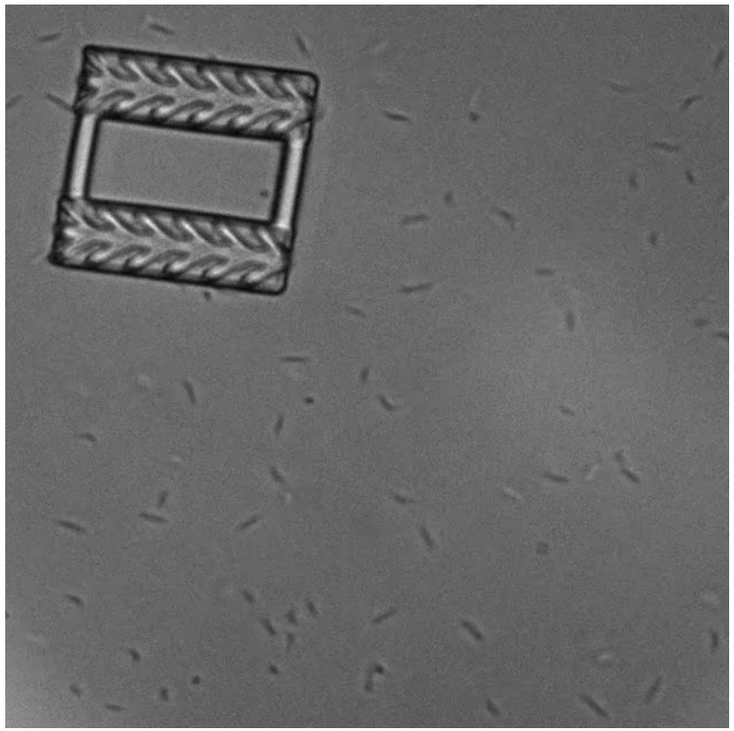
Bio-hybrid micro-shuttles controlled by light patherns



Viridiana Carmona Sosa

Supervisor
Prof. Roberto Di Leonardo

PhD Seminar
May 25th, 2022

DiLeonardoLab

Goal: micromachines for miniaturized labs

Design of autonomous micromachines that can be remotely controlled by light signals to perform tasks inside lab on chips:

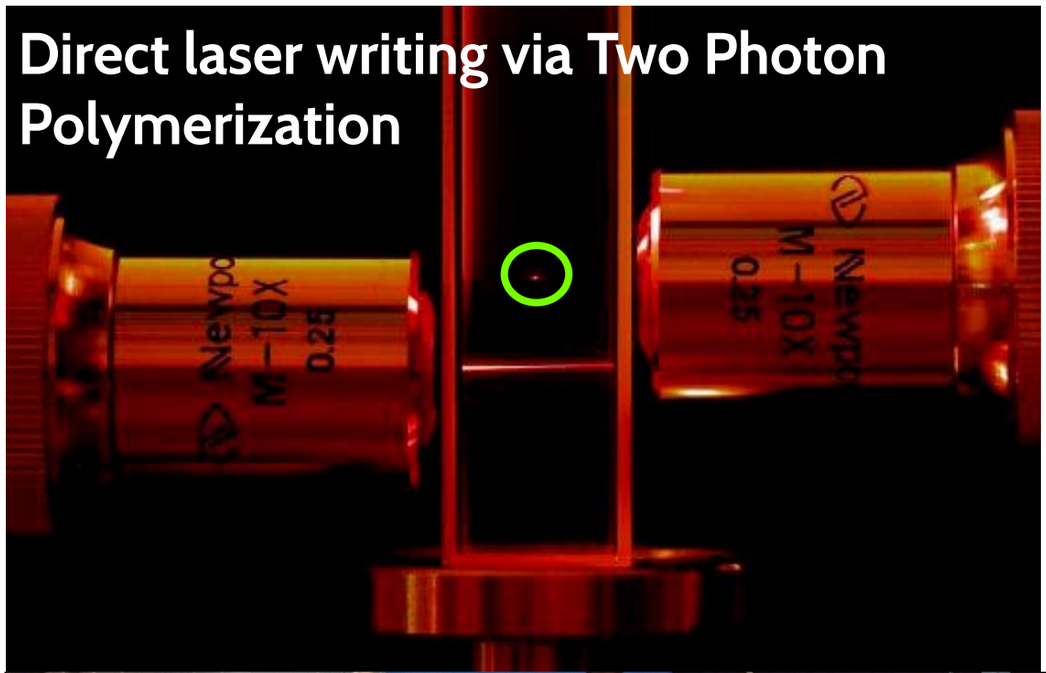
- cell sorting
- targeted cargo delivery

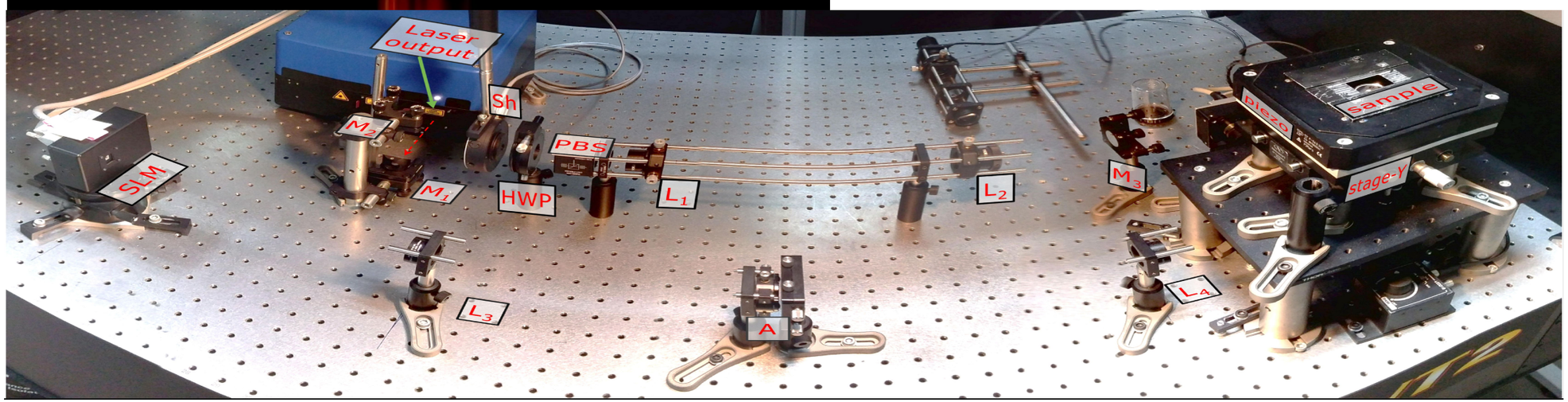
Strategy: biohybrid micromachines

1. Use direct laser writing to fabricate a passive 3D chassis

2. Use genetically modified bacteria as biological propelling units

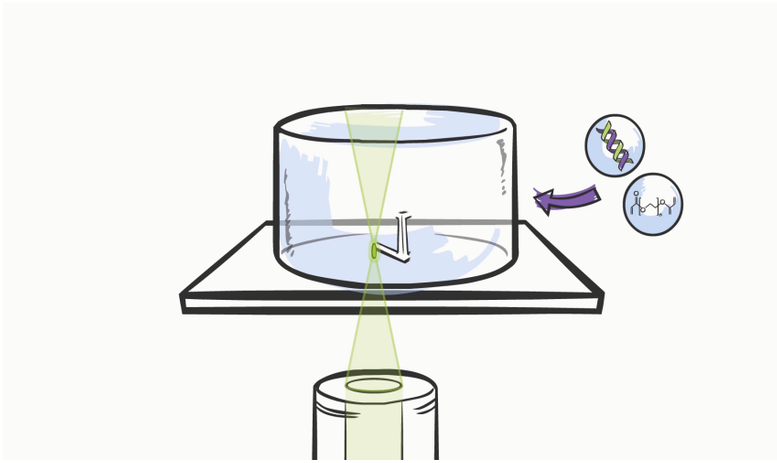
Direct laser writing via Two Photon Polymerization

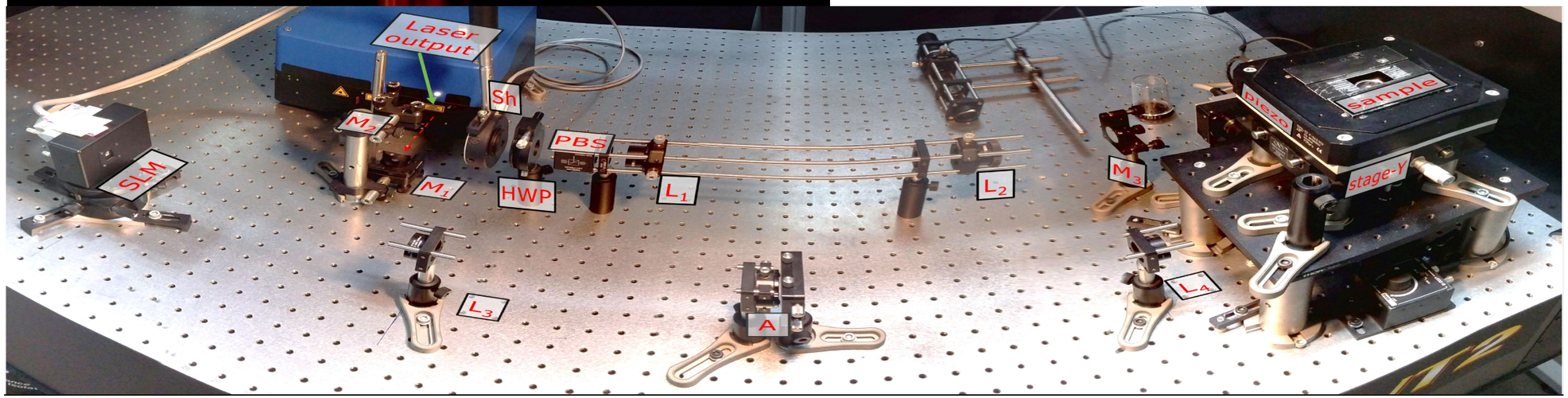




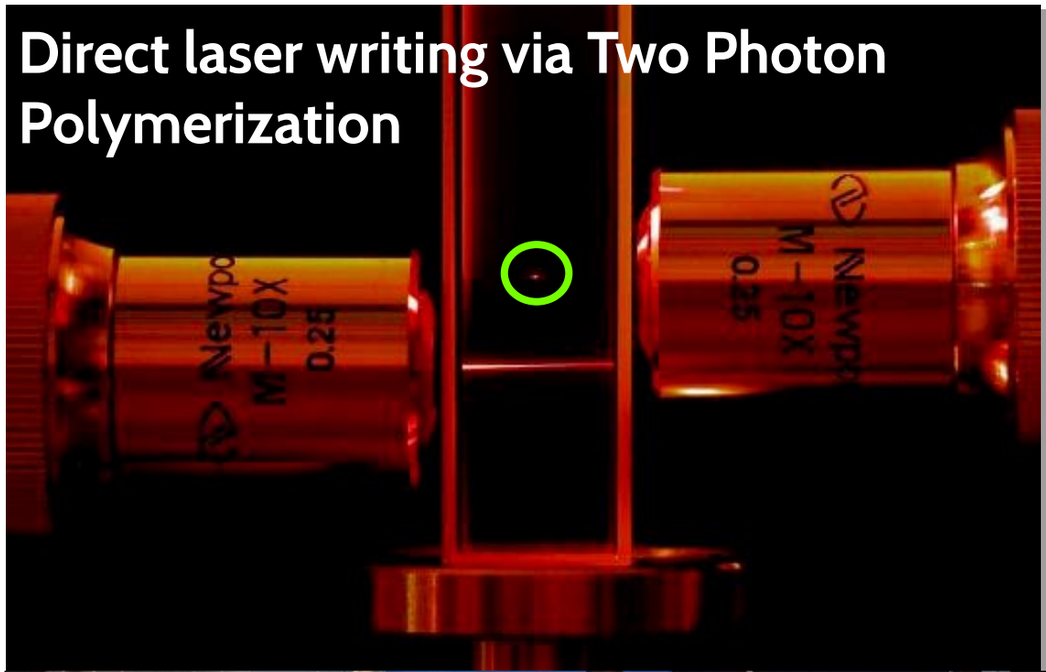
Direct laser writing via Two Photon Polymerization

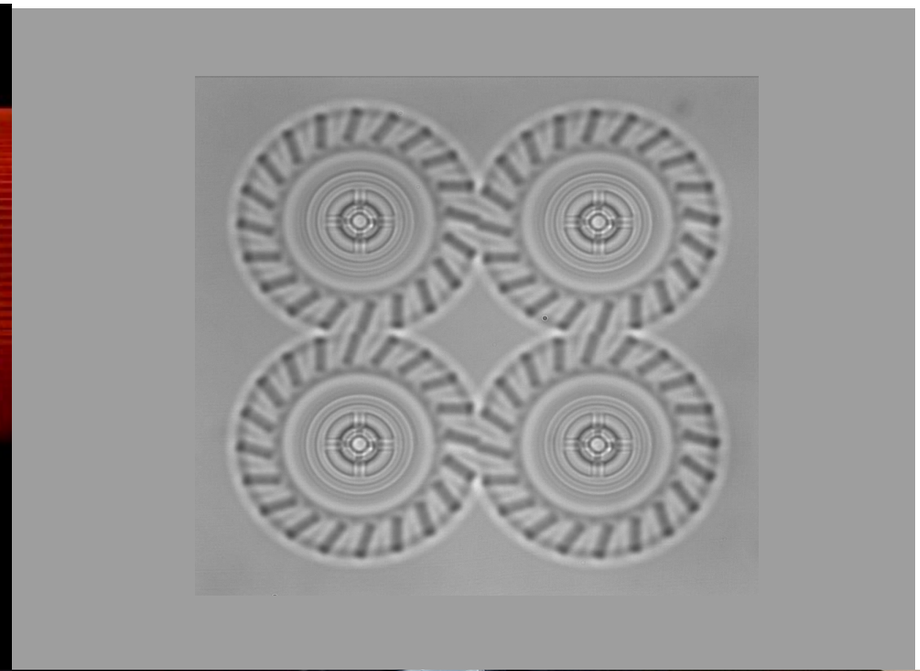
www.microlight.fr/TPP.html

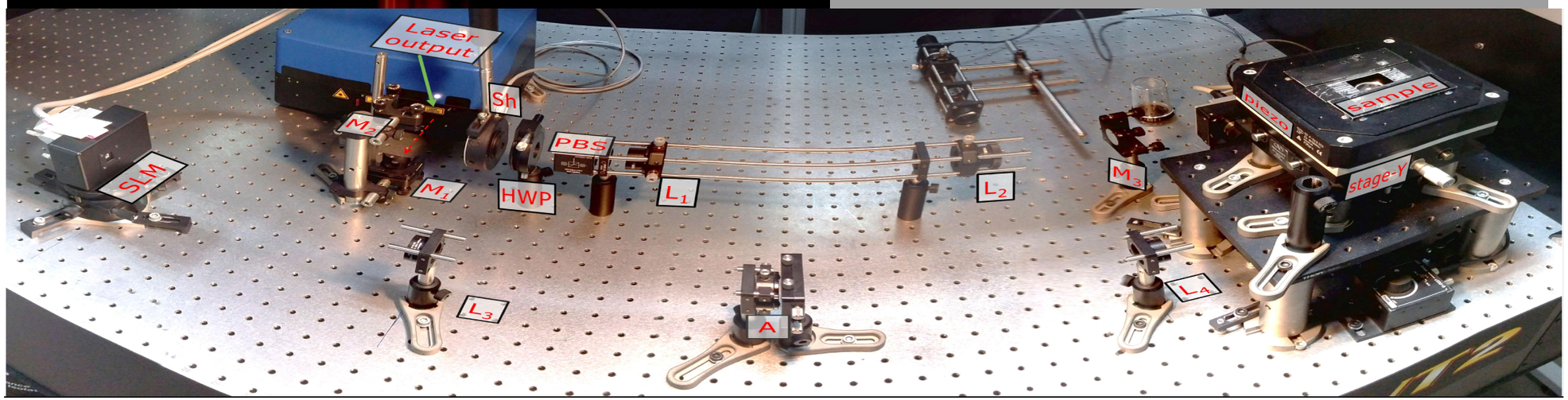




Direct laser writing via Two Photon Polymerization



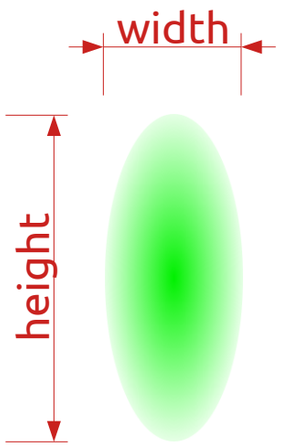




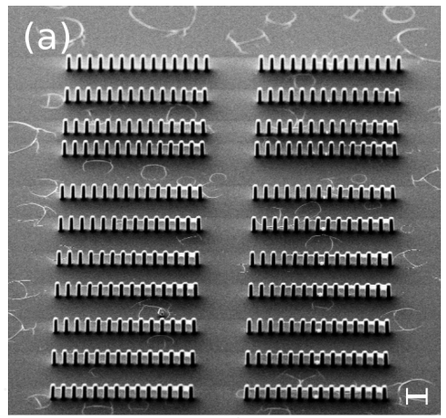
Experimental characterization of voxel size for TPP

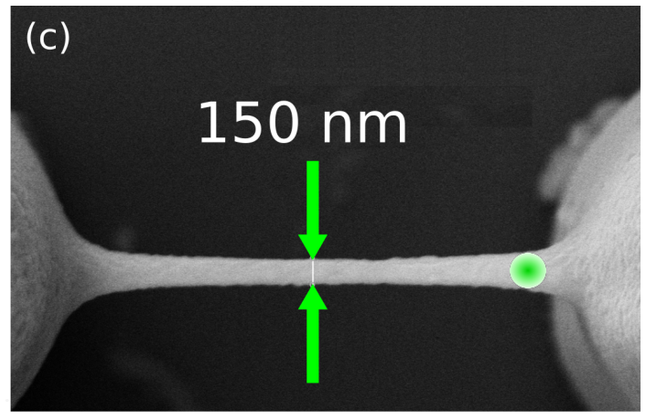
Laser power = 2.5 mW
Scanning speed = 6 µm/s

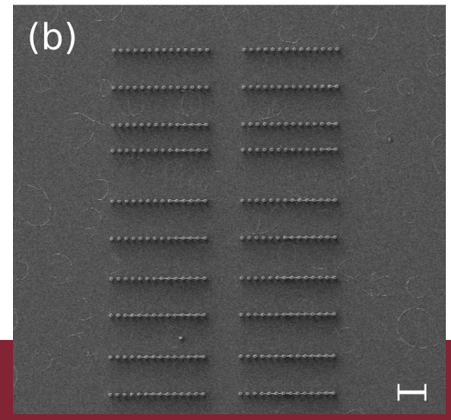
Complex micro and nanostructures require the characterization of the dimensions of the smallest unit of solidified polymer formed in the focal point:

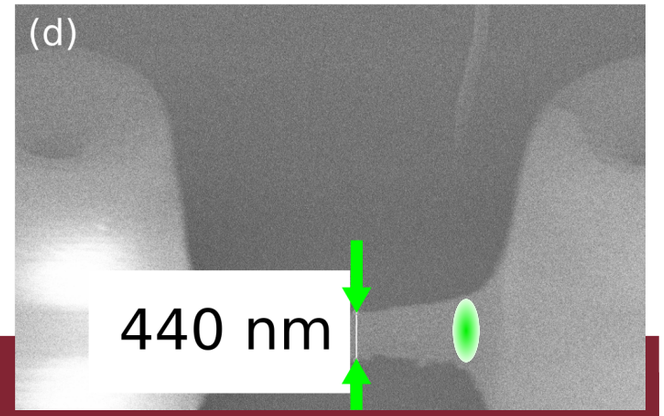


voxel (volumetric pixel)









Experimental characterization of voxel size for TPP

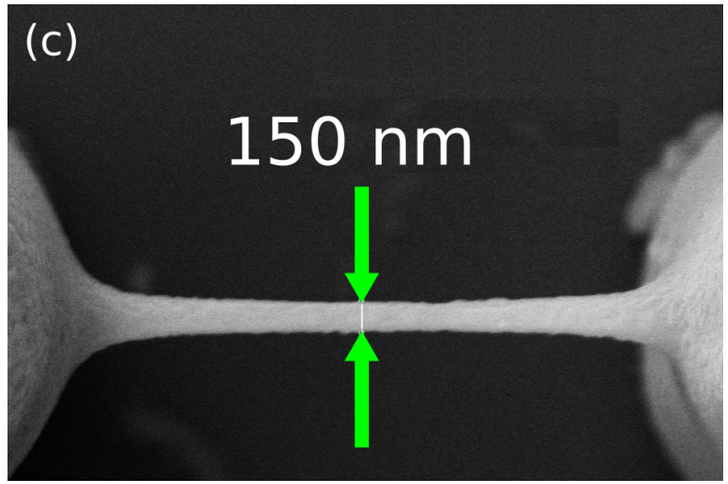
Rate of density of radicals → $\frac{d\rho}{dt} = \alpha I^2(x,y,z)$

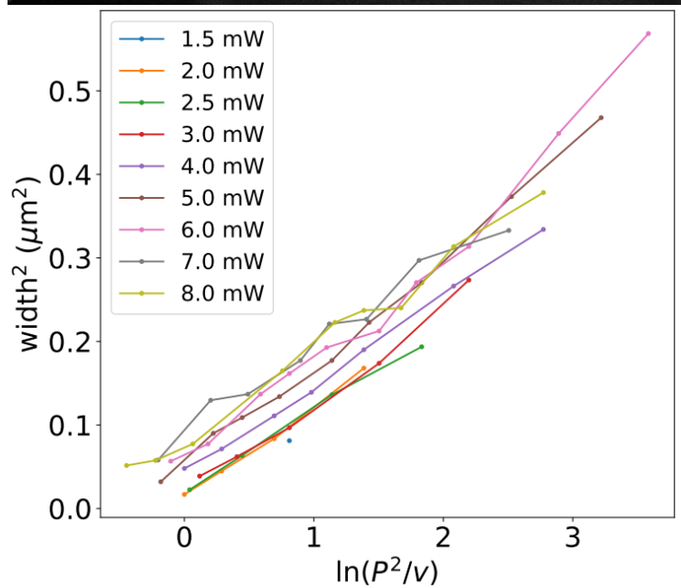
Intensity Gaussian beam → $I(x,y,z) = I_0\left(\frac{W_0}{W(z)}\right)^2 e^{\frac{-2(x^2+y^2)}{W^2(z)}}$

$$\rho(y,z) = \int_{-\infty}^{\infty} \frac{d\rho}{dt} dt = \int_{-\infty}^{\infty} \alpha I^2(x-vt,y,z)$$

$$\rho(y,z) > \rho^* \quad , \qquad z = 0$$

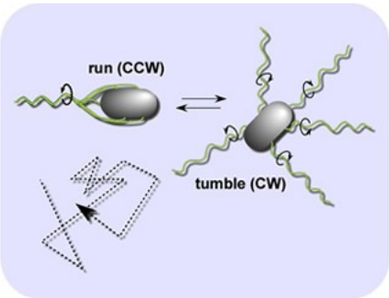
$$\left(\frac{\Delta x}{\sigma}\right)^2 = m_x \ln\left(\frac{P^2}{v}\right) + b$$





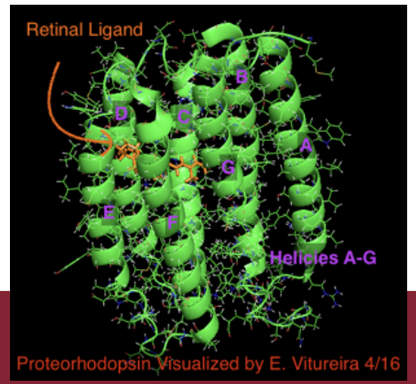
Genetic engineering of bacterial propellers

Genetic engineering of bacteria allows to design optimized strains for their use as biological propellers:



By deleting chemotaxis genes tumbling can be suppressed leading to smooth swimming behavior

BÈJÁ et al. SCIENCE (2000)

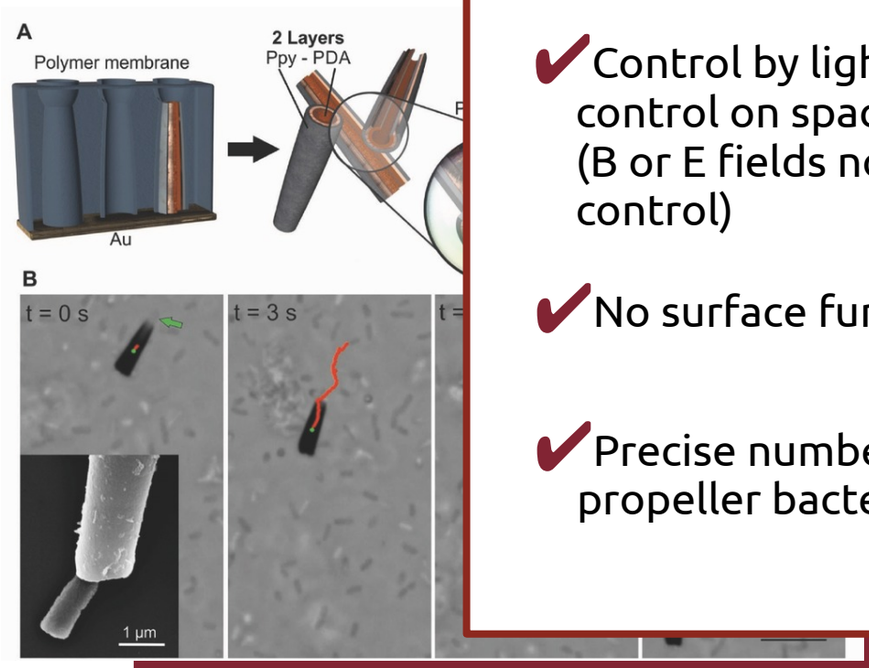


Expression of membrane proteins acting as light driven pumps, allows precise and fast modulation of swimming speed with light

Biohybrid microrobots

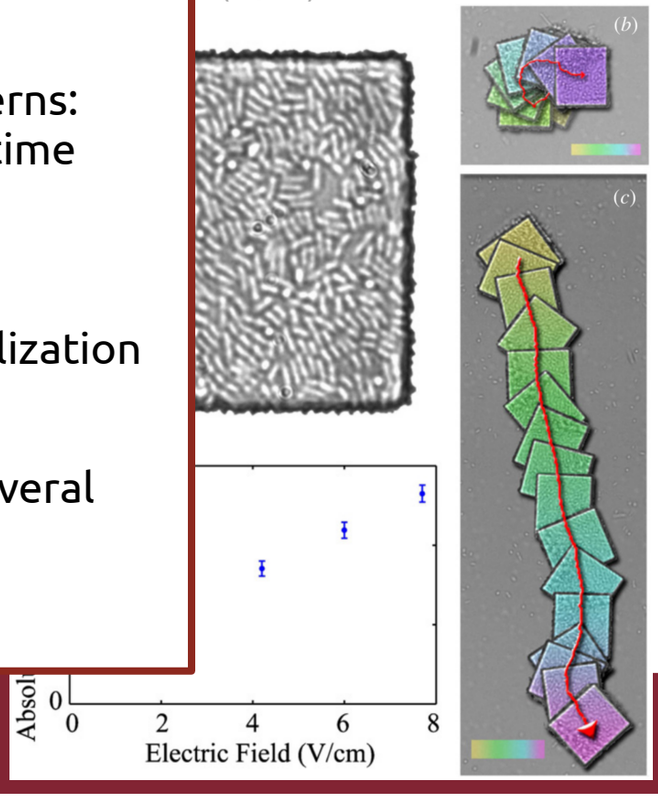
Combination of single cells or a film of cells and synthetic materials, exploiting the sensing and power capabilities of the cells.

STANTON et al. SMALL (2017)



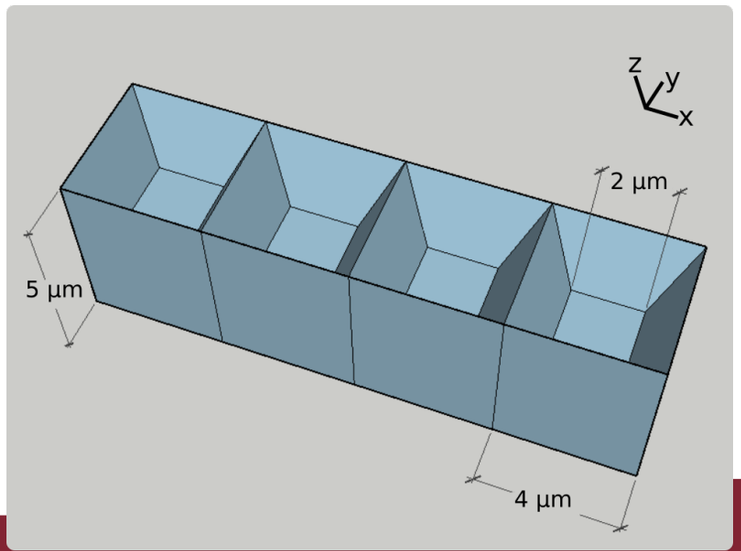
- ✔ Control by light patterns: control on space and time (B or E fields no space control)
- ✔ No surface functionalization
- ✔ Precise number of several propeller bacteria

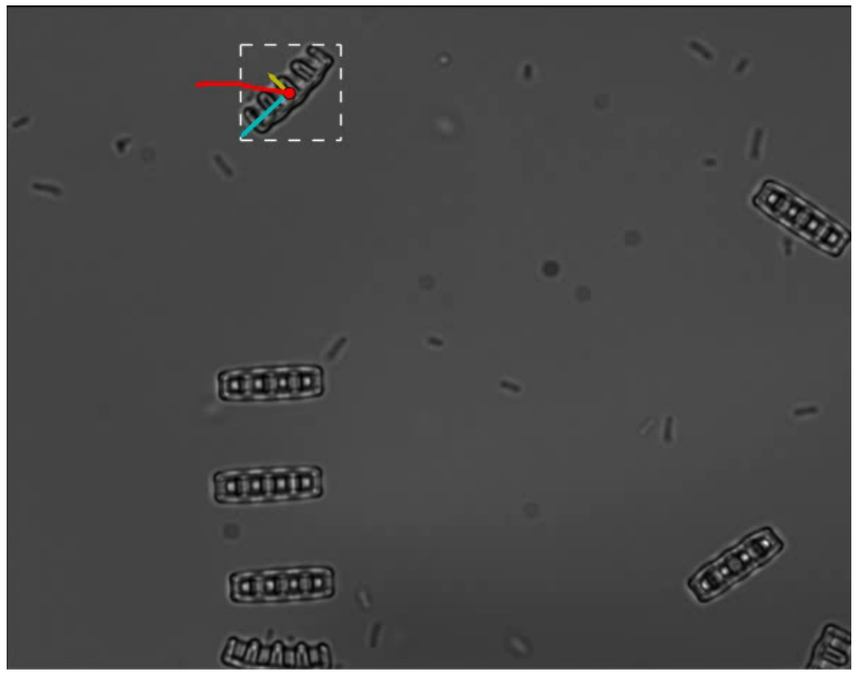
STEAGER et al. J. MICROMECH. MICROENG. (2011)



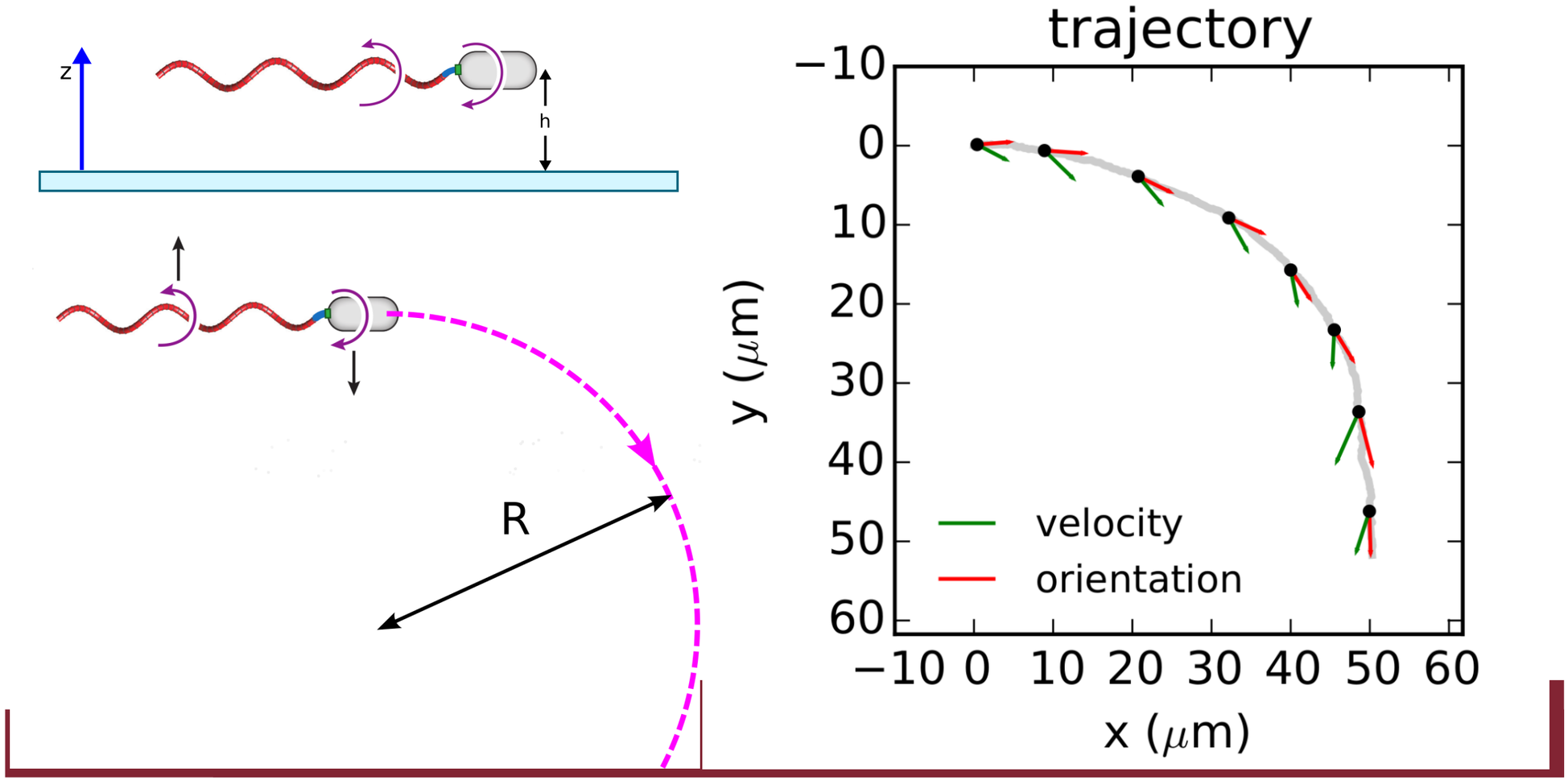
Microshuttles: basic model

First design: a box-type microchamber with enough space for a single bacterium to enter





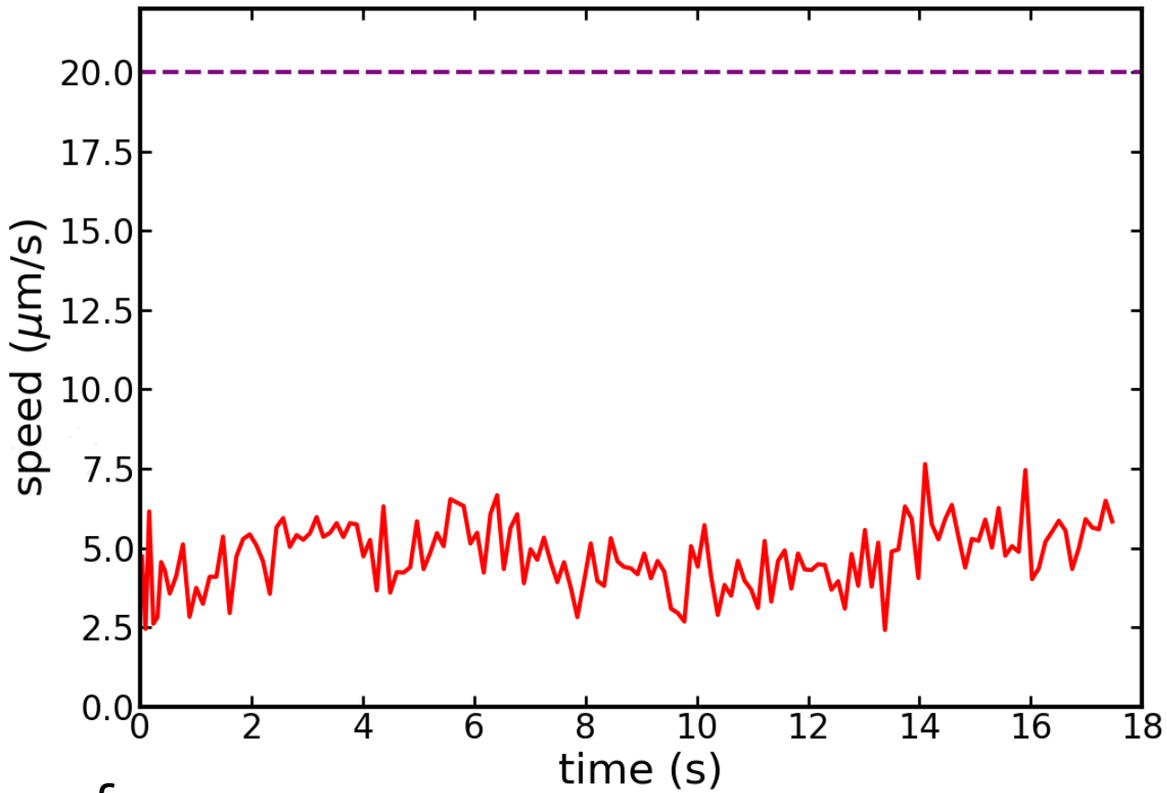
Circular trajectory of bacteria near a surface



Microshuttles: basic model

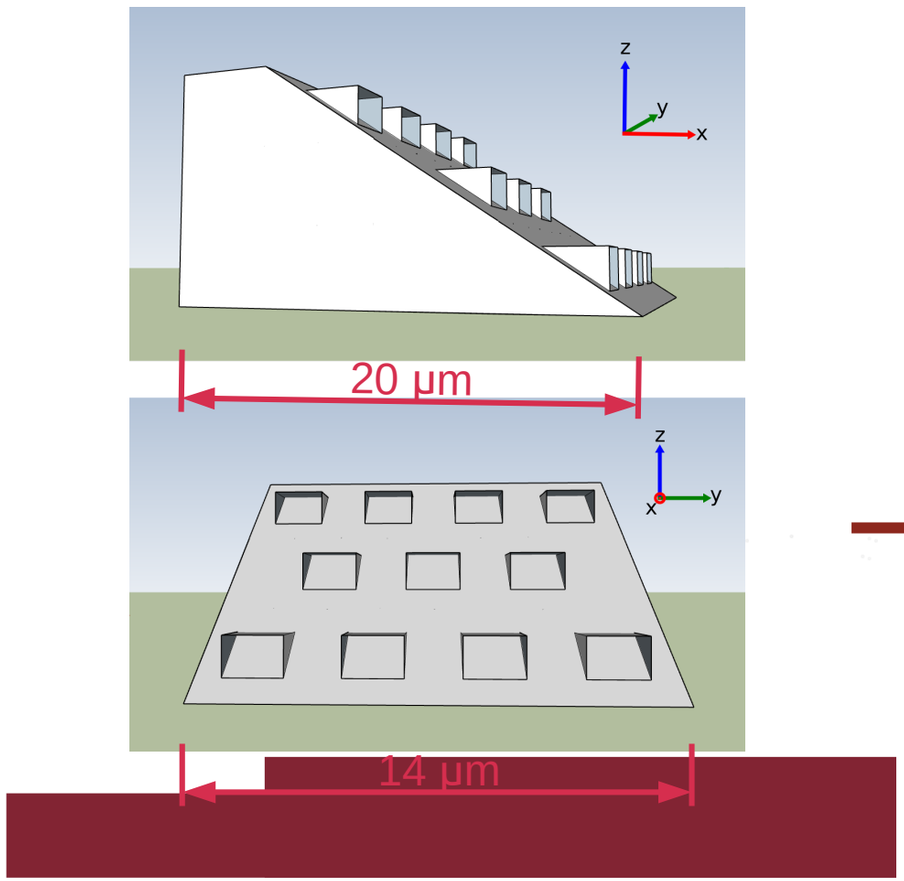
- $|v_{microshuttle}| \sim 5 \frac{\mu m}{s} < |v_{E.\ coli}| \sim 20 \frac{\mu m}{s}$

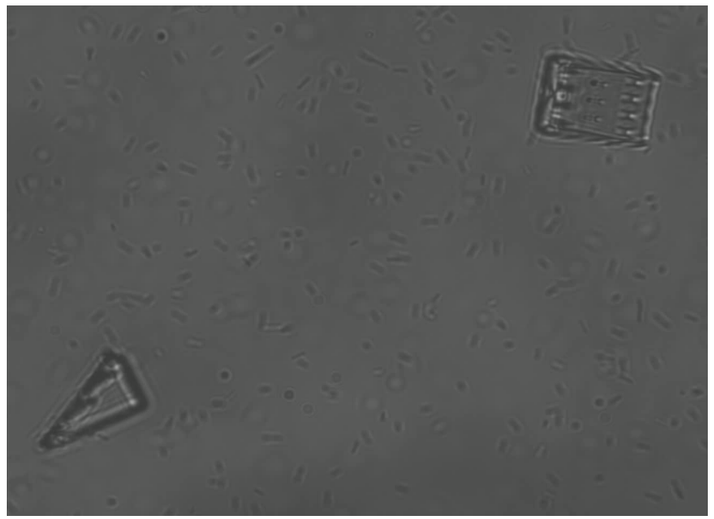
- The circular trajectory hinders an optimal control and steering of the microrobot



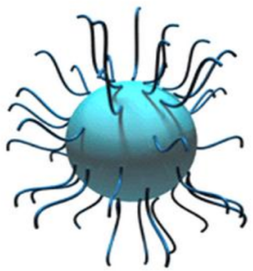
Next step: Increase the number of propeller cells

Microshuttles: implementation of ramps on the robot





Salt in motility buffer



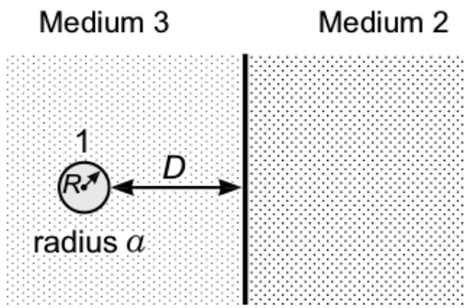
Steric stabilization

Electrostatic stabilization

Adhesion problem

J. N. ISRAELACHILI, INTERMOLECULAR AND SURFACE FORCES , 3RD EDITION, (2011)

Friction and adhesion problem solution: Van der Waals reversal sign



$$F_{Van\ der\ Waals} \propto -A$$

$$A_{\text{total}} = A_{\nu=0} + A_{\nu>0} \approx \frac{3}{4}kT\left(\frac{\varepsilon_1 - \varepsilon_3}{\varepsilon_1 + \varepsilon_3}\right)\left(\frac{\varepsilon_2 - \varepsilon_3}{\varepsilon_2 + \varepsilon_3}\right) + \frac{3h\nu_e}{8\sqrt{2}} \frac{(n_1^2 - n_3^2)(n_2^2 - n_3^2)}{(n_1^2 + n_3^2)^{1/2}(n_2^2 + n_3^2)^{1/2}\{(n_1^2 + n_3^2)^{1/2} + (n_2^2 + n_3^2)^{1/2}\}}.$$

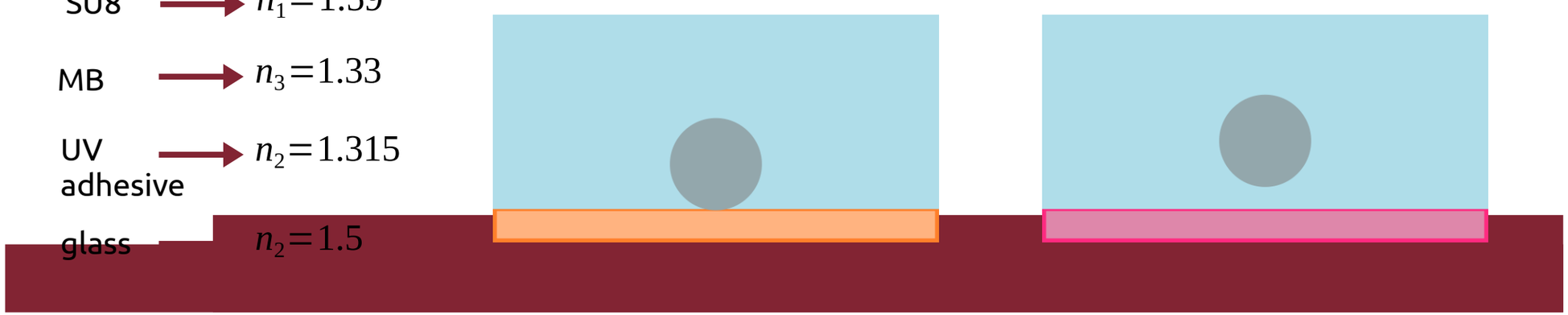
$n_1 > n_3 \wedge n_2 > n_3$ $\qquad$ $n_1 > n_2 > n_3$

SU8 → $n_1 = 1.59$

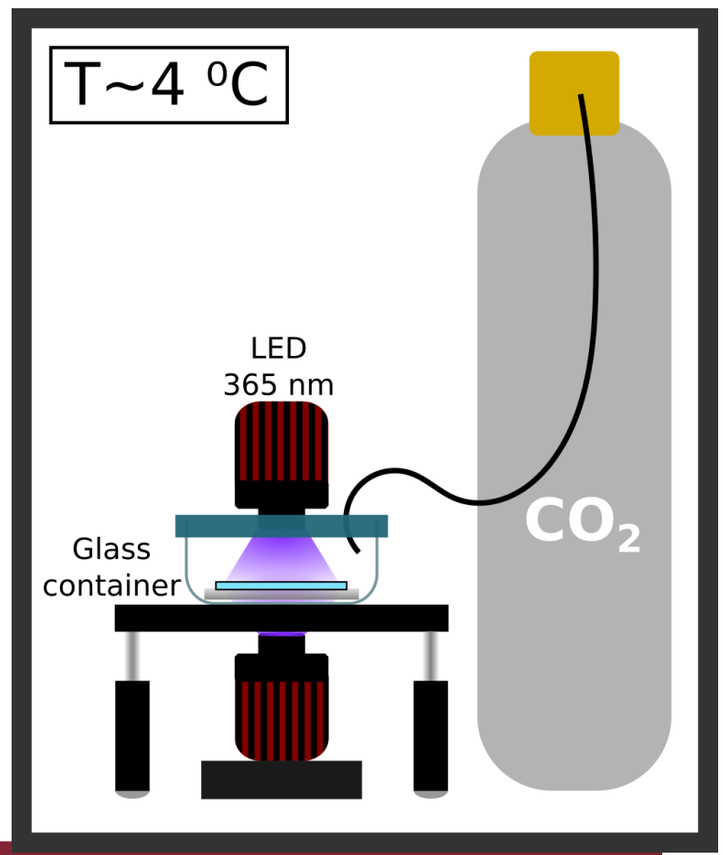
MB → $n_3 = 1.33$

UV adhesive → $n_2 = 1.315$

glass → $n_2 = 1.5$



Van der Waals reversal sign approach

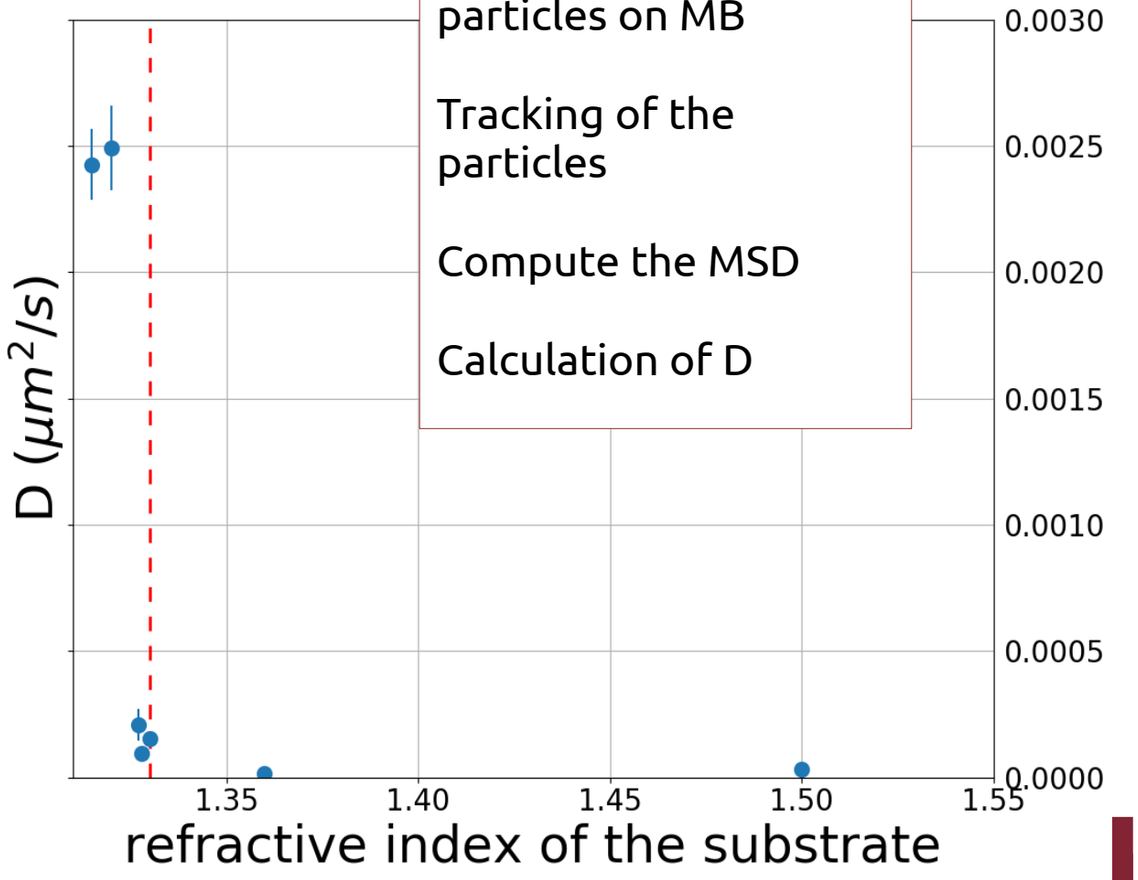


Video of 10 µm PS particles on MB

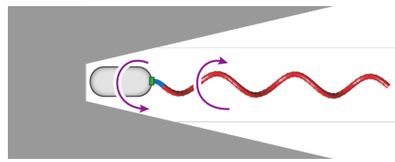
Tracking of the particles

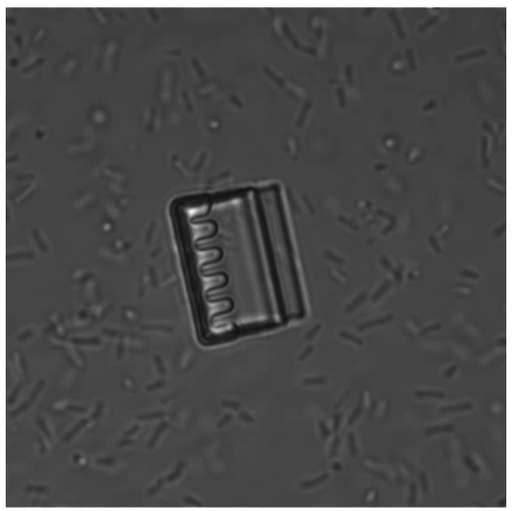
Compute the MSD

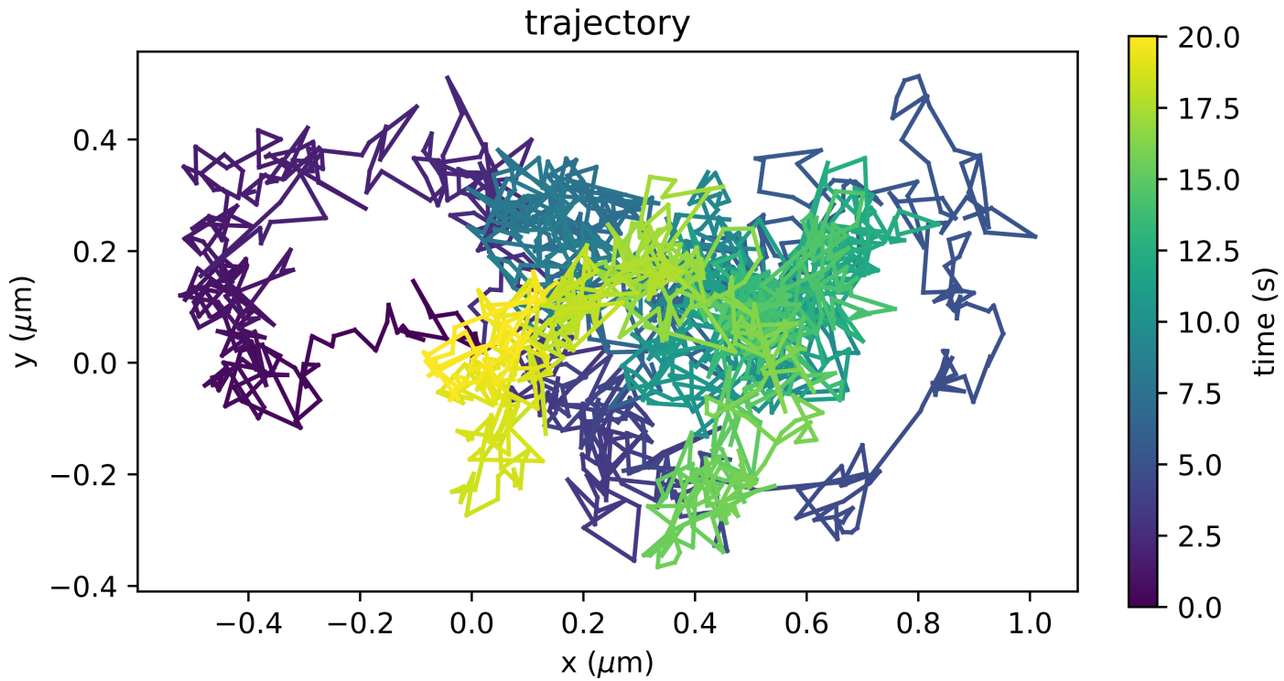
Calculation of D



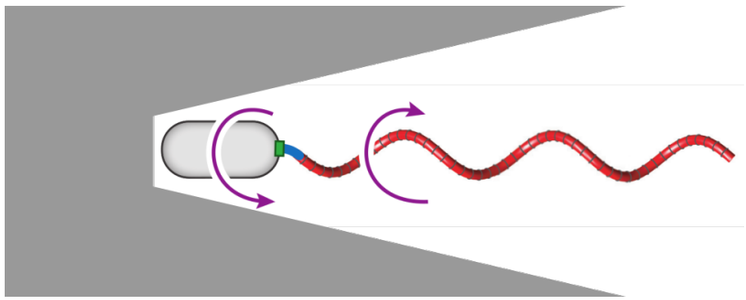
Microshuttle: symmetrical model

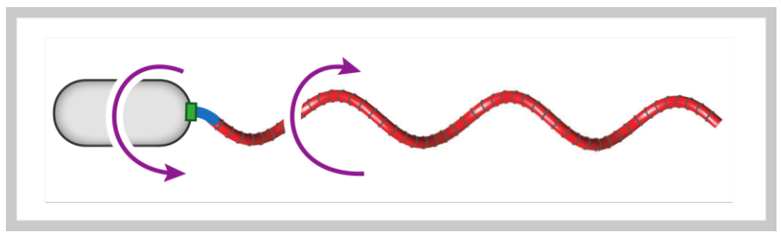




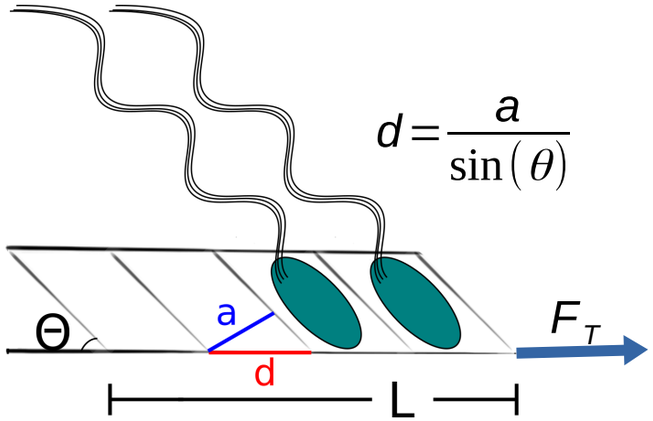


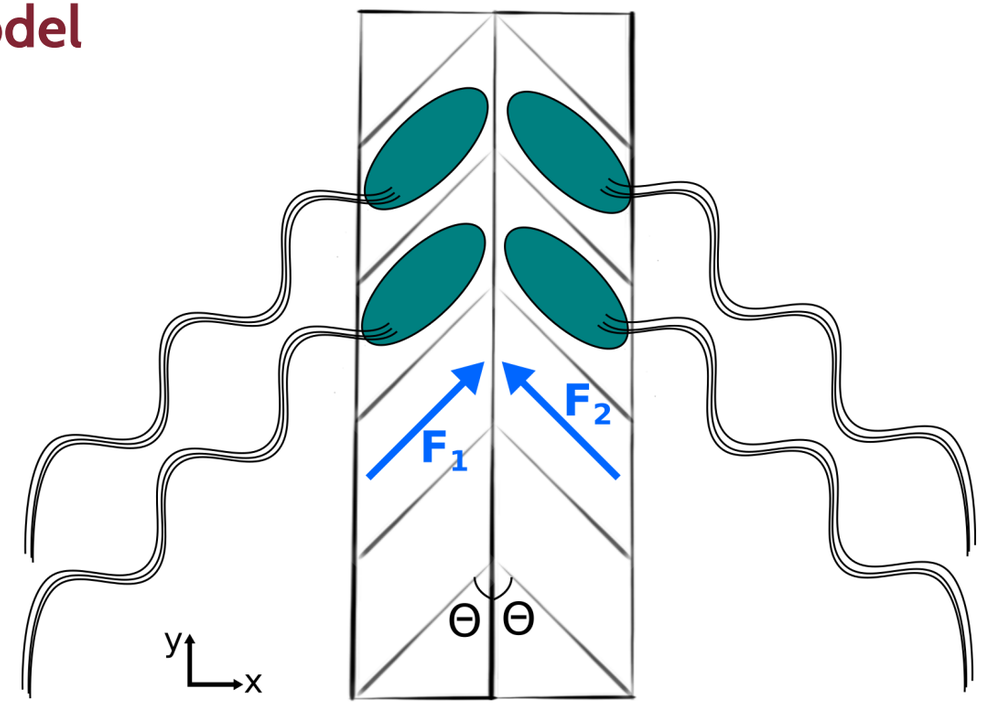
Bundle contained inside de microstructure





Steering microrobot: catamaran model





F_T for N bacteria arranged at Θ

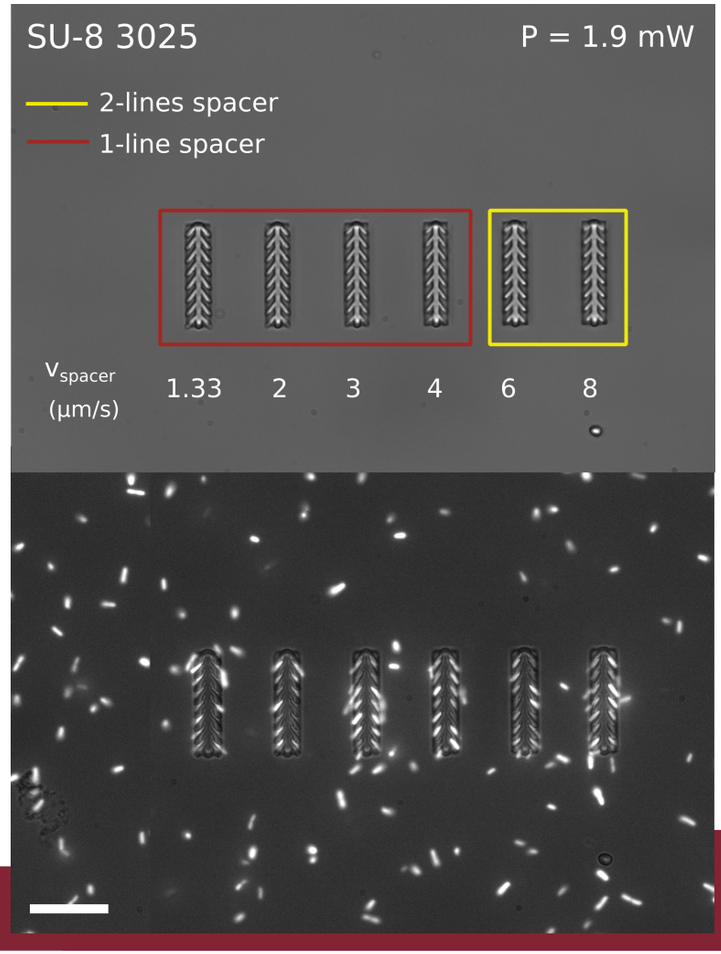
$$F_T = N\, f_{bacterium} \cos(\theta)$$

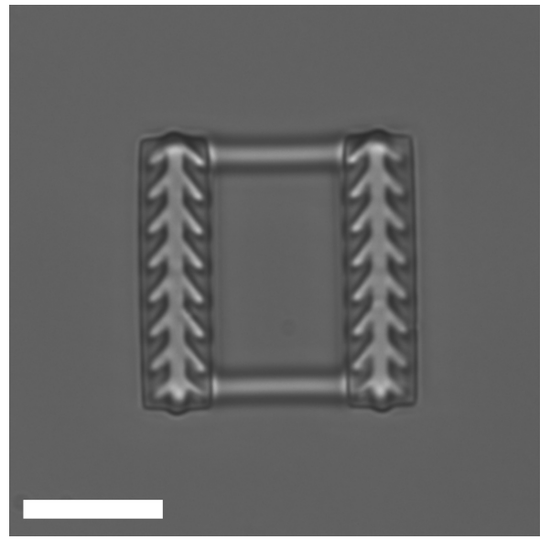
$$= \frac{L}{d} f_{bacterium} \cos(\theta)$$

$$= \frac{f_{bacterium} L}{a} \cos(\theta)\sin(\theta)$$

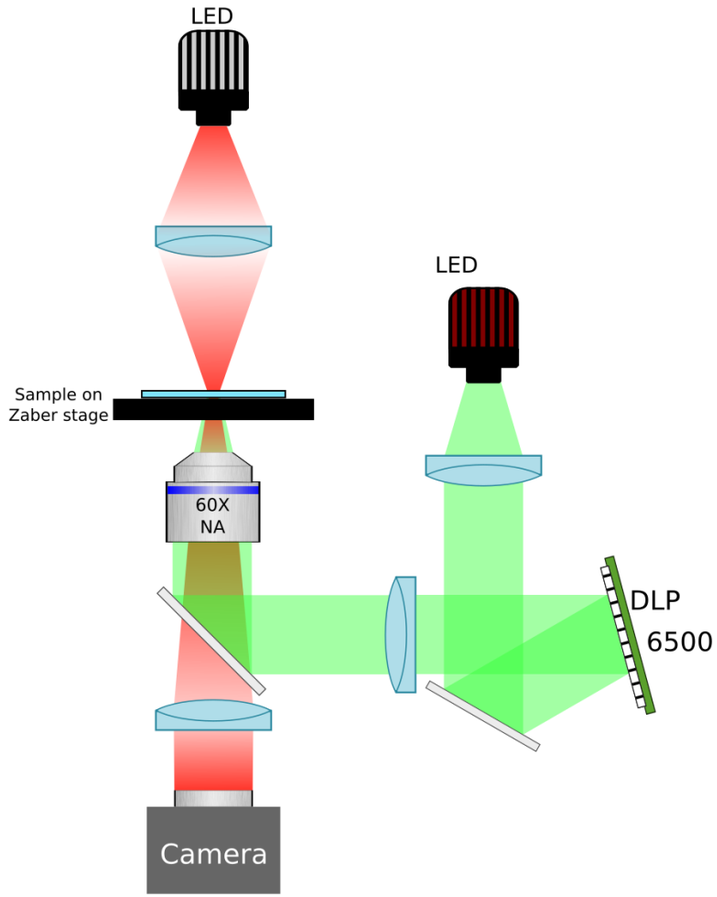
The maximum value of F_T is obtained for Θ = 45˚.

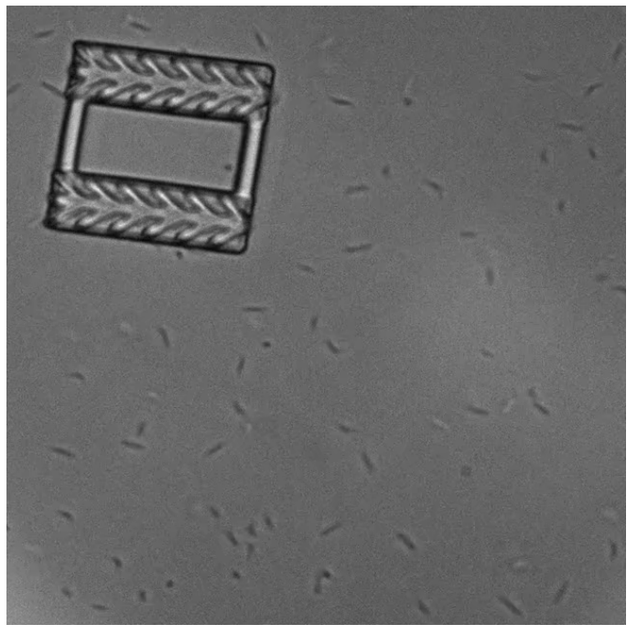
Characterization of the internal spacer microshuttle



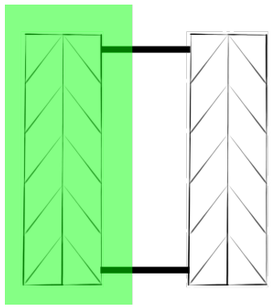


Steering microrobot: catamaran model



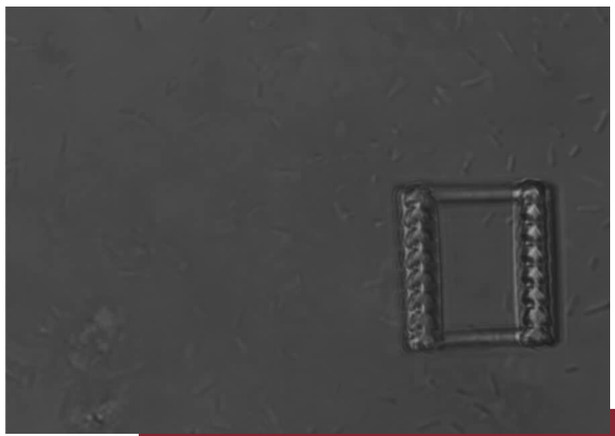


Steering microrobot by light patterns

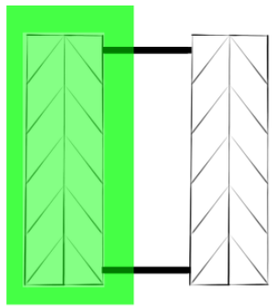


Right turn

3x

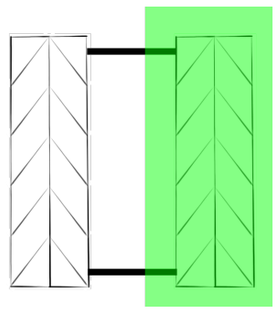


Steering microrobot by light patterns



Right turn

Left turn



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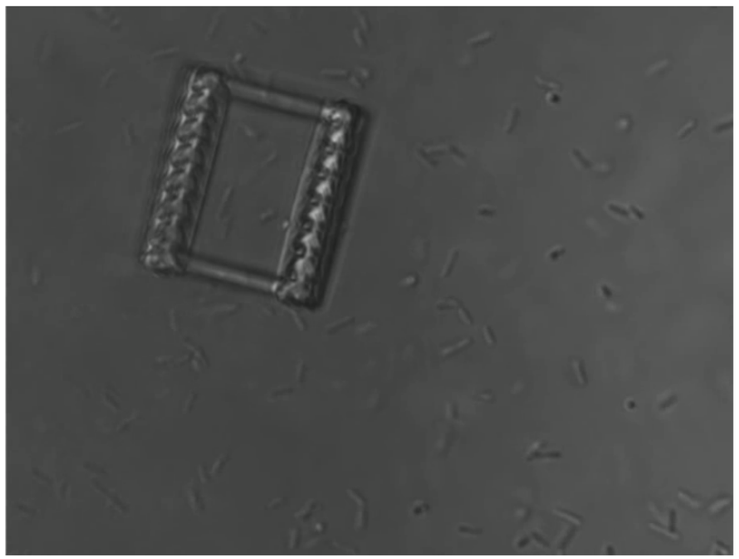

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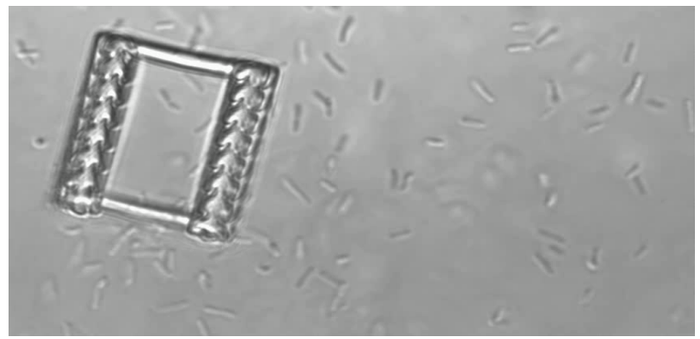
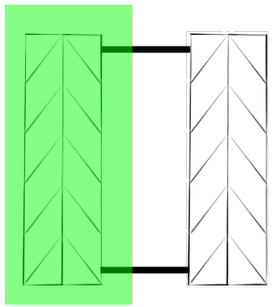
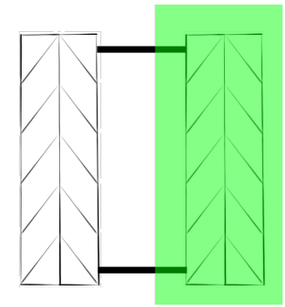


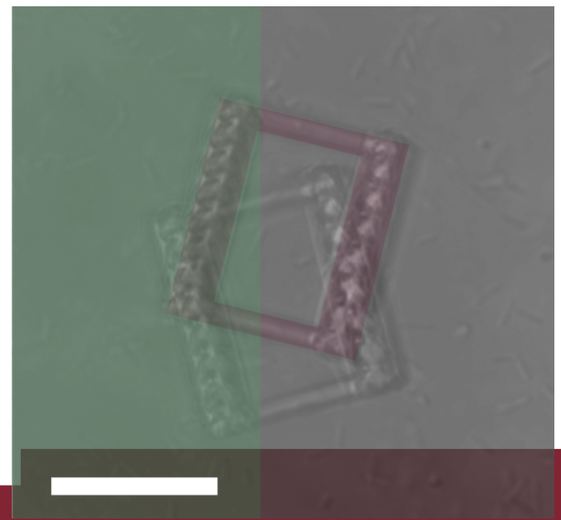
Steering microrobot by light patterns

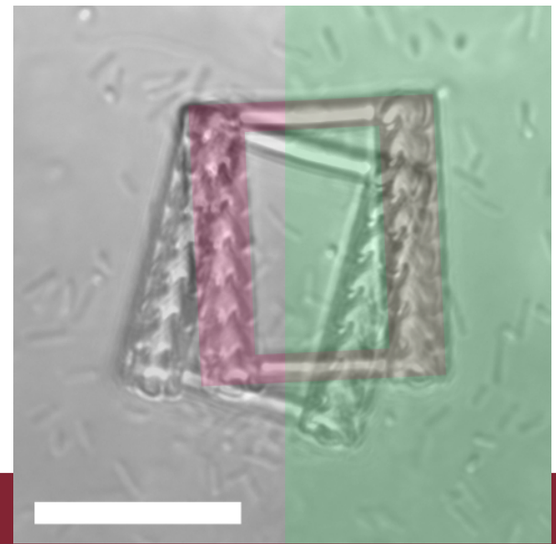


Right turn

Left turn







Conclusions and Perspectives

✔ Control and steering of a biohybrid microrobot by light patterns

✔

✔