For several years Mark Neyrinck has been studying the behavior of infant galaxies using a non-traditional approach: the science of folding. In this article, he recaps and examines how origami mathematics can be used to understand the Universe.

The Origami Cosmic Web

My personal origami voyage began with a colloquium by Robert Lang at the Space Telescope Science Institute in Baltimore. I was working on a new geometrical method [1] of detecting structures that correspond to galaxies in computer models and I was astonished to see a connection to paper origami. I wondered: could origami mathematics be useful to understand the universe?

In Einstein’s theory of general relativity, gravity comes about through distortions of a four-dimensional spacetime “sheet.” But gravity also causes a different kind of sheet to distort and fold: the three-dimensional cosmological sheet of dark matter. It turns out that the way this dark matter folds up to form structures like our galaxy is not unlike origami.

A fresh sheet of origami paper has no folds. Similarly, at the Big Bang, when matter was nearly uniformly distributed in the universe, the cosmological sheet had no folds. But some locations had more matter than others. There, the sheet further bunched up, drawing matter from all around to form galaxies. Elsewhere, the sheet stretched out, forming voids between galaxies. The rich got richer, the poor got poorer.

What do I mean by “folding” for the cosmological sheet? Usually, 2D origami paper folds up in 3D. The 3D cosmological sheet folds up in 6D! But thankfully, a lot of the process can be understood without thinking in 6D, which is impossible! Think of a 2D origami work that afterwards can be squashed into a book without further creasing; much of the structure can be understood with a 2D picture of it. Similarly, the cosmological sheet “folds flat” in 3D, and much of the structure can be understood in 3D.

This folding process is one reason that a galaxy is not just a pile of matter, unstructured and random. Instead, matter folds up to construct it, much like an origami twist fold. And just as pleats must stick out of a folded-up origami twist, filaments of matter must stick out of a galaxy after it forms. For example, Fig. 1 shows two galaxies (twist folds) in a 2D universe. The top twist fold can be folded from paper, but the bottom fold, more typical in cosmological origami, can’t be folded from paper without paper crossing itself. It can happen in cosmology because there are more dimensions to fold in!

Fig. 2 shows a model universe produced with a state-of-the-art computer code [2]; its new technique can resolve the intricate structure inside each galaxy. While the physics computing this is accurate, the pattern is quite idealized: a pentagonal tiling of voids, in which galaxies form at the corners, and cosmic filaments are strung between them.

Fig. 3 shows a paper-origami representation of a galaxy, and a hexagonal system of galaxies, each joined to its neighbor by a filament pleat. The hexagonal space between the galaxies is called a void.

This is just 2D; what about 3D? To make a stab at visualizing 3D origami, visualize a big cube of “ghost Jello,” a special kind of Jello
that can pass through itself as many times as it pleases. A crease in the Jello triggers a reflection, like a mirror; the Jello from one side of the mirror gets pushed through to the other side, ending up inverted (turning a right hand into a left hand).

A 2D galaxy forms like an origami twist fold; similarly, a 3D galaxy forms like a 3D twist fold. What is this? In a 2D twist fold, a polygon rotates by some angle, generating pleats from each edge. In a 3D twist fold, a solid shape (a polyhedron) inverts, and then undergoes a 3D rotation. In doing so, it generates a wealth of structure: from each edge, a pleat; and from each face, a “filament” (an extrusion, like PlayDoh pressed through a pattern, of a 2D twist fold). The simplest, most symmetric example is shown in Fig 4: a tetrahedral twist fold [3]. When many galaxies form together, the network of matter linking them up is known as the “cosmic web.” This cosmic web is like soap-bubble foam, with galaxies at each corner where bubbles meet. Coming back to the question I asked at the beginning: yes, origami mathematics does seem to be useful to understand the universe. Based on my work, it even makes testable predictions: if galaxies rotate (and they do), so must filaments sticking out of them. Furthermore, galaxies joined by a filament should rotate mostly together, like objects attached to ends of a rod. In fact, this is consistent with astronomical observations; nearby galaxies tend to be spinning in the same direction. The approximate model still needs to be fully tested, but even if the details are only roughly right, the concept remains: the universe seems to be one big origami tessellation.

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References

For animations illustrating how 3D twist folds operate, see http://skysrv.pha.jhu.edu/~neyrinck/irrotet and http://skysrv.pha.jhu.edu/~neyrinck/rotet.mov