Counting Particles in Boxes:
What original metrics can we find to quantify collective dynamics?

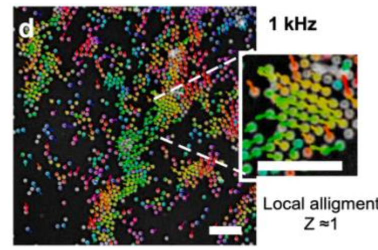

Fig.1. Spontaneously forming particle aggregates. From [1]

Understanding aggregate dynamics is crucial in many contexts: to achieve crystalline order in materials or to control bacterial colonization. Aggregates, in these out of equilibrium systems of colloids or bacteria, exhibit diverse behaviors: transient formation, emergent motion, and random reorientation (see Fig. 1). Multiple physical forces underly these phenomena: diverse interparticle interations (hydrodynamic, depletion, alignment), self-propulsion forces, and thermal noise which affects all processes and makes it hard to read out average features. Although in equilibrium systems it is common to quantify properties such as the collective diffusion of particles which characterizes relaxation of transiently forming groups of particles; strikingly, we lack dynamical parameters to quantify collective dynamics out-of-equilibrium. This prevents comparing theory to experiment and elucidating mechanisms.

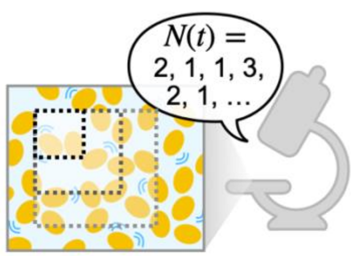

Fig.2. Principle of the Countoscope: Counting particles in boxes

To make progress on these questions, we will use a new analysis technique relying on number fluctuations called the ``Countoscope'' [2]. The principle is like a game! We count the number N(t) of particles (bacteria, colloids or cells) in analysis boxes over time. The number of particles in a box fluctuate due to microscopic dynamics such as diffusion, motility, attraction etc. Interpreting experimental N(t) requires building advanced theories – that remain to be established in this nonequilibrium context. These theories can then disentangle processes and quantify dynamics from the time-dependent statistics of N(t), e.g. by investigating different length scales by considering various analysis box sizes.

Here we will, on the one hand, analyze colloidal statistics in various ways on experimental images. On the other hand, we will develop minimal models to interpret these counts. This internship will be in collaboration with Alice Thorneywork (Oxford University) who investigates various colloidal suspensions experimentally. One starting point could be to understand the dynamic signatures in high order correlation functions (2^{nd} ,3^{rd}, or 4^{th} order).

The internship can lead to a PhD, with the aim of understanding dynamics undergone by various aggregating suspensions. On the long term, this could help us control **the colonization of surfaces by microorganisms**, since long-standing bio-aggregates preferentially form if aggregates are tighter.

Tools used: Analytical work and/or stochastic simulations, related to soft matter/statistical/biological physics

A few references

[1] Alvarez, L., Sesé-Sansa, E., Levis, D., Pagonabarraga, I., & Isa, L. (2025) ArXiv https://arxiv.org/abs/2506.15188

[2] Mackay, E. K., Marbach, S., Sprinkle, B., & Thorneywork, A. L. (2024) Phys. Rev. X https://doi.org/10.1103/PhysRevX.14.041016

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Funding for the internship: YES;

Funding for the PhD: Not guaranteed, but we will support the student to obtain funding (many options)