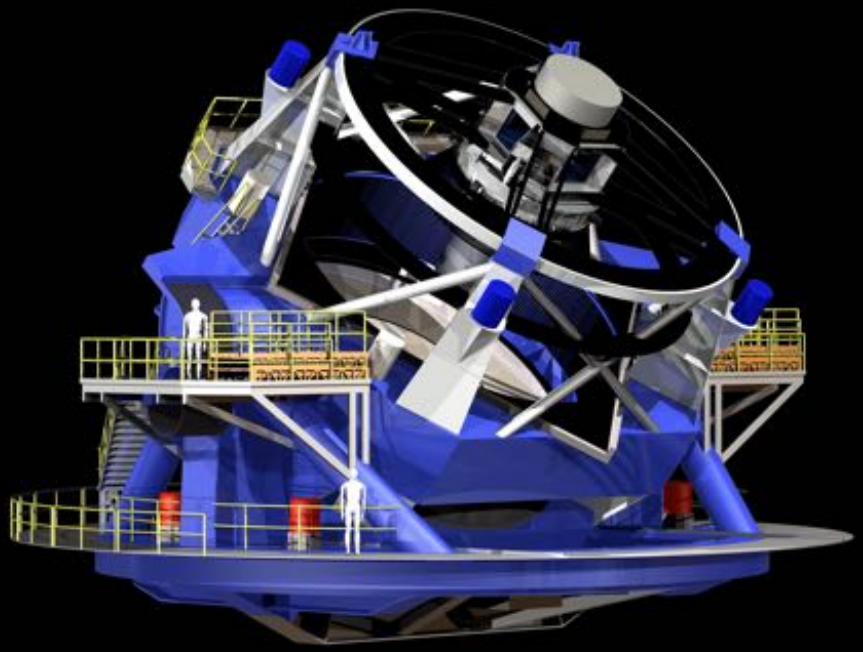
The Large Synoptic Survey Telescope

Lucianne Walkowicz
The Adler Planetarium

Director, LSSTC Data Science Fellowship Program
Member, LSST Science Advisory Committee

What is the LSST?

A survey of 37 billion objects in space and time



What is the LSST?

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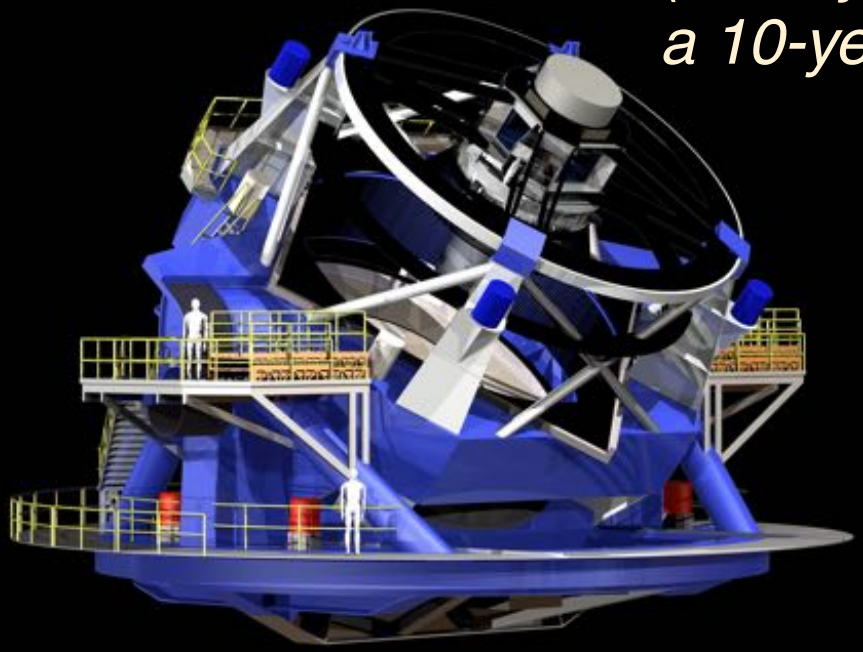
An optical/near-IR survey of half the sky in ugrizy bands to r~27.5 (36 nJy) based on ~825 visits over a 10-year period



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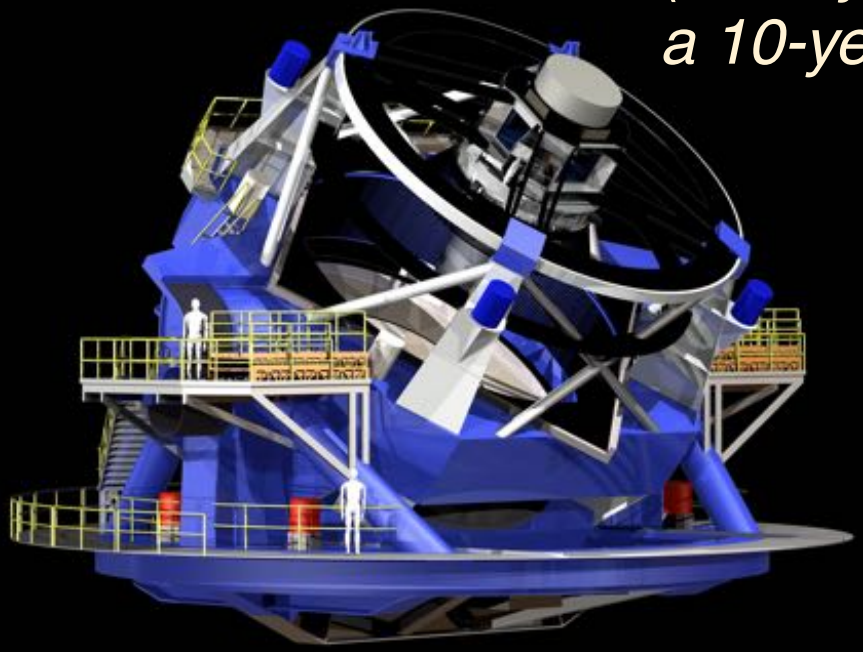


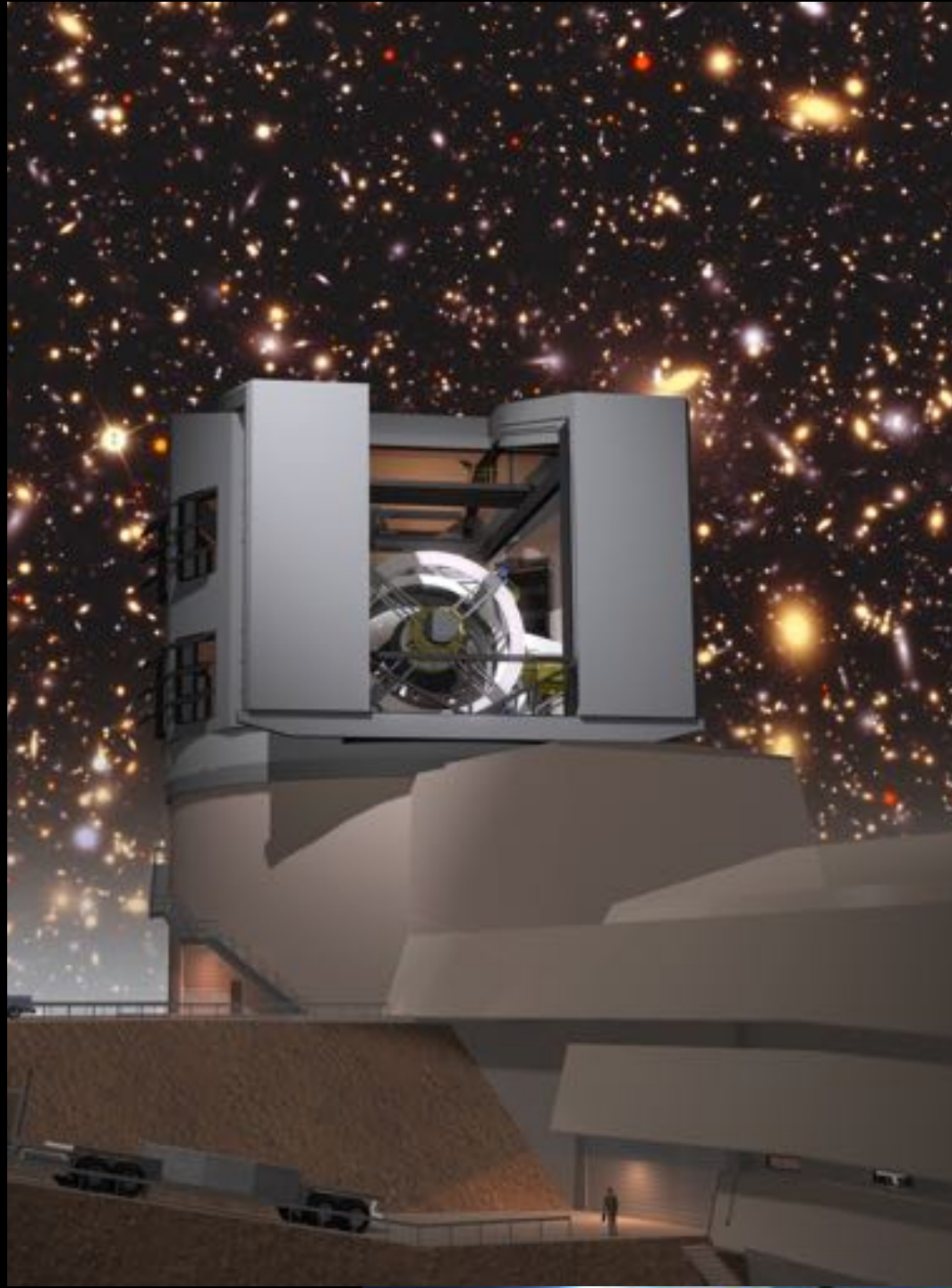
Science Objectives

- The Dark Universe
- The Transient Universe
- Solar System Inventory
- Mapping the Milky Way

LSST
Large Synoptic Survey Telescope

Office of Science
U.S. DEPARTMENT OF ENERGY

NSF



Private Contributions via LSST Corporation

Charles Simonyi
Bill & Melinda Gates
+…

Member Institutions

Adler Planetarium
California Institute of Technology
Carnegie Mellon University
Chile
Columbia University
Drexel University
Fermi National Accelerator Laboratory
Google, Inc.
Institut de Physique Nucleaire et de Physique des Particules (IN2P3)
Istituto Nazionale Di Astrofisica (INAF)
Johns Hopkins University
Kavli Institute for Particle Astrophysics and Cosmology (KIPAC) - Stanford University
Kentucky Association for Research with LSST (KARL)
Las Cumbres Observatory Global Telescope Network
Lawrence Livermore National Laboratory (LLNL)
Los Alamos National Laboratory (LANL)
National Optical Astronomy Observatory
Northwestern University
Princeton University
Purdue University
Rutgers University
SLAC National Accelerator Laboratory
Space Telescope Science Institute
Texas A & M University
The Institute of Physics of the Academy of the Czech Republic
The Pennsylvania State University
The University of Arizona
The University of Chicago
University of California at Davis
University of Illinois at Urbana-Champaign
University of Oxford
University of Pennsylvania
University of Pittsburgh
University of Portsmouth
University of Washington

International Contributors

Argentina
- Observatorio Astronómico de Córdoba
- UNC – CONICET (OAC-IATE)

Australia
- CAASTRO
- The University of Western Australia (UWA)

Brazil
- Laboratorio Interinstitucional de e-Astronomia (LIneA)
- Laboratorio Nacional de Astrofisica (LNA)
- Rede Nacional de Ensino e Pesquisa (RNP)
- Academic Network at Sao Paulo (ANSP)
- Americas Pathways (AMPATH)

Canada - University of Toronto (UofT)

China - LSST-China Consortium

Croatia - Ruđer Bošković Institute (RBI)

Denmark
- Aarhus University (AU)
- Neils Bohr Institute (NBI)

France
- IN2P3

Germany
- Astronomisches Rechen-Institut, Zentrum für Astronomie de Universität Heidelberg (ARI/ZAH)
- Deutsches Elektronen-Synchrotron (DESY)
- Leibniz-Institut für Astrophysik Potsdam (AIP)
- Ludwig-Maximilians-Universität (LMU)
- Max Planck Institute for Astrophysics (MPA)
- Max Planck Institute for Astronomy (MPIA)
- Max Planck Institute for Extraterrestrial Physics (MPE)

Hungary
- Eötvös Loránd University (ELTE)
- Konkoly Observatory

India
- Inter-University Centre for Astronomy and Astrophysics (IUCAA)

Italy
- Istituto Nazionale di Astrofisica (INAF)

Korea
- Korea Astronomy and Space Science Institute (KASI)

New Zealand - University of Auckland (UOA)

Poland - National Centre for Nuclear Research (NCBJ)

Serbia - Nano Center

Slovenia - University of Nova Gorica (UNG)

South Africa - The National Research Foundation (NRF)

Spain
- Barcelona-Madrid Consortium (BCN-MAD)
- Instituto de Astrofisica de Canarias (IAC)

Sweden
- Stockholm University Department of Astronomy (SU-Astronomy)
- Stockholm University Department of Physics (SU-Physics)

Switzerland
- Eidgenoessische Technische Hochschule Zuerich (ETH Zurich), Institute for Astronomy

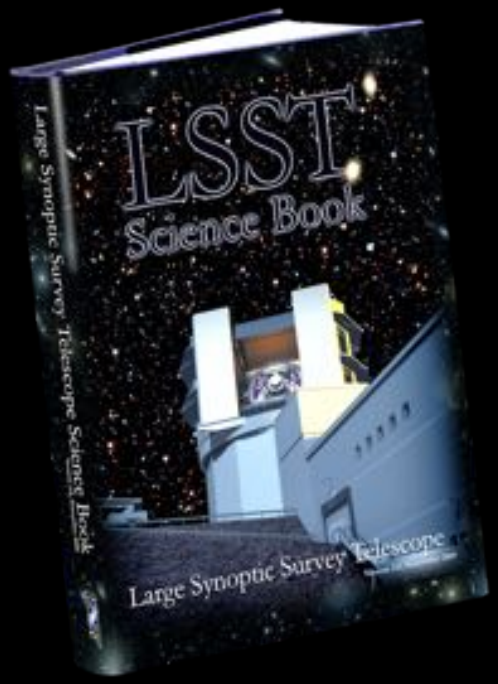
Taiwan
- Academia Sinica Institute of Astronomy & Astrophysics (ASIAA)
- Graduate Institute of Astronomy of National Central University (NCU)

United Kingdom
- Science and Technology Facilities Council (STFC) - UK LSST Consortium

Science Collaborations

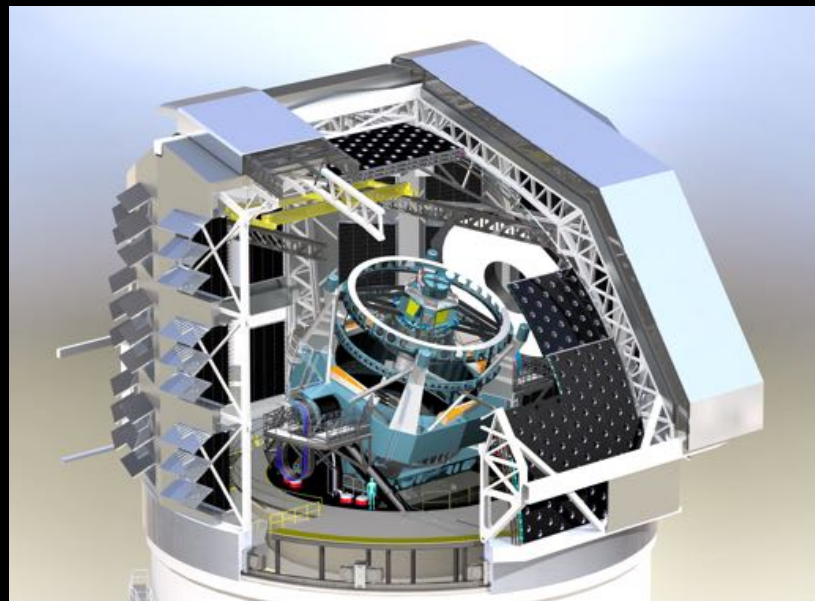
- Galaxies
  - Chair(s): Manda Banerji (Institute of Astronomy); Sugata Kaviraj (University of Hertfordshire); DM Liaison: Robert Lupton
- Stars, Milky Way, and Local Volume
  - Chair(s): John Bochanski (Rider University); John Gizis (University of Delaware); Nitya Jacob Kallivayalil (University of Virginia); DM Liaison: Colin Slater
- Solar System
  - Chair(s): Meg Schwamb (Gemini Observatory Northern Operations Center); David Trilling (Northern Arizona University); DM Liaison: Mario Juric
- Dark Energy
  - Chair(s): Eric Gawiser (Rutgers The State University of New Jersey); Phil Marshall (KIPAC); DM Liaison: Robert Lupton
- Active Galactic Nuclei
  - Chair(s): Niel Brandt (Pennsylvania State University); DM Liaison: Željko Ivezić
- Transients/variable stars
  - Chair(s): Federica Bianco (New York University); Rachel Street (LCO); DM Liaison: Melissa Graham, Eric Belm
- Strong Lensing
  - Chair(s): Charles Keeton (Rutgers-The State University of New Jersey); Aprajita Verma (Oxford University); DM Liaison: Jim Bosch
- Informatics and Statistics
  - Chair(s): Tom Loredo (Cornell University); Chad Schafer (Carnegie Mellon University); DM Liaison: Leanne Guy

Why do the LSST Science Collaborations exist?



Collaborations played big role in making the science case for LSST

Now they help lay ground work for making the best use of LSST



Telescope Site

Atmospheric limited seeing (0.7” in r)


LSST 2017

LSST 2018

Photo by Gianluca Lombardi

System Requirements

Light bucket

Agile

Large Field-of-View

Excellent image quality

Fast Readout

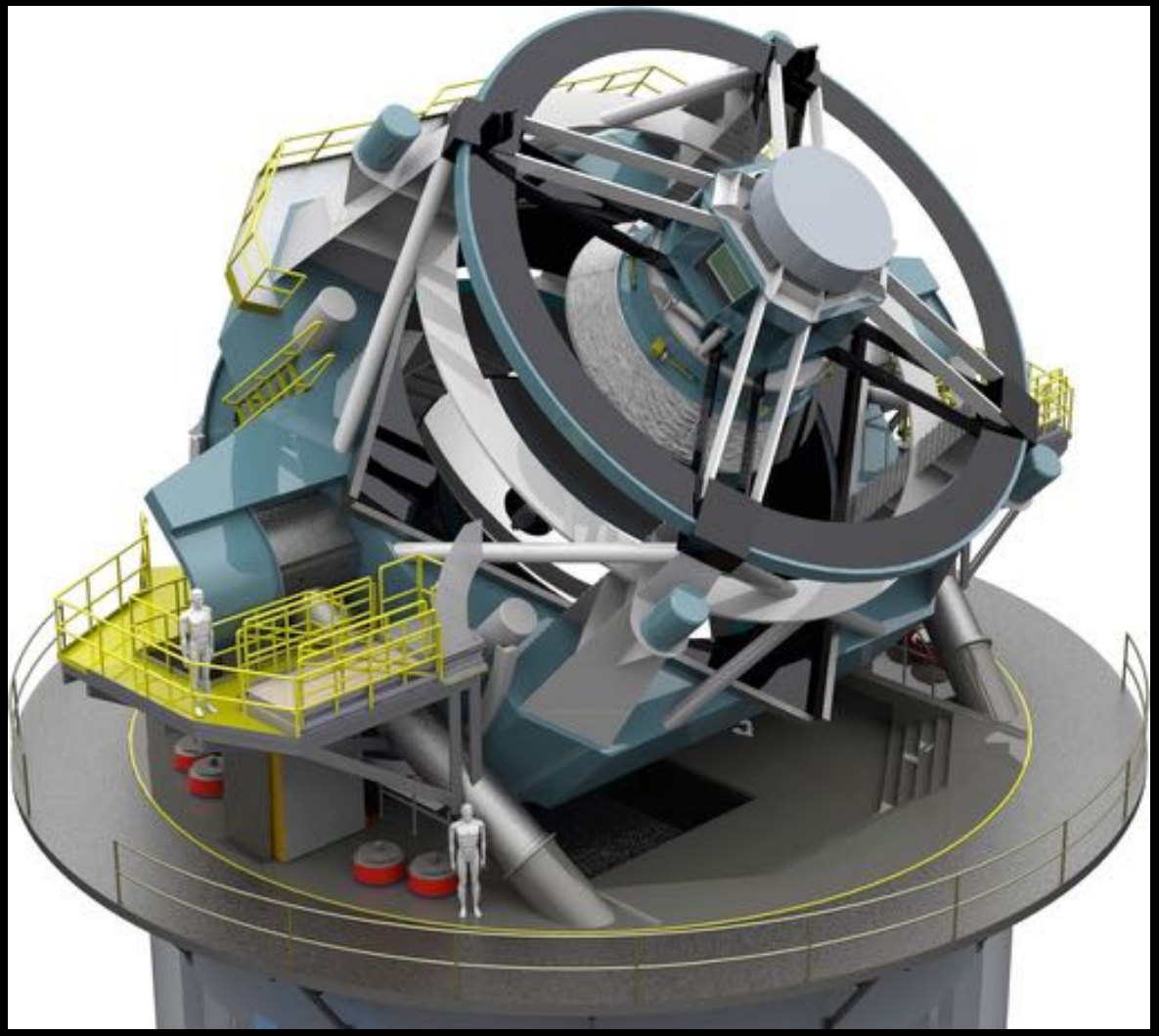
Sophisticated Software

20 TB of data a night!

LSST
Large Synoptic Survey Telescope

8.4m mirror
(6.7m effective)

5 sec slew+settle



LSST Mirrors Completed

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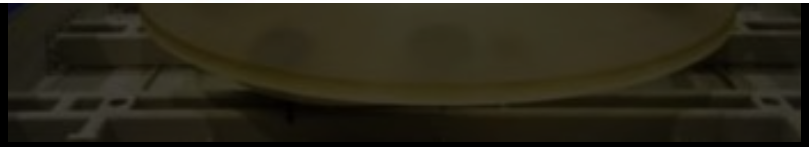
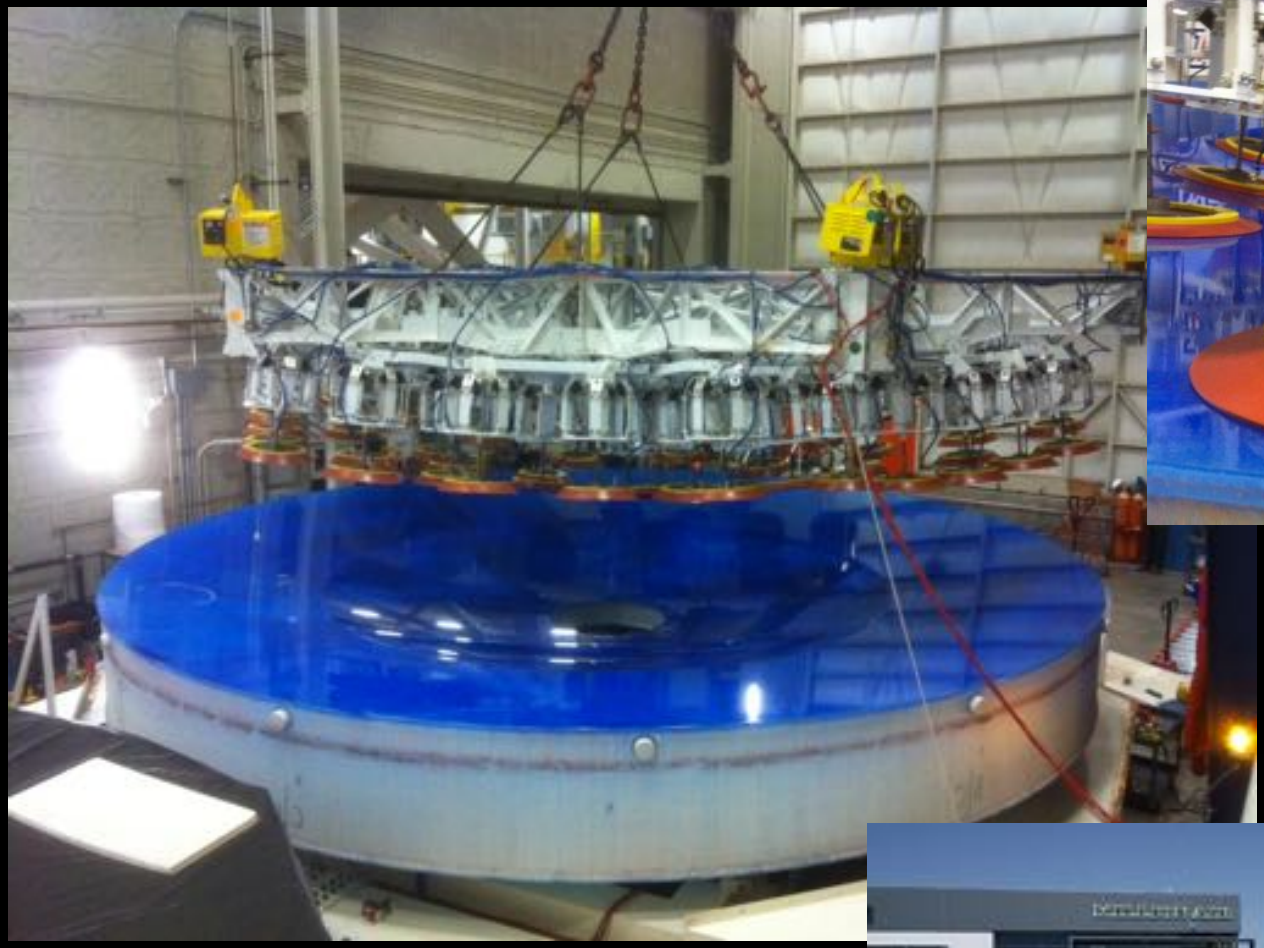
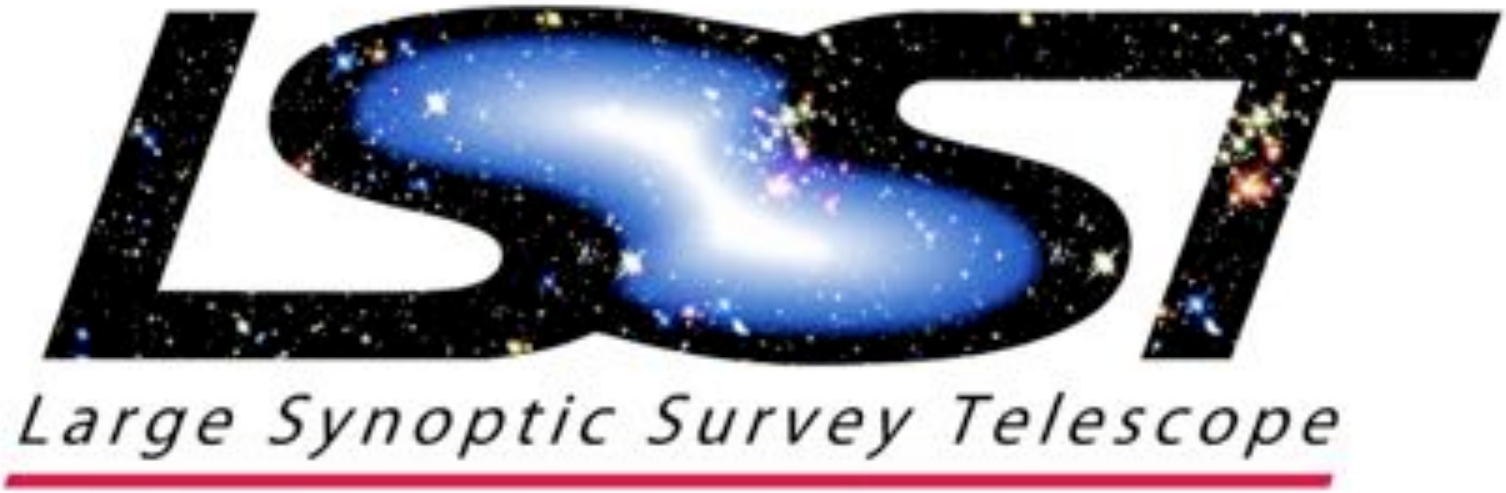


M1/M3 Mirror Completion



How to move a very big mirror:



How to move a very big mirror:

Large Synoptic Survey Telescope

The finished Primary/Tertiary mirror cell moves from CAID to Richard F. Caris Mirror Lab at the University of Arizona

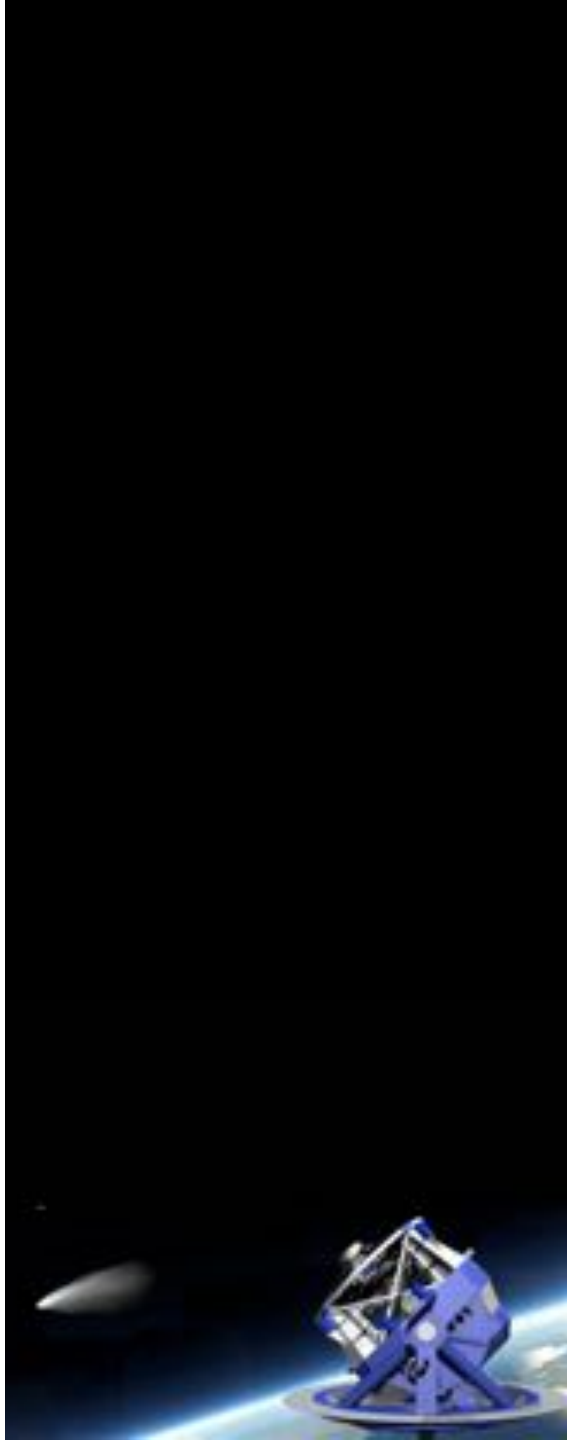
October 10, 2018

LSST Astronomy
@LSST

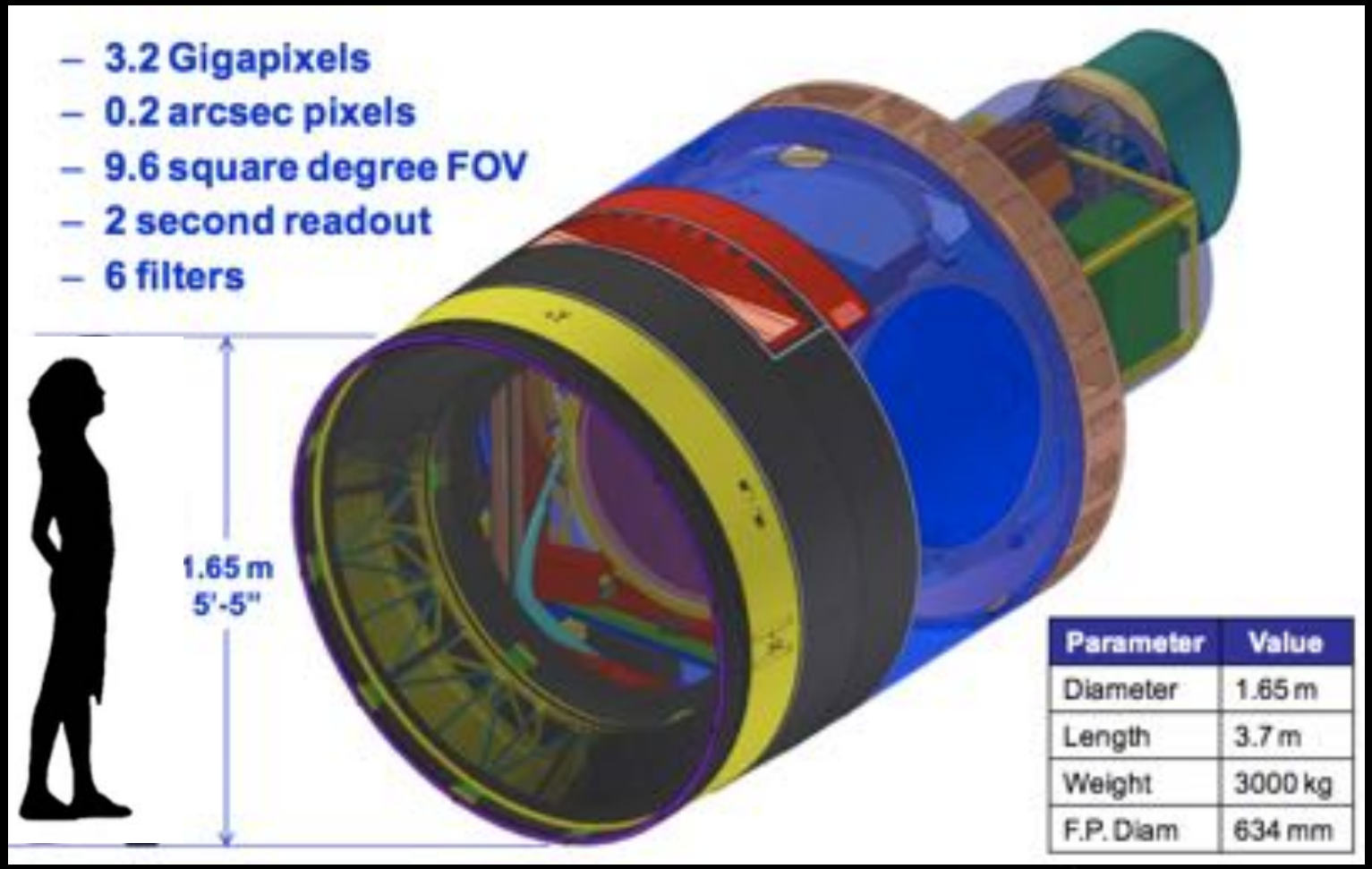
Following

Last night the @LSST Coating Chamber traveled 8.7 km, from 11pm to 3:45am, starting at TPC @PuertoCoquimbo and stopping at the outskirts of Coquimbo, Chile. That's an average of about 2 km per hour! Photo: Manuel Paredes/NSF/AURA/Gemini #NSFScience

1:40 PM - 30 Oct 2018

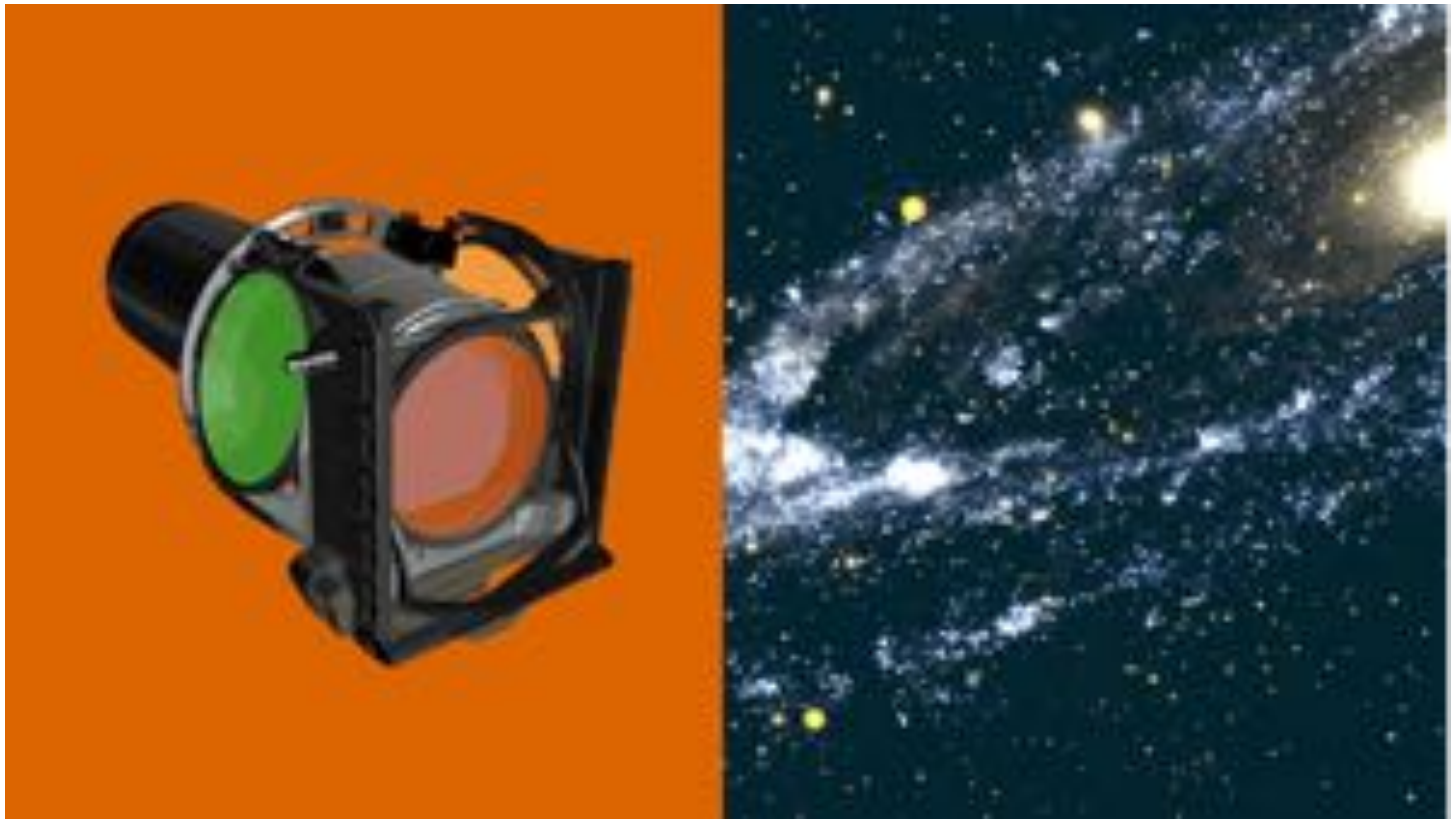


LSST Camera

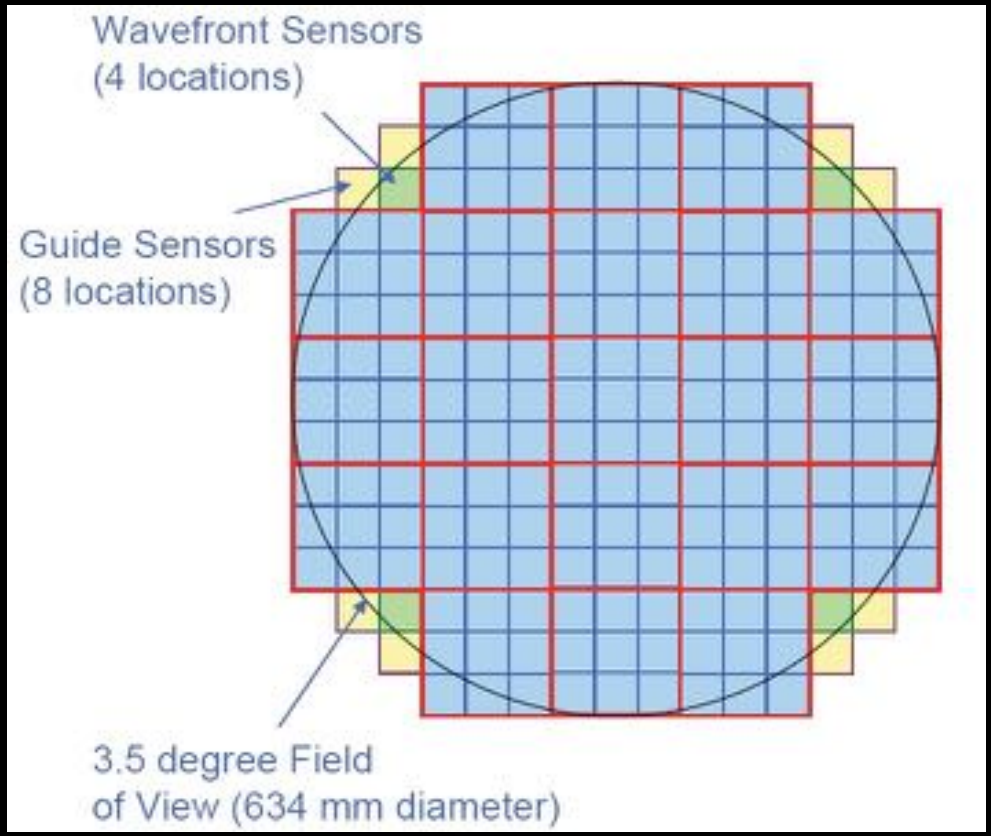


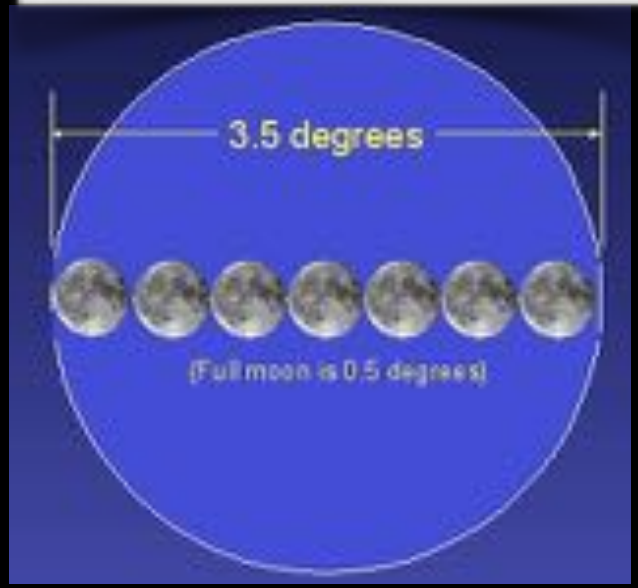
Displaying *one LSST image*
would take *1500 HD TV screens*!

A Multicolor View of the Universe

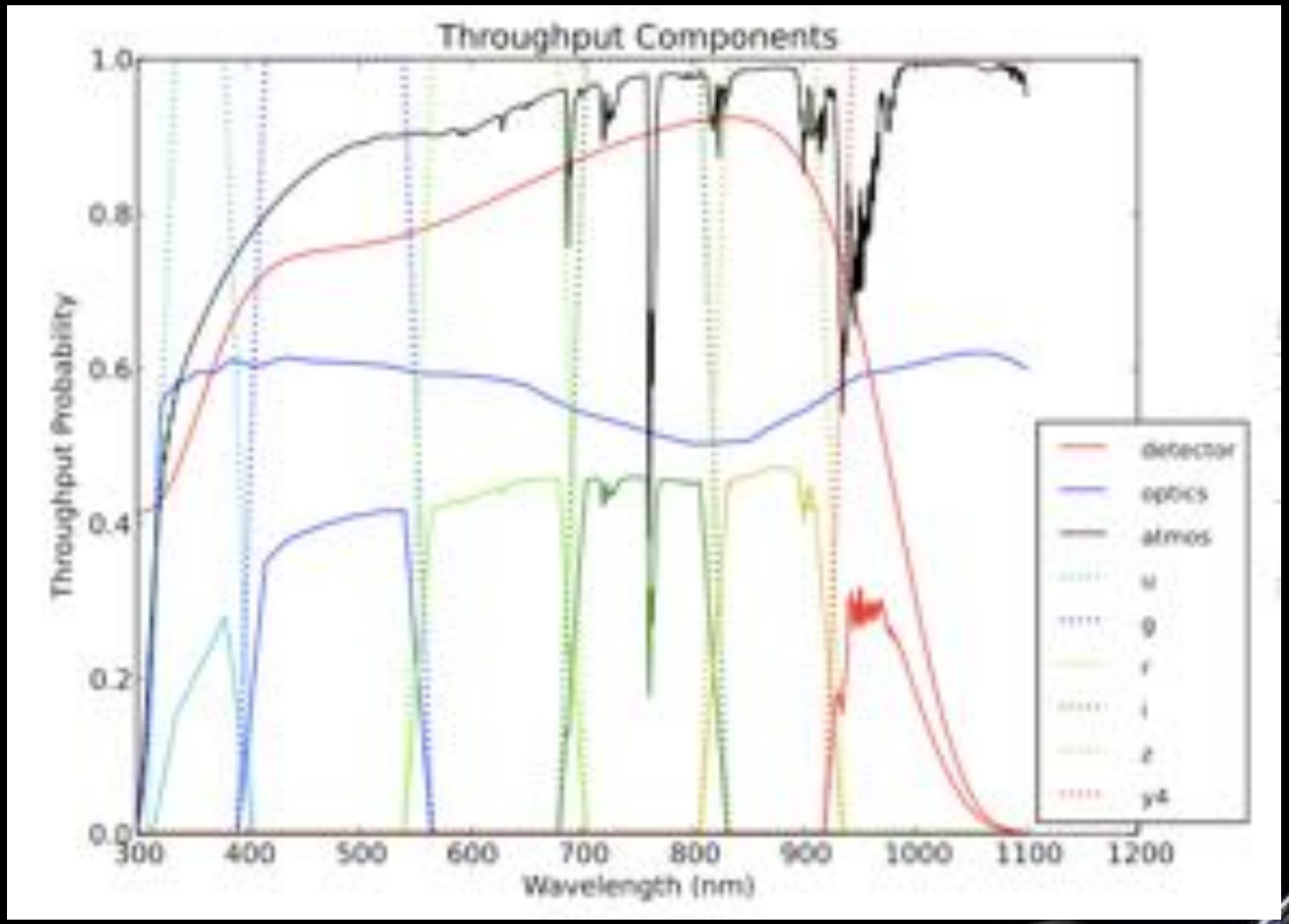


CCD Rafts/Field of View





ugrizY Filters



u: 26.1 g: 27.4 r: 27.5 i: 26.8 z: 26.1 y: 24.9

Observing Strategy in Development

Main Survey
90% of time

18,000 sq deg to uniform depth over 10 years

Visit: two 15 sec consecutive exposures

Same pointing revisit within 1 hour

Mini Surveys
10% of time

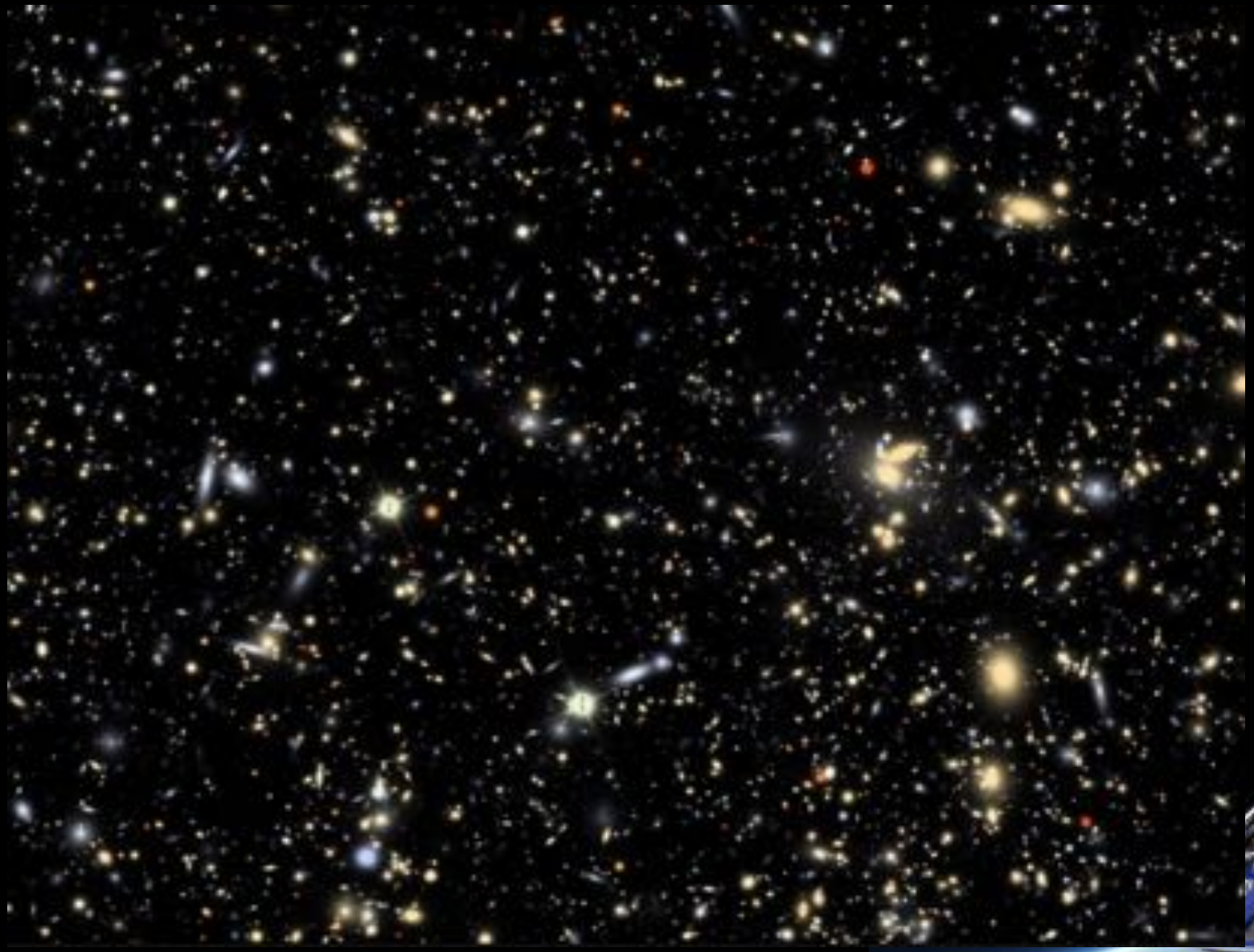
A variety of different surveys planned/proposed

some fields set: Elais S1, XMM-LSS, Extended Chandra Deep Field-South, and COSMOS

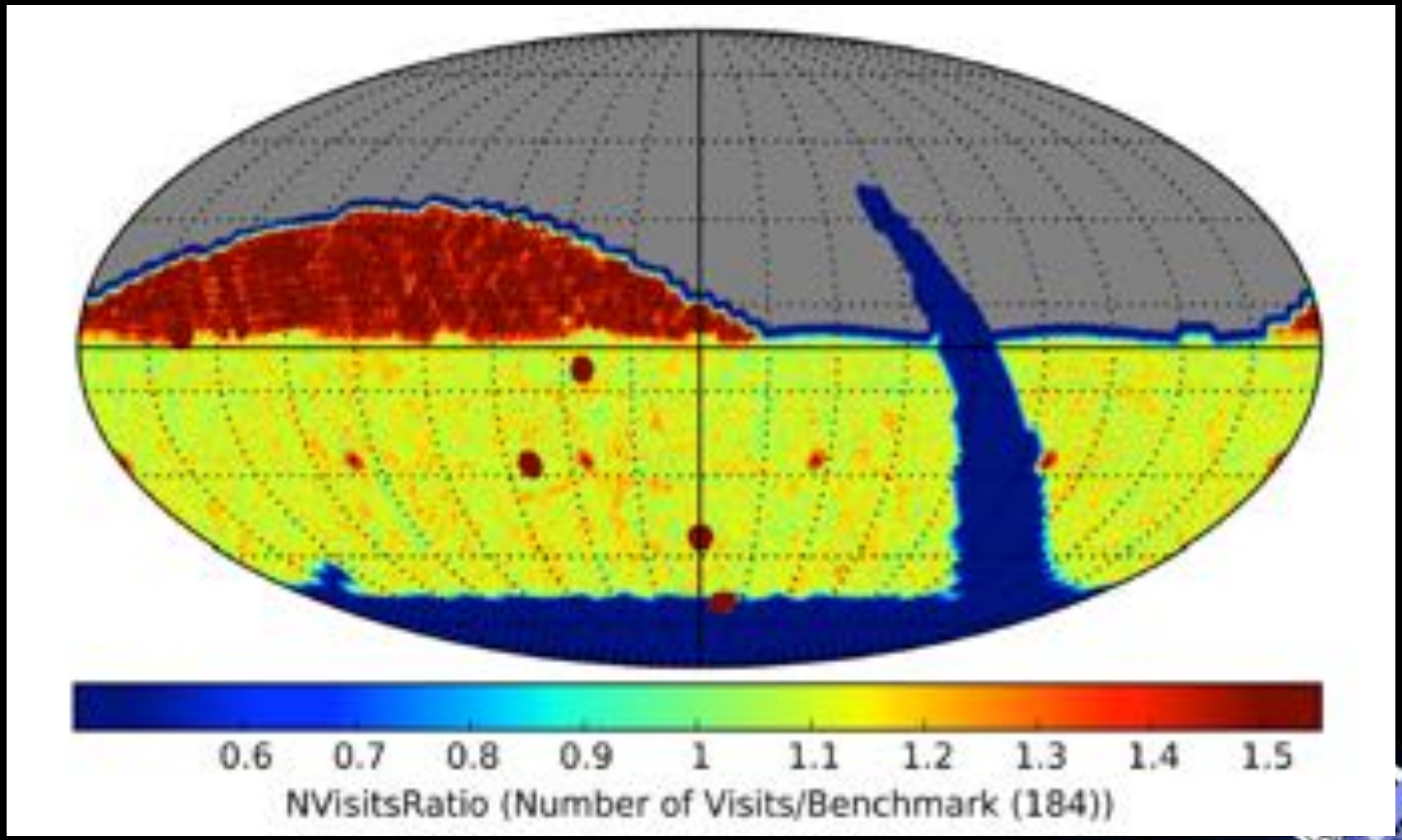
Galactic plane, northern ecliptic spur, south celestial pole, twilight..?

Large Synoptic Survey Telescope

Example simulation: 1.7ppm of the survey



Studying observing strategy with simulations



ls.st/o5k

Large Synoptic Survey Telescope

Science-Driven Optimization of the LSST Observing Strategy

LSST Science Collaborations: Phil Marshall, Timo Anguita, Federica B. Bianco, Eric C. Bellm, Niel Brandt, Will Clarkson, Andy Connolly, Eric Gawiser, Zeljko Ivezic, Lynne Jones, Michelle Lochner, Michael B. Lund, Ashish Mahabal, David Nidever, Knut Olsen, Stephen Ridgway, Jason Rhodes, Ohad Shemmer, David Trilling, Kathy Vivas, Lucianne Walkowicz, Beth Willman, Peter Yoachim, Scott Anderson, Pierre Antilogus, Ruth Angus, Iair Arcavi, Humna Awan, Rahul Biswas, Keaton J. Bell, David Bennett, Chris Britt, Derek Buzasi, Dana I. Casetti-Dinescu, Laura Chomiuk, Chuck Claver, Kem Cook, James Davenport, Victor Debattista, Seth Digel, Zoheyr Doctor, R. E. Firth, Ryan Foley, Wen-fai Fong, Lluis Galbany, Mark Giampapa, John E. Gizis, Melissa L. Graham, Carl Grillmair, Phillipe Gris, Zoltan Haiman, Patrick Hartigan, et al. (52 additional authors not shown)

(Submitted on 14 Aug 2017)

The Large Synoptic Survey Telescope is designed to provide an unprecedented optical imaging dataset that will support investigations of our Solar System, Galaxy and Universe, across half the sky and over ten years of repeated observation. However, exactly how the LSST observations will be taken (the observing strategy or "cadence") is not yet finalized. In this dynamically-evolving community white paper, we explore how the detailed performance of the anticipated science investigations is expected to depend on small changes to the LSST observing strategy. Using realistic simulations of the LSST schedule and observation properties, we design and compute diagnostic metrics and Figures of Merit that provide quantitative evaluations of different observing strategies, analyzing their impact on a wide range of proposed science projects. This is work in progress: we are using this white paper to communicate to each other the relative merits of the observing strategy choices that could be made, in an effort to maximize the scientific value of the survey. The investigation of some science cases leads to suggestions for new strategies that could be simulated and potentially adopted. Notably, we find motivation for exploring departures from a spatially uniform annual tiling of the sky: focusing instead on different parts of the survey area in different years in a "rolling cadence" is likely to have significant benefits for a number of time domain and moving object astronomy projects. The communal assembly of a suite of quantified and homogeneously coded metrics is the vital first step towards an automated, systematic, science-based assessment of any given cadence simulation, that will enable the scheduling of the LSST to be as well-informed as possible.

Comments: 312 pages, 90 figures. Browse the current version at this https URL, new contributions welcome!

Subjects: **Instrumentation and Methods for Astrophysics (astro-ph.IM)**; Cosmology and Nongalactic Astrophysics (astro-ph.CO); Earth and Planetary Astrophysics (astro-ph.EP); Astrophysics of Galaxies (astro-ph.GA); Solar and Stellar Astrophysics (astro-ph.SR)

Cadence optimization still happening!

Large Synoptic Survey Telescope (LSST)

Call for White Papers on LSST Cadence Optimization

Željko Ivezić, Lynne Jones, Tiago Ribeiro,
the LSST Project Science Team,
and the LSST Science Advisory Committee

Document-28382

Computing

*The computing cluster at the **LSST Archive** at NCSA will run the processing pipelines.*

- Single-user, single-application data center
- Commodity computing clusters.
- Distributed file system for scaling and hierarchical storage
- Local-attached, shared-nothing storage when high bandwidth needed

Long Haul Networks to transport data from Chile to the U.S.

- *2x100 Gbps from Summit to La Serena (new fiber)*
- *2x40 Gbps for La Serena to Champaign, IL (path diverse, existing fiber)*

Data Products

http:// ls.st / dpdd

Prompt

A stream of ~10 million time-domain events per night, detected and transmitted to event distribution networks within 60 seconds of observation.

A catalog of orbits for ~6 million bodies in the Solar System.

Data Releases

A catalog of ~37 billion objects (20B galaxies, 17B stars), ~7 trillion observations ("sources"), and ~30 trillion measurements ("forced sources") accessible through online databases.

Reduced single-epoch, deep co-added images.

User generated

Services and computing resources at the Data Access Centers enabling limited analysis, production, and federation of added value products.

Web APIs enabling the use of remote analysis tools.

Public LSST pipeline code for deeper insight into LSST data products.

Prompt Data Products

Alert generation (60 sec)

Forced photometry (~1 day)

- automatic on all new sources
- on request for limited coordinates

Limited alert subscription/filtering

- small # of alerts per pointing
- very basic criteria - no classification

Alert Firehose Support

LSST computing is sized for 10M alerts/night (average), 10k/visit (average), 40k/visit (peak)

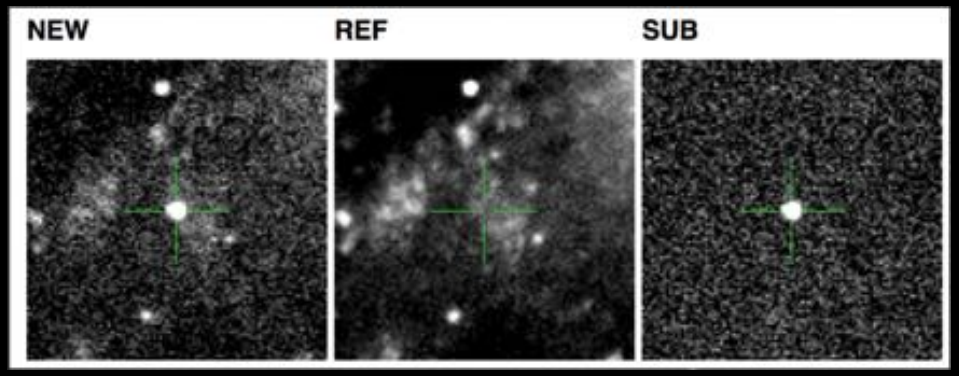
Alert filtering service, to select subsets of alerts, as well as serve the full stream to external event brokers.

Dedicated networking for moving data from Chile to the US

Dedicated image processing clusters

New image differencing pipelines with improved algorithms

Alert Packets Contain Useful Information



The photometric, astrometric, and shape characterization of the detected source

30x30 pixel (on average) cut-out of the difference image (FITS) - 30x30 pixel (on average) cut-out of the template image (FITS)

The time series (up to a year) of all previous detections of this source

Various summary statistics (“features”) computed of the time series

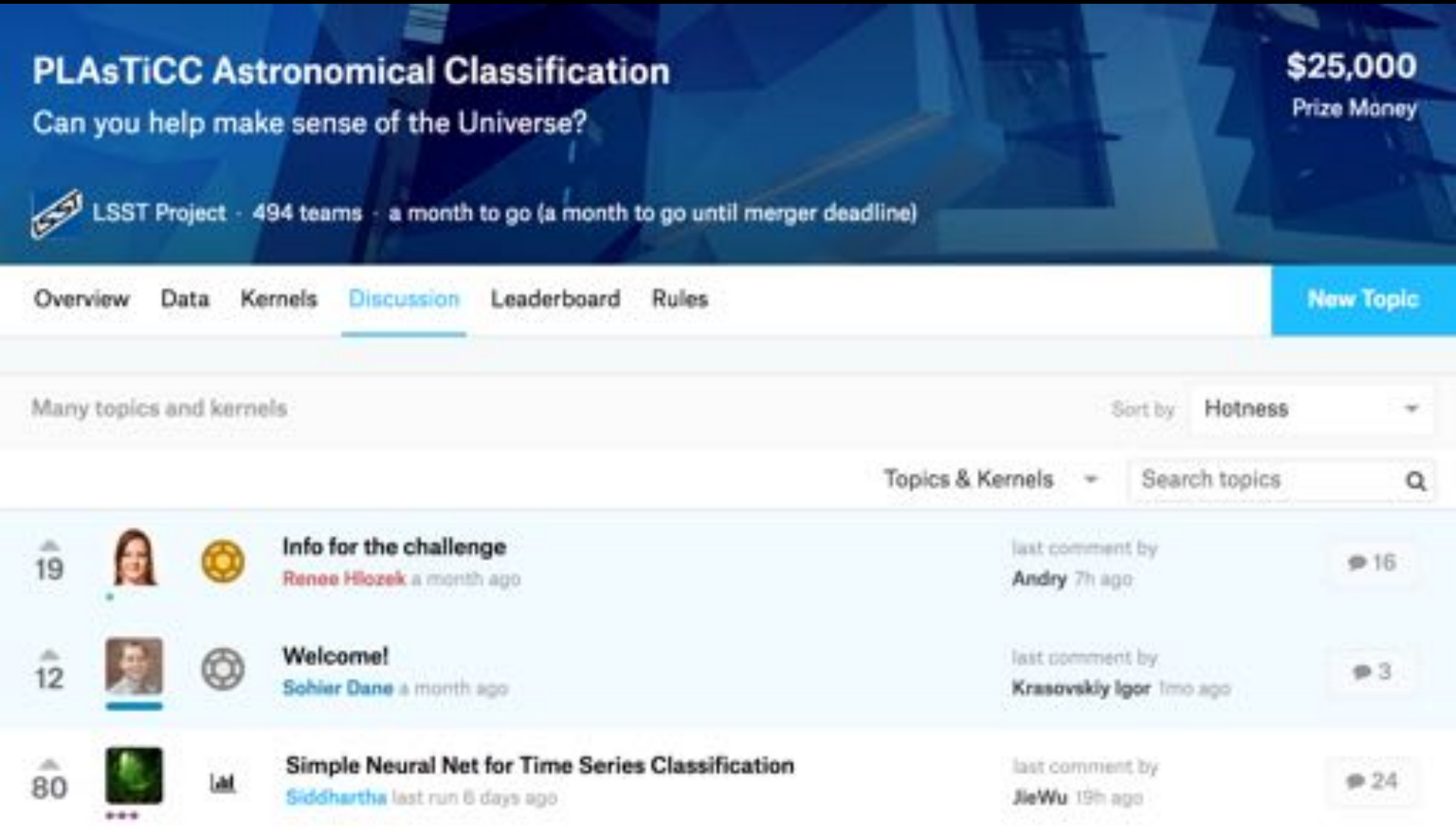
Discovery ≠ Characterization ≠ Classification

Something's Happening	How it's Happening	Why it's Happening

While LSST doesn't provide *classification,*
it does provide the means to *characterize*

- ⟶ Nightly products (real time)
- ⟶ Aggregate products (data releases)
- ⟶ Contextual information (neighbors, cross-catalogs)

PLAsTiCC Kaggle Challenge



Spectroscopic Follow-up Resources

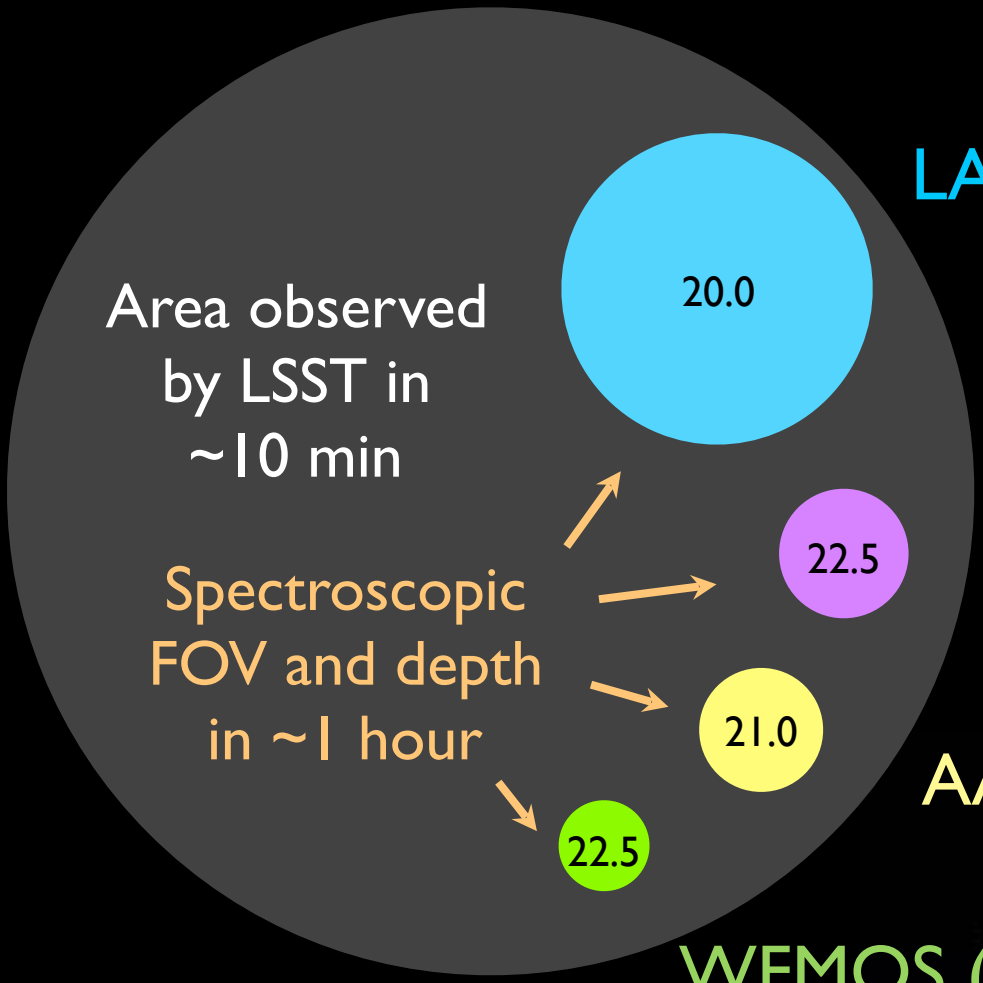


Figure adapted from Adam Myers

Multimessenger Co-observing

Multiple wavebands provide SED constraints

e.g. radio (SKA), GW (LIGO), X-ray (LOFT, eROSITA), IR (Euclid)

Multiple potential contexts:

Main survey, ToO, Deep Drilling Fields

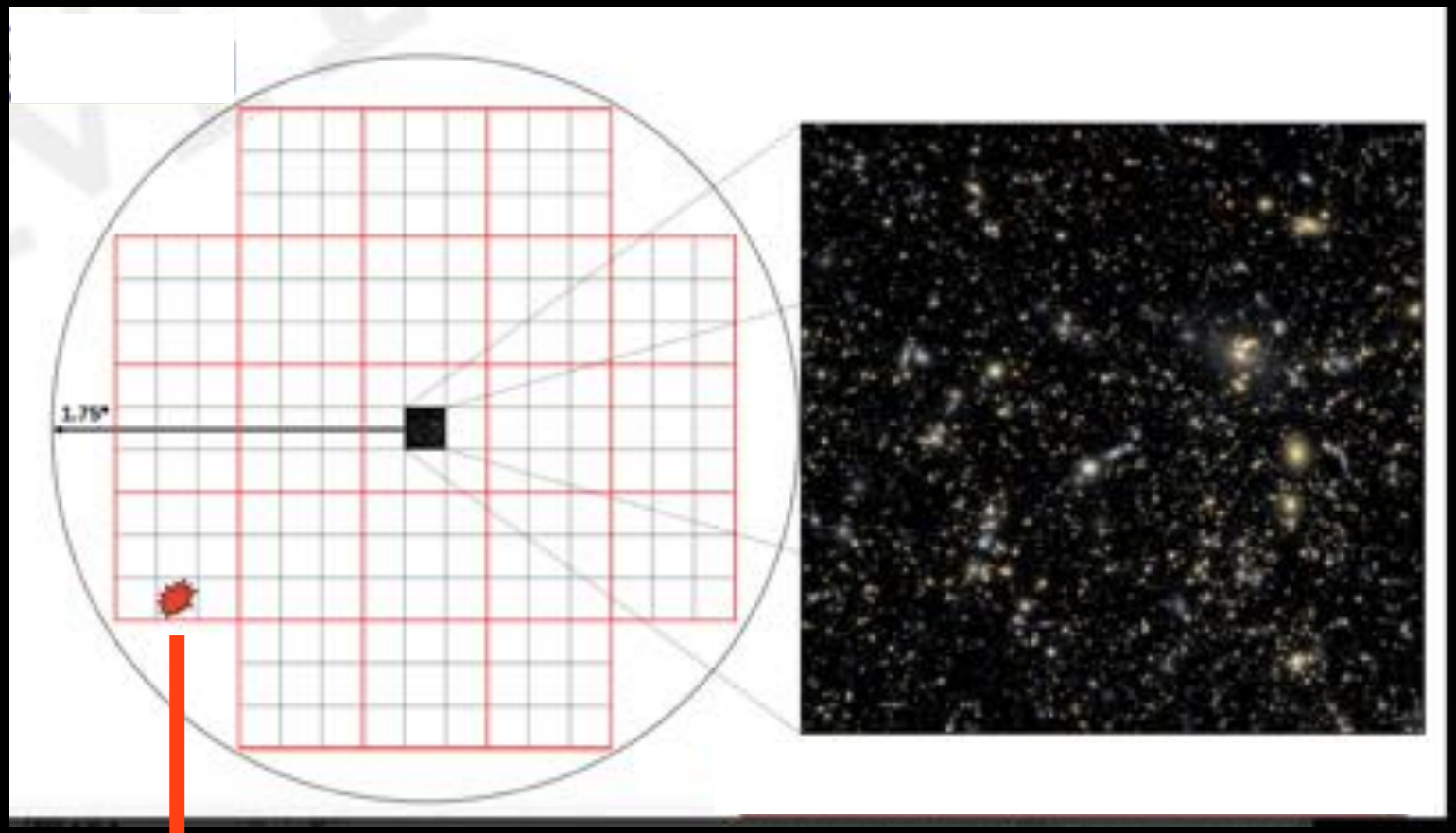
Logistical issues require forethought

Programmatic: Target Updates

Data access/ information sharing

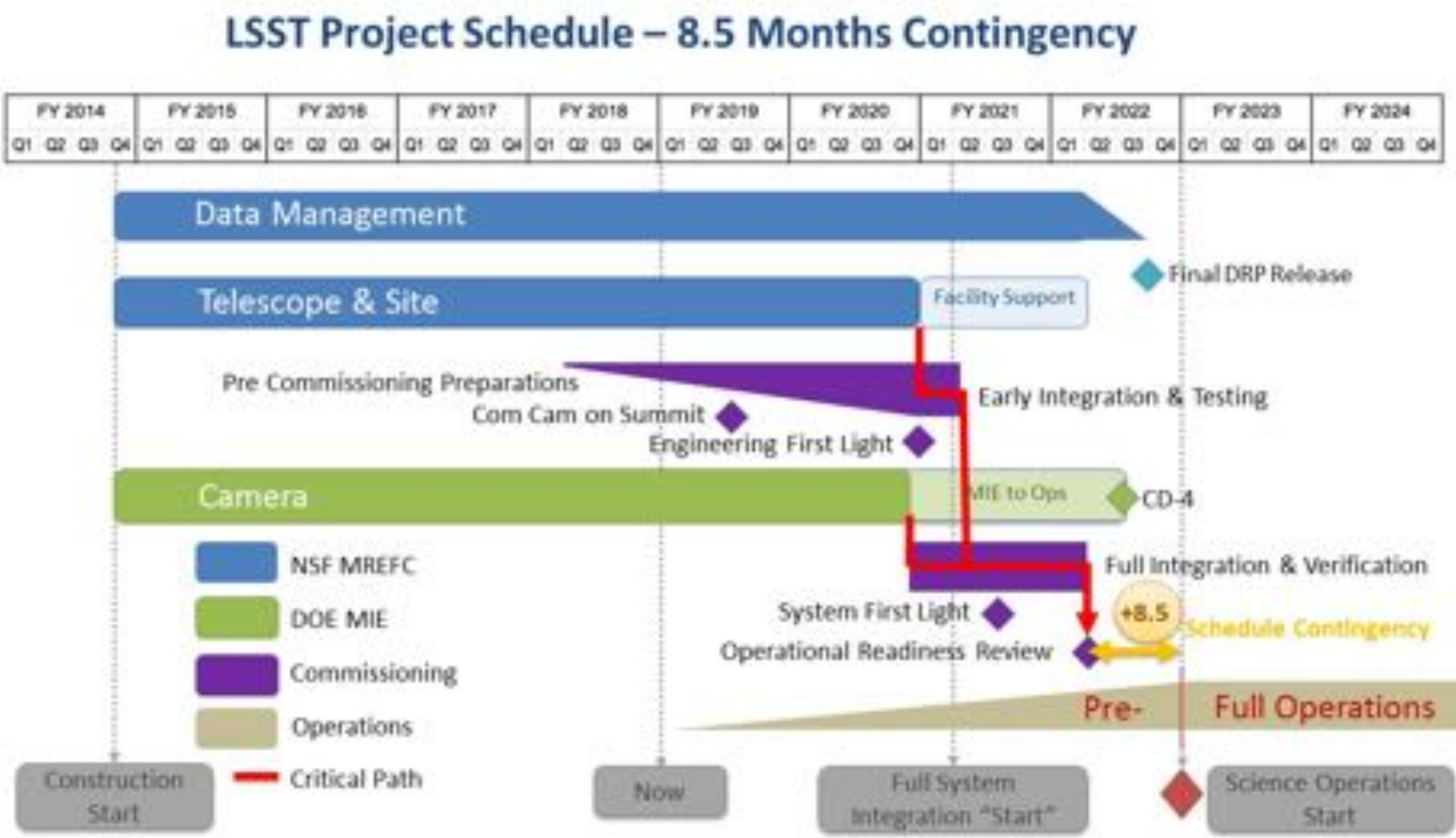
Large scale collaboration/communication

Synergy between a-LIGO / LSST



LSST field-of-view well-matched to localize LIGO events

LSST is coming soon!



https://www.lsst.org/participate

- Be informed by subscribing to our Project Digest
- Or join the Scientists Mailing List
- The community.lsst.org forum is available for technical discussion and community-based software support
- Participate in the call for community white papers on the survey strategy by November 30th 2018
- Read the Community Observing Strategy Evaluation Paper (COSEP) on arxiv and contribute methods to evaluate existing survey strategies through the living document in GitHub.
- Become an Institutional Member of LSSTC
- Become an International Contributor to support Operations
- Join a Science Collaboration
- Interact with the LSST Science Advisory Committee
- Visit the LSST Data Management Pages for information on downloading the Open Source Software stack and accessing data sets; begin by reading the User's Guide
- Visit the LSST Simulation Website for information on the LSST Image and Operations Simulations efforts.
- Join the Team - LSST is Hiring

The LSST Science Book contains a wealth of science cases

https://www.lsst.org/scientists/scibook

LSST System Design
System Performance
Education and Public Outreach
The Solar System
Stellar Populations
Milky Way & Local Volume Structure
The Transient & Variable Universe
Galaxies
Active Galactic Nuclei
Supernovae
Strong Lenses
Large-Scale Structure
Weak Lensing
Cosmological Physics

Large Synoptic Survey Telescope

Thanks!

Project Timeline