

LET THERE BE LIGHT AND SOUND: DEVELOPING A TOOLKIT TO INTERROGATE STRUCTURES IN DAIRY

Wave Scattering in Complex Matter:
Advances in Material Characterisation and the Design of Materials
Session 3: Characterisation of soft or liquid materials



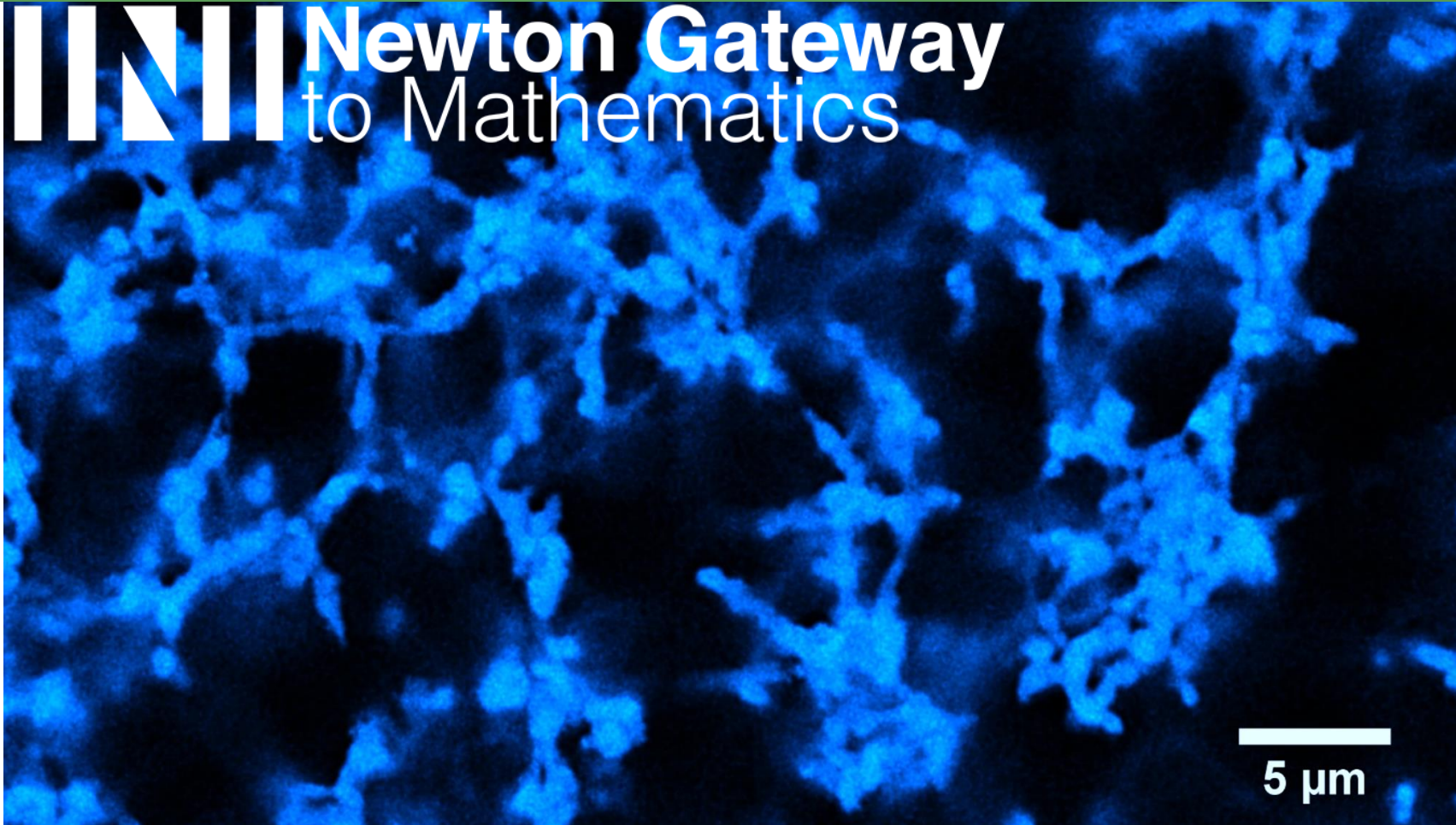
IOP | Institute of Physics
Food Physics Group

31st May 2023
Isaac Newton Institute, Cambridge

Zachary J. Glover

PhD, MSc, BSc (hons), MInstP

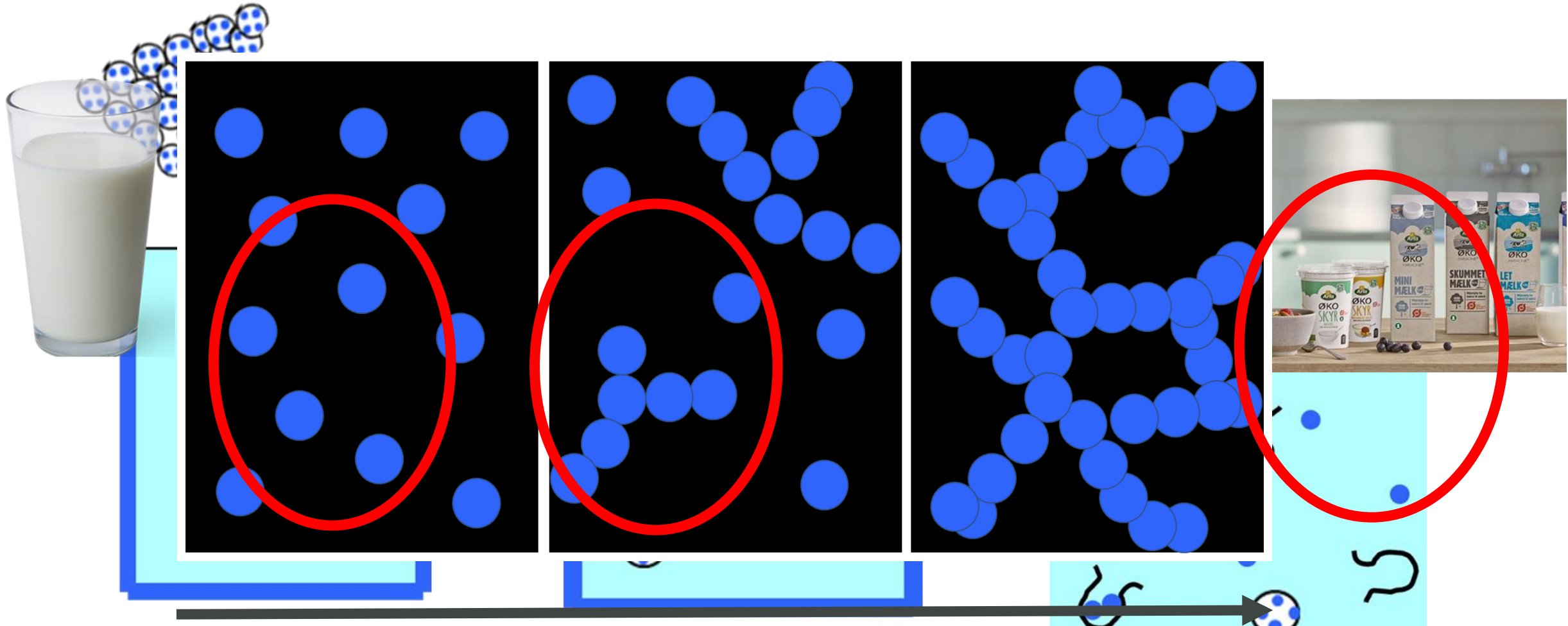
INI Newton Gateway
to Mathematics



5 μm

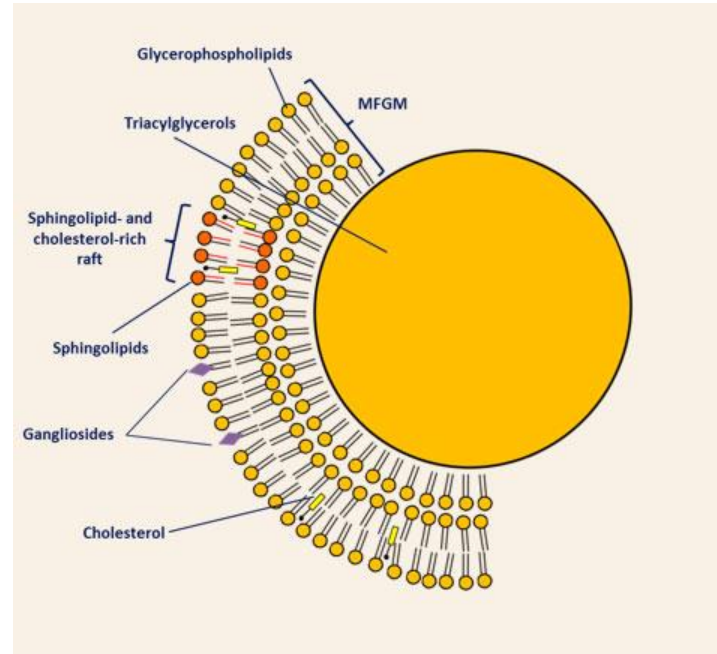
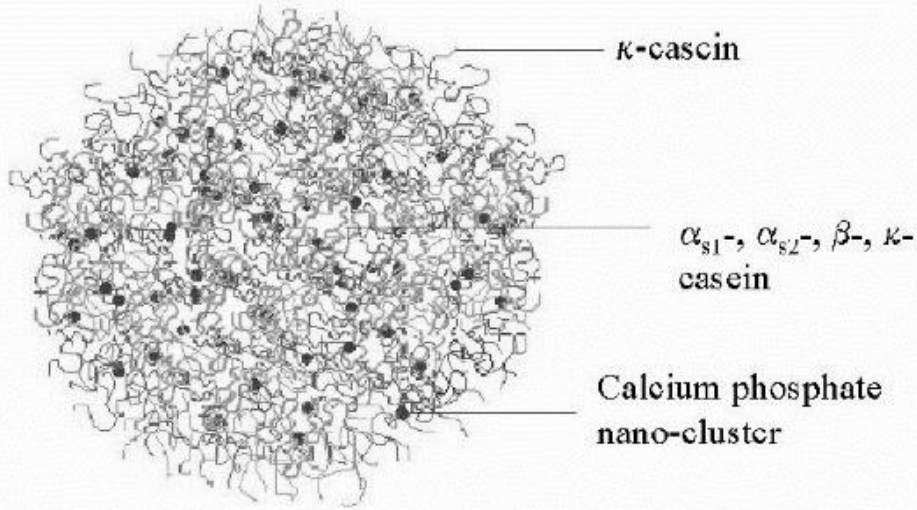


RECONSTITUTION AND STRUCTURE FORMATION

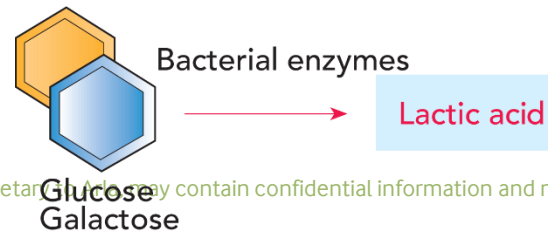
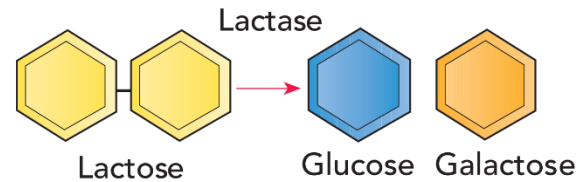
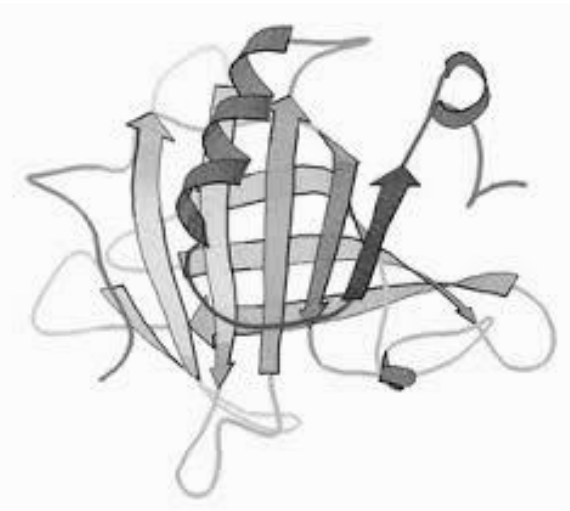


TIME

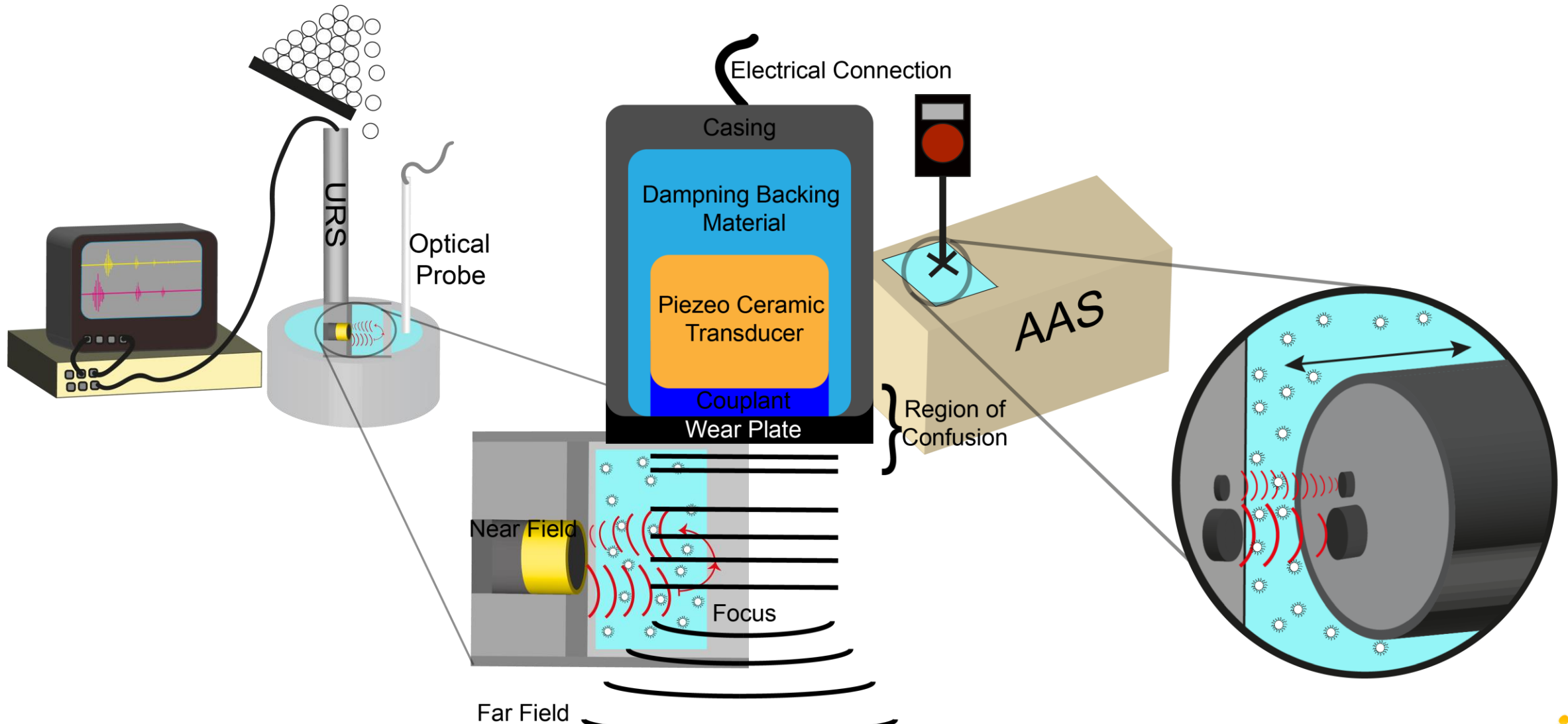
DAIRY MACRO-COMPONENTS



Water	87 %
Lactose	~ 5 %
Fat	~ 3- 5 %
Protein	~ 3 – 4 %
Minerals	< 1 %



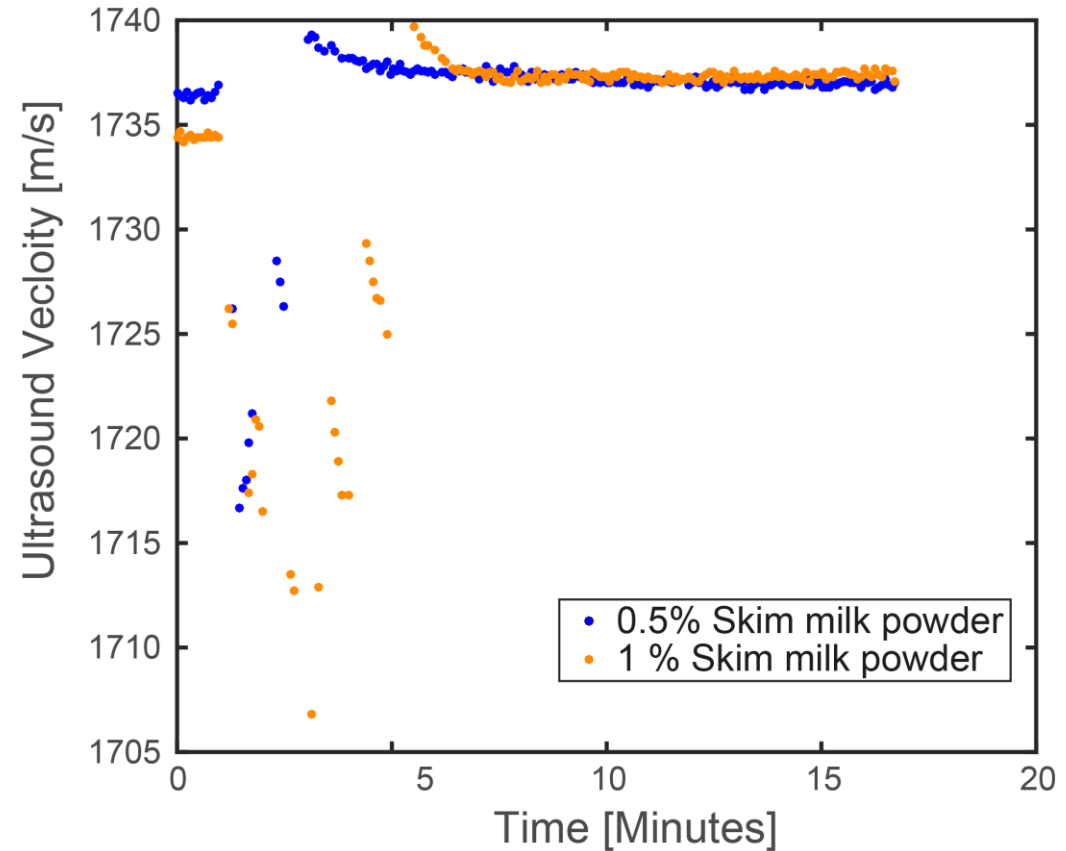
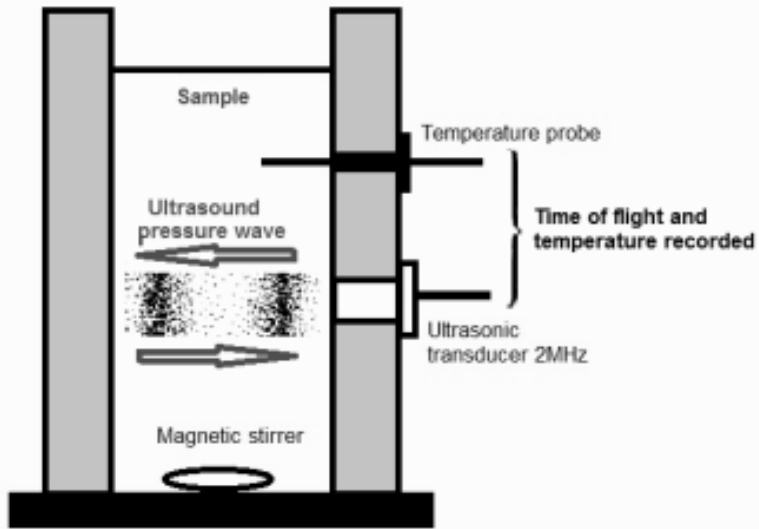
ULTRASOUND SPECTROSCOPY



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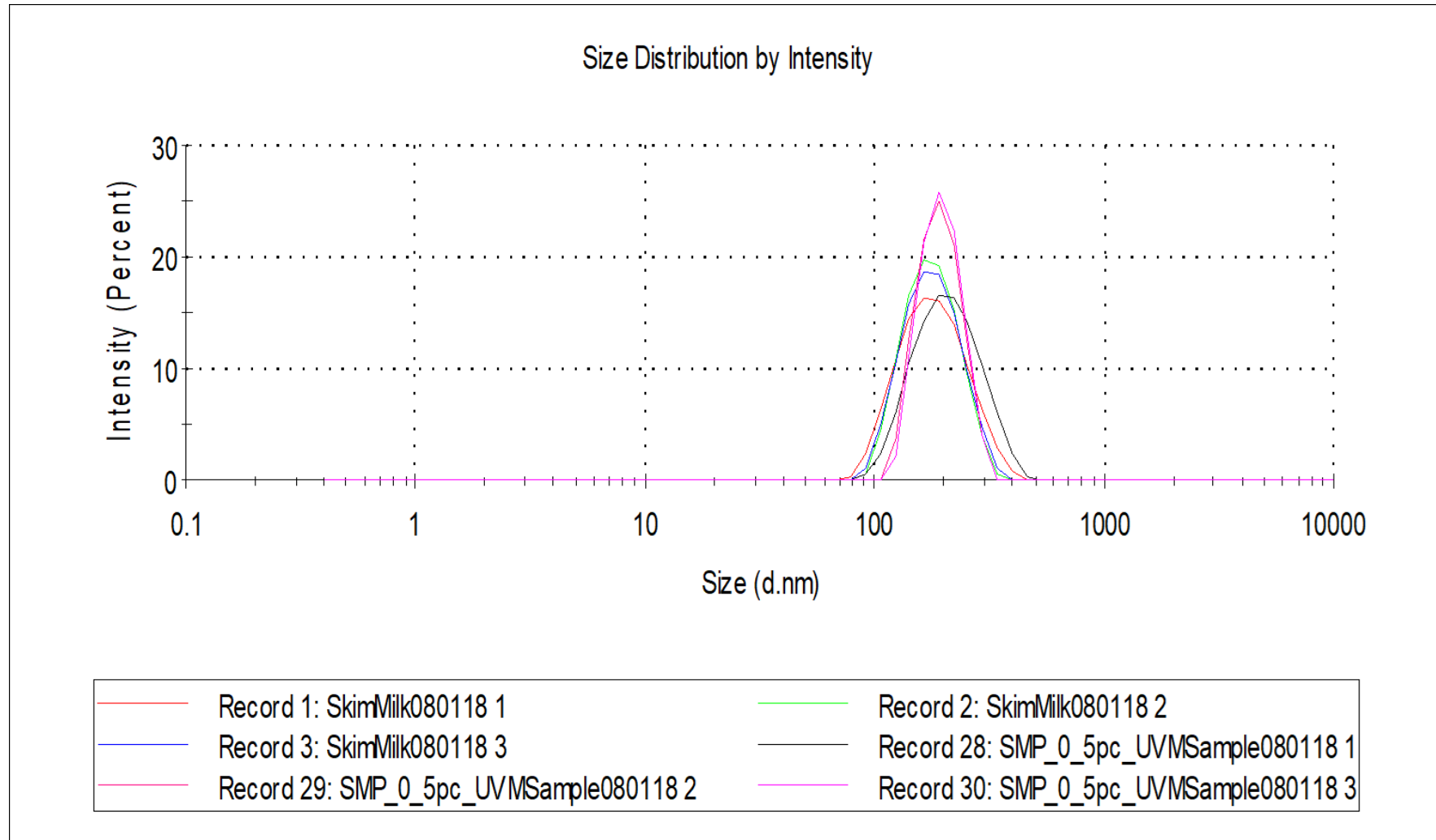


ULTRASONIC VELOCITY OF RECONSTITUTED SKIM MILK MEASURED IN UVM AT 35 °C

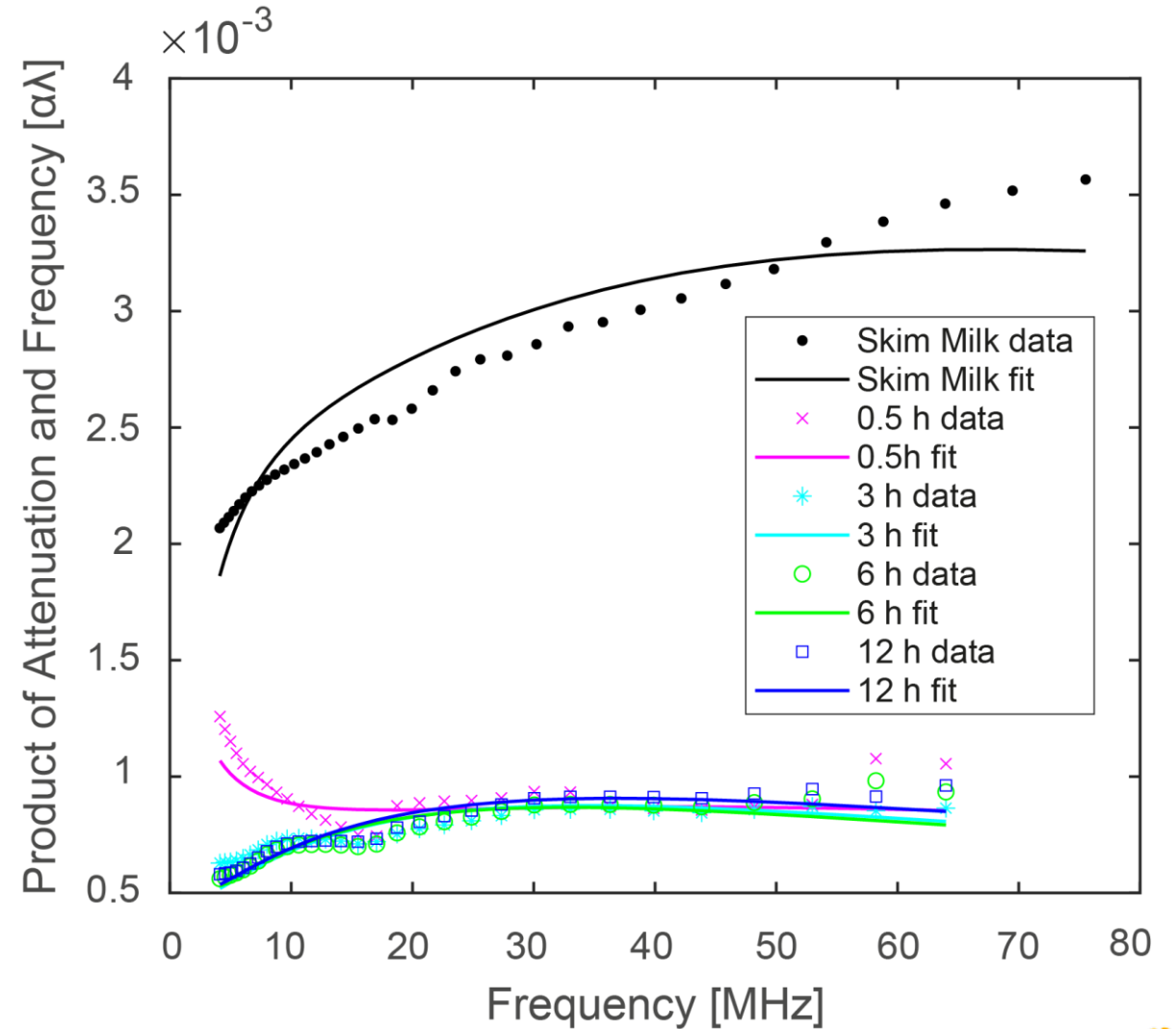
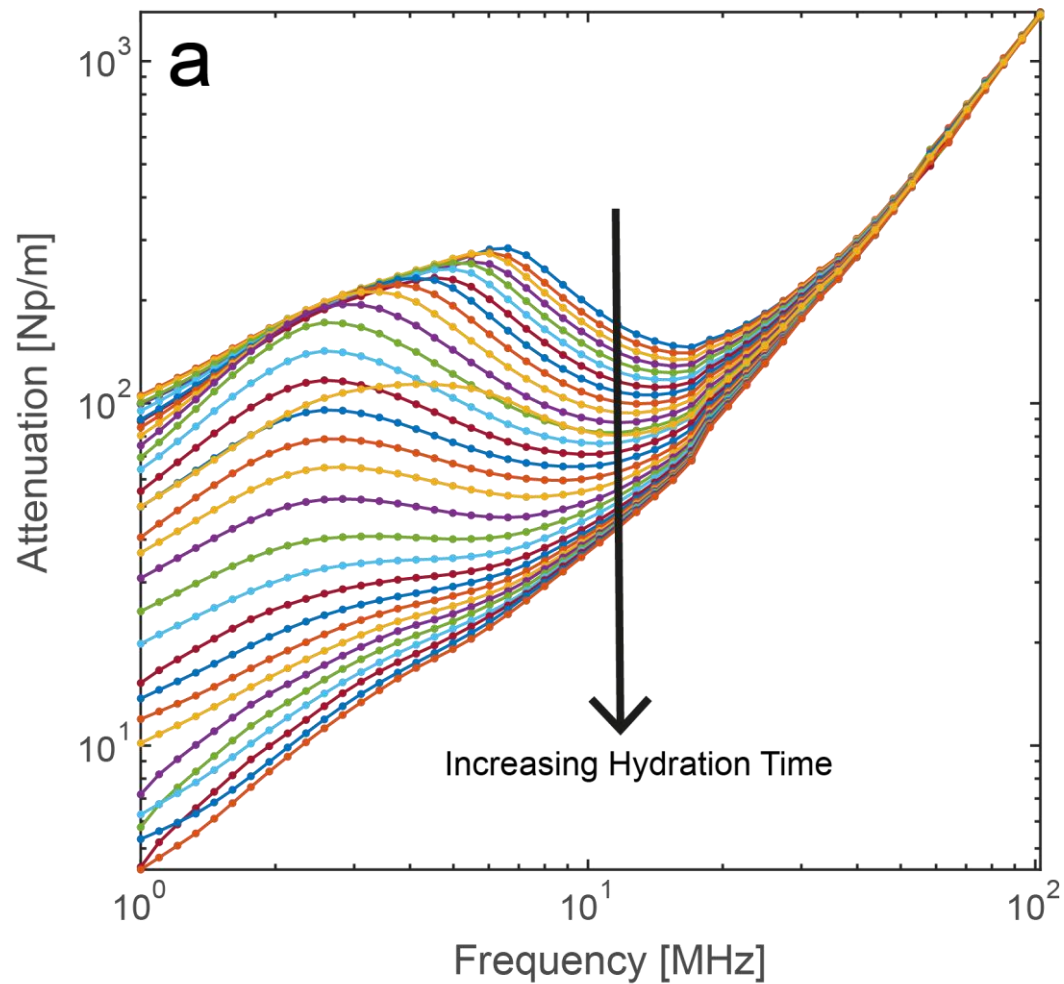


	0.5 % SMP	1 % SMP
Dissolution time (mins)	2.1	4.7
Change in Velocity (m/s)	2.2	5.3

ZETASIZER PSD FOR SKIM MILK POWDER AFTER 1 HOUR IN UVM AT 35 °C

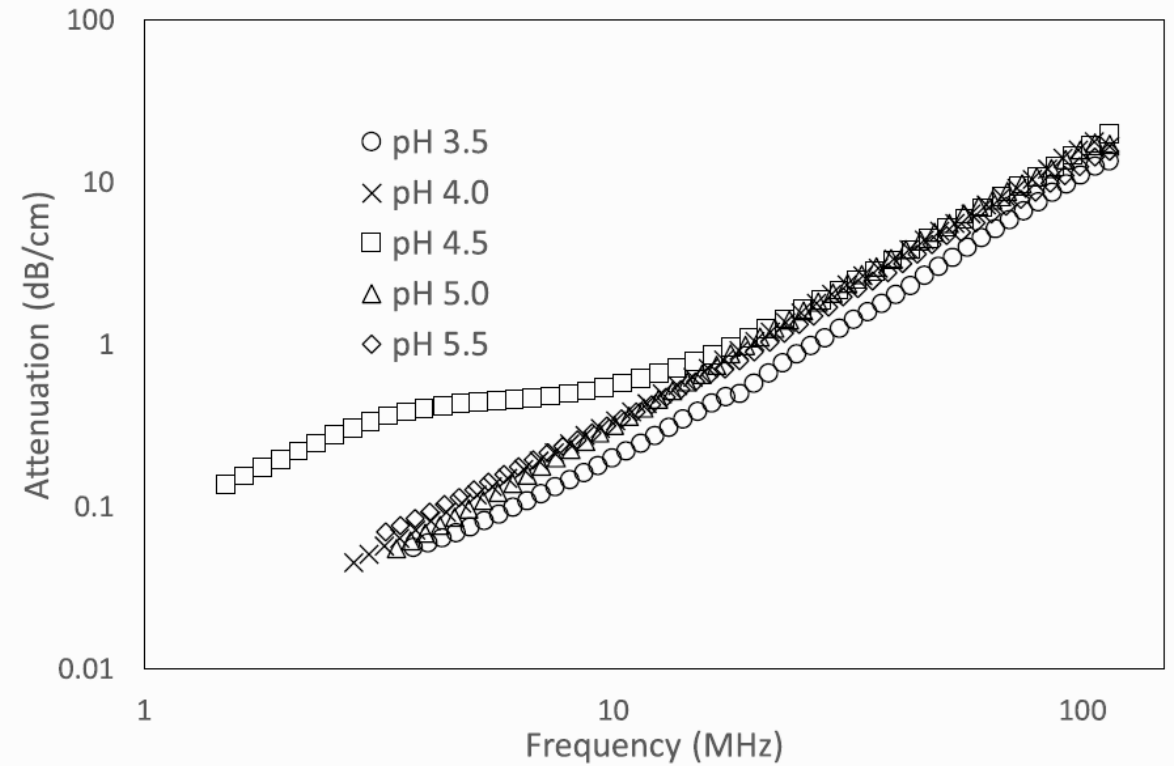
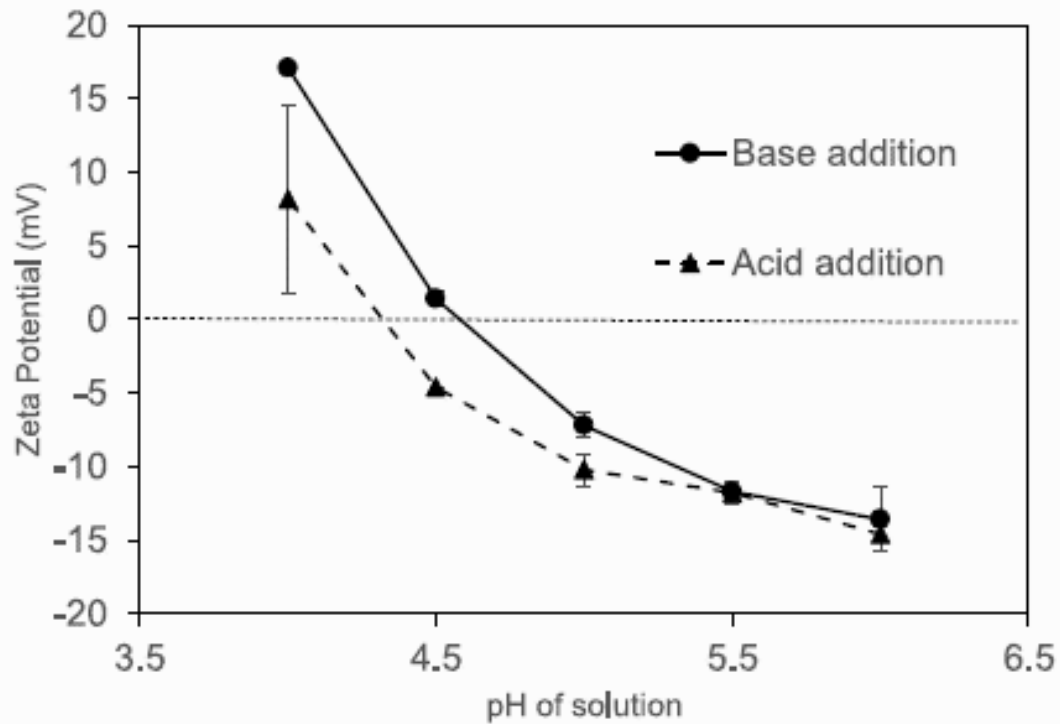


MONITORING REHYDRATION IN SKIM MILK POWDER ANALOGUES



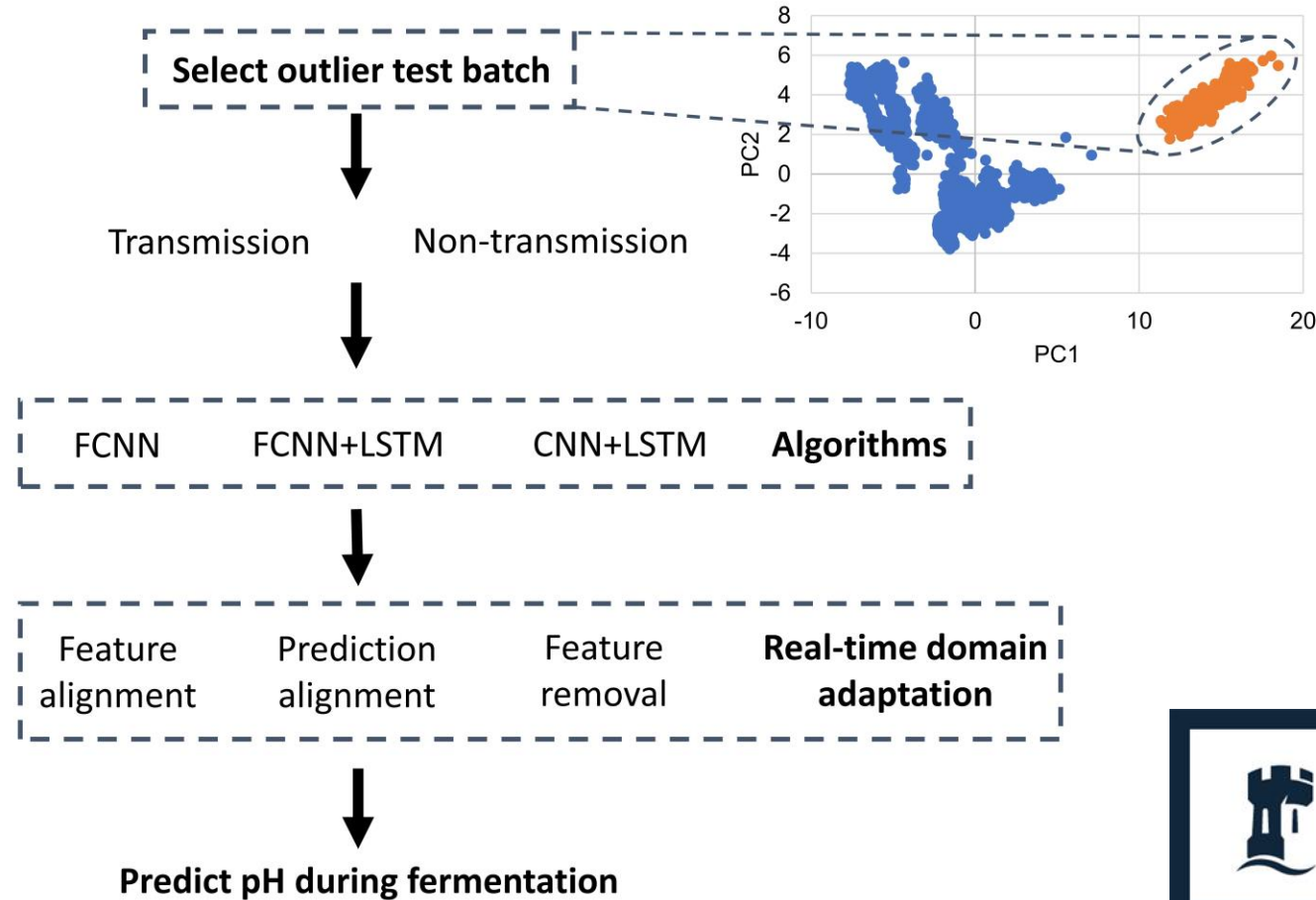
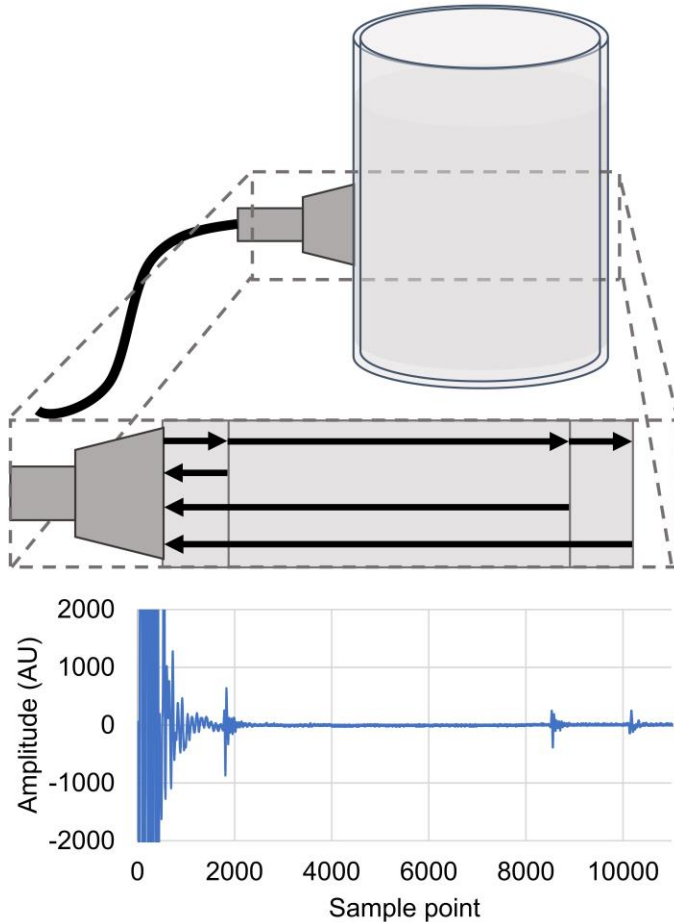
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ULTRASONIC DETECTION OF AGGREGATION

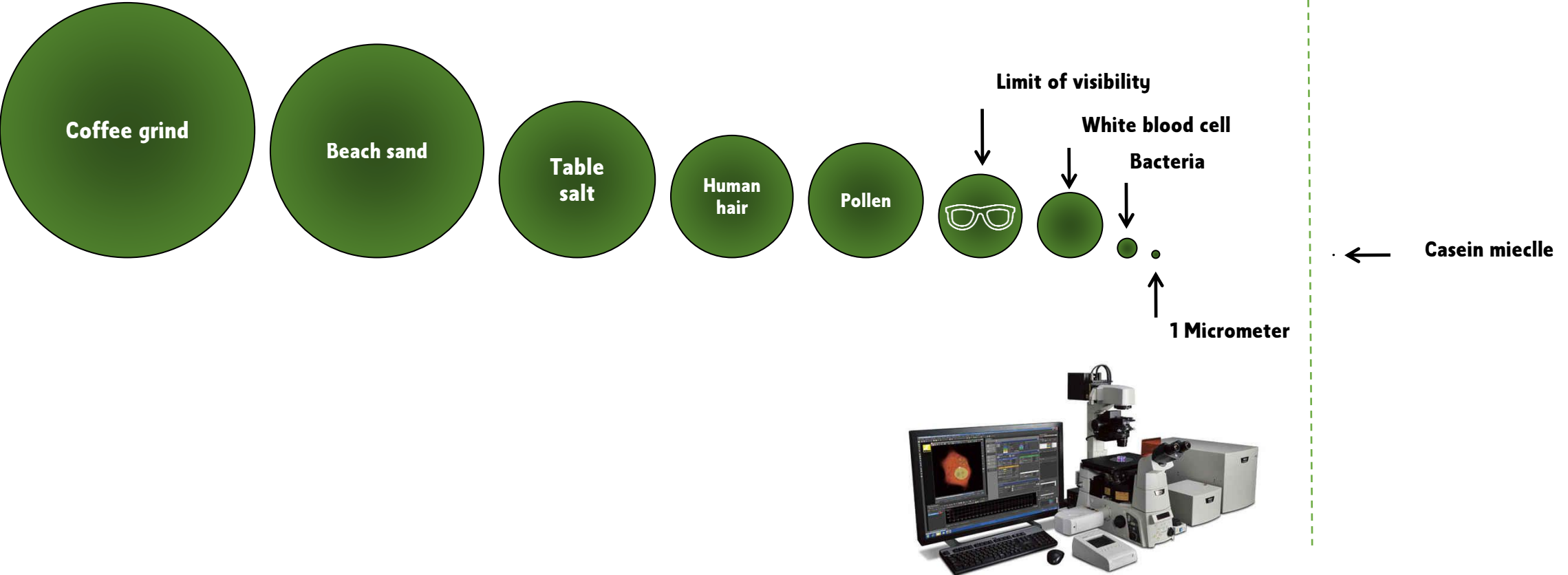


MACHINE LEARNING AND DOMAIN ADAPTATION TO MONITOR YOGHURT FERMENTATION USING ULTRASONIC MEASUREMENTS

Machine learning and domain adaptation to monitor yoghurt fermentation using ultrasonic measurements

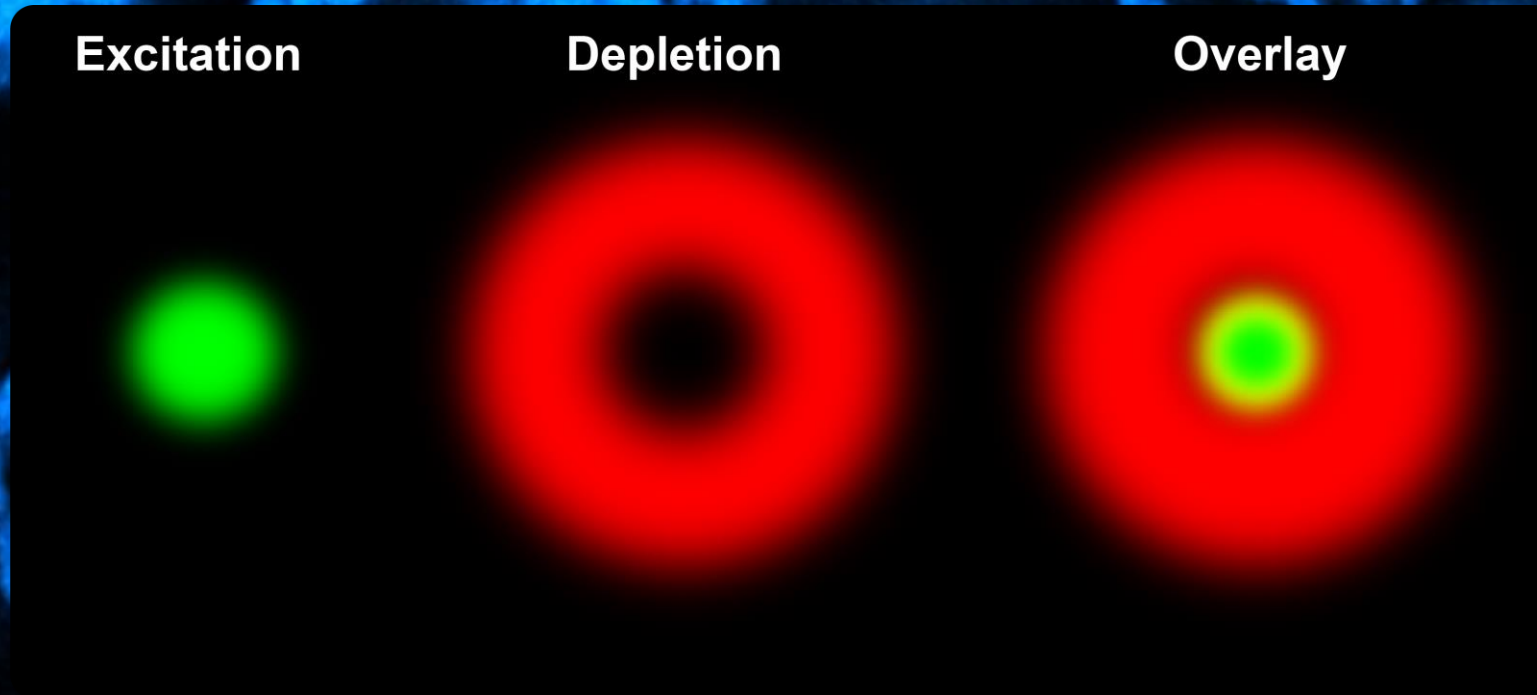


VISUALISATION: LIMITED BY MICROSCOPE RESOLUTION



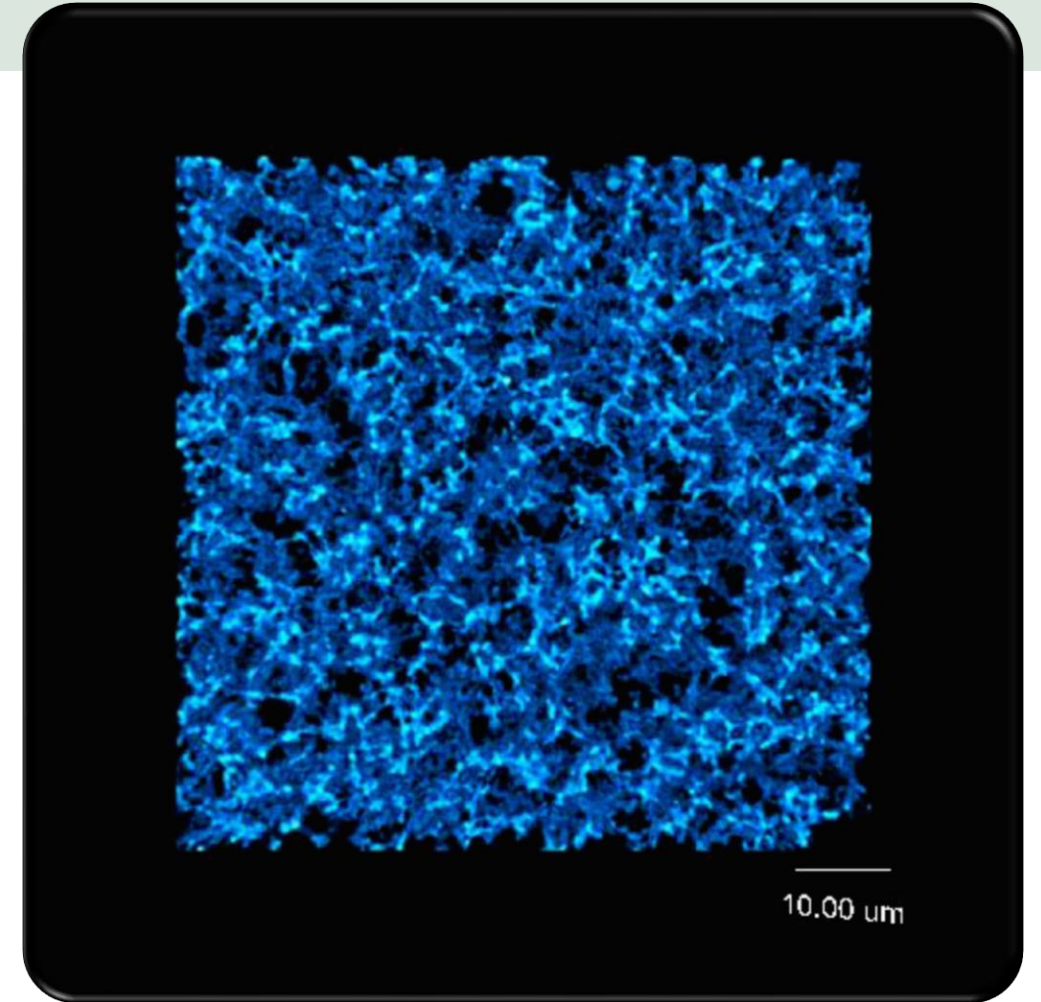
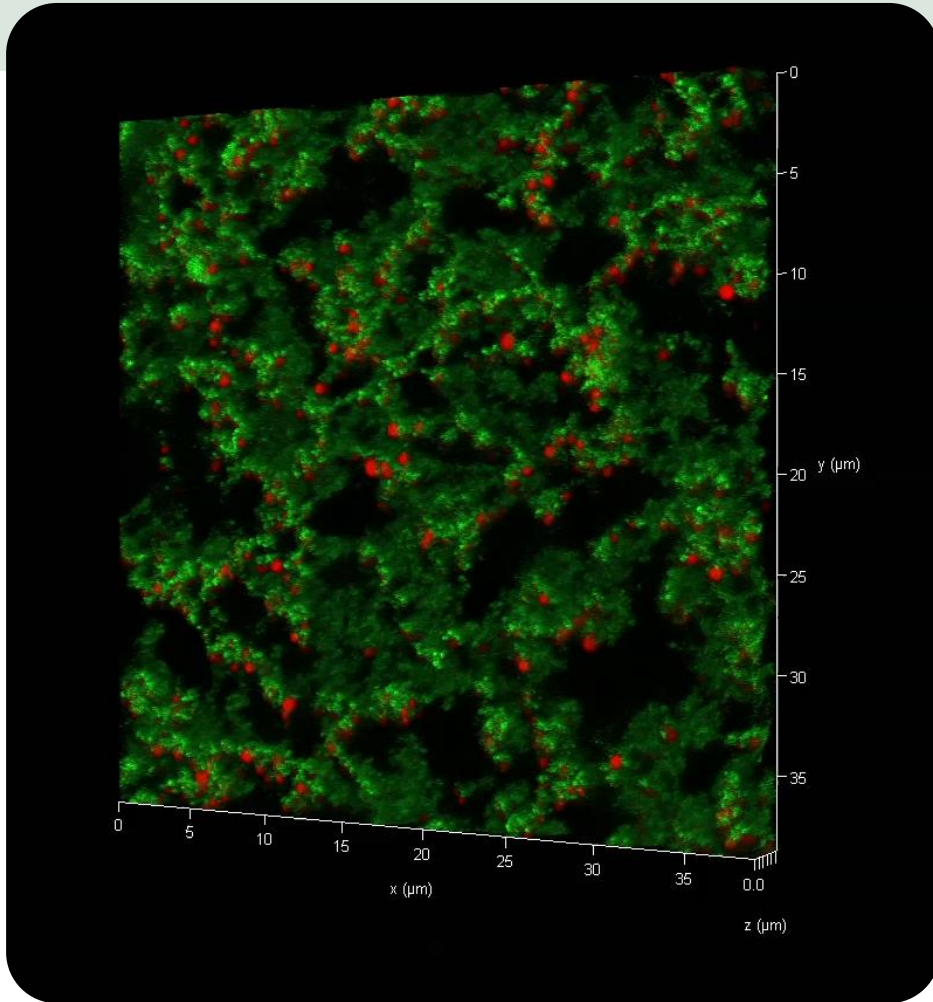
SUPER-RESOLUTION MICROSCOPY

STED: Stimulated Emission Depletion Microscopy



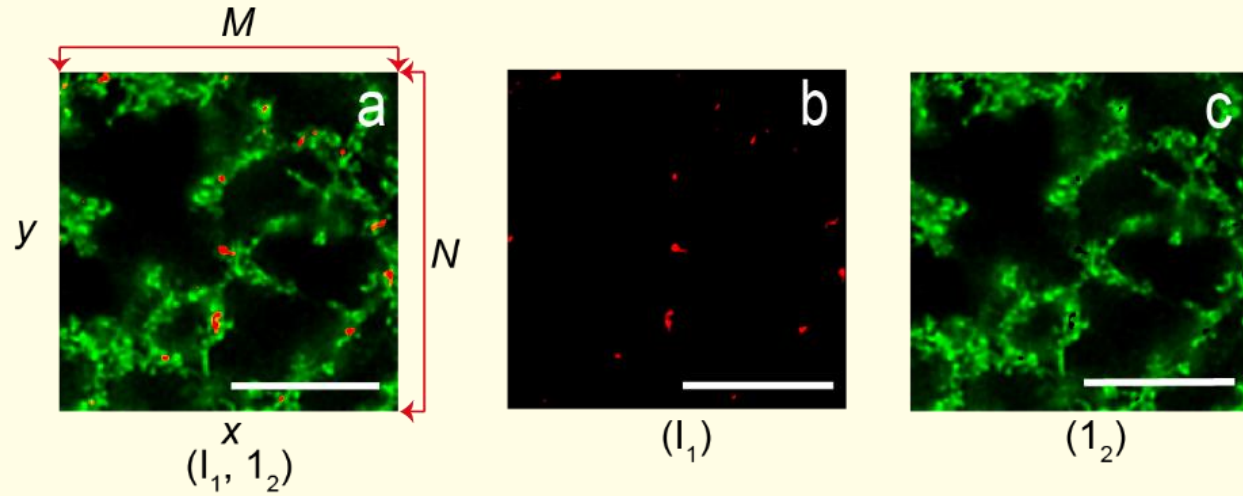
5 μm

3D- STED Images



Left: Acid Induced Whole Milk Gel

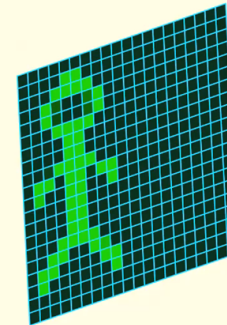
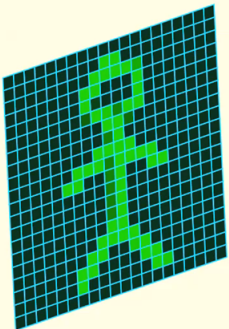
Right: Rennet Induced Skim Milk Gel



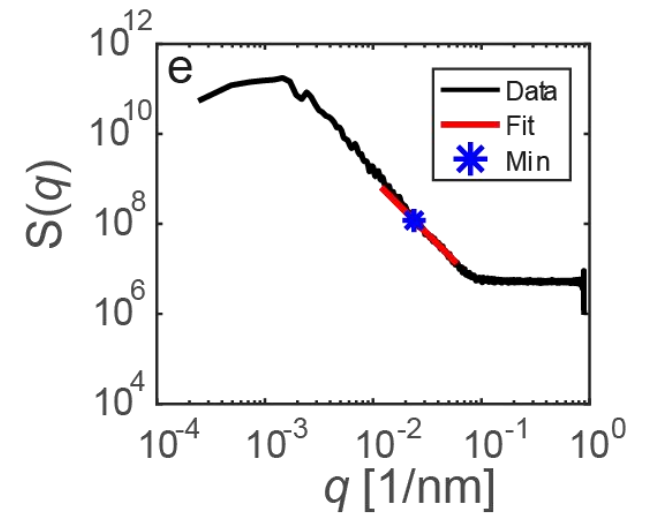
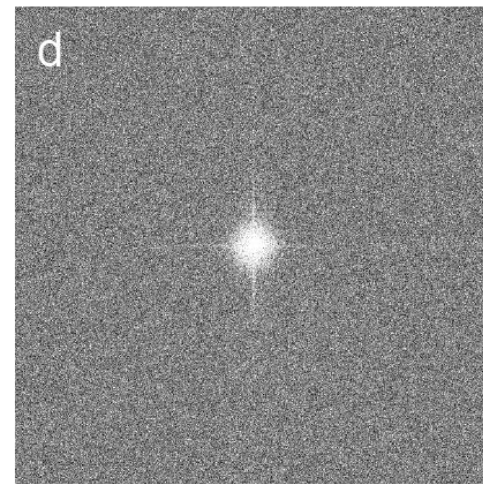
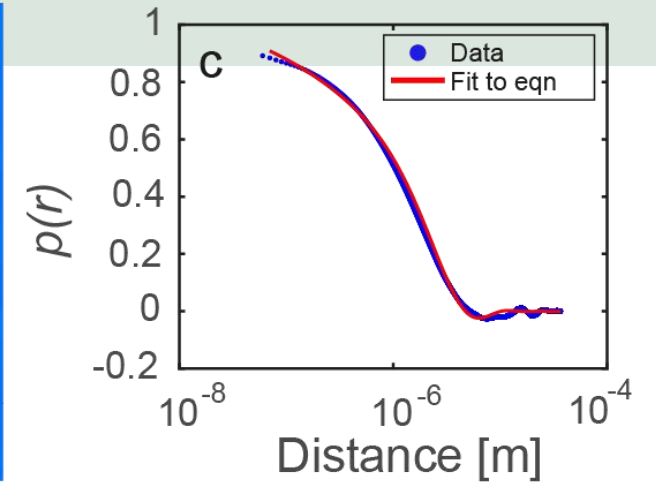
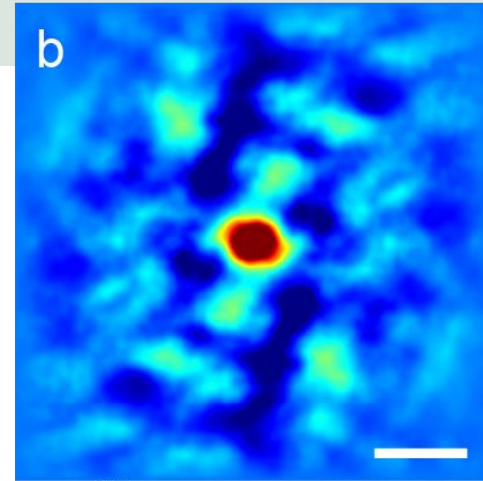
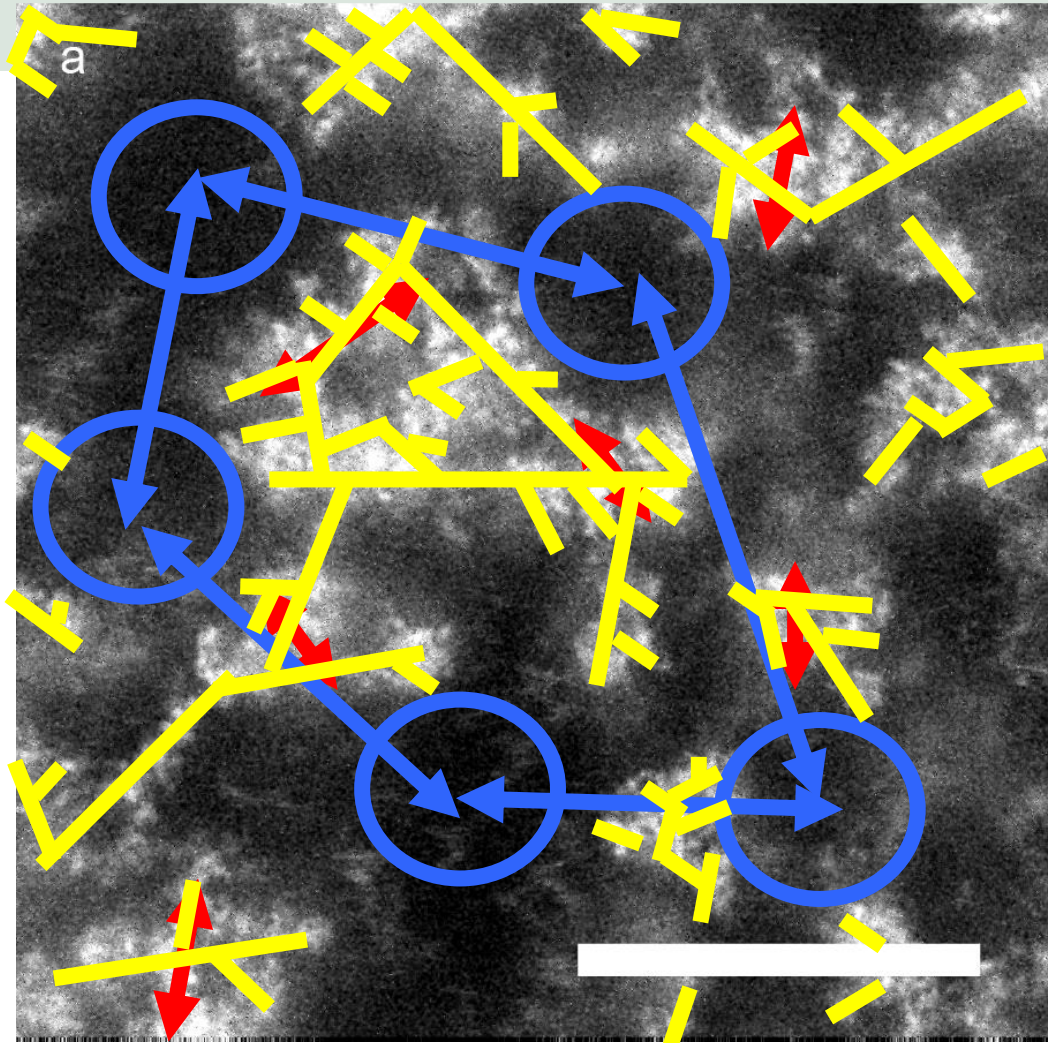
$$C(a, b) = \sum_{x=1}^M \sum_{y=1}^N I_1(x, y) \cdot I_2(x - a, y - b)$$

2D Spatial Autocorrelation

2D Spatial Cross-correlation



PROTEIN NETWORK IMAGE ANALYSIS

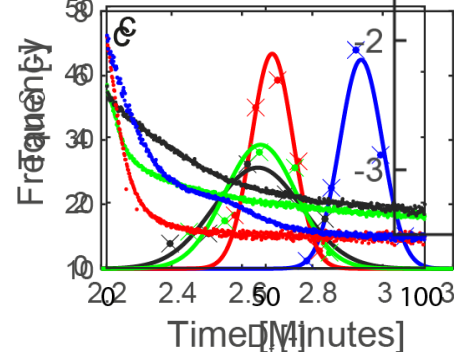
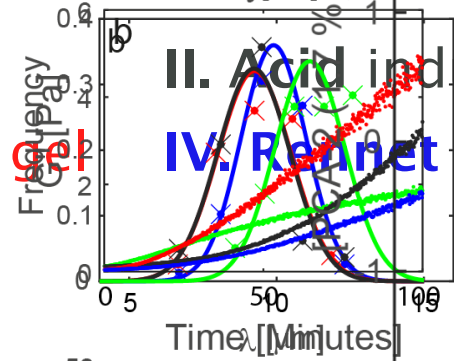
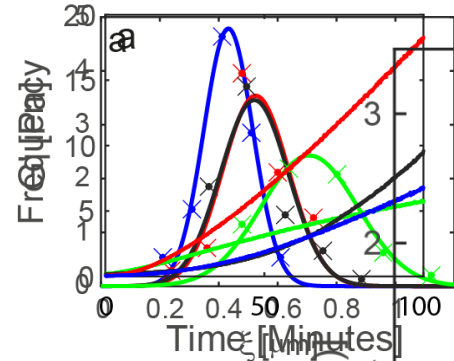


ξ – Protein Length λ – Interpore Distance **Df – Fractal Dimension**

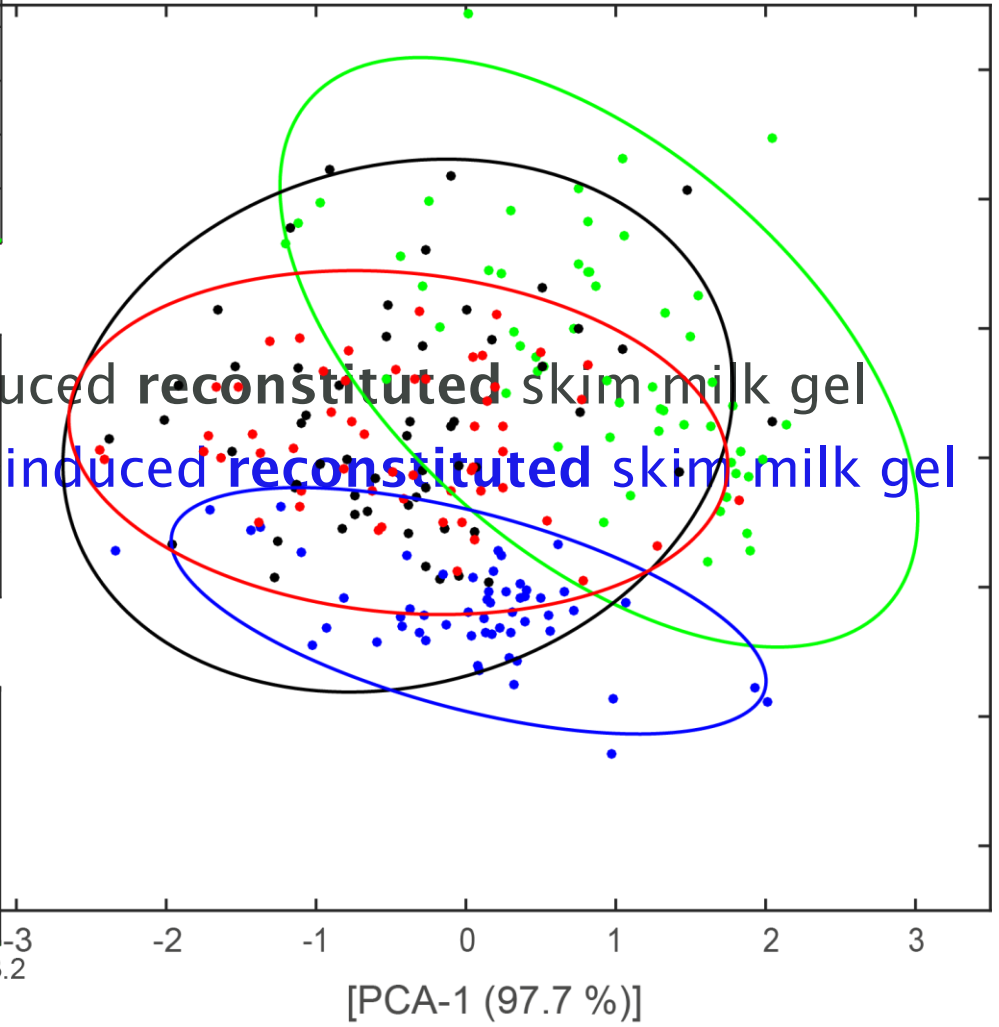
SAMPLE RHEOLOGY AND IMAGE DATA

I. Acid induced fresh skim milk gel

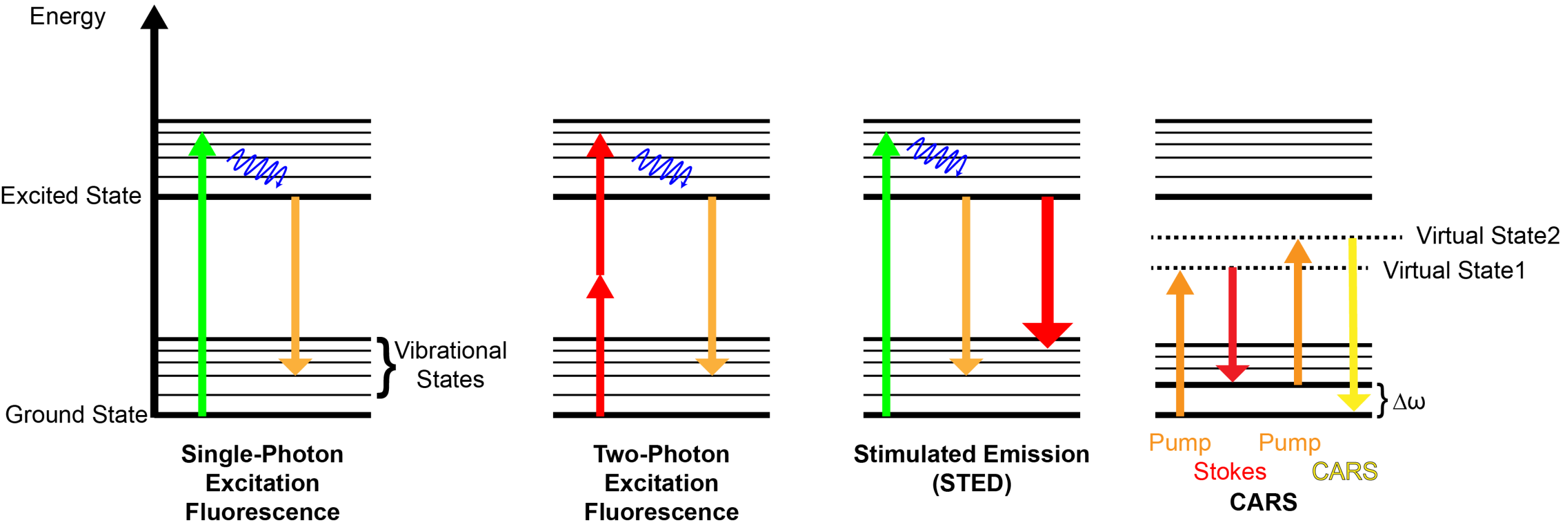
III. Rennet induced fresh skim milk gel



II. Acid induced reconstituted skim milk gel
IV. Rennet induced reconstituted skim milk gel

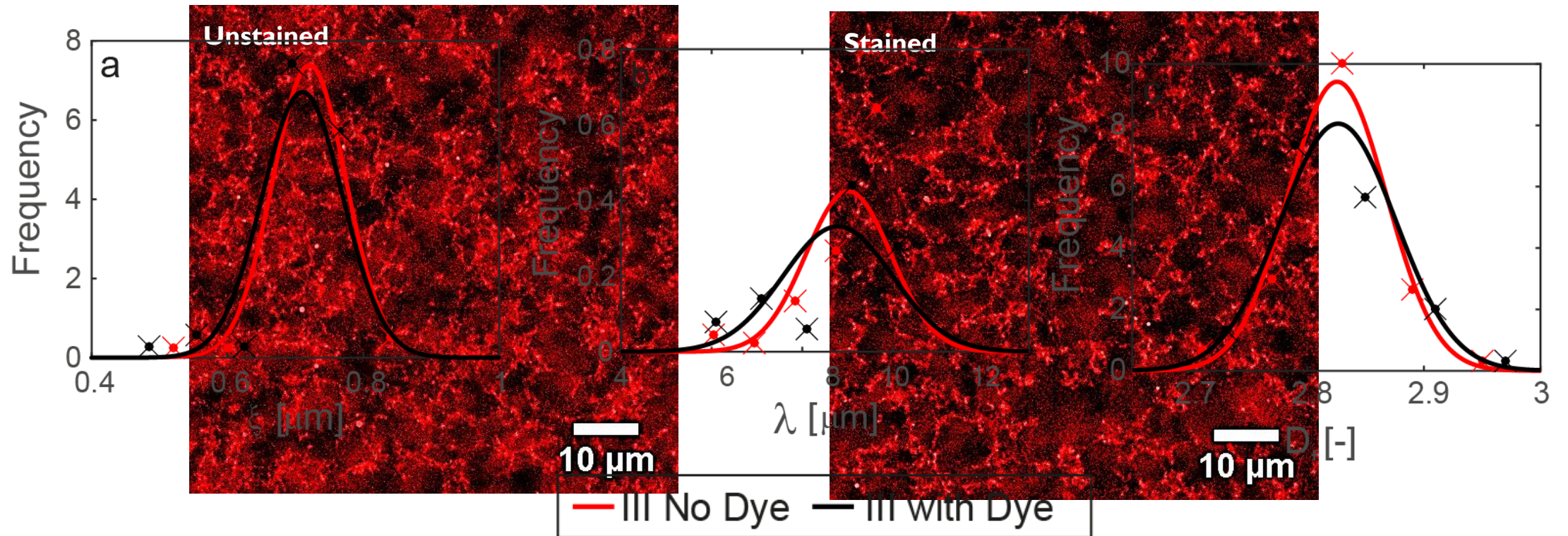


MODES OF EXCITATION



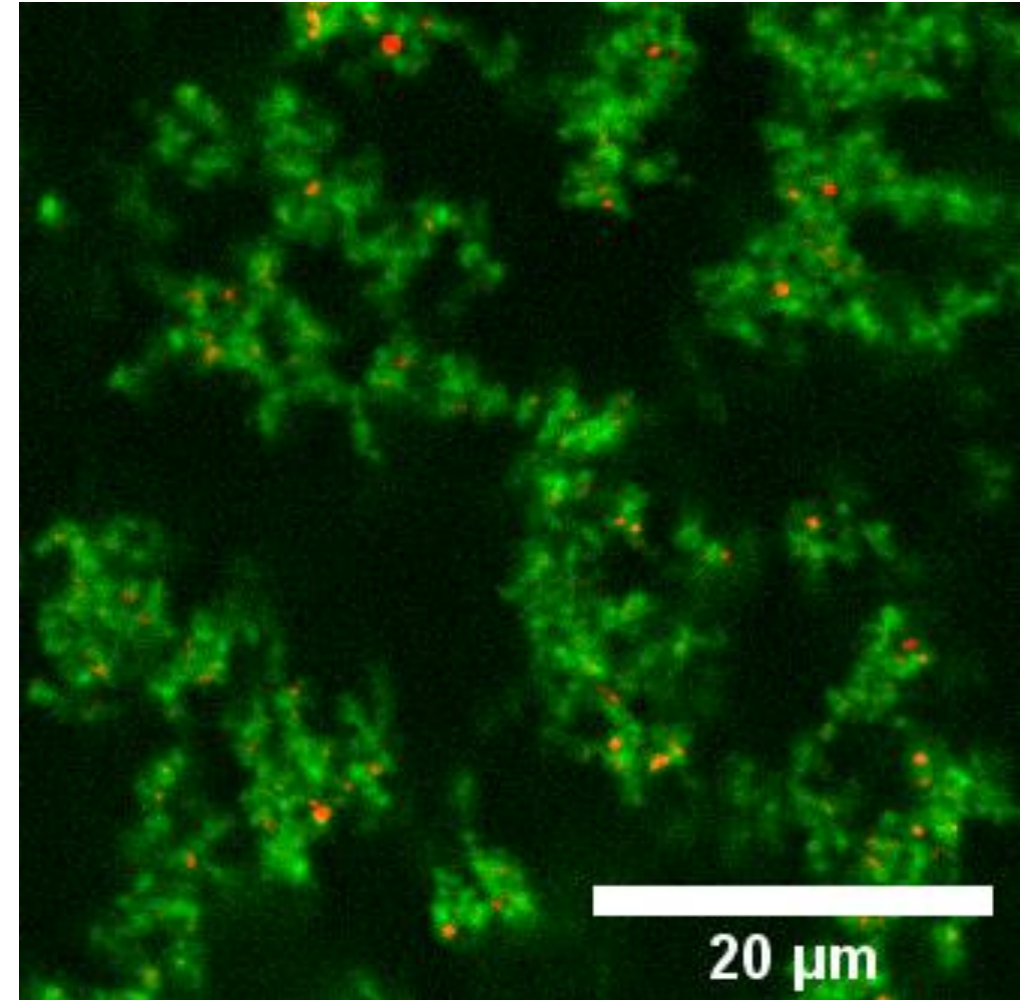
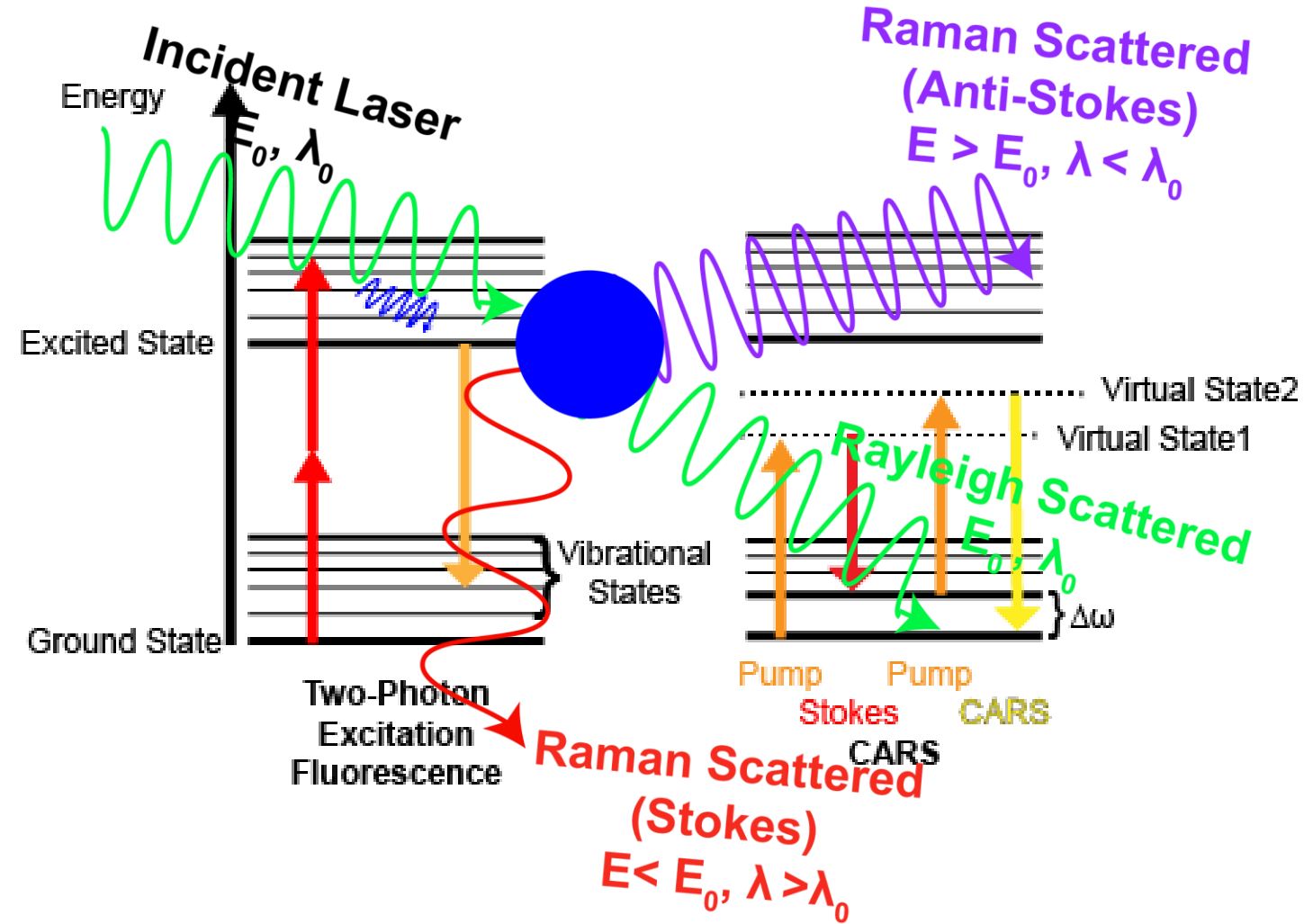
CARS IMAGING

Coherent Anti-Stokes Raman Scattering Microscopy (CARS)



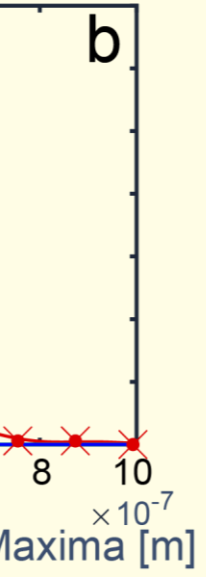
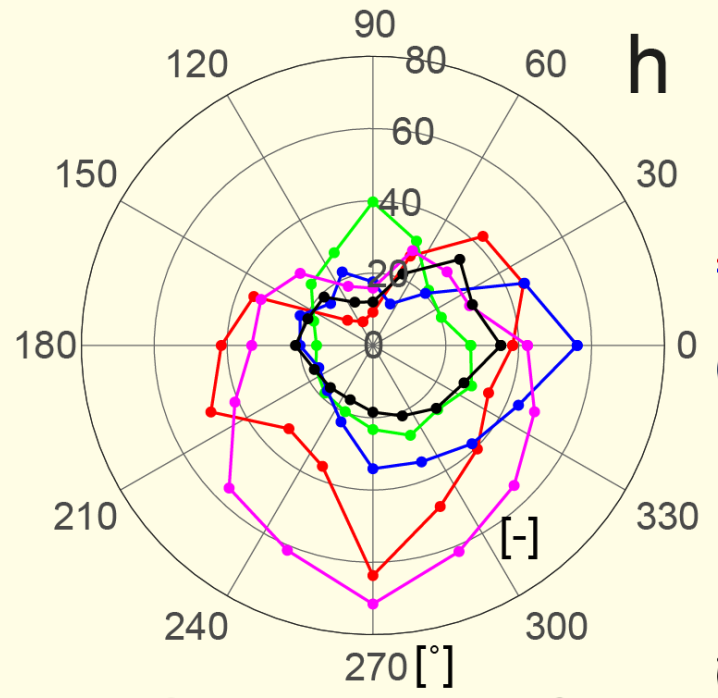
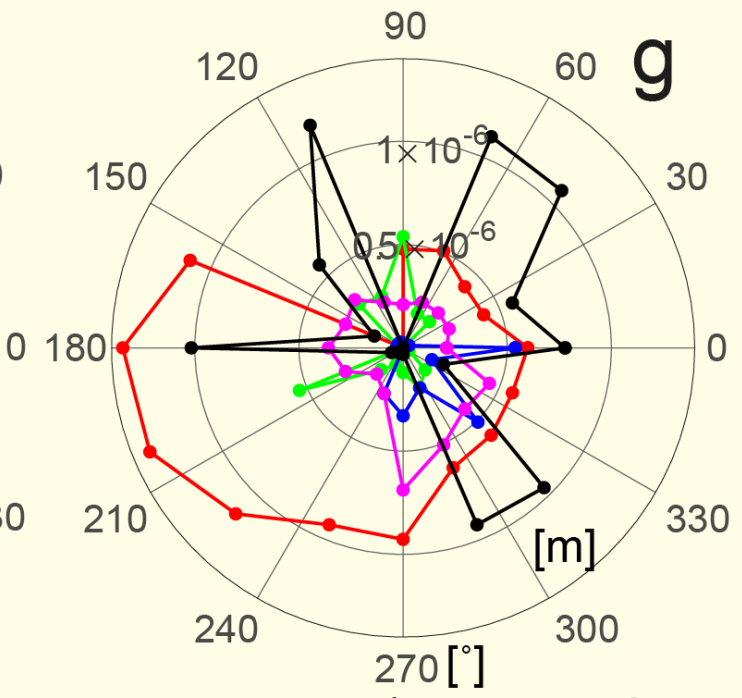
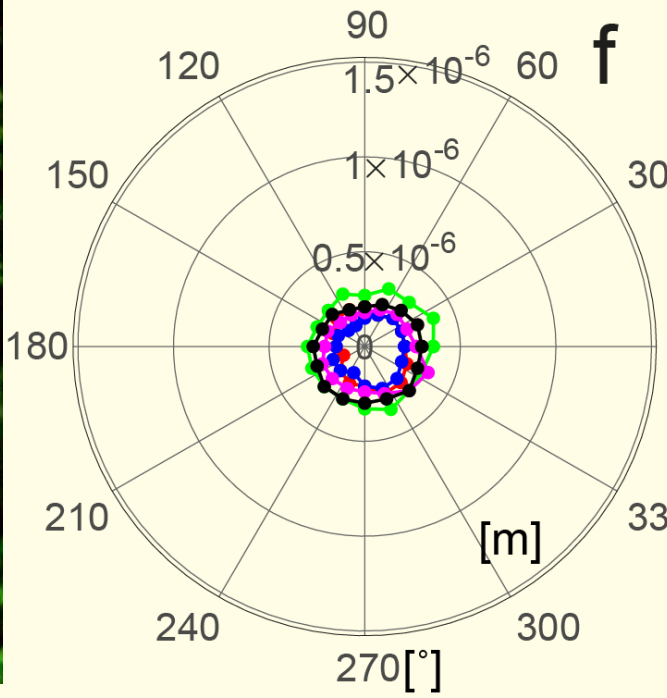
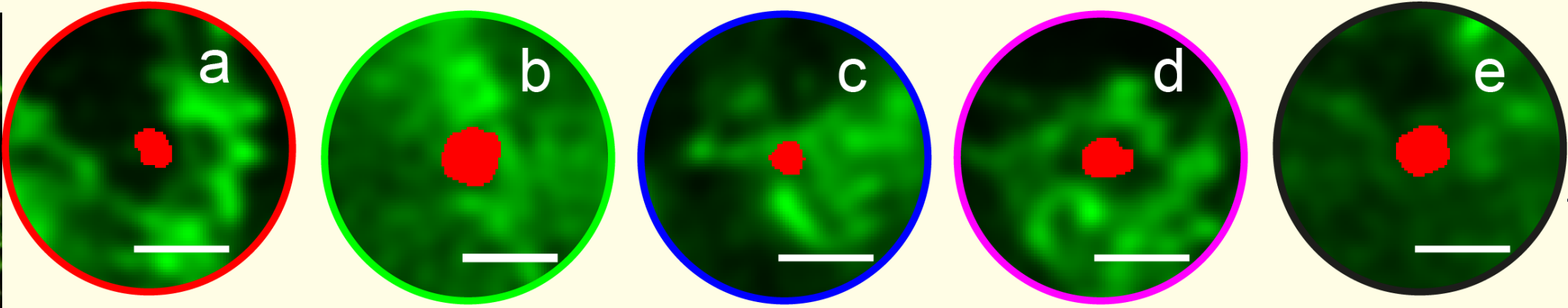
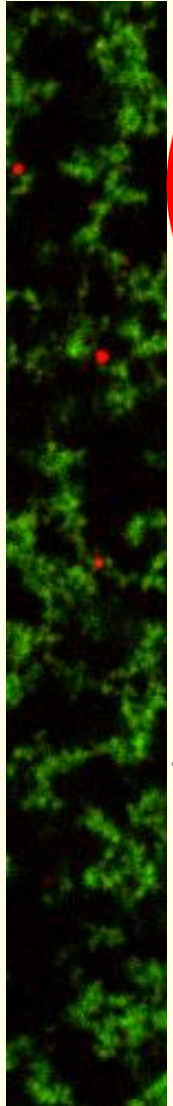
— C-H Stretch: Targeting Proteins

2-PHOTON EXCITATION AND CARS MICROSCOPY



N-Alkane Vibration - C-H Stretch to image fat droplets
2PE of Atto 488 NHS - for protein

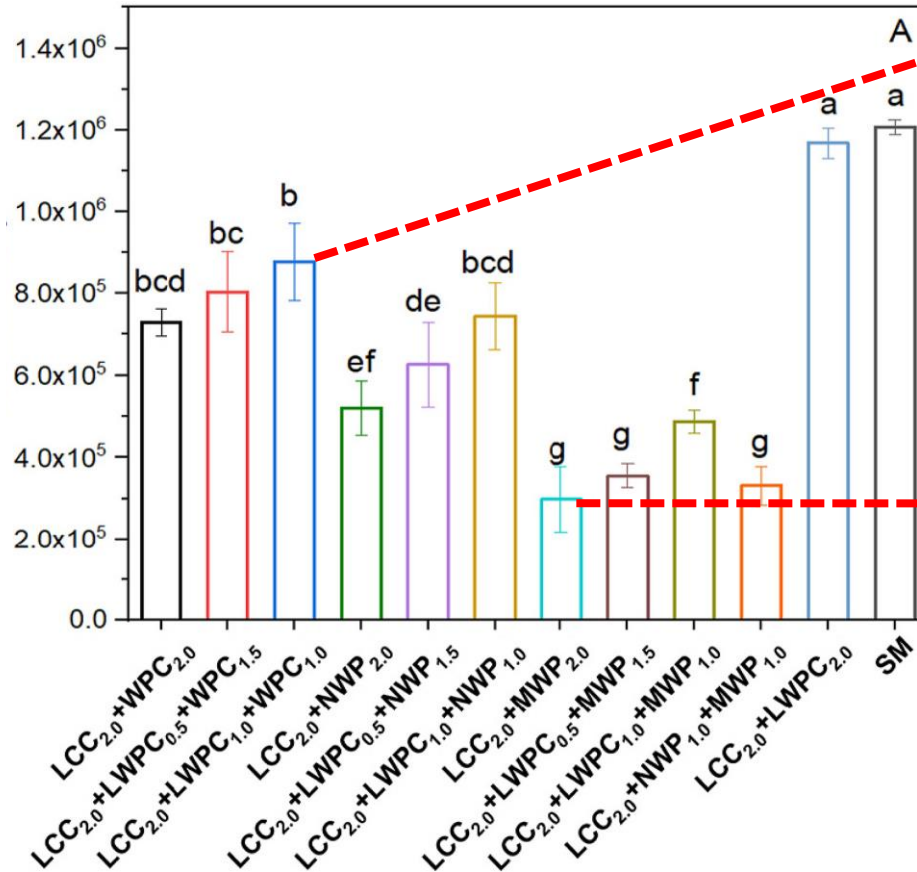
Two Component Image Analysis



MPa

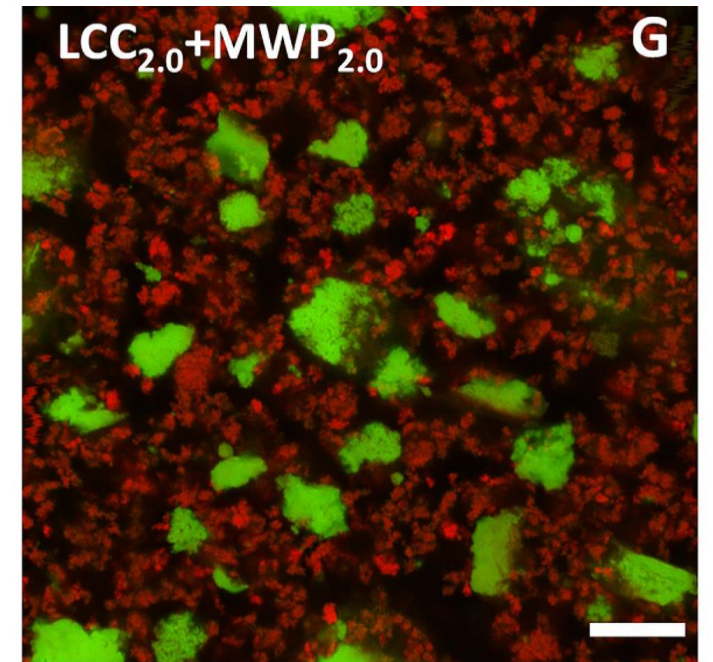
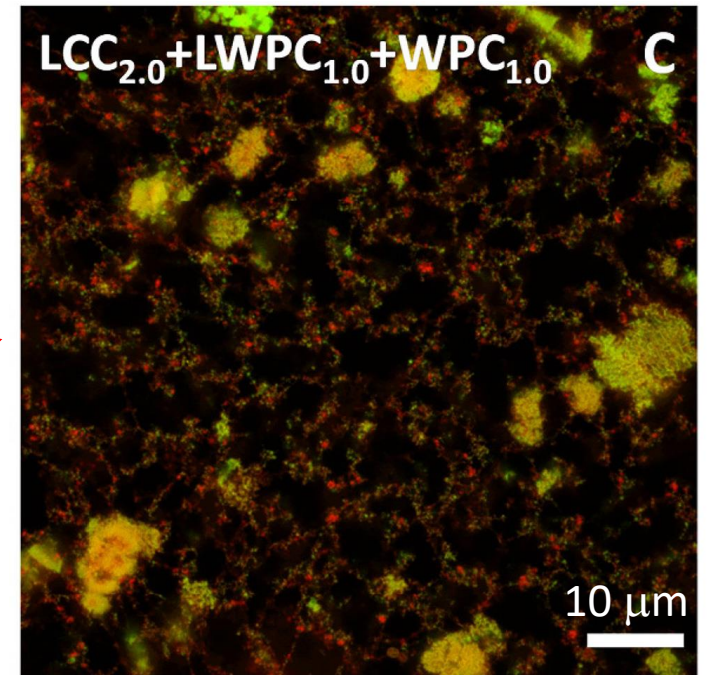
SPATIAL LOCALIZATION OF WHEY AND CASEINS

Cross-correlation at zero lag



High correlation = co-localized

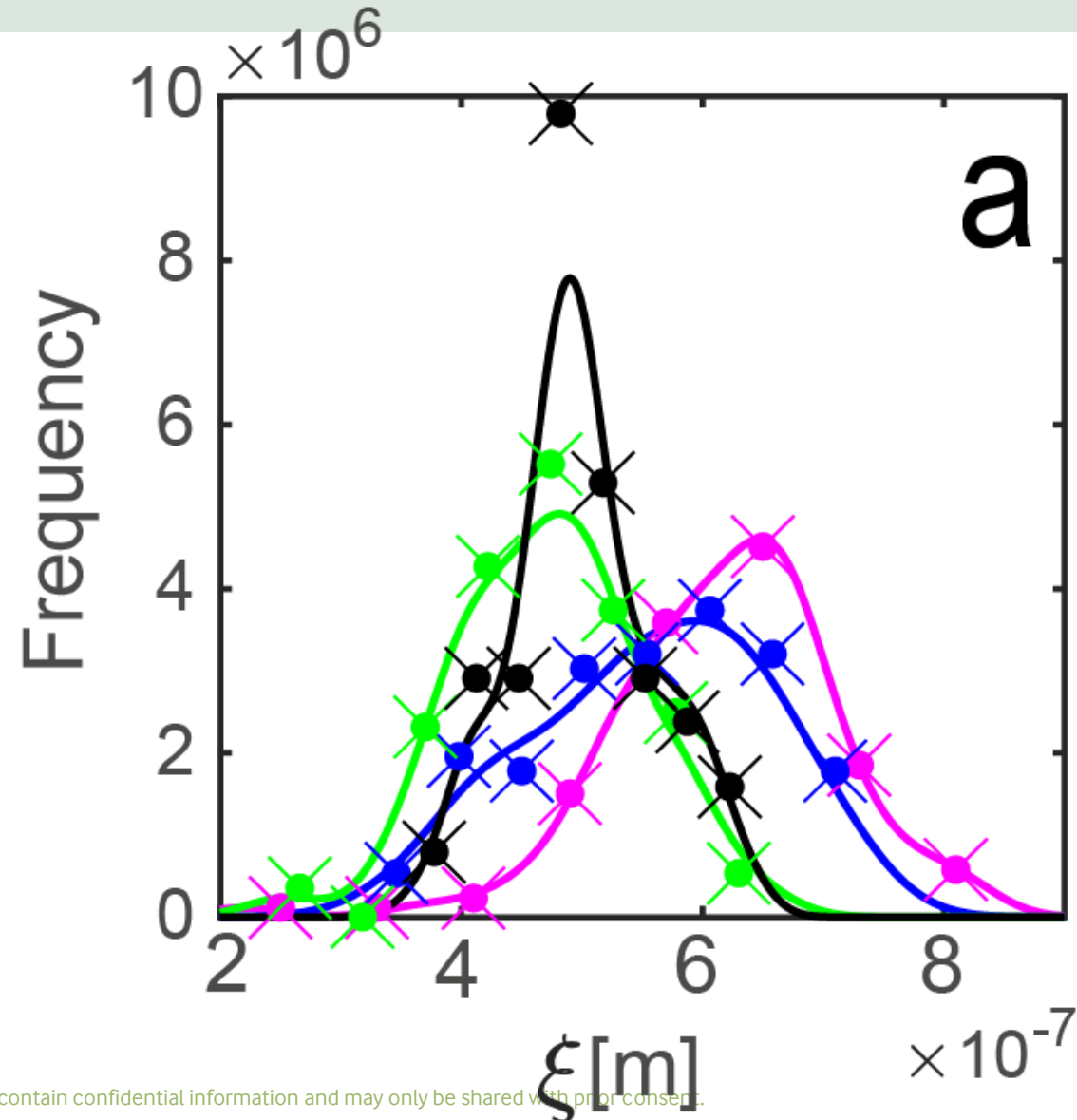
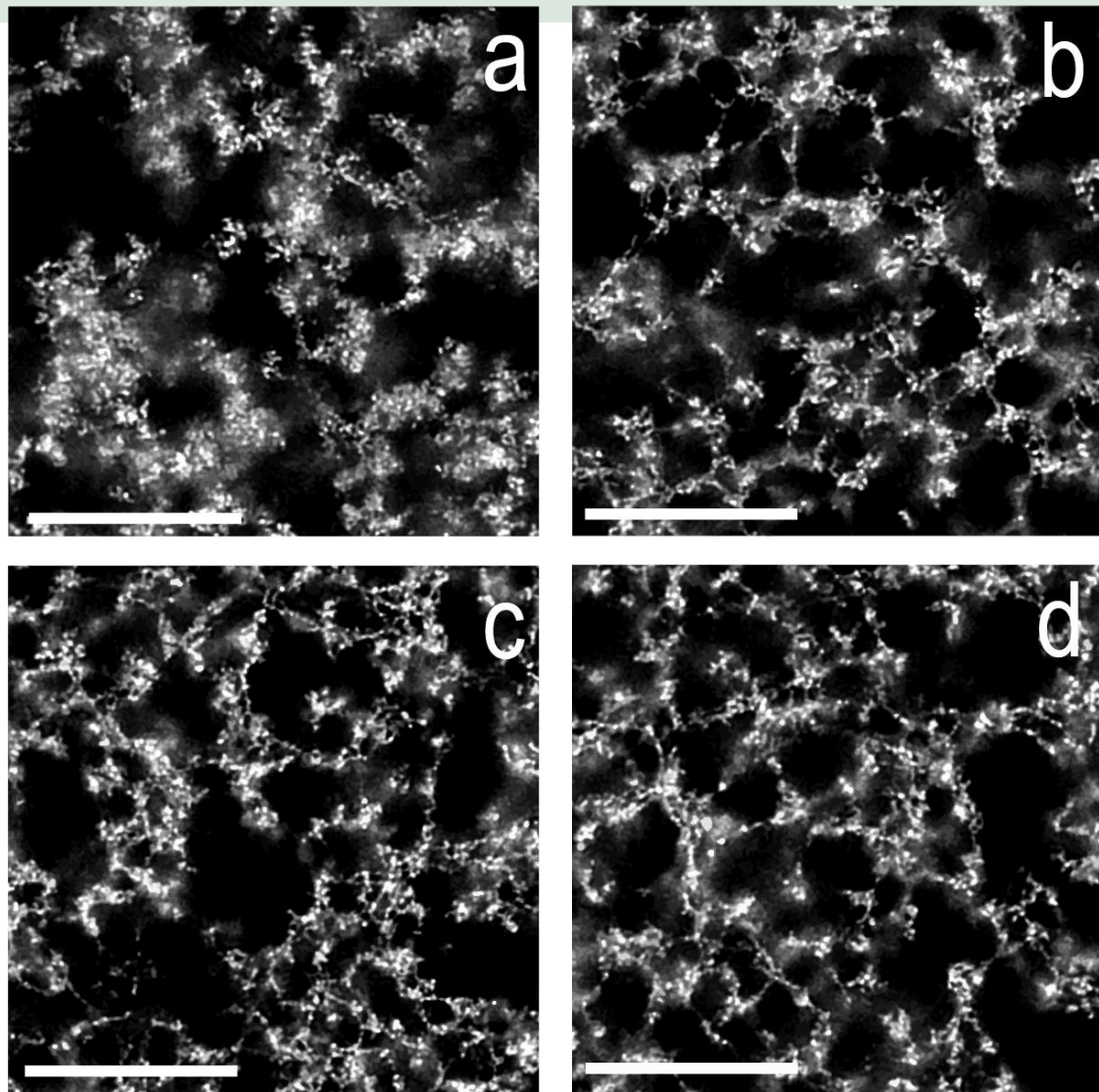
Low correlation = spatially separated



Casein = Green
Whey = Red

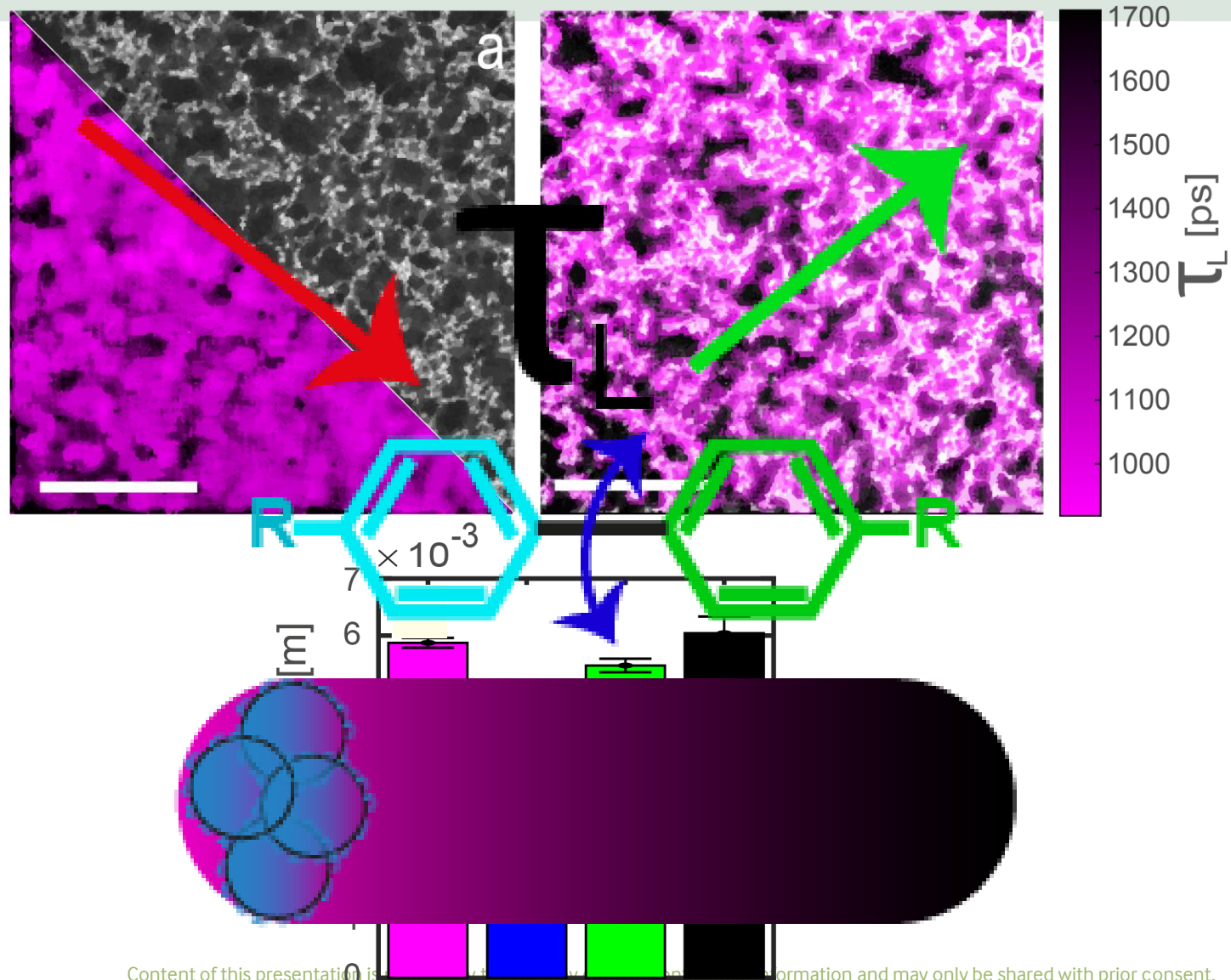
DYNAMIC MOISTURE LOSS AND SPATIAL VISCOSITY

Fresh Skim Milk (a), Fresh Heated Skim Milk (b), Reconstituted Skim Milk (c), Reconstituted Heated Skim Milk (d)

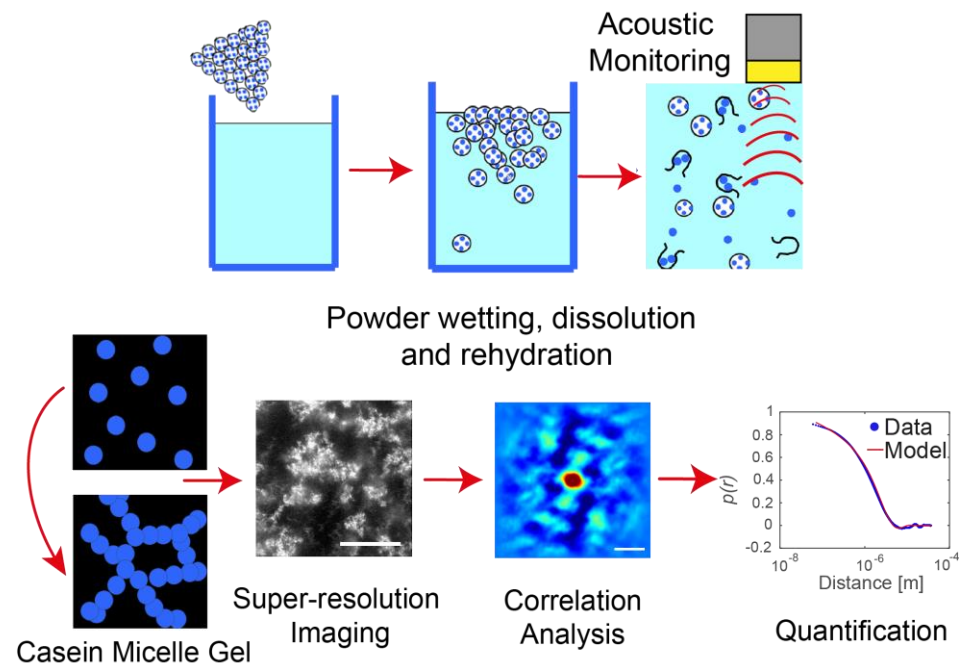


SPATIAL MICRO-VISCOSITY

Fresh Skim Milk (a), Fresh Heated Skim Milk (b), Reconstituted Skim Milk (c), Reconstituted Heated Skim Milk (d)



CONCLUSIONS



We have developed a toolkit using both light and sound to:

- **Monitor power reconstitution and particle aggregation**
- **Conduct super-resolution imaging & perform quantitative correlation-based image analysis**
- **Work is ongoing to develop and apply to operationalise the learnings**

THANK YOU FOR YOUR ATTENTION

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DaMBIC (Danish Molecular Bioimaging Center)

SDU 

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