Chiral active nematics in a channel

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Chirality

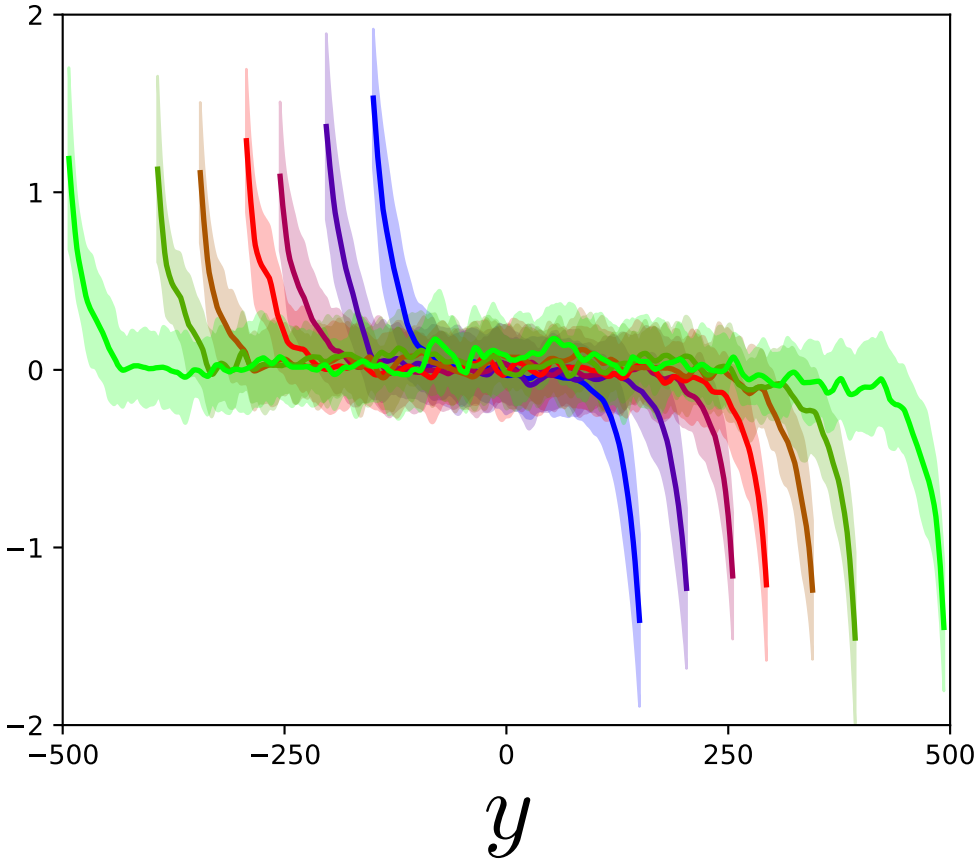
Clockwise Anti-Clockwise

Human fibrosarcoma cells

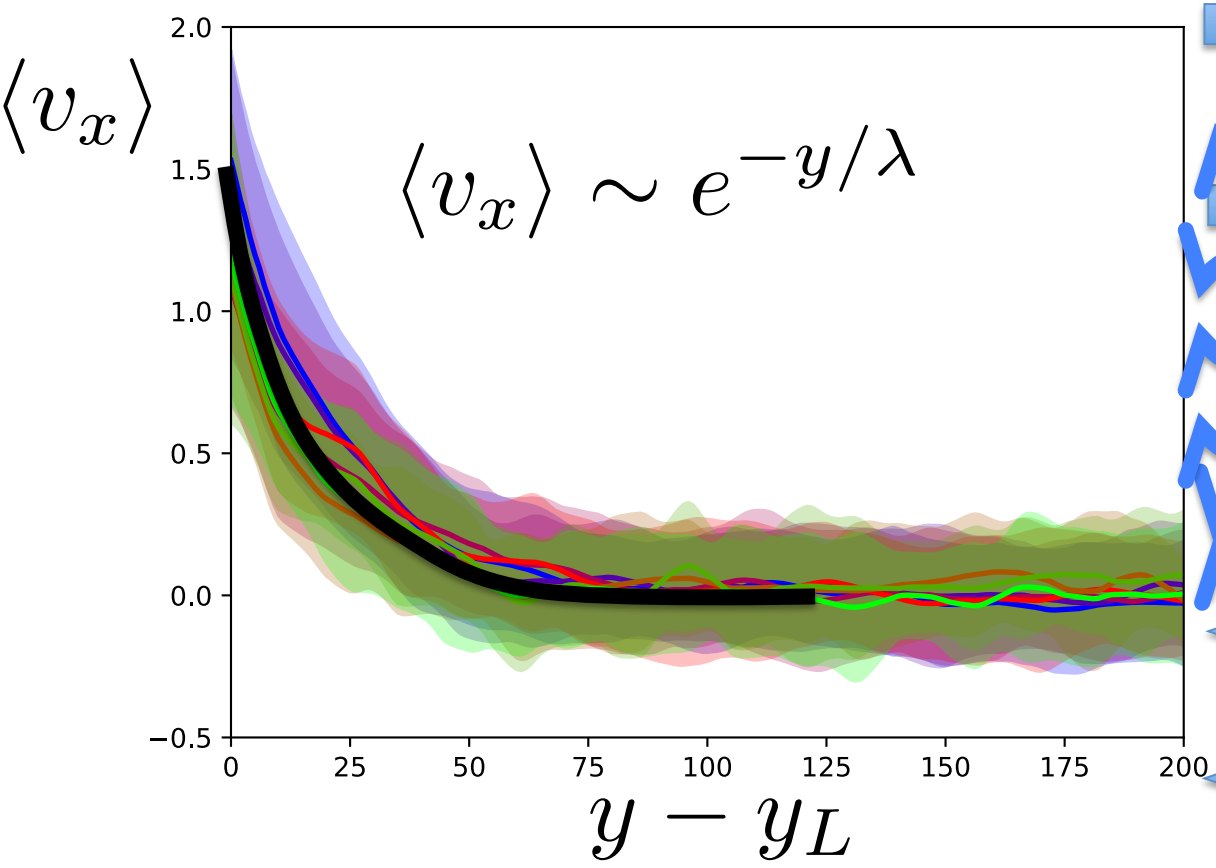
Clearly some orientational order

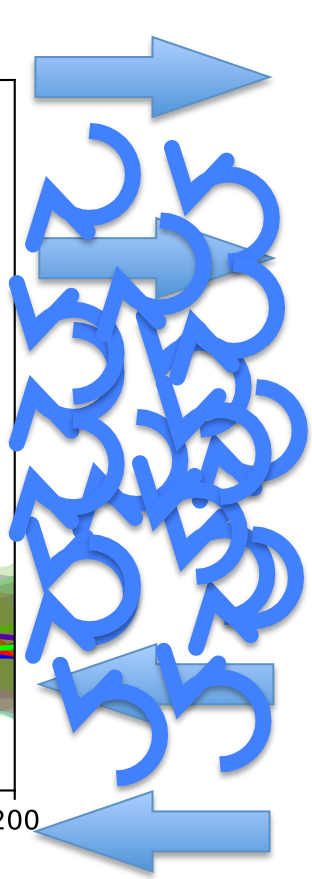
Observe net flows

$\langle v_x \rangle$

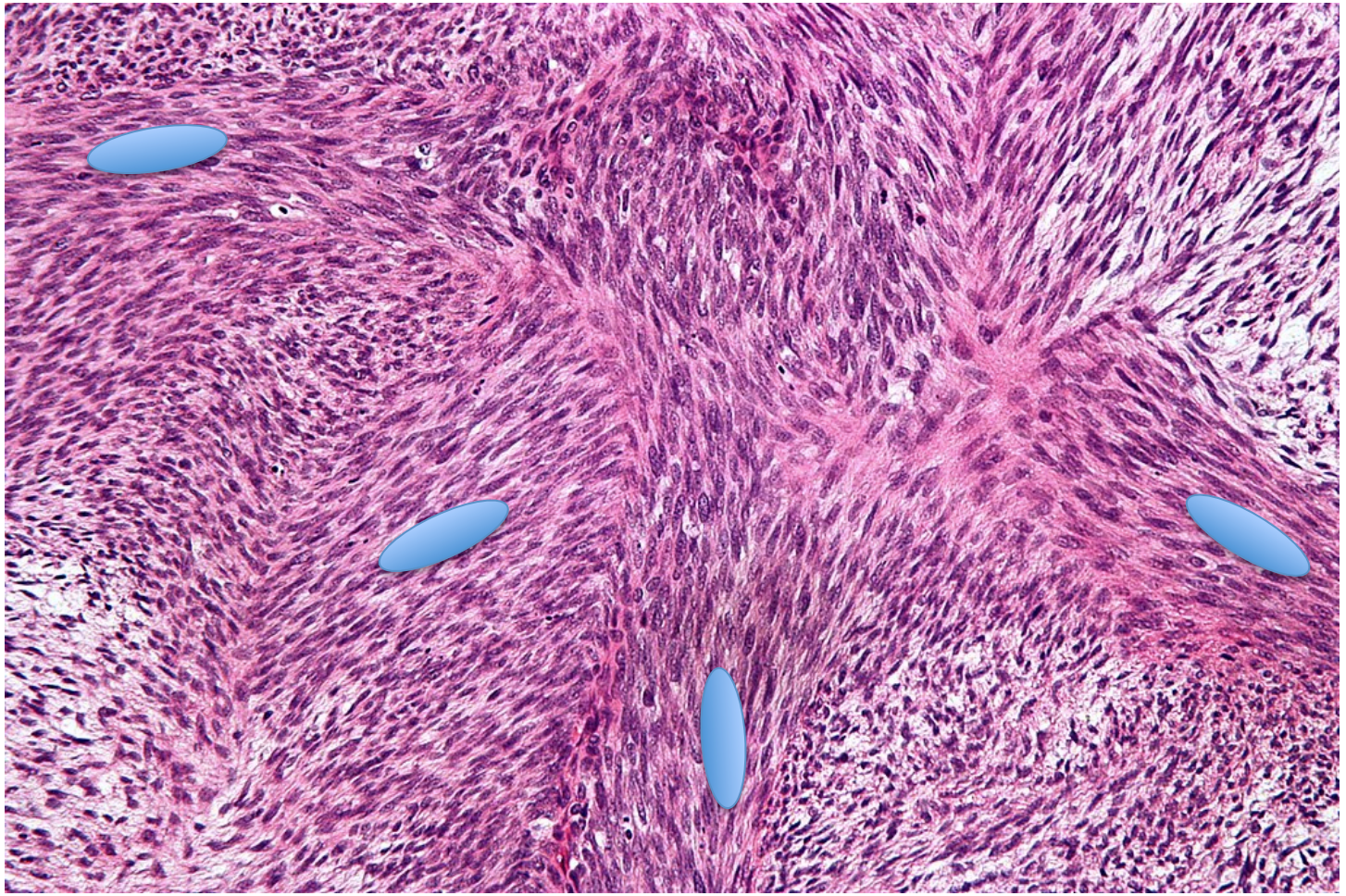


Average flow is fastest at the boundary

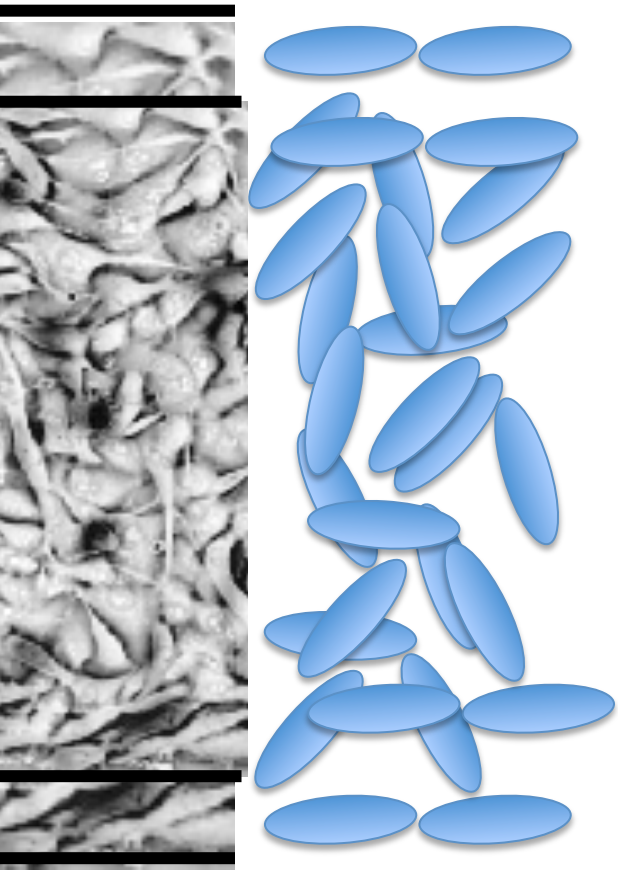


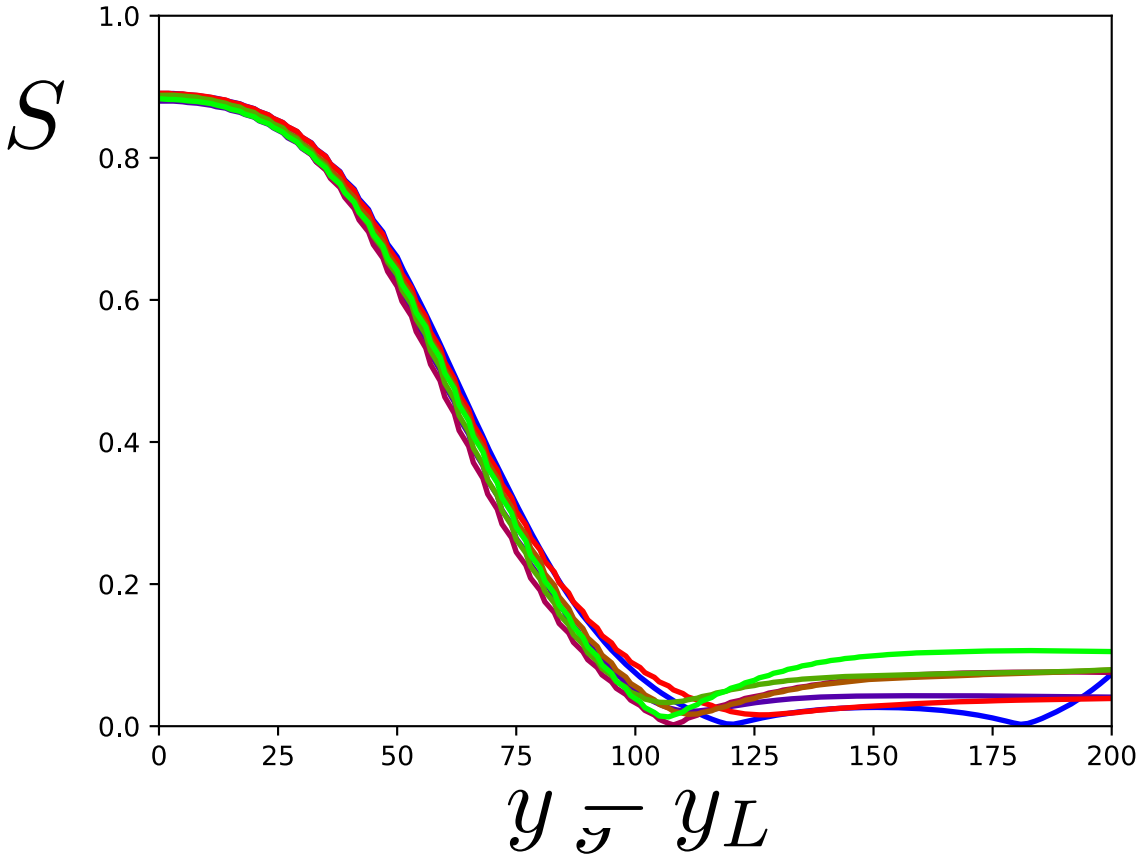


The cells are generally elongated



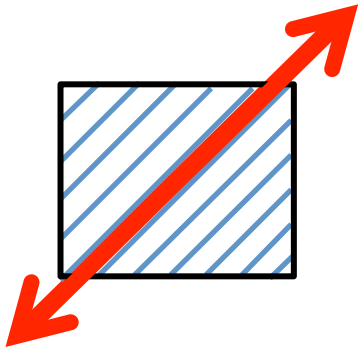
Generally ordered at the boundary





Describing a liquid crystal

Volume element of nematic material



$$\underline{\hat{n}}(\underline{r}) = -\underline{\hat{n}}(\underline{r})$$

Order parameter: S

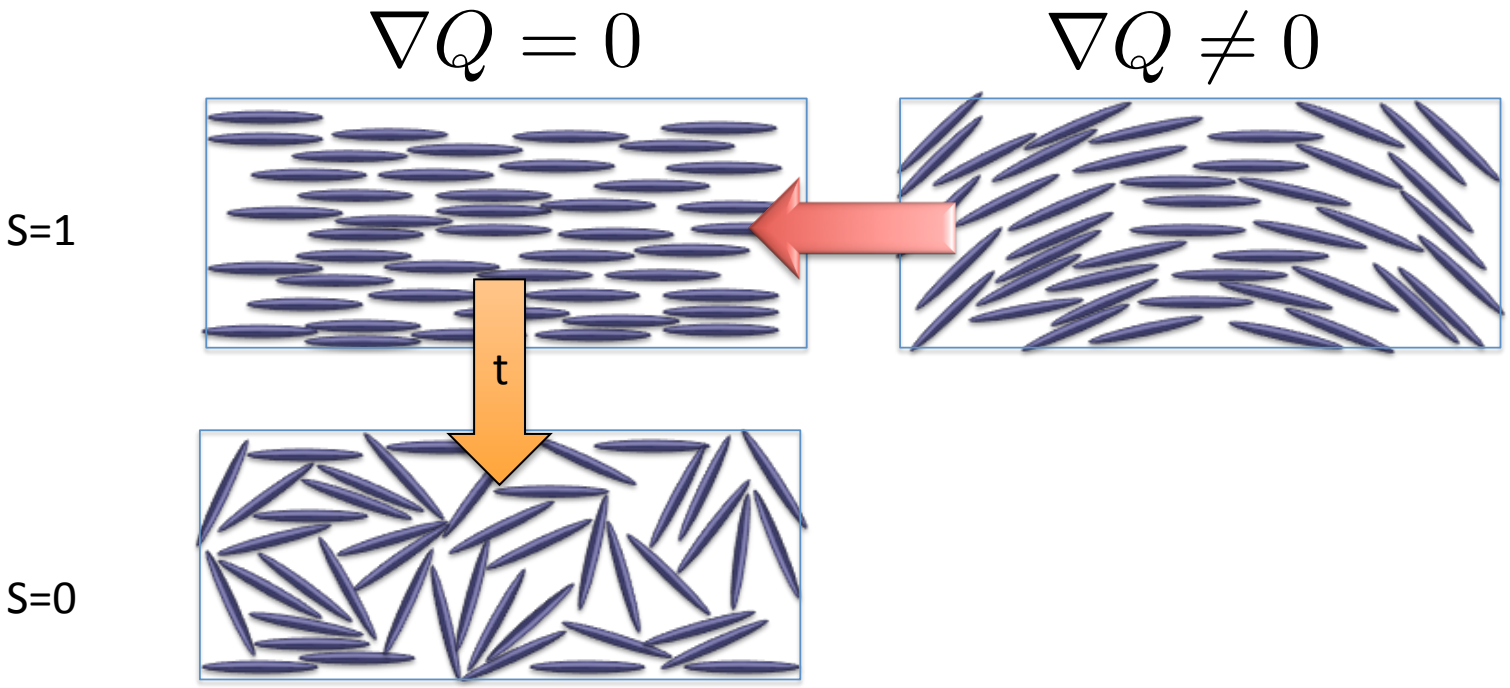
$$\mathbf{Q}_{ij} = S[\hat{n}_i \hat{n}_j - \delta_{ij}/3]$$

$$S = \mathrm{tr}\mathbf{Q}^2$$

Free energy of a liquid crystal

$$F = \int dA \left[\frac{a_2 t}{2} tr\mathbf{Q}^2 + \frac{a_4}{4} (tr\mathbf{Q}^2)^2 + \frac{k}{2} |\nabla \mathbf{Q}|^2 \right]$$

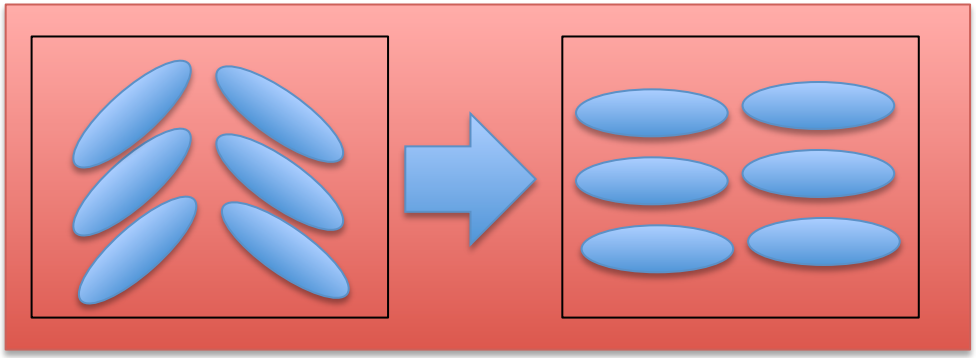
k - Elastic bending constant

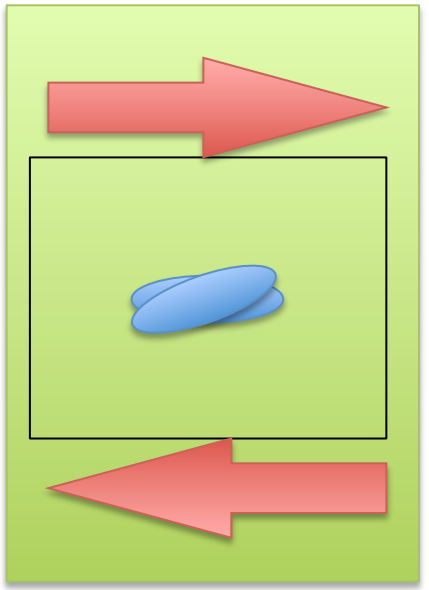


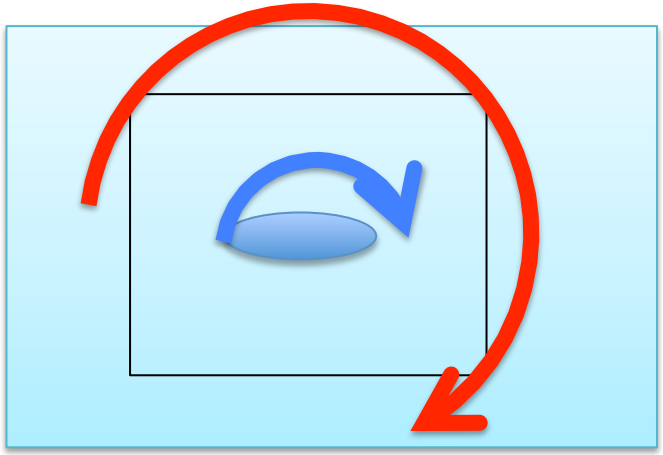
Physics of Liquid Crystals, De Gennes & Proost

Dynamical equation for Q_{ij}

$$\frac{D\mathbf{Q}_{ij}}{Dt} = \lambda S u_{ij} + [\mathbf{Q}, \omega]_{ij} + \gamma^{-1}\mathbf{H}_{ij}$$



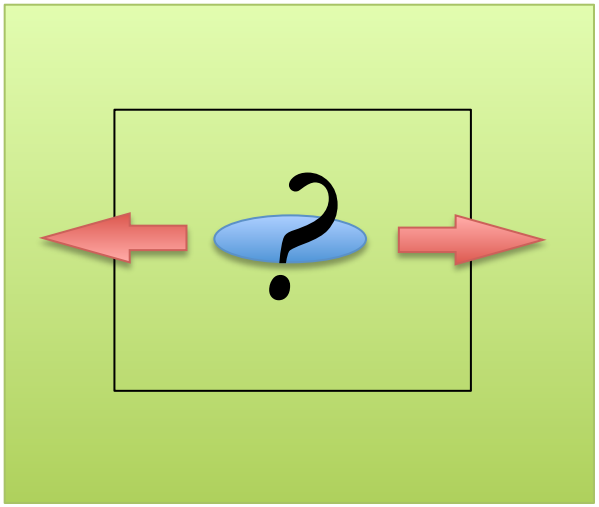




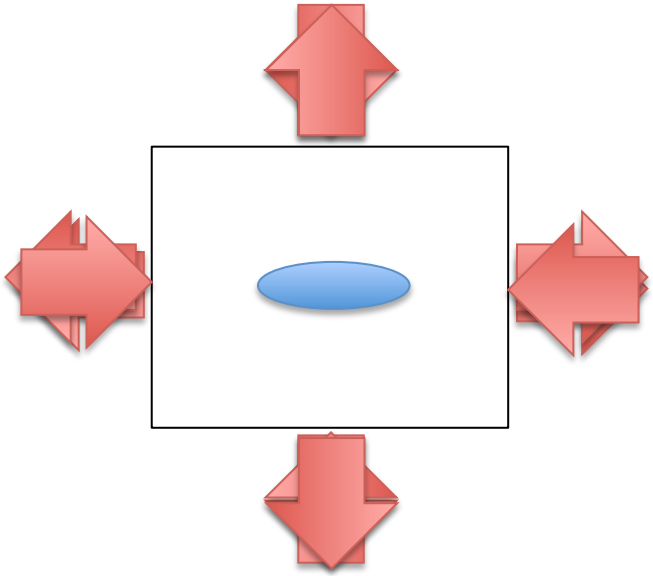
Also need to describe the flow

$$\rho \frac{Dv_i}{Dt} = \partial_j^2 v_i - \partial_i p + \partial_j \sigma_{ij}^{\alpha}$$

$$\partial_i v_i = 0$$



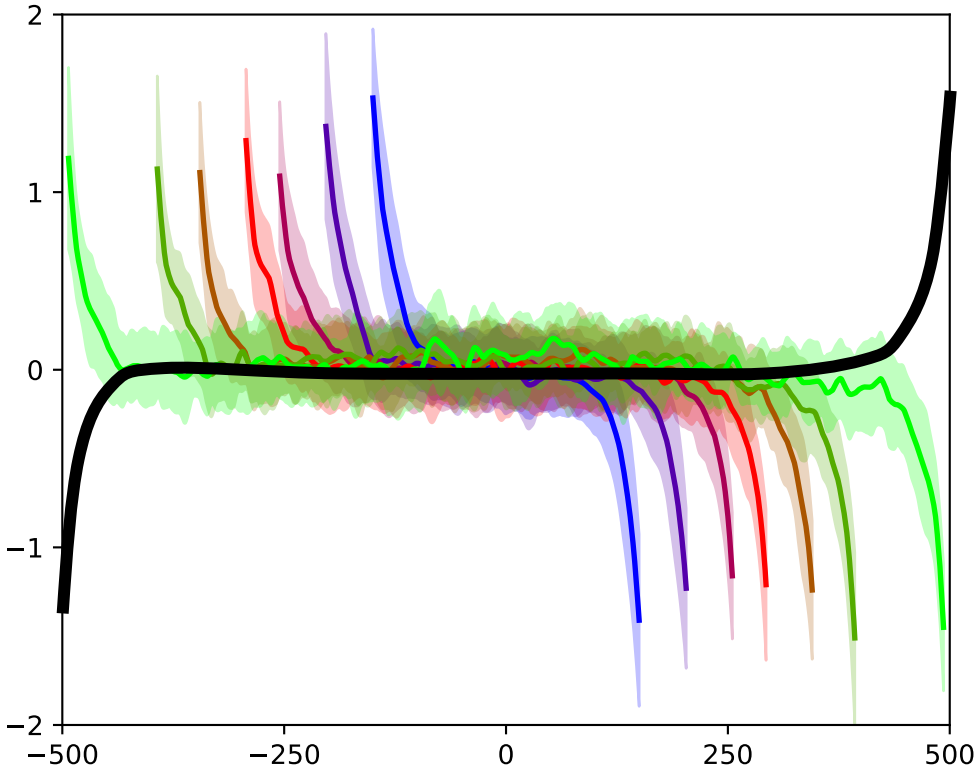
What form should the active stress take?



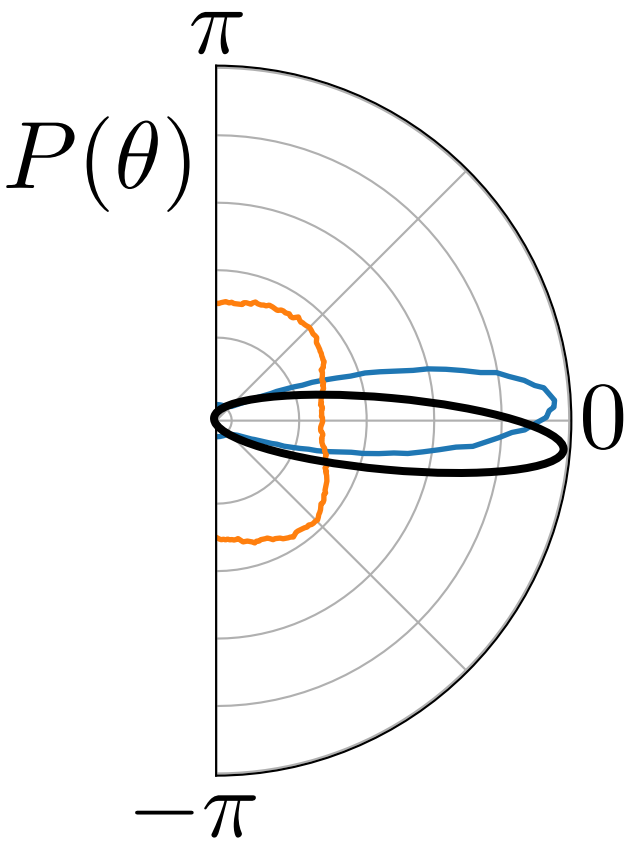
$$\sigma_{ij}^{\alpha} = \alpha Q_{ij}$$

$$\alpha < 0$$

The system appears to be chiral

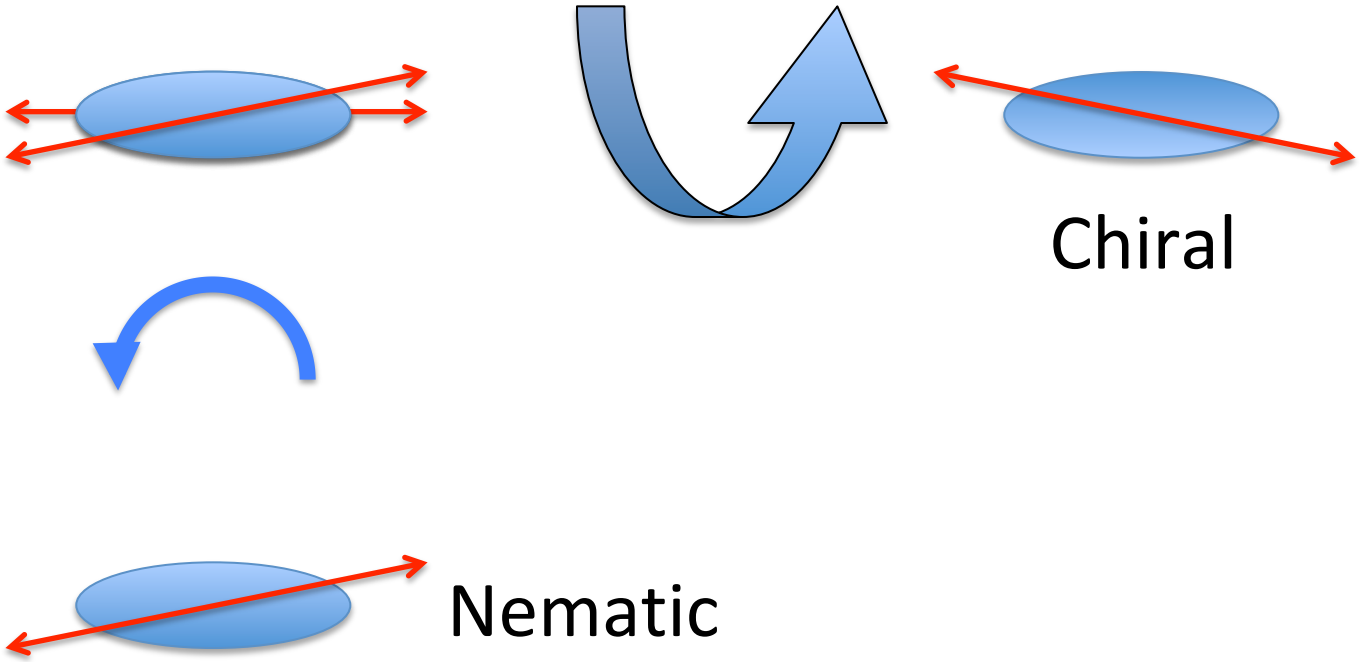


Liquid crystal also has chiral character



Modify the active stress to capture chirality

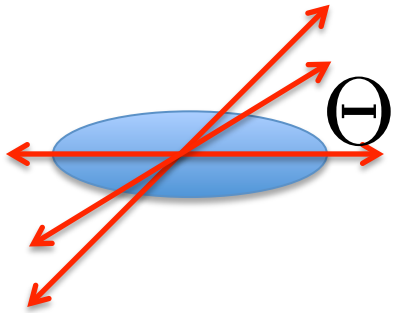
$$\sigma_{ij}^{\alpha} = \alpha Q_{ij}$$



This controls the degree of chirality

$$\sigma_{ij}^{\alpha} = \alpha Q_{ij} + \tau \epsilon_{ik} Q_{kj}$$

$\alpha = 0$

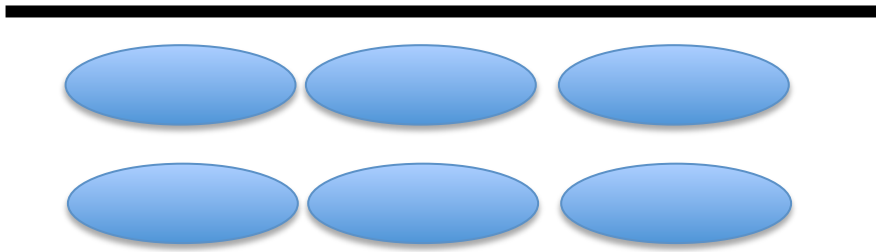


$\tau = 0$

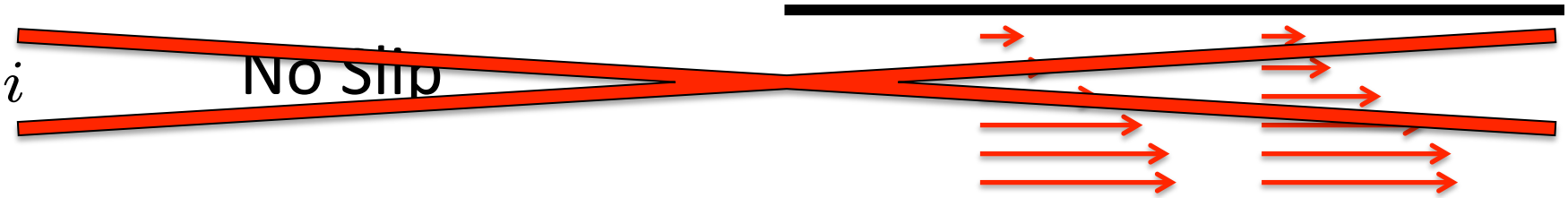
$$\Theta = \tan^{-1}(\sqrt{\alpha^2 + \tau^2})$$

2 Boundary conditions

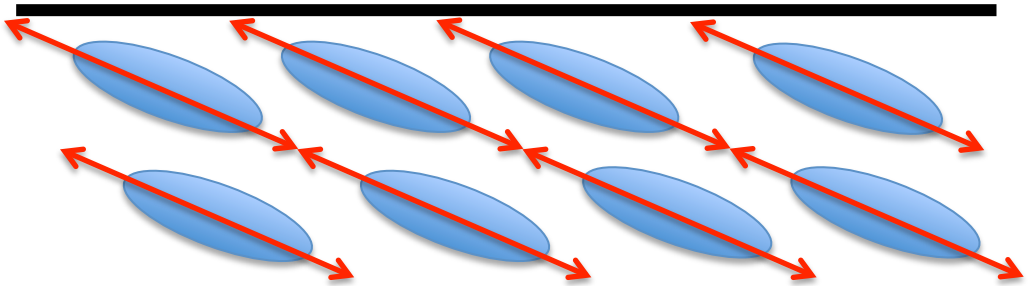
Q_{ij} Alignment



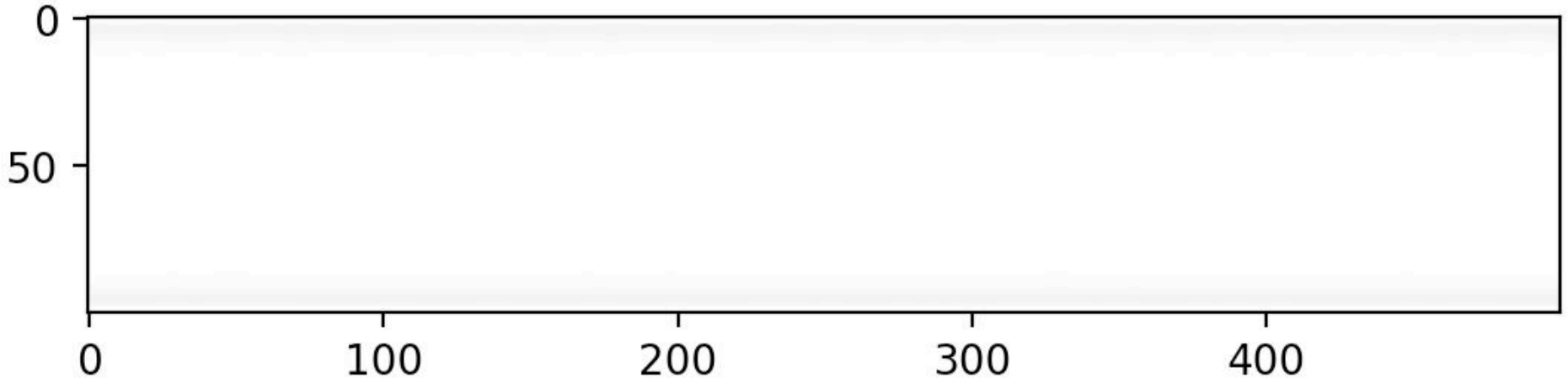
v_i No Slip



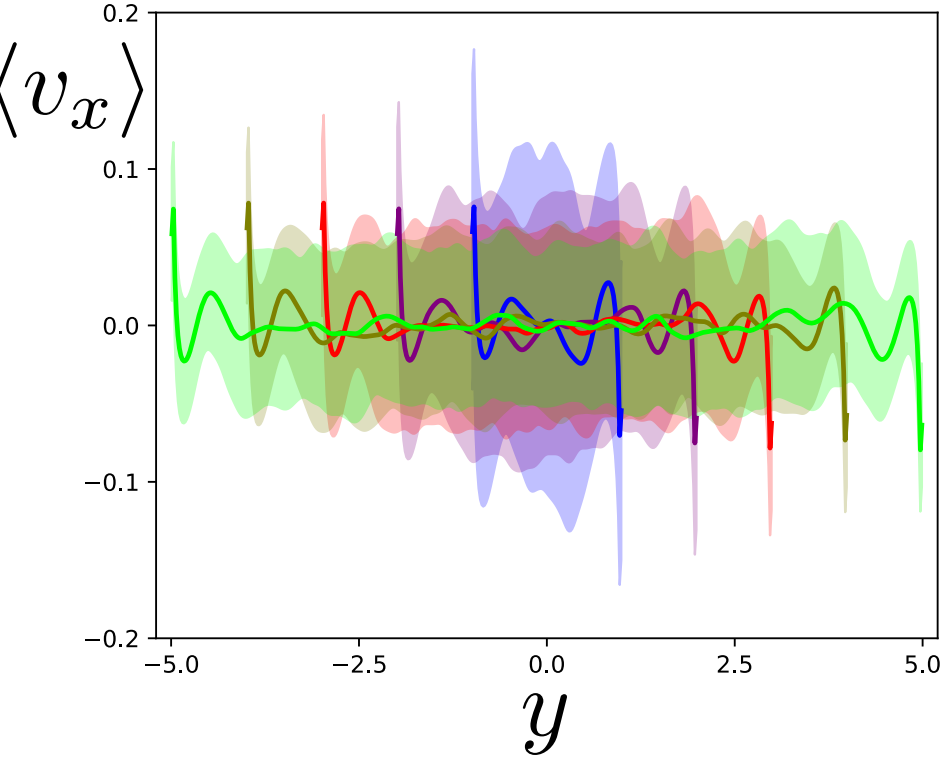
σ_{ij} Force Balance

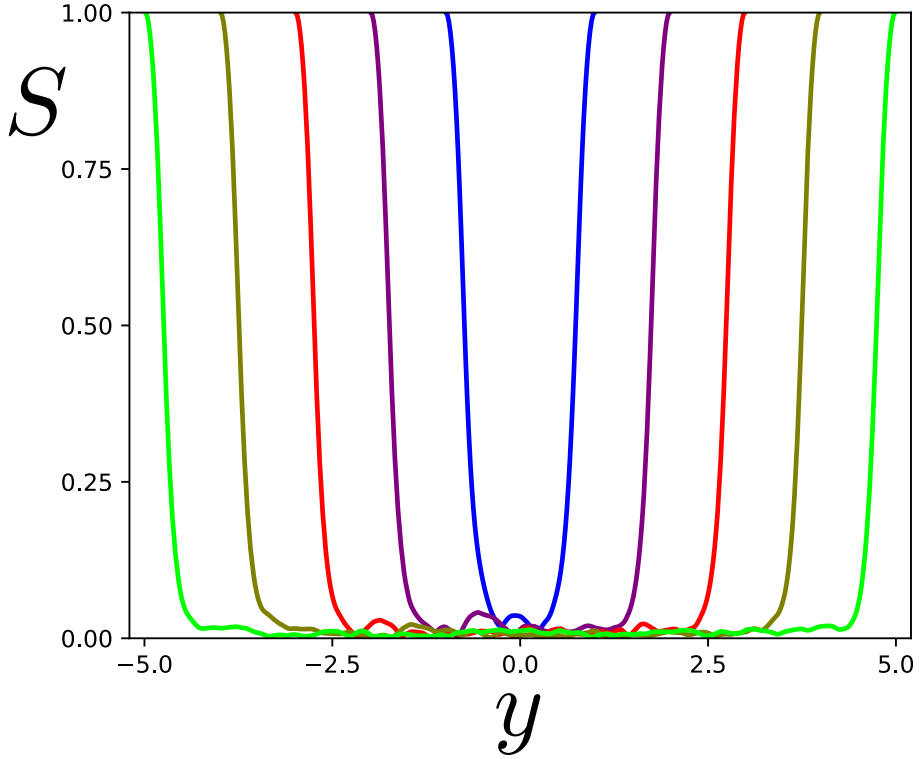


Simulate these equations on a computer

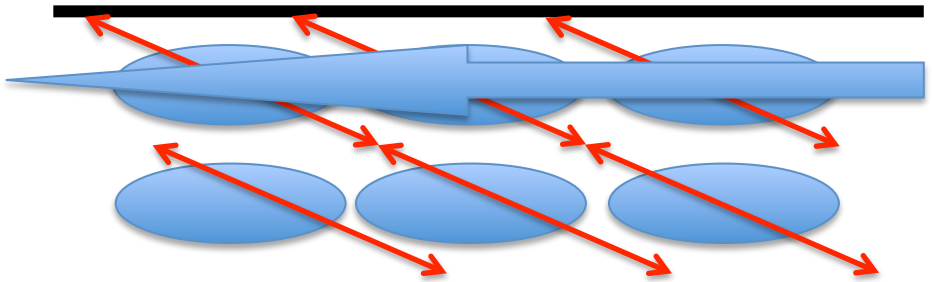


Recreates the flow and nematic profile



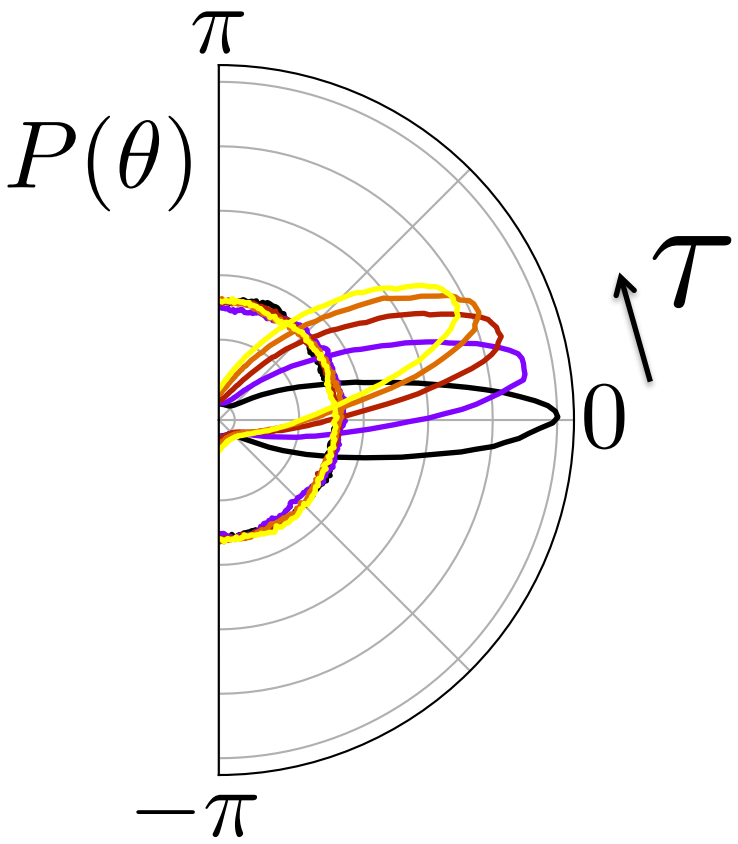


Why does this lead to boundary flows?

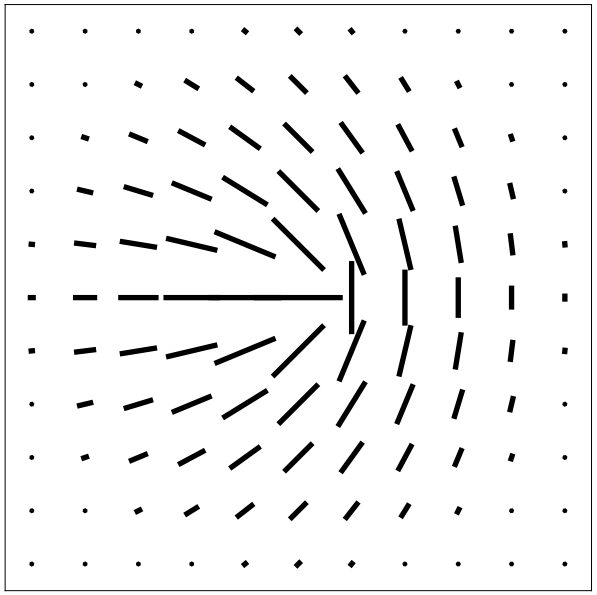


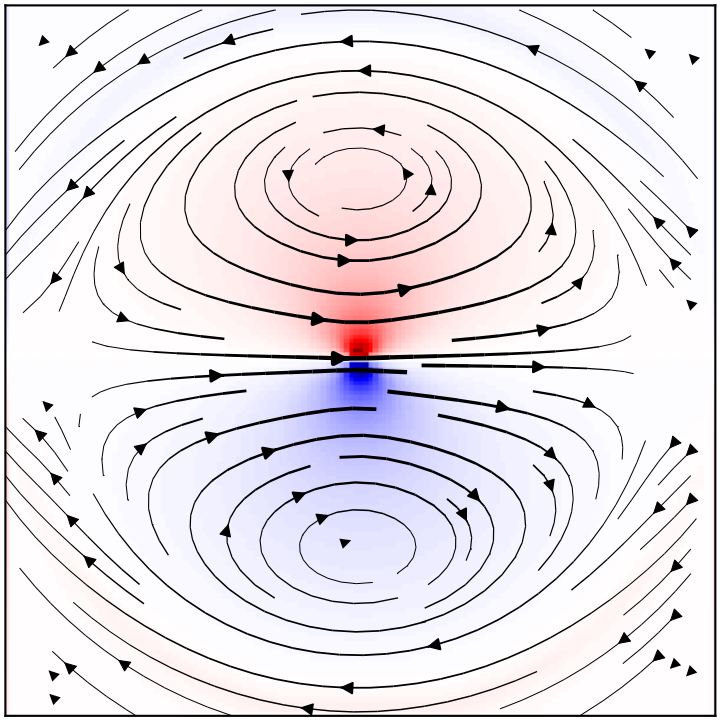
What controls the boundary width?

The angle of the cells near the boundary depends on the chiral stress



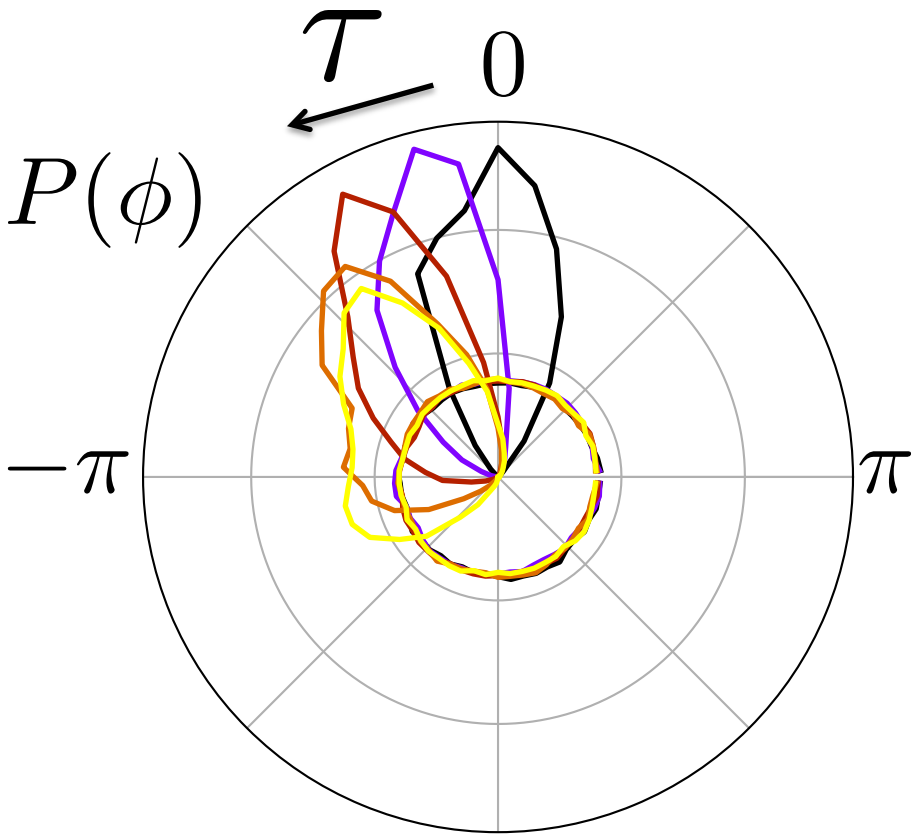
What about the topological defects?

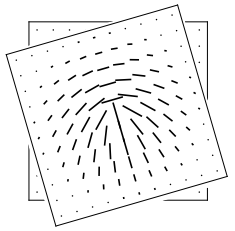


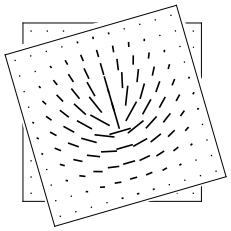


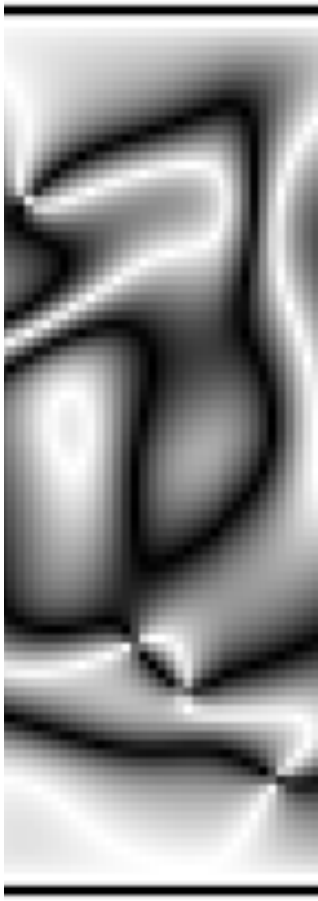
+1/2 defect

Defects are aligned near the boundaries

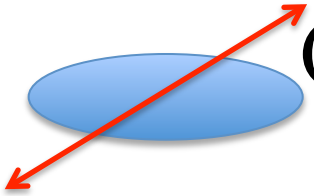




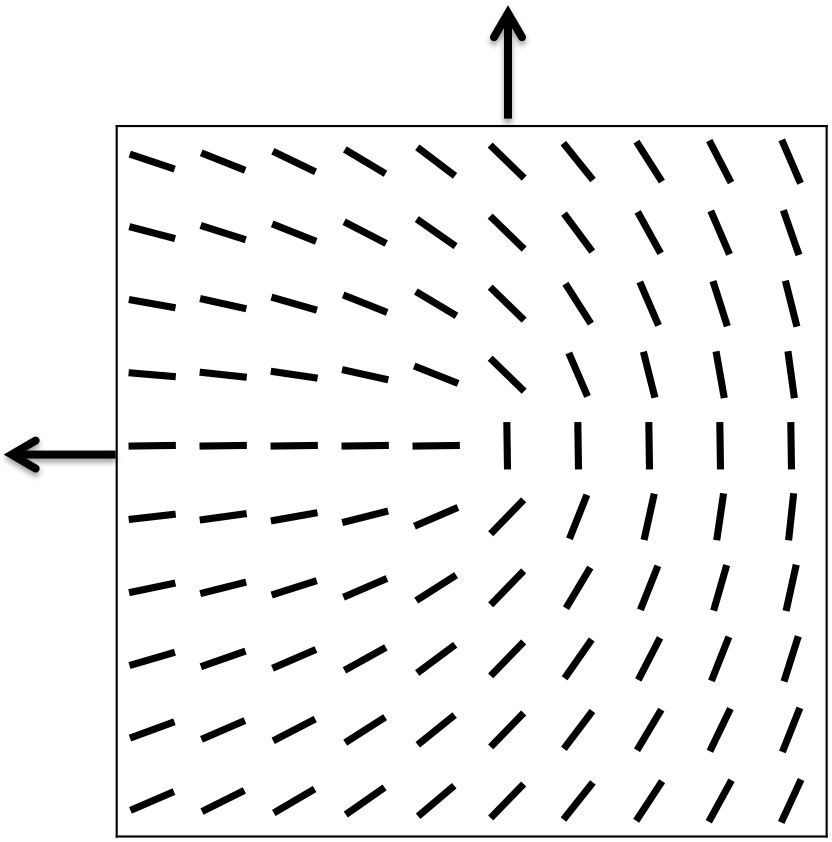




Why are the defects tilted?

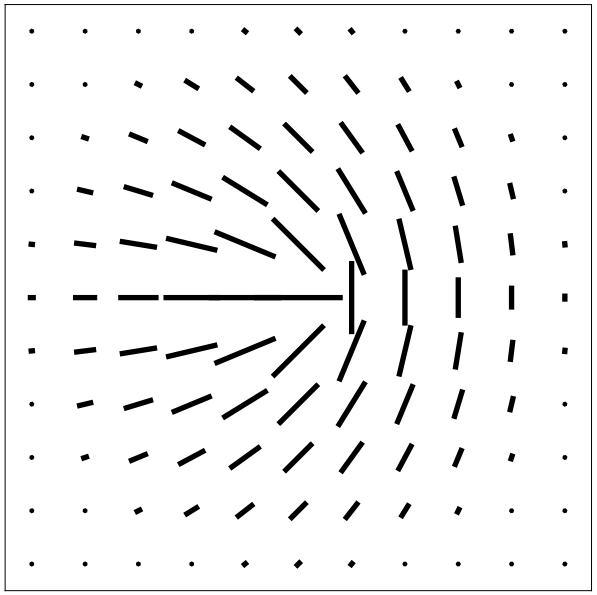


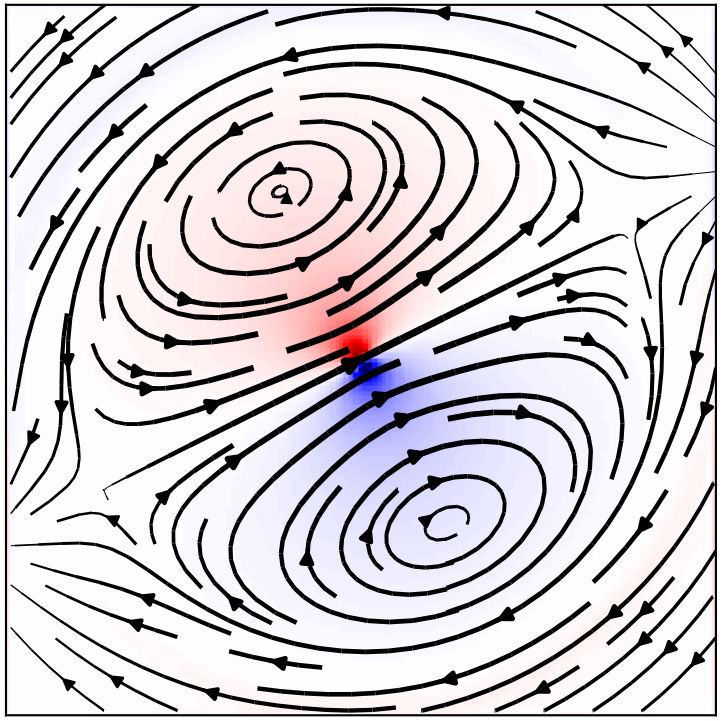
$$\Theta = \tan^{-1}(\sqrt{\alpha^2 + \tau^2})$$



$$\Delta\phi_F = 2\Delta\Theta$$

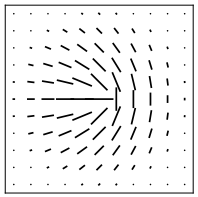
We see this in the defects

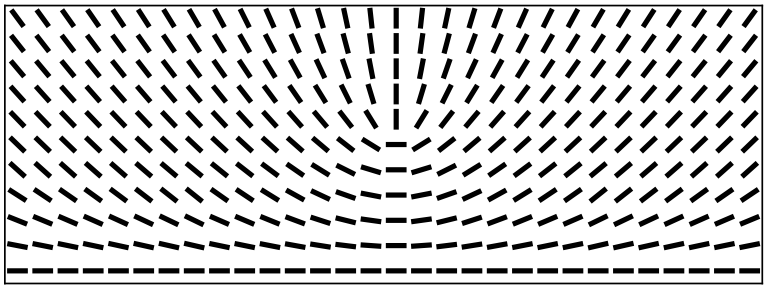


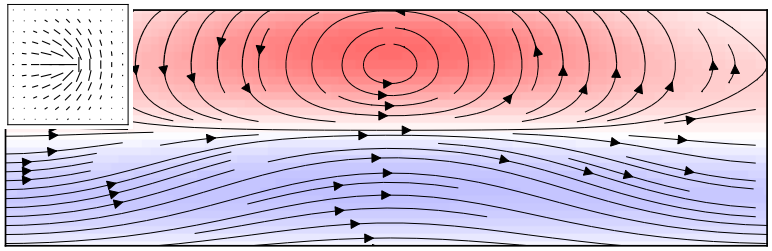


What happens at the boundaries?

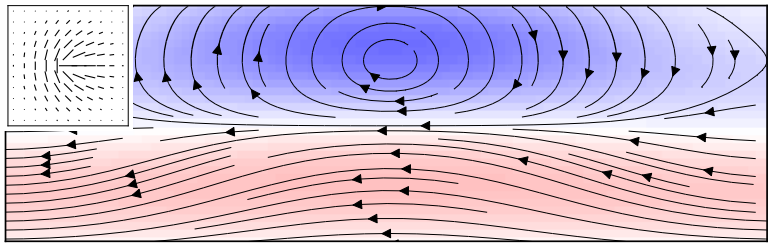
Elastic forces



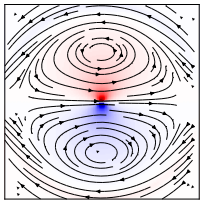


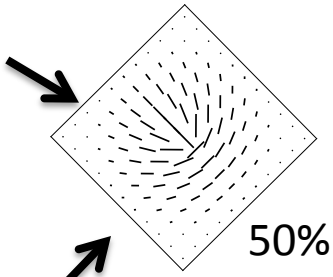


Or

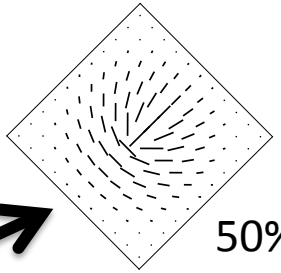


Flow alignment





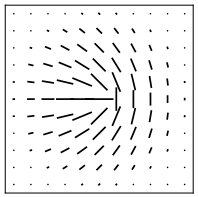
50%

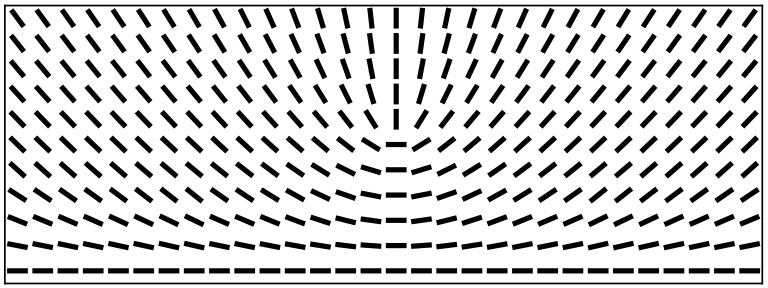


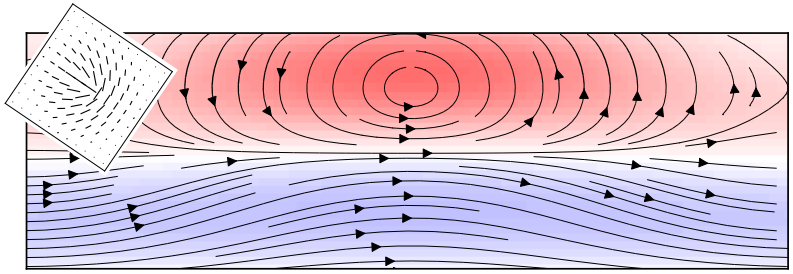
50%

But the defects are chiral

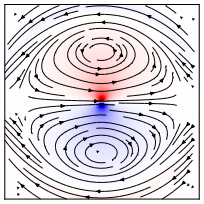
Elastic forces



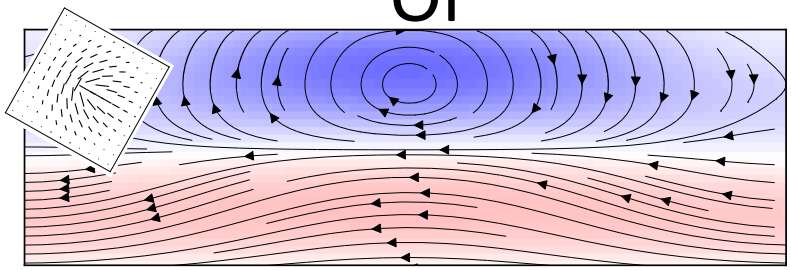


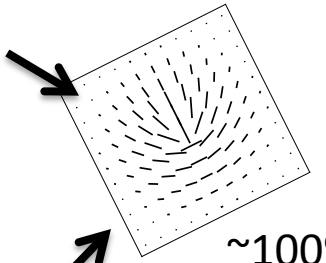


Flow alignment

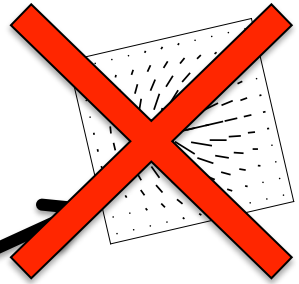


Or

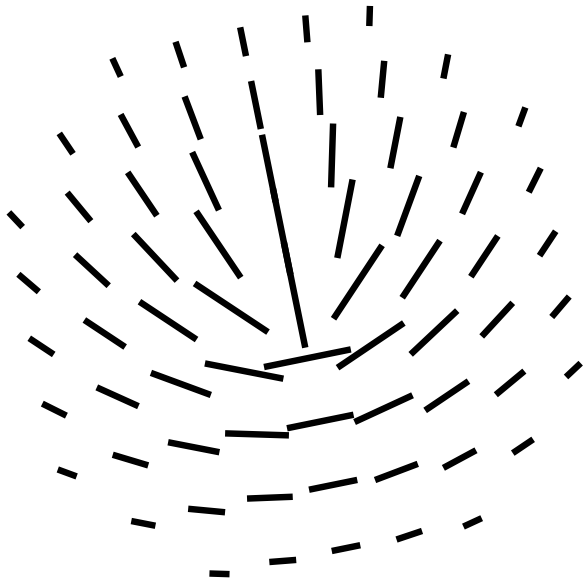




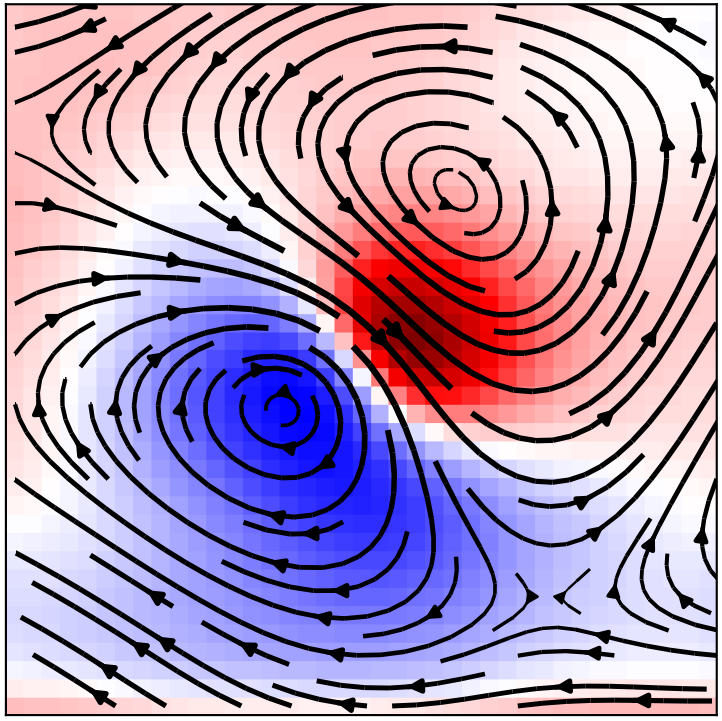
~100%



Observe this directly

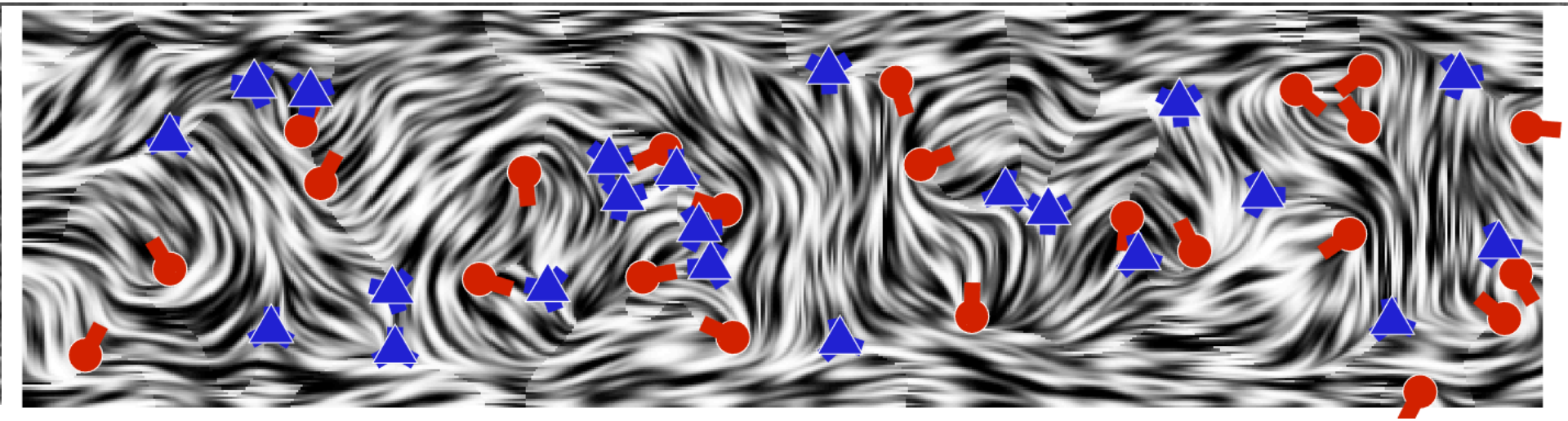


Average orientation

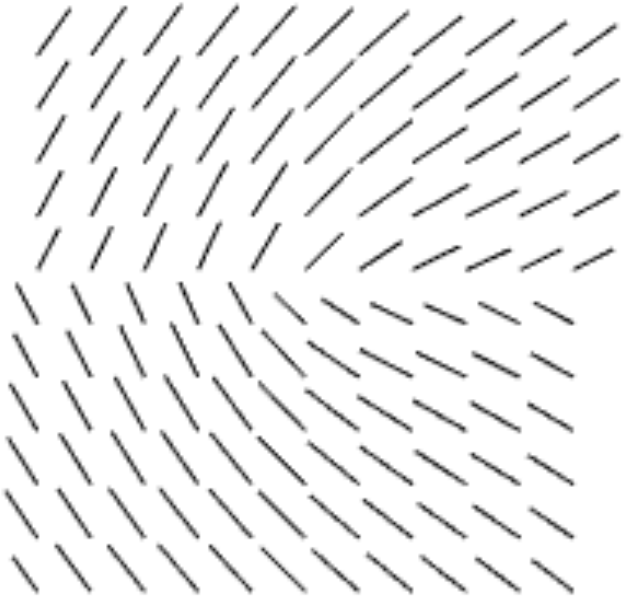


Average flow

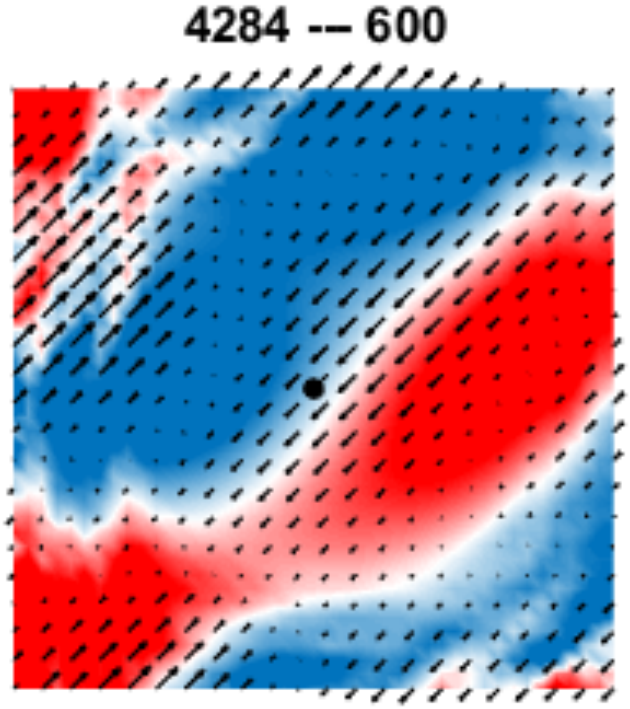
Can detect defects in the experiments



Observe chiral flows around the defects

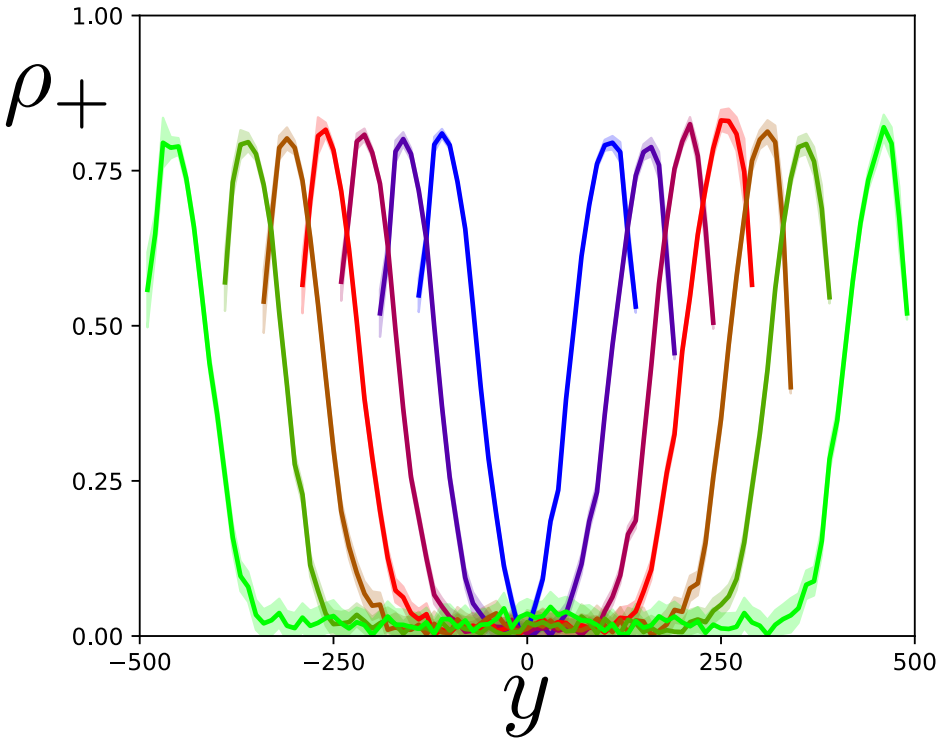


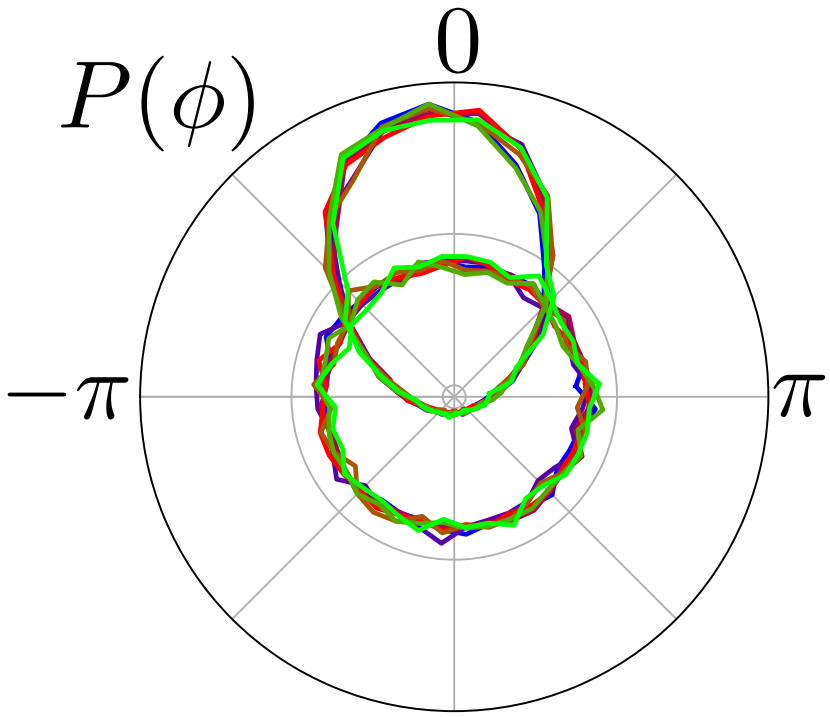
Average orientation



Average flow

Observe the same results





Conclusions

- Human fibrosarcoma cells exhibit chiral active behaviour
- This can be understood using the framework of active nematics

Acknowledgments

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