Rheology of active fluids under confinement

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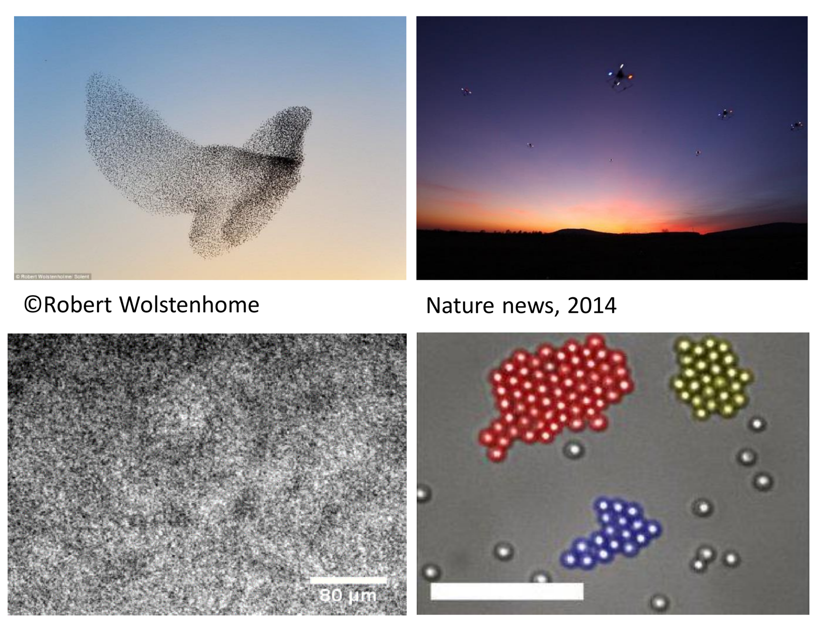
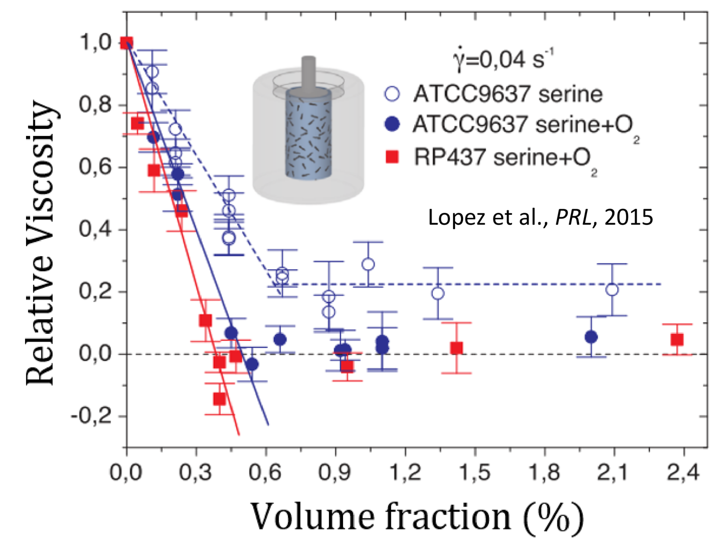
1. Unusual rheology

Active matter

- ❑ Self-propulsion
- ❑ Novel properties



Palacci et al., *Science*, 2013 (Scale bar = 10 μm)



Active superfluids

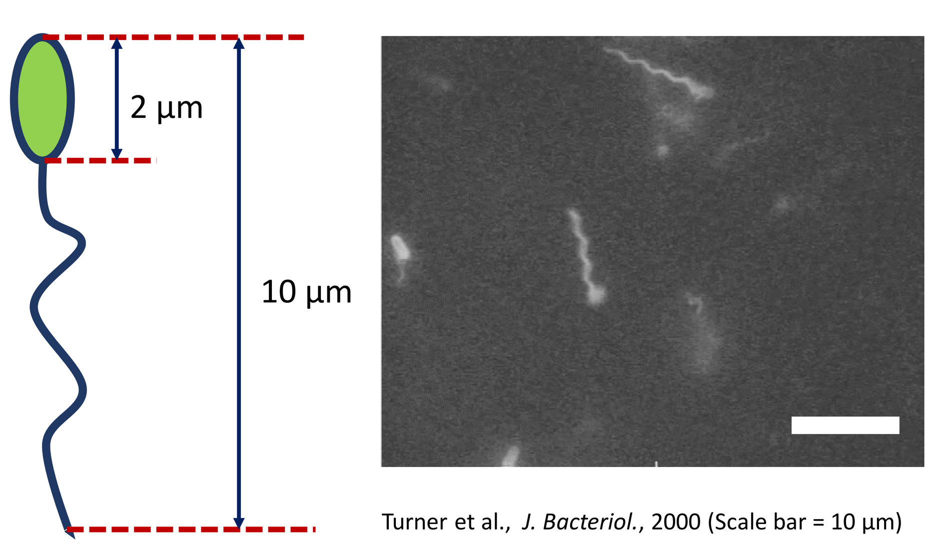
- ❑ Active particles reduce viscosity
- ❑ Can be turned turned into “superfluids”

Key question Different rheology under confinement?

2. *E. coli* and viscometer

E. Coli as active particle

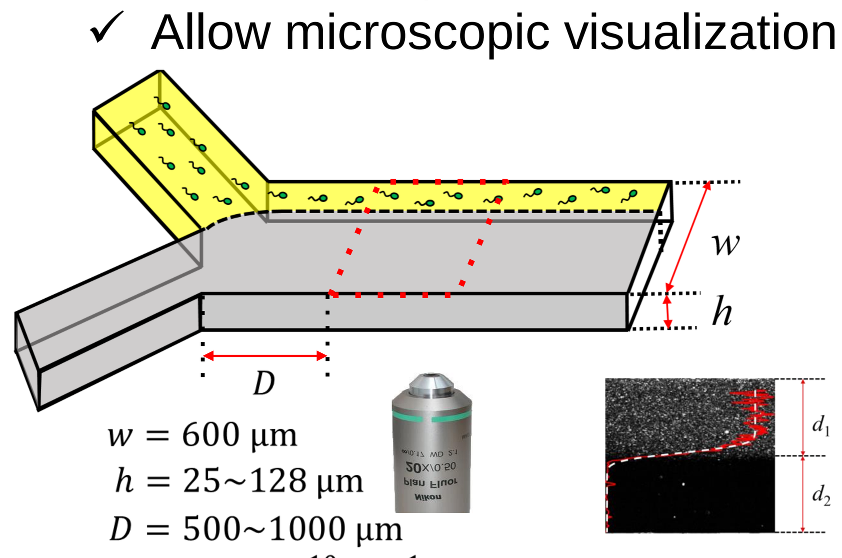
- ❑ Found in the lower intestine of warm-blooded organisms
- ❑ A rod-shaped body and a long thin flagellum



Turner et al., *J. Bacteriol.*, 2000 (Scale bar = 10 μm)

Microfluidic viscometer

- ❑ Advantages :
  - ✓ Less sample required
  - ✓ Low viscosity measurement
  - ✓ Allow microscopic visualization



$w = 600\ \mu m$
$h = 25\sim128\ \mu m$
$D = 500\sim1000\ \mu m$
$n = 1.6 \times 10^{10}\ ml^{-1}$

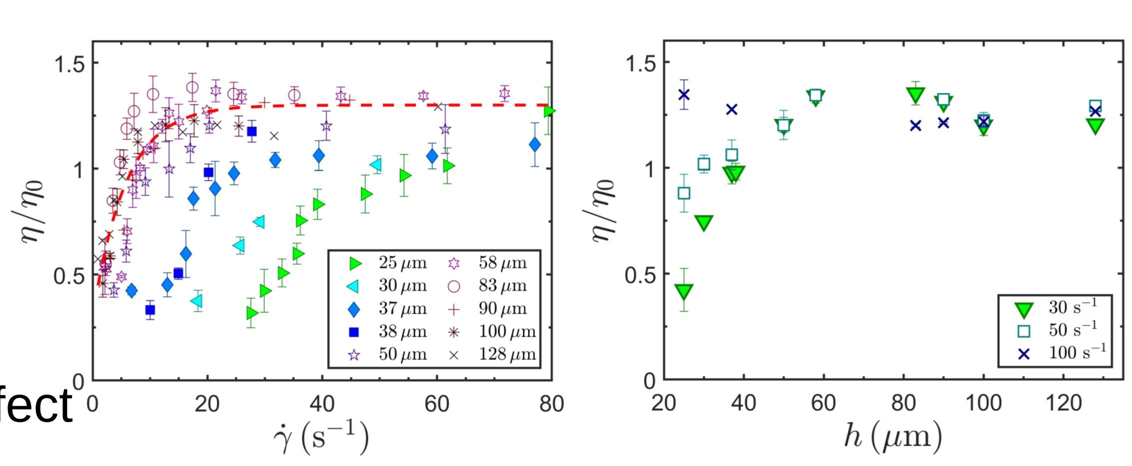
Relative viscosity $= \dfrac{\eta_1}{\eta_2} = \dfrac{d_1}{d_2}$

Guillot et al., *Langmuir*, 2006; Gachelin et al., *PRL*, 2013

3. Viscosity reduction

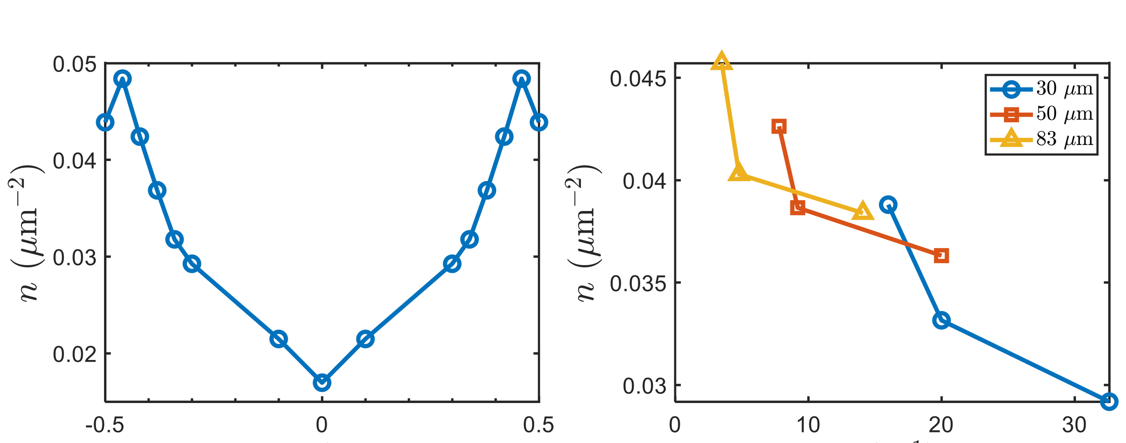
Rheology

- ❑ Low shear rate
  - ✓ Shear thickening
  - ✓ Confinement reduces viscosity
- ❑ High shear rate
  - ✓ Plateau
  - ✓ No confinement effect



Spatial distribution

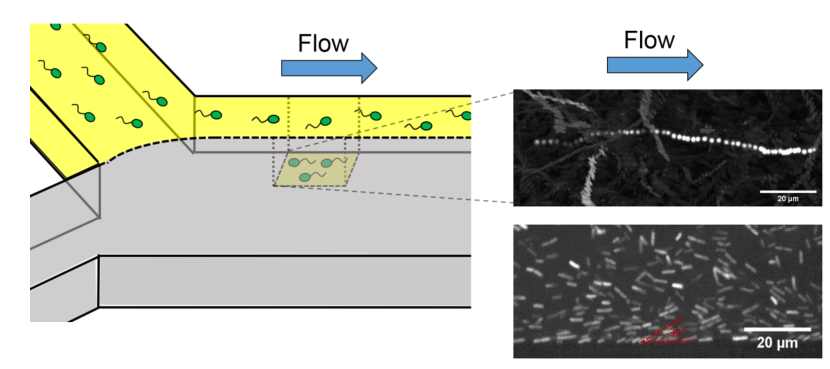
- ❑ Higher concentration near wall
- ❑ Lower wall concentration upon increasing shear rate
- ❑ Confinement effect is boundary effect



4. Upstream swimming

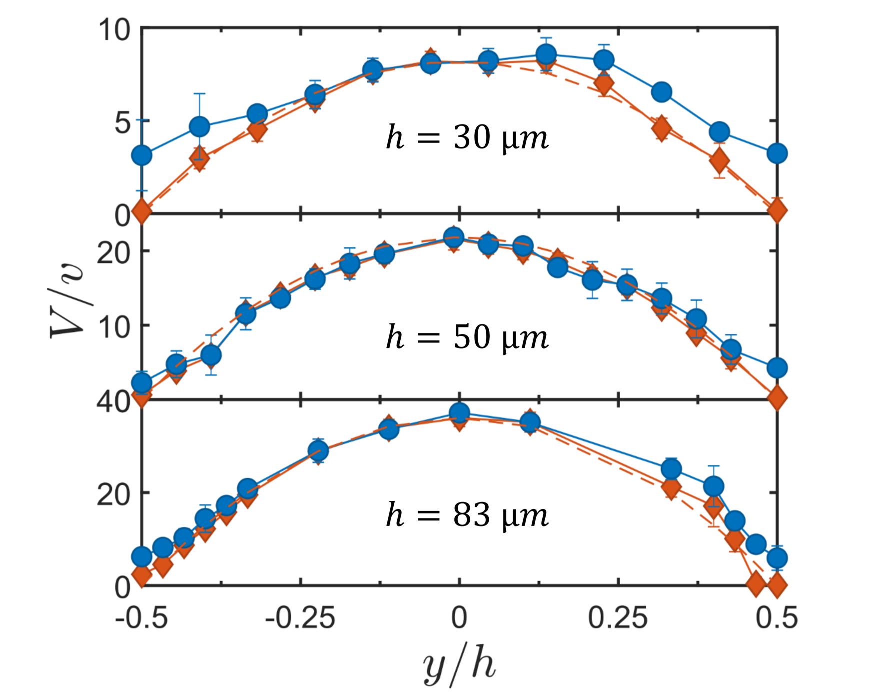
Relative motion near walls

- ❑ Relative motion near walls, indicating upstream swimming



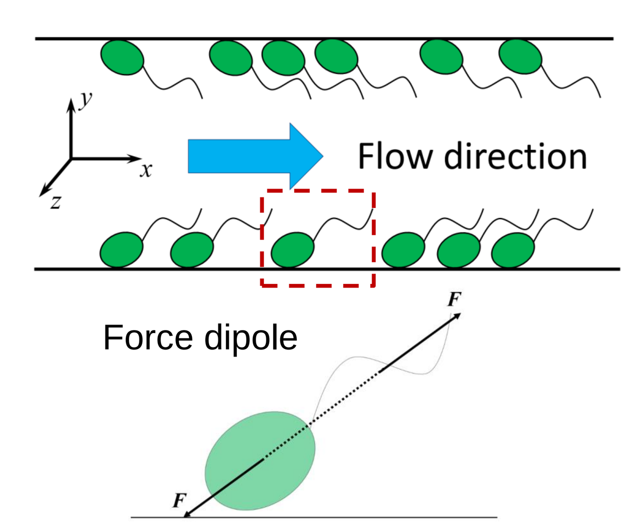
Velocity profile

- ❑ Strong relative motion in confinement

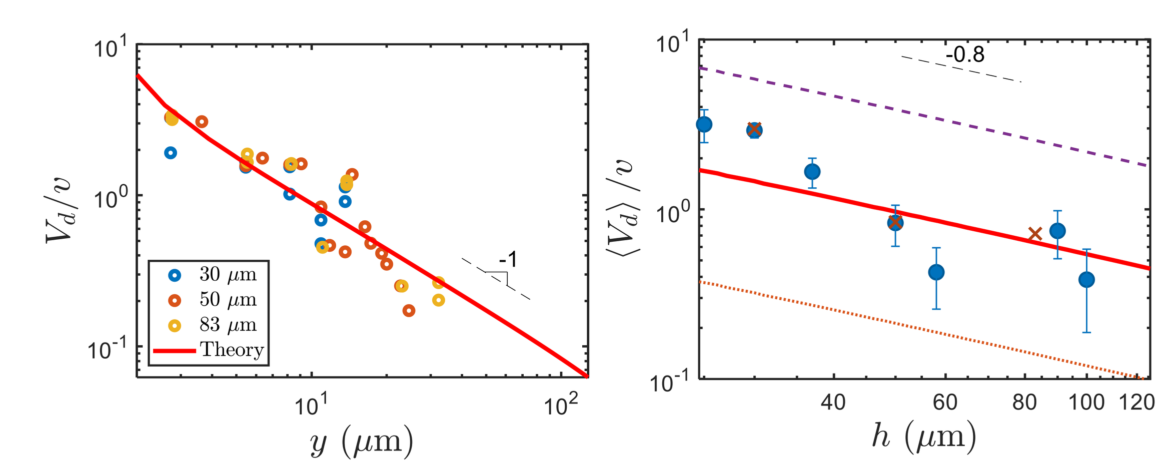


5. Model: boundary layers

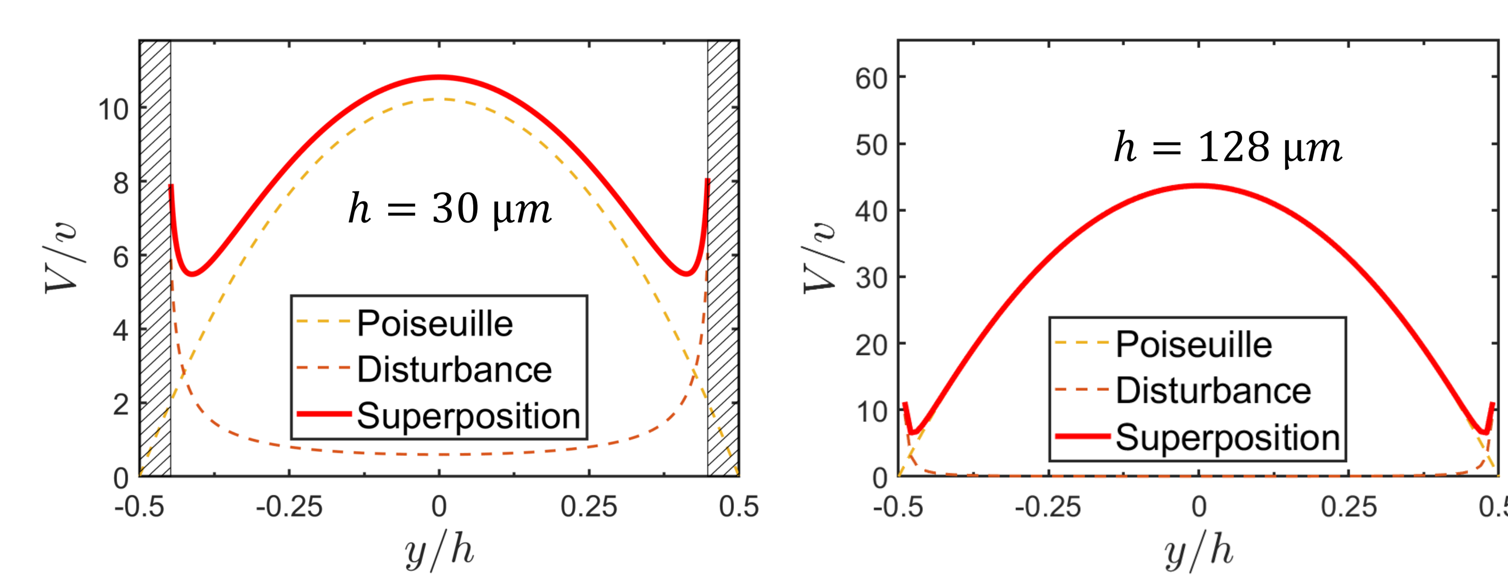
Boundary layer model



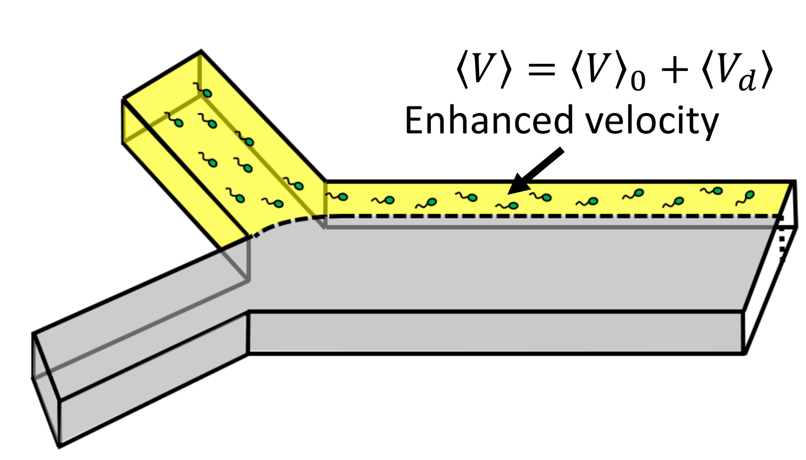
Quantitative comparison with experiment

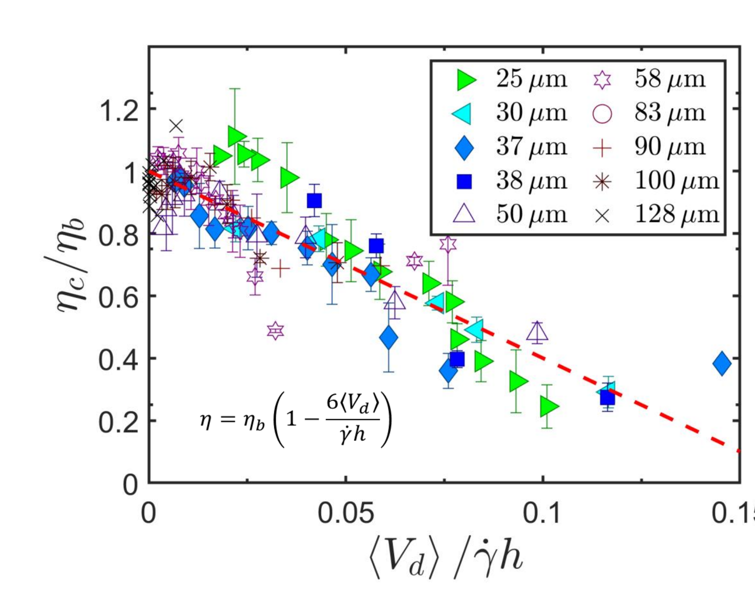


Enhanced flow under different degrees of confinement



Collapsing rheology curves





5. Conclusions

- ❑ Confinement *reduces* the viscosity of *E. coli* suspensions at low shear rates.
- ❑ The origin of confinement effect is an *upstream swimming boundary layer* of *E. coli* pushing fluid forward.
- ❑ With the boundary layer model, we *collapse* the rheology curves under different degrees of confinement onto a master curve.

References

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[5] K. Drescher, J. Dunkel, L. H. Cisneros , S. Ganguly, and R. E. Goldstein, Fluid dynamics and noise in bacterial cell–cell and cell–surface scattering, PNAS 108, 10940–10945 (2011).