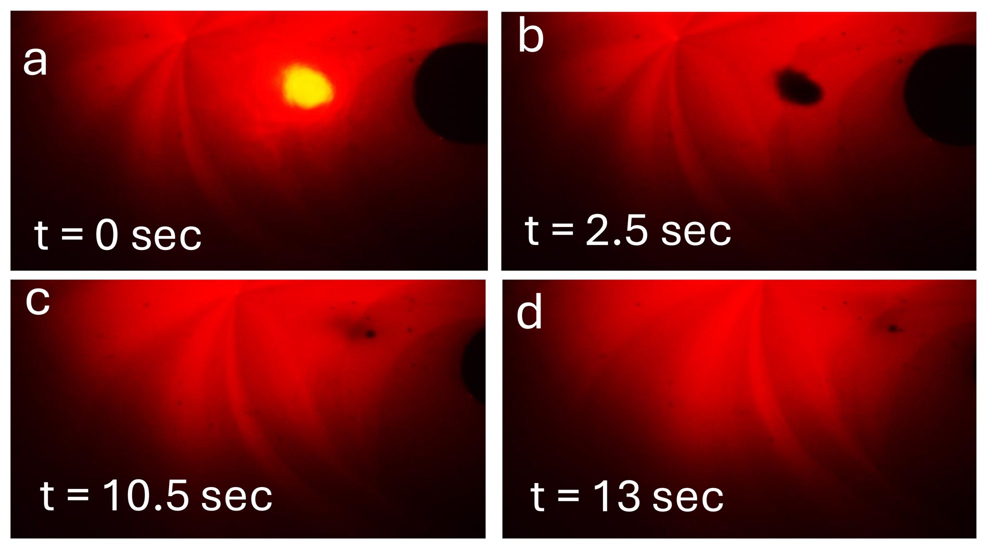
Non-equilibrium fluctuations and diffusion in quasi-2D fluids

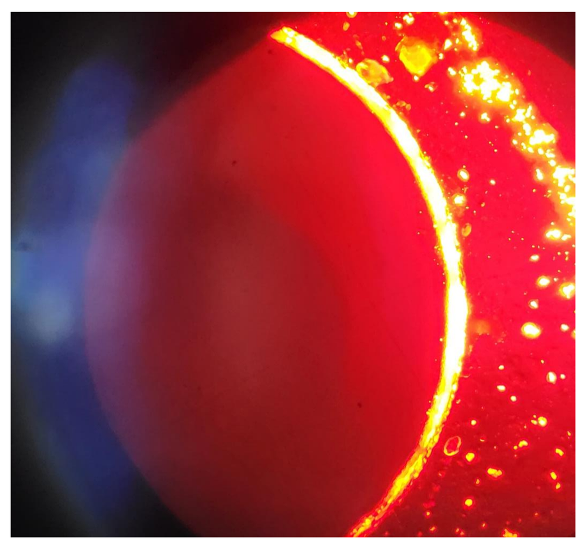
Breanne Evans, Olivia Rourke, Alex Short, Dr. Jonathan Fernsler, Department of Physics
California Polytechnic State University, San Luis Obispo

CAL POLY
Bailey College *of* Science & Mathematics

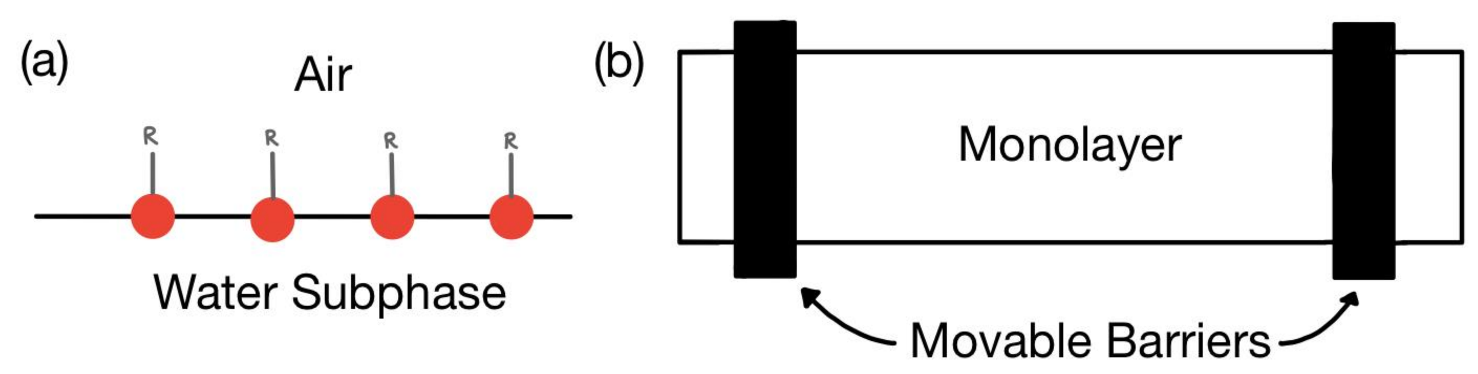
Abstract

Diffusion is the primary mechanism for molecular transport in biological systems, traditionally described by Fick's law and Brownian motion. However, recent observations of non-equilibrium fluctuations far exceeding molecular scales challenge these models. These "Giant Fluctuations," predicted to be larger in two dimensions, are explored here using quasi-2D systems such as freely-suspended liquid crystal films and Langmuir monolayers.

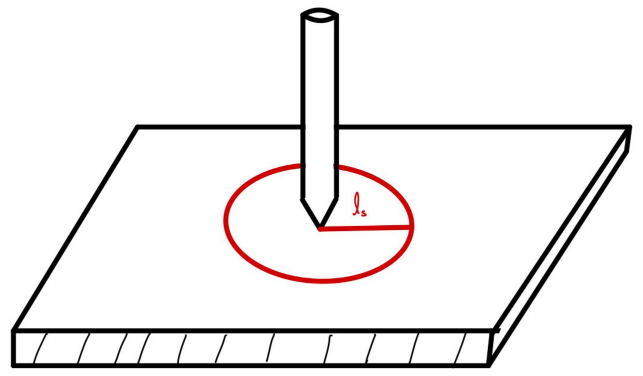




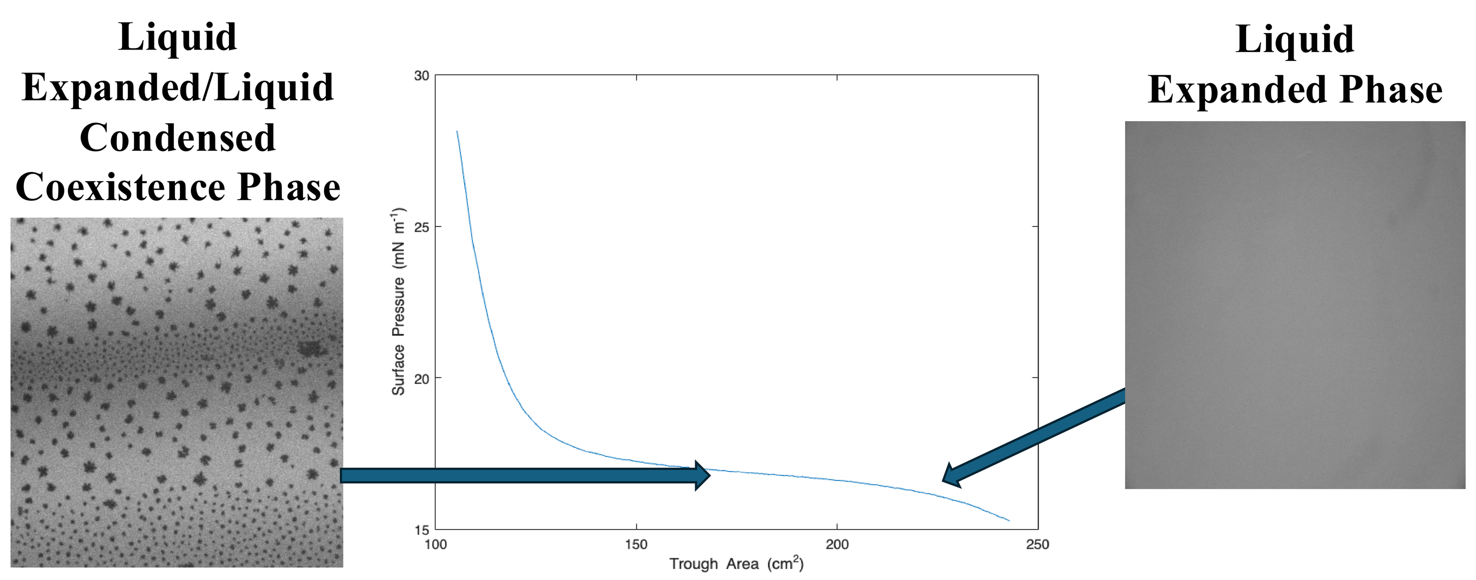
Lipid Monolayers



(a) Single layer of lipid oriented into a monolayer along a nanopure water subphase. (b) Top-down schematic of Langmuir trough with movable barriers to adjust surface area.



The Saffman length (ℓ_s) for a quasi-2D system dictates whether energy dissipation predominantly occurs within the membrane or in the surrounding fluid.

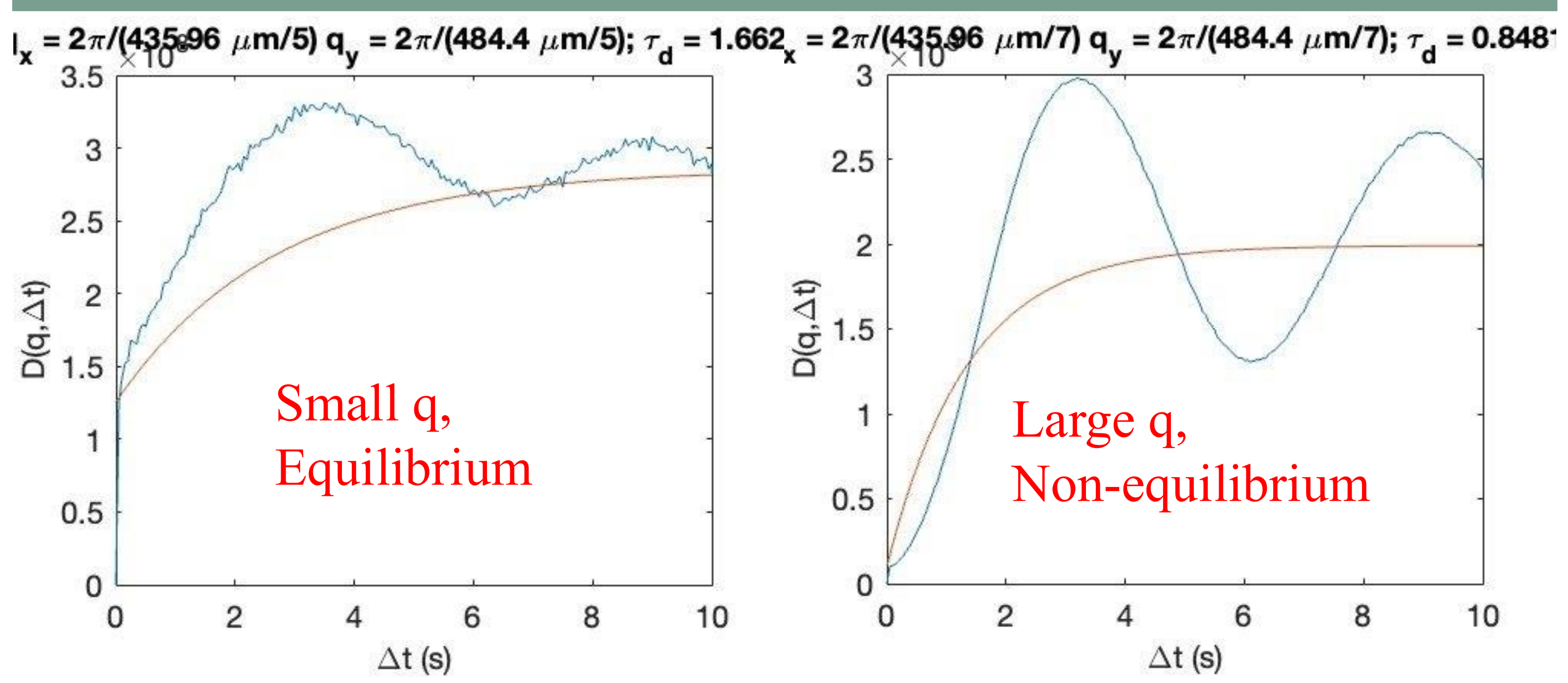


Isotherm at 23 °C of heneicosanoic acid compressing through the L2 -> LC phase transition.

Preliminary Results

We analyze videos of the Langmuir Monolayers during FRAP procedures and during diffusion to quantify at which length, time, and intensity scales fluctuations can be observed. A variety of statistical quantities, such as concentration correlation functions and structure functions are computed.

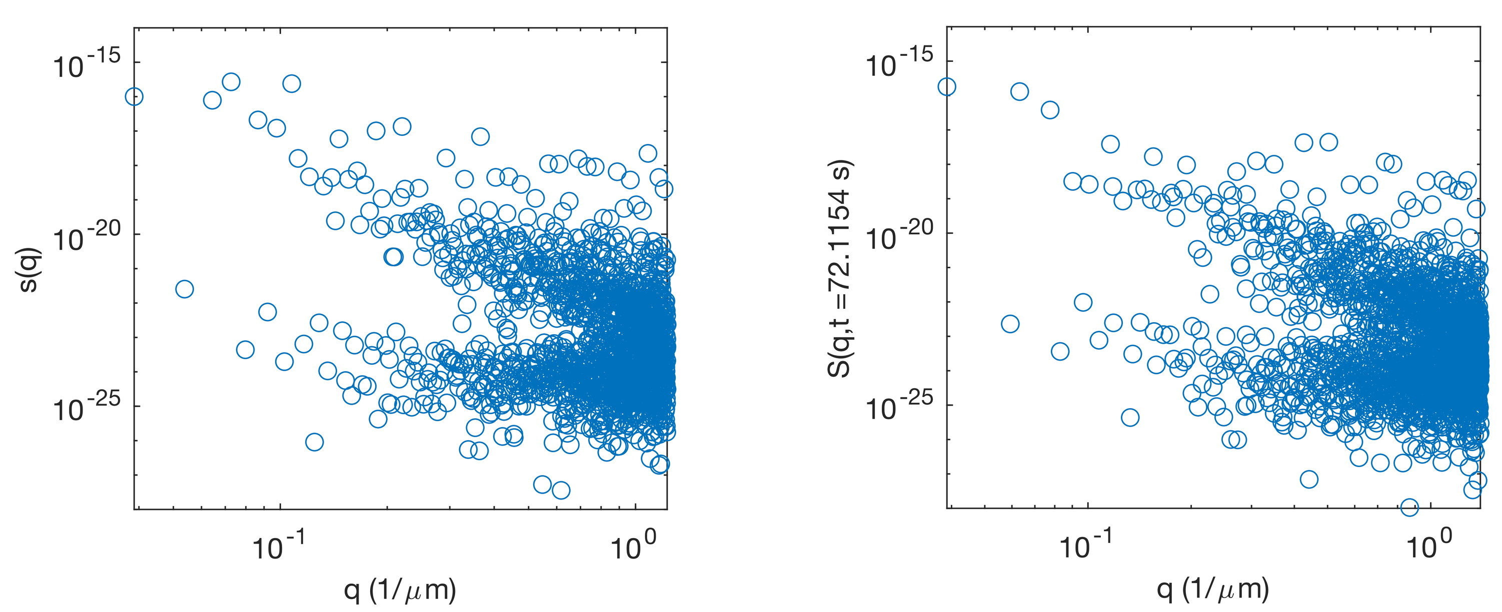
Structure Functions



$$D(\vec{q},\Delta t) = \left\langle \left|\Delta \hat{I}(\vec{q},\Delta t)\right|^2 \right\rangle$$

Small q values (larger length scales) show a gradual rise while large q values (small length scales) show a much steeper rise (faster decay)

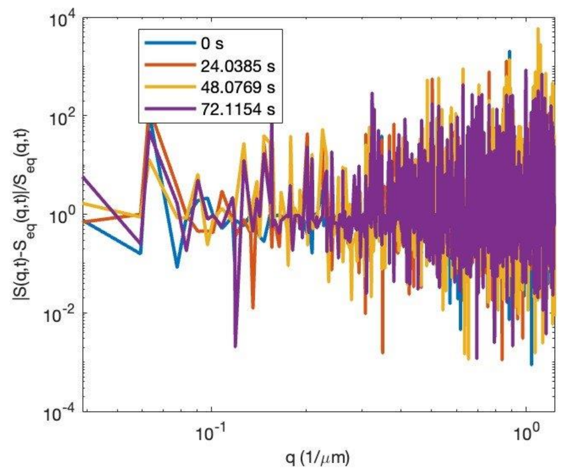
Structure Factors



$$\langle \delta c \delta c^* \rangle_t = \left\langle \left|\hat{I}(q,t) - \langle \hat{I}(q,t)\rangle_t\right|^2 \right\rangle$$

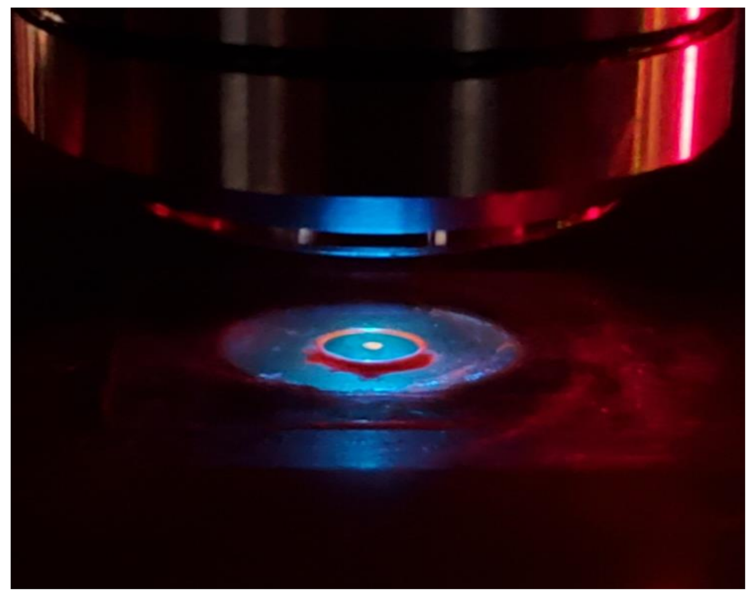
Equilibrium (left) versus non-equilibrium (right) structure factors, which are averaged two dimensional Fourier transforms

The structure factor shows no q dependence which suggests the experimental behavior is similar to classical diffusive mechanics, using Fick's Law

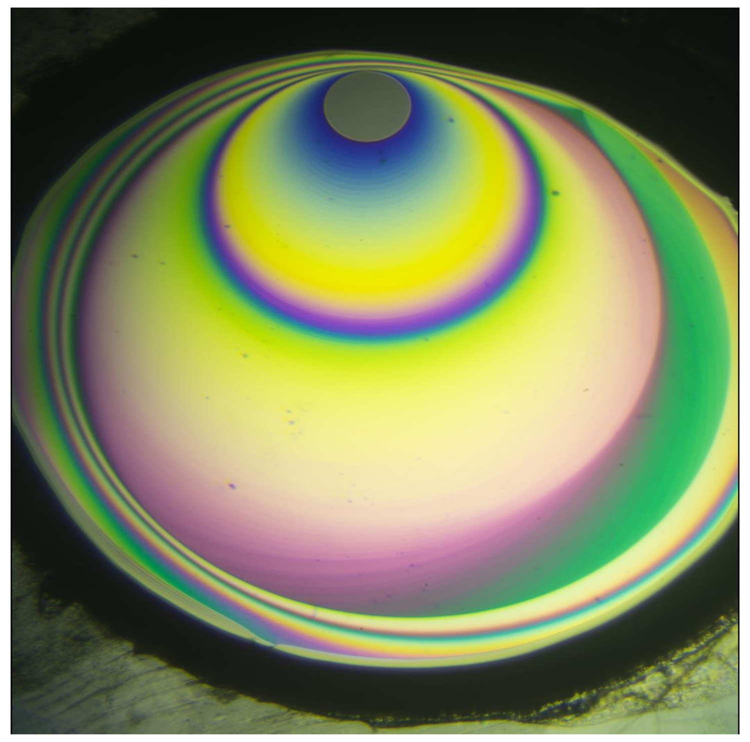


Freely Suspended Liquid Crystal Films

Liquid Crystal films containing embedded quantum dots are drawn over a ~3mm hole to create a quasi-2D fluid in which the dots can diffuse and aggregate.

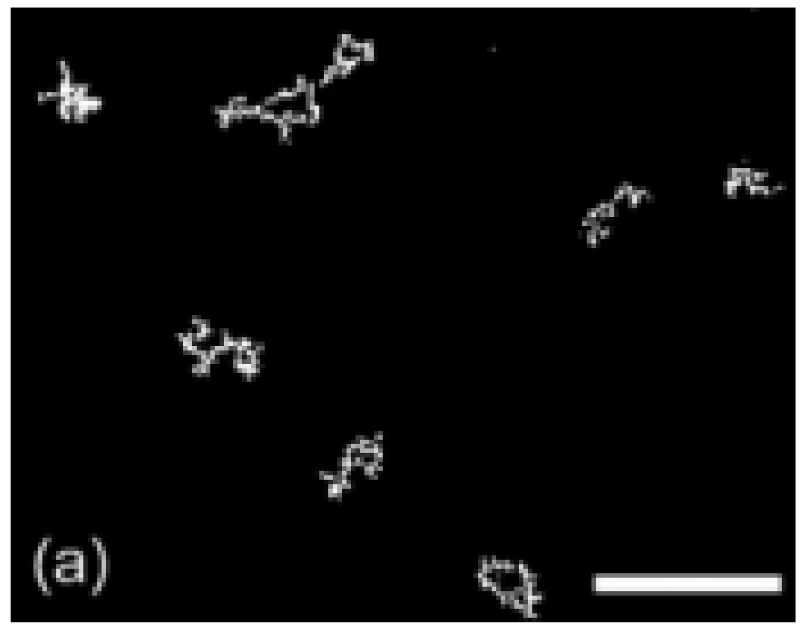


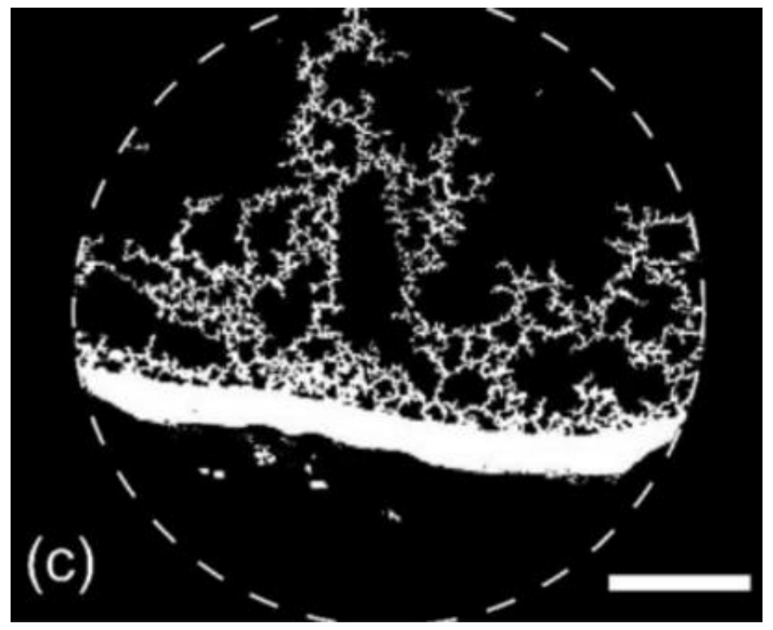
The entire film (3 mm in diameter) is shown, drawn across a circular hole in a thin glass slip.



Quantum Dot Aggregation

Nanoparticles embedded in a two-dimensional fluid (in this case a smectic LC) will diffuse and eventually aggregate together into clusters. These clusters will form fractal structures in the liquid crystal and exhibit growth over time due to diffusion.





Acknowledgements

We thank the National Science Foundation Grant DMR 2104573 for funding this research and Dr. Fernsler for serving as a mentor and advisor. Additionally, thank you to Dr. Kuriabova for developing the theory behind these fluctuations.

References

[1] Atkinson, Markus J. "Island Diffusion On Free-Standing Films of Smectic Liquid Crystal." 2010.
[2] Bechhoefer, J., et al. "Experiments on Tracer Diffusion in Thin Free-Standing Liquid-Crystal Films." *Physical Review Letters*, vol. 79, no. 24, 1997, pp. 4922–4925., doi:10.1103/physrevlett.79.4922.
[3] Brogioli, Doriano, and Alberto Vailati. "Nonequilibrium Fluctuations during Diffusion in Liquid Layers." *Physical Review E*, vol. 96, no. 1, 2017, doi:10.1103/physreve.96.012136.
[4] Meienberg, K., et al. (2015). Nanoparticle Aggregation and Fractal Growth in Fluid Smectic Membranes. Molecular Crystals and Liquid Crystals. 611. 14-20. 10.1080/15421406.2015.1027990.
[5] Vailati, Alberto, and Marzio Giglio. "Giant Fluctuations in a Free Diffusion Process." *Nature*, 1 Nov. 1997, adsabs.harvard.edu/abs/1997Natur.390..262V.