The Large Synoptic Survey Telescope

Presentation to P5
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Large Synoptic Survey Telescope

History:

The need for a facility to survey the sky *Wide, Fast and Deep*, has been recognized for many years.

1996-2000 “*Dark Matter Telescope*”
Emphasized mapping dark matter

2000- “*LSST*”
Emphasized a broad range of science from the same multi-wavelength survey data
Wide+Deep+Fast: Etendue

Keck Telescope

Primary mirror diameter

Field of view

0.2 degrees

10 m

3.5 degrees

LSST
Massively Parallel Astrophysics

- Dark matter/dark energy via weak lensing
- Dark matter/dark energy via baryon acoustic oscillations
- Dark energy via supernovae
- Dark energy via counts of clusters of galaxies
- Galactic Structure encompassing local group
- Dense astrometry over 20000 sq.deg: rare moving objects
- Gamma Ray Bursts and transients to high redshift
- Gravitational micro-lensing
- Strong galaxy & cluster lensing: physics of dark matter
- Multi-image lensed SN time delays: separate test of cosmology
- Variable stars/galaxies: black hole accretion
- QSO time delays vs z: independent test of dark energy
- Optical bursters to 25 mag: the unknown
- 5-band 27 mag photometric survey: unprecedented volume
- Solar System Probes: Earth-crossing asteroids, Comets, trans-Neptunian objects
LSST Ranked High Priority

- NRC Astronomy Decadal Survey
- NRC New Frontiers in the Solar System
- NRC Quarks-to-Cosmos
- Quantum Universe
- Physics of the Universe
- SAGENAP
- NSF OIR 2005-2010 Long Range Plan
NSF LSST Funding Timeline

- 2004  R&D proposal to NSF AST
- 2005  $14.2M  LSST R&D grant
- 2006  LSST NSF MREFC Proposal
- 2009  NSB approval to begin construction
- 2013  First light and commissioning
LSST Probes Dark Energy and Dark Matter

- Weak lensing (multiple probes)
- Baryon acoustic oscillations
- Counts of massive clusters vs redshift
- Supernova cosmology (complementary to JDEM)
- Mass power spectrum on very large scales tests CDM paradigm
- Shortest scales of dark matter clumping tests models of dark matter particle physics

The LSST survey will address all with a single dataset!
Weak Gravitational Lensing Heritage

1983-2000  Weak gravitational lens experiments using Blanco telescope

2000  First detection of cosmic shear

2000-2005  Deep Lens Survey

1996-  Emerging need for an all-sky deep multi-wavelength facility with controllable systematic errors

Today, several distinct groups worldwide are pursuing weak lens cosmology on a variety of telescopes.

2-degree by 2-degree mass map of one of five Deep Lens Survey fields. All four clusters examined in this field have been verified with spectroscopy and X-ray observations (2005)
Precision weak lensing shear requires deep imaging to 26.5 mag and good PSF:

New technology telescopes deliver the requisite image quality
20 minute exposure on 8 m Subaru telescope
Point spread width 0.52 arcsec (FWHM)

1 arcminute
Figure of Merit

Area surveyed (number of objects found) to some SNR at some photon flux limit, per unit time:

\[
\frac{N}{t} = \frac{\Phi_{\text{obj}}^2 A \Omega \text{QE} \varepsilon}{(\text{SNR})^2 \Phi_{\text{sky}}(\delta\Omega)}
\]

- **Science goals**
  - \( A \) – aperture
  - \( \varepsilon \) – observing eff.

- **Apparatus & Eff.**
  - \( \Omega \) – camera FOV
  - \( \text{QE} \) – det. Eff.

- **site & optics**
  - \( \Phi_{\text{sky}} \) – sky flux
  - \( \delta\Omega \) – seeing footprint
Relative Etendue ($= A\Omega$)

All facilities assumed operating 100% in one survey
Pan-STARRS-4 as an LSST Precursor

- The total etendue = 0.15 x LSST.

- To search for asteroids, PS-4 will use an ultra wide-band filter - unsuitable for lensing or for photo-z’s.

- Weak lensing will require separate observing time with narrow band filters.

- Funded partially by the USAF, PS-4 will consist of four 1.8 m telescopes, each with a 1.4 Gpixel camera.

- A single prototype, PS-1, is currently under construction.
DE Science Drives Short Exposures

- Weak lensing requires exquisite control of shape systematics.
- One needs hundreds of exposures per filter per sky patch for chopping.
- Short exposures allow us to optimally weight.
- Many exposures with sky rotated on detector permit another chop.
- These require high etendue and short exposures.
20000 sq.deg WL survey shear power spectra

Require: shear error < 0.0002
Critical Issues

- WL shear reconstruction errors
  - Show control to better than required precision using existing new facilities ✓

- Photometric redshift errors
  - Develop robust photo-z calibration plan ✓
  - Undertake world campaign for spectroscopy (✓)

- Photometry errors
  - Develop and test precision flux calibration technique ✓
Subaru 10 sec Exposures

Raw de-trailed PSF corrected

Single exposure in 0.65 arcsec seeing

\( \langle \text{shear} \rangle = 0.04 \)

\( \langle \text{shear} \rangle < 0.0001 \)
Residual Subaru Shear Correlation

Test of shear systematics: Use faint stars as proxies for galaxies, and calculate the shear-shear correlation.

Compare with expected cosmic shear signal.

Conclusion: 200 exposures per sky patch will yield negligible PSF induced shear systematics. Wittman (2005)
Photometric Redshifts

Calibration: angular correlation between photo-z and spectroscopic samples enables high precision photo-z:  http://www.lsst.org/Science/Phot-z-plan.pdf
Together with angular correlations of galaxies, this training set enables LSST 6-band photo-z error calibration to better than required for precision cosmology.

Systematic error: 
0.003(1+z) \textit{calibratable}

Need 20,000 spectroscopic redshifts
2-parameter Errors from LSST WL

\[ \frac{p}{\rho} = w_0 + w_a (1-a) \]

Two cosmologies

Effect of joint analysis of LSST 2-point and 3-point shear data + Planck CMB
30,000 LSST Supernovae to $z = 1$

Simulated Hubble diagram

Simulated light curves

Deep field sample from LSST
Precision vs Integrated Luminosity

Planck priors included
Free parameters: $\omega_m$, $\omega_b$, $\theta_s$, $\Omega_b$, $Y_p$, $n_s$, $\Delta_\phi$
Conservative estimates: angular scales $> 10'$
Precision vs Integrated Luminosity

Planck priors included
Free parameters: $\omega_m$, $\omega_b$, $\theta$, $\Omega_k$, $Y_p$, $n_s$, $\Delta_s$
Conservative estimates: angular scales > 10'

$\sigma (w_a) \times \sigma (w_p)$

WL
WL+BAO+SNe

$A \Omega t$ (m$^2$ deg$^2$ years)
Physics of Dark Matter

Strong gravitational lensing with multiple images provides a sensitive probe of dark matter mass distributions. LSST will find many of these.

Image of a z=1.7 galaxy being multiply lensed by a z=0.4 mass cluster
Detailed map of dark matter
LSST and Fundamental Physics

• Unique experiment for DE physics:
  – Five separate types of probes from the same experiment.
  – Precision control of systematics enabled by multiple chops.
  – Ultra-deep $2\pi$ sky coverage.

• Incisive probe of dark matter clumping on scales relevant to the underlying physics.
LSST Project Organization

- The LSST is a public/private project with public support through NSF-AST and DOE-OHEP.

- Private support is devoted primarily to project infrastructure and fabrication of the primary/tertiary and secondary mirrors, which are long-lead items.

- NSF support is proposed to fund the telescope. DOE support is proposed to fund the camera.

- Both agencies would contribute to data management and operations.

LSST Organization Chart
The LSST Corporation

• The project is overseen by the LSSTC, a 501(c)3 non-profit Arizona corporation based in Tucson.

• LSSTC is the recipient of private funding, and is the Principal Investigator organization for the NSF D&D funding.
There are 15 LSSTC Institutional Members

- Brookhaven National Laboratory
- Harvard-Smithsonian Center for Astrophysics
- Johns Hopkins University
- Las Cumbres Observatory, Inc.
- Lawrence Livermore National Laboratory
- National Optical Astronomy Observatory
- Research Corporation
- Stanford Linear Accelerator Center
- Stanford University –KIPAC
- The Pennsylvania State University
- University of Arizona
- University of California, Davis
- University of Illinois at Champaign-Urbana
- University of Pennsylvania
- University of Washington
Funding and Management Configuration

Funding Sources

LSST Collaboration Institutions

Joint Oversight - tbd

DOE
LSSTC Private
NSF

LSSTC
PMO

LLNL
BNL
SLAC

Universities

LSSTC Staff

NOAO
NCSA

Relationships established by MoA's

PMO: Program Management Office
LSST Optical Design

- $f/1.23$
- $<0.20$ arcsec FWHM images in six bands: 0.3 - 1 $\mu$m
- $3.5$ ° FOV $\rightarrow$ Etendue = 319 m$^2$deg$^2$

![Polychromatic diffraction energy collection](image1.png)

![LSST optical layout](image2.png)
Mirror Designs

Primary/Tertiary Mirror

- **Unique Monolithic Mirror:** Primary and Tertiary Surfaces Polished Into Single Substrate
- **Cast Borosilicate Design**

Secondary Mirror

- **Thin Meniscus Low Expansion Glass Design for Secondary Mirror**
- **102 Support Actuators**
Telescope Structure

Altitude over azimuth configuration
LSST Site Selection Process – 2 Finalists
Selection Upcoming in June

San Pedro Mártir

Cerro Pachón
The LSST Focal Plane

- Guider Sensors (yellow)
- Wavefront Sensors (red)
- 3.5 deg FOV
- Illumination Limit
- 3.2 Gpixels

The Large Synoptic Survey Telescope (LSST) is an astronomical survey telescope designed to conduct an all-sky survey of the visible universe.
The LSST CCD Sensor

32 segments/CCD
200 CCDs total
6400 Total Outputs

Detail of output port

Detail of one edge

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The Data Management Architecture

- **Infrastructure Layer**
  - Computing, storage, and networking hardware and system software at each facility

- **Middleware Layer**
  - Distributed processing, data access, user interface, and system operations services

- **Application Layer**
  - Data Pipelines and Products and the Science Data Archive
Infrastructure Layer

- Long-Haul Communications
- Archive/Data Access Centers
- Base Facility
- Mountain Site
Project Management Controls Status

Currently:

- Reference Design nearly complete
- Full WBS with dictionary and task breakdown
- Schedule is complete
- Construction cost allocation complete and cost estimate nearly complete

To Do:

- Task-based estimate (due May 31)
- Integrated cost/schedule
- Concept Design Review
- Operations document and operations budget
- Functional performance requirements document
Basic timeline for the LSST

- **FY2004 - 2008**: R&D phase, long-lead items started
- **FY2009 - 2012**: Construction
- **Dec, 2012**: First engineering light
- **FY2013**: Commissioning and early science
- **FY 2014 - 2024**: Operations
# Coordinating the NSF and DOE Support

- DOE follows: Program and Project Management for the Acquisition of Capital Assets,” DOE Order 413.3

- NSF follows new policy modeled in-part after DOE model: “Guideline for Planning and Managing the Major Research Equipment and Facilities Construction Account,” November 22, 2005

### NSF

<table>
<thead>
<tr>
<th>Conceptual Design Stage</th>
<th>Readiness Stage</th>
<th>Board Approved Stage</th>
<th>Construction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concept development – Expend approximately 1/3 of total pre-construction planning budget</td>
<td>Prelim design over ~1-2 years, Expend approx 1/3 of total pre-construction planning budget</td>
<td>Final design over ~1 year, Approx 1/3 of total pre-construction planning budget</td>
<td>Expenditure of budget and contingency per baseline</td>
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<tr>
<td>Develop construction budget based on conceptual design</td>
<td>Construction estimate based on Prelim design, Update op $ estimate</td>
<td>Construction ready budget &amp; contingency estimates</td>
<td>Refine op $ budget</td>
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<tr>
<td>Estimate op $</td>
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</table>

### DOE

**PROJECT ACQUISITION PROCESS AND CRITICAL DECISIONS**

<table>
<thead>
<tr>
<th>Mission</th>
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</thead>
<tbody>
<tr>
<td>Operations</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Project Planning Phase</th>
<th>Project Execution Phase</th>
<th>Construction</th>
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<tbody>
<tr>
<td>Preconceptual Planning</td>
<td>Preliminary Design</td>
<td>Final Design</td>
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<tr>
<td>Conceptual Design</td>
<td>Construction</td>
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<tr>
<td>CD -0</td>
<td>CD -1</td>
<td>CD -2</td>
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<tr>
<td>Approve Mission Need</td>
<td>Approve Preliminary Baseline Range</td>
<td>Approve Performance Baseline</td>
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</table>

See Page 2 for CD -0 to Construction, and Project Closeout and Final Budget Implications
## Funding Requests in Then-Year dollars

### Construction funding request in Then-Year dollars

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<thead>
<tr>
<th>Source</th>
<th>Amount</th>
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<tr>
<td>Total</td>
<td>$330M</td>
</tr>
<tr>
<td>NSF MREFC</td>
<td>$190M</td>
</tr>
<tr>
<td>DOE</td>
<td>$101M</td>
</tr>
<tr>
<td>Private</td>
<td>$39M</td>
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</tbody>
</table>

### Operations starting in FY2013

- **FY2014 → $25.5M** (first full year of operation)
- Total for 10 years of operation → **$295M**
The LSST Construction Cost

Total Construction Cost in 2006 USD: $297M

Total Construction Cost in THEN-YEAR USD: $330M

- **Telescope/Site**: $129.7M (39%)
- **Camera**: $101.1M (30%)
- **Data Mgmt**: $88.5M (27%)
- **Prog Mgmt**: $10.3M (3%)

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<table>
<thead>
<tr>
<th></th>
<th>R&amp;D Phase</th>
<th>MIE Phase</th>
<th>Operations Phase***</th>
<th>Totals</th>
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<tr>
<td></td>
<td>FY06</td>
<td>FY07</td>
<td>FY08</td>
<td>FY09</td>
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<tr>
<td></td>
<td>Q1 only</td>
<td>Q2 to Q4</td>
<td>FY15 on</td>
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<tr>
<td>Total Loaded Labor $M</td>
<td>$3.1</td>
<td>$4.5</td>
<td>$4.7</td>
<td>$6.1</td>
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<td>Total Labor Contingency $M</td>
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<td>$6.1</td>
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<td>Subtotal of Labor $ w/Contingency</td>
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<td>$4.5</td>
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<td>$6.1</td>
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<td>M&amp;S</td>
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<td>$5.0</td>
<td>$6.7</td>
<td>$24.0</td>
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<td>M&amp;S Contingency</td>
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<td>$1.3</td>
<td>$1.8</td>
<td>$8.0</td>
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<td>Subtotal of M&amp;S w/Contingency</td>
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<td>$6.3</td>
<td>$8.5</td>
<td>$32.0</td>
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<td>Subtotal of Loaded Labor+M&amp;S</td>
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<td>$9.5</td>
<td>$11.4</td>
<td>$30.1</td>
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<tr>
<td>Total of Contingencies</td>
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<td>$1.3</td>
<td>$1.8</td>
<td>$8.0</td>
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<td>Contingency as % of Base</td>
<td>5%</td>
<td>14%</td>
<td>16%</td>
<td>27%</td>
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<tr>
<td>Total</td>
<td>$4.3</td>
<td>$10.8</td>
<td>$13.2</td>
<td>$38.1</td>
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### Estimates in Base Year 2006 ($M)

<table>
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<th>Escalated to Then-Year $M</th>
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<tbody>
<tr>
<td>Escalation added to Total (3%/year)</td>
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<tr>
<td>Escalated to Then-Year $M</td>
<td>$4.3</td>
</tr>
<tr>
<td>Cumulative of phase (escalated)</td>
<td>$4.3</td>
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<tr>
<td>Cumulative TPC*** (escalated)</td>
<td>$4.3</td>
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</tbody>
</table>

### Notes

- MIE ends after Q1 of FY13.
- Operations starts Q2 of FY13.
- **Total project cost includes R&D, MIE fabrication phase, and commissioning.
- **Observatory operations is shared with NSF; budget here is DOE portion only (~40%) of total observatory operations. Staffing includes camera operations, maintenance and participation in data archive center.
• Review held March 8-9, 2006, chaired by Lowell Klaisner.

• The Committee reviewed the technical design of the camera and the cost and schedule of the project as a whole.

• The Committee supported the project moving forward and the investment requested from DOE and SLAC.

• Reviewers identified concern with technical risk associated with the sensor production, and too little float in the technically-limited schedule.

• All issues are being worked by the project now. Fallback options have been identified if the prototype sensors do not meet specifications and an improved integration concept mitigates risk in the schedule.
Overall Summary

- The LSST will be a world-leading facility for astronomy and cosmology. A single database will enable a large array of diverse scientific investigations. The project has broad support in the astronomy community, and it is therefore a key component of NSF’s long-term plan for the field.

- Of particular interest to HEP, LSST will measure properties of dark energy via weak lensing, baryon oscillations, Type 1a supernovae, and measurements of clusters of galaxies. It will test models of dark matter through strong lensing. No other existing or proposed ground-based facility has comparable scientific reach.

- The synergy in technical and scientific expertise between the astronomy and HEP communities will be essential to the project’s success.

- A detailed initial design is in place for all major components of the system. With appropriate funding from NSF and DOE, the project is on-track to achieve first light in 2013.