The Large Synoptic Survey Telescope

Presentation to the SLAC
Experimental Program Advisory Committee
24 January 2006

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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.

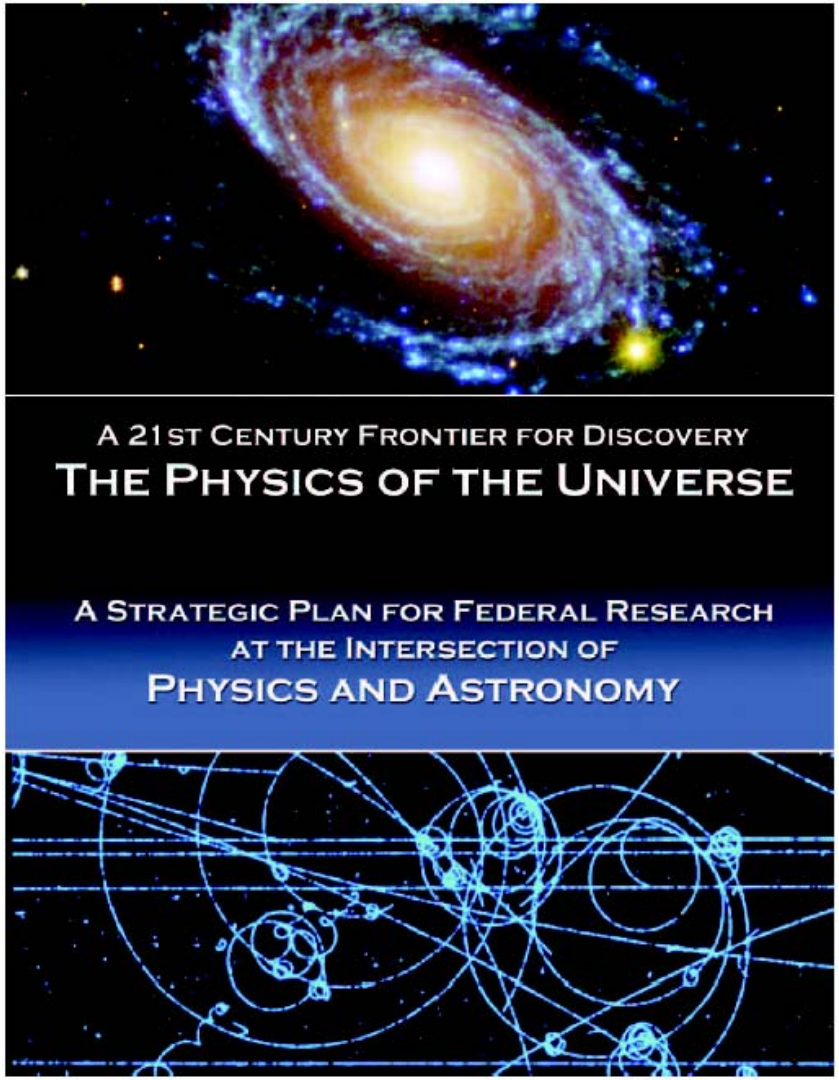
- LSST will enable a wide variety of complementary scientific investigations, utilizing a common database. These range from searches for small bodies in the solar system to precision astrometry of the outer regions of the galaxy to systematic monitoring for transient phenomena in the optical sky.

- Of particular interest for cosmology, LSST will provide strong constraints on models of dark matter and dark energy through studies of cosmic shear, the distribution of clusters of galaxies, measurement of baryon acoustic oscillations, systematic monitoring of a large number of Type 1a supernovae, and the detection of gravitationally lensed supernovae .

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.***

Concept Heritage



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.

Concept Heritage

Smaller Facilities in US Program

	Unification				ParticleWorld			Birth of the Universe	
Question	1	2	3	4	5	6	7	8	9
Mini-BooNE							X		
MECO	X				X				
Reactor ν Experiments							X		
CLEO-c					X				
K0PI0									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						

Concept Heritage

Ground-Based Dark Energy Experiment

Status: CD-0 Approved in November 2005

Mission Need

Scientists have long assumed that the expansion of the Universe is slowing down due to the gravitational attraction of matter. The original discovery of dark energy, using type Ia supernovae, was made in 1998 by two teams using ground-based and space-based measurements. This type of supernova always explodes with a known brightness and its apparent brightness can therefore be used as a measure of distance. The measurement of the brightness versus the redshift of the supernova indicates how much the Universe has expanded since that time. What the scientists found was that the Universe wasn't slowing down as expected, but rather it is speeding up, due to a previously unknown dark energy. The discovery has since been confirmed by a number of methods. The discovery of dark energy was named Science Magazine's Breakthrough of the Year in 1998 its confirmation was named Breakthrough of the Year in 2003.

Concept Heritage

Option 3: Build a next-generation wide-field telescope along with the world's largest optical imaging camera and associated data acquisition system. This concept would allow measurements of galaxy shape distortions caused by weak gravitational lensing to determine the growth of galaxy clusters over time. It is expected that other agencies or institutions would provide funding for the telescope. Such a facility could obtain sequential images of the entire visible sky every few nights and the data collection area would be two orders of magnitude larger than any existing facility. Data will be of use to the larger astrophysics and astronomy community for many different science topics. The data would provide high precision dark energy constraints at the approximately 2 – 3% level.

LSST Project Organization

- **Three main sub-project teams:**

Telescope/Site (NSF):

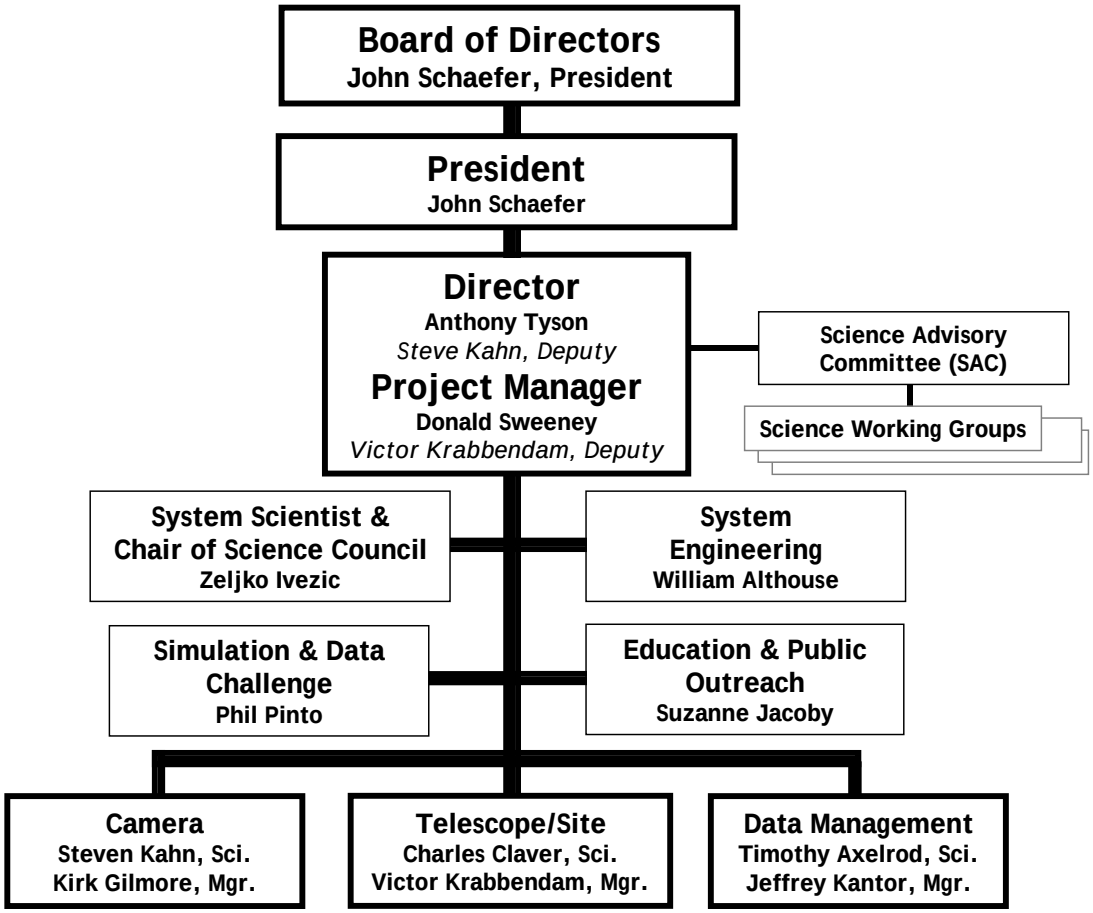
NOAO, U. of Arizona, LLNL

Camera (DOE):

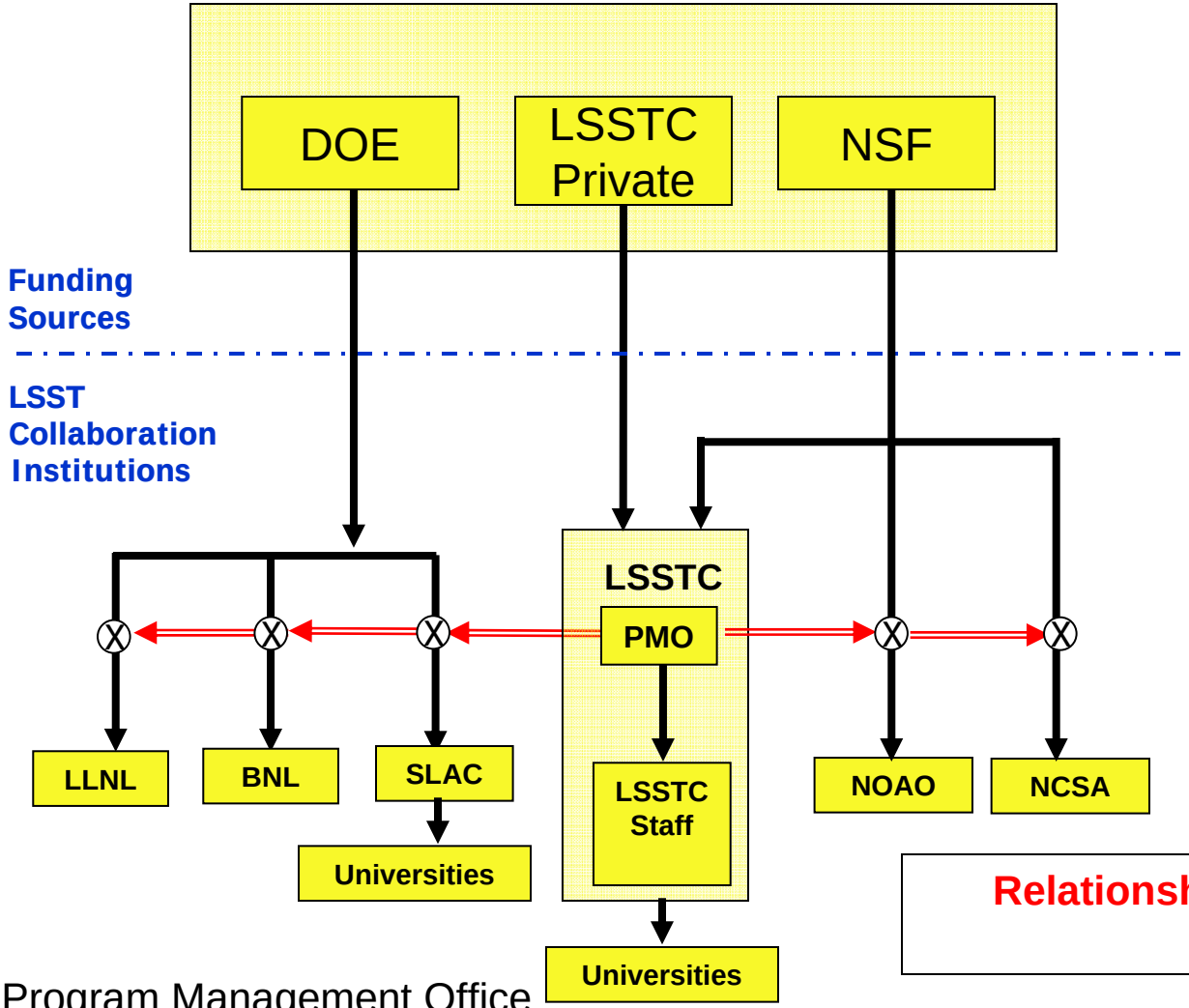
SLAC, BNL, LLNL, Harvard, UIUC, UCSC, OSU, U. of Penn, …

Data Management (Both):

NCSA, LSSTC, LLNL, SLAC, U. of Arizona, U. of Washington, Princeton, Harvard, …



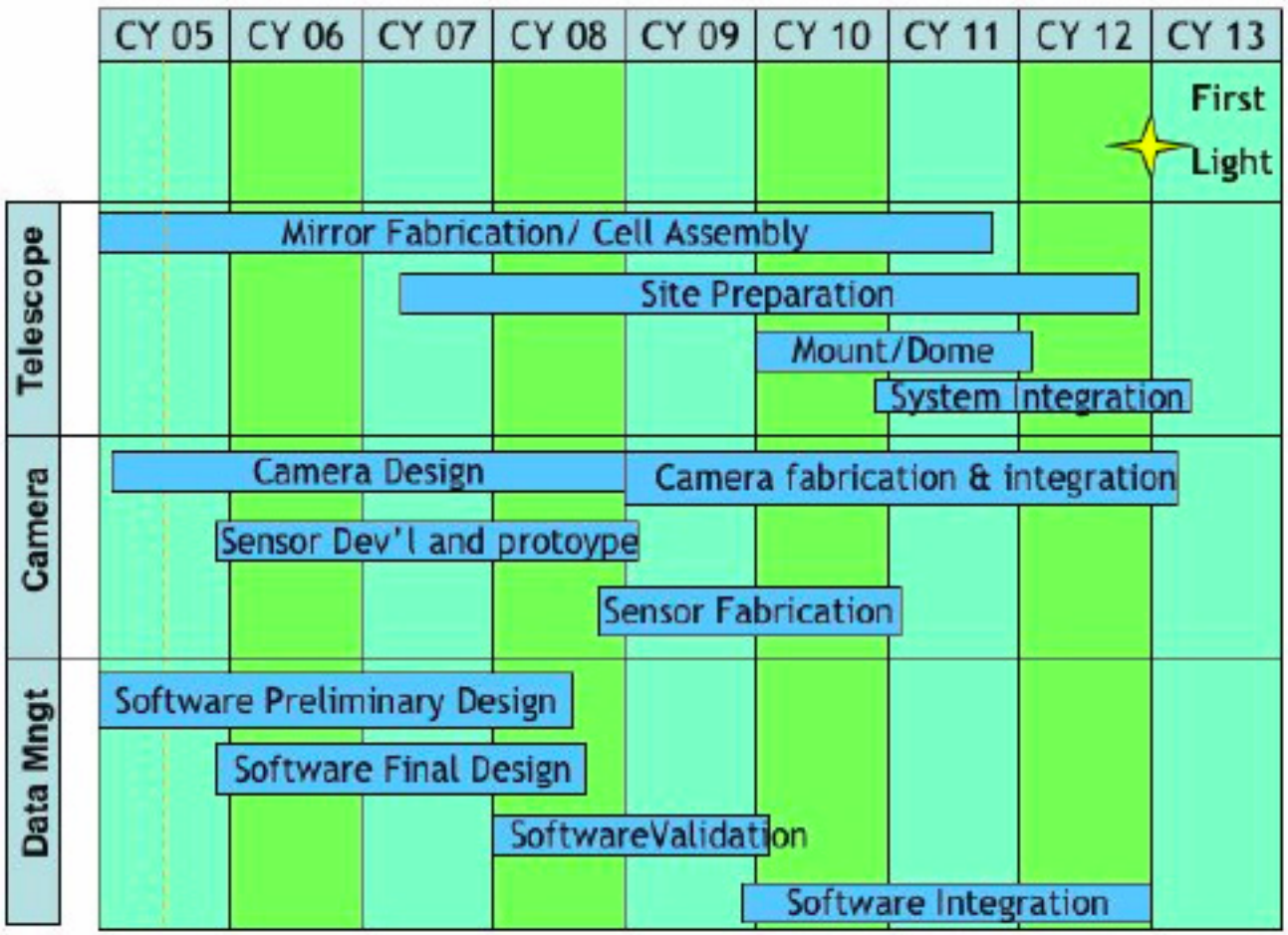
Possible Funding and Management Configuration



Relationships established by MoA's

PMO: Program Management Office

Project Baseline Schedule Plans



Near Term Decision Schedule

- **NSF Contract for Design & Development - $14.1M awarded September 2005.**
- **SLAC EPAC Review - January 24-25, 2006.**
- **SLAC Director's Review - March 8-9, 2006.**
- **P5 Deliberations on New CD-0 Initiatives - Spring 2006.**
- **Submission of NSF Construction Proposal - November 2006.**
- **DOE CD-1 Review - Early FY07 (Anticipated)**

LSST as an HEP Experiment

- **The discovery of the "dark universe" has posed some of the most pressing questions facing modern theoretical physics.**

- **The existence of dark matter requires a whole new particle sector. Attempting to understand what dark matter is, and what its relation may be to supersymmetry is certainly among the major goals of particle physics.**

- **Dark energy is an even greater puzzle. The implied mass scale is ~ milli-eV - not the regime where we were expecting to find new physics.**

- **Future accelerator experiments may yield new clues on these phenomena, but it is clear that we need to quantitatively improve the cosmological constraints. Of particular importance is to measure both the kinematic and dynamic history of the cosmic expansion.**

LSST as an HEP Experiment (cont'd)

- **The LSST database will be a "gold mine" for cosmology.**

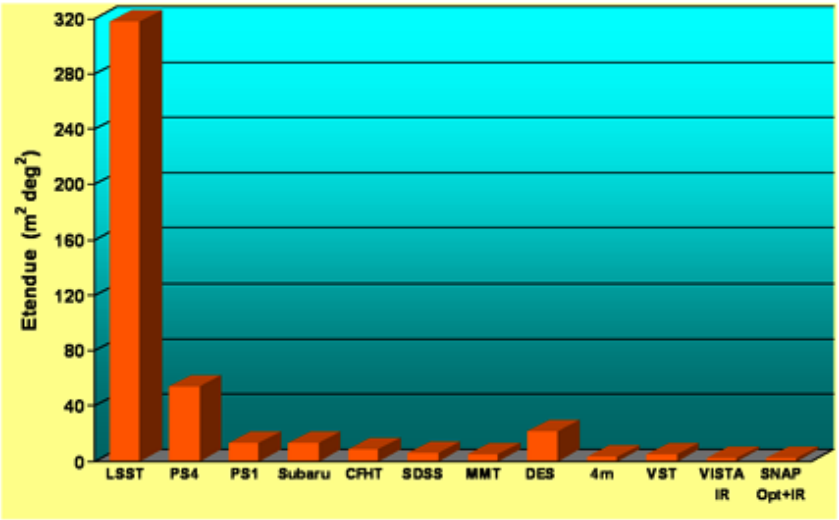
- **Key measurements will include:**
  - **2- and 3-point auto- and cross-correlation measurements of cosmic shear.**
  - **The number density and power spectrum of clusters of galaxies.**
  - **The measurement of baryon acoustic oscillations as a function of redshift.**
  - **The Hubble diagram for a large sample of well-measured Type 1a SNe out to z = 1.2.**
  - **The discovery of a sizable number of gravitationally lensed SNe.**

High Étendue is Key

- **The key figure-of-merit for a survey experiment is the étendue-time product: $A\Omega T$.**

- **This is the equivalent of "integrated luminosity" for an accelerator-based experiment.**

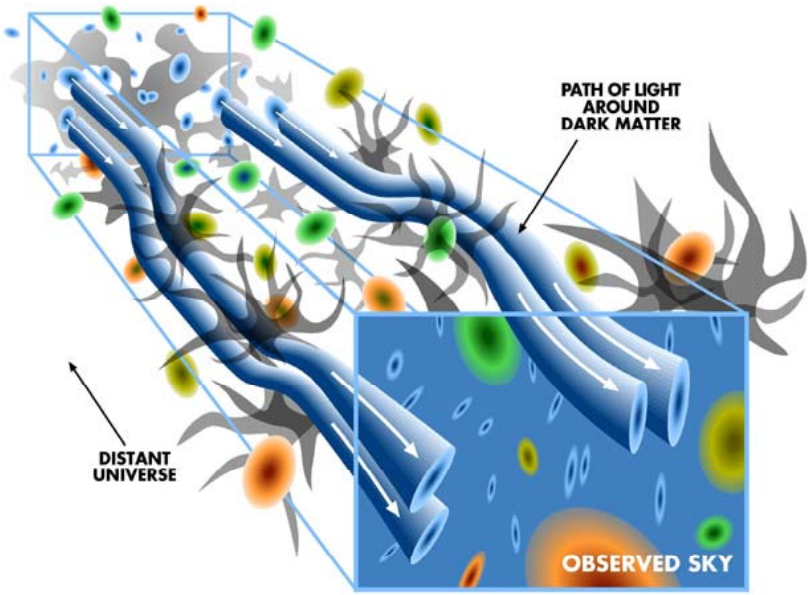
- **LSST will provide a nearly 2 order of magnitude increase in étendue-time over existing surveys, and at least a factor 5 higher étendue than any other proposed survey!**



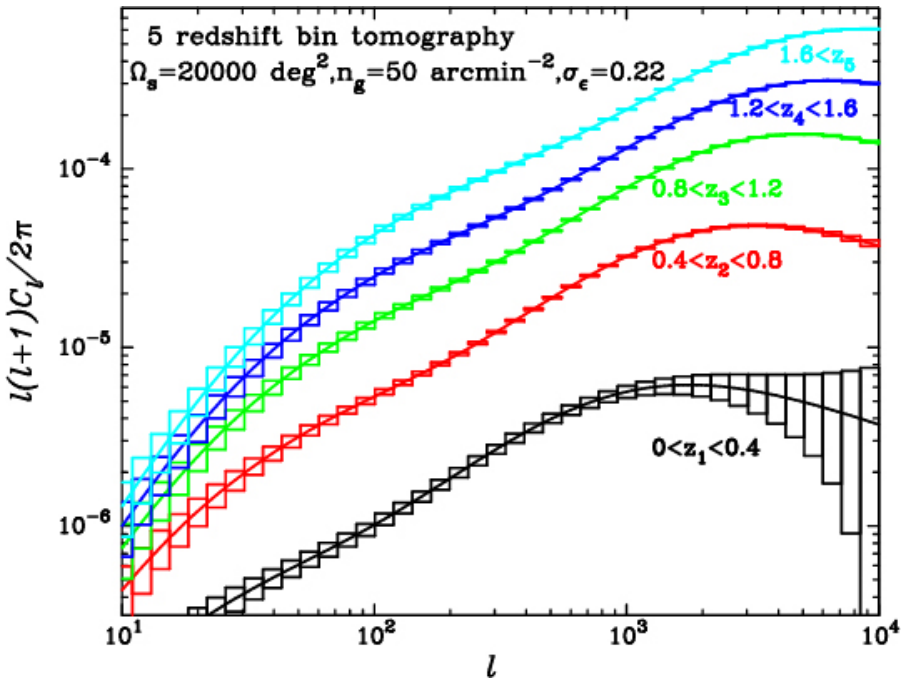
Cosmic Shear

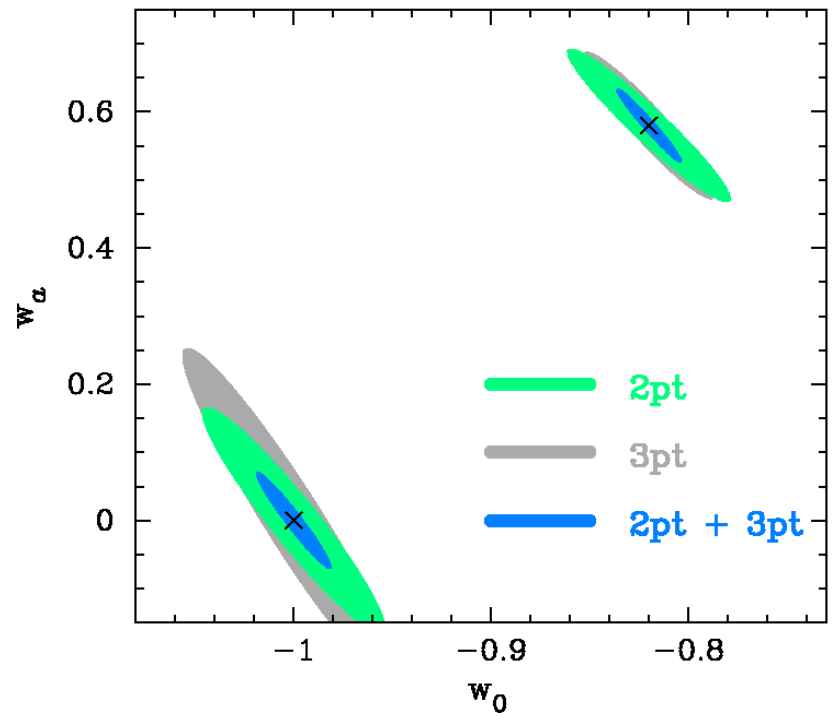
- "Cosmic shear" is the systematic and correlated distortion of the appearance of background galaxies due to weak gravitational lensing by the clustering of dark matter in the intervening universe.

- There are multiple possible probes of cosmic shear - 2- and 3-point autocorrelation functions, and cross-correlations between different redshift bins, with the CMB, and with foreground galaxies.



Cosmic Shear





Cosmic Shear - Dealing with Systematics

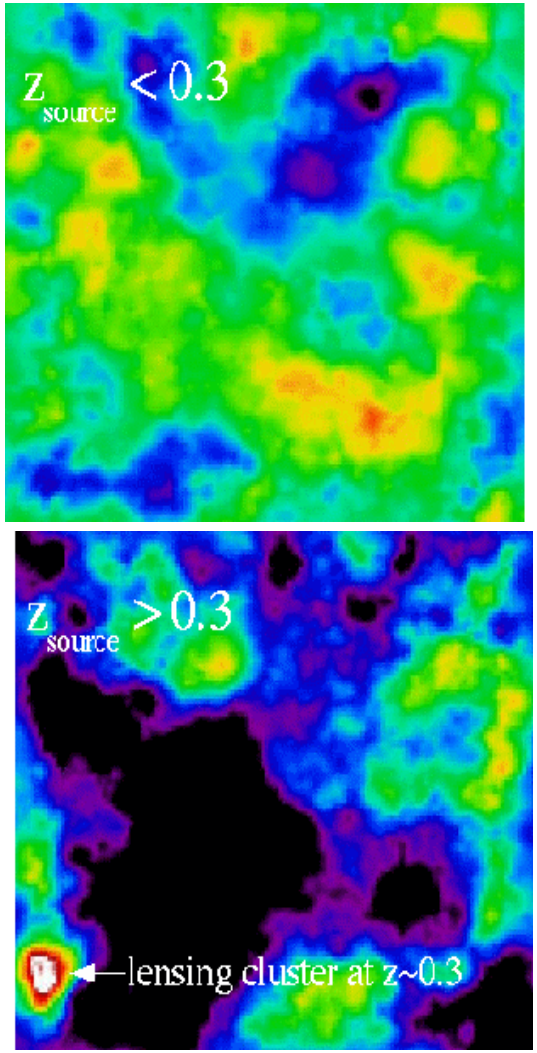
- The cosmic shear signal on larger angular scales is at a very low level.
- To make this measurement, we must be confident that we understand and can remove spurious sources of shear.
- Significant attention is being given to the control of the PSF of the system during the design stages.
- However, of crucial importance is that LSST will take ~ 400 exposures (r band) of each region of sky. By correlating the shear of galaxies in different exposures, we can eliminate the potential effects of the atmosphere and the optics in our analysis.
- The ability to do this is a direct result of the fast readout speed of the camera - a feature unique to LSST!

Clusters of Galaxies

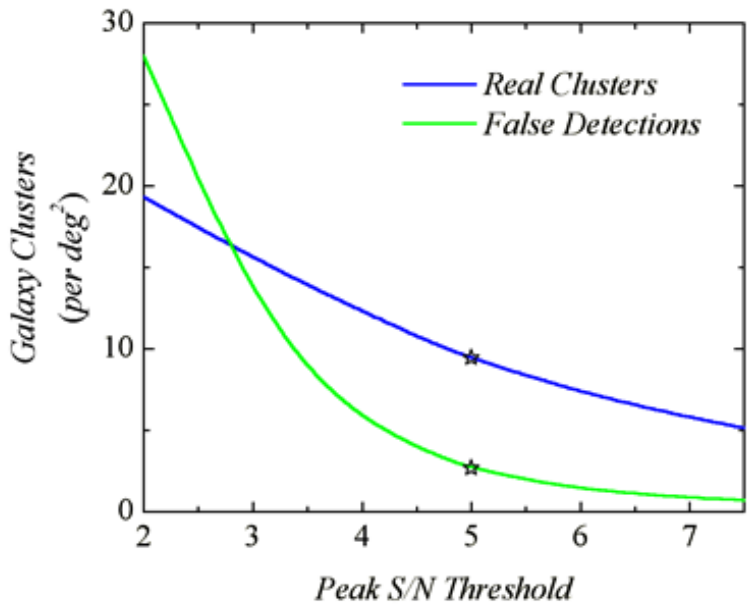
- Clusters of galaxies are the most massive bound structures in the Universe, and both their number density and spatial power spectrum are sensitive to the growth of structure.

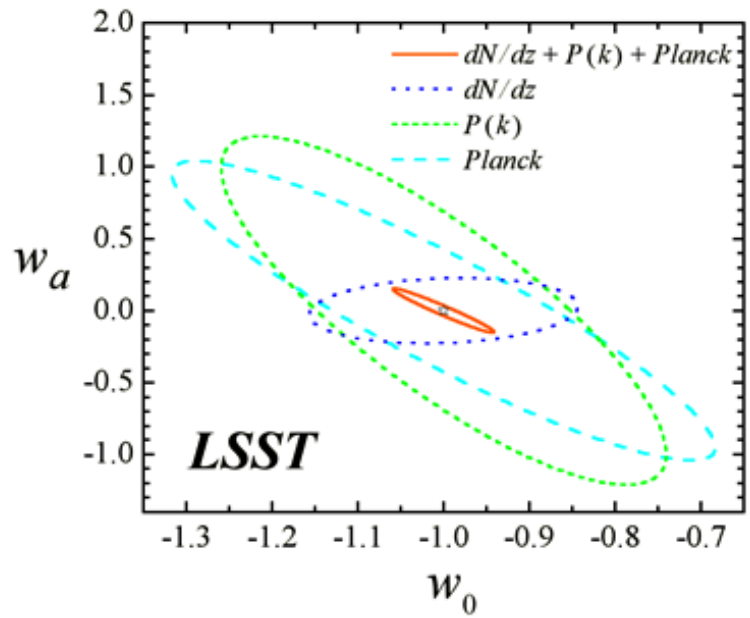
- LSST will detect clusters via weak gravitational lensing and measure their redshifts from the galaxy colors. ~ 200,000 clusters will be discovered.

- Weak lensing probes the dark matter directly. Baryonic tracers can be biased and must be calibrated.



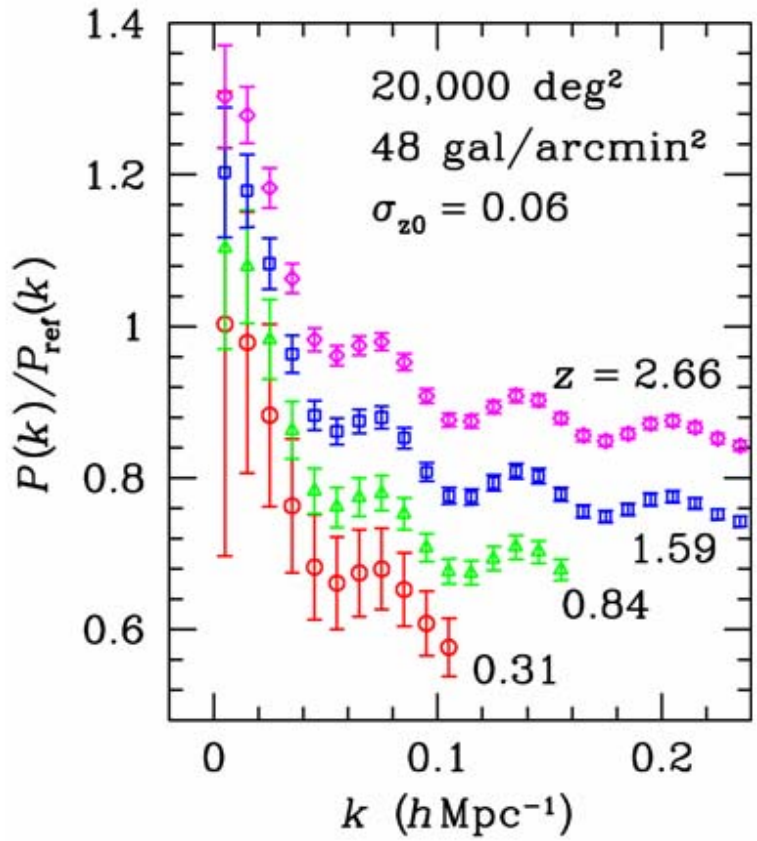
Clusters of Galaxies





Baryon Acoustic Oscillations

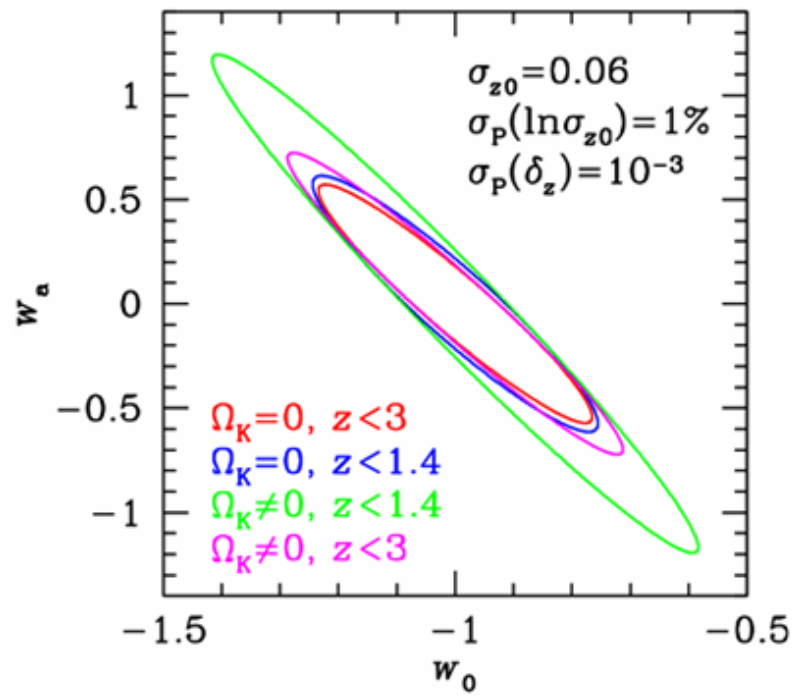
- Prior to recombination, acoustic waves, supported by photon pressure, create a characteristic scale in the Universe, called the "sound horizon".
- After recombination, this scale becomes frozen in the matter distribution. It provides a "standard ruler", giving an angular diameter distance as a function of redshift.
- LSST can measure this effect in the galaxy-galaxy power spectrum.



Baryon Acoustic Oscillations

- The "new" feature introduced by measurement of the BAO's is the ability to constrain the expansion history at higher redshift, before DE became dominant.

- This is important for breaking the degeneracy between non-zero curvature and alternate forms of dark energy. Allowing Ω_K to depart from zero, weakens constraints on w and w_a.

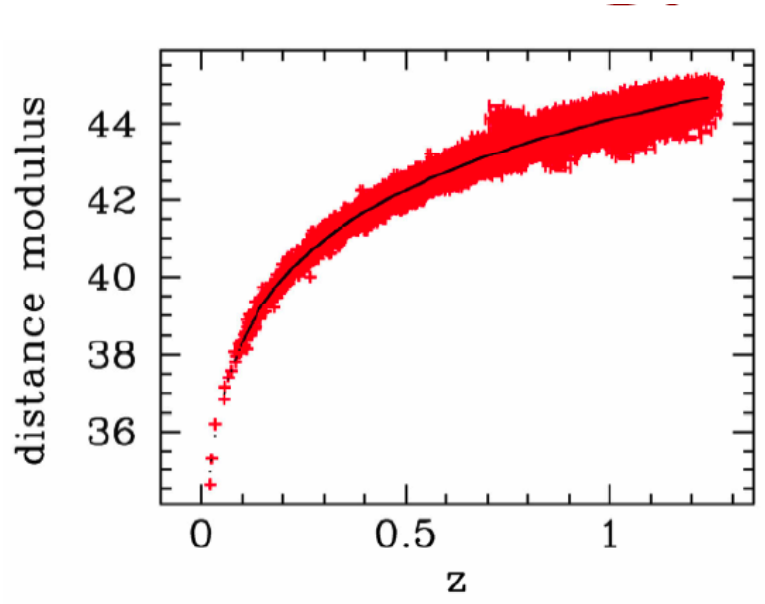


Type 1a Supernovae

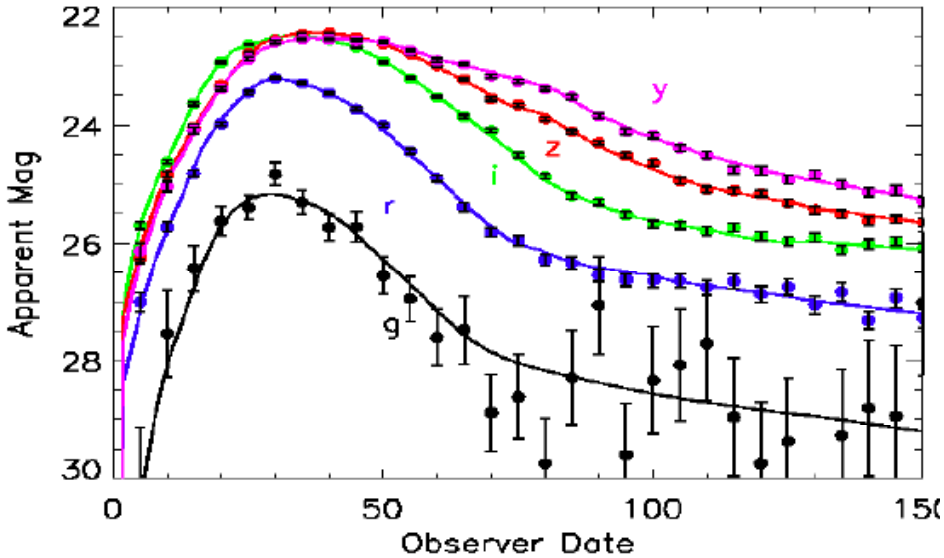
- LSST will discover a very, very large number of Type 1a SNe, in both its normal survey mode (~ 280,000 yr^{-1}), and in a "deep" survey mode (~ 30,000 yr^{-1}).

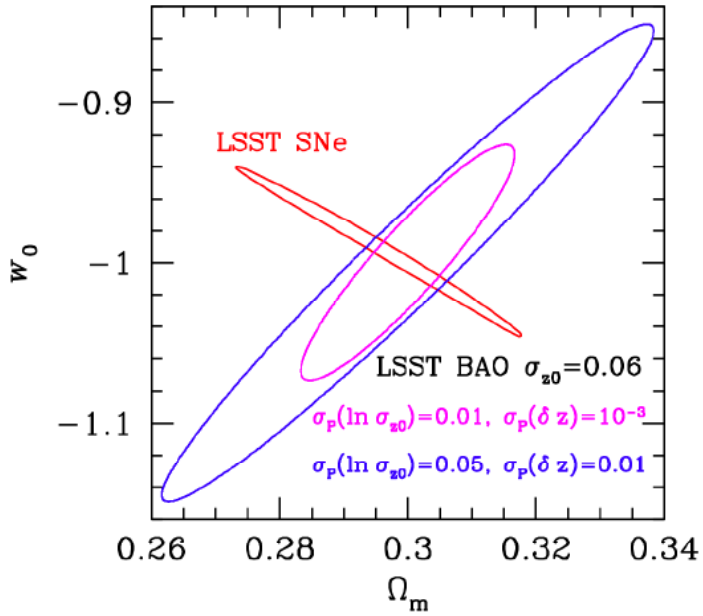
- These can be used to study possible systematics, as well as to constrain cosmological parameters.

- The SNe discovered in the deep mode, will have well-sampled, multi-color light curves - sufficient for deriving redshifts directly from the photometric data.



Type 1a Supernovae





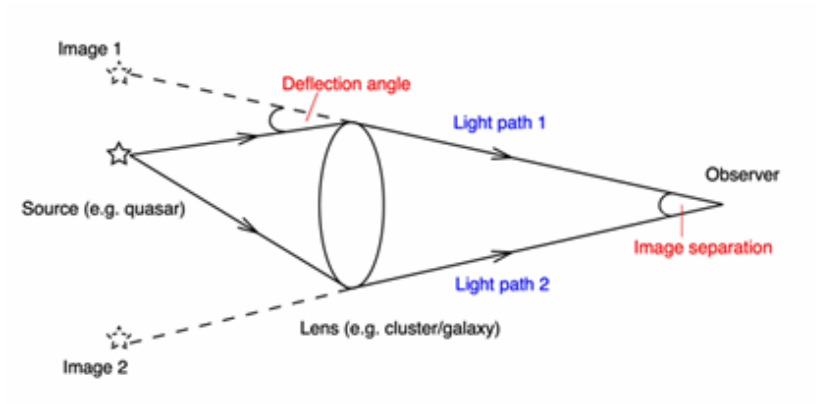
Gravitationally Lensed Supernovae

- Background objects can be multiply imaged - a phenomenon called strong gravitational lensing.

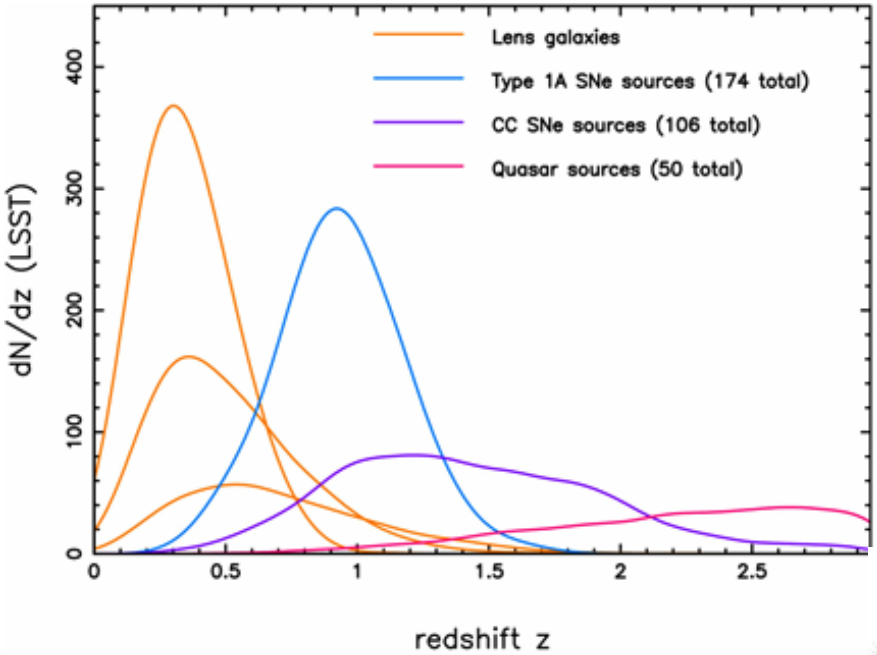
- ~ 1 in 1000 high redshift sources should exhibit multiple images. To date, these are relatively rare. But LSST will find huge numbers given it very large étendue.

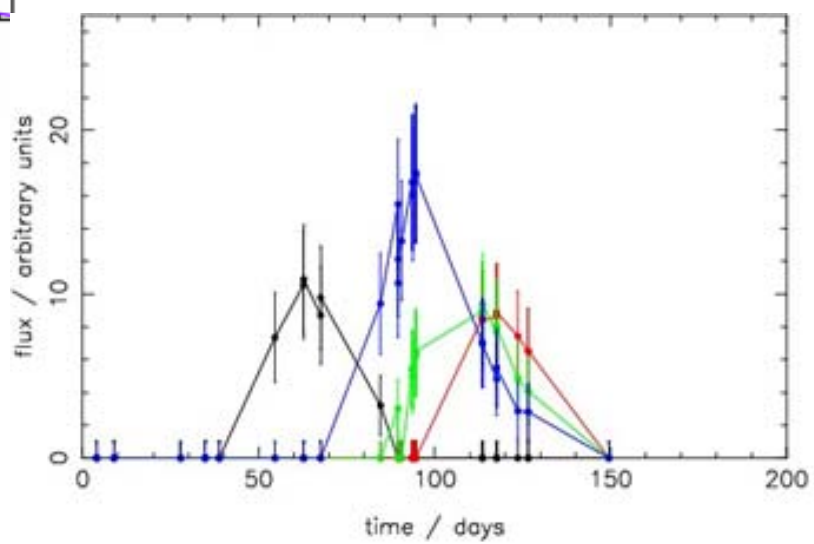
- Time variable sources yield time delays between the images, which carry a wealth of information about geometry and about the distribution of dark matter in the lens galaxy.

- LSST will be the first survey to detect gravitationally lensed SNe.



Gravitationally Lensed Supernovae





Summary

- **The LSST database provides a wealth of information - via multiple probes - for constraining dark energy and dark matter.**

- **High étendue-time is key. For most of these diagnostics, the error contours scale like SQRT($A\Omega T$). No other planned or proposed survey is close to LSST in this parameter.**

- **This field is still in its infancy. It is quite likely that innovative new analyses will be discovered prior to construction or during operations.**