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Movie Camera to the Stars

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The Earth's fastest telescope aims to make the best sky map ever created.

by Laurence Marschall



Computer

rendering shows LSST as it should appear when completed in 2014. In a relentless campaign of 30-second views, the telescope will open a movie-like window on heavenly bodies that change or move on rapid timescales: exploding supernovas, hazardous asteroids, and objects in the distant Kuiper belt.

Image courtesy of Todd Mason, Mason Productions INC./LSST Corporation

As evening blankets Cerro Pachon, a remote and arid peak in northern Chile, a giant eye begins its vigil. Two metal shutters at one end of a large building on the summit slide apart like the lids of a waking dragon, revealing a squat, almost spherical structure of steel and glass. Once the shutters are fully open, the electronic eyeball turns skyward and begins to gaze in one direction, but only for 30 seconds. Then, having seen all it needs, it shifts its attention to another patch of sky.

The giant eye is connected to a giant brain, a computer of enormous speed and capacity. Most of the billions of things this eye sees each night are starlike specks or gauzy smudges of light. They may seem vague or inconsequential, but no matter; the brain remembers everything, storing each image for future recall. The brain is thinking, too. All through the night, even while waiting for the next image to arrive, it is comparing what it has just seen with stored images of the same part of the sky to see if anything has changed. It recognizes and records these changes in a vast electronic logbook. The brain notes worlds the size of Pluto, slowly moving through the dim vastness at the edge of the solar system. It notes distant stars winking out momentarily as an orbiting planet blocks the light. Every few minutes it catches the flash of a supernova, a star blowing itself into oblivion in a far-off galaxy. It keeps track of hundreds of thousands of asteroids, including a few that might be on a collision course with Earth. When a particularly interesting or distressing object appears, it sends messages to subscribing astronomers around the world.

While this scenario is futuristic, it is not a work of fiction. A unique collaboration of researchers in academia and the private sector is currently at work to make this giant eye a reality. The team's project, the [Large Synoptic Survey Telescope](#), or LSST, stands poised to radically alter the way that scientists study the sky. Once the telescope is up and

running, around 2014, astronomers will maintain continuous automated surveillance of the heavens, calling up images of the sky with no more effort than the click of a mouse.

In the broadest sense, the goal is to make the greatest-ever digital map of the sky, according to Zeljko Ivezic, the University of Washington astronomer charged with coordinating LSST's science initiatives. The [largest sky survey to date](#) contains about 300 million sources of light. LSST will blow that away, capturing some 10 billion stars, galaxies, and other objects, including some that are one-hundredth the brightness of anything detectable in a survey of the sky today. "This will be the first survey in the history of astronomy that will catalog more objects in the sky than there are people on Earth," Ivezic says.

Yet making history's most complete star map is just the beginning. Instead of rendering a static picture like other such maps, LSST will capture the sky in motion, a kind of time-lapse cinematography of the cosmos. "We'll compare the images we get tonight with all the accumulated images of the same part of the sky on other nights and look for what's there now that wasn't there before. This is how we are going to find [killer asteroids](#) and a few million other solar system objects," Ivezic says. "It will be the greatest movie ever made."

That movie will capture much that changes in the universe, both near the Earth and far away. "What is remarkable is the ability to do a lot of different kinds of science all at once, from investigating the profound unsolved problems of cosmology to probing the evolution of the solar system and the structure of the Milky Way," says Christopher Stubbs, a Harvard University astronomer who sits on the project's board. When LSST's data are [made available online](#), moreover, "everyone, even high schoolers, will be able to use it to make astronomical discoveries," Stubbs says. "It will mean a revolution in the sociology of doing science."

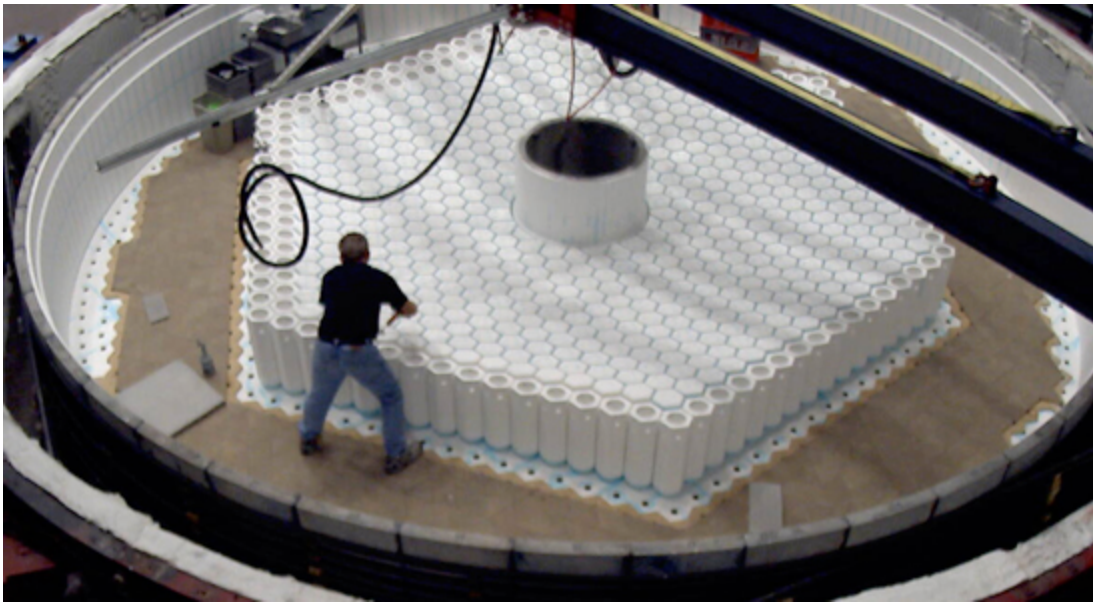
LSST's lofty goals helped attract the attention of one of the legends of the computer industry, engineer Wayne Rosing, who spearheaded development at Apple and Sun Microsystems. He [signed on as an LSST partner](#) in 2005. "The LSST pushes the envelope in every respect, and I hope that I can contribute in many ways," he says. But that is only part of what attracts partnerships with giant corporations like Google. If you already provide access to much of the digital information on planet Earth, it's just good business to stake a claim to the rest of the universe when you get the chance.

A New Way to Study the Sky

The Large Synoptic Survey Telescope represents a giant leap from the technology of today. Even the renowned Keck Observatory in Hawaii and the orbiting Hubble Space Telescope are basically snapshot cameras, shifting their gaze fitfully around the sky like hyperactive schoolchildren, doling out precious slots of observing time to a long succession of researchers. With such scarcity, astronomers must carefully choose the objects that interest them and propose projects to a "time allocation committee" of their peers, who judge whether the project merits a place on the telescope's overloaded schedule. The lucky astronomer who passes muster gets to spend a few hours or a few nights pointing the telescope at the designated objects, collecting data for the next year of desk work back home.

As a result of this catch-as-catch-can process, modern telescopes monitor the heavens only incompletely, a bit here and a bit there. The data they collect are distributed through professional journals and preserved on the hard drives of astronomers scattered around the globe. That is fine as far as it goes, but according to Anthony Tyson, a physicist at the University of California at Davis and now the director of the LSST project, it will not be possible to answer the great questions in astronomy and cosmology without a technological breakthrough. For more than a century, engineers have been building bigger and bigger mirrors to collect as much light as possible, but that misses an essential part of the problem. Instead of bigger mirrors, Tyson says, "we need something that goes wider, deeper, and faster than any instrument" we have today. In other words, LSST—a movie camera to the stars.

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A worker sets up

the mold for LSST's huge main mirror.

Image courtesy of LSST Corporation

The heart of LSST is a main mirror 8.4 meters (about 28 feet) in diameter, which will, in a matter of seconds, register vanishingly faint objects in distant galaxies over an area spanning about 50 full moons. That huge bite will enable the telescope to scan the heavens far more quickly and deeply than any other previous research instrument, so rapidly that it will compile a set of digital sky images—a complete map of the half of the universe in its field of vision—in just three days. (To capture the other half of the universe would require an identical telescope halfway around the world.) By repeating this sequence over and over, LSST will record a nearly continuous movie of the heavens.

As Tyson and his colleagues envision it, LSST will keep a systematic record of everything it captures, effectively transferring the entirety of it to computer memory for posterity (hence synoptic, meaning “allowing to see the whole”). All of the pictures it takes will be available to anyone who wants them in a matter of minutes, and access will be as simple as leafing through a photo album. The technology—a kind of anytime, anywhere machine—could transform the practice of astronomy in a fundamental way. Instead of traveling to the site of a telescope, an astronomer will be able to call up the region of interest from a database whenever he or she wants. LSST will even mine data on its own: By scanning images automatically and comparing them with pictures of the same region taken earlier, it will recognize the sudden brightening of a star or an object in motion from frame to frame.

Unraveling the Mysteries of the Universe

Casting its unblinking gaze to the heavens, LSST will capture a wide sweep of cosmic events and [unravel mysteries](#) that have long gone unsolved. Take the inexplicable flashes of light that sporadically illuminate the night sky. On April 20, 2006, two small sky-monitoring cameras thousands of miles apart—one in Chile, the other in the Canary Islands—both recorded a bright starlike spot of light that rotated with the heavens for about 10 minutes before vanishing. Such flashes have been reported in the past by naked-eye observers and occasionally recorded on observatory images. Even so, some astronomers have hesitated to consider the flashes real; others, while granting their reality, have been reluctant to assign them deep significance. Yet soon enough, LSST's remarkable imaging ability may tell us whether the flashes result from mundane local events—like sunlight glinting off a bit of satellite debris in orbit around Earth—or by a new and exotic type of stellar explosion halfway across the galaxy.

Cosmologists, meanwhile, say that LSST will help them measure the expansion of the universe, which seems to be propelled by an unseen force, [a kind of “dark energy”](#) that works against the force of gravity. Cosmic expansion and the dark energy thought to drive it can be studied by tracking the trajectory of light coming from faraway supernovas, extremely powerful stellar explosions. Most of the time observers do not see supernovas simply because no one is looking in the right direction, and cosmologists today “have just a few thousand of them on which their calculations can be based,” Ivezić says. “But LSST will give us 10 million supernovas to work with, vastly increasing the precision of that work.”

LSST will also help map the distribution of matter throughout the universe. This task is far more complicated than just taking a picture and counting all the bright things out there, because 90 percent of the material in the universe is in the form of mysterious dark matter that does not shine. Shiny or not, dark matter still exerts a gravitational force that bends light rays passing near it. As a result, light coming from a distant galaxy will be deflected by otherwise invisible globs of dark matter, causing it to appear stretched and deformed. The extent of the distortion indicates how much unseen matter is out there, pulling on the light.

With current telescopes, such subtle distortions are drowned out by far more intense distortions on the ground: the flexing of the telescope's mirror as the temperature changes, for instance, or blurring caused by turbulent air above the observatory. As it stands, astronomers have found it difficult to sort the distant, cosmic distortions from the local events. LSST would solve the problem by taking several thousand pictures of the same area of sky. Distortions produced in the telescope itself will change from picture to picture, so by averaging the pictures in a computer—finding the distortions common to all—scientists can tease out the subtle effects and produce an accurate dark-matter map.

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Mapping the Solar System and the Milky Way

LSST will also keep a close eye on conditions closer to home, tracking objects within our galaxy and solar system, including asteroids and comets that could someday collide with Earth. To find immediate threats, Tyson says, it is necessary to differentiate incoming objects from bodies locked in place in the asteroid belt. "Each faint asteroid must be captured in many separate exposures for computers to distinguish it from numerous other asteroids and then piece together its orbit," he explains. Right now, planetary scientists are searching for hundreds of [potentially threatening asteroids](#) approaching Earth. LSST would allow us to locate many more and determine their trajectories with precision, giving us time to intervene if one is on a deadly course.

With its keen eye for anything that moves, LSST should also reshape our understanding of the solar system as a whole by discovering millions of new objects, mostly in its shadowy outer realms. Astronomers like Michael Brown of Caltech have been pushing current telescopes to the limit trying to locate [new bodies in the Kuiper belt](#) (a vast population of small bodies orbiting the sun past Neptune) and beyond. Thought to consist of remnants from the formation of the solar system, the Kuiper belt will be analyzed in greater detail than ever before possible through the LSST's relentless scrutiny. Discoveries may include planets the size of Mars or larger, but lying much farther from the sun than Pluto.

The LSST will also help reveal the life history of the Milky Way, Ivezić says. "Roughly speaking, our galaxy looks like a pizza pie with an orange in the center—that's the galactic bulge—and then there is a very tenuous halo around the pie," he explains. "We don't know much about most of those stars in the halo, because they are so faint. We can see only halfway to the edge of the galaxy, but the closer you get to the edge, the more information you can gain about how the galaxy was formed. We think it was formed by cannibalizing nearby smaller galaxies." The idea is that the bigger the Milky Way grows, the more new galaxies it could attract, growing larger still.

The theoretical engine of this growth turns out to be complex: New galaxies get [pulled in and stretched around](#) the halo like strings of spaghetti, maintaining the signature of their independent origin; galaxies closer to the central bulge get mixed up with other old structures, losing the hallmarks of their original form. To validate this mechanism as real, astronomers will use the LSST to see more of the halo. "For the first time, we will be able to see the stars all the way to the edge of the Milky Way," Ivezić says. "Not only will we see them as points of light, but we will also be able to measure their motion across the sky. From their colors, we'll be able to estimate their chemical composition. Putting all this together will tell us a lot about the formation and evolution of the Milky Way."

Heaven's Dream team

Building a machine with such ambitious goals requires a large, dedicated team. Project director Tyson became involved through a long-standing interest in mapping dark matter by measuring the effects of gravitational lensing, the process by which matter bends light. His ambitious research hit a roadblock during the 1990s due to the pernicious effects of local distortions. Frustrated, Tyson realized he needed a totally new type of telescope, one that could take wide-field images of the deepest universe in a matter of seconds. Nothing like that existed at the time.

One day in 1998 Tyson received a call from noted optical designer Roger Angel, director of the Steward Observatory Mirror Lab at the University of Arizona, who had heard about Tyson's needs. Angel, it so happened, had already worked out the design for a wide-angle telescope that might do the job. The two started talking up the idea among their colleagues, and within a few years the concept of a survey telescope like LSST was firmly implanted in the astronomical community.

Good ideas are a dime a dozen, though, while real telescopes are expensive. Funding for astronomy is [far more limited](#) than that available for cancer research, say, and compared with most other fields of science, the number of professional astronomers is astonishingly small (the membership of the American Astronomical Society would just about fit into Radio City Music Hall). Though its estimated cost of \$400 million is considerably less than the \$2 billion-plus sticker for the Hubble Space Telescope, LSST is an expensive project—quadruple the cost of each of the Keck telescopes.

Yet support for the telescope kept growing. In 2000 about a hundred enthusiastic scientists and engineers convened in Aspen, Colorado, and formed the LSST collaboration. Then, in 2001, the National Academy of Sciences' "decadal survey" of astronomy—a summary of the field's primary goals for the next 10 years—[listed a survey telescope as a high priority](#) for the field. In 2003 the most interested players formalized a public-private LSST Corporation, able to solicit private donations and grants. The group submitted a proposal to the National Science Foundation, soon garnering a seed grant of \$15 million to support preliminary design.

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To drum up further support, Tyson and his colleagues went on the campaign trail in 2006 and 2007, giving talks at universities and at the technical centers of companies like Google—and the dollars began to trickle in. A big break came four months ago, when Tyson announced two major gifts: \$20 million [from the Charles Simonyi Fund](#) for Arts and Sciences and \$10 million from Microsoft founder Bill Gates.

From Vision to Reality

Even as the money situation improves, the technological challenges of building LSST are as daunting as ever, says Lawrence Livermore physicist Don Sweeney, the LSST project manager, in charge of coordinating the facility's erection from soup to nuts. "The system will collect data hundreds of times faster than the fastest telescopes of today through an enormous field of view," he says, "presenting technological hurdles in three big parts."

The first is the telescope itself. Not only will it need to process wide-angle images, but it will need to do so rapidly, concentrating light efficiently enough to capture, within seconds, objects less than one-millionth the brightness of what can be seen with the naked eye. Such fast wide-field optics require a radically new design, involving three mirrors: a smaller secondary mirror near the mouth of the telescope and two highly curved mirrors, the primary and tertiary, arranged concentrically at the back end.

LSST's three mirrors will focus light on an array of digital chips that are part of a [novel type of camera](#)—the second challenge Sweeney is charged with seeing through. The chips in a typical personal digital camera are less than an inch square and contain some 5 or 6 million pixels. LSST images, more than two feet across, will require a camera with 3.2 billion pixels and microchips far bigger than any single silicon chip ever made. The camera's detector, still in the planning stages, will be made of large panels each containing 200 individual chips, all linked together so that their output can be combined to form individual pictures. Even the camera shutter will require special engineering: Imagine an eyelid bigger than a manhole cover, able to snap open or closed in an instant without shaking the sensitive telescope and able to withstand millions of such repeated cycles?. With all its electronic and mechanical parts, the camera will be about the size of a small SUV. "It will be, by far, the biggest camera ever built," Sweeney says.

The flood of data this behemoth will produce would choke most computers. Pictures will stream out so quickly that, by current estimates, just one minute of observing time on LSST will generate 72 gigabytes of data, enough to fill a pack of 100 CD-ROMs. It will require new technology to transfer and store a fire-hose stream like this—the third challenge on Sweeney's list. Fortunately, the LSST's high demands are paralleled by rapid advances in technologies like motion picture animation, medical imaging, and broadband Web-based video, which is one reason why Silicon Valley corporations are getting involved.

Slowly the LSST is turning from dream machine into a nuts-and-bolts tool for the next great round of astronomical exploration. It is not easy to tell when a telescope crosses the divide between idea and reality, but surely the casting of its main mirror is an important milestone. That one was reached in March 2008, when technicians loaded 26 tons of borosilicate glass into a huge rotating oven located under the football stadium at the University of Arizona and turned up the heat to 2,150 degrees Fahrenheit. Members of the LSST team, donors, dignitaries, and reporters popped in for a ceremony marking the event. Then the crowds departed, leaving the scientists at the helm the task of producing, for astronomers and the public alike, what could be the most amazing movie ever made.

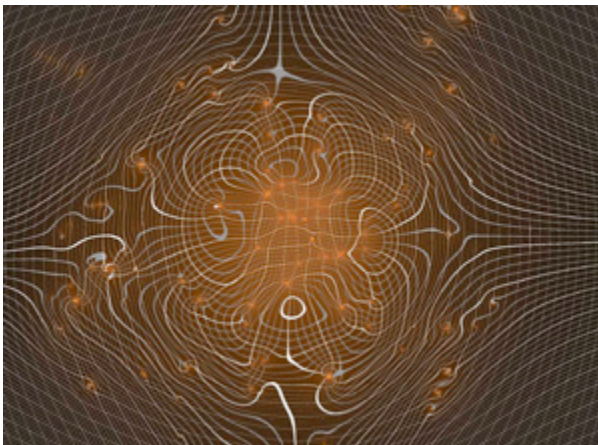


Galaxy cluster

CL0024 as seen by Hubble

Image courtesy of NASA/ESA/M.J. LEE and H. Ford (Johns Hopkins University)

Sleuthing Dark Matter



Dark matter and related gravitational distortions in the cluster.

Image courtesy of LSST Corporation

Cosmologists say a scaffolding of dark matter holds the universe together in an invisible web. Though other telescopes have provided evidence that dark matter actually exists, LSST will be able to map it precisely by rapidly scanning the heavens for gravitational distortions that only dark matter can explain. As LSST scans the same cosmic turf again and again, it will statistically analyze the bending and arcing of light from distant heavenly bodies, making it possible to render intricate maps that may include dark-matter structures as large as 500 million light-years across. With the ability to find especially remote dark-matter distortions, LSST will help chart the evolution of the universe from its birth.