Marianne Liebi– Material Science at Large Scale Facilities

# Small-angle scattering (SAXS/SANS)

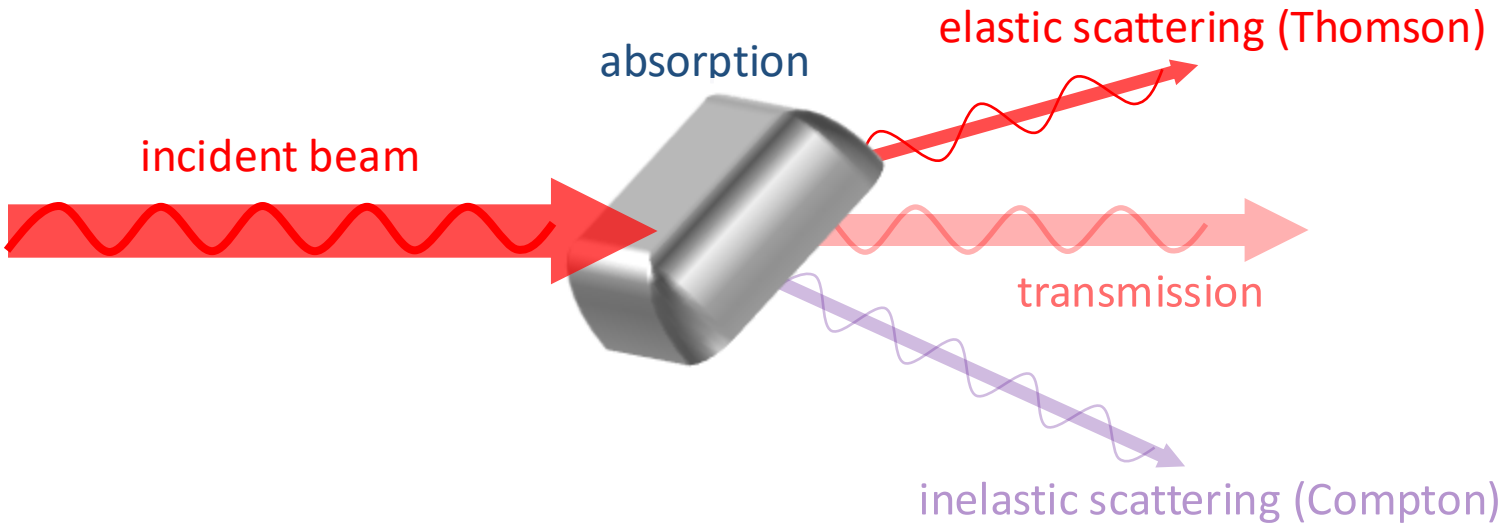
EPFL Master Course 2025 MSE435

# Course program

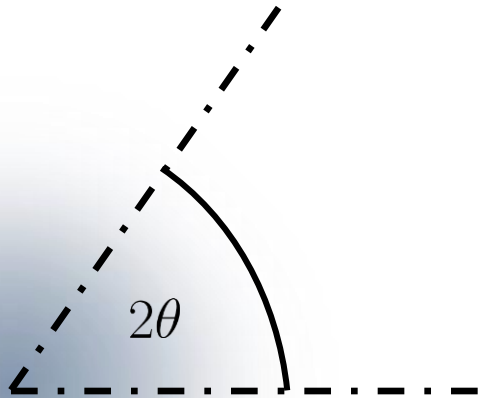
| Dates | Content | Lecturer |
|---|---|---|
| 08.09.25 | Introduction, sources, beamlines, detectors | Steven Van Petegem |
| 15.09.25 | Excursion to PSI | Marianne Liebi |
| 22.09.25 | Holiday | |
| 29.09.25 | Interaction with matter | Steven Van Petegem |
| 06.10.25 | Fluorescence | Marianne Liebi |
| 13.10.25 | X-ray absorption spectroscopy | Marianne Liebi |
| 20.10.25 | Break | |
| 27.10.25 | Diffraction I | Steven Van Petegem |
| 03.11.25 | Small angle scattering | Marianne Liebi |
| 10.11.25 | Diffraction II | Steven Van Petegem |
| 17.11.25 | Phase contrast / Tomography | Steven Van Petegem |
| 24.11.25 | Coherent imaging | Marianne Liebi |
| 01.12.25 | Neutron imaging | Steven Van Petegem |
| 08.12.25 | PEEM / Magnetic scattering | Steven Van Petegem |
| 15.12.25 | Case study presentations | Steven Van Petegem / Marianne Liebi |

# Interaction of X-rays with matter

interaction with electrons



# Elastic scattering of photons

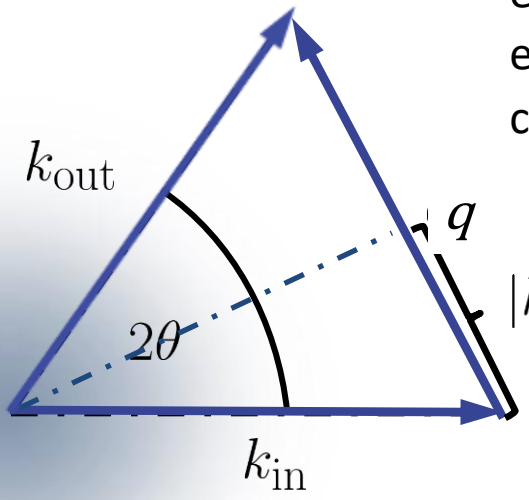



elastic scattering: no loss in photon energy but direction or of the photon can change: scattering angle 2θ



Philip Willmott: Synchrotron and X-ray Free Electron Laser

# Elastic scattering of photons




elastic scattering: no loss in photon energy but direction or of the photon can change: scattering angle 2θ

$$q = 2|k| \sin\theta = (4\pi/\lambda) \sin\theta$$

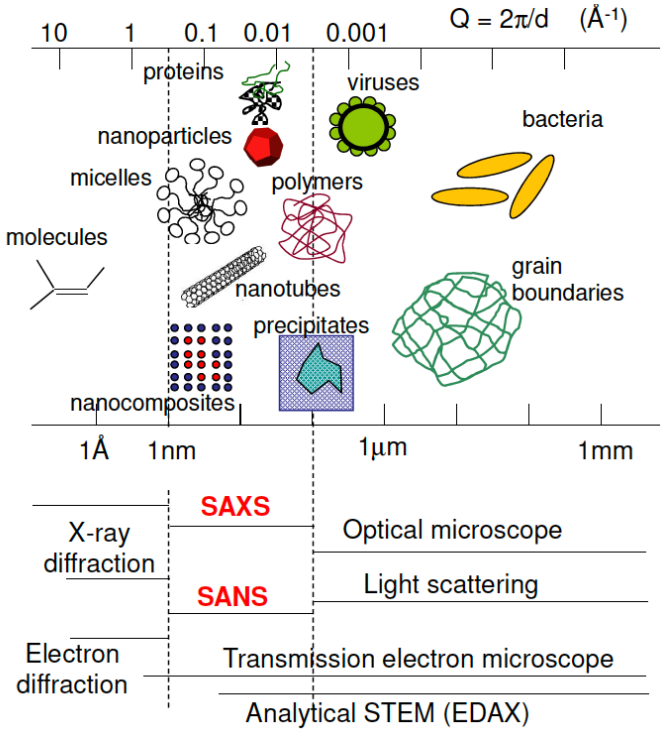
wave vektor $k = 2\pi/\lambda$

*scattering vector* $\boldsymbol{q} = \boldsymbol{k}_{in} - \boldsymbol{k}_{out}$

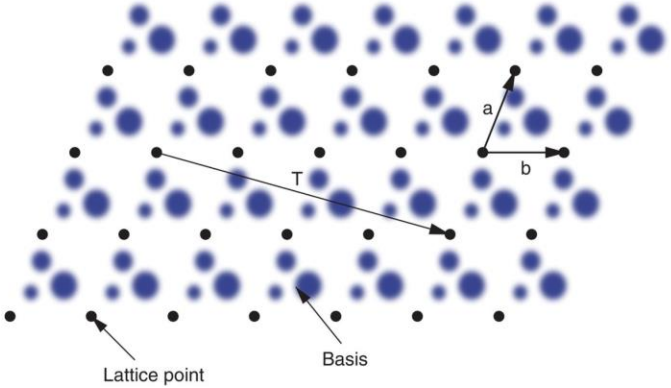


Philip Willmott: Synchrotron and X-ray Free Electron Laser

# Size range comparison

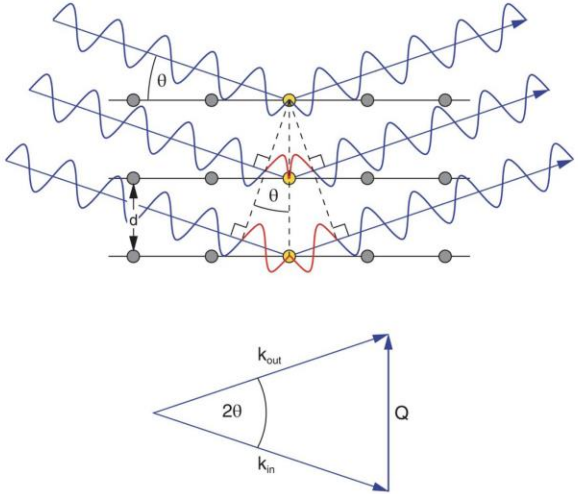


# Diffraction on crystals and Bragg's law




If one derives it from an analogy with the slits, the distance between the atoms is the grating distance and the size of the atoms is the width of the slit.

## Bragg's law



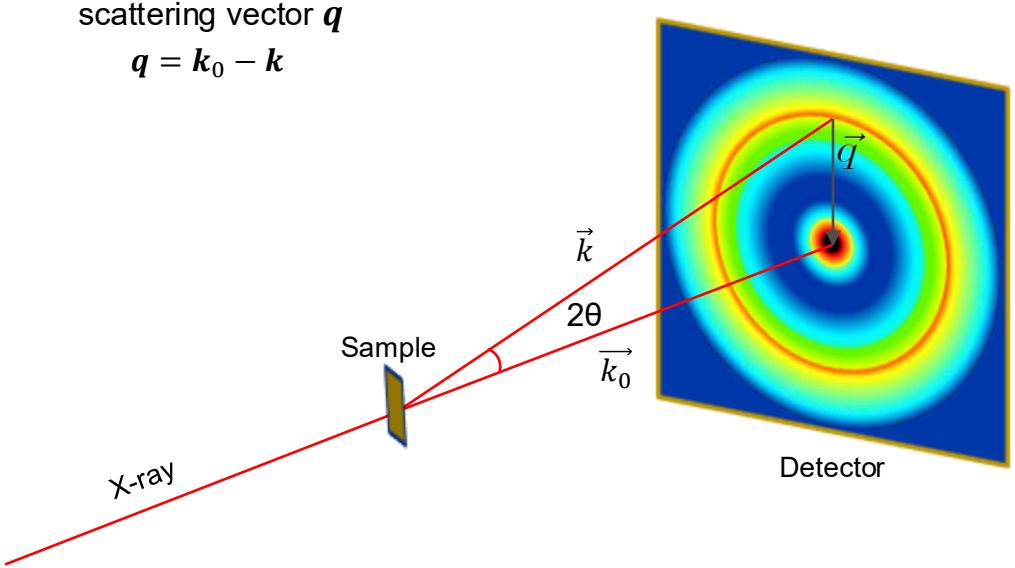

Willmott, P., John Wiley & Sons, Ltd: 2019 (2nd Edition).

$$m\lambda = 2d\sin\theta.$$

# Scattering/Diffraction

scattering vector $\boldsymbol{q}$

$$\boldsymbol{q} = \boldsymbol{k}_0 - \boldsymbol{k}$$




$$|\vec{q}| = q = \frac{4\pi\sin(\theta)}{\lambda}$$

light λ = 400 to 600 nm

X-ray tube λ = 1 to 2 Å

Cu Kα = 1.5406 Å

synchrotron λ = 0.1 to 5 Å

thermal neutrons λ = 1 to 10 Å

electrons λ = 0.025 Å

X-ray energy mostly given in keV

Electronvolt = eV

Energy of an electron after being accelerated from rest in a potential of 1 V

1 eV = 1.6022 x $10^{-19}$ J

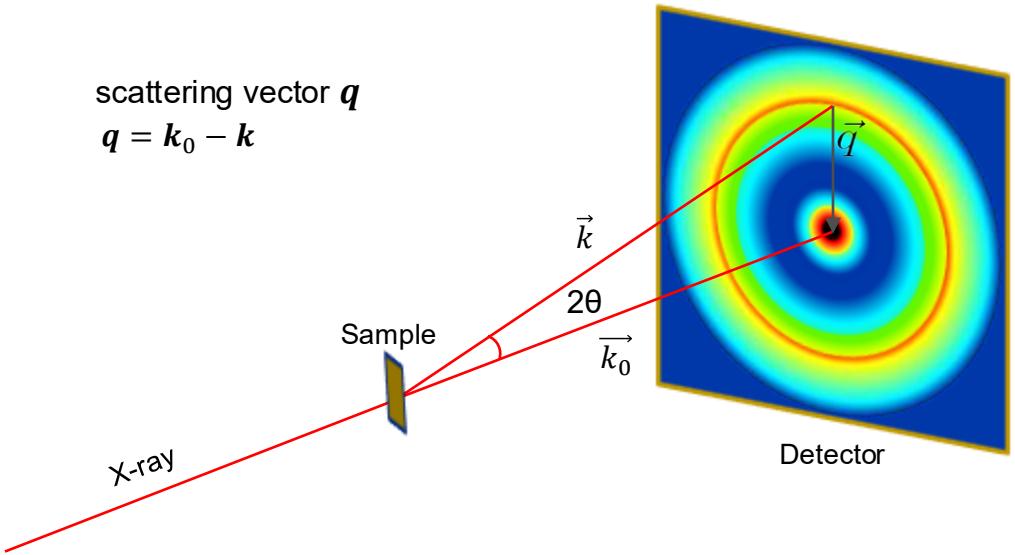
$E = hc / \lambda$

*h* is Planck's constant (6.6261 x $10^{-34}$ Js)

*c* is the speed of light (2.9979 x $10^{8}$ m/s).

λ [Å] = 12.3984/E [keV]

# Scattering/Diffraction




$$|\vec{q}| = q = \frac{4\pi\sin(\theta)}{\lambda}$$

Bragg's law

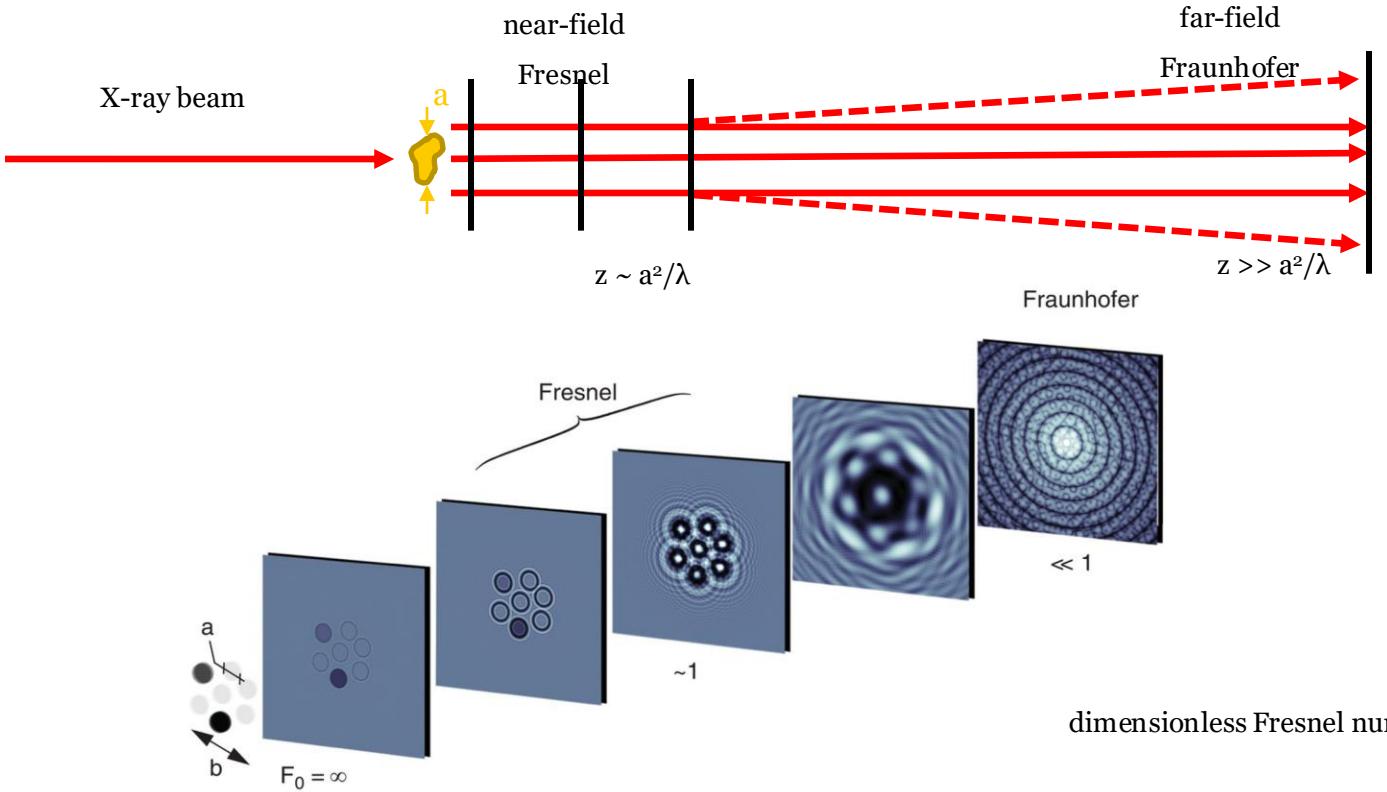
$$d = \frac{2\pi}{q}$$

SAXS: scattering from variation in electron density distribution, NOT from single atoms as in XRD

larger structures → smaller angles
XRD/WAXS: 10 cm detector distance

SAXS: several m detector distance

# Far-field Fraunhofer Regim




dimensionless Fresnel number $F_o=a^2/z\lambda$

Willmott, P., John Wiley & Sons, Ltd: 2019 (2nd Edition).

# Demonstration: Fourier-Transform

Initial Python coding and refactoring:

Brian R. Pauw

http://www.lookingatnothing.com

With input from:

Samuel Tardif

Windows compatibility resolution:

David Mannicke

Chris Garvey

Windows compiled version:

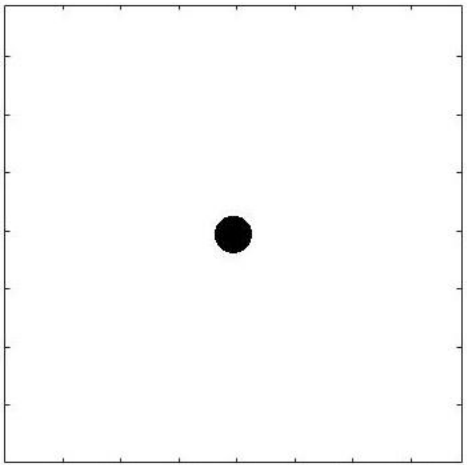
Joachim Kohlbrecher

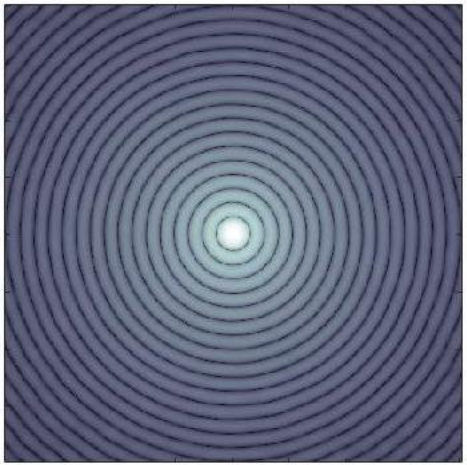
Sample images:

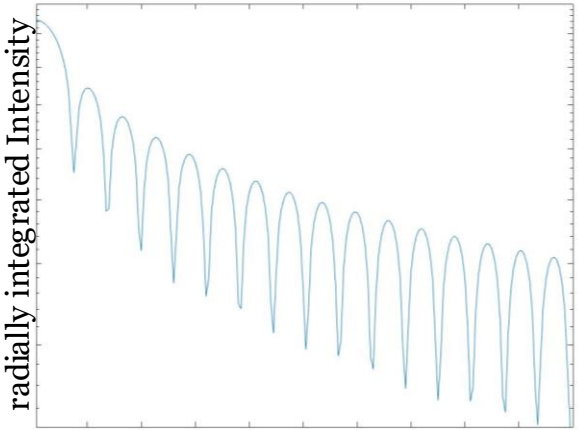
simulation

https://phet.colorado.edu/sims/html/wave-interference/latest/wave-interference_en.html

# small-angle scattering





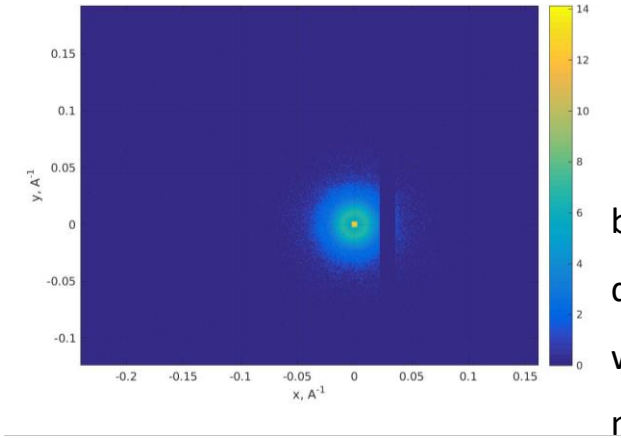



Fourier transform

radial integration

$$|\vec{q}| = q = \frac{4\pi\sin(\theta)}{\lambda}$$

# small-angle scattering: first analysis step




raw data: 2D scattering pattern

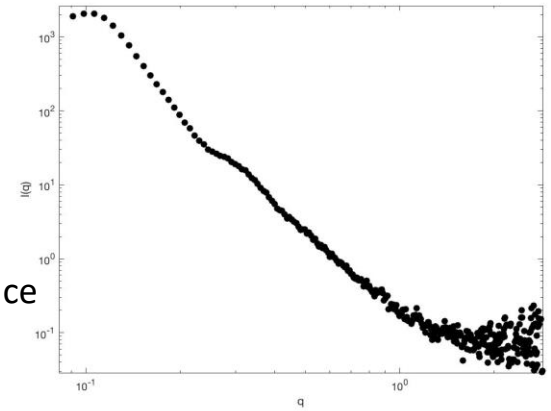
(example measured on a Labsource)

beam center

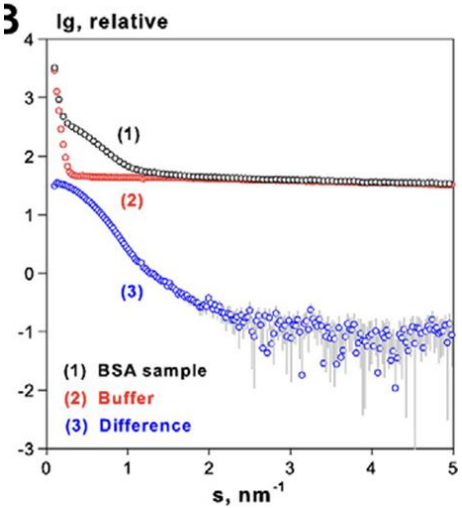
detector distance

wavelength λ

mask




average scattering profile I(q)

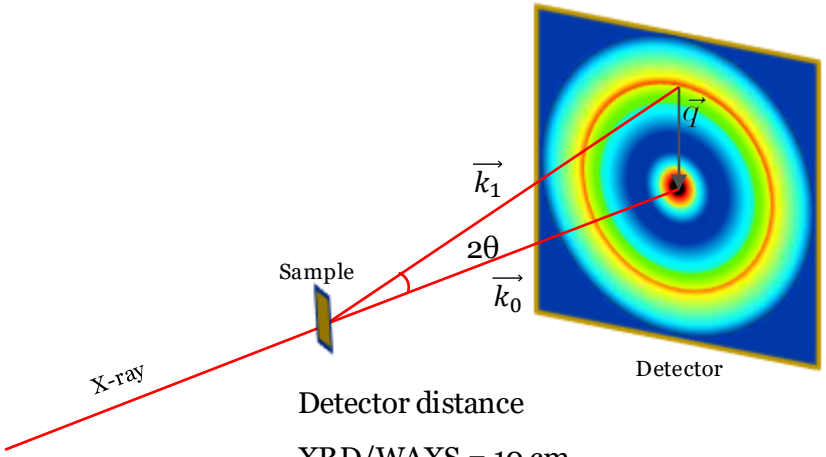



background substraction

particles in solution: measure only solvent

solid sample on support: measure only support material

# SAXS/WAXS at a labsource




scattering vector $q$

$$\boldsymbol{q} = \boldsymbol{k}_0 - \boldsymbol{k}$$

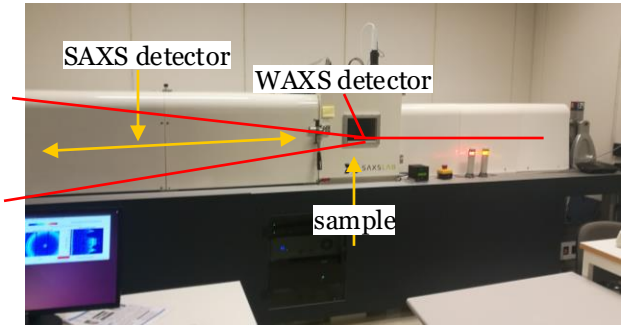
$$|\vec{q}| = q = \frac{4\pi\sin(\theta)}{\lambda}$$

Detector distance

XRD/WAXS = 10 cm

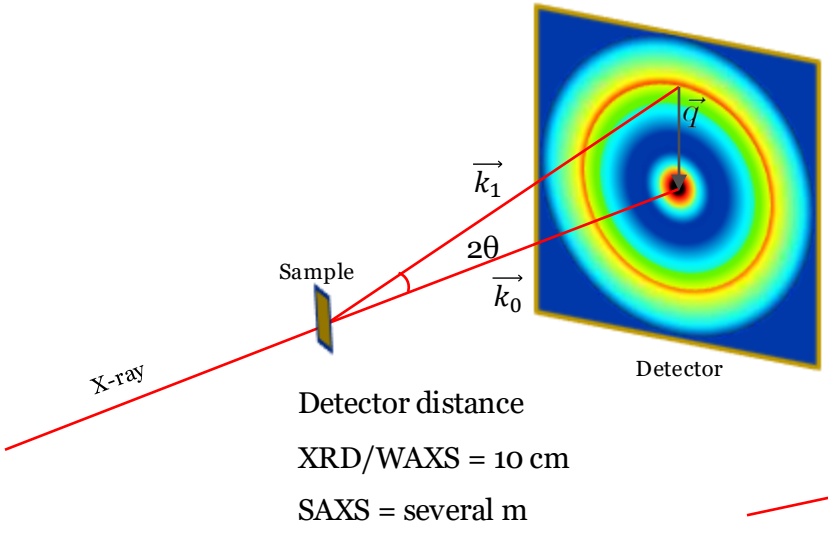
SAXS = several m

SAXSLAB instrument at CMAL, Chalmers




→ new Labsource SAXS available at EPFL!

# SAXS/WAXS
# at a synchrotron beamline




scattering vector $q$

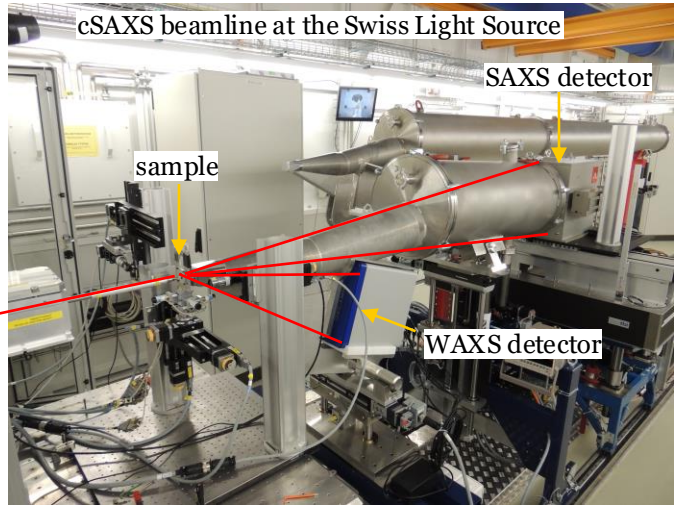
$$\vec{q} = \vec{k_0} - \vec{k_1}$$

$$|\vec{q}| = q = \frac{4\pi\sin(\theta)}{\lambda}$$

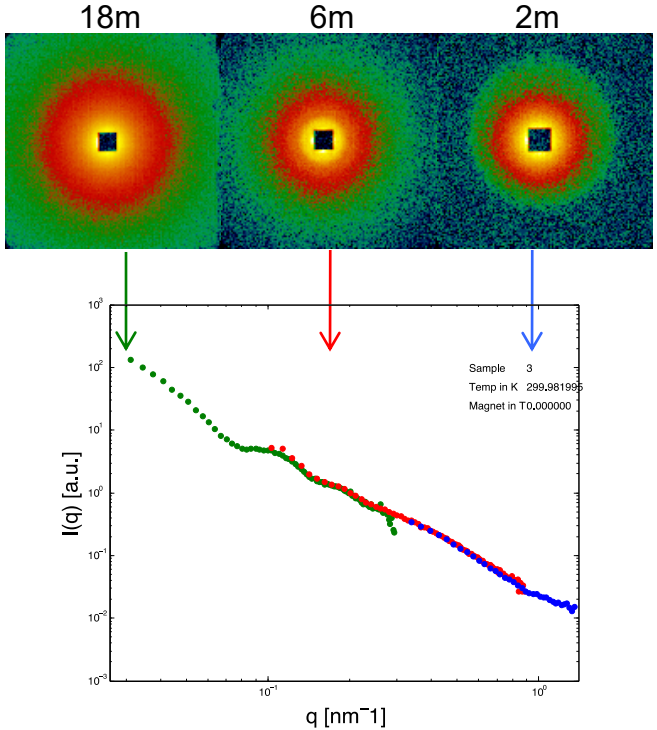
Detector distance

XRD/WAXS = 10 cm

SAXS = several m



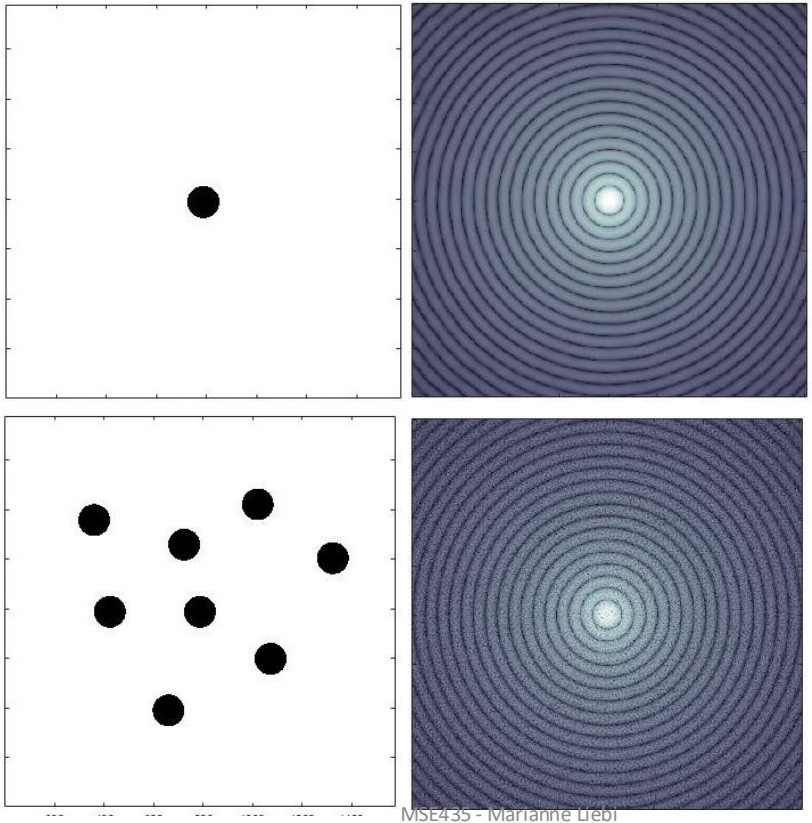
# SANS: radial integration




vesicles July 2010

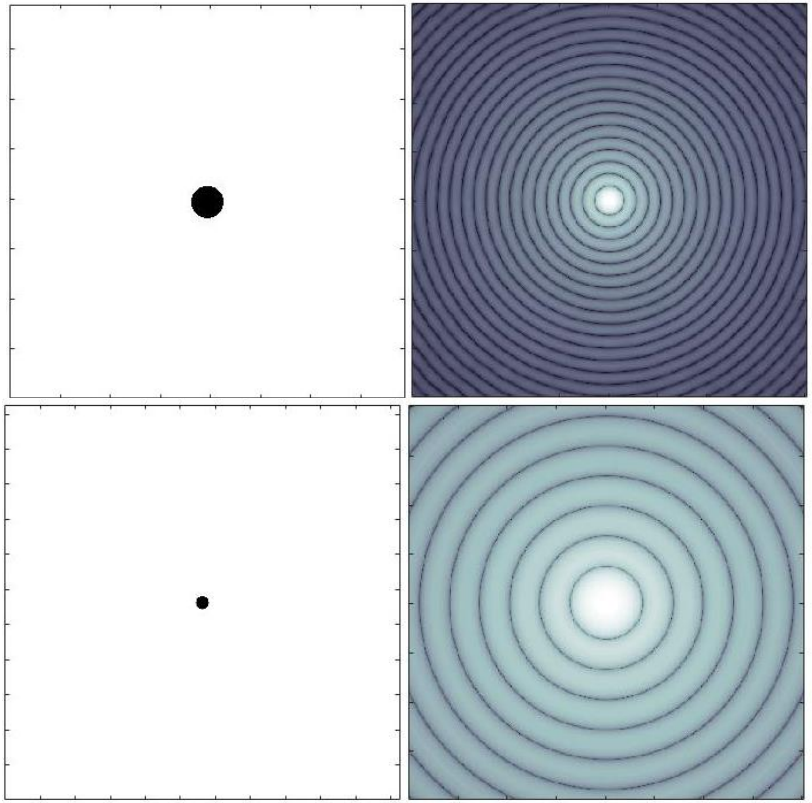
SANS instruments at SINQ

# small-angle X-ray scattering



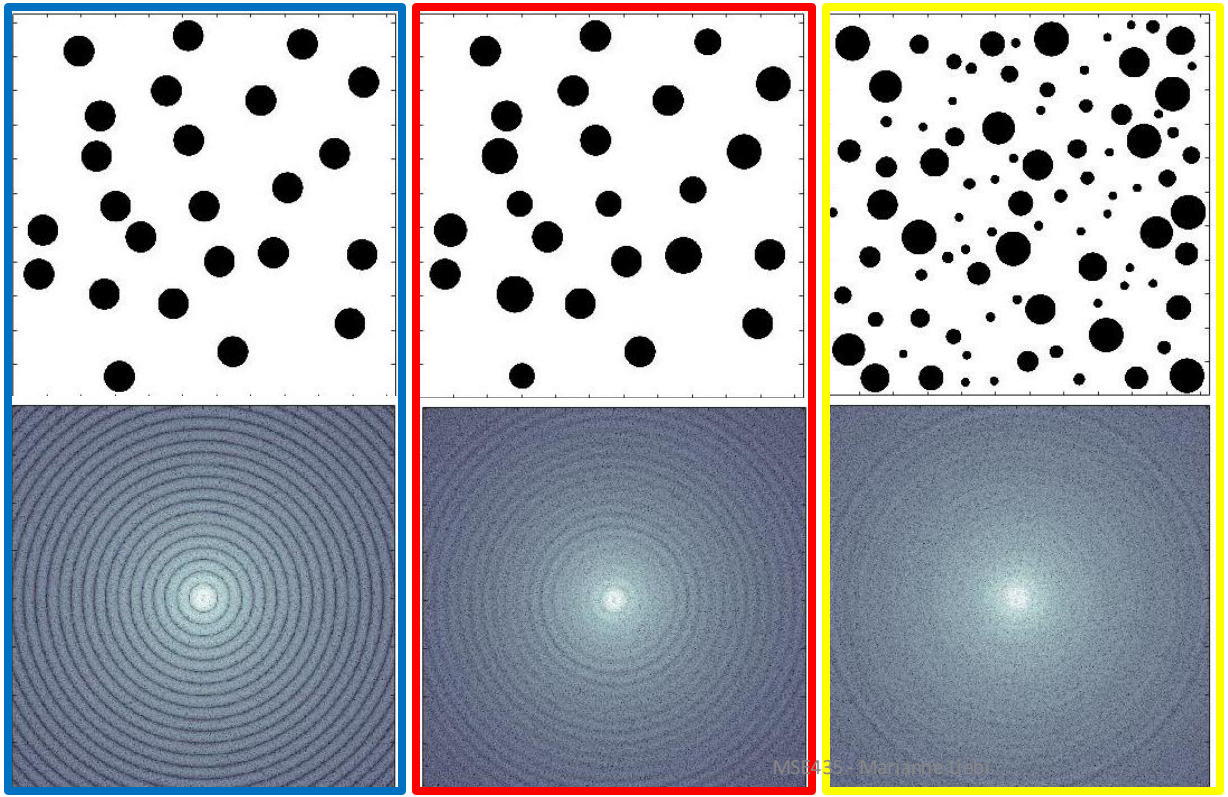
scattering pattern shows
average over particle ensemble

# small-angle X-ray scattering size

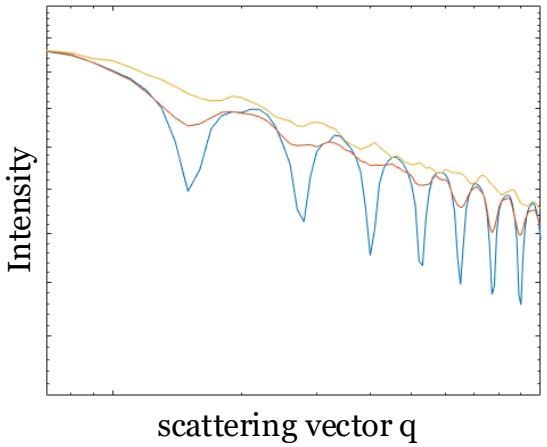


smaller structures scatter at larger angles

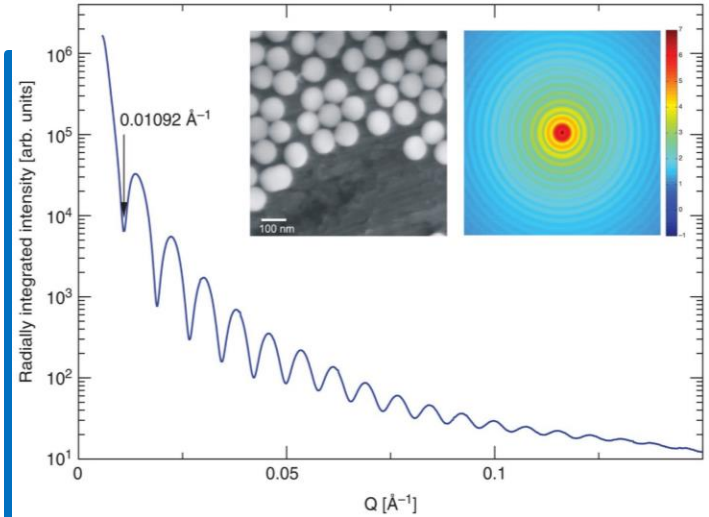
# small-angle X-ray scattering
# polydispersity



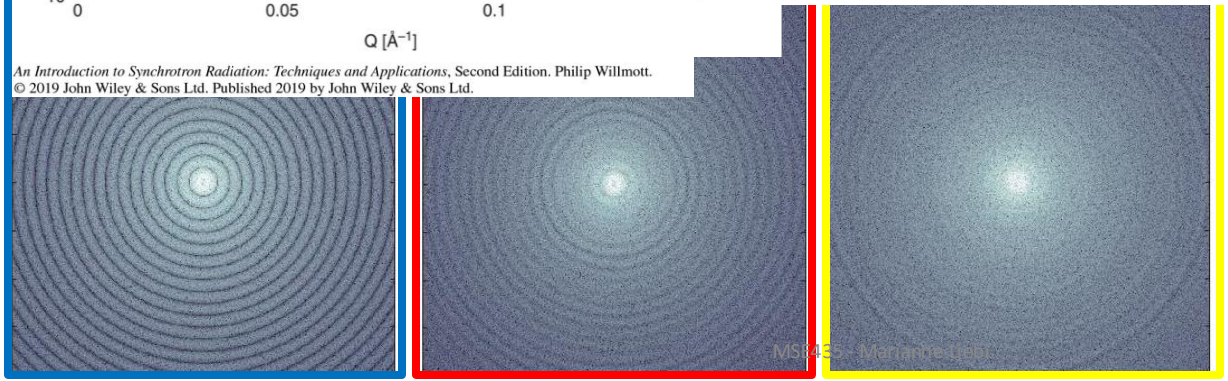
effect of polydispersity

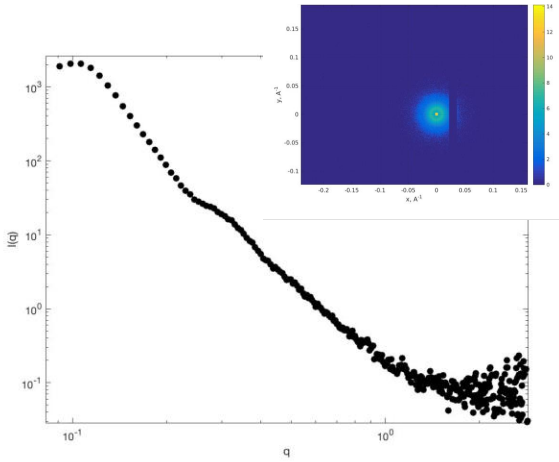


# small-angle X-ray scattering
# polydispersity

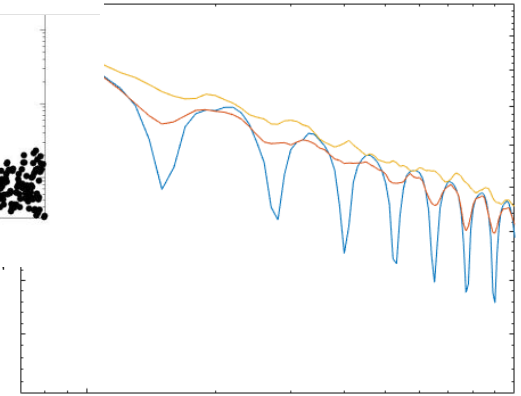



*An Introduction to Synchrotron Radiation: Techniques and Applications*, Second Edition. Philip Willmott.

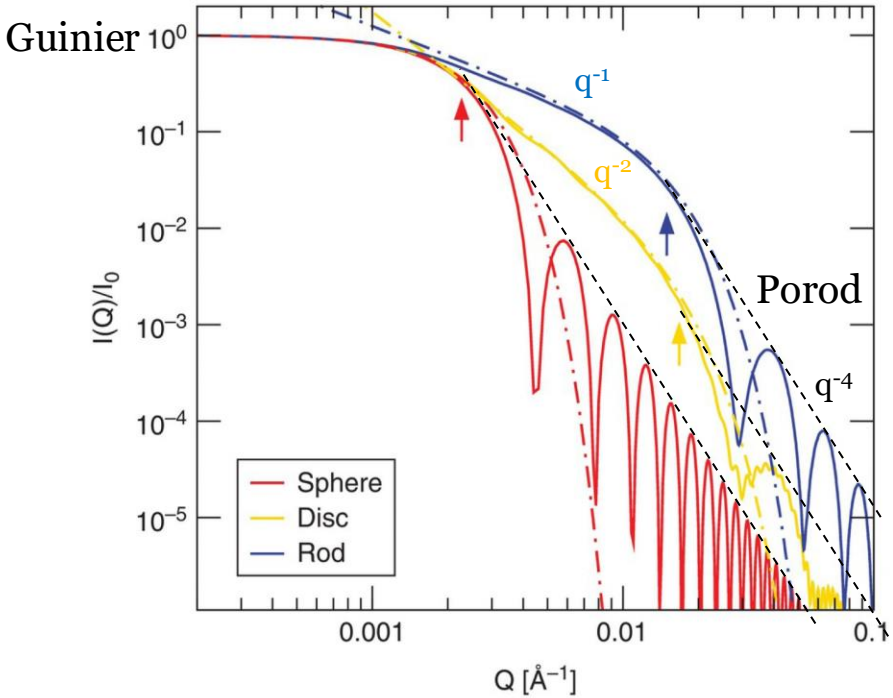



polydispersity



scattering vector q

# small-angle X-ray scattering
# size & shape




*An Introduction to Synchrotron Radiation: Techniques and Applications*, Second Edition. Philip Willmott.


sphere, disc and rod with the same characteristic length (radius of gyration) → same scattering at low $q$ (Guinier regime)

intermediate region depends on fractal dimension
$q^{-1}$: rod

$q^{-2}$: disk

at high $q$: Porod regime $q^{-4}$

# Small-angle scattering

- Fraunhofer approx. Fourier theorem:

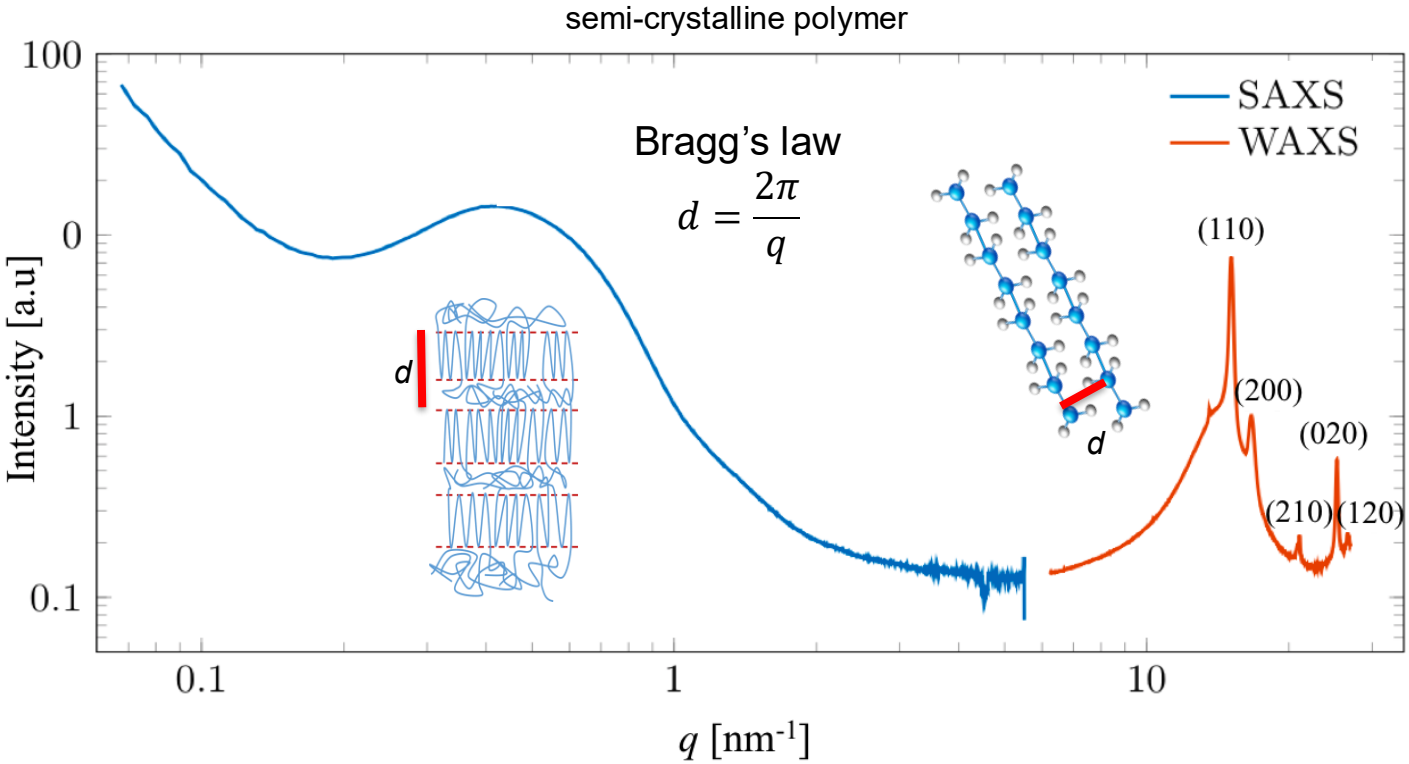
the field distribution at a distant detector is the Fourier transform of the electric field distribution in the exit plane of a sample

BUT we don't measure field but the intensity, which is the squared field: complex quantity: complex part (the phase) get lost → **the phase problem**

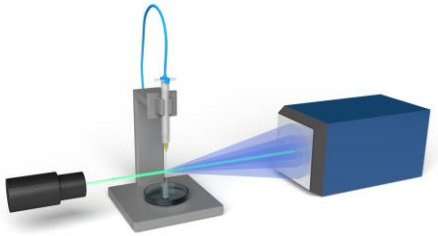
→we cannot directly calculate back the particles shape and size, different approaches to retrieve information from the scattering pattern

- **model independent**
- mathematically model the SAXS curve
- pair distance distribution function (PDDF)
- iterative phase retrival

# Small-angle scattering: any peaks?

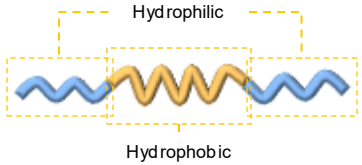


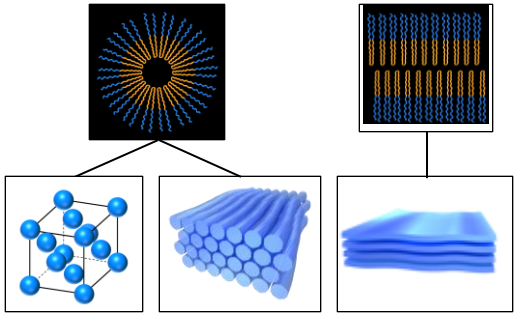
# Small-angle scattering: any peaks?

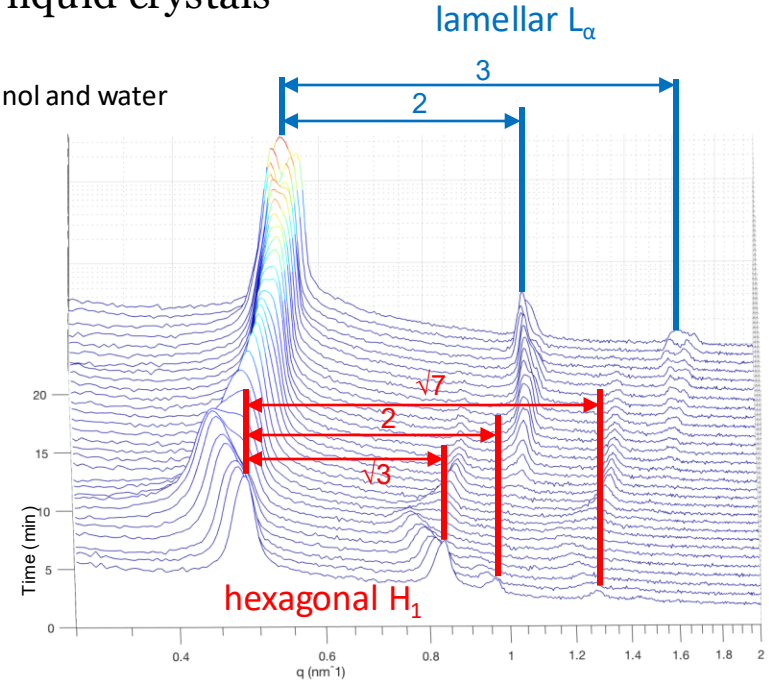


## 3D printing of lyotropic liquid crystals

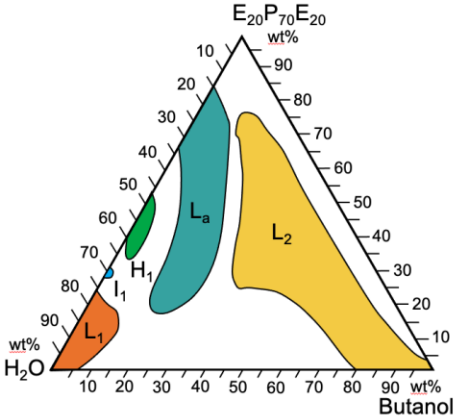
Pluronic F-127 ($EO_{100}PO_{70}EO_{100}$), 1-butanol and water






time-resolved measurements of phase changes after 3D printing




Rodriguez-Palomo A., Lutz-Bueno, V., Guizar Sicairos, M. , Kádár, R., Andersson, M., Liebi M. *Additive Manufacturing* **2021**, 47, 102289.

# Small-angle scattering

**low q**: information about interaction s between the particles and particle size, no information about shape of particle
**intermediate q**: in the order of the particle size, particle shape
**high q**: Porod's region contrast at the interface between the particle and their surrounding, measure of surface area

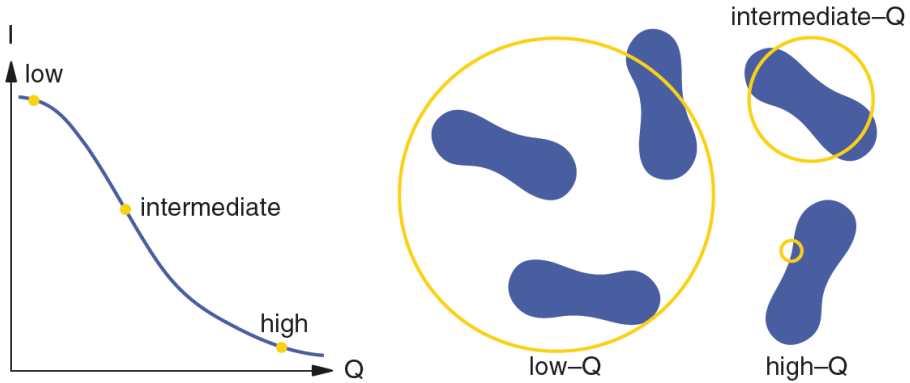
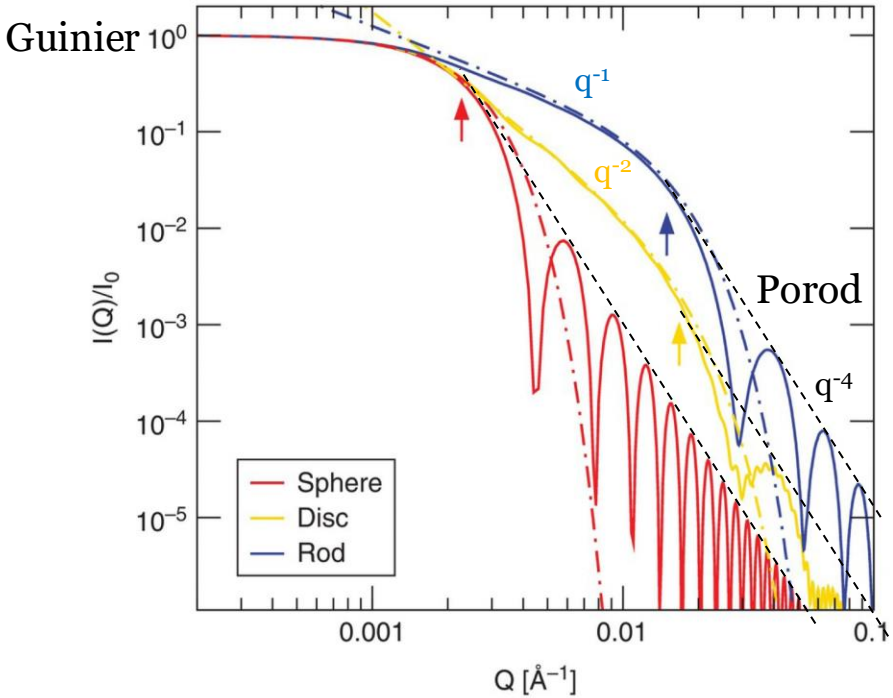



***Figure 5.67*** *The three Q-domains of SAXS.*

Willmott, P. (2011). Scattering Techniques. An Introduction to Synchrotron Radiation, John Wiley & Sons, Ltd: 133-221.

# small-angle X-ray scattering
# size & shape

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sphere, disc and rod with the same characteristic length (radius of gyration) → same scattering at low $q$ (Guinier regime)

intermediate region depends on fractal dimension
$q^{-1}$: rod

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at high $q$: Porod regime $q^{-4}$

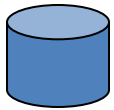
# Guinier approximation

- Radius of gyration $R_G$: "weight average" of all radii present in the sample in analogy to mechanics

solid sphere radius *R*: $R_G^2 = \frac{3}{5}R^2$

thin rod length *L:* $R_G^2 = \frac{1}{12}L^2$

thin disc radius *R*: $R_G^2 = \frac{1}{2}R^2$

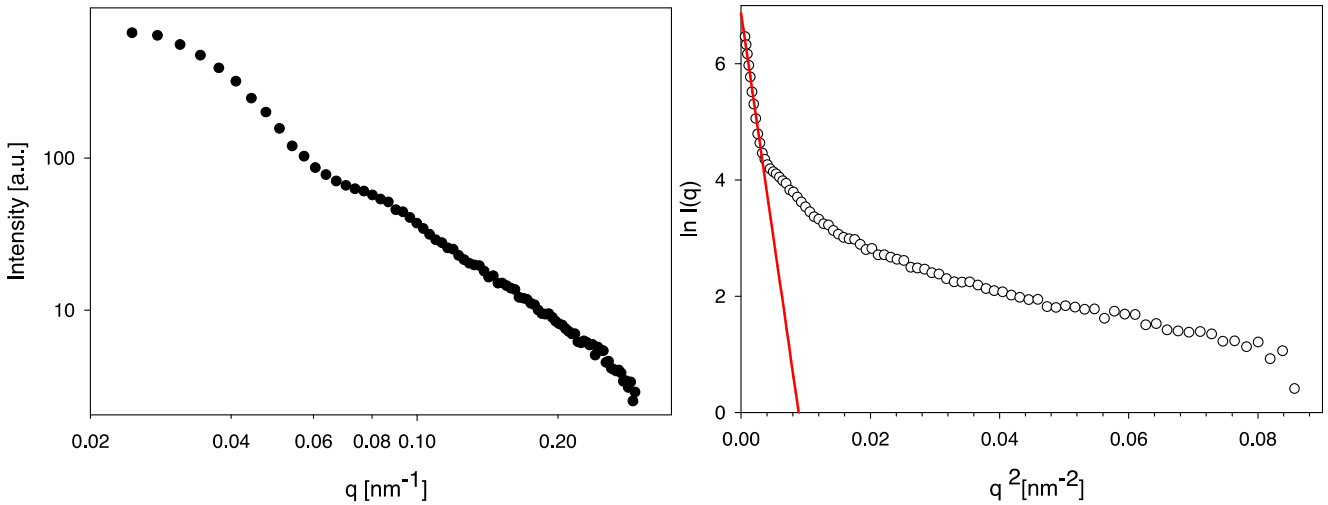


cylinder of height *h* and radius *R*: $R_G^2 = \frac{R^2}{2} + \frac{h^2}{12}$

# Guinier approximation

Guinier approximation valid only in the region of small q values, $R_G$ can be derived

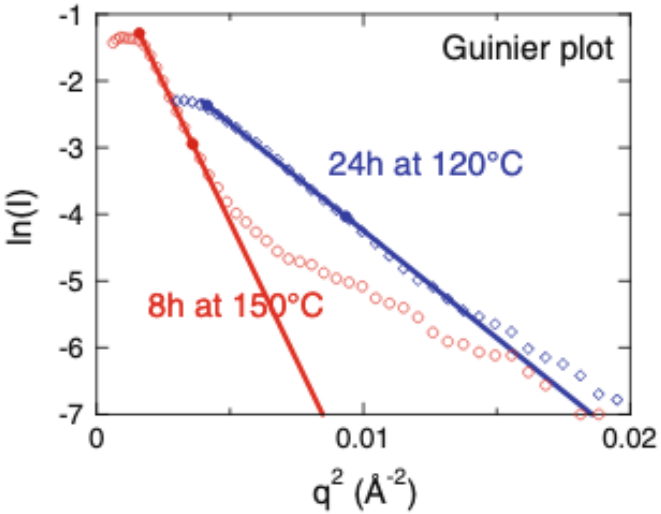
$$I(q) \approx I(0)e^{-(1/3)q^2 R_G^2}$$



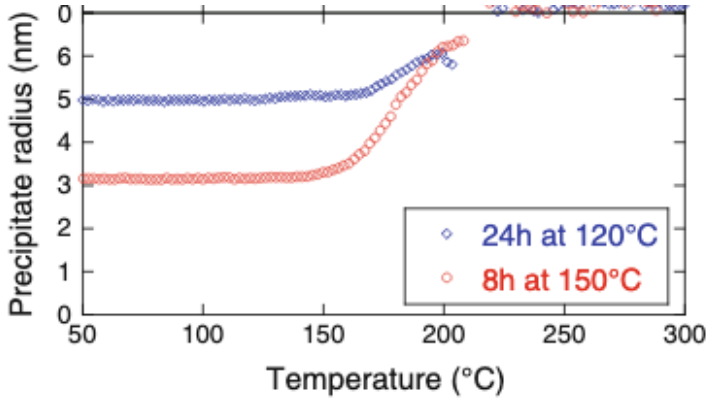

A not existing linear range indicates the presence of very large structures which scatter at low *q*, perhaps outside the accessible *q* range → change detector distance, change λ, check with SLS

# SAXS on metal alloys

SAXS measurements on Al-Mg-Li alloy for two aging conditions




Evolution of precipitate radius during ramp heating experiments on these two initial aging conditions




Deschamps A. and De Geuser F. Metallurgical and Materials Transactions A, 44, 2013, 77-86

# Small-angle scattering: Power law

Slope of the scattering curve: power law behavior

$q^{-D}$ with D the **fractal dimension**

How does the mass changes as a function of the size

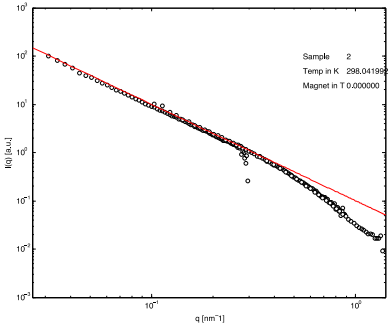
rod-like D=1

disk-like D=2

in general: the higher D, the more compact is the structure

D=4 Porod scattering

→ sharp interphase of two phases, information about surface area



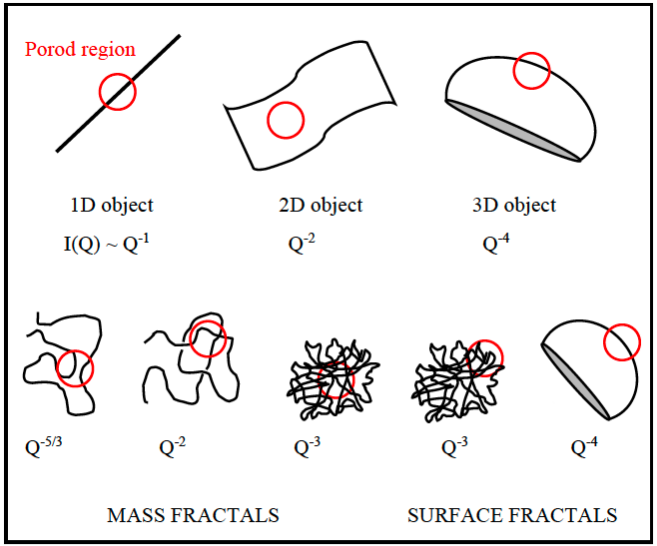
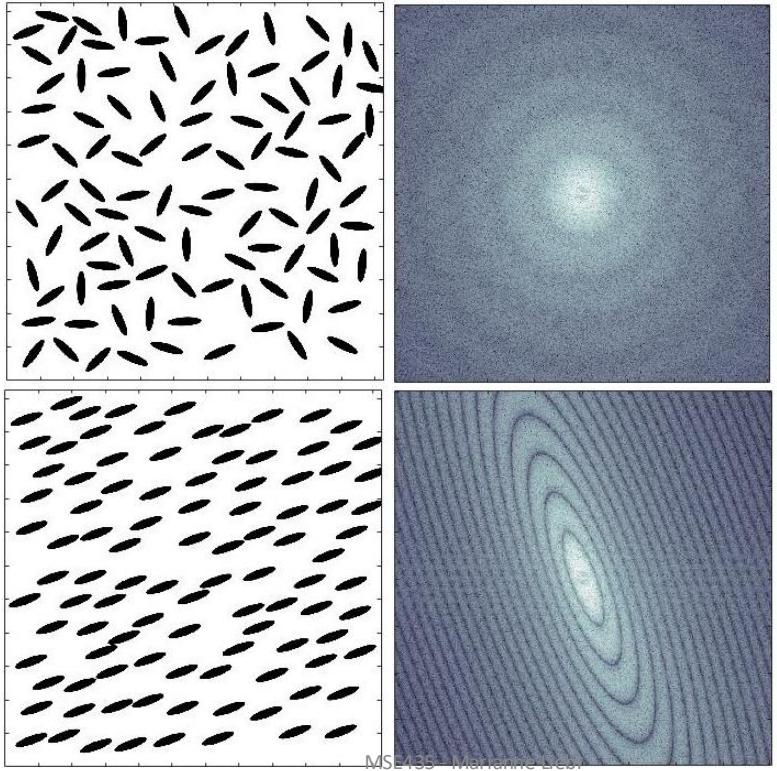




Figure 7: Assortment of Porod law behaviors for different shape objects.

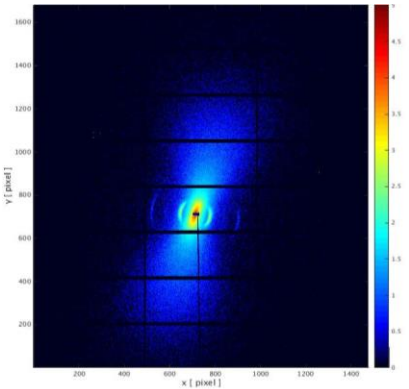
# small-angle X-ray scattering: anisotropic particles



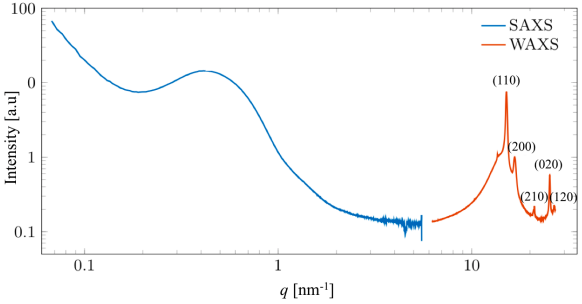
anisotropic and aligned particles produce anisotropic scattering

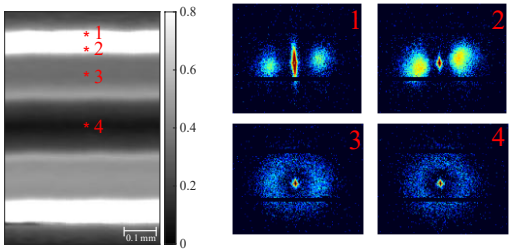
→ direct determination of orientation of nanoparticles!

# SAXS of anisotropic materials

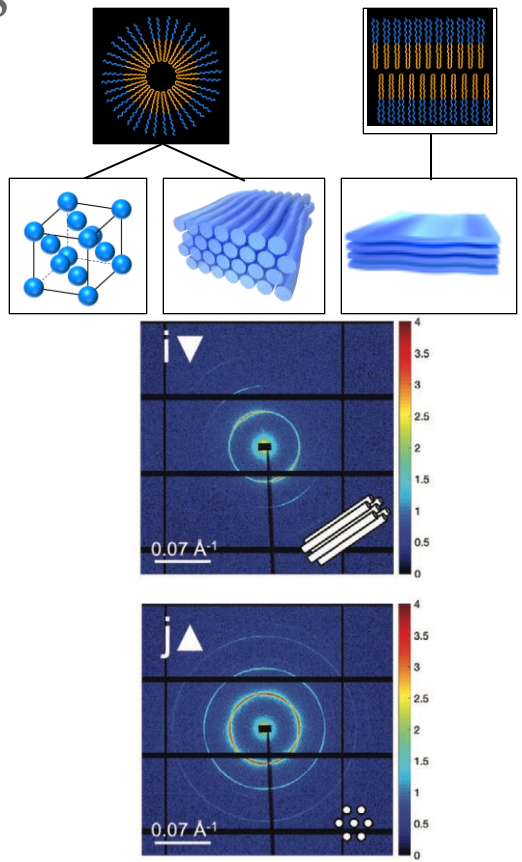


SAXS signal from mineralized collagen in human bone



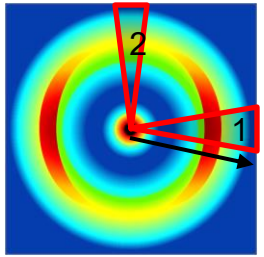



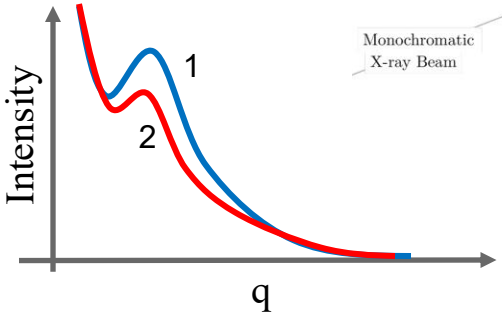

SAXS signal from different layers in injection-molded polymers

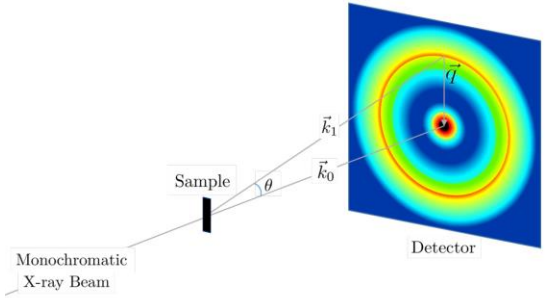



SAXS signal from liquid crystals oriented in flow

# SAXS of anisotropic materials

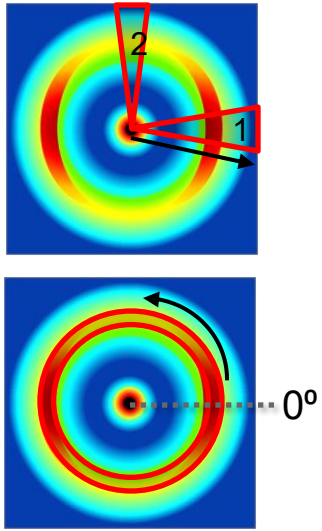


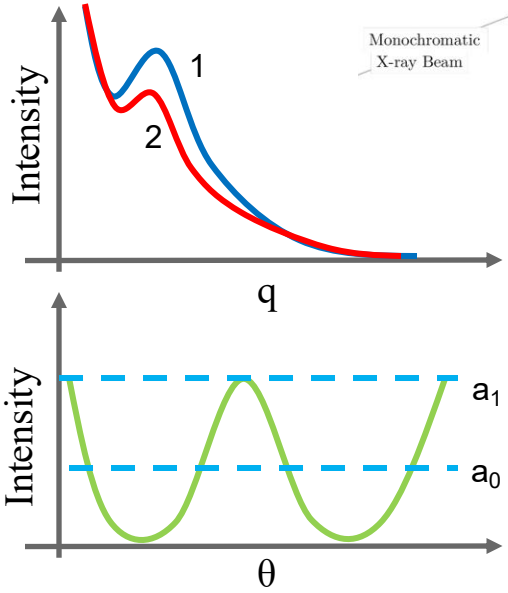



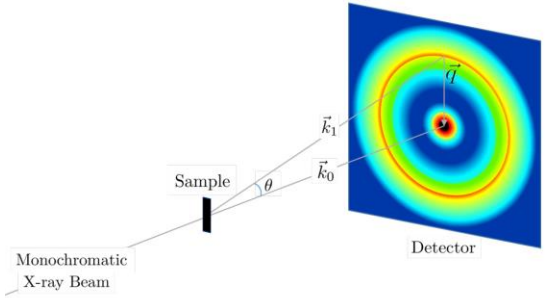




$$|\vec{q}| = q = \frac{4\pi}{\lambda} sin\frac{\theta}{2}$$

# SAXS of anisotropic materials

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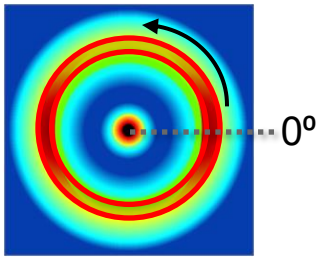
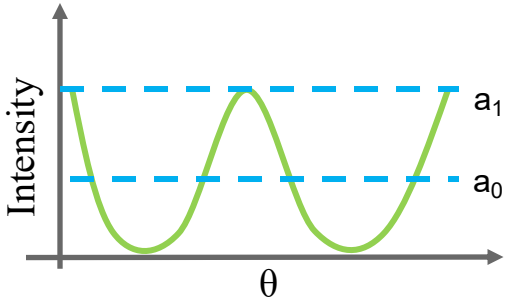
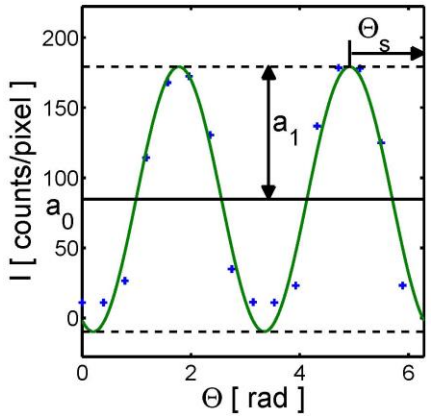



$$I(n_\Theta) \approx a_0 + a_1 \cos(2\pi n_\Theta / N_\Theta - \Theta_s)$$

$\frac{a_0}{a_1}$ degree of orientation

Bunk, O. *et al*. Multimodal x-ray scatter imaging. *New Journal of Physics* **11**, (2009).

# Small-angle scattering

- Fraunhofer approx. Fourier theorem:

the field distribution at a distant detector is the Fourier transform of the electric field distribution in the exit plane of a sample

BUT we don't measure field but the intensity, which is the squared field: complex quantity: complex part (the phase) get lost → **the phase problem**

→we cannot directly calculate back the particles shape and size, different approaches to retrieve information from the scattering pattern

- model independent
- **mathematically model the SAXS curve**
- pair distance distribution function (PDDF)
- iterative phase retrival

# Mathematical modelling of Small-angle scattering

$$I(q) = (\rho_P - \rho_M)^2 N_P V_P^2 P(q) S(q)$$

$\rho_P - \rho_M$ : contrast in scattering length density between particle and matrix

for X-rays: electron density difference

for neutrons: neutron scattering length density difference

$N_P$: number of particles

$V_P$: volume of particles

**Formfactor P(q)**

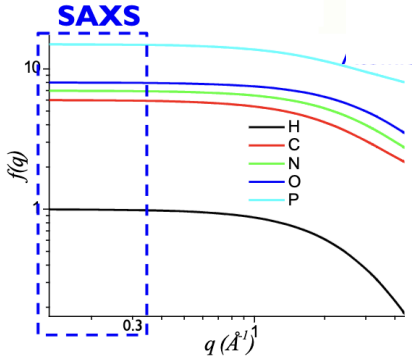
Intra-particle interference

shape, size

**Structure factor S(q)**

Inter-particle interference

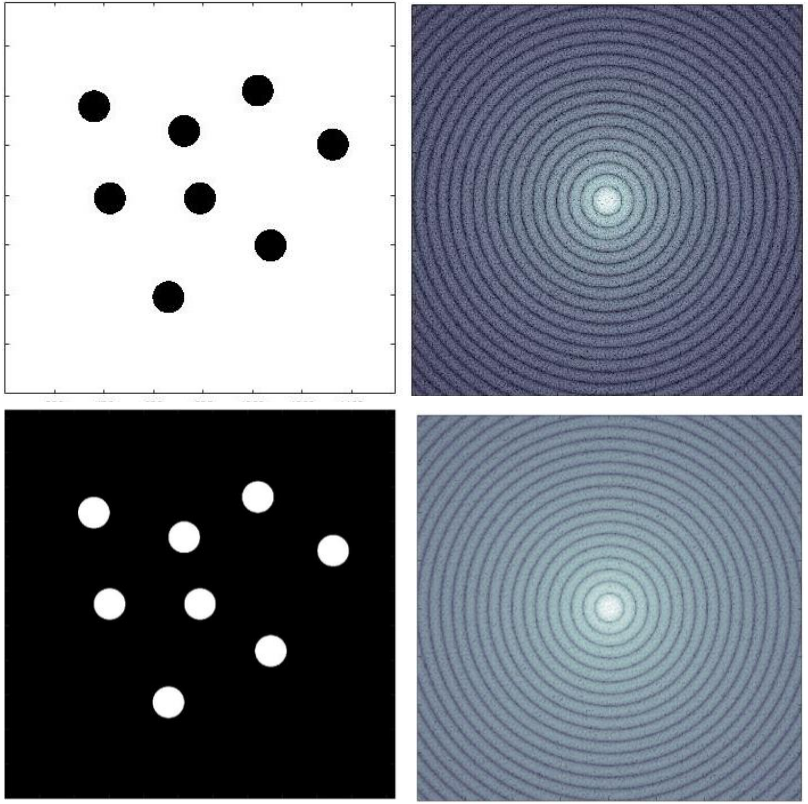
spacing, interactions




Data taken from International Tables for Crystallography, Vol. C, Table 6.1.1.1

note that the atomic form factor in the SAXS regime is a constant

# small-angle X-ray scattering



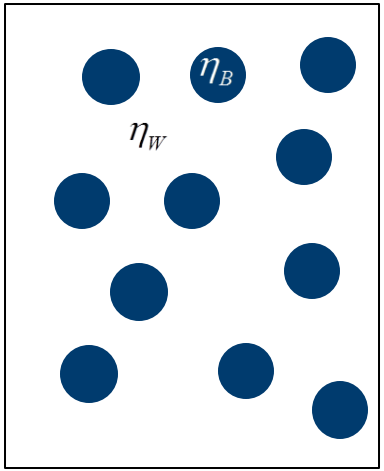
Babinet's principle:

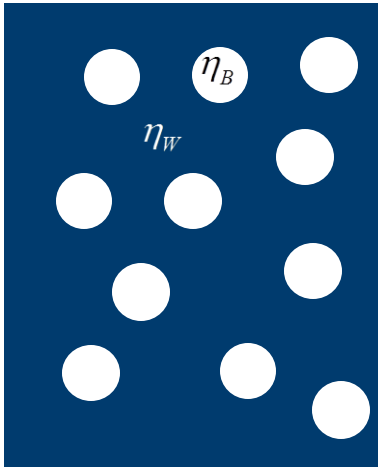
particle vs. pores

same diffraction pattern apart from overall intensity

# Babinet's principle: particles or pores?

two structures where only the scattering length densities are exchanged give the same scattering (incoherent scattering may be different)




$$I(\mathbf{q}) \propto (\eta_B - \eta_W)^2$$

- contrast is relative
- loss of phase information (is $\eta_B > \eta_W$?)

# Model dependent fitting: Formfactor

$$I(q) = (\rho_P - \rho_M)^2 N_P V_P^2 P(q) S(q)$$

### 3.1. Spheres & Shells

#### 3.1.1. Sphere.

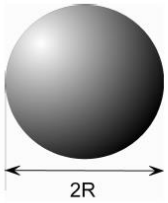



FIGURE 3.1. Sphere with diameter $2R$

$$I_{\text{Sphere}}(Q,R) = K^2(Q,R,\Delta\eta) \tag{3.1a}$$

with

$$K(Q,R,\Delta\eta) = \frac{4}{3}\pi R^3 \Delta\eta\, 3\frac{\sin QR - QR\cos QR}{(QR)^3} \tag{3.1b}$$

The forward scattering for $Q = 0$ is given by

$$\lim_{Q\to 0} I_{\text{Sphere}}(Q,R) = \left(\frac{4}{3}\pi R^3 \Delta\eta\right)^2$$

Input Parameters for model `Sphere`:

`R`: radius of sphere $R$
`- - -`: not used
`- - -`: not used
`eta`: scattering length density difference between particle and matrix $\Delta\eta$

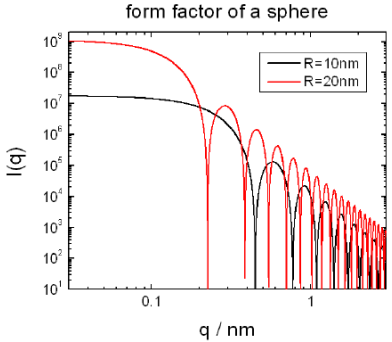



FIGURE 3.2. Scattering intensity of spheres with radii $R = 10$nm and $R = 20$nm. The scattering length density contrast is set to 1.

sasfit manual: https://kur.web.psi.ch/sans1/SANSSoft/sasfit.pdf

# Model dependent fitting: Structure factor

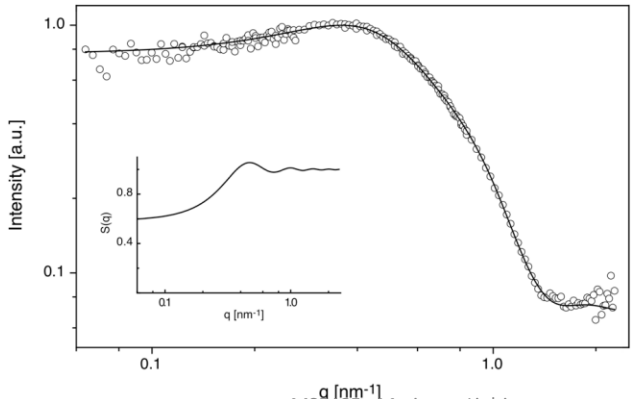
$$I(q) = (\rho_P - \rho_M)^2 N_P V_P^2 P(q) S(q)$$

Formfactor P(q)

Structure factor S(q)

Interacting particles

→Measure different concentrations




example: Phospholipid micelle

ellipsoidal form factor

hard sphere structure factor (hard sphere radius larger than radius of micelles)

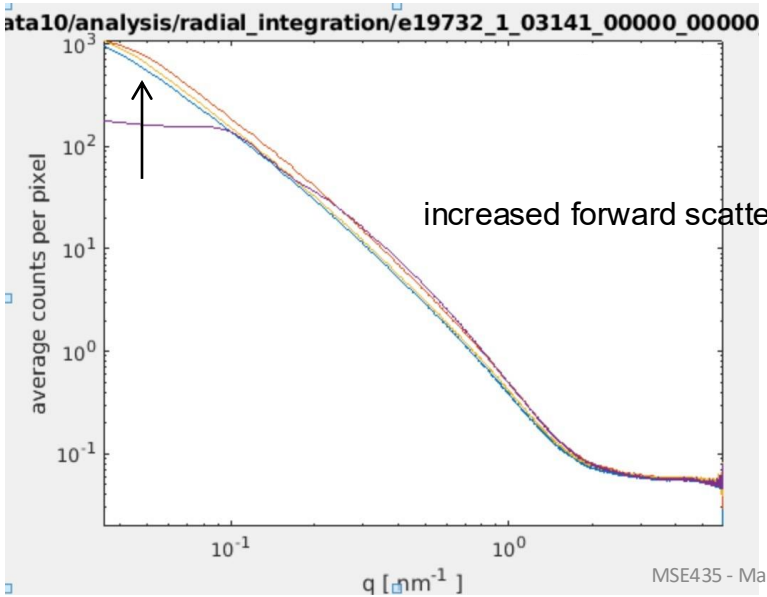
→ self-assembly & surfactants



Beck, P., et al. (2010). Langmuir **26**(8): 5382-5387.

# Model dependent fitting: Structure factor

$$I(q) = (\rho_P - \rho_M)^2 N_P V_P^2 P(q) S(q)$$

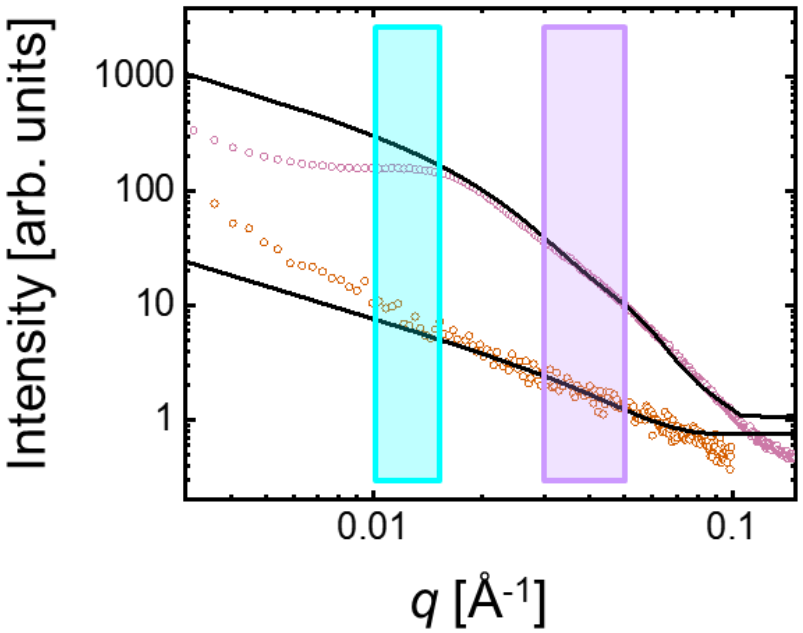



Structure factor S(q)

Interacting particles

increased forward scattering: typical sign of aggregation

# Example: cellulose nano crystals (CNC) and cellulose nano fibrils (CNF)




4 wt% CNC dispersion (pink)

what does the slope say on the shape?

0.25 wt% CNF dispersion (orange)

Corona, P. T., Berke, B., Guizar-Sicairos, M., Leal, L. G., Liebi, M., & Helgeson, M. E. (2022). Fingerprinting soft material nanostructure response to complex flow histories. *Physical Review Materials*, *6*(4), 1–14. https://doi.org/10.1103/PhysRevMaterials.6.045603

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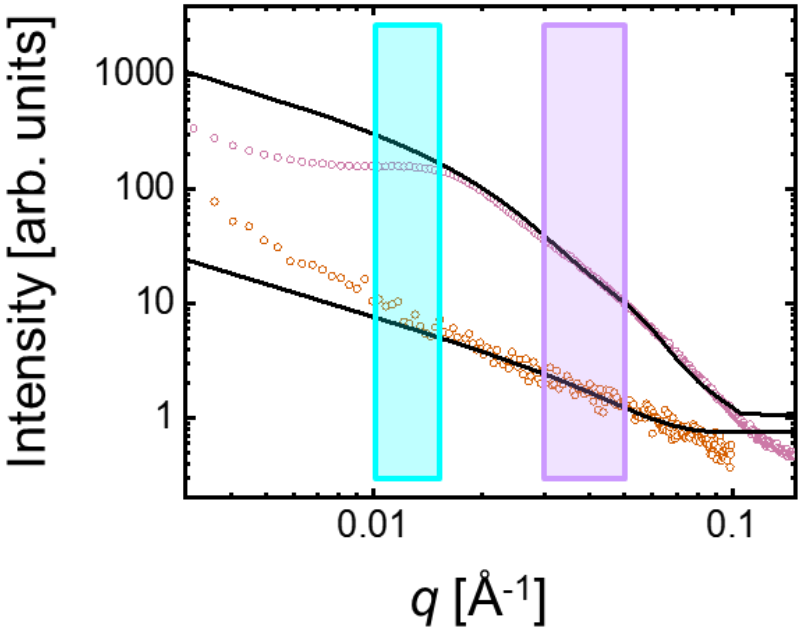
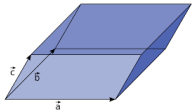
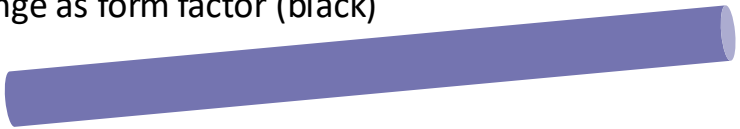



4 wt% CNC dispersion (pink): parallelepiped shape with cross section dimensions of 6 nm and 18 nm as form factor (black)



0.25 wt% CNF dispersion (orange): cylindrical shape with particle radius of 6 nm, length longer than the measured q-range as form factor (black)



what indicates the deviation from fit with a structure factor at low q?

Corona, P. T., Berke, B., Guizar-Sicairos, M., Leal, L. G., Liebi, M., & Helgeson, M. E. (2022). Fingerprinting soft material nanostructure response to complex flow histories. *Physical Review Materials*, *6*(4), 1–14. https://doi.org/10.1103/PhysRevMaterials.6.045603

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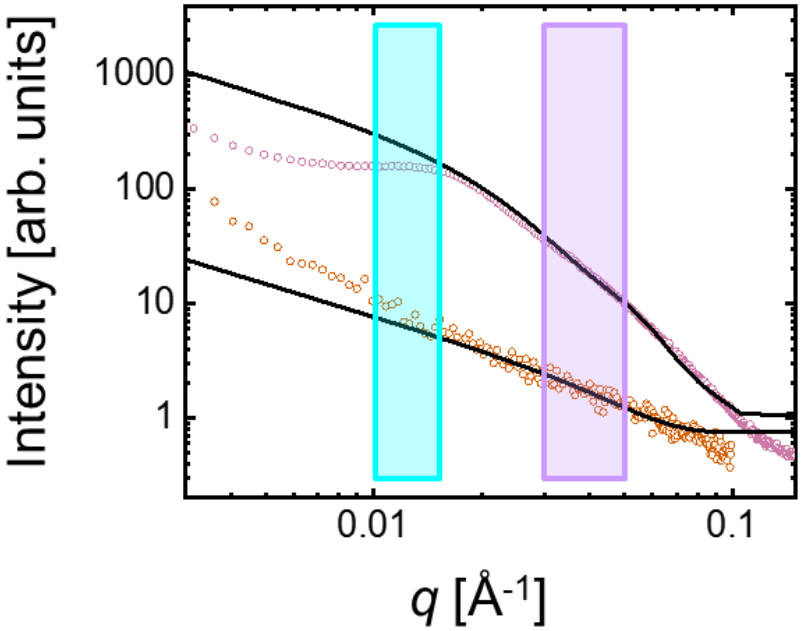
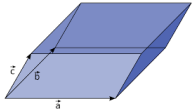



4 wt% CNC dispersion (pink): parallelepiped shape with cross section dimensions of 6 nm and 18 nm as form factor (black) at low q (blue box) deviation due to a **structure factor contribution for repulsive interaction**



0.25 wt% CNF dispersion (orange): cylindrical shape with particle radius of 6 nm, length longer than the measured q-range as form factor (black) at low q (starting from blue box) deviaiton due to a **structure factor contribution for attractive interaction**

Corona, P. T., Berke, B., Guizar-Sicairos, M., Leal, L. G., Liebi, M., & Helgeson, M. E. (2022). Fingerprinting soft material nanostructure response to complex flow histories. *Physical Review Materials*, *6*(4), 1–14. https://doi.org/10.1103/PhysRevMaterials.6.045603

# Small-angle scattering

- Fraunhofer approx. Fourier theorem:

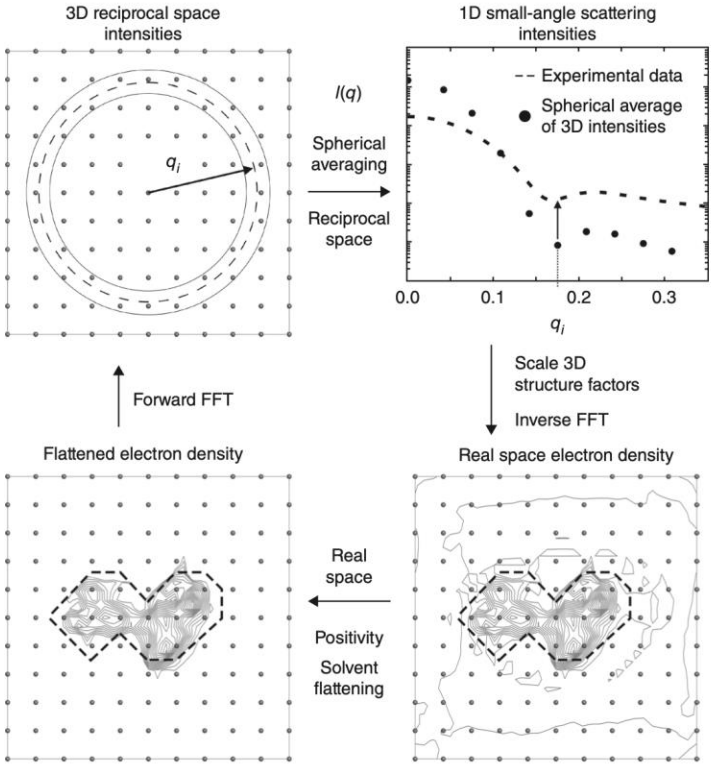
the field distribution at a distant detector is the Fourier transform of the electric field distribution in the exit plane of a sample

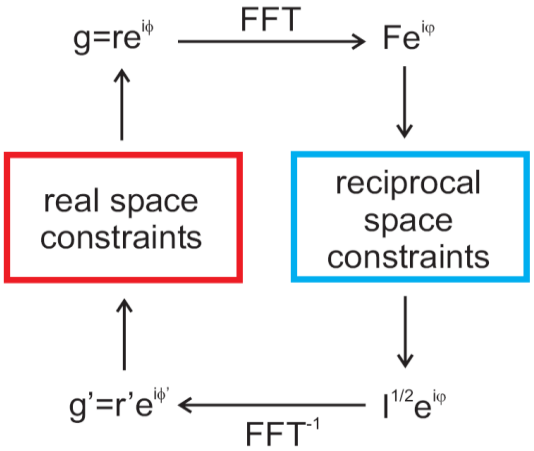
BUT we don't measure field but the intensity, which is the squared field: complex quantity: complex part (the phase) get lost → **the phase problem**

→we cannot directly calculate back the particles shape and size, different approaches to retrieve information from the scattering pattern

- model independent
- mathematically model the SAXS curve
- pair distance distribution function (PDDF)
- **iterative phase retrival**

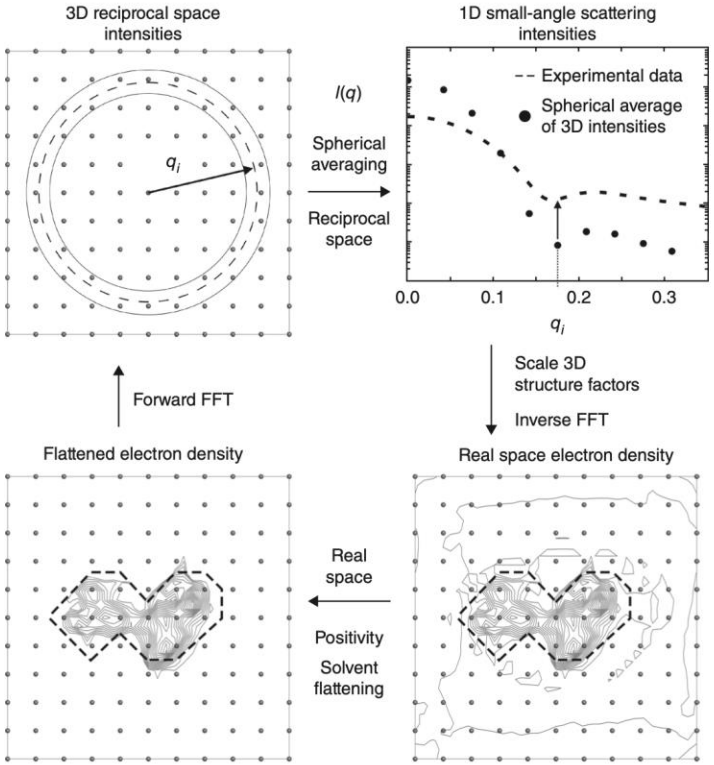
# SAXS analysis: iterative approach




Grant, T. D., *Nature Methods* **2018,** *15*, 191.

# SAXS analysis: iterative approach



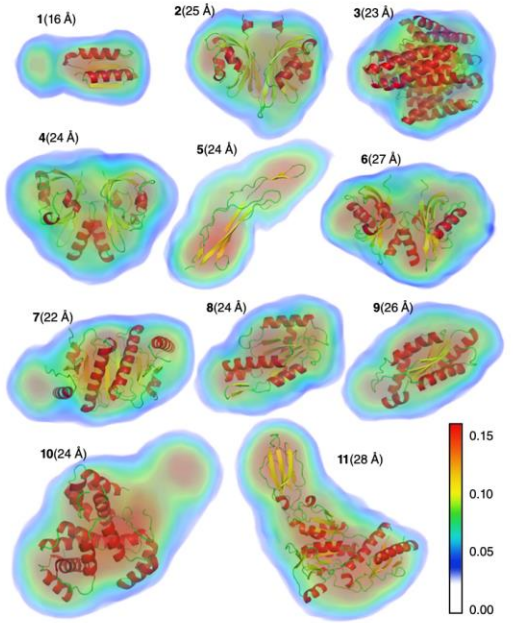



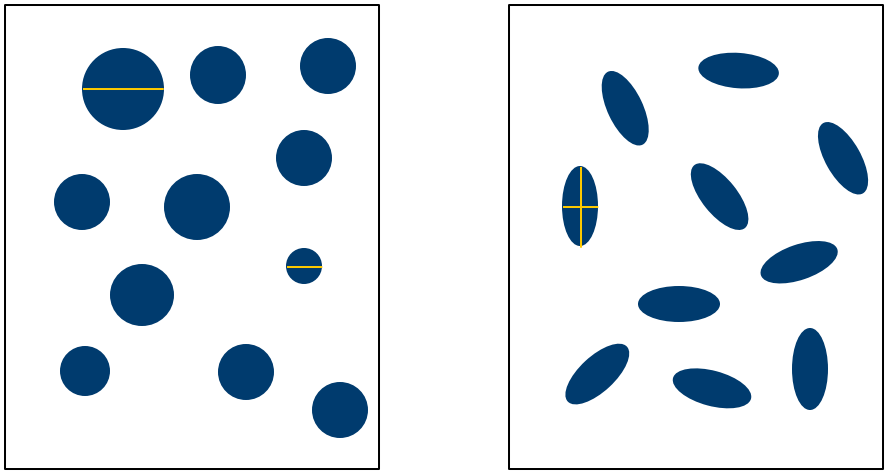

**Figure 2** | Electron density reconstructions from experimental solution scattering data for samples 1–11 (**Supplementary Table 1**). Electron densities are shown as volumes colored according to density (color bar indicates electron density values in $e^-/Å^3$). X-ray crystal structures (for PDB IDs, see **Supplementary Table 1**) are shown in cartoon format. Estimated resolutions of the solution scattering reconstructions are shown next to sample ID (see Online Methods).

Grant, T. D., *Nature Methods* **2018,** *15*, 191.

# Polydispersity is the devil…

Small-angle scattering is a statistical method of all length scales in a sample

particle polydispersity or particle shape?



# X-rays vs. neutrons

•Wavelengths in the order of atomic distances

•Penetrate into matter from µm to many cm deep

- scattered by nucleus of atoms
- scattering contrast depends on mass number A, is isotope-specific

$$n_{neutrons} = \sqrt{\frac{E_{kin} - \overline{V}}{E_{kin}}} \cong 1 - \frac{\overline{b} n_a}{2\pi} \lambda^2$$

→ contrast matching!

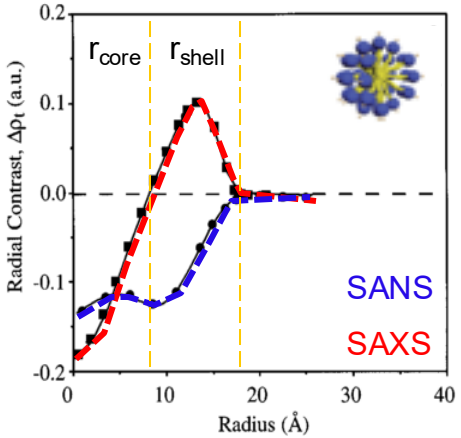
- Interact with magnetic moment in shell of atom
  →magnetic structures and magnetism

- scattered by electronic shell of atoms
- Scattering contrast proportional to order number (number of electrons)

$$n_{x-ray} = 1 - \frac{\overline{Z} r_e n_a}{2\pi} \lambda^2$$

- Larger flux possible→ faster, lower concentrations, smaller beam

# SAXS vs. SANS as complementary contrast



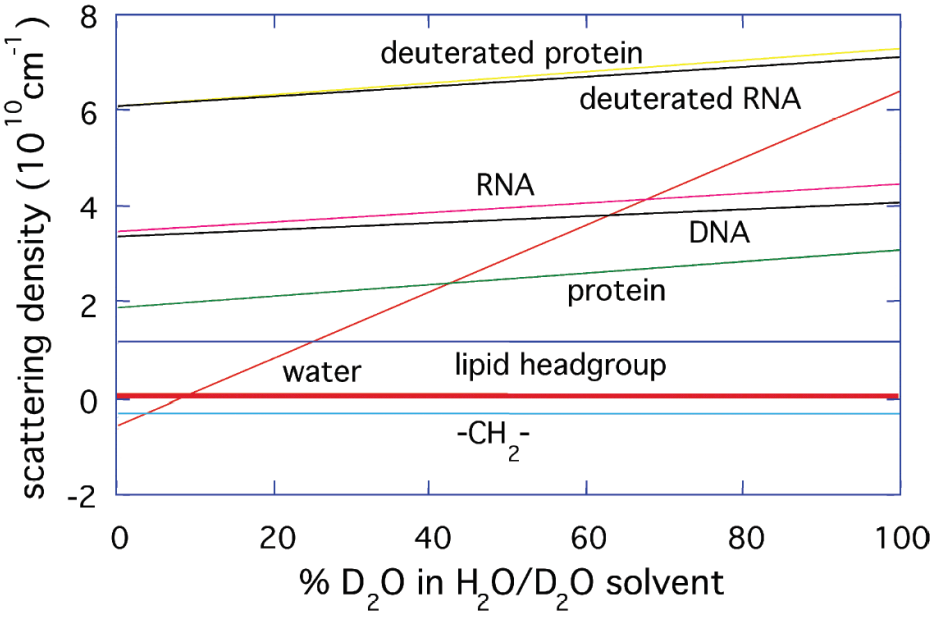

SANS contrast is mainly between the full micelle and the solvent

→ overall size of micelles

SAXS headgroups have a higher contrast then lipid tails

→ internal structures

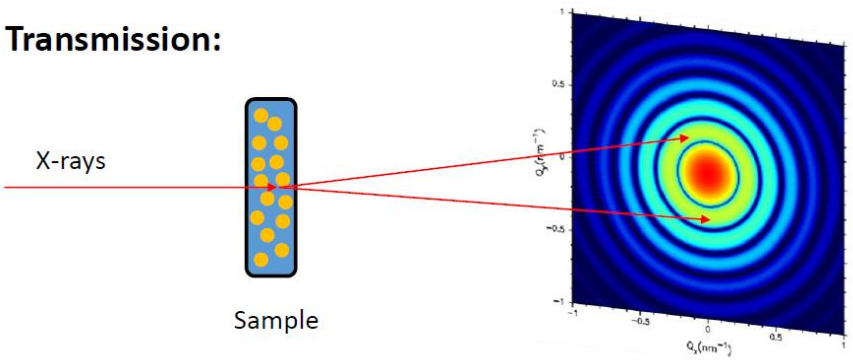
# Contrast matching in SANS



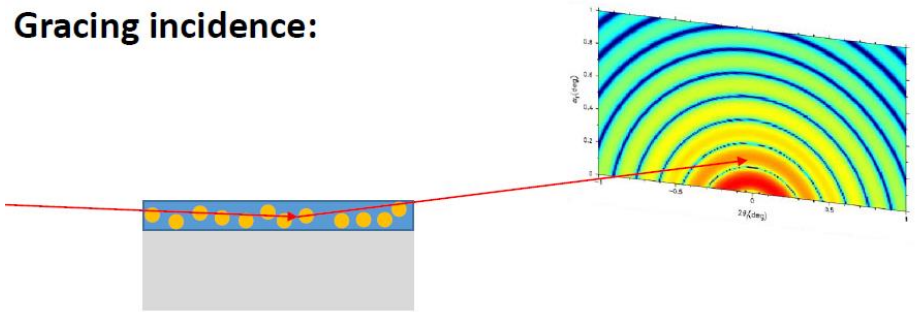

Scattering length density different for isotopes! Hydrogen and Deuterium!

# SAXS at gracing incidence: GISAXS

**Transmission:**




**Gracing incidence:**



# GISAXS

Extensive article on GISAXS including theoretical background, experimental consideration and application examples:

Renaud, G., Lazzari, R., & Leroy, F. (2009).
Probing surface and interface morphology with Grazing Incidence Small Angle X-Ray Scattering.
*Surface Science Reports*, *64*(8), 255–380.
https://doi.org/10.1016/j.surfrep.2009.07.002

# X-ray scattering at synchrotrons

**High Brilliance allows for**

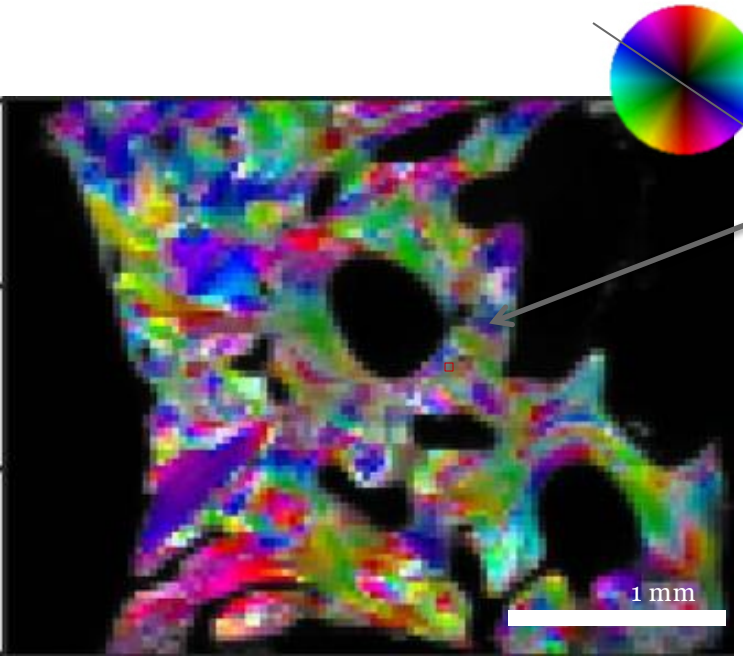
Low divergence ⇒ high angular resolution scattering/diffraction patterns

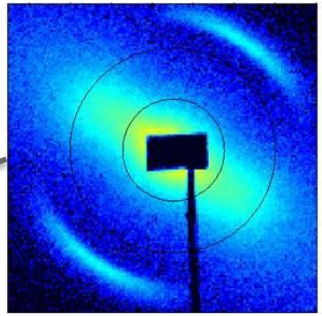
Tight focus ⇒ small sample sizes e.g., protein crystals ~ 1 $mm^3$

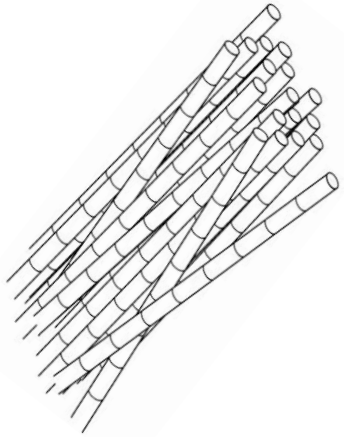
Low emittance ⇒ large working distance between focussing optics and sample ⇒ bulky sample environments

High flux ⇒ rapid data acquisition, time-resolved studies down to ms regime or shorter

# Scanning SAXS: imaging with SAXS contrast



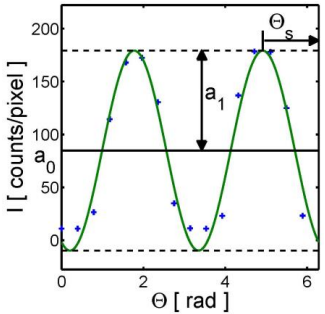





Hue: scattering orientation

Saturation: degree of orientation

Value: isotropic scattering




$$I(n_\Theta) \approx a_0 + a_1 \cos(2\pi n_\Theta / N_\Theta - \Theta_s)$$

# X-ray scattering at synchrotrons

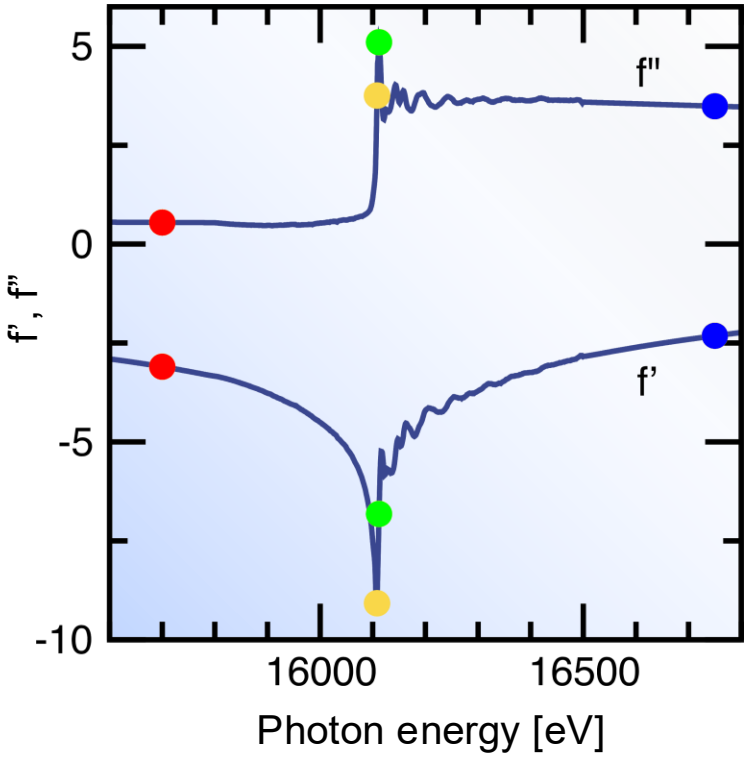
**Acess to high photon energies:**

Penetrate deep into samples, e.g., aeronautical components, large fossils, concrete, etc.

**Tunability of energy:**

Abrupt changes to atomic scattering amplitudes as one crosses an absorption edge

"Anomalous" signal

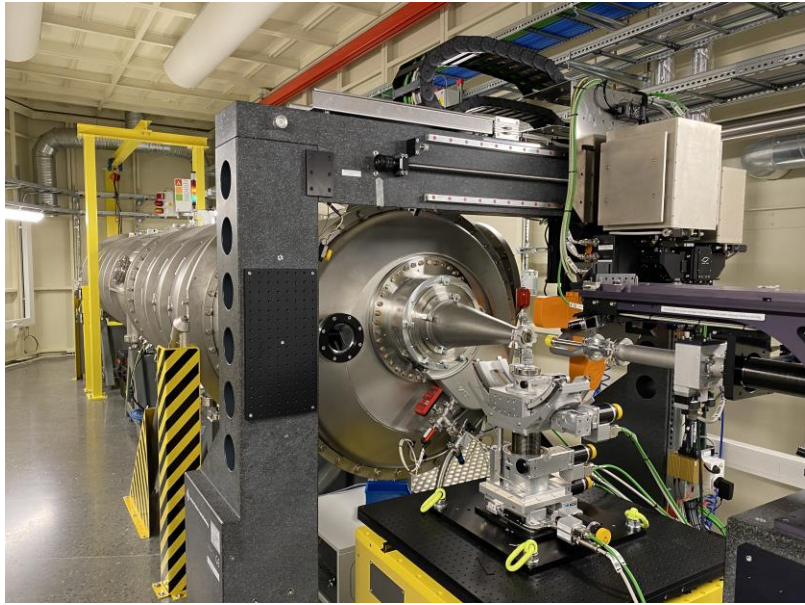


# X-ray scattering at synchrotrons

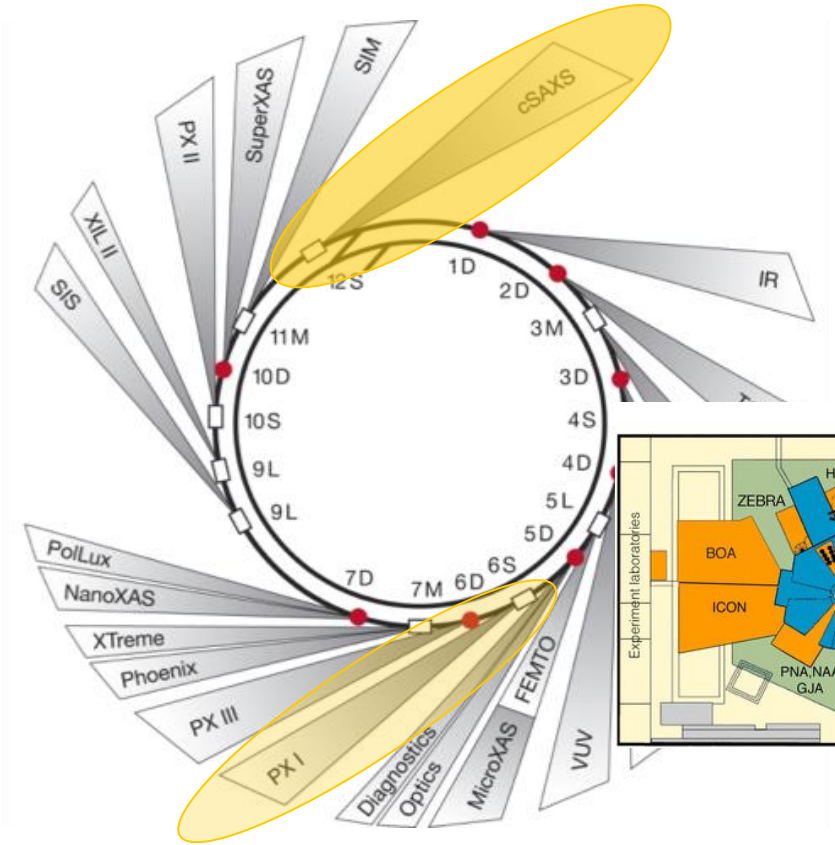
state-of the art detectors

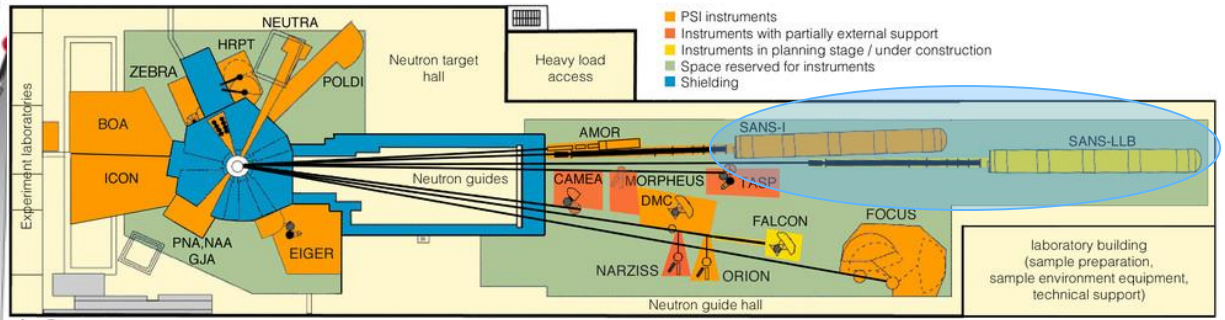
shared sample environemnts (e.g. Rheo-SAXS)

Large flight tubes and low emittance: Ultra small angle X-ray scattering



# Small angle scattering at PSI: SAXS and SANS



# Practical consideration for an experiment

X-ray vs. neutrons (vs. light)

what size range is of interest → q-range: detector distance and energy

beamsize: resolution vs. flux-density and beam damage

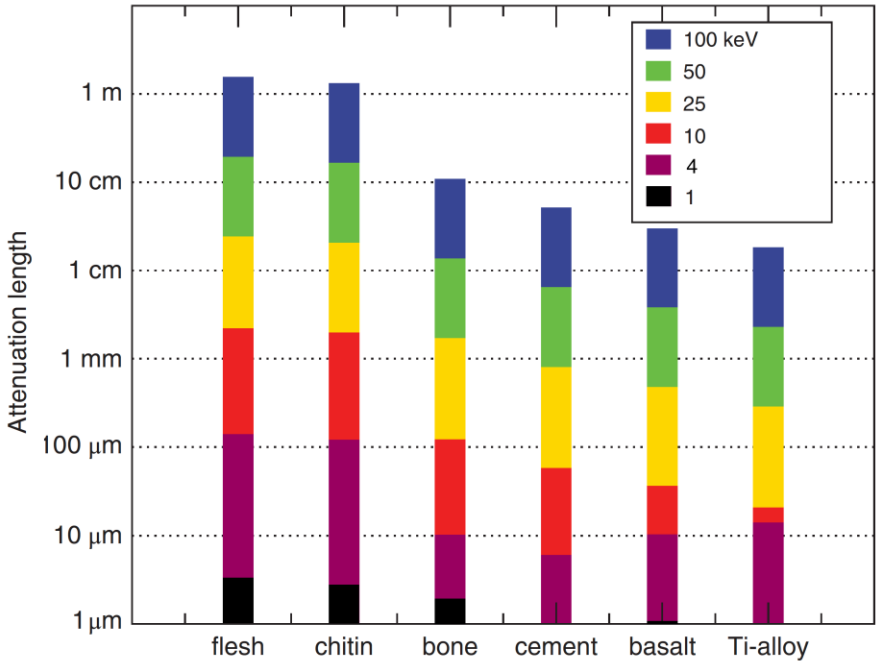
exposure time: signal to noise, detector speed

detector saturation

thickness of sample, for X-rays energy:

- number of scatterer proportional to intensity $I(q) = (\rho_{\mathrm{P}} - \rho_M)^2 \boldsymbol{N_P} V_P^2 P(q) S(q)$
- but absorption (Lambert-Beer law): intensity decays exponentially with thickness $I = I_0\, e^{-N_i \sigma z}$
- maximum at the absorption length i.e. where transmission is 1/e, ~ 30%

# Sample thickness and X-ray energy



# Exercise case study

You want to measure your sample with SAXS for that you need to

- choose the beamline
- define X-ray energy and sample-to-detector distance

- what size (range) do you need to probe? → define q-range
- energy depends on sample transmission and thickness → use online calculator
  - check with 1mm and 10 um sample thickness
- chose a beamline which covers the energy range you need
- what is the minimum distance you need to place your detector for measuring your relevant size, when you have a 1mm beamstop blocking the direct beam, mounted 1cm in front of the detector
- what is the maximum q you will reach at this position considering the detector area available?

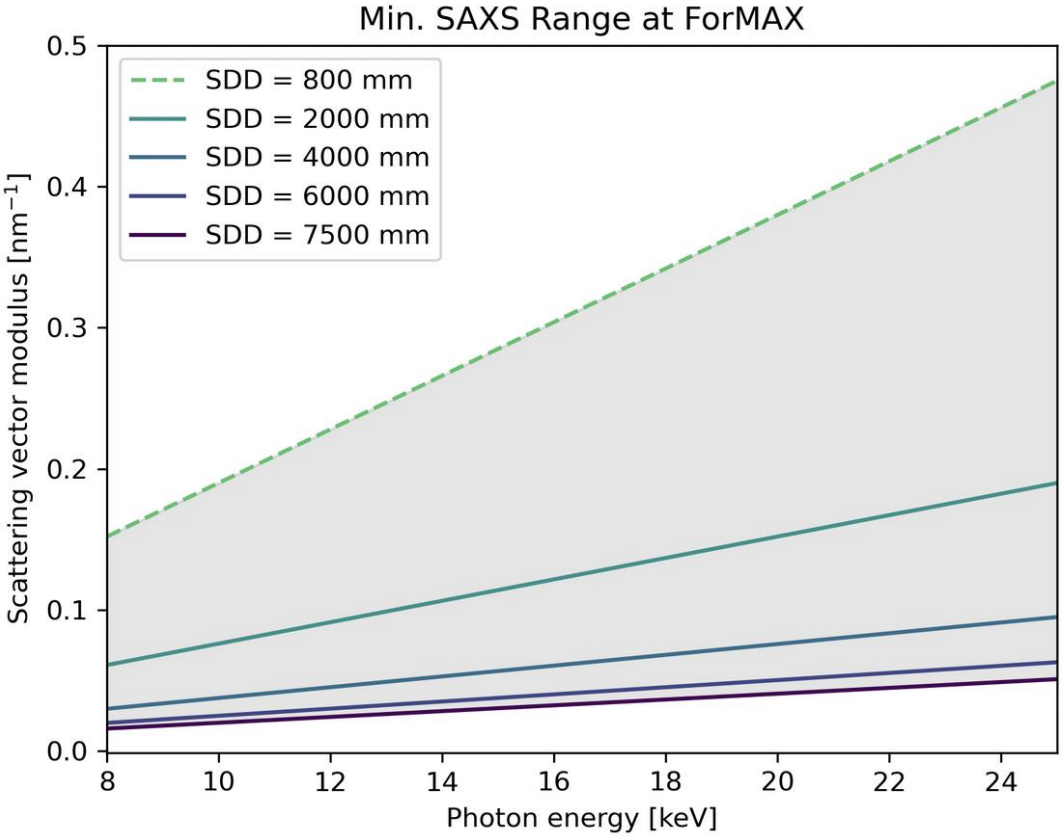
# some SAXS beamline specifics (from beamline webpages)

- cSAXS@SLS
  - 4.4 – 17.9 keV
  - Pilatus 2M, pixel size 172 µm x 172 µm, active area: 254 x 289 $mm^2$
  - 7200 m or 2100 mm
- PX-I@SLS
  - 4.4 – 17.9 keV
  - EIGER X 16M, pixel size: 75 µm x 75 µm, active area: 311.1 x 327.2
  - max 2000 mm
- P62@DESY
  - 3.5 keV - 35.0 keV
  - Eiger2 X 9M (in vacuum), pixel size: 75 µm x 75 µm, active area: 233.1 mm x 244.7 mm
  - 1.5m up to 12.0m
- ForMAX@MAXIV
  - 8-25 keV
  - EIGER2 X 4M, pixel size: 75 µm x 75 µm, active area: 155.1 mm x 162.2 mm
  - detector distance. 800 – 7600 mm

# Example from proposal to ForMAX@MAXIV

**C) Experimental method(s), specific requirements.**

The proposed experiment plans to measure simultaneous scanning SAXS/WAXS with a beamsize of $25\mu m$ and a photon energy of 12.4 keV. We aim to measure samples extracted from the inferior and superior sides of each femoral neck, yielding a dataset of 180 samples in total. In order to obtain the full characterization of bone scattering parameters, we need a q-range of 0.02 – 2 $nm^{-1}$ in the SAXS regime in order to capture the collagen equatorial scattering and sufficient mineral scattering, as well as a WAXS q-range of 10-40 $nm^{-1}$ in the aim of obtaining the hydroxyapatite 002 peak (~18.2 $nm^{-1}$) in the full azimuthal range. Previous experiments at the beamline have proven the feasibility of the suggested setup in using sample-to-detector distances of 7m and 130mm for the SAXS and WAXS respectively.


Min. SAXS Range at ForMAX
SDD = 800 mm
SDD = 2000 mm
SDD = 4000 mm
SDD = 6000 mm
SDD = 7500 mm
Scattering vector modulus [nm$^{-1}$]
Photon energy [keV]
0.0
0.1
0.2
0.3
0.4
0.5
8
10
12
14
16
18
20
22
24