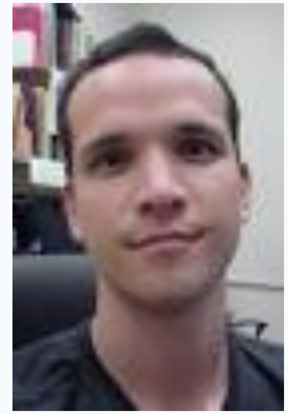
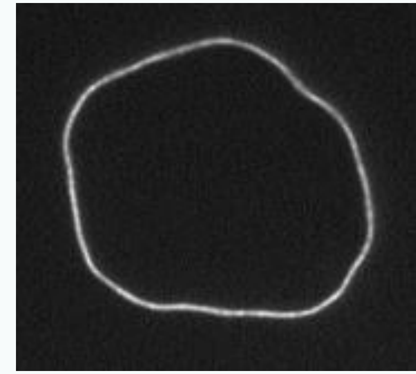
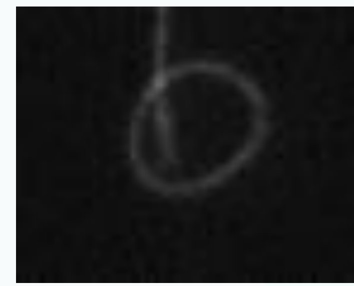
Dynamic of isotropic active gels

Tim Sanchez







Seth Fraden

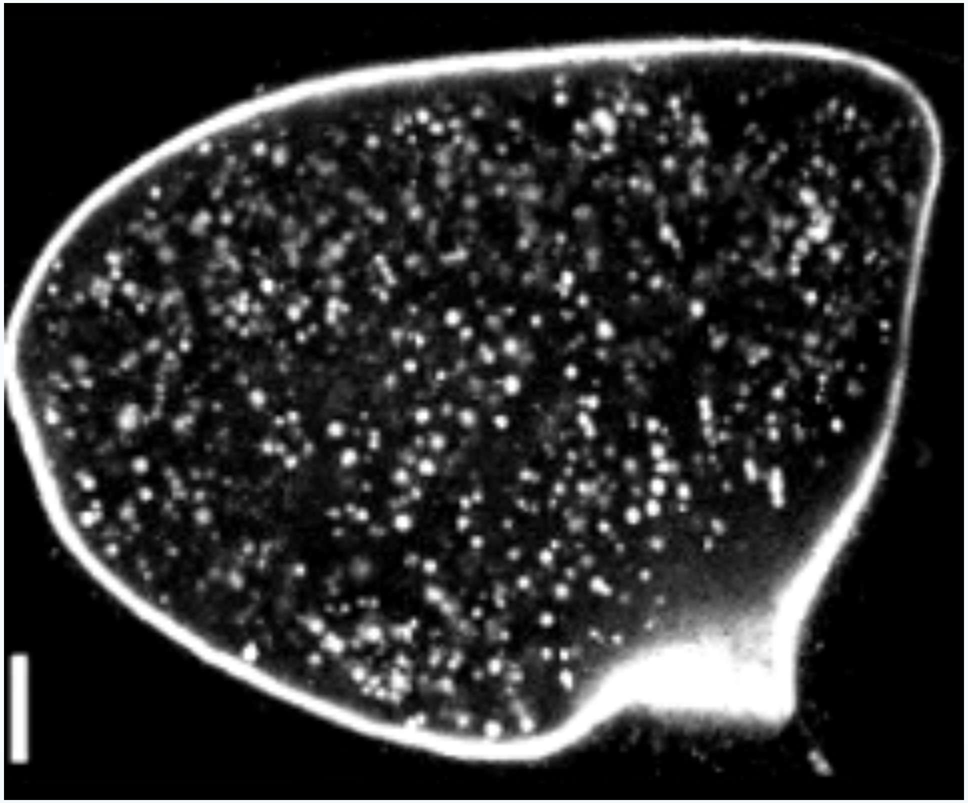
J.F. Joanny

Spontaneous flow transition in active polar gels

R. Voituriez[1], J. F. Joanny[1] and J. Prost[1,2]

[1] *Physicochimie Curie (CNRS-UMR168), Institut Curie, Section de Recherche 26 rue d'Ulm, 75248 Paris Cedex 05, France*
[2] *ESPCI - 10 rue Vauquelin, 75231 Paris Cedex 05, France*

Bioinspired soft active matter

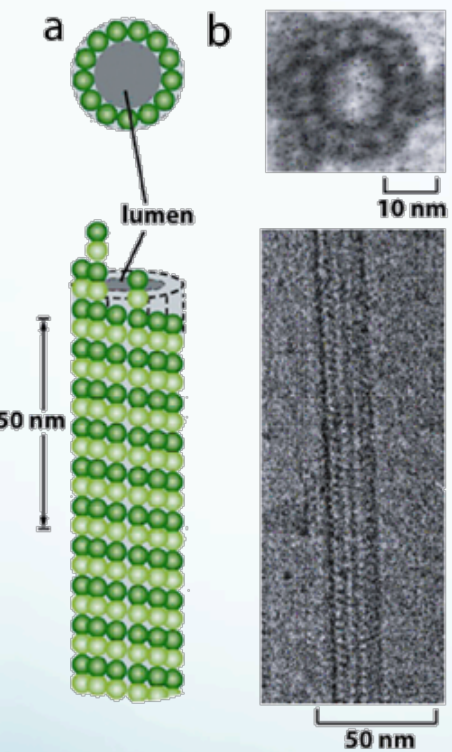


Cytoplasmic streaming
in *Drosophila* oocyte

goal: use efficient energy transducing proteins to assemble biomimetic non-equilibrium materials from the bottom-up

Building blocks

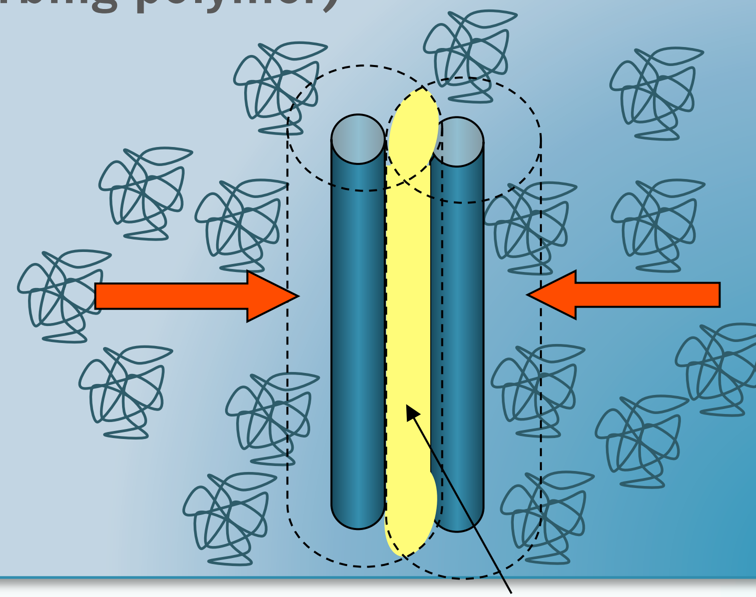
Microtubules



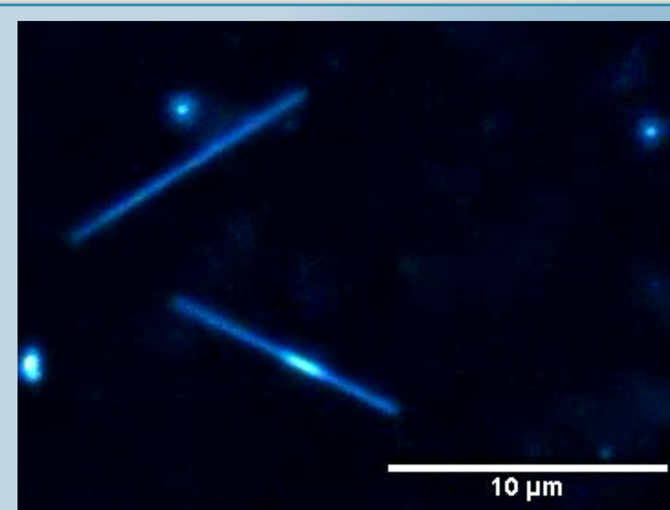
- microns long rigid filaments
- stabilized with GMCPP

Filament bundling induced by a crowding agent (non-adsorbing polymer)

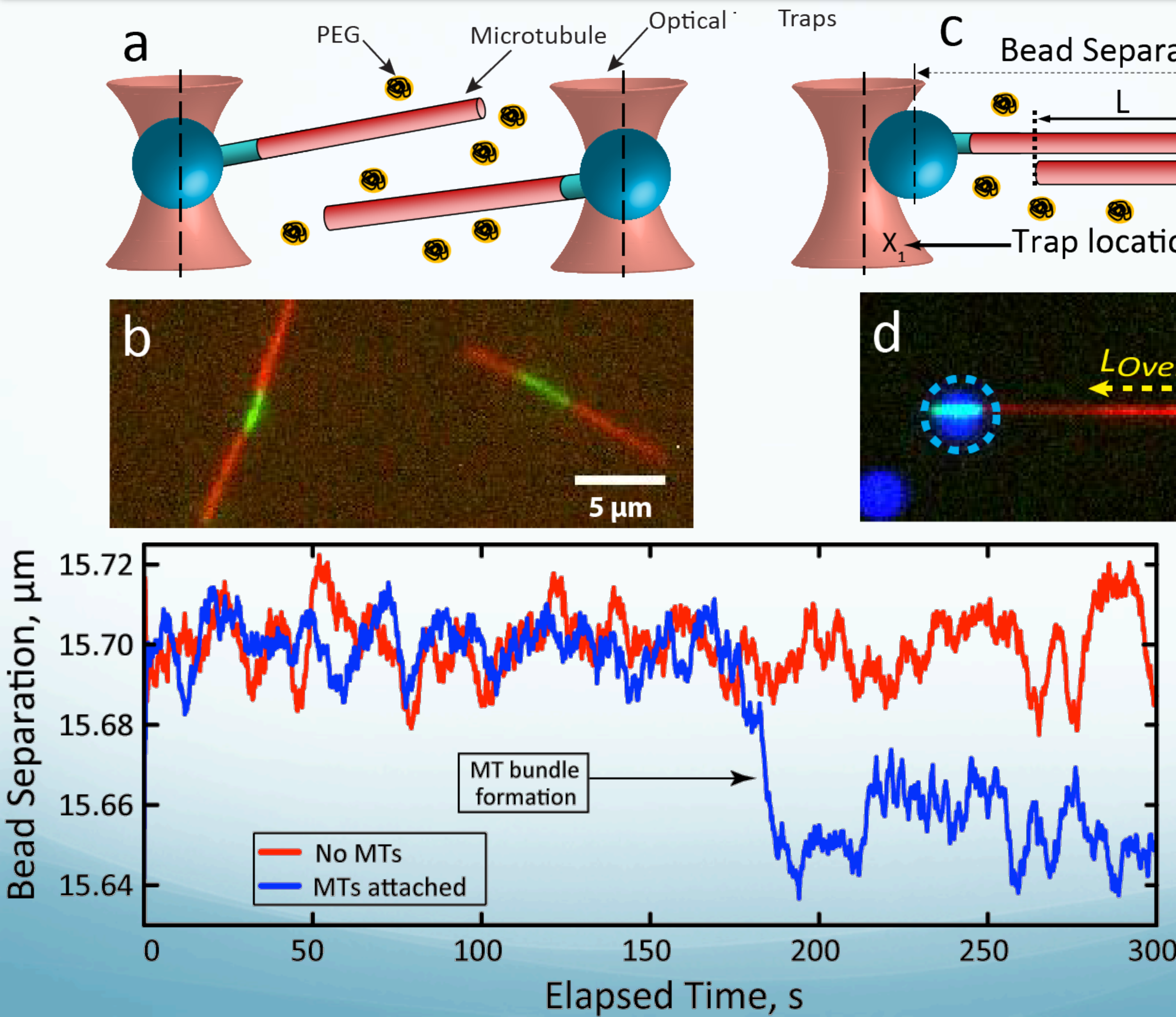
depletion effect: attractive interactions with tunable strength and range



bundling dynamics visualized with darkfield microscopy



Measuring filament cohesion energy

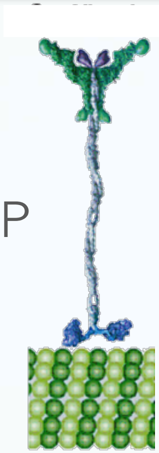


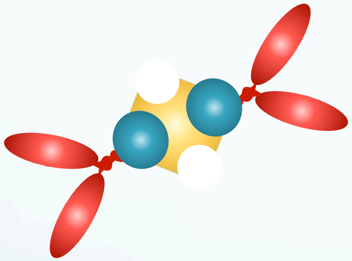
contractile force ~ 10-100 fN

Third component: kinesin motors

kinesin

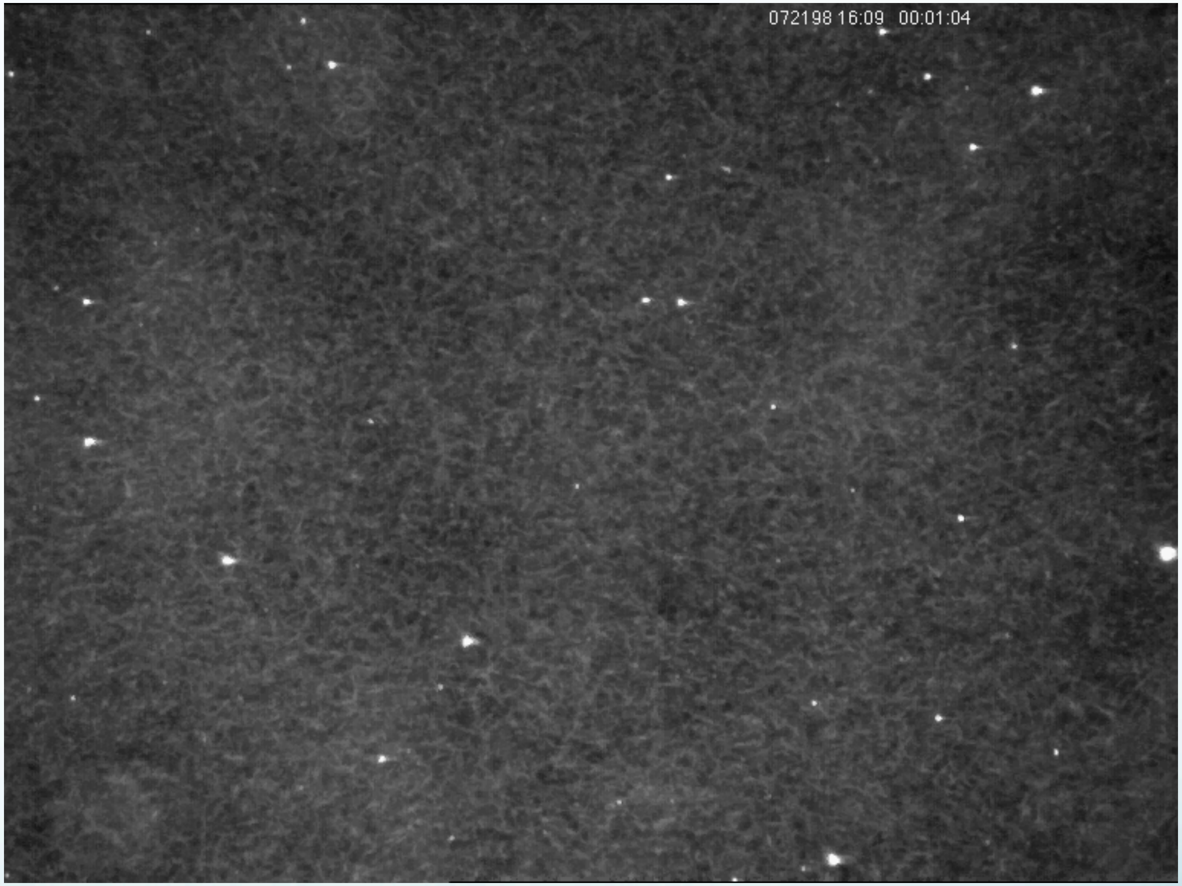
- kinesin convert energy from ATP hydrolysis to move along MT





biotin labeled kinesin bound into multimeric clusters.

Needlec, Surrey, Leibler, 1998, 2001



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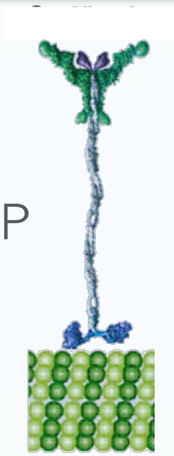

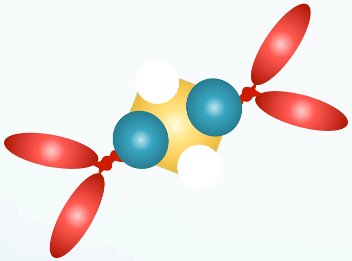

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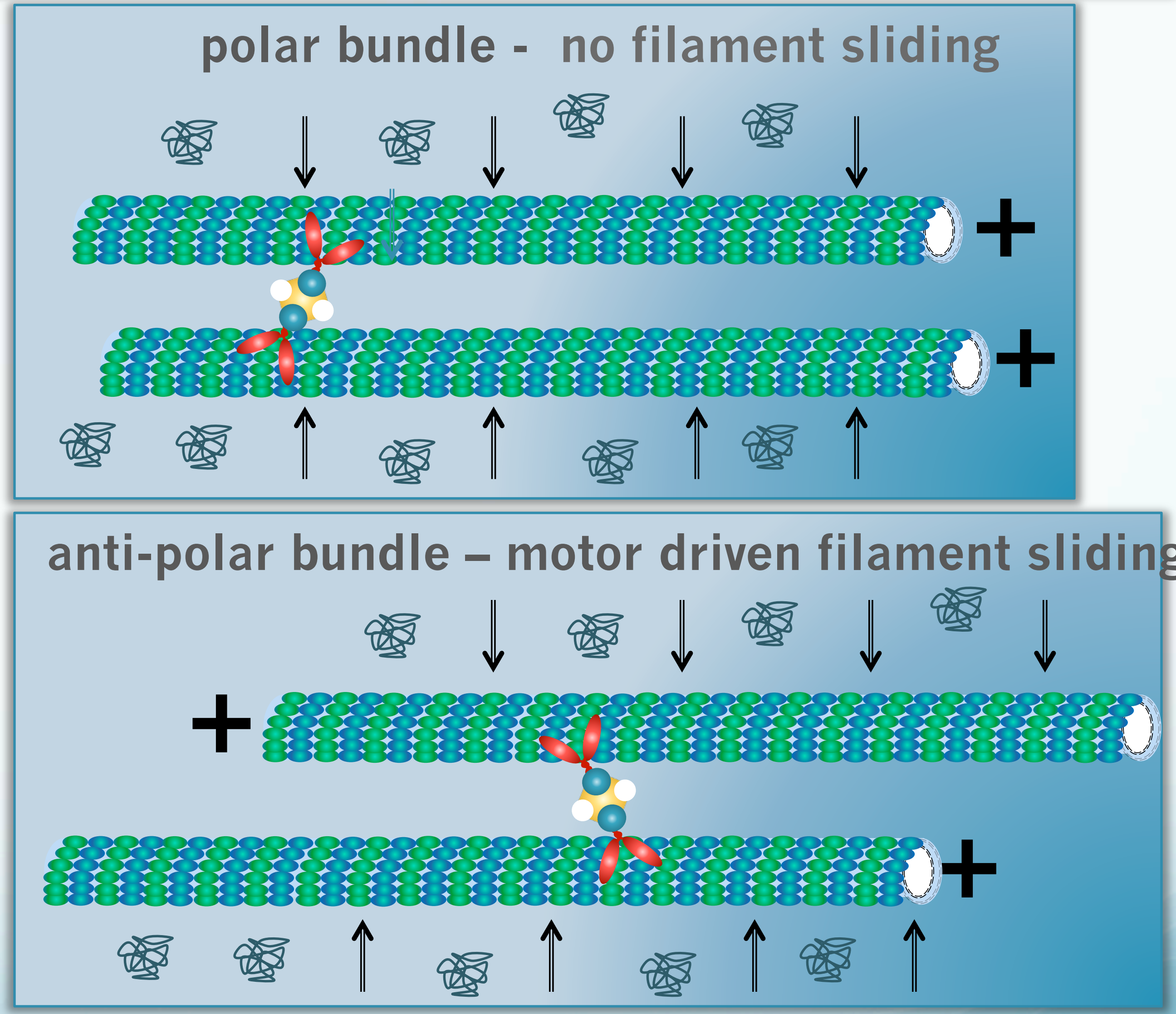
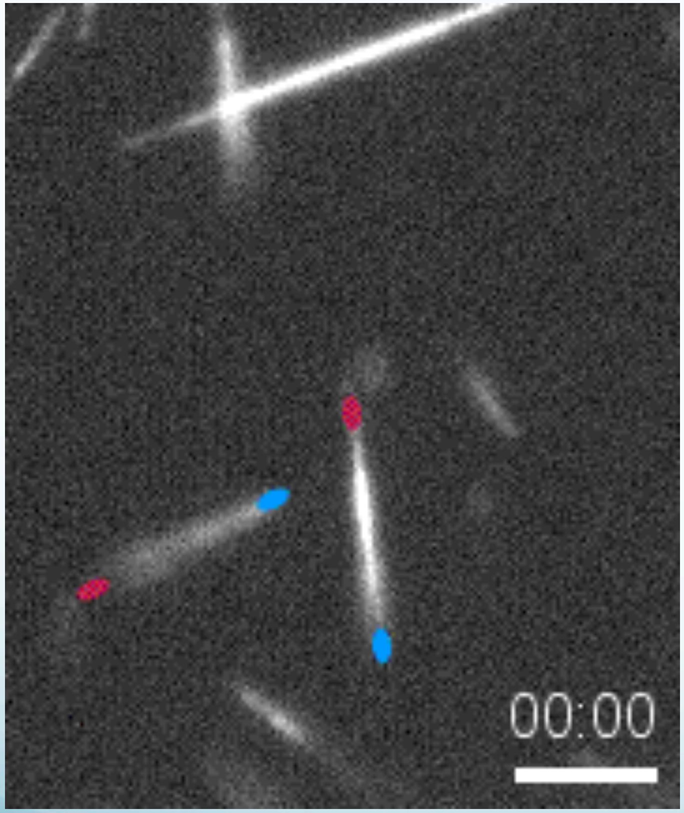


➢ bundle geometry increases filament sliding efficiency

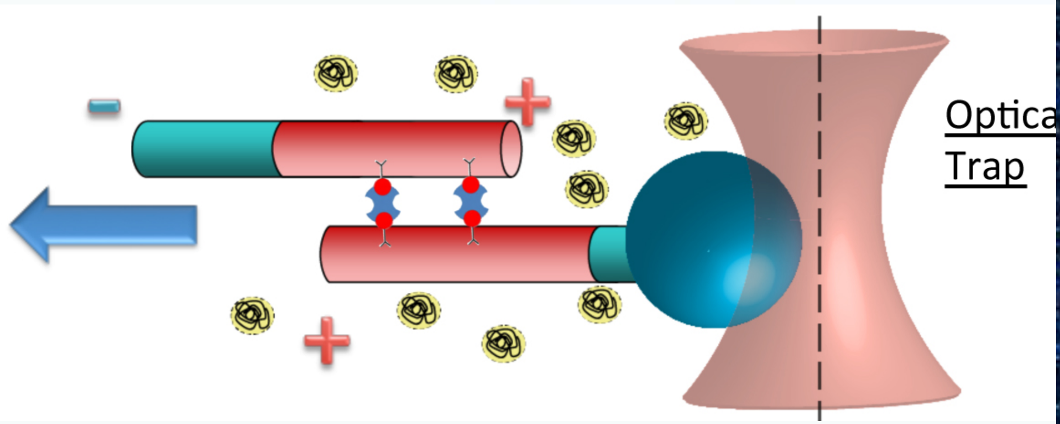
Isolated active MT bundles

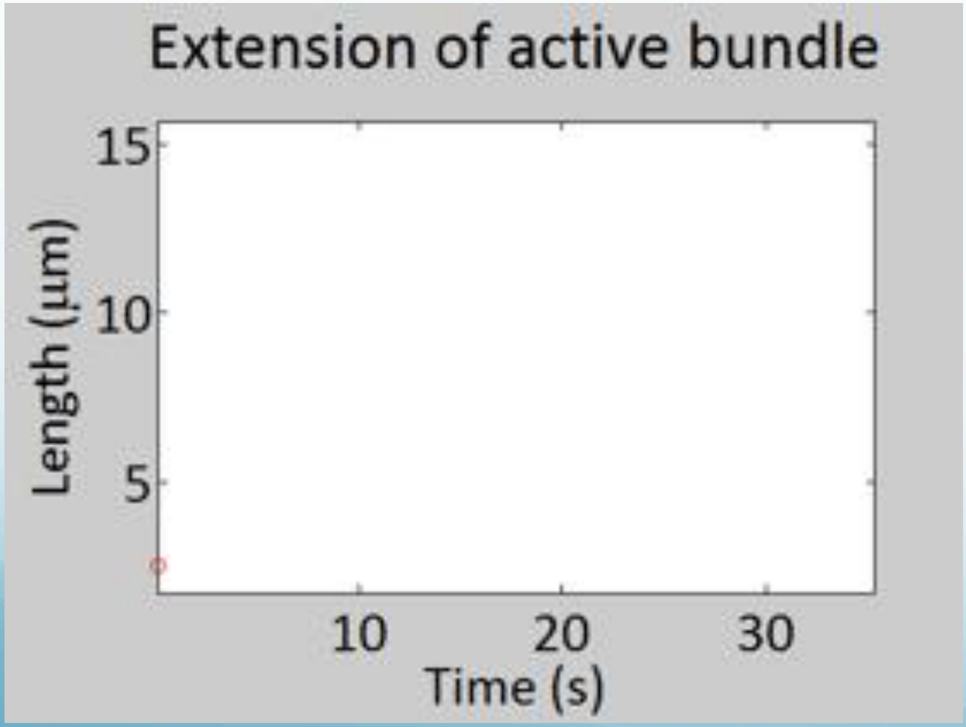
Dilute active MT bundle observed with darkfield microscopy in quasi 2D confinement

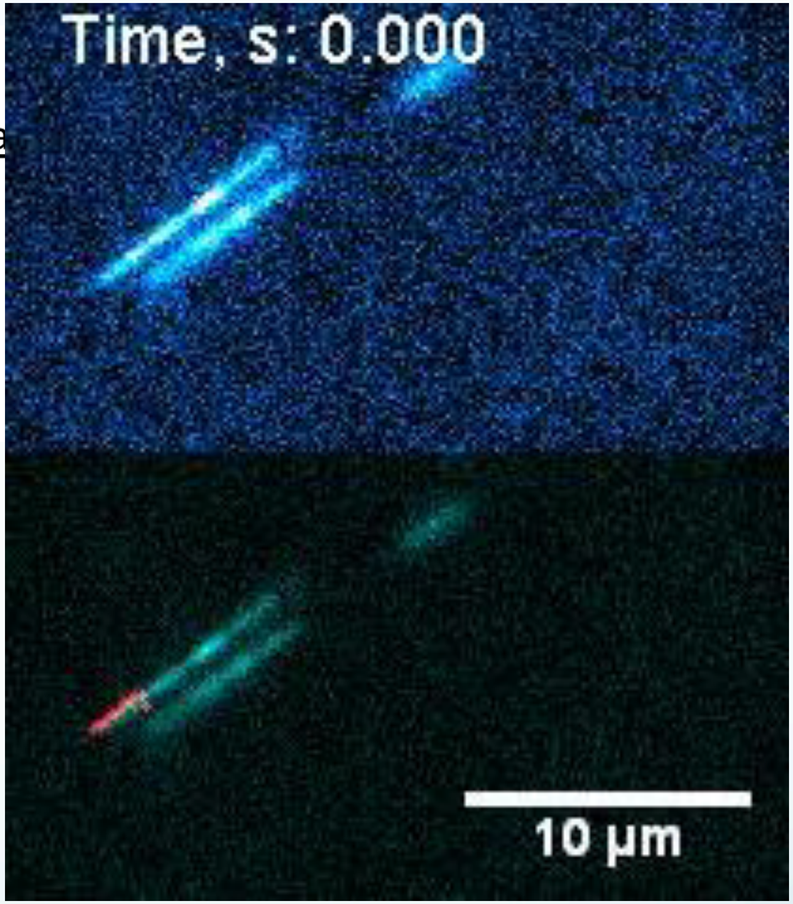


- isolated bundles are static, locally polarity sorted
- bundle recombination reinitializes polarity sorting

Motor driven bundle extension velocity



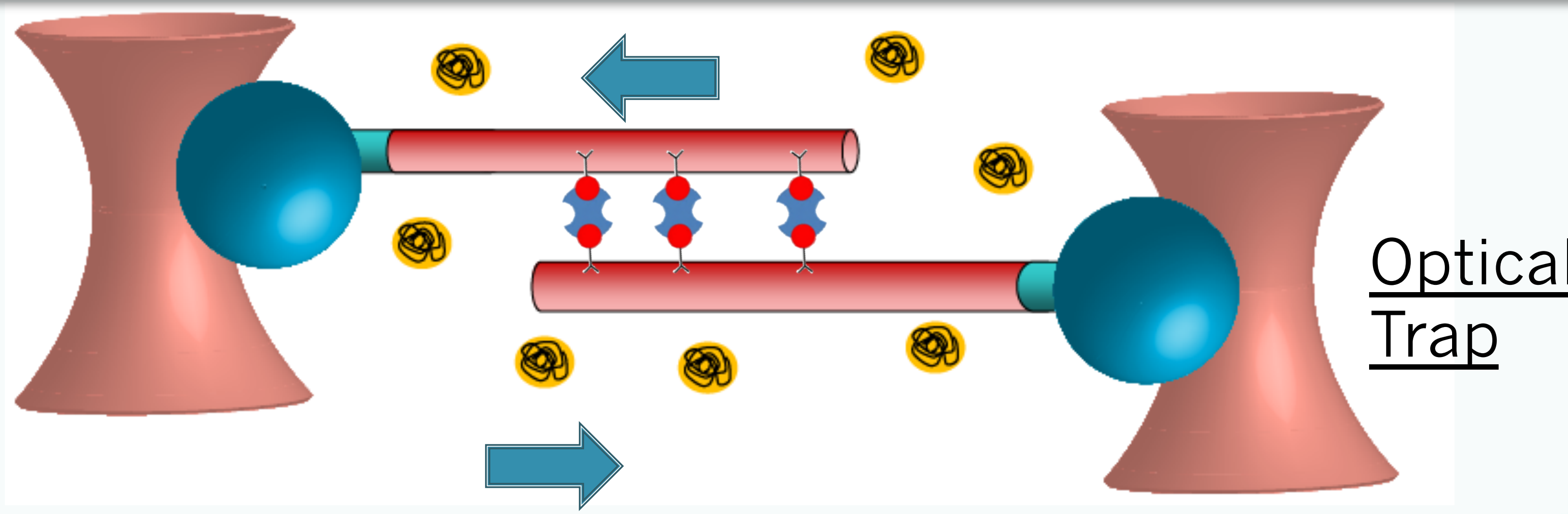


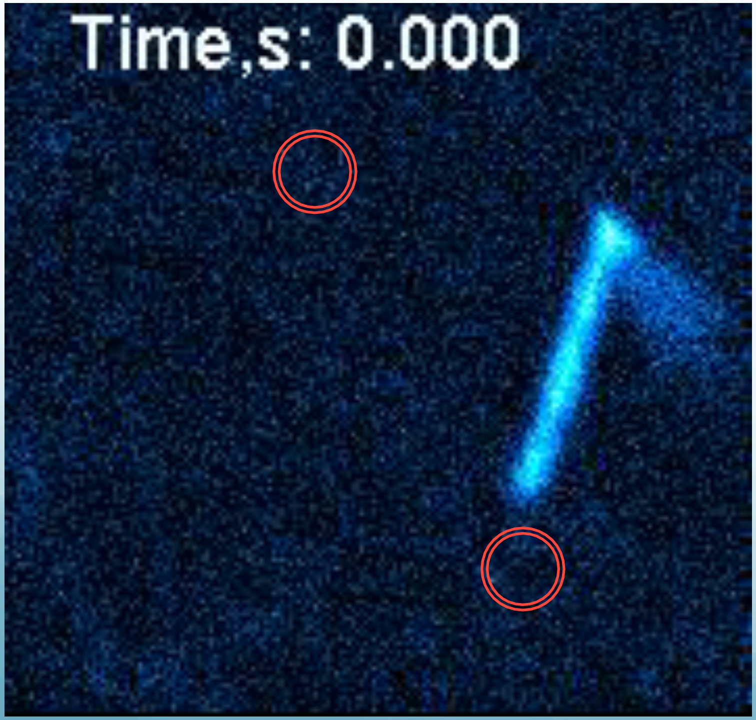


Extension speed (N=8)

0.18±0.02 μm/s

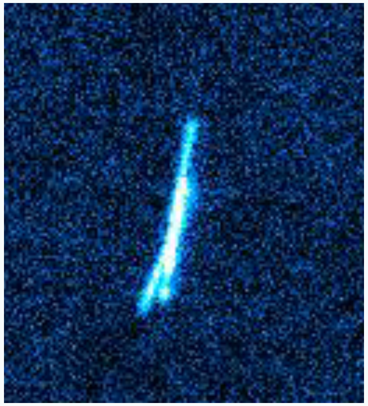
buckling and fracture of active MT bundles

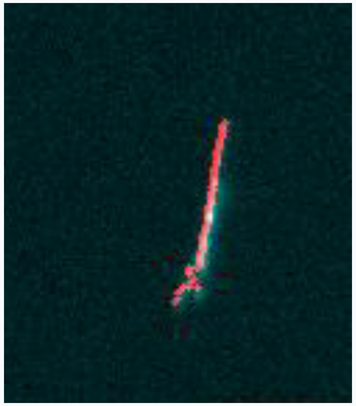


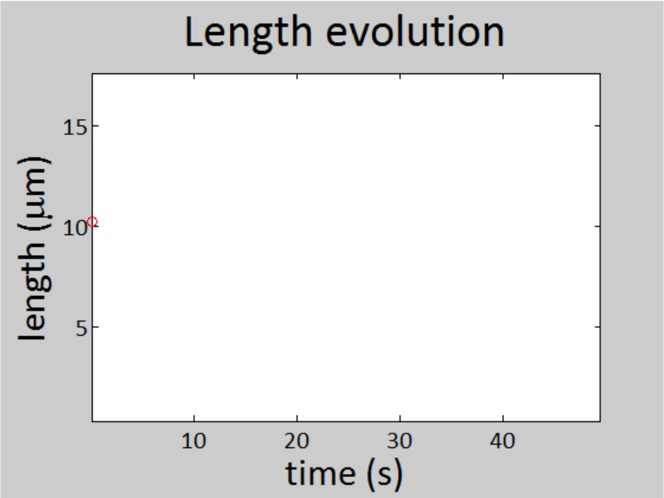


motor driven extension drives bundle buckling and fracture

Mechanics of internally driven buckling

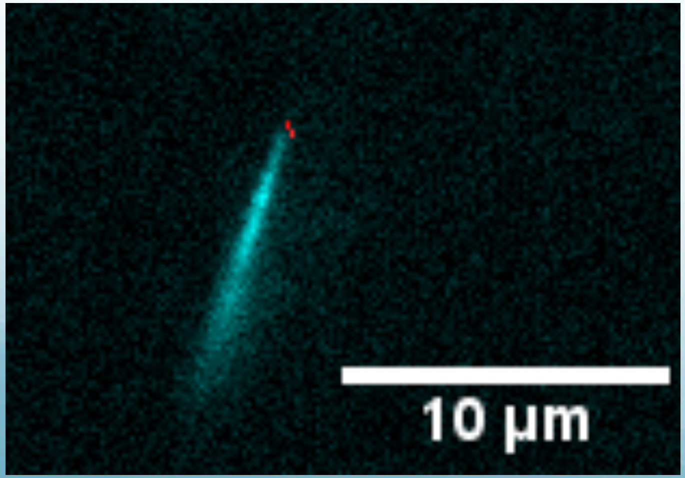


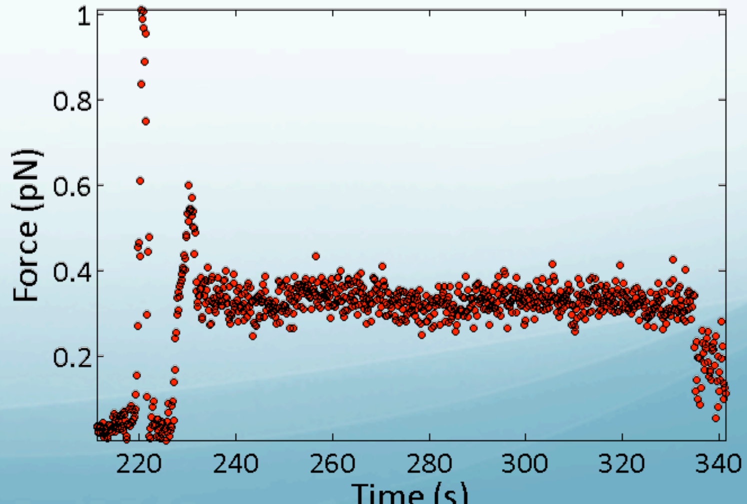




Buckle extension speed
0.09±0.04 μm/s

Force generation of a buckling bundle





Outline

1. building blocks of microtubule based active matter

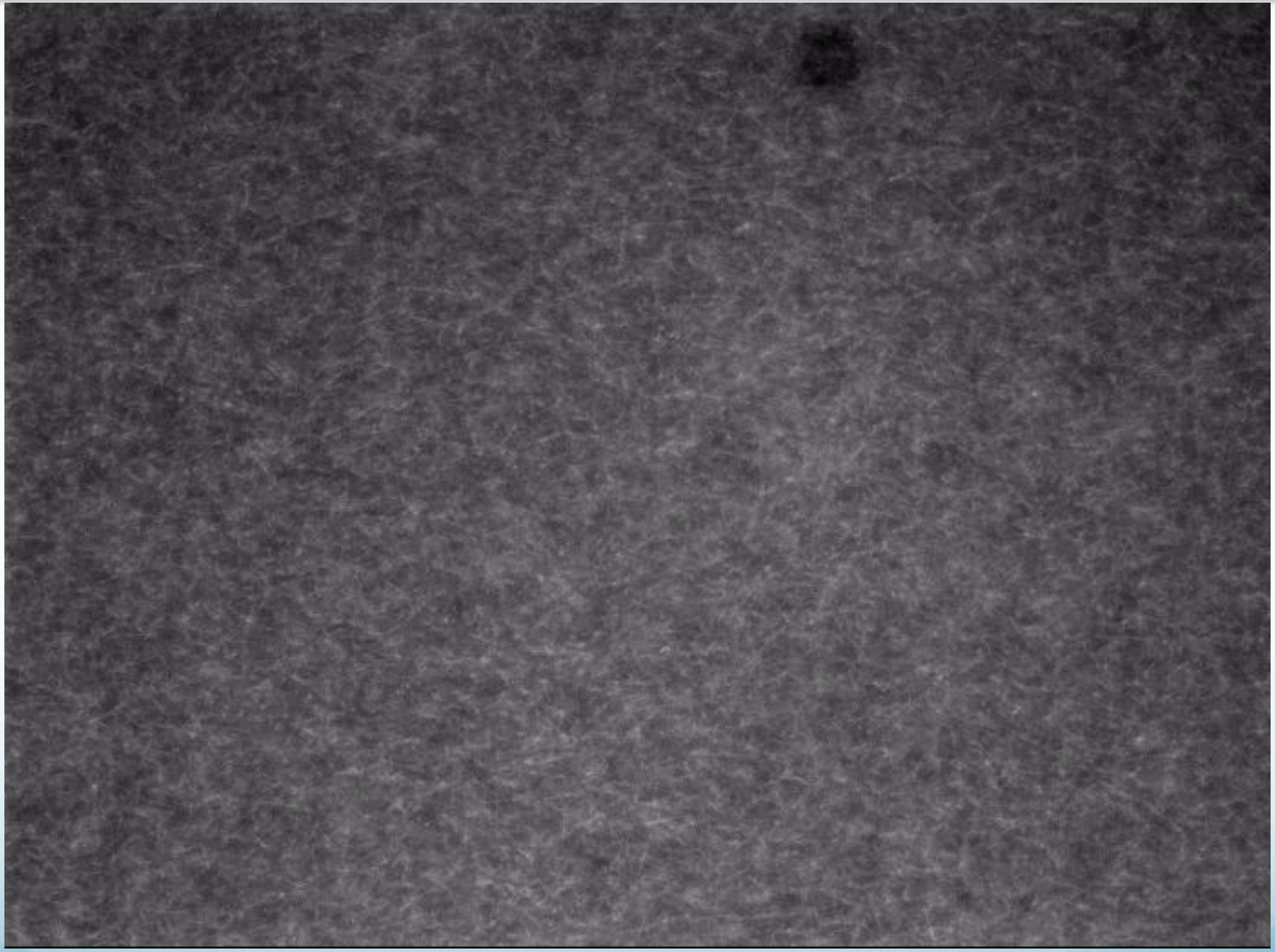
microtubules + kinesin clusters + cohesion → extensile bundles

structural motif that drives non-equilibrium dynamics of diverse active soft materials

2. bulk isotropic active gels

3. confined active gels

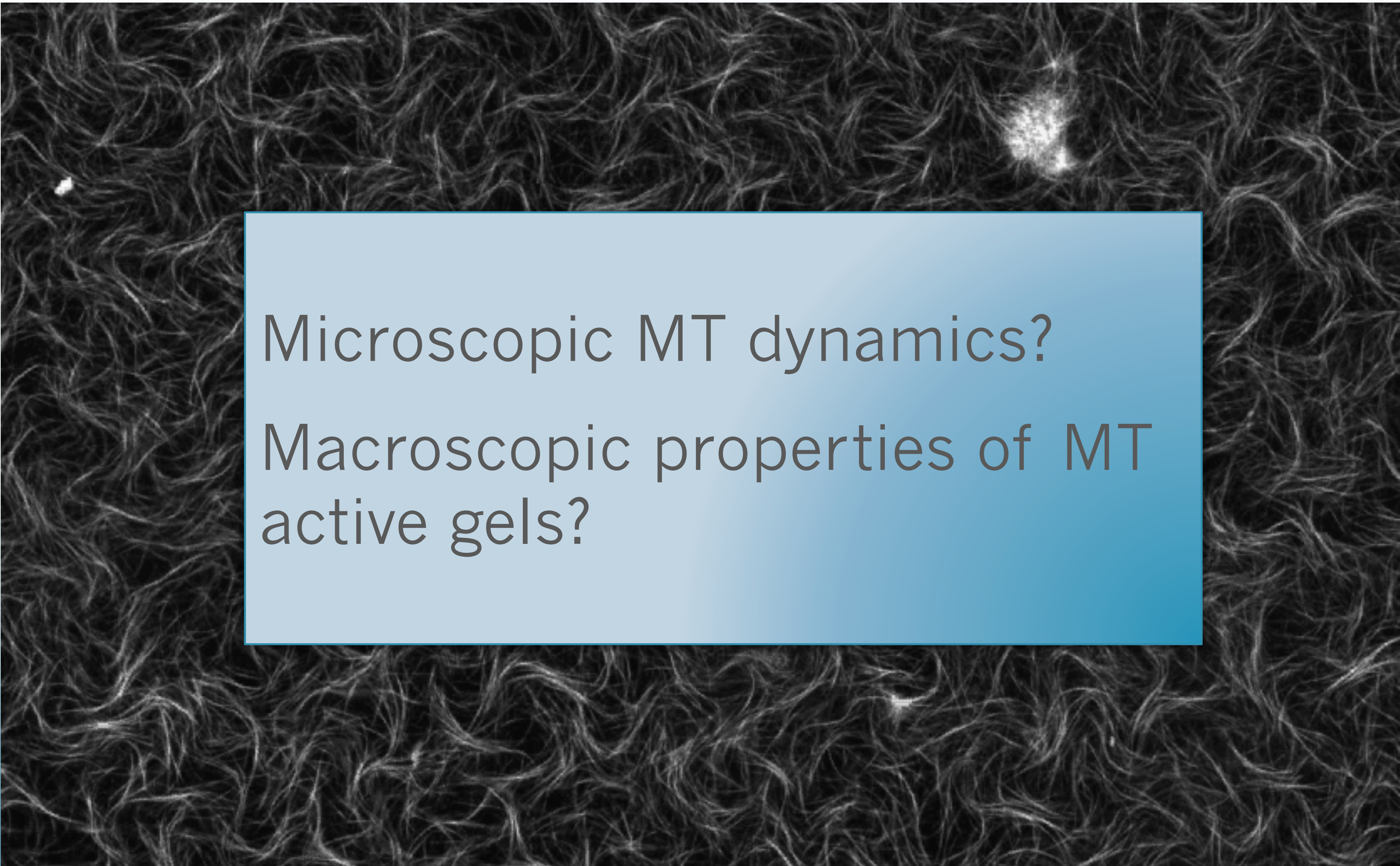
Active MT bundles at high concentration turbulent like steady state



100 μm

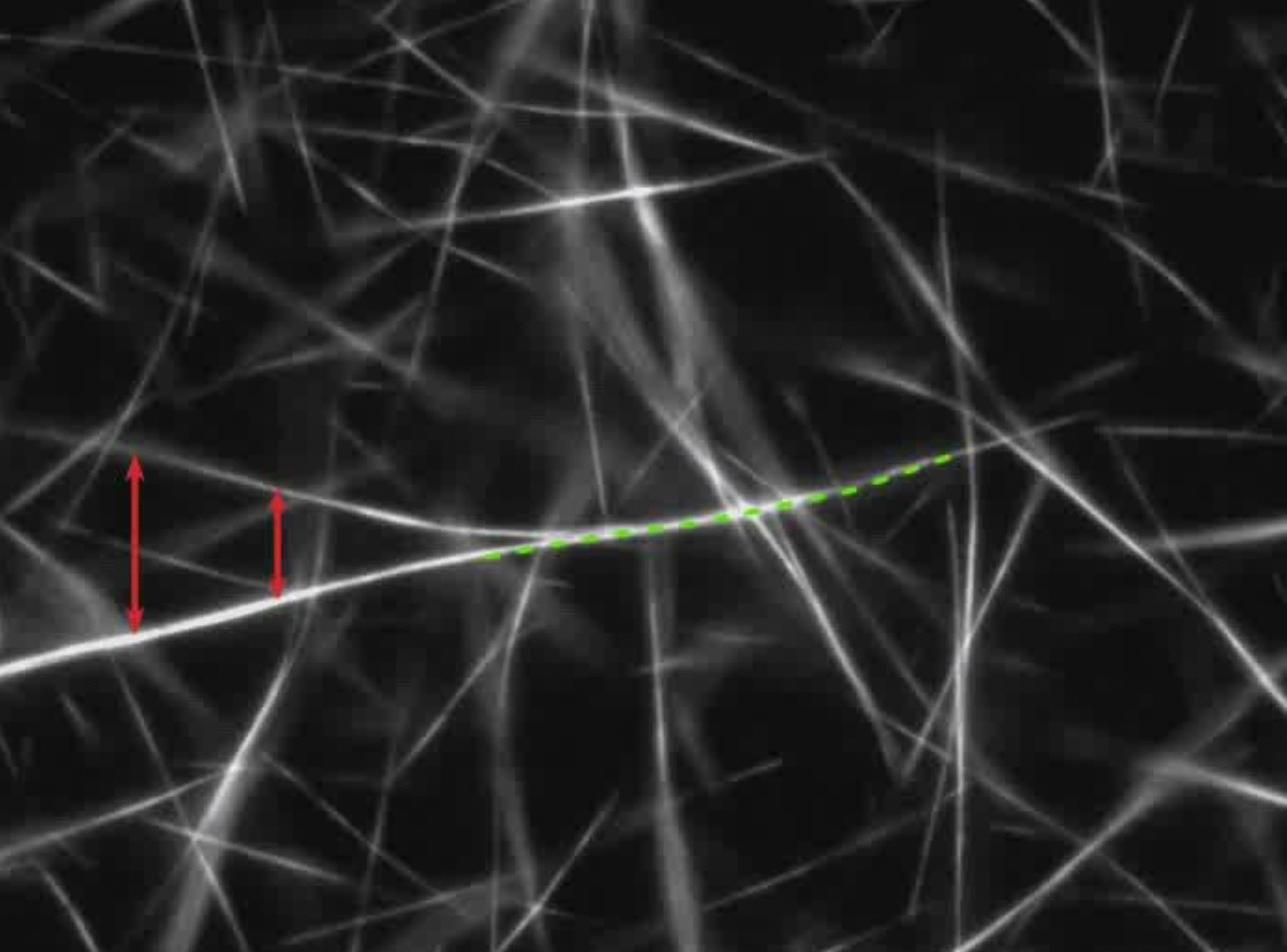
ATP regeneration – dynamics persist for > 24 hrs

1500 μm

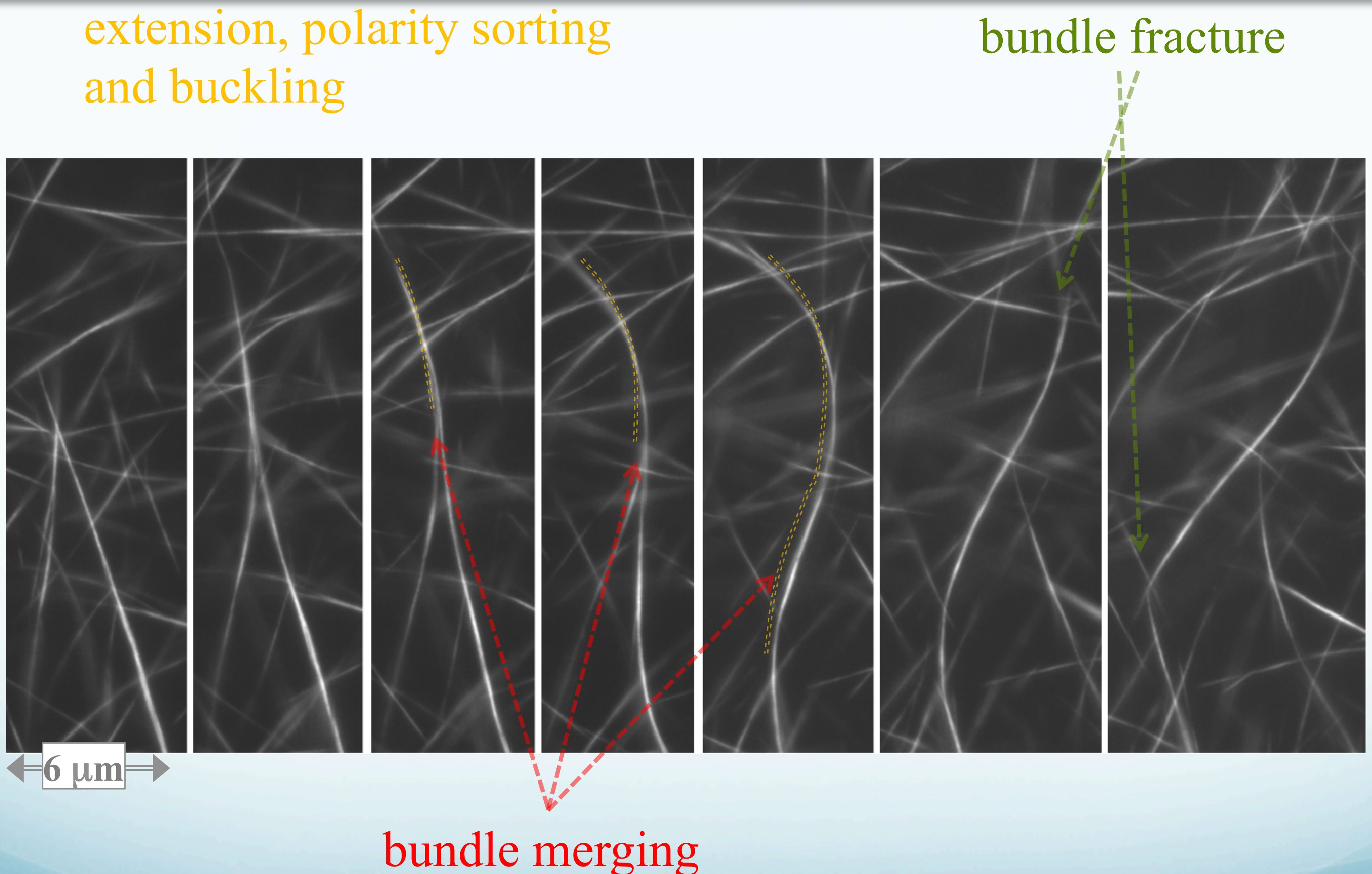


Microscopic MT dynamics?

Macroscopic properties of MT active gels?

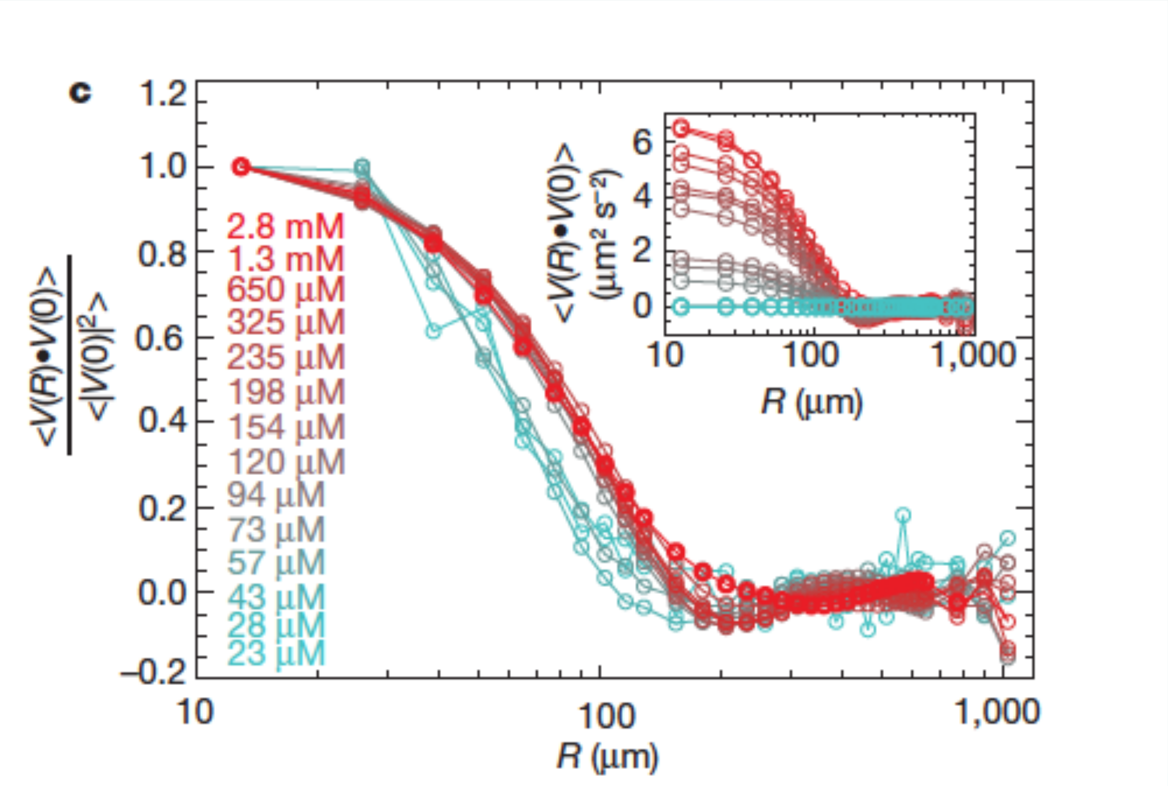


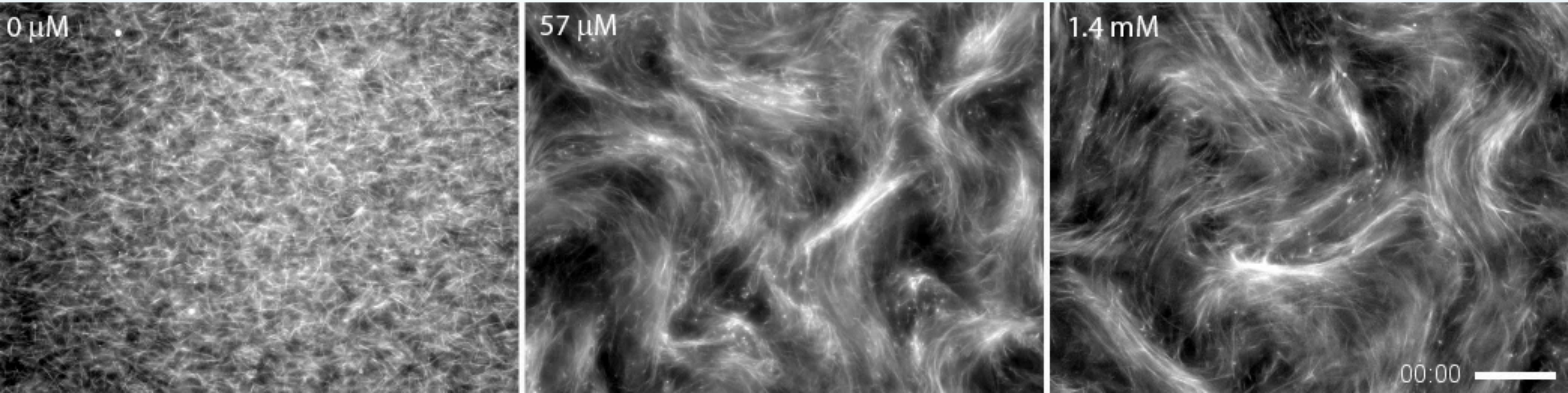
Microscopic MT dynamics



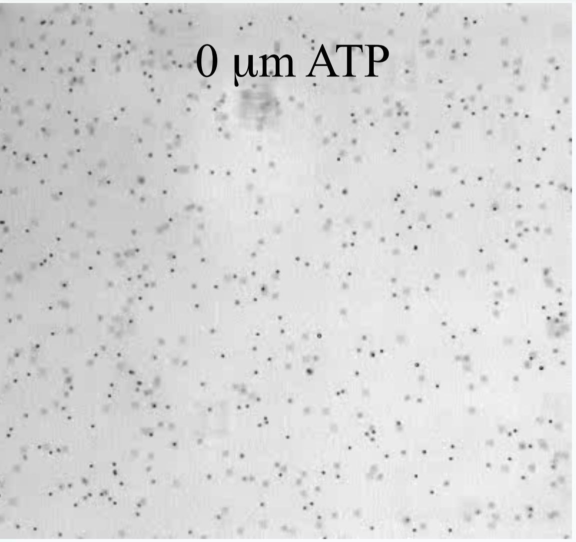
isotropic active gels – repeating cascades of bundle merging, extension, buckling and fracture

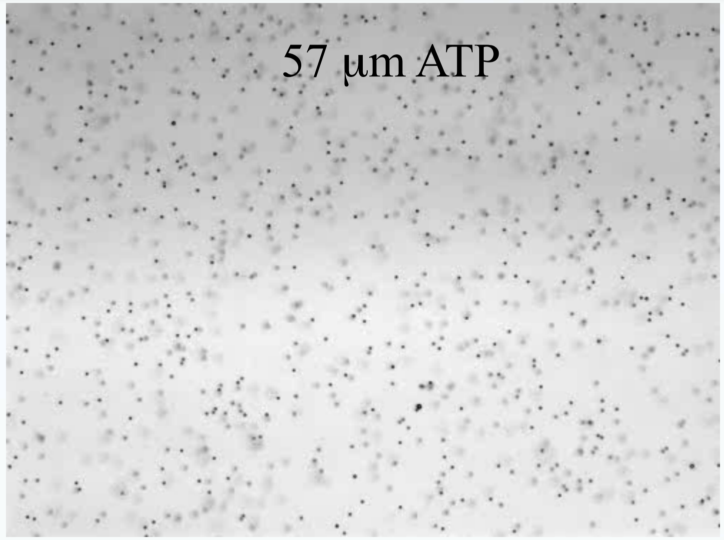
Spontaneous fluid flow

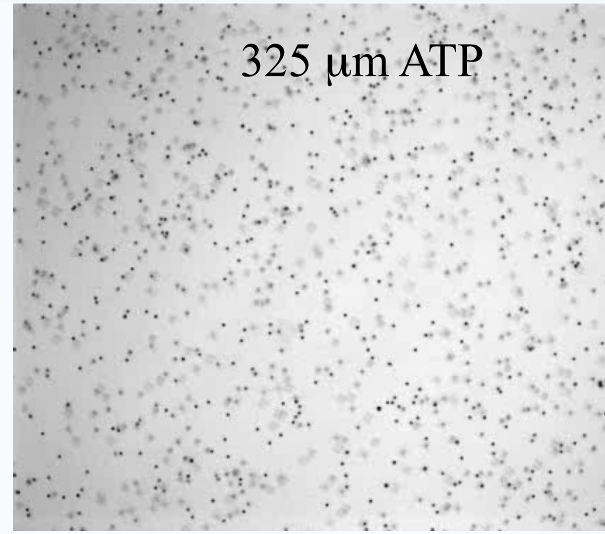


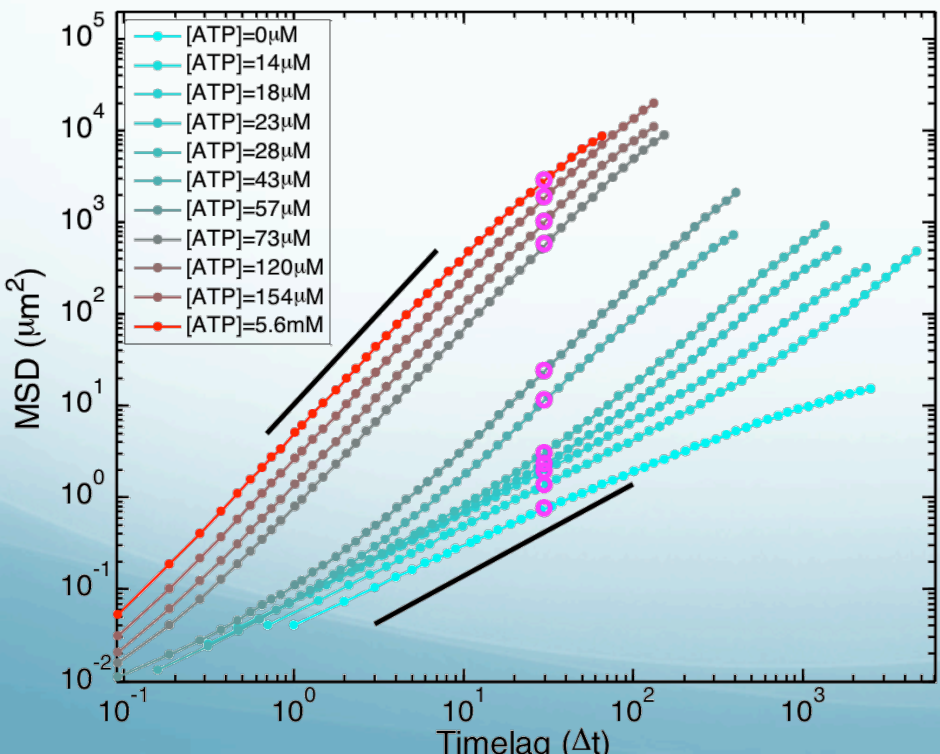


Enhanced and tunable mixing









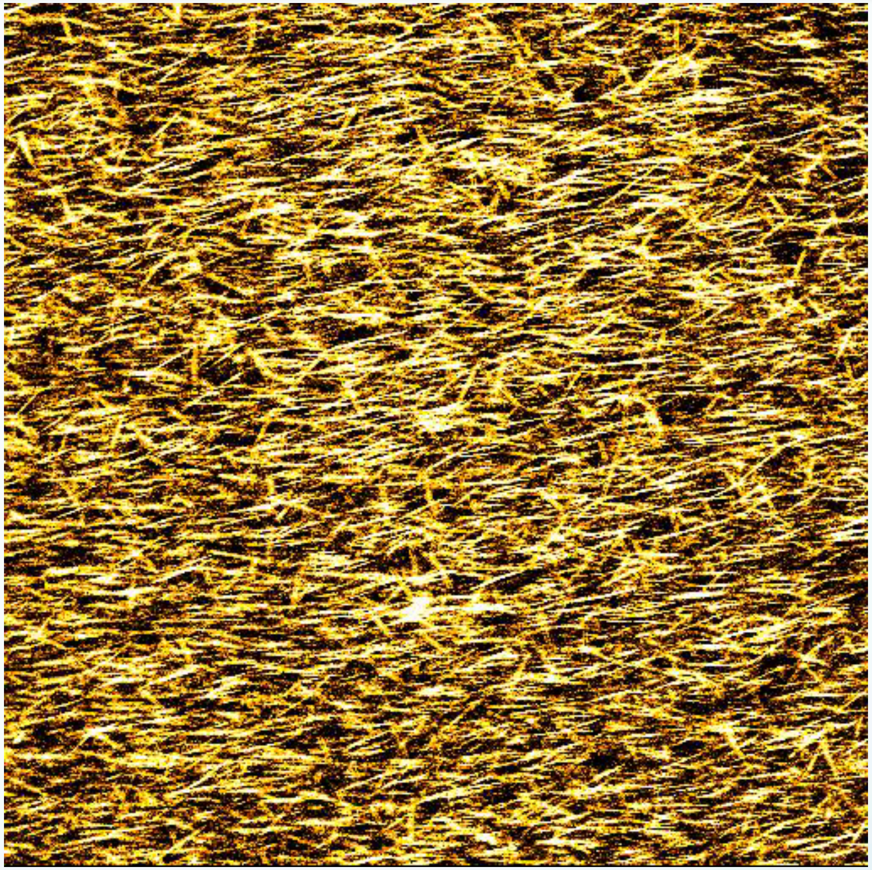
Enhanced transport and mixing of passive particles

Tunable mean square displacement from sub-diffusive to ballistic

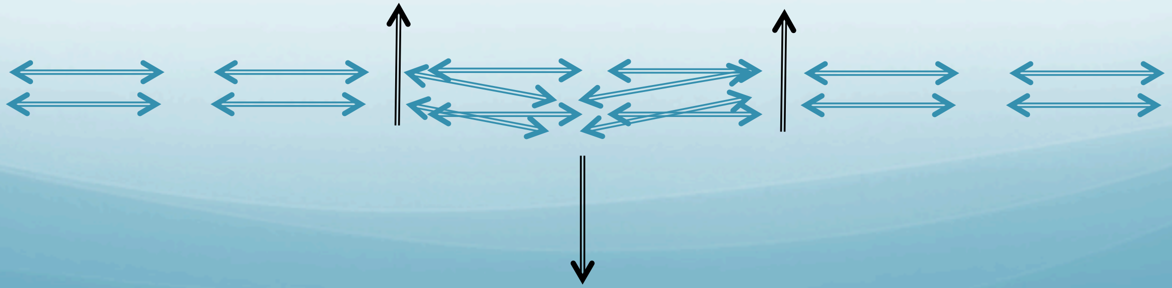
Particles on average do not go anywhere <x(t)>=0

Spontaneous bend instability

What is the appropriate hydrodynamic description of active isotropic gels?



aligned extensile filaments are unstable against bend fluctuations



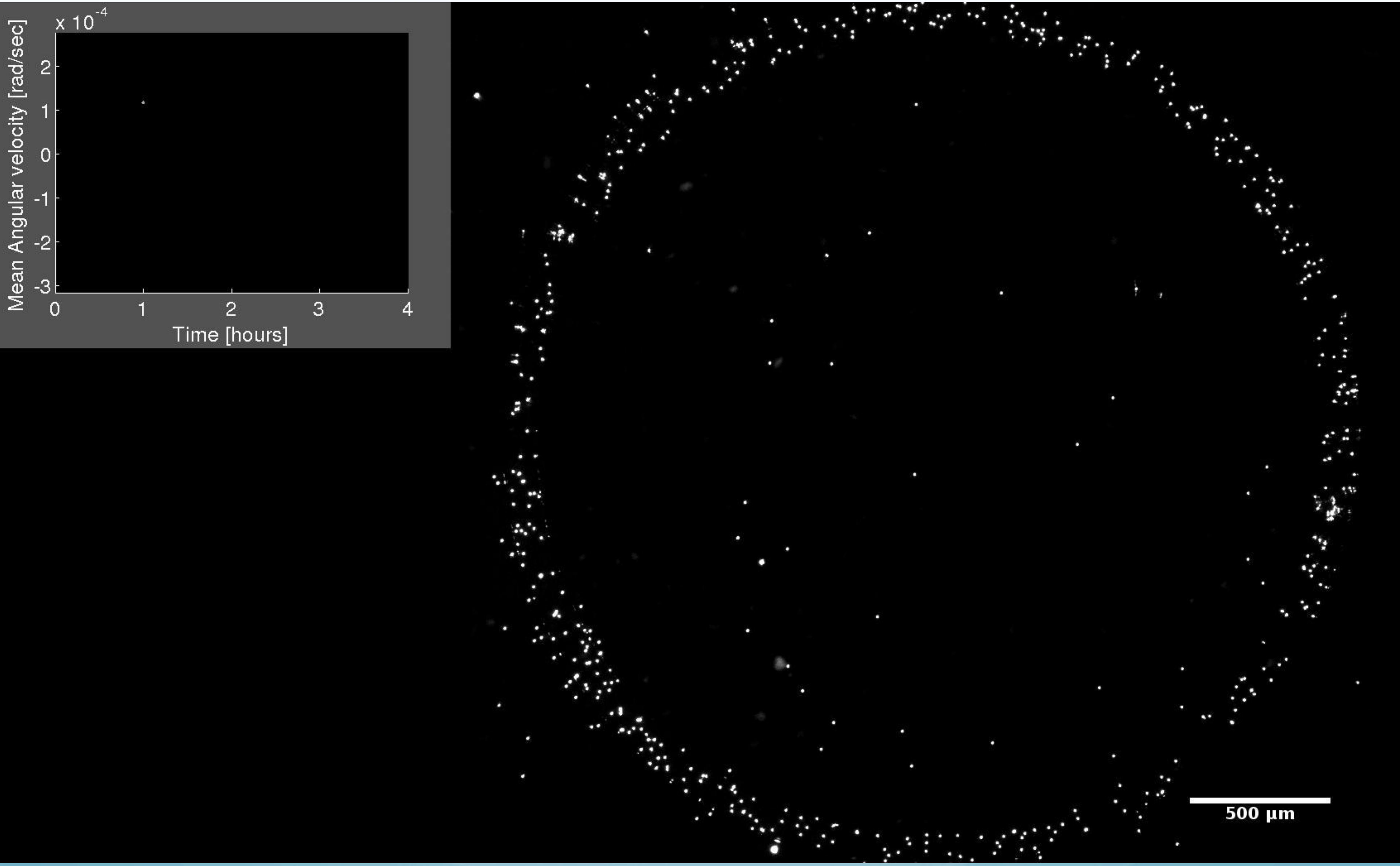
Outline

1. **building blocks of microtubule based active matter**

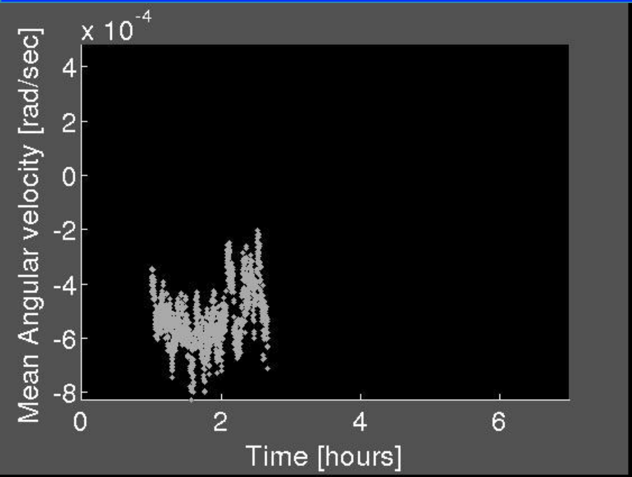
2. bulk isotropic active gels

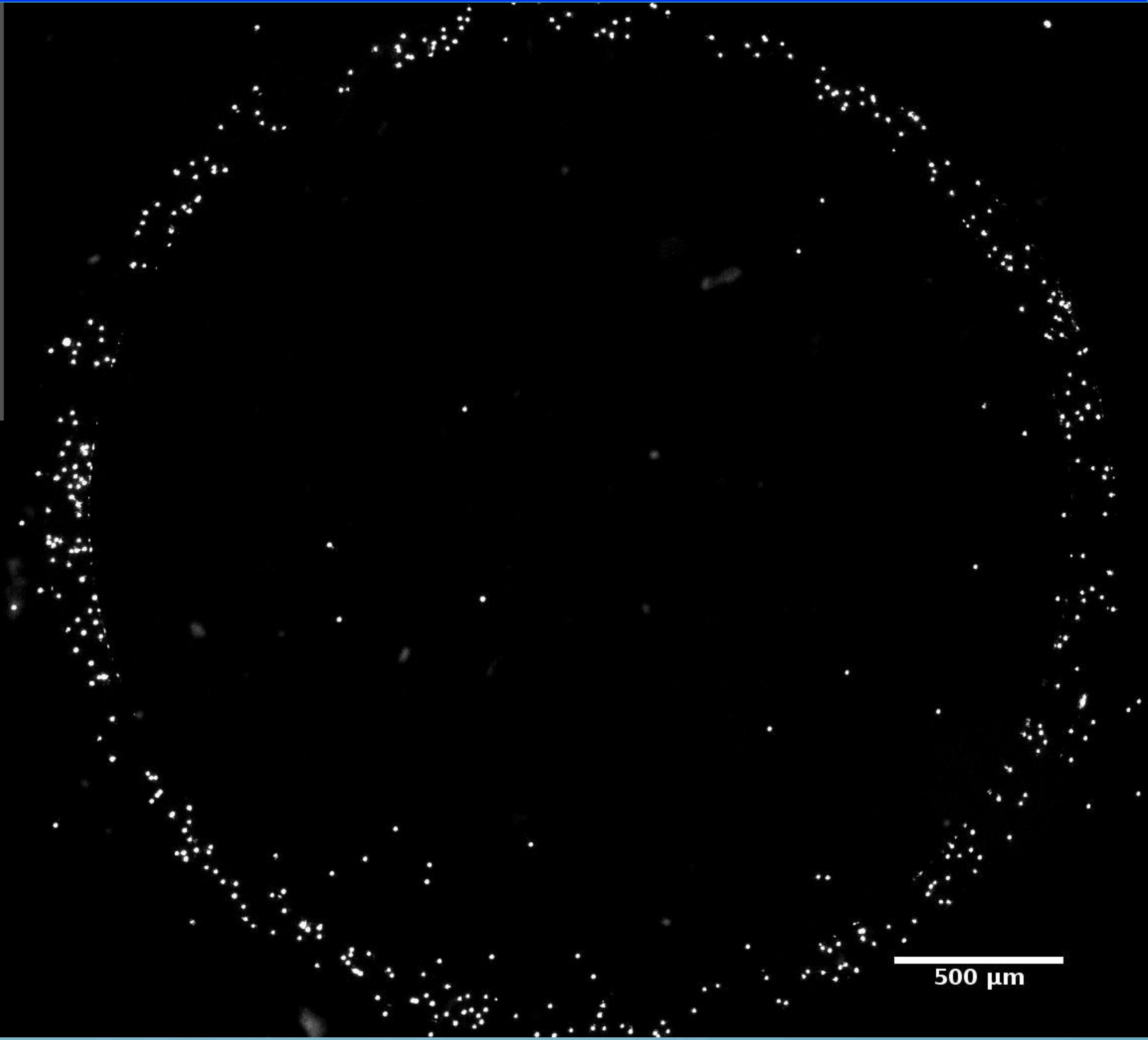
3. **confined active gels**

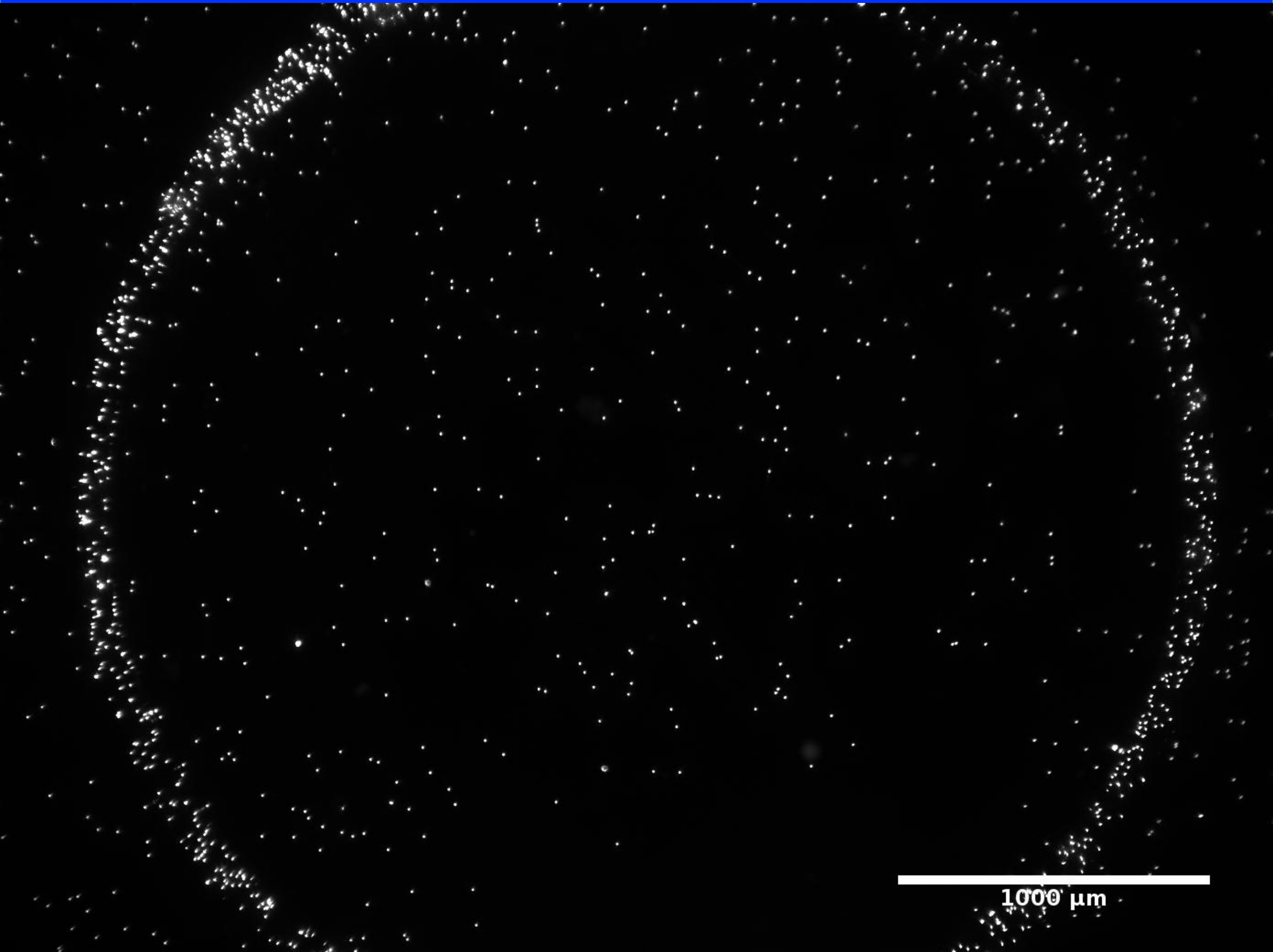
low ATP – no net circulation currents



Intermediate ATP – large fluctuations in mean angular velocity circulation

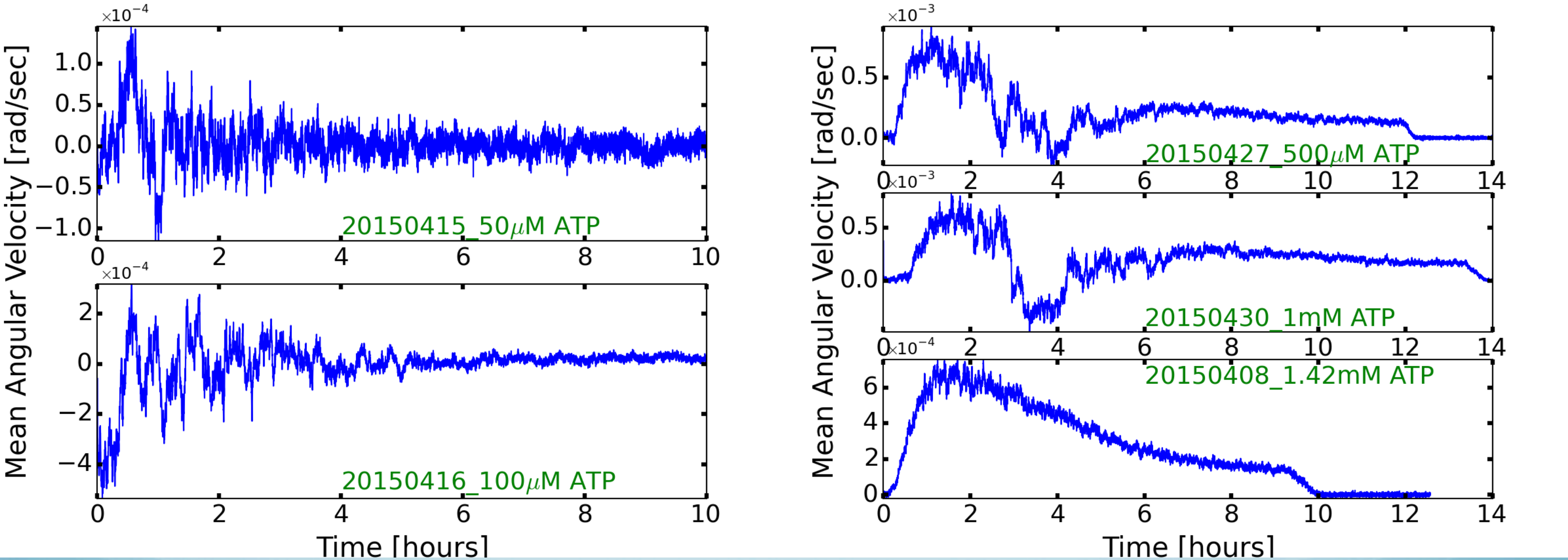


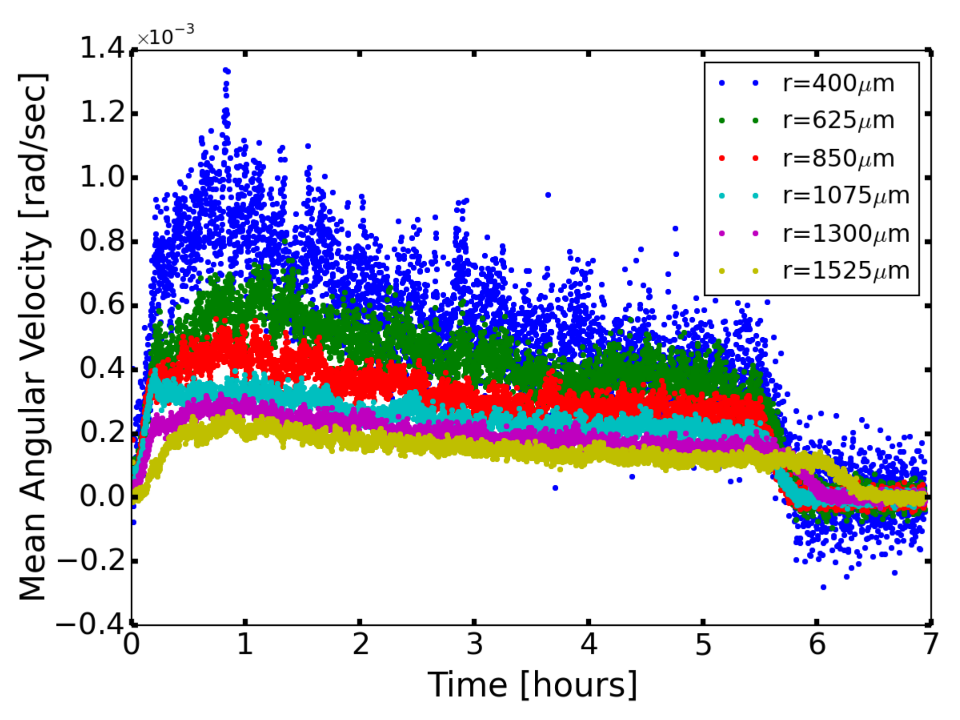


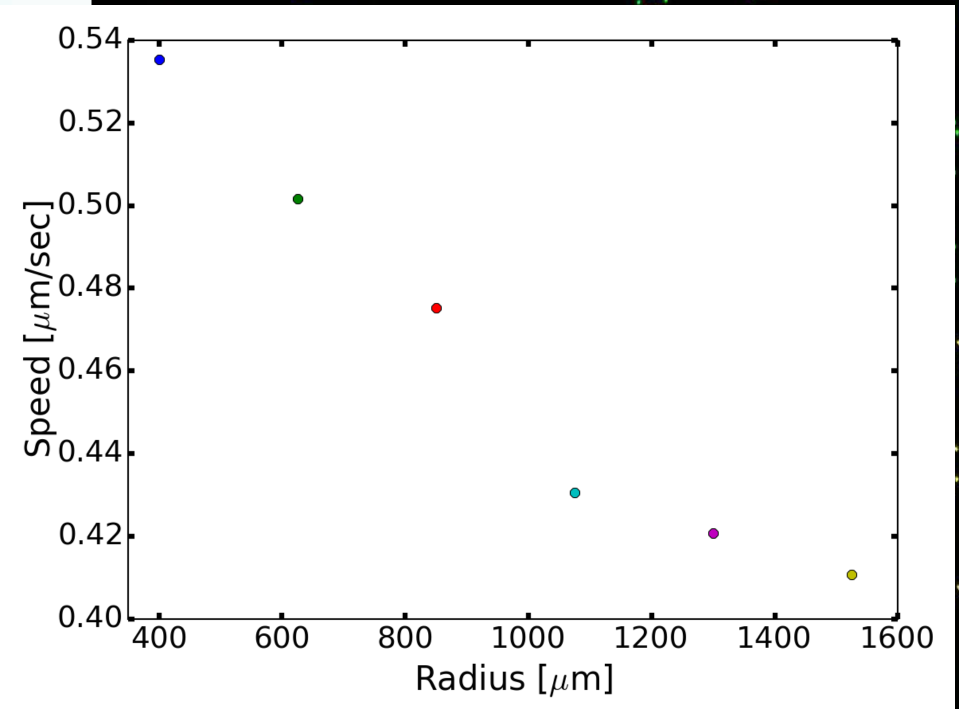

1000 µm

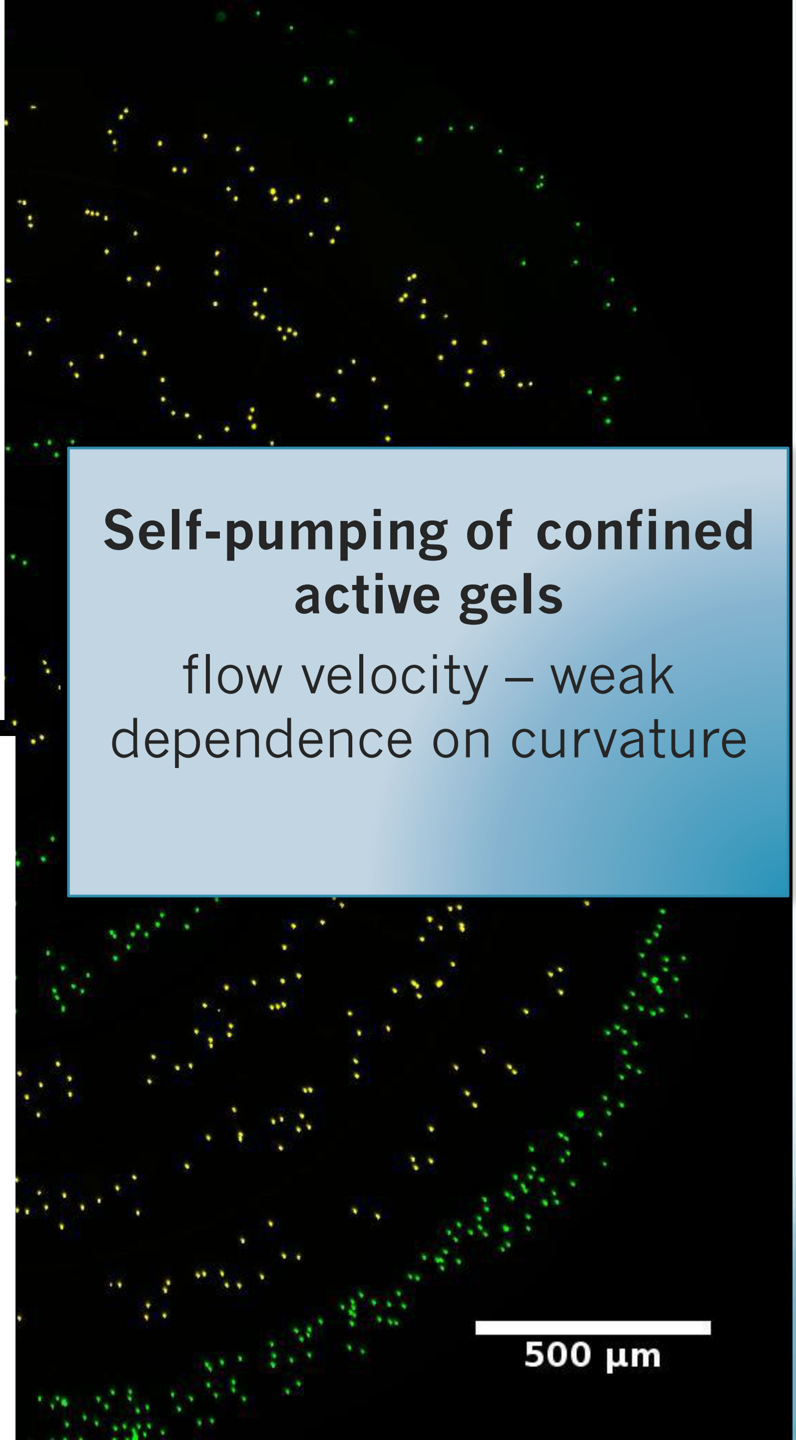
Spontaneous fluid flow

ATP dependence





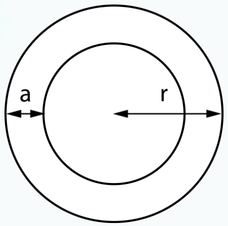




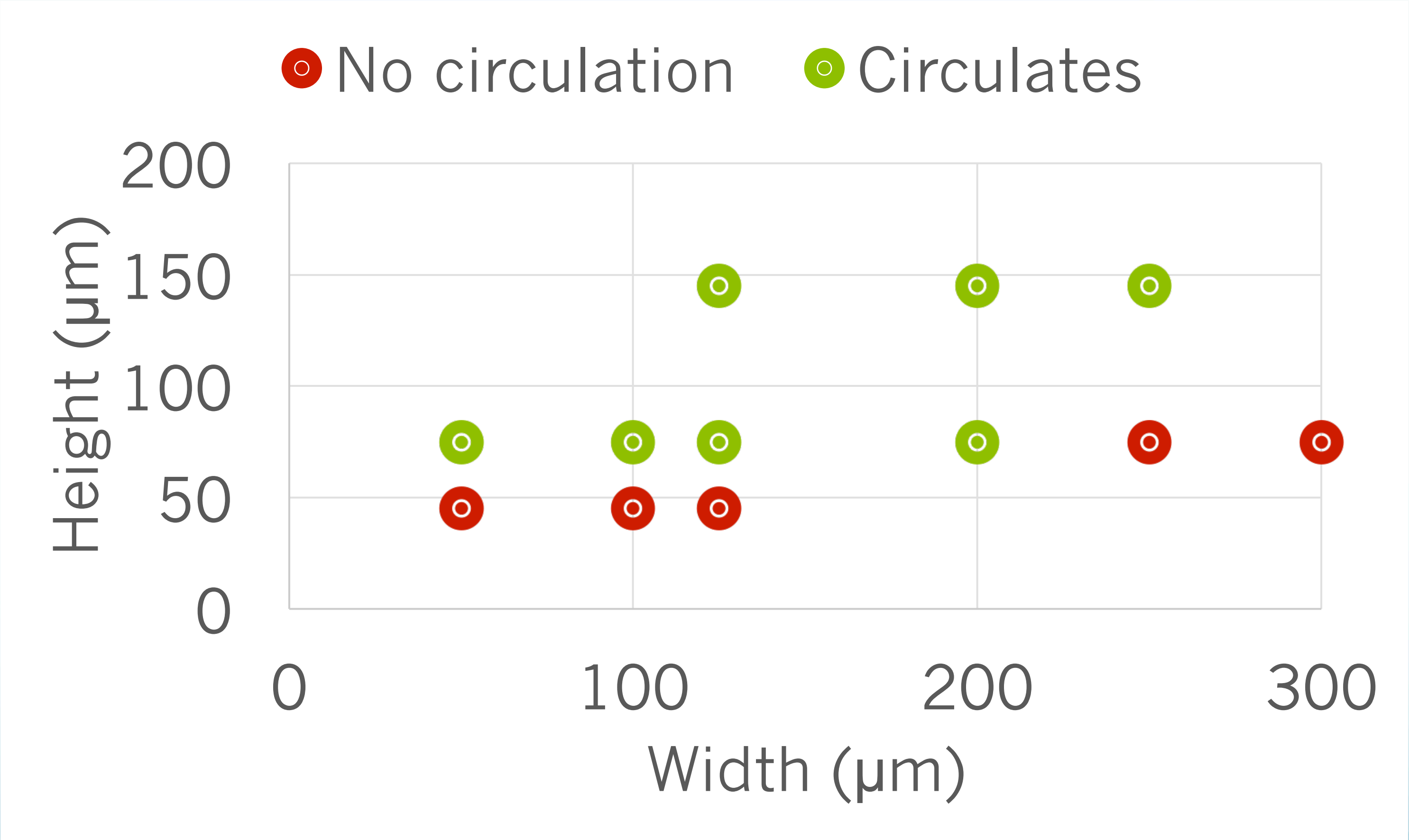
Self-pumping of confined active gels

flow velocity – weak dependence on curvature

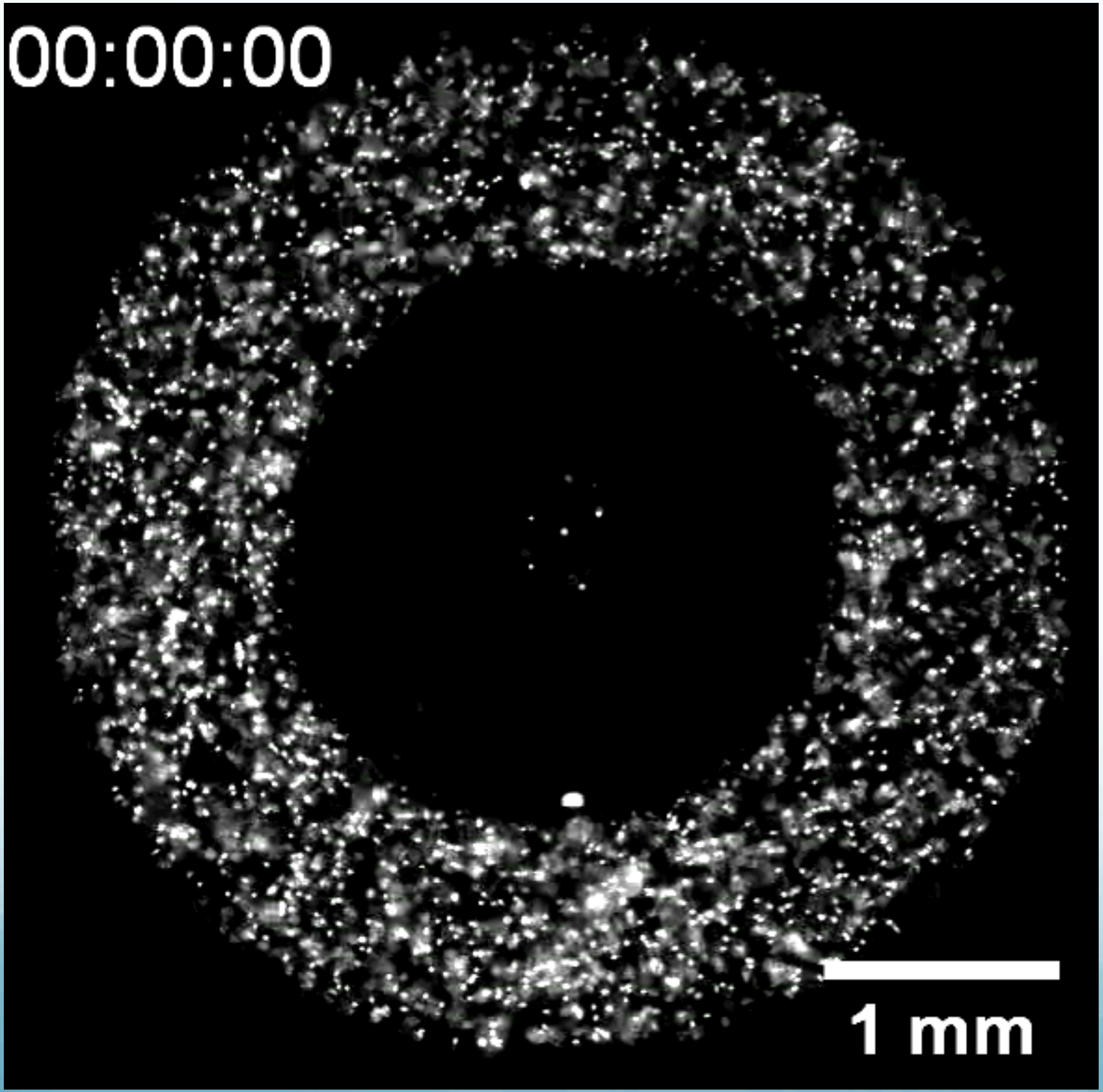
Circulation Phase diagram



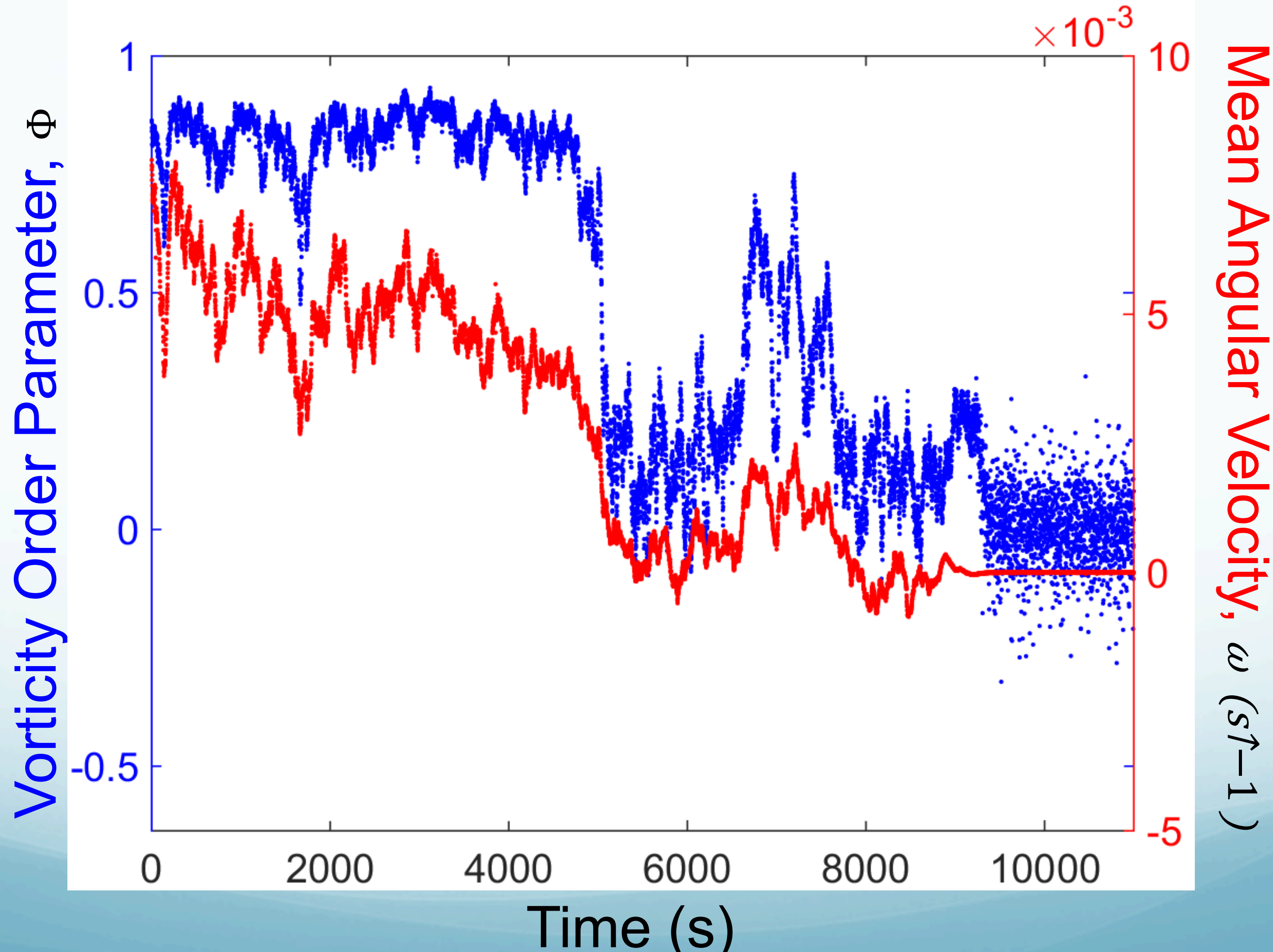
a=125μm,
r=1500μm



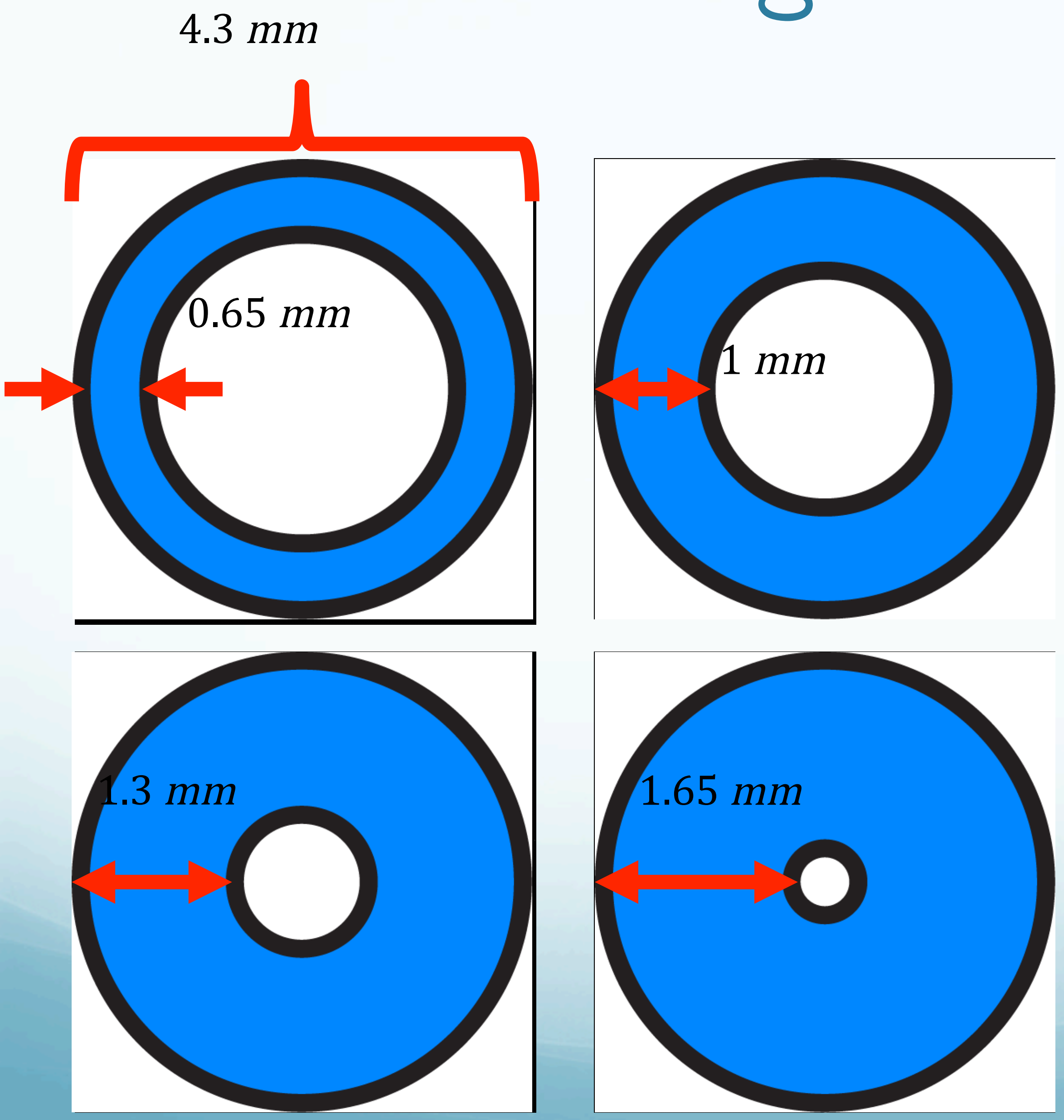
Donuts



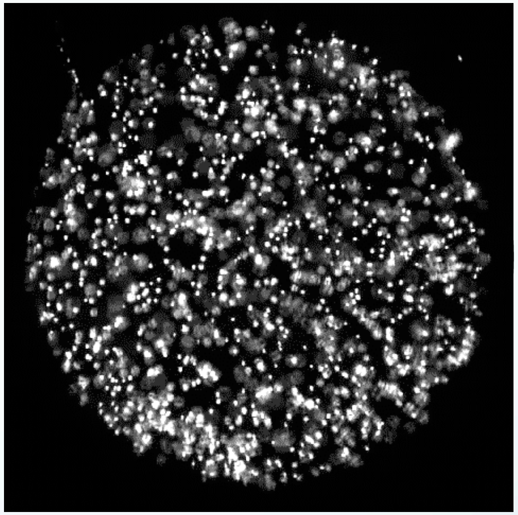
Vorticity Order Parameter vs Time



Shrinking Inner Radii

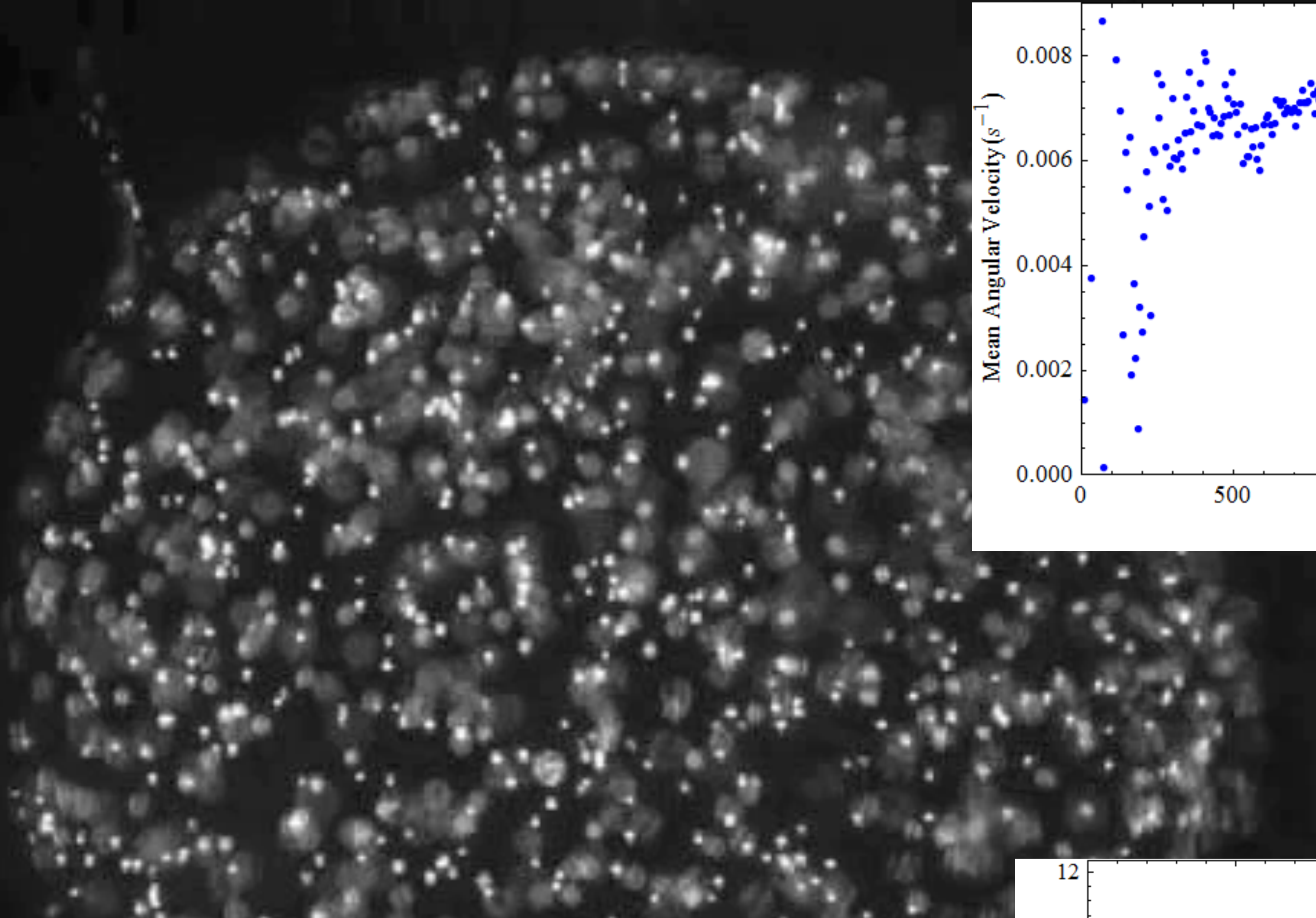


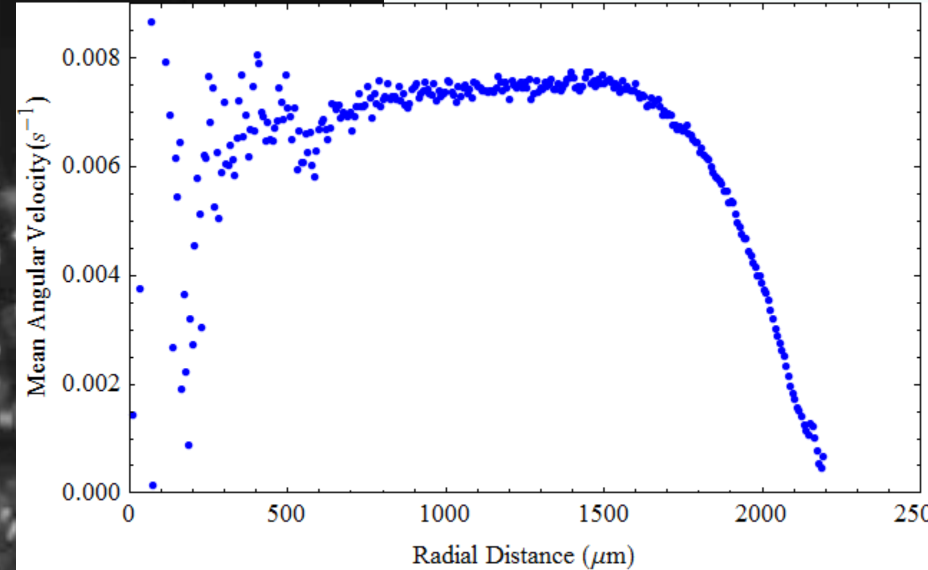
Disk



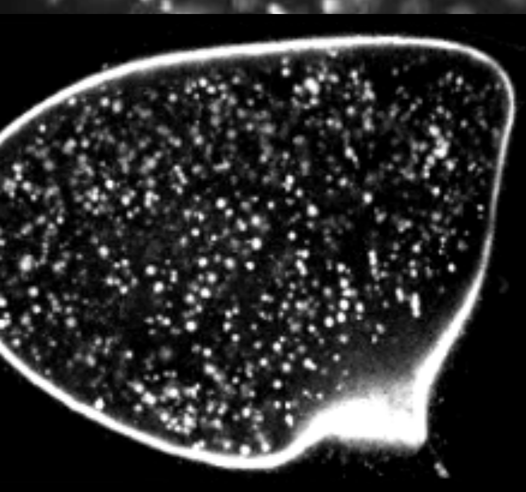
1 MM

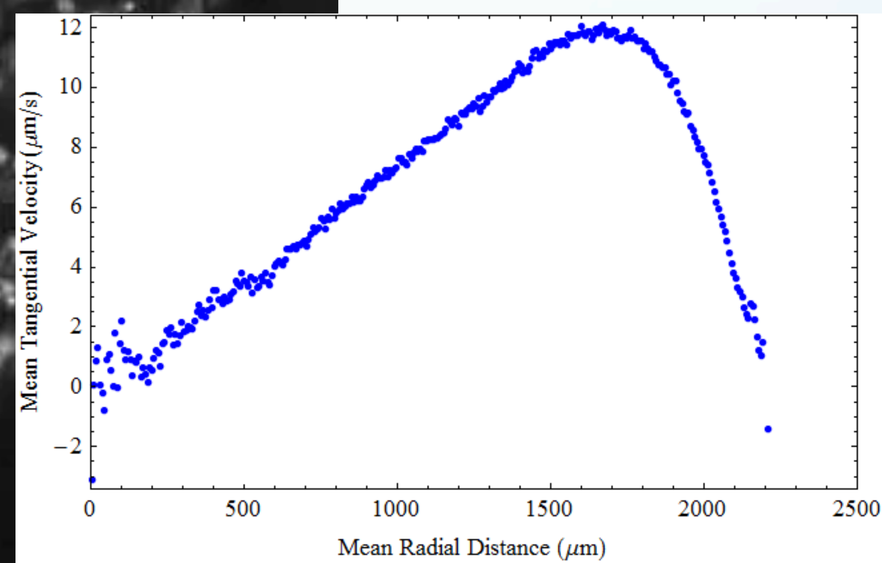
300X Real Time



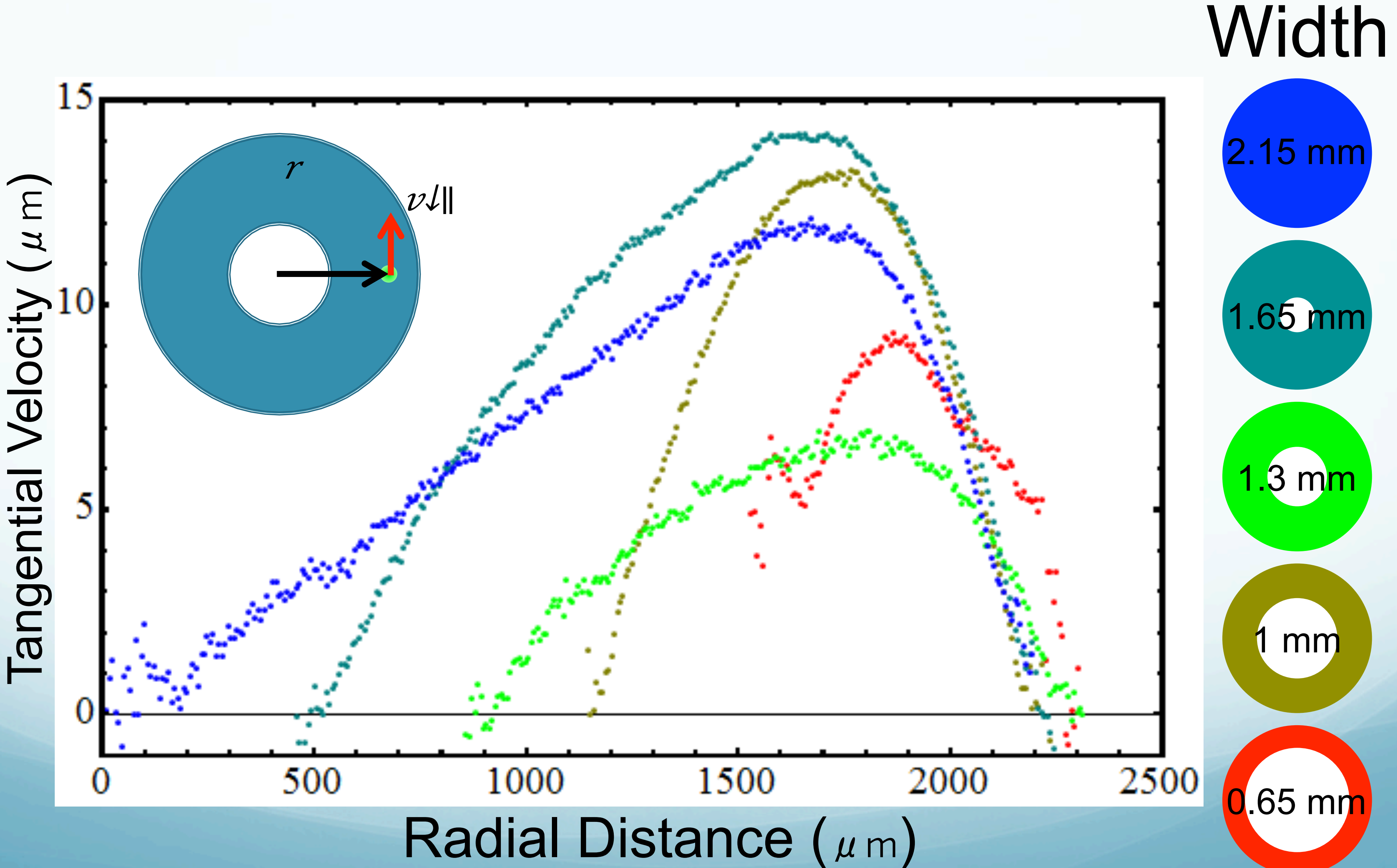


$$v = \omega \times r$$

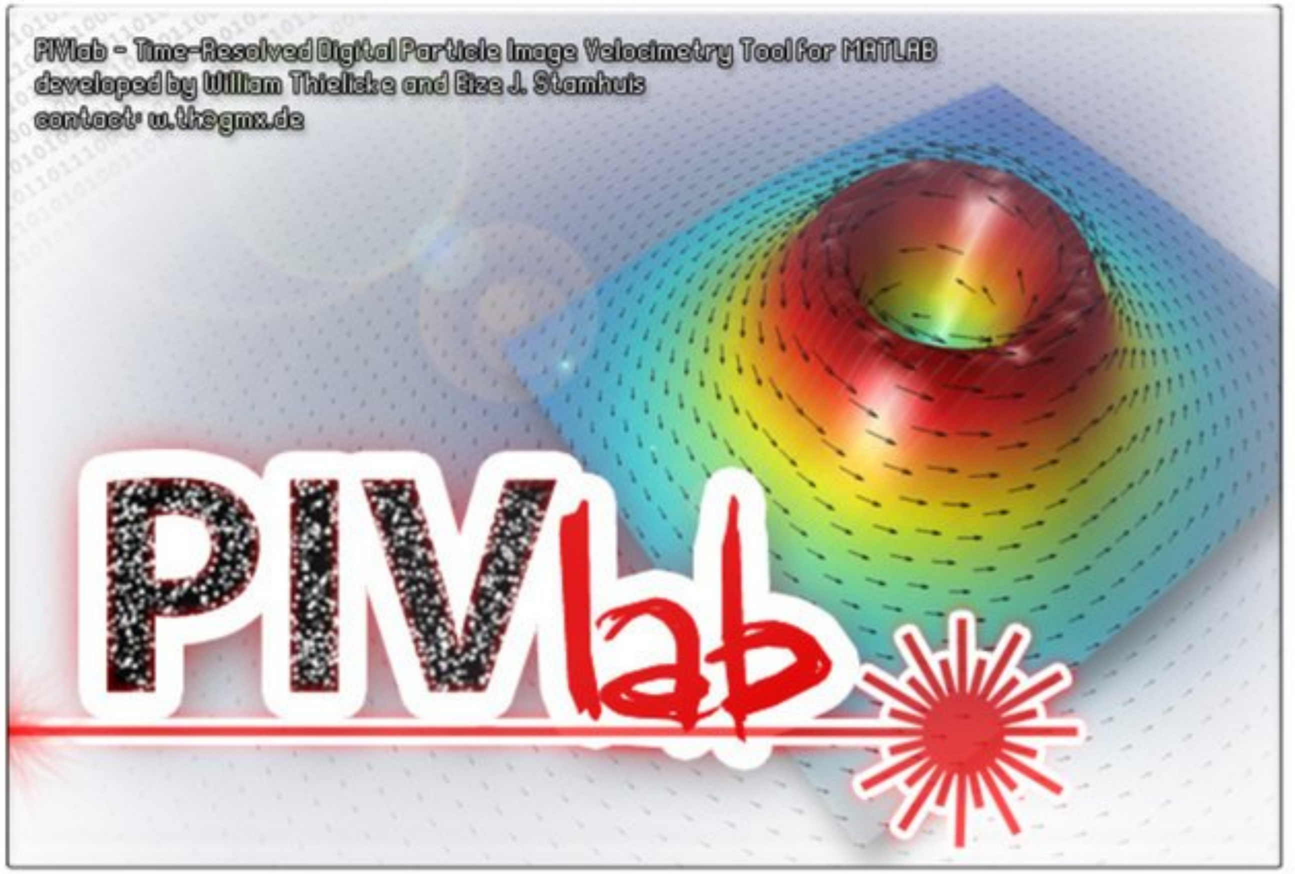


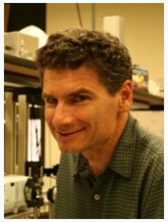


Flow Profile

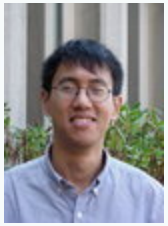


Particle Image Velocimetry (PIV)



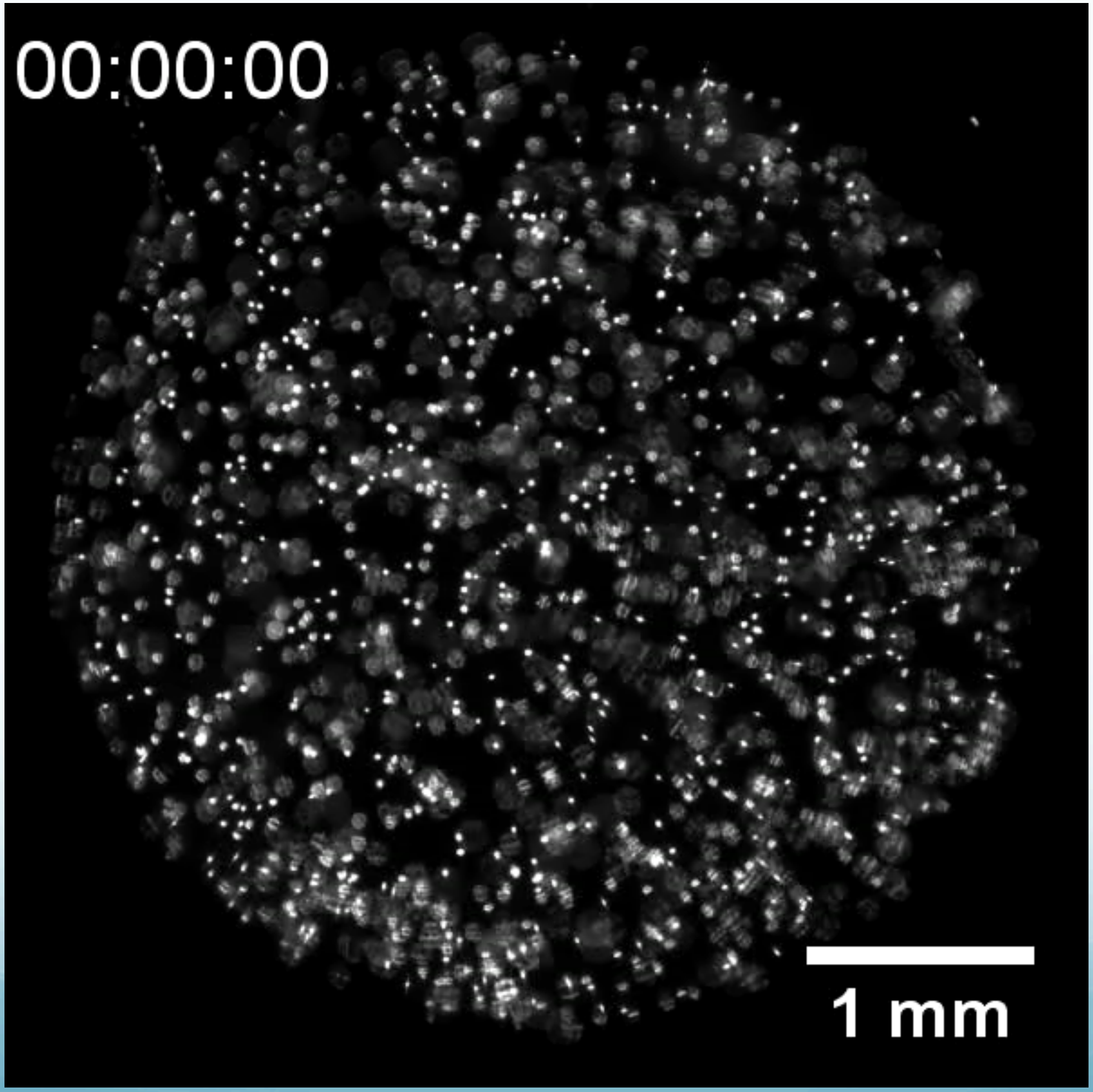


Seth Fraden



Daniel Chen

Disk



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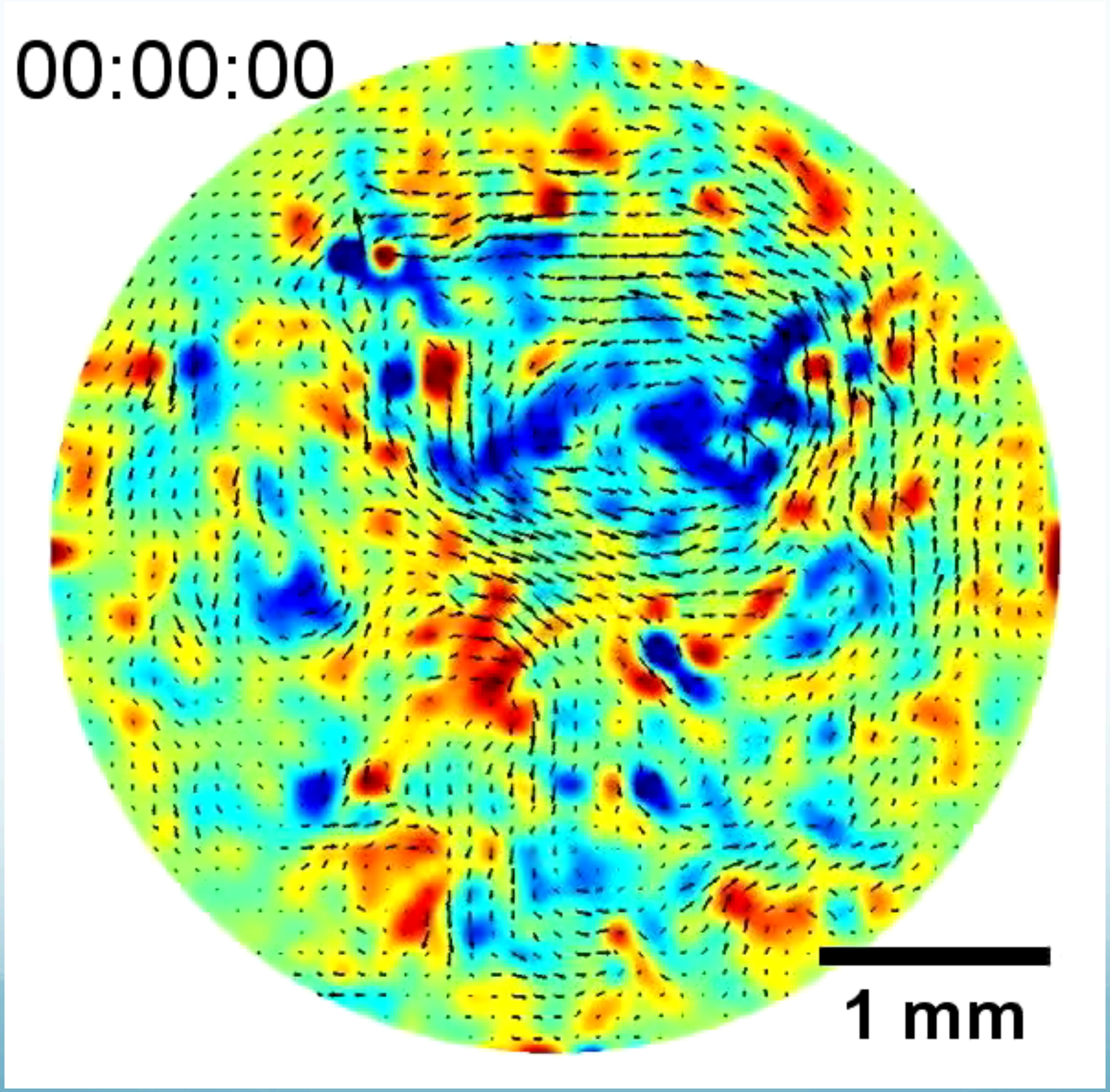
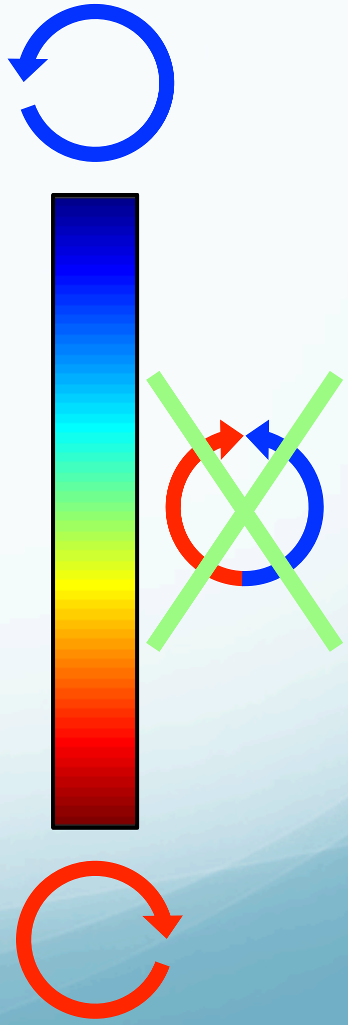
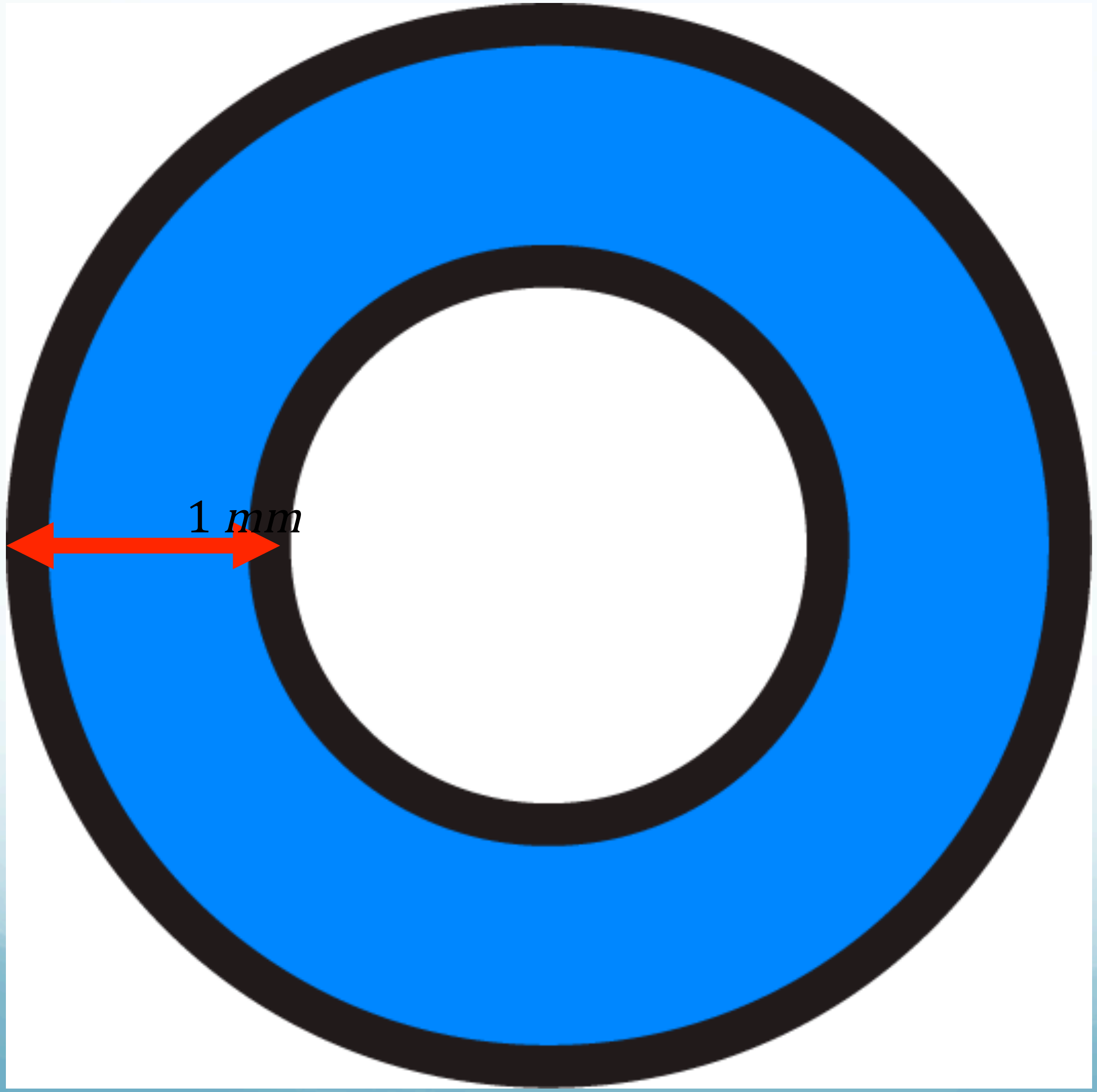
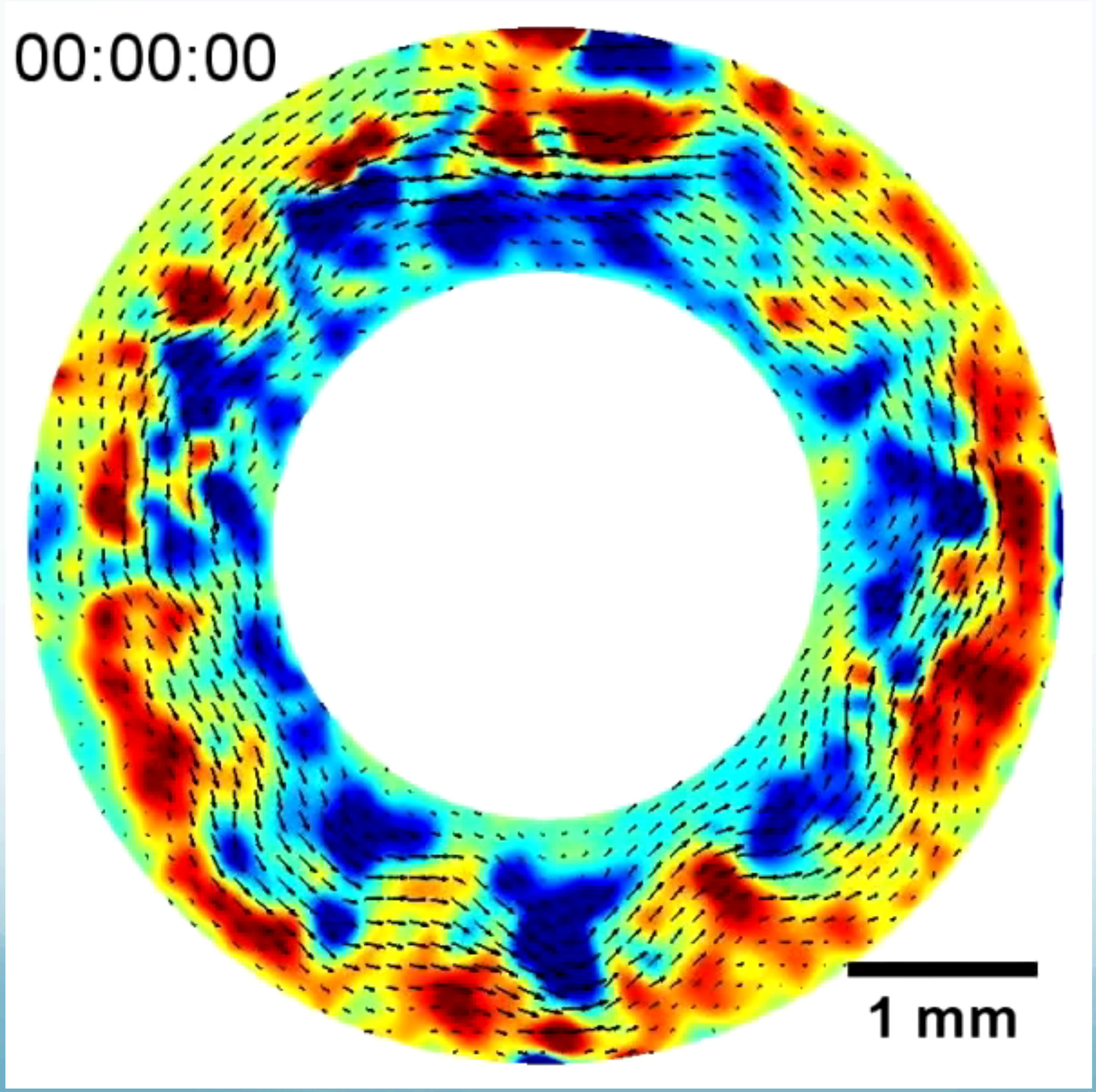


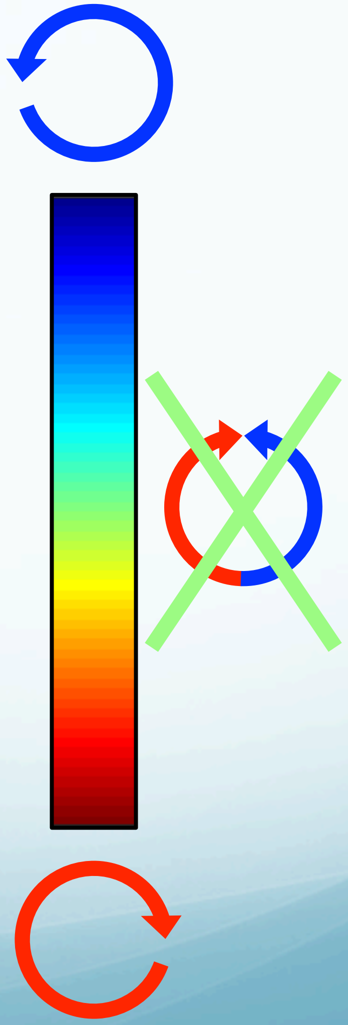


Donuts

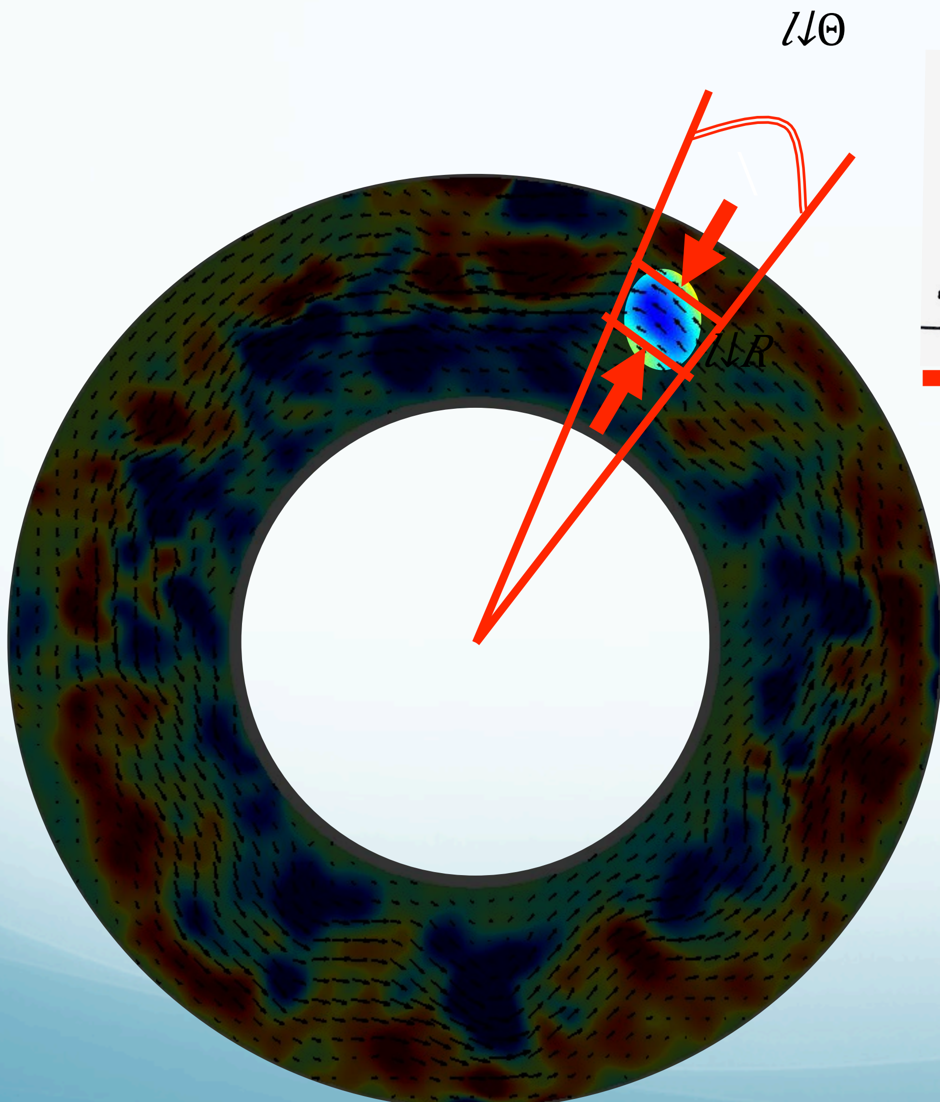


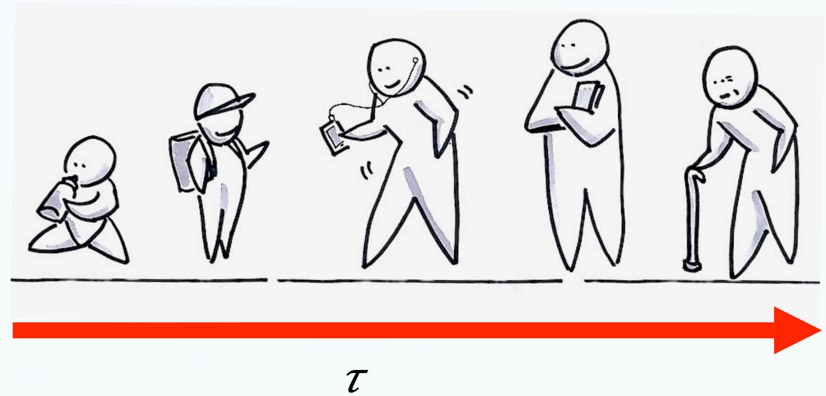
Donuts





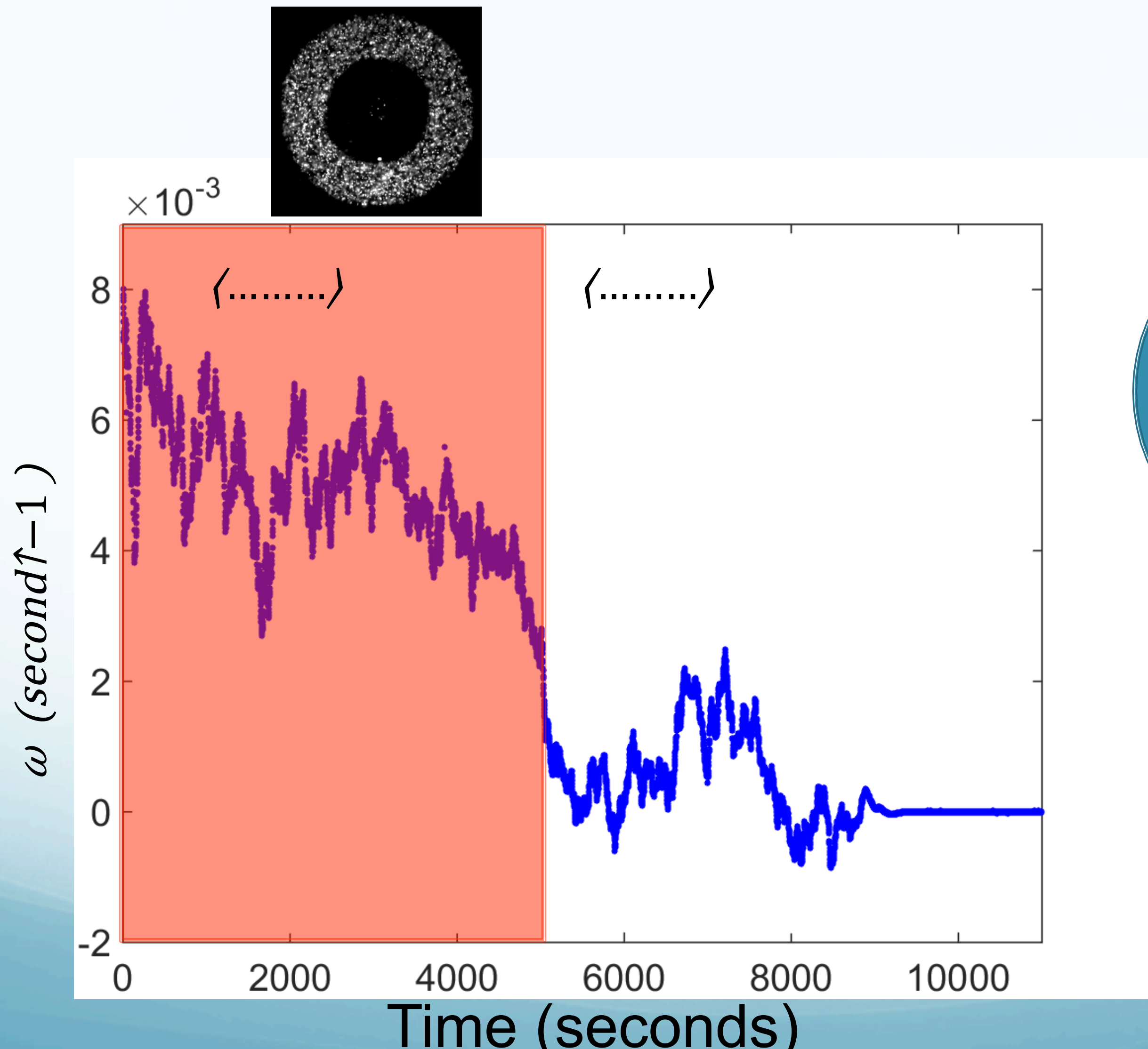
Local Vorticities

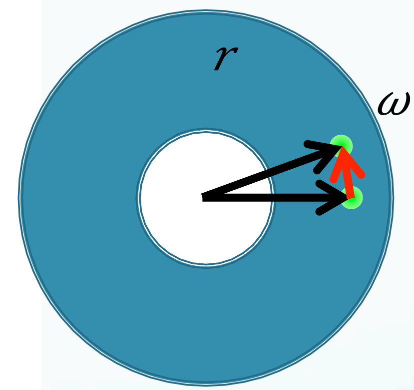


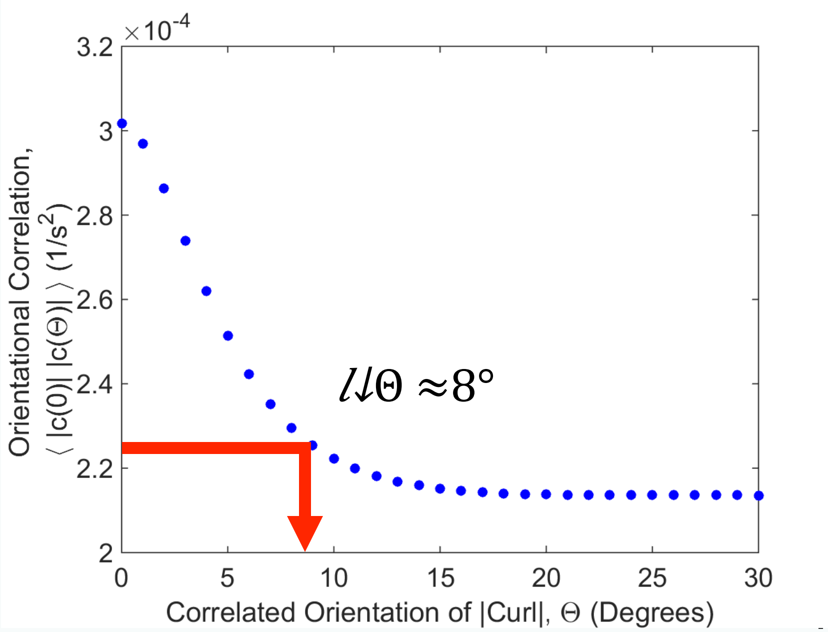


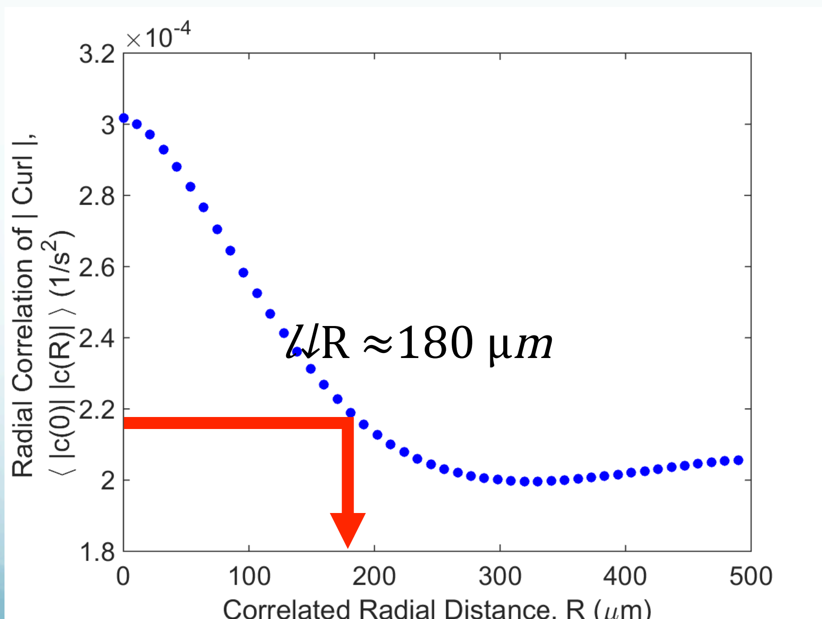
$$\begin{cases} \langle |C(0)|\,|C(R)|\rangle \sim e^{-R/l_R} \\ \langle |C(0)|\,|C(\Theta)|\rangle \sim e^{-\Theta/l_\Theta} \\ \langle |C(0)|\,|C(T)|\rangle \sim e^{-T/\tau} \end{cases}$$

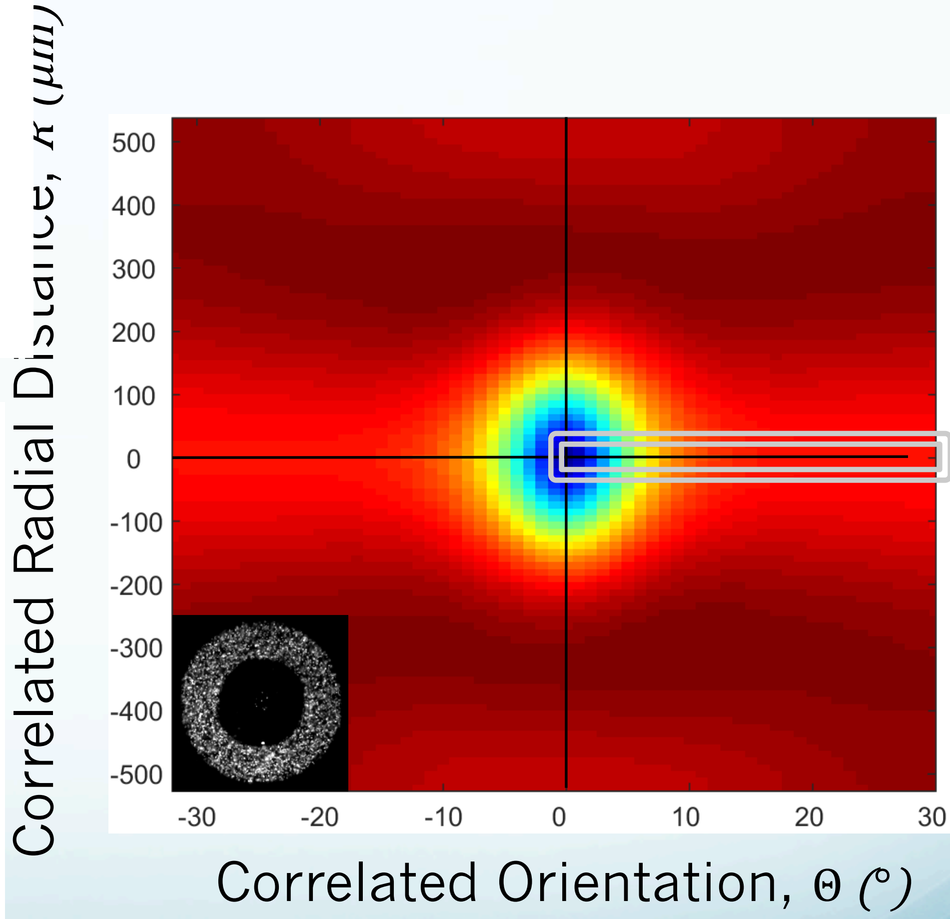
Local Vorticity



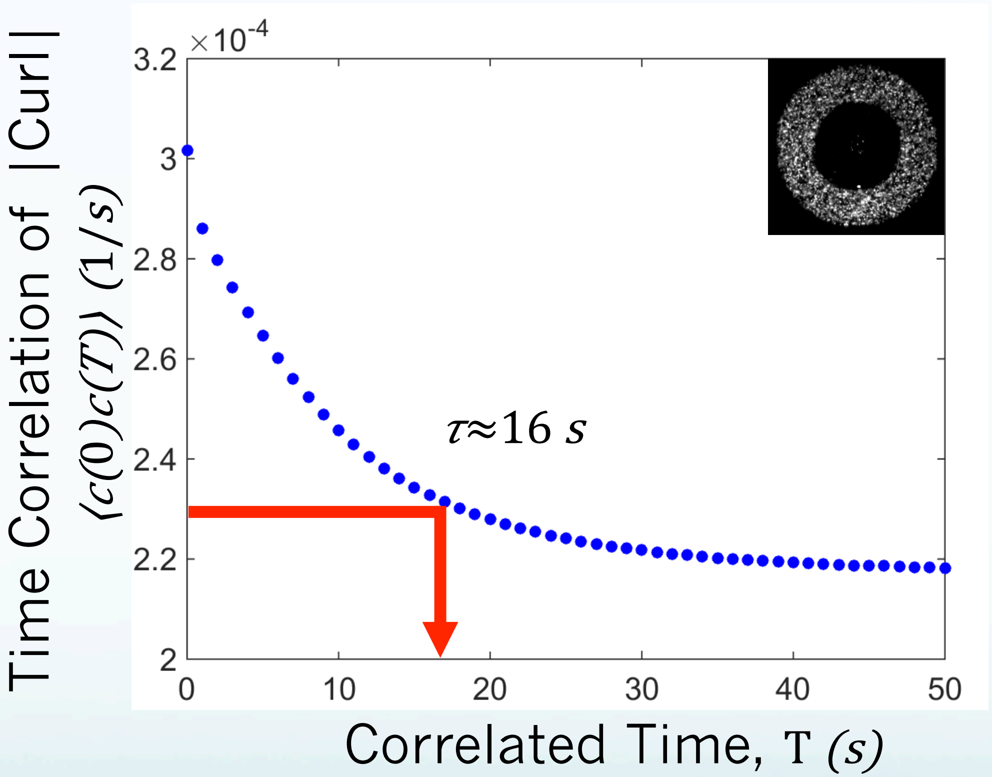



×10^-4
Orientational Correlation,
⟨ |c(0)| |c(Θ)| ⟩ (1/s^2)
Correlated Orientation of |Curl|, Θ (Degrees)
𝑙/Θ ≈8°
3.2
3
2.8
2.6
2.4
2.2
2
0
5
10
15
20
25
30

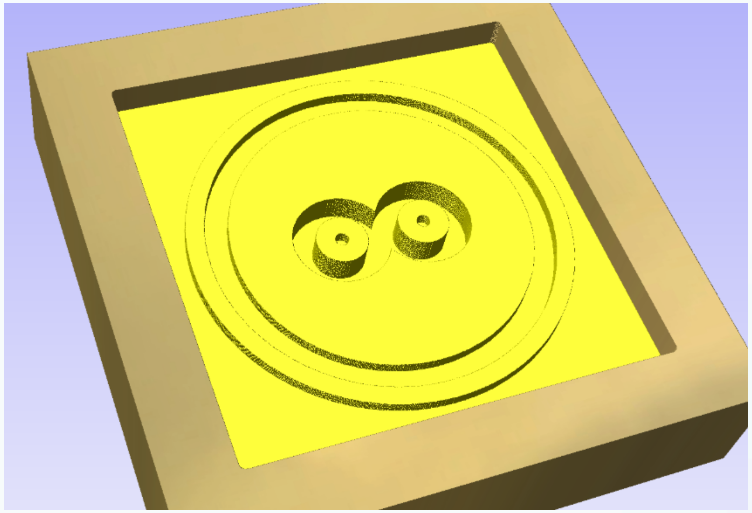

×10^-4
Radial Correlation of | Curl |,
⟨ |c(0)| |c(R)| ⟩ (1/s^2)
Correlated Radial Distance, R (μm)
𝑙/R ≈180 μm
3.2
3
2.8
2.6
2.4
2.2
2
1.8
0
100
200
300
400
500

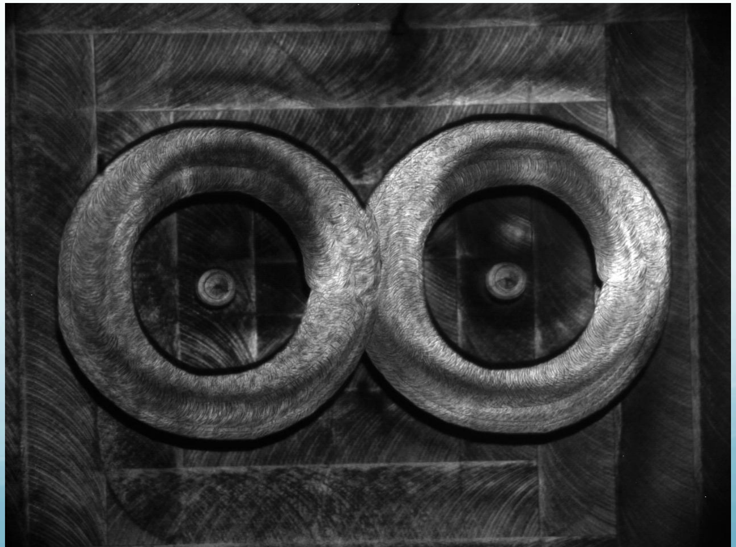

Correlated Radial Distance, R (μm)
Correlated Orientation, Θ (°)
500
400
300
200
100
0
-100
-200
-300
-400
-500
-30
-20
-10
0
10
20
30

Lifetime of a local Vorticity

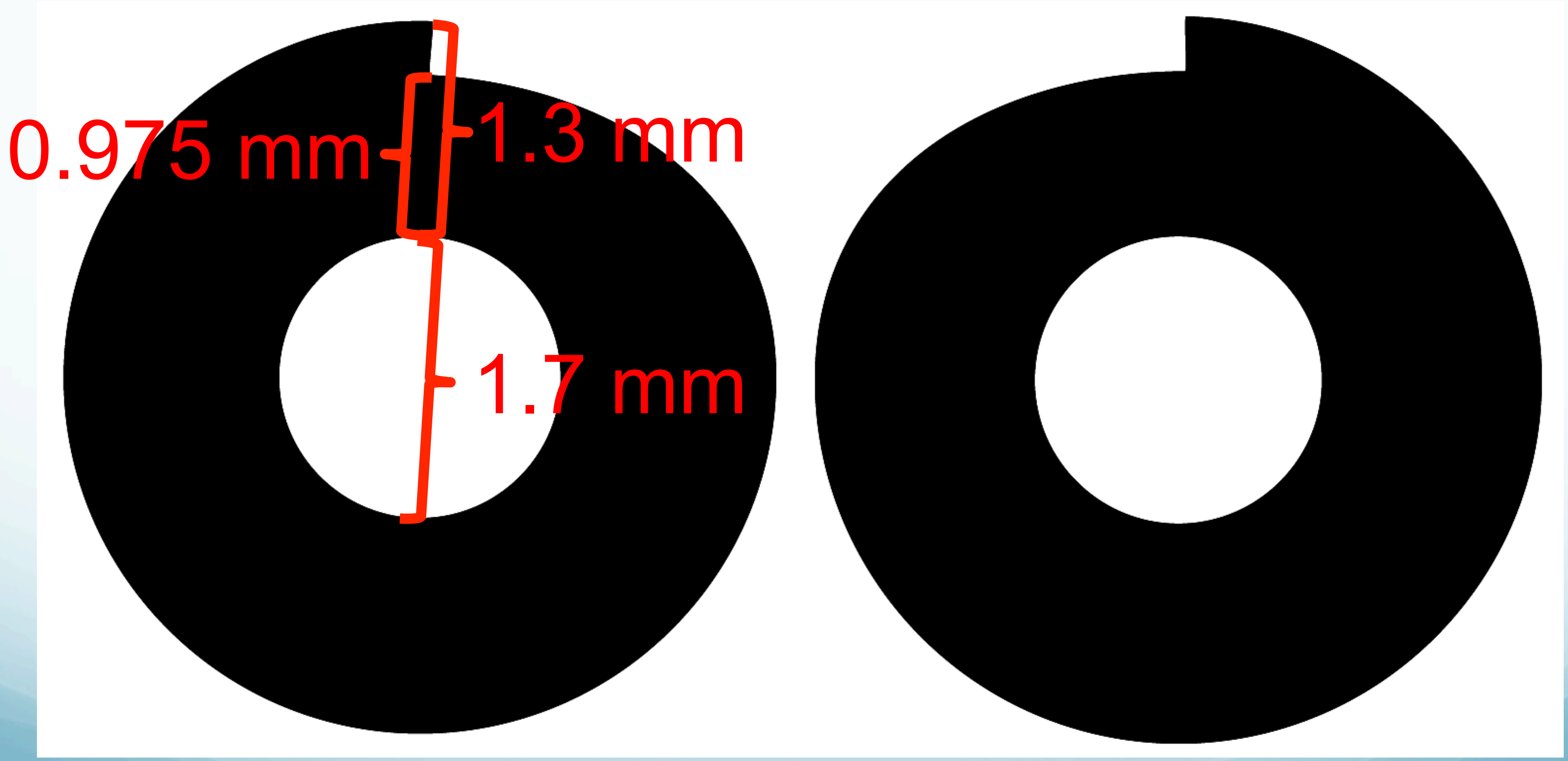


CNC + COC Embossing

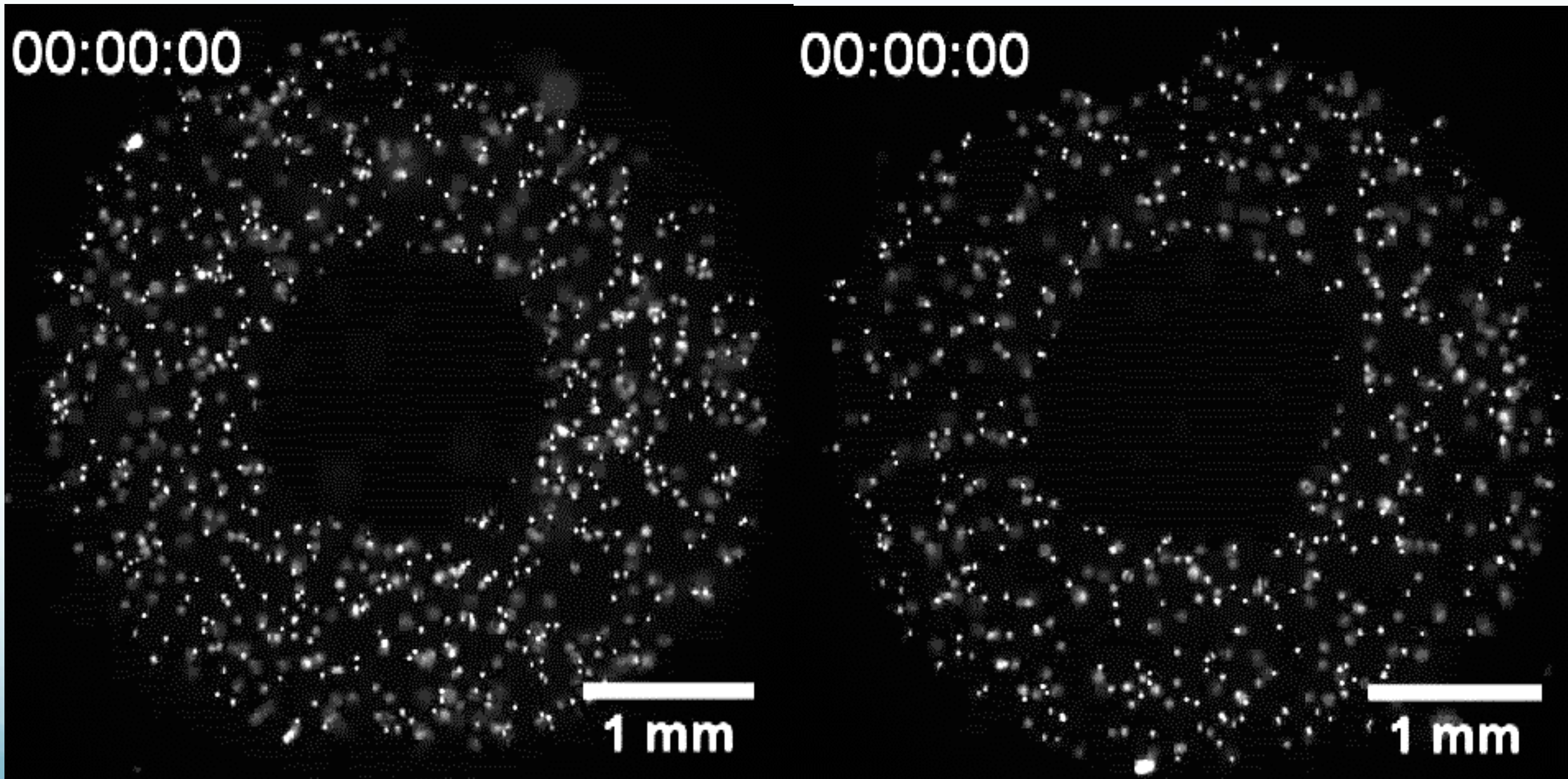




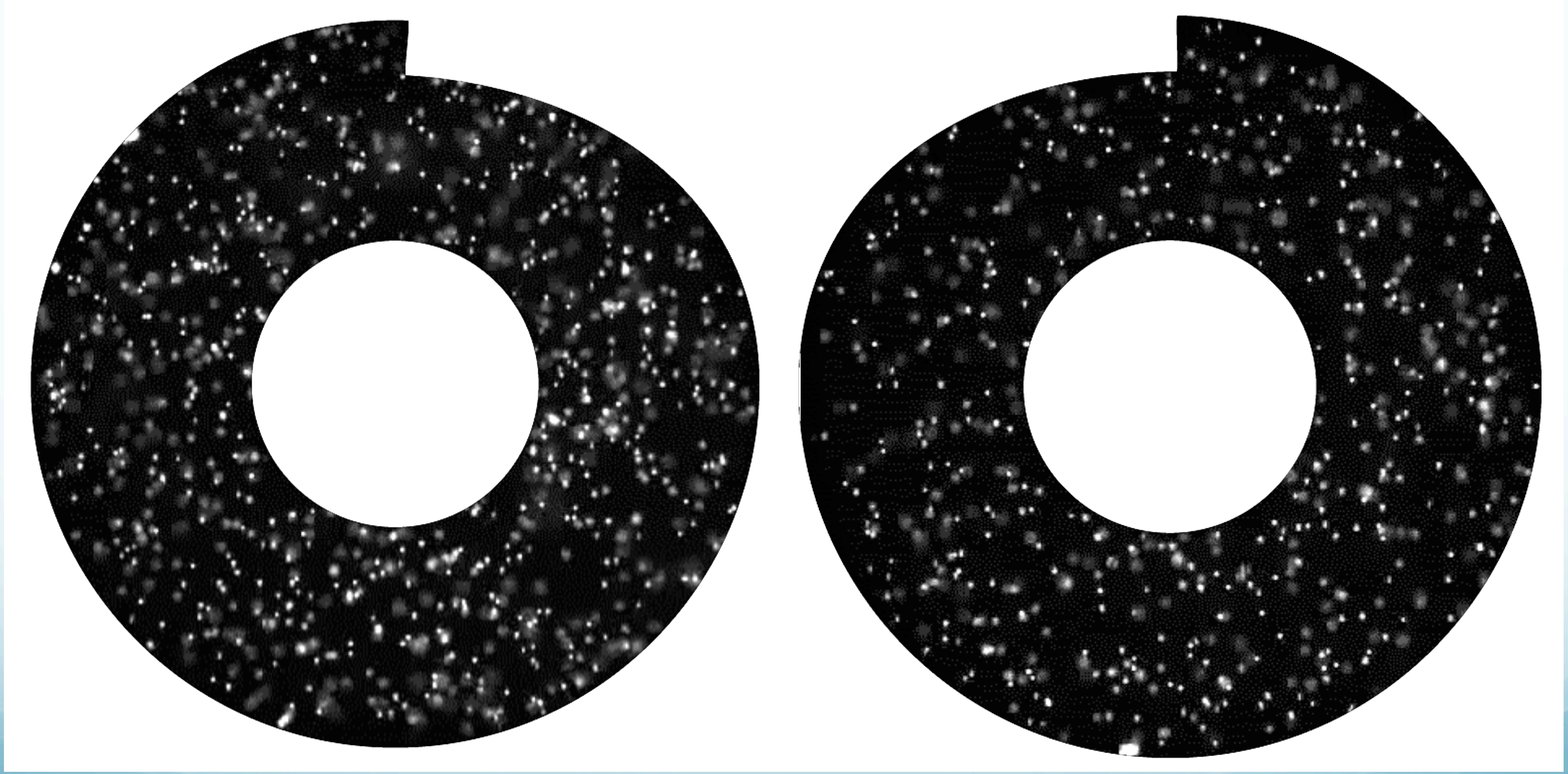
Chiral flows



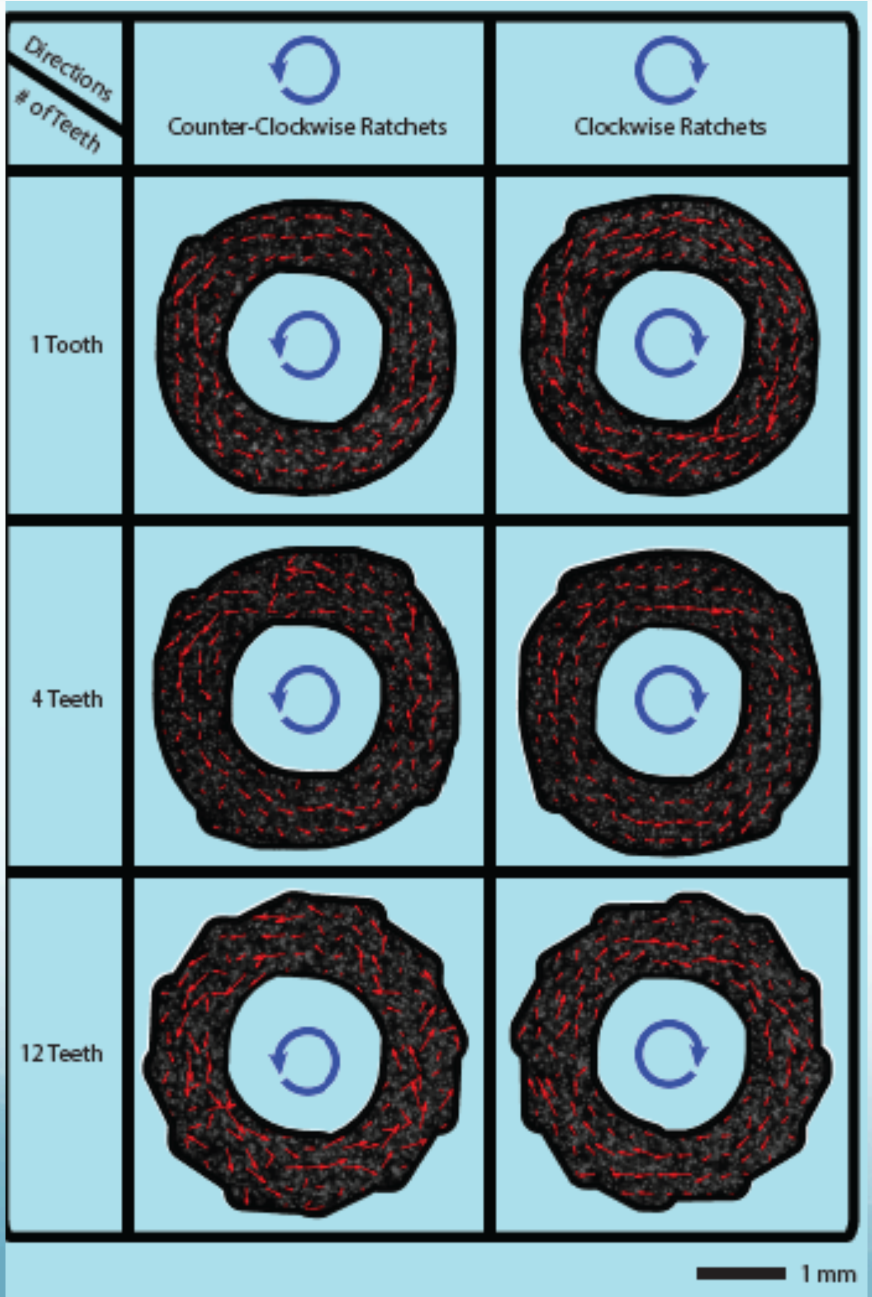
Chiral flows

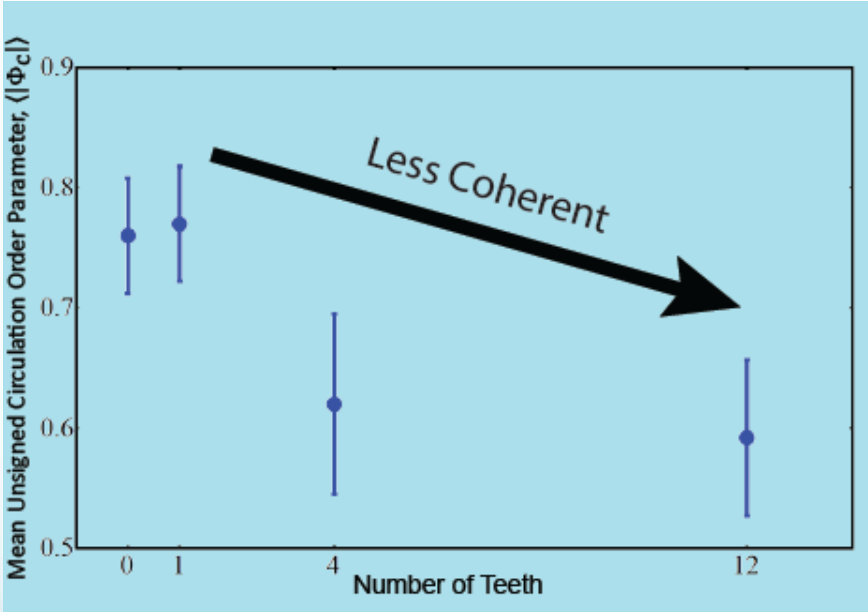


Chiral flows

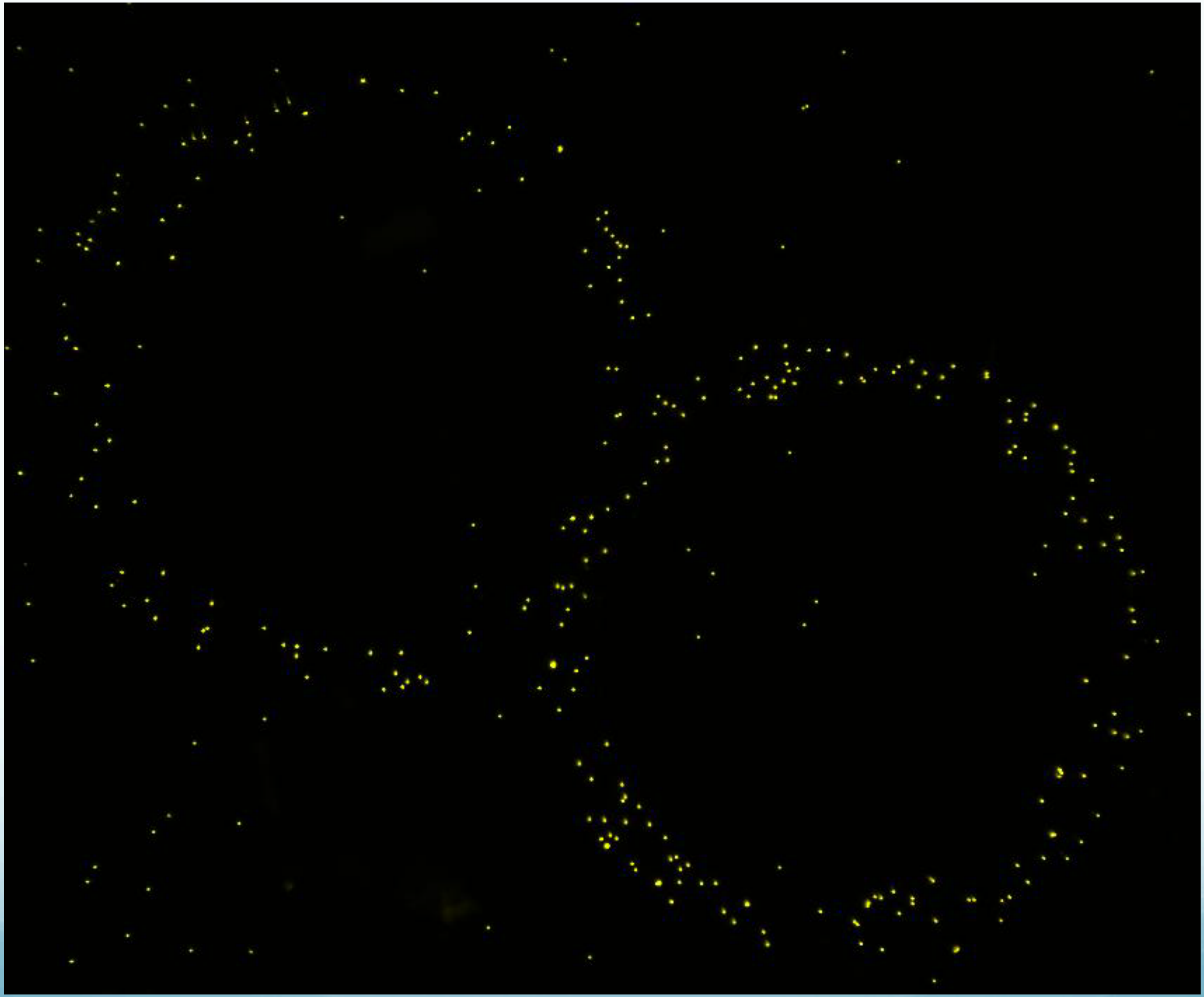


Increasing surface roughness decreases efficiency





Spontaneous flow in more complex geometries



Spontaneous flow in more complex geometries