# New DESI results weigh in on gravity

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### Observations made with the Dark Energy Spectroscopic Instrument line up with predictions from Einstein's theory of general relativity

DESI observes the sky from the Mayall Telescope, shown here during the 2023 Geminid meteor shower. Image credit: KPNO/NOIRLab/NSF/AURA/R. Sparks

Gravity has shaped our cosmos. Its attractive influence turned tiny differences in the amount of matter present in the early universe into the sprawling strands of galaxies we see today.

A new study using data from the Dark Energy Spectroscopic Instrument, or DESI, has traced how this cosmic structure grew over the past 11 billion years, providing the most precise test to date of gravity at very large scales.

DESI is an international collaboration of more than 900 researchers from more than 70 institutions around the world, including the University of Michigan, and is managed by the Department of Energy's Lawrence Berkeley National Laboratory.

The new DESI result validates our leading model of the universe and limits possible theories of modified gravity, which have been proposed to explain the observed accelerated expansion of the universe.

"This is the first time that DESI has looked at the growth of cosmic structure," said Dragan Huterer, professor of physics at the University of Michigan and co-lead of DESI's group analyzing and interpreting the cosmological data.

"DESI data have a tremendous ability to probe modified gravity and improve constraints on models of dark energy. And it's only the tip of the iceberg."

In their new study, DESI researchers found that gravity behaves as predicted by Einstein's theory of general relativity.

"General relativity has been very well tested at the scale of solar systems, but we also needed to test that our assumption works at much larger scales," said Pauline Zarrouk, a cosmologist at the French National Center for Scientific Research working at the Laboratory of Nuclear and High-Energy Physics, who co-led the new analysis. "Studying the rate at which galaxies formed lets us directly test our theories and, so far, we're lining up with what general relativity predicts at cosmological scales."

The study also provided new upper limits on the mass of neutrinos, the only fundamental particles whose masses have not yet been precisely measured.

Previous neutrino experiments found that the sum of the masses of the three types of neutrinos should be at least 0.059 eV/c2. For comparison, an electron has a mass of about 511,000 eV/c2. DESI's results indicate that the sum should be less than 0.071 eV/c2, leaving a narrow window for neutrino masses.

The DESI collaboration has shared results in several studies posted to the online repository arXiv.

The complex analysis used nearly 6 million galaxies and quasars whose light was emitted between 1 and 11 billion years ago. With just one year of data, DESI has made the most precise overall measurement of the growth of structure, matching previous efforts in precision that took decades to make.

## How Michigan helped create DESI


DESI is a state-of-the-art instrument that can capture light from 5,000 galaxies simultaneously. It does this using 5,000 tiny, robotic "eyes" that independently capture light from their target of interest.

Gregory Tarlé, U-M professor emeritus of physics, led the team that made the robotics that precisely control the position of each eye, which collect light with optical fibers.

"We control the position to better than one tenth the diameter of a human hair," Tarlé said. "These robotics move the position of the fiber very accurately to look at different galaxies and they do this every 15-20 minutes."

The results provide an extended analysis of DESI's first year of data. The researchers anticipate sharing another update on their measurements of dark energy and the expansion history of our universe in spring 2025. The collaboration is currently analyzing the first three years of collected data.

The experiment is now in its fourth of five years surveying the sky and plans to collect roughly 40 million galaxies and quasars by the time the project ends.

"Without the instrumentation built by Greg's group, we're not having this discussion," Huterer said. "Without those 5,000 eyes in the sky, we wouldn't be doing any of this now."

Although DESI's survey officially began in 2021, the process of approving and funding the instrument began more than a decade ago.

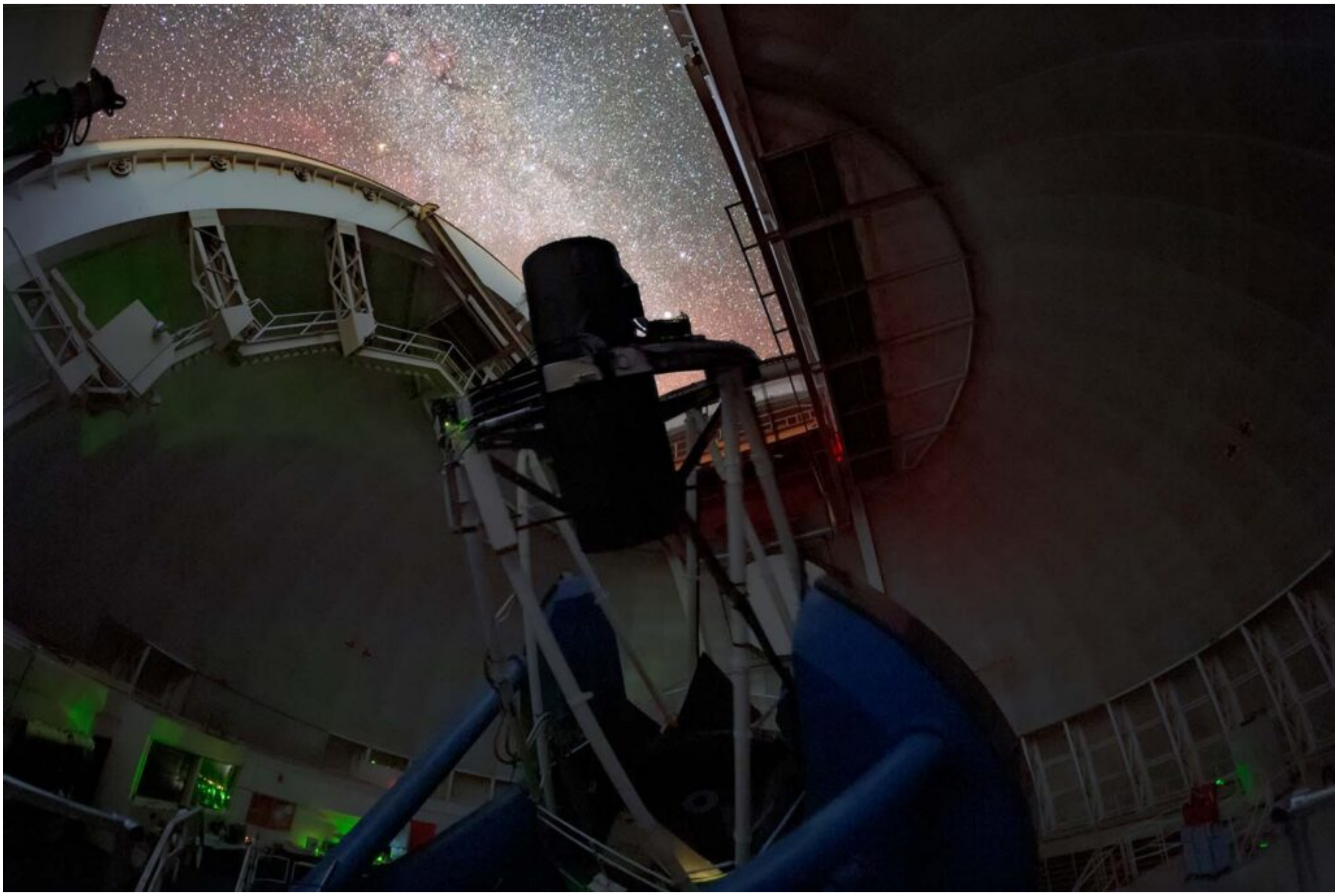

Gregory Tarlé

"After almost a decade of work, to have everything working with the instrument and to be getting real science out of it, it just feels good," Tarlé said.

DESI was constructed and is operated with funding from the DOE Office of Science. DESI is mounted on the U.S. National Science Foundation's Nicholas U. Mayall 4-meter Telescope at Kitt Peak National Observatory, a program of the National Science Foundation National Optical-Infrared Astronomy Research Laboratory, or NOIRLab.

In addition to Tarlé and Huterer, several other U-M researchers were involved in publishing the data and associated reports: research scientist Michael Schubnell, postdoctoral research fellow Uendert Andrade, and graduate students Otavio Alves, Sikandar Hanif and Jiaming Pan.

The DESI collaboration is honored to be permitted to conduct scientific research on Iolkam Du'ag—also known today as Kitt Peak—a mountain with particular significance to the Tohono O'odham Nation.



The Dark Energy Spectroscopic Instrument imaging the night sky in 2022. Image credit: KPNO/NOIRLab/NSF/AURA/T. Slovinský

### A growing understanding of an expanding universe

The findings build on work announced in April, when DESI made the largest 3D map of our universe to date and revealed hints that dark energy might be evolving over time. The April results looked at a particular feature of how galaxies cluster known as baryon acoustic oscillations, abbreviated BAO.

The new analysis, called "full-shape analysis," broadens the scope to extract more information from the data, measuring how galaxies and matter are distributed on different scales throughout space. The study required months of additional work and cross-checks. Like the previous study, it used a technique to hide the result from the scientists until the end, mitigating any unconscious bias.

The newly released expanded results are consistent with the experiment's earlier preference for an evolving dark energy, adding to the anticipation of the upcoming analysis.

"At the present epoch, dark matter makes up about a quarter of the universe, and dark energy makes up another 70%, and we don't really know what either one is," said Mark Maus, a doctoral student at Berkeley Lab and UC Berkeley who worked on theory and validation modeling pipelines for the new analysis. "The idea that we can take pictures of the universe and tackle these big, fundamental questions is mind-blowing."

Huterer shares that excitement, saying the upcoming data release will be a major input that will help inform how we think about a number of the universe's mysteries. But, for him, the one that stands out most is the one that's part of DESI's name.

"The most important thing is still dark energy," Huterer said. "And this is only the first salvo of analysis."

DESI is supported by the DOE Office of Science and by the National Energy Research Scientific Computing Center, a DOE Office of Science user facility. Additional support for DESI is provided by the U.S. National Science Foundation; Science and Technology Facilities Council of the United Kingdom; Gordon and Betty Moore Foundation; Heising-Simons Foundation; French Alternative Energies and Atomic Energy Commission; National Council of Humanities, Sciences, and Technologies of Mexico; Ministry of Science and Innovation of Spain; and by DESI member institutions.