When to tumble and when to run

Readings for today

- Huo, H., He, R., Zhang, R., & Yuan, J. (2021). Swimming Escherichia coli Cells Explore the Environment by Lévy Walk. Applied and Environmental Microbiology, 87(6), e02429-20.

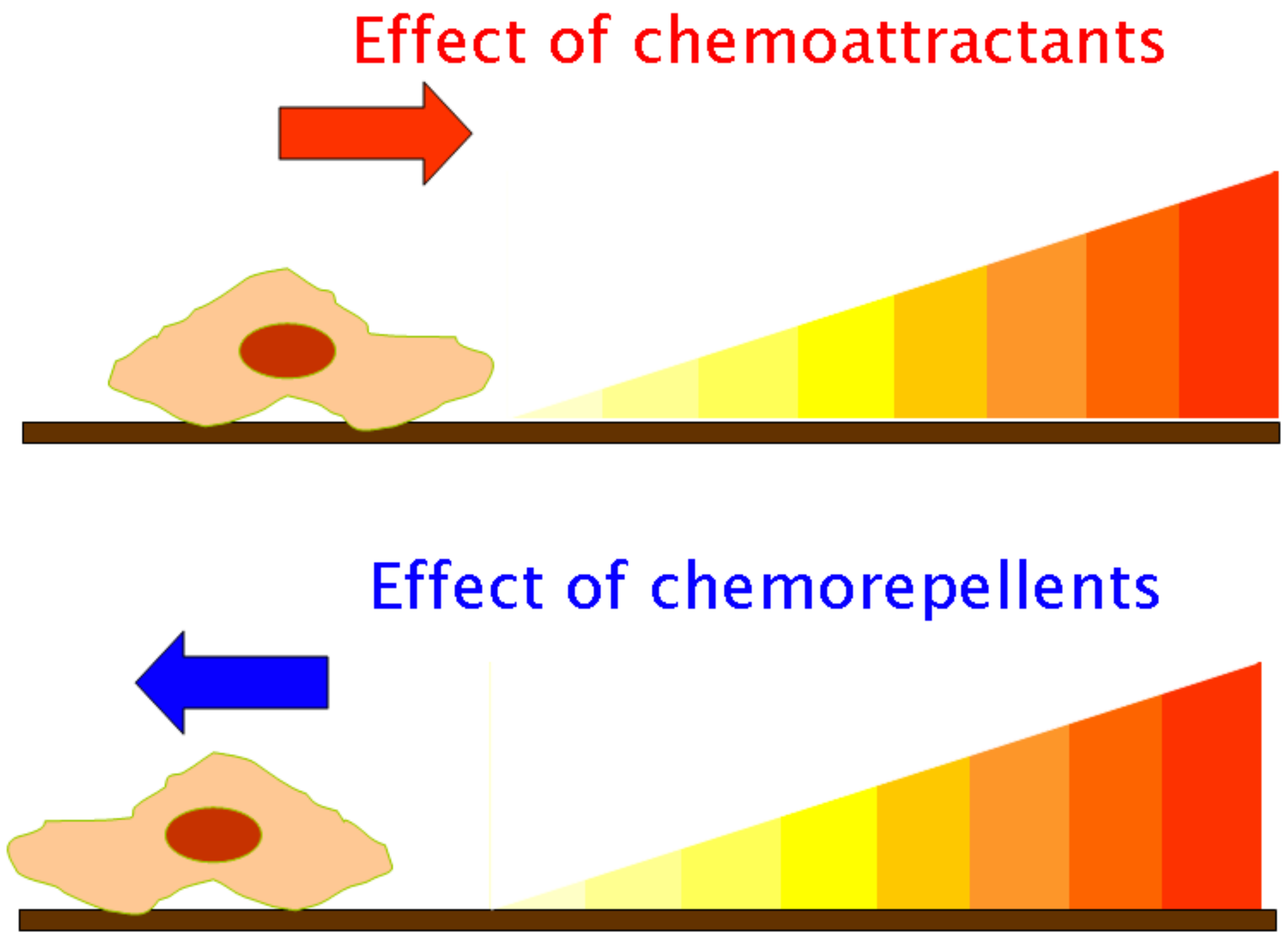
Topics

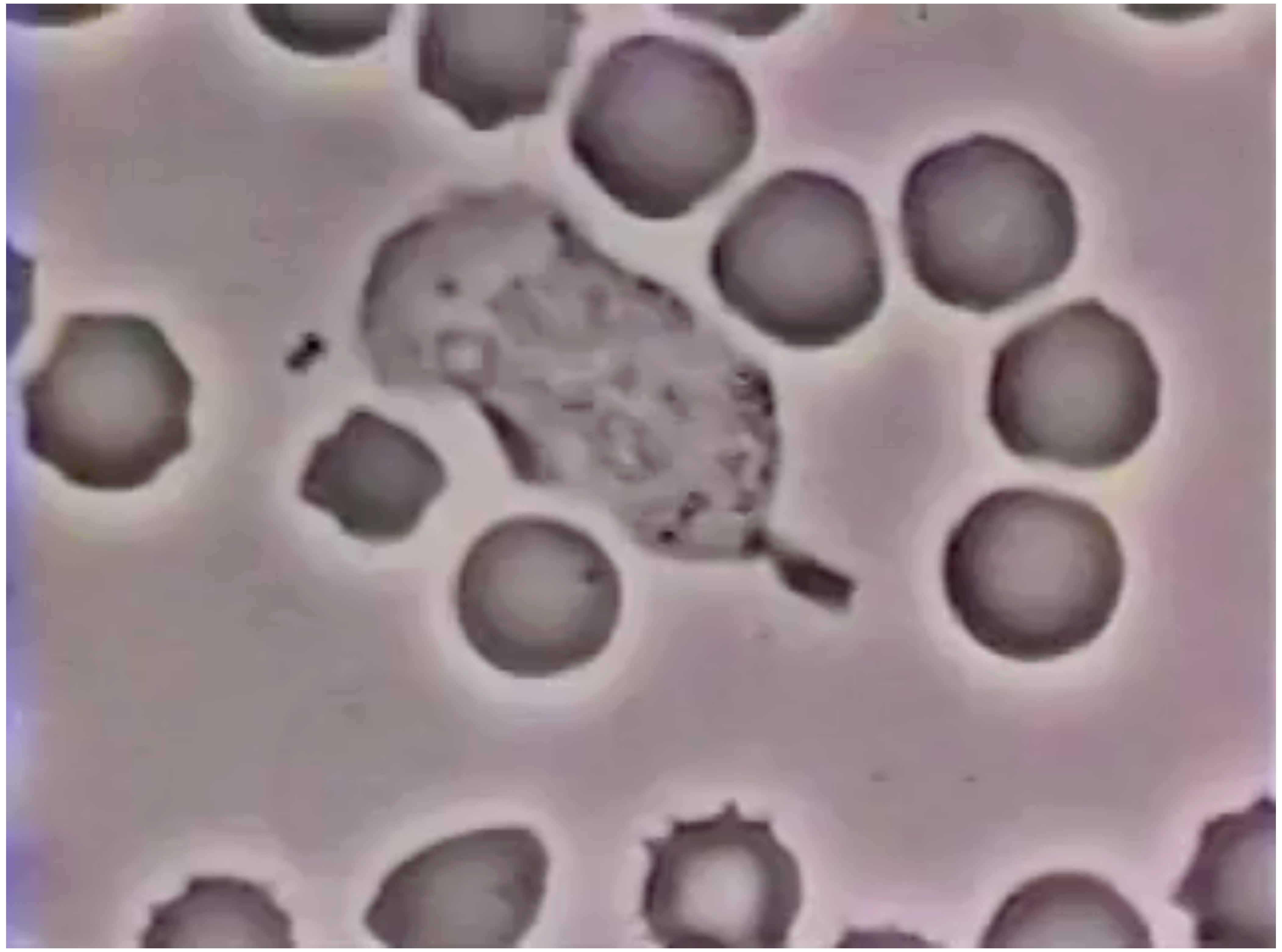
- A review of simple chemotaxis
- Lévy flights and Lévy walks
- The “sniff” valentino

A review of simple chemotaxis

Chemotaxis

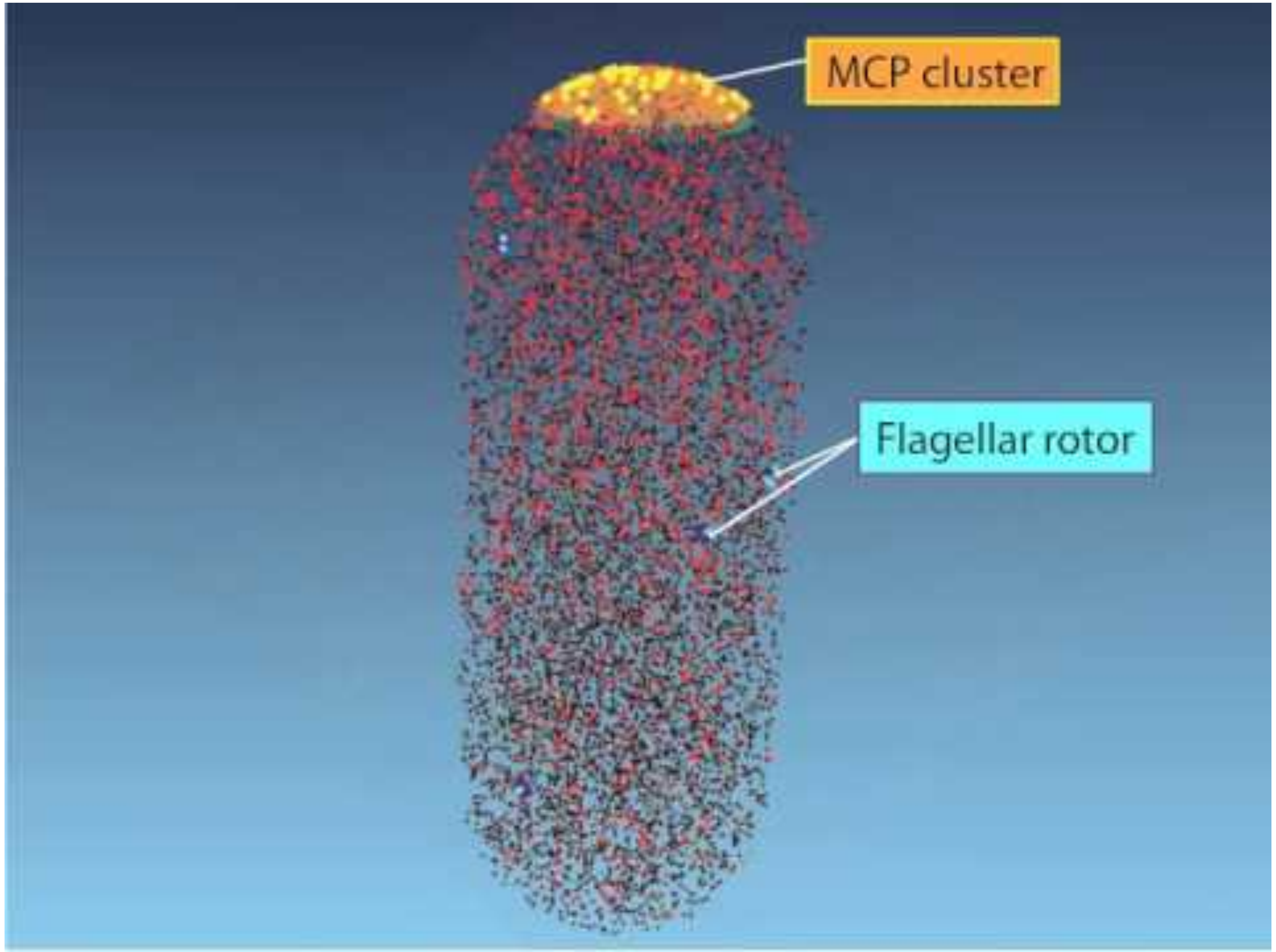
Movement in response to a chemical stimulus.





https://routledgetextbooks.com/textbooks/9780815344506/videos.php

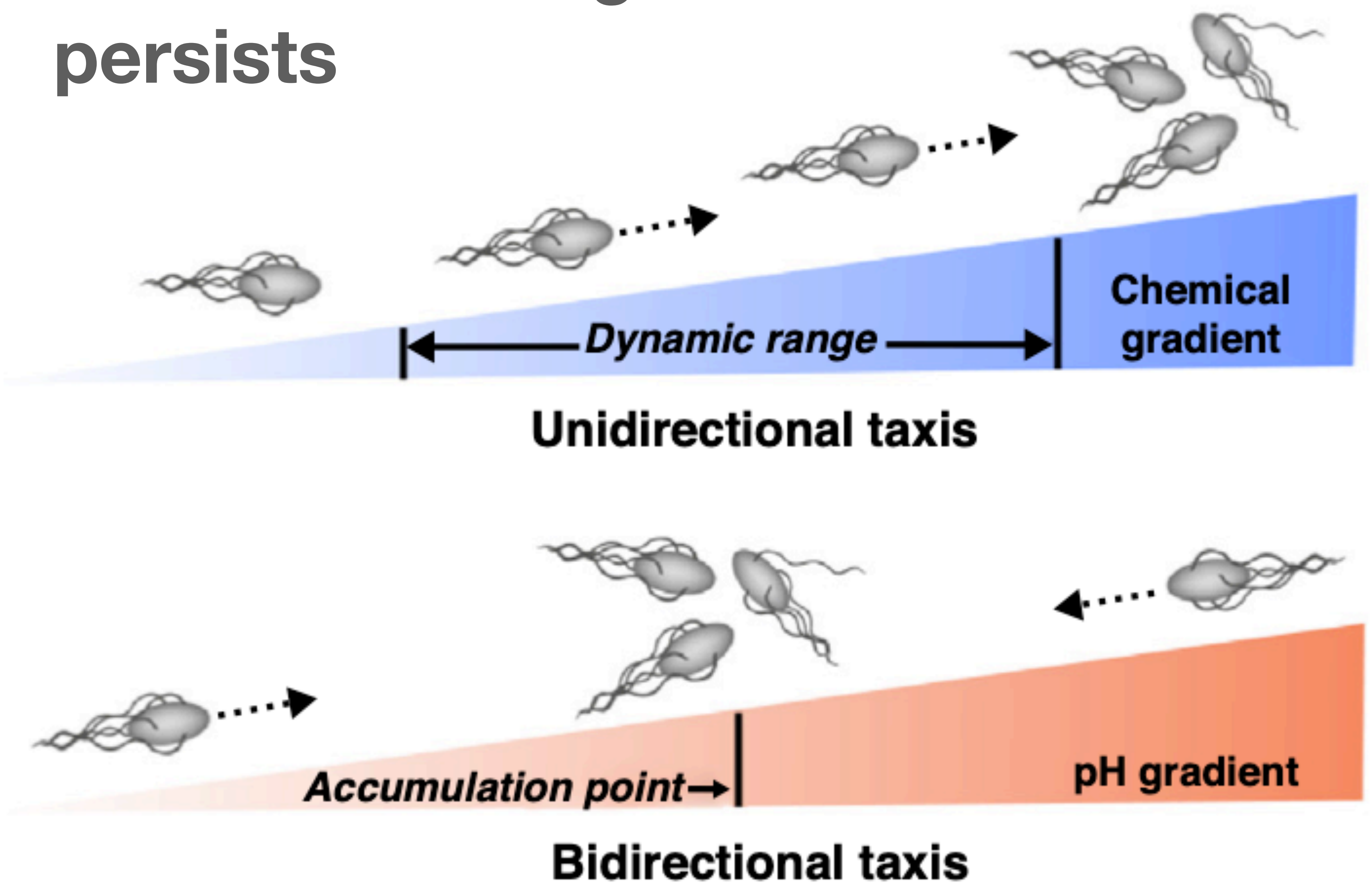
A review of e. coli



https://www.youtube.com/watch?v=LgPDOSou1tw

The "klinokinesis with adaptation" algorithm

Keep moving in the same direction if the gradients persists



Calculate gradient

olfactory scent magnitude

$$\nabla o = o_t - o_{t-1}$$

Calculate state

$$\eta_t \sim U(0,1)$$

random number from 0 to 1

Make decision

random turn

state change probability

$$\theta_t = \begin{cases} U(-\pi,\pi), & \text{if } \Delta o > 0 \;\&\; \eta_t > \rho_+ \\ U(-\pi,\pi), & \text{if } \Delta o \le 0 \;\&\; \eta_t \le \rho_- \\ \theta_{t-1}, & \text{otherwise} \end{cases}$$

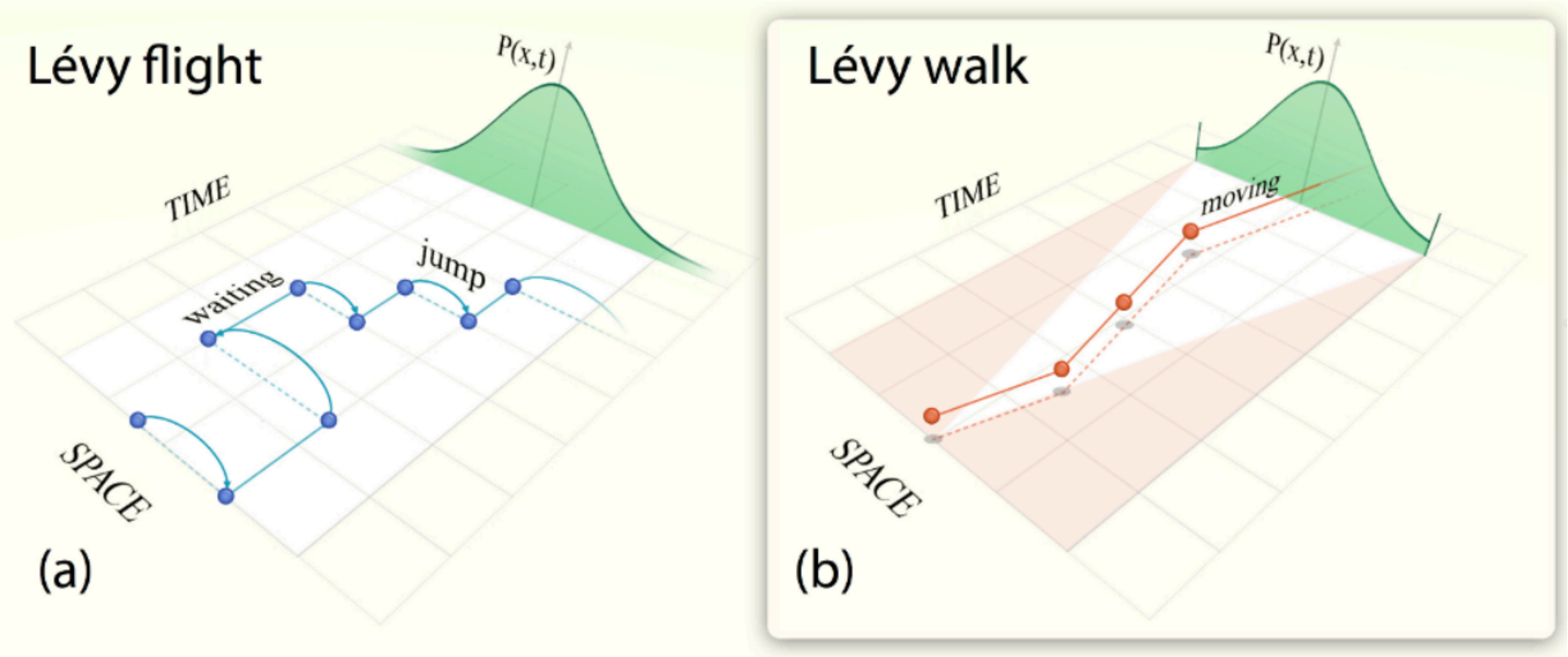
movement angle

keep going

(Bi & Source, 2018)

Lévy flights and Lévy walks

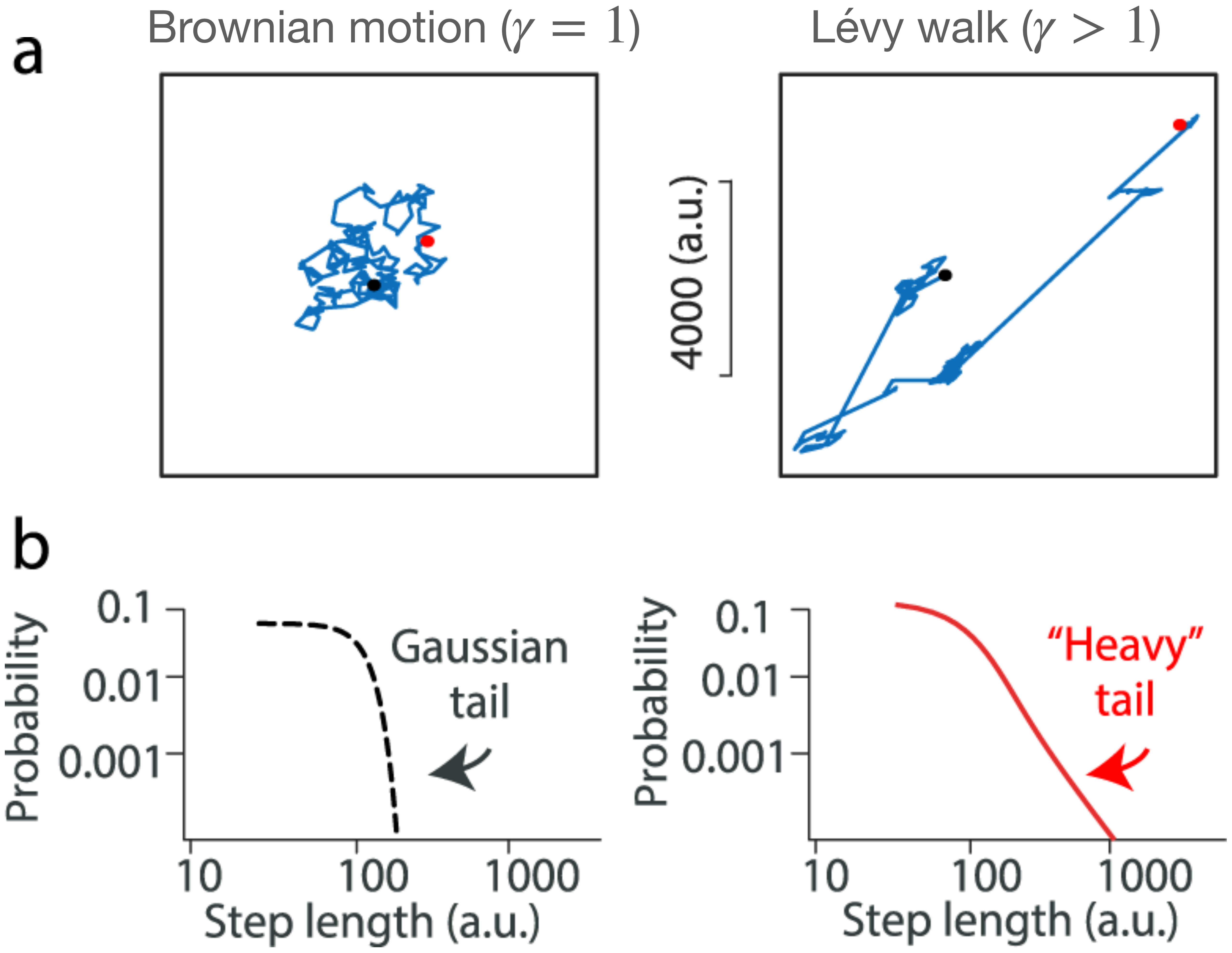
Lévy flights and Lévy walks



(Zaburdaev et al. 2015)

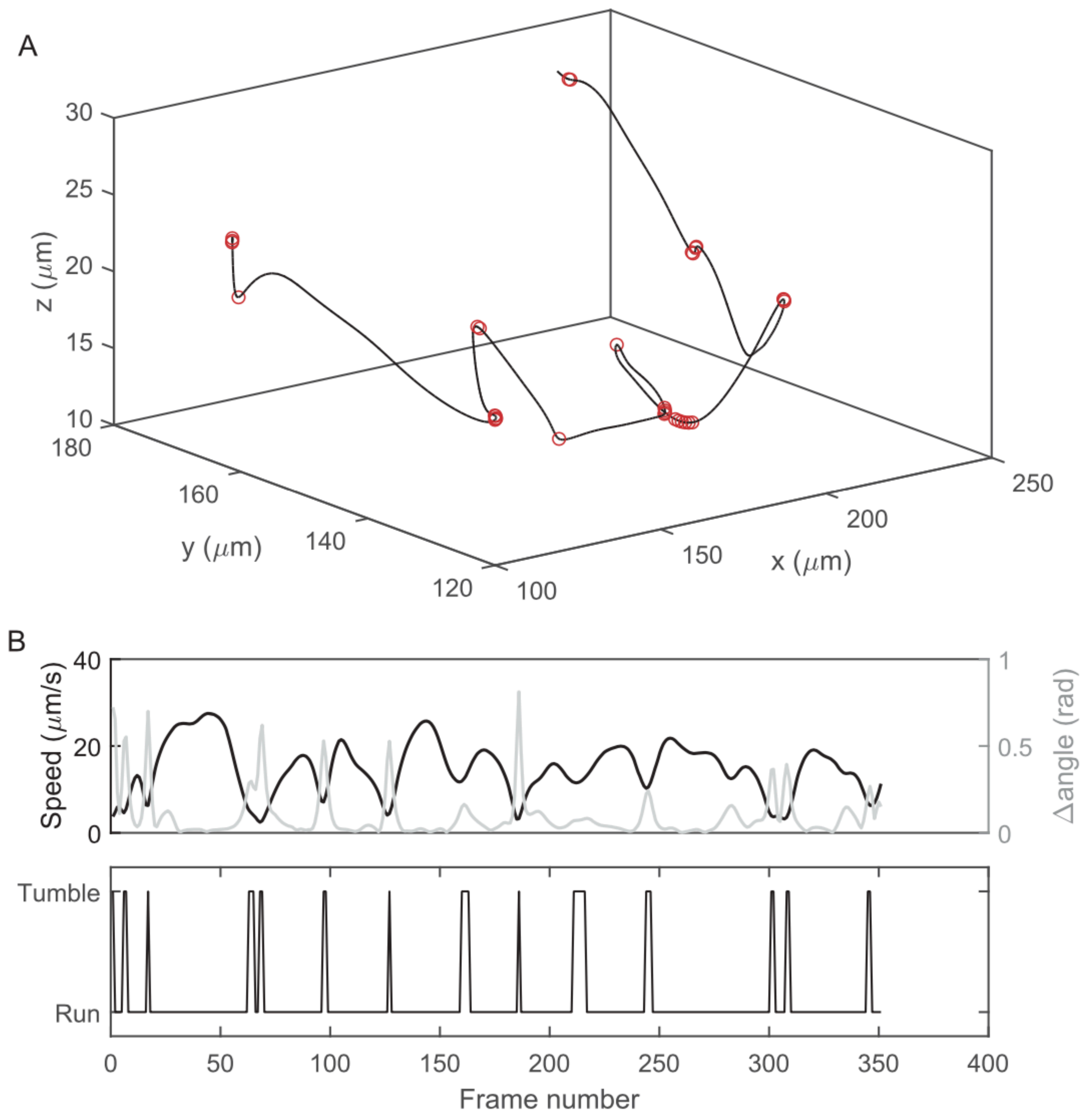
Power Law

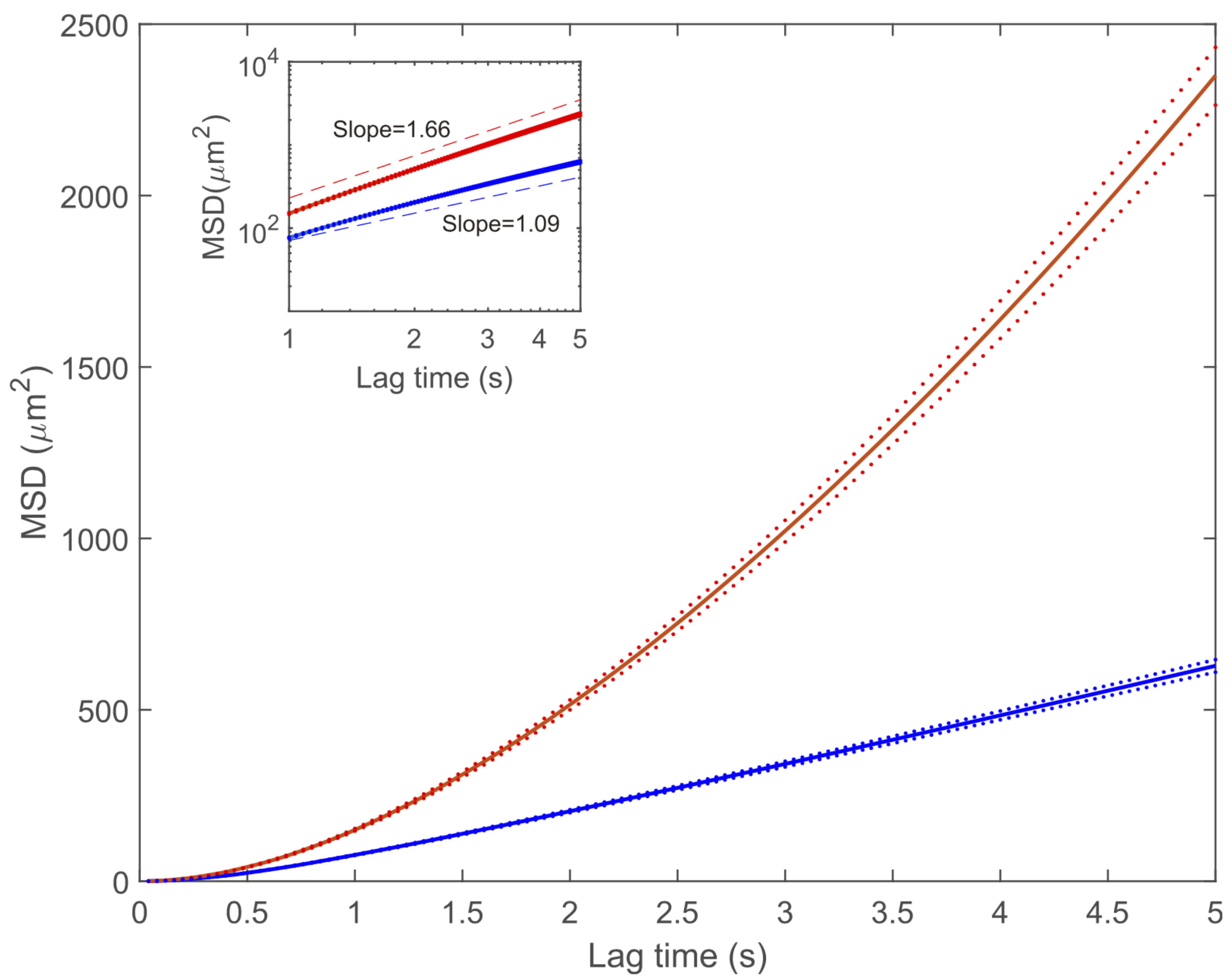
Lévy walks produce probability distributions with “heavy” (aka- long) tails, compared to Brownian motion.

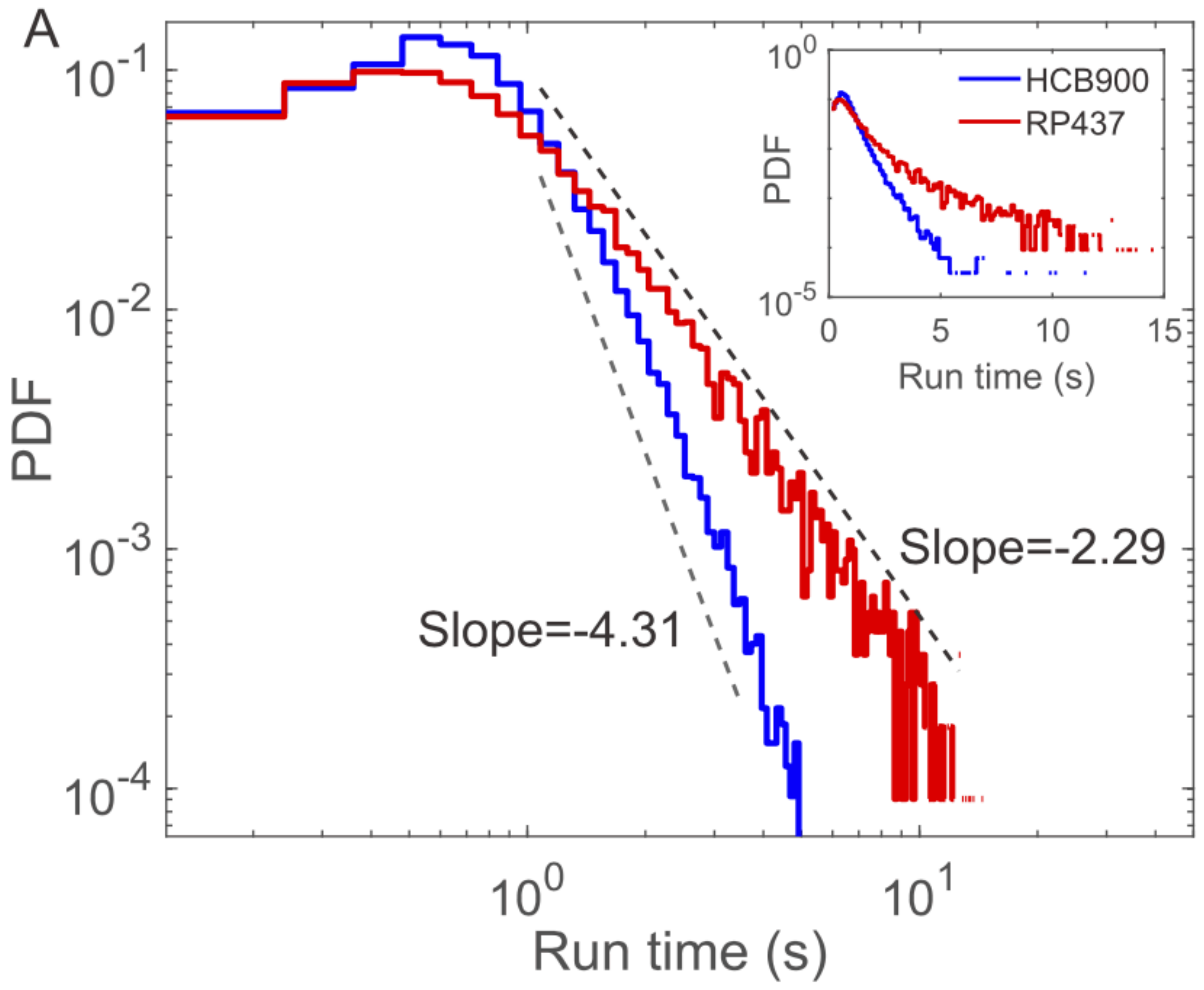


(Liu et al. 2021)

Do *e coli* use Lévy motion to explore?





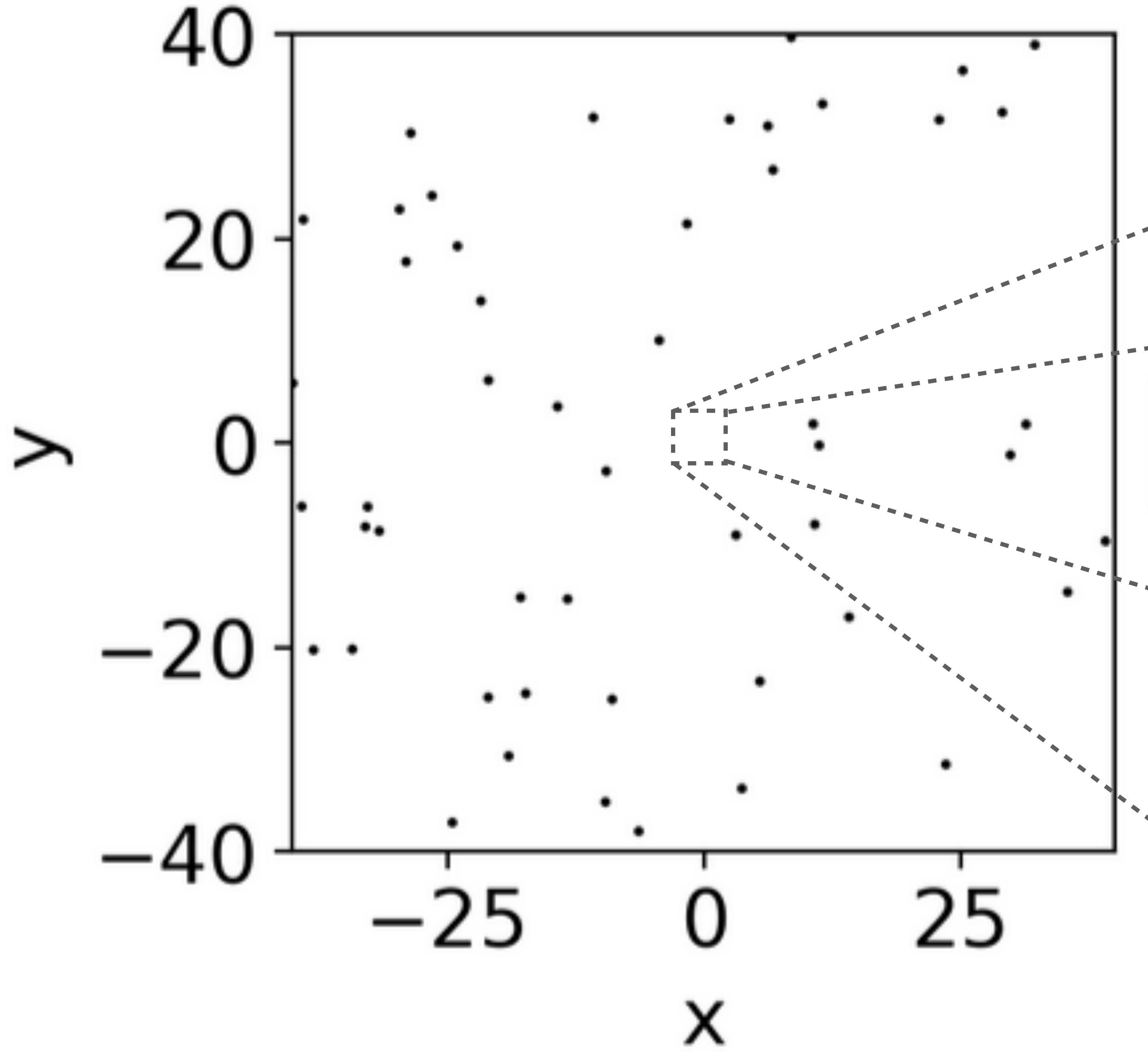


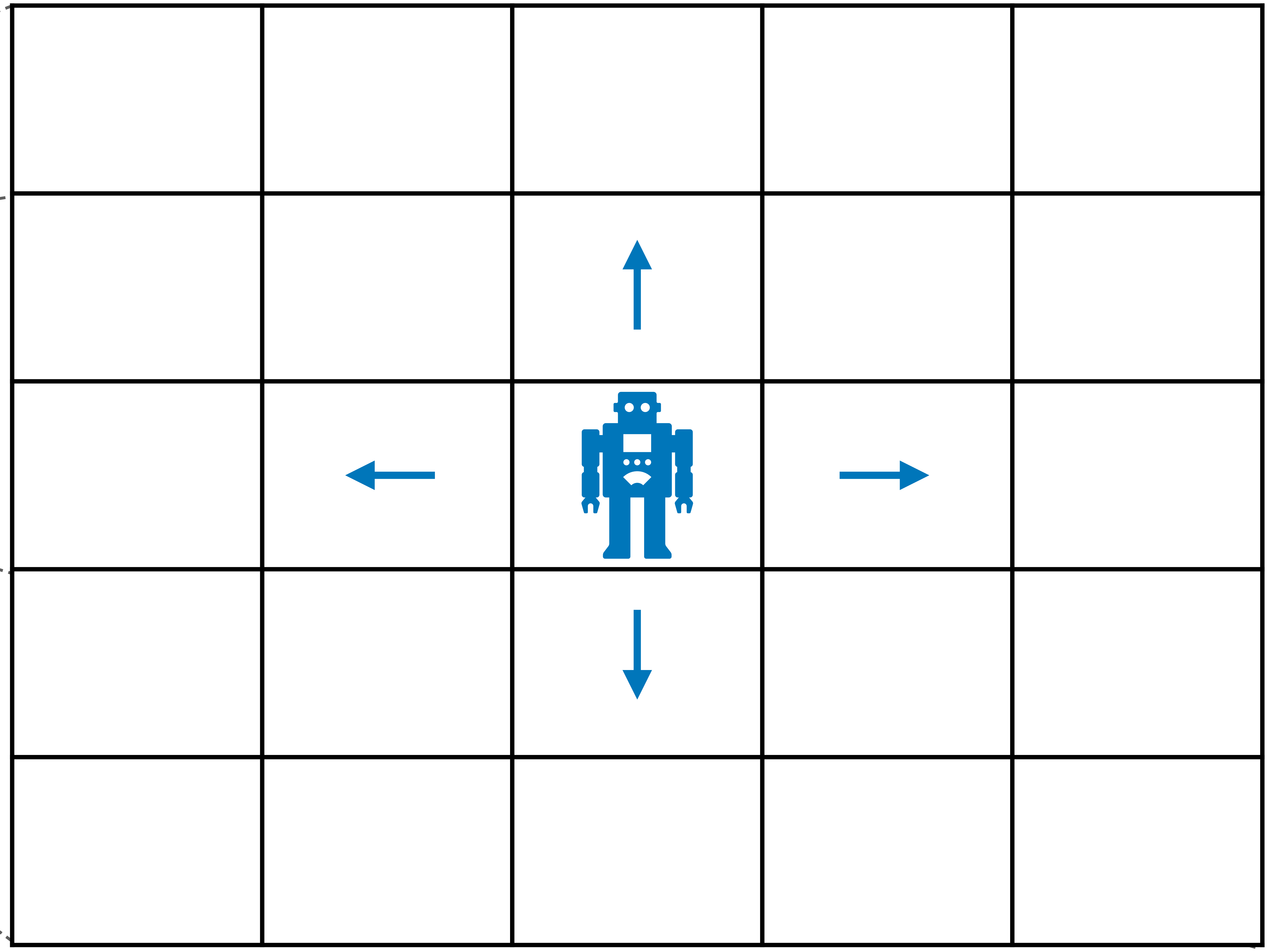
Compared to mutants (HCB900) who lack a critical part of the chemotaxis pathway, wild type *e coli* exhibit super diffusivity in their movements consistent with a Lévy walk process.

(Huo et al. 2021)

The “sniff” valentino

Moving to a grid world

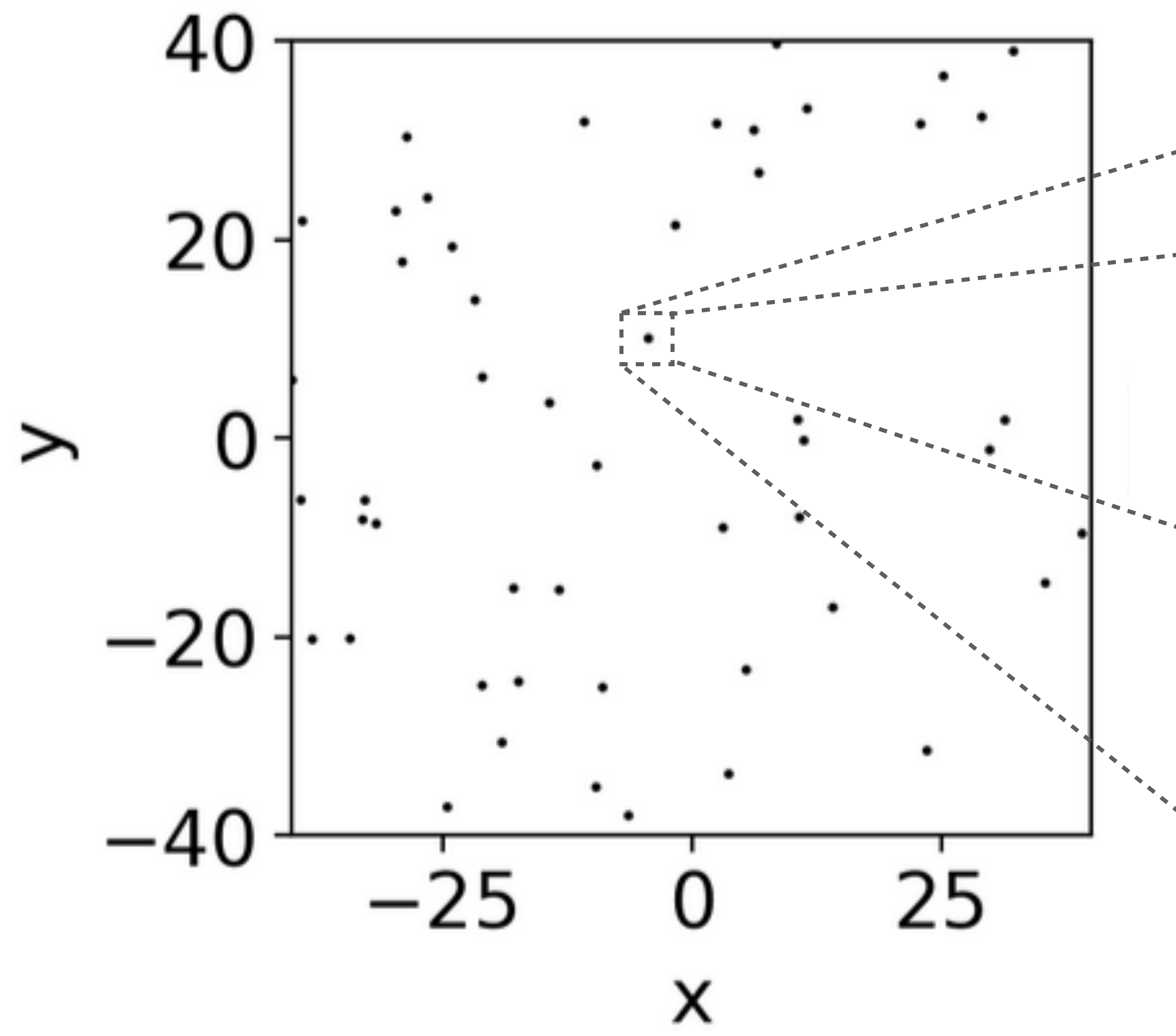


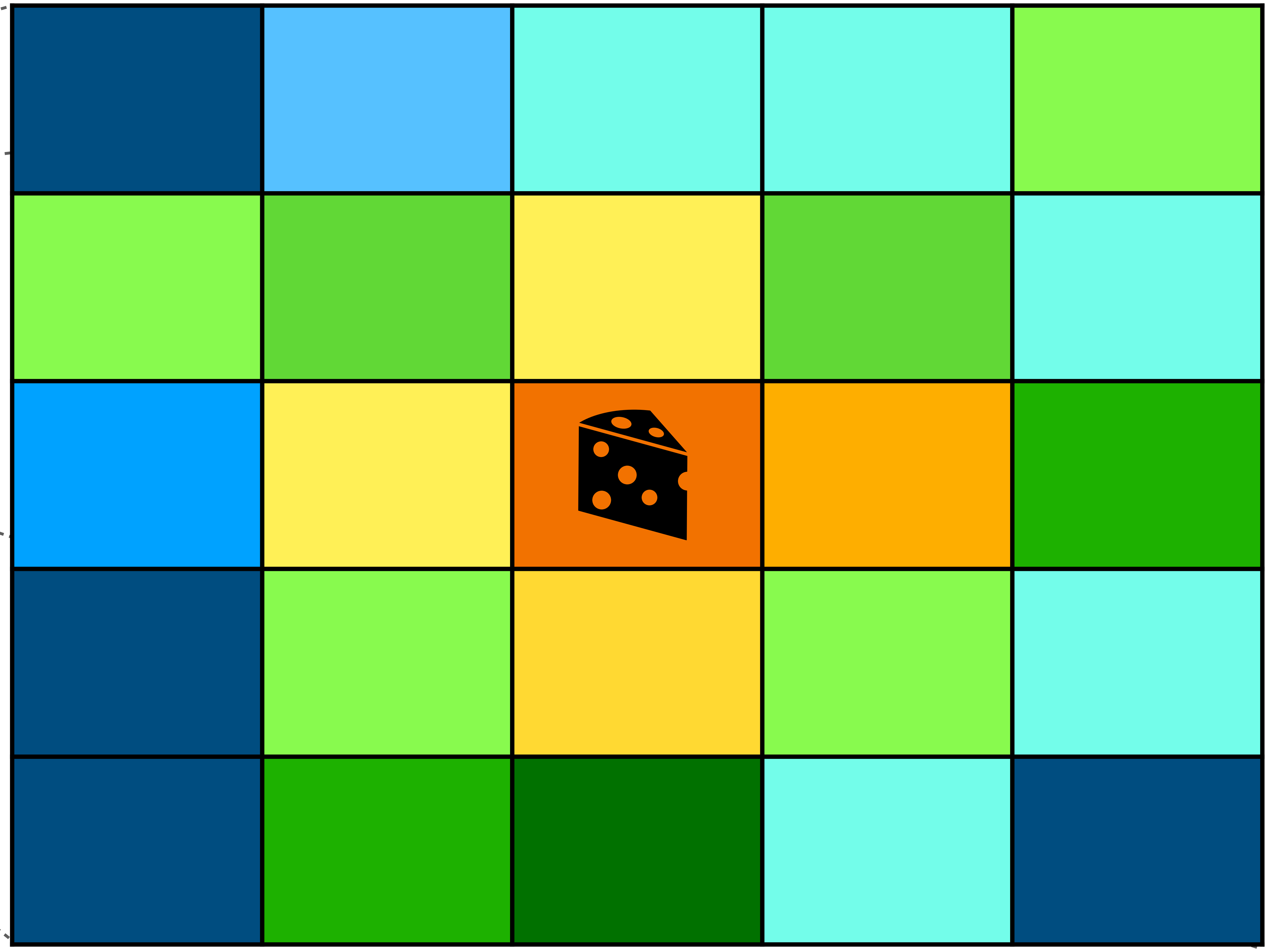


Four choices

up, $\theta_{\uparrow}$; down, $\theta_{\downarrow}$; left, $\theta_{\leftarrow}$; right, $\theta_{\rightarrow}$

Moving to a grid world





Targets

Emit scents as a noisy gradient up to the location of the target itself.

Two algorithms to compare

Algorithm 1 Rando

Set n_{max} number steps
for $step = 1, \dots, n_{max}$ **do**
    Select direction: $\theta_s \sim U(1,4)$
    Move 1 step in θ_s direction
end for

Algorithm 2 Sniff

Set n_{max} number steps
Set probability of tumble when $\Delta o > 0$, ρ_+
Set probability of tumble when $\Delta o \leq 0$, ρ_-
for $step = 1, \dots, n_{max}$ **do**
    Sample gradient: $\Delta o = o_s - o_{s-1}$
    Sample state: $\eta_t \sim U(0,1)$
    Sample new direction: $\theta' \sim U(1,4)$
    if $\Delta o > 0$ **and** $\eta_s > \rho_+$ **then**
        $\theta_s = \theta'$
    else if $\Delta o \leq 0$ **and** $\eta_s \leq \rho_-$ **then**
        $\theta_s = \theta'$
    else
        $\theta_s = \theta_{s-1}$
    end if
    Move 1 step in θ_s direction
end for

Take home message

- The algorithm for chemotaxis in *e. coli* is simple: keep going if a gradient is increasing, otherwise turn and tumble.
- This produces the Lévy walk structure of *e. coli* movements.

Lab 2: Basic chemotaxis

URL: https://coaxlab.github.io/BIX-book/notebooks/lab2-chemotaxis.html