On a Cold Chilean Mountaintop

From an isolated location in the northwest corner of Chile, LSA Physics Professor Tim McKay is part of a team of scientists working to craft a veritable Rand McNally of the heavens. They are using the things that can be seen — stars, planets, supernovae — to map the things that can't be seen — dark matter, expansion, and the mysterious dark energy. If done right, mapping could transform our understanding of the universe. McKay explains how.

by *Karl Leif Bates*

PHOTO Dave Gerdes

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As Danish astronomer Tycho Brahe compiled a map of heavenly objects from his observatory near Copenhagen, the sudden appearance of a bright new star in November 1572 gave him a shocking idea.

He compared the brilliant object's position relative to other landmarks in his meticulously assembled catalog and, as the exploding star faded, Tycho concluded that it had to be a lot farther away than the moon and the fast-moving planets.

If Tycho's measurements of this supernova were to be believed, then the heavens were not fixed in place as everyone then believed and the universe might be a really big place. The model was broken and the maps were going to have to be redrawn.

Indeed they have been, pretty much continuously, as ever more powerful telescopes and cameras come on line and increasingly challenging theories try to make sense of it all. The universe is not only way bigger than Tycho could have imagined, it's much more active and diverse.

LSA Physics Professor Tim McKay is one of many modern astronomers still using supernovae and a host of other celestial beacons to map the universe. Objects that emit light, things like galaxies and the stars that make them up, are the keys to cosmic mapping. But observing them often reveals features of the universe that can't even be seen, like cosmic expansion, dark matter, and dark energy.

Mapping the universe by charting visible galaxies is different from mapping the Earth for one inescapable reason: The universe is really big. Even the nearest galaxies are so far away that the light they emit takes millions, or even billions, of years to get to us. When we look at distant galaxies, we see them not as they are now, but as they were long ago, when the light left them. Short-lived supernovae are long gone by the time we see them. The more distant a galaxy is, the deeper in the past we see it.

Mapmakers of the universe are also historians. And mapping the light from ever more distant galaxies led to the first great discovery of modern cosmology: the expanding universe.

Expansion and Mapping

In the 1920s, American astronomer Edwin Hubble — for whom the famous telescope is named — combined his measurements of distances to galaxies with astronomer Vesto Slipher's measurements of galaxy spectra or the colors of light they shone. He found a remarkable connection: As galaxies became more distant, their colors became redder. This red-shift was caused by the lightwaves themselves literally being stretched as the universe expands.

Hubble saw increasing wavelengths coming from the distant galaxies as if they were moving away, in any direction he looked. Their light was being stretched out, and the more remote the galaxy, the larger the stretching. In other words, the universe appeared to be expanding.

By mapping galaxy distances and spectra carefully, Hubble came up with a speed for universal expansion, called the Hubble constant. And that bit of mapping, in turn, led to the theoretical notion of a "Big Bang" from which all energy and matter arose. Albert Einstein's theory of General Relativity provides a plausible explanation for all of these observations.

Decades of subsequent research extended Hubble's observations enormously, mapping galaxies 50 times more distant than he could, and further confirming his initial conclusion: The universe has been expanding for a long time.

In 2010, Nick Risinger embarked on a different kind of mapping project. Without the aid of high-tech equipment and only his retired father to assist him, Risinger's ambitious goal was to photograph an image of the entire night sky. One year later, Risinger had logged more than 60,000 miles and had snapped more than 37,400 exposures to stitch together this stunning image. The Photopic Sky Survey is described on Risinger's website as a project that "portrays a world far beyond the one beneath our feet and reveals our familiar Milky Way with unfamiliar clarity. When we look upon this image, we are in fact peering back in time, as much of the light—having traveled such vast distances—predates civilization itself." To learn more, visit **skysurvey.org**.

The Evidence of Things Unseen

But mapping galaxies also has revealed some things that can't be seen. In 1933, Hubble's California colleague, Fritz Zwicky, measured the positions and motions of hundreds of galaxies in a dense cluster of galaxies called Coma more than 300 million light years away. To his surprise, he found them moving very fast relative to one another, faster than their gravity would allow without the cluster flinging itself apart.

Zwicky thought the cluster would need a lot more mass than it apparently had to stay stable. He postulated the presence of some unseen heft, now called "dark matter," to account for the missing mass. But

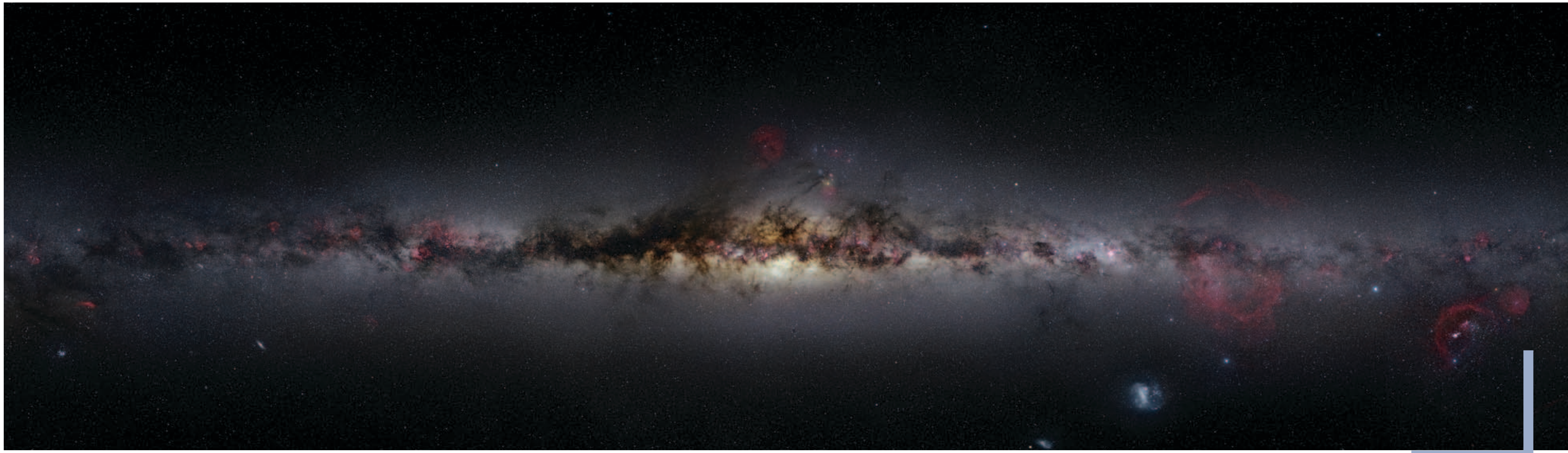

PHOTO Nick Risinger

to solve the problem, the cluster needed perhaps 10 parts of dark matter to every part of luminous matter.

An enormous amount of work by sky mappers since then has confirmed the influence — if not the actual appearance — of this invisible dark matter on galaxy formation and motions. The current understanding is that each visible galaxy is surrounded by a much larger, and much more massive, "halo" of dark matter.

"We don't know exactly what dark matter is, but we do see its effect everywhere we look," McKay says. Dark matter now seems to be everywhere there is ordinary matter, and nowhere that there isn't.

Dark matter today seems less mysterious than it did, thanks in part to a massive collaborative mapping project in the 1990s called the Sloan Digital Sky Survey (SDSS), of which McKay was a key part. Using a 2.5-meter telescope with a 120-megapixel camera in New Mexico, SDSS was capable of imaging 1.5 square degrees of sky at a time, about eight times the area of an average full moon. In all, it mapped about a third of the dome of space.

Hubble and Einstein were holding up just fine under this scrutiny until 1998, when two teams of astronomers measuring Hubble's expansion history came to a startling conclusion: The universe isn't just expanding — it's apparently speeding up. By examining very distant supernovae, they were measuring the expansion rate billions of years in the past, and they found that the rate then was slower than it is now. Hubble's constant wasn't.

Acceleration is a shocking idea. If anything, cosmic expansion was expected to slow, as all the matter in the universe exerted gravitational pull. For Einstein's general relativity to still work, there has to be some other unseen force pushing the cosmos apart harder than it's being pulled together. Or it could be that Einstein is wrong and we need an entirely new theory.

> "Watching this happen in the astronomy community was an interesting sociological experiment," says McKay. "When do you decide to believe something crazy?"

But dozens of new observations looking deeper in space and further back in time have confirmed acceleration. Astronomers have taken to calling the mystery "dark energy," and now they want to find it.

With its giant team of scientists, the Sloan project marked the beginning of a new era in mapping the universe: the age of collective big-science projects. "SDSS laid the groundwork for doing collective mapping," McKay says. No longer would lone scientists like Hubble or Zwicky be sufficient to map the heavens. There's simply too much data and too many faint but important signals for a single human mind to grasp, McKay says.

Sometime early next year, McKay and hundreds of his colleagues will take the lens cap off a bigger-better "mapper" on a mountaintop in Chile and begin the Dark Energy Survey (DES), an attempt to find this secret force accelerating the cosmic expansion. They have built a new refrigerator-sized 570 megapixel digital camera, called DECam, to use on the four-meter telescope at the Cerro Tololo Inter-American Observatory. DECam will be capable of imaging three square degrees of sky at a time — deeper, wider, and further back in time. Key parts of the $35 million camera were designed and built at U-M (see p. 15).

The simple act of mapping — seeing what's there and charting it — has always led to new insights about the universe. The way we're seeing things now, McKay says, is that only about four percent of the universe is ordinary matter: planets, stars, random bits of rock and ice. Another 26 percent is dark matter, which can't be seen directly, but behaves in a predictable fashion and exerts its influence on any light that streams past on its way to our telescopes.

But those two kinds of matter only account for 30 percent of what it takes to explain today's map of the universe. For Einstein's general relativity to hold its spot at the table, there has to be another 70 percent of something, the dark energy, working opposite the gravitational force of light and dark matter to create the acceleration that seems to be happening.

The Dark Energy Survey, mapping the universe from a cold Chilean mountaintop, won't be able to take a picture of dark matter or dark energy directly. But by making a more extensive, detailed, and precise map, and watching carefully for galaxy clusters, supernovae and other subtle features, astronomers hope to get that much closer to understanding where we are and where we're headed. That's what maps are for.

Karl Leif Bates is a science writer and a former U-M Knight-Wallace Journalism Fellow.

PHOTO Courtesy of Société Européenne de Systémes Optiques

The Telescope That Blue Built

LSA RESEARCHERS HELPED CONSTRUCT A NEW, POWERFUL TELESCOPE THAT COULD SHED LIGHT ON THE MYSTERIES OF DARK ENERGY

"To measure the effect of dark energy, you need to look at a lot of galaxies," says Gregory Tarlé, an LSA professor of physics. And to look at a lot of galaxies, you need a big telescope. Enter the Dark Energy Camera, or DECam, the powerful four-meter, wide-field survey telescope that will go on line in early 2012 to help astronomers take stock of the sky, specifically to study dark energy through a project called the Dark Energy Survey (DES).

LSA had a role in designing and building parts of this giant machine, which will be housed at the Cerro Tololo Inter-American Observatory (CTIO) in Chile.

"We helped build a filter changer for the camera that will move five different filters into the optical path," says Tarlé. "These will provide data to measure red shift, a key to understanding dark energy."

Because the telescope is so massive, the filter changer is roughly "the size of a door," says Tarlé. An enormous changer will move the filters in and out of the camera to create the right exposures. The five filters, each as big as a manhole cover, and the instrument shutter were originally specified by Michael Schubnell, a research scientist in the Department of Physics.

The telescope's optical lenses (pictured above) were designed on campus by Rebecca Bernstein, now an associate professor of astronomy and astrophysics at the University of California Santa Cruz.

All the parts for DECam, including those from U-M and from astrophysics laboratories around the globe, have been integrated together at the Fermi National Accelerator Laboratory in Illinois and are awaiting transport to CTIO. The goal is to have DECam providing data by April 2012.

A campus DES team consisting of three graduate students, three full-time postdoctoral students, one research scientist, and six faculty will begin looking at the DECam data as soon as it becomes available. They will share and analyze information with each other and with researchers at other institutions in much the same collaborative way the telescope itself was constructed. "Once we do any analysis, the goal is to make it completely available to other researchers," says Tarlé.