

**Is randomness an effective strategy
(for exploration)?**

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.
- Hein, A. M., & McKinley, S. A. (2012). Sensing and decision-making in random search. Proceedings of the National Academy of Sciences, 109(30), 12070-12074.

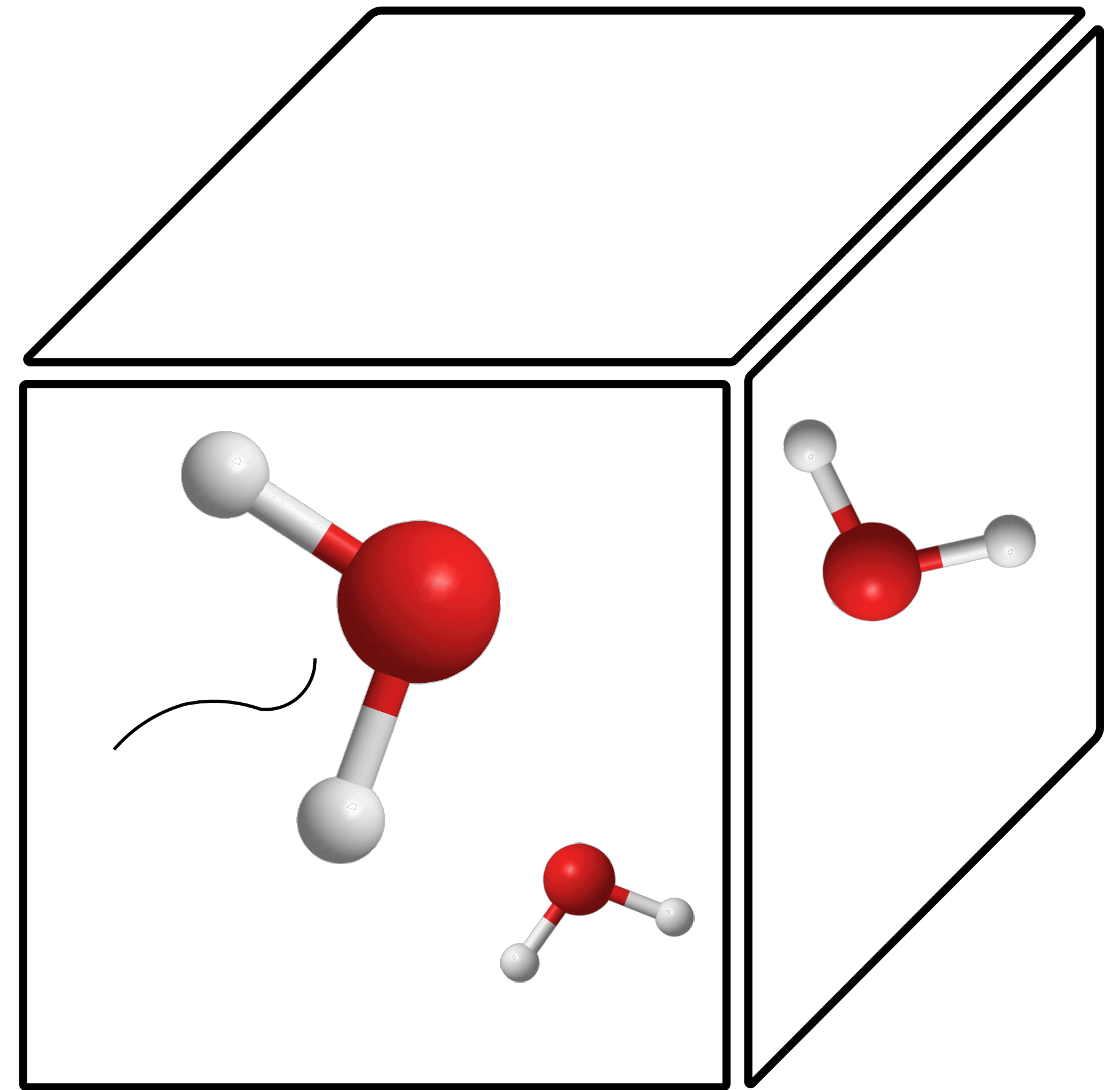
Topics

- Simple forms of exploration
- The value of simple sensing

Simple forms of exploration

What is the optimal way to explore?

An optimal exploration policy is one that samples every option at least once.



Brownian motion

In 1D space

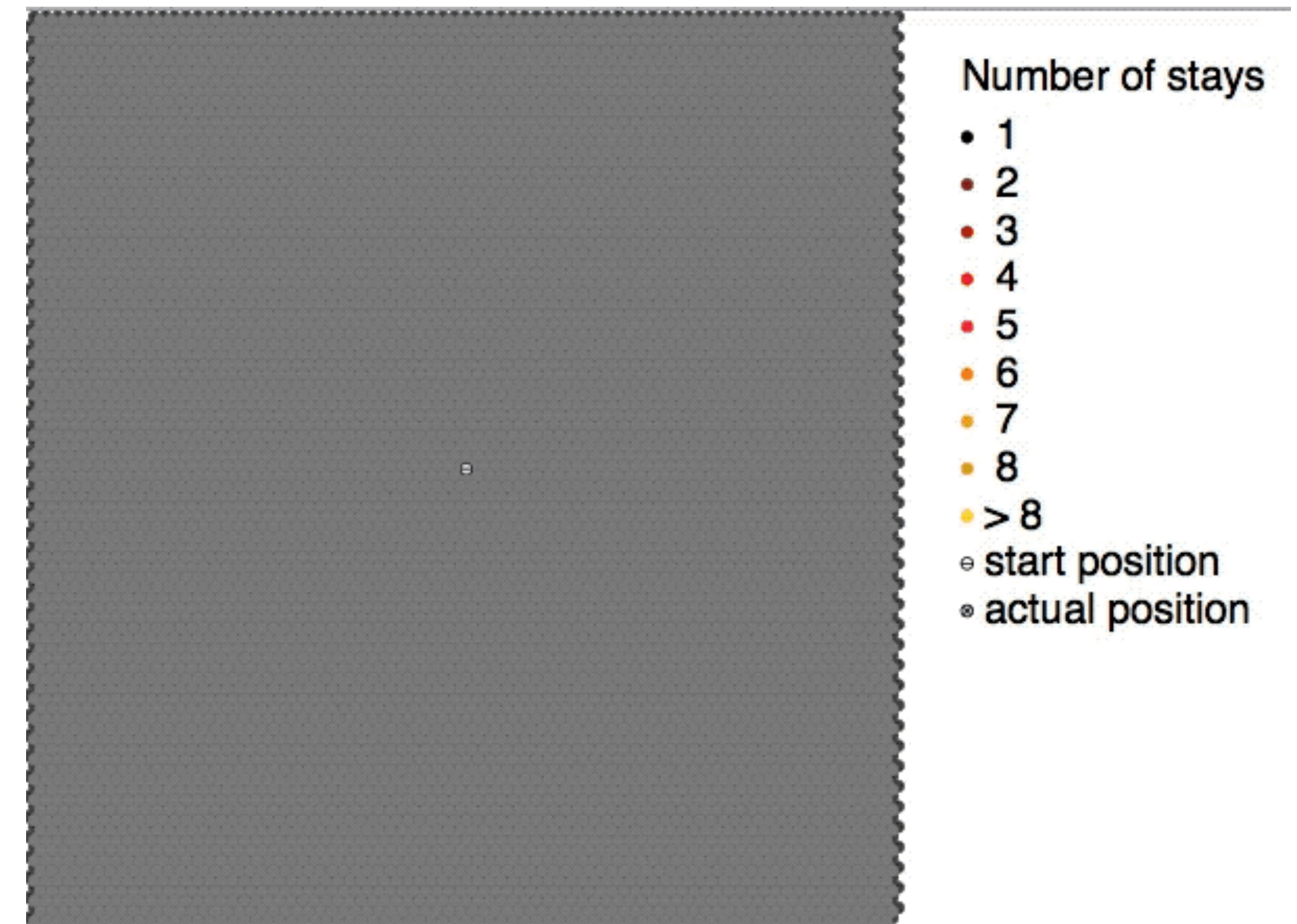
$$x_i = x_{i-1} + u_i, \quad u_i \sim N(\mu, \sigma)$$

In 2D space

$$\theta_i = v_i 2\pi, \quad v_i \sim U(-\pi, \pi)$$

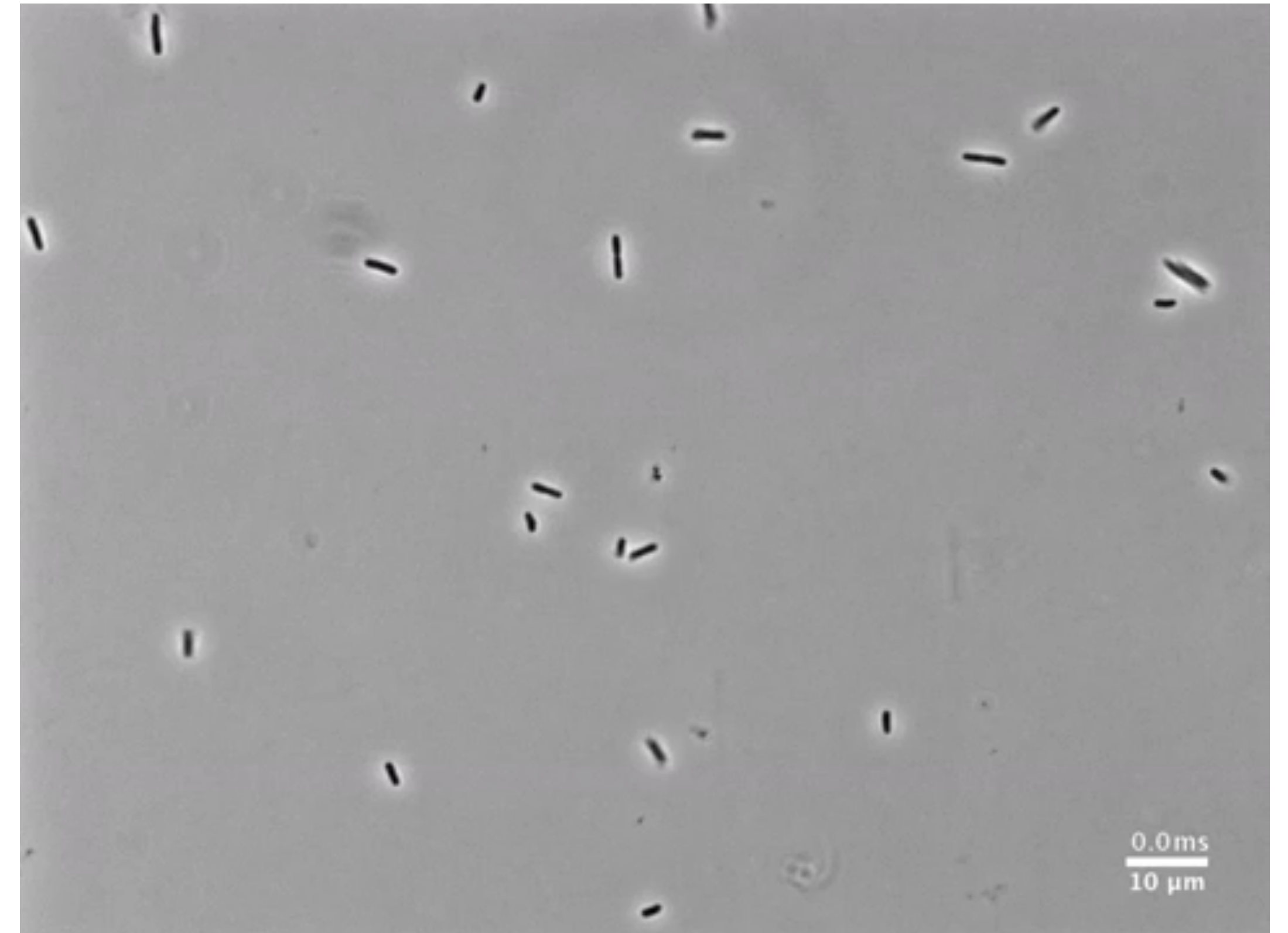
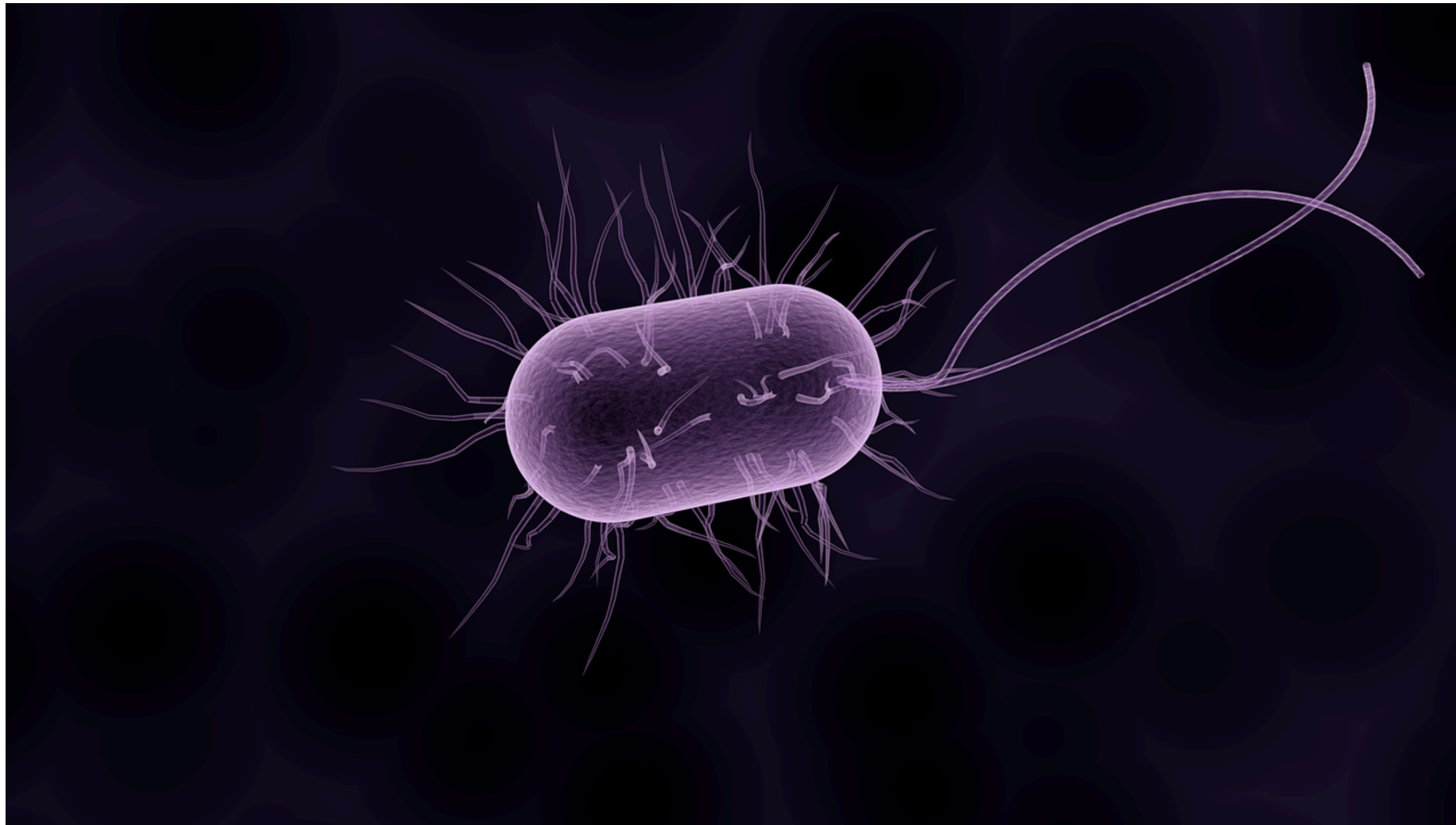
$$x_i = x_{i-1} + u_i \cos(\theta_i)$$

$$y_i = y_{i-1} + u_i \sin(\theta_i)$$



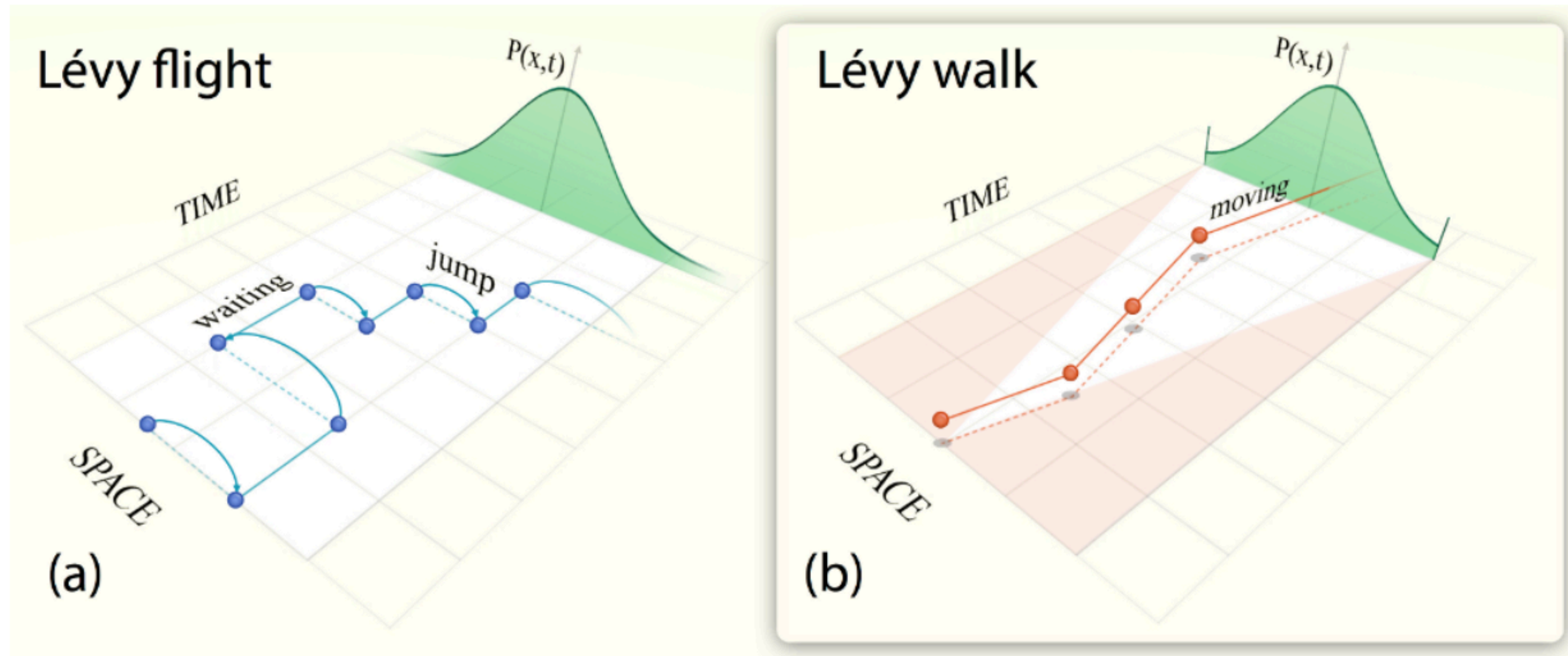
2D random walk of a silver adaptor on a Ag(111) surface (source: Wikipedia; Marburg et al. 2017)

Organism: E. Coli

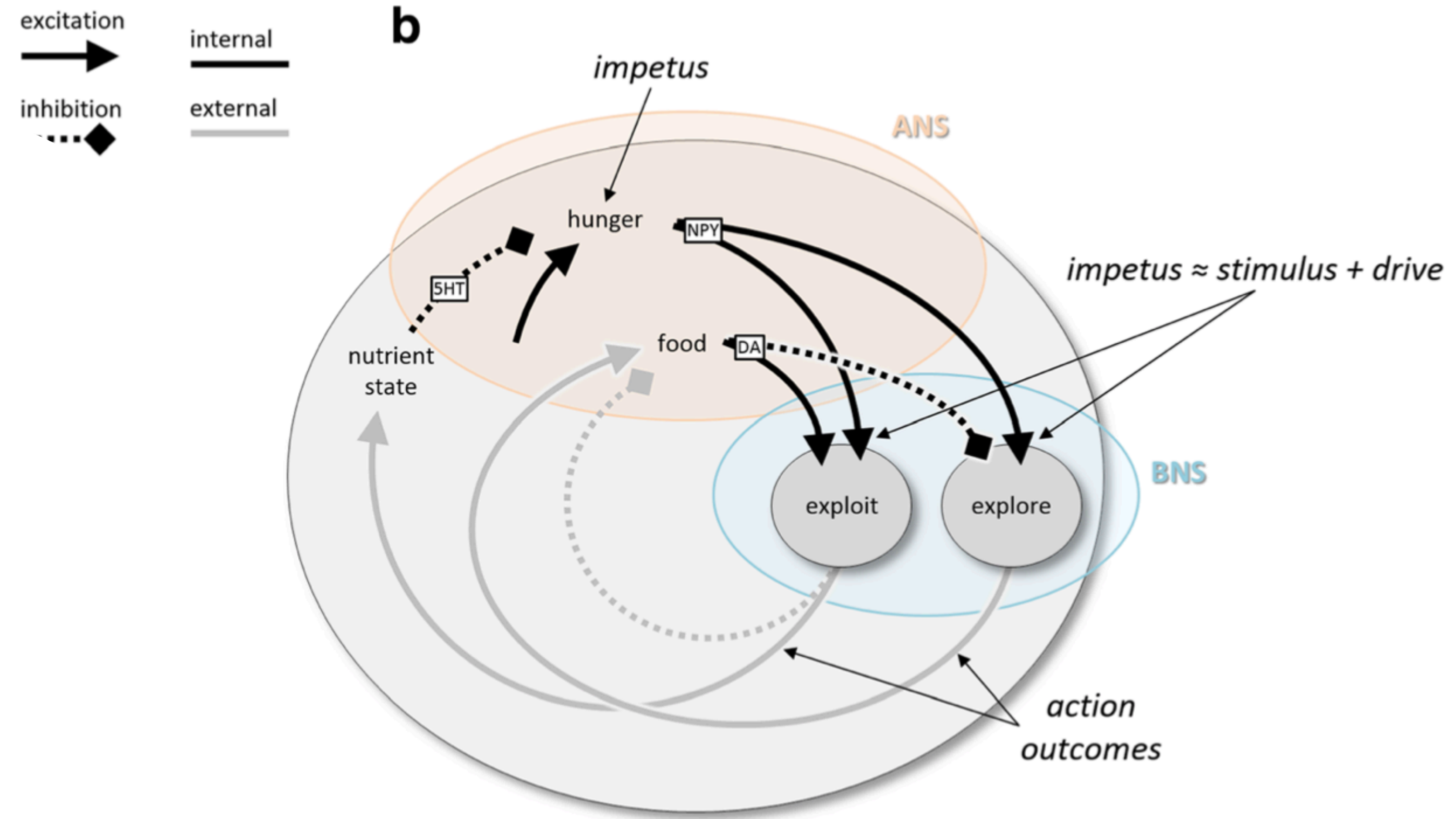
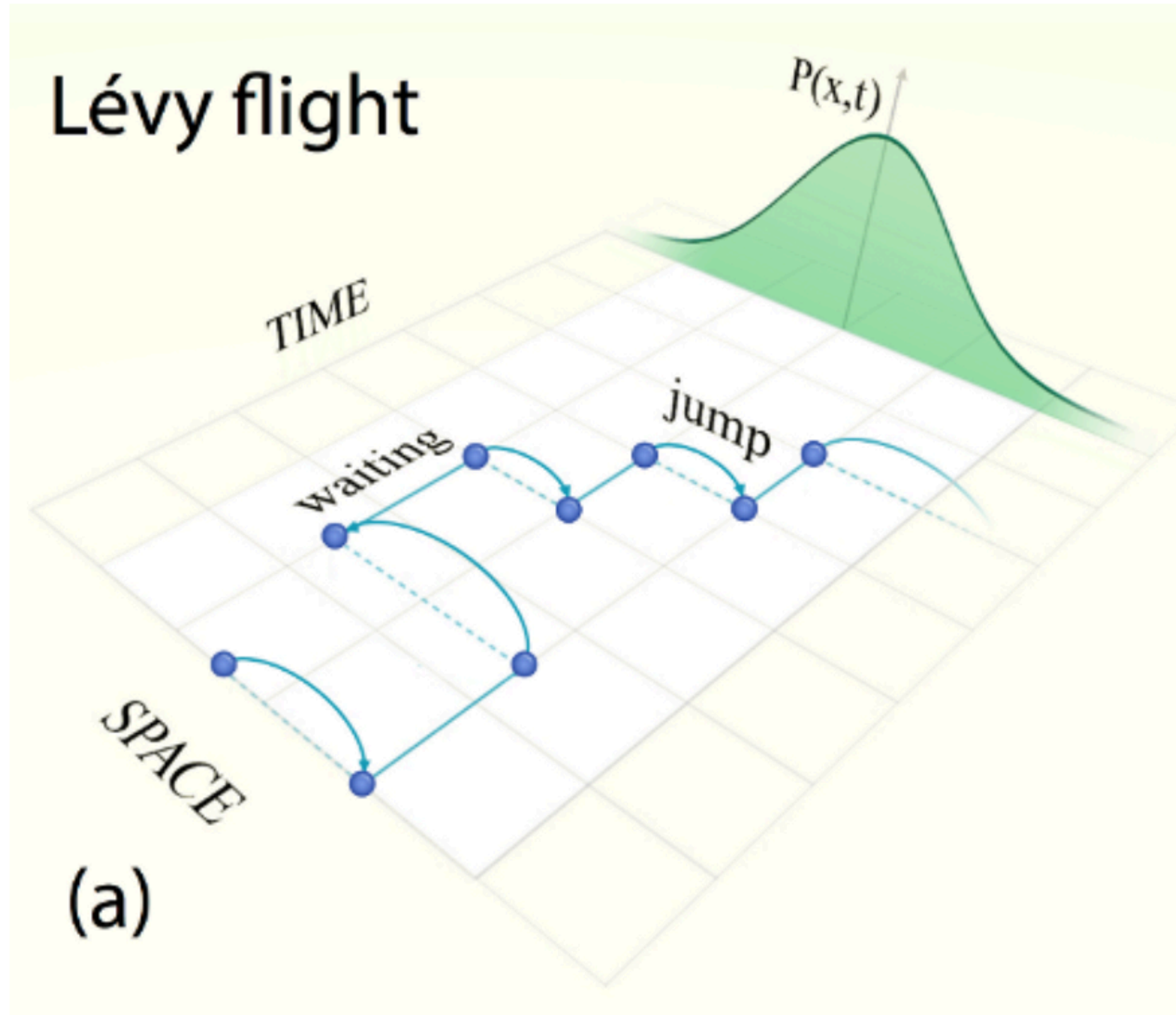


<https://www.youtube.com/watch?v=CldjFTSr4fY>

Lévy flights and Lévy walks



Lévy flights as explore-exploit processes



Lévy walk vs. Brownian motion

Random walk in 2D space

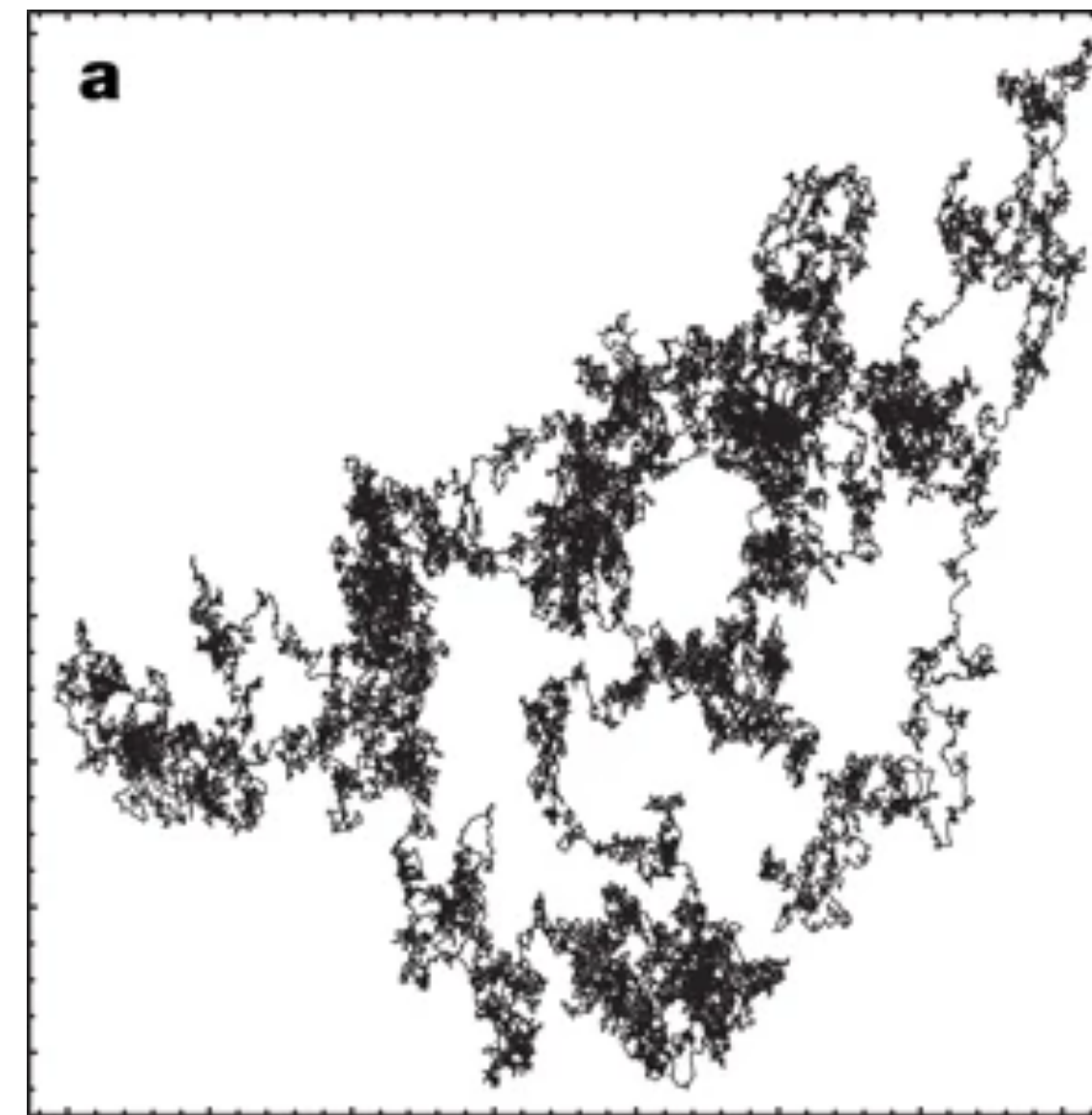
$$\theta_i = v_i 2\pi, \quad v_i \sim U(-\pi, \pi)$$

$$\delta_i = u_i^{-\frac{1}{\gamma}}, \quad u_i \sim N(\mu, \sigma)$$

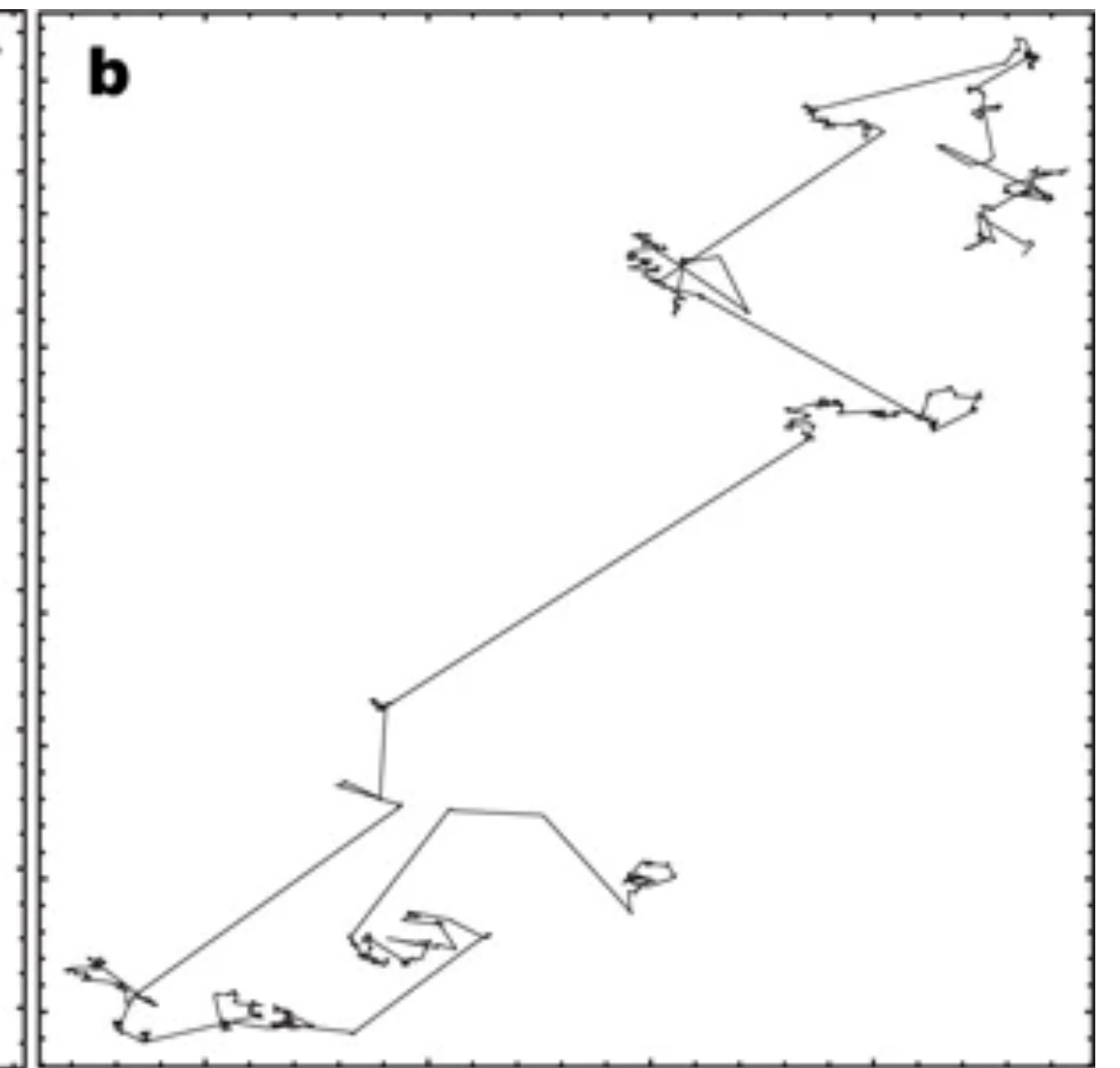
$$x_i = x_{i-1} + \delta_i \cos(\theta_i)$$

$$y_i = y_{i-1} + \delta_i \sin(\theta_i)$$

Brownian motion ($\gamma = 1$)

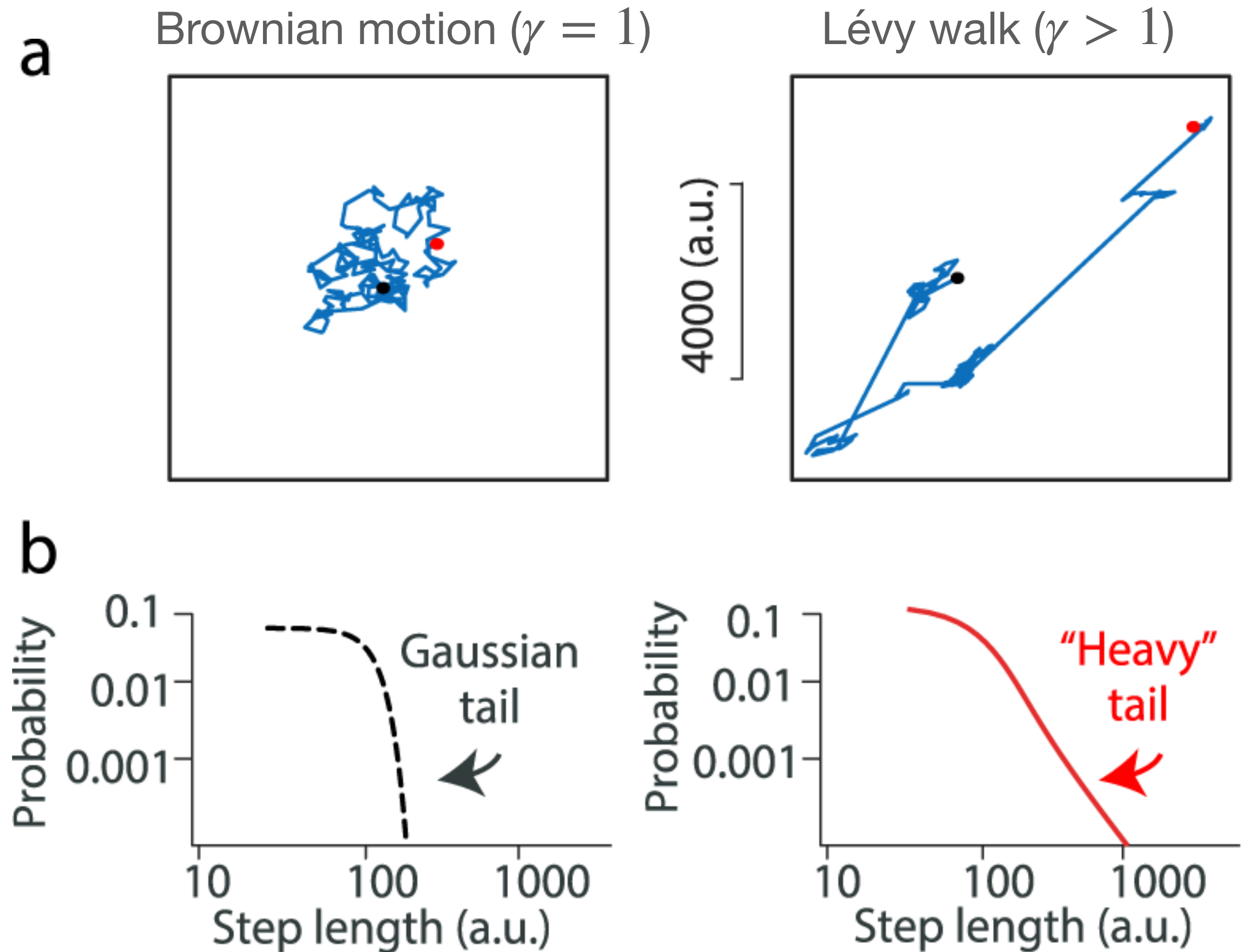


Lévy walk ($\gamma > 1$)

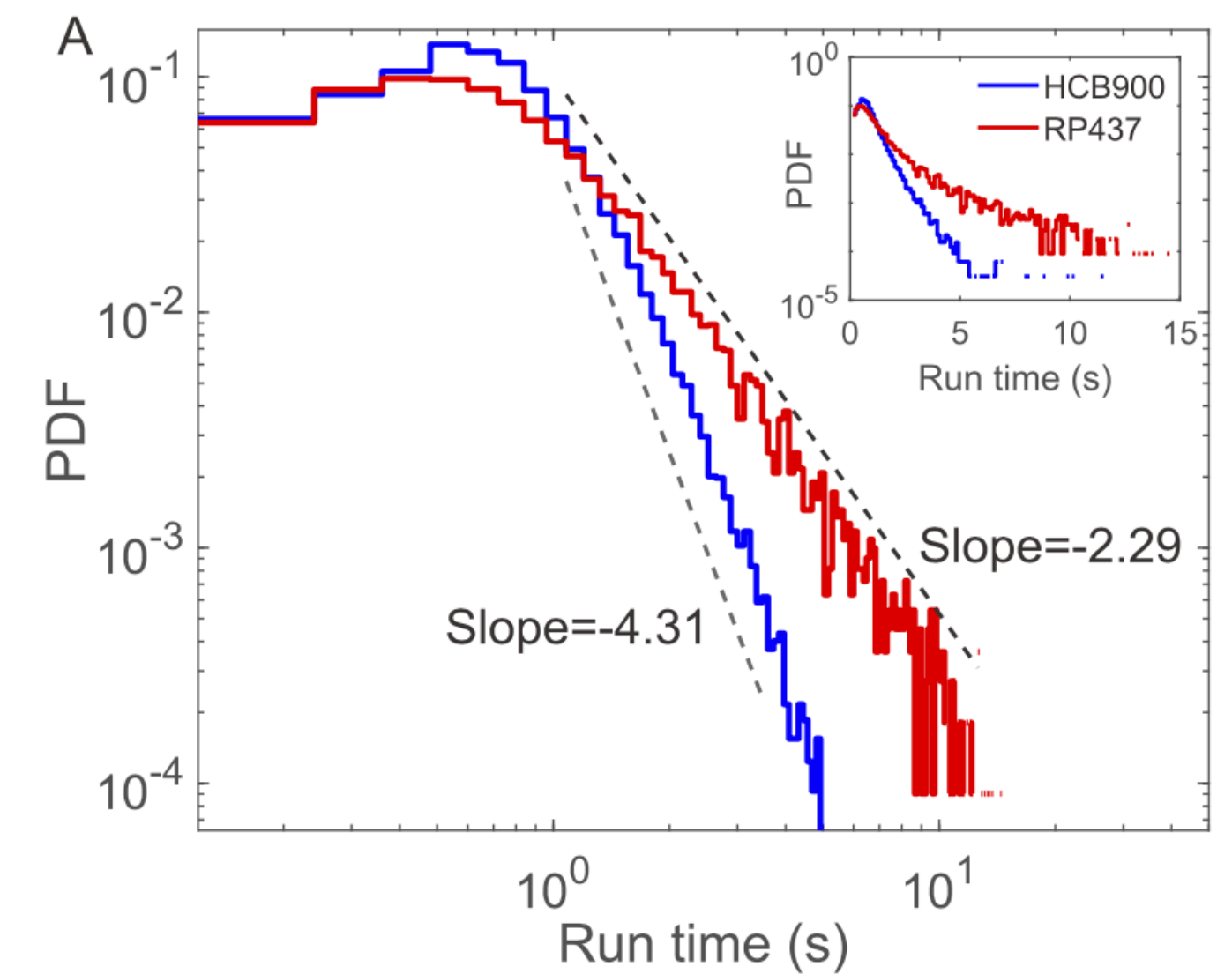
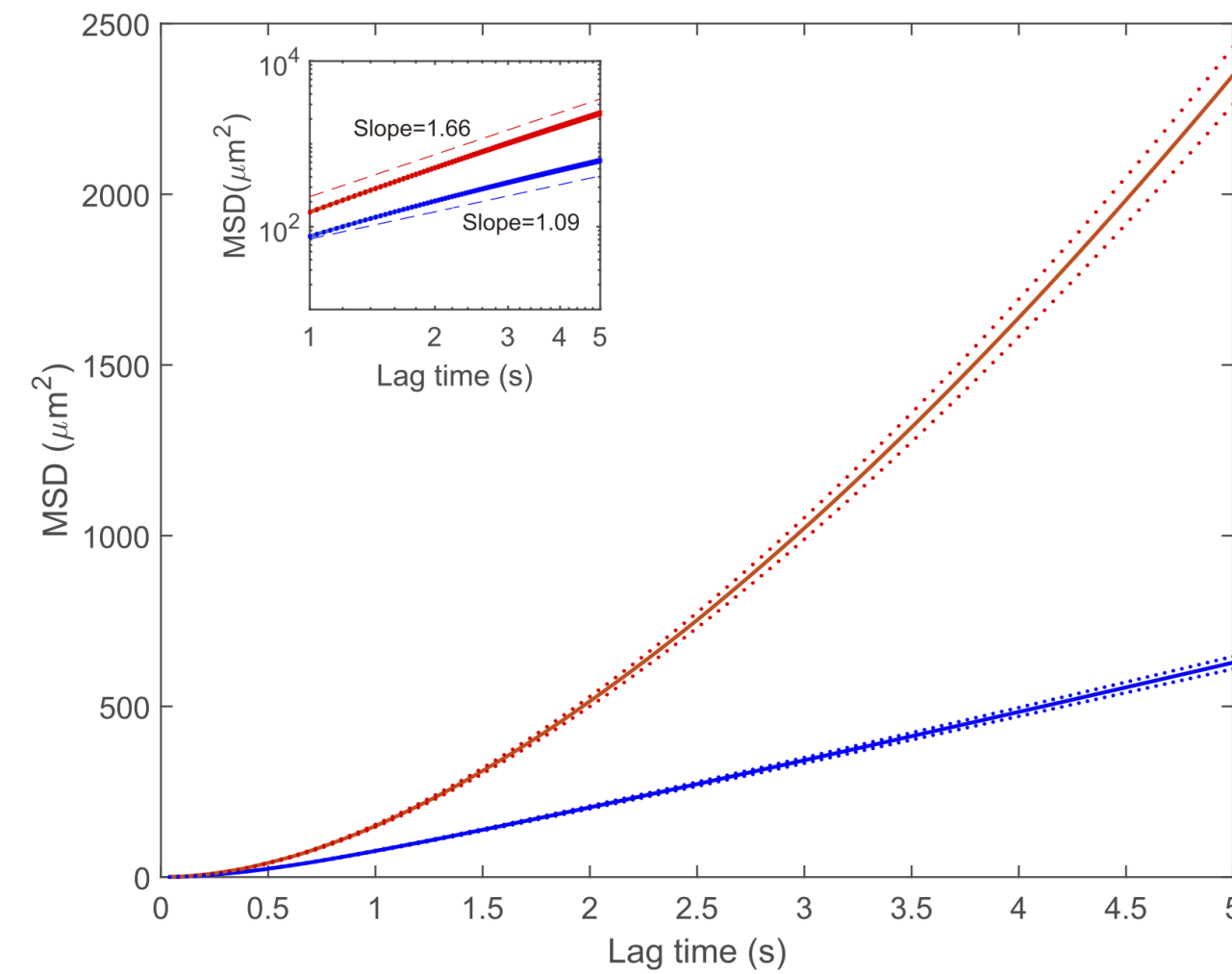
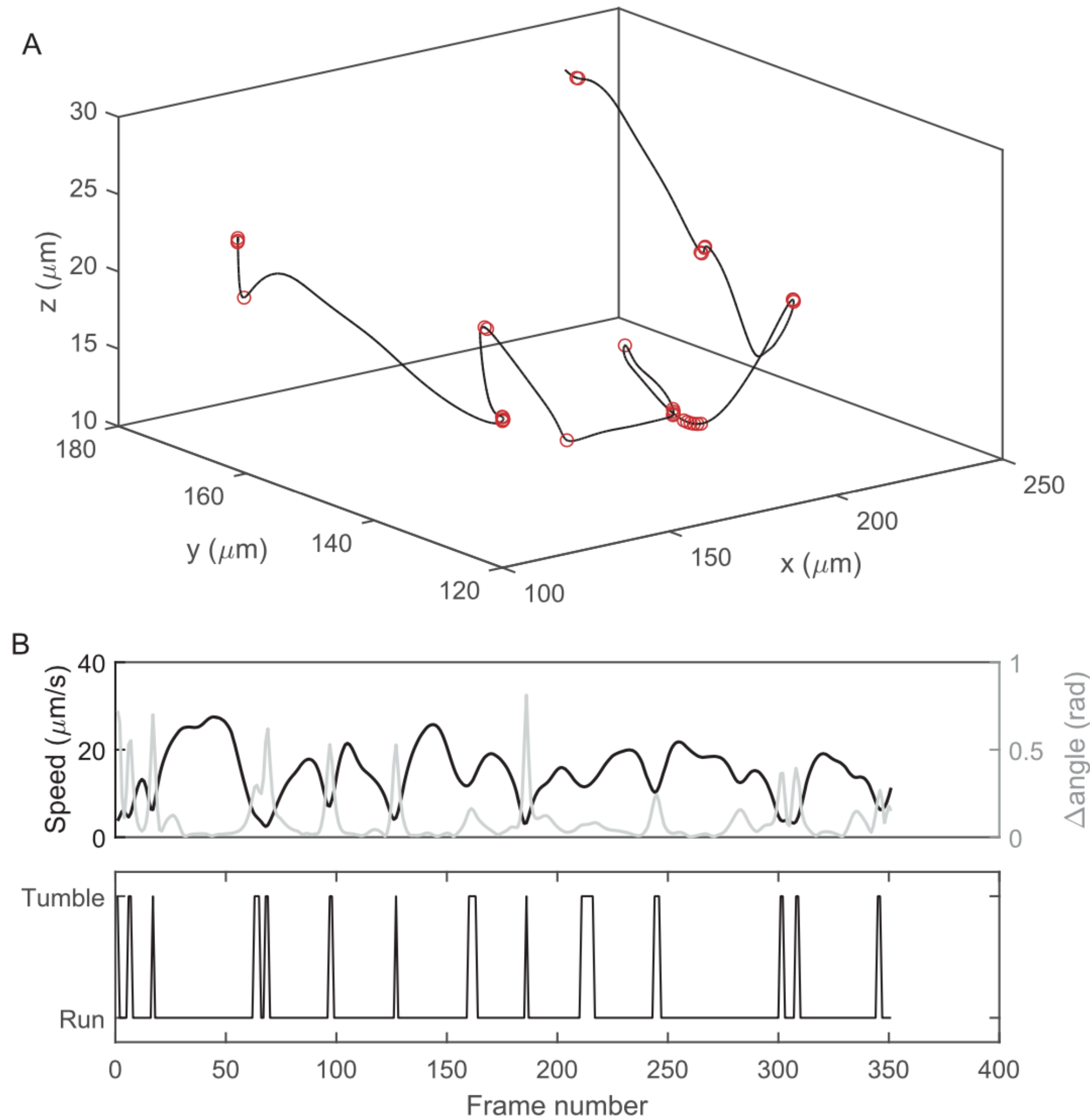


Power Law

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



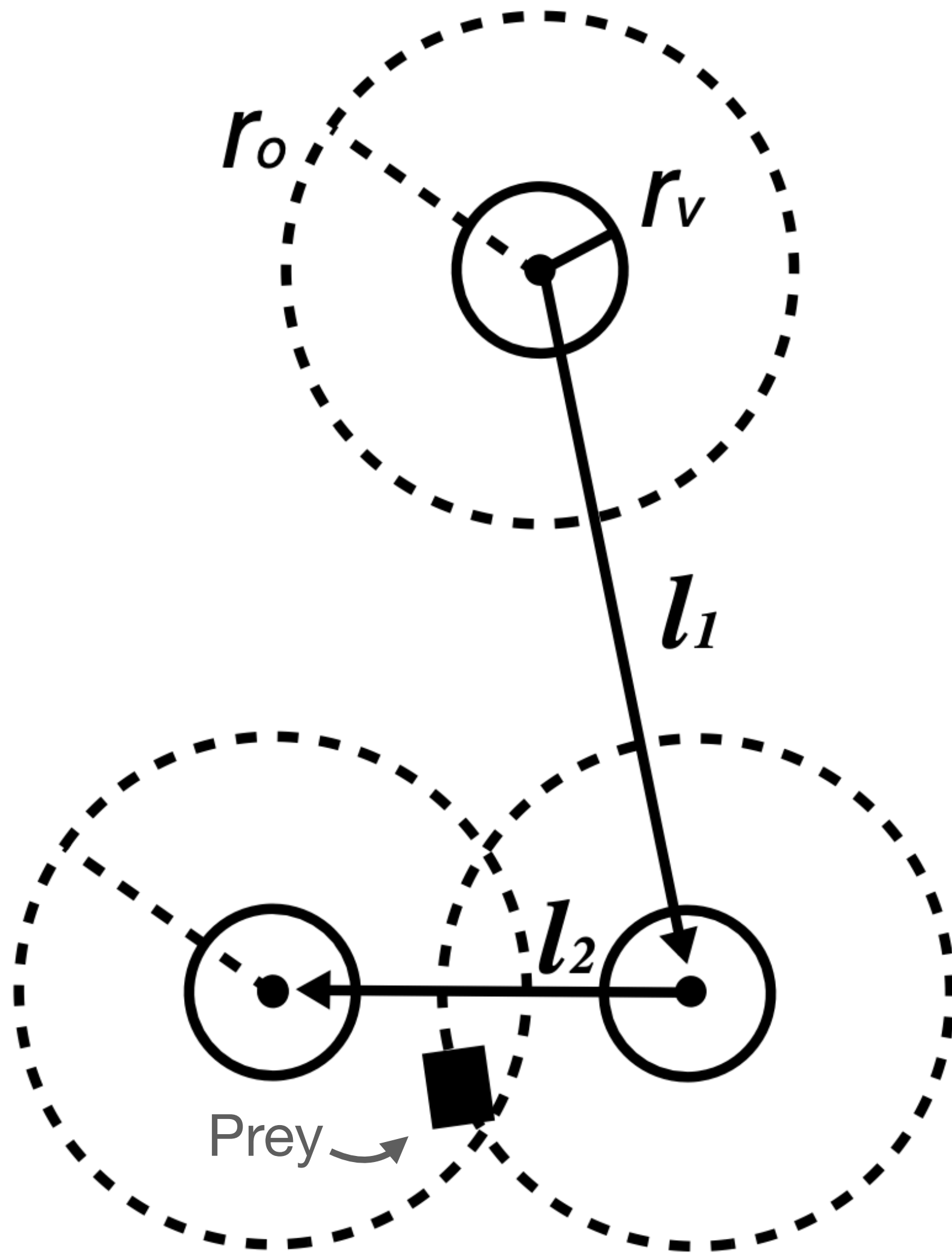
Do *e coli* use Lévy motion to explore?



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 value of simple sensing

Bacteria as predators

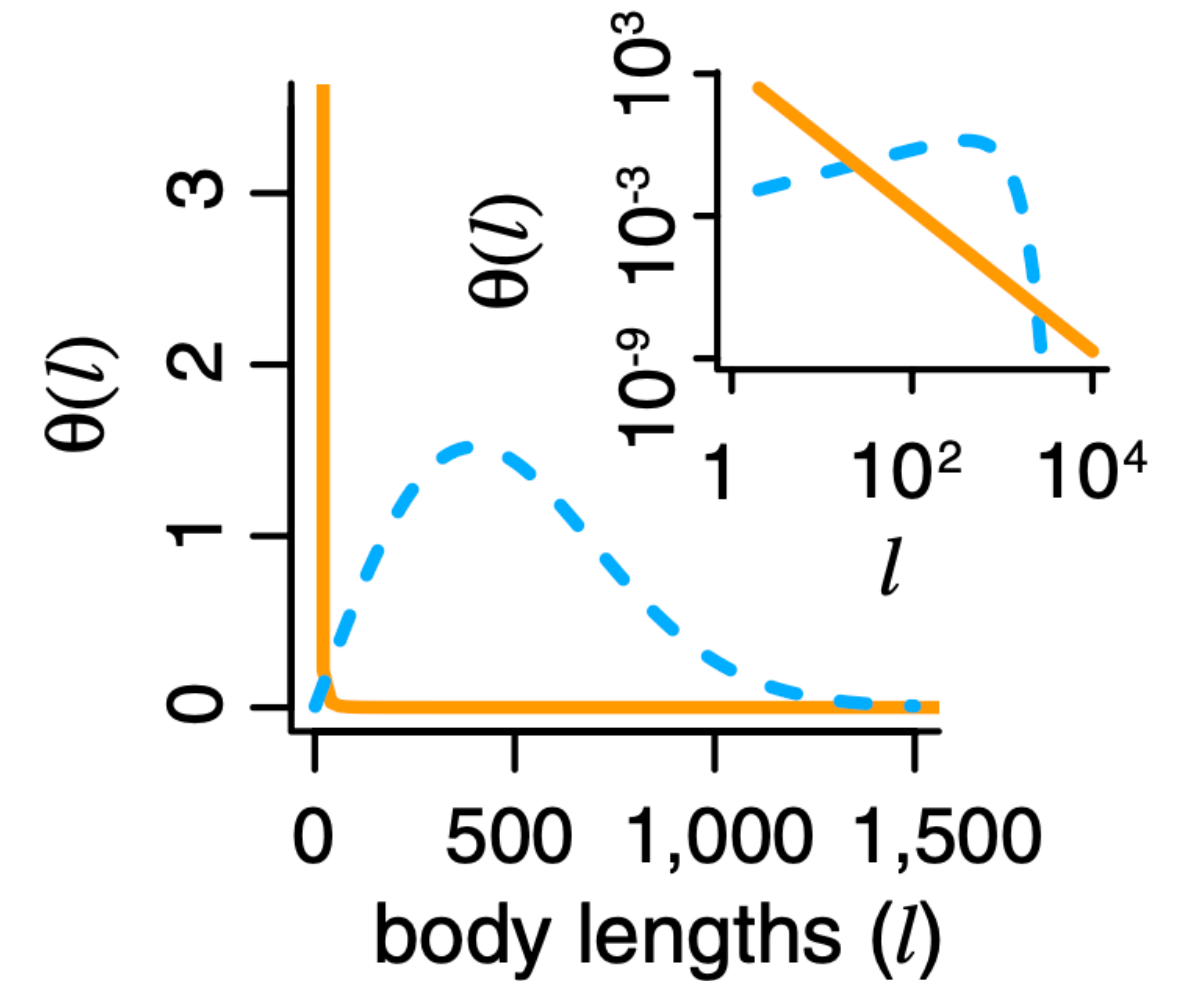


Two types of senses

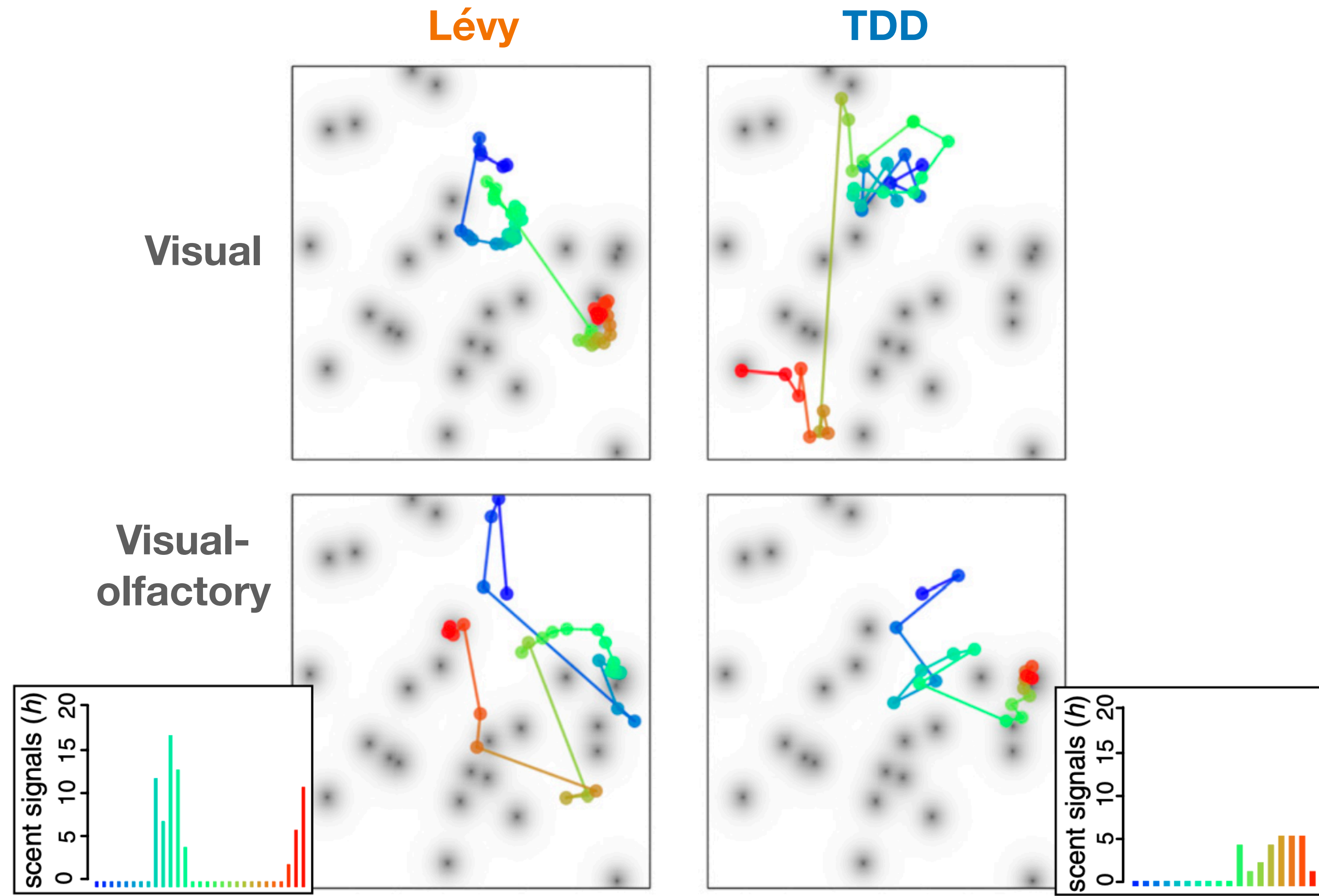
- Visual
- Visual-olfactory

Two types of search

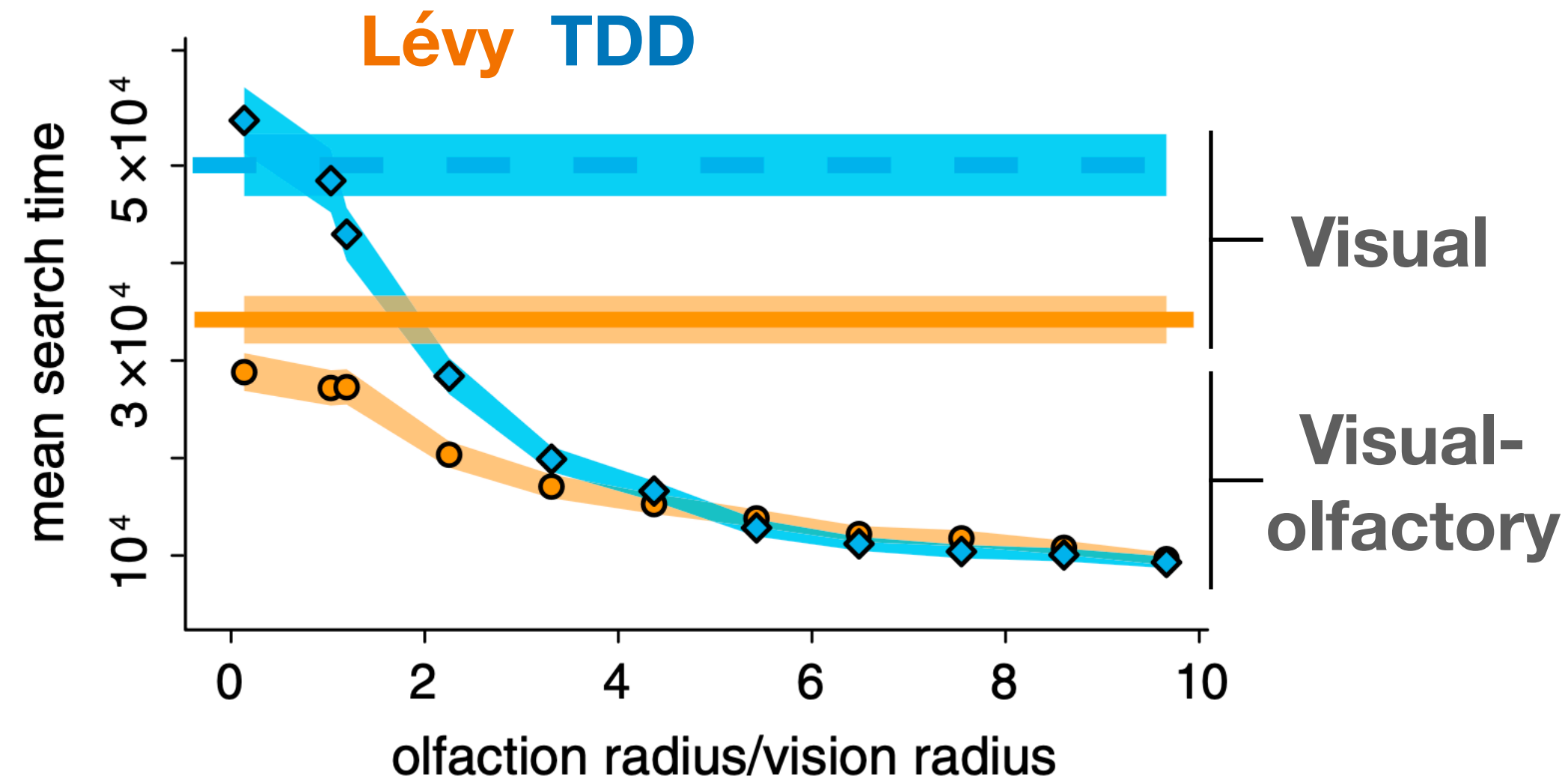
- **Lévy**: $\theta(l) = (\alpha - 1)l_m^{\alpha-1}l^{\alpha-1}$
- **True distance distribution (TDD)**:
 $\theta_T(l) = 2\eta\pi l e^{-\eta\pi^2}$



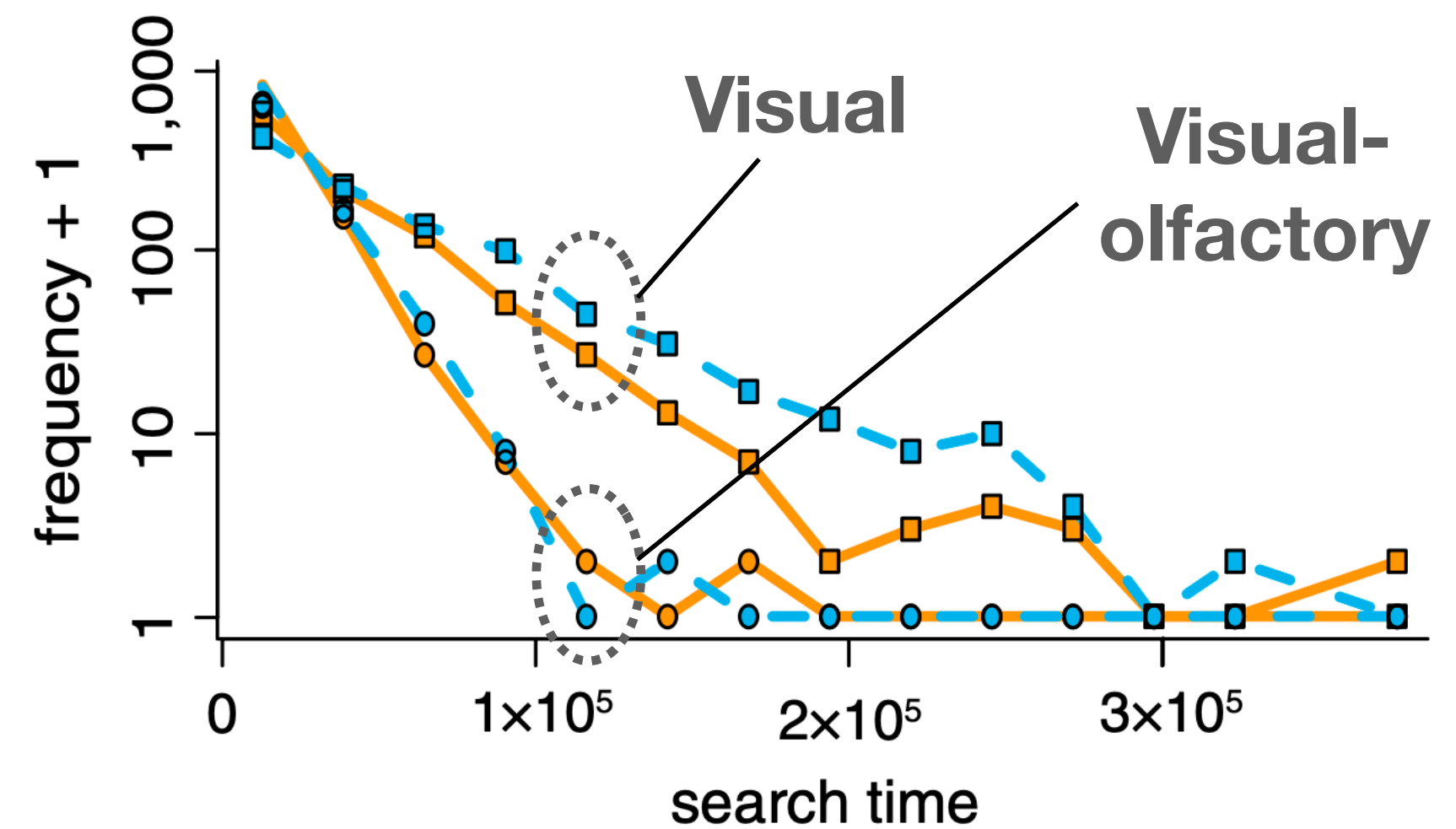
Example search patterns



Example search patterns



Lévy search is more efficient than TDD



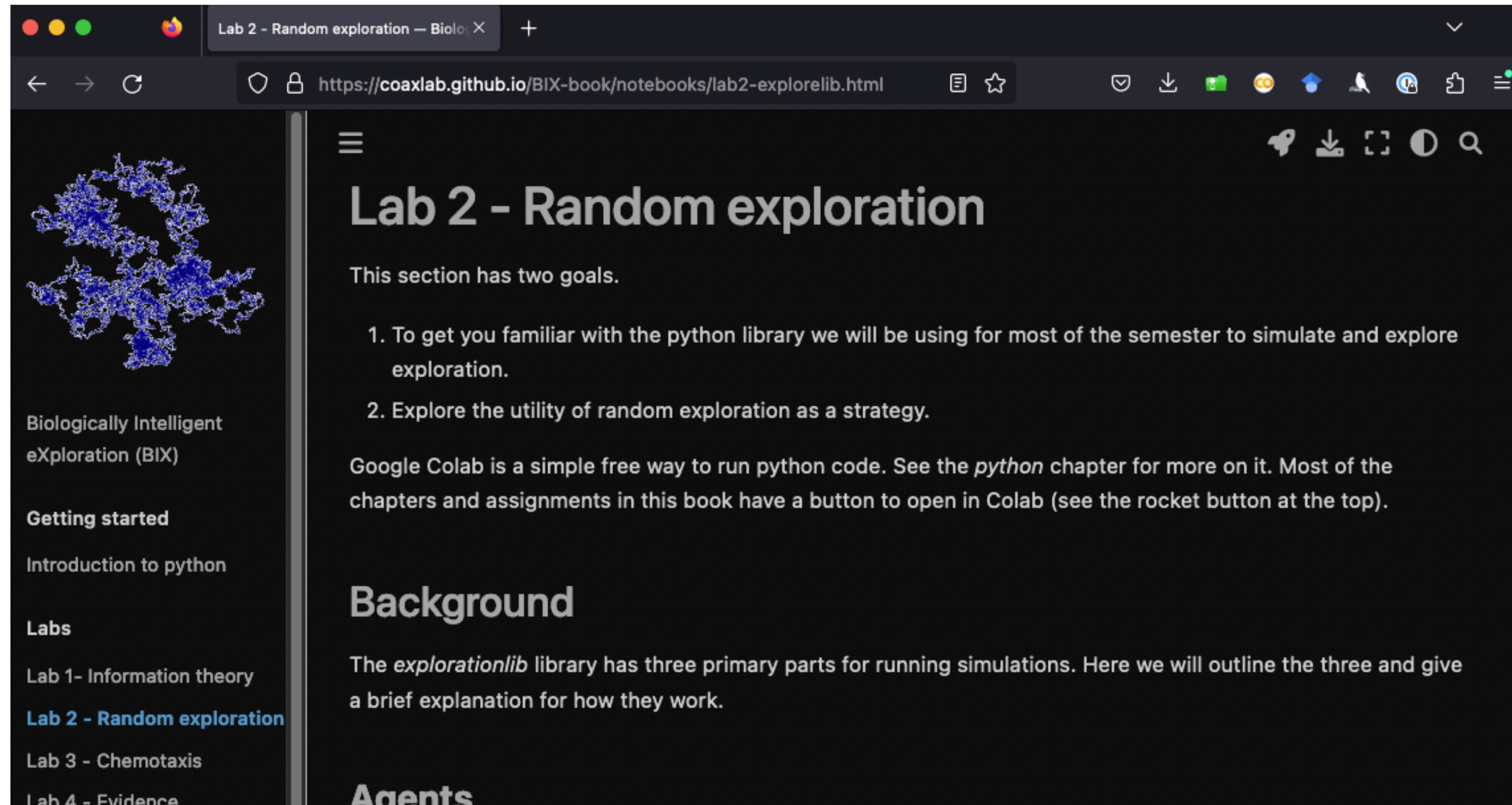
Increasing sensory channels boosts search efficiency

Take home message

- Organisms without brains can effectively explore.
- They use Lévy flight processes to increase efficiency of random exploration (*e. coli*).
- Adding sensory modalities improves local efficiency of random search strategies.

Lab time!

<https://coaxlab.github.io/BIX-book/notebooks/lab2-explorelib.html>



The screenshot shows a web browser window with the following elements:

- Browser Tab:** "Lab 2 - Random exploration — Biolo X"
- Address Bar:** <https://coaxlab.github.io/BIX-book/notebooks/lab2-explorelib.html>
- Left Sidebar:**
 - Logo: A blue fractal-like shape.
 - Text: "Biologically Intelligent eXploration (BIX)"
 - Section: "Getting started"
 - Link: "Introduction to python"
 - Section: "Labs"
 - Link: "Lab 1- Information theory"
 - Link: "Lab 2 - Random exploration" (highlighted in blue)
 - Link: "Lab 3 - Chemotaxis"
 - Link: "Lab 4 - Evidence"
- Main Content Area:**
 - Section: "Lab 2 - Random exploration"
 - Text: "This section has two goals."
 - List:
 1. To get you familiar with the python library we will be using for most of the semester to simulate and explore exploration.
 2. Explore the utility of random exploration as a strategy.
 - Text: "Google Colab is a simple free way to run python code. See the *python* chapter for more on it. Most of the chapters and assignments in this book have a button to open in Colab (see the rocket button at the top)."
 - Section: "Background"
 - Text: "The *explorationlib* library has three primary parts for running simulations. Here we will outline the three and give a brief explanation for how they work."
 - Section: "Agents" (partially visible)
- Top Navigation Bar:** Includes icons for a rocket (Colab), download, full screen, moon (dark mode), and search.