The Standard Cosmology Model May Be Breaking

Measurements of millions of galaxies suggest that dark energy changes over time and is more complicated than previously thought.

By **David Ehrenstein**

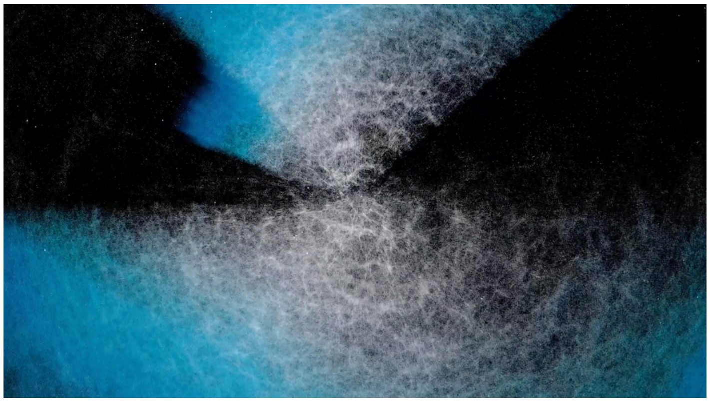
Dark energy—the cosmic constituent causing the expansion of the Universe to accelerate—is changing with time, according to results announced last week at the American Physical Society's Global Physics Summit in Anaheim, California. These findings, which call into question the conventional model of cosmology known as ΛCDM, come from measurements by the Dark Energy Spectroscopy Instrument (DESI) of the distances and spectra of millions of galaxies and quasars, the largest dataset of its kind. The researchers are more confident now than they were last year when making similar but more cautious claims. The proposed time-evolving dark energy would have implications for the fate of the Universe and for theories that attempt to unify gravity with quantum mechanics.

DESI is installed on a telescope in Arizona, where it records spectra of 5000 celestial objects simultaneously. The new results come from measurements of nearly 15 million quasars and galaxies, but the DESI collaboration expects to map 50 million during five total years of operation.
Credit: M. Sargent/Berkeley Lab

Dark energy makes up about 68% of the Universe, yet cosmologists don't know what it is. To determine which dark-energy models might be correct, cosmologists need high-precision data on the expansion history of the Universe. DESI is expected to record images and spectra from 50 million celestial targets over a period of five years using a telescope at the Kitt Peak observatory in Arizona.

From these data, DESI researchers determine the distances between galaxies. Events in the early Universe led to a particular intergalaxy distance becoming slightly more common than others. This so-called baryon acoustic oscillation scale serves as a "standard ruler" that can be measured by DESI at every epoch going back 11 billion years. By tracking how this ruler changes over time, researchers can estimate the expansion history of the Universe. DESI's latest results come from the first three years of data taking, which includes nearly 15 million galaxies and quasars, more than twice as many as were included in the one-year results reported last year (see **Research News: High-Precision Map of the Universe Defies Conventional Cosmology**).

The current understanding of the expansion history is contained in the ΛCDM model. This model, which has passed a wide range of observational tests for over 25 years, includes dark matter and ordinary matter, along with the simplest version of dark energy, called the cosmological constant (represented by Λ). This version of dark energy has a permanently fixed energy density that exerts an outward pressure on space that doesn't decrease as the Universe grows larger. By contrast, the density of matter is continually diluted as space expands, which



Earth is at the center in this animation in which each dot represents a galaxy or quasar mapped by DESI.
Credit: DESI Collaboration; KPNO; NOIRLab; NSF; AURA; R. Proctor

reduces the strength of the contraction force provided by gravity. So with the cosmological constant, the accelerated expansion is unrelenting, and gravity can never win.

But this picture is not supported by DESI's observations. Team member Enrique Paillas of the University of Arizona reported at the conference that the new data—when combined with other datasets—favor a time-evolving (or dynamical) dark energy, in contradiction with ΛCDM. Combining DESI's results with both cosmic microwave background (CMB) observations and supernova data (an alternative technique for cosmic distance measurement), the researchers find that ΛCDM is disfavored with a significance of 4.2σ. This significance means that the probability that this discrepancy is a statistical fluke is less than 0.01%.

One benefit of the additional data is that the team can now draw conclusions about dark energy with high statistical significance without needing to include every dataset, says DESI cospokesperson Alexie Leauthaud of the University of California, Santa Cruz. "Previously, we kind of threw everything but the kitchen sink" into the analysis, she says. But now the collaboration can look at various combinations (such as DESI with just CMB or with just supernovae), and they still see a preference for time-evolving dark energy.
The DESI analysis also shows that dark energy is evolving in a way that was not expected, Leauthaud says. Dark energy's ratio of pressure to energy density, called w, is fixed at −1 in ΛCDM, but in the DESI analysis, its value 11 billion years ago was about −1.4, and today it's about −0.7. Leauthaud says that any value below −1 leads to complications for theoretical models, such as the requirement of interactions between dark energy and dark matter, or the need for multiple types of dark energy. In addition, DESI's results suggest that the accelerated expansion of the Universe began around seven billion years ago, reached a peak about two billion years ago, and has been slowing down ever since. If it continues, this slowdown could eventually lead to a contraction of the Universe—the opposite of the fate predicted by ΛCDM. "Theorists are going to have a great time" trying to explain the results, she says.

"It looks much more believable now than it did last year," says cosmologist Rocky Kolb of the University of Chicago regarding the claim of dynamical dark energy. He says the discovery seems to mark a major change for cosmology. On the other hand, he's maintaining some skepticism because "there's no compelling theoretical reason for dynamical dark energy."

Harvard string theorist Cumrun Vafa is "very excited" by the DESI results, which line up with a hypothesis he and his colleagues developed in 2018 [**1**] (see **Trend: Cosmic Predictions from the String Swampland**). They proposed that string theories, which are attempts to unify general relativity with quantum mechanics, are not compatible with a cosmological constant. Instead, Vafa and colleagues suggested that dark energy evolves at a rate proportional to its strength. The DESI results "align remarkably well—both qualitatively and quantitatively—with this prediction," Vafa says.

David Ehrenstein is a Senior Editor for ***Physics Magazine***.

REFERENCES

1. G. Obied *et al.*, "De Sitter space and the swampland," **arXiv:1806.08362.**