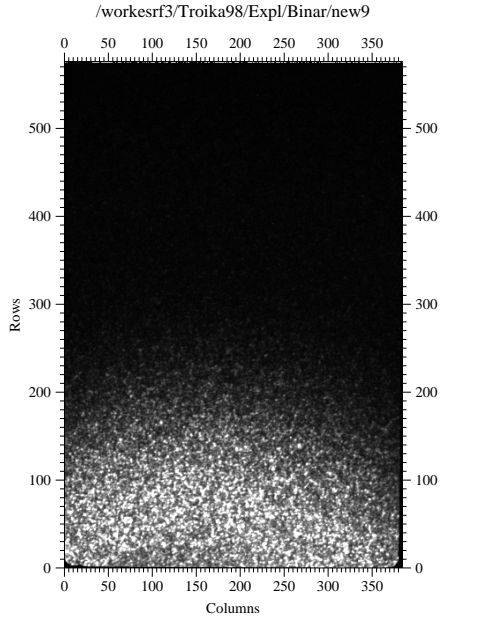


Focussing with zone plates (Fe_3Al)



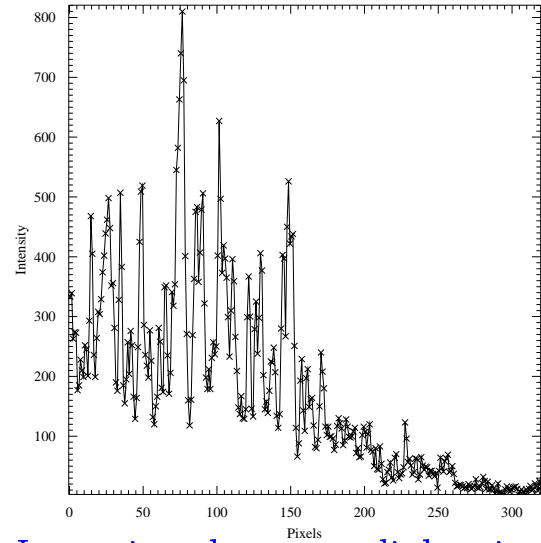
Fresnel Zone Plate

Phase separation in AlLi

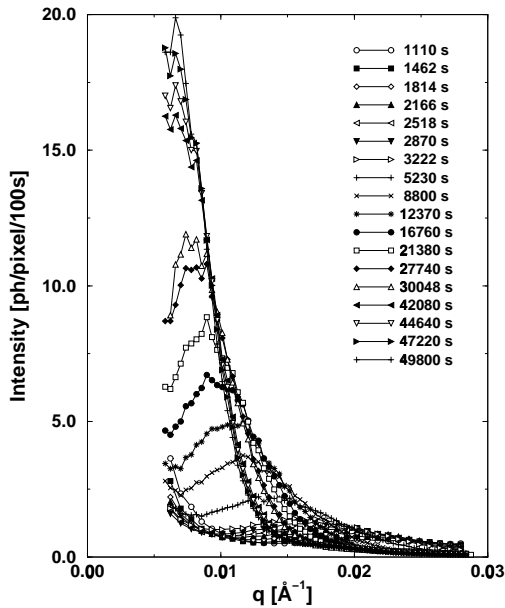


Scattering from an AlLi under partially-coherent x-ray illumination at Troika beamline ESRF.

1-D Slice: /workesrf3/Troika98/Expl/Binar/new9



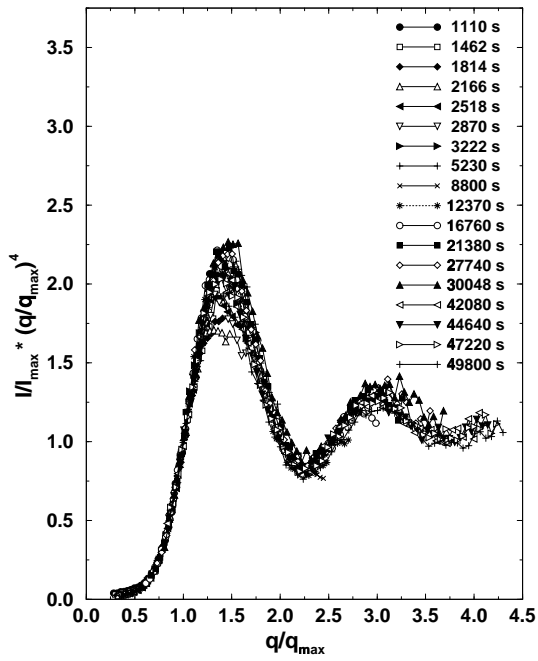
Intensity along a radial strip.



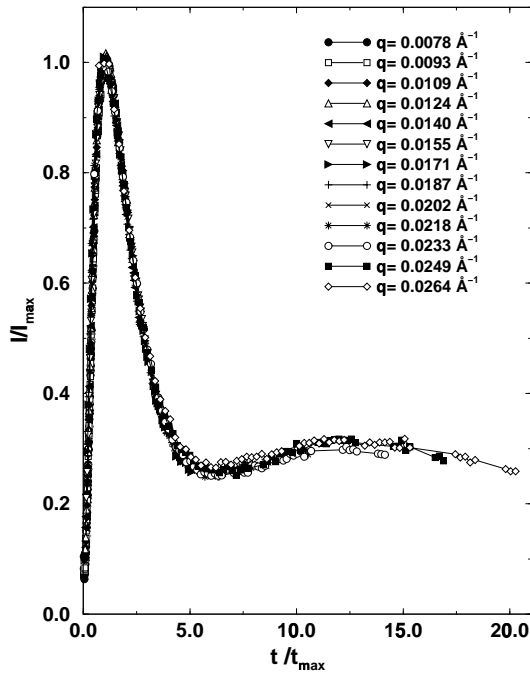
Time evolution of a $S(q)$

Livet et al, PRE (2001)

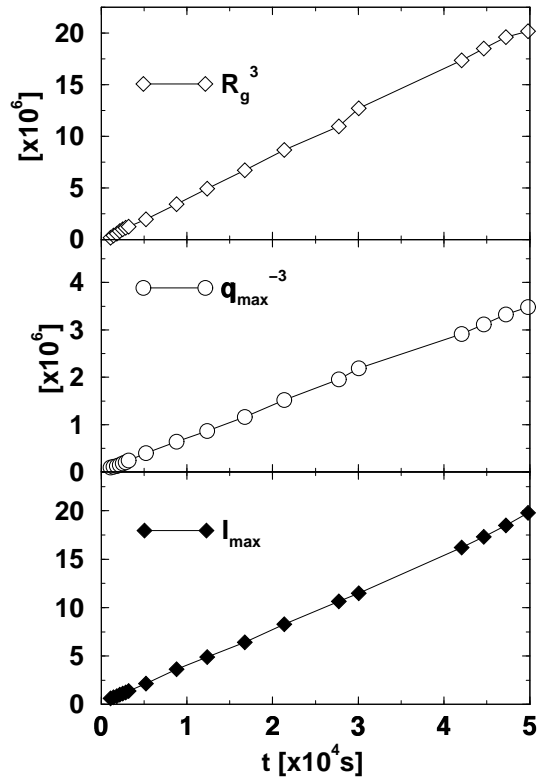
Alli: Dynamic Scaling



Porod's Law $S(q/q_{\max})$

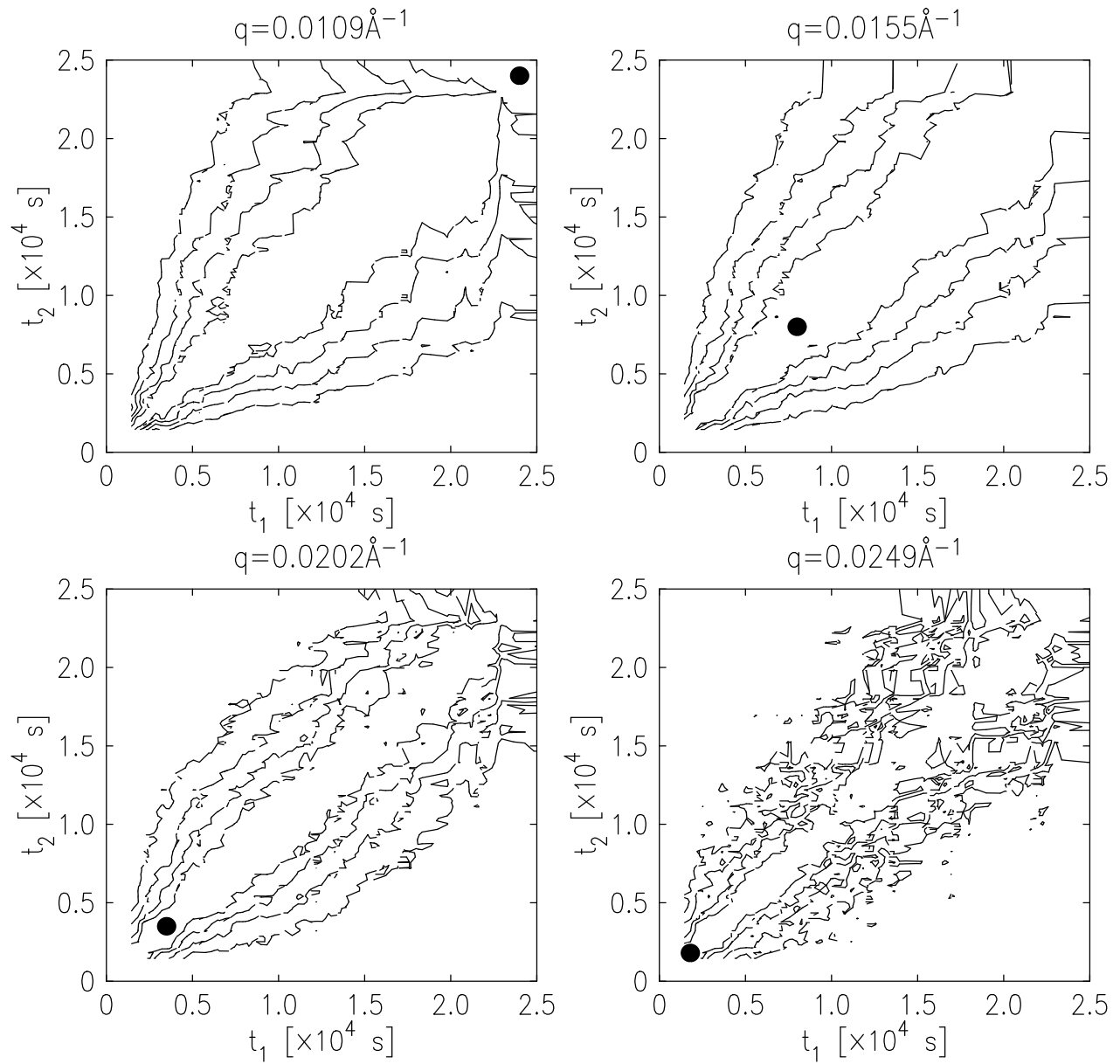


$S(t/t_{\max})$



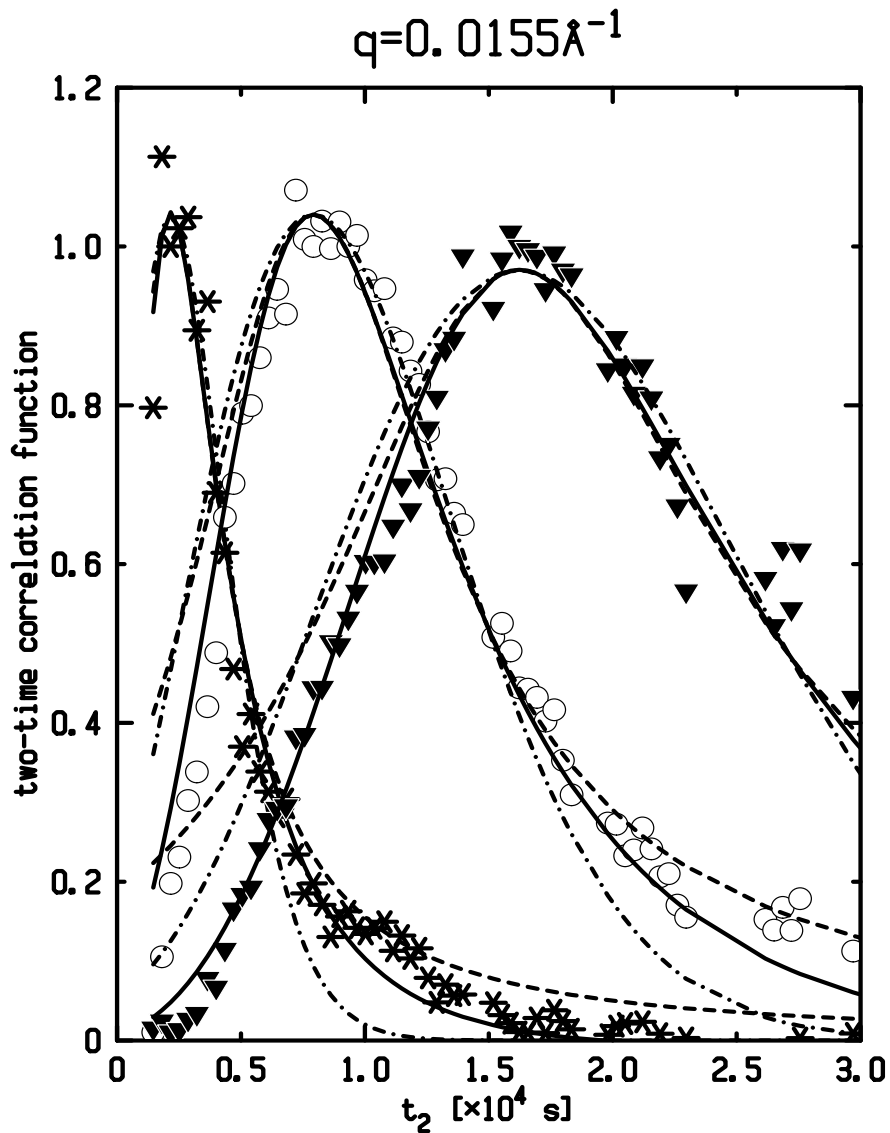
$q_{\max} \sim t^{\frac{1}{3}}$

Alli: Two-Time Correlations



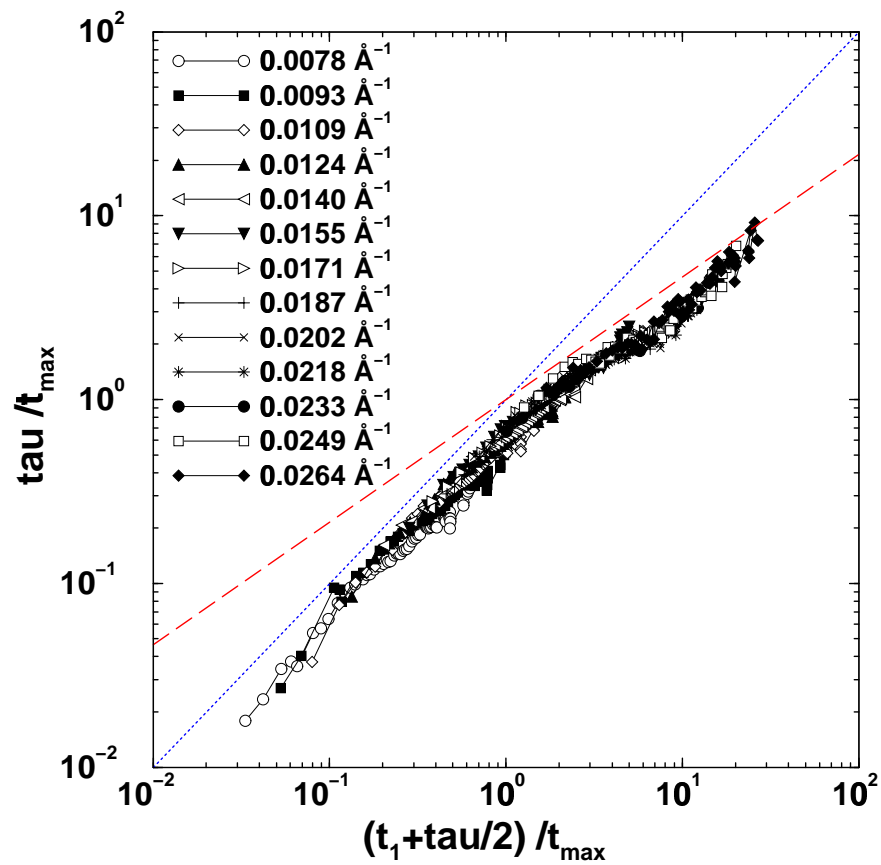
Contour plots of two-time correlation functions; contour levels are 0.2, 0.4, 0.6, 0.8 . The black dots indicates t_{max} for the given q .

Alli: Two-Time Correlations



Correlation function $C_{norm}(q, t_1, t_2)$ for $t_1 = 2163$ s; 7920 s; 16230 s. Solid lines are fits to scaling form. For comparison, the dash-dot line is a Gaussian and dashed line is a Lorentzian with the same height and width.

AllLi: Two-Time scaling



Scaled correlation times for all q values (from fitting scaling form).
The dotted line has slope 1 and the dashed line has slope 2/3.

Requirements of XIFS

1. Scattering Volume comparable to coherence volume (diffraction limited beam resolved by detector).
2. Broad scattering (i.e. disorder so there is interesting structure within beam)
3. Sufficient counts per correlation time (like about 1)
4. Sufficient number of correlations times measured (either many times at one speckle or many speckles and times with the same time constant).

Possible systems to study

1. polymers, glasses (visco-elastic effects)
2. critical scattering
3. quasi-crystals (phasons)
4. low dimensional systems
5. charge density waves
6. grain boundaries, domain walls, defect motion
7. switching in ferroelectrics, piezoelectrics
8. colloids
9. non-equilibrium systems

Summary

1. Emphasized the kinetics measurements are important (especially for Material's Science).
2. Explained how XIFS works.
3. Gave several examples to show what can be learned.

So why don't more people do it?

1. Requires high brilliance (APS, ESRF, ERL).
2. Puts severe requirements on beamline.
3. Is a time resolved measurement. These are not typically done and harder than static measurements.

Aside: A similar case can be made for time resolved x-ray diffraction. For sub-microsecond time scales, the pulse structure of the typical synchrotron can get in the way. So a "CW" source would be advantageous.