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U-M helps illuminate deepest mysteries of the universe

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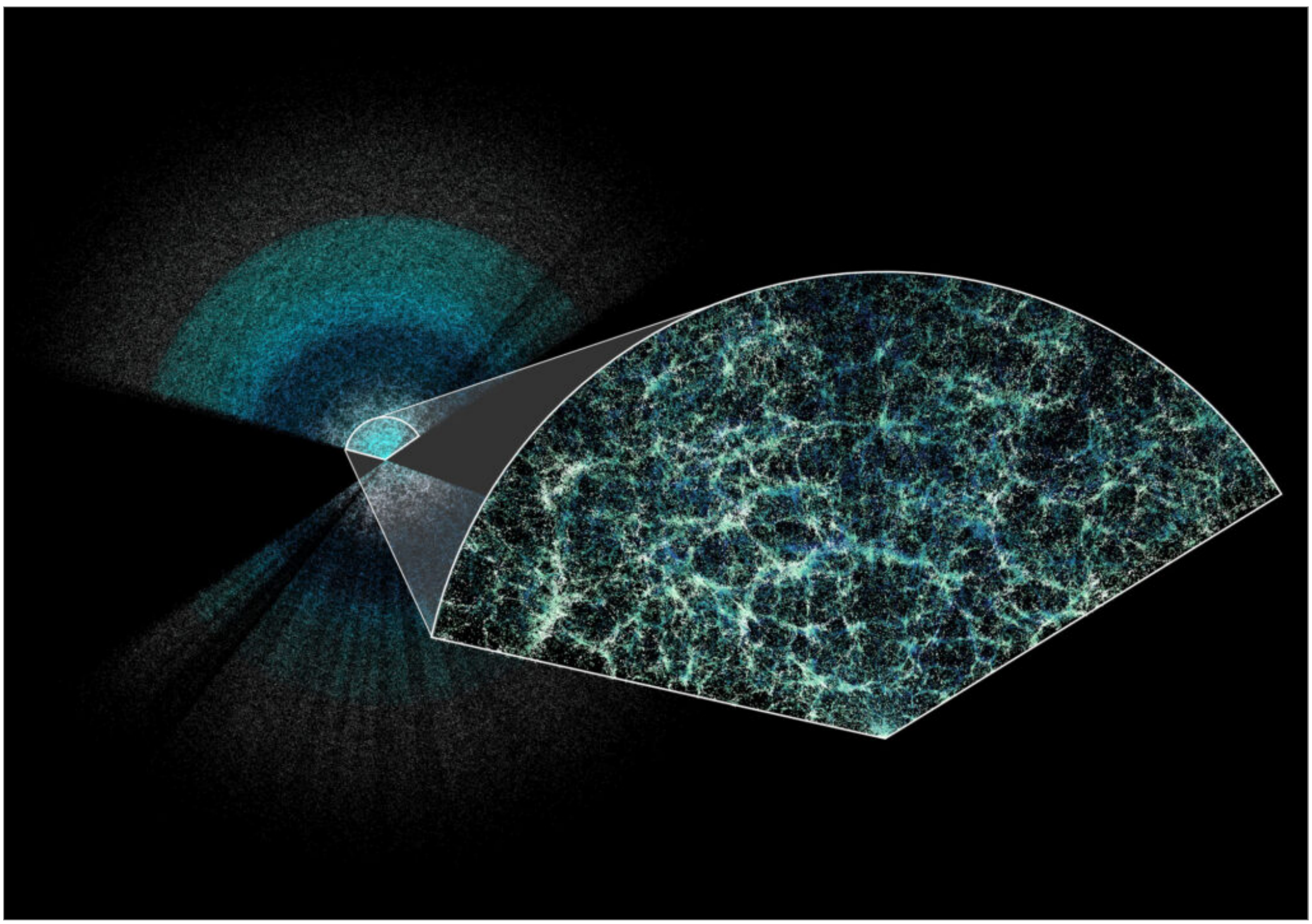
Topics: Research

Approximately 14 billion years ago, the universe burst into being with the Big Bang, sending matter and energy into motion and setting the stage for everything from galaxies to the planet where we live.

While humanity has long recognized that the universe consists of stars, planets and galaxies composed of matter found in the periodic table, dark matter and dark energy are far less evident or understood, despite exerting a much greater influence over the universe as a whole.

Dragan Huterer, associate chair of the Department of Physics and professor of physics in LSA, is a theoretical cosmologist working at the interface of data theory and cosmology. Unlike astrophysics, which focuses on celestial objects like galaxies and black holes, cosmology explores the universe's most overarching concepts, including the Big Bang theory, dark matter and dark energy.



A 3D map of the universe by the Dark Energy Spectroscopic Instrument, or DESI. In this cross-section, Earth is positioned at the center. The zoomed-in area reveals the

fundamental structure of matter throughout the cosmos. (Claire Lamman, DESI collaboration)

"We can't answer why the Big Bang occurred or what existed before it," Huterer said. "But one of humanity's most amazing feats is that we know what happened just moments after it occurred. In fact, we arguably know more about the Big Bang aftermath than we do about the human brain, despite being able to physically study the brain. That's a paradoxical thing."

Over a century ago, scientists discovered that the universe is expanding. This finding was soon followed by the identification of dark matter, which dominates in galaxies, gravitationally binding matter together. However, scientists expected that as the density of matter decreased, the expansion of the universe would slow.

Yet in the late 1990s, researchers made the surprising discovery that the expansion of the universe began accelerating a few billion years ago, which is relatively late in its timeline. This acceleration is attributed to dark energy, a phenomenon even less understood than dark matter. Dark energy drives the universe's accelerated expansion by pushing matter apart, and its effects are evident in the way it influences the formation and growth of galaxies over time.

"It's unclear exactly what dark energy is," Huterer said. "It may be a new force, or possibly a particle with unusual properties causing the universe to expand faster and faster."

Dragan Huterer

In the beginning, the universe was smooth and consistent throughout, similar to soup. Over time, matter began to clump together, forming structures such as galaxies. Dark energy works against this clumping by pushing matter apart, acting in opposition to gravity. If the universe had been dominated by dark energy from the beginning, galaxies would never have formed. Because dark energy only became significant relatively late, for reasons still unknown, it changed the expansion rate of the universe and impacted how structure developed.

Albert Einstein famously studied pollen particles suspended in water to understand how invisible molecules drive their motion and distribution. Similarly, to a cosmologist, each galaxy represents a particle. The more galaxies scientists observe, the better they can analyze their distribution. By studying clustering patterns, the Dark Energy Spectroscopic Instrument, or DESI, team can observe the effects of dark energy and infer its properties.

Dark energy was first revealed through observations of distant supernovae, a discovery that earned the 2011 Nobel Prize in Physics for providing evidence of the universe's accelerated expansion. Huterer co-authored the first paper to use the term "dark energy" with his Ph.D. adviser Michael Turner at the University of Chicago, who coined the term.

Since its discovery, physicists have believed that dark energy has energy density that is constant in time. However, recent findings from the DESI, a project in which Huterer is a key collaborator, suggest that dark energy is actually evolving over time. DESI data reveal that its effect on the universe's accelerated expansion has decreased by about 10% over the past 4.5 billion years, challenging the prevailing assumption that dark energy density remains constant.

DESI uses advanced spectroscopic mapping and 5,000 robotic arms to measure the redshifts of galaxies and quasars, enabling researchers to map the universe's expansion and create a 3D record of how it has evolved over time. By tracking baryon acoustic oscillations, which are large-scale density variations left over from the early universe, scientists can reconstruct shifts in the rate of cosmic expansion. Using machine-guided observational mapping combined with powerful computational analysis, DESI processes vast datasets to uncover universe-scale patterns that would otherwise remain hidden.

The team adopted mathematical models of galaxy distributions, applying statistical techniques to compare them against theoretical predictions. They meticulously account for errors, such as atmospheric obstructions or misidentifying stars as galaxies, while applying machine learning to detect subtle patterns signaling deviations from the standard dark energy model. This integrated approach enables researchers to test cosmological models and investigate phenomena such as the possible decay of dark energy across billions of light-years and over cosmic timescales.

"Decades ago, cosmology was a purely theoretical field, led by abstract theories and imagination," Huterer said. "But since the 1990s, it has become a highly quantitative science, producing vast amounts of data that have taught us so much about the universe. Today, converting observations into results requires a great deal of computation and cosmological simulations, as well as attention to systematic errors in both theory and measurements."

The DESI project brings together approximately 1,000 scientists to map the 3D positions of about 50 million galaxies using the Kitt Peak telescope in Arizona. Once the data are collected, members of the collaboration analyze the distribution of galaxies using statistical methods adapted for cosmology. By analyzing the distribution of millions of galaxies, the team can identify large-scale patterns and draw conclusions about dark matter and dark energy in the universe.

"This work is heavily computational, but based on theory," Huterer said. "The possibility that dark energy density is changing over time has the scientific community excited. If confirmed, this would be as big a discovery as that of dark energy itself. It's really wonderful to be paid to work on these exciting developments that help us better understand the universe."

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