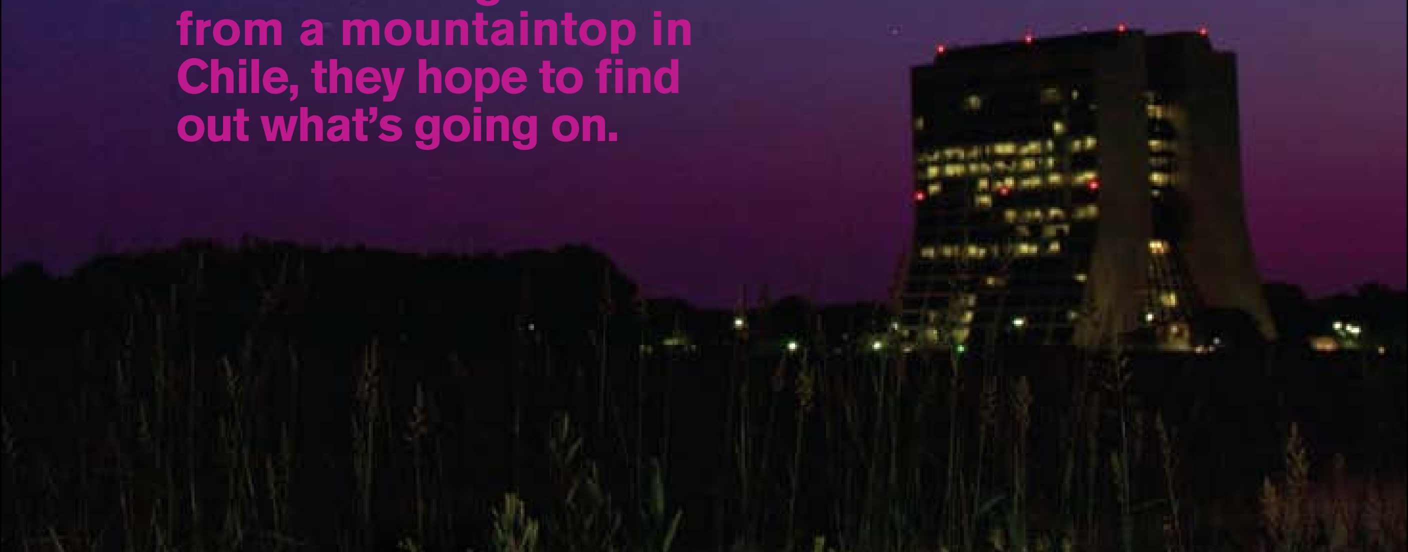
The Fermilab team that will use the Dark Energy Camera to peer deep into the dark includes, from left, physicists John Peoples, Brenna Flaugher, Juan Estrada, and Tom Diehl.

Photography by Reidar Hahn

Dark Energy Camera scans ancient skies

Gazing into space, scientists wonder why the universe is expanding ever faster. What mysterious force is at work? By recording the light from hundreds of millions of galaxies from a mountaintop in Chile, they hope to find out what's going on.



By Kristine Crane

Imagine a camera that takes pictures of the universe not only as we see it today but back through time, closer to when the universe began, capturing images of roughly 300 million galaxies.

At Fermilab in Batavia, Illinois, Brenna Flaugher and her colleagues are building such a device. Called the Dark Energy Camera, it will survey the skies of the Southern Hemisphere and peer far back in time, allowing scientists to see galaxies as they were when the universe was only a few billion years old.

The goal is to search for signs of dark energy—the ubiquitous, invisible substance believed to make up 70 percent of the universe.

For Flaugher, who spent 15 years studying subatomic physics, the prospects were so intriguing that she changed the focus of her career.

"I have gone from studying the smallest known things in the universe—quarks—to galaxy clusters, the biggest things we know," she says. "The thing that makes both fun is that you get to think about the origins of the universe."

A mysterious force

Eighty years ago, Edwin Hubble discovered that our universe is expanding, with galaxies becoming increasingly distant from each other. Scientists reasoned that the gravitational attraction among galaxies must slow this expansion. But then in 1998, two independent teams of scientists discovered a perplexing change in the expansion rate of the universe: for the first eight billion years after the big bang, gravity indeed had slowed the expansion, as predicted. Then, roughly five billion years ago, the expansion began to speed up.

What caused this acceleration?

The preliminary answer is dark energy, a mysterious "antigravity force." When the universe was young, gravity was the dominant force. But over time, matter spread out enough to significantly diminish the gravitational attraction between galaxies. Dark energy, a repulsive force, began to overpower the gravitational force and push the galaxies ever faster apart.

Confirming the existence of dark energy and understanding its origin would have profound implications for our understanding of the universe. But an even more radical outcome would emerge if scientists discovered that dark energy does not exist. Instead, some theoretical models suggest that an extra spatial dimension causes the universe to expand ever more rapidly, unraveling Einstein's general theory of relativity. The Dark Energy Survey, scheduled to be up and running in 2011, might reveal which explanation is correct.

"It's throwing the tools of the digital age onto the old question of where we are," says Craig Hogan, the director of the Center for Particle Astrophysics at Fermilab.

A fateful conversation

In the summer of 2003, former Fermilab director John Peoples and University of Chicago physicist John Carlstrom shared a cab on their way back from an astrophysics conference in Seattle. The subject of dark energy was already on Peoples' mind, and Carlstrom was working on the South Pole Telescope, whose construction would soon begin in Antarctica. Since 2007, the telescope has recorded the microwave background radiation left over from the big bang, looking for distortions that mark giant clusters of galaxies. But the telescope is unable to determine how far away, and hence how old, galactic clusters are—information crucial for connecting its observations to dark energy calculations.

What they needed, the two physicists agreed, was a project that would fill the gap by determining how far these clusters are from Earth.

"The prospect was exciting," Peoples recalls. At the time, he had just finished directing the Sloan Digital Sky Survey. The project, which makes observations from a telescope in New Mexico, has provided three-dimensional maps of nearly one million galaxies and 120,000 quasars in the Northern Hemisphere. Combined with data recorded at other observatories, the measurements indicate that 96 percent of the universe is composed of dark matter and dark energy.

Is gravity the problem?

Mounted on a telescope in Chile, the Dark Energy Camera will peer deeper into the sky and unveil more galaxies at greater distances than any previous project, including the Sloan Digital Sky Survey. It will collect data on the distances of supernovae from Earth; the large-scale clustering of galaxies; the abundance of massive galaxy clusters; and the bending of light caused by galaxies and clusters of galaxies.

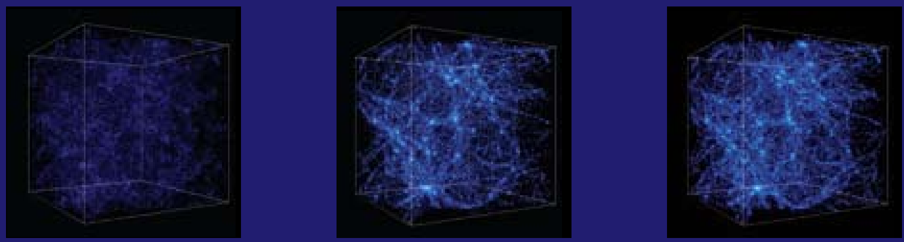
Scientists will use these four methods to determine how fast the universe has been expanding and the rate at which galaxies and clusters formed over cosmic time. Two of those methods will yield answers that are independent of the role that gravity played in the evolution of the universe. The other two will provide answers that depend on the theory of gravity.

"If all four measures show the same result, it means that our current ideas about dark energy are correct; if they differ, there is either a problem in our understanding of gravity or some other explanation," says Flaugher, who is spearheading the camera's construction. The $50-million Dark Energy Survey involves 120 scientists from 13 institutions in the United States, Brazil, Spain, and the United Kingdom. University College London is responsible for polishing the five lenses that make up the optical system of the camera.

The Expansion of the Universe

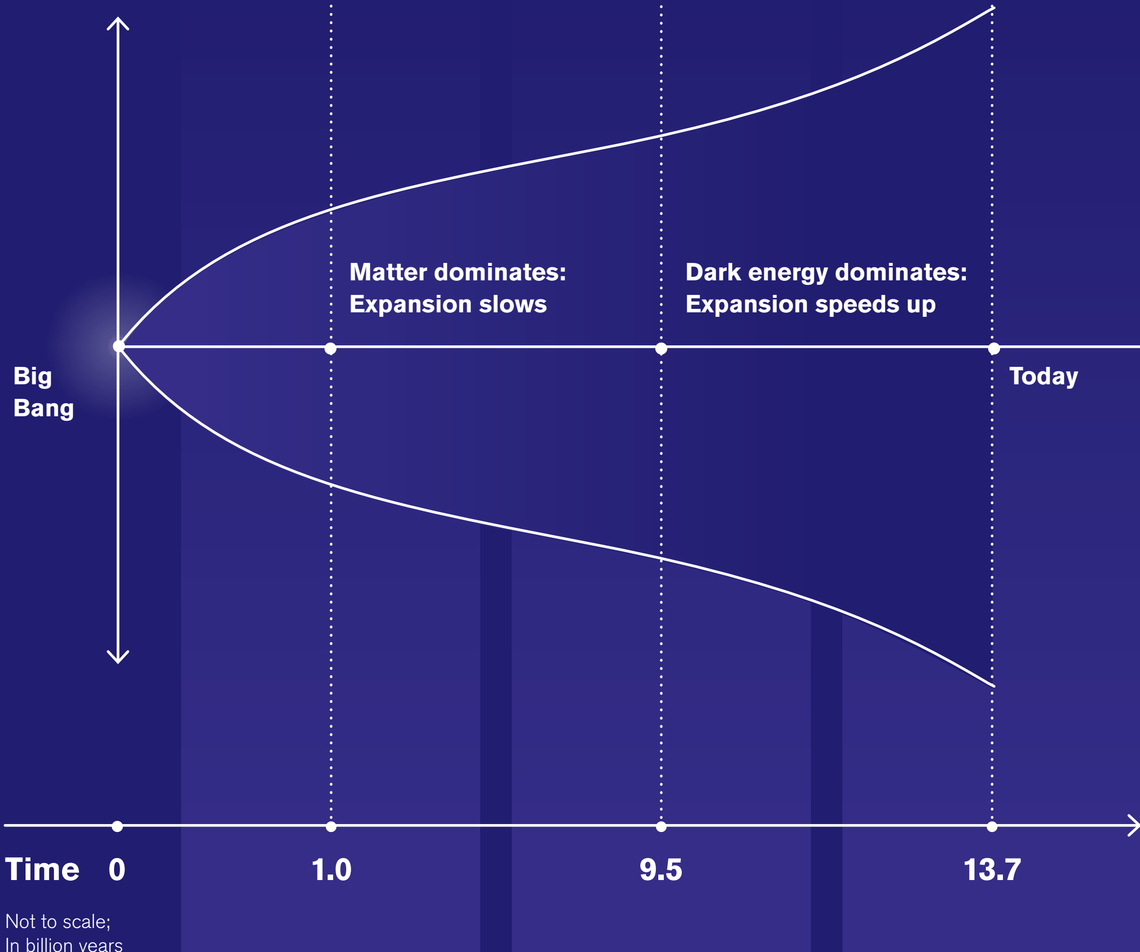
Galaxy Formation

Over billions of years, gravity draws matter together into a web of structure. The bright spots are where galaxies form.

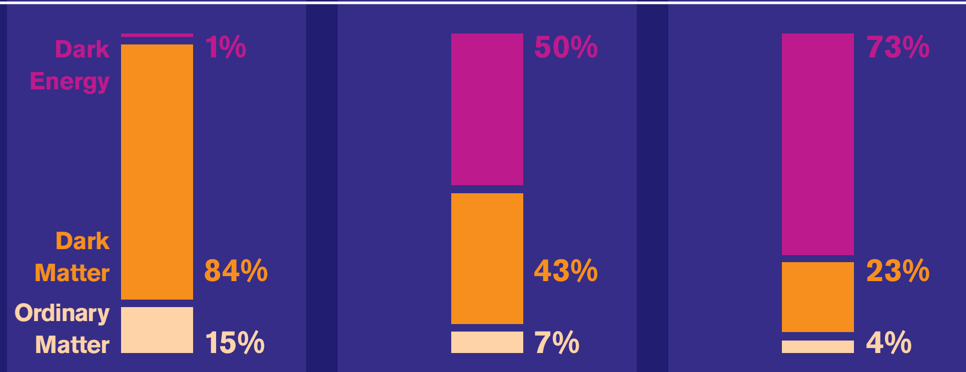


Size of the Universe

Not to scale



Energy and Matter Content



Simulations and visualization of galaxy formations by Andrey Kravtsov, The University of Chicago, and Anatoly Klypin, New Mexico State University

The Spanish groups provide the electronics that will process faint signals of light that traveled billions of years across the universe before landing in the "eyes" of the Dark Energy Camera.

Traveling back in time

At the forefront of Fermilab's construction team is physicist Juan Estrada, who joined the project as a Fermilab Wilson Fellow in 2004. Estrada was a postdoctoral researcher studying the top quark at Fermilab's DZero experiment when he became attracted by the prospect of working on the Dark Energy Camera.

As an undergraduate in Argentina, Estrada had studied the properties of the vacuum, and he was eager to re-visit an issue that he considers the biggest problem in physics: the mysterious energy that seems to come from empty space in our universe.

To do that, he first had to learn astronomy. "Fermilab gave me the opportunity to learn something I had never done before," Estrada says.

He learned how an astronomical camera works from a retired Fermilab engineer, Tom Droege, who practices astronomy from his home observatory. By taking apart and reassembling Droege's camera, Estrada learned the basic steps of building a camera, valuable lessons for the construction of the Dark Energy Camera.

When complete, the Dark Energy Camera will be the size of a Smart car. What makes it so powerful are 74 delicate detectors, called charge-coupled devices or CCDs, each three by six centimeters in size and 0.250 millimeters thick. As in an ordinary digital camera, they are the camera's "film" that records incoming light. The CCDs will sit on a plate about half a meter in diameter, located a few centimeters behind the camera's set of lenses.

Cooled to minus 100 degrees Celsius to reduce background noise, the Dark Energy Camera's superb CCDs will record longer wavelengths of light than other optical cameras do. This will allow it to see light from fast-receding galaxies that has shifted to longer wavelengths, toward the red end of the spectrum, in the same way a siren drops in tone as it moves away. The fastest-moving galaxies are also the farthest away, as Hubble discovered. What's more, the light we see from the farthest galaxies is the oldest because it has taken longer to reach us. And so through this chain of inferences from reddest to fastest to farthest to oldest, the Dark Energy Camera will be able to see distant galaxies as they looked billions of years ago, closer to the universe's infancy.

"We are mapping the distribution of the galaxies from what the local universe looks like now to a time when the universe was just a few billion years old," says Dark Energy Survey collaborator Joe Mohr, physics and astronomy professor at the University of Illinois, Urbana-Champaign.

Reviving an old scope

Crafting the CCDs requires a unique process developed by engineers at Lawrence Berkeley National Laboratory. The final steps of the manufacturing process take place in a clean room inside a dome-shaped building at Fermilab. The lab's technicians were already familiar with the assembly of silicon detectors used in particle physics experiments; now they produce an average of four CCDs per week for the camera.

Once all the CCDs are ready—a milestone the team expects to reach next year—technicians will finish assembling the camera and ship it to the Cerro Tololo Inter-American Observatory in Chile, where it will be placed atop a four-meter telescope called the Blanco.

The Dark Energy Camera will give new life to the 40-year-old telescope, which met the survey's criteria beautifully, according to Peoples: "It was a marriage made in heaven."

From Chile to Illinois

The Dark Energy Survey collaboration will use the telescope for five years between September and February, taking images on 105 nights each year and sending a few hundred images per night to the University of Illinois, Urbana-Champaign. Each image comprises 520 million pixels, equivalent to about 1 gigabyte of data, with information on the redshifts and brightness of about 200,000 galaxies and other celestial objects too faint to be seen by a simple household camera.

A supercomputer, which Mohr calls the "mother ship," will store all these images and automatically detect the objects they contain, producing a catalog of galaxies with their brightnesses, positions on the sky, and other properties. The science team will analyze and interpret this information, searching for clues that might help explain cosmic acceleration.

So what will scientists find out?

"None of us is a prophet," says Ofer Lahav, chair of astrophysics at the University College London, who co-chairs the scientific committee of the Dark Energy Survey collaboration with Fermilab's Josh Frieman. Lahav says the findings will lead to a more complex view of dark energy, or perhaps a modified version of gravity.

Especially if it's the latter, revisiting Einstein's theory of relativity would be "a big shake-up to the foundations of physics," says Lahav. "Either way it's exciting."

While future surveys aim to probe even deeper into the sky for answers about dark energy, the Dark Energy Survey will be the first to take a stab at solving the mystery, says Lahav.

In a Fermilab clean room, Ken Schultz and Kevin Kuk check the alignment of the prototype camera's front window.

"It is among the surveys that will push the subjects of dark energy and modified gravity to a new level," he says.

But that is not all.

The big payoff

The Dark Energy Survey collaboration expects that its data on stars, quasars, and galaxies will lead to hundreds if not thousands of scientific publications. The collaboration will make its data public a year after it has been taken, an approach also used for the data collected by the Sloan Digital Sky Survey and the Hubble Space Telescope.

The Sloan survey, which mapped a quarter of the sky, has generated more than 2400 scientific publications so far. Its results have been cited more often than those from any other observatory, including the Hubble.

The Dark Energy Survey collaboration hopes to be equally successful. Its survey of the southern sky will cover an area smaller than the Sloan survey of the northern sky, but it will go deeper, further back in time.

"It's a small project for a really big scientific payoff," says Flaugher. Most importantly, it might answer what she and her colleagues consider "the biggest question out there."

Although Flaugher won't wager a guess on whether the findings will confirm or deny the existence of dark energy, she is certain about one thing.

"I don't want to argue about it anymore," Flaugher says. "We need data, data, and more data."

In a few years, she'll have it.