Scattering principles and its application to nanoparticles dispersions.

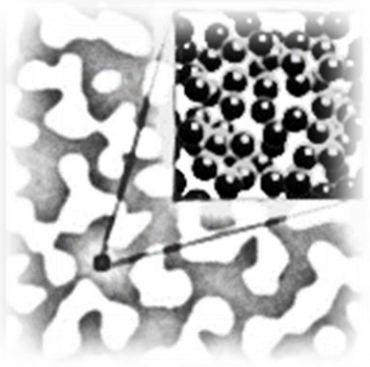
thomas.gibaud@ens-lyon.fr

2026
Grenoble
SAXS-SANS 2026 - Nouveautés et fondamentaux

Examples:

1- α-cristallin and hard sphere glasses
2- Casein micelles and fractal gels
3- Lysozyme and arrested phase separations







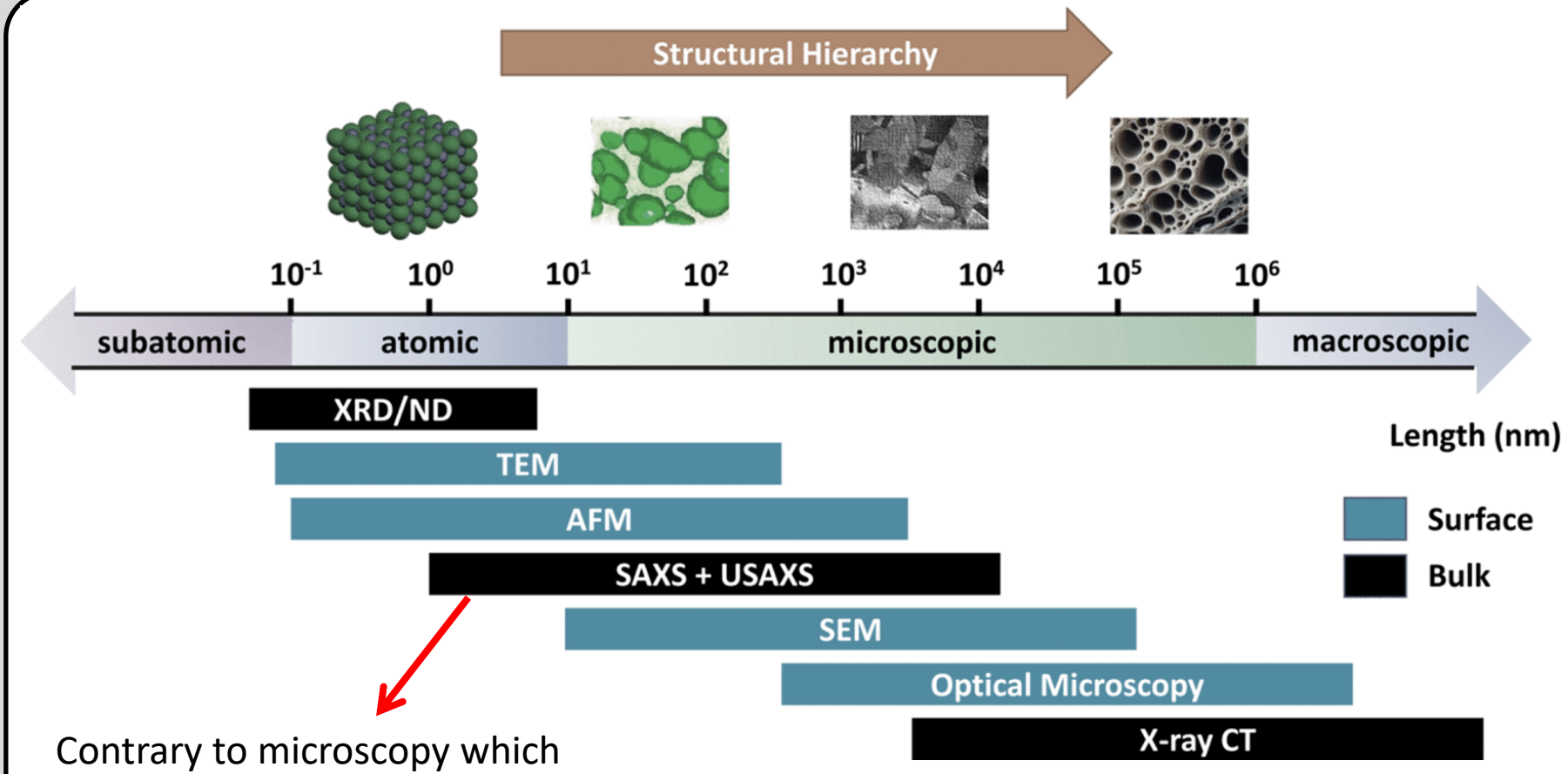
Structure
SAXS/SANS
microscopy

Mechanical properties
Rheology

State diagram
of the dispersion

Dynamics
DLS, XPCS
microscopy

Probing structures at different length scale



Contrary to microscopy which produce real space images SAXS/SANS produce images in the reciprocal (Fourier) space

$q=2\pi/d$

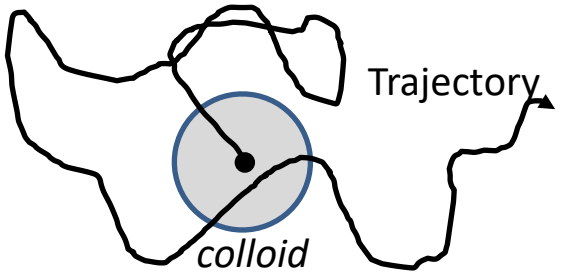
Zhang, Fan, and Jan Ilavsky. "Bridging length scales in hard materials with ultra-small angle X-ray scattering–a critical review." IUCrJ 11.5 (2024): 675-694.

Nanoparticles as big atoms

W Poon, Science 304, 830 (2004)

Dynamics

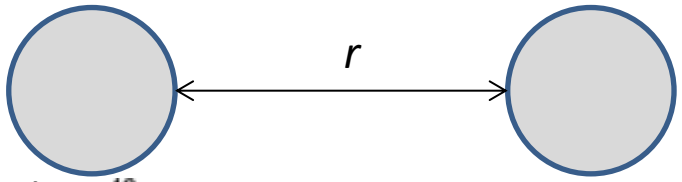
Thermal energy k_BT induces Brownien motion

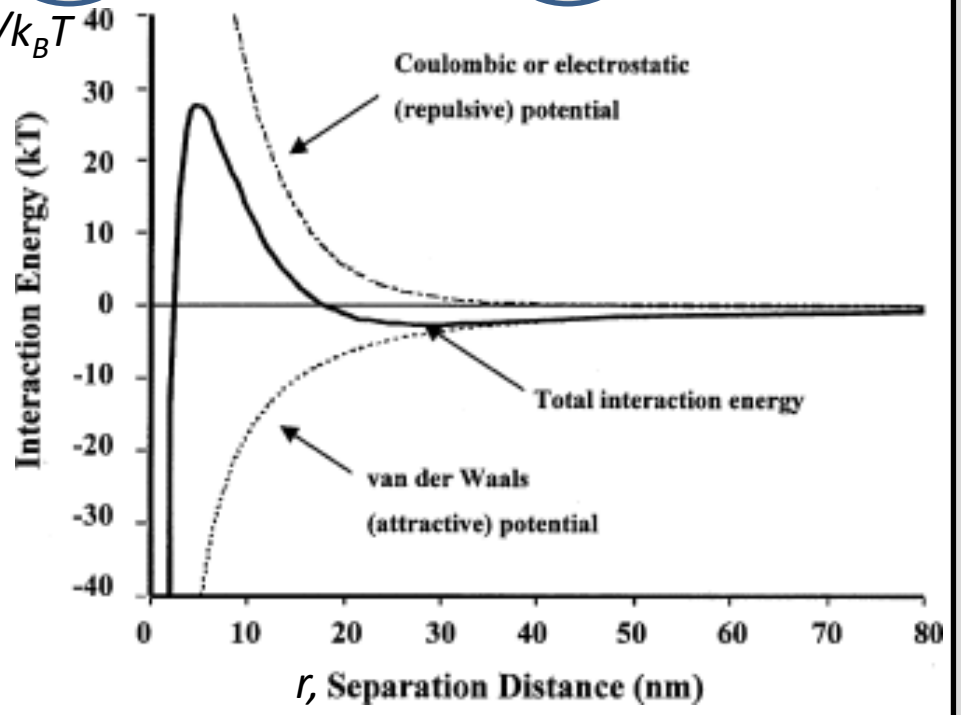


A 1μm colloid diffuse on its size in about 1s in water

Interaction potential

Ex: DLVO





Big atoms?

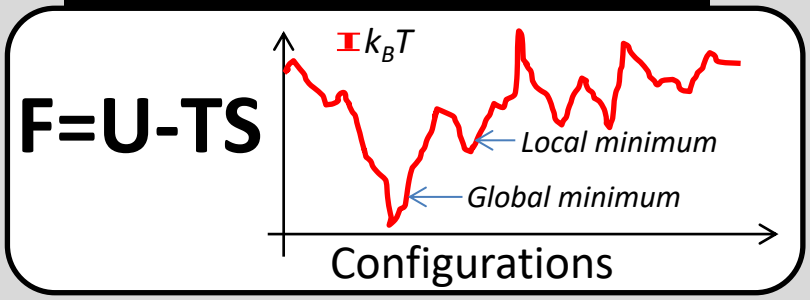
- **Larger length scale/Slower dynamics**
- **Solvent mediated interactions**
- **Variety of interactions and shape**
- **“Soft” mechanical properties**
- **…**

Proteins = Colloids?

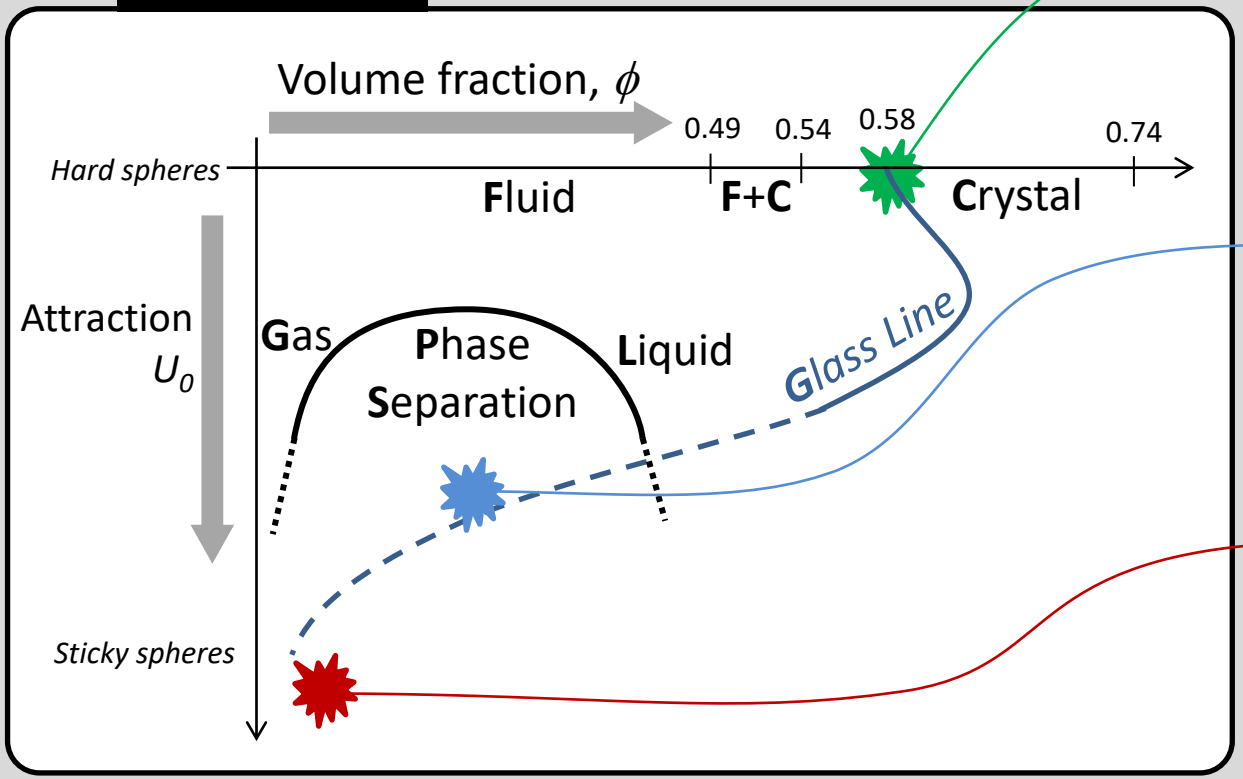
Potential and limits of a colloid approach to protein solutions. A Stradner, P Schurtenberger. Soft Matter 16, 307 (2020)

Colloids state diagram

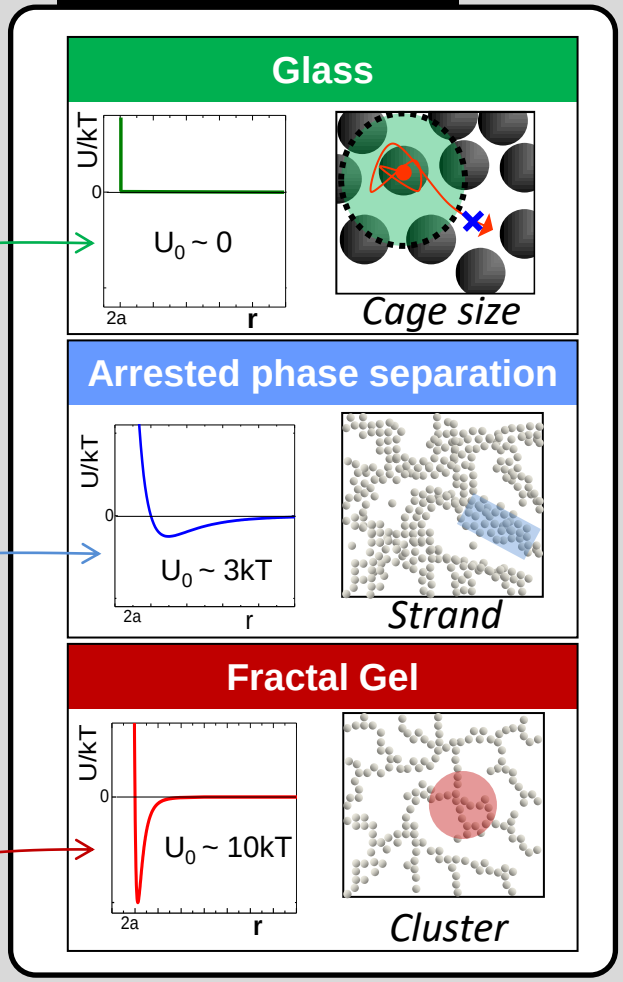
Equilibrium/Out of equilibrium



State diagram



Out of equilibrium Soft solids

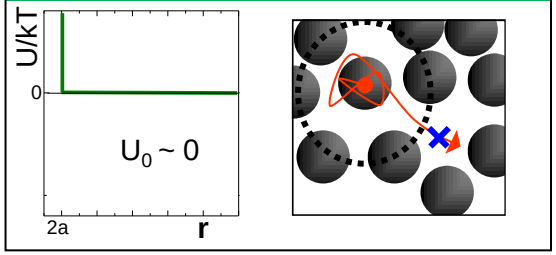


Colloidal spheres may struture in complex soft solids

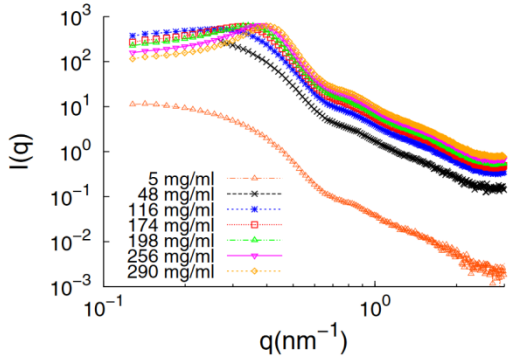
F. Sciortino. "One liquid, two glasses." Nature materials 1, 145 (2002).
R. Mezzenga, P. Schurtenberger, A. Burbidge, M. Michel. Understanding foods as soft. Nat. materials 4, 729 (2005)
V. Trappe and P. Sandkühler. "Colloidal gels—low-density disordered solid-like states." COCIS 8, 494 (2004)

Scattering as a fingerprint of structure at different lengthscales

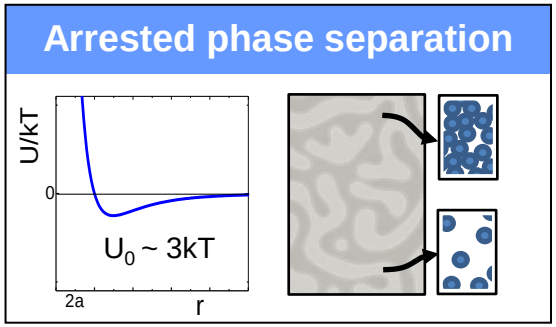
Glass



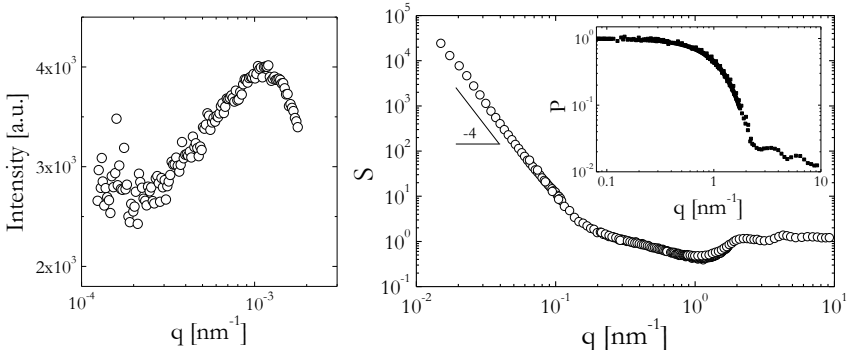
Dense Fluid like structure



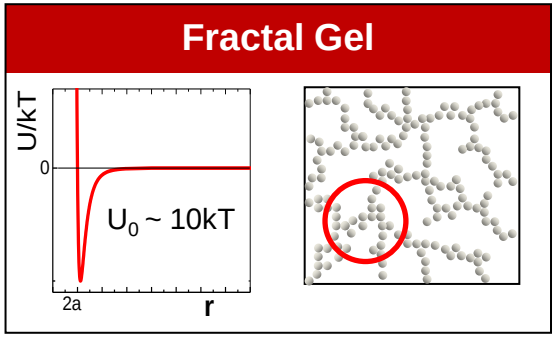
Arrested phase separation



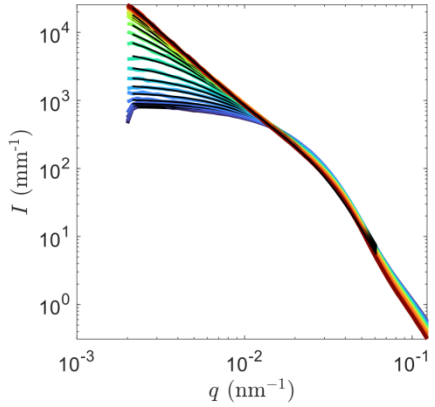
Bi-continuous Network with a sharp interfaces between the 2 phases



Fractal Gel



Network= Dense packing of fractal clusters



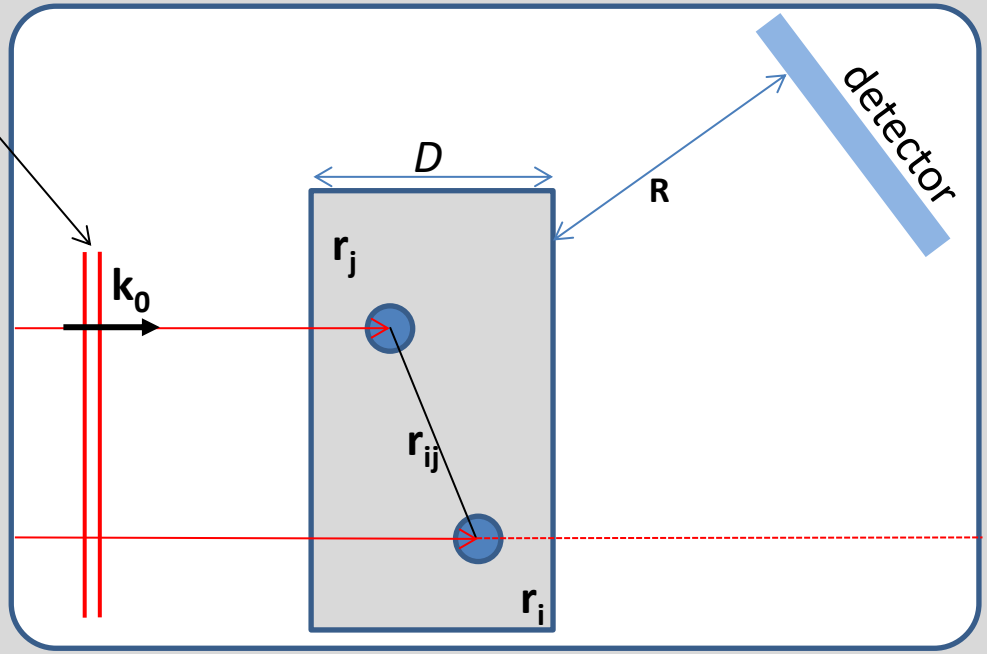
Scattering

1. Incident beam

$$E_0(\mathbf{r},t) \propto e^{i(\mathbf{k}_0\cdot\mathbf{r}-\omega t)}$$

with $$|\mathbf{k}_0| = \frac{2\pi}{\lambda}$$

$\lambda \simeq 0.1$nm



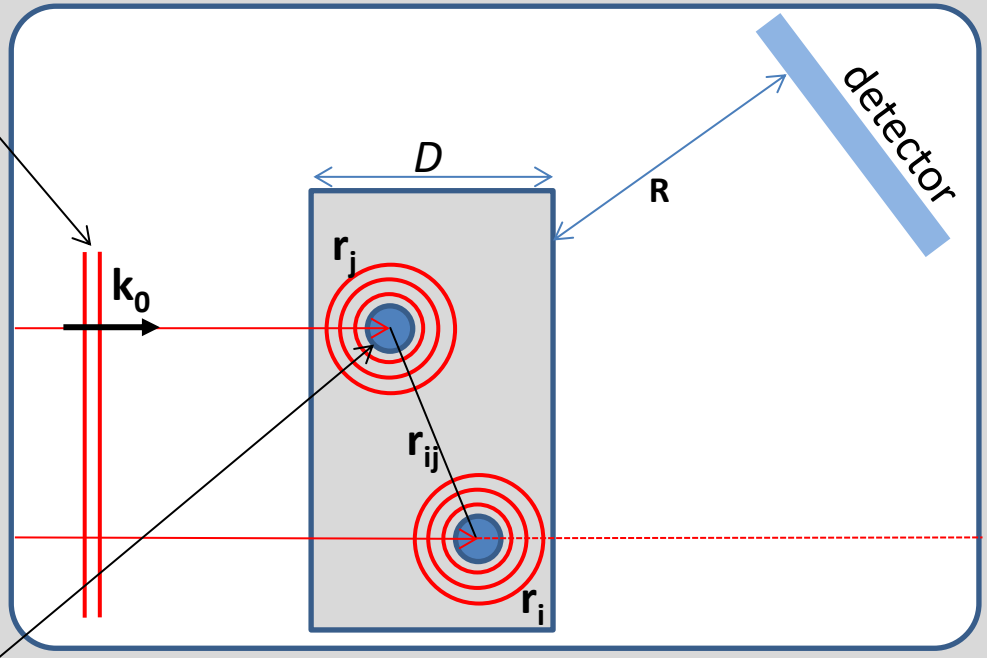
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2. Each electron (the scatterer, r_e=2.8x10^{-6}nm << λ) acts as a secondary point source and emit a spherical wave with wave vector $\mathbf{k}_s$

Elastic scattering: $|\mathbf{k}_0| = |\mathbf{k}_s|$

Single scattering: secondary waves do not interact with other scatterers.

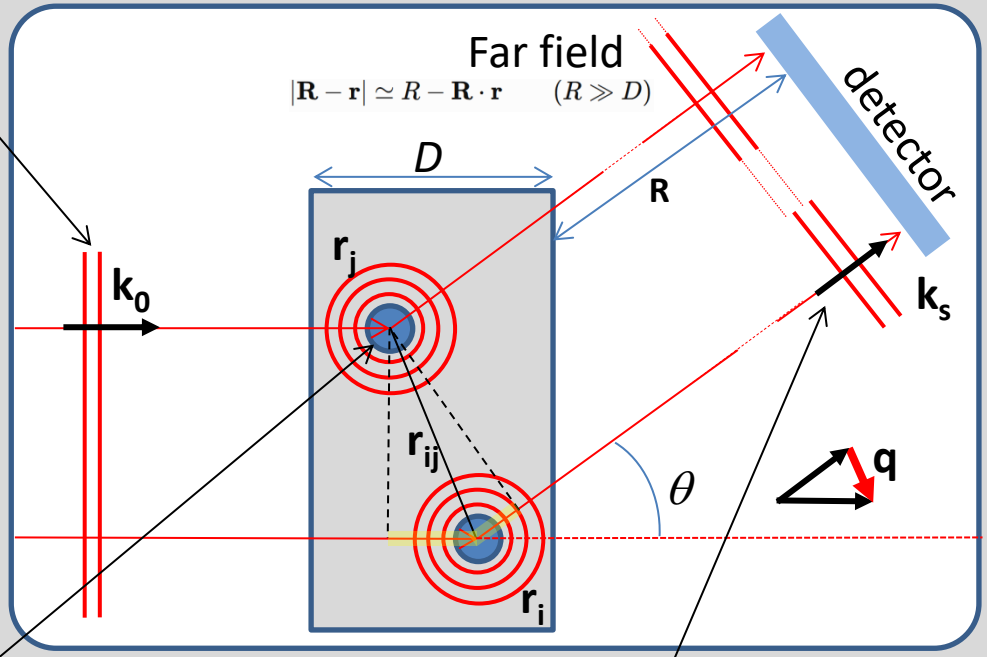
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3. In the far field limit, the scattered wave becomes a plane wave. The phase shift between 2 scatterers positioned at $\mathbf{r}_i$ and $\mathbf{r}_j$:

$$\Delta\phi_{ij} = -\mathbf{q}\cdot(\mathbf{r}_j - \mathbf{r}_i)$$

$$\mathbf{q} = \mathbf{k}_s - \mathbf{k}_0$$

$$q = |\mathbf{k}_s - \mathbf{k}_0| = \frac{4\pi}{\lambda}\sin\left(\frac{\theta}{2}\right)$$

Scattering

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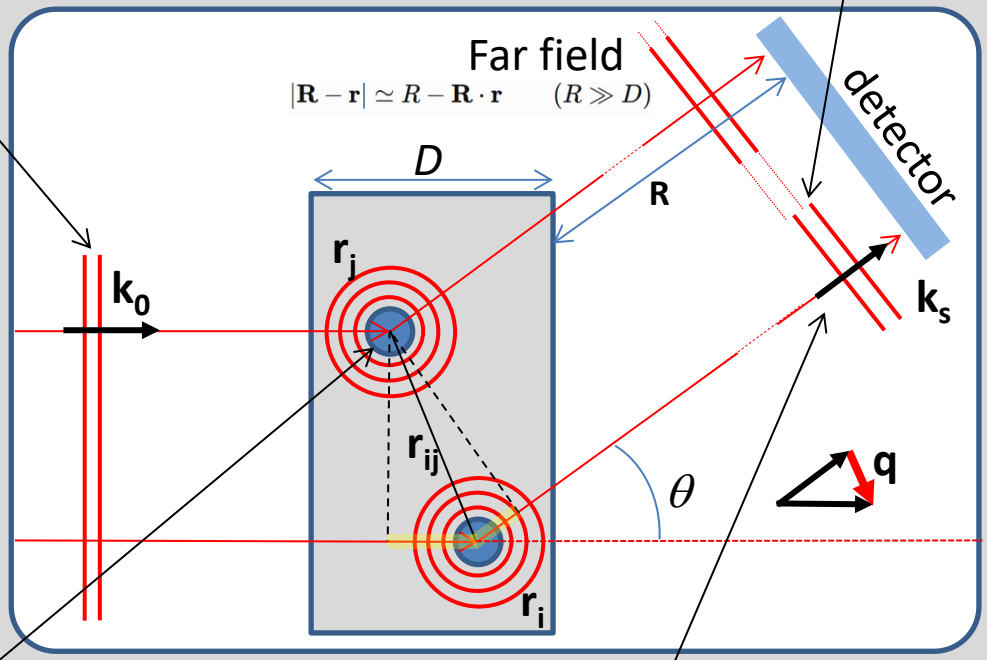
with $|\mathbf{k}_0| = \frac{2\pi}{\lambda}$

$\lambda \simeq 0.1$nm

4. Amplitude of the **interference** between 2 scatterers:

$$A(\mathbf{q}) = r_e e^{i\mathbf{q}\cdot\mathbf{r}_i} + r_e e^{i\mathbf{q}\cdot\mathbf{r}_j}$$

$$r_e e^{i\mathbf{q}\cdot\mathbf{r}_i}\left[1 + e^{i\Delta\phi_{ij}}\right]$$



2. Each electron (the scatterer, r_e=2.8x10^{-6}nm << λ) acts as a secondary point source and emit a spherical wave with wave vector $\mathbf{k}_s$

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Scattering

1. Continuous limit

3D Fourier transform

$$A(\mathbf{q}) = r_e \sum_{i=1}^{N} e^{i\mathbf{q}\cdot\mathbf{r}_i} \quad \text{Scatterers: } r_e\rho(\mathbf{r})d^3r \quad A(\mathbf{q}) = r_e \int_V \rho(\mathbf{r}) e^{i\mathbf{q}\cdot\mathbf{r}} d^3r = r_e \mathcal{F}\left[\rho(\mathbf{r})\right](\mathbf{q})$$

2. Decomposition of the scattering density

$$\rho_{\text{solution}}(\mathbf{r}) = \rho_{\text{solvent}}(\mathbf{r}) + \Delta\rho(\mathbf{r}) \quad A(\mathbf{q}) = r_e \int \left[\underbrace{\rho_{\text{solvent}}(\mathbf{r})}_{A_{\text{solvent}}(q)} + \underbrace{\Delta\rho(\mathbf{r})}_{A_{\Delta\rho}(q)}\right] e^{i\mathbf{q}\cdot\mathbf{r}}\, d^3\mathbf{r}$$

3. SAXS output: time average intensity per unit volume

$$\underbrace{\langle I(q)\rangle_t}_{I_{\text{sample}}(q)} = \frac{1}{V}\left[\underbrace{\left\langle |A_{\text{solvent}}(q)|^2 \right\rangle_t}_{I_{\text{bck}}(q)} + \left\langle |A_{\Delta\rho}(q)|^2 \right\rangle_t + 2\,\text{Re}\left\langle A^*_{\text{solvent}}(q) A_{\Delta\rho}(q)\right\rangle_t\right]$$

Solvent dynamics >> particle dynamics

$$I(q) = I_{\text{sample}}(q) - I_{\text{bck}}(q) \simeq \frac{r_e^2}{V}\left\langle \left| \int_V \Delta\rho(\mathbf{r}) e^{i\mathbf{q}\cdot\mathbf{r}}\, d^3\mathbf{r} \right|^2 \right\rangle_t$$

Units

$$I(q) = I_{\text{sample}}(q) - I_{\text{bck}}(q) \simeq \frac{r_e^2}{V} \left\langle \left| \int_V \Delta\rho(\mathbf{r}) e^{i\mathbf{q}\cdot\mathbf{r}}\, d^3\mathbf{r} \right|^2 \right\rangle_t$$

1. The Core Physical Constant

- $r_e = 2.81794 \times 10^{-15}$ m
- r_e : classical radius of electron

2. Electron Density

- $[L^{-3}]$ $\rho_e(\vec{r})$: electron density

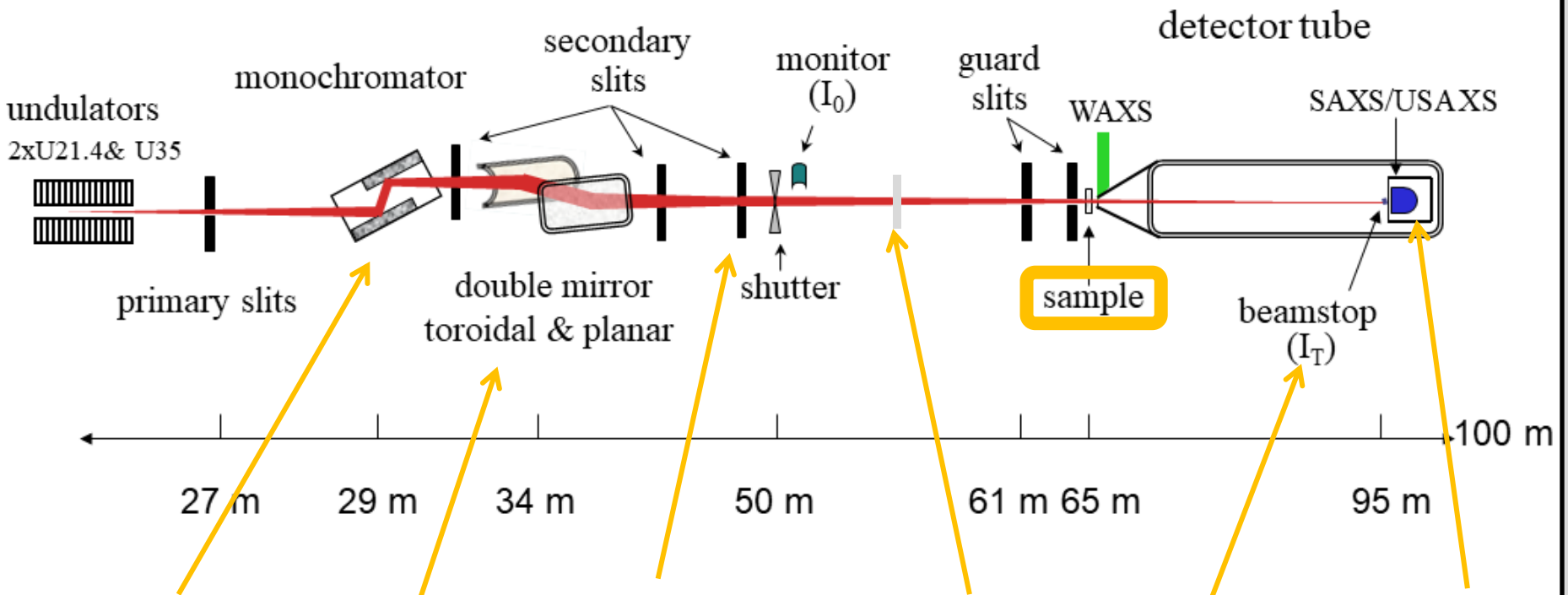
3. Scattering Amplitude (Direct Spatial Integration)

- $[L]$ $A(\vec{q}) = \int_{V_{\text{tot}}} r_e\, \rho_e(\vec{r}) e^{-i\vec{q}\cdot\vec{r}} d\vec{r}$

4. Absolute Intensity (Volume-Normalized Modulus)

- $[L^{-1}]$ $I(\vec{q}) = \frac{1}{V_{\text{tot}}} \langle |A(\vec{q})|^2 \rangle_t$

Beam line setup, example ID02 @ ESRF



Monochromator: set photon energy (bragg law)

$$E_{\max} = eV,$$
$$\lambda_{\min} = \frac{hc}{eV}.$$

Focusing and collimation grazing-incidence mirrors, such as Kirkpatrick–Baez (KB) optics, or compound refractive

$$n = 1 - \delta + i\beta.$$

Slits
- Beam Size
- Beam collimation
- Background reduction

Attenuators: reduce the photon flux

$$T = \frac{I}{I_0} = e^{-\mu x}$$

Beamstop:
- blocks the direct beam
- monitors the transmitted intensity

Detector distance: set q range

Camera: Fps,Integration time, …

Theyencheri Narayanan, Michael Sztucki, Thomas Zinn, Jérôme Kieffer, Alejandro Homs-Puron, Jacques Gorini, Pierre Van Vaerenbergh, and Peter Boesecke. Performance of the time-resolved ultra-small-angle x-ray scattering beamline with the extremely brilliant source. Applied Crystallography, 55(1):98–111, 2022.

Absolute intensity

What we measure during one acquisition: Number of photons in a pixel

$$N_{pixel}(\vec{q}) = \eta\ (\phi_0\ A\ T)\ t_{acq}\ \Delta\Omega\ e\ I(\vec{q}) + \mathrm{BG}$$

Beamline

- η : detector efficency
- ϕ_0 : incident flux == photons number per unit time and surface area
- A : section of the X-ray beam on the sample
- T : sample transmission
- $(\phi_0\ A\ T)$: integrated transmitted flux
- t_{acq} : acquisition time
- e : sample thickness
- $A\ e = V_{tot}$: sample volume inside the X-ray beam
- Δ : pixel size; r : distance between sample and pixel
- $\Delta\Omega = \left(\frac{\Delta}{r}\right)^2$: solid angle for one pixel
- Calibration, check $I_{\mathrm{H_2O}}(q \simeq 0.1 - 3\ \mathrm{nm}^{-1}) \simeq 1.6 \times 10^{-2}\ \mathrm{cm}^{-1}$.

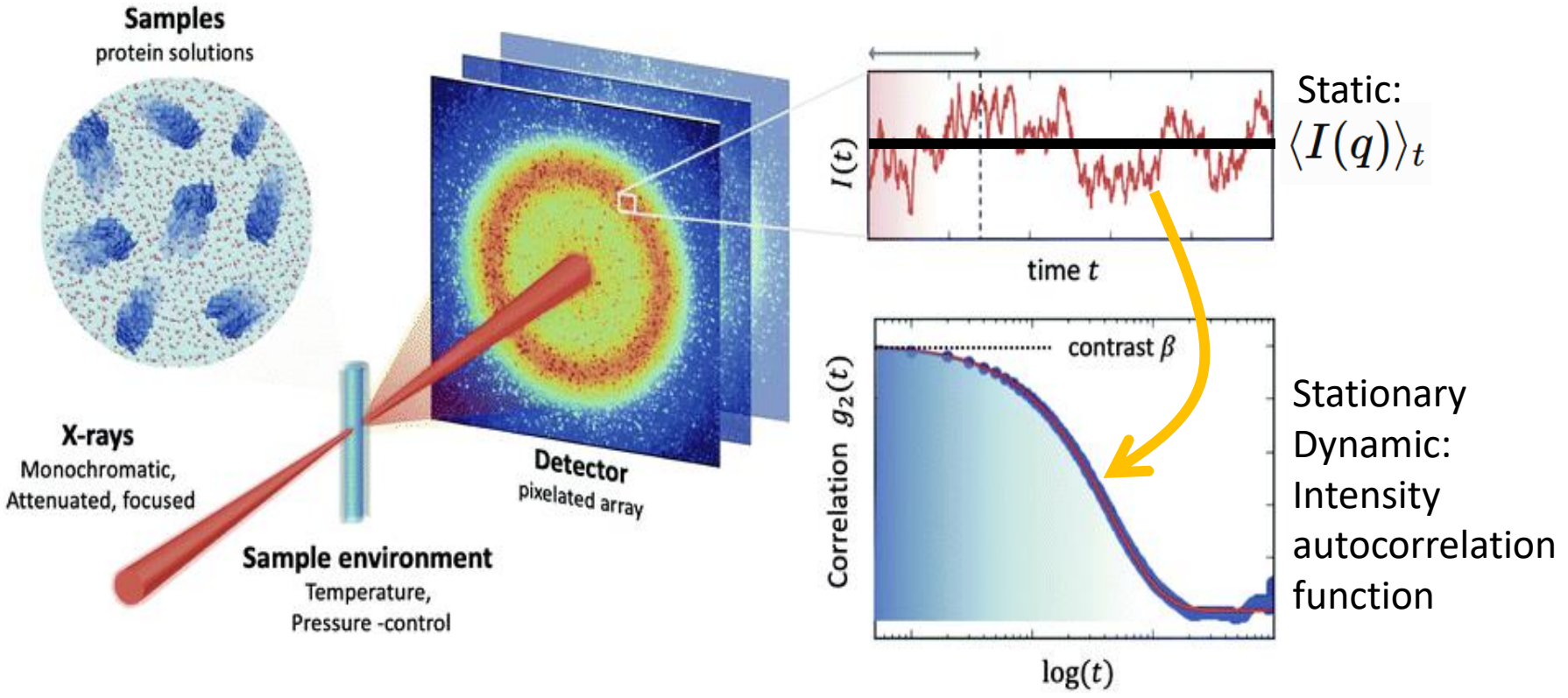
$$I(\mathbf{q}) = \frac{I_{\mathrm{corr,solution}}(\mathbf{q})}{e_{\mathrm{solution}}} - \frac{I_{\mathrm{corr,solvent}}(\mathbf{q})}{e_{\mathrm{solvent}}}, \quad [\mathrm{L}^{-1}]$$

Note on scattering and averages

- Spatial averaging, isotropy/anisotropy
- Temporal averaging,

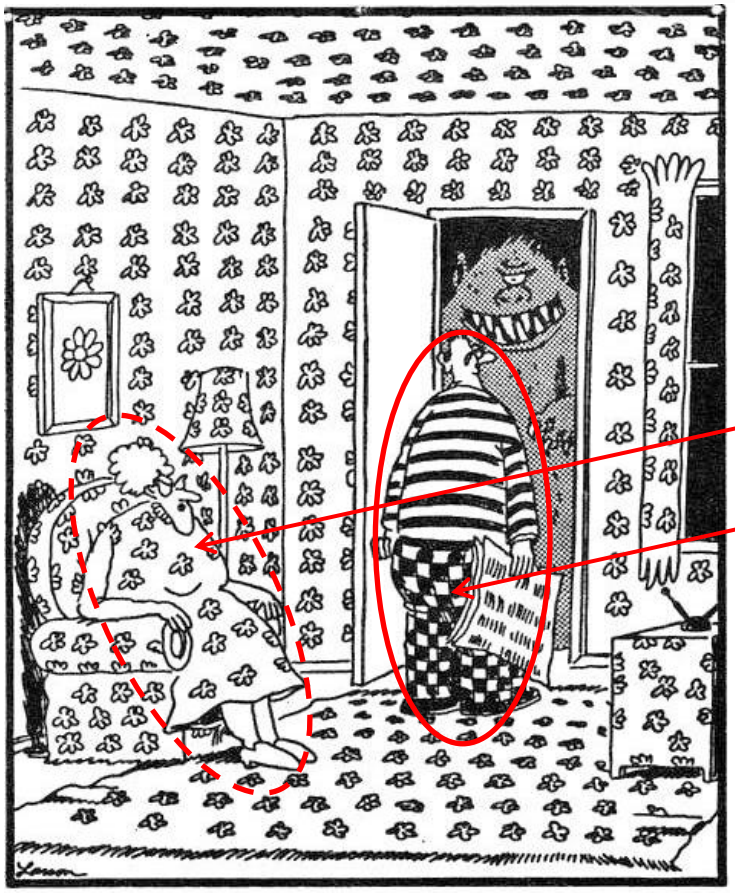
$$I(q) = I_{\text{sample}}(q) - I_{\text{bck}}(q) \simeq \frac{r_e^2}{V}\left\langle \left| \int_V \Delta\rho(\mathbf{r}) e^{i\mathbf{q}\cdot\mathbf{r}}\, d^3\mathbf{r} \right|^2 \right\rangle_t$$

One pixel on the camera contains the average over
the whole scattering volume
≠ image in real space

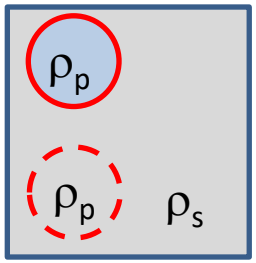


Note on Scattering contrast $\Delta\rho$ (electron density in SAXS)

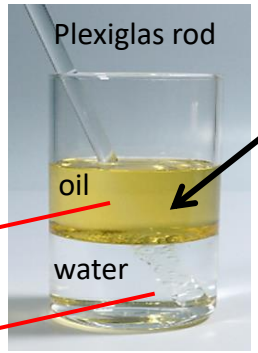
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When the monster came, Lola, like the peppered moth and the arctic hare, remained motionless and undetected. Harold, of course, was immediately devoured.



$\Delta\rho^2=(\rho_p-\rho_s)^2$

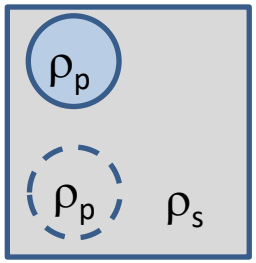


Matched contrast between
The rod and the solvent
No scattering
Same index of refraction

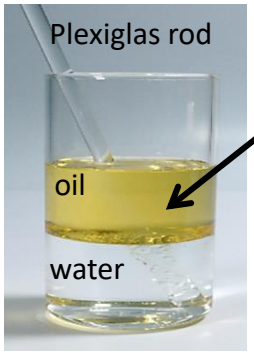
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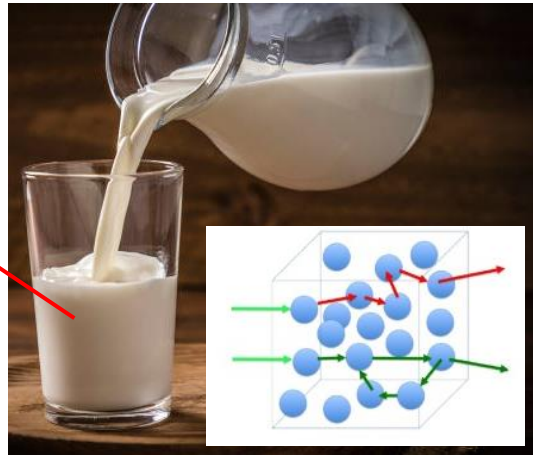




$\Delta\rho^2=(\rho_p-\rho_s)^2$



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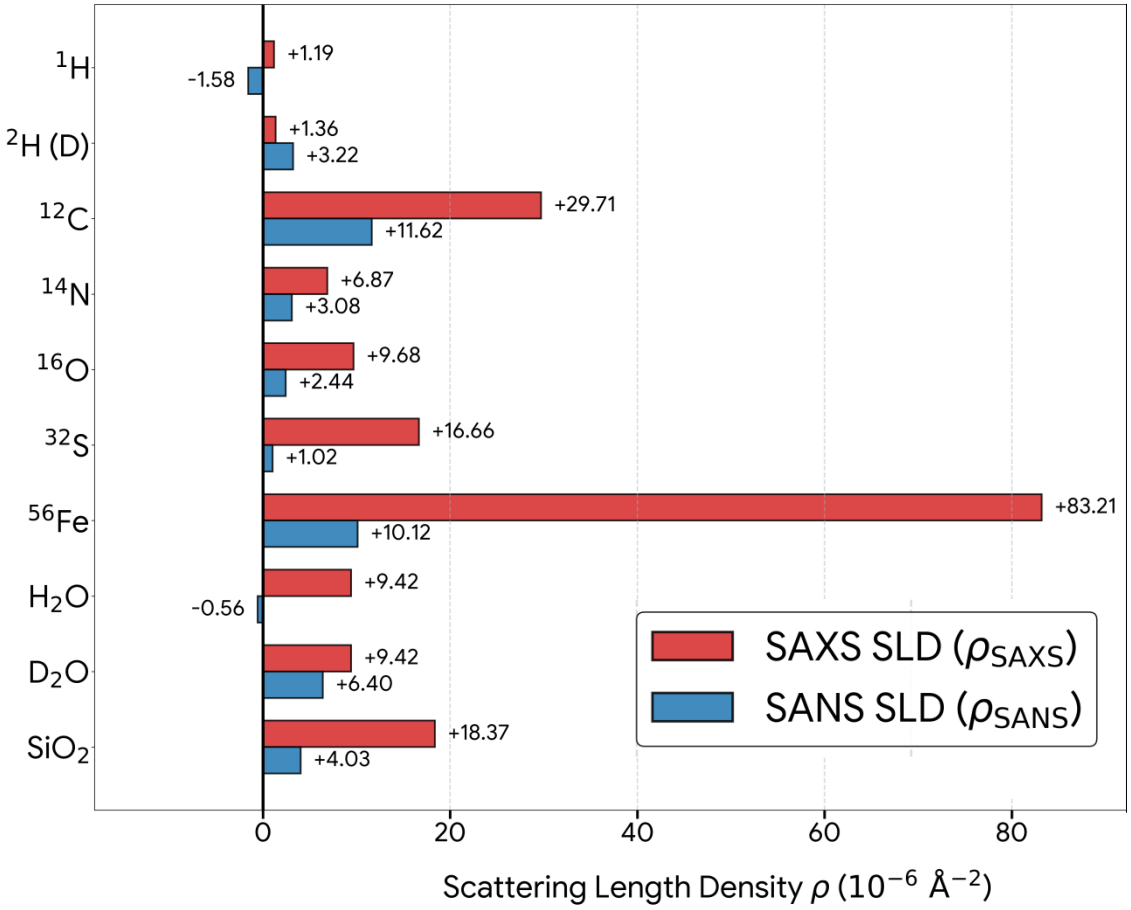


Multiple scattering: lost the q dependency

Note on Scattering and contrast – SAXS vs SANS

Electron scattering density $\rho_e(e/nm^3) = \frac{N_e}{v(nm^3)} = \frac{N_e N_{Avogadro} d(g/cm^3)}{10^{21} M(g/mol))} = \frac{602 N_e d(g/cm^3)}{M(g/mol))}$

ρ_{SLD}=scattering ***length*** density (SAXS) = $r_e\rho$ [L^{-2}]



Scattering applied to undeformable particles (colloids)

Single scattering in the far field limit

Scattered intensity

$$I(\mathbf{q}) = \frac{r_e^2}{V} \left| \mathcal{F}\left[\Delta\rho(\mathbf{r})\right](\mathbf{q}) \right|^2$$

Scattering wave vector $\mathbf{q} = \mathbf{k}_s - \mathbf{k}_0$

Classical Thomson scattering length $r_e = \dfrac{e^2}{4\pi\varepsilon_0 m_e c^2} = 2.818 \times 10^{-6}\,\mathrm{nm}$

Electron-density contrast $\Delta\rho_p(\mathbf{r}) = \rho_p(\mathbf{r}) - \rho_{\mathrm{solvent}}$

In the case of undeformable particles

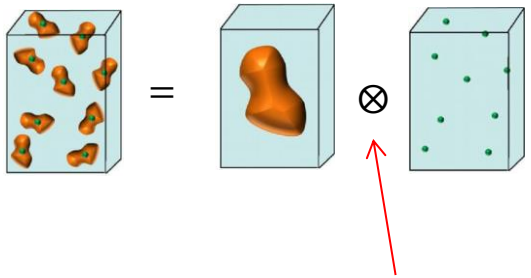
$$I(\mathbf{q}) = \phi\, r_e^2 \Delta\rho^2 V_p P(\mathbf{q}) S(\mathbf{q})$$

ϕ	Volume fraction of the particles	
$\Delta\rho$	Average contrast between solvent and the particle [e/nm^3]	
V_p	volume of the particle [nm^3]	
P(q)	Form factor (no unit)	*P(q→0)=1*
S(q)	Structure factor (no unit)	*S(q→∞)=1*

Scattering applied to undeformable particles (colloids)

Real Space

$$\Delta\rho(r) = \Delta\rho_{colloid}(r) \otimes \sum \delta r_i$$



Convolution

As long as the colloids are undeformable

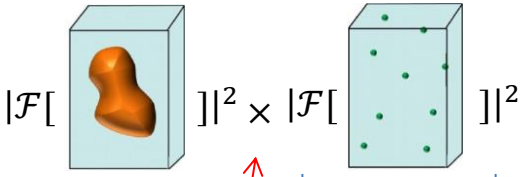
Fourrier Space

$$I(q) \propto |\mathcal{F}[\Delta\rho(r)]\,|^2$$

$$I(q) \propto |\mathcal{F}[\Delta\rho_{colloid}(r) \otimes \sum \delta r_i]|^2$$

$$I(q) \propto |\mathcal{F}[\Delta\rho_{colloid}(r)]|^2 \times |\mathcal{F}[\sum \delta r_i]|^2$$

Wiener–Khinchin theorem



P(q) Form Factor

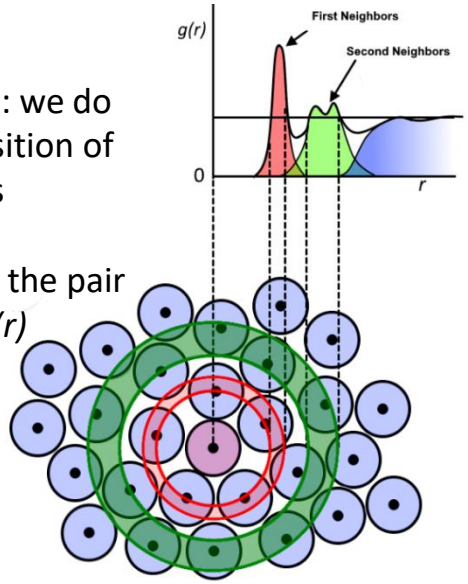
S(q) Structure Factor

Product

Scattering with colloids is simple!

Yes, but …

- Lost phase information: we do not know the exact position of each individual colloids
- We are **only** sensitiv to the pair distribution function *g(r)*



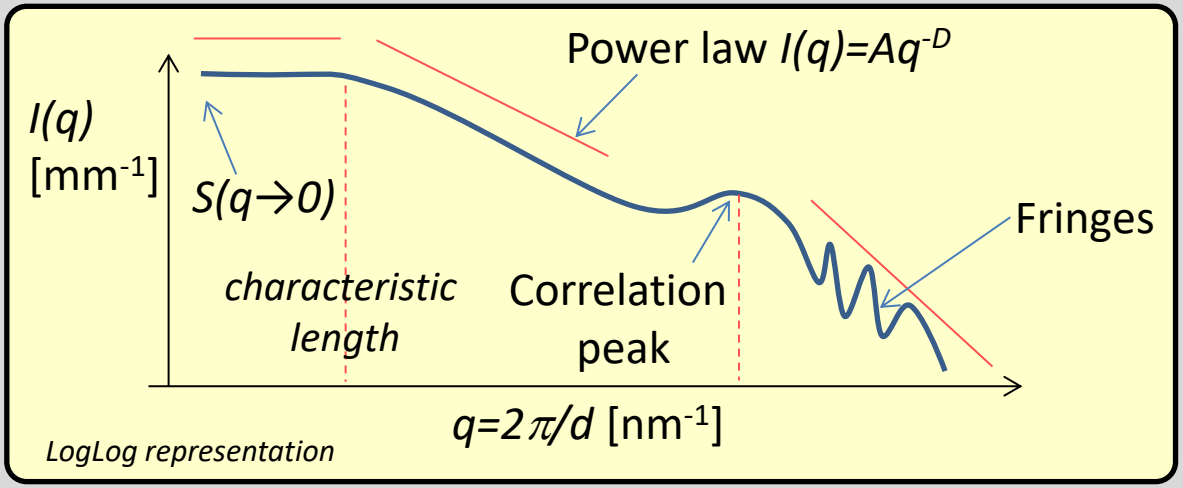
Many real space configurations have the same *g(r)*

Structure factor

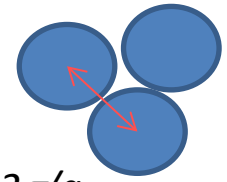
$$S(q) = 1 + \mathrm{N/V} \int [g(r) - 1]\, e^{-i\mathbf{q}\cdot\mathbf{r}} d\mathbf{r}.$$

"Small angle neutron scattering." F Cousin. EPJ web of conferences. 104. EDP Sciences, 2015

Useful properties of the scattering intensity



Correlation peak =pseudo period



$d=2\pi/q_{peak}$

Invariant: in a 2 phases system

$$Q = \int_0^\infty q^2 I(q) dq = 2\pi^2 r_e^2 (\Delta\rho_e)^2 \phi(1-\phi)$$

Require absolute intensity

Q [nm^{-4}]

Structure factor

$$S(q,\phi) = \frac{I(q,\phi)}{I(q,\phi_0)} \frac{\phi_0}{\phi}$$

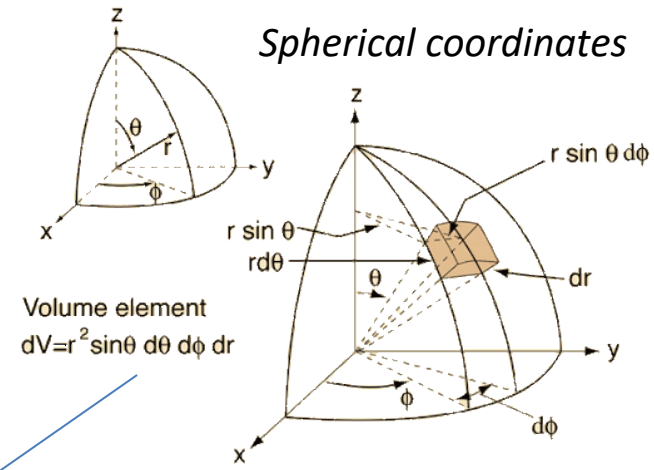
S(q→0), long wavelength limit. At equilibrium, related to the compressibility β_T:

$$S(0) = \frac{N}{V} k_B T \beta_T$$

Power law $I(q)=Aq^{-D}$	Interpretation
D=0	Homogeneous and continuous
D=1	filament
D=2	sheet
D=d_f	fractal
D=4	Smooth interface, $A=2\pi\Delta\rho^2 S_v$ Sv=surface area (S) per unit volume (V) of the sample (S/V).
3<D<4	Rough interface with D=6-d_s

Form factor *P(**q**) of a sphere*

$$\Delta\rho_p(\mathbf{r}) = \begin{cases} \Delta\rho, & r \le R, \\ 0, & r > R, \end{cases} \quad \text{and} \quad V_p = \frac{4\pi R^3}{3}$$



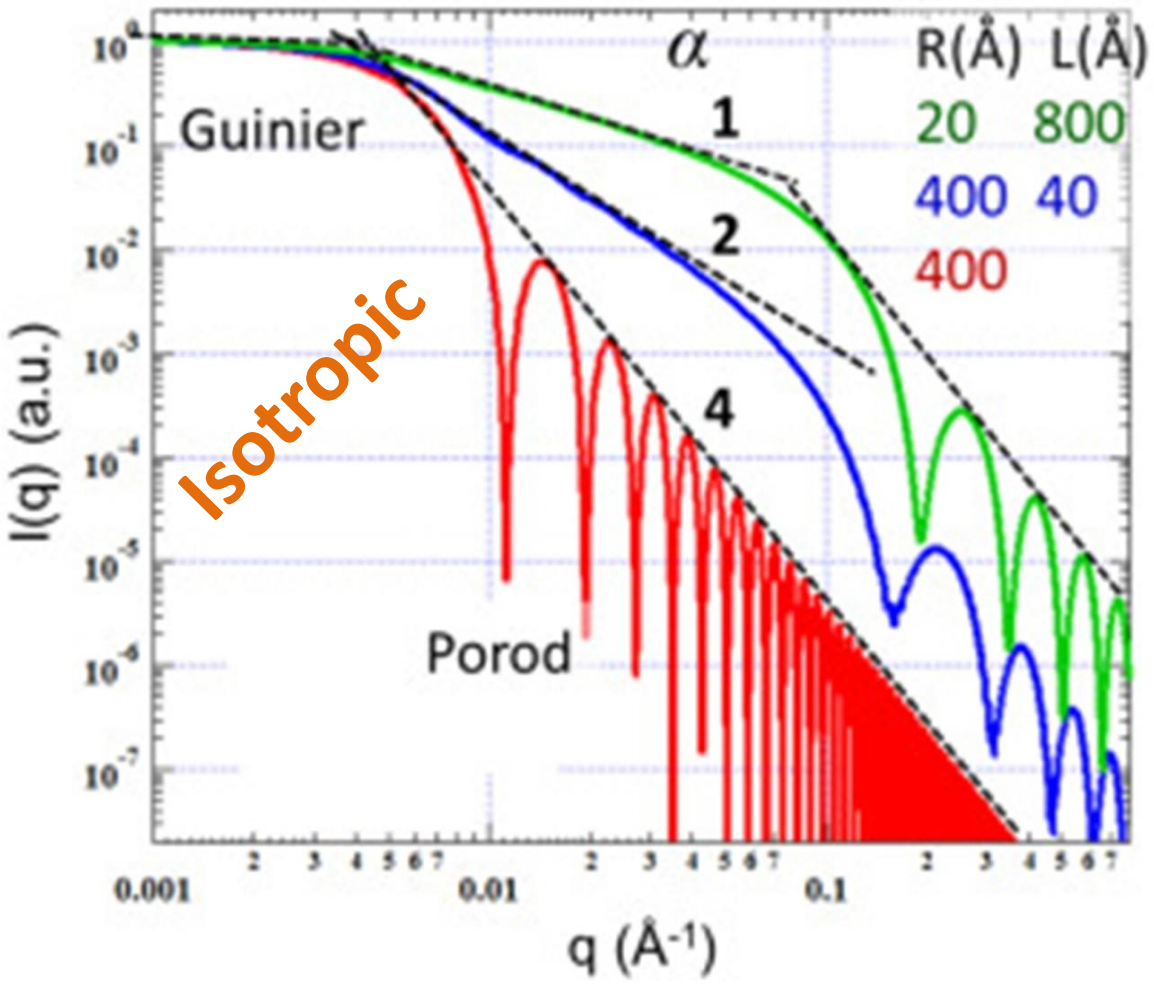
$$P(\mathbf{q}) = \frac{\left|\mathcal{F}[\Delta\rho_p(\mathbf{r})]\,(\mathbf{q})\right|^2}{(\Delta\rho V_p)^2} \quad \text{and} \quad P(0) = 1$$

$$A(\mathbf{q}) = r_e \int_V \Delta\rho(\mathbf{r}) e^{i\mathbf{q}\cdot\mathbf{r}}\, d^3\mathbf{r} = r_e \Delta\rho \int_0^R r^2 dr \int_0^\pi \sin\theta\, d\theta \int_0^{2\pi} d\phi\, e^{iqr\cos\theta}$$

$$A(q) = 4\pi r_e \Delta\rho \frac{\sin(qR) - qR\cos(qR)}{q^3}$$

$$P(q) = \left[3\frac{\sin(qR) - qR\cos(qR)}{(qR)^3}\right]^2$$

Form factor *P(**q**)* and the shape of the particle





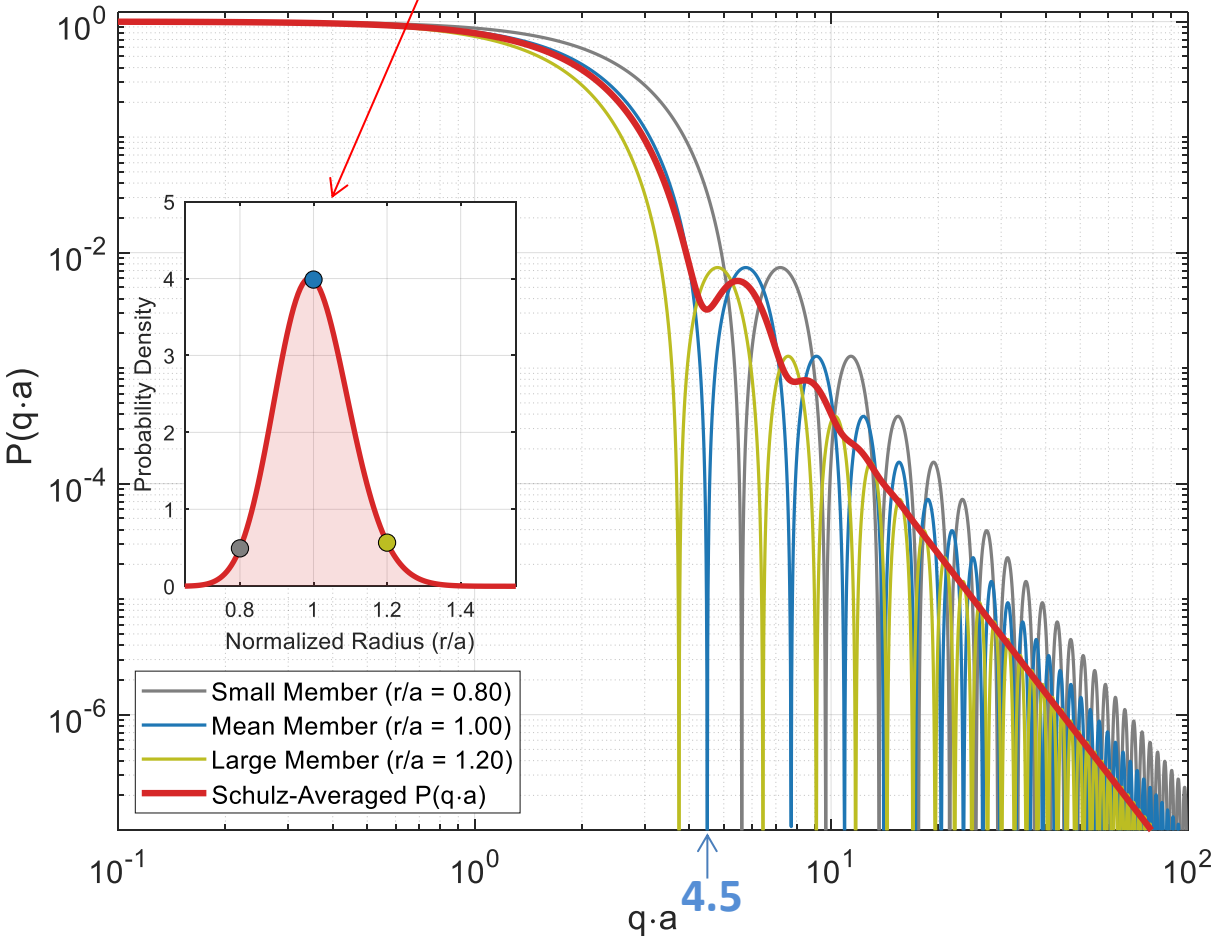
F. Herrera, G. Rumi, P. Y. Steinberg, A. Wolosiuk, P. C. Angelomé, *ChemCatChem* 2023, 15, e202300490.

Form factor *P(**q**)* and polydispersity

$$P_{\text{poly}}(q) = \frac{\int_0^\infty f(R)\, V(R)^2\, P(q,R)\, dR}{\int_0^\infty f(R)\, V(R)^2\, dR}$$

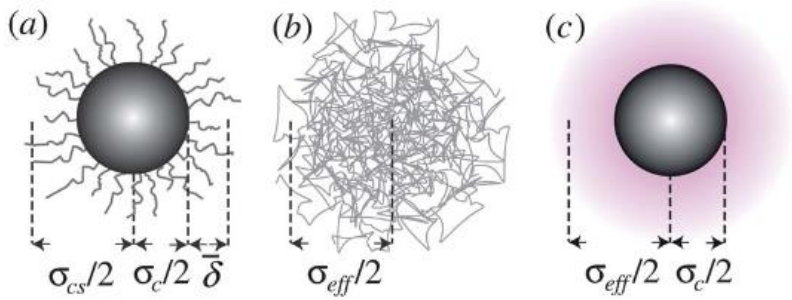
weighted sum of the form factor of each particles

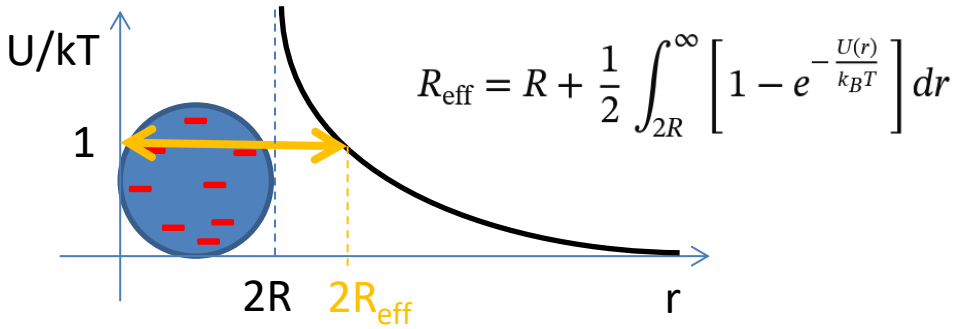
S(q)=1



How to measure *P(q)?*

- *I(q)* at Low volume fraction: $\langle d \rangle = 2R\left(\frac{\phi_{\max}}{\phi}\right)^{1/3} \gg 2R$
- **In practice** make a series in volume fraction and plot $I(q, \phi)/\phi$
  Trade of between too low ϕ: noisy and to high ϕ : $S(q) \neq 1$
- ⚠ in attractive systems, it is hard to measure P(q) due to aggregation even at low phi
- ⚠ in soft sphere systems you may consider an effective radius (Barker-Henderson effective radius) to calculate $\langle d \rangle$

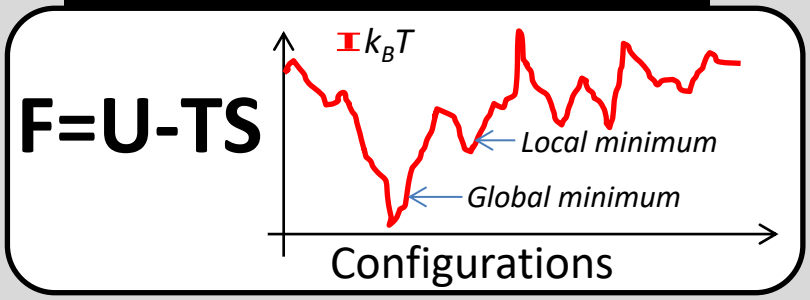




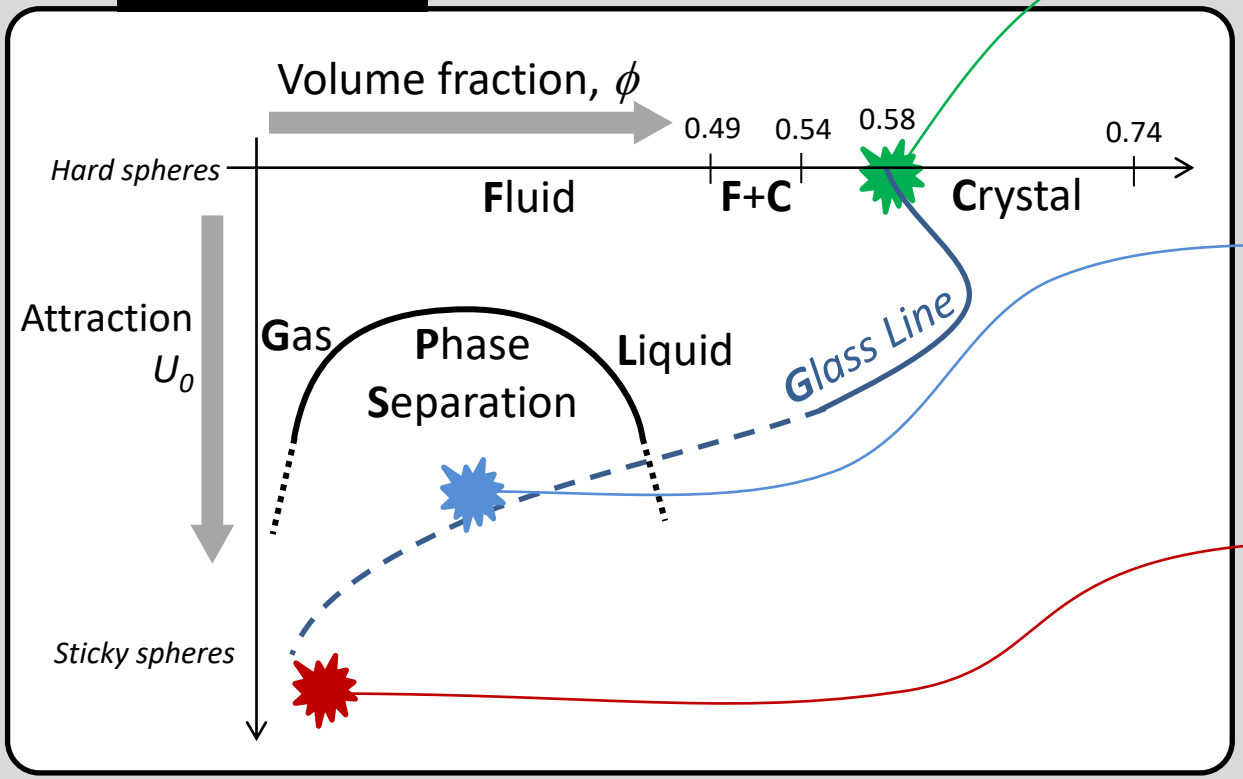
Structure and kinetics in the freezing of nearly hard spheres. J. A. Perera-Burgos, et al. Soft Matter 9, 239 (2013).
In search of colloidal hard spheres. C. Patrick Royall, Wilson C. K. Poon and Eric R. Weeks. Soft Matter 9, 17 (2013).
Self-Consistent Field Calculations of Interactions between Chains Tethered to Spherical Interfaces. M. R. Tomlinson, et al., Macromolecules, 29, 415(1996).

Colloids state diagram

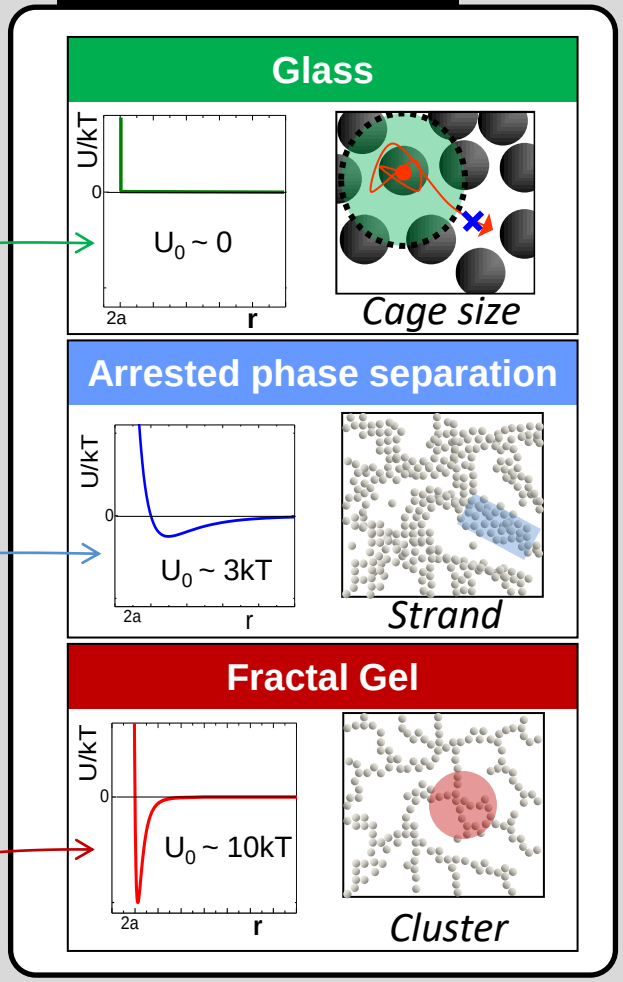
Equilibrium/Out of equilibrium



State diagram



Out of equilibrium Soft solids

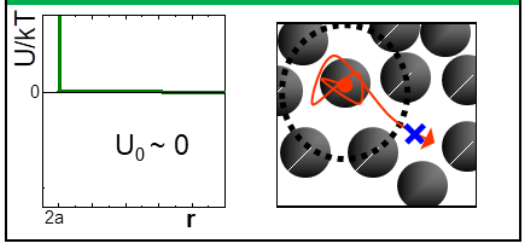


Colloidal spheres may struture in complex soft solids

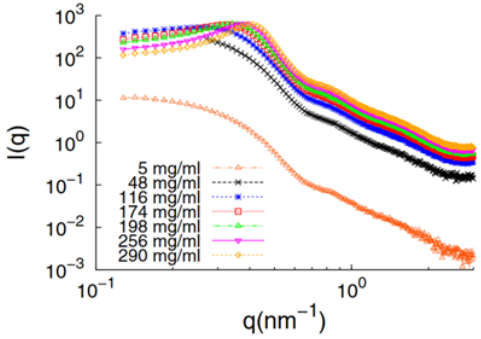
F. Sciortino. "One liquid, two glasses." Nature materials 1, 145 (2002).
R. Mezzenga, P. Schurtenberger, A. Burbidge, M. Michel. Understanding foods as soft. Nat. materials 4, 729 (2005)
V. Trappe and P. Sandkühler. "Colloidal gels—low-density disordered solid-like states." COCIS 8, 494 (2004)

Examples:

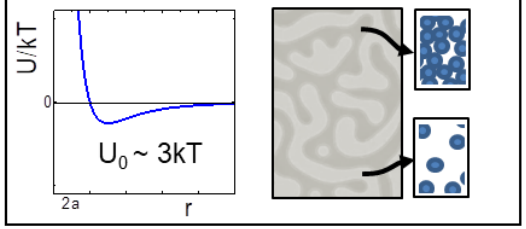
Glass



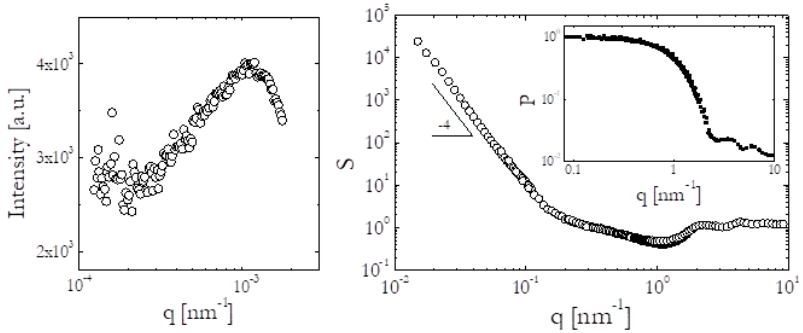
Dense Fluid like structure



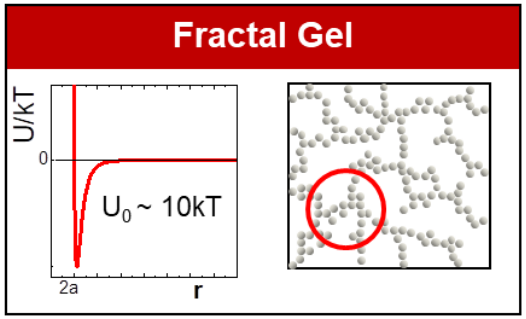
Arrested phase separation



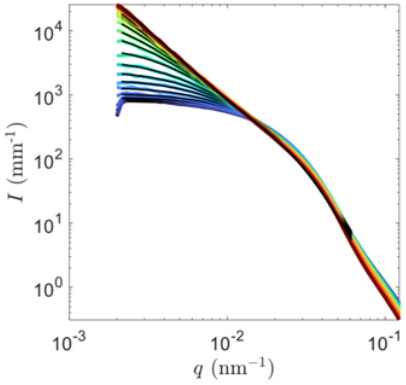
Bi-continuous Network with a sharp interfaces between the 2 phases



Fractal Gel



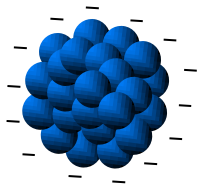
Network= Dense packing of fractal clusters



α-crystallin an eye lens protein that behave like a hard sphere

= chaperon protein in the eye lens

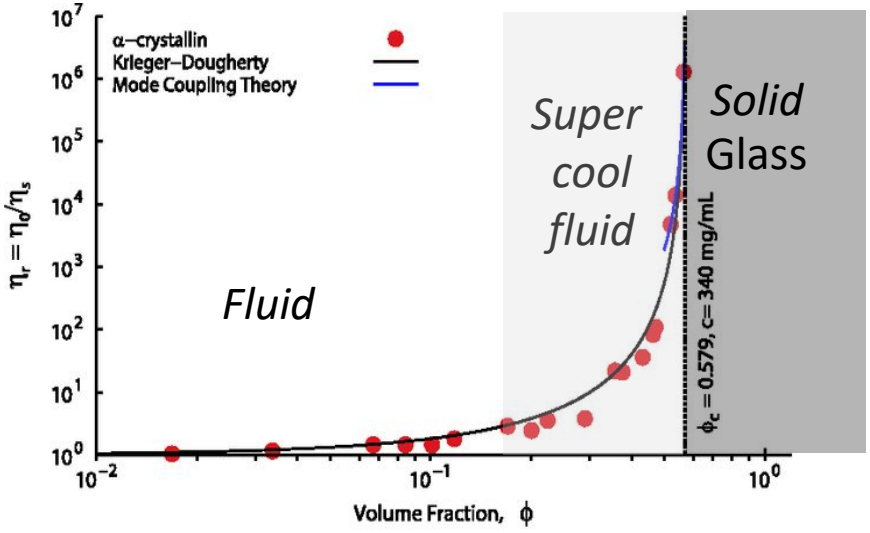
Globular Proteins
α-crystallin



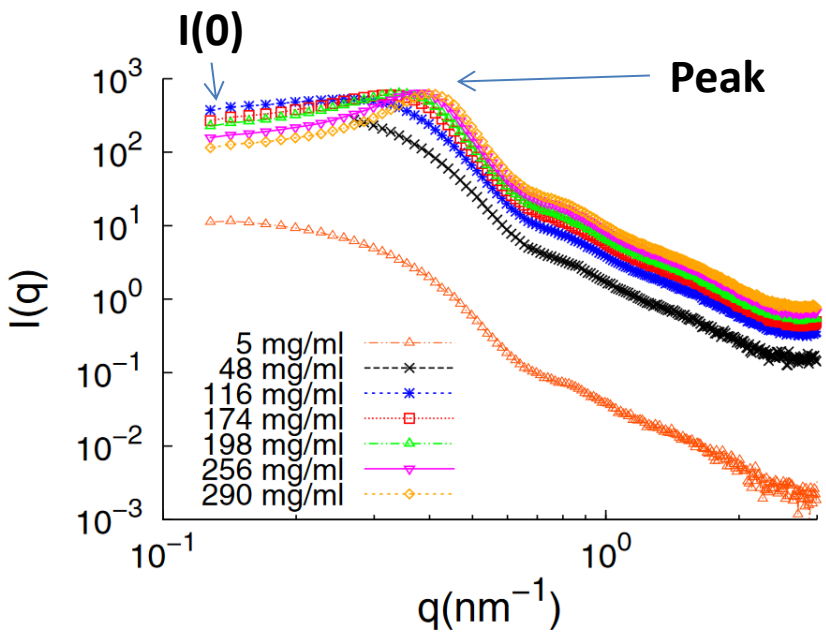
~ 800 kDa
multisubunit protein
polydisperse
repulsive interactions

Hard sphere-like glass transition in eye lens α-crystallin solutions. G Foffi, G Savin, S Bucciarelli, N Dorsaz, GM Thurston, A Stradner, P Schurtenberger. PNAS 111 16748 (2014)

Viscosity



Scattering



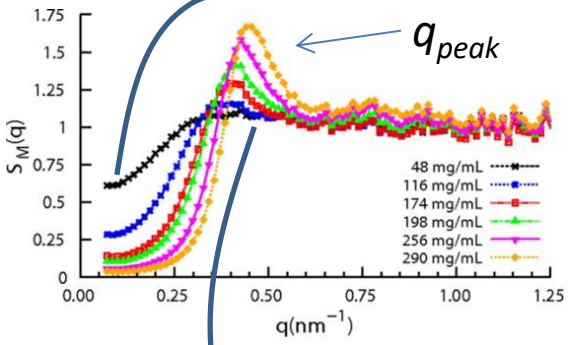
- Structure factor
- Neighbour peak and its q-position with ϕ
- S(0), from compressibility to the equation of state
- Solving the Ornstein Zernike equation

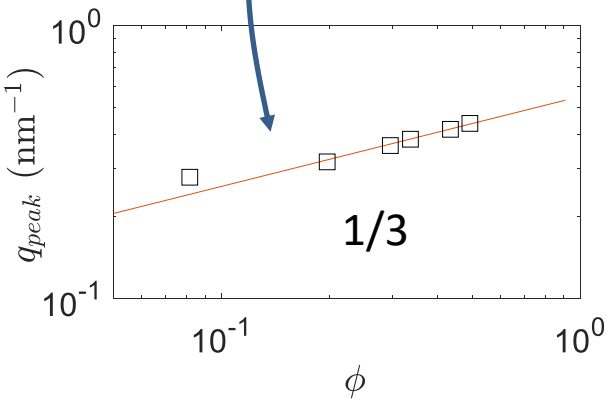
α-crystallin, interparticle distance & compressibility

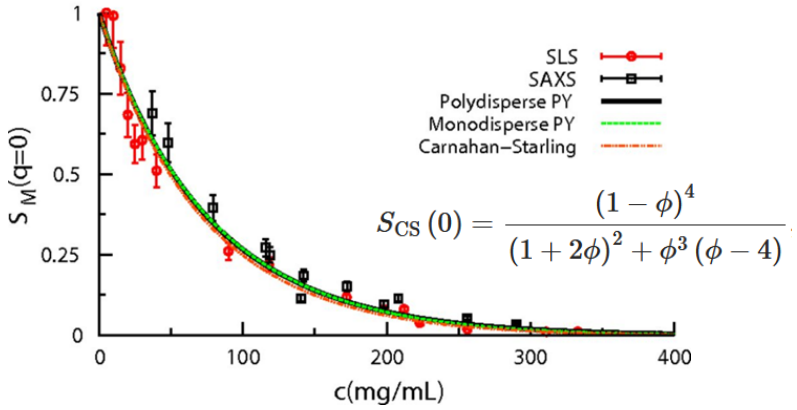
Structure Factor

$$S(q) = \frac{I(q,c)c_0}{I(q,c_0)c}$$

Form Factor







$$S_{CS}(0) = \frac{(1-\phi)^4}{(1+2\phi)^2 + \phi^3(\phi-4)}$$

ρ is the number density (N/V)

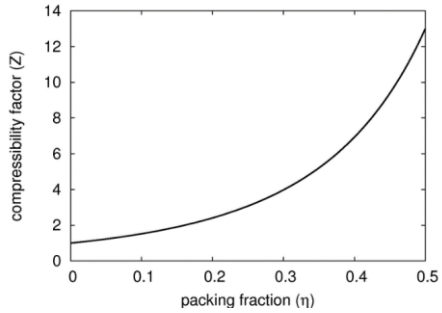
κ_T is the **isothermal compressibility**, defined as:

$$\kappa_T = -\frac{1}{V}\left(\frac{\partial V}{\partial P}\right)_T$$

Carnahan–Starling:

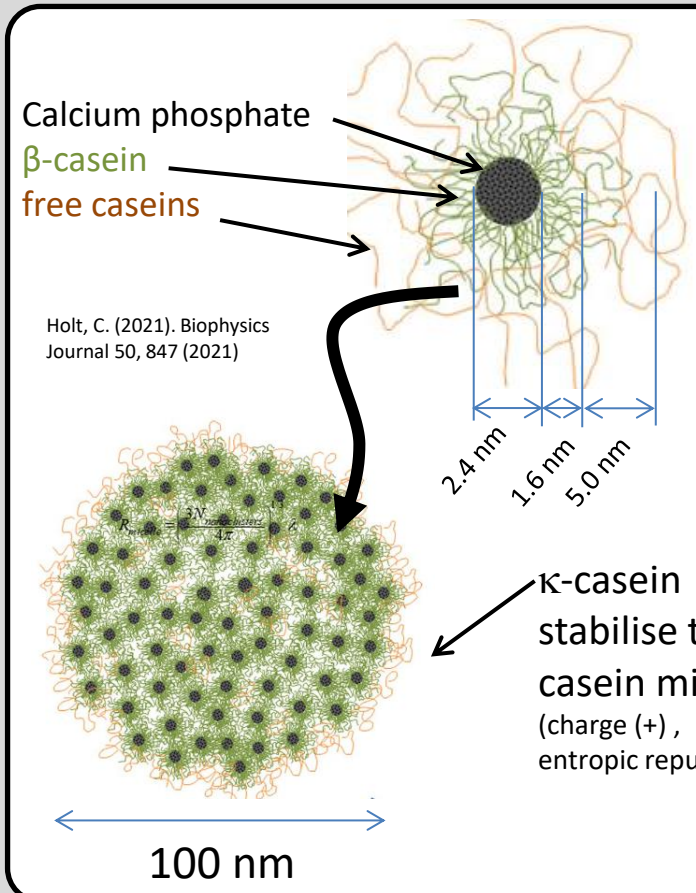
Equation **O**f **S**tate for hard spheres

$$Z = \frac{pV}{Nk_BT} = \frac{1}{(1-\phi)^3}\left(1 + 3\phi + 3\phi^2 - \phi^3\right)$$



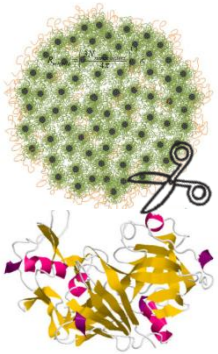
Casein micelles and the early stage of cheese making

= carrier of proteins and salts with low solubilities



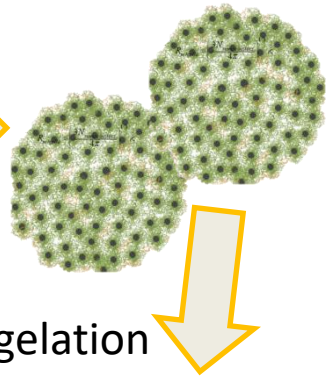
- Time resolved SAXS and gelation
- Isosbestic point
- Computing the radial distribution function
- Invariant
- A fractal network

Gelation



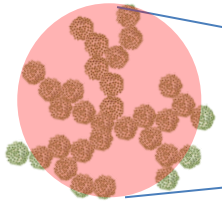
Chymosin:
Emzyme that
Cut κ-casein

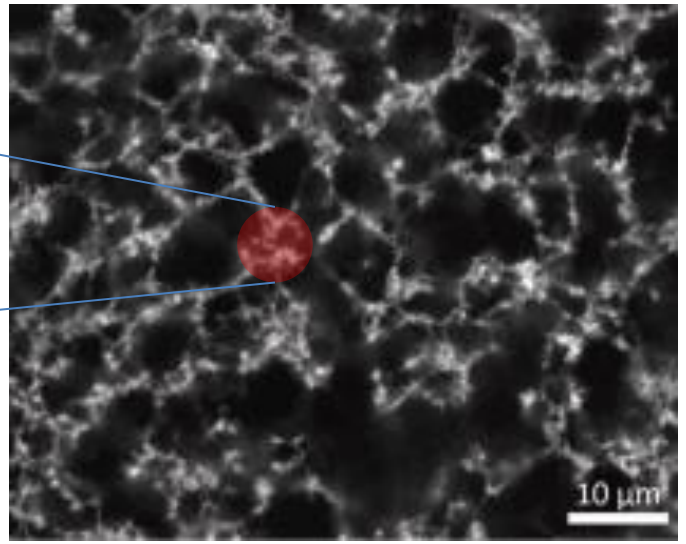
Agregation



gelation

Confocal image

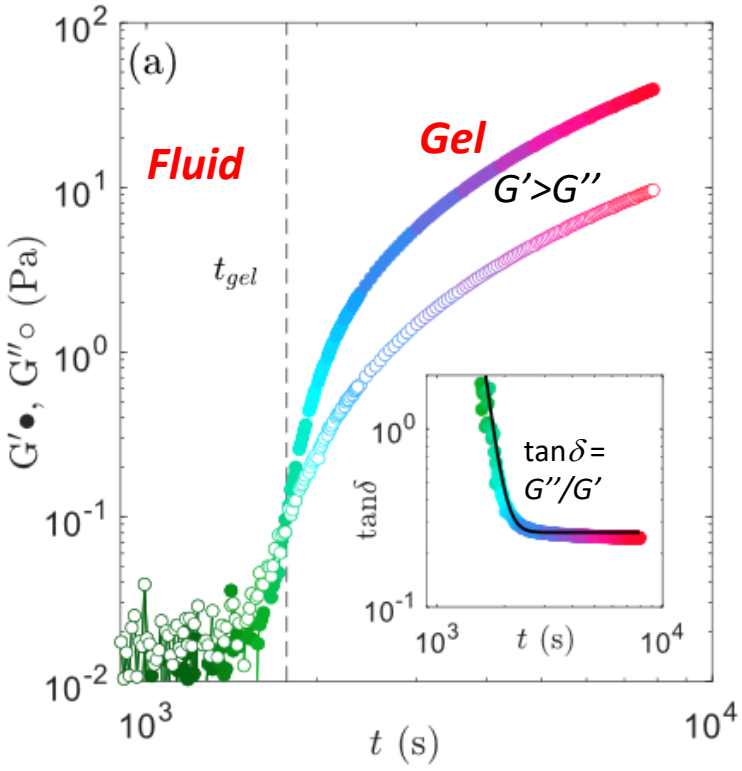




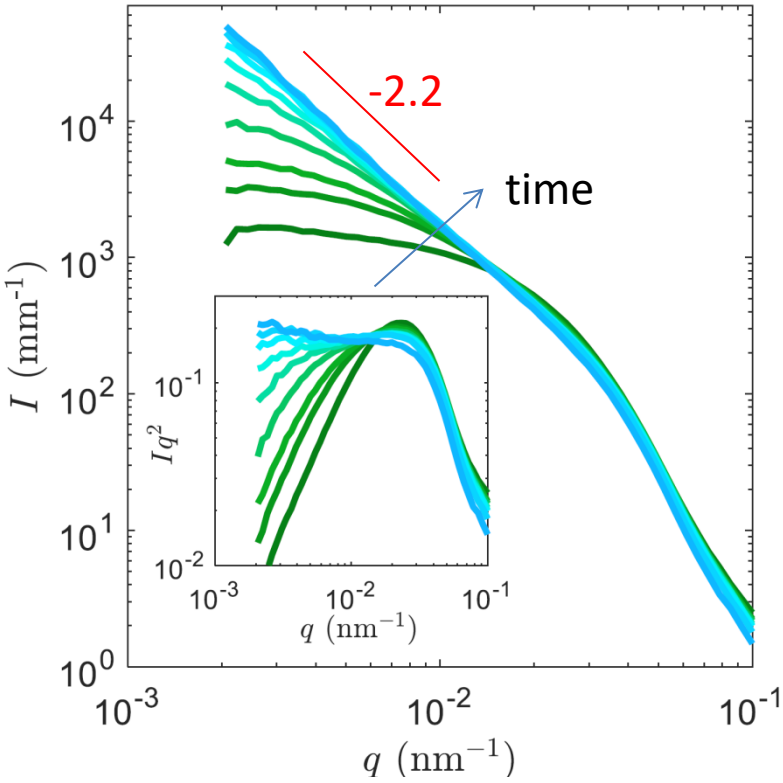
Gel = Network of particles
Can we be more specific?

Casein micelles and fractal gels

Rheology



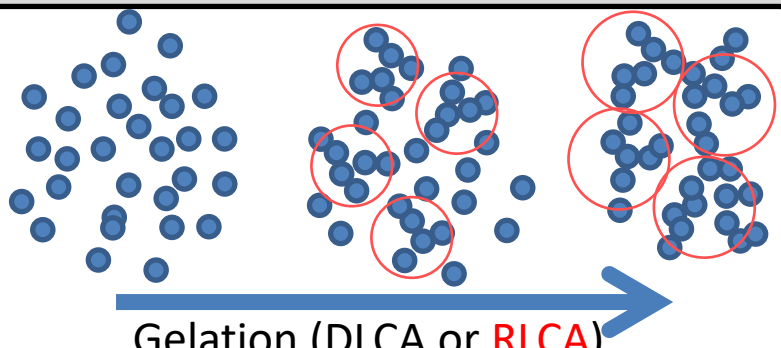
SAXS



Interpretation

How do you form a solid with a volume fraction of 10%?

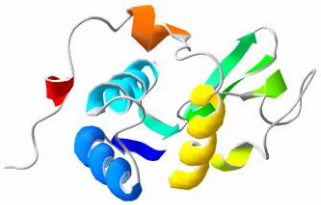
fractal clusters of size ξ and fractal dimension d_f



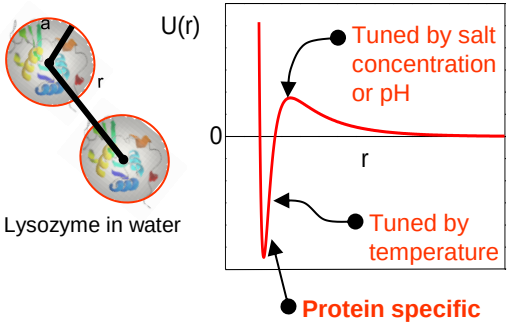
Lysozyme

= enzyme (glycoside hydrolase)

Interaction potential



Globular protein
4.5x3x3nm monodisperse
Charged: pH=7.8→+8e

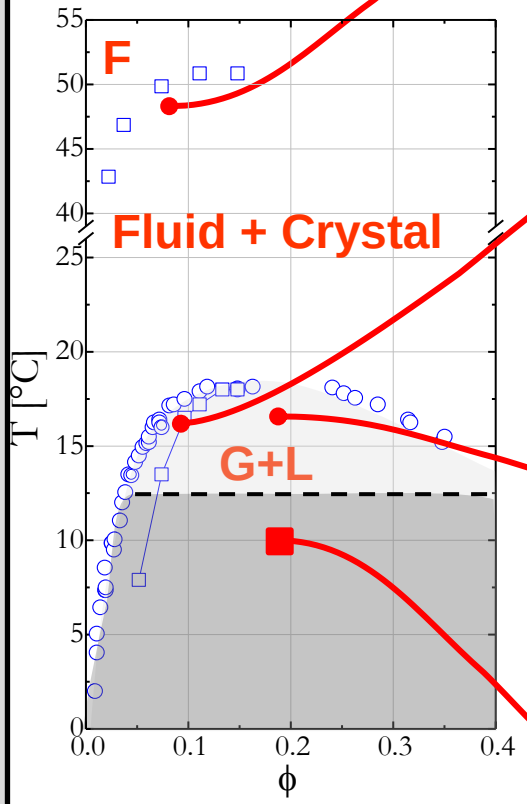


Interplay between Spinodal Decomposition and Glass Formation in Proteins Exhibiting Short-Range Attractions. F Cardinaux, T Gibaud, A Stradner, P Schurtenberger PRL 99, 118301 (2007)

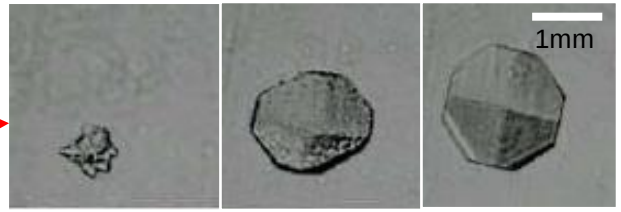
- Phase separation
- A multiscale structure

State diagram

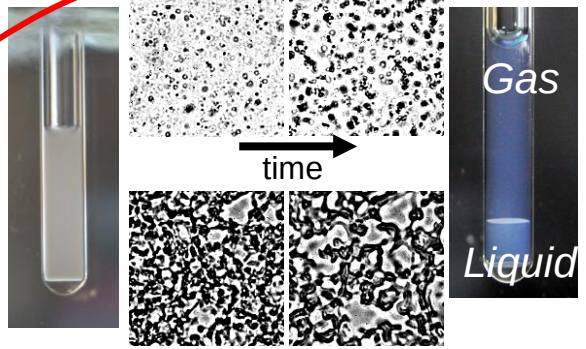
[Hepes] = 20mM → pH=7.8
[NaCl] = 500mM



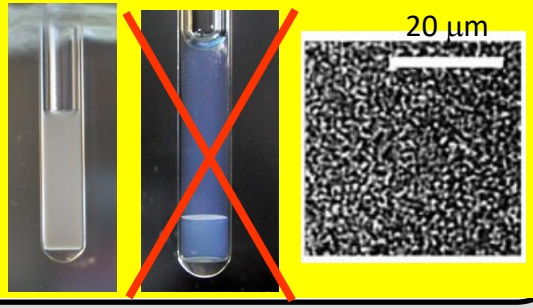
Crystallization



Phase separation

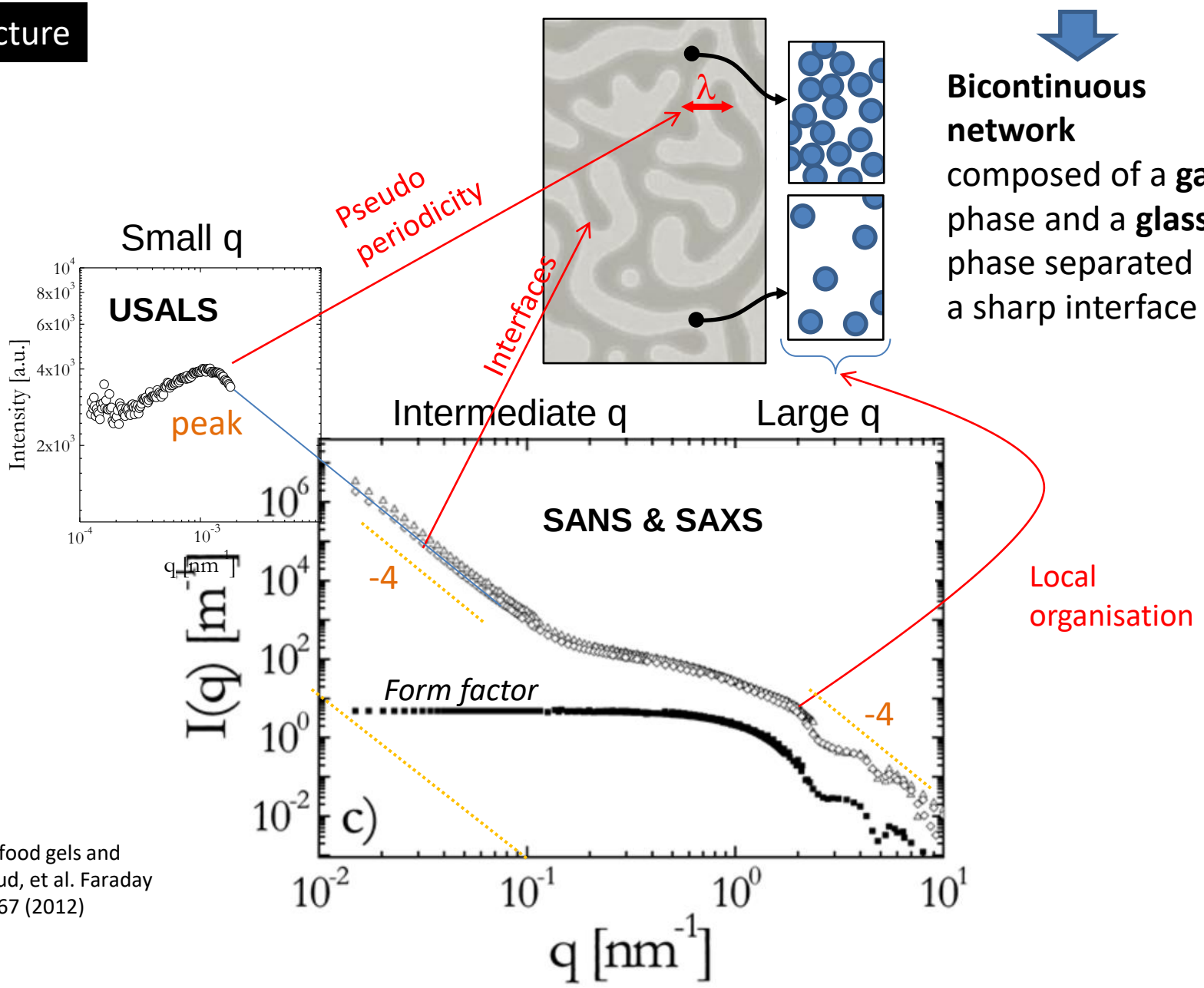


Arrested phase separation



Lysozyme and arrested phase separation

Structure



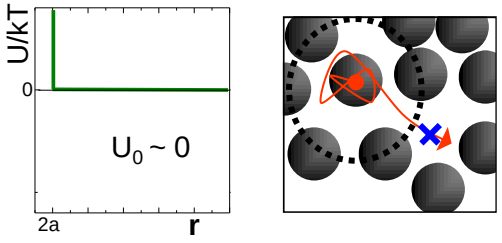
Bicontinuous network composed of a **gas** phase and a **glassy** phase separated by a sharp interface

New routes to food gels and glasses. T Gibaud, et al. Faraday Discuss. 158, 267 (2012)

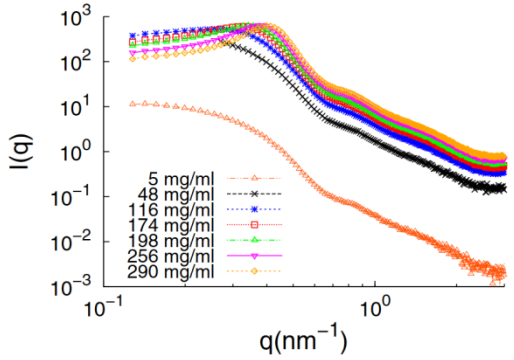
Conclusion

Thank you for your time and attention
thomas.gibaud@ens-lyon.fr

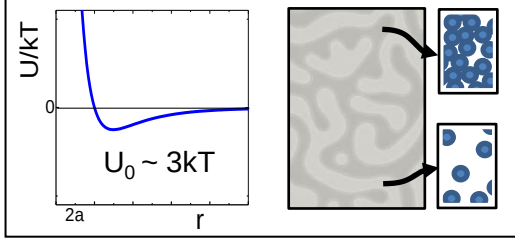
Glass



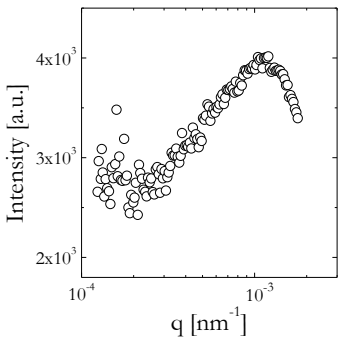
Dense Fluid like structure

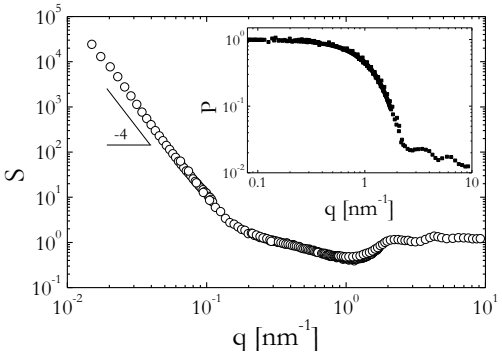


Arrested phase separation

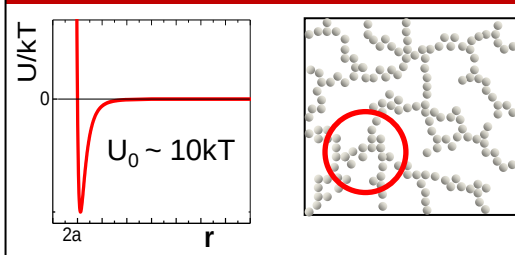


Bi-continuous network

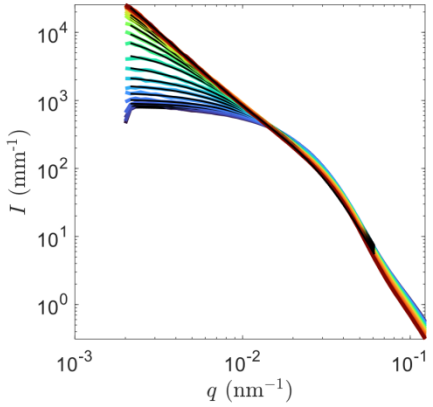




Fractal Gel



Network=
Dense packing of fractal clusters



Conclusion

Thank you for your time and attention
thomas.gibaud@ens-lyon.fr

Resource suggestions

As Marianne Emperor says: **you are not alone!**

- **Workshop:** Bombannes, HERCULES, ICSM Hands-On SAXS/SANS School, …
- **Books/articles:**

Neutrons, X-rays, and Light: Scattering Methods Applied to Soft Condensed Matter (2024), Scattering Methods and their Application in Colloid and Interface Science (2018), …

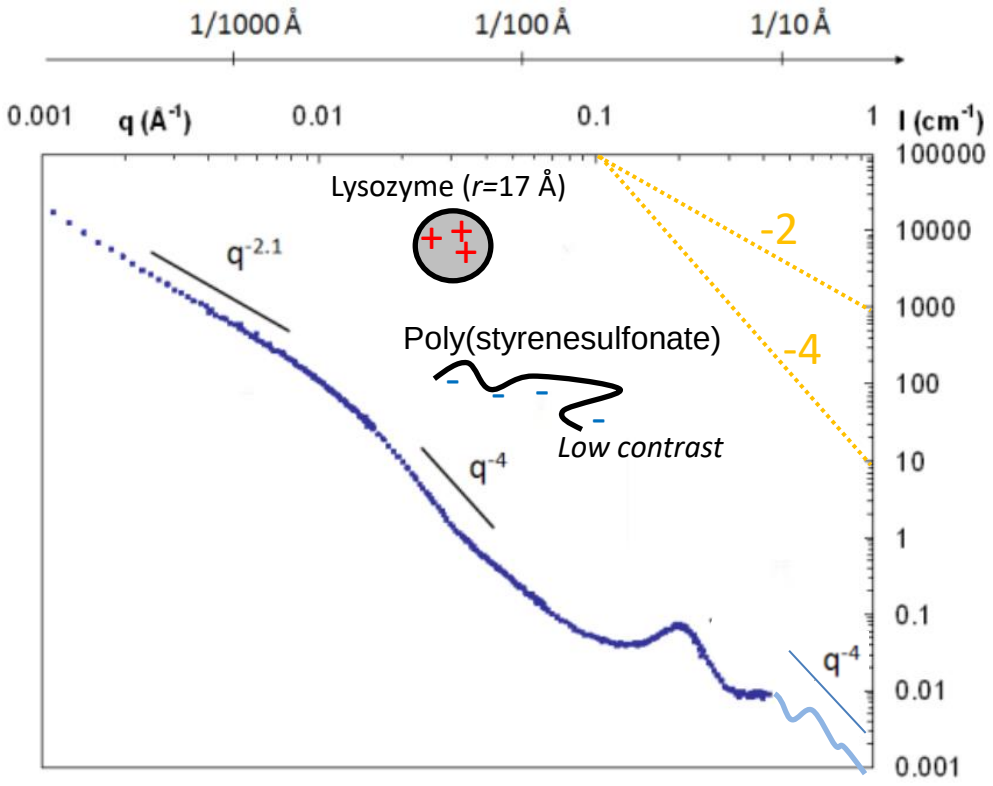
- **Online:** SAStutorials.org
- **Software:** saxsview, sasview, …
- **Exercises:** https://perso.ens-lyon.fr/thomas.gibaud/cocogelsaxs/
  a) Background subtraction, invariant and form factor
  b) Hard spheres dispersions: $I(q,\phi)$
  c) Fractal gels kinetics: $I(q,t)$

Thanks for the support

Institut des Sciences de la Terre d'Orléans ISTO
RÉCIPROCS
ICMN Interfaces, Confinement, Matériaux et Nanostructures UMR 7374
Anton Paar
xenocs Exploring the very small
GDR SoPhy
Malvern Panalytical a spectris company
Société Française de Physique
FRANCE 2030 PROGRAMME DE RECHERCHE MATÉRIAUX ÉMERGENTS
GDR Groupement de recherche DUMBIO
2F DN Fédération Française de Diffusion Neutronique

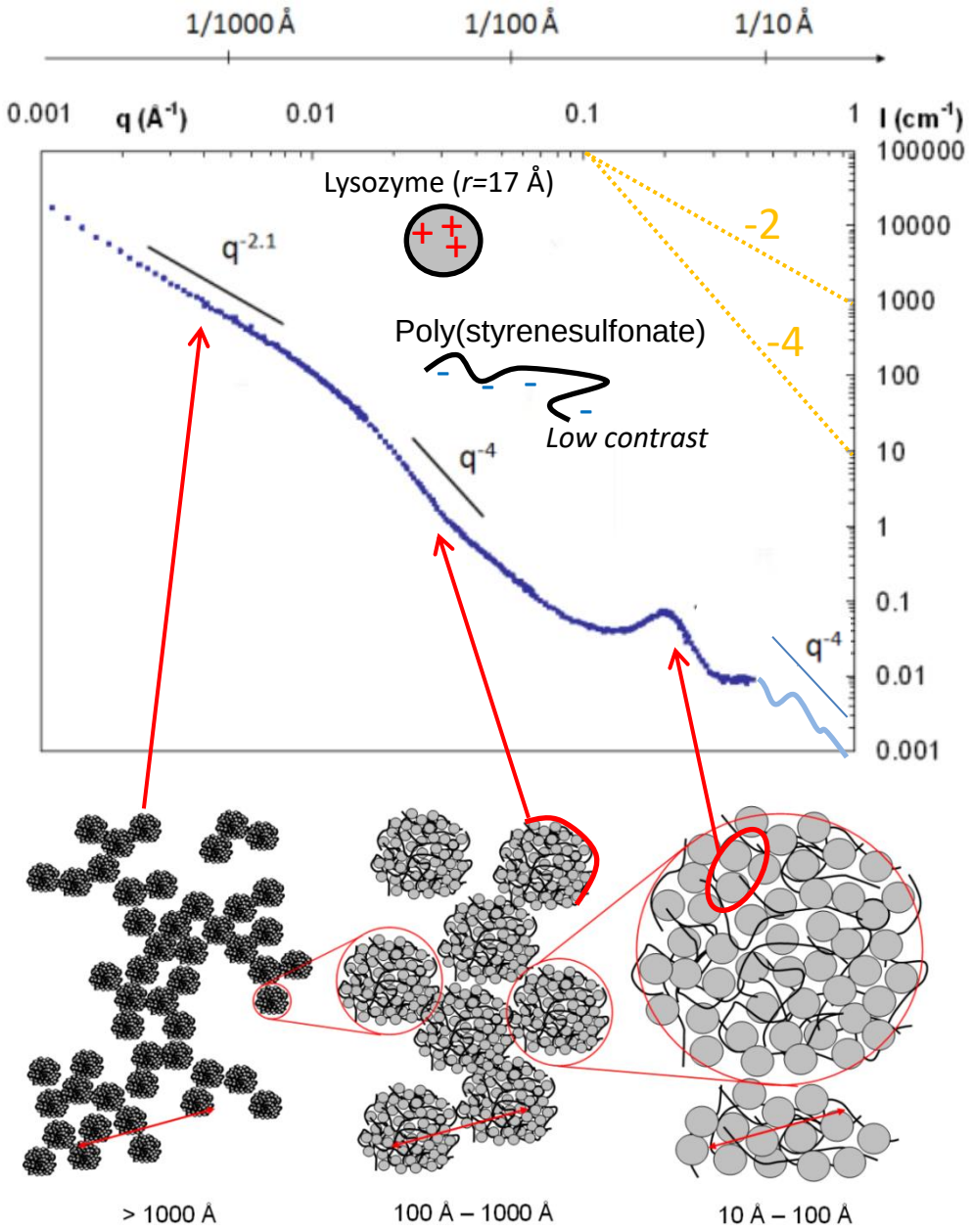
colleagues,
presentations from others

Test: Guess the structure



Power law $I(q)=Aq^{-D}$	Interpretation
D=0	Homogeneous and continuous
D=1	filament
D=2	sheet
$D=d_f$	**fractal**
D=4	**Smooth interface**, $A=2\pi\Delta\rho^2 S_v$ Sv=surface area (S) per unit volume (V) of the sample (S/V).
3<D<4	Rough interface with $D=6-d_s$

Test: Guess the structure

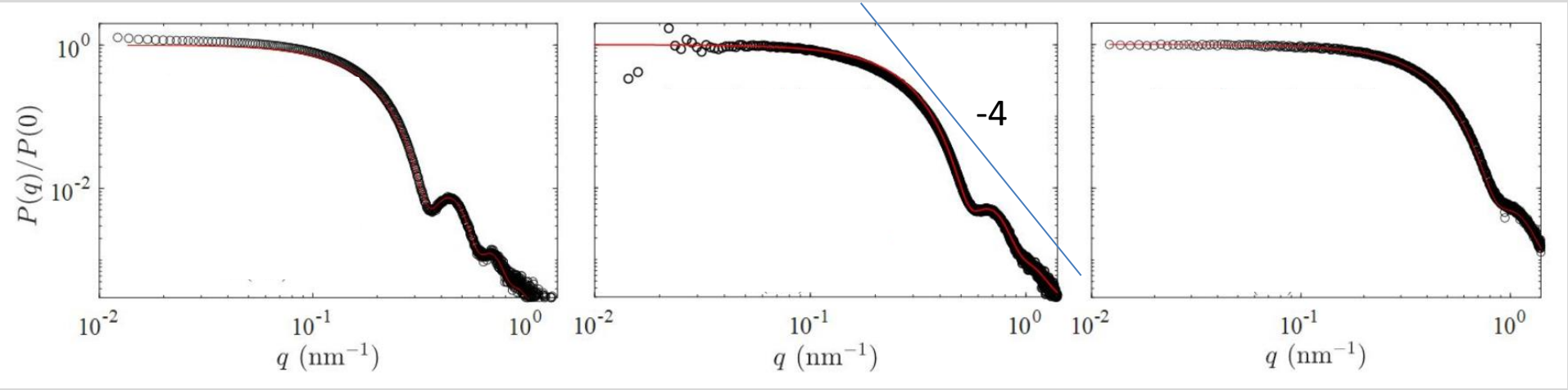


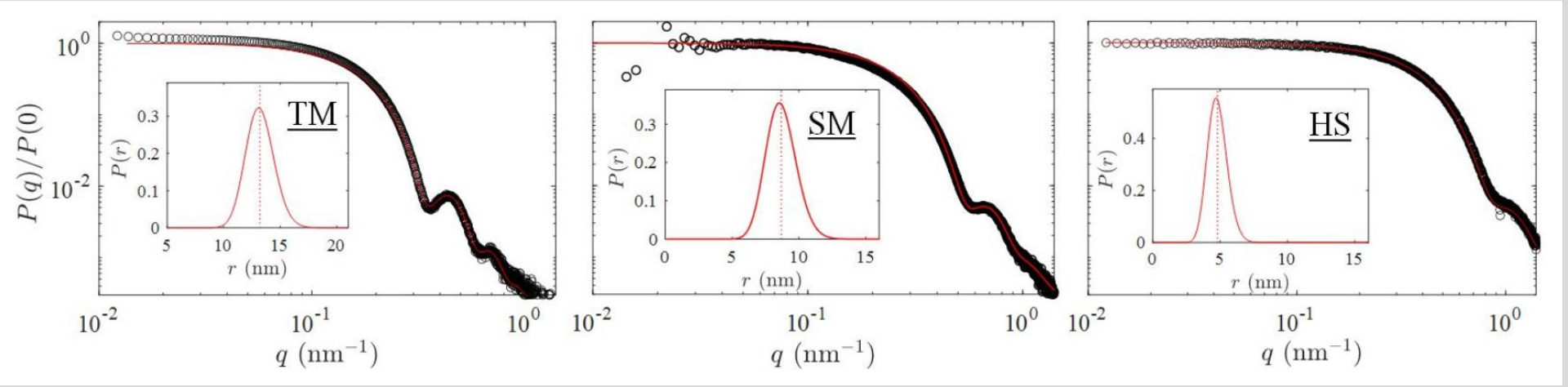
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Fabrice Cousin, Jérémie Gummel, Daniel Clemens, Isabelle Grillo, François Boué; Multiple Scale Reorganization of Electrostatic Complexes of Poly(styrenesulfonate) and Lysozyme. *Langmuir* 26, 7078 (2010)

Eye-Balling SAXS
Scaling Arguments for Structural Guesswork

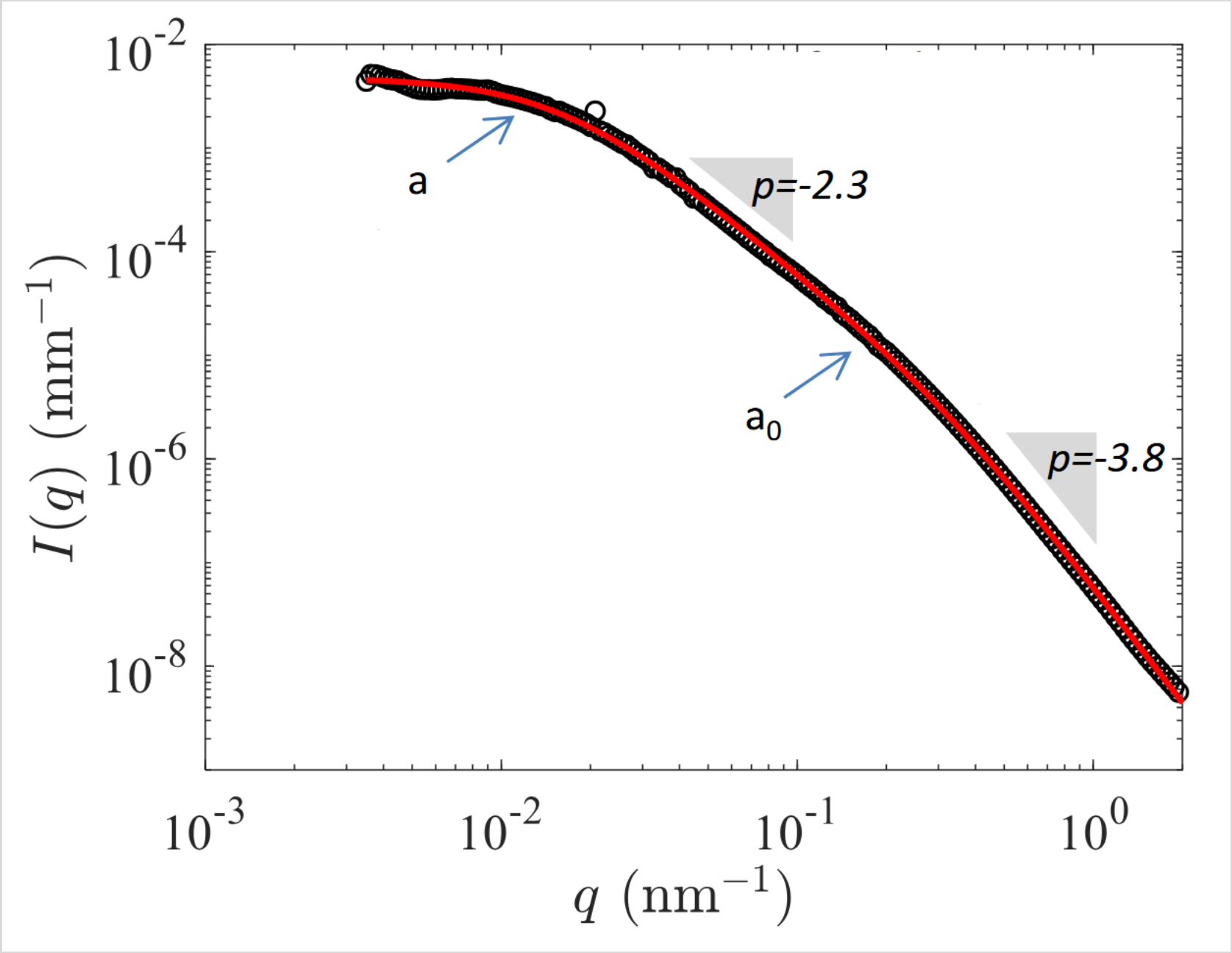
form factor



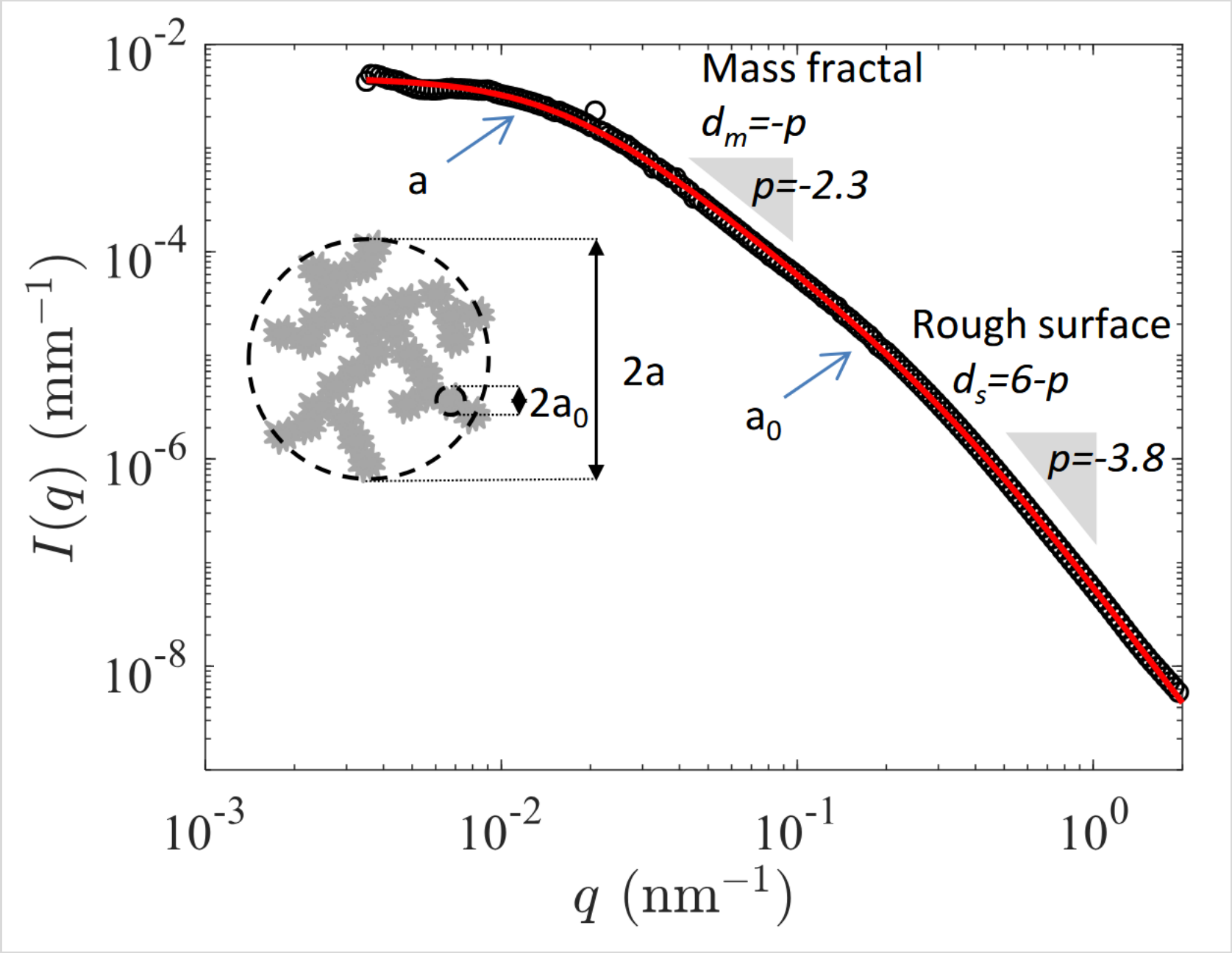


Isosbestic points in time resolved SAXS: from spectroscopic analogy to model free structural markers during colloidal gelation. *Soft Matter* 2026

1. Fumed silica form factor



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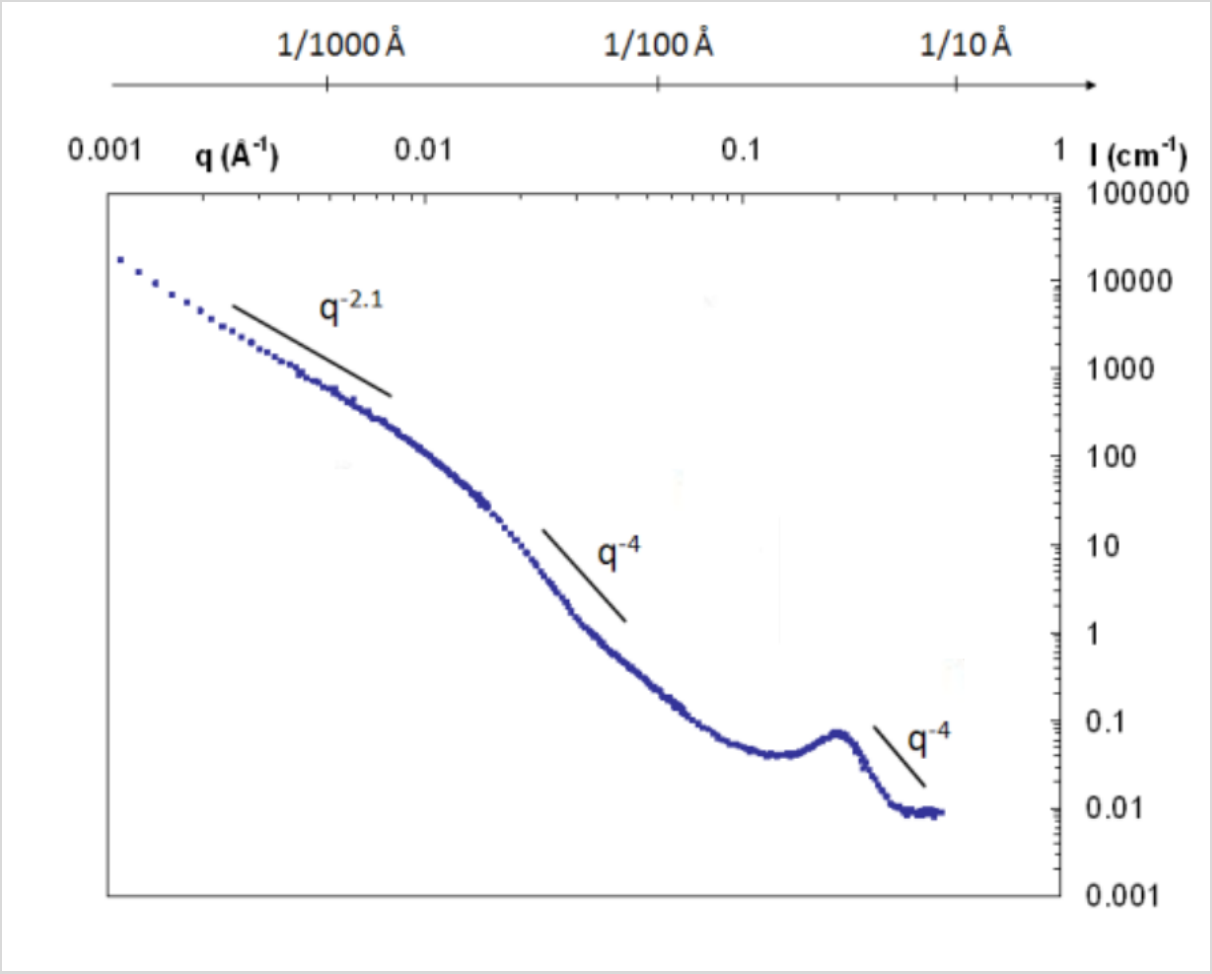
1. Mixture of Lysozyme and polystrenesulfonate

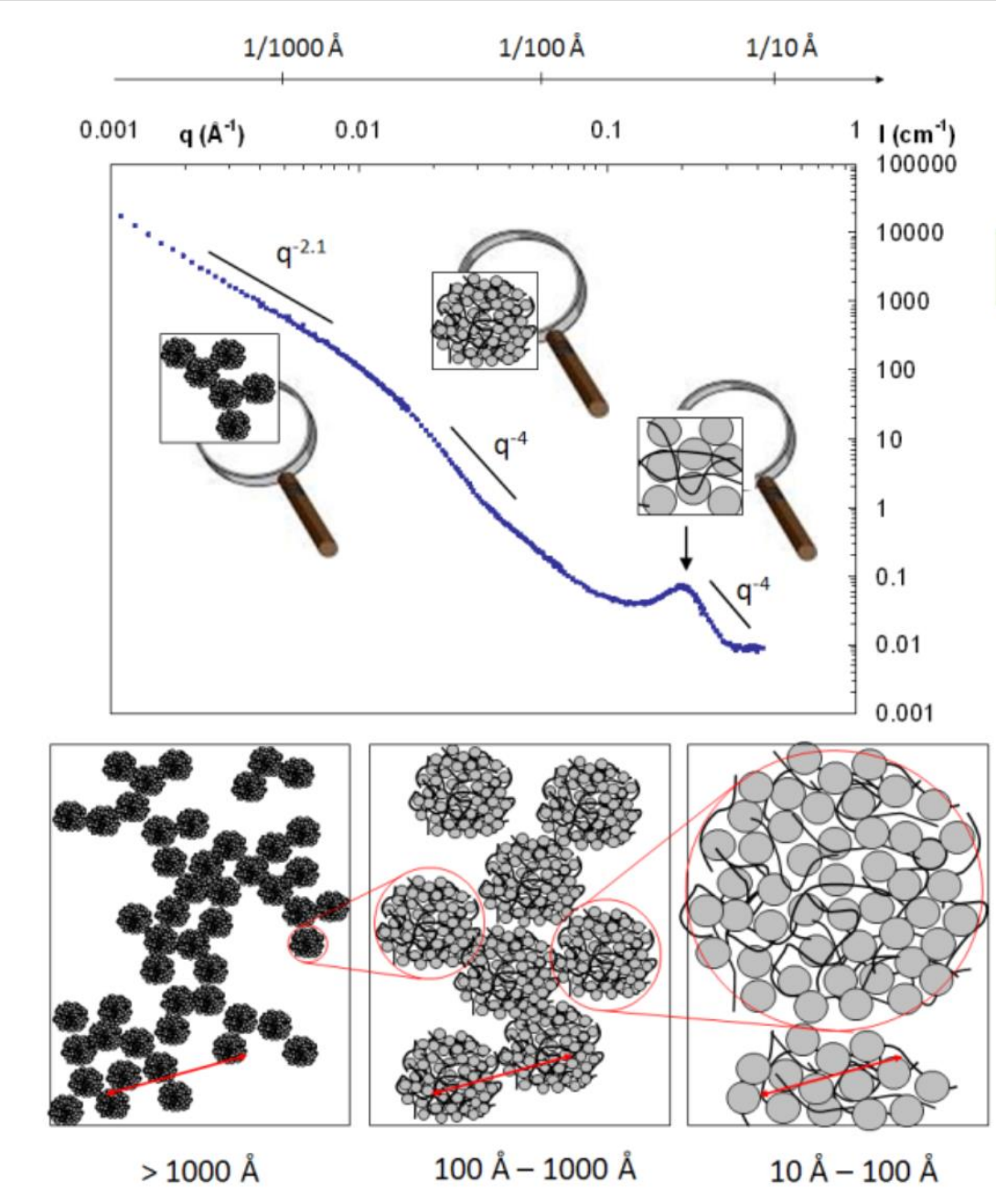


Negative charge



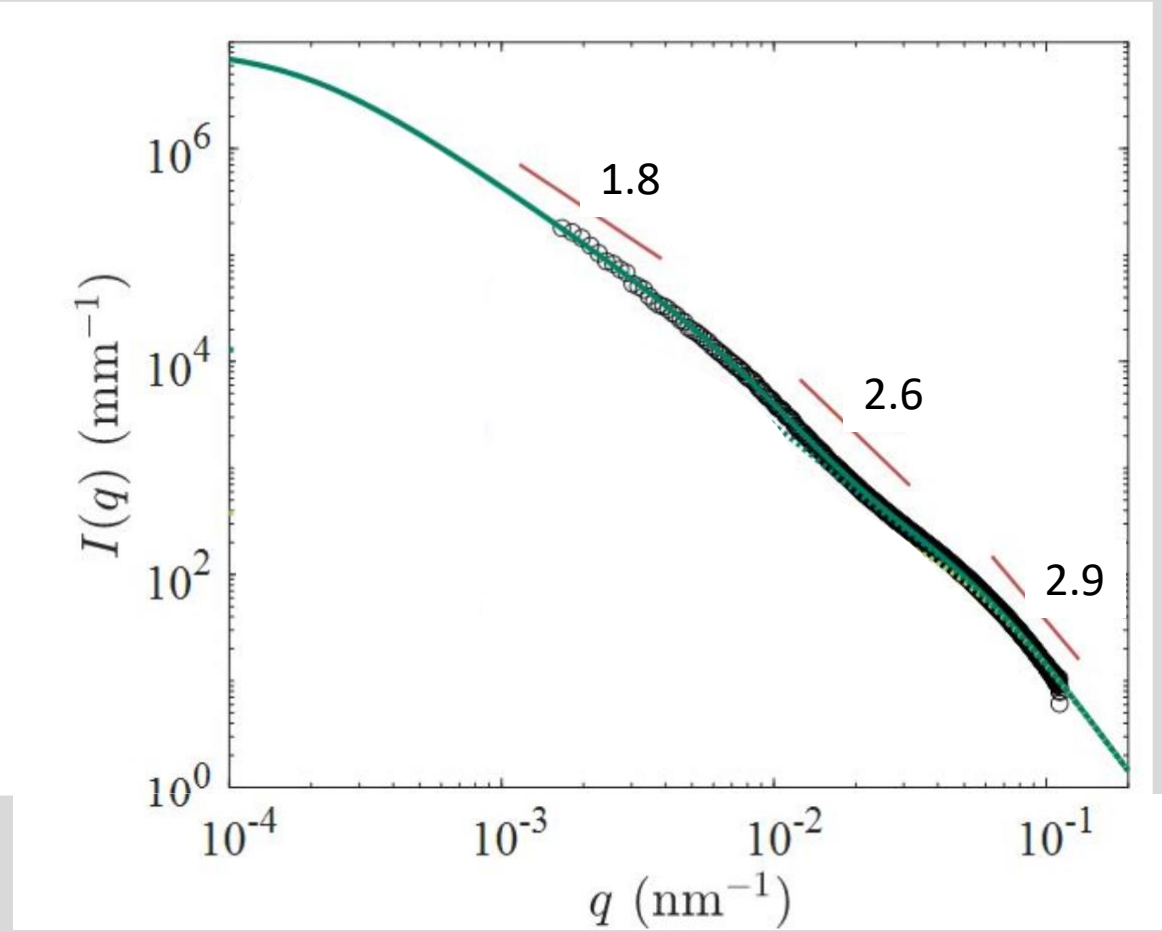
Negative charge



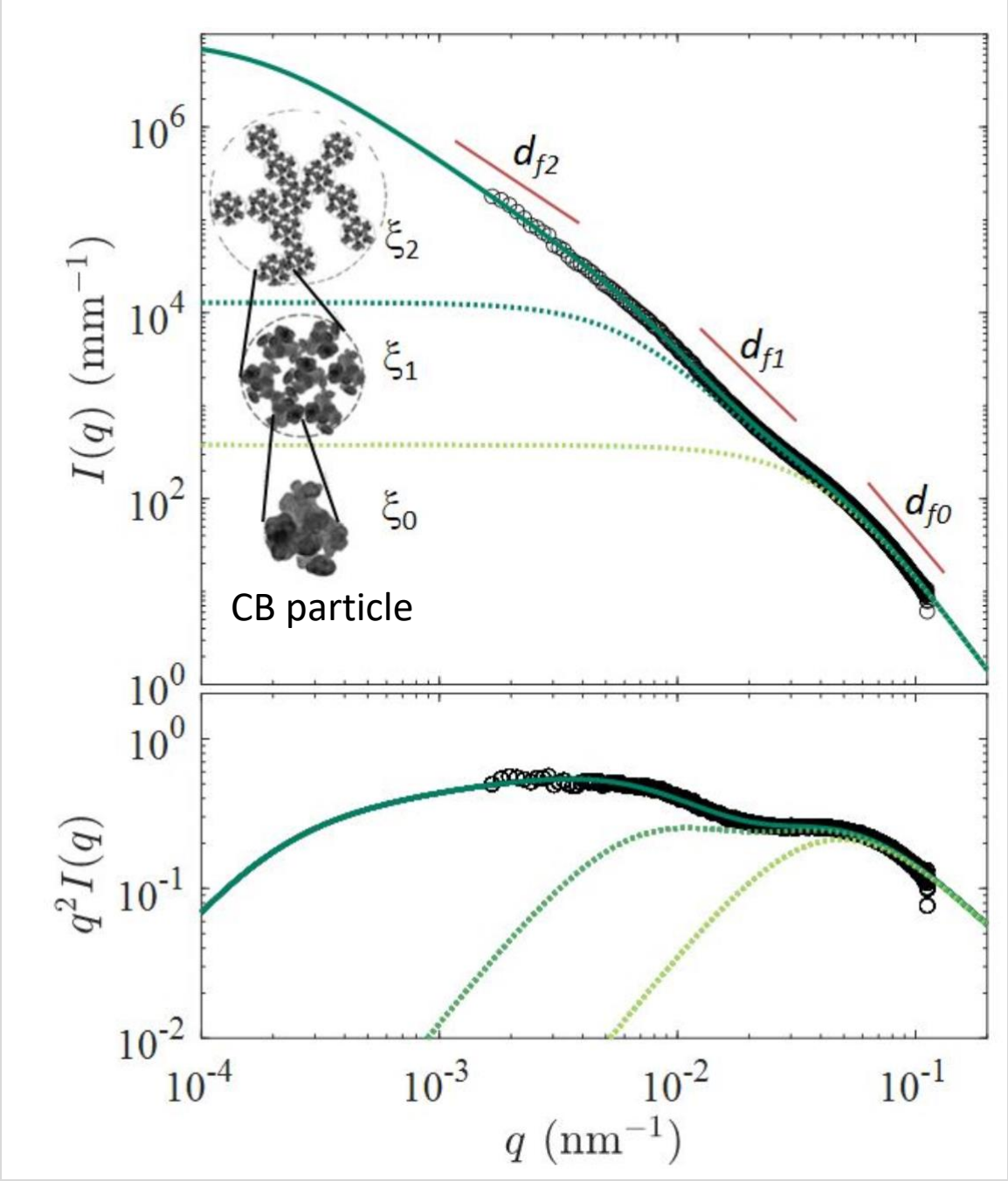


Fabrice Cousin, Jérémie Gummel, Daniel Clemens, Isabelle Grillo, François Boué; Multiple Scale Reorganization of Electrostatic Complexes of Poly(styrenesulfonate) and Lysozyme. Langmuir 18 May 2010; 26 (10): 7078–7085

Carbon black gels

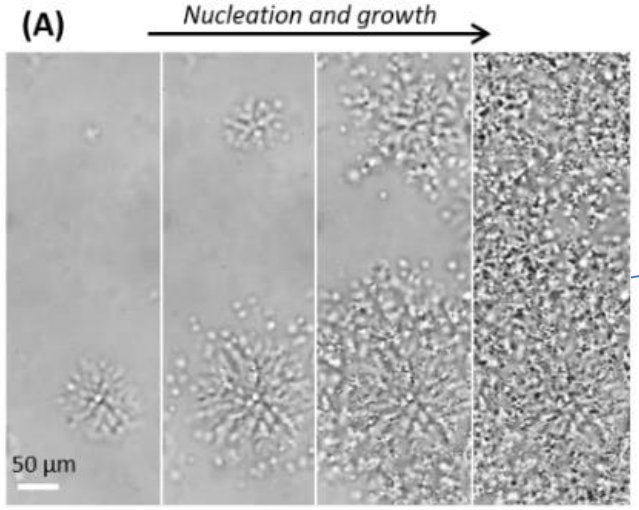


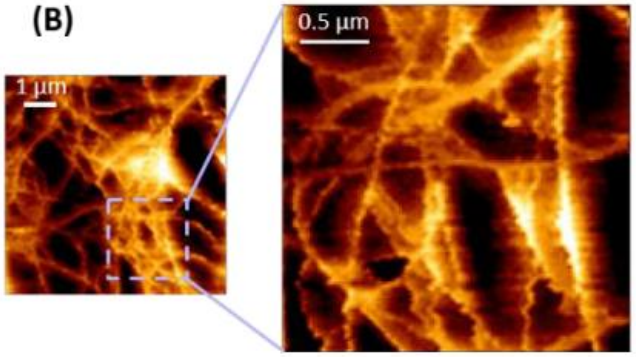
Carbon black gels

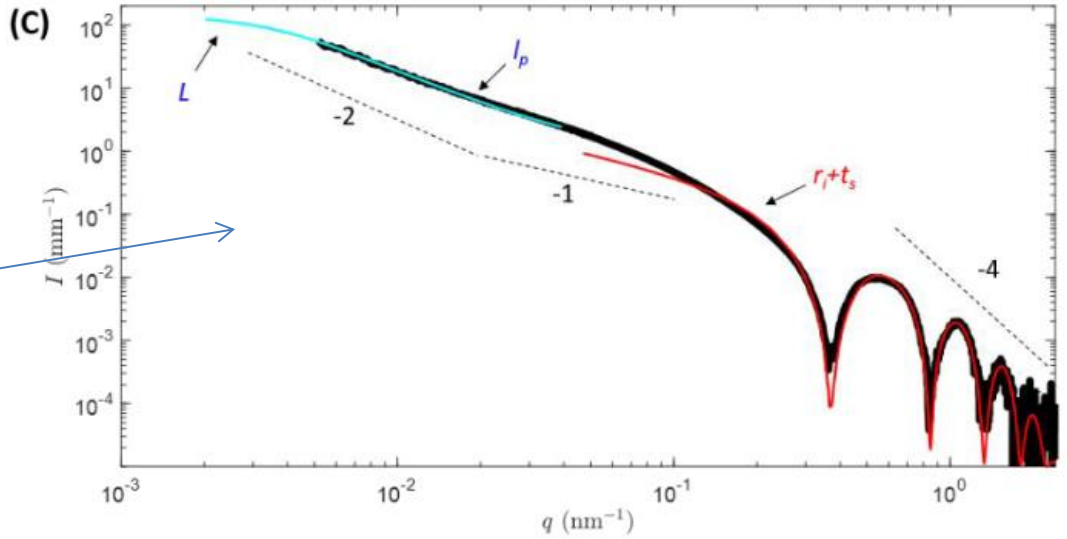


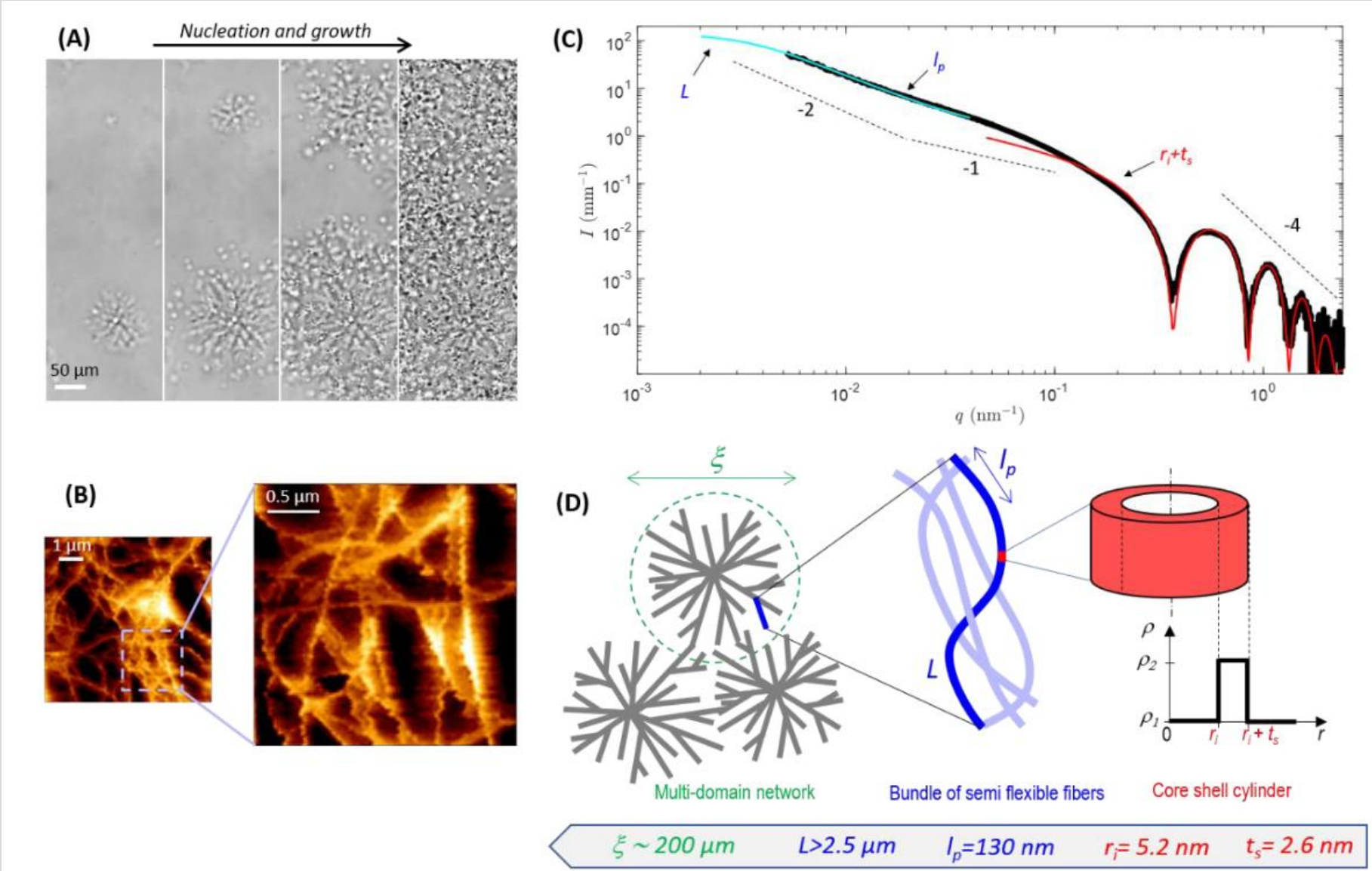
Chèvremont, William, et al. "Tracking microscopic inter-cycle irreversibility across the yielding transition through constant-amplitude oscillatory fatigue experiments in a colloidal fractal gel with Rheo-Echo-XPCS." Physical Review Materials 10.9 (2026): 093606.

3. Supramolecular gels





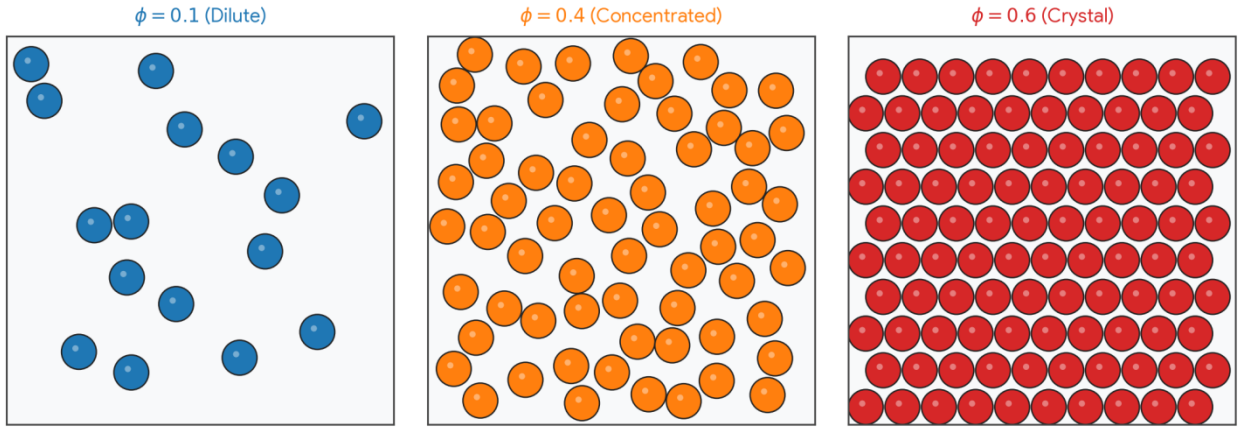


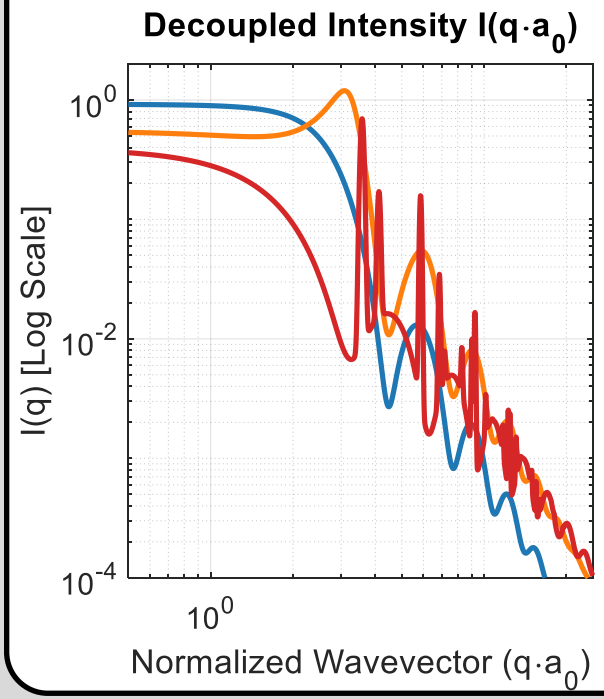


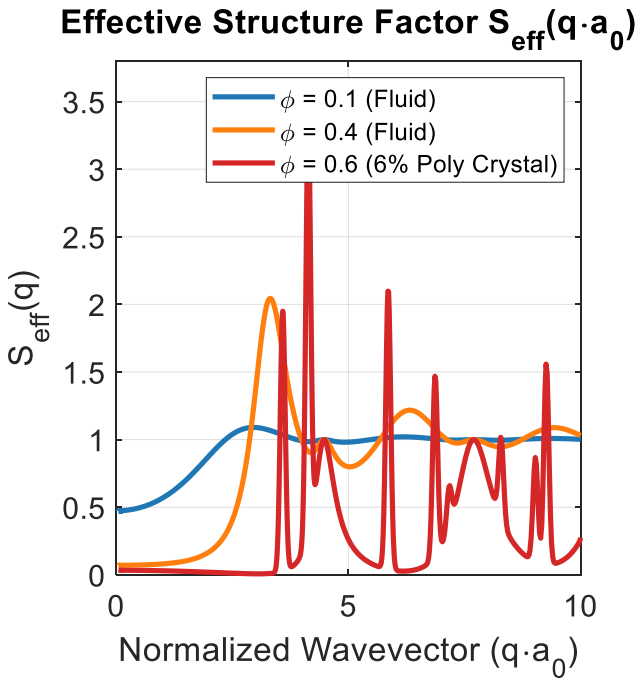
Chiral and conductive viologen-based supramolecular gels exhibiting tunable charge-transfer propertiesV Andrieux, T Gibaud, J Bauland, T Divoux, S Manneville, S Guy, ... Journal of Materials Chemistry C 11, 12764 (2023)

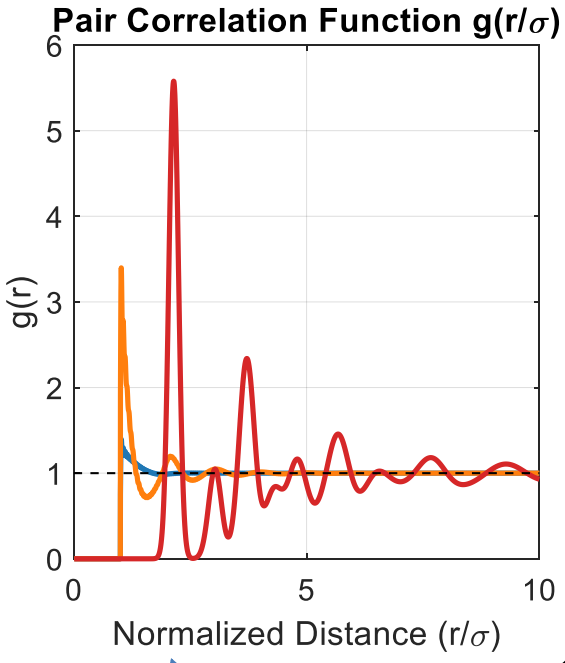
Structure factor *S(**q**)*

Example
Hard spheres

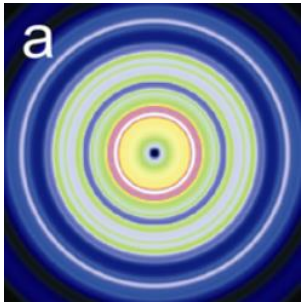


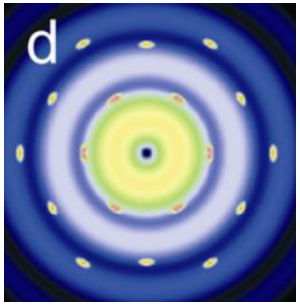


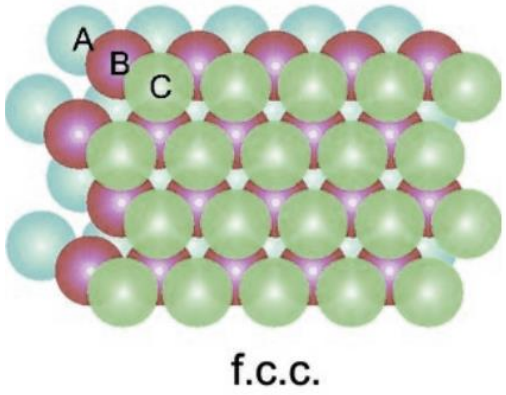




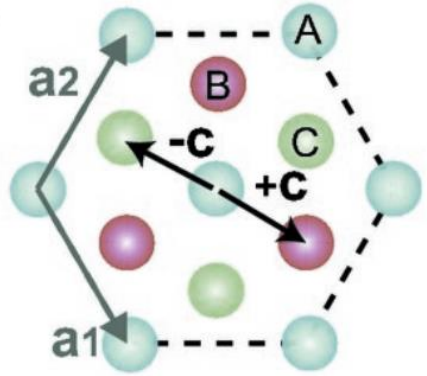
Face-Centered Cubic (FCC)







f.c.c.



Miller Index (hkl)	Exact Formula ($q \cdot a_0$)	Numerical Value
(111)	$\pi\sqrt{3/2}$	3.8476
(200)	$\pi\sqrt{2}$	4.4429
(220)	2π	6.2832
(311)	$\pi\sqrt{11/2}$	7.3677
(222)	$\pi\sqrt{6}$	7.6953
(400)	$2\sqrt{2}\pi$	8.8858
(331)	$\pi\sqrt{19/2}$	9.6830
(420)	$\pi\sqrt{10}$	9.9346