Emergent counter-current swimming of Zooplankton

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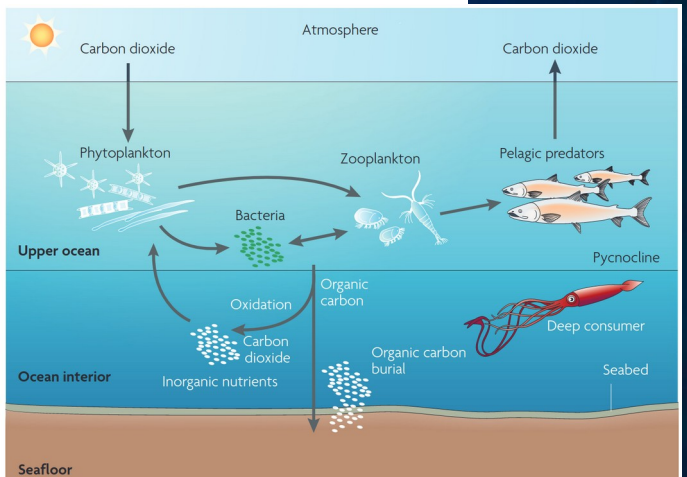
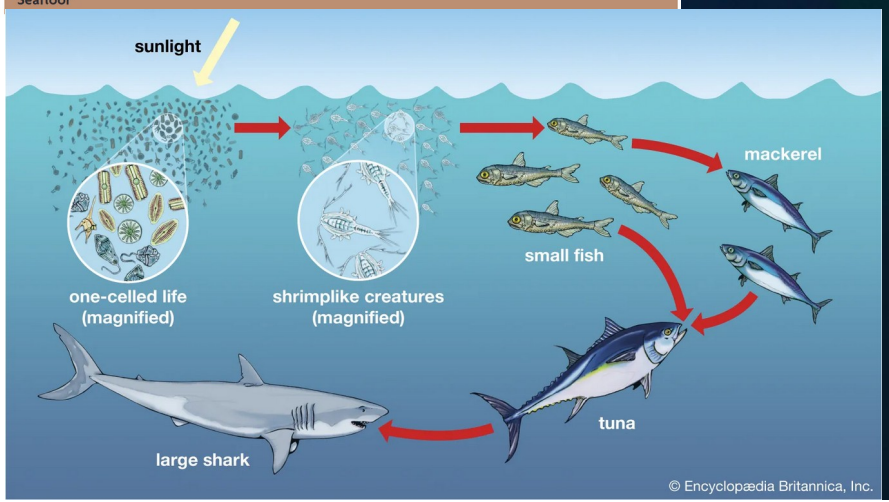
NORDITA
The Nordic Institute for Theoretical Physics

Introduction

A phytoplankton bloom seen from space. A bloom triggered by a cyclone in 2019 covered nearly 250,000 square kilometers in the South Pacific Ocean. Credit: Alamy

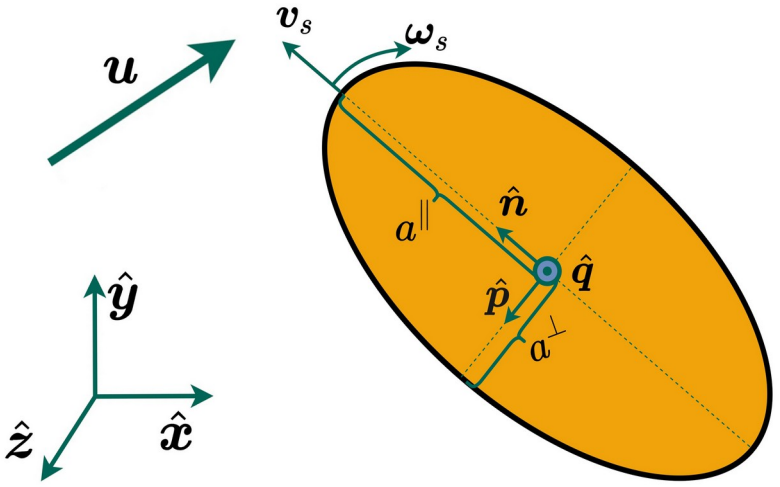


Nature reviews microbiology 5.10 (2007): 813-819.



Model

$$\boldsymbol{v} = \boldsymbol{u}_{\text{flow}}(\boldsymbol{x}, t) + v_{\text{swim}}\hat{\boldsymbol{n}}$$



$$\boldsymbol{\omega} = \boldsymbol{\Omega}_{\text{flow}}(\boldsymbol{x}, t) + \Lambda\hat{\boldsymbol{n}} \times \mathbb{S}_{\text{flow}}(\boldsymbol{x}, t)\hat{\boldsymbol{n}} + \boldsymbol{\omega}_{\text{swim}}$$

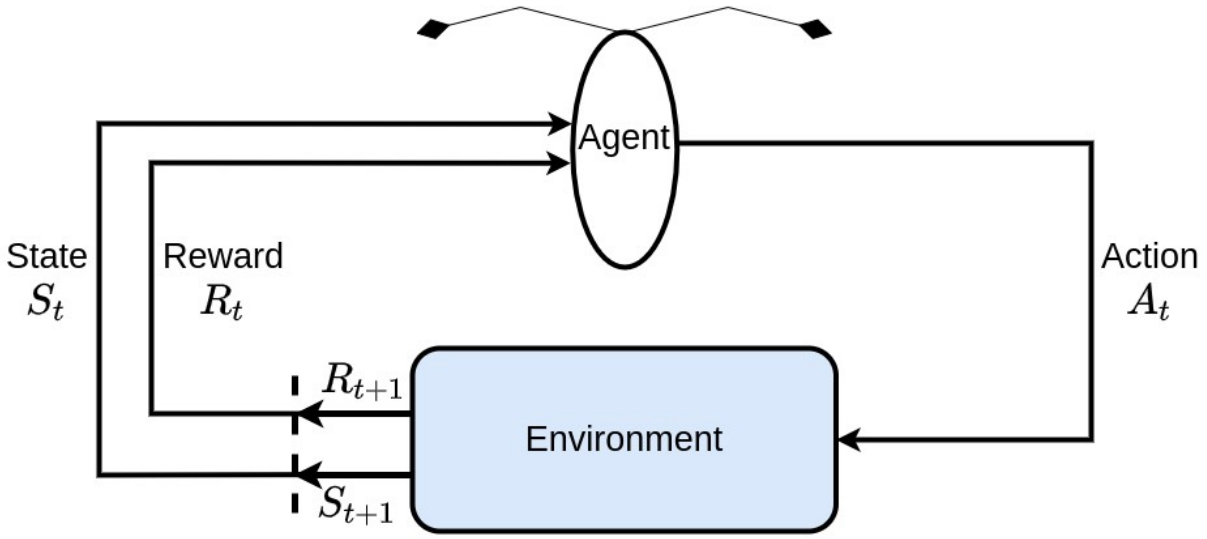
$$\Lambda = \frac{\lambda^2 - 1}{\lambda^2 + 1}, \quad \lambda = \frac{a^{\parallel}}{a^{\perp}}$$

Active control

Smart Swimmer

Ability to accomplish complex goals

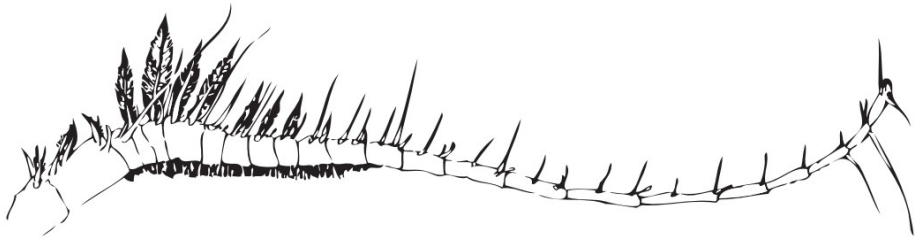
Life 3.0 , Max Tegmark



Reinforcement learning an introduction, R. Sutton and A. Barto.

$$Q(s,a) = Q(s,a) + \alpha\left[R + \gamma \max_{a'} Q(s',a') - Q(s,a)\right]$$

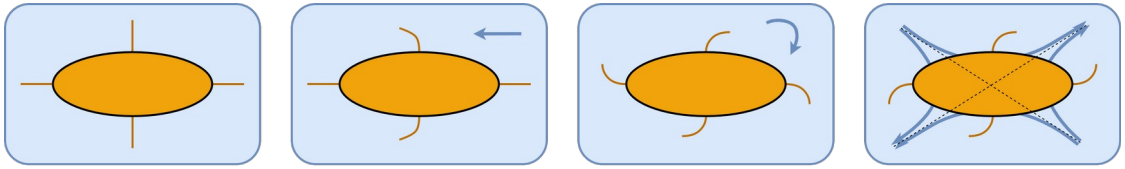
Sensing abilities



Small, Wet, and Rational, Andre Visser

Can they distinguish?

Small, Wet, and Rational, Andre Visser



Advection | Slip velocity (Translational) | Slip velocity (Angular) | Fluid strain

Goal

Avoid high strain ?

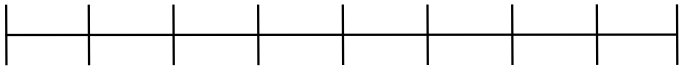
Plankton: wonders of the drifting world, Christian Sardet.

State and Actions

Signals

$$\frac{\partial u_i}{\partial x_j}$$

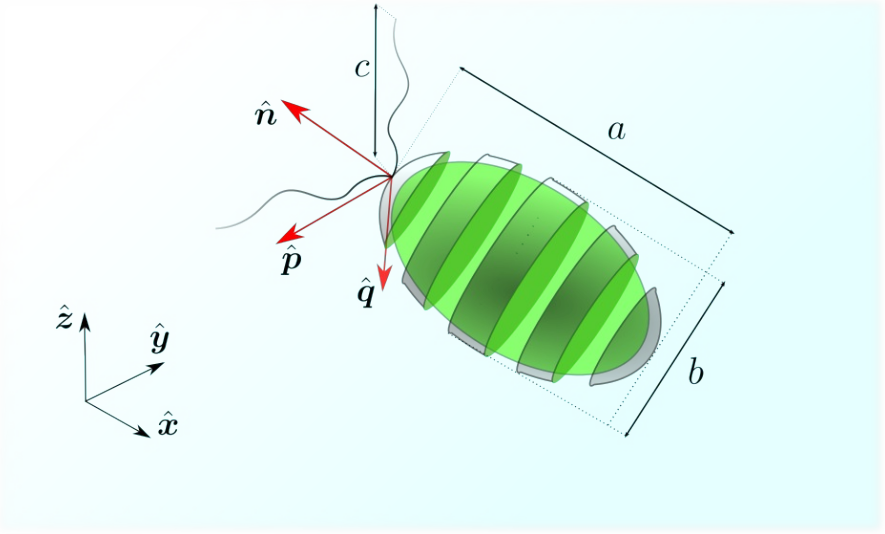
$$\mathrm{tr}(\mathbb{S}^2)$$



$$\frac{\partial}{\partial x_k}\frac{\partial u_i}{\partial x_j}$$

$$\boldsymbol{p}\cdot\nabla\mathrm{tr}(\mathbb{S}^2)>0 \qquad \boldsymbol{p}\cdot\nabla\mathrm{tr}(\mathbb{S}^2)<0$$

$$\boldsymbol{q}\cdot\nabla\mathrm{tr}(\mathbb{S}^2)>0 \qquad \boldsymbol{q}\cdot\nabla\mathrm{tr}(\mathbb{S}^2)<0$$



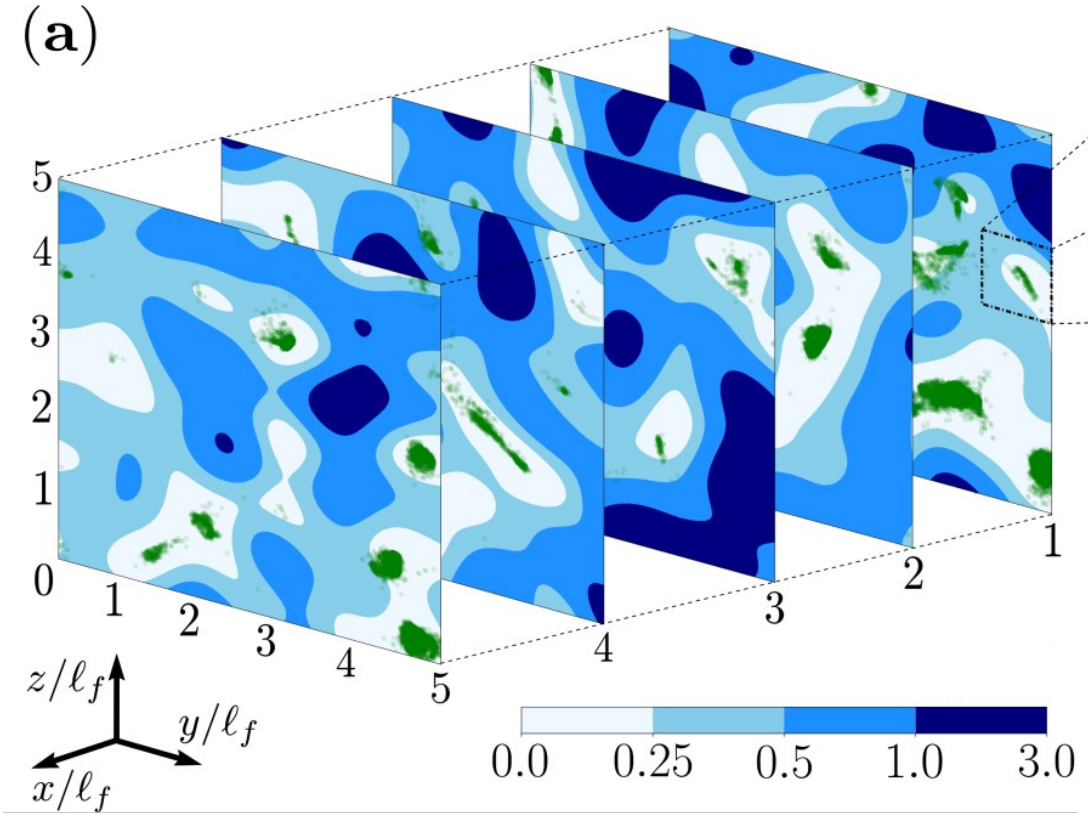
Actions

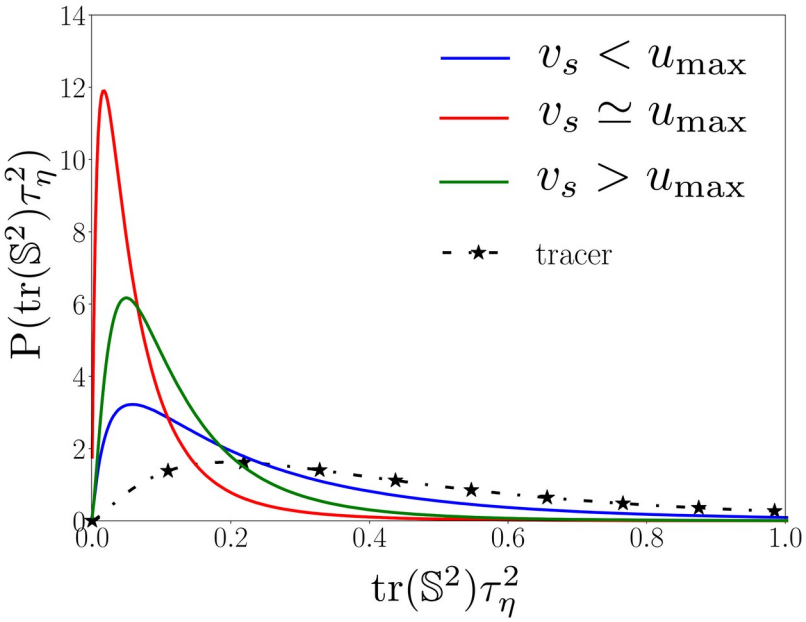
$$\boldsymbol{\omega}_{\text{swim}} = \omega_q + \omega_p$$

Reward

$$R \propto -\mathrm{tr}(\mathbb{S}^2)$$

Optimal Navigation





Mousavi, N., Qiu, J., Mehlig, B., Zhao, L., & Gustavsson, K. (2023).
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Optimal Navigation

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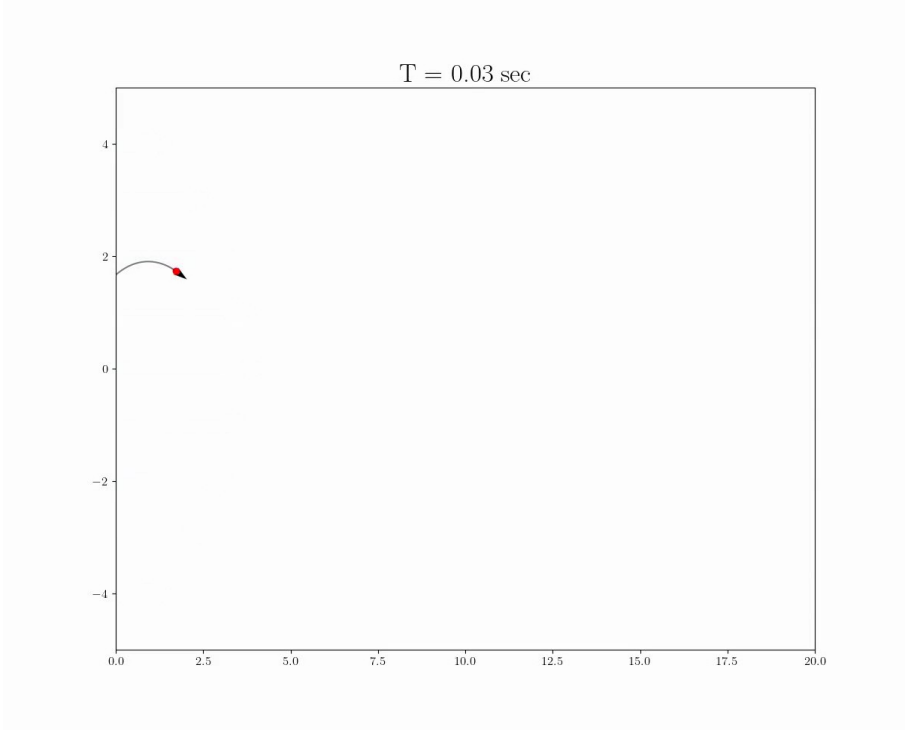
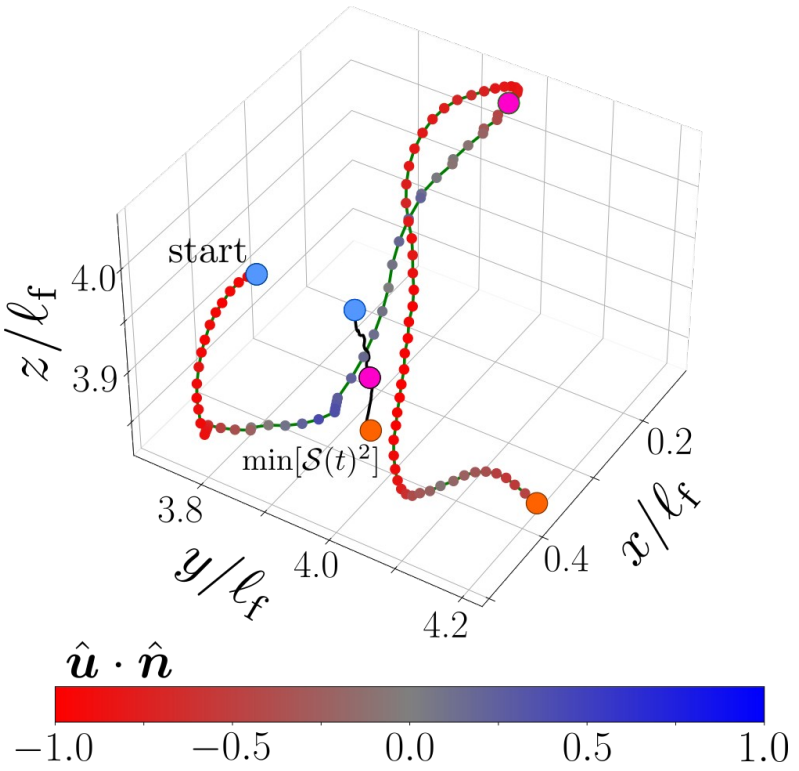
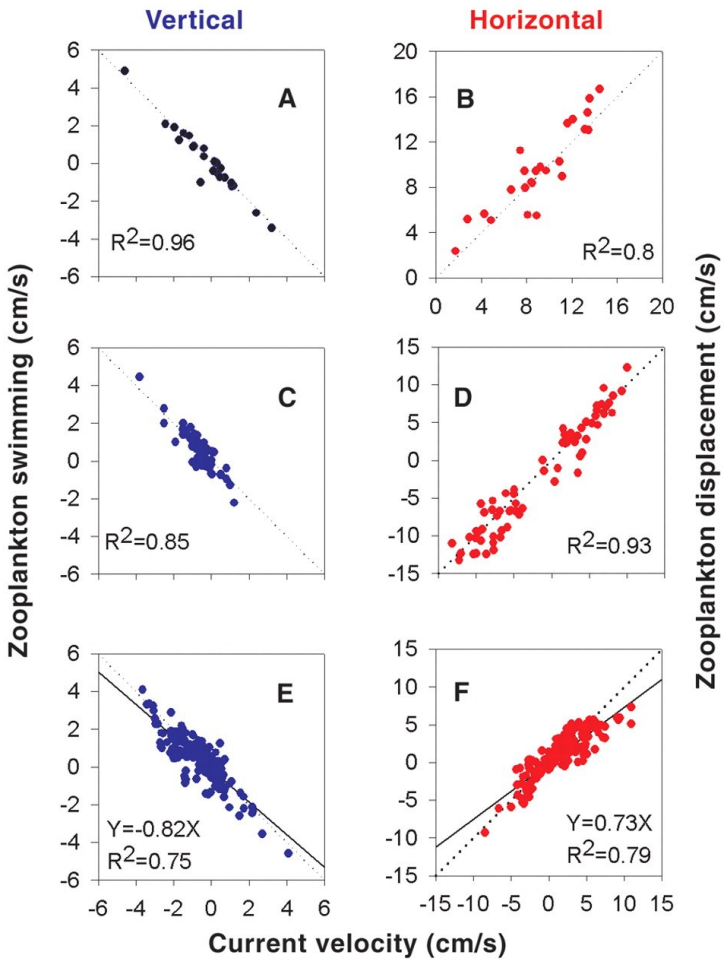
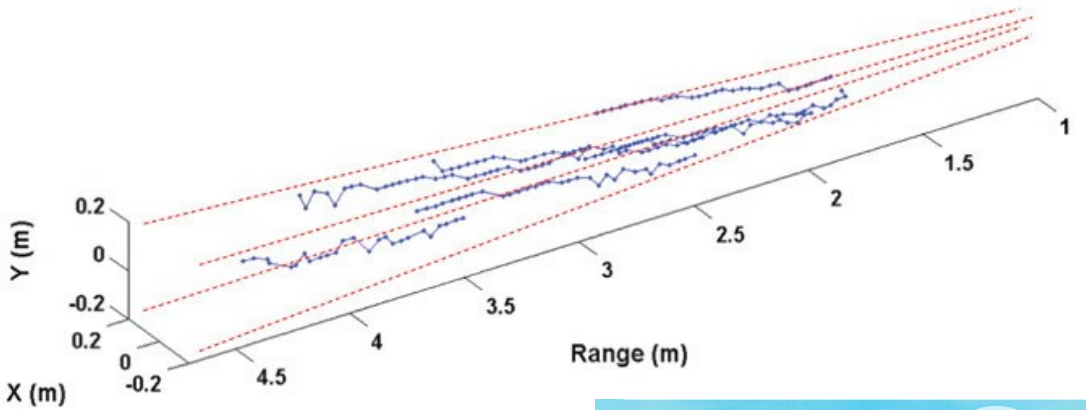




Counter-current swimming in nature





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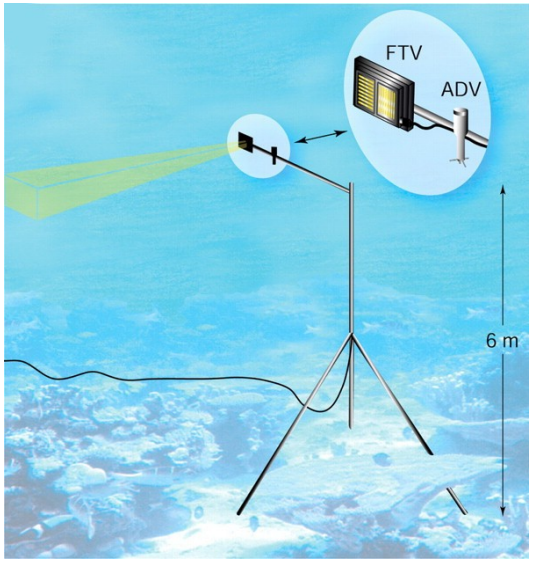

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