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DYNAMICS SLOWDOWN DURING EARLY STAGES OF BACTERIAL COLONISATION

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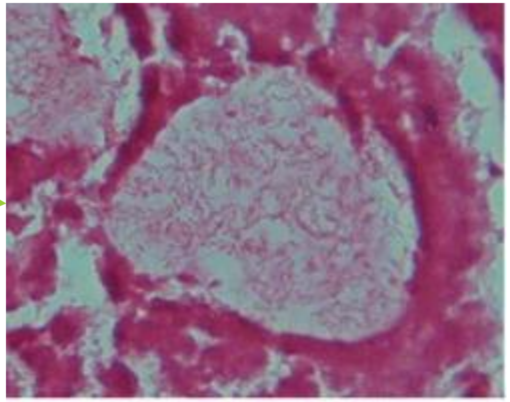
MICRO-ORGANISMS SURFACE INTERACTIONS

- Biofouling
- Infections
- Food-processing industry
- Biofuel production

yachting-pages.com



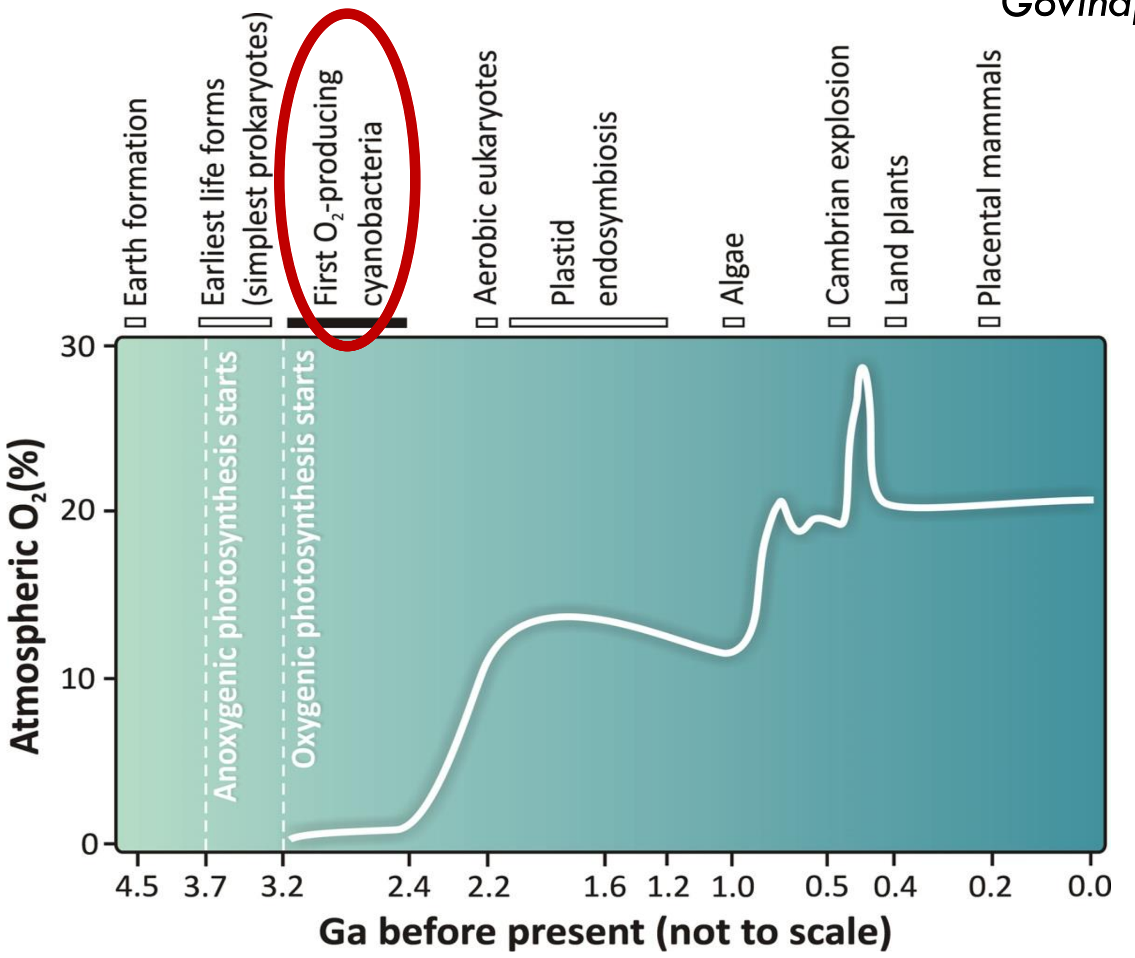
T. Bjarnsholt, 2013

famille-schlegel.com

CYANOBACTERIA: PRIMITIVE ORGANISMS

Govindjee et Dimitriy Shevala, 2011

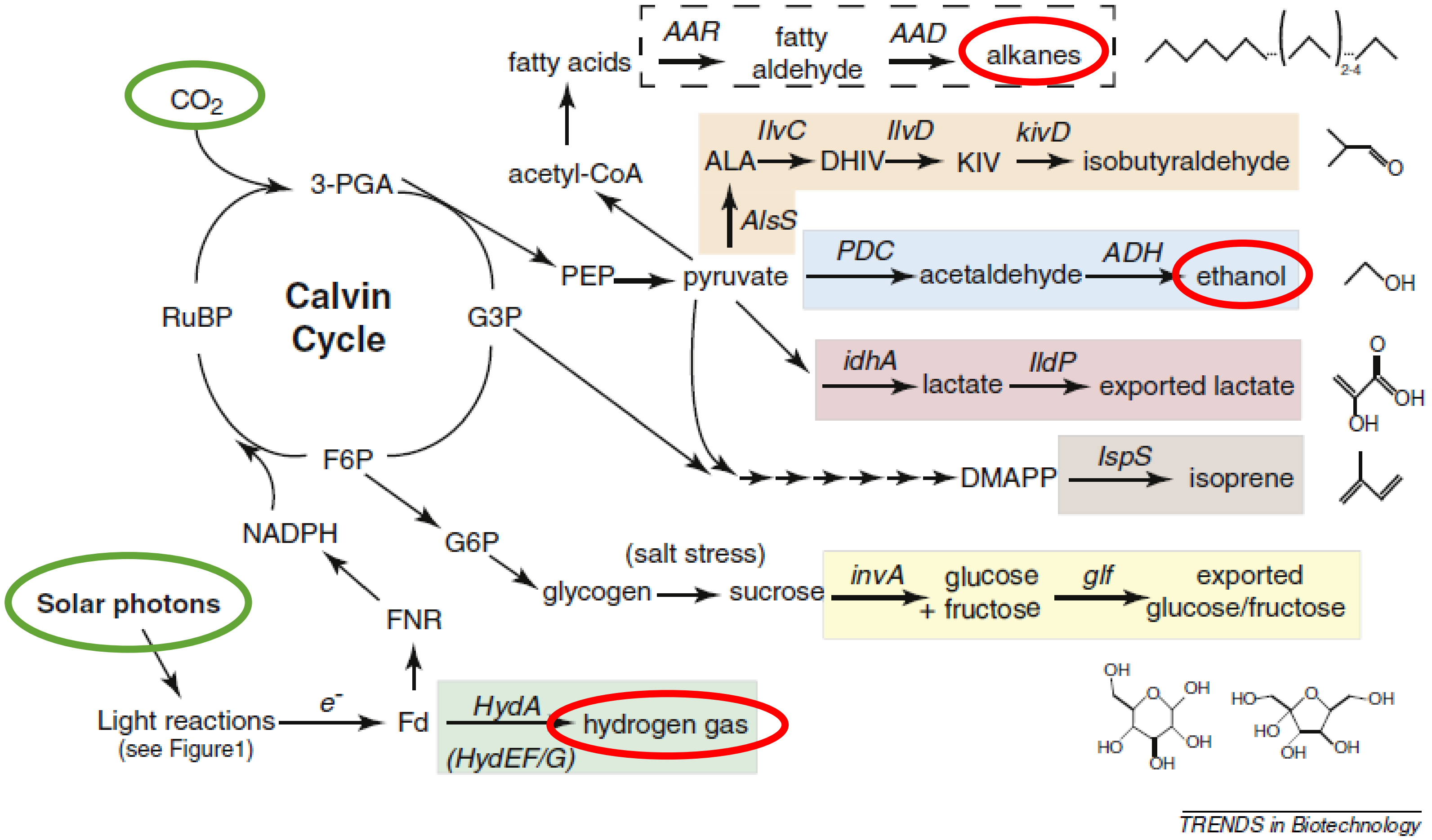
- Primitive organisms, which enabled the transition to more evolved forms of life.



Evolution of the oxygene rate in atmosphere plotted against time

CYANOBACTERIA'S POTENTIAL

Ducat et al., 2011



Different products from cyanobacteria

Photosynthetic efficiency :

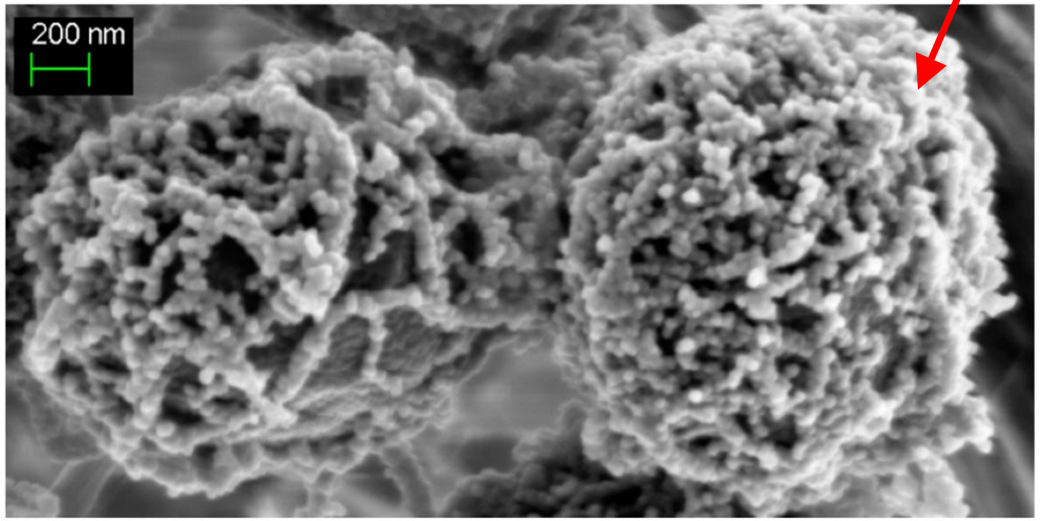
- Cyanobacteria : 3 – 9 %
- Average terrestrial organisms: 0.25 – 3%

M. Brenner, 2006
G. Dismukes et al., 2008

20minutes.fr

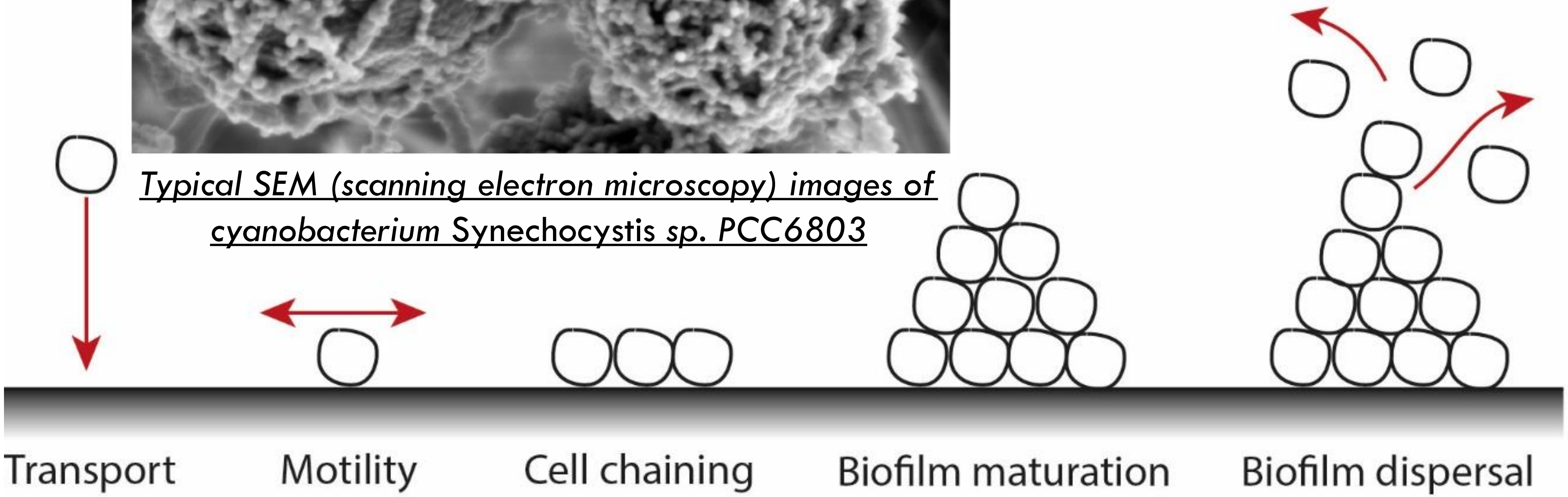
BIOFILM FORMATION

Mantle of Exopolysaccharides (EPS)



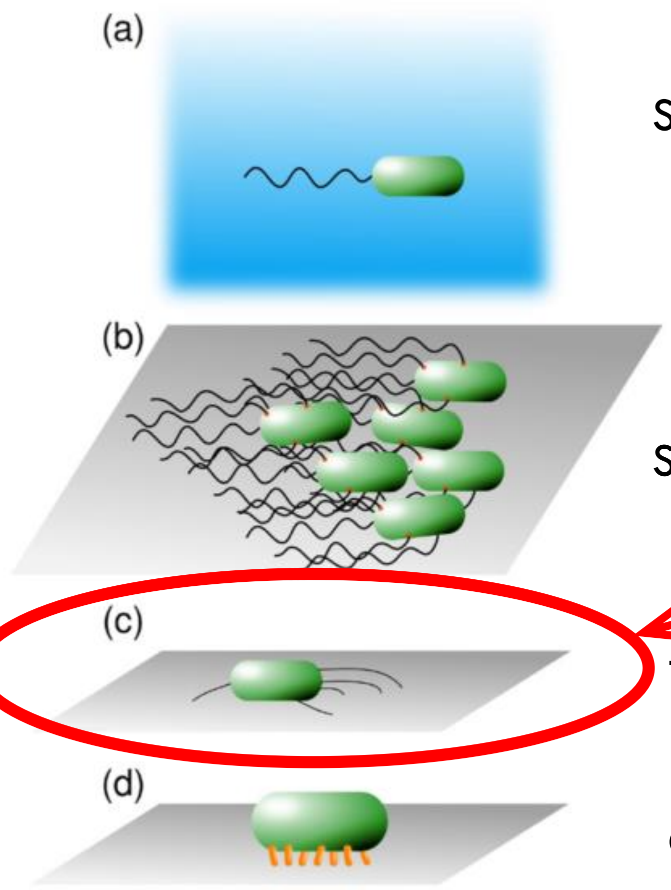
C. Cassier-Chauvat & F. Chauvat, 2015

Typical SEM (scanning electron microscopy) images of cyanobacterium Synechocystis sp. PCC6803



Different stages of biofilm formation

DIFFERENT KIND OF MOTILITY



Swimming motility

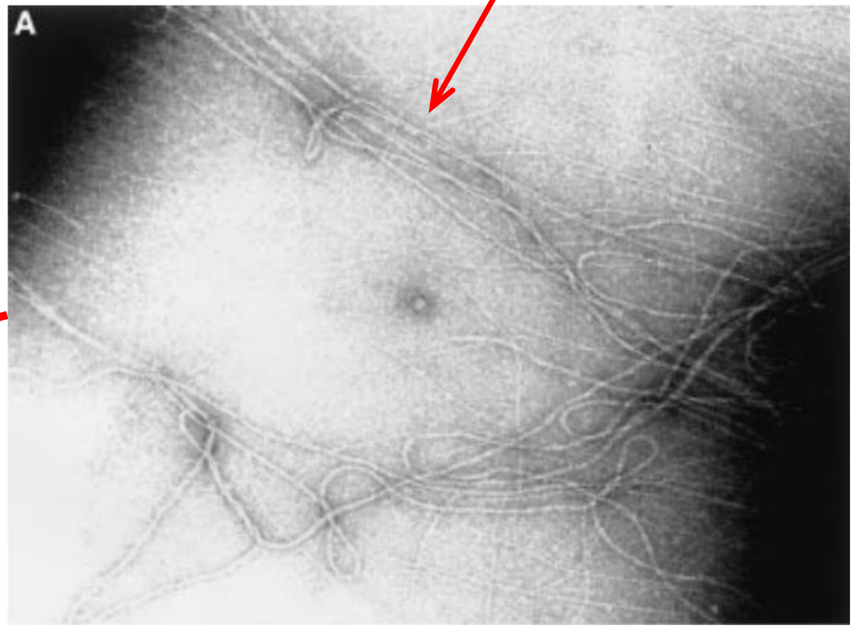
Swarming motility

Twitching motility

Gliding motility

M. Mazza, Journal of Physics D: Applied Physics, 2016

Type IV Pili



D. Bhaya et al., Molecular Biology, 2000

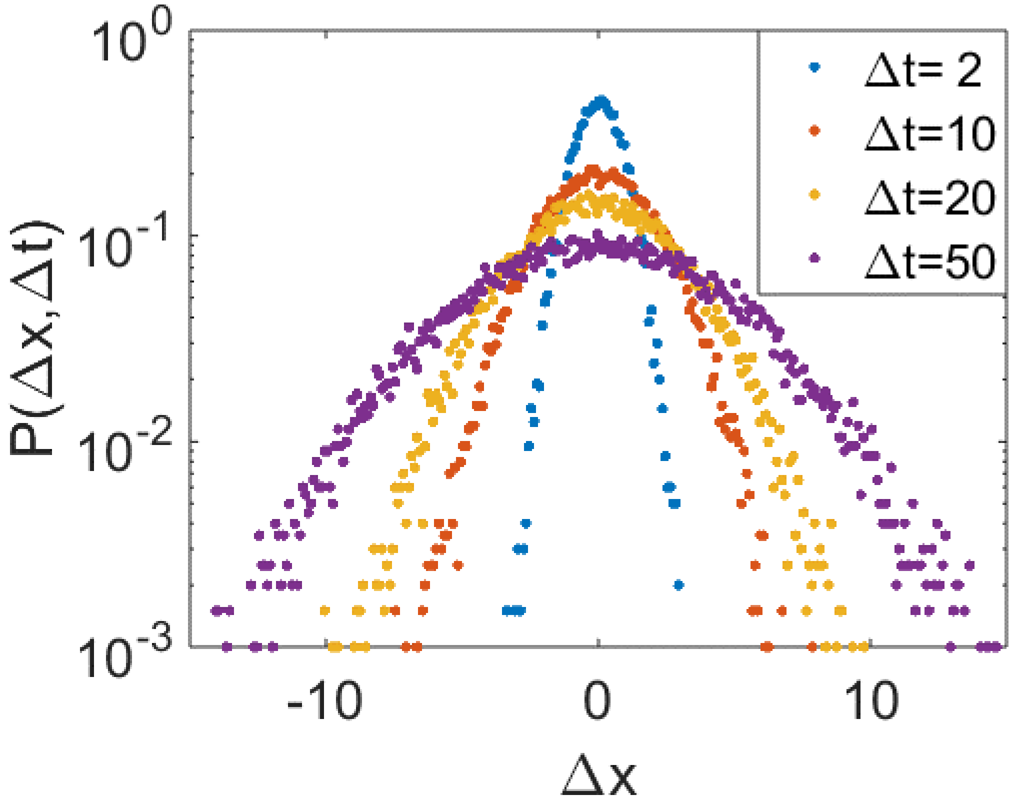
STUDYING DIFFUSION

Definition of the Mean Squared Displacement (MSD):

$$MSD(\Delta) = \left\langle \left(X(\Delta) - X_0 \right)^2 \right\rangle$$

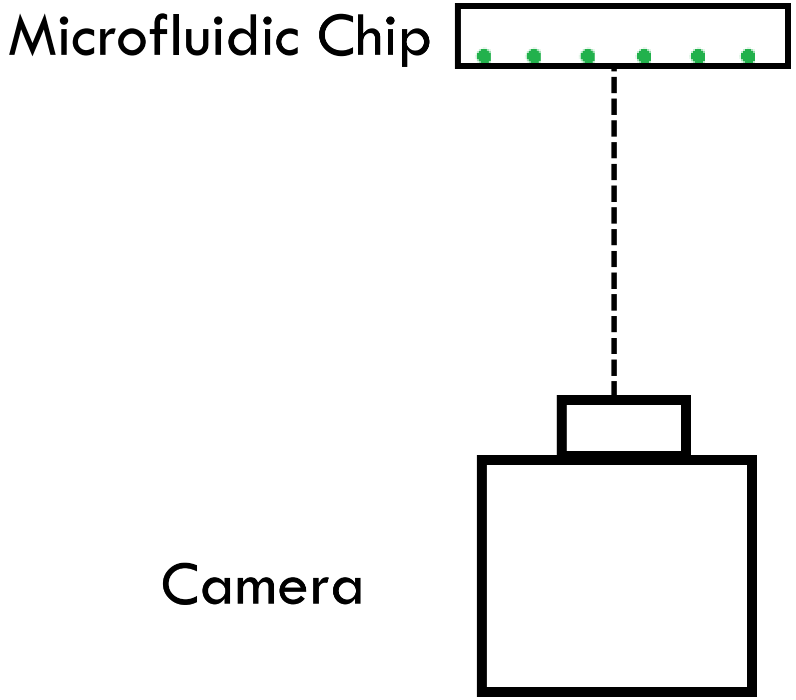
In the case of a 2-D Fickian behaviour:

$$MSD(\Delta) = 4D\Delta$$

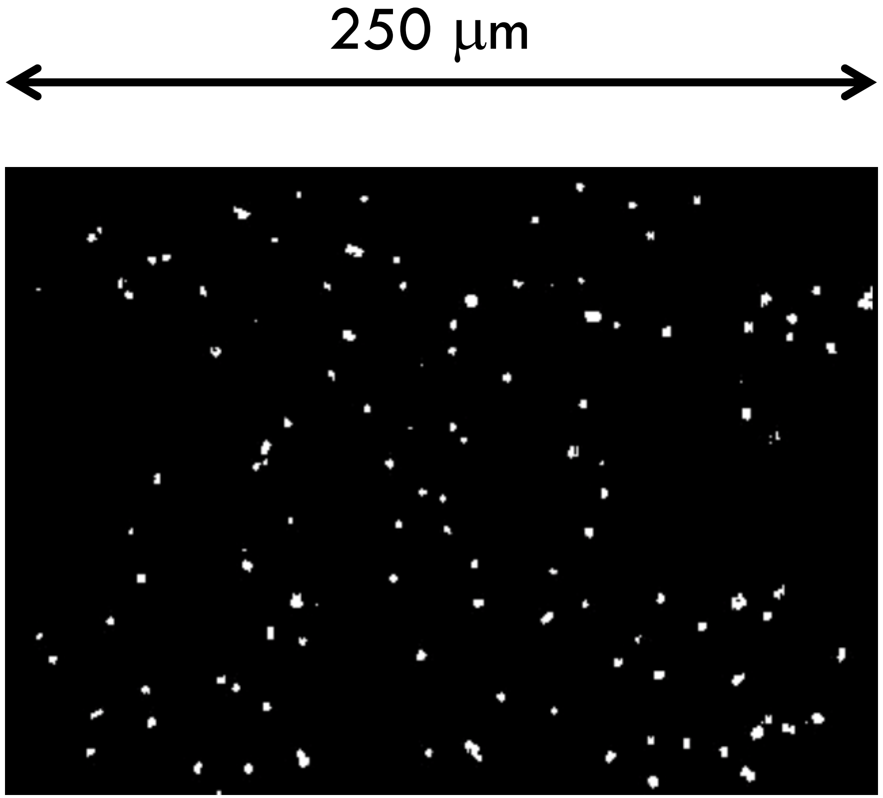


Displacement probabilities at different times Δ for simulated Brownian motion

EXPERIMENTAL SETUP

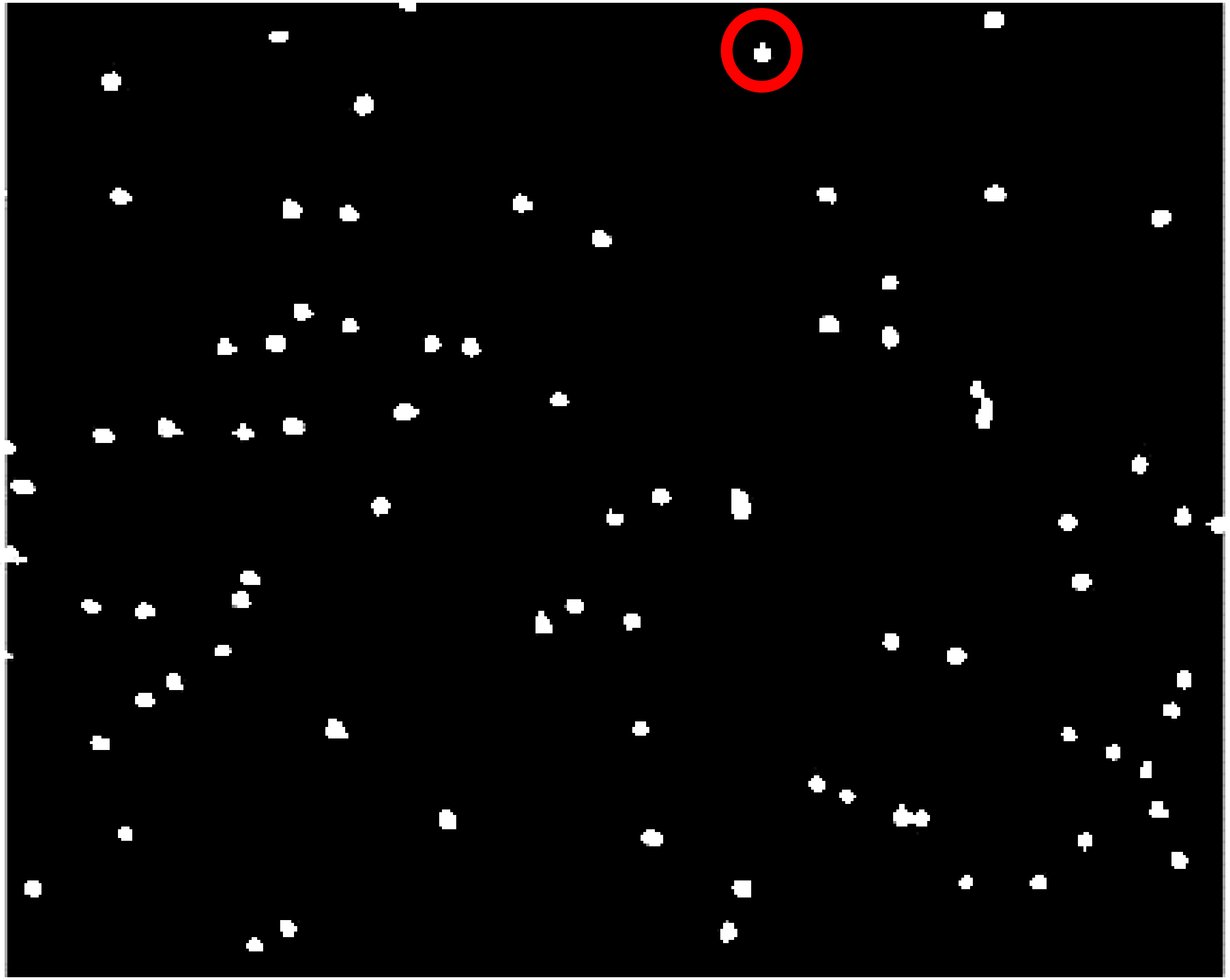


Experimental setup

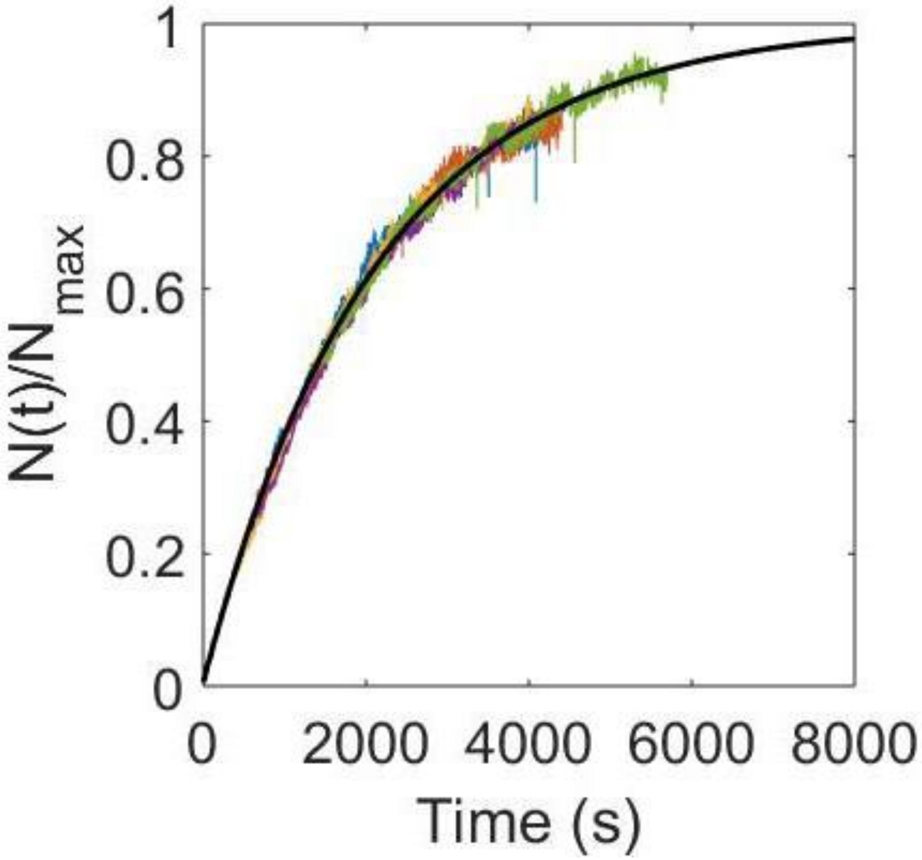


Binary images

VIDEO



DIFFUSIVE DYNAMICS SLOWDOWN



Temporal evolution of the detected number of bacteria

Bacterial transport towards the surface via a sedimentation process.

DIFFUSIVE DYNAMICS SLOWDOWN

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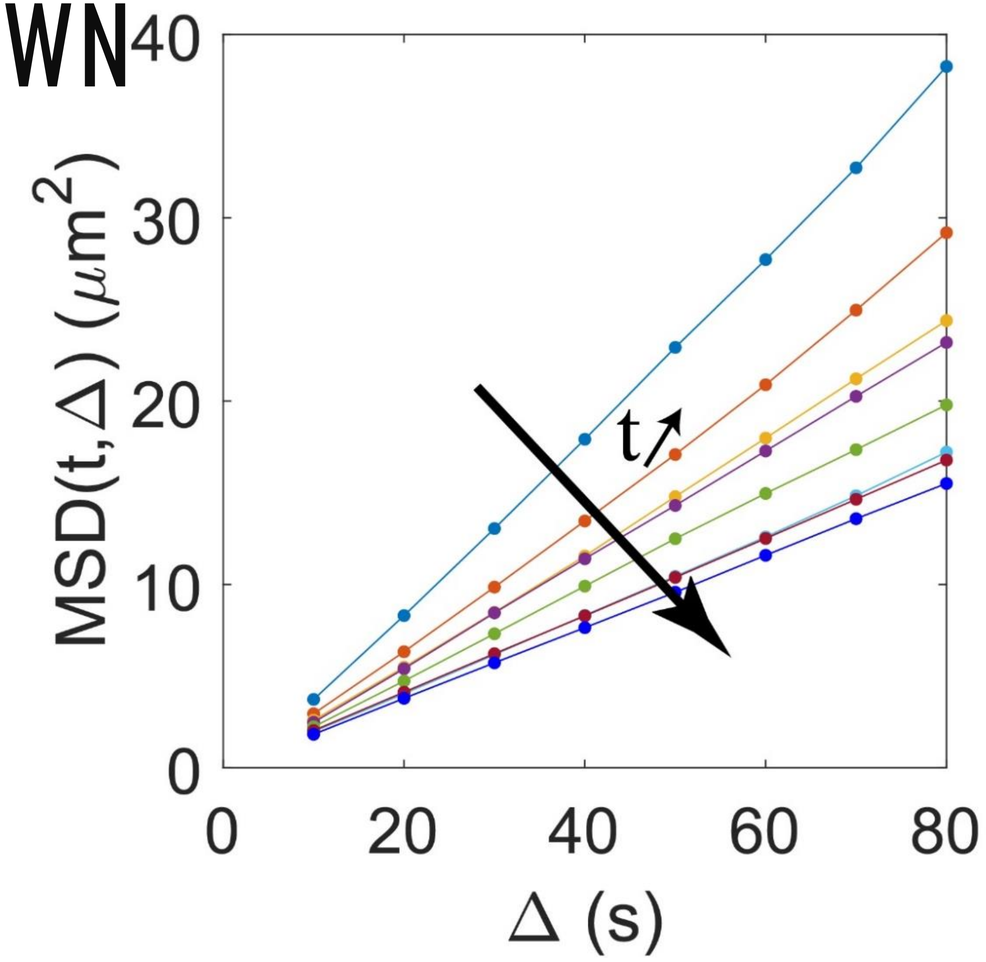
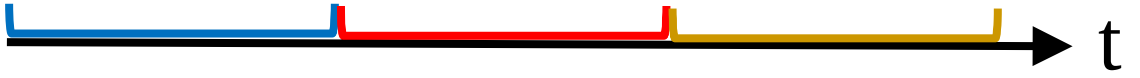
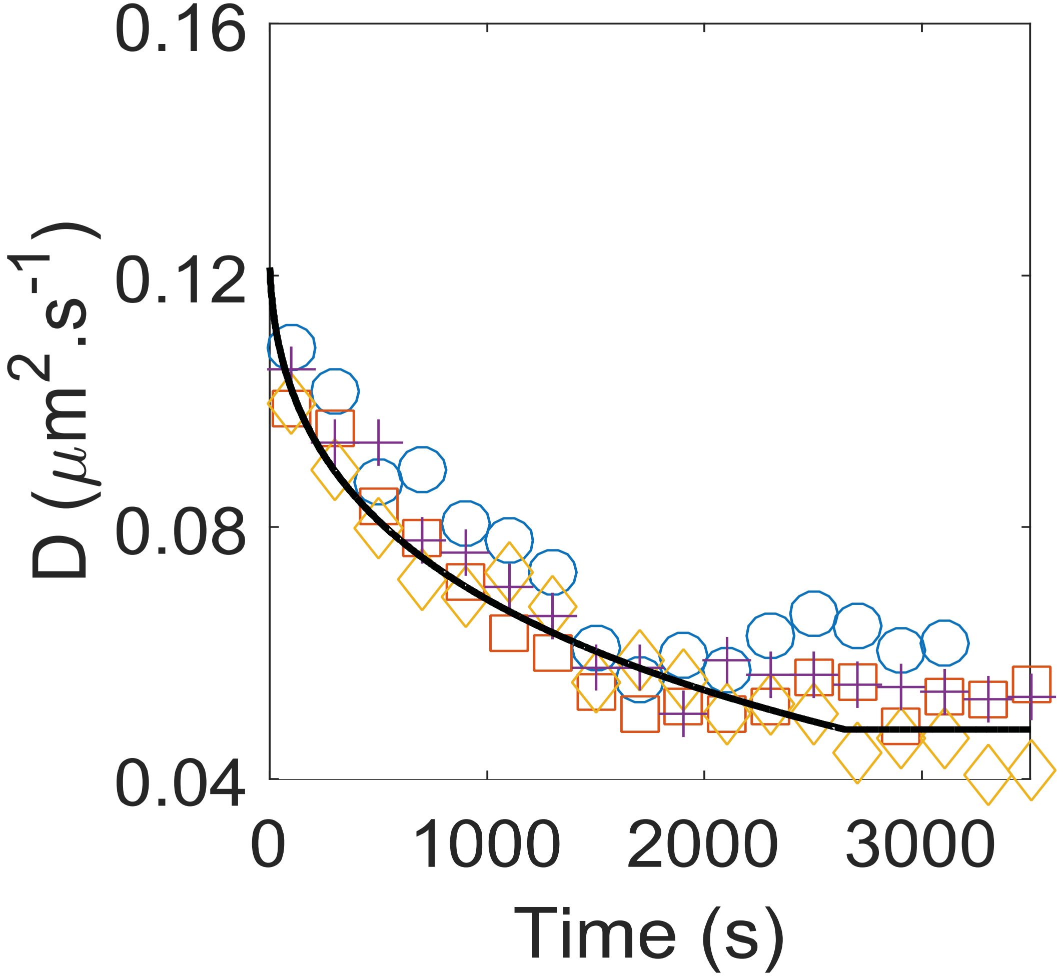




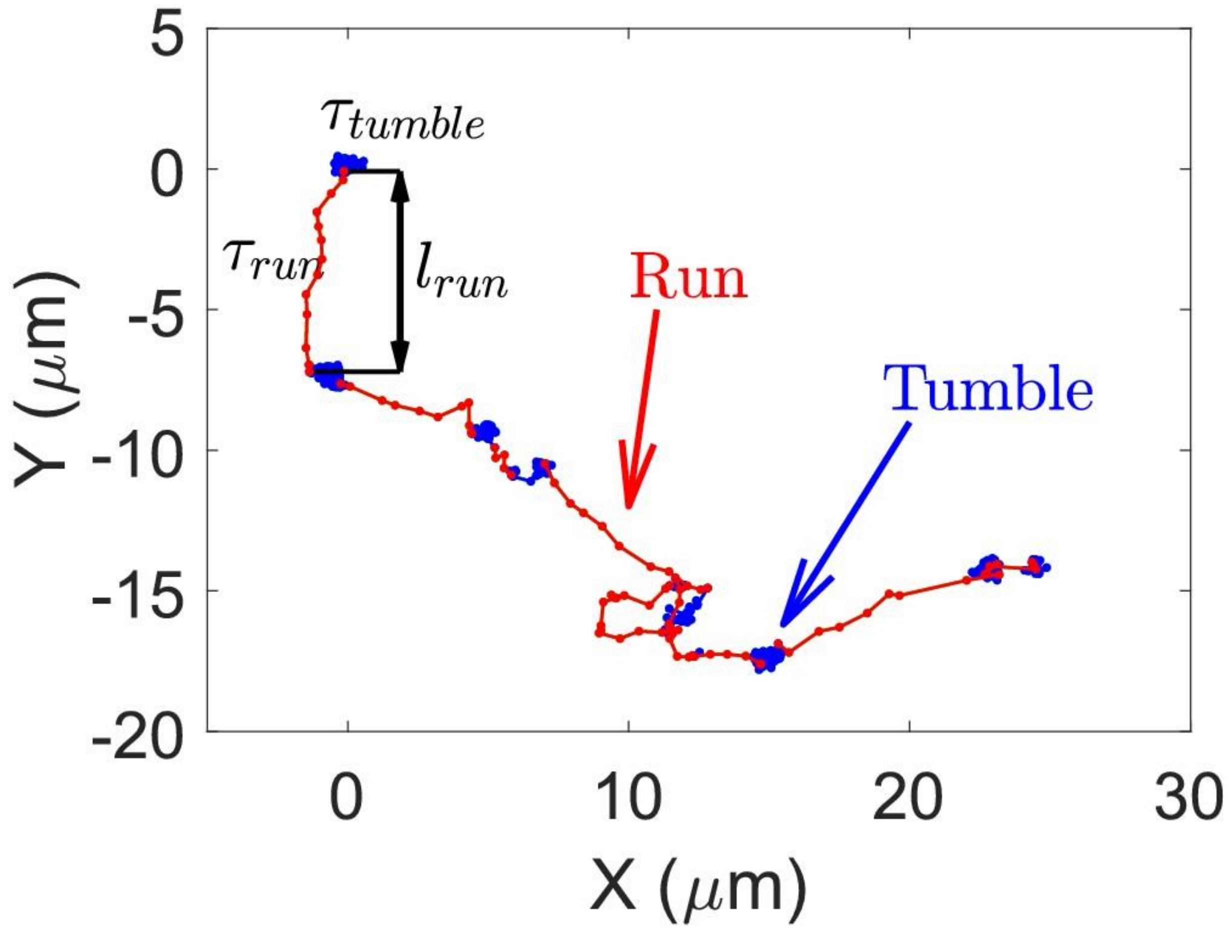
DIFFUSIVE DYNAMICS SLOWDOWN



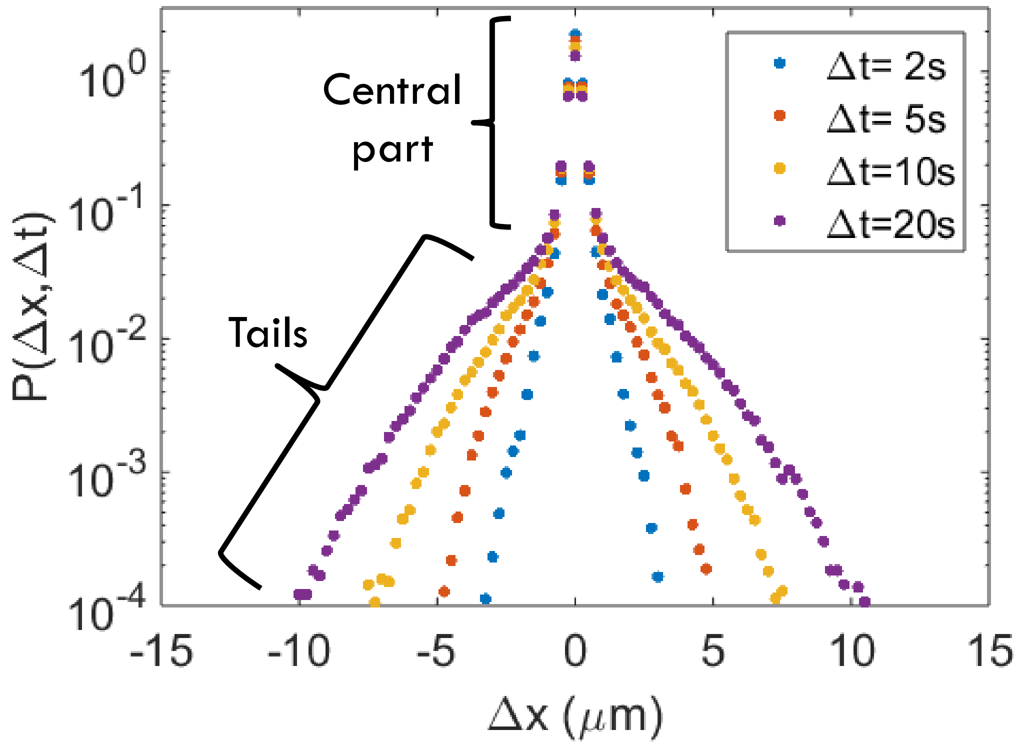
Temporal evolution of the diffusion coefficient

Diffusion coefficient decreases with time

INTERMITTENT MOTILITY

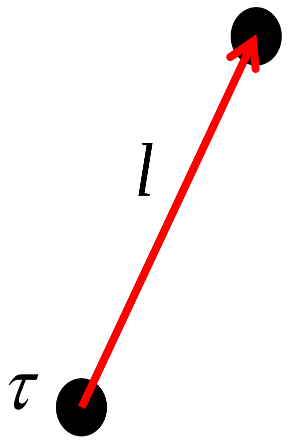


A typical trajectory of 668s duration, divided into run and tumble periods

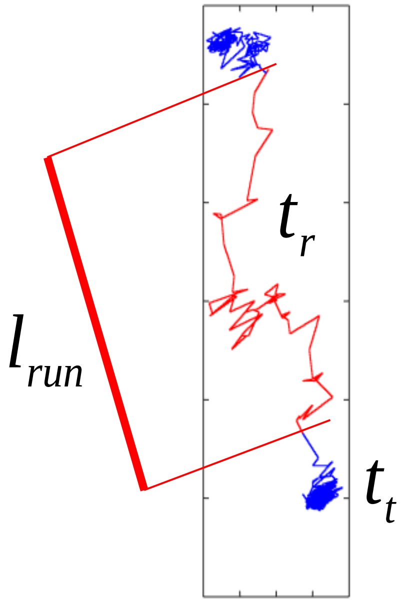


Experimental displacement probabilities

ANALYTIC FORMULA FOR THE DIFFUSION COEFFICIENT : CONTINUOUS-TIME RANDOM WALK (CTRW) MODEL



CTRW model parameters



Experimental parameters

$$l = l_{run}$$
$$\tau = t_t + t_r$$

$$D = \frac{1}{4}\frac{\langle l^2 \rangle}{\langle \tau \rangle}$$

Bouchaud & Georges, 1990

ANALYTIC FORMULA FOR THE DIFFUSION COEFFICIENT

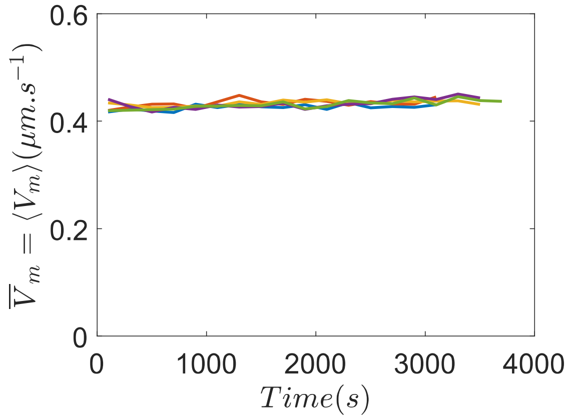
$$D = \langle l^2 \rangle / 4 \langle \tau \rangle$$

Ballistic hypothesis:

$$\langle l^2 \rangle = \langle \tau_{run}^2 V_m^2 \rangle \approx V_m^2 \langle \tau_{run}^2 \rangle$$

$$D \sim V_m^2 \frac{\langle \tau_{run}^2 \rangle}{\langle \tau \rangle}$$

$$V_m = \langle \frac{l_{run}}{\tau_{run}} \rangle$$



Bhaya, et al., 2015

Golestatnian, et al., 2015

COVERED SURFACE PROPORTION S(T)

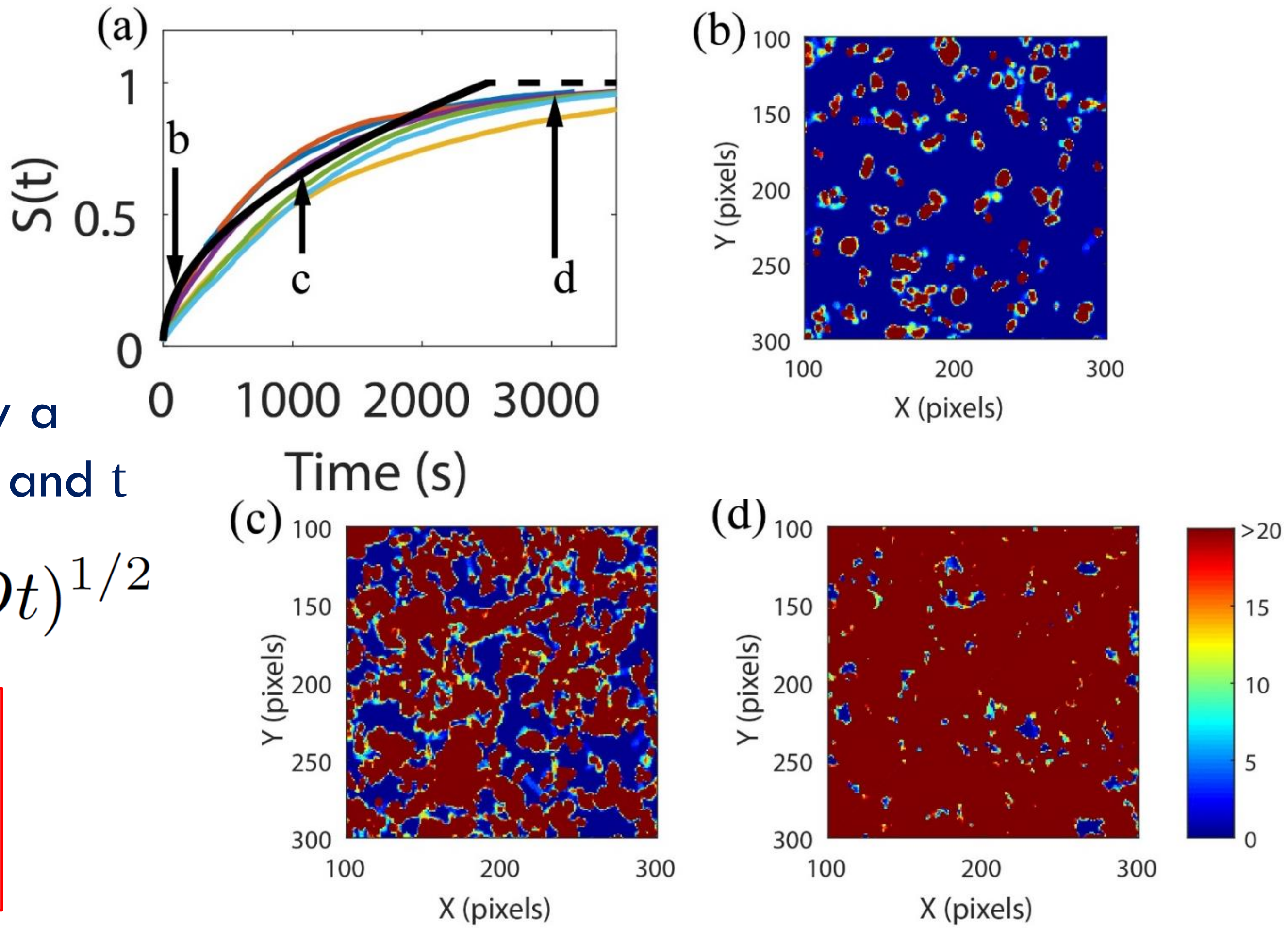
$$S(t) = \int_0^t p(t')X(t-t')\,\mathrm{d}t'$$

Bacteria landing at time t'

Area covered by a particle between t' and t

$$X(t) = d \times (4Dt)^{1/2}$$

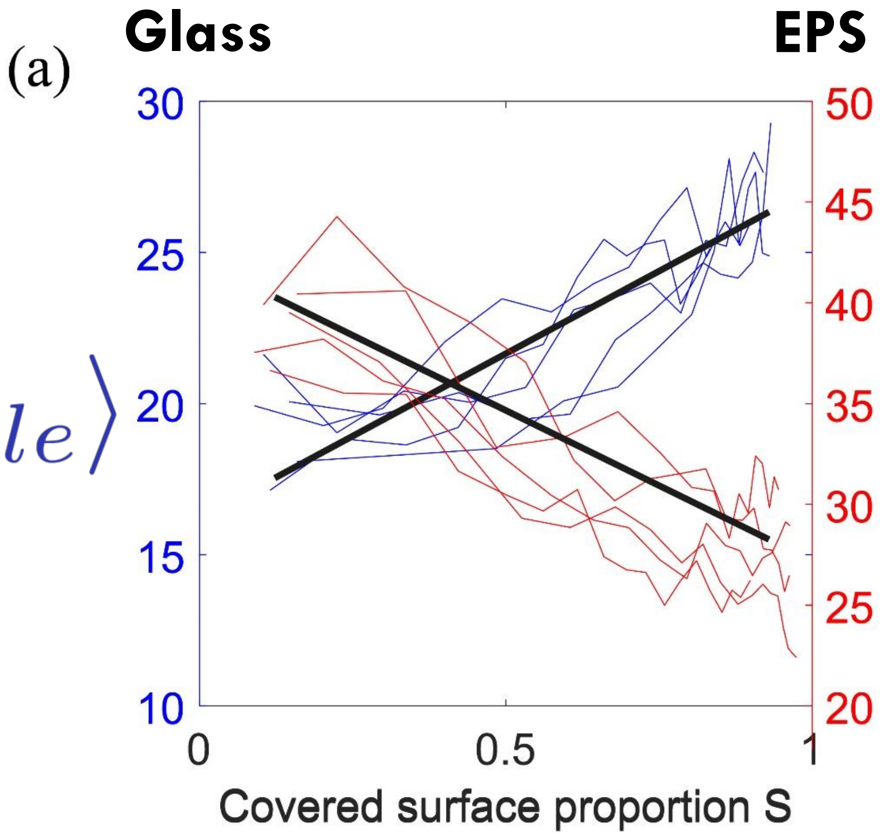
$$S(t) \sim A \times t^{1/2}$$



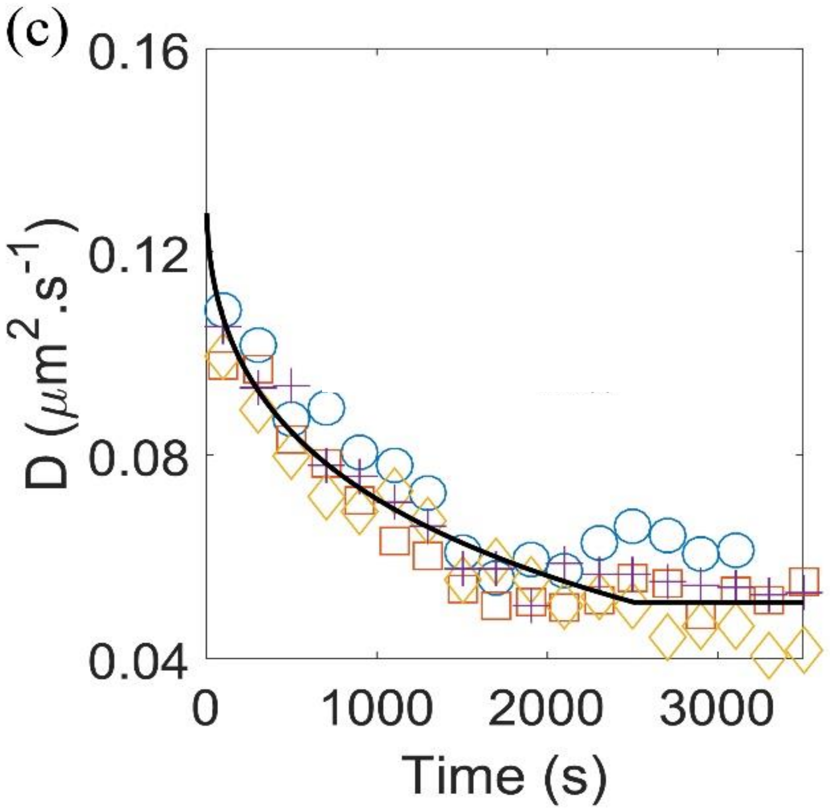
Experimental colonisation maps drawn at different experiment times

COVERED SURFACE PROPORTION S(T)

$\langle \tau_{tumble} \rangle$



$\langle \tau_{run}^2 \rangle$



$$\langle \tau \rangle \approx \langle \tau_{glass} \rangle (1 - S(t)) + \langle \tau_{eps} \rangle S(t)$$

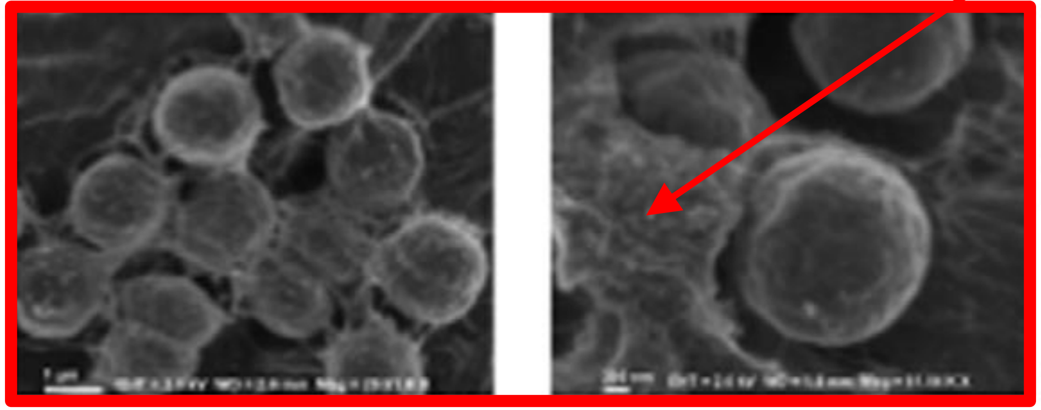
$$\langle \tau_{run}^2 \rangle \approx \langle \tau_{run,glass}^2 \rangle (1 - S(t)) + \langle \tau_{run,eps}^2 \rangle S(t)$$

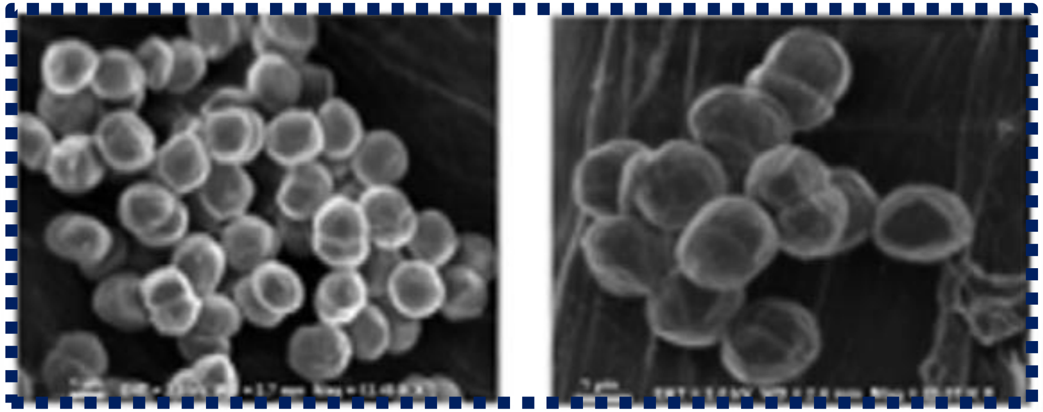
$$D \sim V_m^2 \frac{\langle \tau_{run}^2 \rangle}{\langle \tau \rangle}$$

WHAT HAPPENS WITH MUTANTS ?

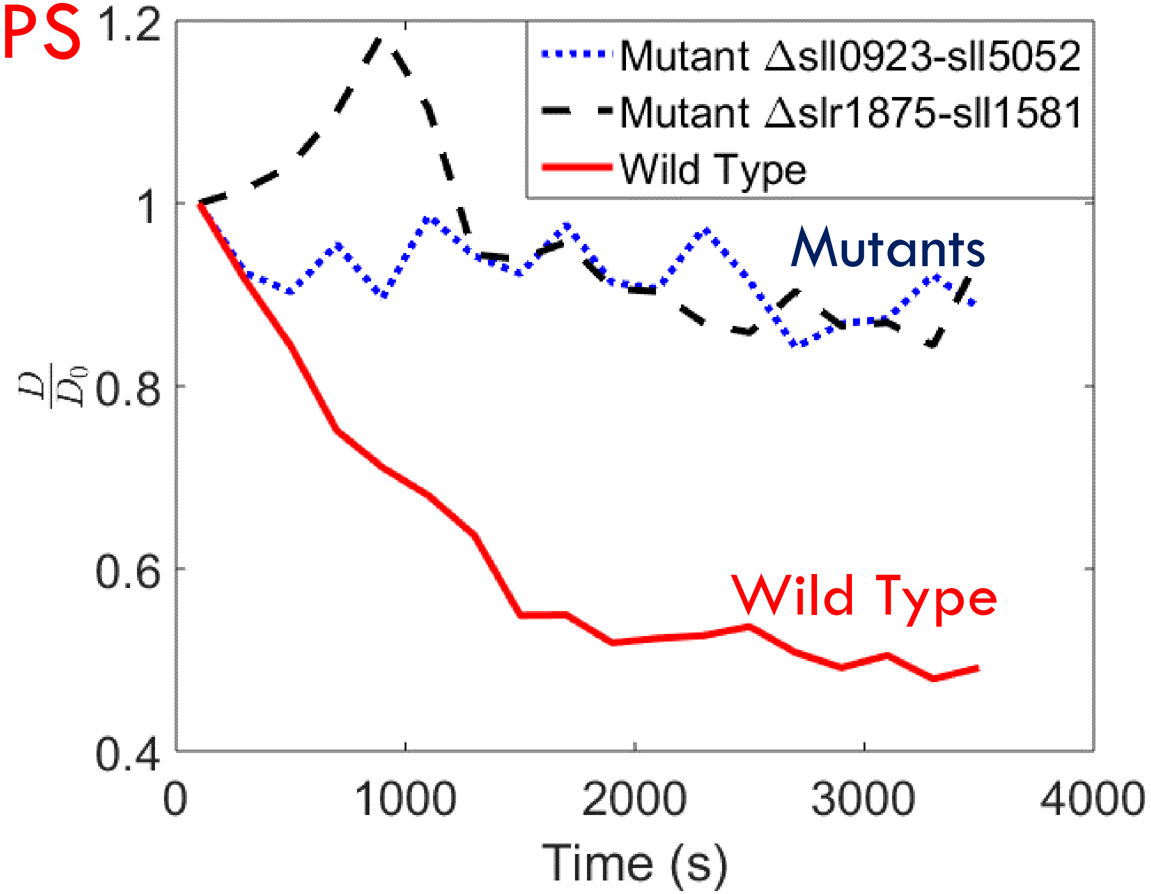
Jittawuttipoka et al., 2015

Wild Type Cells



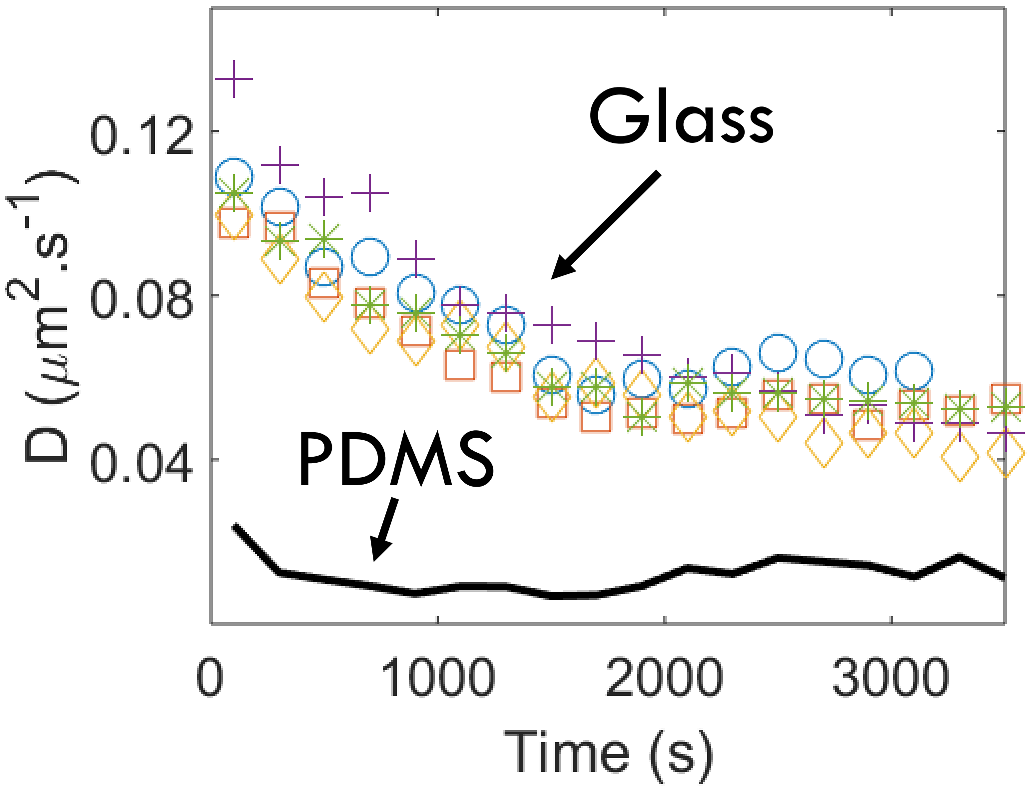


Mutant cells – Deficient in EPS production



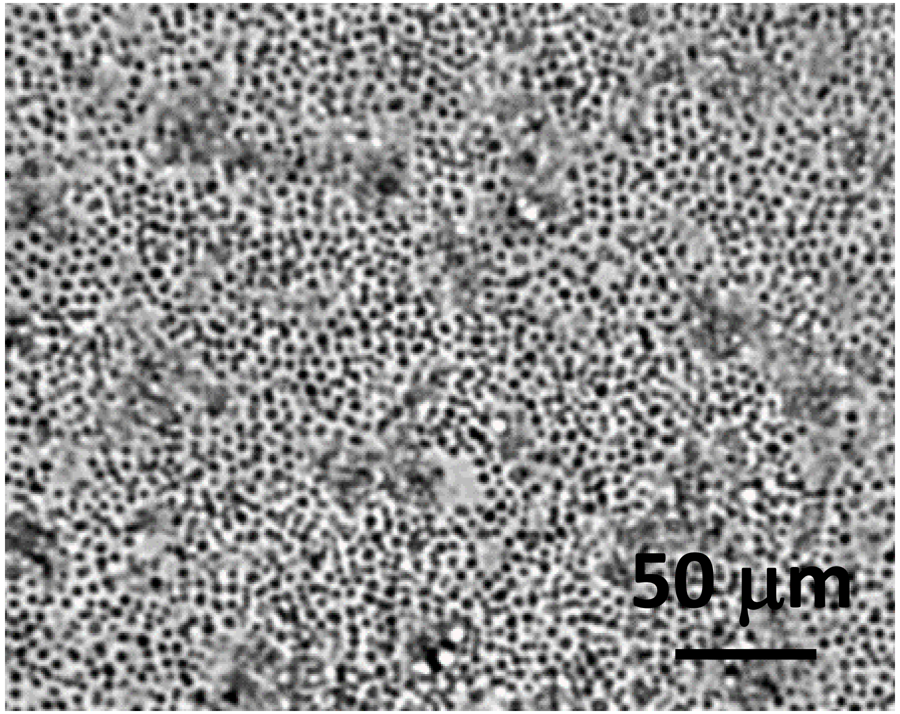
Decrease of the relative diffusion coefficient with time

COMPARISON OF DIFFERENT SURFACES

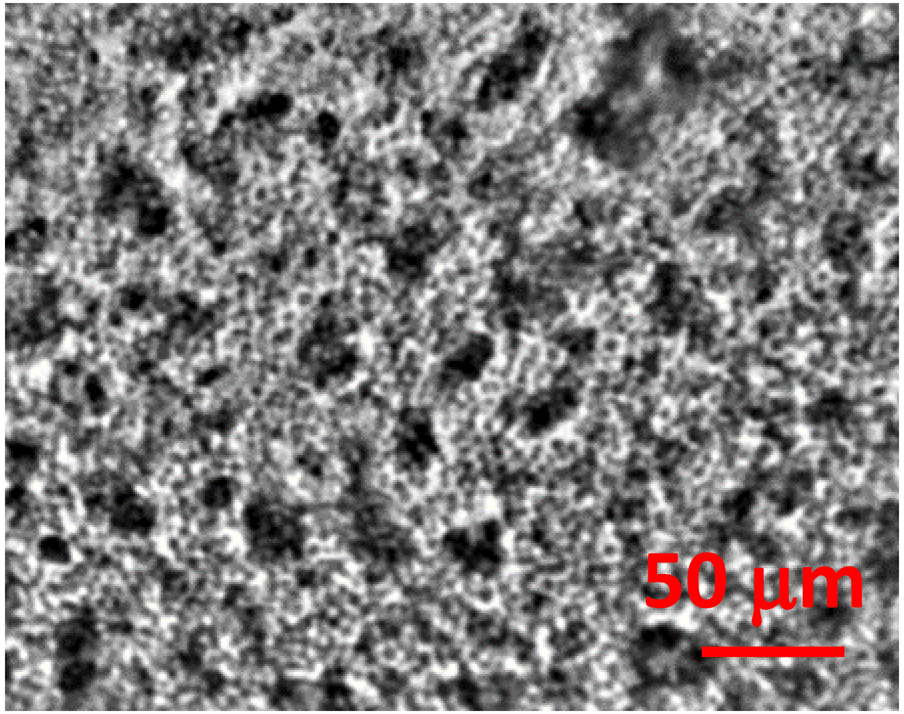


Temporal evolution of the diffusion coefficient on glass and on a PDMS surface

SURFACE COLONISATION AFTER ONE WEEK OF CULTURE



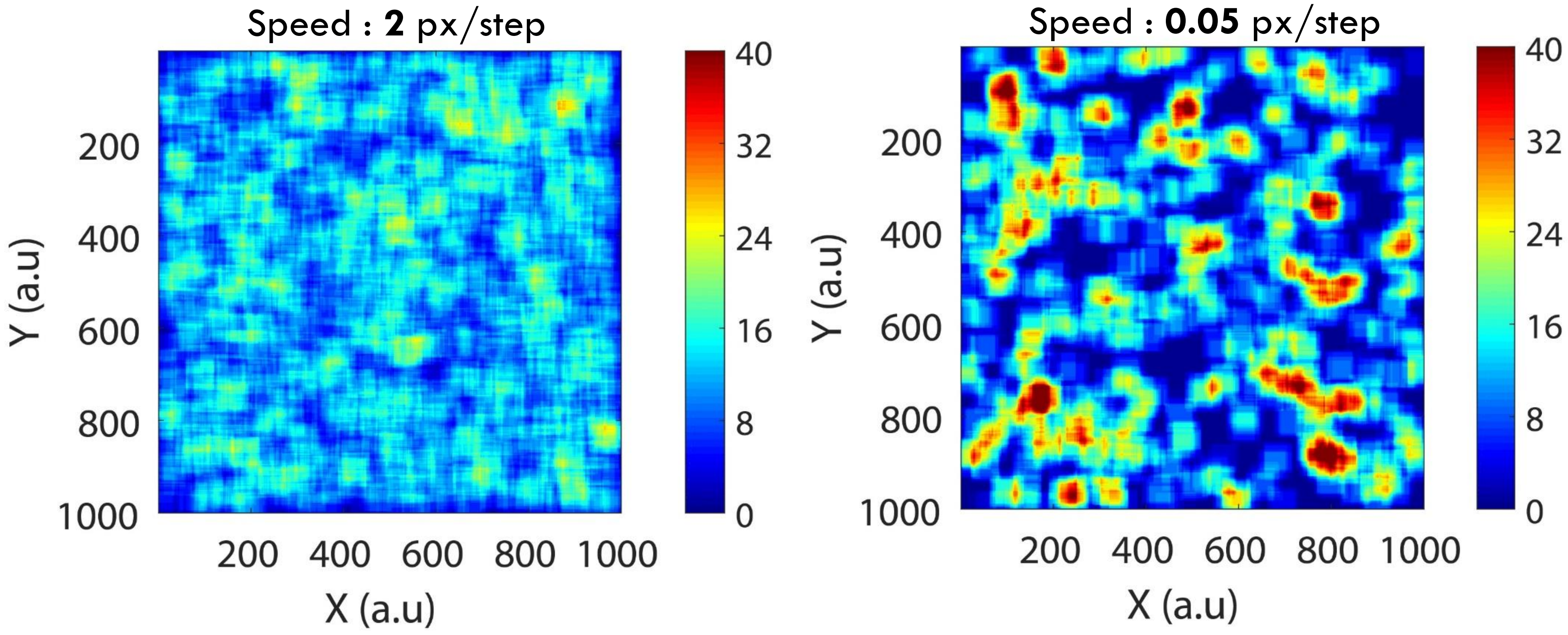
Colonisation on a glass surface: diffusion enables an homogeneized colonisation.



Colonisation on a PDMS surface: adhesion leads to the formation of numerous micro-colonies.

COLONISATION AFTER ONE WEEK: MODEL

- Numerical computations model



CONCLUSIONS

- Cyanobacterium *Synechocystis* sp. PCC 6803 diffusive dynamics decreases with time.
- Dynamics is well described with an intermittent model.
- This decrease can be linked to a progressive surface covering with the EPS dropped by the bacteria. EPS-depleted mutants do not exhibit such a decrease.
- Early dynamics can be linked to the shape of microcolonies growing on surface.

ACKNOWLEDGEMENTS

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- Annick Méjean
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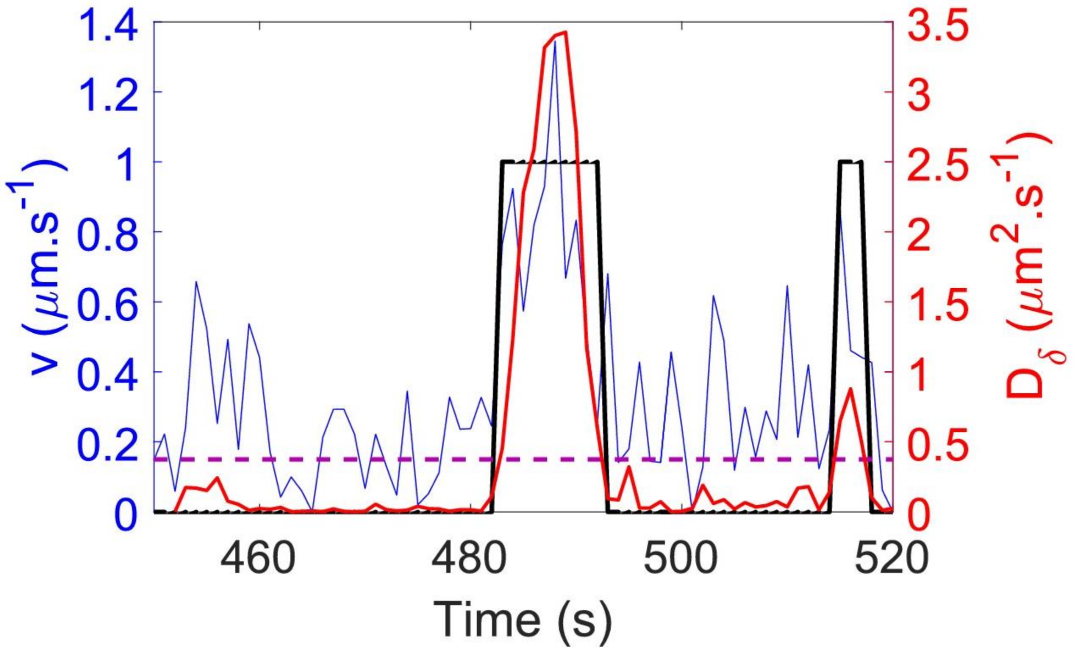
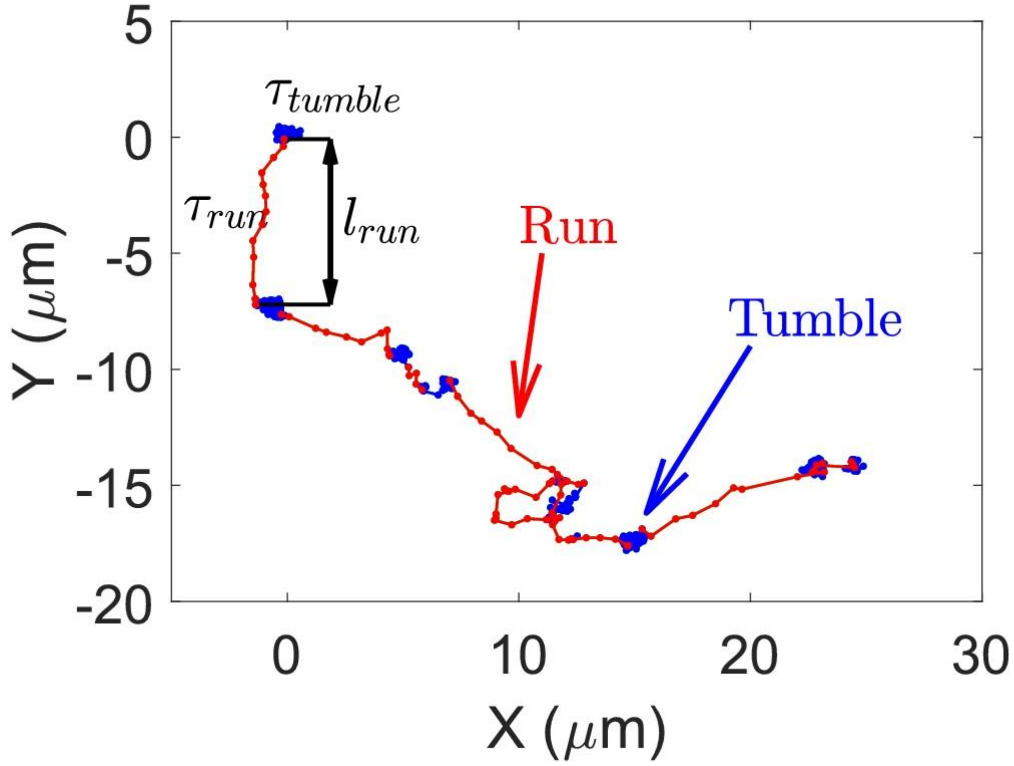
- Jean-Pierre Thermeau
- Guillaume Chau, Elnaz Pashmi & Chau Minh N'guyen

INTERMITTENT MOTILITY



Temporal evolution of D_δ (red) and instantaneous speed (blue)

$$D_\delta(t) = \frac{(X(t-\delta/2) - X(t+\delta/2))^2}{\delta}$$



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Bhaya, et al., 2015

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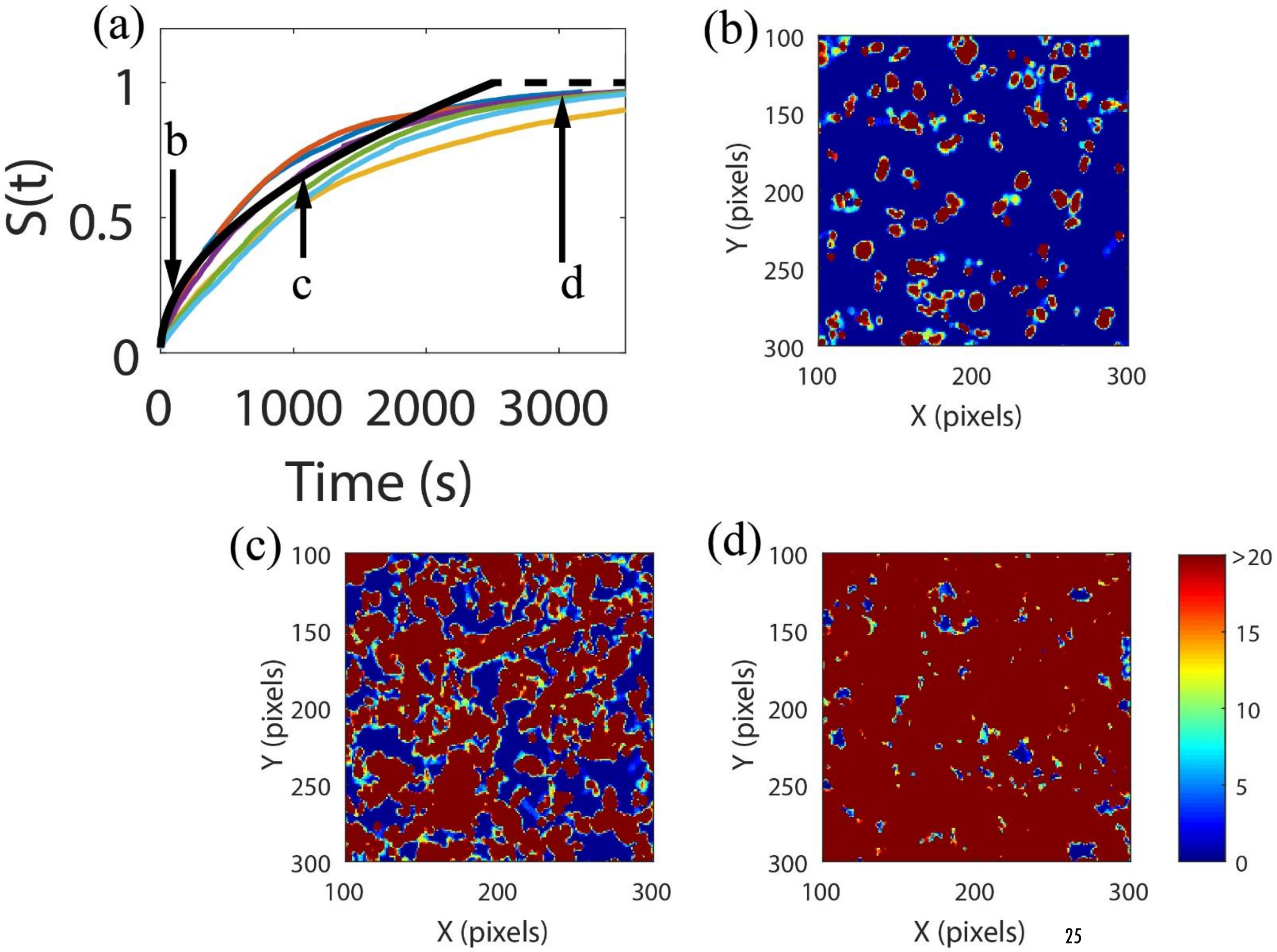

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