The Large Synoptic Survey Telescope

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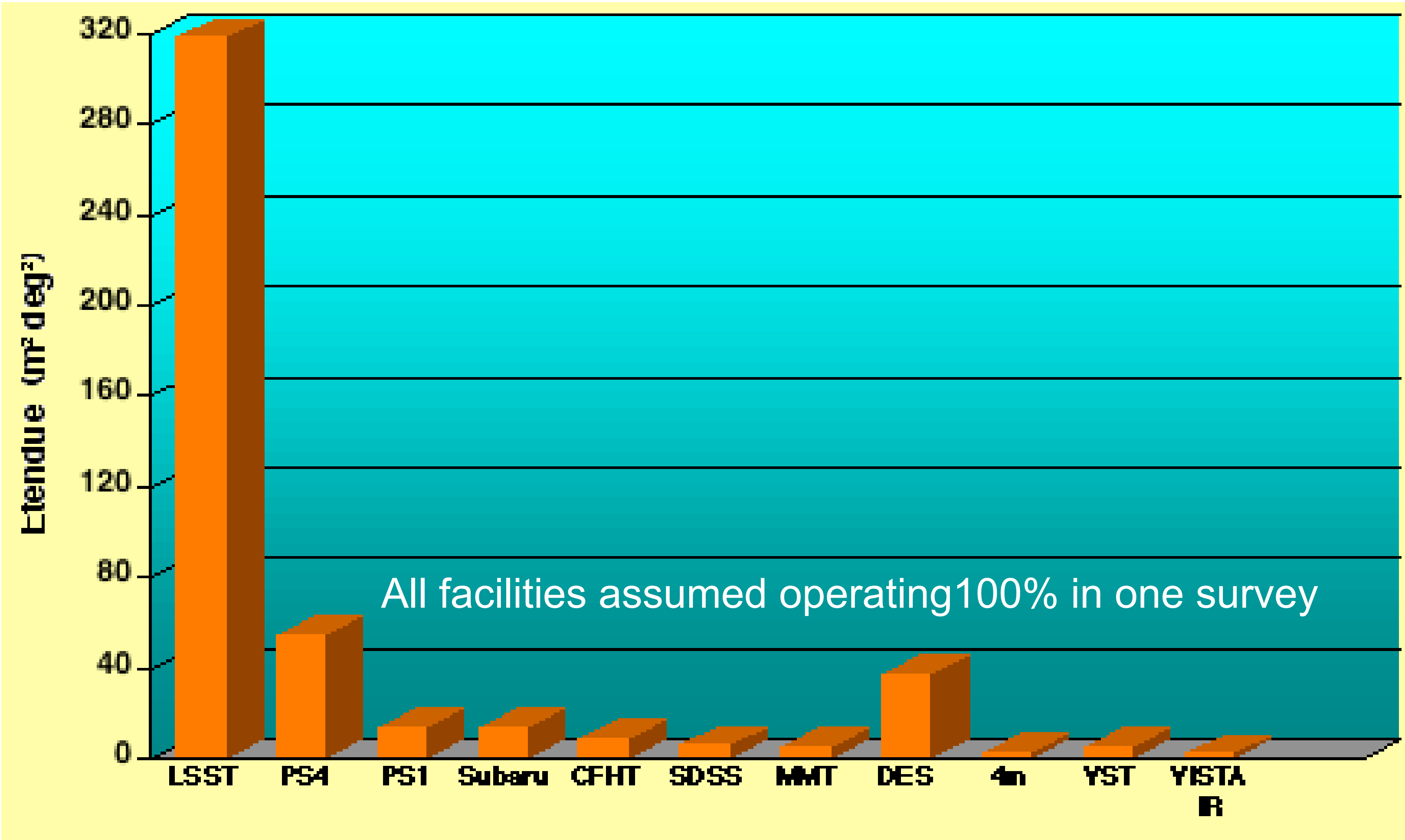
What is the LSST?

- The LSST will be a large, wide-field ground-based telescope designed to provide time-lapse digital imaging of faint astronomical objects across the entire visible sky every few nights.

- LSST will enable a wide variety of complementary scientific investigations, utilizing a common database. 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.

- Of particular interest for cosmology and fundamental physics, LSST will provide strong constraints on models of dark matter and dark energy through statistical studies of the shapes and distributions of faint galaxies at moderate to high redshift.

Relative Etendue (= AΩ)



Massively Parallel Astrophysics

Large Synoptic Survey Telescope

- 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 and Dark Energy

- The only observational handle that we have for understanding the properties of dark energy is the expansion history of the universe itself. This is parametrized by the Hubble parameter:

$$H(z) = \frac{\dot{a}}{a}$$

- Cosmic distances are proportional to integrals of $H(z)^{-1}$ over redshift. We can constrain $H(z)$ by measuring luminosity distances of standard candles (Type 1a SNe), or angular diameter distances of standard rulers (baryon acoustic oscillations).

- Another powerful approach involves measuring the growth of structure as a function of redshift. Stars, galaxies, clusters of galaxies grow by gravitational instability as the universe cools. This provides a kind of cosmic "clock" - the redshift at which structures of a given mass start to form is very sensitive to the expansion history.

LSST Probes Dark Energy in Multiple Ways

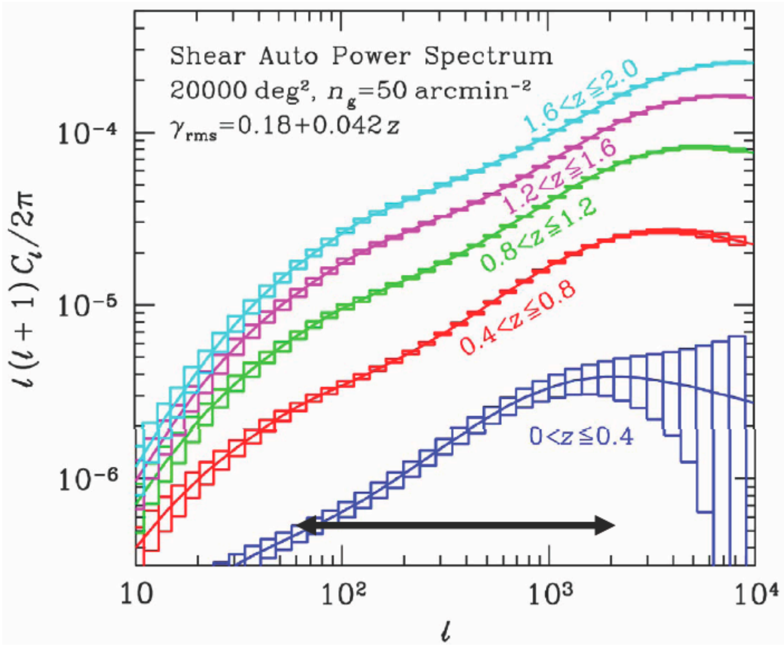
Large Synoptic Survey Telescope

- Cosmic shear (growth of structure + cosmic geometry)
- Counts of massive structures vs redshift (growth of structure)
- Baryon acoustic oscillations (angular diameter distance)
- Measurements of Type 1a SNe (luminosity distance)
- 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!

LSST and Cosmic Shear

- The simplest measure of cosmic shear is the 2-pt correlation function measured with respect to angular scale.
- This is usually plotted as a power spectrum as a function of multipole moment (similar to the CMB temperature maps).
- Note the points of inflection in these curves. This is a transition from the linear to the non-linear regime.
- The growth in the shear power spectrum with the redshift of the background galaxies is very sensitive to *H(z)*. This provides the constraints on dark energy.

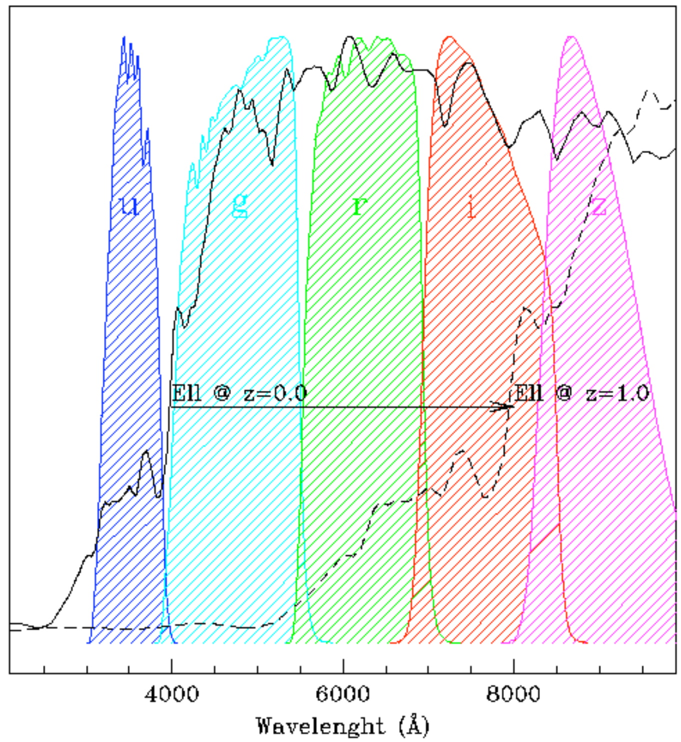


Photometric Redshifts

- Galaxies have distinct spectra, with characteristic features at known rest wavelengths.

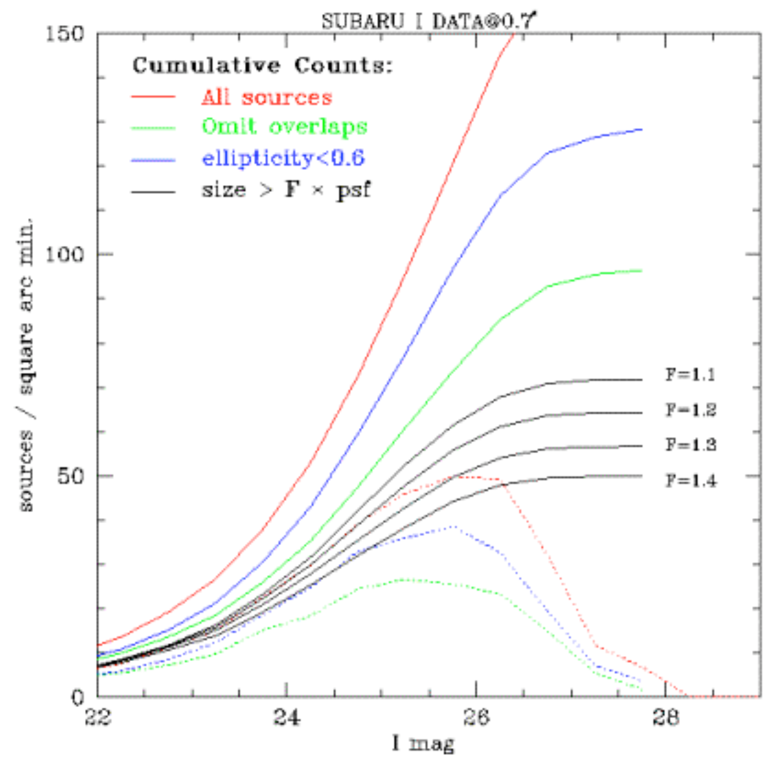
- Accurate redshifts can be obtained by taking spectra of each galaxy. But this is impractical for the billions of galaxies we will use for LSST cosmic shear studies.

- Instead, we use the colors of the galaxies obtained from the images themselves. This requires accurate calibration of both the photometry and of the intrinsic galaxy spectra as a function of redshift.



LSST is Optimally Sized for Measurements of Cosmic Shear

- On small scales, the shear error is dominated by shape noise - it scales like the sqrt of the number of galaxies per squ. arcmin.
- On larger scales, cosmic variance dominates - it scales like the sqrt of the total solid angle of sky covered.
- From the ground, the number of galaxies per squ. arcmin levels off at mag 26.5.
- With the LSST etendue, this depth can be achieved over the entire visible sky.



Cosmic Shear - Dealing with Systematics

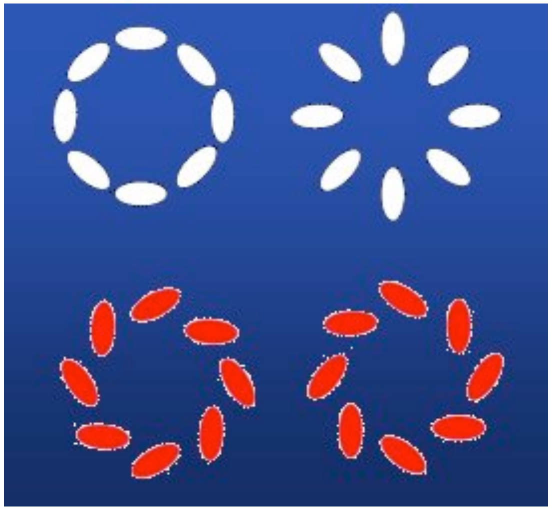
- The cosmic shear signal on larger angular scales is at a very low level.
- To make this measurement, we must be confident that we understand and can remove spurious sources of shear. These can arise in the atmosphere or in the optics of the telescope and camera.
- LSST is the first large telescope designed with weak lensing in mind. Nevertheless, it is essentially impossible to build a telescope with no asymmetries in the point spread function (PSF) at the level we require.
- Fortunately, the sky has given us some natural calibrators to control for PSF systematics: There is one star per square arcmin bright enough to measure the PSF in the image itself. Light from the stars passes through the same atmosphere and instrumentation, but is not subject to weak lensing distortions from the intergalactic medium. By interpolating the PSF's, we can deconvolve spurious shear from the true cosmic shear signal we are trying to measure. The key issue is how reliable is this deconvolution at very low shear levels.

Cosmic Shear Systematics: E-B mode Decomposition

The shear is a spin-2 field and consequently we can measure two independent ellipticity correlation functions. The lensing signal is caused by a gravitational potential and therefore should be curl-free. We can project the correlation functions into one that measures the divergence and one that measures the curl: E-B mode decomposition.

E-mode (curl-free)

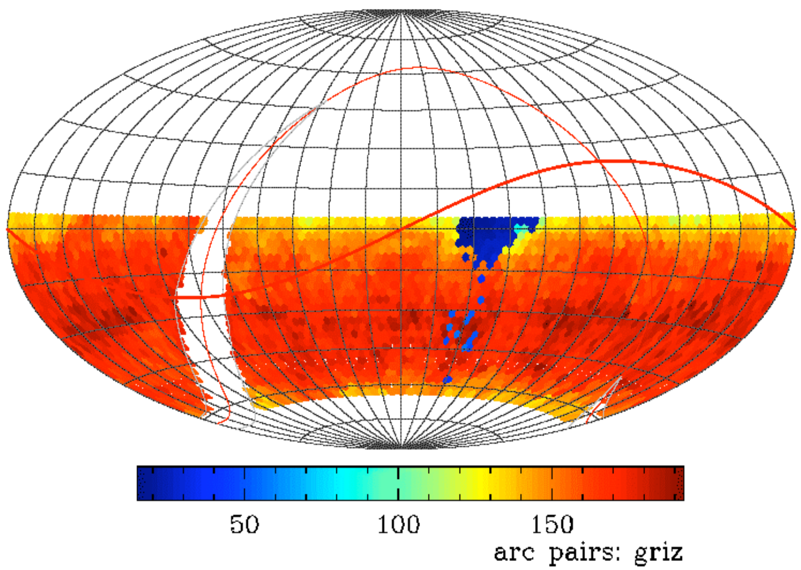
B-mode (curl)



A residual B-mode is an indication of spurious shear in the analysis.

Measuring Shear Residuals Directly

- A key aspect of the LSST design is that we have very short exposure times (15 s). This enables us to obtain several hundred visits per field in each color over the life of the survey - nearly 1,000 visits overall.
- Using brighter galaxies, which are visible in every exposure, we can thus directly measure the residual spurious shear contributions as a function of environmental conditions.
- This allows us to optimize the shear extraction algorithms, leading to tremendous reduction in systematics.
- Experience in particle physics expts shows that the systematic errors fall faster than root N - more like 1/N.

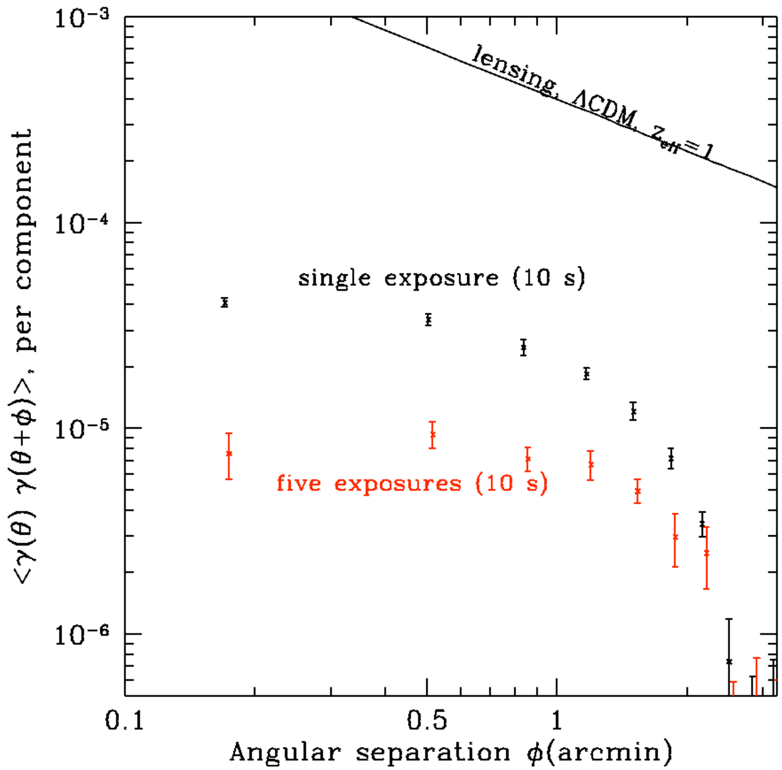


Residual Subaru Shear Correlation

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

Compare with expected cosmic shear signal.

Conclusion: 500 exposures per sky patch will yield negligible PSF induced shear systematics.
Wittman (2005)

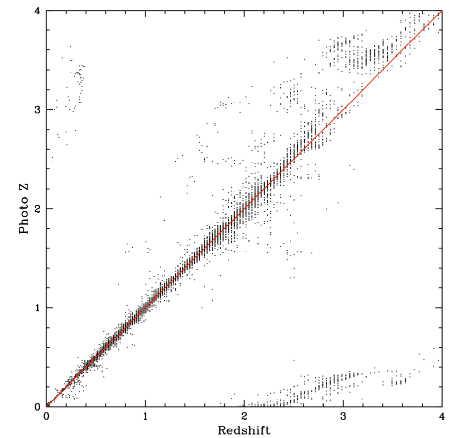


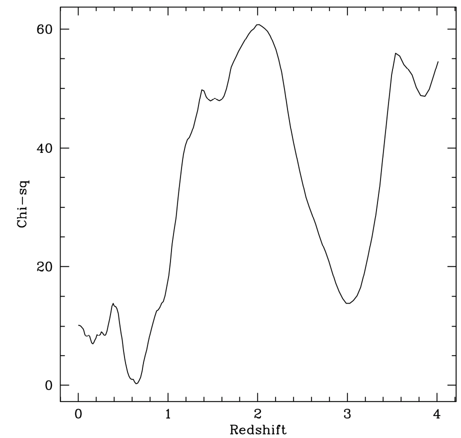
Systematics in Photo-z's

- Photometric redshift accuracy is limited by the statistical quality of the data and by the location of the key spectral features with respect to the passbands which are used.

- The dominant features are the Balmer and Lyman breaks at 400 nm and 91 nm, respectively. As these move through the bands, the noise in the photo-z inversion rises and falls.

- There can also be catastrophic failures due to multiple minima associated with confusion between these two features.



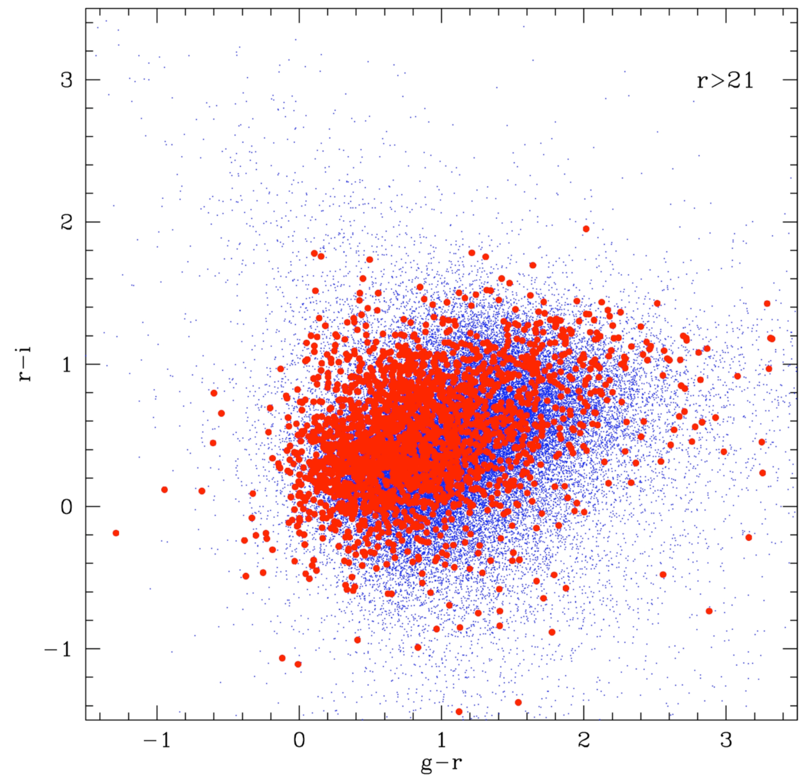


Systematics in Photo-z's

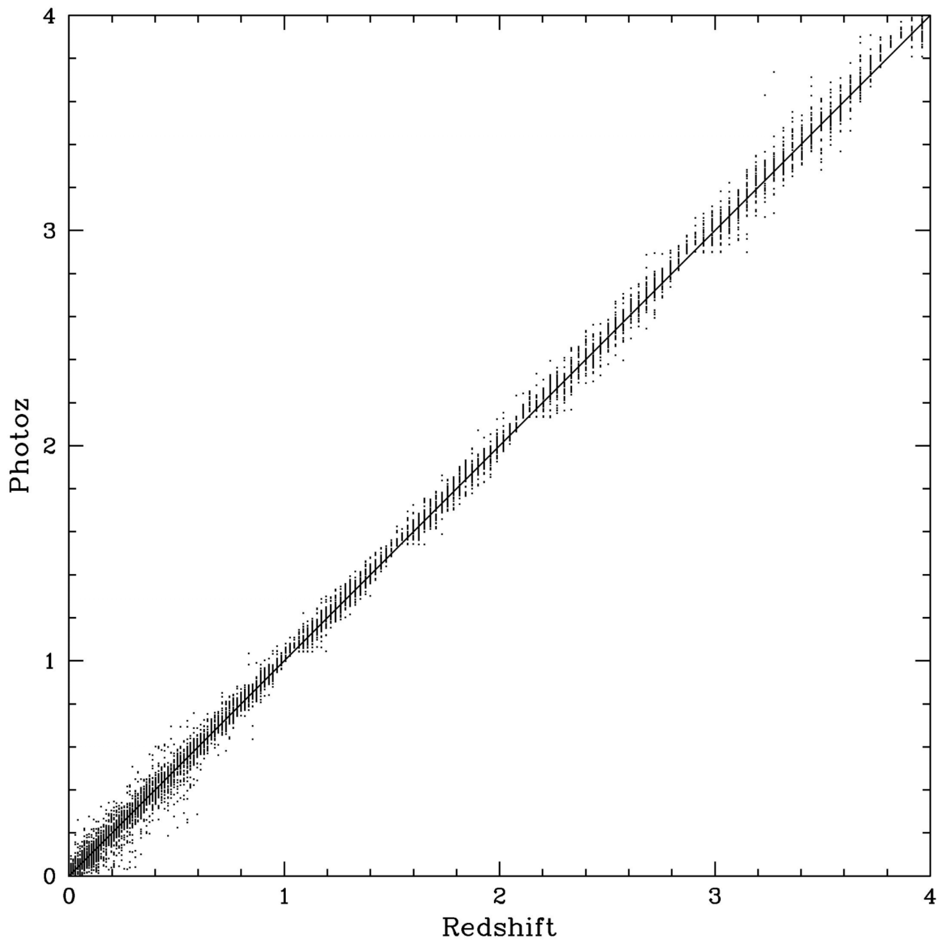
- There are various statistical issues that can be investigated using Monte Carlo techniques to quantify the impact of photo-z errors on dark energy parameter estimations. Priors on size and mag can help to reduce the catastrophic failures.

- But we are still left with the fundamental issue of calibration, since we don't know the distribution of intrinsic galaxy spectra at higher redshifts.

- Brute force calibration would require an enormous number of spectroscopic measurements. Fortunately, it appears that making use of the intrinsic clustering properties of galaxies can reduce this number to a manageable level.



12-band Super Photo-z Training Set



Using angular correlations this training set enables LSST photo-z error calibration to better than required precision

Systematic error:
0.003(1+z) *calibratable*
Need 20,000 spectroscopic redshifts overall.

Precision vs Integrated Luminosity

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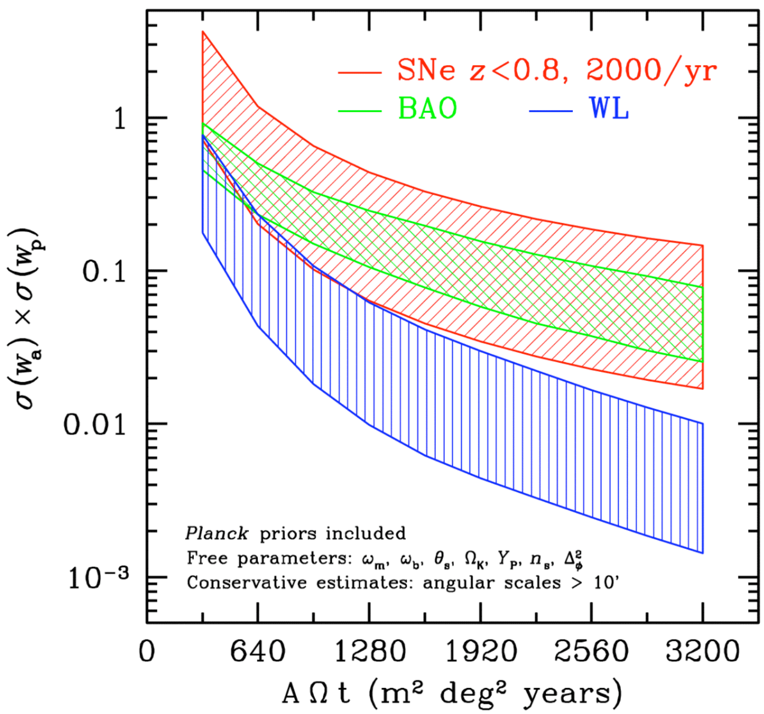
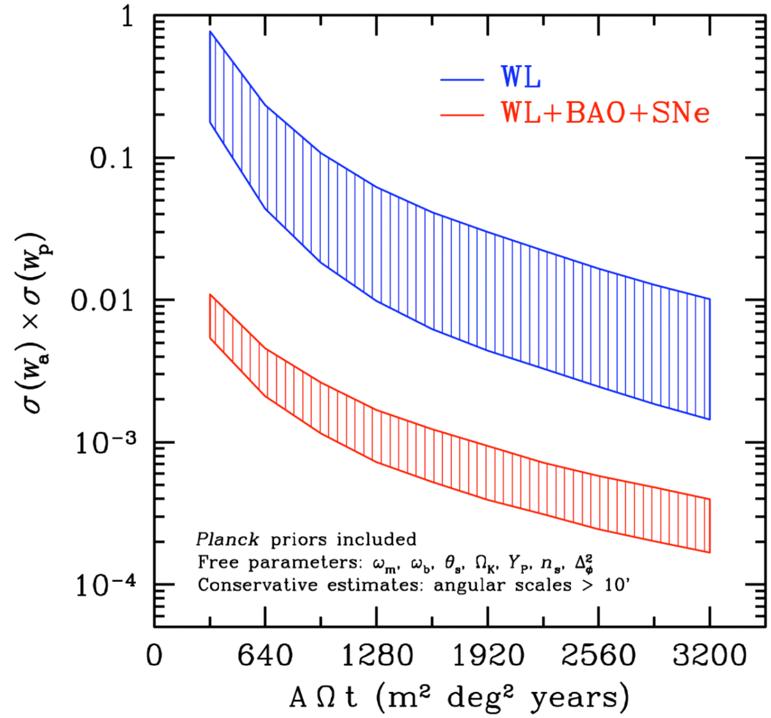
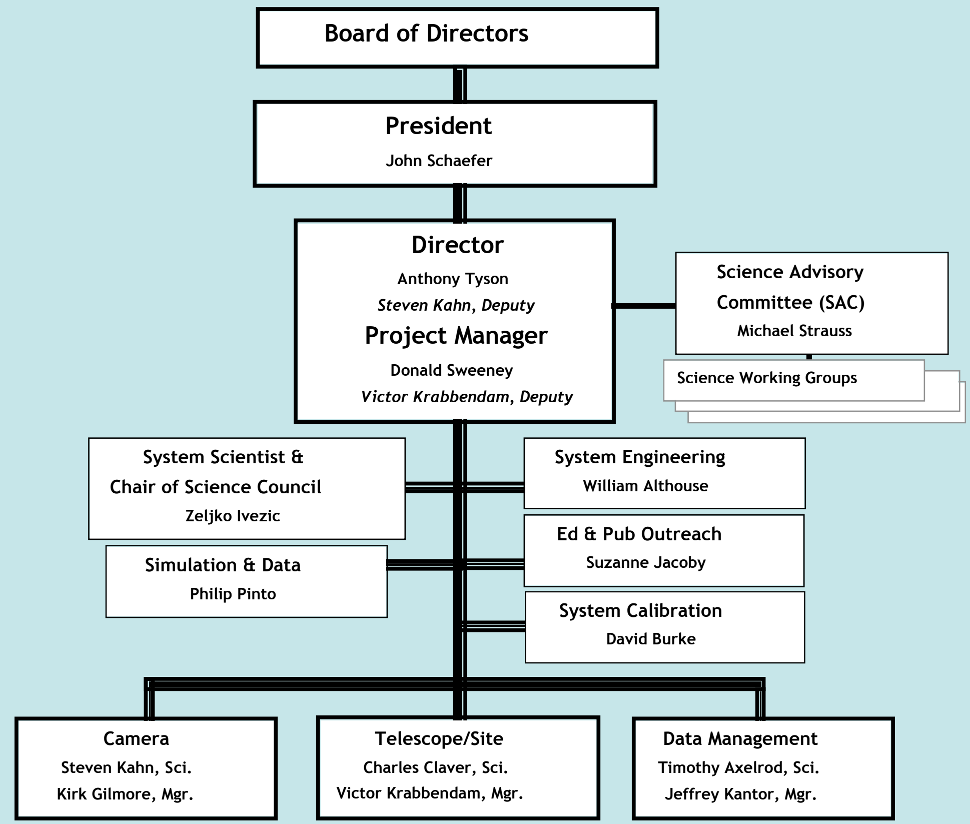




LSST Project Organization

- 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.



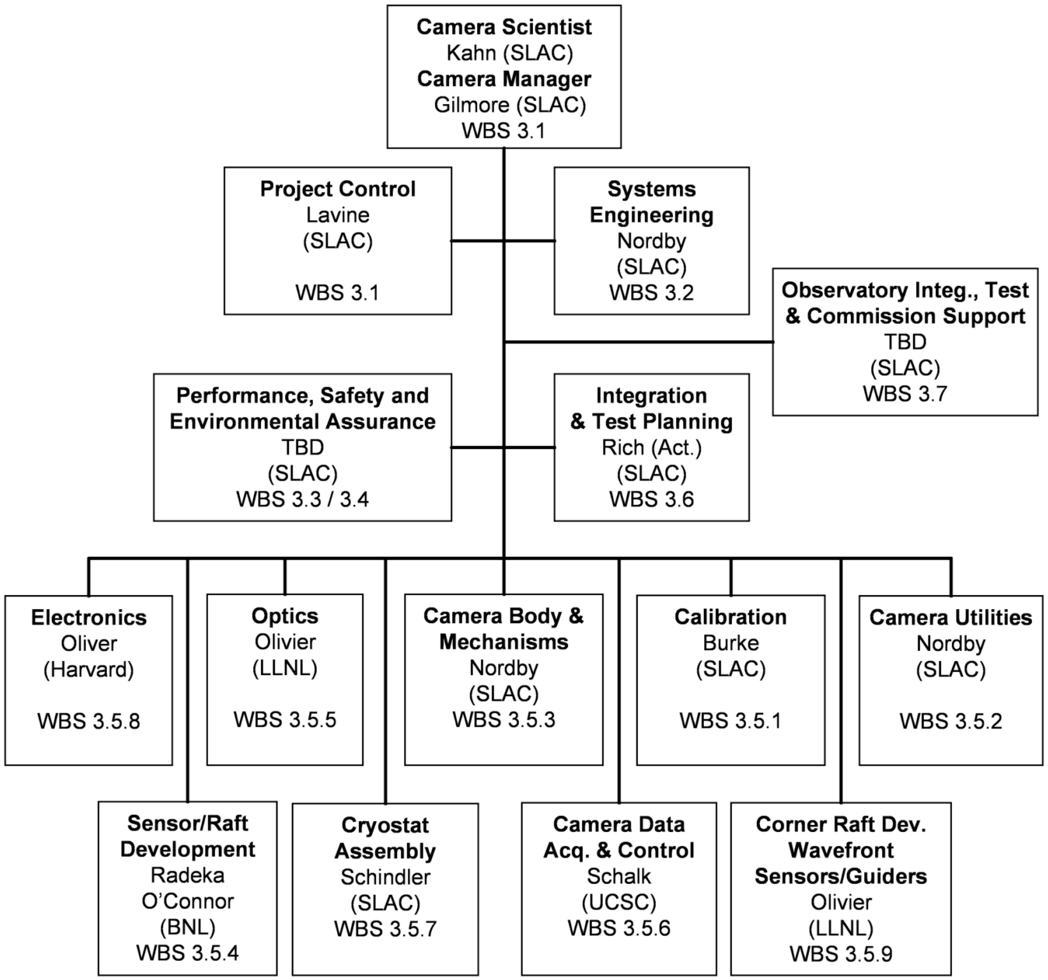
LSST Organization Chart

There are 22 LSSTC Institutional Members

- Brookhaven National Laboratory
- California Institute of Technology
- Columbia University
- Google Corporation
- Harvard-Smithsonian Center for Astrophysics
- Johns Hopkins University
- Las Cumbres Observatory
- Lawrence Livermore National Laboratory
- National Optical Astronomy Observatory
- Princeton University
- Purdue University
- Research Corporation
- Stanford Linear Accelerator Center
- Stanford University –KIPAC
- The Pennsylvania State University
- University of Arizona
- University of California, Davis
- University of California, Irvine
- University of Illinois at Champaign-Urbana
- University of Pennsylvania
- University of Pittsburgh
- University of Washington

Camera Team Organization Chart

Large Synoptic Survey Telescope



Involvement of University-Based HEP Groups

- Brandeis – Jim Bensiger (fac), Kevan Hashemi, Hermann Wellenstein (tech)
- Caltech – Alan Weinstein (fac)
- Columbia – Stefan Westerhoff (fac)
- Florida State - Kurtis Johnson, Jeff Owens, Harrison Prosper, Horst Wahl (fac)
- Harvard – Chris Stubbs (fac), John Oliver (tech)
- Ohio State – Klaus Honscheid, Richard Hughes, Brian Winer (fac)
- Purdue – John Peterson, Ian Shipsey (fac)
- Stanford – Pat Burchat (fac)
- UC- Irvine – David Kirkby (fac)
- UCSC – Terry Schalk (fac) + new hire
- U. Cincinnati – Brian Meadows, Mike Sokoloff (fac)
- UIUC – Jon Thaler (fac)
- U. Pennsylvania – Bhuvnesh Jain (fac), Rick Van Berg, Mitch Newcomer (tech)
- U. Washington – Leslie Rosenberg (fac)
- Wayne State – David Cinabro (fac)

Possible International Involvement in LSST

- LSST will be a unique facility in the world. There is essentially no foreign competition for a survey telescope with this capability.

- As a result, significant interest has been expressed overseas in the possibility of international participation in the project. We have held meetings with representatives from many institutes in the UK, Germany, and France to discuss possible roles. Ultimately, we would like to see a significant financial contribution from the European Southern Observatory, but this still needs to be worked out.

- The most extensive interactions have been with the French IN2P3 labs, specifically in connection with the camera development. French scientists and engineers are now working closely with us in design studies for key components of the camera.

LSST Science Collaborations

Large Synoptic Survey Telescope

1. Supernovae: M. Wood-Vasey (CfA)
2. Weak lensing: D. Wittman (UCD) and B. Jain (Penn)
3. Stellar Populations: Abi Saha (NOAO)
4. Active Galactic Nuclei: Niel Brandt (Penn State)
5. Solar System: Steve Chesley (JPL)
6. Galaxies: Harry Ferguson (STScI)
7. Transients/variable stars: Shri Kulkarni (Caltech)
8. Large-scale Structure/BAO: Andrew Hamilton (Colorado)
9. Milky Way Structure: Connie Rockosi (UCSC)
10. Strong gravitational lensing: Phil Marshall (UCSB)

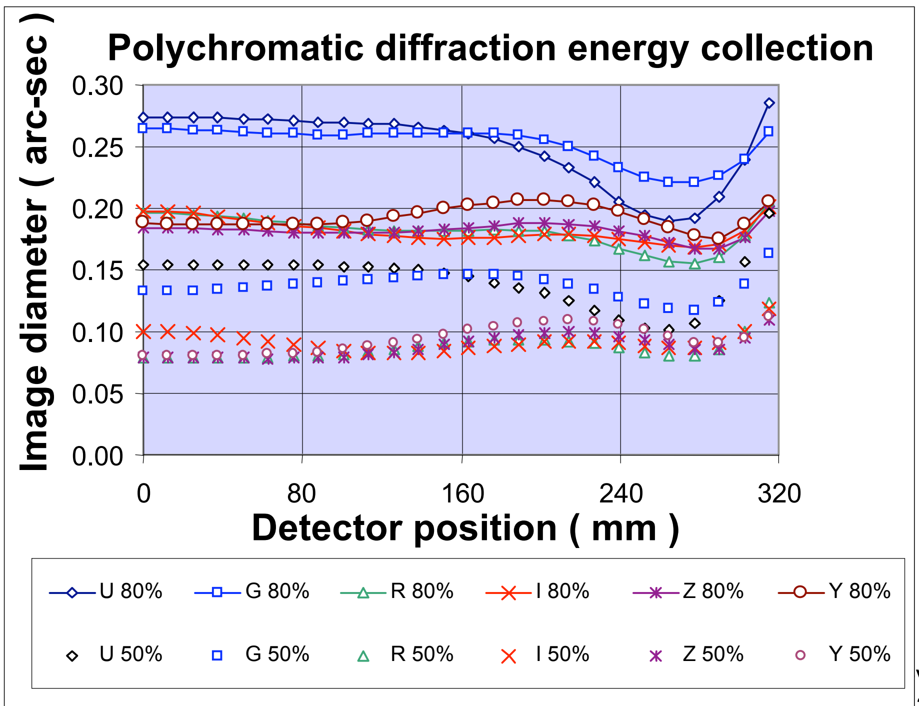
171 signed on already, from member institutions and project team.

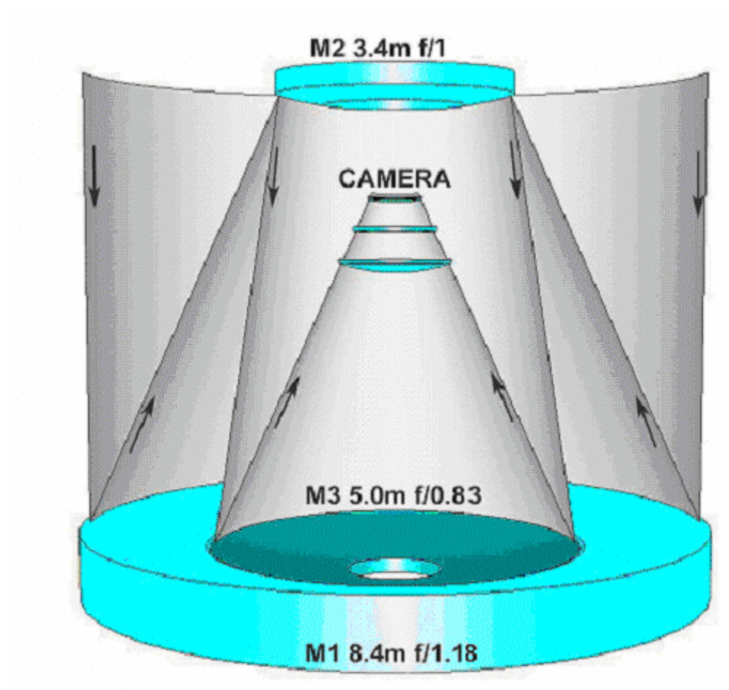
The LSST will be on El Penon peak in Northern Chile in an NSF compound

1.5m photometric calibration telescope

LSST Optical Design

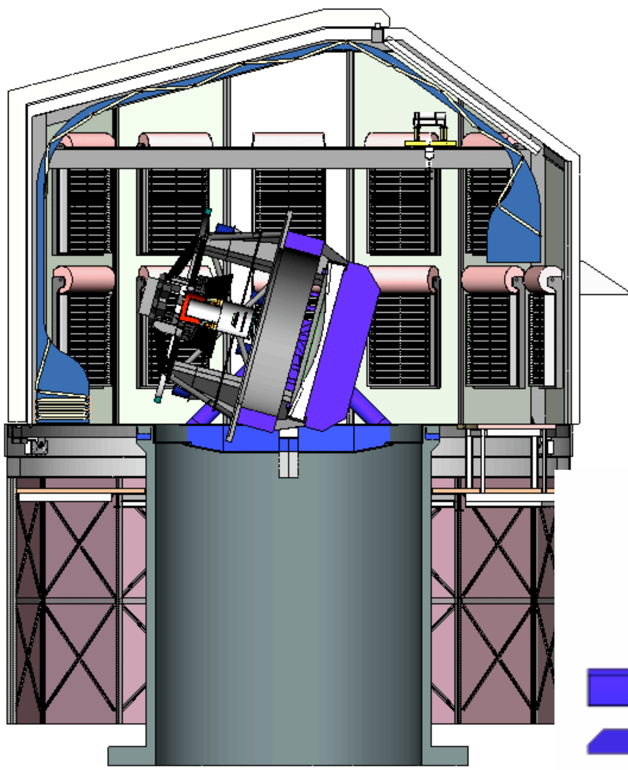
- ***f/1.23***
- **< 0.20 arcsec FWHM images in six bands: 0.3 - 1 μm**
- **3.5 ° FOV → Etendue = 319 m^2deg^2**



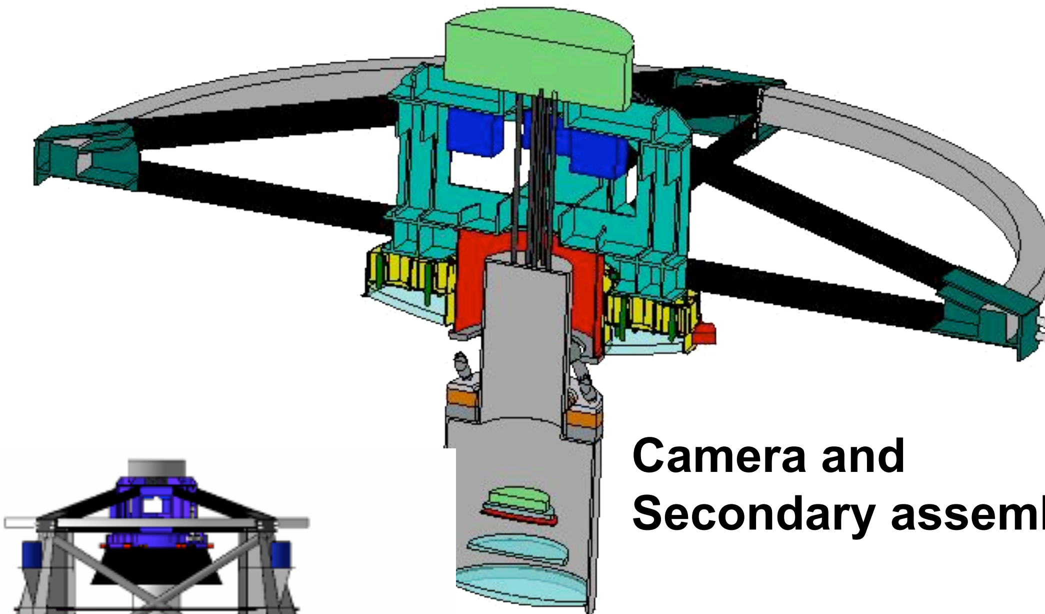


LSST optical layout

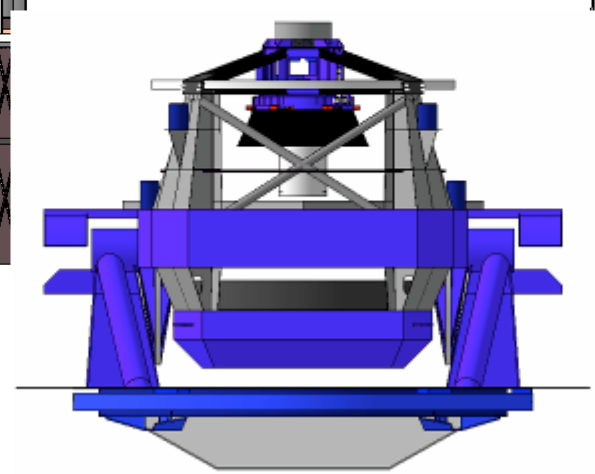
The Telescope Mount and Dome



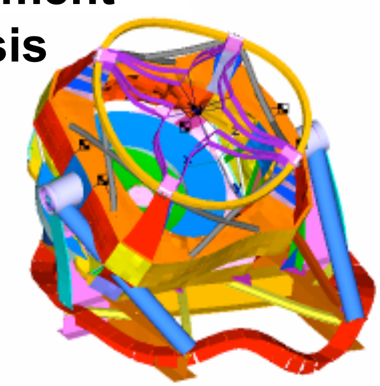
Carrousel dome



Camera and Secondary assembly



Altitude over azimuth configuration



Finite element analysis

The LSST camera will have 3 Gigapixels in a 64cm diameter image plane

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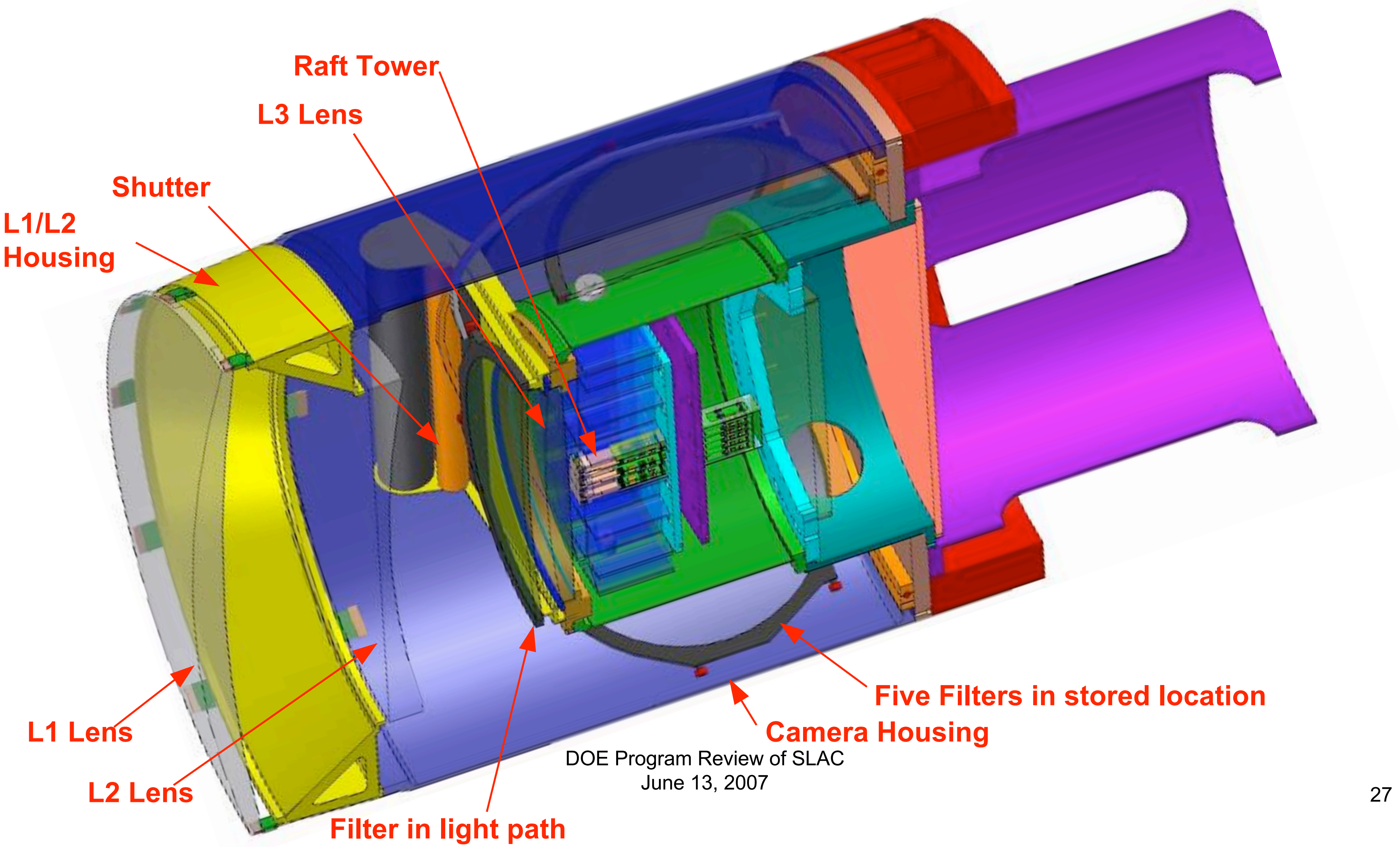
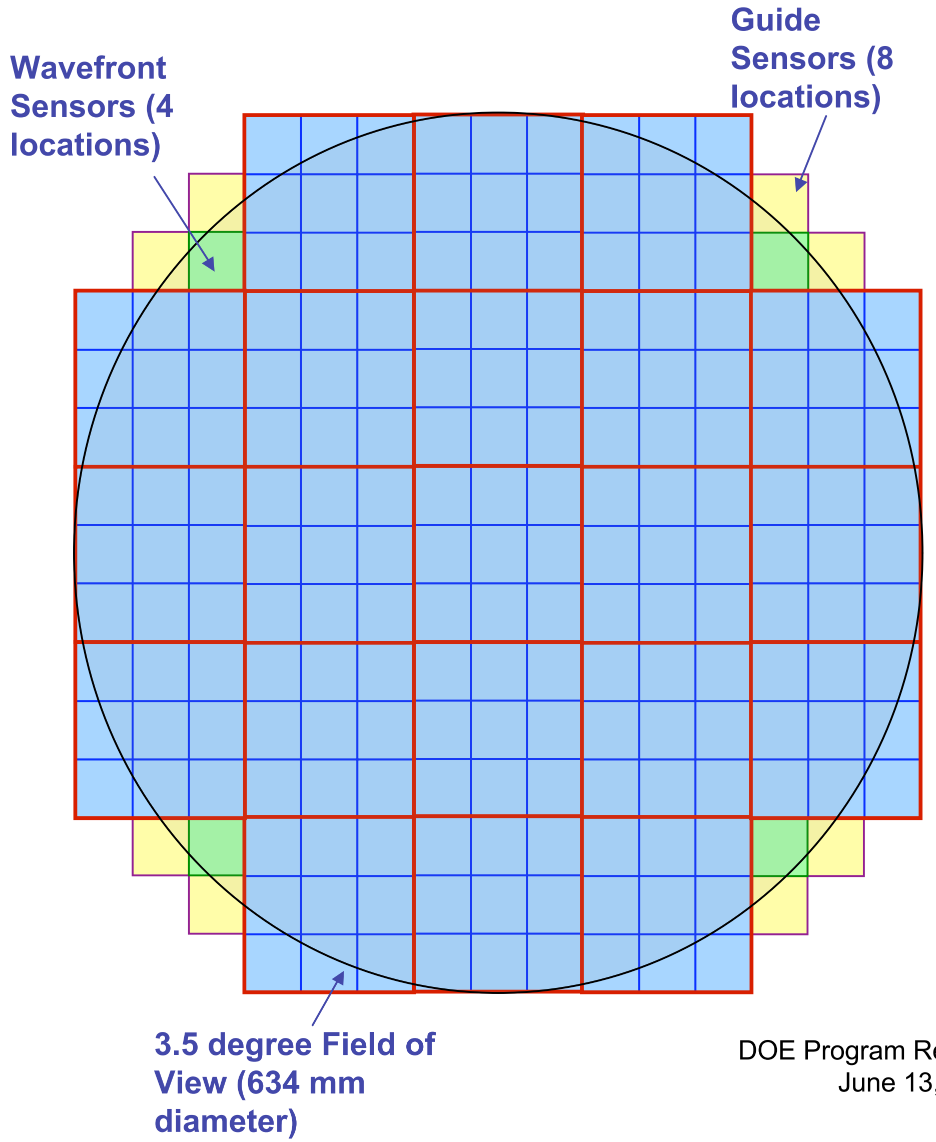
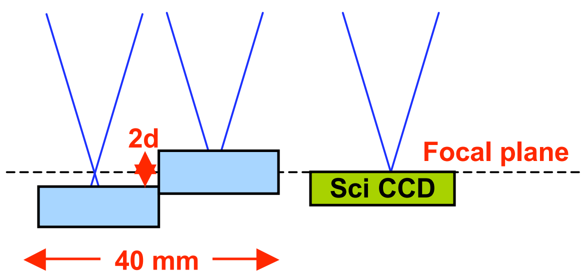


The LSST Focal Plane

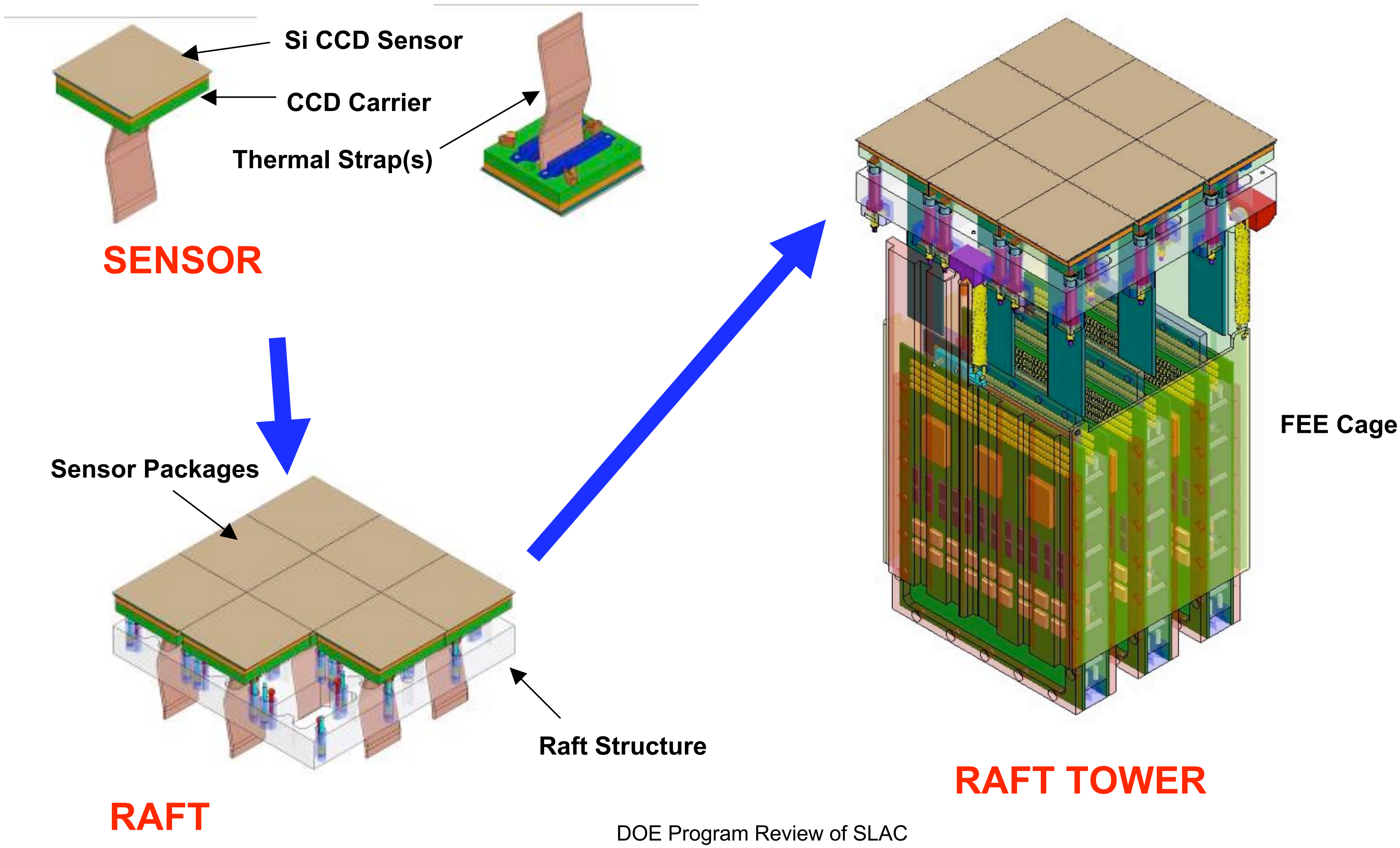


Wavefront Sensor Layout



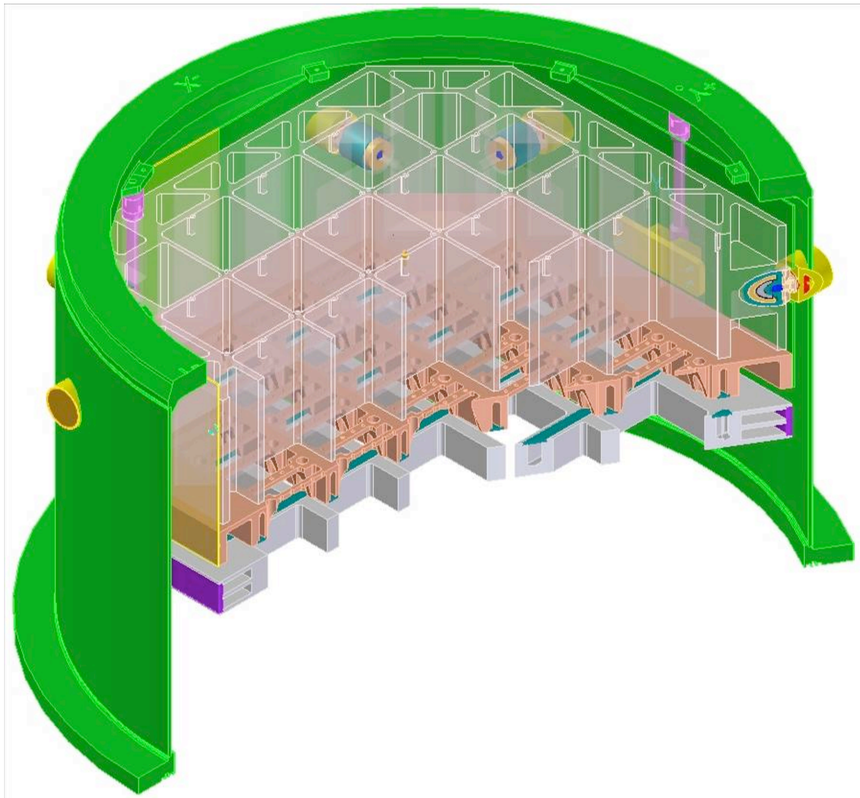
Curvature Sensor Side View Configuration

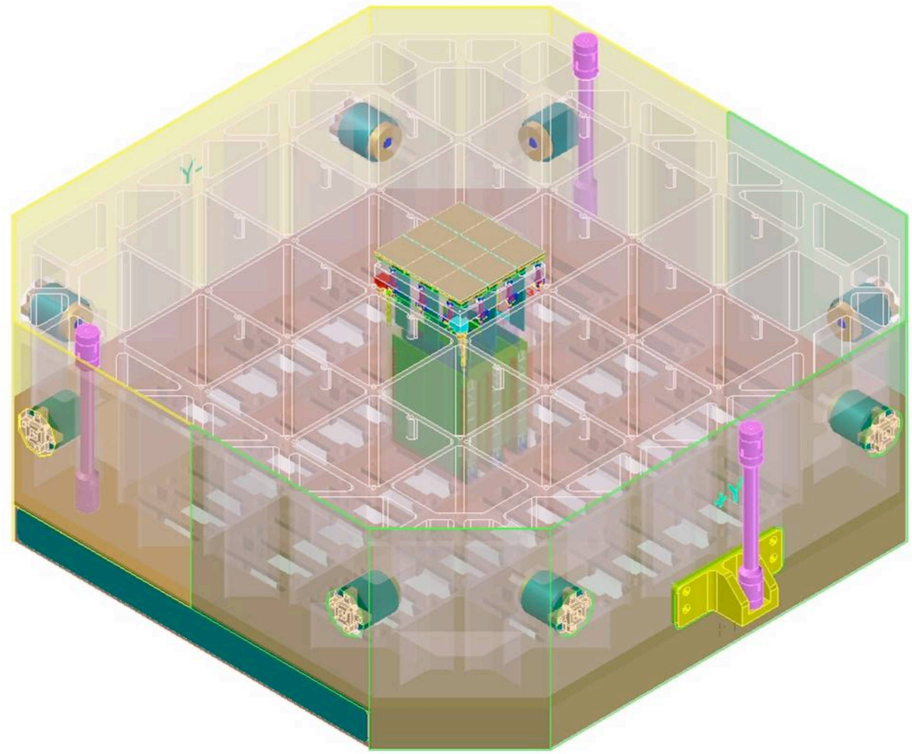
Raft Towers



Si CCD Sensor
CCD Carrier
Thermal Strap(s)
SENSOR
Sensor Packages
Raft Structure
RAFT
FEE Cage
RAFT TOWER

Cryosat Assembly

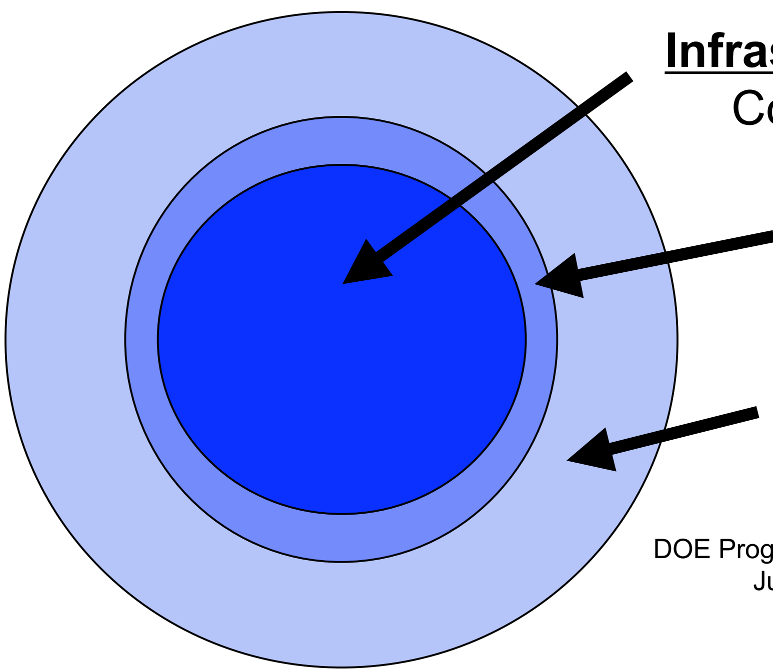




The LSST Data Management Challenge:

LSST generates 6GB of raw data every 15 seconds that must be calibrated, processed, cataloged, indexed, and queried, etc. often in real time

LSST Data Management Model

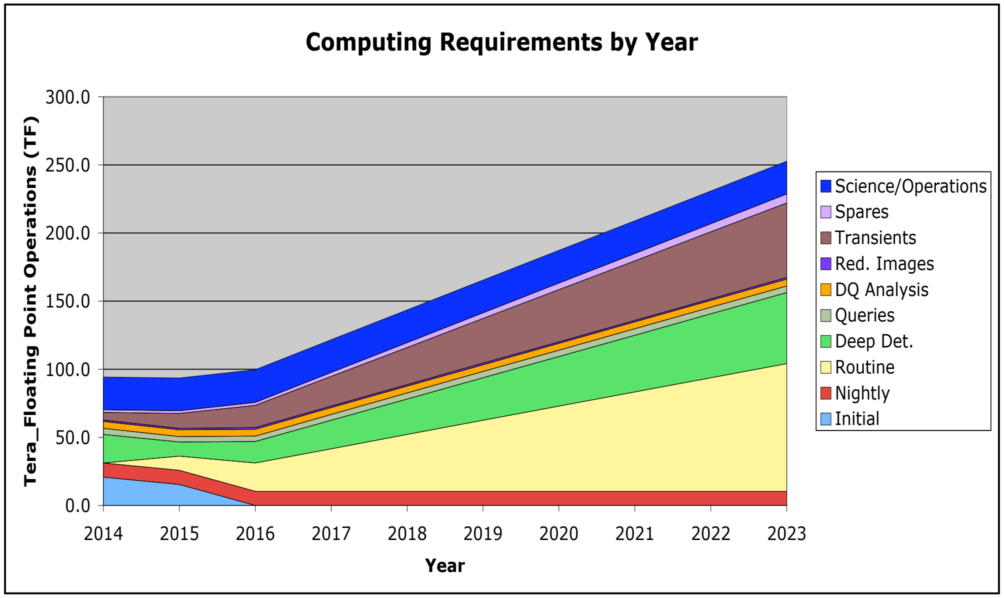


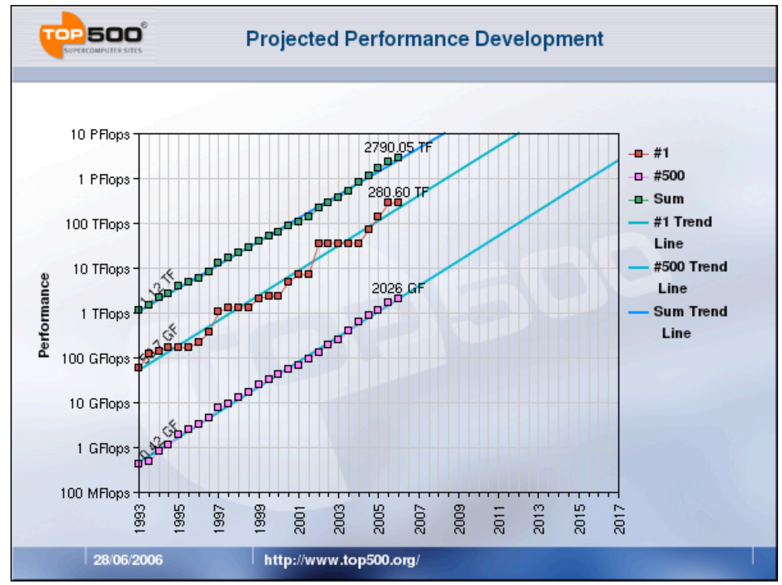
Infrastructure → Hardware
Computers, disks, data links, ,,,

Middleware → Interface wrapper
Device drivers, system management,…

Applications → Science
Image processing, database queries, …

Computing Requirements





Project Schedule

- Reference Design complete
- Full WBS with dictionary and task breakdown
- Task-based estimate complete
- Integrated cost/schedule complete
- NSF MREFC proposal submitted February 2007
- NSF Concept Design Review for September 2007
- Possible DOE CD-1 review early in FY08
- Planning for “first light” ~ March 2014

Summary

- 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.

- This project is emerging as a strong candidate for the next major large-scale PPA experimental program at SLAC, following BaBar and GLAST. An extensive team has been formed, with SLAC in a key leadership role.

- We have been successful at achieving a close collaboration between particle physicists and astrophysicists, both within the laboratory, and within the project as a whole.

- An MREFC proposal has been submitted to the NSF, and the formal review process will begin in September. If all goes well, the project is on-track to achieve first light early in 2014.