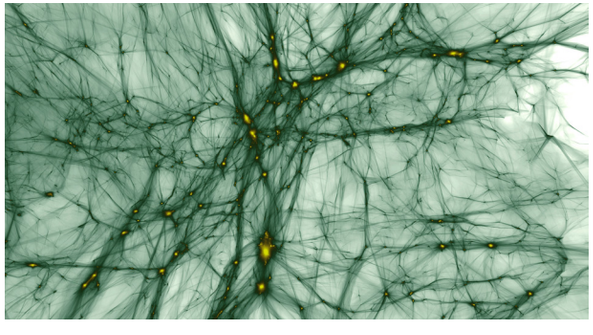
Folding a Tactile Cosmos: cosmic origami and spiderwebs — *Mark Neyrinck*

About five years ago, I went to a stunning colloquium by origamist and former physicist, Robert Lang. His work includes designing solar panels for a NASA spacecraft that could unfold. He discussed origami and its beautiful mathematics. I had been working on a geometrical method of detecting structures in computer simulations of structure formation in the Universe, and I wondered: what could we learn by thinking about cosmic structures in origami terms?

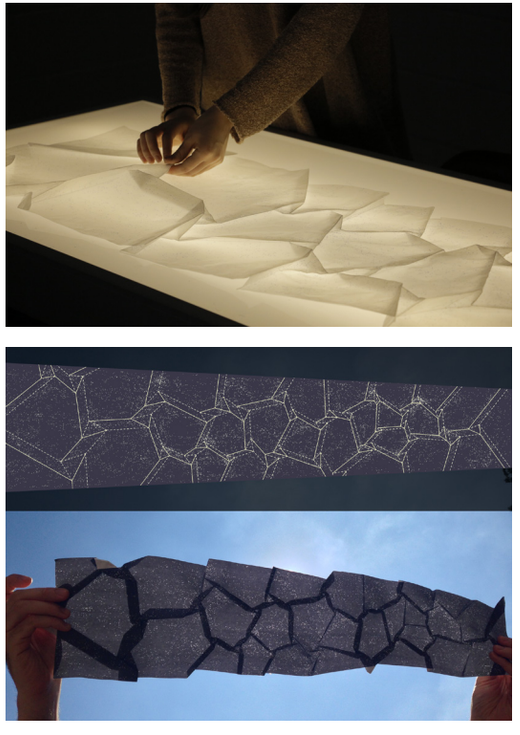
It is rare that an artistic medium links conceptually so closely to a physical process. We think that something called the "dark-matter sheet" really does fold up to build structures in the cosmos. The folding operations happen in an unhelpfully abstract position-velocity phase space, but concrete, clarifying origami concepts still apply to the folded-up structure if the abstract velocity coordinates are squashed flat. Knowledge has increased in both directions: from science to origami, and from origami to science. It is especially valuable for tactile understanding, which is usually absent in astronomy. I recall a professional meeting where I handed out origami to fold - this was the only point of the conference where all attendees were fully engaged, not a single laptop out.



Origami ideas of a folding "dark matter sheet" enabled this rendering, courtesy Ralf Kähler (KIPAC/SLAC/Stanford). Simulation by Oliver Hahn and Tom Abel

Scientifically, this origami view has led to my toy "origami" approximation of the large-scale arrangement of matter in the Universe, which helps to explain, for example, why matter filaments typically extend from galaxies and why nearby galaxies connected by filaments tend to rotate in a similar direction.[1]

Recently, I designed an origami tessellation from a patch of the VIPERS galaxy survey. Students and I folded it in an "Origami Mathematics and Cosmology" short course at Johns Hopkins. It was deeply engaging for everyone involved. At the top, tiny white dots show the raw locations of galaxies in the survey. The yellow crease lines show where to fold the pattern.



Origami representations of the VIPERS survey, http://vipers.inaf.it, by the author and students in the 2015 "Origami Mathematics and Cosmology" course at JHU. Top panel photographed by Ben Andrew

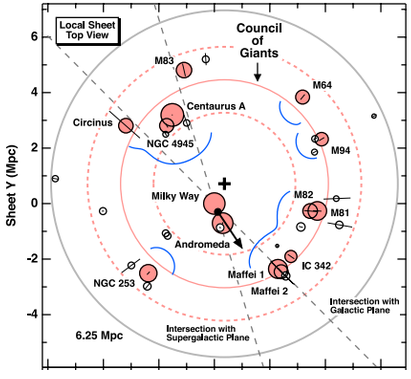
These designs are based on a vast patch of the universe billions of light-years away, but the next design focuses on the close-to-home "Council of Giants",[2] our nearest dozen or so galaxies that happen to be in a flat arrangement. Robert Lang has written about the correspondence between origami tessellations and "spiderwebs", i.e. spatial networks of threads that can be strung up entirely in tension.[3] This led to our recent paper exploring the

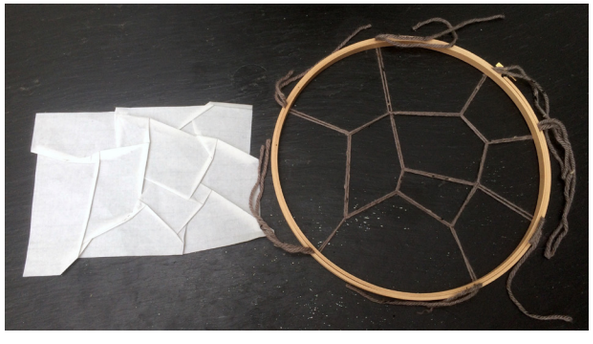
1 Mark C. Neyrinck, "Tetrahedral collapse: a rotational toy model of simultaneous dark-matter halo, filament and wall formation", *Monthly Notices of the Royal Astronomical Society* 460, no. 1 (2016): 816-826.

2 Marshall L McCall, "A Council of Giants", *Monthly Notices of the Royal Astronomical Society* 440, no. 1 (2014): 405-426.

3 Robert J Lang, A. Bateman, "Every spider web has a simple flat twist tessellation" in Origami^5: *Fifth International Meeting of Origami Science, Mathematics, and Education*, eds. P Wang-Iverson, RJ Lang, Y Mark (2011): 455–473; Robert J Lang, "Spiderwebs, Tilings, and Flagstone Tessellations" in *Origami^6: I. Mathematics* (2015): 189; Robert J Lang, *Twists, Tilings, and Tessellations: Mathematical Methods for Geometric Origami* (CRC Press 2018)

shared geometry of these networks.[4] Here are my approximate origami and dreamcatcher (spider web) representations of this Council of Giants.





Scientific, origami and dreamcatcher/spiderweb views of the Council of Giants

The correspondence between origami tessellations, spiderwebs, and the cosmic web gives a rigorous underpinning to the observation that the cosmic web is spiderweb-like, made by artists (e.g. Tomas Saraceno[5]), scientists,[6] and journalists. Practically in astronomy, this correspondence could be of use to correct galaxy distances in galaxy surveys, to match these networks' geometry.

Concepts related to folding can help to understand a lot in nature, beyond cosmology. The study of projections of folded forms is essentially catastrophe theory, which explains some

4 Mark C. Neyrinck, Johan Hidding, Marina Konstantatou, and Rien van de Weygaert, "The cosmic spiderweb: equivalence of cosmic, architectural, and origami tessellations", submitted to Roy Soc Open Science (2018), arXiv:1710.04509

5 Philip Ball, "World of webs", *Nature* 543 (2017): 314–314.

6 Mario Livio, "From Spider Webs to the Cosmic Web", Huffington Post (2012); Benedikt Diemer and Isaac Facio, "The Fabric of the Universe: Exploring the Cosmic Web in 3D Prints and Woven Textiles", *Pubs. Astr. Soc. Pacific* 129, 058013 (2017).

non-intuitive effects in a wide variety of fields, from stock market crashes to light playing on the bottom of a swimming pool. I was talking about spiderwebs and origami to Allan McRobie, a Cambridge structural engineer, and expert on spiderweb-like structures. He has been looking at catastrophe theory and folding in art and drawing. Whereas the cosmic web described in the "origami spider web" is entirely angular, his work on catastrophe theory is all about smooth curves - the angular spider web is only an approximation to the reality. Both perspectives help to understand the structure.

This wonderful conversation reminded me that all we have to understand the universe is our artistic mind, which cannot grasp the universe in its raw, entirely objective form. To know the universe and how we occupy it as well as possible requires multiple ways of viewing, most of which involve art.

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