Swimmers 3: many swimmers

Julia Yeomans
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Ramin Golestanian

SP Thampi, R Golestanian, JM Yeomans
Instabilities and topological defects in active nematics, EPL **105** (2014) ARTN 18001
Velocity correlations in an active nematic, Phys Rev Lett **111**, 118101 (2013)

Dense active systems – lots of examples

Liquid crystals & topological defects

Microtubules and kinesin experiments

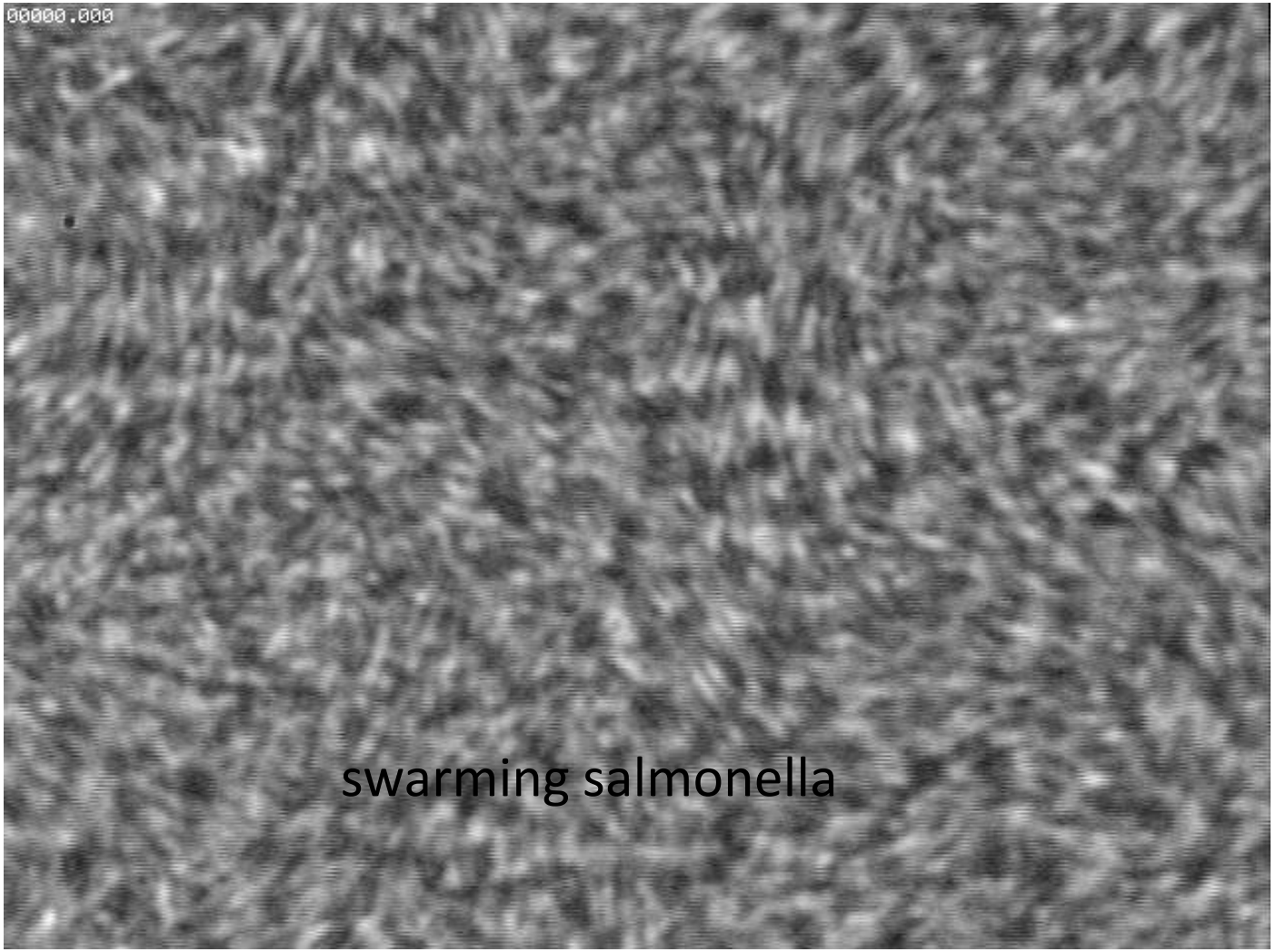
Continuum theory for active nematics: the active stress and instabilities

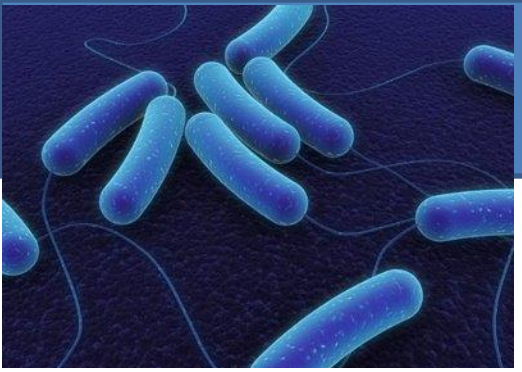
Simulation results and comparison to the experiments

Explanation in terms of defect dynamics?

Bacteria

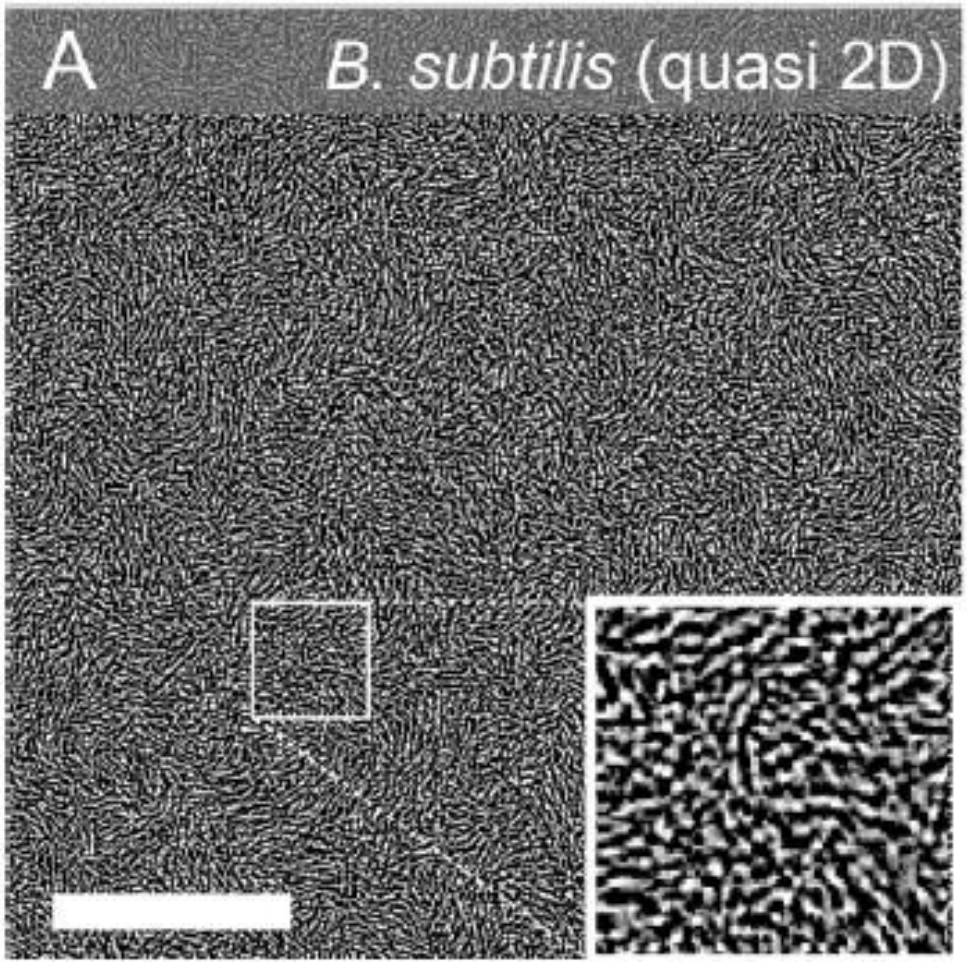
http://webmac.rowland.org/labs/bacteria/index.html

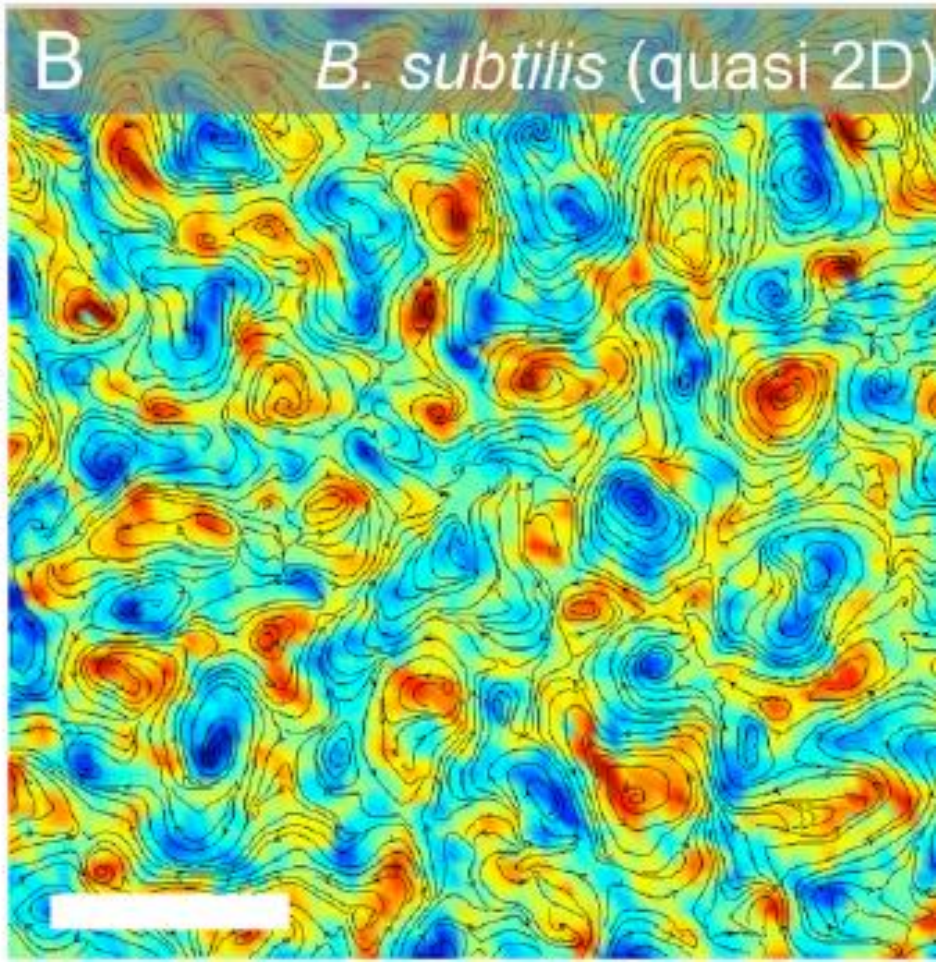




Bacteria

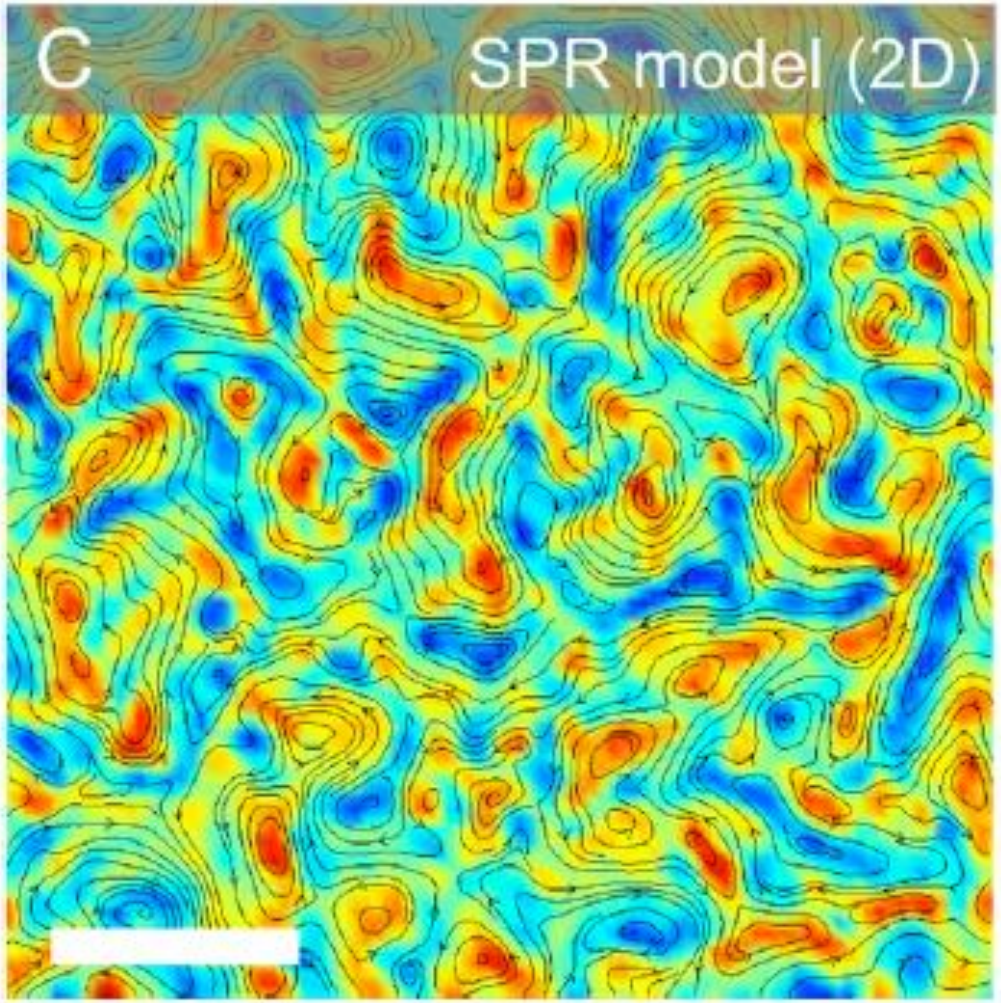
vorticity



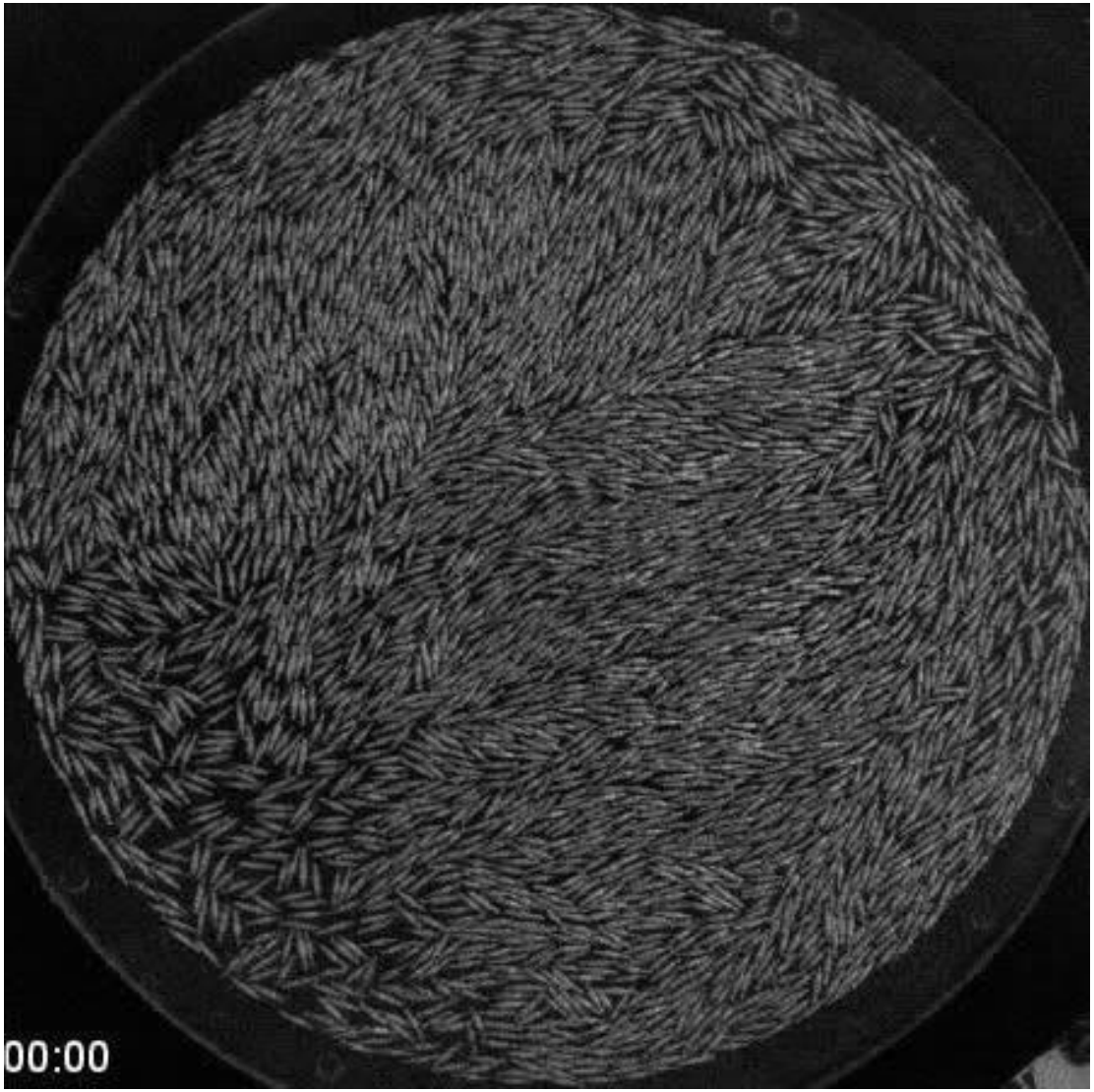


Wensink, Dunkel, Heidenreich, Dresher, Goldstein, Lowen, Yeomans, PNAS 2012

Discrete simulations

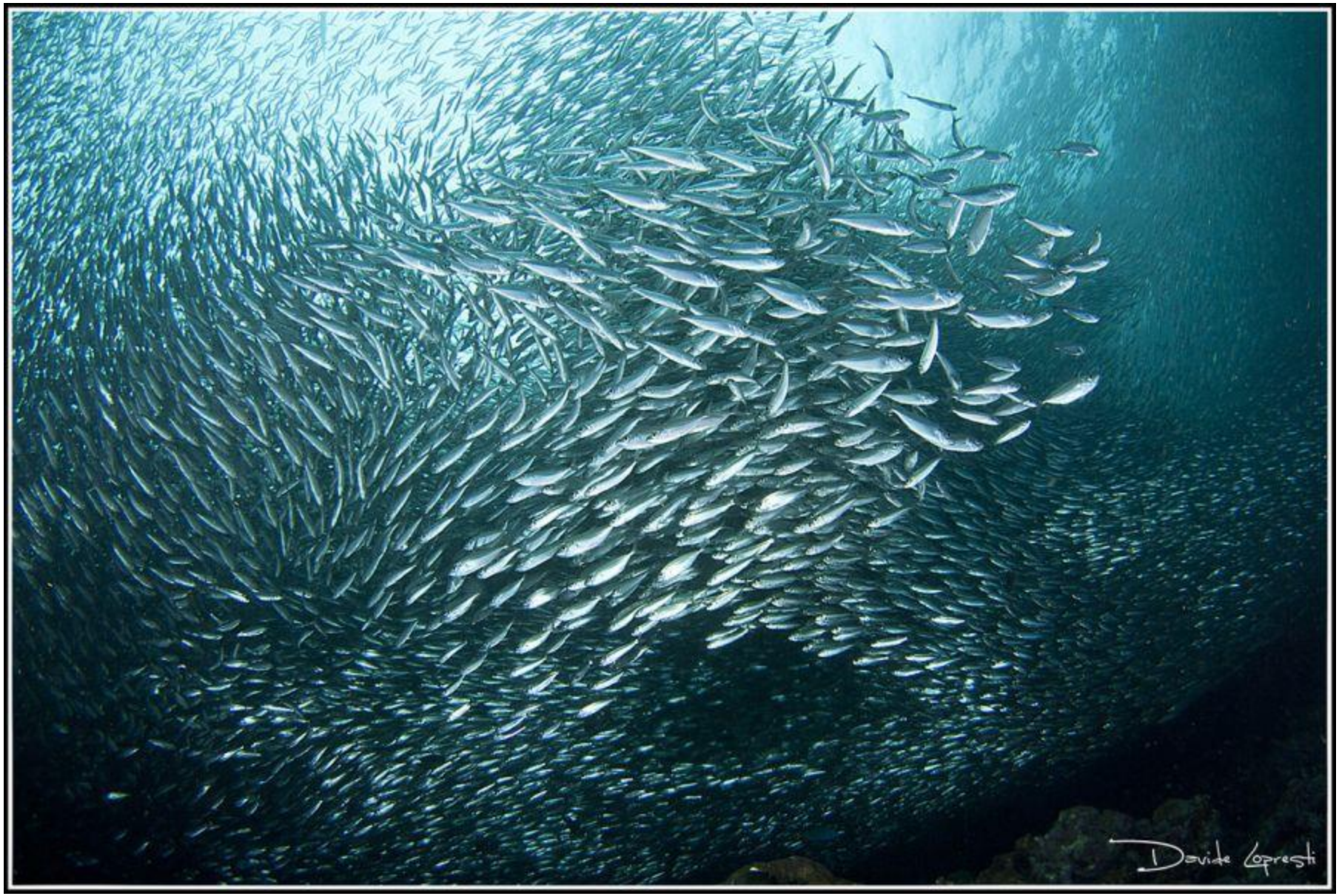


Driven grains

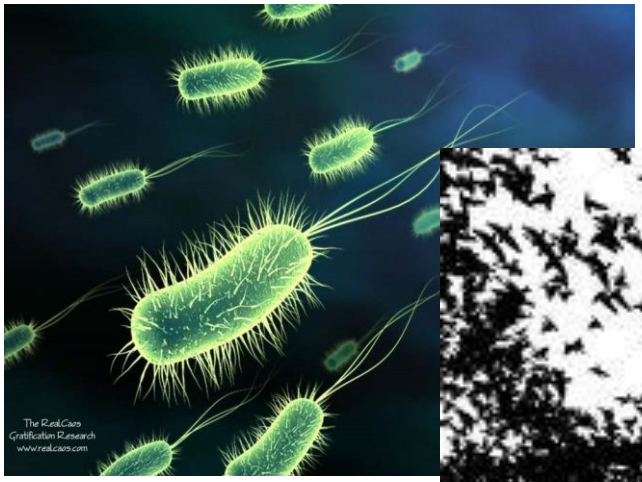


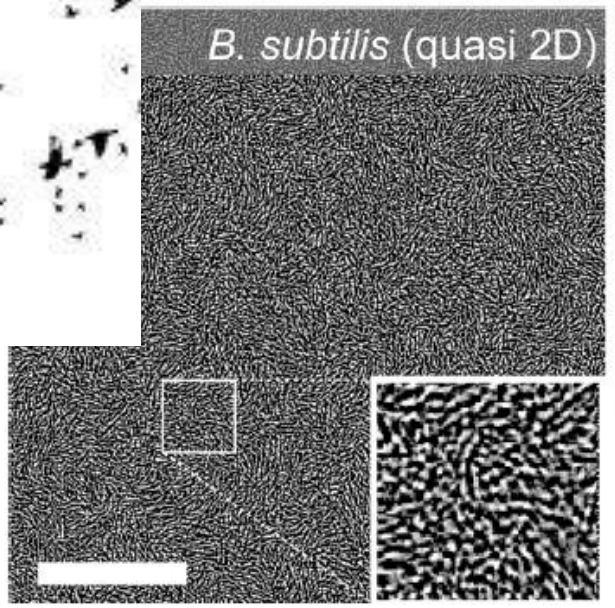
V Narayan, S Ramaswamy, N Menon - Science, 2007

Fish?

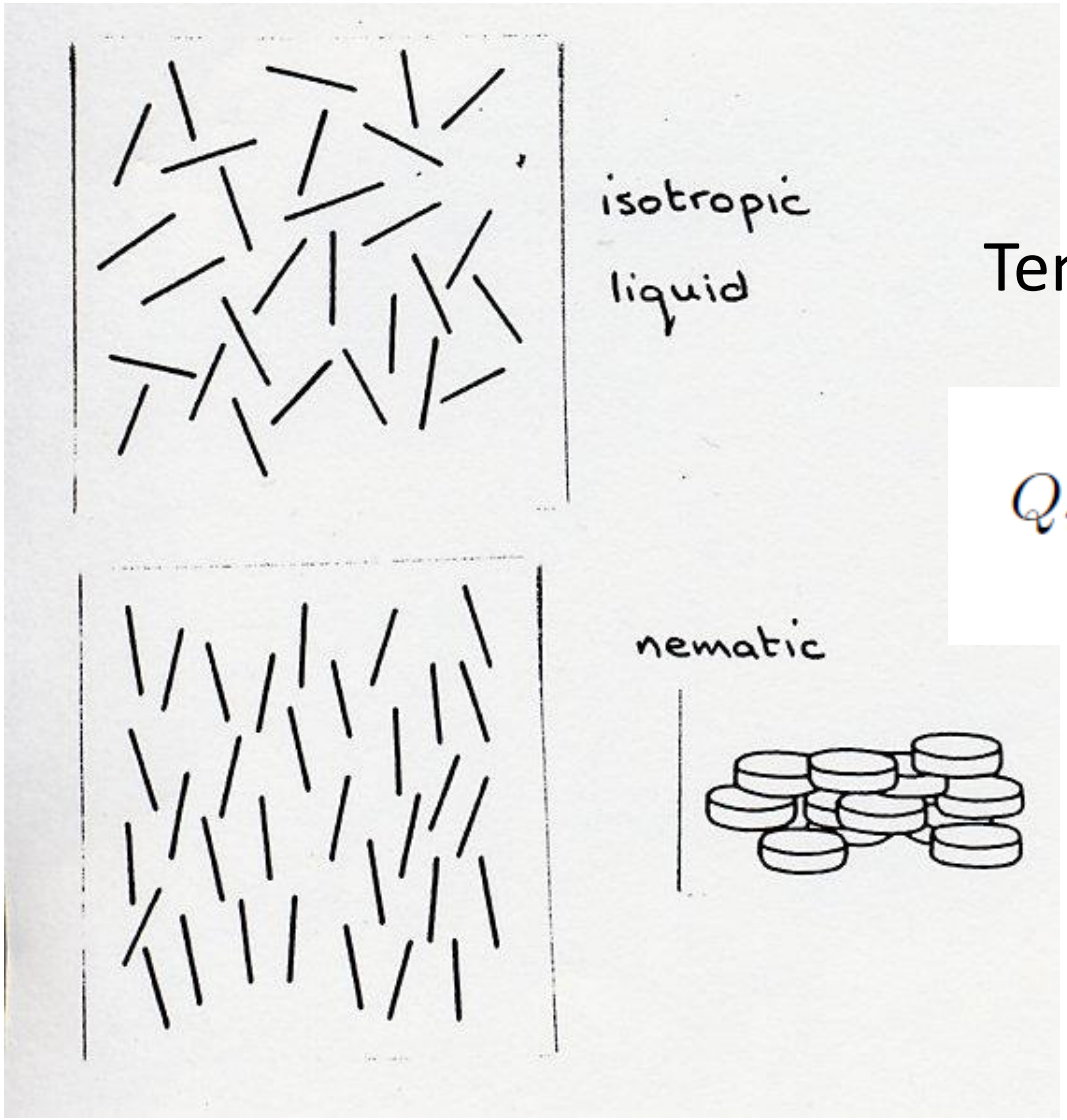


concentration





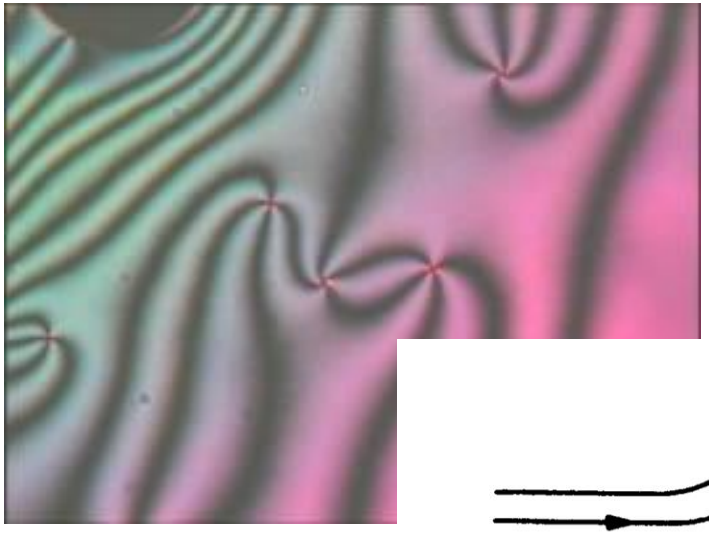
Liquid crystals

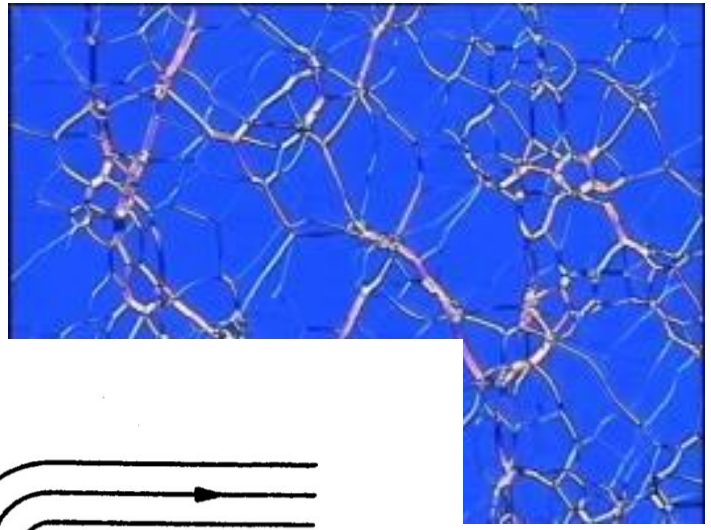


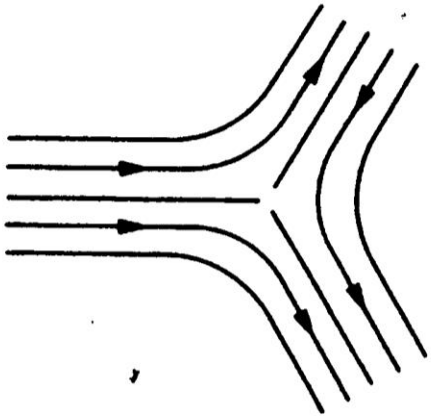
Tensor order parameter Q

$$Q_{ij} = \langle \frac{1}{2}(3n_i n_j - \delta_{ij}) \rangle$$

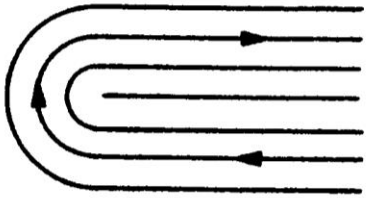
Topological defects







$m = -\frac{1}{2}$



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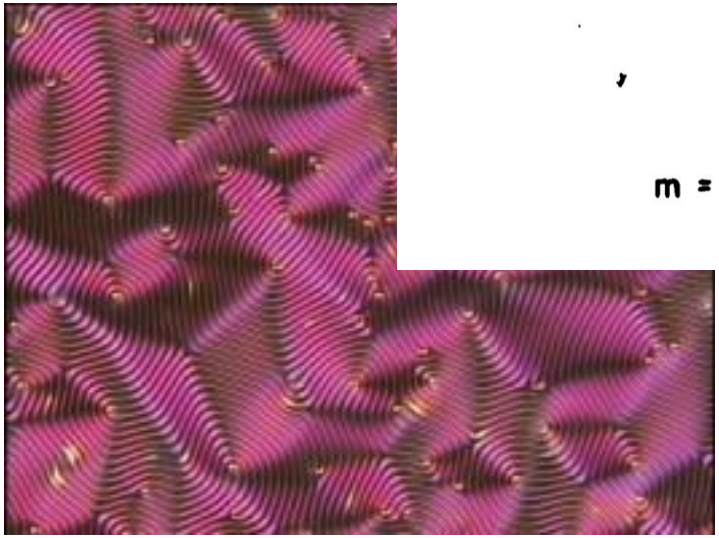
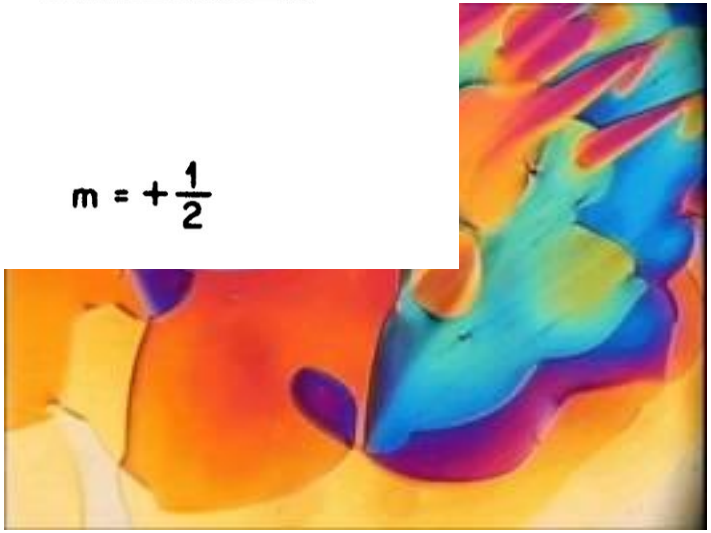
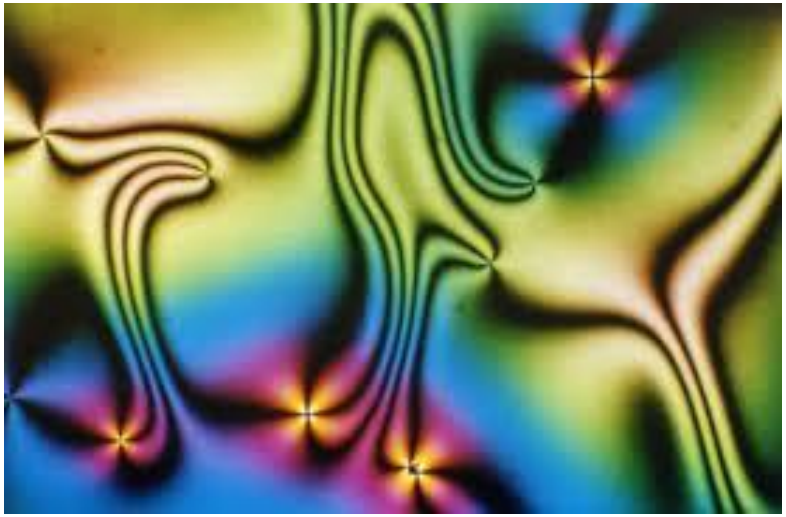
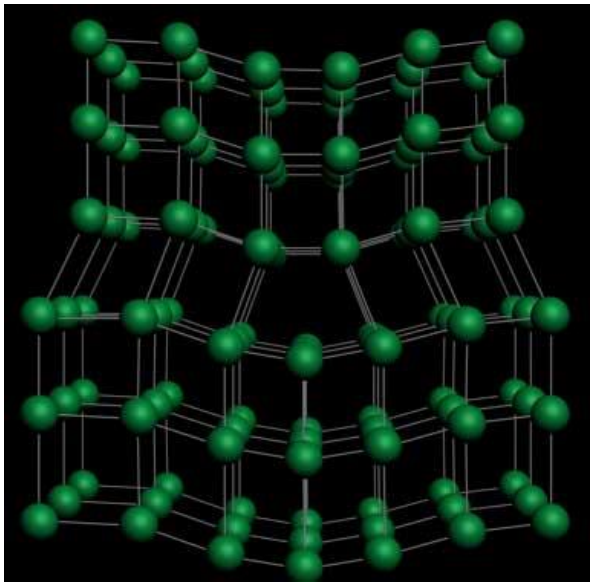


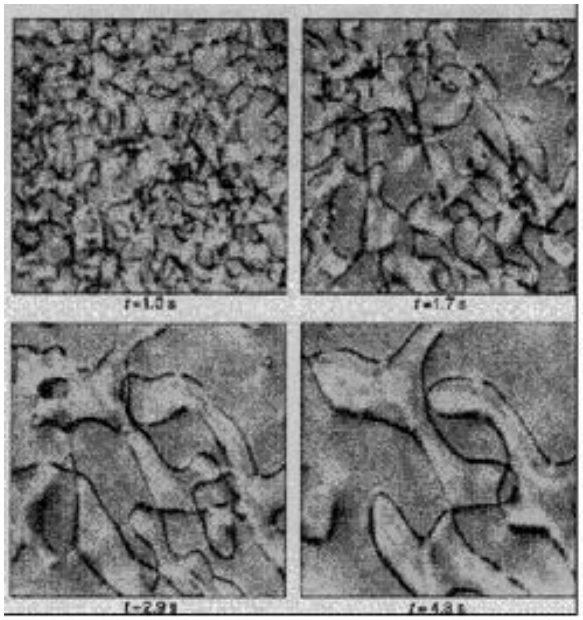




liquid crystals



crystal dislocations

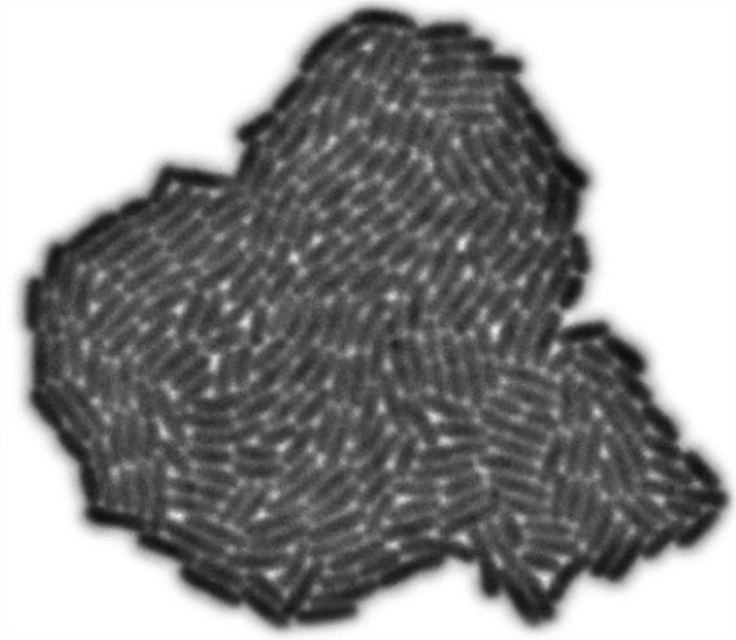


cosmic strings in the early universe

magnetic monopoles in spin ice

topological insulators

quantum vortex in a superfluid



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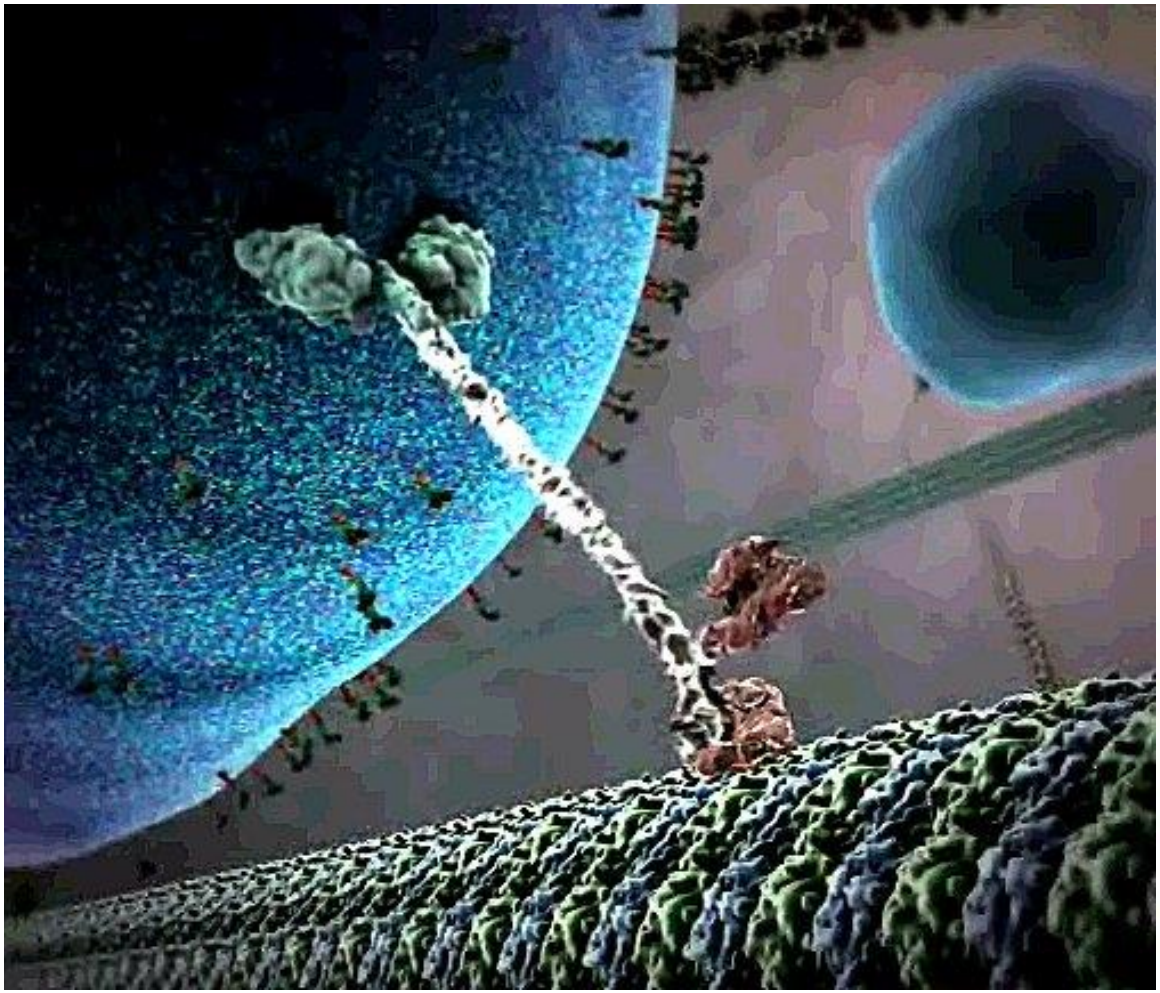
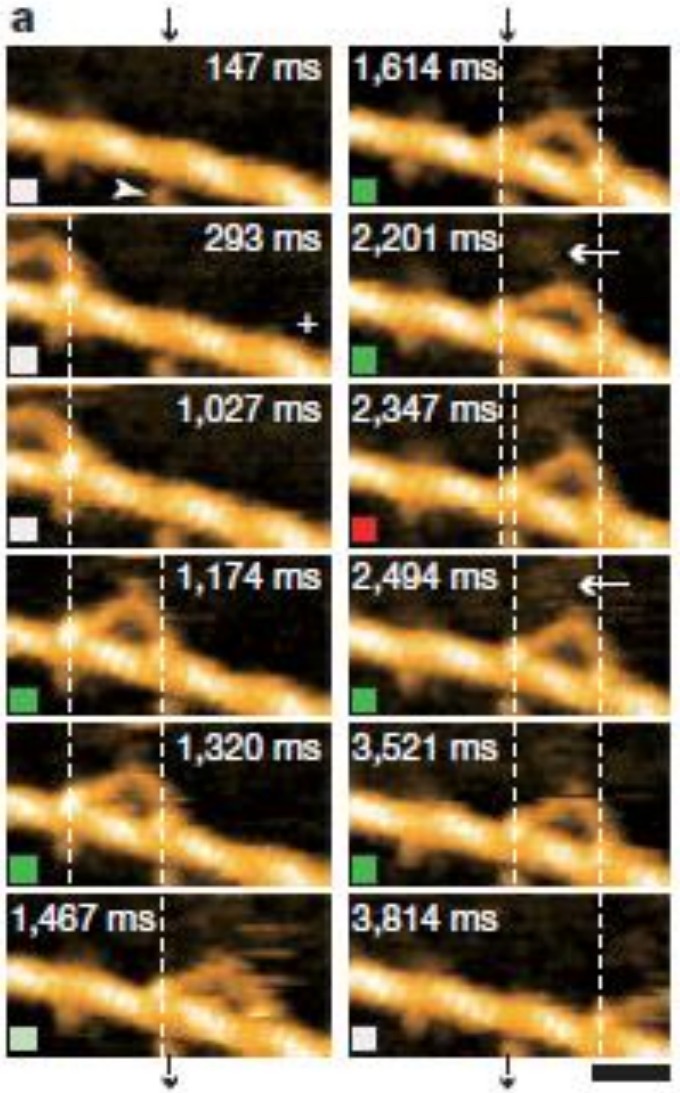
Molecular motors

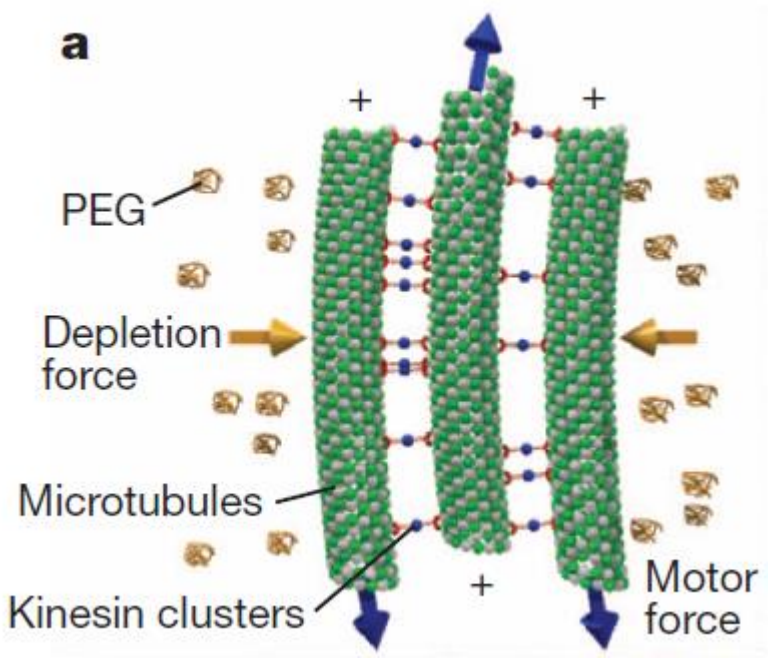


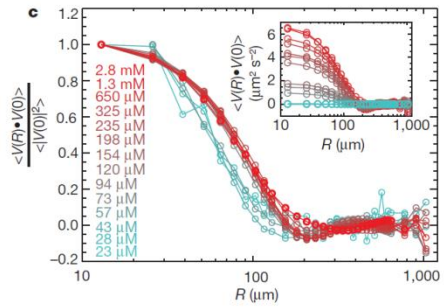
YouTube –Inner Life of a Cell

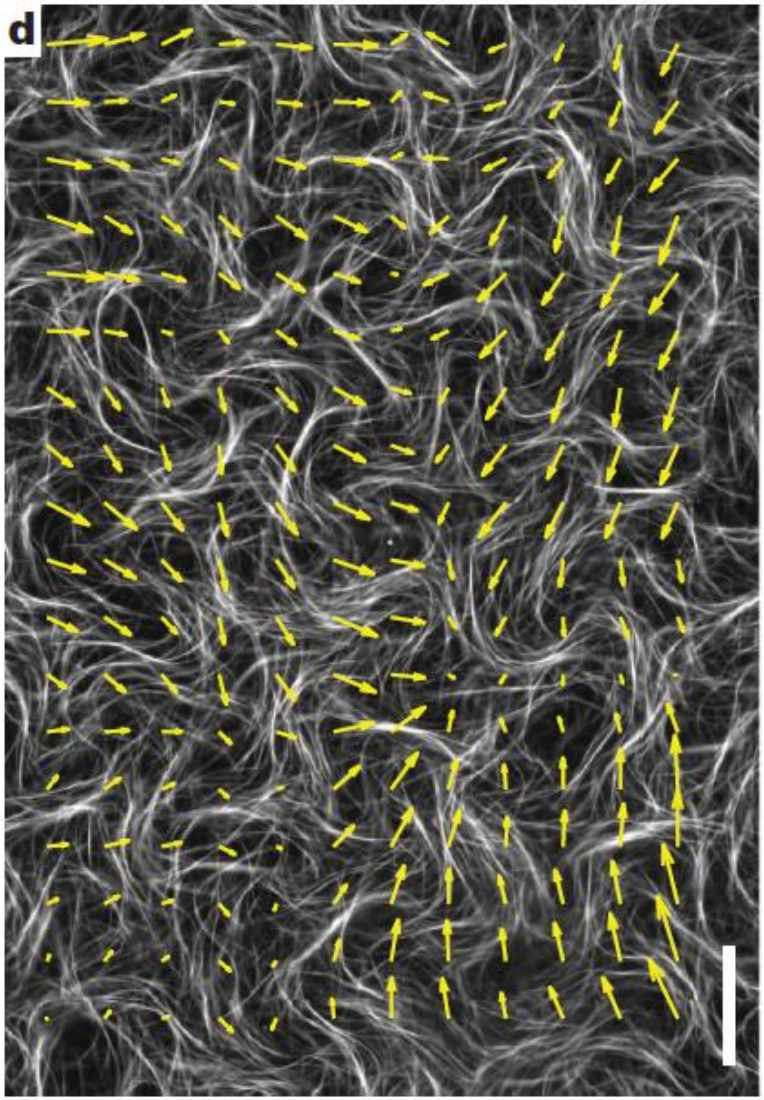


Kodera, Yamamoto, Ishikawa, Ando

Molecular motors

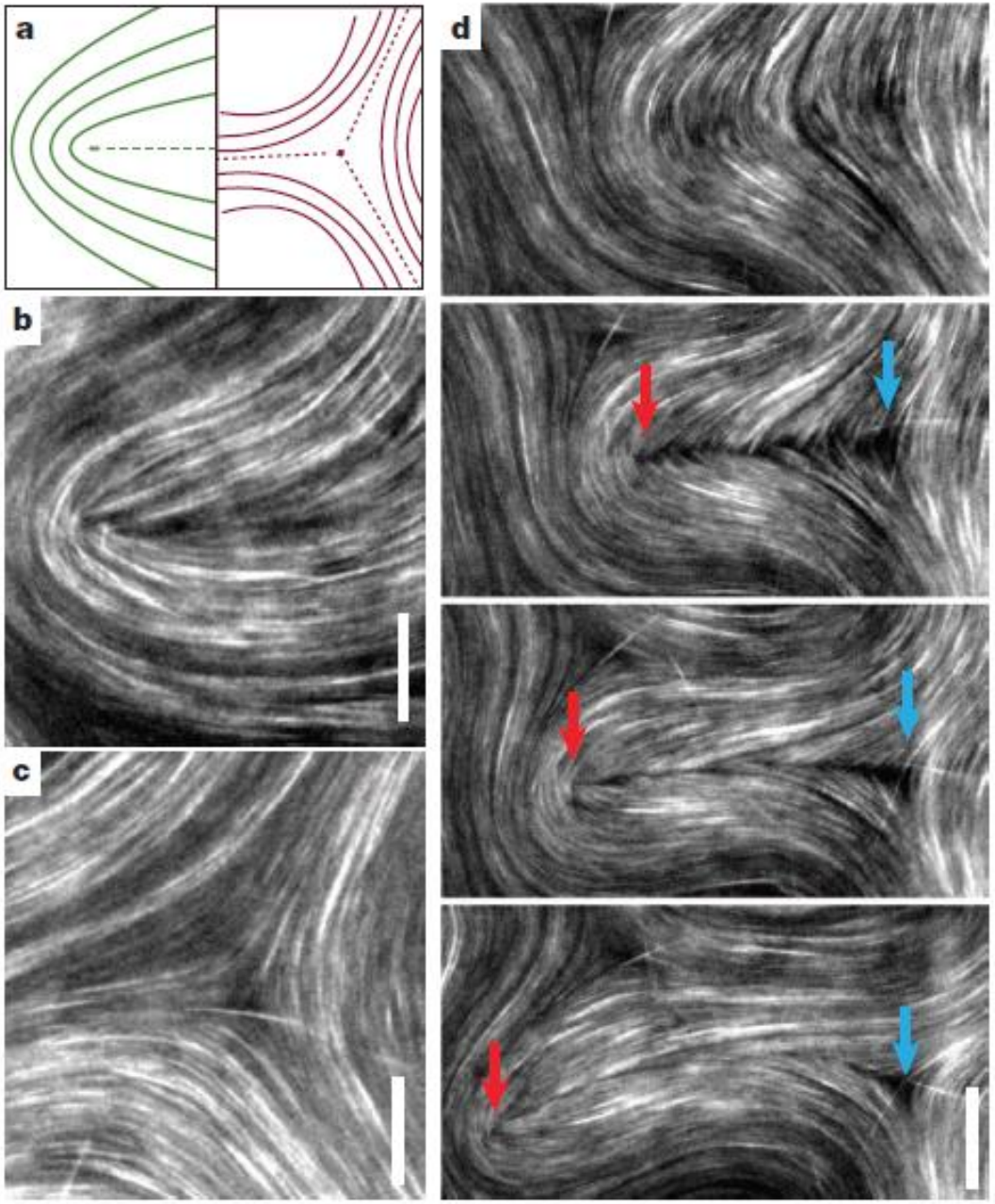






Sanchez, Chen, DeCamp, Heymann, Dogic, Nature 2012

nature11591-sv4.mov



nature11591-sv6.mov

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

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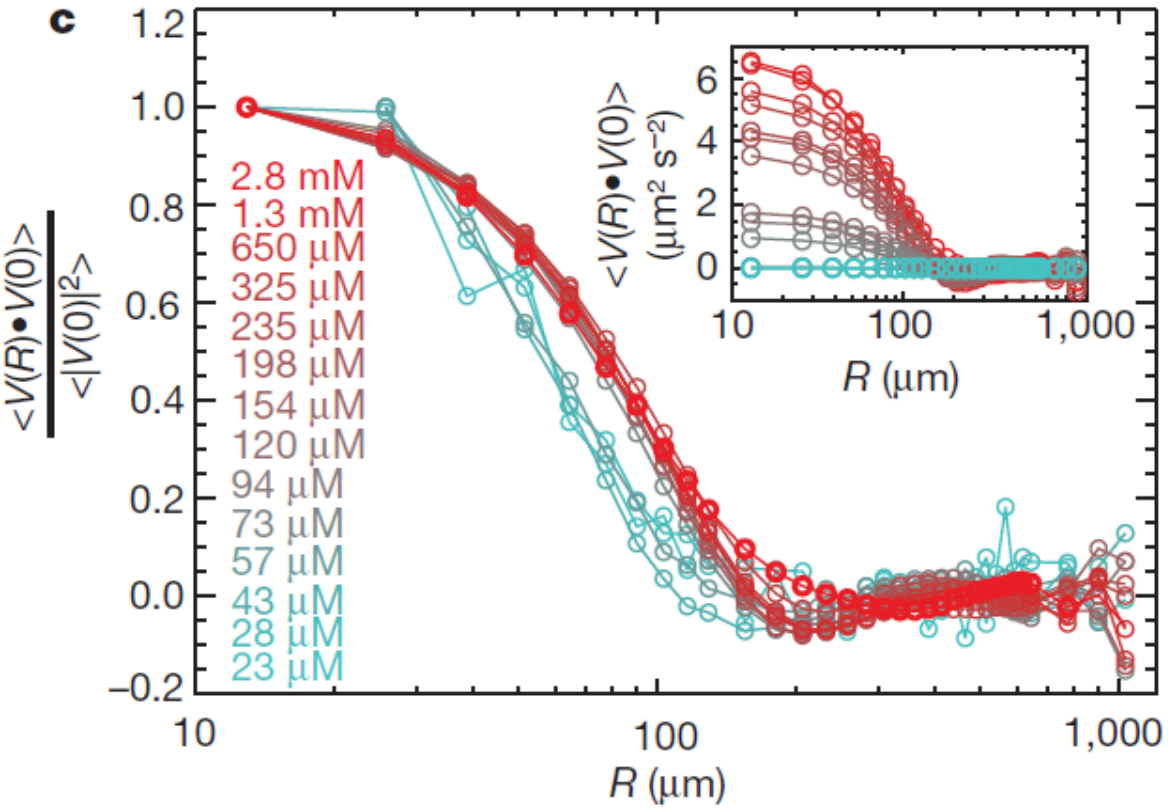

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Continuum equations of liquid crystal hydrodynamics

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

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$$S_{ij} = (\lambda E_{ik} + \Omega_{ik})(Q_{kj} + \delta_{kj}/3) +$$

$$(Q_{ik} + \delta_{ik}/3)(\lambda E_{kj} - \Omega_{kj}) - 2\lambda(Q_{ij} + \delta_{ij}/3)(Q_{kl}\partial_k u_l)$$

$$E_{ij} = (\partial_i u_j + \partial_j u_i)/2$$

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$$H_{ij} = -\delta \mathcal{F}/\delta Q_{ij} + (\delta_{ij}/3)\mathrm{Tr}(\delta \mathcal{F}/\delta Q_{kl})$$

$$\mathcal{F} = K(\partial_k Q_{ij})^2/2 + A Q_{ij} Q_{ji}/2 + B Q_{ij} Q_{jk} Q_{ki}/3 + C(Q_{ij} Q_{ji})^2/4$$

Continuum equations of liquid crystal hydrodynamics

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$$-\lambda(Q_{ik} + \delta_{ik}/3)H_{kj} - \partial_i Q_{kl}\frac{\delta \mathcal{F}}{\delta \partial_j Q_{lk}} + Q_{ik}H_{kj} - H_{ik}Q_{kj}$$

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

$\zeta > 0$ extensile

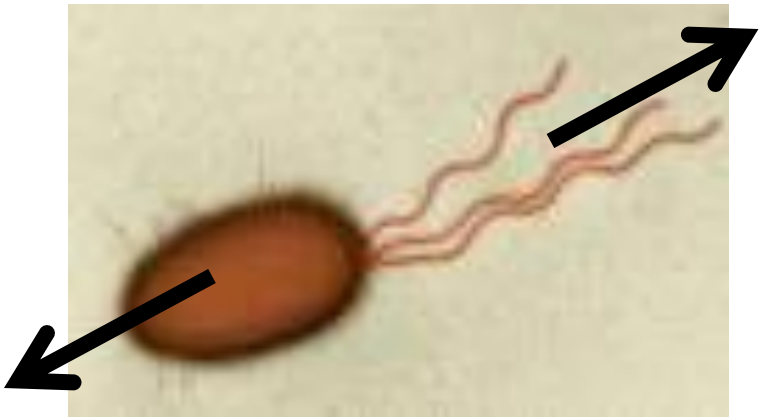
$\zeta < 0$ contractile

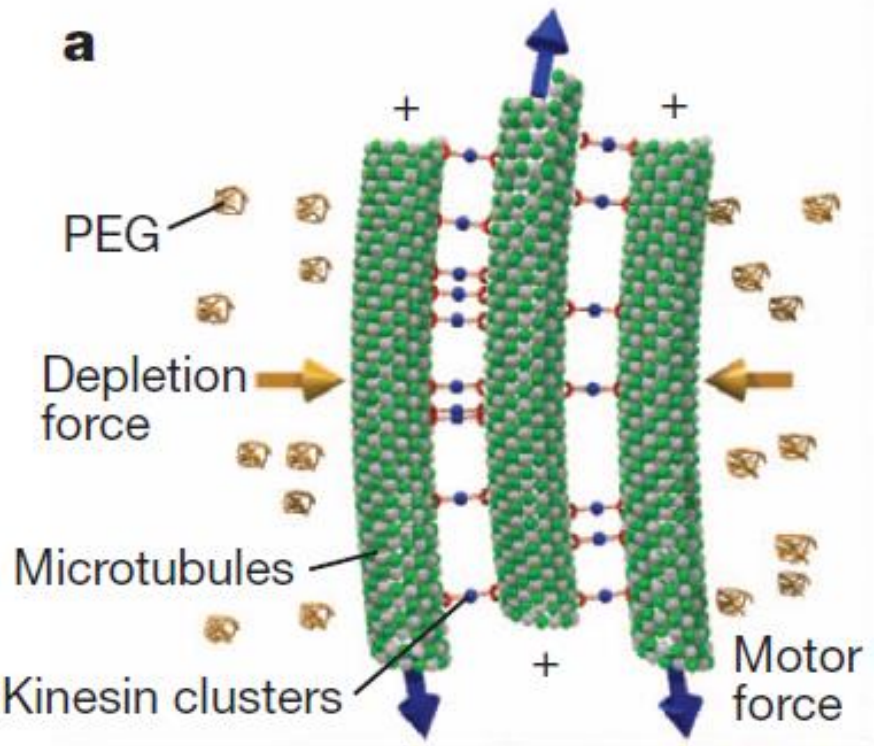
Active term in the stress tensor

Active contribution to the stress $-\zeta Q_{\alpha\beta}$

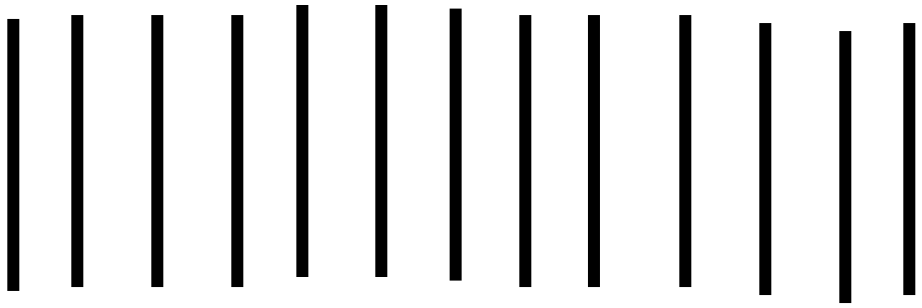
Hatwalne, Ramaswamy, Rao, Simha, PRL 2003

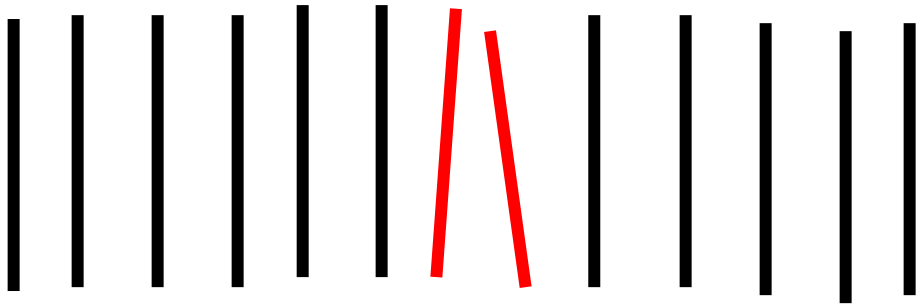
Consequence of a dipolar source term

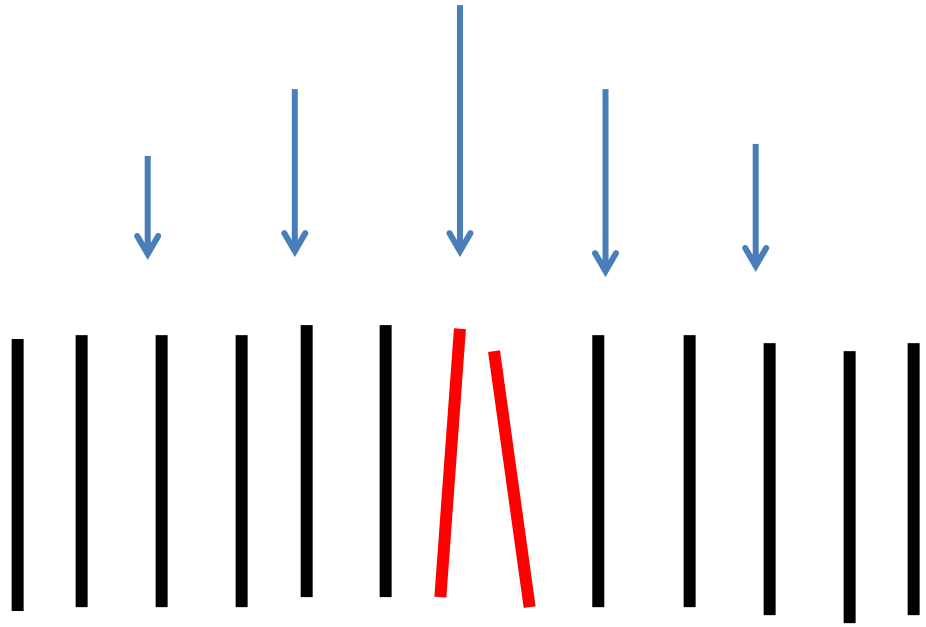


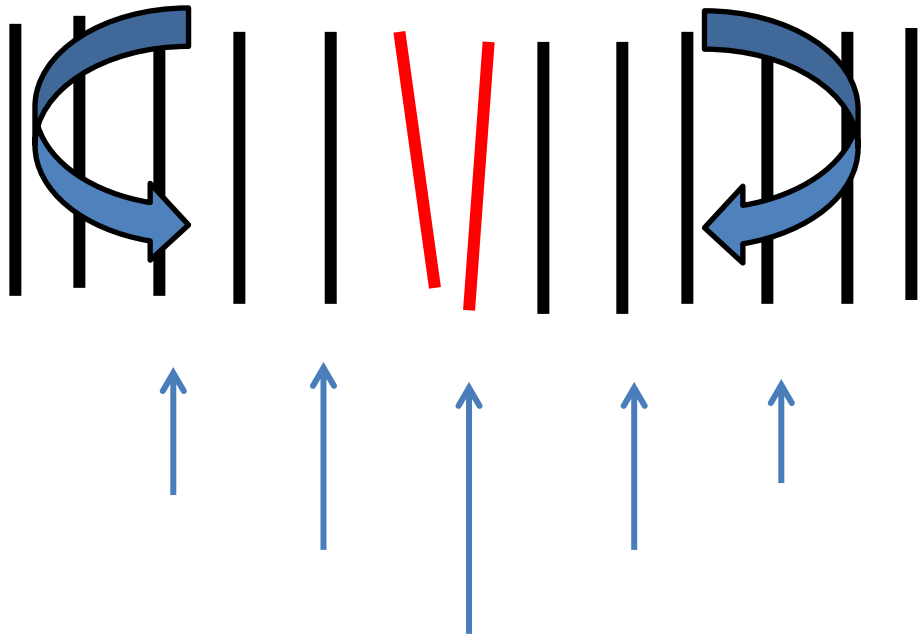


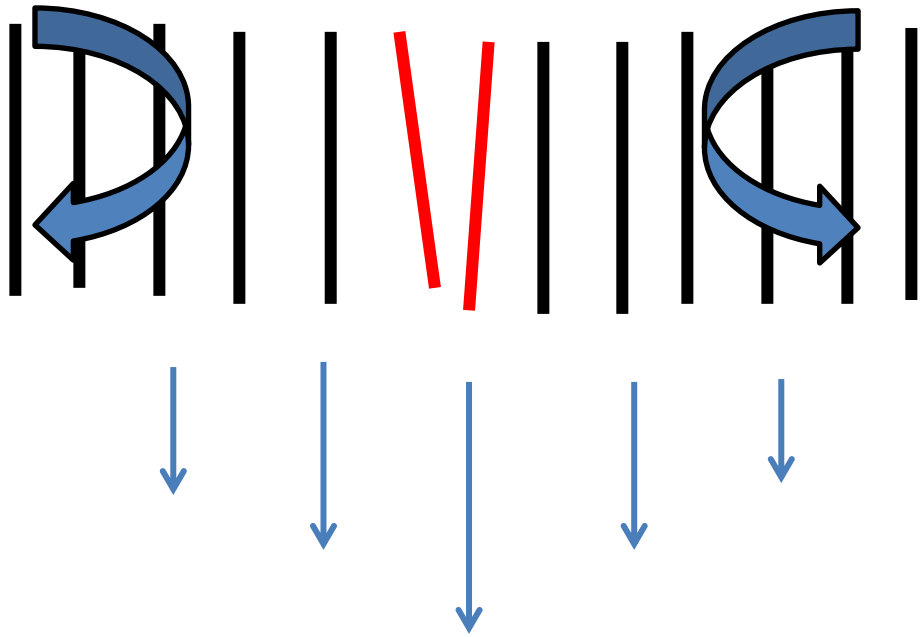
Instabilities



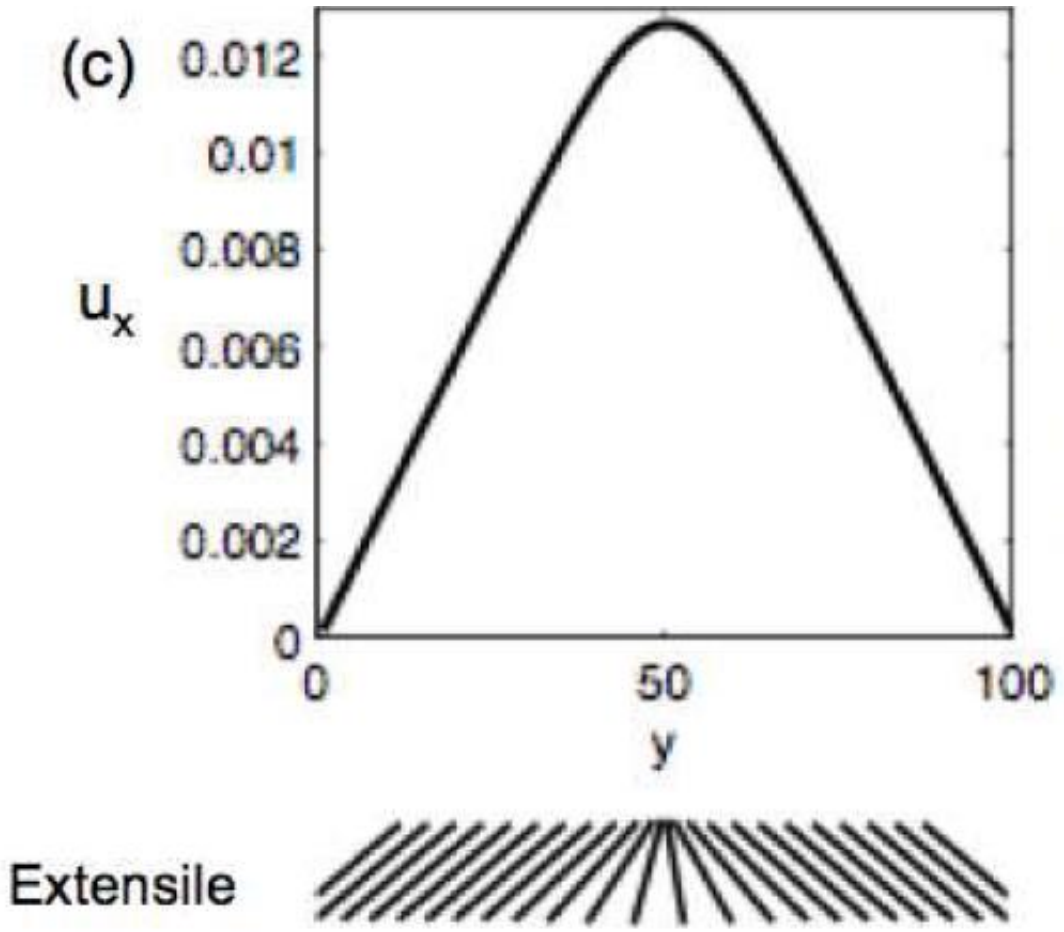








1D active flow



Voituriez, Joanny, Prost EPL (2005)

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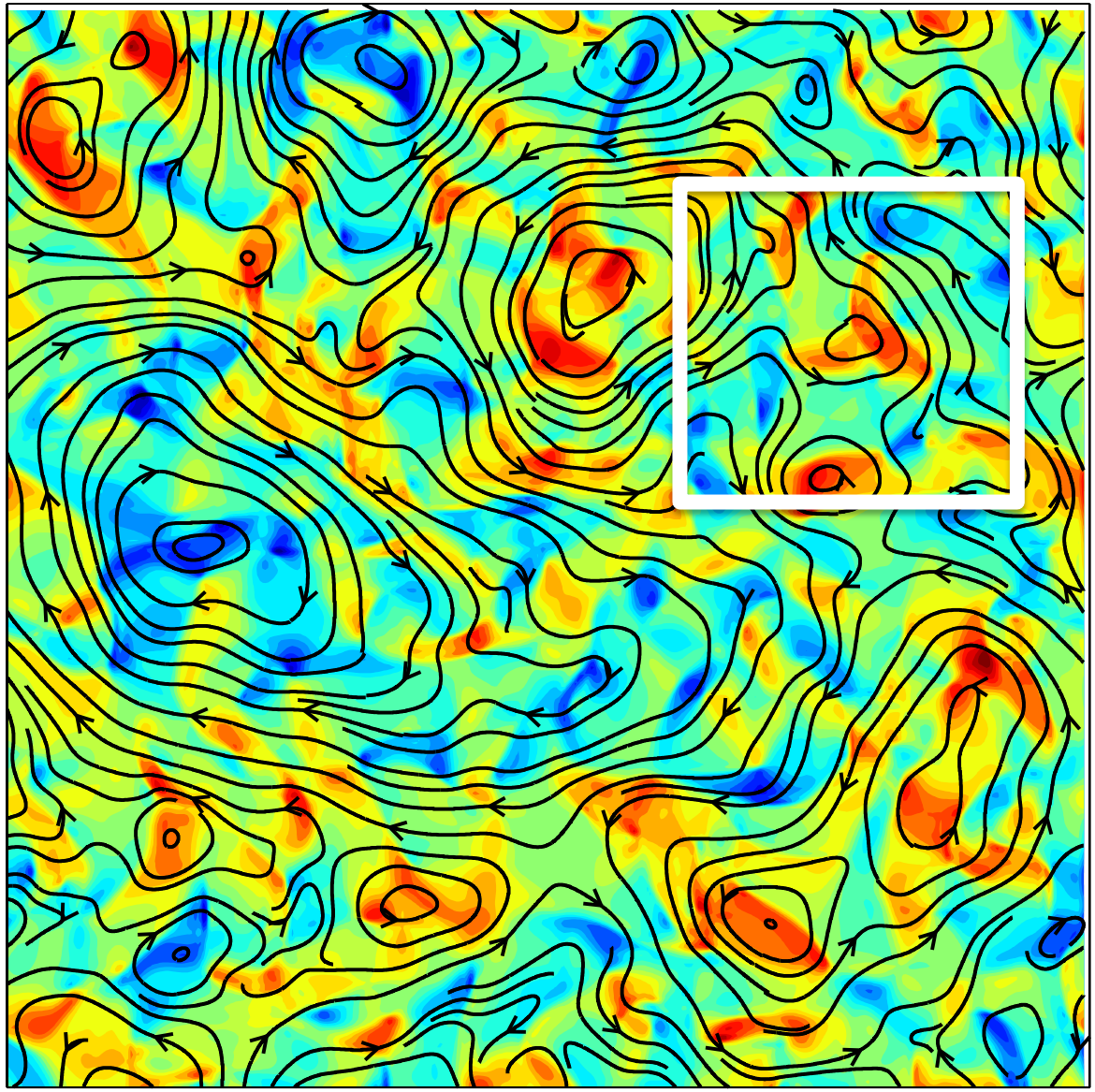
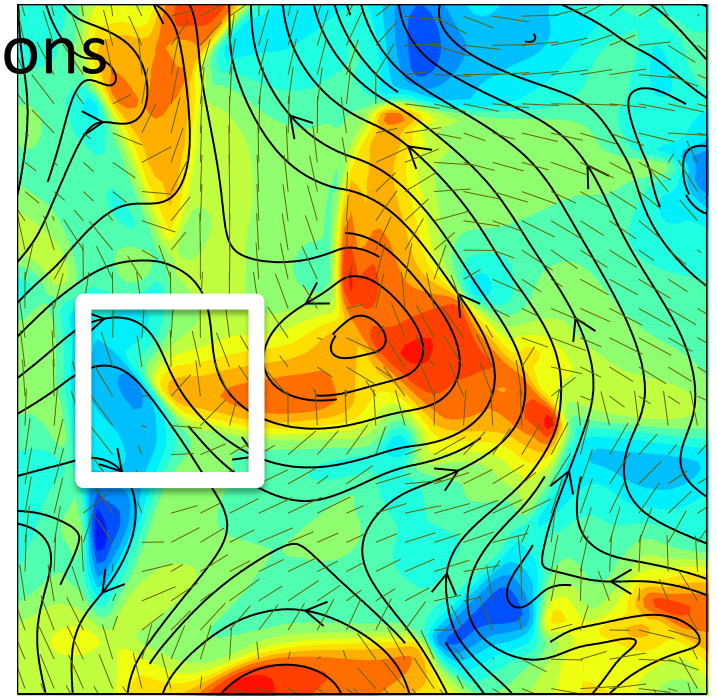
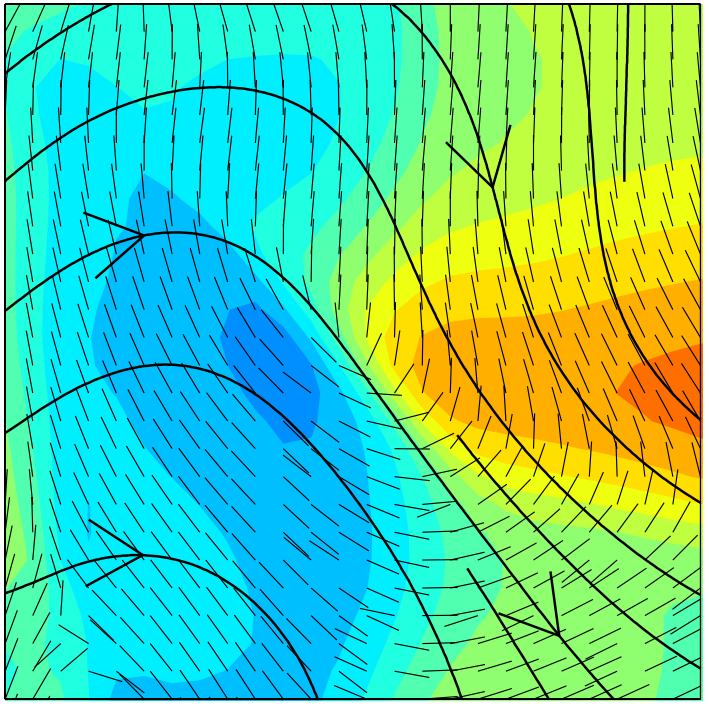
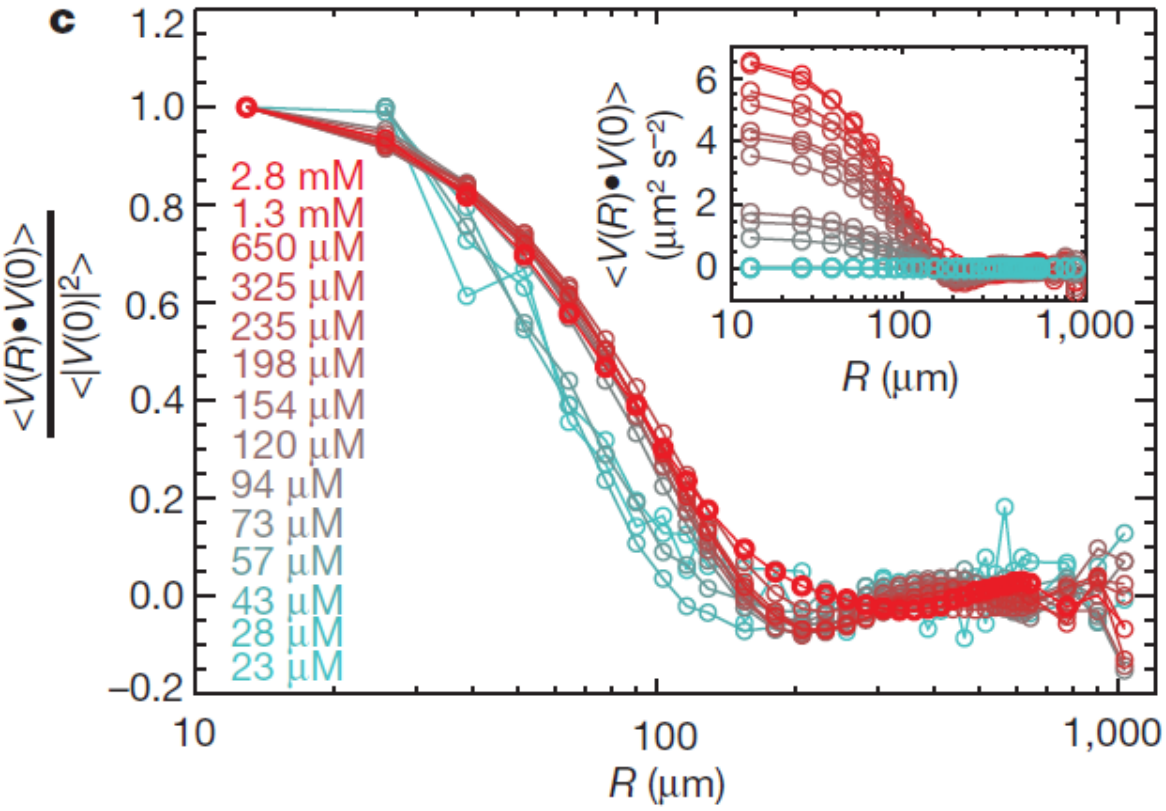
Active turbulence in extensile suspensions







<vv>: experiments



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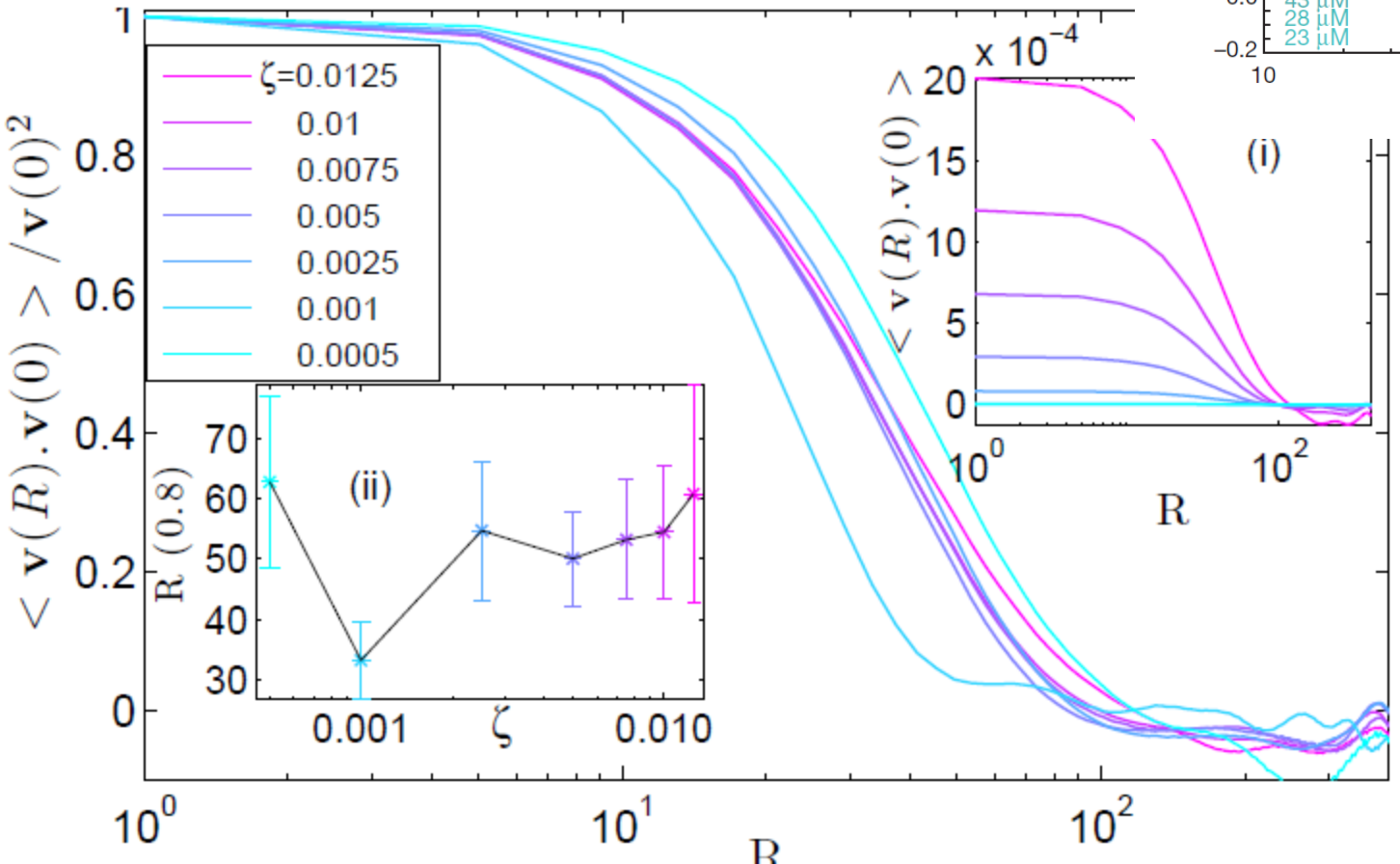

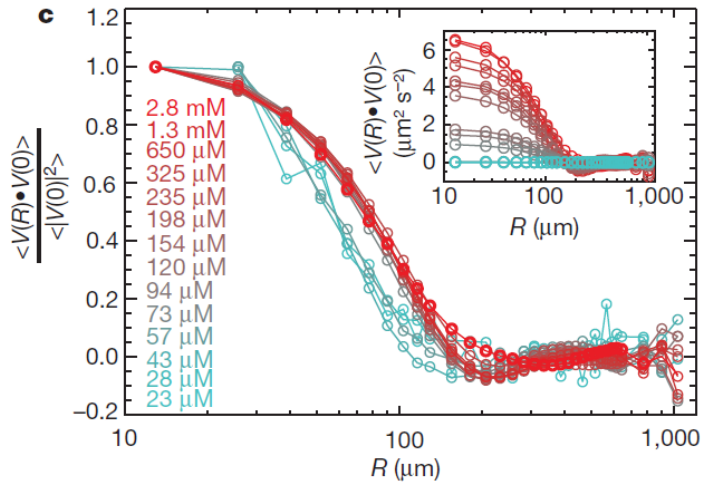

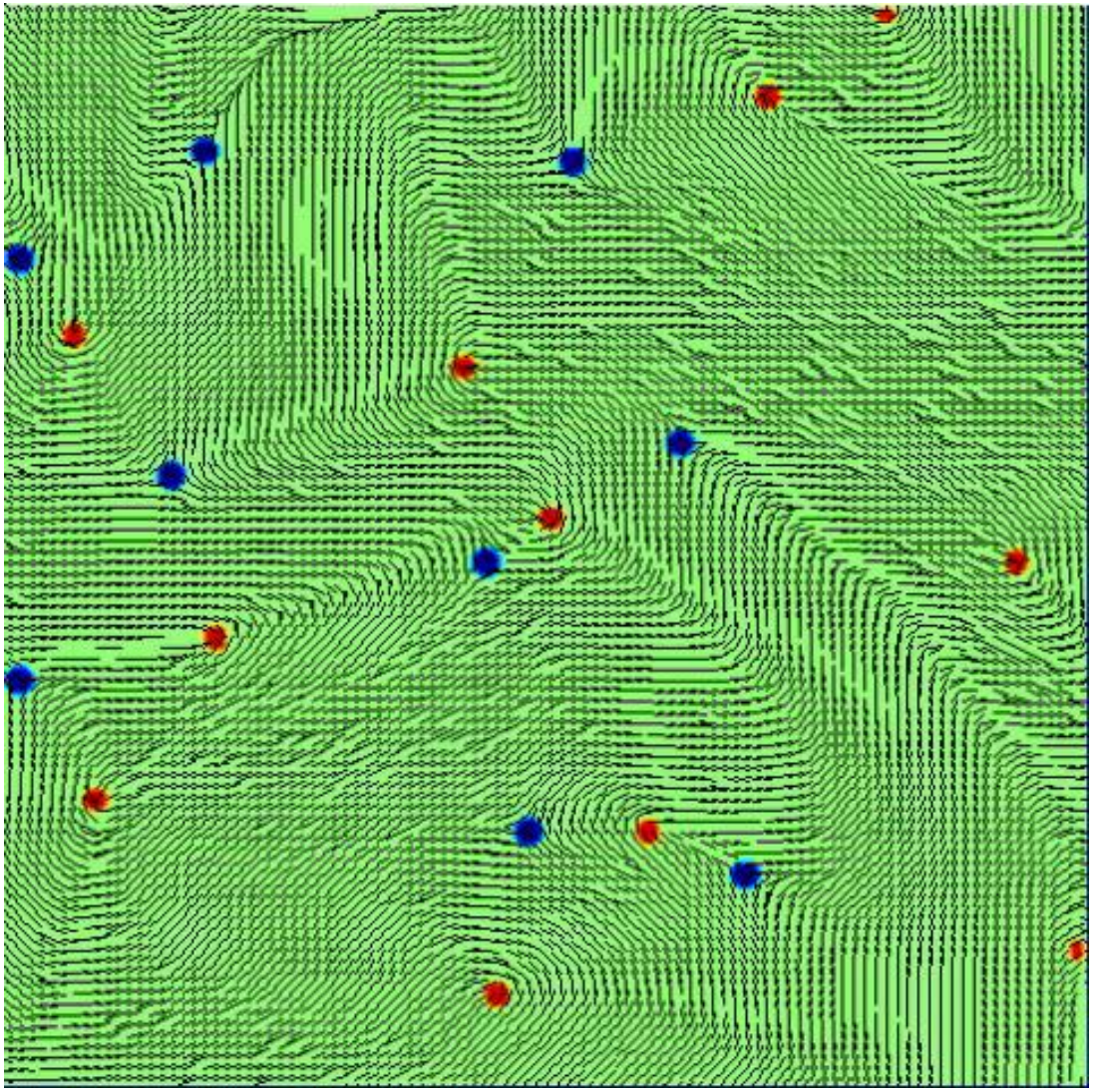

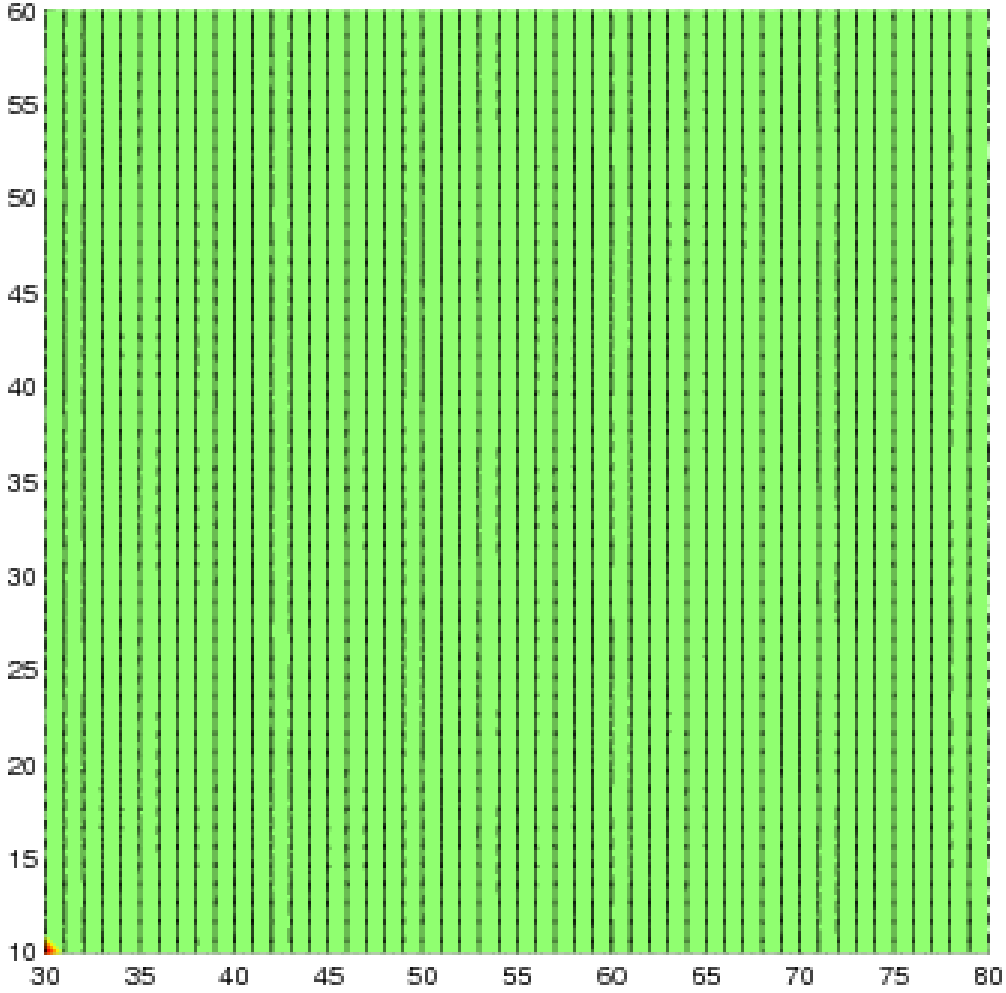
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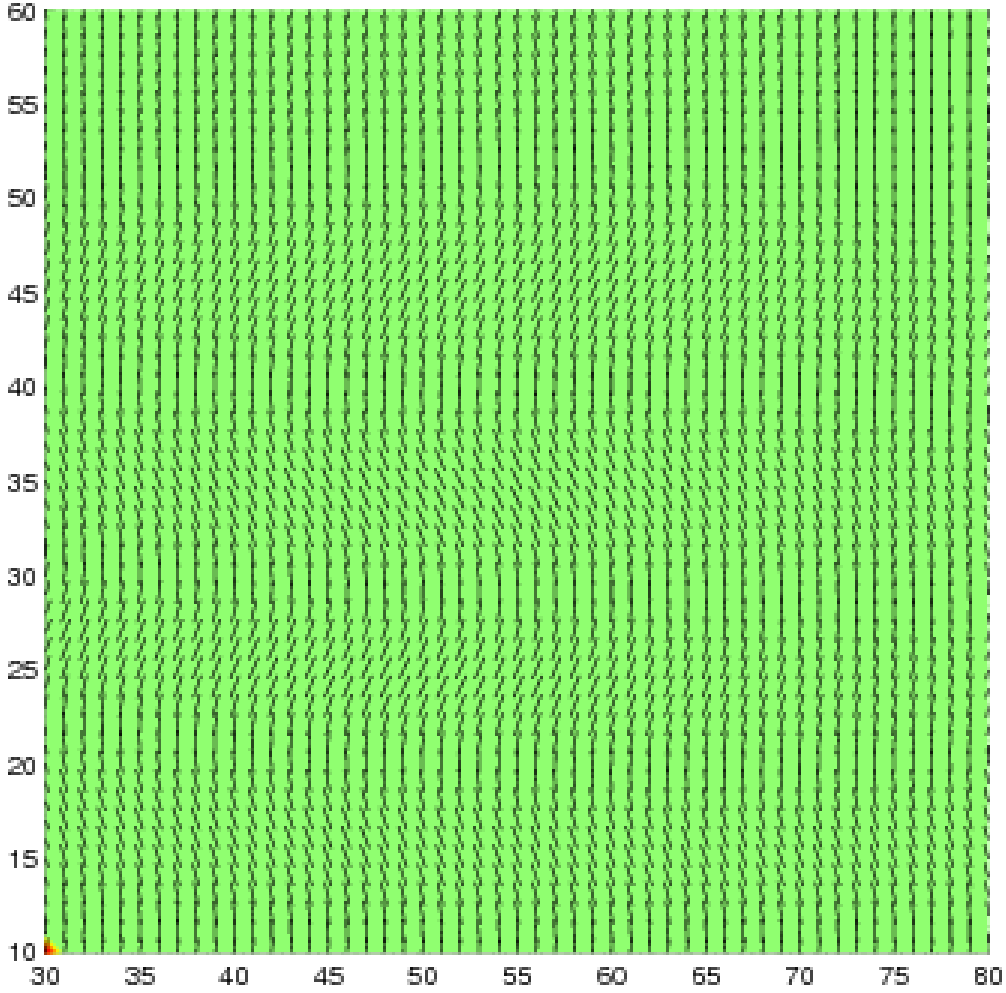
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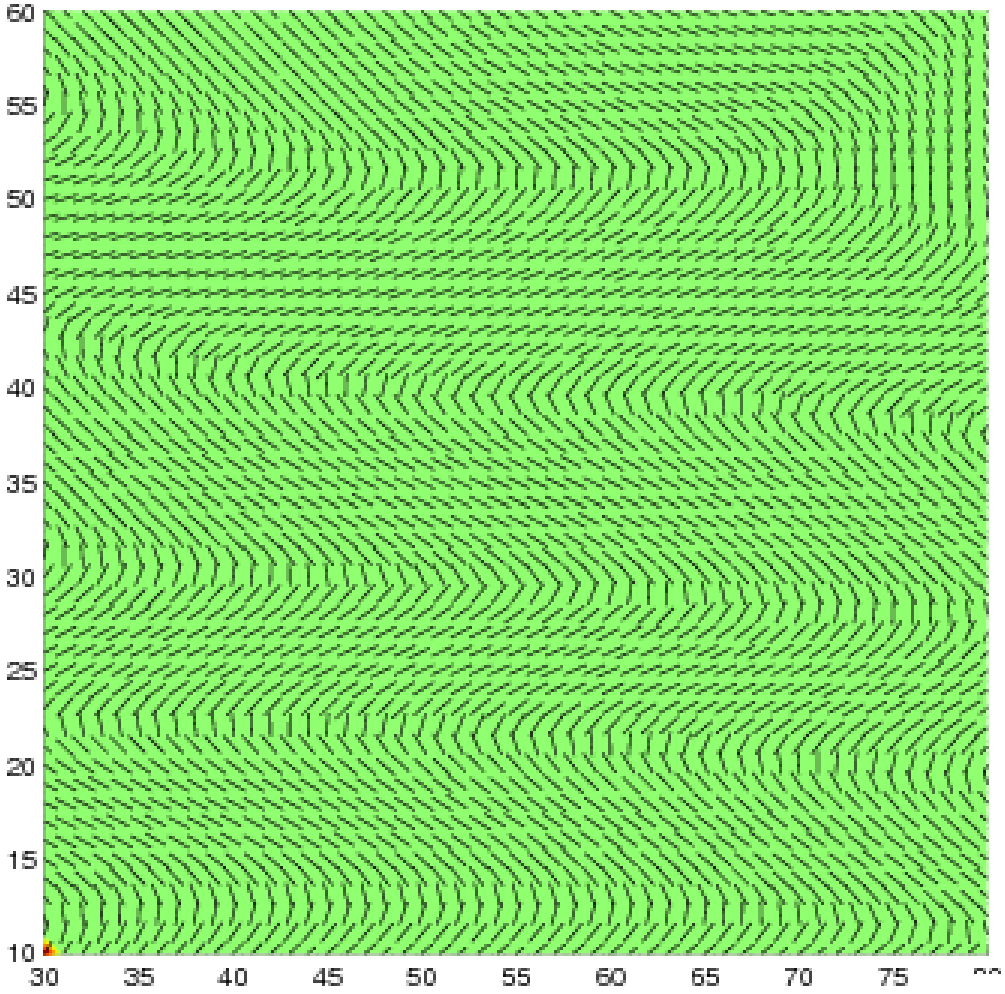
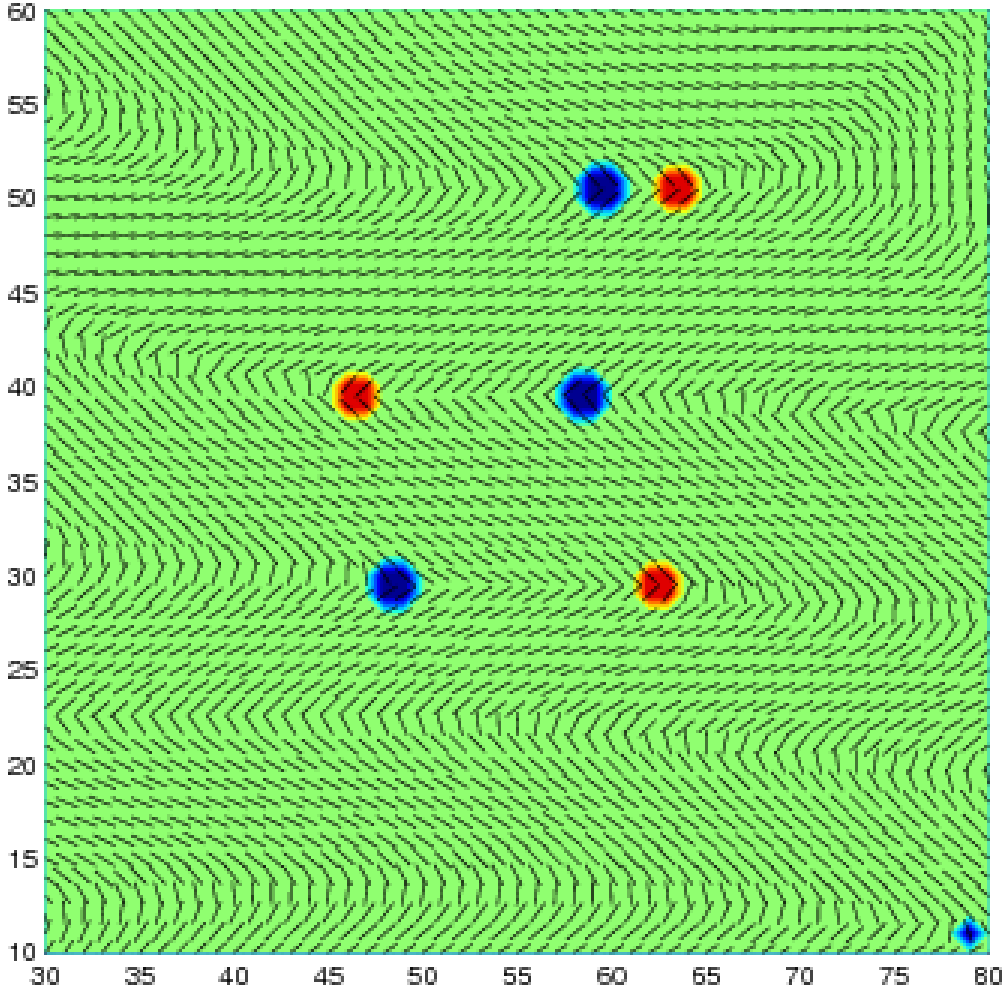


$$\ell \sim \sqrt{\frac{\kappa}{\zeta}}$$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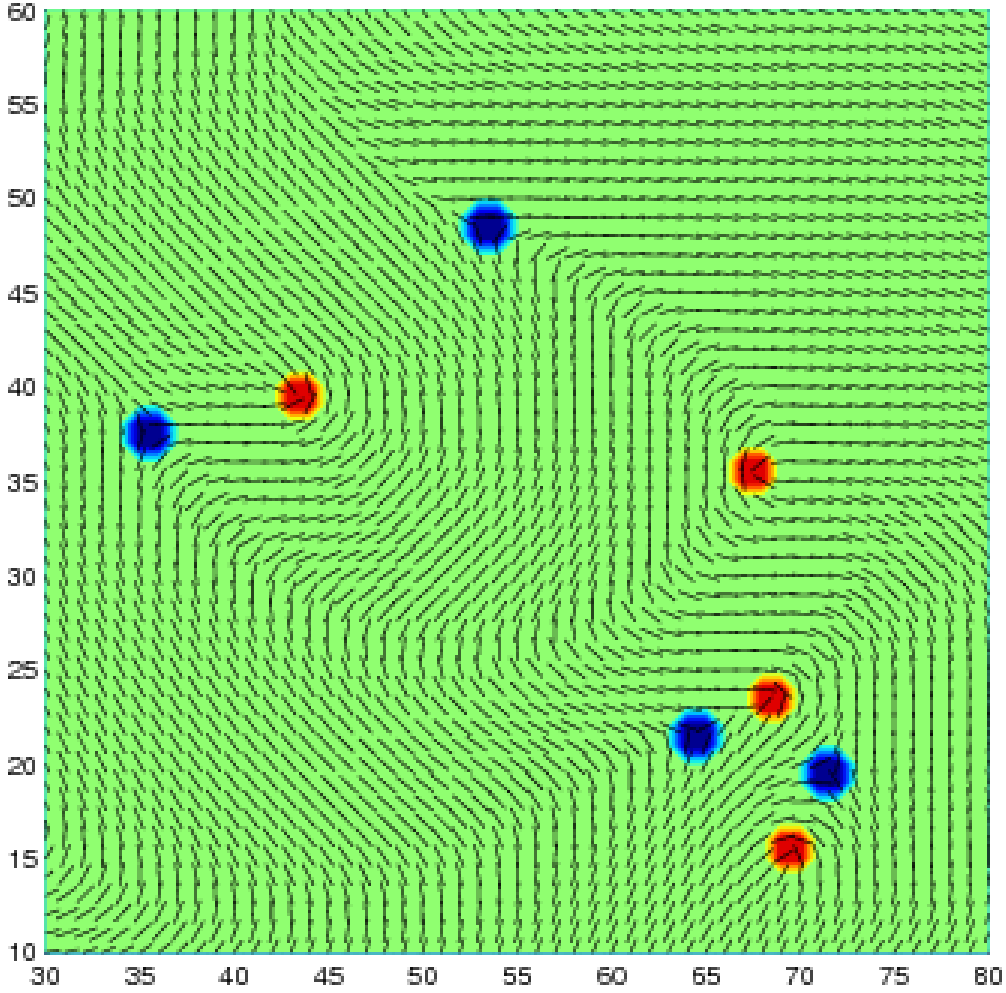
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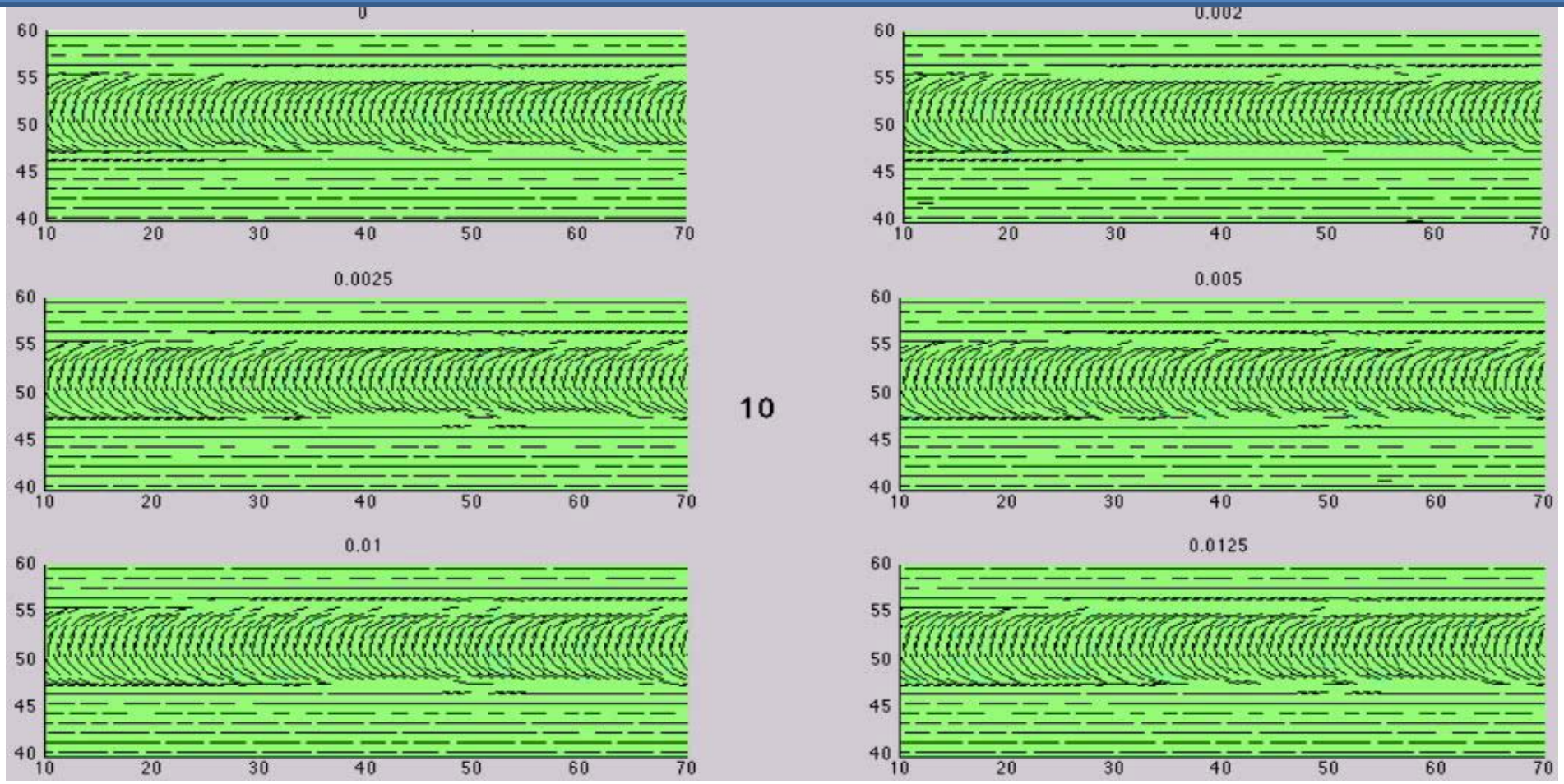
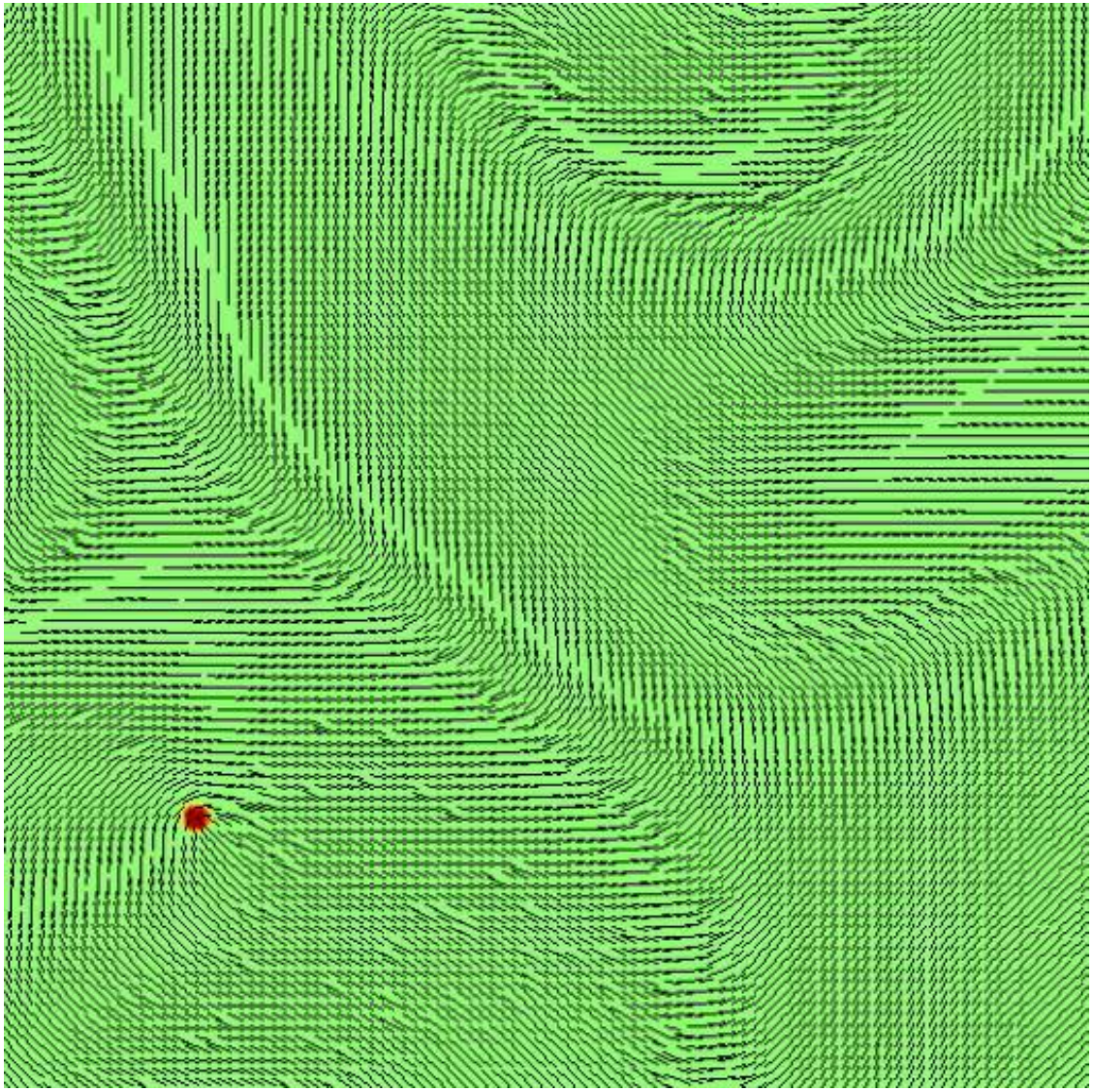
55
60
65
70
75
80

Defect formation: bend deformation

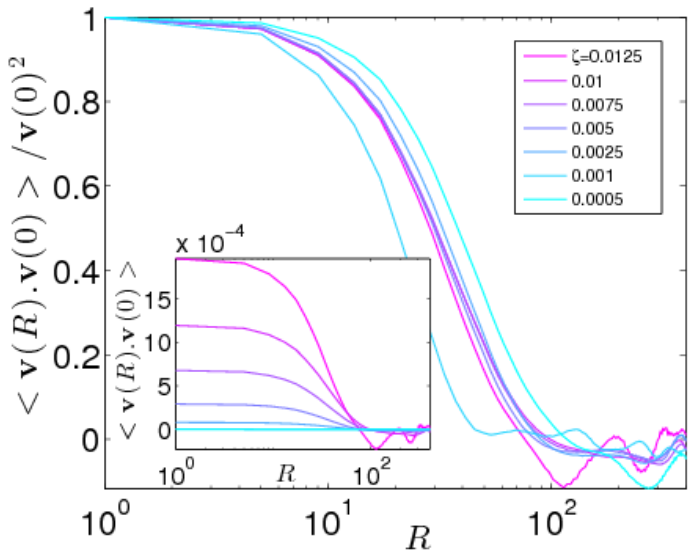


(e) creation (f) annihilation

Low activities



scaling of correlation functions with activity



correlation functions of

velocity

vorticity and order parameter