

How do you explore without a brain?

Readings for today

- Reid, C. R., Latty, T., Dussutour, A., & Beekman, M. (2012). Slime mold uses an externalized spatial “memory” to navigate in complex environments. *Proceedings of the National Academy of Sciences*, 109(43), 17490-17494.
- 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.

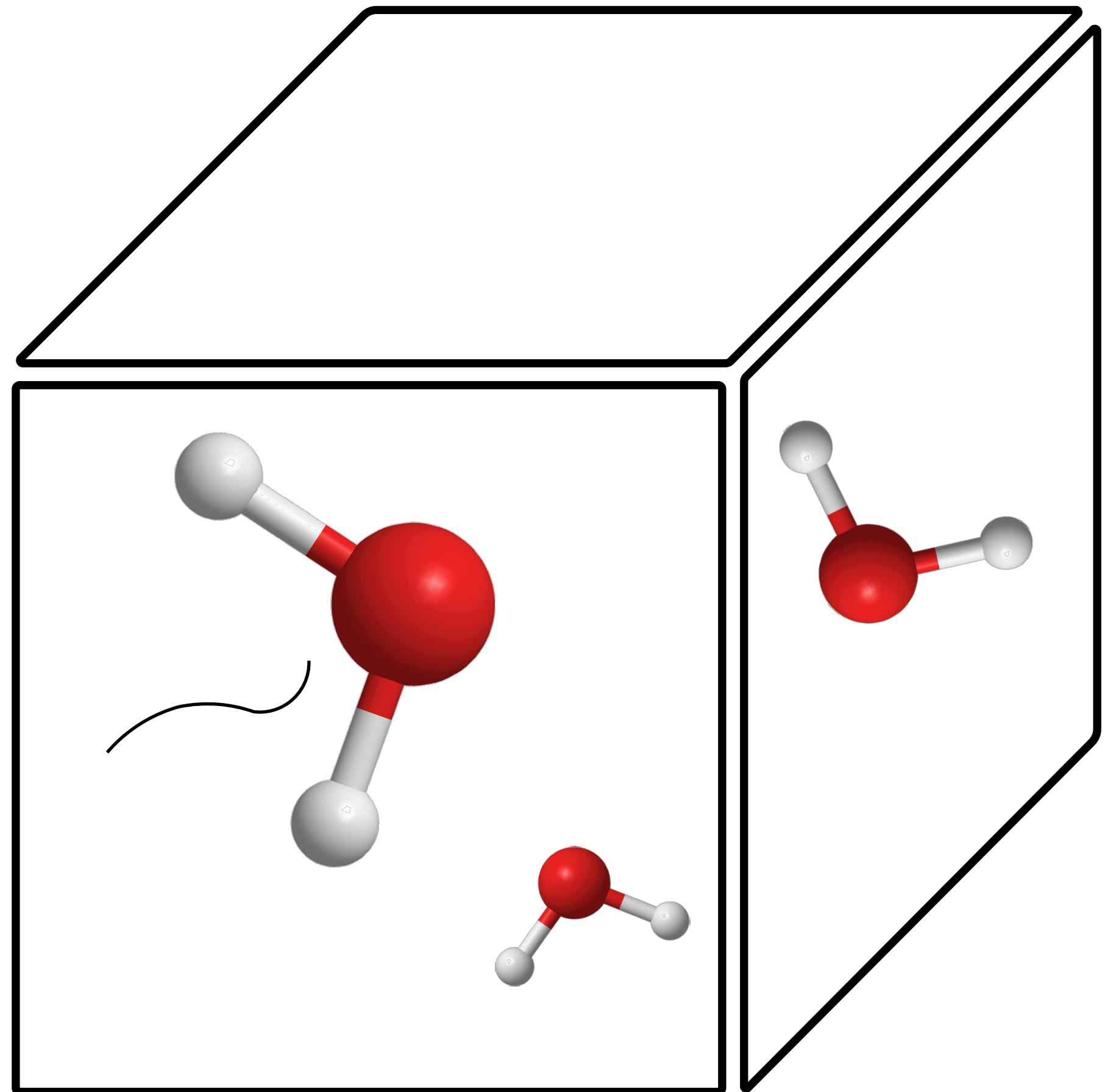
Topics

- Simple forms of exploration
- Organisms that explore without brains

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

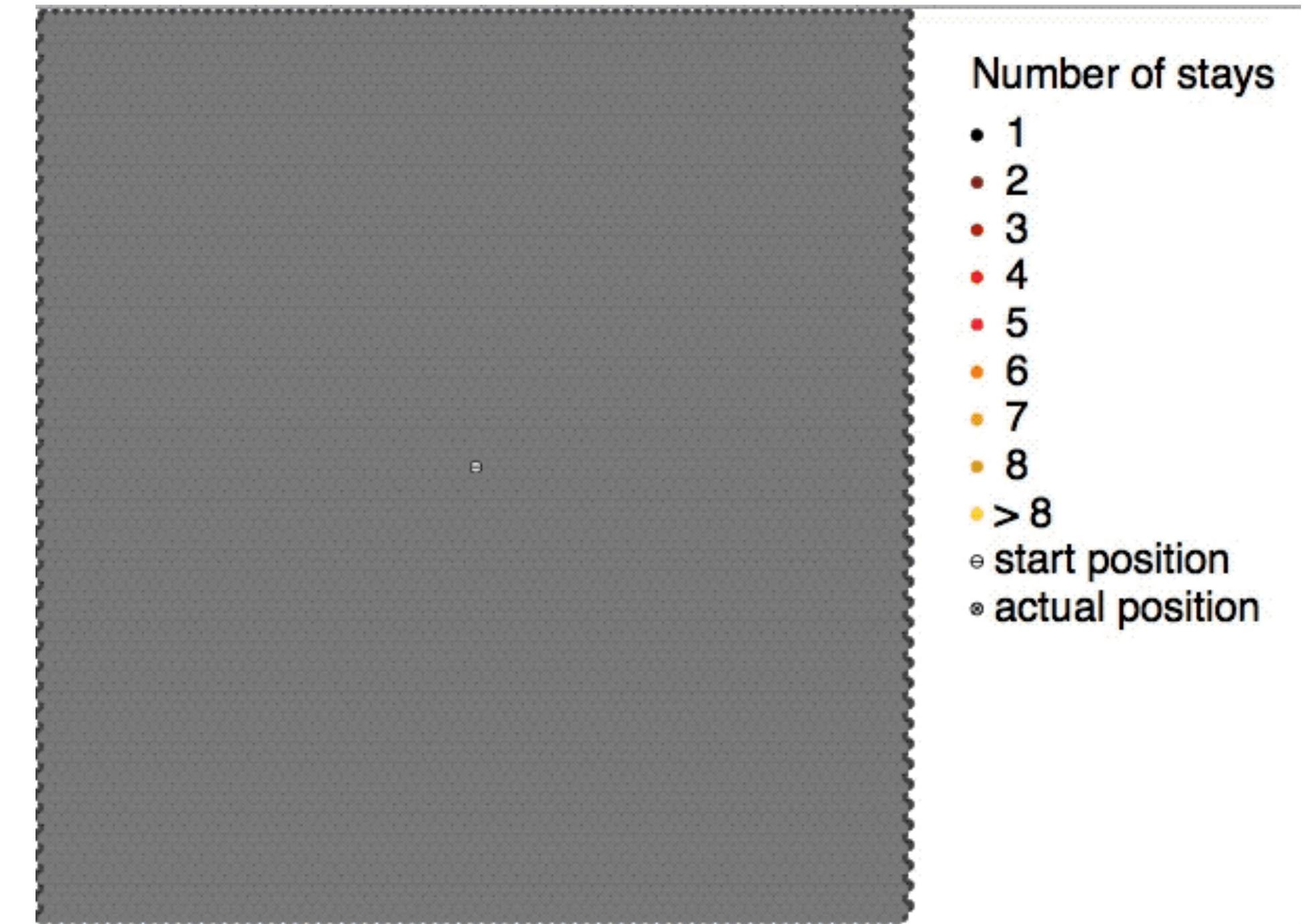
$$x_i = x_{i-1} + u_i, \quad u_i \sim N(\mu, \sigma)$$

In 2D space

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

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

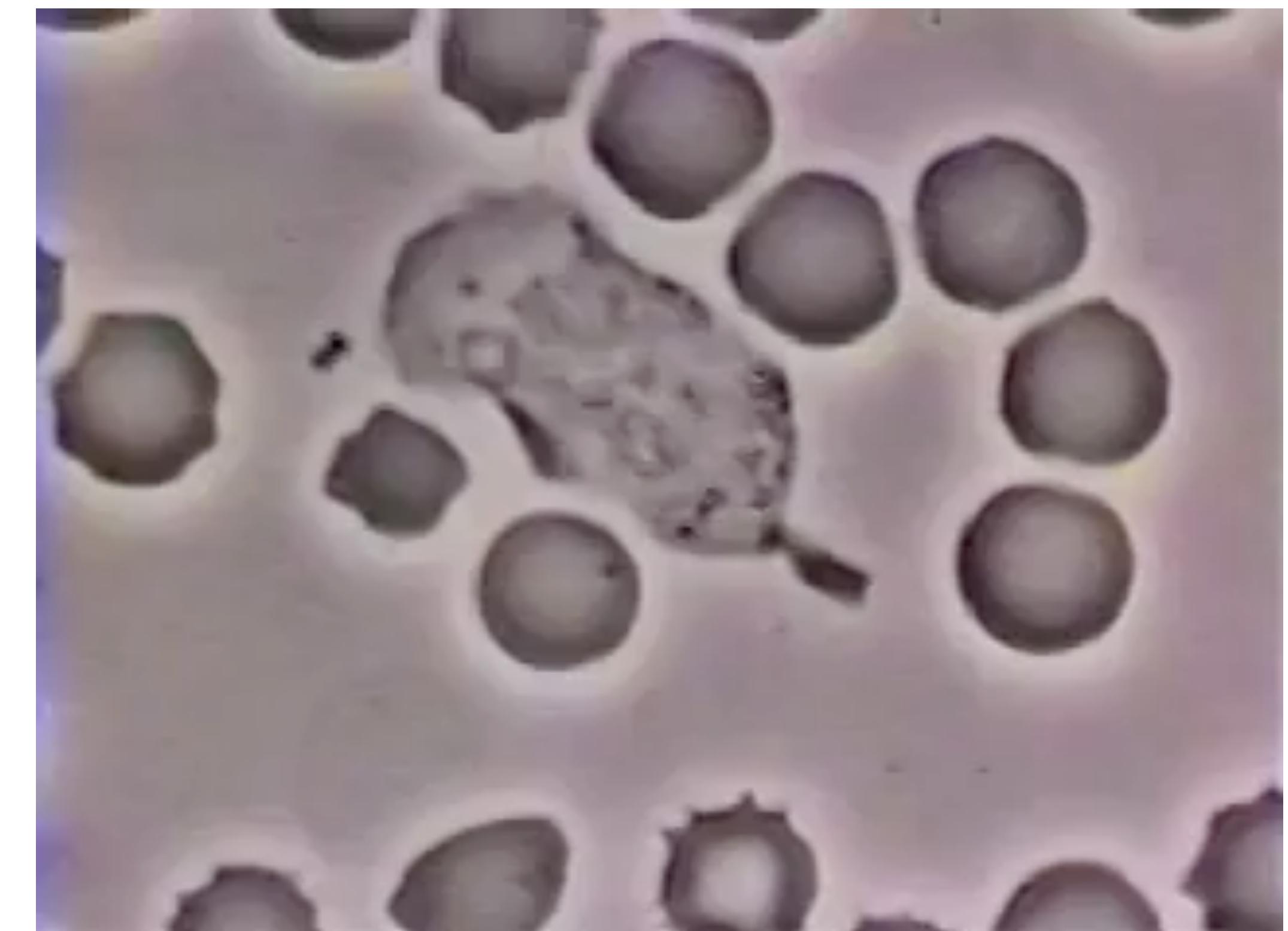
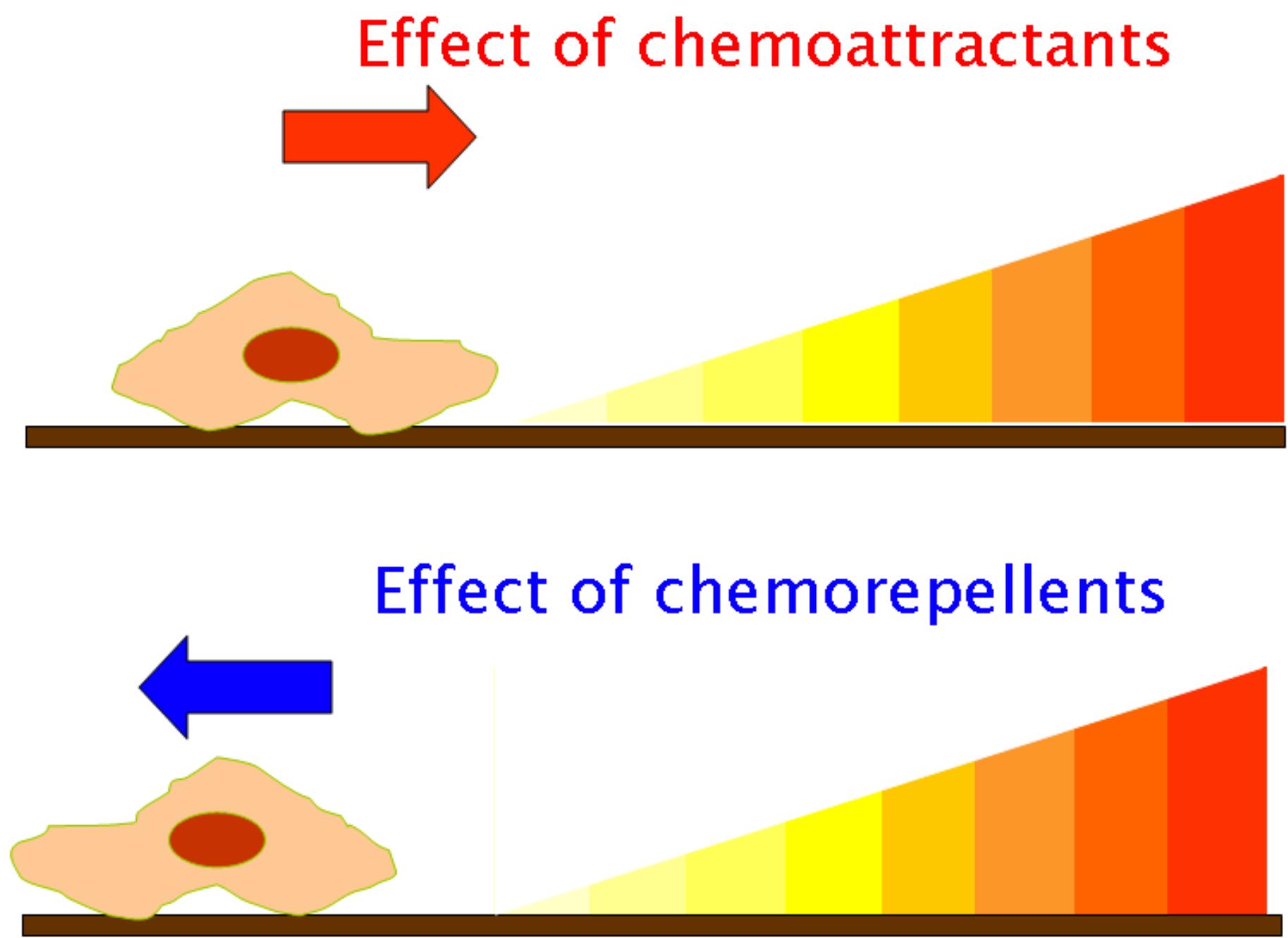
$$y_i = y_{i-1} + u_i \sin(\theta_i)$$



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

Chemotaxis

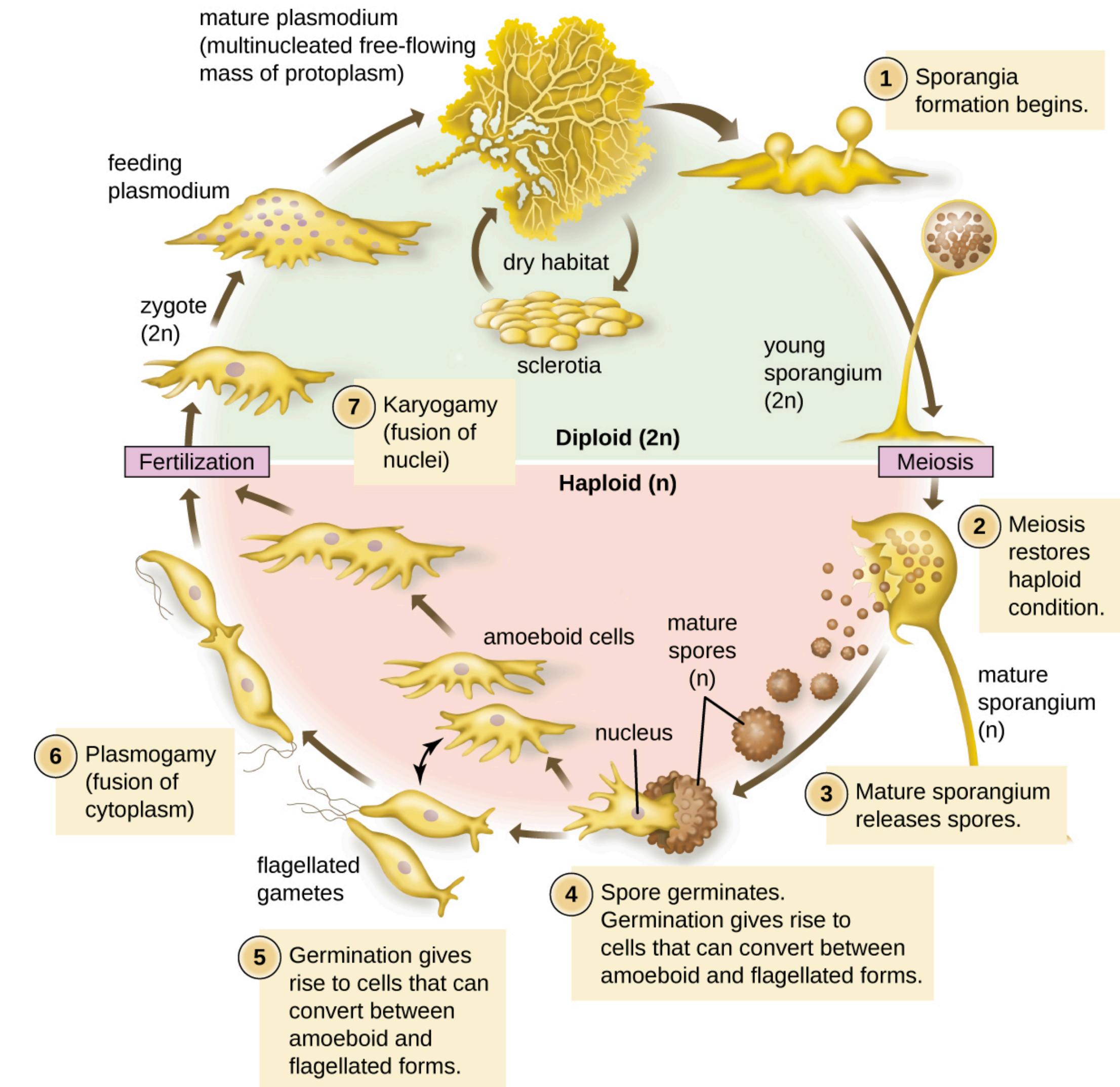
Movement in response to a chemical stimulus.



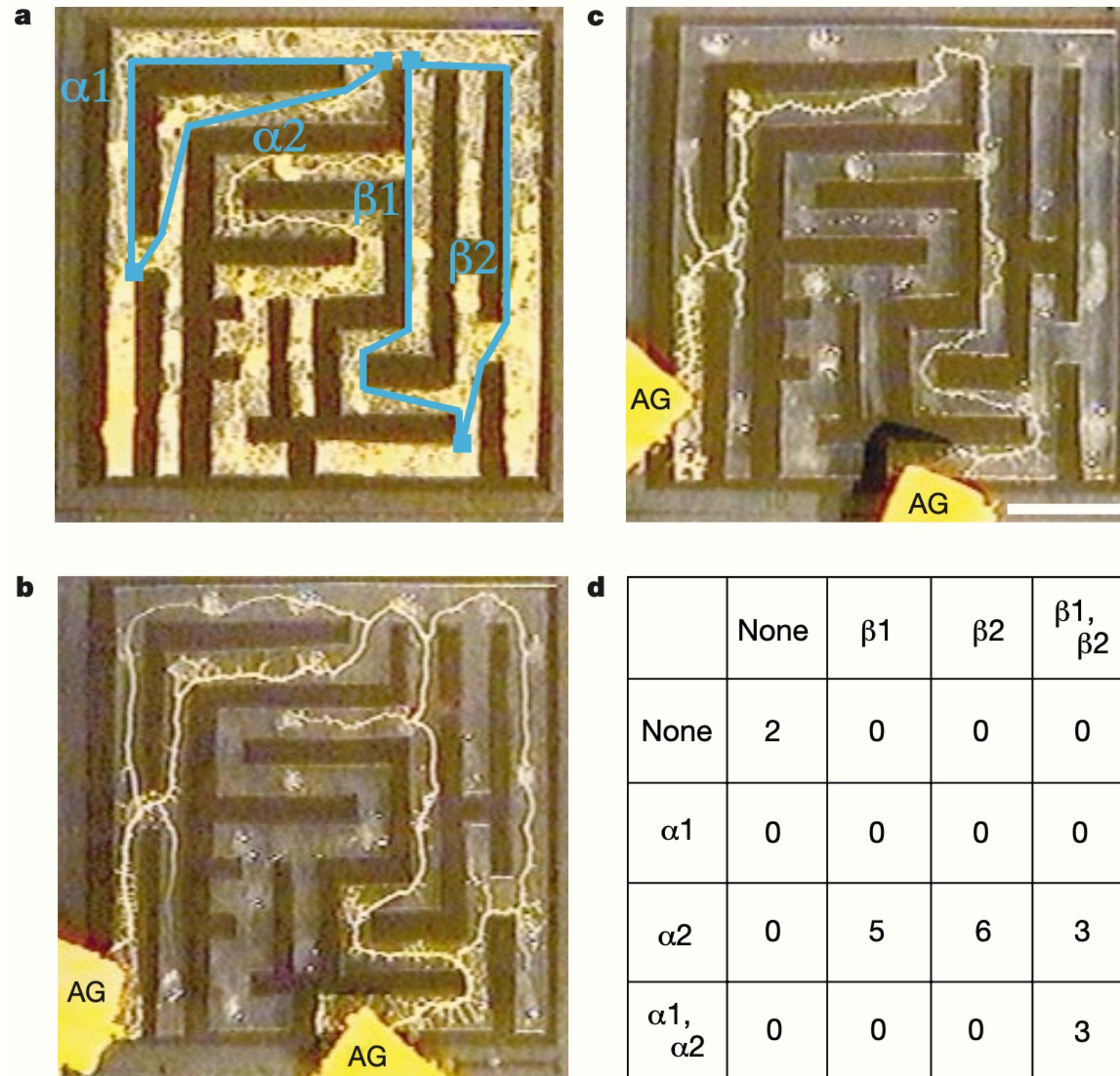
<https://routledgetextbooks.com/textbooks/9780815344506/videos.php>

Organisms that explore without a brain

Organism 1: slime mold

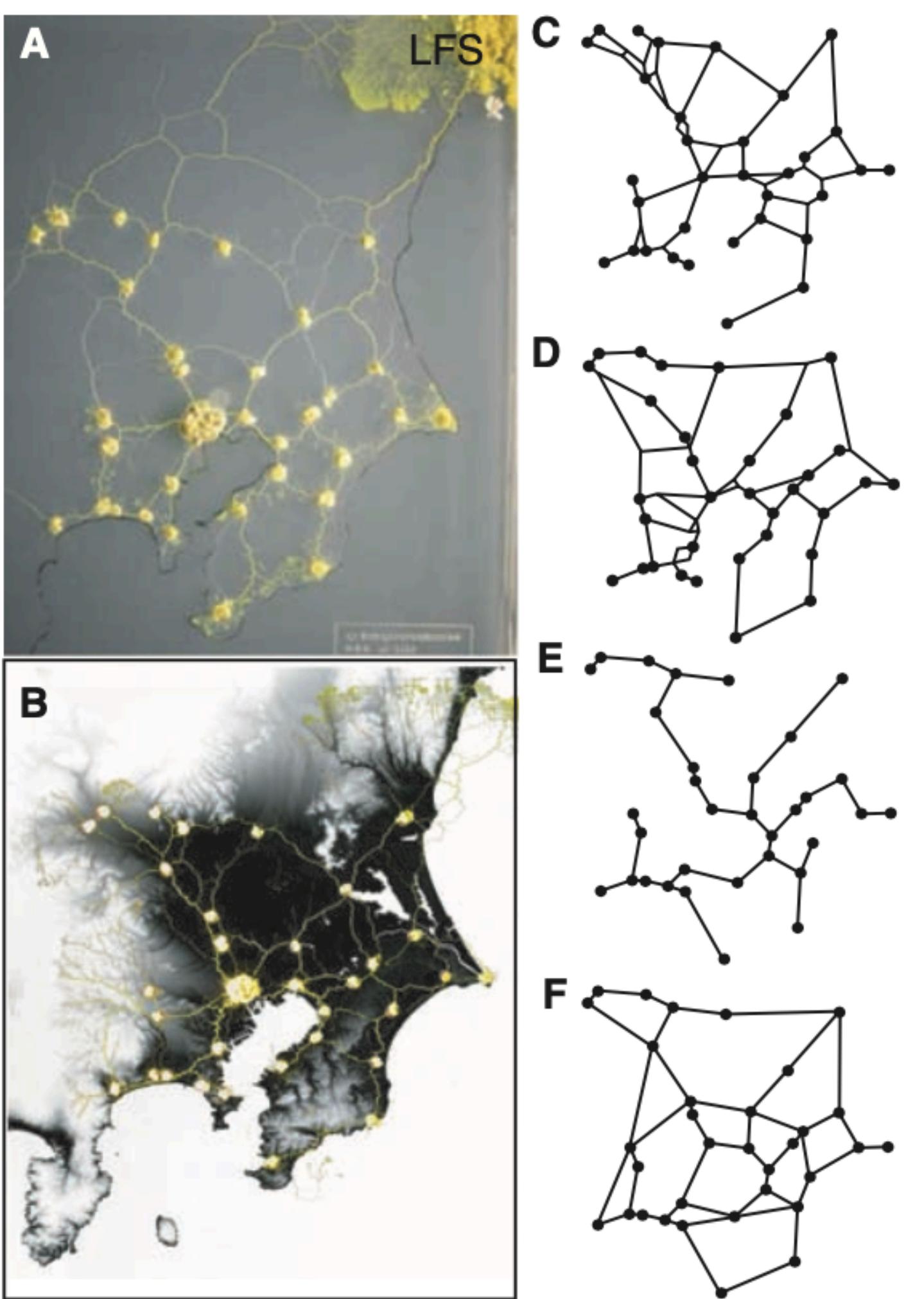


Slime mold navigation

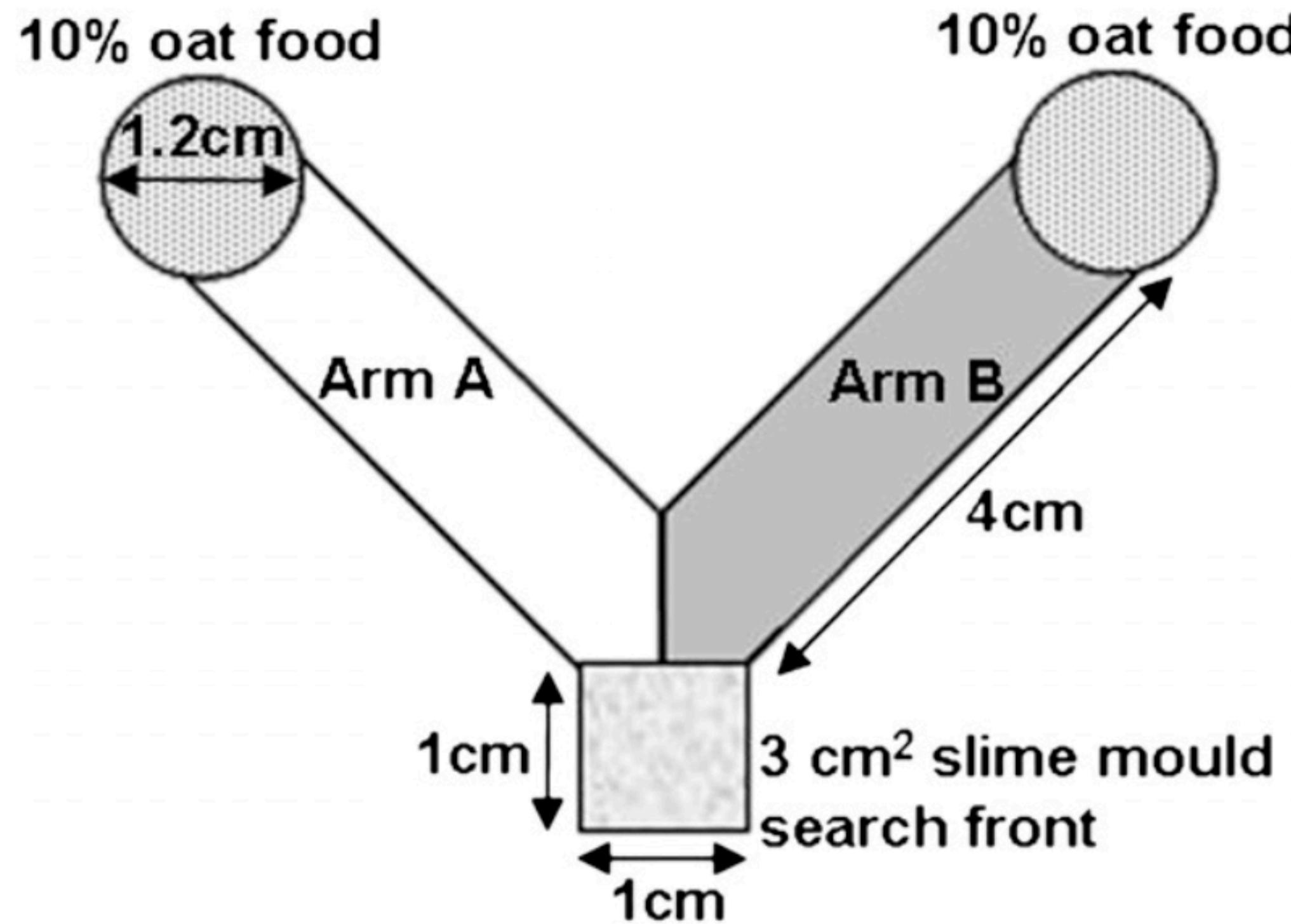


Slime molds can find optimal foraging routes through nutrients (and obstacles)

Path minimization

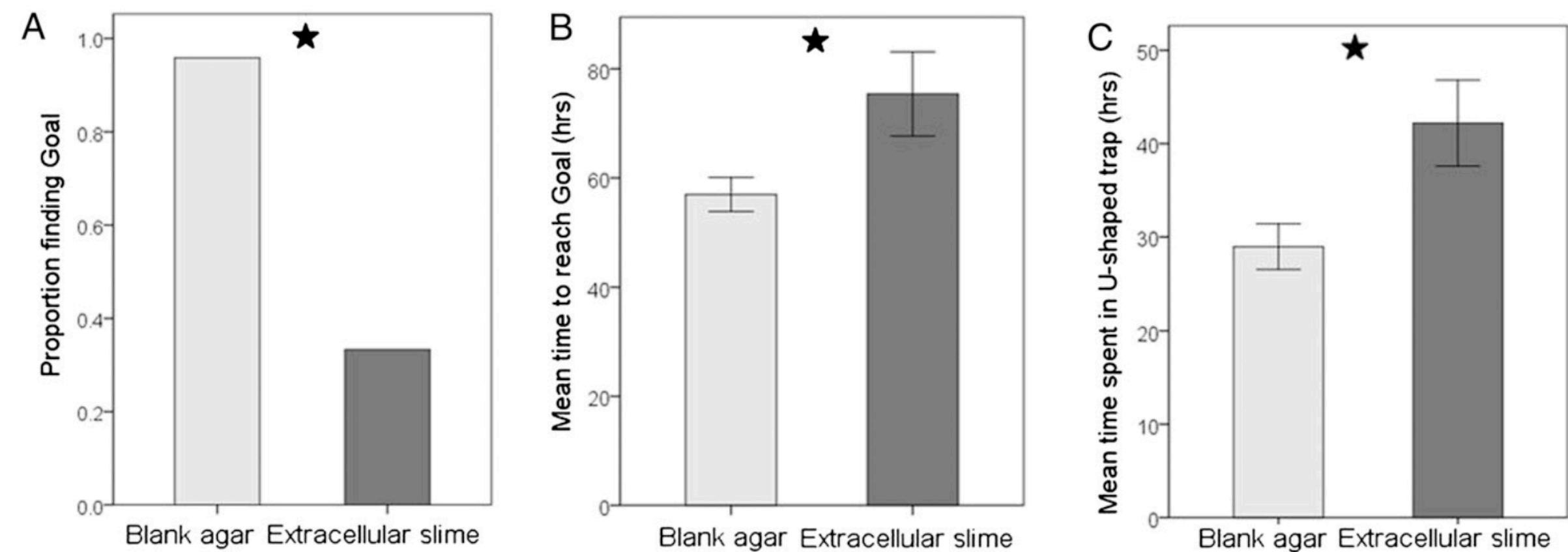
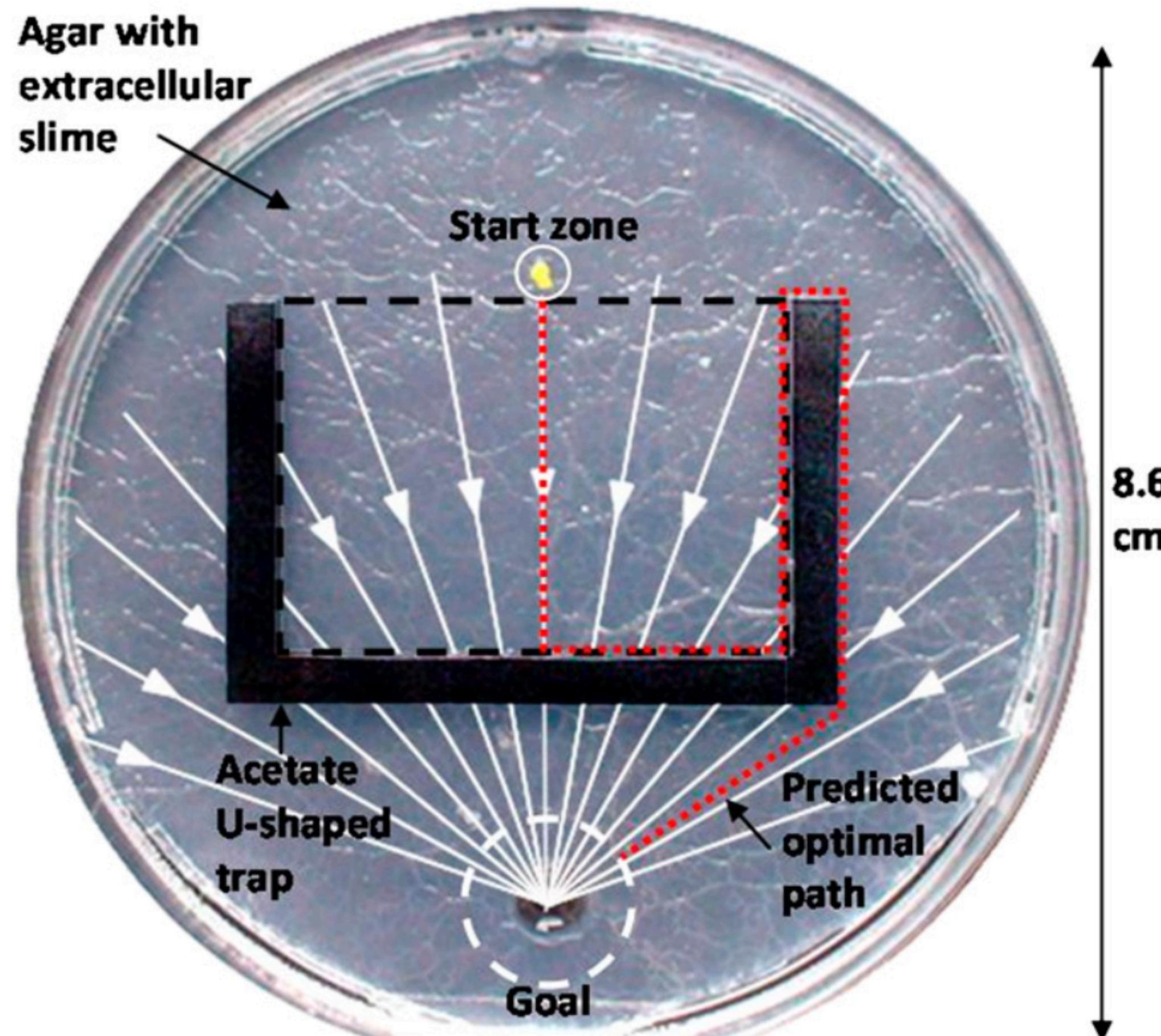


Making choices



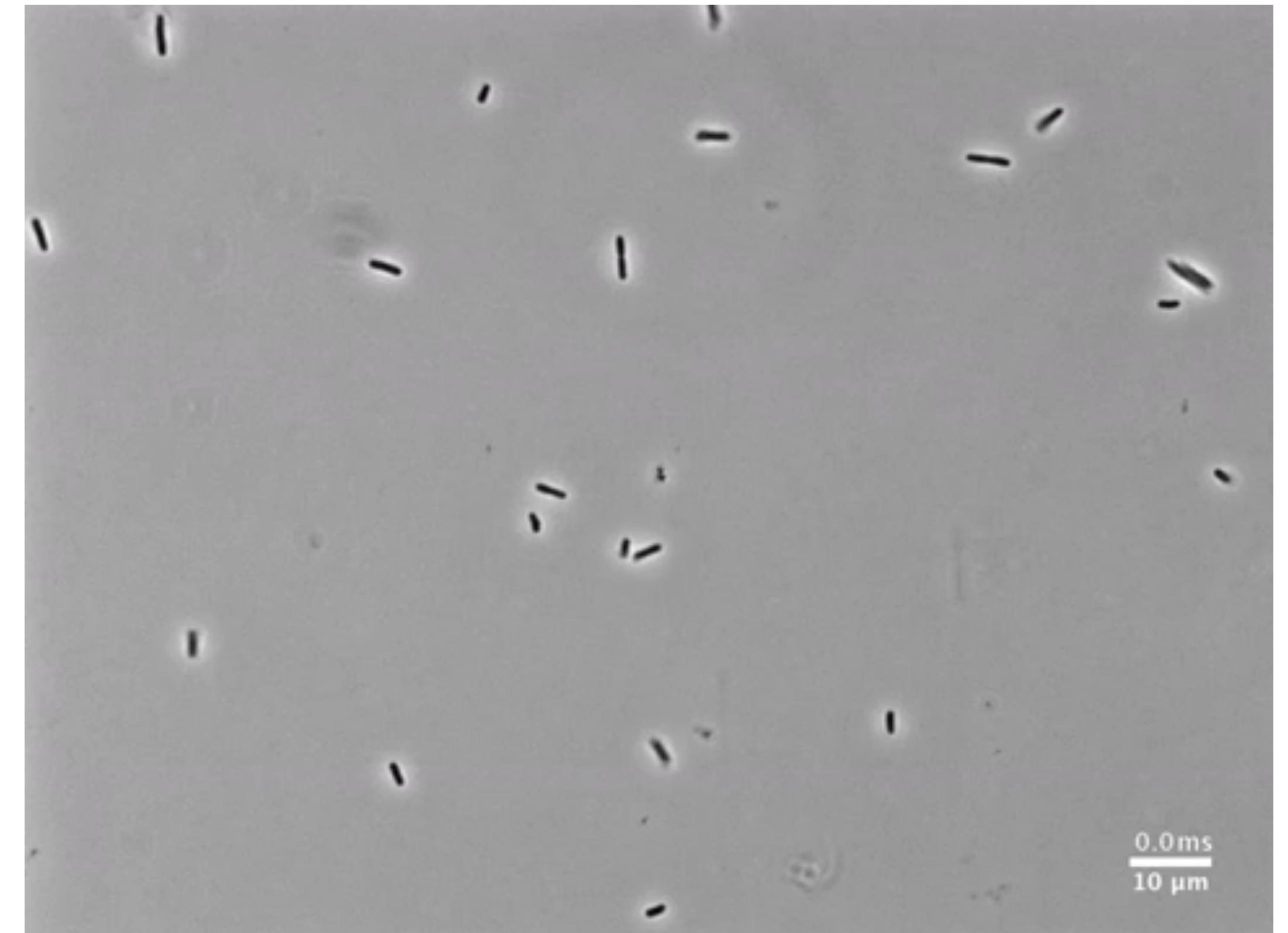
- Arm B contained extracellular slime (naturally secreted by slime molds).
- 39/40 molds chose arm without slime mold.
- Indicates it has been there before.

Spatial memory



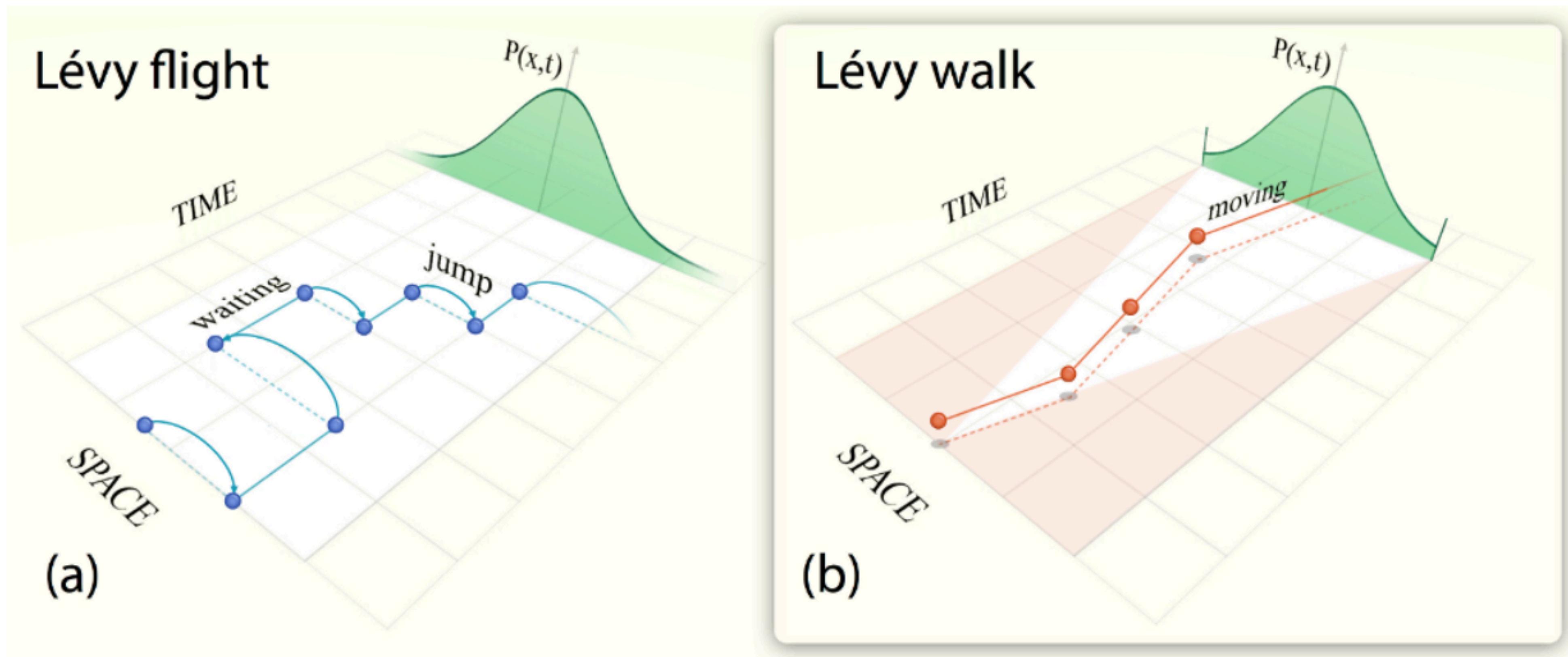
- Presence of extracellular slime impaired slime mold's ability to “solve” the maze.
- Chemical “I've been here” trail.

Organism 2: E. Coli



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

Lévy flights and Lévy walks



Lévy walk vs. Brownian motion

Random walk in 2D space

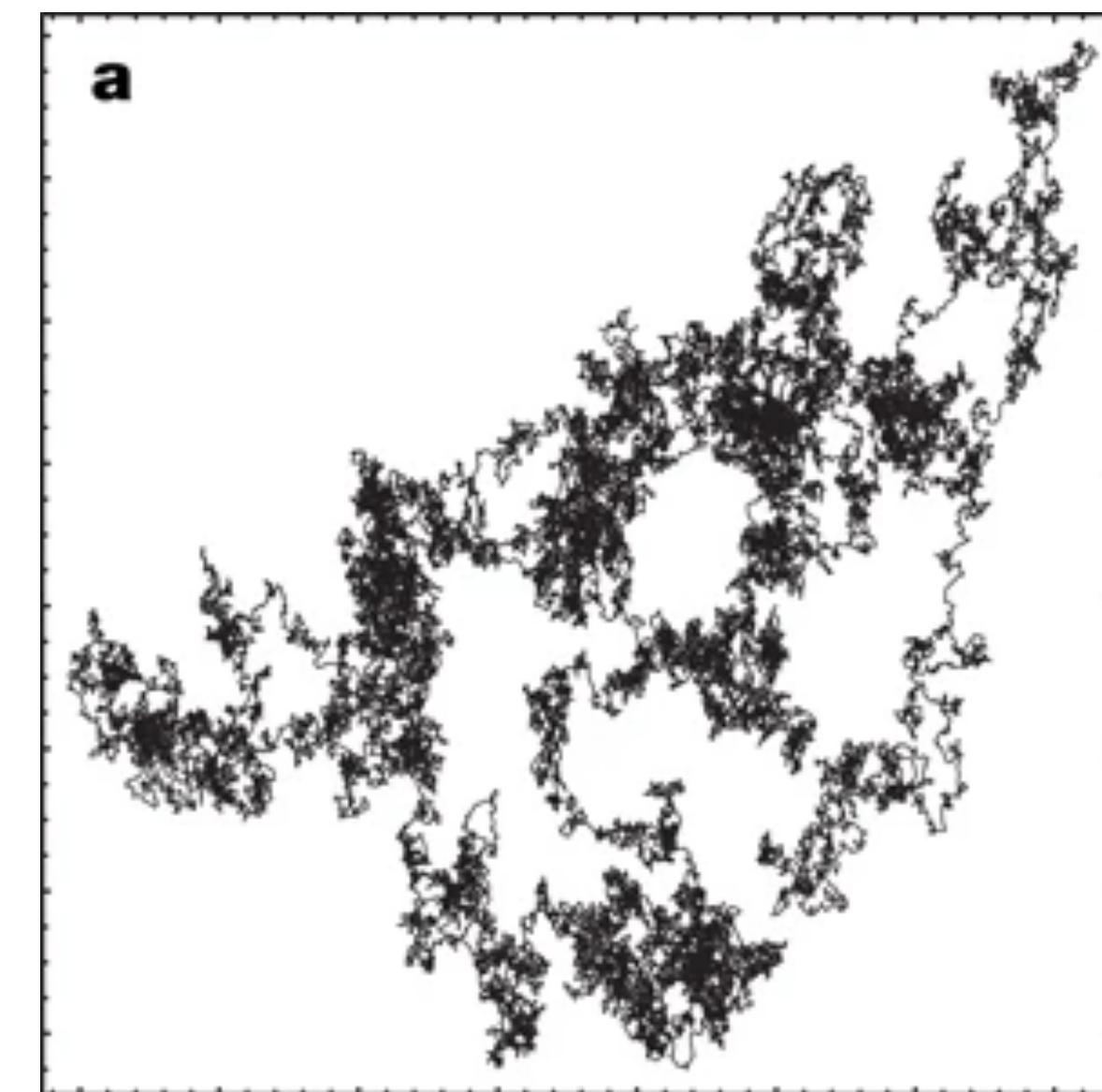
$$\theta_i = v_i 2\pi, \quad v_i \sim U(-\pi, \pi)$$

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

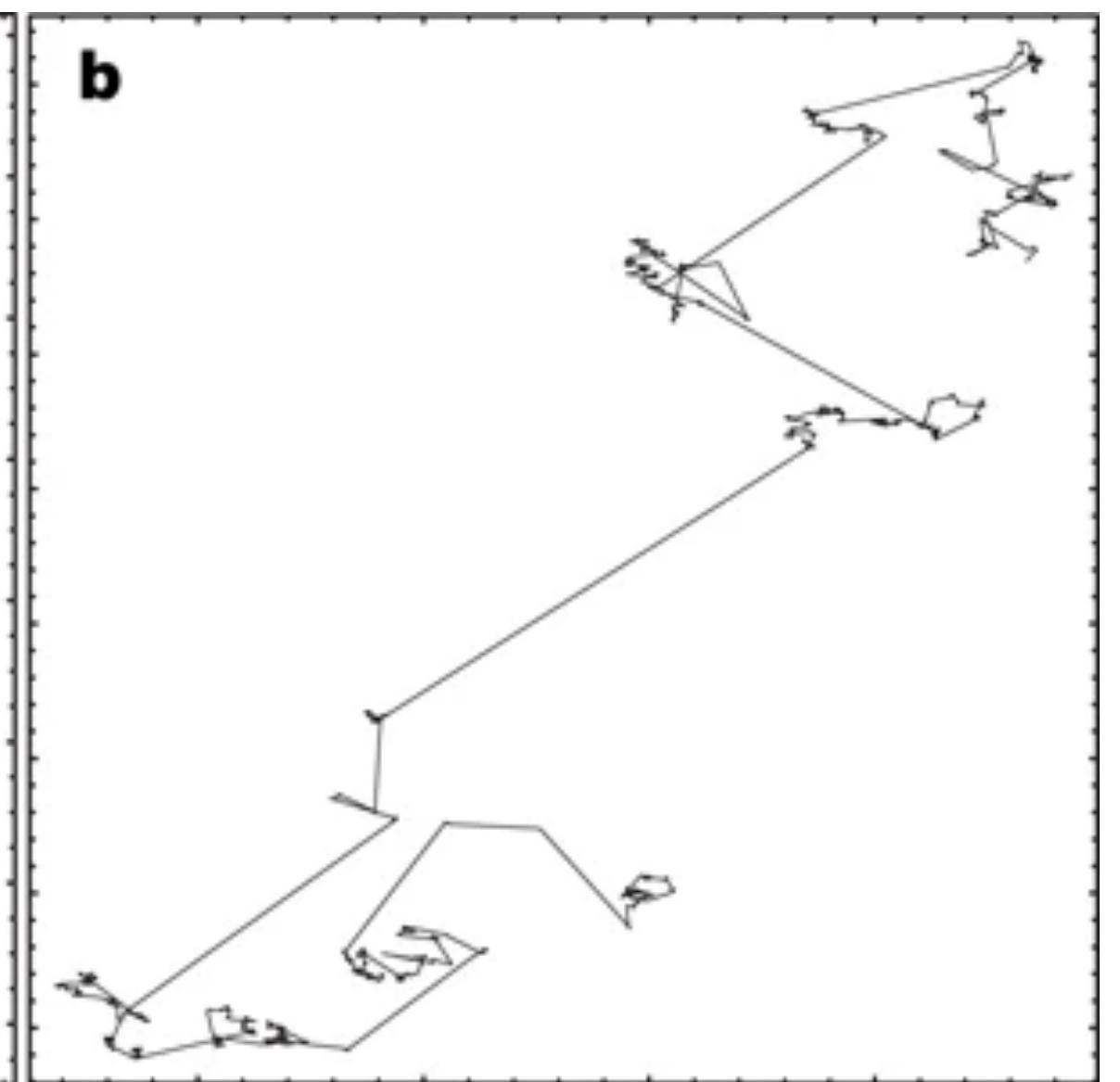
$$x_i = x_{i-1} + \delta_i \cos(\theta_i)$$

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

Brownian motion ($\gamma = 1$)

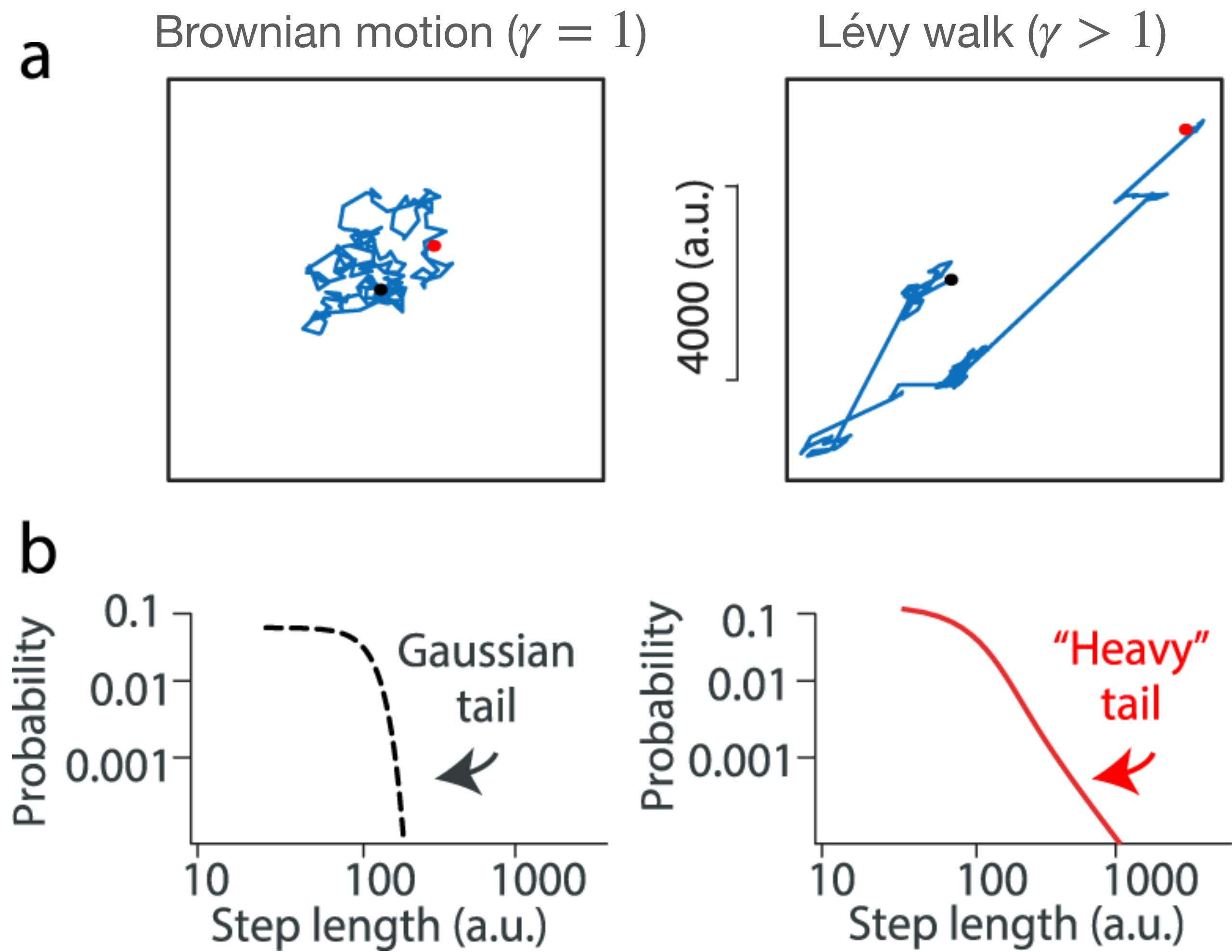


Lévy walk ($\gamma > 1$)

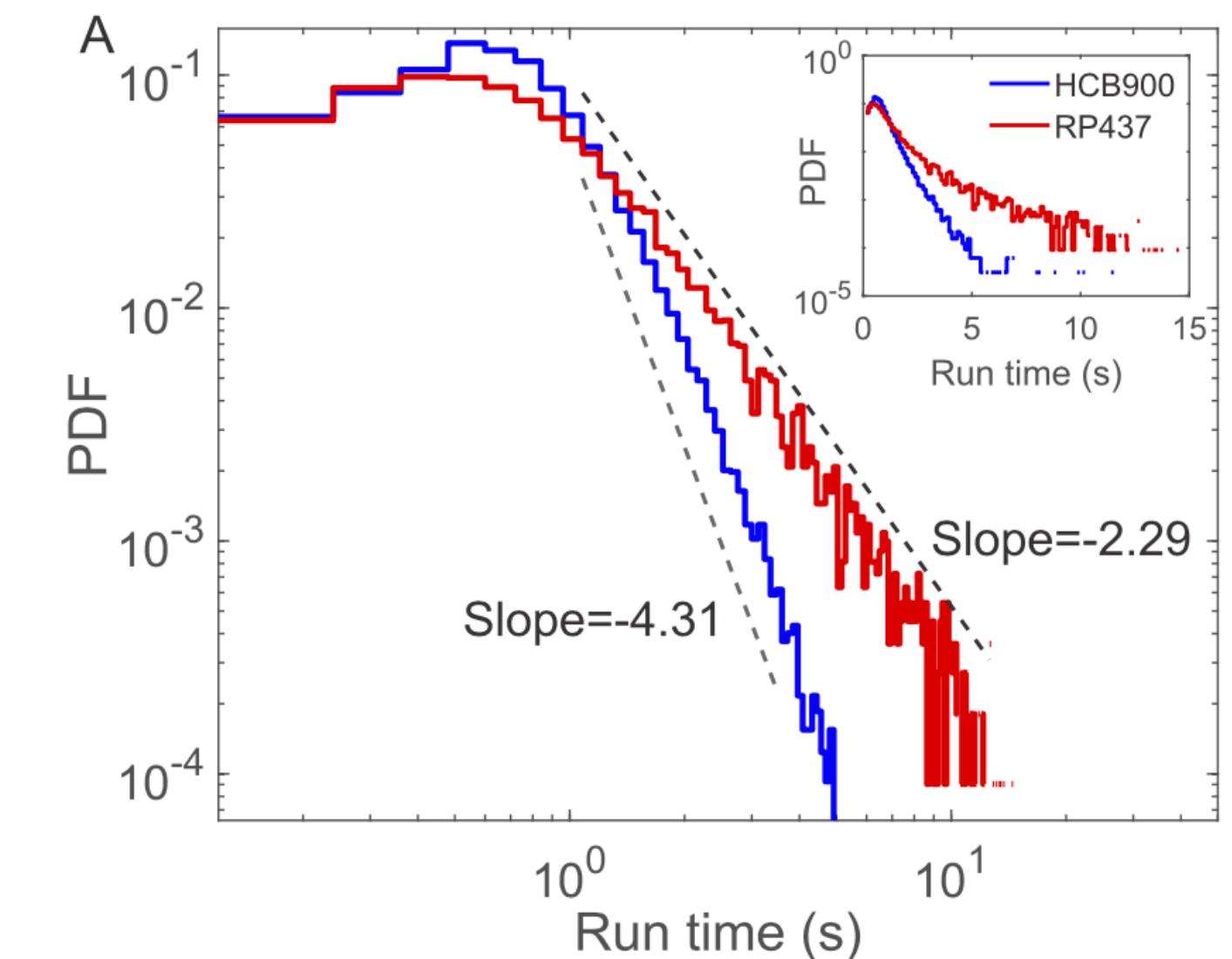
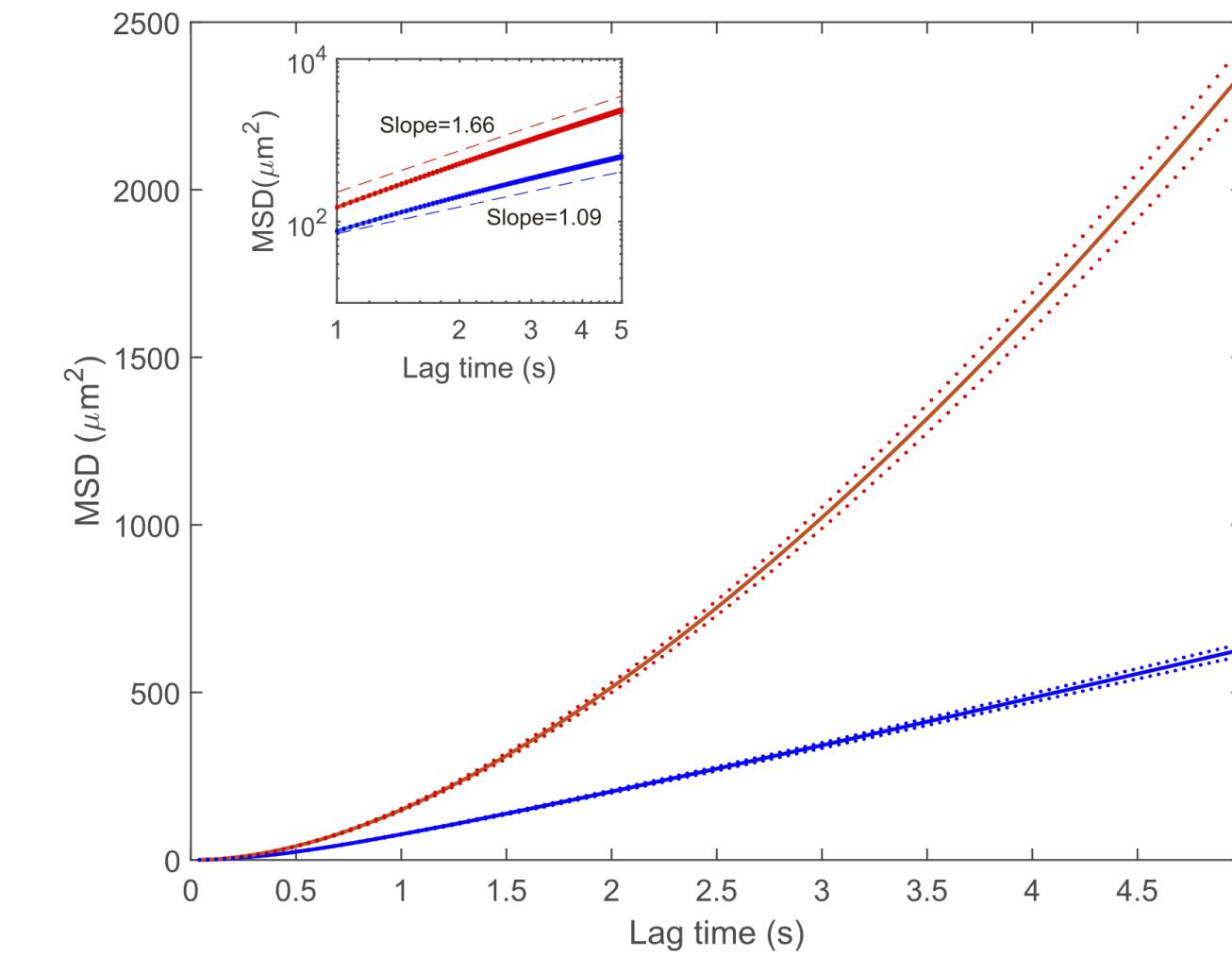
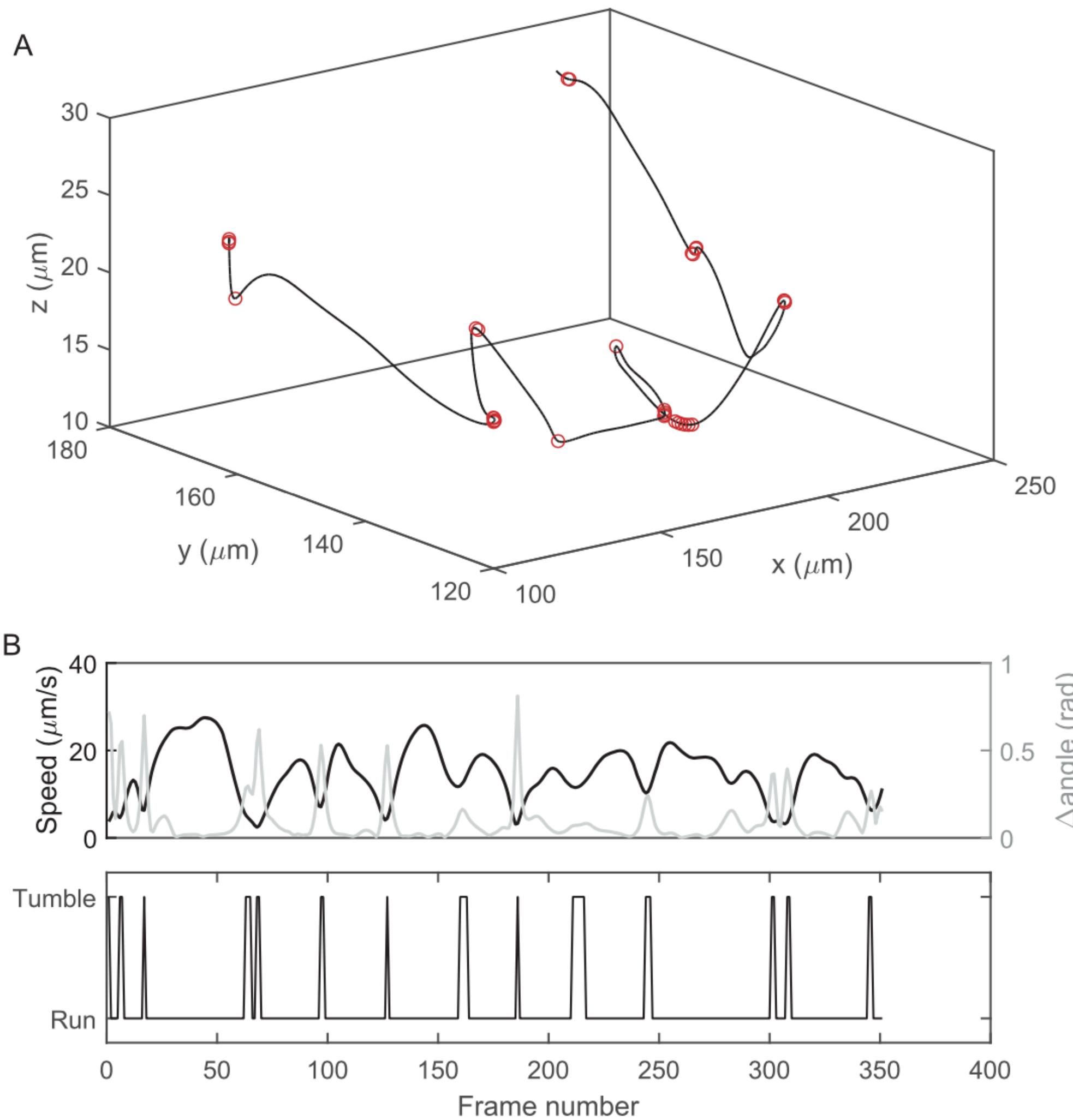


Power Law

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

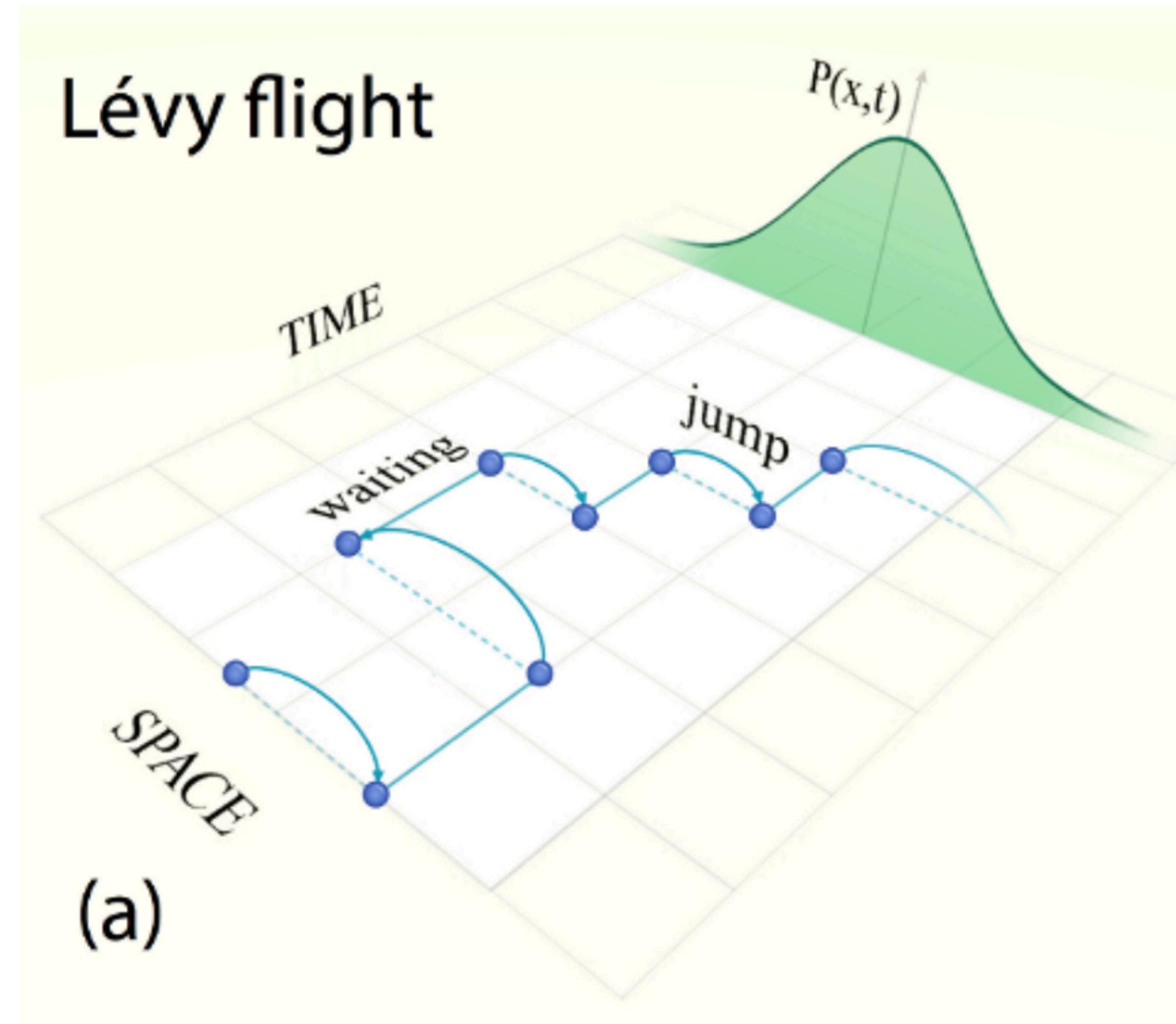


Do *e coli* use Lévy motion to explore?

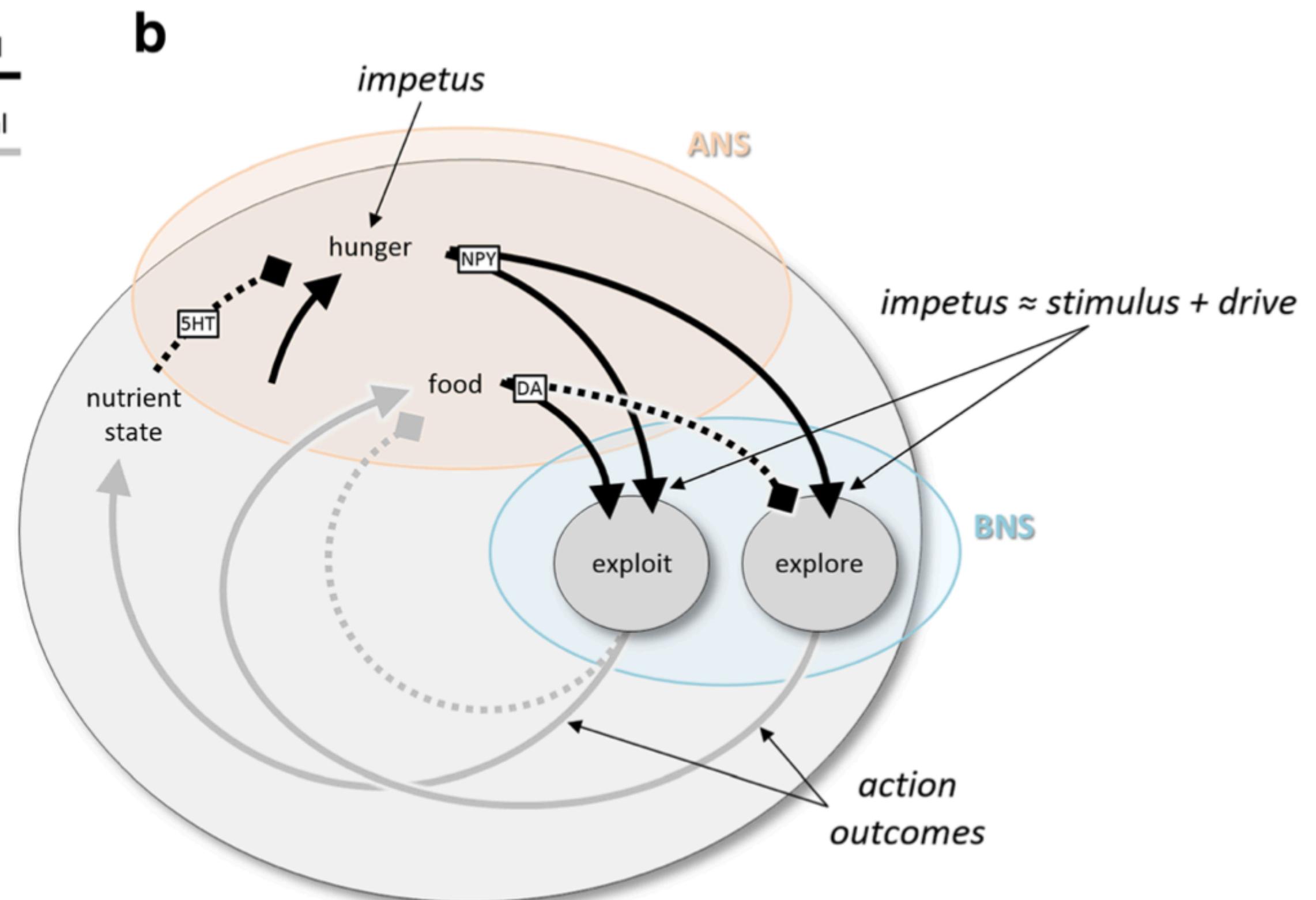


Compared to **mutants (HCB900)** who lack a critical part of the chemotaxis pathway, **wild type *e coli*** exhibit super diffusivity in their movements consistent with a Lévy walk process.

Lévy flights as explore-exploit processes



excitation
internal
external
inhibition



Take home message

- Organisms without brains can effectively explore.
- They use sensory signals as a drive for movement (slime mold, *e. coli*).
- They find optimal (i.e., shortest) paths through the environment (slime mold).
- They use Lévy flight processes to increase efficiency of random exploration (*e. coli*).

Lab 2: Random exploration

URL: <https://github.com/CoAxLab/BiologicallyIntelligentExploration/tree/main/Labs>

The screenshot shows a Jupyter Notebook interface with the following details:

- Title Bar:** Shows the notebook file name "Lab2-Random_exploration.ipynb" and various toolbar icons.
- Breadcrumbs:** Displays the file path: "Users > timothyv > Cloud > Google Drive > Classes > BIX_2022 > Labs > Lab2-Random_exploration.ipynb".
- Toolbar:** Includes buttons for "Code", "Markdown", "Run All", "Clear Outputs of All Cells", "Outline", "Select Kernel", and a cell editor.
- Section Header:** A large, bold section header "**Lab 2: Random exploration**" is visible.
- Text Content:** A paragraph states: "This lab has a few goals:" followed by a bulleted list:
 - to get you familiar with the Python library we'll be using to simulate and explore exploration
 - to introduce you to Levy walk and Brownian motion agents
- Section Header:** A section header "**Install *explorationlib***" is shown with a dropdown arrow.
- Text Content:** A paragraph explains: "Colab notebooks come with many of the code libraries we will need. However, they do not come with *explorationlib*. This is a module that we will be using; it was built by Erik Peterson to support this course. Let's Install it."
- Code Cell:** A code cell contains the following Python command:

```
!pip install --upgrade git+https://github.com/coaxlab/explorationlib
!pip install --upgrade git+https://github.com/MattChanTK/gym-maze.git
!pip install celluloid # for the gifs
```
- Language Label:** The word "Python" is located at the bottom right of the code cell area.