Various phases of active matter emerging from bacteria and some future perspectives

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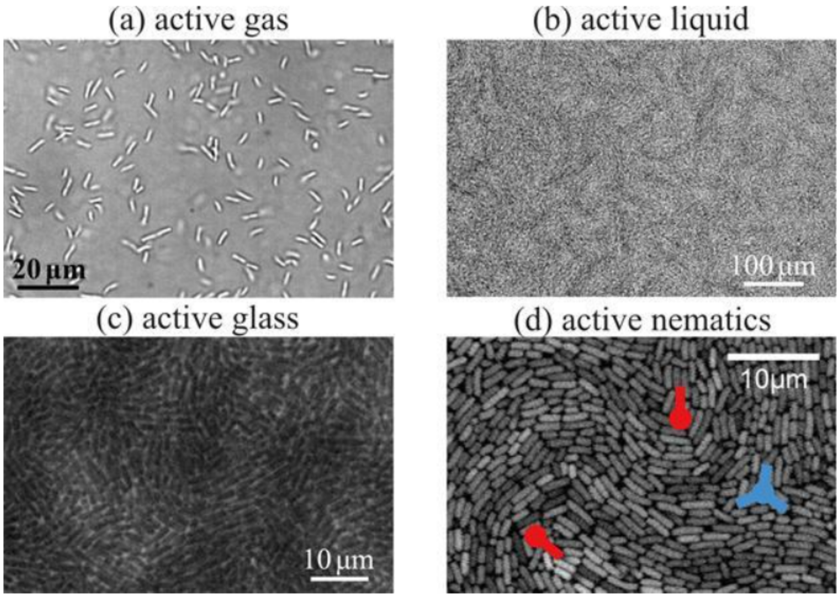
Populations of bacteria have been one of the model experimental systems model for studying the rich collective dynamics of active matter, as they often allow for comparison with theoretical models and are also linked potentially to various life phenomena. Recent studies of dense bacterial populations have highlighted this aspect even more, showing that various phases of active matter arise (see figure) and bring rich implications for both physics and biology. Based on this background, I will feature active gas, active liquid, active glass and active liquid crystal states observed in bacterial populations and discuss how these differ from their thermal counterparts, mentioning some future perspectives. The talk will be partially based on a perspective article [1] that the speaker co-authored recently.

Among the different phases observed in bacteria, the active gas state, i.e., dilute suspension of bacteria swimming more or less independently, is arguably the simplest. Nevertheless, it shows interesting features that would be impossible for thermal systems, such as spontaneous rectification and concentration. This aspect is even more pronounced in the active liquid state, characterized by strongly correlated motion of swimming bacteria in dense suspension. Besides a well-known demonstration of the ability of bacterial suspension to turn a suspended gear, the speaker's group recently showed the emergence of topological edge states, akin to those studied in condensed matter systems. When bacterial suspension becomes even denser, it can transition to glassy states. There are two recent experiments that showed bacterial glass transitions, one from the speaker's group, which interestingly reached different conclusions about the relationship of translational and orientational degrees of freedom near the transition. I will overview and compare the two experiments and propose a scenario to interpret the two conclusions consistently. Finally, dense bacterial populations are also known to develop orientational order akin to that of nematic liquid crystal. I will review some studies showing characteristic properties of topological defects in such active nematic systems and discuss their potential relevance to biofilm formation. The talk will be concluded with the speaker's view on the potential role of active matter physics in life sciences.



Various phases of active matter observed in bacteria [1]. The panels (a)(b) are adapted from [1], (c) from [2], and (d) from [3].

References:

[1] K. A. Takeuchi and D. Nishiguchi, arXiv:2604.13575.

[2] H. Lama et al., PNAS Nexus 3, pgae238 (2024).

[3] T. Shimaya and K. A. Takeuchi, PNAS Nexus 1, pgac269 (2022)