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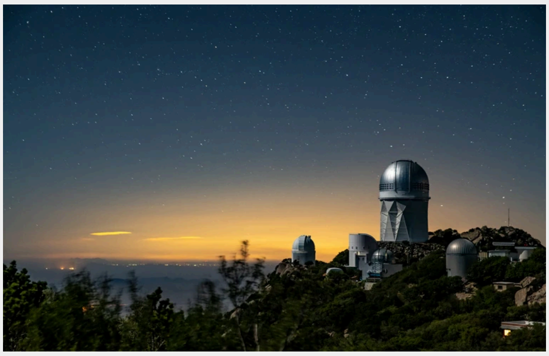
Dark energy is tearing the Universe apart. What if the force is weakening?

The first set of results from a pioneering cosmic-mapping project hints that the repulsive force known as dark energy has changed over 11 billion years, which would alter ideas about how the Universe has evolved and what its future will be.

By Davide Castelvecchi



The Dark Energy Spectroscopic Instrument (DESI) at Kitt Peak Observatory in Arizona is collecting data to reconstruct how the Universe has expanded over billions of years. Credit: Marilyn Sargent/Berkeley Lab

The fate of the Universe might not be as dark and empty as cosmologists have long suspected. That's one potential implication emerging from an innovative project that has produced some of the biggest maps ever made of the Universe.

At a meeting of the American Physical Society in Sacramento, California, in early April, researchers released initial results from the Dark Energy Spectroscopic Instrument (DESI), based at the Kitt Peak National Observatory near Tucson, Arizona. DESI started mapping the Universe in 3D in 2020 and was designed to measure the elusive force, known as dark energy, that is pushing galaxies apart.

The surprising early results suggest that dark energy could be weakening over time.

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"That's really a hint that something could be happening," says cosmologist Nathalie Palanque-Delabrouille at Lawrence Berkeley National Laboratory in California, who is DESI's spokesperson.

Although the study was based on only the first of the five years planned for data collection, it is already one of the largest maps ever made of the Universe, and it reveals the effects of dark energy across an unprecedented 11 billion years of cosmic history (DESI collaboration. Preprint at arXiv https://doi.org/mtqw; 2024).

If confirmed, the hints that dark energy might be weakening would bring the first substantial change in decades to the generally accepted theoretical model of the Universe. And if dark energy is not constant, that would hold implications for theories of how the Universe has evolved and for what its future might hold.

But researchers say that the evidence for changes in dark energy is still very uncertain. That was the overwhelming sentiment at a gathering of cosmologists on 15–16 April at the Royal Society in London. The standard cosmological model remains strong, most cosmologists agree — and has been working better and better as the years go by.

Wendy Freedman, an astronomer at the University of Chicago in Illinois, calls the hints of a weakening "tantalizing", but says it will require a lot more data to see if they pan out. "Time will tell if they stand the test of time."

Opposites attract

At the largest scales, the cosmos is ruled by gravity, and Einstein's general theory of relativity allows for gravity to be repulsive as well as attractive. Whereas ordinary forms of energy — which includes the mass of matter — result in an attractive force, general relativity also predicts that some more-exotic forms of energy could produce repulsive gravity.

Dark energy was discovered in 1998, when two teams of astronomers used supernova explosions in distant galaxies to measure how the rate of cosmic expansion has changed. Their results indicated that the rate has accelerated over time, pushed by some unseen repulsive force that would later be dubbed dark energy. The name was intended to echo the [equally mysterious entity known as dark matter]() — which is invisible but can be measured by its gravitational influence on galaxies.

The 1998 data that led to the discovery of dark energy had large error bars, and they were consistent with the simplest possible assumption: that dark energy is spread uniformly across space, earning it the name cosmological constant, or Λ. A consensus emerged around a theory called Λ cold dark matter (ΛCDM), in which cosmic history is largely the result of a struggle between the pull of dark matter and the push of dark energy.

A section of a map of the Universe based on observations made by DESI shows patterns in the arrangements of galaxies. Credit: Claire Lamman/DESI collaboration; custom colormap package by cmastro

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Save for small deviations that remain unexplained, all of the evidence cosmologists have collected so far has strengthened this ΛCDM model. The gold standard was set in 2013 by the Planck space mission of the European Space Agency (ESA), which mapped the relic radiation from the early Universe, called the cosmic microwave background. The data from that mission are in "exquisite" agreement with the model, says senior Planck researcher George Efstathiou, a cosmologist at the University of Cambridge, UK. The current Universe, Planck found, is about 70% dark energy, 25% dark matter and 5% ordinary matter — the stuff of stars, planets and people.

Many fates

The standard assumption of ΛCDM is that the expansion of the Universe will continue to accelerate, and that most galaxies would ultimately disappear from view. But theorists have developed hundreds of other models of dark energy; many posit that dark energy could be getting slowly diluted, and the Universe's expansion will start to slow down. Another possibility is that dark energy is getting stronger and will ultimately rip galaxies apart.

For a long time, the hints from observations were too vague to answer even the most basic questions about dark energy: exactly how strong is it, and is it constant or slowly changing? DESI is the first in a new generation of experiments aimed at providing some answers. Others include ESA's Euclid mission, which launched into space last year; the massive, 8-metre telescope of the Vera C. Rubin Observatory nearing completion in the Chilean Andes; and NASA's Nancy Grace Roman Space Telescope, scheduled to launch in 2027. Another telescope, called eROSITA, part of a Russian–German space mission, has mapped the Universe in the X-ray spectrum.

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"There's a whole slew of projects that are about to start taking data or have just started," Palanque-Delabrouille said at the Royal Society meeting. "This is really unique in the history of cosmology."

All of these efforts rely on mapping the distribution of matter in the Universe over vast distances, which — because of the time that light takes to reach Earth — also means over vast stretches of time. DESI does not take pictures of the sky in the way that an ordinary telescope camera does, but instead collects light from selected locations in its field of view. It does so by pointing optical fibres at objects — typically galaxies or quasars — with its 5,000 robotic arms, and routing that light to sensitive spectrographs. The spectrum of each object reveals its distance, because the farther away the object is, the faster it moves away, and the more its spectrum has 'redshifted' towards longer wavelengths.

To reconstruct the history of cosmic expansion from its 3D data, the DESI team uses one of the most well-established techniques in cosmology. It looks at the relic of what used to be sound waves in the primordial Universe.

As space expanded and matter cooled over time, the waves became frozen in the distribution of protons and neutrons (known collectively as baryons) across the Universe. That imprint, called baryon acoustic oscillations, or BAO, is still detectable today in how galaxies are scattered across space.

The BAO features are the largest structures in the Universe. "If we could see them individually, we would see a shell," Palanque-Delabrouille explains. "It's like when you throw pebbles in a lake. If you throw just one pebble, you can see its waves expanding out," she says. "If you throw too many pebbles at once, all the ripples they produce will overlap with one another."

Immense scope

DESI doesn't just see the BAOs in the current Universe. Its 3D map stretches back in time, and by measuring how the average size of the features has grown over time, cosmologists can reconstruct the rate of expansion — and from that, the strength of dark energy. The instrument's results are in principle still compatible with all the options — a dark energy that is constant, weakening or even strengthening.

At the most basic level, the DESI results provide solid confirmation of the original discovery, says Ofer Lahav, a cosmologist at University College London who is part of the DESI collaboration. "To me, it's spectacular that you can confirm that the Universe is accelerating, and more or less get the same value people have claimed 25 years ago," he says.

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"The instruments, data and measurements are spectacular," says Marc Kamionkowski, a theoretical cosmologist at Johns Hopkins University in Baltimore, Maryland.

Kamionkowski says that he is cautious about interpreting the results as indicating that dark energy is weakening. He says that they could be an effect of the particular type of analysis the team did. Pedro Ferreira, a theoretical physicist at the University of Oxford, UK, agrees, pointing to a study he published last year with his colleague William Wolf, which called for cosmologists to change how they interpret dark-energy data (W. J. Wolf and P. G. Ferreira *Phys. Rev. D* **108**, 103519; 2023). Ferreira adds that he is pessimistic that even the coming high-powered studies together will be able to pin down a theoretical model for dark energy.

But researchers hold out hope that the extra data will point in new directions.

The standard model was created as the simplest possible theory for the Universe, but the actual physics of its contents is probably more complicated, says Eleonora Di Valentino, a cosmologist at the University of Sheffield, UK. "I don't believe that ΛCDM can be the final answer," she says.

Cosmologist James Peebles — a chief architect of the standard model that helped to earn him a Nobel Prize in 2019 — agrees. "I find it very difficult to imagine that ΛCDM is the end of the story," says Peebles, who is at Princeton University in New Jersey. "It's too simple."

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