COLLECTIVE BACTERIAL DYNAMICS IN CURVED SPACES

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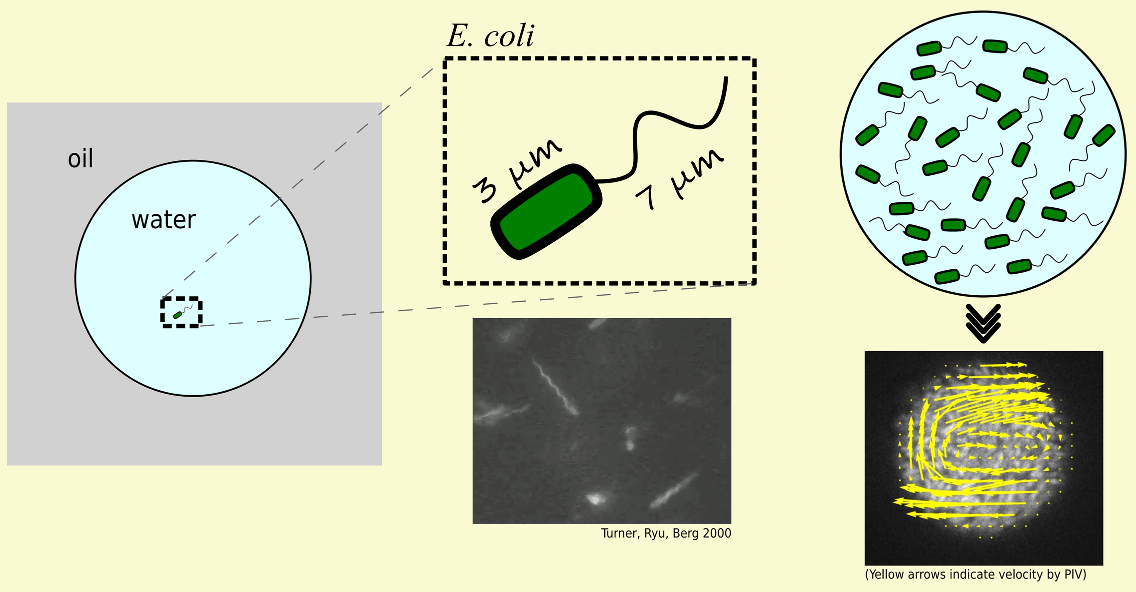
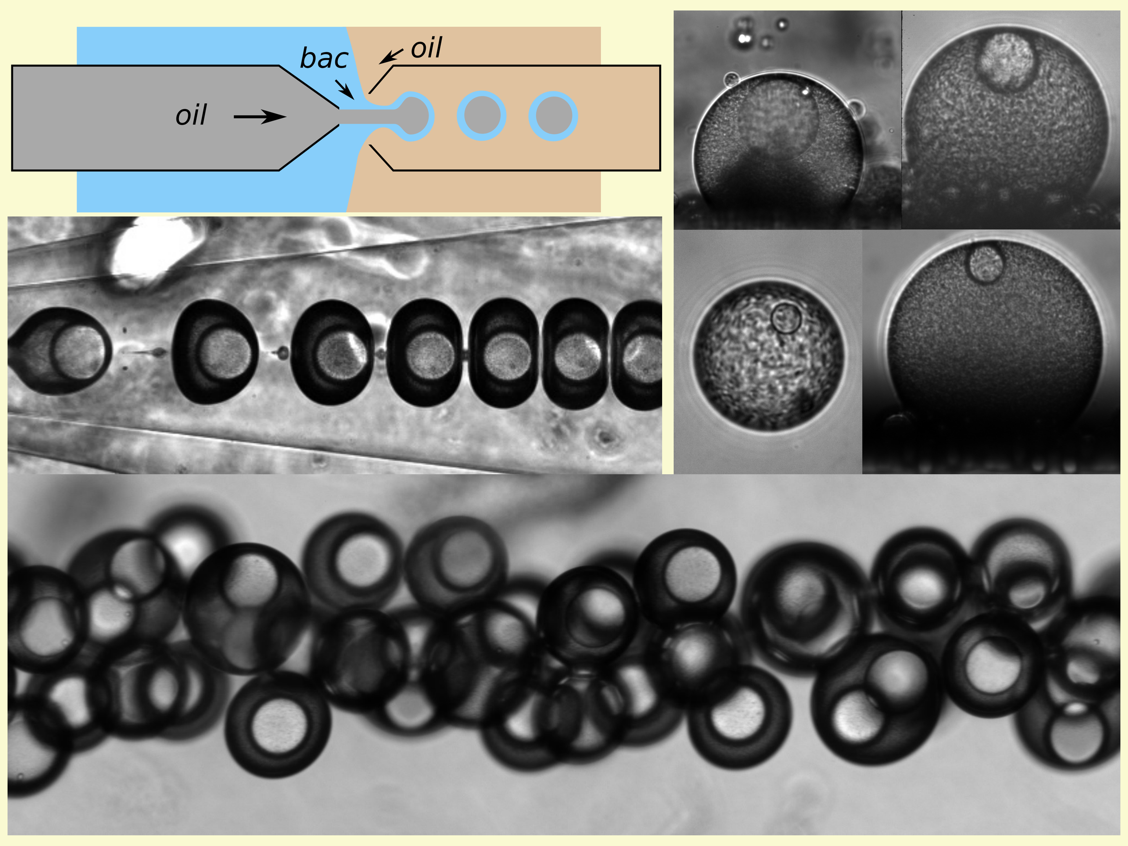
Project description

Under confinement, active matter behaves differently and exhibit novel original nonequilibrium phenomena. In this project, we investigate the collective dynamics of E. coli bacteria in droplets, a type of curved confinement ubiquitous in nature and industry. By contrasting with the observations in bulk, we reveal the unique role of confinement in active matter and gain insights into its biological and ecological significance.

Experiment

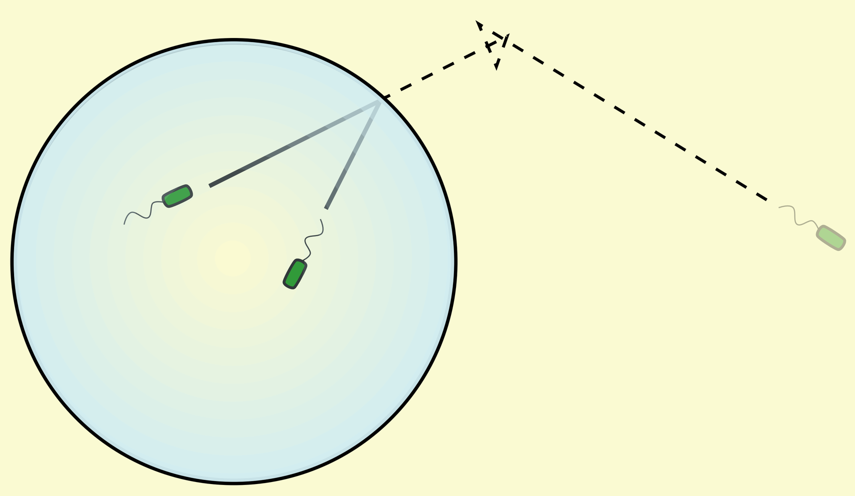
E. coli is the most common and well studied organism which is now widely used as a model system for investigating the properties of active matter.



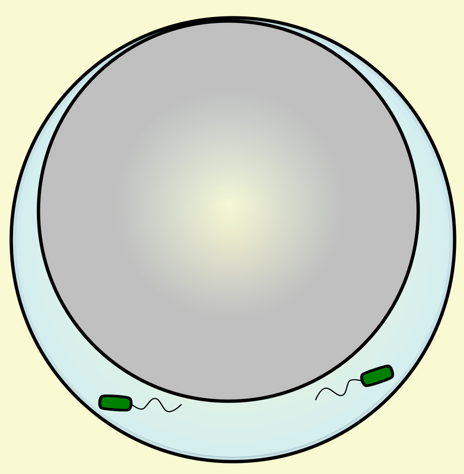


Double emulsion microfluidics are recently developed technique that can provide us with well controlled geometries to study confinement effects.

Confinement

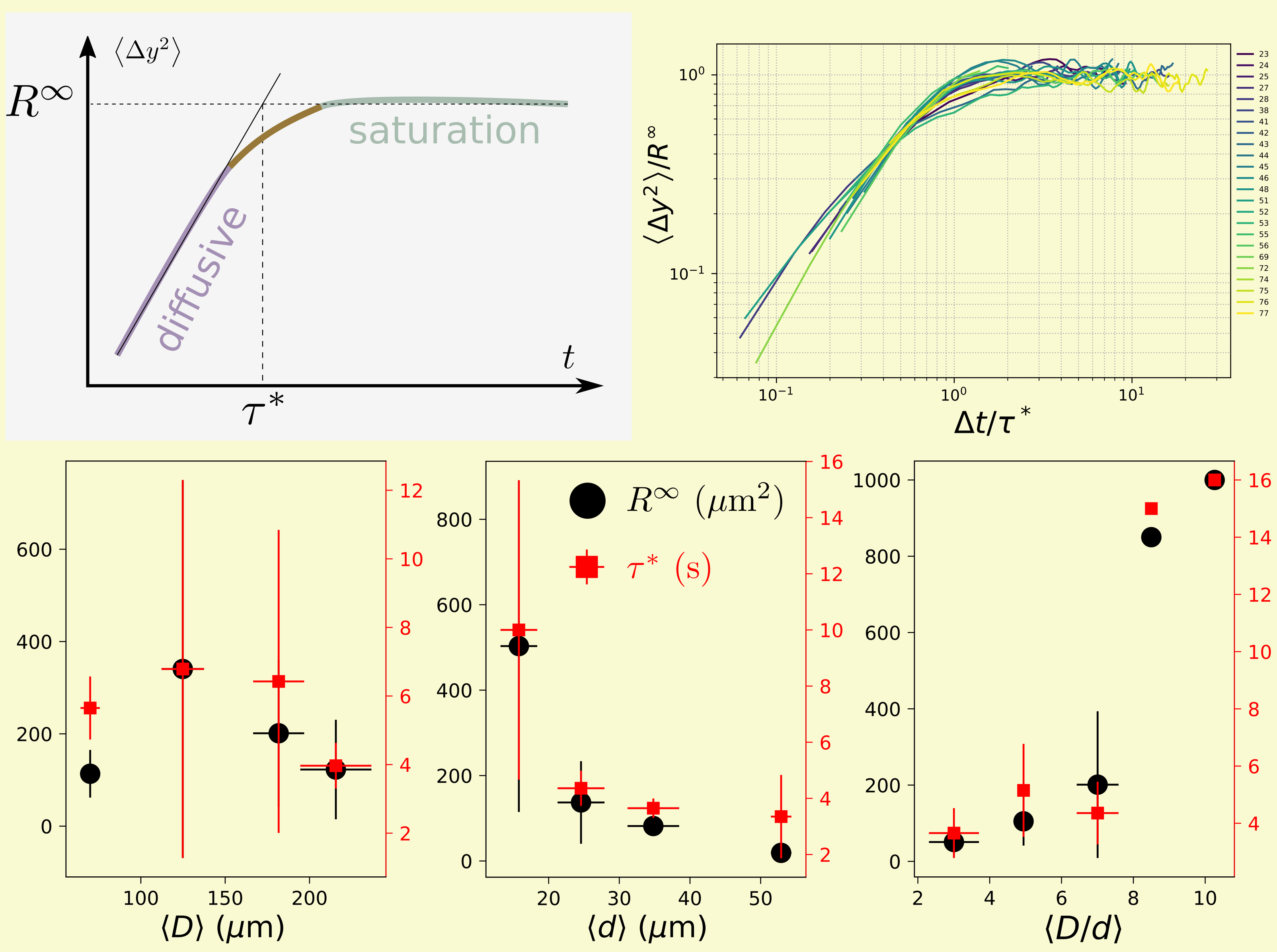


Cut off natural swimming paths



Thin shell - reduced dimensions

"Random" walk in curved space



Swimming bacteria produce fluctuations, which lead to motions of the oil inner droplets. At low bacterial concentration, the mean square displacement (MSD) of inner droplets shows a diffusive regime at short times due to such fluctuations, followed by a saturation at long times due to the curved confinement. The saturation value Rinf, as well as the transition time tau*, are used to characterize the bacterial fluctuations.

At high bacterial concentration, the MSD of inner droplets shows a superdiffusive regime at very short times, which can likely be attributed to the emergence of collective motion. A new time scale of the superdiffusive-diffusive transition arises. How such time scale couples with the collective motion time scale, and how they are influenced by the curved confinement, are intriguing questions to study further.

Stochastic model

fluctuating velocity

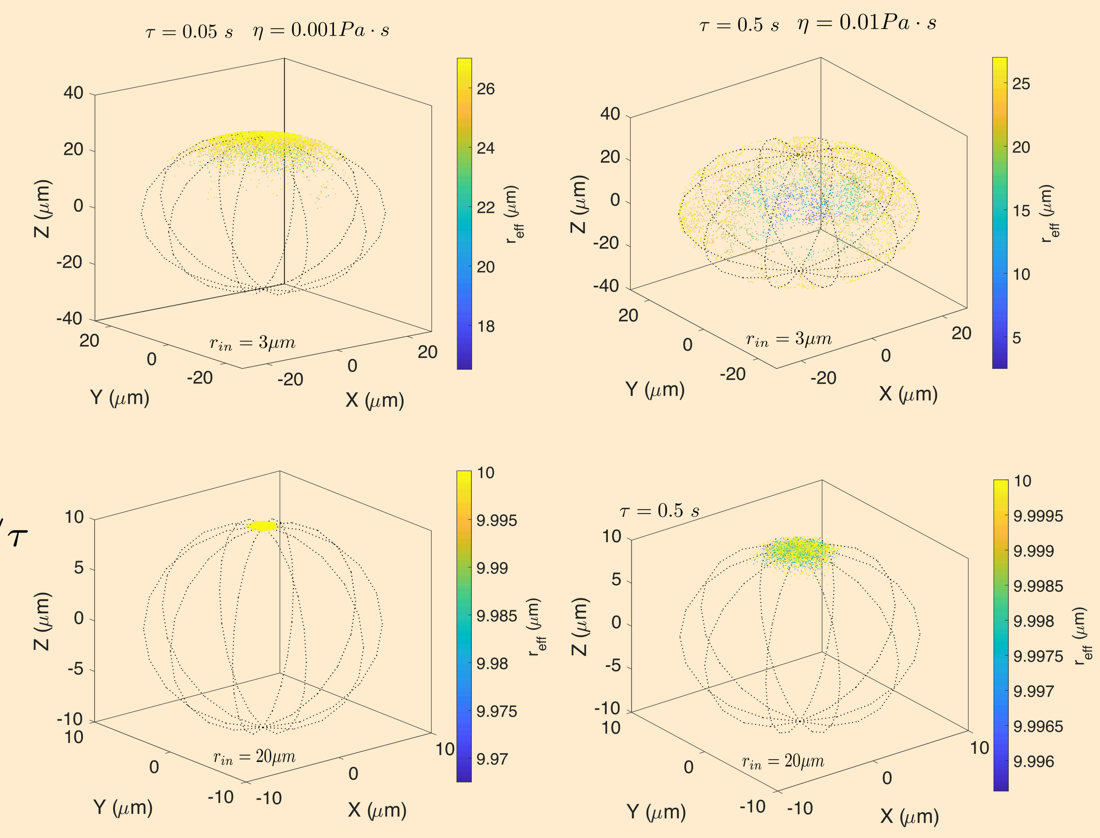
$$\dot{\mathbf{r}} = \mathbf{u} - \tilde{v}\hat{\mathbf{z}}$$

sedimentation velocity

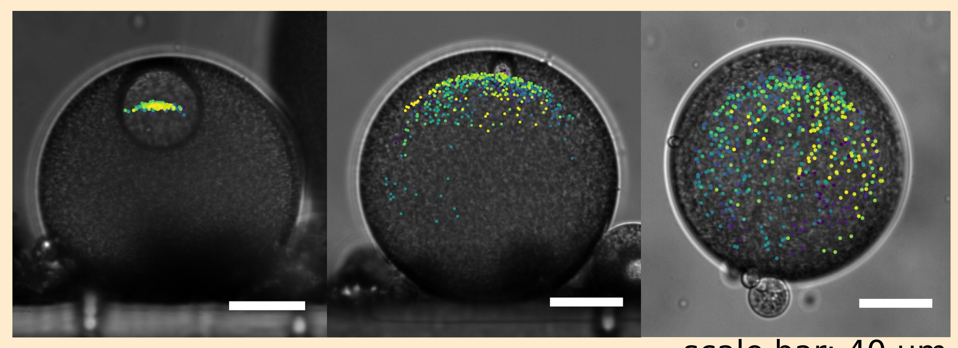
$$\langle \mathbf{u}(\mathbf{t}) \rangle = 0$$

$$\langle u_i(t) u_j(t') \rangle = v_b^2 \delta_{ij} e^{-|t-t'|/\tau}$$

$$\tilde{v} = \frac{2 r_i^2 g \Delta\rho}{9\eta}$$



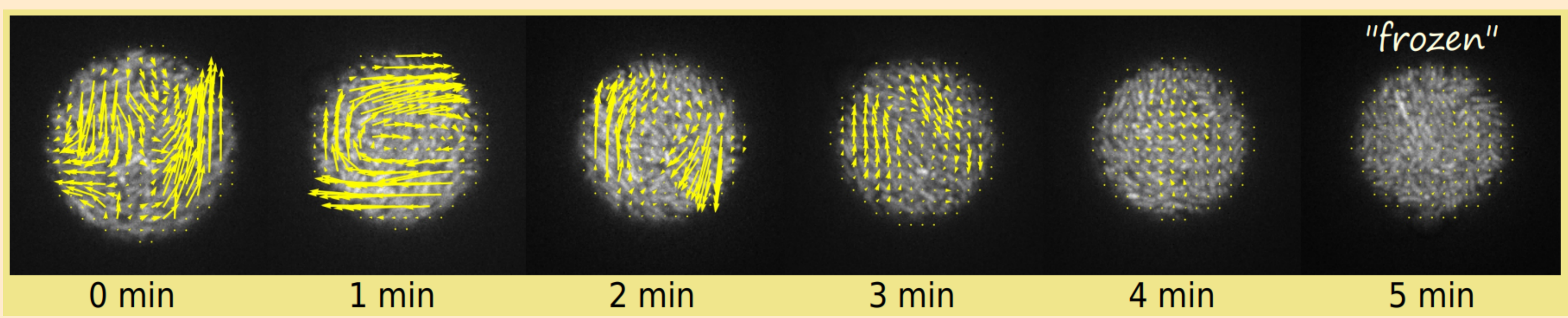
An Ornsetein-Uhlenbeck process is used to produce the exponentially correlated fluctuating velocity.

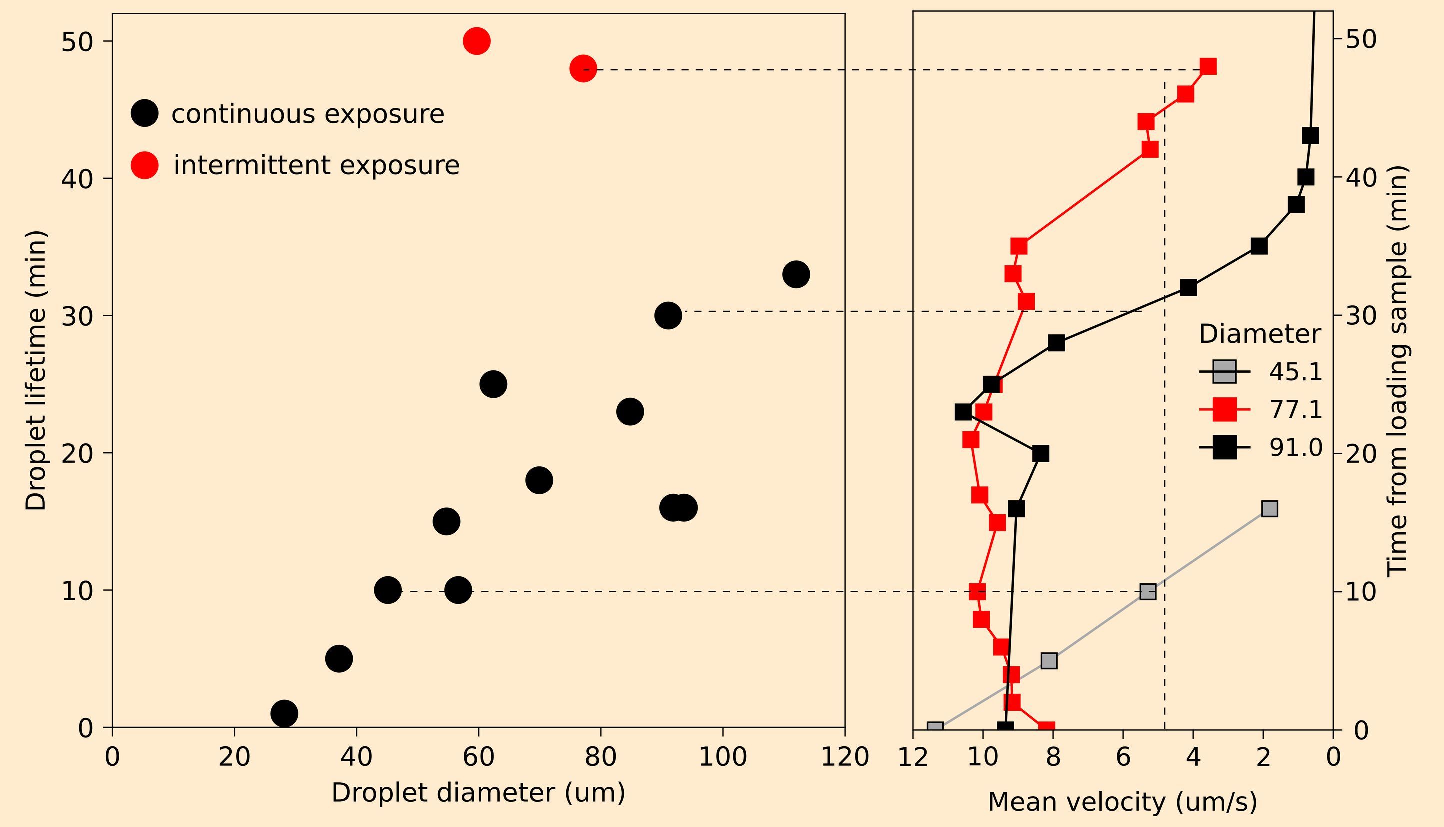


scale bar: 40 μm

Collective motion and jamming

The emergence of collective motion leads to more interesting phenomena and further complicates the experiment. For example, the "jamming" in dense bacterial droplet makes it difficult to obtain steady states.





The time dependence of bacterial motion makes quantitative measurements impossible. Hence, we take a step back and look into the "jamming" phenomenon. A robust size dependence is identified: smaller droplets jam faster. We also notice a correlation between the jamming time scale and light exposure time. Future experiment protocols at high concentration will adapt to these observations.

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