New hints from one of the most extensive surveys of the cosmos to date suggest that mysterious dark energy may be evolving in ways that could shift how astronomers understand the universe.

Dark energy is a term scientists use to describe an energy or force that accelerates the expansion of the universe. But — although it represents 70% of the energy in the cosmos — researchers still have no idea exactly what dark energy is, said Mustapha Ishak-Boushaki, professor of physics and astrophysics at the University of Texas at Dallas.

Ishak-Boushaki is a cochair of a working group for the Dark Energy Spectroscopic Instrument collaboration, known as DESI. The instrument, now in its fourth year of surveying the sky, can observe light from 5,000 galaxies at the same time. When the project concludes next year, it will have measured the light of about 50 million galaxies.

The collaboration, which includes more than 900 researchers, shared the latest data release from DESI's first three years of observations on March 19. Among its findings are the measurements of nearly 15 million galaxies and quasars, some of the brightest objects in the universe. Ishak-Boushak helped lead the analysis of the latest DESI data release, which suggests that dark energy — long called a "cosmological constant" given that astronomers thought it was unchanging — is behaving in unexpected ways and may even be weakening over time.

"The discovery of dark energy, nearly 30 years ago, was already the biggest surprise of my scientific lifetime," said David Weinberg, a professor of astronomy at The Ohio State University who contributed to the DESI analysis, in a statement. "These new measurements offer the strongest evidence so far that dark energy evolves, which would be another mind-blowing change to our understanding of how the universe works."

The findings bring astronomers another step closer to unmasking the mysterious nature of dark energy, which may mean that the standard model of how the universe works could also require an update, scientists say.

A deep look at the universe

The Dark Energy Spectroscopic Instrument is atop the National Science Foundation's Nicholas U. Mayall 4-meter Telescope at Kitt Peak National Observatory in Tucson, Arizona. The instrument's 5,000 fiber-optic "eyes" and extensive surveying capabilities are enabling scientists to build one of the largest 3D maps of the universe and track how dark energy has influenced and shaped the cosmos over the past 11 billion years.

It takes time for the light from celestial objects like galaxies to travel to Earth, which means that DESI can effectively see what the cosmos was like at different points in time, from billions of years ago to the present.

"DESI is unlike any other machine in terms of its ability to observe independent objects simultaneously," said John Moustakas, a professor of physics at Siena College and colead of the data release.

The newest findings include data on more than double the cosmic objects that were surveyed and presented less than a year ago. Those 2024 revelations first hinted at how dark energy may be evolving.

"We're in the business of letting the universe tell us how it works, and maybe the universe is telling us it's more complicated than we thought it was," said Andrei Cuceu, a postdoctoral researcher at the US Department of Energy's Lawrence Berkeley National Laboratory, which manages DESI, and cochair of DESI's Lyman-alpha working group, in a statement. "It's interesting and gives us more confidence to see that many different lines of evidence are pointing in the same direction."

Mounting cosmic evidence

DESI can measure what scientists call the baryon acoustic oscillation, or BAO, scale — essentially how events that occurred early in the universe left behind patterns in how matter is distributed across the cosmos. Astronomers look to the BAO scale, with separations of matter by about 480 million light-years, as a standard ruler.

"This separation scale is like a really gigantic ruler in space that we can use to measure distances, and we use the combination of these distance and redshifts (speed objects are moving away from us) to measure the expansion of the universe," said Paul Martini, a coordinator of the analysis and professor of astronomy at The Ohio State University.

Measuring dark energy's influence across the history of the universe shows how dominant a force it has been.
Researchers began to notice when they combined these observations with other measurements of light across the universe such as exploding stars, the gravity-warped light of distant galaxies, and the light leftover from the dawn of the universe, called the cosmic microwave background, the DESI data shows that dark energy's impact could be weakening over time.
"If this continues then eventually dark energy will not be the dominant force in the universe," Ishak-Boushak said in an email. "Therefore the universe expansion will stop accelerating and will go at a constant rate or even in some models could also stop and collapse back. Of course, these futures are very remote and will take billions and billions of years to happen. I've worked on the question of cosmic acceleration for 25 years, and my perspective is, if the evidence continues to grow, and it is likely to, then this will be huge for cosmology and all of physics."

Solving an enduring mystery
There isn't enough evidence yet to declare a groundbreaking discovery that definitively says dark energy is evolving and weakening, but that could change within just a couple of years, Ishak-Boushak said.
"My first big question is if we will continue to see evidence for evolving dark energy as our measurements get better and better," Martini said. "If we do get to the point where the evidence is overwhelming, then my next questions will be: How does dark energy evolve? And what are the most likely physical explanations?"
The new data release could also help astrophysicists better understand how galaxies and black holes evolve and the nature of dark matter. Although dark matter has never been detected, it is believed to make up 85% of the total matter in the universe.
Scientists involved with the collaboration are eager to improve their measurements using DESI.
"Whatever the nature of dark energy is, it will shape the future of our universe," said Michael Levi, DESI director and a scientist at the Lawrence Berkeley National Laboratory. "It's pretty remarkable that we can look up at the sky with our telescopes and try to answer one of the biggest questions that humanity has ever asked."
A new experiment called Spec-S5, or Stage 5 Spectroscopic Experiment, could measure more than 10 times as many galaxies as DESI to study both dark energy and dark matter, Martini said.

"Spec-S5 would use telescopes in both the northern and southern hemispheres to map galaxies across the entire sky," Martini said. "We are also excited about how the (Vera) Rubin telescope will study supernovae, and provide a new, uniform dataset to study the (universe's) expansion history."
Other space observatories, like the Euclid space telescope and the Nancy Grace Roman Space Telescope, set to launch in 2027, will also contribute more key measurements of dark matter and dark energy in the coming years that could help fill in the gaps, said Jason Rhodes, an observational cosmologist at NASA's Jet Propulsion Laboratory in Pasadena, California. Rhodes, who is not involved in DESI, is the US science lead for Euclid and principal investigator for NASA's Euclid dark energy science team.
Rhodes, who calls the results intriguing, said the data shows a slight but persistent tension between measurements from the early days of the universe and those from the later universe.
"(This means) that our simplest model of dark energy doesn't quite allow for the early universe we observe to evolve into the late universe we observe," Rhodes said. "DESI results (and some other recent results) seem to indicate that a more complex model of dark energy is preferred. This is truly exciting because it may mean that new, unknown, physics governs the evolution of the universe. DESI has given us tantalizing results that may indicate a new model of cosmology is needed."

Some 13.8 billion years ago, the universe began with a rapid expansion we call the big bang. After this initial expansion, which lasted a fraction of a second, gravity started to slow the universe down. But the cosmos wouldn't stay this way. Nine billion years after the universe began, its expansion started to speed up, driven by an unknown force that scientists have named dark energy.

But what exactly *is* dark energy?

The short answer is: We don't know. But we do know that it exists, it's making the universe expand at an accelerating rate, and approximately 68.3 to 70% of the universe is dark energy.

A Brief History

It All Started With Cepheids

Dark energy wasn't discovered until the late 1990s. But its origin in scientific study stretches all the way back to 1912 when American astronomer Henrietta Swan Leavitt made an important discovery using Cepheid variables, a class of stars whose brightness fluctuates with a regularity that depends on the star's brightness.

All Cepheid stars with a certain period (a Cepheid's period is the time it takes to go from bright, to dim, and bright again) have the same absolute magnitude, or luminosity – the amount of light they put out. Leavitt measured these stars and proved that there is a relationship between their regular period of brightness and luminosity. Leavitt's findings made it possible for astronomers to use a star's period and luminosity to measure the distances between us and Cepheid stars in far-off galaxies (and our own Milky Way).

Around this same time in history, astronomer Vesto Slipher observed spiral galaxies using his telescope's spectrograph, a device that splits light into the colors that make it up, much like the way a prism splits light into a rainbow. He used the spectrograph, a relatively recent invention at the time, to see the different wavelengths of light coming from the galaxies in different spectral lines. With his observations, Silpher was the first astronomer to observe how quickly the galaxy was moving away from us, called redshift, in distant galaxies. These observations would prove to be critical for many future scientific breakthroughs, including the discovery of dark energy.

Redshift is a term used when astronomical objects are moving away from us and the light coming from those objects stretches out. Light behaves like a wave, and red light has the longest wavelength. So, the light coming from objects moving away from us has a longer wavelength, stretching to the "red end" of the electromagnetic.

Discovering an Expanding Universe

The discovery of galactic redshift, the period-luminosity relation of Cepheid variables, and a newfound ability to gauge a star or galaxy's distance eventually played a role in astronomers observing that galaxies were getting farther away from us over time, which showed how the universe was expanding. In the years that followed, different scientists around the world started to put the pieces of an expanding universe together.

In 1922, Russian scientist and mathematician Alexander Friedmann published a paper detailing multiple possibilities for the history of the universe. The paper, which was based on Albert Einstein's theory of general relativity published in 1917, included the possibility that the universe is expanding.

In 1927, Belgian astronomer Georges Lemaître, who is said to have been unaware of Friedmann's work, published a paper also factoring in Einstein's theory of general relativity. And, while Einstein stated in his theory that the universe was static, Lemaître showed how the equations in Einstein's theory actually support the idea that the universe is not static but, in fact, is actually expanding.

Astronomer Edwin Hubble confirmed that the universe was expanding in 1929 using observations made by his associate, astronomer Milton Humason. Humason measured the redshift of spiral galaxies. Hubble and Humason then studied Cepheid stars in those galaxies, using the stars to determine the distance of their galaxies (or nebulae, as they called them). They compared the distances of these galaxies to their redshift and tracked how the farther away an object is, the bigger its redshift and the faster it is moving away from us. The pair found that objects like galaxies are moving away from Earth faster the farther away they are, at upwards of hundreds of thousands of miles per second – an observation now known as Hubble's Law, or the Hubble-Lemaître law. The universe, they confirmed, is really expanding.

Expansion is Speeding Up, Supernovae Show

Scientists previously thought that the universe's expansion would likely be slowed down by gravity over time, an expectation backed by Einstein's theory of general relativity. But in 1998, everything changed when two different teams of astronomers observing far-off supernovae noticed that (at a certain redshift) the stellar explosions were dimmer than expected. These groups were led by astronomers Adam Riess, Saul Perlmutter, and Brian Schmidt. This trio won the 2011 Nobel Prize in Physics for this work.

While dim supernovae might not seem like a major find, these astronomers were looking at Type 1a supernovae, which are known to have a certain level of luminosity. So they knew that there must be another factor making these objects appear dimmer. Scientists can determine distance (and speed) using an objects' brightness, and dimmer objects are typically farther away (though surrounding dust and other factors can cause an object to dim).

This led the scientists to conclude that these supernovae were just much farther away than they expected by looking at their redshifts.

Using the objects' brightness, the researchers determined the distance of these supernovae. And using the spectrum, they were able to figure out the objects' redshift and, therefore, how fast they were moving away from us. They found that the supernovae were not as close as expected, meaning they had traveled farther away from us faster than anticipated. These observations led scientists to ultimately conclude that the universe itself must be expanding faster over time.

While other possible explanations for these observations have been explored, astronomers studying even more distant supernovae or other cosmic phenomena in more recent years continued to gather evidence and build support for the idea that the universe is expanding faster over time, a phenomenon now called cosmic acceleration.

But, as scientists built up a case for cosmic acceleration, they also asked: Why? What could be driving the universe to stretch out faster over time?

Enter dark energy.

What Exactly *is* Dark Energy?

Right now, dark energy is just the name that astronomers gave to the mysterious "something" that is causing the universe to expand at an accelerated rate.

Dark energy has been described by some as having the effect of a negative pressure that is pushing space outward. However, we don't know if dark energy has the effect of any type of force at all. There are many ideas floating around about what dark energy could possibly be. Here are four leading explanations for dark energy. Keep in mind that it's possible it's something else entirely.

Vacuum Energy

Some scientists think that dark energy is a fundamental, ever-present background energy in space known as vacuum energy, which could be equal to the cosmological constant, a mathematical term in the equations of Einstein's theory of general relativity. Originally, the constant existed to counterbalance gravity, resulting in a static universe. But when Hubble confirmed that the universe was actually expanding, Einstein removed the constant, calling it "my biggest blunder," according to physicist George Gamow.

But when it was later discovered that the universe's expansion was actually accelerating, some scientists suggested that there might actually be a non-zero value to the previously-discredited cosmological constant. They suggested that this additional force would be necessary to accelerate the expansion of the universe. This theorized that this mystery component could be attributed to something called "vacuum energy," which is a theoretical background energy permeating all of space.

Space is never exactly empty. According to quantum field theory, there are virtual particles, or pairs of particles and antiparticles. It's thought that these virtual particles cancel each other out almost as soon as they crop up in the universe, and that this act of popping in and out of existence could be made possible by "vacuum energy" that fills the cosmos and pushes space outward.

While this theory has been a popular topic of discussion, scientists investigating this option have calculated how much vacuum energy there should theoretically be in space. They showed that there should either be so much vacuum energy that, at the very beginning, the universe would have expanded outwards so quickly and with so much force that no stars or galaxies could have formed, or… there should be absolutely none. This means that the amount of vacuum energy in the cosmos must be much smaller than it is in these predictions. However, this discrepancy has yet to be solved and has even earned the moniker "the cosmological constant problem."

Quintessence

Some scientists think that dark energy could be a type of energy fluid or field that fills space, behaves in an opposite way to normal matter, and can vary in its amount and distribution throughout both time and space. This hypothesized version of dark energy has been nicknamed quintessence after the theoretical fifth element discussed by ancient Greek philosophers.

It's even been suggested by some scientists that quintessence could be some combination of dark energy and dark matter, though the two are currently considered completely separate from one another. While the two are both major mysteries to scientists, dark matter is thought to make up about 85% of all matter in the universe.

Space Wrinkles

Some scientists think that dark energy could be a sort of defect in the fabric of the universe itself; defects like cosmic strings, which are hypothetical one-dimensional "wrinkles" thought to have formed in the early universe.

A Flaw in General Relativity

Some scientists think that dark energy isn't something physical that we can discover. Rather, they think there could be an issue with general relativity and Einstein's theory of gravity and how it works on the scale of the observable universe. Within this explanation, scientists think that it's possible to modify our understanding of gravity in a way that explains observations of the universe made without the need for dark energy. Einstein actually proposed such an idea in 1919 called unimodular gravity, a modified version of general relativity that scientists today think wouldn't require dark energy to make sense of the universe.

The Future

Dark energy is one of the great mysteries of the universe. For decades, scientists have theorized about our expanding universe. Now, for the first time ever, we have tools powerful enough to put these theories to the test and really investigate the big question: “what is dark energy?”

NASA plays a critical role in the ESA (European Space Agency) mission Euclid (launched in 2023), which will make a 3D map of the universe to see how matter has been pulled apart by dark energy over time. This map will include observations of billions of galaxies found up to 10 billion light-years from Earth.

NASA's Nancy Grace Roman Space Telescope, set to launch by May 2027, is designed to investigate dark energy, among many other science topics, and will also create a 3D dark matter map. Roman's resolution will be as sharp as NASA’s Hubble Space Telescope's, but with a field of view 100 times larger, allowing it to capture more expansive images of the universe. This will allow scientists to map how matter is structured and spread across the universe and explore how dark energy behaves and has changed over time. Roman will also conduct an additional survey to detect Type Ia supernovae.

In addition to NASA’s missions and efforts, the Vera C. Rubin Observatory, supported by a large collaboration that includes the U.S. National Science Foundation, which is currently under construction in Chile, is also poised to support our growing understanding of dark energy. The ground-based observatory is expected to be operational in 2025.

The combined efforts of Euclid, Roman, and Rubin will usher in a new “golden age” of cosmology, in which scientists will collect more detailed information than ever about the great mysteries of dark energy. Additionally, NASA's James Webb Space Telescope (launched in 2021), the world’s most powerful and largest space telescope, aims to make contributions to several areas of research, and will contribute to studies of dark energy.

NASA's SPHEREx (the Spectro-Photometer for the History of the Universe, Epoch of Reionization, and Ices Explorer) mission, scheduled to launch no later than April 2025, aims to investigate the origins of the universe. Scientists expect that the data collected with SPHEREx, which will survey the entire sky in near-infrared light, including over 450 million galaxies, could help to further our understanding of dark energy.

NASA also supports a citizen science project called Dark Energy Explorers, which enables anyone in the world, even those who have no scientific training, to help in the search for dark energy answers.