**Name: Quan Manh Nguyen**

**Faculty Supervisor: Julien Tailleur**

**Direct Supervisor: Sunghan Ro**

**Term: Fall 2023**

**September 9, 2023**

**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)