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Probing models of minimal swimming vehicules



in vivo with microalgae phototaxis.



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Motivations

- Unicellular algae, like Chlamydomonas Reinhardtii, are living examples of microscopic phototactic vehicles [1,2].
- The study of their swimming behavior at single cell and population levels unveils properties of their sensorimotor system.
- Microrobots operating in a low Reynolds number regime would benefit from the understanding of their living counterparts.

Characterization

Algaegraphy



An experimental device from previous artworks by Lia Giraud (below: the sample

PSL*

UPMC

This tool is then	 a a ^v	•				n 7				•		a -		• •	n. n		•	2	a	
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of various microalgae	 		• • •	• •	A	· ·	· · · · · ·	a 19	Second	a antaologica de antao	พระมายกรีเมืองการ	n 3 helenaar Mathemar	a mana 3	a a	1	•	. a	2	,	a a

The density of cells (A) is monitored through the gray level intensities:







As a circular area is exposed to constant light, we measure:

light profile center borde

Micro level

- The sensitivity and the dynamic range of the algae from the density at the center (Ac) for various light intensities.
- The **spatial resolution** (s) as the slope on the border of the algae bump.
- The **formation time** where the bump to reach maximal resolution and its persistence time.

Measures of algae accumulation



Other data from microscope recordings allows to get independent estimations for parameters of the model using single cell trajectories and population dynamics.







The variations in the number of cells in the field of view reflect the changes of position of the light source in the microchamber.

Collective behavior

At high density of cells, the interactions between individual behaviours leads to specific patterns of cell density, as shown here,



Dynamics and variation with light intensity of density at the center A_{c} and spatial resolution s.

Models of phototaxis

Desynchronization in the beating of flagella.





The dynamics of the 2 flagella (considered as oscillators) can be reduced to their phase difference φ :

$$d\phi_t = [\Delta \omega + Ksin(\phi_t)]dt + \sigma(I)dW$$

With:

- $\Delta \omega$: the difference of beating frequency.

Run and Tumble trajectories

Transient desynchronizations generate rapid reorientations of the swimming path of algae at random times i.e.

$T \sim Poisson(r_{I})$

where the rate of the Poisson process depends on light intensity.





which could not be explained if cell trajectories are independent. See also «vortex» in

bit.ly/1K7se2a



• *K*: the coupling constant. • $\sigma(I)$: fluctuations due to the stochasticity of biochemical signals.

• *I*: Light intensity.

Population dynamics.



• In the above example, the tumbling rate depends on the distance from the light source *l* as well as the orientation relative to the light source θ : $r(l, \theta) = \frac{A}{1 + e^{\alpha_l l - \alpha_l \cos(\theta) - \beta}}$

• Macro and micro data will give us independent estimations of the diffusion coeffcient as well as the dependance of the tumbling rate on the light intensity.

References

[1] Goldstein, Raymond E., Green Algae as Model Organisms for Biological Fluid Dynamics, Annual Rewiew of Fluid Mechanics, 2015.

[2] Braitenberg, Valentino, Vehicles, Experiments in Synthetic Psychology, MIT Press, 1986.