The Large Synoptic Survey Telescope

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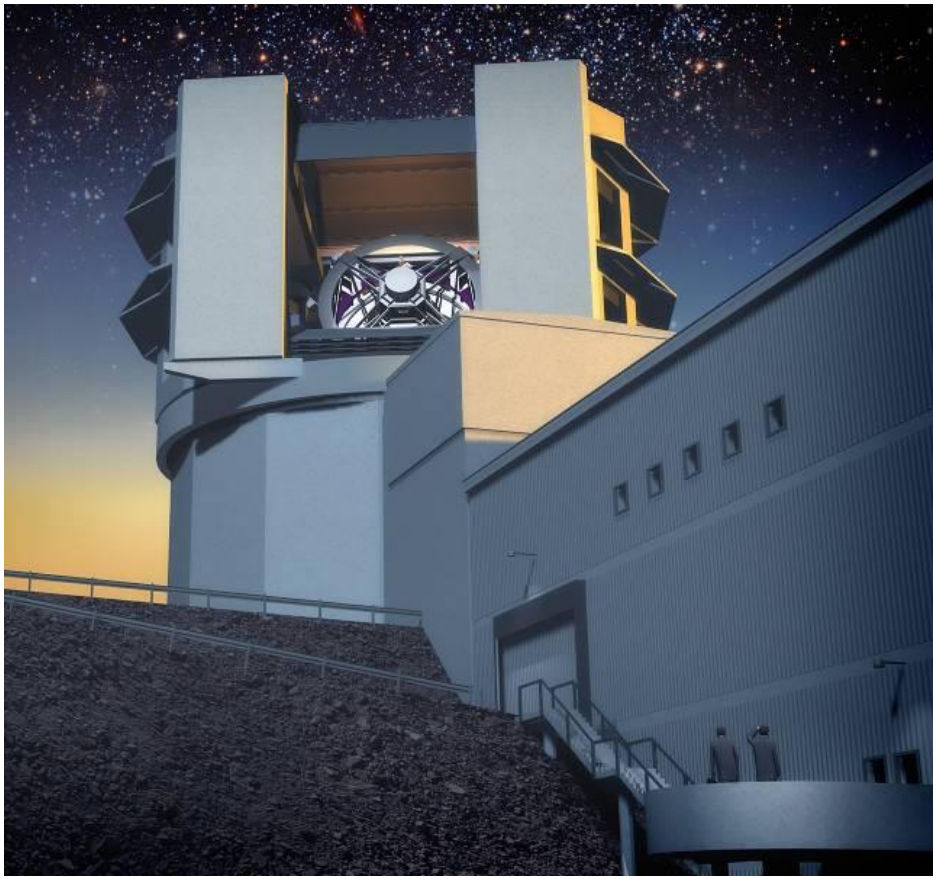


LSST in a Nutshell

Large Synoptic Survey Telescope

- The LSST is an integrated survey system designed to conduct a decade-long, deep, wide, fast time-domain survey of the optical sky. It consists of an 8-meter class wide-field ground based telescope, a 3.2 Gpix camera, and an automated data processing system.

- Over a decade of operations the LSST survey will acquire, process, and make available a collection of over 5 million images and catalogs with more than 37 billion objects and 7 trillion sources. Tens of billions of time-domain events will be detect and alerted on in real-time.

- The LSST will enable a wide variety of complementary scientific investigations, utilizing a common database and alert stream. These range from searches for small bodies in the Solar System to precision astrometry of the outer regions of the Galaxy to systematic monitoring for transient phenomena in the optical sky. LSST will also provide crucial constraints on our understanding of the nature of dark energy and dark matter.

Summary of High Level Requirements

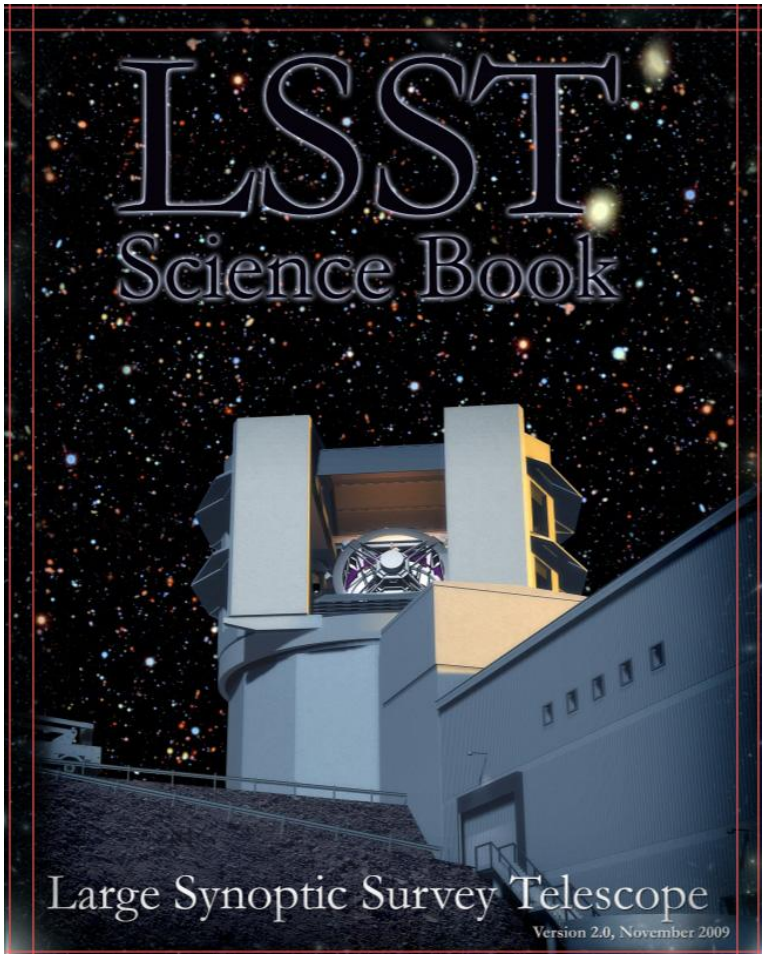
Large Synoptic Survey Telescope

Survey Property	Performance
Main Survey Area	18000 sq. deg.
Total visits per sky patch	825
Filter set	6 filters (ugrizy) from 320 to 1050nm
Single visit	2 x 15 second exposures
Single Visit Limiting Magnitude	u = 23.5; g = 24.8; r = 24.4; I = 23.9; z = 23.3; y = 22.1
Photometric calibration	2% absolute, 0.5% repeatability & colors
Median delivered image quality	~ 0.7 arcsec. FWHM
Transient processing latency	60 sec after last visit exposure
Data release	Full reprocessing of survey data annually

The LSST Science Book

Large Synoptic Survey Telescope

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

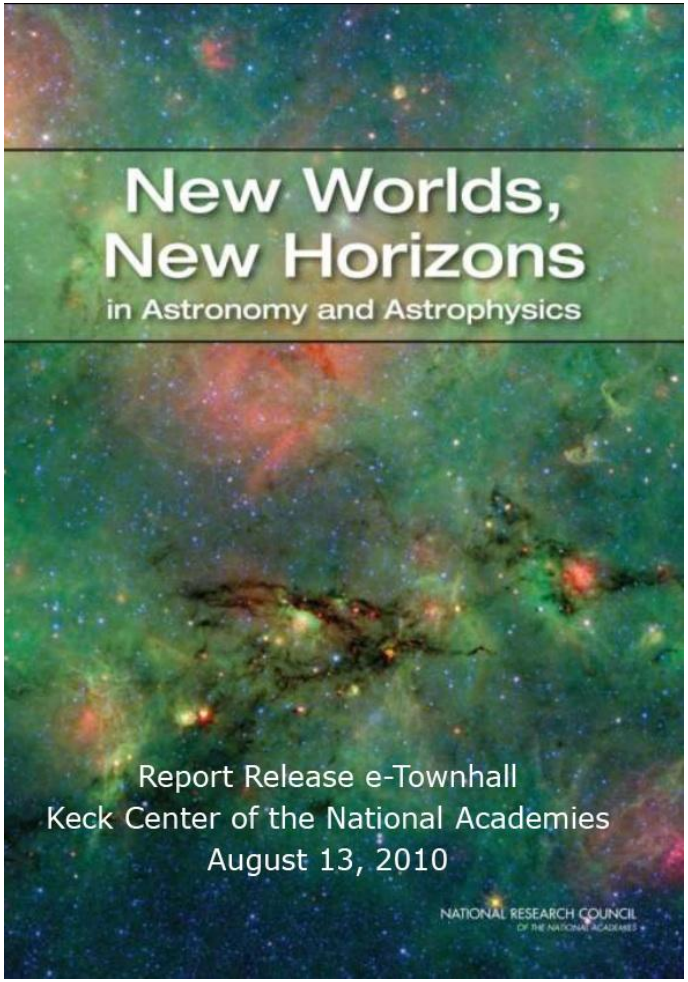


Astro2010 Endorsement

Large Synoptic Survey Telescope

- LSST ranked as the highest priority large ground-based facility for the next decade.

- "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.'"



Four Key Science Themes Used to Define the Science Requirements

Large Synoptic Survey Telescope

- Taking a census of moving objects in the solar system.
- Mapping the structure and evolution of the Milky Way.
- Exploring the transient optical sky.
- Determining the nature of dark energy and dark matter.

The techniques associated with these four themes stress the system design in complementary ways. By designing the system to to accomplish these specific goals, we ensure that LSST will in fact enable a very broad range of science.

LSST is a Public/Private, Interagency Project

Large Synoptic Survey Telescope

- **The National Science Foundation:**
  - Support for the telescope and site facility construction, the data management system, and the education and public outreach components.
  - Funded under the Major Research Equipment and Facility Construction (MREFC) line. Total projected cost is $473M.
- **The Department of Energy:**
  - Support for the camera fabrication.
  - Funded as a Major Item of Equipment (MIE), through the Office of High Energy Physics in the Office of Science. Total projected cost is $165M.
- **Private Support:**
  - Key donors include the Lisa and Charles Simonyi Fund for Arts and Sciences, Bill Gates, Richard Caris, the W.M. Keck Foundation, Research Corporation for Science Advancement, Wayne Rosing and Dorothy Largay, Eric and Wendy Schmidt, and Edgar Smith.
  - Total Support is ~ $40M.
  - Funded development of the primary/tertiary mirror, the secondary mirror blank, preliminary site preparation, as well as early sensor studies and some data management activities.

Omnibus Bill Budget Language

NSF:

"This Act includes $200,000,000 for Major Research Equipment and Facilities Construction. Funds are provided at the request level for all projects for which construction has already begun, and remaining funds are for the initiation of the Large Synoptic Survey Telescope (LSST) project. If NSF determines that LSST requires additional funding in fiscal year 2014, NSF may submit a transfer proposal to provide such funds."

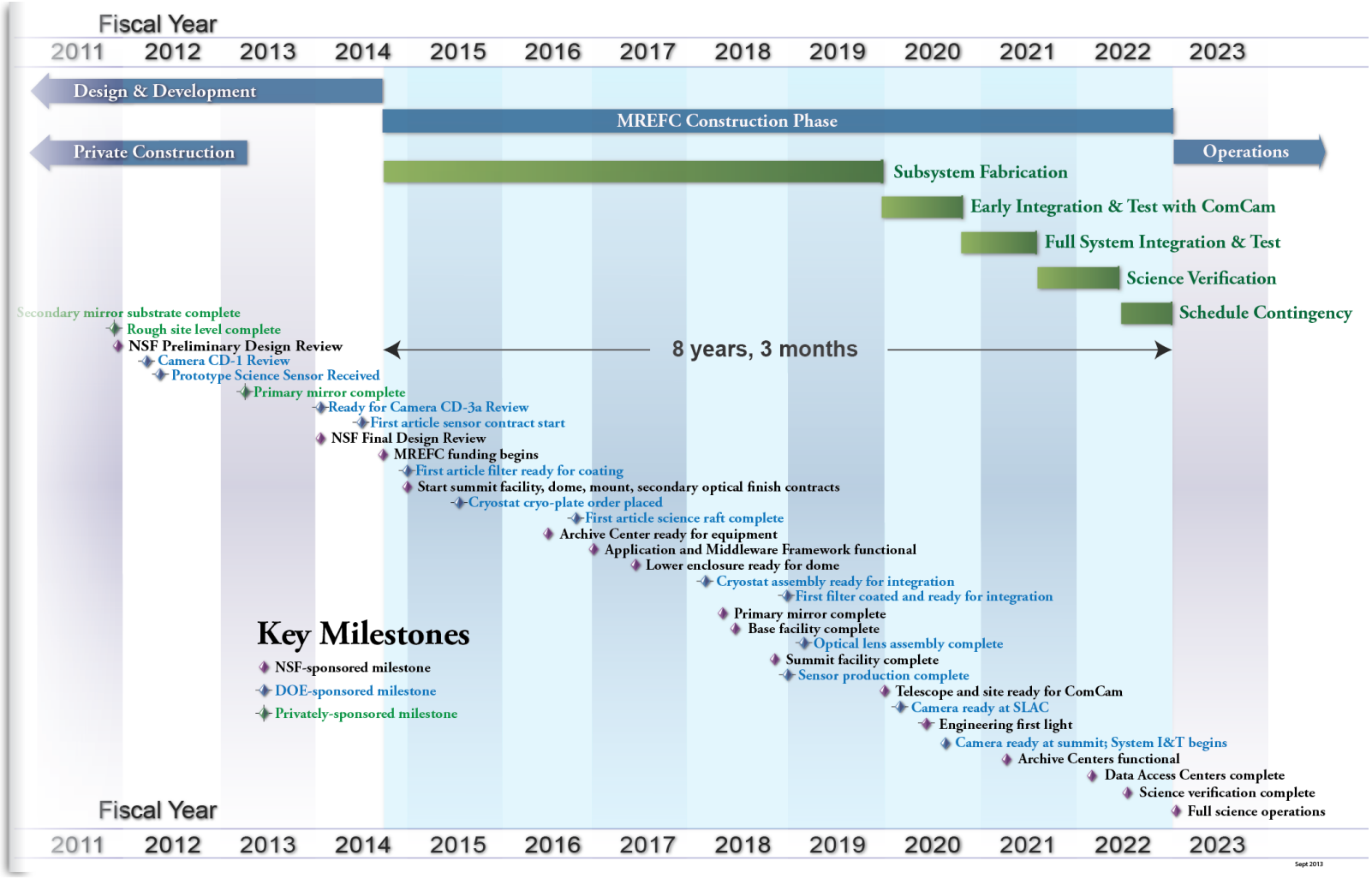
In fact, NSF provided the full request of $27.5M in FY14 for LSST.

At its meeting on May 6-7, the National Science Board approved the *construction start* for LSST on July 1. The award of the cooperative agreement is imminent, pending a few remaining financial clarifications.

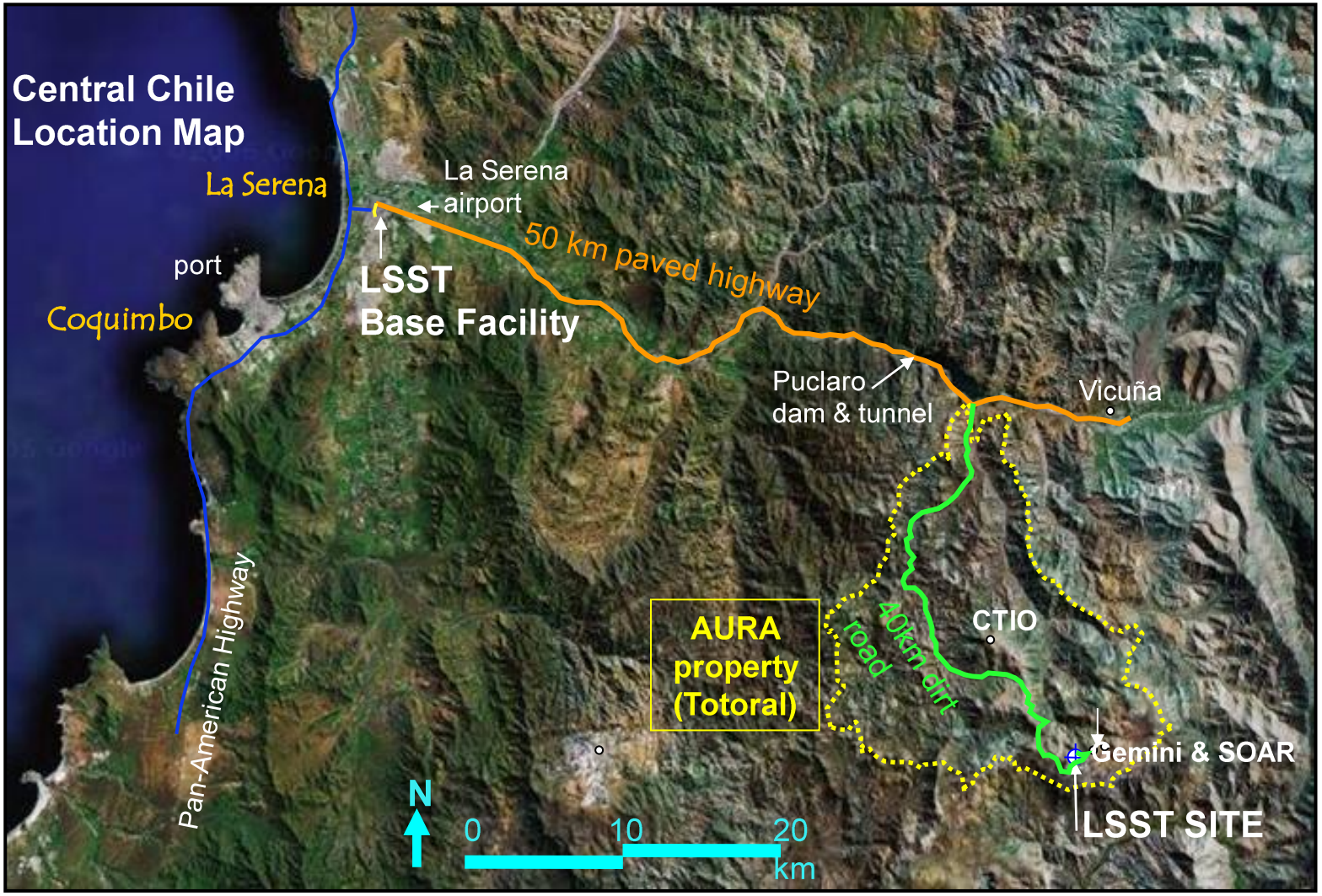
DOE:

Office of High Energy Physics budget was $5,000,000 *above* the PBR. We have been allotted the full $22M expected for the camera in FY14.

Integrated Project Schedule



LSST Will be Sited in Central Chile

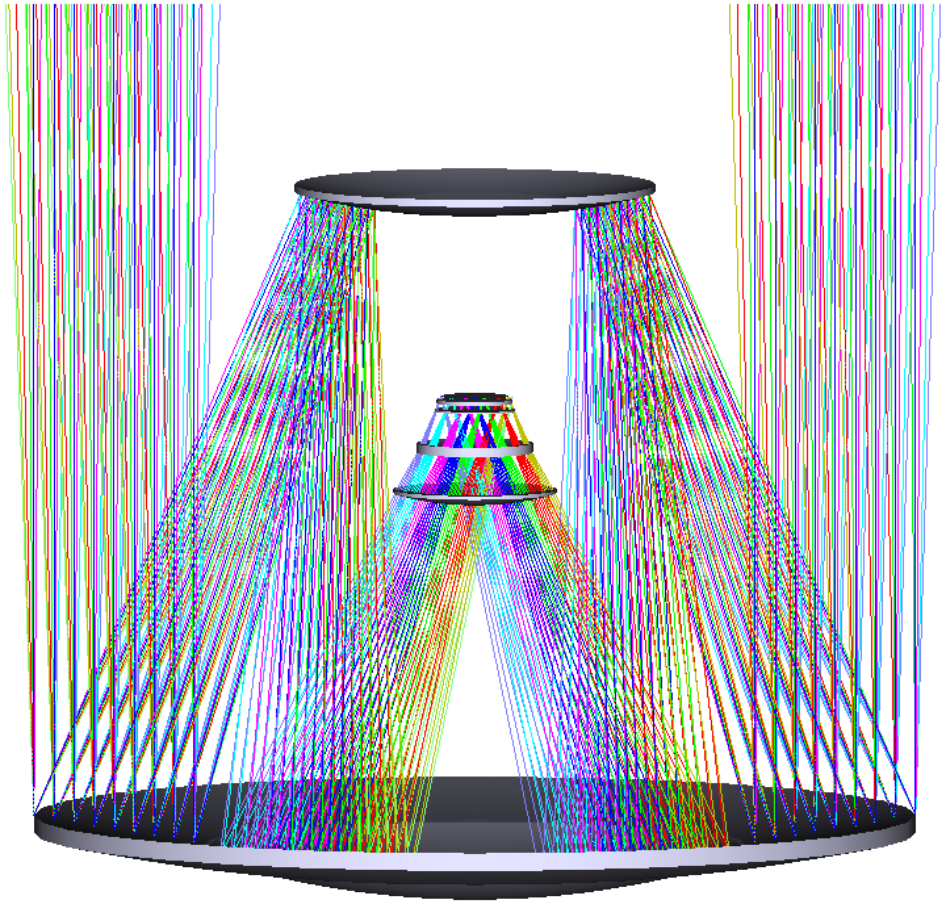


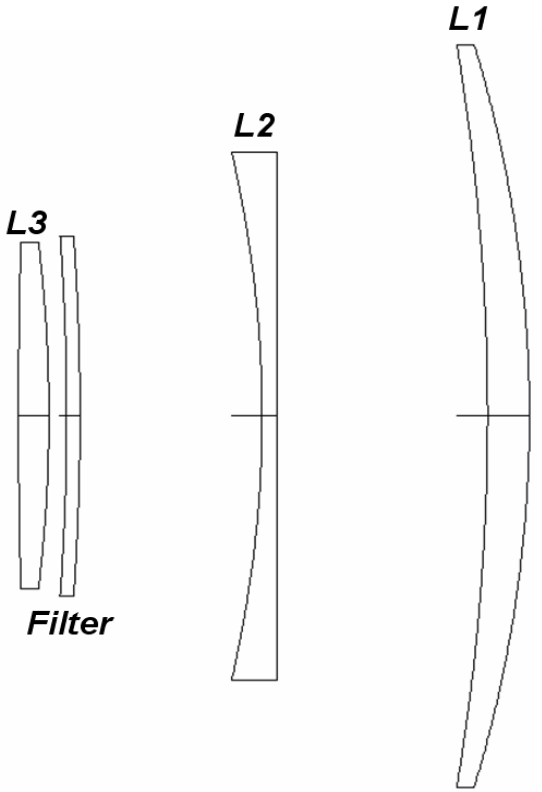
Dome and Facility Design

Large Synoptic Survey Telescope

Modified Paul-Baker Optical Design

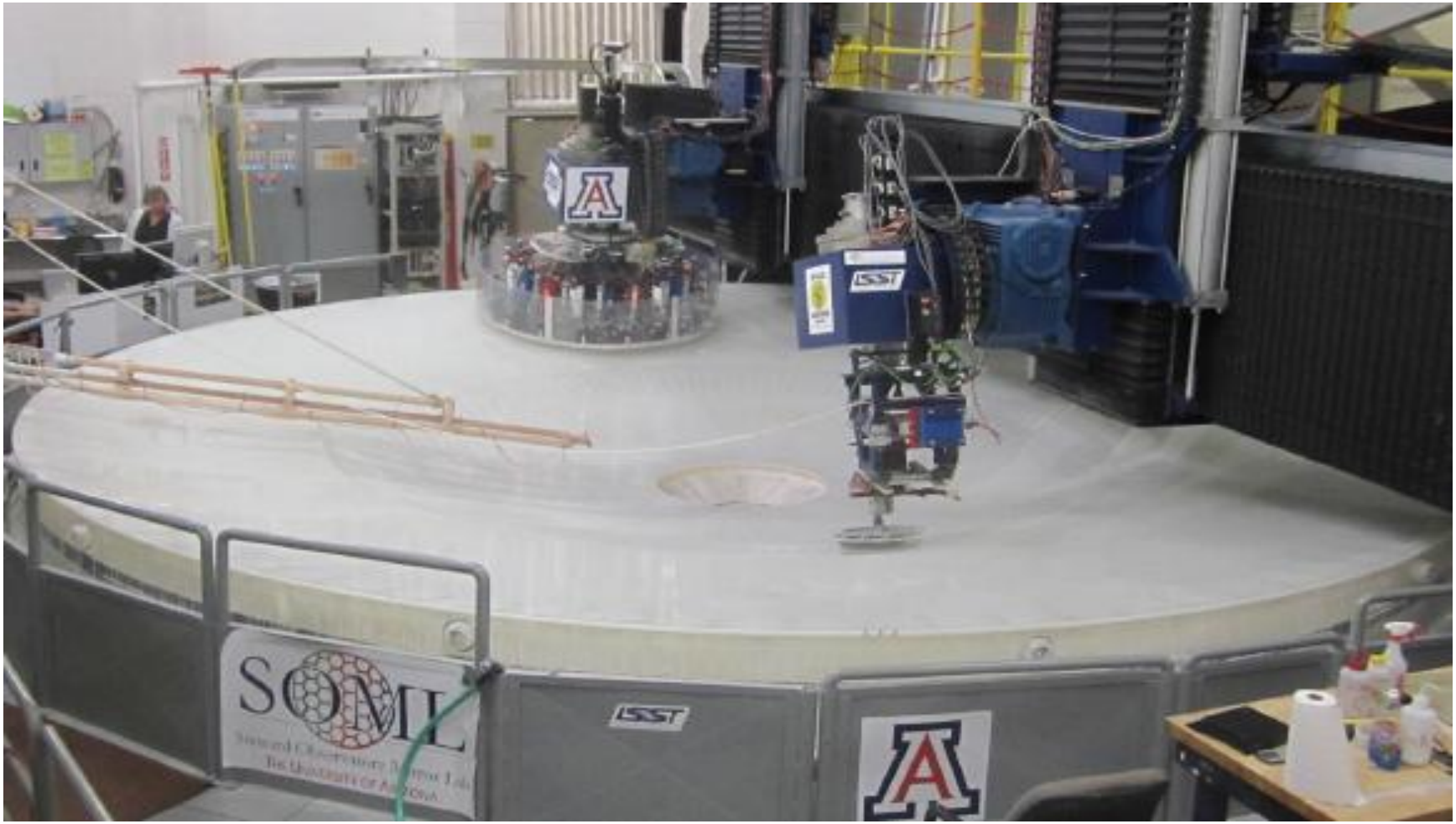
Large Synoptic Survey Telescope



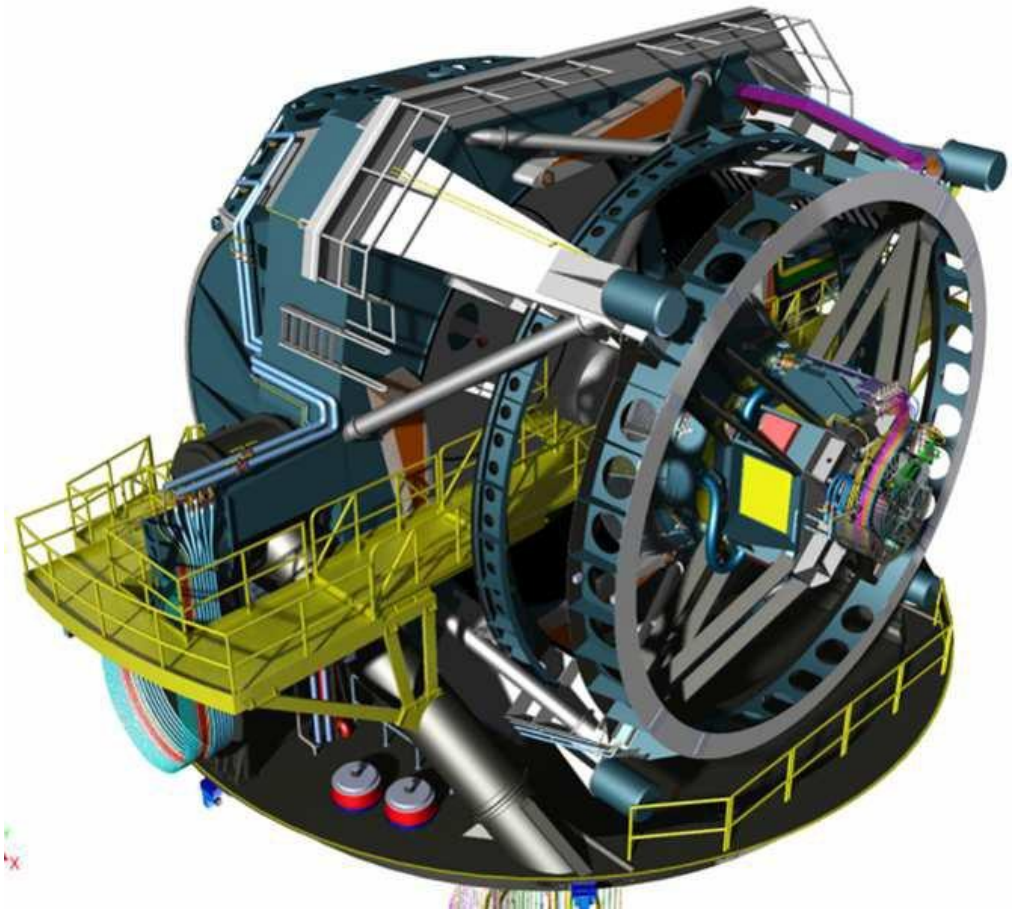


Primary/Tertiary Fabricated as a Single Monolith

Large Synoptic Survey Telescope



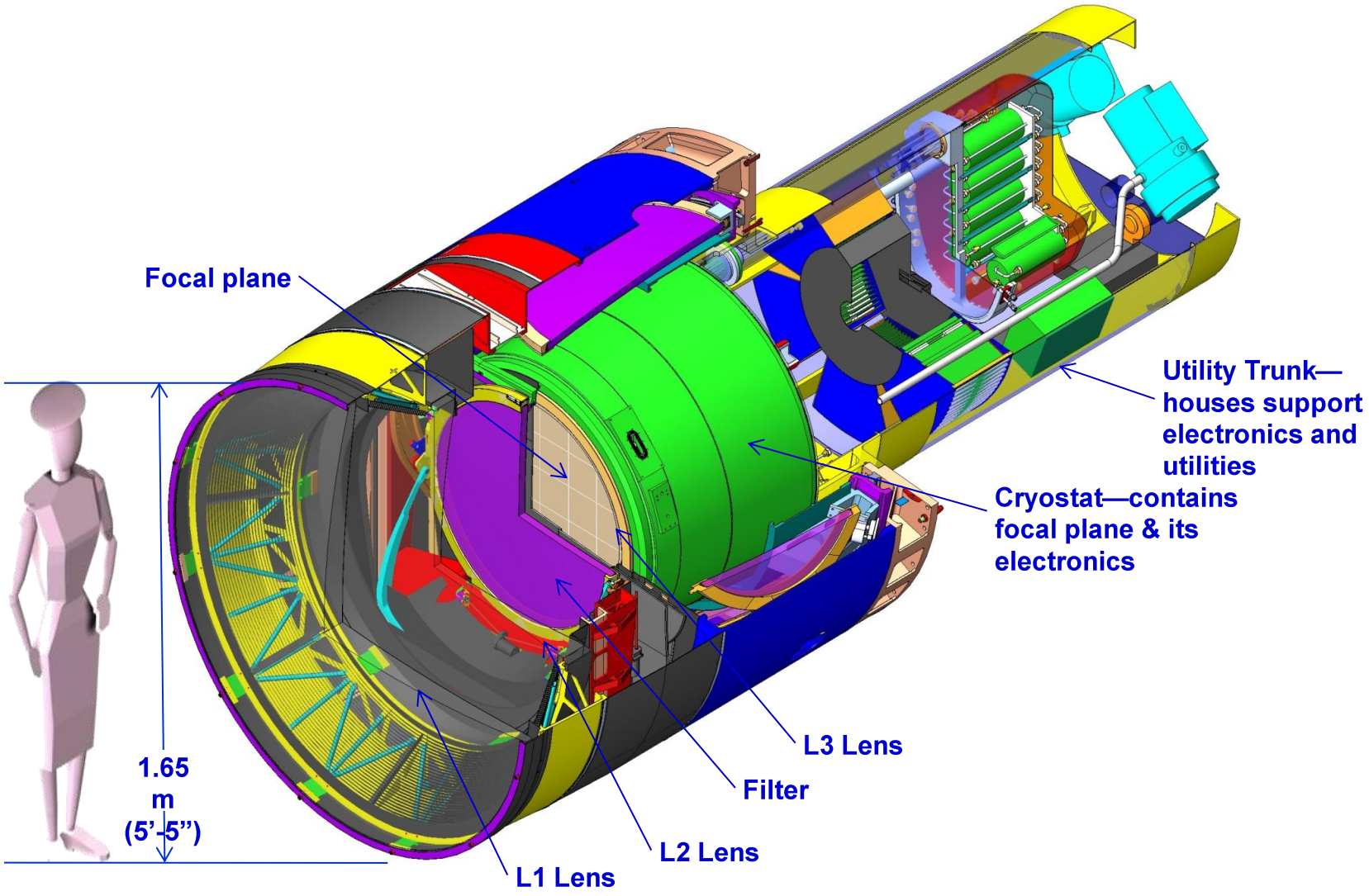
Telescope Mount Enables Fast Slew and Settle



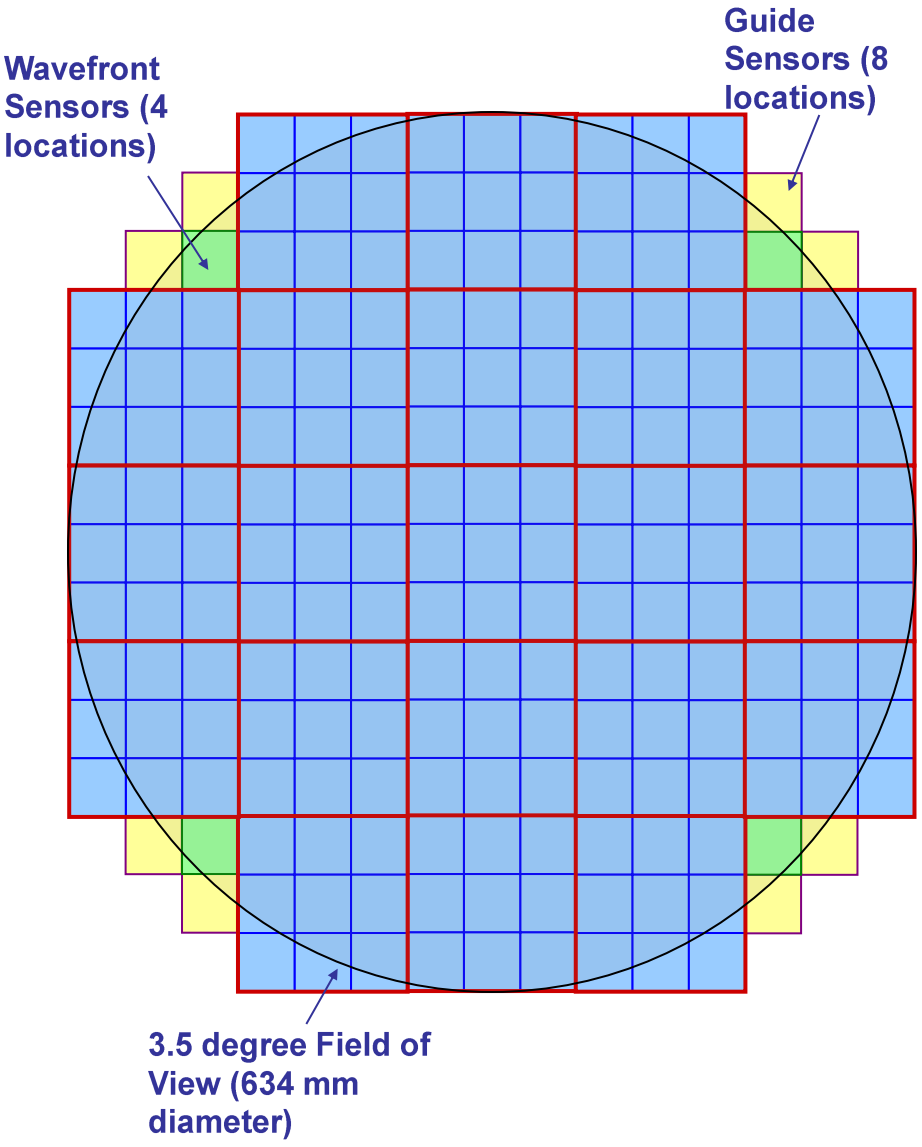
- Points to new positions in the sky every 39 seconds
- Tracks during exposures and slews 3.5° to adjacent fields in ~ 4 seconds

3.2 Billion Pixel Camera

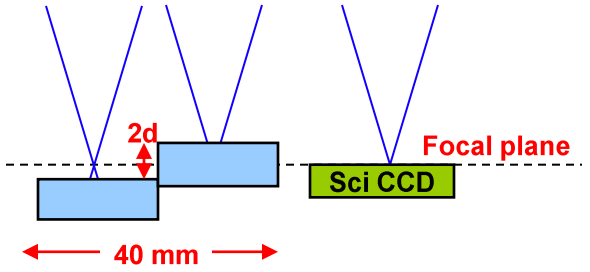
Large Synoptic Survey Telescope



The LSST Focal Plane - 64 cm in Diameter

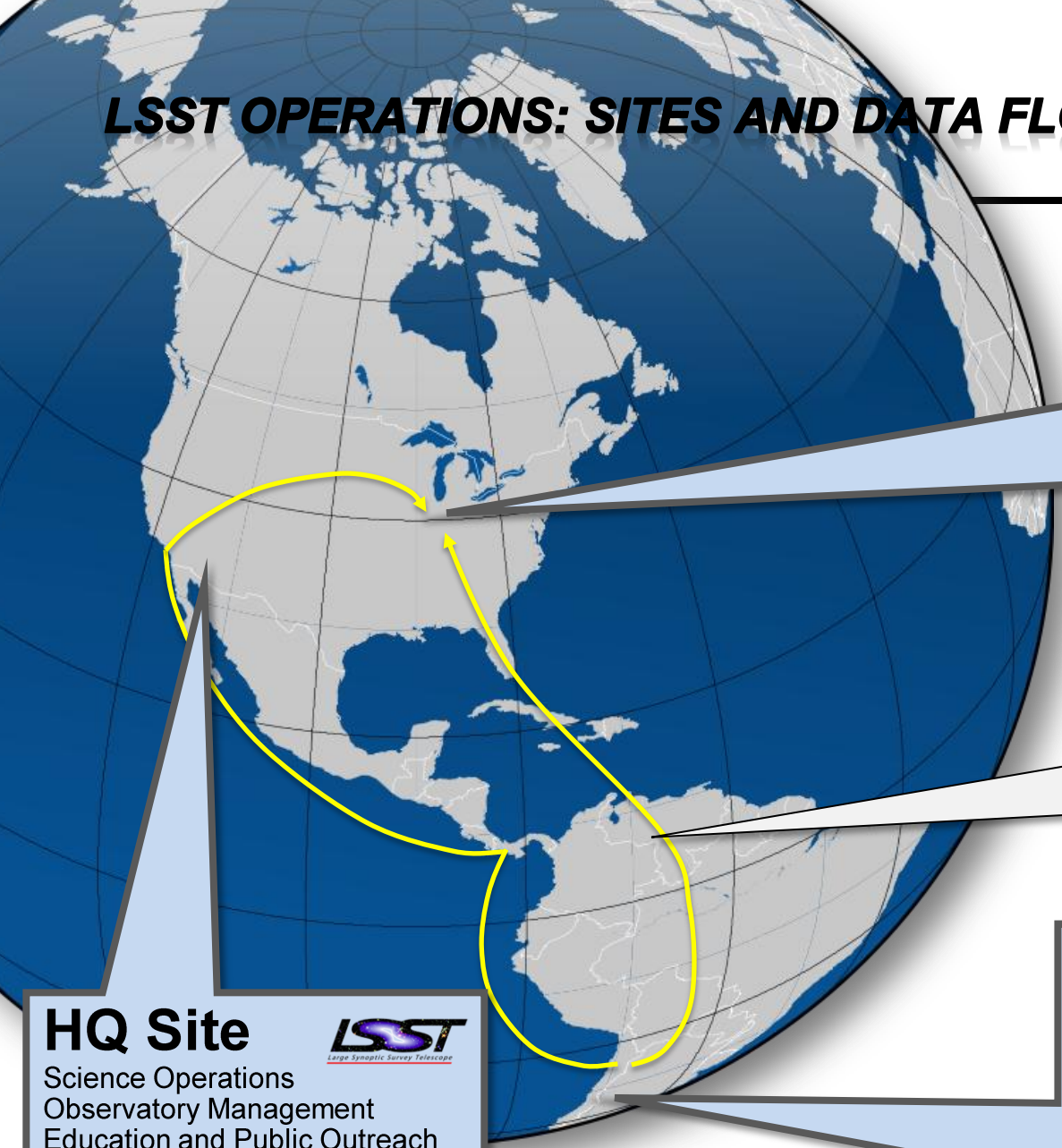


Wavefront Sensor Layout



Curvature Sensor Side View Configuration

LSST OPERATIONS: SITES AND DATA FLOWS



Archive Site

Archive Center

Alert Production
Data Release Production
Calibration Products Production
EPO Infrastructure
Long-term Storage (copy 2)

Data Access Center

Data Access and User Services

Dedicated Long Haul Networks

Two redundant 40 Gbit links from La Serena to Champaign, IL (existing fiber)

HQ Site

Science Operations
Observatory Management
Education and Public Outreach

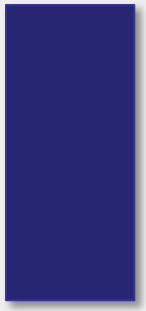
Summit and Base Sites

Telescope and Camera
Data Acquisition
Crosstalk Correction
Long-term storage (copy 1)
Chilean Data Access Center

LSST From the User's Perspective

Large Synoptic Survey Telescope

- 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.



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

- Services and computing resources at the Data Access Centers to enable user-specified custom processing and analysis.
- Software and APIs enabling development of analysis codes.

Stellar Populations

Large Synoptic Survey Telescope

- LSST will individually resolve and detect billions of stars in the Milky Way and neighboring Local Group galaxies,

- Studies of field stars and stellar associations can address a multitude of astrophysical issues associated with star formation and evolution, the assembly of the MW galaxy, and the origin of the chemical elements.

- Key techniques for these investigations include:
  - Construction of color magnitude diagrams
  - Trigonometric parallaxes to establish absolute distances
  - Stellar proper motions to separate associations from background stars and from one another
  - Using RR Lyrae and other variables as “standard candles”
  - Using eclipsing binaries to measure stellar masses

Expected Precision of Proper Motion and Parallax Measurements

Large Synoptic Survey Telescope

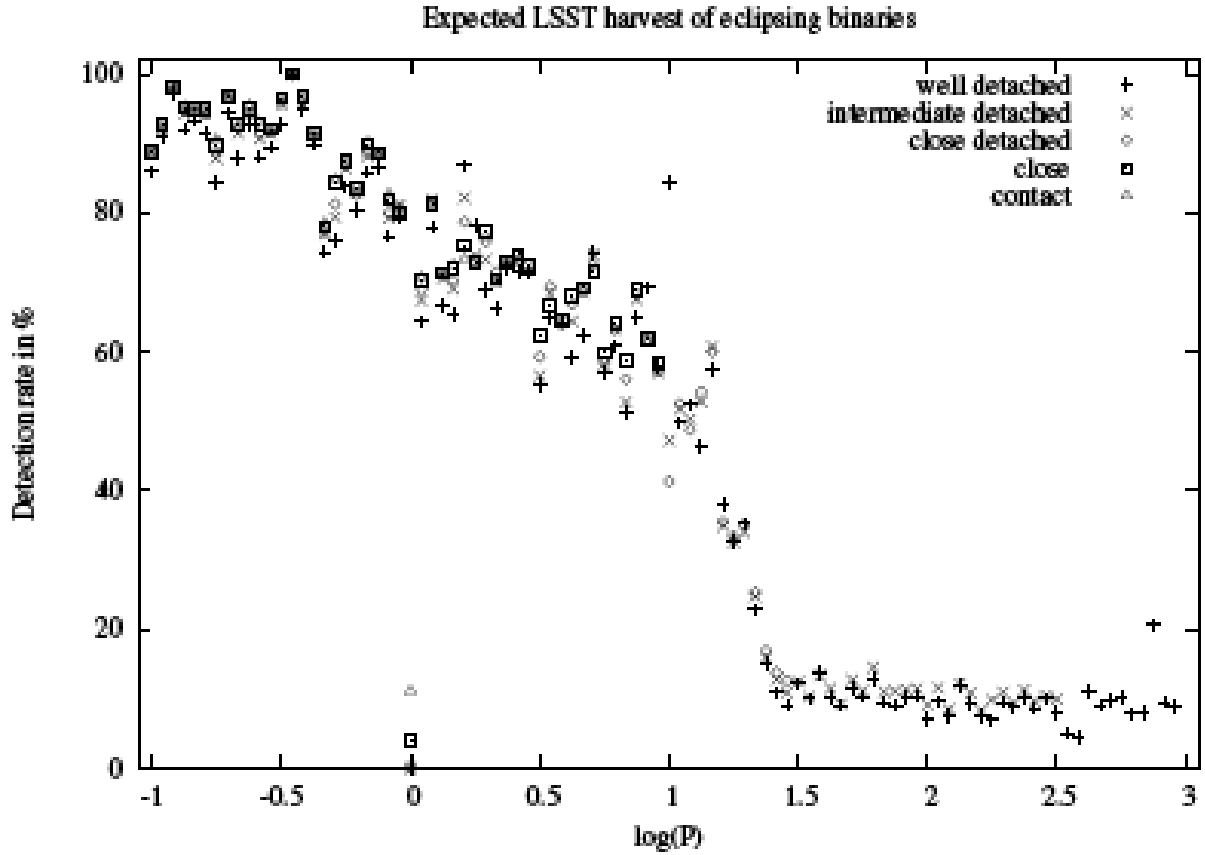
Table 3.3: The expected proper motion, parallax, and accuracy for a ten-year long baseline survey.

r	σ^a_{xy}	σ^b_π	σ^c_μ	σ^d_1	σ^e_C
mag	mas	mas	mas/yr	mag	mag
21	11	0.6	0.2	0.01	0.005
22	15	0.8	0.3	0.02	0.005
23	31	1.3	0.5	0.04	0.006
24	74	2.9	1.0	0.10	0.009

[a] Typical astrometric accuracy (rms per coordinate per visit).
[b] Parallax accuracy for 10-year long survey.
[c] Proper motion accuracy for 10-year long survey.
[d] Photometric error for a single visit (two 15-second exposures).
[e] Photometric error for stacked observations (see Table 1).

Eclipsing Binaries Provide Precision Mass Estimates, Testing Stellar Evolution Models

Large Synoptic Survey Telescope



Transients and Variable Stars

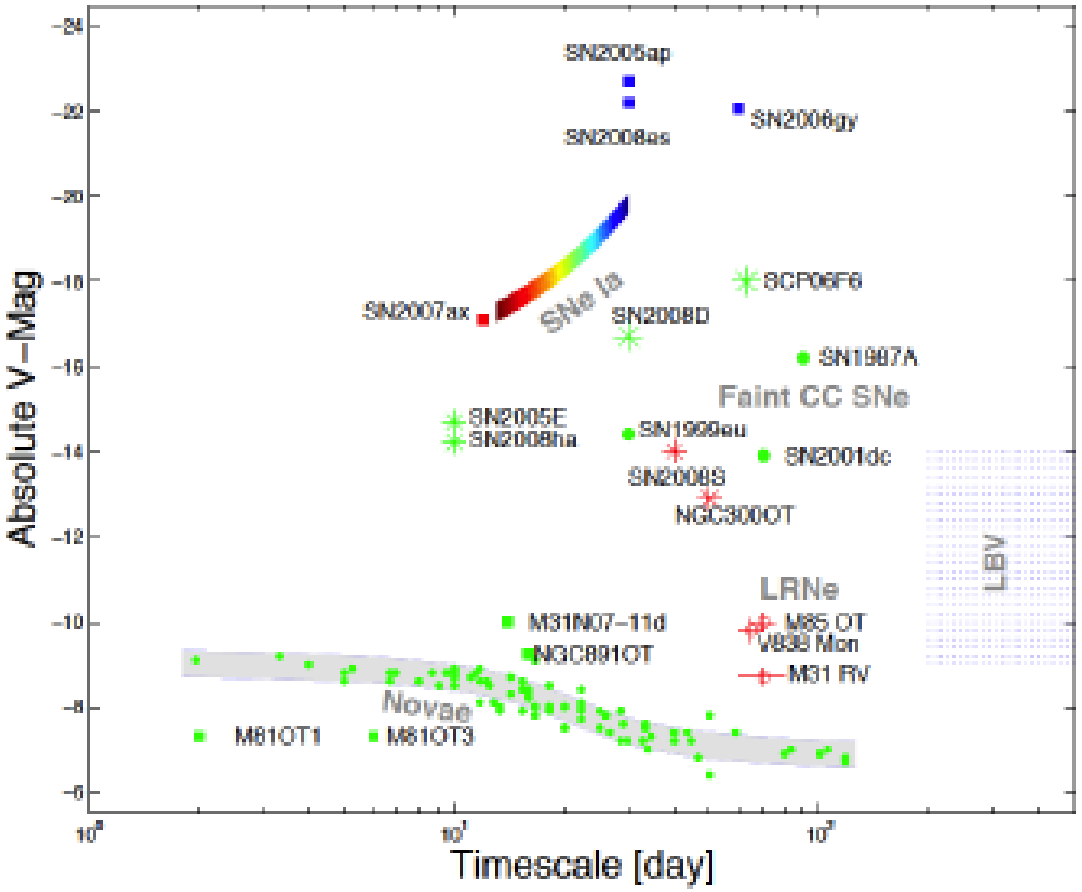
Large Synoptic Survey Telescope

- LSST's unique time sampling allows the detection of stellar variability on timescales from seconds to years.

- A wide range of phenomena can be studied with such a rich dataset:
  - Explosive events (supernovae, novae, gamma-ray bursts)
  - Periodic variability associated with binarity
  - Intrinsic stellar variables like Cepheids, RR Lyrae, Miras, which are important for distance measurements
  - Geometrical effects such as gravitational microlensing
  - Dimming of stars as they are occulted by transiting planets

Our Knowledge of Explosive Transients is Very Limited - Much of the Phase Space Has Been Unexplored

Large Synoptic Survey Telescope



Detailed Simulations Give a Rough Idea of the Content of the Transient and Variability Samples

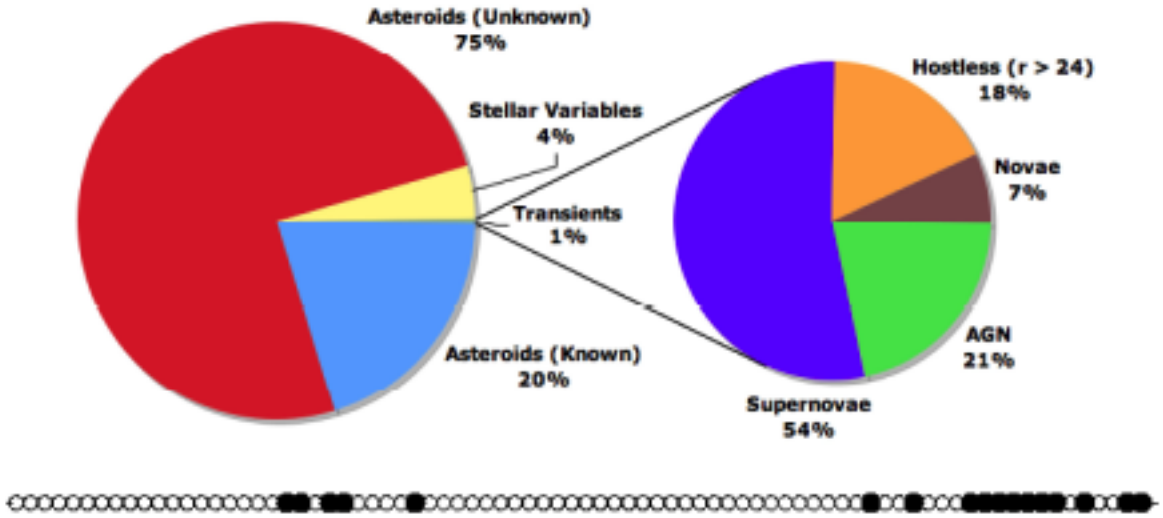


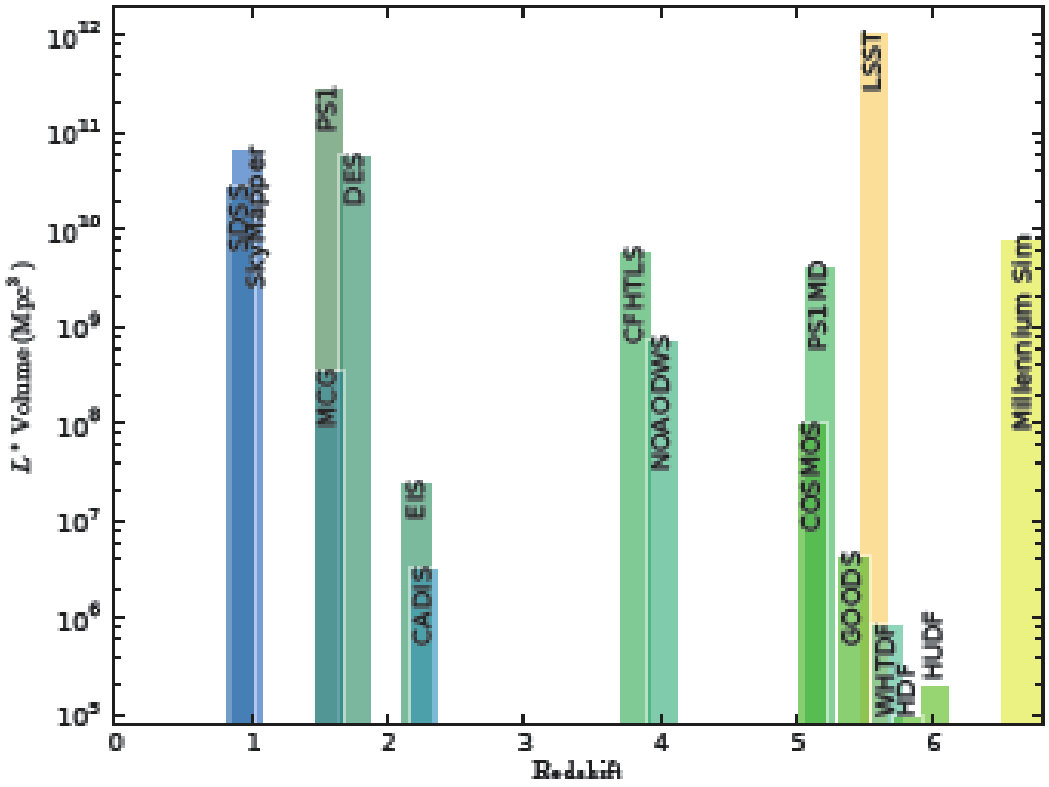
Figure 8.4: 28 COVET transients were discovered during a pilot run in 2008A (7 hours) – two novae and the remainder background supernovae and AGN. Transients with no point source or galaxy host to a limiting magnitude of $r > 24$ are classified as hostless. Of the 2,800 candidates, the COVET pipeline automatically rejected 99% as asteroids or Galactic objects. (Preliminary version from Kasliwal et al. 2009c, in preparation.)

Galaxies

Large Synoptic Survey Telescope

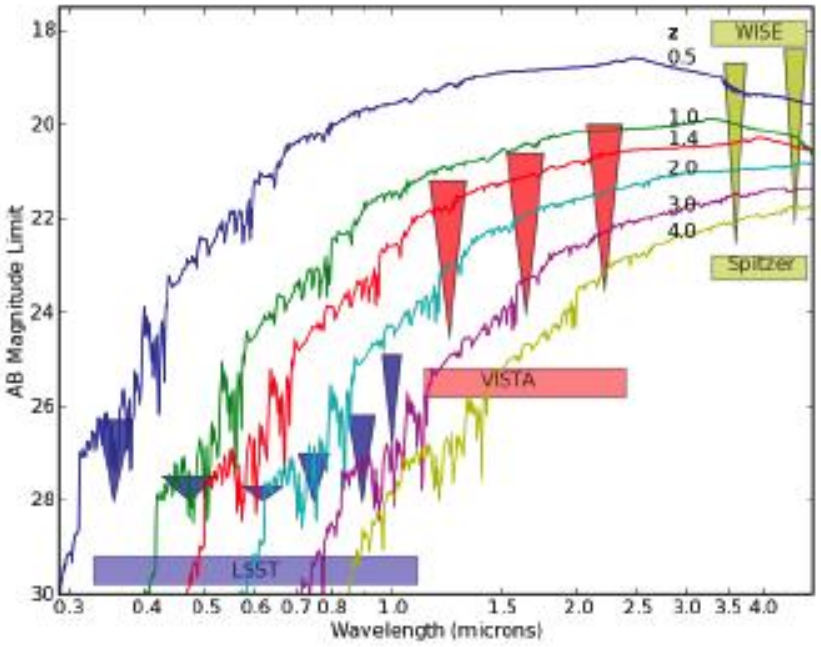
- LSST will be a unique tool for studies of galaxy formation and galaxy properties.
- The database will include photometry for 10^{10} galaxies from the Local Group to $z > 6$.
- We will have 6-band photometry for 4×10^{9} galaxies.
- Key diagnostic tools will include:
  - Luminosity functions
  - Color-luminosity relations
  - Size-luminosity relations
  - Quantitative morphological classifications
  - Dependence on environment

LSST Probes a Co-Moving Volume Two Orders of Magnitude Larger than Current or Near-Future Surveys

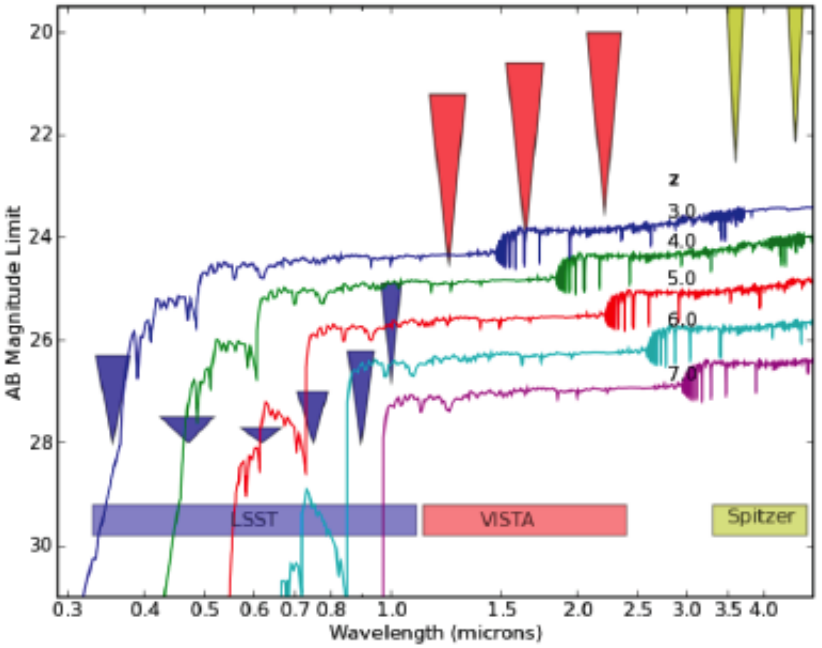


The Expected Sensitivity Leads to Near Complete Samples Out to High Redshifts

Large Synoptic Survey Telescope



Fiducial Red Sequence Galaxy



Fiducial Lyman-Break Galaxy

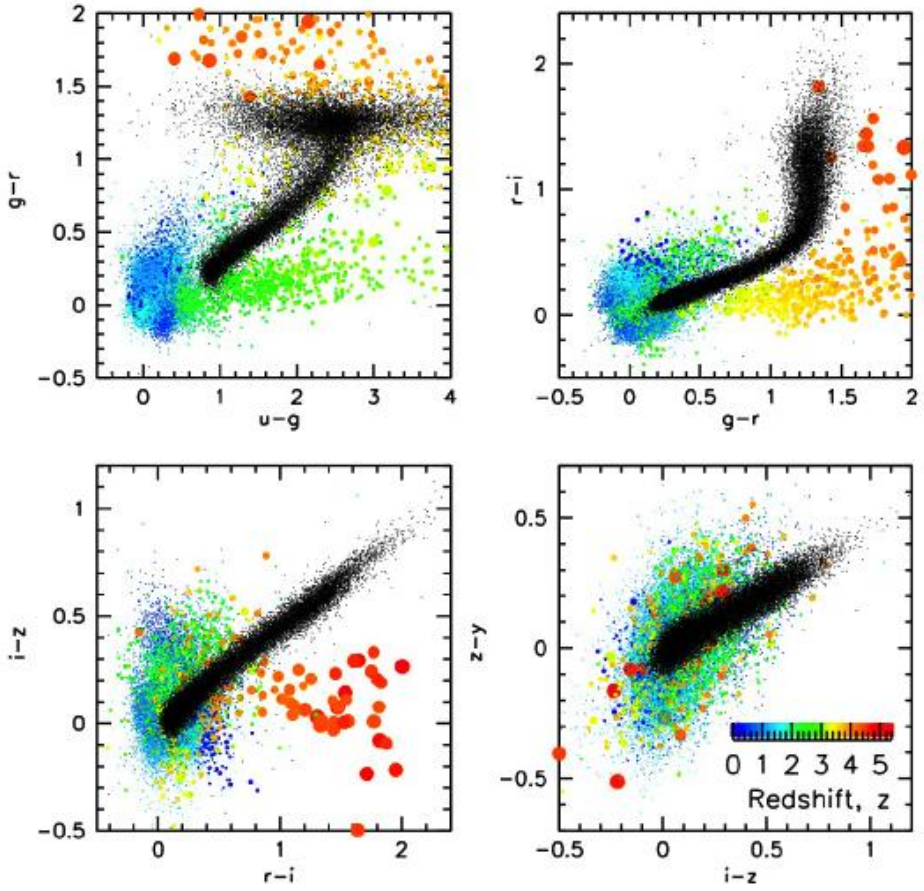
Active Galactic Nuclei

Large Synoptic Survey Telescope

- In recent years, we have learned that the formation and growth of central black holes plays a crucial role in galaxy evolution through “AGN feedback”.
- The enormous dynamic range offered by LSST in luminosity and redshift will revolutionize our understanding of AGN demography and the correlation between AGN properties and their host dark matter haloes.
- LSST will produce a high purity sample of > 10^7 optically-selected AGNs. This is at least an order of magnitude larger than current AGN samples using all wavelengths.

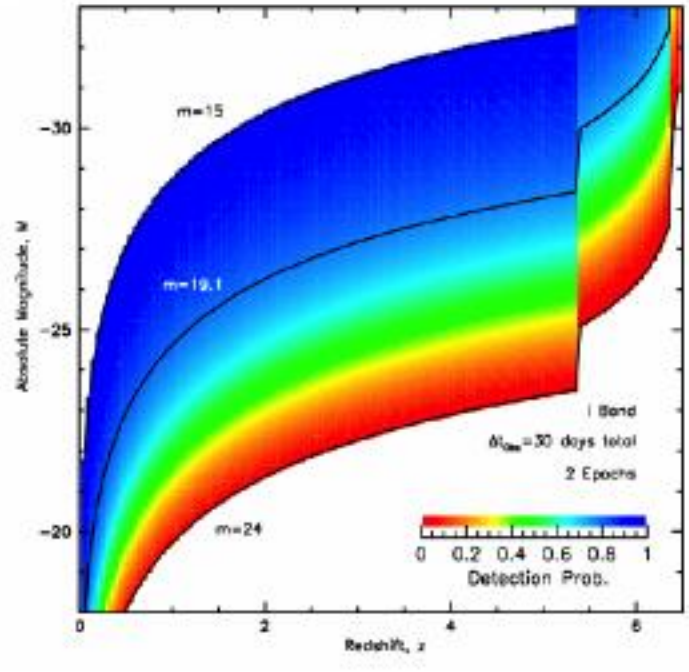
AGNs Can Be Separated From Field Stars Via Their Colors and Absence of Proper Motion

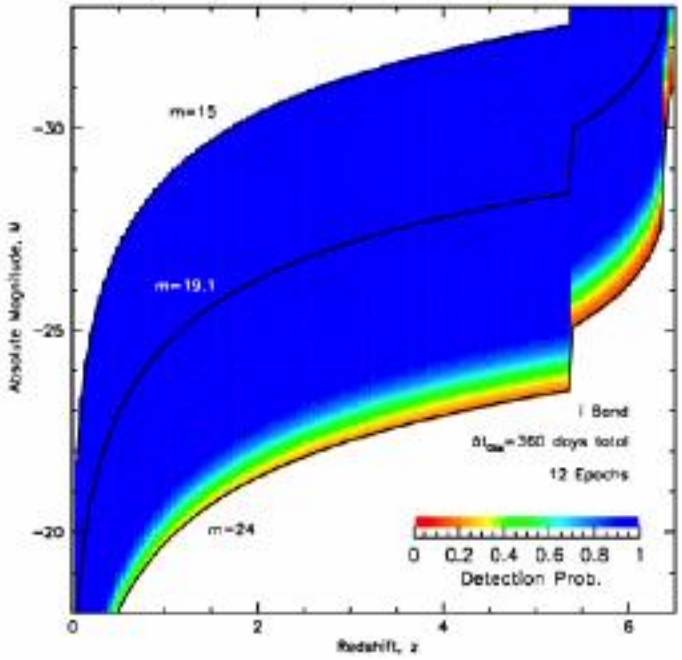
Large Synoptic Survey Telescope



Intrinsic Variability is a Key Tool in Providing Unambiguous AGN Identifications

Large Synoptic Survey Telescope





Precision Cosmology: Constraints on Dark Energy

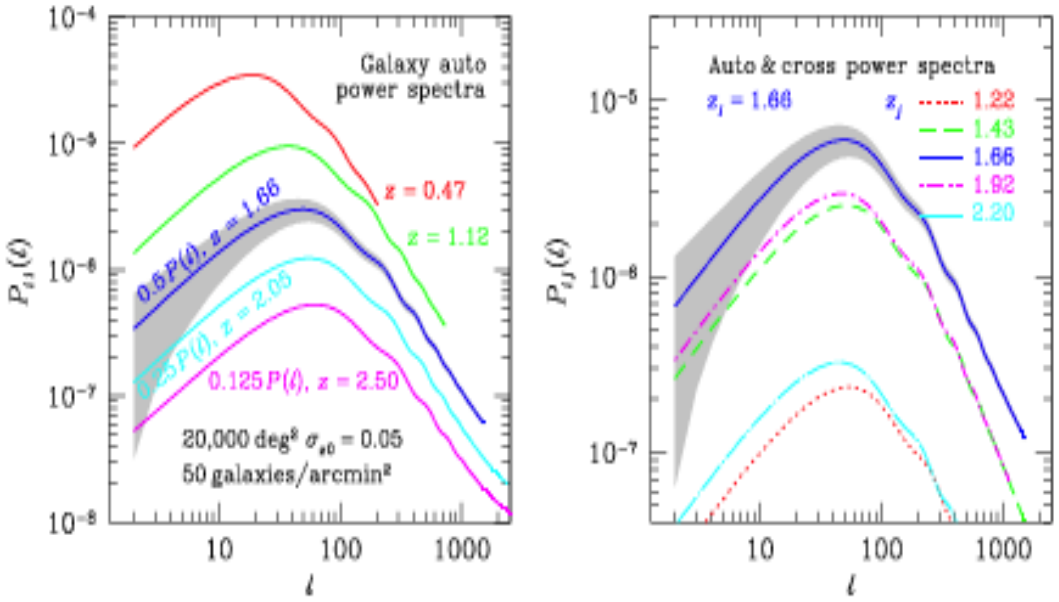
Large Synoptic Survey Telescope

- LSST will probe the nature of Dark Energy via a distinct set of complementary probes:
  - SNe Ia's as "standard candles"
  - Baryon acoustic oscillations as a "standard rulers"
  - Studies of growth of structure via weak gravitational lensing
  - Studies of growth of structure via clusters of galaxies

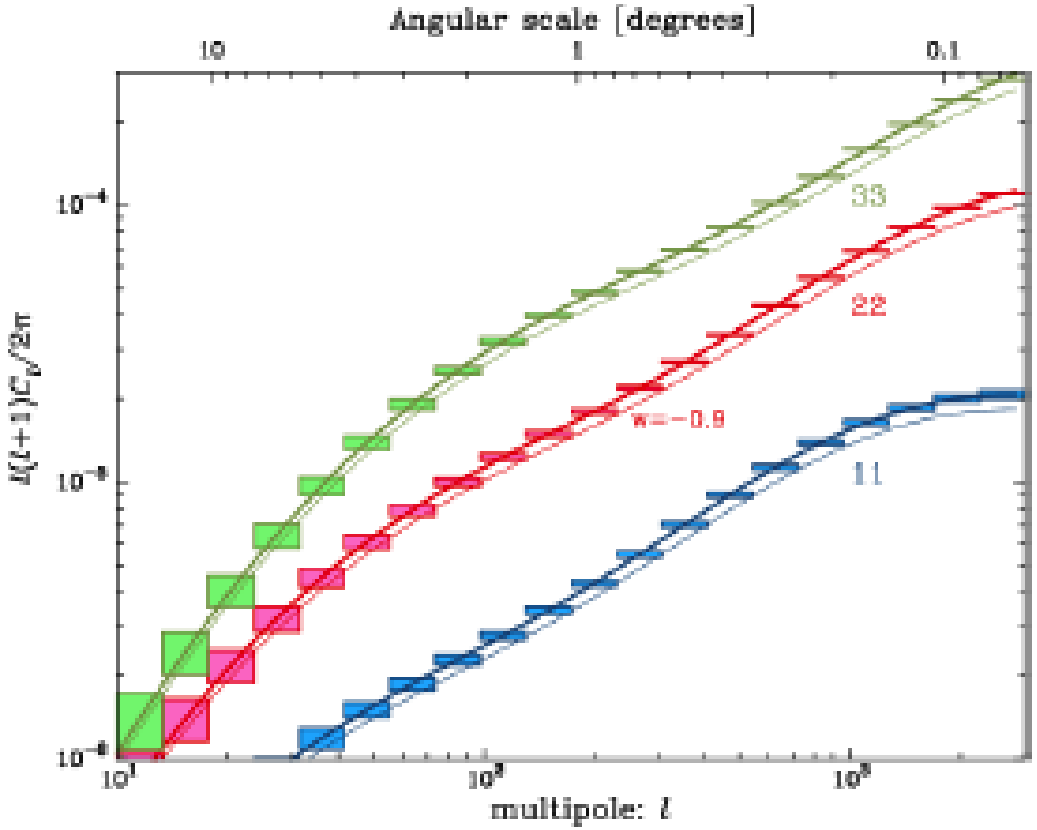
- In conjunction with one another, this rich spectrum of tests is crucial for reduction of systematics and dependence on nuisance parameters.

- These tests also provide interesting constraints on other topics in fundamental physics: the nature of inflation, modifications to GR, the masses of neutrinos.

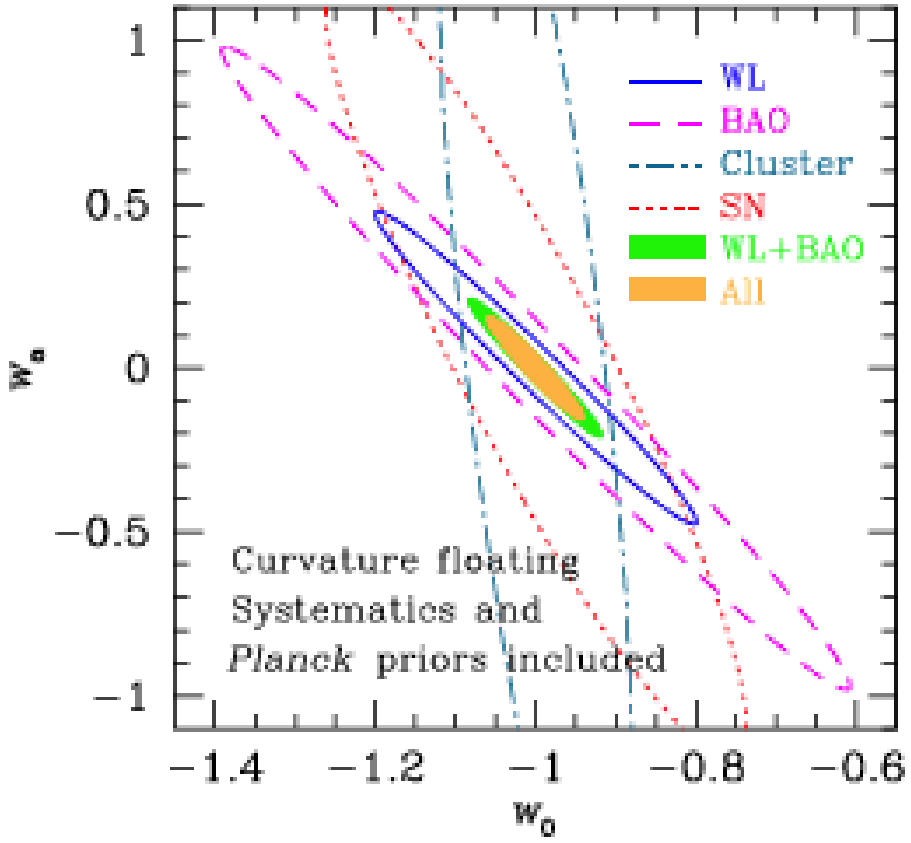
LSST Predictions for Galaxy Auto and Cross Power Spectra



Shear Power Spectra as a Function of Redshift



Separate and Joint Constraints on the Dark Energy Equation of State



Closing Comments

Large Synoptic Survey Telescope

- The LSST science opportunities are extremely rich - ranging from studies of the smallest objects in the solar system to the structure and dynamics of the Universe as a whole.

- Most of the requisite investigations can be performed using data from a single coherent survey program. This is “massively parallel astrophysics” in its purest form.

- LSST is ideally suited to complement upcoming experiments in gravitational wave astrophysics. Its 9.6 squ deg field of view is optimal for identifying the electromagnetic counterpart of merger events. It will discover and catalog unprecedented numbers of short-period binaries. It will catalog billions of galaxies to high redshift. It will unambiguously detect tens of millions of AGN.