Emergent Self-Organizations of Dense Active Droplet Systems

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Self-organization refers to the emergence of ordered arrangements in systems without external intervention. It occurs due to the local interactions between individuals and is often far from equilibrium. This phenomenon is observed in nature, including bird flocking, fish schooling, and cellular slime molds. Inspired by these living organisms, synthetic chemicals and theoretical models are generated to investigate self-organized patterns and non-equilibrium dynamics. However, developing synthetic systems to generate complex group organizations with tunable interactions that provide experimental evidence for simulations has been challenging. Active single emulsions are excellent systems for probing self-organization due to their ease of manipulation and adjustable interaction strength. Individual emulsion droplets can move along chemical gradients and interact with neighboring droplets. Chasing behavior is a type of non-reciprocal interaction between two droplets where complex dynamics are known to arise within groups of droplets. In this work, we aim to investigate the self-organization of a high number density of chasing droplets. First, we experimentally explore factors affecting the self-organization of droplets and qualitatively summarize various organized patterns. Then we use theoretical calculations to quantify experimental results and develop a theoretical model to simulate the behaviors of chasing droplets. By integrating simulations with experiments, we can predict and rationalize the collective organization of group droplets under different conditions. Our work demonstrates how chemically minimal systems can achieve diverse organizational patterns and collective behaviors reminiscent of biological systems.