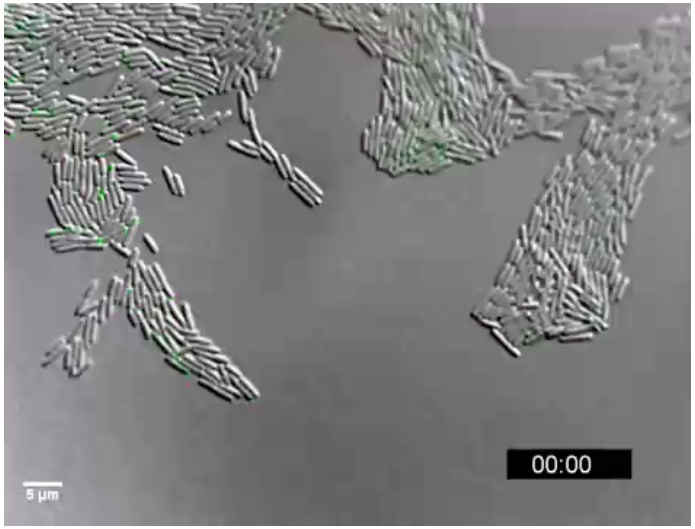
Teaser movie: Twitching

Twitching is one type of gliding: a near-surface motility mechanism, driven by irregular and jumpy cellular motion.



YouTube (Dr. Lori Burrows, McMaster University)

Lecture 5: confined nanoparticles and walking bacteria

S-RSI Physics Lectures:
Soft Condensed Matter Physics

Jacinta C. Conrad
University of Houston
2012

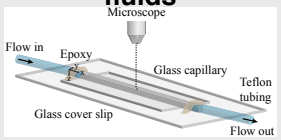
Note: I have added links addressing questions and topics from lectures at:
http://conradlab.chee.uh.edu/srsi_links.html
Email me questions/comments/suggestions!

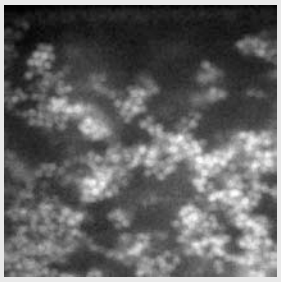
Soft condensed matter physics

- Lecture 1: statistical mechanics and phase transitions via colloids
- Lecture 2: (complex) fluid mechanics for physicists
- Lecture 3: physics of bacteria motility
- Lecture 4: viscoelasticity and cell mechanics
- **Lecture 5: Dr. Conrad's work**

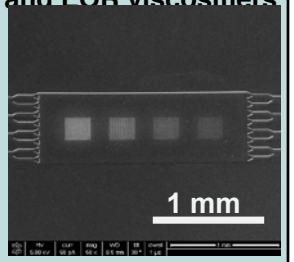
Lab theme: "particles" near surfaces

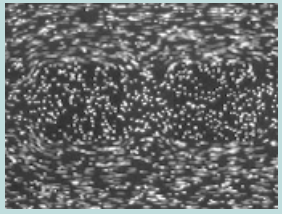
Models of drilling fluids



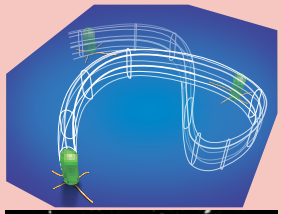


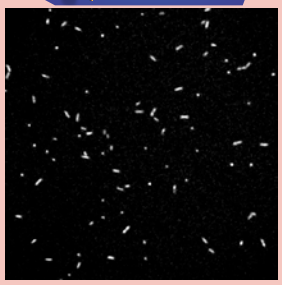
Nanoparticle probes and EOR viscosifiers





Antifouling surfaces





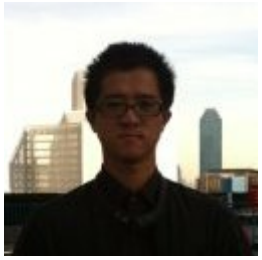
jcconrad@uh.edu / cónradlab.chee.uh.edu

Why do surfaces modify transport?

Topic 1: nanoparticle transport

How do nanoparticles and colloids change their behavior when moving in porous media?

Students:



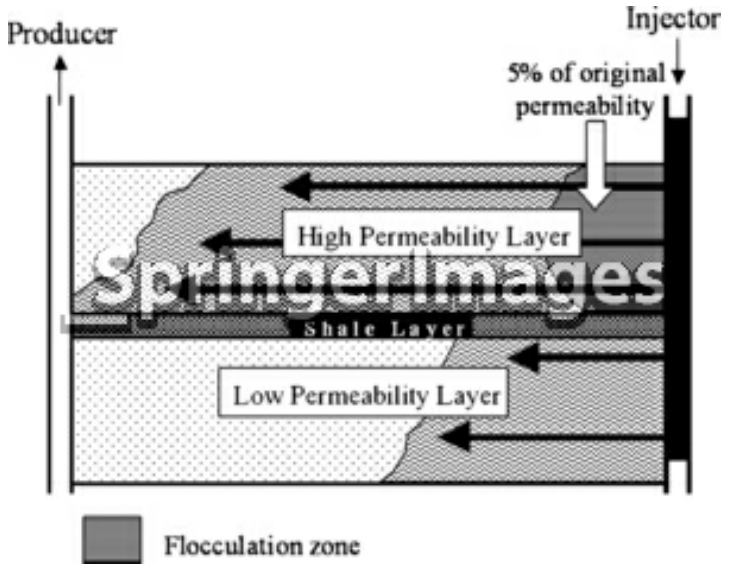
Kai He

Firoozeh Babaye Khorasani

Rahul Pandey

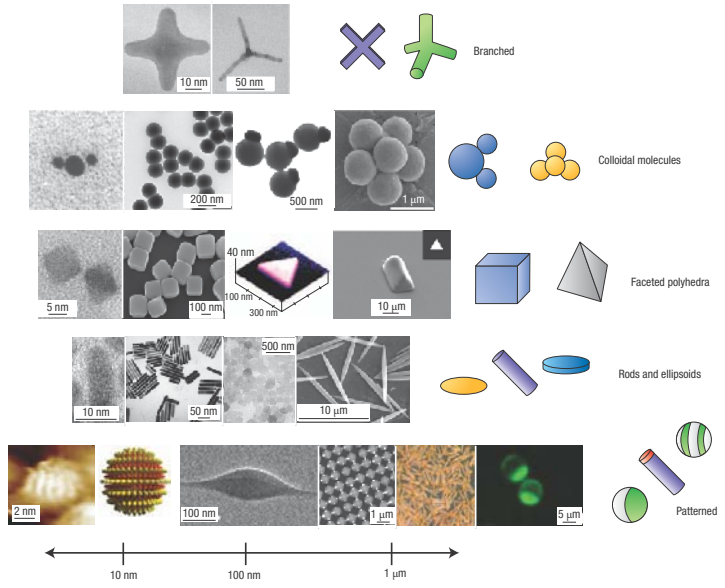
in collaboration with Ramanan Krishnamoorti (UH)

Application: enhanced oil recovery



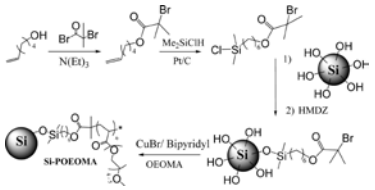
SpringerImages

Nanoparticle “zoo”

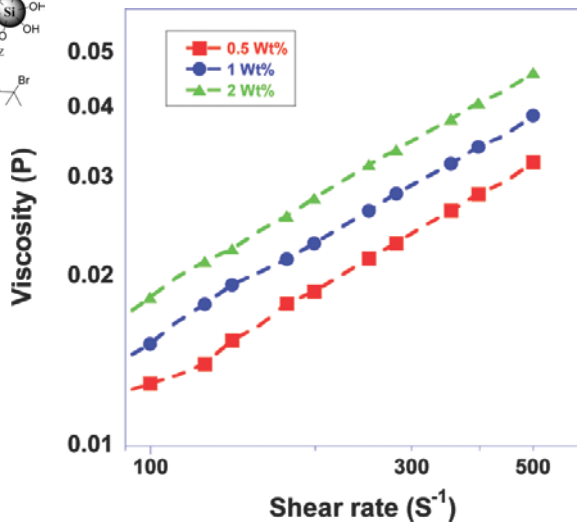


Glotzer and Solomon, *Nat. Mater.* (2007)

Nanoparticles as viscosifiers



Suspensions of silica particles coated in polymer brushes (top) exhibit large increases in viscosity with increasing shear rate (left).



Ponnapati *et al.*, *Ind. Eng. Chem.* (2011)

Measurements: relaxation time

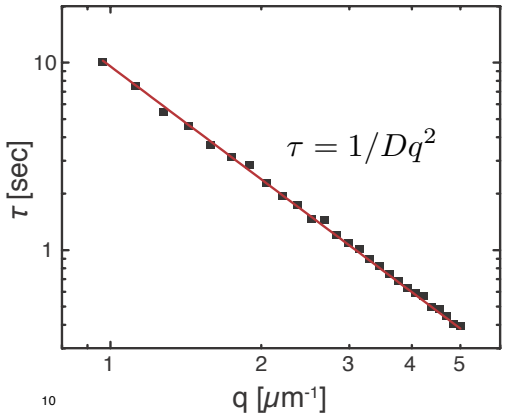
Recall: diffusion time for a spherical particle $D = \frac{k_B T}{6\pi\eta a}$

η = viscosity
a = nanoparticle radius

Units on the diffusion coefficient: [D] = length^2 / time

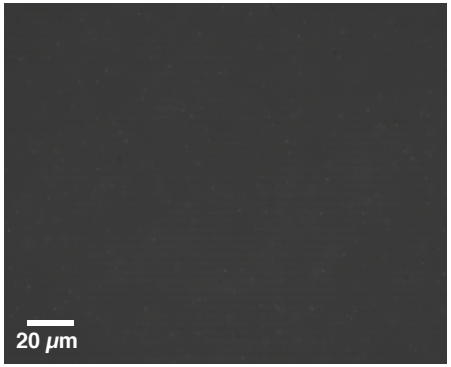
Measurements: measure the relaxation time τ that it takes a particle to diffuse as a function of the wave vector q.

The wave vector $q = 2\pi / L$, where L is a length scale.



Differential dynamic microscopy

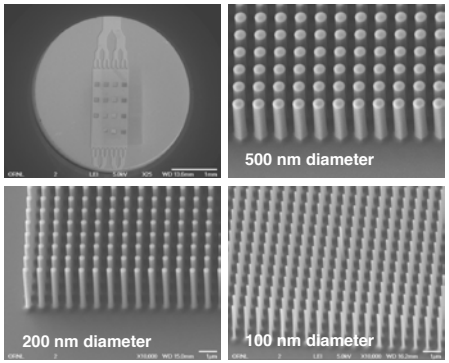
Key idea: subtract microscopy images in a time series, and analyze the changes in intensity.

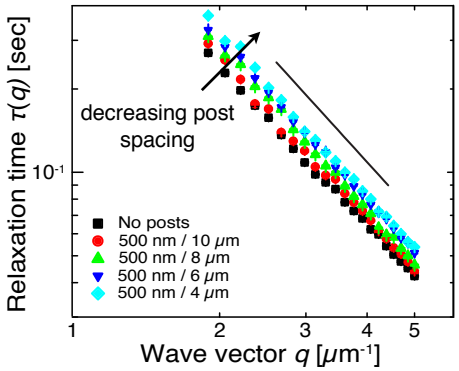


Kai He, FIroozeh Babaye Khorasani, and others

Open question: effect of confinement?

Approach 1: fabricate model porous media using advanced microfabrication techniques.





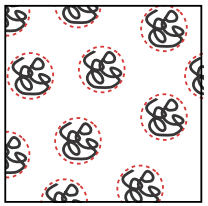
Fascinating open question: the scaling of the relaxation time does not follow the scaling of the pore width or pore area!

Kai He and others

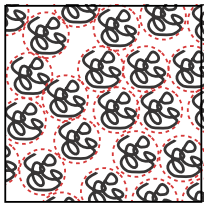
Open question: effect of confinement?

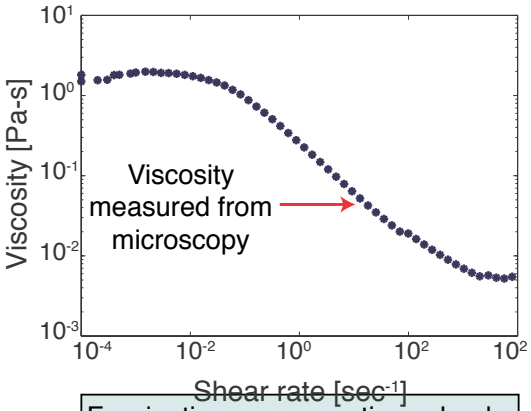
Approach 2: measure dynamics of nanoparticles in polymer solutions close to the overlap concentration (c^*) at which polymer coils begin to overlap.

$c < c^*$



$c \approx c^*$

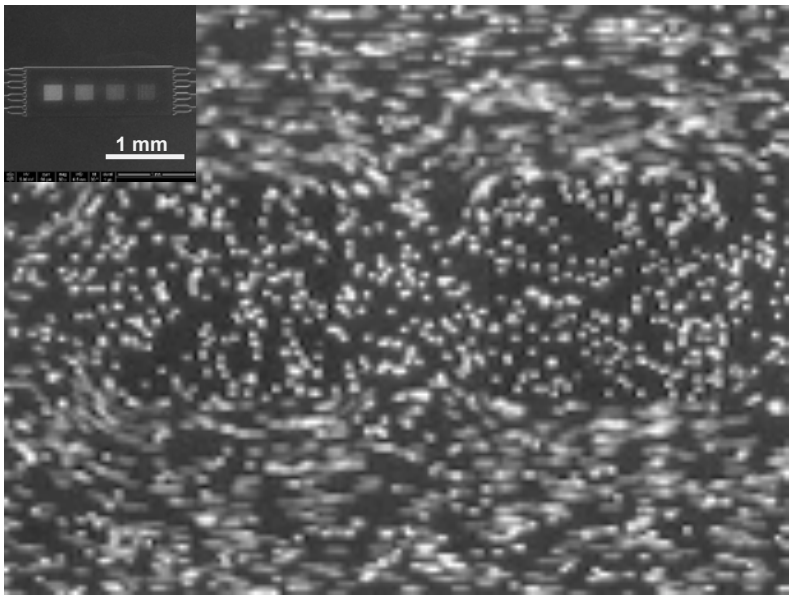




Fascinating open question: why do we measure a viscosity that does not correspond to a quiescent (unsheared) sample?

Firoozeh Babaye Khorasani, Yousuf Janoowala, and others

Going forward: flow properties



Topic 2: walking bacteria

How do microbial species attach to and/or move on surfaces?

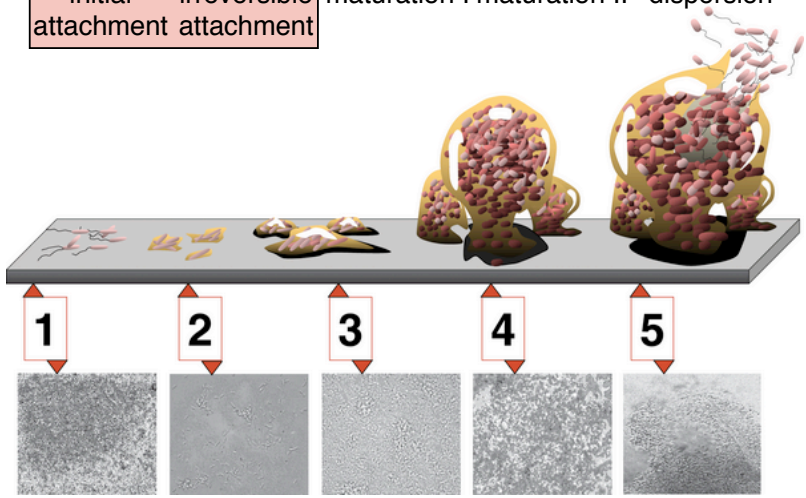
Students:

Sumedha Sharma Jinsu Kim

in collaboration with Gerard Wong (UCLA), Richard Willson (UH), Debora Frigi Rodrigues (UH)

Model of biofilm formation

initial attachment | irreversible attachment | maturation I | maturation II | dispersion



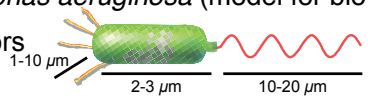
Physics techniques can offer new insight into how bacteria move on and attach to surfaces.

Image: D. Davis / MSU CBE

Pseudomonas aeruginosa

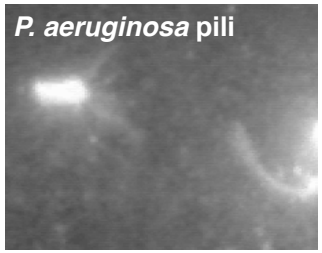
Pseudomonas aeruginosa (model for biofilm formation):

pili: linear actuators



flagellum: rotary motor

L. Burrows (McMaster)

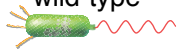


H. C. Berg (Harvard/Rowland)
playback 10×

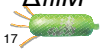
Pilus **stall force**: 70–110 pN
(Maier et al., PNAS (2002))

Biologists can engineer mutants missing one or more appendages:

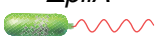
wild-type



Δ*fliM*

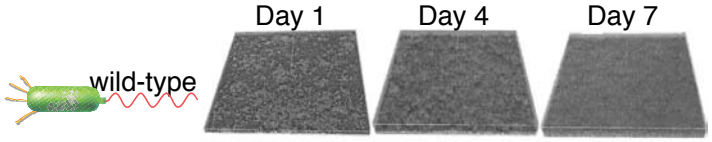


Δ*pilA*



Motility affects biofilm morphology

P. aeruginosa and isogenic knockout mutant strains



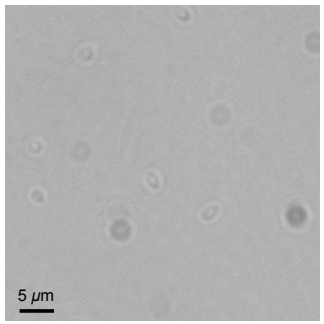
Klausen *et al.*, Mol. Microbiol. **48**, 1511-1524 (2003)

Question: how does motility affect biofilm formation?

Flagellum-driven near-surface motility

Find two ways of moving using single flagellum in our bacteria:

Δ*pilA*



movie duration: 30 sec
(real time)
glutamate-FAB medium
medium flow rate 3.75 mL / hr

wild-type

movie duration: 60 sec
(real time)

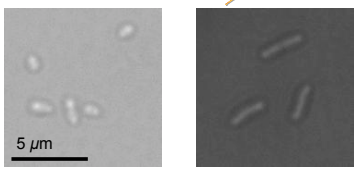
Two types of flagella-driven motility:

- swimming near the surface in curved trajectories
- spinning while self-tethered via the flagellum

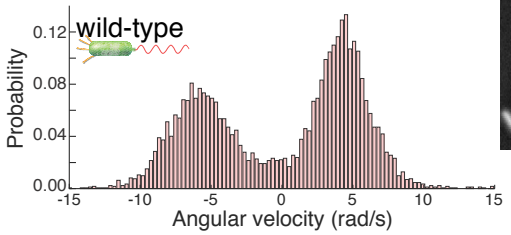
Surface-attached bacteria spin

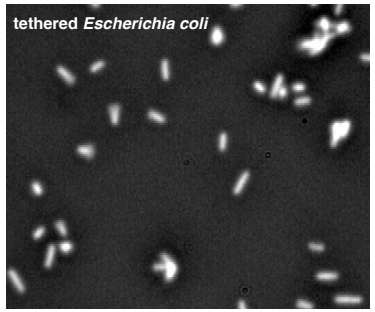
Δ*pilA*

wild-type



playback at real time





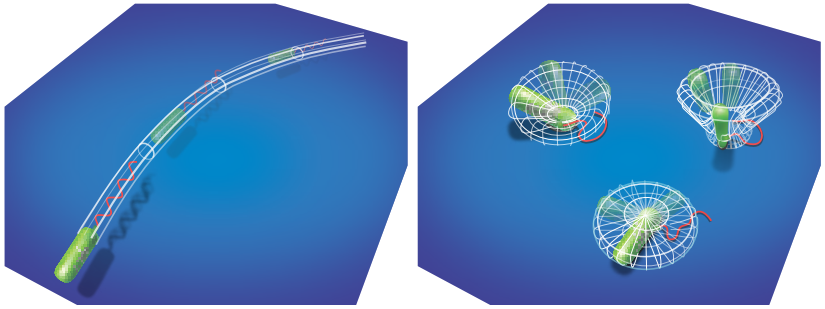
Howard Berg (Harvard/Rowland)
playback 10×

Spinning results from rotation of the motor while the flagellum is attached to the surface.

JCC*, Gibiansky*, Jin, Gordon, Motte, Matthews, Stopka, Zelasko, Shrout, and Wong, *Biophys. J.* (2011)

Flagellum-driven: swimming and spinning

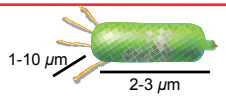
Swimming **Spinning**

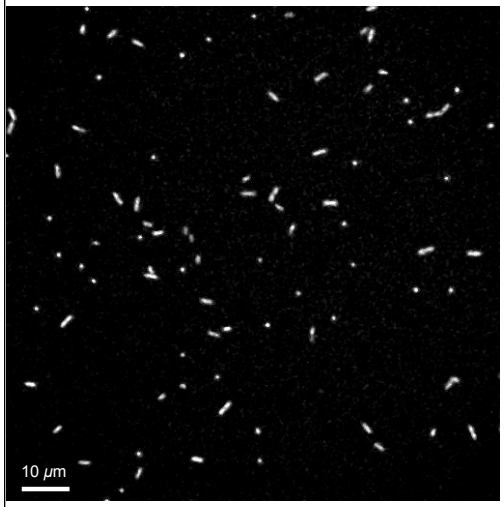


How would you move with grappling hooks?

Pili drive walking and crawling mechanisms

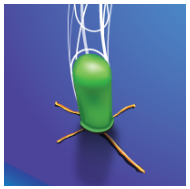
pili
"linear actuators"



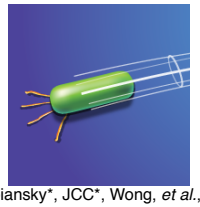


movie duration 62.5 min (sped up 150x)

Walking for areal exploration

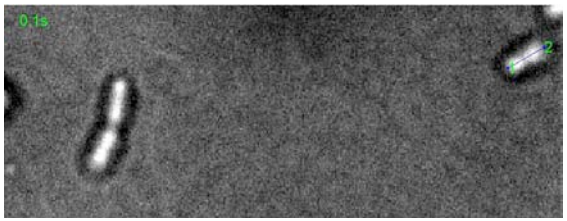


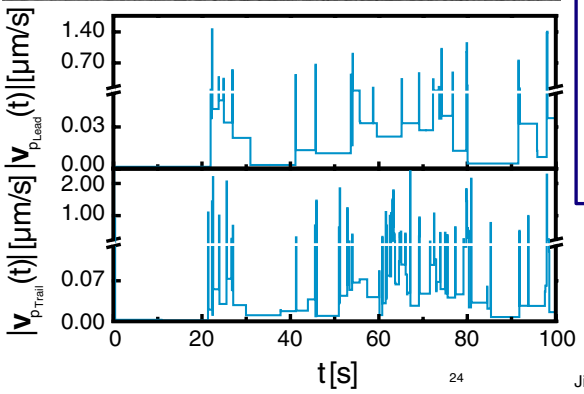
Crawling for long-distance travel

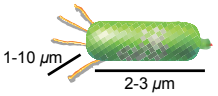


Gibiansky*, JCC*, Wong, *et al.*, *Science* (2010)
JCC*, Gibiansky*, Wong, *et al.*, *Biophys. J.*, (2011)

Snap and release

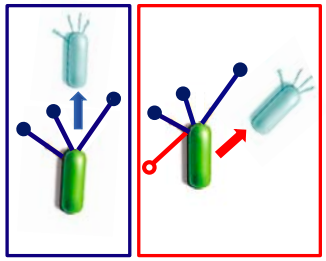






Δ*fliM*

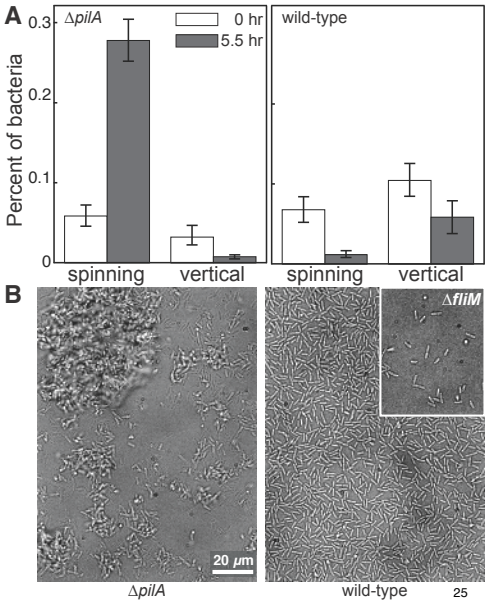
Alternating
Pull ⟷ Release



- Attached pilus tip
- Released pilus tip
- Pilus under tension
- Pilus release

Jin*, JCC*, Gibiansky, and Wong, *PNAS* (2011)

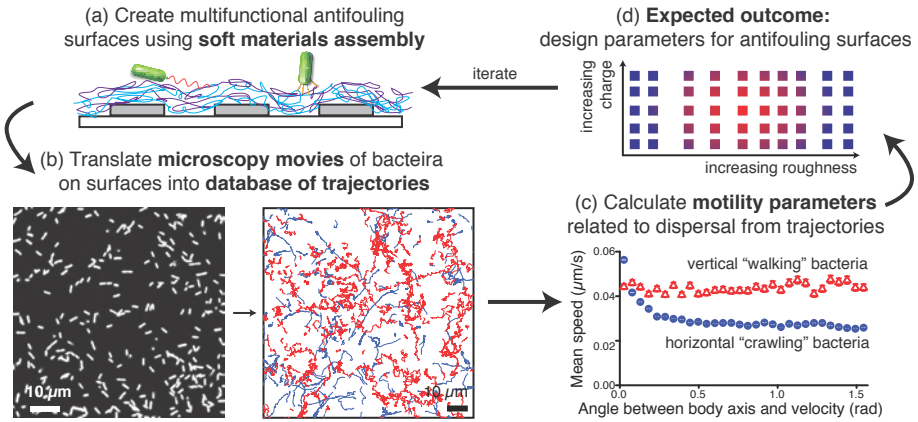
Motility defects change biofilm morphology



	# dividing	# attaching
Δ*pilA*	79	18
wild-type	95	75

- Without pili: biofilm grows by cell division, leading to clusters where cells attach.
- Pili: bacteria detach and redistribute and form a flat biofilm that resists removal.

Outlook: engineering surfaces

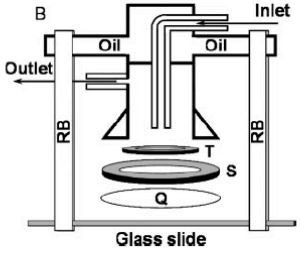


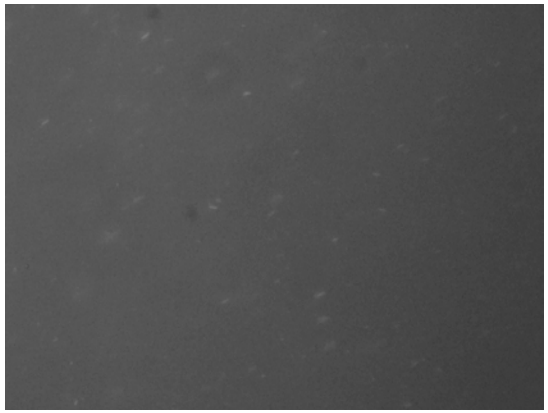
How do we engineer surfaces?

- Surface elasticity (layer-by-layer coatings, moduli 0.1 – 100 MPa)
- Surface charge (layer-by-layer coatings, surface charge)
- Surface topography (wrinkling, 10 nm – 10 μm)

Deposition of bacteria during flow

Approach: study deposition of bacteria on engineered surfaces using different flow geometries.



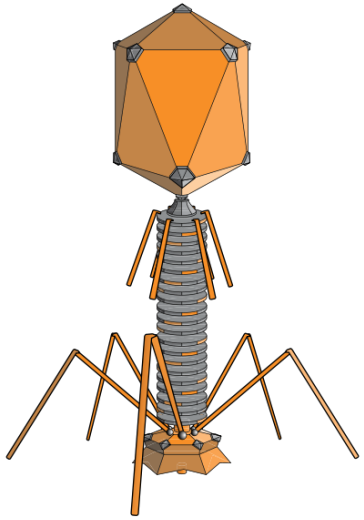


bacteria are ~3 μm long
playback at 50×

Sumedha Sharma and others

Promoting surface attachment of phage

Bacteriophage are viruses that infect bacteria. They can be engineered to express antibodies to proteins on their outer surface.

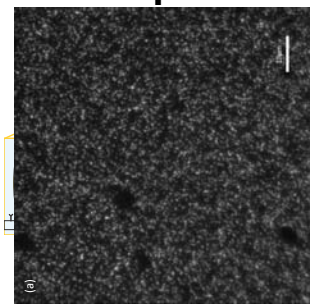
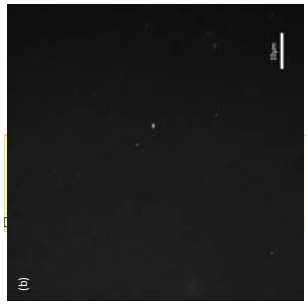
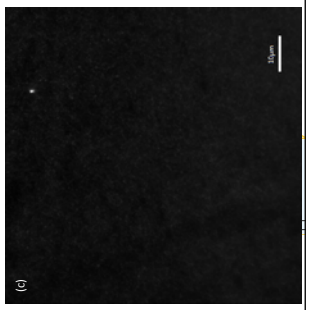


Wikipedia

Detecting phages on surfaces

Approach: incubate fluorescent linker-phage with surfaces with opposite linker and image with microscopy to monitor attachment.

Predicted attachment:

+	-	-
		
Biotin-phage + neutravidin-surface	Biotin-phage + BSA surface	Biotin-phage + bare surface

Open question: what are rates of attachment? will this strategy work for a "sandwich" assay for detection?

Jinsu Kim and others

Summary

- We work on problems surrounding the interaction of particles with surfaces.
  - How surfaces affect the diffusion and transport of nanoparticles for enhanced oil recovery.
  - How colloids flow in microchannels for 3-d printing and drilling fluids.
  - How bacteria move on surfaces for antifouling coatings.
  - How bacteriophage attach to surfaces for ultrasensitive diagnostics.
- Our work in soft condensed matter is interdisciplinary, as is much of modern science and engineering.