BACTERIAL DYNAMICS IN CURVED SPACES

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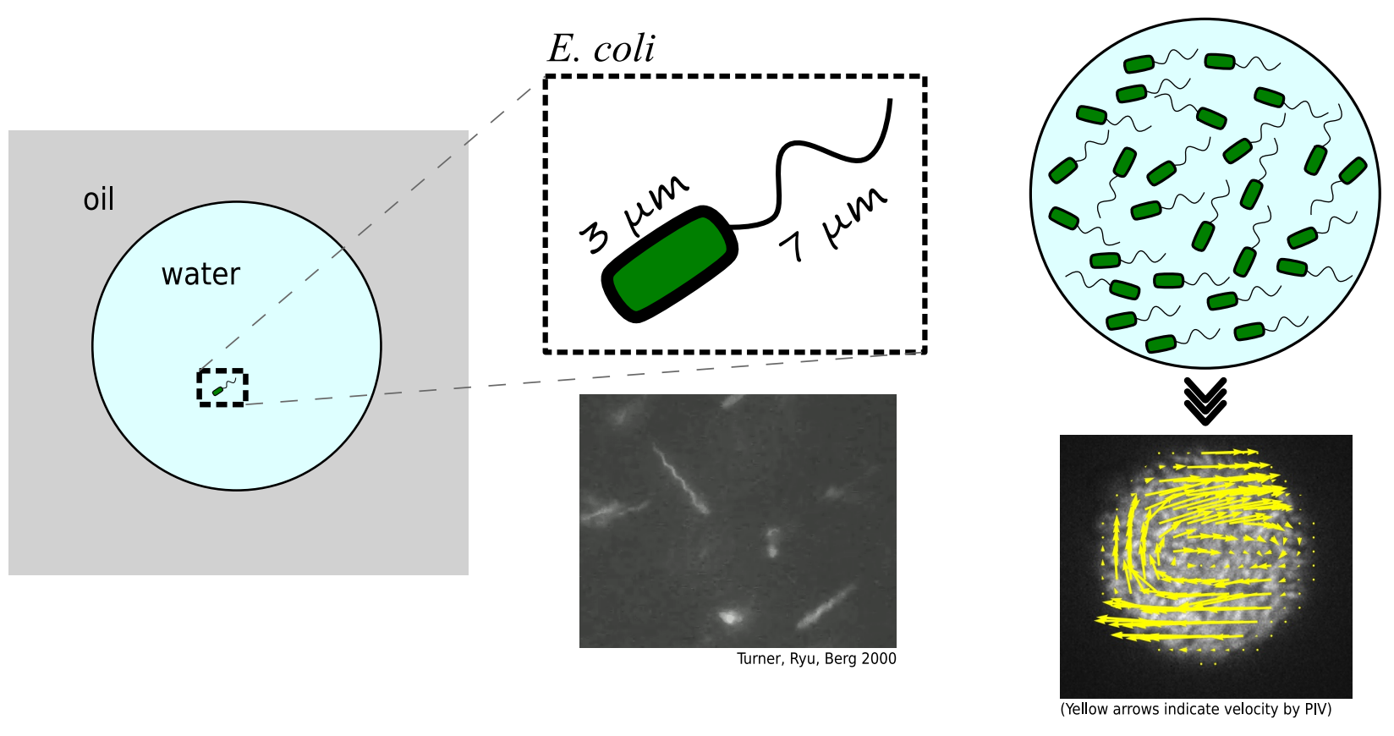
Short project title: **BACURV**

Project description

The interplay between complex environments and active matter suggests a possibility to control and engineer active matter by carefully designing the confinement structures. It is now well established that confinement may influence transport, rheology, pressure, spatial distribution and collective motion of active matter. Curved confining walls, which are ubiquitous in biological systems, show their own, specific rich and intriguing effects on active matter. Here, using a double emulsion system, where the inner and outer droplet sizes can be independently controlled, we experimentally investigate the influence of curved confinement on an active bath of *Escherichia coli* bacteria. In particular, we analyze the fluctuations of the inner droplet using the framework of a stochastic "active noise" model, and show that the strength of active noise is not an intrinsic property of an active bath, but depends on the confinement curvature. Our results pose new challenge to active matter theory and suggest new methods to control active matter.

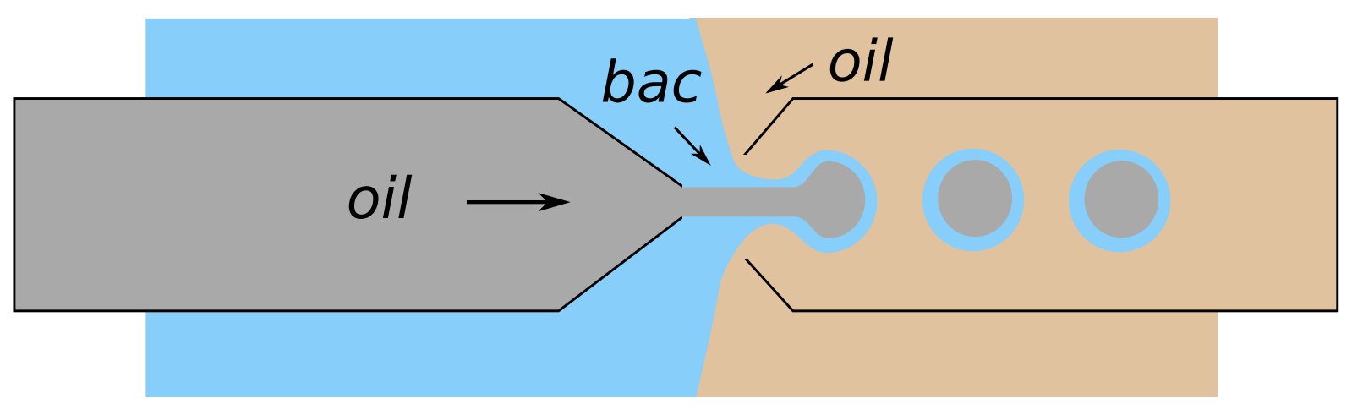
Experiment

E. coli: a run and tumble strain, which is genetically modified to carry green fluorescence protein.



Turner, Ryu, Berg 2000

(Yellow arrows indicate velocity by PIV)



Double emulsion:
Outer phase: hexadecane + 1% SPAN80
Middle phase: E. coli suspension + 1% PVA
Inner phase: hexadecane + 1% SPAN80

Rotating microscope:
The observation is made with a 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 by extracting the mean square displacement as a function of the model parameters (OD (concentration), inner droplet diameter d and outer droplet diameter D).

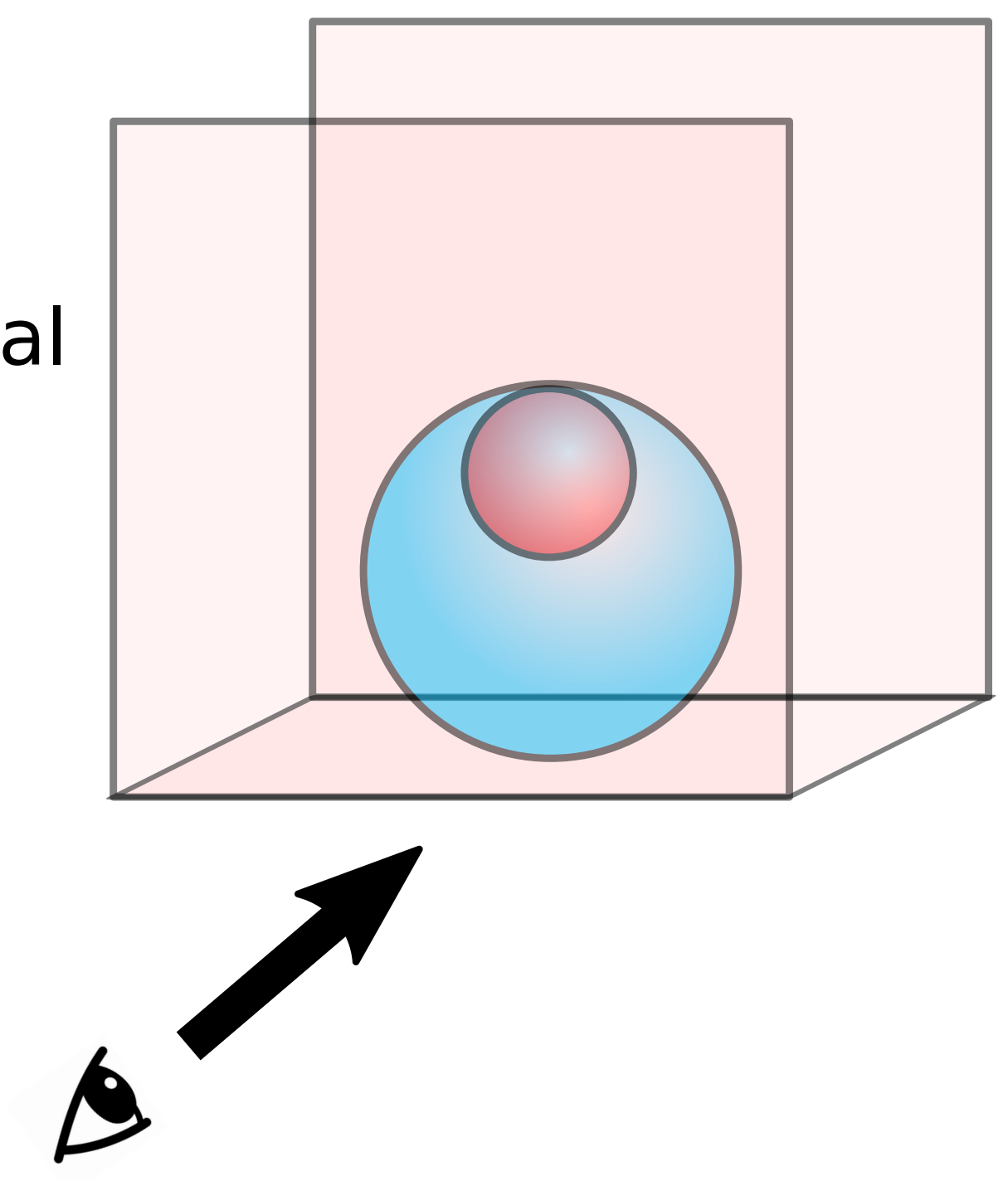
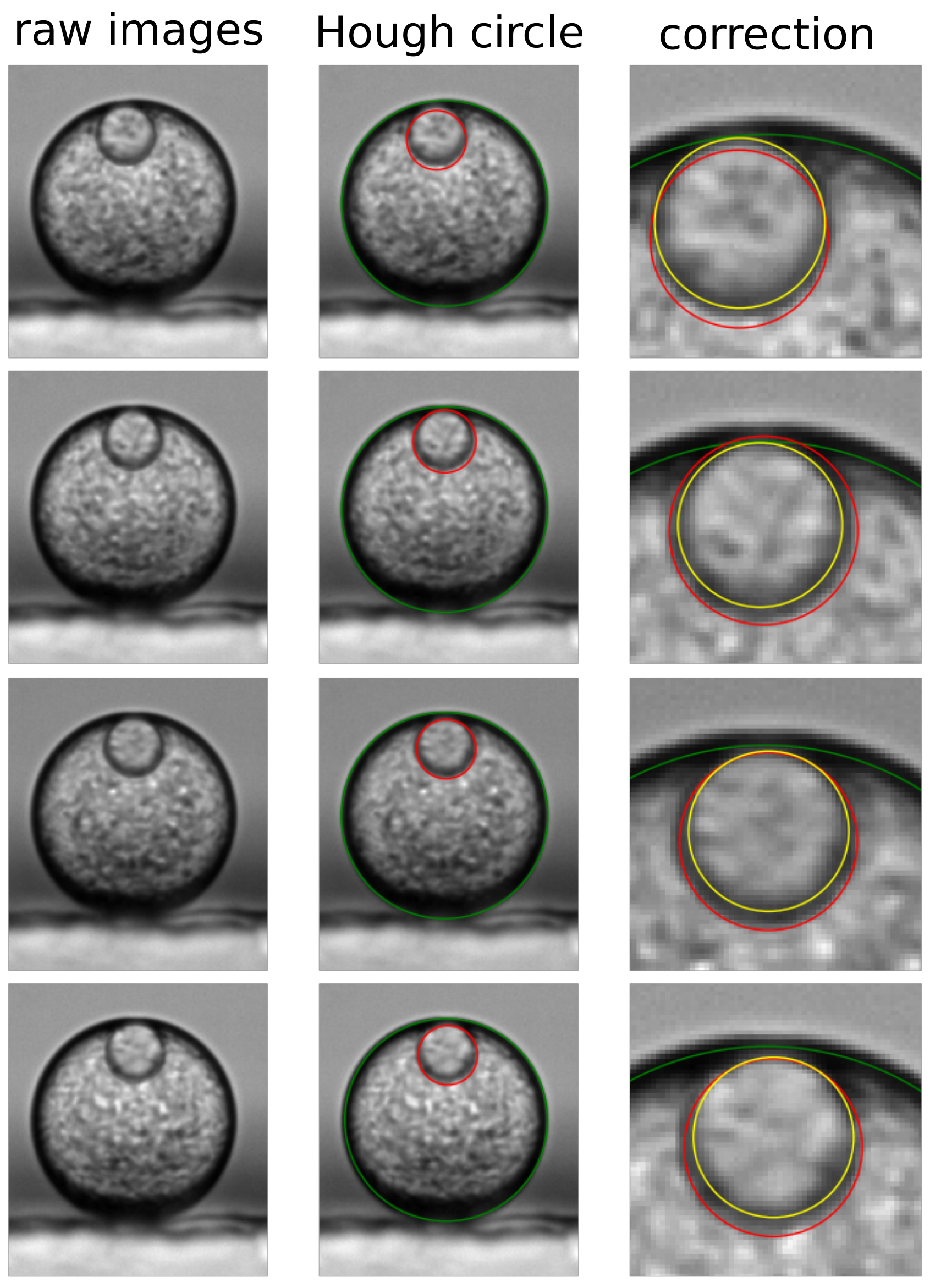
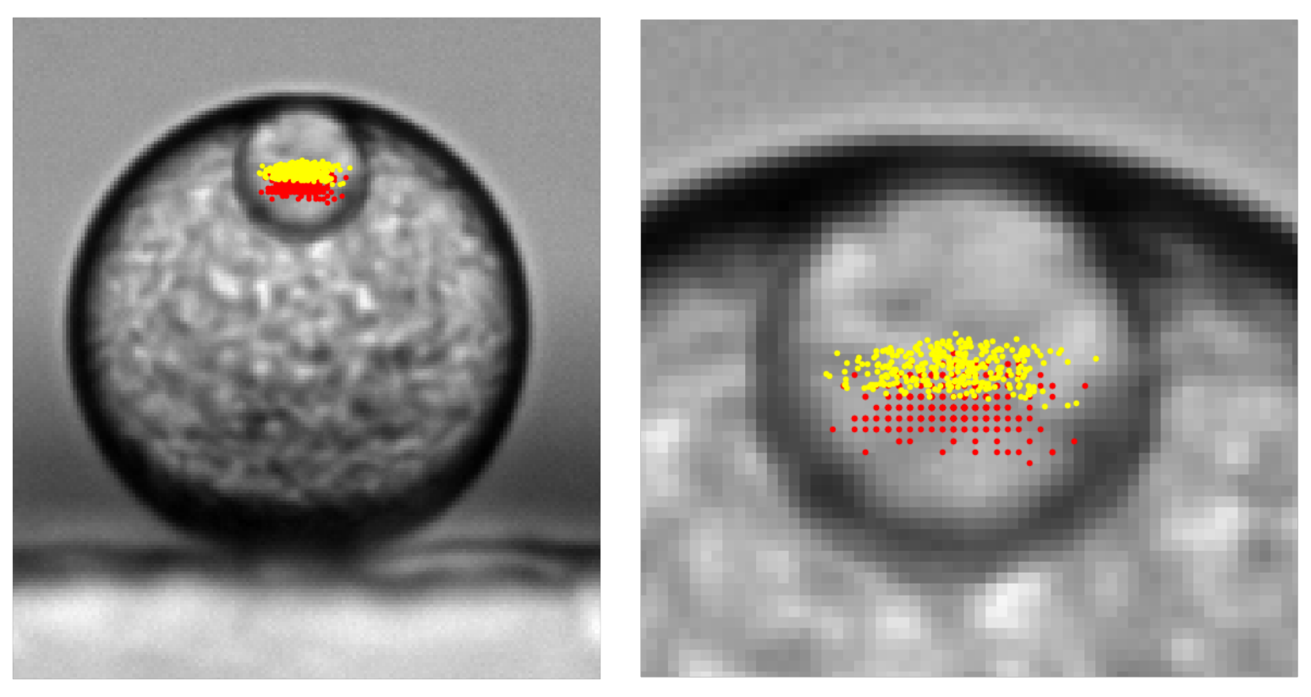


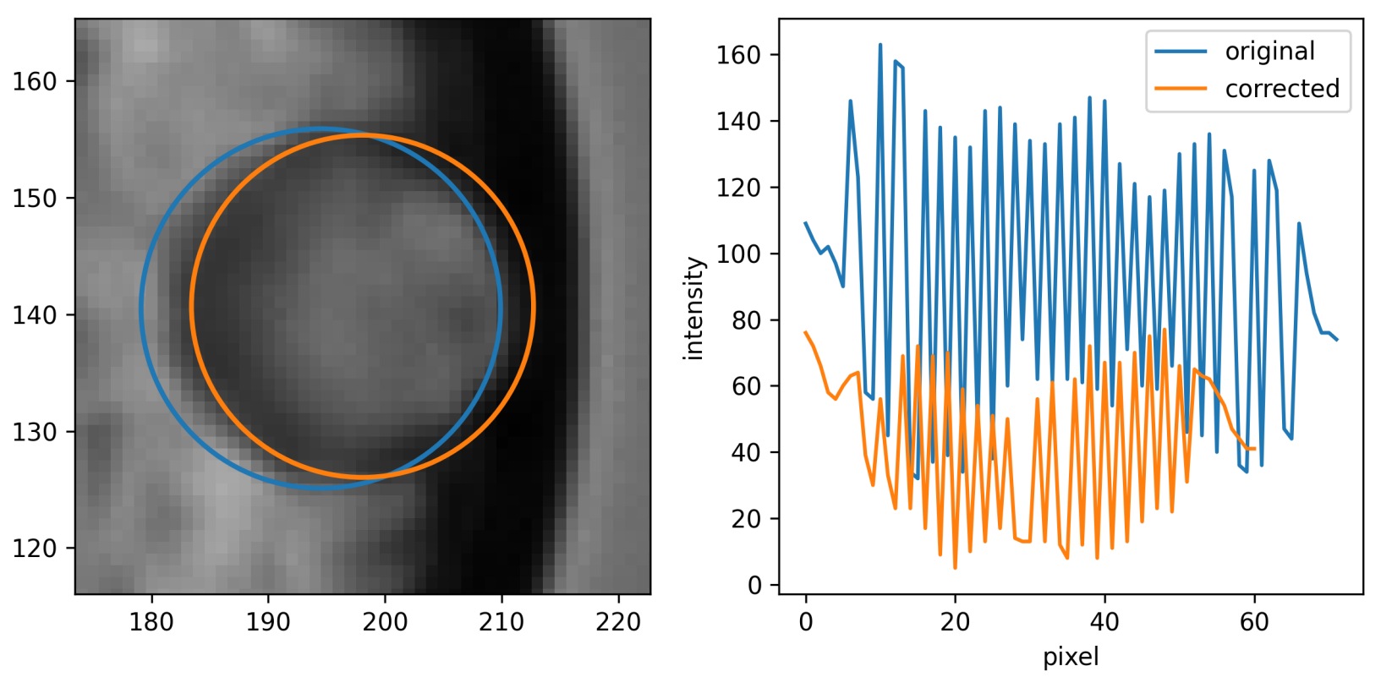
Image analysis

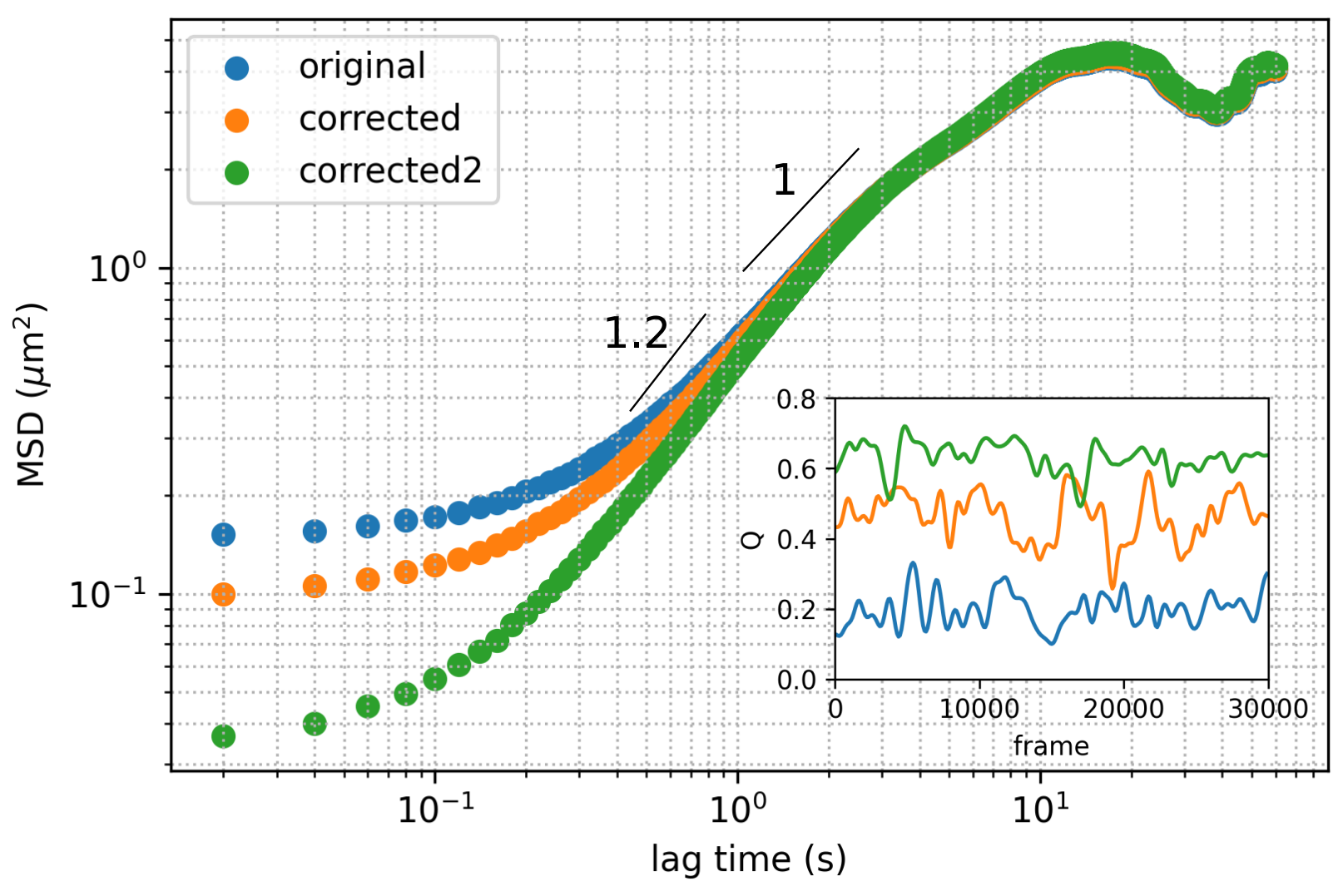




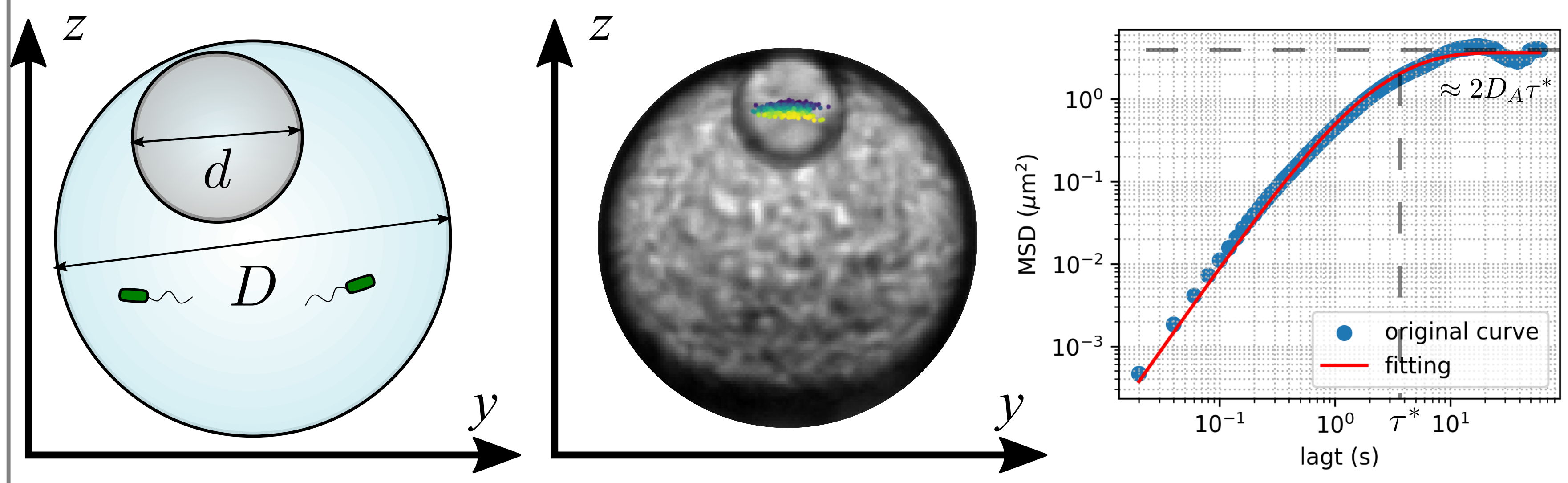
Circle detection quality: droplets have dark edges in the images. If we extract the pixel intensity profile along the contour of a detected circle, better detection shows smaller fluctuations. Based on this idea, we define detection quality Q as the following:

$$Q = 1 - \frac{\sigma_{\text{contour}}}{\sigma_{\text{image}}}$$





Stochastic model



The motion of inner droplets can be described using a Langevin type equation

$$\dot{y} = -\mu k y + \eta^A + \eta^T$$

where the contribution from the bath of swimming bacteria is modelled as exponentially correlated noise. The mean square displacement (MSD) of the inner droplet is

$$\langle \Delta y^2(t) \rangle = \frac{2D_A}{\mu k} \frac{1 - e^{-\mu k t} - \mu k \tau (1 - e^{-t/\tau})}{1 - (\mu k \tau)^2}.$$

The predicted MSD is characterized by a short time diffusive regime and a long time saturation regime (let $1/\mu k = \tau^*$):

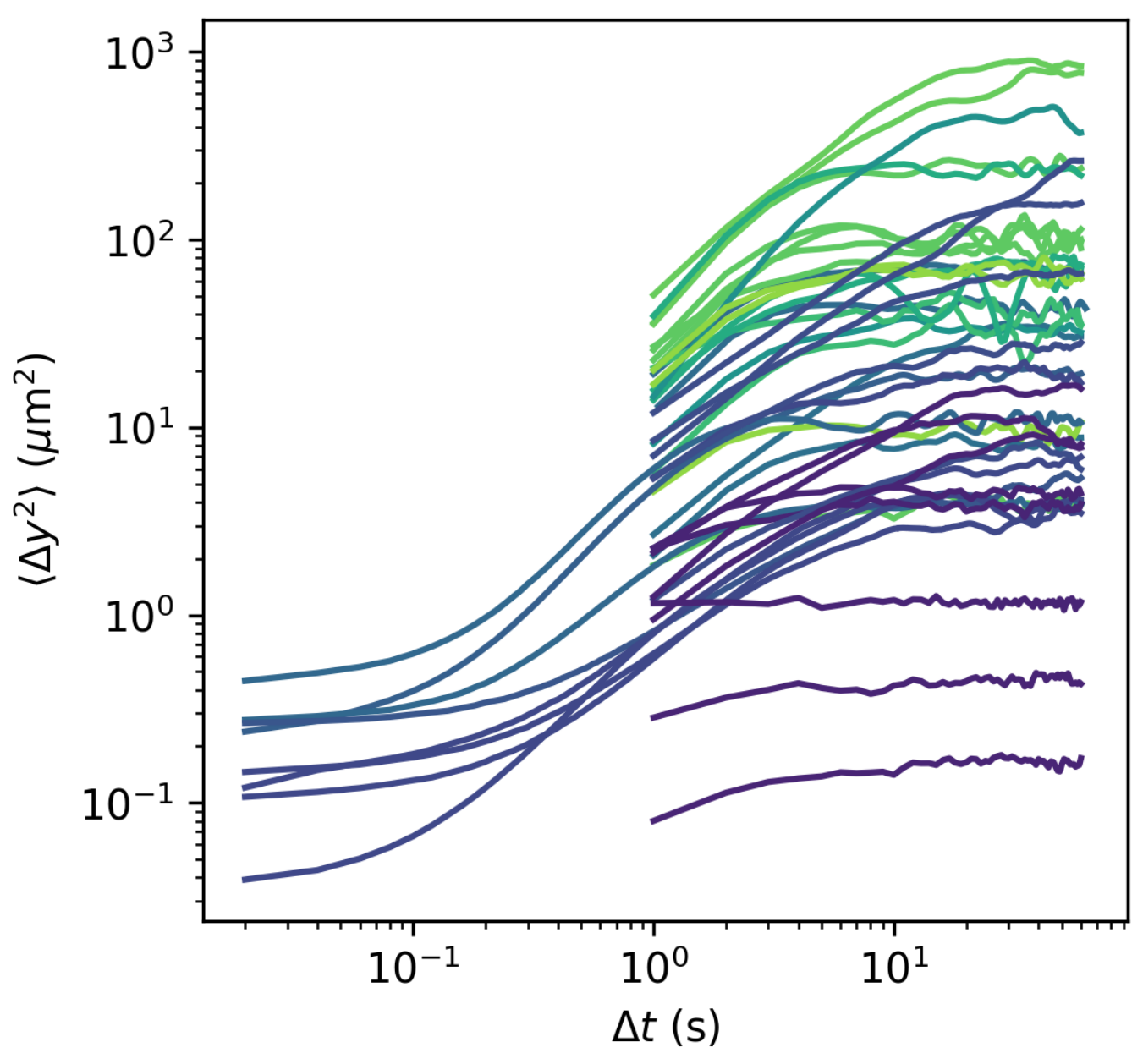
$$t \ll \tau^* : \langle \Delta y^2(t) \rangle = \frac{2D_A}{1 - (\tau/\tau^*)^2}(t - \tau)$$

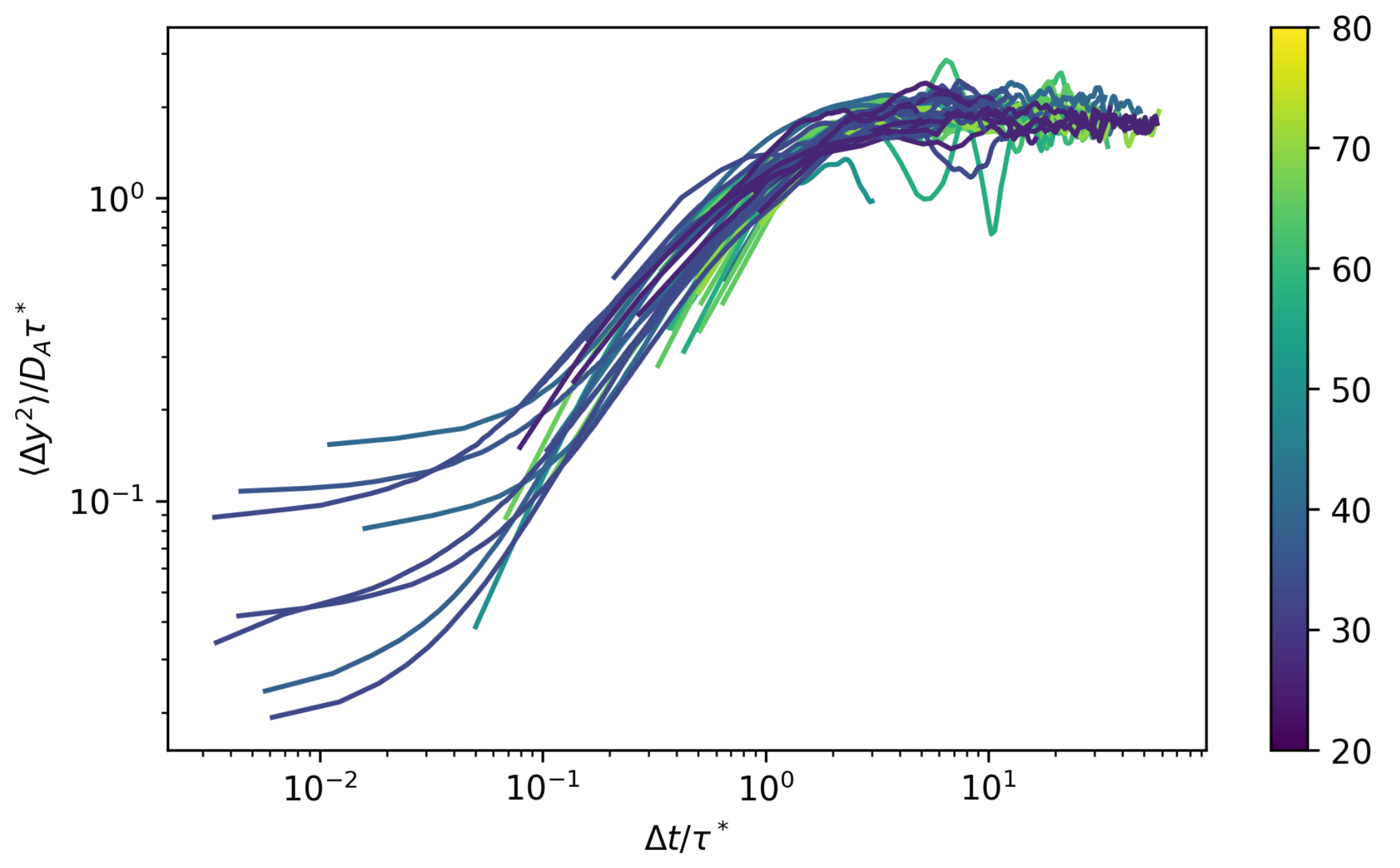
$$t \to \infty : \langle \Delta y^2(t) \rangle = \frac{2D_A \tau^*}{1 + \tau/\tau^*}$$

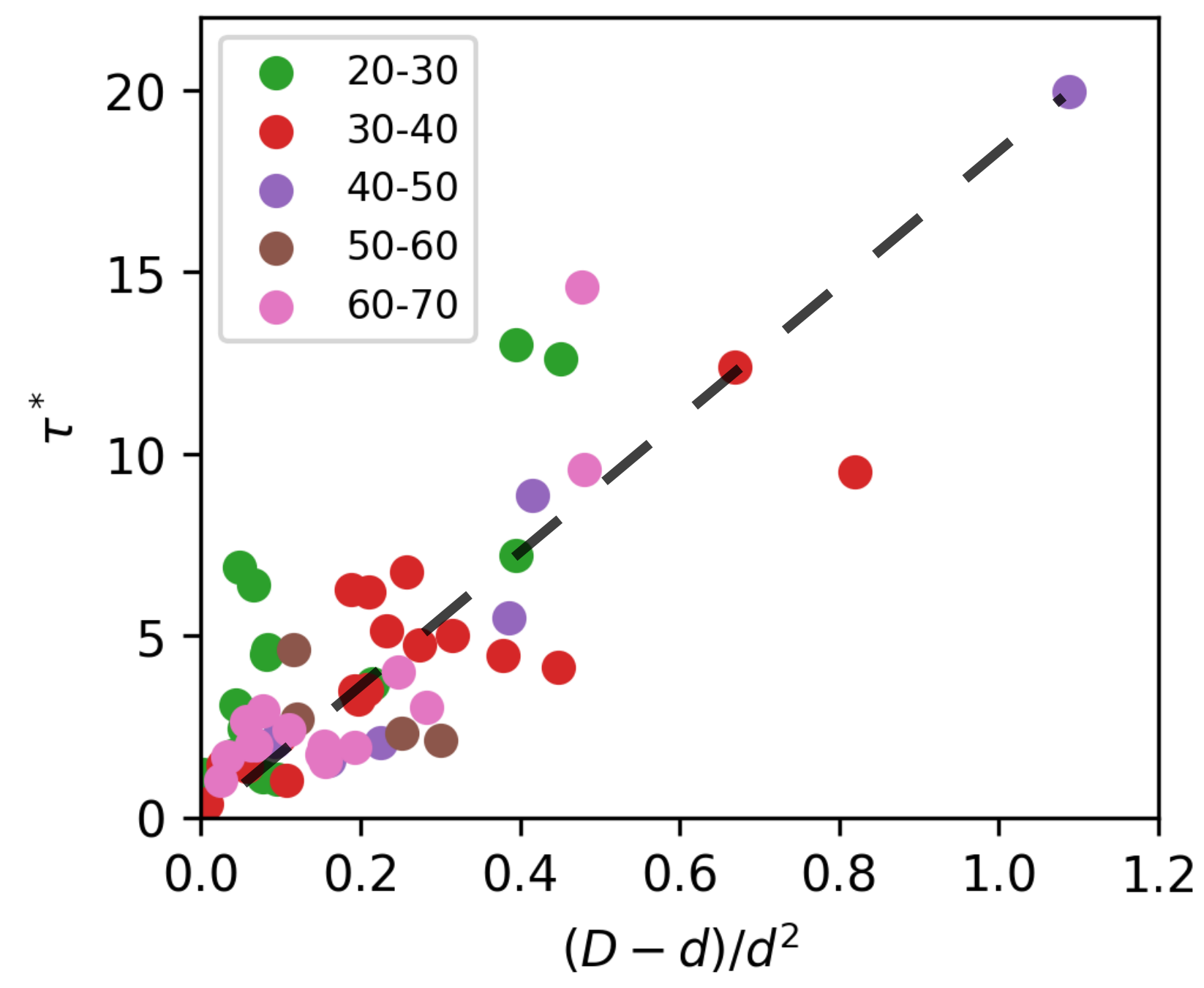
τ, the correlation time of the active noise, is usually much smaller compared to the spring relaxation time τ^*. Therefore, the motions of inner droplets are essentially described by only D_A and τ^* in this model. As a first order hypothesis:

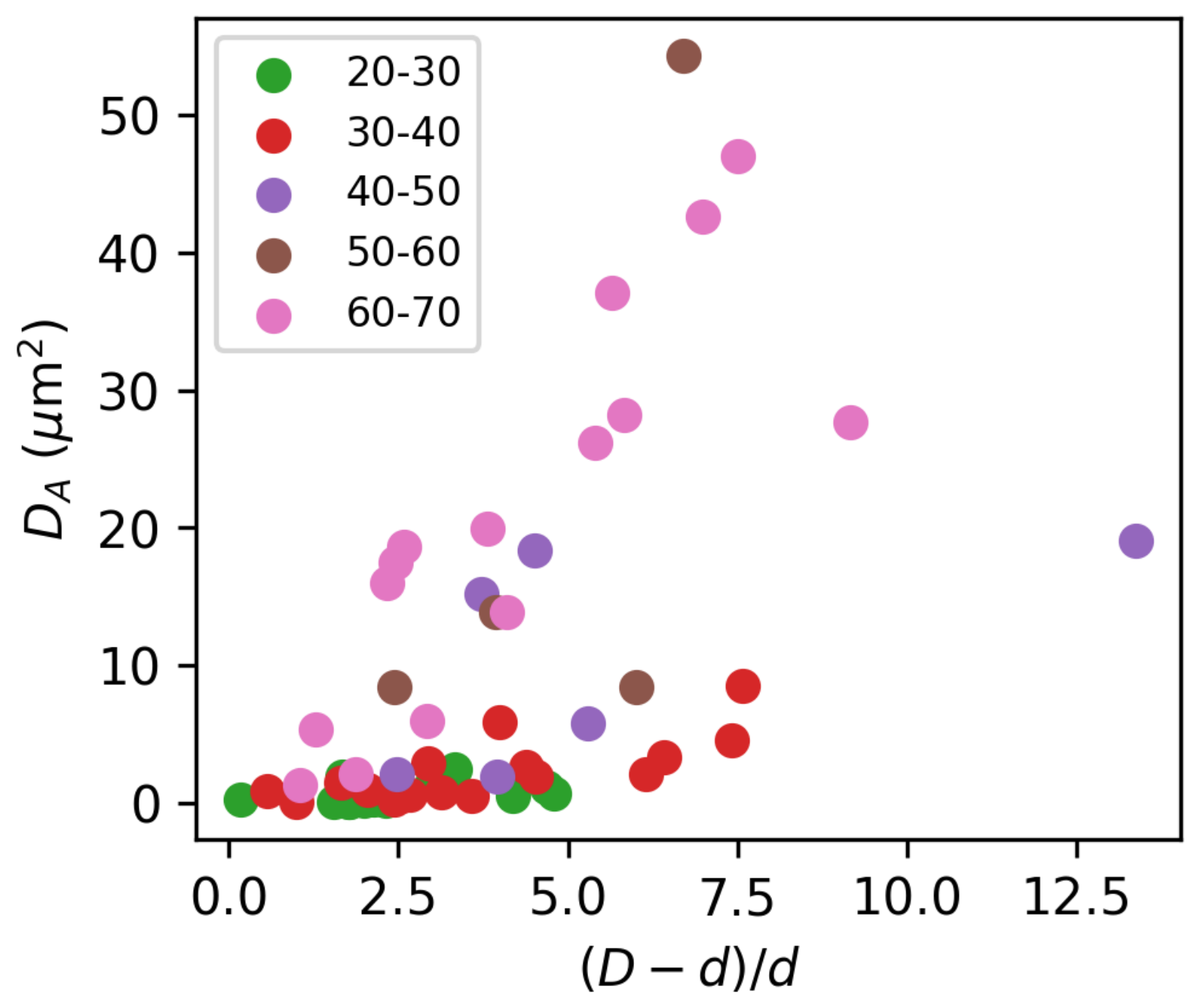
$$\tau^* = \frac{9\eta}{2\Delta\rho g} \frac{r_o - r_i}{r_i^2} = \frac{9\eta}{\Delta\rho g} \frac{D - d}{d^2} \qquad D_A \propto \frac{n}{d}$$

Results









Future work

1. The current tracking starts to reveal a superdiffusive regime at short times. We want to improve the tracking technique to be able to measure accurately the correlation time of inner droplet motion, and see how it depends on the confining geometry.
2. Preliminary analysis shows that bacterial activity is also correlated with outer droplet size. We need to do more experiment to find out the underlying mechanism, so that we can design more controlled experiment.

References

1. Xiao-Lun Wu and Albert Libchaber. “Particle Diffusion in a Quasi-Two-Dimensional Bacterial Bath.” *PRL* (2000)
2. Claudio Maggi, Matteo Paoluzzi, Nicola Pellicciotta, Alessia Lepore, Luca Angelani, and Roberto Di Leonardo. “Generalized Energy Equipartition in Harmonic Oscillators Driven by Active Baths.” *PRL* (2014)
3. Simin Ye, Peng Liu, Fangfu Ye, Ke Chen, and Mingcheng Yang. “Active Noise Experienced by a Passive Particle Trapped in an Active Bath.” *Soft Matter* (2020)