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Cosmology

Our best understanding of the universe may be wrong...

Karmela Padavic-Callaghan

DARK energy is one of the most mysterious features of our universe – we don't know what it is, but it controls how the universe is expanding, as well as its ultimate fate. Now, a study of millions of celestial objects has revealed that we may have been thinking about it all wrong, with potentially dramatic consequences for the cosmos.

"This is the biggest hint we have about the nature of dark energy in the approximately 25 years since we discovered it," says Adam Riess at Johns Hopkins University in Maryland.

The result comes from three years' worth of data gathered by the Dark Energy Spectroscopic Instrument (DESI) in Arizona. By combining this data with other measurements, such as maps of the cosmic microwave background radiation and supernovae, the DESI team has concluded that dark energy may have changed over time – directly contradicting the standard model of cosmology, called lambda-CDM.

Cutting-edge knowledge

"This is the cutting edge of human knowledge," says DESI team member Will Percival at the University of Waterloo in Canada. "We're seeing something amazing with the whole universe."

DESI is mounted on a telescope and works by measuring the "redshift" of light emitted by distant galaxies, or how the wavelengths of that light are stretched as it travels through the universe. From this, researchers can determine how much the universe has expanded during the light's journey and calculate how this expansion is changing. So far, the team has analysed light from nearly 15 million galaxies and other bright objects in the sky.

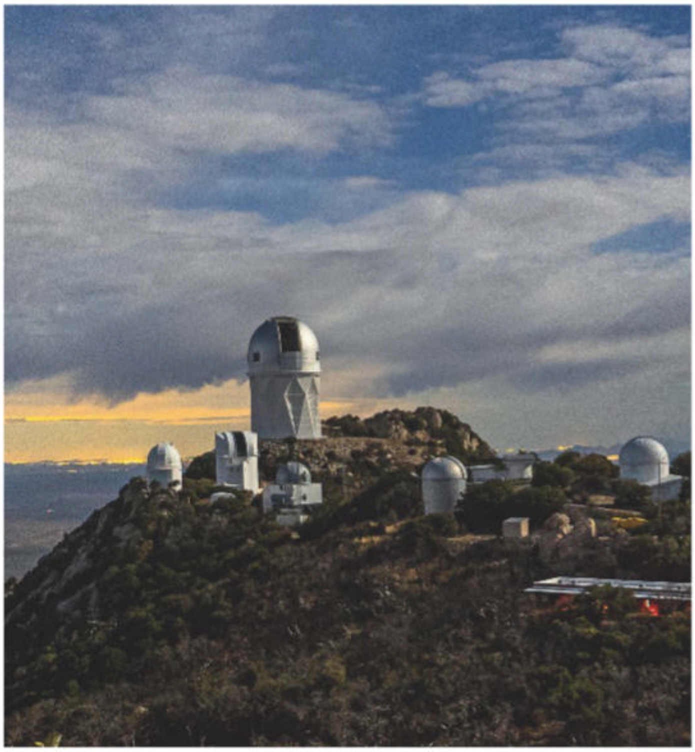
For decades, physicists have agreed that the universe is expanding at a fixed rate of acceleration, a cosmological constant known as lambda that has been interpreted as the push of dark energy. But in April 2024, DESI's measurements showed the first hints that the universe may actually be accelerating less quickly over time – making the cosmological constant not so constant.

"This is the biggest hint we have about the nature of dark energy since we discovered it"

Riess, who isn't on the DESI team, says that, at the time, he wasn't sure whether the finding would persist with more data. In fact, it has only become stronger. "It's very exciting to me that it appears that [the team] did not find any problem in the analysis after another year, and after they've added more data. If anything, the result is more significant," he says.

That said, the finding still doesn't meet the "5 sigma" statistical level that physicists conventionally use to mark a discovery as genuine, rather than a statistical fluke. The current analysis reaches at most 4.2 sigma, but team member Mustapha Ishak-Boushaki at the University of Texas at Dallas says the team believes that, as DESI keeps taking data, the result should hit 5 sigma within two years. "This result about dark energy is something that we did not expect to happen in our lifetime," he says.

One reassurance, says Ishak-Boushaki, is that the finding doesn't rely only on data from DESI, but also on several other surveys of the universe. Riess compares the situation to a multi-legged stool, where breaking one leg – or removing one dataset – doesn't make the conclusion fully crumble.



MARILYN SARGENT/UNIVERSITY OF CALIFORNIA/LAWRENCE BERKELEY NATIONAL LABORATORY

The DESI survey is being conducted on the Mayall 4-metre telescope in Arizona

Weaker dark energy

Assuming the legs hold, the universe could look very different from our current picture of it. If dark energy keeps becoming weaker, the universe may reach a state where it is expanding at a constant rate instead of faster and faster, says Ishak-Boushaki. Some dramatic scenarios also become more plausible, such as the "big crunch", where the cosmos starts contracting instead of expanding and eventually collapses in on itself, he says.

The exact future of the universe remains an open question, and DESI isn't the only tool researchers are using to answer it. Riess points to several other surveys of the universe, such as NASA's Nancy Grace Roman Space Telescope and the Vera Rubin Observatory in Chile, which are designed to help shed light on the true nature of dark energy.

While mathematical models for a universe with changing dark energy still need to catch up with these observations, Percival says he expects future theoretical work will help design even more experiments that will directly test our assumptions about this mysterious force.

"As far as theoretical models, Pandora's box just opened. We were stuck with a cosmological constant," says Ishak-Boushaki. "We are not stuck anymore." ▮

...or it may be too right

The finest ever map of the cosmic microwave background suggests our best model of the universe works just fine, making it hard to know where cosmologists go next, finds **Matthew Sparkes**

OUR latest and best ever map of the early universe is five times more detailed than anything we have had before, but while it precisely backs up the leading model of the universe, it is also a double-edged sword because it offers no clues to solving some of cosmology's biggest mysteries.

The map shows the cosmic microwave background (CMB), a faint remnant radiation from the early stages of the universe. It began as the earliest light, just 380,000 years after the big bang, but billions of years of the universe expanding have shifted its frequency from the visible spectrum to microwave.

Now, new data from the Atacama Cosmology Telescope (ACT) has given us a clearer image of the CMB – albeit only from the half of the sky that can be imaged from the observatory's location in Chile.

Jo Dunkley at Princeton University, who worked on the project, says that the data has given us a more precise look at the ingredients of the universe, its size, its age and its expansion rate. But the really key discovery was that nothing contradicted the current leading model of the universe, known as lambda-CDM.

Previous data put the age of the universe at 13.8 billion years and the rate at which it is expanding – known as the Hubble constant – at 67 to 68 kilometres per second per megaparsec distance from Earth. ACT data essentially confirms this, at higher precision. The Hubble constant is related to, but distinct from, the cosmological constant that drives dark energy (see left)

The CMB was first mapped by NASA's Cosmic Background Explorer (COBE) in the 1980s and 90s, then by NASA's Wilkinson Microwave Anisotropy Probe (WMAP) in the 2000s and then in yet greater detail by the European Space Agency's Planck spacecraft from 2009 to 2013. Each mission provided more detailed maps of the CMB, advancing our knowledge of cosmology and understanding of the early universe.

One limitation of ACT is that it is a ground-based telescope, unlike these earlier, space-based missions, which is why it is limited to just one half of the sky. Despite this, ACT gives not only better resolution and sensitivity than these previous maps, but it also measures the polarisation of the CMB, or the orientation in which its light waves oscillate, revealing some information about how the CMB radiation has evolved.

"We were quite ready to see something departing from the standard model, some subtlety. But we haven't"

"By looking at the polarisation of the CMB in better detail, we could have seen something different. We could have seen the standard cosmological model breaking," says Dunkley. "Because whenever you look at the universe in a different way, you can't be sure that your original model is still going to work. We were quite ready to see something departing from that model, some subtlety. But we haven't."

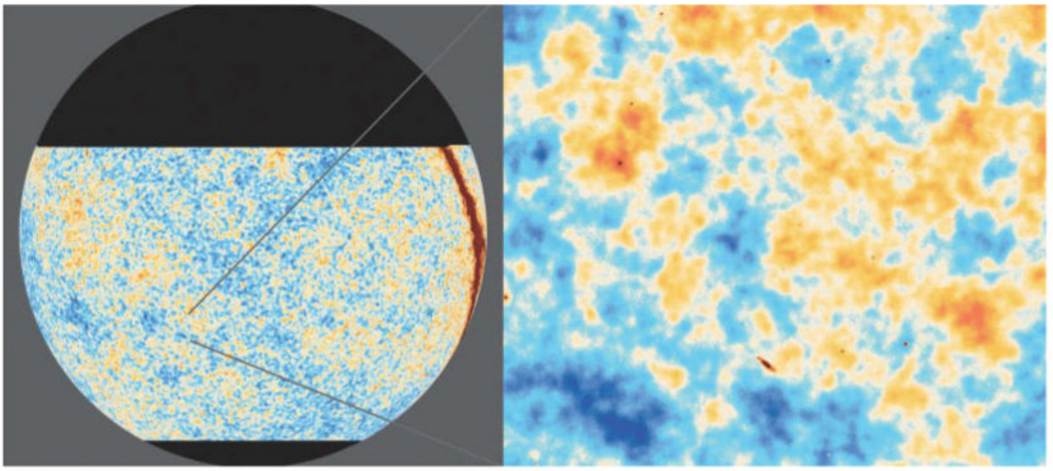
This may be reassuring for those working on lambda-CDM, but hasn't been welcome news for all scientists. Colin Hill at Columbia University in New York says that he was hoping to see evidence for an unexplained phenomenon – perhaps a new type of energy or particle – which could help explain the so-called Hubble tension: the discrepancy between the rate of expansion in the universe given by the lambda-CDM standard model and what we measure directly.

"We've all just been blown away by how consistent [the ACT data] really is with the standard model. We're all trying to poke and prod the model from different aspects and look for a place where it's going to crack, and where nature will give us something to sink our teeth into. And so far, nature hasn't yielded that crack," says Hill.

He says that the most viable theories for the Hubble tension discrepancy require phenomena that don't appear in the ACT data, which is currently the best we have. This will force scientists back to the drawing board to seek another explanation. "The new measurements are going to put theorists, including myself, into an even tighter straitjacket," says Hill. "It deepens the mystery."

ACT collected the data for this new map between 2017 and 2022, but has now been shut down. Dunkley says that we are unlikely to get a higher resolution map soon, although a new telescope in Chile will start work later this year. As for the other half of the sky, only two locations on Earth are likely to be able to host new telescopes that would yield results: Greenland and Tibet. Dunkley says that Greenland doesn't yet have the necessary infrastructure for such a project, and Tibet is politically sensitive.

Jens Chluba at the University of Manchester, UK, says that while scientists on the project have already been working with the data, the open release of the map will spark a flurry of activity. "The whole cosmology community can get their hands on the data and do all kind of cross-analysis with their datasets," says Chluba.



ACT COLLABORATION; ESA/PLANCK COLLABORATION

More intense (orange) and less intense (blue) radiation shown in the new CMB image