The universe caught suppressing cosmic structure growth

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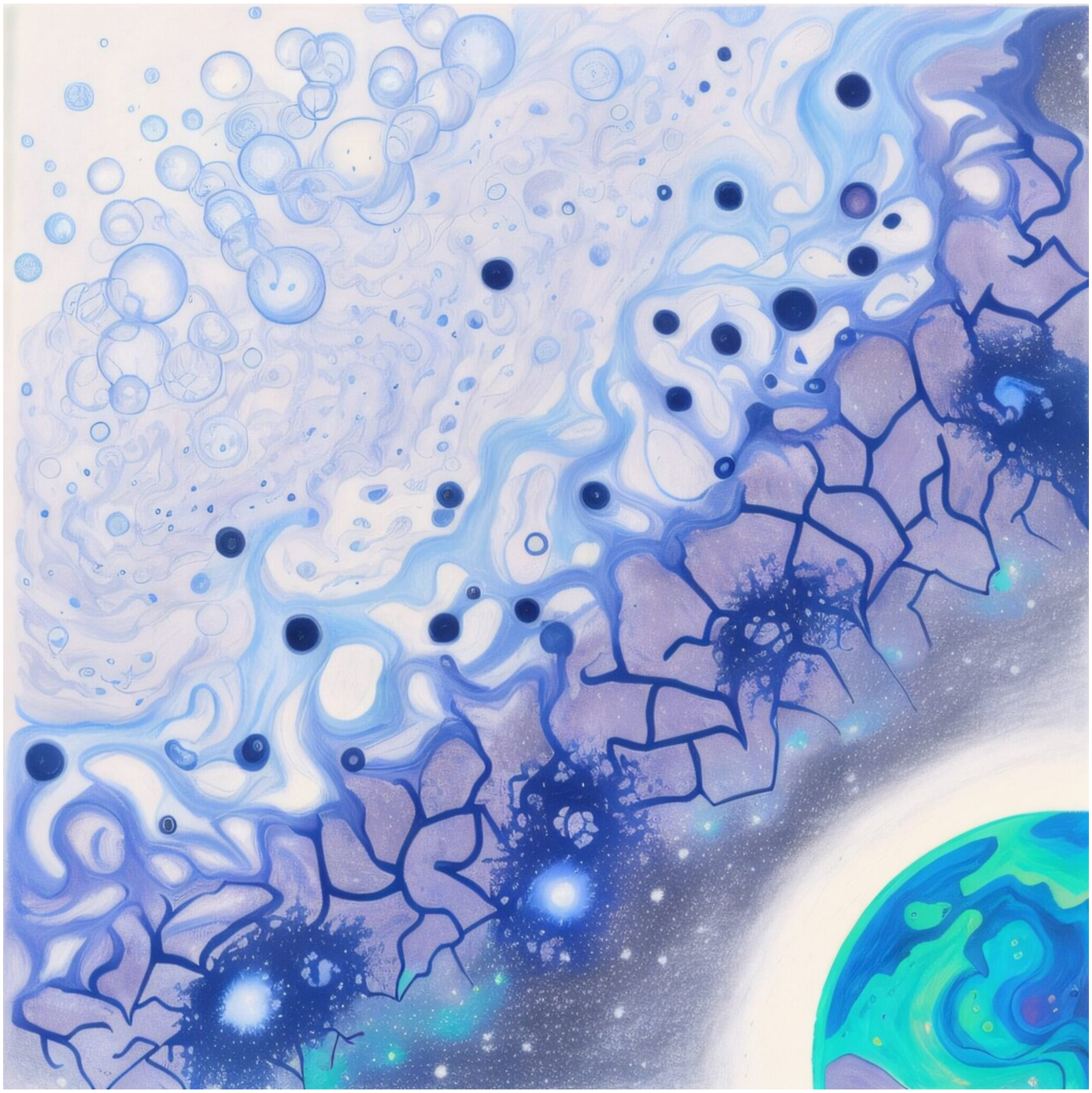

An artist’s representation of matter in the early universe slowly coalescing into large cosmic structures in the late universe. Image credit: Minh Nguyen, University of Michigan and Thanh Nguyen (spouse)

As the universe evolves, scientists expect large cosmic structures to grow at a certain rate: dense regions such as galaxy clusters would grow denser, while the void of space would grow emptier.

But University of Michigan researchers have discovered that the rate at which these large structures grow is slower than predicted by Einstein's Theory of General Relativity.

They also showed that as dark energy accelerates the universe's global expansion, the suppression of the cosmic structure growth that the researchers see in their data is even more prominent than what the theory predicts. Their results are published in *Physical Review Letters*.

Galaxies are threaded throughout our universe like a giant cosmic spider web. Their distribution is not random. Instead, they tend to cluster together. In fact, the whole cosmic web started out as tiny clumps of matter in the early universe, which gradually grew into individual galaxies, and eventually galaxy clusters and filaments.

"Throughout the cosmic time, an initially small clump of mass attracts and accumulates more and more matter from its local region through gravitational interaction. As the region becomes denser and denser, it eventually collapses under its own gravity," said Minh Nguyen, lead author of the study and postdoctoral research fellow in the U-M Department of Physics.

"So as they collapse, the clumps grow denser. That is what we mean by growth. It's like a fabric loom where one-, two- and three-dimensional collapses look like a sheet, a filament and a node. The reality is a mixture of all three cases, and you have galaxies living along the filaments while galaxy clusters—groups of thousands of galaxies, the most massive objects in our universe bounded by gravity—sit at the nodes."

The universe is not only made of matter. It also likely contains a mysterious component called dark energy. Dark energy accelerates the expansion of the universe on a global scale. As dark energy accelerates the expansion of the universe, it has the opposite effect on large structures.

"If gravity acts like an amplifier enhancing matter perturbations to grow into large-scale structure, then dark energy acts like an attenuator damping these perturbations and slowing the growth of structure," Nguyen said. "By examining how cosmic structure has been clustering and growing, we can try to understand the nature of gravity and dark energy."

Nguyen, U-M physics professor Dragan Huterer and U-M graduate student Yuewei Wen examined the temporal growth of large-scale structure throughout cosmic time using several cosmological probes.

First, the team used what's called the cosmic microwave background. The cosmic microwave background, or CMB, is composed of photons emitted just after the Big Bang. These photons provide a snapshot of the very early universe. As the photons travel to our telescopes, their path can become distorted, or gravitationally lensed, by large-scale structure along the way. Examining them, the researchers can infer how structure and matter between us and the cosmic microwave background are distributed.

Nguyen and colleagues took advantage of a similar phenomenon with weak gravitational lensing of galaxy shapes. Light from background galaxies is distorted through gravitational interactions with foreground matter and galaxies. The cosmologists then decode these distortions to determine how the intervening matter is distributed.

"Crucially, as the CMB and background galaxies are located at different distances from us and our telescopes, galaxy weak gravitational lensing typically probes matter distributions at a later time compared to what is probed by CMB weak gravitational lensing," Nguyen said.

To track the growth of structure to an even later time, the researchers further used motions of galaxies in the local universe. As galaxies fall into the gravity wells of the underlying cosmic structures, their motions directly track structure growth.

"The difference in these growth rates that we have potentially discovered becomes more prominent as we approach the present day," Nguyen said. "These different probes individually and collectively indicate a growth suppression. Either we are missing some systematic errors in each of these probes, or we are missing some new, late-time physics in our standard model."

The findings potentially address the so-called S8 tension in cosmology. S8 is a parameter that describes the growth of structure. The tension arises when scientists use two different methods to determine the value of S8, and they do not agree. The first method, using photons from the cosmic microwave background, indicates a higher S8 value than the value inferred from galaxy weak gravitational lensing and galaxy clustering measurements.

Neither of these probes measures the growth of structure today. Instead, they probe structure at earlier times, then extrapolate those measurements to present time, assuming the standard model. Cosmic microwave background probes structure in the early universe, while galaxy weak gravitational lensing and clustering probe structure in the late universe.

The researchers' findings of a late-time suppression of growth would bring the two S8 values into perfect agreement, according to Nguyen.

"We were surprised with the high statistical significance of the anomalous growth suppression," Huterer said. "Honestly, I feel like the universe is trying to tell us something. It is now the job of us cosmologists to interpret these findings.

"We would like to further strengthen the statistical evidence for the growth suppression. We would also like to understand the answer to the more difficult question of why structures grow slower than expected in the standard model with dark matter and dark energy. The cause of this effect may be due to novel properties of dark energy and dark matter, or some other extension of General Relativity and the standard model that we have not yet thought of."

More information: Nhat-Minh Nguyen et al, Evidence for Suppression of Structure Growth in the Concordance Cosmological Model, *Physical Review Letters* (2023). DOI: 10.1103/PhysRevLett.131.111001

Provided by University of Michigan

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