Contact-free manipulation and probing of single biological and soft matter objects

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- Overview on selected contact free techniques
- Scope of applications
- MicroSAXS/WAXS cameras
- Contact free techniques: applications & challenges

Acknowledgements

ESRF-ID13 beamline team

Manfred Burghammer et al.,

Silvia Santucci (optical tweezers)

Rita Graceffa (inkjet systems; now at APS BioCAT)

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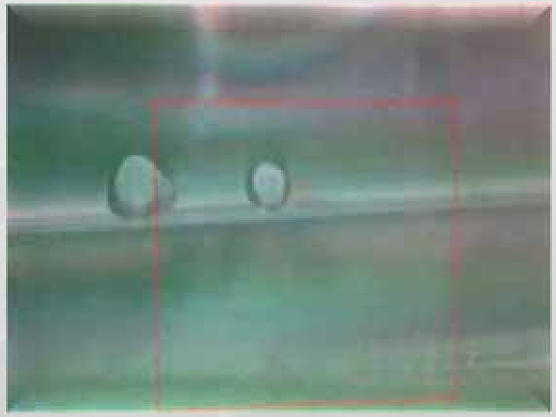
Dan Cojoc (optical tweezers)

Institute of Biophysics and Nanosystems Research (Graz-Austria)

Heinz Amenitsch (optical tweezers)

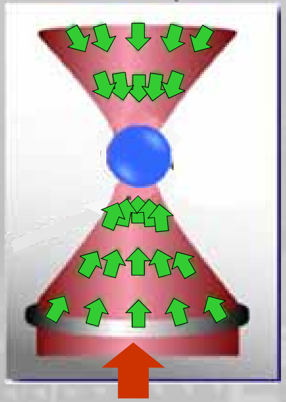
Contact-free and quasi contact-free manipulation

Optical Tweezers



Particles in capillary

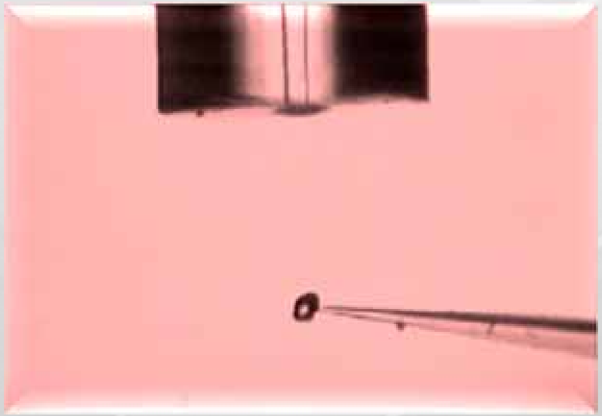
gradient force



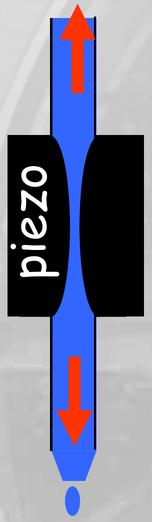
scattering force

focused laser beam

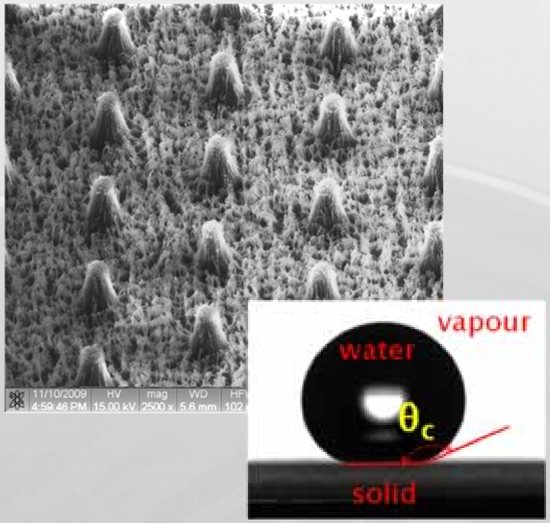
Inkjet

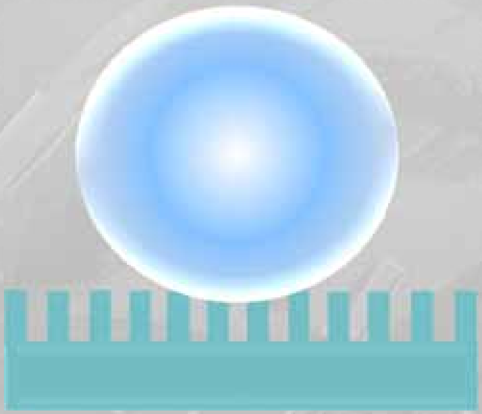


stroboscopic display



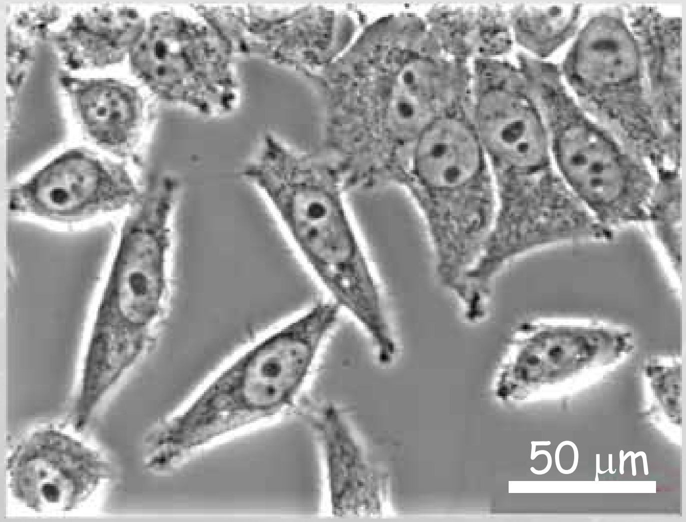
Superhydrophobic Surface



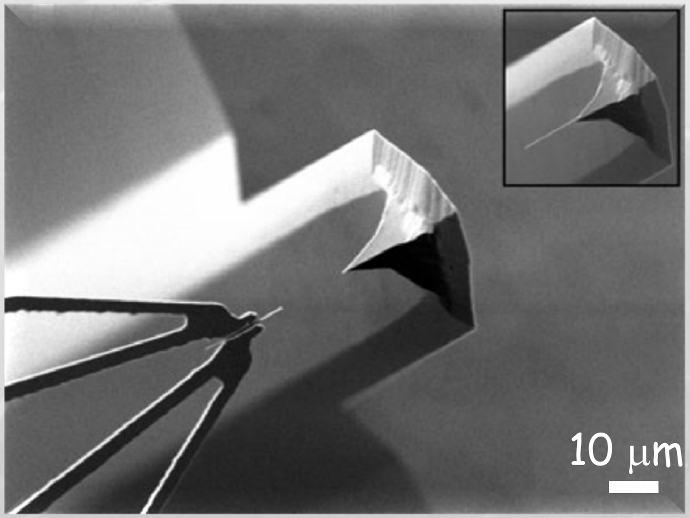


Scope of applications

HeLa cells @ r.t.



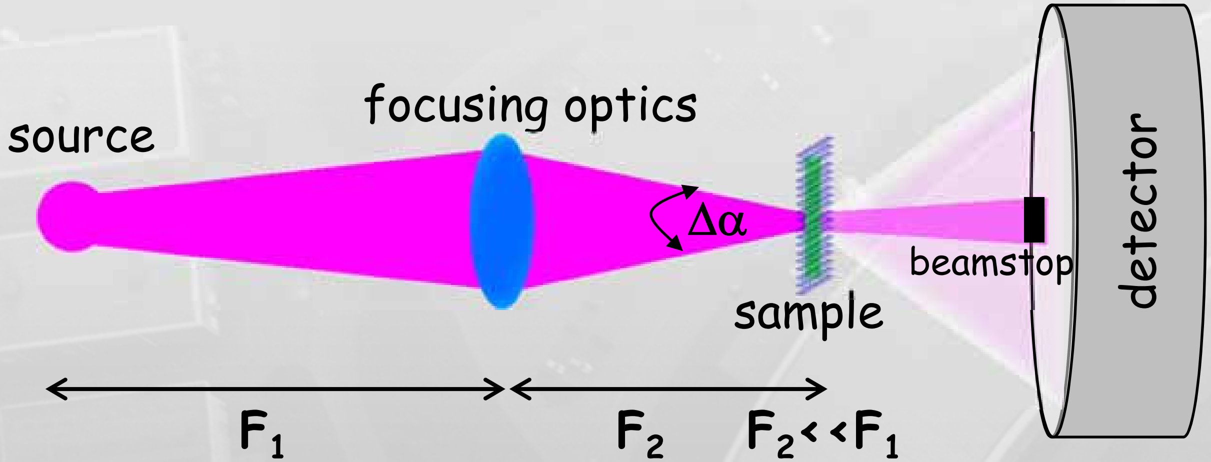
Nano-grippers (NanoHand project)



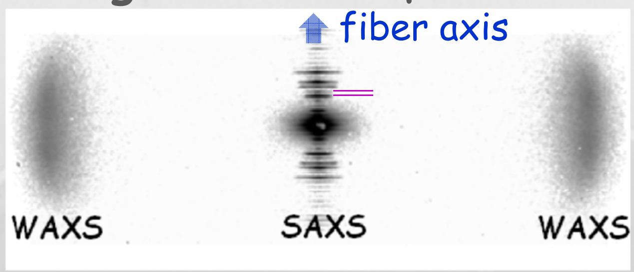
- Single objects: positioning, manipulation & assembly
- Probing of objects in functional states, often in aqueous environments
- Raster probing: heterogeneity & distribution of radiation damage
- Avoid deformation of "soft" objects by "contact" forces
- Avoid surface induced processes and shearing effects by walls
- Reduce sample volumes!

Probing by microSAXS/WAXS pinhole camera

contrast: large scale density fluctuations, aggregation, shapes

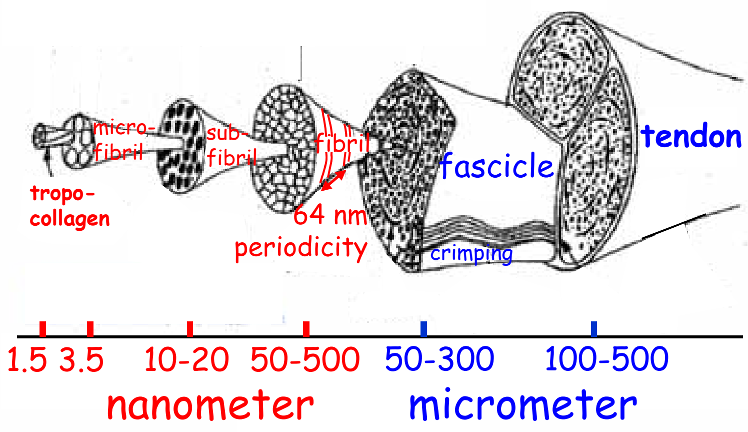


collagen fiber-5 µm beam

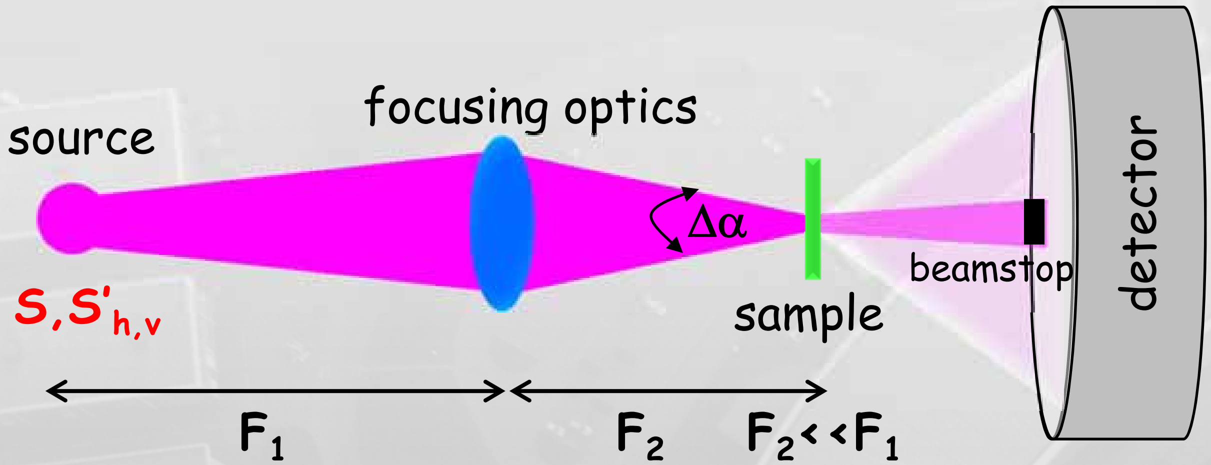


Resolution	
reciprocal space	order resolution ($\Delta\alpha$)
real space	raster-increment (focal spot)

Hierarchical tendon structure



MicroSAXS/WAXS pinhole camera



undulator source parameters

ESRF 6 GeV

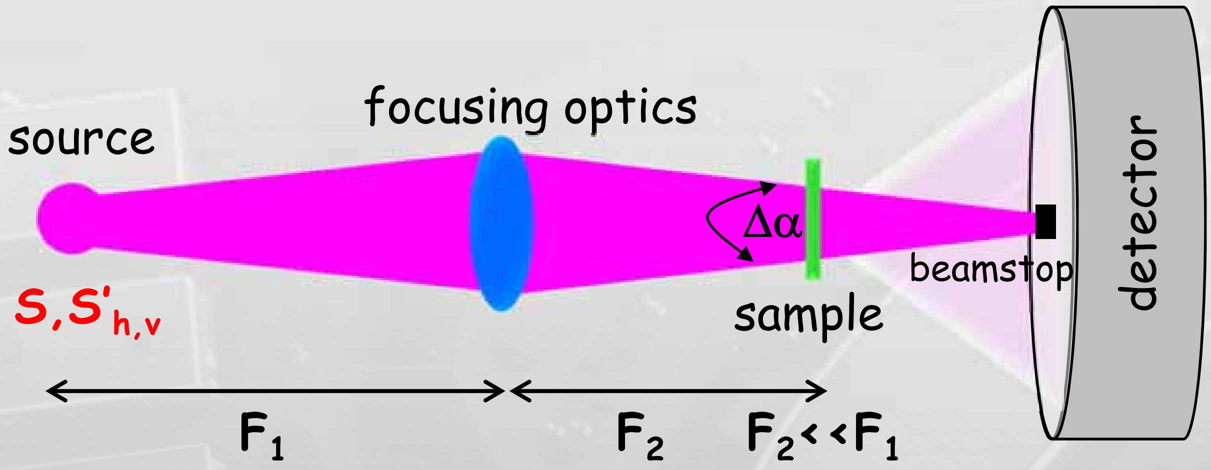
low-β: ID13 (microSAXS/WAXS)

$S_{h/v}$ (μm; fwhm)

$S'_{h/v}$ (μRad; fwhm)

$Br_{13\ keV}$ (Ph/s/mm²/mrad²/0.1%bw) ~$2*10^{21}$ (upgrade)

SAXS/WAXS pinhole camera



undulator source parameters

ESRF 6 GeV

high-β: ID02 (high resolution SAXS)

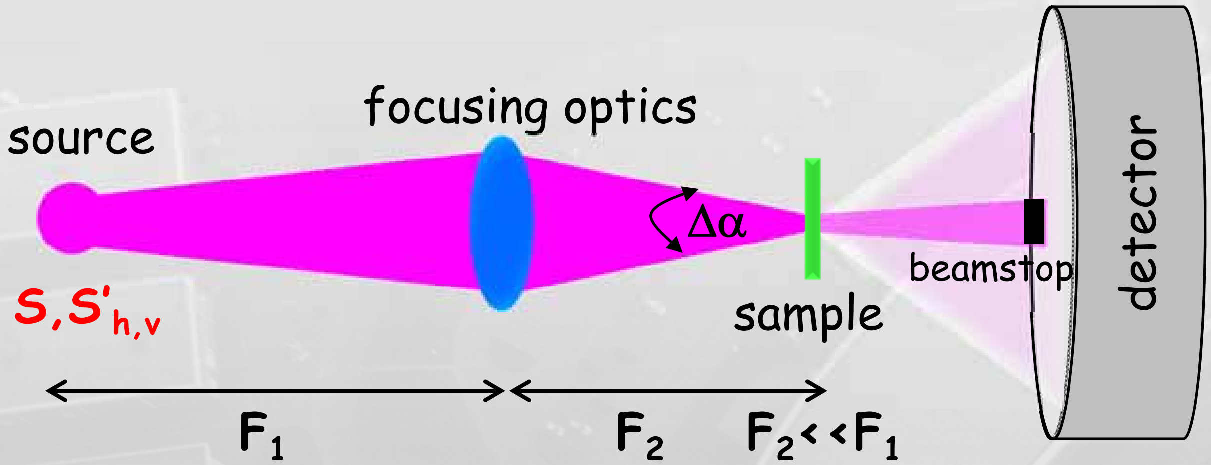
$S_{h/v}$ (μm; fwhm)

$S'_{h/v}$ (μRad; fwhm)

$Br_{13\ keV}$ ~$2*10^{21}$ (upgrade)

(Ph/s/mm²/mrad²/0.1%bw)

MicroSAXS/WAXS pinhole camera



undulator source parameters

	ESRF 6 GeV	CHESS-ERL 5 GeV		
	low-β: ID13	high-coherence	high-flux	nanofocus
$S_{h/v}$ (μm; fwhm)		21 μm fwhm		
$S'_{h/v}$ (μRad; fwhm)		5 μRad fwhm		
$Br_{13\ keV}$ (Ph/s/mm²/mrad²/0.1%bw)	~$2*10^{21}$ (upgrade)	~$9*10^{22}$		

Bilderback et al., *NJP* (2010) **12**, 035011

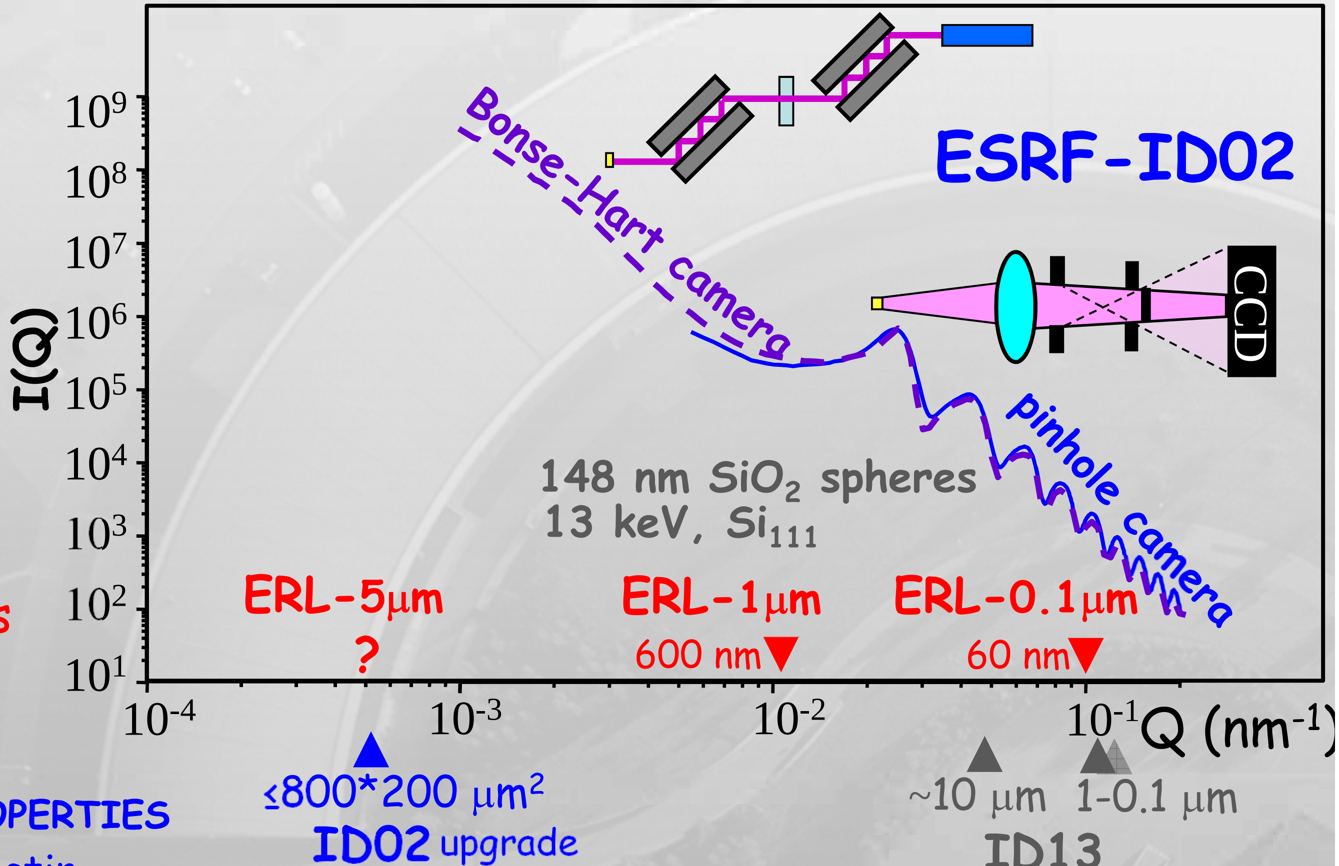
Brilliance and SAXS pinhole camera

ESRF: ID02 (high-β)

ID13 (low-β)

ERL pinhole SAXS

ERL SAXS camera for ultrasmall sample volumes



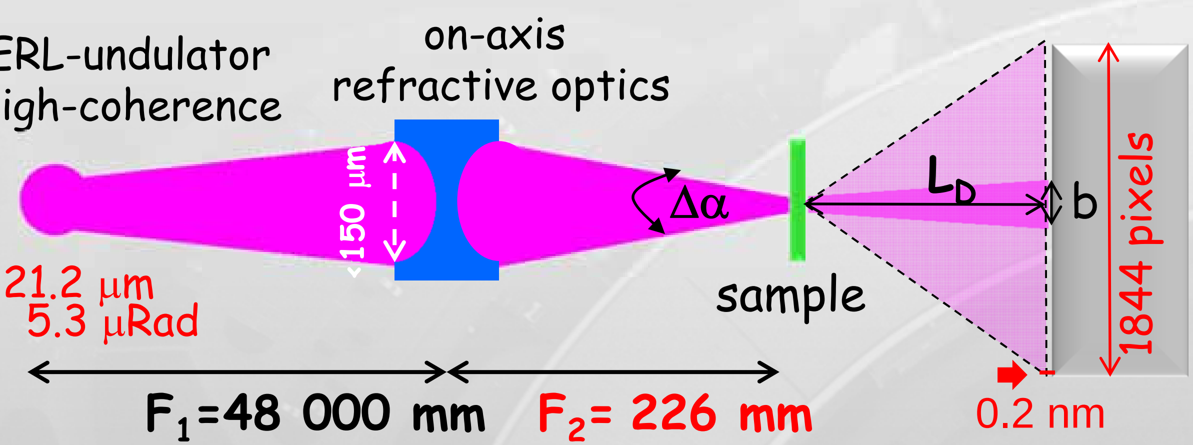
COLLECTIVE PROPERTIES

- self assembly: actin…
- transient processes: flames…
- biomimetic systems: biomineralization…
- mesoscopic processes: active matter…

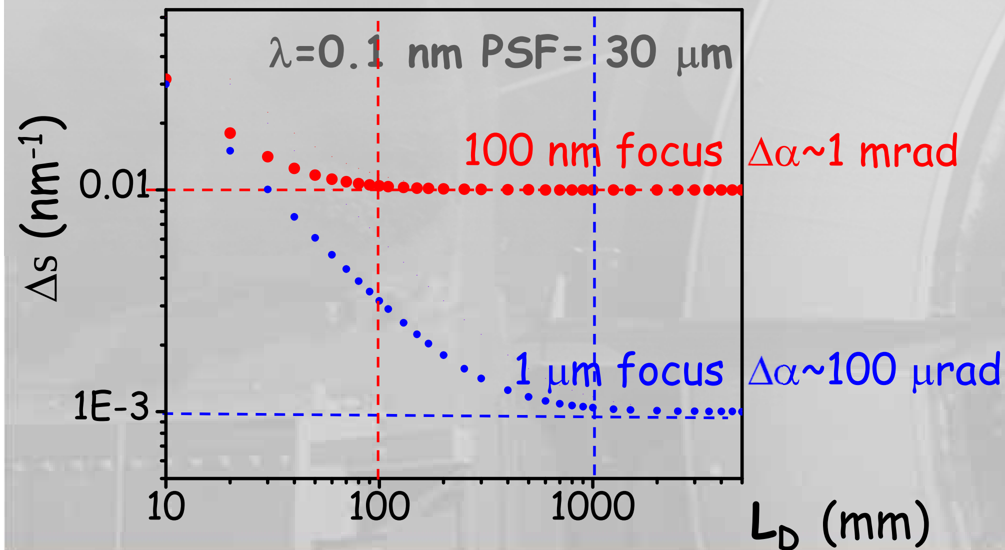
INDIVIDUAL PROPERTIES

- single objects: cells, fibrils…
- local heterogeneity

ERL microSAXS/WAXS pinhole camera



Order resolution - Δs

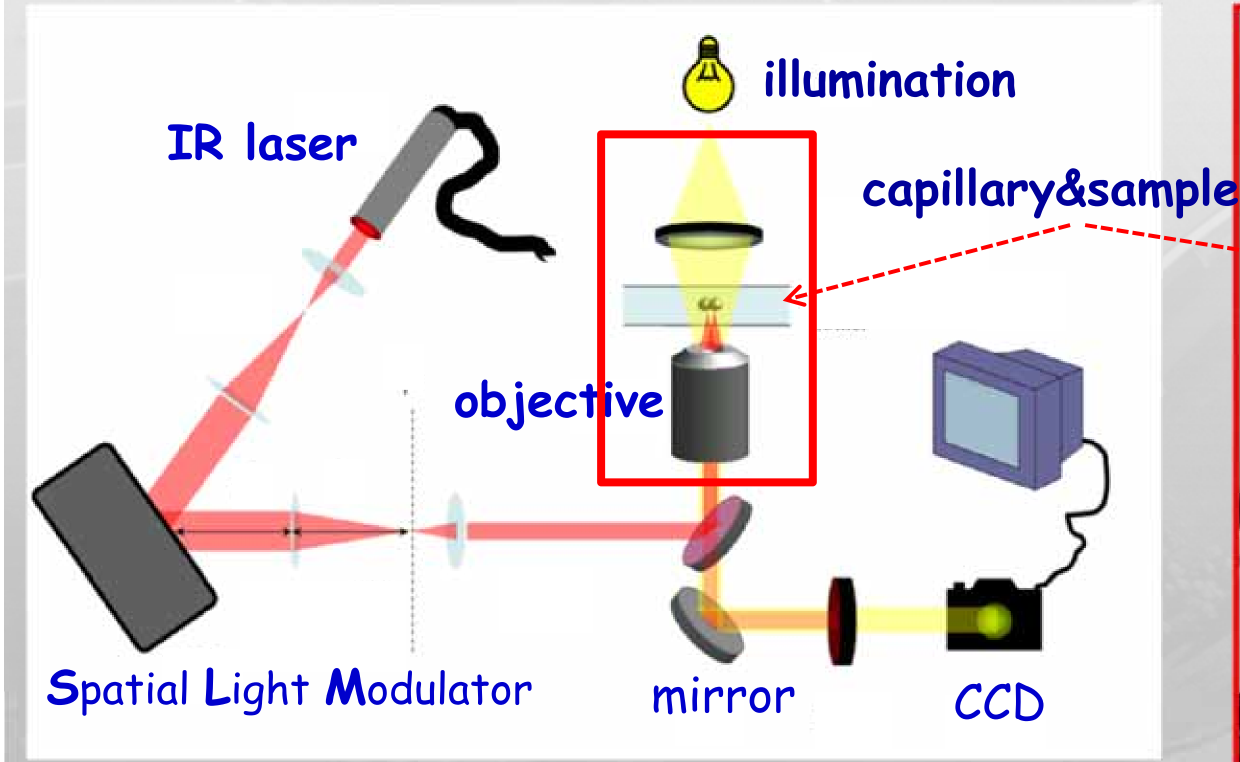


source&optics detector

$$\Delta s = \sqrt{(\Delta\alpha/\lambda)^2 + (\Delta\alpha_d/\lambda)^2}$$

$$\Delta\alpha_d = \sqrt{(b^2 + PSF^2)/L_D^2}$$

Optical tweezers: 10^{-10} - 10^{-13} N forces



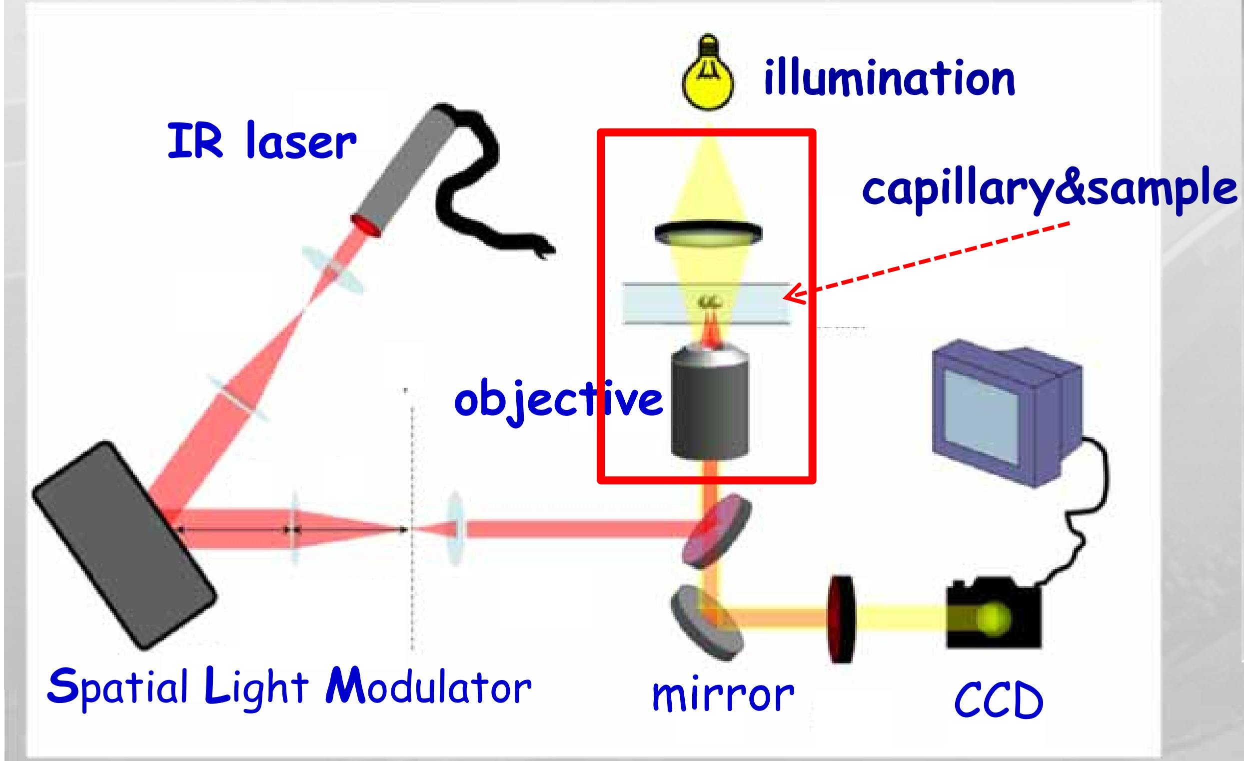
ESRF optical tweezers setup

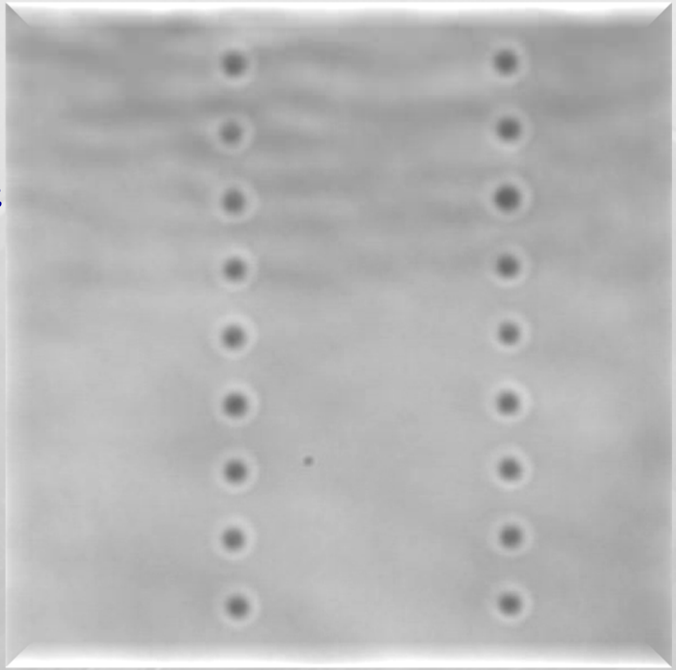
Ashkin, *PRL* (1970) **24**, 156

Ashkin et al., *Opt. Lett.* (1986) **11**, 288

Santucci et al.,
Anal. Chem. (2011) **83**, 4863

Optical tweezers: 10^{-10} - 10^{-13} N forces

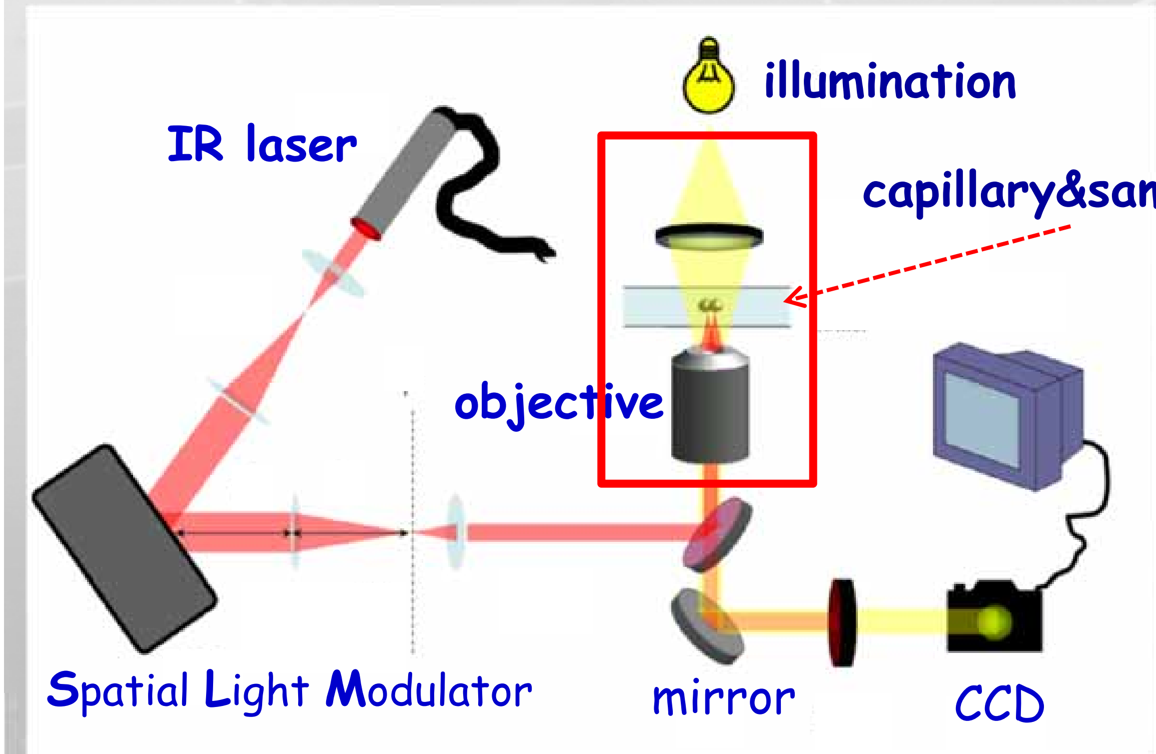


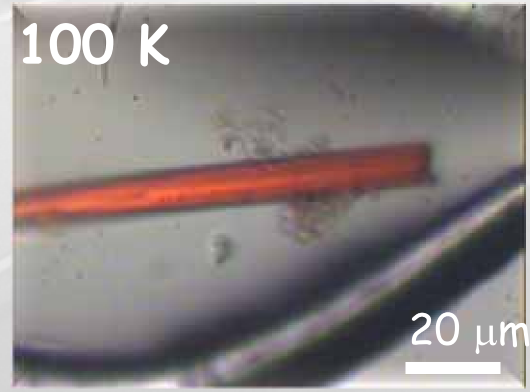


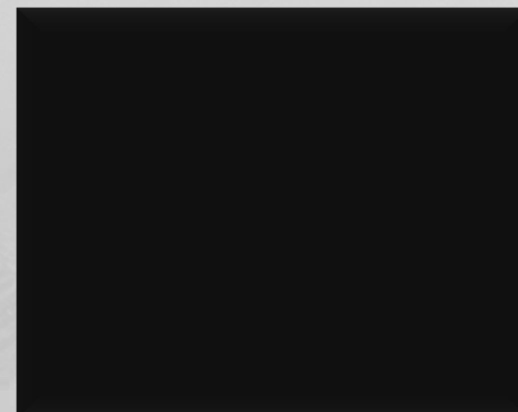
SiO_2 microbeads
Padgett group
Univ. St. Andrews UK

Ashkin, *PRL* (1970) **24**, 156
Ashkin et al., *Opt. Lett.* (1986) **11**, 288

Optical tweezers: 10^{-10} – 10^{-13} N forces







Room temperature μPX radiation damage evolution?

Santucci et al., *Anal. Chem.* (2011) **83**, 4863

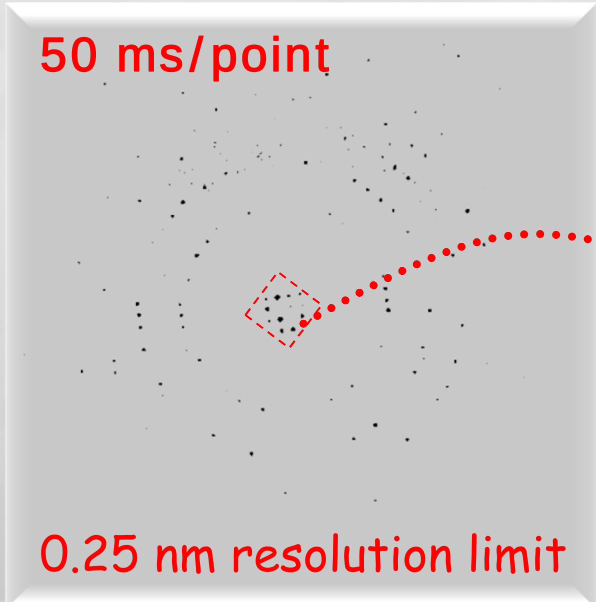
Ashkin, *PRL* (1970) **24**, 156

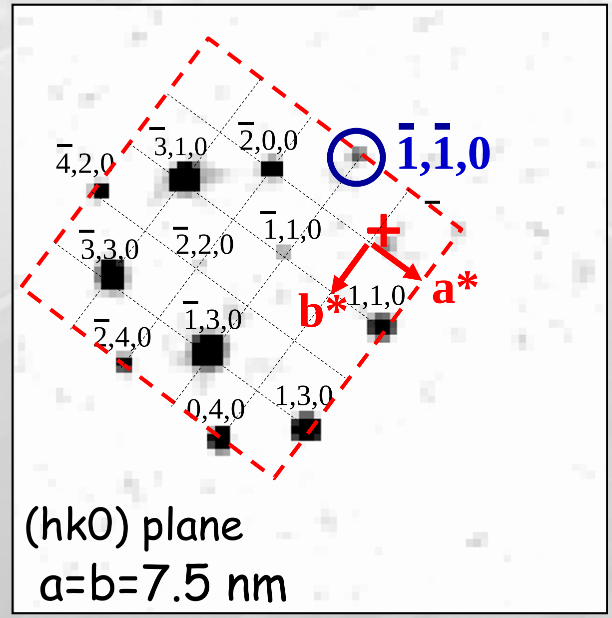
Ashkin et al., *Opt. Lett.* (1986) **11**, 288

Optically trapped insulin crystal

Insulin crystal trapped in capillary

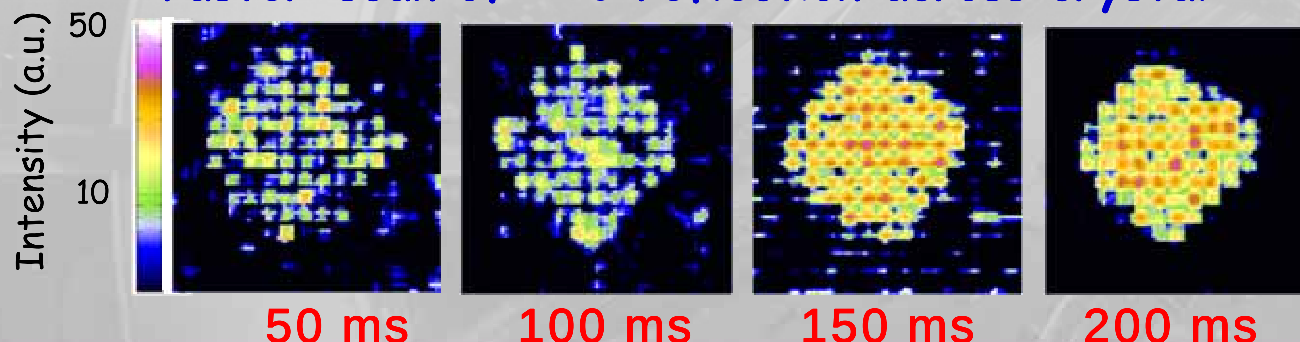
averaged raster-scan





Santucci et al.,
Anal. Chem. (2011) **83**, 4863

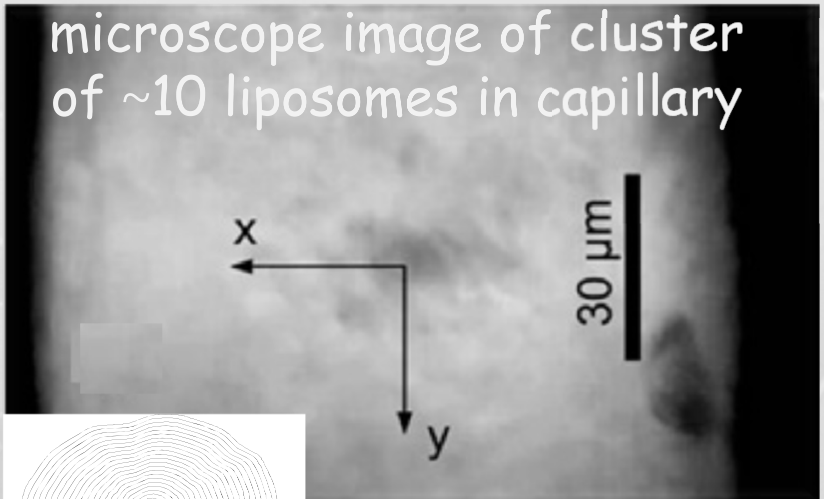
raster-scan of $\bar{1}\bar{1}0$ reflection across crystal

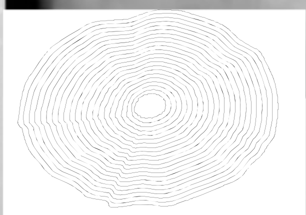


Optical tweezers challenges

- Protein microcrystals and serial crystallography
- Radiation damage studies
- Small soft and biological objects
- *Aggregation, fusion, reaction…*

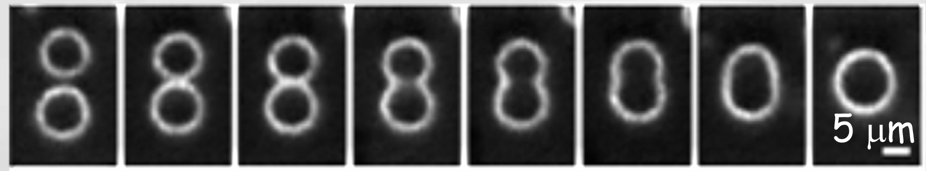
Optically trapped liposomes





~1 µm

multiwalled liposome, phospholipid membranes



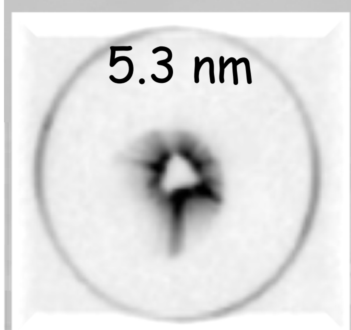
0 (sec) 3.6 4.2 4.8 5.4 6.6 7.8 10.8

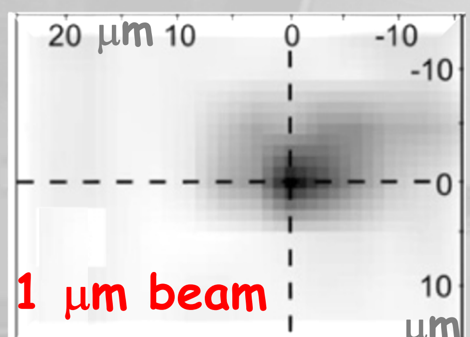
peptide induced liposome fusion

Nomura et al., *PNAS* (2004) **101**, 3420

MD simulation (Stevens, Sandia Lab)

raster-diffraction image

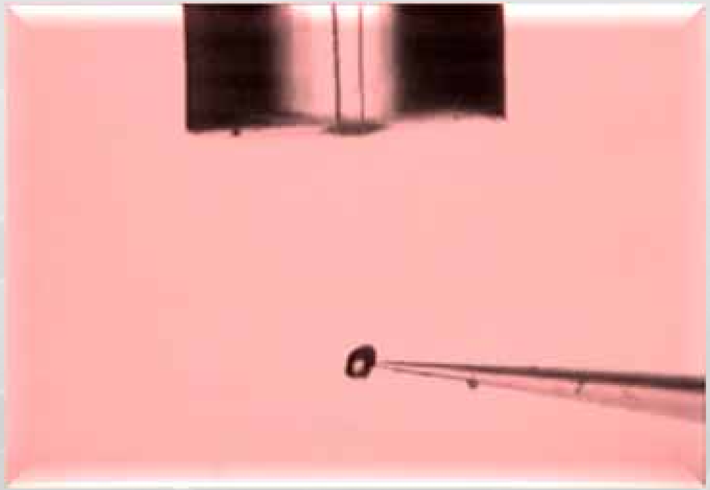


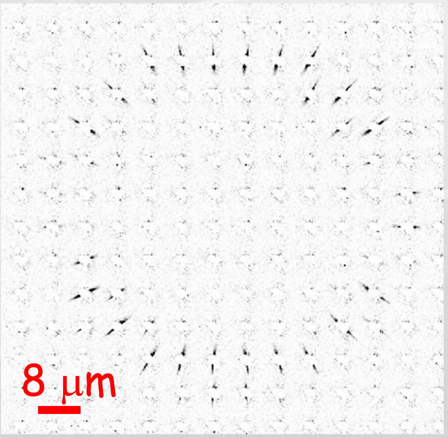


Challenge: probing of single liposome

Cojoc et al., *APL* (2007) **91**, 223107

Inkjet systems generate wall-free reaction volumes



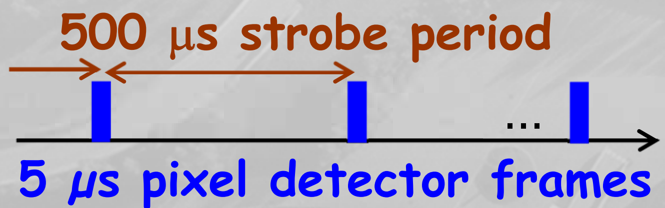


stroscopic SAXS

1 μm beam-8 μm raster

ballistic (~2m/s) water microdrops
drop-on-demand inkjet system
268 picoliters - 80 μm ϕ
stroscopic display

triggering sequence



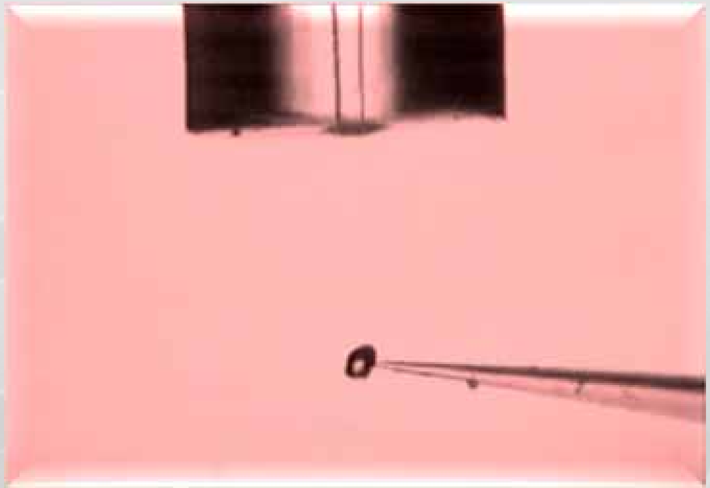
MEDIPIX: 256x256 pixels

Graceffa et al., *APL* (2009) **94**, 62902

Rita Graceffa, *PhD thesis*, Grenoble (2010)

10 s ≡ 2*10^4 microdrops/point

Inkjet systems & BioSAXS



ballistic (~2m/s) water microdrops
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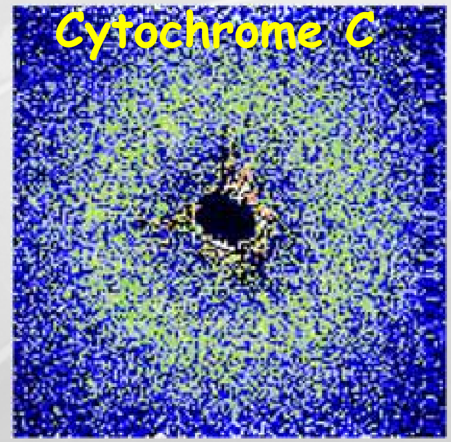
Graceffa et al., *APL* (2009) **94**, 62902

Rita Graceffa, *PhD thesis*, Grenoble (2010)



stroscopic BioSAXS

1 μm beam-center drop

triggering sequence

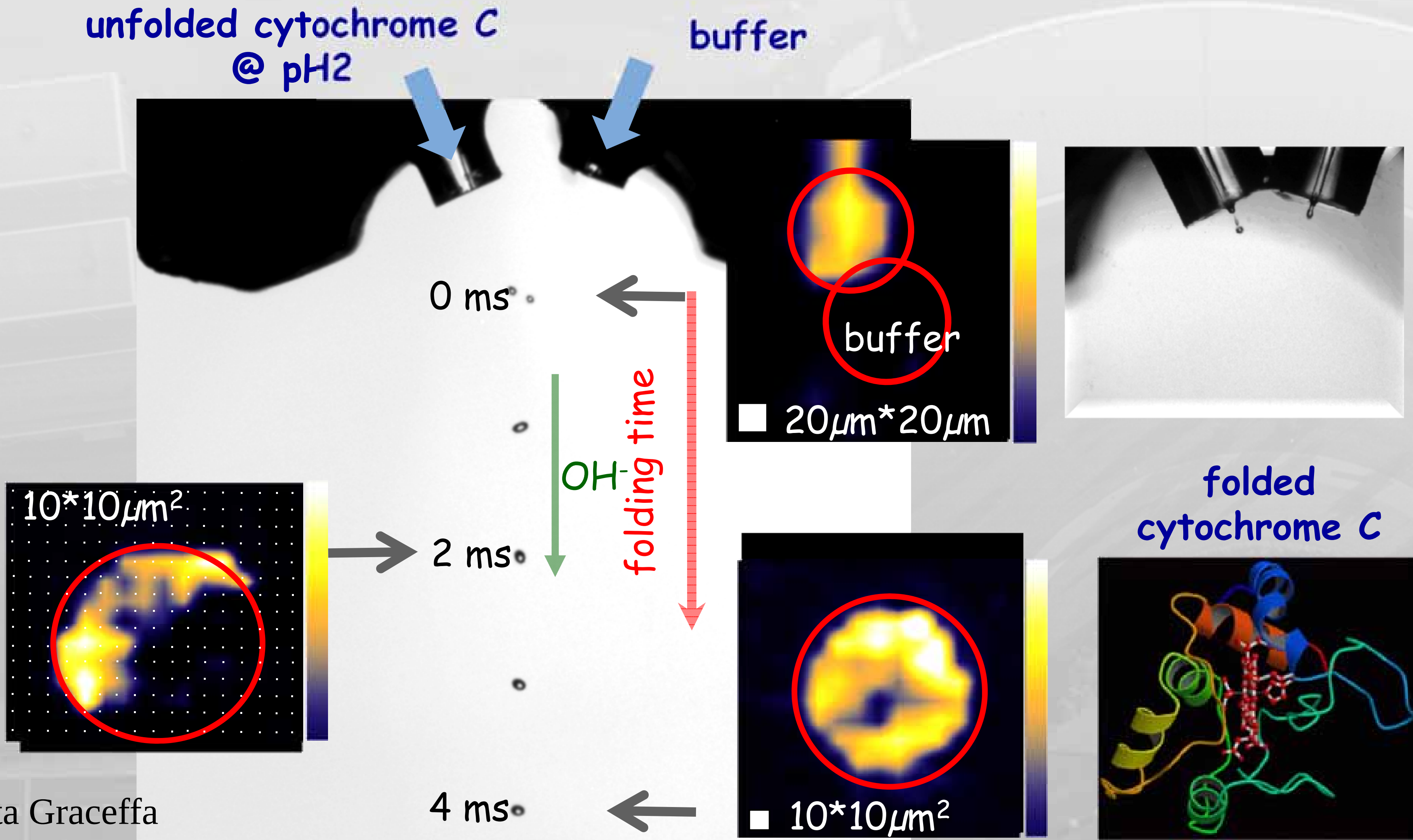
500 μs strobe period

5 μs pixel detector frames

MEDIPIX: 256x256 pixels

10 s ≡ 2×10^4 microdrops/point

Inkjet systems & BioSAXS

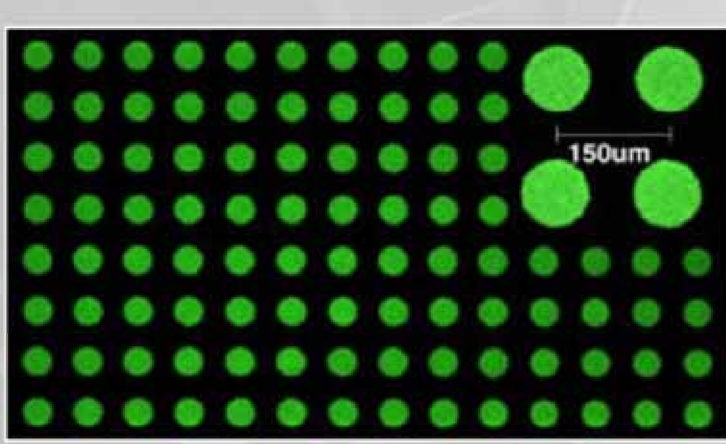


Rita Graceffa
PhD thesis, Grenoble (2010)

Inkjet challenges

Microdrops

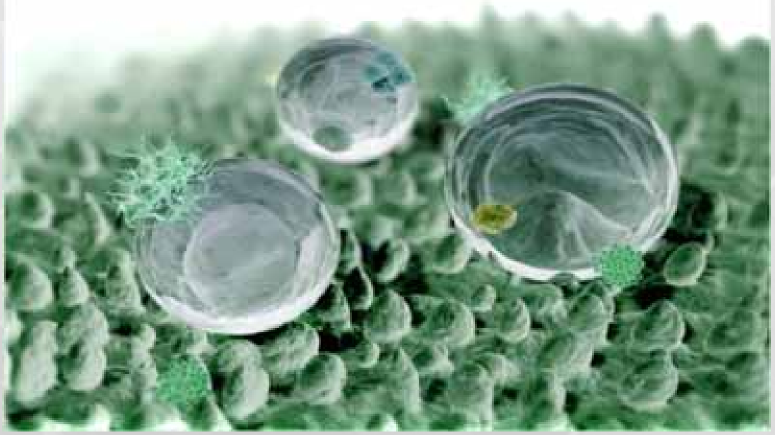
- **In flight** Fewer and smaller microdrops in stroboscopic sequence
  Single microdrop scattering at ERL?
  BioSAXS with <1 nl overall solution consumption
  Microdrop coalescence: subms mixing time, no shearing
- **Deposition** Protein chips, microdrop spreading, 2D films, nanocrystals…

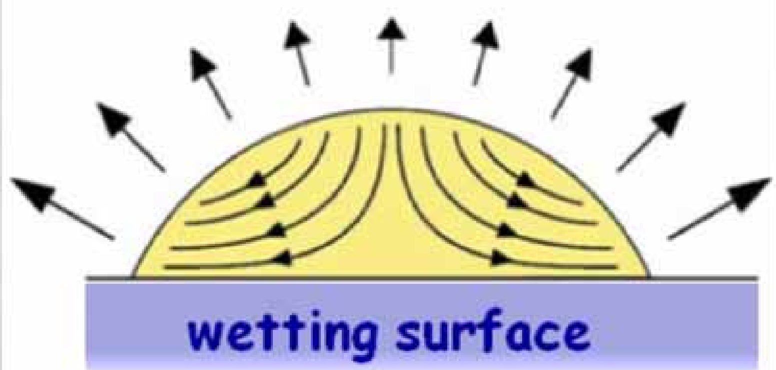


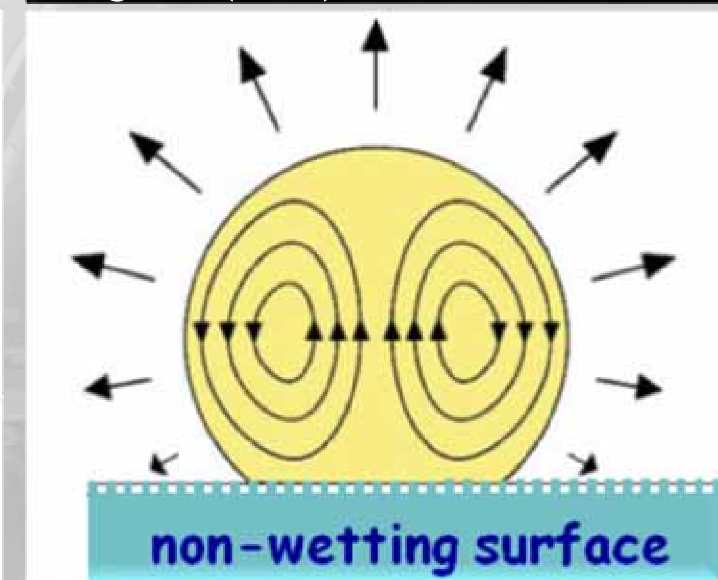
protein microarray by inkjet technology
Laurell lab - Lund University

Quasi contact-free superhydrophobic surfaces

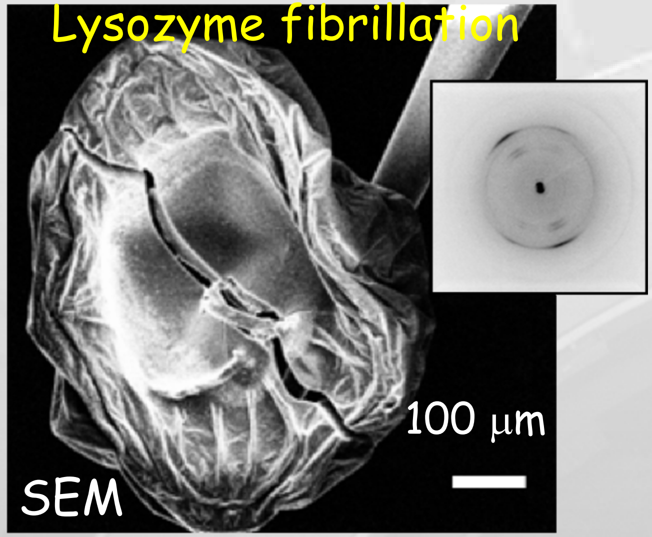
non-wetting plant leave



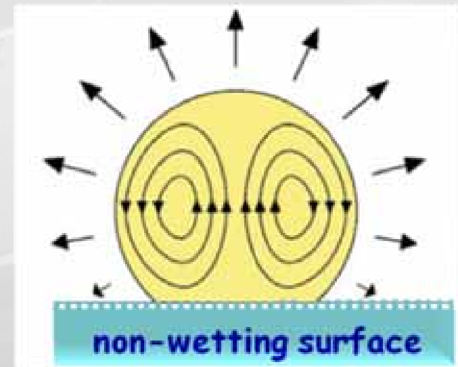


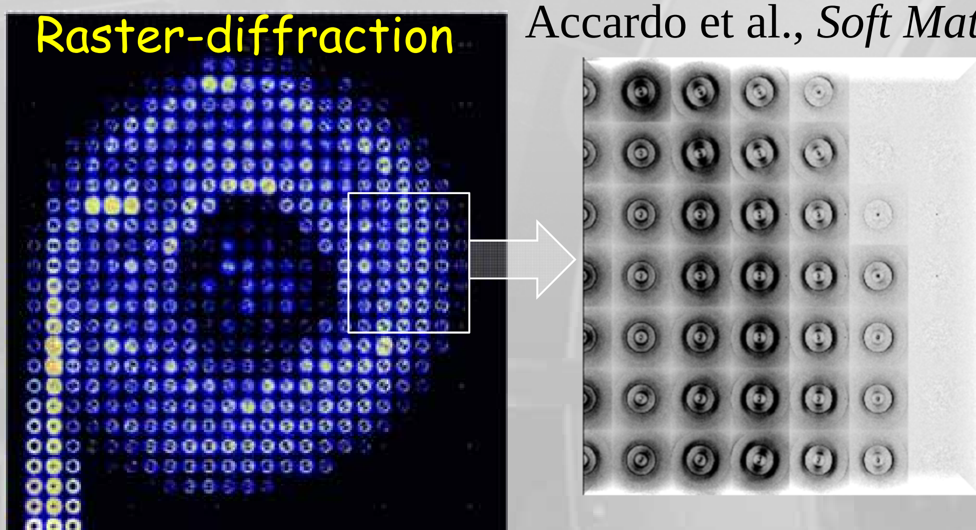


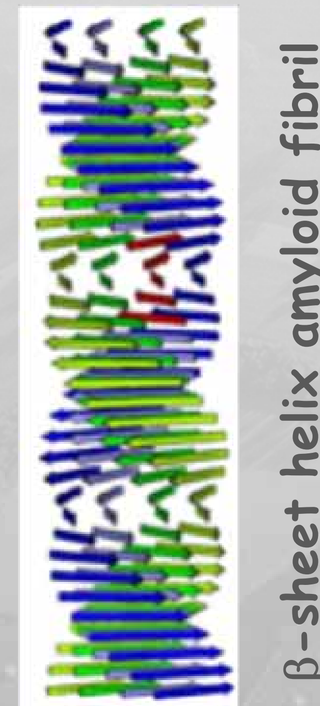
Peptide and protein precipitation



Accardo et al., *Soft Matter*, ASAP, 13.6.2011





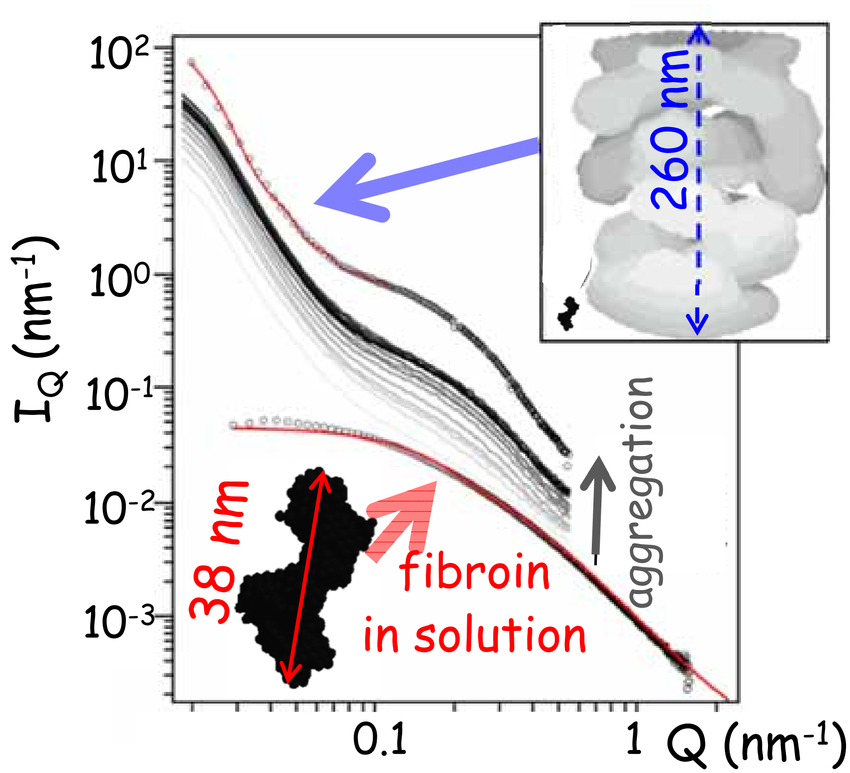


Hauser et al., *PNAS* (2011) **108**, 1361

Blake et al., *Structure* (1996) **4**, 989

β-sheet aggregation

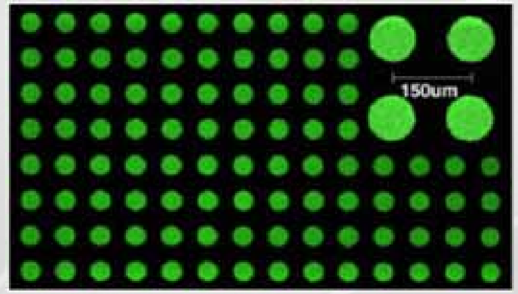
BioSAXS: silk fibroin aggregation

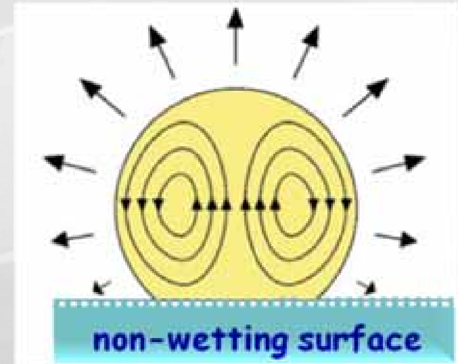


Microfluidic cell

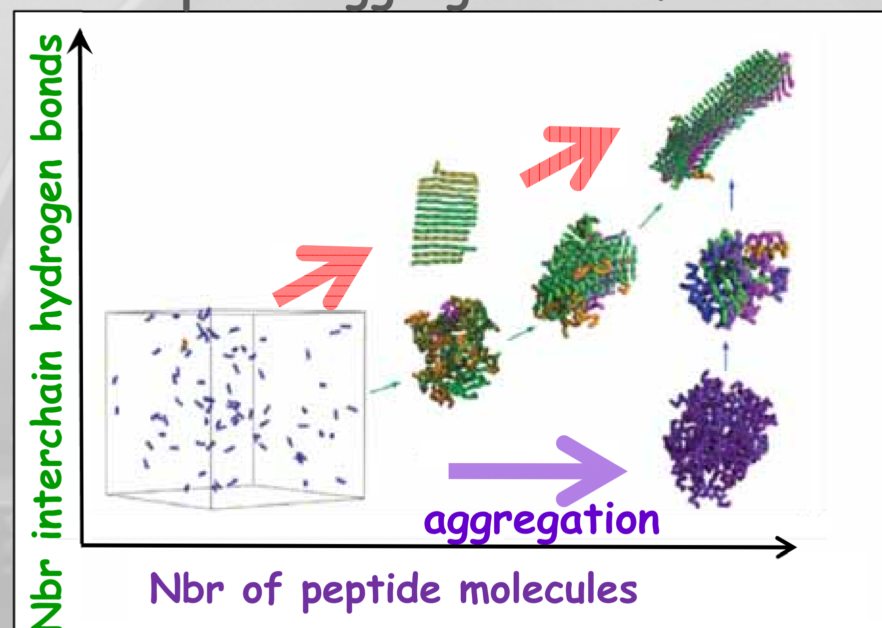
ml-scale liquid consumption

Martel et al., *JACS* (2008), **130**, 17070





Peptide aggregation simulation

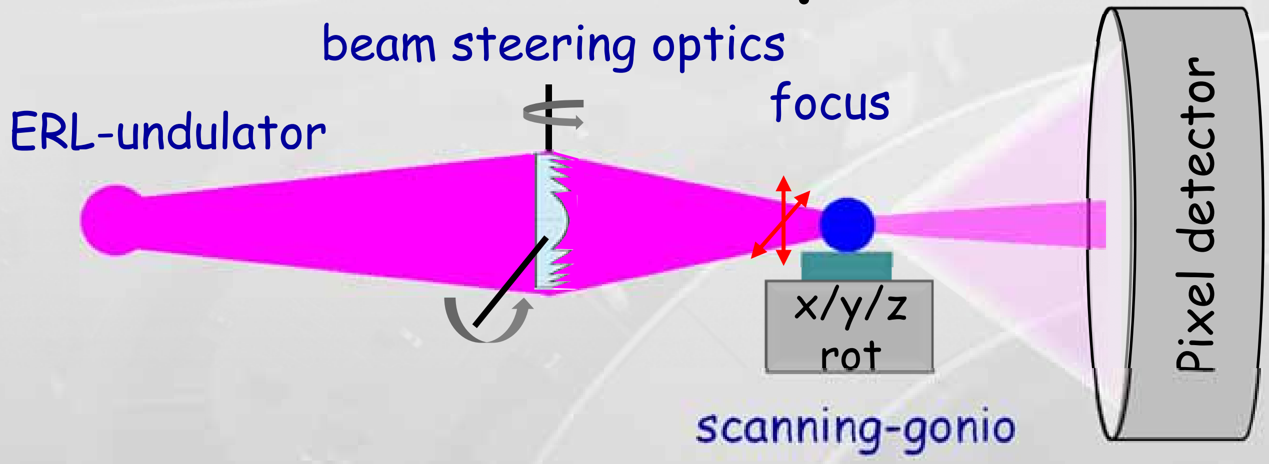


Auer et al., *HFSP Journal* (2007) **1**, 137

Superhydrophobic surfaces challenges

- **BioSAXS** — pL - nL drops, μm to subμm beams
- **Faster scans** — continuous scan with subms patterns, kinetics
- **Coherent imaging** — complementary approach, in situ processes…
- **Stability** — avoid sample movements during fast scans

Generic ERL micro/nanoprobe camera



Undulator source	5-25 keV range
Focusing optics	~50 nm to ~5 µm focus; automated switching
Fresnel lens	beam steering option for fast raster-scans
Coherent beam	optimize BL for coherent imaging
Raster goniometer	continuous scan capability
Pixel detector	≤50 µm pixels; <10 µs readout/frame; ≥2Kx2K pixels
Other probes	optical microscopy, XRF, Raman…
Stability	temperature, noise-level, ventilation…

Thank you