THE COSMIC SPIDERWEB

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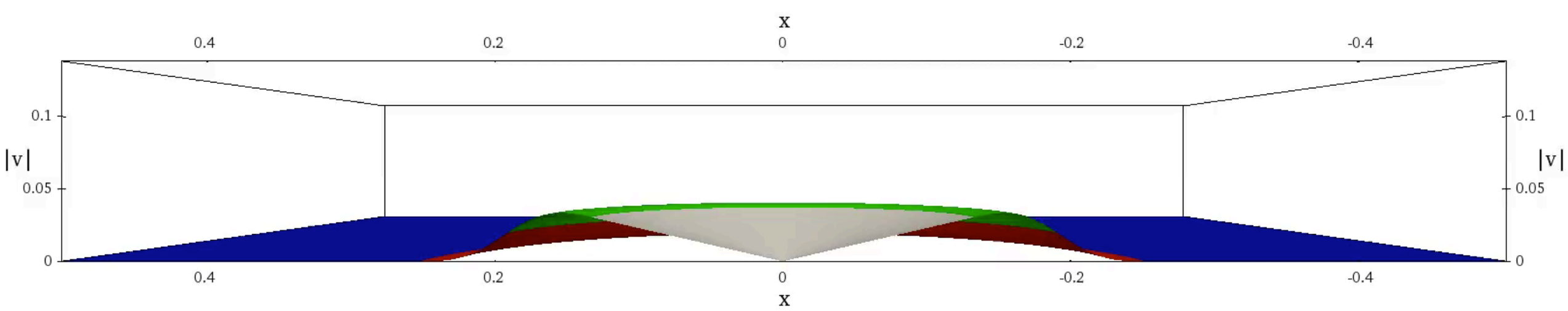
OUTLINE

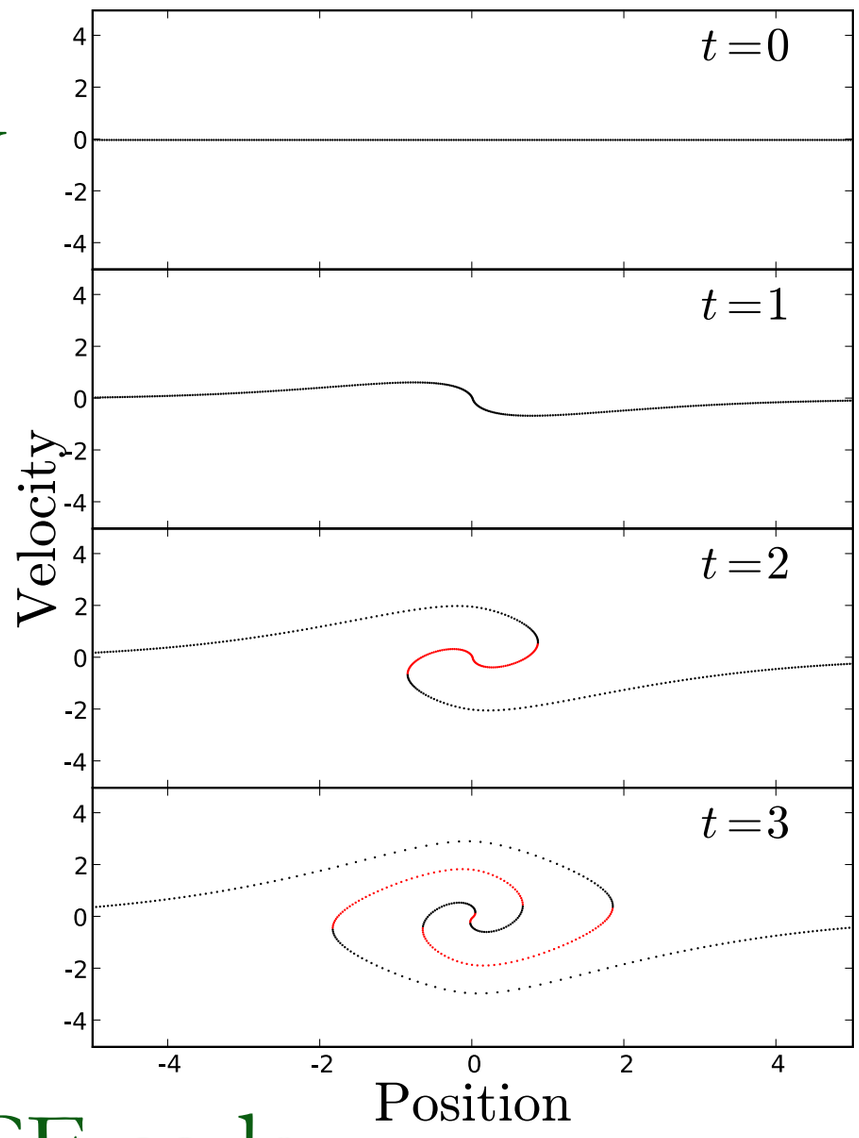
1. Analytic? Not quite, but the cosmic web is simpler than sometimes thought — adhesion model
2. Also can be understood as an architectural ‘spiderweb’, with cosmological use?

Zel'dovich Approximation: particles go ballistically along a gradient of a potential

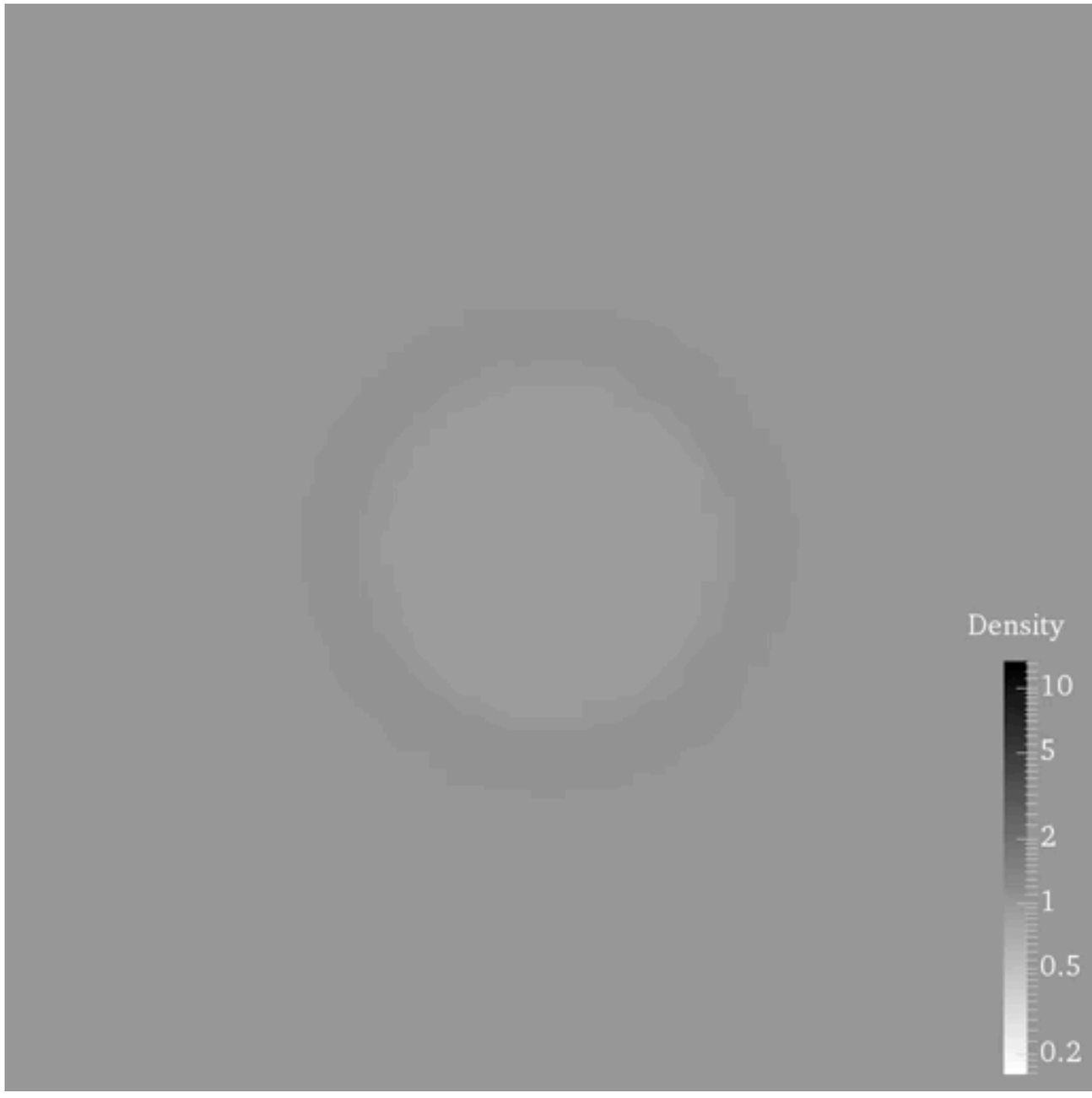
$$\boldsymbol{x}(\boldsymbol{q}, t) = \boldsymbol{q} - D_+(t)\boldsymbol{\nabla}_q \Phi_0(\boldsymbol{q})$$



In full gravity



ColDICE code
(Sousbie & Colombi 2016)



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Adhesion

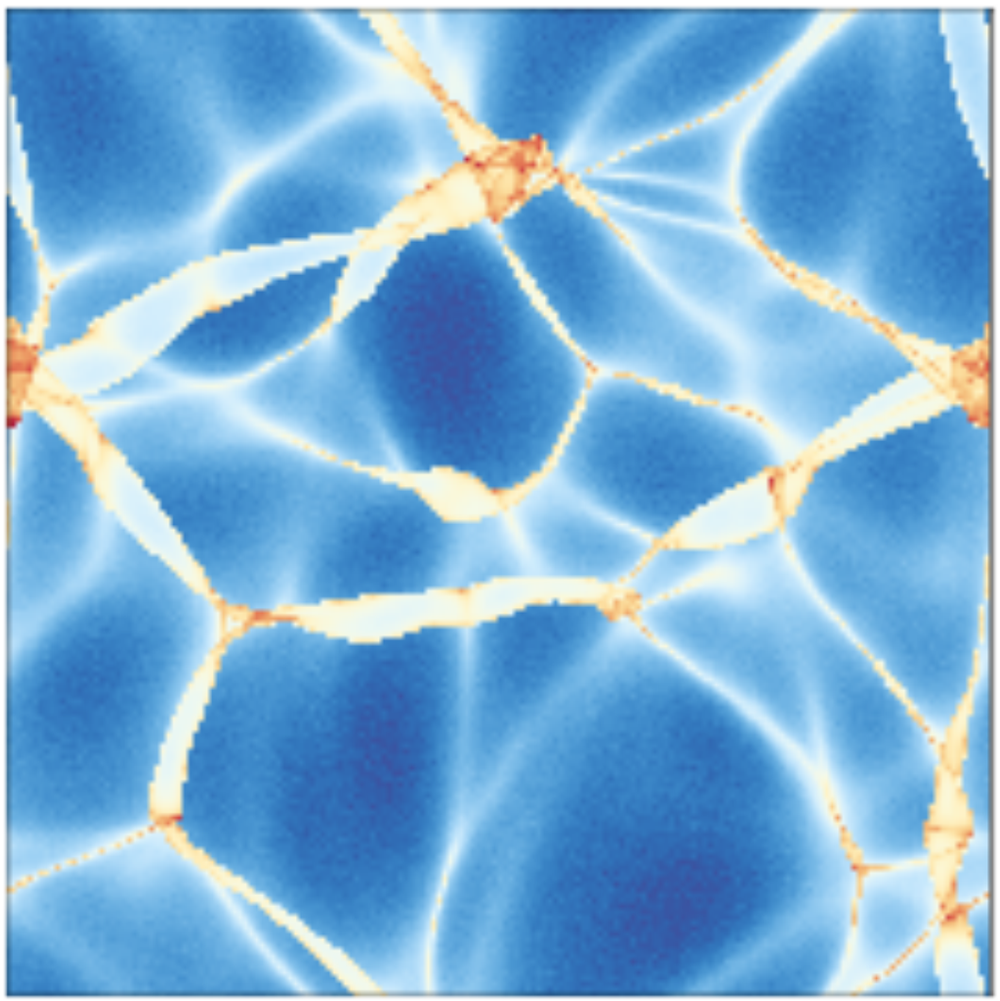
Add a viscosity ν, and take the limit to zero.

Streams stick together

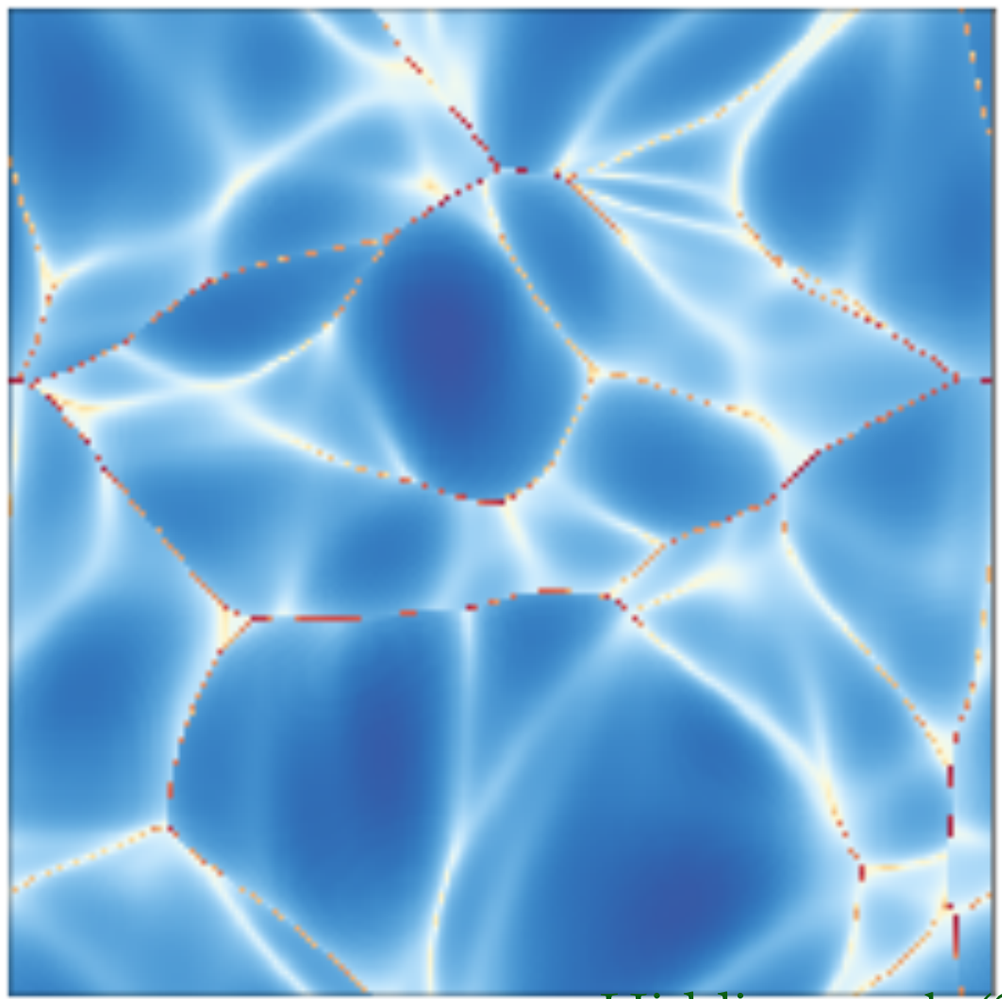
$$\frac{\partial \boldsymbol{u}}{\partial D_+} + (\boldsymbol{u} \cdot \boldsymbol{\nabla}_x)\boldsymbol{u} = \nu \nabla_x^2 \boldsymbol{u}.$$

(Gurbatov & Saichev 1984; Kofman et al. 1990; Gurbatov et al. 2012)

Zeldovich



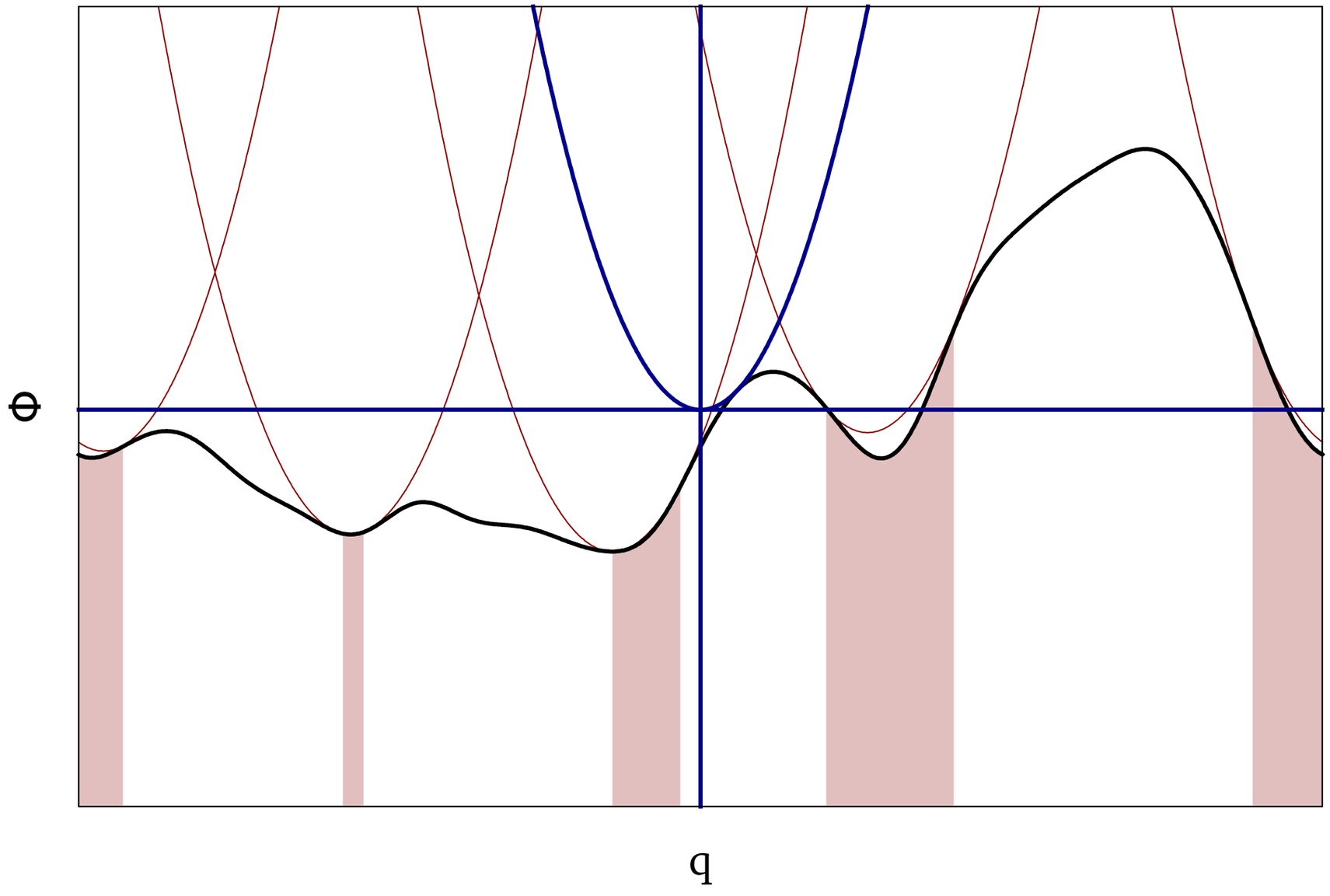
Adhesion



Hidding et al. (2018)

Eulerian position of a patch is the apex of a parabola touching two vertices

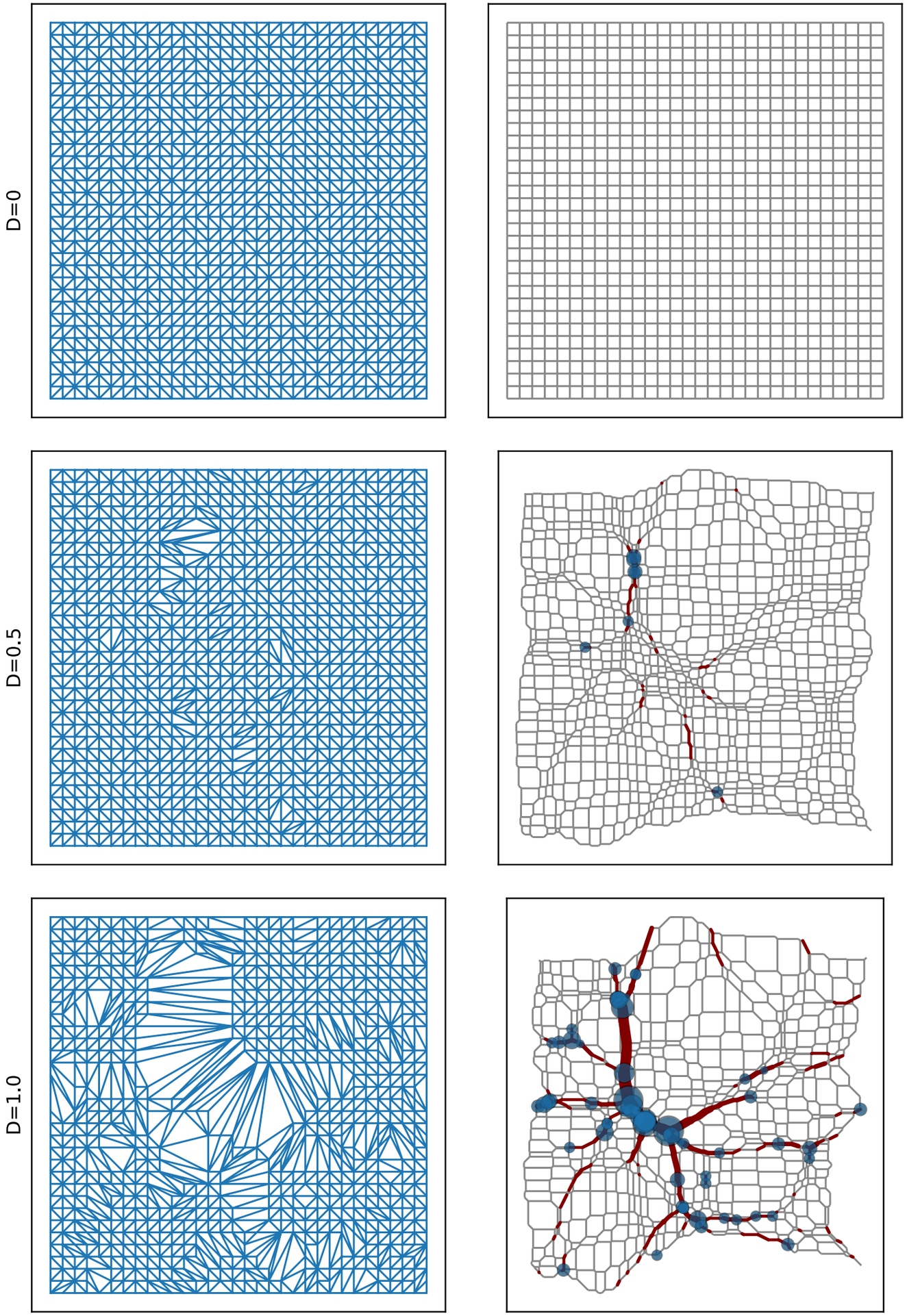
(Pogosyan 1989, Kofman et al. 1992)



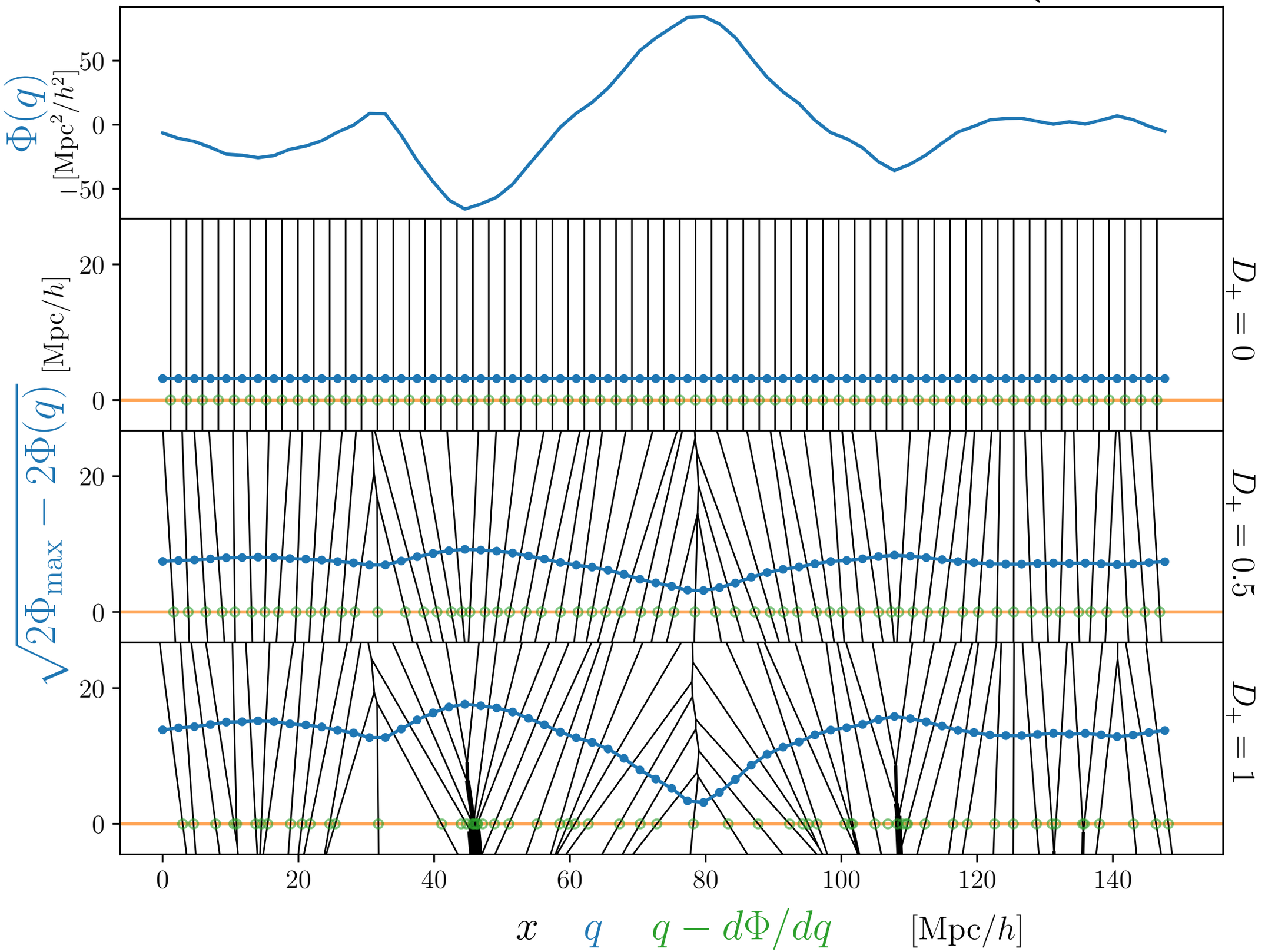
Equivalent to a Legendre transform (Vergassola et al. 1994) …

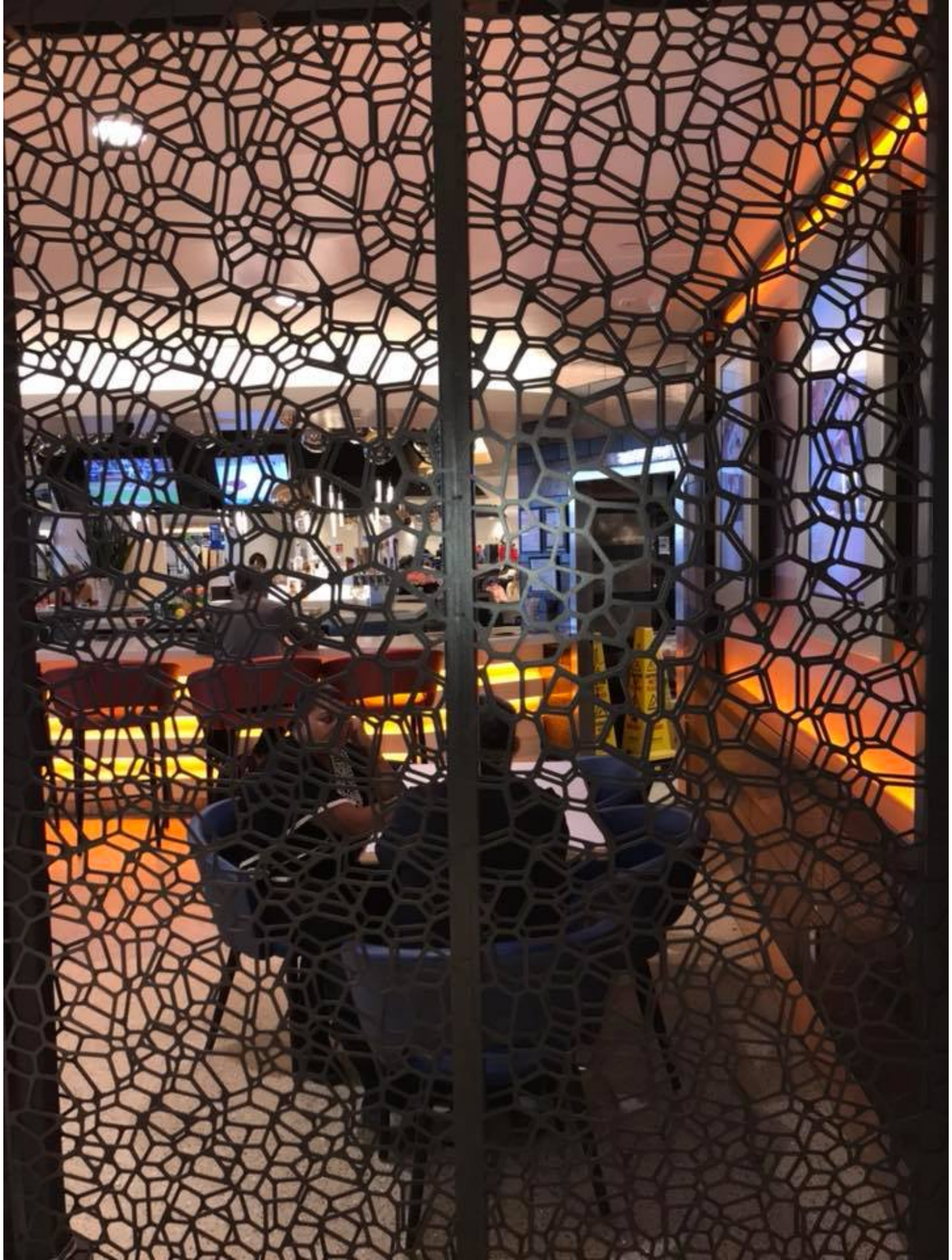
… a convex hull method, to a sectional Voronoi ("power") tessellation (Hidding et al. 2012, 2016, 2018)

Wonderful interactive code at https://github.com/jhidding/adhesion-example



Gradient of potential taken with sectional Voronoi tessellation instead of FFT (no PBC's!)

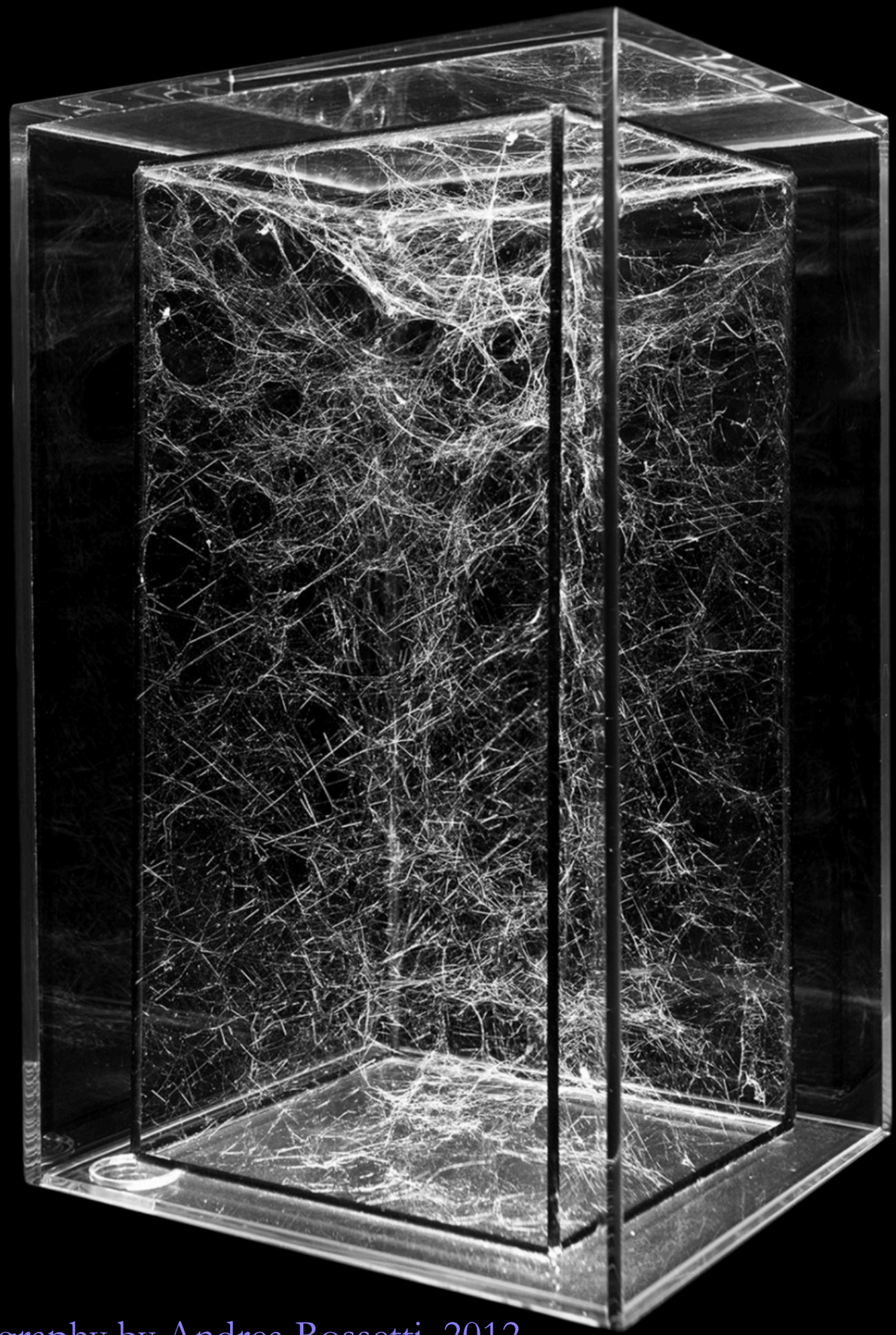




Sectional Voronoi diagrams also appear in architecture!

(MN, Hidding, Konstantatou & van de Weygaert 2018)

SPIDERWEBS



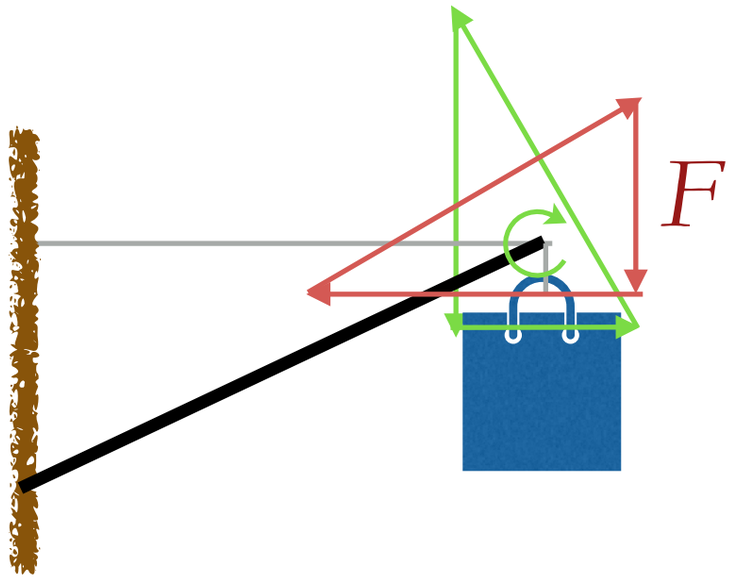
Tomás Saraceno
“Social .. Quasi Social .. Solitary ..
Spiders ... On Hybrid Cosmic Webs”
at Esther Schipper Art Gallery, Berlin, Germany, 2012 © Photography by Andrea Rossetti, 2012

Tomás Saraceno, *14 Billions (working title)*

Structural-engineering spiderwebs:

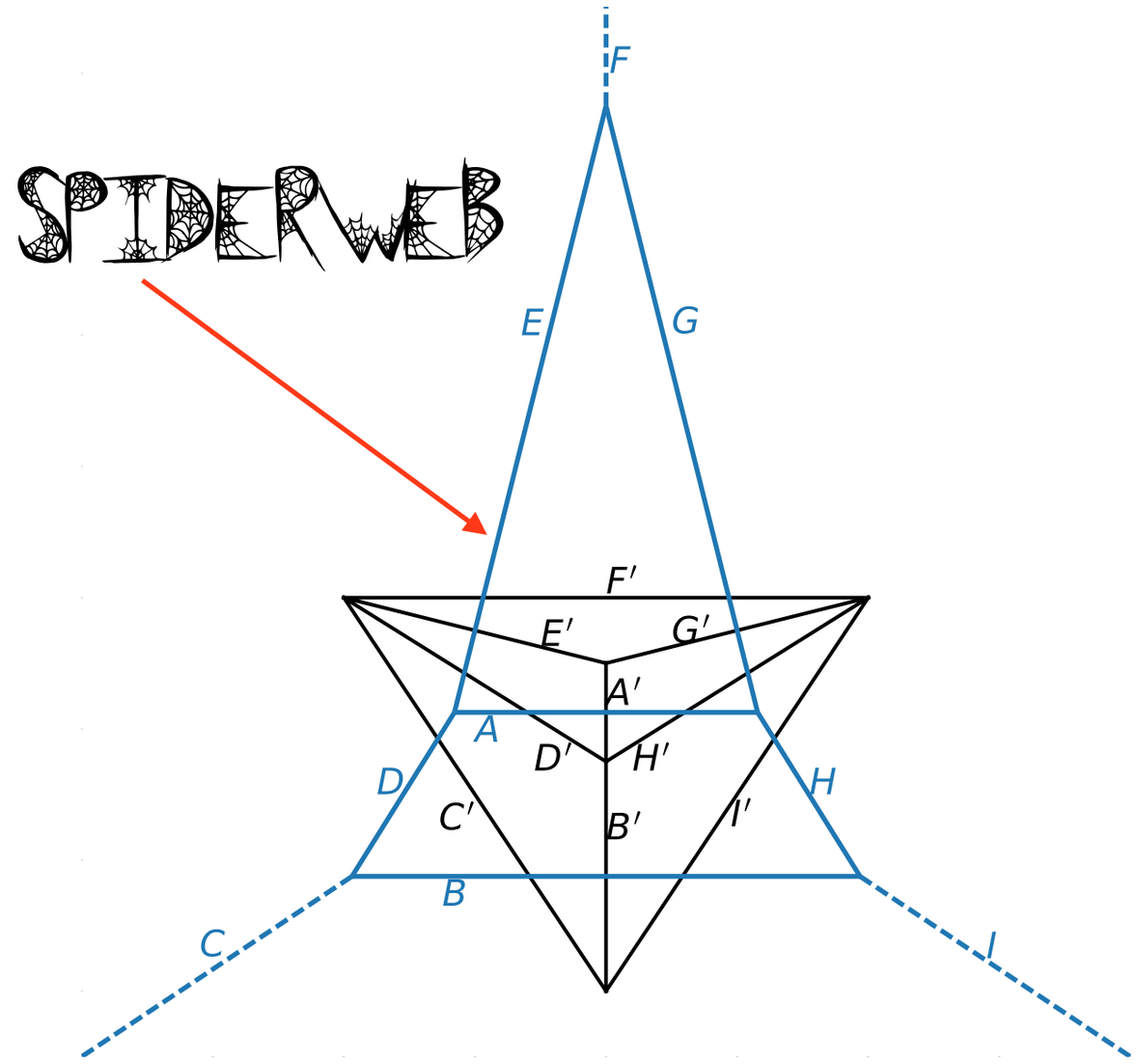
"Force polygons"

James Clerk Maxwell: perpendicular construction



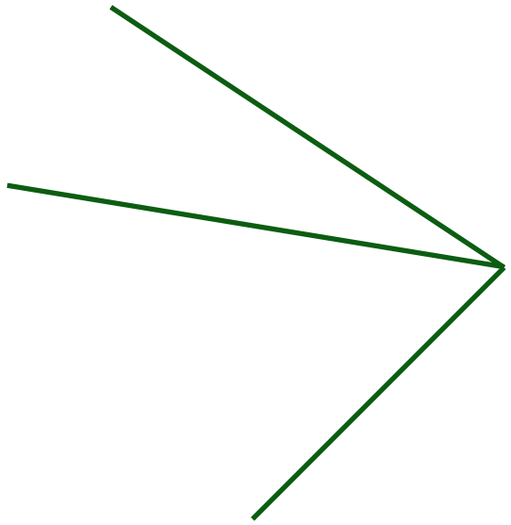
Structural-engineering spiderwebs
Force polygons → force diagram

Form/force diagrams are reciprocal duals (Maxwell 1860's)
⊥ edges, e.g. Voronoi↔Delaunay

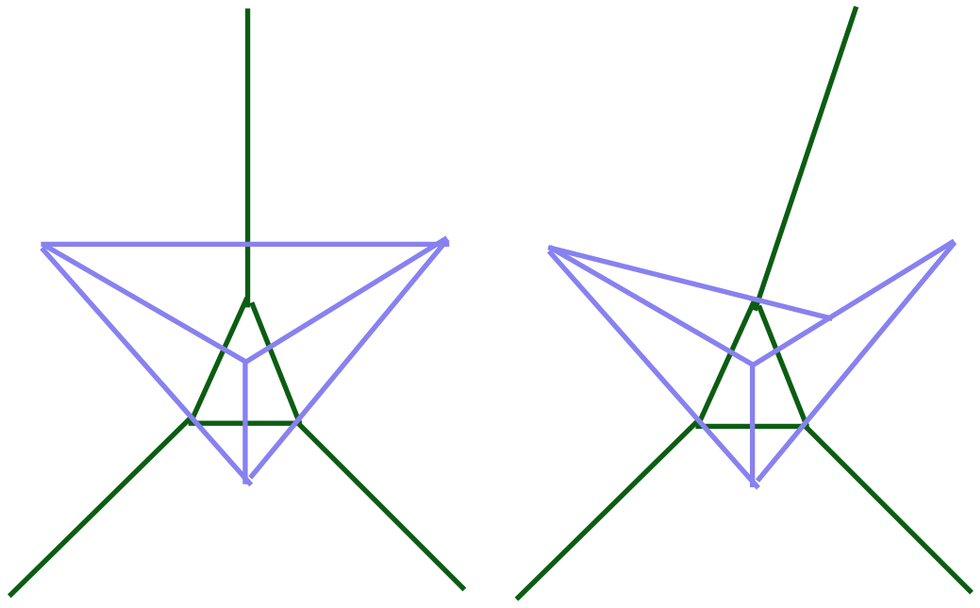


What sort of thing is *not* a spiderweb?

An obvious case …

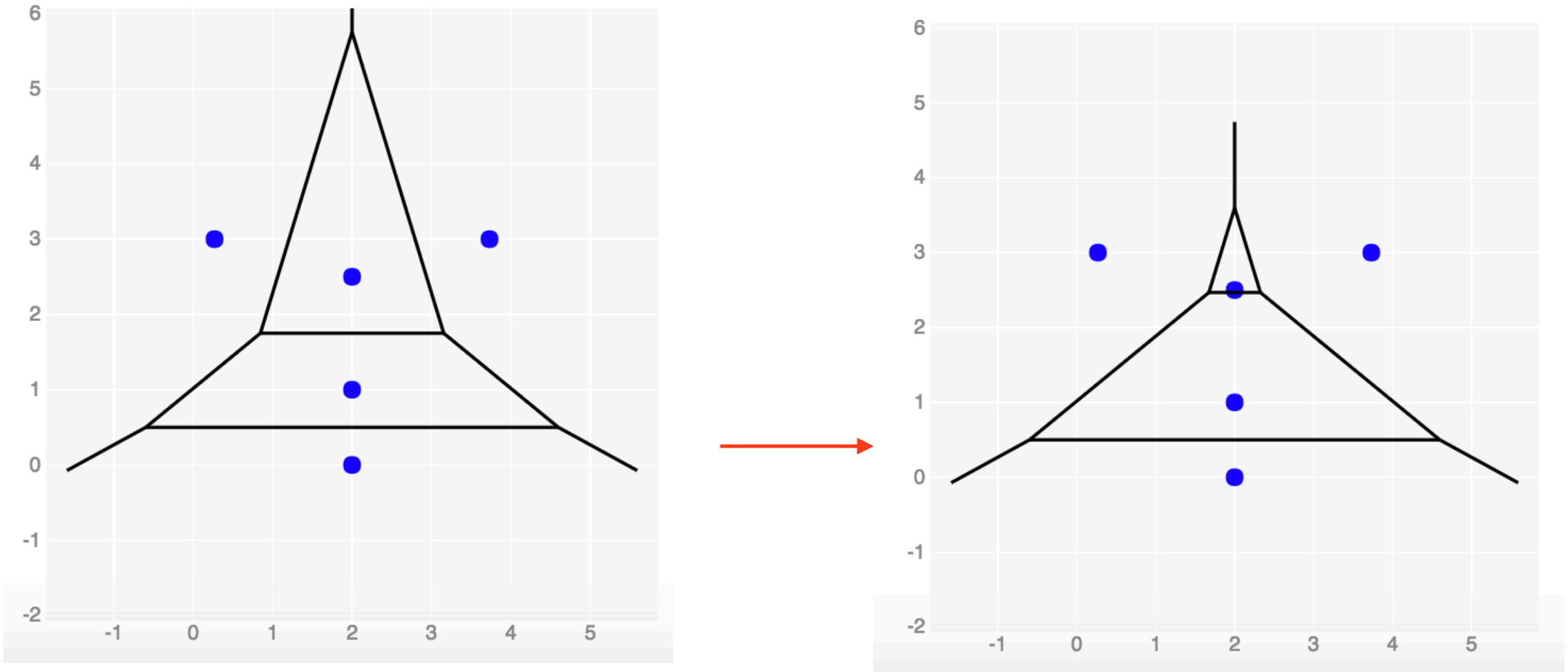


More subtle: force diagram cannot close



Ash & Bolker (1986), see also Whiteley et al. (2013) showed that in 2D, spiderwebs and sectional Voronoi tessellations are the same

Each polygon can shrink/enlarge, sides sliding perpendicular to dual edges



http://github.com/neyrinck/sectional-tess/

Lang & Bateman 2011, Lang 2015, 2018: each 2D spiderweb gives an origami tessellation

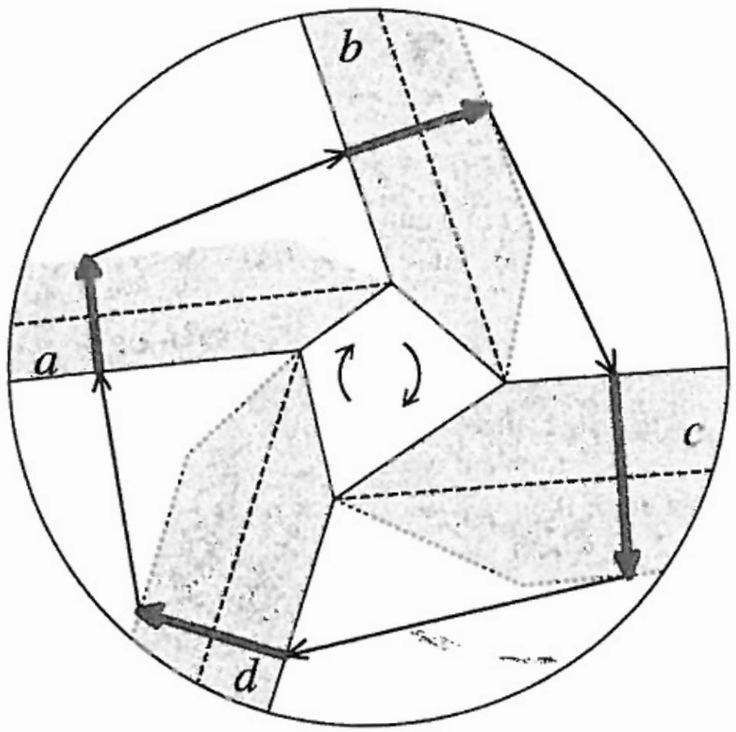
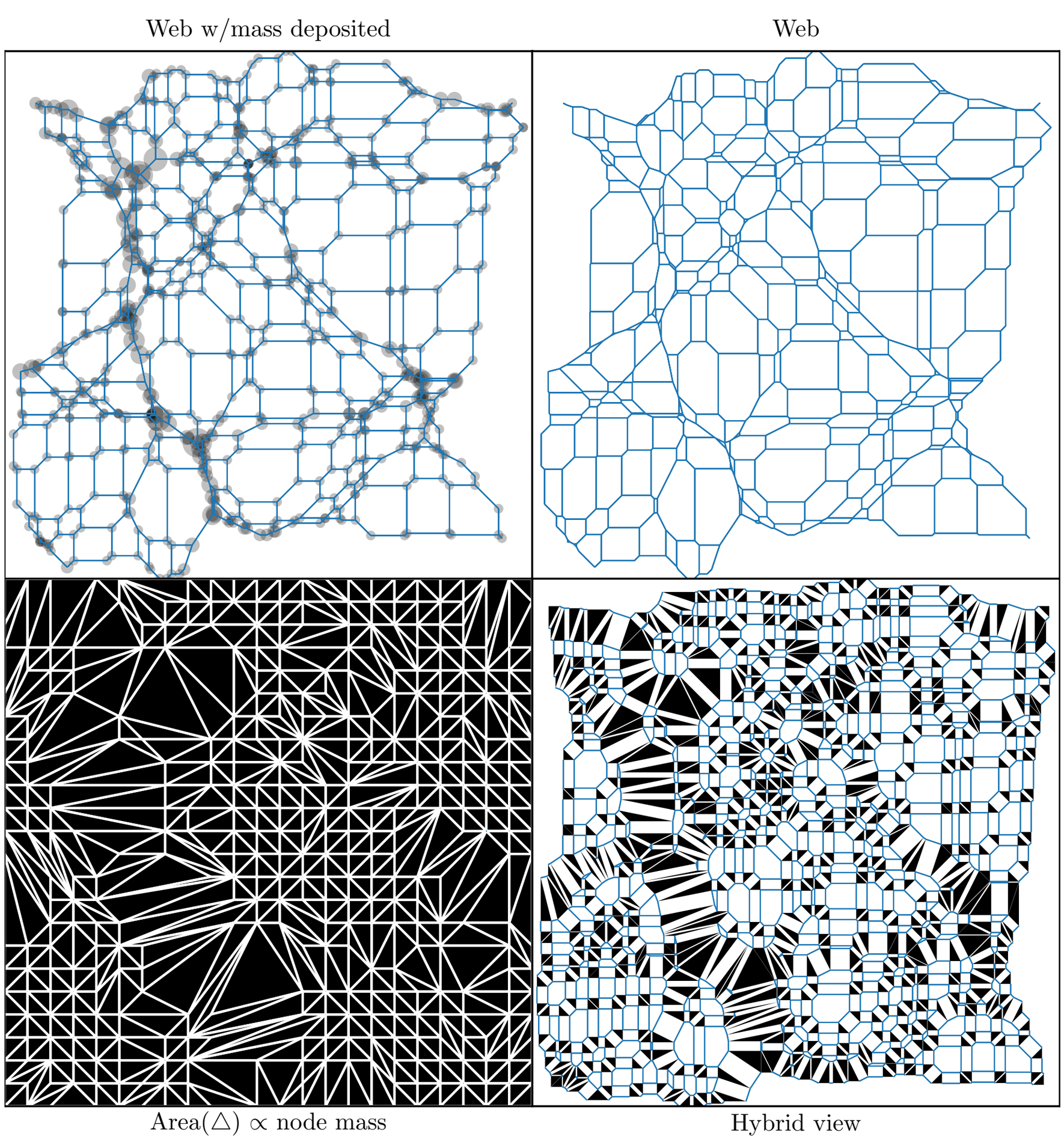


FIGURE 1. A simple flat twist. (a) Crease pattern: Mountain folds are solid, and valley folds are dashed. Light-gray regions are not visible in the folded form. (b) The folded form.

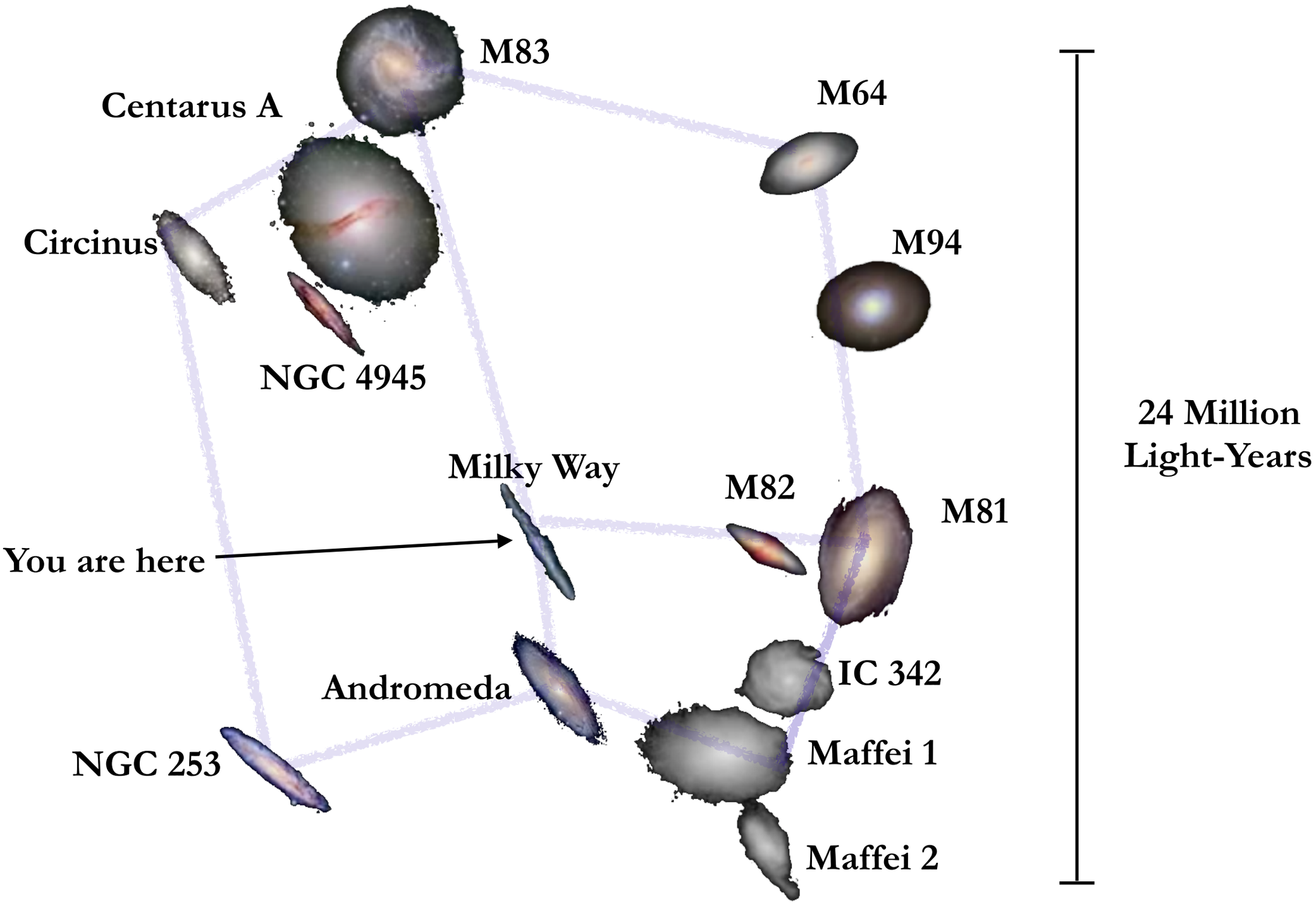
“Minkowski sum” of Eulerian + Lagrangian space is ~ an origami crease pattern



On display at STSci

Our Local Universe: a convenient spiderweb!

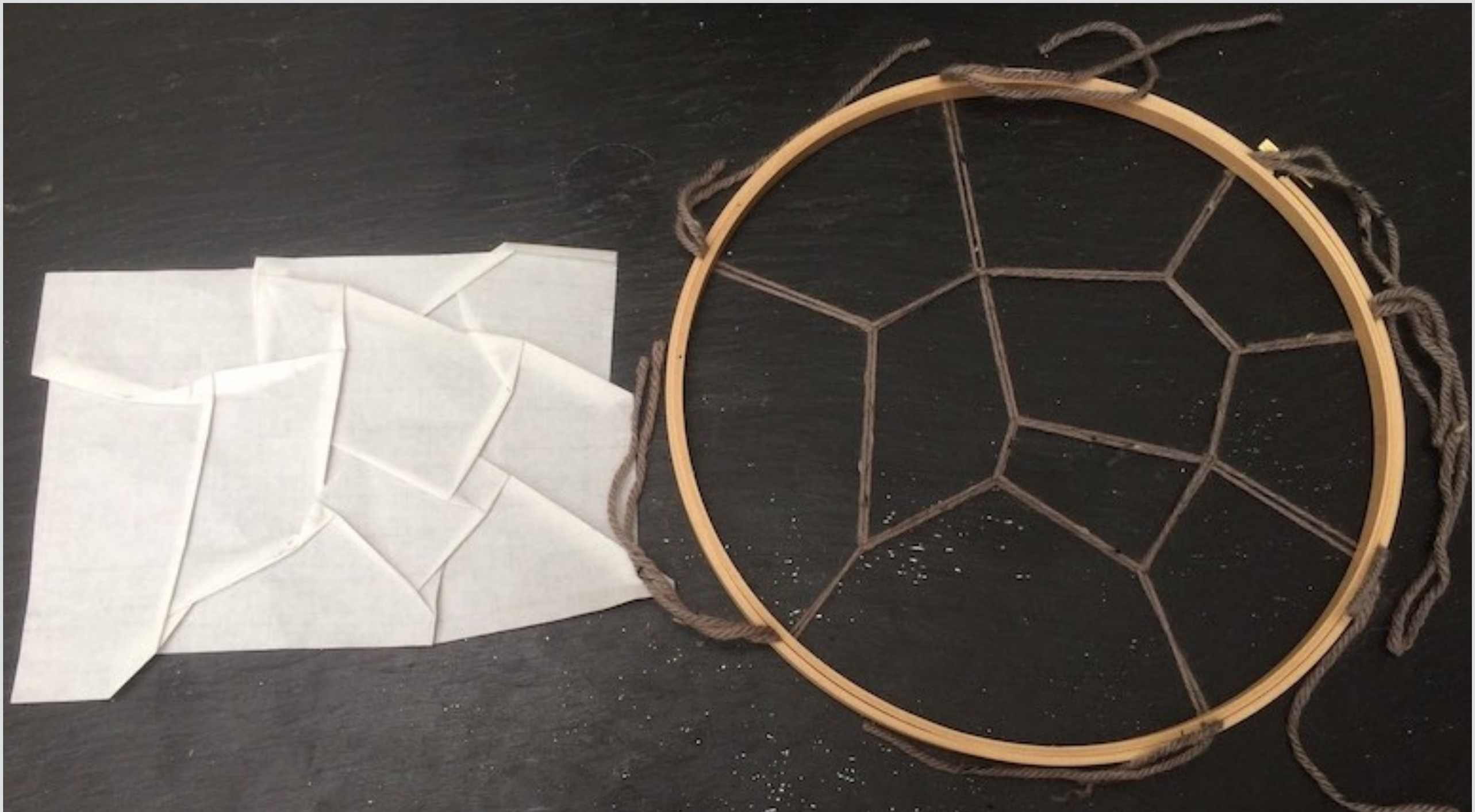
COUNCIL OF GIANTS (McCall 2014)



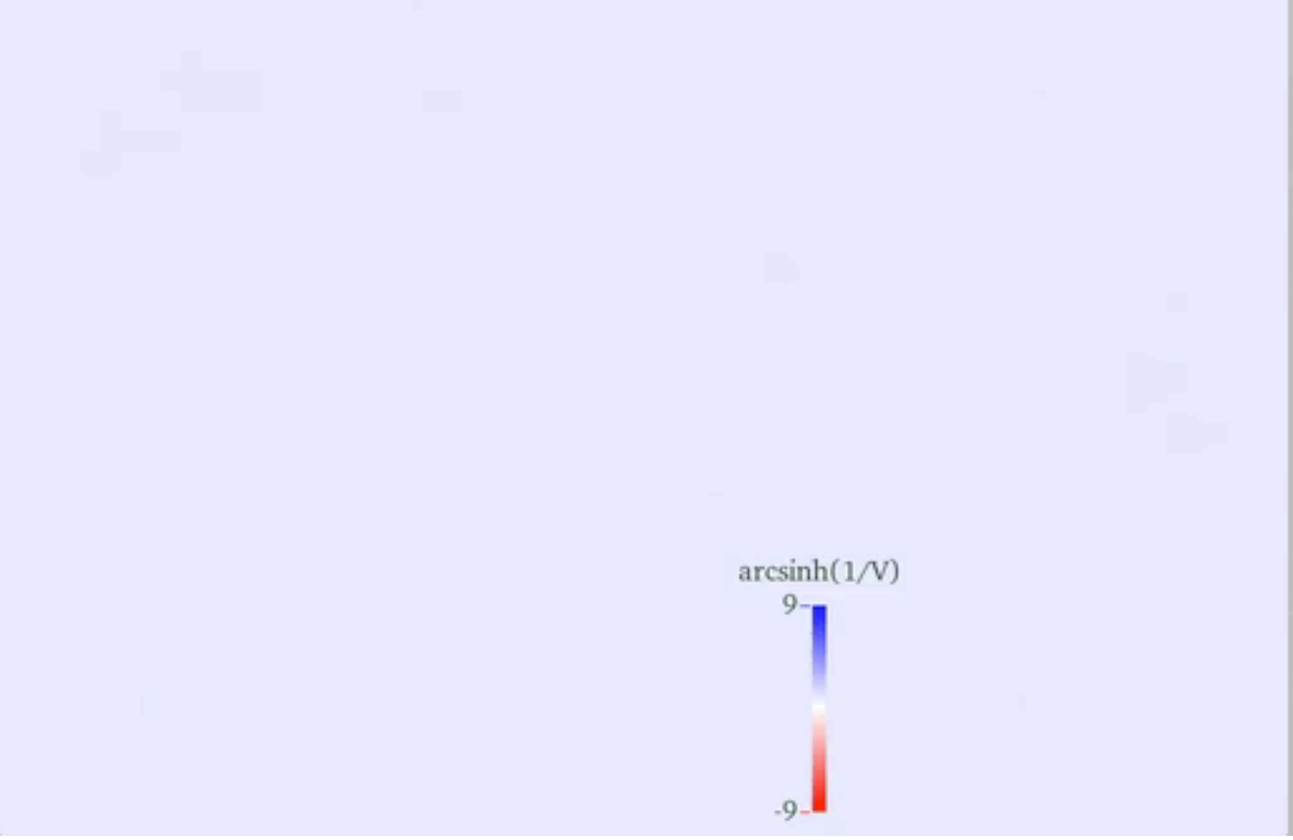
Assembled by Mark Neyrinck, using images from Marshall McCall's (2014)
Council of Giants YouTube video, https://www.youtube.com/watch?v=VzL7xGzfNlU

cosmic web = origami tessellation = spiderweb

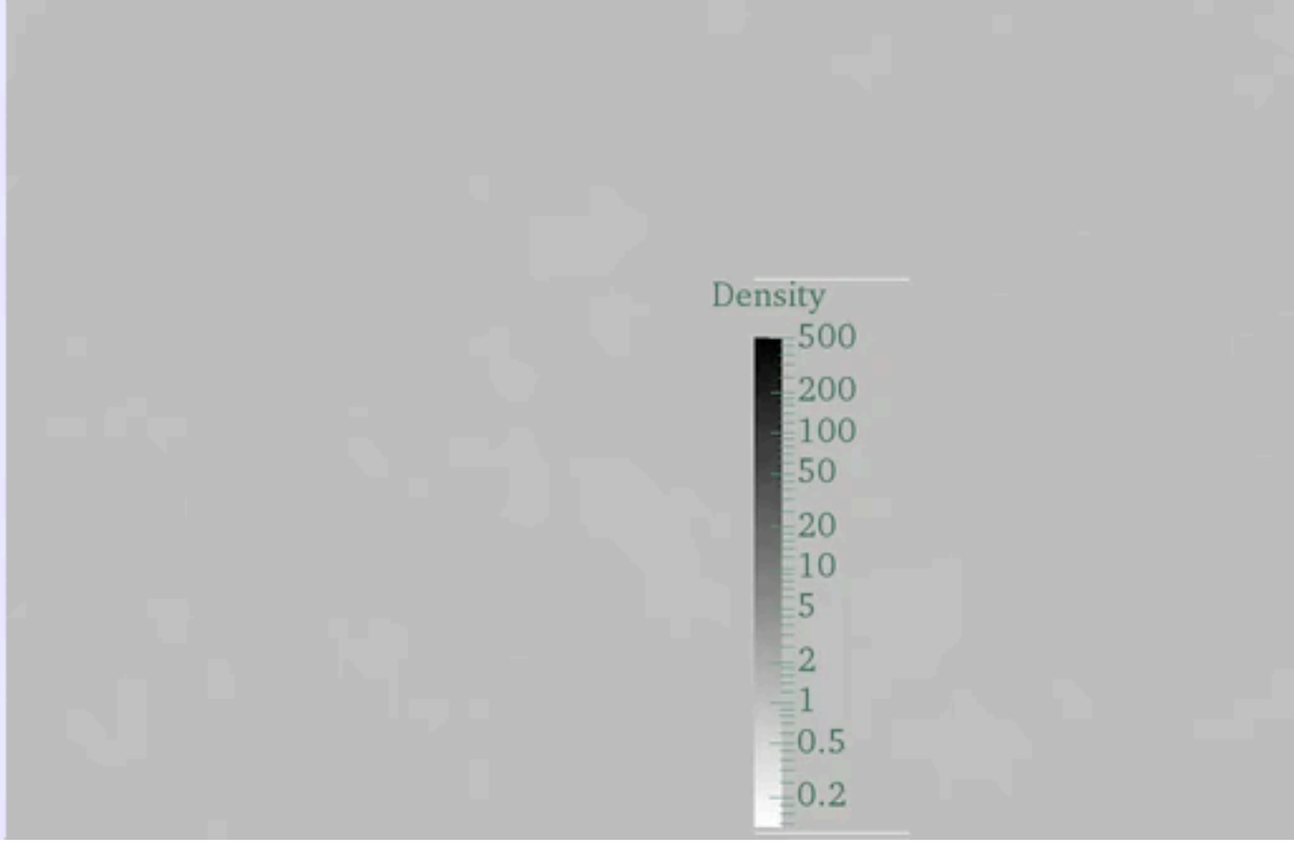
example, "Council of Giants" (McCall 2014)



Eulerian-Lagrangian 2D universe (run with ColDICE (Sousbie & Colombi 2016)

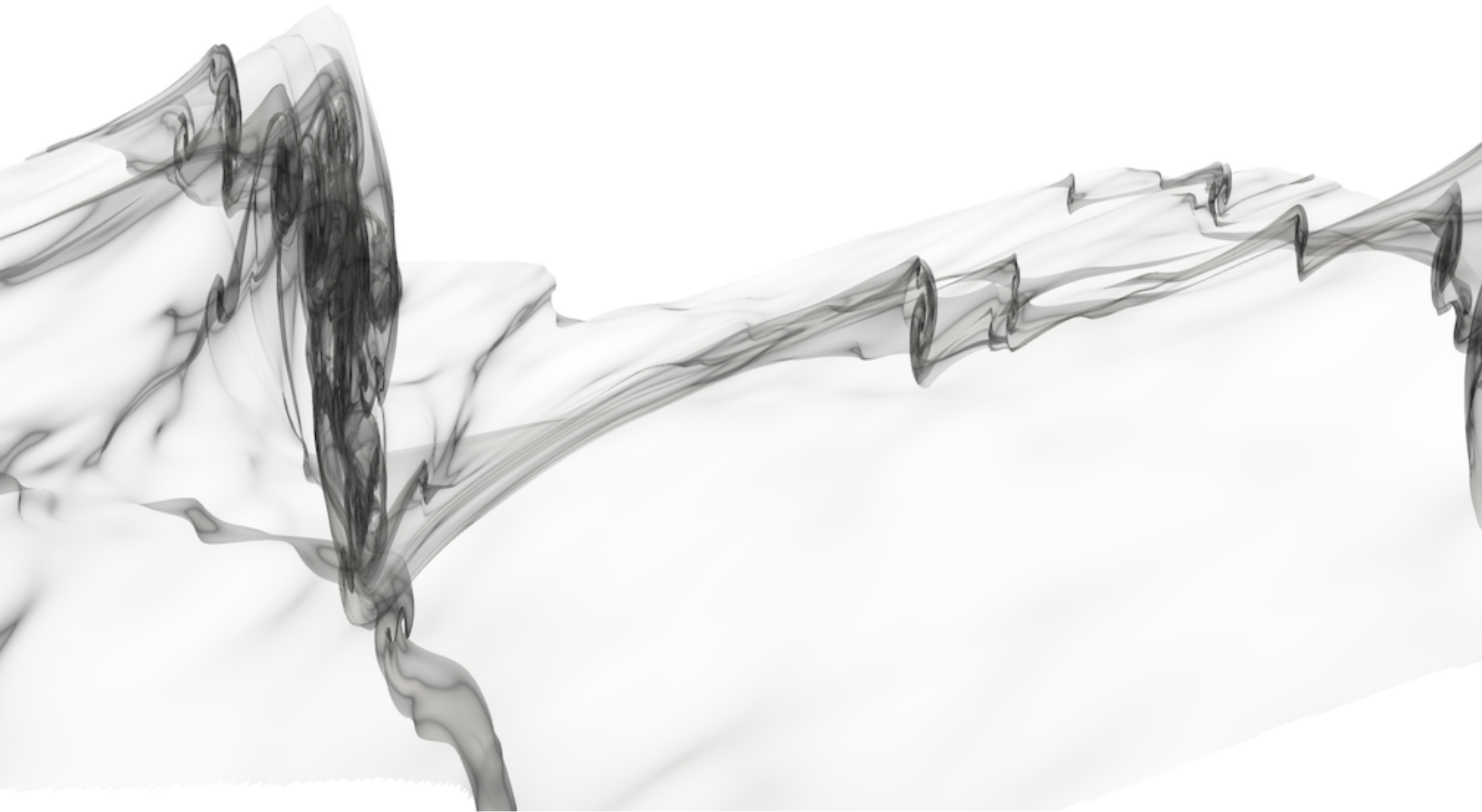


Initial (Lagrangian) coordinates log-density

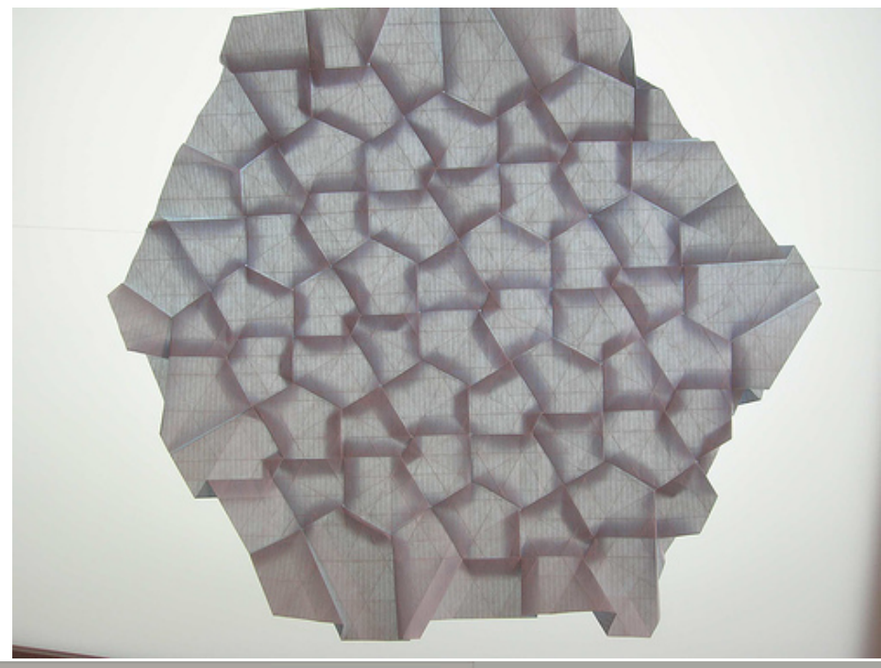


(Eulerian) log-density

Folding in 4 dimensions — hard to visualize!



Looking more like an origami tessellation:



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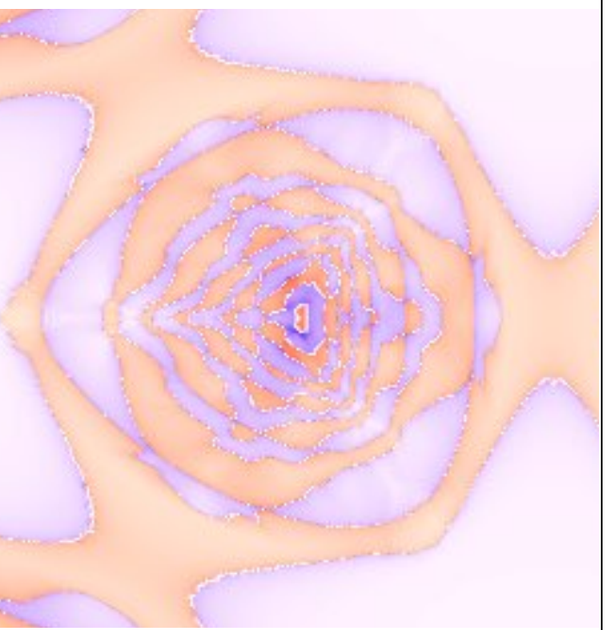
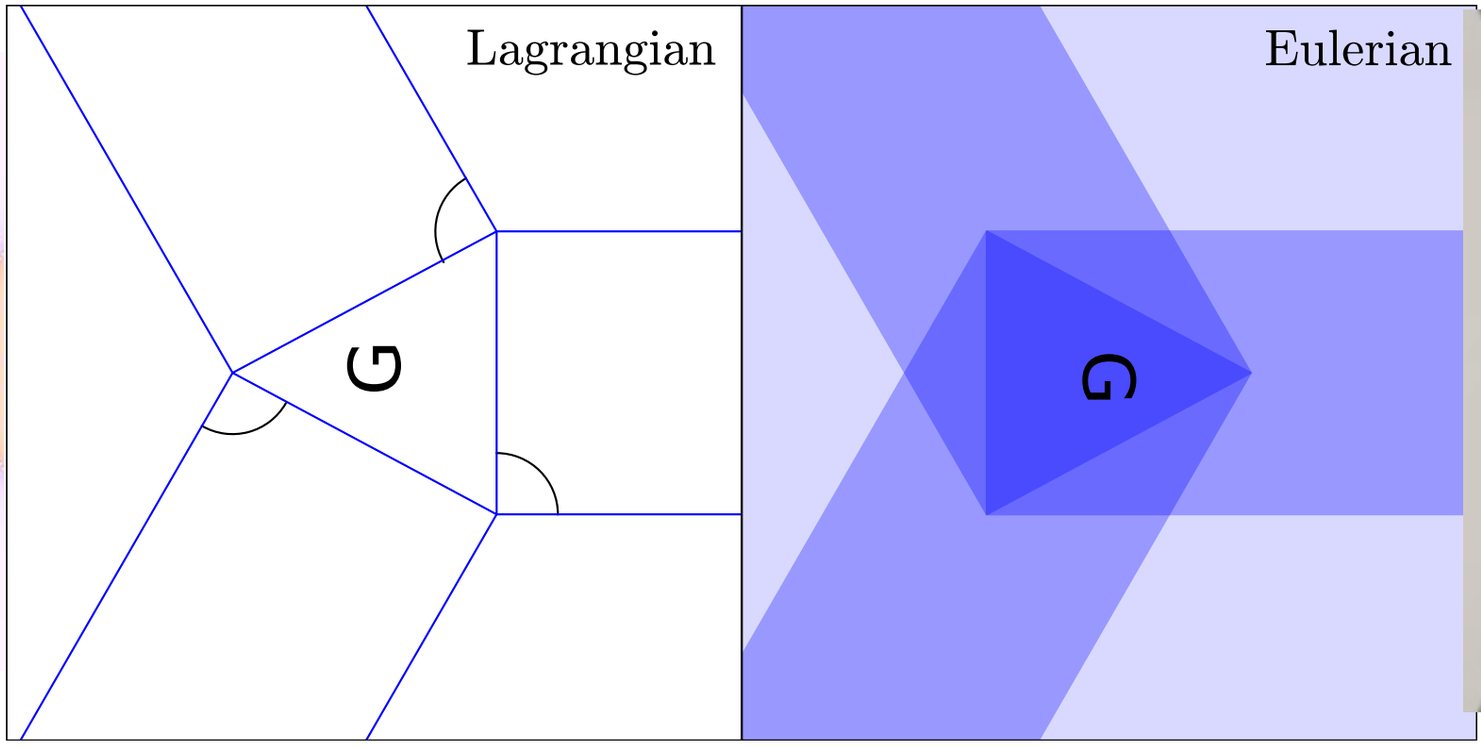
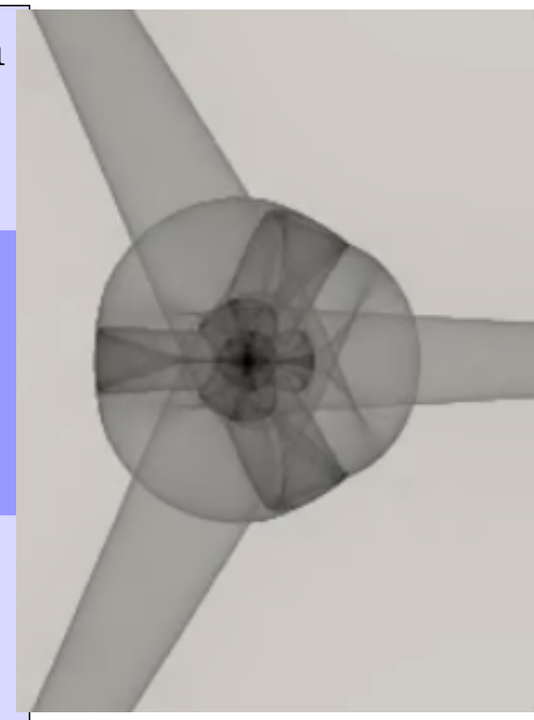
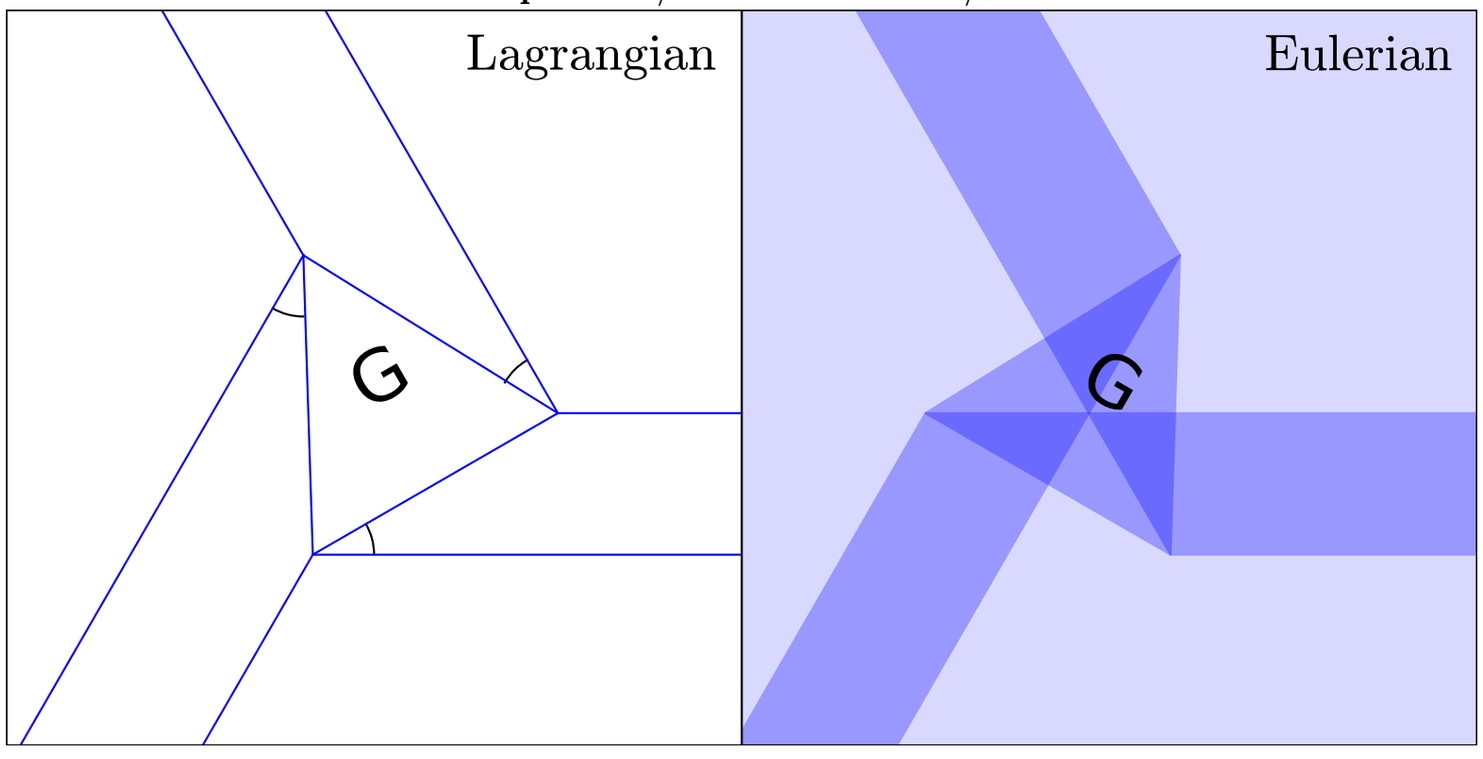
2D twist fold: a polygon rotates through some angle. A pleat extrudes from each face



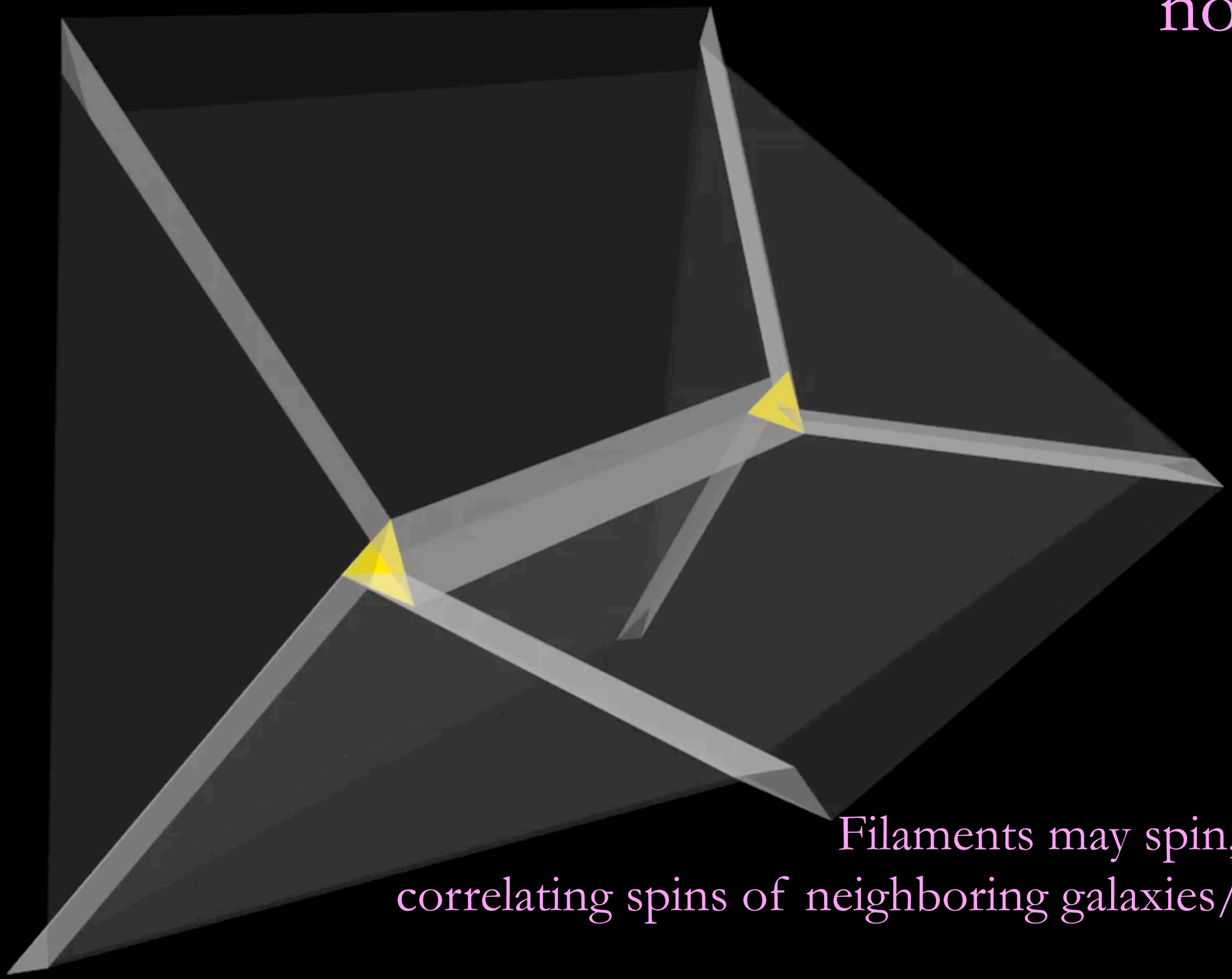




Top: $\alpha = \pi/2$. **Bottom:** $\alpha = \pi/6$.



Changing a spin parameter for two joined nodes



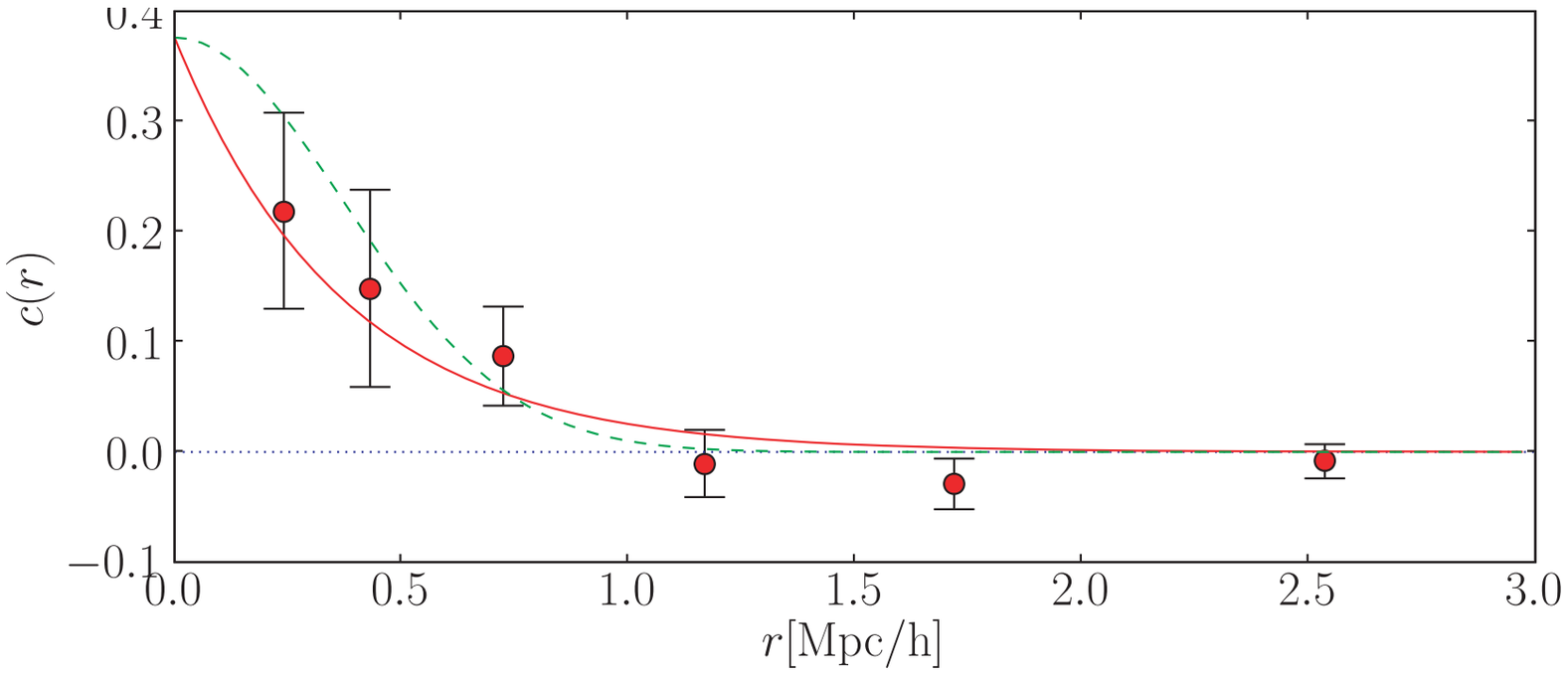
Filaments may spin, slightly correlating spins of neighboring galaxies/clusters

Can origami ideas help scientifically?

"Twisting" is a major feature of origami-like collapse.

Chirality/spin correlation observed in SDSS (Slosar et al. 2008)

Correlations between neighboring galaxy spins can give intrinsic alignments of their major axes — this systematic needs to be understood for weak lensing



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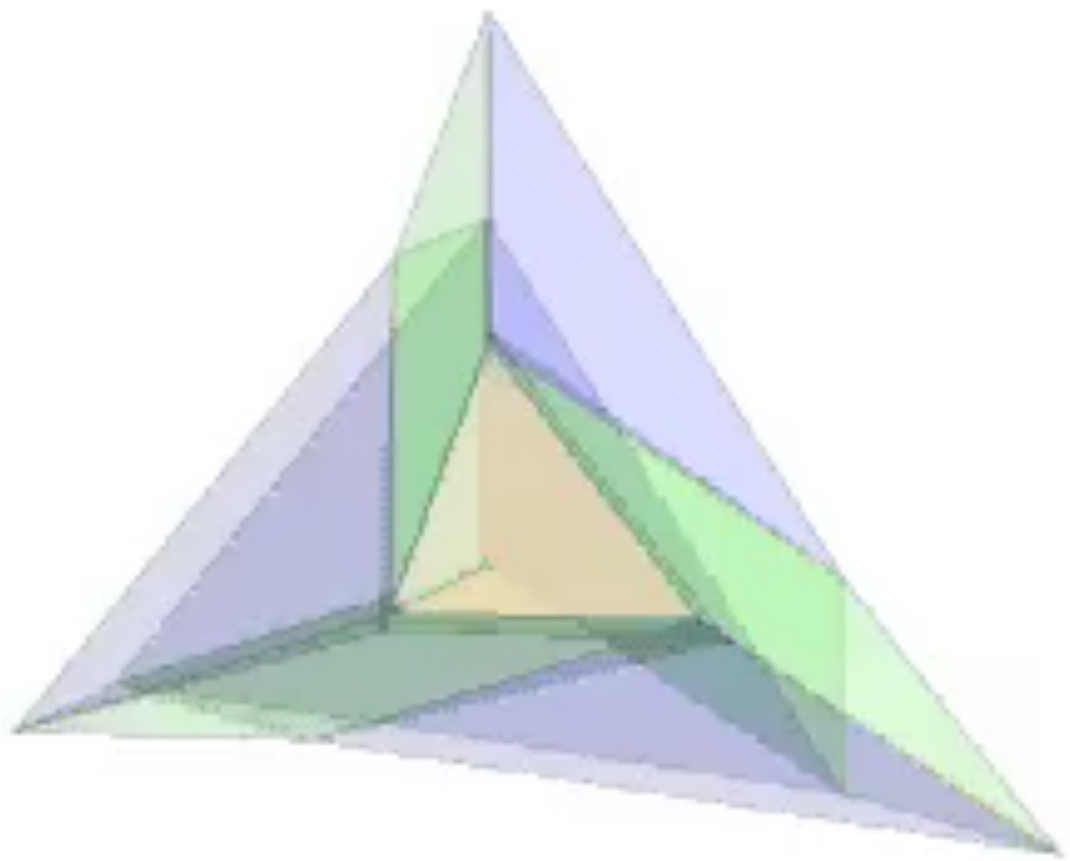
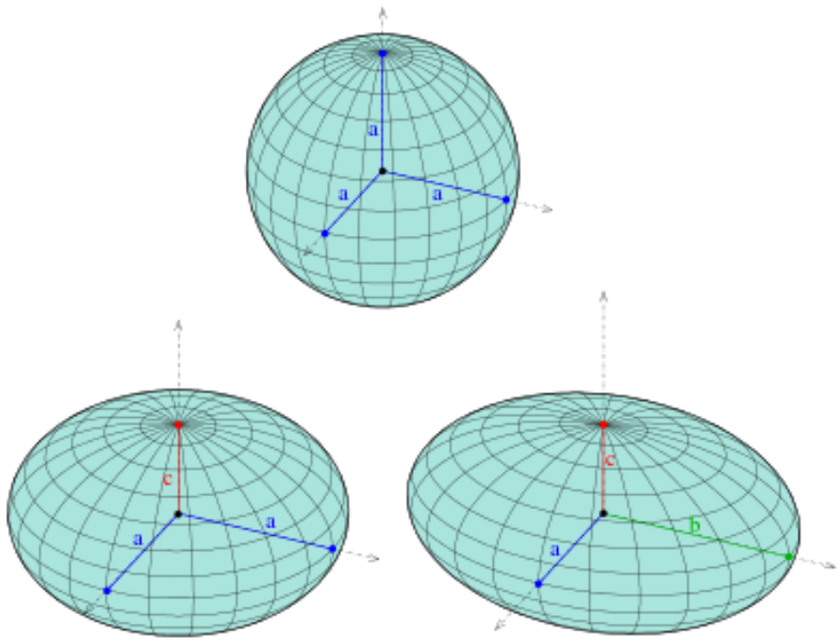
3D? Polyhedron inverts and rotates through some 3D angle.

- An extruded 2D twist fold (filament/Toblerone) from each face
- A planar pleat (wall) from each Toblerone face
- Some simple laws relate filament rotations

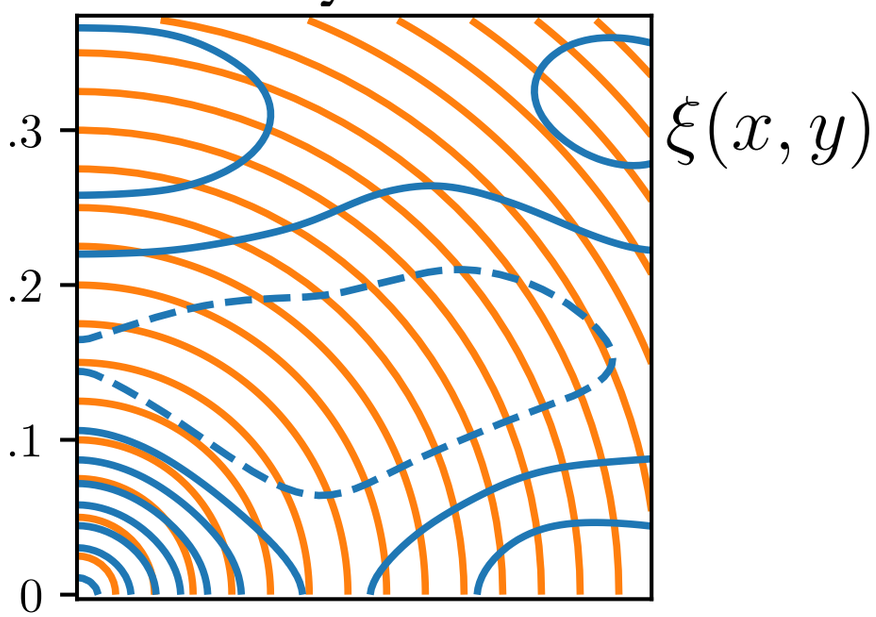


(Neyrinck 2016)

Spiderweb useful for cosmology, in principle!
sensitive to shear (e.g. redshift/distance mapping, ~Alcock-Paczynski)
1% error in x-y scaling factor in idealized case;
several% with correlation function

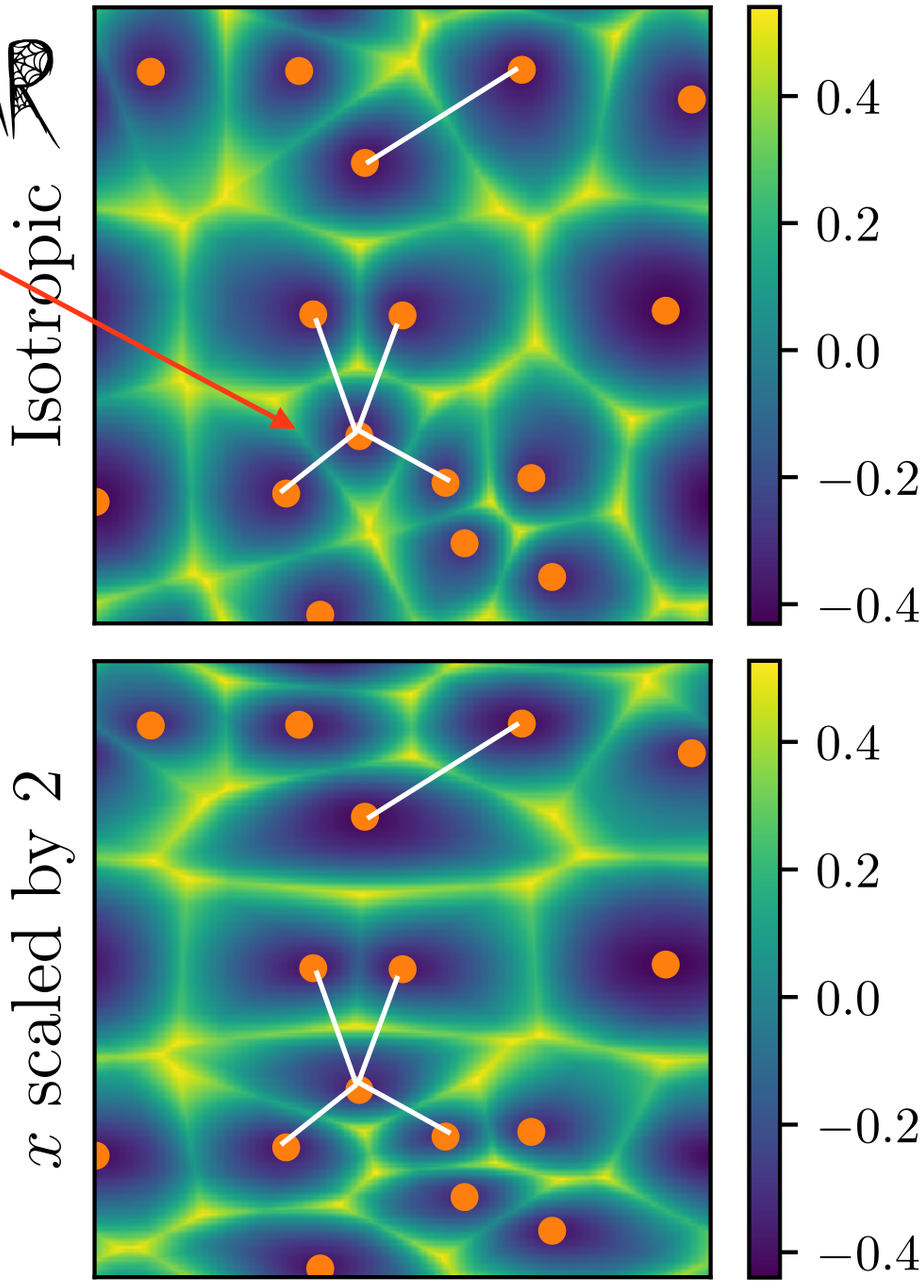


Alcock-Paczynski



PERPENDICULAR

Skewed



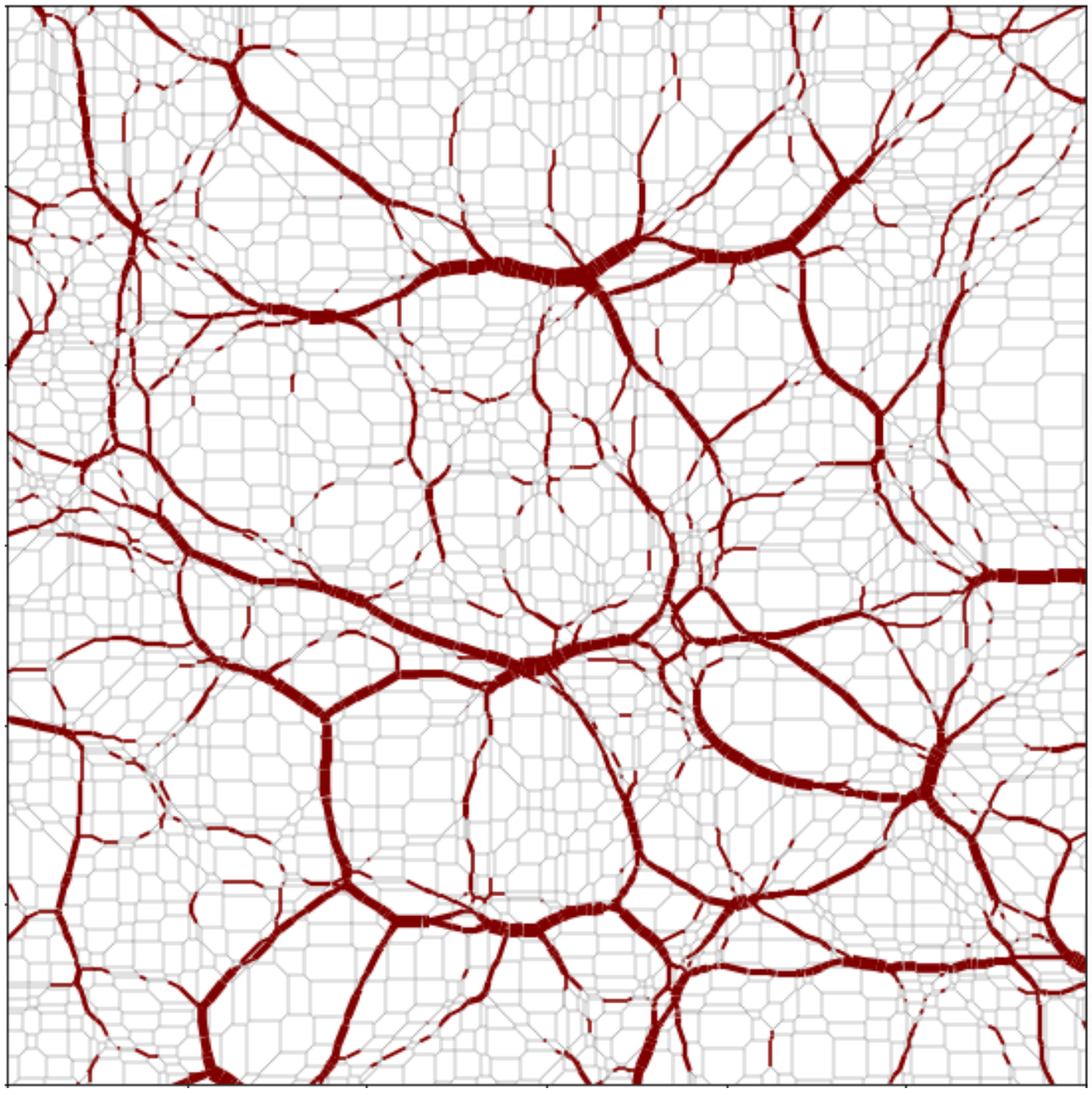
Testing spiderwebness: Any cosmic web built from a potential displacement field is a spiderweb, in real space

- 3D print it and see how much weight it can hold!
- Or build it out of string and see if any strands always sag

What if it's not a spiderweb?

- Observations were not converted into a cosmic web in a way consistent with adhesion — substructure within adhesive filaments, walls, nodes in the real universe! also strands need to be included within voids
- Still, worth trying a standard cosmic web definition
- Redshift-space distortions! (but could be a probe of them)
- Rotational (curl) component of displacement field — unexpected vorticity?

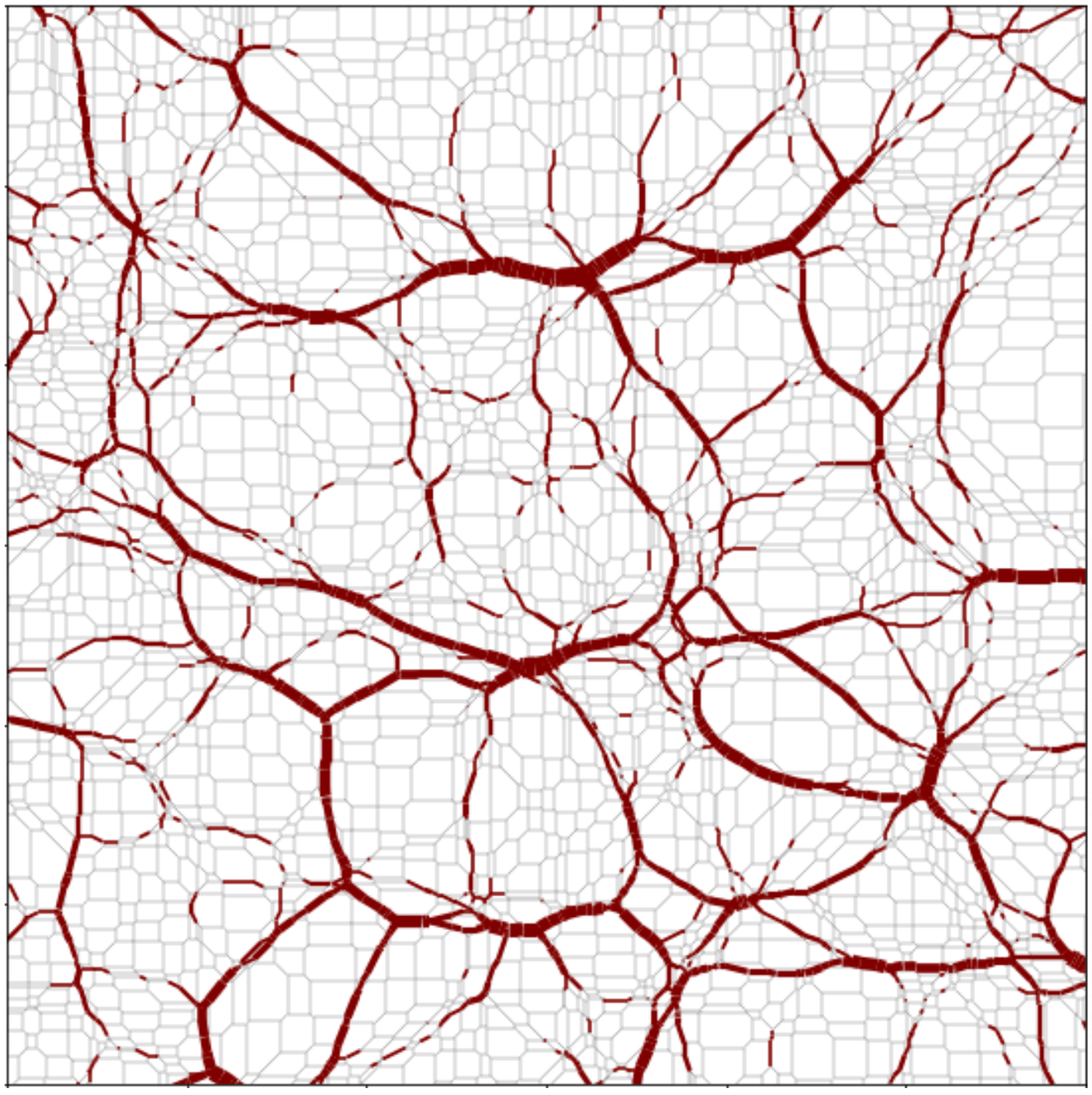
The circulatory system is a fractal of maximal surface area, to distribute nutrients efficiently to a volume



photographer Jan Kriwol and artist Markos Kay, *"human after all"*

See *Scale* (West 2017)

The cosmic web may be a fractal surface/volume efficiently transporting matter into galaxies? Indeed, surface dimension ~ 2.5



photographer **Jan Kriwol** and artist **Markos Kay**, ***"human after all"***

See *Scale* (West 2017)

Conclusions

- A cool example of art + science!
- Origami, “analytic” geometry, structural engineering, cosmology interacting and helping each other

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