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PROJECT OFFICE UPDATE

Major steps forward have taken place this quarter, including the scheduling by the National Science Foundation (NSF) of the LSST Preliminary Design Review (PDR) for the week of August 29th in Tucson. The NSF PDR is a major assessment point on the path to receiving construction funding from NSF. This week-long review of the project will assess the robustness of the technical design and completeness of the budget and construction planning.

To get us ready for that review, the LSST Board of Directors has assembled an external, non-advocate review panel to assess the readiness of the LSST Project for the NSF PDR. At the three-day, mid-July review, the panel is requested to provide the LSST Board with an exit briefing that contains: an overall summary of panel assessment of project readiness, a commented list of significant problems revealed, and high-priority recommendations.

On the Department of Energy (DOE) -side of the equation, we're happy to announce that the DOE approved a key milestone in development of the LSST camera: CD-0. This "Critical Decision Zero" for a Stage IV Ground-Based Dark Energy experiment formally establishes the need for such a project as part of the agency's mission, designates a stream of funding for it, and names the LSST as the first option for meeting that mission need. For more information: https://news.slac.stanford.edu/features/lsst-camera-passes-first-funding-milestone-0

Two snowstorms in June brought almost 3 ft of snowfall to Cerro Pachón, more than had been seen in 10 to 15 years. The snow-drifted road shown here was one the LSST Board of Directors walked on in April during their visit to the LSST site. Photographer Jeff Barr explains "The picture is taken at the southwest end of the main hill where the access road curves around the end before the final slope up to the top."

Under the leadership of LSST System Scientist Zeljko Ivezic, a significantly updated version of the LSST overview paper is now available as http://arxiv.org/abs/0805.2366 and linked to http://www.lsst.org/overview

We welcome two new members to the LSST team: Data Management Project Scientist Mario Juric and Document Specialist Robert McKercher. Mario has a strong data management background and has done extensive work with SDSS and Pan-STARRS data. He will start in January. Rob is already on the job in the LSST Project Office and has a background in both journalism and digital library science, making him the perfect wrangler for our large and growing pile of documentation.

While temperatures exceed 110°F in Arizona, it's winter in Chile, as evidenced in these beautiful pictures of the first snow at CTIO. The LSST webcams remain operational for the time being, even though site preparation is nearly complete on Cerro Pachón as we go to press. Images are updated every minute at http://www.lsst.org/lsst/webcam.

Article written by Suzanne Jacoby

ASTROVIZ 2011: DO I NEED MY (3D) GLASSES FOR THIS?

Astronomy Visualization, AstroViz, was the topic of a workshop held at The University of Washington (UW) in early June. AstroViz workshops have been taking place since 2005, bringing together individuals with a broad range of backgrounds, interests and expertise to discuss the development of visualization for use in both research and education.

With support from Microsoft Research, UW astronomy professor and workshop organizer Andrew Connolly facilitated the two-day discussion of visualization in astrophysics, ranging from user interactivity with massive datasets,

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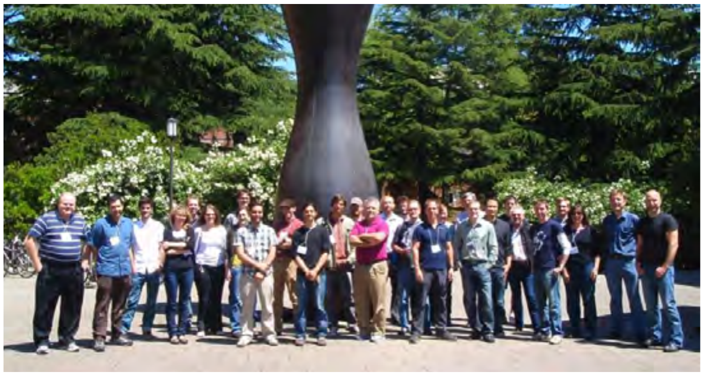

Participants in the AstroViz 2011 Workshop held on the University of Washington campus.

high-dimensional data, and the line between art and science. The 40 participants shared ideas on how to convey information from increasingly complex datasets and looked ahead to techniques and trends that LSST can tap into. As LSST Image Simulation Scientist, professor Connolly described how our ability to interact visually with data, and to do so rapidly, is critical when learning how to separate interesting astrophysical objects from the hundreds of thousands of transient and variable sources that the LSST will discover every night.

The workshop was held at the UW's new digital planetarium, which was upgraded in 2011 transforming the dome into an 8-million pixel digital display. By using images streamed from World Wide Telescope (WWT; www.worldwidetelescope.org) and an innovative 6-projector display system that uses home theatre equipment, the UW capability can be replicated at planetariums everywhere for under $40,000.

Marcus Lehto , Creative Director for Bungie Studios, talked about "The Role of Skies in Halo", the immensely popular science fiction video game franchise where hundreds of millions of user hours have been spent in online play. Lehto demoed images from Halo in the planetarium dome, moving through virtual worlds with an Xbox controller, and showing how artwork for non-play "Skybox" areas are built up layer by layer. The Graphics processing units (GPUs) used to render the realistic worlds in Halo in real-time have transformed video gaming. In turn, gaming drives the development of computer technologies that are used far beyond just visualization, even extending to the processing and analysis of the stream of images from the LSST.

Another AstroViz highlight was Nick Risinger, who showed his Photopic Sky Survey (http://skysurvey.org/), a 5,000 megapixel photograph of the entire night sky stitched together from 37,440 exposures. His year-long effort to photograph the sky and process them into a unique beautiful composite was worth the effort as we all were held spell-bound, Nick included, with the Photopic survey projected full-dome for the first time ever.

Photopic Sky /survey. Image credit: Nick Risinger

LSST's observing cadence will allow for imaging the entire sky visible from Cerro Pachón a couple times a week, for ten years, essentially producing a full-color, digital movie of the night sky. Astrovisualization techniques such as those discussed at this workshop will be used to maximize the science and public value of LSST. And yes, you will need your 3D glasses for that! The AstroViz 2011 agenda is online at http://ssg.astro.washington.edu/astroviz.shtml

Article written by Suzanne Jacoby and Andy Connolly

SEARCHING FOR DWARF GALAXIES AND BIG WAVES – MARLA GEHA

Marla Geha is the co-chair of the Milky Way and Local Volume Structure science collaboration with Beth Willman. This collaboration's primary science goals are to map the main components of the Milky Way, to find small dwarf galaxies orbiting the Milky Way, and to trace out any lumpiness or substructure in the Milky Way that can provide evidence of dwarf galaxy satellites destroyed by its gravity. Accomplishing these goals will require data across the full sky.

"LSST's camera has a large field of view and by stitching together many of these images, we hope to reconstruct the Galaxy in which we live.

"Data from LSST will answer a wide variety of scientific questions. Usually astronomical data are taken with a very specific purpose in mind, which often can't be used to answer other astronomical questions. LSST will serve so many different purposes. This allows for conversations among people in different sub-disciplines of astronomy that normally don't have much to say to each other. The LSST All Hands Meeting in August 2010 was a great example of this – terrific energy and interaction in one room.

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Marla Geha... (Cont.)

Marla Geha

"My own interest in LSST is in finding the faintest satellite galaxies orbiting the Milky Way. Before 2005 the eleven satellite galaxies known were thought to be the Milky Way's only companions. The Sloan Digital Sky Survey, the first digital mapping of the full sky, has discovered an additional fourteen, and many more are expected. These new dwarf galaxies are ultra-faint, that is, several million times fainter than the Milky Way, and less luminous than any other known galaxy. Most of their mass is composed of dark matter – whatever it may be – and LSST will help find hundreds more of these elusive objects. In completing a census of satellites around the Milky Way, LSST will provide a more complete picture of the Milky Way neighborhood as well as finding new 'laboratories' in which we can study dark matter."

Marla defines perhaps her biggest challenge as finding time for her research and excelling as a teacher: "being a professor is enjoyable but requires a lot of work – especially when you are the type of person who enjoys it and wants to do it right." One of the courses that Marla teaches as an Assistant Professor at Yale University is a non-science major course, Frontiers of Astrophysics, which might have among its 80-100 students the future senators, decision makers, and corporate leaders who will affect research funding and national priorities. In some respects classes such as this may have greater impact on future science and technology success than those training scientists and engineers. Marla is acutely aware that it is critical to engage these students in the facts and process of science. She hopes to fold some of the LSST education and public outreach efforts into her classes.

Her career has taken Marla from a B.S. at Cornell University to an M.S. at New Mexico State University to a Ph.D. in Astronomy and Astrophysics at the University of California at Santa Cruz to researching and teaching at Yale University since 2008. Having won several prizes and fellowships, she was named one of Popular Science's "Brilliant 10" in 2009. The only complaint she has about Yale's location is the lack of surfing in Connecticut. Nevertheless, Marla is able to collaborate with several other surfing astronomers to find time to catch some big waves and produce outstanding science in other parts of the world.

By Anna H. Spitz with Marla Geha

LSST KEY PLAYER IN SEA CHANGE OF DATA AVAILABILITY

LSST continues to be recognized as a leader in the new astronomical research paradigm of Data Intensive Astronomy by pushing the envelope on all aspects: data mining, data sharing, and cyberinfrastructure. LSST's contributions to the advancement of computational systems, the fostering of the next generation of cross-disciplinary scientists, and investments in the developing world's cyber-infrastructure contribute to narrowing the gap between awareness of increasingly massive data collections and understanding of the knowledge within them.

Data Mining

Discovery of the unusual or unexpected in scientific data often guides the most fundamental breakthroughs in physical sciences. And while the expansion of data and computational resources have enabled new modes of discovery, as scientific data grows in size, our ability to understand it and to find the unexpected rapidly diminishes with current models of analysis.

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Jeff Kantor, Project Manager for LSST Data Management, estimates that by the end of its survey LSST will have contributed an additional 100,000-plus terabytes of data to the trove of publically accessible astronomical data. Traditional methods of frame-by-frame searching to look for discrepancies within the data will be overwhelmed.

Data intensive astronomy utilizes statistical data analyses to enable rapid information extraction, knowledge discovery, and scientific decision support. This new paradigm came about to address the disconnect between the potential for exciting scientific breakthroughs to be found in massive datasets and the limitations of traditional analysis.

As an example of LSST's contributions to the advances in data science necessary for data intensive astronomy, Kirk D. Borne, chair of the LSST Informatics and Statistics science collaboration and an associate professor of astrophysics and computational science at George Mason University, cites an international research effort to create an open-source database technology called SciDB. Designed to address extreme-scale science and inspired primarily by the needs of the LSST, the resulting architecture will enable analytics and knowledge generation on a scale that is practically unattainable with existing systems. Community support will ensure that SciDB and similar technologies will be available to meet the needs of data intensive science.

As much as astronomy needs computational advances, a new breed of scientist also must be fostered. New modes of interdisciplinary collaboration will require training and skills at the interface of astronomy, physics, computer science, statistics, and information science: astroinformatics. Borne recommends the development of astroinformatics as a formal sub-discipline of astronomy education and research. It provides a natural context for the integration of research and education – the excitement and experience of research and discovery are enabled and infused within the classroom through a portable informatics paradigm.

Data Sharing

The image archive produced by the LSST survey and the associated object catalogs that are generated from that data will be made available to the U.S. and Chilean scientific communities with no proprietary period. The LSST Education and Science Collaboration teams have generated ideas for Citizen Science research projects that engage the public in monitoring, classifying, and annotating data for the advancement of astronomical research. By encouraging the involvement of educators, amateur astronomers, and citizen scientists as well as the traditional research community, LSST extends its scientific potential and increases the diversity of those participating in the exploration.

Željko Ivezić, professor of astronomy at University of Washington and LSST Project Scientist, seconds the value of data-sharing. In a recent presentation at The Case for International Sharing of Scientific Data: A Focus on Developing Countries, an international symposium in Washington, DC, he said projects like the Sloan Digital Sky Survey have discovered that data-sharing produces a number of benefits, including the extraction of more science from the dataset and the democratization of expensive and limited astronomy resources throughout a broad community. "More users yield more science," he observed.

Cyberinfrastructure

If data-sharing enables world-wide, cross-discipline coeval science and empowers small teams in developing countries to "do 'big' science," as Ivezić puts it, then LSST's collaborations, positioning of its full dataset in Chile and the US, a user-friendly data management system, and investments in Chile's network and computing infrastructure position the project at the forefront of data intensive astronomy.

At meetings for the May symposium in Santiago, Chile, Towards a Digital Society through Advanced Connectivity Infrastructure, Kantor highlighted collaborations with REUNA and AmLight that will provide La Serena, Chile to Santiago networks and Santiago to Urbana-Champaign, Illinois networks. He also identified the LSST Chilean DAC and the new Chilean National Laboratory for High Performance Computing, networked with most major research universities in Chile by REUNA (with LSST investment), as the basis of a grid-based virtual laboratory for data intensive science, not just for astronomy.

At the same meetings Ed Seidel, Assistant Director for the Mathematical and Physical Sciences Directorate of the National Science Foundation, discussed the new NSF Director's emphasis on economic development enabled by science, technology, and international collaboration. He cited LSST as a "model" for such projects. By making its data public and contributing to the development of Chile's cyberinfrastructure, LSST satisfies two goals. LSST enables the production of more and better quality science, and it practices good citizenship by empowering the developing world.

Article written by Robert McKercher and Suzanne Jacoby

A simple recipe: Take a lot of mass – a galaxy or cluster of galaxies – and place it in the line of sight to a distant object to create a powerful tool for studying cosmology and galaxy structure. This technique, gravitational lensing, provides information not only about the magnified source but also about the foreground lens. LSST will contain more strong gravitational lensing events - those where multiple images of the background source form - than any other survey before it, opening up a wealth of possibilities to answer some of the most fundamental questions about the Universe. The survey's large volume, high accuracy photometry and multi-filter time series will produce some big advances in strong lensing science.

This E-News article is based on Chapter 12 of the LSST Science Book: Strong Gravitational Lensing. The Authors of Chapter 12 are:

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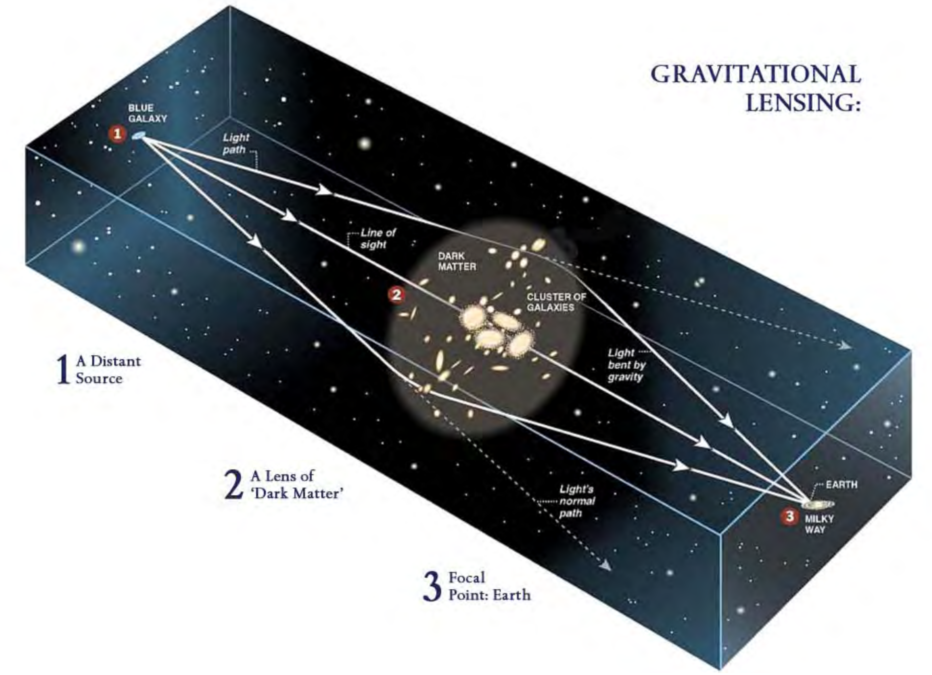

Strong gravitational lensing bends light from a distant source to create distorted or multiple images. Credit: Tony Tyson, Greg Kochanski and Ian Dell'Antonio; Frank O'Connell and Jim McManus, adopted from The New York Times, www.lsst.org/lsst/science/scientist_dark_matter

A Primer on Lensing

The geometric configuration of the lensing setup and its result are simple: light leaves a distant source (1) and then passes through a massive foreground object – a galaxy, group or cluster and its associated dark matter. The gravity of this object acts as a lens (2), bending and focusing the light toward observers on Earth (3): the LSST will see distorted images of the background source. Strong gravitational lensing occurs when the density of the intermediate object is so high that it creates multiple images of the background object.

A good lens model fits the positions of the multiple images, but it also predicts the time delay of the ray in comparison to a light ray traveling in a direct path in empty space. Although researchers cannot calculate the time delay of single ray, they can calculate the difference between two images for a multiply imaged source. So a time variable background object, such as an active galactic nucleus (AGN), not only constrains the mass distribution of the lensing galaxy, but allows the distance to the lens to be backed out as well. As Phil Marshall, Chair of the LSST Strong Lensing Science Collaboration puts it, "such well-calibrated lenses provide a high precision optical bench for cosmology experiments." LSST will open up the time domain in a way no previous optical telescope has.

Sometimes the image of the light sources forms a ring. Using the lens equation, scientists can determine the direct relationship between this Einstein Ring and the mass of the lensing object. This allows precise measurement of the mass of distant objects to further refine their characteristics.

"Weighing galaxies is difficult," says Marshall. "Strong lensing allows us to measure the mass of galaxies and clusters to an accuracy of a few percent."

Strong Gravitational Lenses in the LSST Survey

LSST will discover an immense number of strong gravitational lenses, thanks to its high spatial resolution and outstanding image quality. The sample will be big enough to reveal many rare, exotic strong lensing events

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as well. The typical objects' lensing cross-section is a strong function of its mass, but because galaxies are far more numerous than the more massive groups and clusters, most strong lenses are produced by massive elliptical galaxies. However, researchers expect to find thousands of group and cluster-scale lenses too.

Galaxy lenses. Researchers expect massive elliptical galaxies at redshift 0.5-1.0 to dominate the galaxy-scale lens population. For this reason, the typical gravitational lens will look like a bright red galaxy with some residual blue flux around it. Because the detection of the systems relies on scientists' abilities to distinguish the lens light from the source light, edge-on spirals may be easier to use as lenses in some cases. The Sloan Lens ACS Survey leads the way in detecting galaxy-sized lenses. Marshall predicts: "LSST will increase the number of galaxy-scale strong lens detections by an order of magnitude over Dark Energy Survey, and by a factor of 100 over the current sample. And we expect to find nearly 10,000 lensed quasars during the survey - and measure the time delays in several thousand of them." The LSST lensed quasar sample will be around two orders of magnitude larger than the current largest survey of lensed quasars. Because we understand well the light curves of supernovae (SNe), scientists can use strongly lensed supernovae to provide accurate estimates of time delays between images. Redshifts of imaged SNe will typically be around z ~ 0.8 while the redshifts of the giant elliptical galaxies acting as lenses at about z ~ 0.2. LSST should find about 330 lensed supernovae. "No-one has ever seen a strongly-lensed supernova," says Marshall, "but we expect them to be pretty useful. LSST will enable their use on an industrial scale - and may even find the first one."

Hubble Image of Abell 2218 is an example of gravitational lensing. It shows the arc-like pattern spread across the picture - an illusion caused by the gravitational field of the cluster. The process magnifies, brightens and distorts images of source objects and creates a "zoom lens" to view objects. Using galaxy clusters as cosmic telescopes, LSST will help measure the luminosity function of z > 7 galaxies (the time of rapid reionization). Credits: W.Couch (University of New South Wales), R. Ellis (Cambridge University), and NASA.

When a galaxy lenses an image of a distant quasar, we gain information about the foreground lens galaxy and the background source on a number of different length scales: macrolensing (~ 1 arcsec) due to global mass distribution, millilensing (~ 1 milliarcsec) from dark matter substructure, and microlensing (~ 1 microarcsec) as stars in the lens galaxy cross in front of the source. All of these, and the size of the source as well, have effects on the image fluxes, which have to be disentangled. LSST's well-sampled six-band light curves will make this possible.

Galaxy cluster lenses. In 1986 researchers discovered the first giant arc in Abell 370 and have discovered many more in the intervening years. Most of the high-mass galaxy clusters have core surface densities high enough to create conspicuous strong lensing features such as multiple images, arcs and arclets. The number of lensed arcs in a cluster is a strong function of cluster mass. The ability to detect and identify strongly lensed features depends on the source size, the image quality and the detailed properties of cluster mass distributions. Cluster strong lensing is very useful in exploring the mass distribution in clusters, which is critical to understanding properties of dark matter. Measurements of strong lensing combined with weak lensing measurements allow study of the density profile of clusters over a large range of radii leading to a test of structure formation models.

LSST's high resolution will provide a strong advantage over other ground-based surveys in identifying systems of multiple images by their colors and morphologies. LSST will likely detect around 1,000 multiple image systems.

LSST will Probe Many Mysteries with Strong Lenses

LSST will provide opportunities to measure the gross mass structures of massive galaxies as they operate as strong gravitational lenses, allowing researchers to trace their evolution. LSST data alone will produce accurate

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measurements of image positions, fluxes, and time delays for several thousand lensed quasars, AGN and supernovae. It will also detect approximately 10,000 lensed galaxies, which can then be modeled. LSST's statistically complete sample will provide the opportunity to measure the mass function and mass evolution of massive galaxies over a wide redshift range up to and including the era of their formation ($z \sim 1\text{-}2$, several billion years after the Big Bang). Marshall says, "We expect the LSST strong lenses to provide the best assessment of the distribution of massive galaxy density profiles out to $z \sim 1.5$." Follow-up observations will supplement and enhance the LSST data. Spectroscopic redshifts will allow absolute mass measurements, which sharpen up when the lens strength and stellar dynamics are combined; high-resolution infra-red imaging will further expand the opportunities.

Galaxy groups, the most common galaxy environment in the local Universe, may be the sites of many of the changes in galaxy morphology and star formation rate between $z \sim 2$ and today. Although galaxy groups have been very well studied at low redshifts, little is known about those at moderate redshifts ($0.3 < z < 1$); they are difficult to detect and assumptions need to be made to determine mass estimates. Strong lensing provides the most precise method to measure object masses beyond the local Universe. The large sample size (about 1,000 groups), wide redshift range, and rigorous mass measurements will permit unprecedented study of mass in galaxy groups.

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Cosmography is the measurement of the distance scale of the Universe and its associated fundamental parameters. The large number of strong lenses observed with LSST will allow statistical approaches to cosmography. By combining the constraints from time delays with those from galaxy clustering and supernovae, researchers will be able to achieve higher accuracy on the dark energy equation of state parameters. "A few hundred well-measured LSST time delay lenses will give us a very interesting, complementary measurement of the accelerating expansion of the Universe," says Marshall.

Chromatic variability is observed in lensed Active Galactic Nuclei (AGN), compact regions at the center of a galaxy which display a much higher than normal luminosity over a broad spectral region. This variability implies that the effective size of the emission region, the accretion disk, varies with wavelength. With LSST's larger sample size, scientists will be able to probe disk structure as a function of AGN luminosity, black hole mass and host galaxy properties.

The interstellar medium (ISM) in galaxies causes extinction of light passing through it. Because gravitationally lensed multiply imaged background sources provide two or four sight-lines through the deflecting galaxy, scientists can determine the differential extinction curve of the intervening galaxy. LSST's combined sample of lensed quasars and supernovae will permit statistical studies of extinction properties of high redshift galaxies and the evolution of those dust distributions with redshift and their difference among galaxy types – for the first time outside the Local Group.

Large amounts of dark matter exist in galaxy clusters. LSST data will provide opportunities for examination of dark matter distributions and its interaction with the baryonic mass component. With the LSST sample of over about 1,000 clusters capable of strong lensing, scientists will be able to probe and place limits on the self-interaction cross-section of dark matter, follow the growth of dark matter structure through cosmic time, and use well-calibrated clusters as cosmic telescopes to study hard-to-observe lower luminosity galaxies.

The cluster mass function is one of the four most promising dark energy probes. LSST will offer a unique opportunity to study the cluster dynamics in unprecedented detail and thereby construct a well-calibrated mass function that will allow quantification of the effects of dark energy. Marshall says, "The mass function is most sensitive to cosmology at the massive end - and it's these massive clusters that make the most striking strong lenses. Combining weak and strong lensing for cluster mass measurement on a grand scale with LSST is an enticing prospect."

From the masses of the heaviest galaxies, to the nature of dark matter and even dark energy, strong lensing science with the LSST will provide unprecedented opportunities for investigations into fundamental mysteries of the Universe.

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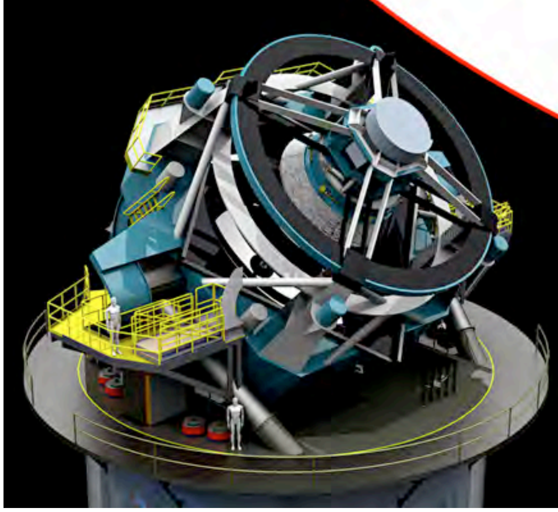

Large Synoptic Survey Telescope