# The Large Synoptic Survey Telescope

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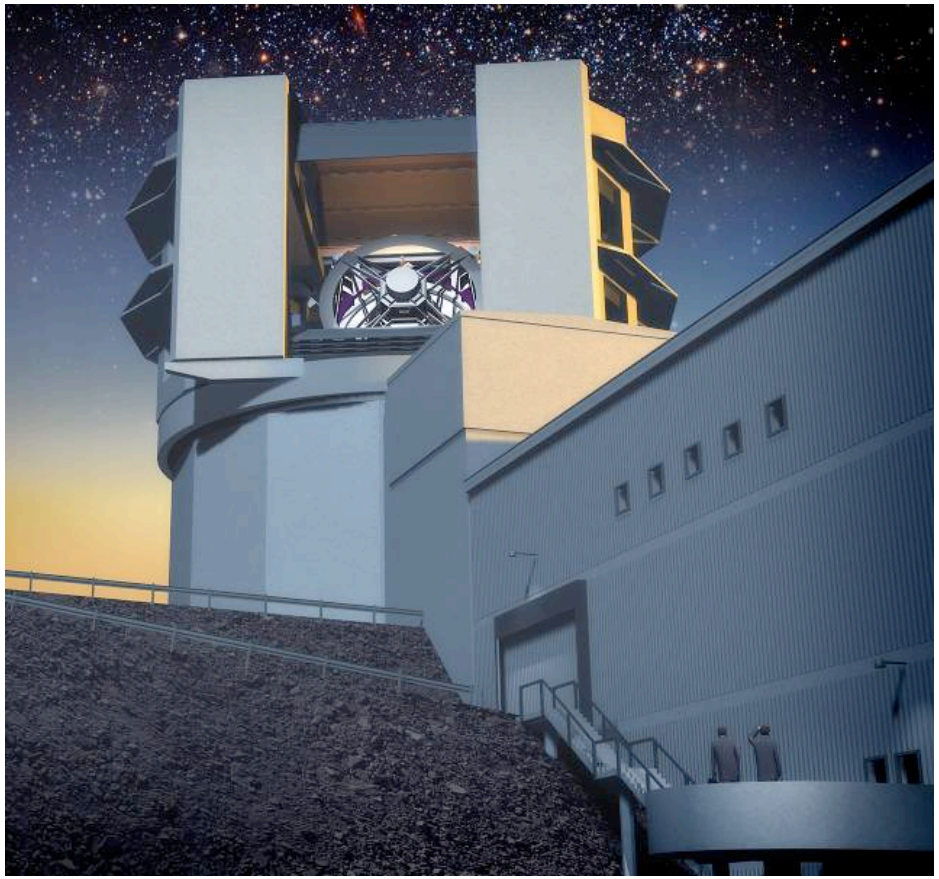


# (for the LSST Collaboration!)

# What is the LSST?

Large Synoptic Survey Telescope

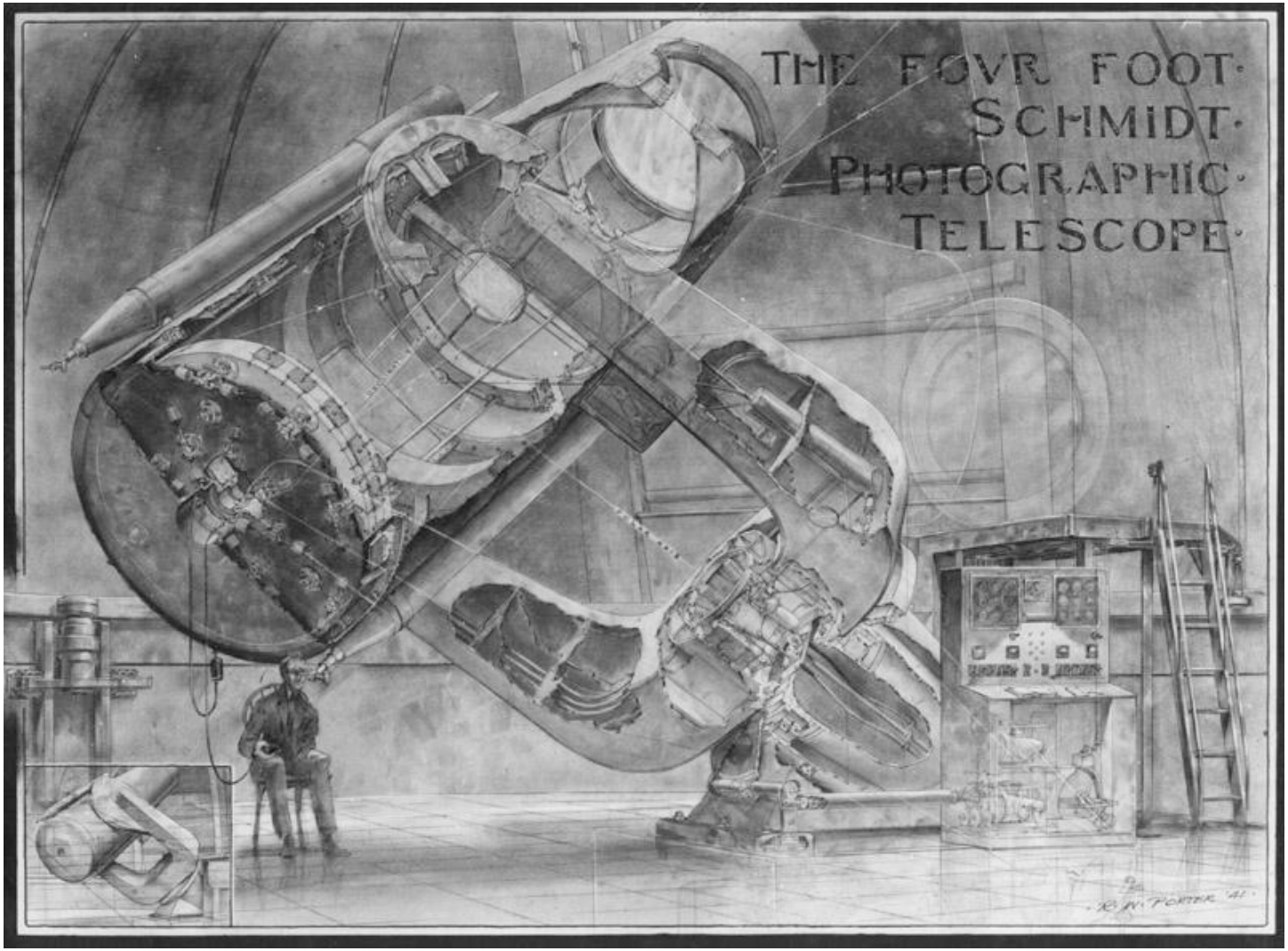
- The LSST will be a large, wide-field ground-based telescope designed to provide time-lapse digital imaging of faint astronomical objects across the entire visible sky every few nights.

- 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.

# Wide-Field Imaging is Not New…

Large Synoptic Survey Telescope



# However, LSST will go *Wide, Deep, and Fast:*

Large Synoptic Survey Telescope

- The solid angle surveyed per unit time, to some limiting flux, *F,* at a signal-to-noise ratio, *SNR*, in exposures of time, *t*, is given by:

$$\frac{d\Omega}{dt} = F^2 \frac{A\Omega\varepsilon}{SNR^2}\left[\Phi_{sky}\delta\Omega + \alpha_{\mathrm{det}}/t\right]$$

Here $A\Omega$ is the étendue of the telescope, $\varepsilon$ is the efficiency of the system, $\Phi_{sky}$ is the sky intensity, $\delta\Omega$ is the size of the seeing-limited PSF, and $\alpha_{\mathrm{det}}$ is proportional to detector noise and trap depth.

- Large surveys require high étendue. But with conventional optical designs - high étendue requires large detector area.

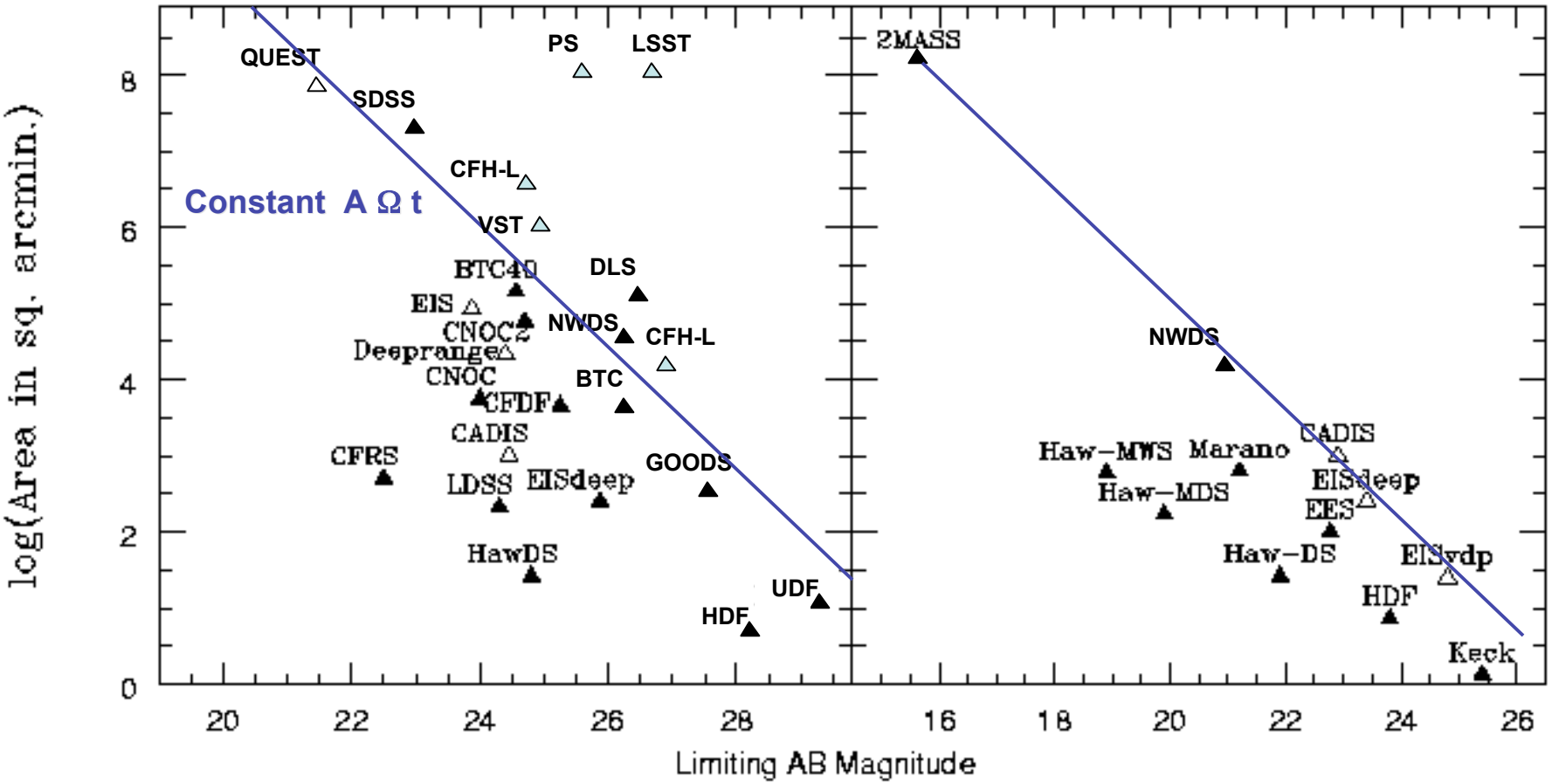
- An experiment like LSST has only become possible now because of the relatively recent development of large format CCD arrays!

# Some Recent Optical and Near IR Surveys

Large Synoptic Survey Telescope

Optical

Near IR

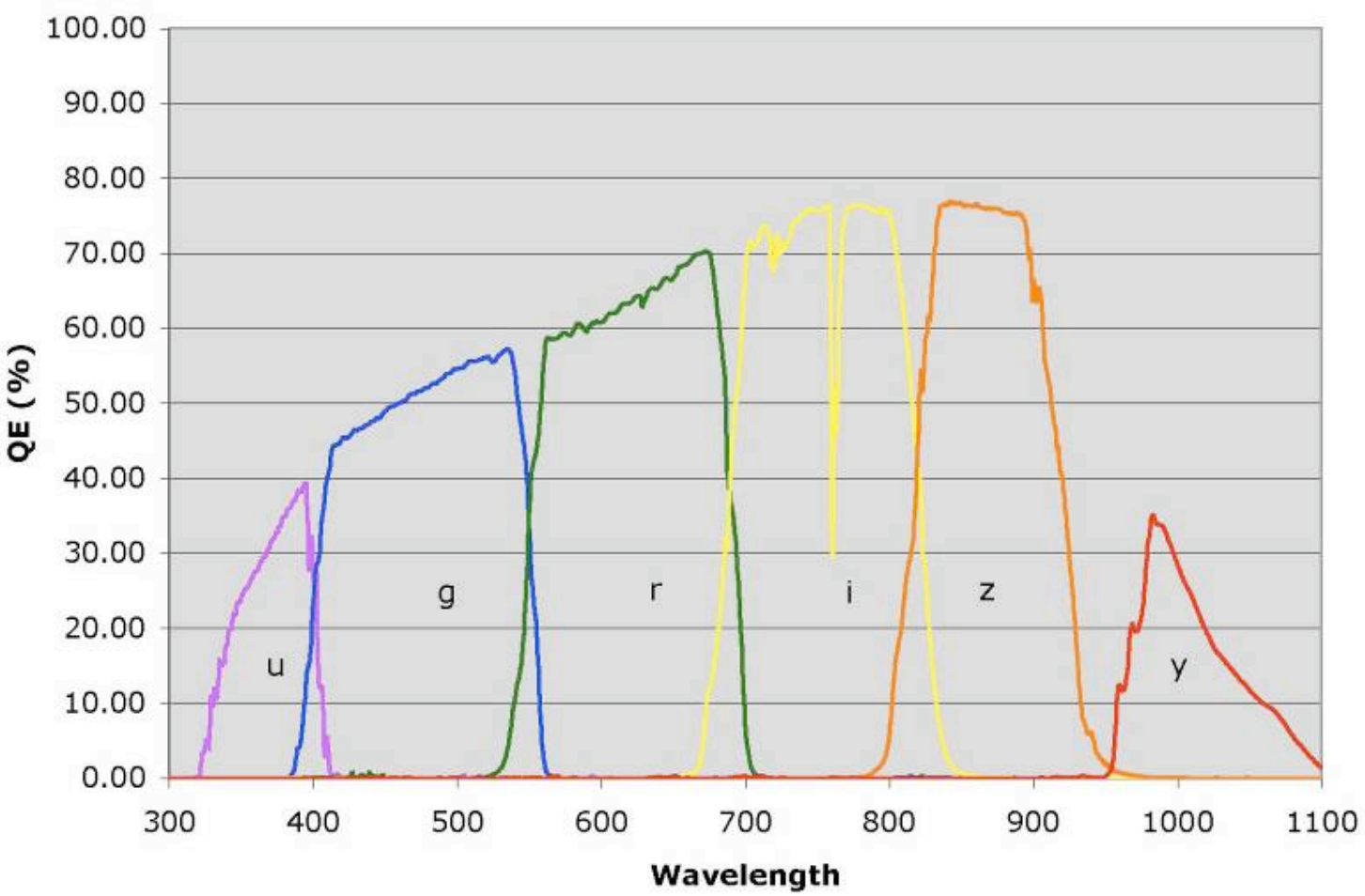


# LSST Survey

Large Synoptic Survey Telescope

- 6-band Survey: *ugrizy* 320–1080 nm
- Frequent revisits: 2 x 15 s, 25 AB mag/visit
- Sky area covered: > 20,000 deg$^2$, 0.2 arcsec / pixel
- Each 9.6 sq.deg FOV revisited ~ 1000 times
- 10-Year Duration: Yields 27.7 AB magnitude @ 5$\sigma$
- Photometric precision: 0.01 mag absolute; 0.0005 mag reptability

# LSST Filter Set and System Throughput



# LSST and Dark Energy

Large Synoptic Survey Telescope

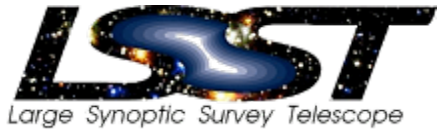
- The only observational handle that we have for understanding the properties of dark energy is the expansion history of the universe itself. This is parametrized by the Hubble parameter:

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

- 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



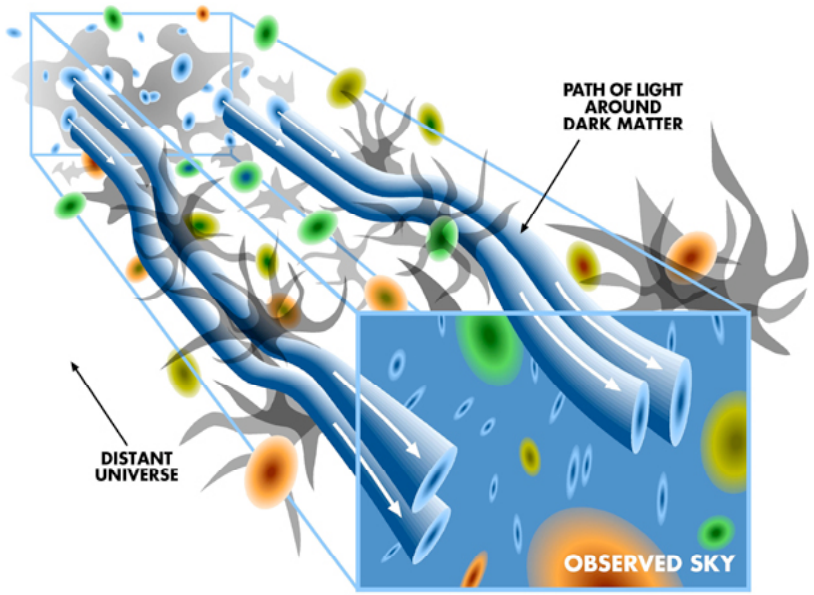

- Cosmic shear (growth of structure + cosmic geometry)
- Counts of massive structures vs redshift (growth of structure)
- Baryon acoustic oscillations (angular diameter distance)
- Measurements of Type 1a SNe (luminosity distance)
- Mass power spectrum on very large scales tests CDM paradigm
- Shortest scales of dark matter clumping tests models of dark matter particle physics

***The LSST survey will address all with a single dataset!***

# Cosmic Shear

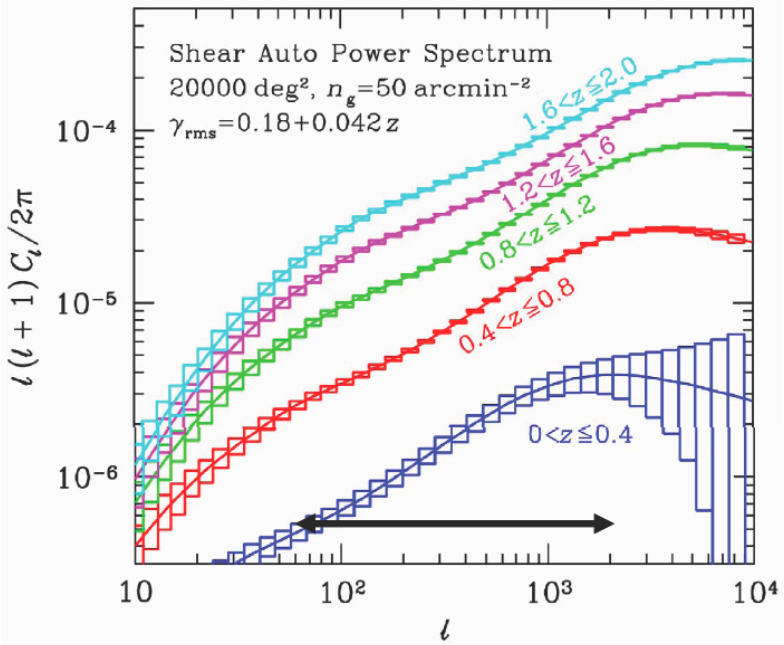
Large Synoptic Survey Telescope

- The term “cosmic shear” refers to the systematic and correlated distortion of the appearance of background galaxies due to weak gravitational lensing by the clustering of dark matter in the intervening universe.
- As light from background galaxies passes through the intergalactic medium, it gets deflected by gravitational potentials associated with intervening structures. A given galaxy image is both displaced and sheared.
- The effect is detectable only statistically. The shearing of neighboring galaxies is correlated, because their light follows similar paths on the way to earth.



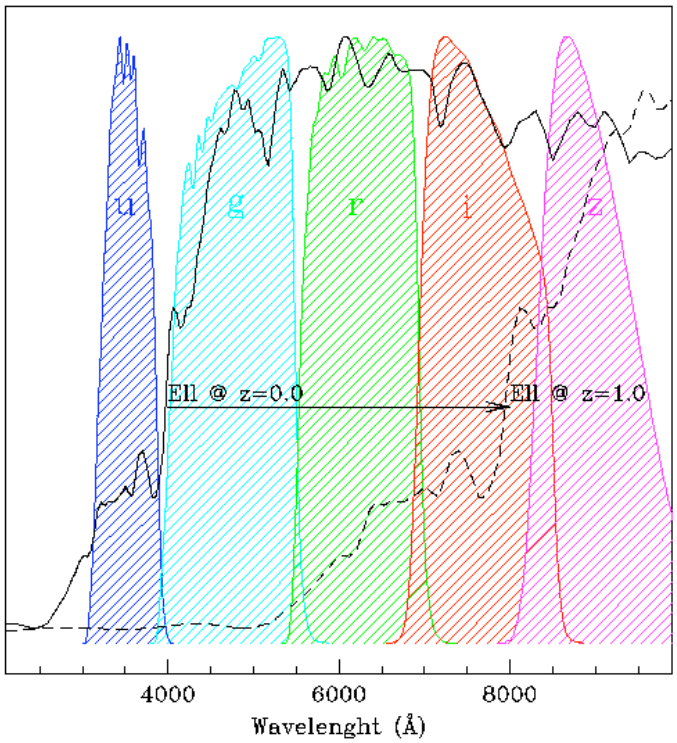
# LSST and Cosmic Shear

- 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

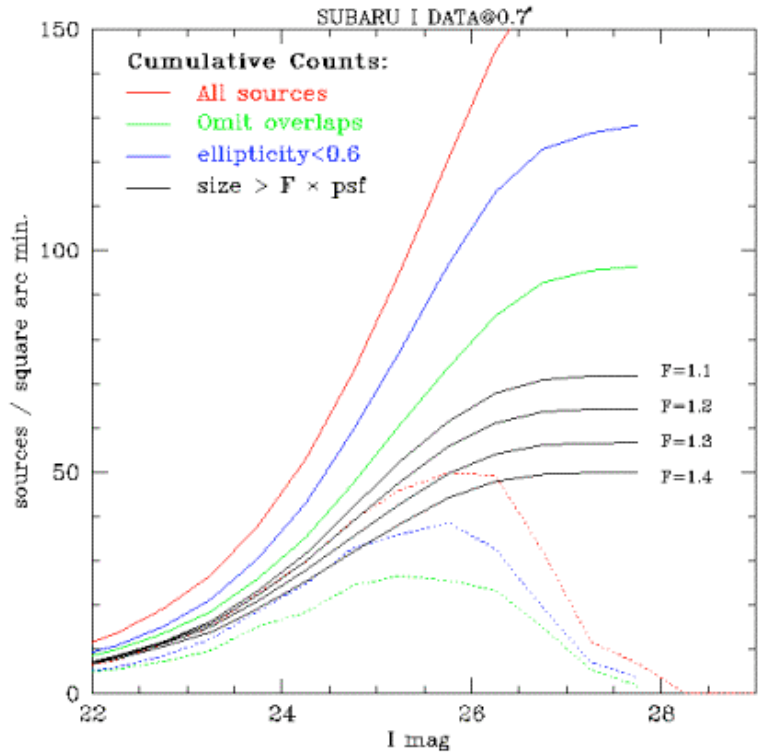
- Galaxies have distinct spectra, with characteristic features at known rest wavelengths.
- Accurate redshifts can be obtained by taking spectra of each galaxy. But this is impractical for the billions of galaxies we will use for LSST cosmic shear studies.
- Instead, we use the colors of the galaxies obtained from the images themselves. This requires accurate calibration of both the photometry and of the intrinsic galaxy spectra as a function of redshift.



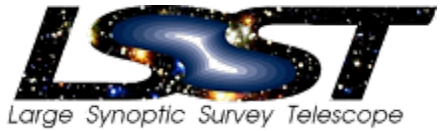
# LSST is Optimally Sized for Measurements of Cosmic Shear

Large Synoptic Survey Telescope

- 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.

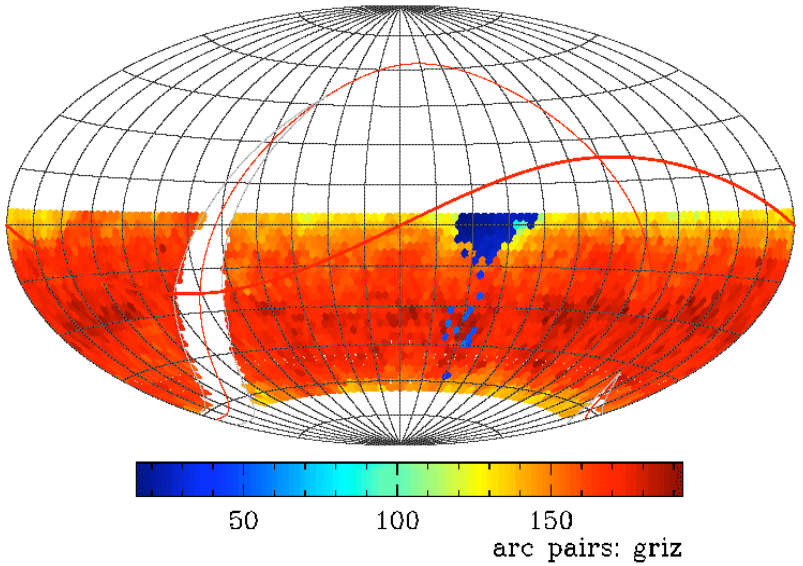
- To make this measurement, we must be confident that we understand and can remove spurious sources of shear. These can arise in the atmosphere or in the optics of the telescope and camera.

- 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.

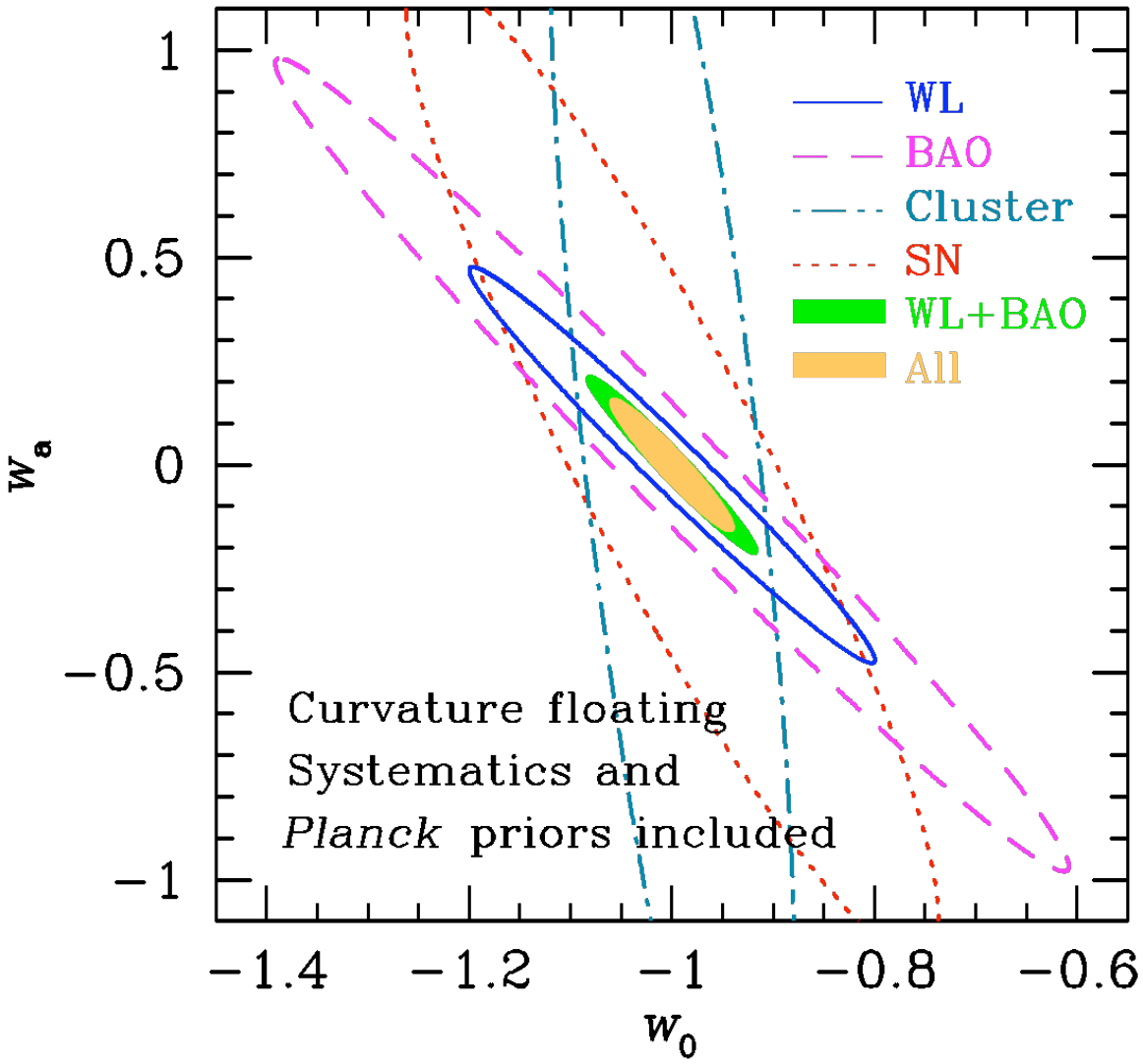
- Fortunately, the sky has given us some natural calibrators to control for PSF systematics: There is one star per square arcmin bright enough to measure the PSF in the image itself. Light from the stars passes through the same atmosphere and instrumentation, but is not subject to weak lensing distortions 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.

# 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.

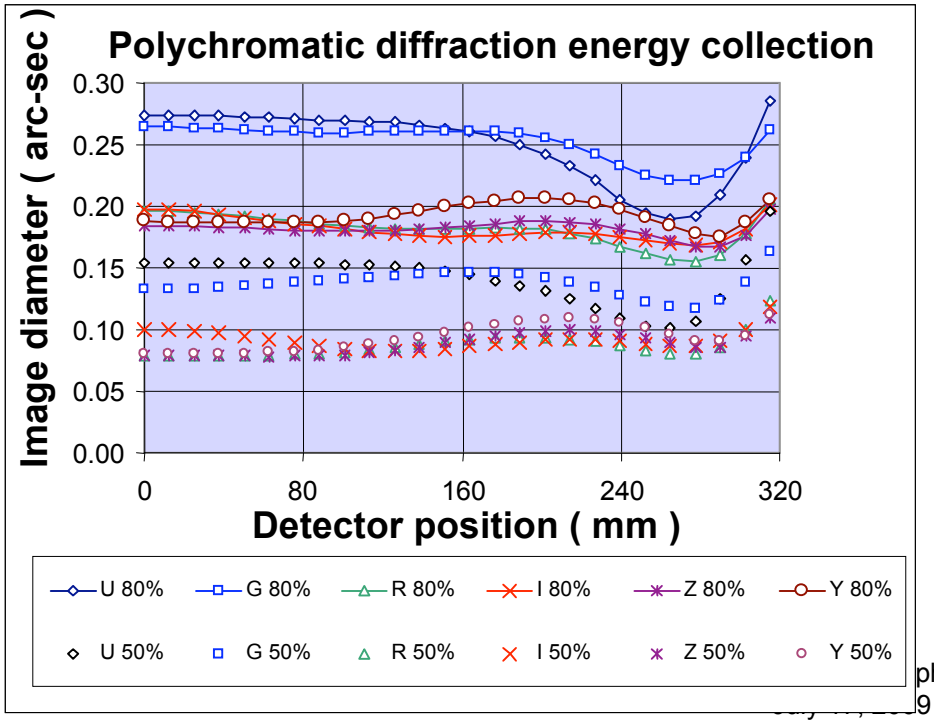


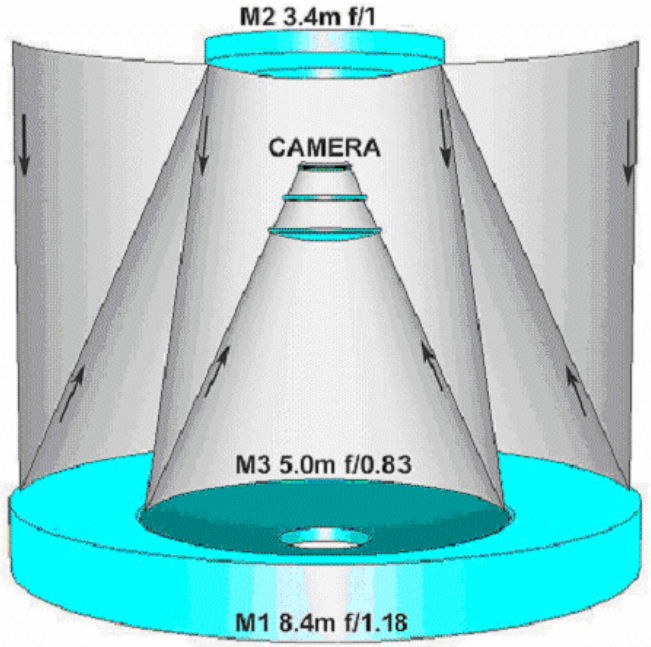
# LSST Precision on Dark Energy Parameters



# LSST Optical Design

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



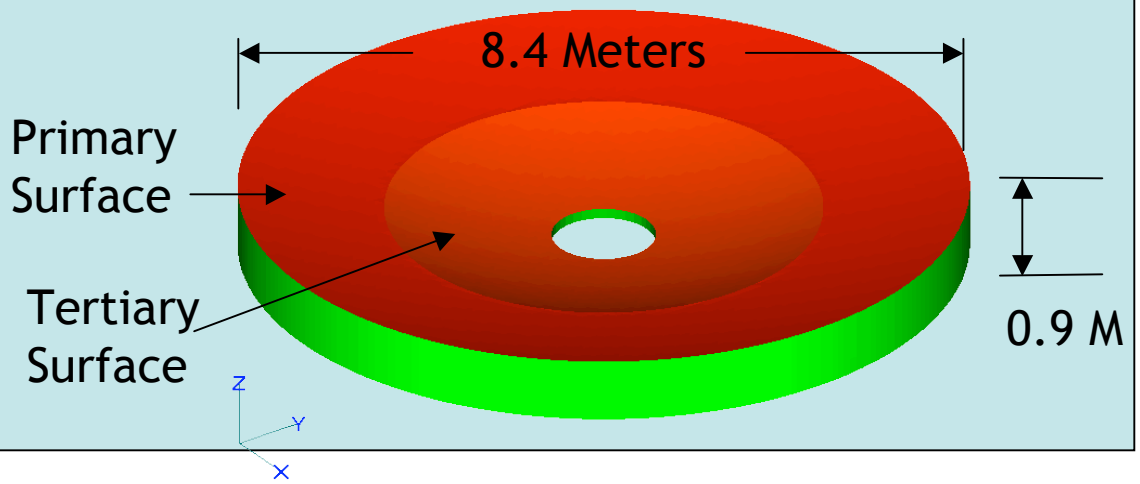




**LSST optical layout**

# Mirror Designs

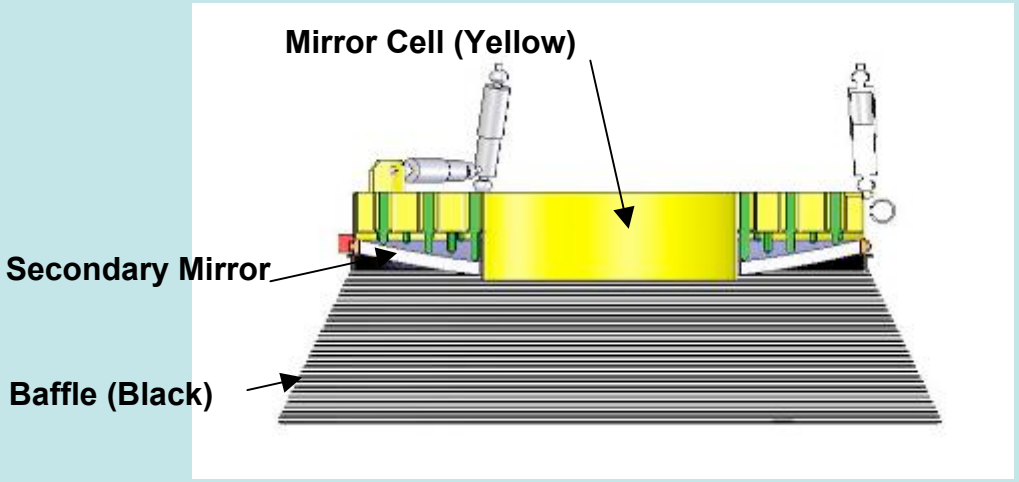
## *Primary/Tertiary Mirror*

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



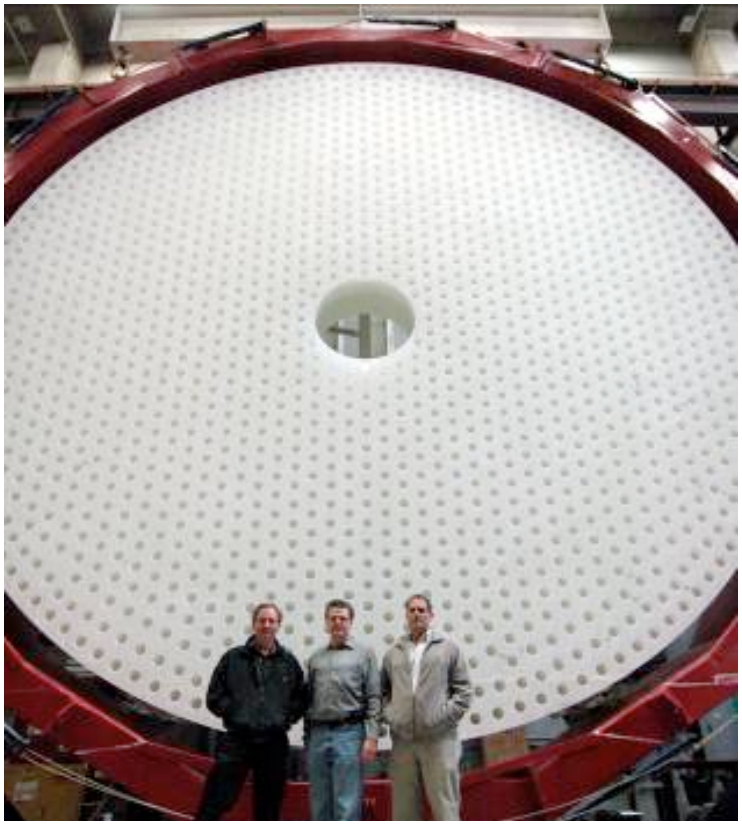

## *Secondary Mirror*

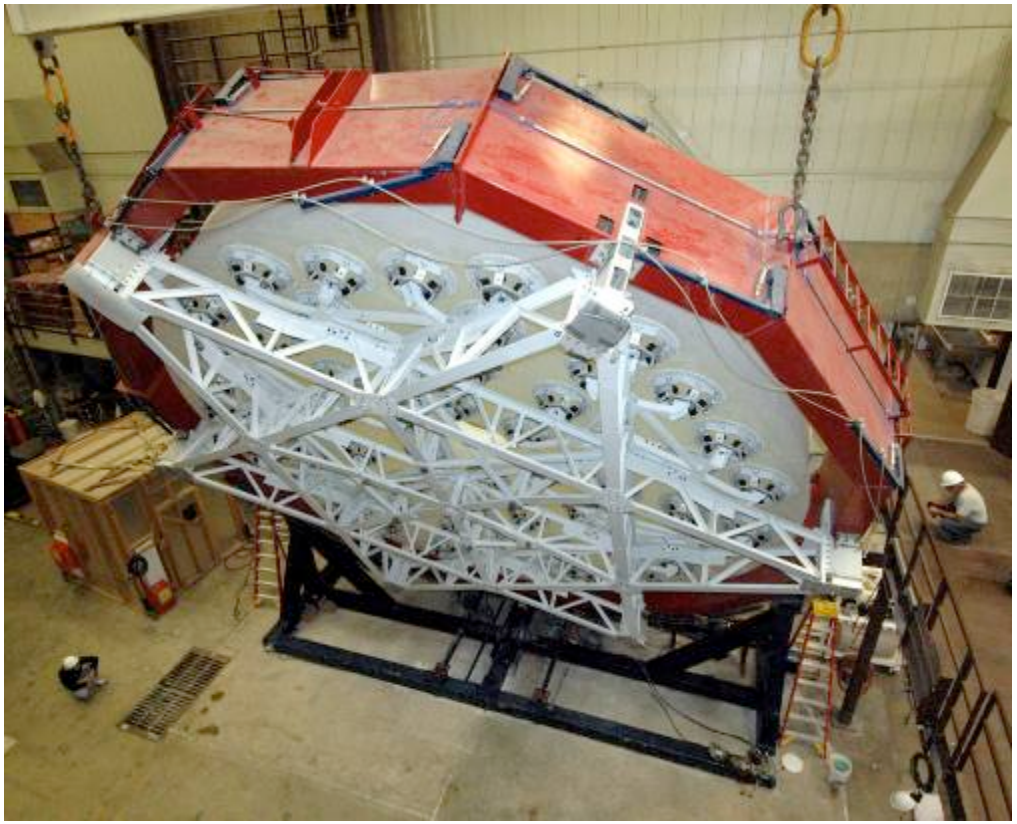
- *Thin Meniscus Low Expansion Glass Design for Secondary Mirror*
- *102 Support Actuators*



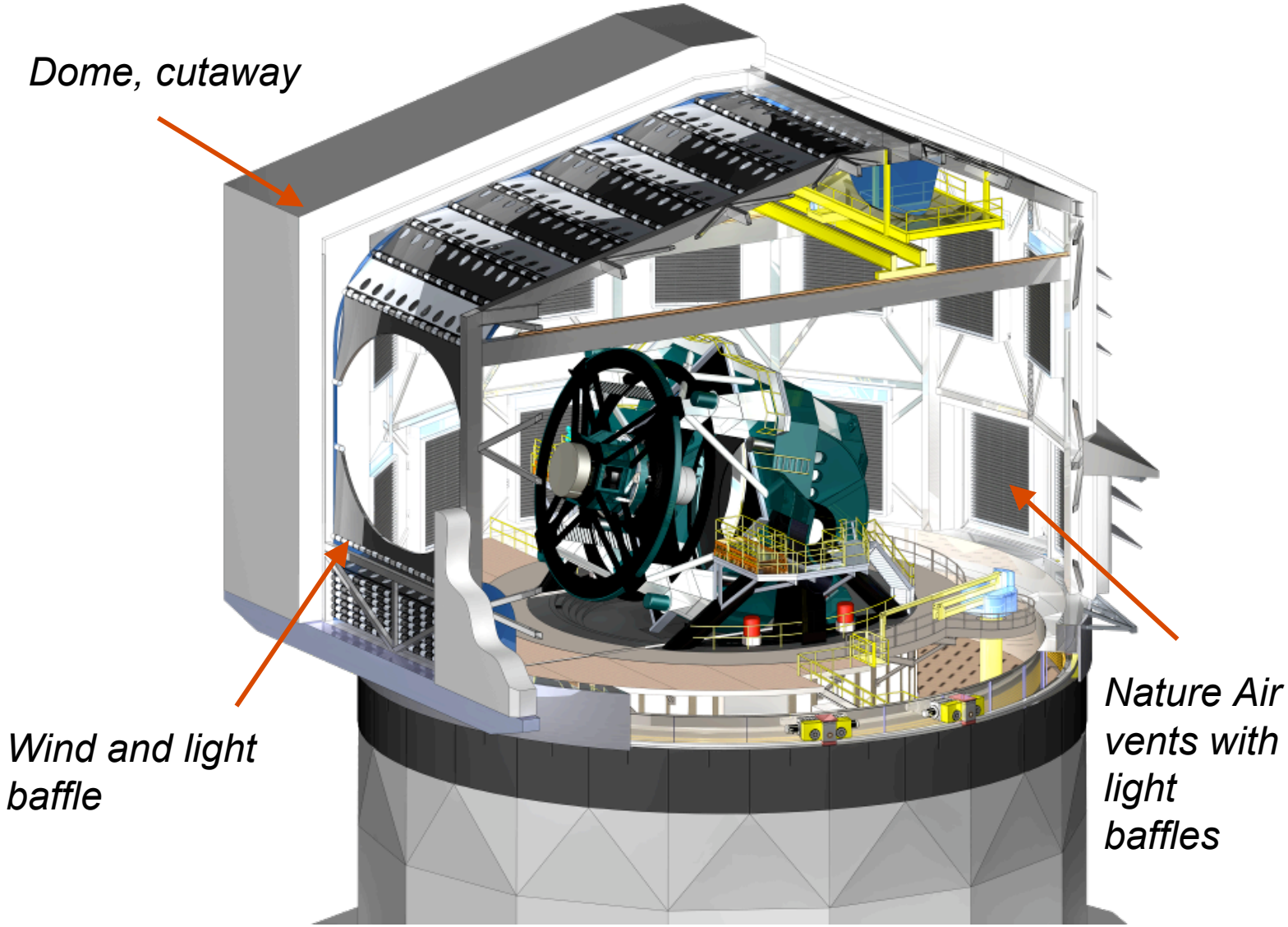
# The Primary/Tertiary Blank was Spin Cast at the Steward Observatory Mirror Lab

Large Synoptic Survey Telescope



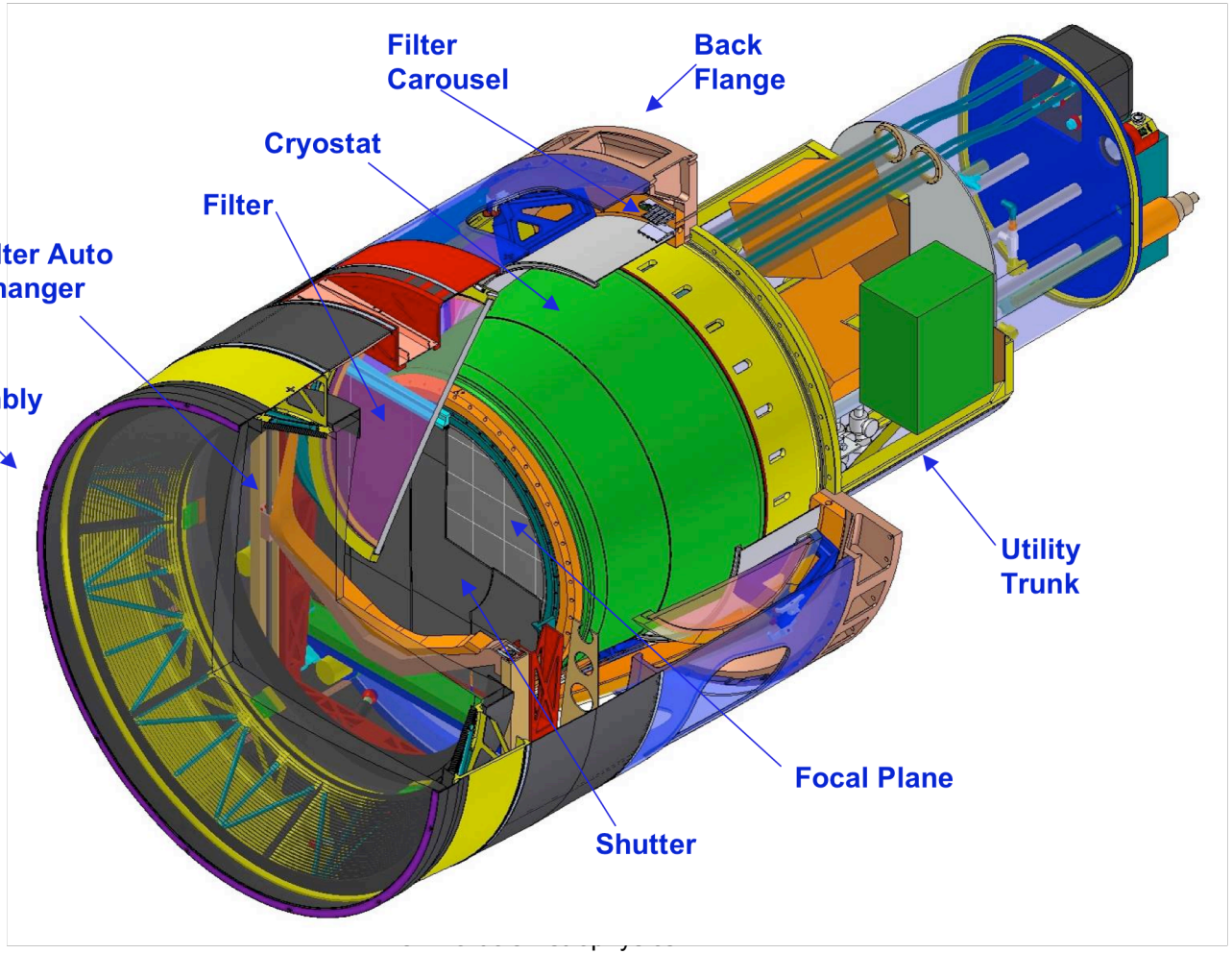


# Detail of the Dome Design

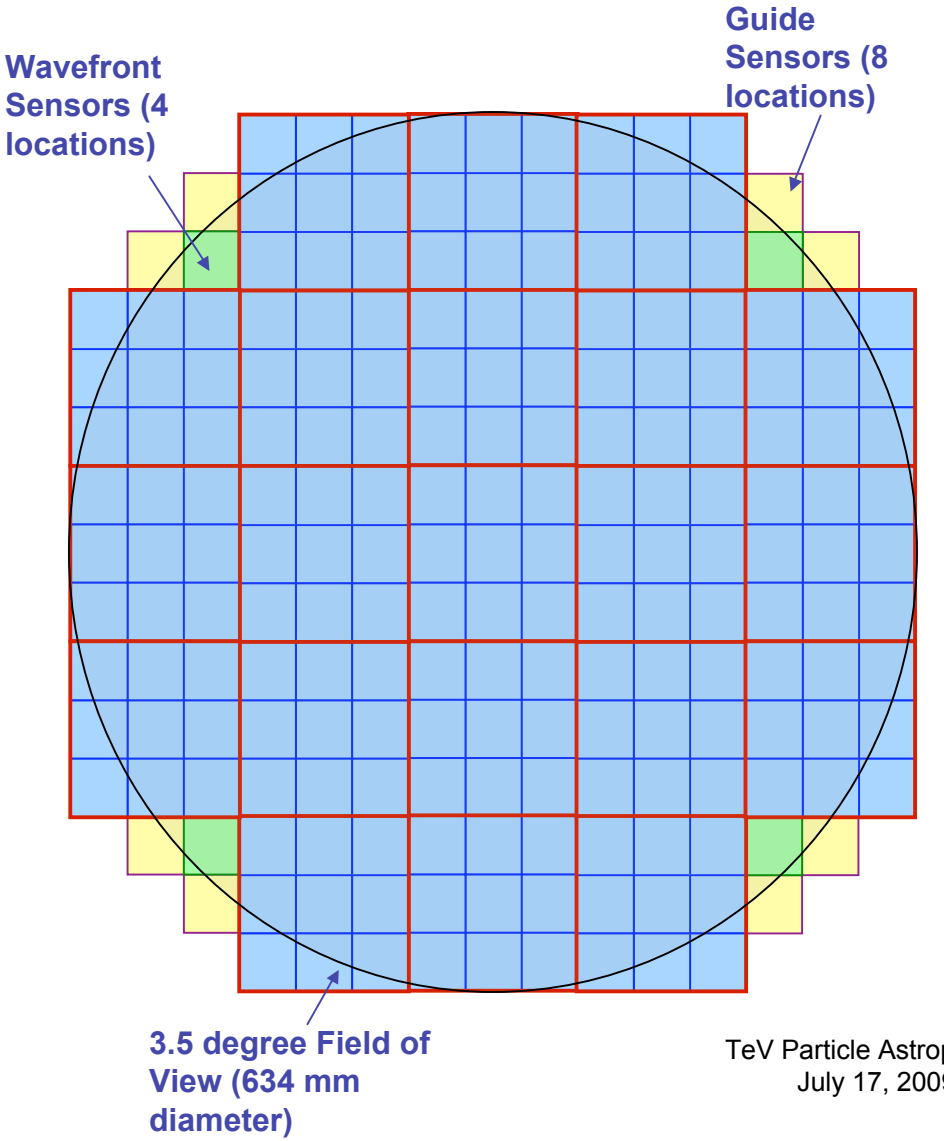


# El Penon Peak with SOAR, Gemini-South, and LSST

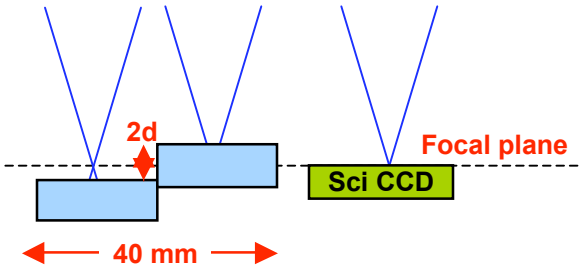
# Overview of the LSST Camera



# The LSST Focal Plane - 64 cm in Diameter



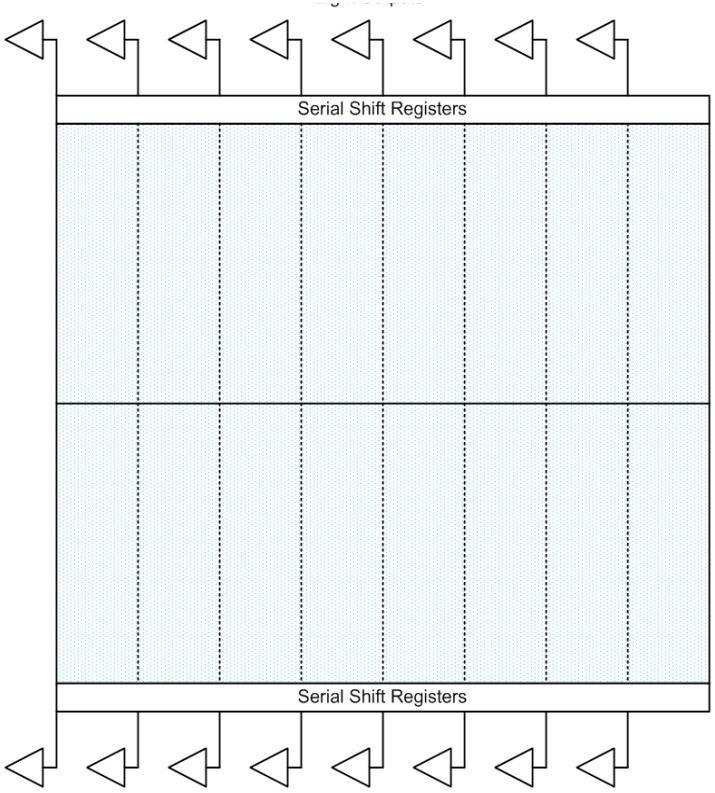

**Wavefront Sensor Layout**

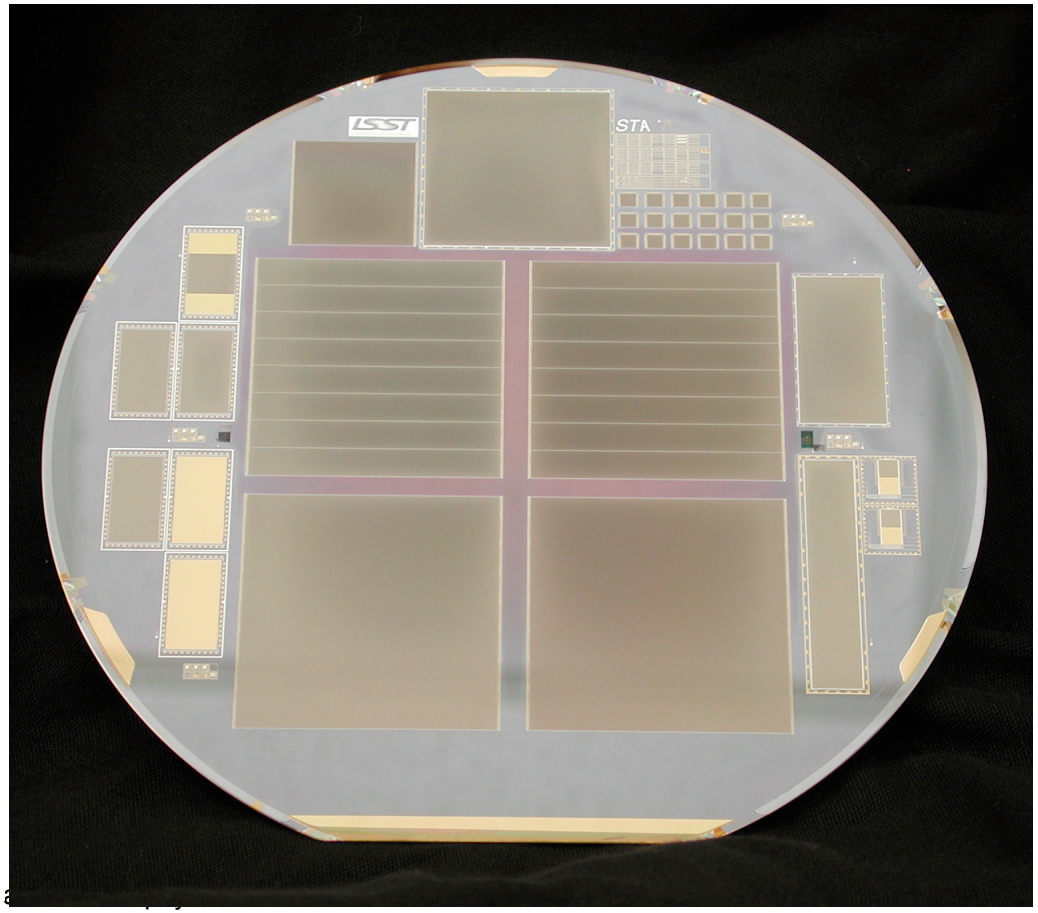



**Curvature Sensor Side View Configuration**

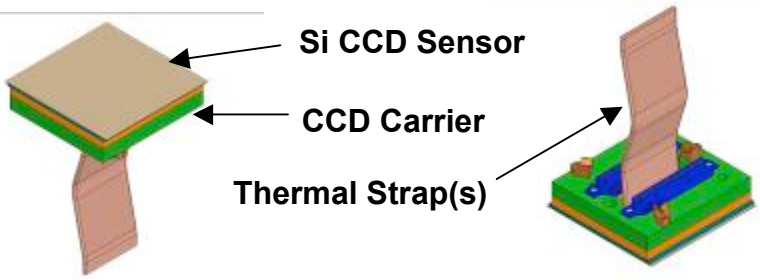
# The LSST CCD Sensor

16 segments/CCD
200 CCDs total
3200 Total Outputs

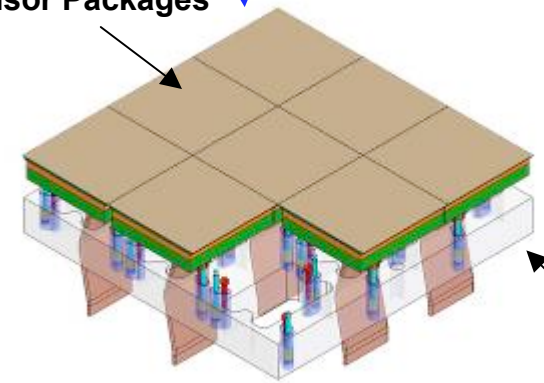


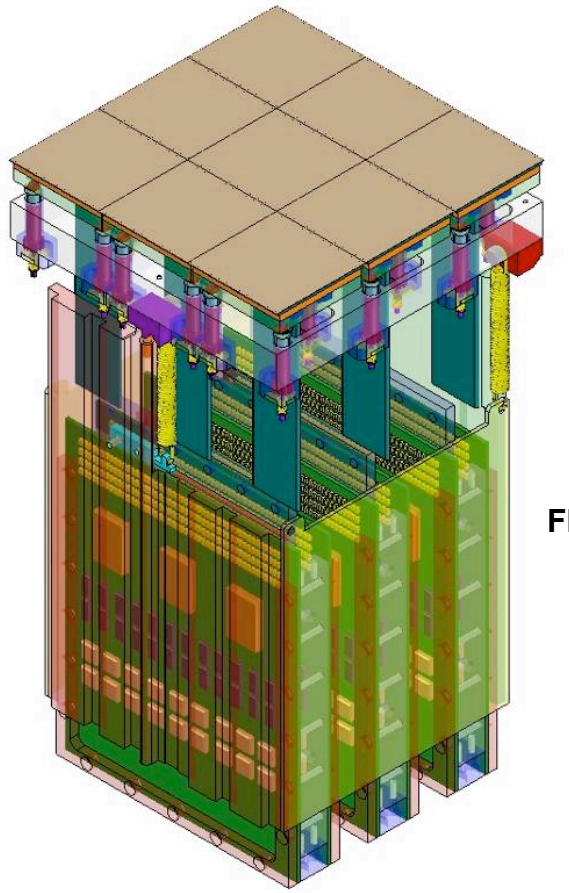
# Raft Towers




SENSOR




RAFT



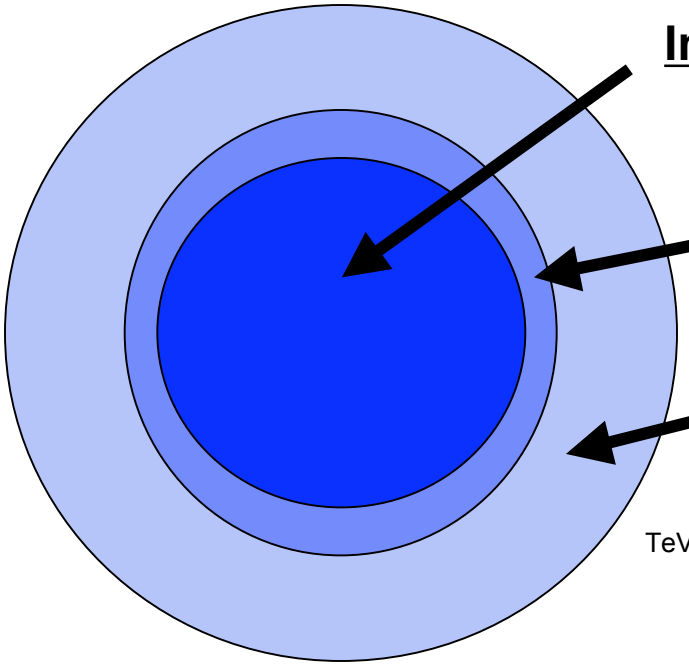

RAFT TOWER

# The LSST Data Management Challenge:

Large Synoptic Survey Telescope

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

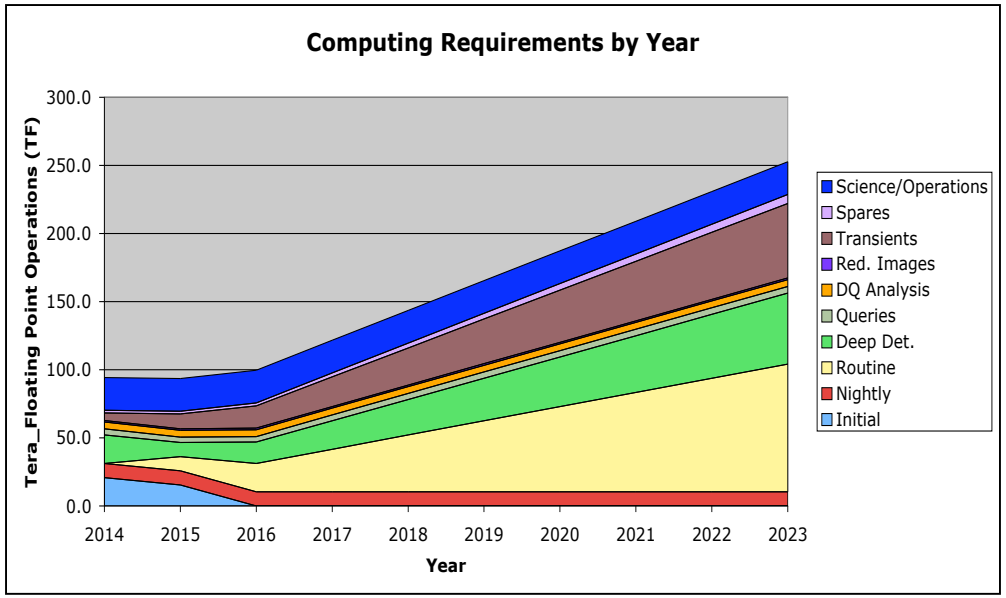


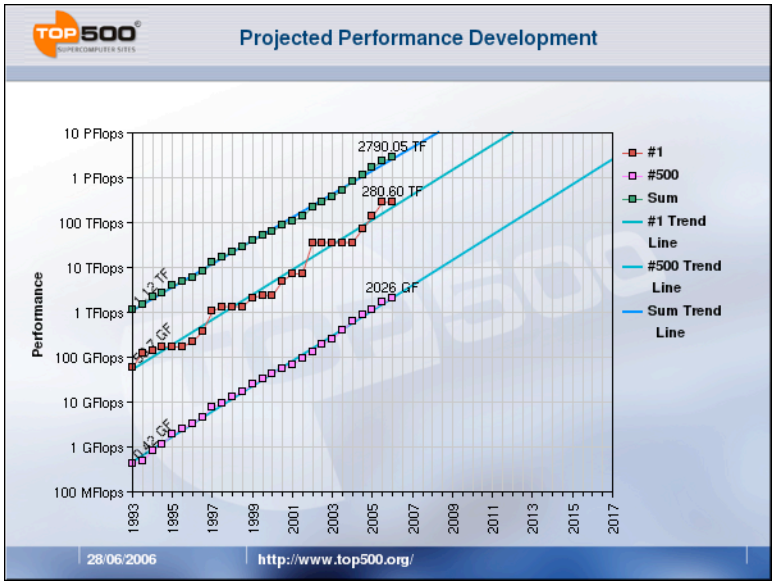
**Infrastructure → Hardware**
Computers, disks, data links, ,,,

**Middleware → Interface wrapper**
Device drivers, system management,…

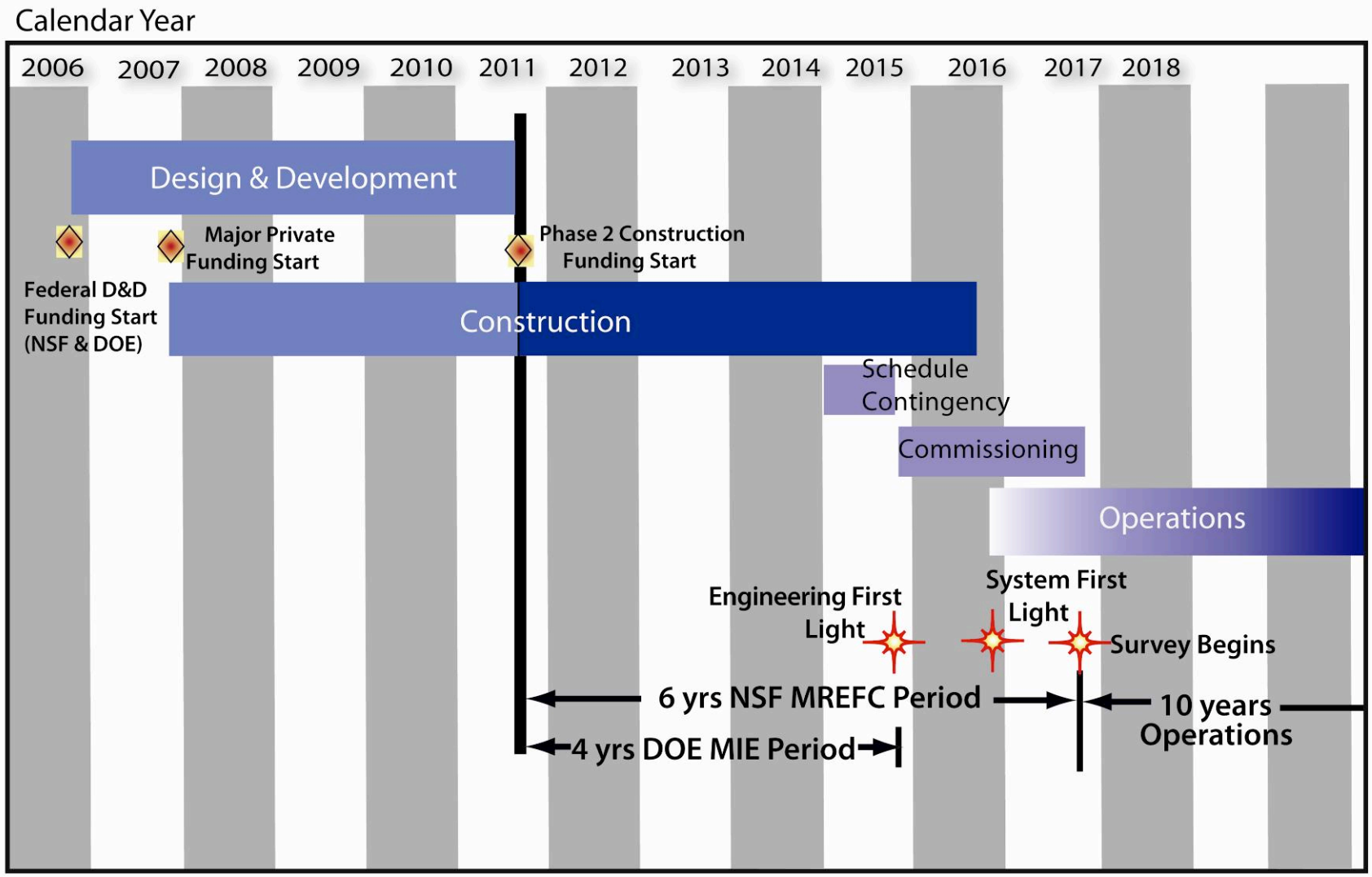
**Applications → Science**
Image processing, database queries, …

# Computing Requirements



# LSST schedule with FY-2012 MREFC start date



# Summary

Large Synoptic Survey Telescope

- 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.

- 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 mid-2016.