Dispersion of motile bacteria in a porous medium: Experimental data and theory

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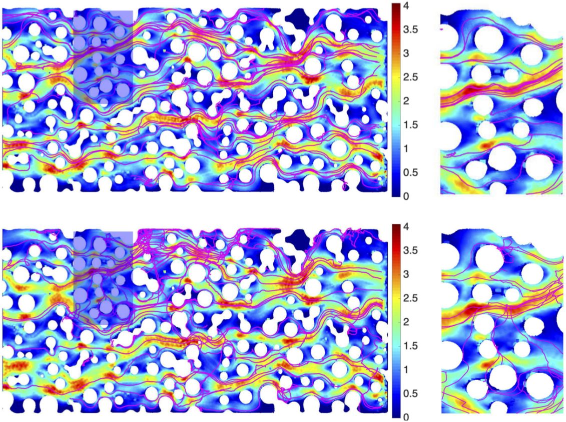
Experiment (Creppy et al., Phys. Rev. Fluids, 2019)



Trajectories of motile bacteria at (top) $u_m = 98\mu$m/s and (bottom) $u_m = 43\mu$m/s.

- Mean flow $u_m = 18, 43, 66, 98, 113, 139$ and 197μm/s
- Average pillar diameter $\ell_0 = 35$ μm
- Characteristic time $\tau_v = \ell_0 / u_m$

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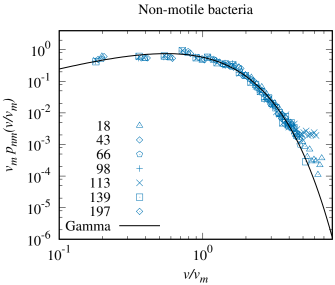
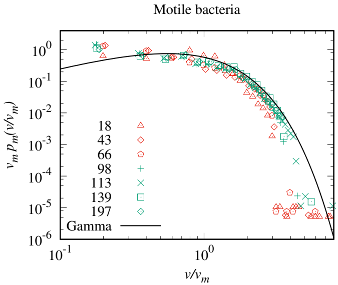
Particle speeds





- Speed distributions for (left) non-motile and (right) motile bacteria.
- Non-motile bacteria speed proxy for flow speed, follows Gamma-distribution
- Motile bacteria speed shows effect of motility

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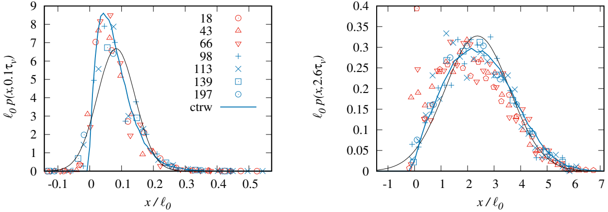
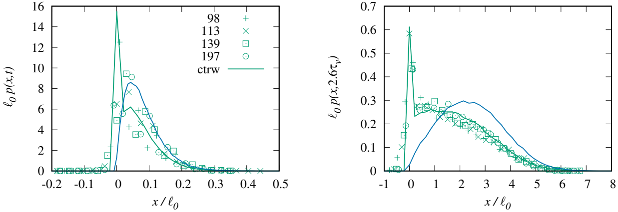
Bacteria dispersion

Non-motile bacteria (snapshots at $t = 0.1\tau_v$ and $t = 2.6\tau_v$)



Motile bacteria $u_m \geq 98\mu$m/s



– Retardation due to motility
– Scaling with flow rate
– Model (solid lines) captures data

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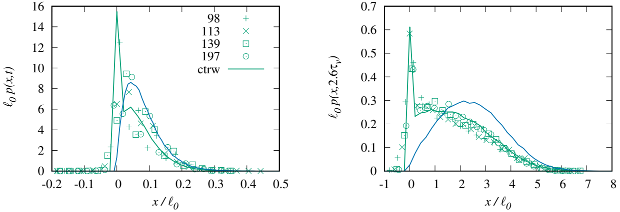
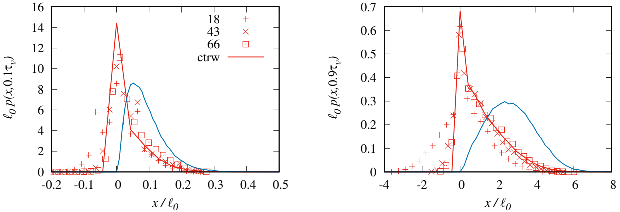
Bacteria dispersion

Motile bacteria $u_m \geq 98\mu$m/s



Motile bacteria $u_m \leq 66\mu$m/s



– Stronger retention with decreasing flow rate, data grouped in two families

– $u_m \leq 66\mu$m/s: Forward tails scale with flow rate

– Model (solid lines) captures data

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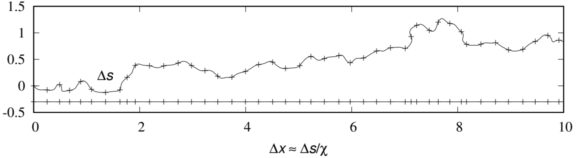
Continuous time random walks

Schematic of the representation of a particle trajectory in the CTRW approach.



Non-motile particles

$$x_{n+1} = x_n + \ell_c, \qquad t_{n+1} = t_n + \frac{\ell_c}{v_n}, \qquad p(v) = \frac{v p_e(v)}{\langle v_e \rangle}$$

– Transport by advection only, characteristic time $\tau_v = \ell_0 / u_m$
– Characteristic length scale $\ell_c \approx 2\ell_0$ times grain size
– Flux-weighted Eulerian speed distribution because $\Delta s = v \Delta t$.

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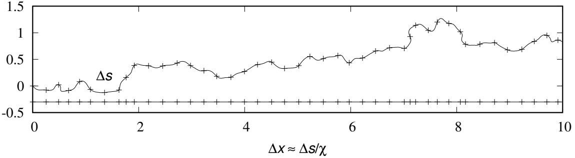
Schematic of the representation of a particle trajectory in the CTRW approach.



Motile particles

$$x_{n+1} = x_n + \ell_c, \qquad t_{n+1} = t_n + \frac{\ell_c}{v_n} + \tau_n,$$

– τ_n: Poissonian trapping with rate γ and trapping time τ_c, $\gamma \neq 1/\tau_c$.
– Fraction of trapped bacteria: $\rho = \gamma\tau_c/(1 + \gamma\tau_c)$
– $u_m \geq 98\mu$m/s: $\tau_c \approx 2.5\tau_v \sim 1/u_m$, $\gamma = 0.16/\tau_v \sim u_m$, $\rho \approx 0.3$
– $u_m \leq 66\mu$m/s: $\tau_c \approx 2\tau_v$, $\gamma = 0.5/\tau_v$, $\rho \approx 0.5$
– $u_m = 18\mu$m/s: close to swimming velocity $v_s \approx 12\mu$m/s.

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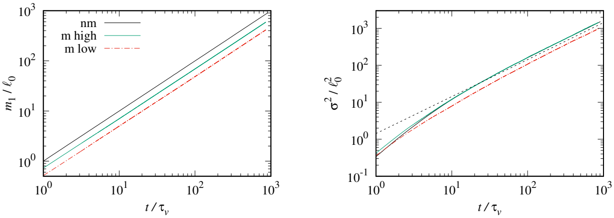
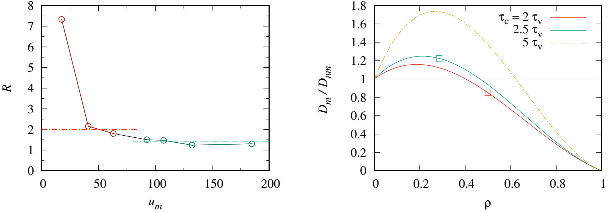


– Retardation coefficient $R = 1/(1-\rho)$.

– Dispersion coefficient $D_m = D_{nm}(1-\rho) + u_m^2 \tau_c \rho (1-\rho)^2$



– Grouping into families manifests in asymptotic transport behaviors

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Conclusions

- Motile bacteria motion captured by CTRW based on flow statistics and Poissonian trapping model.
- Dispersion and trapping mechanisms scale with flow rate.
- Data grouped in two families with enhanced trapping at low flow rates.
- Bacteria motility can enhance or decrease dispersion.

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