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Probing models of minimal swimming vehicles in vivo with microalgae phototaxis.



David Colliaux¹, Lia Giraud², Claude Yéprémian³, Pierre Bessière¹ and Jacques Droulez¹

¹ISIR, UMR7222 CNRS/Sorbonne Universités, Paris ²SACRe Ph.D candidate, PSL Research University, EnsadLab and LCLCP-UMR 7574, ³CCE, UMR 7245 CNRS/Muséum National d'Histoire Naturelle, Paris

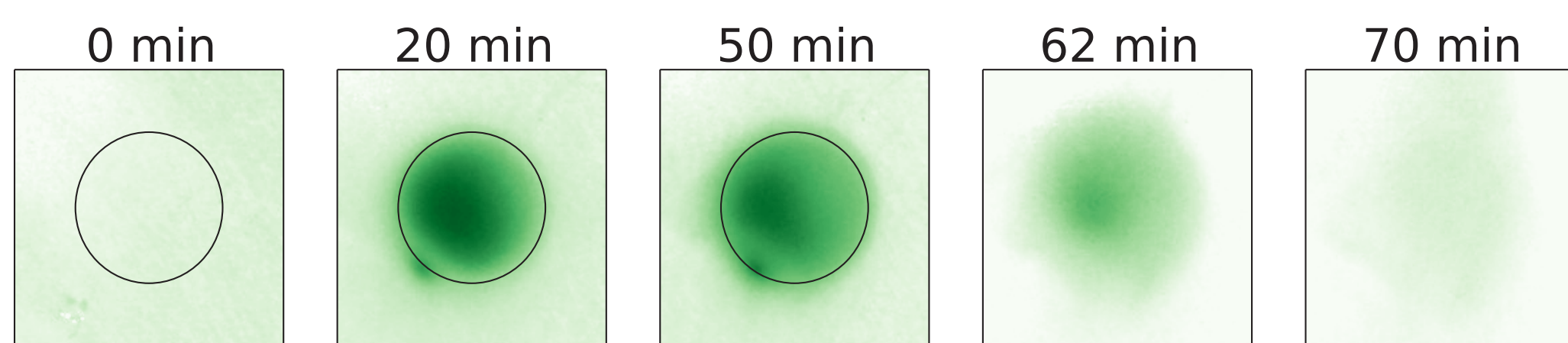


Motivations

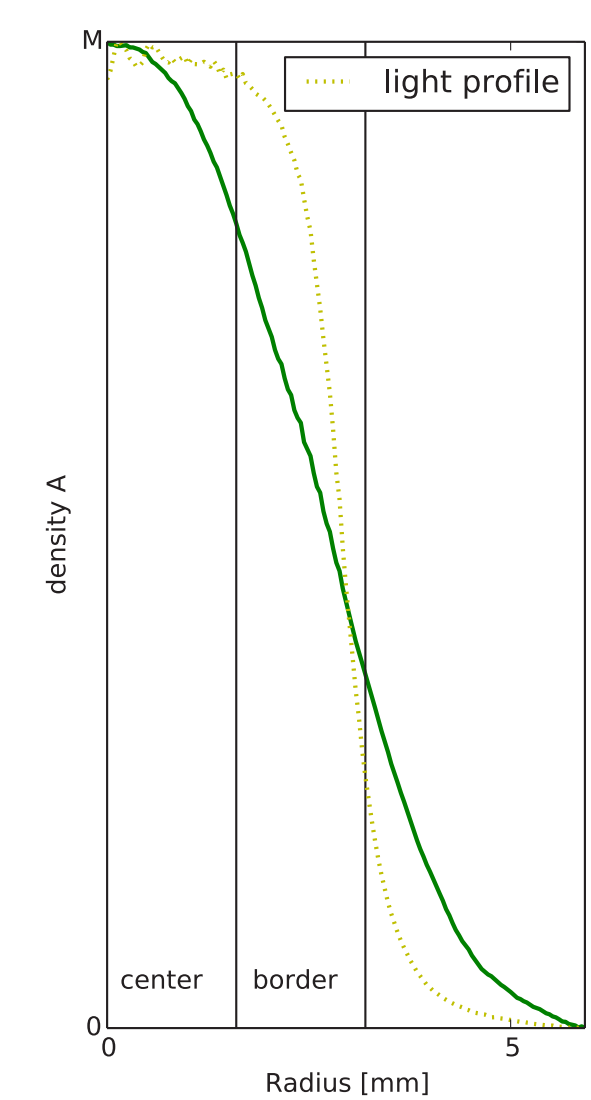
- Unicellular algae, like *Chlamydomonas Reinhardtii*, are living examples of microscopic phototactic vehicles [1,2].
- The study of their swimming behavior at single cell and population levels unveils properties of their sensorimotor system.
- Microrobots operating in a low Reynolds number regime would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

Characterization

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



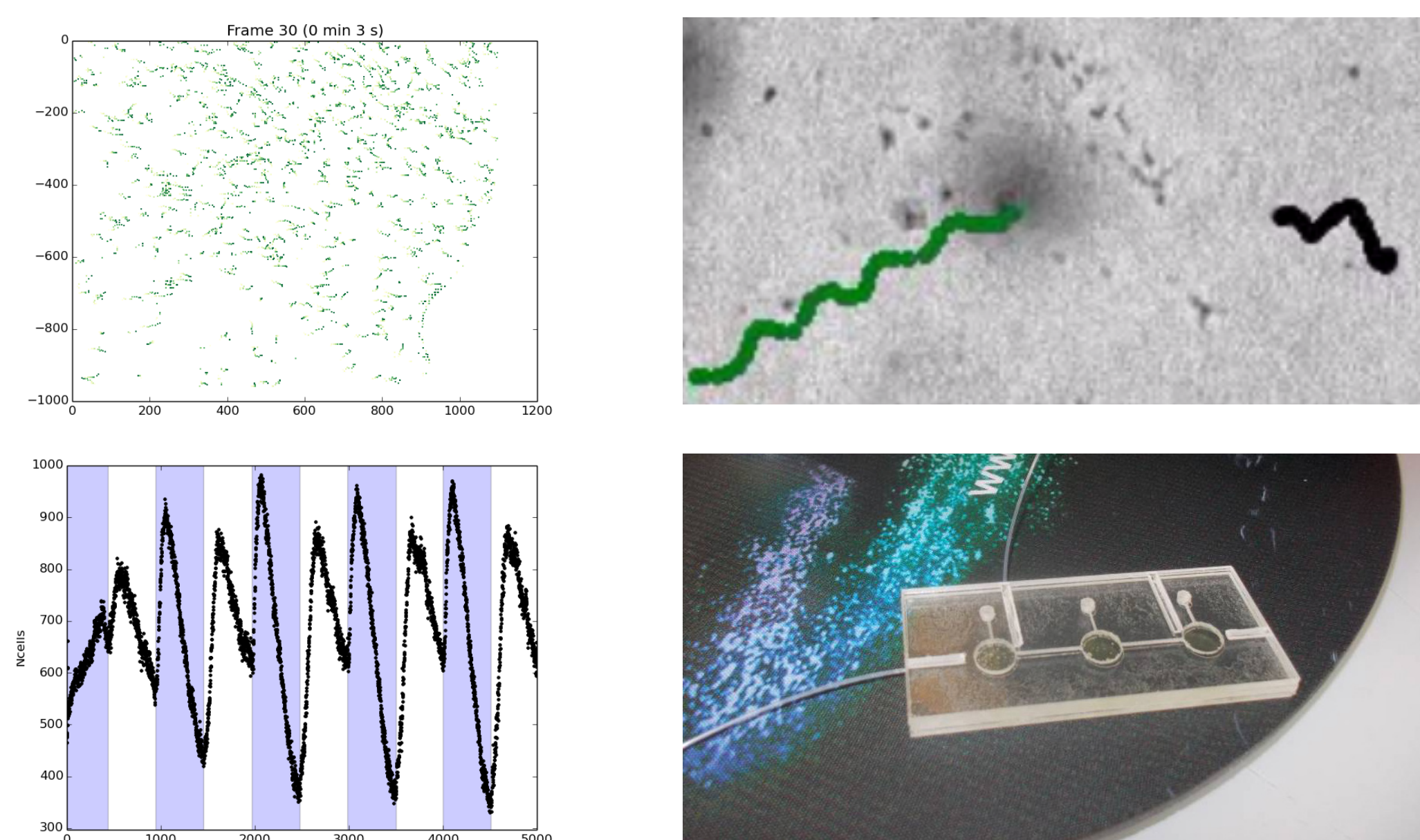
As a circular area is exposed to constant light, we measure:



- The **sensitivity** and the **dynamic range** of the algae from the density at the center (A_c) 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.

Micro level

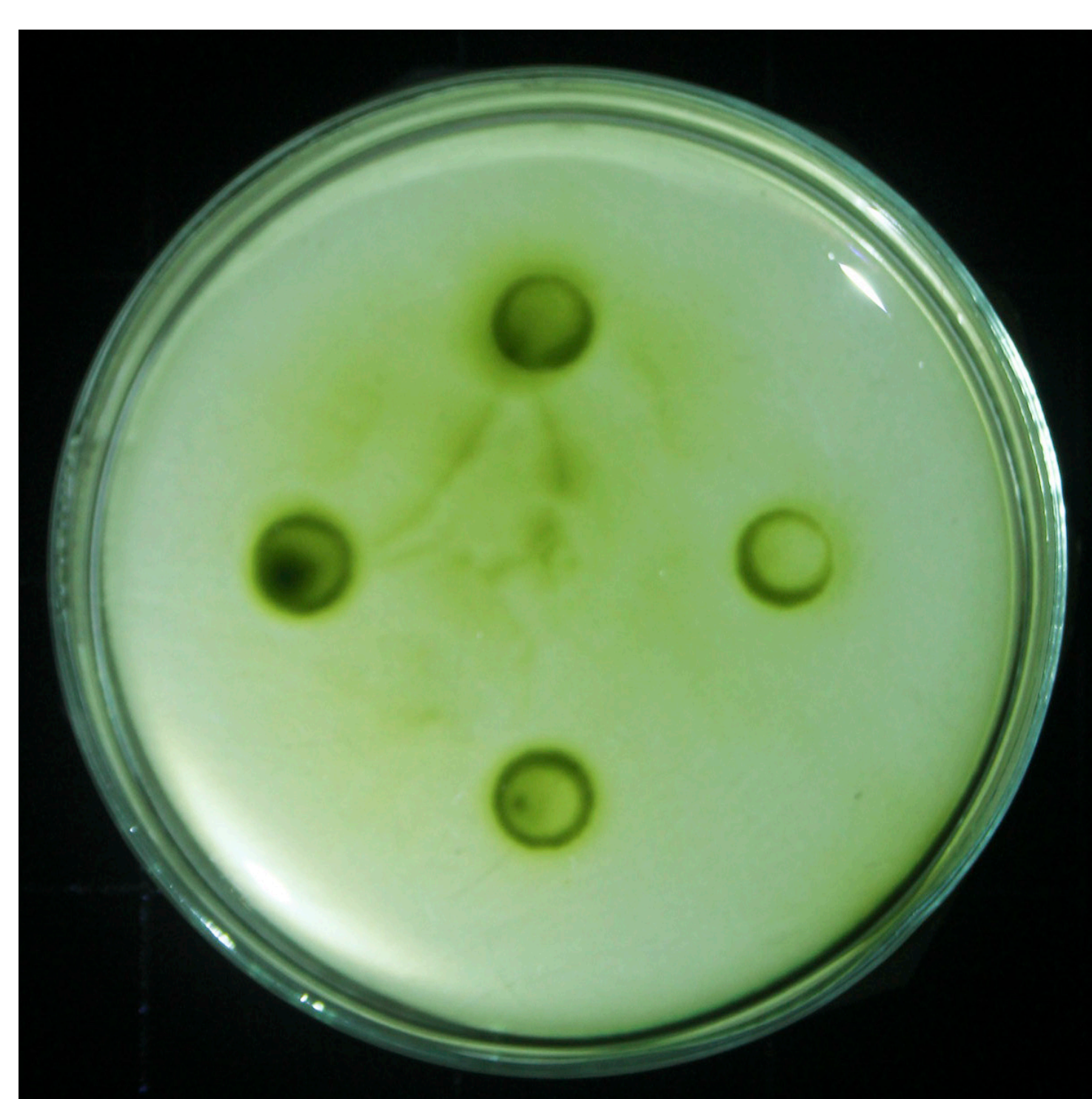
Other data from microscope recordings allows to get independent estimations for parameters of the model using single cell trajectories and population dynamics.



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

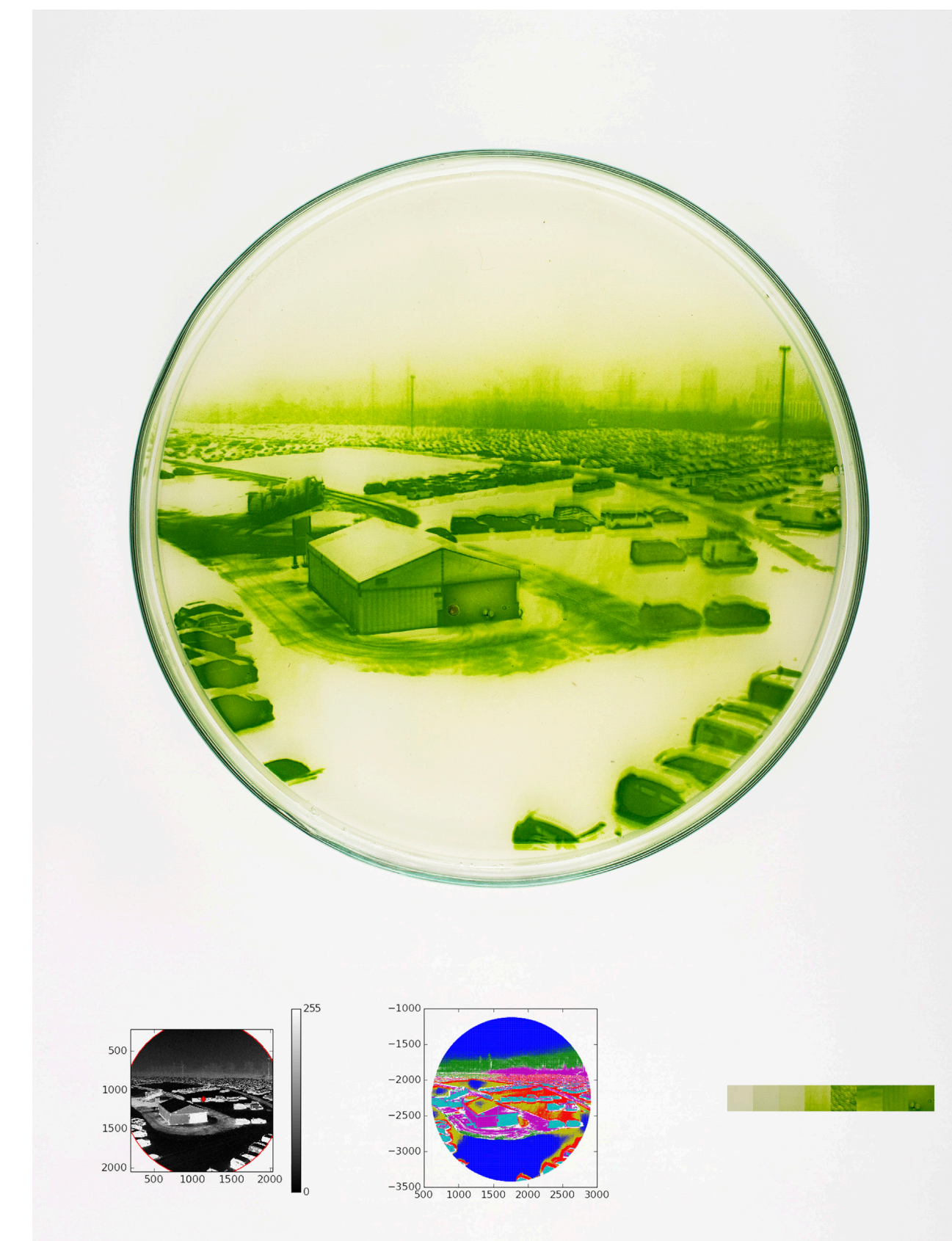
At high density of cells, the interactions between individual behaviours leads to specific patterns of cell density, as shown here,



which could not be explained if cell trajectories are independent. See also «vortex» in bit.ly/1K7se2a

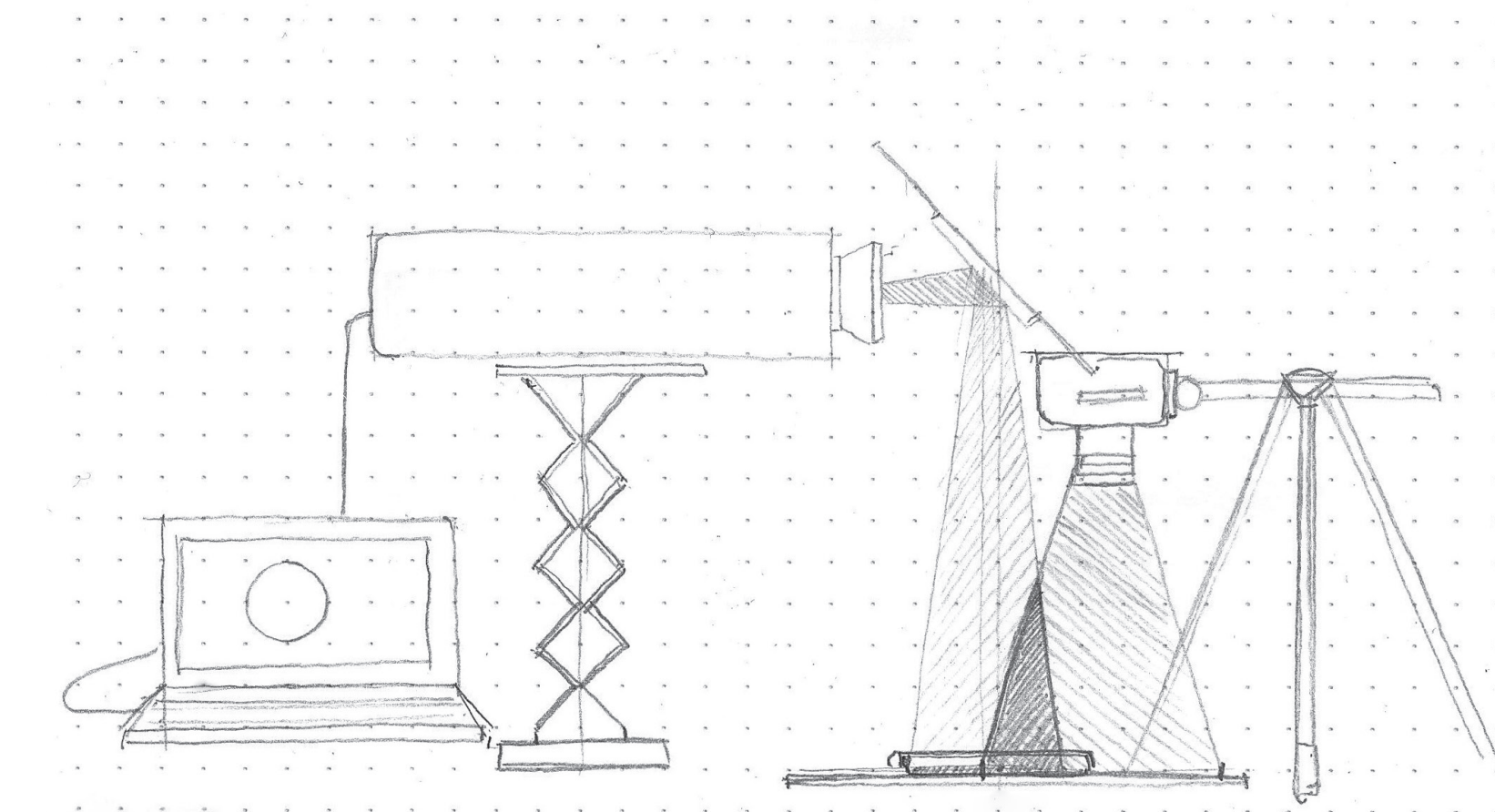


Algaography



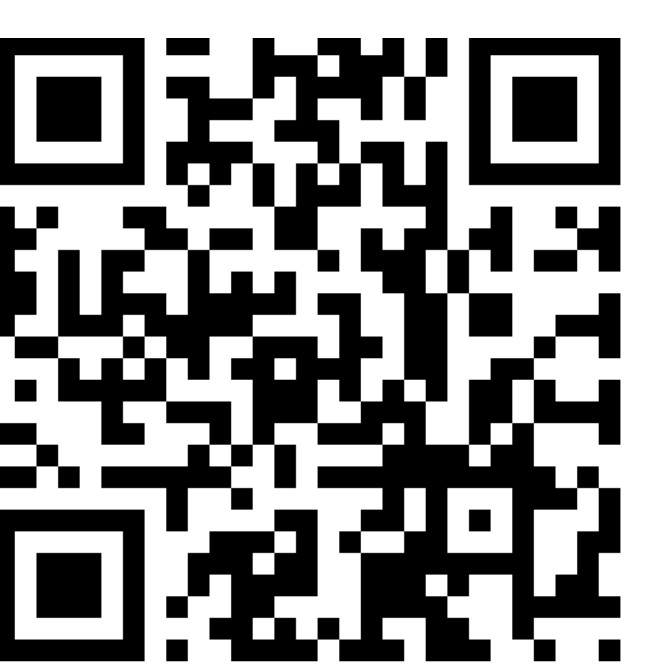
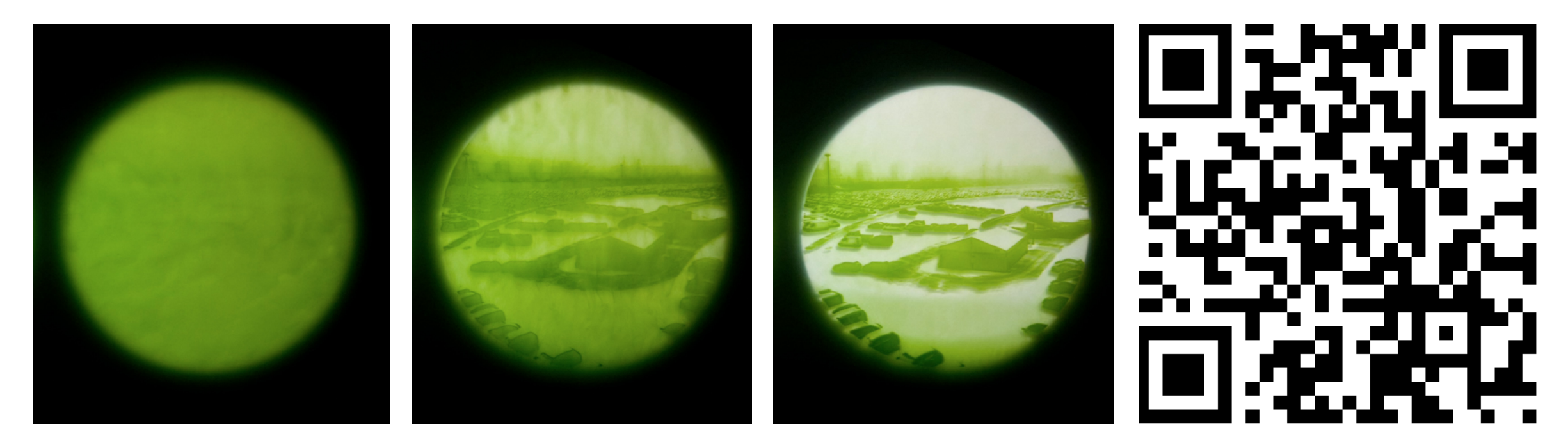
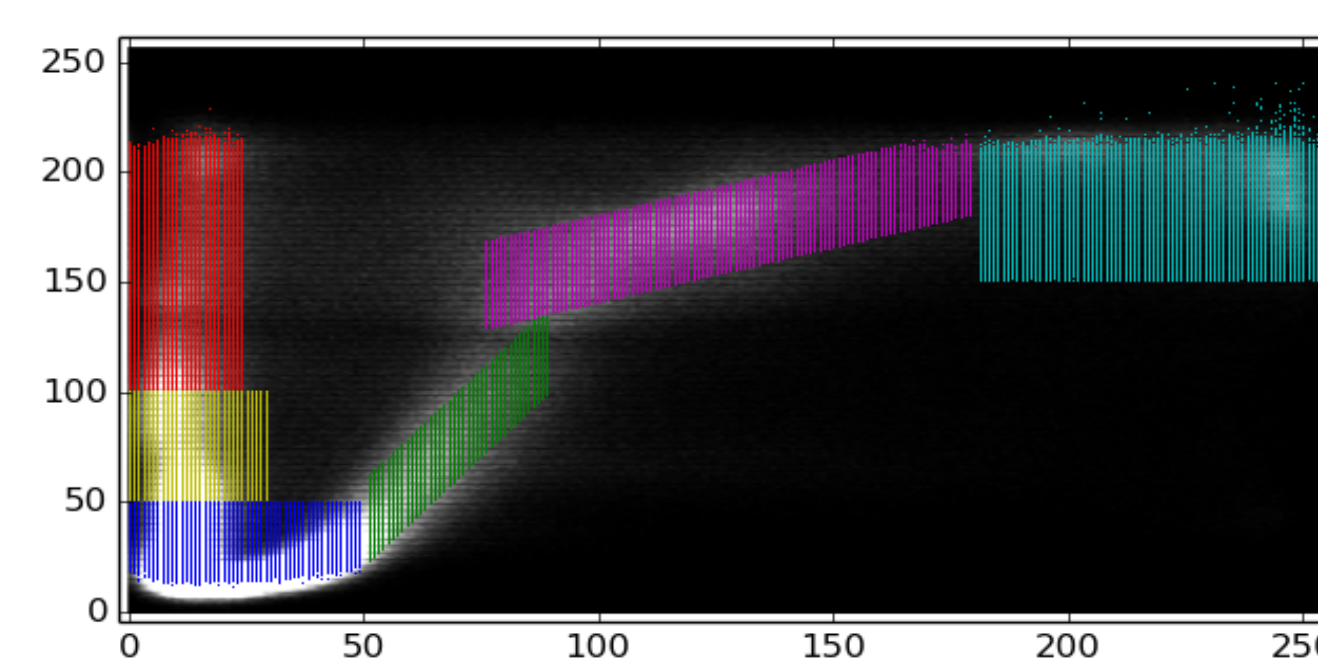
An experimental device from previous artworks by Lia Giraud (below: the sample *Paysage* from *Cultures* and the device *Flasher/Exposer*) created to record the formation of alive images is diverted to investigate the phototaxis of microalgae.

The density of algae depending on the light intensity (right figure) shows saturation at high levels of light intensity (in light blue) and diffusion at low light levels (in yellow).

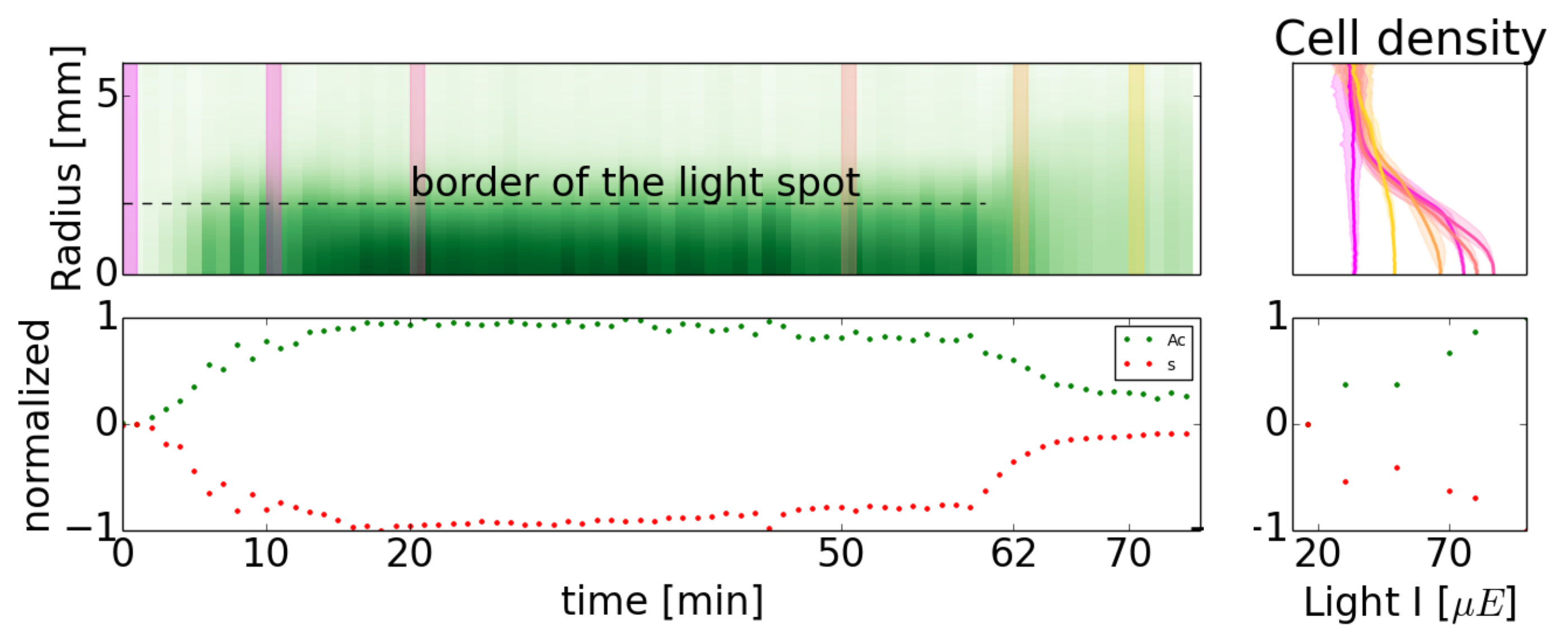


This tool is then extended to characterize the phototaxis of various microalgae species over a range of light intensities.

<https://vimeo.com/107184851>



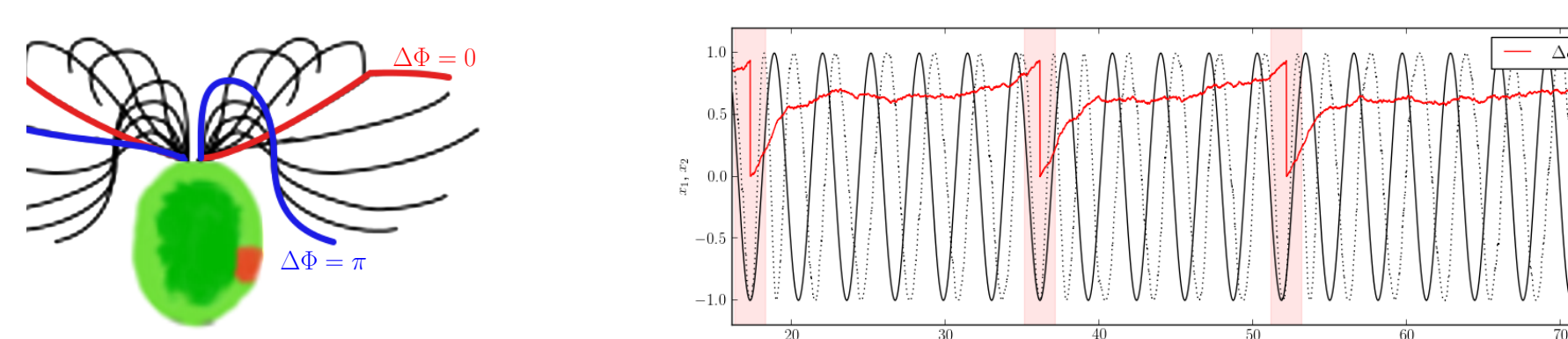
Measures of algae accumulation



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 :

$$d\phi_t = [\Delta\omega + K\sin(\phi_t)]dt + \sigma(I)dW_t$$

With:

- $\Delta\omega$: the difference of beating frequency.
- K : the coupling constant.
- $\sigma(I)$: fluctuations due to the stochasticity of biochemical signals.
- I : Light intensity.

Population dynamics.

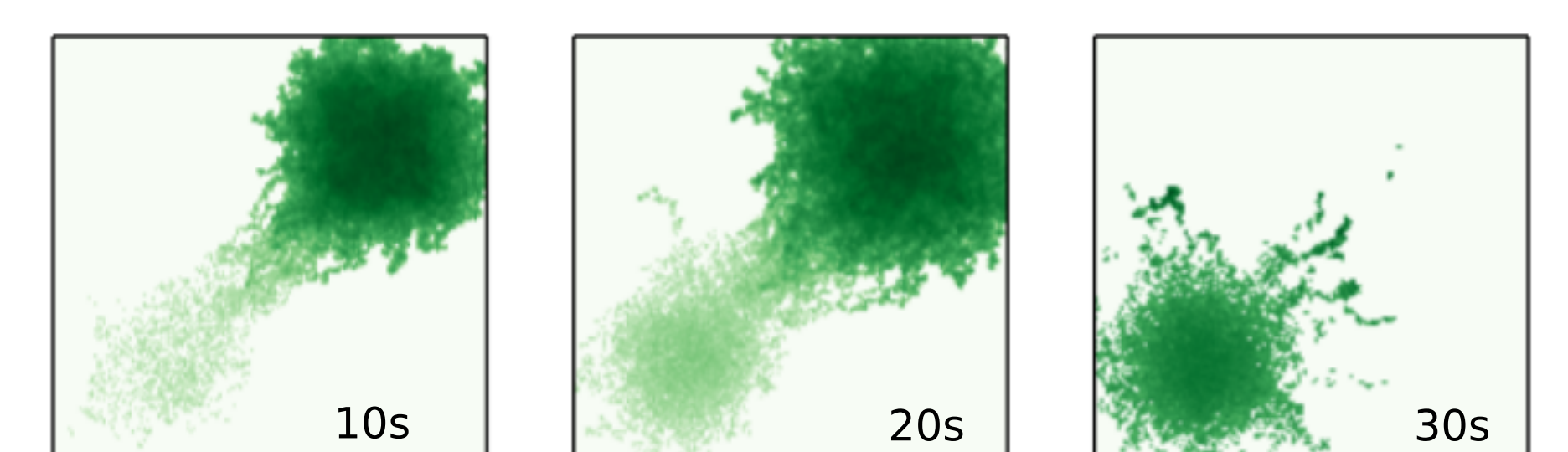
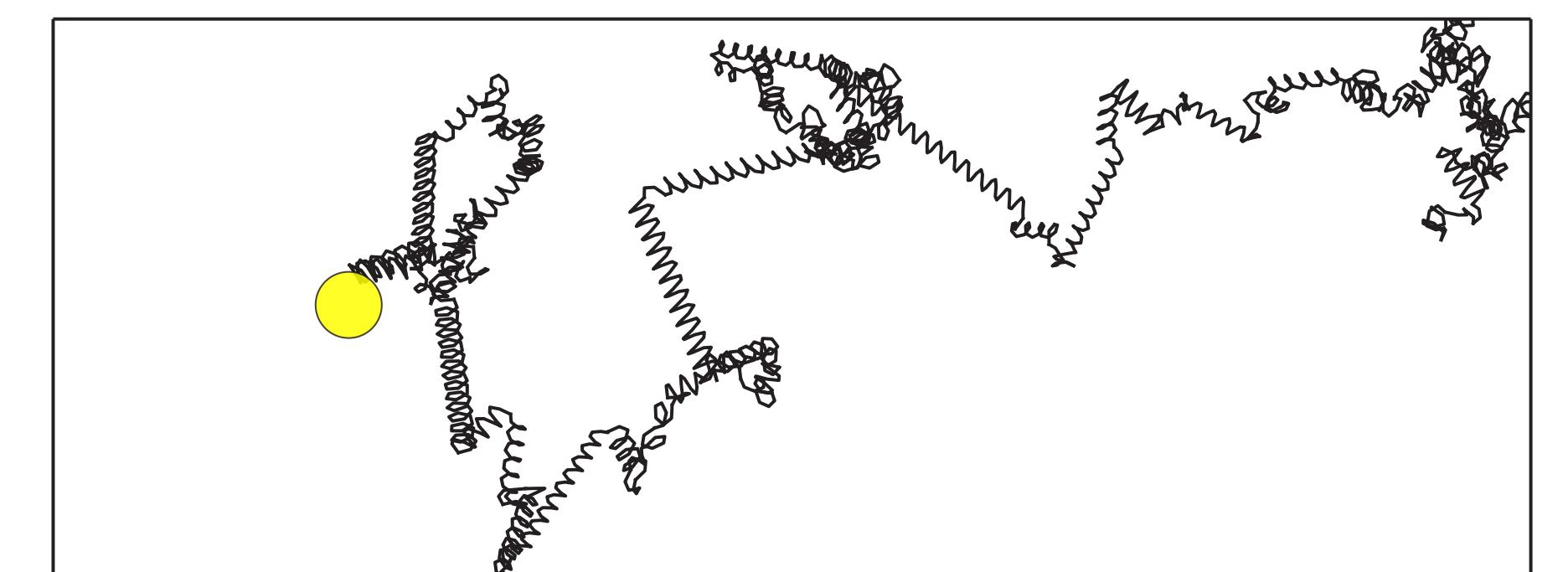
- In the above example, the tumbling rate depends on the distance from the light source l as well as the orientation relative to the light source θ : $r(l, \theta) = \frac{A}{1 + e^{\alpha_1 l - \alpha_2 \cos(\theta) - \beta}}$
- Macro and micro data will give us independent estimations of the diffusion coefficient as well as the dependance of the tumbling rate on the light intensity.

Run and Tumble trajectories

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

$$T \sim \text{Poisson}(r_t)$$

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



References

- [1] Goldstein, Raymond E., Green Algae as Model Organisms for Biological Fluid Dynamics, Annual Review of Fluid Mechanics, 2015.
- [2] Braitenberg, Valentino, Vehicles, Experiments in Synthetic Psychology, MIT Press, 1986.