

Summary (or more precisely: excerpts) from Emerging Opportunities: Soft Materials and Bioscience

Chairs: Stefan Vogt and Byeongdu Lee

Gayle Woloschak, Biological Studies with the Bionanoprobe
Breakout

Stephen Cheng, Giant surfactants based on Precisely Functionalized POSS Nano-
atoms: Tuning from Crystals to Frank-Kasper Phases and Quasicrystals

Hyungjung Kim, Use of Coherence in Hard X-rays to Study Dynamics and
Structures

Bob Leheny, New Opportunities in Soft Matter Research Employing High Energy
X-rays (**workshop summary**)

Bob Fischetti, Thoughts from June workshop on Biology and Life Science
(**workshop summary**)



Soft Materials

- Review some topics and issues in soft matter where the enhanced (coherent) flux at high energy provided by the APS-U should have significant impact.
- Draw on ideas from recent *“Workshop on Early Experiments and Opportunities in Soft Matter with the APS MBA Upgrade”* and related discussions.
- Key areas for opportunity in soft matter with APS-U:
 1. Understanding and control of defects in ordered phases
 2. Spatial and Temporal Heterogeneity of Out-of-Equilibrium Dynamics
 - a) Intermittency in glassy systems
 - b) Nonlinear response to mechanical stress
 3. Interactions and Assembly at Fluid Interfaces
 4. Structure and Dynamics of Biomembranes



1. Soft materials under deformation and flow:

- Soft matter typically displays strongly nonlinear response to mechanical stress
e.g., shear thinning, shear thickening, thixotropy

Shear thickening

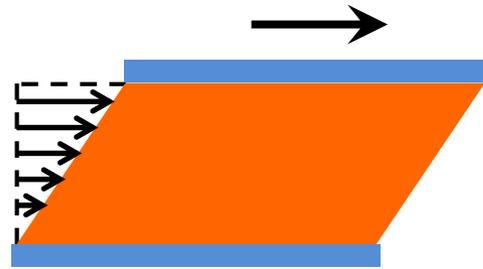
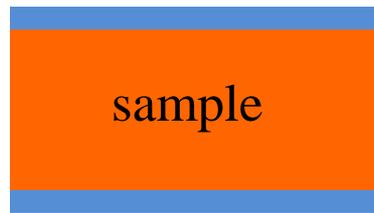


- Origin of nonlinear response is stress-induced changes to microstructure.
- But, Identifying connections between the microscopic and macroscopic behavior remains a central challenge.

→ X-ray scattering with *in situ* stress/flow is a powerful probe.



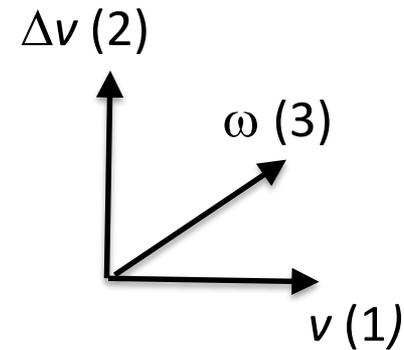
E.g., SAXS with *In Situ* Shear



$$v_1 = \dot{\gamma}x_2$$

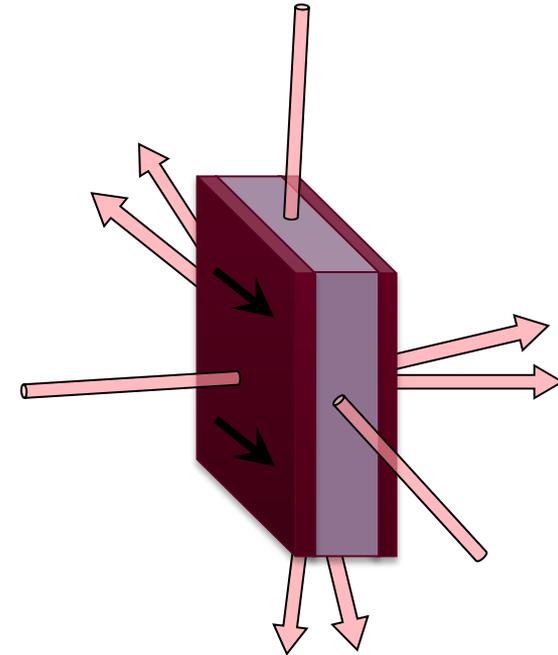
$$v_2 = v_3 = 0$$

$\dot{\gamma}$ = "shear rate"



Choice of scattering plane: v - Δv , v - ω , Δv - ω
leads to different information about shear-induced structure.

- SAXS in v - ω plane is easiest & most commonly realized.
- But, v - Δv plane arguably most informative regarding structural changes.
- And, for XPCS, Δv - ω has arguably most promise.

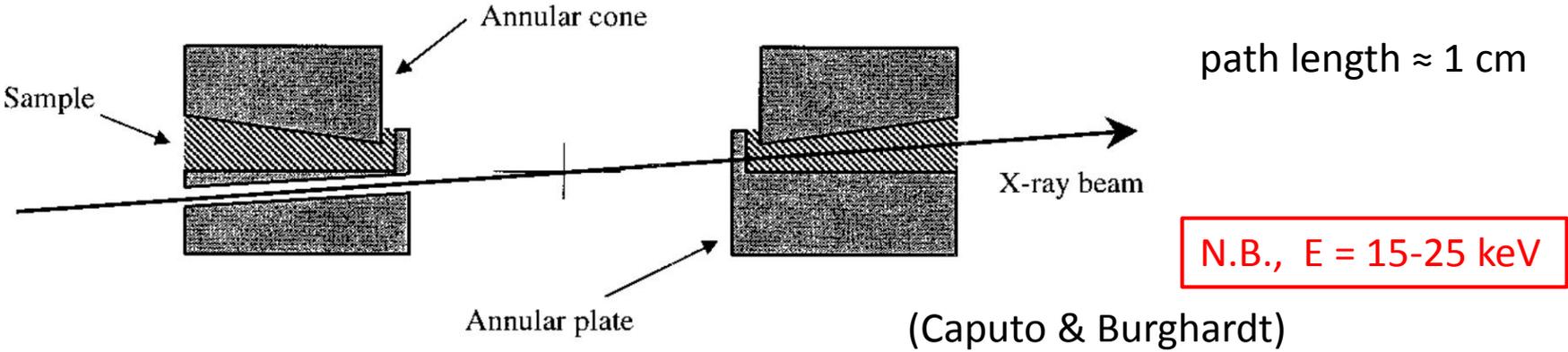


High energy x-rays key to realizing SAXS in v - Δv and Δv - ω planes.

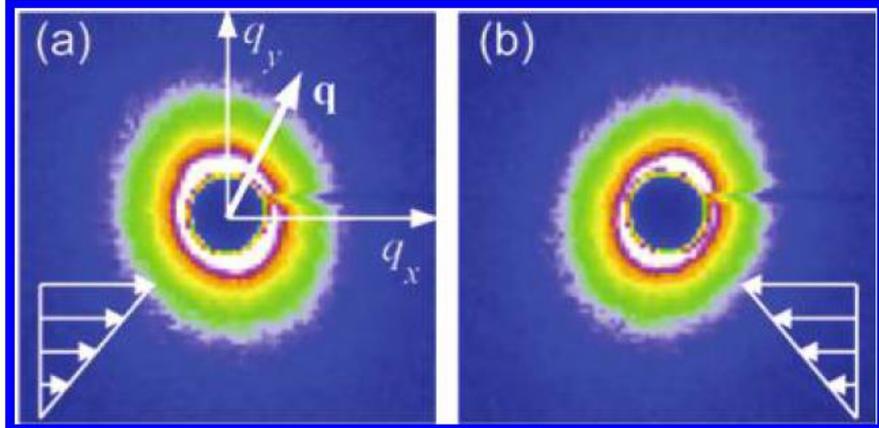


SAXS in ν - $\Delta\nu$ plane:

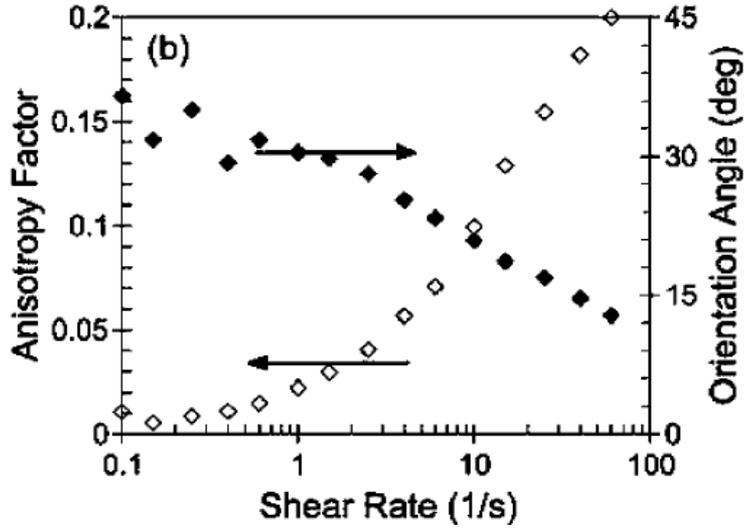
Example from Wes Burghardt's group:



Results from polymer/clay nanocomposites:

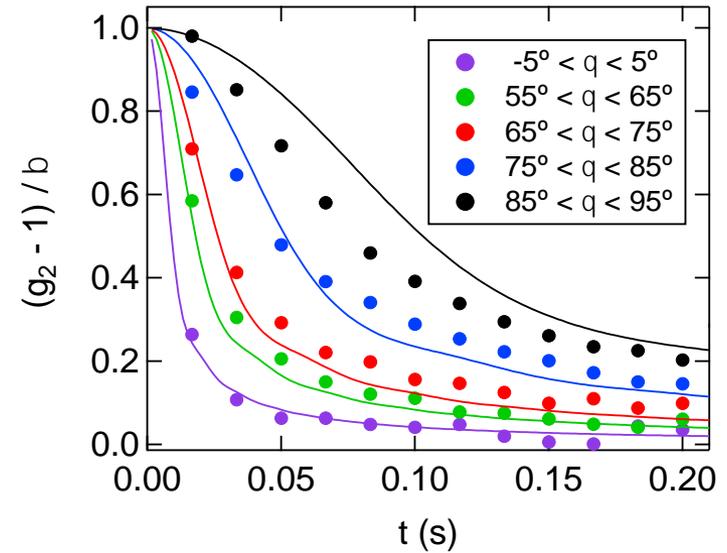
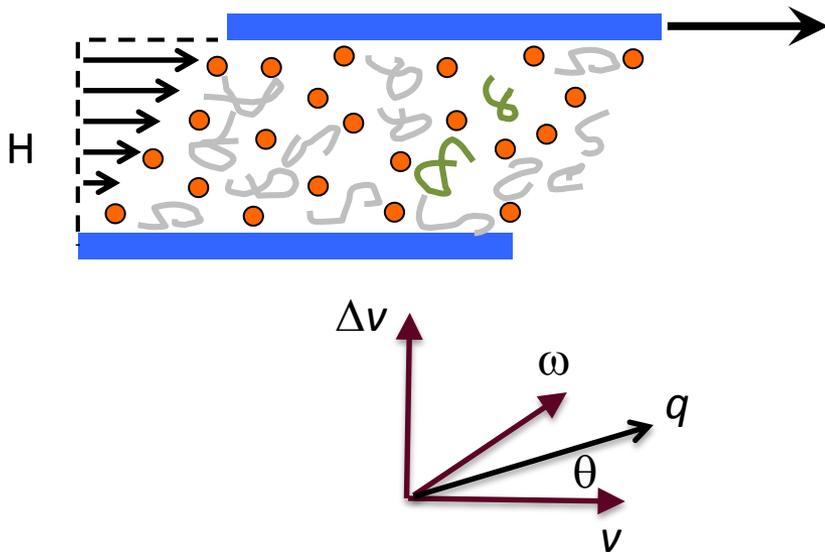


(Dykes, Torkelson, & Burghardt, *Macromolecules* **45**, 1622, 2012)



N.B., both degree and direction of anisotropy probed; unique capability of ν - $\Delta\nu$ plane





$$g_2(\mathbf{q}, t) = 1 + \beta \exp[-2Dq^2t] \times \frac{\sin^2(q_{\parallel} \dot{\gamma} H t / 2)}{(q_{\parallel} \dot{\gamma} H t / 2)^2} \times \exp[-(t/\tau_T)^2]$$

Intrinsic dynamics

Shear

Transit

Problem:

For scattering in v - ω plane, correlation function determined by shear, not intrinsic dynamics.

Shear (or transit) dictates $g_2(q, t)$ except at very small Peclet numbers:

$$\text{Pe} = \dot{\gamma} R^2 / D \lesssim 0.01$$

→ Nonlinear effects on intrinsic dynamics inaccessible...

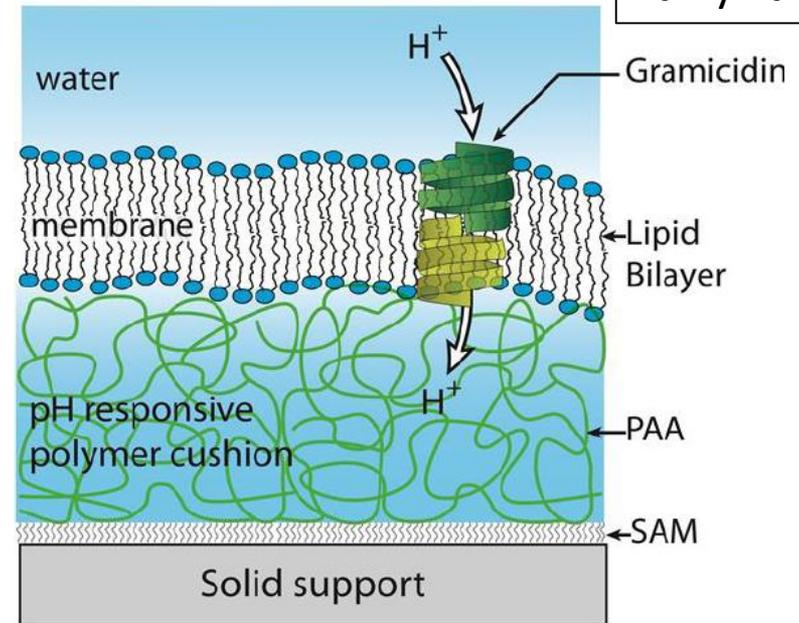


v) (Single) lipid bilayer membranes

Tonya Kuhl
Larry Lurio

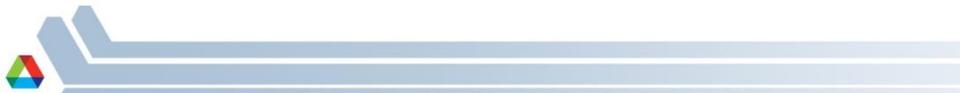
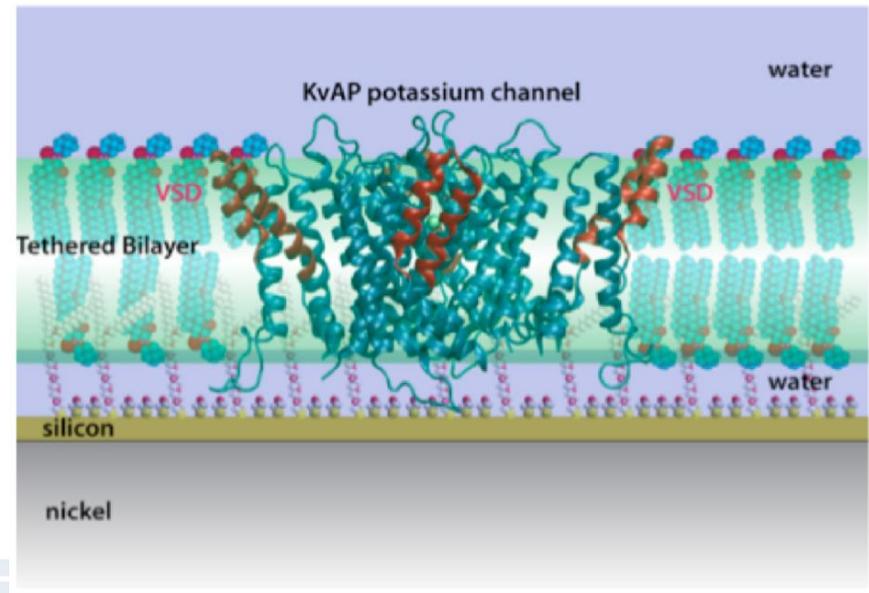
a) Polymer-cushioned membrane platforms

- Mimic nanostructured chemical and physical environment of cell membrane.
- GID for in-plane structure.
- XPCS for membrane fluctuations
→ viscoelasticity.



b) Supported membranes with controlled electrochemical potential

- Structure of ion pumps and gated ion-channels upon opening/closing.



Biosciences



Macromolecular Crystallography - scientific topics

- **Membrane proteins** (~30% of all proteins) – many grown in lipidic cubic phase (LCP)
 - Receptors – signaling across cellular membrane (>800 proteins in family)
 - Kinases – regulatory control via ATP driven phosphorylation (>500 proteins in family)
 - Transporters – move ions, small molecules or macromolecules across membrane (active and diffusion)
 - Neurotransmitter transporters – transport neurotransmitters across neuron membranes
 - Ion channels - Na, K, Ca, and proton pumps
- **Understanding protein synthesis and better antibiotics**
 - Ribosomes and polysomes (large macromolecular assemblies)
- **Large macromolecular complexes and molecular machines**
 - Nuclear pore complexes (>120 nm in diameter) responsible for molecular trafficking
 - Kinetochores: large complex assemblies (50-100 nm) that attach chromosomes to microtubules during mitosis
 - Transcription initiation machines – large, multicomponent assembly that aligns DNA for transcription

Improving human health

Scientific opportunity

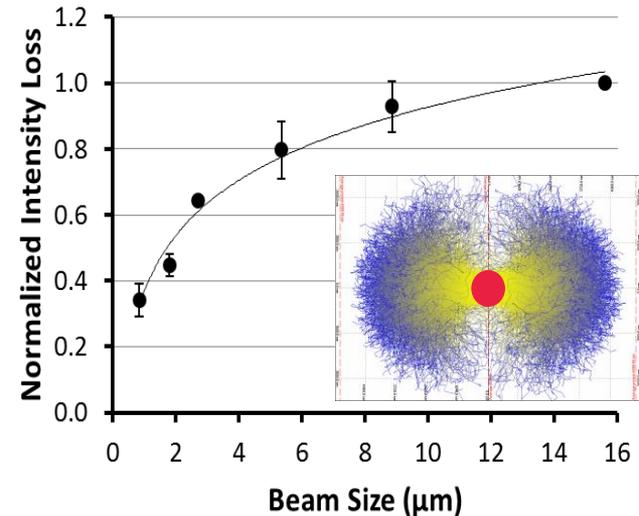
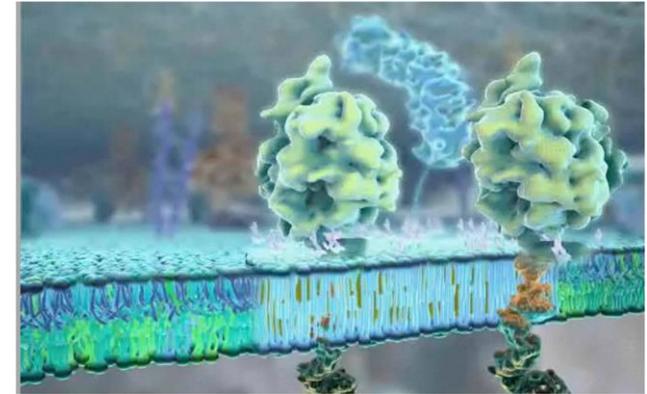
Membrane proteins and proteins complexes mediate cellular responses, act as cellular gateways, have been implicated in many diseases, and are the target of many drugs.

Breakthrough techniques

Microcrystallography has recently enabled the determination of high impact, 3D structures of these complexes. Crystals tend to be small (<10 μm), inhomogeneous and weakly scattering. Recording full data sets requires merging partial data sets from many crystals.

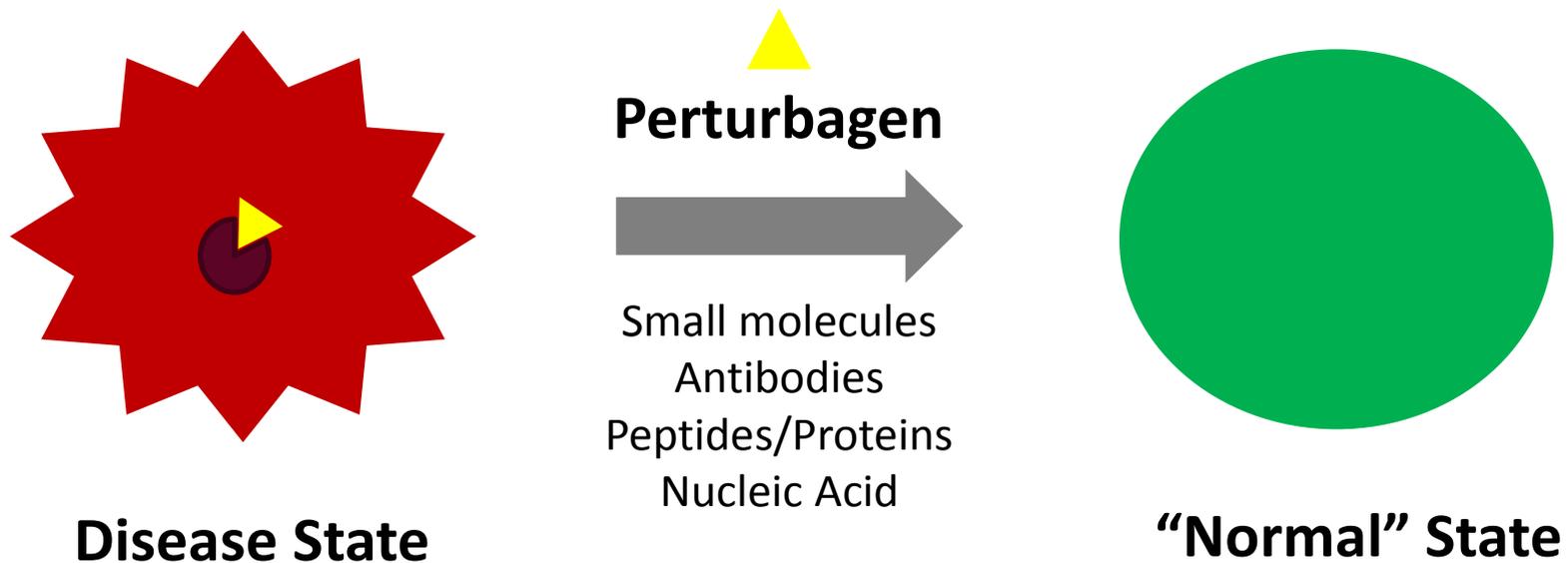
APS MBA enabler

Will allow one to obtain critical data from nano-crystals (>500 nm), and to mitigate the effects of radiation damage by exploiting both the high brightness and high X-Ray energy of the new MBA-lattice.



Submicron beam size reduces radiation damage

Molecular Recognition for Therapeutic Intervention



Want to solve 1000 structures per day!



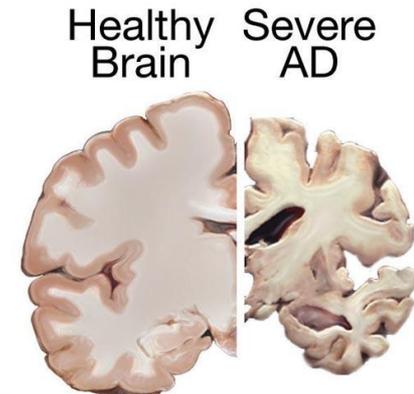
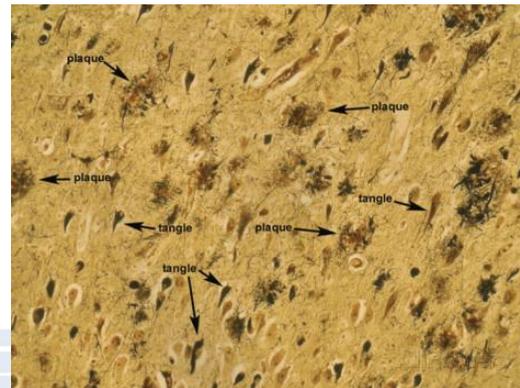
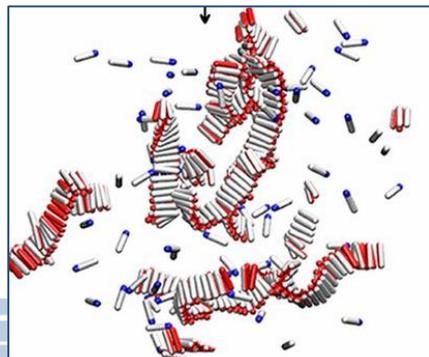
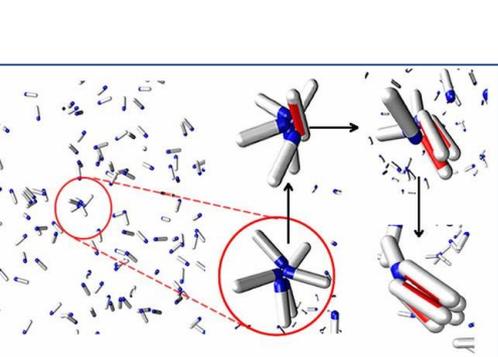
Molecular Pathology– science case

extend standard pathological studies of tissue to the order, orientation and abundance of specific molecular species

distribution and form of **molecular architecture** within intact tissue samples

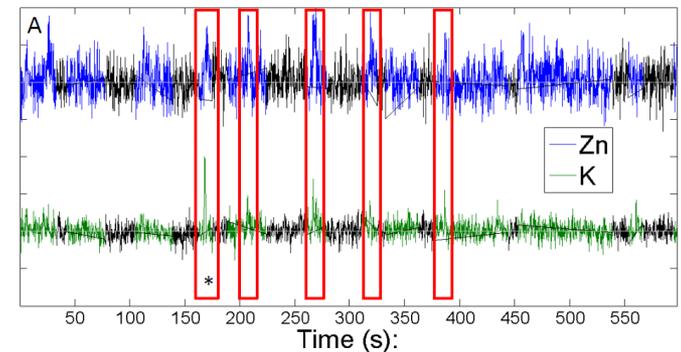
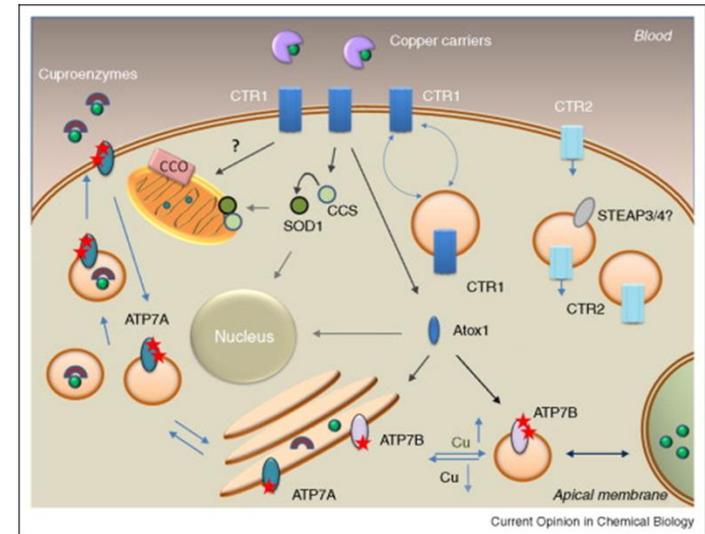
Molecular pathology

- Molecular basis of disease propagation in **Alzheimer's Disease**
 - multiple 'strains' of plaques (benign vs. malignant?)
- Underlying structure of **atherosclerotic plaques**
 - stable vs unstable?
- Impact of mutations in lignin biosynthesis on **cellulose organization** in plants
 - design of varieties with greater digestability
- Molecular architecture of specialized structures
 - **Nodes of Ranvier**
 - specialized regions of tendons...
 - site-specific variations in structure of connective tissues



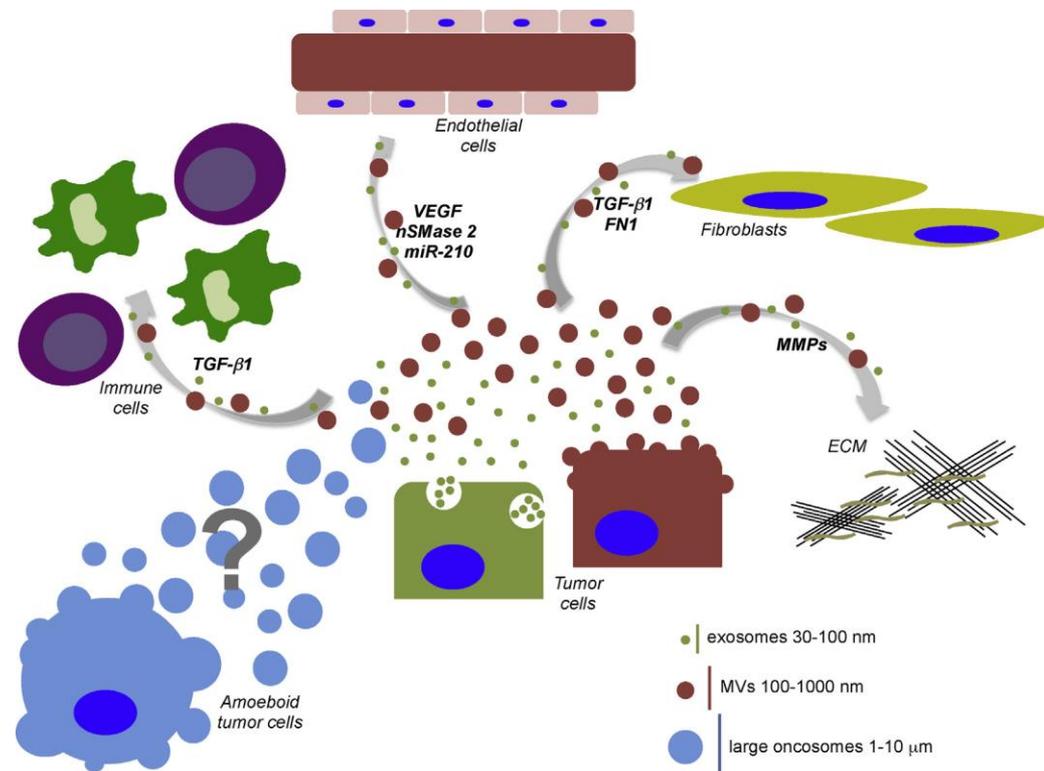
Inorganic Physiology

- Which metal binds to which protein, and what reaction(s) does it carry out?
 - Catalysts
 - *Crystallography and x-ray absorption*
- How are metal concentrations controlled
 - Sensors
 - Chaperones
 - Pumps
 - *Crystallography and x-ray absorption*
 - *XRF imaging & metal specific fluorophore*
- Where are metals localized, and at what concentration?
 - *XRF imaging & metal specific fluorophore*
- How does this function as a system?
 - *Time-dependent studies*
- Need responses on the minutes time-scale
- Would like to follow a single system over time (vs. measuring a series of freeze-quench snapshots)
- Would like good enough statistics to measure not just the mean, but also the distribution in composition



Cell-to-Cell Signalling in Physiological Processes and Diseases - e.g. Cancer Microvesicles

- Extracellular vesicles play important roles and are responsible for cell-cell signalling in normal physiology and disease pathologies, e.g., cancer.
- **Apoptotic particles**
 - released from cells undergoing apoptosis (programmed cell death).
 - largest microvesicles: > 1 micron
 - physiology poorly understood
- **Microparticles**
 - 100 nm to 1 micron in diameter
 - released from blebbing of the cell membrane
 - essential for cell-cell signalling
- **Exosomes**
 - 10-100 nm
 - Also essential for cell-cell signalling.
 - Produced inside the cell and then exported.
- **Oncosomes**
 - 1-10 micron, new type of microvesicles
 - Released from amoeboid tumour cells.
 - Functions are uncertain in cancer
- **Nano FTIR and tip-enhanced Raman available (10 nm resolution)**



Extracellular Vesicles in Cancer: Exosomes, Microvesicles and the Emerging Role of Large Oncosomes. V. R. Minciacci, M. R. Freeman, D. Di Vizio, *Seminars Cell Develop. Biol.*, 2015, 40, 41–51.

X-ray nanoprobe cannot characterise the small microvesicles as yet

Themes:

- Complexity & Heterogeneity
- Multi-scale (time and/or spatial)
- *in situ / operando / realtime*

Key enablers:

- Spatial resolution, with high flux
 - Low signal levels (reduced background)
 - Large field of view & statistics
- Coherence:
 - Correlation techniques & lensless imaging
- High energy -> penetration depth



Observations / questions / thoughts ...

- XPCS
- Fluctuation microscopy
- SAXS/WAXS
- EXAFS
- PDF
- Crystallography
- Bragg Coherent Diffractive Imaging
- Ptychography

⇒ boundaries between techniques seem to be 'weakening'

⇒ Opportunity for their 'combination', or comprehensive analysis?



Thank you very much for your attention!!!

