Giant Number Fluctuations In 3-D Bacterial Active Turbulence

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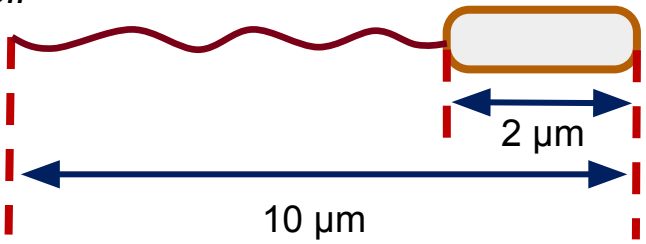
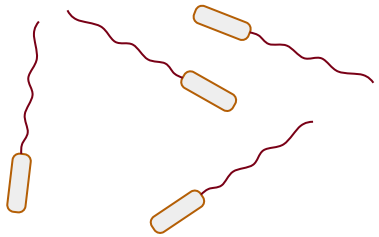
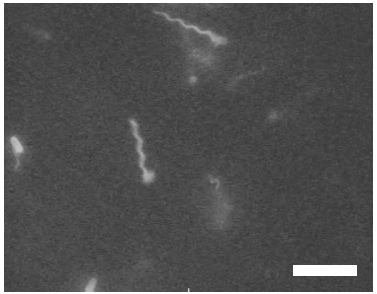
E. coli and bacterial active turbulence

E. coli



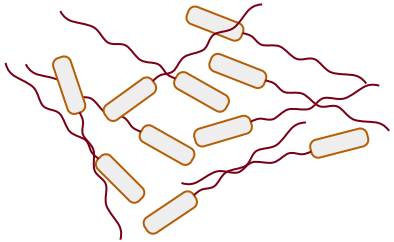
Low concentration



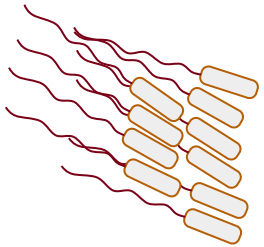


Turner et al., *J. Bacteriol.*, 2000 (Scale bar = 10 μm)

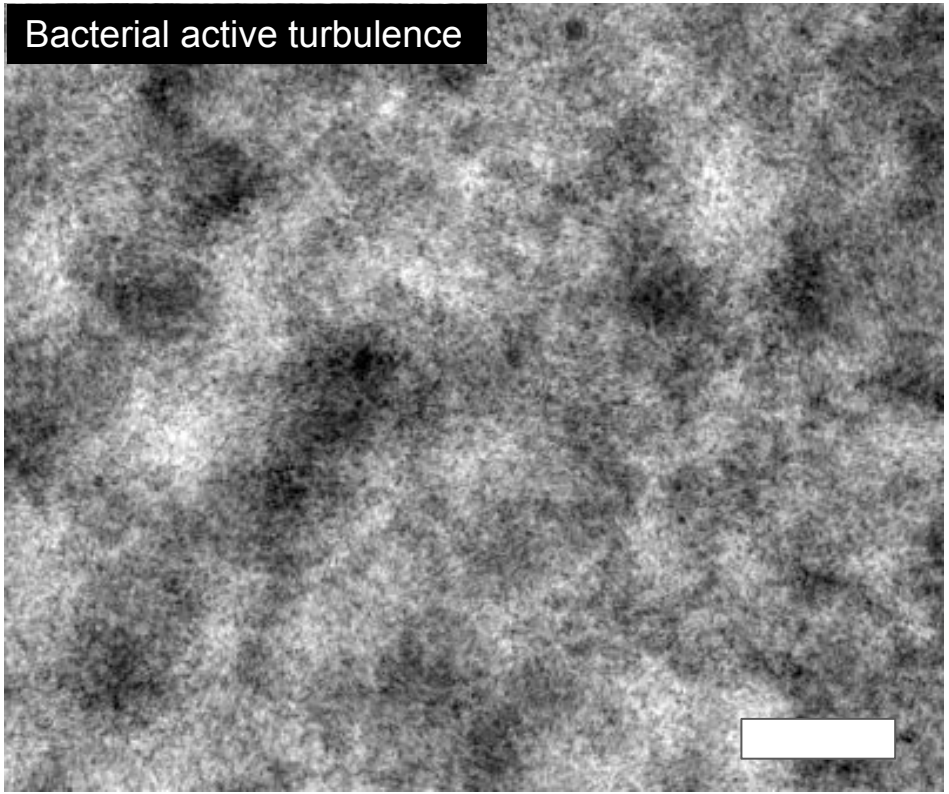
High concentration



self-organize



Bacterial active turbulence



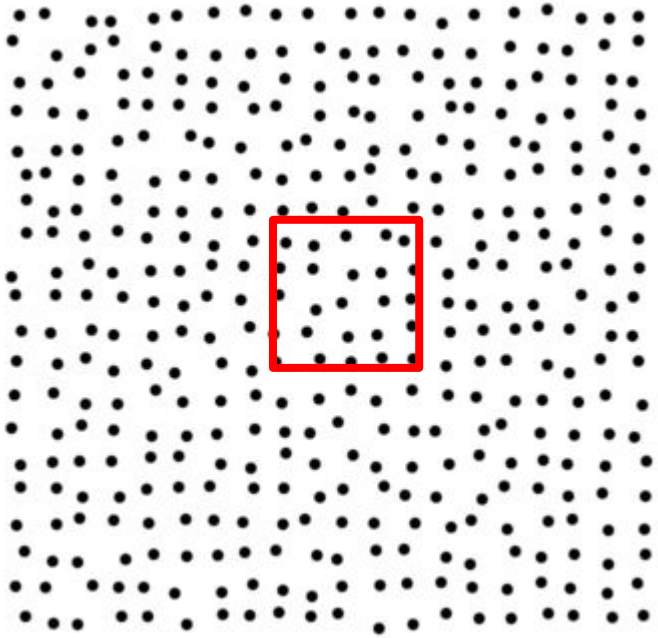
50 μm

Giant number fluctuations (GNF)

Definition Anomalously strong dependence of the ***variance*** of the number of particles on the **mean** number

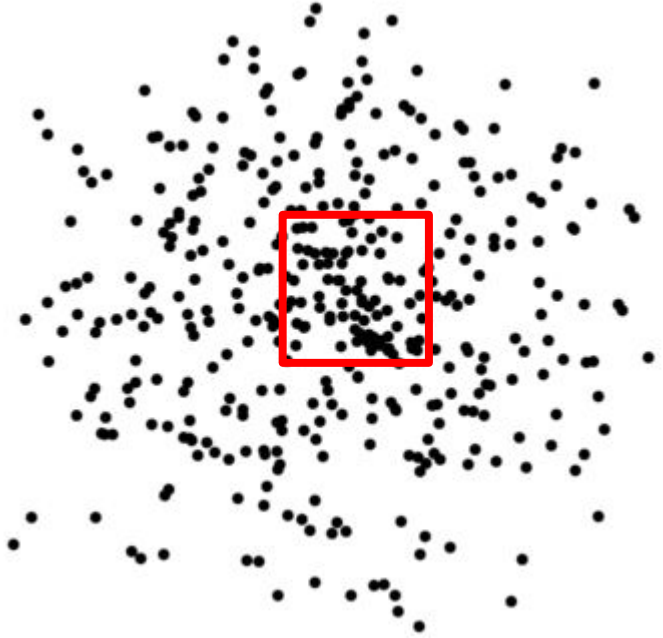
"degree of chaos"

equilibrium



$$\Delta N \sim N^{0.5}$$

active



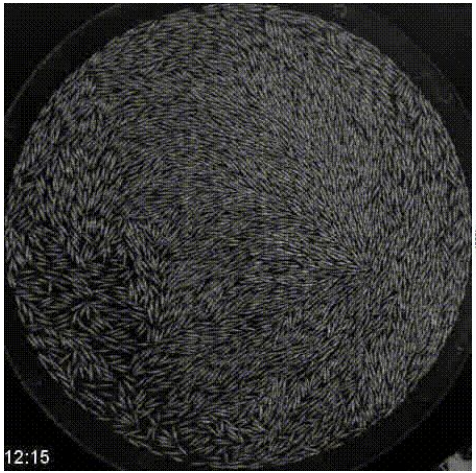
$$\Delta N \sim N^{0.5+\alpha}$$

Giant number fluctuations (GNF)

Definition Anomalously strong dependence of the ***variance*** of the number of particles on the **mean** number

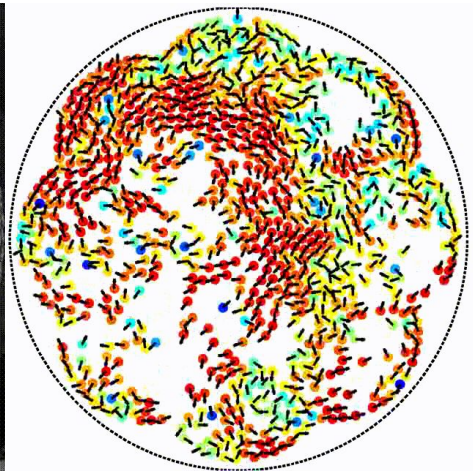
"a landmark of collectively moving ordered active particles"

Shaking rods



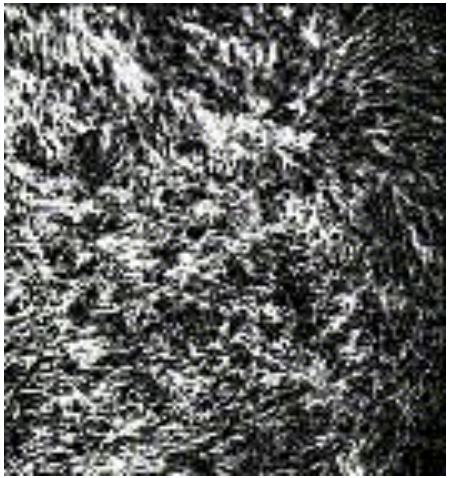
Narayan (2007)

Shaking disks



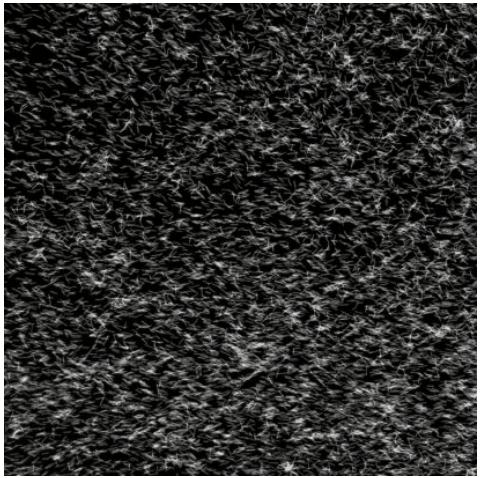
Deseigne (2010)

Actin filaments



Schaller (2013)

Bacteria



Nishiguchi (2017)

Theory
Toner and Tu (1995, 1998)
Simha and Ramaswamy (2002, 2003)
Saintillan and Shelly (2008)
Toner (2012, 2019)

Simulation
Mishra (2006)
Chate (2008)
Saintillan (2012)
Dey (2012)
Ngo (2014)
Mahault (2019)

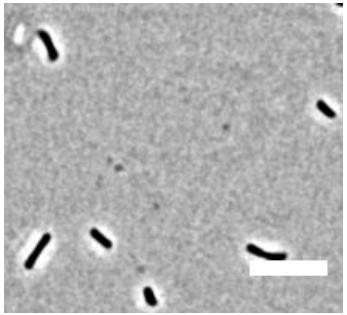
Experiment
Narayan (2007)
Sokolov (2009)
Deseigne (2010)
Zhang (2010)
Palacci (2013)
Schaller (2013)
Nishiguchi (2017)
Kawaguchi (2017)
Karani (2019)

Measurement GNF in 3D

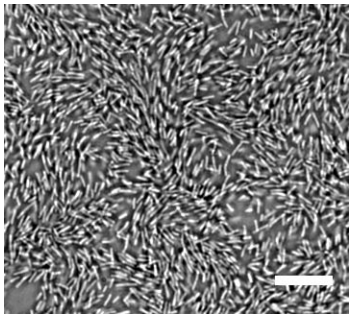
$$\Delta N \sim N^{0.5+\alpha}$$

- Definite measurement of α
  - 0.13 to 0.5
  - Presence of frictional walls
  - Quantitative understandings
    - Concentration dependence
    - Dimensionality effect
    - ...

Quasi-2D bacterial suspensions

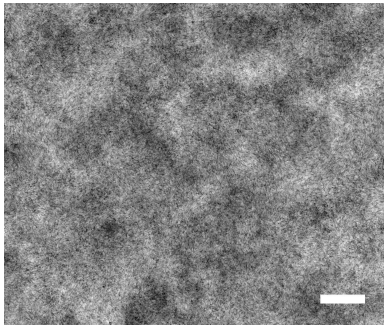


10 µm



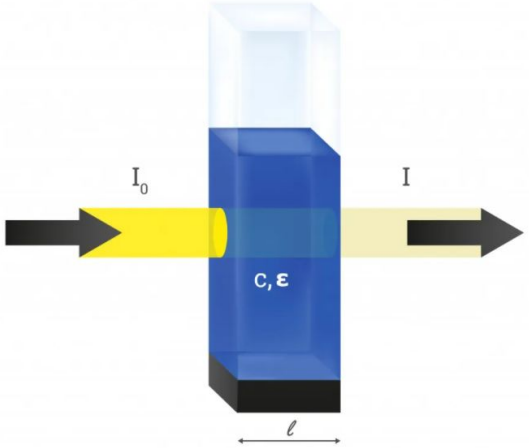
30 µm

3D bacterial suspensions



50 µm

Measurement GNF in 3D: Beer-Lambert law



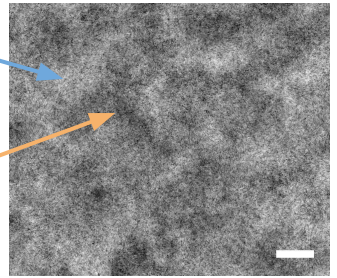
$$\log \frac{I_0}{I} \propto c$$

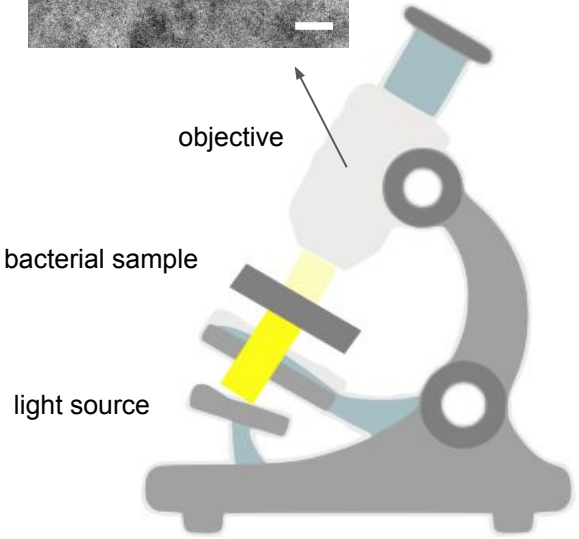
Light attenuation is proportional to solution concentration

https://www.scienceabc.com/pure-sciences/what-is-beers-law.html

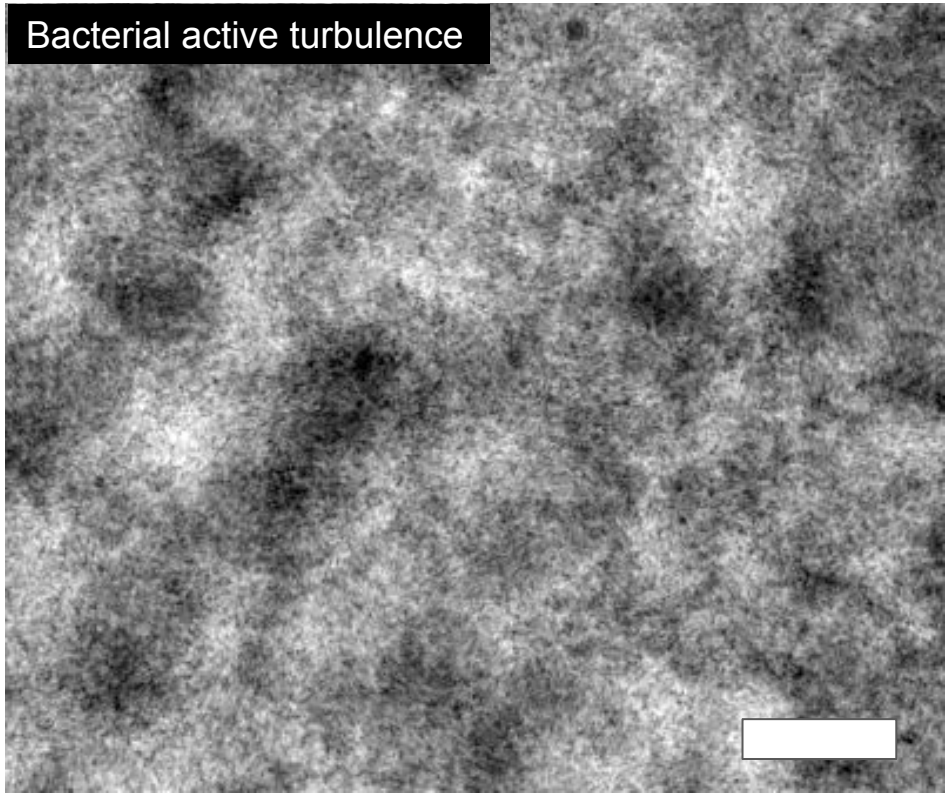
low concentration

high concentration

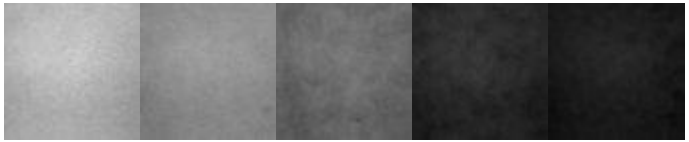




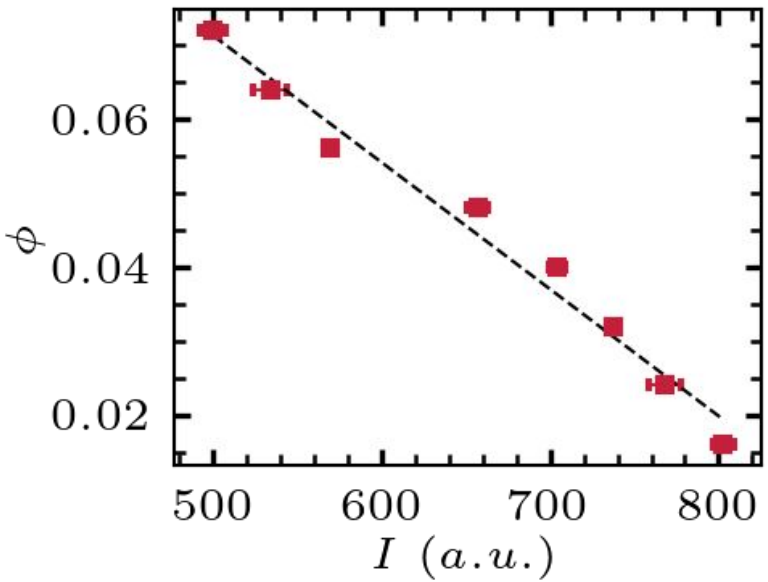
Concentration and light: quantitative relation



Different concentration - Same illumination

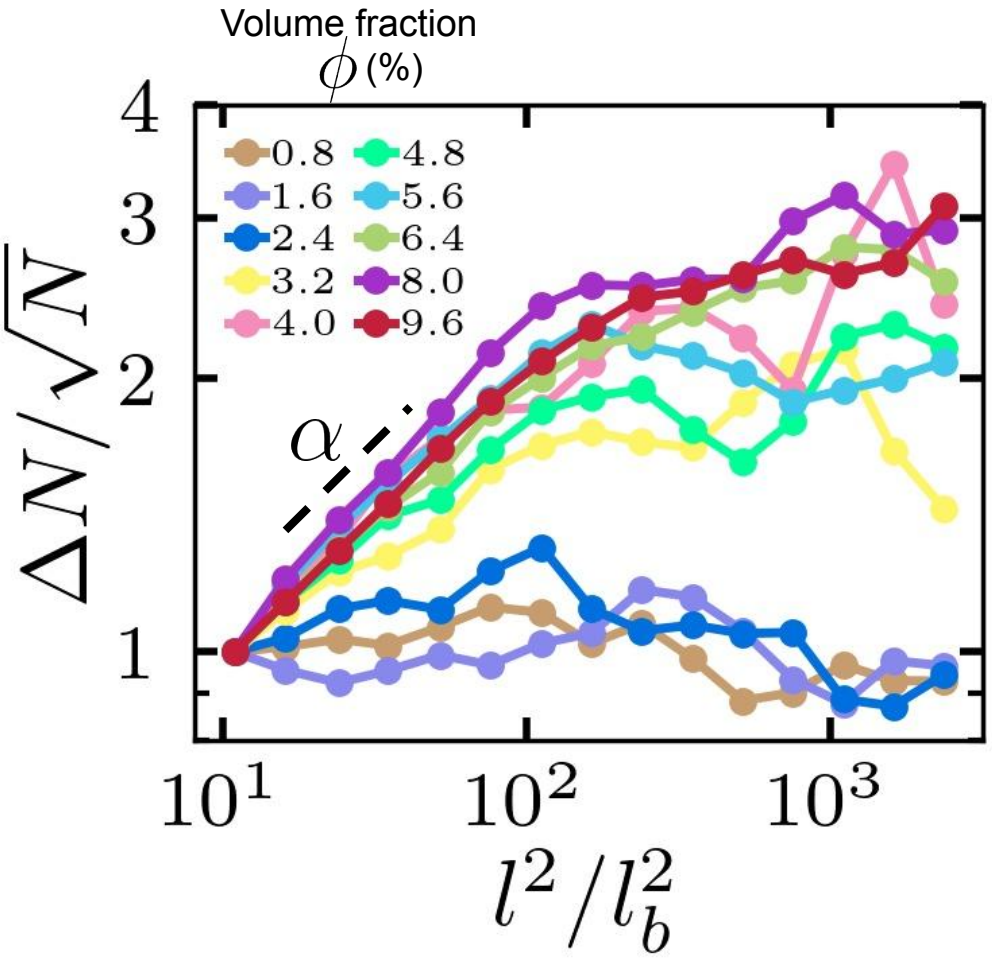


Volume fraction ϕ 0.016 0.032 0.048 0.064 0.080



★ A similar idea $\Delta I \propto \Delta c$ can be found in Wilson (2011)

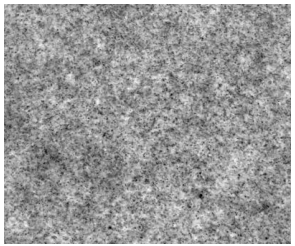
GNF at different concentrations



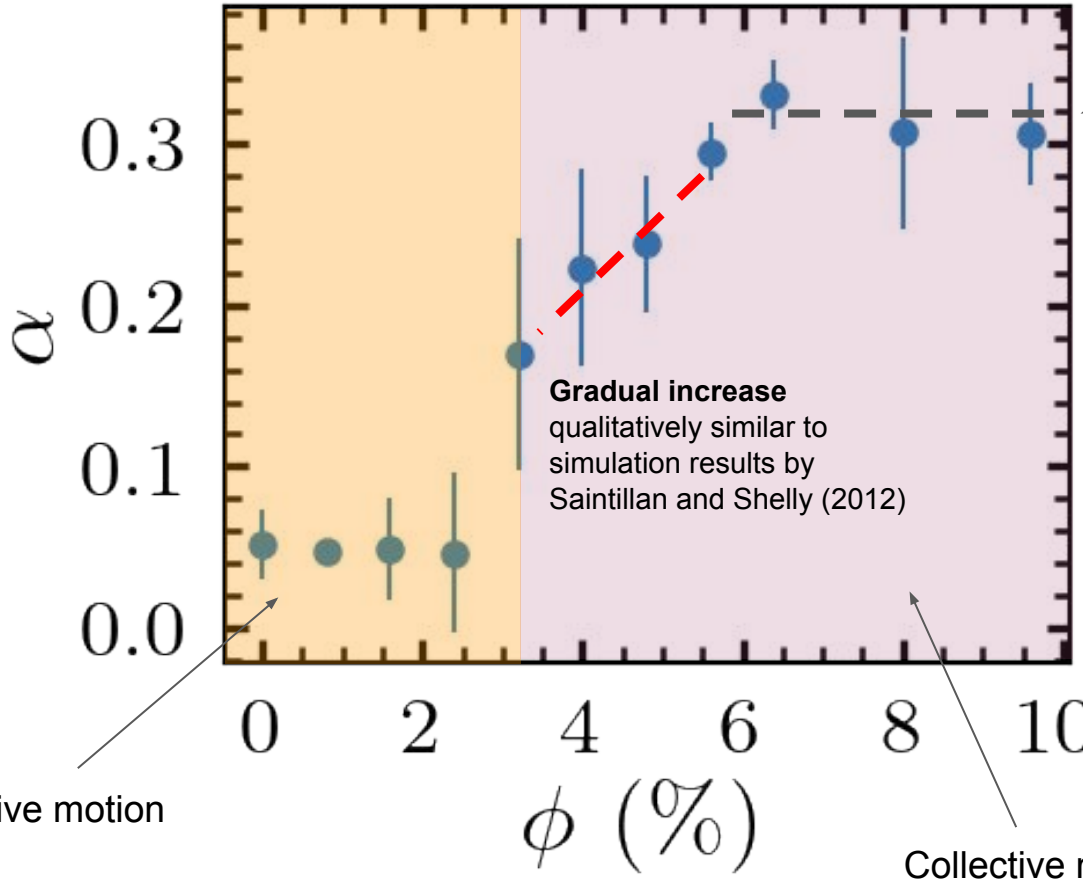
$$\Delta N/\sqrt{N} \sim N^{\alpha}$$

- α measures the magnitude of GNF

GNF at different concentrations



1.6%

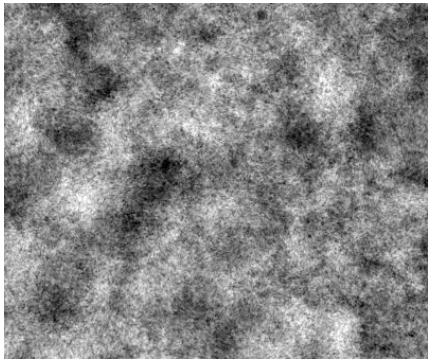


$\alpha \approx 0.32$
Close to the 3D prediction by Simha and Ramaswamy (2002)

Gradual increase
qualitatively similar to simulation results by Saintillan and Shelly (2012)

No collective motion

Collective motion

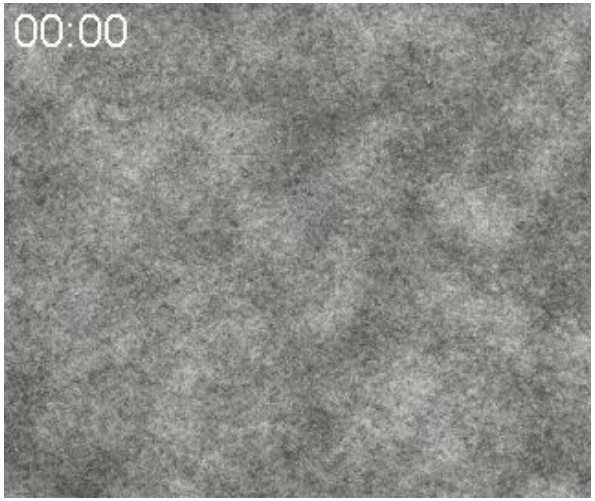


6.4%

Simha and Ramaswamy (2002); Saintillan and Shelly (2012)

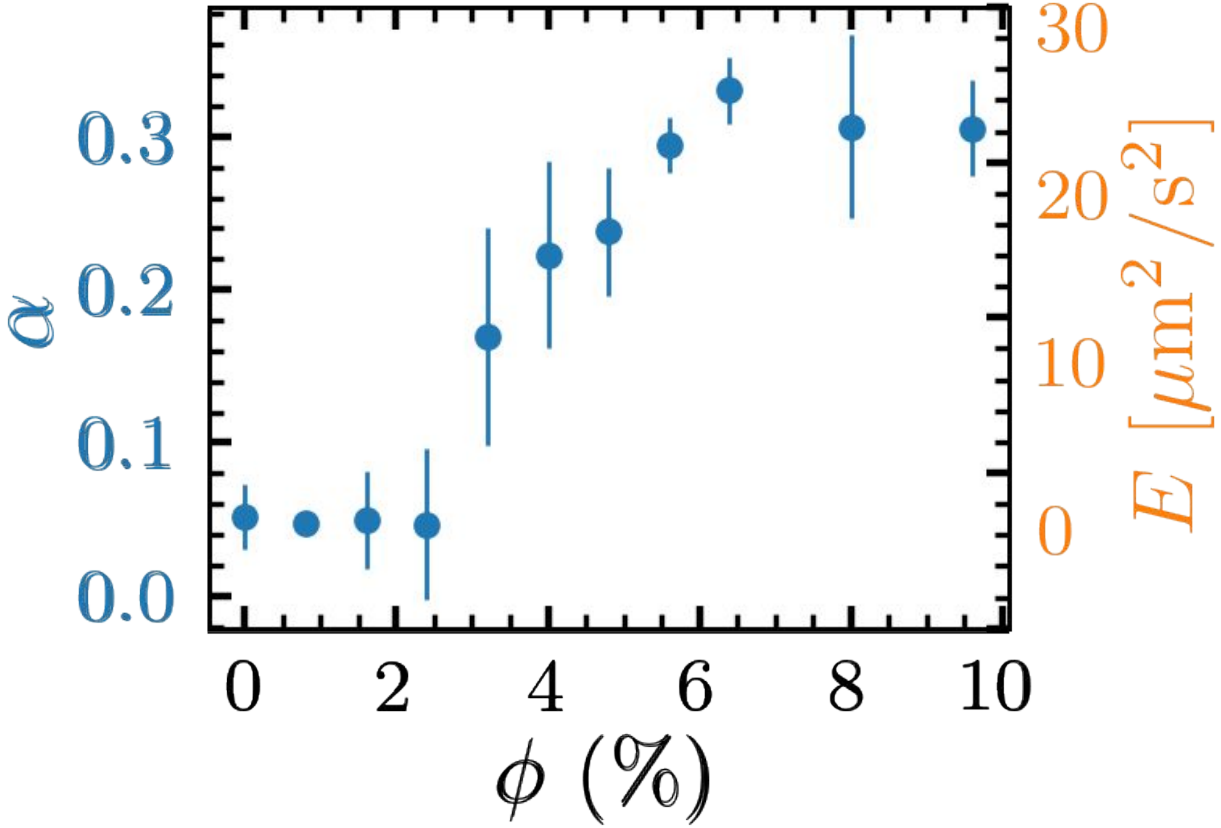
GNF and kinetic energy: global correlation

Particle image velocimetry (PIV)

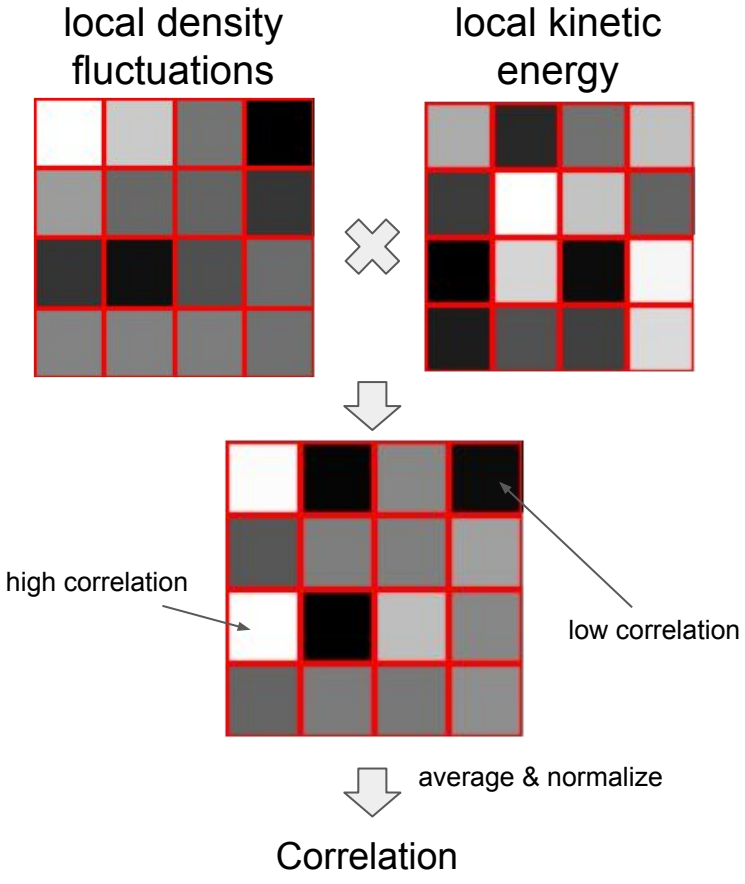


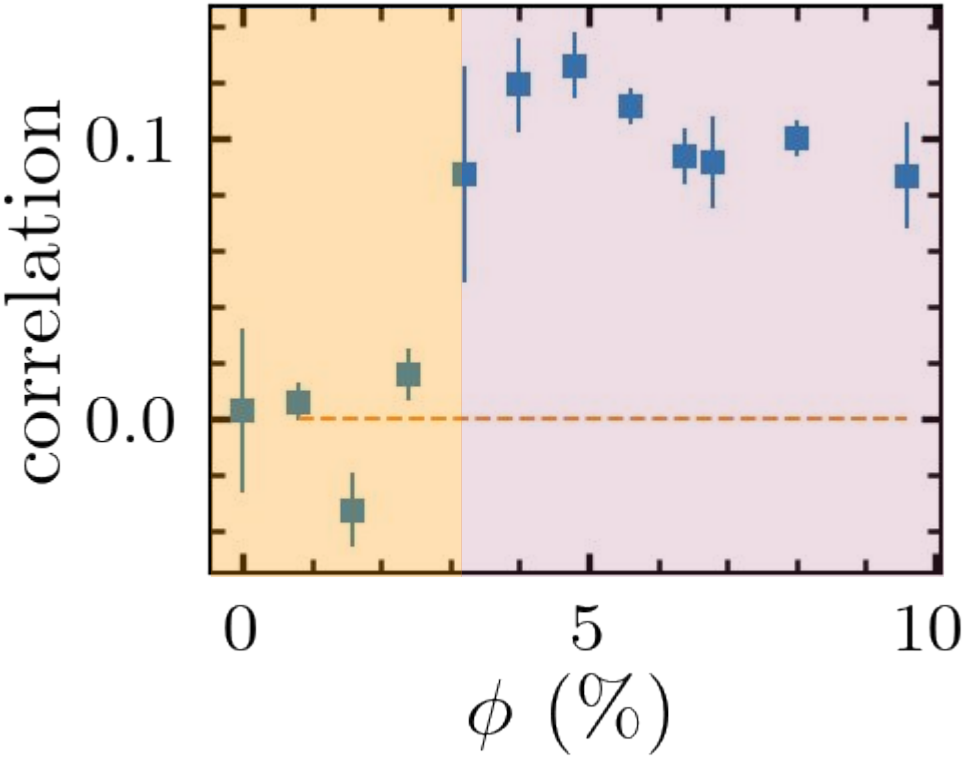
Kinetic energy:

$$E = \frac{1}{2}\langle |\boldsymbol{v}|^2 \rangle$$



GNF and kinetic energy: local correlation





Conclusions

- 1st measurement of GNF in 3D bacterial suspensions
- Confirmation of theoretical prediction and simulation results
- Coupling between GNF and kinetic energy over different length scales

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