Contractile microtubules generate active membranes and foams

Zvonimir Dogic
Department of Physics
Biomolecular Science and Engineering

Remi Boros

Bezia Lemma

Dan Needleman

Radhika Subramanian

Hydrodynamic Fluctuations and Instabilities in Ordered Suspensions of Self-Propelled Particles

R. Aditi Simha* and Sriram Ramaswamy†

Centre for Condensed-Matter Theory, Department of Physics, Indian Institute of Science, Bangalore 560 012, India

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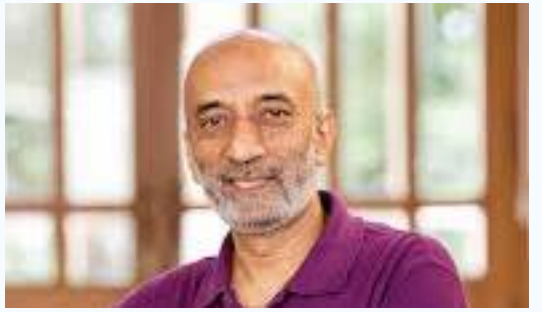


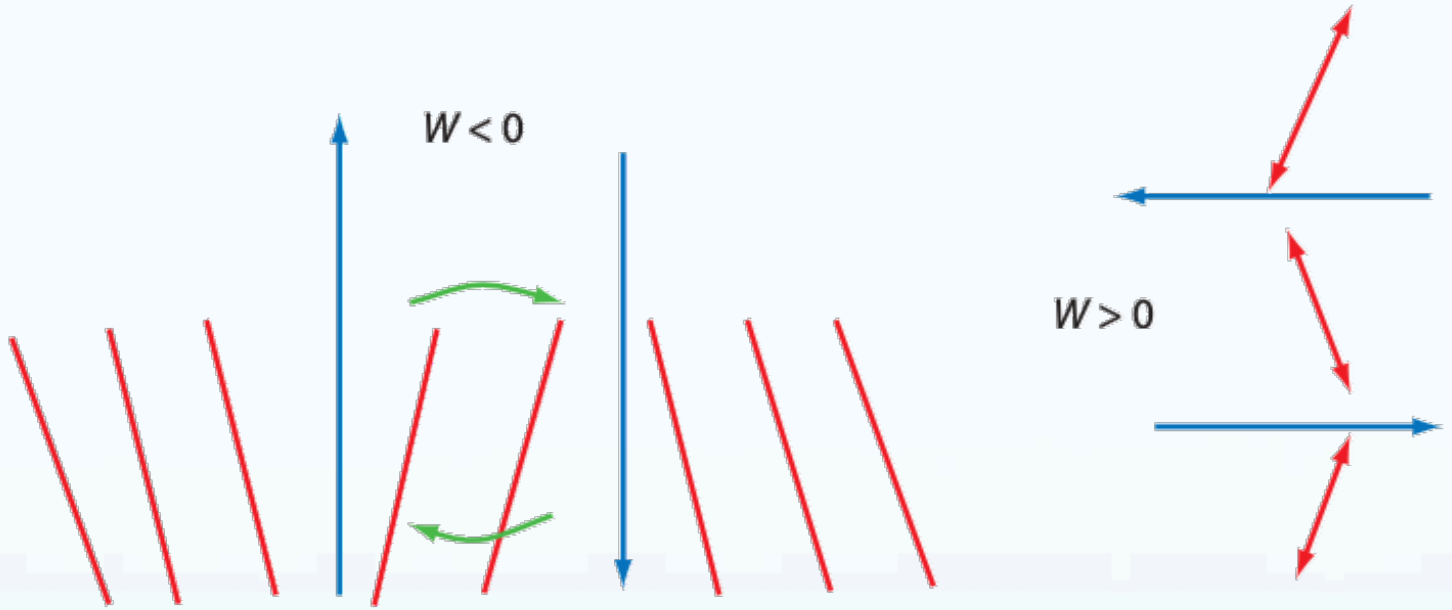
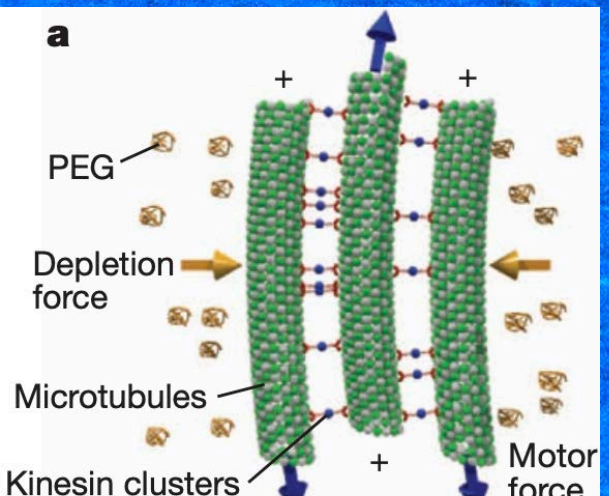


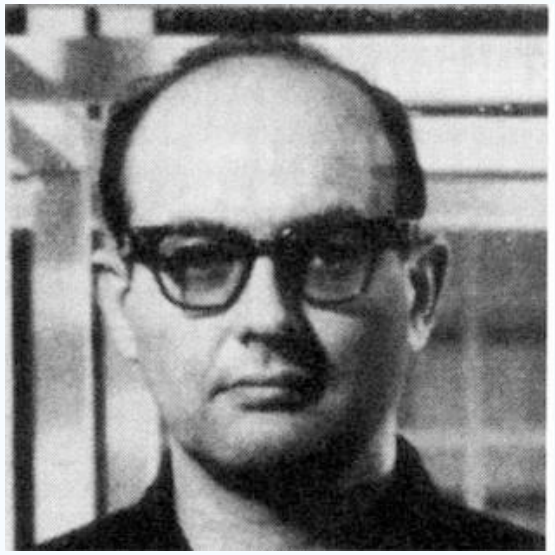
Figure 7

The heart of the generic instability of ordered active filaments. Long-wavelength splay produces shear flows that further distort a row of parallel contractile force dipoles (*left*). Similarly, bend disrupts extensile filaments (*right*).


a
+
+
PEG
Depletion force
Microtubules
+
Kinesin clusters
Motor force

500 µm

Bend instability is ubiquitous in nature (and art)



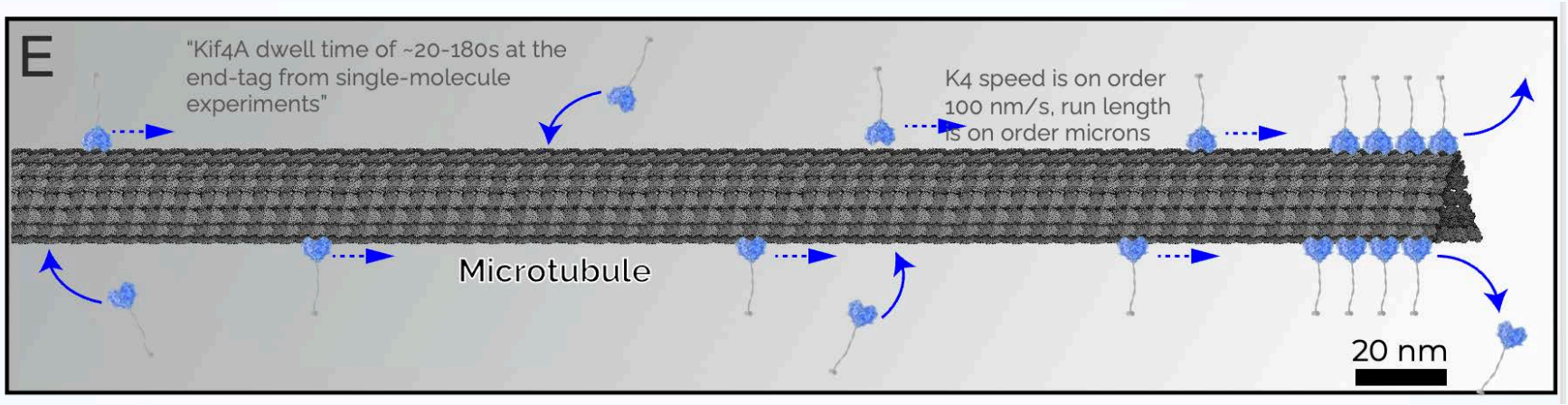
Sol LeWitt: A Retrospective

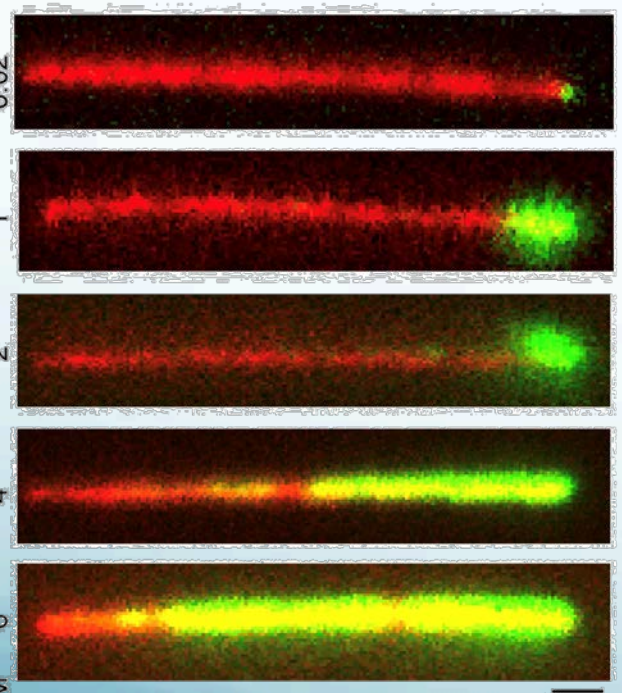
Whitney Museum (December 2000)

Connecting microscopic motor dynamics to macroscale behaviors

Goal: determine how changing microscopic motor-dynamics influences MT self-organization

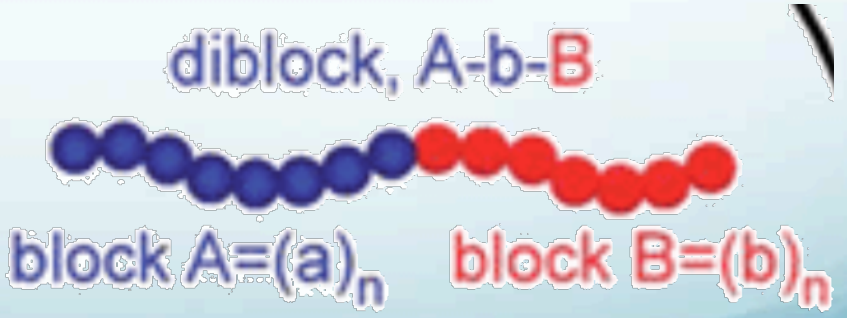
Kinesin-4 motors accumulate on MT tips





Spatially heterogeneous filament encoded in microscopic motor dynamics

Reminiscent of amphiphilic molecules

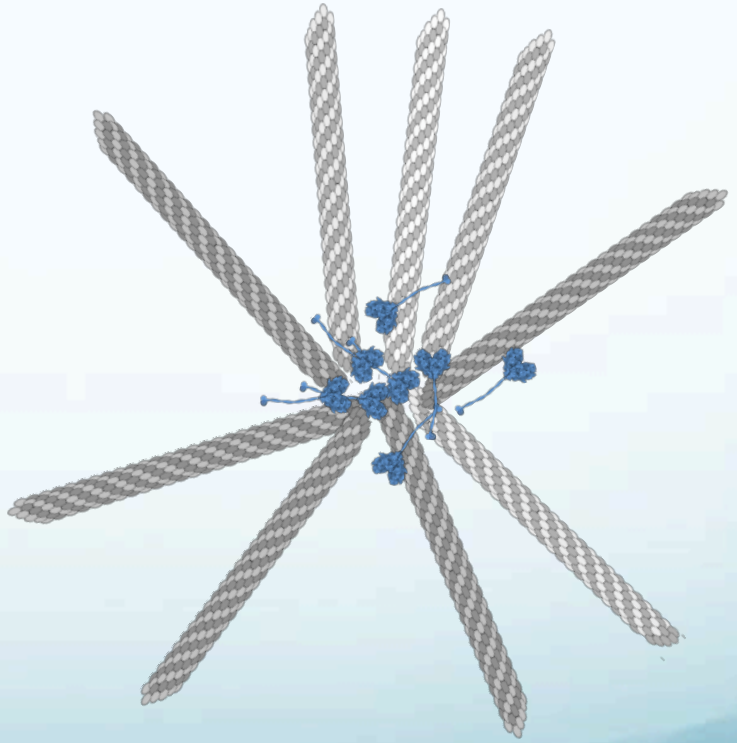


Wijeratne et. al. 2022

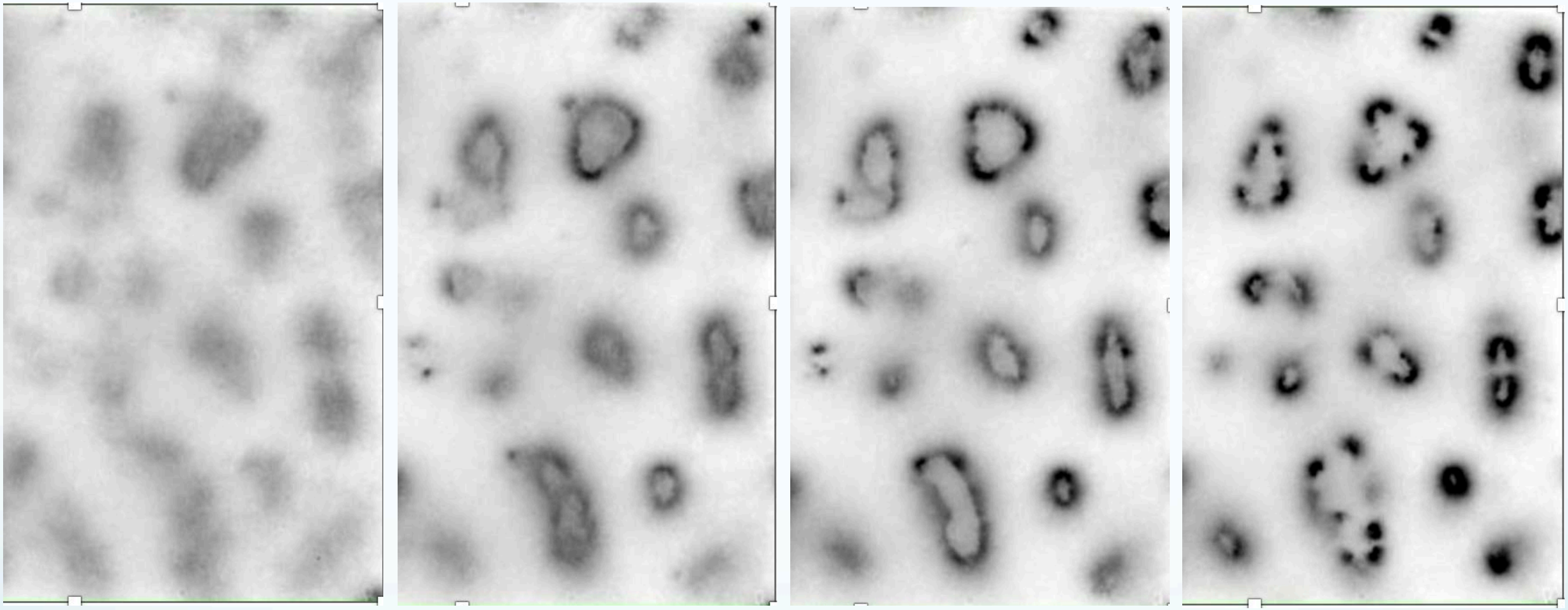
Kinesin-4 driven initial contraction

initial isotropic contraction leads to formation of asters

Asters – radially splayed microtubules splayed outwards

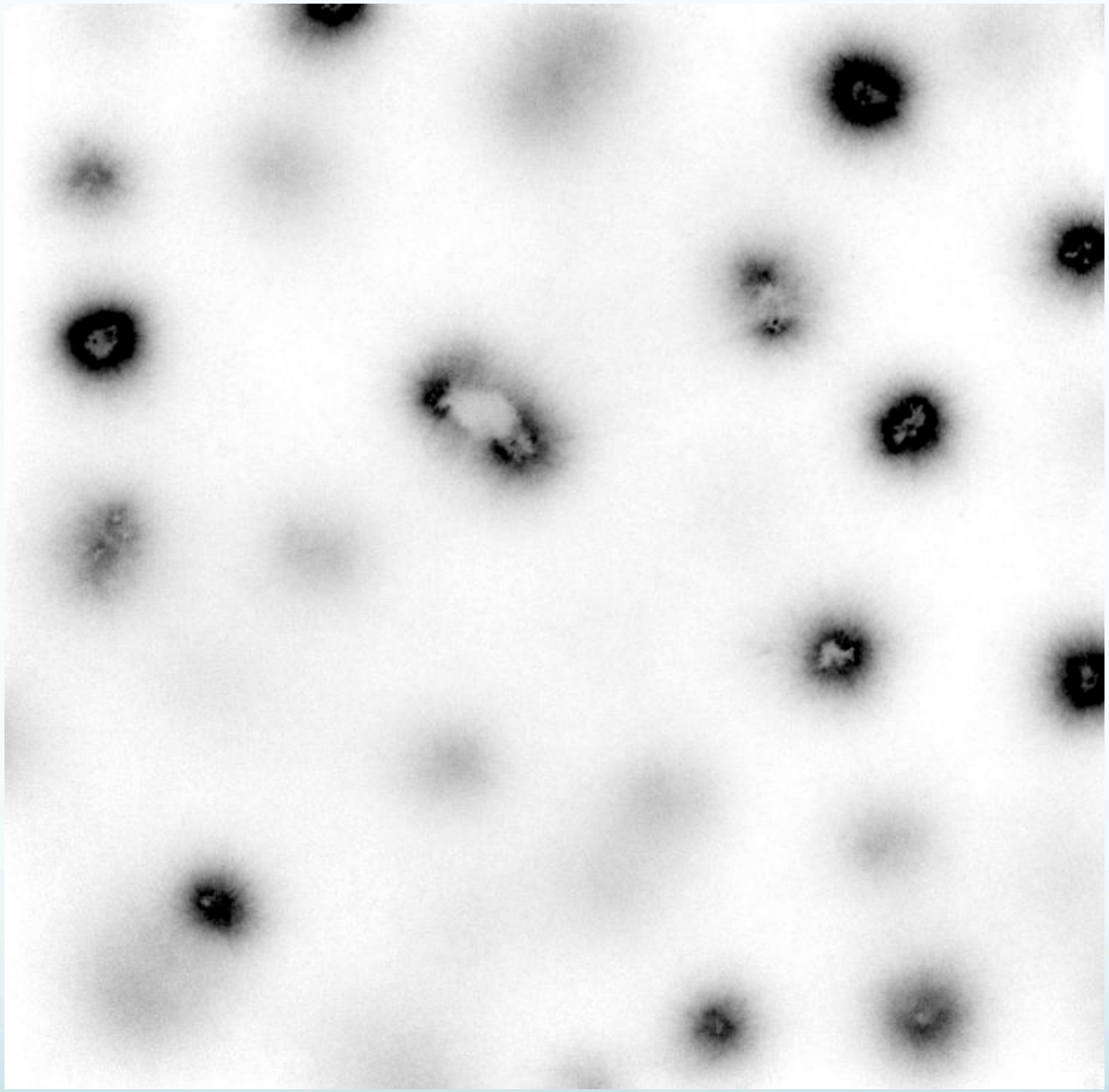


Initial contraction with secondary instability

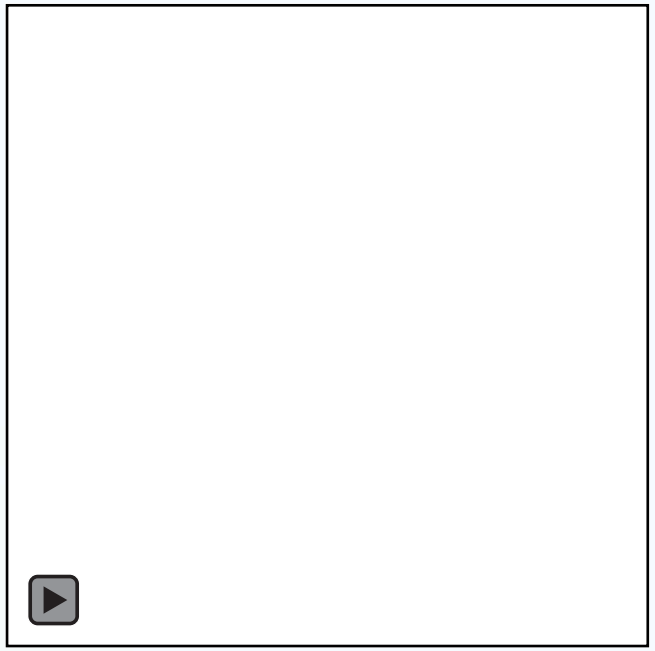


larger contractile structures → MT monolayer vesicles → secondary instability

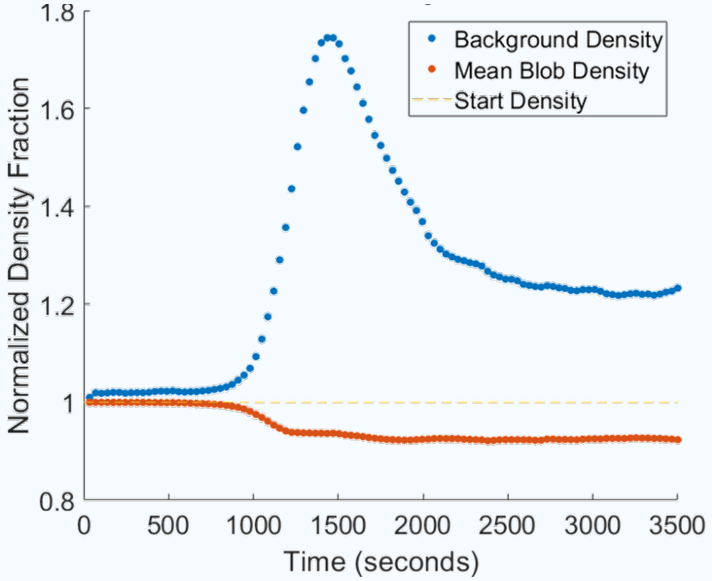
Expansion of contracted droplets



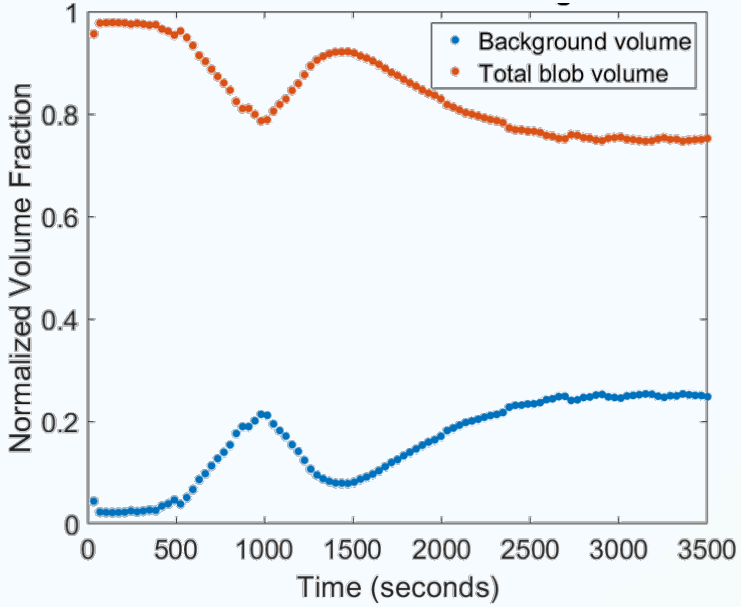
Expansion of contracted droplets - quantitative analysis



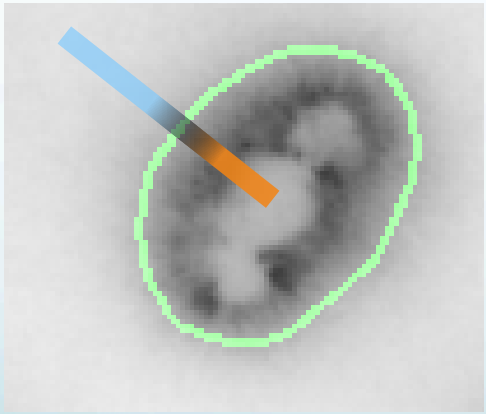
Vesicle density vs time

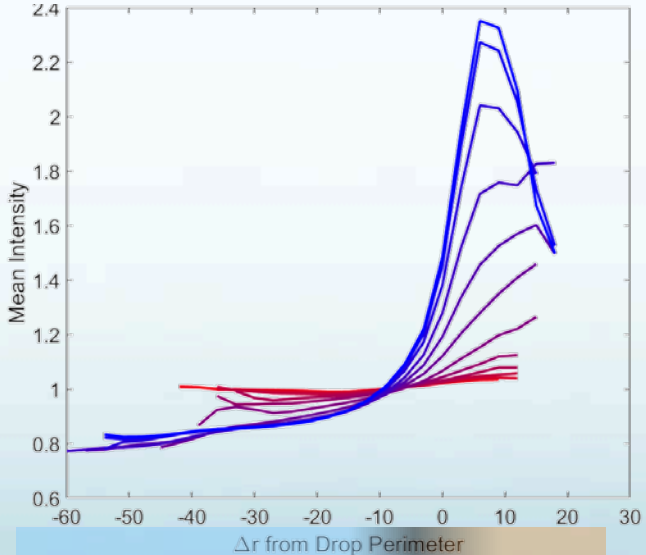


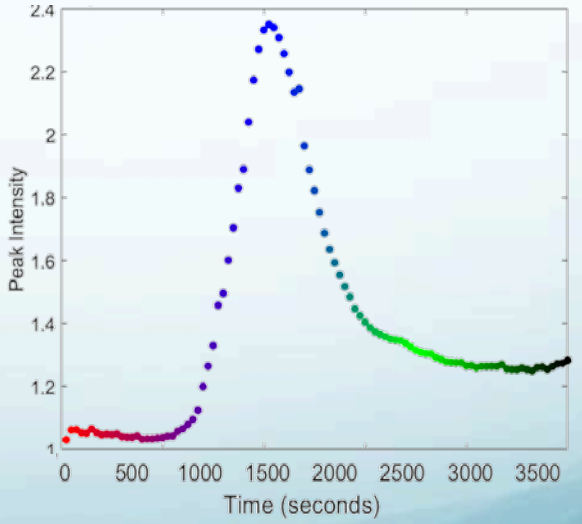
Volume fraction vs. time



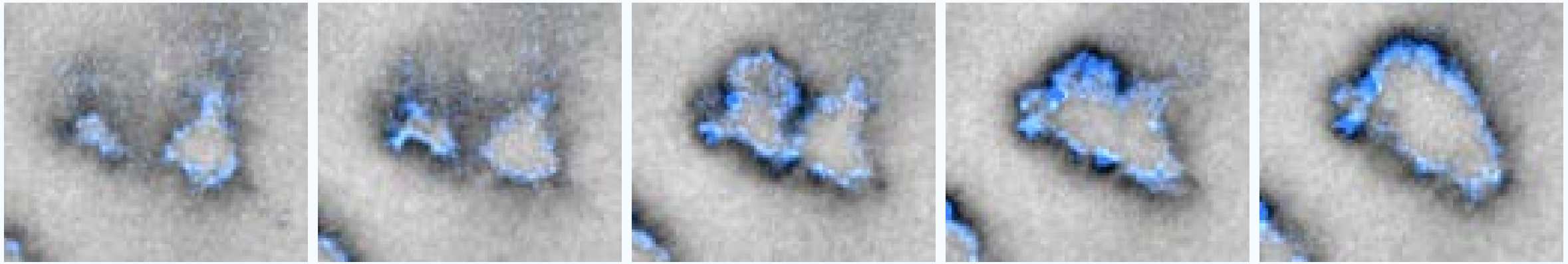
Edge density profile vs. time

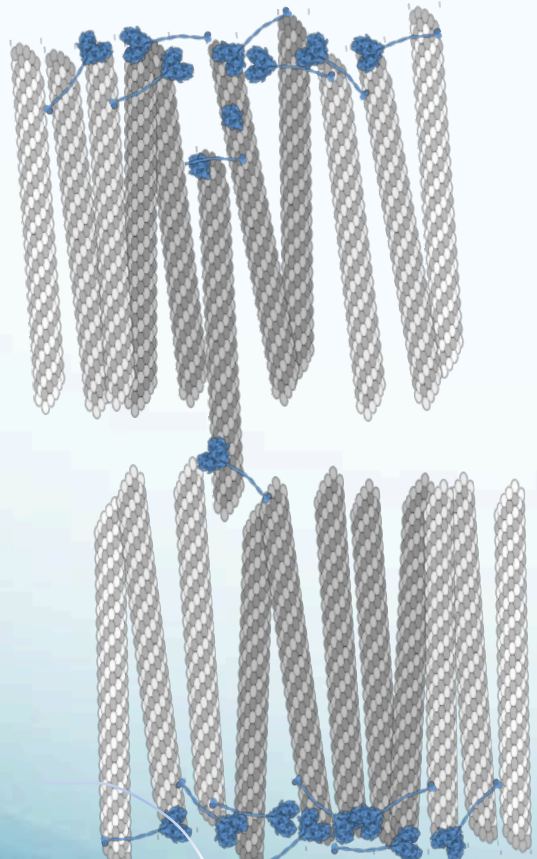




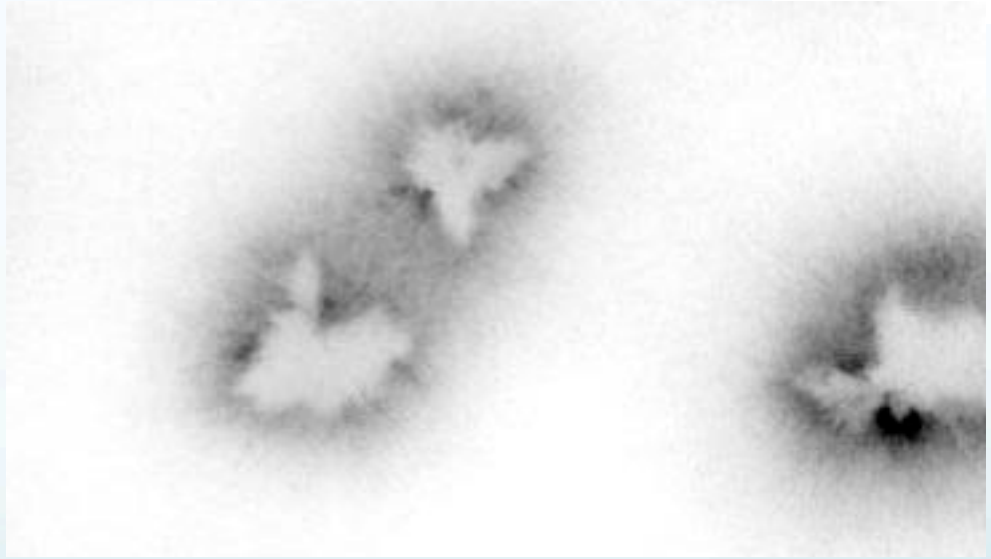


Coalescence of expanding vesicles

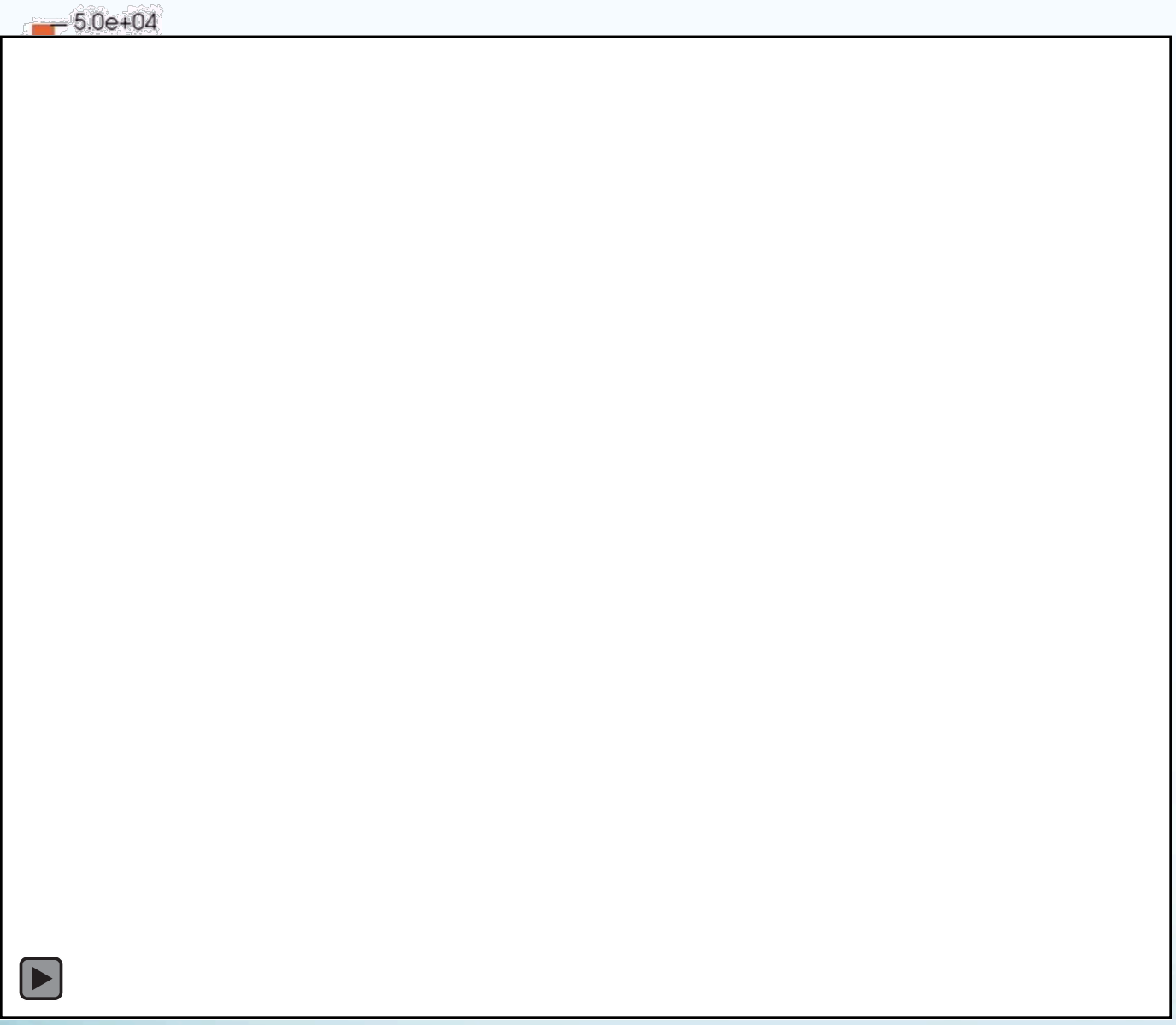




Expanding polar monolayers annihilate each other



Motor driven MT self-organization



Initial stages of kinesin-4 driven MT self-organization

Isotropic contraction

↓

Formation of maximally contracted asters

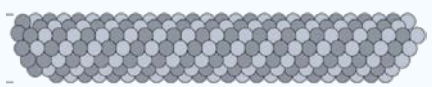
↓

Asters expand into monolayer vesicles

↓

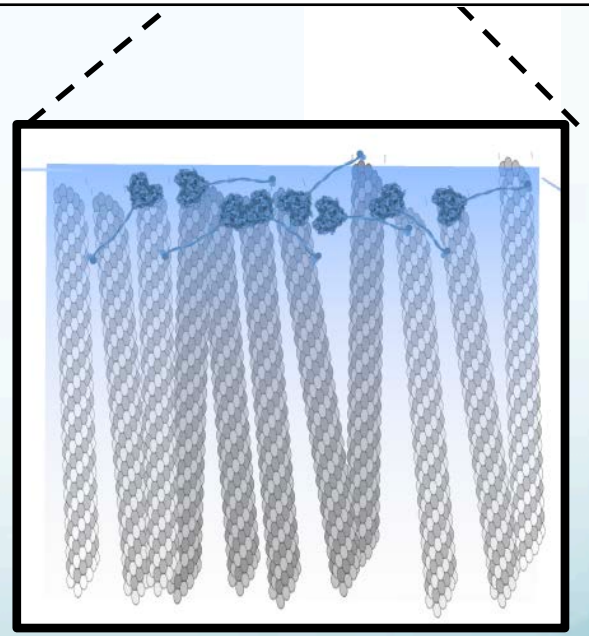
Continuous vesicle expansion and coalescence

Longer time-scales –formation of a polar monolayer



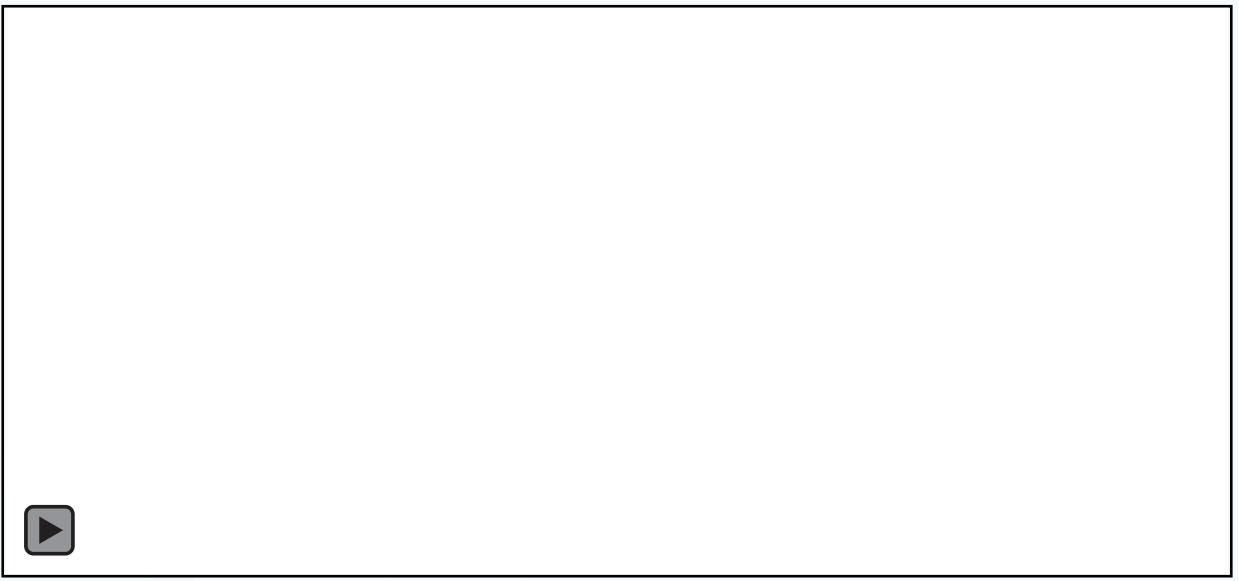
low activity (kinesin) and low MT concentration

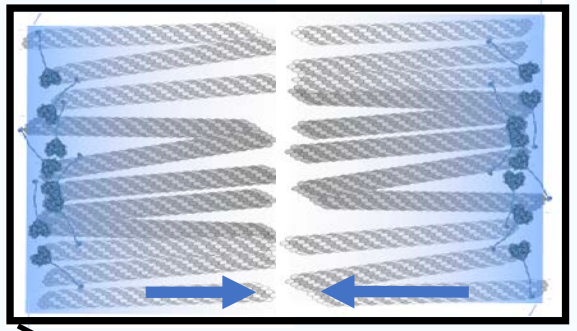
active stresses lead to membrane deformations



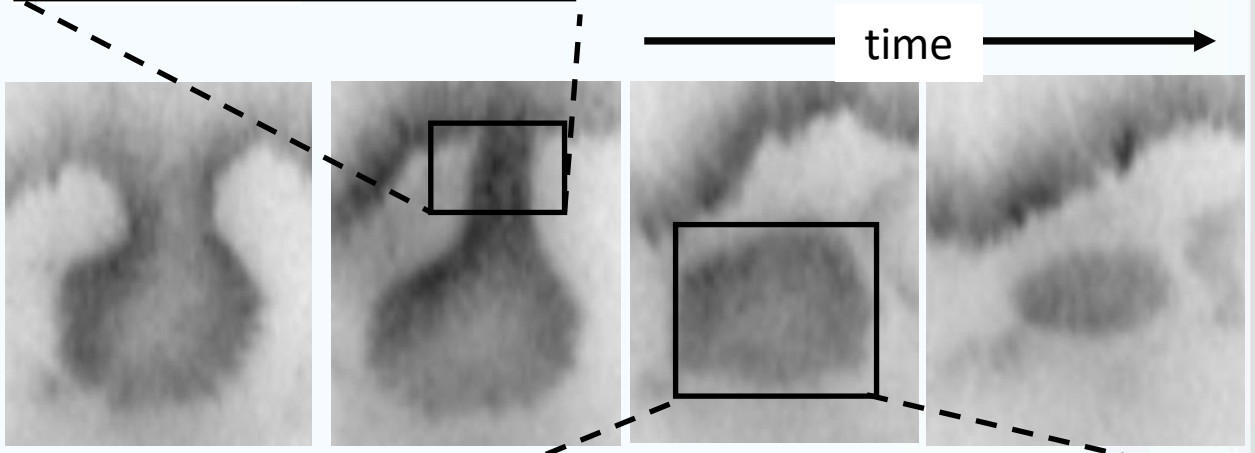
Longer time-scales – formation of a macroscale polar monolayer

Polar MT monolayers at high activity





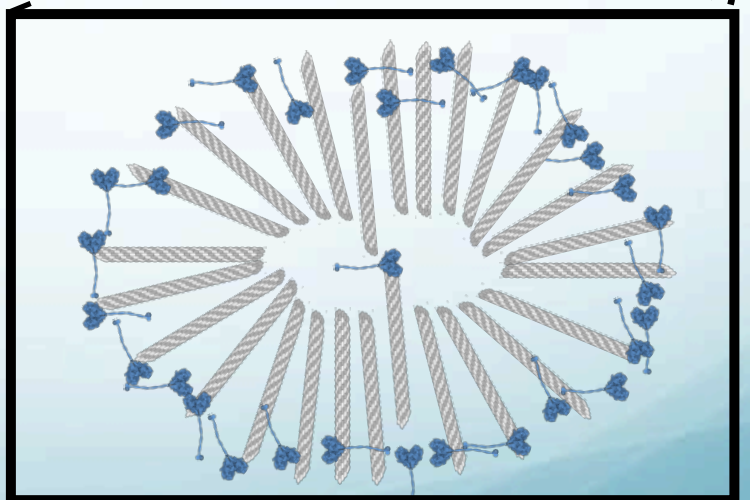
unstable configuration – membrane disassembly



Active stresses drive large deformation of extended MT monolayers

asymmetry in curvature generation – frequent inward invaginations

Inverted vesicles – unstable configuration - **disassembly**



Membrane fluctuations and disassembly

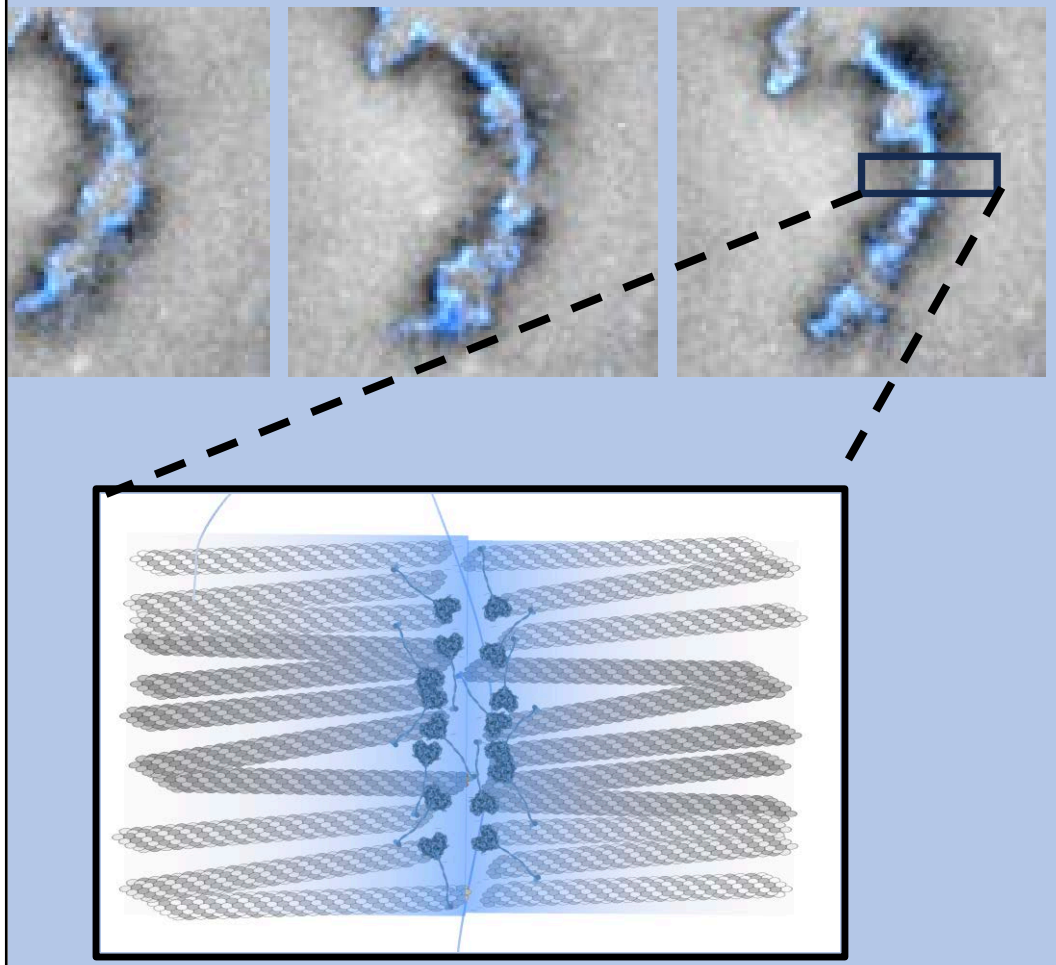
ce high curvature

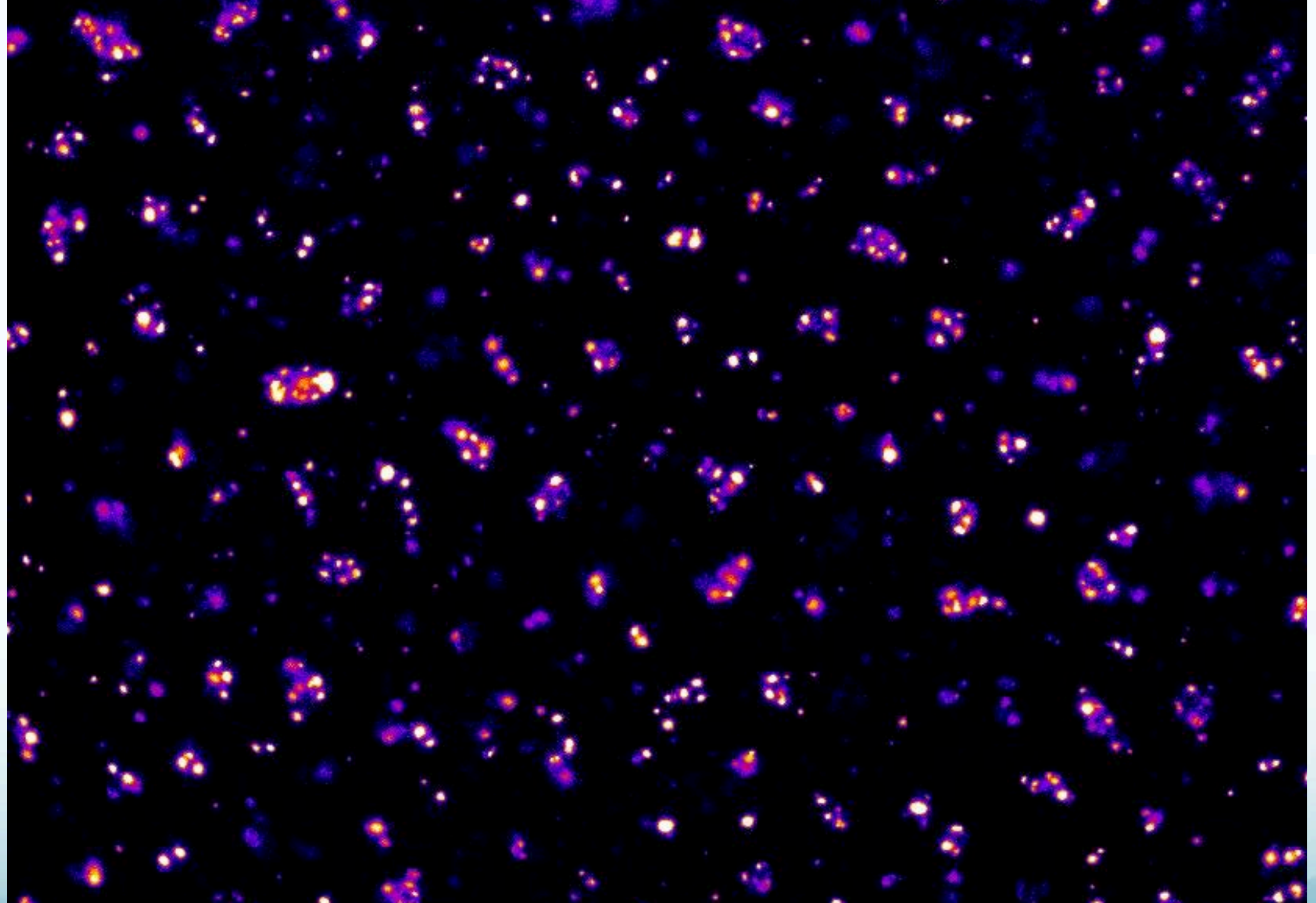
ate disassembly of MTs

embled MTs

he membrane

Long-time dynamics – zippering and bilayer formation

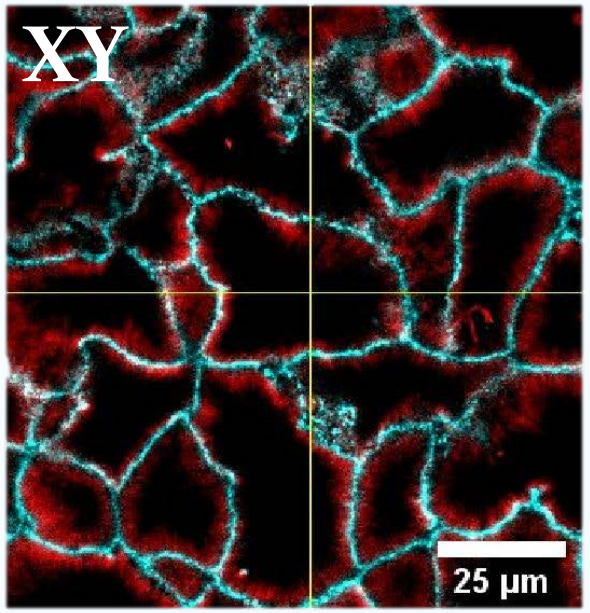


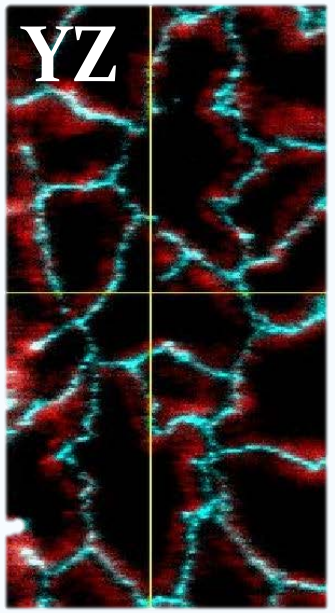


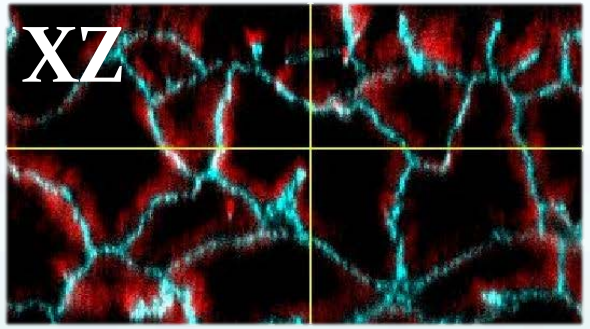
active solid foams

z-scan of an active foam

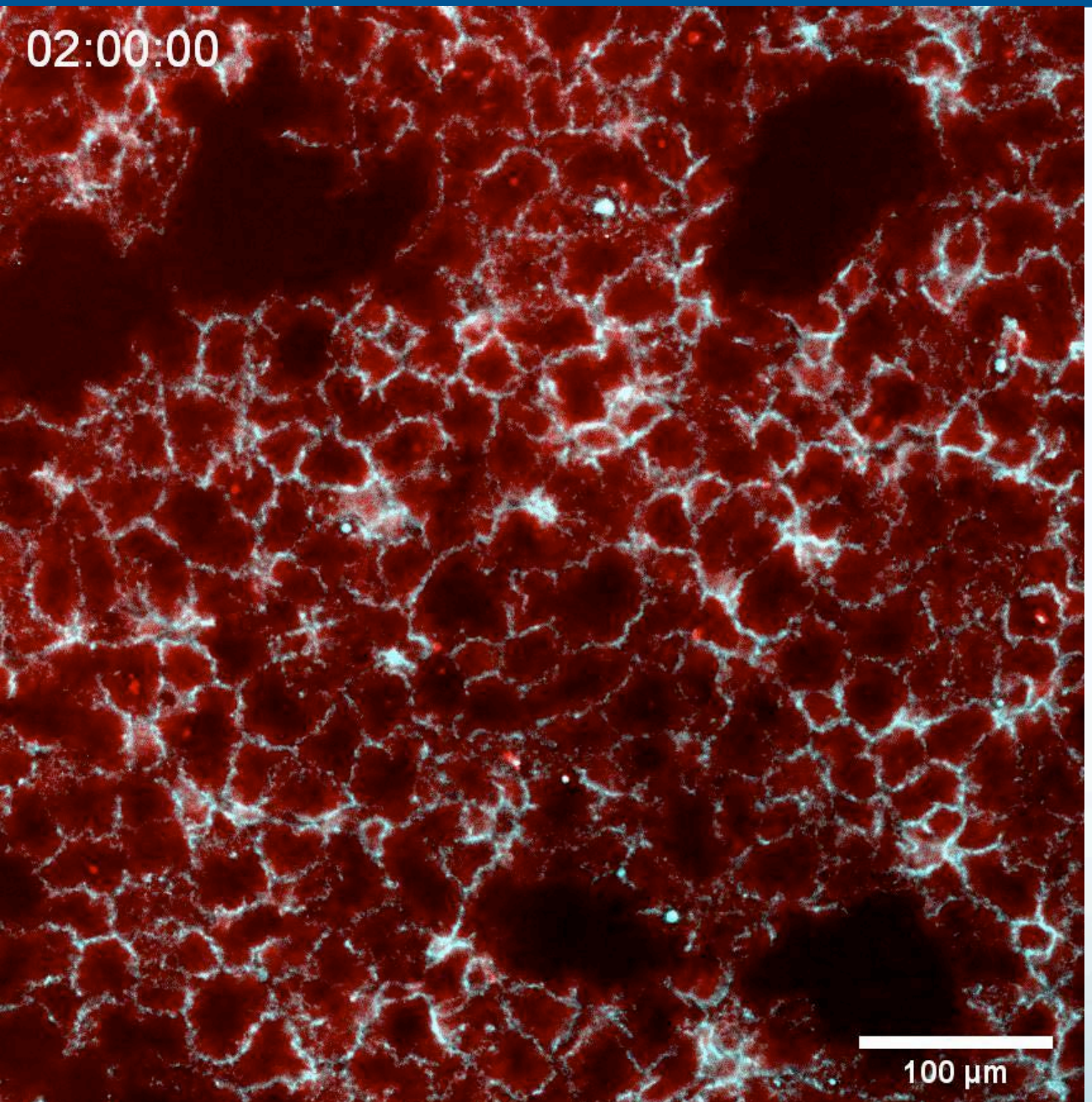
foam composed of closed cells







Active foams exhibit pulsatile dynamics



Pulsatile dynamics of active foams

Self-annihilation of foam cells which shrink below a critical size

Foam can form either closed or open networks

Long term steady-state: active foams

changing microscopic dynamics from inter-filament sliding to tip accumulation changes patterns of microtubule self-organization

contractile to extensile dynamics - initial contraction and formation of aster-like structure is followed by subsequent expansion – complex kinetic pathways

active polar solid membranes – non-equilibrium bending fluctuations couple with local disassembly

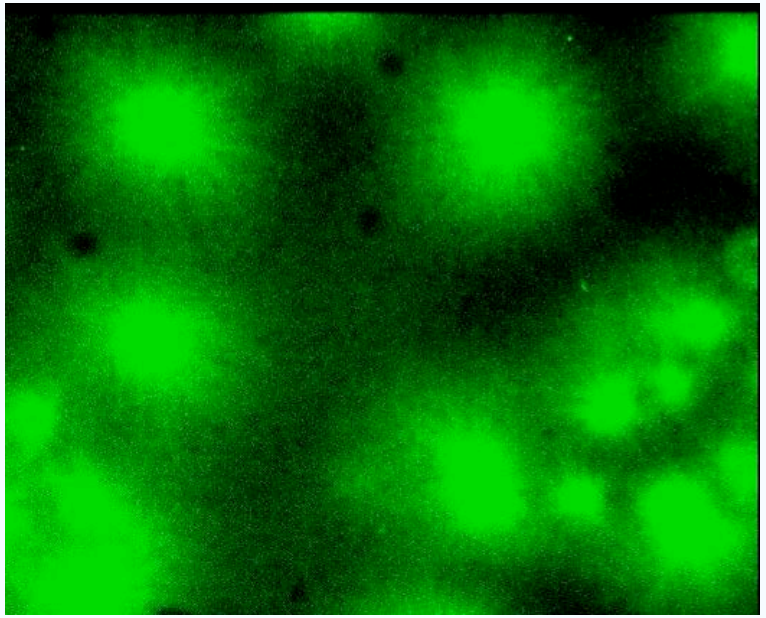
active apolar foams - long-term steady state structure – exhibit non-equilibrium pulsatile dynamics

Are there broader implications?

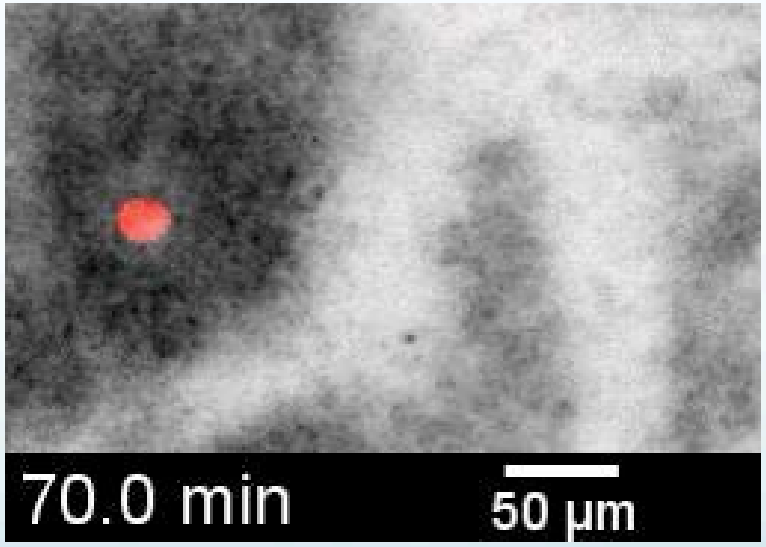
Assembly and disassembly of MT vesicles in actin/MT composites

Microtubule dynamics in *X. Laevis* extracts

Formation of contractile and subsequent expansio of microtubule asters



Spontaneous division of microtubule asters



Cheng and Ferrell, 2019