

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.

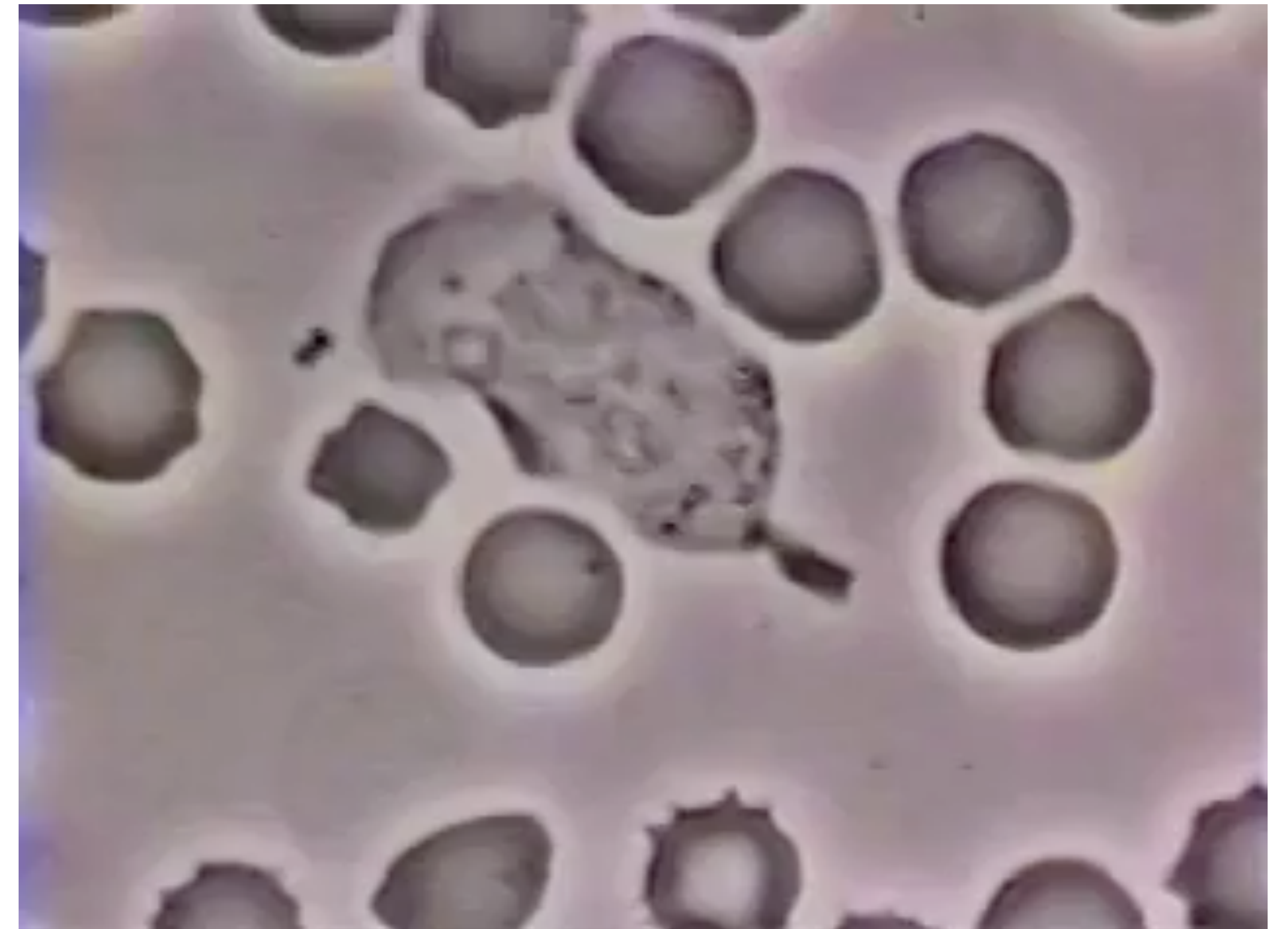
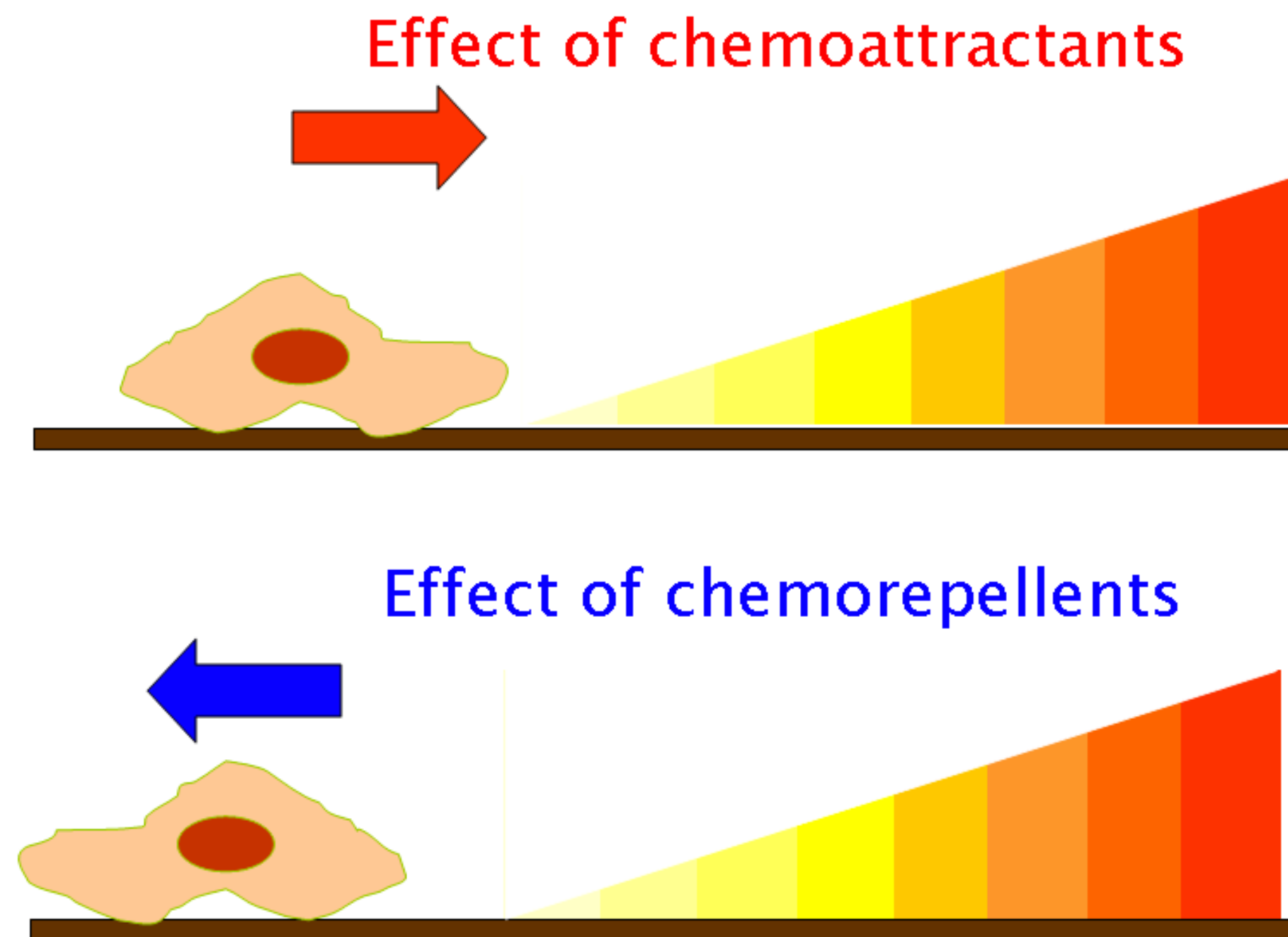
Topics

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

A review of simple chemotaxis

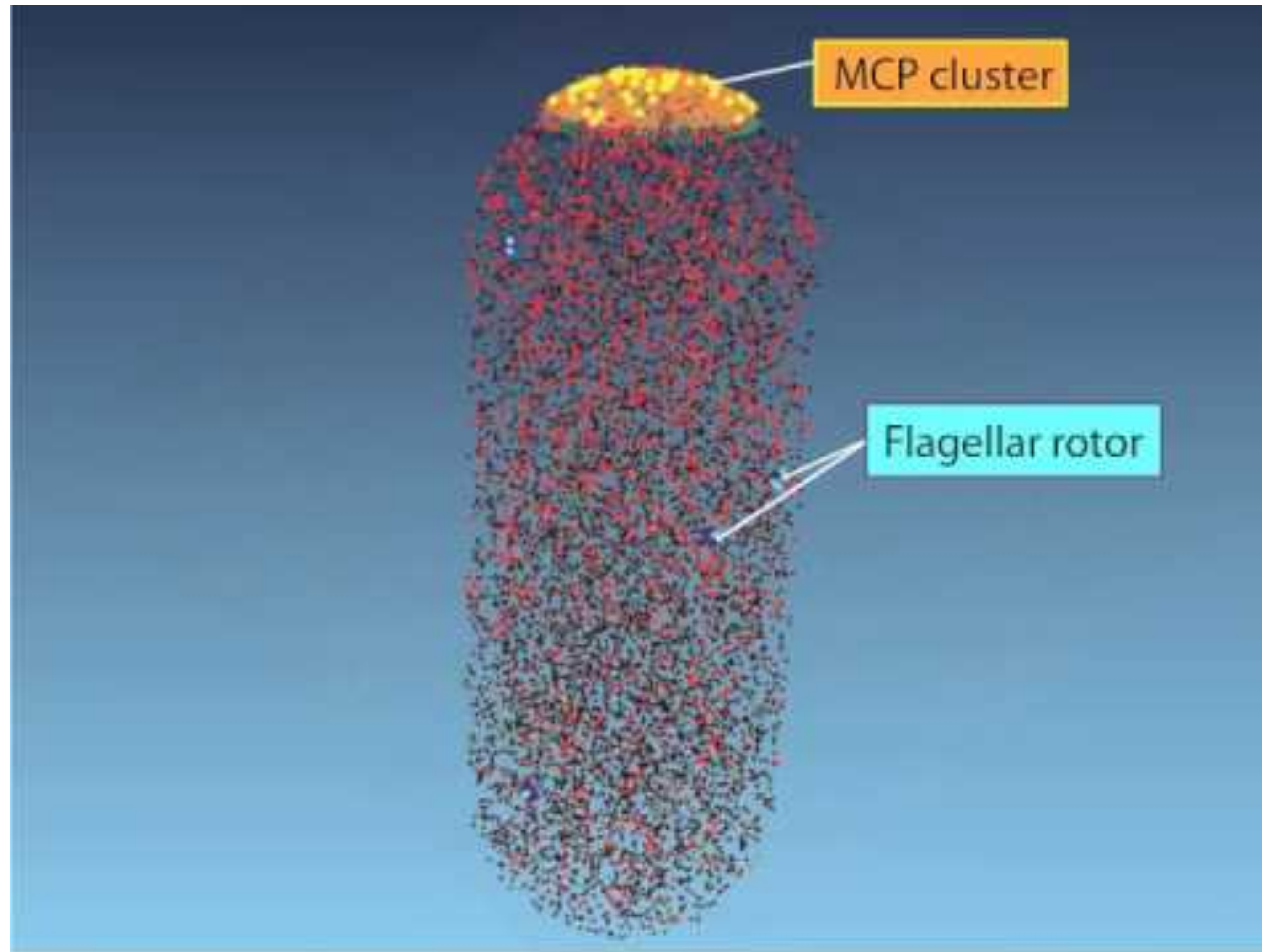
Chemotaxis

Movement in response to a chemical stimulus.



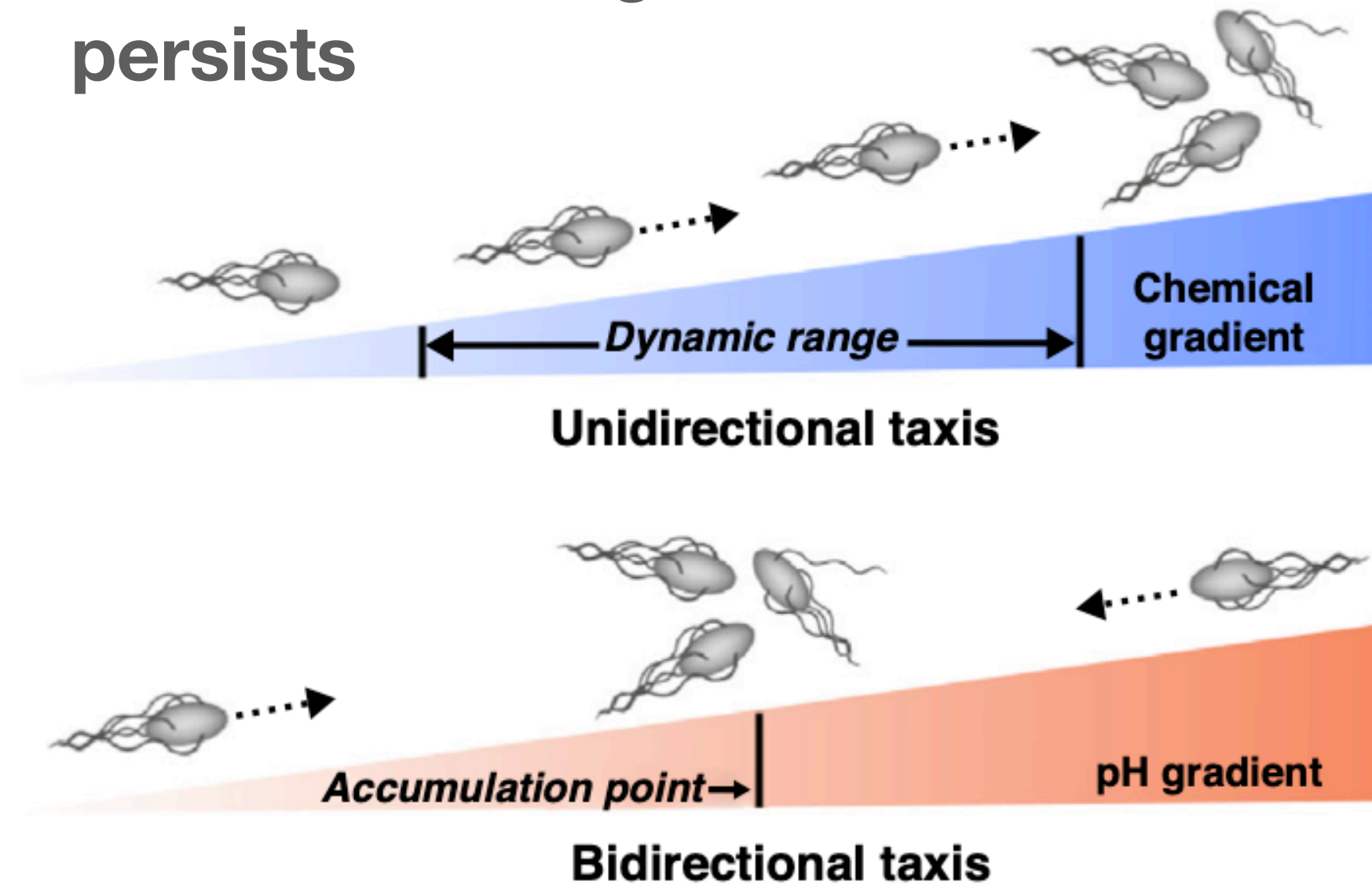
<https://routledgetextbooks.com/textbooks/9780815344506/videos.php>

A review of e. coli



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

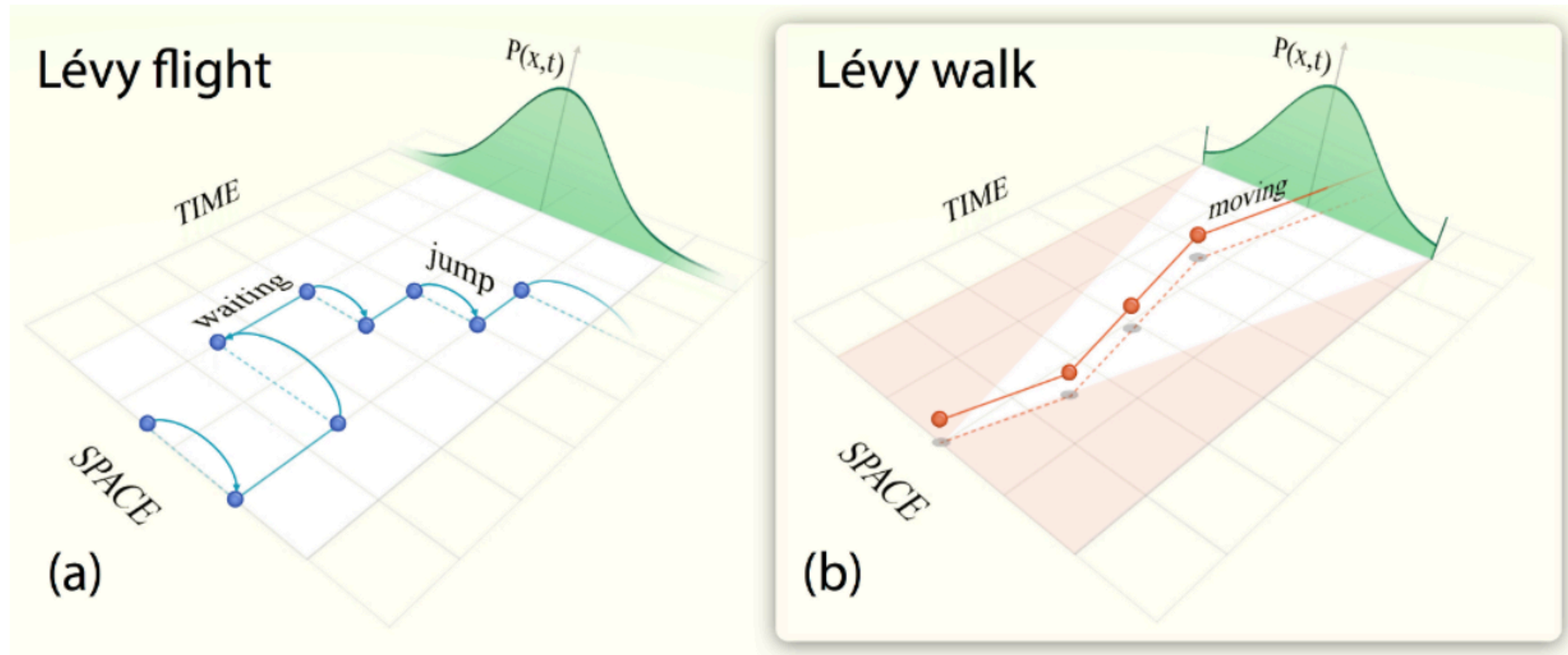
$$\theta_t = \begin{cases} U(-\pi, \pi), & \text{if } \Delta o > 0 \text{ \& } \eta_t > \rho_+ \\ U(-\pi, \pi), & \text{if } \Delta o \leq 0 \text{ \& } \eta_t \leq \rho_- \\ \theta_{t-1}, & \text{otherwise} \end{cases}$$

movement angle

keep going

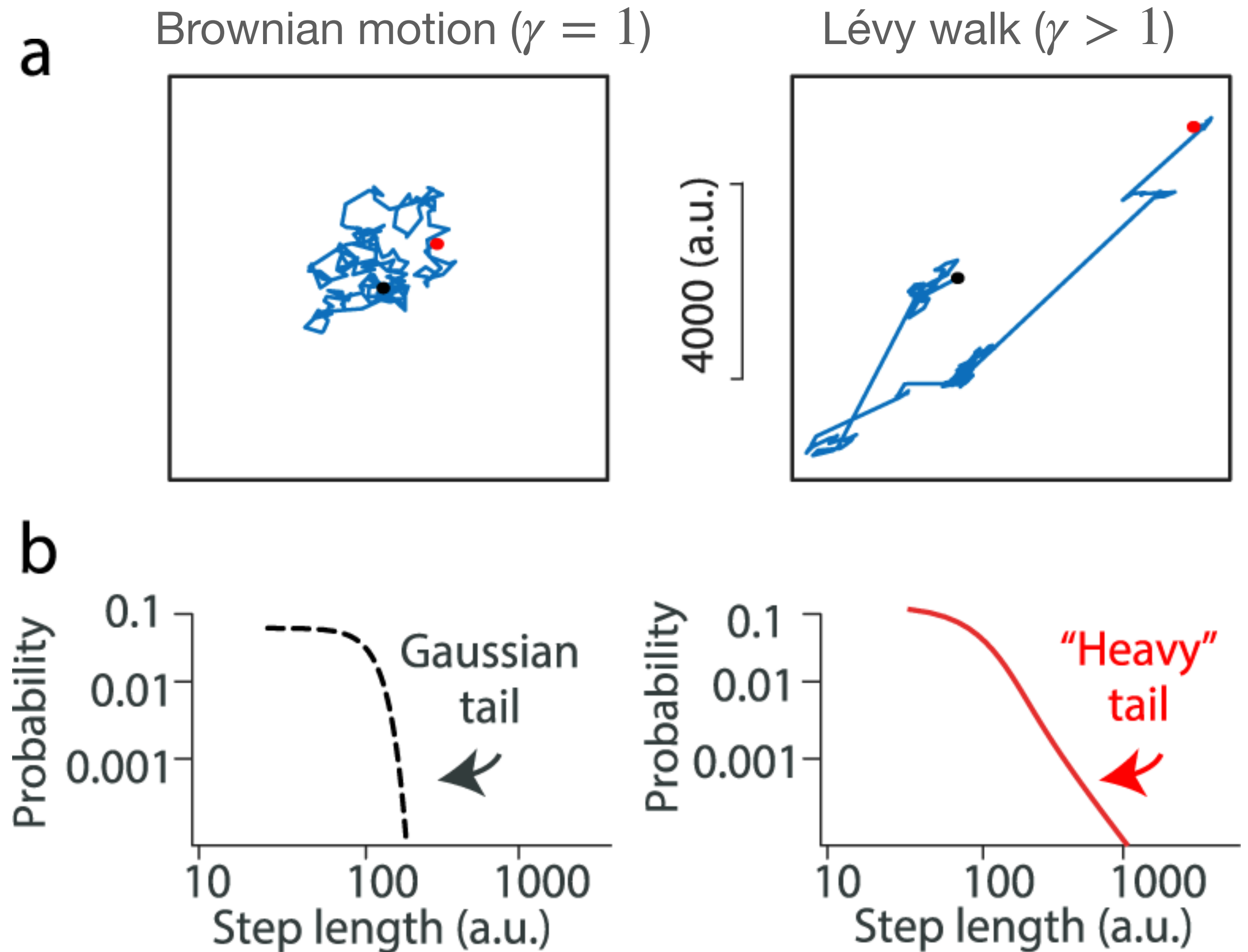
Lévy flights and Lévy walks

Lévy flights and Lévy walks

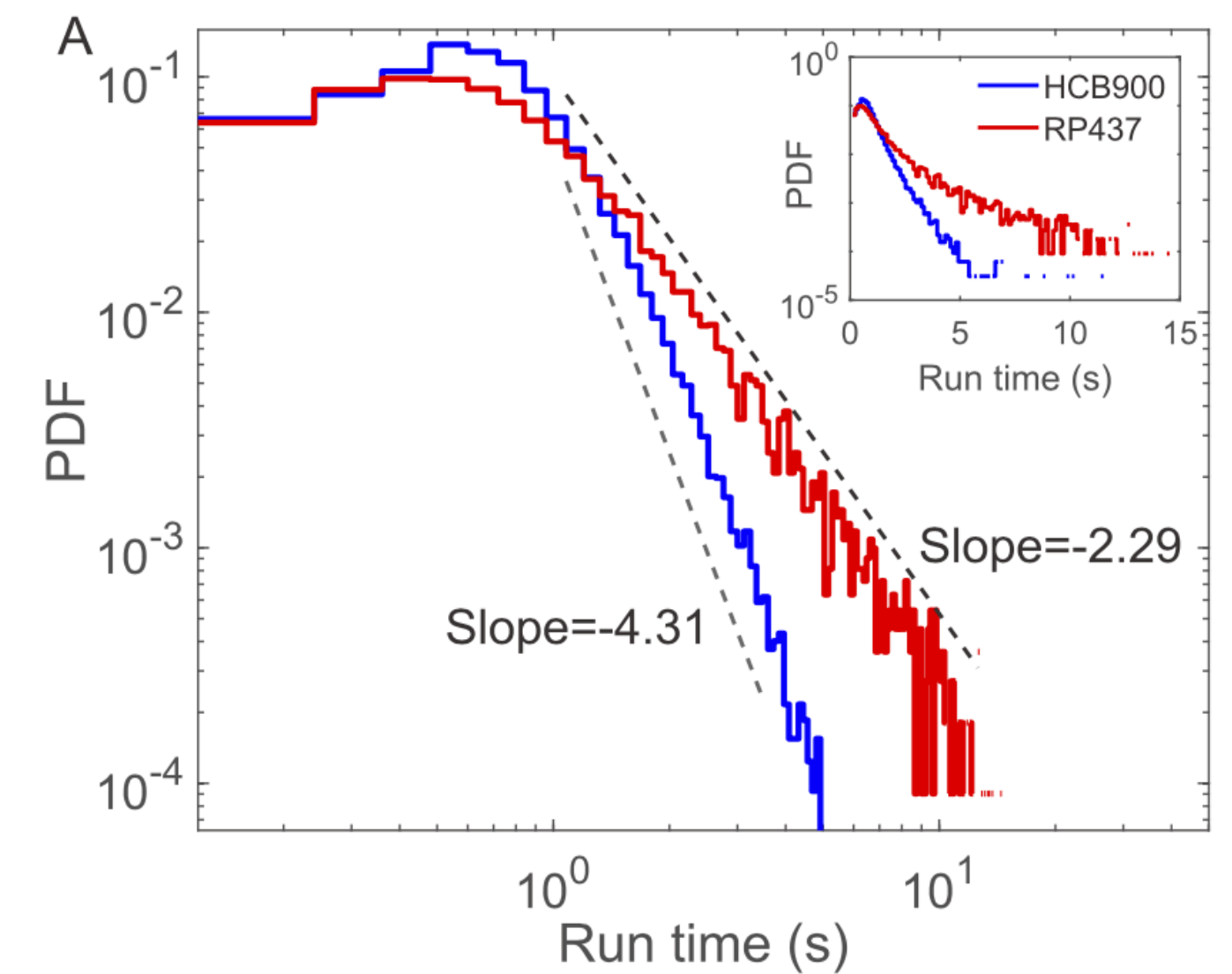
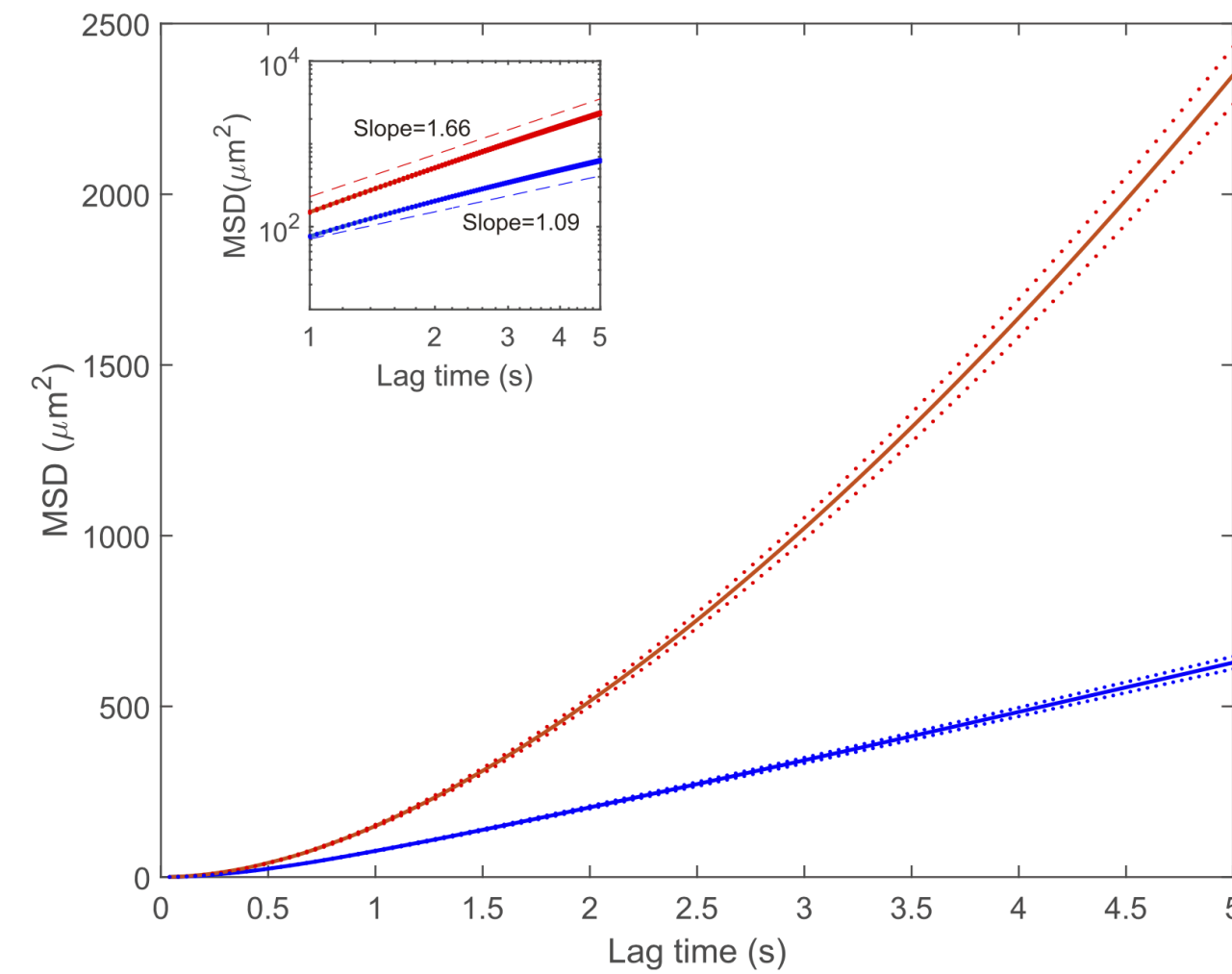
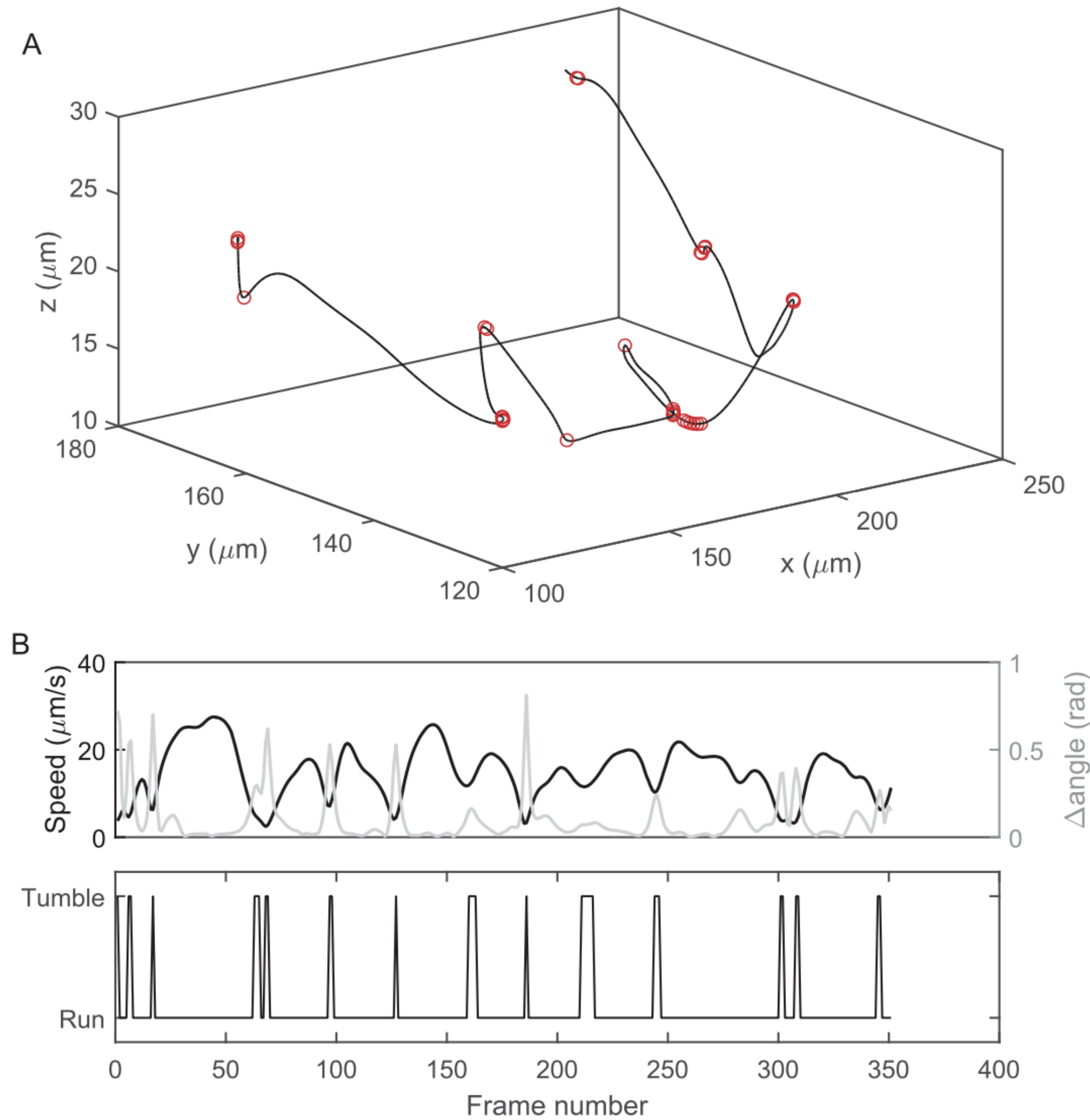


Power Law

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



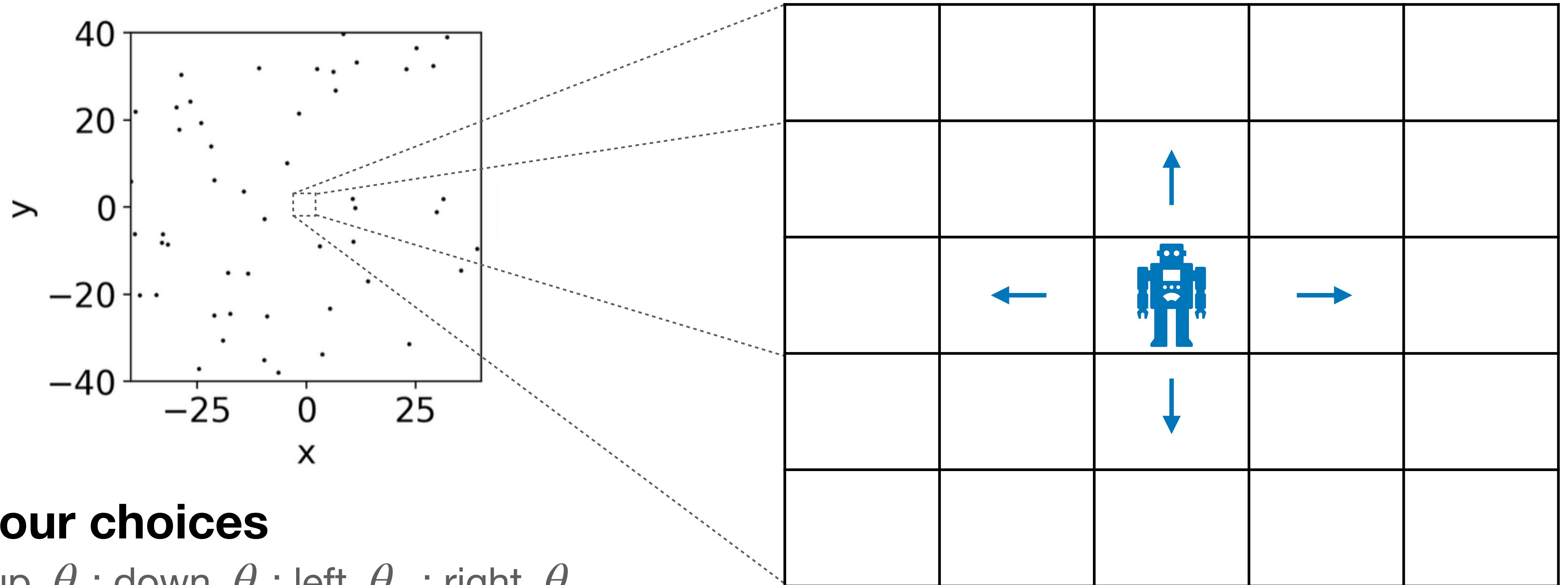
Do *e coli* use Lévy motion to explore?



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.

The “sniff” valentino

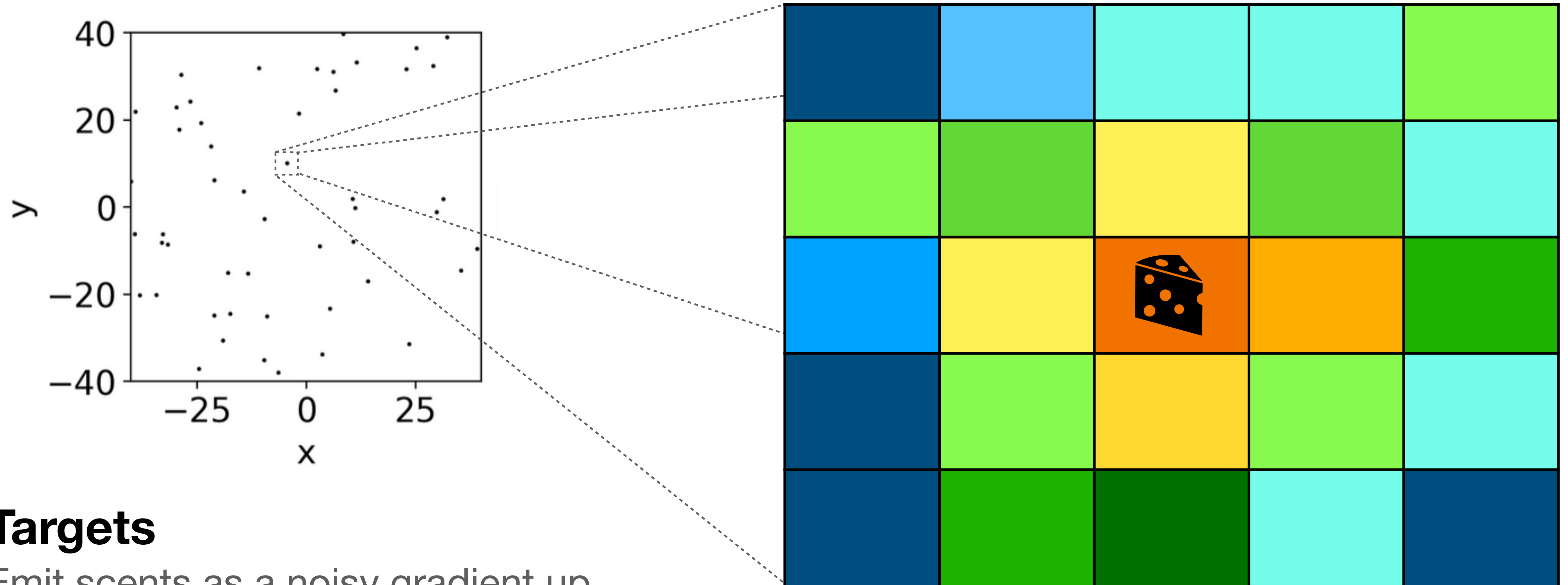
Moving to a grid world



Four choices

up, θ_{\uparrow} ; down, θ_{\downarrow} ; left, θ_{\leftarrow} ; right, θ_{\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

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

Algorithm 2 Sniff

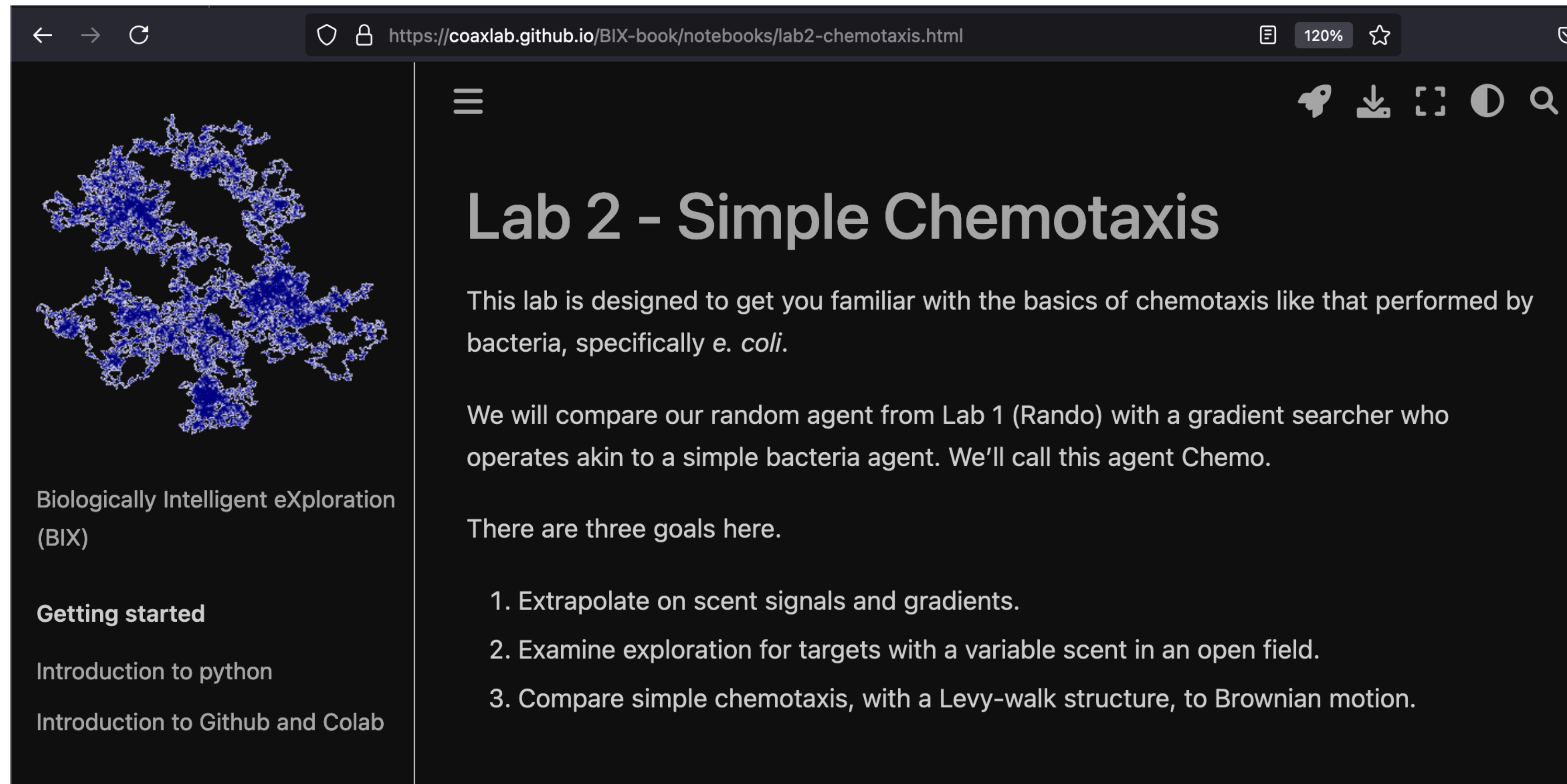
```
1: Set  $n_{max}$  number steps
2: Set probability of tumble when  $\Delta o > 0$ ,  $\rho_+$ 
3: Set probability of tumble when  $\Delta o \leq 0$ ,  $\rho_-$ 
4: for  $step = 1, \dots, n_{max}$  do
5:   Sample gradient:  $\Delta o = o_s - o_{s-1}$ 
6:   Sample state:  $\eta_t \sim U(0, 1)$ 
7:   Sample new direction:  $\theta' \sim U(1, 4)$ 
8:   if  $\Delta o > 0$  and  $\eta_s > \rho_+$  then
9:      $\theta_s = \theta'$ 
10:  else if  $\Delta o \leq 0$  and  $\eta_s \leq \rho_-$  then
11:     $\theta_s = \theta'$ 
12:  else
13:     $\theta_s = \theta_{s-1}$ 
14:  end if
15:  Move 1 step in  $\theta_s$  direction
16: 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>



The screenshot shows a web browser window displaying a Jupyter Notebook titled "Lab 2 - Simple Chemotaxis". The browser's address bar shows the URL <https://coaxlab.github.io/BIX-book/notebooks/lab2-chemotaxis.html>. The notebook interface has a dark theme. On the left sidebar, there is a blue fractal image and a list of navigation links: "Biologically Intelligent eXploration (BIX)", "Getting started", "Introduction to python", and "Introduction to Github and Colab". The main content area on the right has the title "Lab 2 - Simple Chemotaxis" and the following text:

This lab is designed to get you familiar with the basics of chemotaxis like that performed by bacteria, specifically *e. coli*.

We will compare our random agent from Lab 1 (Rando) with a gradient searcher who operates akin to a simple bacteria agent. We'll call this agent Chemo.

There are three goals here.

1. Extrapolate on scent signals and gradients.
2. Examine exploration for targets with a variable scent in an open field.
3. Compare simple chemotaxis, with a Levy-walk structure, to Brownian motion.