Swimming in 2D porous media

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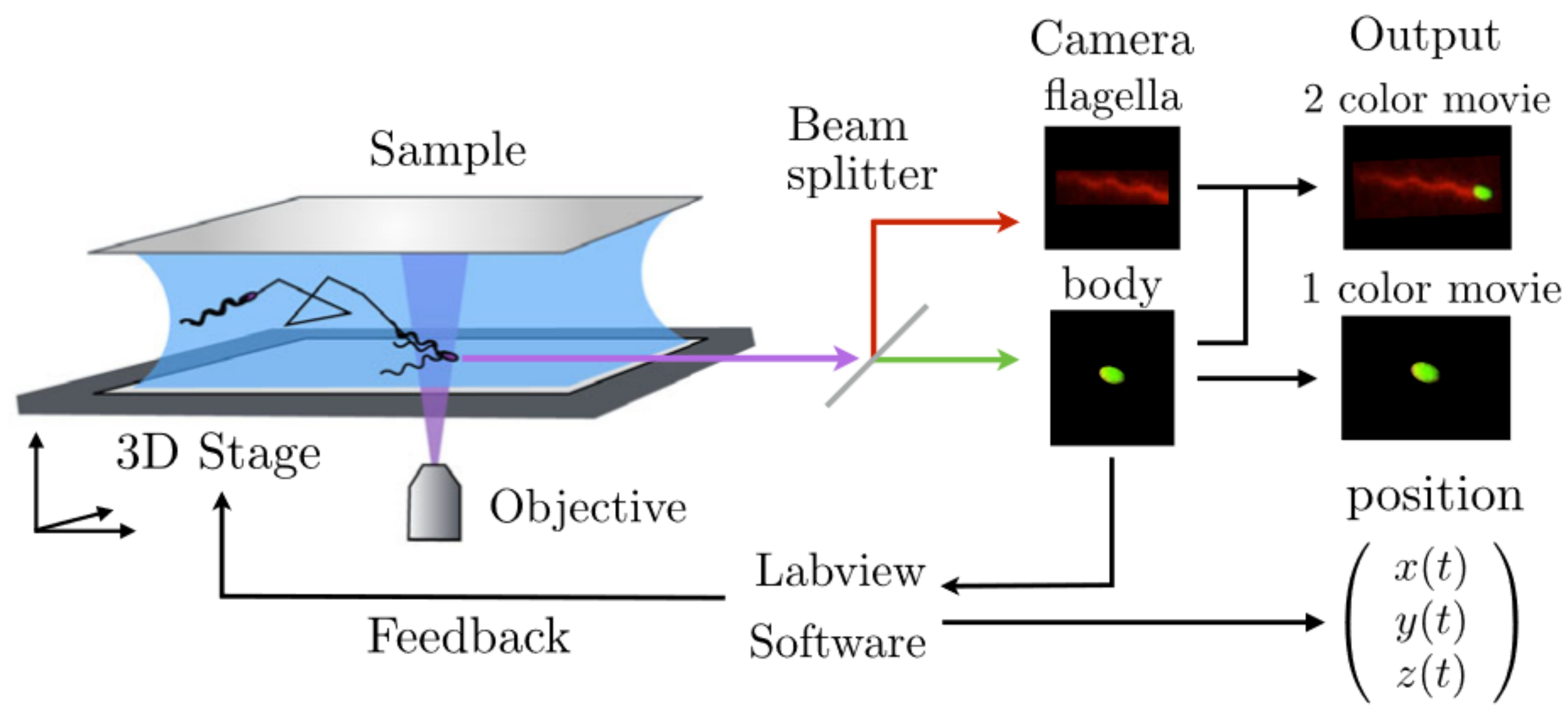
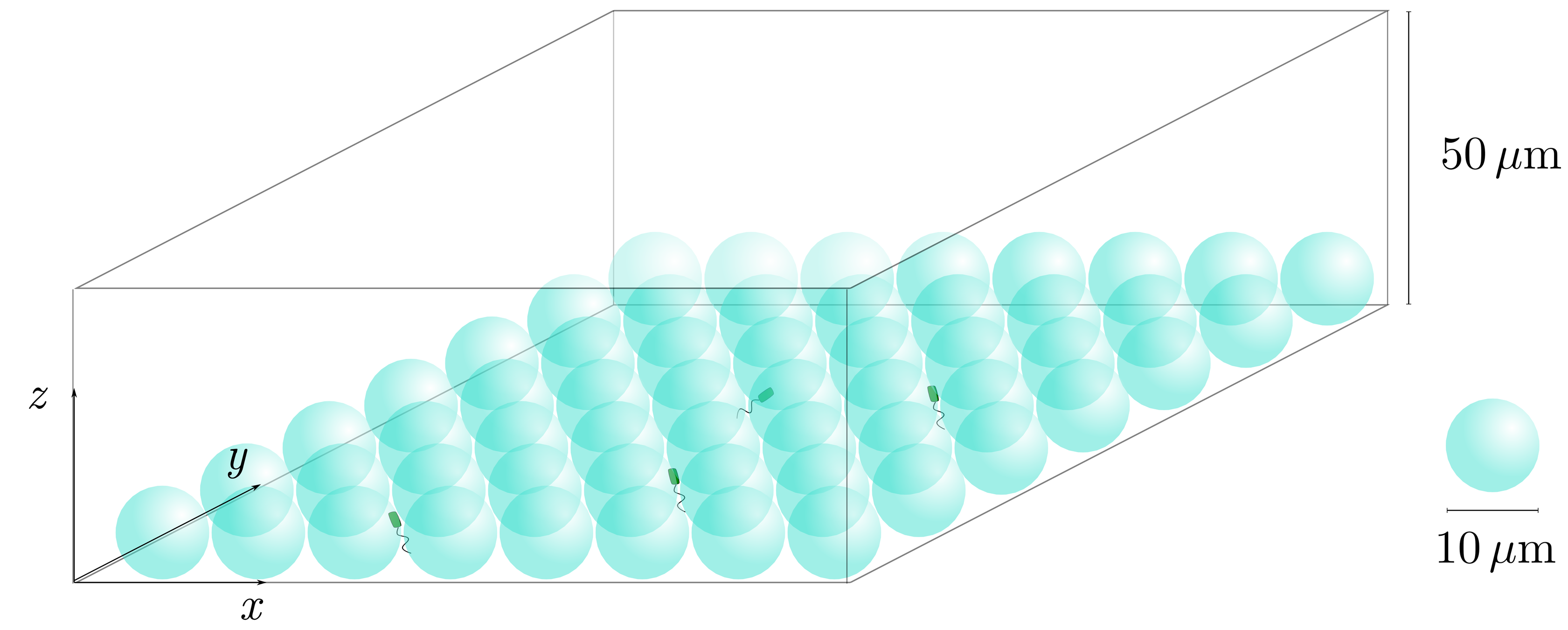
Context

Bacteria are microswimmers commonly found in complex environments, such as substrate surface, porous media and external flows. How they adapt to these environments is not only crucial to their suvival, but also important for the biological processes they are involved in, such as biofilm formation and infection. Due to the ecological and medical relevance of bacterial motility in complex environments, it has been investigated in more detail, thanks to the development of fast video microscopy. Here, we study the motility of the model microswimmer E. coli near glass surface, in the presence of a layer of oil droplets (3 um and 10 um in diameter). This droplet system simulates a soft tissue surface, while permitting direct and simultaneous imaging of both bacteria and obstacles.

Experiment

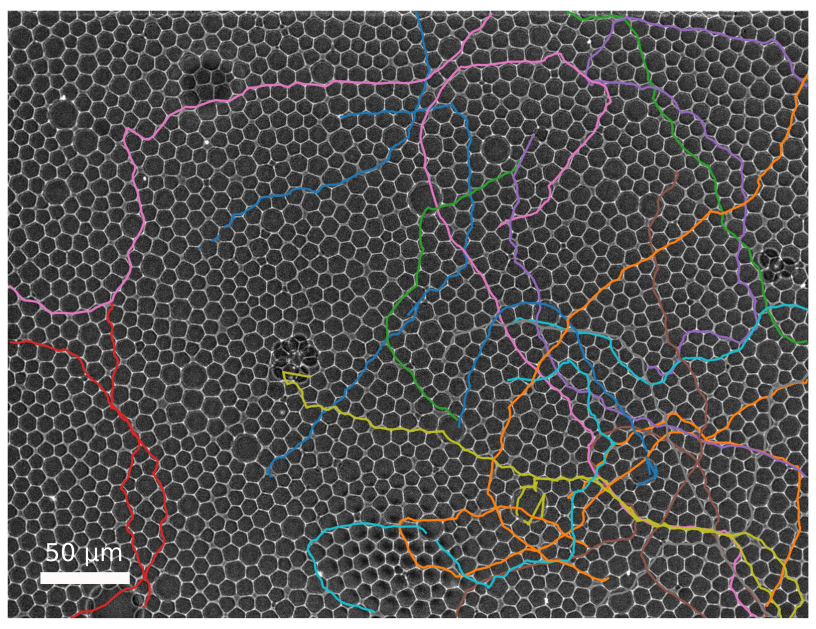


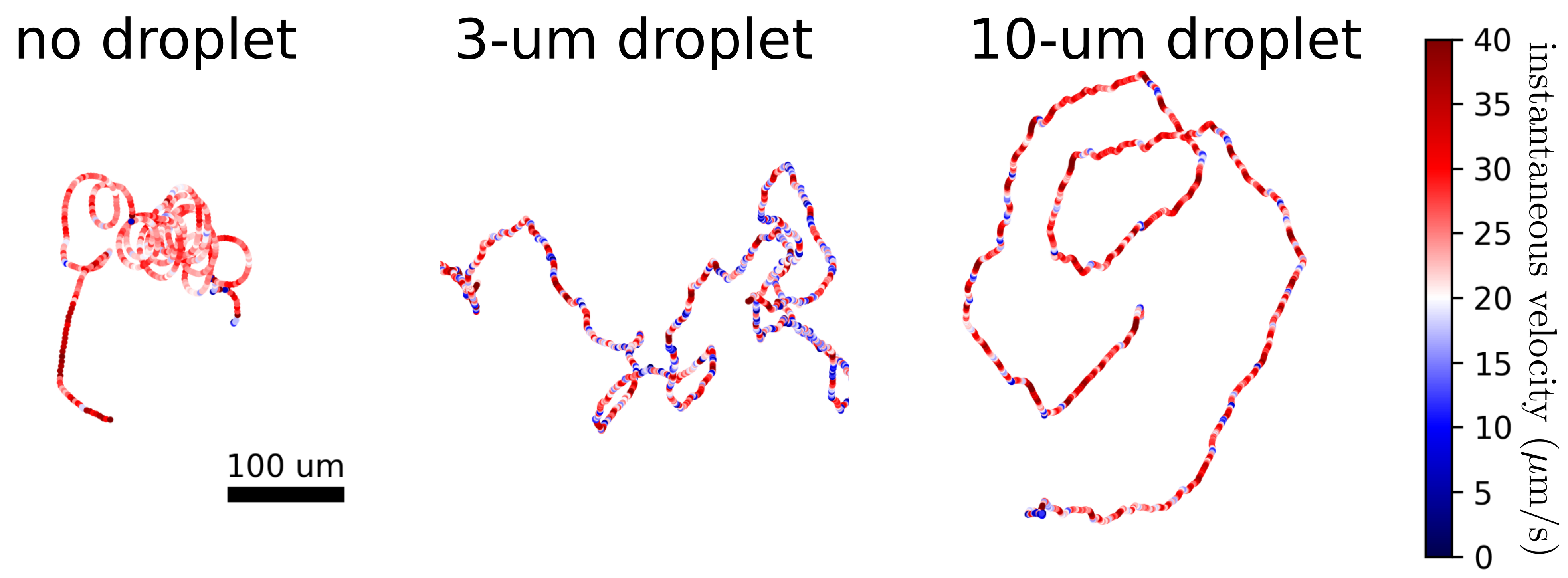
3D Lagrangian tracking microscope



E. coli swimmer: run-and-tumble strain with body and flagella fluorescence in the green and red respectively (AD62)
Droplet: Fluorinert FC-40 ($\rho = 1.85$ g/cm^3)

Different swimming mode

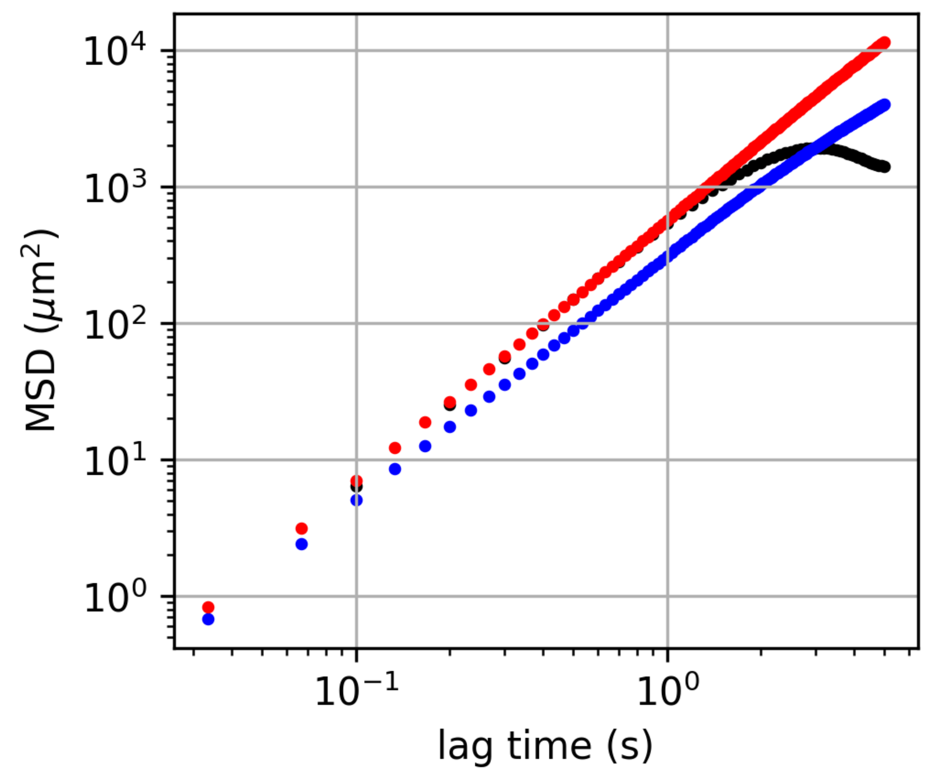


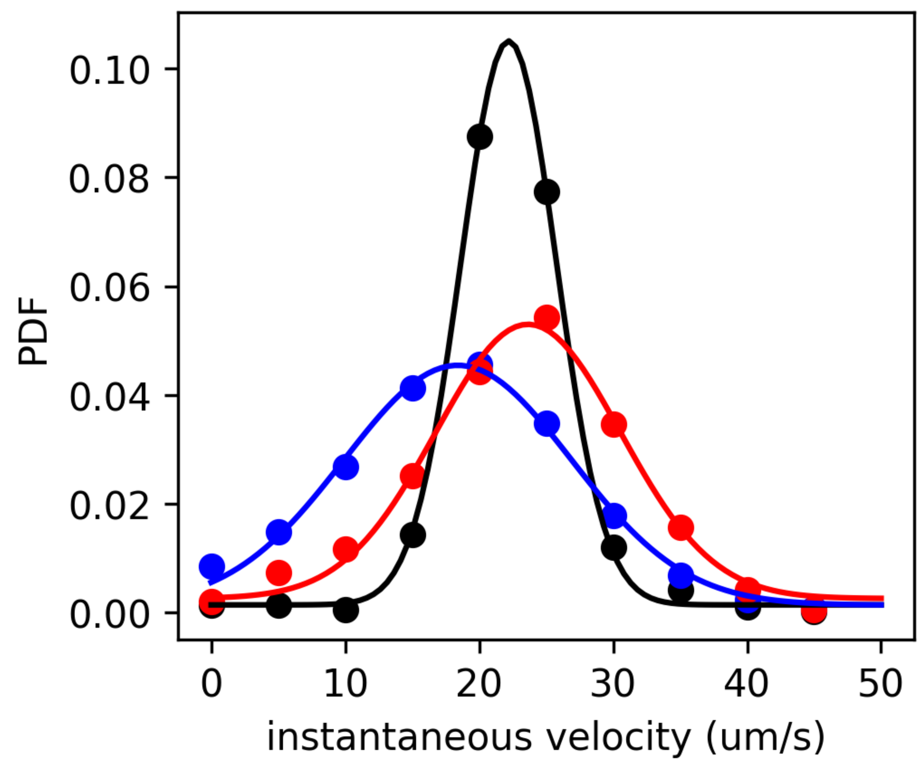


In the absence of droplet, E. coli swims in circles near a solid substrate. In a layer of 3-micron droplets, we observe qualitative difference in the trajectory, which is characterized by frequent slowing down and the absence of well-defined circles. In a layer of 10-micron droplets, the trajectories get more straight, like enlarged circles.

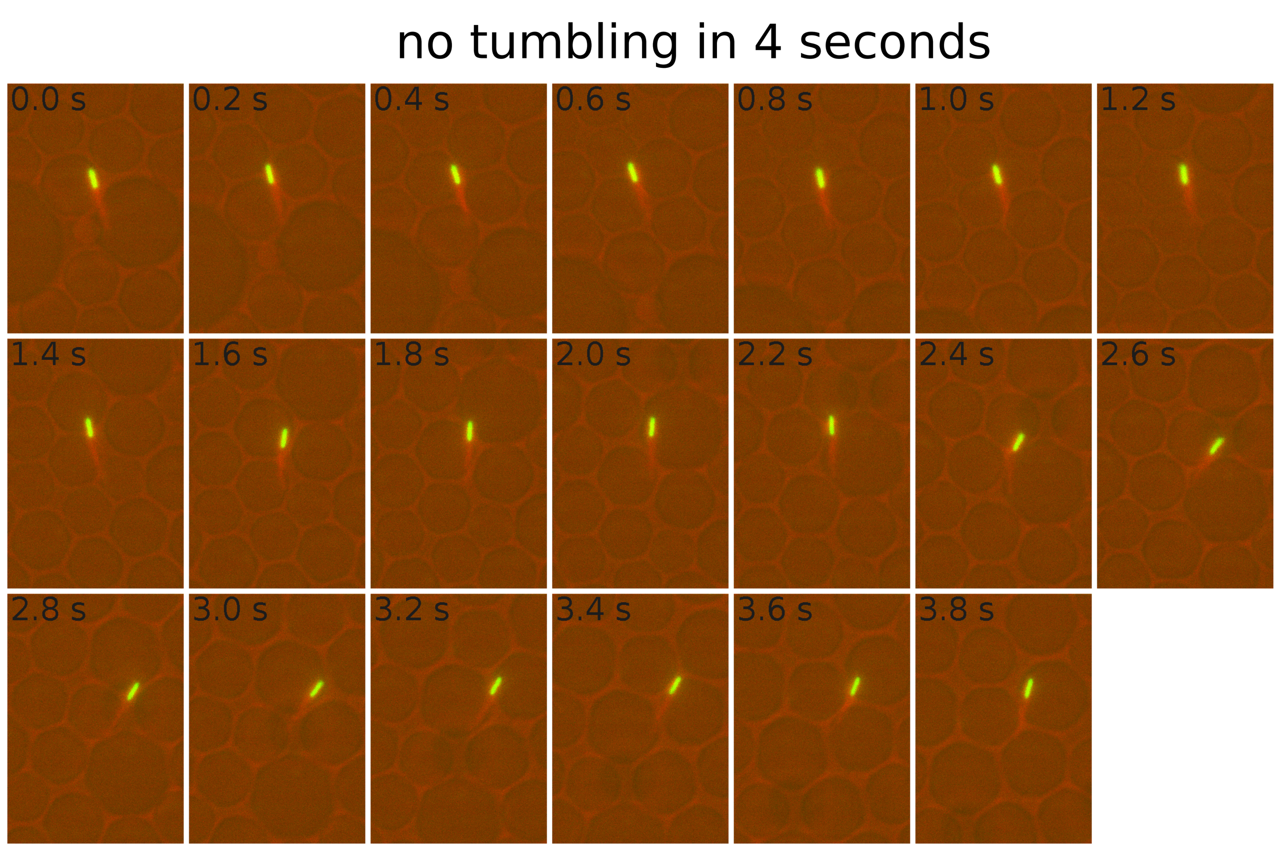
The mean square displacement (MSD) suggests that droplets of both sizes enhance the persistence of bacterial swimming near glass surface.

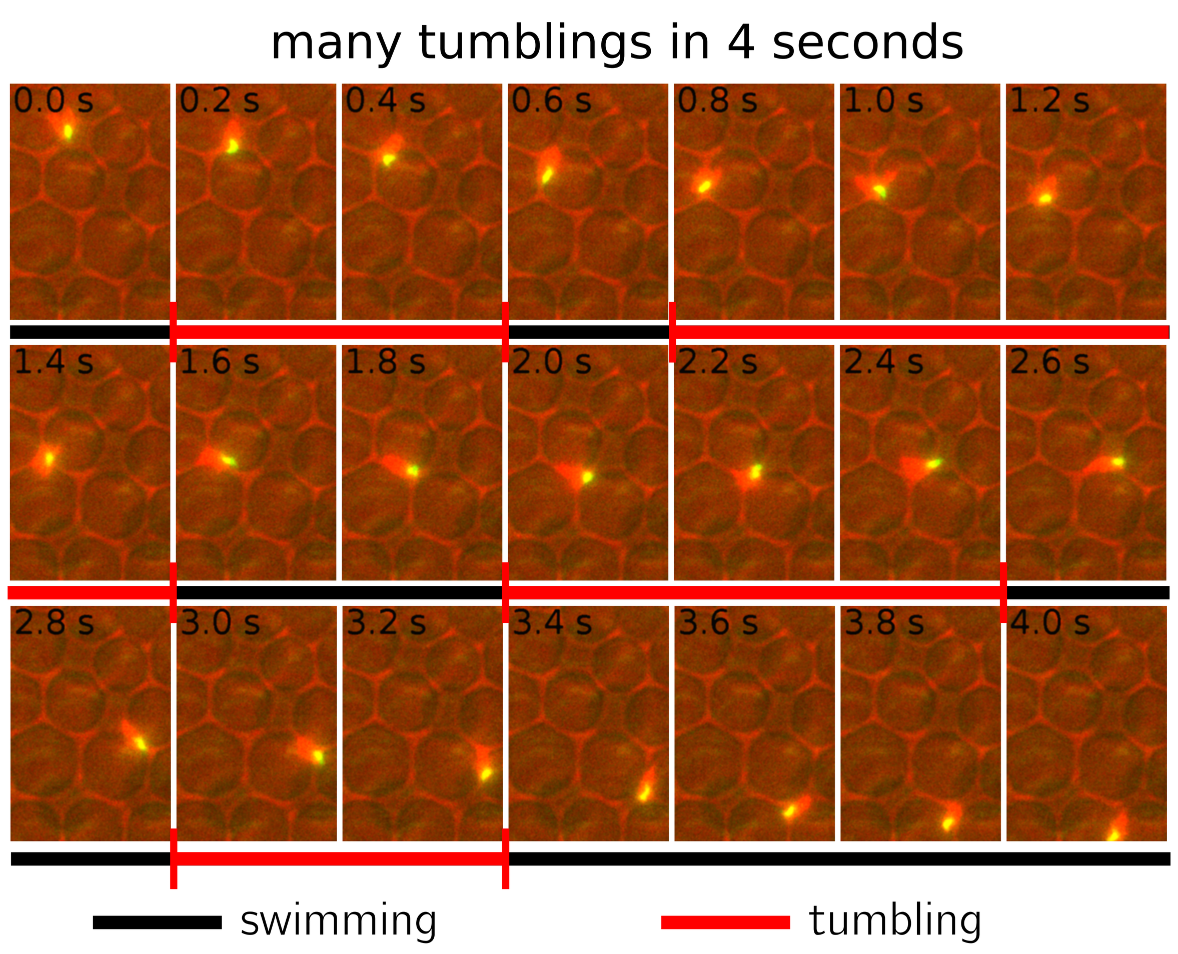
The instantaneous velocity distribution reveals an interesting effect of the droplets: they broaden the velocity distribution, adding more weights to both small and large velocity tails.





Geometry-controlled tumbling?





Two instances of E. coli bacteria swimming in a 10-micron droplet layer are shown. In one instance, the bacterium hardly tumbles, corresponding to the "large circle" above. In another instance, the bacterium tumbles many times within 4 seconds. Two hypotheses:
- although we try to spread droplets towards a perfect single layer, there are imperfections leading to local variations of pore size;
- the bacteria in these two instances have different shapes, in particular the lengths of their flagella. Long flagella may prevent tumbling in porous media.

References

1. Lauga et al., "Swimming in Circles: Motion of Bacteria near Solid Boundaries." Biophysical Journal (2006)
2. Bhattacharjee and Datta, "Bacterial Hopping and Trapping in Porous Media." Nature Communications (2019)
3. Junot et al.,"Run-to-Tumble Variability Controls the Surface Residence Times of E. Coli Bacteria." Physical Review Letters (2022)