TECHNISCHE UNIVERSITÄT DARMSTADT

Thesis (B.Sc. / M.Sc.)
Chiral Active Matter with Nematic Order

Fachbereich 18
Elektrotechnik und Informationstechnik
Selbstorganisierende Systeme

Department 18
Electrical Engineering and Information Technology
Self-Organizing Systems

Prof. Dr. Heinz Koeppl
Head of lab

Sascha H. Hauck
Project supervisor

Rundeturmstraße 12
64283 Darmstadt

Phone: +49 6151 16 - 57 243
sascha.hauck@tu-darmstadt.de
https://www.bcs.tu-darmstadt.de

Date
March 22, 2022

Collective behaviour of large scale ensembles of agents or particles is ubiquitous in nature. It is often characterized by the emergence of regular spatio-temporal dynamics from a disordered state without any central coordination. Examples include colonies of bacteria, schools of fish, flocks of birds, groups of people, and many more [1, 2]. A popular model to analyse such dynamics is a system of self-propelled particles (SPPs) that align their direction of motion to the average heading in their neighbourhood. This model is known as the Vicsek model [3]. Under such an update rule the system either converges to complete alignment or remains in a disordered state. However, many of the experimentally observed collective dynamics do not fall into these two categories. More specifically, regular, coherent and irregular, disordered dynamics are present simultaneously. A genuine coexistence of dynamical regimes was originally found in networks of non-locally coupled oscillators and called a chimera state [4, 5]. This is a state of the particle system where groups of oscillators are synchronized while other oscillators undergo chaotic dynamics.

We recently showed that chimera states could also be found in systems of SPPs [6]. In that work, we investigated the parameter region of so-called in-phase coupling where particles tend to align with each other upon interactions. This results into the emergence of polar order of particle motion. We are interested to conduct the further research on collective behaviour that results from out-of-phase coupling. We believe that one might observe the emergence of nematic order, where two subpopulations move in opposite directions, in potential combination with chimera states. Nematic order has been observed in SPP systems [7, 8, 9], but exclusively under specifically designed rules that impose orientational division. In contrast to that, our model suggests a way to favour nematic interactions implicitly via a so-called phase lag parameter.

A potential candidate should be familiar with some of the following:

- Non-linear dynamical systems
- Partial differential equations
- Statistical / mathematical physics
- Numerical analysis of ordinary / stochastic / partial differential equations
- C++ and MATLAB / Python

For further information, please contact Sascha H. Hauck.

TECHNISCHE UNIVERSITÄT DARMSTADT

References

[1] T. Vicsek and A. Zafeiris. Collective motion. *Physics Reports*, 517:71–140, 2012.

[2] Gerhard Gompper, Roland G. Winkler, Thomas Speck, Alexandre Solon, Cesare Nardini, Fernando Peruani, Hartmut Löwen, Ramin Golestanian, U. Benjamin Kaupp, Luis Alvarez, Thomas Kiørboe, Eric Lauga, Wilson C. K. Poon, Antonio DeSimone, Santiago Muiñẽos Landin, Alexander Fischer, Nicola A. Soöker, Frank Cichos, Raymond Kapral, Pierre Gaspard, Marisol Ripoll, Francesc Sagues, Amin Doostmohammadi, Julia M. Yeomans, Igor S. Aranson, Clemens Bechinger, Holger Stark, Charlotte K. Hemelrijk, François J. Nedelec, Trinish Sarkar, Thibault Aryaksama, Mathilde Lacroix, Guillaume Duclos, Victor Yashunsky, Pascal Silberzan, Marino Arroyo, and Sohan Kale. The 2020 motile active matter roadmap. *Journal of Physics: Condensed Matter*, 32, 2020.

[3] T. Vicsek, A. Czirók, E. Ben-Jacob, I. Cohen, and O. Shochet. Novel type of phase transition in a system of self-driven particles. *Phys. Rev. Lett.*, 75:1226–1229, 1995.

[4] Y. Kuramoto and D. Battogtokh. Coexistence of coherence and incoherence in nonlocally coupled phase oscillators. *Nonlinear Phenomena in Complex Systems,*, 5:380–385, 2002.

[5] D. M. Abrams and S. H. Strogatz. Chimera states for coupled oscillators. *Phys. Rev. Lett.*, 93, 2004.

[6] Nikita Kruk, Maistrenko Yuri, and Heinz Koeppl. Self-propelled chimeras. *Phys. Rev. E*, 98, 2018.

[7] Francesco Ginelli, Fernando Peruani, Markus Bär, and Huguens Chaté. Large- scale collective properties of self-propelled rods. *Phys. Rev. Lett.*, 104, 2010.

[8] Aurelio Patelli, Ilyas Djafer-Cherif, Igor S. Aranson, Eric Bertin, and Hugues Chaté. Understanding dense active nematics from microscopic models. *Phys. Rev. Lett.*, 123, 2019.

[9] Sandrine Ngo, Anton Peshkov, Igor S. Aranson, Eric Bertin, Francesco Ginelli, and Hugues Chaté. Large-scale chaos and fluctuations in active nematics. *Phys. Rev. Lett.*, 113, 2014.