The laws of physics have not always been symmetric, which may explain why you exist

May 23 2023

Credit: Pixabay/CC0 Public Domain

For generations, physicists were sure the laws of physics were perfectly symmetric. Until they weren't.

Symmetry is a tidy and attractive idea that falls apart in our untidy universe. Indeed, since the 1960s, some kind of broken symmetry has been required to explain why there is more matter than antimatter in the universe—why, that is, that any of this exists at all.

But pinning down the source behind this existential symmetry violation, even finding proof of it, has been impossible.

Yet in a new paper published in *Monthly Notices of the Royal Astronomical Society*, University of Florida astronomers have found the first evidence of this necessary violation of symmetry at the moment of creation. The UF scientists studied a whopping million trillion three-dimensional galactic quadruplets in the universe and discovered that the universe at one point preferred one set of shapes over their mirror images.

This idea, known as parity symmetry violation, points to an infinitesimal period in our universe's history when the laws of physics were different than they are today, with enormous consequences for how the universe evolved.

The finding, established with a high level of statistical confidence, has two primary consequences. First, this parity violation could only have imprinted itself on the future galaxies during a period of extreme inflation in the earliest moments of the universe, confirming a central component of the Big Bang theory of the origin of the cosmos.

Parity violation would also help answer perhaps the most crucial question in cosmology: Why is there something instead of nothing? That's because parity violation is required to explain why there is more matter than antimatter, an essential condition for galaxies, stars, planets and life to form in the way they have.

"I've always been interested in big questions about the universe. What is the beginning of the universe? What are the rules under which it evolves? Why is there something rather than nothing?" said Zachary Slepian, a UF astronomy professor who supervised the new study. "This work addresses those big questions."

Slepian worked with UF postdoctoral researcher and the study's first author, Jiamin Hou, and Lawrence Berkeley National Laboratory physicist Robert Cahn to conduct the analysis. The trio published their findings May 22 in the journal *Monthly Notices of the Royal Astronomical Society*. The same researchers first proposed the idea of searching for parity violation using quadruplets of galaxies in a paper that was also recently published in *Physical Review Letters*.

Parity symmetry is the idea that physical laws shouldn't prefer one shape over its mirror image. Scientists usually use the language of "handedness" to describe this trait, because our left and right hands are mirror images we are all familiar with. There is no way to rotate your left hand in three dimensions to make it look like your right hand, which means they are always distinguishable from one another.

Parity violation would mean that the universe does have a preference for either left- or right-handed shapes. To discover the universe's handedness, Slepian's lab imagined all the possible combinations of four galaxies connected by imaginary lines in space. This makes for a 3D object called a tetrahedron, like a lopsided pyramid—the simplest shape that has a mirror image. They defined right- and left-handed galactic tetrahedrons based on how galaxies were connected to their closest and farthest partners in these imaginary shapes.

Their method required analyzing a trillion imaginary tetrahedrons for each of a million galaxies, a mind-boggling number of combinations. "Eventually we realized we needed new math," Slepian said.

So Slepian's team developed sophisticated mathematical formulas that allowed the immense calculations to be performed in a reasonable period. It still required a considerable amount of computational power. "UF's unique technology we have here with the HiPerGator supercomputer allowed us to run the analysis thousands of times with different settings to test our result," he said.

The technical aspects of the analysis make it difficult to say whether the universe prefers "right-handed" or "left-handed" shapes, but the scientists saw clear evidence that the cosmos does have a preference. They established their finding with a degree of certainty known as seven sigma, a measure of how unlikely it is to achieve the result based on chance alone. In physics, a result with a sigma value of five or higher is typically considered reliable because the odds of a chance result at this level are vanishingly small. A similar analysis, conducted by a former Slepian lab member, identified the same universal shape preference, albeit with slightly less statistical confidence due to differences in the study design.

Although the scientists are confident in this signal of parity violation, it remains possible that uncertainty in the underlying measurements could explain the asymmetry. Thankfully, much larger samples of galaxies from next-generation telescopes could provide enough data to erase these uncertainties in just a few years. Slepian's group at UF will perform their analysis on this new, more robust data as part of the Dark Energy Spectroscopic Instrument telescope team.

This is not the first time parity violation has been spotted, but it is the first evidence of parity violation that could affect the three-dimensional clustering of galaxies in of the universe. One of the fundamental forces, the weak force, also violates parity. But its reach is extremely limited, and it cannot influence the scale of galaxies. That galactic influence would require a parity violation to occur right at the moment of the Big Bang, a period known as inflation.

"Since parity violation can only be imprinted on the universe during inflation, if what we found is true, it provides smoking-gun evidence for inflation," Slepian said.

Nor could the weak force's parity violation explain the abundance of matter. In a symmetrical universe, the Big Bang should have created equal amounts of matter and antimatter, which would have annihilated one another and left the universe devoid of stars and planets. Since we clearly ended up with a universe made mostly of matter, physicists have long sought some sign of an asymmetry in early creation.

The findings by Slepian's lab can't yet explain how we ended up with this crucial abundance of matter. The "how" will require new physics going beyond the Standard Model, which explains our current universe. But the new results do strongly suggest that there was an asymmetry at the earliest moments of the Big Bang.

Now the race is on for scientists to produce a theory that can explain the mirror-image preference of the universe and the excess of matter.

More information: Jiamin Hou et al, Measurement of parity-odd modes in the large-scale 4-point correlation function of Sloan Digital Sky Survey Baryon Oscillation Spectroscopic Survey twelfth data release CMASS and LOWZ galaxies, *Monthly Notices of the Royal Astronomical Society* (2023). DOI: 10.1093/mnras/stad1062

Robert N. Cahn et al, Test for Cosmological Parity Violation Using the 3D Distribution of Galaxies, *Physical Review Letters* (2023). DOI: 10.1103/PhysRevLett.130.201002

Provided by University of Florida