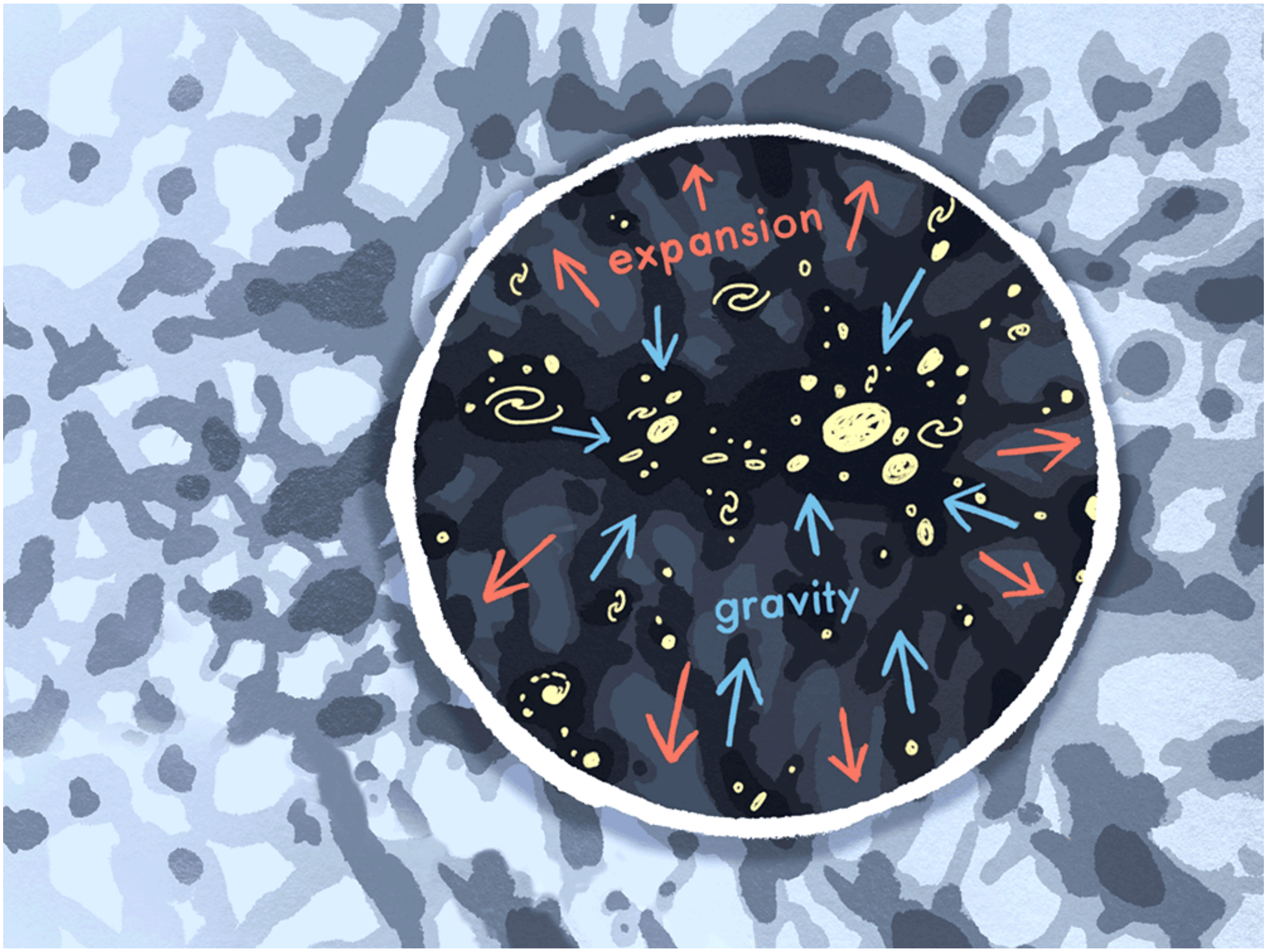
Shedding Light on Dark Matter and Dark Energy



Jessie Muir (Ph.D. '18) created this illustration for *LSA Magazine*, showing how dark matter and dark energy influence the Universe along with a timeline of how cosmologists' understanding of each has changed. For the full illustration, view on a computer screen or tablet.

A team of LSA researchers found that the standard model of cosmology may be coming under pressure based on new data about the growth rate of large cosmic structures.

by Jordyn Imhoff

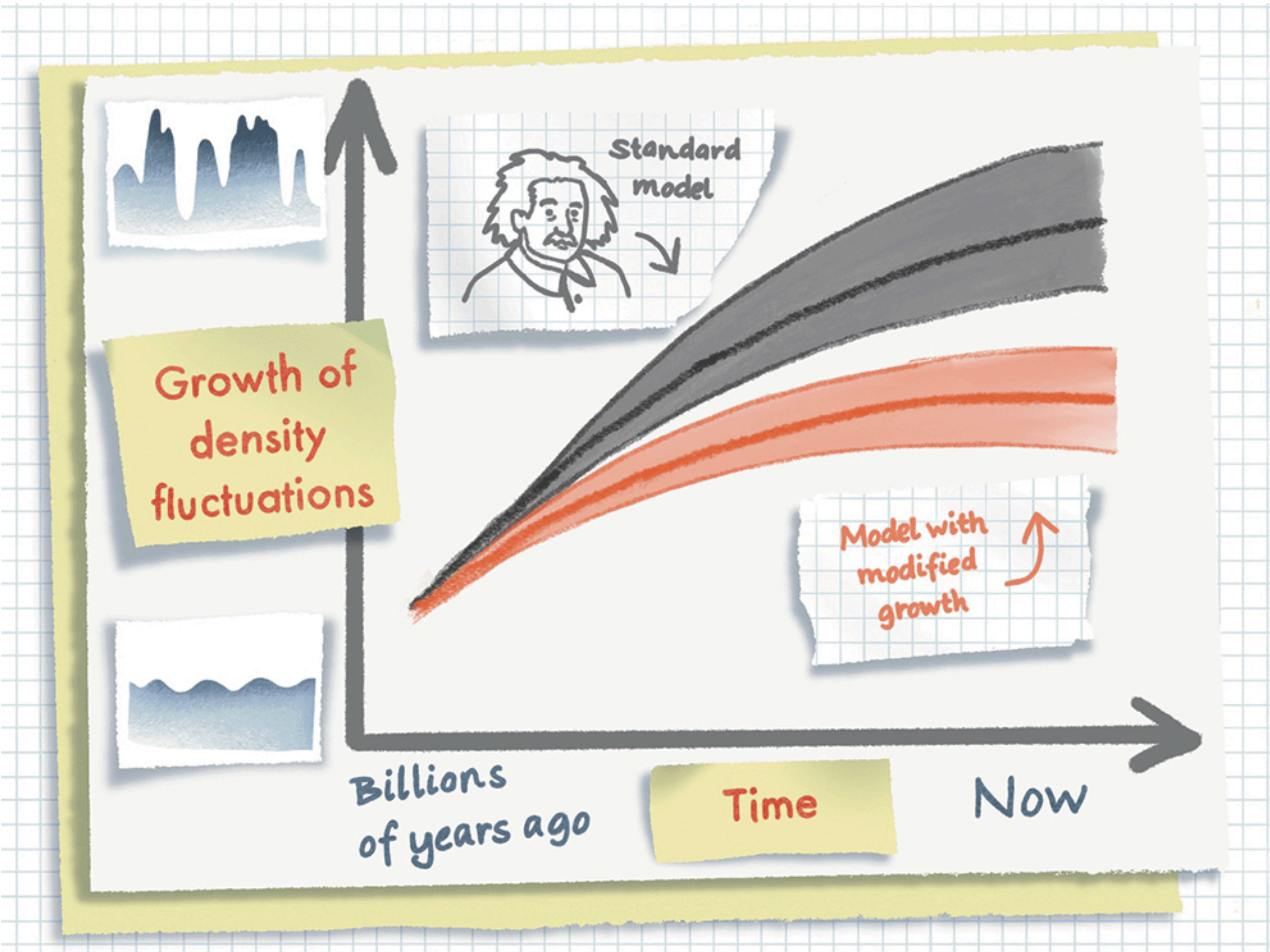
If you've ever had to calculate the energy of an object at rest, you can thank one of the most revered physicists of all time, Albert Einstein. His theory of special relativity proposed that mass is equivalent to energy. That famous $E=mc^2$ mathematical equation (or infamous, depending on how you felt about your high school science classes), was born from this theory, with E representing energy, m representing mass, and c representing the speed of light—a constant.

The theory inspired Einstein's theory of general relativity, which was published 10 years later and outlines our current understanding of gravity. General relativity explains how the gravity of massive structures in the Universe distorts the fabric of space, leading to the bending of light that passes near those structures. Gravity also affects how cosmic structures clump together, like how galaxies become galaxy clusters. Dark matter holds galaxies and galaxy clusters together with gravity, while dark energy repels and counteracts gravity, causing the Universe to expand at an accelerating rate.

Together, all these structures are part of one big, cosmic web that scientists like LSA's Dragan Huterer and **Nhat Minh Nguyen**, a Leinweber Postdoctoral Research Fellow, study. And according to their research, led by Nguyen, it may be time to reevaluate our long-held cosmological beliefs.

“Cosmology, the study of our 13.8-billion-year-old Universe, has been a highly quantitative science since the 1990s,” says Huterer, a physics professor and member of the Leinweber Center for Theoretical Physics. “In many cases, scientists are arguing the second or third decimal point.”

Einstein’s theory of general relativity has been a theoretical foundation for the current standard cosmological model: the Lambda-CDM model. Although not much is known about dark matter and dark energy, cosmologists know they take up most of the Universe’s mass and energy.



Jessie Muir’s illustration shows the difference between the standard, Lambda-CDM model and the LSA team’s findings. Researchers Nhat Minh Nguyen and Dragan Huterer discovered that the Universe’s growth is much more suppressed than previously believed.

Johannes Ulf Lange and Uendert dos Santos Andrade, two other Leinweber Postdoctoral Research Fellows working in cosmology, are currently exploring scientific theories related to dark matter and dark energy.

“Although these properties dominate the mass-energy content of the Universe and their basic effects on cosmology are reasonably well understood, their physical origin is still unknown. The physical nature of dark matter and dark energy remain two of the most perplexing conundrums in physics,” Huterer says.

Remember the Lambda-CDM model mentioned previously, created with Einstein’s theory of general relativity in mind? Nguyen and Huterer’s research findings, published in Physical Review Letters, suggest that that theory may not be in agreement with current measurements in cosmology. The data suggests that dark energy slows down the growth of the cosmic web more than the amount the Lambda-CDM model predicts, and the growth suppression becomes even more prominent as the Universe’s expansion accelerates.

“The physical nature of dark matter and dark energy remain two of the most perplexing conundrums in physics.”

—Physics Prof. Dragan Huterer

“Modern cosmology relies heavily on two main fundamental hypotheses: Einstein’s theory of general relativity as the correct theory of gravity on cosmological scales, and the cosmological principle, which is the hypothesis that the Universe is homogeneous and isotropic at a sufficiently large scale,” Andrade explains.

“Within this framework, along with observable evidence accumulated over the last two decades, cosmologists can build a model that better fits current observational datasets.”

A Cosmology Renaissance

Relax; we’re not saying Einstein was completely wrong.

“The deviation of growth from the standard model could be due to new interactions between dark matter and dark energy. … None of these interactions were considered by the standard model. Dark matter and dark energy were also not the main concerns of Einstein’s [theory of]general relativity, so their new properties won’t prove Einstein wrong,” Nguyen explains.

“Being a scientist means we’re always looking for surprises and trying to pose better questions so the field advances,” Huterer adds. He and Nguyen seek to make discoveries that may inspire a direction of new physics, and to one day understand the physical nature of mass and energy in the Universe.

According to Huterer, it’s not atypical to see small deviations in cosmological data, with statistical significance of 2-sigma, or two standard deviations from the data’s mean, being commonplace. However, Nguyen and Huterer’s research produced a highly significant result of 4-sigma. For context, statistical evidence of 5-sigma is considered solid evidence for a new phenomenon, so seeing 4-sigma evidence is pretty exciting.

“We’re entering an era with extremely large data sets—maps of millions of galaxies—becoming available,” says Lange, an astronomer who researches dark energy across time periods of the Universe and conducts public outreach to make his work accessible to the average person. “This is a fast-moving field, and that’s what makes working on cosmology so exciting.”

Huterer concurs. “I hope to live long enough to see the nature of dark energy explained. I’m hopeful because it seems like we’re coming into a golden age of cosmology.”

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