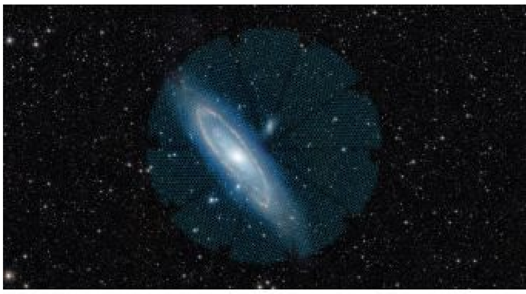
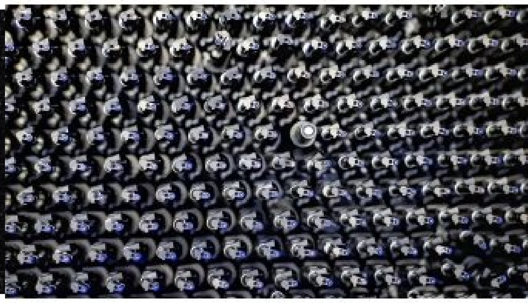
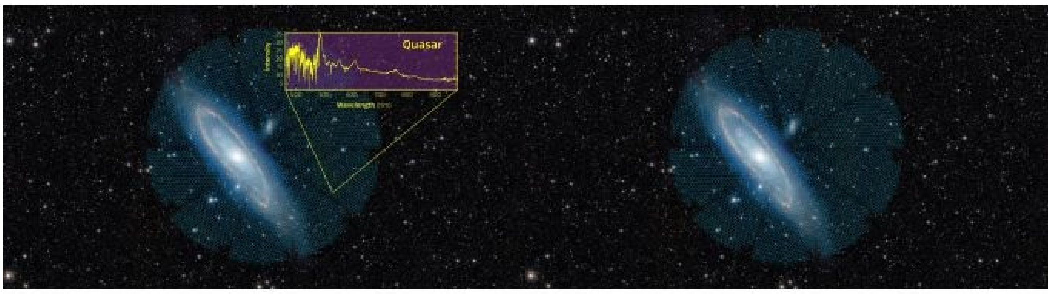
Creating a 3D Map of the Universe

A quest to map the universe and unravel the mysteries of dark energy has begun officially on 17 May 2021, at Kitt Peak National Observatory, a programme of NSF's NOIRLab. Over the next five years, the Dark Energy Spectroscopic Instrument (DESI) will capture the light from tens of millions of galaxies and other cosmic objects. During its four-month trial run, which just concluded, the project already collected millions of observations.

By gathering light from some 30 million galaxies, project scientists say that DESI will help them construct a 3D map of the universe in unprecedented detail. DESI will do this by collecting spectra, which spread out the light from celestial objects into the colours of the rainbow, revealing information such as the chemical composition of the objects being observed and their relative distances and velocities. This data will help astronomers better understand the repulsive force associated with dark energy, which drives the acceleration of the universe's expansion across vast cosmic distances.

DESI is an international science collaboration managed by the US Department of Energy's Lawrence Berkeley National Laboratory (Berkeley Lab) with primary funding from the Department's Office of Science. DESI resides at the retrofitted Nicholas U. Mayall 4-meter Telescope at Kitt Peak National Observatory, a programme of NSF's NOIRLab.

Most detailed cartographic map of the universe

Jim Siegrist, associate director for high energy physics at DOE, said: "We are excited to see the start of DESI, the first next-generation dark energy project to begin its science survey. We also congratulate Berkeley Lab, which continues to enhance our capabilities for studying the nature of dark energy, since leading the initial discovery in 1999. DOE's Berkeley Lab successfully led the 13-nation DESI team, including US government, private and international contributions, in the design, fabrication and commissioning of the world's premier multi-object spectrograph. The strong interagency collaboration with NSF has enabled DOE to install and operate DESI on their Mayall telescope, which is required to carry out this amazing experiment. Along with its primary mission of dark energy studies, the dataset will be of use by the wider scientific community for a multitude of astrophysics studies."

This photo shows a small section of the DESI focal plane and some of the instrumentâ€™s one-of-a-kind robotic positioners. DESI includes 5000 robotically controlled optical fibers to gather spectroscopic data from an equal number of objects in the telescopeâ€™s field of view. The optical fibers, which are installed in the robotic positioners, are backlit with blue light in this image. (Credit: DESI collaboration)

"The combination of the Mayall telescope and DESI instrument is now the best astronomical survey machine on the planet," said Arjun Dey, the DESI project scientist for NOIRLab and the DESI Observing Operations lead. "Its initial five-year mission, hopefully the first of many, will produce the most detailed cartographic map of our accelerating, expanding universe ever created. I can't wait to see what it will discover!"

"The DESI experiment is an excellent example of the amazing science that can be achieved when government agencies collaborate to make the most of national observatory facilities like the Mayall telescope," says Chris Davis, NSF programme director for NOIRLab.

What sets DESI apart from previous sky surveys? "We will measure ten times more galaxy spectra than ever obtained," said the project director, Berkeley Lab's Michael Levi. "These spectra get us a third dimension." Instead of two-dimensional images of galaxies, quasars, and other distant objects, he explained, the instrument collects light, or spectra, from the cosmos such that it "becomes a time machine where we place those objects on a timeline that reaches as far back as 11 billion years ago".

Dark energy and gravity

“DESI is the most ambitious of a new generation of instruments aimed at better understanding the cosmos, in particular its dark energy component,” said project co-spokesperson Nathalie Palanque-Delabrouille, a cosmologist at France’s Alternative Energies and Atomic Energy Commission (CEA). She said the scientific program — including her own interest in quasars — will allow researchers to address with precision two primary questions: what is dark energy, and to what degree does gravity follow the laws of general relativity, which form the basis of our understanding of the cosmos.

“It's been a long journey from the first steps that we took almost a decade ago to design the survey, then to decide which targets to observe, and now to have the instruments so that we can achieve those science goals,” Palanque-Delabrouille said. “It's very exciting to see where we stand today.”

The formal start of DESI’s five-year survey follows a four-month trial run of its custom instrumentation that captured four million spectra – more than the combined output of all previous spectroscopic surveys.

“It is extremely gratifying to see this incredible and innovative instrument perform so well at this critical point in the project,” said Parker Fagrelius, DESI operations supervisor at NOIRLab. “I am very excited to see what the DESI Survey can uncover about dark energy, but also what new and interesting phenomena we will discover along the way that we didn’t even know to look for!”

The disk of the Andromeda Galaxy (M31), which spans more than 3 degrees across the sky, is targeted by a single DESI pointing, represented by the large circular overlay. The smaller circles within this overlay represent the regions accessible to each of the 5000 DESI robotic fiber positioners. In this sample, the 5000 spectra that were simultaneously collected by DESI include not only stars within the Andromeda Galaxy, but also distant galaxies and quasars. The example DESI spectrum that overlays this image is of a distant quasar that is 11 billion years old. (Credit: DESI collaboration/DESI Legacy Imaging Surveys/LBNL/DOE & KPNO/CTIO/NOIRLab/NSF/AURA/unWISE)

150,000 objects per night

The instrument includes new optics that increase the field of view of the telescope and also includes 5000 robotically controlled optical fibres to gather spectroscopic data from an equal number of objects in the telescope’s field of view.

“We’re not using the biggest telescopes,” said David Schlegel, who is the DESI project scientist. “It’s that the instruments are better and very highly multiplexed, meaning that we can capture the light from many different objects at once.”

In fact, the telescope “is literally pointing at 5,000 different galaxies simultaneously,” Schlegel said. On any given night, he explained, as the telescope is moved into a target position, the optical fibres align to collect light from galaxies as it is reflected off the telescope mirror. From there, the light is fed into a bank of spectrographs and CCD cameras for further processing and study.

“It’s really a factory that we have – a spectra factory,” said survey validation lead, Christophe Yeche, who is also a cosmologist at CEA. “We can collect 5000 spectra every 20 minutes. In a good night, we collect spectra from some 150,000 objects.”

“But it’s not just the instrument hardware that got us to this point – it’s also the instrument software, DESI’s central nervous system,” said Klaus Honscheid, a professor of physics at Ohio State University who directed the design of the DESI instrument control and monitoring systems. He credits scores of people in his group and around the world who have built and tested thousands of DESI’s component parts, most of which are unique to the instrument.

Distribution of galaxies

As the universe expands, galaxies move away from each other, and their light is shifted to longer, redder wavelengths. The more distant the galaxy, the greater its redshift. By measuring galaxy redshifts, DESI researchers will create a 3D map of the universe. The detailed distribution of galaxies in the map is expected to yield new insights into the influence and nature of dark energy.

“Dark energy is one of the key science drivers for DESI,” said project co-spokesperson Kyle Dawson, a professor of physics and astronomy at the University of Utah. “The goal is not so much to find out how much there is — we know that about 70% of the energy in the universe today is dark energy — but to study its properties.”

The universe is expanding at a rate determined by its total energy content, Dawson explained. As the DESI instrument looks out in space and time, “we can literally take snapshots today, yesterday, 1 billion years ago, 2 billion years ago – as far back in time as possible,” he said. “We can then figure out the energy content in these snapshots and see how it is evolving.”

Source: NOIRLab, the preeminent US national centre for ground-based, nighttime optical and infrared astronomy.

The disk of the Andromeda Galaxy (Messier 31), which spans more than 3 degrees across the sky, is targeted by a single DESI pointing, represented by the large circular overlay. The smaller circles within this overlay represent the regions accessible to each of the 5000 DESI robotic fiber positioners. In this sample, the 5000 spectra that were simultaneously collected by DESI include not only stars within the Andromeda Galaxy, but also distant galaxies and quasars. (Credit: DESI collaboration/DESI Legacy Imaging Surveys/LBNL/DOE & KPNO/CTIO/NOIRLab/NSF/AURA/unWISE)