NOVEL PROPERTIES AND EMERGENT COLLECTIVE PHENOMENA OF ACTIVE FLUIDS

A DISSERTATION

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Acknowledgements

Dedication

To my beloved family for supporting me over the years.

Abstract

Contents

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Chapter 1

Introduction

- Chapter 1 briefly describe the history and significance of active fluid research.
- Chapter 2 presents the experimental techniques used in this theis.
- Chapter 3 talks about one of the emergent properties: reduced viscosity. Large portion of this chapter have been published in [1].
- Chapter 4 talks about another emergent property: giant number fluctuation. This work is under preparation for submission.
- Chapter 5 presents the study on the transition from disordered state to active turbulence in light-powered bacterial suspensions. This work is conducted with a close collaboration with Yi Peng and Xiang Cheng. Large portions of this chapter has been published in [2]. Yi Peng, Zhengyang Liu and Xiang Cheng conceived the experiment. Zhengyang Liu constructed the light-powered bacteria. Yi Peng performed the experiment. Zhengyang Liu and Yi Peng did the data analysis. All authors contribute to the model development and writing of the manuscript.
- Chapter 6 summarizes the contributions of this thesis and provides the outlook

on future research.

- Appendix A shows details of the construction of light-powered *E. coli*.
- Appendix B provides details of several particle tracking tools I developed.
- Appendix C shows details of photolithography.

1.1 Active Fluids

Active fluids are suspensions of active agents such as cells, particles and biological macromolecules that are capable of utilizing chemical energy to sustain their self-propulsion. The concept roots from a broader class of matter: soft matter, which includes polymers, surfactants and colloidal grains [3]. Active fluids, like soft matter, are known for their complexity and flexibility. The unique self-propulsion has endowed active fluids with more intrguing and counter-intuitive properties, especially the emergent self-organized collective phenomena[4]. The research on collective phenomena dates back to the 1980s, when flocking birds, schooling fish, herding beasts and even human crowds (Fig. **??**a-c) were regarded as an orientationally ordered phase of living matter, in analogy with ferromagnetic spins [5, 6, 7, 8, 9, 10]. This idea has since evoked enormous research interest. More recently, besides macroscopic systems, smaller and more laboratory accessible model systems have joined. As examples, actin filaments powered by motor proteins and bacteria exhibit turbulence-like swirling patterns, and synthetic active colloids form dynamic clusters [11, 12, 13, 14, 15, 16, 17]. Observations have revealed that most patterns of collective motion are universal in different systems. As of today, these universal patterns can be qualitatively reproduced by simple models with collision rules and noise. And quantitative description is developing with more observations available, which is bound to have impactful applications, including understanding the reaction of panic crowd and predicting the migration of fish schools [18].

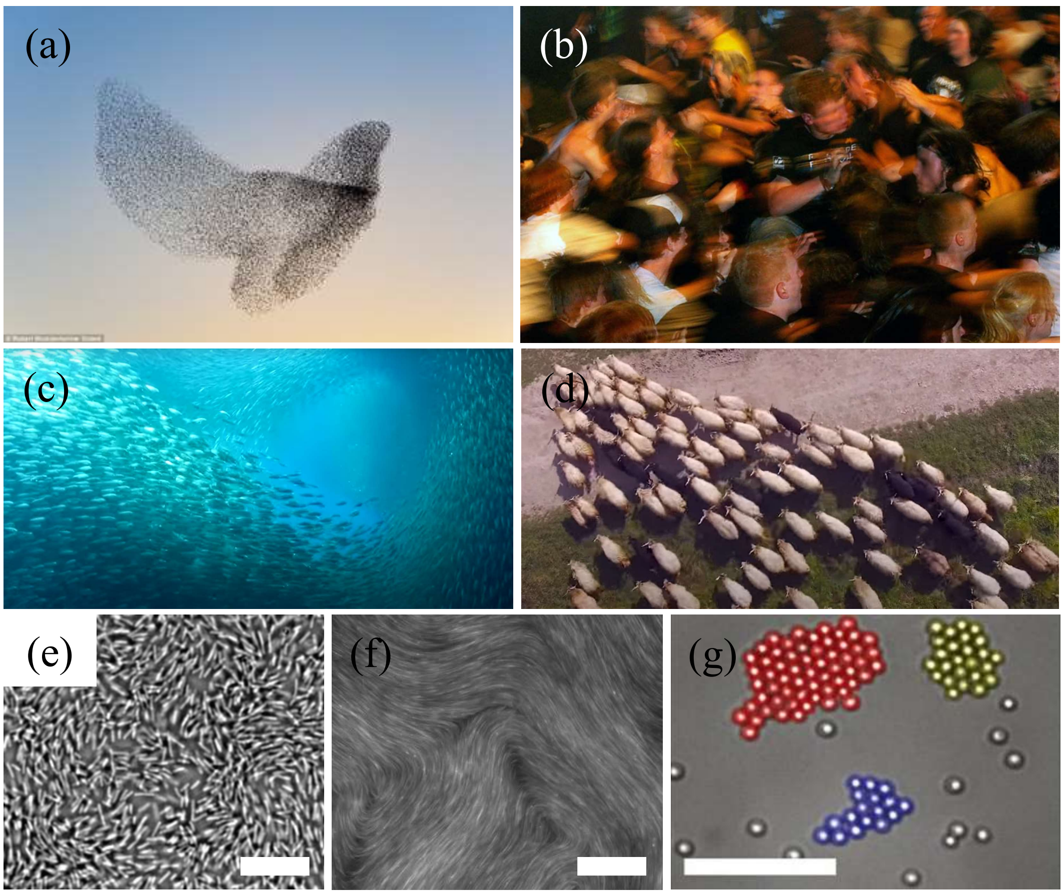

Figure 1.1: (a) Flocking birds, (b) people in a mosh pit at heavy metal converts, (c) schooling fish, (d) herding sheeps, (e) swarming bacteria (f) microtubule and (g) clustering active Janus particles. Scalebars in (e) and (g) are 10 µm. Scalebar in (f) is 200 µm. Images courtesy of Robert Wolstenhome (a), Ulrike Biets (b) [10], biographic (c, d), DeCamp (f) [19] and Palacci (g) [14].

Besides collective phenomena, active fluids also exhibits other emergent properties such as unusual diffusion and rheology. Polystyrene spherical tracer particles, typically a few microns across, show higher diffusivity in bacterial suspensions and active microtubules [20, 21].

1.2 Emergent Properties

1.3 Rheology

1.4 Collective motion

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