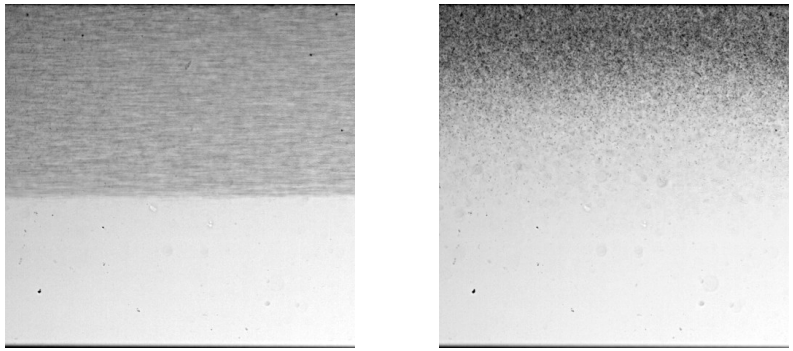
Viscosity of confined bacterial suspensions



Zhengyang Liu

Co-authors: Kechun Zhang and Xiang Cheng

UNIVERSITY OF MINNESOTA

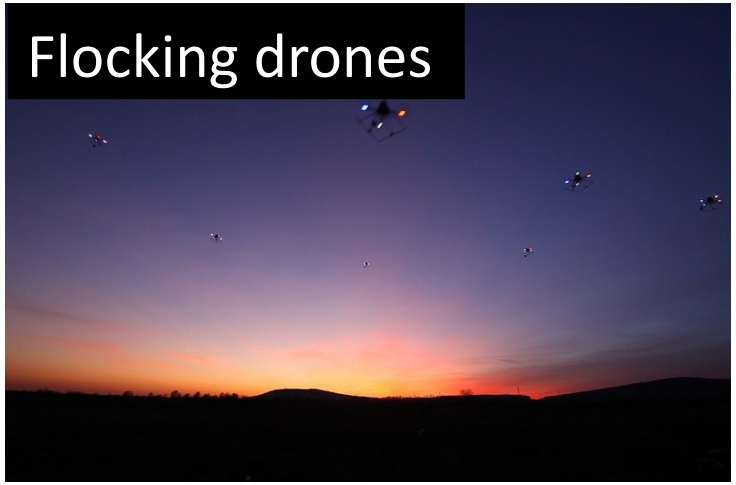
CEMS | Chemical Engineering & Materials Science

Active matter is ubiquitous

Flocking birds

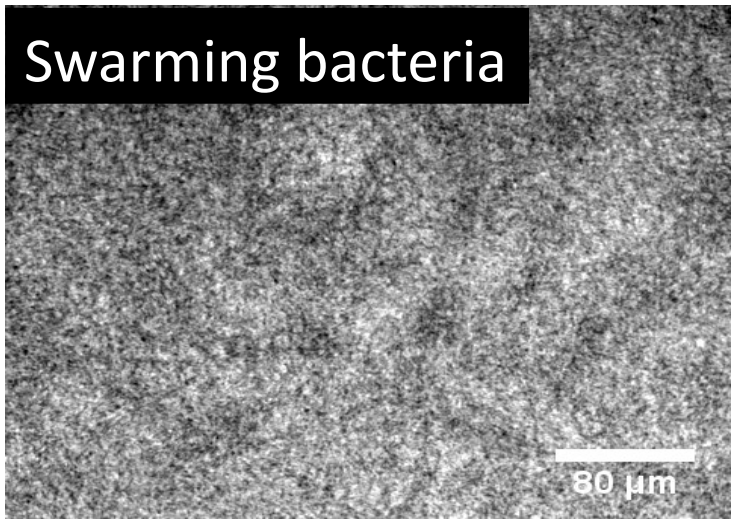
©Robert Wolstenhome

Flocking drones

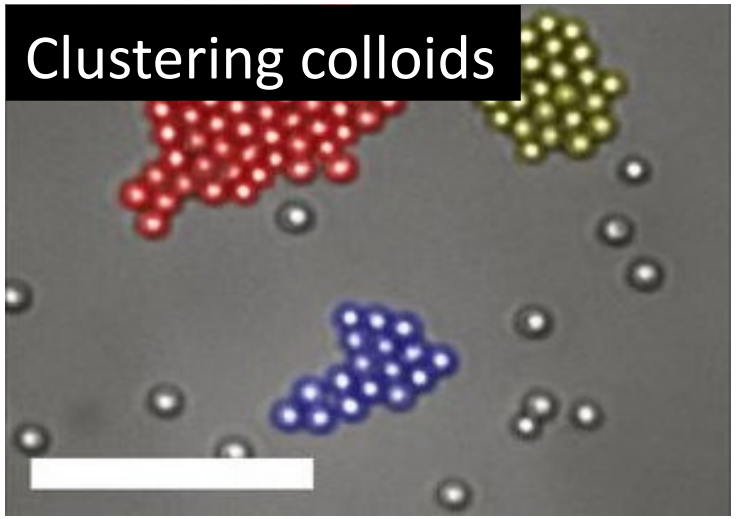


Nature news, 2014

Swarming bacteria

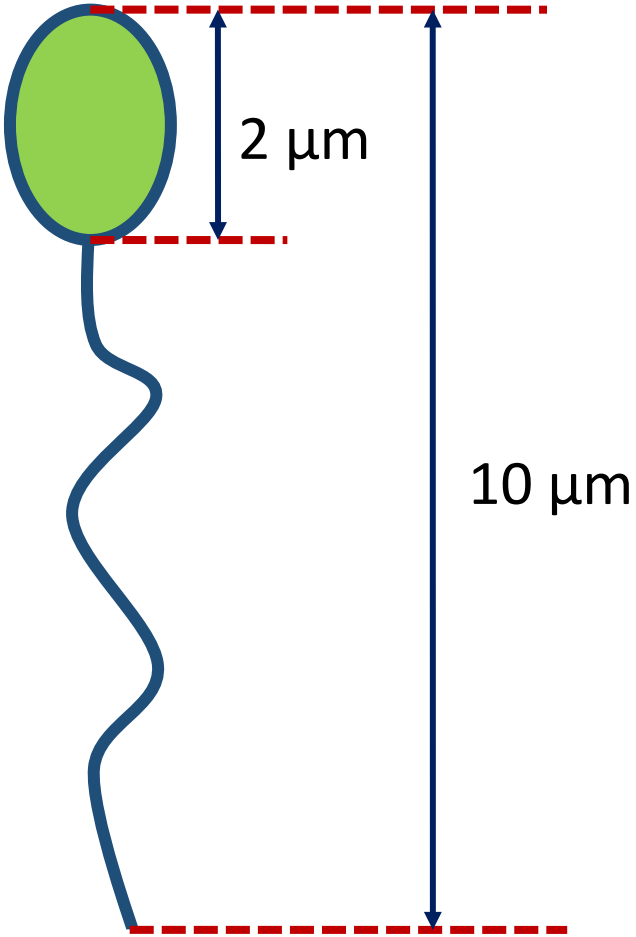


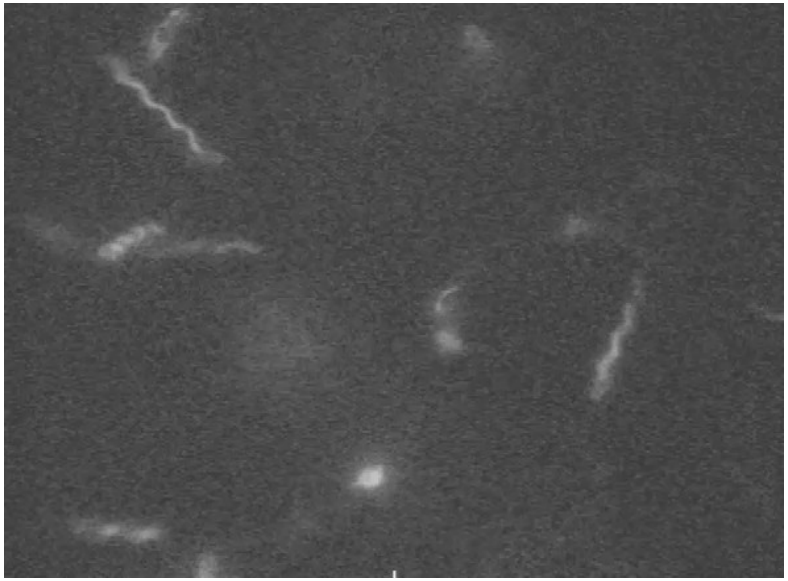
Clustering colloids



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

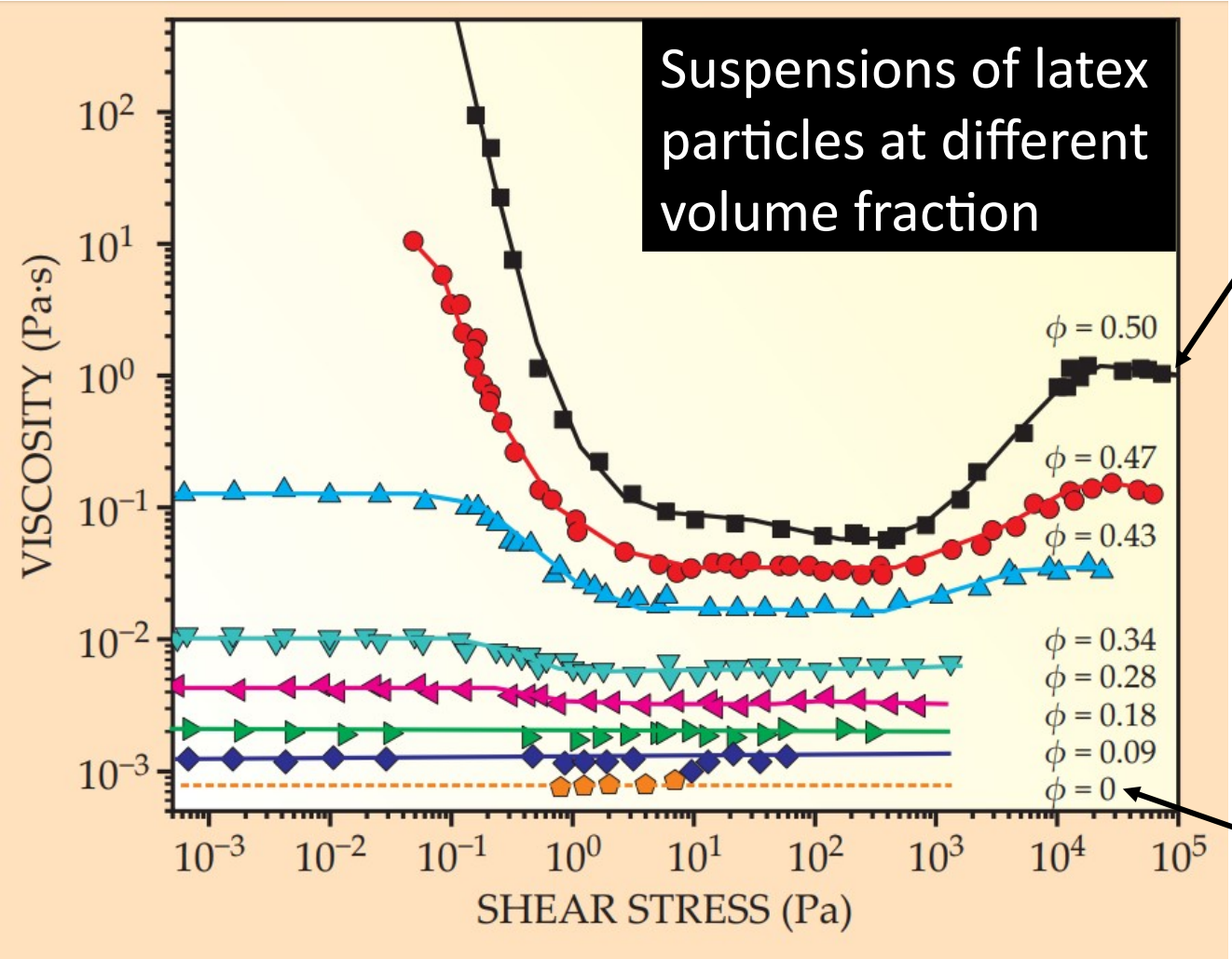
E. coli suspensions as model active matter





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

Suspension rheology



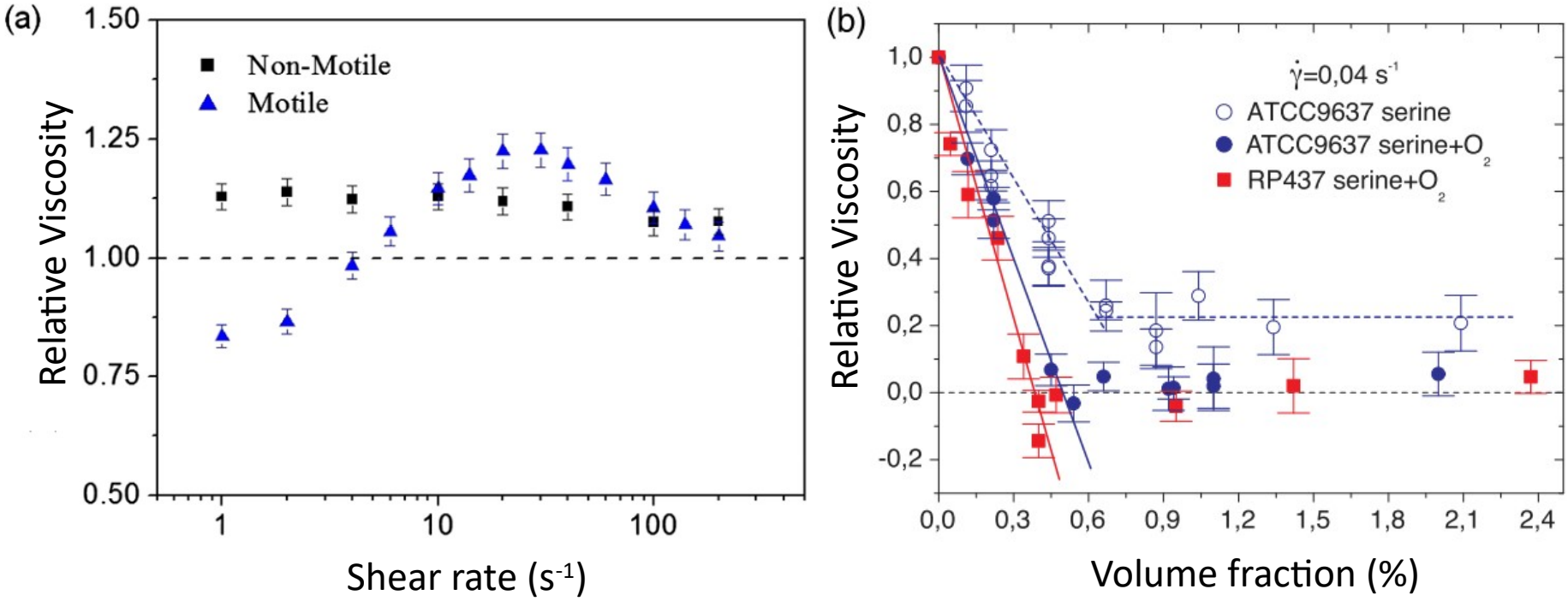
Concentrated suspension

Pure water

(Adapted by) Wagner and Brady, *Physics Today*, 2009

(Original) Laun, *Die Angew. Makr. Chem.*, 1984

Bacterial suspensions have interesting rheology

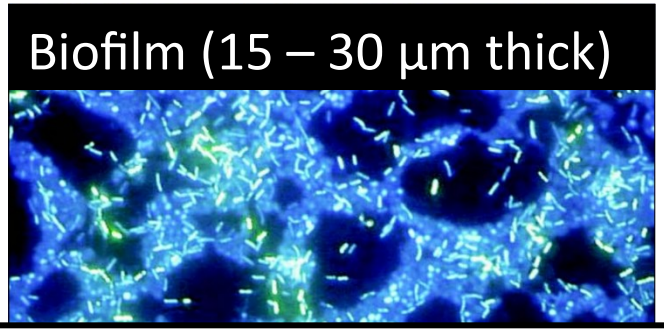


- Active particles can reduce the viscosity of their suspending fluid to zero, showing “superfluid” behavior

Gachelin et al., *PRL*, 2013; Lopez et al., *PRL*, 2015

Confinement is frequently encountered

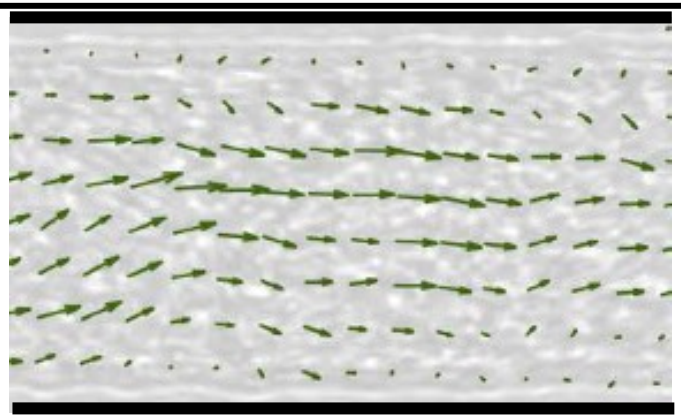
Natural processes



Does confinement change the rheology of bacterial suspensions?

Fundamental interest

Lushi et al., *PNAS*, 2014



Wioland, *New J. Phys.*, 2016

Concentration dependent dynamics

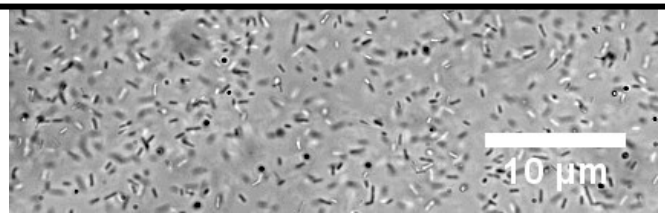
$$nL^3$$

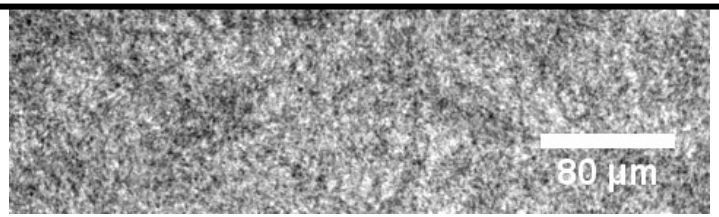
Number density

Total length (~10 μm for *E. coli*)

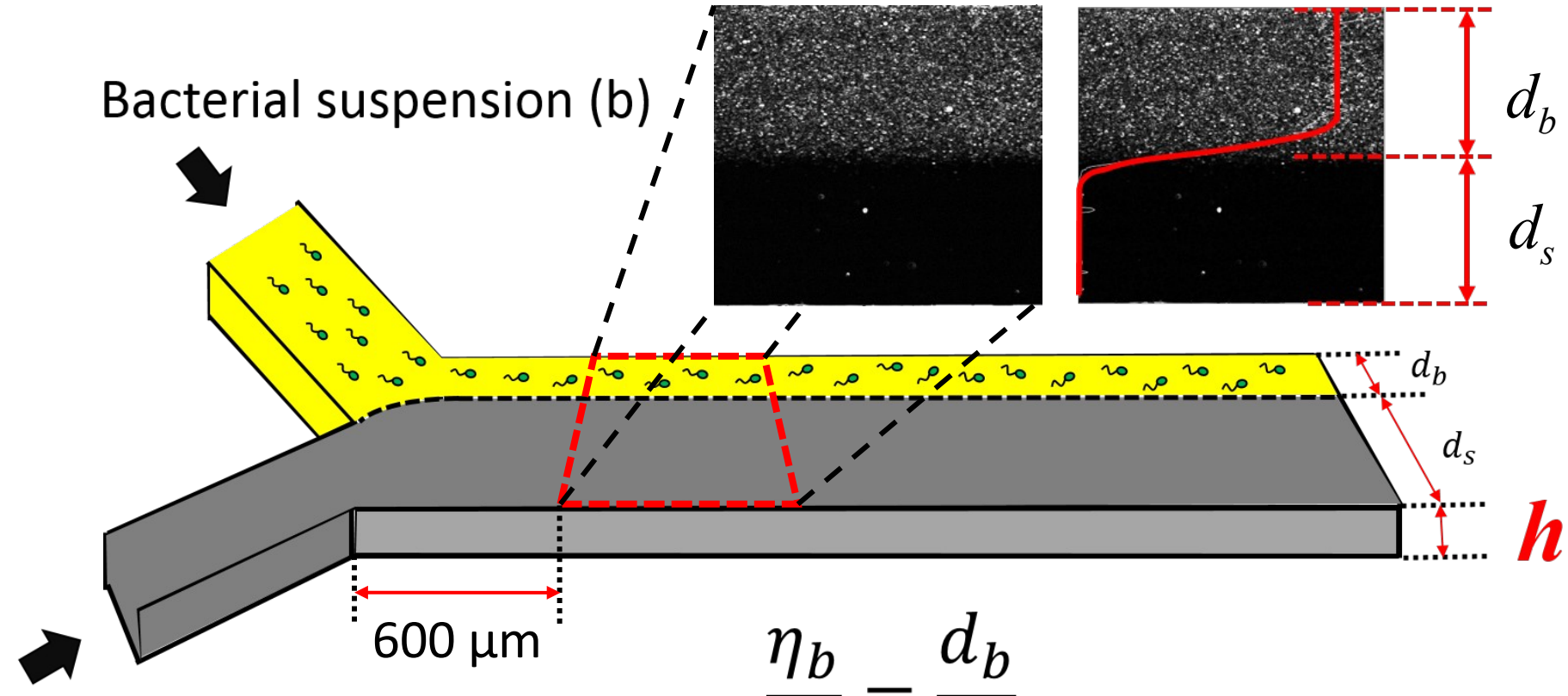
Dimensionless number:
degree of hydrodynamic coupling

Does confinement effect change in different dynamics (intrinsic length scale)?



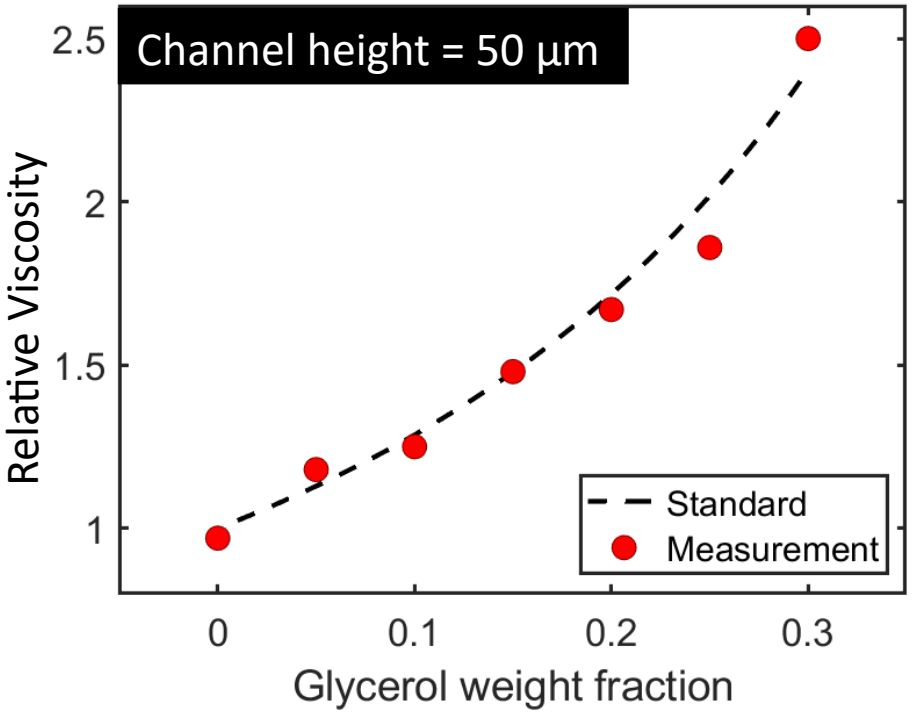


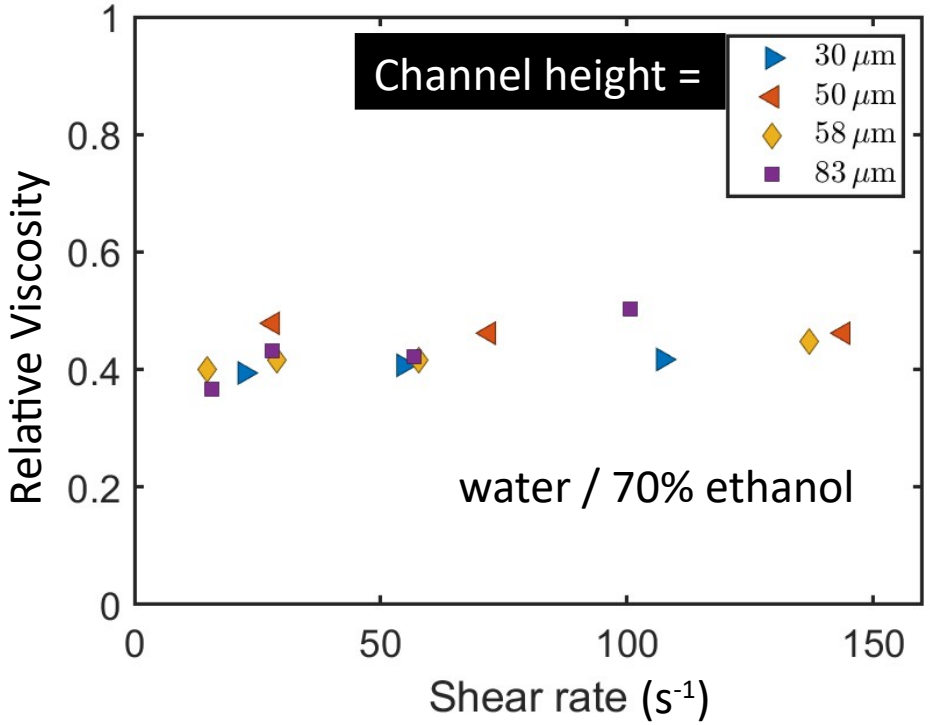
Microfluidic channel viscometer



$$\frac{\eta_b}{\eta_s} = \frac{d_b}{d_s}$$

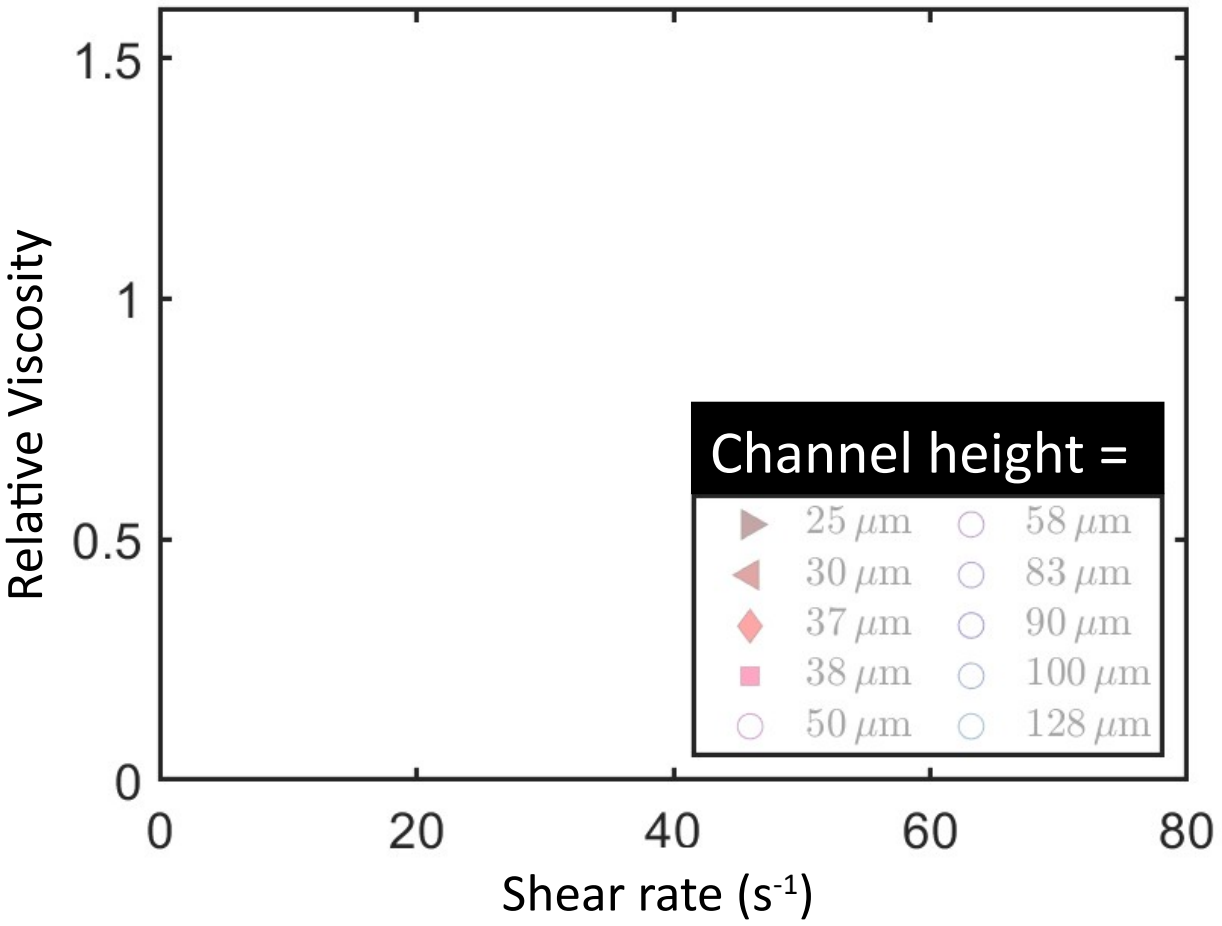
Calibration of the viscometer



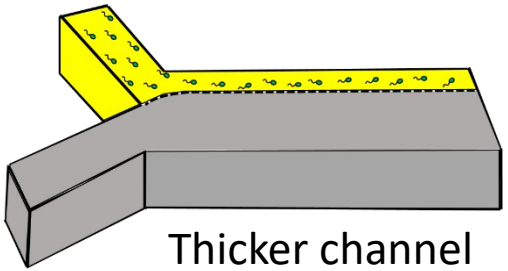


- For a specific channel height, the viscosity measurements agree with the standard values
- The viscosities measured with channels of various heights agree with each other

Low concentration suspensions

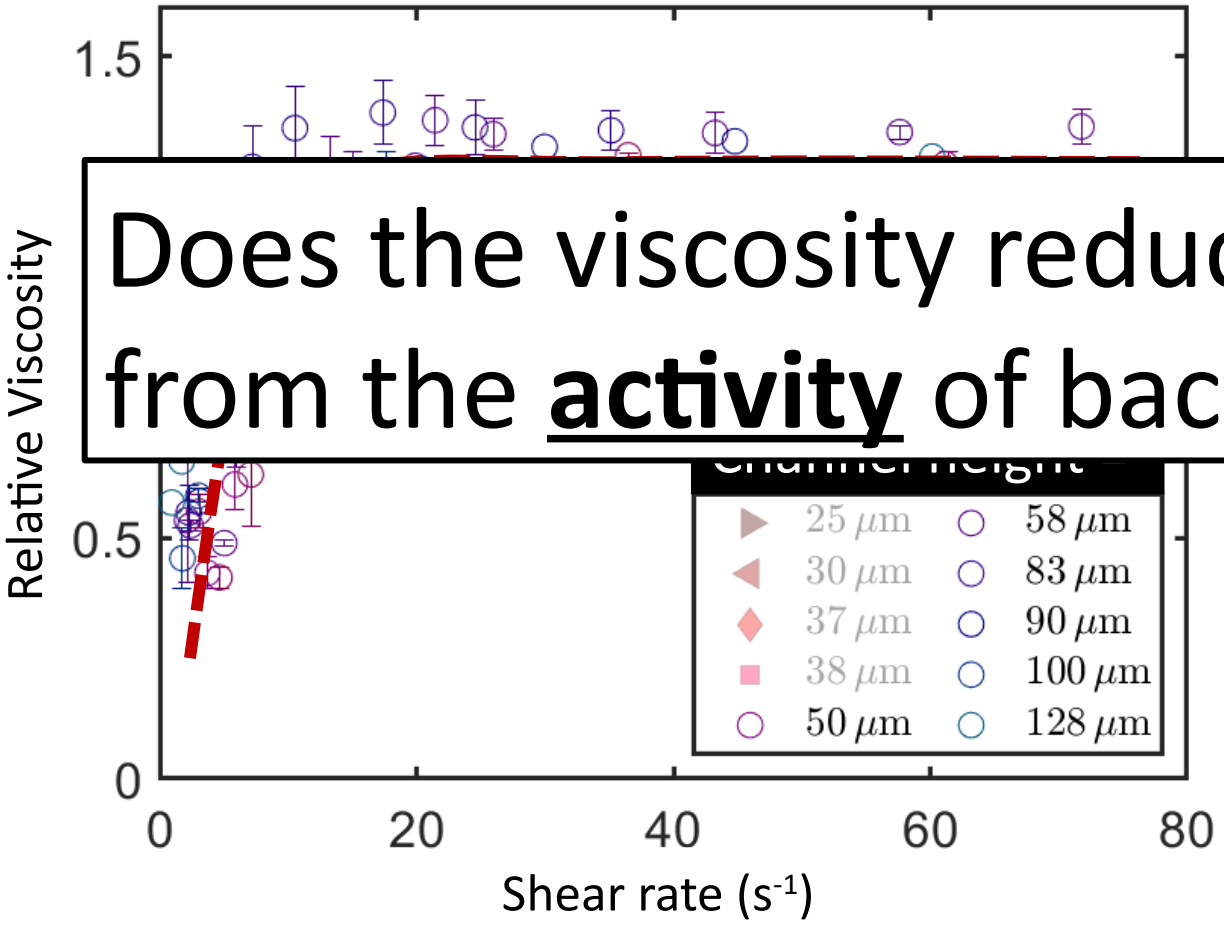


$$nL^3 = 16$$



Thicker channel

Low concentration suspensions

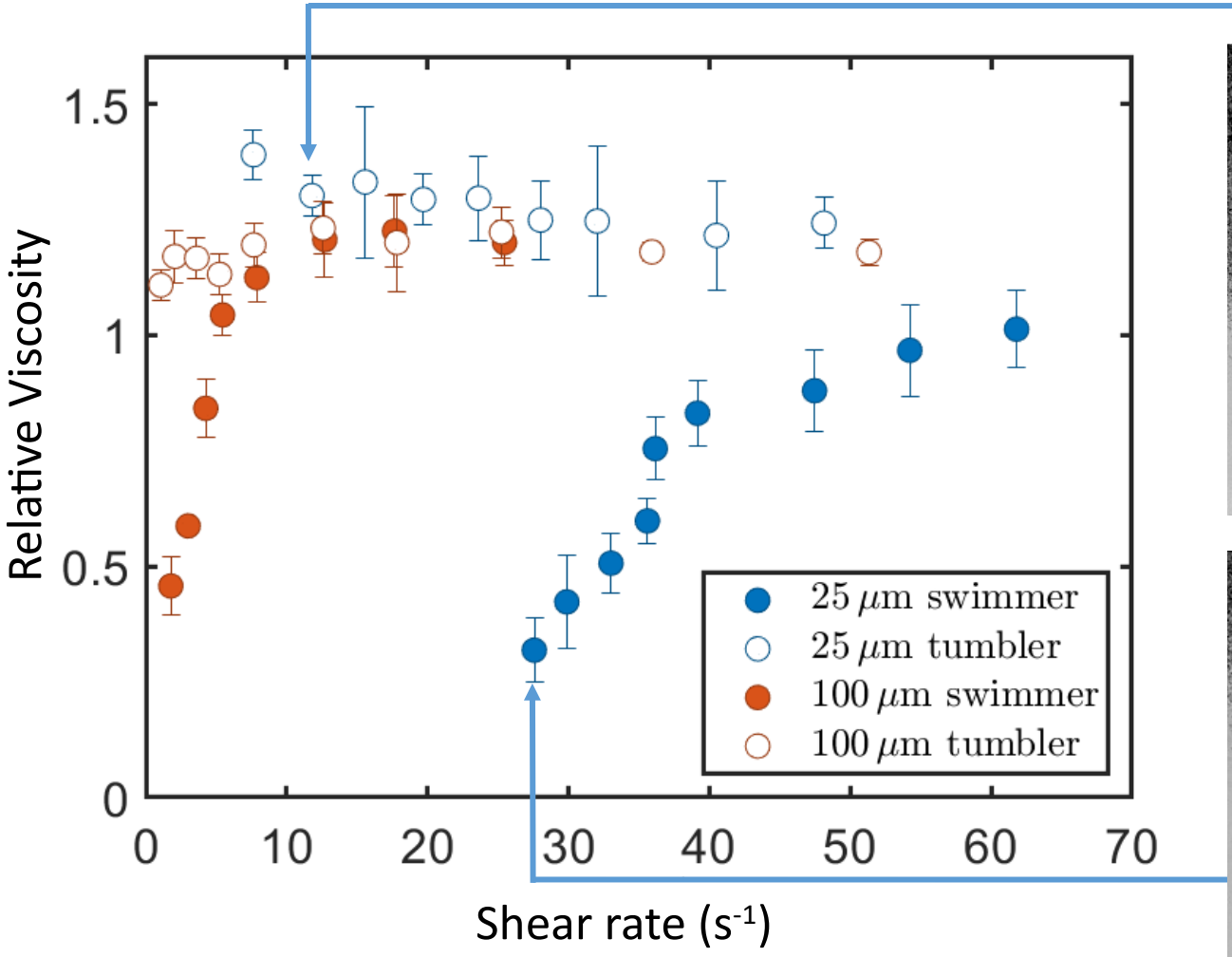


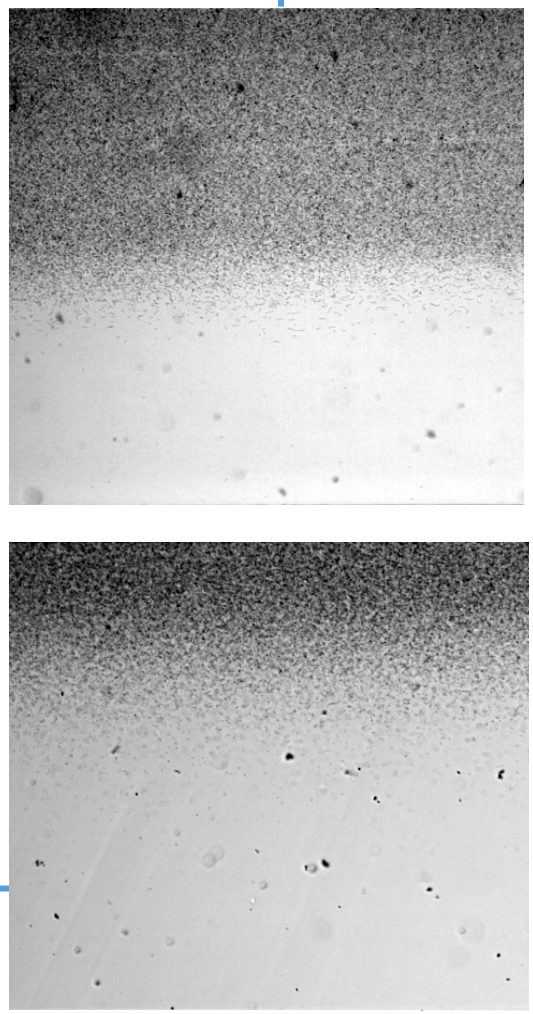
$$nL^3 = 16$$

Does the viscosity reduction result from the **activity** of bacteria?

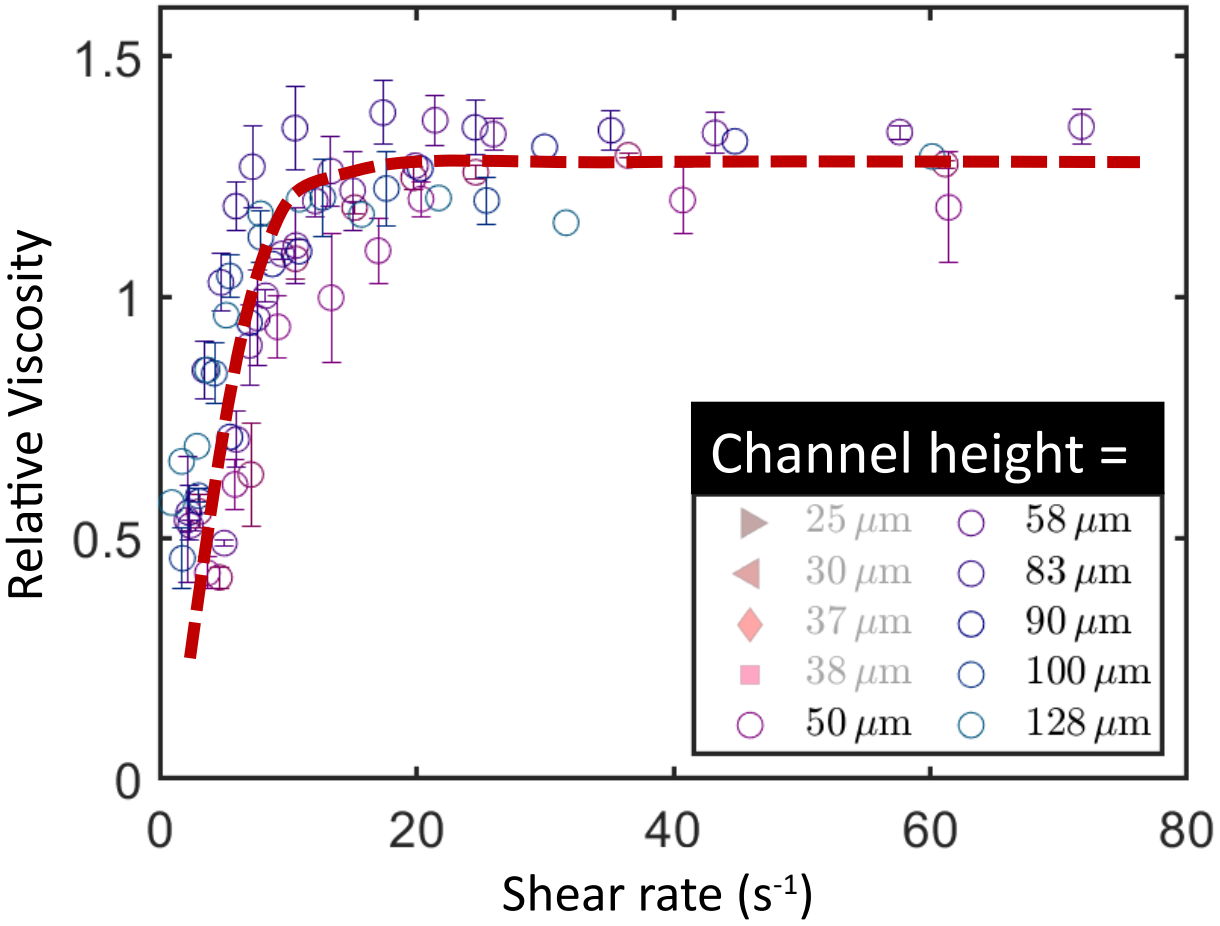
Thicker channel

Activity reduces viscosity

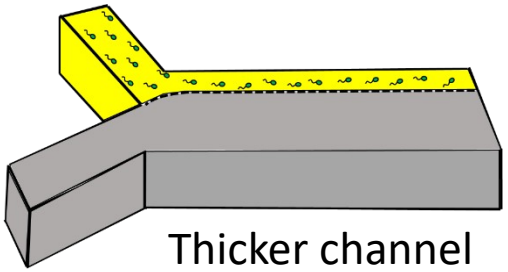




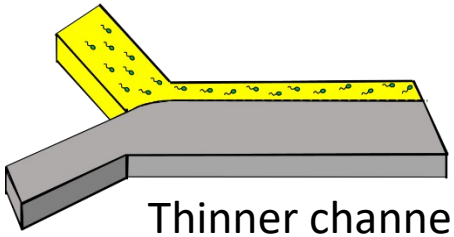
Low concentration suspensions



$$nL^3 = 16$$

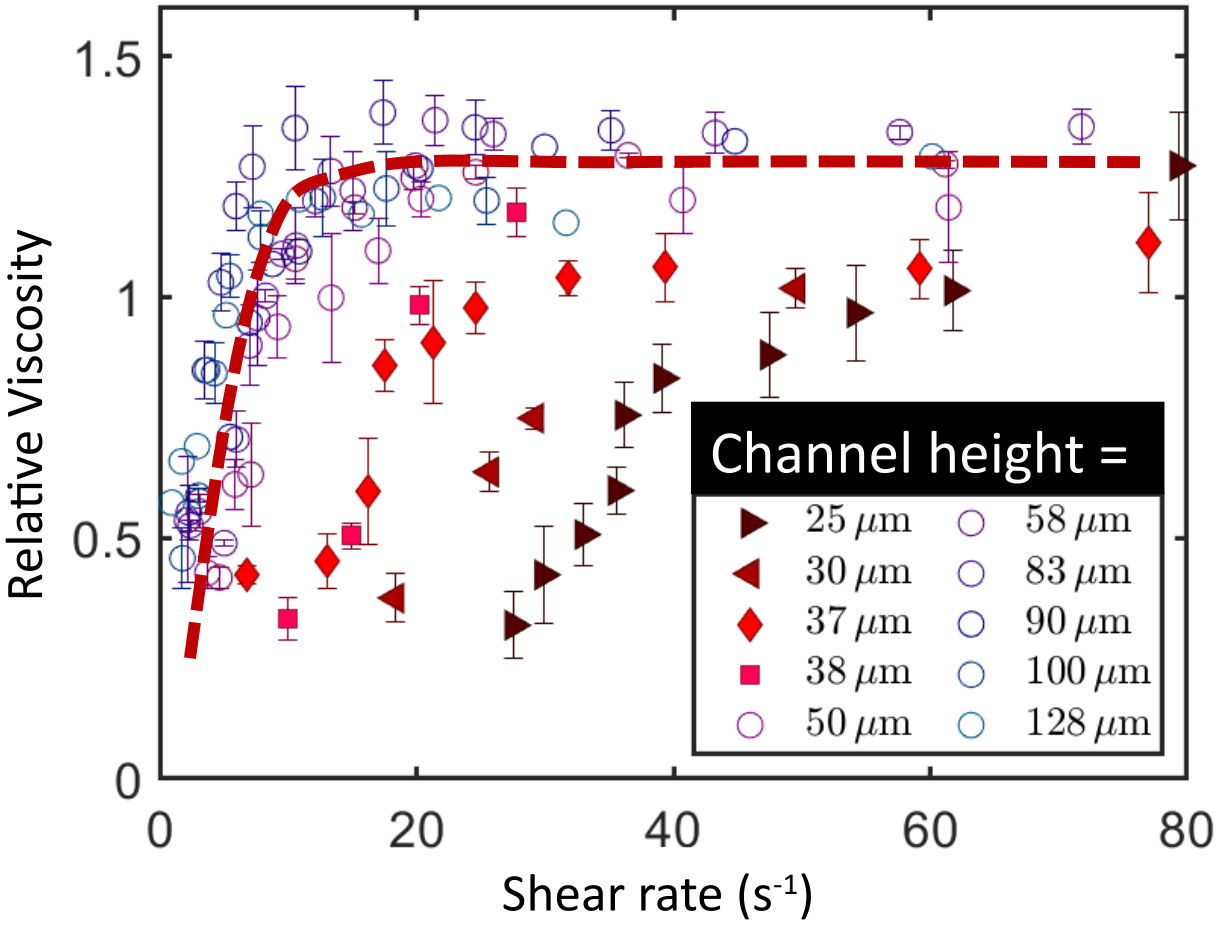


Thicker channel

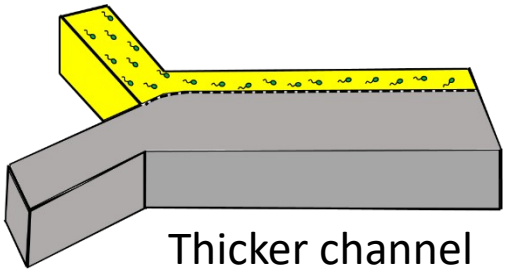


Thinner channel

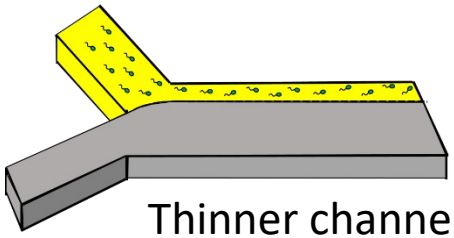
Low concentration suspensions



$$nL^3 = 16$$

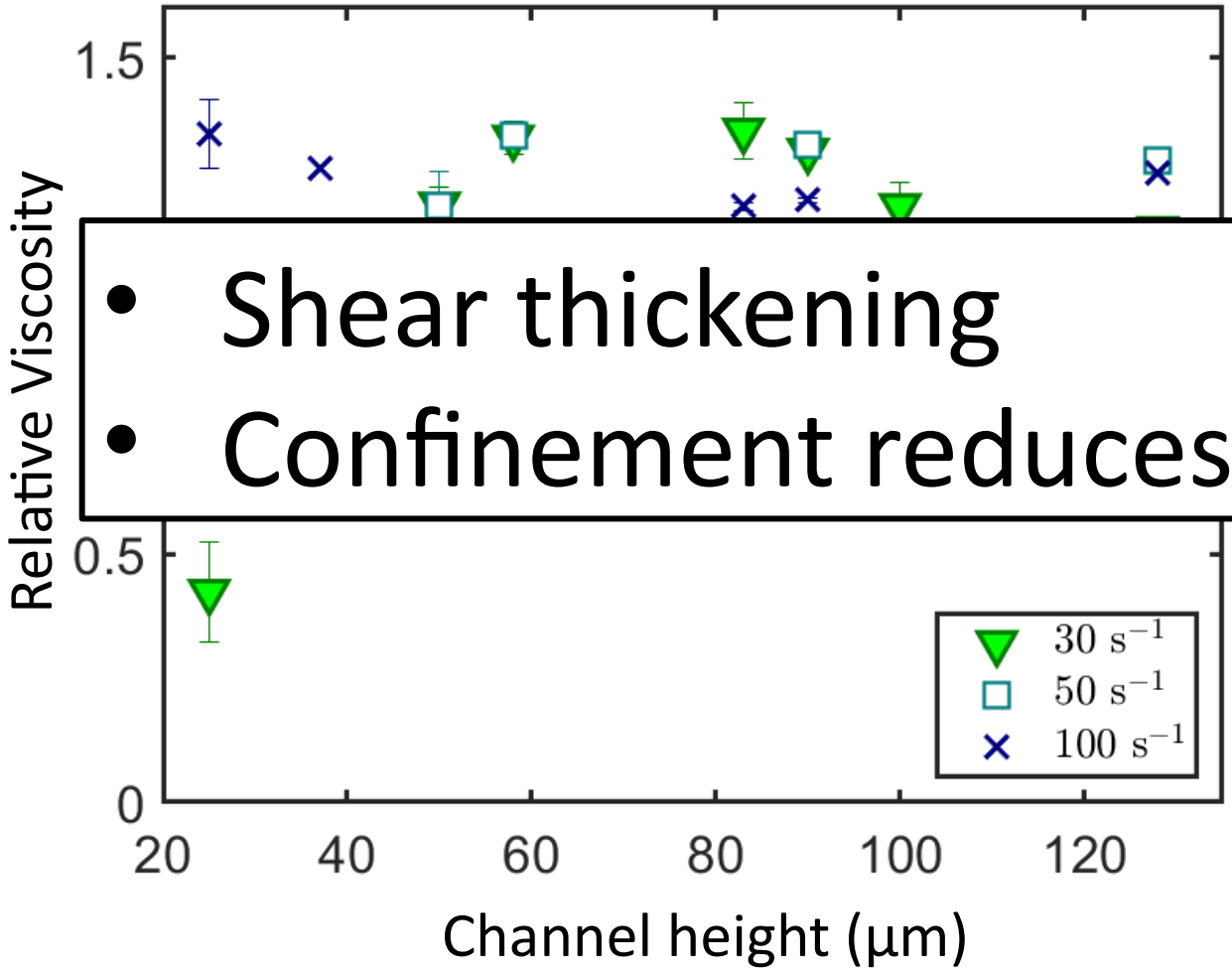


Thicker channel



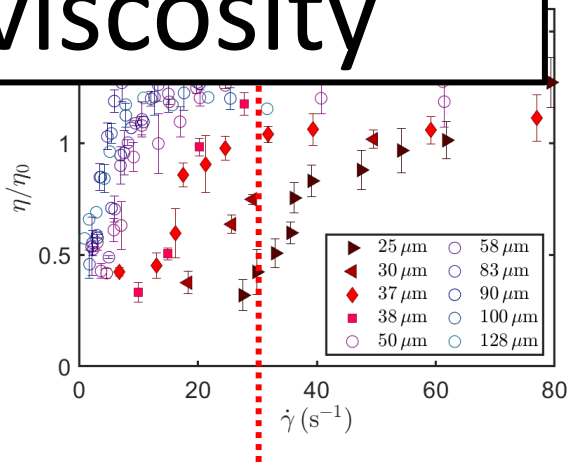
Thinner channel

Low concentration suspensions

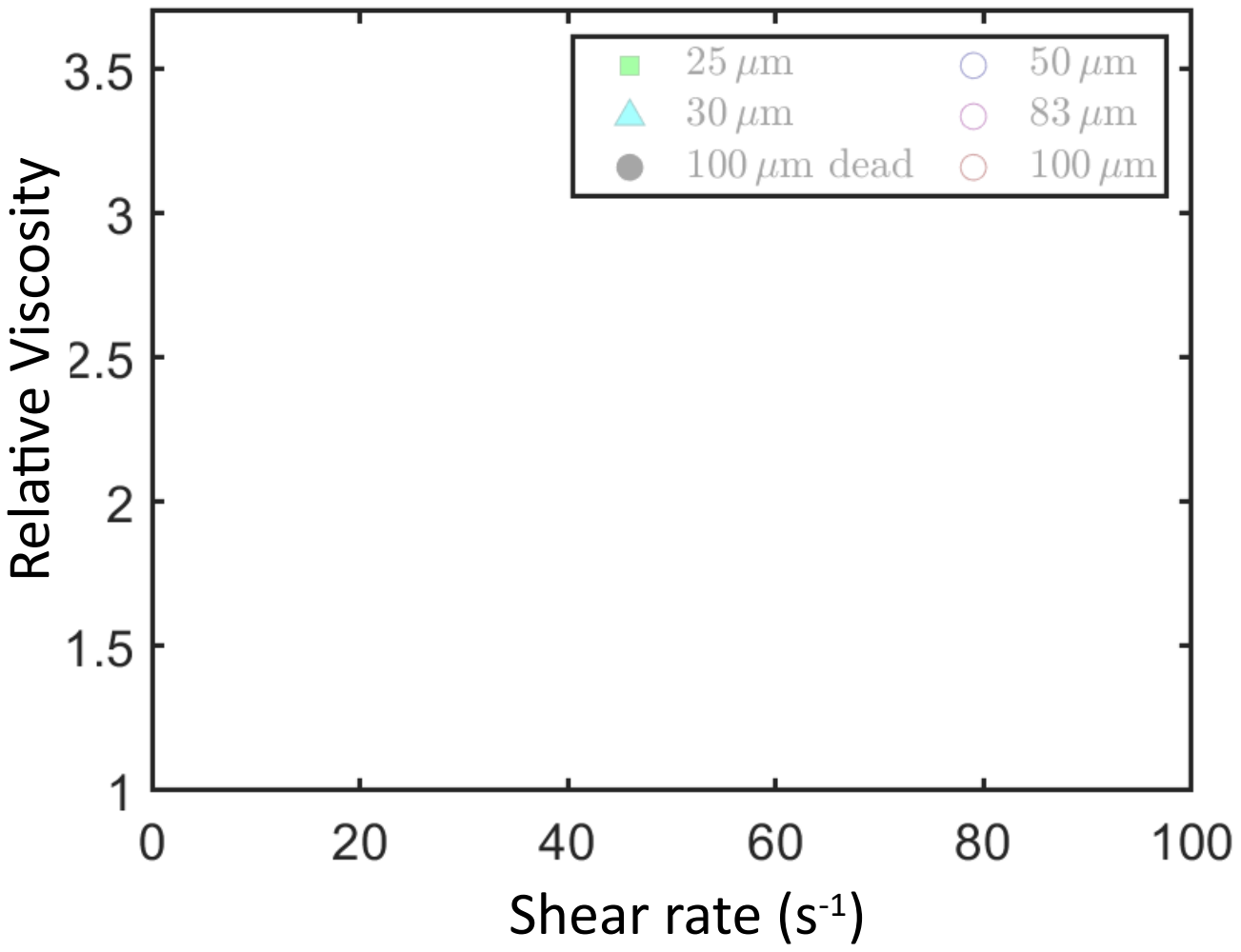


$$nL^3 = 16$$

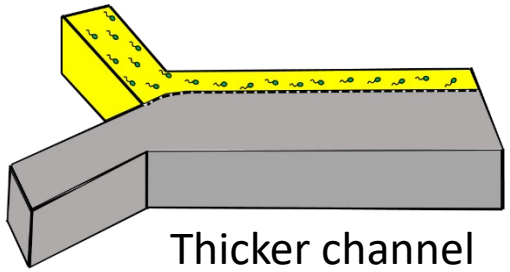
- Shear thickening
- Confinement reduces viscosity



High concentration suspensions

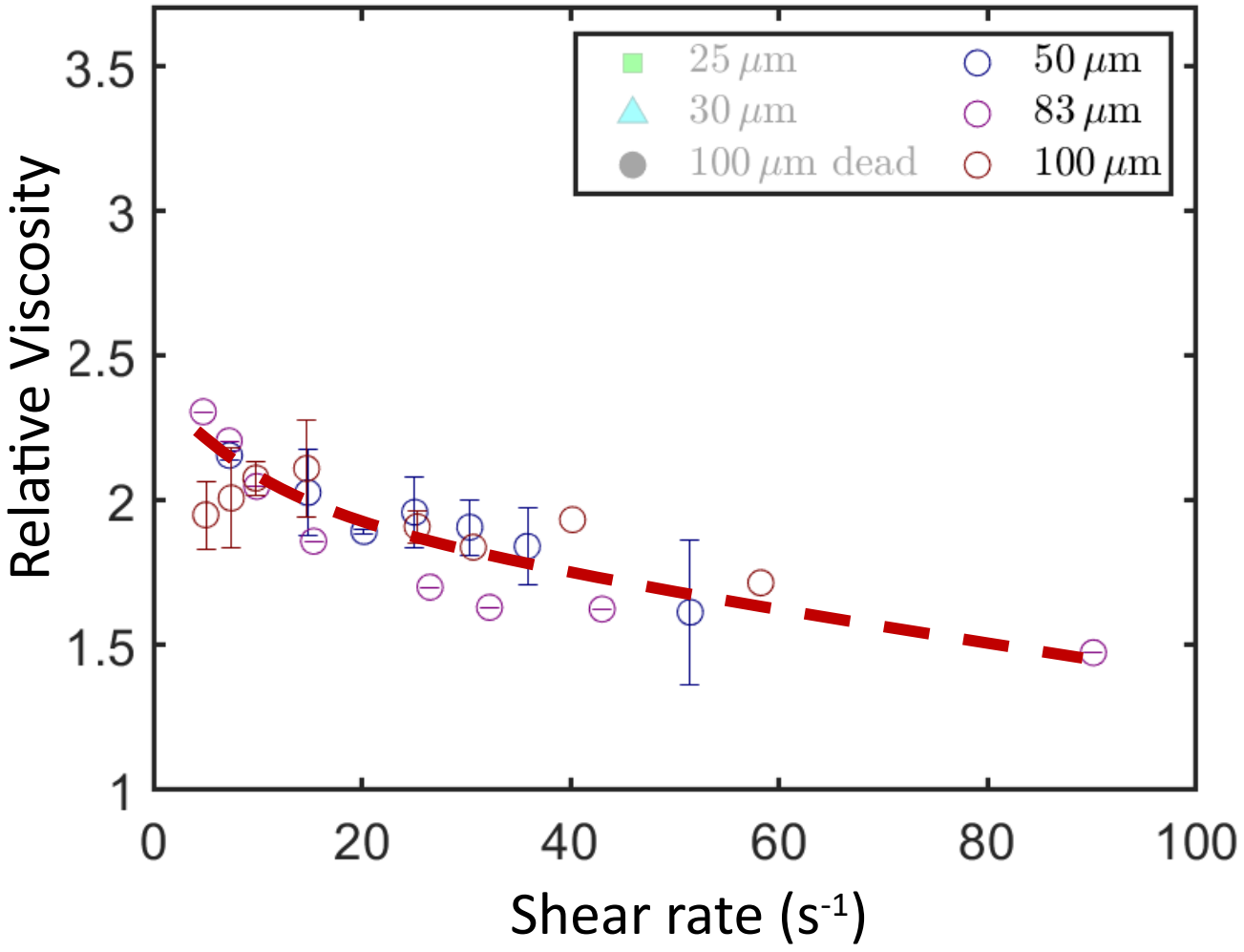


$$nL^3 = 35$$

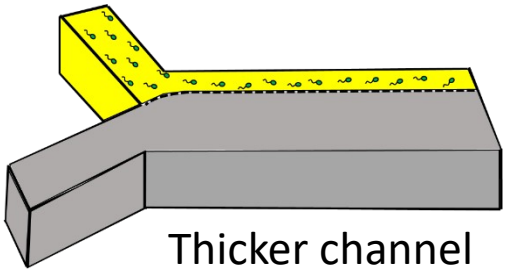


Thicker channel

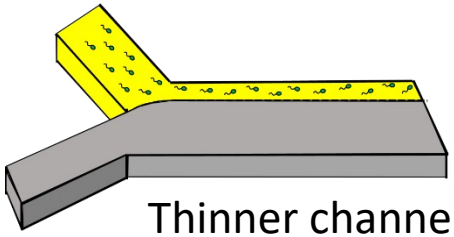
High concentration suspensions



$$nL^3 = 35$$

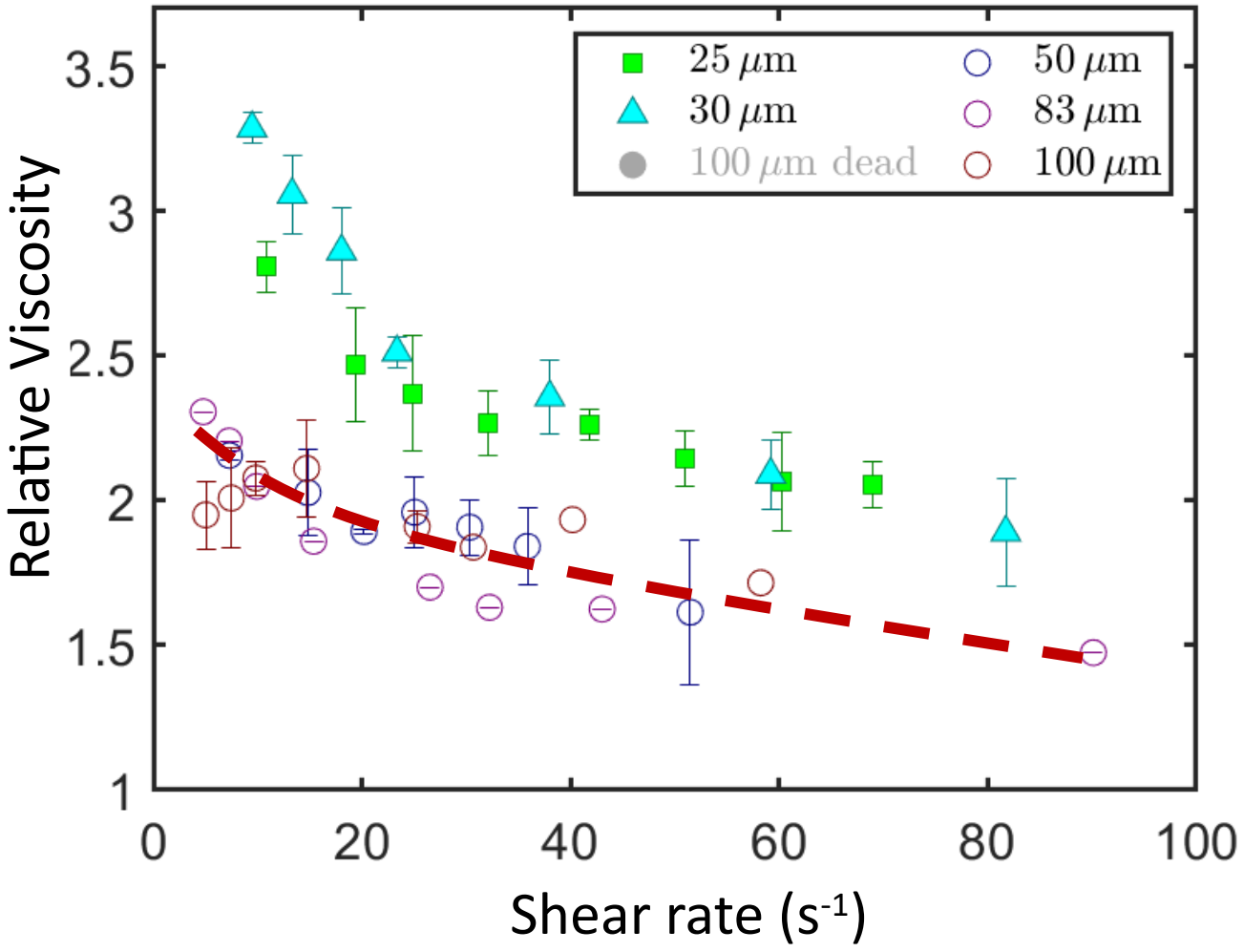


Thicker channel

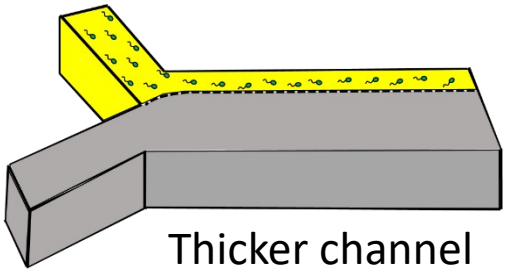


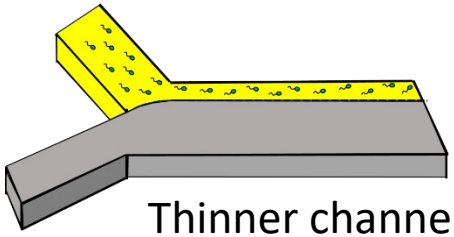
Thinner channel

High concentration suspensions

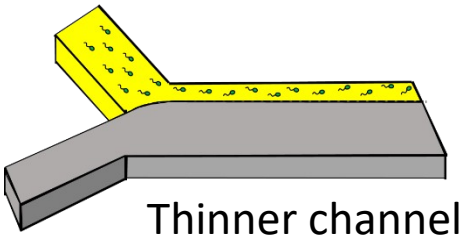


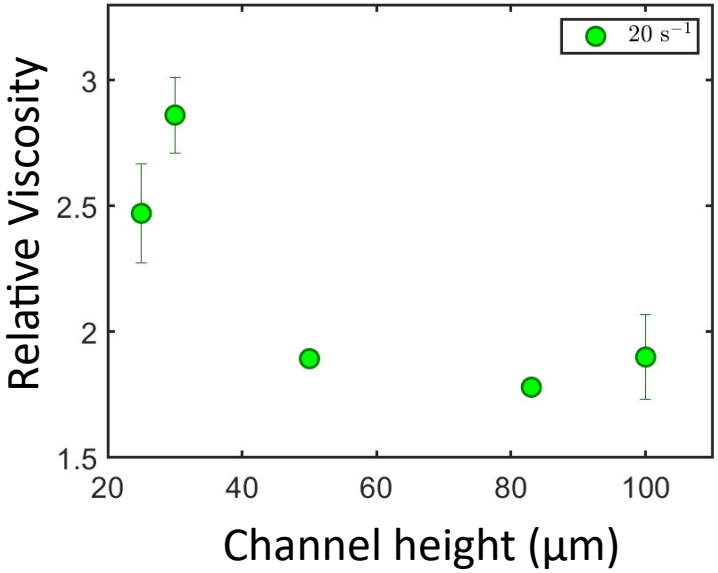
$$nL^3 = 35$$


Thicker channel


Thinner channel

High concentration suspensions





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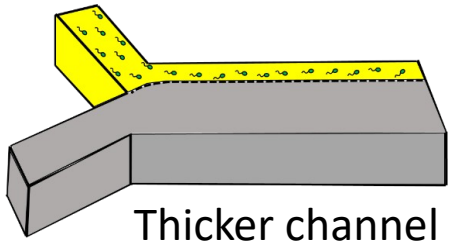
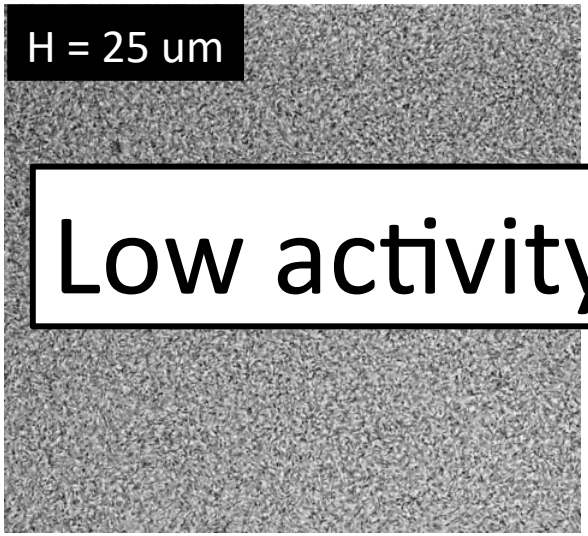
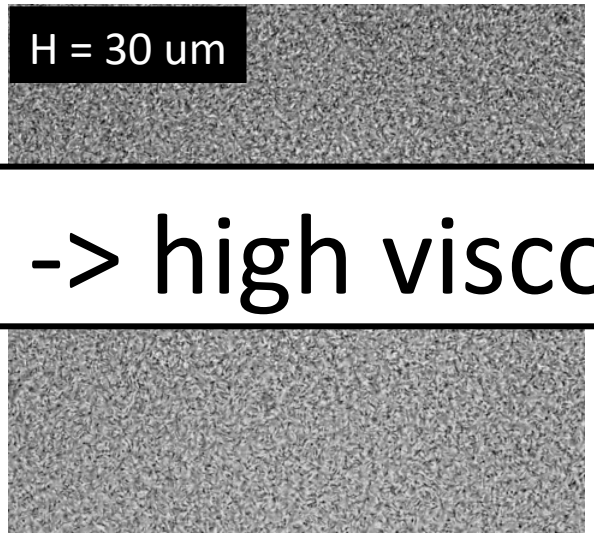
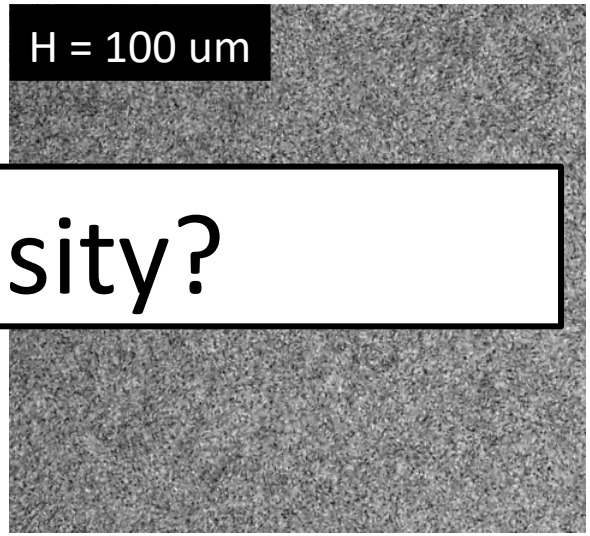


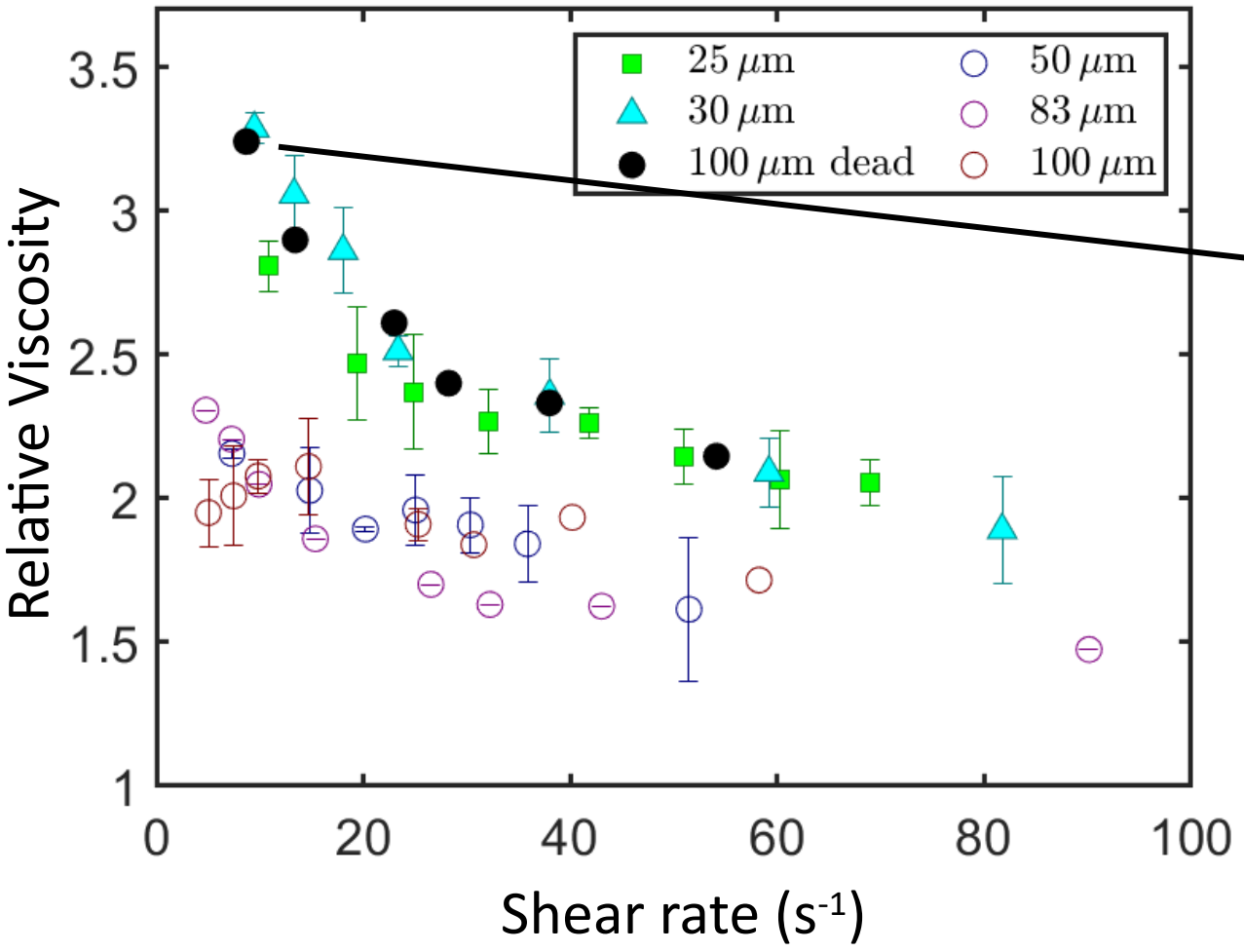




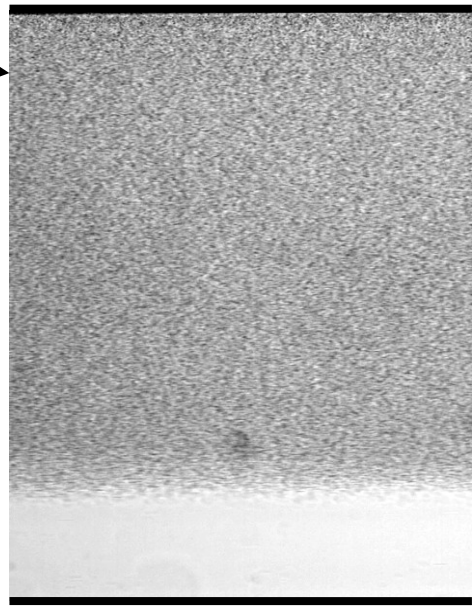


Low activity -> high viscosity?

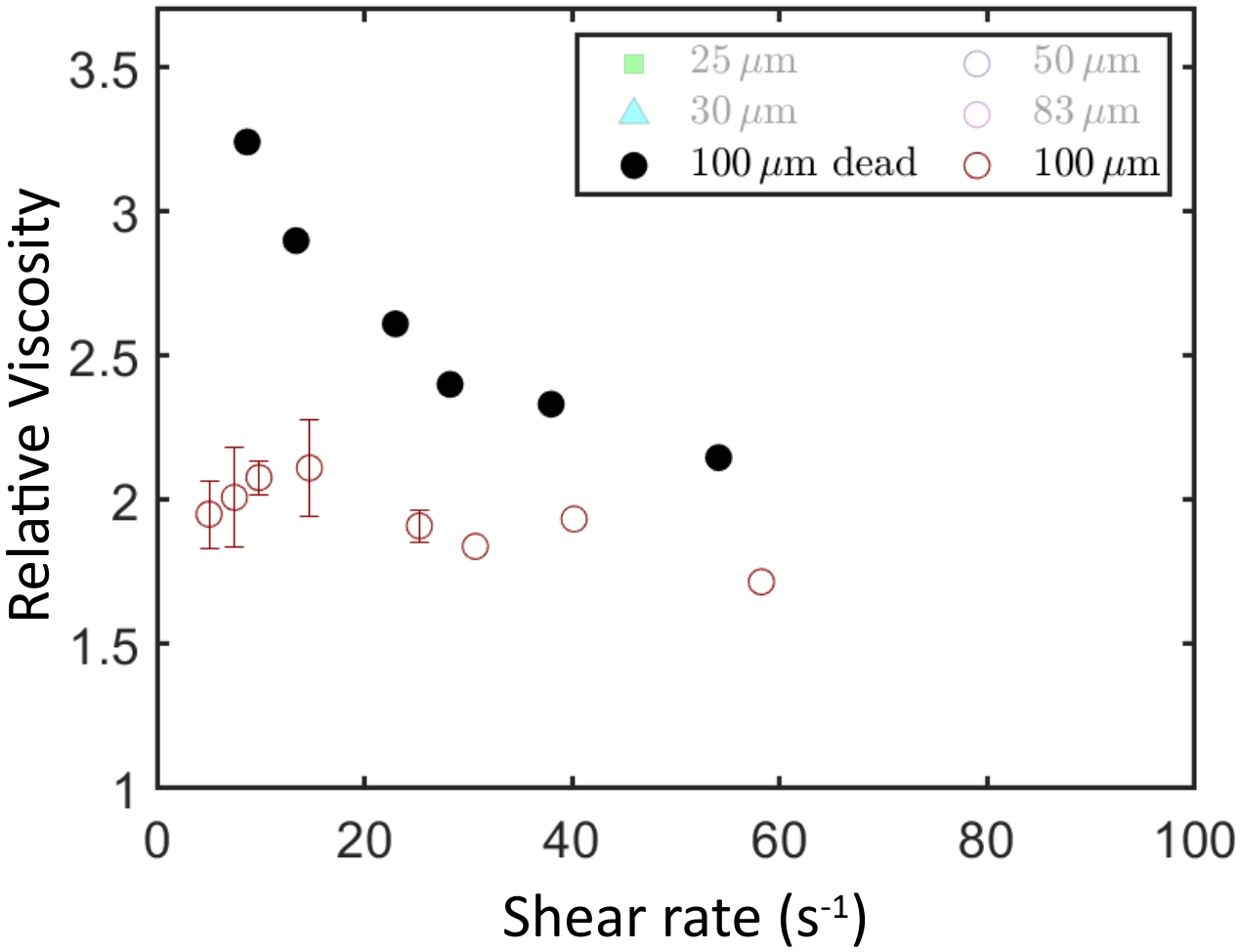
High concentration suspensions



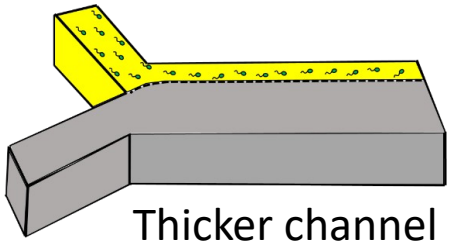
$$nL^3 = 35$$



High concentration suspensions

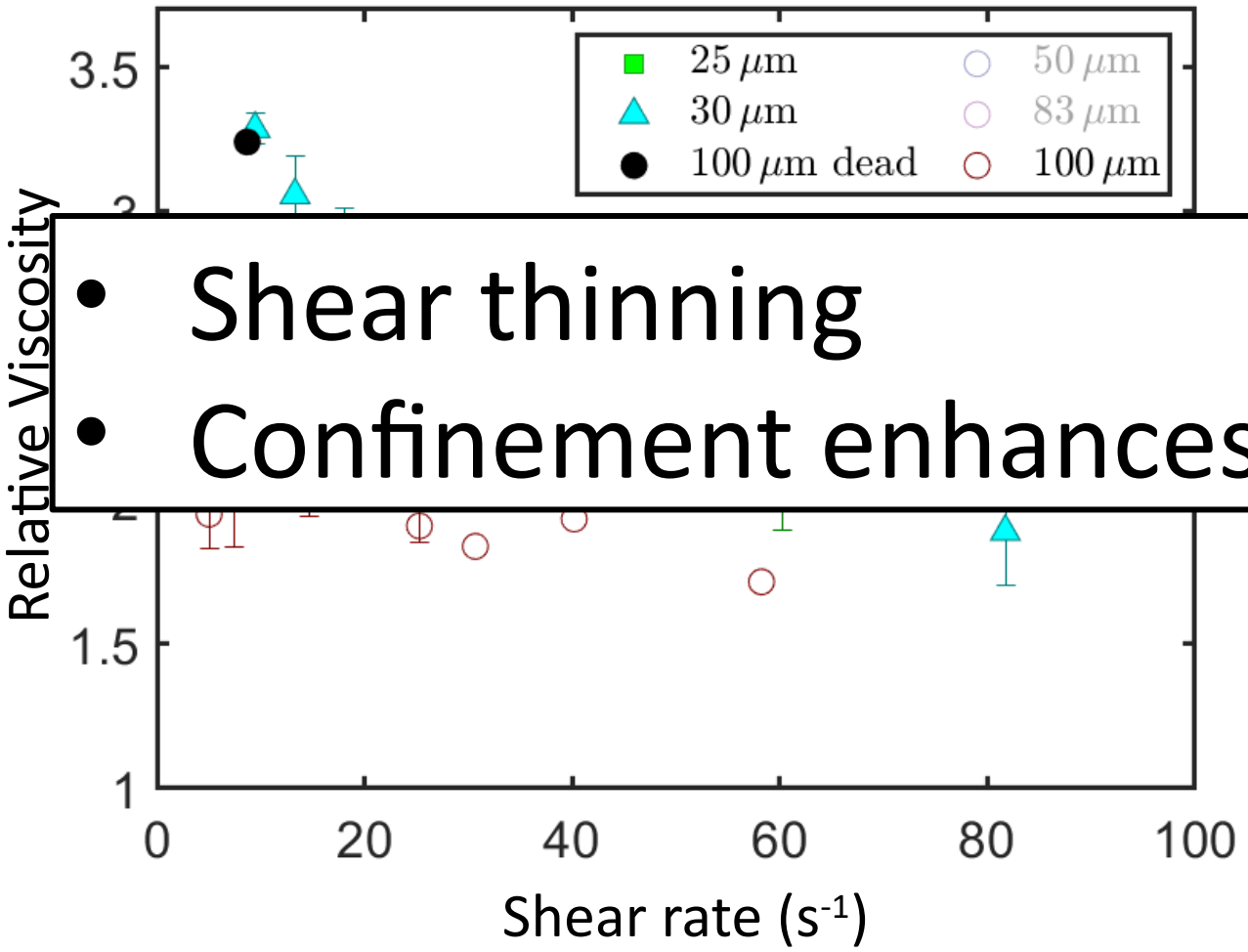


$$nL^3 = 35$$



High concentration suspensions

$$nL^3 = 35$$



- Shear thinning
- Confinement enhances viscosity

Thicker channel

Summary

Concentration	Response to external shear	Confinement effect
Semi-dilute	Shear thickening	Reduce viscosity
Concentrated	Shear thinning	Enhance viscosity

Discussion

Low concentration

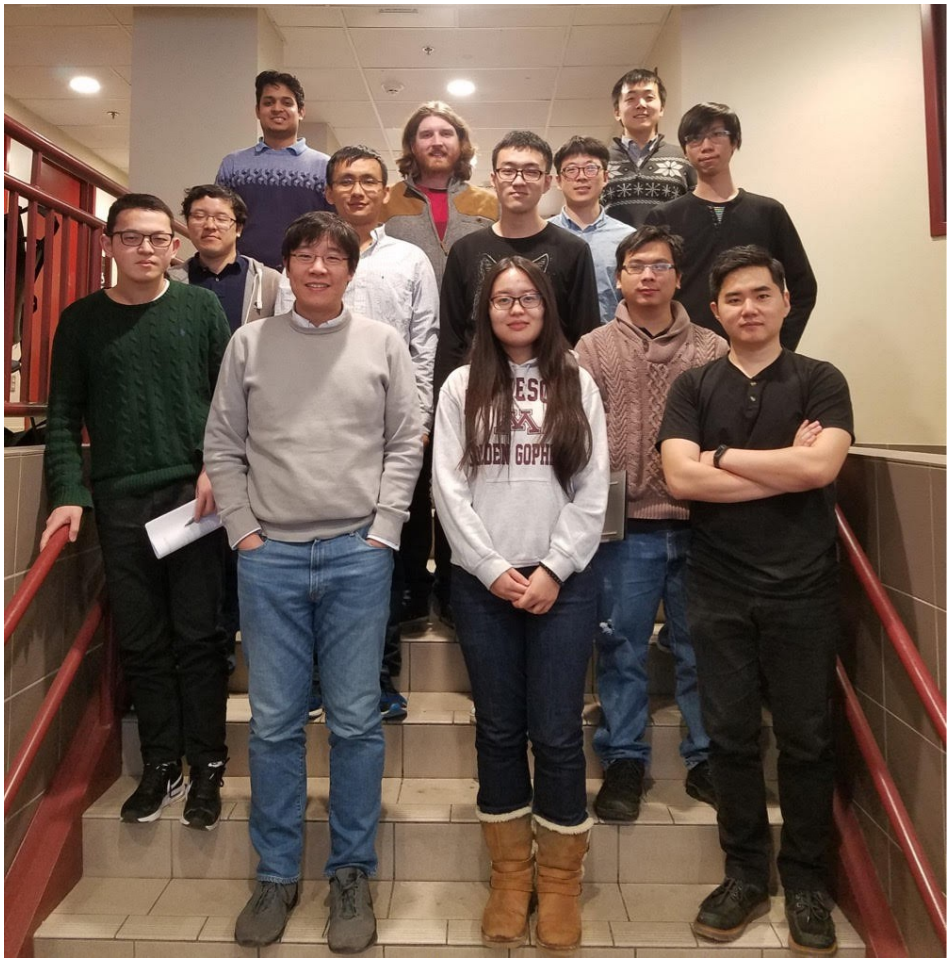
The confinement effect on rheology of active matter have not been fully understood.

My results can help improve the models to better predict the rheological properties of active matter.

Acknowledgement

Group members

Dr. Shuo Guo
Dr. Yi Peng
Dr. Kyle Welch
Seunghwan Shin
Truong Pham
Yangming Kou
Ting-Pi Sun
Chen Fan
Shashank Kamdar



Thank you!

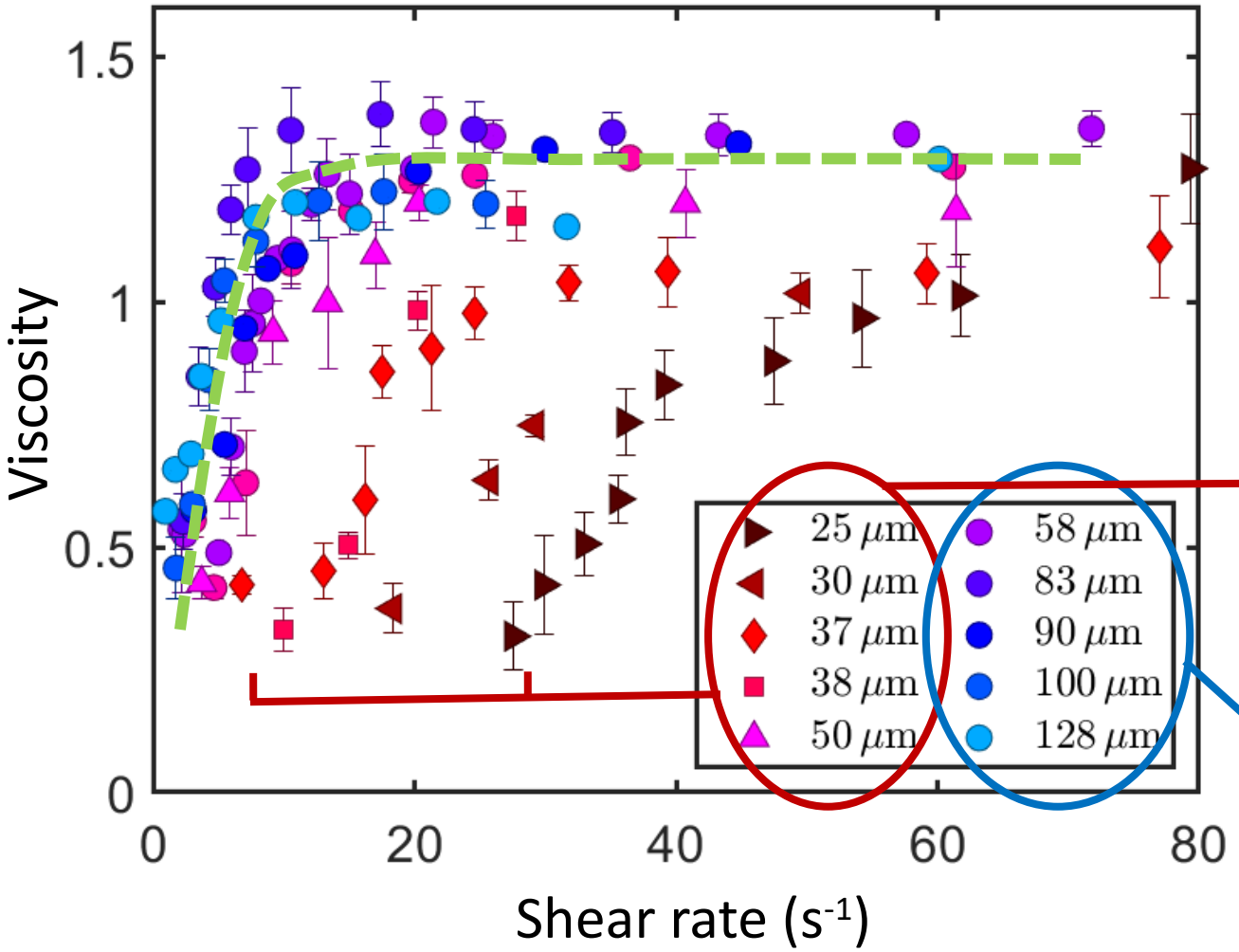
Thank you!

Thank you!

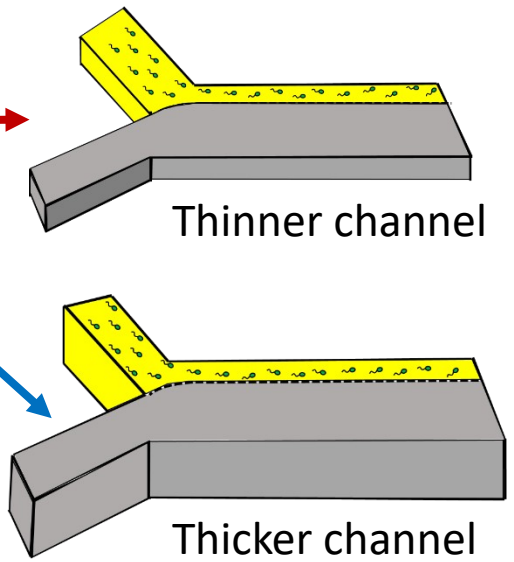
Outline

- Active fluid: with properties such as enhanced diffusivity and reduced viscosity, active fluids have the potential to find use in many processes including mixing, coating and printing.
- We are interested in the viscosity because it is counter-intuitive and meanwhile useful.
- Efforts have been made to elucidate the shear rate dependence of viscosity for bulk active fluids.
- Confinement is common in natural context of active fluids. While confinement plays an essential role in modifying the behaviors and properties of active fluids, its effect remains lacking of experimental evidence and is not well understood.

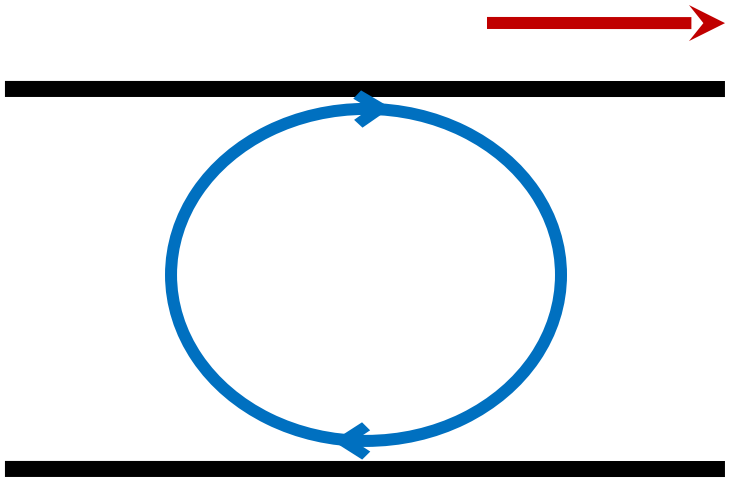
Viscosity of semi-dilute suspensions



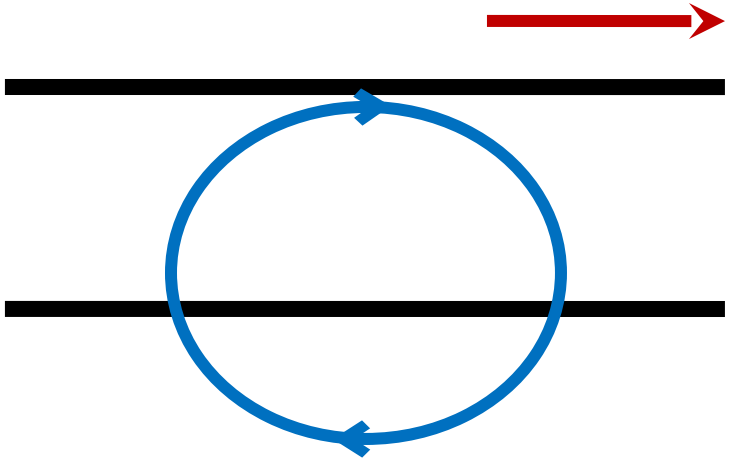
$$nL^3 = 16$$



Swarming reduces viscosity



The vortex of bacteria effectively reduce the stress caused by the external shear



The vortex of bacteria is subject to a strong confinement, making the configuration no longer stable.