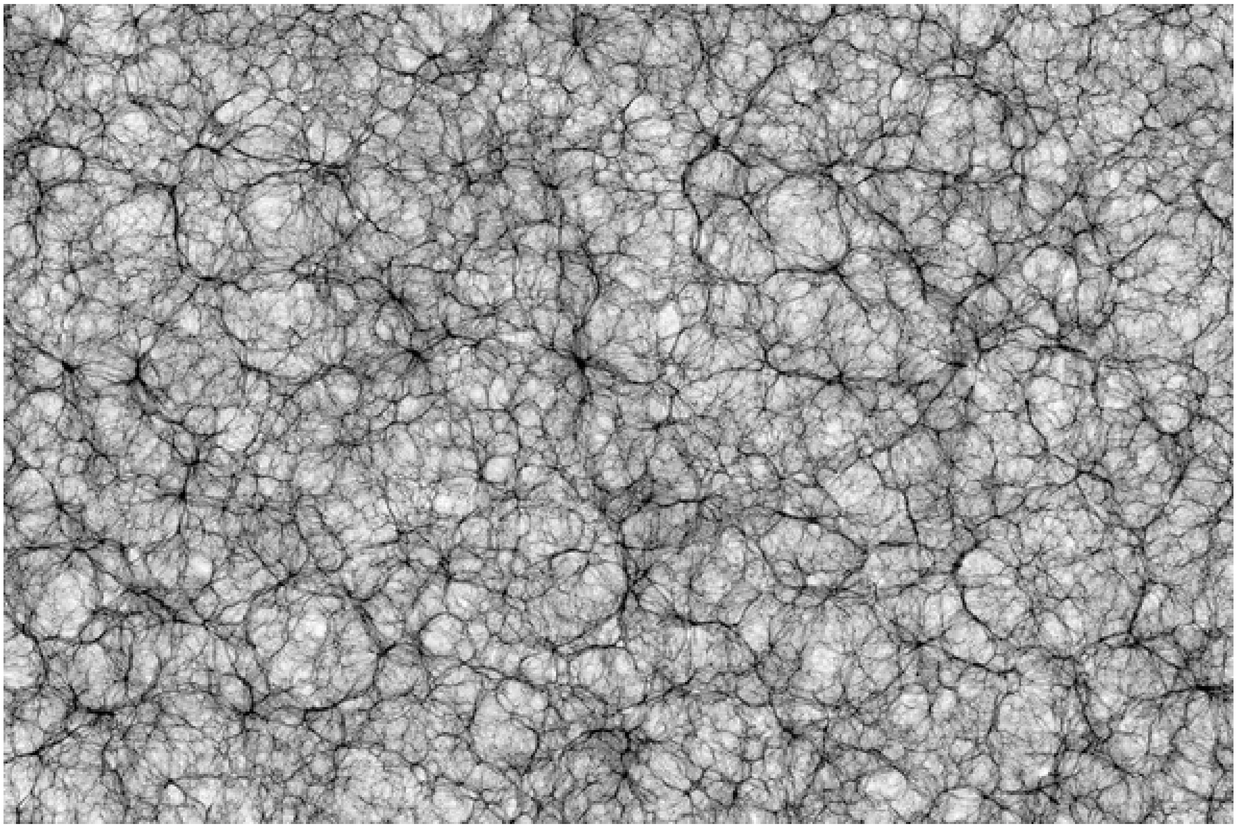
ASTRONOMY

A Possible Crisis in the Cosmos Could Lead to a New Understanding of the Universe

Several unexplained measurements are threatening to upend scientists' understanding of the universe's origin and fate

By Michael D. Lemonick on October 30, 2023



Dark matter distribution simulation. Credit: SPL/Science Source

Back in the mid-1990s, cosmologists—who study the origin, composition and structure of the universe—were beginning to worry that they were facing a crisis. For starters, two astronomers had observed that a huge swath of the cosmos, a billion light-years or so across, was moving in a direction inconsistent with the general expansion of the universe. Worse, astrophysicists using the Hubble Space Telescope, then relatively new, had determined that the cosmos was between eight billion and 12 billion years old. The problem: even the high end of that range couldn't account for stars known to be closer to 14 billion years old, leading to the nonsensical implication that the stars existed before the universe did. "If you ask me," astrophysicist Michael Turner told *Time* magazine at the time, "either we're close to a breakthrough or we're at our wits' end." But the first observation was never confirmed. And the impossibly old stars were explained a few years later with the discovery that a mysterious, and still unknown, dark energy had turbocharged the expansion of the universe, making it look younger than it actually is.

Now, however, cosmologists are facing a brand-new problem—or rather a couple of problems. The Hubble constant (named, as the telescope is, for Edwin Hubble, who discovered the expansion of the universe in the 1920s) is the number that shows how fast the cosmos is expanding; it's been measured with greater and greater accuracy over the past few decades. Yet there's still some uncertainty because two independent methods of calculating it have come up with different answers, giving rise to what's called the "Hubble tension." Although the numbers aren't dramatically different, they're enough at odds to worry theorists. "In particle physics," said David Gross of the Kavli Institute for Theoretical Physics at the University of California, Santa Barbara, at a conference in 2019, "we wouldn't call it a tension or a problem but rather a crisis."

Another issue is that the tendency of matter to clump together in the early universe is inconsistent with how it clumps together today. Known as the sigma-eight, or S_8, tension, it is like a "little brother or sister of the Hubble tension.... So [it is] less significant but worth keeping an eye on," says Adam Riess of the Space Telescope Science Institute, who shared of the 2011 Nobel Prize in Physics for his co-discovery of dark energy.

Both problems could signal that scientists are misunderstanding something big about physics, and a recent paper in the journal *Physical Review Letters* adds to the suspicion that this might be the case—for the S_8 tension, at least. In the so-called standard model of cosmology, the universe started off almost but not quite uniformly dense. We know that because the oldest light we can see, known as the cosmic microwave background, shows only tiny variations in temperature from one point on the sky to the next, reflecting variations in the density of energy and matter in the cosmos. As the universe expanded, gravity, as described by Einstein's general theory of relativity, amplified those variations to create the huge variations we see today in the form of clusters and superclusters of galaxies. That process is somewhat suppressed, however, by dark energy—the still mysterious force causing the expansion of the universe to accelerate rather than slow down—which pushes matter apart before the density variations can get even greater.

In the new paper, scientists argue that this suppression of clustering is too large to explain with the standard model. Not only that, says Robert Caldwell, a cosmologist at Dartmouth College, who did not participate in the new study, "it seems like the timing of whatever's causing the acceleration is not in synchrony with the effect on the clumpiness," he explains. That is to say, the suppression of the growth of the so-called large-scale structure of the universe—the web of galaxies, clusters and other cosmic structures that are bound by gravity—begins to kick in later than you'd expect to see from dark energy alone. This observation suggests that some theory of gravity other than general relativity might conceivably be at play, the authors argue. "It's a thought-provoking analysis," says Benjamin Wandelt of the Lagrange Institute in France, who also wasn't involved in the study. "Exciting if true—but changing general relativity is a high price to pay."

So is it true? The answer so far is that nobody knows for sure. "It's an interesting paper," says David Weinberg, chair of the astronomy department at the Ohio State University, who wasn't involved in the study, "but I wouldn't say it's a big deal on its own." The investigation does, however, "fit into a larger set of papers that are maybe finding a discrepancy between the level of matter clustering in the present-day universe, compared to what we would predict based on what we observe in the cosmic microwave background," he says. These discrepancies would be small enough to make theorists wary that they might not be significant at all, except that they all tend to point in the same direction, with modern-day density variations below what you'd expect, based on the standard model.

"If they're real," Weinberg says, "the implications are very profound because you would probably have to modify the theory of gravity on cosmological scales in order to explain it." And, he adds, "that's not easy to do." (To be clear, this kind of change would be different from "modified Newtonian dynamics," or MOND, a theory of modified gravity proposed to explain away dark matter. Here, too, the idea of tinkering with general relativity has been tough for astrophysicists to entertain.)

What might be different in this case is that the authors—Nhat-Minh Nguyen, Dragan Huterer and Yuewei Wen, all at the University of Michigan—didn't set out to solve the problem of the S_8 tension. They were interested in whether the history of the universe's expansion was consistent with the history of structure growth. "We expected," says Nguyen, lead author of the paper, "that they would, in fact, be consistent." When the researchers found this wasn't the case, he adds, they went back and rechecked their analysis to make sure they weren't missing something. "But we found that we weren't," Nguyen says. The inconsistency, it turned out, might be explained by some additional force layered on top of gravity and dark energy—a force that would add to the tendency of dark energy to tamp down structure formation. Or it could suggest that dark energy itself became stronger at some point, Caldwell says. "That's what excited me about the paper," he adds.

Caldwell doesn't consider the paper definitive, though. Jo Dunkley, a physicist at Princeton University, who also wasn't involved with the work, agrees. "This is interesting," she says, "but to me, it is too soon to say that this shows significant evidence of a problem" with the standard model of cosmology. And a few scientists, including David Spergel, former chair of astrophysics at Princeton and now president of the Simons Foundation, think the argument isn't very convincing. "[The authors] ignore recent measurements that are consistent with standard theory," says Spergel, who wasn't part of the study. "And as this paper argues, analyses of large-scale structure at [nearby distances] are probably underestimating the important role that galaxy winds play in driving gas out of galaxies. I'm not sure I would have published this paper."

On Spergel's first point, Nguyen agrees that he and his colleagues need to do more research. "We're looking into more datasets from new, presumably independent experiments of the same observables," he says. But Nguyen also points out that in the "recent measurements" that Spergel cites, the latter's team actually references Nguyen and his colleagues' latest work and the idea of tweaking with general relativity as a possible solution to the S_8 tension. And, Nguyen argues, "the community is still divided over the role of [winds] in reconciling S_8."

In short, everyone, including Nguyen and his co-authors, agree that their results are not definitive. "It's useful to play these exercises," says Nico Hamaus of the Ludwig Maximilian University of Munich in Germany. "That's exactly how you find loopholes in the models, and if we can really substantiate such things, that really means there's something going on that we don't understand." But even if definitive confirmation comes, the Hubble tension remains, and almost everyone agrees that problem is a much bigger deal.

And "tensions" aren't even the only things that keep cosmologists up at night. In a recent op-ed in the *New York Times* entitled "The Story of Our Universe May Be Starting to Unravel," astrophysicist Adam Frank of the University of

Rochester and Marcelo Gleiser of Dartmouth College cite the thorniest issues facing cosmology. They focus primarily on the Hubble tension (but, interestingly, not the S_8 tension) and also point to discoveries by the James Webb Space Telescope of surprisingly large galaxies that formed surprisingly soon after the big bang. “We may be at a point,” they write, “where we need a radical departure from the standard model, one that may even require us to change how we think of the elemental components of the universe, possibly even the nature of space and time.”

In other words, stay tuned.

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