



The CLEAN PAPER

WHAT THE PAPER SAYS · WHAT IT DOESN'T · WHY IT MATTERS

DESI's sharpest cosmic ruler, and a careful maybe about dark energy

DESI measured the universe's expansion history with the most precise baryon-acoustic ruler yet built, from six million objects. On its own, that ruler agrees with the standard model in which dark energy is a constant. Only when DESI is combined with the cosmic microwave background and a supernova sample does a preference for evolving dark energy appear — at 2.6σ to 3.9σ depending on which supernovae are added, below the threshold physicists require for a discovery and sensitive to the data it is paired with. A real question made precise, not an answer.

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A ruler made of sound

Early in the universe, before there were stars, the hot plasma of ordinary matter and light rang. Pressure waves ran through it at more than half the speed of light, until the universe cooled enough for atoms to form and the ringing stopped — freezing a faint preferred distance into the distribution of matter. That distance, the *sound horizon*, is about 150 megaparsecs (roughly 490 million light-years) today, and it shows up as a slight excess of galaxies separated by that span, in every direction and at every epoch. Cosmologists call it the baryon acoustic oscillation, or BAO, and they use it as a standard ruler: measure how big that frozen scale looks on the sky at different distances, and you chart how fast the universe has expanded across its history.

The Dark Energy Spectroscopic Instrument (DESI) was built to measure that ruler better than anyone has. Its first data release maps the BAO scale in galaxies, quasars, and the Lyman-alpha forest of distant gas clouds — over six million objects, spread across seven redshift bins from redshift 0.1 to 4.2. To keep human expectation out of the result, the team ran the analysis *blind*, hiding the cosmological answer from themselves until the methods were locked. It is, by a wide margin, the most precise BAO measurement made.



DESI is mounted on the Nicholas U. Mayall 4-metre Telescope at Kitt Peak, Arizona. The instrument feeds thousands of optical fibres into spectrographs, turning positions on the sky into spectra and redshifts for millions of galaxies and quasars.

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What is DESI

The **Dark Energy Spectroscopic Instrument** is a spectrograph on the Nicholas U. Mayall 4-metre telescope at Kitt Peak, Arizona. It does not see dark energy directly — nothing can, since dark energy gives off no light. Instead it records the spectra of about 5,000 galaxies and quasars at once, reads each object’s redshift from how the expanding universe has stretched its light, and builds a three-dimensional map of millions of them. Dark energy is then inferred from how that map shows cosmic expansion changing over time. For the full chain — from the robotic fibres to the acoustic ruler — see How DESI works.

The headline that travelled from it was that dark energy might not be a constant — that the mysterious thing accelerating the universe’s expansion could be *weakening* over time, cracking the standard cosmological model. That claim is not made up, but it is easy to over-read. The honest version is more specific, and more interesting: DESI’s own ruler, on its own, agrees with the plain-vanilla model. The hint of something new appears only when you combine DESI with other data — and how strong the hint looks depends on which other data you choose.

DESI’s baryon-acoustic ruler by itself is consistent with a constant dark energy (a cosmological constant). The preference for *evolving* dark energy emerges only when DESI is combined with the cosmic microwave background and a supernova sample — and its strength shifts with which supernova sample is used.

Standard ruler, and the two ways dark energy can vary

The BAO scale is a *standard ruler*: because we know its true length from the physics of the early universe, comparing its true length to its apparent size at a given distance tells us how much the universe had expanded by then. Measured across many distances, the ruler traces the whole expansion history — which is what dark energy governs.

In the standard model, called Λ CDM, dark energy is a *cosmological constant*: a fixed energy density of empty space that never changes. Physicists label its behaviour with an “equation of state” parameter, w , which for a true cosmological constant is exactly -1 , everywhere and always.

To test that, you can relax it two ways. The simpler is to let w be some other constant (still fixed in time) — this is “wCDM.” The richer is to let w change as the universe expands, described by two numbers: w_0 , its value today, and w_a , how fast it drifts. This “ w_0w_a CDM” model reduces to Λ CDM at the single point $w_0 = -1$, $w_a = 0$. A preference for w_0 greater than -1 with w_a negative is what “evolving dark energy” means here: dark energy that was more repulsive in the past and is easing off now.

What the authors did

- Measured the BAO scale from DESI’s first year of data — galaxies, quasars, and the Lyman-alpha forest — over six million objects in seven redshift bins spanning $0.1 < z < 4.2$.

- Ran the analysis **blind**, concealing the cosmological result until the methodology was fixed, to guard against confirmation bias.
- Fit the standard flat Λ CDM model to DESI BAO alone, then in combination with a big-bang-nucleosynthesis prior and the cosmic microwave background (CMB) from Planck and ACT.
- Extended the model two ways: a constant dark-energy w (w CDM), and a time-varying $w_0 w_a$ ($w_0 w_a$ CDM).
- Tested the time-varying model by combining DESI+CMB with three different type Ia supernova compilations in turn — Pantheon+, Union3, and DES-SN5YR — rather than picking one.
- Placed limits on the summed mass of the neutrinos, and checked how those limits move if the dark-energy background is allowed to vary.

What they found

- **DESI BAO alone are consistent with the standard model.** They give a matter density $\Omega_m = 0.295 \pm 0.015$, and, when dark energy is allowed a constant w , $w = -0.99 (+0.15/-0.13)$ — sitting right on the cosmological-constant value of -1 .
- Combined with the CMB and its lensing, DESI gives $\Omega_m = 0.307 \pm 0.005$ and a Hubble constant $H_0 = 67.97 \pm 0.38 \text{ km s}^{-1} \text{ Mpc}^{-1}$ (68.52 ± 0.62 when paired with nucleosynthesis and the CMB’s acoustic scale instead).
- **In the time-varying model, the combinations prefer evolving dark energy** — $w_0 > -1$ and $w_a < 0$. The preference is 2.6σ for DESI+CMB, and when a supernova sample is added it becomes 2.5σ , 3.5σ , or 3.9σ for Pantheon+, Union3, or DES-SN5YR respectively (sigma measures how far a result sits from the standard-model expectation; 5σ is the usual threshold for a claimed discovery, and it is not a statement that the interpretation is correct — guide).
- Left free, the summed neutrino mass is bounded tightly — under 0.072 eV (95% confidence) for DESI+CMB — but the paper is explicit that this bound loosens substantially if the dark-energy background is allowed to depart from Λ CDM.

What this does not prove

- It does **not** show that dark energy is evolving. DESI’s own ruler is consistent with a cosmological constant; the hint of evolution appears only in *combined* fits, and only in the richer two-parameter model.
- It does **not** mean “ Λ CDM is dead” or “Einstein was wrong.” The strongest number, 3.9σ , is below the 5σ convention physicists require before calling something a discovery — and the standard model remains a good fit to DESI alone.
- The result is **not** sample-independent. Swapping the supernova compilation moves the significance from 2.5σ to 3.9σ — more than a full sigma. A signal whose size depends that much on which external dataset you bolt on is a hint to be pursued, not a measurement to be banked.
- The DESI-*alone* lean toward $w_0 > -1$ is driven **partly by a single anomalous point** — the redshift-0.51 galaxy bin, which sits slightly high against Λ CDM. But this is where the paper does its home-

work: it treats that point as a statistical fluctuation, and shows that replacing *all* of DESI’s low-redshift ($z < 0.6$) measurements with the older SDSS ones leaves the dark-energy result unchanged. The odd point tugs DESI on its own; it does **not** prop up the combined hint. (Independent groups have since looked harder at its role.) So this caveat cuts the opposite way from how it is sometimes told: the result was stress-tested against its most anomalous data, and held.

- The neutrino-mass limit is **not** a model-independent verdict. It is tight only if the background expansion is held to Λ CDM; relax that, and the bound relaxes with it.

How strong is the evidence

- **Very strong as a distance measurement.** The BAO ruler is one of the cleanest tools in cosmology, DESI’s is the most precise yet, and the blind analysis is exactly the safeguard you want against reading a hoped-for answer into the data.
- **Genuinely intriguing, but not decisive, as a dark-energy claim.** A 2.6σ preference from DESI+CMB, rising to 3.9σ with the most constraining supernova set, is the kind of result that earns more telescope time — not the kind that overturns a model. The honest reason for caution is the spread across supernova samples; to their credit, the authors also checked that their single most anomalous BAO point does not drive the result — exactly the homework a claim like this needs.
- The paper is careful with itself: it reports the significance three ways rather than quoting the largest, and it flags the model-dependence of its neutrino result. The overreach, where it exists, is in the retelling, not the paper.

Why it matters

For a quarter-century, “dark energy” and “cosmological constant” have been used almost interchangeably, because every measurement was consistent with a w of exactly -1 . DESI is the first dataset precise enough that, combined with others, it can even *ask* whether that -1 drifts — and get an answer that is not a flat no. That is a real shift in what the data can do, and it is why the result deserves attention. But the same precision is what lets us see how conditional the hint is: alive in some data combinations, quiet in others, and sensitive above all to which supernova catalogue is paired with DESI. The right posture is neither dismissal nor a revolution announced early. It is to watch the next, larger DESI release — DR2, already out in 2025 — and the independent supernova samples, and see whether the drift firms up or fades. This is what a genuine maybe looks like in cosmology, and it is worth reporting as a maybe.

Clean summary

DESI has measured the universe's expansion history with the best baryon-acoustic ruler yet built, from six million objects. On its own, that ruler agrees with the standard model in which dark energy is a constant. Combine it with the cosmic microwave background and a supernova sample, and a preference emerges for dark energy that changes over time — at 2.6σ to 3.9σ , depending on which supernovae you add. That is a real and interesting hint, not a discovery: it stays below the threshold physicists demand, and it shifts with which supernova data you pair it with. Dark energy might be evolving. DESI has made that a question worth asking precisely — not yet a question it has answered.

Sources

DESI Collaboration, arXiv:2404.03002 (published in JCAP)

<https://arxiv.org/abs/2404.03002>

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