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Motility Induced Phase Separation in Complex Systems

Project Overview

Provide an explanation/background of your UROP project that includes with whom you are conducting research.

Self-propelled particles are endowed with new properties which have attracted a lot of attention and motility-induced phase separation (MIPS) is one of them [1]. When selfactive particles have a large-enough propulsion speed and interact with repulsive forces, they spontaneously separate into a high-density phase and a low-density one. This is similar to an equilibrium liquid-gas separation, except that it happens in the absence of attractive interaction between the particles, something that would be impossible in equilibrium. Motility-induced phase separation can also be observed in the presence of quorum-sensing interactions that lead to a slowdown of the particle at high density [1]. The mean-fieldish nature of this interaction has allowed the group of Professor Tailleur to derive a complete theory of MIPS in this case. Recently, progress has been made for repulsive pairwise interactions [2,3,4]. However, real systems typically involve both repulsive forces and quorum-sensing-like interactions, and this more general case has never been explored theoretically, despite its experimental relevance. The same is true for pairwise forces with attractive tails, which exhibits a richer phase diagram than simple MIPS. We aim to use analytical calculations and simulations to explore these cases and provide a comprehensive theory of MIPS in these richer settings.

Personal Responsibilities & Goals

Describe your planned role in the project. Be as specific as you can about your personal research duties/responsibilities, expected deliverables, and research goals you hope to accomplish by the end of term.

At the beginning of the term, I will do calculations to familiarize myself with the coarse-graining and approximation techniques in the literature. After that, I will also learn simulation techniques already used by students in the group. I will use the techniques I learn to explore the phase diagram and the macroscopic dynamics of

the systems. I will first focus on the mixing of pairwise forces and quorum sensing and hopefully complete it in the spring semester. After that, I might continue to address the case of pair potential with attractive tails.

Personal Statement

Briefly state why you are interested in this UROP and explain what you hope to gain from it.

I like statistical physics and biophysics; this project gives me a flavor of both. I like the counterintuitive phenomena, the tractable calculations, and the potential applications of this field, for example with pattern formation arising as a result of MIPS.

I hope to gain experience with calculations and simulations in stochastic dynamics and thermodynamics, which have a wide range of usage. I also hope to get a taste of biophysics research to see if I like the field. The structure of the group will be new to me, with me working with both Professor Tailleur and his graduate students, which I believe will be a helpful experience.

[1] M.E. Cates, J. Tailleur, "Motility-Induced Phase Separation", Ann. Review Cond. Matt. Phys. 6, 219-244 (2015)
[2] A. P. Solon, J. Stenhammar, M. E. Cates, Y. Kafri, J. Tailleur, "Generalized thermodynamics of Motility-Induced Phase Separation: Phase equilibria, Laplace pressure, and change of ensembles", New Journal of Physics 20, 075001 (2018)
[3] T. Speck, “Coexistence of active Brownian disks: van der Waals theory and analytical results”, Phys. Rev. E 103, 012607 (2021)
[4] A. K. Omar, H. Row, S. A. Mallory, J. F. Brady, “Mechanical theory of nonequilibrium coexistence and motility-induced phase separation”, Proc. Nat. Acad. Sci. USA 120, e2219900120 (2023)