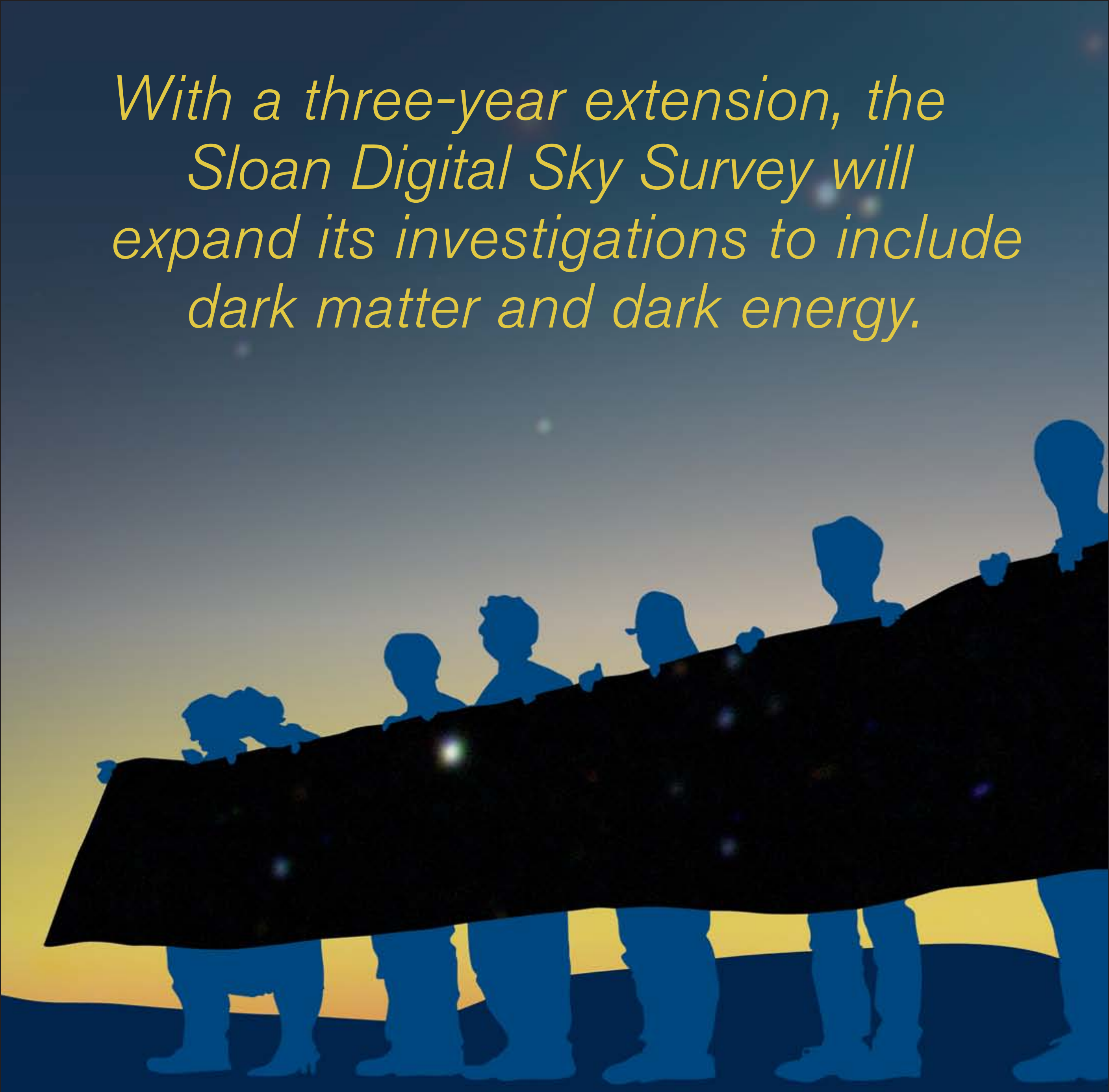


With a three-year extension, the Sloan Digital Sky Survey will expand its investigations to include dark matter and dark energy.

More of the UNIVERSE

by Kelen Tuttle

Members of the Sloan Digital Sky Survey unfurled a 20-foot image of the sky from the experiment's first light in 1998.

Illustrations: Sandbox Studio

The control room of Apache Point Observatory, on a peak above the high chaparral of New Mexico's Lincoln National Forest, contains not only the usual racks of computers, rolling office chairs, and brimming coffee cups, but also an entire wall of TV monitors. After darkness sets in each night, these monitors continually display the telescope's view of the heavens. Intricate images of distant stars and galaxies scroll across the screens with such speed that every 54 seconds a completely new swath of sky illuminates the room.

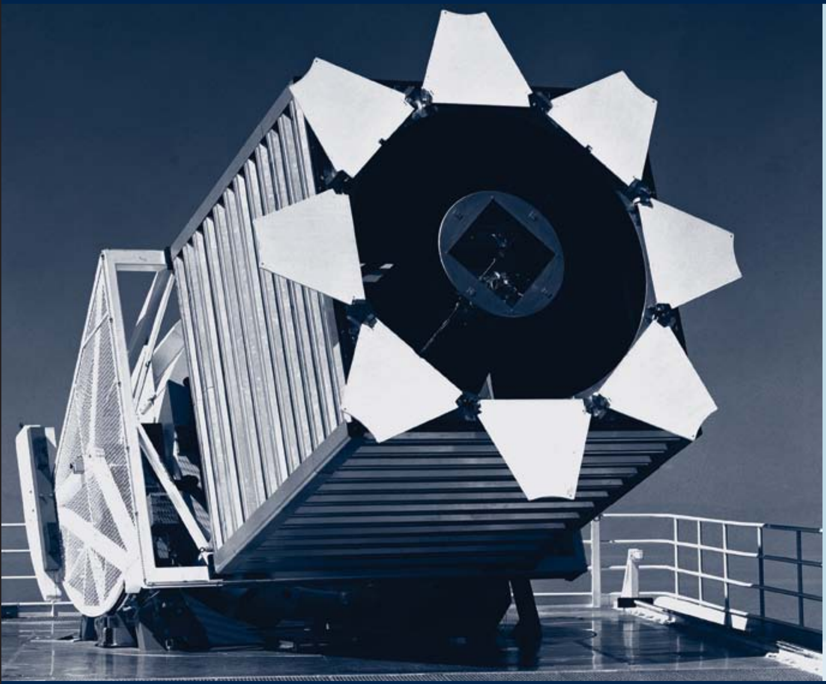
The Sloan Digital Sky Survey is the largest astrophysical study ever undertaken. Over the past five years, SDSS has mapped 25 percent of all that is visible to earth-bound observers, and identified more than 100 million stars, galaxies, and quasars. Now, with additional funding from the National Science Foundation, the Alfred P. Sloan Foundation, and 23 participating institutions, the survey will continue through mid-2008, extending its horizons to study the expansion of the universe and the formation of galaxies.

"This will allow us to continue exploring the most fundamental nature of our universe," says Richard Kron of Fermilab and the University of Chicago, director of the Sloan Digital Sky Survey. "What does it look like? What is it made of? How is it structured and how does it change with time?"

The extension, which officially began on July 1, 2005, seeks to expand knowledge about the universe on three fronts. The first, known as Legacy, will continue mapping the skies to create a contiguous chart of the universe beyond our galaxy. The second will observe supernovae to measure the amount of dark energy in the universe. The third will painstakingly gauge the movement of stars in the Milky Way to determine how much dark matter the galaxy contains and how it is distributed.

These three missions, combined with the unprecedented field of view and sharp images of Apache Point Observatory's 2.5-meter telescope, make the Sloan Digital Sky Survey revolutionary to astrophysics. While other telescopes also take high-resolution digital images of the universe, the Sloan survey is the first to do so on such a grand scale. The Survey's smooth, complete picture of the heavens offers researchers the data they need to create a more complete description of the universe's dynamics and intricacies.

"As a result of the Sloan Digital Sky Survey, astrophysics research is acquiring the style of high-energy physics experiments," says Steven Kahn, deputy director of the Kavli Institute for Particle Astrophysics and Cosmology at SLAC, a contributor to the SDSS extension. "We're recruiting teams of particle physicists to analyze massive amounts of data that will answer some of the most perplexing questions about the structure, composition, and expansion of the universe."



The SDSS 2.5-meter telescope has a remarkably wide-angle view, and was made specifically to create a map of the sky. The telescope's camera uses electronic sensors that turn light into a stream of digitized data. The telescope also uses two spectrographs, instruments that probe the composition and distance of celestial objects.

Photo: Fred Ullrich, Fermilab

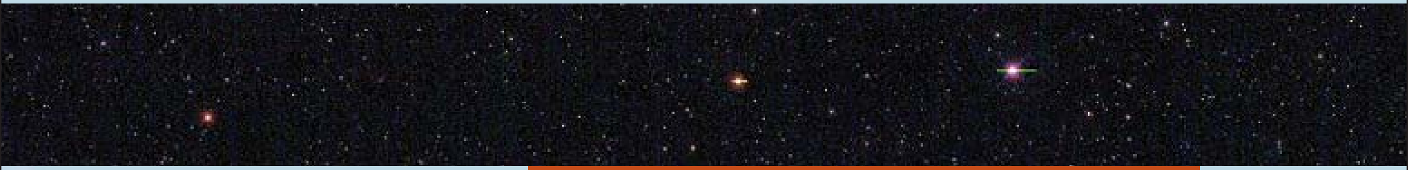


Image: Stephen Kent/SDSS Collaboration

Legacy: mapping the universe

The Survey's first run mapped 7000 square degrees of the sky, the equivalent of almost 30,000 full moons placed edge-to-edge in a grid across the sky. The first run mapped this huge area in optical light; the second run will complete a three-dimensional map of the universe with a follow-up spectroscopic survey.

As a prism splits light into its discrete colors, spectroscopy splits the light of distant objects into discrete wavelengths. Because of the accelerating expansion of the universe, more distant objects recede more quickly. As a result, these wavelengths shift toward the red end of the optical spectrum as the distant object travels away from earth. By observing the extent to which the wavelengths are skewed, or redshifted, researchers can determine how quickly the object recedes. In this manner, Legacy will reveal the distances of the 100 million stars, galaxies, and quasars it has already mapped in optical light.

"Every last square degree of that quarter of the sky will be recorded in both optical and spectroscopic surveys, helping us to better understand the three-dimensional shapes of structures in the universe," says Stephen Kent, head of survey operations at Sloan and head of Fermilab's Experimental Astrophysics Group. "This will offer insight into what our world and our universe are made of."

In addition to Legacy's map of the universe, the SDSS extension will also begin two completely new projects seeking to illuminate the mysterious presence of dark matter and dark energy. These phenomena, which only entered the consciousness of mainstream theory in the 1980s and 1990s, are necessary to describe today's more detailed observations of the universe. Yet dark matter and dark energy do not seem to be composed of any type of matter or energy previously known.

"This reflects a profound lack of understanding of the fundamental laws of physics," says Kahn. "At various times in the history of science, people thought they were closing in on a complete picture of the universe, only to have their hopes dashed when small unexplained issues exploded into the dominant theories of the next century." While the case for dark matter and dark energy is strong, researchers need to make sure their understanding of the properties of these phenomena are well-founded before they completely revise current theory to take them into account.

Supernovae: the search for dark energy

A decade ago, researchers believed that the universe expanded outward solely as a result of the force of the big bang; thus, the speed of expansion should decrease with each passing moment. Yet observations of supernovae indicate the opposite: the expansion of the universe appears to be accelerating.

The main evidence for the acceleration of the expansion of the universe comes from type 1A supernovae: stars that have become too massive for their own good, causing them to implode and then burst in dazzling supernovae explosions. By measuring the apparent brightness of these explosions and the redshift of that light, researchers can infer both the distance to a supernova and how quickly it recedes from earth. By calculating how the motions of distant (and thus old) supernovae compare to close (and thus more recent) supernovae, researchers determine how the expansion of the universe has changed over time.

In the late 1990s, this type of evidence showed that the universe's expansion is actually accelerating. It was as if researchers had thrown a ball up into the air, and instead of falling back down, it continued upward, gaining speed as it went. These calculations suggested that something mysterious and unexplained by modern theory pushes the universe apart. Dubbed dark energy, this inexplicable force is of intense interest to astrophysicists not only because it appears to be the dominant form of energy, accounting for 70 percent of everything in the universe, but also because it is so unexpected.

"There is really something new about this," says Kahn. "It's very interesting to both astrophysicists and particle physicists because it shifts our whole understanding of what the universe is made of."

Unlike previous supernovae observations, the Sloan extension will track large numbers of distant supernovae in a large swath of sky. Previous searches have focused on either relatively close supernovae across many degrees of the sky, or have tracked distant supernovae in a very narrow band of sky. By filling in this gap of knowledge, the Sloan extension will offer a significantly better understanding of the expansion of the universe. The new measurements will confirm or revise the estimate that 70 percent of the universe is made of dark energy, signaling the initial direction that new dark energy theories must take.

The dome for the 0.5-meter photometric telescope. It has the less glamorous job of automatically observing many standard star fields every clear night during the survey, in order to calibrate the data from the main telescope. By performing this time-consuming yet crucial chore, the telescope gives its larger companion the freedom to efficiently scan the skies without interruption.

Photo: Reidar Hahn, Fermilab

SEGUE: the search for dark matter

If 70 percent of the universe is composed of dark energy, nearly all of the remaining 30 percent is made up of dark matter. Although dark matter has never been directly observed, stars in the outer parts of our galaxy are observed to travel faster than can be explained by the gravitational pull of luminous matter alone. This suggests that dark matter helps to propel their movement.

Looking out into the halo of the galaxy—the fluffy areas where fewer stars exist than in the plane of the galaxy—the Sloan's first run survey did not find the expected smooth distribution of stars. Instead, the halo was filled with streams of the remains of small galaxies that once orbited the Milky Way but have now been torn apart by gravitational forces.

"These galaxies left behind a trail of breadcrumbs, leading us back to what the Milky Way looked like millions of years ago and suggesting that, as a result of the gravitational tug of dark matter, the galaxy formed from the amalgamation of many smaller objects," says Kent. "The Sloan Extension for Galactic Understanding and Exploration (SEGUE) will study the Milky Way's dark matter in more detail to help us understand both our galaxy's beginnings and its future."

Using high-resolution imaging and spectroscopy to track the detailed movement of stars in the Milky Way, SEGUE will allow researchers to precisely determine the location and structure of dark matter. SEGUE's imaging reveals motion perpendicular to the telescope's line of sight—an object's side-to-side movement—and spectroscopy divulges the motion in the line of sight—the forward-backward movement.

Because previous studies of this sort have been fragmentary, observing only a fraction of what the Sloan extension will take in, SEGUE will allow for significantly more accurate and broadly applicable conclusions.

"Right now, our best understanding of dark matter comes from numerical computer simulations that try to create structures in the universe similar to those we observe today," says Kent. "Yet these simulations are difficult to test observationally, given that we can only observe luminous matter such as stars."

SEGUE will offer an unparalleled look at the dynamic realities of dark matter. By watching luminous objects respond to dark matter's gravitational pull, researchers and theorists will for the first time have precise data for comparison with numerical computer simulations. These additional observations may lead to new theories of dark matter's structure and perhaps even a clue to its properties. SEGUE is a big step forward, because other than indirectly observed mass, nothing is currently known about dark matter.

Together, the three projects comprising the Sloan Digital Sky Survey extension will not only map the universe as we understand it today, but should also offer many new insights into its fundamental nature. "These three goals make for a very ambitious project," says Kent. "We're taking not just one leap forward, but two. We're pushing back the frontiers of astrophysics."