Polar pattern formation by filaments gliding on (flat and curved!) lipid membranes

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You can also visit vimeo.com/558478323 for a video version of this poster!

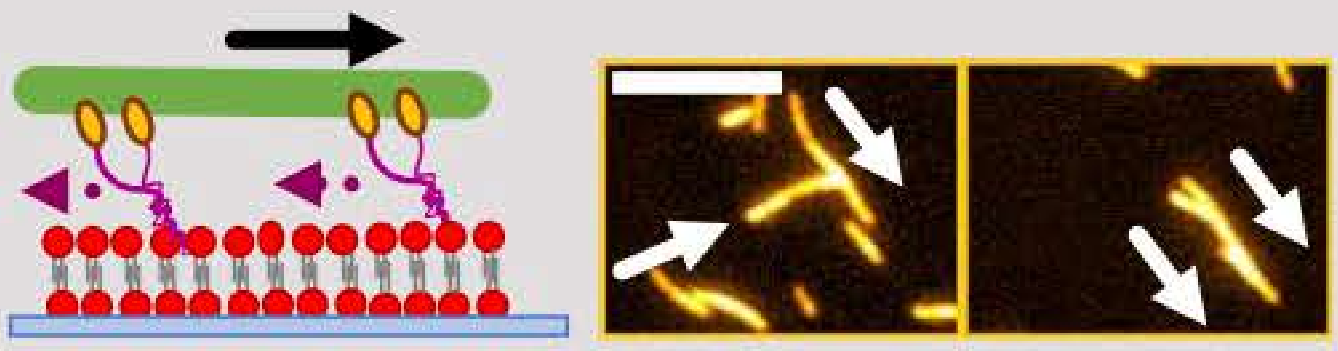
Introduction: *filaments gliding on a membrane exhibit* ***nematic*** *alignment*

The properties of collective patterns depend strongly on the agents' shape and on the specific velocity-aligning mechanism between them. For example, actin filaments propelled by molecular motors stuck on a glass surface are known to align very weakly during binary collisions. However, at high density, multi-particle collisions can still lead to macroscopic order (forming patterns such as density waves and nematic lanes).

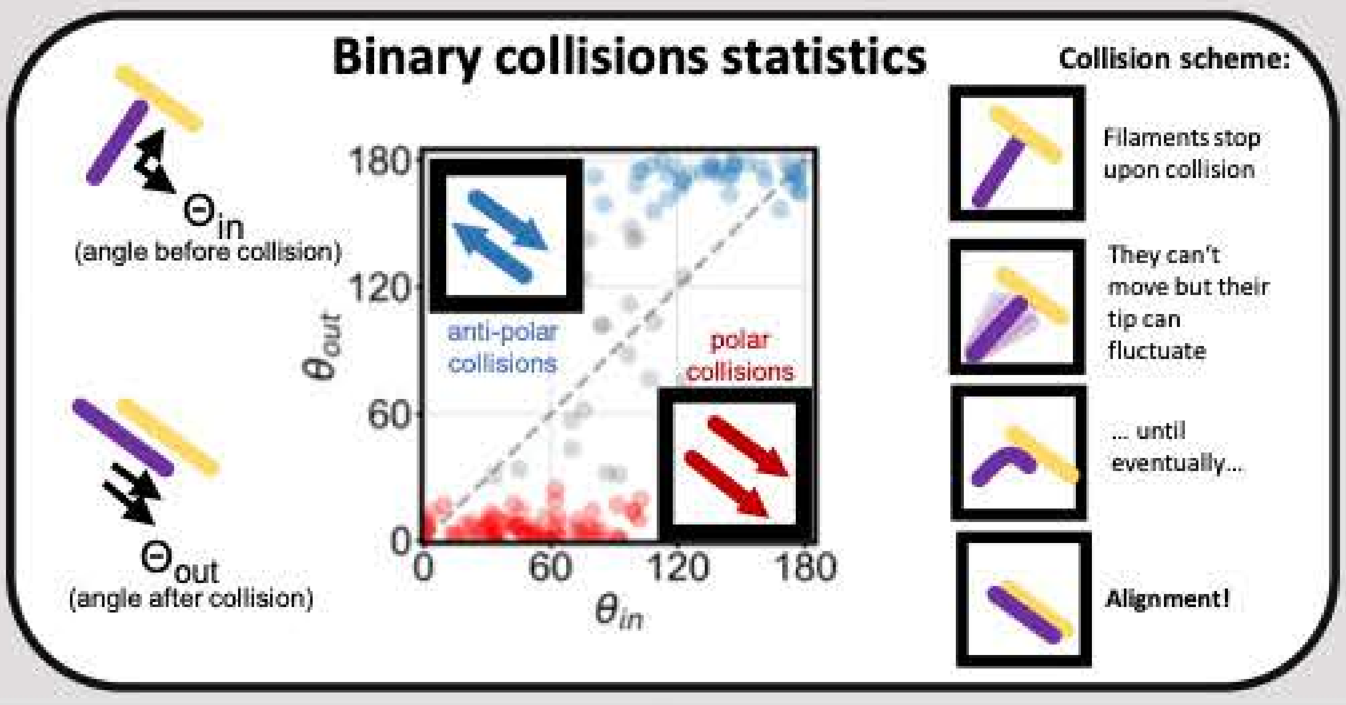
Can we modify this simple system to see what happens if, instead, filaments strongly align?
What would then be corresponding macroscopic order?

To answer this question, we introduce a system of **gliding filaments on a fluid membrane** (supported lipid bilayer or SLB). Because motors now slip on the fluid membrane they push less effectively. Therefore, filaments **stop** and eventually **strongly align** upon collision. We describe the emerging structures and find out they are **polar** despite the microscopic nematic symmetry.

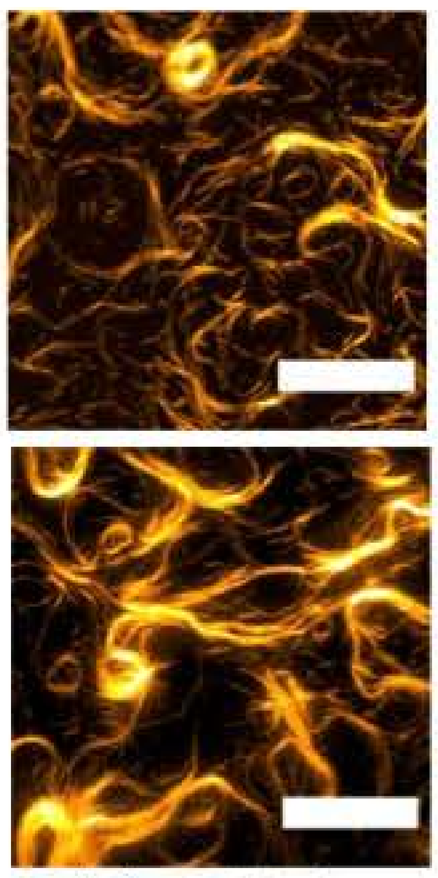
We then also identify polarity sorting mechanisms, including one based on +1/2 nematic defects, and study the effect of confinement inside giant vesicles (GUVs). We also perform experiments featuring passive defects to further prove their polarity sorting effect.



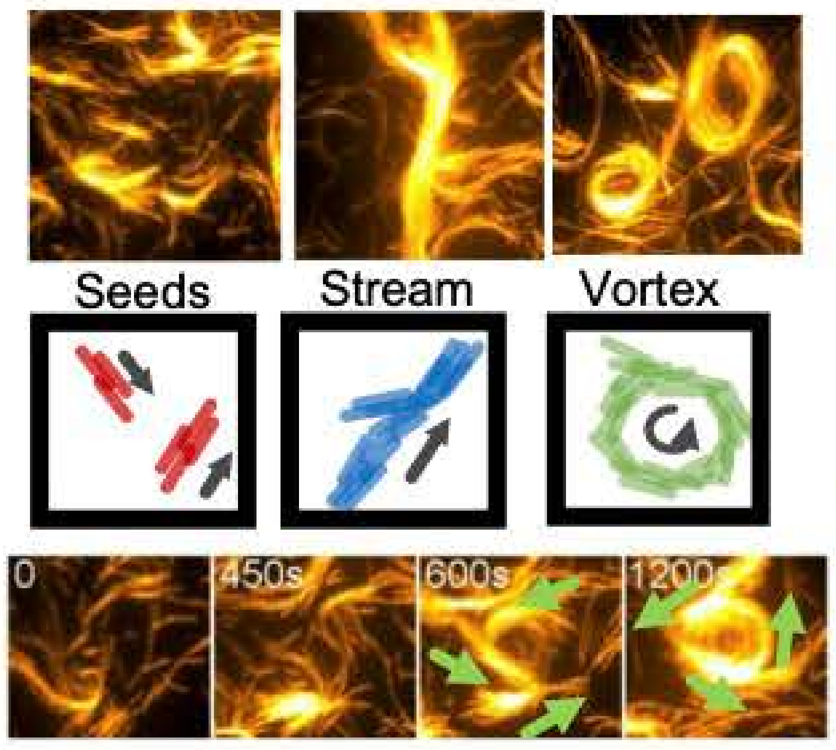
Filaments on a fluid membrane align because of motor's slippage. The interaction is strong and nematic, as proven by measuring individual collisions. Scale bars: 2 micron



Filaments gliding on a SLB form ***polar*** *patterns*

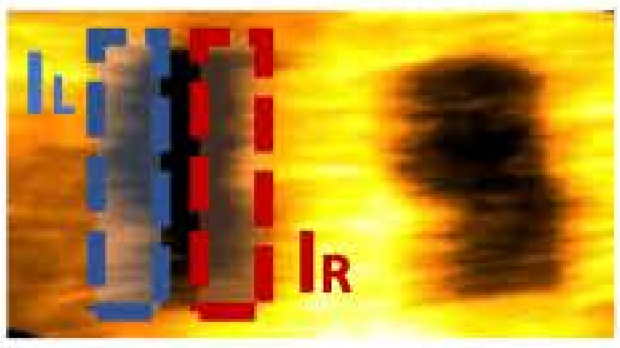


Scale bars: 100 micron

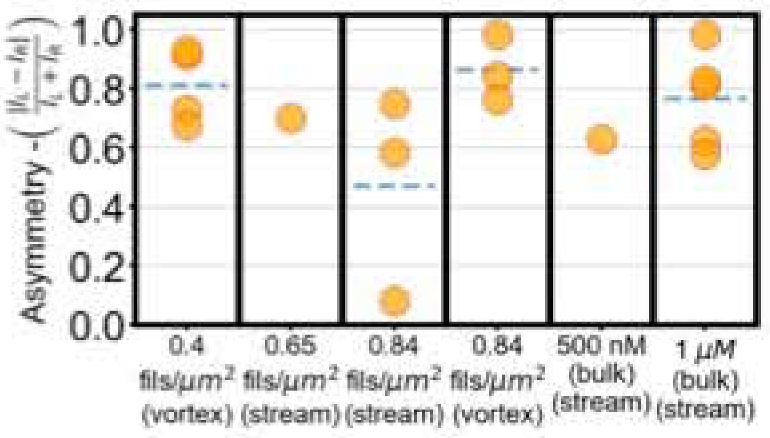


Seeds can merge into a stream or – in this case – a vortex!

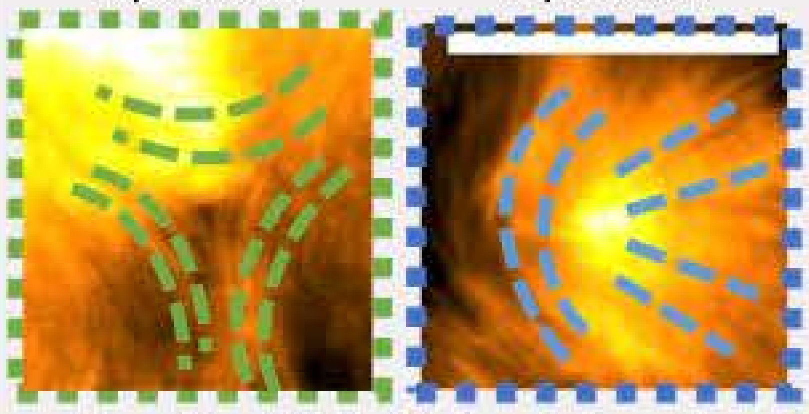
As the density is increased**, filaments assemble into patterns.**
Despite a **microscopic nematic symmetry**, filaments exhibit **polar patterns**.
This is due to the filaments stopping upon collision. Similarly oriented filaments can indeed accumulate against the same obstacle and later on move together as a polar cluster**. This leads at high density to collective polar structures.**
We measure polarity observing asymmetric recovery after photobleaching.
Most structures at all densities are found to be highly polar.



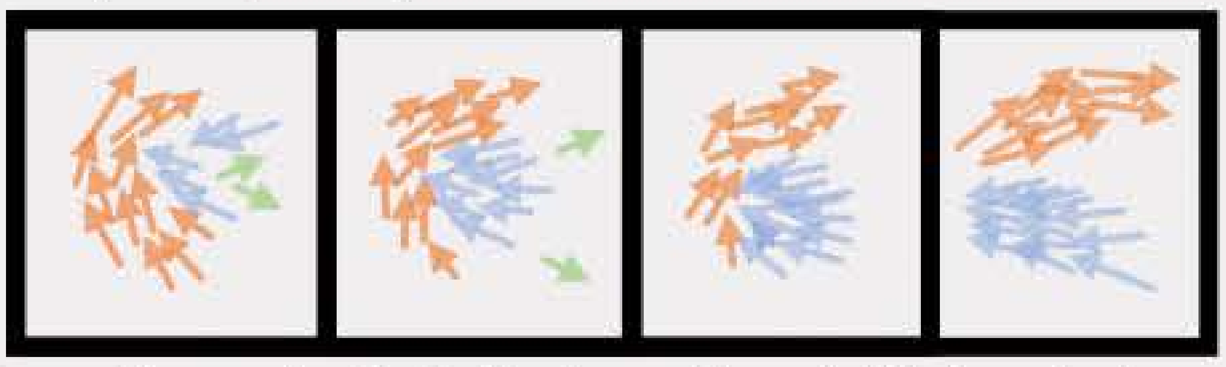
Direction of motion.
I_L recovers before I_R!



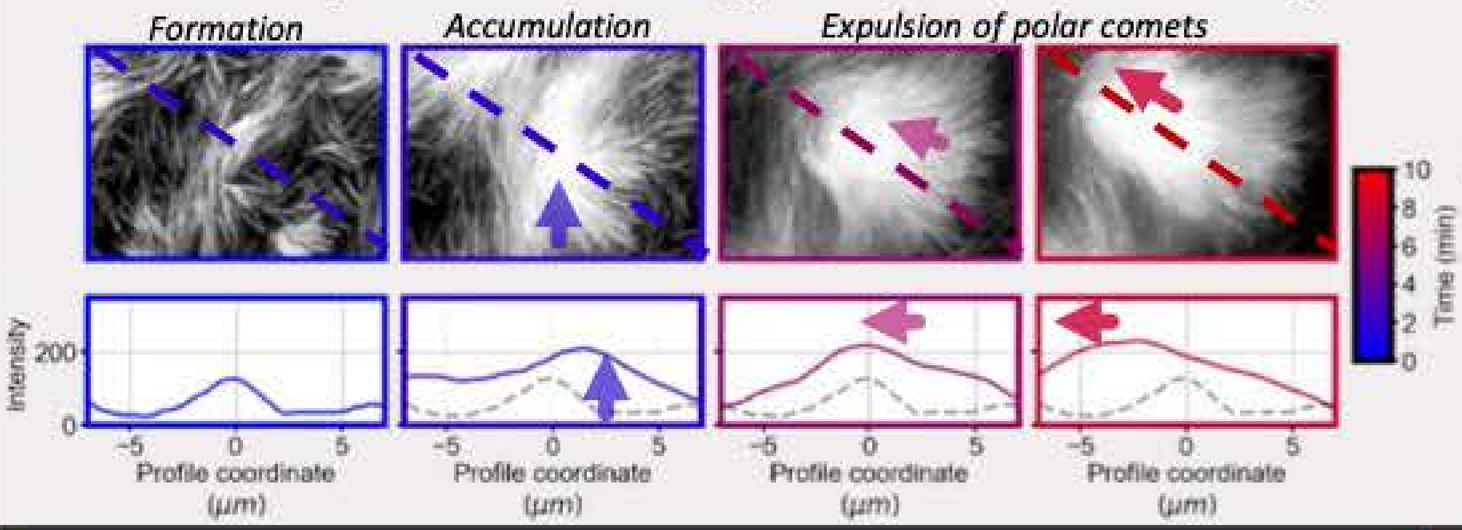
Hot point: +1/2 nematic defects act as wedges that trap and polarity sort filaments



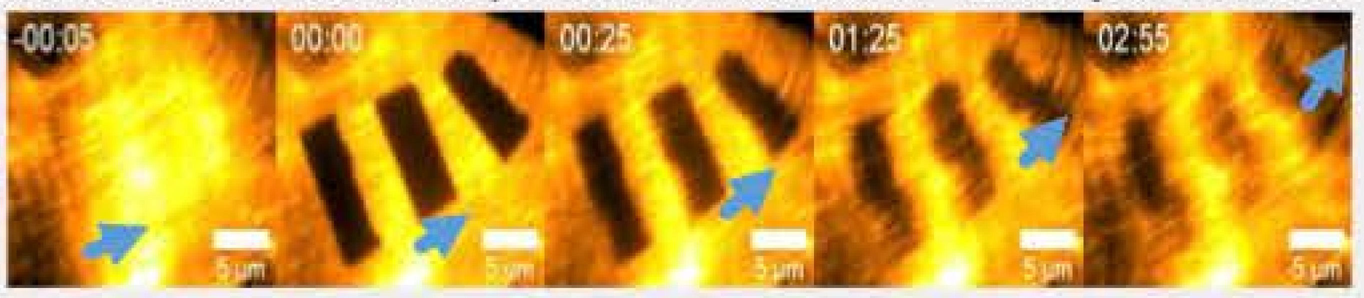
We observe the formation of ±1/2 transient, active nematic defects composed of gliding filaments. Negative -1/2 defects do not play any role. Conversely, because of their **concave shape**, positive +1/2 defects act as wedges which effectively **trap filaments** in their core. When the defect dissolves, the filaments have been **polarity sorted**, as only one direction of motion has been selected by the wedge-trap, and move together as polar „comets".
Thus defects shape the active flow!



Formation of +1/2 defects and of resulting polar comets. See scheme on the right →

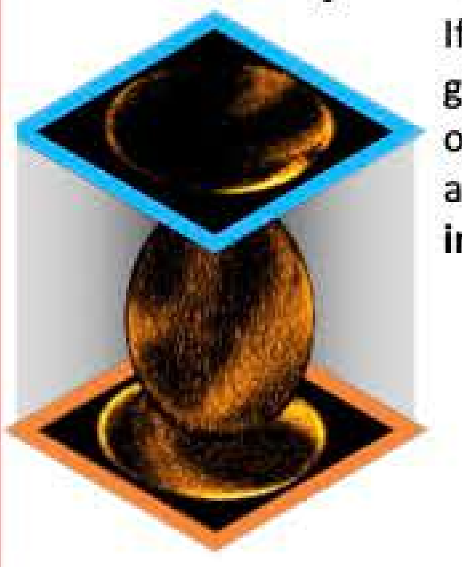


... this results eventually in the formation of **thick, polar lanes.**



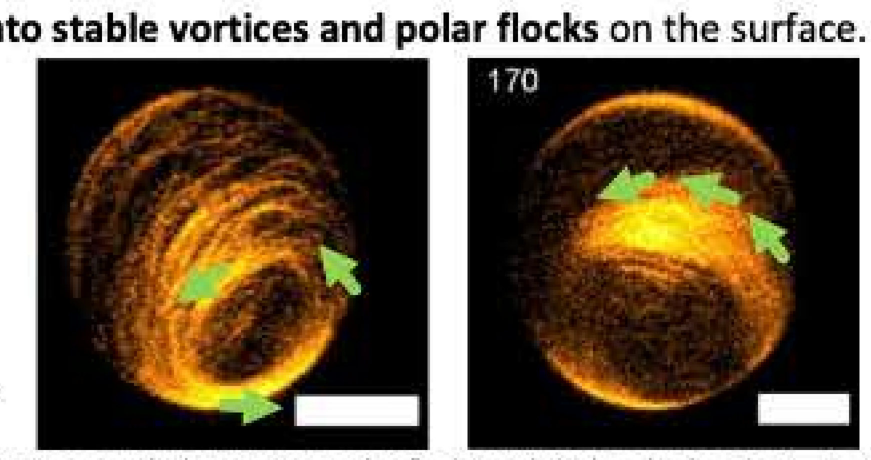
Scale: 5 micron

Outlook#1 : Filaments confined in a giant spherical vesicle form polar flocks and vortices!



3D reconstruction and projections. Actin forms GUV-spanning polar patterns

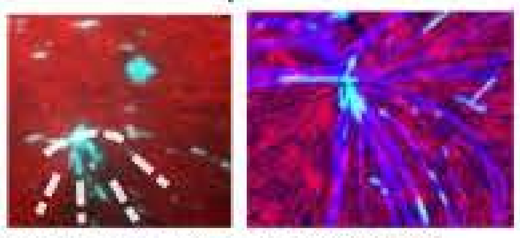
If motors are bound on the inside membrane of a giant vesicle, filaments **glide on a sphere** and we can observe it with confocal microscopy. Confinement in a 2D spherical topology, leads filaments to assemble **into stable vortices and polar flocks** on the surface.



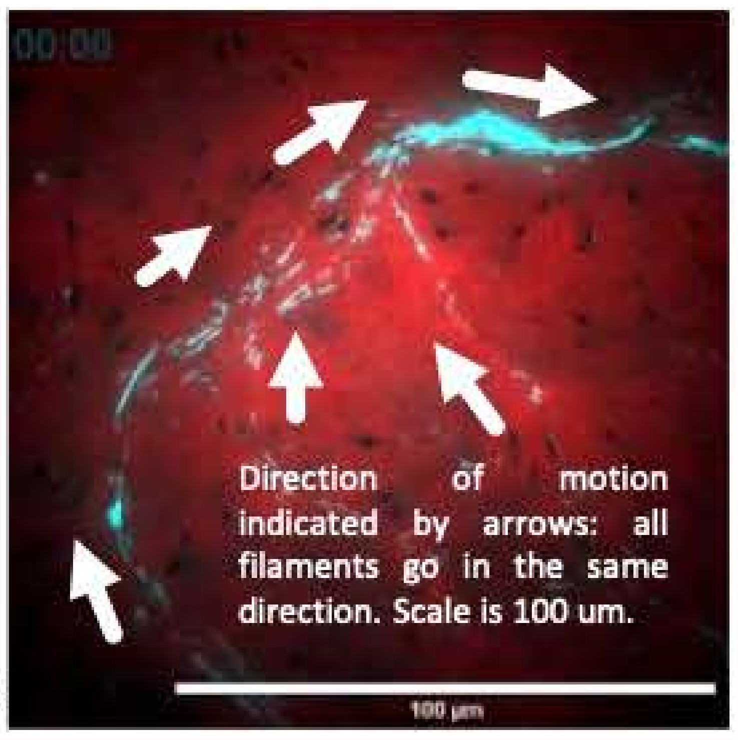
Patterns include vortices, polar flocks and thick polar bands. Scale: 10 um

Outlook#2 : Filaments moving in a passive nematic also exhibit polar order!

Microtubules gliding in a **passive actin-based nematic material** do align with the local director but then surprisingly assemble into **polar lanes**! This means *passive* defects and deformations also can mediate the formation of polar structures!



Picture and time-projection of MTs gliding in a +1/2 defect.
Passive defects polar-sort and up-concentrate filaments, leading to the formation of polar structures.
On the right, polar lanes formed over time , arrows indicate motion.



Direction of motion indicated by arrows: all filaments go in the same direction. Scale is 100 um.

References: *Sciortino and Bausch*, **PNAS 2021** + others in preparation // See e.g. Schaller, Nature 2010 or Suzuki, Science 2018 for results on collectively gliding filaments.