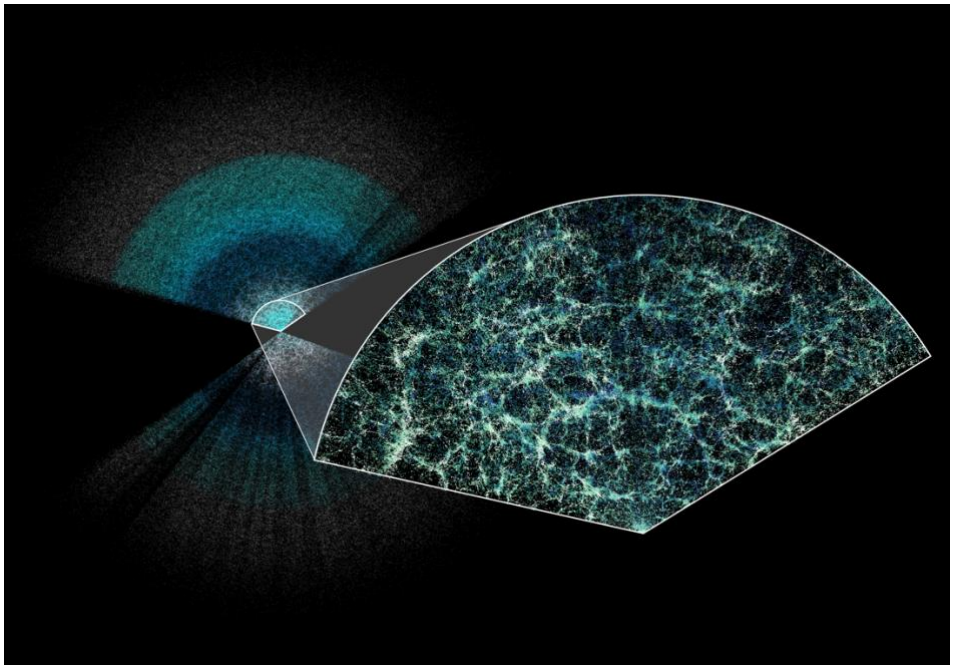
First Results from DESI Make the Most Precise Measurement of Our Expanding Universe

Researchers have used the Dark Energy Spectroscopic Instrument to make the largest 3D map of our universe and world-leading measurements of dark energy, the mysterious cause of its accelerating expansion.



Caption: DESI has made the largest 3D map of our universe to date. Earth is at the center of this thin slice of the full map. In the magnified section, it is easy to see the underlying structure of matter in our universe. Credit: Claire Lamman/DESI collaboration; custom colormap package by cmastro

- **DESI mapped galaxies and quasars with unprecedented detail, creating the largest 3D map of the universe ever made and measuring how fast the universe expanded over 11 billion years**
- **This is the first time that scientists have measured the expansion history of that distant period (8-11 billion years) with a precision of better than 1%, providing a powerful way to study dark energy**
- **With just its first year of data, DESI has surpassed all previous 3D spectroscopic maps combined and confirmed the basics of our best model of the universe – with some tantalizing areas to explore with more data**
- **Researchers from CIEMAT, ICCUB, ICE-CSIC, IFAE and IFT have actively contributed to these important results.**

Author: Lauren Biron

Barcelona/Madrid, April 4, 2024.- With 5,000 tiny robots in a mountaintop telescope, researchers can look 11 billion years into the past. The light from far-flung objects in space is just now reaching the Dark Energy Spectroscopic Instrument (DESI), a project managed by the Lawrence Berkeley National Laboratory (LBNL), enabling us to map our cosmos as it was in its youth and trace its growth to what we see today. Understanding how our universe has evolved is tied to how it ends, and to one of the biggest mysteries in physics: dark energy, the unknown ingredient causing our universe to expand faster and faster.

To study dark energy's effects over the past 11 billion years, DESI has created the largest 3D map of our cosmos ever constructed, with the most precise measurements to date. This is the first time scientists have measured the expansion history of the young universe with a precision better than 1%, giving us our best view yet of how the universe evolved. Researchers shared the analysis of their first year of collected data in multiple papers that will be posted today on the arXiv and in talks at the American Physical Society meeting in the United States and the Rencontres de Moriond in Italy. These are the first 4th generation results on dark energy.

[embed flythrough video]

"At the moment it looks like the first results from DESI are in agreement with the predictions of the current model", said Hui Kong, postdoctoral researcher at IFAE, Barcelona, and main author of one of the studies made public today. "There are some hints pointing at small temporal variations in the density of dark energy, but we will need more data to confirm them."

Our leading model of the universe is known as Lambda CDM. It includes both a weakly interacting type of matter (cold dark matter, or CDM) and dark energy (Lambda). Both matter and dark energy shape how the universe expands – but in opposing ways. Matter and dark matter slow the expansion down, while dark energy speeds it up. The amount of each influences how our universe evolves. This model does a good job of describing results from previous experiments and how the universe looks throughout time.

However, when DESI's first-year results are combined with data from other studies, there are some subtle differences with what Lambda CDM would predict. As DESI gathers more information during its five-year survey, these early results will become more precise, shedding light on whether the data are pointing to different explanations for the results we observe or the need to update our model. More data will also improve DESI's other early results, which weigh in on the Hubble constant (a measure of how fast the universe is expanding today) and the mass of particles called neutrinos.

[embed Hubble diagram and Hubble diagram explained]

"DESI, even with just the data from its first year, is already the spectroscopic survey with most collected data in the history and it goes on increasing this quantity with one million galaxies per month", said Eusebio Sánchez, a researcher at CIEMAT, Madrid. "This amazing data sample makes possible to measure the expansion history of the Universe with an unprecedented precision. We are sure that DESI will increase our knowledge about the Universe and perhaps will allow us to make revolutionary discoveries".

DESI's overall precision on the expansion history across all 11 billion years is 0.5%, and the most distant epoch, covering 8-11 billion years in the past, has a record-setting precision of 0.82%. That measurement of our young universe is incredibly difficult to make. Yet within one year, DESI has become twice as powerful at measuring the expansion history at these early times as its predecessor (the Sloan Digital Sky Survey's BOSS/eBOSS), which took more than a decade.

Traveling back in time

DESI is an international collaboration of more than 900 researchers from over 70 institutions around the world. The instrument was constructed and is operated with funding from the DOE Office of Science, and sits atop the U.S. National Science Foundation's Nicholas U. Mayall 4-meter Telescope at Kitt Peak National Observatory, a program of NSF's NOIRLab.

Looking at DESI's map, it's easy to see the underlying structure of the universe: strands of galaxies clustered together, separated by voids with fewer objects. Our very early universe, well beyond DESI's view, was quite different: a hot, dense soup of subatomic particles moving too fast to form stable matter like the atoms we know today. Among those particles were hydrogen and helium nuclei, collectively called baryons.

Tiny fluctuations in this early ionized plasma caused pressure waves, moving the baryons into a pattern of ripples that is similar to what you'd see if you tossed a handful of gravel into a pond. As the universe expanded and cooled, neutral atoms formed and the pressure waves stopped, freezing the ripples in three dimensions and increasing clustering of future galaxies in the dense areas. Billions of years later, we can still see this faint pattern of 3D ripples, or bubbles, in the characteristic separation of galaxies – a feature called Baryon Acoustic Oscillations (BAOs).

Researchers use the BAO measurements as a cosmic ruler. By measuring the apparent size of these bubbles, they can determine distances to the matter responsible for this extremely faint pattern on the sky. Mapping the BAO bubbles both near and far lets researchers slice the data into chunks, measuring how fast the universe was expanding at each time in its past and modeling how dark energy affects that expansion.

[embed BAO animation]

"DESI is already more precise than all previous BAO surveys over the whole cosmic history", said Violeta González Pérez, a researcher at the Theoretical Physics Department of the

Universidad Autónoma from Madrid. "Its data allow us to study cosmic mysteries that lie beyond our current understanding of the Universe".

Using galaxies to measure the expansion history and better understand dark energy is one technique, but it can only reach so far. At a certain point, light from typical galaxies is too faint, so researchers turn to quasars, extremely distant, bright galactic cores with black holes at their centers. Light from quasars is absorbed as it passes through intergalactic clouds of gas, enabling researchers to map the pockets of dense matter and use them the same way they use galaxies – a technique known as using the "Lyman-alpha forest."

"We use quasars as a backlight to basically see the shadow of the intervening gas between the quasars and us," said Andreu Font-Ribera, a scientist at the Institute for High Energy Physics (IFAE) in Spain who co-leads DESI's Lyman-alpha forest analysis. "It lets us look out further to when the universe was very young. It's a really hard measurement to do, and very cool to see it succeed."

[embed Lyman alpha rendering]

Researchers used 450,000 quasars, the largest set ever collected for these Lyman-alpha forest measurements, to extend their BAO measurements all the way out to 11 billion years in the past. By the end of the survey, DESI plans to map 3 million quasars and 37 million galaxies.

State-of-the-art science

DESI is the first spectroscopic experiment to perform a fully "blinded analysis," which conceals the true result from the scientists to avoid any subconscious confirmation bias. Researchers work in the dark with modified data, writing the code to analyze their findings. Once everything is finalized, they apply their analysis to the original data to reveal the actual answer.

"The fact that the analysis was carried out using data-blinding techniques provides us with an extra level of confidence in the results obtained," says Héctor Gil Marín, researcher at the Institute of Cosmos Sciences of the University of Barcelona (ICCUB) and the Institut d'Estudis Espacials de Catalunya (IEEC). Blind analyses are already standard practice in fields such as experimental particle physics or clinical studies. Gil-Marín and other researchers at ICCUB have developed and implemented what turned out to be a very robust and difficult-to-decipher way to conceal the results of galaxy clustering in DESI until the analysis is completed. "We are confident that the extra effort involved in this will enhance the confidence and integrity of the DESI results," says Gil-Marín.

DESI's data will be used to complement future sky surveys such as the Vera C. Rubin Observatory and Nancy Grace Roman Space Telescope, and to prepare for a potential upgrade to DESI (DESI-II) that was recommended in a recent report by the U.S. Particle Physics Project Prioritization Panel.

"It is exciting to see how the DESI results provide a precise view of how the Universe is" mentioned Francisco Javier Castander, a researcher of the Instituto de Ciencias del Espacio

(ICE-CSIC) and the Institut d'Estudis Espacials de Catalunya (IEEC). "Moreover, this is only the beginning, with the new data we are gathering our measurements will be even more precise".

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; the Science and Technology Facilities Council of the United Kingdom; the Gordon and Betty Moore Foundation; the Heising-Simons Foundation; the French Alternative Energies and Atomic Energy Commission (CEA); the National Council of Humanities, Sciences, and Technologies of Mexico; the Ministry of Science and Innovation of Spain; and by the DESI member institutions.

The DESI collaboration is honored to be permitted to conduct scientific research on Iolkam Du'ag (Kitt Peak), a mountain with particular significance to the Tohono O'odham Nation.

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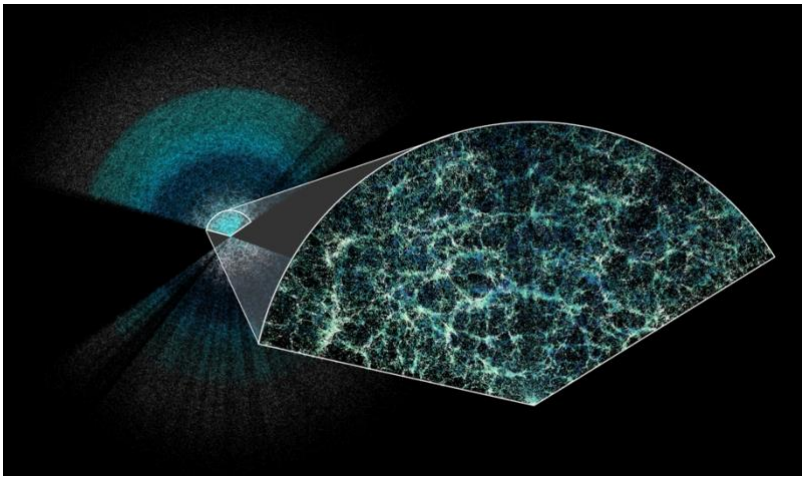
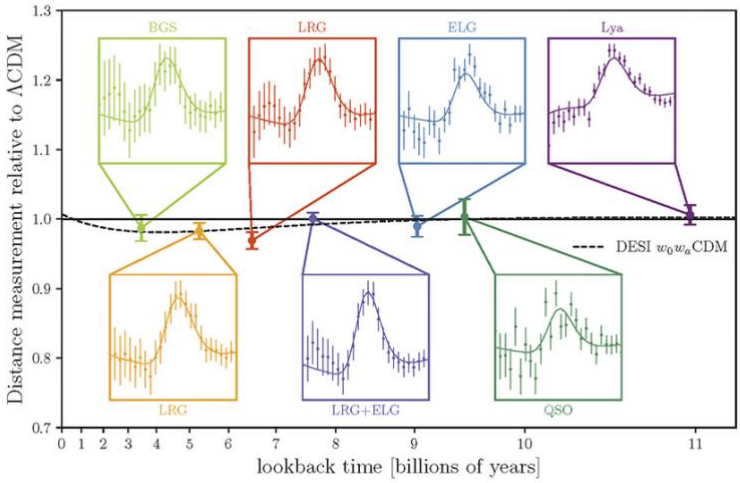
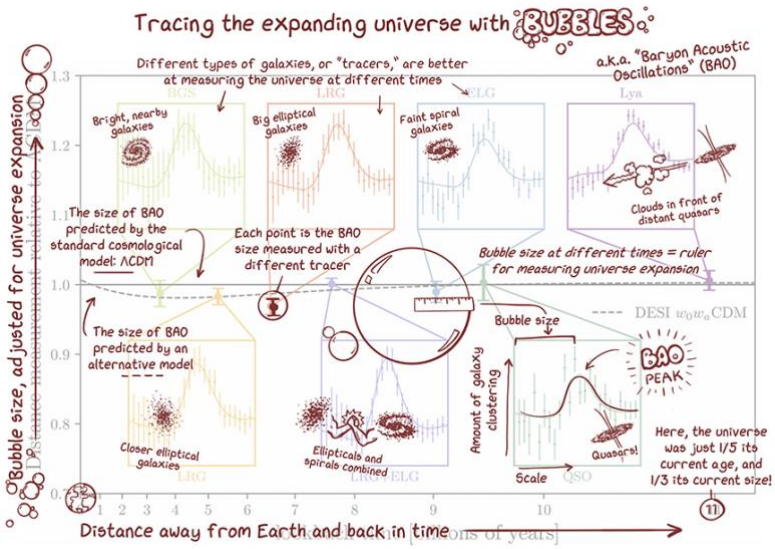
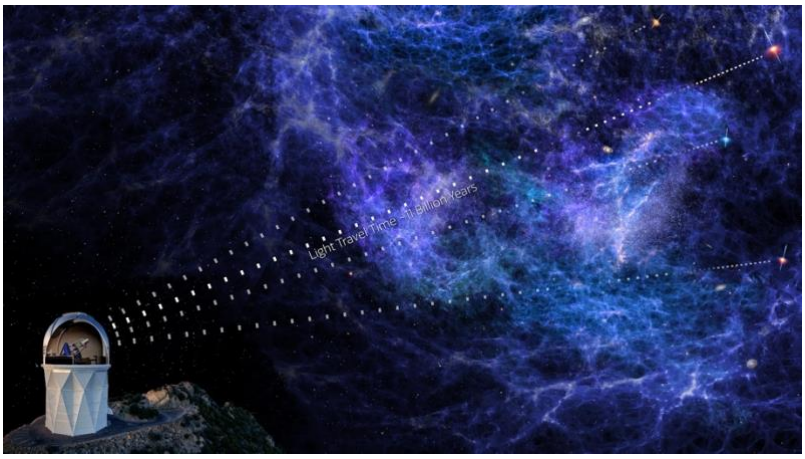
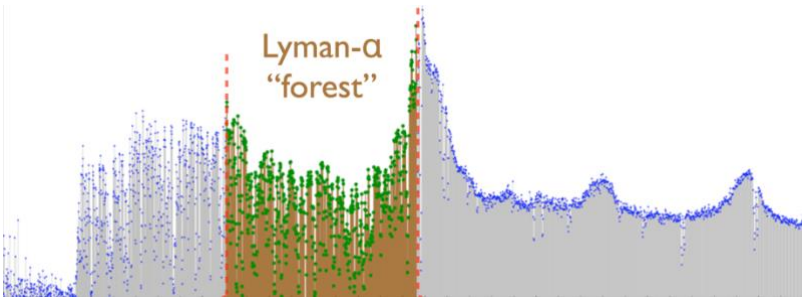
Participant institutions in DESI include the Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT), the Instituto de Ciencias del Espacio (ICE-CSIC), the Institut de Ciències del Cosmos de la Universitat de Barcelona (ICCUB), the Institut de Física d'Altes Energies (IFAE), the Instituto de Física Teórica (IFT - UAM/CSIC), the Instituto de Astrofísica de Andalucía (IAA) and the Instituto de Astrofísica de Canarias (IAC).

A complete list of participant institutions and more information about DESI is available in: https://www.desi.lbl.gov.

Images

 Feature Image (various sizes in folder)	Caption: DESI has made the largest 3D ma the center of this thin slice of the full map. see the underlying structure of matter in ou Credit: Claire Lamman/DESI collaboration; cmastro

DESI-Slice_Original Size_4288x3000px_300DPI.png (Largest version ^)	
BAO-Animation_1080x1920px_Sound.mp4	Video for embed: https://www.youtube.com/watch?v=hoOyO Caption: This animation shows how baryon cosmic ruler for measuring the expansion o Credit: Claire Lamman/DESI collaboration
DESI Robot Animated Fly Though Videos (Recommend version without text)	(B-roll - no youtube video available) Caption: This animation shows a 3D model movement of the 5,000 robotic positioners i bump into one another. Credit: David Kirkby/DESI collaboration
DESI VR Flight Stereoscopic Video (This folder contains shorted videos for social media – horizontal and vertical– with bumpers for credit)	Video for embed: https://youtu.be/jRYUt9n Caption: In this 360-degree video, take an i galaxies mapped using coordinate data from Credit: Fiske Planetarium, CU Boulder and
 	Caption: DESI's Hubble diagram plots a ch acoustic oscillations, or BAO "bubbles" – a amount of dark energy determines how fast the size of the bubbles. The solid line is hov bubbles will be, while the dashed line show model where dark energy evolves with time determine which model is a better descriptio Credit: Arnaud de Mattia/DESI collaboratio *Suggest pairing this with the the Hubble dia* *the expanding universe with bubbles":* Caption: A simplified explanation of the dif diagram. Credit: Claire Lamman/DESI collaboration

 Hubble Diagram and Annotation (Largest versions are available in the folder along with some sized down versions for LBNL)	
 Full Size_Lyman-alpha Forest_8000x4500px.tif 1MB_Lyman-alpha Forest_2000x1125px.jpg 500KB_Lyman-alpha Forest_2000x1125px.jpg	Caption: This artist's rendering shows light intergalactic clouds of hydrogen gas. Resea about distant cosmic structure. Credit: NOIRLab/NSF/AURA/P. Marenfel *Suggest pairing this image with the Lyman-*
 Lyman-A Forest_Graph_2310×844px.png	Caption: As light from a distant quasar pass wavelengths of light are absorbed. Plotting "Lyman-alpha forest" (emphasized here in information about the distant clouds of gas Credit: David Kirkby/DESI collaboration

IFT

The Institute for Theoretical Physics (IFT) UAM-CSIC was officially created in 2003 as a joint research center belonging to the Spanish National Research Council (CSIC) and the Autonomous University of Madrid (UAM). It is the only Spanish center dedicated entirely to research in Theoretical Physics. The IFT members develop research in the frontiers of Elementary Particle Physics, Astroparticles and Cosmology, in order to understand the fundamental keys of Nature and the Universe. They are also leading many research projects, both at the national and international level. The IFT is part of the strategic line `Theoretical Physics and Mathematics´ of the Campus of International Excellence (CEI) UAM+CSIC established in 2009. Since 2012, it is credited as Severo Ochoa Centre of Excellence. Besides purely scientific activity, in the IFT is also conducted intensive training tasks of young researchers and professionals through the graduate program in Theoretical Physics with mention of excellence from the CEI and the Ministry of Education. In addition, the Institute carries out the important task of transferring knowledge to society through several outreach programs.

For more information and interviews, please contact:

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