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PROJECT OFFICE NEWS

Participants at the 2010 LSST AHM, Ritz-Carlton Dove Mountain, AZ

Welcome to the 11th quarterly issue of LSST E-News, where spirits are high but serious, as we recover from a successful All Hands Meeting, plan for the January 2011 AAS Meeting, and most importantly strategize how to move forward after receiving top ranking in the Astro2010 Decadal Survey. The hard work has begun, including meetings with the lead agency NSF to schedule our next review and work out funding scenarios. Both the NSF and DOE have named new program managers to guide us through the funding process: Fred Borcherding at the DOE and Nigel Sharp at NSF. Approval is a multi-phase effort at the DOE; CD-0 completion, which will state the DOE "mission need" for participation in LSST as a dark energy experiment, is anticipated by the end of the year. LSST Director Tony Tyson has more to say about this process in the next article.

Being ranked as the #1 priority for ground based astronomy in the NRC's Astro2010 Decadal Survey was exciting enough, made even better by the timing: the announcement took place on the final morning of the 2010 LSST All Hands Meeting (AHM). For the 218 people in attendance, watching the live eTownhall broadcast was a moment to remember. This AHM, our fifth, featured daily plenary sessions and approximately 35 breakout sessions over the 5-day meeting. Our post-meeting survey documents a high rate of satisfaction from attendees, with 90% rating the meeting productive, 96% found it to be enjoyable, and 97% anticipate attending the next AHM.

With the All Hands Meeting behind us, attention now turns to the 217th meeting of the American Astronomical Society, taking place in Seattle, WA, January 9-13, 2011. Again this year LSST will have a strong presence at the meeting, starting with a full-day "splinter meeting" on the UW campus on Sunday, January 9th. In addition to our exhibit and poster session, LSST will have a AAS Special Session titled "Community Science with LSST" on Monday, January 10, 2011, from 2:00pm-3:30pm with six speakers and a panel discussion.

This article written by Suzanne Jacoby and Don Sweeney

DIRECTOR'S THOUGHTS ON Astro2010

In August, the Astronomy and Astrophysics Decadal Survey "New Worlds and New Horizons in Astronomy and Astrophysics," convened by the National Research Council for the National Academy of Sciences, ranked the LSST as its top priority for the next large ground-based astronomical facility. This so-called "Astro2010" report is important input to the coordinated planning process at the national funding agencies. We are working with the agencies to move LSST into construction, navigating parallel coordinated tracks at DOE and NSF.

From the beginning of this project we envisioned LSST as a community endeavor, with the data and the software open. We had open focused workshops, posters at meetings, and formed community-based LSST science collaborations. These science collaborations, together with project personnel, produced the LSST

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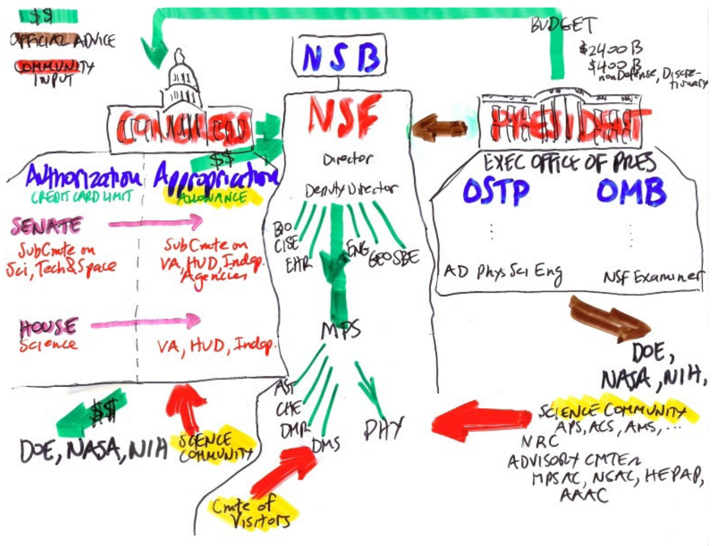
In This Issue

Science Book. Attendance at our "All-Hands" meetings has increased every year, and it would be an understatement to say that our most recent All-Hands meeting was successful. Held just north of Tucson August 9-13, it overlapped with the 2010 NRC decadal survey Astro2010 public release.

For the 218 attending the All-Hands meeting — many of them students - Friday August 13 at 9am was a thrilling moment. Astro2010 ranked LSST as its highest priority for new ground-based facilities. In their words: "The top rank accorded to LSST is a result of (1) its compelling science case and capacity to address so many of the science goals of this survey and (2) its readiness for submission to the MREFC process as informed by its technical maturity, the survey's assessment of risk, and appraised construction and operations costs. Having made considerable progress in terms of its readiness since the 2001 survey, the committee judged that LSST was the most 'ready-to-go.'"

I believe that this ranking reflects the community's perception that LSST will open new windows on the universe, providing an exciting and wide-spread capability for data mining the sky for new science. That community extends beyond professional scientists to the general public and their curiosity about the sky. For scientists it is LSST's "Big Picture" and the huge statistical samples covering 20 billion objects that present unique opportunities, many of which are recounted in the Science Book. These opportunities - and more - depend not only on the quantity but the quality of the data. This is where LSST will have to deliver. Like previous surveys, much of the science enabled by our data products will be done at the faint end, where most of the survey volume resides. It was apparent at this recent All-Hands meeting that the science collaborations are enthusiastically engaging with the simulations in an effort to understand in some detail the sensitivity of their science to the parameters of the survey, including photometric and astrometric precision. Not surprisingly, in many cases the science is enabled by uncommon control of data quality and uniformity. This was difficult enough in the SDSS and other recent surveys. Considerable effort was spent on detecting and understanding systematics. LSST will produce a SDSS volume of data nightly!

Many regard LSST as the lighthouse project for looming Big Data challenges that are faced by most areas of science and engineering. Gone are the days when a lone postdoc reviewing raw images can grasp the full landscape of the data completeness and accuracy, or discover that pesky sample bias or systematic error. Novel tools for data exploration and visualization must be utilized. Efficient human-assisted tools for automated data quality assessment must be developed. Indeed the very process of discovery in some cases will be automated. Discovering the unexpected in petabytes of data is an exciting challenge. For us, controlling systematics and understanding selection effects is an LSST system-wide issue, from hardware to survey cadence to software algorithms extending beyond pipelines to data analysis.



The major facilities funding process, as illustrated by astrophysicist and viewgraph artist Michael Turner circa 2006 when he was Assistant Director for MPS at the NSF. The Congressional committee names have since changed, but the process remains the same.

This data-to-knowledge challenge at the petascale is one area where our funding partners see potential spin-off. Together with the breakthrough astrophysics, this will be an important theme as we advance through the approval process at NSF and DOE. The recent Astro2010 report is important input to the coordinated planning process at the agencies. We are working with the agencies to make that happen soon, moving along parallel coordinated tracks at DOE and NSF. Three years ago the NSF LSST CoDR review panel report said that we were ready for Preliminary Design Review. With the decadal survey looming, it was a naturally conservative decision for the agencies to wait for the Astro2010 report. For their part (the LSST camera), DOE is beginning to advance us through their Critical Design phases.

At NSF our next review is PDR (stay tuned!), and then Final Design Review. The key element in the NSF approval process is the National Science Board. NSB must approve all major NSF facility construction, the so-called "MREFC" approval, and this has several phases. NSF's Division of Astronomical Sciences plans to brief the NSB on the Astro2010 report soon. While Astro2010 has now confirmed LSST's high degree of readiness, this is a necessary but not sufficient condition on our way towards MREFC approval. As illustrated in the accompanying colorful graphic, funding major facilities is a non-linear process involving review committees, the agencies, Office of Management and Budget, Office of Science and Technology policy, and Congress. We will continue to engage the community and work with our funding agencies and private supporters to open new windows on the universe with LSST. We are on our way!

This article written by Tony Tyson.

This E-News article is based on Chapter 9 of the *LSST Science Book:* Galaxies. Authors of Chapter 9 are:

- Henry C. Ferguson
- Lee Armus
- L. Felipe Barrientos
- James G. Bartlett
- Michael R. Blanton
- Kirk D. Borne
- Carrie R. Bridge
- Mark Dickinson
- Harold Francke
- Gaspar Galaz
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- Kirk Gilmore
- Jennifer M. Lotz
- R. H. Lupton
- Jeffrey A. Newman
- Nelson D. Padilla
- Brant E. Robertson
- Rok Roškar
- Adam Stanford
- Risa H. Wechsler

Galaxies are some of the most spectacular objects imaged by telescopes. Their various forms and sizes, from giant ellipticals to graceful spirals to dwarf and merging galaxies, seem unbelievably distant and large, yet still somehow familiar to us. For galaxy researchers, however, they also reveal the characteristics of elusive dark matter because galaxies are thought to have formed hierarchically around peaks in the dark matter density distribution. Within this framework, astronomers are able to understand the large-scale clustering of galaxies as a tracer of underlying dark matter and of how gas made up of subatomic particles (baryonic matter) cools and collapses to form stars and then how its energy feeds back into the gas to regulate continued star formation. What we don't have yet is a solid understanding of the basic physics of galaxy evolution. This process is stochastic and so testing the models and developing understanding requires large statistical data sets - such as those LSST will produce. LSST will expand on the power of large surveys such as Sloan Digital Sky Survey (SDSS), PanSTARRS-1, Dark Energy Survey, and SkyMapper, as astronomers use its data to figure out the basic physics of galaxy formation and evolution.

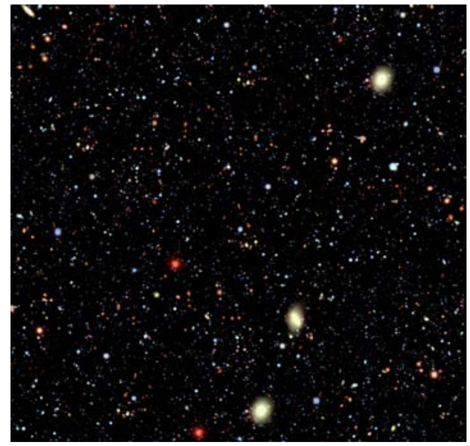
LSST will be a unique tool to study galaxies. Its database will have measurements for 10^{10} galaxies, from the local group to those with redshifts of z > 6, or a distance of approximately 5.2 gigaparsecs (5.2 billion parsecs equals about 2 x 10^{22} miles or 3 x 10^{22} kilometers - or looking back in time over 12 billion years). Over the ~12 billion years of lookback time that LSST can access, astronomers expect that galaxies evolve in luminosity, color, size, and shape. Although LSST will not produce the deepest or highest resolution survey, it will deliver by far the largest database.

The Galaxies Science Collaboration's core science will consist of measuring the distributions of galaxies' properties and their correlations with redshift and environment. Both LSST's all-sky and deep field data will add to accurate photometric redshifts and correlation functions and provide catalogs of clusters, groups, overdensities (a greater than expected density of matter) on various scales, and voids. LSST will detail properties including luminosities, colors, sizes, and morphologies and derived properties including stellar masses, ages, and star formation rates. Researchers will study particularly the "tails" of the distributions, for example, galaxies with unusual surface brightness or morphology, to understand short-lived phases of galaxy evolution and probe star formation in a wide range of environments. With massive statistics, the data can be sliced in all sorts of interesting ways to try to reveal the underlying physics or test models.

LSST's "deep drilling" fields, those observed more frequently and co-added to reach fainter limits, will allow significantly enhanced science because the fields present a number of opportunities for coordinated deep multiwavelength imaging to select targets for narrow field follow-up with other observatories. Astronomers will be able to follow-up with extensive spectroscopic observations to yield three-dimensional probes of large-scale structure. This flood of information will promote a more complete picture of galaxy formation and evolution.

Defining, Studying & Understanding Galaxy Types

As a rule, galaxies fall into two populations: a 'red sequence' of massive galaxies - which generally contain old, passively evolving stellar populations - and a less massive 'blue sequence'



Deep Lens Survey data, co-added to demonstrate LSST depth.

of galaxies with ongoing star formation. Why does this bimodality exist? How does it correlate with the morphological characteristics of galaxies, and how do these evolve as a function of time and environment? Such questions dominate a great deal of the discussion in galaxy formation and generate questions for research projects. With its sensitivity out to 1 micron, LSST will produce the largest samples of both blue- and red-sequence galaxies out to z~2. One can begin to look in exquisite detail at the transition from the blue to the red sequence in the outskirts of clusters or in other environments.

Despite significant increases in data over the last decade, understanding of star formation in *high-redshift star forming galaxies* (z > 2) remains undeveloped. LSST will provide data for roughly 10^9 galaxies at z > 2, 10^7 of which will be at z > 4.5 leading to better understanding of how important mergers are and the relations between galaxy properties and dark matter halo mass. By combining clustering measurements with luminosity-function measurements, LSST observations will constrain the duty-cycle of star-formation in galaxies, and help to determine

Continued on p. 4

In addition to those listed as authors of the Galaxies Science Book chapter, the following are members of the Galaxies Science Collaboration:

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- Leopoldo Infante
- Željko Ivezić
- Vishal Kasliwal
- Lori Lubin
- Vera Margoniner
- Dara Norman
- Mirela Obric
- Casey Papovich
- Jim Pizagno
- Andrew Ptak
- Andy Rasmussen
- Sam Schmidt
- Tony Tyson
- Ovidiu Vaduescu
- Michael Vogeley

the environmental factors that influence this duty cycle. LSST will combine the power of multi-band photometry for color selection and the unprecedented combination of wide area and deep imaging to reveal the rarest, most massive high-redshift galaxies. Characterizing these galaxies will establish new constraints on early hierarchical structure formation and reveal the galaxy formation process associated with high-redshift ($z = 5$-6) quasars. These quasars have supermassive black holes (mass greater than 1,000,000,000 Suns) and researchers are trying to explain them in the context of the formation of galaxies in rare density peaks of dark matter.

The evolution of *galaxy merger* rate with time is poorly constrained. LSST will provide enormous amounts of data for counting mergers as a function of redshift and for quantifying trends as changes in color with morphology or incidence of active galactic nuclei versus merger parameters. How important are galaxy mergers to star formation and the growth of galaxies over time? LSST has the depth, volume, and wavelength coverage needed to perform a study of mergers between normal galaxies out to redshift $z \sim 2$, to produce a statistical study of very luminous mergers out to $z \sim 5$, and to provide the datasets needed to address this question and refine the understanding of mergers.

LSST will reveal more *galaxies at lower surface brightness* than any previous observations. Observations of this category will advance a better understanding of the "outliers" of galaxies, of the merger history of galaxies, of the role of tidal stripping in groups and clusters, and of the lowest surface brightness dwarf galaxies and their evolution. Galaxies at extremely low surface brightness include spiral galaxies with low surface brightness disks, dwarf galaxies, tidal tails and streams and intracluster light (tidal streams from the early stages of galaxy formation now smoothed out into a diffuse stellar halos interspersed among the galaxies). Dwarf galaxies are difficult targets and the local Universe census of these objects is limited. Gas-poor dwarf-elliptical galaxies within about 20 Mpc will be relatively easy to identify in the LSST images, and for many a distance determination from surface-brightness fluctuations will be possible. An important question for the LSST studies will be the extent to which systematic effects in the images (such as scattered light, sky subtraction issues, deblending, and flat-fielding) will limit researchers' ability to select these low-surface brightness galaxies.

Members of the Galaxies Science Collaboration Team will work with colleagues to analyze all these data but unique new collaborations will be needed. *Galaxy Zoo*, launched in 2007, is a project, which harnesses the interest of the general public and the connectivity of the internet to produce powerful contributions to scientific research. *Galaxy Zoo* received more than 50 million classifications during its first year and continues to expand. LSST data sets will be available to the hundreds of thousands of eyes now involved in galaxy classification and LSST E/PO, Galaxies Science Collaboration, scientists at George Mason University, and outreach specialists at Adler Planetarium and Johns Hopkins University have developed *Merger Zoo* to focus this group of citizen scientists on the questions about mergers and interactions. *Merger Zoo* has launched using SDSS data and is ready to apply the flood of data from LSST.

Galaxies and Dark Matter

Connecting galaxies to their underlying dark matter halos provides cosmological context to them and provides detailed merging and formation histories. The distribution of galaxy properties changes radically from the low-mass, high star formation rate galaxies near cosmic voids, where halo masses are low, to the quiescent, massive early type galaxies found in the richest cluster, where dark matter halo masses are very high. LSST will greatly expand our ability to cross-correlate the properties of galaxies with environment due to the power of its accurate photometric redshifts, great depth of field, and richness of galaxy properties it will measure.

By combining the studies of galaxies with clustering and gravitational lensing measurements, LSST will be able to provide data to answer questions about galaxies and dark matter, which now tantalize researchers. Some of these questions are:

- How does the visible matter relate to the underlying dark matter network?
- What is the relationship of galaxy properties to the environment and clustering on various scales?
- What is the role of cluster environment in evolution of member galaxies?
- What timescale and with what mechanism does the cluster environment quench star formation and turn galaxies red?
- How do the ubiquitous tidal tails in disrupted dwarf galaxies scale to other areas of the Universe and constrain the clumpiness of dark matter halos?

The Galaxies Science Collaboration team is working hard to prepare for all that LSST will bring to the study of galaxies. Working with other science collaboration teams, engineers, and simulators as well as studying the data being produced by current surveys, they will be poised to answer these and as yet unknown questions about galaxy evolution with LSST.

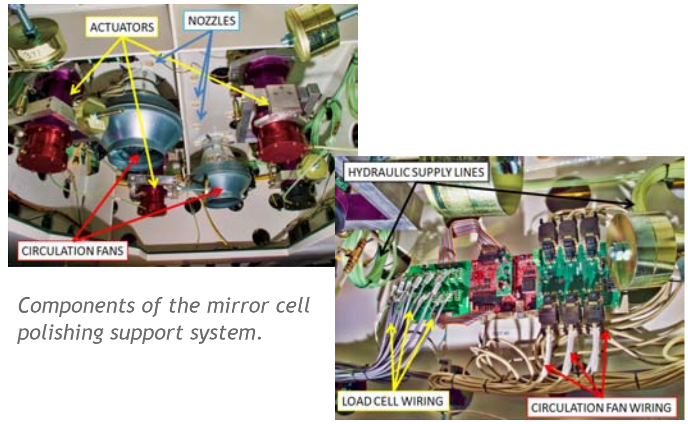
Article by Anna H. Spitz and Henry C. Ferguson

M1/M3 OPTICAL PROCESSING CONTINUES

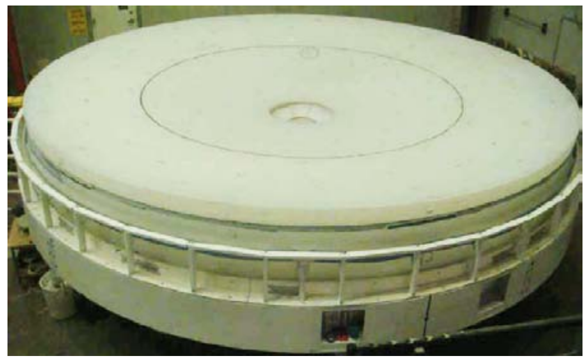
Progress continues with production of the LSST primary (M1) and tertiary (M3) mirrors at the Steward Observatory Mirror Lab. The front surface has been generated and next we move into the grinding portion of the process.

Built into a single piece of glass, dual M1/M3 surfaces have been generated in the substrate (the dark inner circle on the accompanying photo indicates their locations). The next stage in moving toward their final polished state requires enhancements to the mirror cell polishing support system. Installation of 160 hydraulic actuators and load cells, 378 static supports, 64 ventilation fans, over 1500 air circulation nozzles, 1500 feet of hydraulic supply lines, 10,000 feet of electrical wire, and over 1000 electronic connectors is nearly complete. In total, these components enable proper support of the mirror during polishing and test, provide temperature monitoring and control of the glass, and core pressurization to minimize quilting over the mirror core cells. Also shown (upper right) is a view of the underside of the mirror cell illustrating the actuators, fan units, circulation nozzles, and a sample of the wire routing required for operation of the polishing cell. There certainly is a lot going on behind closed doors. Soon the updated cell will be floated via air cart under the Large Optical Generating (LOG) machine to commence loose abrasive grinding.

Article written by Bill Gressler



Components of the mirror cell polishing support system.



LSST M1/M3 blank during cell integration and testing, August, 2010

LSST SOCCER - EARTHQUAKES PREVAIL

LSST Soccer Teams at the 2010 AHM

The gorgeous desert setting of the Ritz-Carlton Dove Mountain created unusual requirements for the now-traditional LSST All Hands Meeting soccer tournament. Only the modest - but of course perfectly manicured - Brisa Lawn was available as a pitch, so our fearless LSST Soccer League President Jeff Kantor adopted international rules for 3-vs.-3 matches, and Engineer Extraordinaire Victor Krabbendam machined custom lightweighted goals. 18 participants were divided into three teams of six, allowing for rapid substitutions as temperatures rose steeply from the 6AM kickoff until the merciful 7:30AM final whistle. Games were a short 24 minutes, allowing each combination of teams to play each morning, and a three-day tournament allowed time for rivalries to build. The captain of the team not currently competing served as referee, with his teammates splayed out around the perimeter of the field to attempt to prevent hard-hit balls from flying off into the surrounding desert, and to retrieve those that escaped at great personal danger of running into cacti. This procedure worked just well enough; by the third day each soccer ball had ricocheted off sufficient cacti to be unable to retain air pressure for more than a few minutes, leading to a hilarious assembly line of balls being retrieved from the desert, re-pumped, and tossed into play barely sooner than they'd be launched into their next spiky encounter. Should we return to this venue in future, we plan to erect a 30-foot-high fence around the field to prevent the balls from crossing the desert except at designated checkpoints.

Day one featured a dominant Northern California Earthquakes team running off to six early points and a strong goal differential, as their years of playing together showed through. Chile showed a penchant for dribbling and taking hard shots to expose the youthful inexperience of the Tucson Thunder. Tucson made some masterful personnel moves overnight, purchasing the contracts of internationals Armin Rest and Jacques Sebag, and the last two days featured close games between three well-matched teams. On day two, inspired presumably by our banquet's after-dinner speaker, who described past floods in Tucson, the Ritz-Carlton grounds crew simulated a 500-year flood by leaving the sprinklers on all night long, and the wet conditions turned our "Beautiful Game" into a slippery one. The grounds crew worked tirelessly to restore the field to prime condition for day three, and the final day of play saw a few masterful technical moves by the Thunder against their natural arch-rival Earthquakes,

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including goals scored on headers, back heels, and a flamboyant nutmeg by Srini Chandrasekharan. The ultimate highlight of the tournament, however, was a day two confrontation between Phil Marshall near midfield and Victor Krabbendam near his own goalbox, who taunted Phil to "bring it on" only to have the Englishman respond by lofting the ball over his head and into the open goal.

In the end, no major injuries were suffered, although tensions ran high as the final standings were determined. An agreement to implement goal-line video technology next year restored the team-building nature of the competition. Although the Thunder beat the Earthquakes twice under the direction of Dr. Rest, they were unable to stop Chile's offense, and the Chileans in turn couldn't unlock the Earthquakes defense, leading to 10 points for Northern California, 8 for Chile, and 7 for the locals. Magnanimous as always, President Kantor procured an ostentatious trophy marked #1 in three locations, clearly a harbinger of the Decadal Survey's virtual trophy awarded to all of LSST the following day. In a combination of complete terror at attempting to drag this through airport security and a tauntingly motivational gesture towards the locals, triumphant Earthquakes captain Jim Bosch arranged for permanent display of the trophy at LSST headquarters in Tucson.

If anyone has information on the whereabouts of Jeff Kantor's souvenir Jabulani ball from South Africa, please contact him. It was last seen flying off into the desert on an unnatural swerving trajectory while emitting a disturbing hiss.

Article written by Eric Gawiser

COLLABORATOR AND TEAMMATE: ERIC GAWISER

Rutgers professor Eric Gawiser, co-chair of the Large-Scale Structure Science Collaboration Team.

He may be most familiar to LSST colleagues as an expert on large-scale structure and galaxies, but some of us have seen Eric Gawiser track down a soccer ball and pass it off to a teammate with the same fervor he brings to his research.

Eric is a member of the *Galaxies* science collaboration and co-chairs the *Large-Scale Structure* science collaboration with Hu Zhan. He runs a thriving research group at Rutgers University where he has been an Assistant Professor in the Department of Physics & Astronomy since 2007. He arrived at Rutgers after postdoctoral positions at the University of California at San Diego and as an NSF Astronomy and Astrophysics Fellow and Andes Prize Fellow at Yale University. His education took him from one coast to another as he completed his A.B. in Physics (1994) at Princeton University and then a Ph.D. (1999) at the University of California at Berkeley. His fascination with cosmology began in high school, but he liked other subjects too. "As an undergrad, I double majored in Physics and Science Policy and was considering a policy career until it came time to apply to graduate school," he says.

His LSST research has allowed him to circle back to the field of his doctorate: "I did a Ph.D. thesis in theoretical cosmology, studying the Cosmic Microwave Background radiation and Large-Scale Structure. Then I moved into observational cosmology, studying galaxy formation using the world's largest telescopes to see very distant young galaxies. Now in LSST I'm involved in the Galaxies and Large-Scale Structure science collaborations, where we're using a mix of theory and simulations to prepare for the incredible LSST dataset. *The Large-Scale Structure* collaboration will measure the clustering of billions of galaxies to probe dark energy, modified gravity, dark matter, neutrino masses and the inflationary potential."

At Rutgers he serves as principal investigator of the Multiwavelength Survey by Yale-Chile (MUSYC) collaboration and is involved in several related astrophysics surveys. He also teaches astronomy for non-science majors and is an Associate at the Hayden Planetarium. Eric defines one of the most satisfying aspects of his work as "mentoring the next generation of scientists." He offers some advice to them: "Science is imperfect, with plenty of politics, but much less than other branches of academia. You need to strike your own ethical balance in terms of how much you're willing to play the game and avoid making enemies, and how much you're going to be the one to speak up when the Emperor has no clothes."

About the trials of research, he notes, "Perhaps the most challenging aspect is knowing when it's right, or at least right with high enough probability to publish. It takes a subtle mix of confidence and caution to be a good researcher - too much confidence and you'd publish things before doing enough checks to be sure they're right; too much caution and you'd never declare it good enough to share with the world."

But for Eric the scientific challenges can lead to great results: "LSST will be a revolution in our ability to measure the histories of cosmic expansion and structure growth. We will be able to use multiple probes and should get redundant results - when we don't, it will identify systematic errors that need correcting. We'll also be able to use the multiple probes to relax typical assumptions about what

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cosmology 'must' look like (essentially the Cosmological Principle that the Universe looks roughly the same in every direction and location) and test them instead. Maybe there won't be any surprises, but if there are, that's a possible Nobel Prize result!"

He continues, "The ambition of LSST is breathtaking — more than an order of magnitude advance in our knowledge of the Solar System, Galaxy, distant Universe, and of things that get brighter or dimmer with time at each distance. The volume of data is unprecedented, but we'll be ready to handle it. LSST is definitely what I want to be working on over the next 15 years."

Eric balances work with exercise by playing soccer twice a week as well as running and bicycling. "Soccer's a great stress release. We've had mini-soccer tournaments at the last two LSST All Hands Meetings, which have really helped the collaborative spirit." In the coming years, expect to see him and his LSST colleagues score a lot of goals!

Article written by Anna Spitz

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