

COLLECTIVE BACTERIAL DYNAMICS IN CURVED SPACES

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Short project title: **BACURV**

Project description

Under confinement, active matter behaves differently and exhibit novel original non-equilibrium phenomena. In this project, we investigate the activity of *E. coli* bacteria confined in droplets, a type of curved confinement ubiquitous in nature and industry.

We are particularly interested in understanding the joint role of confinement and curvature on the effective "temperature" of an active suspension bath and also reveal in this situation, the onset of collective motion of the active swimmers.

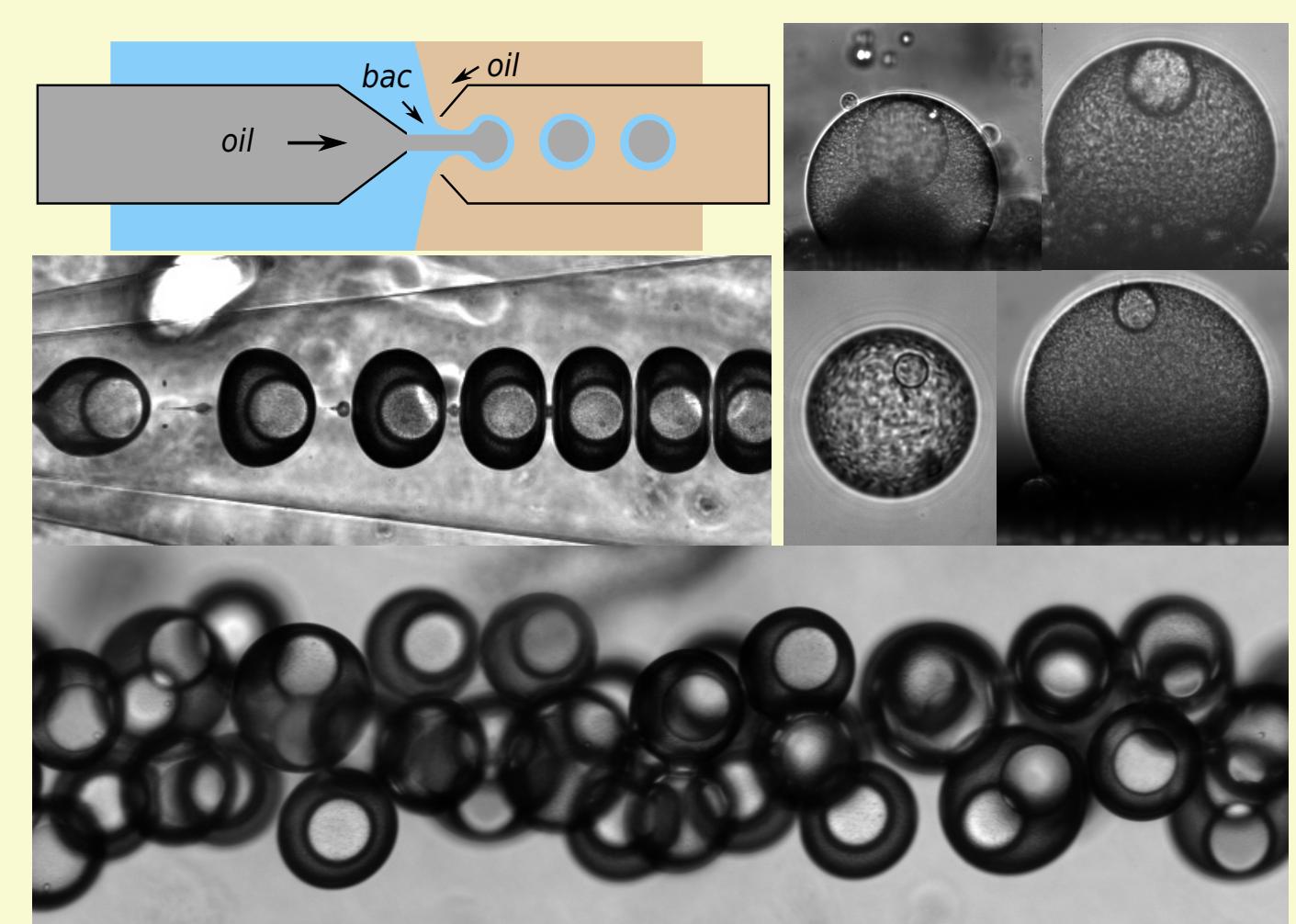
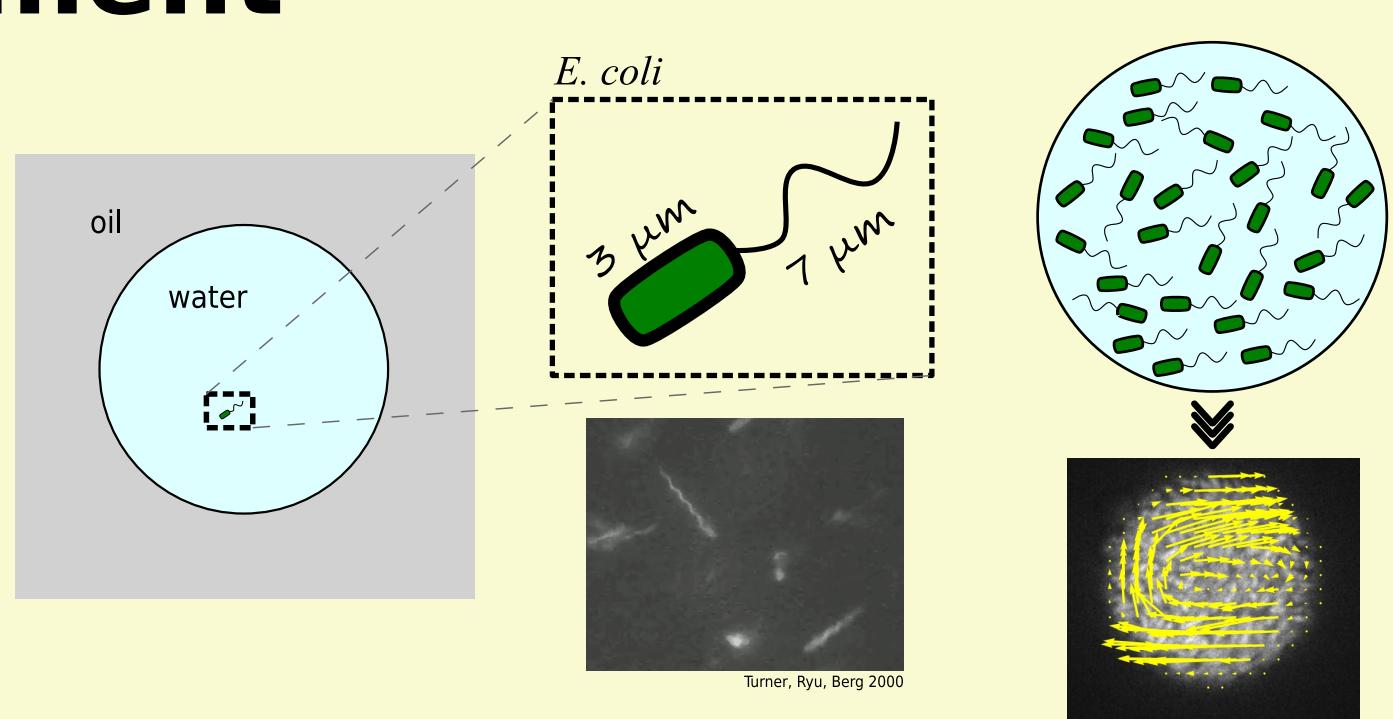
I - To this end, we develop a technique of active double emulsion where curvature and confinement can be varied independently. The observation, are made in a confocal microscope that can be placed on a rotating cradle so that, non-only the dynamics in the horizontal XY plane can be observed but also in the vertical YZ plane. We monitor and characterize the fluctuations in position of the inner droplet and extract the mean-square displacement as a function, of the model parameters (OD (concentration), inner droplet diameter d and outer droplet diameter D).

II - These data are analyzed under the scope of a stochastic model describing the motion of a particle inside an effective thermal bath with colored noise under the influence of gravity and constrained to move in a spherical confinement.

III - A high concentration we observe the onset of collective motion. To be able to control the activity during time of the experiment, we came back to the situation of a single droplet of dense active suspension. We looked at the conditions for which a constant activity can be sustained for long times.

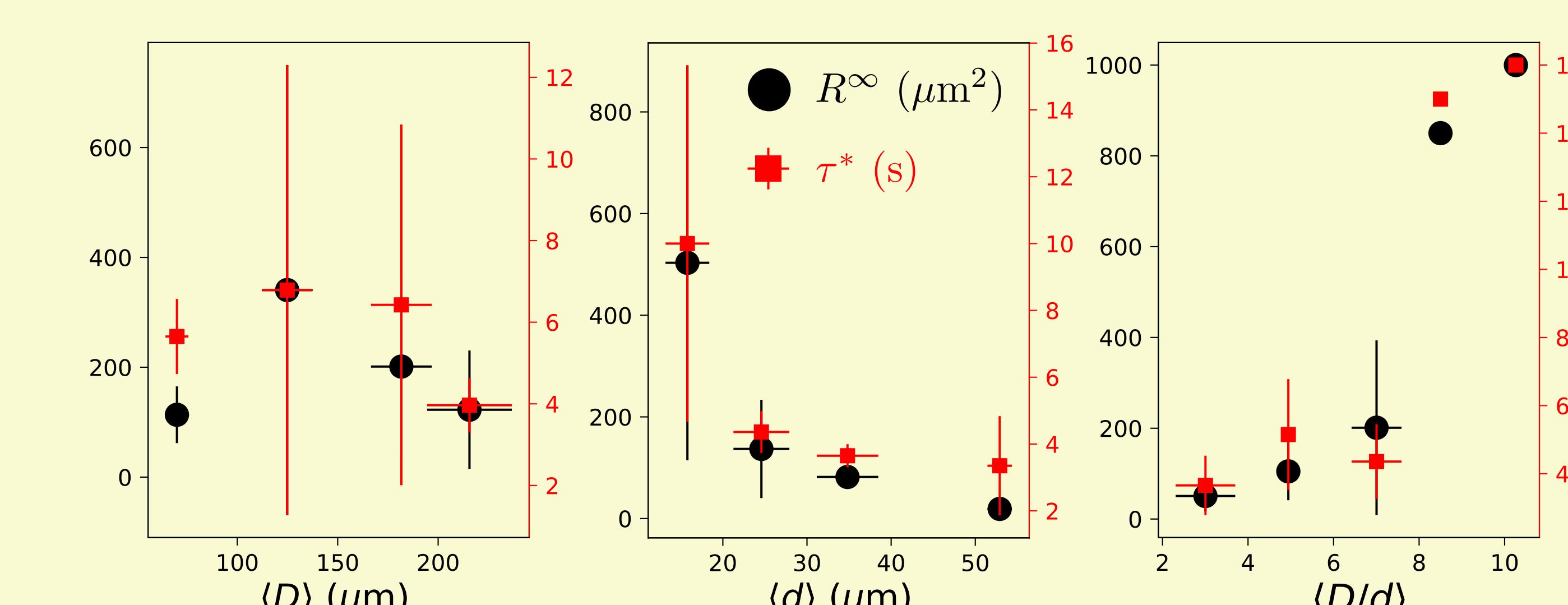
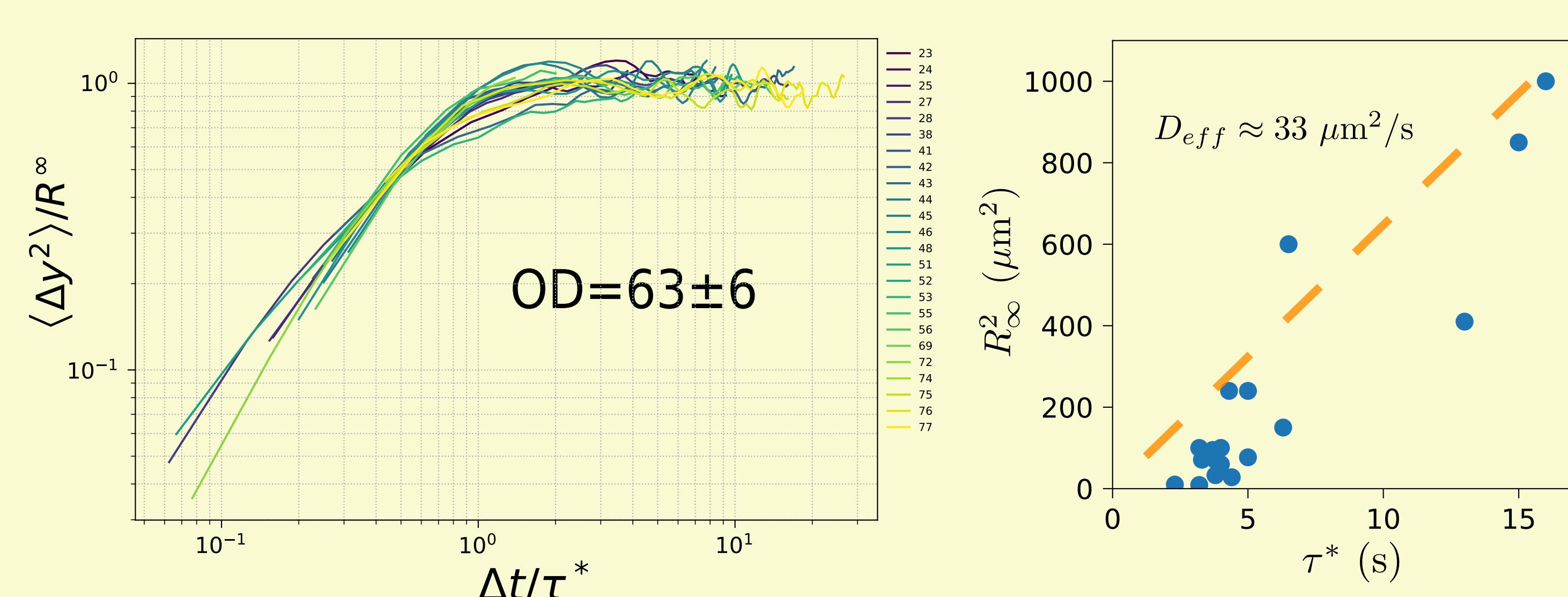
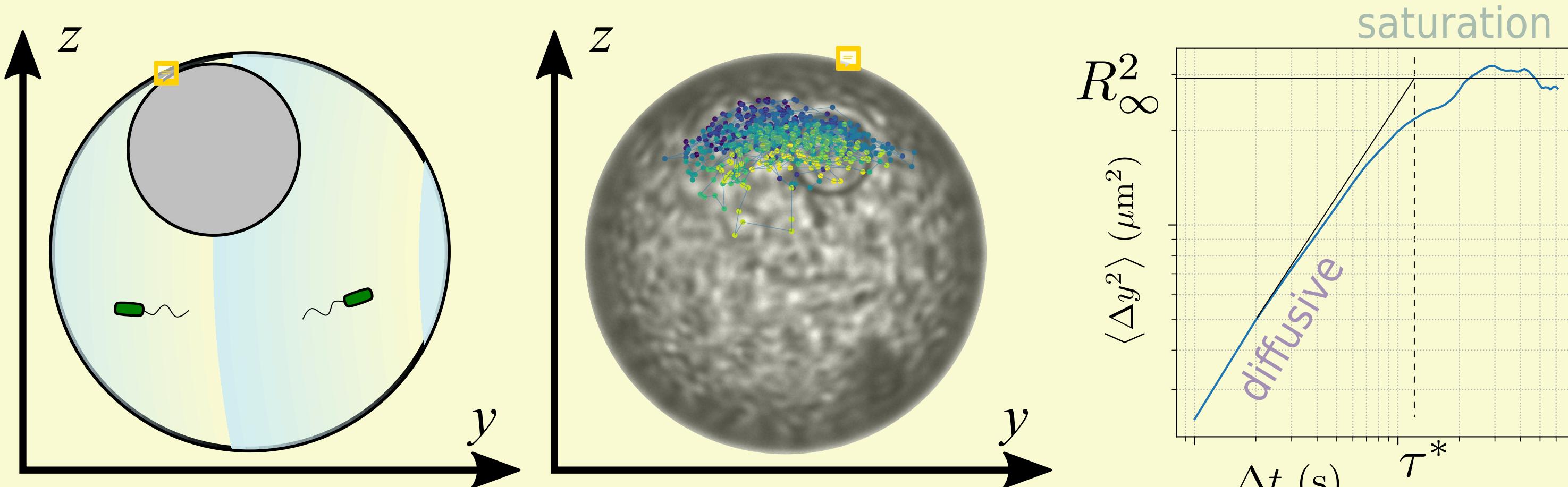
Experiment

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 microfluidic device is recently a developed technique that can provide us curved confinement with well controlled geometries.

Confinement and curvature



Swimming bacteria produce fluctuations, which lead to a stochastic 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, followed by a saturation at long times due to the curved confinement. For example from the temporal fluctuations of the Y axis position of the inner droplet we extract a saturation length and a saturation time. At a given concentration the relation is diffusive. The saturation length increases with the diameter ratio.

Stochastic model

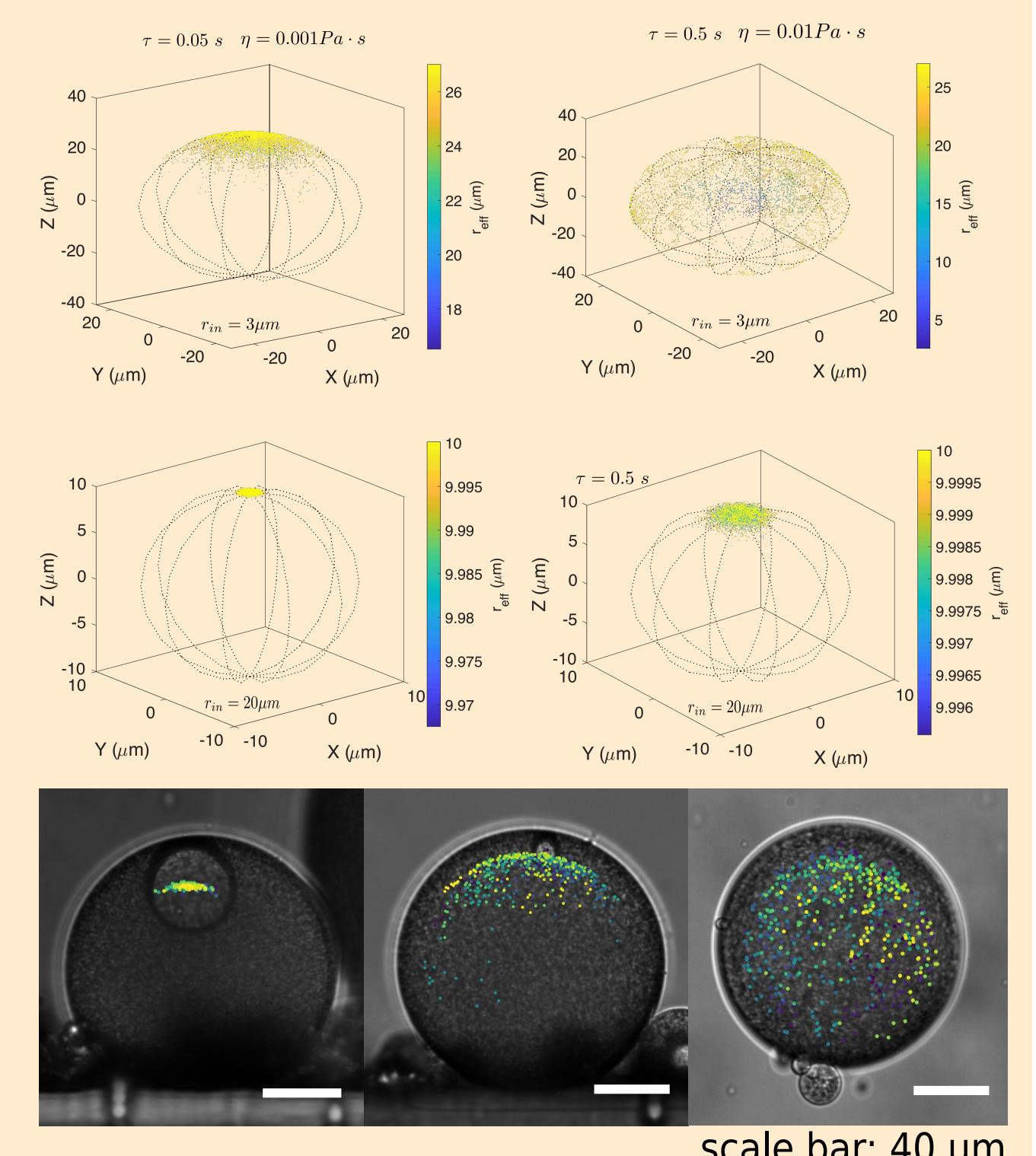
The model is the description of a spherical particle inside a bacterial bath with the influence of gravity and constrained to move inside of a sphere. The system of equations that describe the motion of the inner droplet is given by:

$$\begin{aligned} \dot{x} &= u_x \\ \dot{y} &= u_y \\ \dot{z} &= u_z - \frac{m^* g}{\Gamma} = u_z - \tilde{v} \end{aligned}$$

Where u_i is the fluctuating velocity produced by bacteria, m^* is the buoyant mass, g is the gravity and Γ is the viscous friction coefficient. The velocity produced by bacteria is an active noise that is exponentially time correlated,

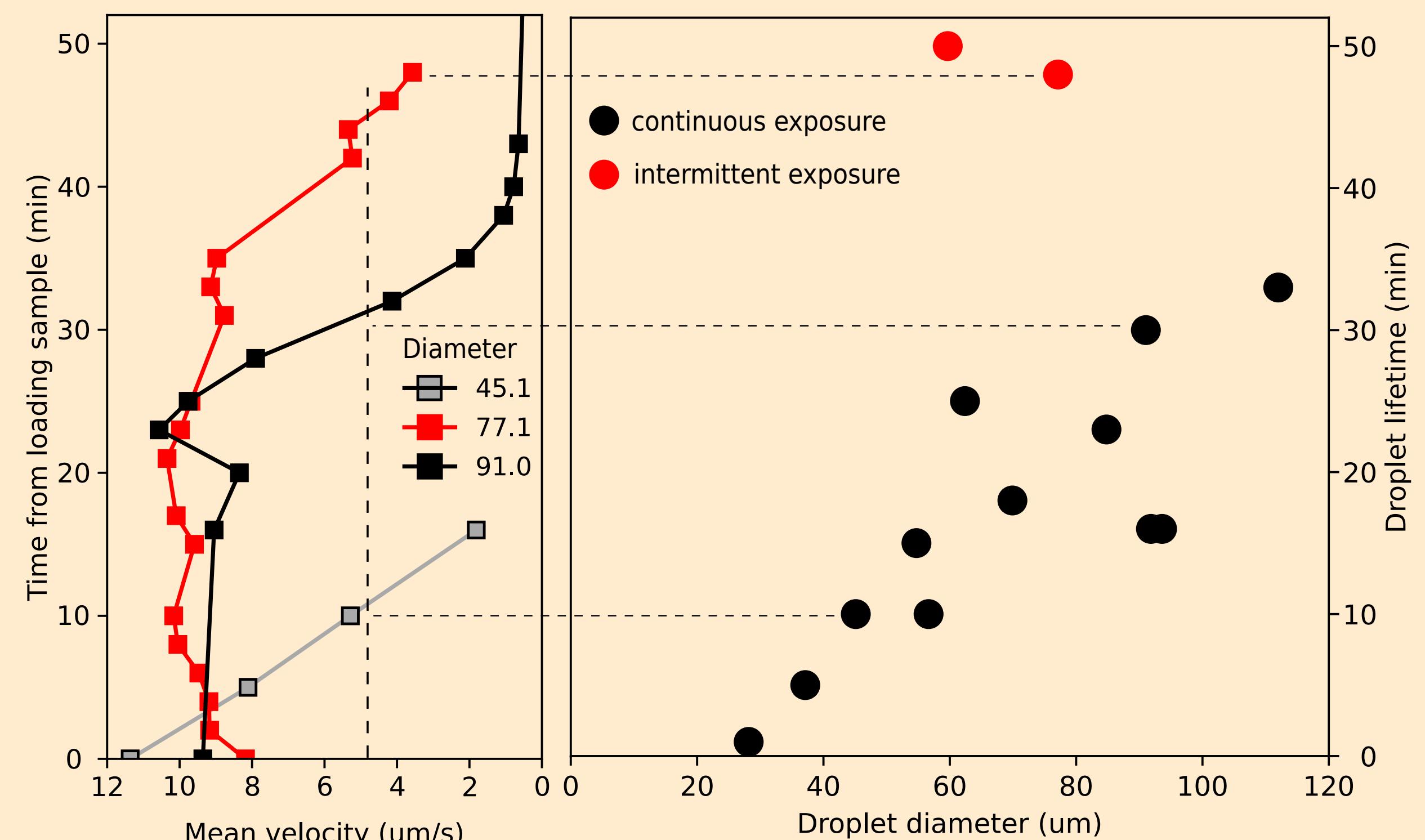
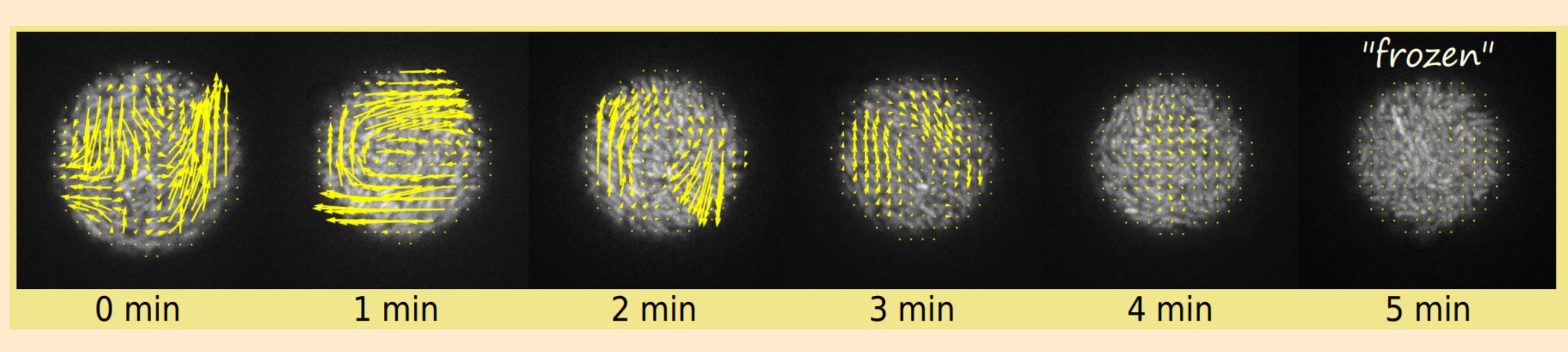
$$\langle u_i(t) u_j(t') \rangle = A_{ij} \delta_{ij} e^{-\nu|t-t'|}$$

with $\nu = \tau^{-1}$ and τ is the correlation time.



Collective motion and jamming

At high bacterial concentration, the MSD of inner droplets shows a super-diffusive regime at short time scales, which can be attributed to the emergence of collective motion. A new time scale of the super-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. To understand these features, we came back to the question of collective motion in a single droplet and observed a time dependent jamming effect that depends on the droplet diameter. This evolution of the activity followed by a strong jamming is somehow problematic as we would like to obtain steady state activity conditions. We found that this time scale can be sensitive to the effective duration of the blue excitation light and also to oxygen supply.



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.

Conclusions and perspectives

For the second year, we wish to continue, complete and quantify the experimental data through the stochastic model in order to clarify the notion of "active thermalization" for a wide range of bacterial density up to collective motion. From an experimental point of view we will also try to set up an automatic Lagrangian tracking of objects within the active droplets. Then we want to approach the second part of the project where we will insert within these active emulsions, structures of different shapes in order to look for example at the degrees of freedom in rotation. These structures of controlled shapes will be manufactured by the ESPCI nanoprinter.

Acknowledgement

