

# An Introduction to Neutron Reflectometry

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ISIS Neutron and  
Muon Source



# Rutherford Appleton Laboratory



**Diamond Light Source**

**Research Complex @ Harwell**

**Electron Bio-Imaging Centre**

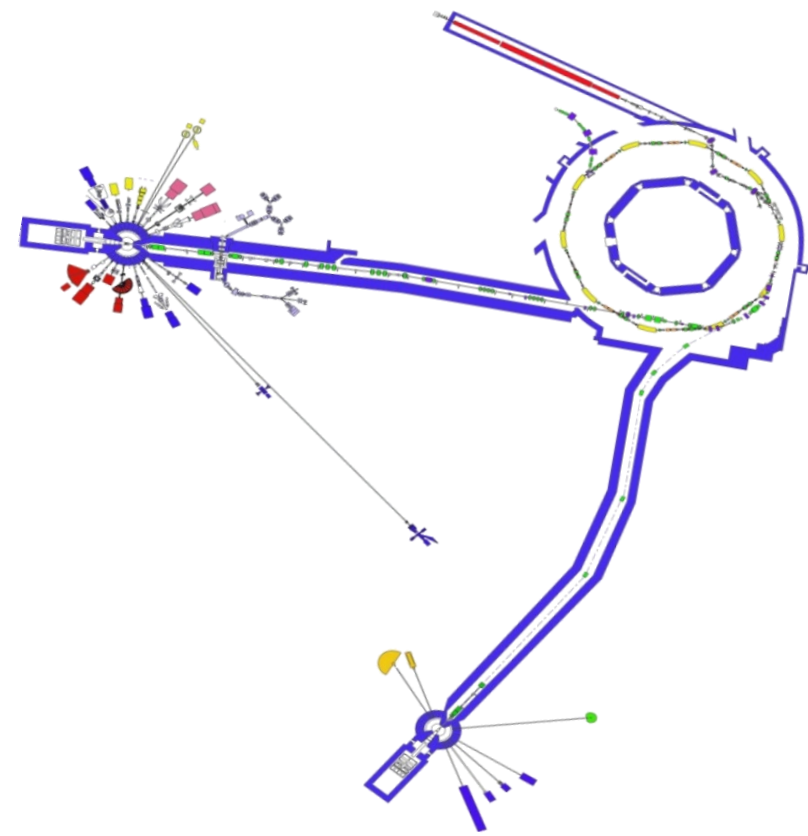
**Rosalind Franklin Institute**

**Central Laser Facility**

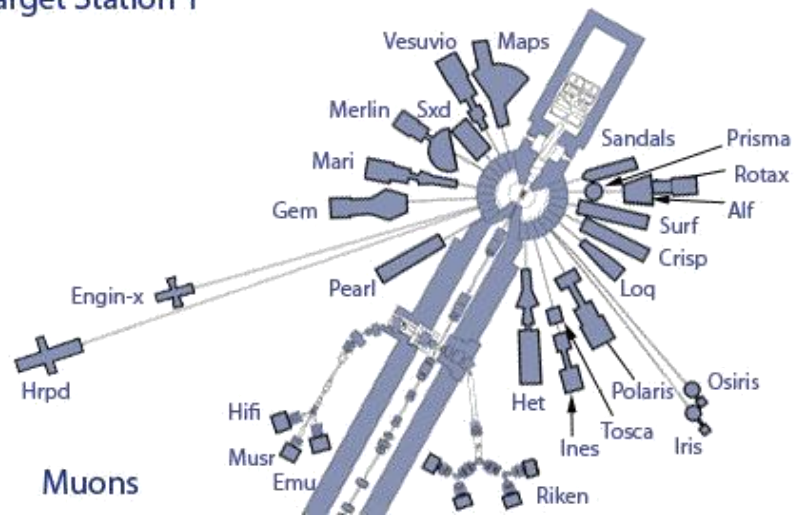
**ISIS Neutron and Muon Source**



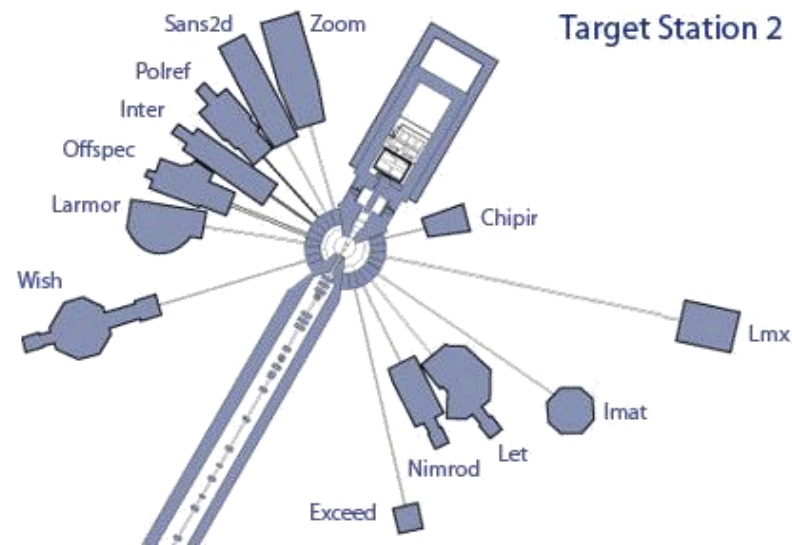
# The ISIS Pulsed Neutron and Muon source



Target Station 1

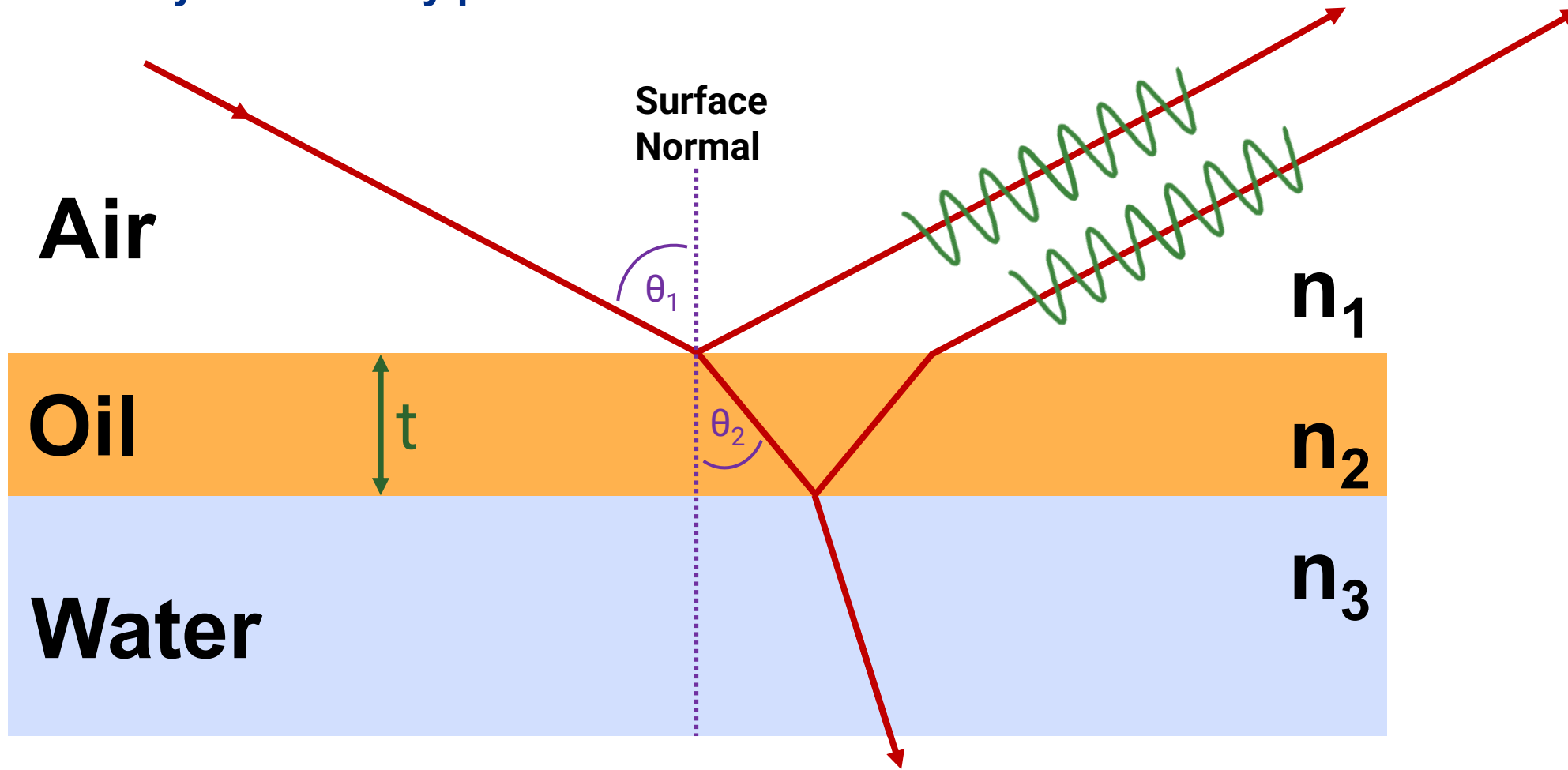


Target Station 2





# Reflectometry from an oily puddle



Snell's Law:

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

Fresnel Coefficients:

$$r_s = \frac{n_1 \cos \theta_1 - n_2 \cos \theta_2}{n_1 \cos \theta_1 + n_2 \cos \theta_2}$$



# Cold Neutrons – a tailor-made probe

- Neutron wavelength in the Ångstrom regime (ISIS TS2 NR ~1 - ~16 Å).

- H / D contrast

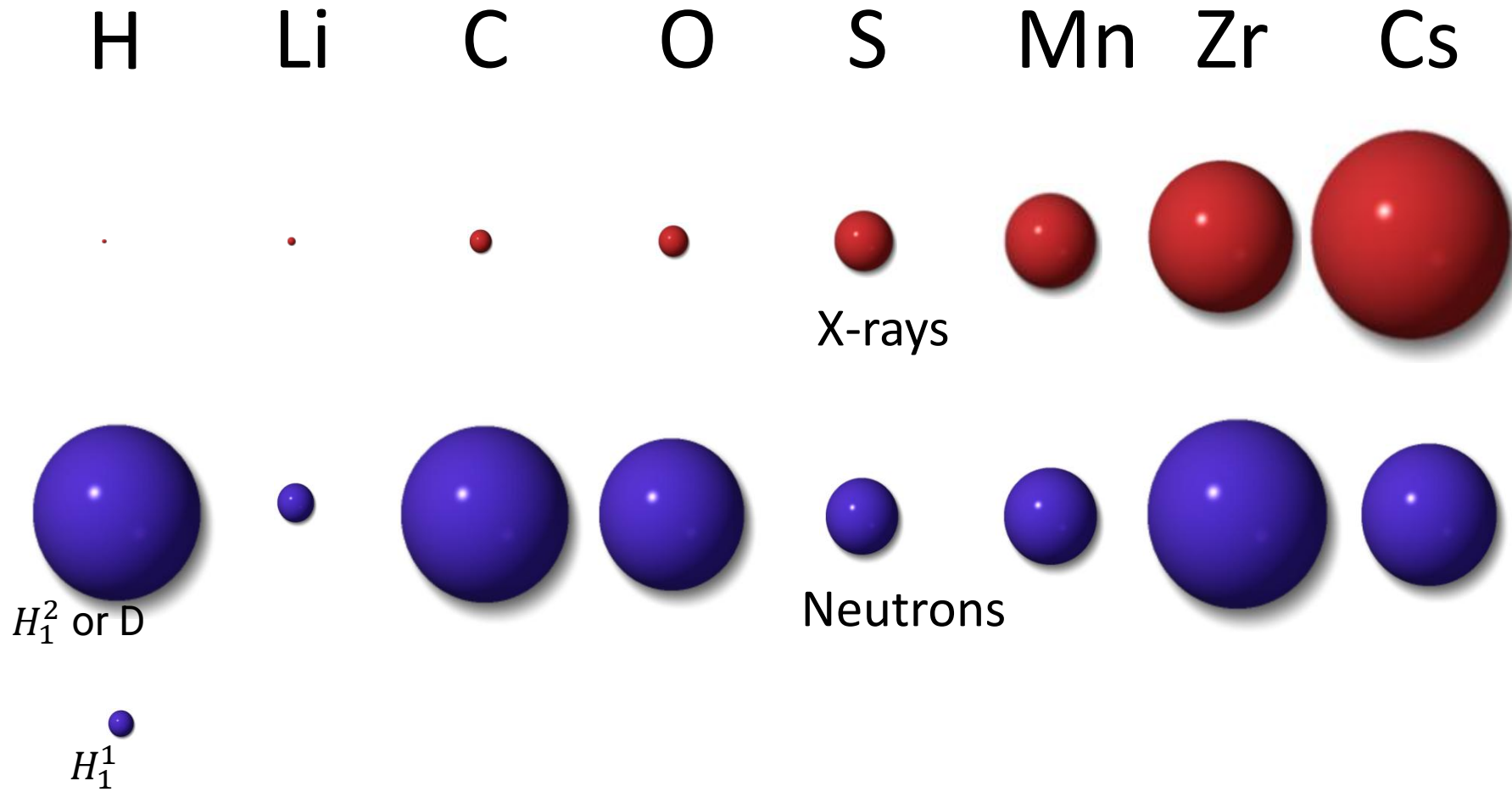
- Magnetic Moment

- Highly penetrating

- Non-Destructive

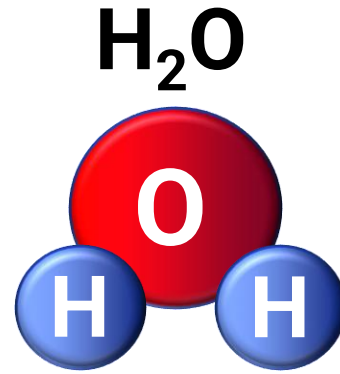


Neutrons interact with the nucleus  
X-rays interact with the electrons

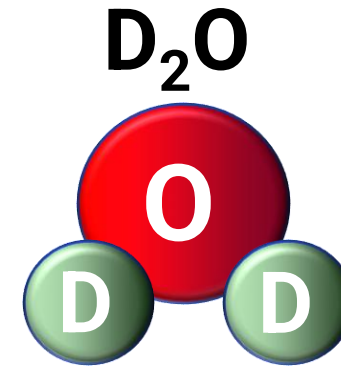


# Isotopic Contrast Variation

Element	Scattering Length (b)/ 10 <sup>-5</sup> Å
Hydrogen (99.98% protium)	-3.74
Deuterium	6.671
Carbon	6.646
Nitrogen	9.36
Oxygen	5.803
Sulphur	2.847
Phosphorus	5.13



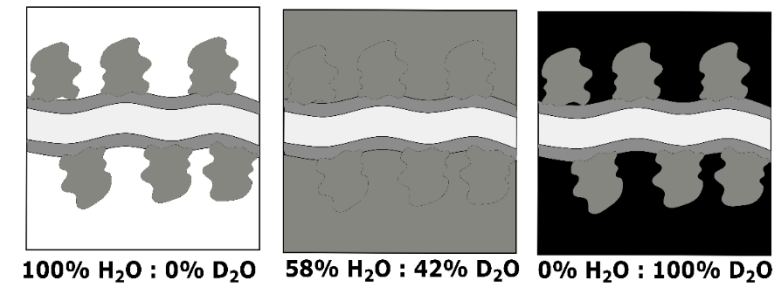
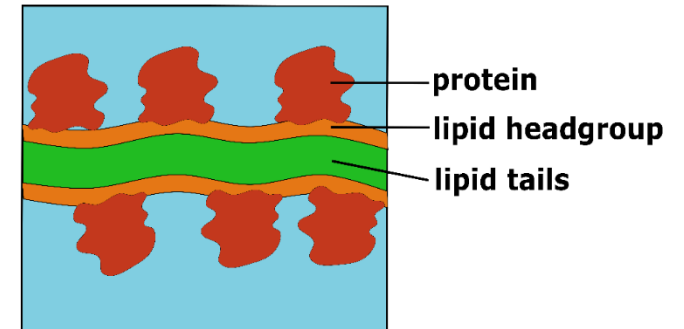
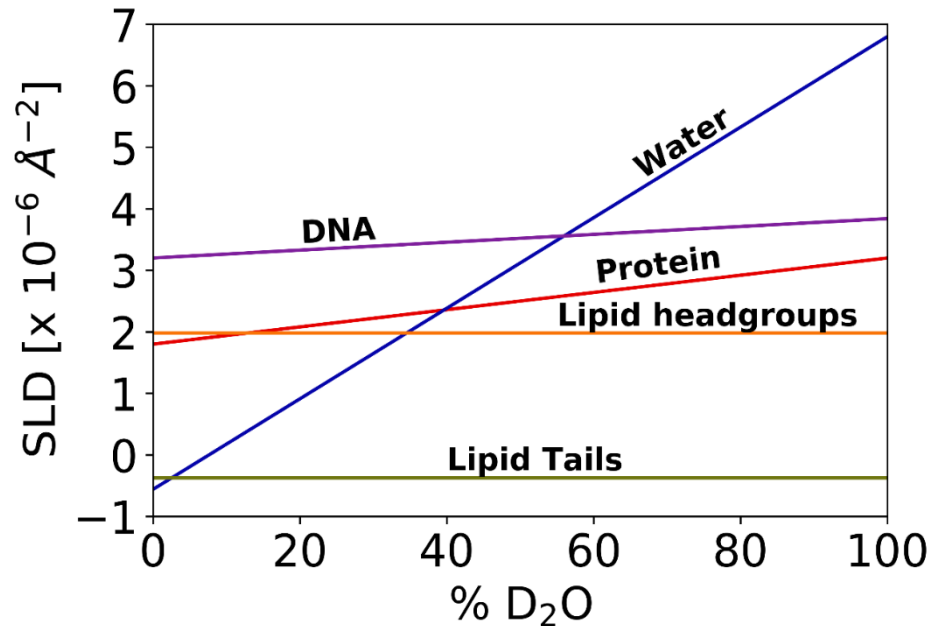
$$n\text{SLD} (\rho) = -0.56 \times 10^{-6} \text{ \AA}^{-2}$$



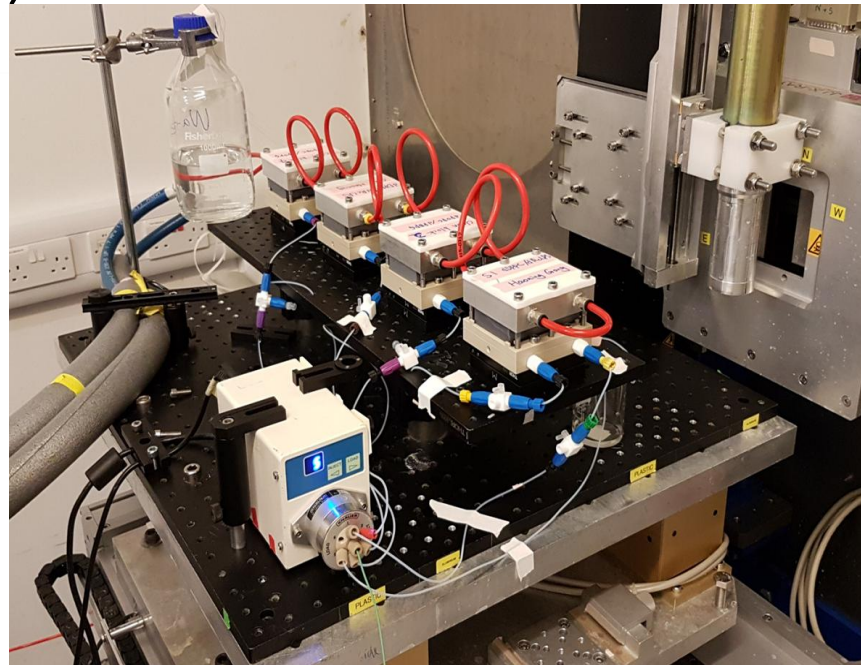
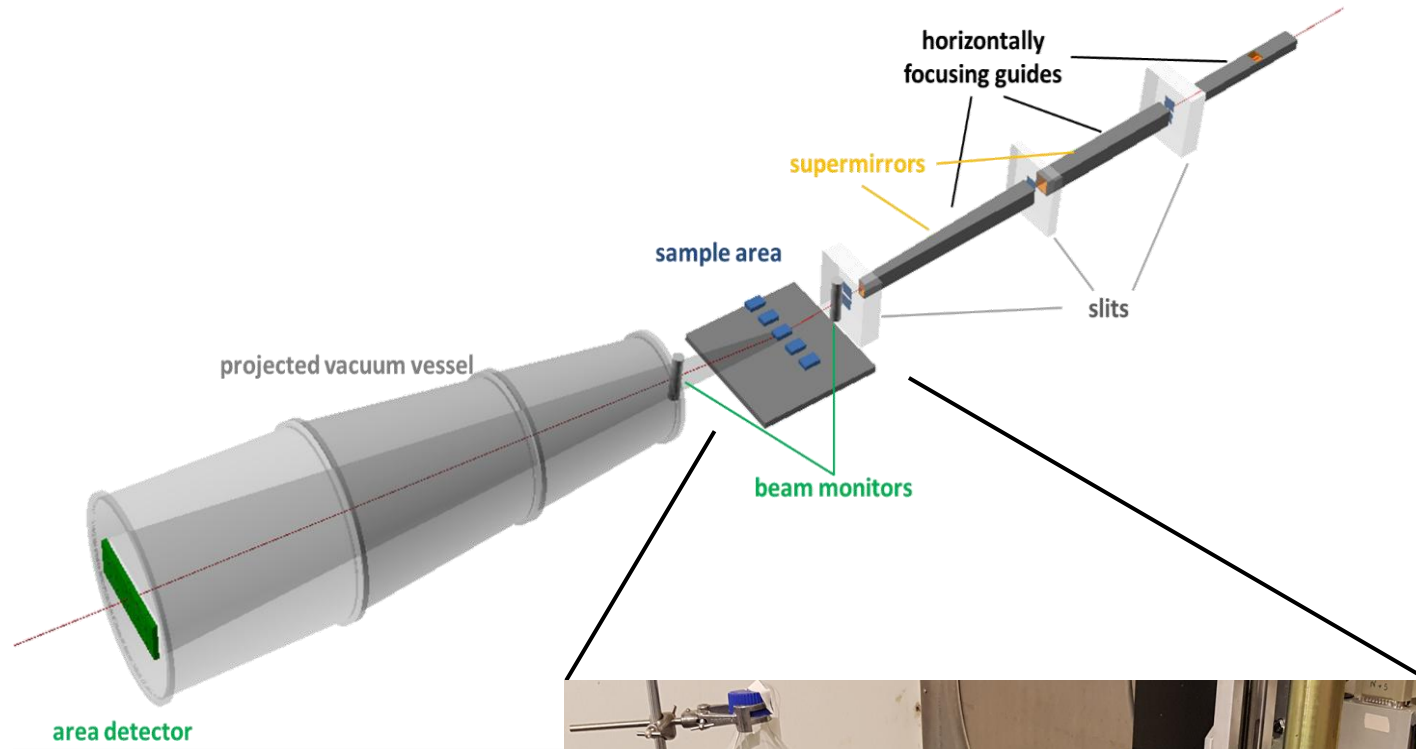
$$n\text{SLD} (\rho) = 6.35 \times 10^{-6} \text{ \AA}^{-2}$$

$$\rho = \frac{\sum b}{V}$$

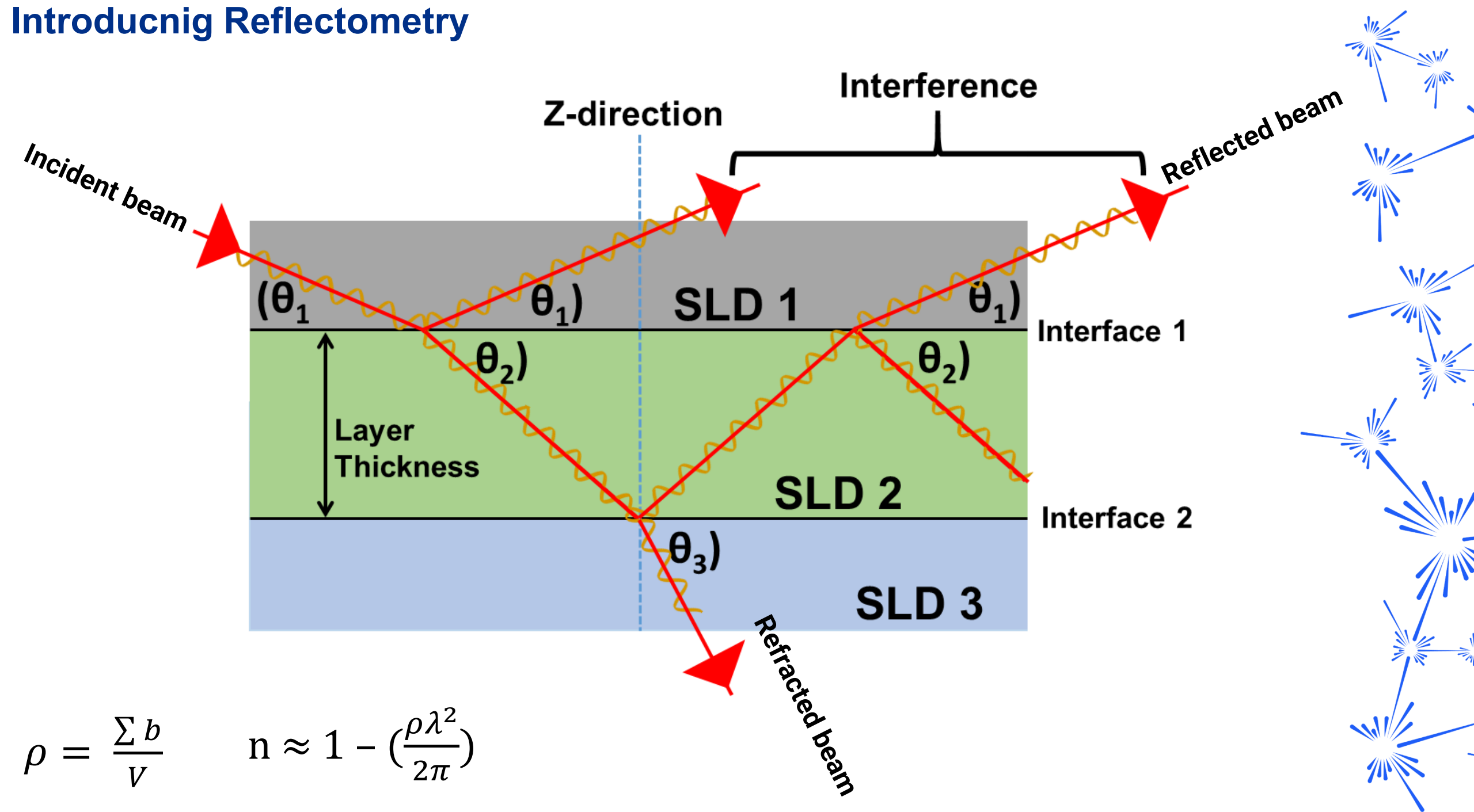
$$n \approx 1 - \left( \frac{\rho \lambda^2}{2\pi} \right)$$



# Neutron Reflectometry



# Introducning Reflectometry

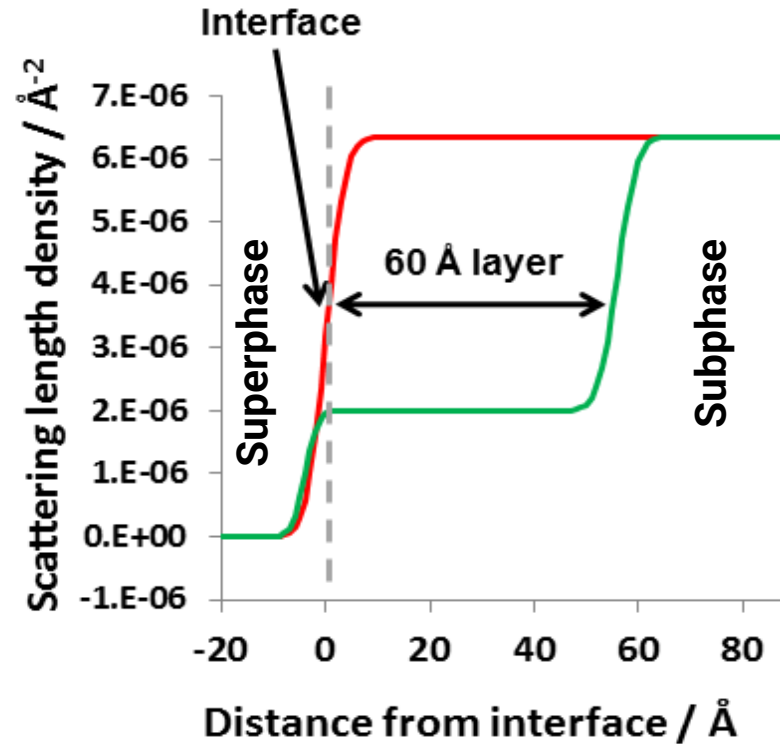
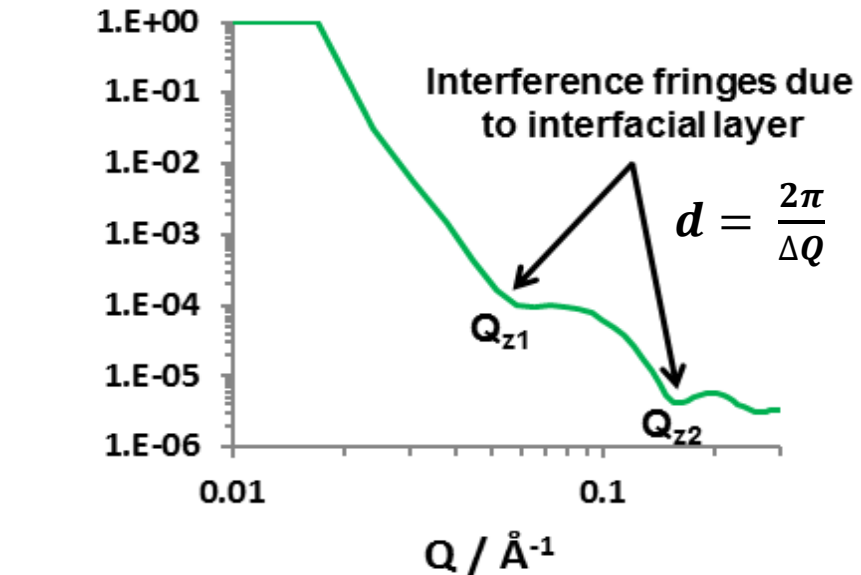
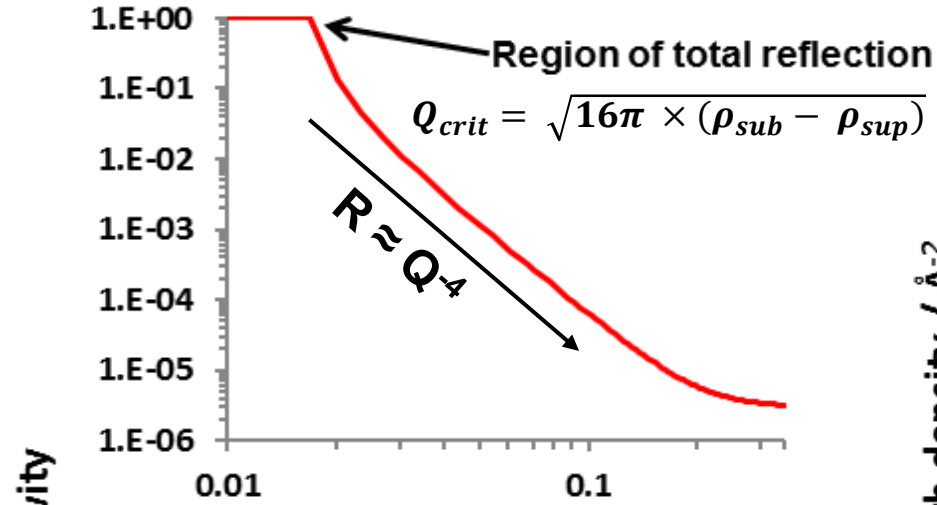


$$\rho = \frac{\sum b}{V}$$

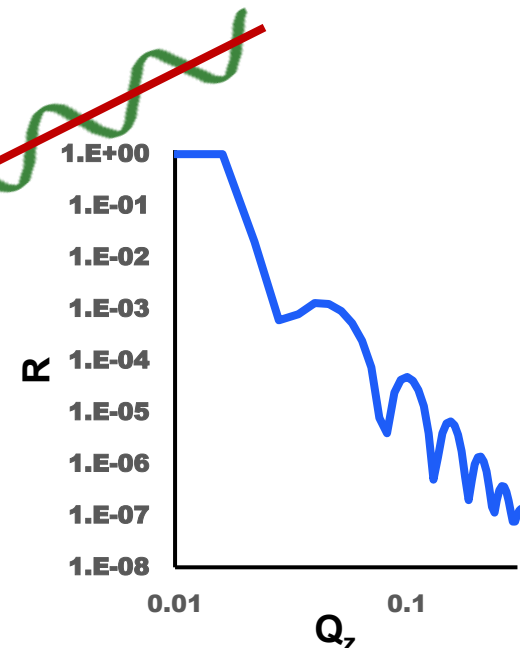
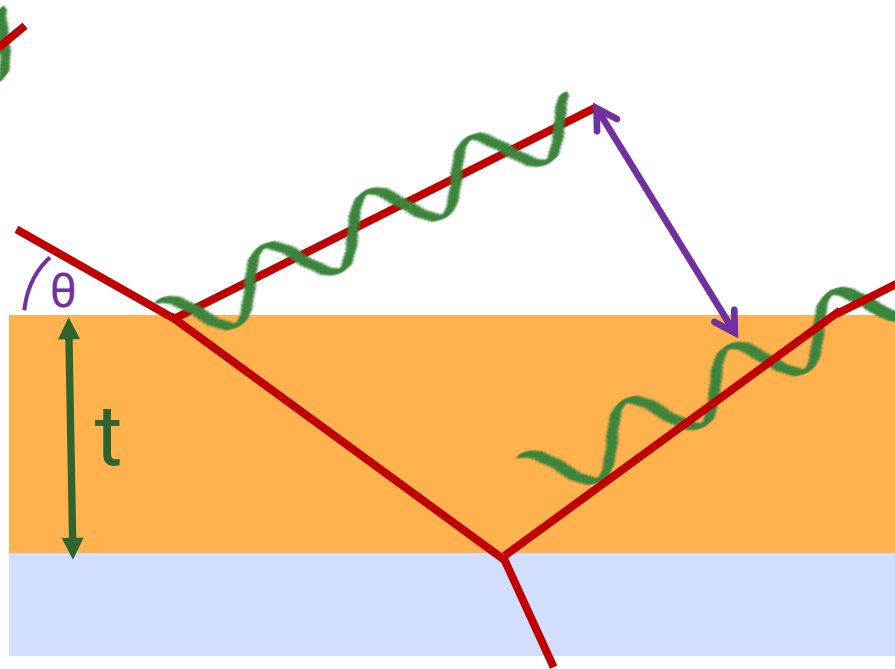
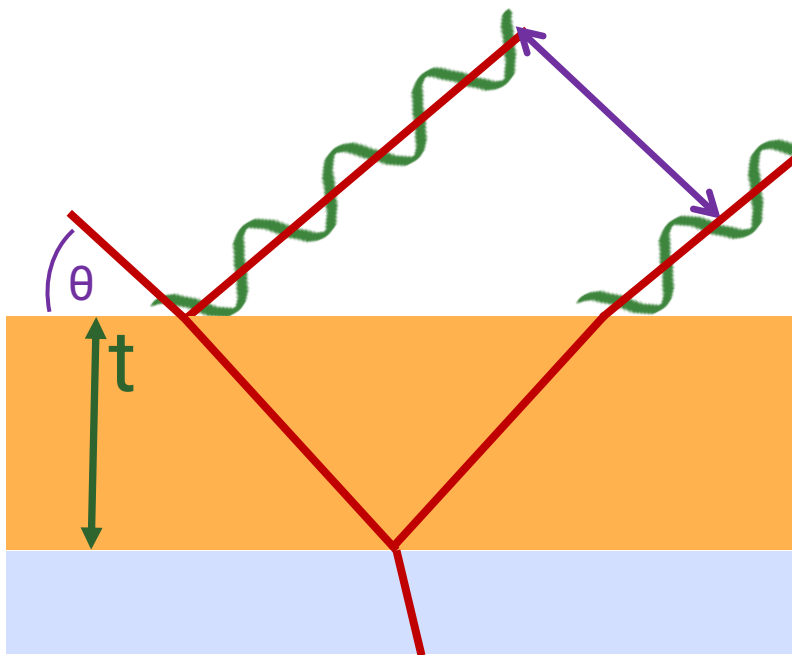
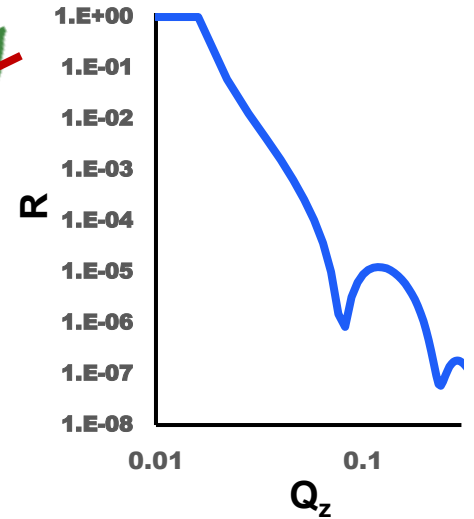
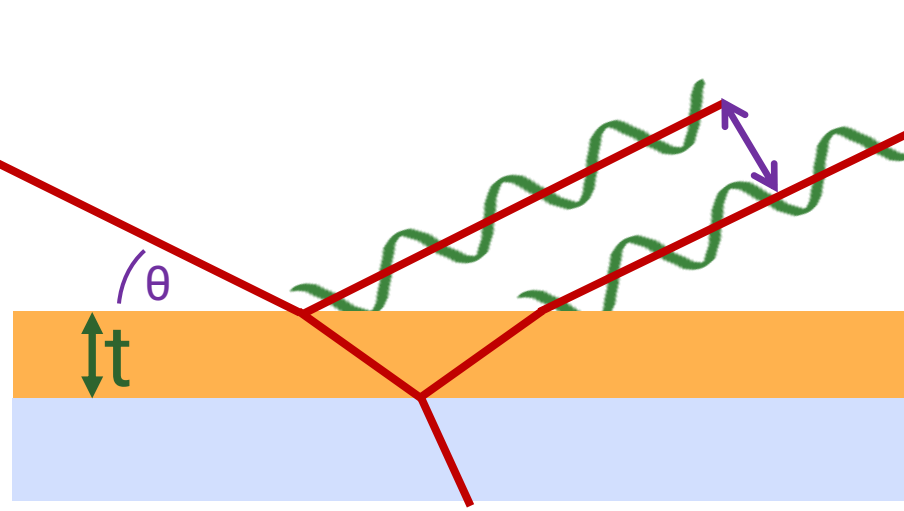
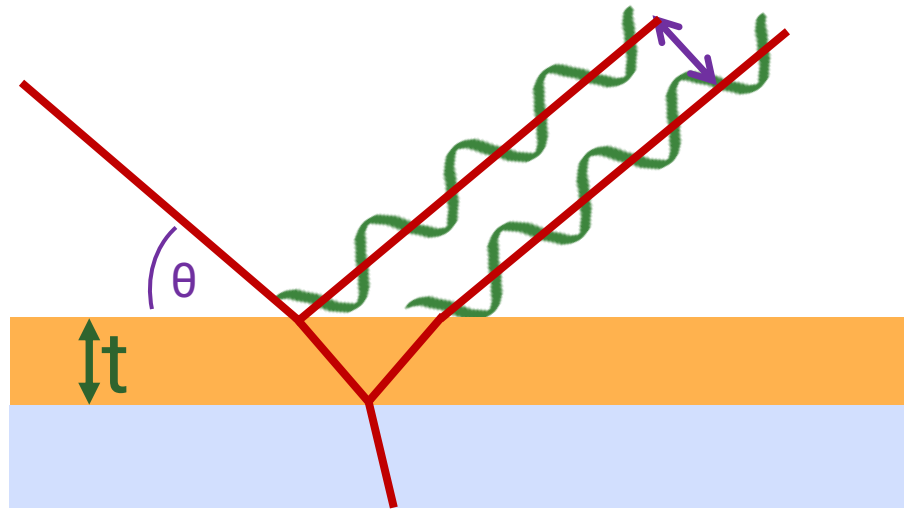
$$n \approx 1 - \left(\frac{\rho \lambda^2}{2\pi}\right)$$

# Reflectometry gives you Thicknesses

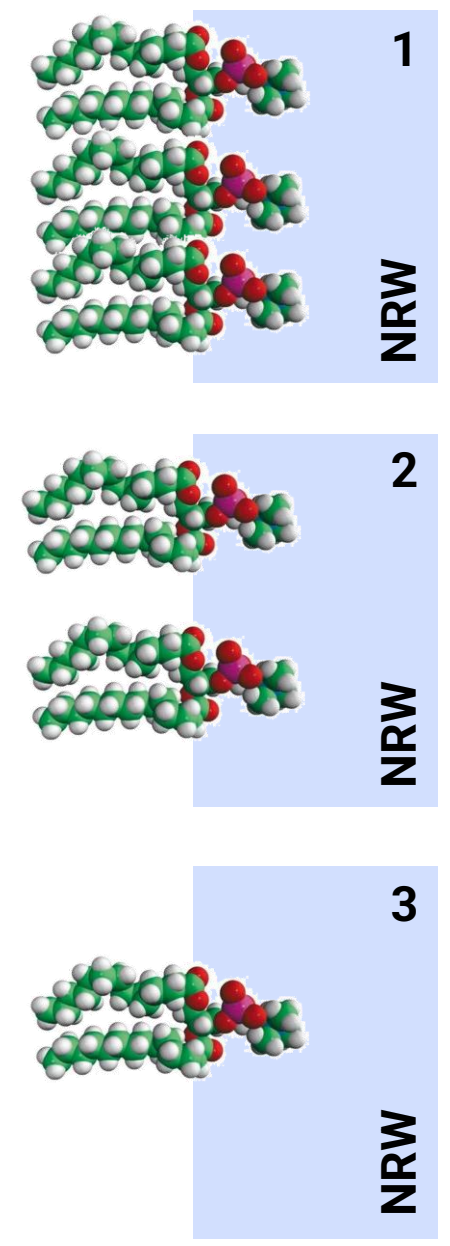
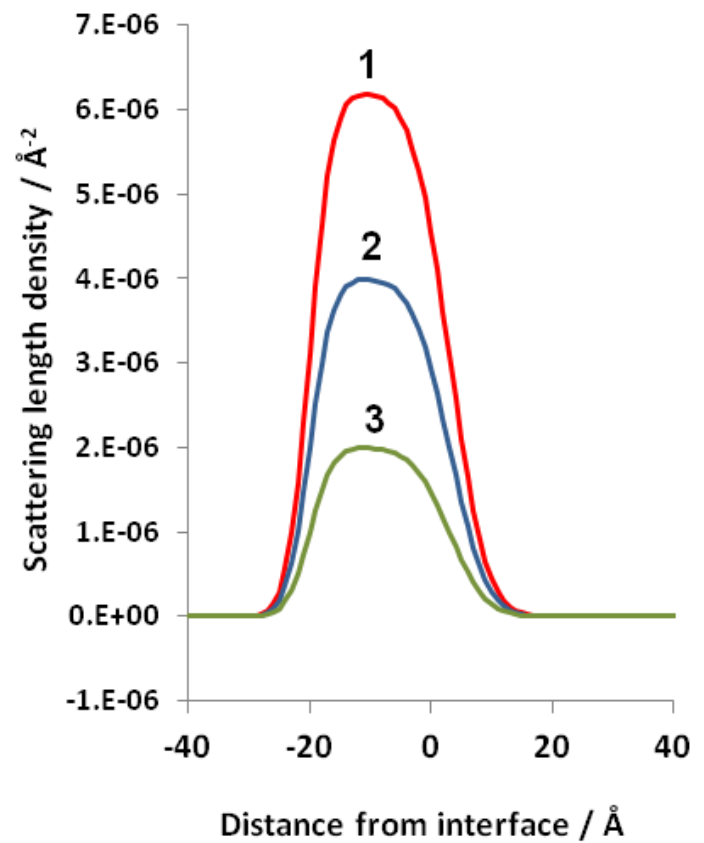
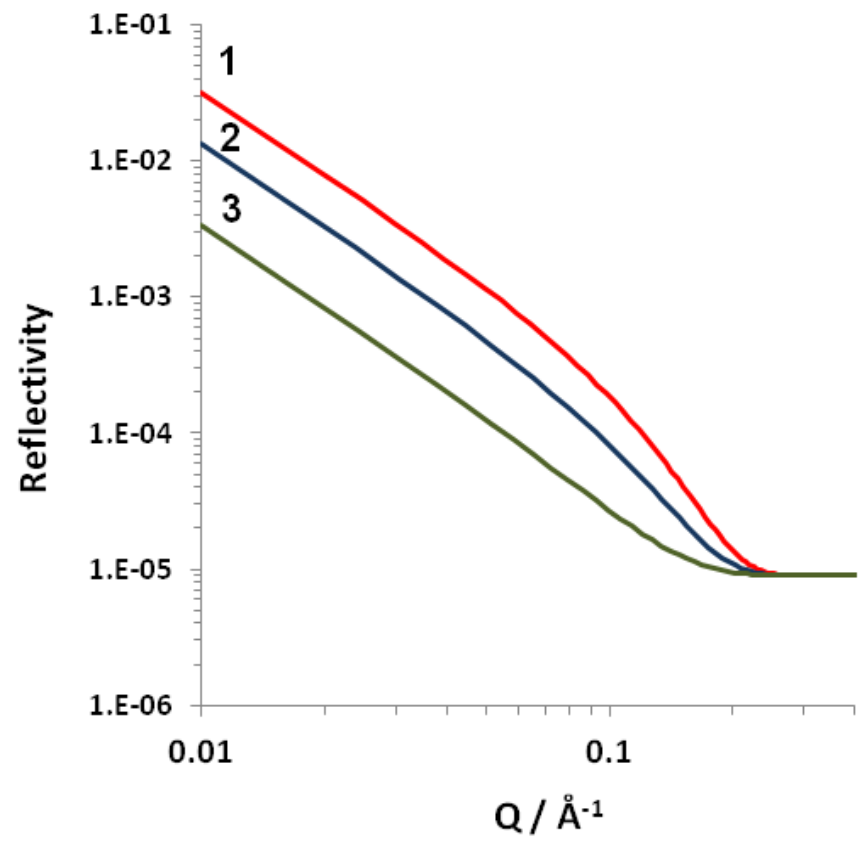
$$Q_z = \frac{4\pi \sin\theta}{\lambda}$$



# Kiessig Fringe Frequency is inversely proportional to Thickness

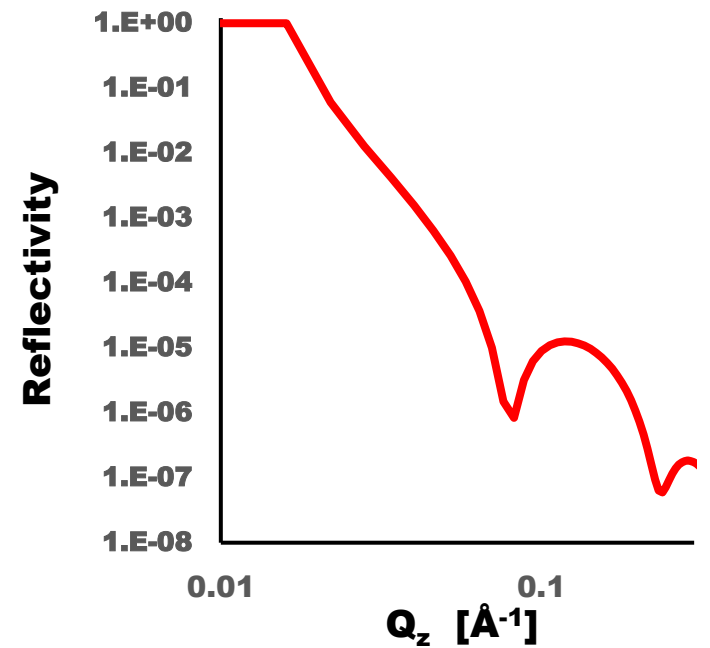
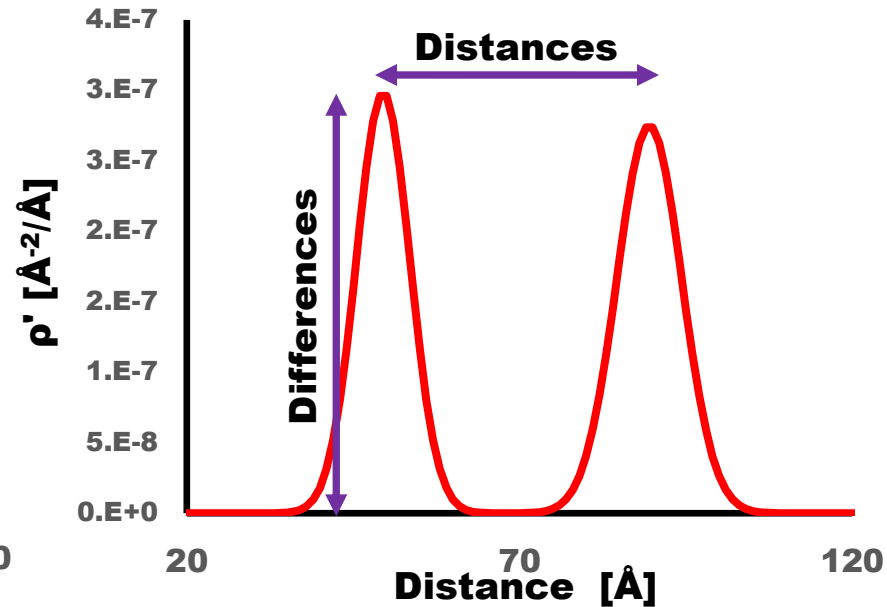
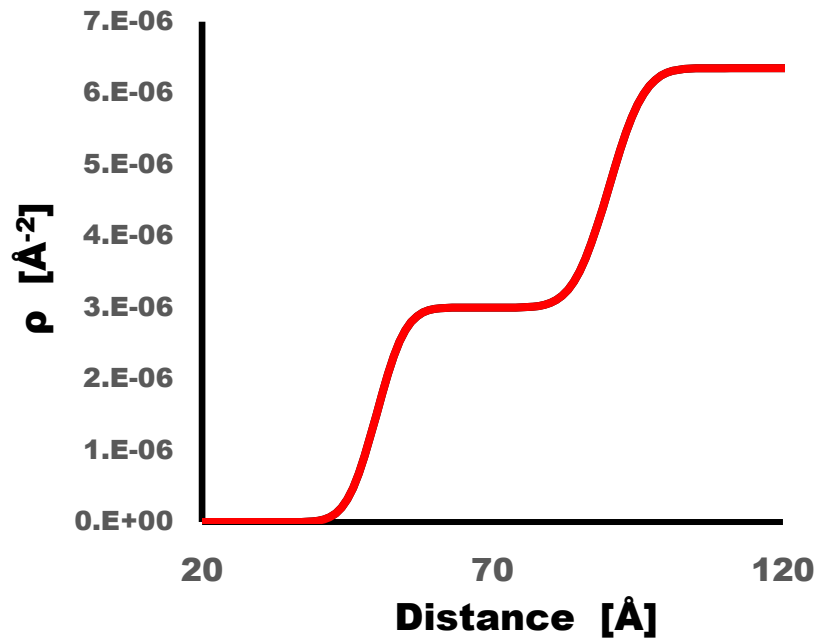


# Reflectometry gives you Composition



# NR ~Describes the Scattering Length Density Profile Across and Interface

$$R(Q_z) \approx \frac{16\pi^2}{Q_z^4} \left| \int_{-\infty}^{+\infty} \rho'(z) \exp(-izQ_z) dz \right|^2$$



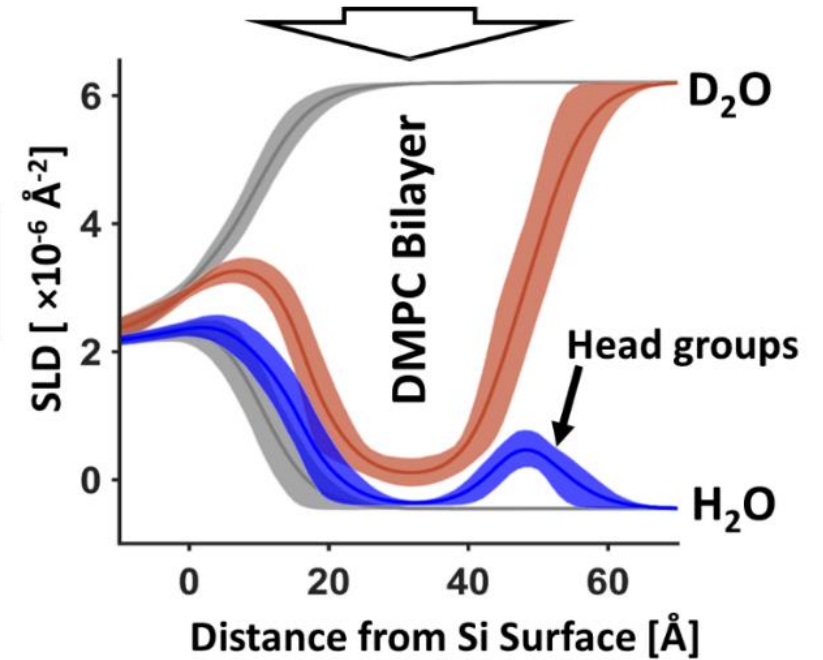
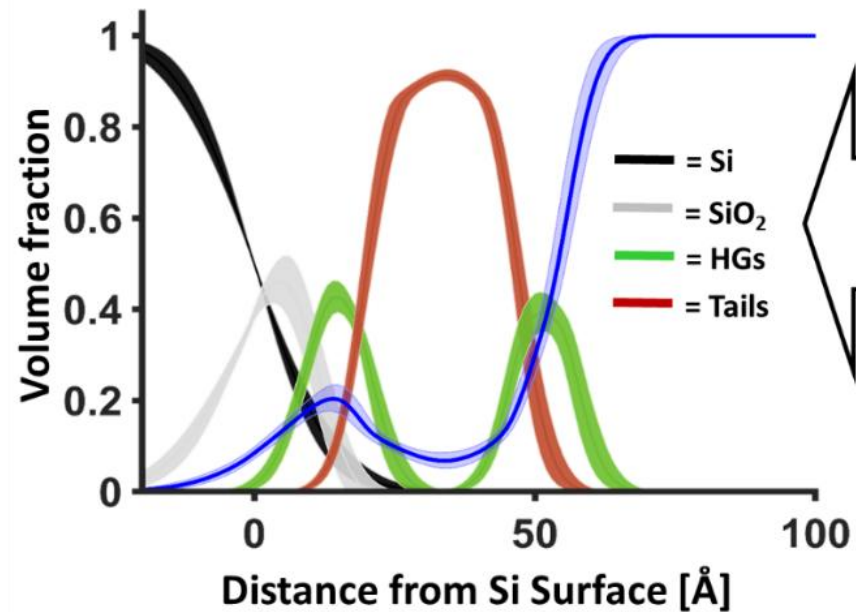
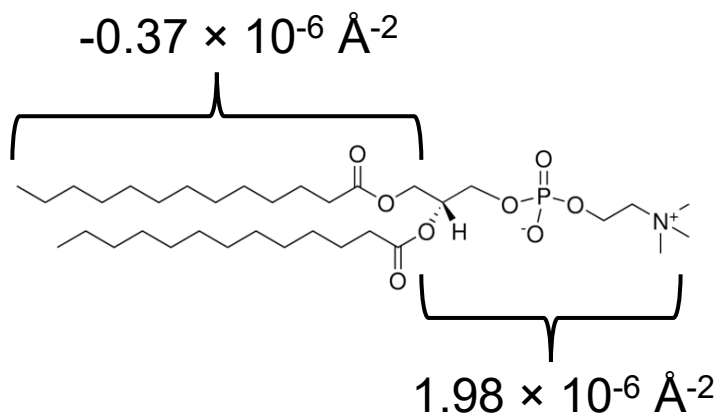
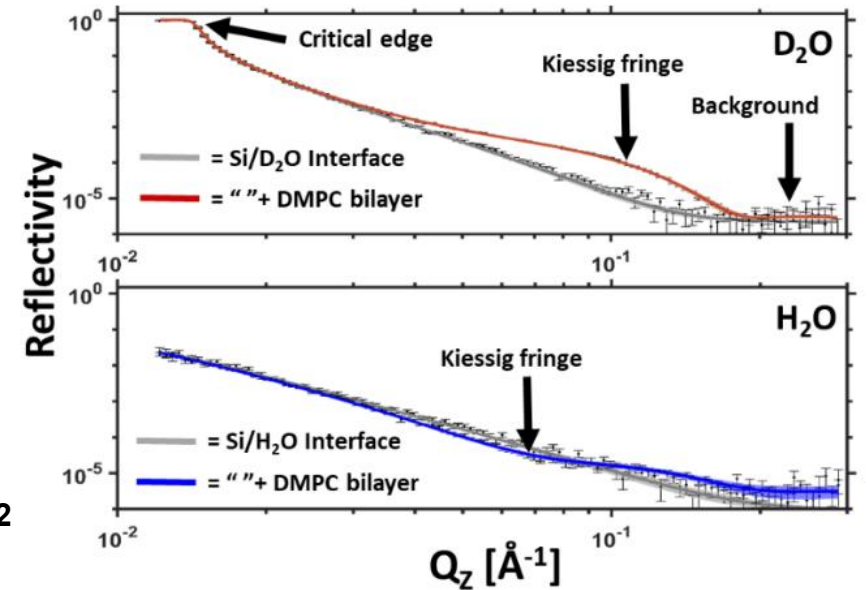
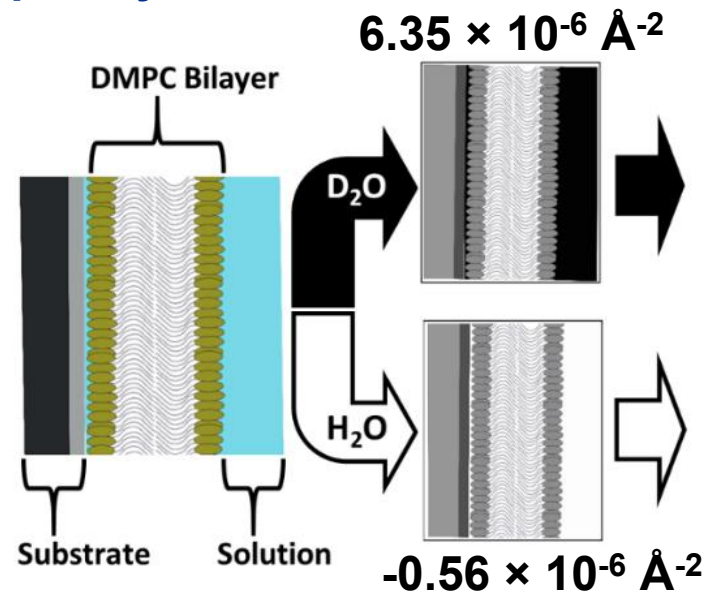
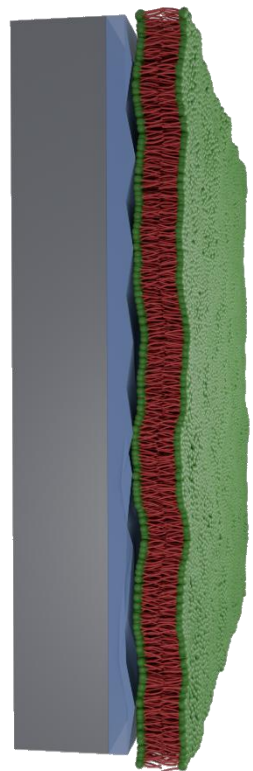
## What you need to resolve your structure:

- Priors information:
  - Simplest form knowledge of the superphase and subphase.
  - Knowledge of the neutron scattering length density of the interfacial components:

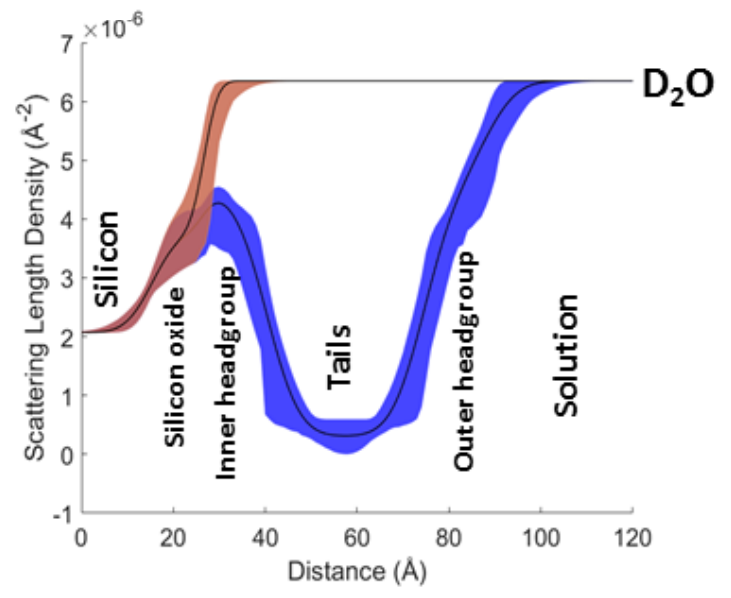
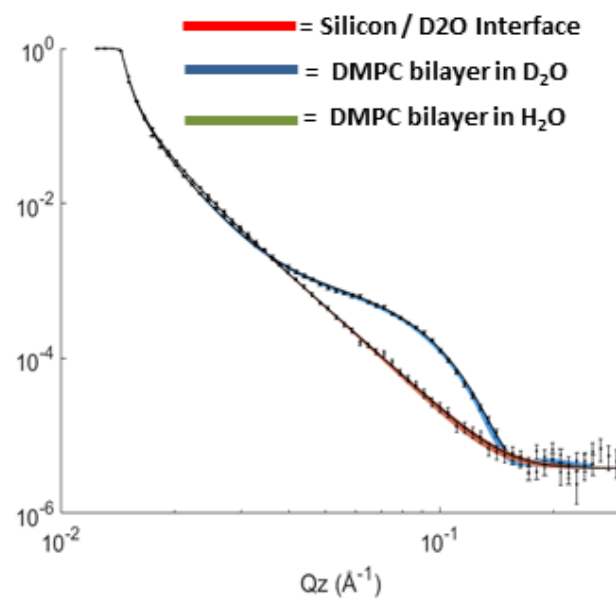
$$\rho = \frac{\sum b}{V}$$



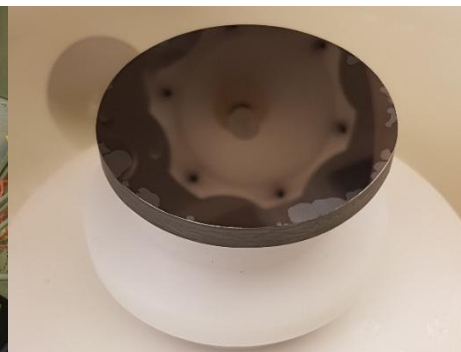
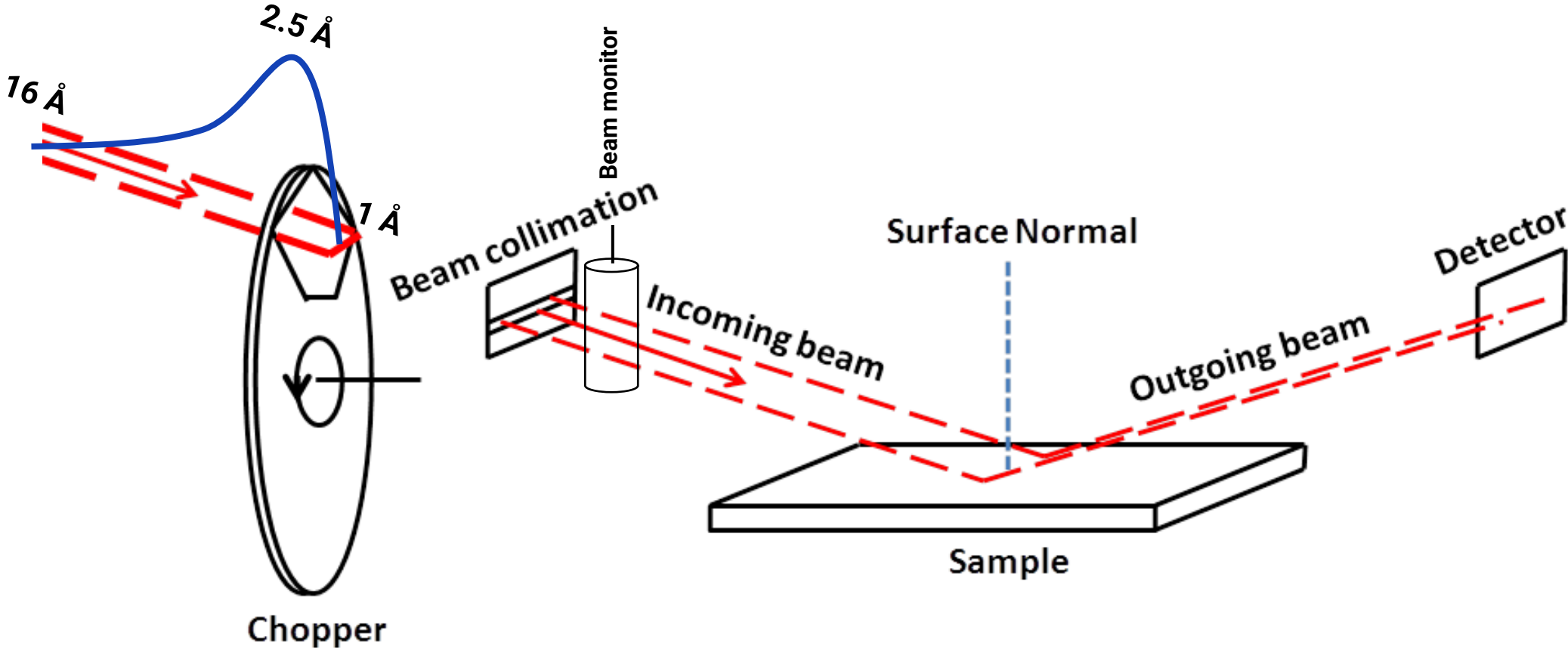
# Reflectometry gives you Structural Complexity



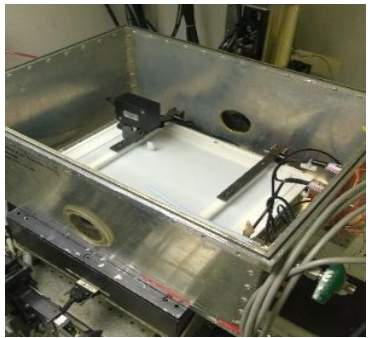
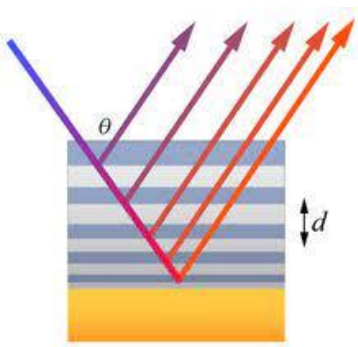
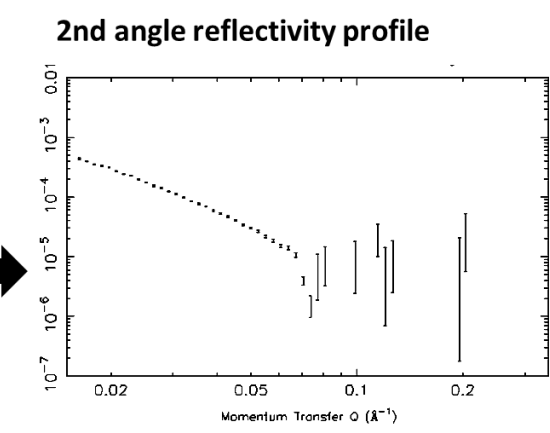
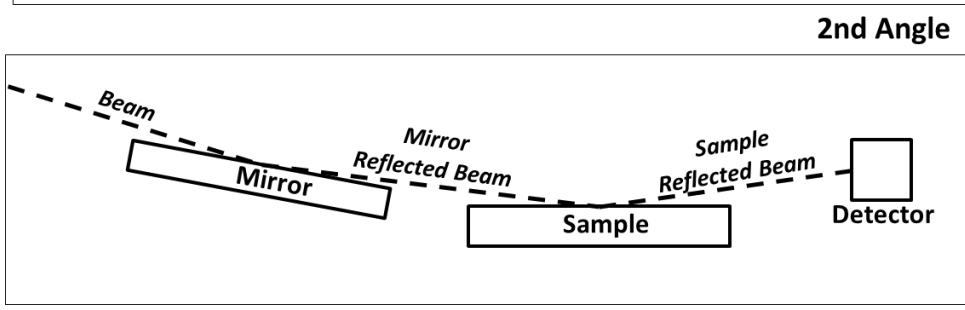
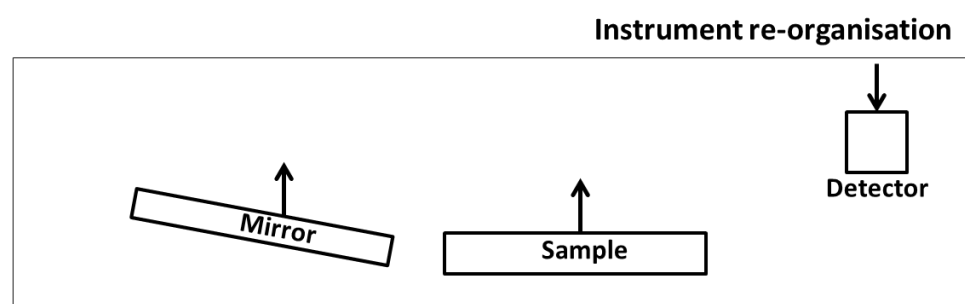
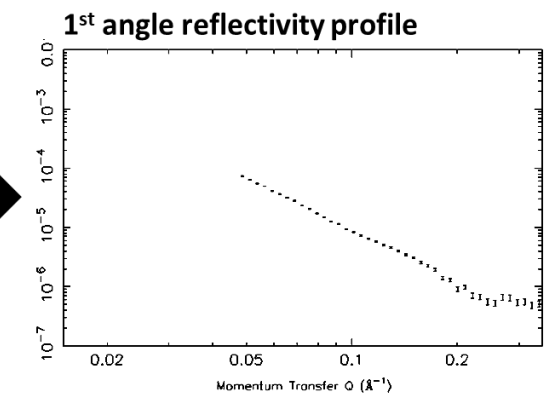
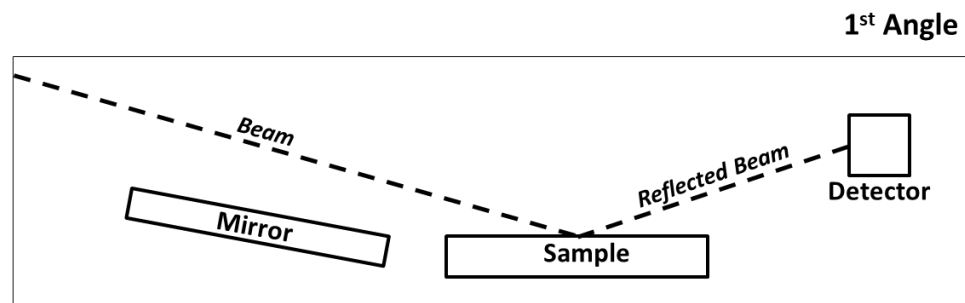
# Beware of ambiguity!



# Neutron Reflectometry Modes: Air/Liquid & Solid/Air



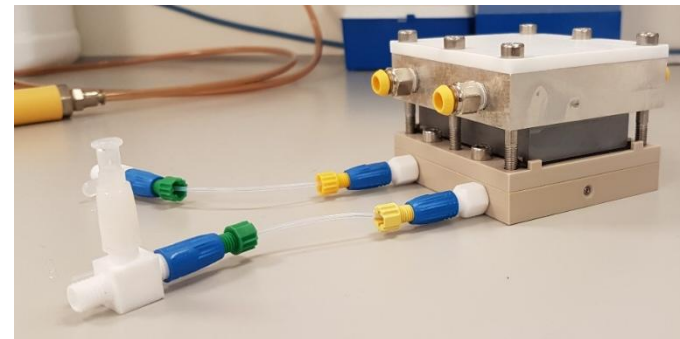
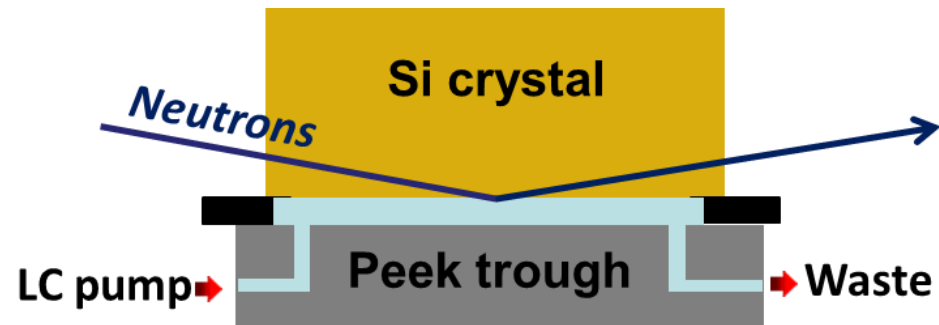
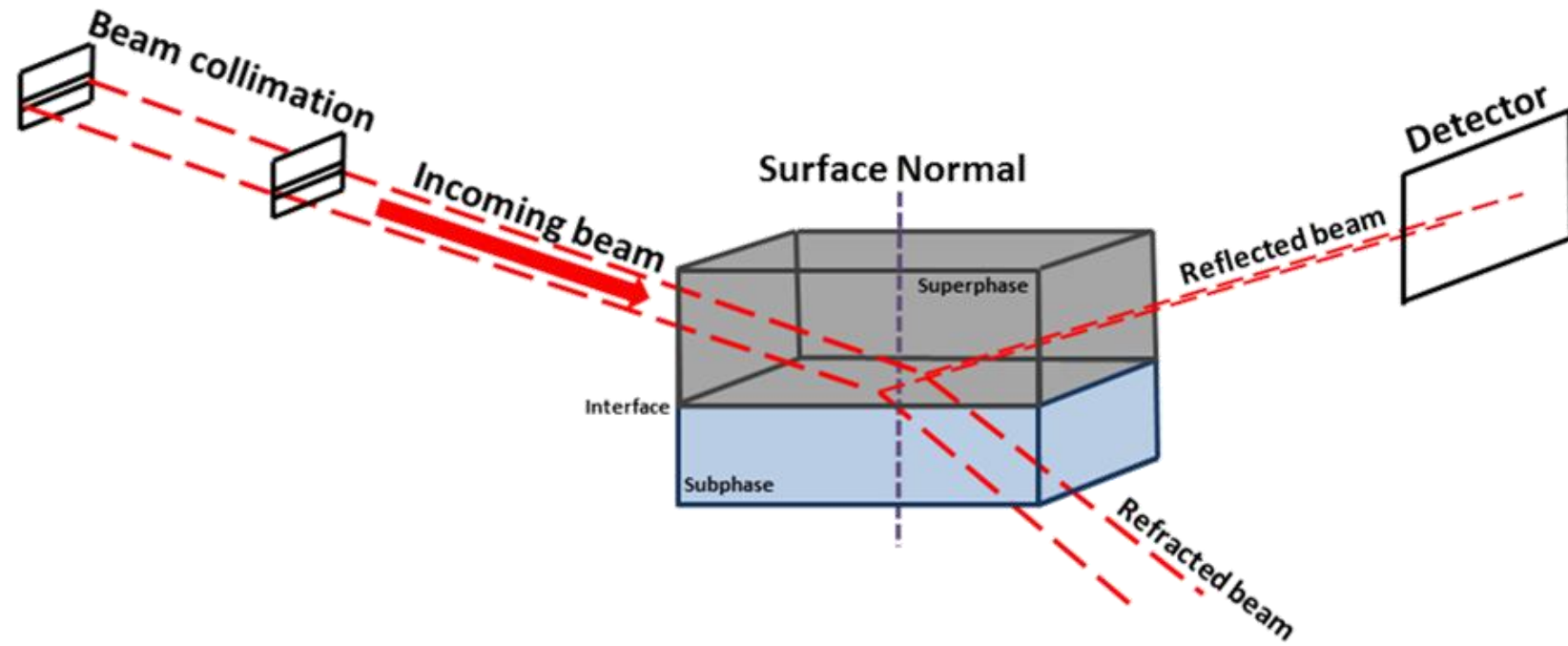
# Neutron Reflectometry : Air/Liquid



$$Q_z = \frac{4\pi \sin\theta}{\lambda}$$



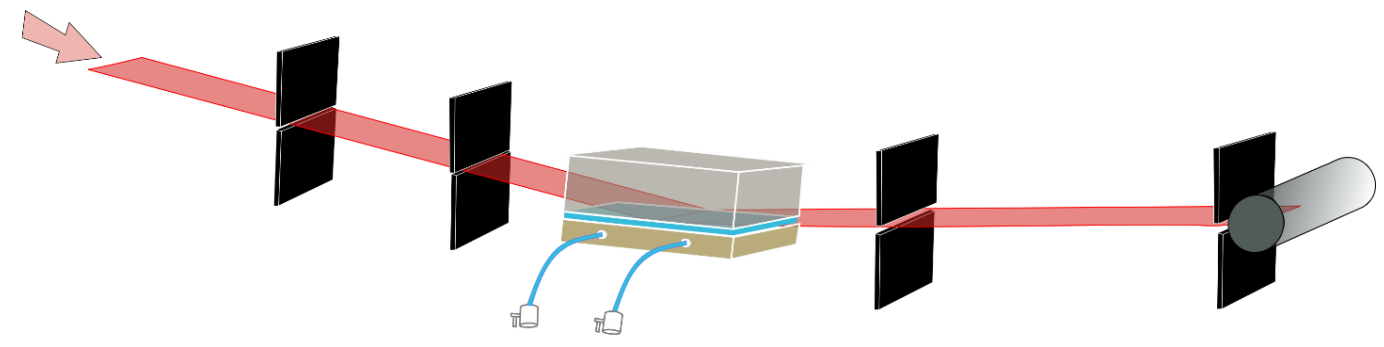
# Neutron Reflectometry: Solid-Liquid



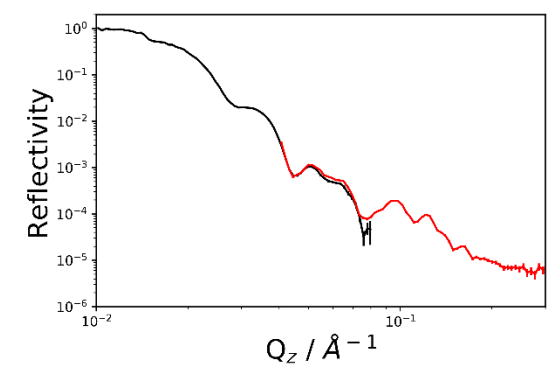
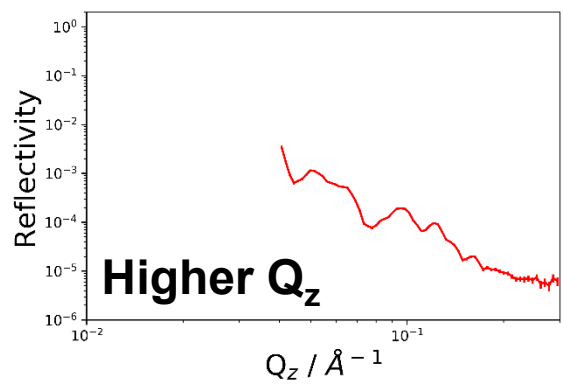
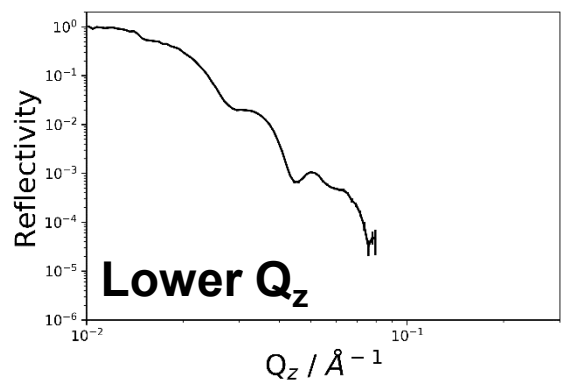
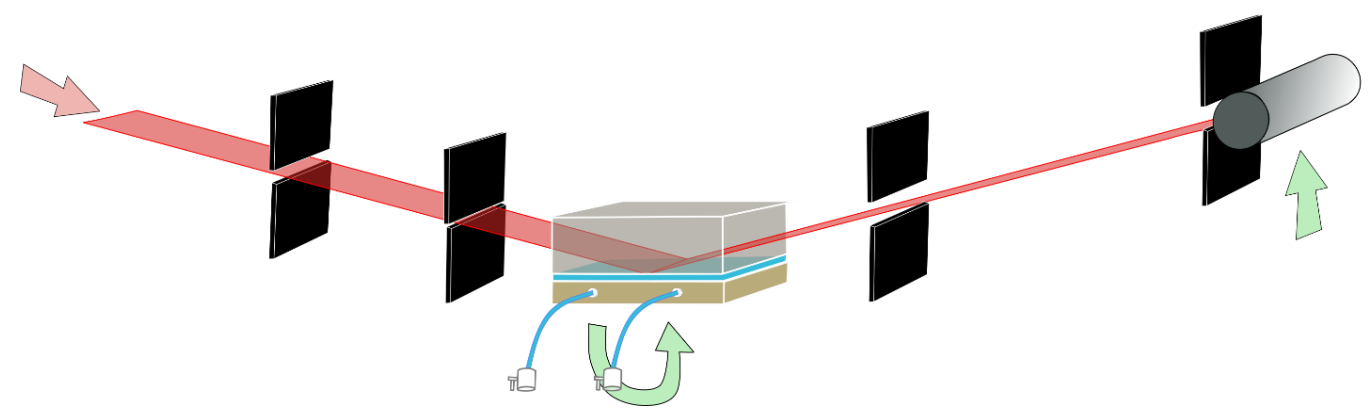
# Neutron Reflectometry: Solid-Liquid / Air-Solid

$$Q_z = \frac{4\pi \sin\theta}{\lambda}$$

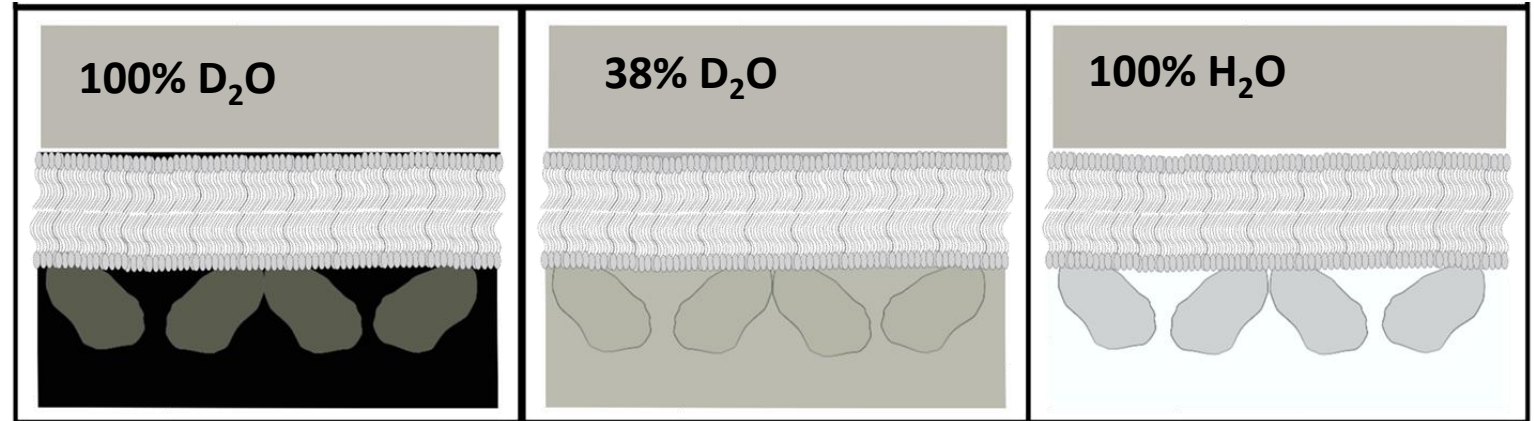
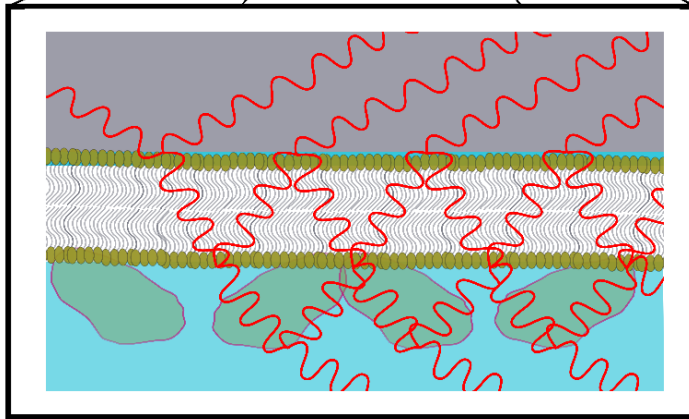
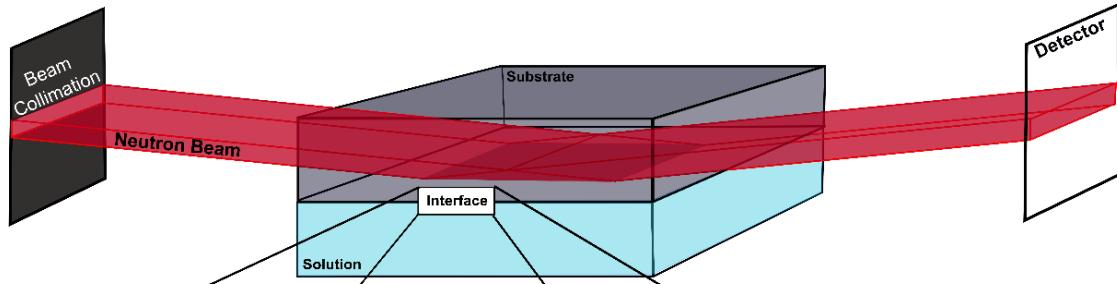
Lower  $Q_z$



Higher  $Q_z$

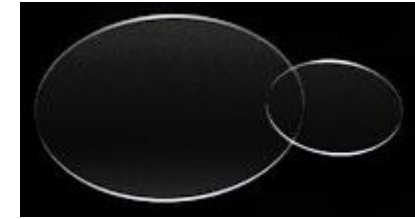
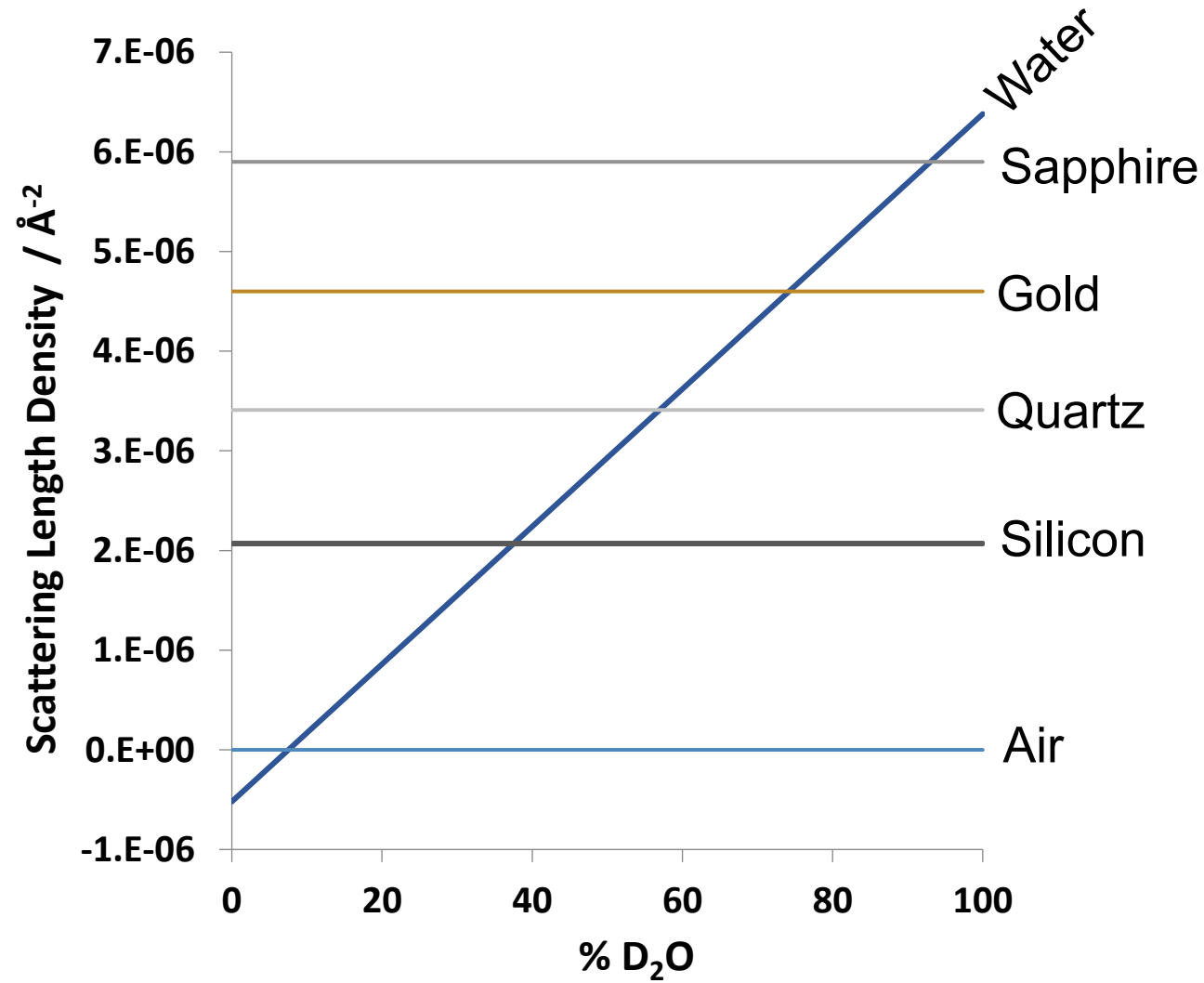


# Soft Matter NR and Isotopic Contrast Variation



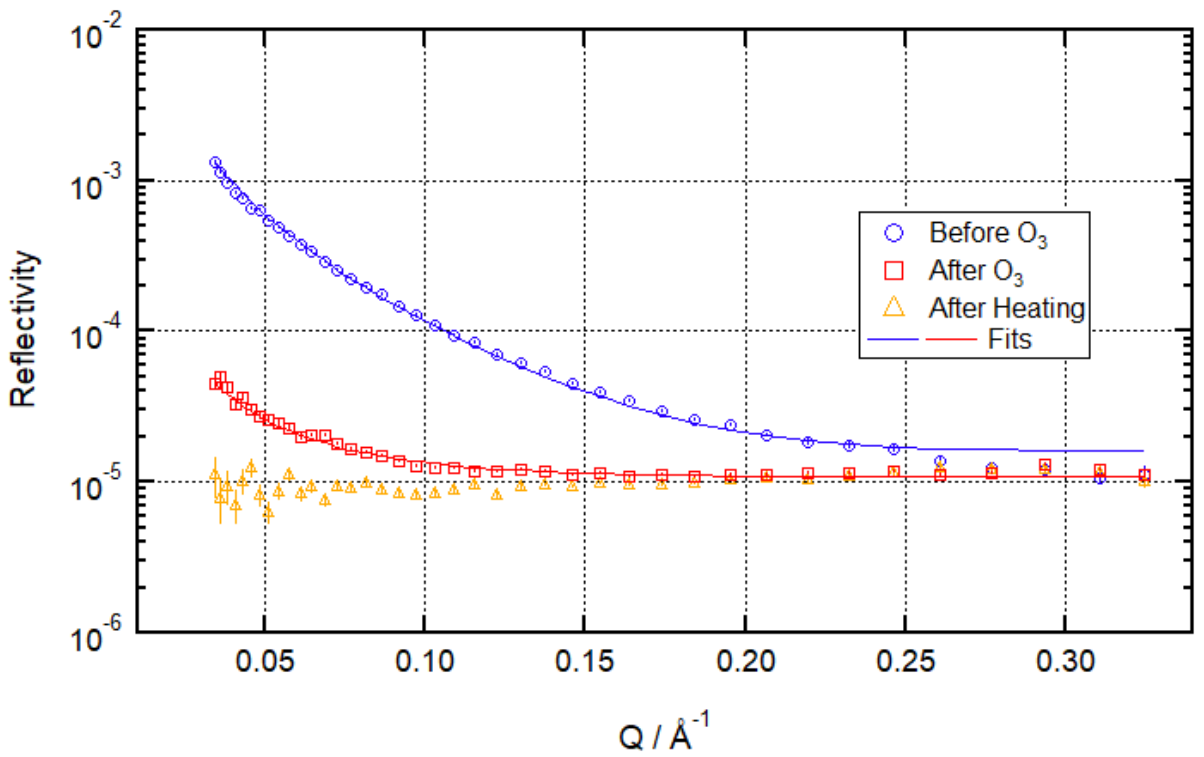
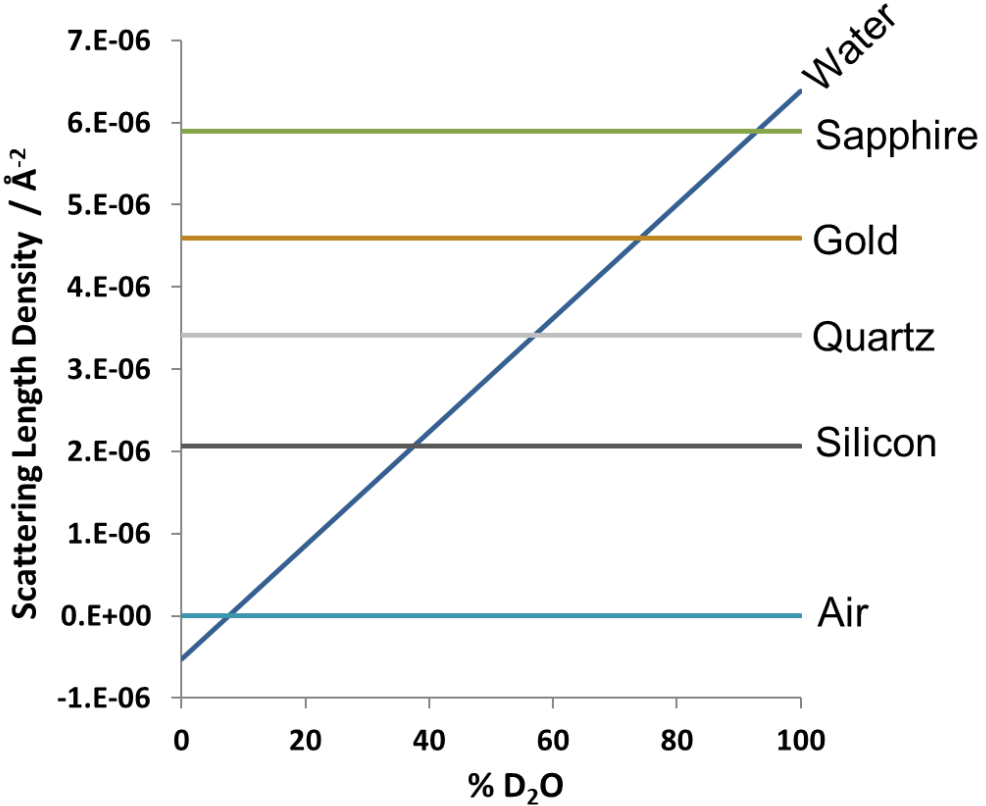
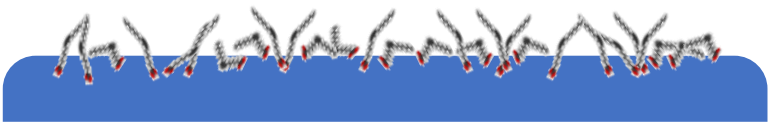
# Isotopic contrast allows for Individual Components to be Identified amongst Complex Samples

## Natural Contrast : Substrates

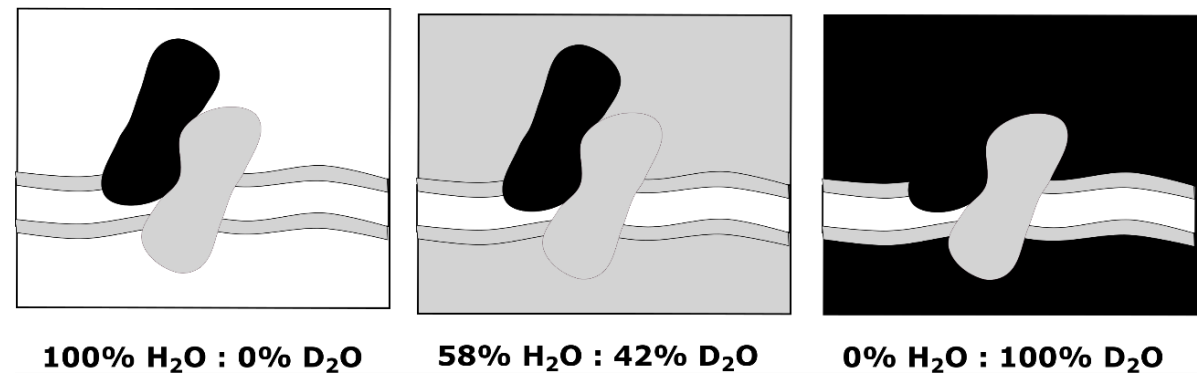
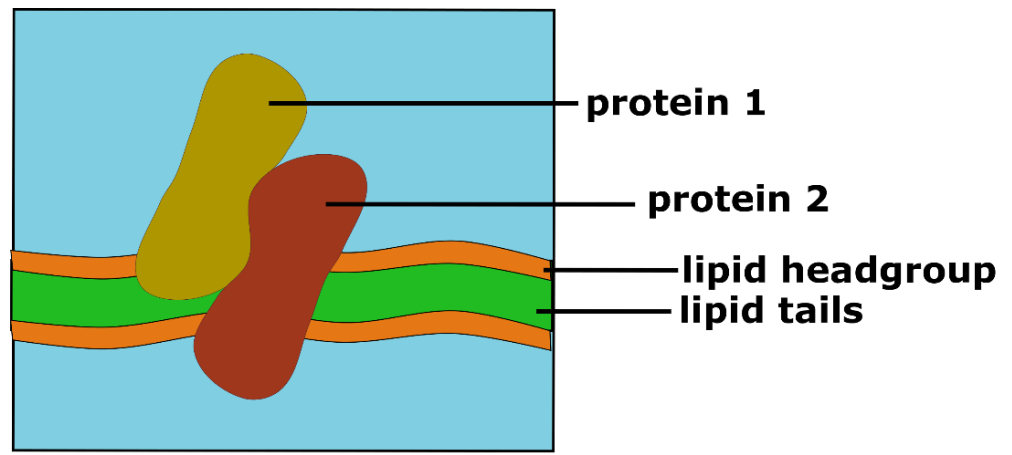
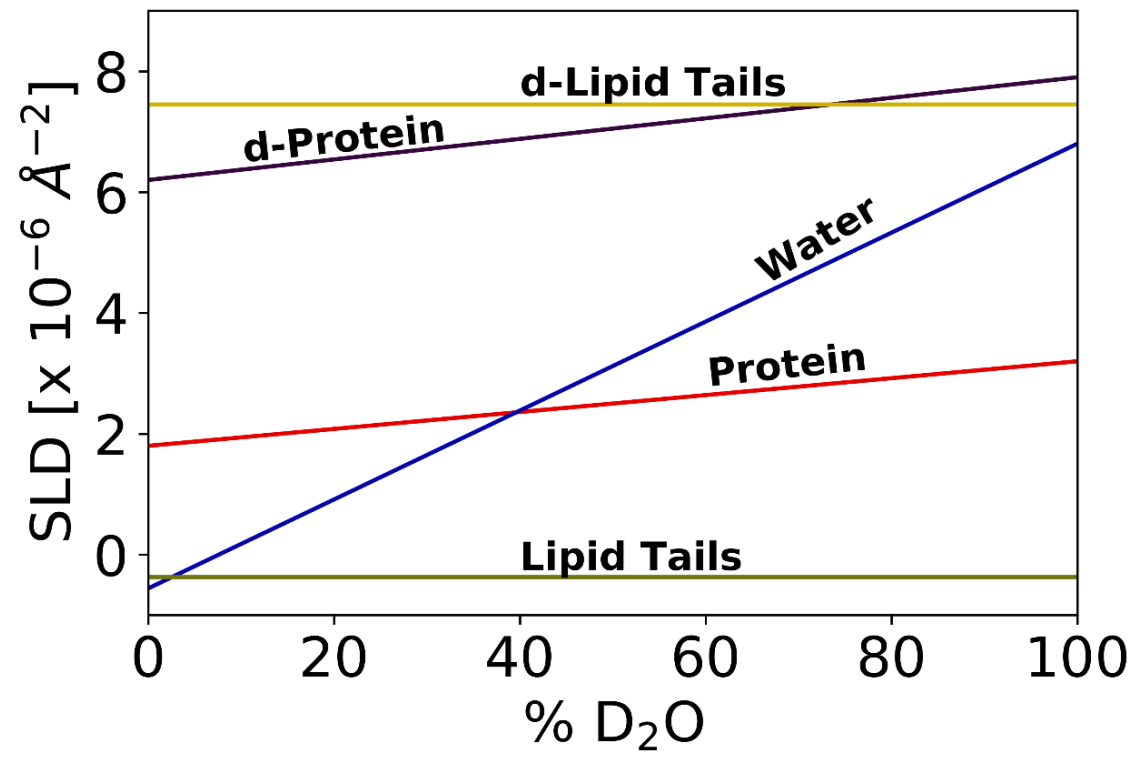


# Isotopic contrast allows for Individual Components to be Identified amongst Complex Samples

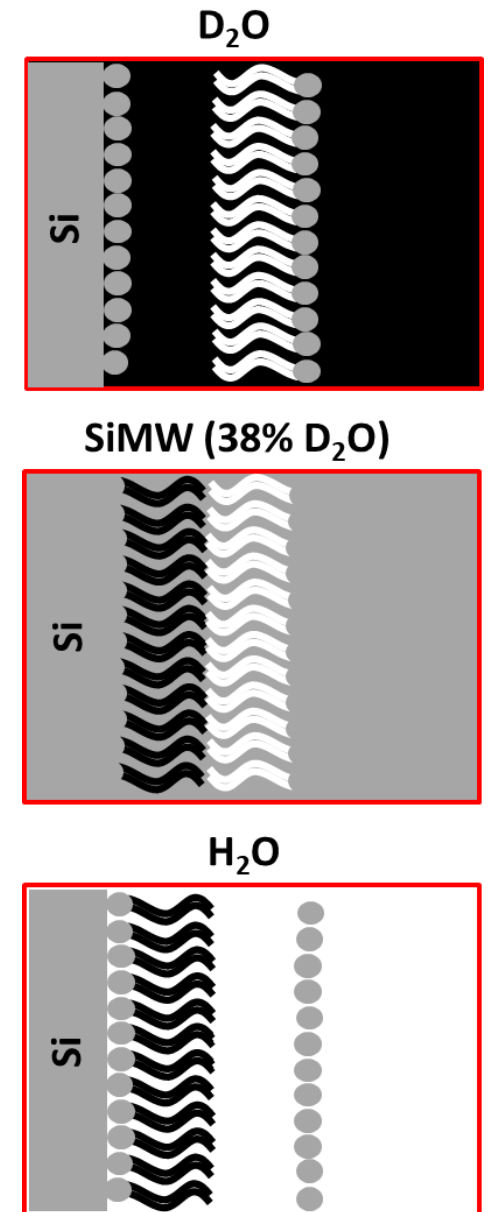
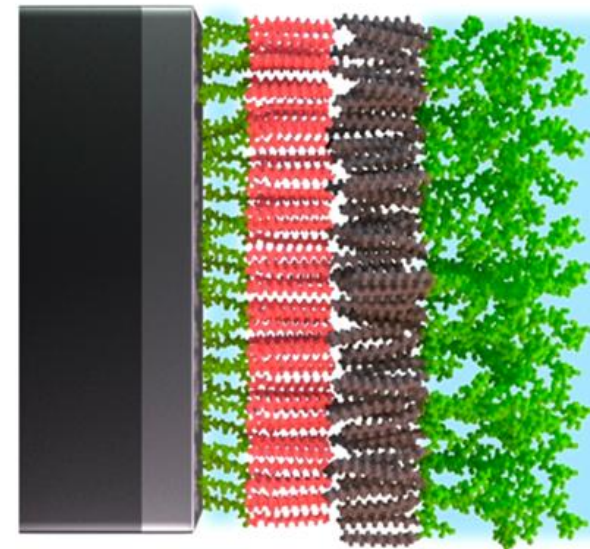
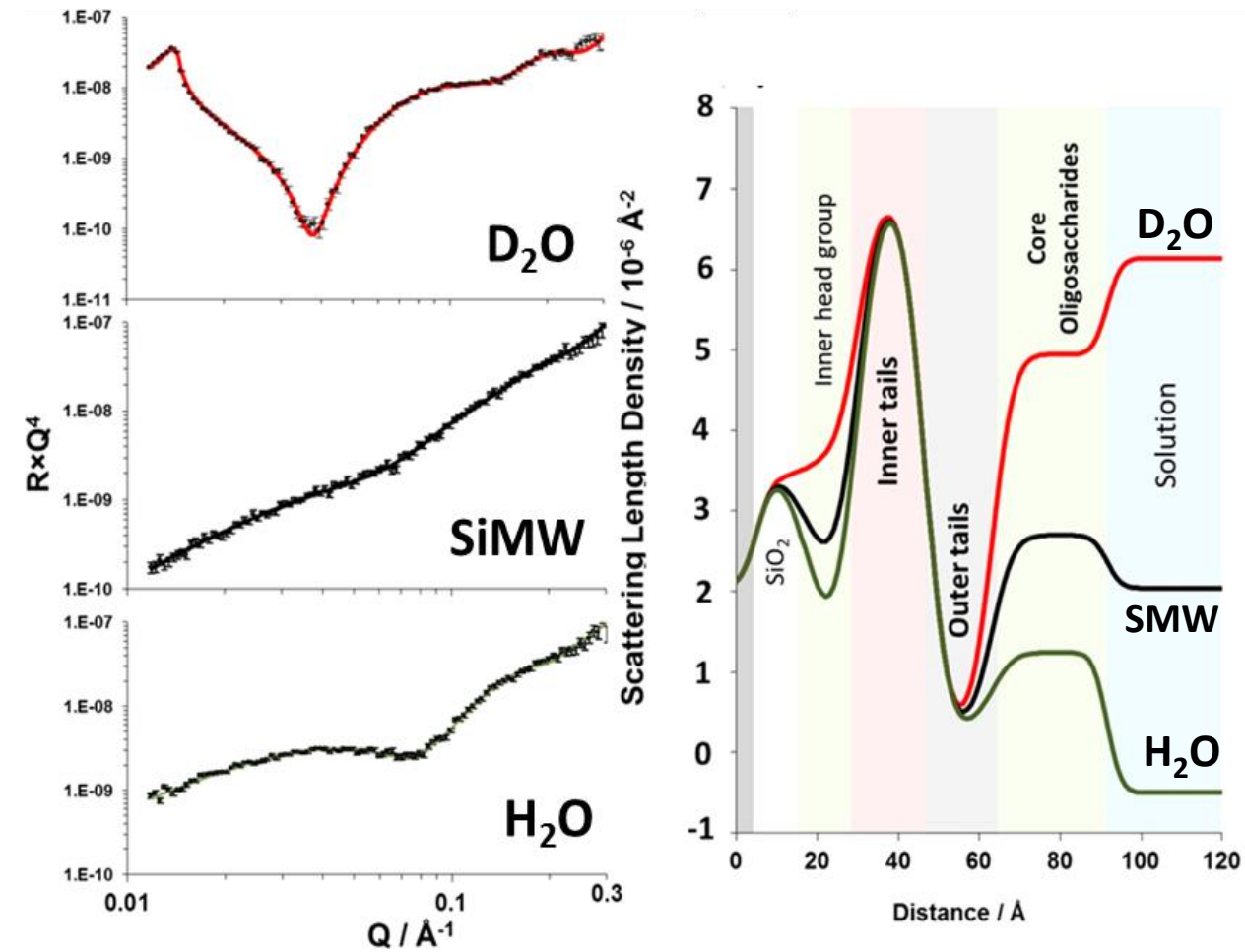
## Natural Contrast : Substrates



# Isotopic contrast allows for Individual Components to be Identified amongst Complex Samples: Deuteration

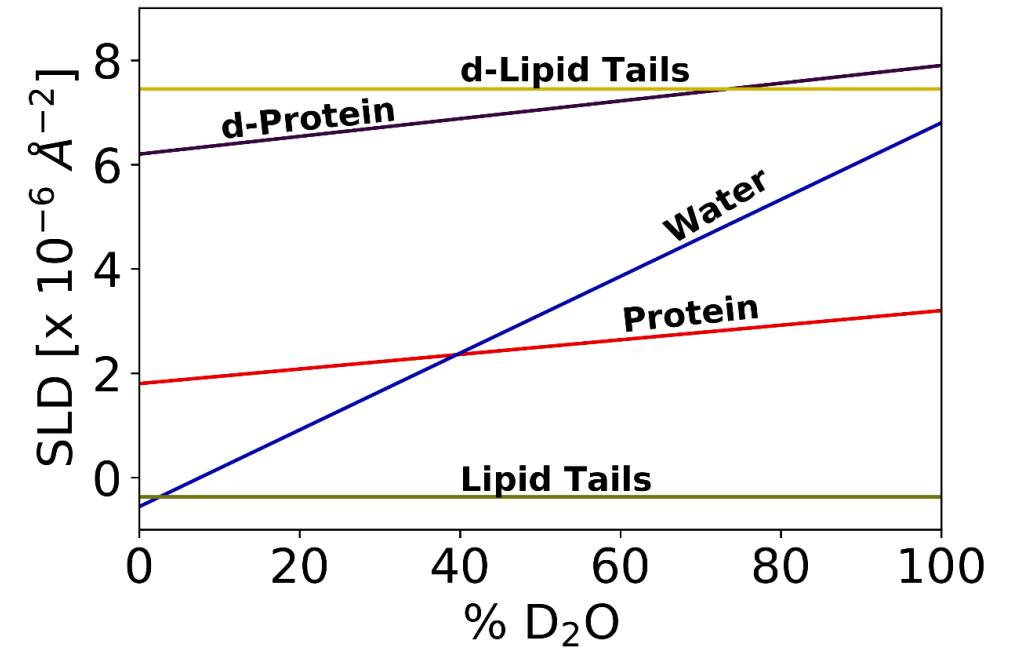
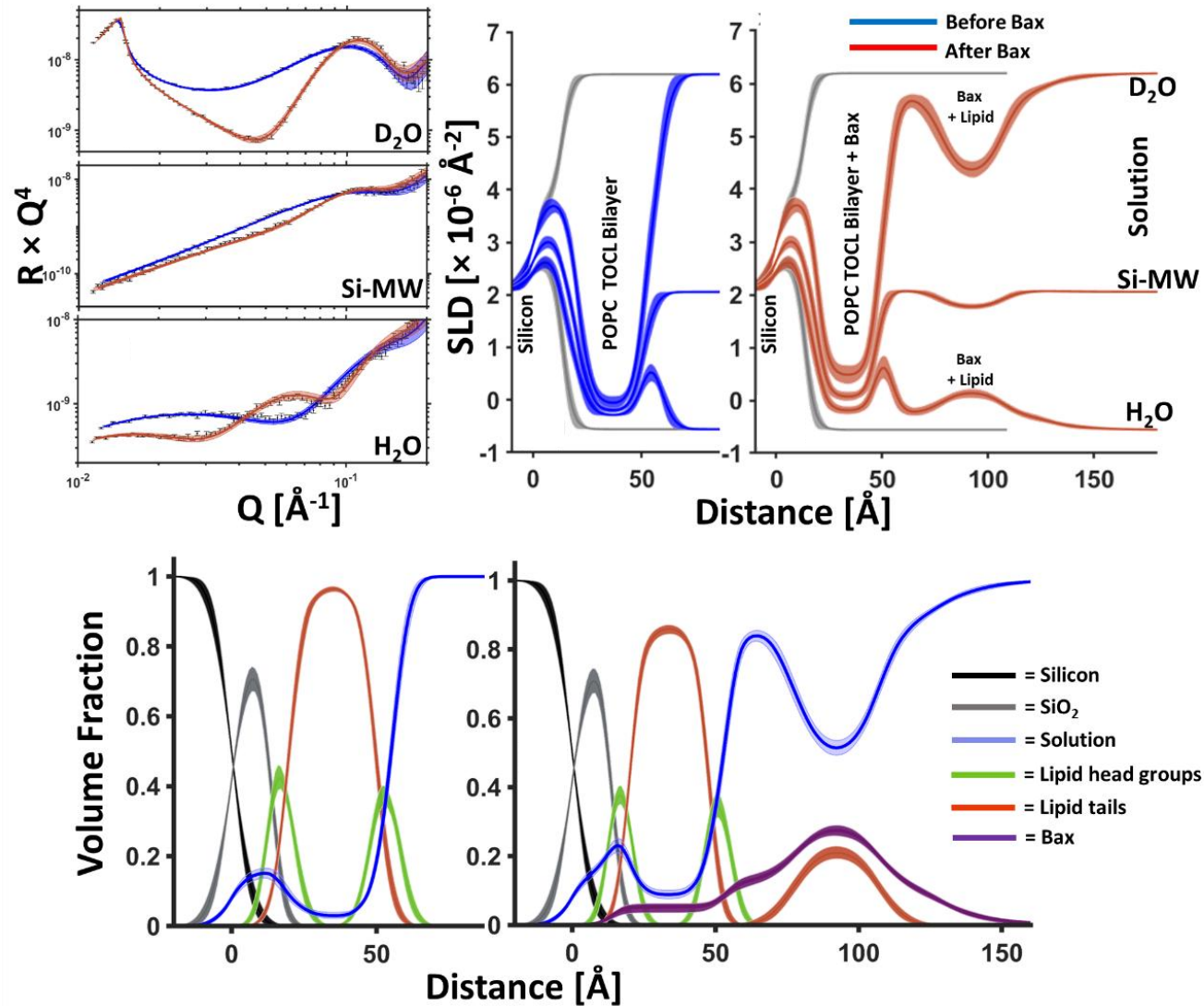


# Mixtures of d- and h- labelled Lipids : Resolving Complexity

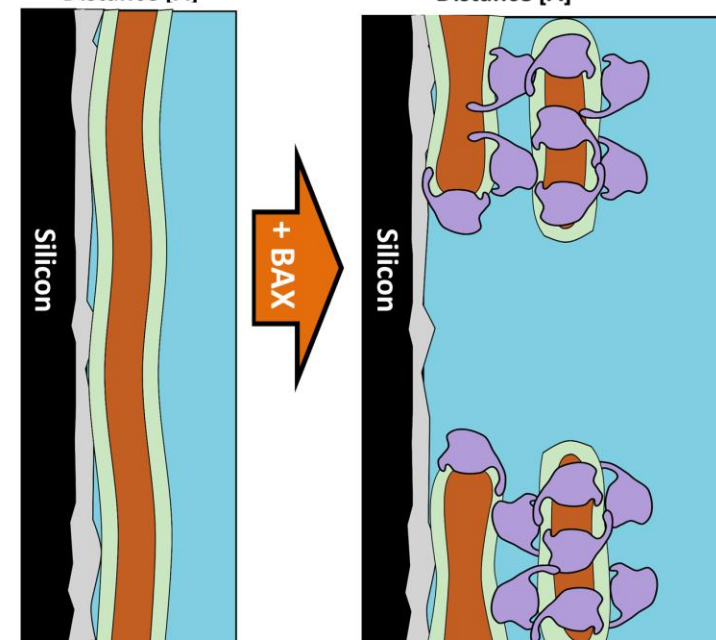
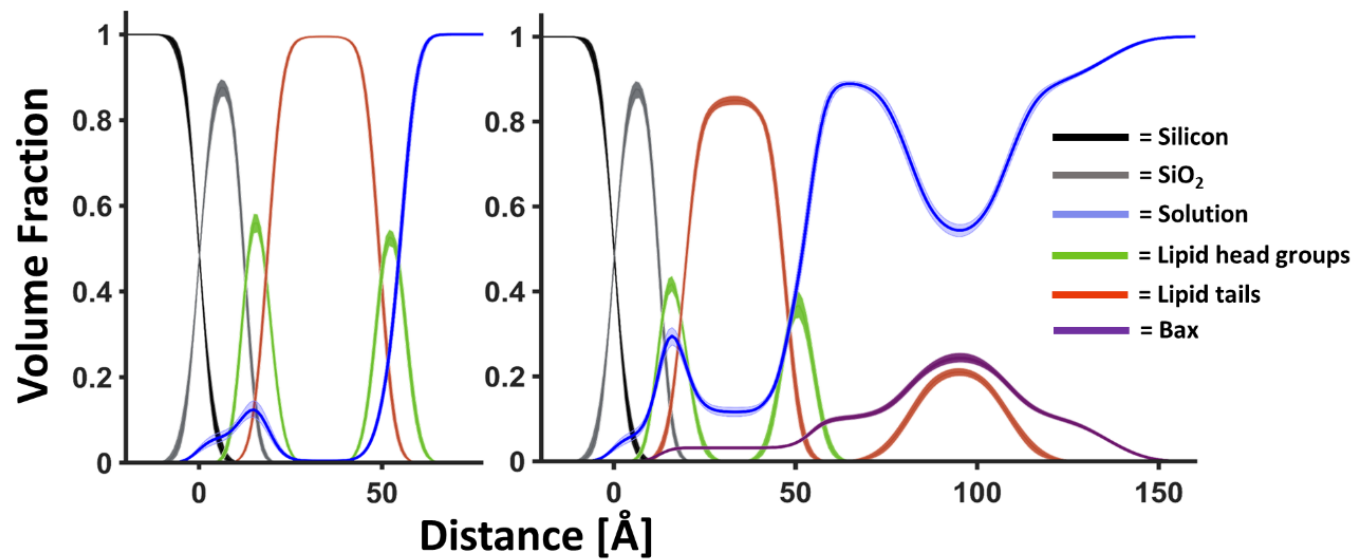
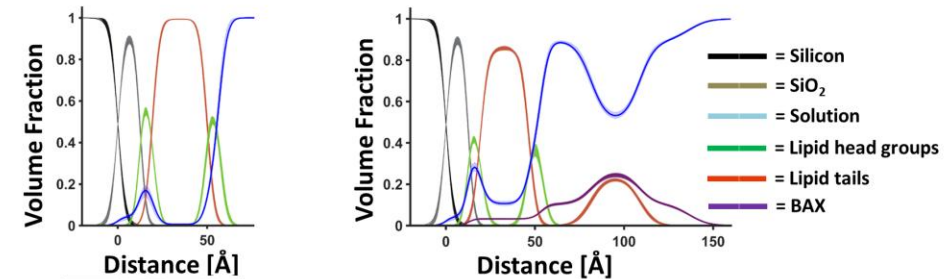
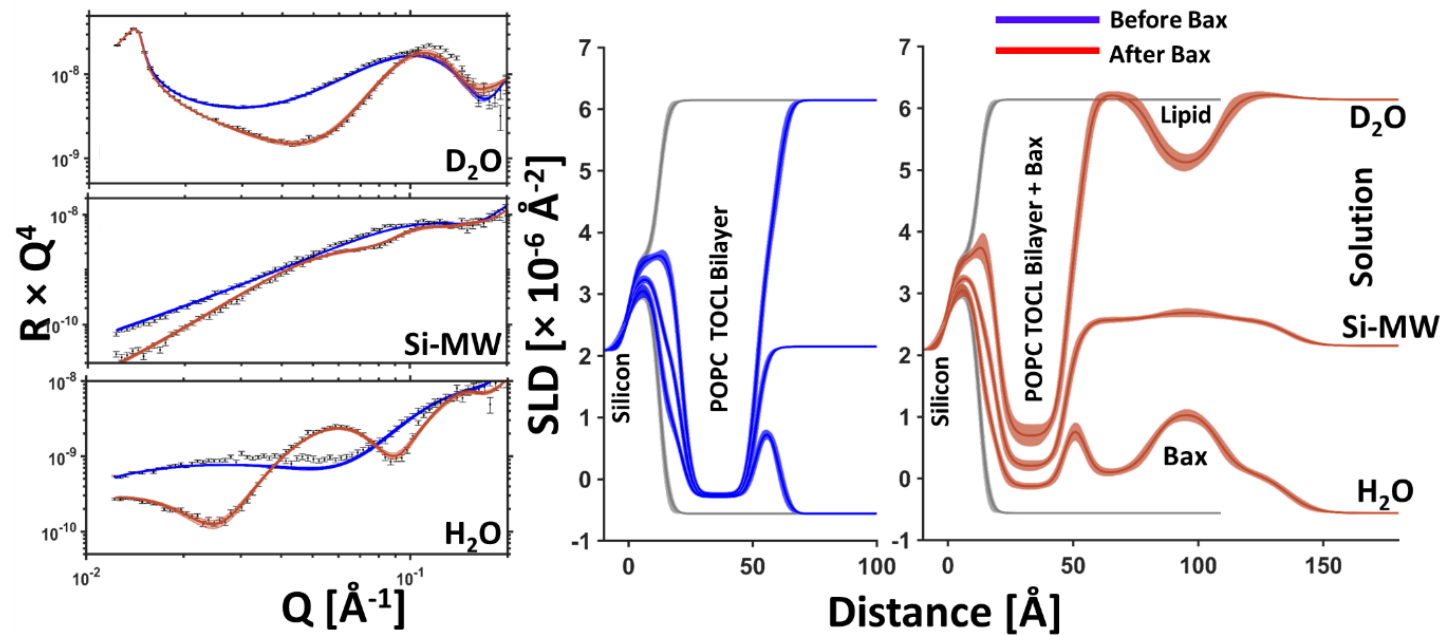


# d-Proteins : Resolving Complexity and Gaining signal

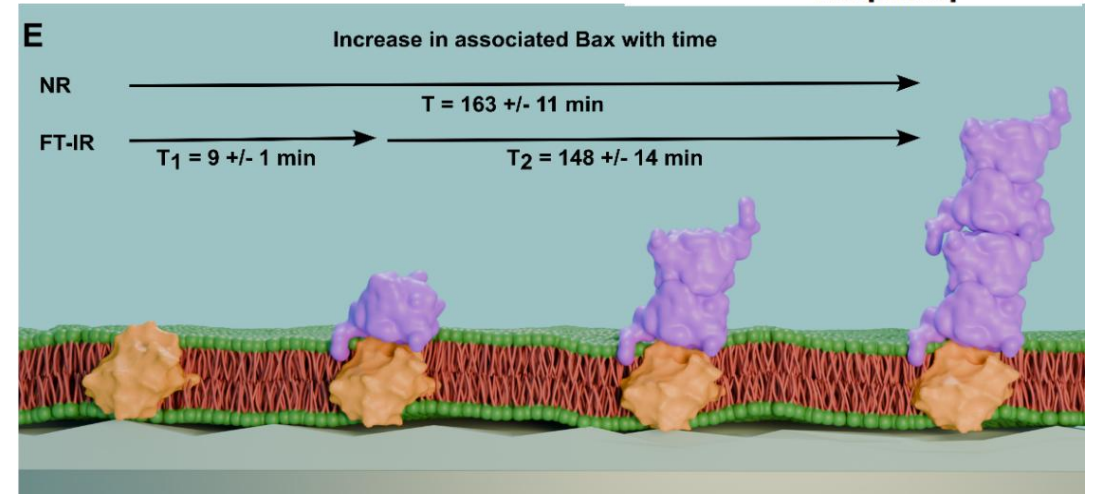
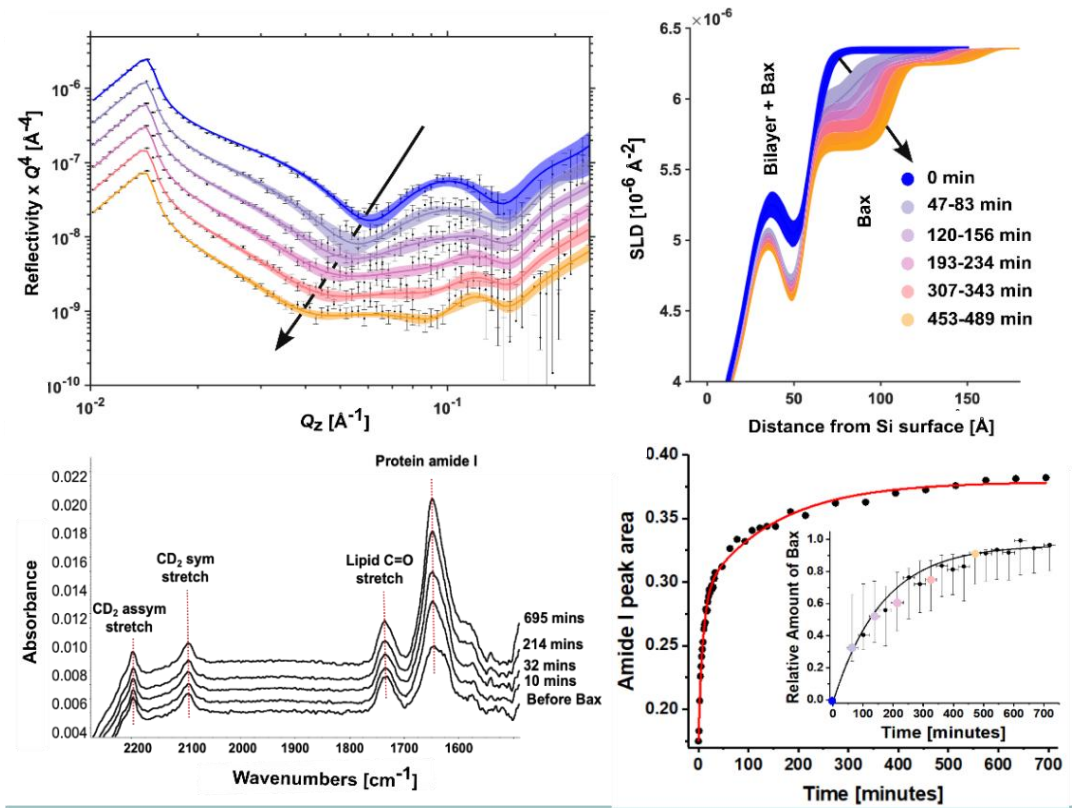
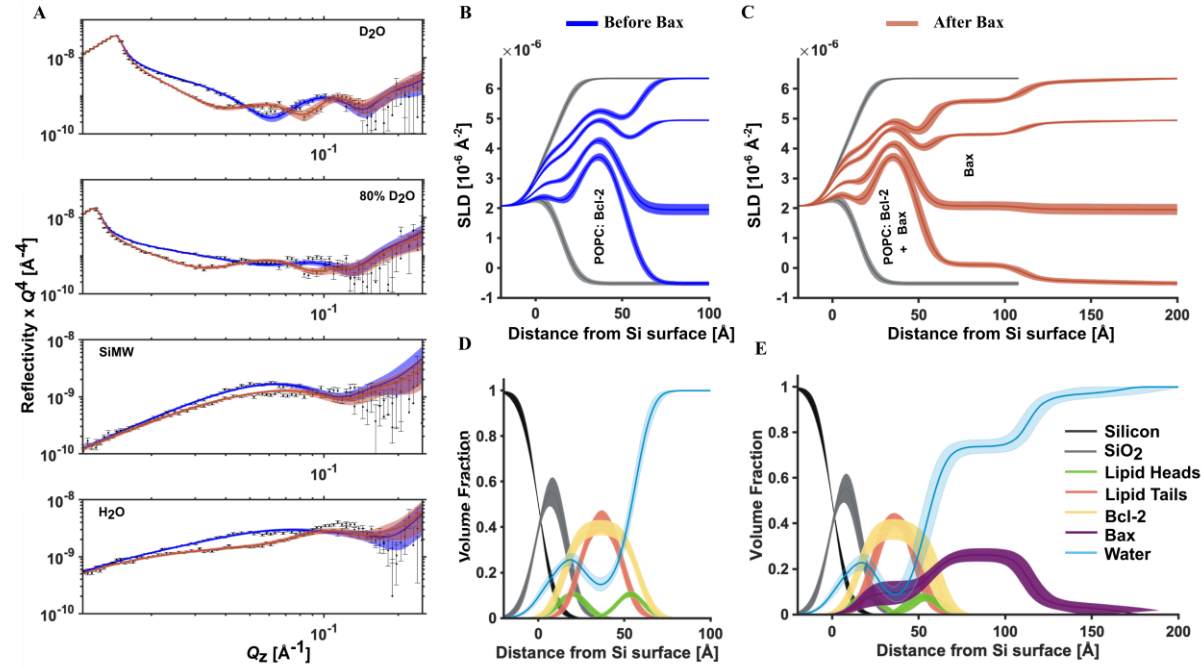
## h-Protein



# d-Proteins : Resolving Complexity and Gaining signal



# Time-Resolved Neutron Reflectometry



**Thank you for listening**



