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Dynamical properties of pure and mixed active matter suspensions

From cytoskeletal dynamics (molecular level) and bacterial swarming (cellular level) to flocks of birds and human crowds (macroscopic level), collections of actively moving interacting agents, also called "active matter", can display unexpected emergent properties [1,2]. Understanding these properties within the framework of a general theory of active matter is a challenge which is currently driving this rapidly growing area of physics. Some of the most important examples of active matter are at the microscale, and include active colloids and suspensions of microorganisms, both as a simple active fluid (single species) and as mixed suspensions of active and passive elements. In this last class of systems, recent experimental and theoretical work has started to provide a window into new phenomena including activity-induced depletion interactions [3] and phase separation [4,5]; and the possibility to extract net work from active suspensions [6]. The ability to govern collective behaviour of such systems could lead to applications ranging from drug microdelivery to bioremediation.

To achieve external control of active matter, we need to critically advance our understanding of the dynamical properties of active suspensions. Theoretical and numerical work has recently explored whether it is possible to develop a thermodynamic approach to active matter [7-9], with efforts focussing in particular on the possibility to define a meaningful pressure and therefore something akin an equation of state. Unfortunately, progress in this area is hindered by the almost complete lack of experimental results.

We have recently developed a simple experimental system to study the behaviour of microorganismal suspensions which are self-compressing through the microswimmers' response to an external stimulus (light), allowing us to tune experimentally the local microorganismal concentration.

The project will build on (and develop) this system to address the following two main points:

1. **Phases of active matter**: Our preliminary results have shown evidence of phases similar to a jammed, liquid and gas states, separated by transition regions. You will develop a quantitative understanding of this phenomenon and a theoretical model to understand its behaviour;
2. **Transport properties in mixed systems**: Building on current research in our group unraveling the physics of colloid-swimmer interactions [10,11] we are interested in understanding how external control of the dynamics of the active component (e.g. induced microswimmer anisotropy/

inhomogeneity) can be used to alter the transport of passive cargo (see also [12]). You will begin by looking at the effect of physical confinement (for which we already have promising preliminary results) and external light stimuli. The work will be based on a combination of experiments, numerical and theoretical modelling.

This project will build on ongoing collaborations with Dr. Idan Tuval (IMEDEA, Spain) expert in modelling and numerical simulations of microorganisms; and Dr. Giorgio Volpe (UCL), an expert in optics and active colloids.

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