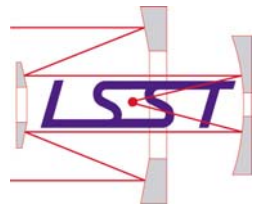




The Large Synoptic Survey Telescope

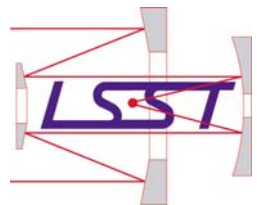
Steven M. Kahn

*Presentation to the SLAC
Program Review
Committee - June 2, 2004*



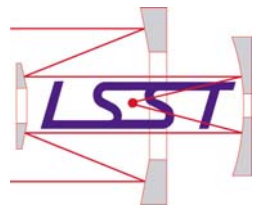
What is the LSST?

- * 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.



Concept Heritage

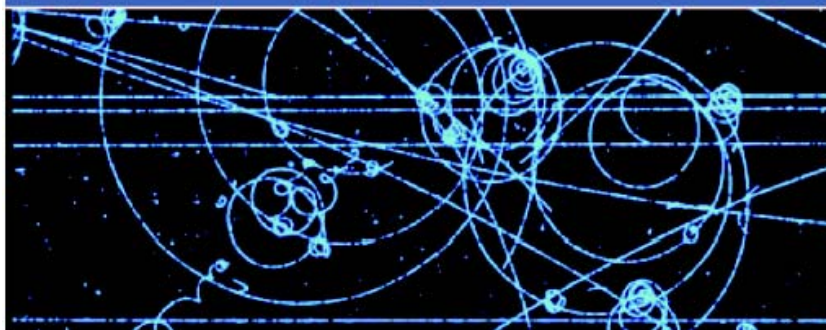
- * The LSST concept has been identified as a national scientific priority by diverse national panels, including three separate NAS committees!
 - “The Committee supports the Large Synoptic Survey Telescope project, which has significant promise for shedding light on the dark energy.” *Connecting Quarks with the Cosmos*.
 - “The SSE [Solar System Exploration] Survey recommends [the construction of] a survey facility, such as the Large-Aperture Synoptic Survey Telescope (LSST)... to determine the contents and nature of the Kuiper Belt to provide scientific context for the targeting of spacecraft missions to explore this new region of the solar system...” *New Frontiers in the Solar System*.
 - “The Large-aperture Synoptic Survey Telescope (LSST) will catalog 90% of the near-Earth objects larger than 300-m and assess the threat they pose to life on Earth. It will find some 10,000 primitive objects in the Kuiper Belt, which contains a fossil record of the formation of the solar system. It will also contribute to the study of the structure of the universe by observing thousands of supernovae, both nearby and at large redshift, and by measuring the distribution of dark matter through gravitational lensing.” *Astronomy and Astrophysics in the New Millennium*.





A 21ST CENTURY FRONTIER FOR DISCOVERY
THE PHYSICS OF THE UNIVERSE

A STRATEGIC PLAN FOR FEDERAL RESEARCH
AT THE INTERSECTION OF
PHYSICS AND ASTRONOMY



Summary of Recommendations

*Ready for Immediate Investment and
Direction Known*

Dark Energy

- * NASA and DOE will develop a Joint Dark Energy Mission (JDEM). This mission would best serve the scientific community if launched by the middle of the next decade. Studies of approaches to the JDEM mission undertaken now will identify the best methodology.
- * A high-priority independent approach to place constraints on the nature of Dark Energy will be made by studying the weak lensing produced by Dark Matter. This is a scientific goal of the ground-based Large-aperture Synoptic Survey Telescope (LSST). Significant technology investments to enable the LSST are required, and NSF and DOE will begin technology development of detectors, optical testing, and software algorithms leading to possible construction with first operations in 2012. NASA will contribute their expertise as appropriate.
- * Another priority method to constrain Dark Energy will be to use clusters of galaxies observed by ground-based Cosmic Microwave Background (CMB) and space-based X-ray observations. A coordinated NSF and NASA effort using this technique will provide independent verification and increase the precision of the overall measurements.



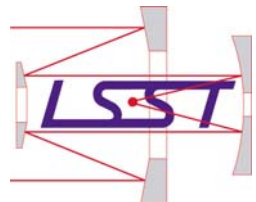
Smaller Facilities in US Program

QUANTUM UNIVERSE

THE FUTURE OF 21ST CENTURY PARTICLE PHYSICS

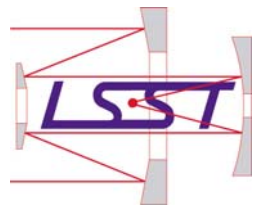
DOE / NSF
HIGH ENERGY PHYSICS ACCELERATOR PROGRAM
QUANTUM UNIVERSE COMMITTEE

Question	Unification				Particle World			Birth of the Universe	
	1	2	3	4	5	6	7	8	9
Mini-BooNE							X		
MECO	X				X				
Reactor ν Experiments							X		
CLEO-c					X				
KOPIO									X
Neutrinoless Double Beta Decay				X			X		
SDSS						X			
LSST		X				X			
Underground Dark Matter Detectors						X			
WMAP		X				X		X	
CMB Polarization								X	
Lattice Computational Facilities					X			X	
Precision Gravity			X						



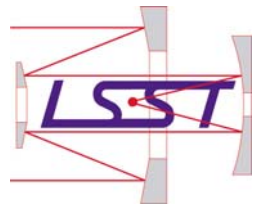
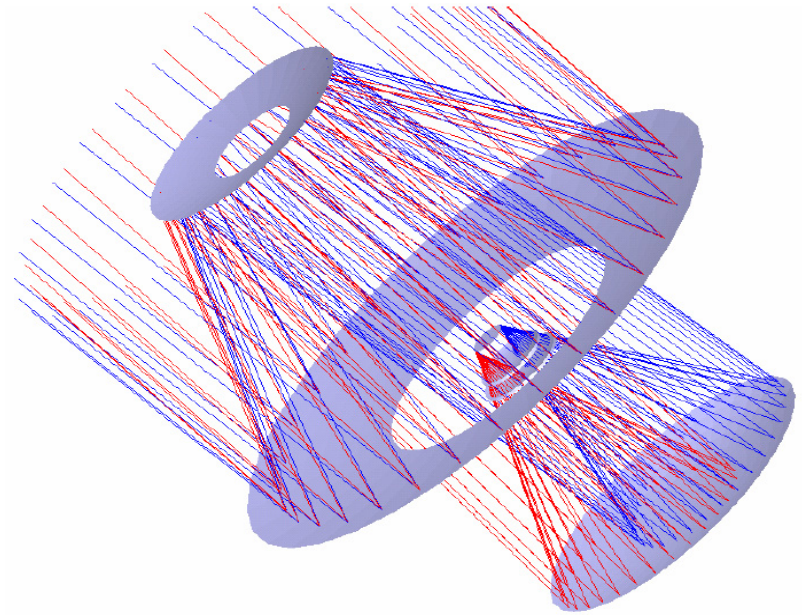
The Essence of LSST is Deep, Wide, Fast!

- * Dark matter/dark energy via weak lensing
- * Dark matter/dark energy via supernovae
- * Galactic Structure encompassing local group
- * Dense astrometry over 30,000 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, TNOs

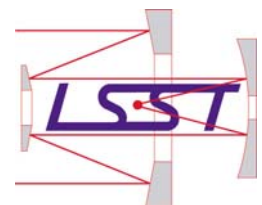
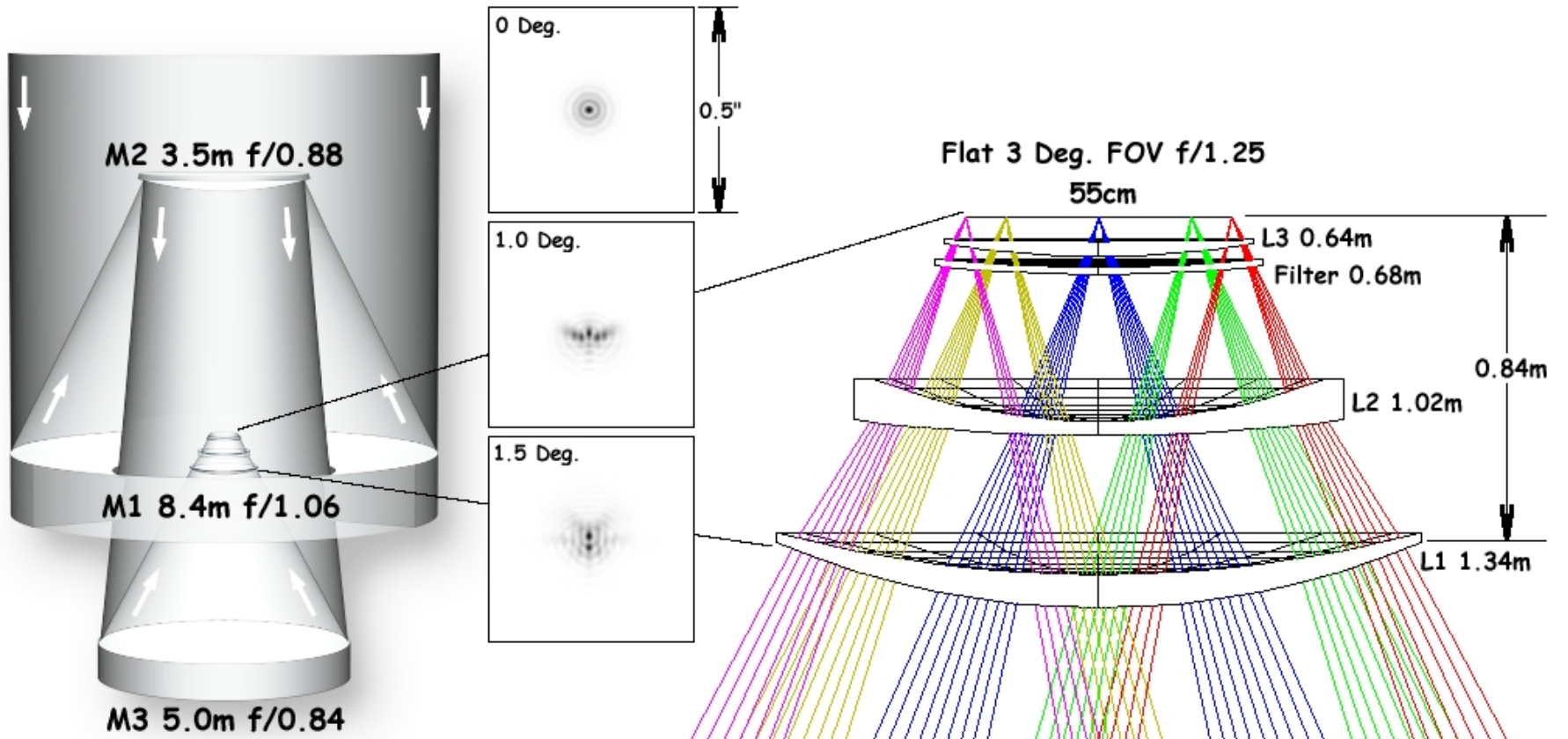


LSST Optical Design

- * The original optical design is based on a concept by Angel et al. (2000), which modifies the Paul-Baker 3-mirror telescope to work at large apertures.
- * Seppala (2002) further developed this approach, simplifying the aspheric surfaces and achieving a flat focal plane.
- * There are three aspheric mirrors feeding three refractive elements in the camera. These yield a 3.5 degree circular field of view, covering a 64-cm focal plane array.

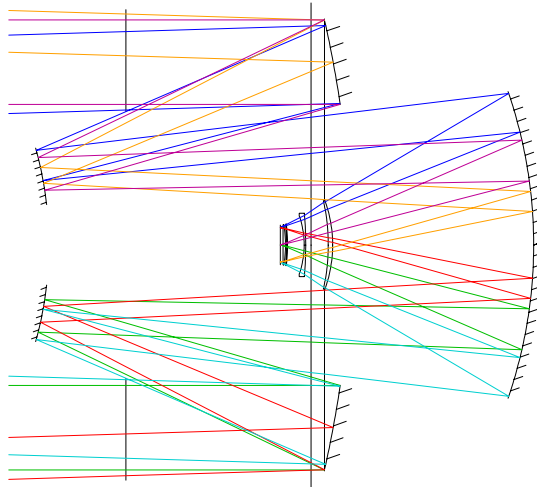


LSST Optical Design

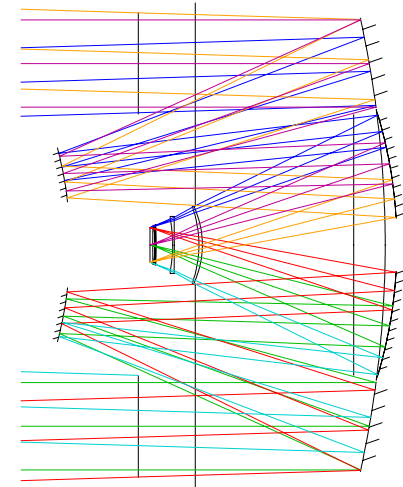


Long versus Short Design

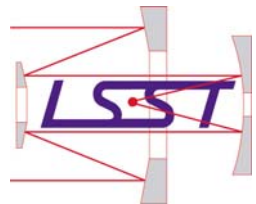
1.6e+03



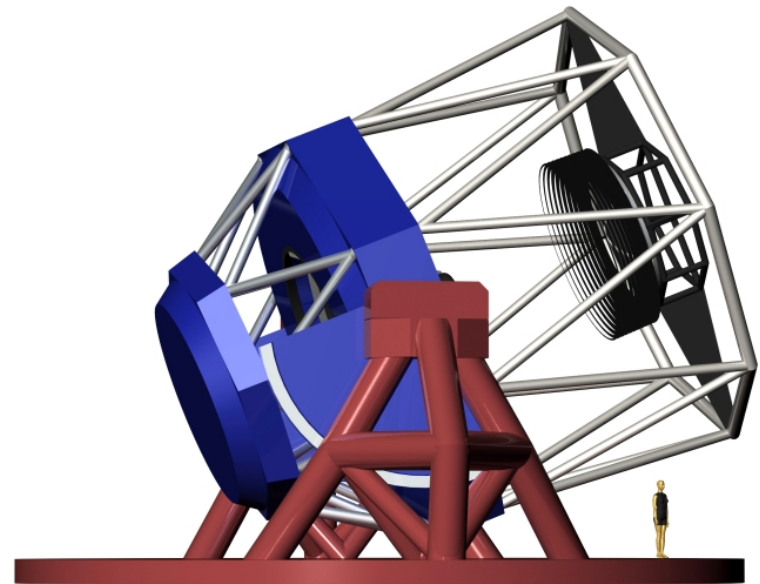
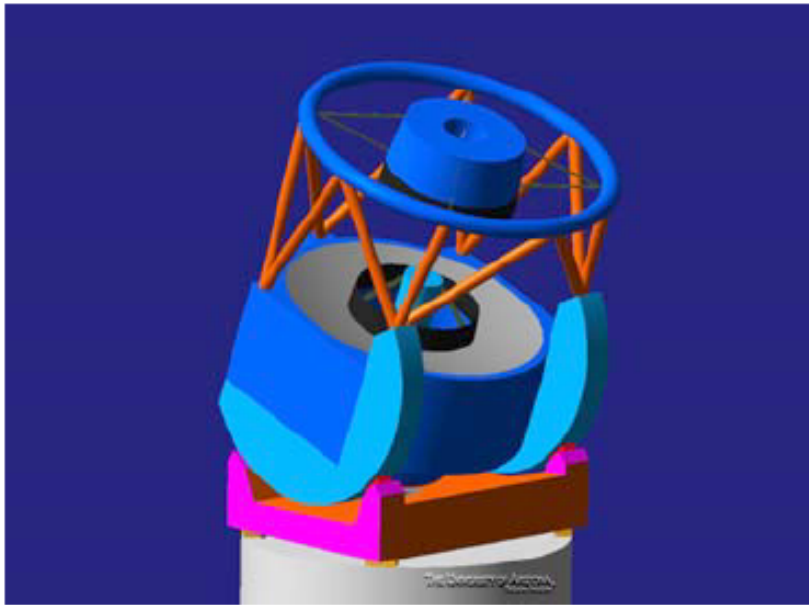
1.6e+03



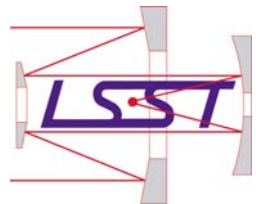
Trade study currently in progress



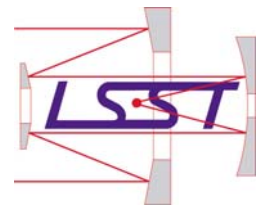
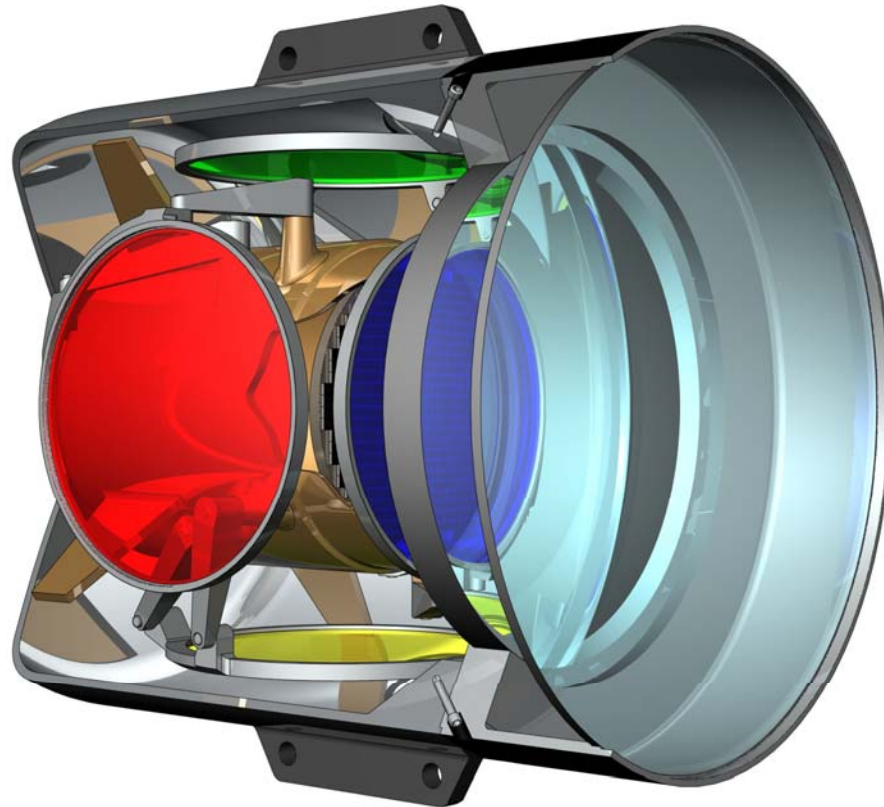
LSST Telescope Mount



Two Possible Configurations.

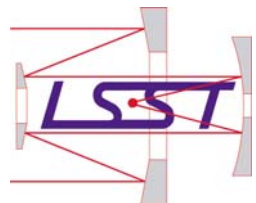


LSST Camera



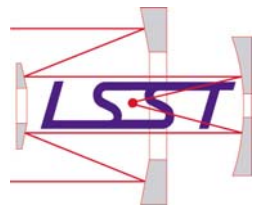
Camera Components

- * Focal plane array
 - 10 μm pixels \rightarrow 0.2 arcsecond/pixel ($\sim 1/3$ seeing-limited PSF)
 - 64 cm diameter \rightarrow 3.5° FOV
 - \rightarrow 2.8 Gpixels
 - integrated front-end electronics
 - 16 bits/pixel, 2 sec readout time \rightarrow 2.8 GB/sec
 - \rightarrow Parallel readout
- * Housings (environmental control)
- * Filters
- * Optics
- * Mechanisms
 - L2 position varies with wavelength (filter)
 - Filters insertion
 - mechanical shutter



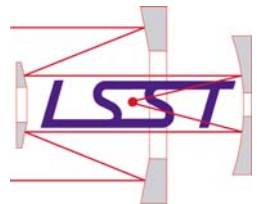
Camera Challenges

- * Detector requirements:
 - 10 μm pixel size
 - Pixel full-well $> 90,000 e^-$
 - Low noise ($< 5 e^-$ rms), fast (< 2 sec) readout ($\rightarrow < -30$ C)
 - High QE 400 – 1000 nm
 - All of above exist, but not simultaneously in one detector
- * Focal plane position precision of order 3 μm
- * Package large number of detectors, with integrated readout electronics, with high fill factor and serviceable design
- * Large diameter filter coatings
- * Constrained volume (camera in beam)
 - Makes shutter, filter exchange mechanisms challenging
- * Constrained power dissipation to ambient
 - To limit thermal gradients in optical beam
 - Requires conductive cooling with low vibration



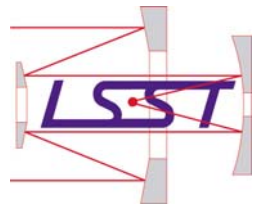
Sensor Technology

- * Main choices: CCD, hybrid CMOS
 - CCDs:
 - Monolithic Si array
 - Routinely used for visible astronomical applications
 - Have been made in high-resistivity, thick format (to achieve sensitivity at 1 μm wavelength) with 15 μm pixel density
 - Slow readout: need $\sim 10 \mu\text{s}$ per pixel to achieve noise level
 - Hybrid CMOS:
 - Hybrid array uses thin planar detector with pixelated back contact “bump bonded” to CMOS readout multiplexer
 - Routinely used for infrared astronomy (with different photo-conversion material)
 - Avoids need for mechanical shutter
 - Can integrate substantial electronics on-chip
 - Low power ($< 1/100$ of CCD) & Fast readout

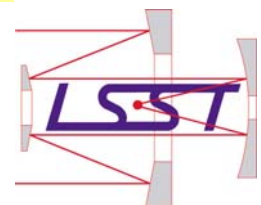
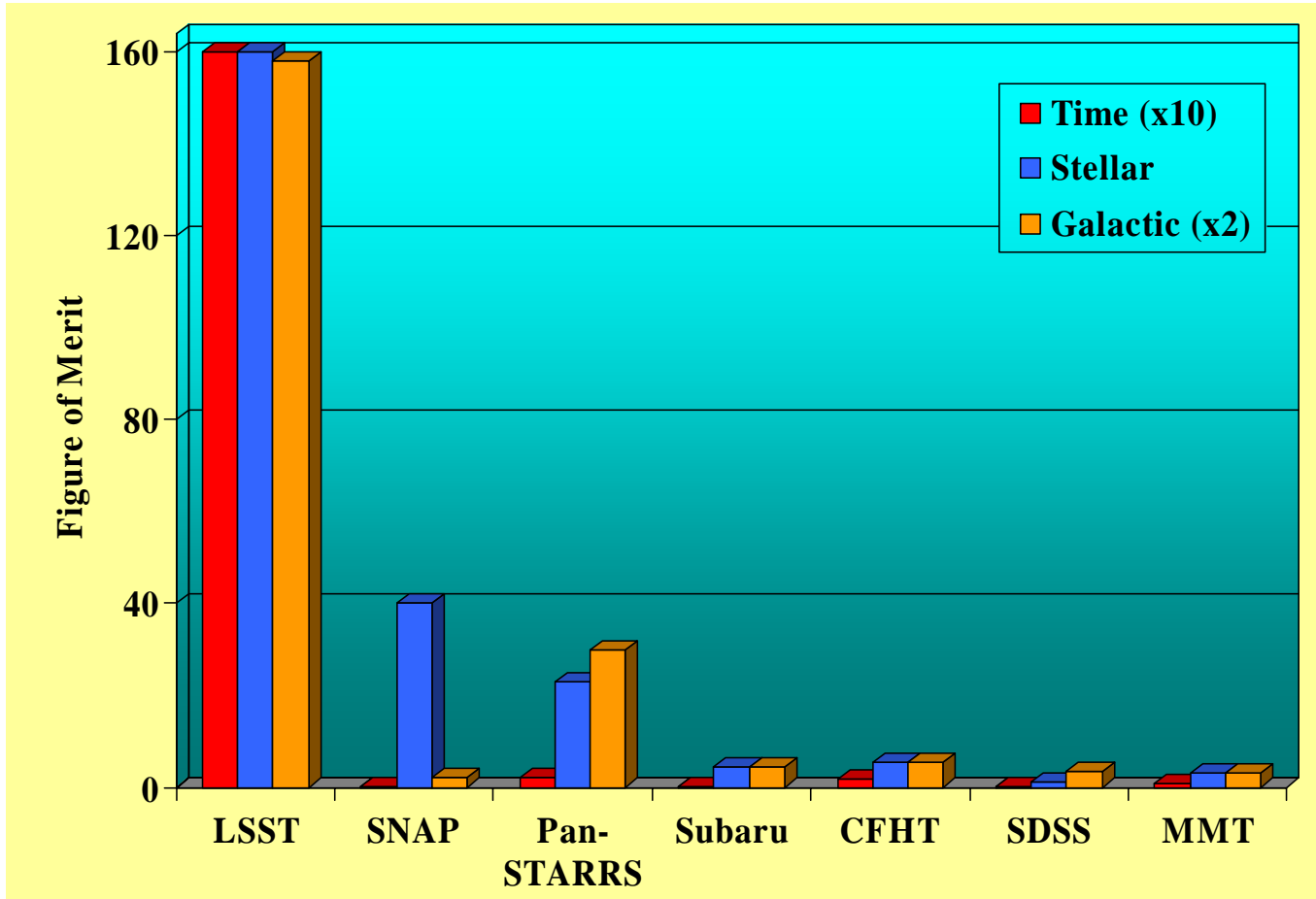


LSST Data Rates

- * 2.8 billion pixels read out in less than 2 sec, every 12 sec
- * 1 pixel = 2 Bytes (raw)
- * Over 3 GBytes/sec peak raw data from camera
- * Real-time processing and transient detection: < 10 sec
- * Dynamic range: 4 Bytes / pixel
- * > 0.6 GB/sec average in pipeline
- * 5000 floating point operations per pixel
- * 2 TFlop/s average, 9 TFlop/s peak
- * ~ 18 Tbytes/night



Relative Survey Power



The LSST Consortium



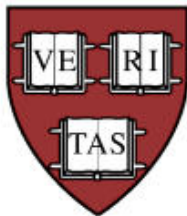
RESEARCH CORPORATION



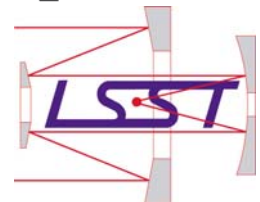
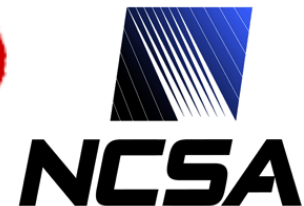
THE UNIVERSITY OF ARIZONA,



UC DAVIS
University of California, Davis



Lucent Technologies
Bell Labs Innovations



LSST Organization

* Three main sub-project teams:

Telescope/Site:

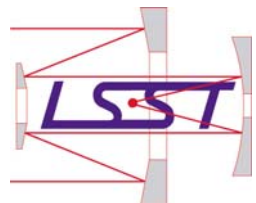
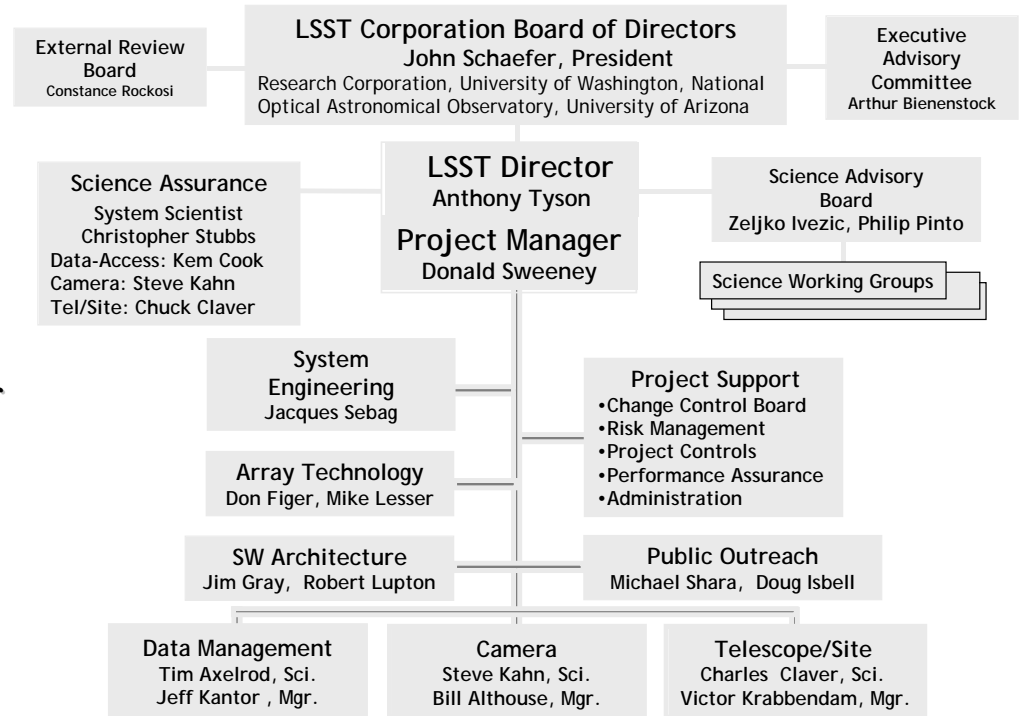
NOAO, U. of Arizona

Camera (DOE):

SLAC, BNL, LLNL, Harvard, U. of Illinois et al.

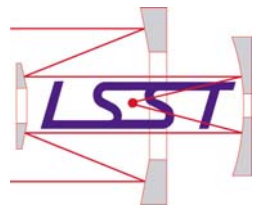
Data Management:

NCSA, LLNL, Princeton et al.

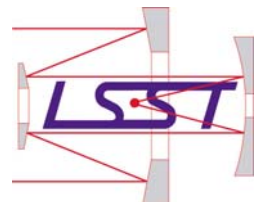
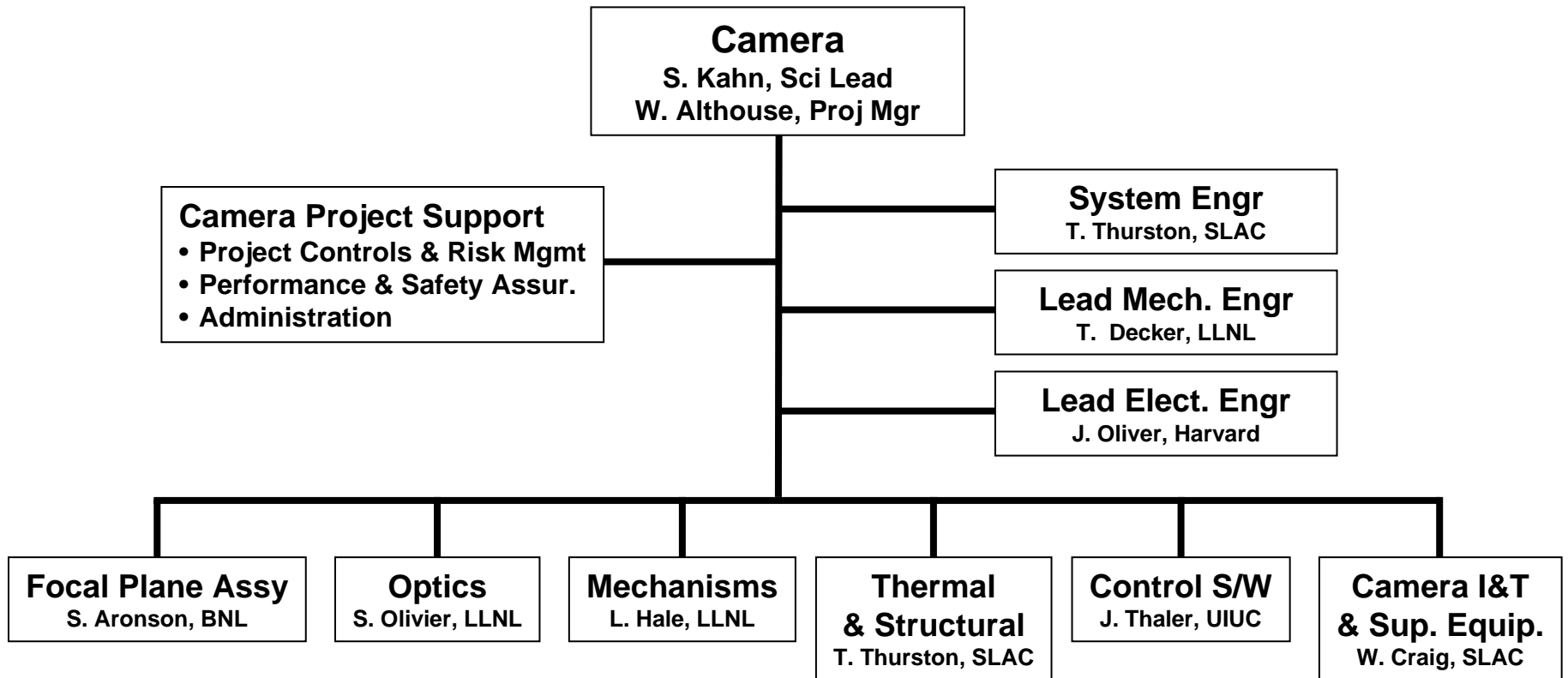


DOE-Funded Institutional Roles

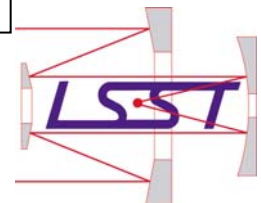
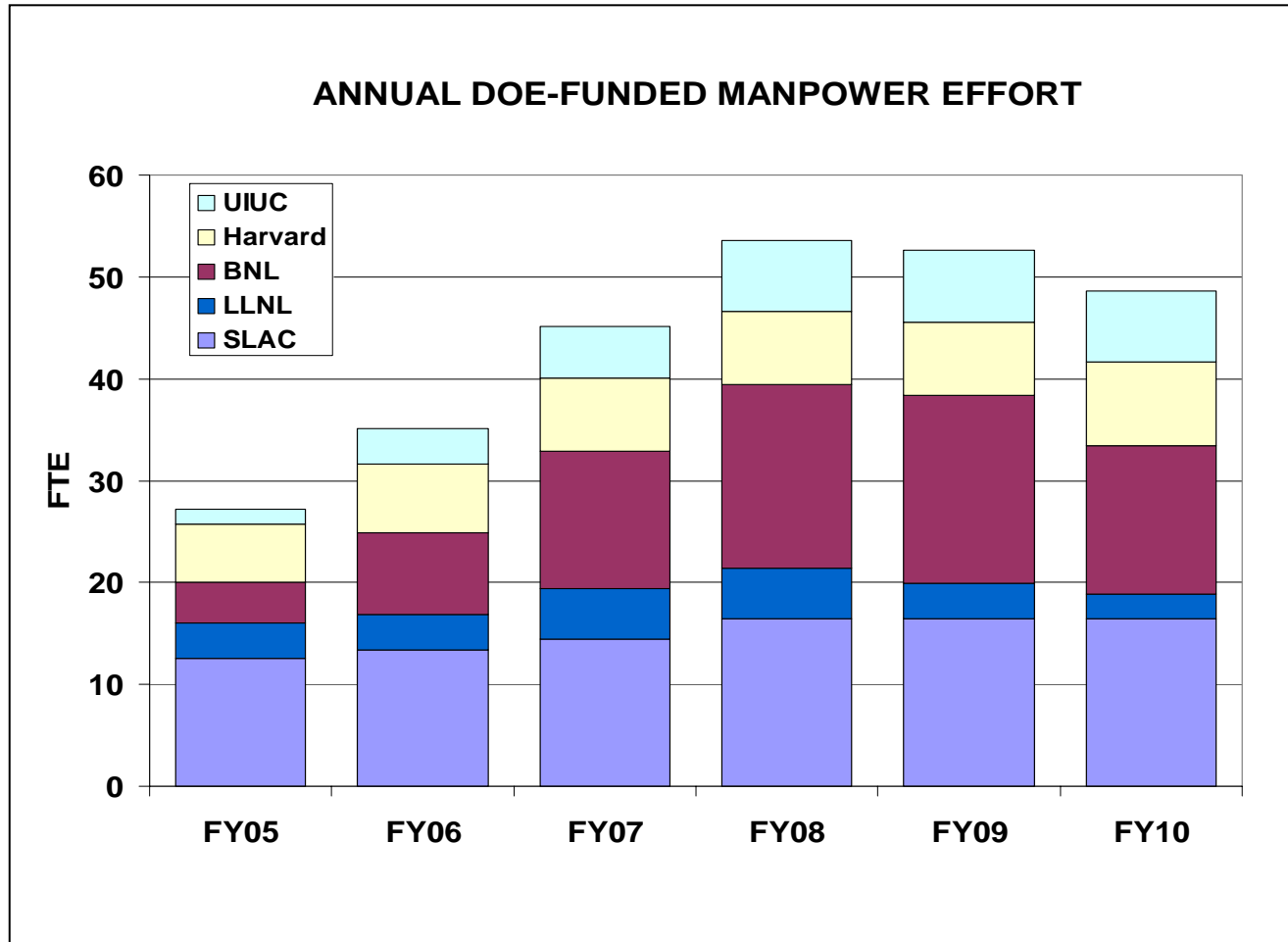
- **SLAC:** overall camera project management; camera mechanical and optical elements; focal plane assembly; camera integration and test; front-end DAQ; supporting science activities, modeling and analysis.
- * **BNL:** sensor and FEE development; integration of sensors with FEE; support for focal plane assembly and test, and camera integration and test; collaboration in the front-end DAQ; supporting science activities, modeling and analysis.
- * **LLNL:** mechanical and optical engineering; participation in the assembly and test of the focal plane; support for camera integration and test; supporting science activities, modeling and analysis.
- * **Harvard:** electronics engineering; support for FEE/sensor integration and test; support focal plane assembly and test, and camera integration and test; supporting science activities, modeling and analysis.
- * **UIUC:** camera control software; support for camera integration and test; supporting science activities, modeling and analysis.



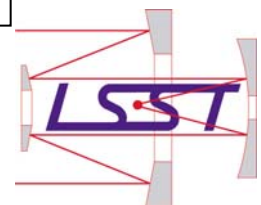
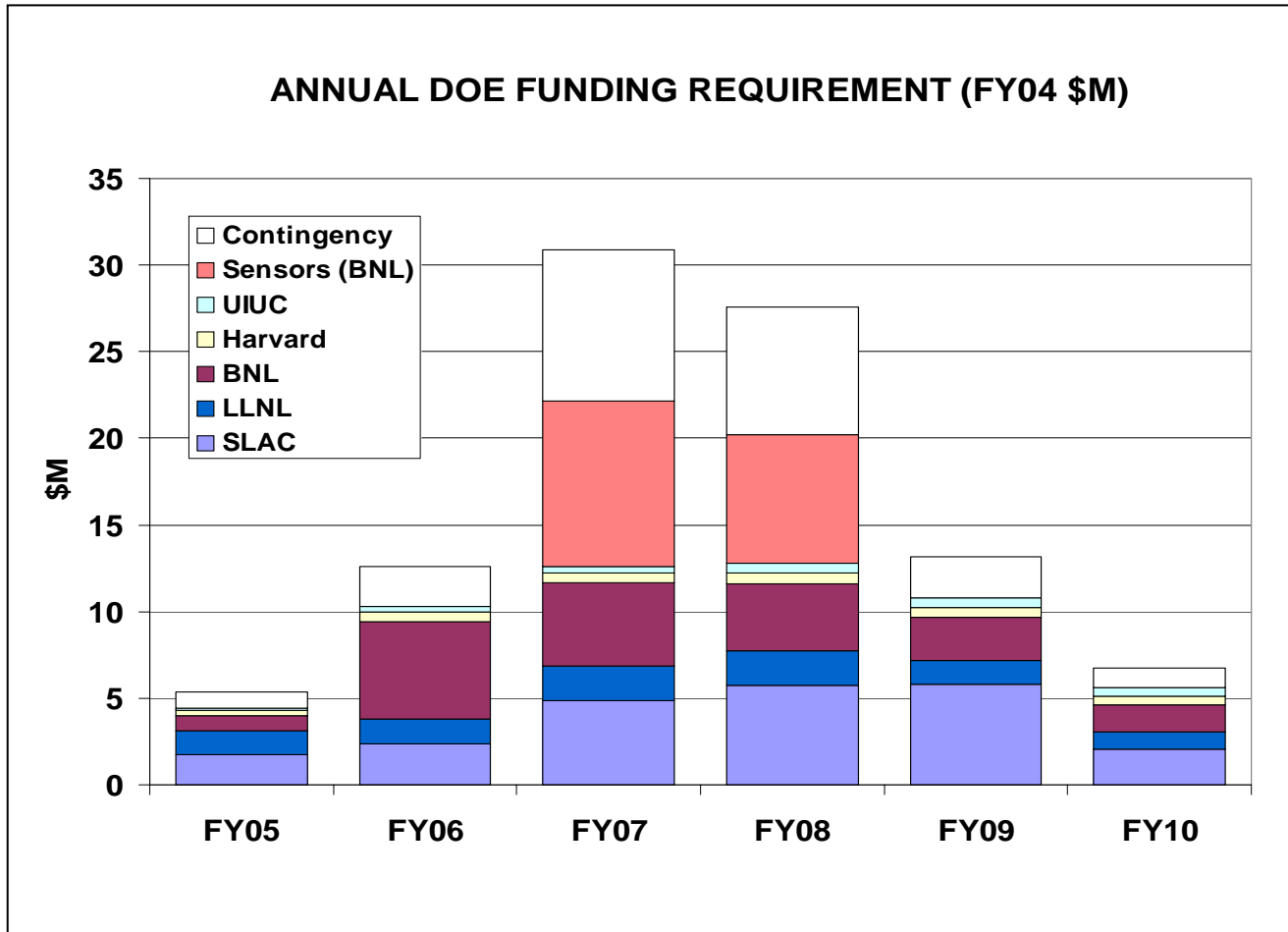
LSST Camera Project Organization



Manpower

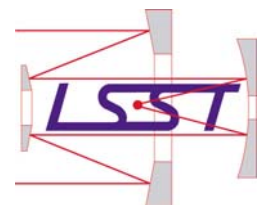
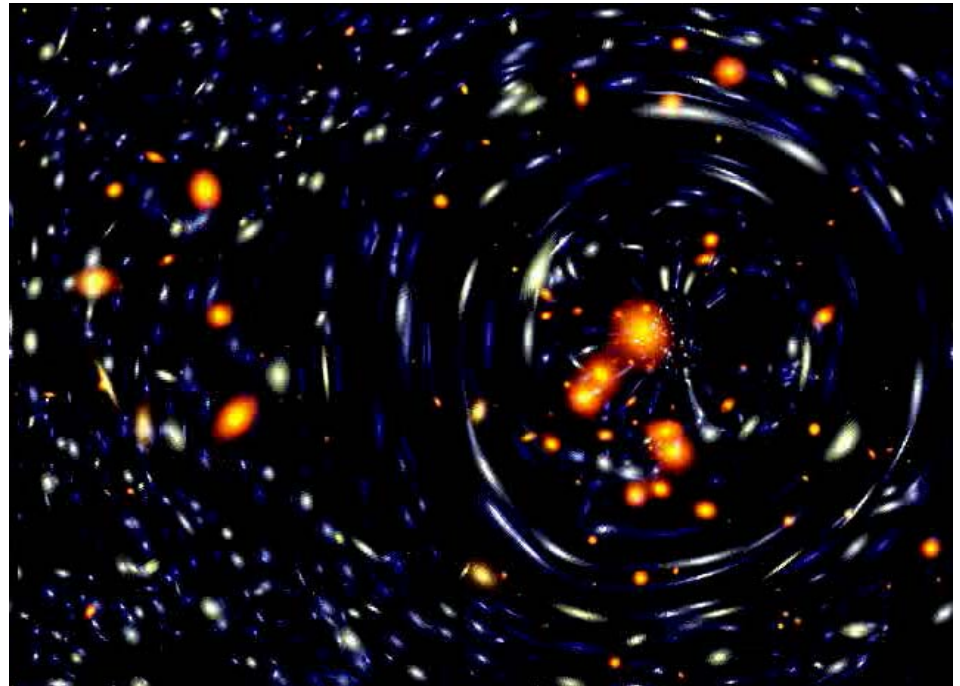


Funding



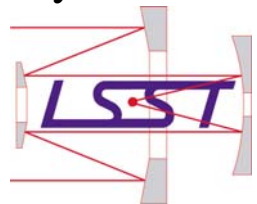
LSST and Dark Energy

- * LSST will measure 250,000 resolved high-redshift galaxies per square degree! The full survey will cover 18,000 square degrees.
- * Each galaxy will be moved on the sky and slightly distorted due to lensing by intervening dark matter. Using photometric redshifts, we can determine the shear as a function of z .
- * Measurements of weak lensing shear over a sufficient volume can determine DE parameters through constraints on the expansion history of the universe and the growth of structure with cosmic time.

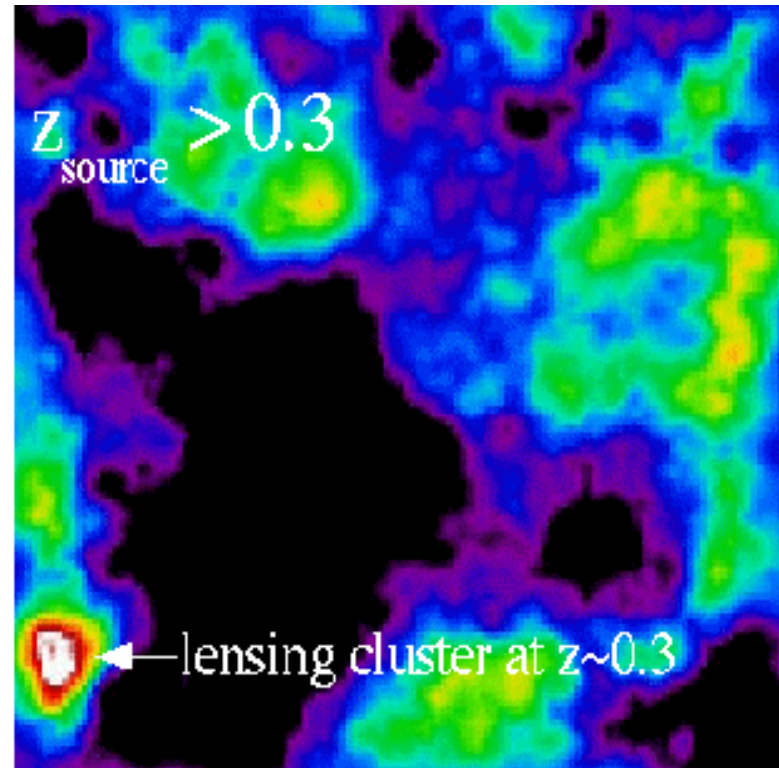
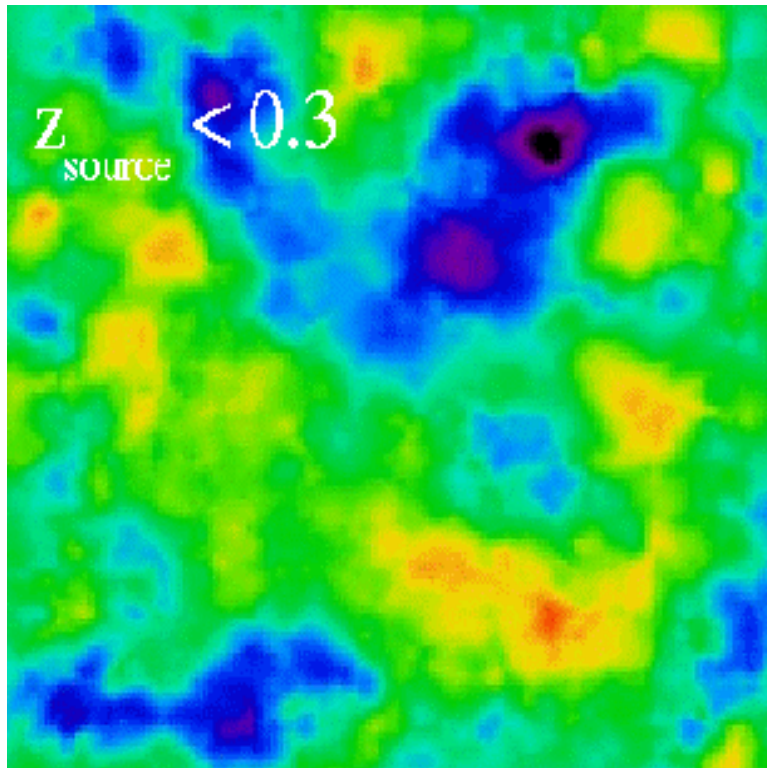


LSST and Dark Energy

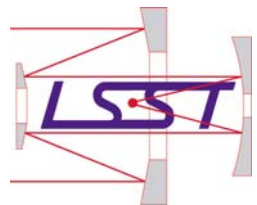
- * The LSST Weak Lensing Survey will constrain DE via three related, but different techniques:
 - *Cluster Tomography*: The measurement of the number density of clusters as a function of mass and redshift - $dN/dMdz$.
 - *Shear Tomography*: The measurement of the large-angle shear power spectrum. With photo- z 's, this can be measured as a function of cosmic time. Combining the shear power spectrum with the CMB fluctuation spectrum places constraints on w and w_a .
 - *Shear Cosmography*: The measurement of WL shear caused by a foreground structure of known redshift depends on the distance of the background galaxy. This provides a redshift-distance measurement, which constrains the underlying cosmological model.
- * These techniques have different dependences and different systematics. Probing the Concordance Cosmological Model in multiple ways is probably the best means we have of discovering new underlying physics.



3D Mass Tomography

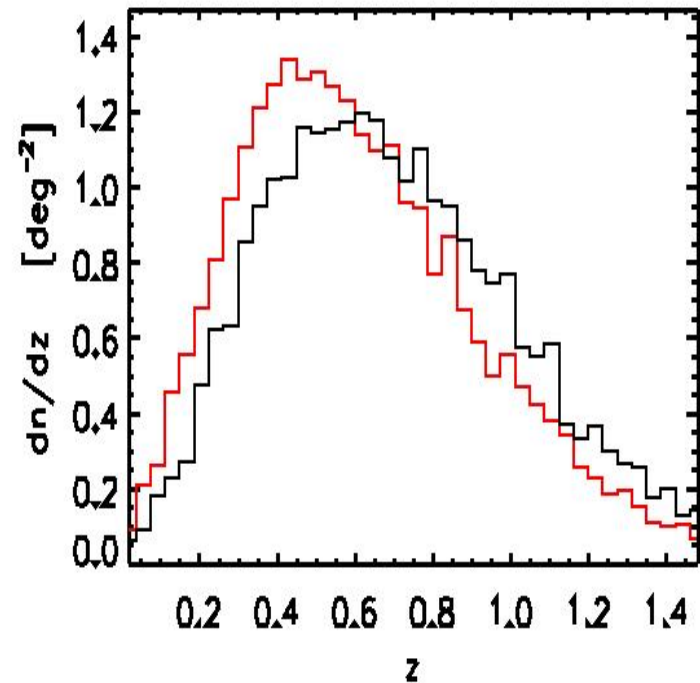


From Wittman et al. 2003.

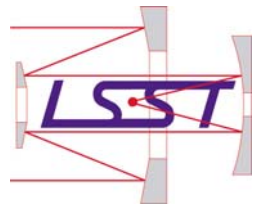


Cluster Counting Via WL Tomography

- * $dN/dMdz$ constrains DE models via the dependences on the co-moving volume element, $dV/d\Omega dz$, and on the exponential growth of structure, $\delta(z)$.
- * Since WL measured DM mass directly, it does not suffer by the various forms of baryon bias and uncertainties in gas dynamical processes.
- * With a sky coverage of 18,000 square degrees, LSST will find 200,000 clusters. A sample this size will yield a measurement of w to 2-3%.

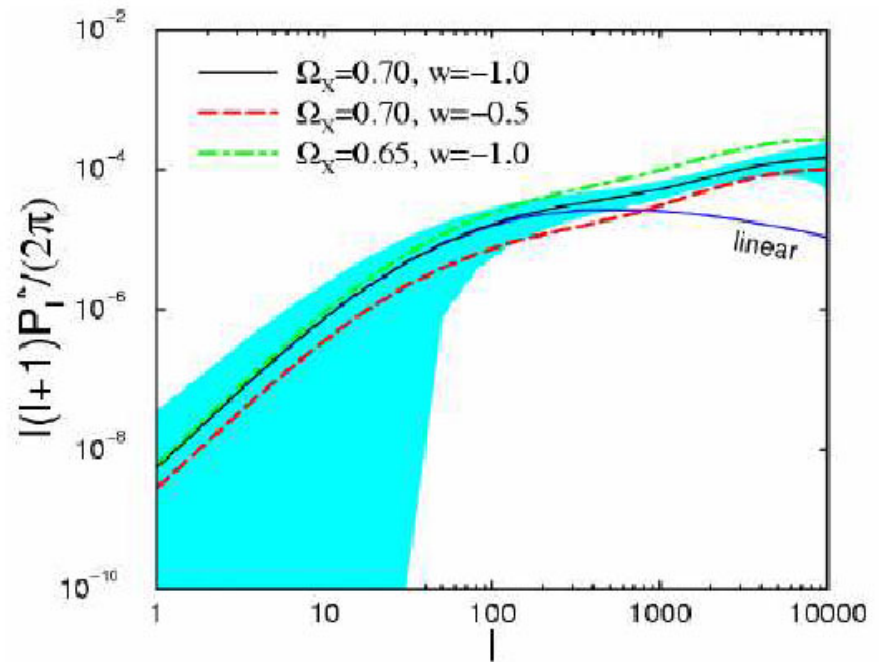


Plot above is for 3% of the LSST sample.

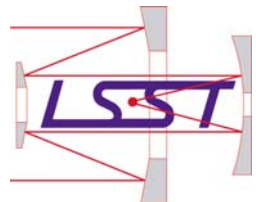


Measurement of the Cosmic Shear Power Spectrum

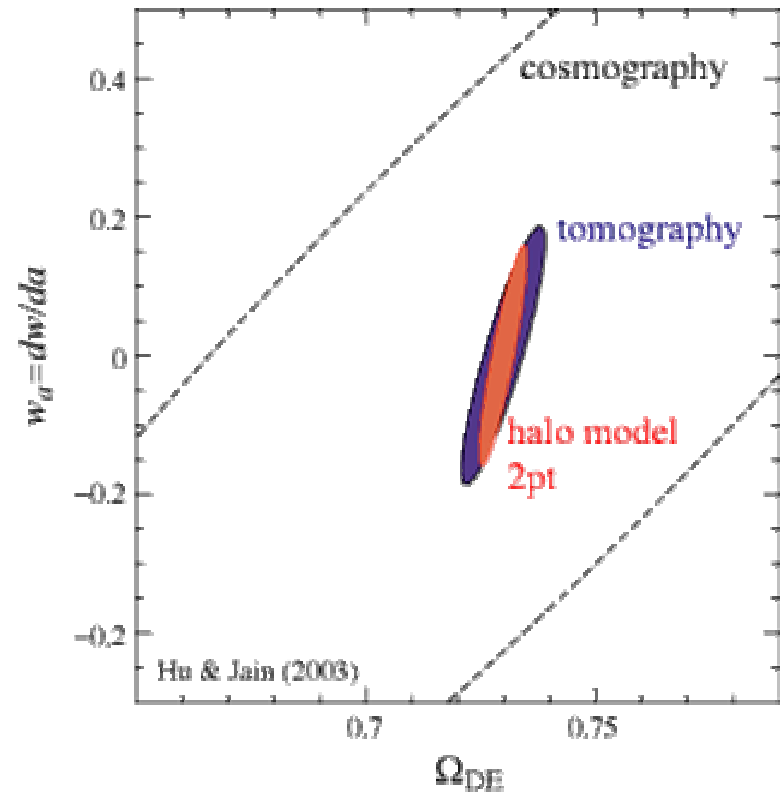
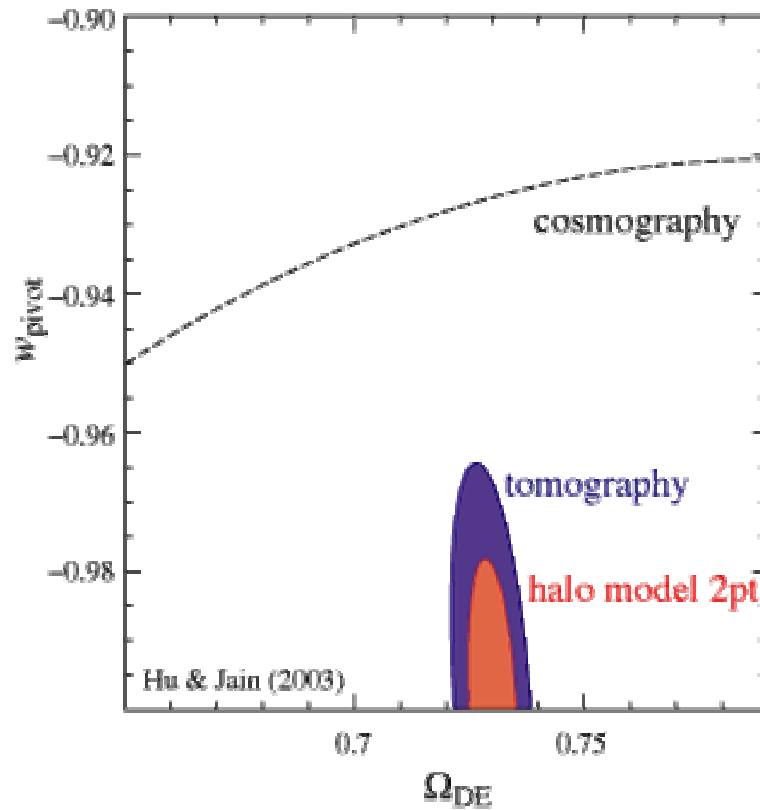
- * An independent probe of DE comes from the correlation in the shear in various redshift bins over wide angles.
- * Using photo-z's to characterize the lensing signal improves the results dramatically over 2D projected power spectra (Hu and Keeton 2002).
- * A large collecting area and a survey over a very large region of sky is required to reach the necessary statistical precision.
- * LSST has the appropriate etendue for such a survey.



One sigma errors for 1000 squ. degree Survey. LSST will have 18,000 squ. deg.



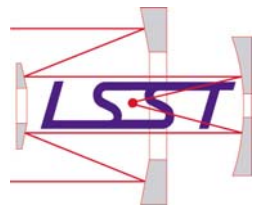
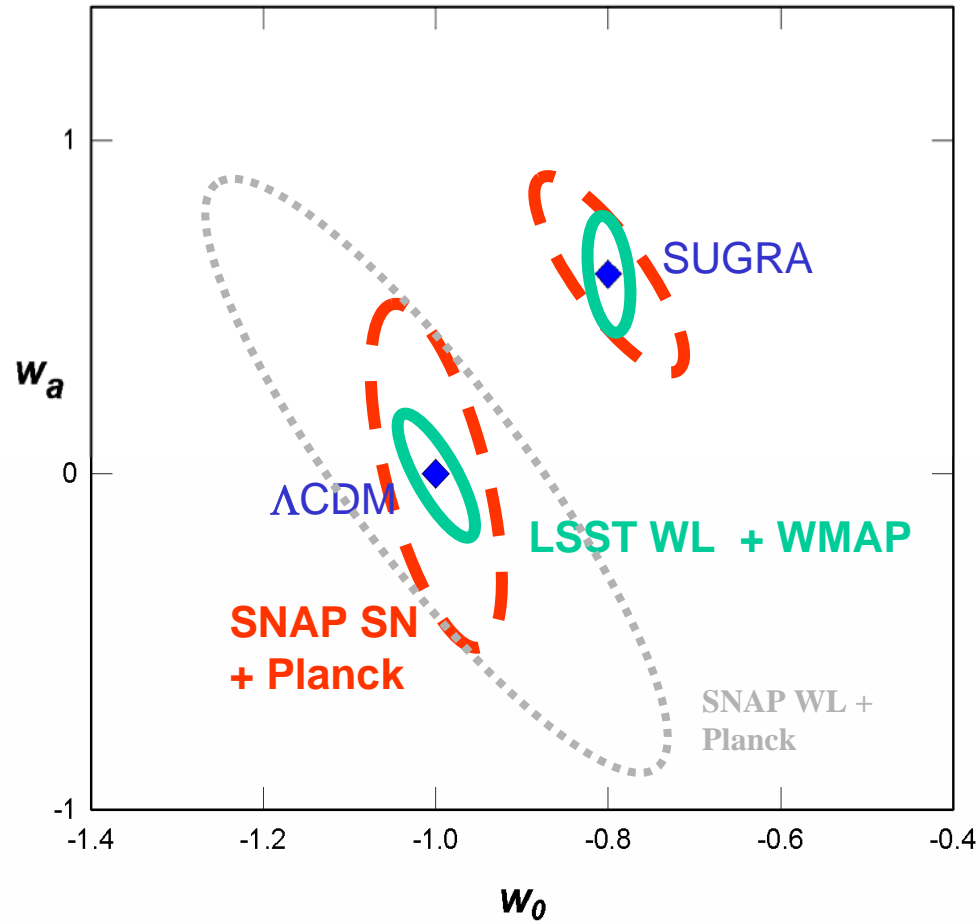
Constraints on DE Parameters



From Hu & Jain (2003)



Constraints on DE Parameters



Summary of LSST Impact on Dark Energy

- * LSST will enable 3D mass tomography through weak lensing over a very large region of sky, 18,000 squ. deg.
- * Such a rich sample of high- z lensed galaxies allows multiple probes of the cosmological model. This breaks degeneracies and lessens the impact of systematics, which affect all techniques in different ways.
- * The LSST WL survey is very complementary to that which is likely to come from JDEM. The JDEM survey will go deeper in redshift, over a smaller field (300 squ. deg.).
- * The LSST database is also nicely complementary to that which will come from SZ surveys and an X-ray cluster survey mission, such as DUO. This mystery of DE is sufficiently important that we should bring every means of investigation available into the mix of constraints.

