BIJEL CAPSULES

J.W. Tavacoli, E.M. Herzig, and P.S Clegg

Institute for Condensed Matter and Complex Systems

and

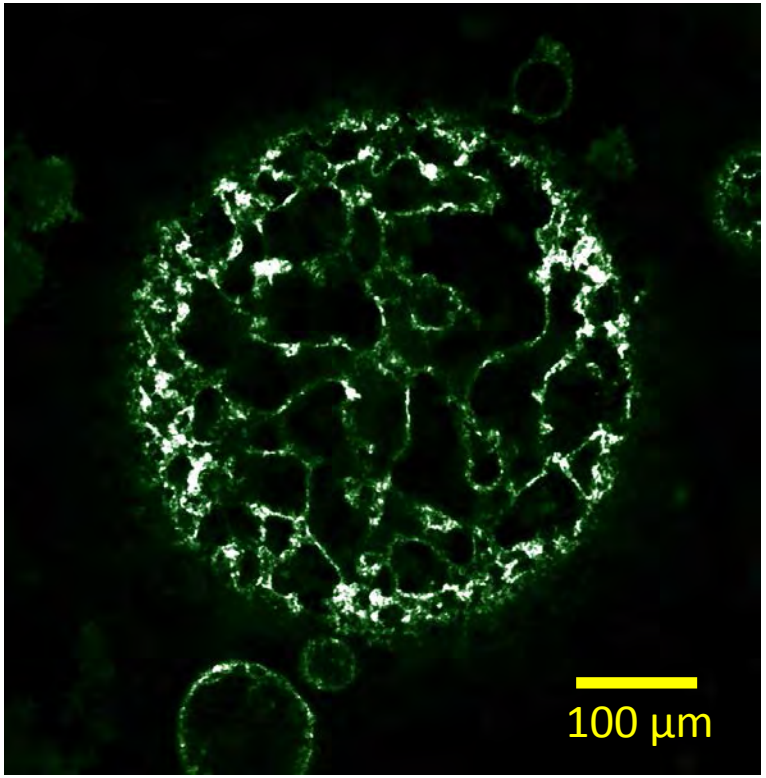
The Edinburgh Complex Fluid Partnership

School of Physics, University of Edinburgh

ECFP

Bijel Capsules:Road Map

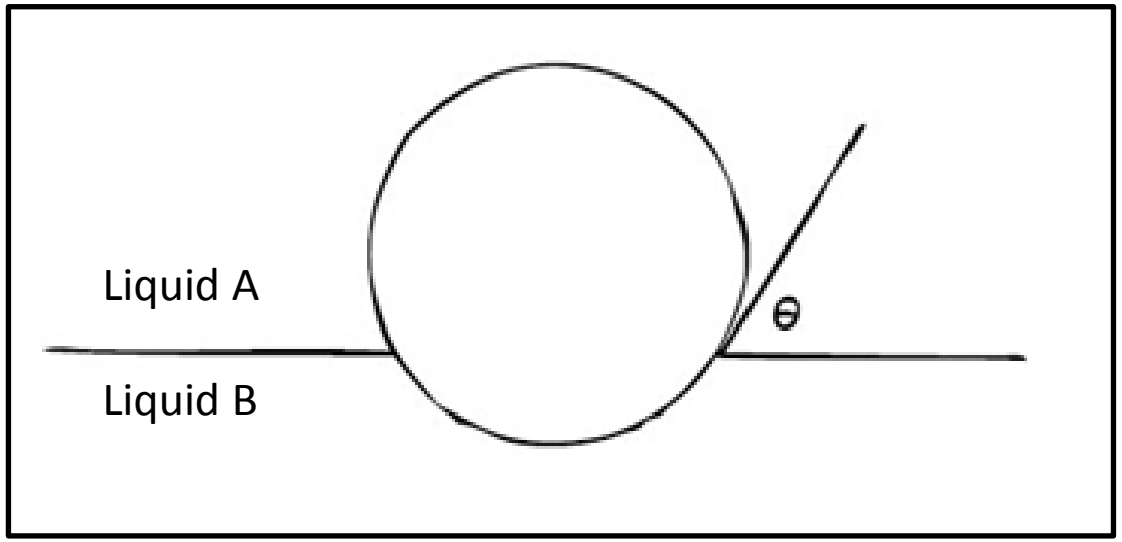
- Colloidal particles as interface stabilisers
- Bijels
- Bijel capsules



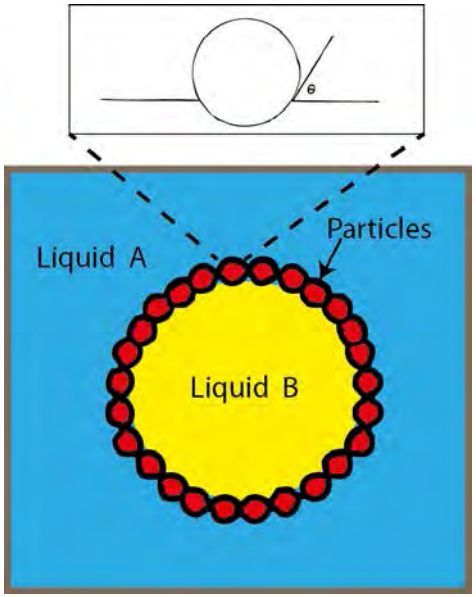
Particles at Interfaces

$$\Delta E = \pi r^2 \gamma_{ow}(1-|\cos\theta|)^2$$

$$> 10\,000 k_B T$$



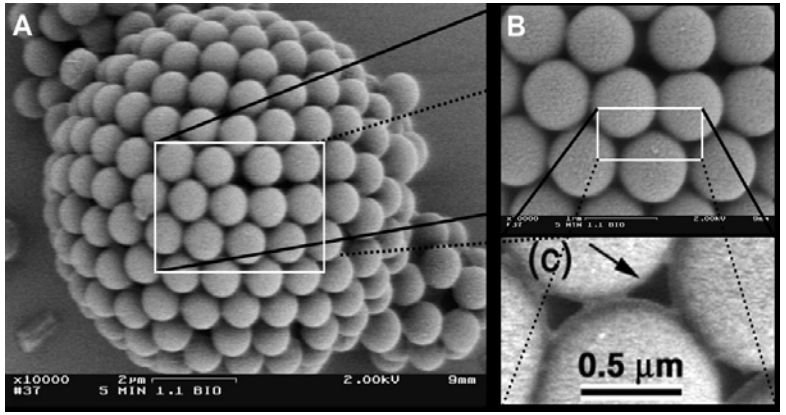
Solid-Stabilised Capsules



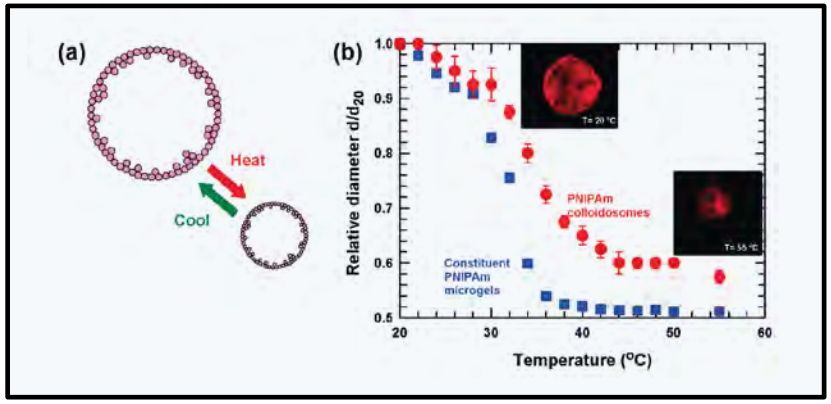
Particle Stabilised Emulsions

Discovered by Ramsden and Pickering (independently)

Colloidosomes



P-NIPAM based capsules

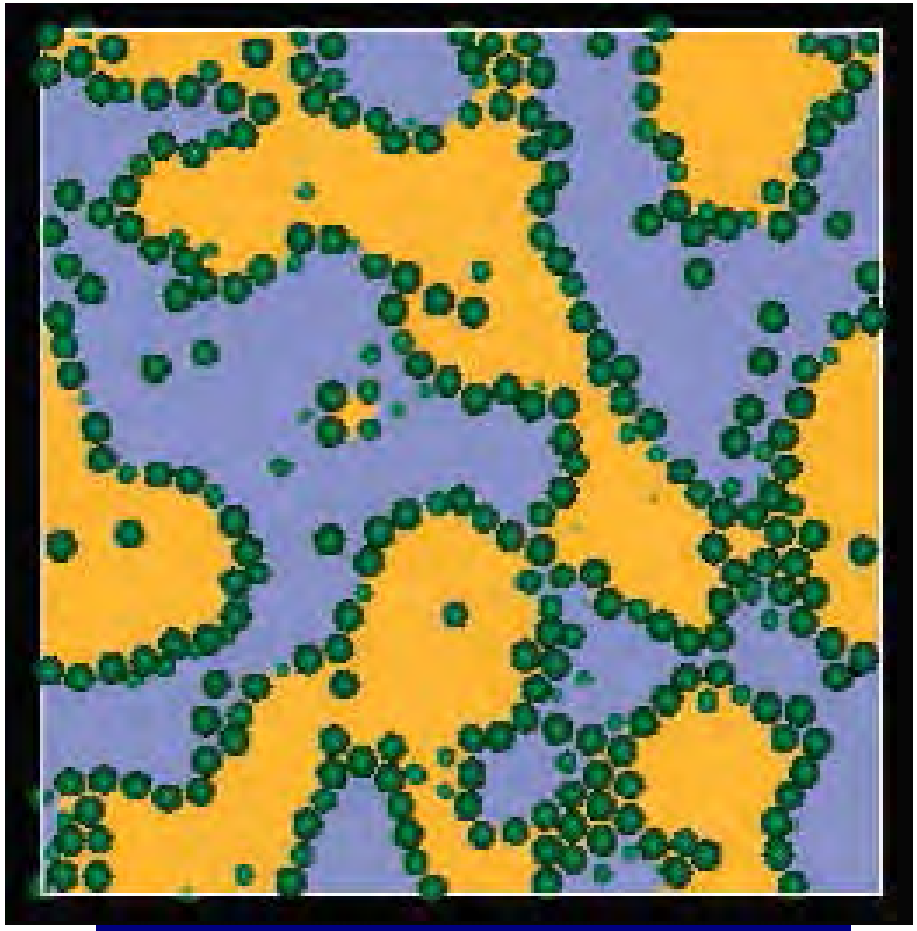


D. Dinsmore et al. Science 298, 1006, (2002)

Shah et al. Langmuir 26(3) 1561 (2010)

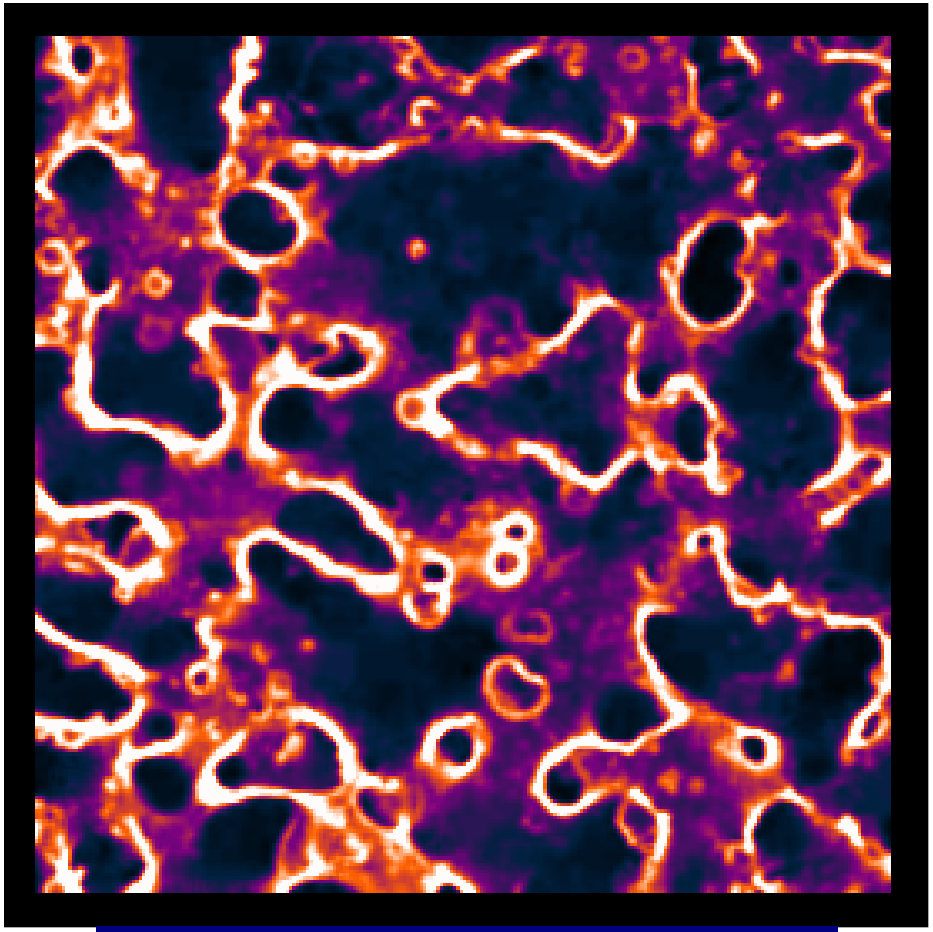
Bicontinuous Interfacially Jammed Emulsion Gel

2 liquid domains stabilised by adsorbed particles
Domains tortuous and entwined



SIMULATION
K. Stratford *et al.* Science **309**, 2198 (2005)

The first bijel: water, lutidine and FITC dyed silica



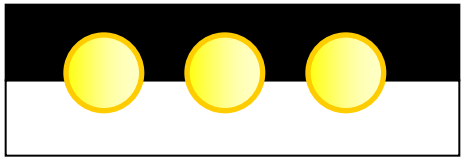
EXPERIMENT
Herzig et al Nature Materials **6**, 966 (2007)

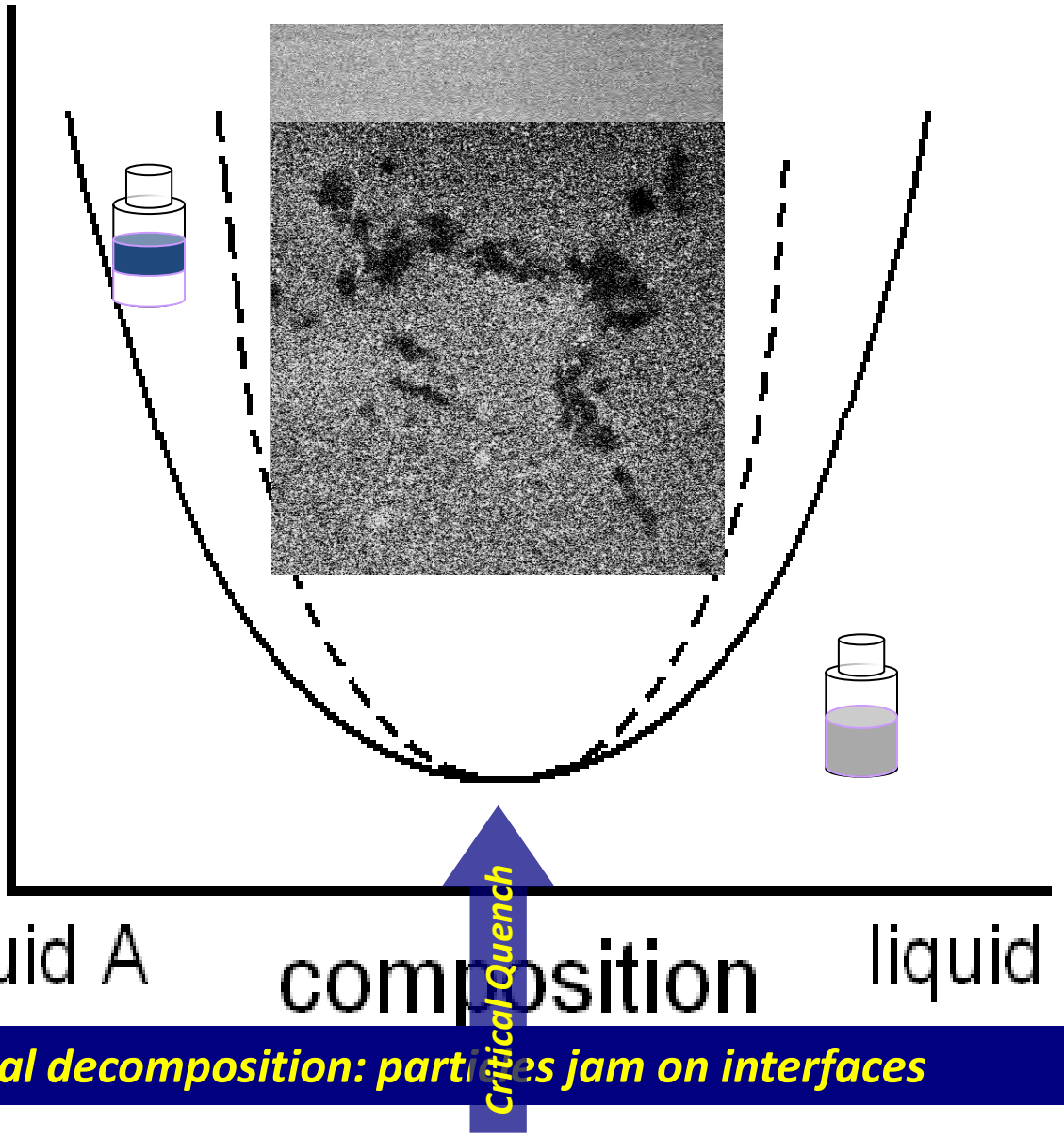
Bijel Fabrication

1) Partially miscible liquids

2) A critical composition

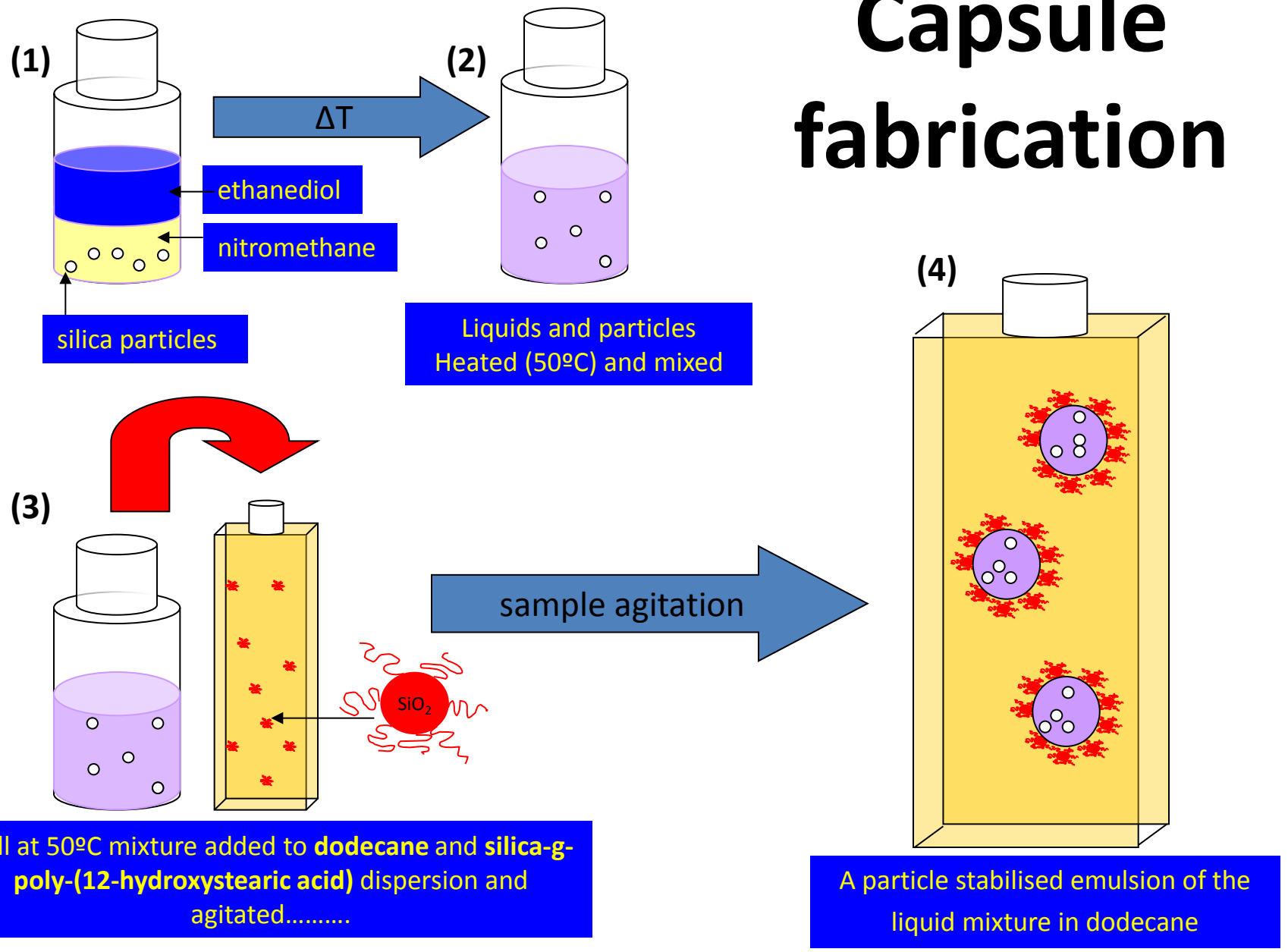
3) Neutrally wetting particles





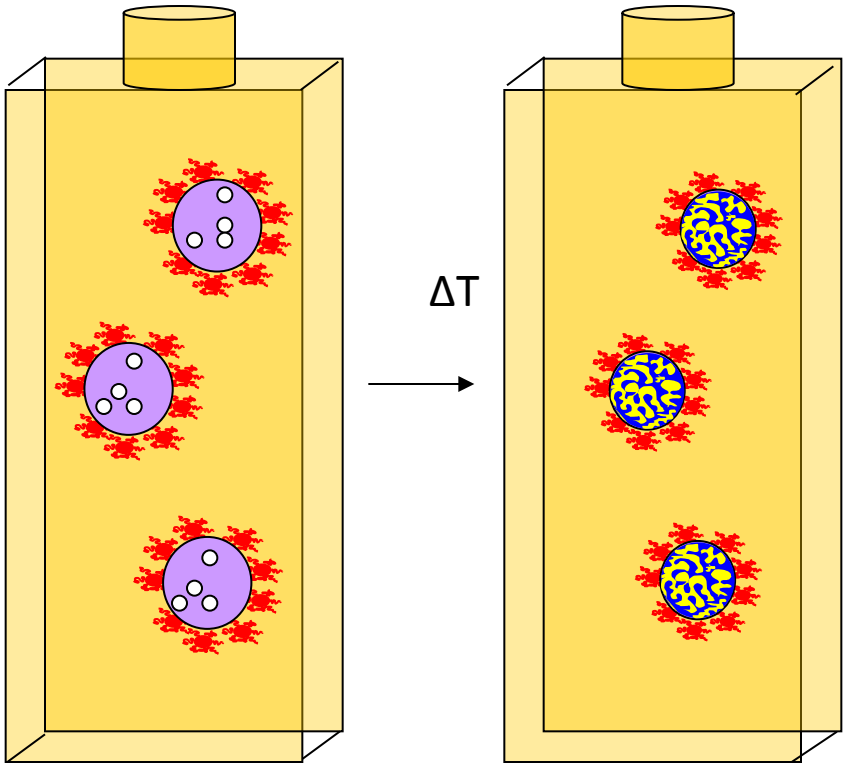
liquids separate via spinodal decomposition: particles jam on interfaces

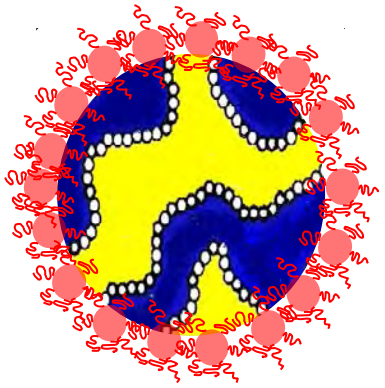
Capsule fabrication

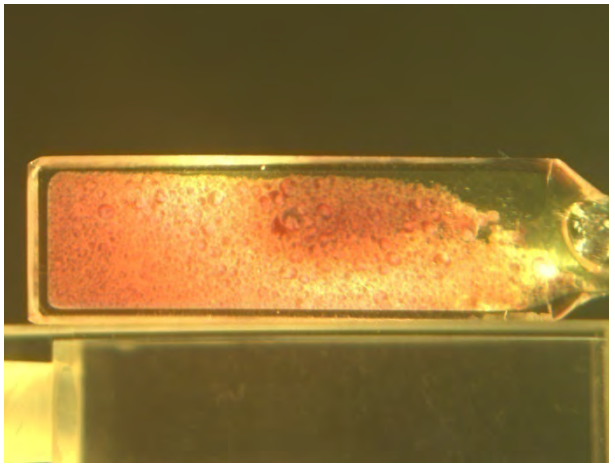


Capsule fabrication

(4) continued



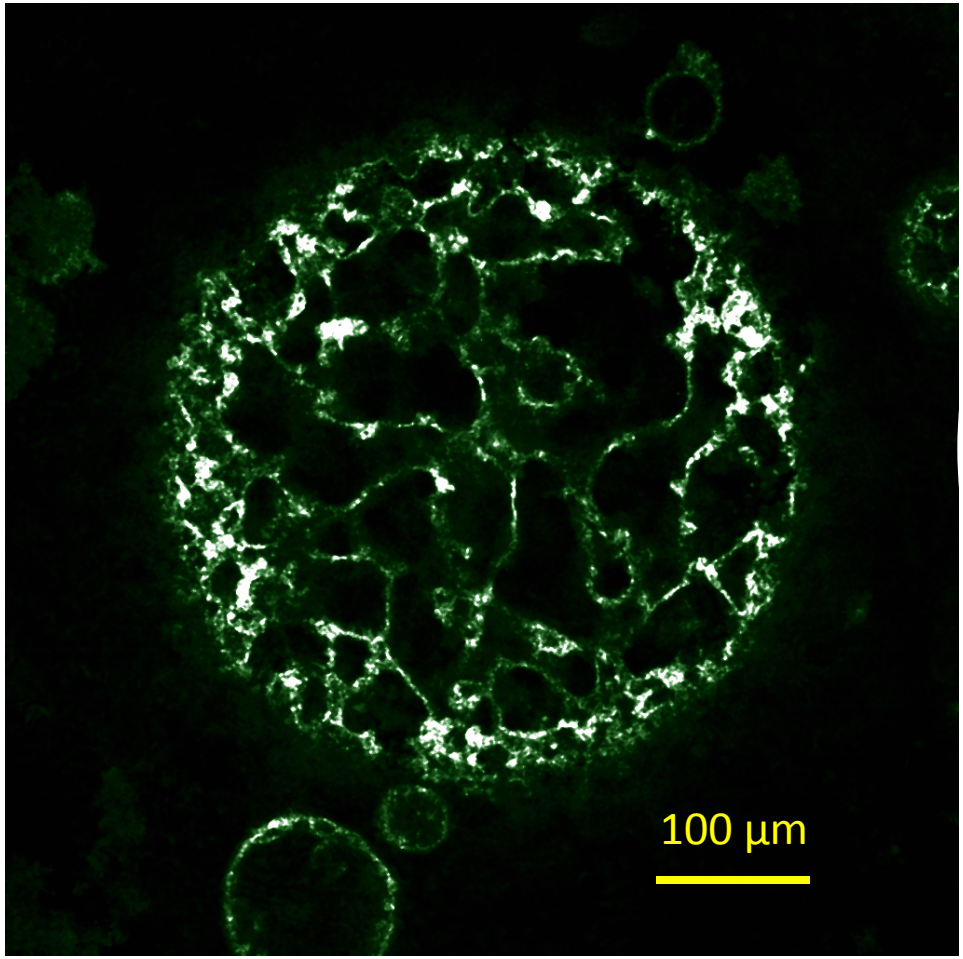


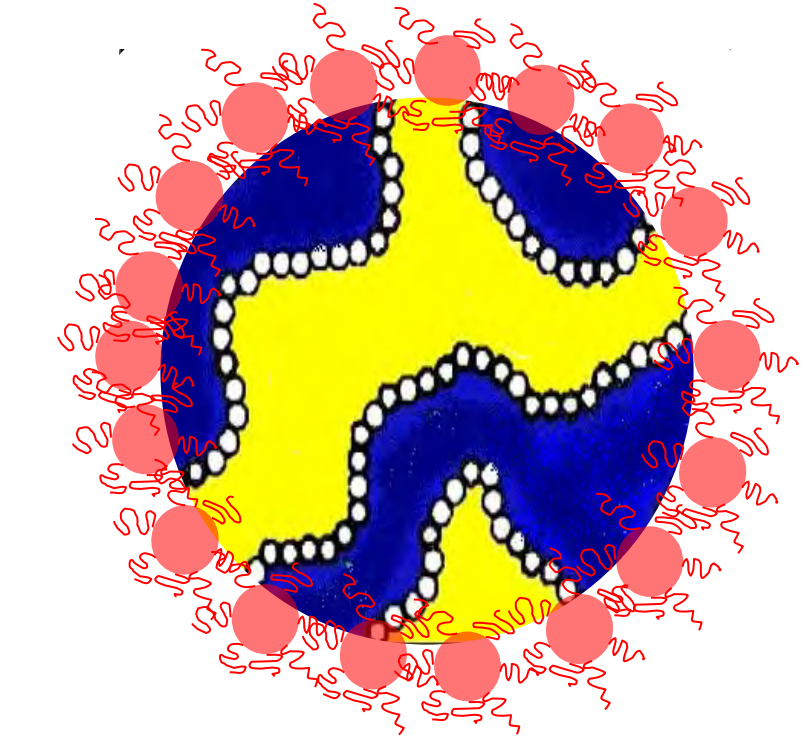


(5) Room temperature quench and bijel formation takes place in emulsion droplets forming the bijel capsule.

A Typical Bijel Capsule

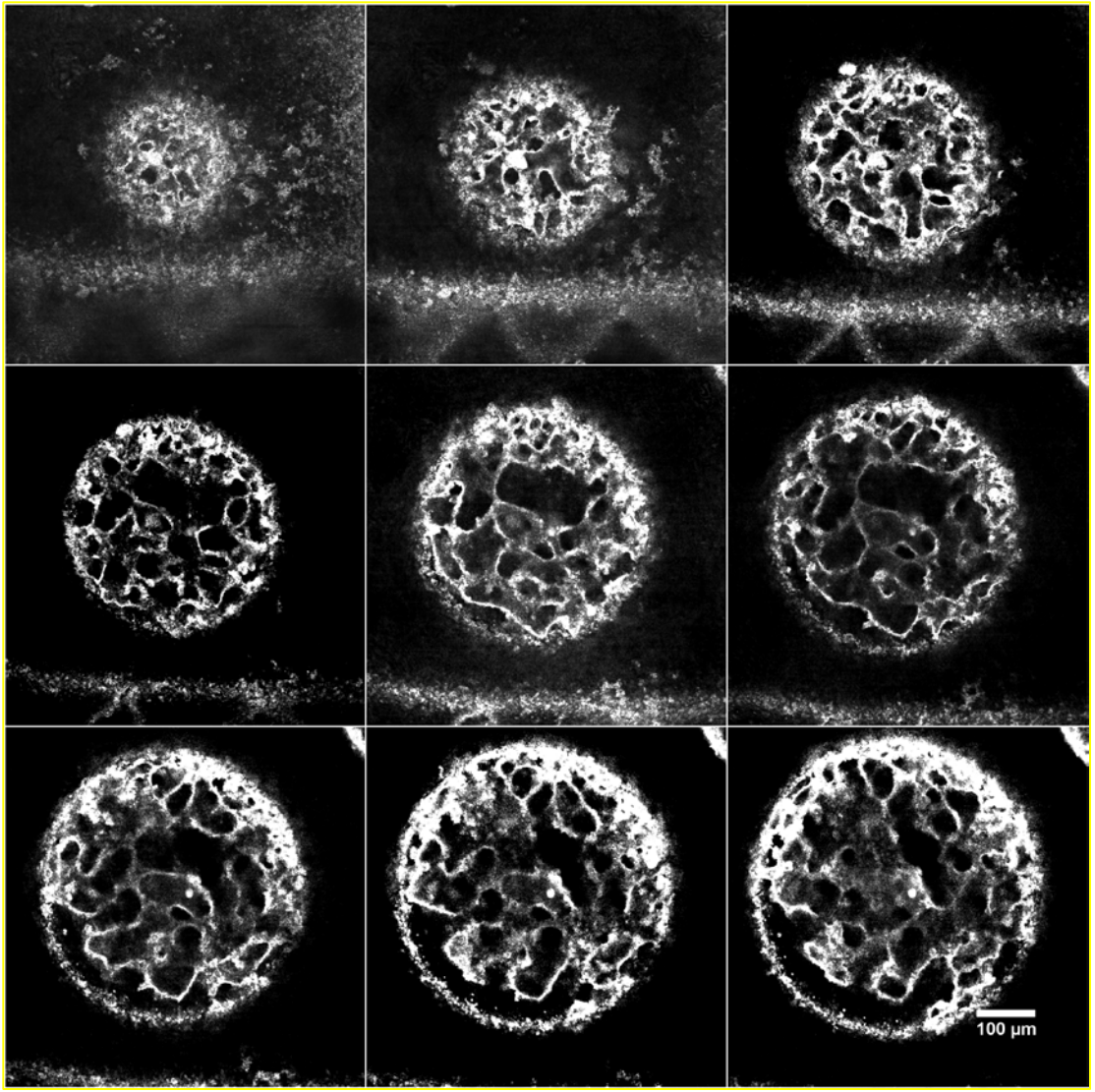
Typical capsule size > 100 µm

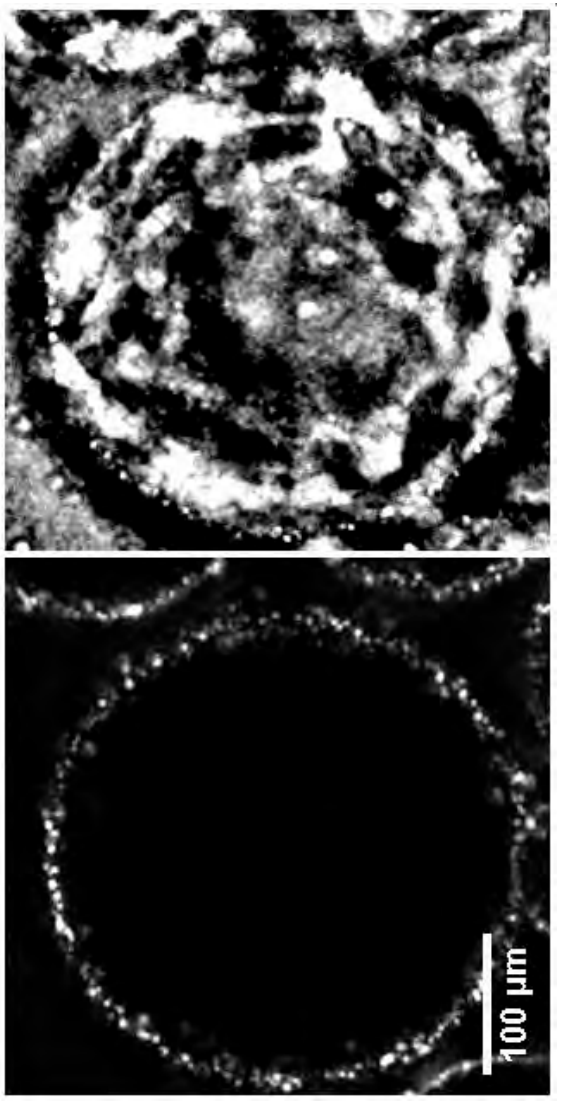




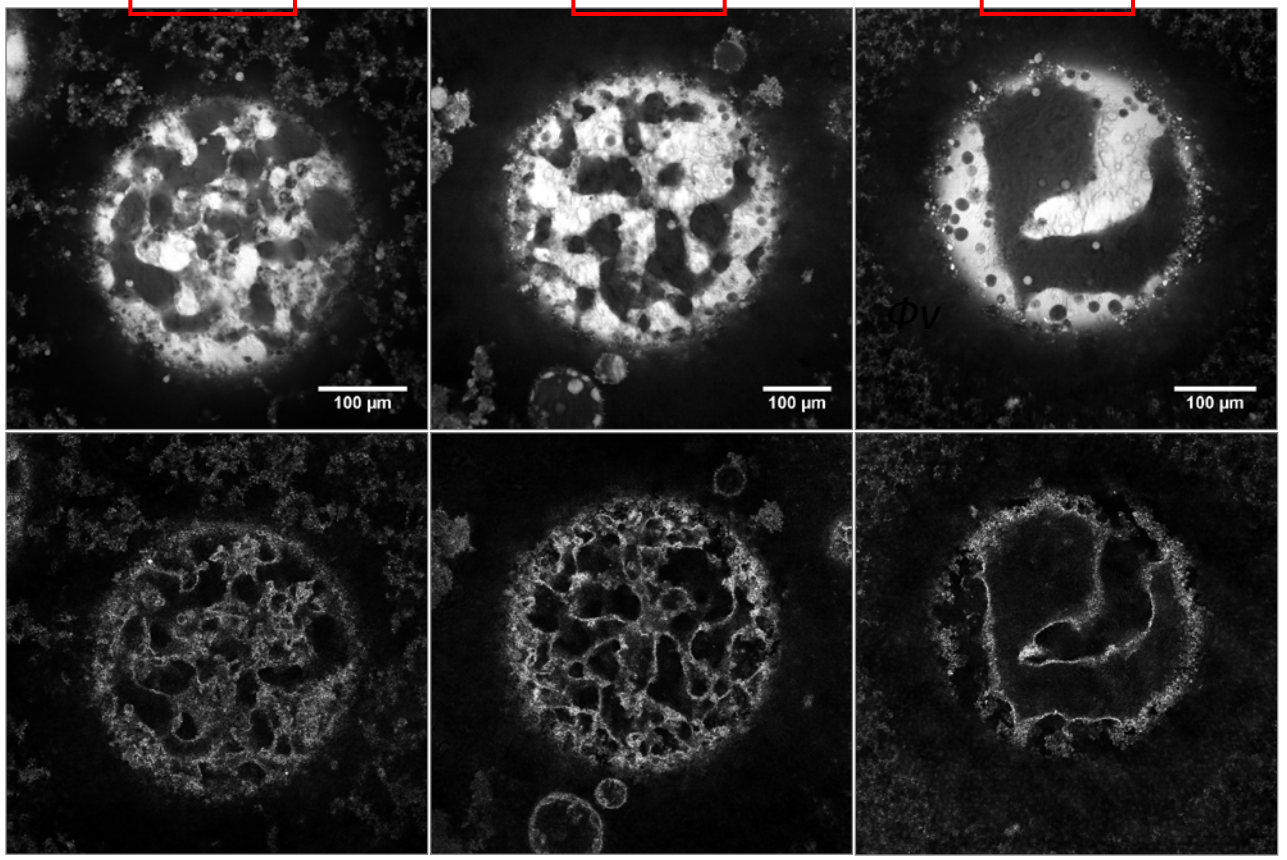
Particle Signal

A More Detailed Look



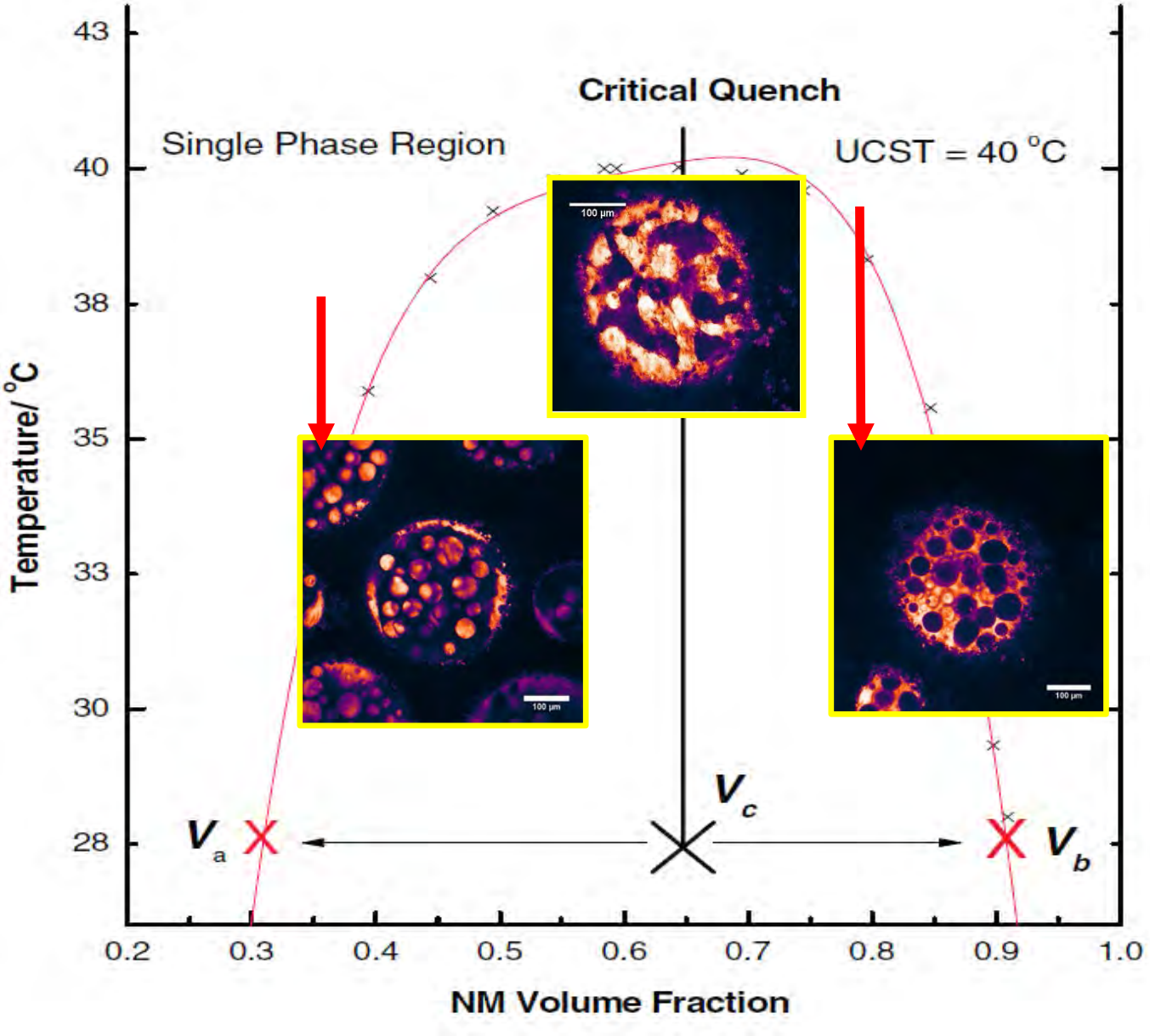


Manipulation of Architecture: Volume fraction

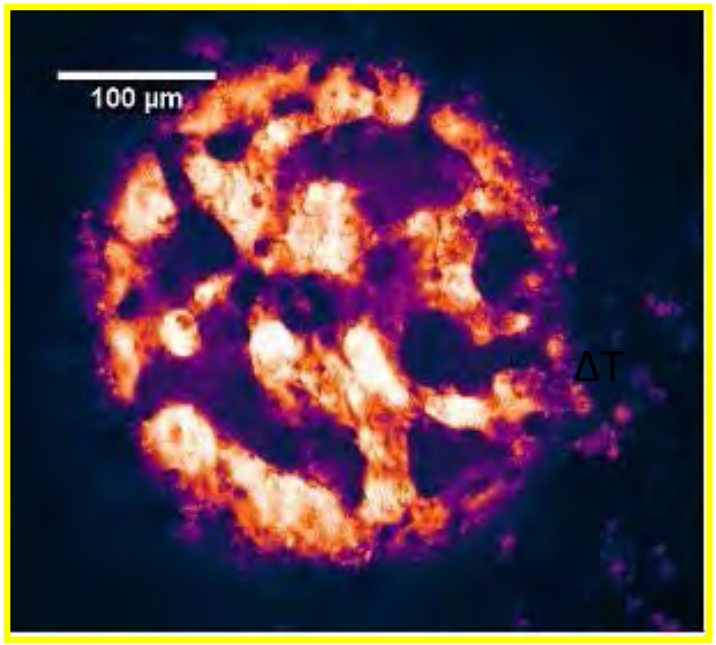


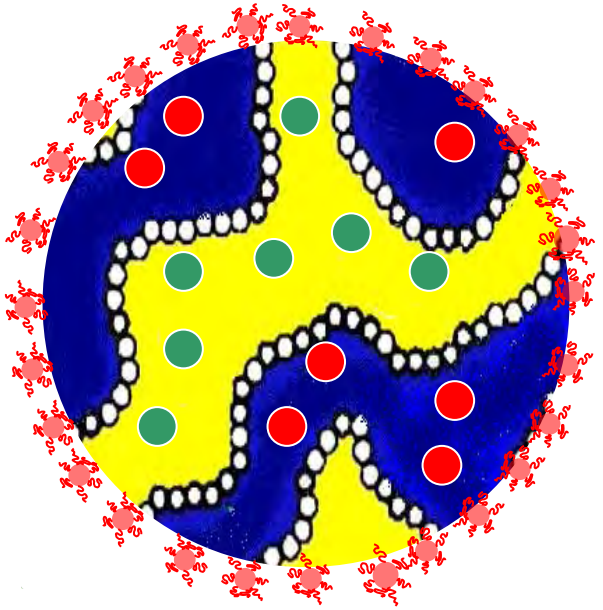
Qualitatively domain size, *d*, decreases with particle volume fraction, Φ_v Area effect

Manipulation of architecture: Composition



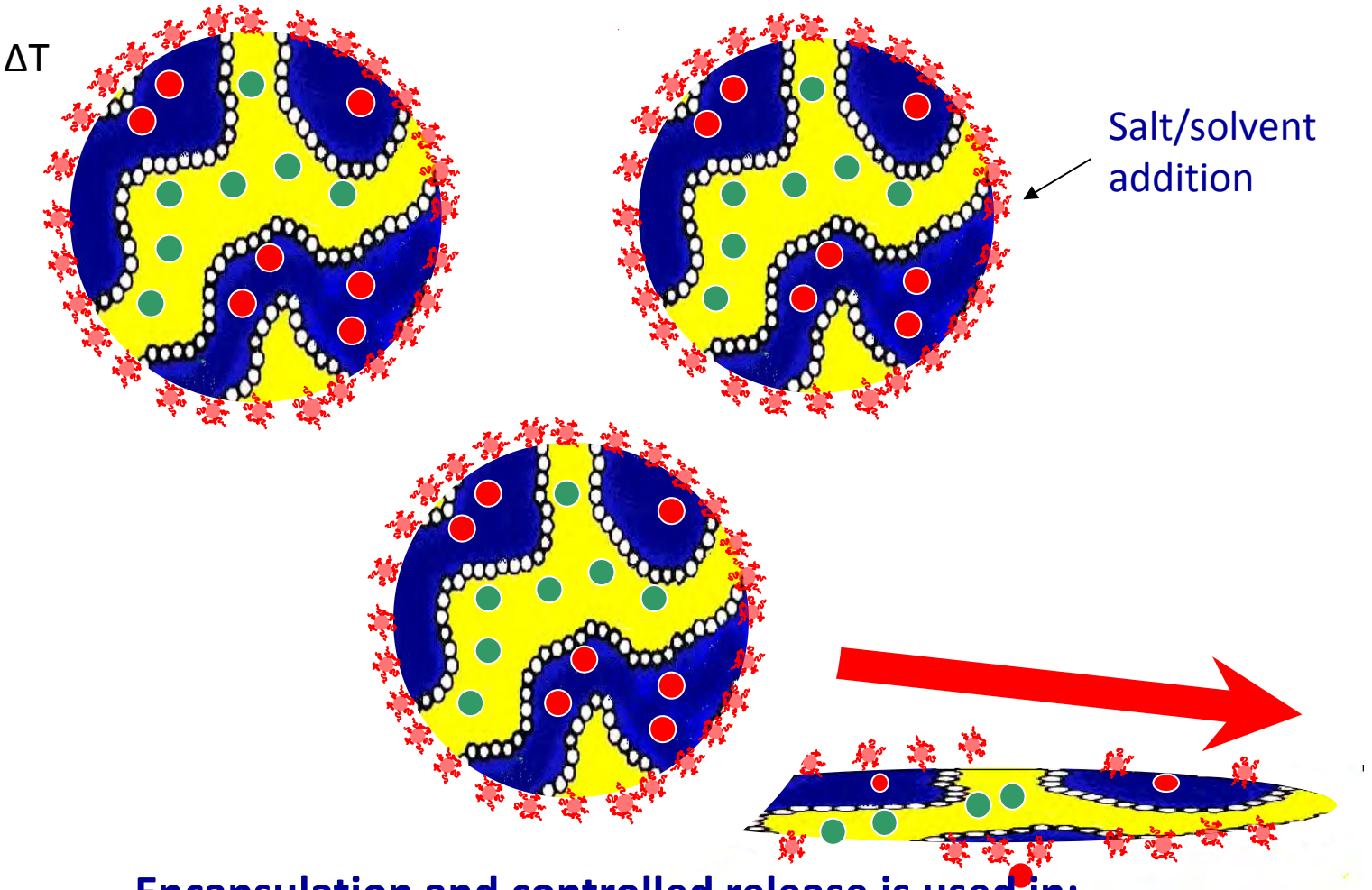
Encapsulation Advantages





Can encapsulate 2 types of materials in equal amounts and release them in unison at equal rates.

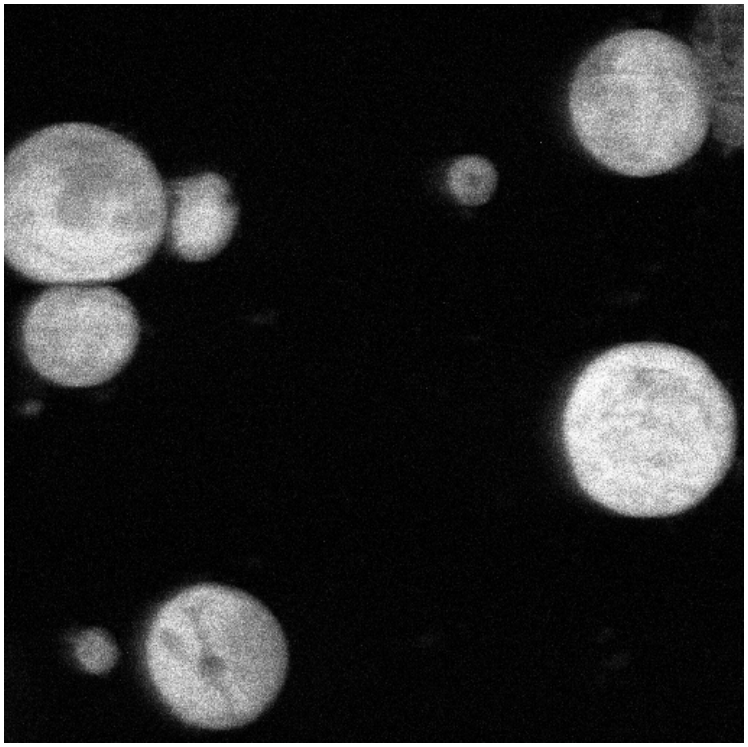
Controlled Release: More Mechanisms

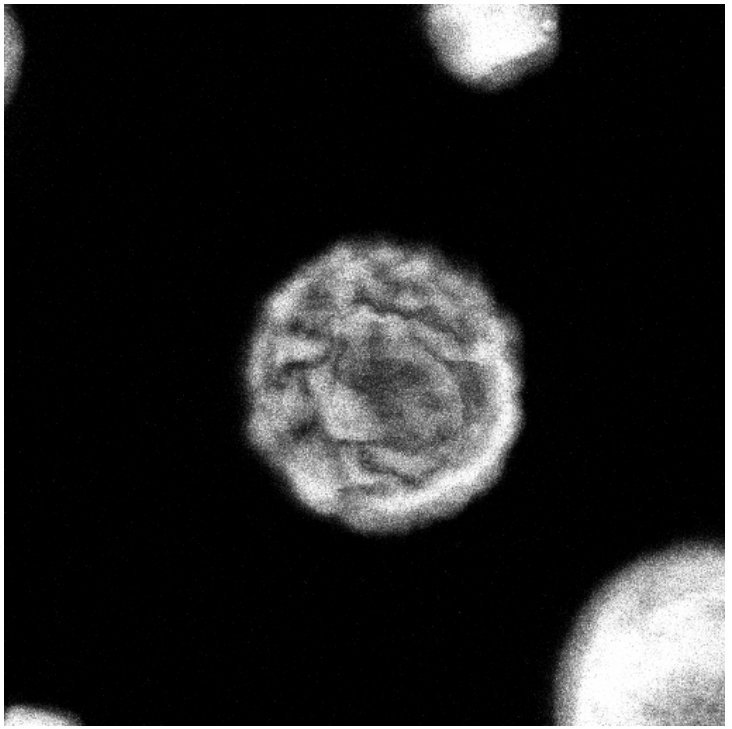


Encapsulation and controlled release is used in:

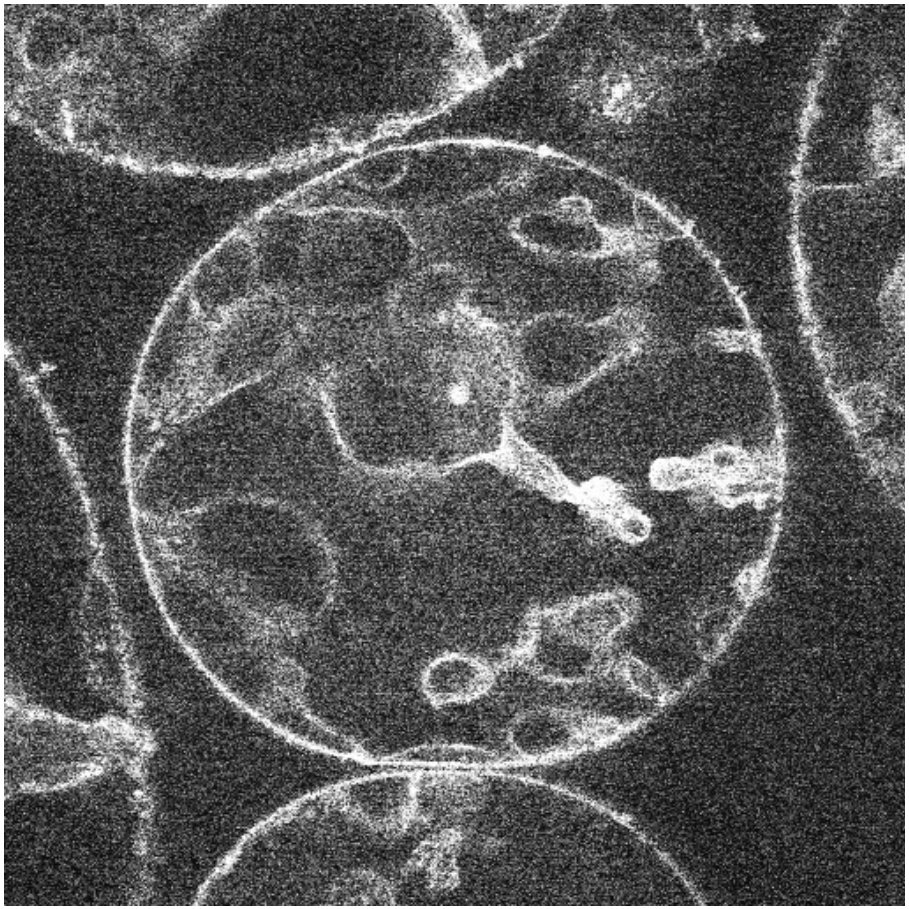
drug delivery, moisturisers, detergents, food flavouring

Triggered release(solvent induced)





T Response (Triggered Mixing)



On warming the capsule back into the single-fluid phase the liquids remix and the particles redisperse.

Useful for:

Keeping small particles inside?

Environmentally responsive Release (good for food flavours)

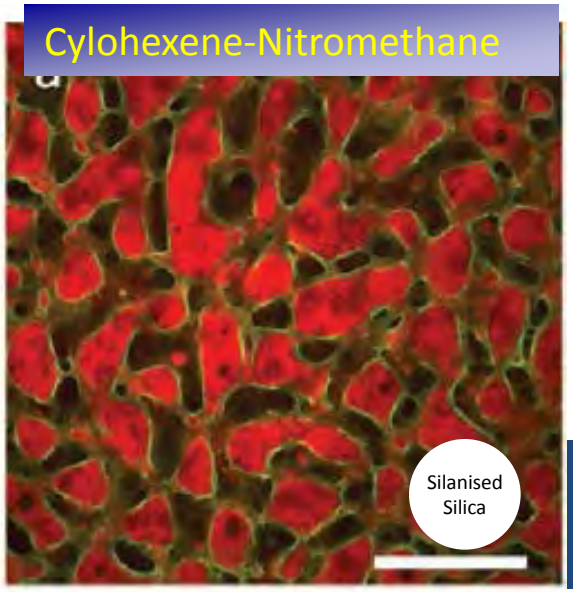
Internal reactions?

Conclusions

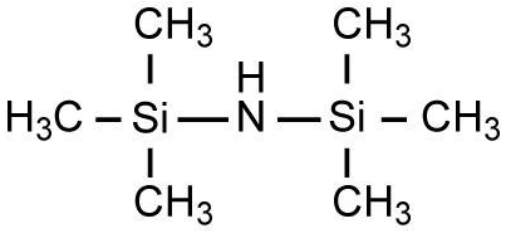
- We have demonstrated the generic route to form bijel capsules using ethanediol and nitromethane
- The ease which domain size can be adjusted should allow control of release rates
- Bijel capsules allow, in principal, equal release rates of chemically distinct ingredients
- Trigger release/reaction
- Eliminate surfactants and polymers from emulsion system while keeping fluid phases continuous
- Dual function stabilizer (can be an active ingredient: TiO2, ZAG)

THANKS FOR LISTENING!

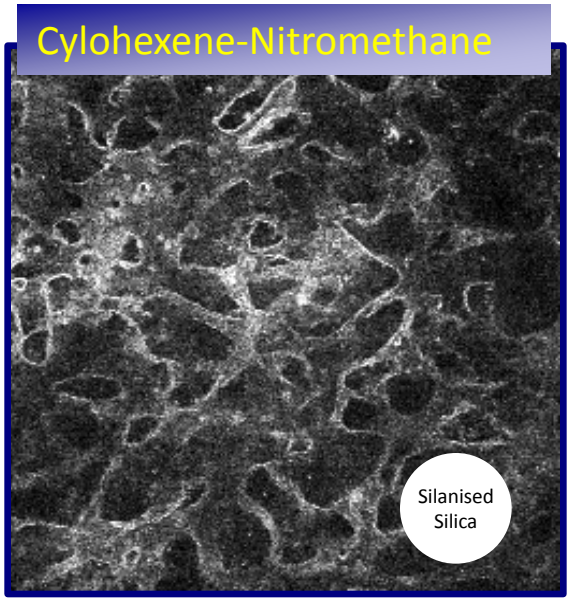
New Bijels

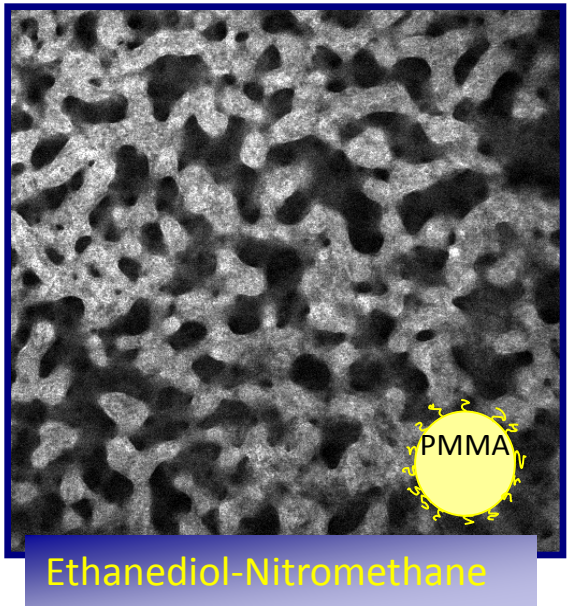


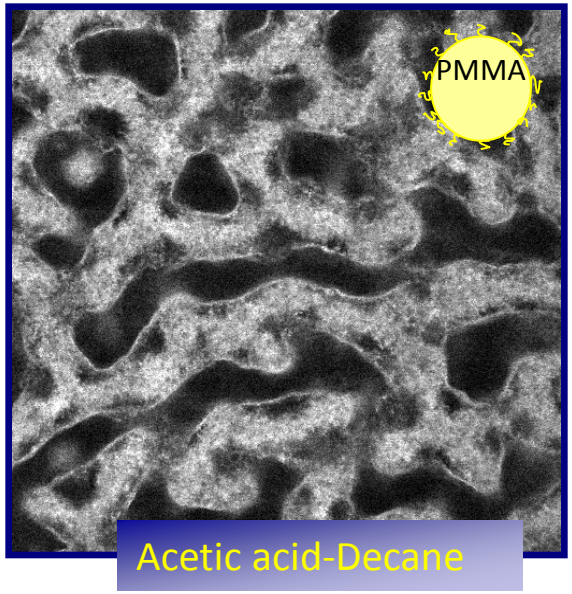
Surface hydrophobicity of Stöber silica tuned with HMDS:



The Ethanediol-Nitromethane system is particularly stable.

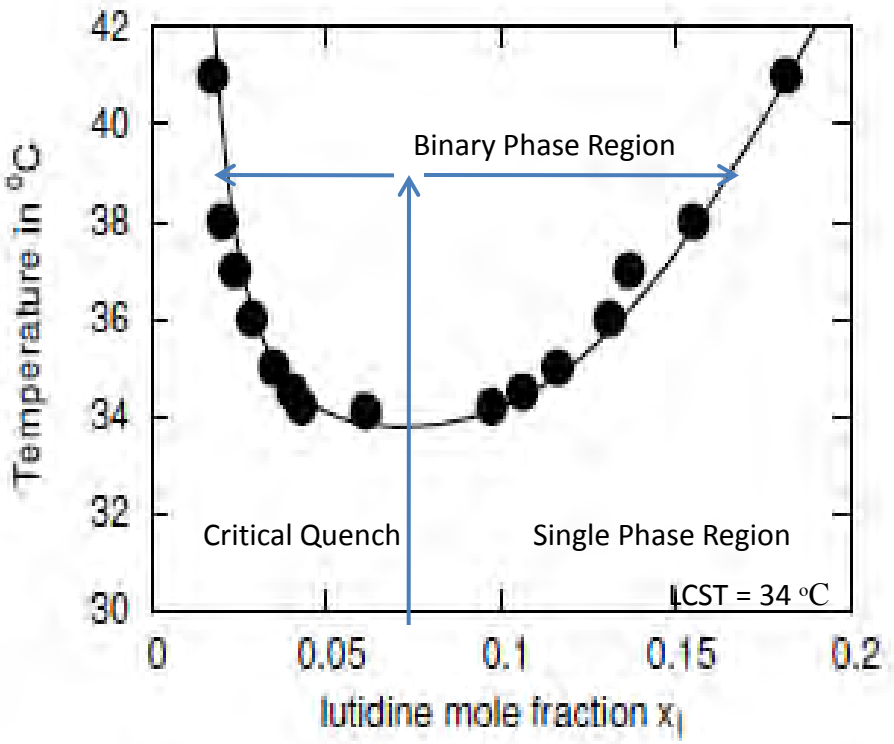






Why is the Nitromethan-Ethanediol System so Nice?

LUTIDINE - WATER

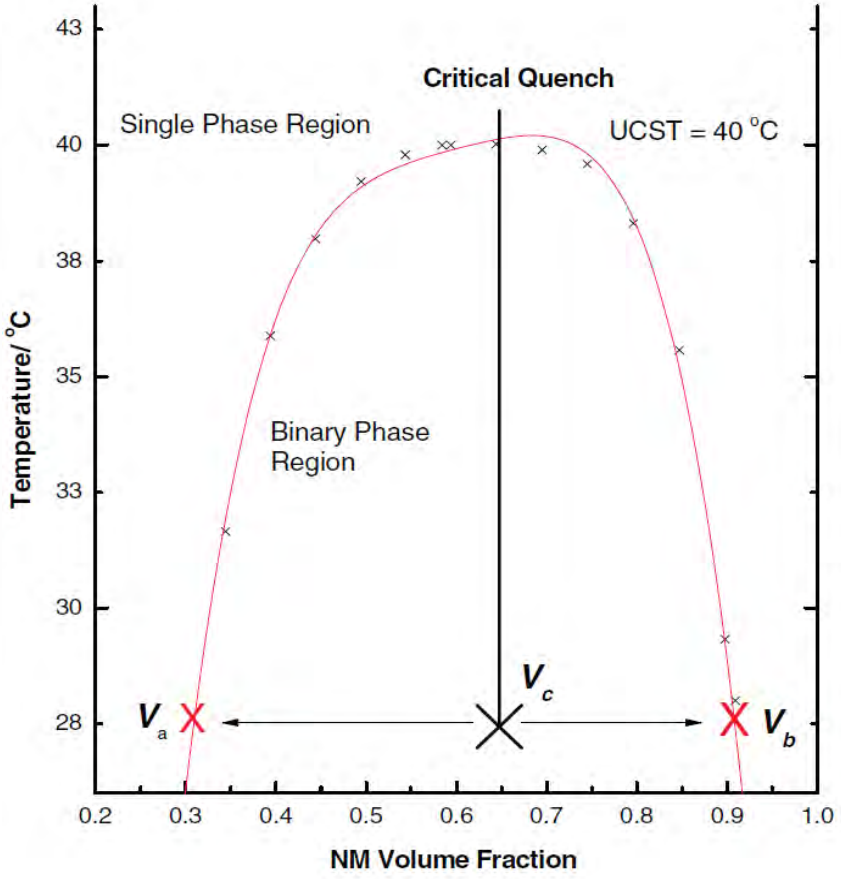


Density water = 1

Density 2,6-lutidine = 0.925

Volume Ratio: L:W - 38.9:61.1

ETHANEDIOL - NITROMETHANE

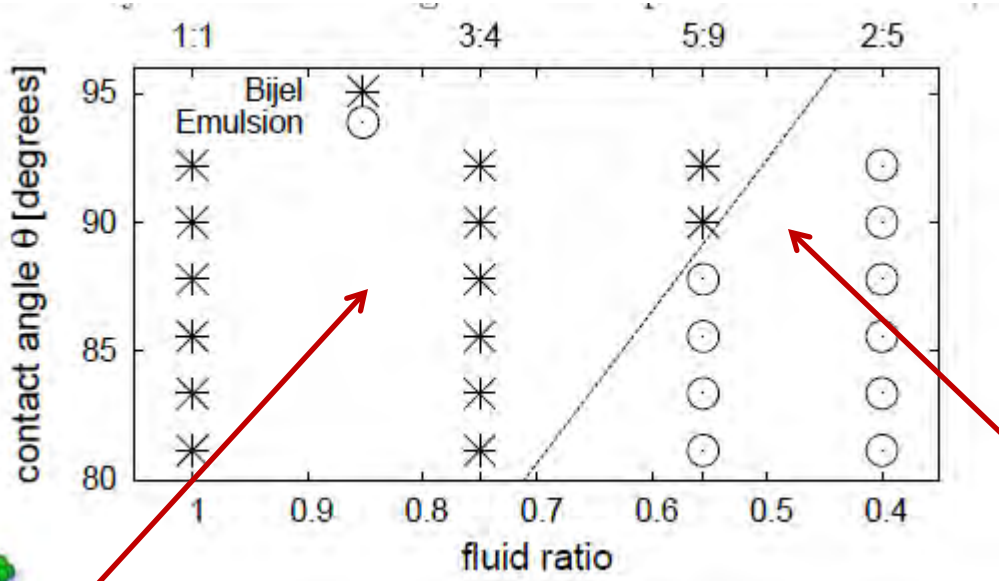


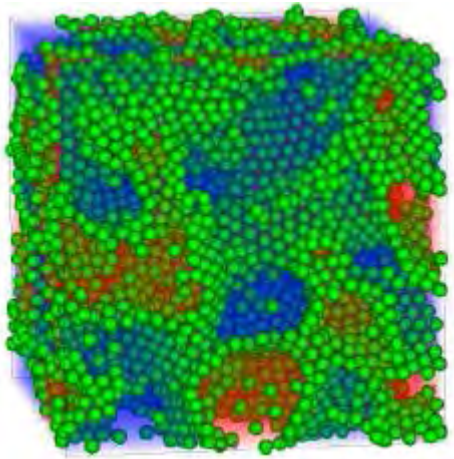
Density ethanediol = 1.1

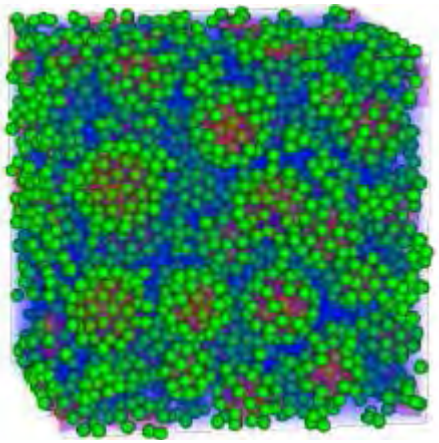
Density nitromethane = 1.1

Volume Ratio: ED:NM - 48:52

Why is the Nitromethan-Ethanediol System so Nice? Equality of Volume

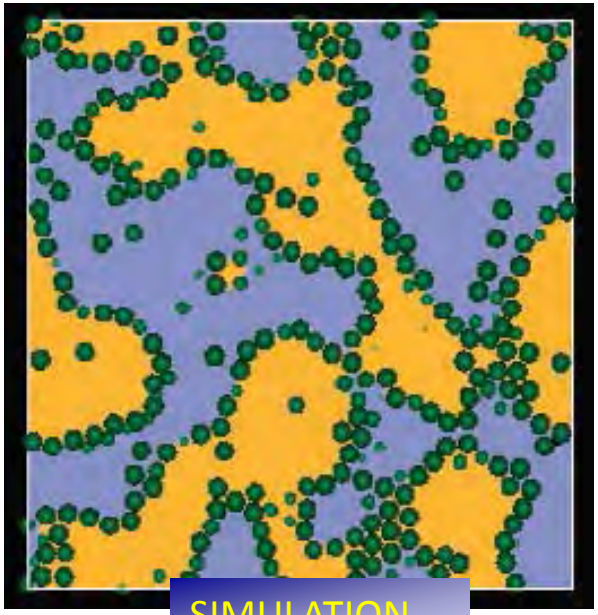






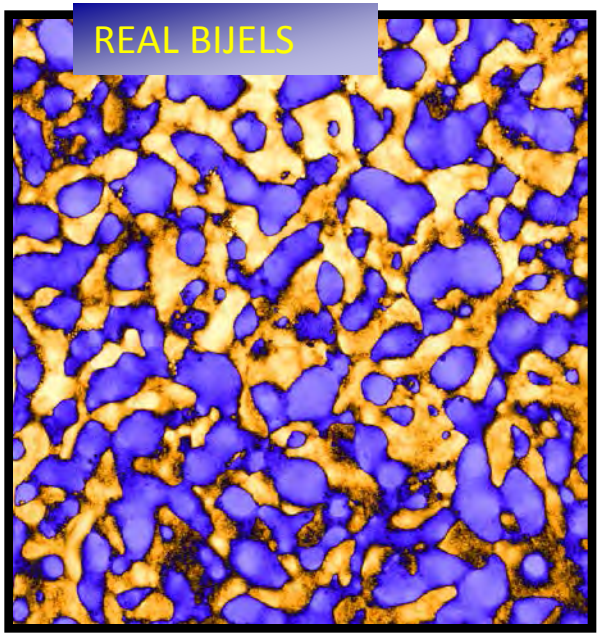
PHYSICAL REVIEW E **83, 046707 (2011)**

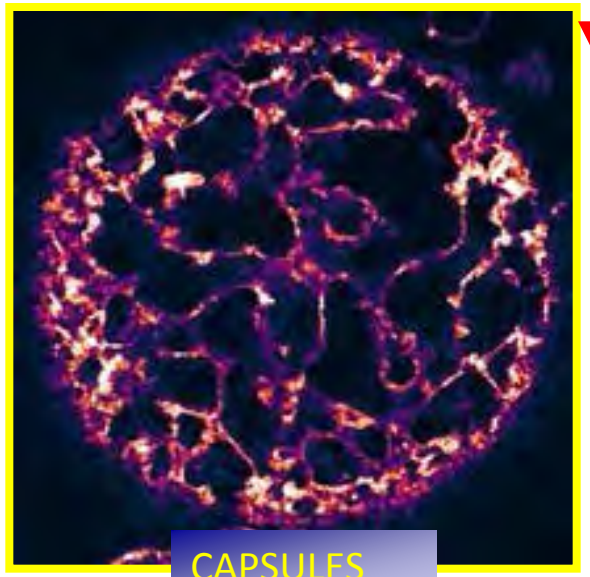
SUMMARY: BIJEL PROGRESSION



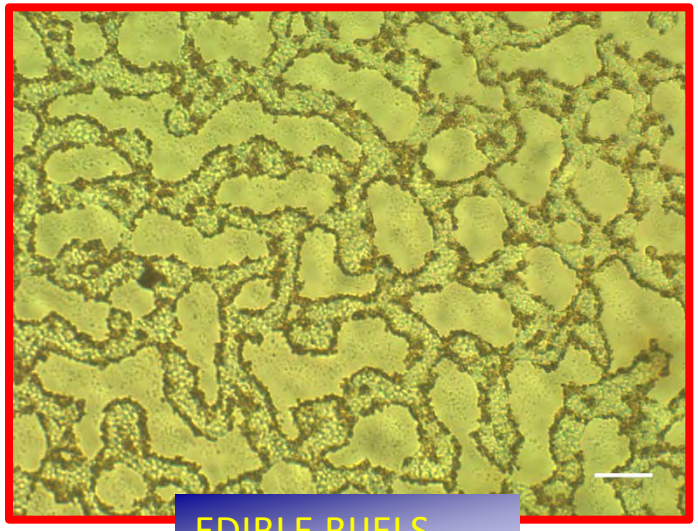
SIMULATION

REAL BIJELS



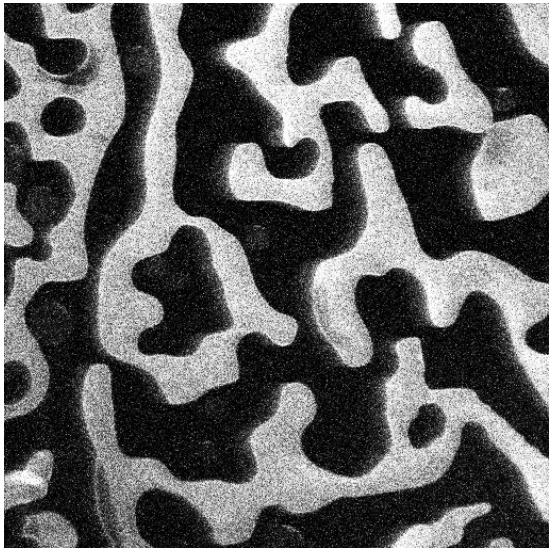


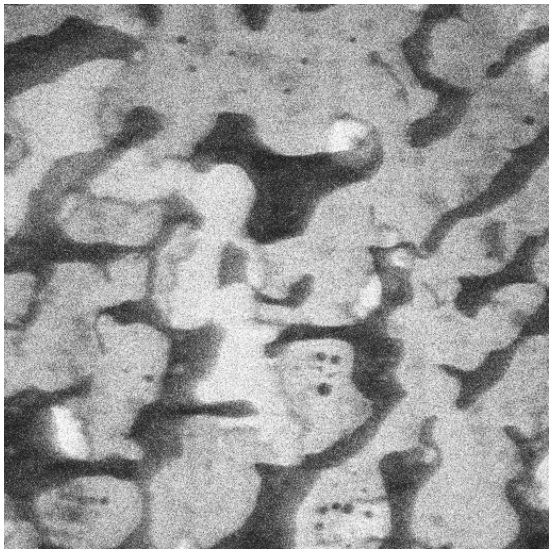
CAPSULES

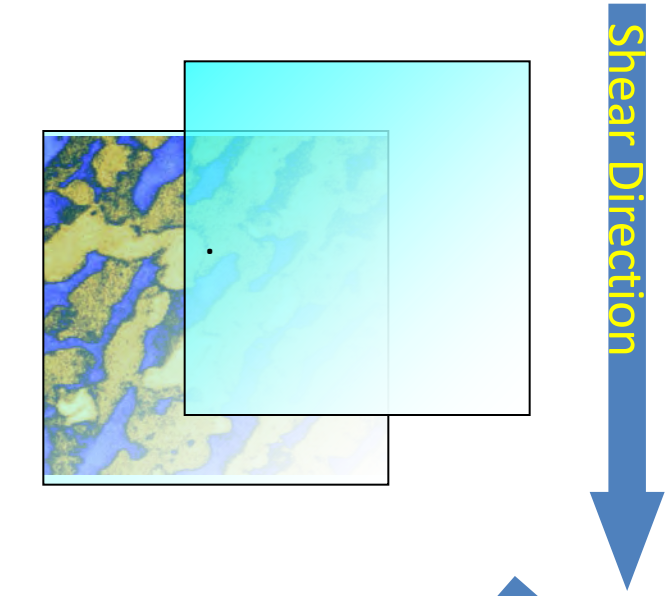


EDIBLE BIJELS

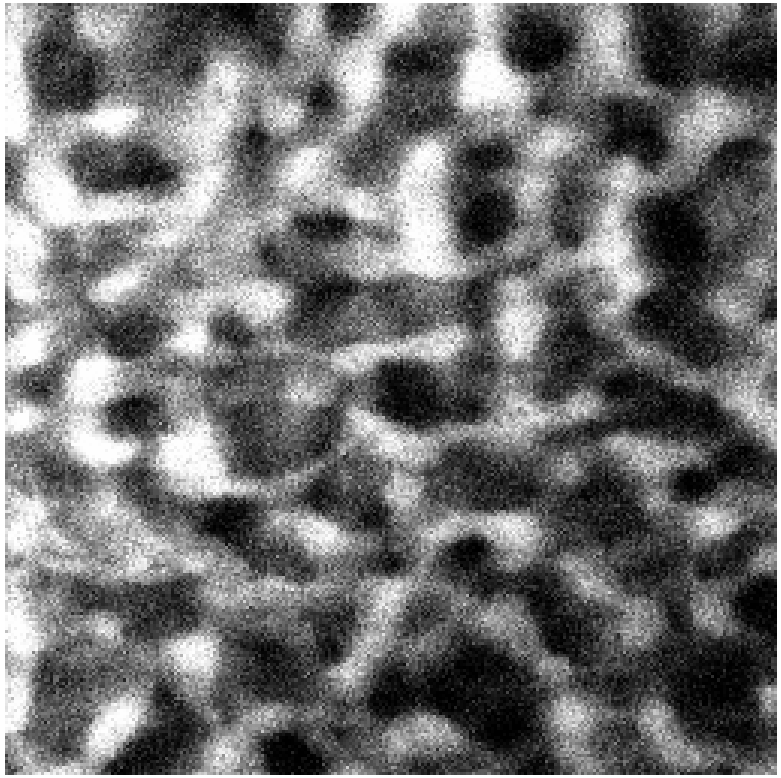
Response to shear

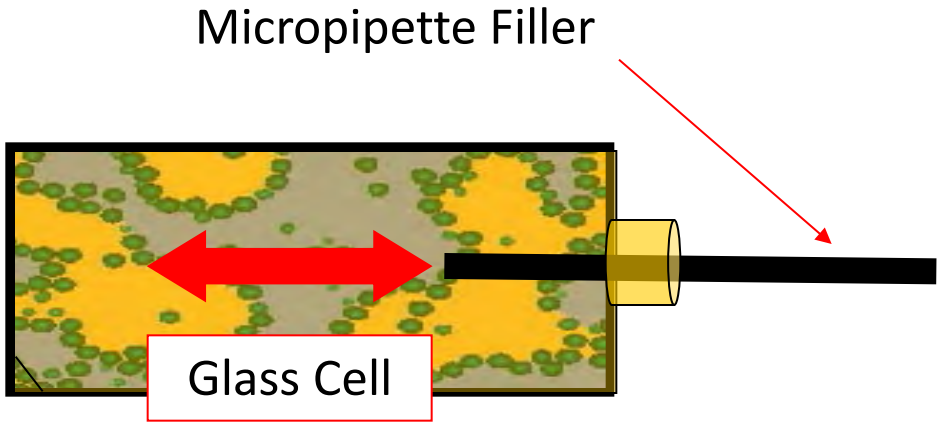






Response to compression

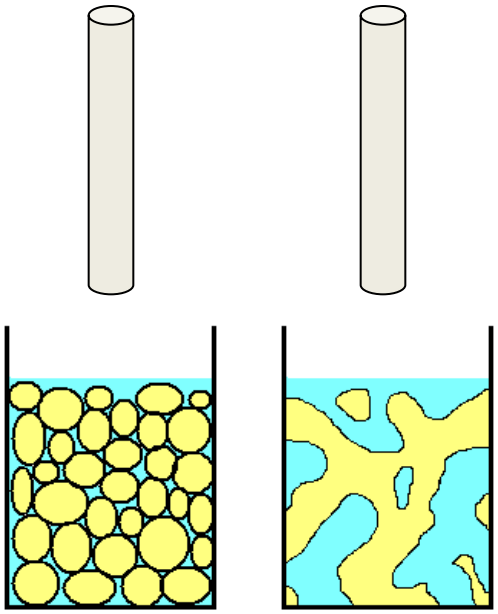


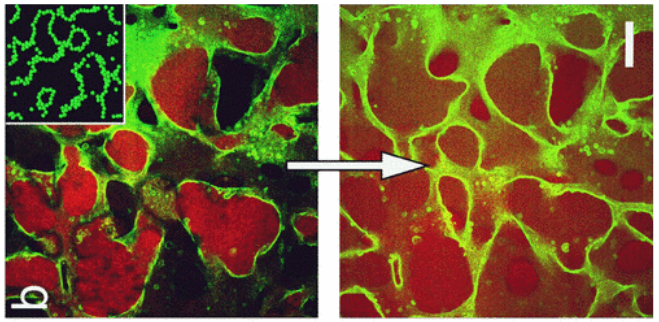


This basic experiment illustrates that the Bijel is elastic. The domains compress but after the removal of the micro syringe the Bijel returns to a near-original state.

Some Properties

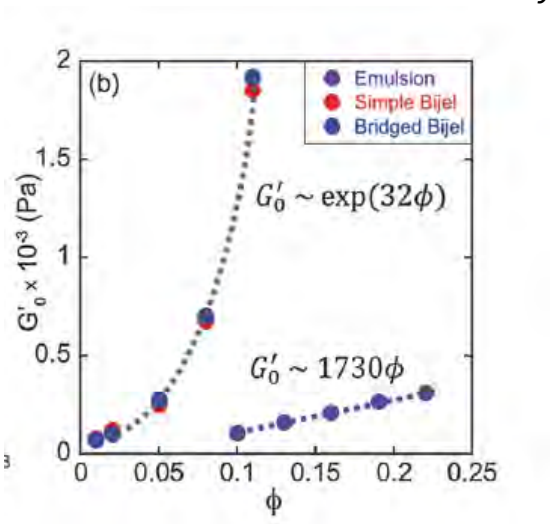
(and possible applications)

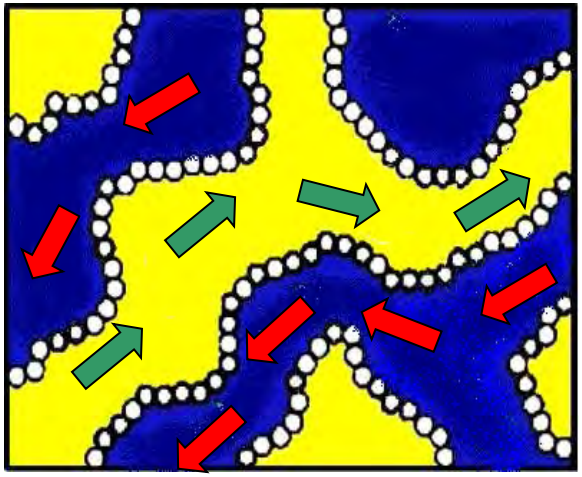




Capillary forces between particles

Sanz et al. *Phys. Rev. Lett.* **103**, 255502 2009





Viscoelastic

Lower Bound Yield Stress = (cylinder weight) / (cylinder area) = 600 Pa

Flow and large surface area

(purification of reactions, scaffold for tissue engineering)

Jessica A. Witt *et al. Soft Matter* DOI: 10.1039/c3sm00130j