Current problems in soft matter materials

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Current problems in soft matter physics

- No overarching unsolved problems – many important problems
- New discoveries in soft materials

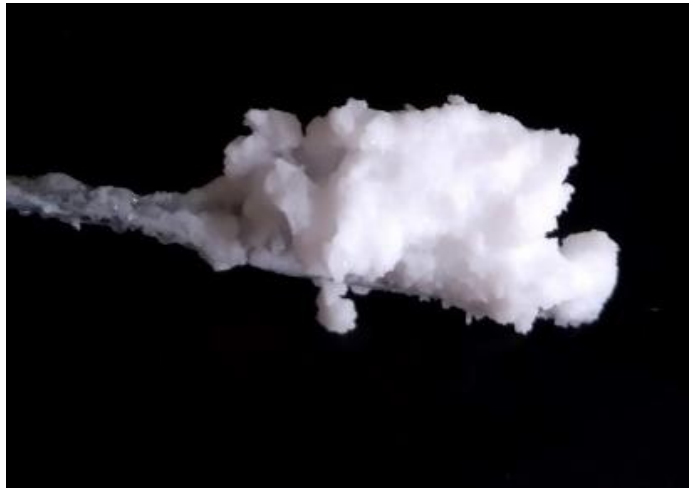
Oil and water do not mix

Add surfactant

Aioli

- Garlic
- Lemon juice
- Salt
- Olive oil

Water-in-oil emulsions with no surfactant

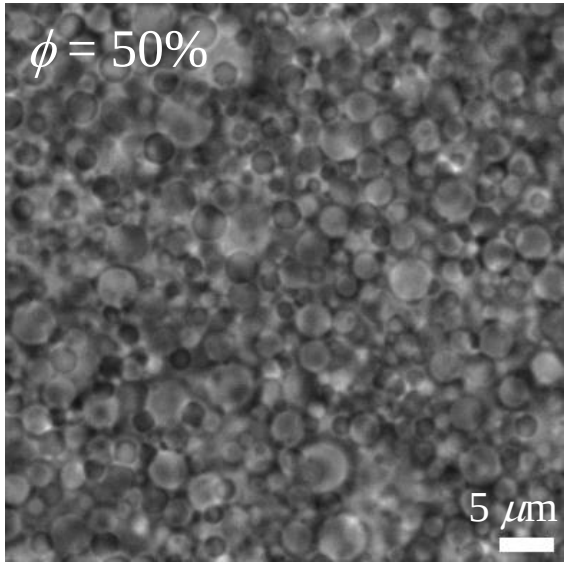


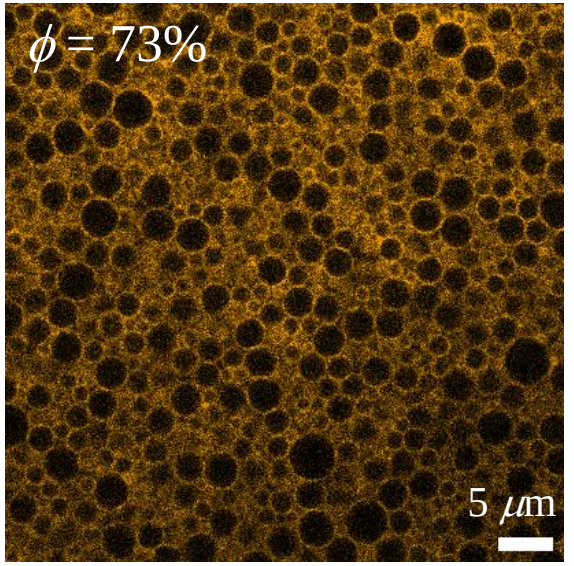
Glycerol in PDMS

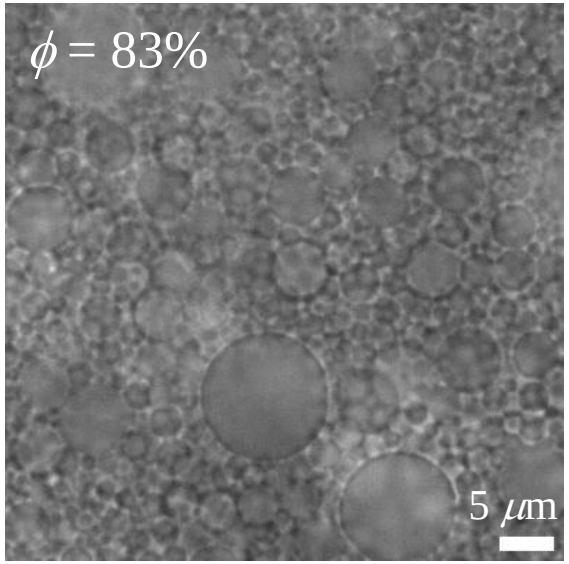
M_w = 5k

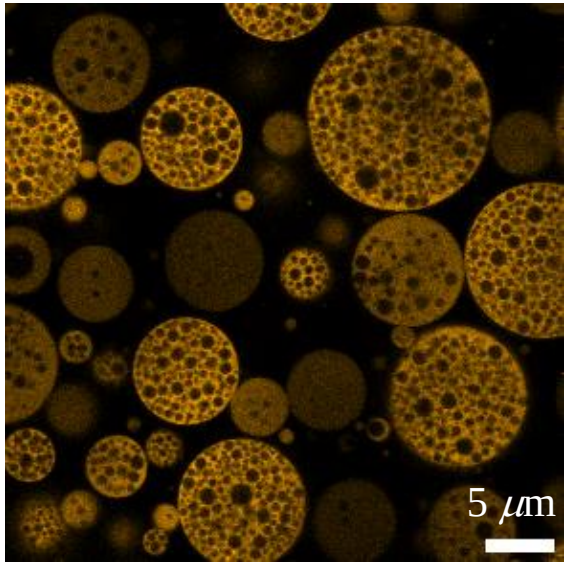
ϕ = 83%

No surfactant whatsoever

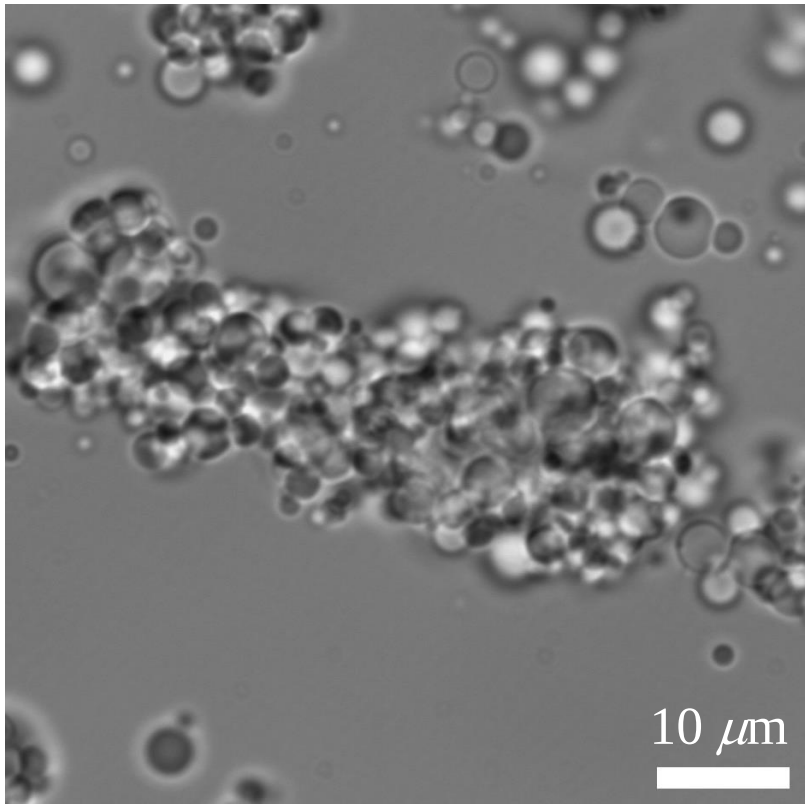




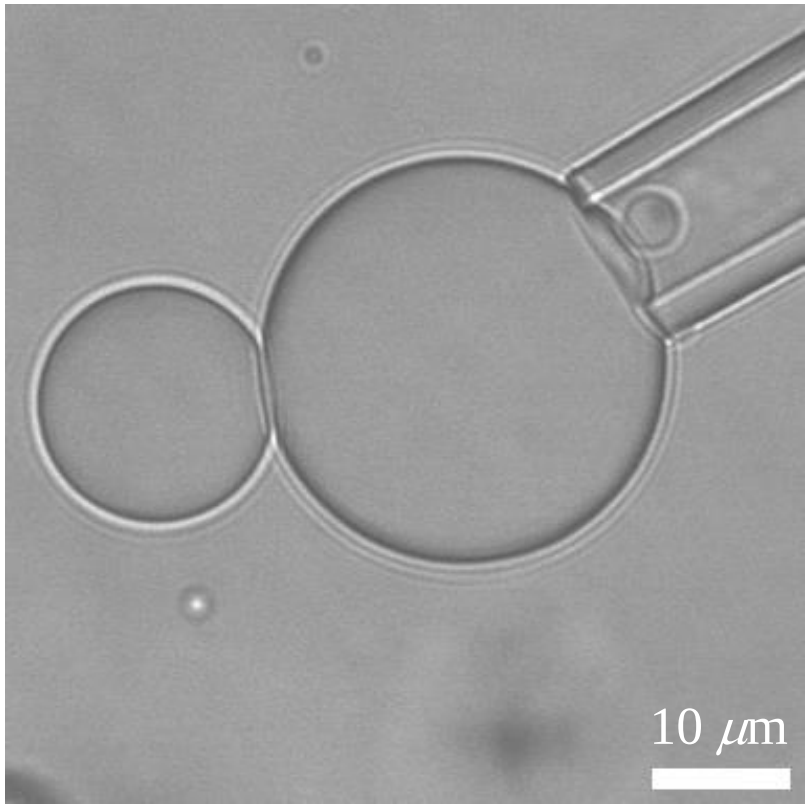




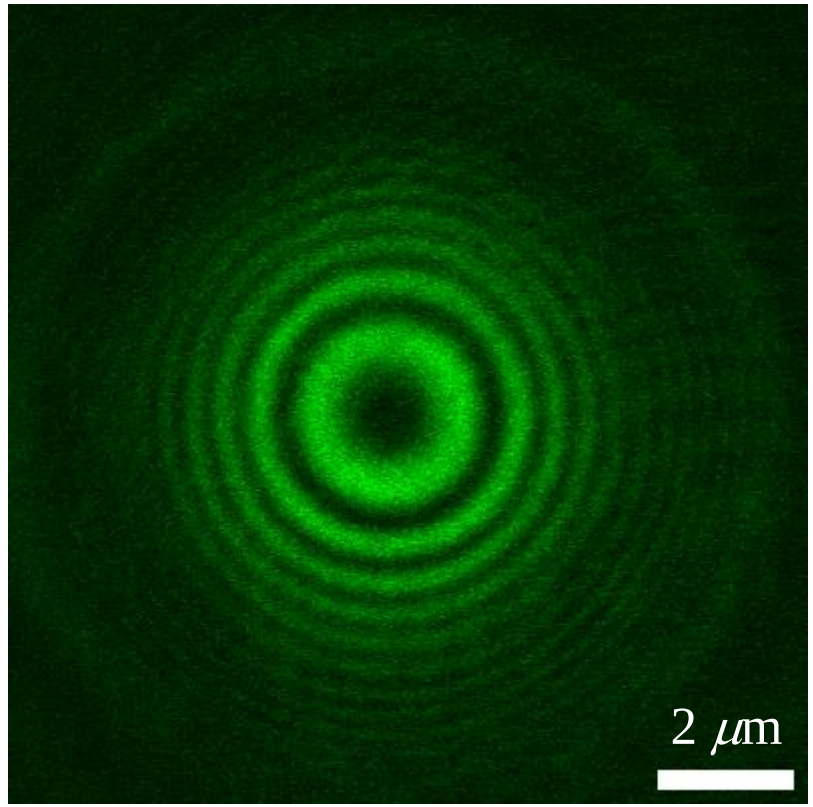
Drops are adhesive



Clusters of
adhesive drops

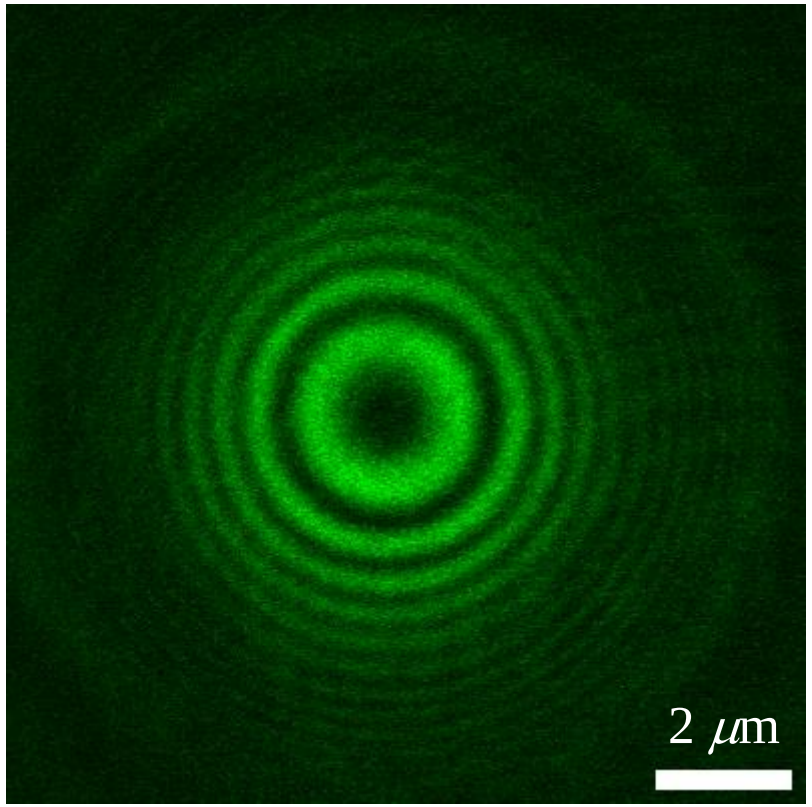


Micropipette aspiration
of pair of drops

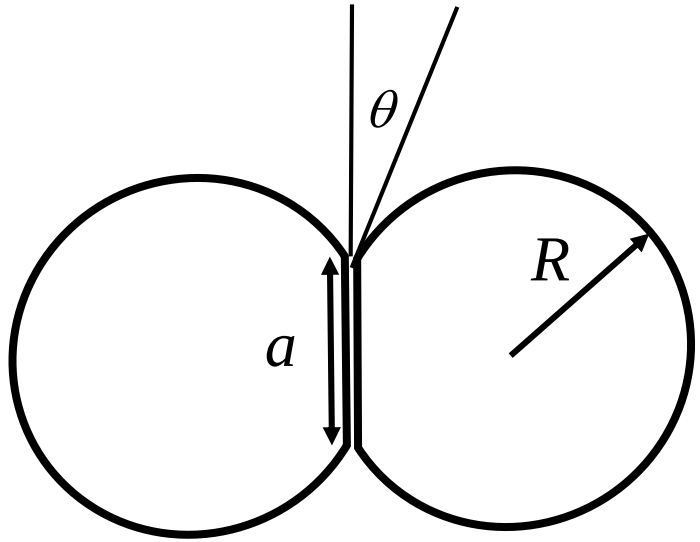


$R \sim 25\ \mu$m

Measure adhesive energy



$R \sim 25\ \mu\text{m}$



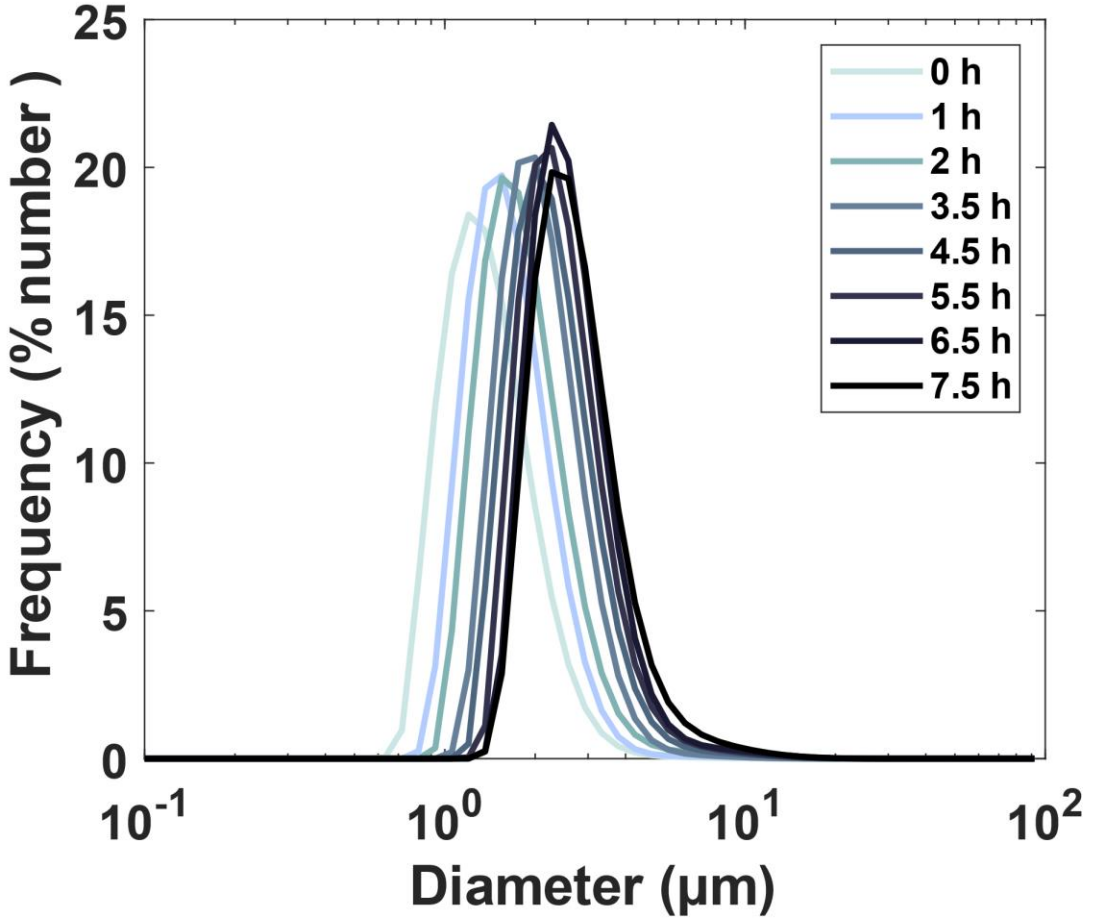
$a \sim 0.7\ \mu\text{m}$

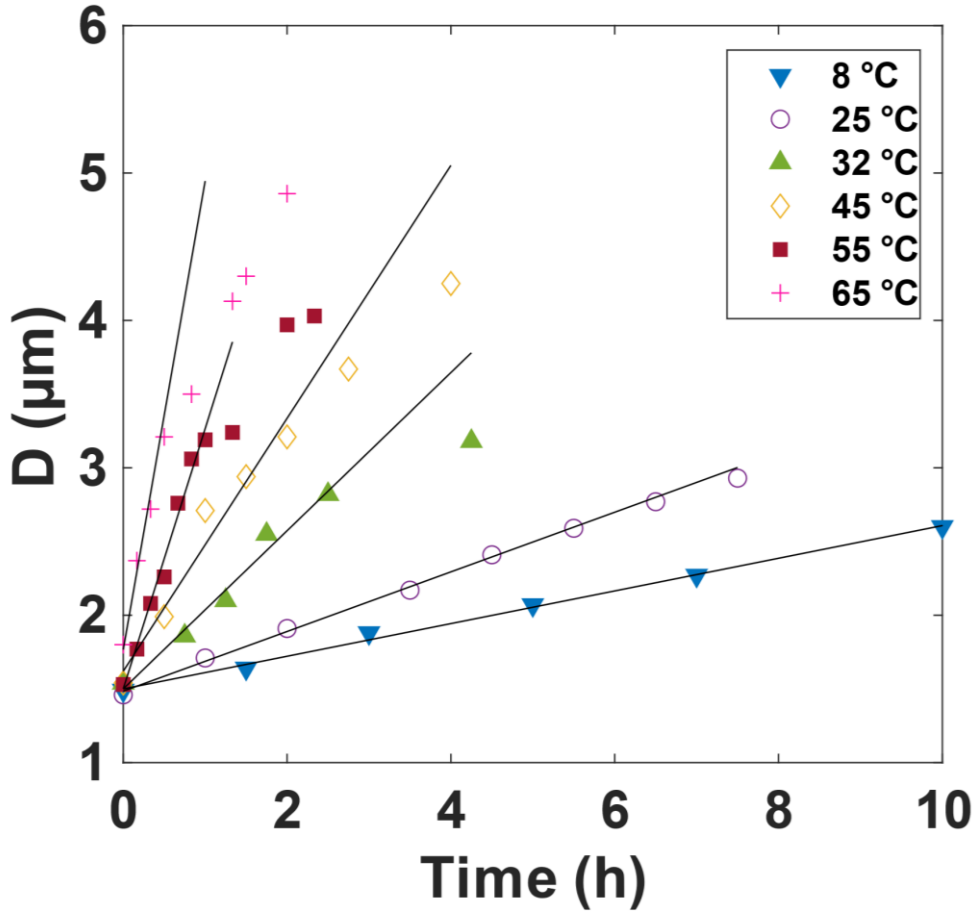
$\theta = 2^\circ$

$$\varepsilon = 2\gamma\left(1-\cos\theta\right)$$

Attractive energy: $\varepsilon a^2 \sim 10^4\ k_B T$

Coalescence of drops

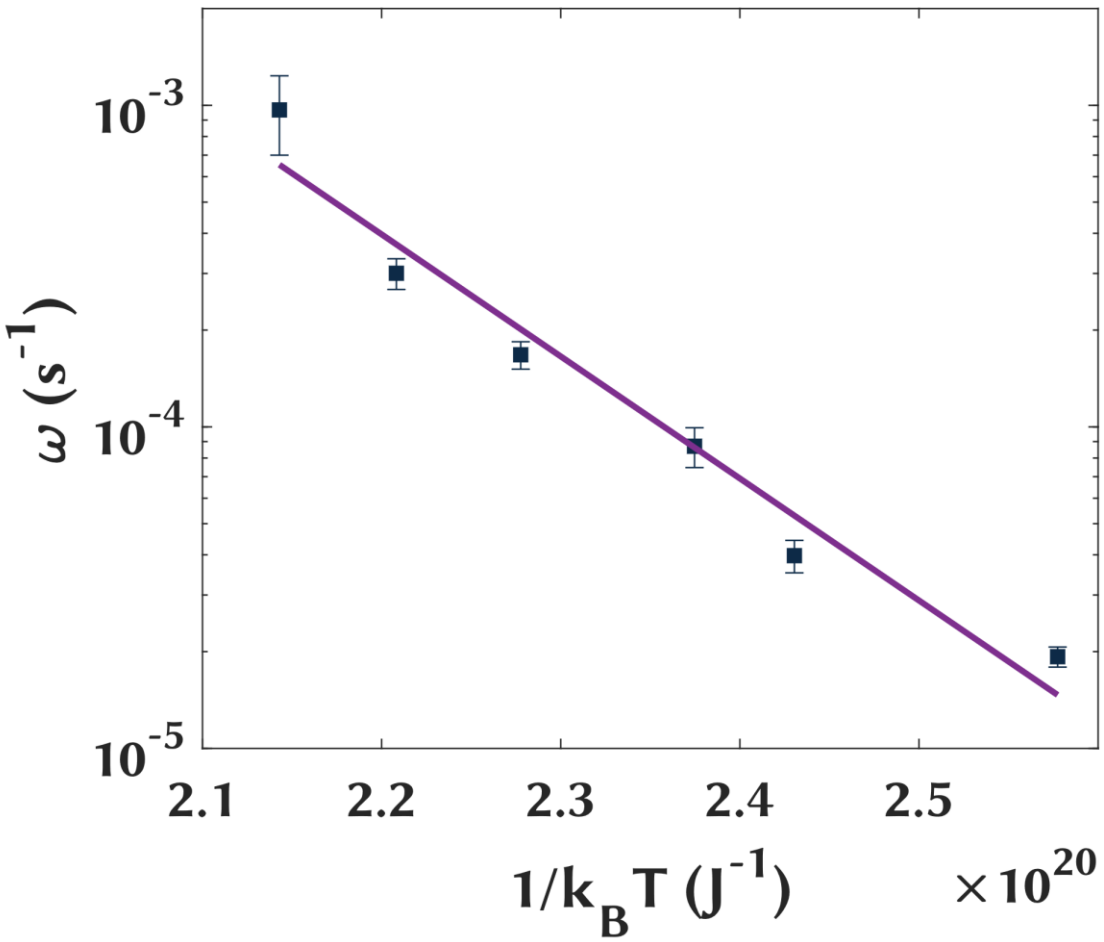




Glycerol in PDMS

ϕ = 76%

Coalescence is activated



Arrhenius behavior

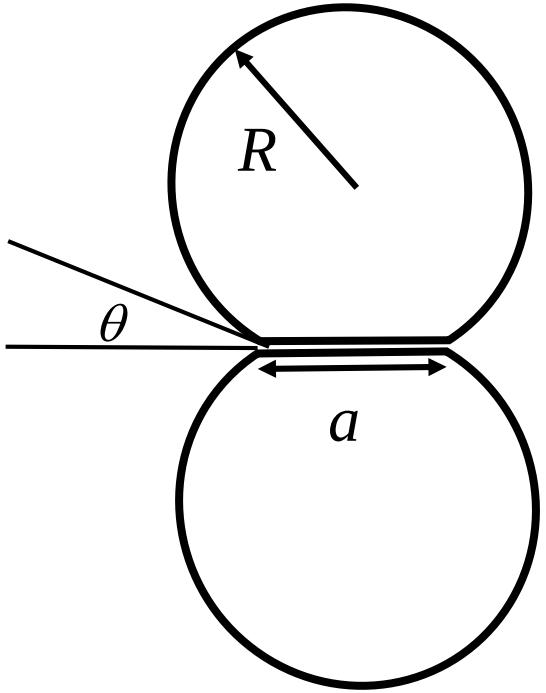
$$\omega = \omega_0 e^{(-E_a/k_BT)}$$

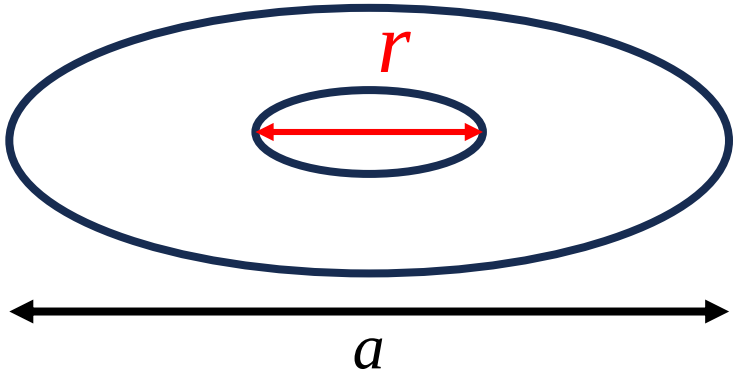
$E_a \sim 20\ k_BT$

By comparison, surfactant stabilizes emulsion:

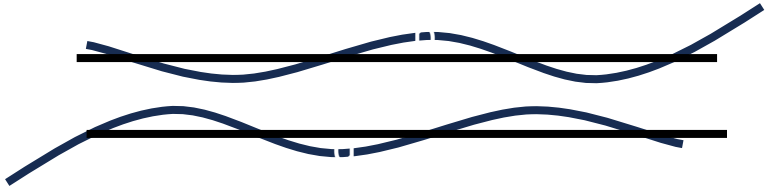
$E_a \sim 30\ k_BT$

Drop coalescence depends on nucleation of hole

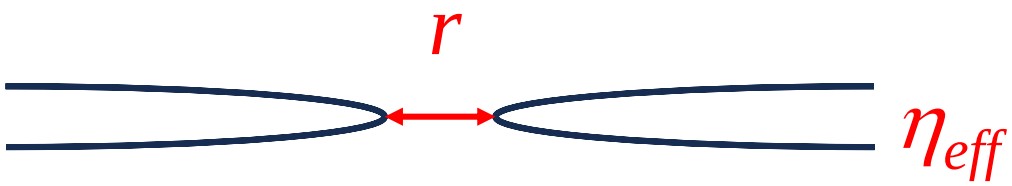




Nucleate hole in interface

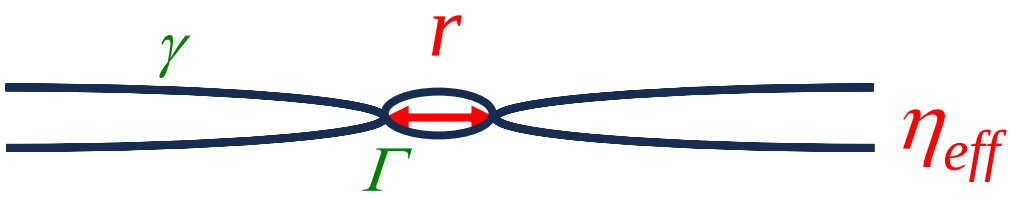


Low surface tension
Fluctuations cause hole



Nucleate hole by
overcoming high curvature

Drop coalescence depends on nucleation of hole



Balance surface tension and line tension

$$E(r) = -2\pi r^2\gamma + 2\pi r\Gamma$$

Minimize energy

$$\Gamma = 2\pi r^*\gamma$$

$$r^* = (E_a/2\pi\gamma)^{1/2}$$

$r^* \sim 0.7$ nm

Nucleation rate of a hole:
Balance surface tension and viscosity

$$k_0 \sim \frac{\gamma}{\eta r^*}$$

$\omega_0 = 10^5\ s^{-1}$

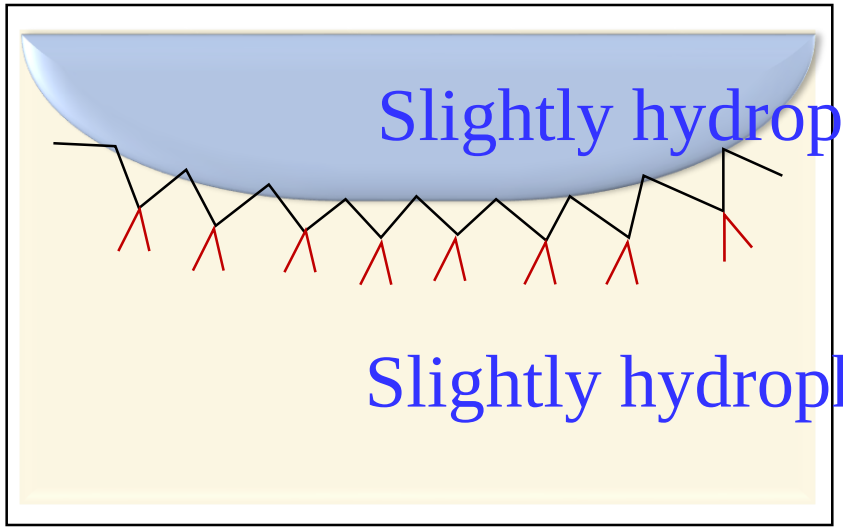
$$\omega_0 \sim k_0 \frac{s}{r^{*2}}$$

$s = za^2/R^2$

$\eta_{eff} \sim 10^7\,\eta_0$

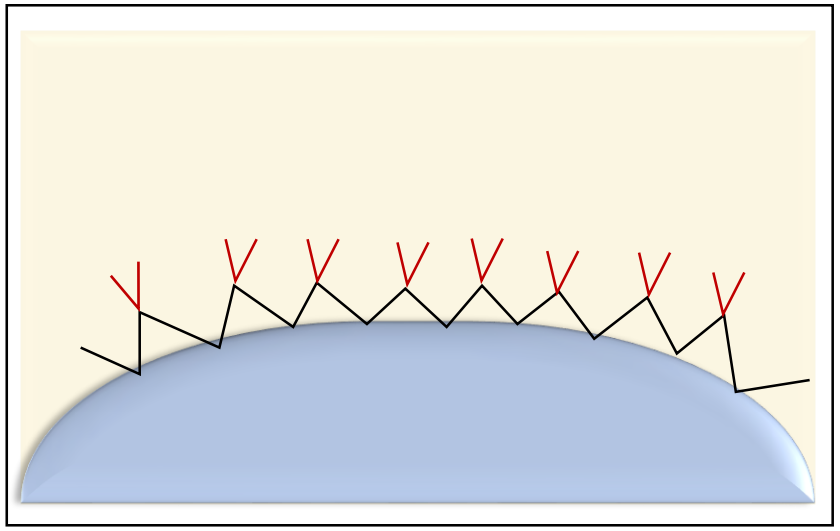
Stability due to a large thin film viscosity

Origin of adhesive interaction

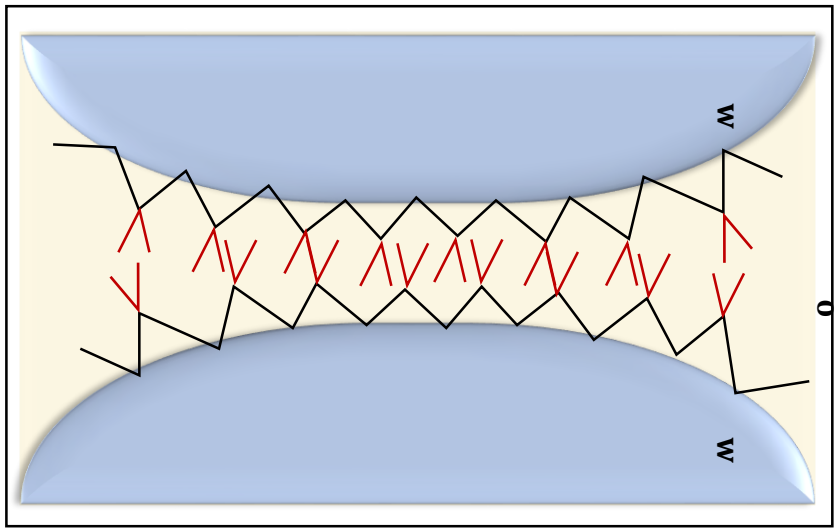


Slightly hydrophilic

Slightly hydrophobic

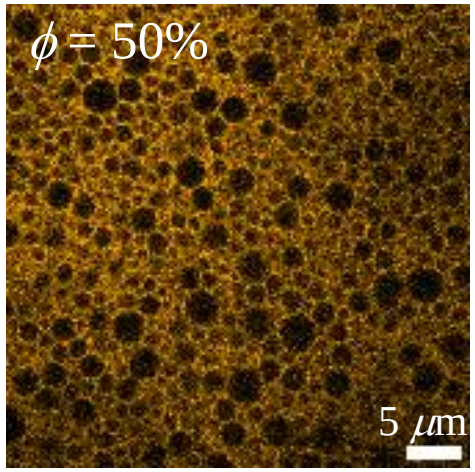


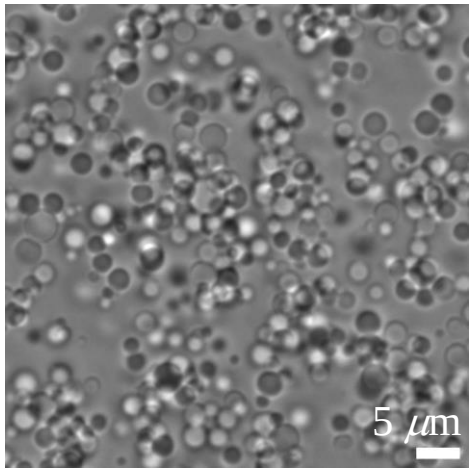
Slightly hydrophobic interfaces attract

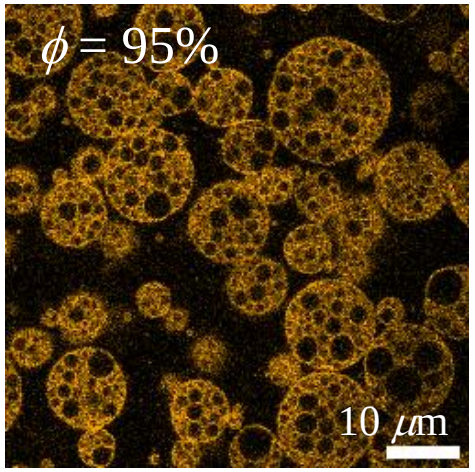


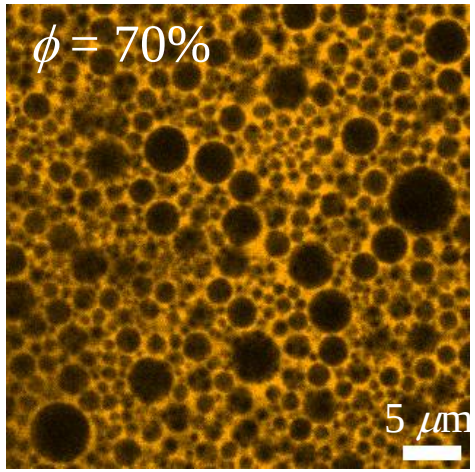
Very thin film separates interfaces

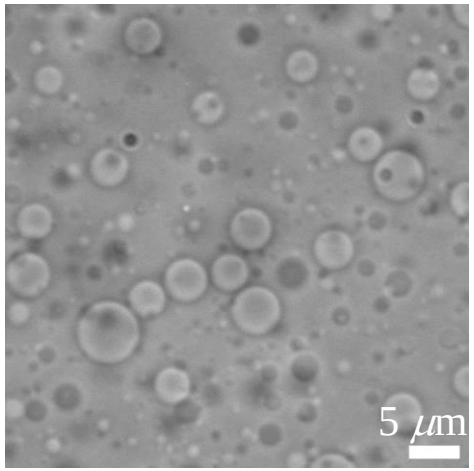
Many oils can be used

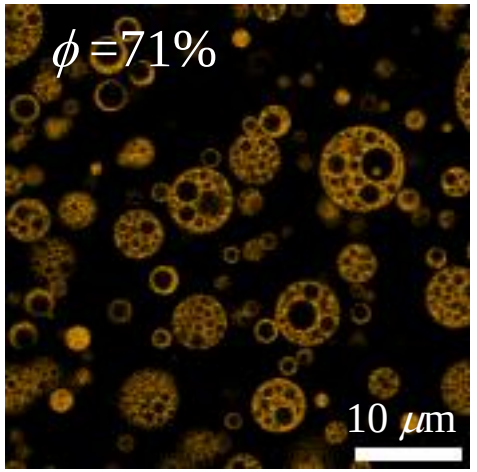












Hydroxy-terminated PDMS oil

Template for new materials

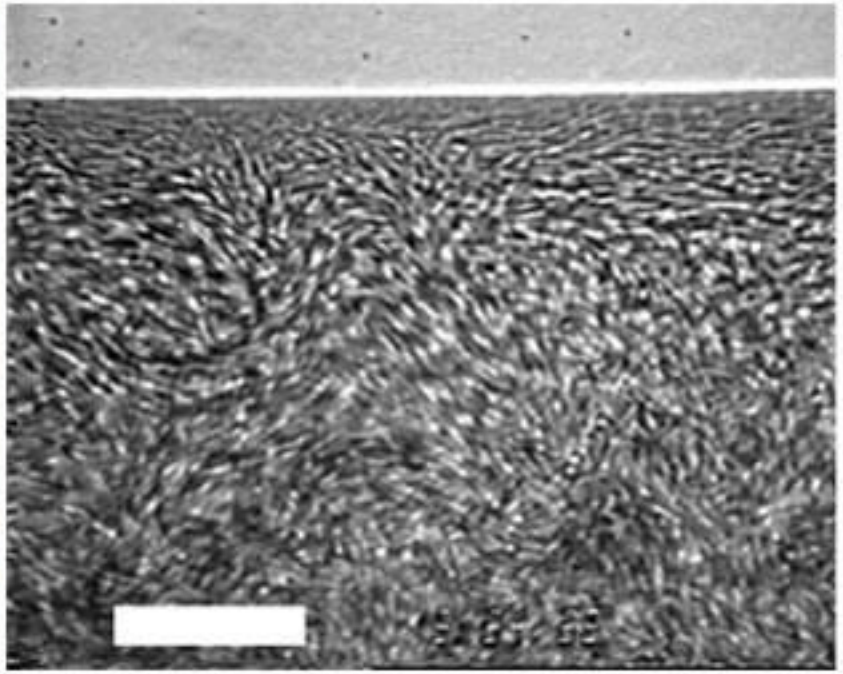
acrylated vegetable oil

Current problems in soft matter physics

- No overarching unsolved problems – many important problems
- New discoveries in soft materials
- Active materials

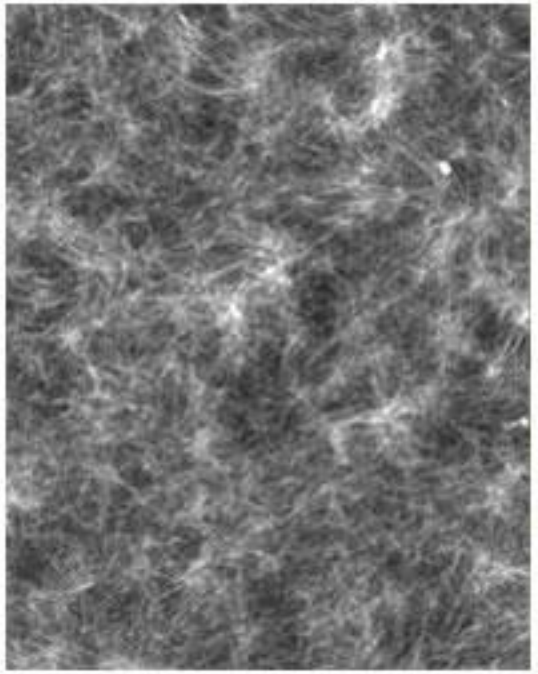
Soft active matter

Bird flocking - Toner



Concentrated swimming bacteria

Hagan group website, Brandeis Unversity



Microtubules on a bed of molecular motors - Dogic

Non-equilibrium behavior

New phenomena

Trending topics in soft matter

- Active matter
- Jamming
- Granular materials

Current problems in soft matter physics

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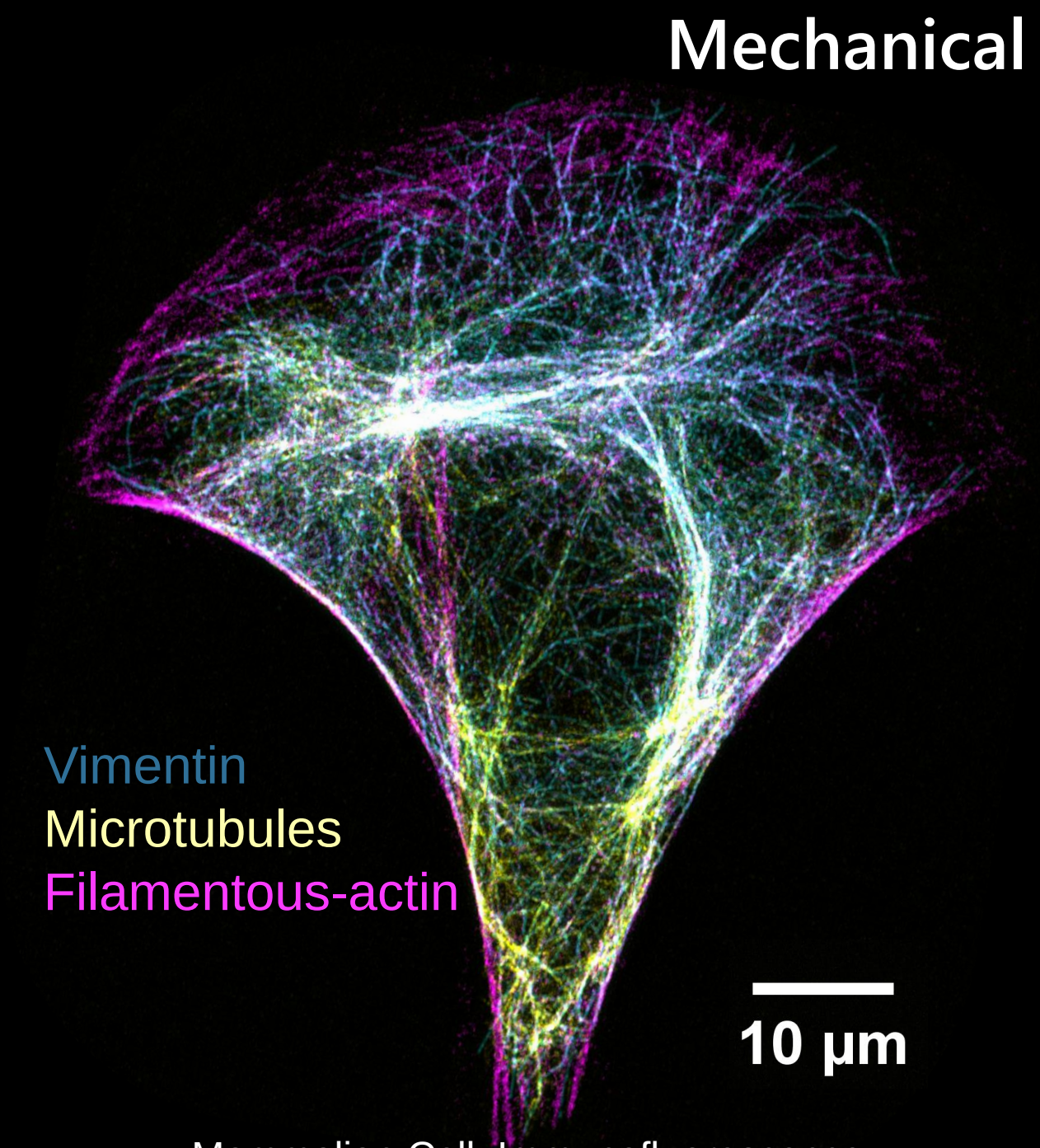
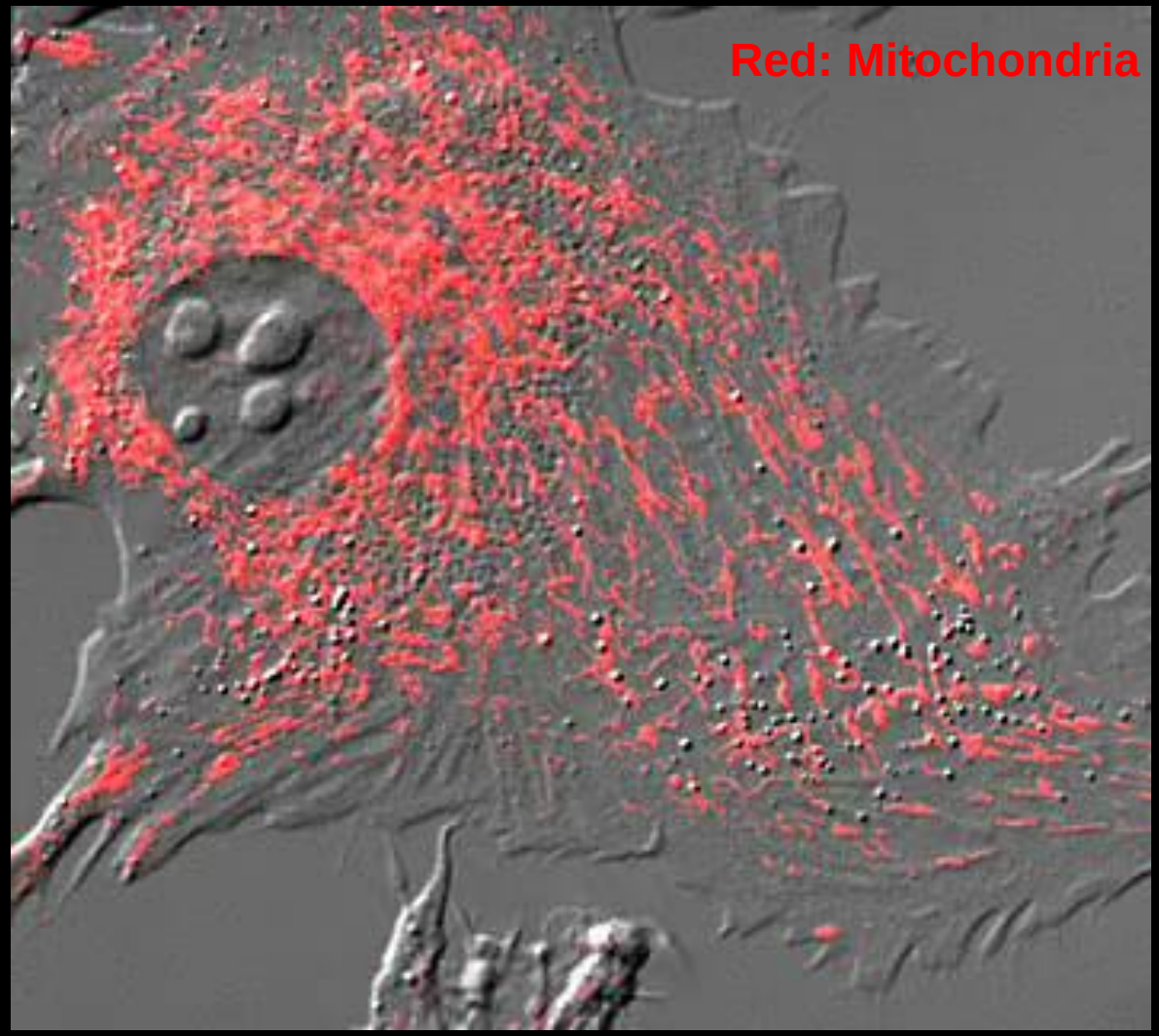
- New discoveries in soft materials
- Active materials
- Biological materials

Mechanical View of Cell



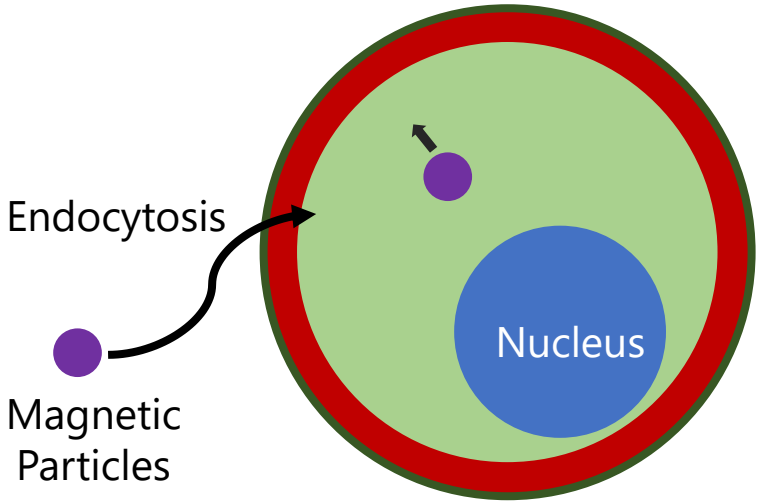
Mammalian Cell, Immunofluorescence

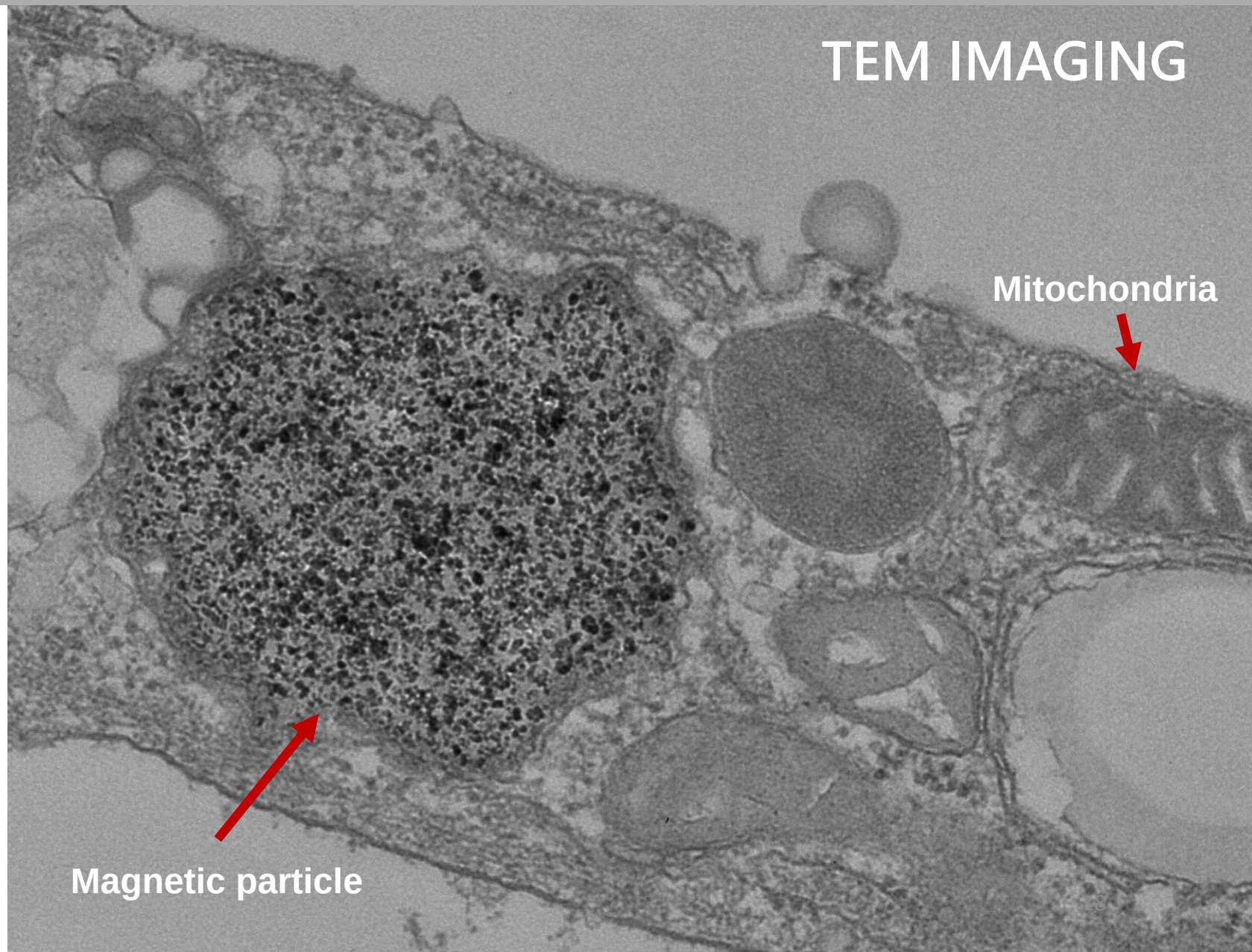


Olympus Science

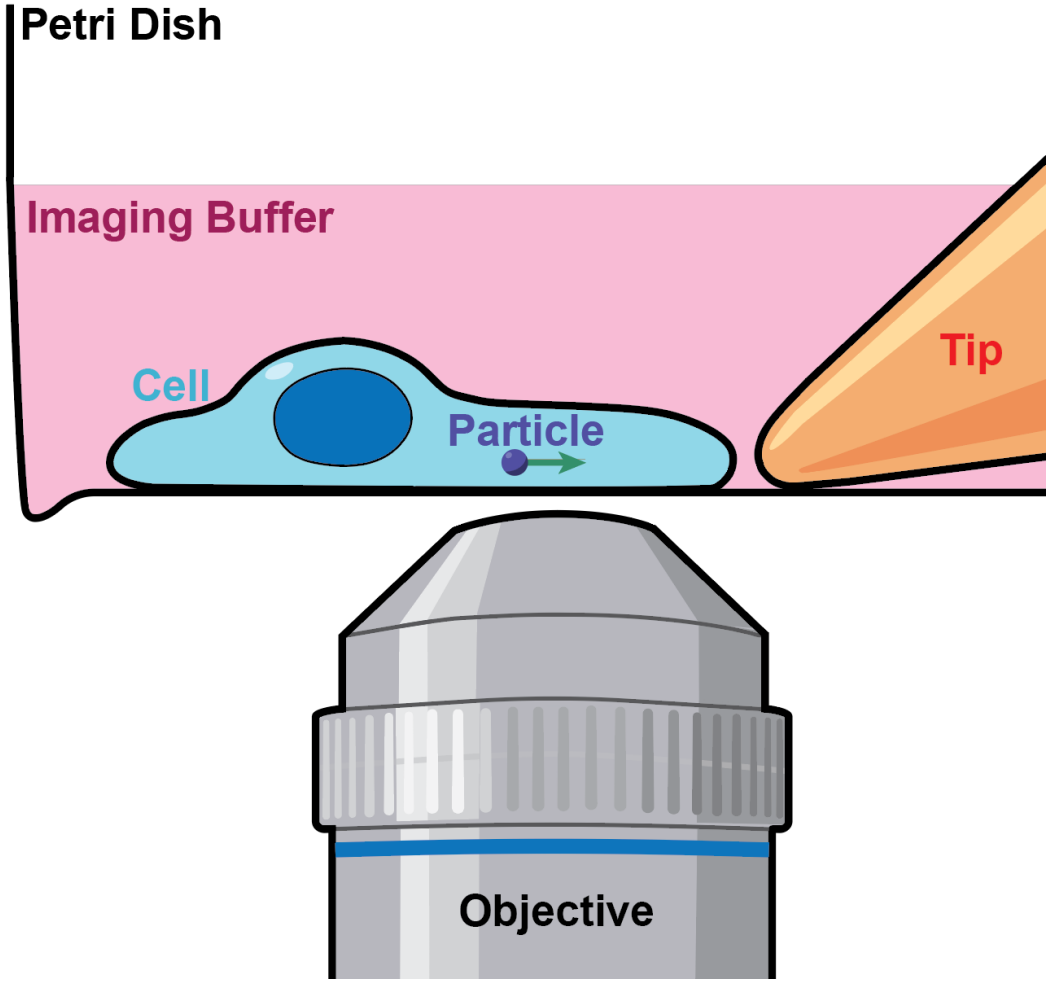
Particle transport in Cell

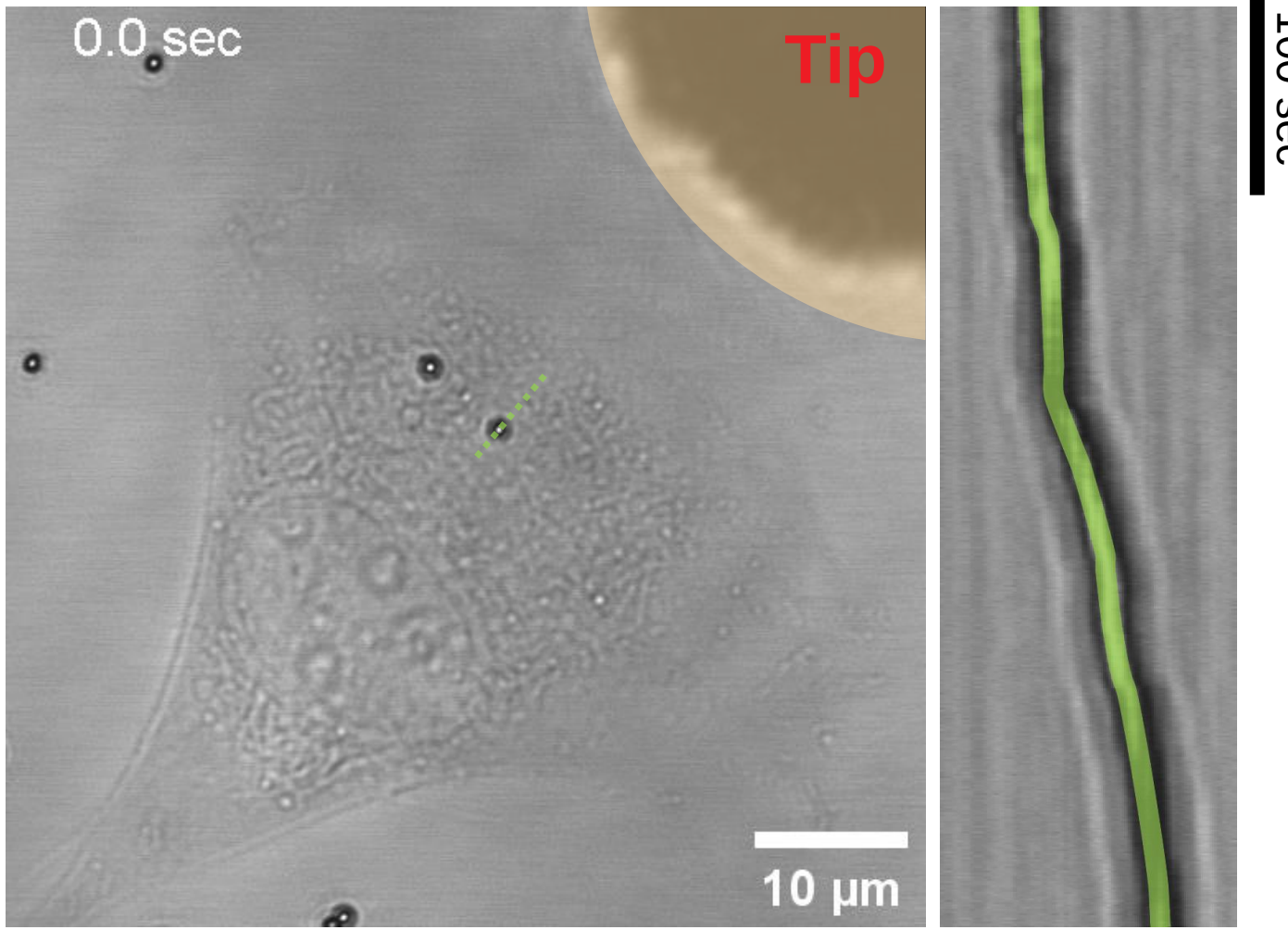
Experiment: Magnetic particles



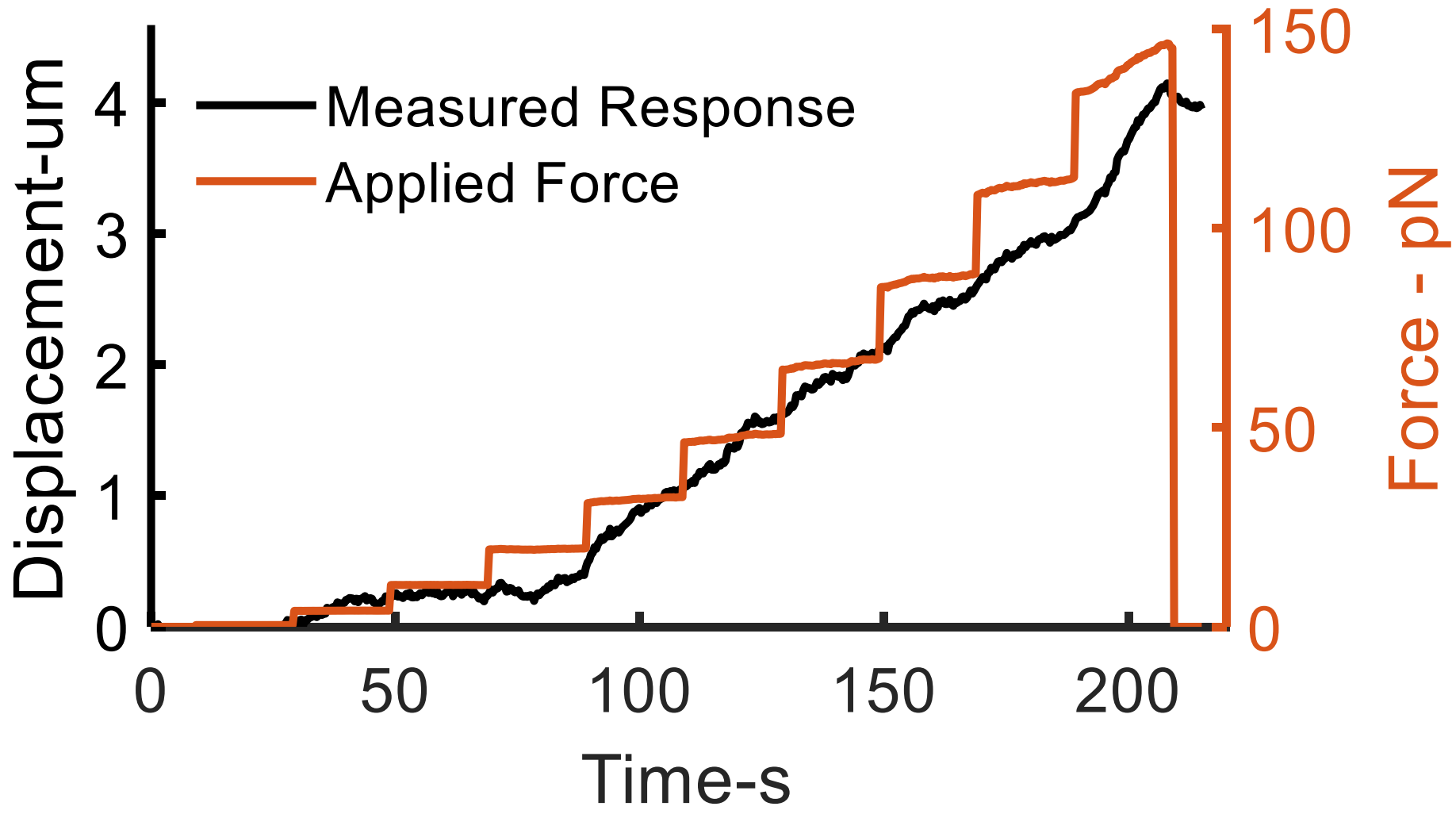


Experiment: Magnetic tweezers





Force and Directional Displacement over Time



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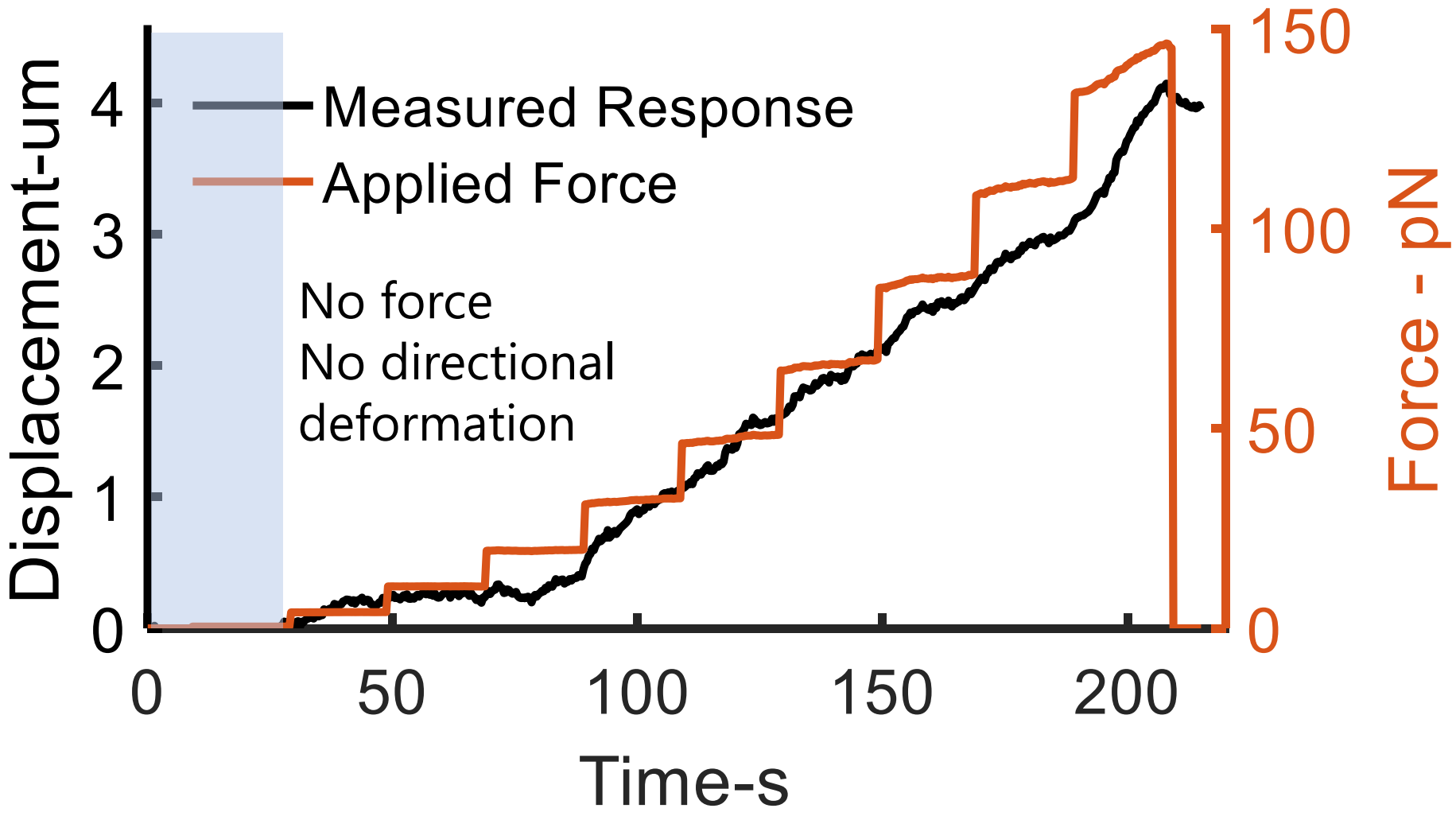

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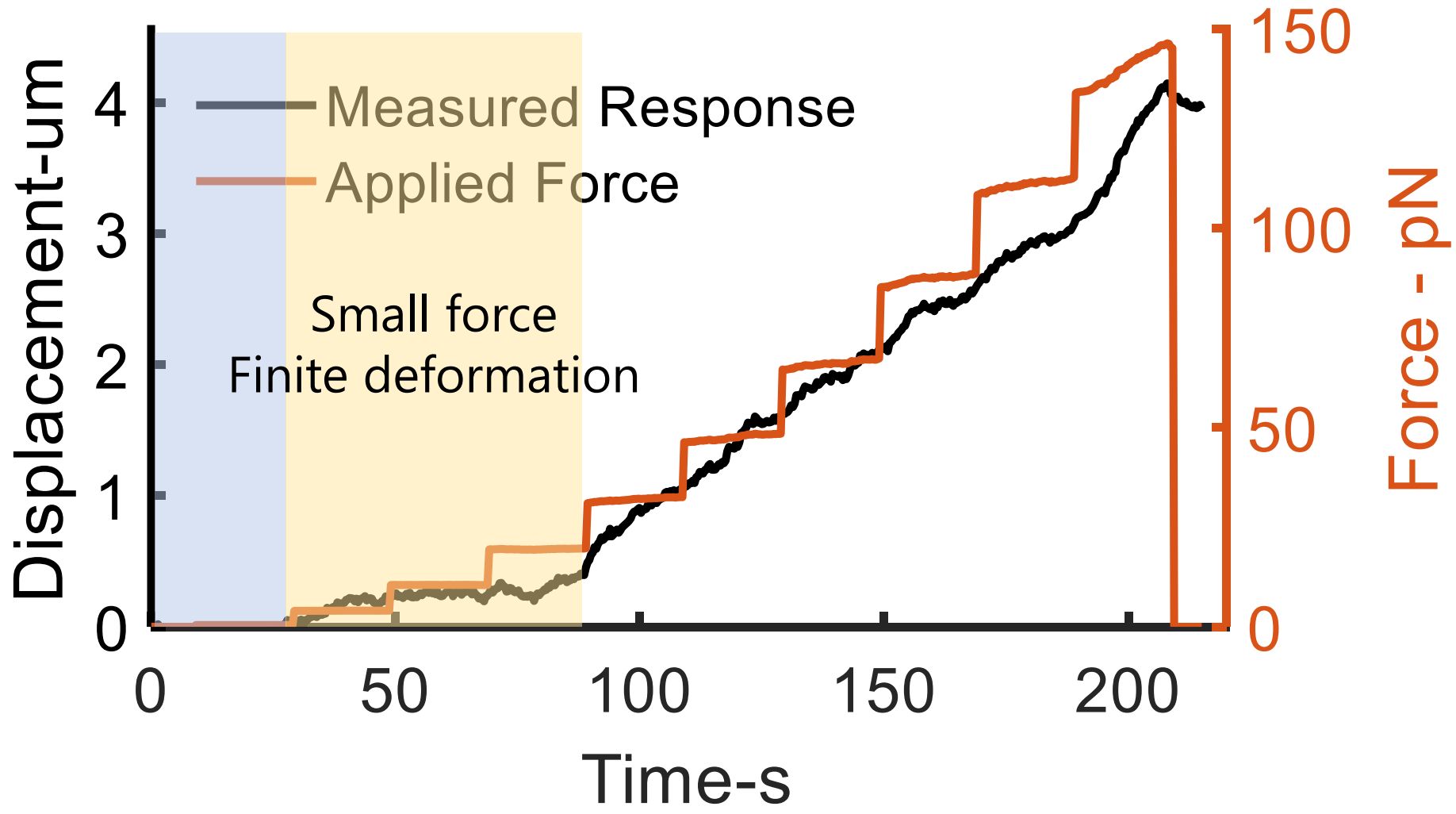

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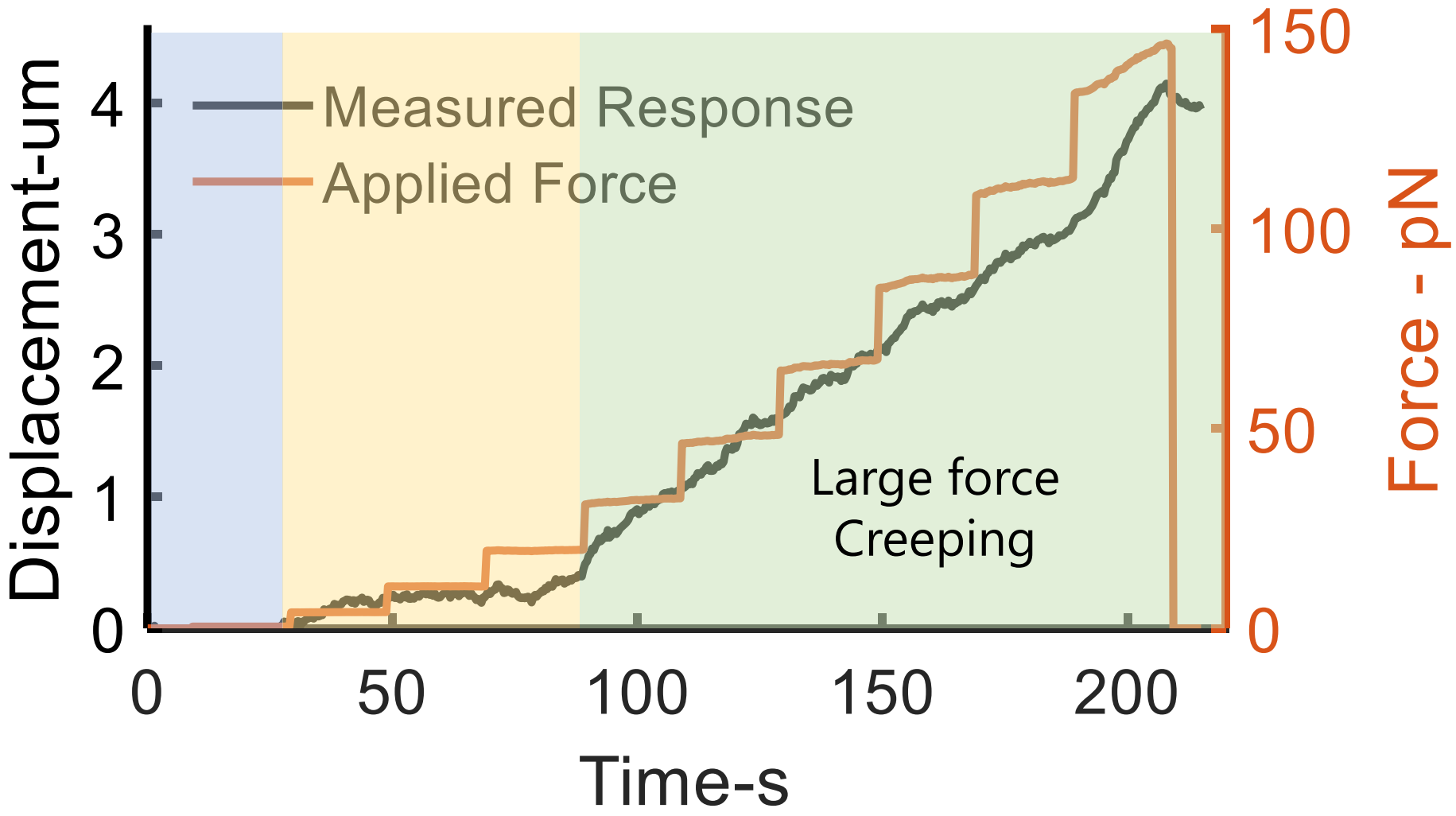
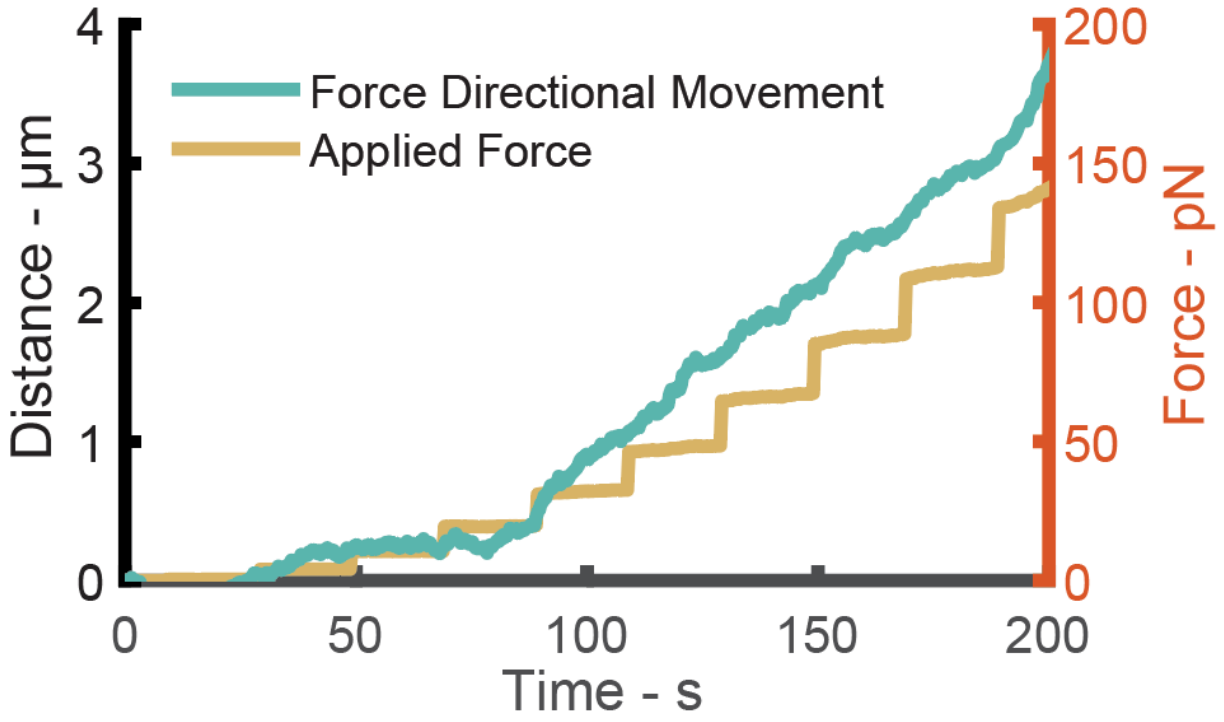
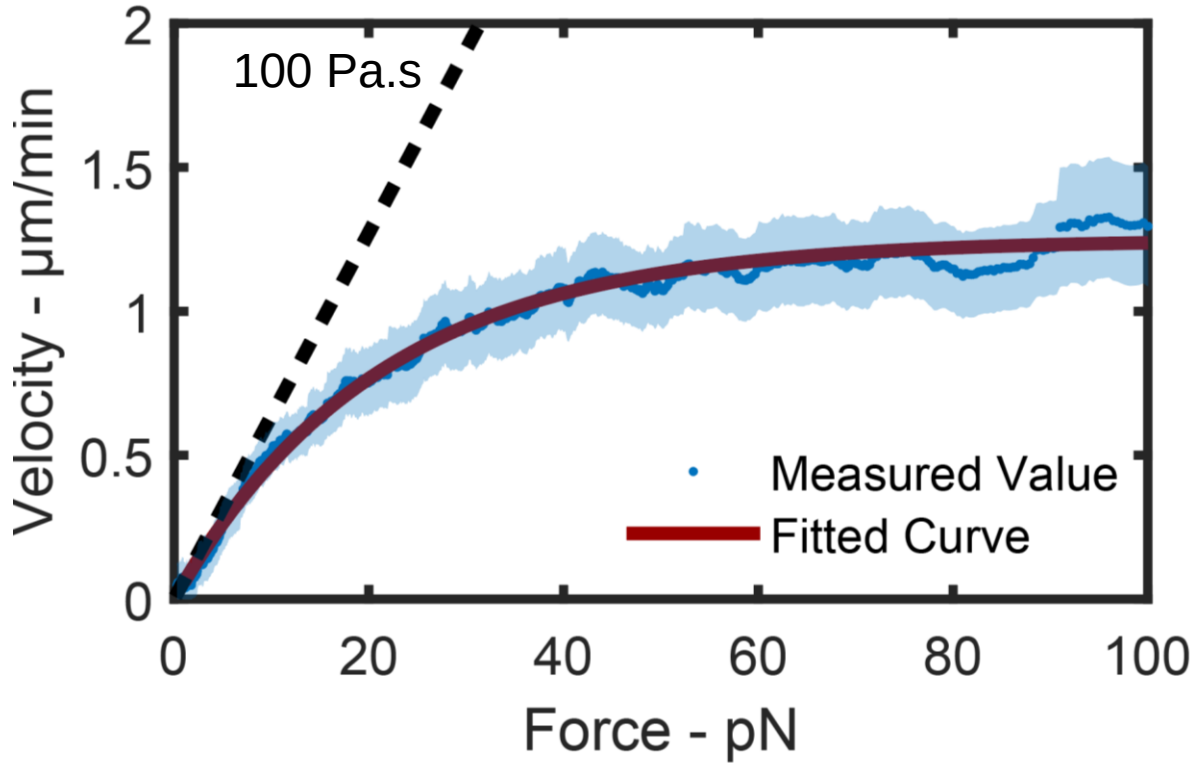


Velocity – force relationship



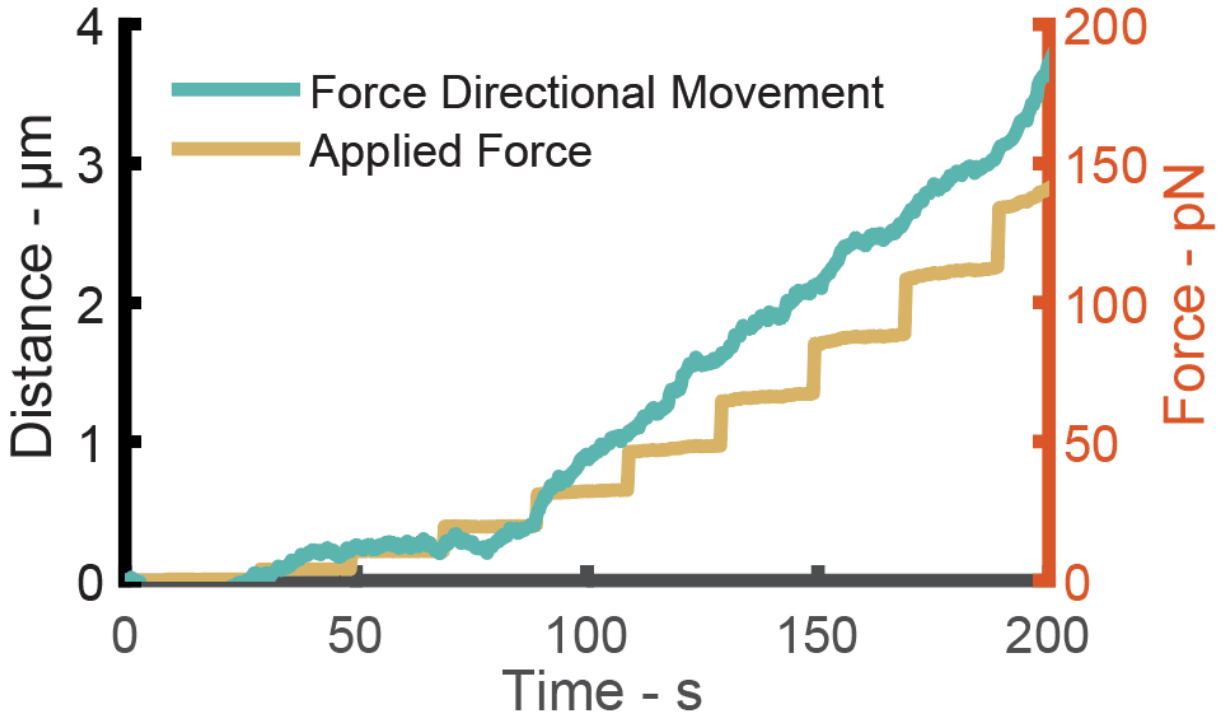
New way to plot data



Not a liquid: velocity not dependent on force

Not a solid: displacement not dependent on force

New constitutive relation for cell rheology



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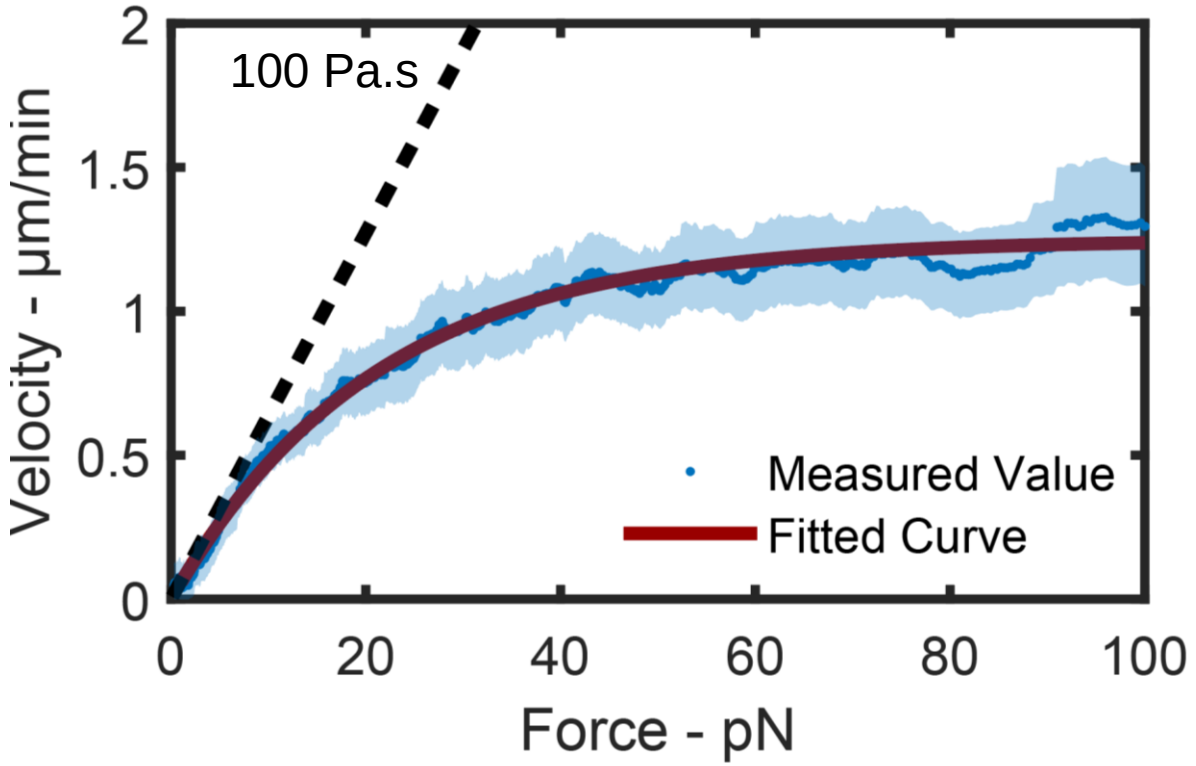
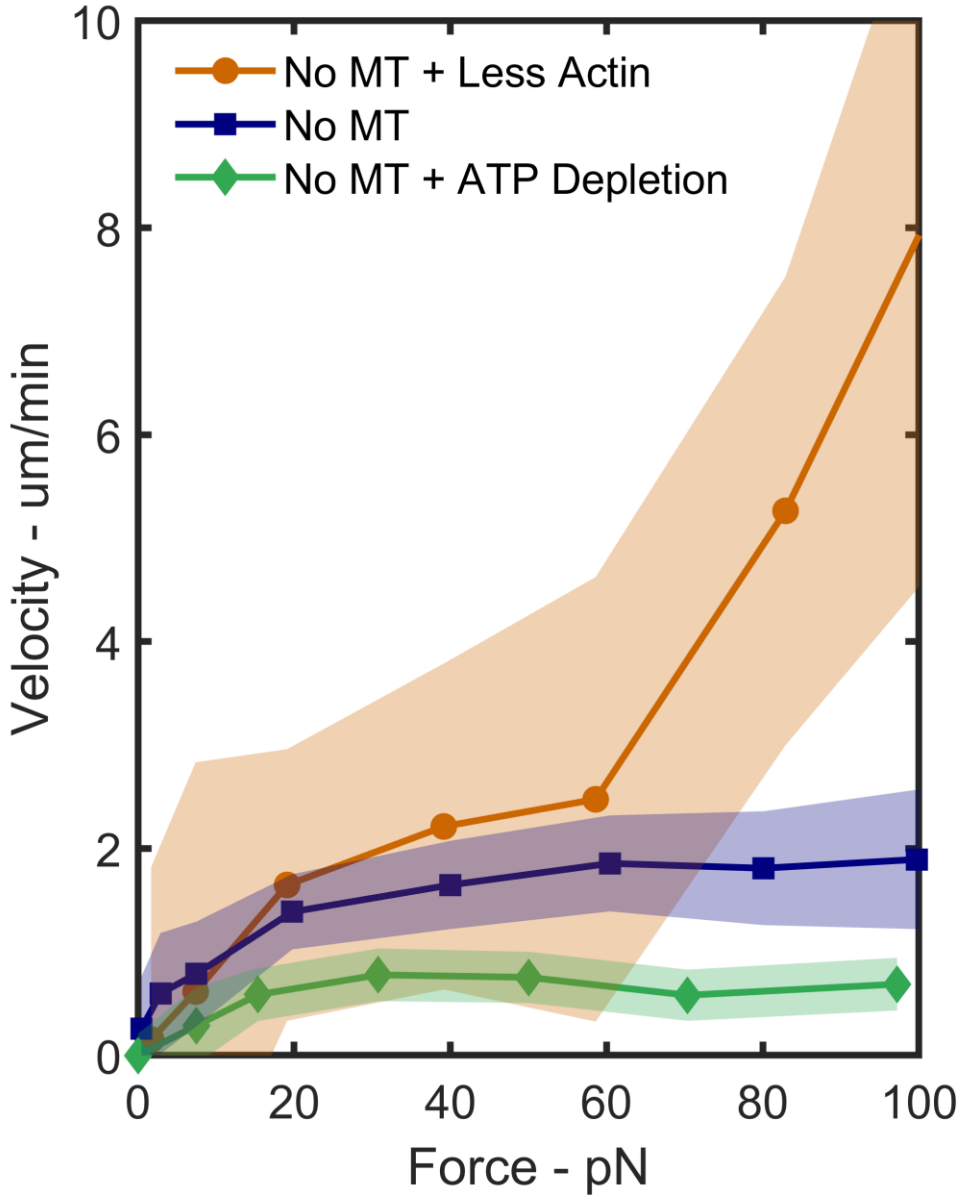
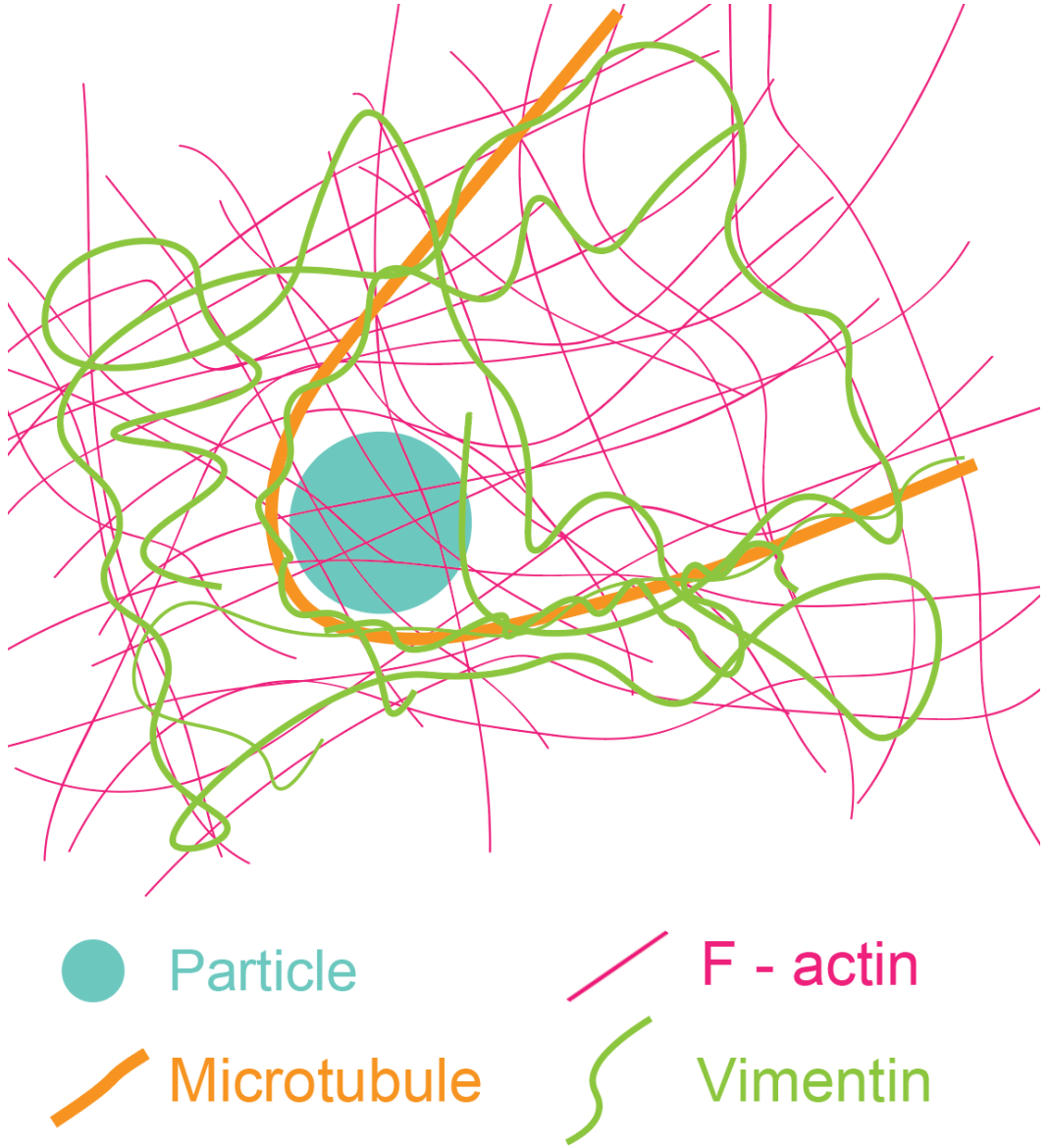


Use this as a probe of cell rheology

Interpenetrating networks in cytoskeleton

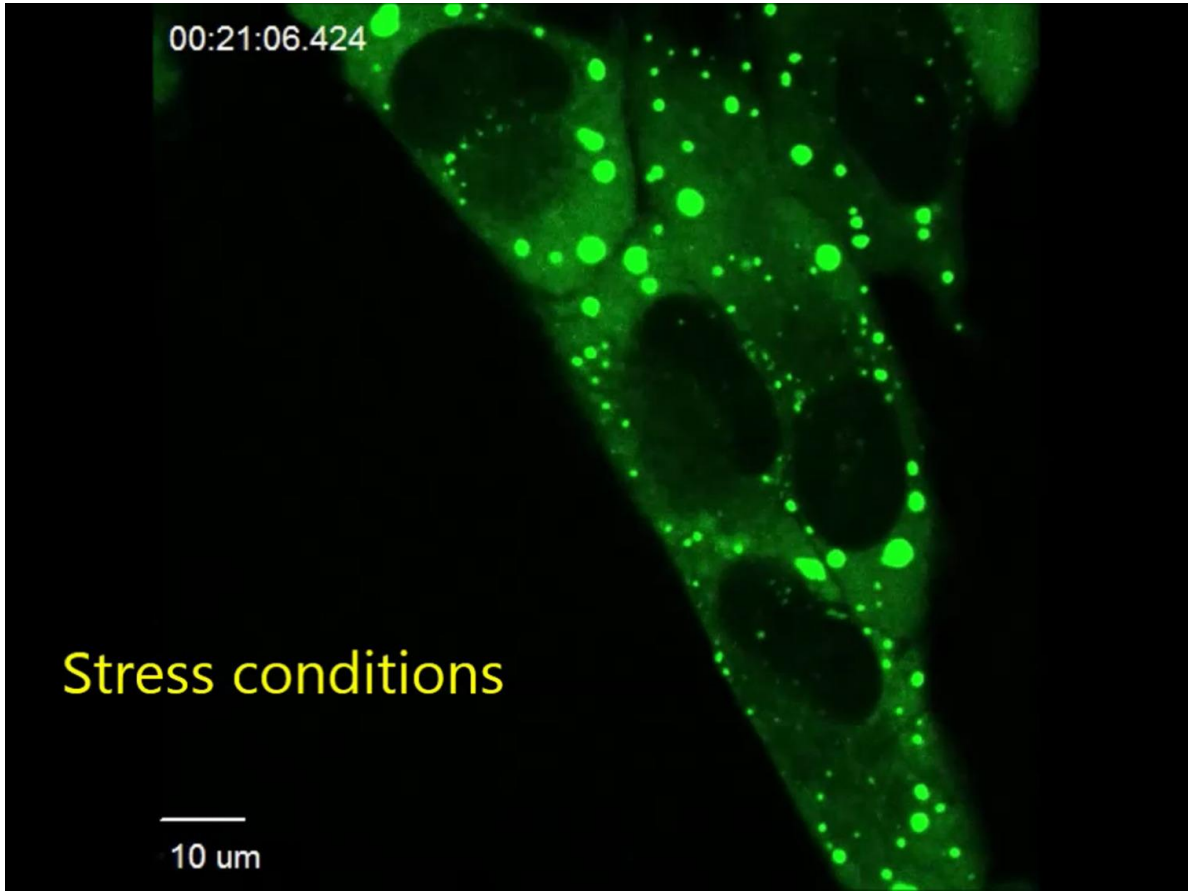




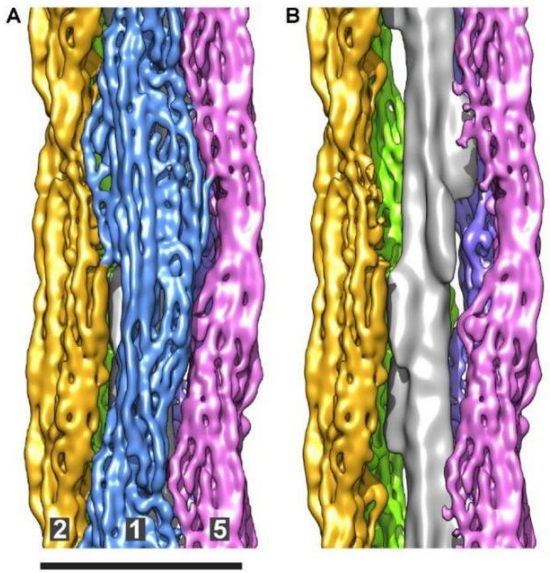
Proteins can undergo phase separation

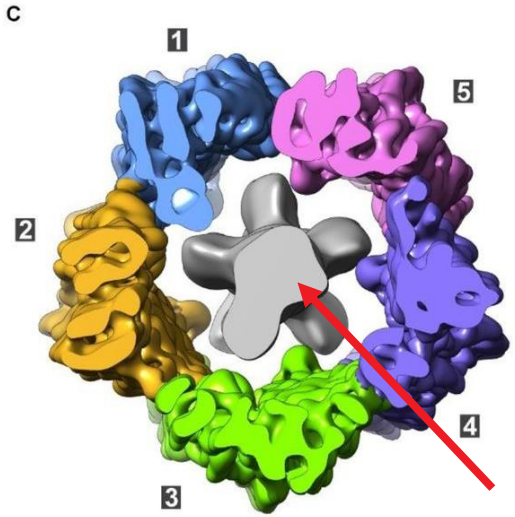
Liquid-liquid phase separation

- Liquid protein condensates
- Can be reconstituted *in vitro*
- Discovered by Cliff Brangwynne

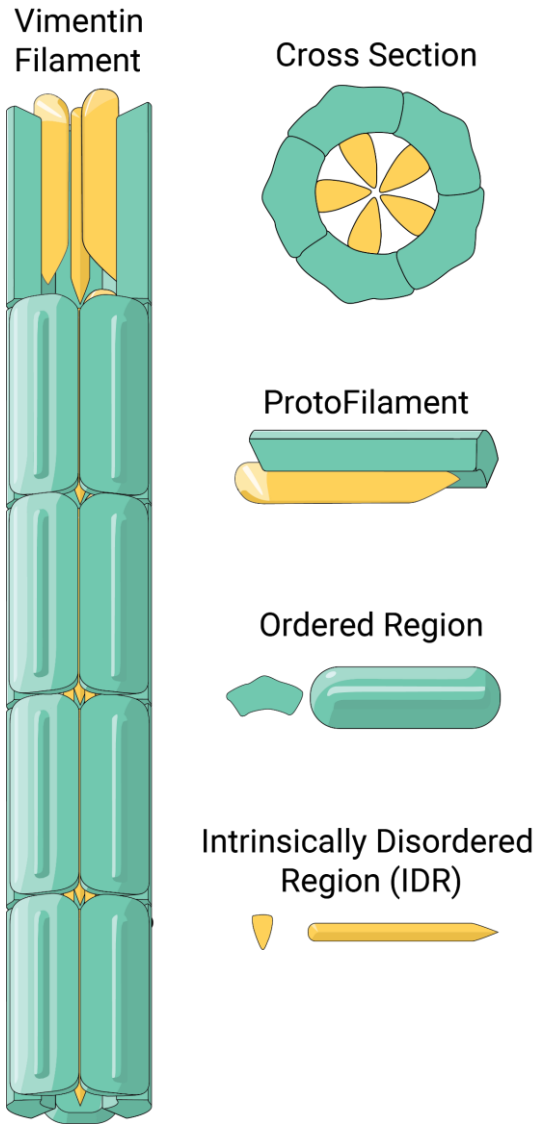


Molecular Structure of Vimentin Intermediate Filaments





IDRs in core



Eibauer, Matthias, et al. "Vimentin filaments integrate low complexity domains in a highly complex helical structure." *bioRxiv* (2023): 2023-05.

Self-assembled surfactant structures

Amphiphilic Molecules
e.g. Lipid, Steroids, Copolymer,
Surfactant (Detergent)...

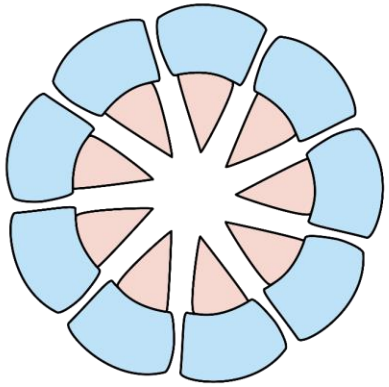
Hydrophilic Head

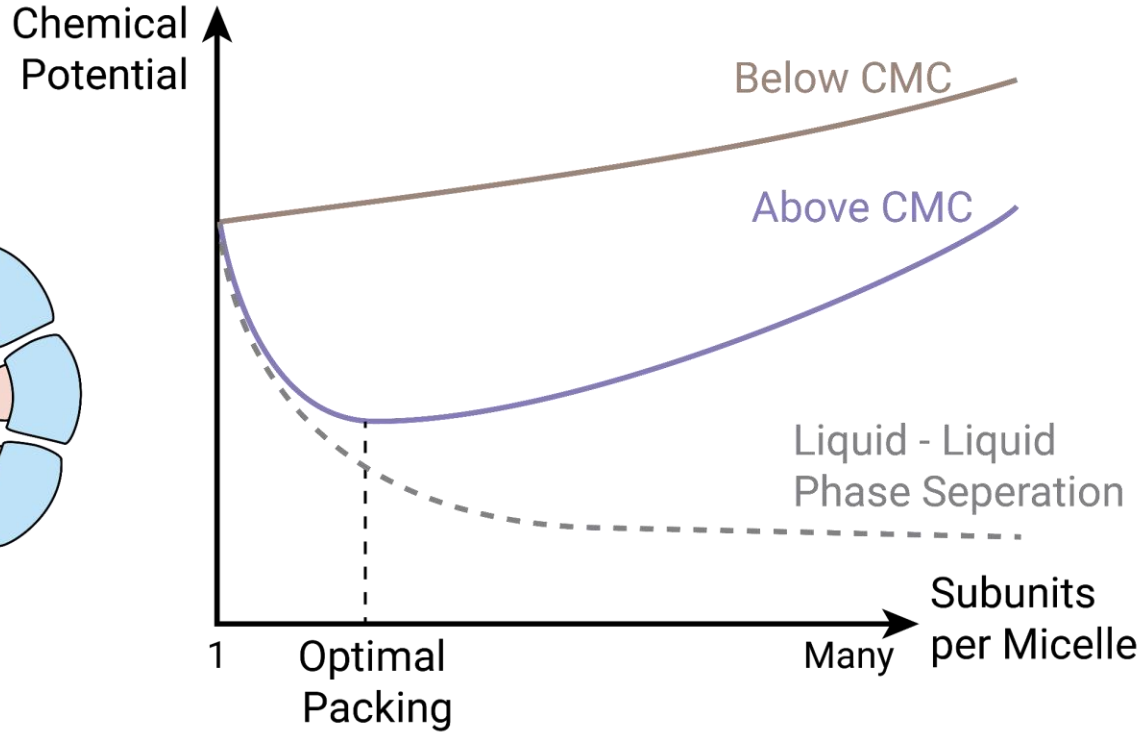
Hydrophobic Tail

Above Critical Micelle Concentration (CMC)

Self-Assemble

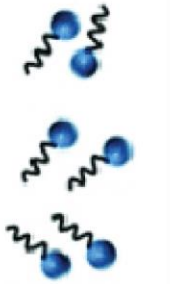
Micelle





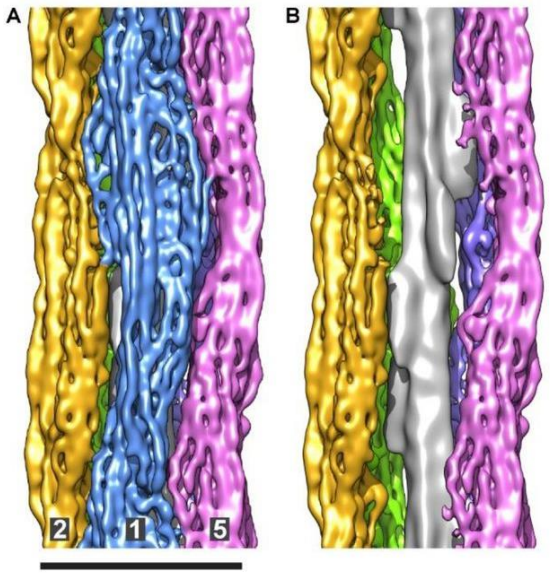
Delicated Phase Behavior bacause of the Amphiphilic Nature of the Moleculer

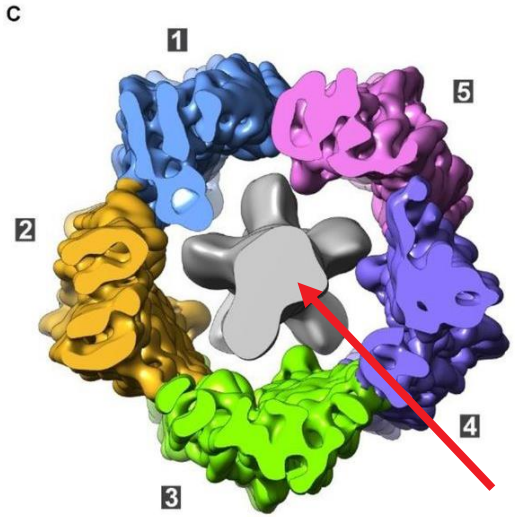
Free Molecule



I. Dierking, A. Neto, Crystals, July 2020 10(7)

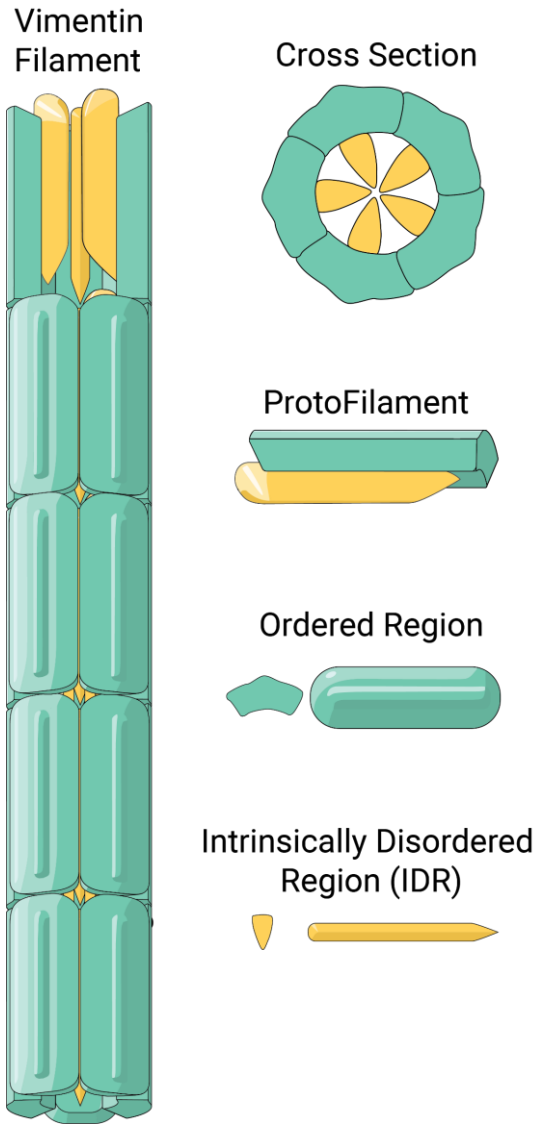
Are Vimentin Intermediate Filaments Worm-like Micelles?





IDRs in core

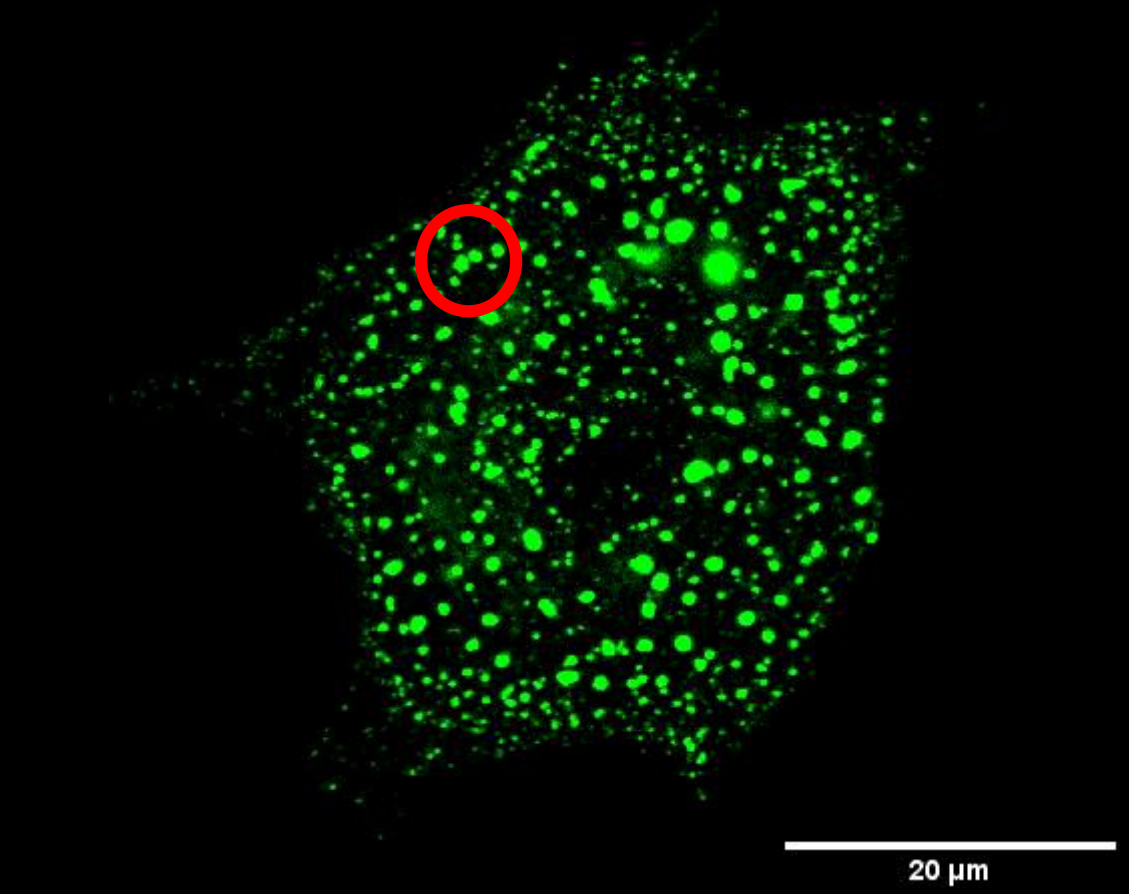
Eibauer, Matthias, et al. "Vimentin filaments integrate low complexity domains in a highly complex helical structure." *bioRxiv* (2023): 2023-05.

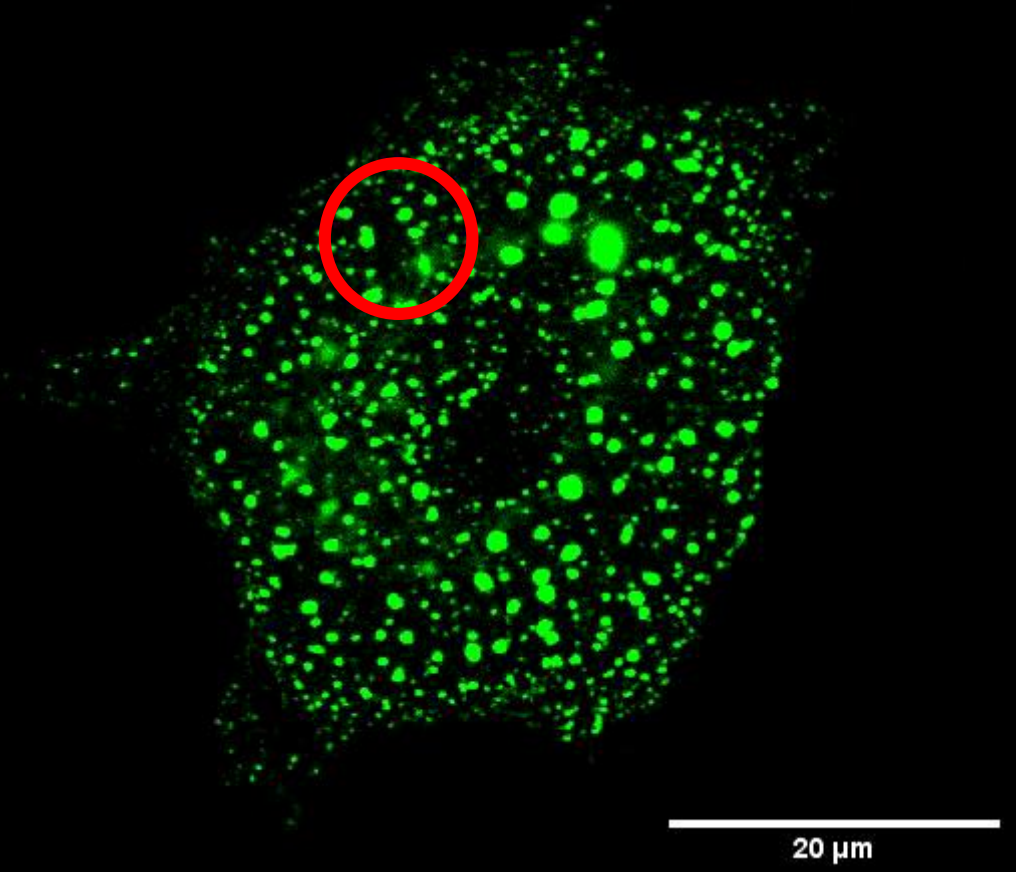


Wormlike Micelles

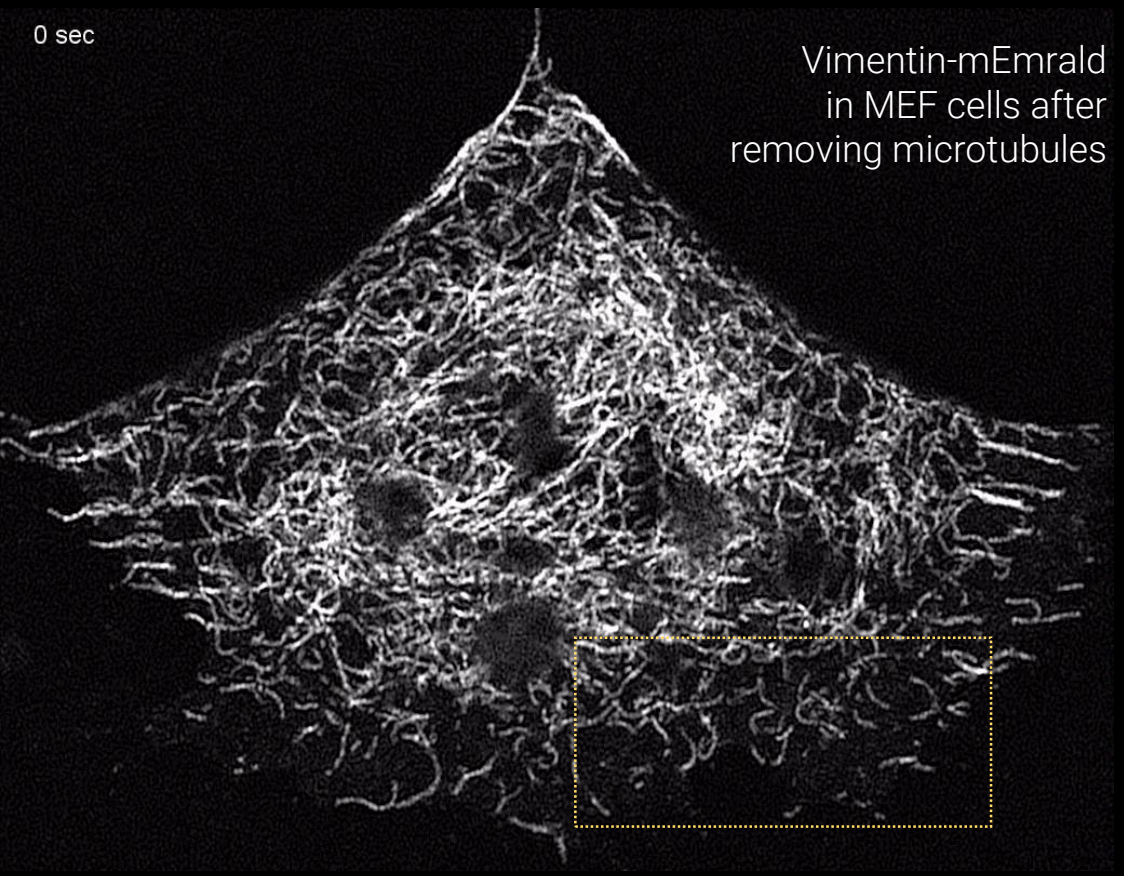
J. Yang Current Opinion in Colloid & Interface Science 7 2002

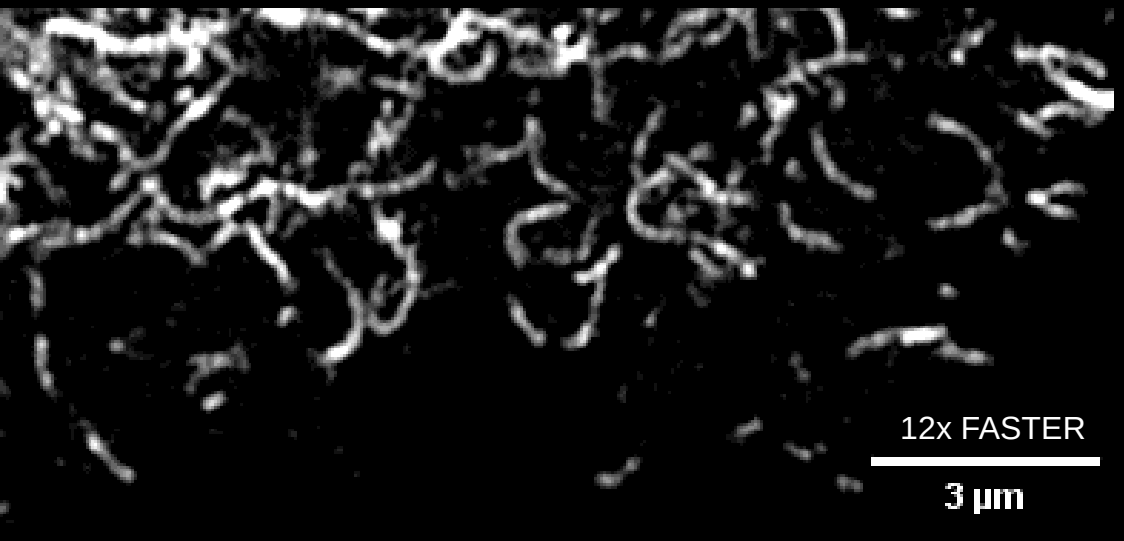
Vimentin mutants form phase-separated droplets

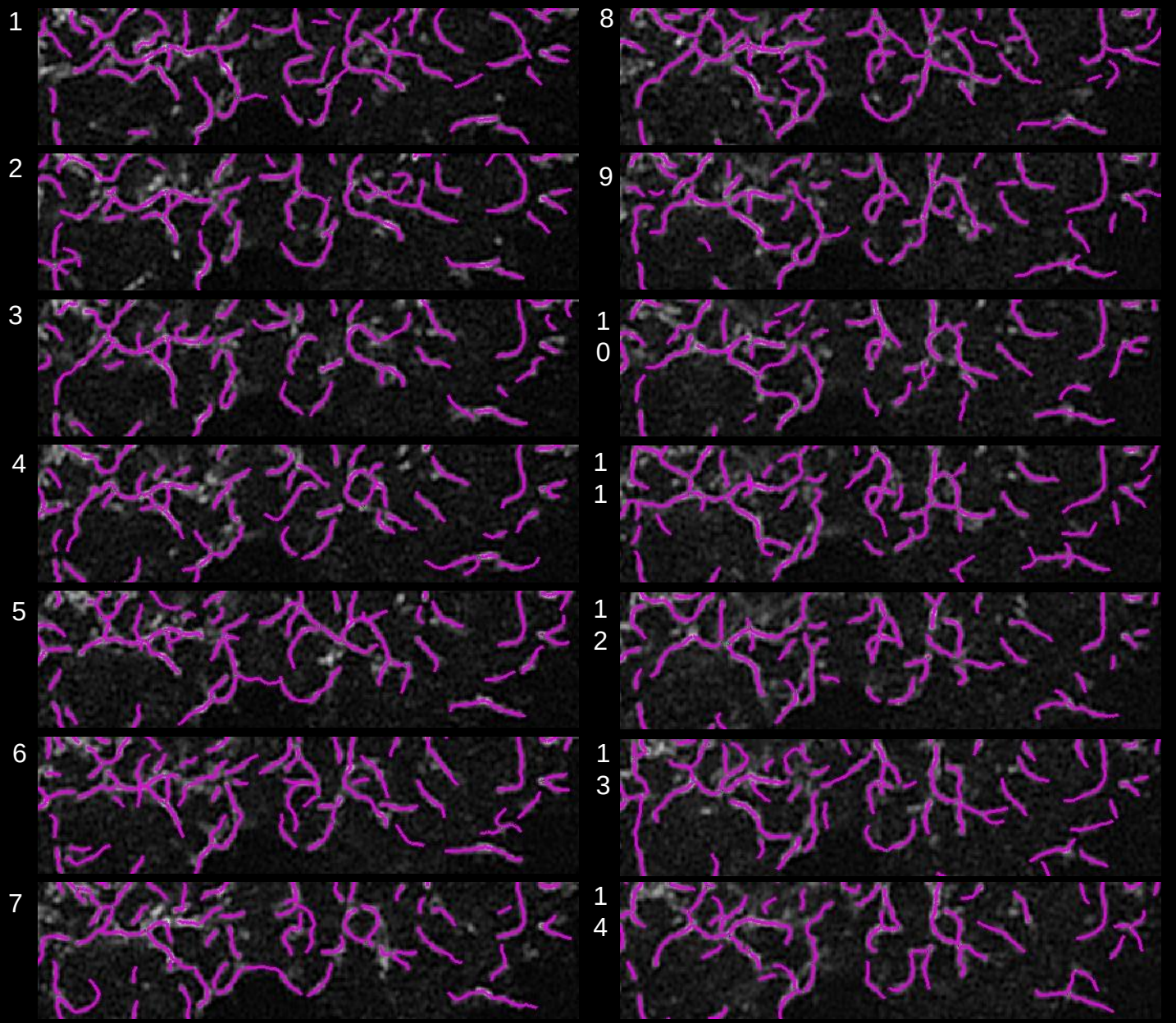




Break-and-Reform Dynamics of Vimentin Network



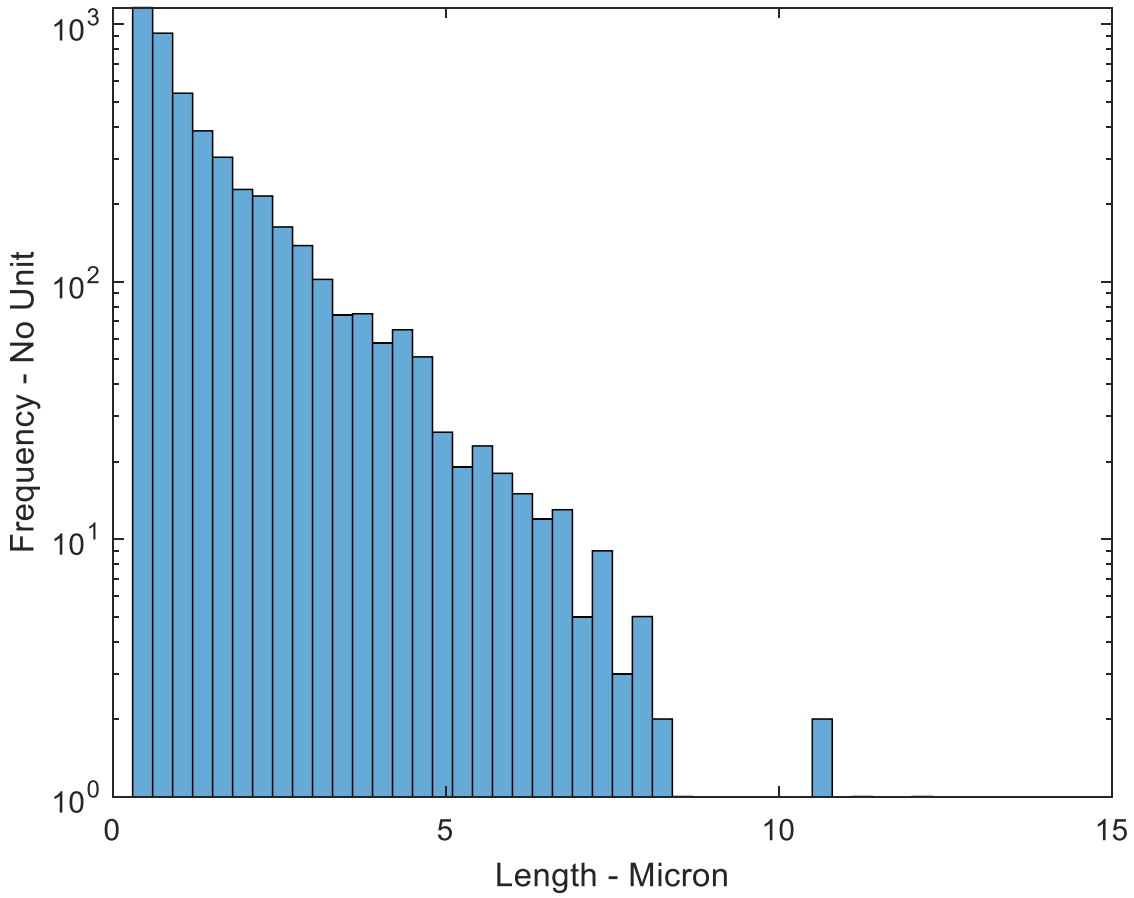




12 sec per frame

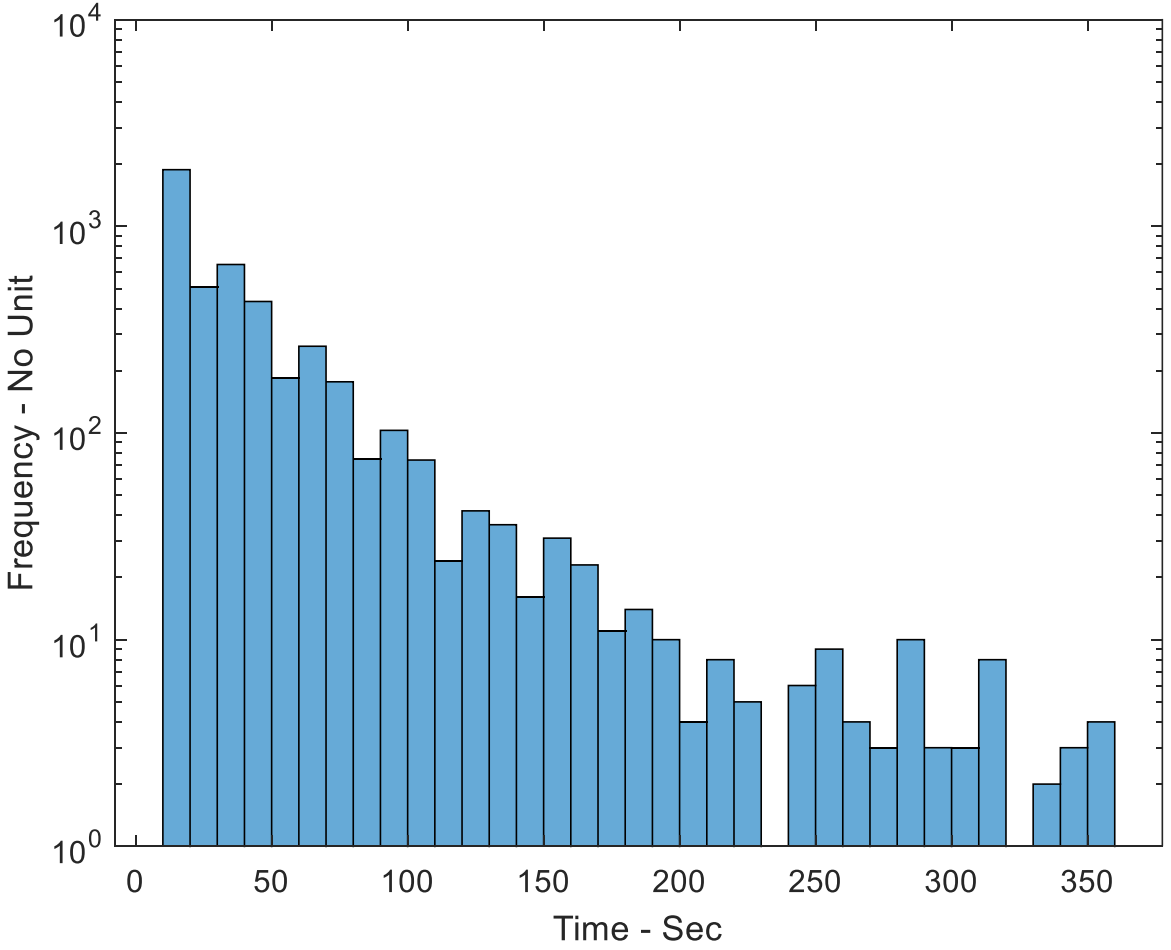
Magenta: extracted filament

Length Distribution



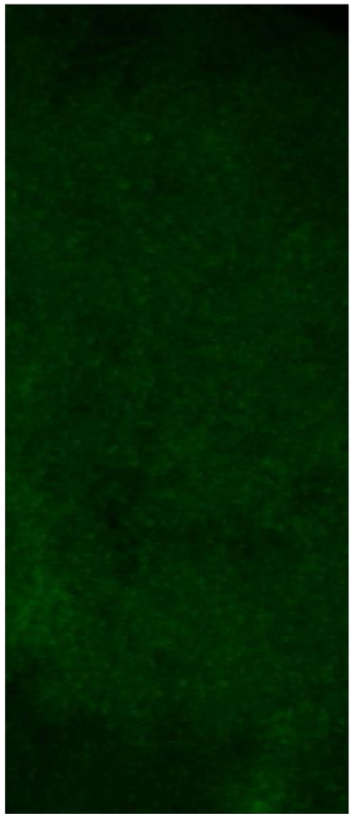
Lengths of filaments follow an exponential distribution

Lifetime Distribution

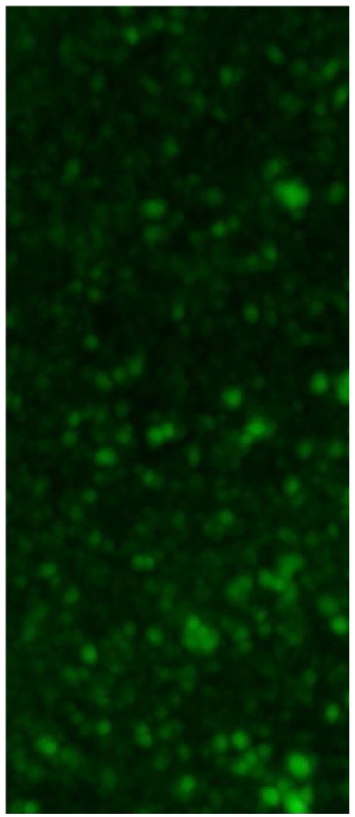


The median lifetime of filament is ~100 seconds

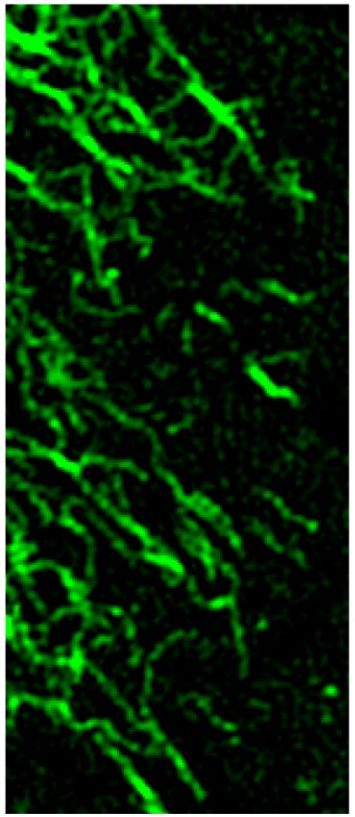
Rich Phase Behavior of Vimentin In Cell



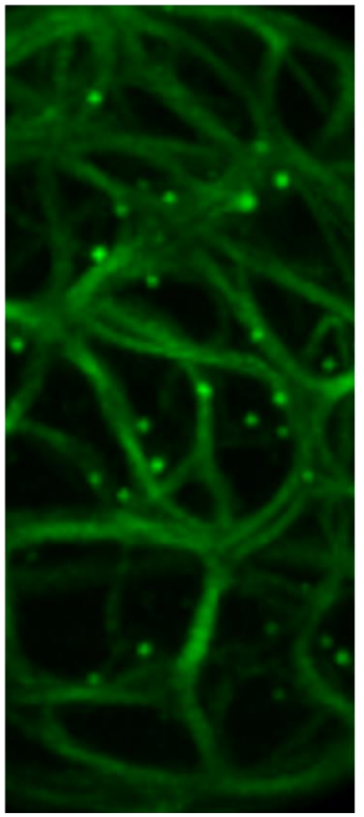
Free Moleculer



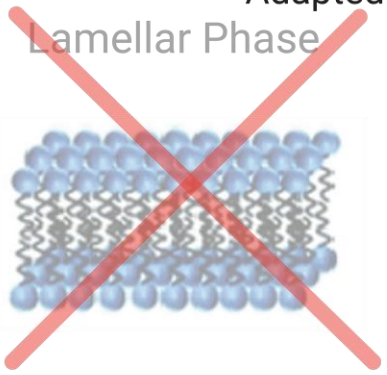
Spherical Micelle



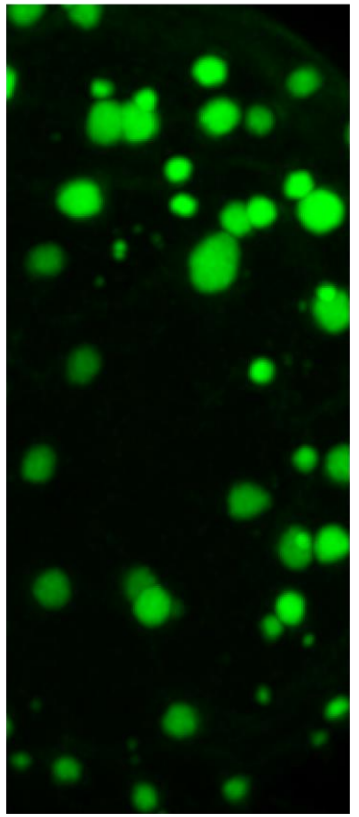
Worm-like Micelle



Hexagonal Phase



Lamellar Phase



Liquid Crystal Phase

Adapted from Prof. Qiaoling Huang

I. Dierking, A. Neto, Crystals, July 2020 10(7)

Worm-like micelle model for vimentin filaments

- Self assembly of network structure
- Phase separation leads to functional structure
- Merging of soft matter materials and biophysics

Current problems in soft matter physics

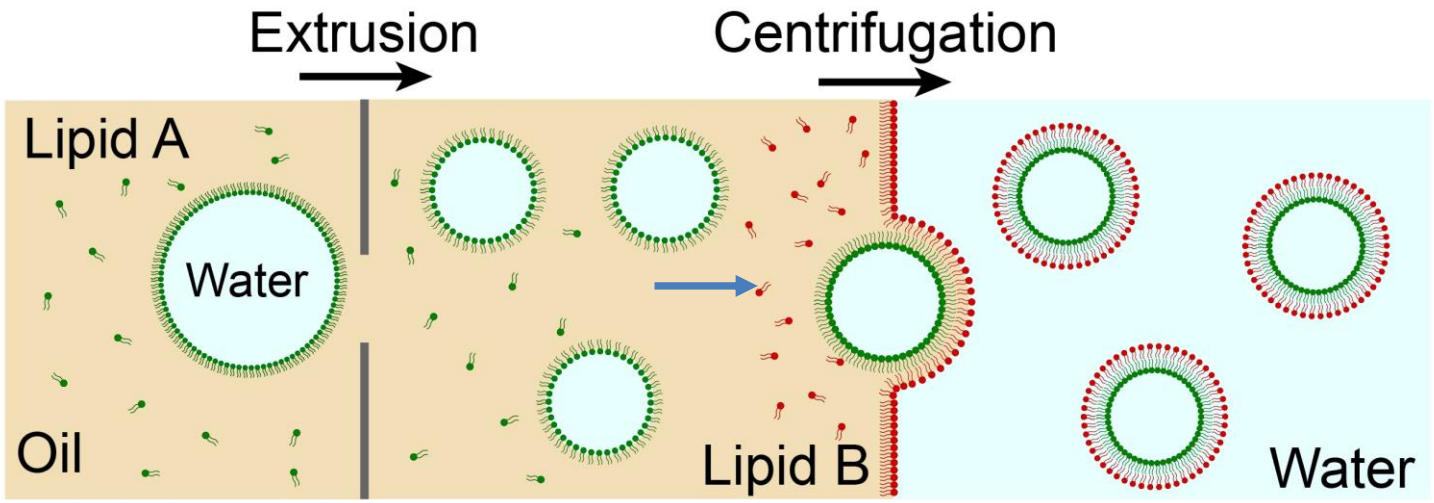
- No overarching unsolved problems – many important problems
- New discoveries in soft materials
- Active materials
- Biological materials
- Soft matter materials for drug delivery

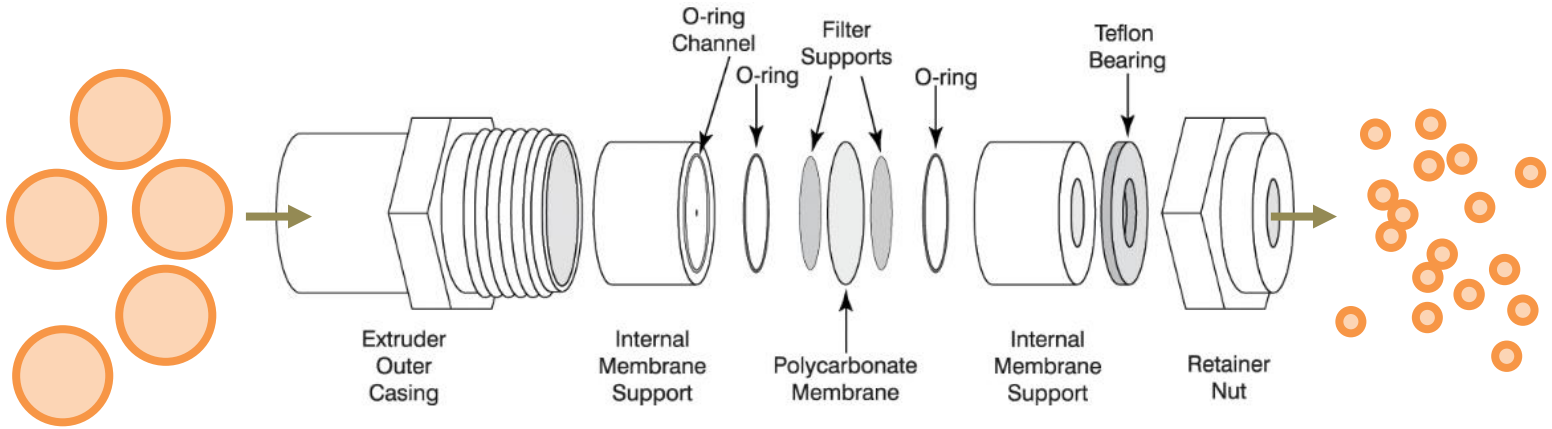
Structured LNPs for mRNA delivery

- Success of the mRNA vaccines during the pandemic showed the importance of drug delivery
- Based on Lipid Nanoparticles
- Great for mRNA; not suitable for many other cell-based drugs
- New opportunities

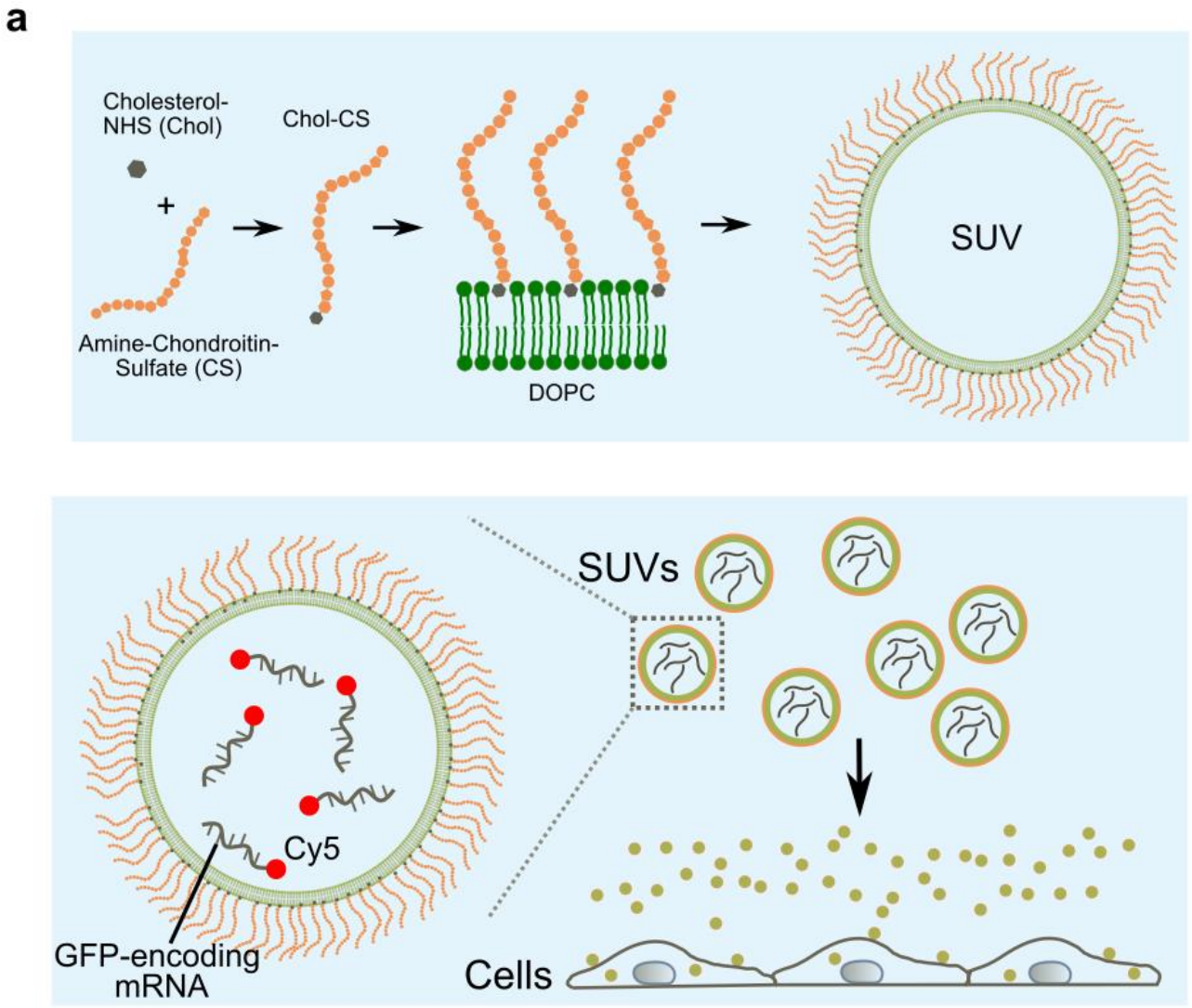
Structured LNPs for mRNA delivery

Inverted emulsion + extrusion method

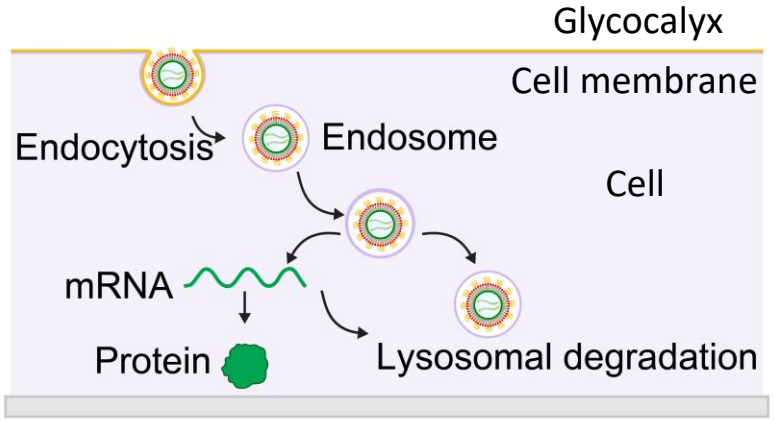


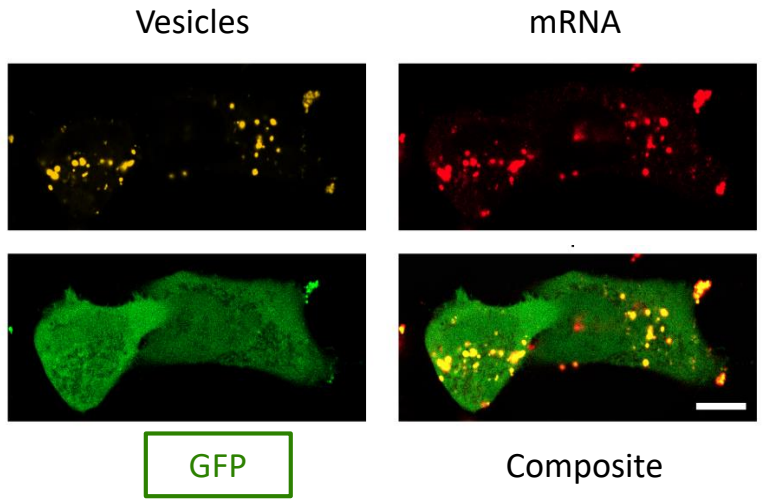


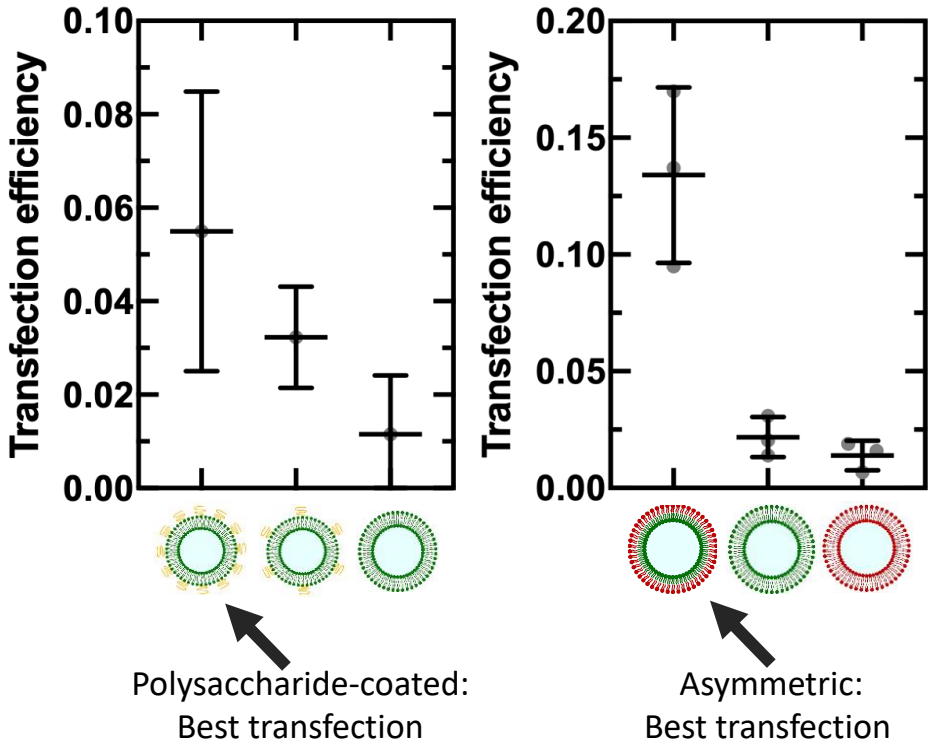
Polysaccharides for targeted drug delivery



Improved delivery and transfection



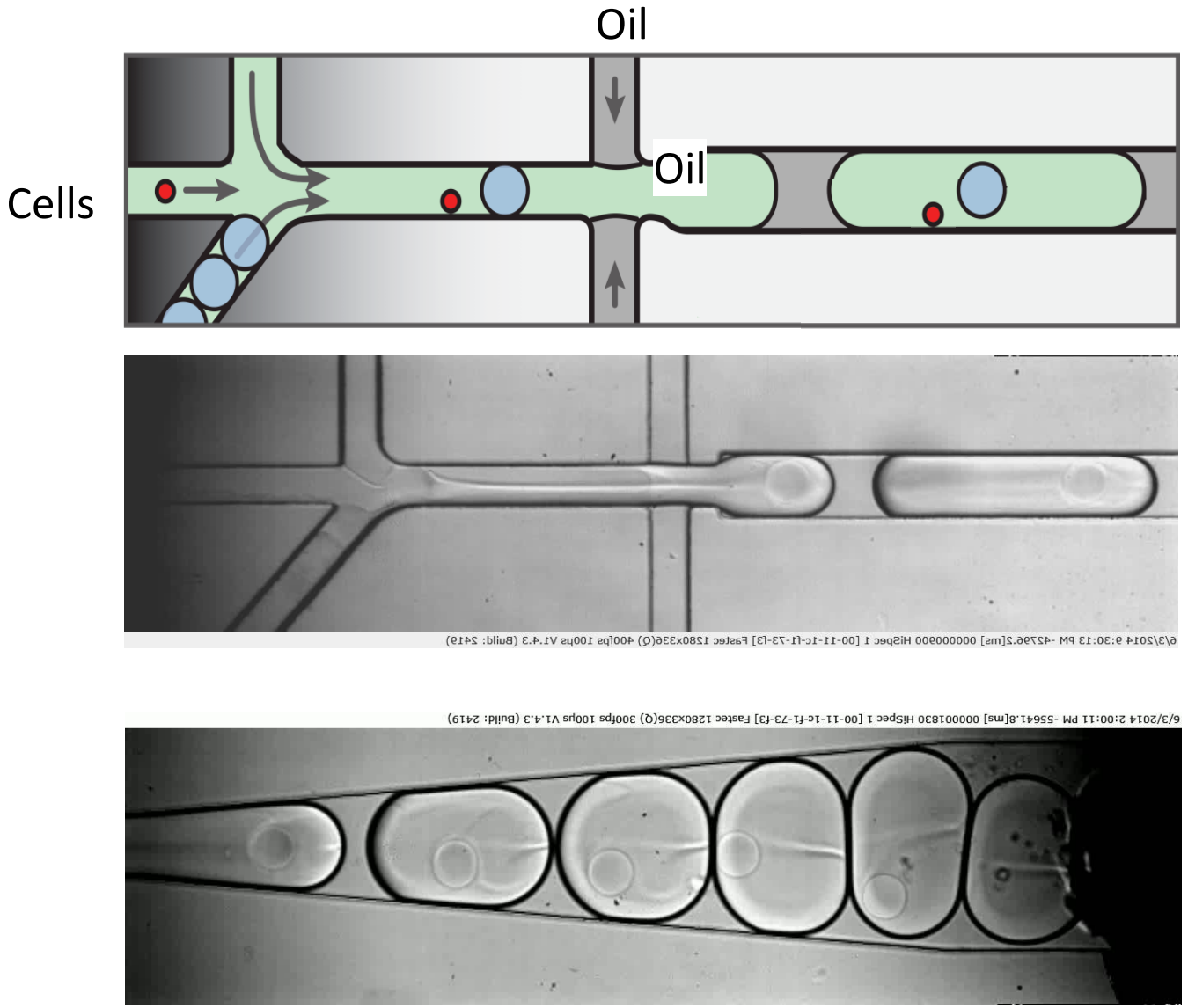




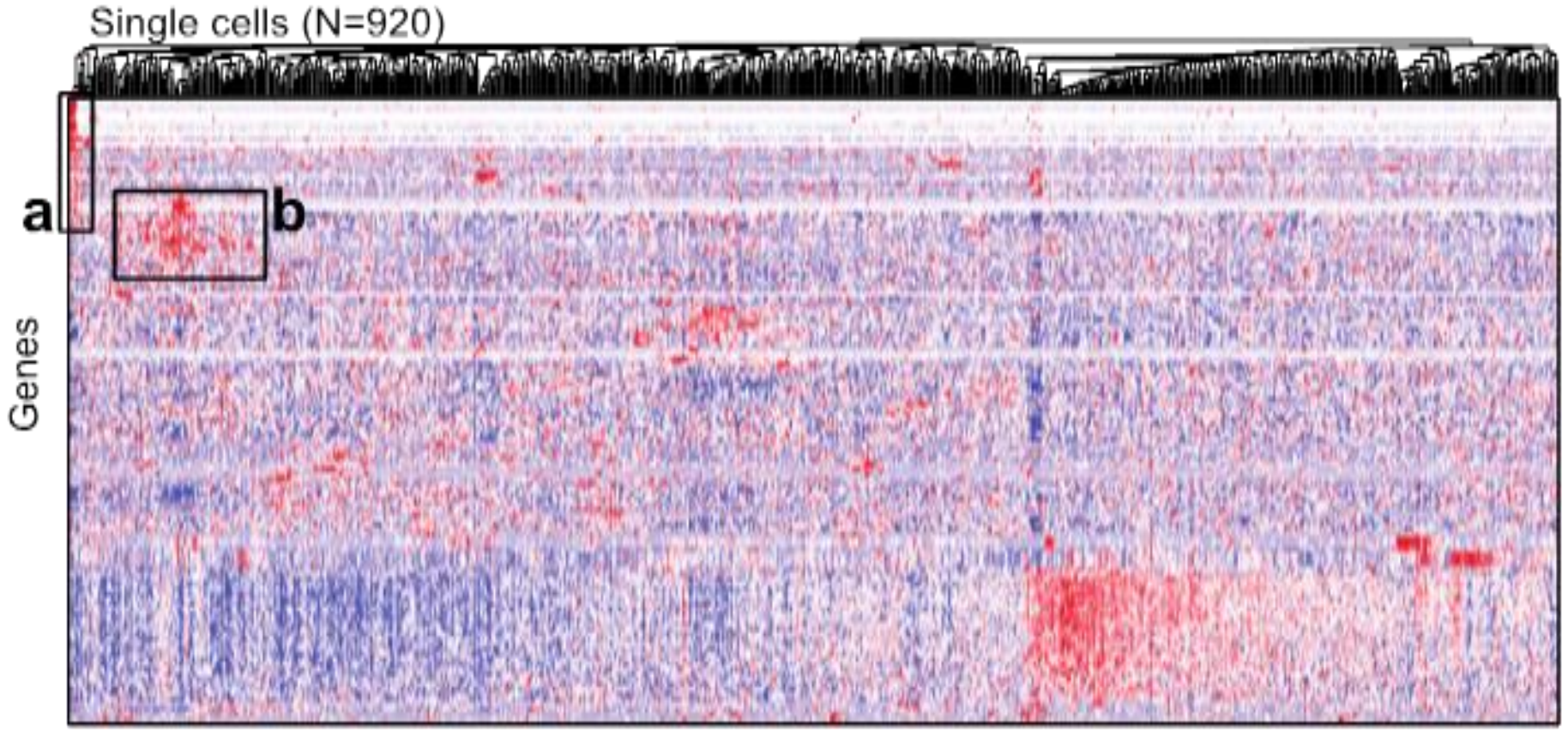
Current problems in soft matter physics

- No overarching unsolved problems – many important problems
- New discoveries in soft materials
- Active materials
- Biological materials
- Soft materials for drug delivery
- Technological applications – startup culture
  - Biotech applications

Add genomic barcode on soft bead



Single-cell sequencing of mRNA from 920 cells



Multi-billion-dollar commercial business in 3 years

Current problems in soft matter physics

- No overarching unsolved problems – many important problems
- New discoveries in soft materials
- Active materials
- Biological materials
- Technological applications – startup culture
  - Biotech applications
- Already have a startup working on drug delivery (Ride Therapeutics)
- We need to also consider how we place our students

Current problems in soft matter physics

- No overarching unsolved problems – many important problems
- New discoveries in soft materials
- Active materials
- Soft matter materials in biophysics
- Soft matter materials for drug delivery
- Startup culture – job creation and opportunities for students

Thank you for your attention