Troïka Beamline ID10A: Coherent Photons for XPCS Studies of Dynamics in Condensed Matter

http://www.esrf.fr/UsersAndScience/Experiments/SCMatter/ID10A

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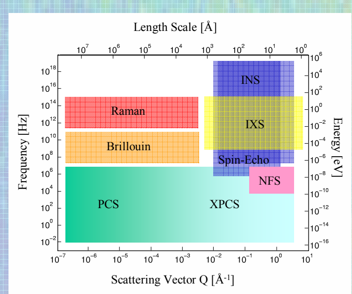
ID10A is a high-brilliance undulator beamline specialized in scattering experiments coherent X-ray beams. The TROIKA I station operates from 7 to 13keV and is optimized for X-ray Photon Correlation Spectroscopy (XPCS) with 0D and 2D detectors in WAXS and GISAXS geometries. The Troika III end-station uses the transmitted beam from ID10A and is optimized for small angle scattering experiments with coherent X-rays and XPCS. The energy range is 7-21keV and the bandwidth can be varied from 10^{-4} (Si(111) channel-cut mono) to 10^{-2} by sending the full undulator line into the experimental hutch with a double reflecting mirror. In this case the coherent intensity exceeds 10^{11} ph/sec.

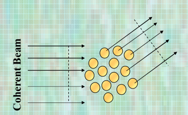
X-ray Photon Correlation Spectroscopy (XPCS)

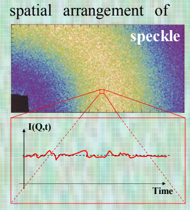
XPCS measures the dynamics of density fluctuations, of wavelength 2π/Q, by evaluating the temporal auto-correlation function of the scattered intensity



XPCS probes slow dynamics at large length scales

Disordered systems illuminated with coherent light give rise to random diffraction (speckle) patterns. A speckle pattern is related to the exact spatial arrangement of disorder





Time evolution of speckles

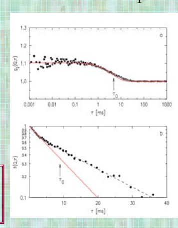
The measured quantity is the intensity autocorrelation function

$$g^{(2)}(Q,\tau) = \frac{\langle I(Q,t)\cdot I(Q,t+\tau)\rangle}{\langle I(Q)\rangle^2}$$

$$g^{(2)}(Q,\tau) = 1+\beta^2|f(Q,\tau)|^2$$

The physical quantity of interest is the normalized intermediate scattering function $f(Q,\tau)$

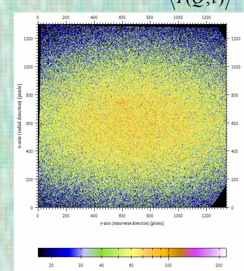
$$f(Q,\tau) = \exp[-\Gamma(Q)\tau]$$



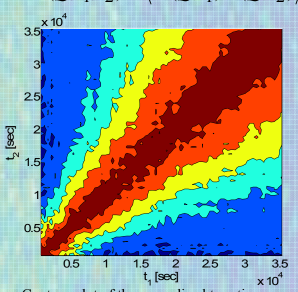
Non-equilibrium dynamics by XPCS: Ordering Kinetics in a Cu-Pd Alloy

After a quench from the disordered to the ordered state, the evolution of speckle intensity around the superlattice peak was quantified by XPCS using the generalized two-time correlation function $C(Q,t_1,t_2)$:

$$D(Q,t) = \frac{I(Q,t)-\langle I(Q,t)\rangle}{\langle I(Q,t)\rangle} \qquad C(Q,t_1,t_2) = \langle D(Q,t_1)D(Q,t_2)\rangle$$



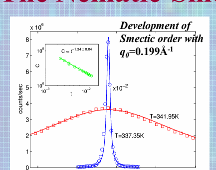
Detector image of superlattice peak 35991 s after the temperature quench



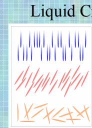
Contour plot of the normalized two-time correlation function $C_{norm}(Q=0.0126\ nm^{-1},t_1,t_2)$. A slowing down of dynamics with age is seen.

K. Ludwig, F. Livet, F. Bley, J-P. Simon, R. Caudron, D. Le Bolloc'h, A. Moussaïd, *Phys. Rev. B* **72**, 144201 (2005)

Surface Dynamics by XPCS: The Nematic-SmecticA Phase Transition

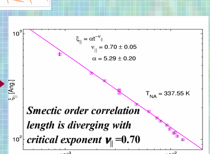


Liquid Crystal Phases :

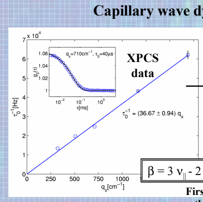


Fits (solid lines) with expression yields

$$S(q)=\frac{C}{1+\xi_{\|}^2(q_z-q_0)^2+\xi_{\perp}^2q_{\perp}^2+\xi_3^4q_{\perp}^4}$$



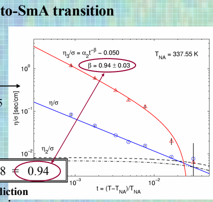
Capillary wave dynamics at the N-to-SmA transition



η viscosity
σ surface tension

$\tau_0^{-1}/q=\sigma/\eta$ yields

$\eta = 2\eta_1/3+\eta_2/3+\eta_3/15$
η_3 is diverging at the N-to-SmA transition
η_1 and η_2 are not



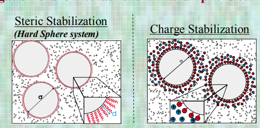
$\beta = 3\nu_{\|} - 2\nu_{\perp} = 3\times0.70 - 2\times0.58 = 0.94$

First test of theoretical prediction that links static and dynamics

A. Madsen, J. Als-Nielsen and G. Grübel, *Phys. Rev. Lett.* **90**, 085701 (2003)

Bulk XPCS: Dynamics of Colloidal Suspensions

Investigation of the interactions in Hard Sphere & in Charged systems

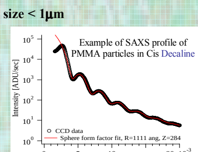


10Å < size < 1μm

STATIC : description of the ensemble correlations via the static structure factor S(Q), related to the intensity I(Q) via:

I(Q) = N F(Q) S(Q)

Number of Particles — Form Factor



DYNAMICS : described by the effective diffusion coefficient D(Q)

• *Dilute non-interacting suspension* (no interparticle interaction)

$D(Q) = D_0 = k_BT/6\pi\eta R$, $S(Q)=1$

Thermally driven fluctuations from colloid-solvent interactions

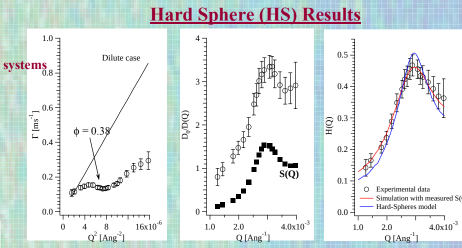
• *Concentrated interacting suspensions* (S(Q)≠1)

$$D(Q)=\frac{D_0}{S(Q)}H(Q)$$

Hydrodynamic function: colloid-colloid indirect interactions

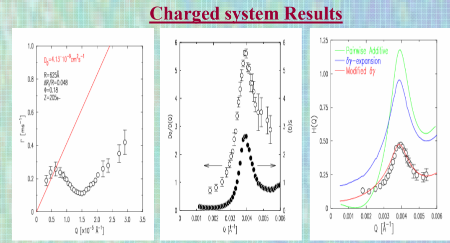
colloid-colloid direct interactions

Hard Sphere (HS) Results



- Hydrodynamic interactions are important in both cases
- Good agreement with theory (δγ- expansion) in HS case
- No general model available for concentrated charged system

Charged system Results

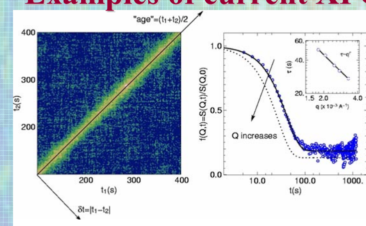


F. Zontone A. Moussaïd, et al, to be buplished; A. Robert, PhD thesis, Universite Joseph Fourier Grenoble (2001)

Examples of current XPCS projects

Relaxations in thermosensitive Gels

Poly(N-isopropyl acrylamide) (PNIPA) gels undergoes temperature induced volume phase transition. To Goal is to determine the nature of the slow relaxations that occurs in collapsed state, using two-time correlation function *C(Q,t1,t2)*

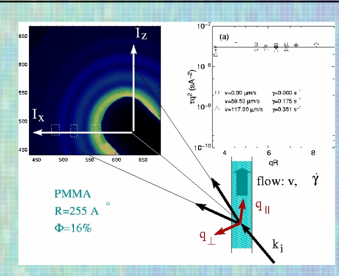


Example of two-time correlation function and an averaged, one-time correlation function for PNIPA gel

E. Geissler, A. Fluerasu, A. Moussaïd, K. Kosik, K. László

XPCS in liquids under shear flow

The flow is used to avoid beam damage. Our experiments prove that for particular scattering geometries, the diffusive dynamics of a suspension of PMMA colloidal particles under shear flow is decoupled from the flow-induced convective dynamics



Andrei Fluerasu, Abdellatif Moussaïd, Anders Madsen, Henri Gleyzolle