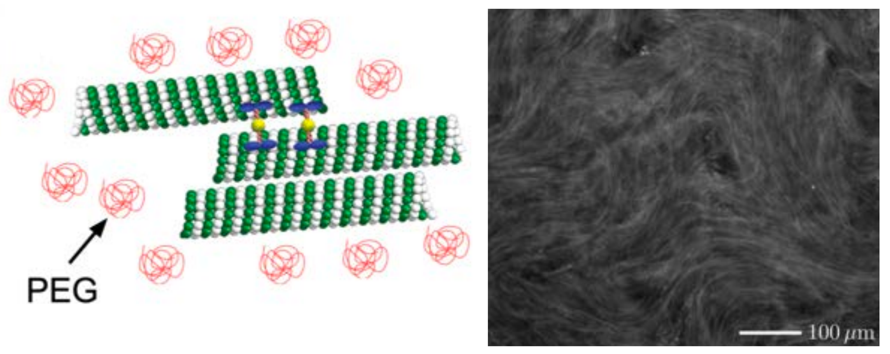
Quantifying Mesoscale Force Transduction In Active Biopolymer Networks

Bennett Sessa and Guillaume Duclos
Department of Physics, Brandeis University, Waltham, MA

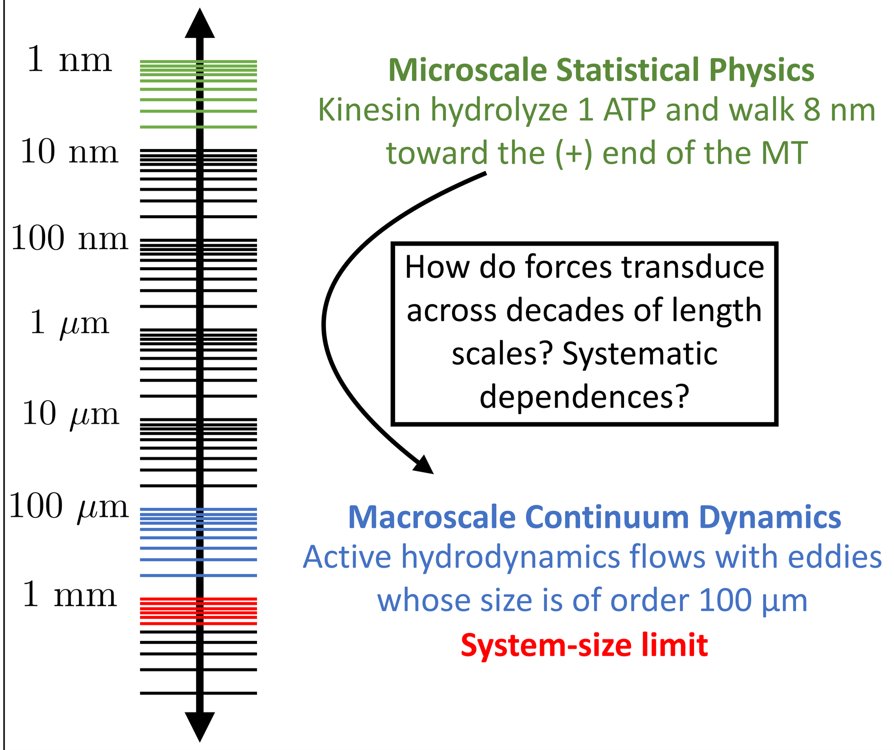
Brandeis bioinspired MRSEC

Introduction

IRG2: To transform materials science by developing controllable far-from-equilibrium materials that crawl, flow, swim and walk, and thus mimic essential traits of living biological organisms.

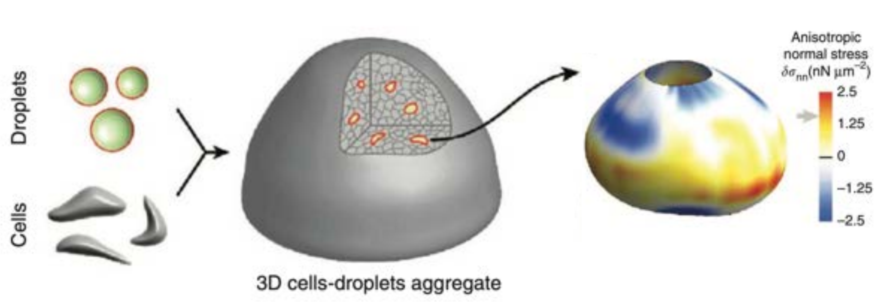


Active network of biopolymers (left) Depletion-induced bundles of microtubules are actively crosslinked by the molecular motor kinesin. (right) Experimental screenshot of bundled active network of microtubules



Liquid Droplets Probe Active Stress

Immiscible, incompressible droplets are used as a mechanical probe of mesoscale activity

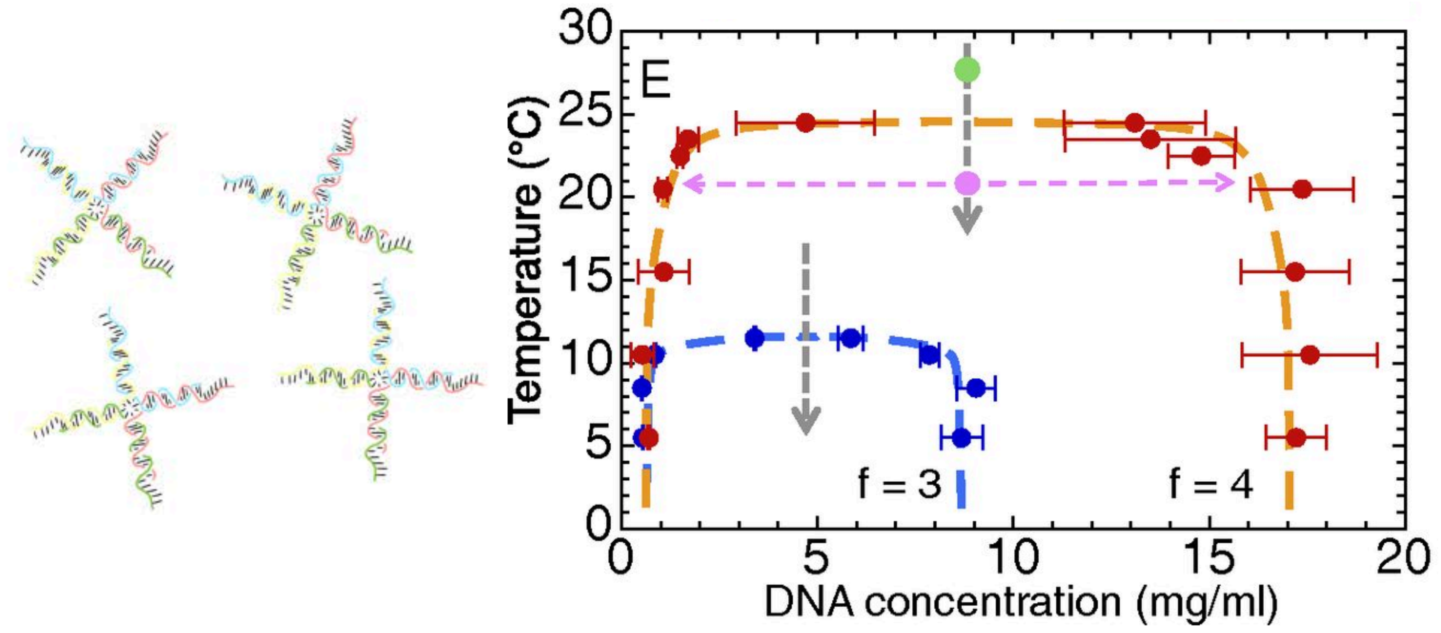


Passive Droplets As Mechanical Probes Campas et al. (2013) dope a living embryo with oil droplets to quantify intracellular mechanical forces. In their work, a droplet's local, mean Gaussian curvature H(θ,ϕ) was related to the local normal anisotropic stress $\delta\sigma_{nn}(\theta,\phi)$ as

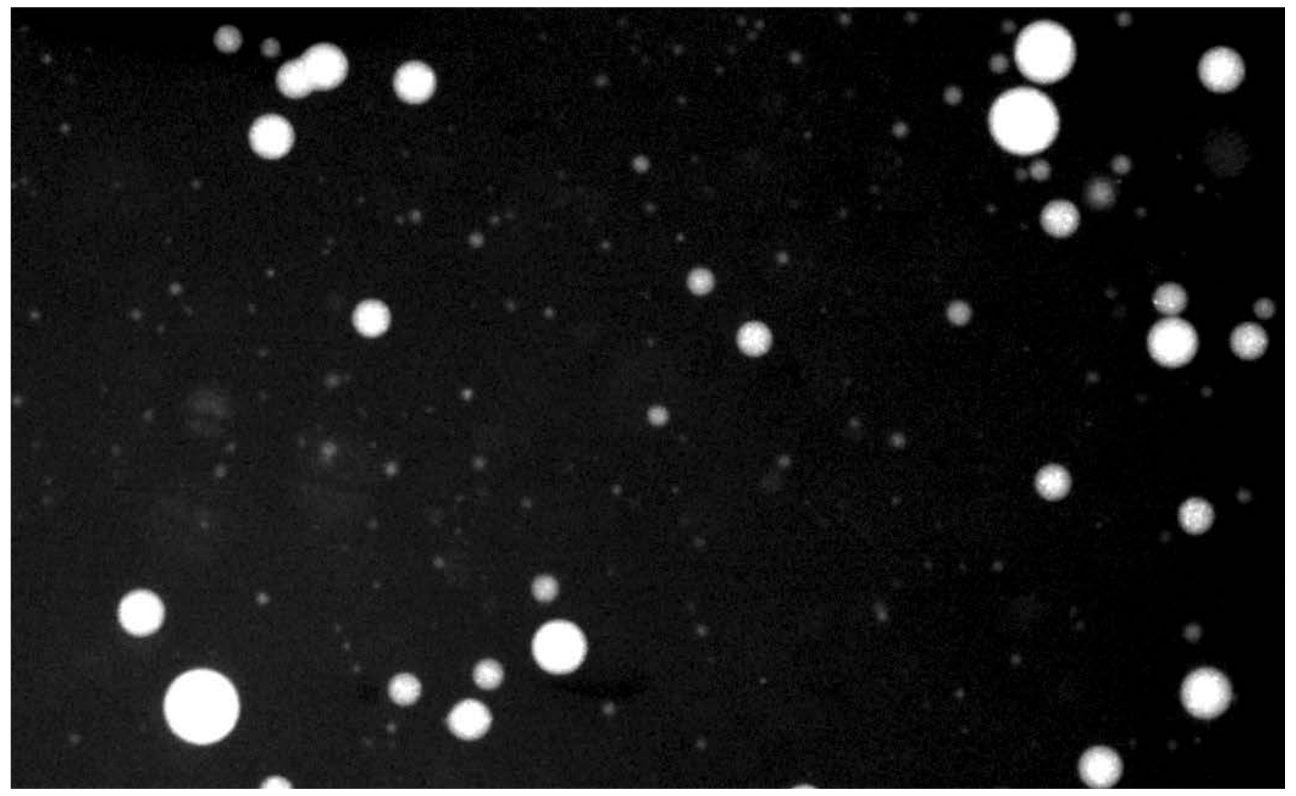
$$\delta\sigma_{nn}(\theta,\phi) = 2\gamma\,\delta H(\theta,\phi) = 2\gamma\left(H(\theta,\phi) - \frac{1}{R}\right),$$

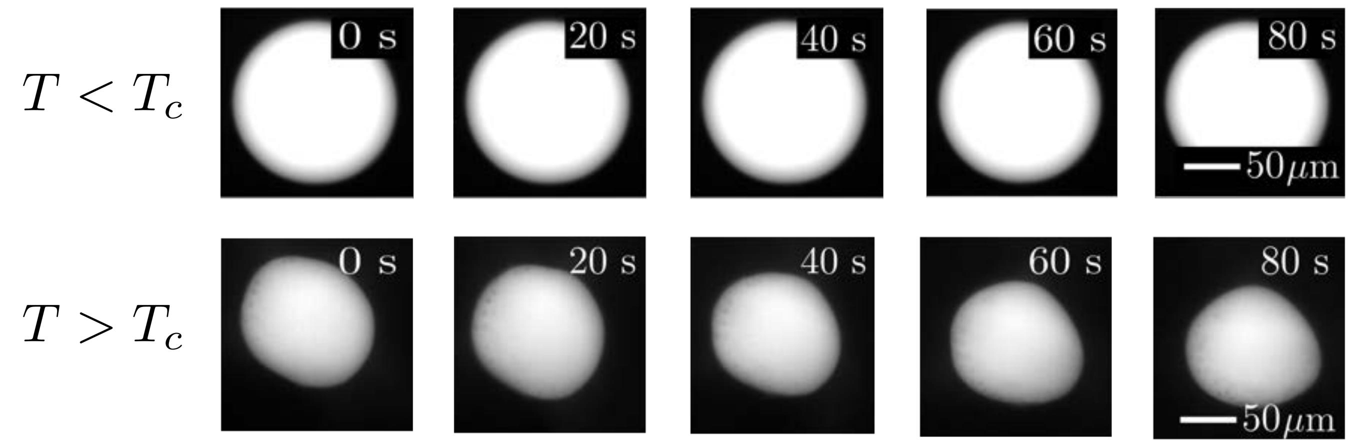
where $\delta H(\theta,\phi) = H(\theta,\phi) - 1/R$ is the anisotropic curvature and $1/R$ is the isotropic curvature, assuming incompressibility.

DNA Nanostar Droplets



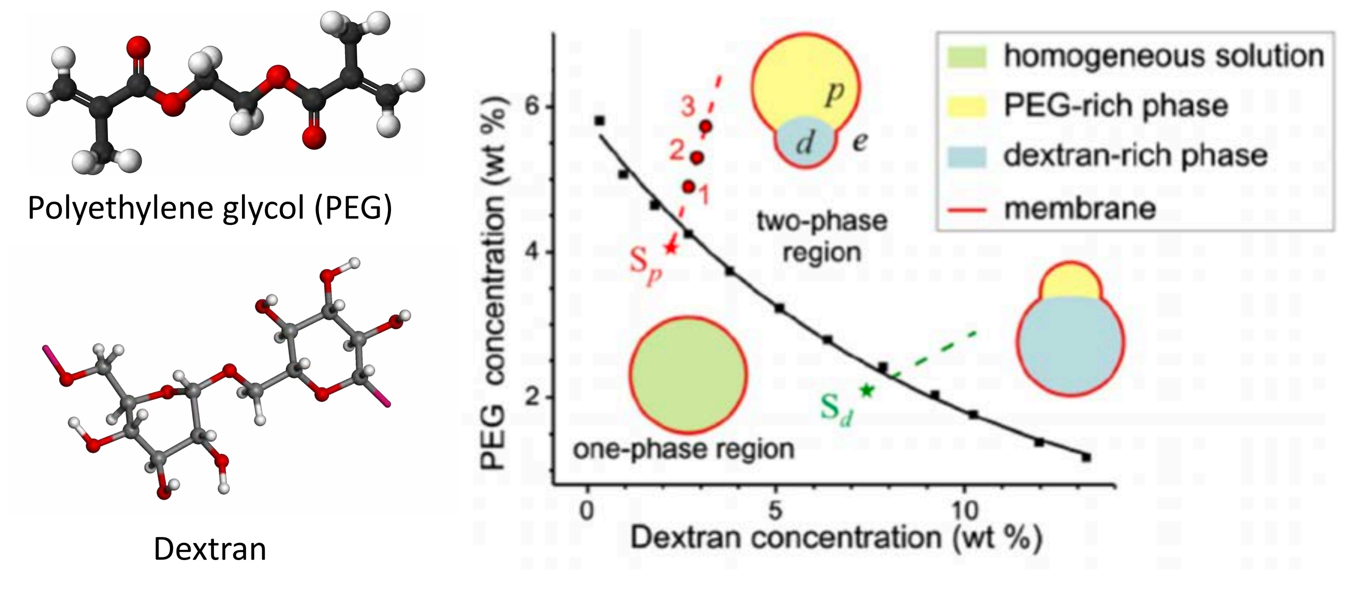
DNA nanostar two-phase system (left) 4 single-stranded DNA oligomers complementarily bind to form tetravalent nanostars. (right) Below a critical temperature, DNA nanostars hybridize via unbound sticky base pairs to form an immiscible phase [2].



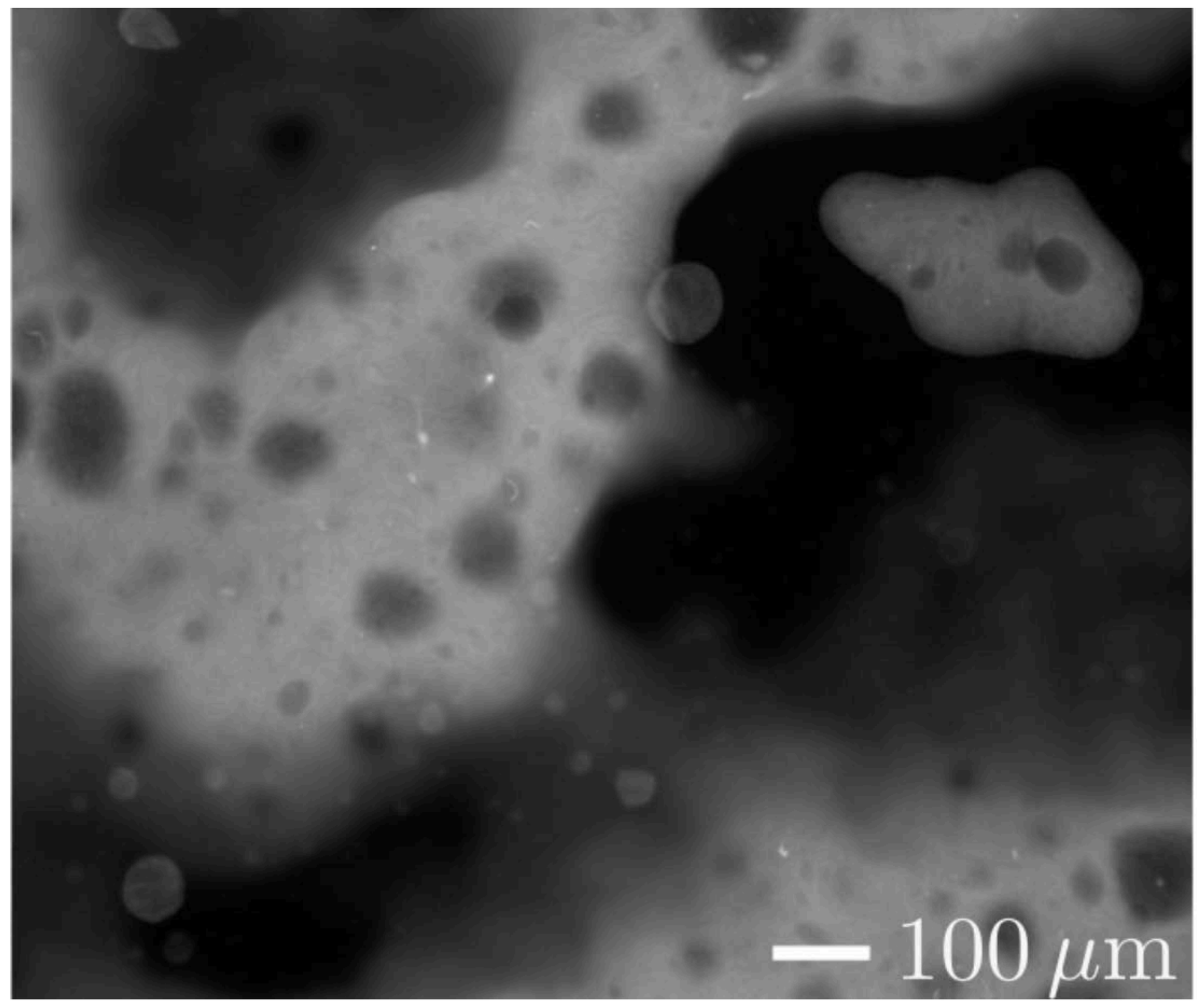


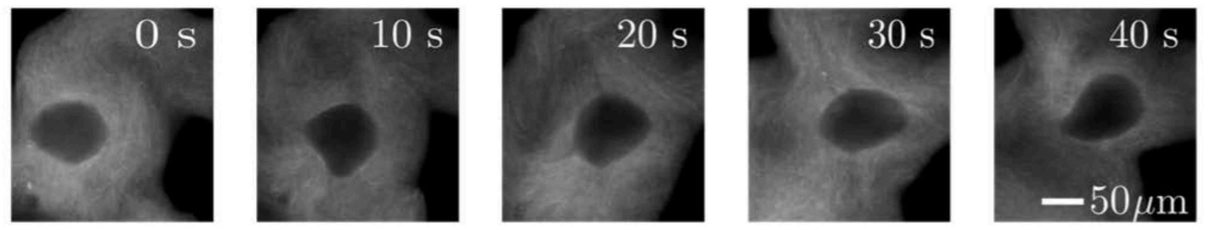
DNA liquid in active network of biopolymers (top) Below the critical temperature, DNA nanostars form a liquid phase. (middle) Surface tension is too high below the critical temperature to deform the droplet. (bottom) Heating the droplet above T_c induces quantifiable deformations, although surface tension is not well-defined.

Active Aqueous Two-Phase System



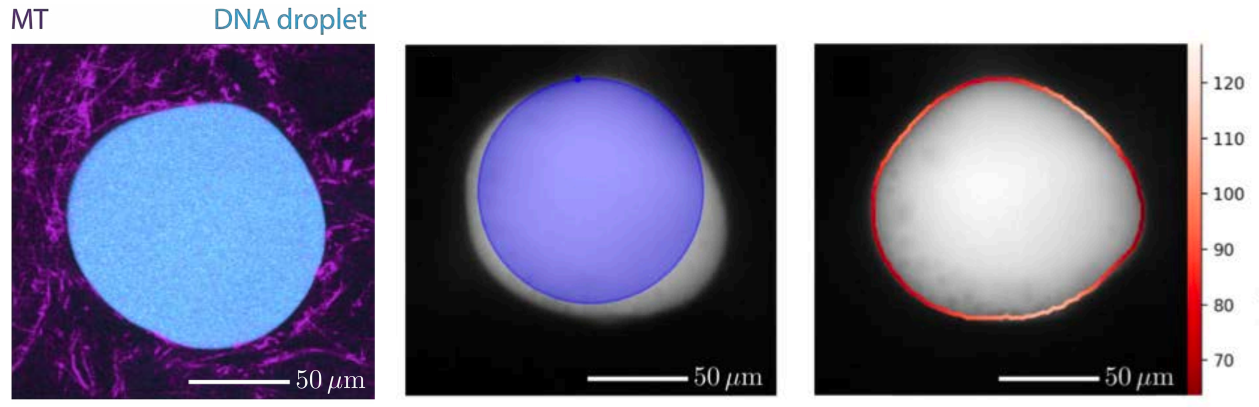
Polymeric, aqueous two-phase system. (left) Functional groups imbue PEG with hydrophobicity and Dextran hydrophilicity. (right) PEG and Dextran phase separate into two immiscible phases with sufficiently high concentrations [6].





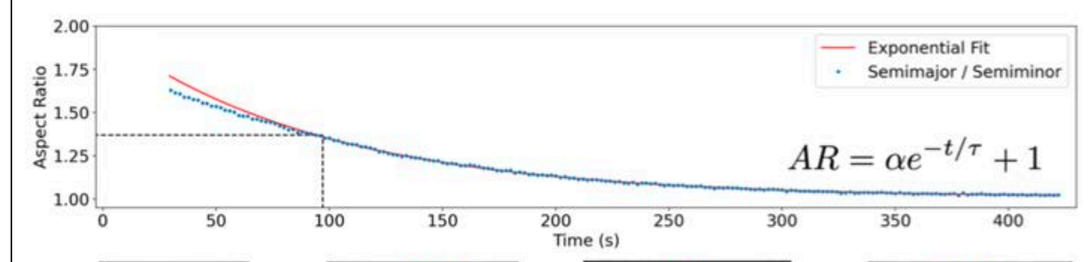
Deformable PEG droplets in active network of biopolymers (top) Microtubules segregate in the Dextran-rich phase and deform PEG-rich droplets. (bottom) PEG droplets undergoing activity-driven deformations. In contrast with DNA liquid, the interfacial tension is sufficiently low to induce deformations with a negative, local mean Gaussian curvature.

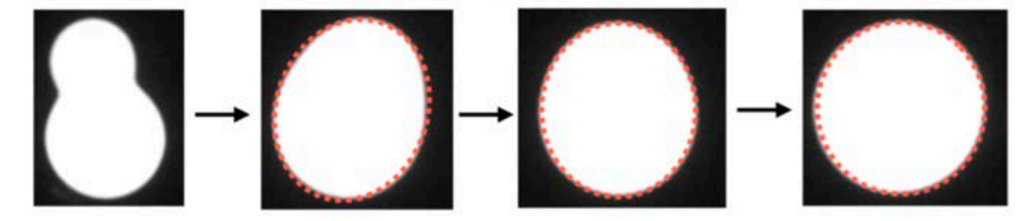
Curvature Quantifies Deformations

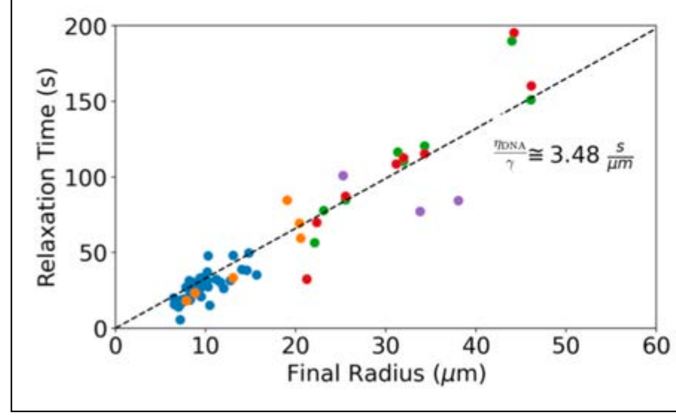


2D Curvature of Deformed Droplets (left) Passive DNA droplets suspended in a bundled active network deform in the presence of activity-driven hydrodynamics. (middle) Radius of curvature quantifies the deformations at a point along the boundary. (right) Deformations quantified along the entire boundary.

Characterization of Material Properties of Liquid Droplets







Surface Tension (top) Two droplets coalesce and relax from an ellipsoid to a sphere in a characteristic relaxation time. (left) Analyzing coalescing droplets of different sizes yields a linear relationship revealing the droplets' material properties.

Conclusion & Outlook

- Passive droplets can be used as probes of stress in active materials, providing invaluable measurement of forces in these systems
- An aqueous two-phase system composed of PEG/Dextran is a suitable probe for active stress given it significantly deforms in the active environment

- My first goal will be to observe transient deformations of an isolated PEG droplet. Presently, the number density of PEG droplets is too high.
- I will then correlate deformations to active hydrodynamics by decomposing the droplet and flow into their radial Fourier harmonics.
- Lastly, I will investigate the systematic dependences of [ATP], [motors] on the active stress measured.

Acknowledgments

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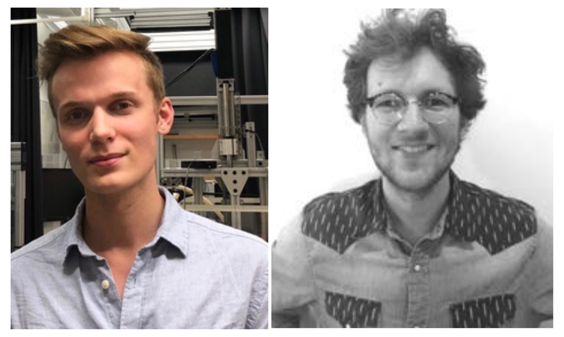

1. S. Biffi, R. Cerbino, F. Bomboi, E. M. Paraboschi, R. Asselta, F. Sciortino, and T. Bellini, Proceedings of the National Academy of Sciences 110, 15633 (2013).
2. Y. Li, R. Lipowsky, and R. Dimova, Proceedings of the New National Academy of Sciences 108, 4731 (2011).