The Large Synoptic Survey Telescope

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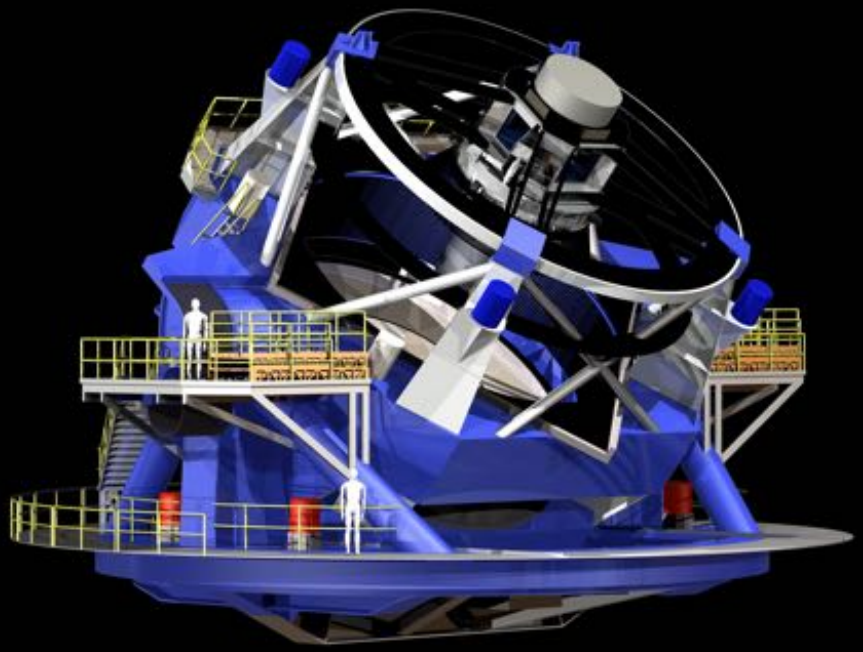
The Adler Planetarium

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



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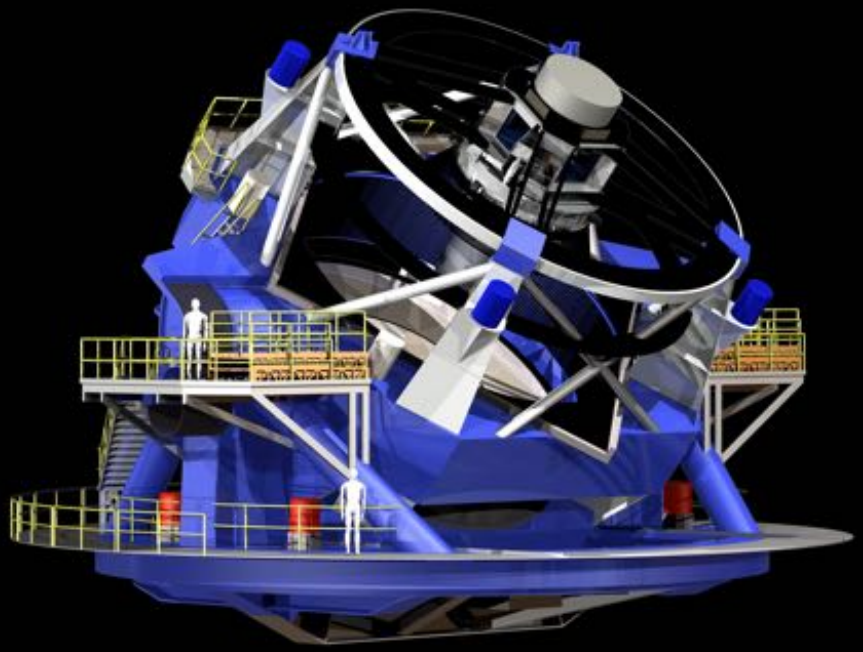
An optical/near-IR survey of half the sky in ugrizy bands to r~27.5 (36 nJy) based on ~825 visits over a 10-year period



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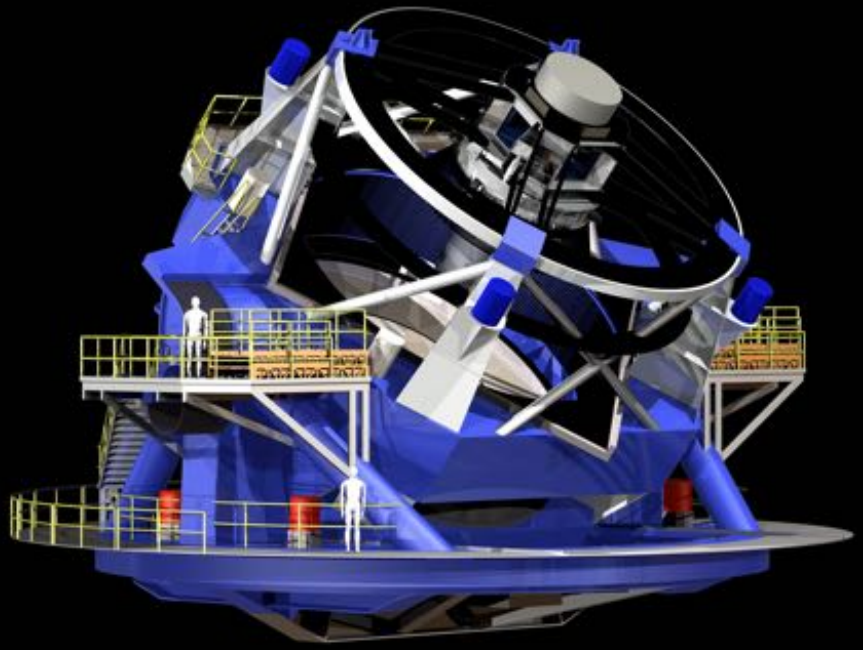


Science Objectives

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

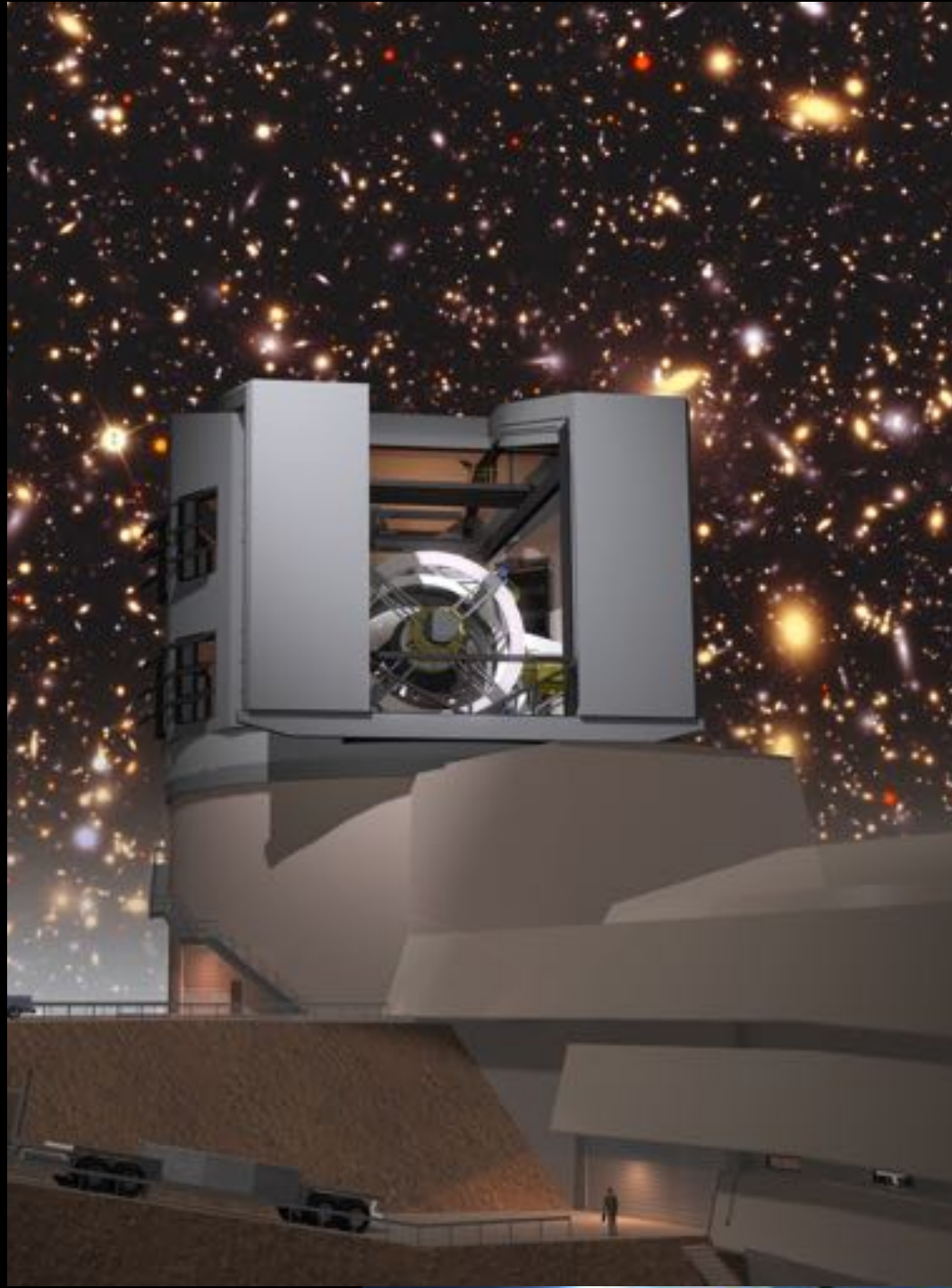
LSST
Large Synoptic Survey Telescope

Office of Science
U.S. DEPARTMENT OF ENERGY

NSF

Private Contributions

Charles Simonyi
Bill & Melinda Gates
+…



Member Institutions

Adler Planetarium
Argonne National Laboratory
Brookhaven National Laboratory (BNL)
California Institute of Technology
Carnegie Mellon University
Chile
Columbia University
Drexel University
Fermi National Accelerator Laboratory
Google, Inc.
IN2P3
Johns Hopkins University
KIPAC - Stanford University
Kentucky Association for Research with LSST (KARL)
LCOGT
Lawrence Livermore National Laboratory (LLNL)
Los Alamos National Laboratory (LANL)
National Optical Astronomy Observatory
Northwestern University
Princeton University
Purdue University
Research Corporation for Science Advancement
Rutgers University
SLAC National Accelerator Laboratory
Space Telescope Science Institute
Texas A & M University
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
- CONICET (OAC-IATE)

Australia
- The University of Sydney - 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)

Canary Islands
- Instituto de Astrofisica de Canarias (IAC)

China
- LSST-China Consortium

Croatia
- Ruđer Bošković Institute (RBI)

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

France
- IN2P3

Germany
- Astronomisches Rechen-Institut, 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
- Eotvos Lorand University (ELTE)
- Konkoly Observatory

India
- 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 Switzerland
- ETH Zurich

Taiwan
- Academia Sinica

United Kingdom
- STFC - UK LSST Consortium

Science Collaborations

Active Galactic Nuclei:

Niel Brandt(Penn State)

Solar System:

David Trilling (Northern Arizona U) & Meg Schwamb (Gemini)

Galaxies:

Michael Cooper(UC Irvine) & Brant Robertson (UCSC)

Transients/Variable Stars:

Rachel Street (LCOGT) & Federica Bianco (NYU)

Stars, Milky Way and Local Volume:

John Bochanski(Rider University), Nitya Kallivayalil(U VA) & John Gizis (U Delaware)

Strong Lensing:

Chuck Keeton (Rutgers) & Aprajita Verma (Oxford)

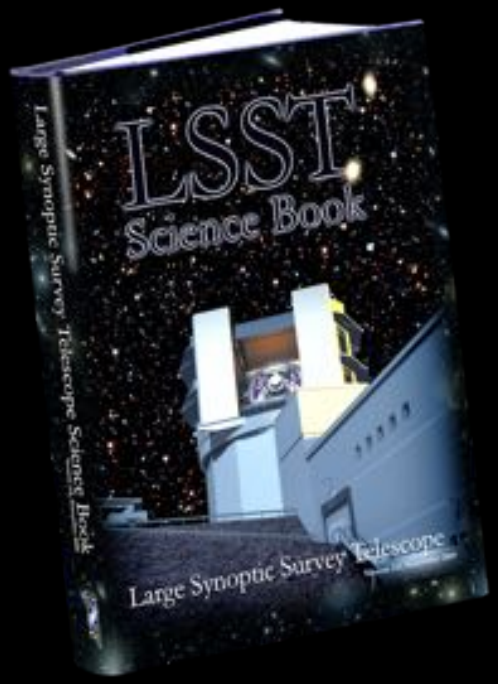
Informatics and Statistics:

Tom Loredo(Cornell) & Chad Schafer(CMU)

Dark Energy (DESC):

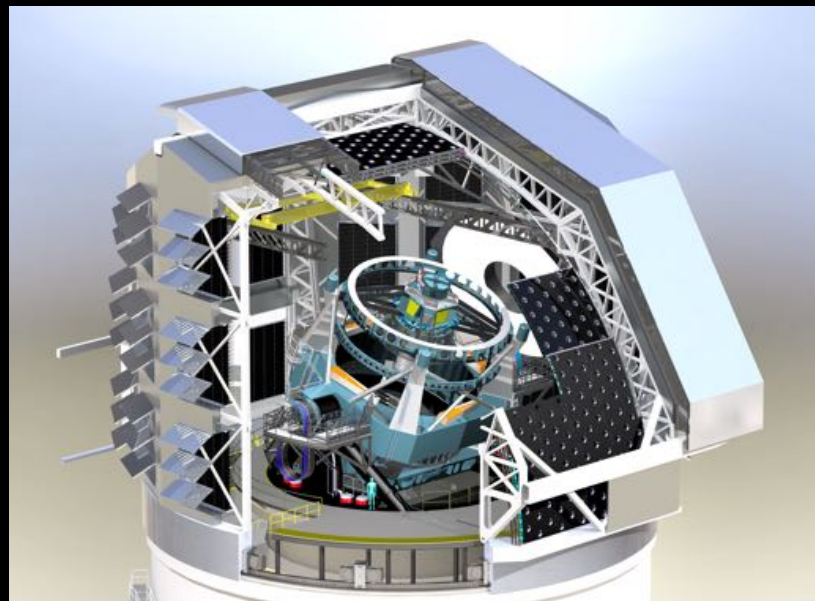
Eric Gawiser (Rutgers) & Phil Marshall (KIPAC)

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

System Requirements

Light bucket
(go faint, short exposures)

Agile

Large Field-of-View

Excellent image quality
(weak lensing)

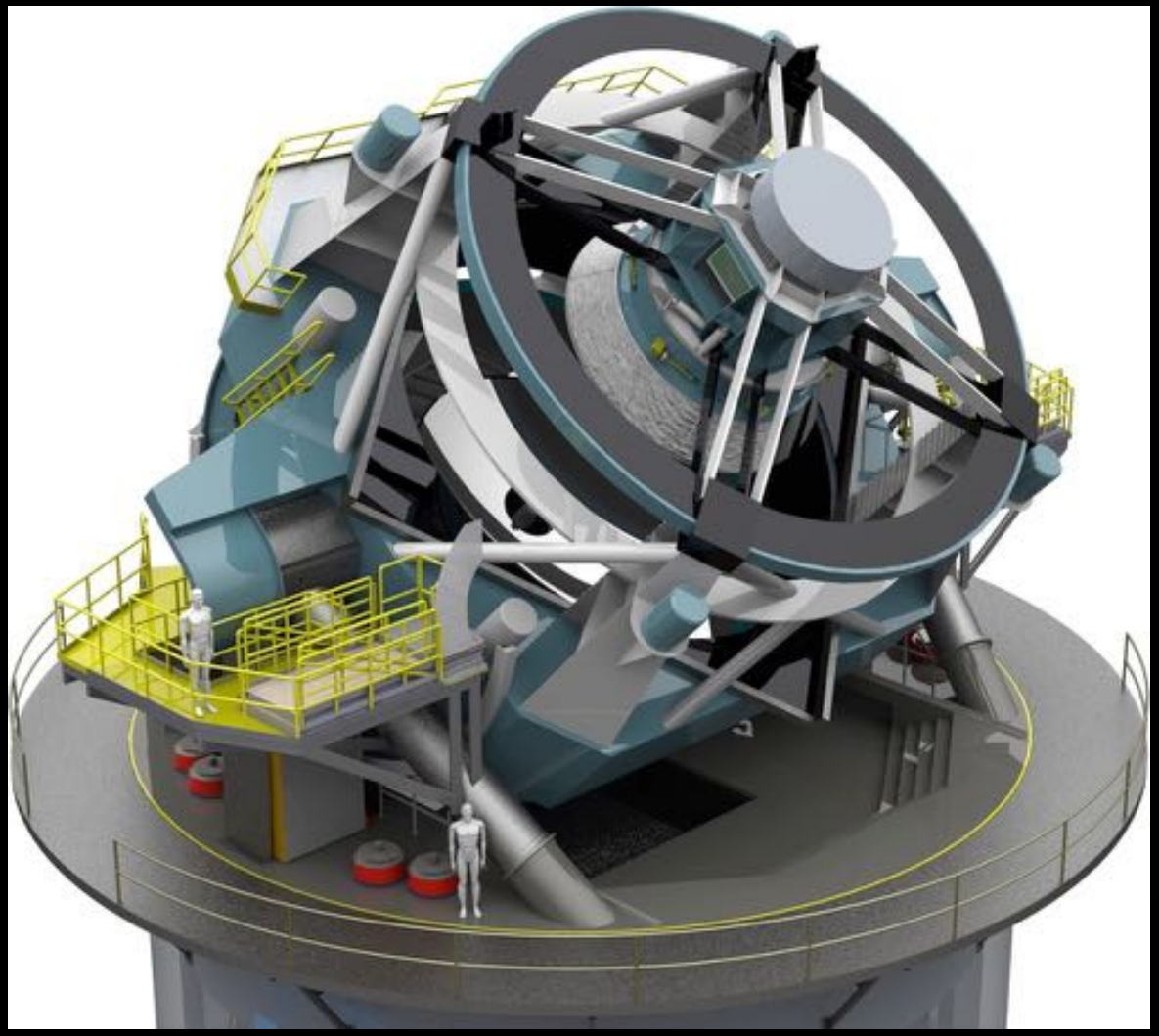
Fast Readout

Sophisticated Software
(20 TB/night, ~30 trillion measurements)

LSST
Large Synoptic Survey Telescope

8.4m mirror
(6.7m effective)

5 sec slew+settle



LSST Mirrors Completed

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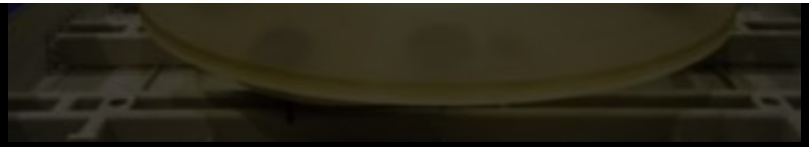
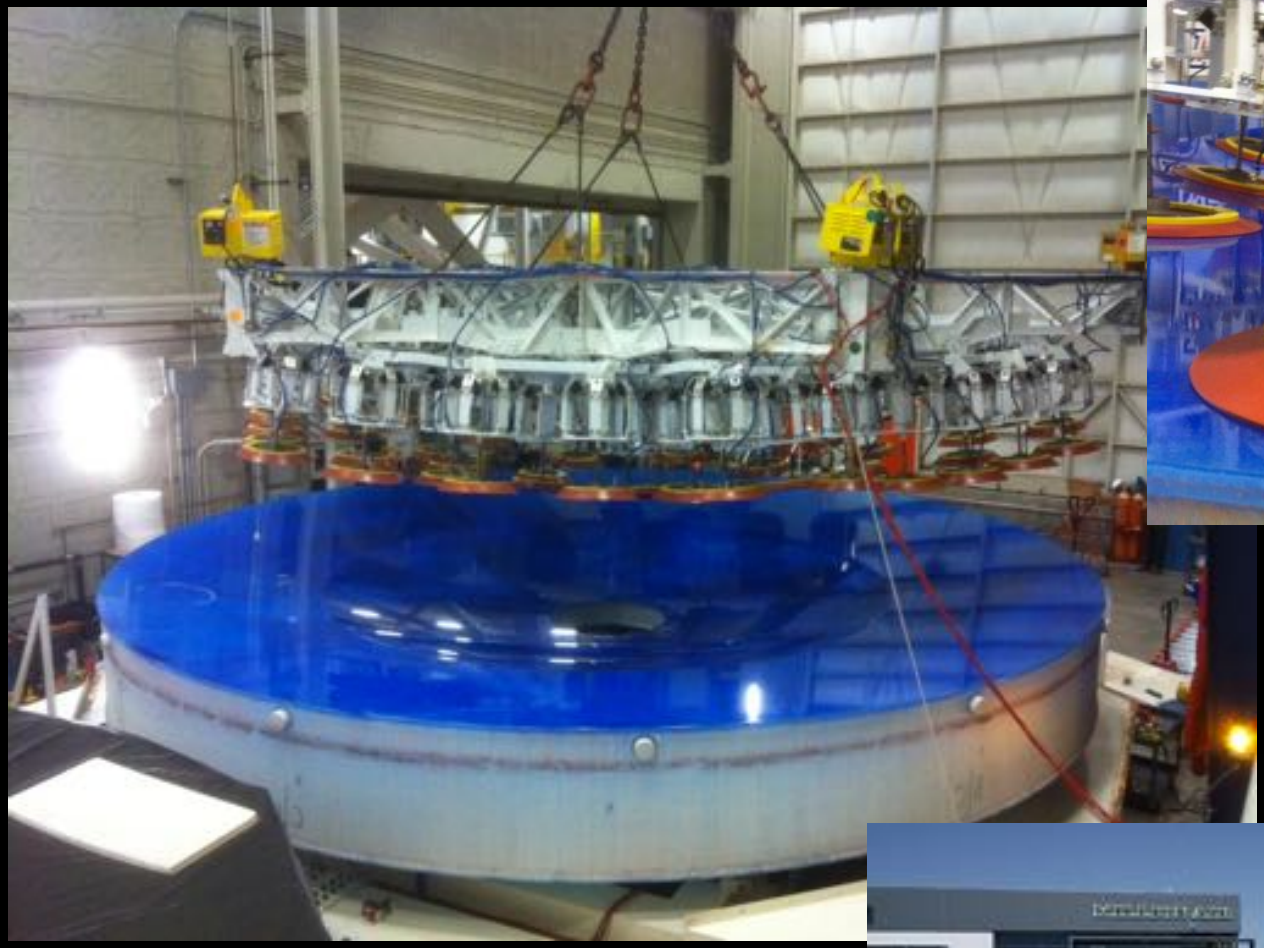
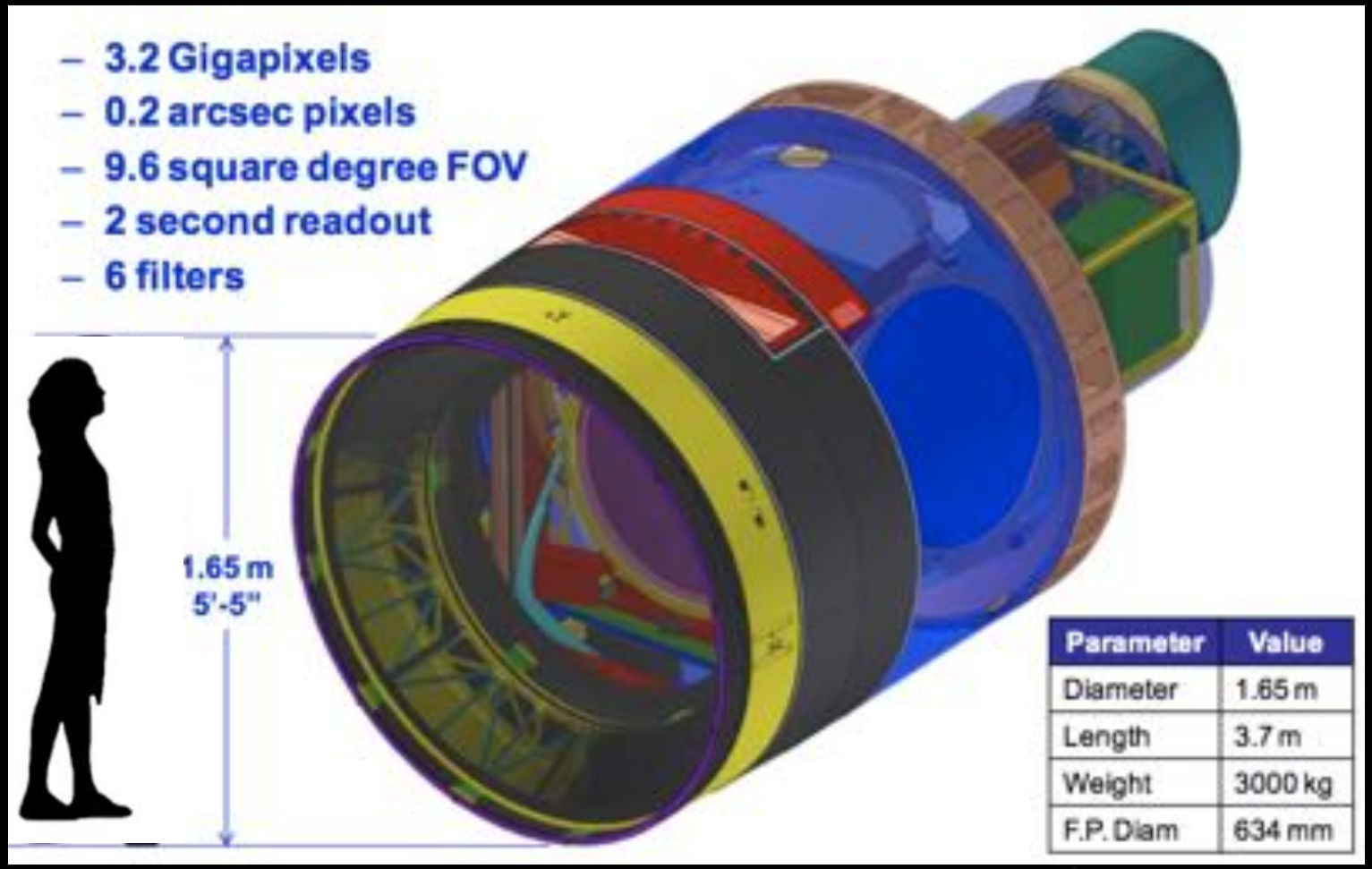


M1/M3 Mirror Completion

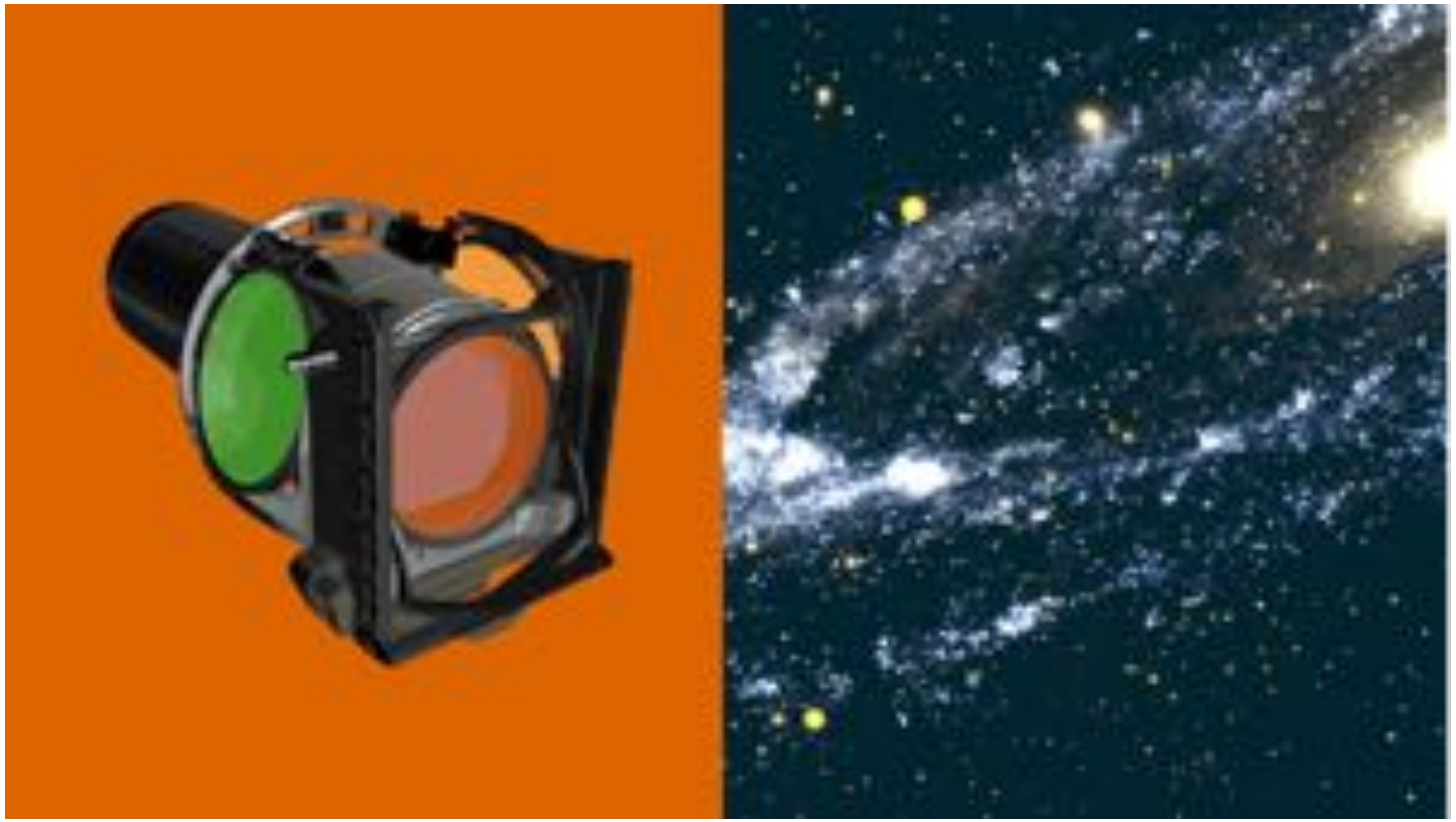


LSST Camera

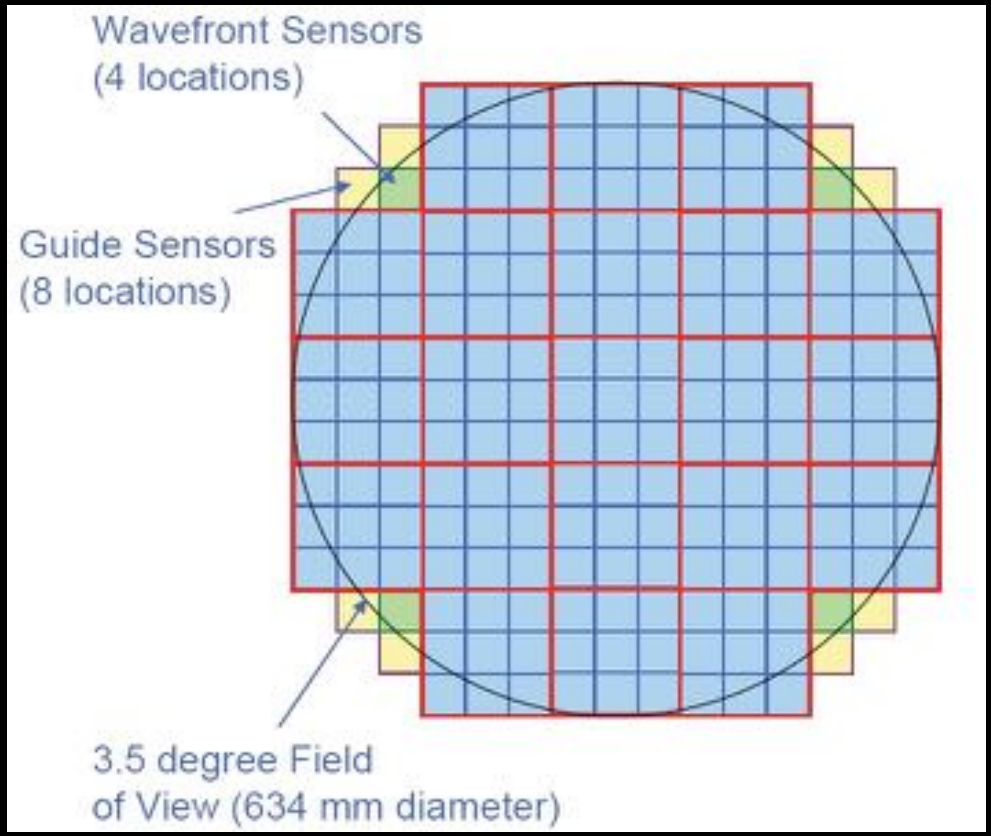


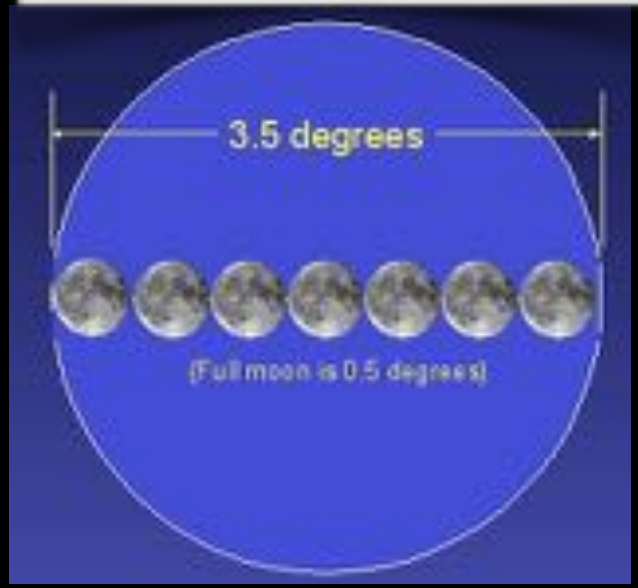
Displaying *one LSST image*
would take *1500 HD TV screens*!

A Multicolor View of the Universe

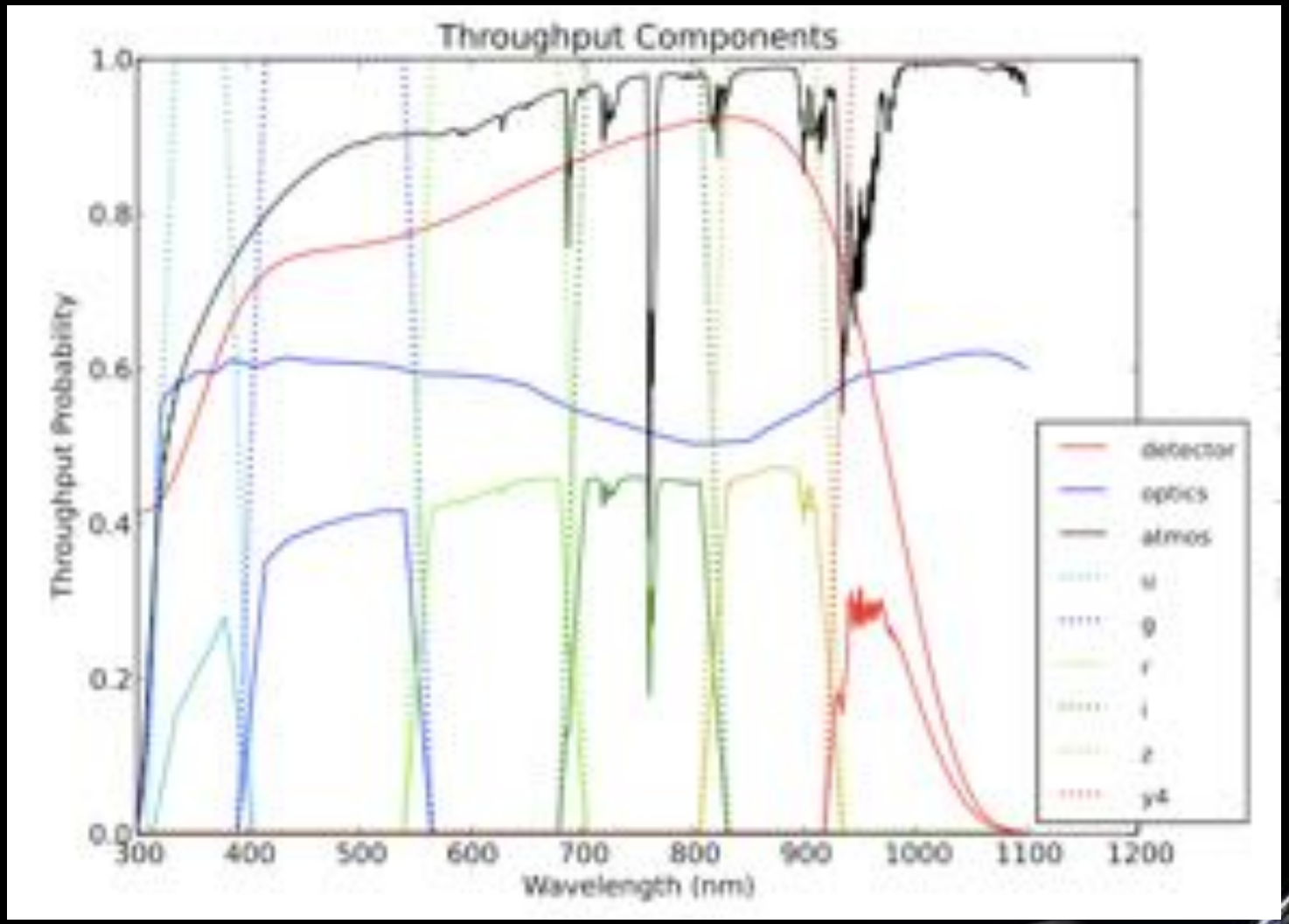


CCD Rafts/Field of View





ugrizY Filters



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

Observing Strategy (For Now)

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

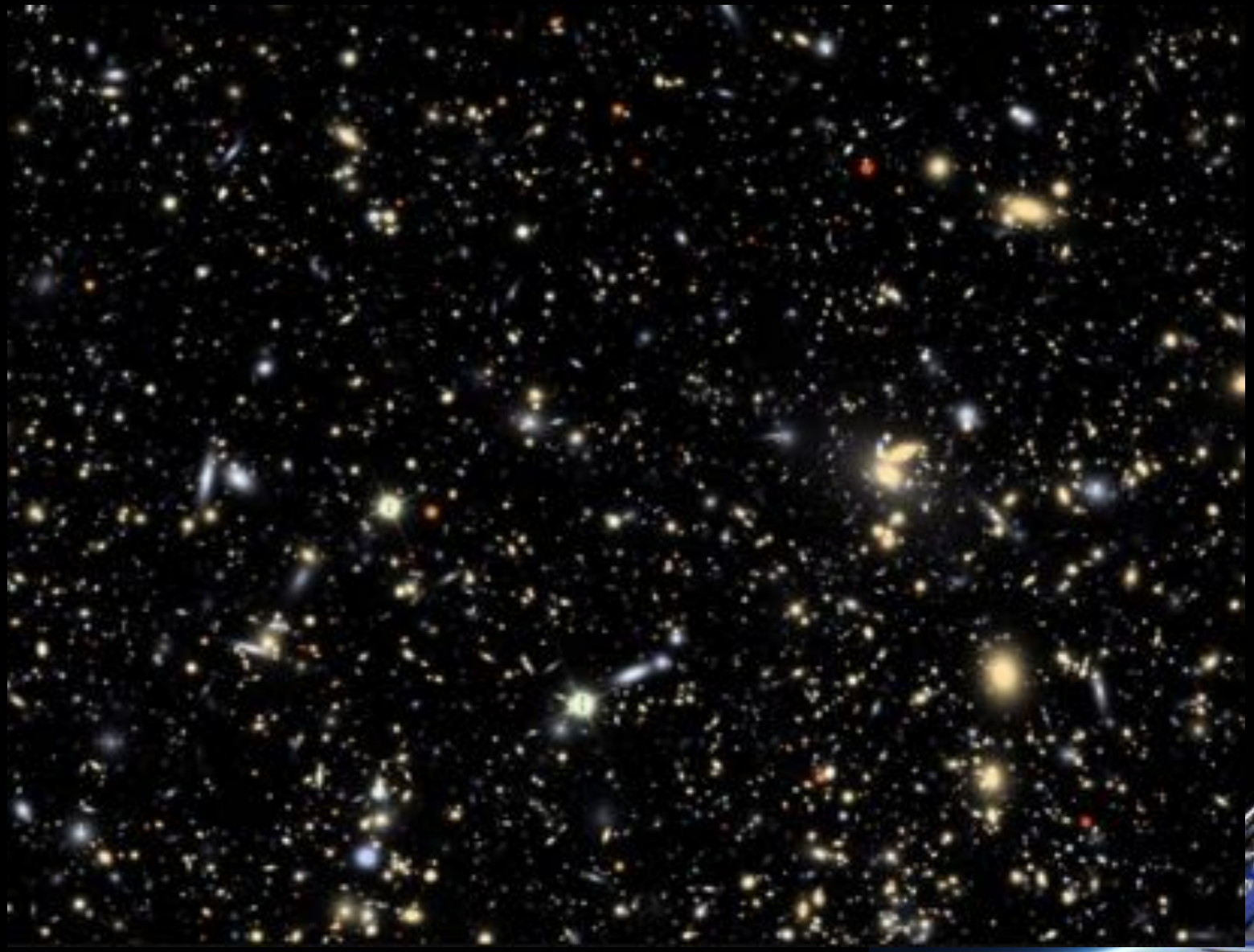
Mini Surveys
10% of time

Continuous 15 sec exposures over ~1 hr/night

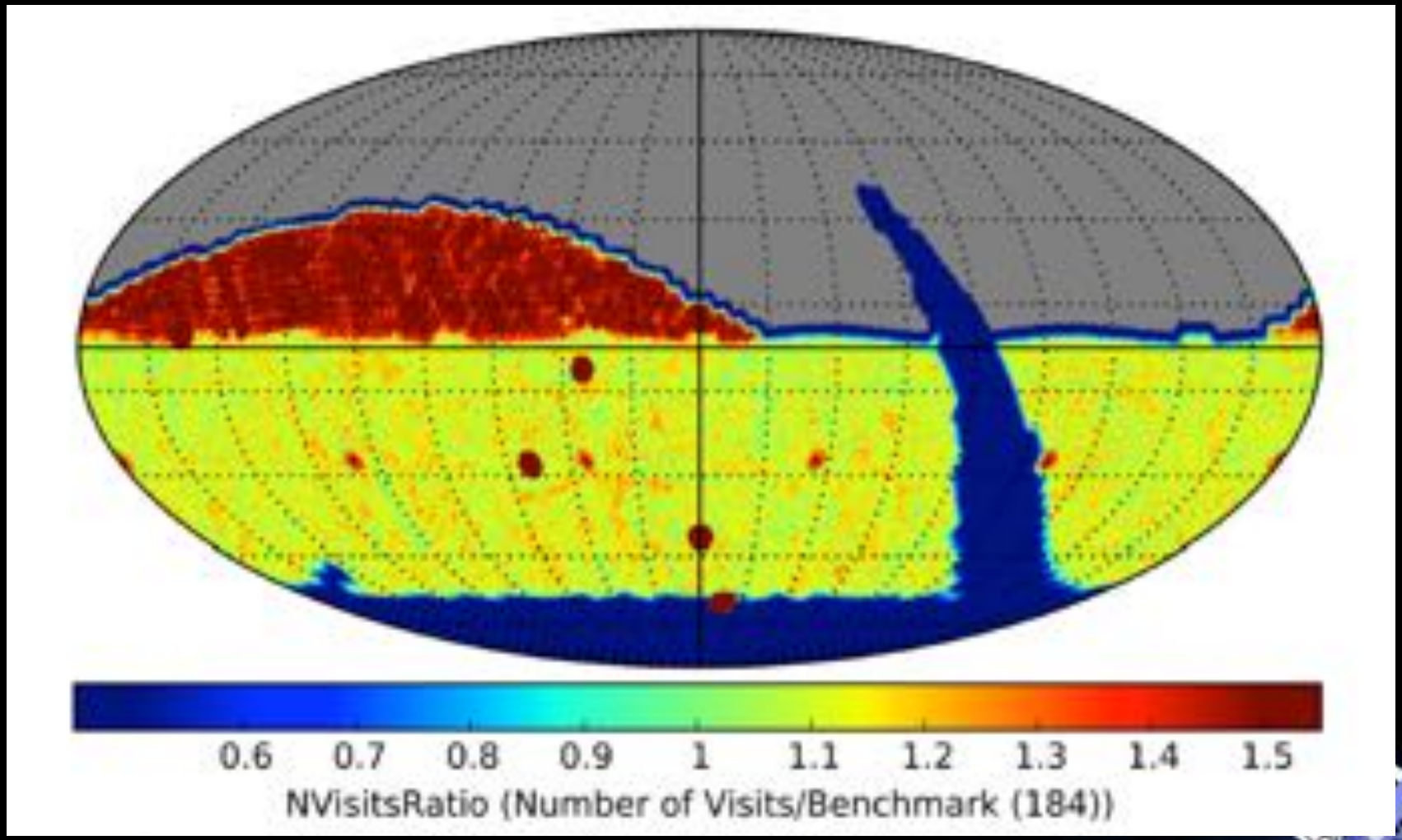
~30 selected fields (300 sq deg)

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)

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)*

The LSST Science Book contains a wealth of science cases

www.lsst.org/lsst/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

Data Products

Application Layer -
Generates open, accessible data products with fully documented quality

Processing Cadence	Image Category (files)	Catalog Category (database)	Alert Category (database)
Nightly "Level 1"	Raw science image Calibrated science image Subtracted science image Noise image Sky image Data quality analysis	Source catalog (from difference images) Object catalog (from difference images) Orbit catalog Data quality analysis	Transient alert Moving object alert Data quality analysis
Data Release (Annual) "Level 2"	Stacked science image Template image Calibration image RGB JPEG Images Data quality analysis	Source catalog (from calibrated science images) Object catalog (optimally measured properties) Data quality analysis	Alert statistics & summaries Data quality analysis

Data Products

http:// ls.st / dpdd

Level 1 *Nightly*

Alerts: 1-10 million/night, issued in 60 sec

Orbits for 6 million solar system objects

Level 2 *Annual*

Catalogs: ~37 billion objects (20B galaxies, 17b Stars);
~7 trillion "sources", ~30 trillion "forced sources"

Deep co-added images

Level 3 *Community*

Services/computing resources at Data Access Centers

Software & APIs to enable development of analysis codes

Data Products

Application Layer -
Generates open, accessible data products with fully documented quality

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What will LSST provide?

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)

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

position

flux, size, and shape

light curves in all bands
(up to a ~year; stretch: all)

variability characterization
(e.g. low-order light-curve moments, probability the object is variable)
cut-outs centered on the object
(template, difference image)

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)

Classification/Characterization

```
# Keep only never-before-seen events within two
# effective radii of a galaxy. This is for illustration
# only; the exact methods/members/APIs may change.
def filter(alert):
     if len(alert.sources) > 1:
          return False
     nn = alert.diaobject.nearest_neighbors[0]
     if not nn.flags.GALAXY:
          return False
     return nn.dist < 2. * nn.Re
```

No cross-match or classification
Intended for simple user-defined filtering

Sophisticated event brokers/classifiers to be developed by the community

See DPDD: https://ls.st/dpdd

Spectroscopic Follow-up Resources

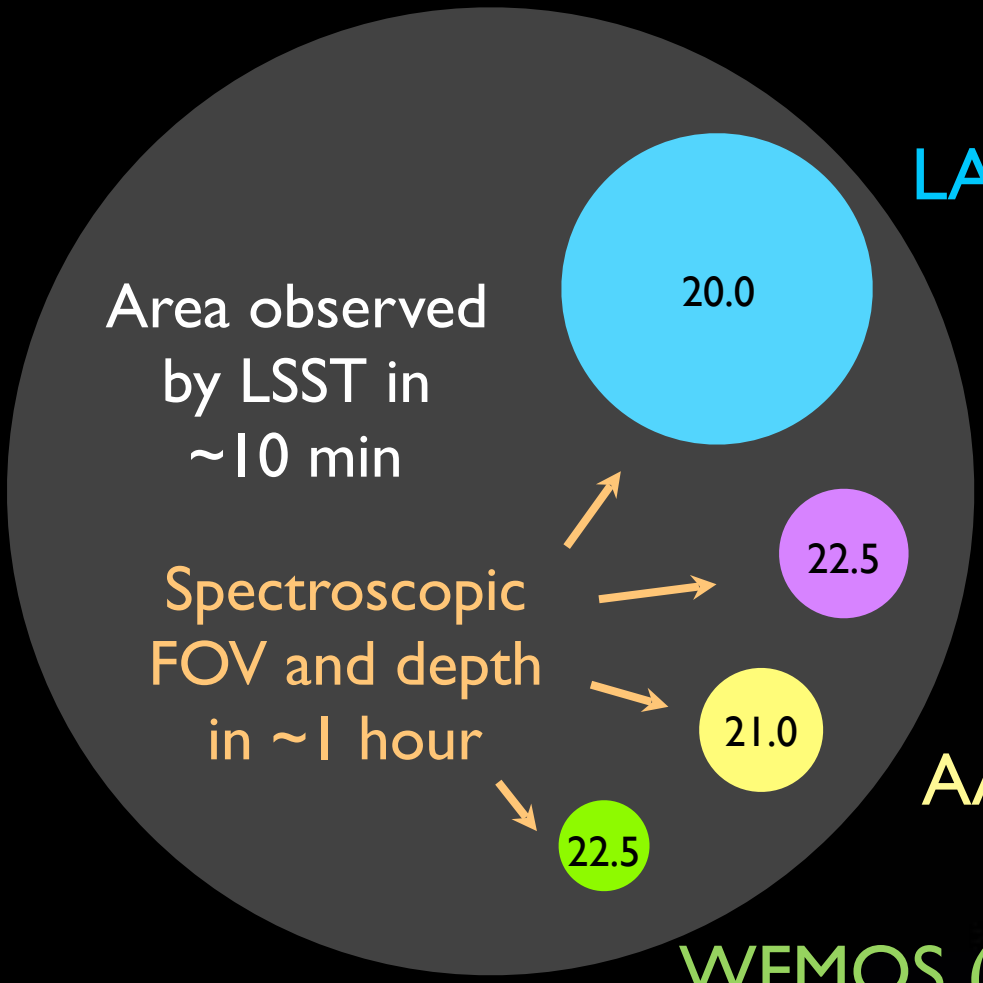


Figure adapted from Adam Myers

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

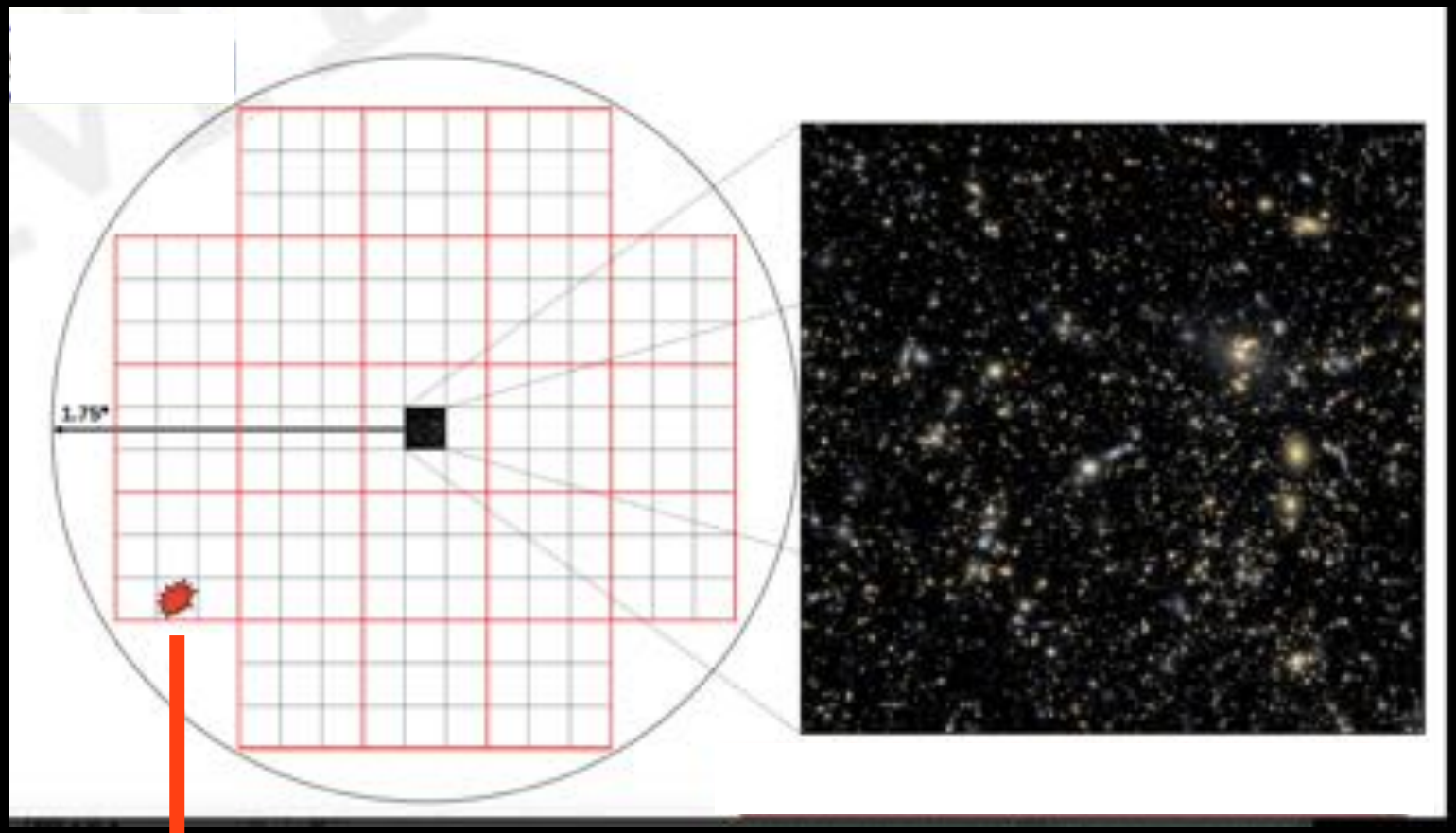
Logistical issues require forethought

Programmatic: Target Updates

Data access/ information sharing

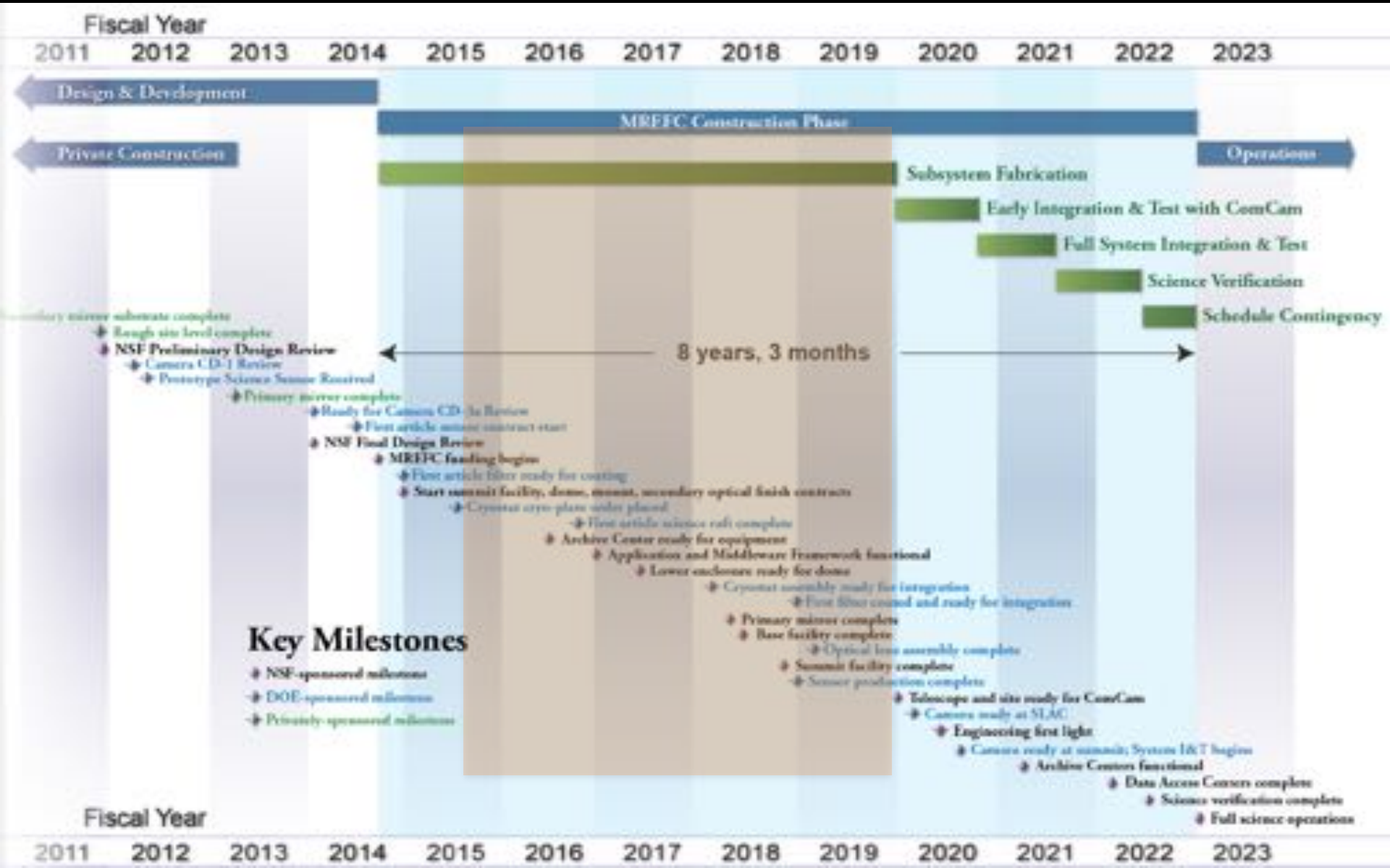
Large scale collaboration/communication

Synergy between a-LIGO / LSST



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

Project Timeline



Large Synoptic Survey Telescope

LSST 2014

CONSTRUCTION START

Primera Piedra

Large Synoptic Survey Telescope

Thanks!