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Electronic Supplementary Information for

Cargo carrying bacteria at interfaces

Liana Vaccari,[a] Mehdi Molaei,[a] Robert L. Leheny,[b] and Kathleen J. Stebe[a]
[a] *Chemical and Biomolecular Engineering, University of Pennsylvania, Philadelphia, PA, 19104, USA; E-mail: kstebe@seas.upenn.edu*
[b] *Department of Physics and Astronomy, Johns Hopkins University, Baltimore, Maryland, 21218, USA.*

S1 Bacterial trajectories

Bacteria at the interface were tracked to obtain the eMSD. 1 out of 10 bacterial trajectories are shown in Fig. S1. A detailed study of bacteria trajectories is the focus of ongoing work.

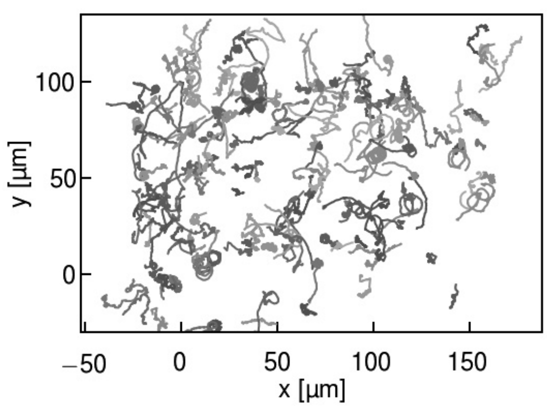

Fig. S1 Trajectories of bacteria trapped on the interface shown as small grey sports in Fig. 1. b. One out of ten trajectories are shown.

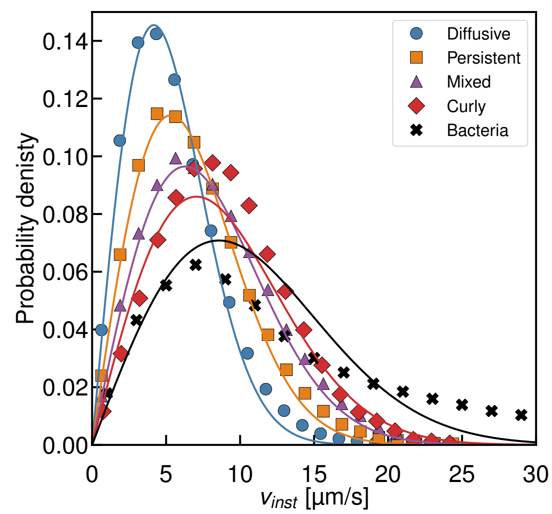

Fig. S2 Probability distribution of the instantaneous velocity of the particles in different populations, symbols, and fit using Rayleigh distribution, solid lines.

S2 Velocity distribution

Fig. S2 shows the probability distribution of the speed of the microbes and the particles in different populations. The data were fit to Rayleigh distribution $PD(v) = 2v/v_0^2[e^{(-v^2/v_0^2)}]$.

S3 Simulated curly trajectories

To guide intuition about the behavior of curly particles, consider a particle that follows a perfectly circular path, with $\mathbf{n}(\tau) = \cos\theta(\tau)\mathbf{e}_x + \sin\theta(\tau)\mathbf{e}_y$. For a particle moving at constant speed,

$$\mathbf{n}(\tau)\cdot\mathbf{n}(\tau+t) = \cos\theta(t)\cos\theta(t+\tau) + \sin\theta(t)\sin\theta(t+\tau) = \cos\theta(t).$$

The direction autocorrelation function can be evaluated:

$$\phi_{\mathbf{n}}(t) = \frac{1}{T}\int_0^T \mathbf{n}(\tau)\cdot\mathbf{n}(t+\tau)d\tau = \cos\theta(t).$$

If $\tau_{\rm osc}$ is the time for one full rotation then $\theta(t) = \frac{2\pi}{\tau_{\rm osc}}t$ and $\phi_{\mathbf{n}}(t) = \cos\frac{2\pi}{\tau_{\rm osc}}t$. This qualitatively captures the oscillatory form of the autocorrelation function for the individual curly trajectories. Applying this in equation 4 in the main text, one can determine MSD

$$\left\langle \Delta r^2(t)\right\rangle = 2v^2\int_0^t d\tau'\int_0^{\tau'}\cos(\frac{2\pi}{\tau_{\rm osc}}\tau)d\tau,$$

which leads to $\left\langle \Delta r^2(t)\right\rangle = (\frac{v\tau_{\rm osc}}{\pi}\sin\frac{\pi}{\tau_{\rm osc}}t)^2$. The curly trajectories observed in the experiment, however, are heterogeneous, each rotating at different speed and radius. Furthermore, randomizing interactions introduce noise to their circular paths. Therefore, to model the eMSD of the curly trajectories we used Monte-Carlo simulation. Using the Monte-Carlo method, we generated 10,000 simulated curly trajectories with different oscillation periods, T, and radii of curvatures, $R = TV/2\pi$, where V is the velocity of the particles along the circular paths. The probability distribution of the speed and the oscillation period are chosen to be similar to the experimental data. Each trajectory lasts for 1000 s with time step of $dt = 1/60\ s$. The displacement at each time step, dx is the sum of the rotational displacement $dx_r = R\cos(2\pi t/T)$ and random displacement, dx_n, with a Gaussian probability distribution with a standard deviation of $2Ddt$. In this term, D, the diffusion coefficient, is chosen to be equal to that of the passive particles at the interface absent bacteria. One out of 100 simulated trajectories are shown in Fig. S3a. We compared the probability of the displacement taking place at 0.1 second, 0.2 s, 1.0 s, and 2 s of simulated trajectories with that of trajectories of the curly population. The result are shown in Fig. S3b. As expected, the simulated van Hove plots also show non-Gaussian shapes with very flat cores. As expected, the displacements take place at 1.0 s are larger than those that occur at 2.0 s due to the oscillatory shapes of the trajectories. The eMSD of the simulated trajectories, plotted in Fig. S3c shows oscillatory shape in long lag time similar to the eMSD of the particles with curly trajectories.

S4 Representative Particles

S4.1 Videos

All videos are shown at 61 frames per second with a resolution of 0.031 microns per pixel.

Video 1 Particle fixed frame video of a curly trajectory.

Video 2 Particle fixed frame video of a diffusive trajectory.

Video 3 Particle fixed frame video of a persistent trajectory.

Video 4 Particle fixed frame video of a mixed trajectory.

S4.2 Trajectories and orientation

Here, we provide four examples of each type of trajectory to show that the data provided in the main text are indeed representative in terms of trajectory shape, evidence of bacteria attachment, and orientation of major axis of colloid-bacteria hybrid. These data show that enhanced migration owing to bacteria adhesion is indeed the norm for these highly motile bacteria that do not form elastic films at interfaces. The orientation angles of these trajectories have not been adjusted as had been done in the main text.

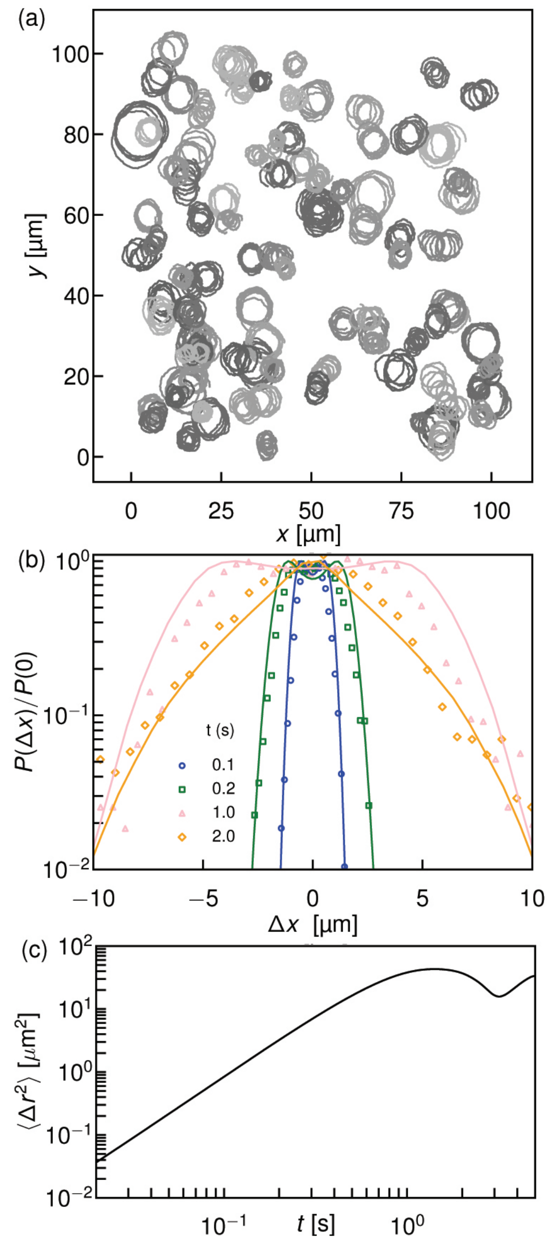

Fig. S3 (a) Simulated curly trajectories. **(b)** The probability of displacement at 0.1 s, 0.2 s, 1 s, and 2 s, solid lines: Displacement of simulated trajectories (shown in (a)) and symbols: Displacement of trajectories of observed curly population (shown in Fig. 1.c).

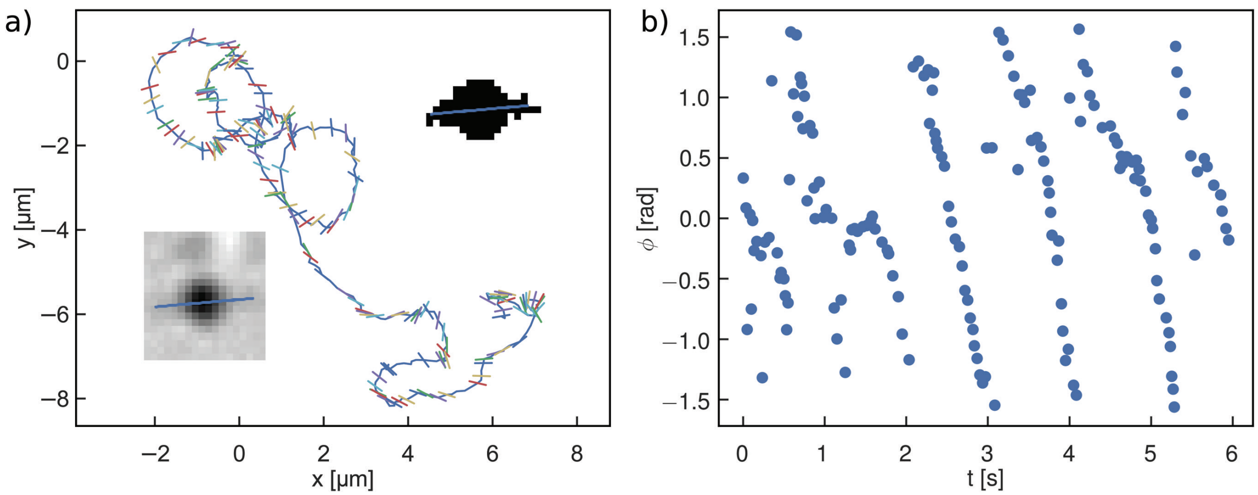

Fig. S4 Orientation of multiple adhered bacteria is tangent to path. (a) Particle trajectory overlain with instantaneous orientation of the major axis of the bacteria-particle aggregate, inset: example of orientation of the aggregate in a given frame in both binary and original image, **(b)** orientation of the aggregate over time, with an angular speed ~ 2.5 radians per second.

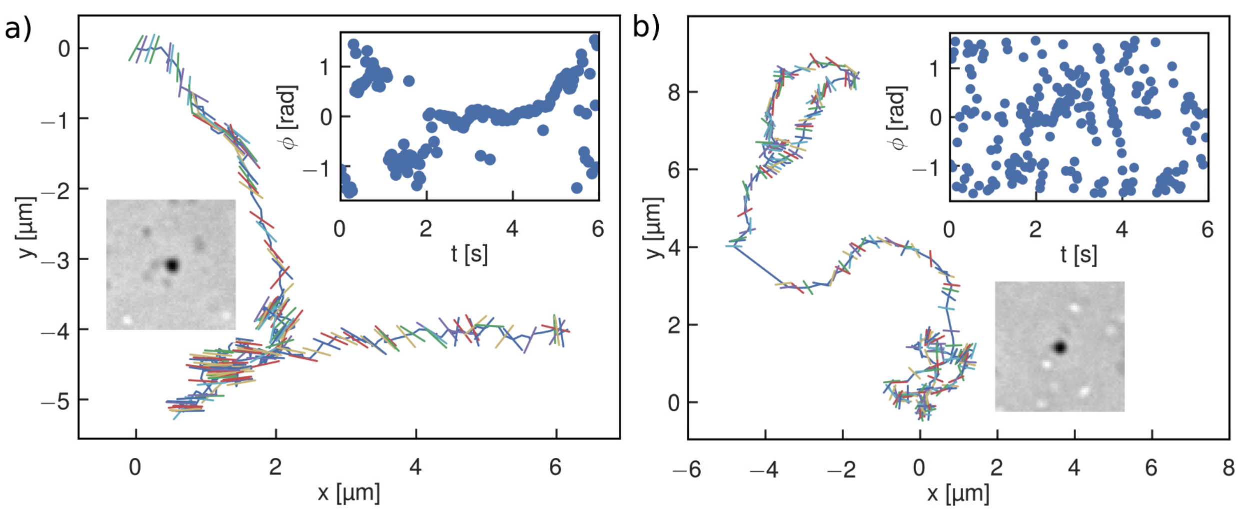

Fig. S5 Orientation of adhered bacteria for persistent and diffusive paths. (a) Example of a persistent particle trajectory overlain with instantaneous orientation of the major axis of the bacteria-particle aggregate, inset: orientation with respect to time, **(b)** example of a diffusive particle trajectory overlain with instantaneous orientation of the major axis of the bacteria-particle aggregate, inset: orientation with respect to time. There is no significant rotation relative to that of the curly trajectories in Figs. **??** and S4.

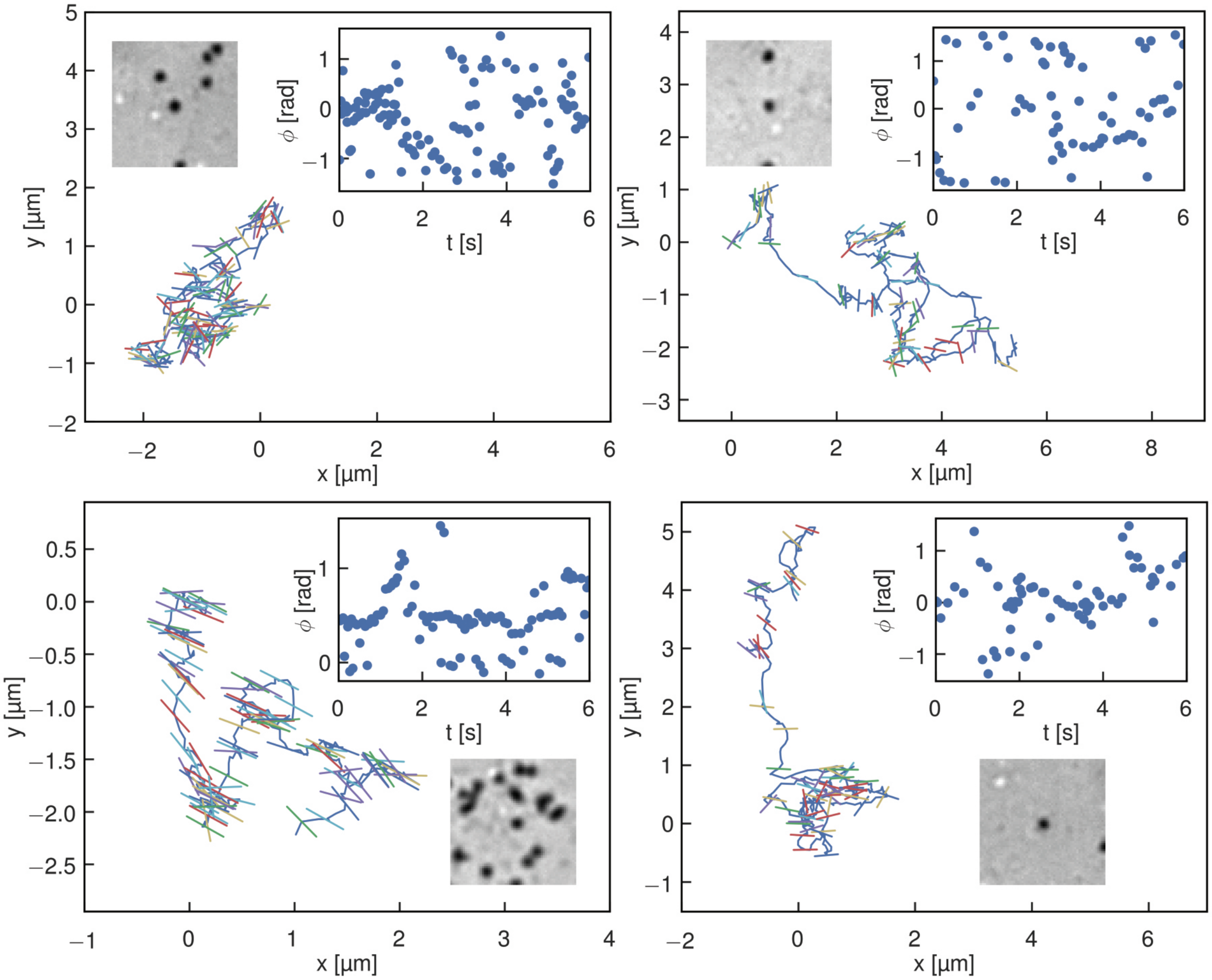

Fig. S6 Diffusive examples.

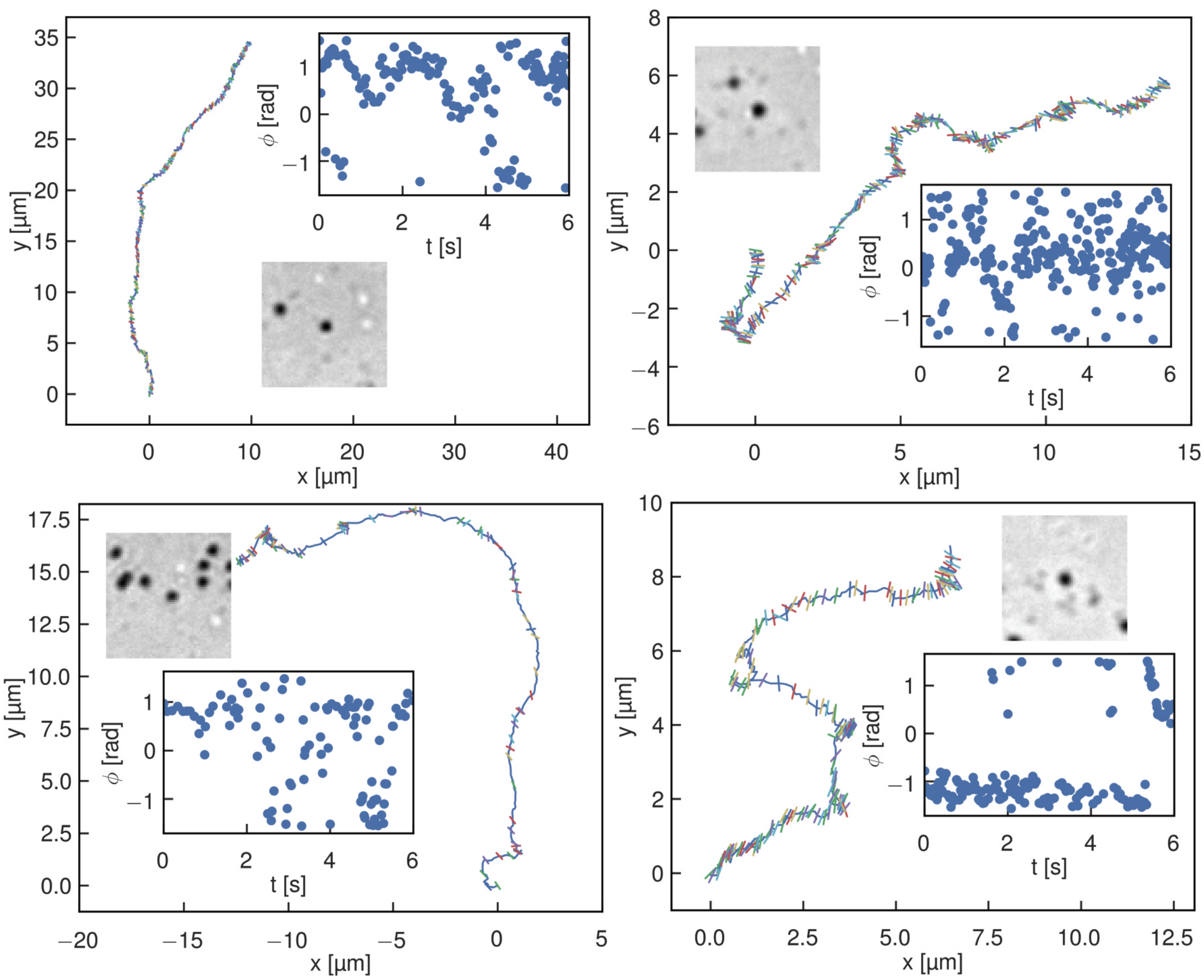

Fig. S7 Persistent trajectory examples.

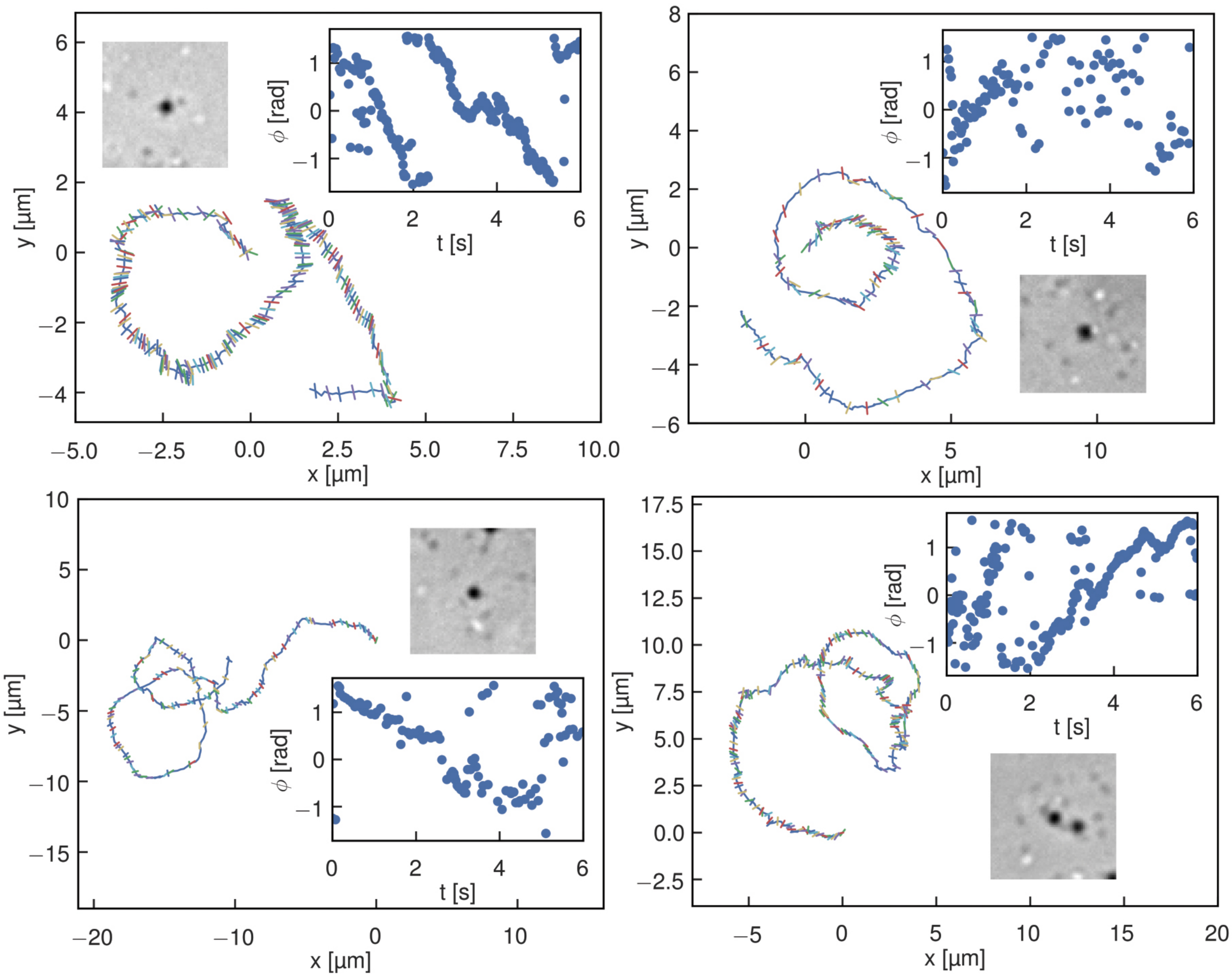

Fig. S8 Mixed trajectory examples.

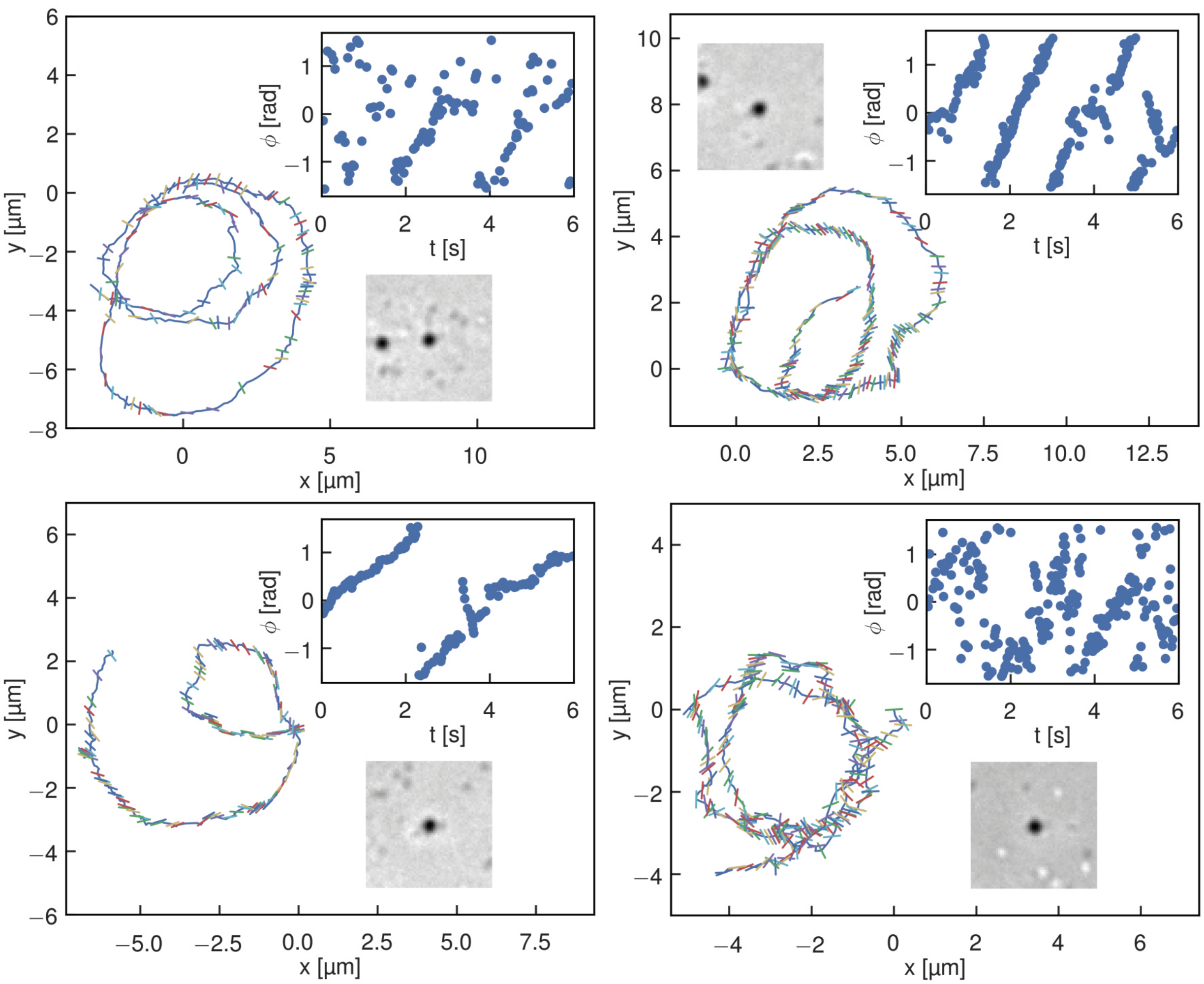

Fig. S9 Curly trajectory examples.