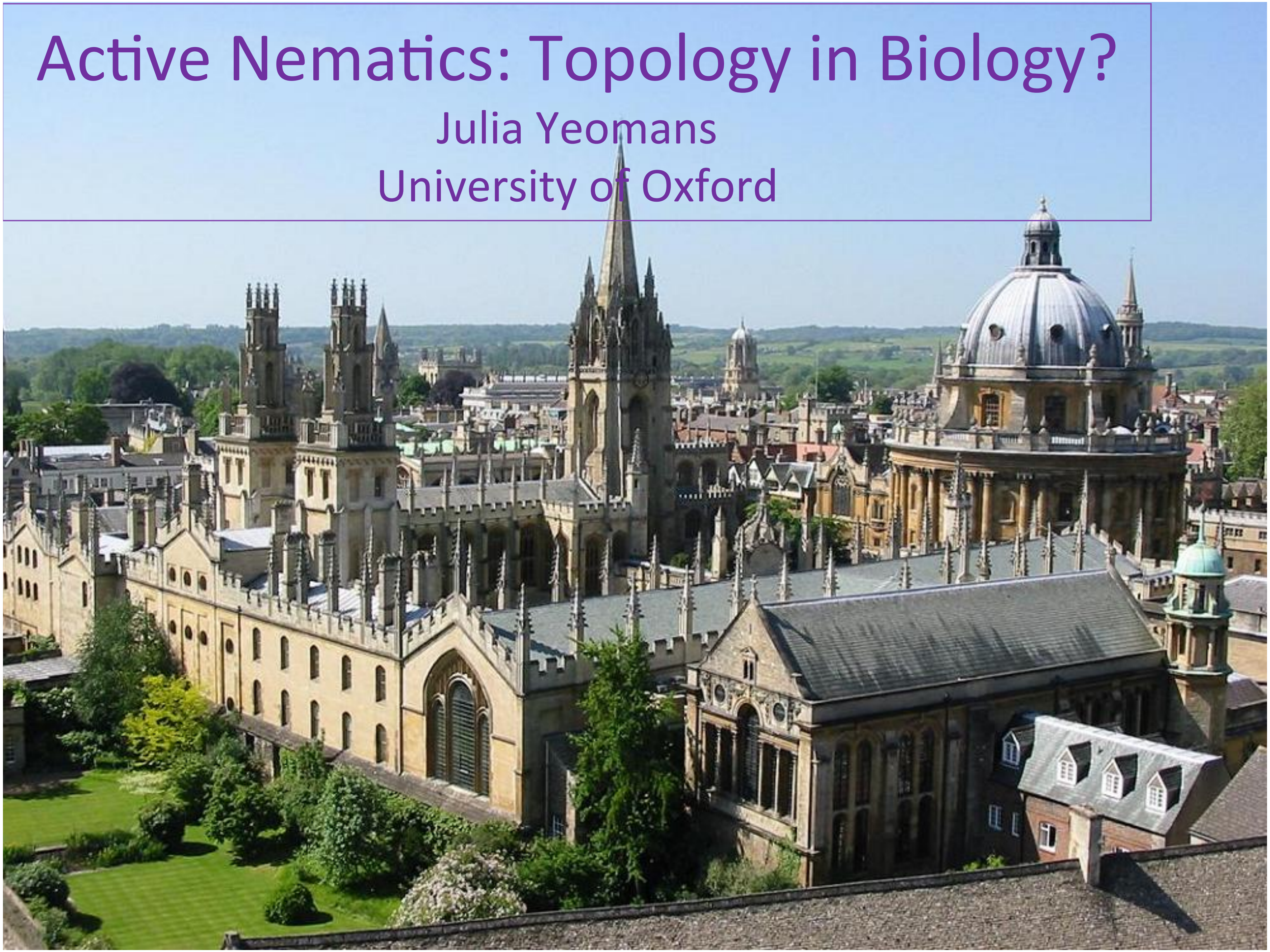
Active Nematics: Topology in Biology?

Julia Yeomans
University of Oxford



Amin Doostmohammadi
University of Oxford

Sumesh P Thampi
now Assistant Prof IIT, Chennai

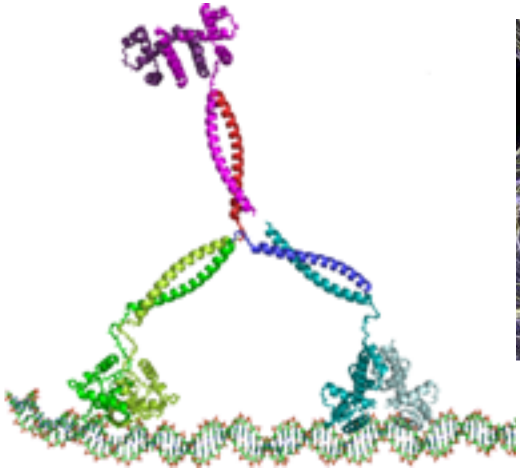
Matthew Blow
University of Edinburgh

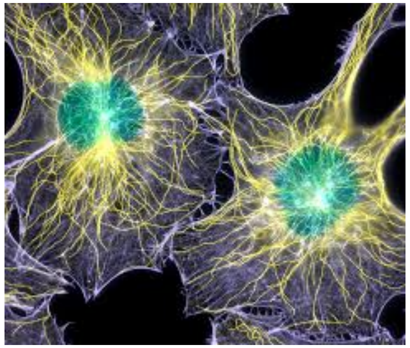
Benoit Ladoux
Thuan Saw

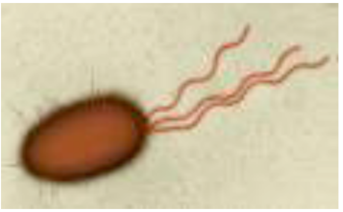
Funding: ERC

Active particles convert energy to motion

Energy enters the system on a single particle level





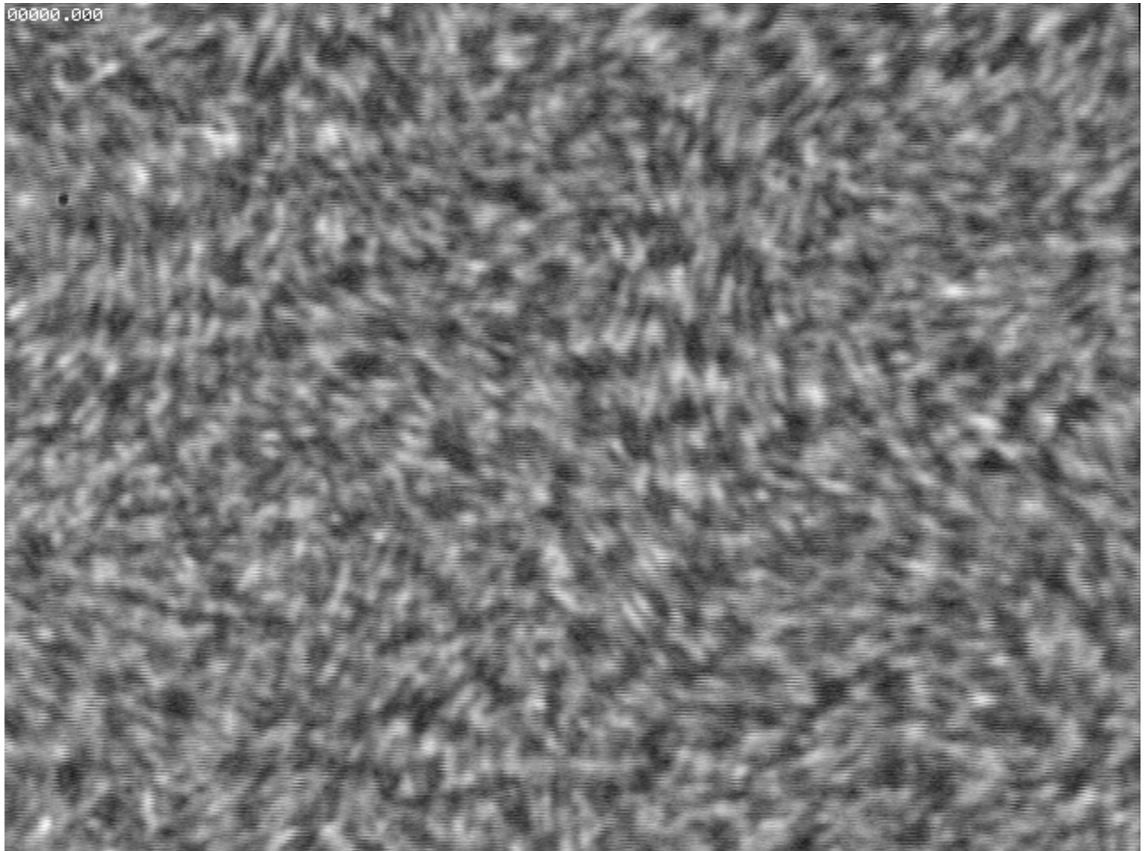


molecular motors

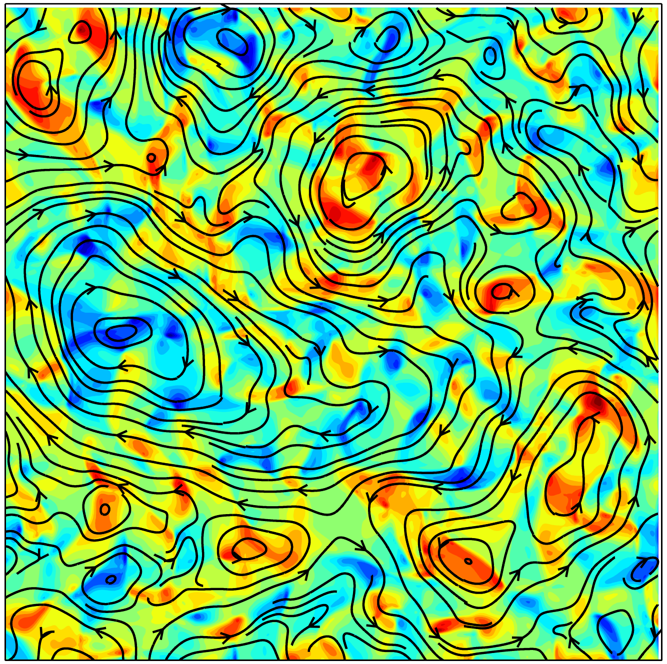
cells

nematic walruses

Active turbulence

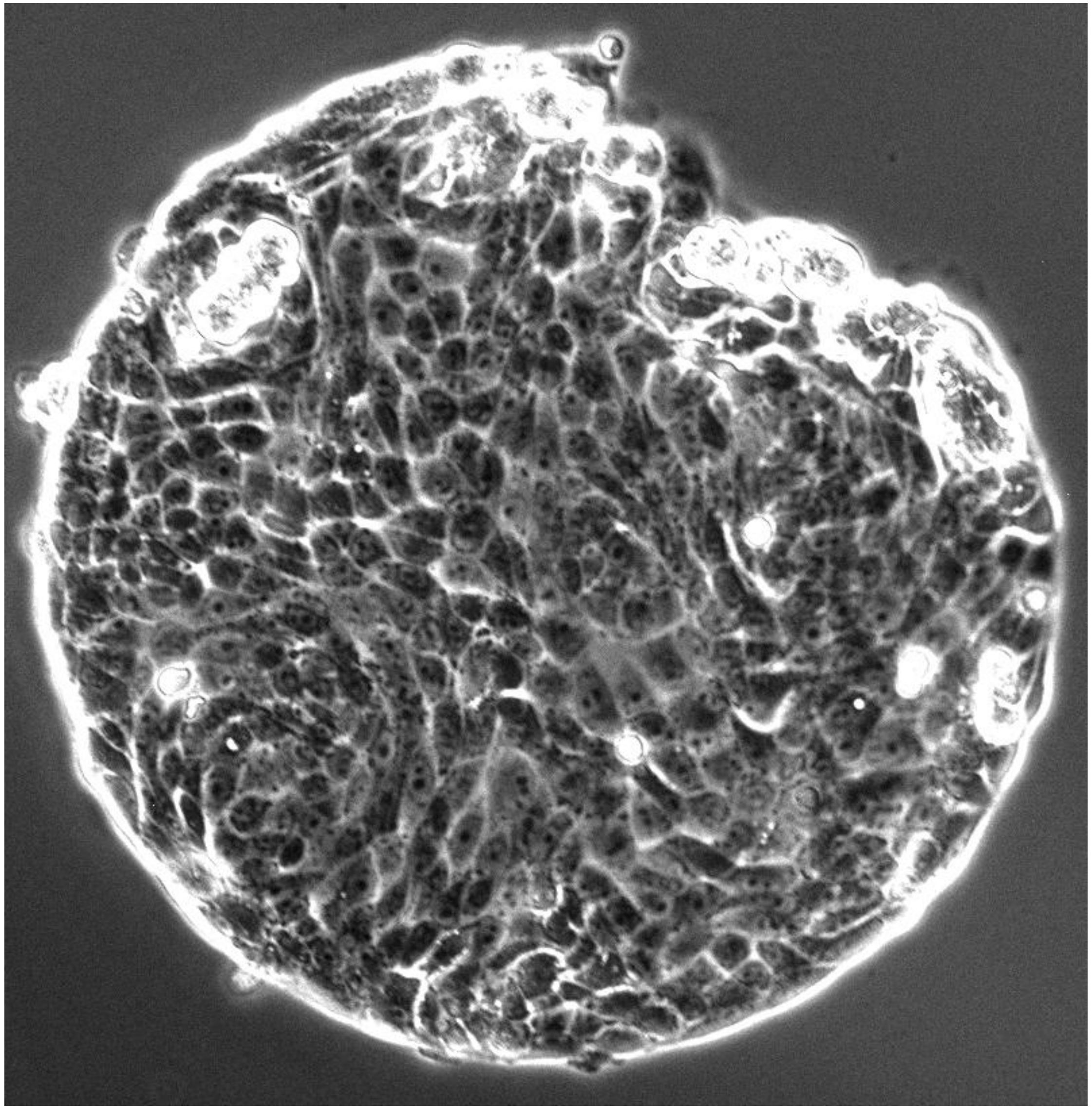


Dense suspension of microswimmers



Vorticity field

Active turbulence of cells



Nematics and their equations of motion

Active flow

Continuum equations for active nematics

The physics of active turbulence

Microtubulues and molecular motors

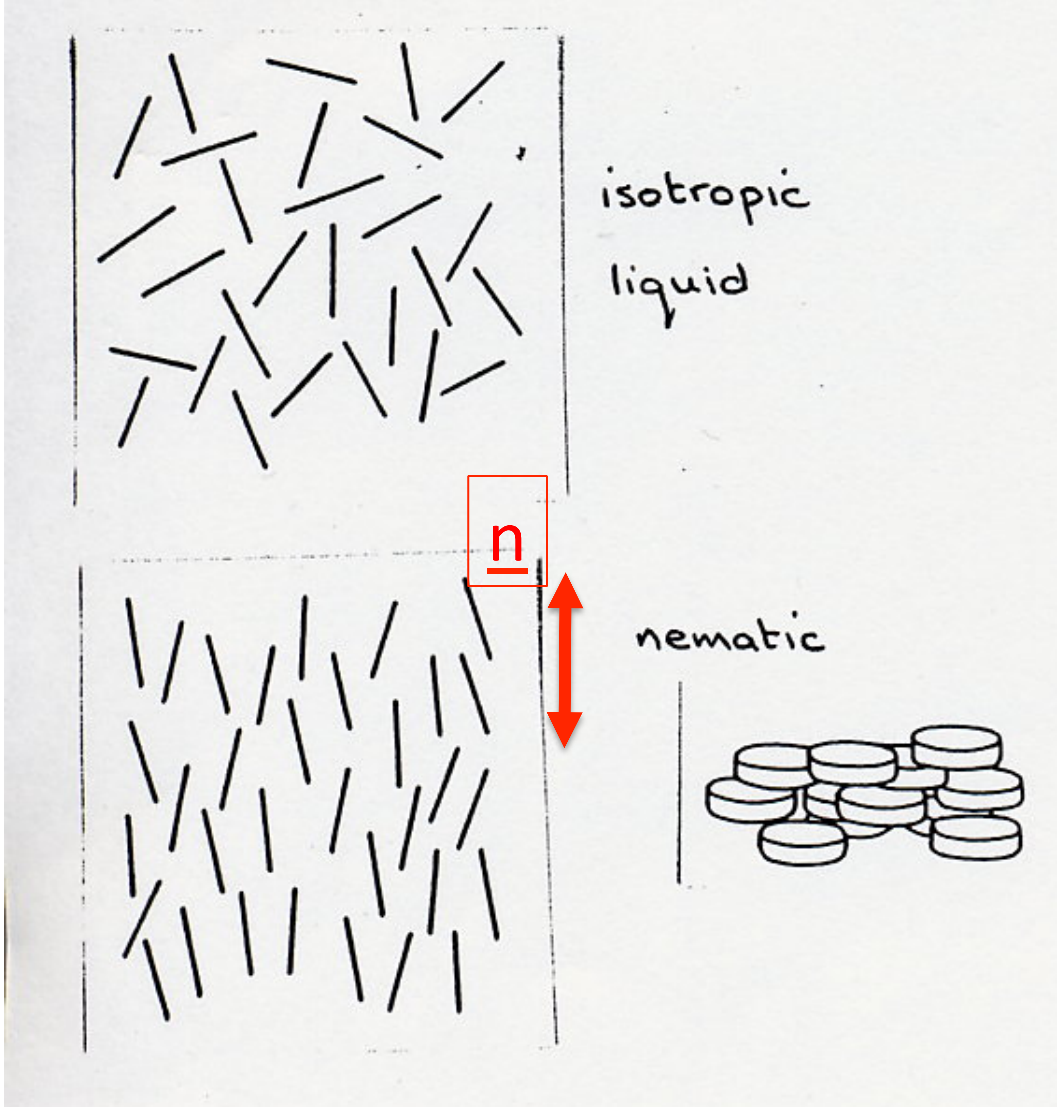
Cell colonies:

Cell division is a sources of activity

Growing cellular colonies and active anchoring

Cell extrusion at topological defects

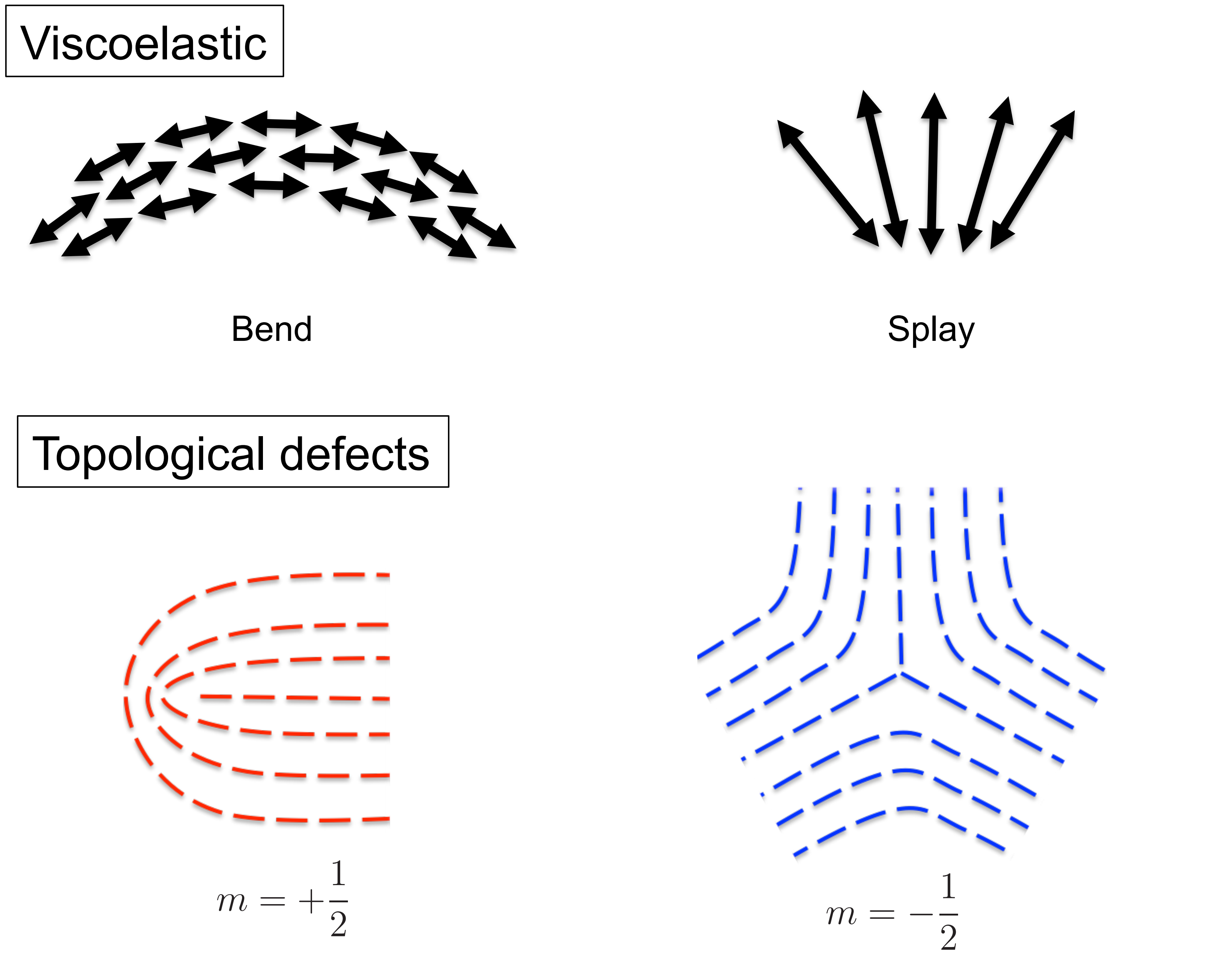
Liquid crystals



nematic symmetry

nematic order parameter n
tensor order parameter Q

$$Q_{ij} = \langle n_i n_j - \frac{\delta_{ij}}{3} \rangle$$


Viscoelastic
Bend
Splay
Topological defects
$m = +\frac{1}{2}$
$m = -\frac{1}{2}$

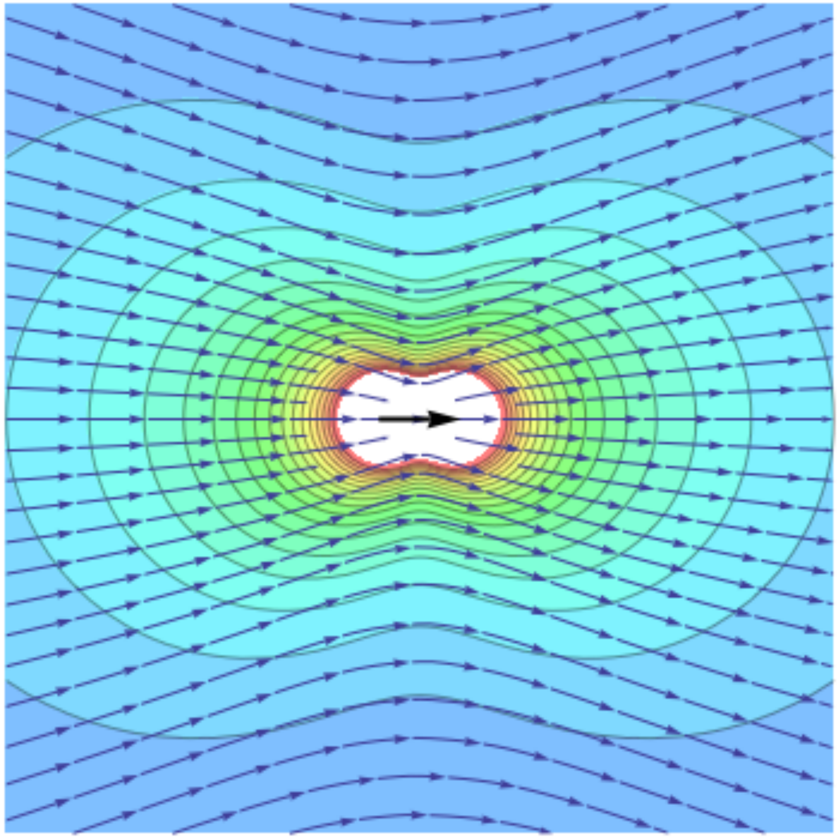
Hydrodynamics of active systems

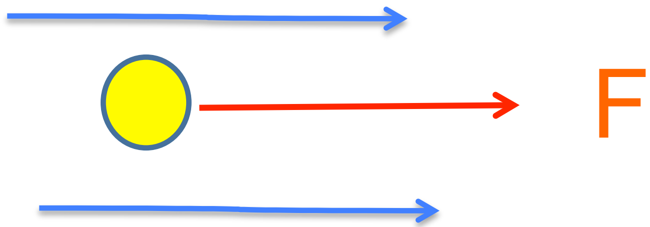
Stokes equations

$$\nabla p = \mu \nabla^2 \mathbf{v} + \mathbf{f}$$

Stokeslet

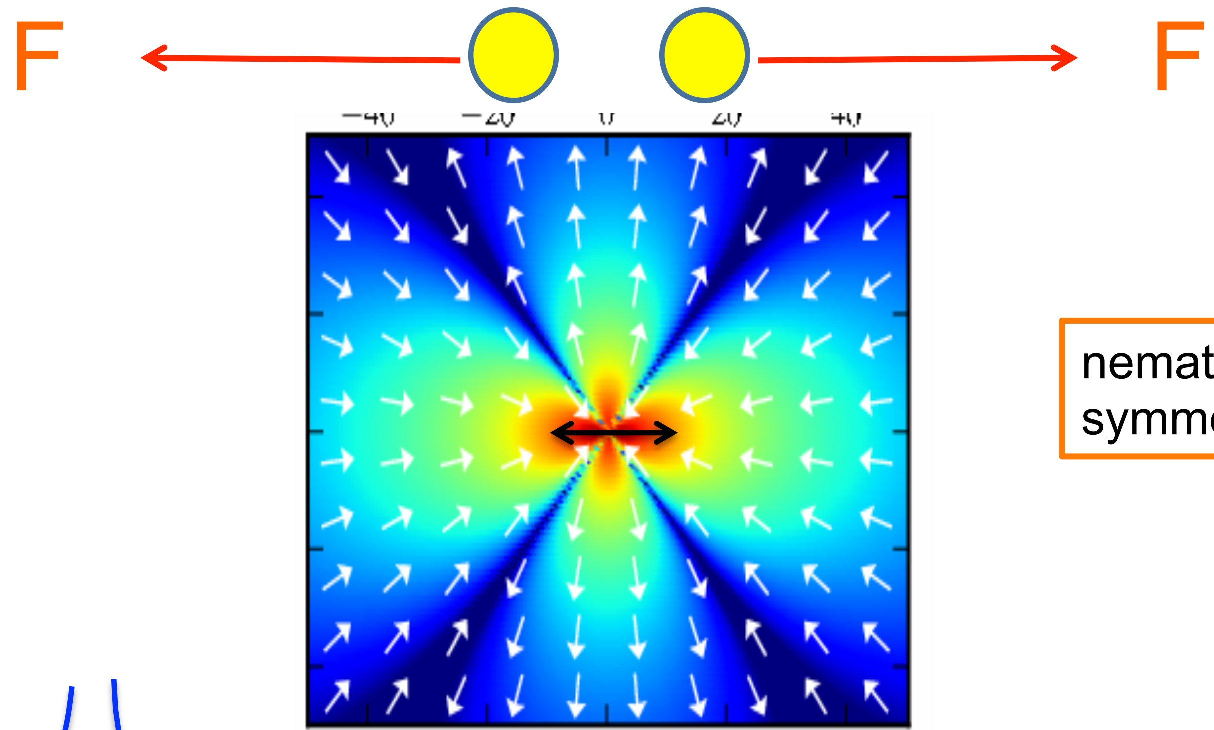
$$\mathbf{v} = \frac{\mathbf{f}}{8\pi\mu} \cdot \left(\frac{\mathbf{I}}{r} + \frac{\mathbf{rr}}{r^3} \right)$$



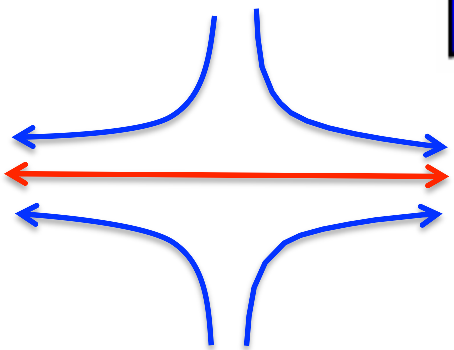


Hydrodynamics of active systems

Swimmers are force free => flow field is dipolar

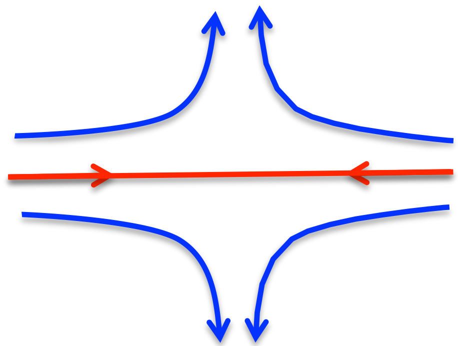


nematic symmetry



extensile

contractile



Continuum equations of active liquid crystal hydrodynamics

$$(\partial_t + u_k \partial_k) Q_{ij} - S_{ij} = \Gamma H_{ij}$$

couples nematic order and shear flows

relaxation to minimum of Landau-de Gennes free energy

$$\rho(\partial_t + u_k \partial_k) u_i = \partial_j \Pi_{ij}$$

viscous + passive + active stress

$$\Pi_{ij}^{active} = -\zeta Q_{ij}$$

1. Active stress => active turbulence

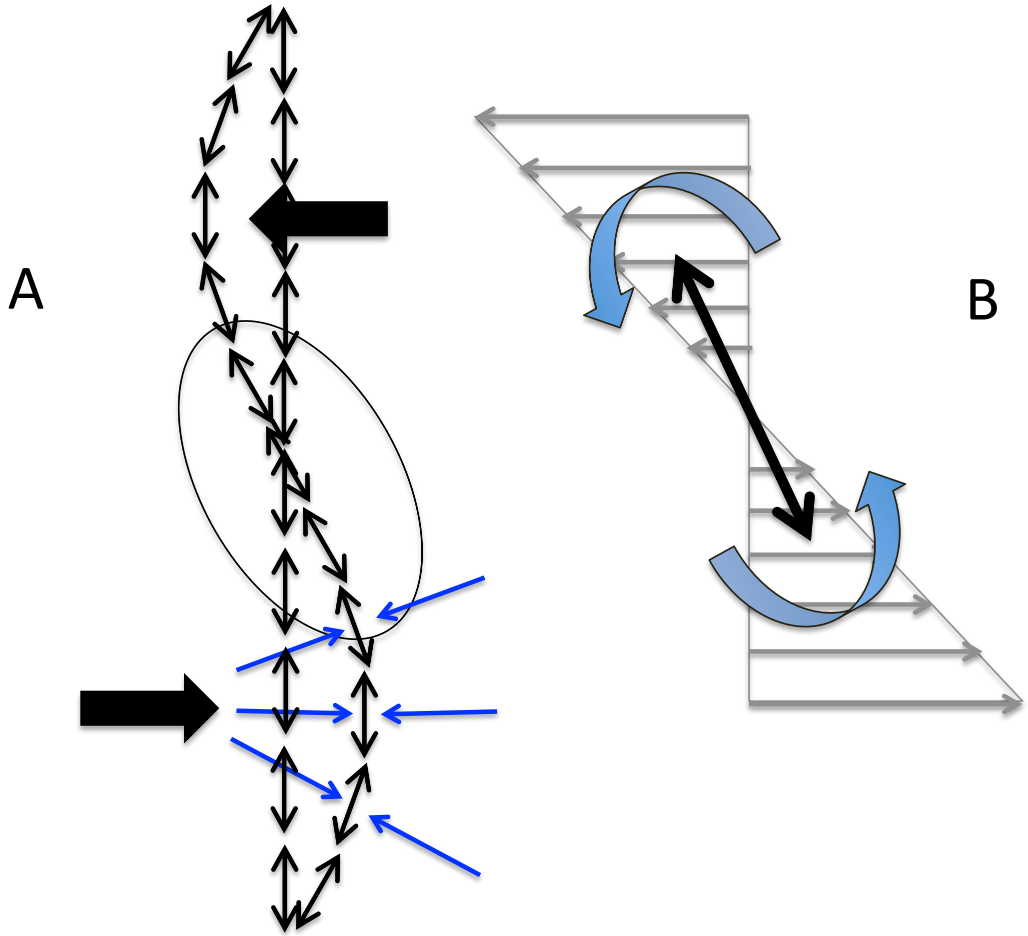
Active contribution to the stress $-\zeta \mathbf{Q}$

Gradients in the magnitude or direction of the order parameter induce flow.

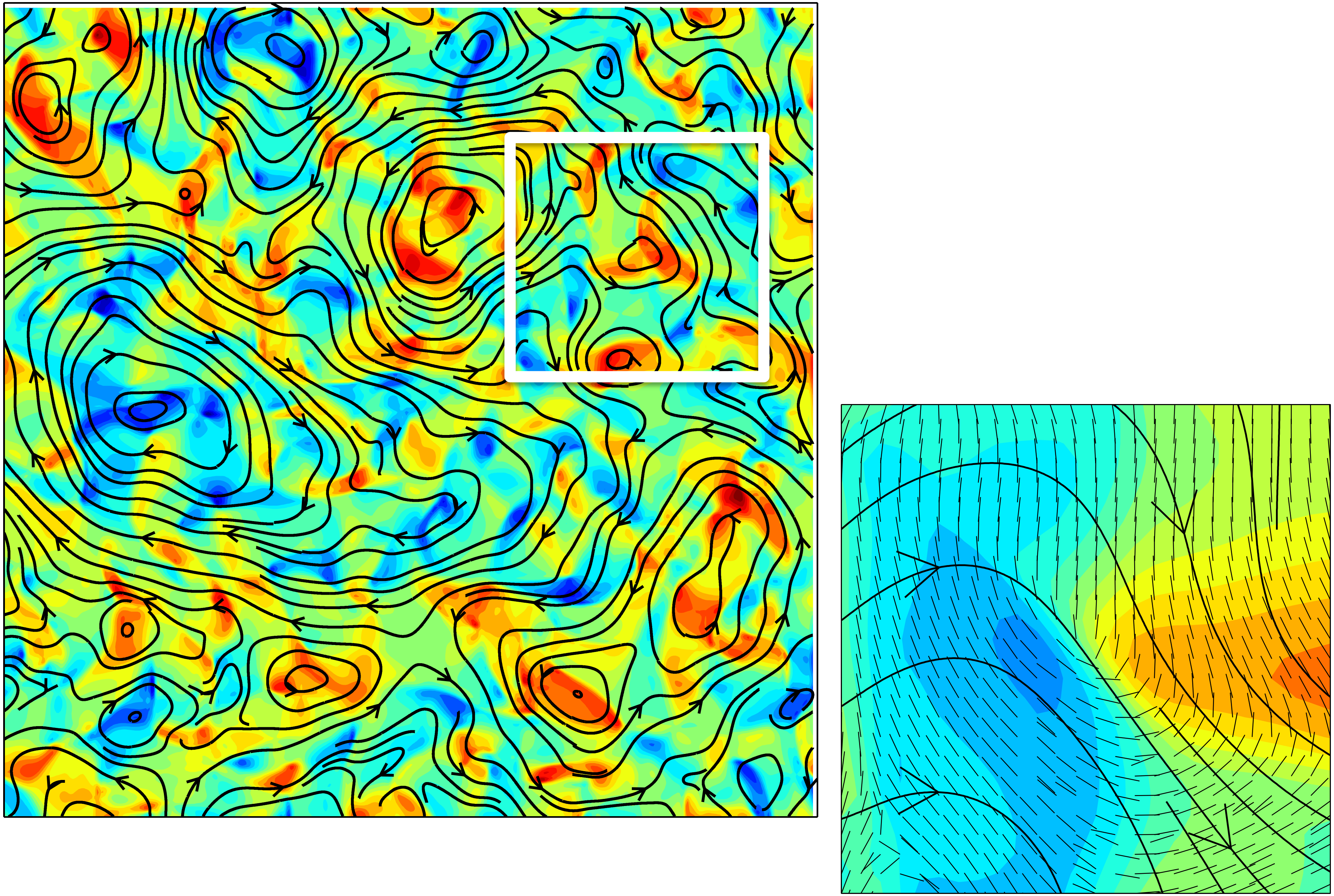
➡ nematic state is unstable to vortical flows

Hatwalne, Ramaswamy, Rao, Simha, PRL 2004

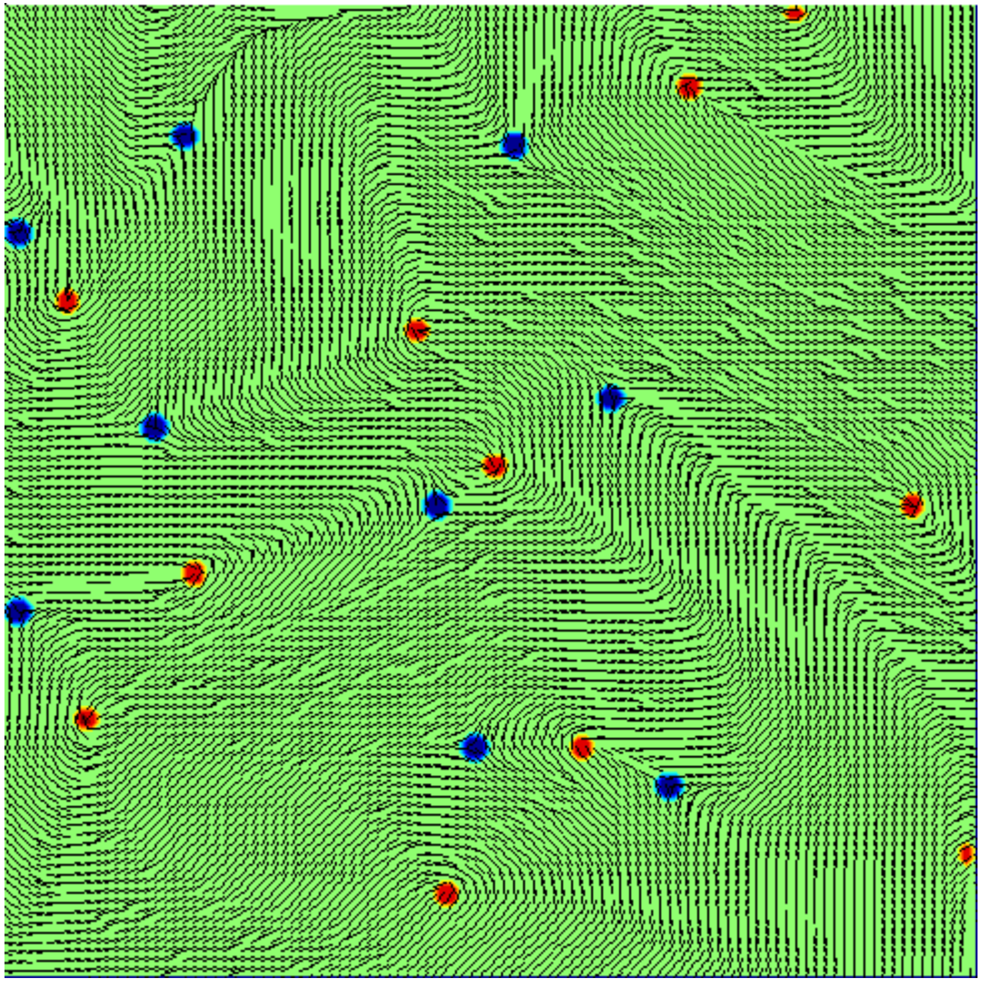
Instabilities in active nematics

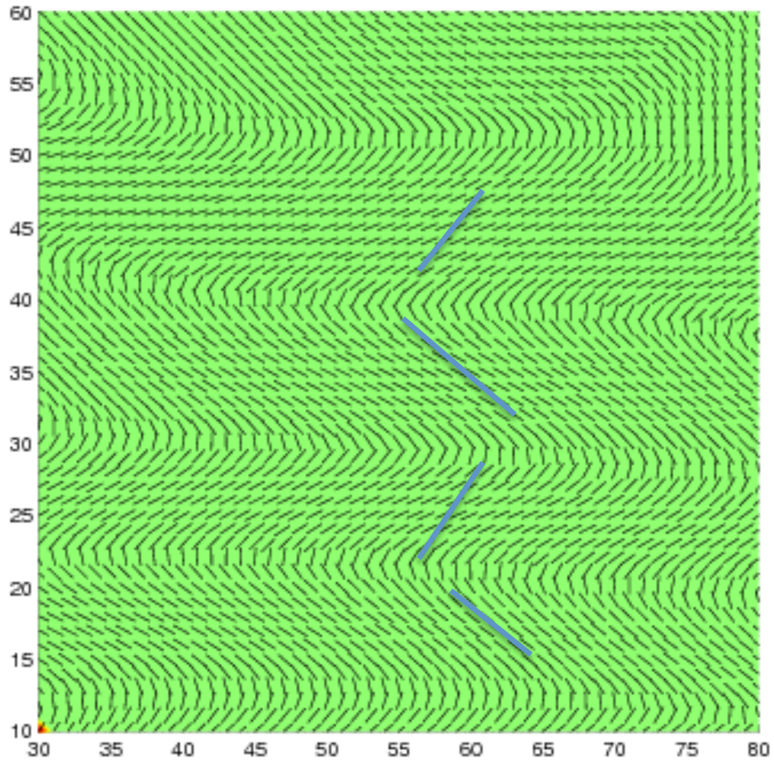


Modelling active turbulence



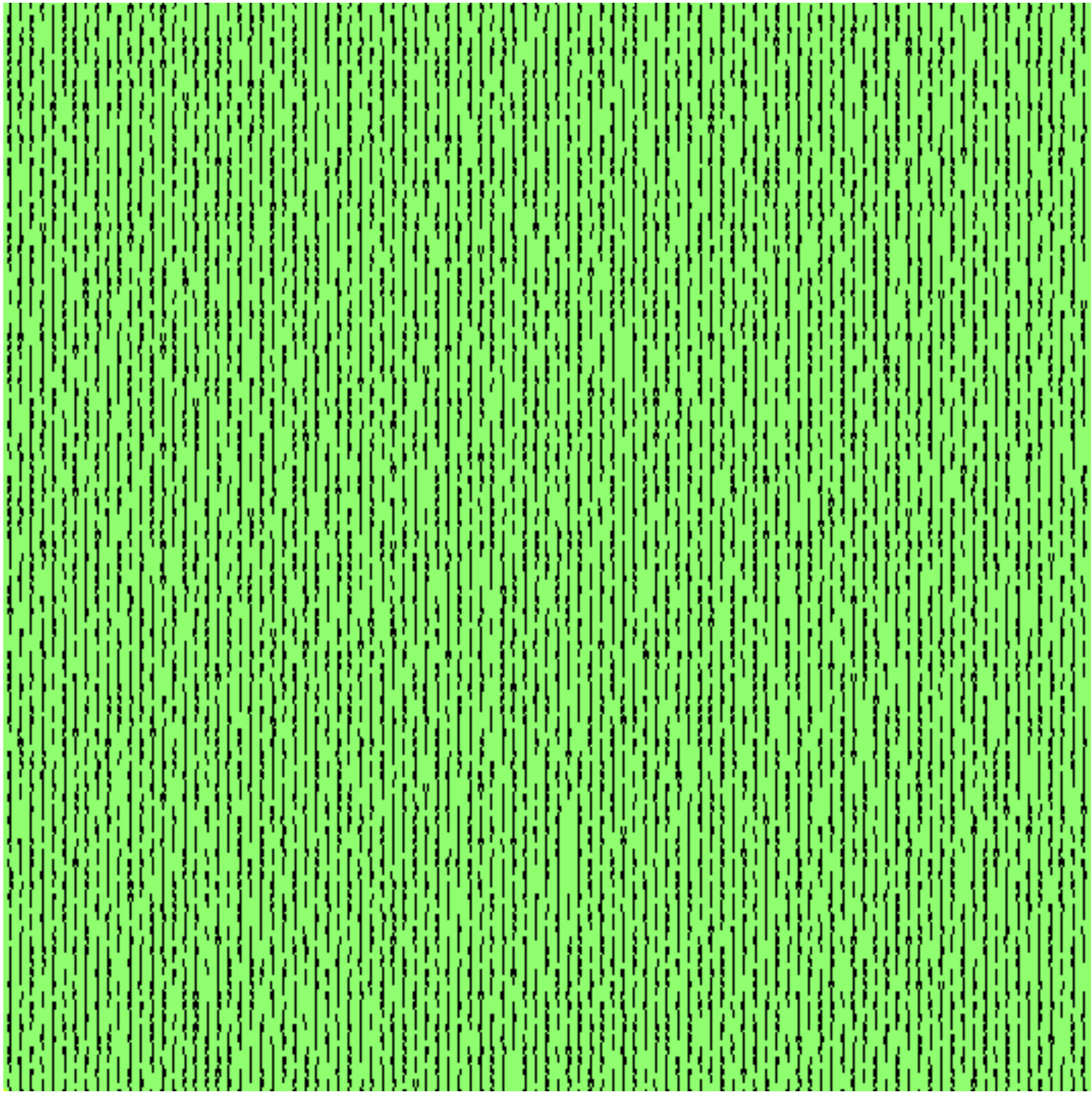
Active turbulence: topological defects are created and destroyed



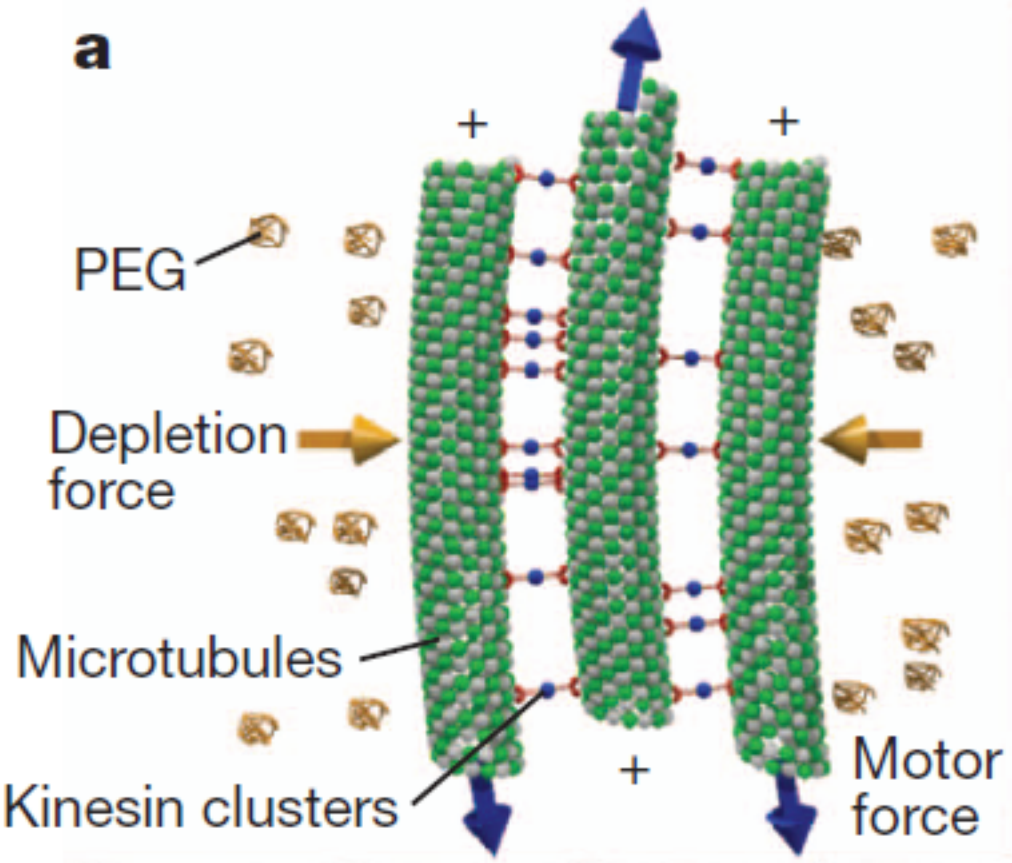


Topological defects form at walls in the director field

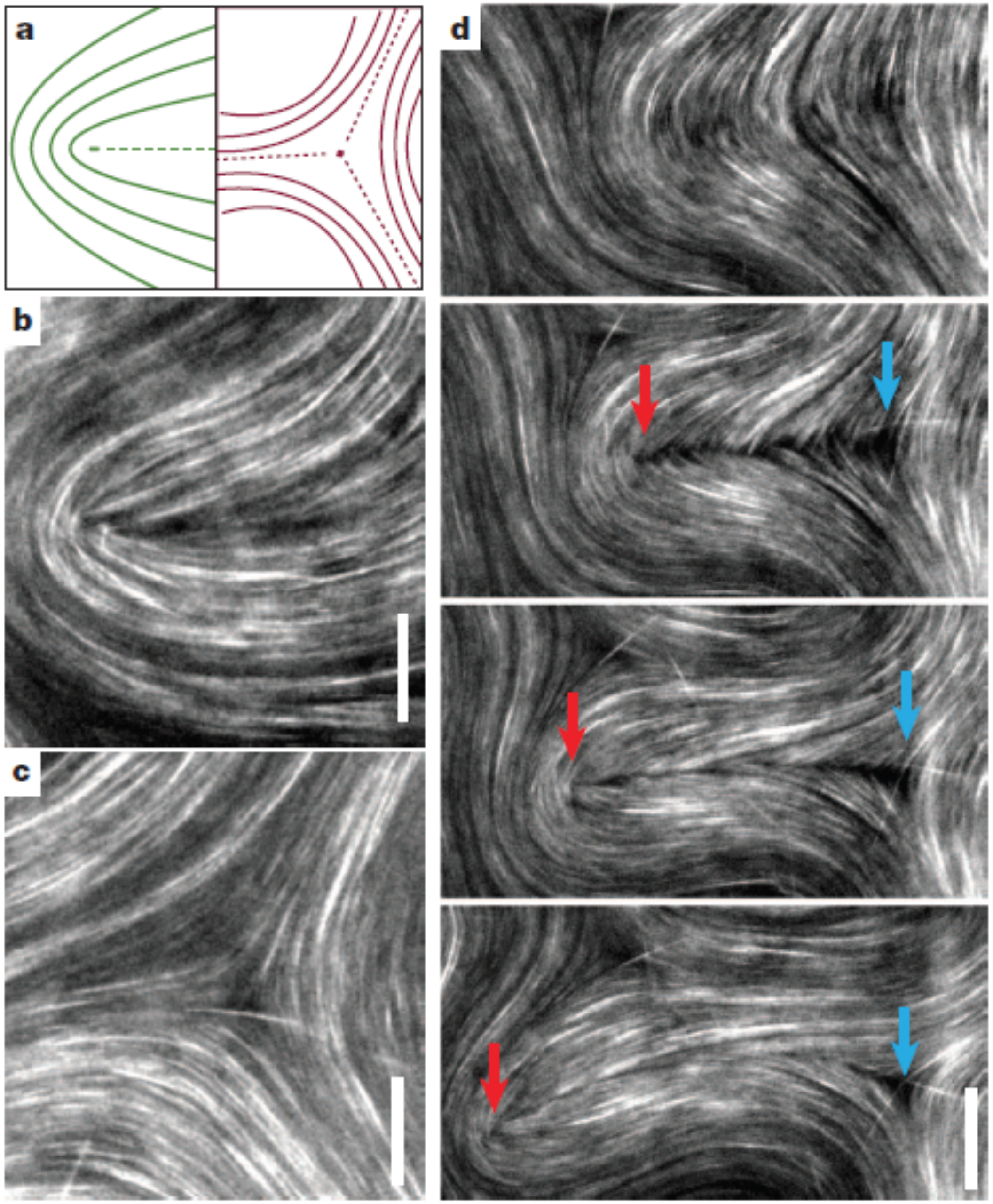
Onset of active turbulence:



Molecular motors

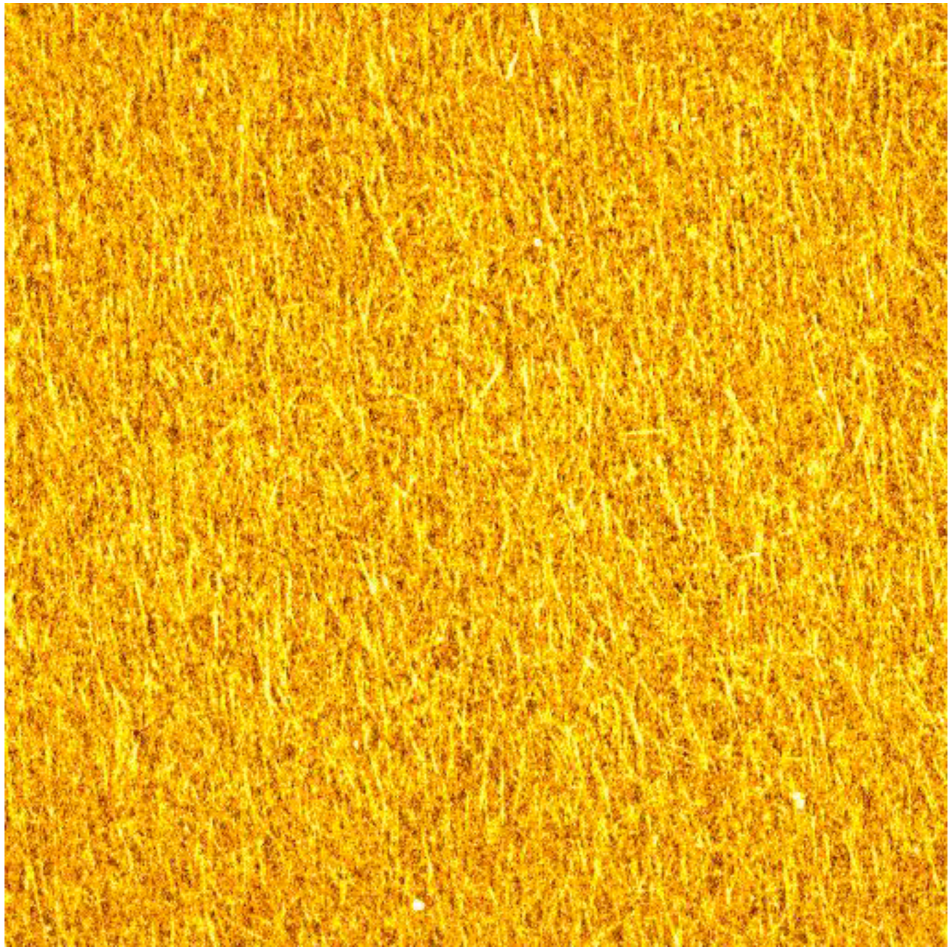


Sanchez, Chen, DeCamp, Heymann, Dogic,
Nature 2012



Sanchez, Chen, DeCamp, Heymann, Dogic, Nature 2012
L. Giomi, M.J. Bowick, Ma Xu, M.C. Marchetti, PRL 110, 228101

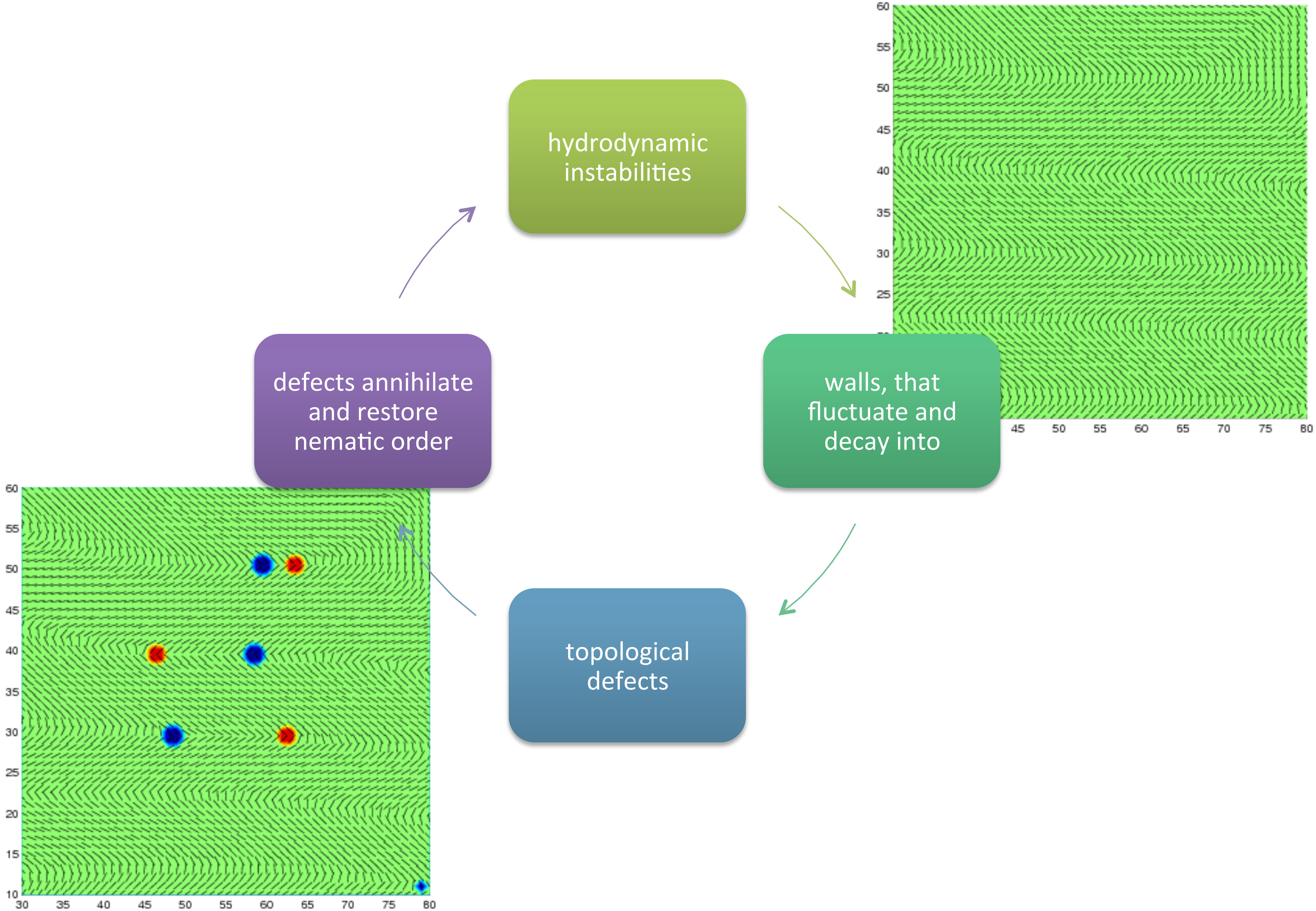
Onset of active turbulence:



Microtubule bundles, D. Chen, Brandeis University

- Stage-1: Walls – driven by hydrodynamic instabilities
- Stage-2: Defects – driven by elasticity and flow

1. Active turbulence



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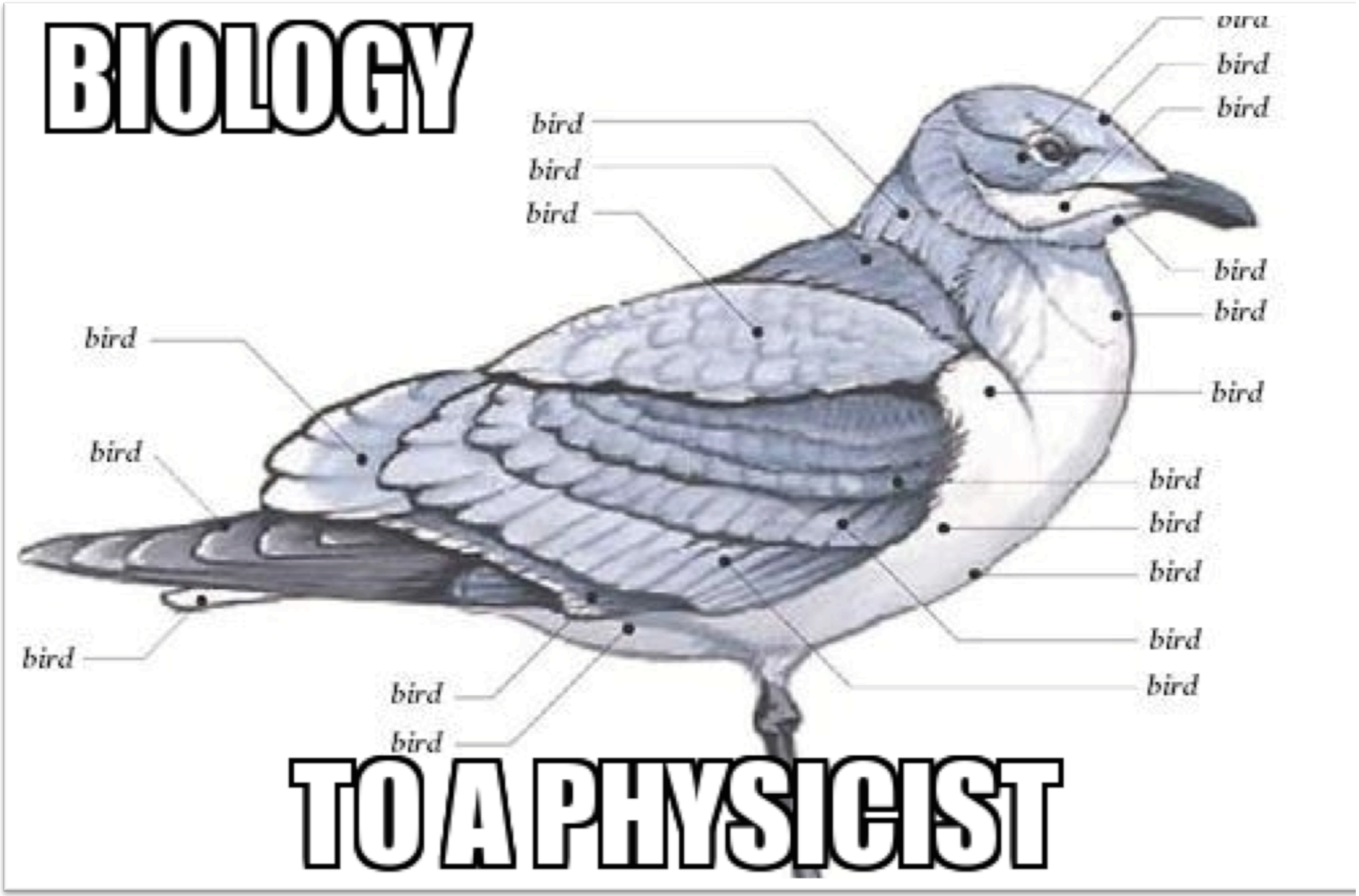
Cell extrusion at topological defects


BIOLOGY
bird
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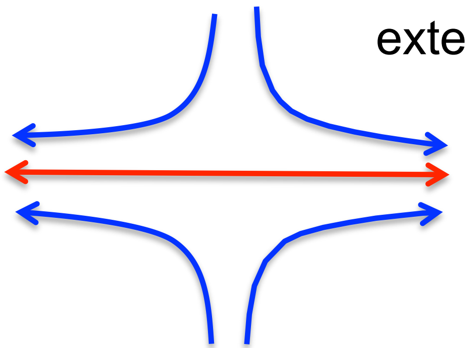
TO A PHYSICIST

Two sources of activity:

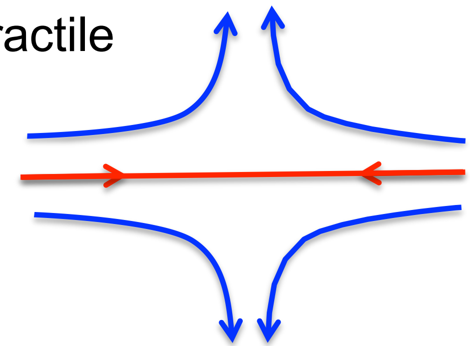
Motility

Cell division

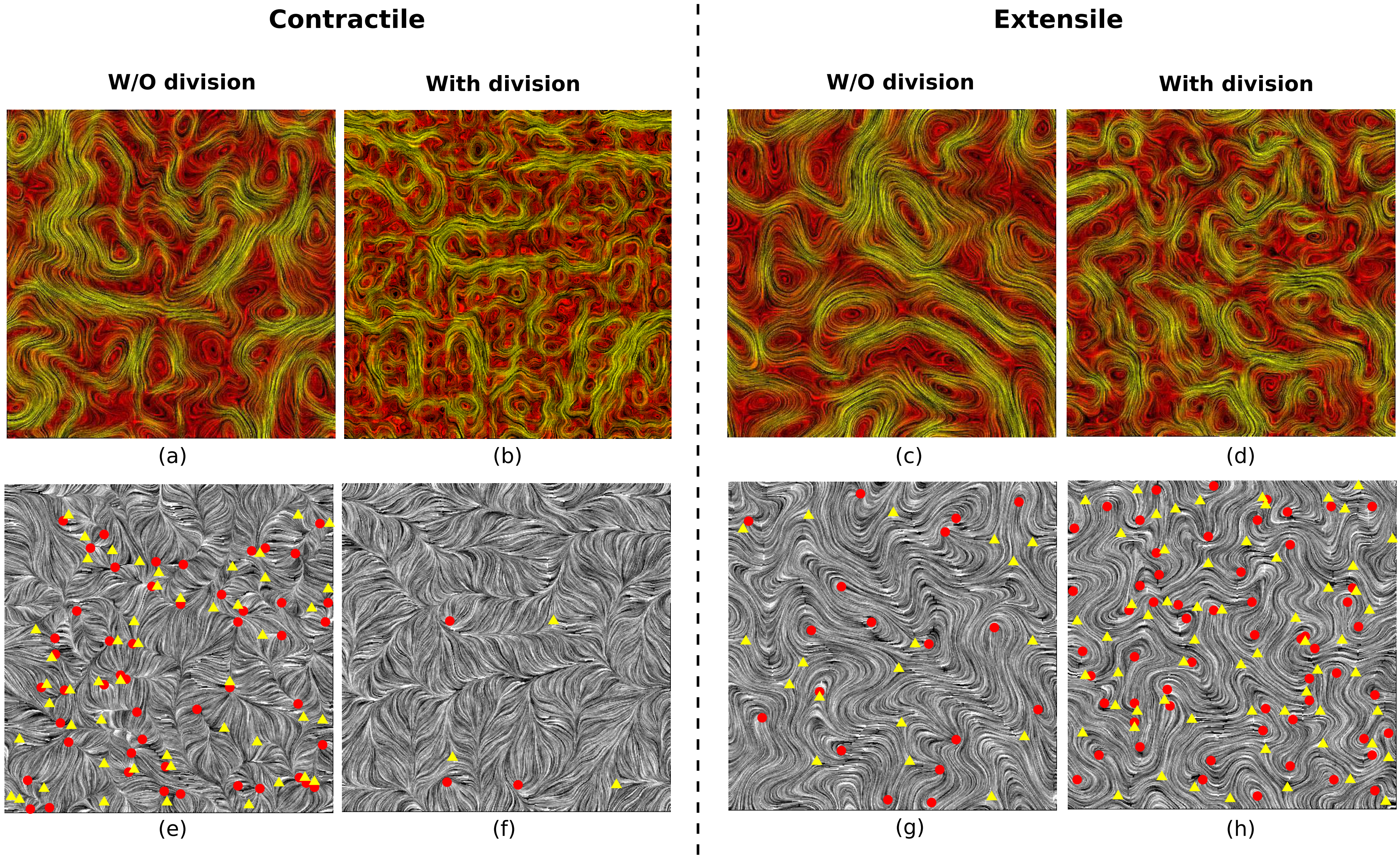


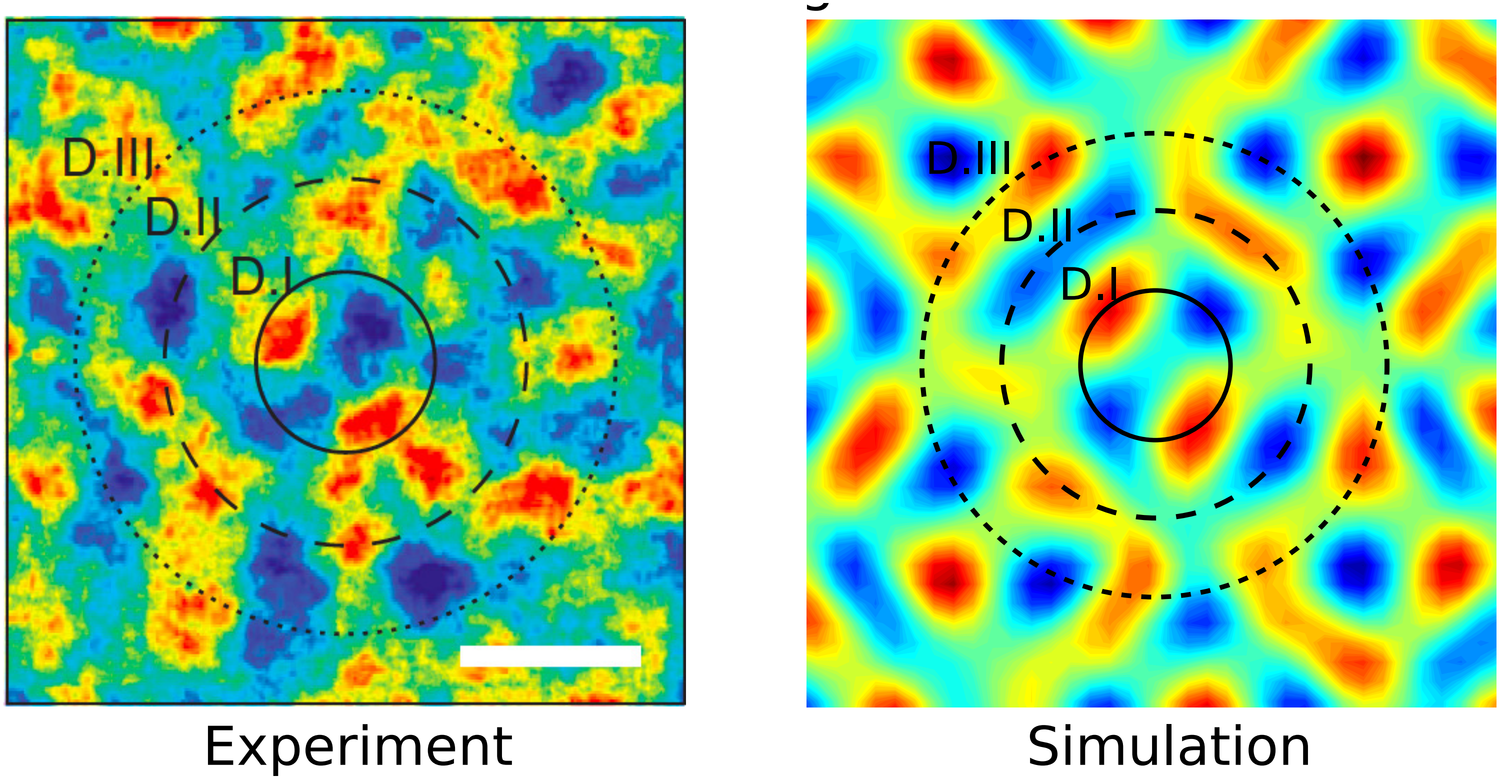
extensile

contractile



2. Division acts as extensile stress

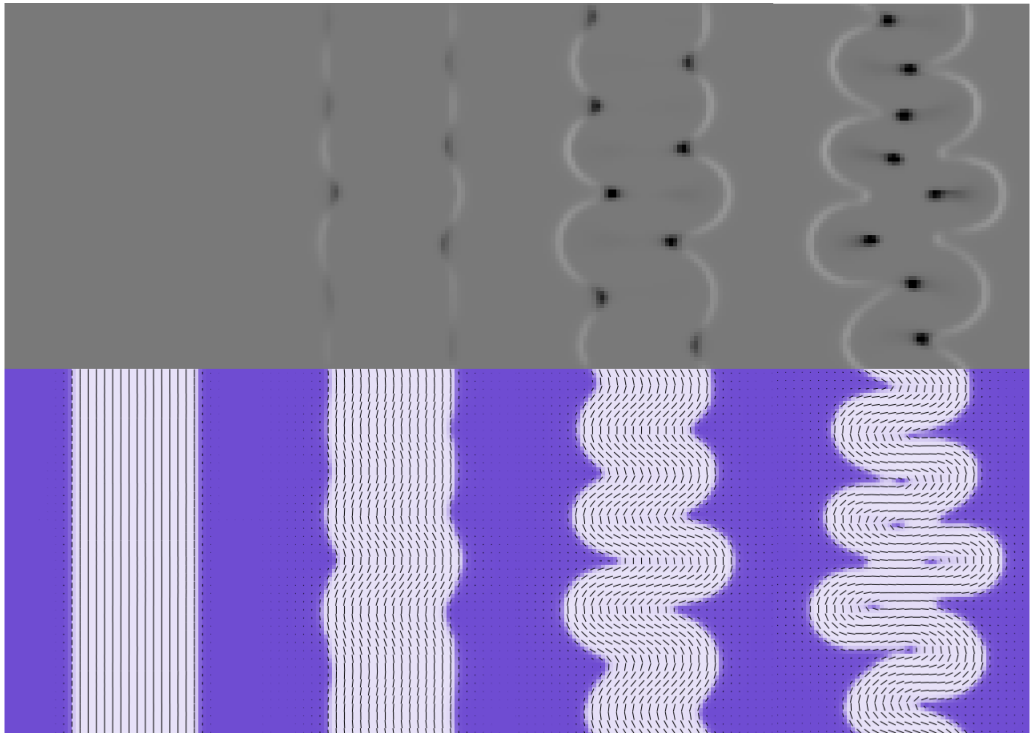




Flow field around dividing epithelial cells

(Contractile + friction)   Lene Oddeschede

The active interface



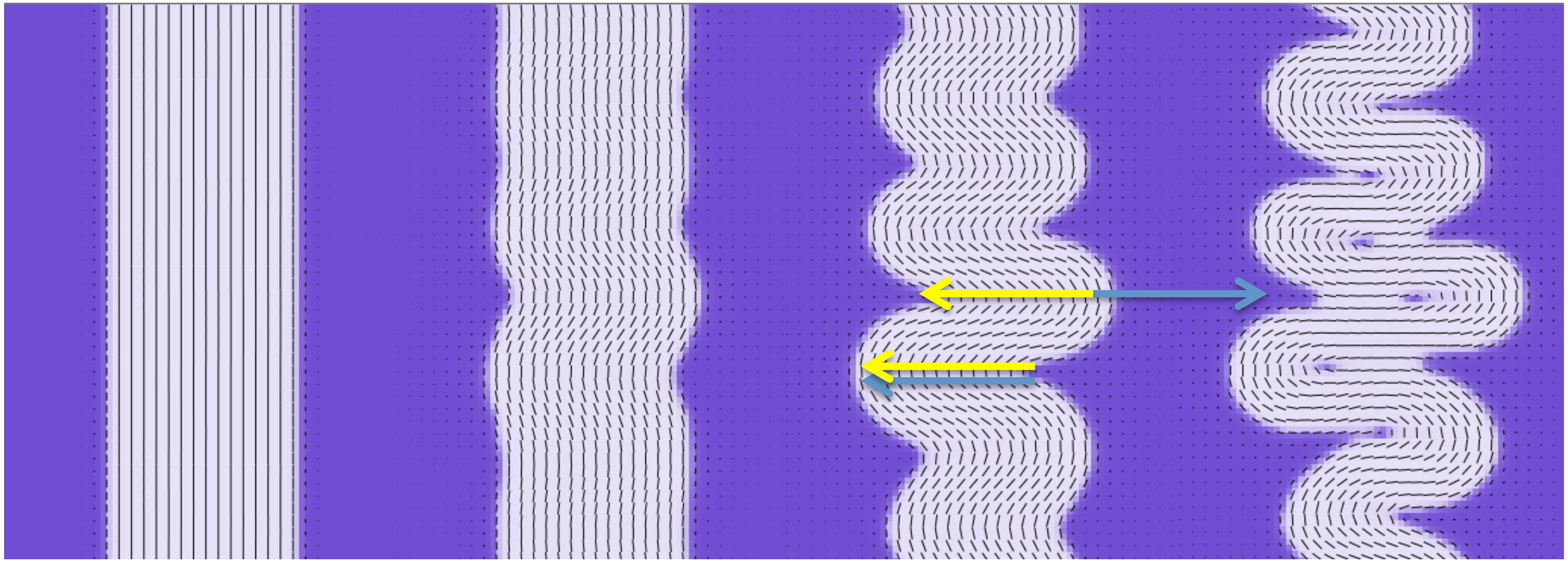
time →

Interface instability is asymmetric

+1/2 topological defects originate from the interface and move into the bulk

Consequence of the active stress

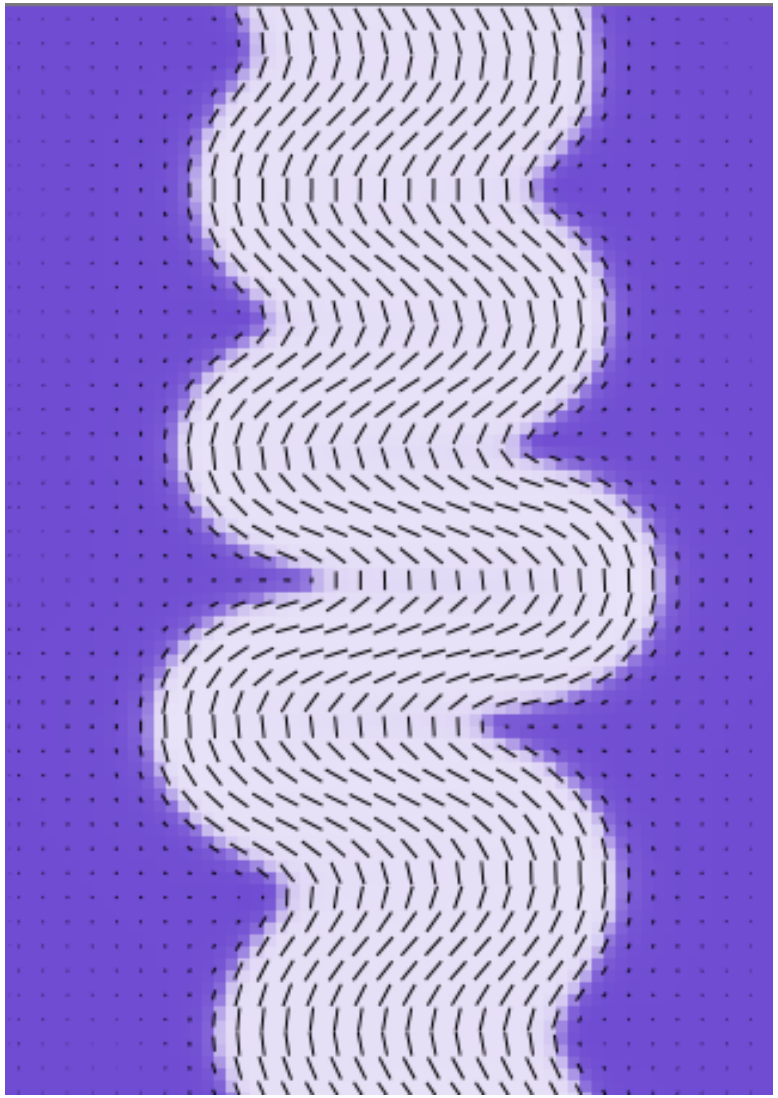
$$\Pi_{ij}^{active} = -\zeta Q_{ij},$$



force due to gradient in direction of order parameter

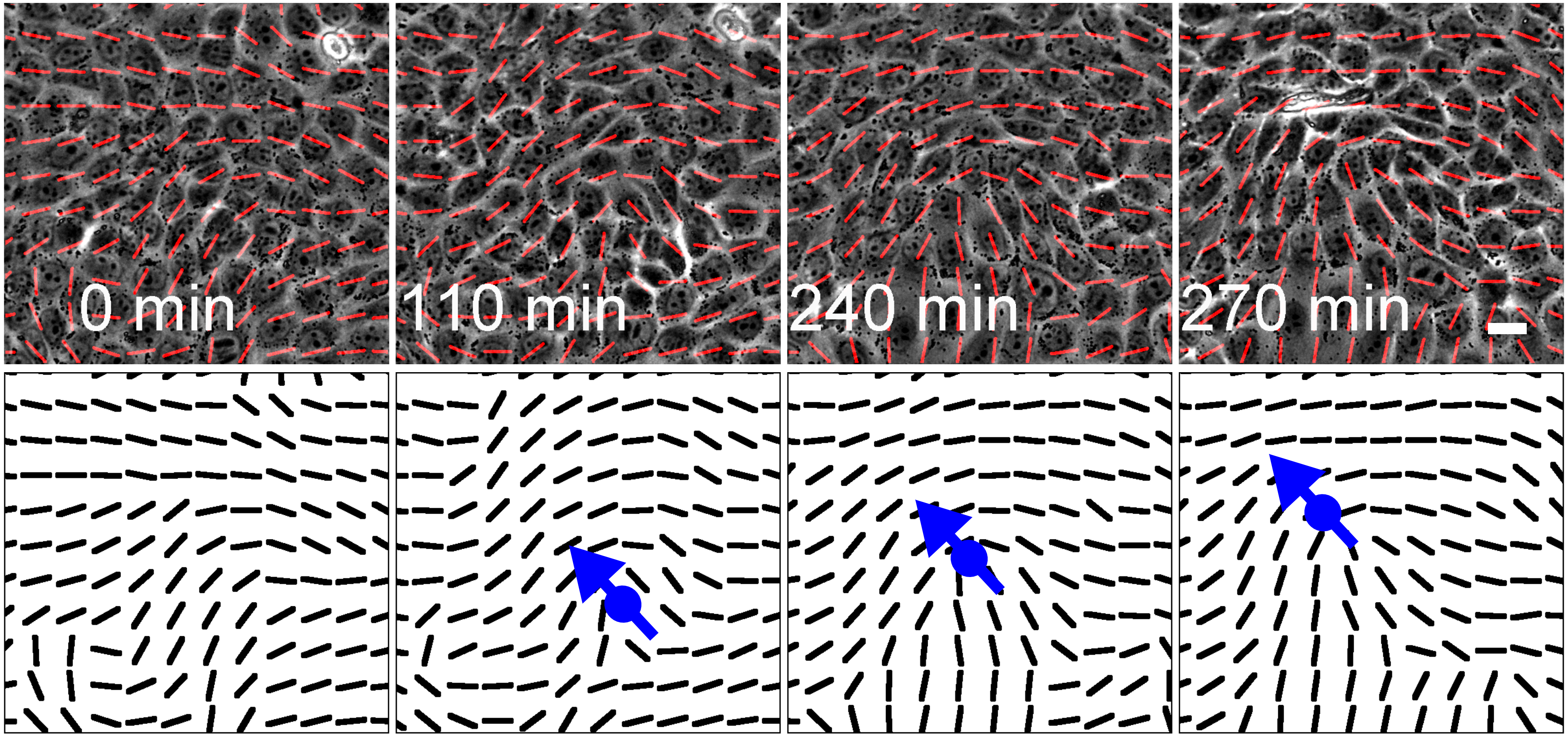
force due to gradient in magnitude of order parameter

Active anchoring



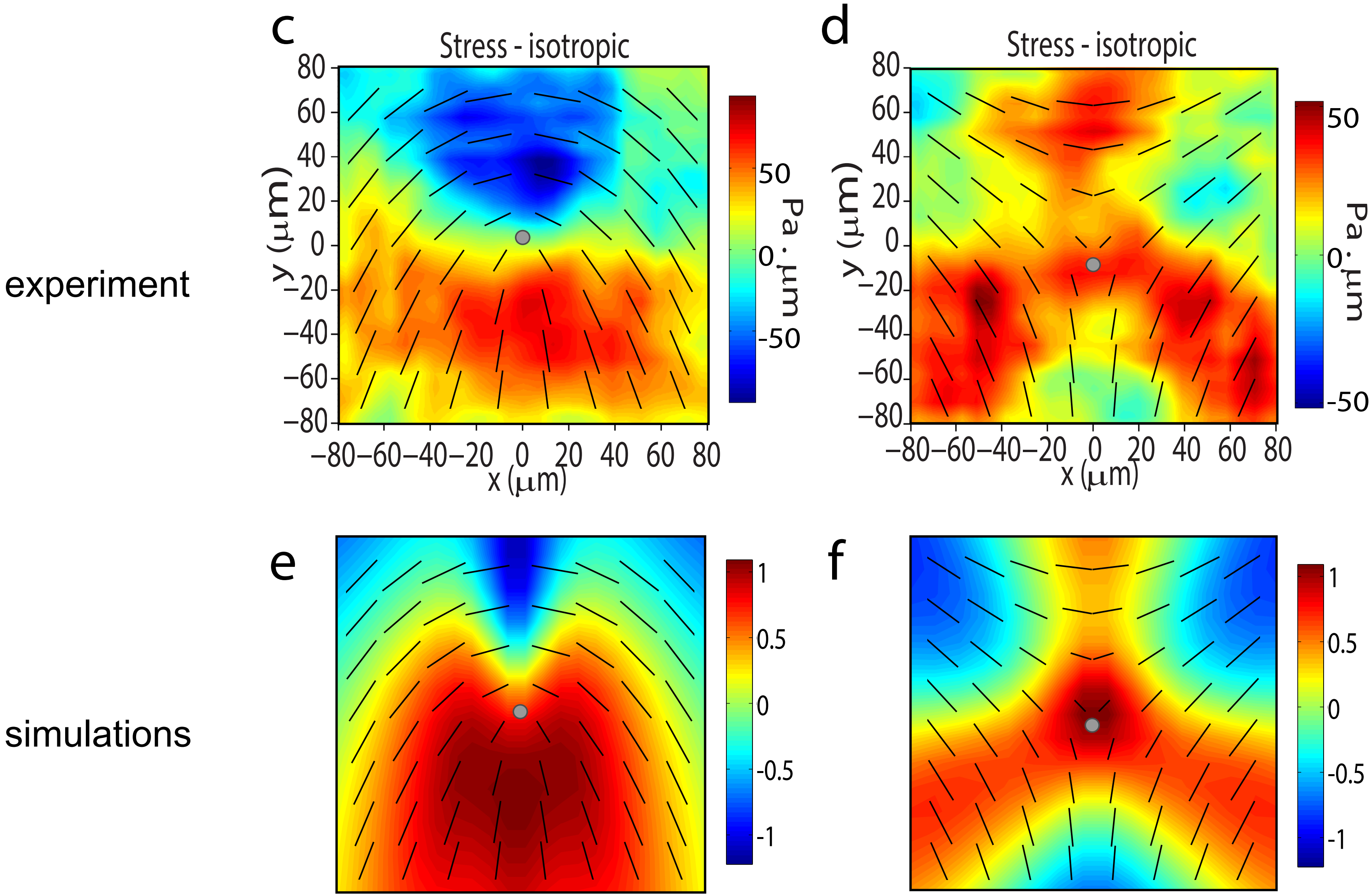
extensile ⇔ planar
contractile ⇔ homeotropic

NB interface shape,
topological defects



Thuan Beng Saw, Amin Doostmohammadi, Vincent Nier, Leyla Kocgozlu,
Sumesh Thampi, Yusuke Toyama, Philippe Marcq,
Chwee Teck Lim, Julia M Yeomans, Benoit Ladoux, submitted

Isotropic stress around a topological defect



ACTIVE NEMATICS

Cell division is a source of activity

Cellular colonies show active anchoring

Cell extrusion occurs preferentially at topological defects

arXiv:1605.00808
Active turbulence in active nematics
Sumesh P. Thampi, Julia M. Yeomans
European Journal: Special Topics

arXiv:1603.00194
The Hydrodynamics of Active Systems
Julia M Yeomans
Lecture Notes, 2015 Enrico Fermi Summer School on Soft Matter Self-Assembly, Vienna