

# Rotating filaments in Wave Dark Matter?

Mark Neyrinck

Mar 30, 2021

**ikerbasque**  
Basque Foundation for Science

eman ta zabal zazu



Universidad  
del País Vasco

Euskal Herriko  
Unibertsitatea

# Outline

1. Art collaboration/synthesis to demystify science and art. Could attract/de-repuls those turned off by traditional physics education. Addresses anti-science/anti-intellectualism
2. SciArt for scientific progress! 🌈 of ways of thinking about physics invaluable. Origami: led to finding about rotating filaments!
3. Wave/Fuzzy Dark Matter phenomenology: how does larger-scale rotation in haloes and filaments affect solitons and vortices?
4. Voids/single-stream regions/waveDM no-interference regions in waveDM seems “cosmic” (non-chaotic)

# Dark Matter Fabric Sheet: Tulle



# Dark Matter Fabric Sheet: Tulle at Science Gallery London

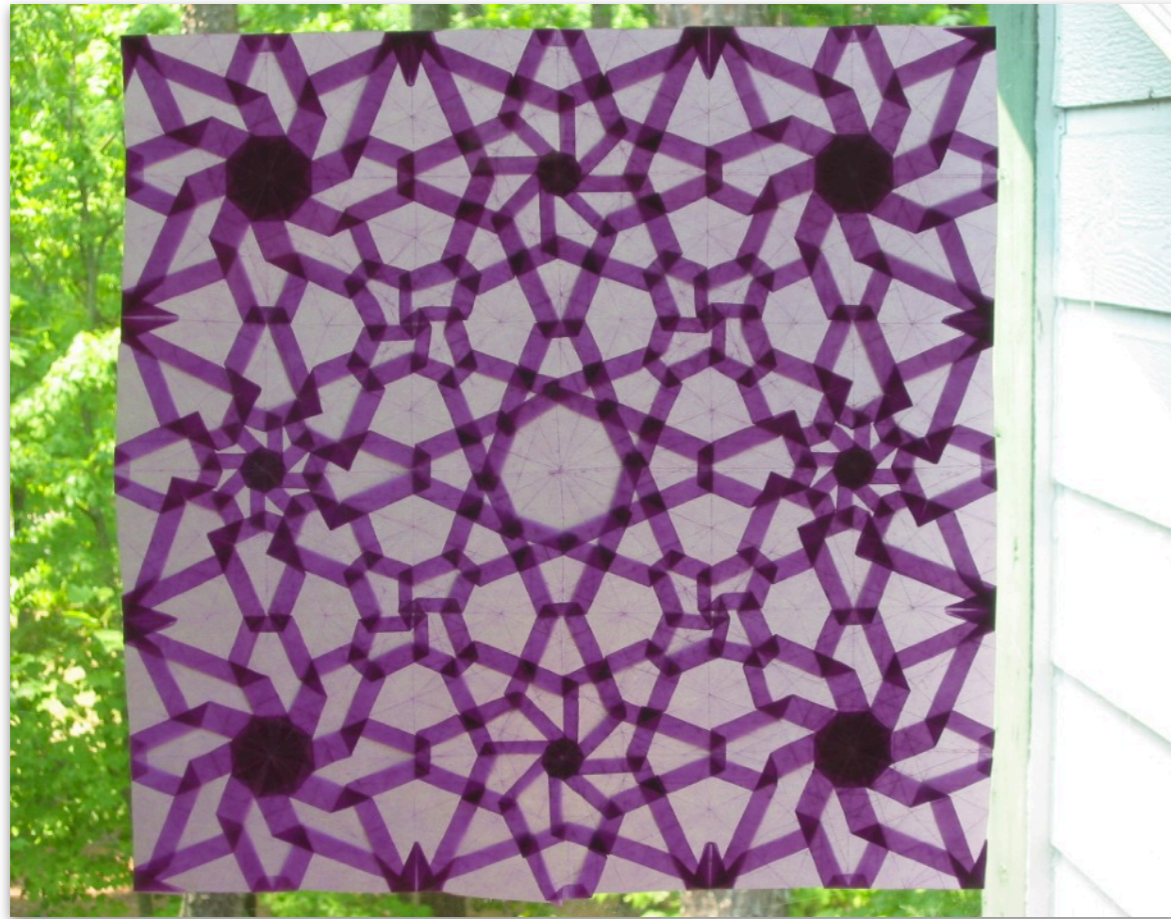


# Crease pattern of a realistic cosmic web

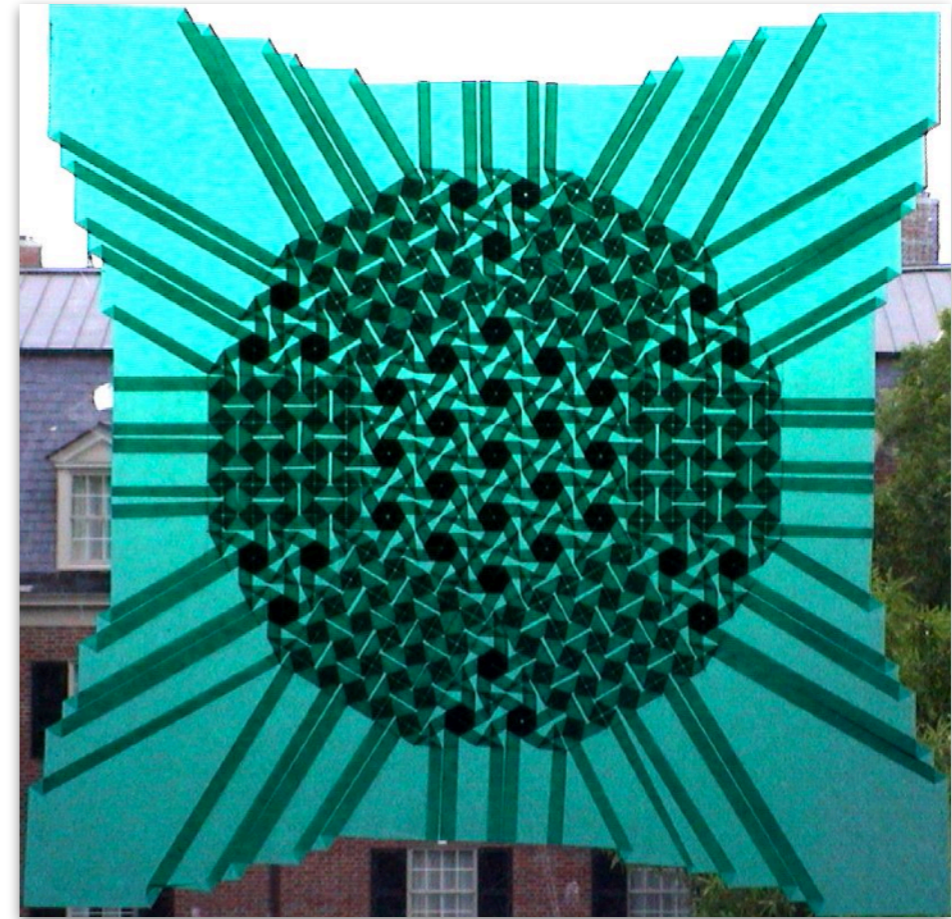


- Colored according to  $(\det J)$
- $J =$  matrix describing the local transformation from initial coordinates

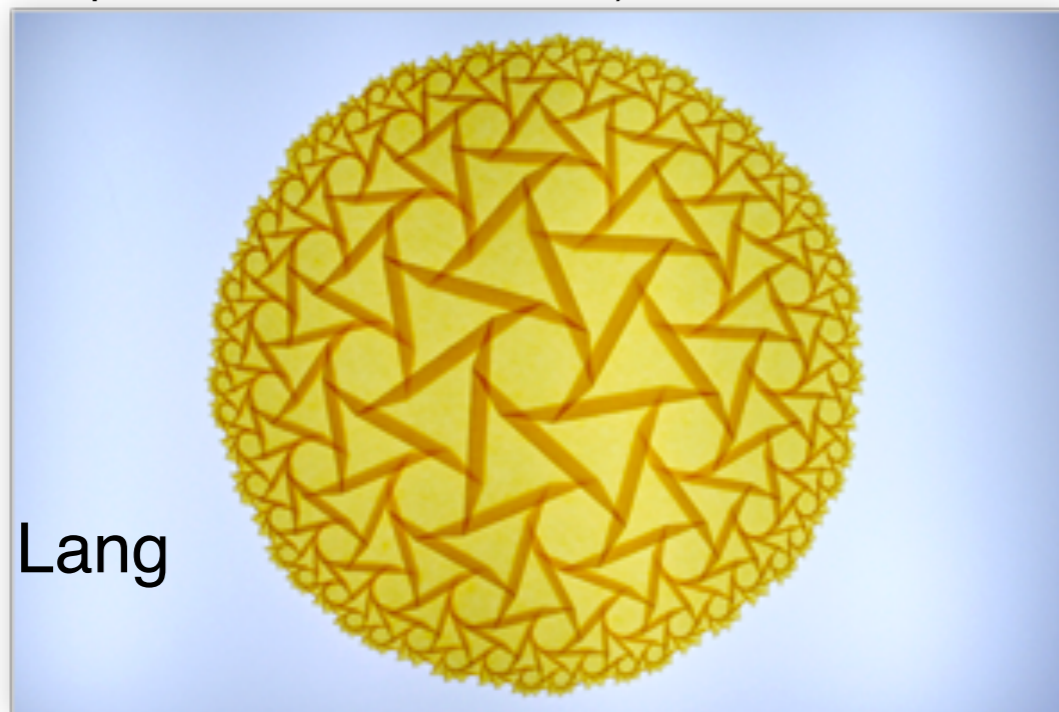
# Origami tessellations



Andy Wilson (based on a floor tiling pattern from the Alhambra)



Andy Wilson



Robert Lang



# COMPARISON OF MOLECULES

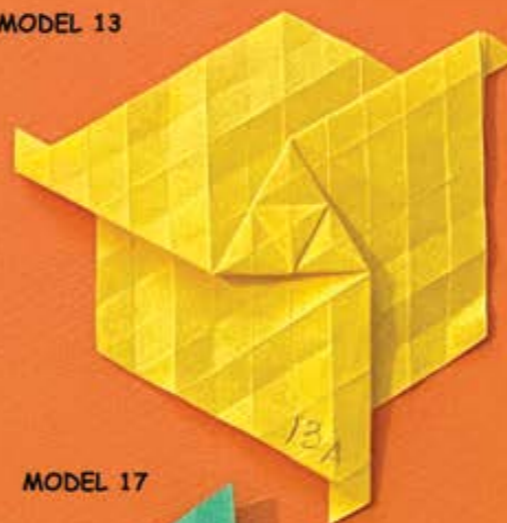
MODEL 11



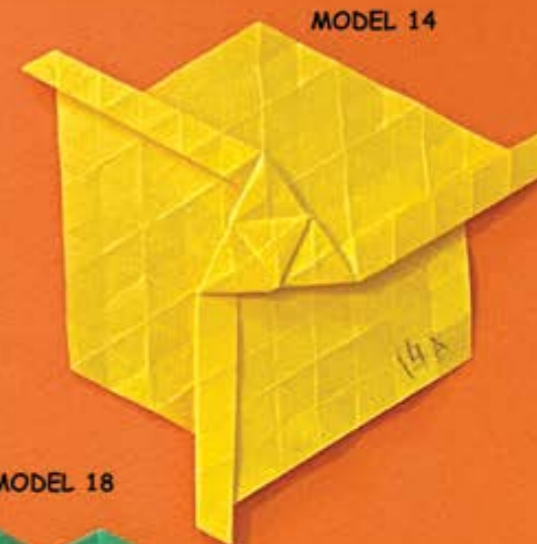
MODEL 12



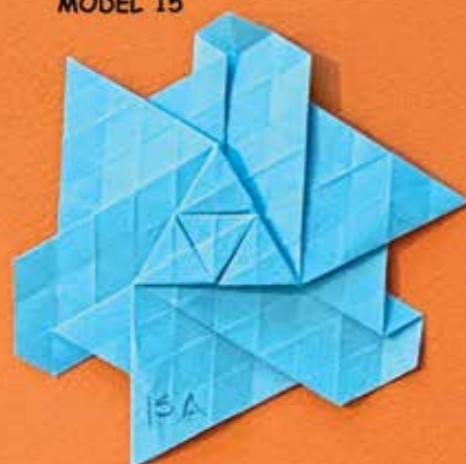
MODEL 13



MODEL 14



MODEL 15



MODEL 16



MODEL 17



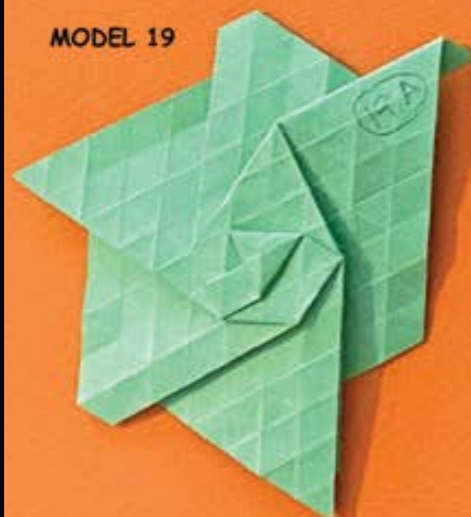
MODEL 18



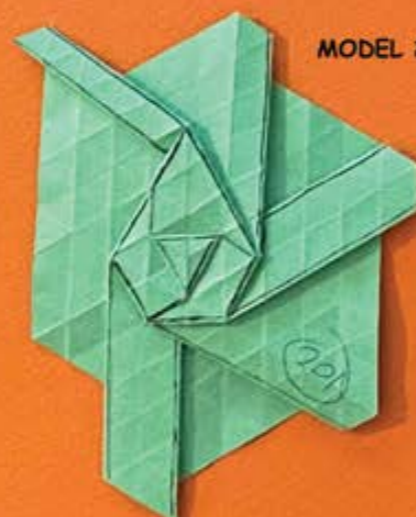
MODEL 22



MODEL 19



MODEL 20



MODEL 21



MODEL 23



MODEL 24



Miguel  
Gañan

Lang & Bateman 2011,  
Lang 2015:  
each spiderweb (An  
arrangement of cables that  
can be entirely in tension)  
gives an origami  
tessellation,

Tension in cable



thickness of filament

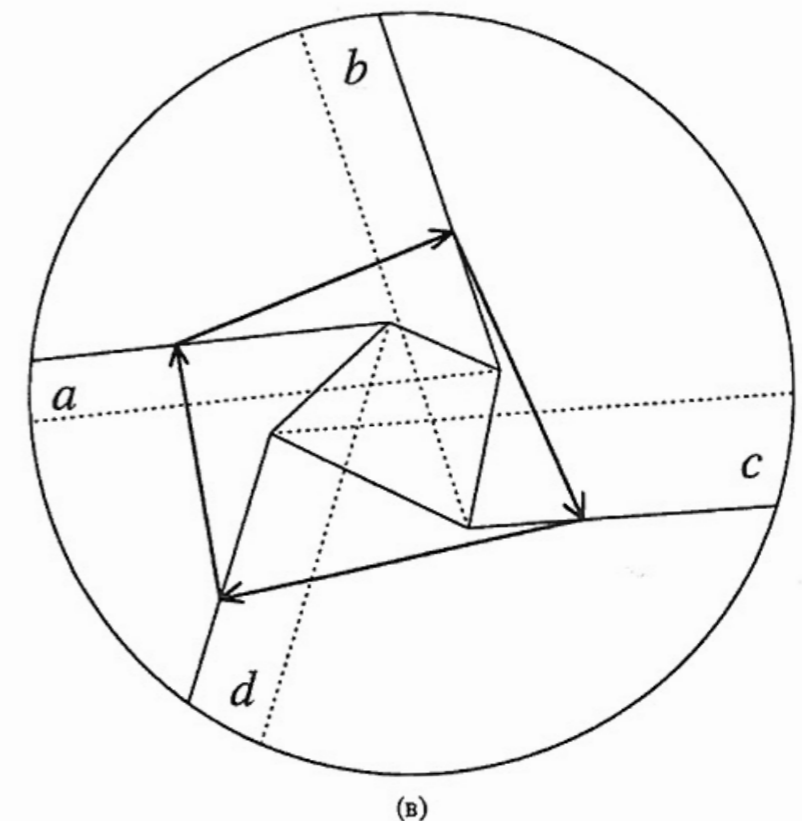
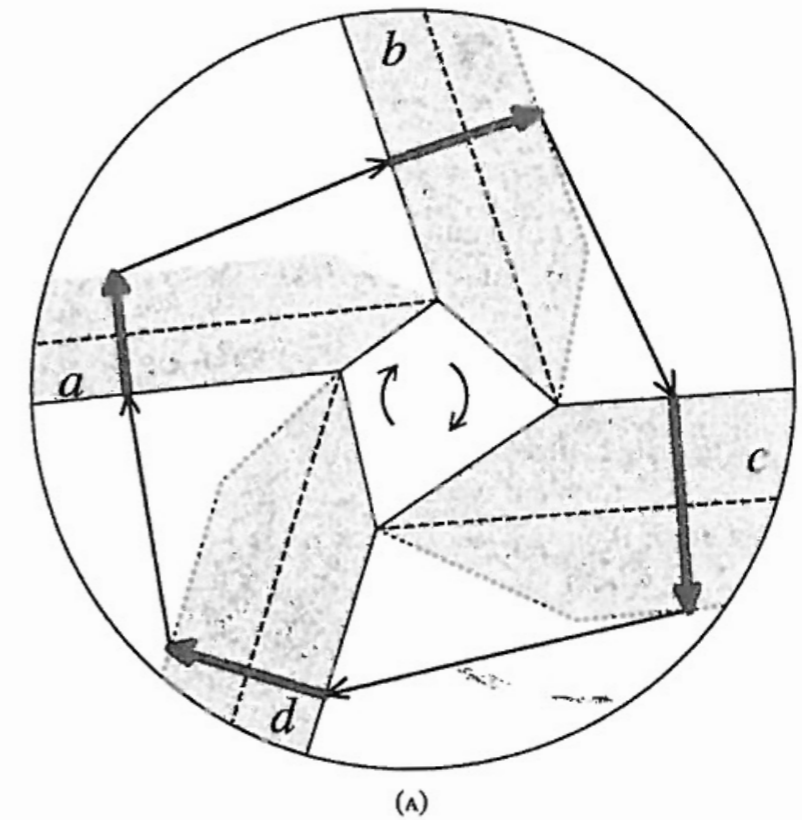
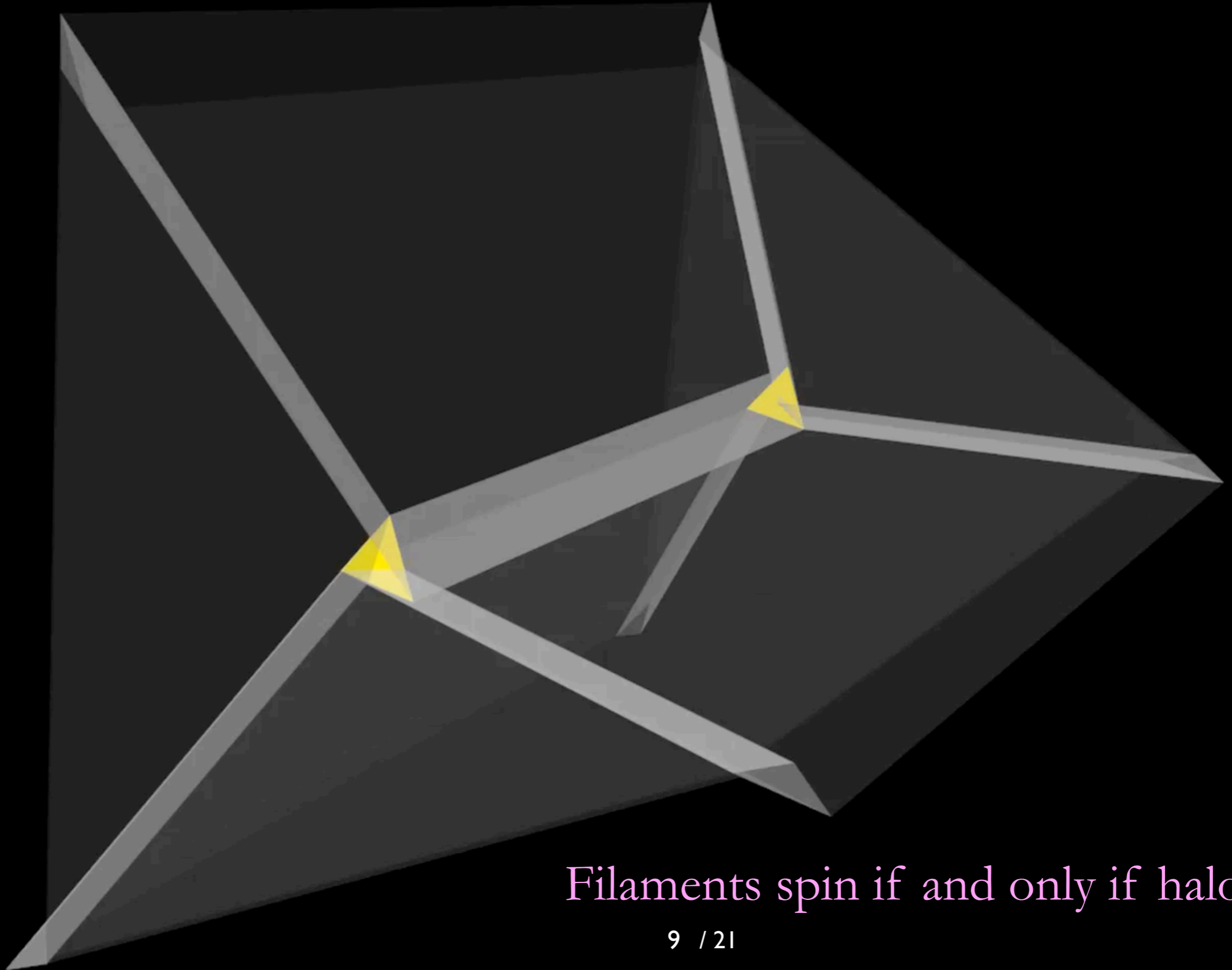


FIGURE 1. A simple flat twist. (a) Crease pattern: Mountain folds are solid, and valley folds are dashed. Light-gray regions are not visible in the folded form. (b) The folded form.

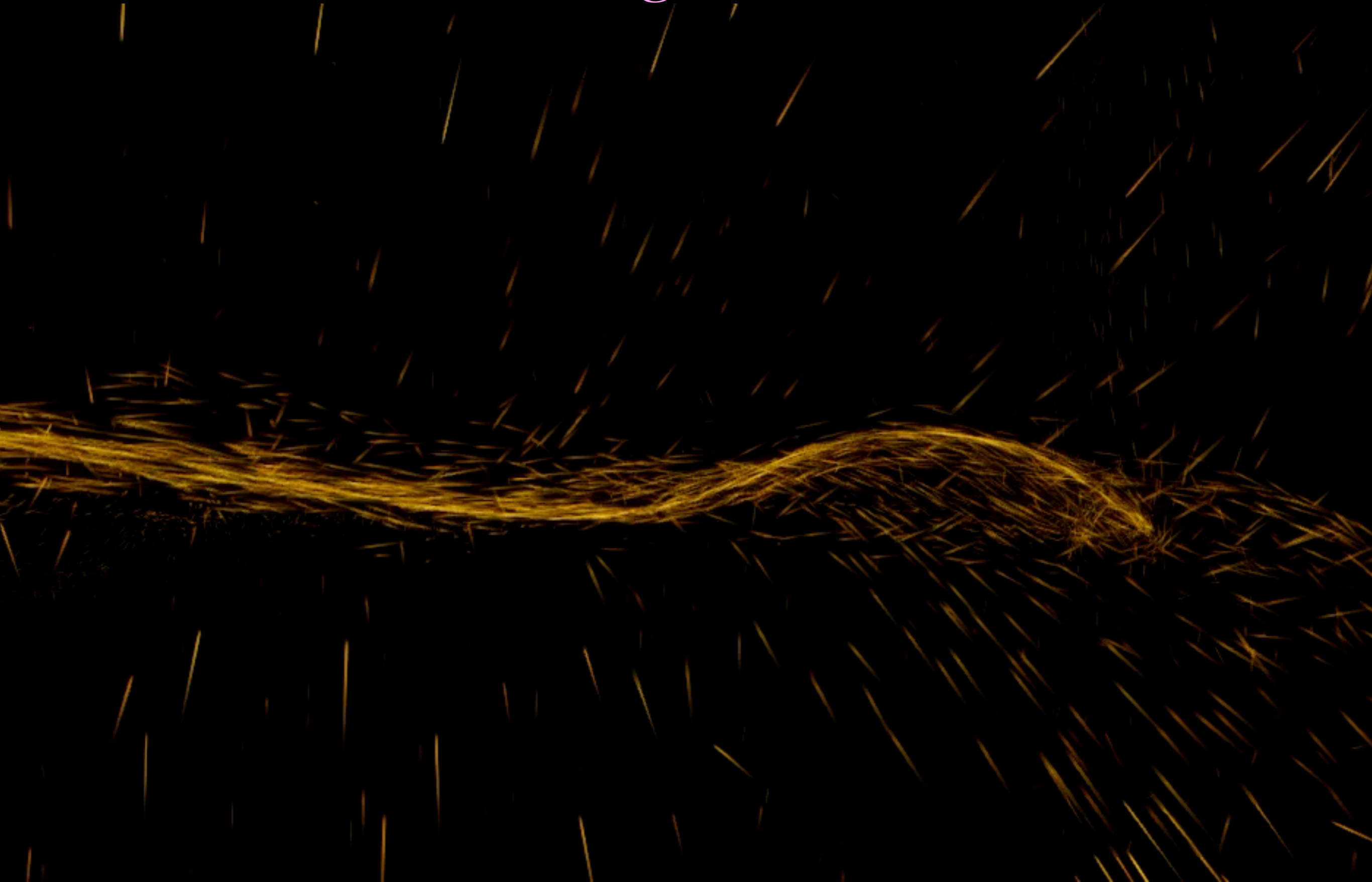


# A 3D origami cosmic web — 3D twist folds



Filaments spin if and only if haloes spin

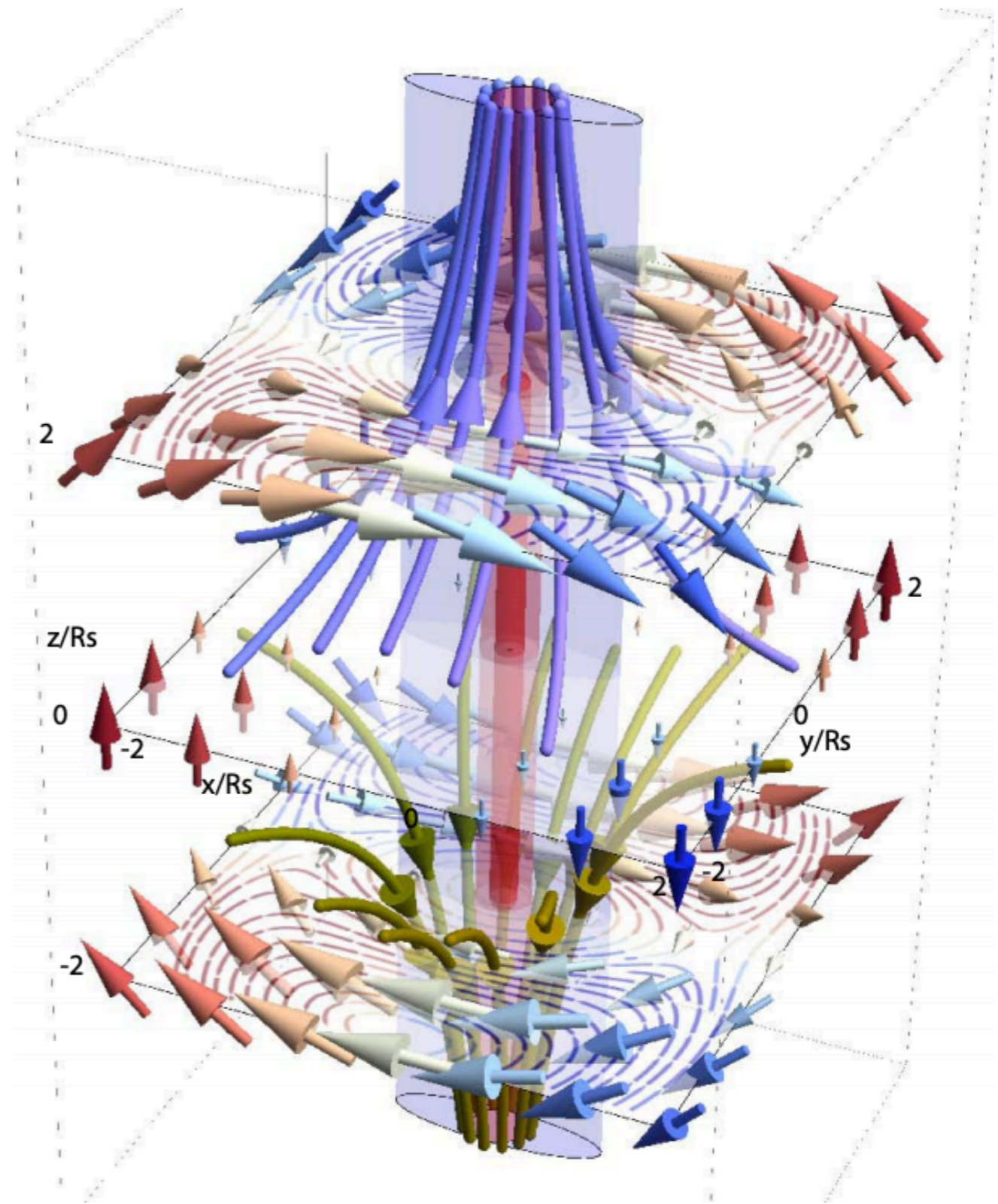
# Rotating filament!



Codis et al. 2015, Laigle, Pichon, Pogosyan ...: considering vorticity around a filament is key to understanding spin-filament alignment.

Small haloes tend to spin with axis aligned with filament axis

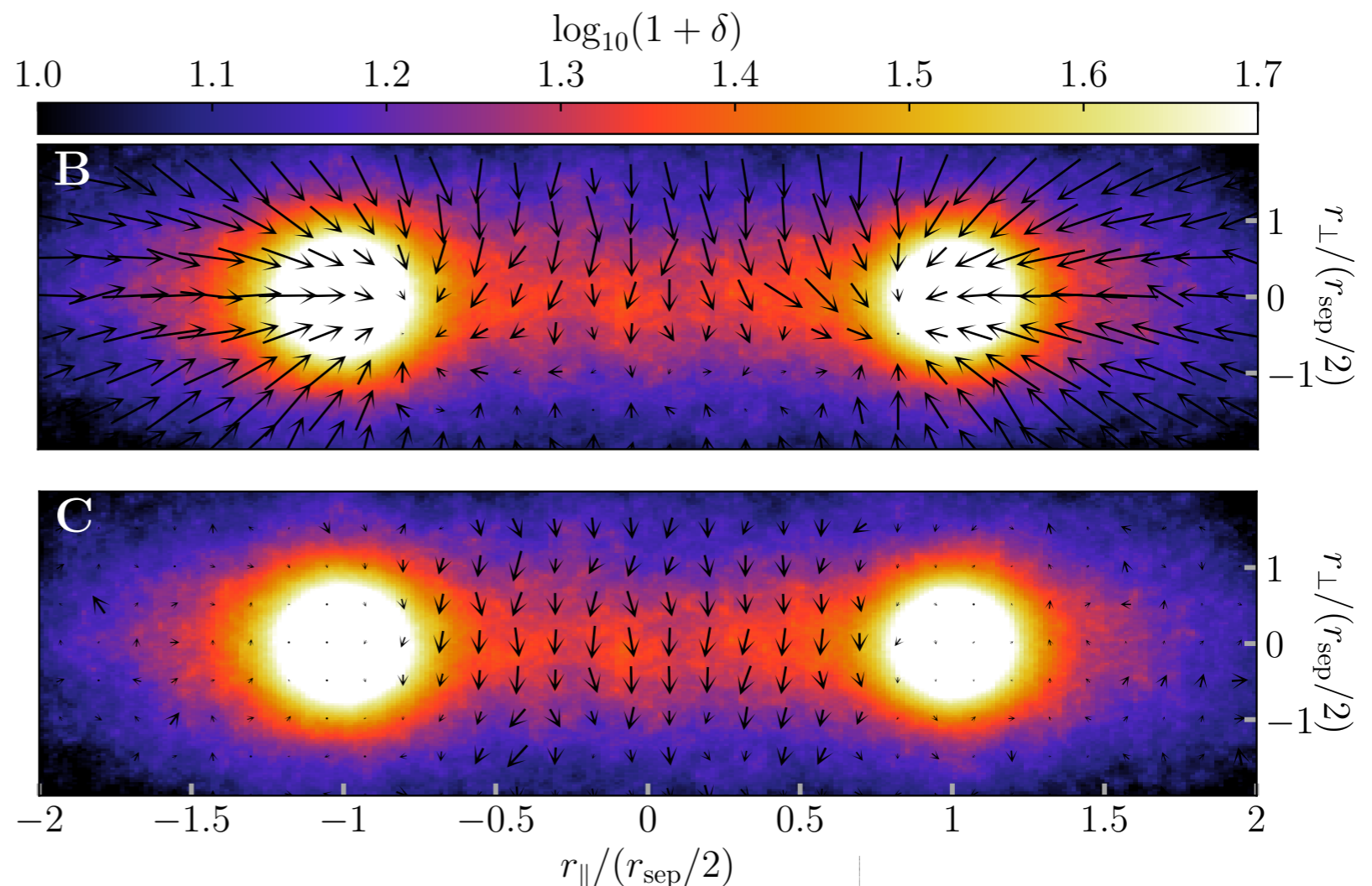
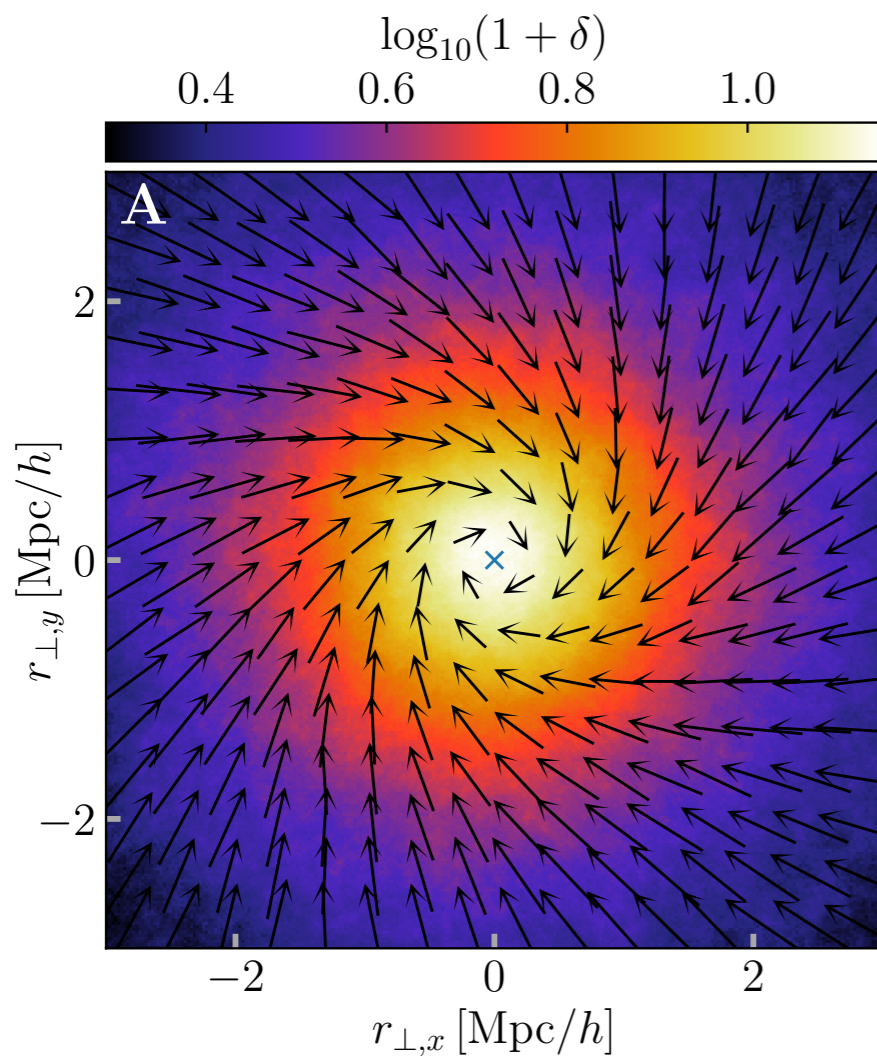
**Do filaments themselves spin?**



with Qianli Xia, Yanchuan Cai, Miguel Aragón-Calvo

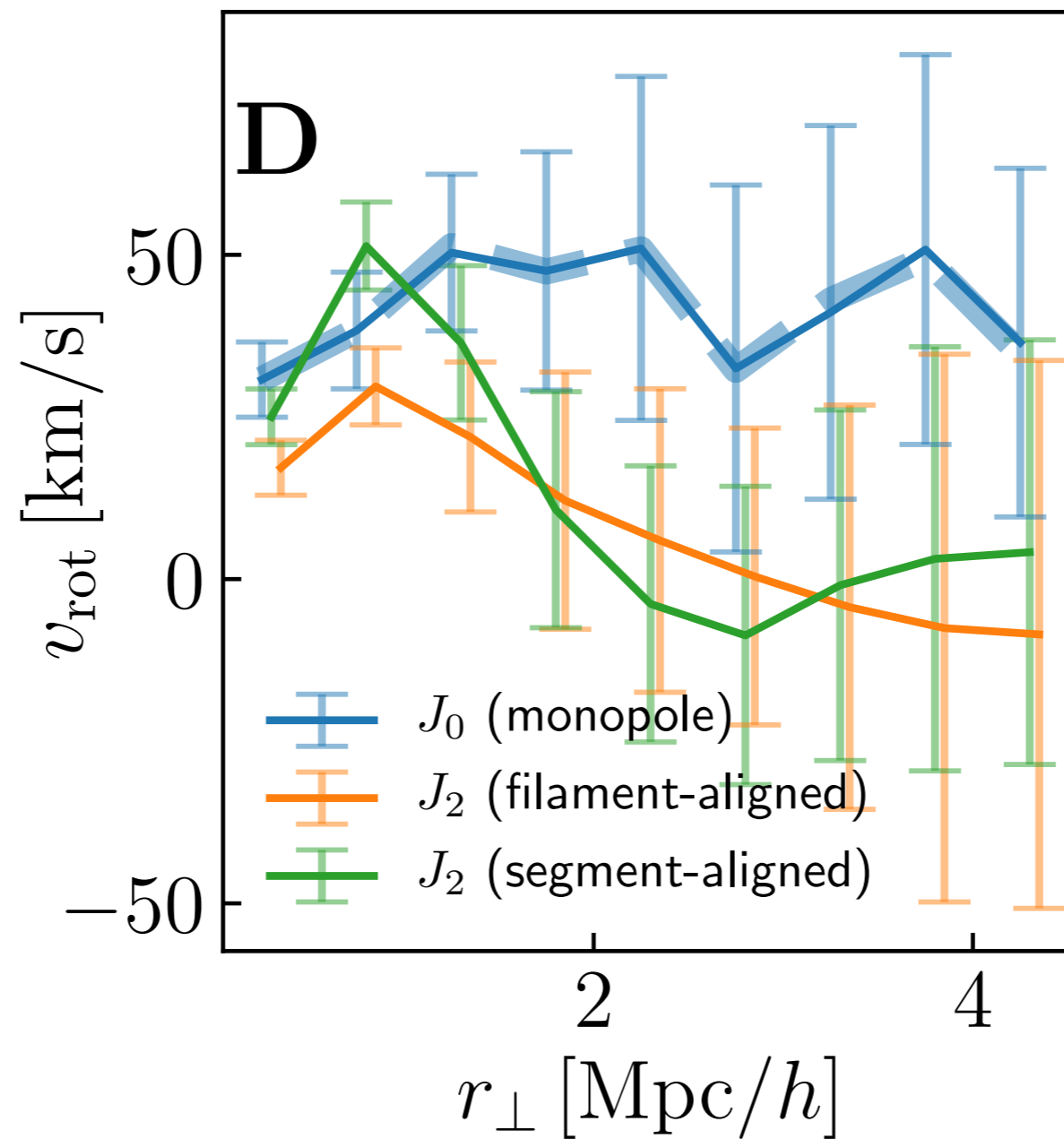



## Stacked Millennium simulation filaments



# Monopole (net spin) comparable to/higher than quadrupole

Illustris filaments  
mono- and quadrupole





Also observationally confirmed!  
Redshift-space signature of  
flows around SDSS filaments

Wang, Libeskind, Tempel, Kang & Guo (2021)  
(appearing very soon)



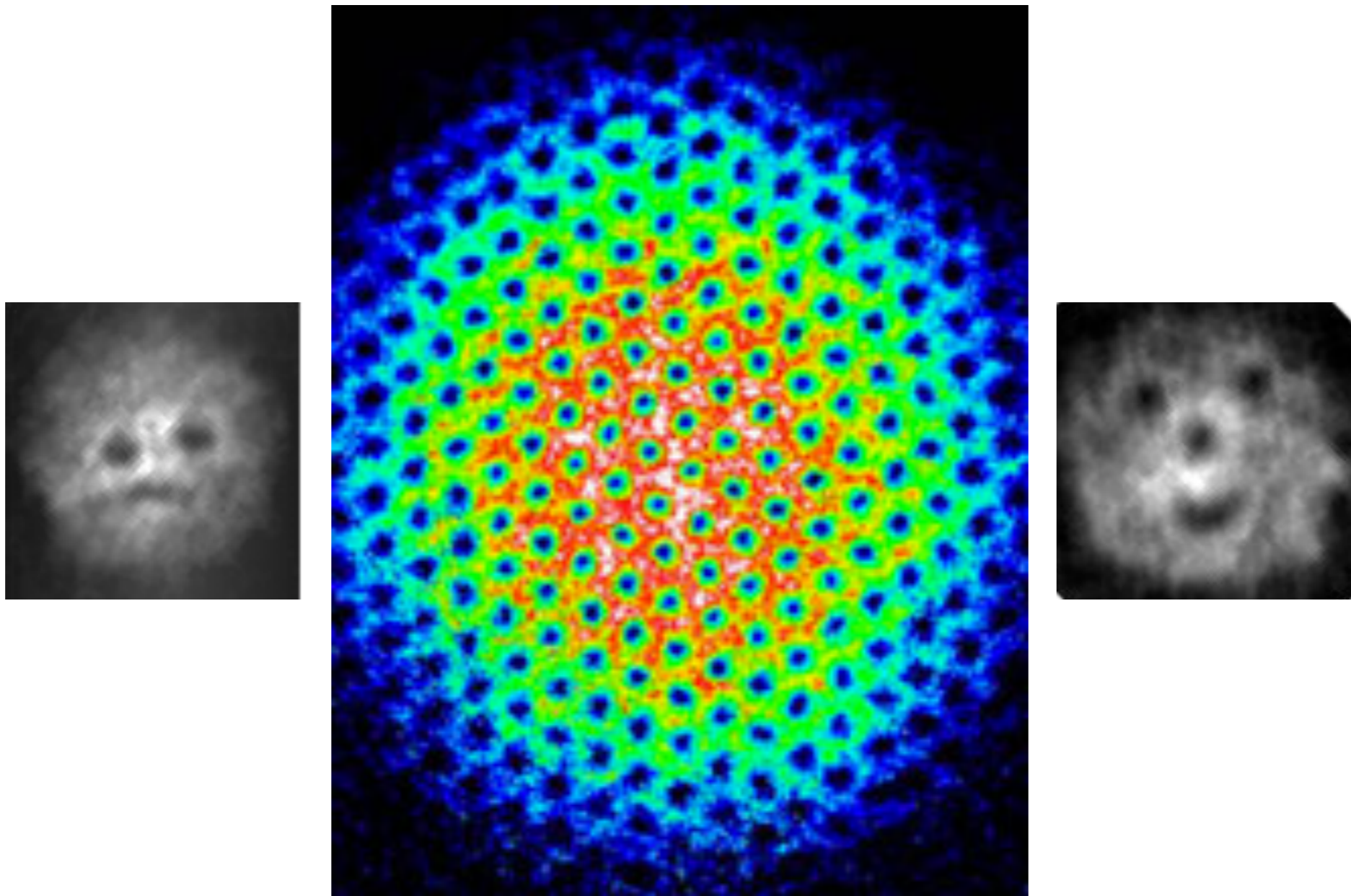
Filaments fold up  
like origami twist folds  
with nonzero spin

That was CDM (also WDM) ...  
what about waveDM?



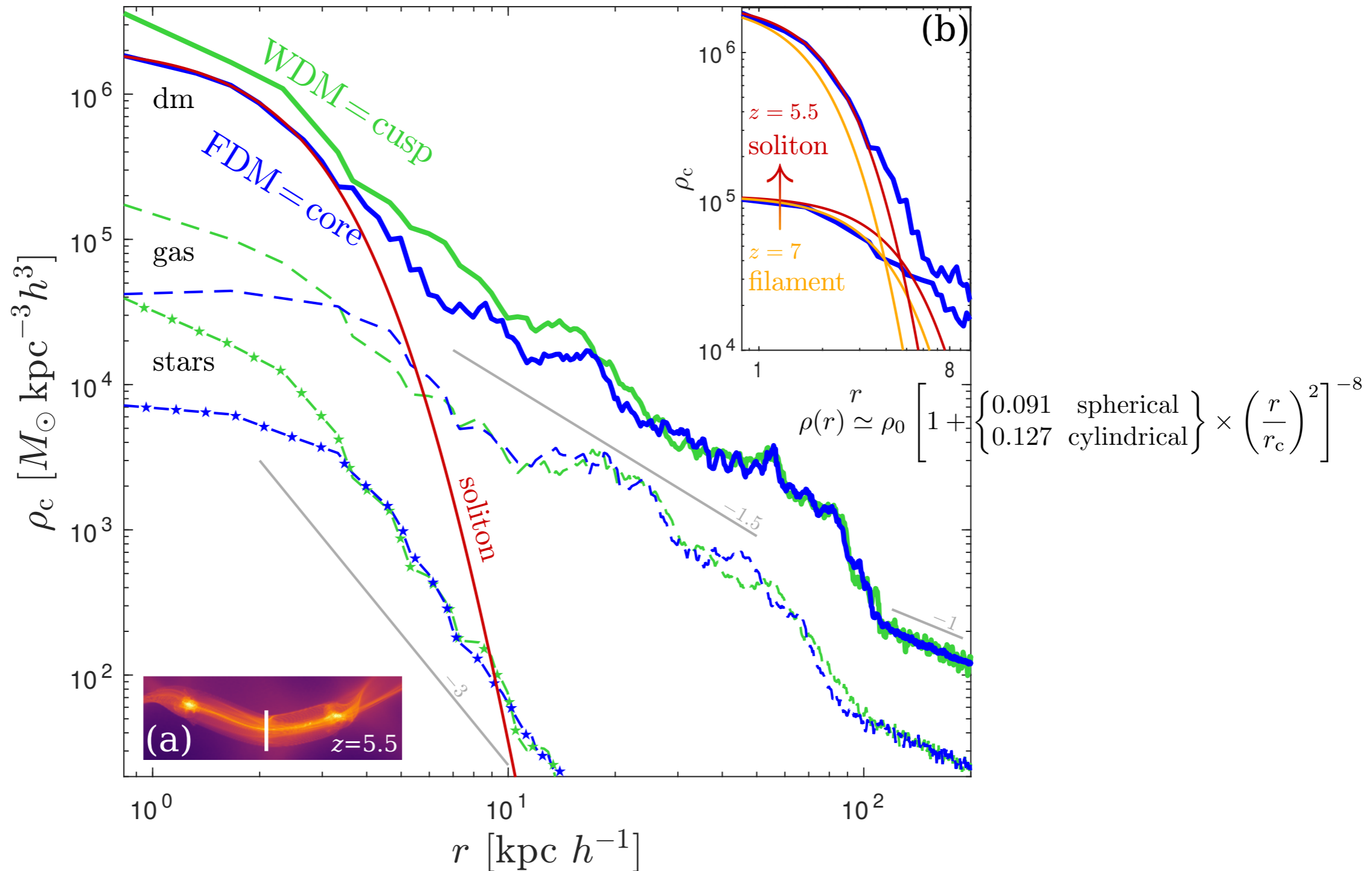


In some circumstances, Bose-Einstein condensates can form vortices, outside of which the velocity field is irrotational ... they can even form a lattice

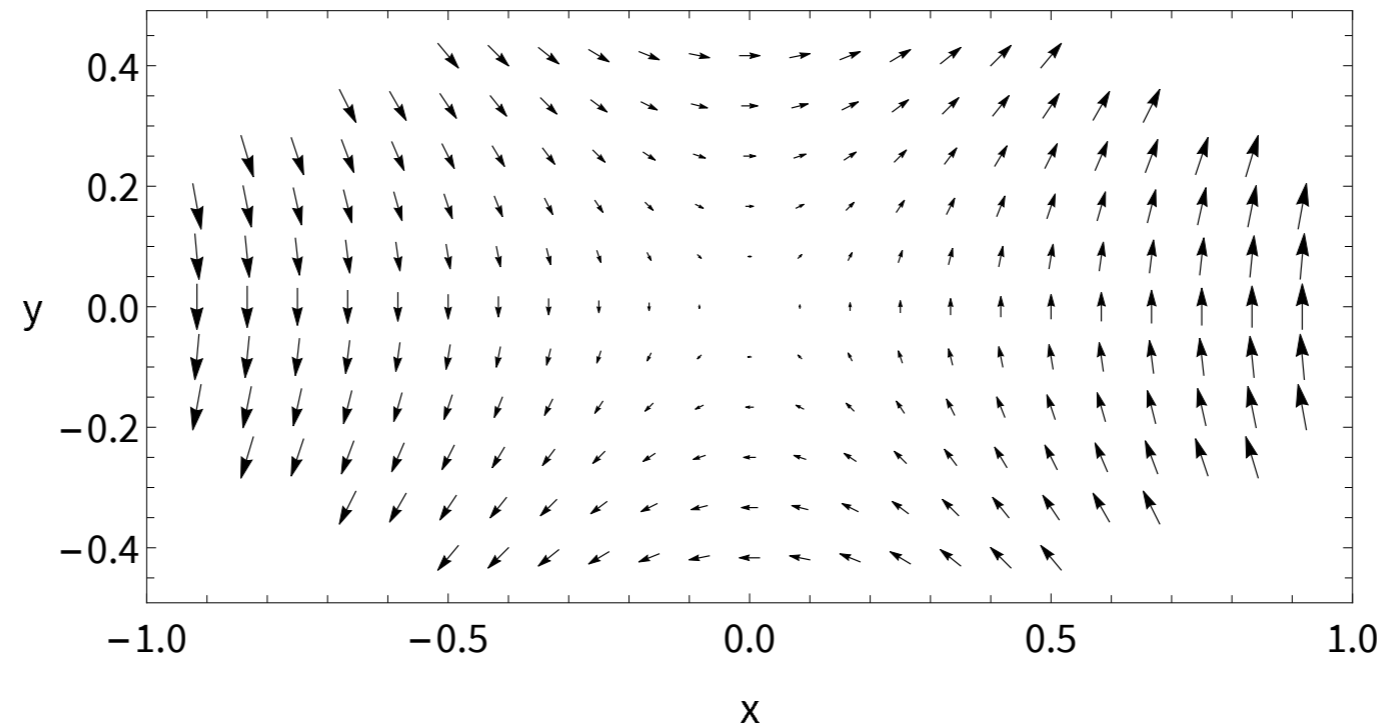


Coddington et al. (2004)

If filaments can have solitons  
(Mocz et al. 2019), and they rotate, might  
vortices thread them?



In waveDM simulations, vortices haven't been seen in solitons. How can things rotate, then, in an irrotational fluid? In a “Riemann S-ellipsoid”

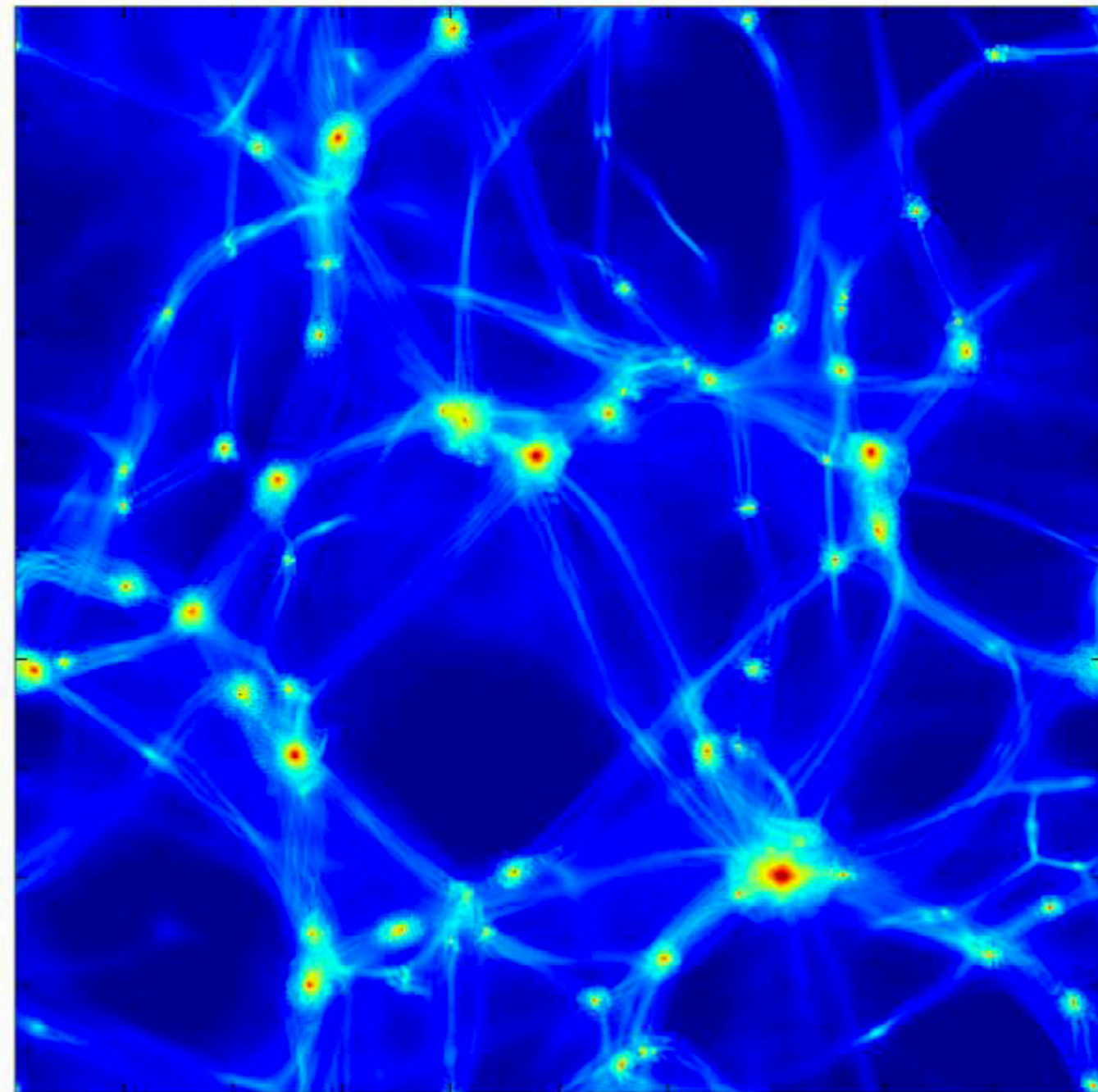


Schobesberger, Rindler-Daller & Shapiro (2021): Specific angular momentum must exceed  $\hbar$ /particle for spin to drive vortices. They could possibly form in the regime of very large self-interactions, though.

Another project with Shy Genel: Voids (single-stream regions in CDM/WDM, with no interference pattern in waveDM) are remarkably laminar/non-chaotic/directly deterministic

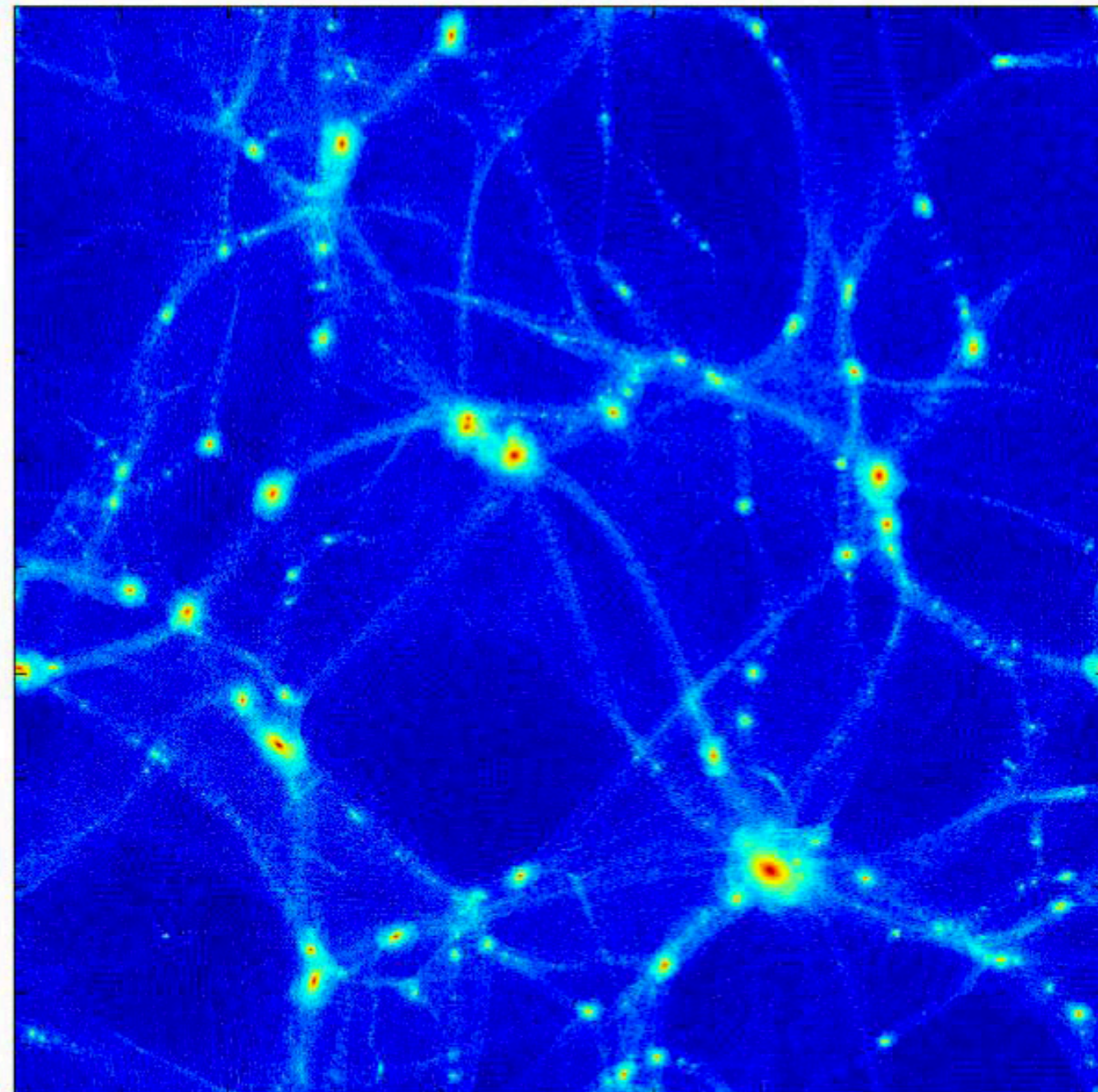
**a**

$\psi$ DM



**b**

CDM



# CONCLUSION

1. Useful for many reasons to bring fresh perspectives and diversity of thought; art is one way of doing so
2. Filaments rotate!
3. Probably no extra observables for Wave/condensate/Fuzzy (WTF) dark matter, except possibly with very strong self-interactions