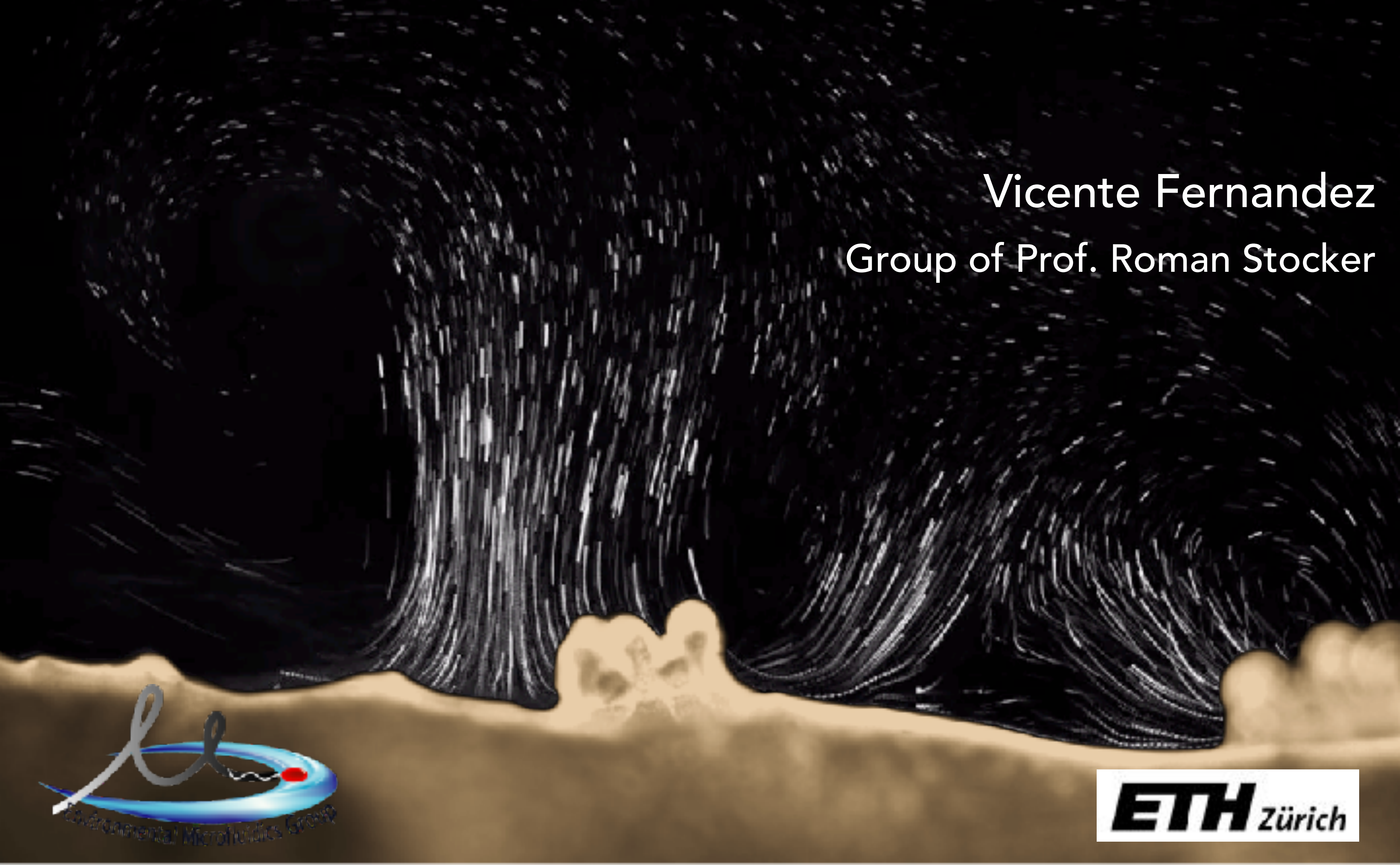
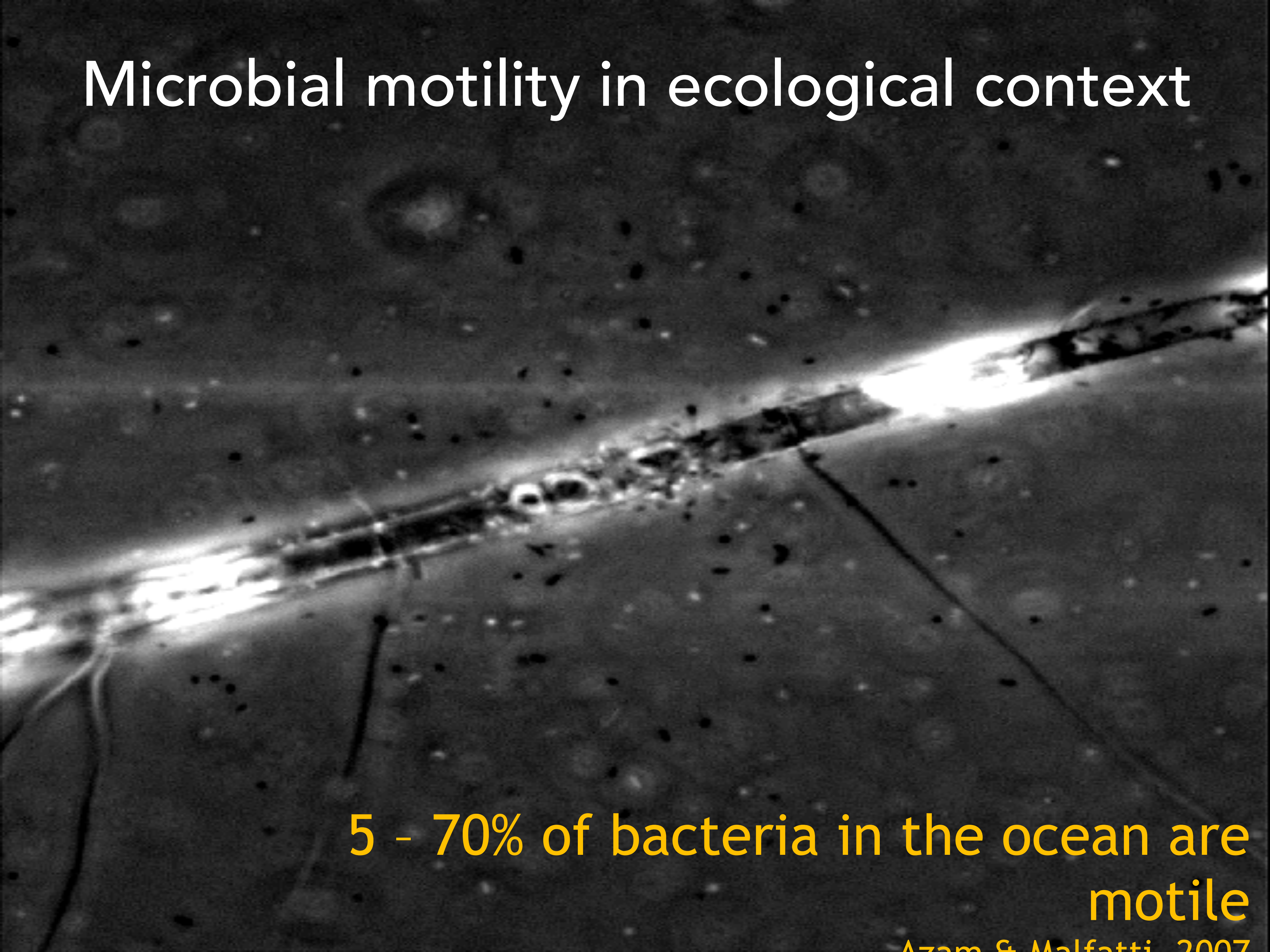
Microbial motility in complex fluid environments

Vicente Fernandez
Group of Prof. Roman Stocker



ETH Zürich

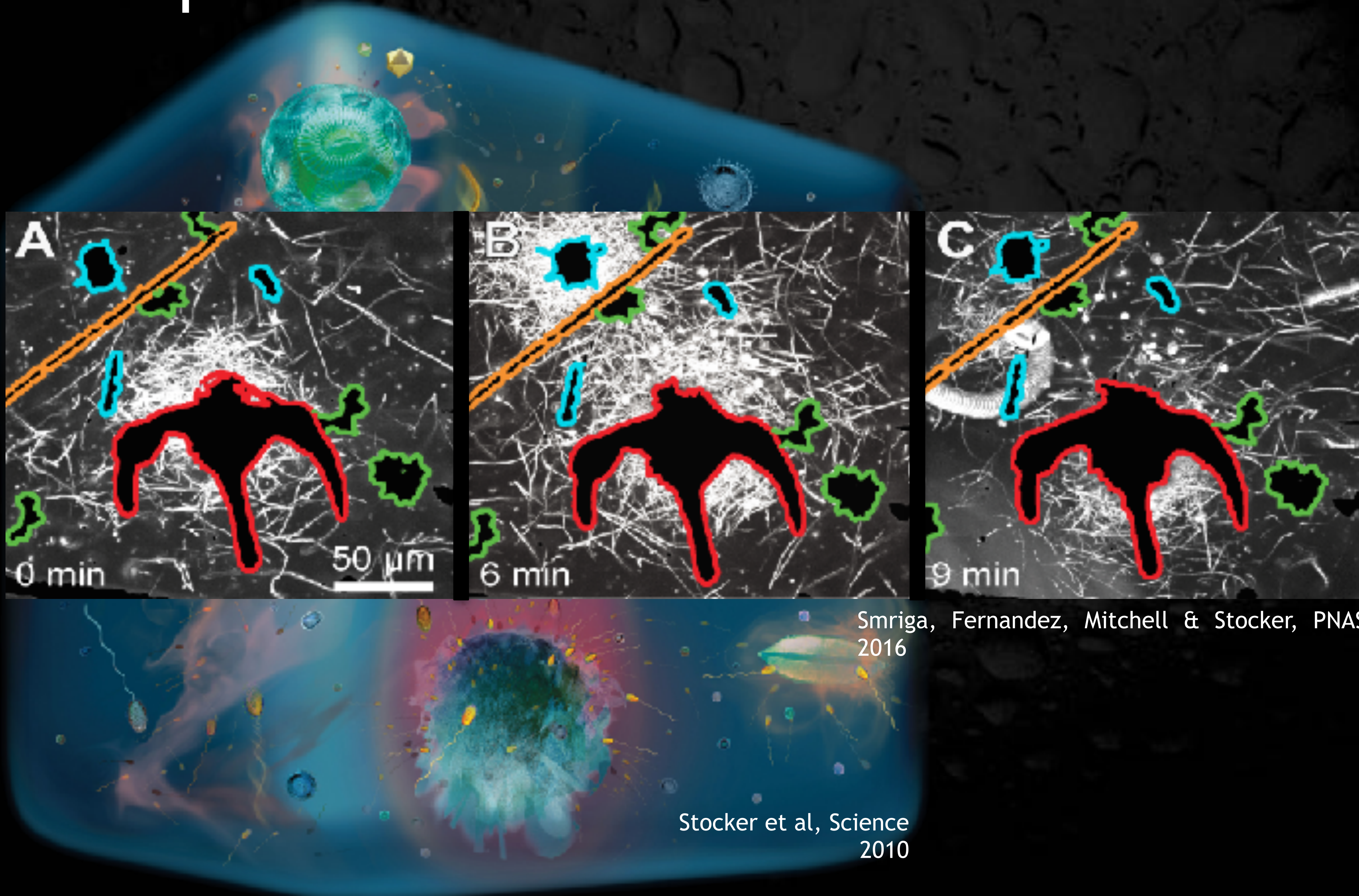
Microbial motility in ecological context



5 – 70% of bacteria in the ocean are motile

Azam & Malfatti, 2007

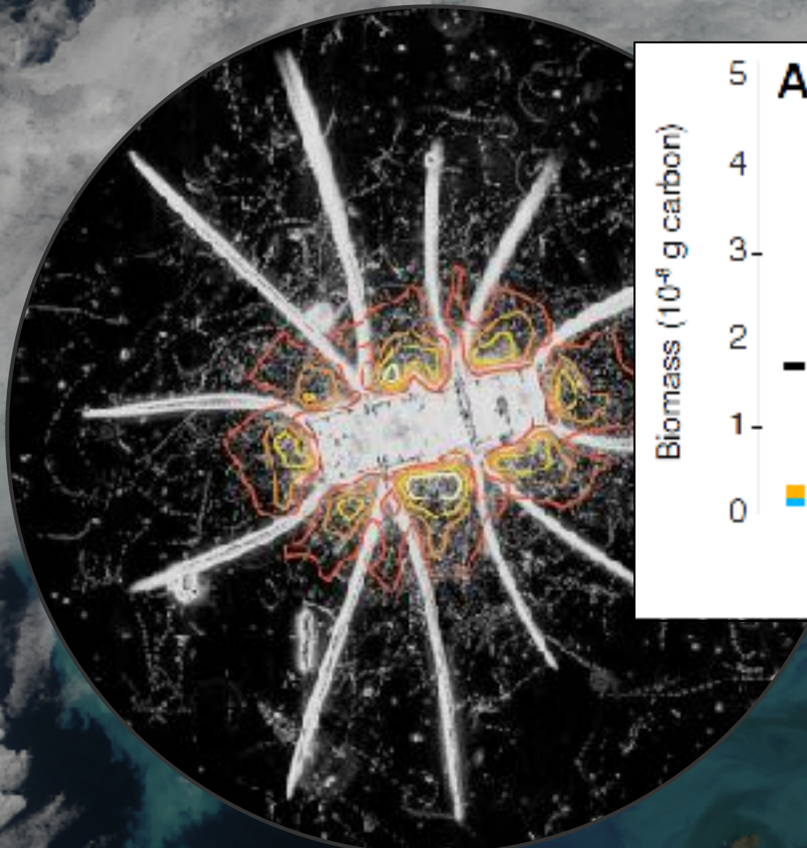
Hotspots dominate the ocean microscale

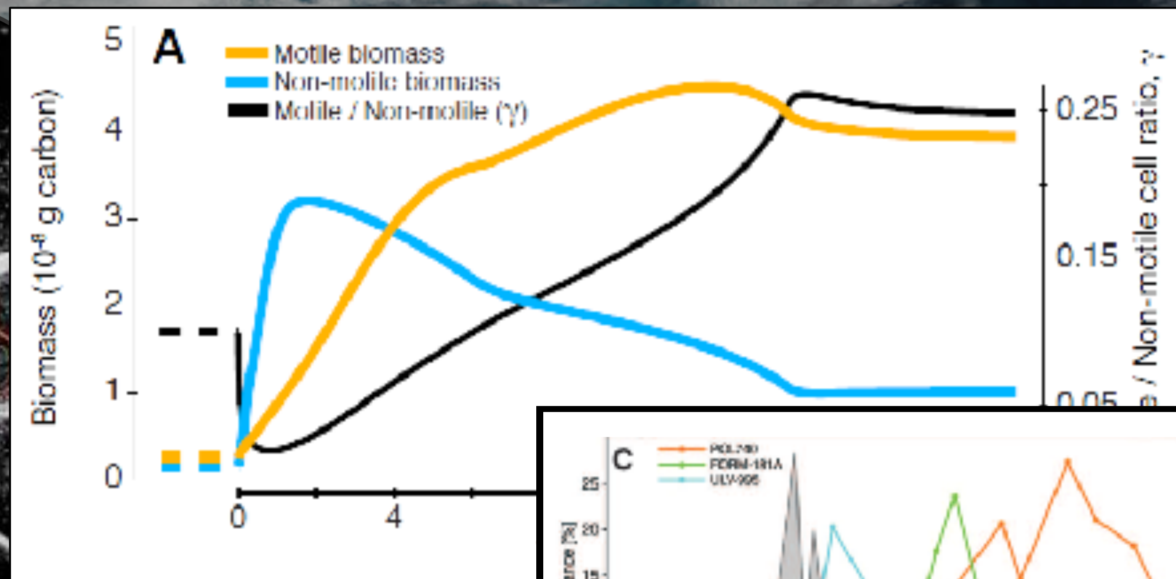


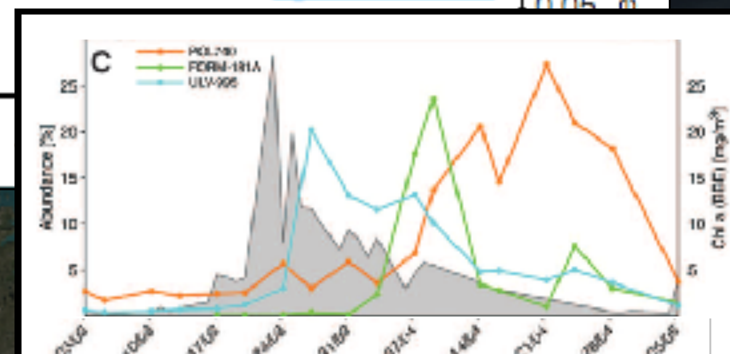
Smriga, Fernandez, Mitchell & Stocker, PNAS 2016

Stocker et al, Science 2010

Bacterial competition in a phytoplankton bloom







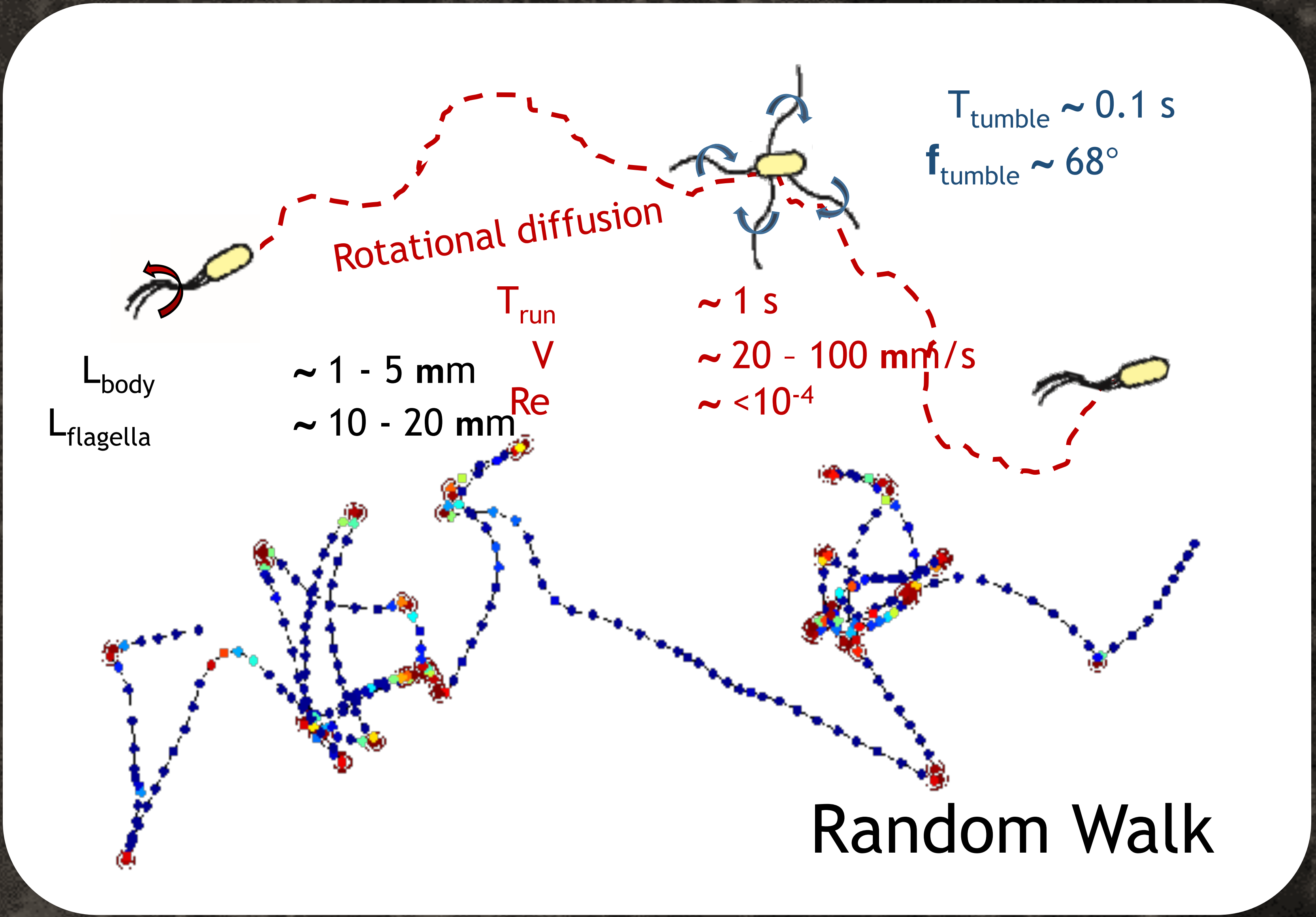
Teeling et al. *Science*, 2012

Motile population dominates biomass after 4 days

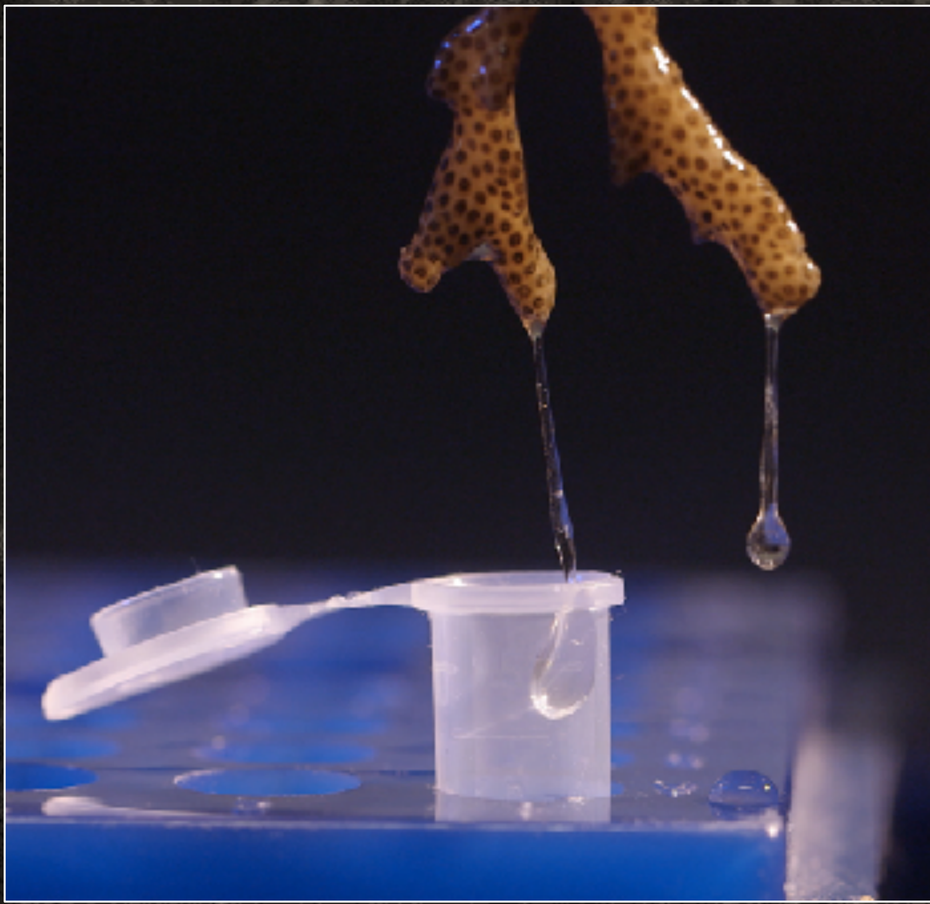
→ Microscale, phycosphere consumption underpins initial macroscale bacterial succession

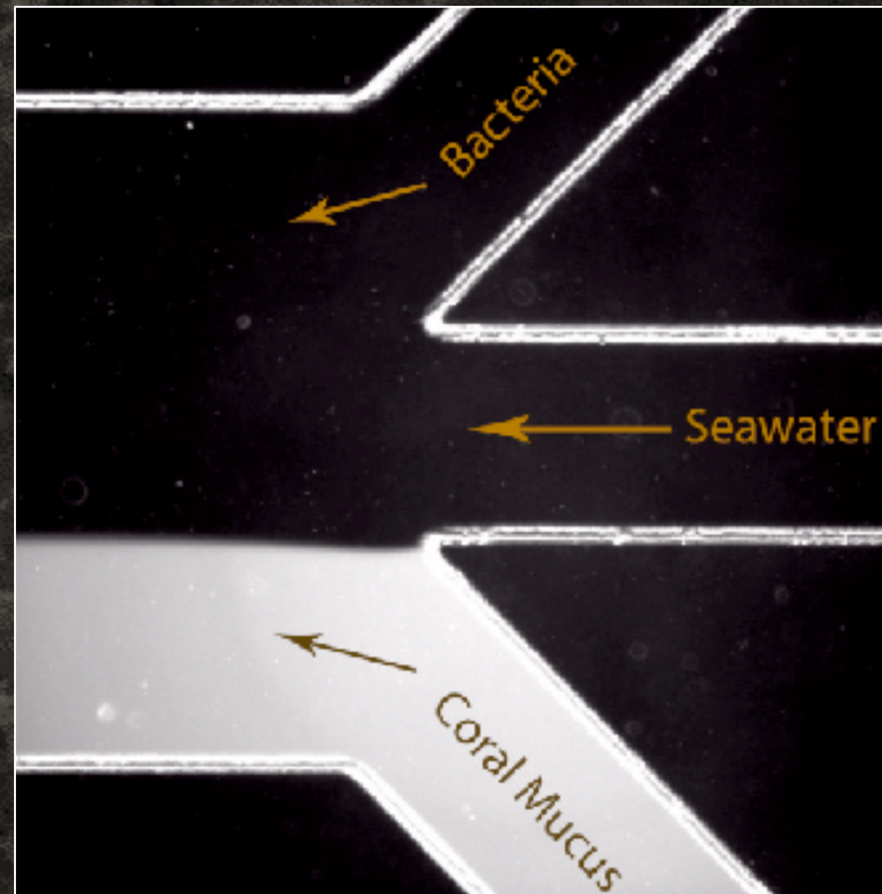
Smriga, Fernandez, Mitchell & Stocker, PNAS

Bacterial motility overview



Chemotaxis Assay



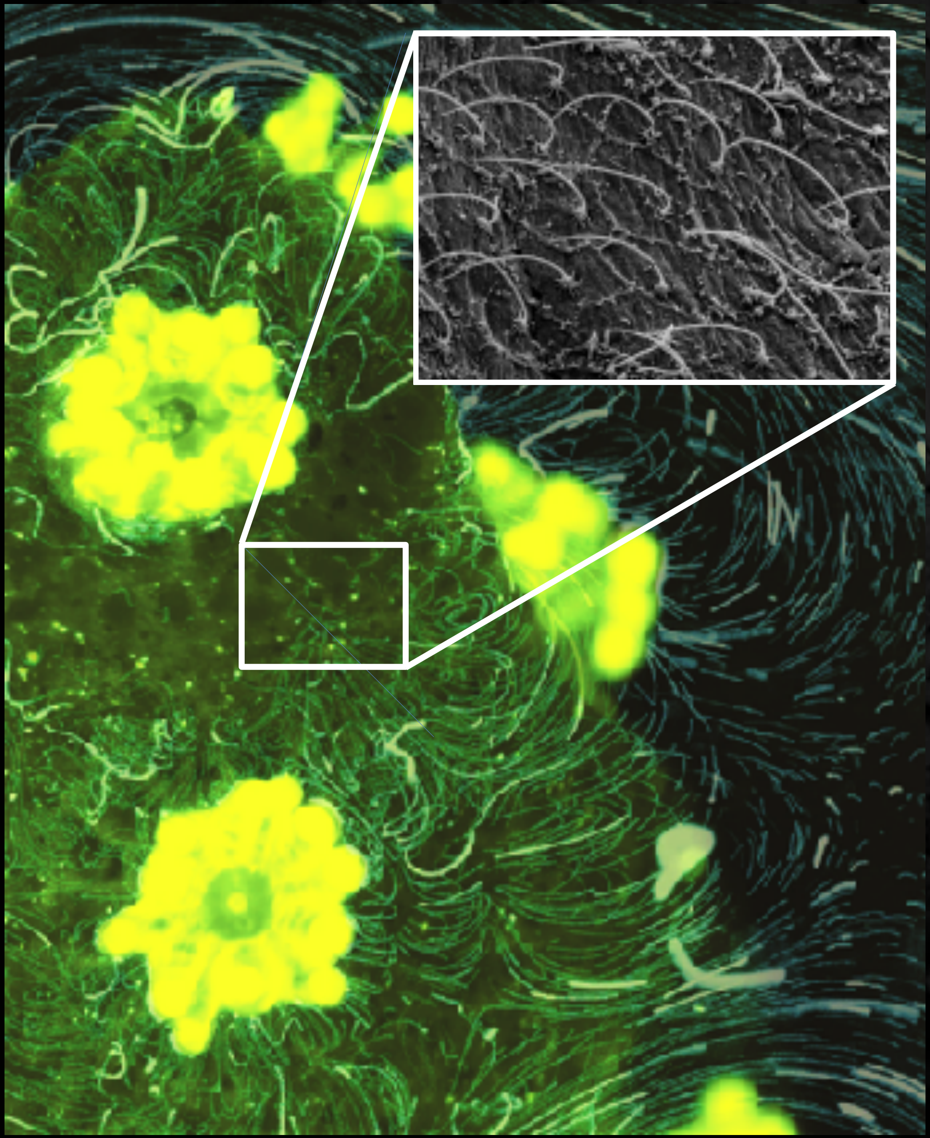


Garren, … & Stocker, ISME J 2014

Chemotaxis towards coral mucus

Migration rate << Swimming speed

The coral microenvironment



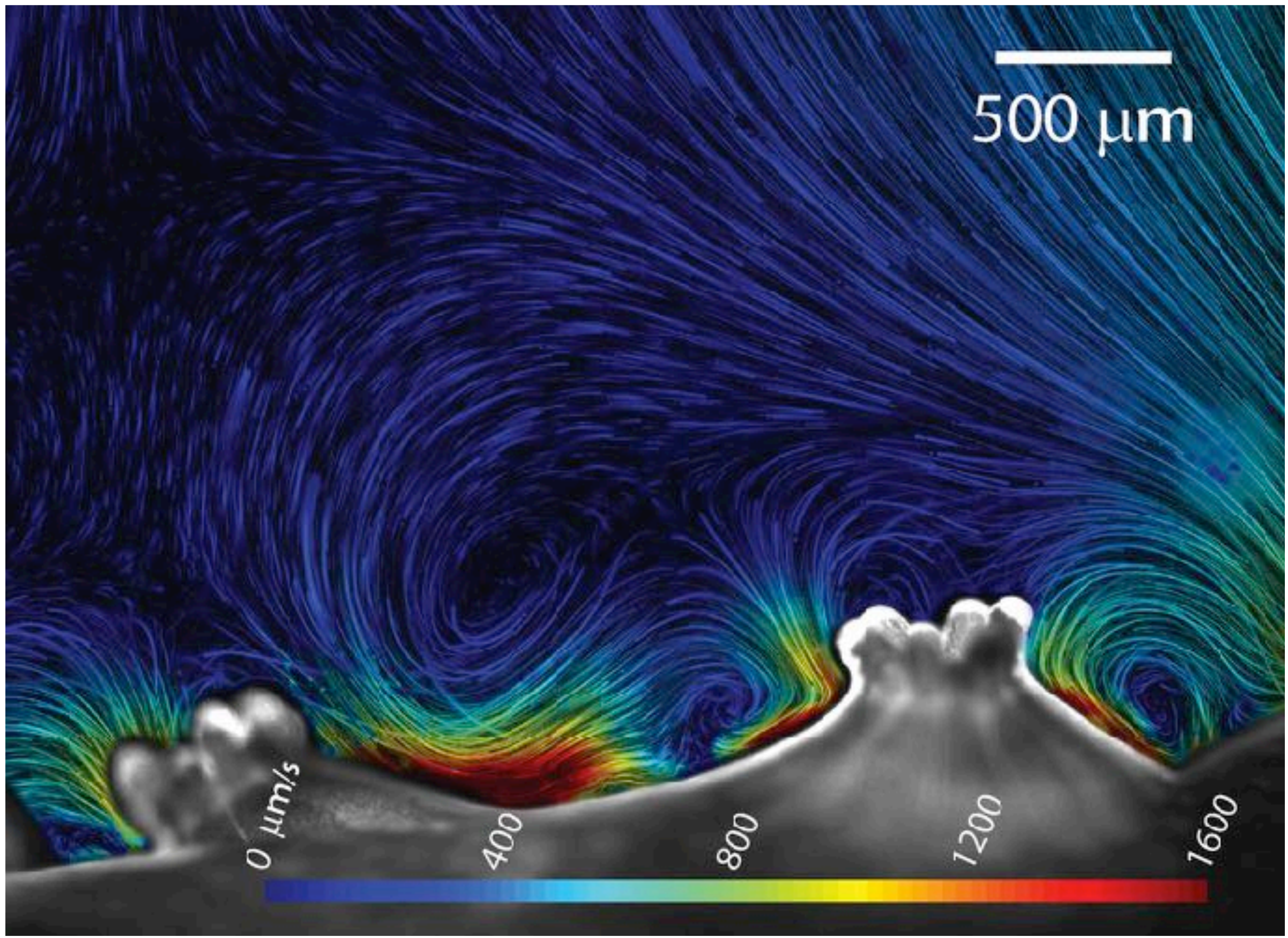
Fluid flow near coral surfaces is surprisingly complicated

Frequent vortices are generated by aligned surface cilia

These vortices help dissipate oxygen for photosynthesis

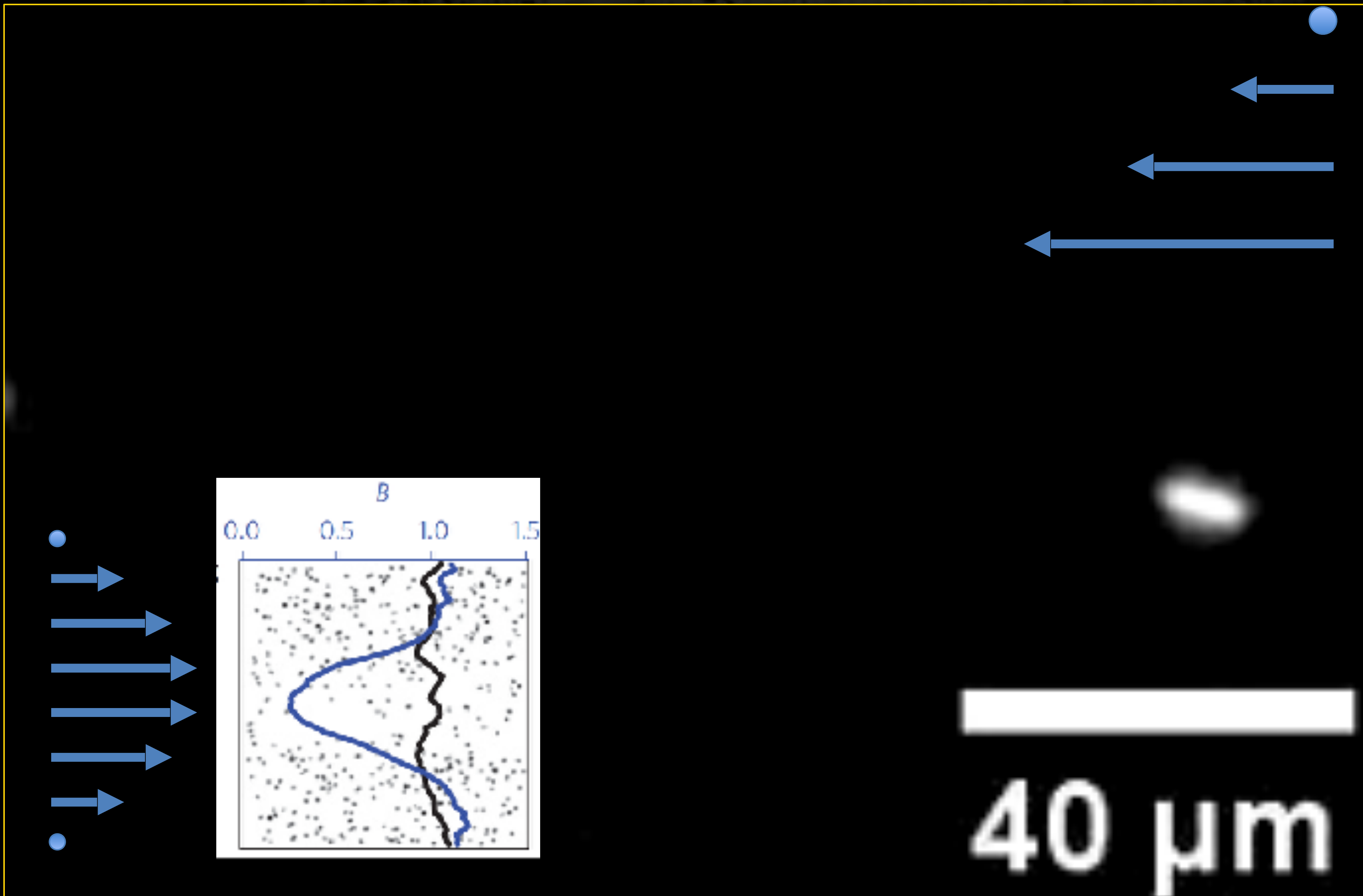
They also provide a 'physical immune system' against pathogenic bacteria

Shapiro, Fernandez, … & Stocker, PNAS 2014

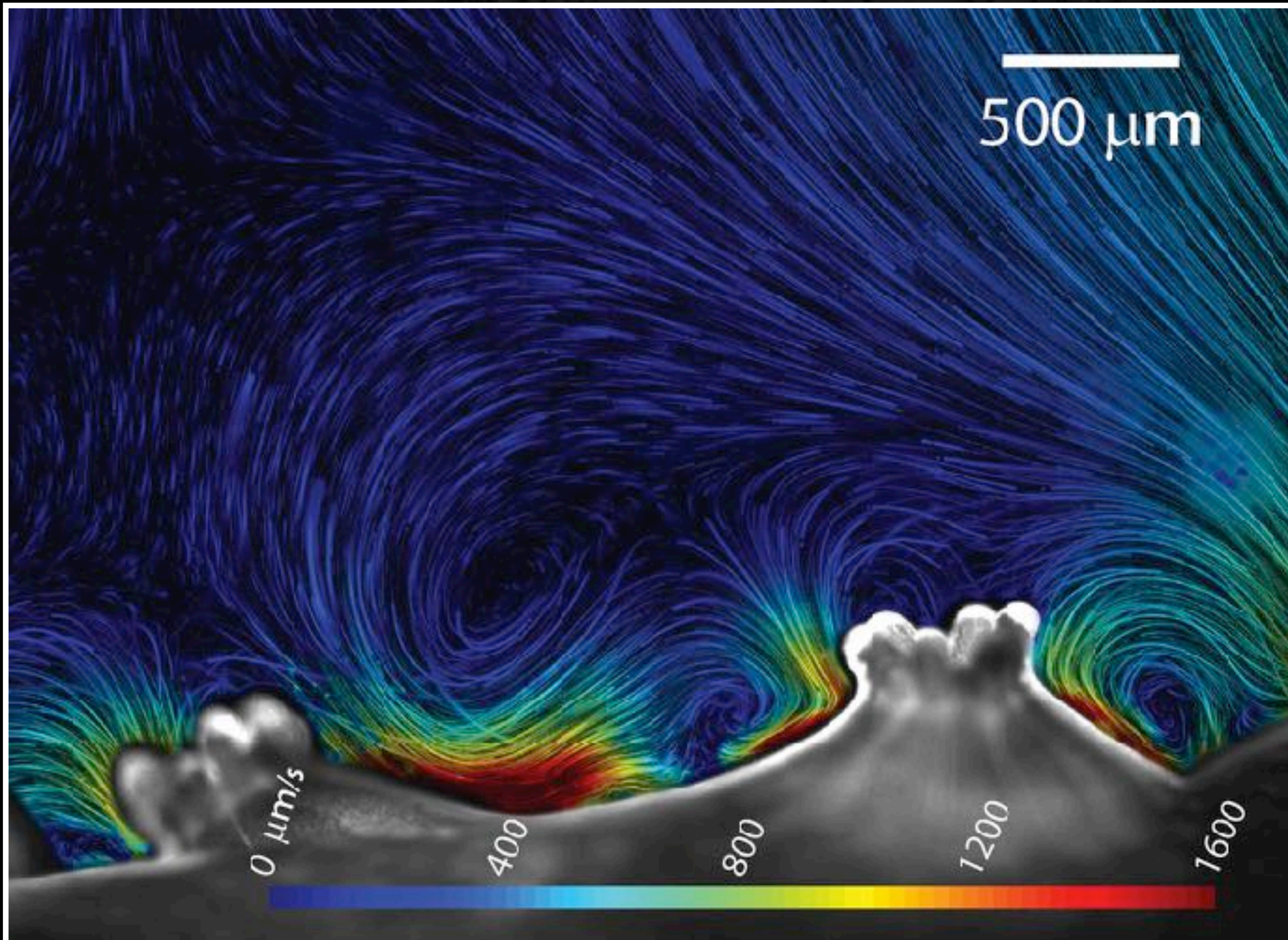


Shapiro, Fernandez, … & Stocker, PNAS 2014

Bacteria in shear flow

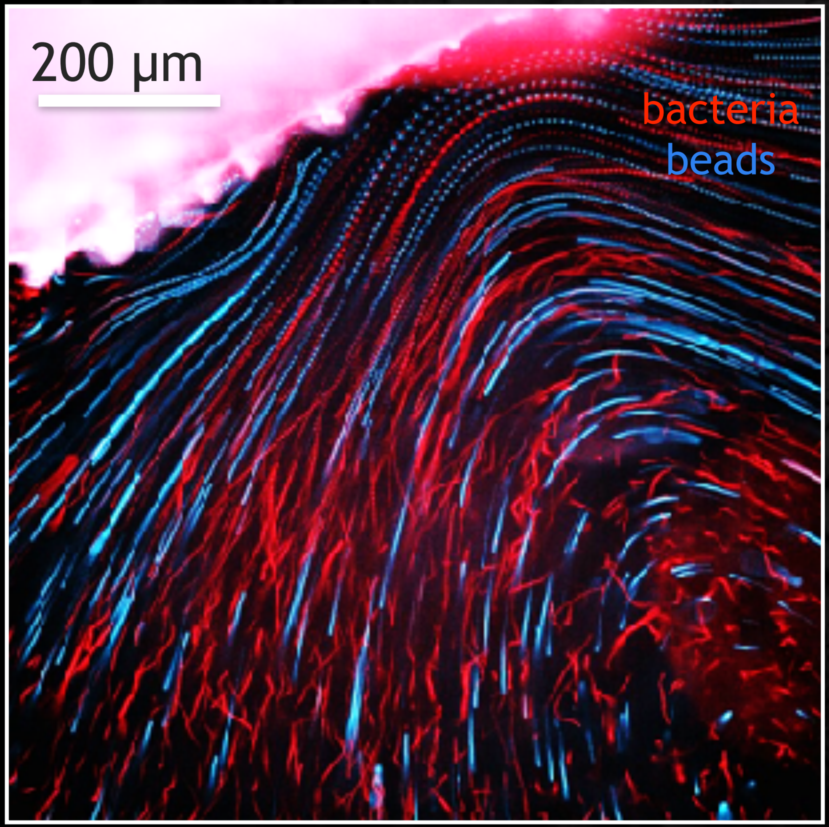


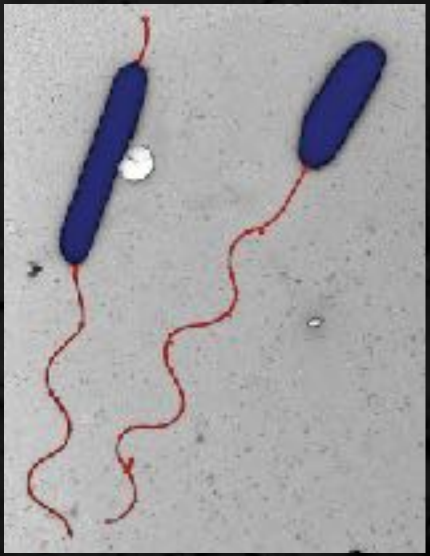
Rusconi, Guasto & Stocker, Nature Physics, 201



Shapiro, Fernandez, … & Stocker, PNAS 2014

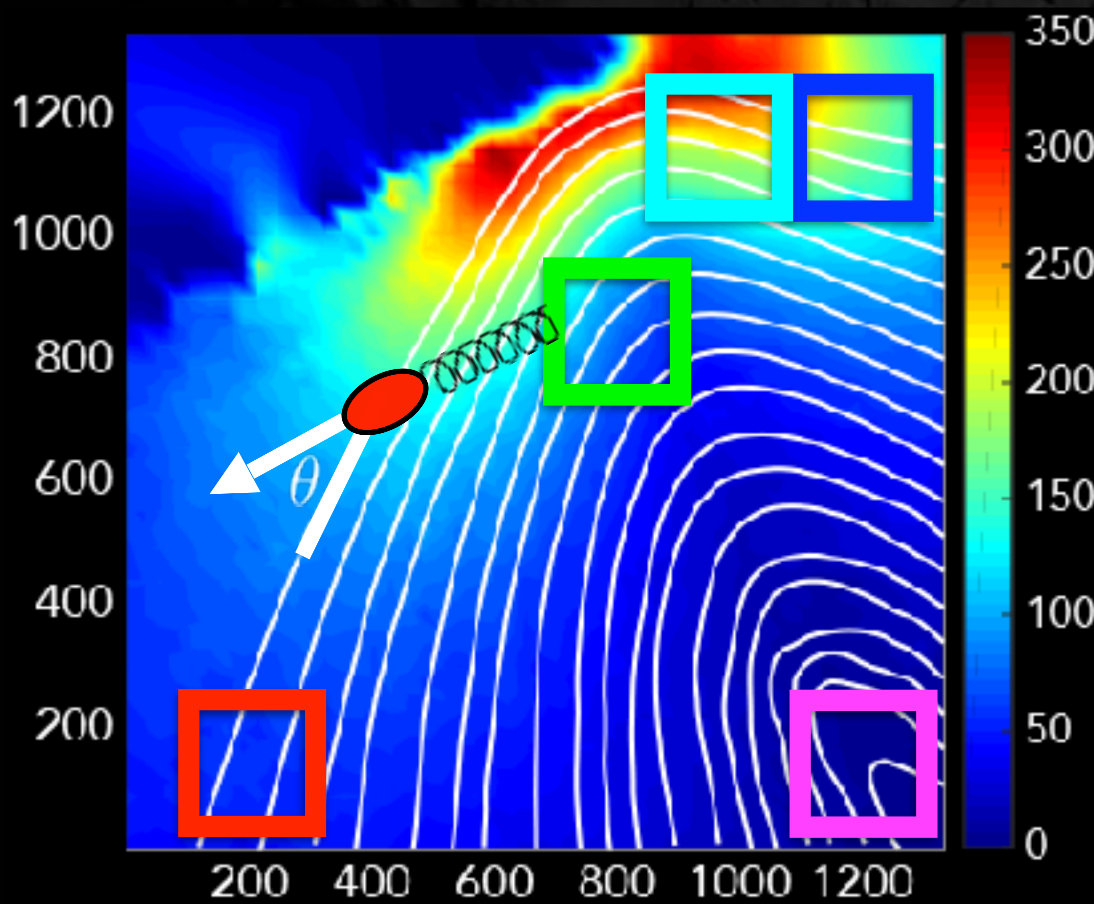
Bacteria do not go with the flow



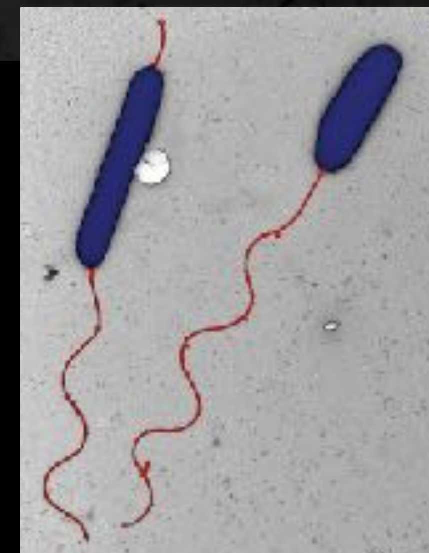


Brumley, … & Stocker, in prep

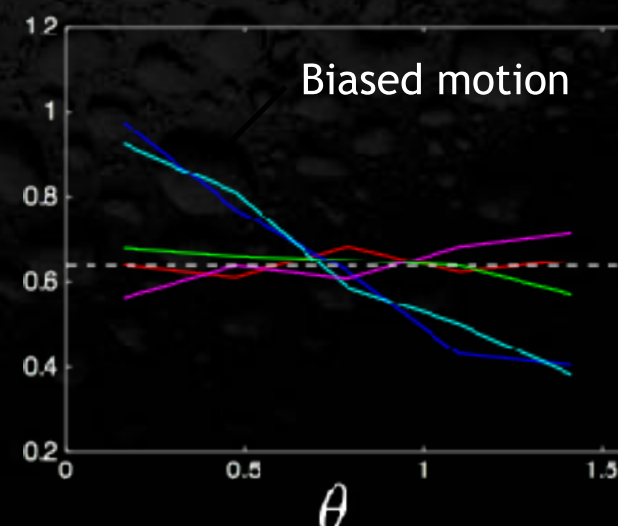
Bacteria do not go with the flow



Cross-streamline migration hindered by flow

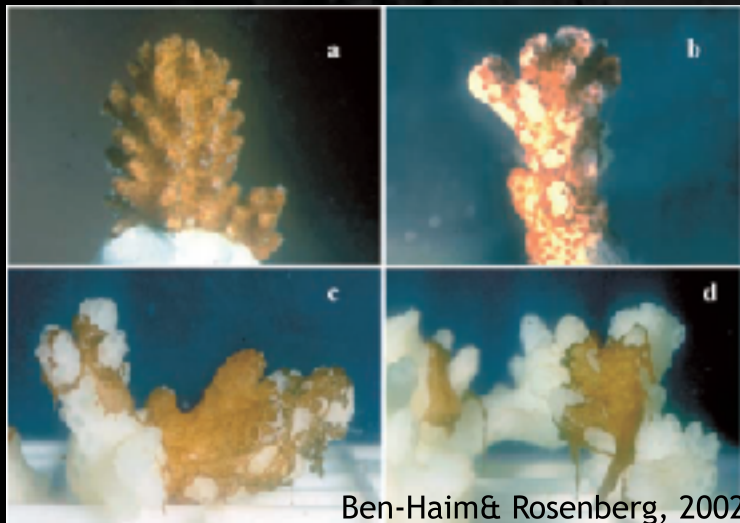


Histogram (140,000 points)

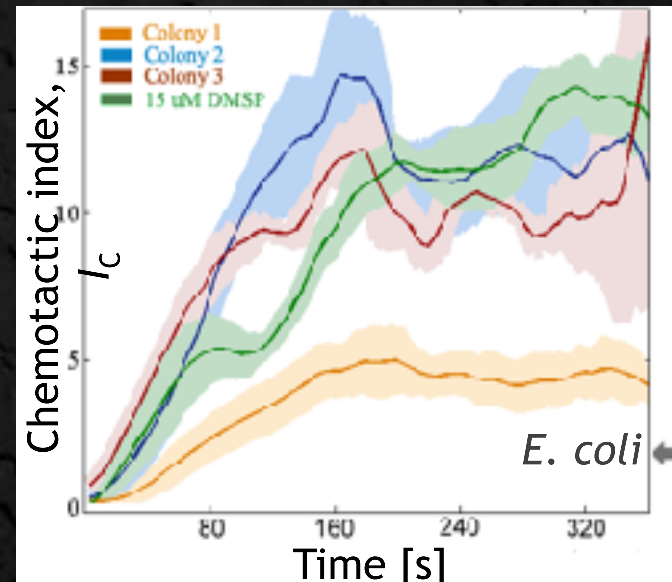


Brumley, … & Stocker, in prep

Bacteria do not go with the flow

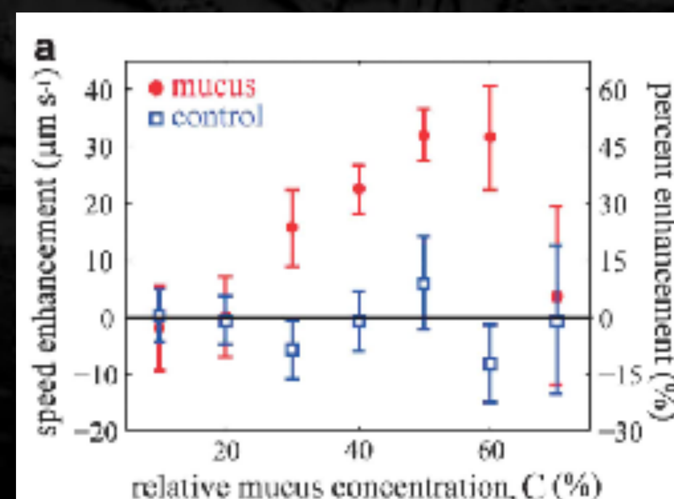


Ben-Haim& Rosenberg, 2002



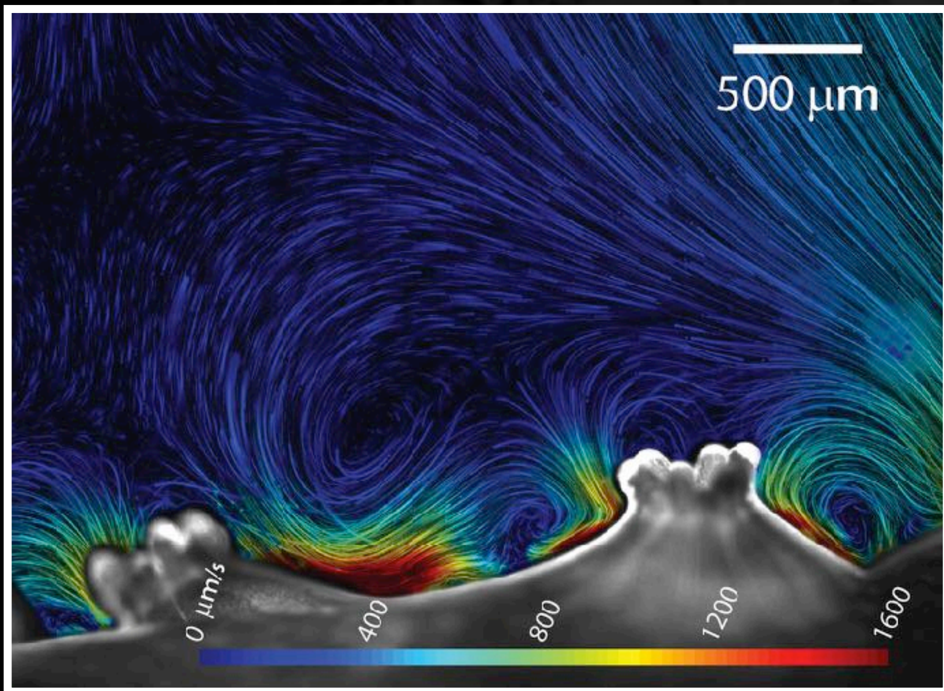
Despite these defenses, vibrio *coralliilyticus* infects and bleaches coral

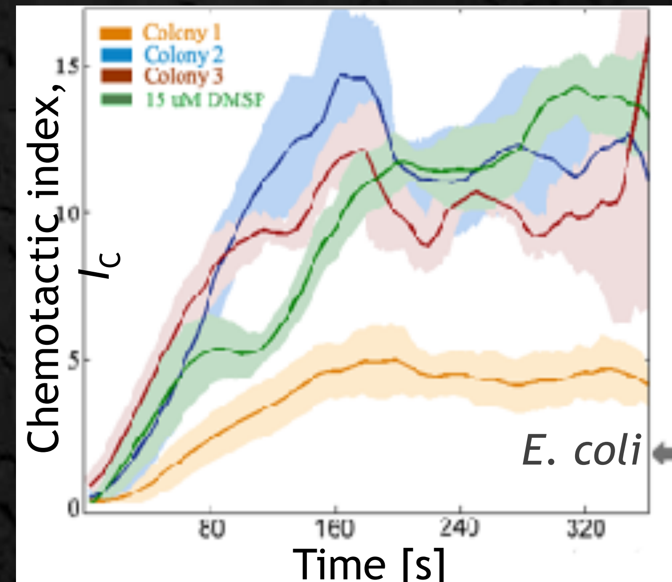
Motility is part of the explanation

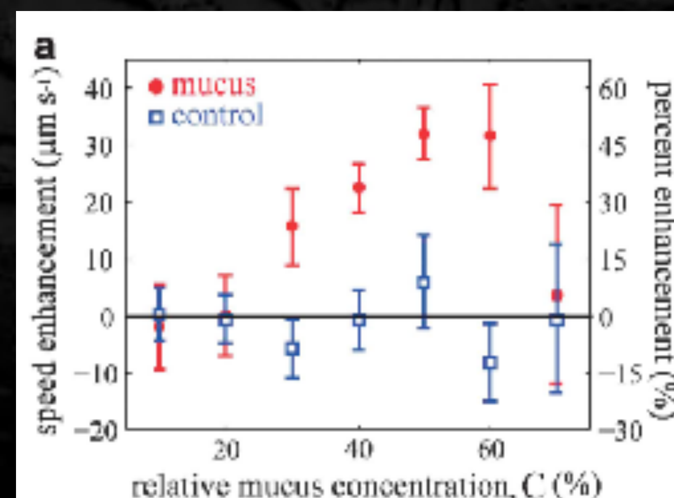


Garren, … & Stocker, ISME J 2013,

Bacteria do not go with the flow



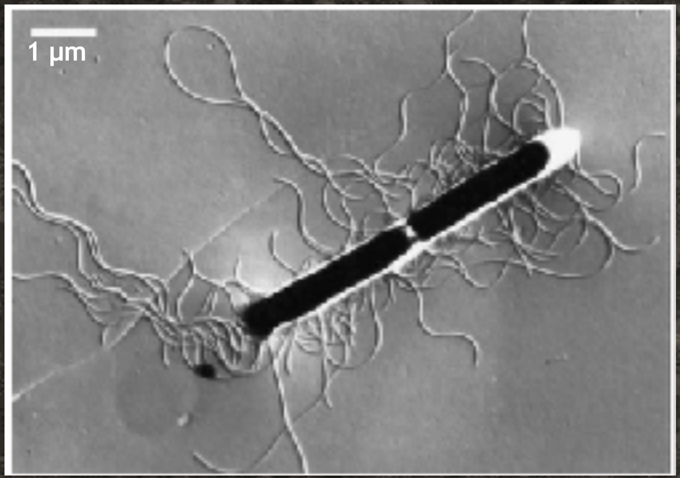




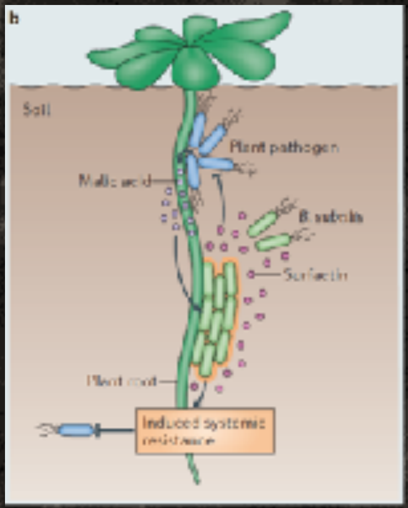
Motility is part of the explanation

Garren, … & Stocker, ISME J 2013,

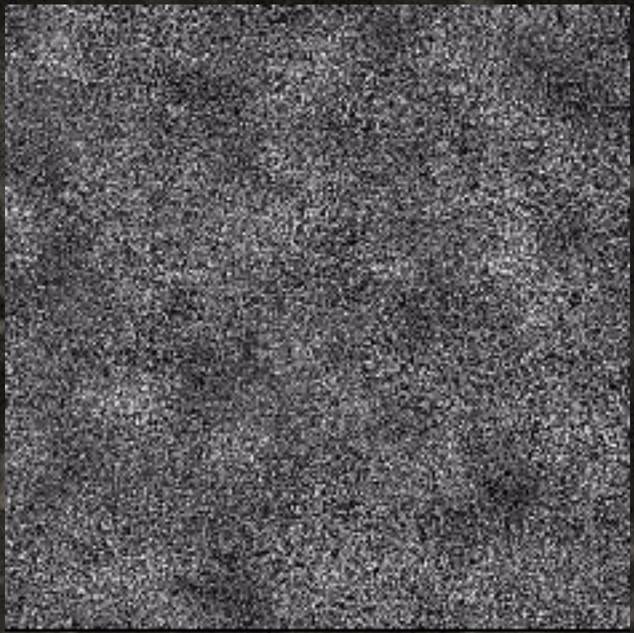
Bacillus subtilis



(Cisneros *et al.* 2007)



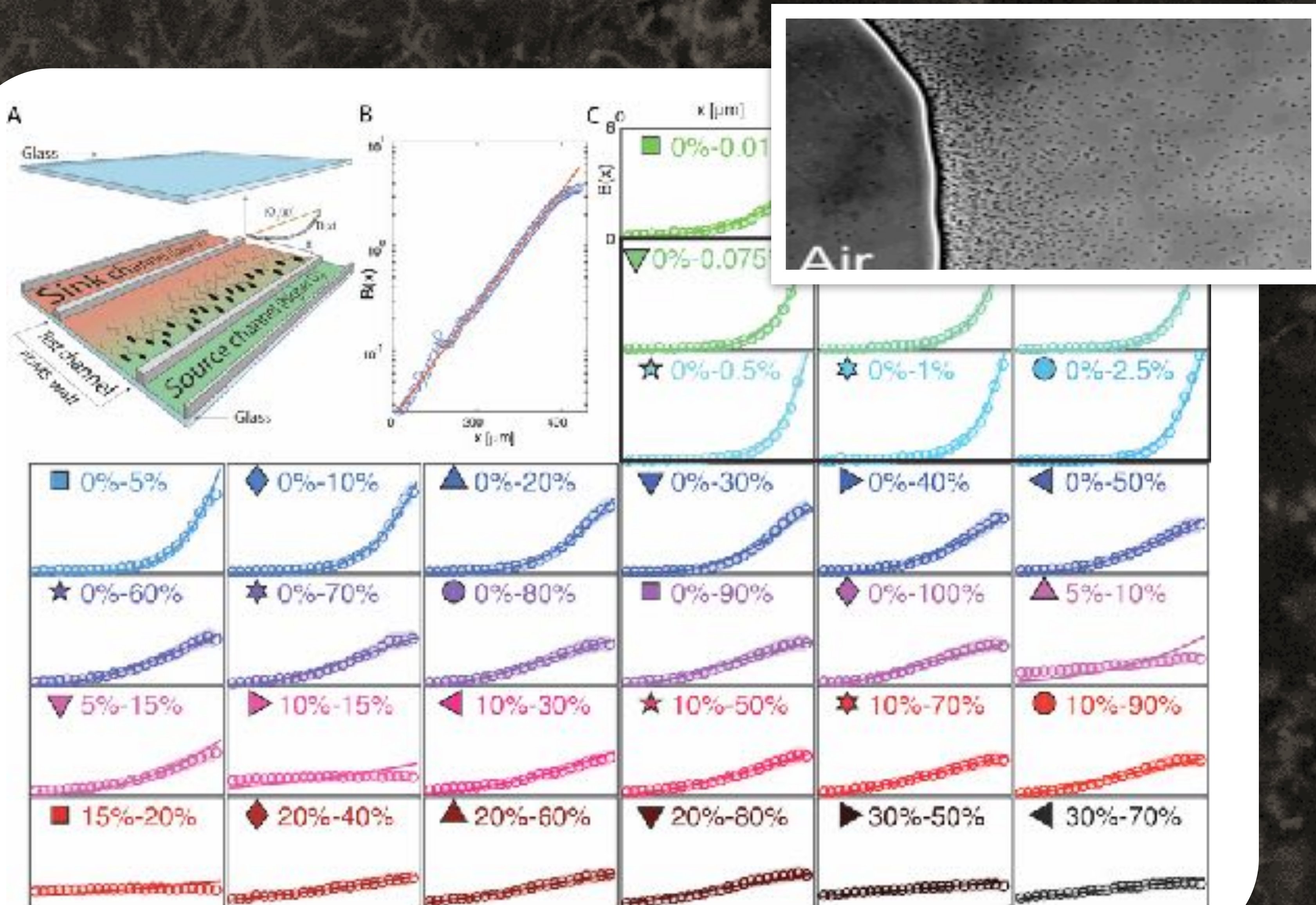
(Vlamakis *et al.* 2013)



(Cisneros *et al.* 2011)

- Rod shaped
- Multiple flagella
- Run and tumble motility
- Flagellar bundles can form at either end
- 20 µm/s swimming speed

Aerotaxis in *B. subtilis*



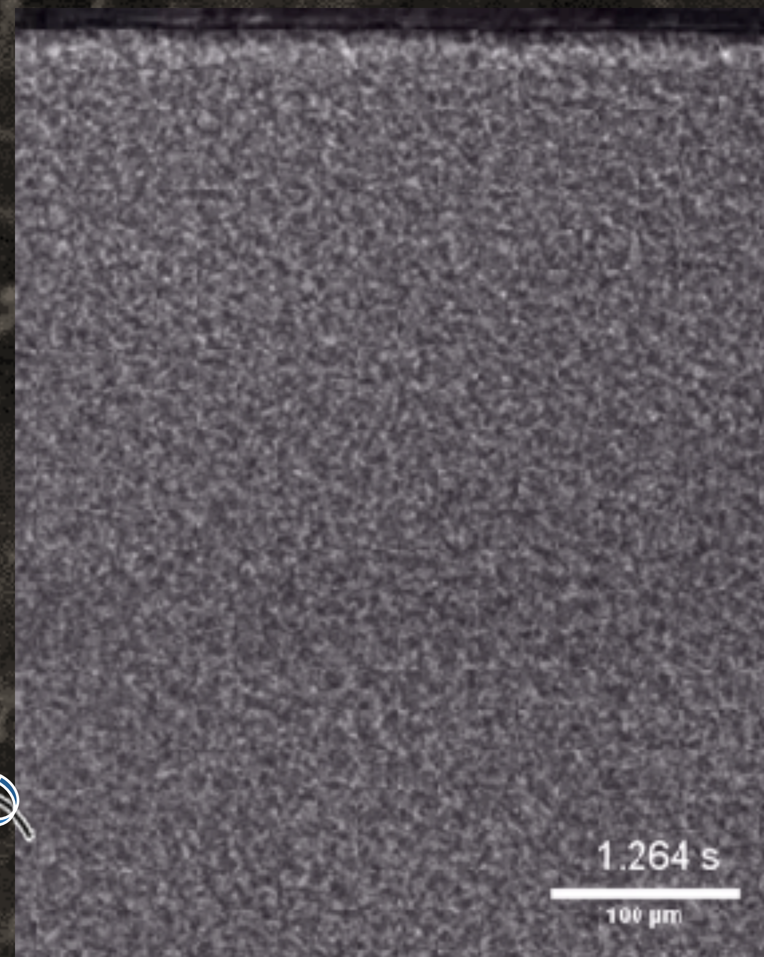
Menolascina *et al. NPJ Syst Biol Appl* 20

Oxygen in dense suspensions

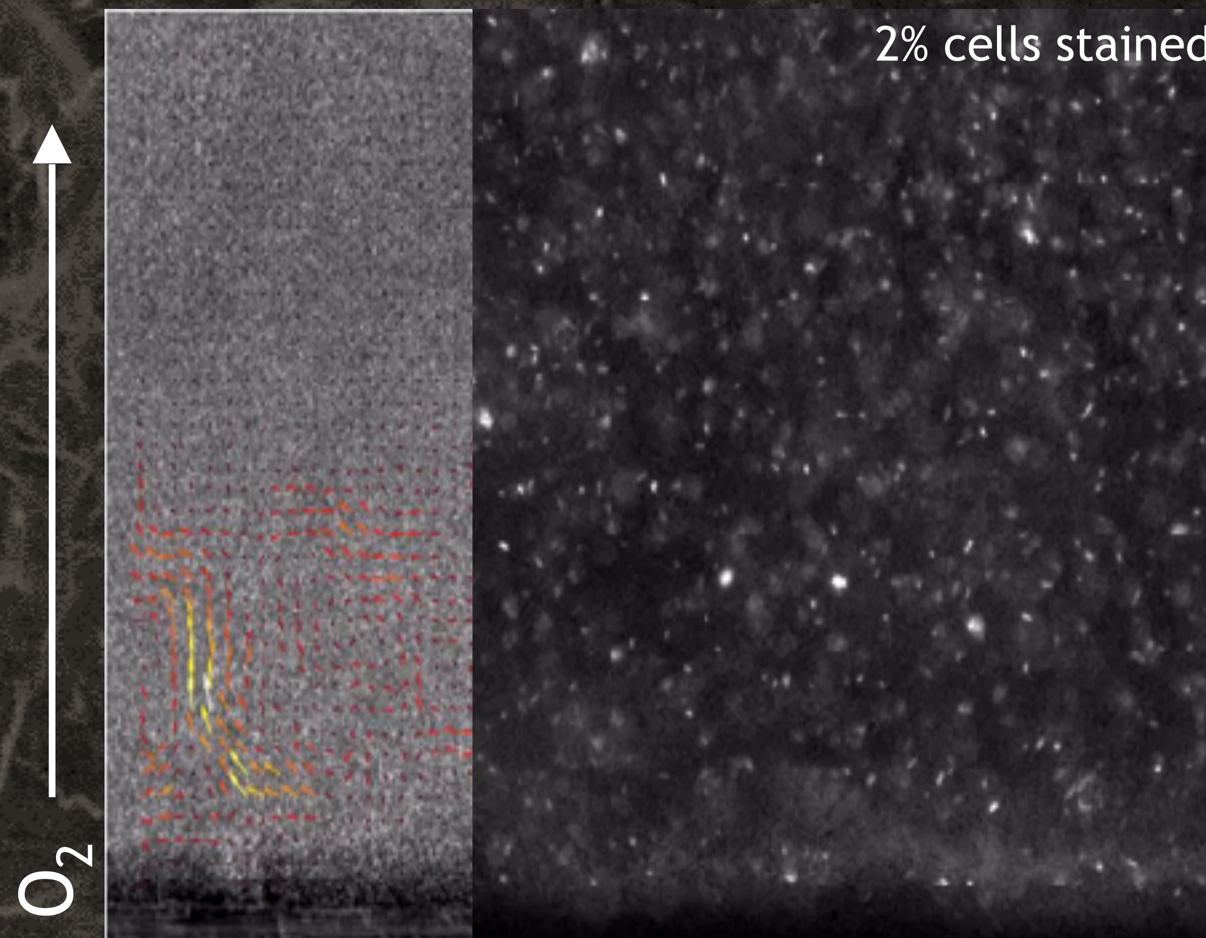
O_2 dependence allows us to exert some control over individuals in an active fluid

- Motility enabled as oxygen increases over a threshold value
- Bias in behavior of individuals in response to a gradient

Are active matter dynamics influenced by aerotactic behavior in individuals?



Tracking individual bacteria

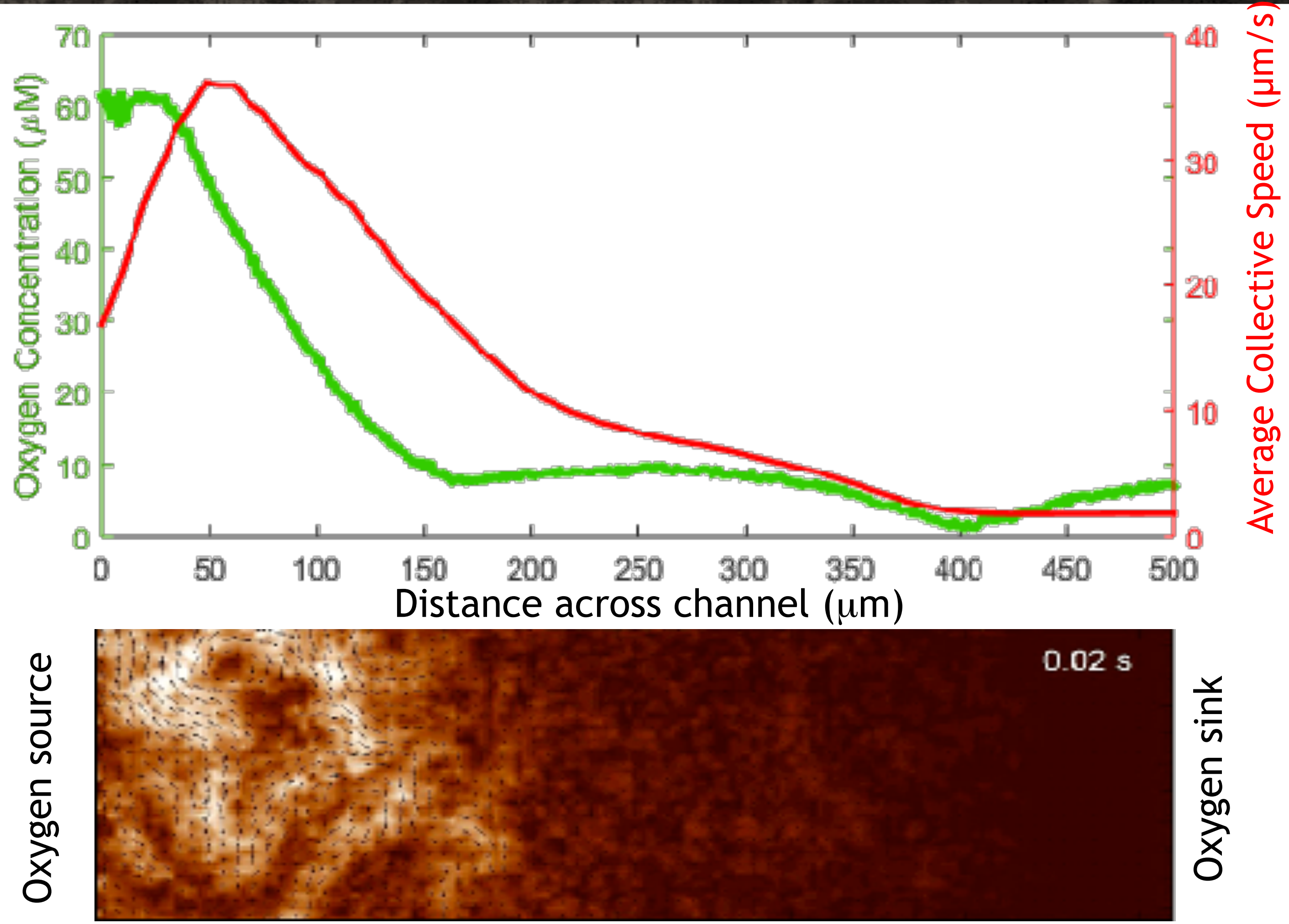


Phase imaging

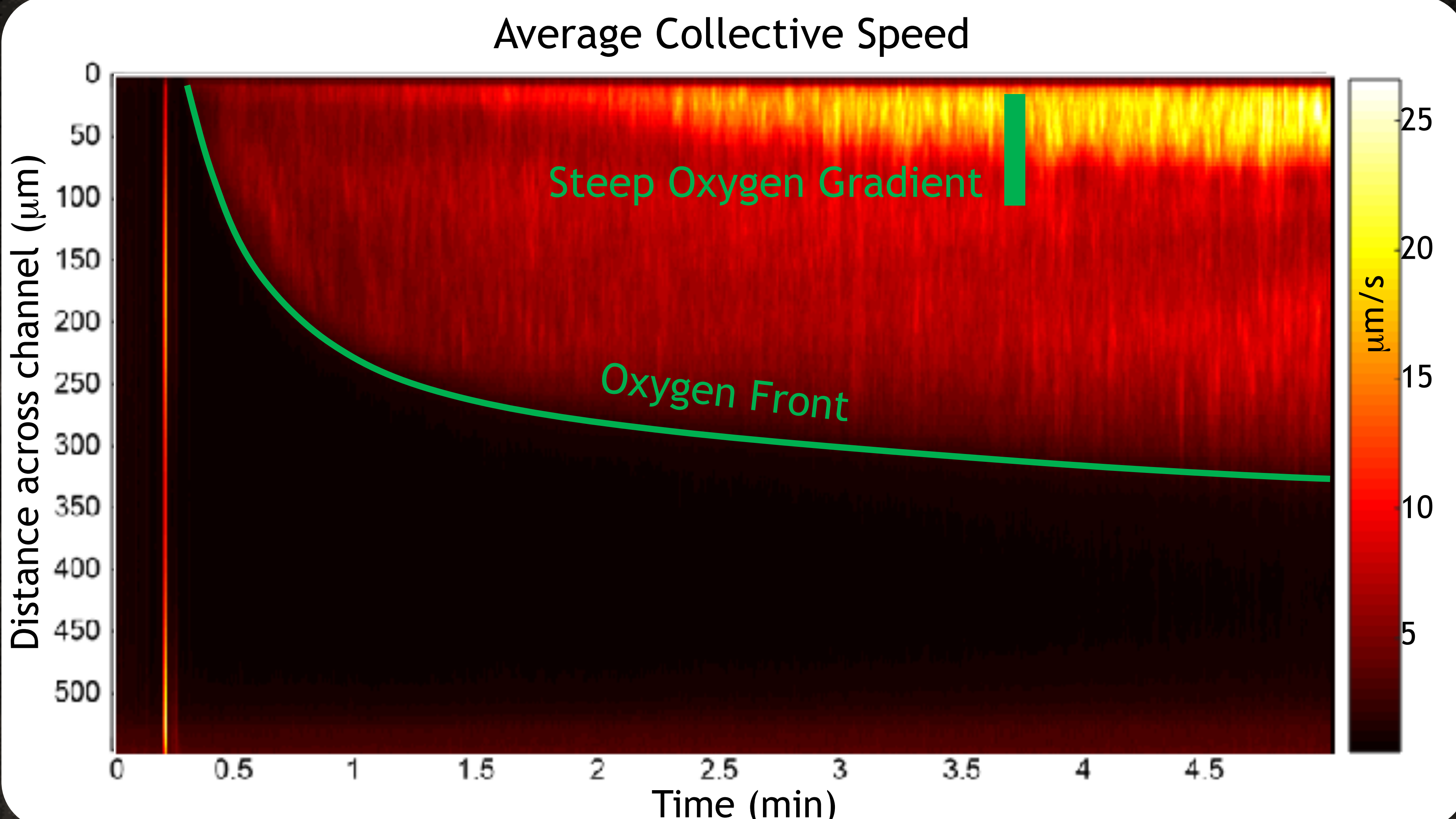
Fluorescently labeled bacteria (not simultaneous)

½ speed

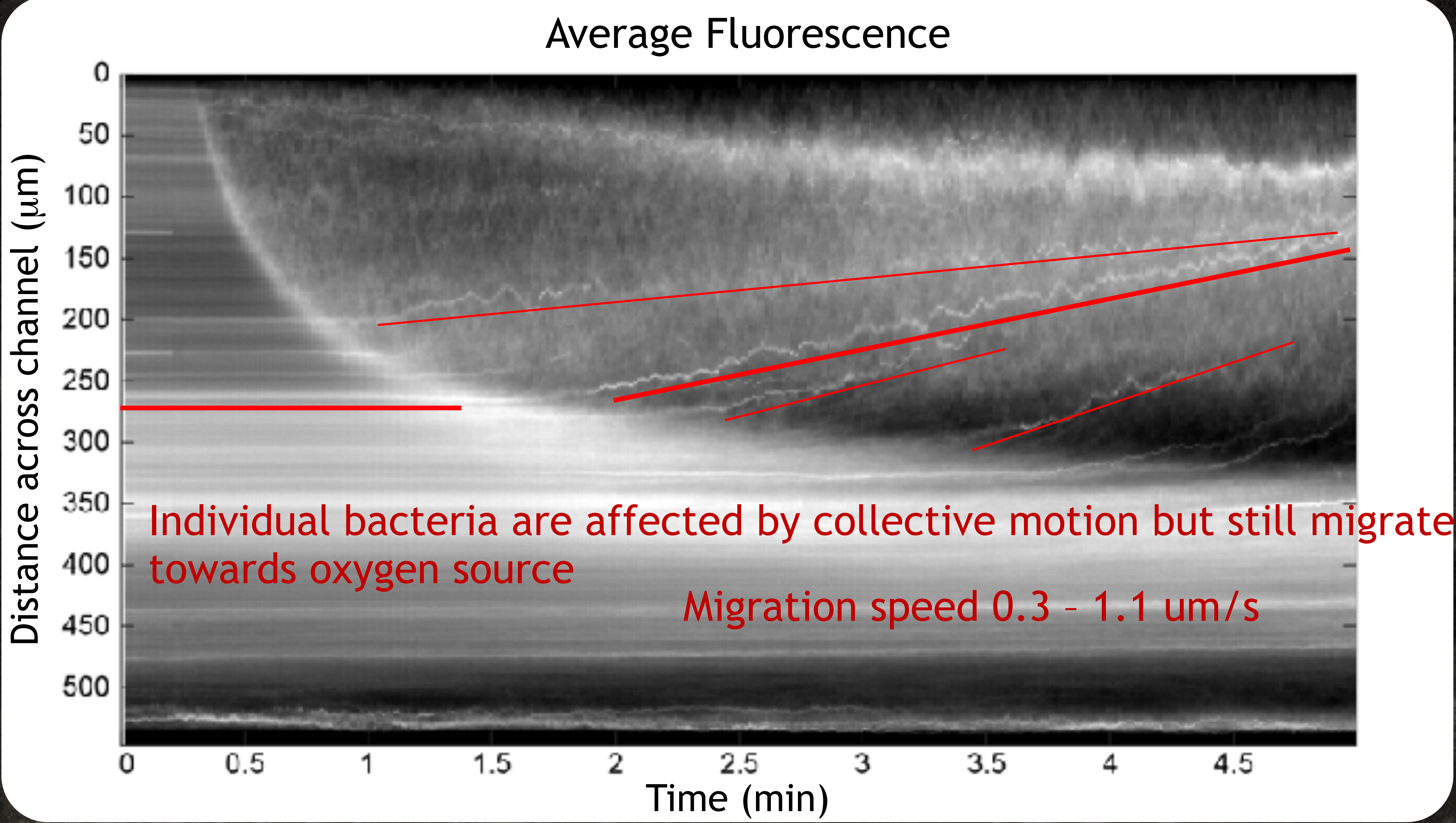
Relationship between oxygen and collective motion

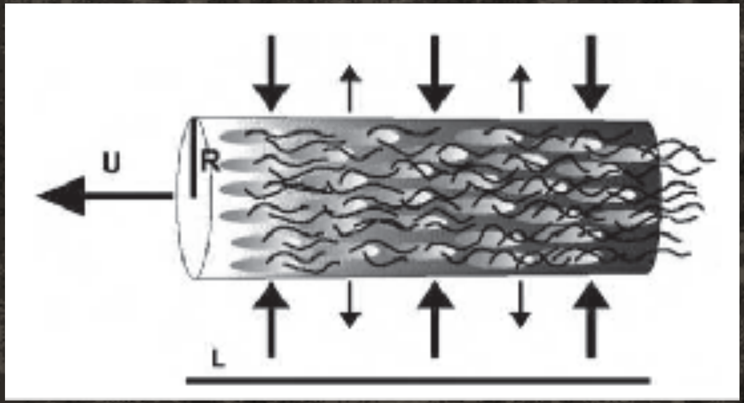


Transient collective speed

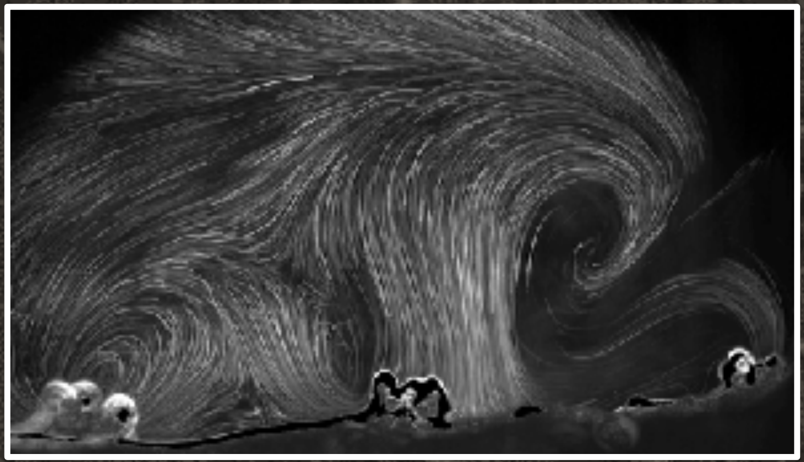


Individual aerotaxis observed in dense suspensions





(Cisneros *et al.* 2007)



- Many challenges for bacteria at small scales (low Re, point measurements, rotational diffusion, high external flow)

- Despite this, individual bacteria are able to navigate their environments

Thanks!

- Roman Stocker
- Steven Smriga
- Orr Shapiro
- Filippo Menolascina
- Jim Mitchell
- Assaf Vardi
- Roberto Rusconi
- Douglas Brumley
- Melissa Garren