Complex optical environments for the study of active systems

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Abstract

From bacterial colonies to bird flocks and human crowds, collective behaviours offer advantages for predator evasion, foraging efficiency, and collective decision-making. Such group behaviours emerge and persist based on how individuals interact with each other and with the environment around them.
Here, we have used optics to create complex yet controlled environments and studied their effect on the dynamics of active systems. Along this general idea, this work explored two directions:

- **active colloids:** we studied the effect of spatial patchiness in the environment on the group formation of active colloids (Janus particles). We demonstrated a non-monotonic relationship between environmental heterogeneity and group dynamics; specifically, we observed that groups become smaller and more stable when the patchiness of the energy landscape is comparable to the size of the particles. Our results provide insights into the importance of patchy landscapes and uneven energy distributions in active matter and hold implications for refining colloidal self-assembly. **microalgae:** we investigated the swimming behaviour of micro-algae in tailored laser illuminations in confined microfluidic chambers. We demonstrated that the run-and-tumble motion of *Chlamydomonas* is characterised by a tumbling frequency that depends both on the local light intensity and the local light gradient. In particular, when exposed to a ring-shaped illumination, the micro-algae tend to climb up the light gradient and accumulate inside the ring. These results bring new insights into the modulation of the motility of *Chlamydomonas* by light and suggest that these cells are capable of adapting their motion both to the light direction and to its gradient.

In conclusion, optics not only represents a unique tool to understand the relevance of environmental characteristics on collective behaviours, but it could also serve to design novel strategies to control the dynamics of both synthetic and biological active systems.

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