Universal non-locality in active systems

Nom des responsables du stage ou thèse: Cesare Nardini
(Theoretical & numerical internship, possibly leading to a Ph.D.)

Nom Laboratoire : SPEC, CEA-Saclay, and LPTMC, Jussieu
e-mail : cesare.nardini@gmail.com **Téléphone** : 06 32 33 27 70
Lieu du stage: Saclay and Jussieu **Stage pouvant déboucher sur une thèse** : OUI

In a nutshell: Describe the generic emergence of long-range correlations in active systems and their universal properties
Expected skills: Basic statistical mechanics methods. Interest in performing analytical and some numerical work

Active systems are formed of units that are able to extract energy from the environment and dissipate it while producing work, as for example by self-propelling. Examples are found everywhere in nature: flocks of birds, animal swarms, suspensions of bacteria and tissues are all biological active systems [1]. Artificial active systems have also been engineered in the lab using catalytic colloidal particles or micro-robots. A strong research activity emerged attempting at describing their collective behavior, with fundamental applications in understanding and controlling biological systems, and the long-term goal of engineering self-assembling materials using active units.

Being far from equilibrium, active systems display features that are in clear contrast with equilibrium ones. For example, systems with polar order (such as flocks of animals) are known to display long-range correlations that decay algebraically with the distance, even in the absence of long-range interactions [2]. These non-local properties are starkly different from those found in equilibrium systems: In those, short-range interactions imply (far from second-order phase-transitions), the absence of longe-range correlations. Moreover, active systems can display true long-range order even in two dimensions, evading the Mermin-Wagner theorem that forbids the existence of a ferromagnetic phase in, for example, the two-dimensional XY model at equilibrium. Recently, my group [3] and others [4,5] have understood that non-locality emerges even more generically in active systems when they do not display any global order.

In this internship, which is thought as a well-defined entry point in the subject and can be naturally continued to a Ph.D., you will study the emergence of non-locality in minimal active matter particle models and assess whether these are independent of system-details. The work will involve both analytical and numerical work (the balance of which can be tilted depending on your interests). If continued to a PhD, you will further study the effect of long-range interactions that are often present in real active systems, specifically the role of interactions mediated by the fluid in which active particles move.

The skills required are a Master-level training in theoretical or statistical physics; no experience on active matter or biophysics is required. What you do not know and is needed, you will learn!

[1] C. Marchetti et al., Rev. Mod. Phys. **85**, 1143 (2013). [2] Toner, Tu, PRE **58**, 4828, 1998. [3] F. De Luca et al., arXiv:2606.14483, 2026. [4] J. Metzger et al., arXiv:2606.14651, 2026. [5] T. Arnoulx de Pirey et al., PRX **14**, 041034, 2024