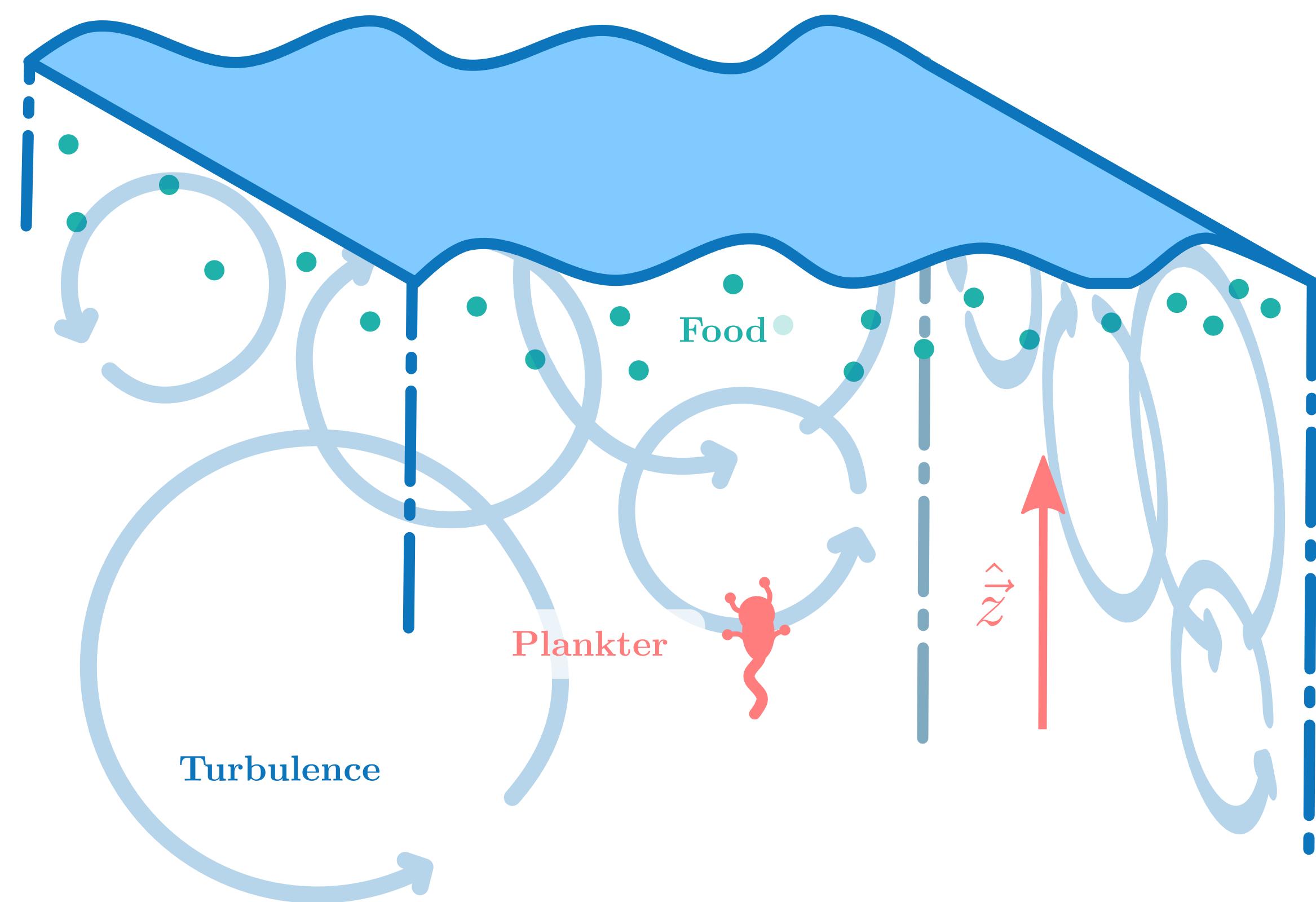


Surfing on turbulence a strategy for plankton navigation.

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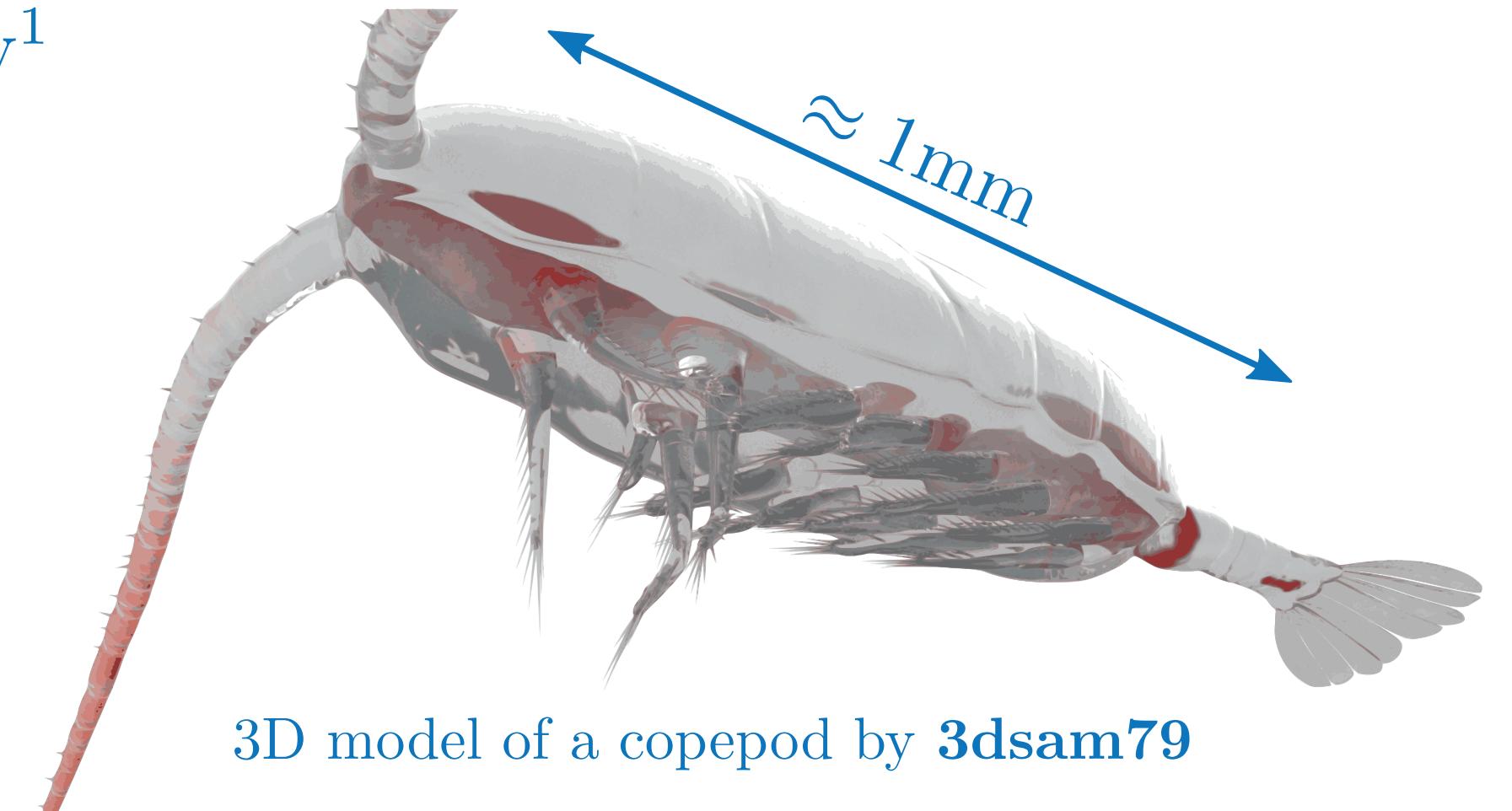


Motivation

Living in a **turbulent environment**, **navigation** is a challenging task for motile planktonic organisms (plankters). Yet **vertical migration** is essential to many of them.

For example, copepods (crustaceans that are a critical link in aquatic food webs) move upwards at night to feed in surface waters, and downwards during the day to escape visual predators [1], [2].

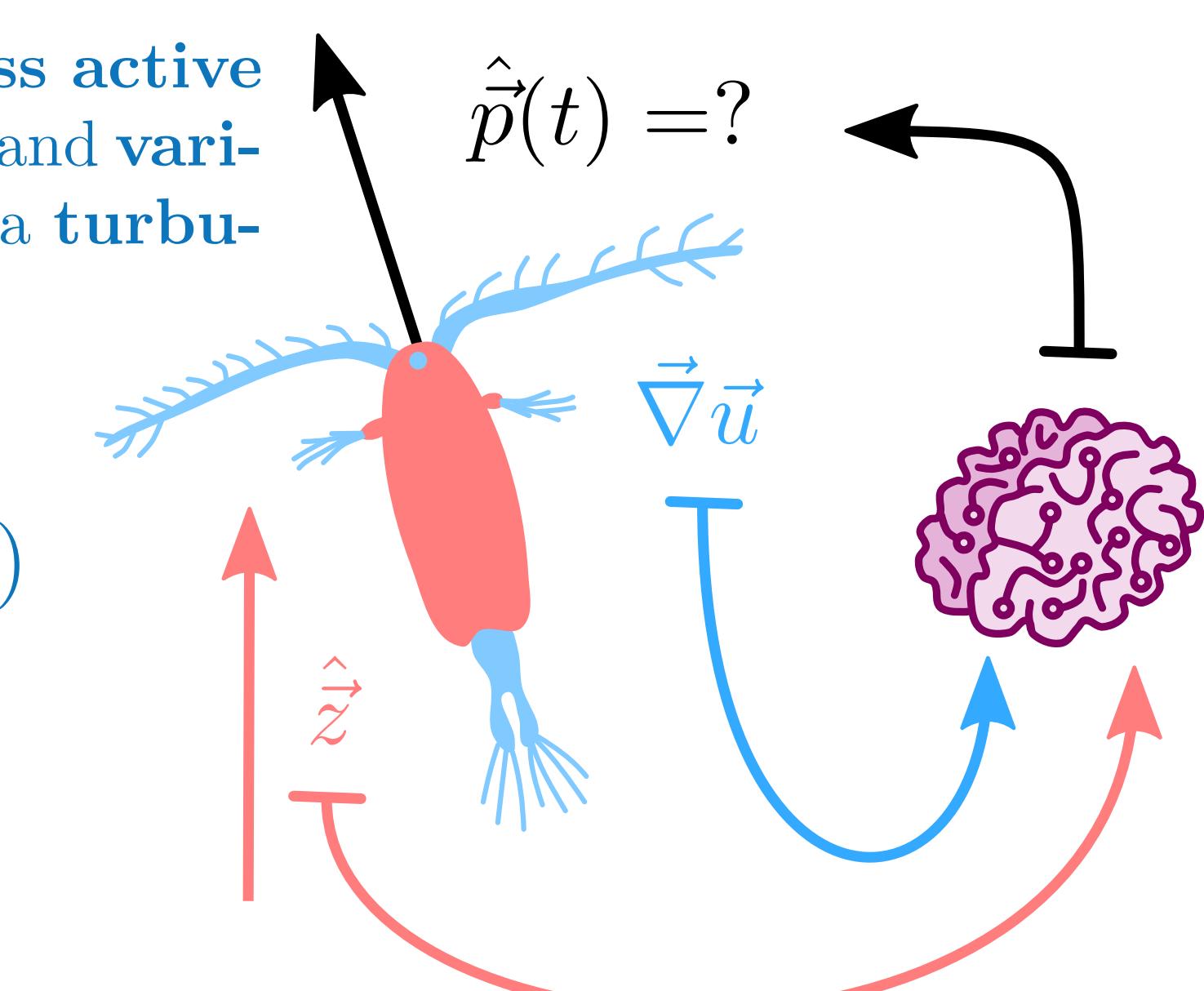
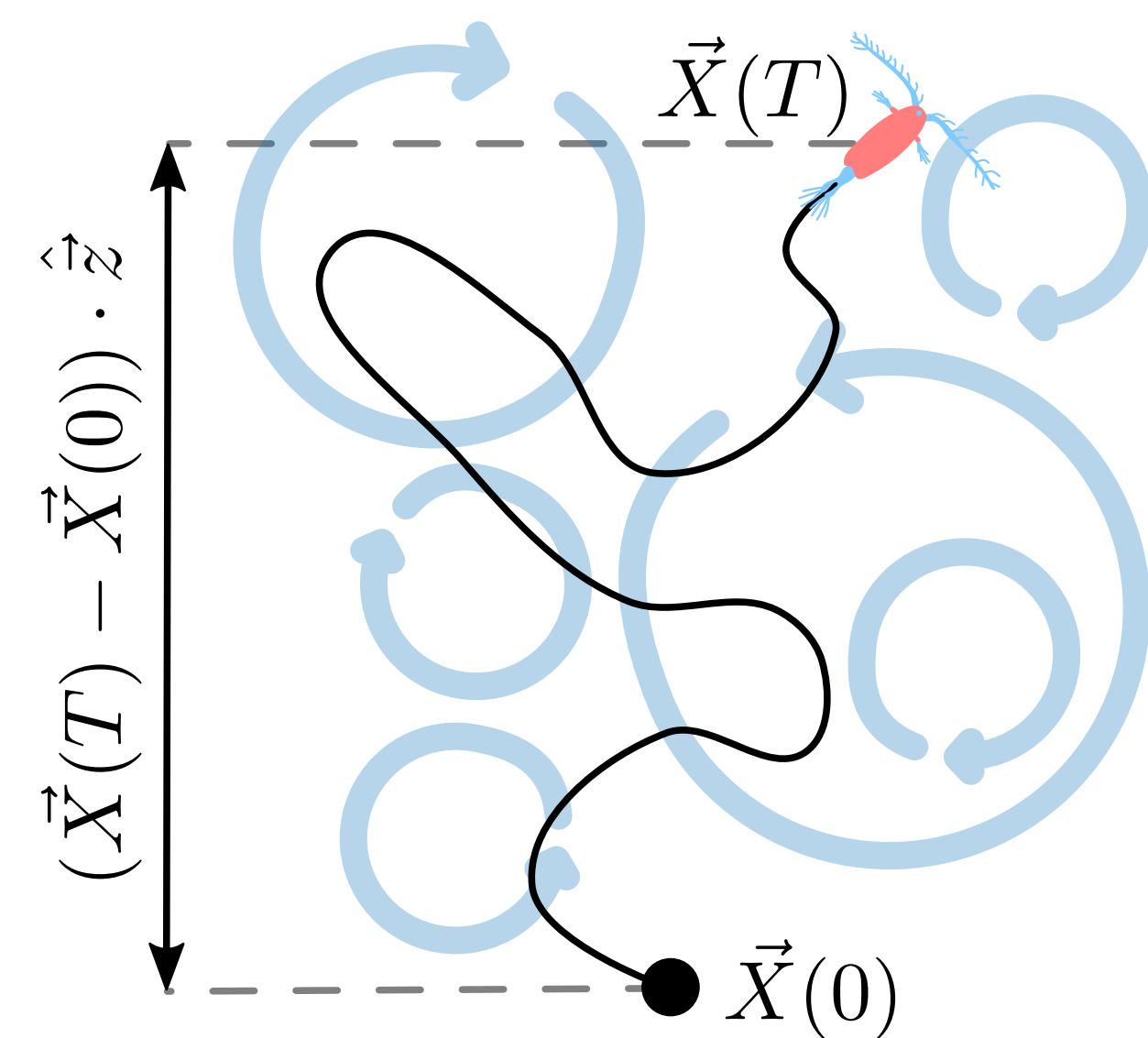
Being equipped with **flow sensors**, can these plankters use local hydrodynamic cues to **migrate faster through turbulence?**



Model and Problem

Plankters are modelled as **inertialess active particles** at constant speed V_{swim} and variable swimming direction $\hat{p}(t)$ in a turbulent flow $\vec{u}(\vec{x}, t)$.

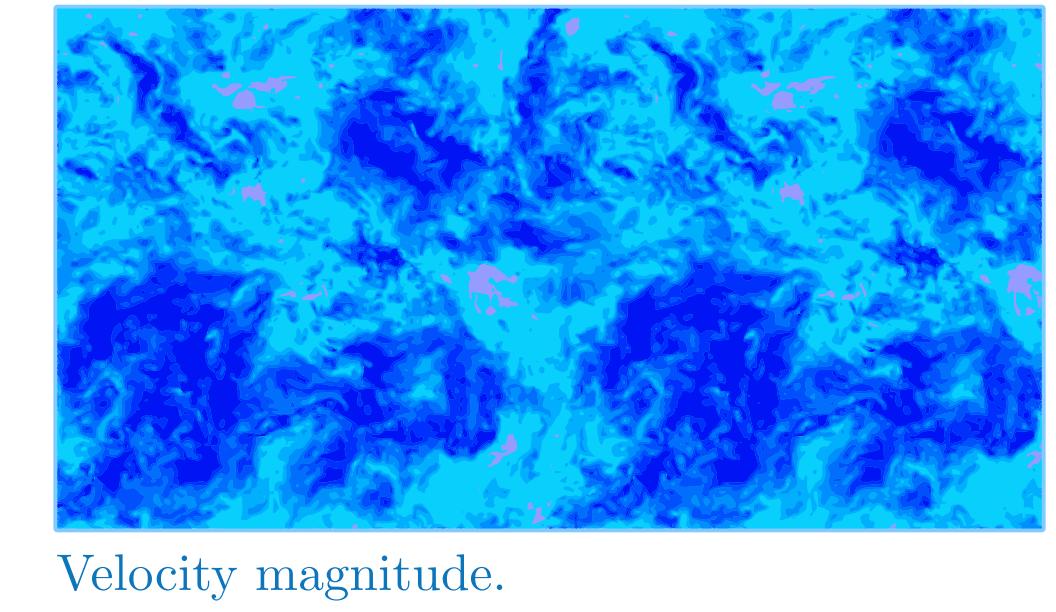
$$\frac{d\vec{X}}{dt} = \vec{u}(\vec{X}, t) + V_{\text{swim}} \hat{p}(t)$$



How to control their swimming direction $\hat{p}(t)$ to maximize their **effective vertical speed** given they can only measure gravity and their **local velocity gradients** $\nabla \vec{u}$?

$$V_{\text{eff.}} = \lim_{T \rightarrow \infty} \frac{\vec{X}(T) - \vec{X}(0)}{T} \cdot \hat{z}$$

Numerical methods



- ▶ Johns Hopkins Turbulence Databases [3]
- ▶ 3D forced homogeneous isotropic turbulence, $Re_\lambda = 418$
- ▶ Runge-Kutta 4 integrator
- ▶ open source code **SHELDON**
<https://github.com/C0PEP0D/sheldon>

Surfing strategy

Using a Taylor expansion of $\vec{u}(\vec{x}, t)$ in the neighborhood of the current time t_0 and position $\vec{X}_0 = \vec{X}(t_0)$, the **velocity field** can be approximated.

$$\vec{u}(\vec{x}, \tau) \approx \vec{u}_0 + (\vec{\nabla} \vec{u})_0 \cdot (\vec{x} - \vec{X}_0) + \left(\frac{\partial \vec{u}}{\partial t} \right)_0 (\tau - t_0)$$

Leading to a solvable local optimization problem of solution:

$$\hat{p}_{\text{surf}} = \frac{\vec{p}_{\text{surf}}}{|\vec{p}_{\text{surf}}|}, \quad \text{with} \quad \vec{p}_{\text{surf}} = \left[\exp \left(\tau (\vec{\nabla} \vec{u}) \right) \right]^T \cdot \hat{z}$$

The **sole free parameter** of the surfing strategy is τ corresponds to the time when the linearization starts to break down.

It is linked to the flow velocity gradients correlation times.

Results

Flow sensing is beneficial for planktonic navigation!

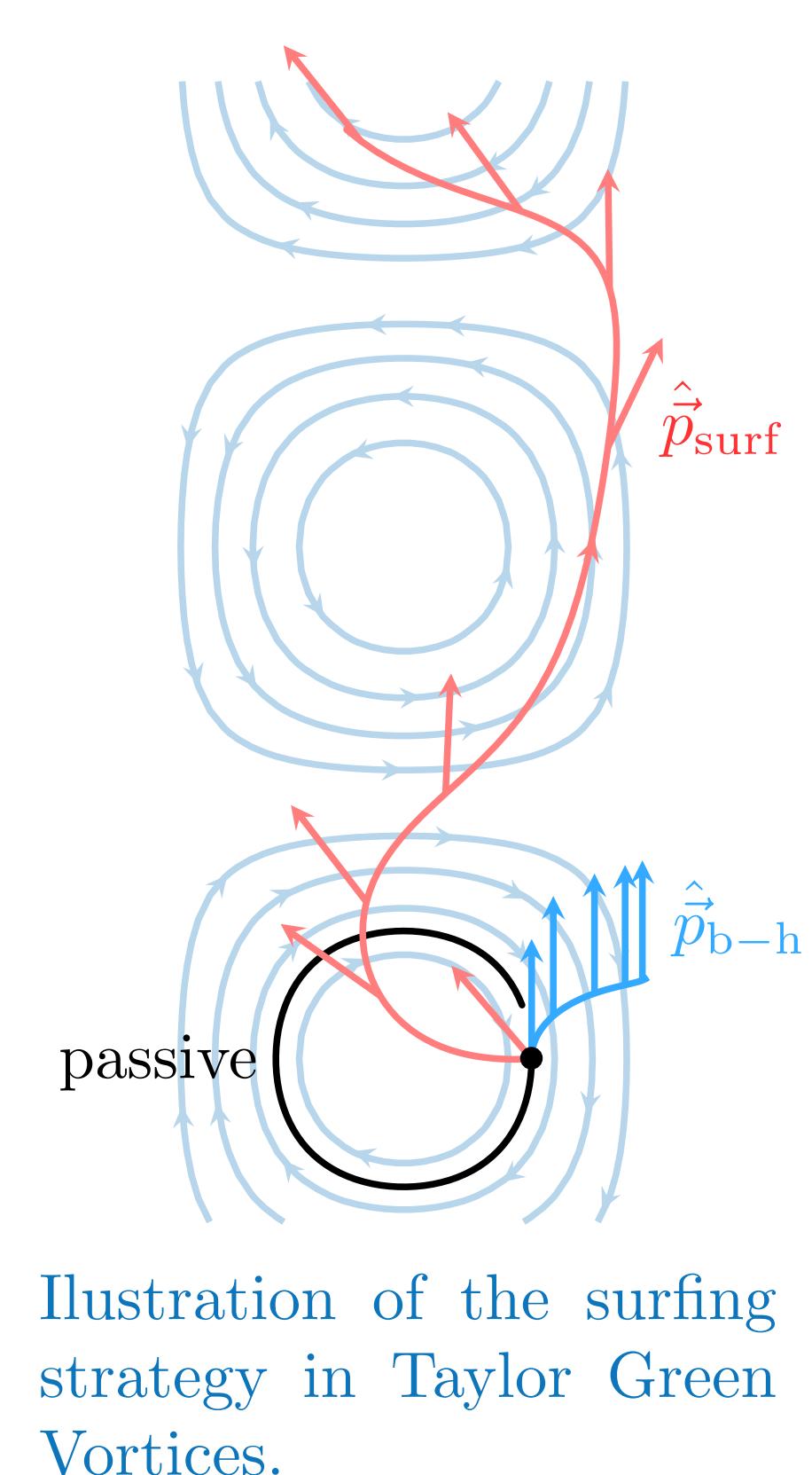
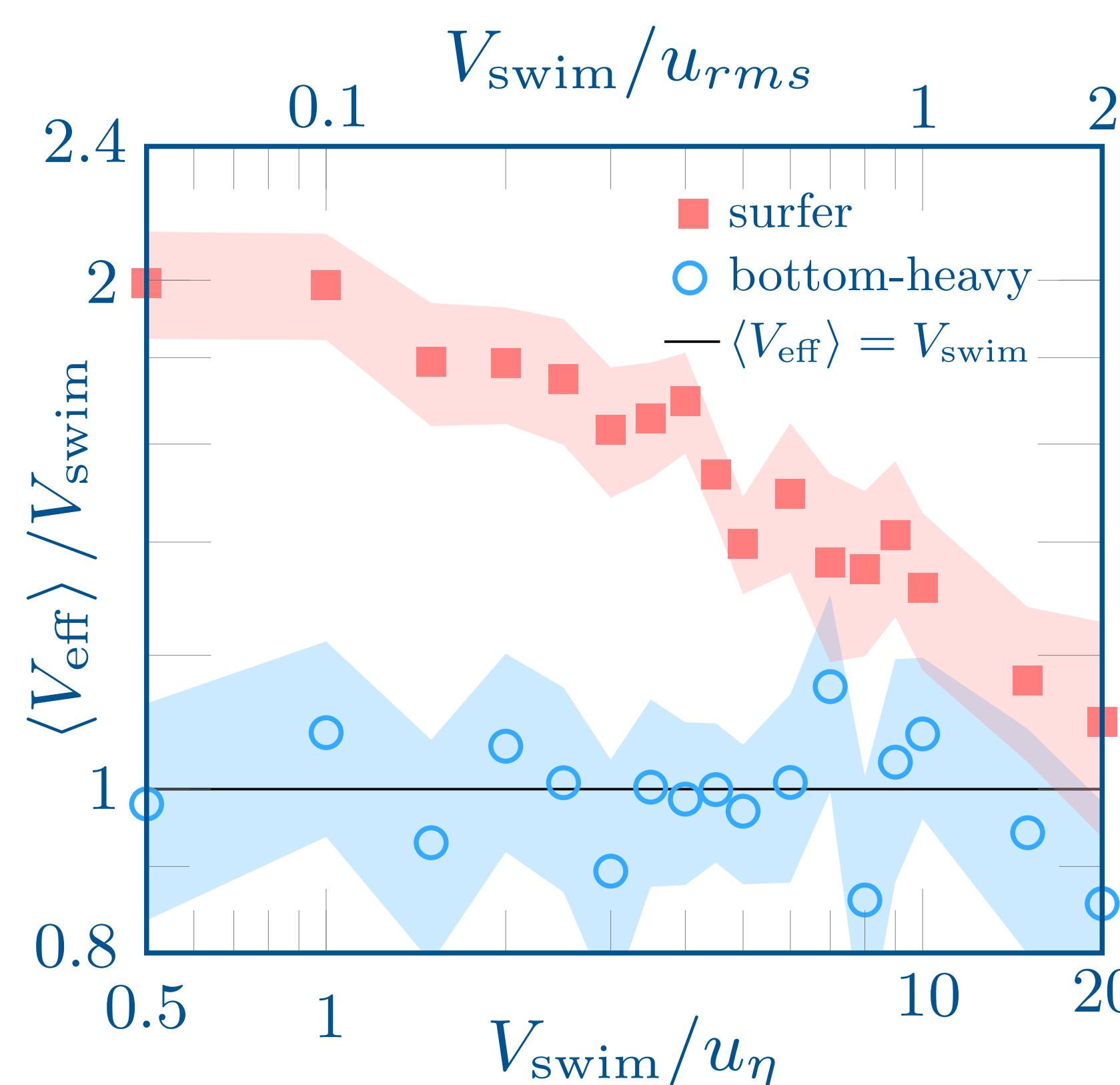


Illustration of the surfing strategy in Taylor Green Vortices.



Moreover:

- ▶ The decrease of performance with V_{swim} is related to **shorter decorrelation times** of the flow sampled by surfers.
- ▶ Surfing would be **beneficial** for the range of parameters corresponding to actual plankton habitats.

Perspectives

- ▶ turbulent channel flow: **inhomogeneous anisotropic flow**
- ▶ **generalization**: memory, odour tracking, energetic constraints ...
- ▶ investigation of the properties of the **flow sampled** by microswimmers

We show that surfers:

- ▶ systematically **outperform** bottom-heavy swimmers that always swim upwards.
- ▶ can reach effective speeds, $V_{\text{eff.}}$, as large as **twice** their swimming speed.
- ▶ are **competitive** with reinforcement learning swimmers [4].

