Active Nematics in Channel Networks

From bifurcations to logical gates

Zhengyang Liu, Claire Doré, Antonio Tavera-Vazquez, Teresa Lopez-Leon

Workshop Defects and Self-Organization
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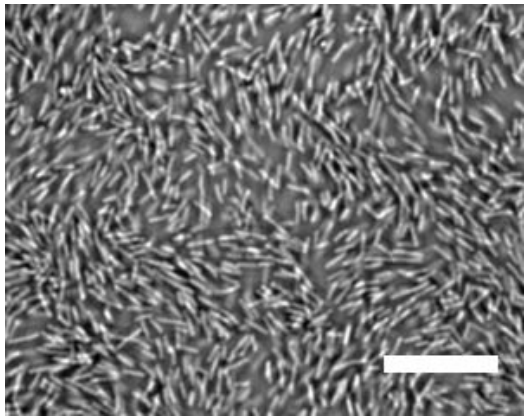
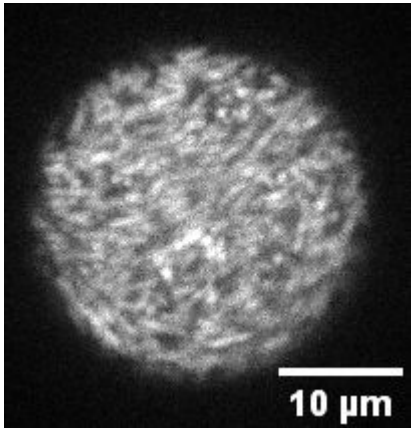
About me

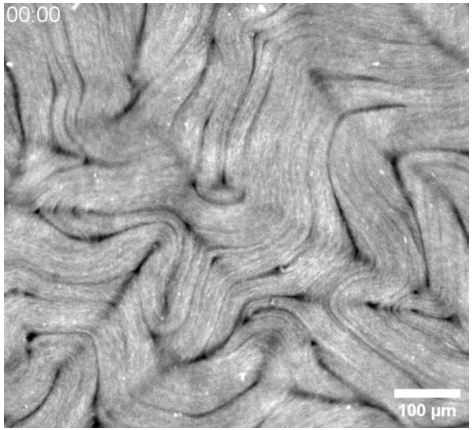
2015 - 2021
PhD
University of Minnesota
With Xiang Cheng



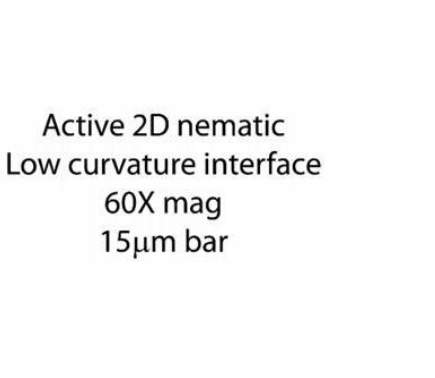
2021 - 2022
Postdoc 1
PMMH, ESPCI
With Eric Clement and Anke Lindner



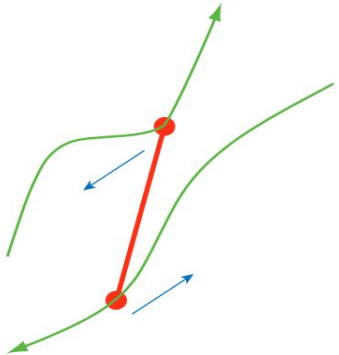
2022 - present
Postdoc 2
Gulliver, ESPCI
With Teresa Lopez-Leon



Active nematics

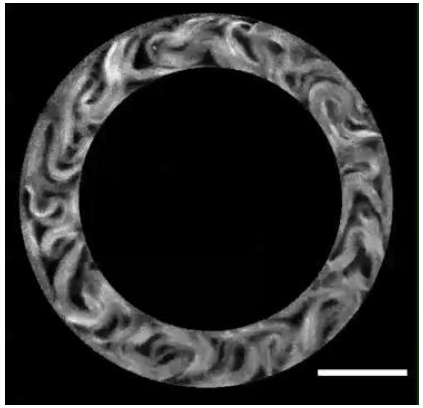


Sanchez et al. 2012

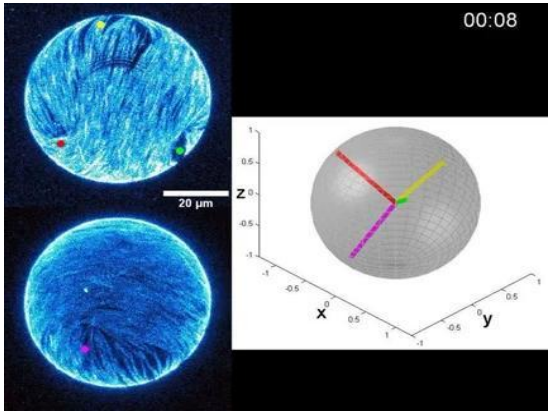


Ramaswamy et al. 2010

Confinement



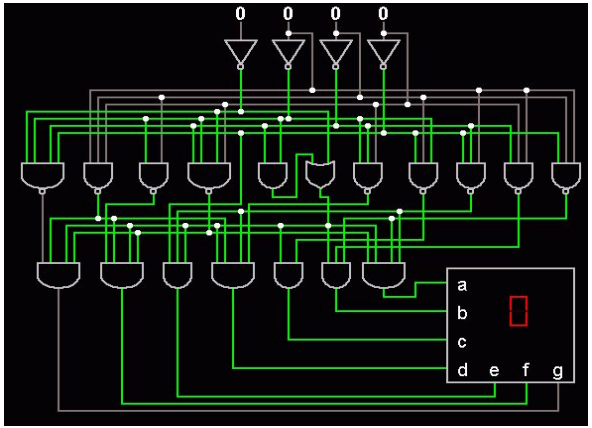
Hardoüin et al. 2020



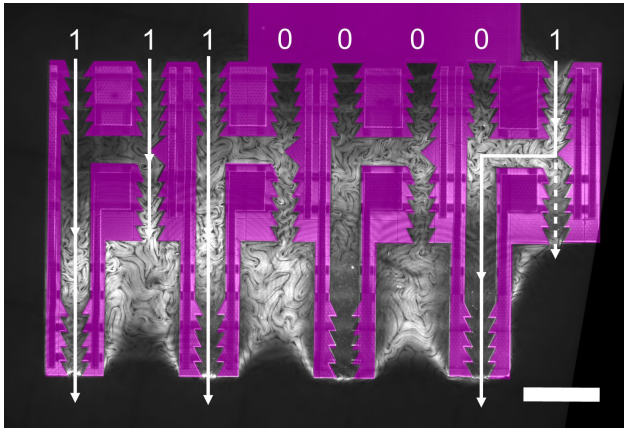
Keber et al. 2014

Can we apply these properties to more complex tasks?

Make flow to “think”

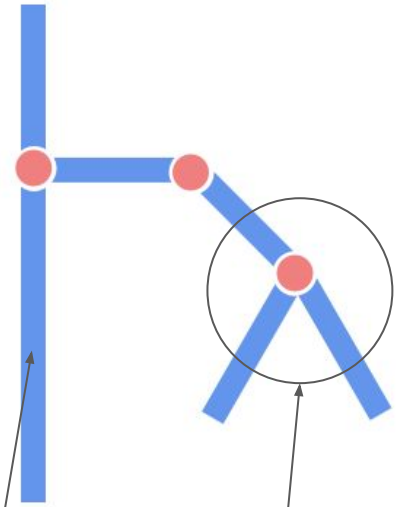


https://www.vivaxsolutions.com/physics/allogicgates.aspx



electrical current -> Active nematic flow

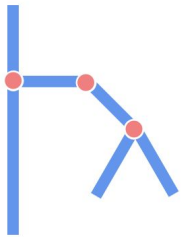
Active flow networks (AFN)



A collection of interconnected **channels** and **bifurcations**, with active matter flowing inside.

Theoretical framework of AFN

$$H =$$



Key points

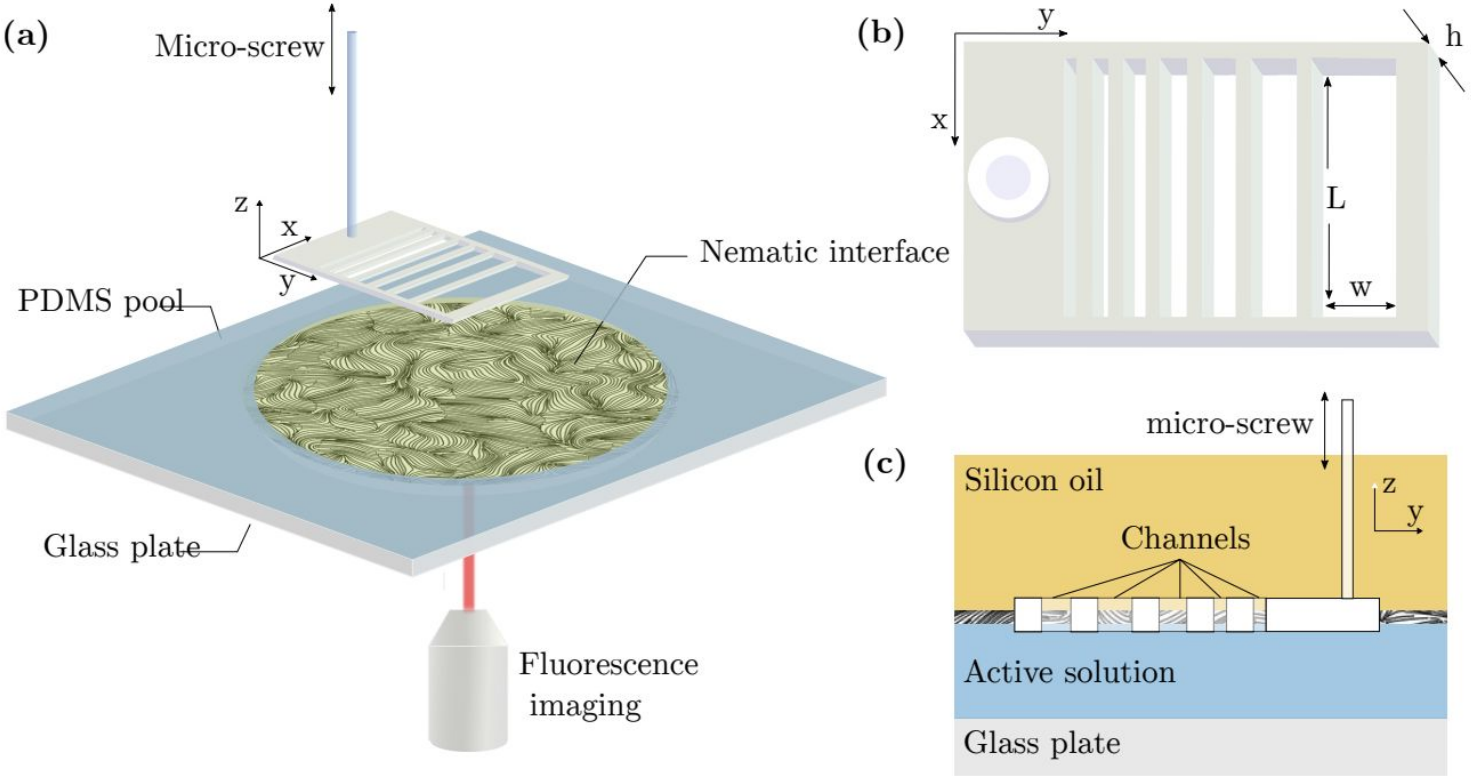
1. Channels: double-well potential
2. Bifurcations: has to choose one direction (polarized state)

$$\mathrm{d}\mathbf{\Phi} = -\nabla H \mathrm{d}t + \sqrt{2\beta^{-1}}\mathrm{d}\mathbf{W}_t$$

"Brownian motion" in the energy landscape

Woodhouse et al. 2016 and 2017

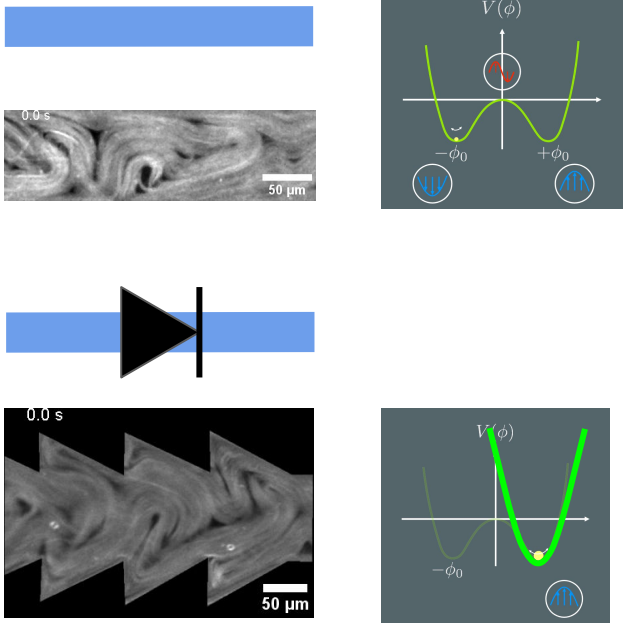
Experiment



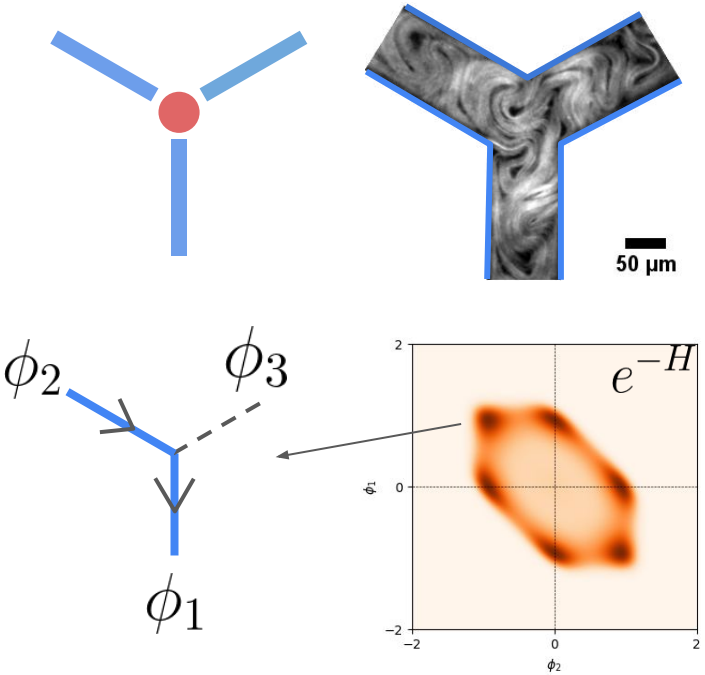
Hardoüin et al. 2019

AFN: channels and bifurcations

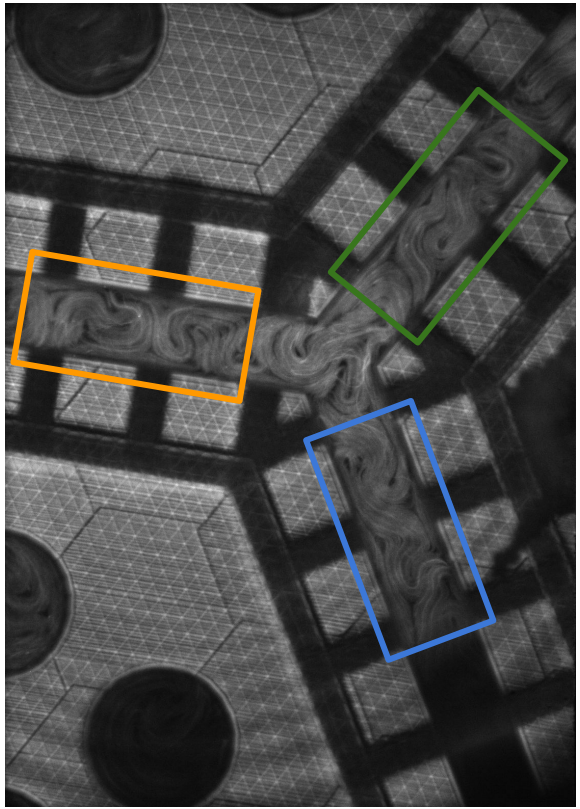
Channels



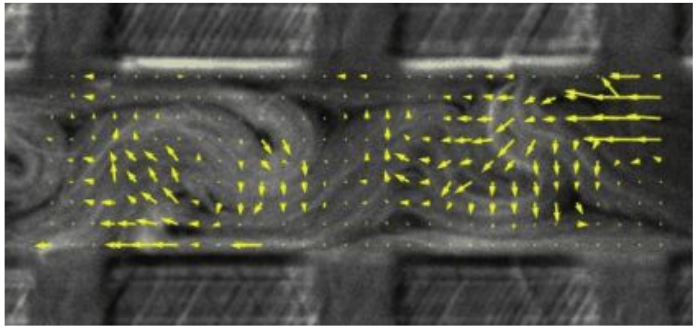
Bifurcations



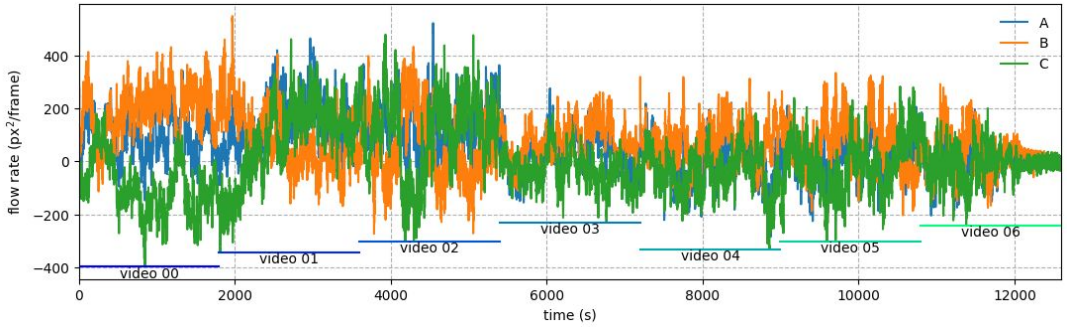
Flow rate measurement



Particle image velocimetry (PIV)

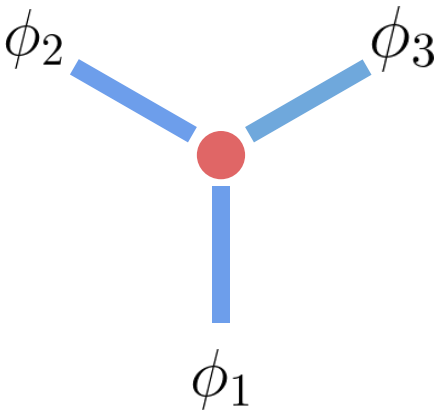


$$\langle Q \rangle = \frac{1}{L} \int_0^L \int_{x_1}^{x_2} v_y(x,y) \mathrm{d}x \mathrm{d}y$$

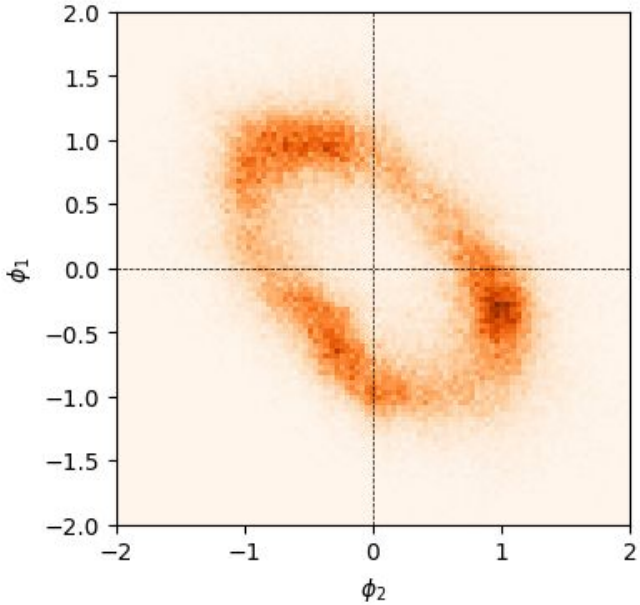


Symmetric straight channels

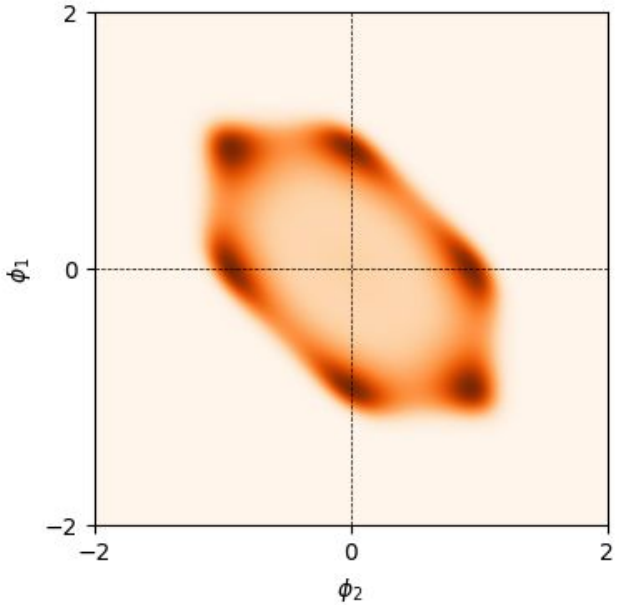
- Does polarized state arise?
  Yes, and also higher energy states with splitting flows. Not all states are equally probable.



experiment

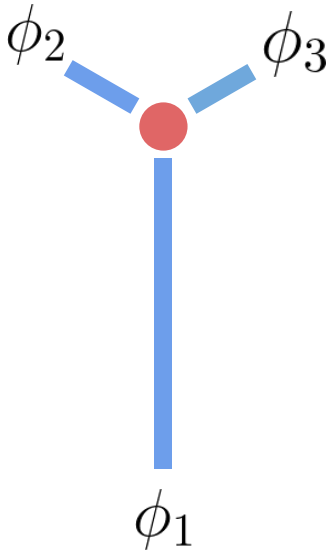


theory

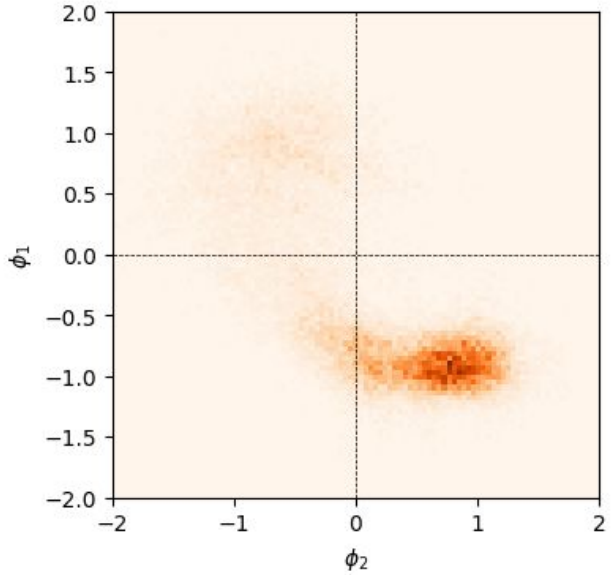


Length effect: extra-long channel

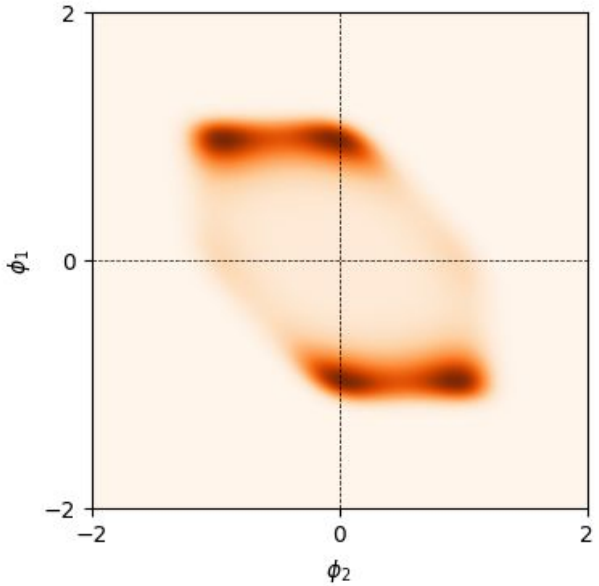
- Does polarized state arise?
  Yes, and longer channel increases the probability of polarized states.



experiment

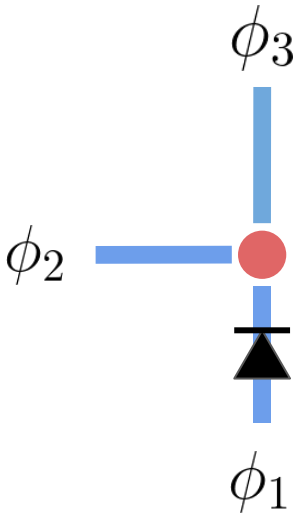


theory

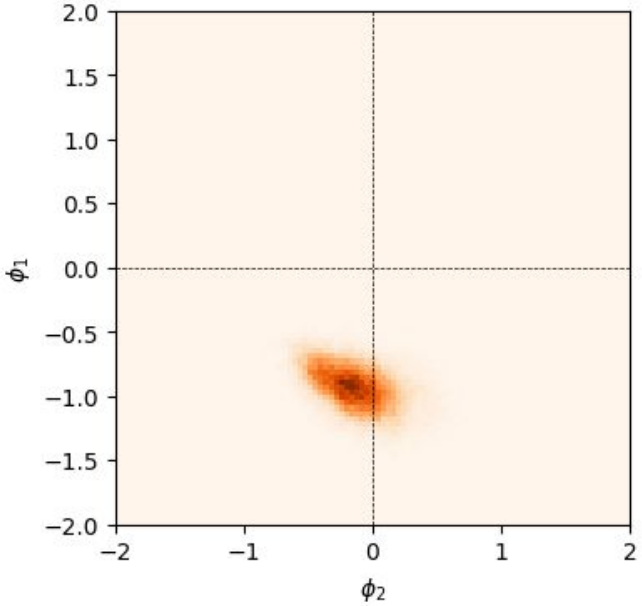


Angle effect

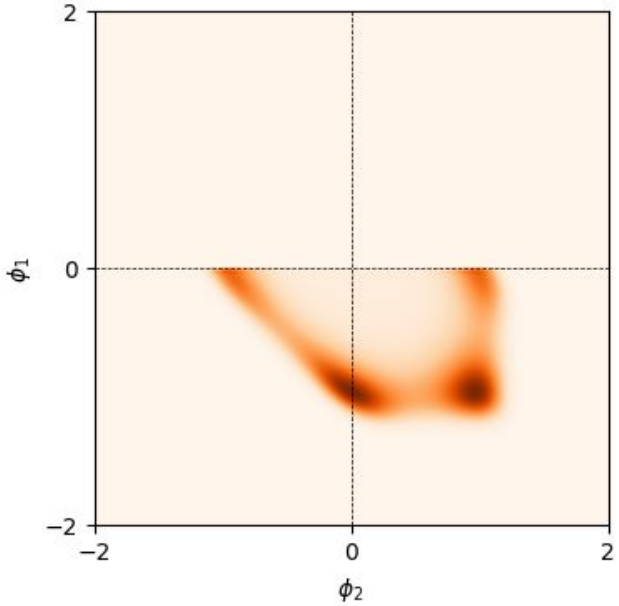
- Does angle matter?
  Yes, turning at angle is much less likely than flow straight.



experiment

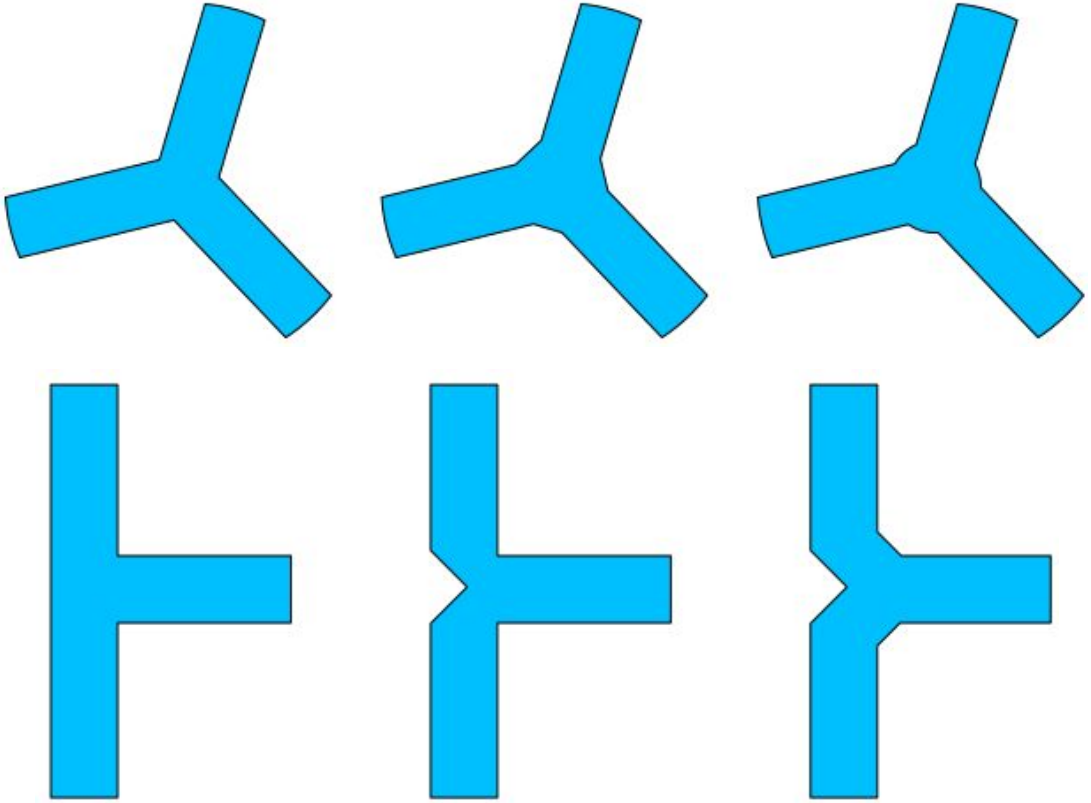


theory

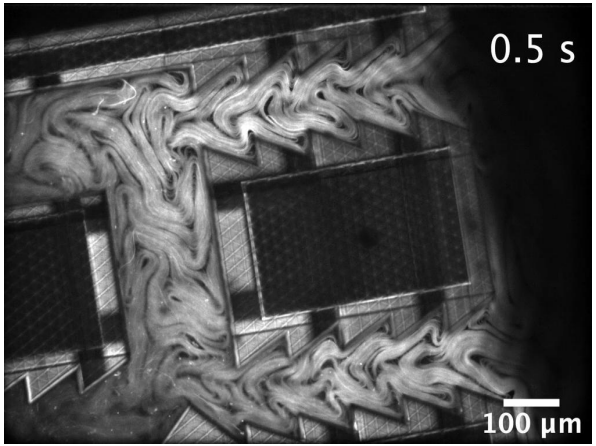


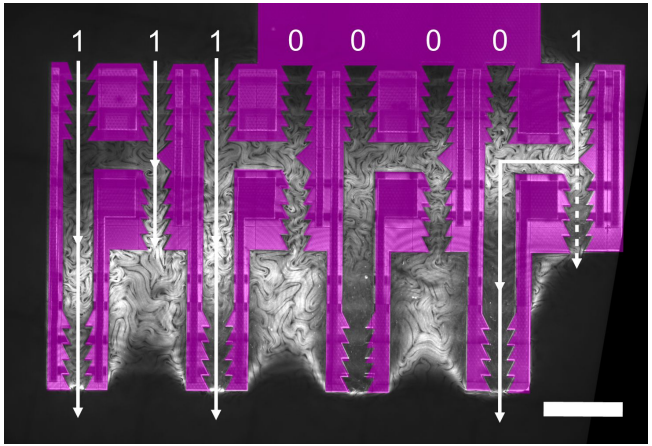
Node geometry

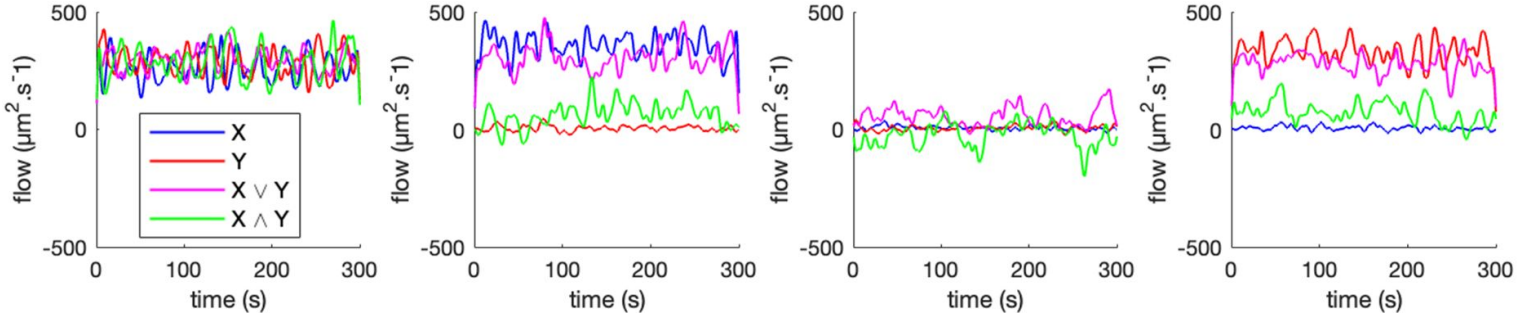
- Does node geometry matter?
  We plan to investigate this.



Preliminary realization of active matter logic










Thank you!

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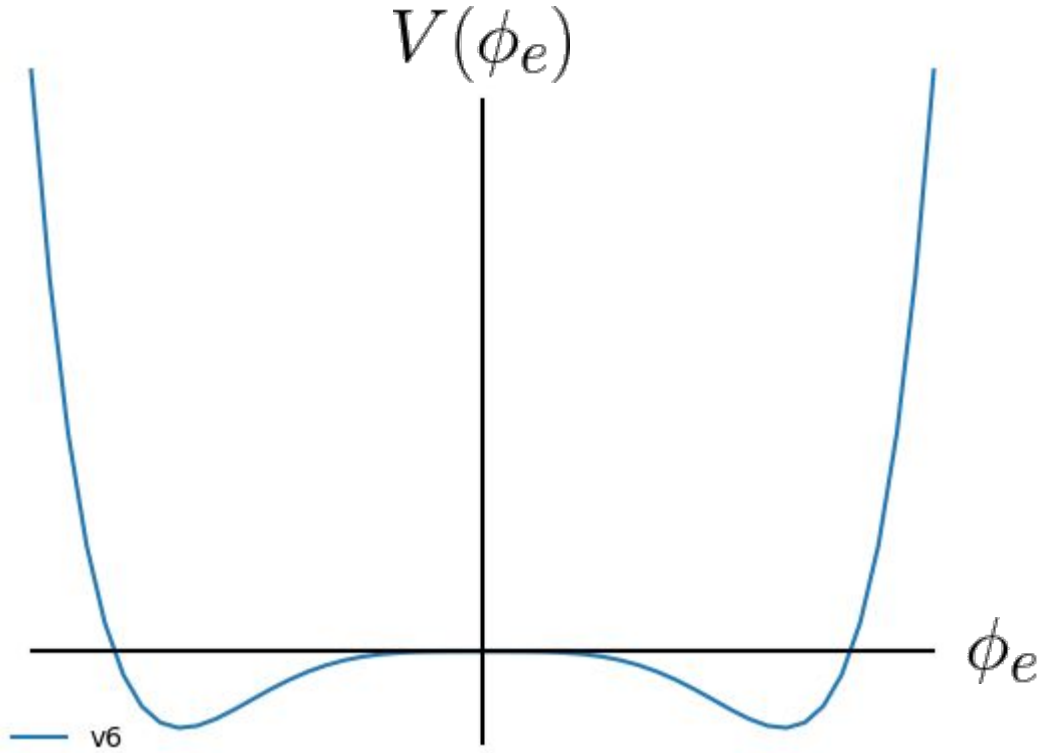
Double well potential for channel flow rate

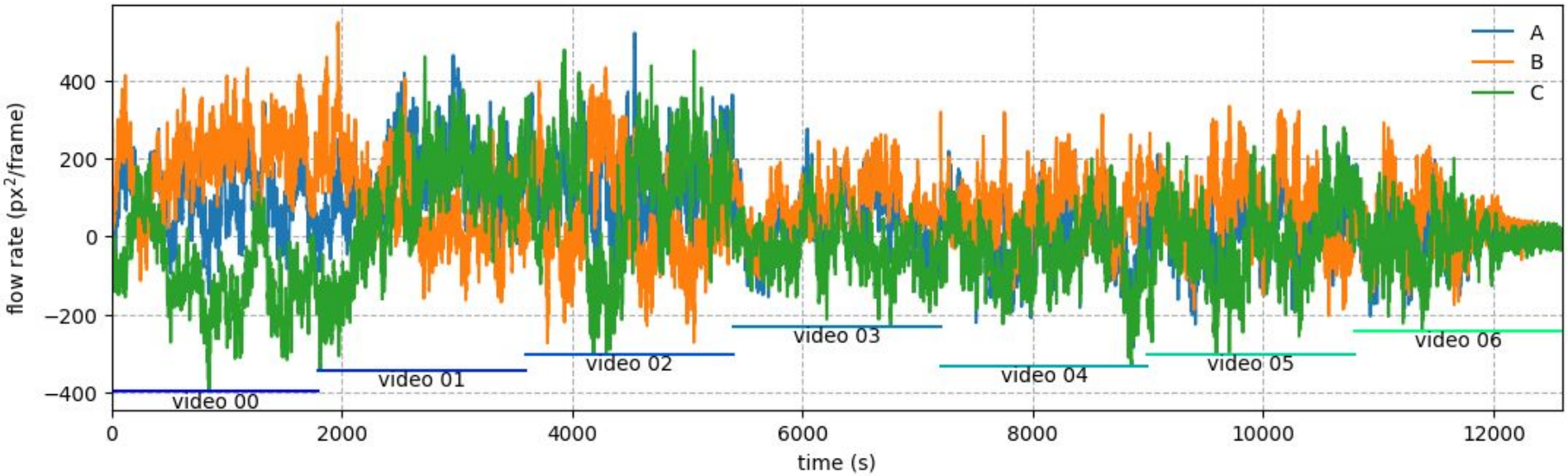
$$V(\phi_e) = -\frac{1}{4}\phi_e^4 + \frac{1}{6}\phi_e^6$$



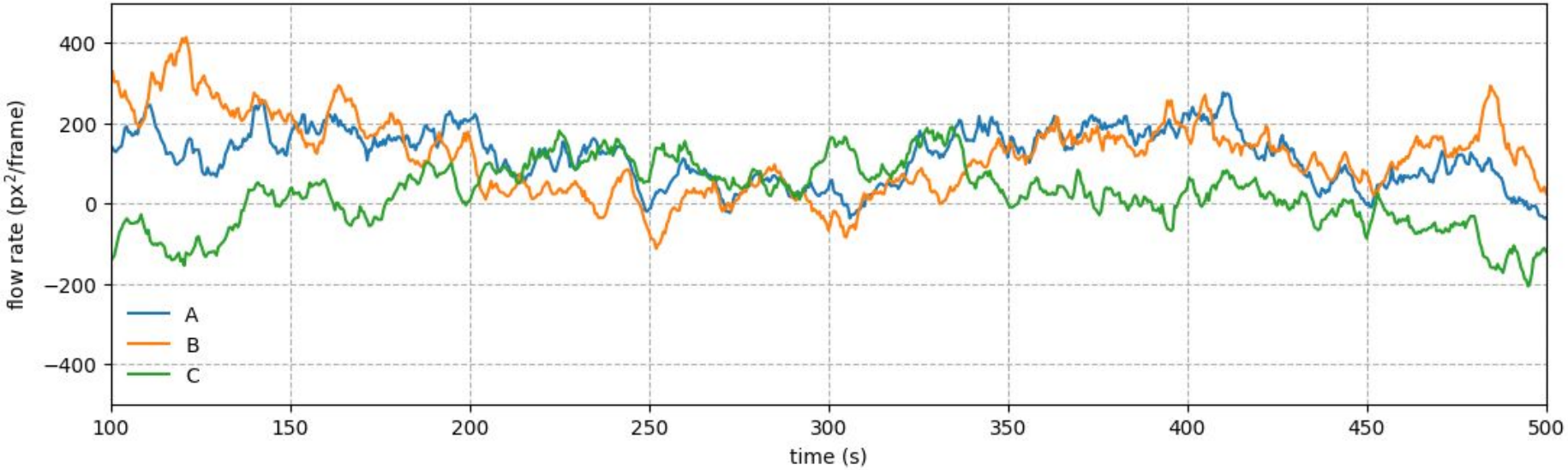
Example data is from Jan 19, 2023, but the features are quite generic.

Why normalize?

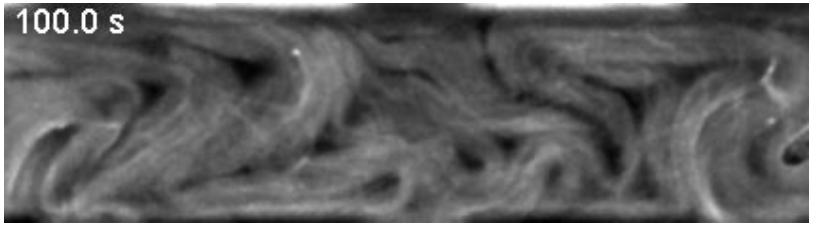
- Long-time fluctuations in flow rate is the nature of AN
- Different samples can have drastically different overall activity



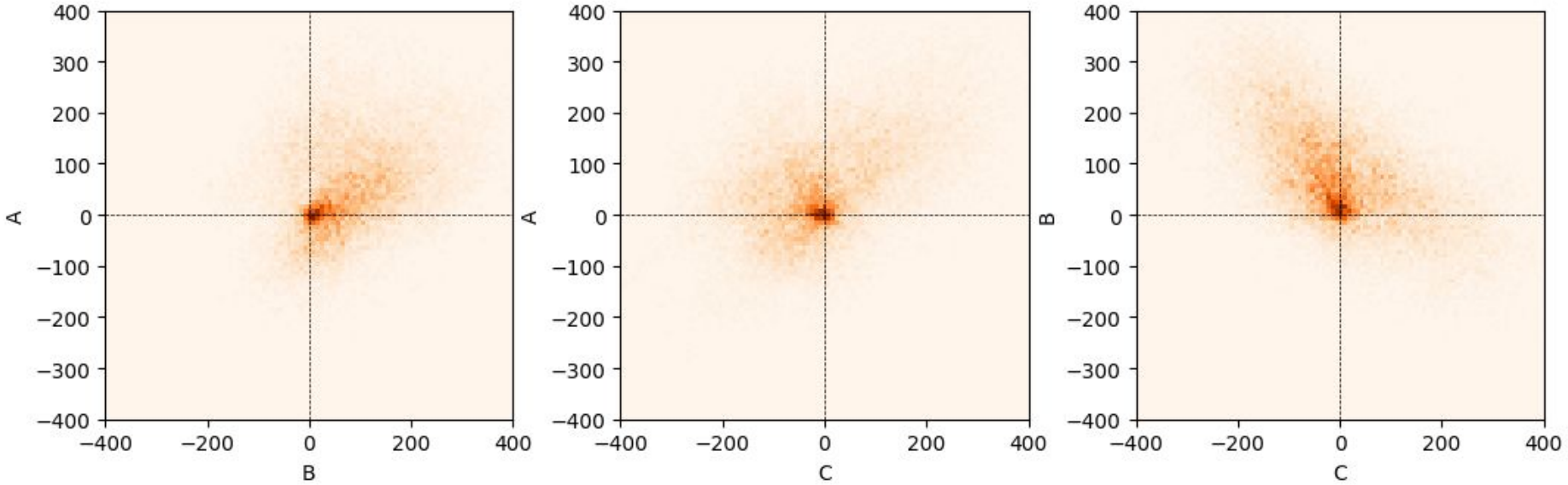
Zoom in [200, 400] (s), what happened?



Channel A:

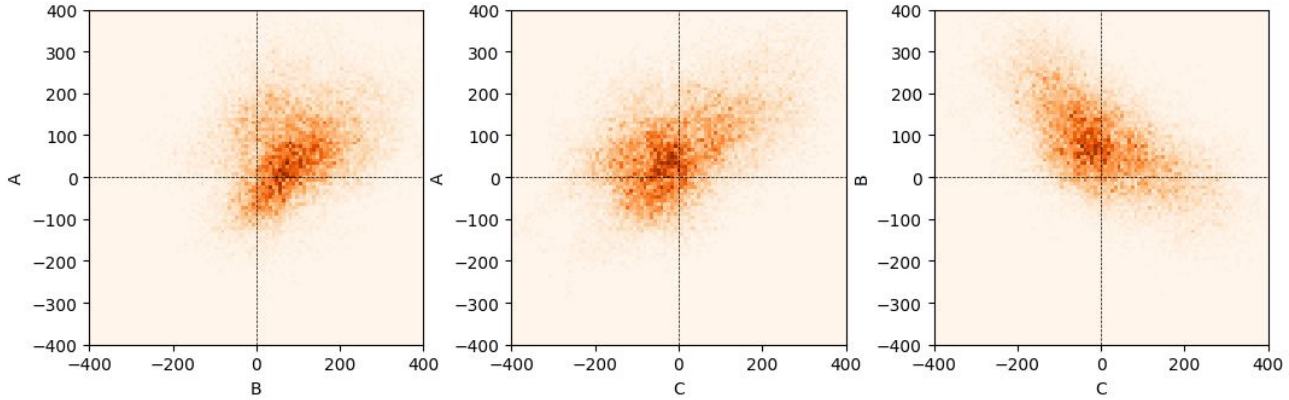


Histogram in physical units, unnormalized (2 samples)

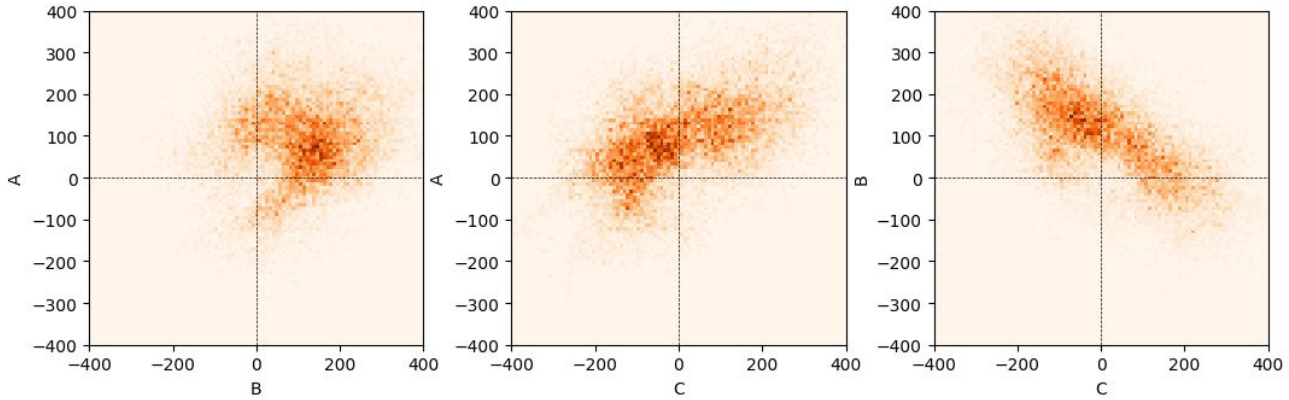


Require max velocity > threshold (e.g. 50 or 100)

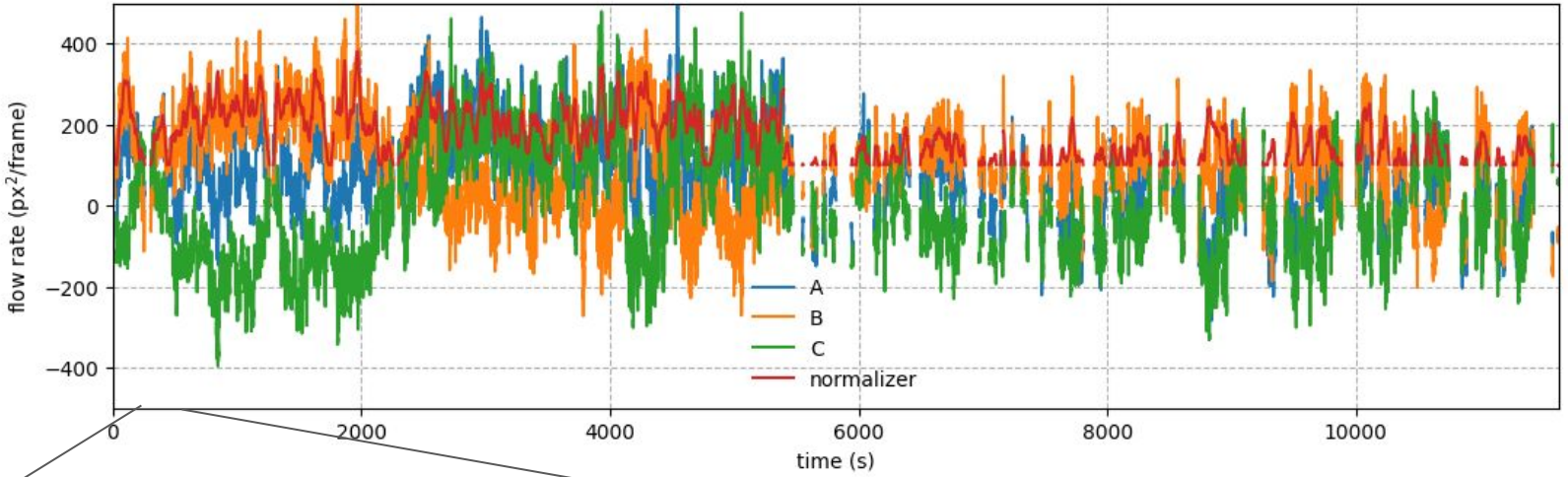
> 50

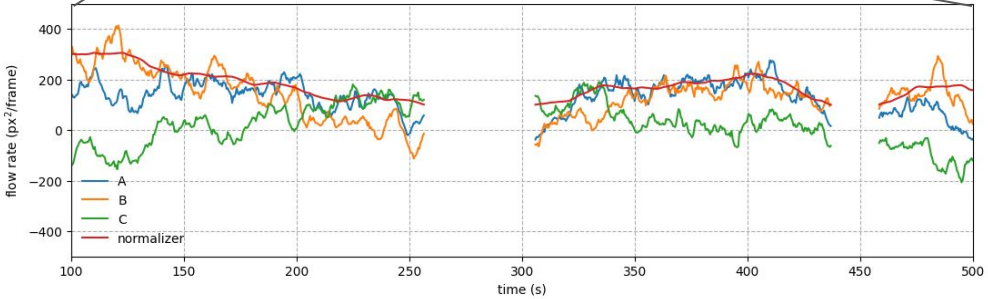


> 100



Who’s dropped?

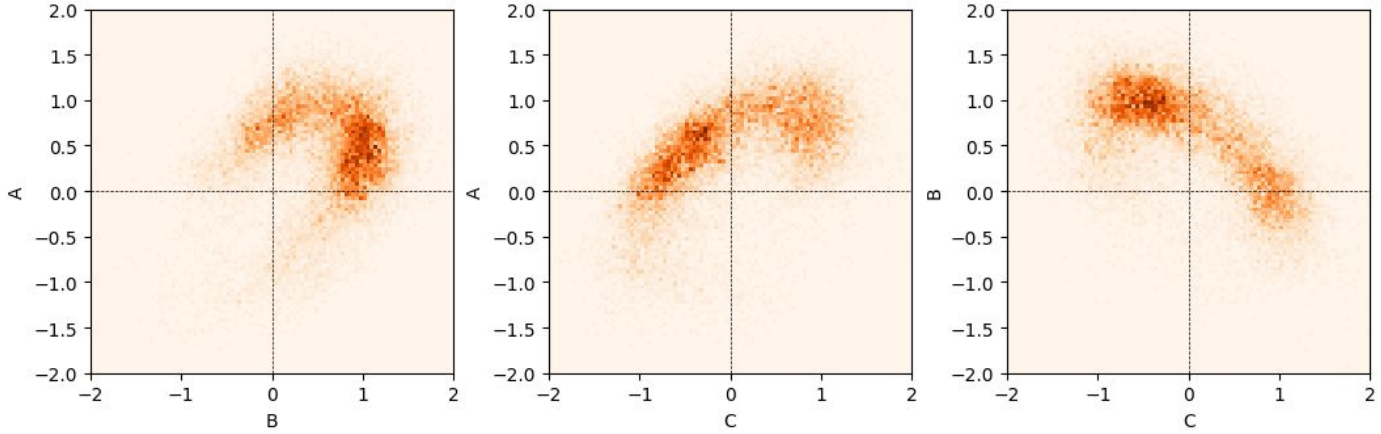




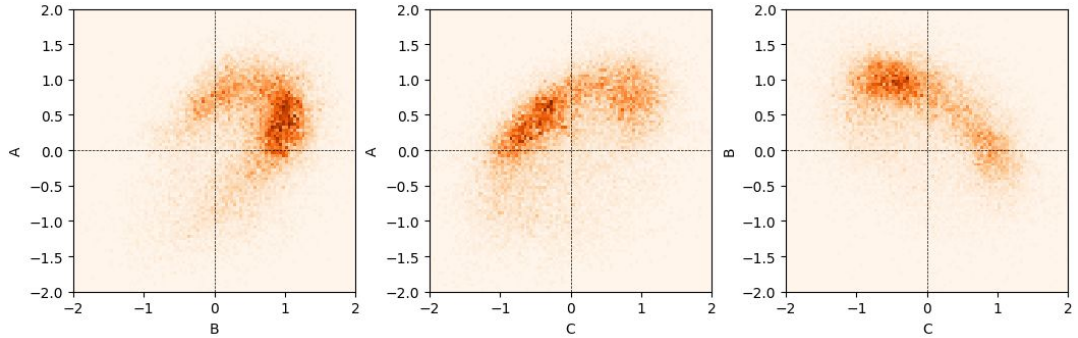
A small fraction of data

Normalize based on thresholded flow rate (>100)

>100



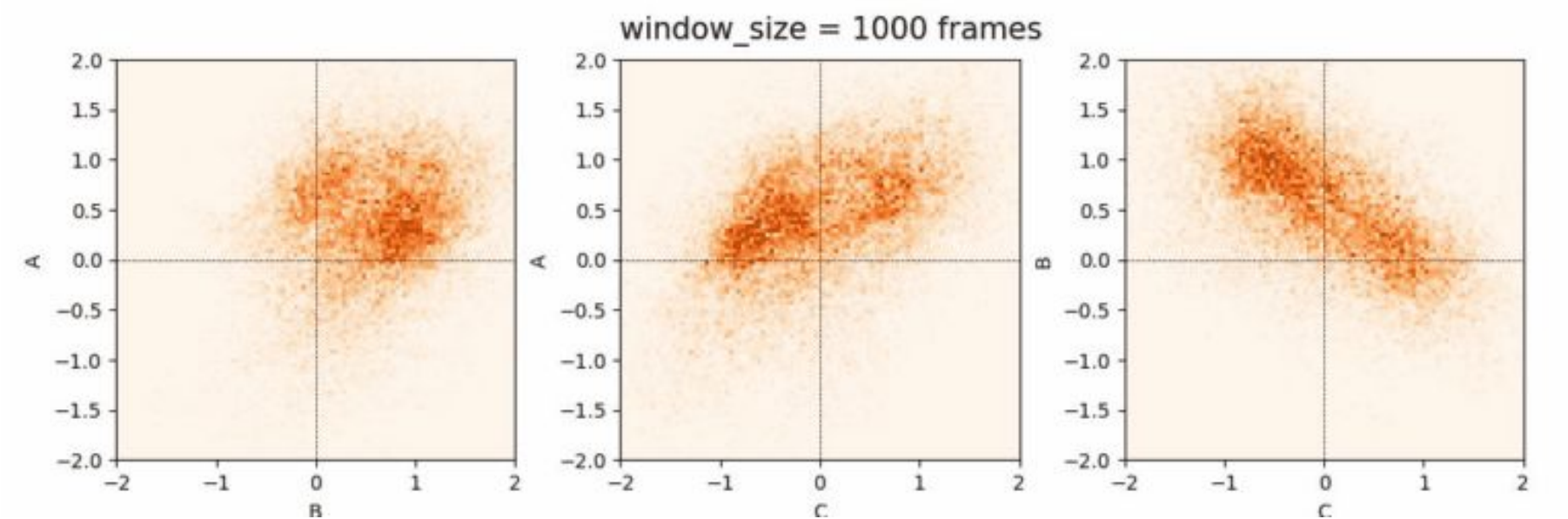
all



W = 50 frames

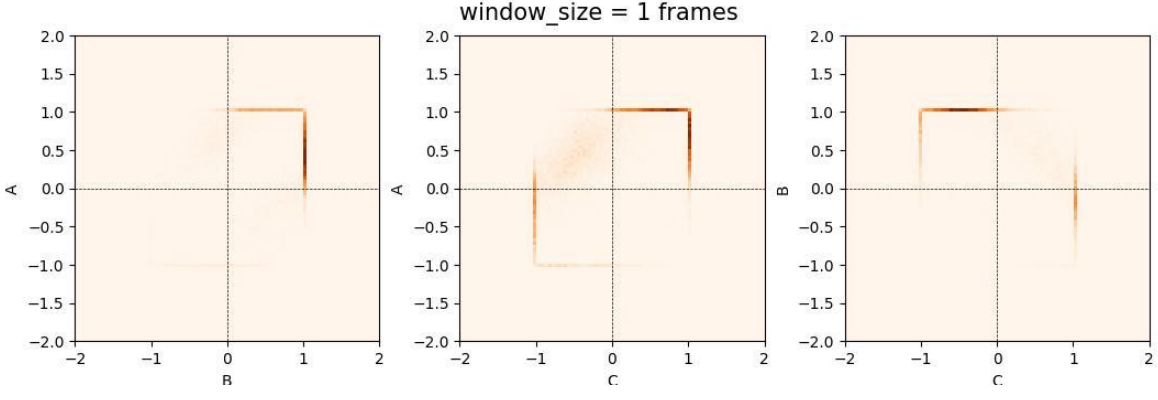
Visualize the averaging window size

- A smooth transition from scattered points to a elliptical contour

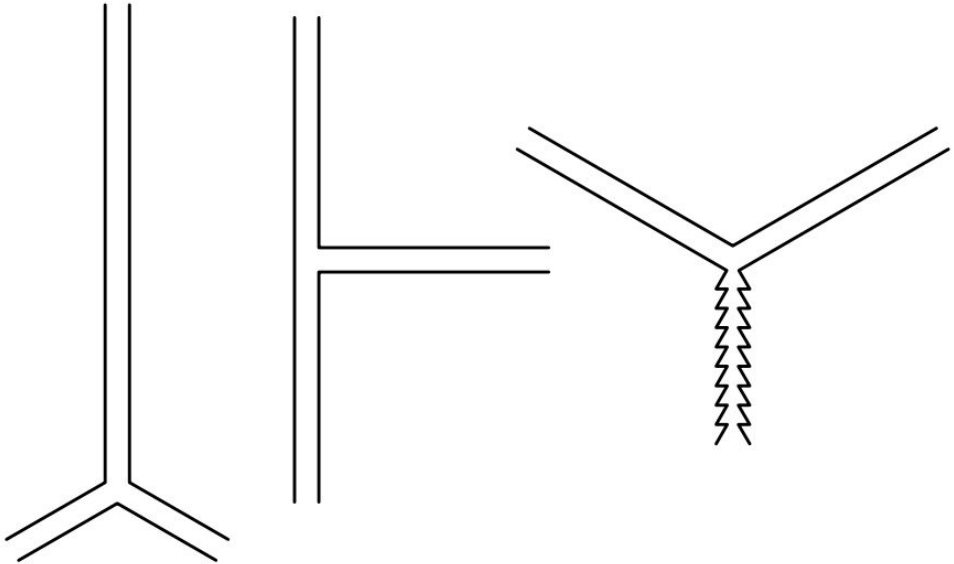


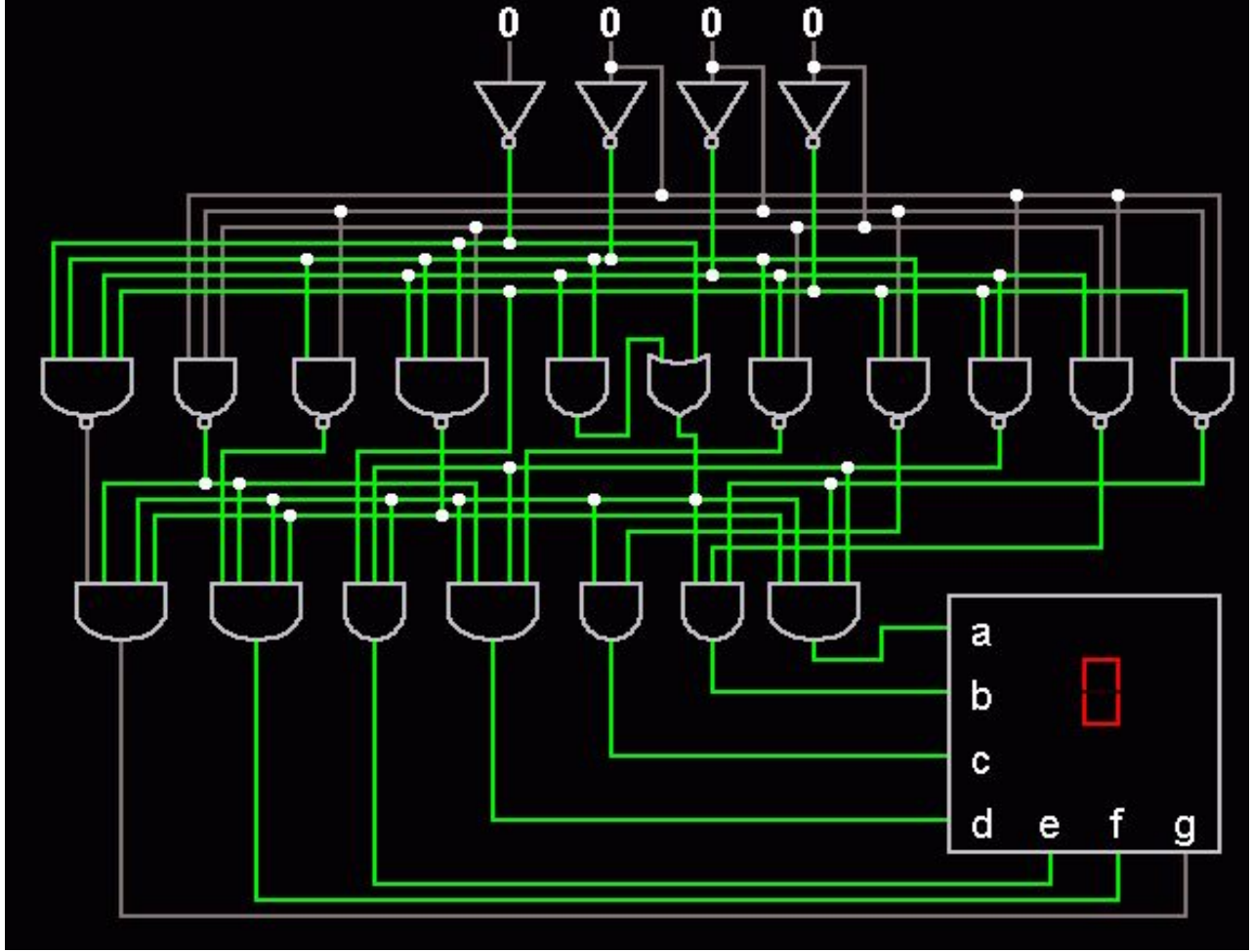
My interpretation of the ellipse

Choosing small averaging window size reveals an ellipse on 2D histogram. This ellipse appear because most flow rate data satisfy mass conservation. When w=1, we use the largest instantaneous absolute velocity as the normalizer. If we observe on a histogram that neither flow rates (say A, B) is 1, it implies that the other flow rate (C) is ±1, mass conservation enforces A, B flow rate to be on the line A+B=±1, which forms two lines on the elliptical contour.



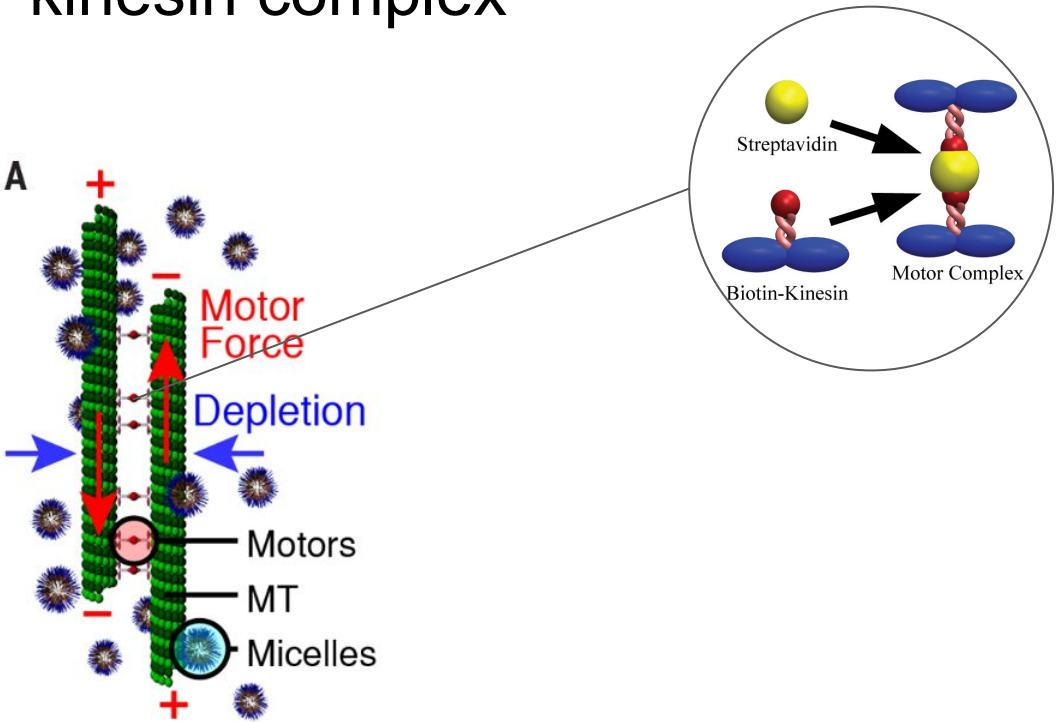
Future directions





https://www.vivaxsolutions.com/physics/allogicgates.aspx

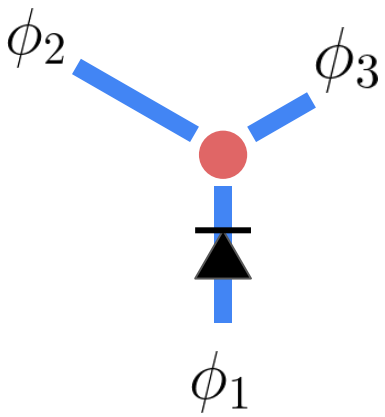
Microtubule + kinesin complex



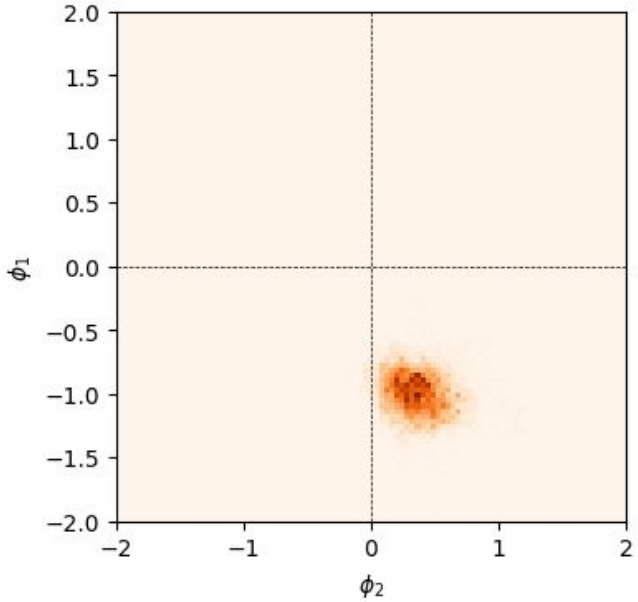
Microtubule + kinesin
Wu et al. 2017

Length effect

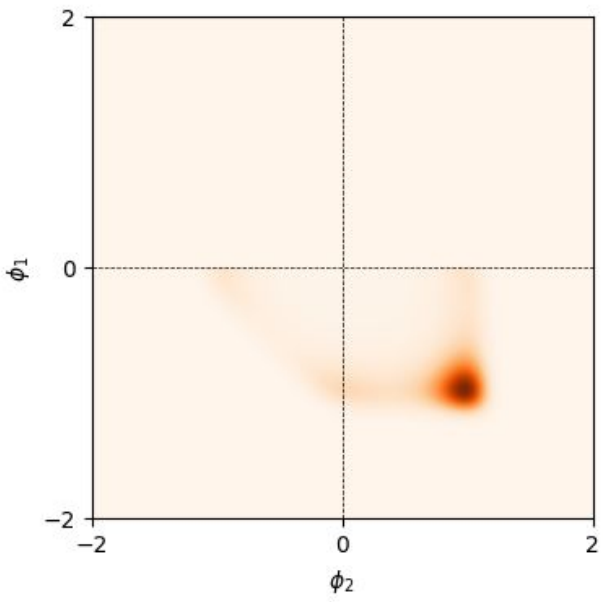
- Does polarized state arise?
  Yes, but not the same as predicted.

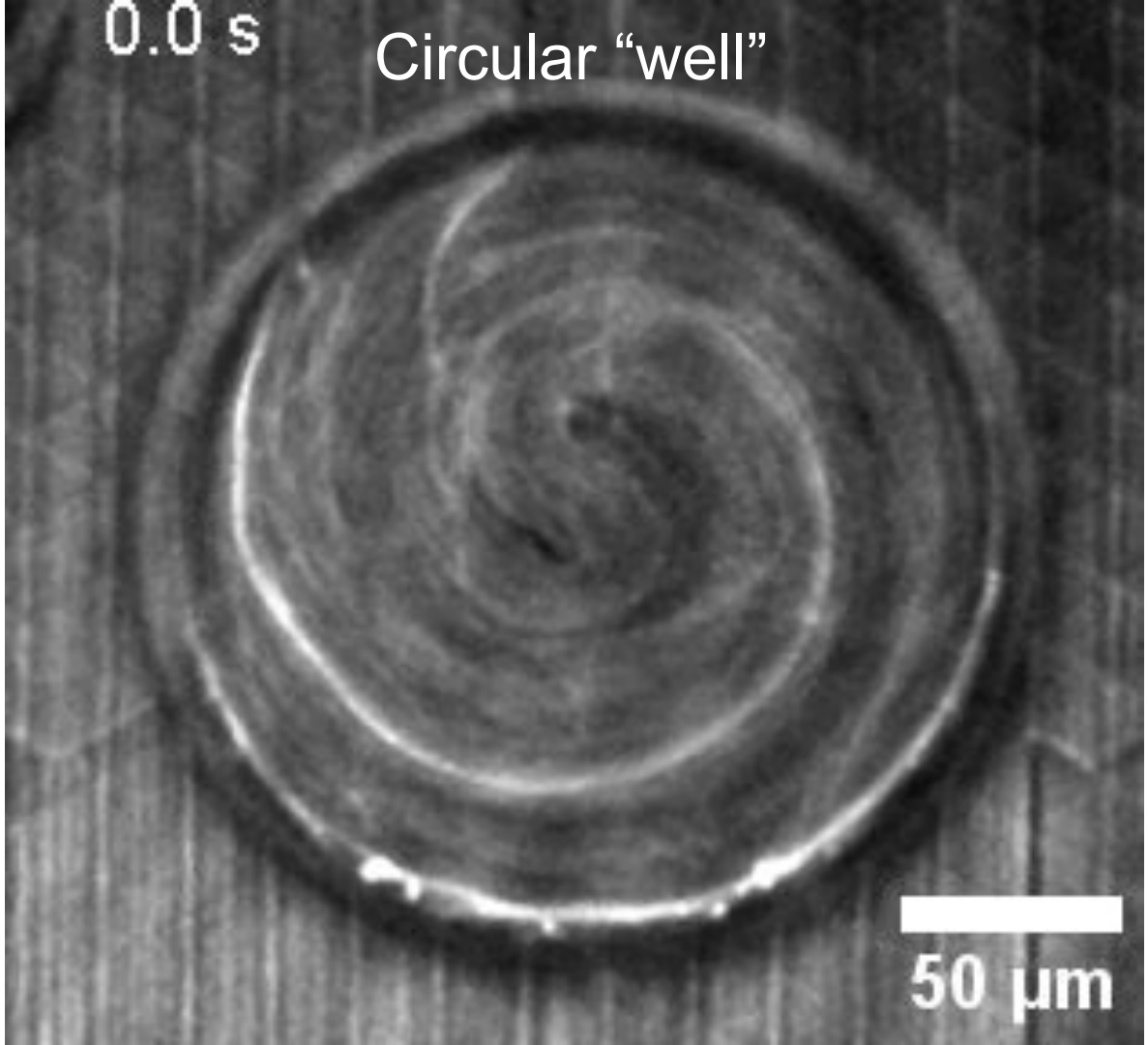


experiment



theory




0.0 s
Circular “well”
50 µm