The Large Synoptic Survey Telescope

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LSST
Large Synoptic Survey Telescope

P5 Comments and Recommendations:

- Dark energy challenges our understanding of fundamental physics.

- These two projects, the Large Synoptic Survey Telescope (LSST) and the SuperNova Aceleration Probe (SNAP) are proposed as collaborative inter-agency projects. In the case of LSST, NSF has been the lead agency with DOE providing substantial resources as the partner agency.

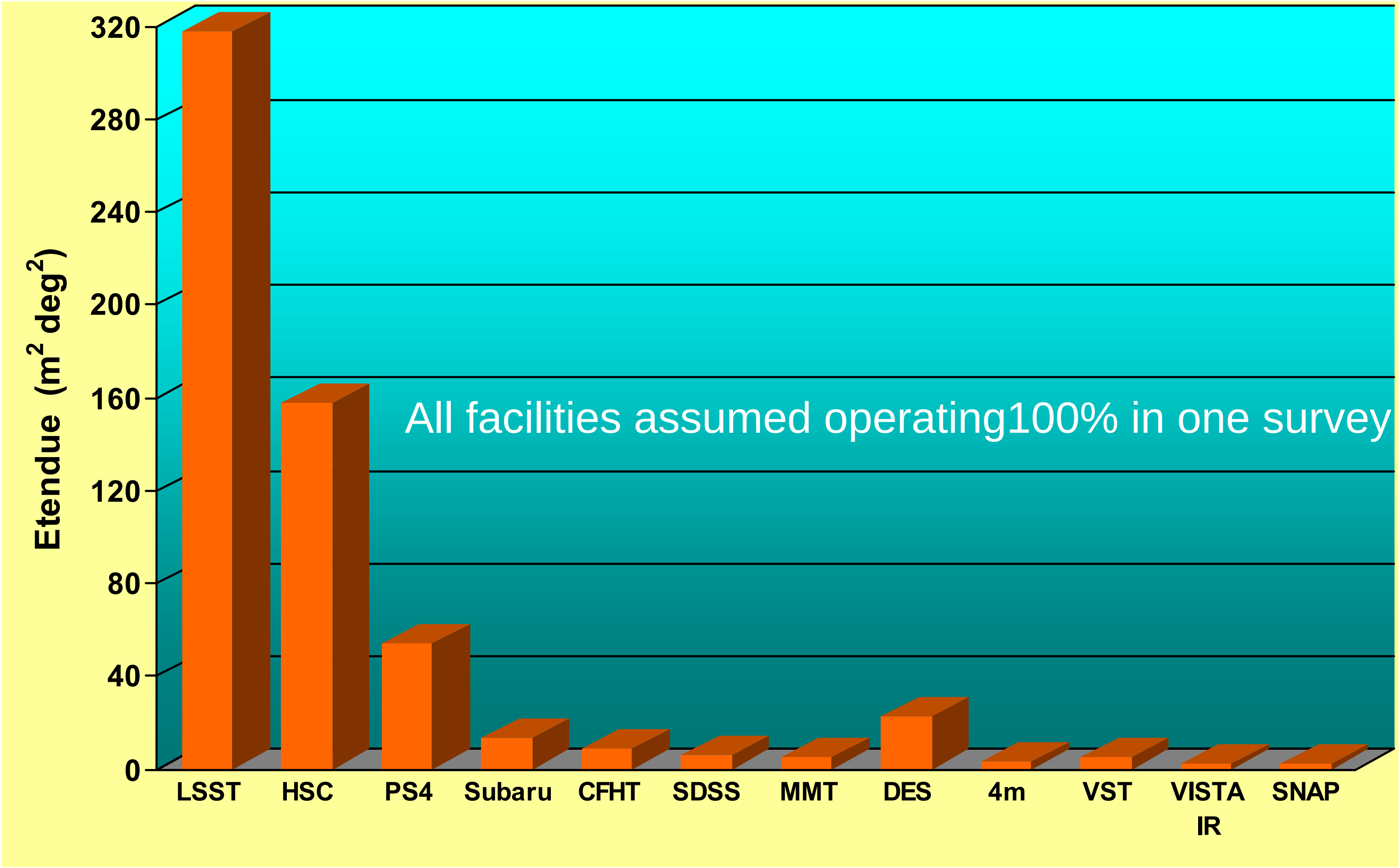
- These experiments are ready for the next stage of design and review, which would be the “Preliminary Design Review Stage” in the case of NSF and LSST, “CD2 Stage” for the DOE parts of LSST, …

- The particle physics community has been particularly active in developing candidates for each of these Stage IV dark energy projects, which benefit from innovative work on detectors and data acquisition techniques developed in particle physics.

Etendue (~*luminosity*) is a fundamental metric of survey capability

Large Synoptic Survey Telescope

Information/time ~ rate of sky coverage ~ Etendue



Single survey – multiple science

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).

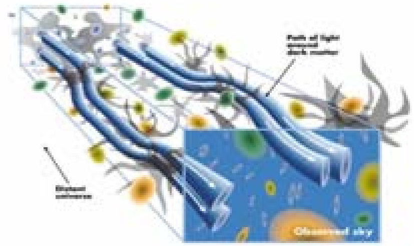
- Another powerful approach involves measuring the growth of structure as a function of redshift. Stars, galaxies, clusters of galaxies grow by gravitational instability as the universe cools. This provides a kind of cosmic “clock” - the redshift at which structures of a given mass start to form is very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

Probes of Dark Energy

Large Synoptic Survey Telescope

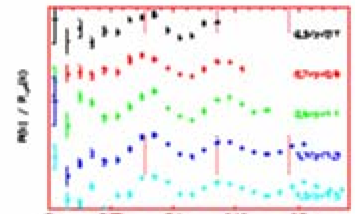
Cosmic Shear
WL

Evolution of dark matter perturbations
Angular diameter distance
Growth rate of structure



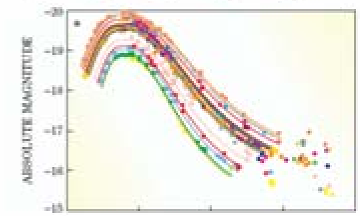
Baryon Wiggles
BAO

Standard ruler
Angular diameter distance



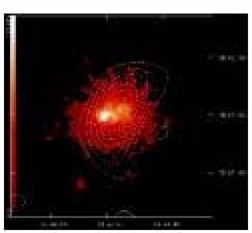
Supernovae

Standard candle
Luminosity distance



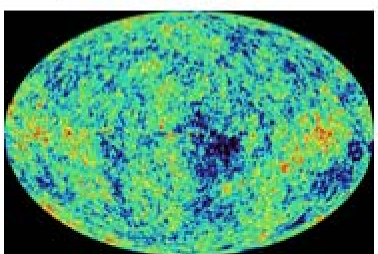
Cluster counts

Evolution of dark matter perturbations
Angular diameter distance
Growth rate of structure



CMB

Snapshot at ~400,000 yr, viewed from z=0
Angular diameter distance to z~1000

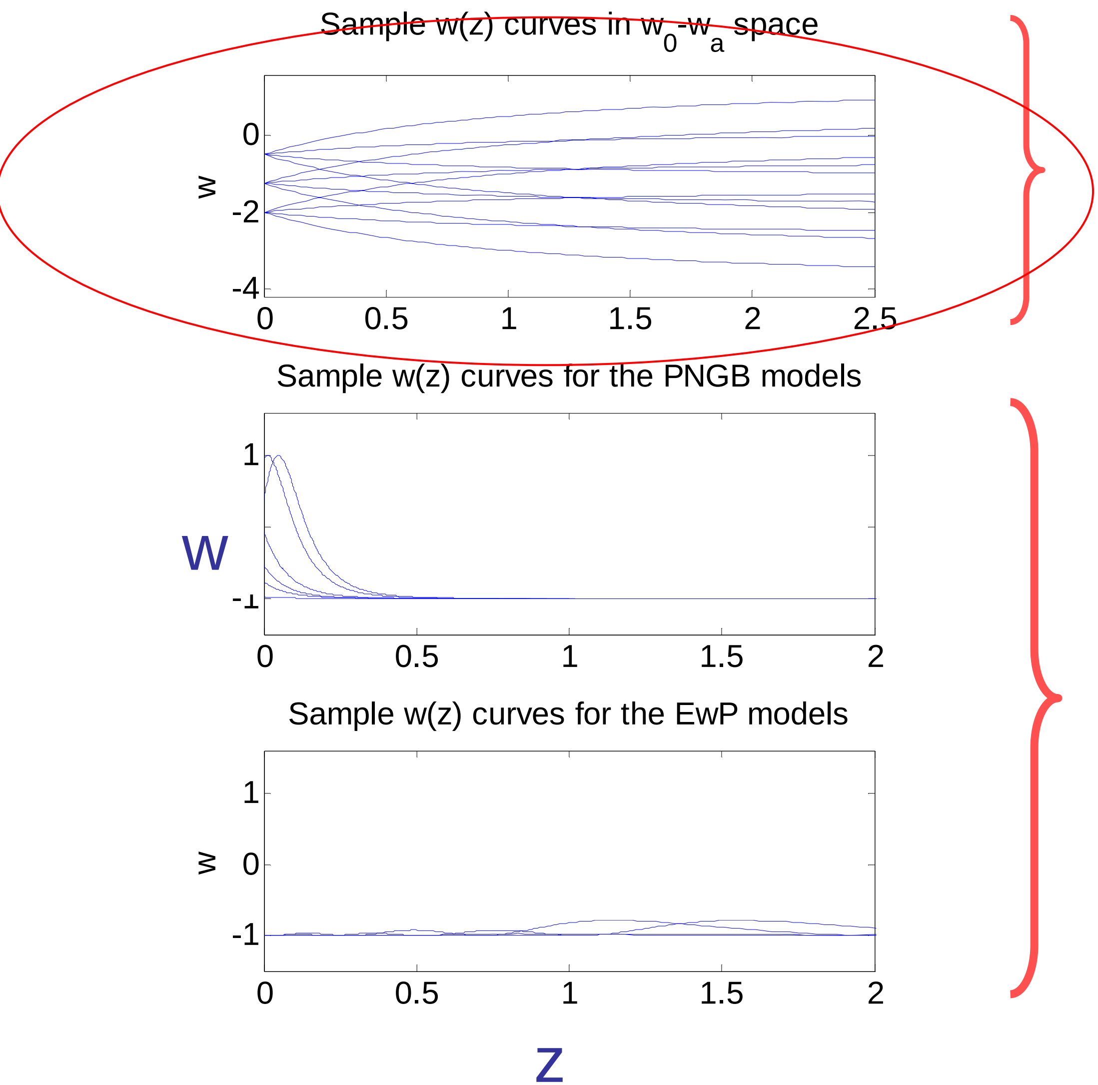


LSST Probes Dark Sector in Multiple Ways

- **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**
- **Multiply lensed SNe**
- **Shortest scales of dark matter clumping tests models of dark matter particle physics**

The LSST survey will address all with a single dataset!
This is the same dataset which produces all LSST science.
i.e. LSST probes dark energy & dark matter all the time.

How good is the DETF w(a) ansatz?

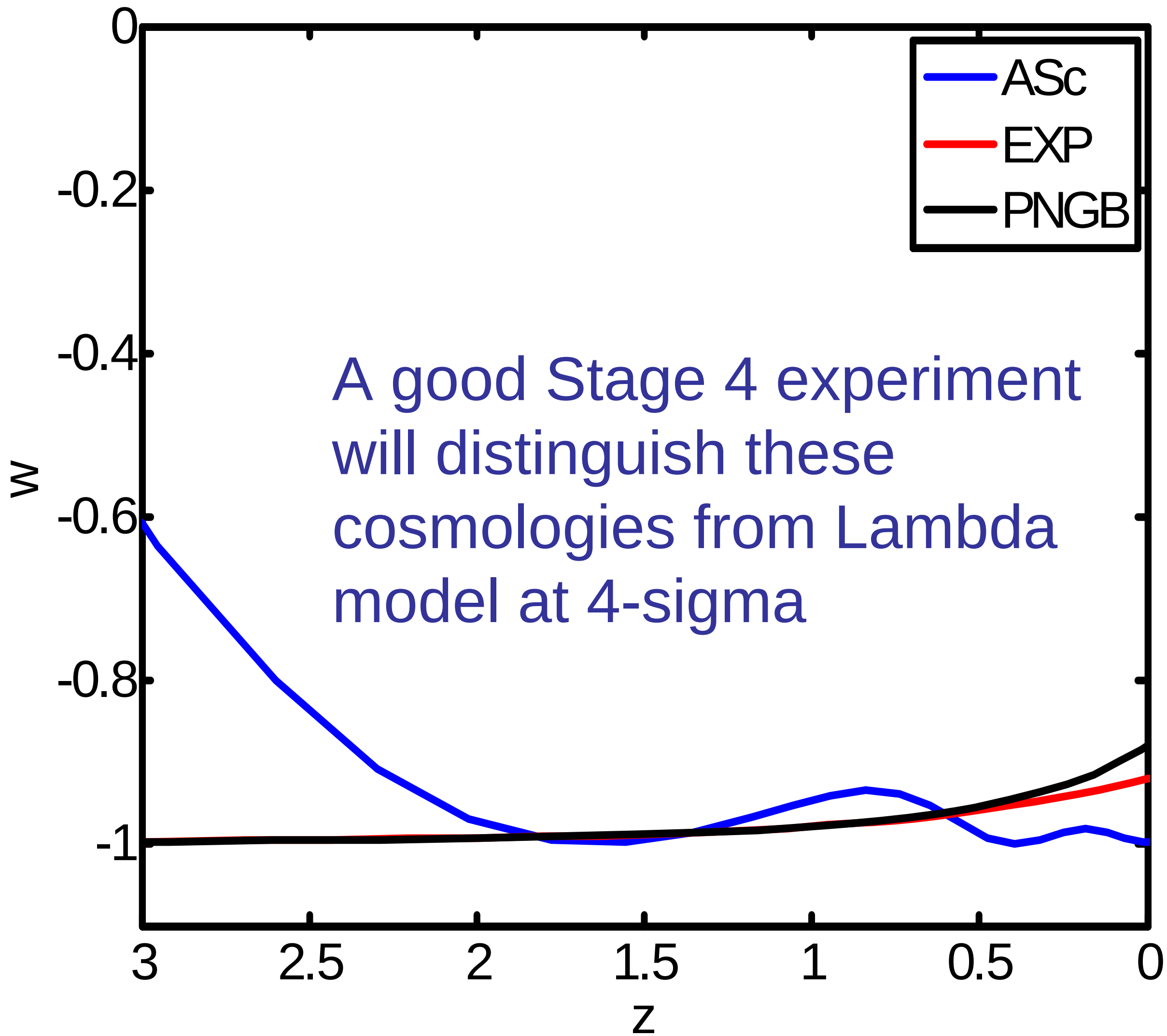


$$w(a) = w_0 + w_a(1 - a)$$

w0-wa can only do these

DE models can do this (and much more)

New physics: departure from w=-1 model



Albrecht 2007

Beyond DETF

Upshot of 9D Figure of Merit:

1) DETF underestimates impact of expts

2) DETF underestimates relative value of Stage 4 vs Stage 3 by 100x

Inverts cost/FoM Estimates S3 vs S4

Albrecht & Bernstein 2007

LSST and Cosmic Shear

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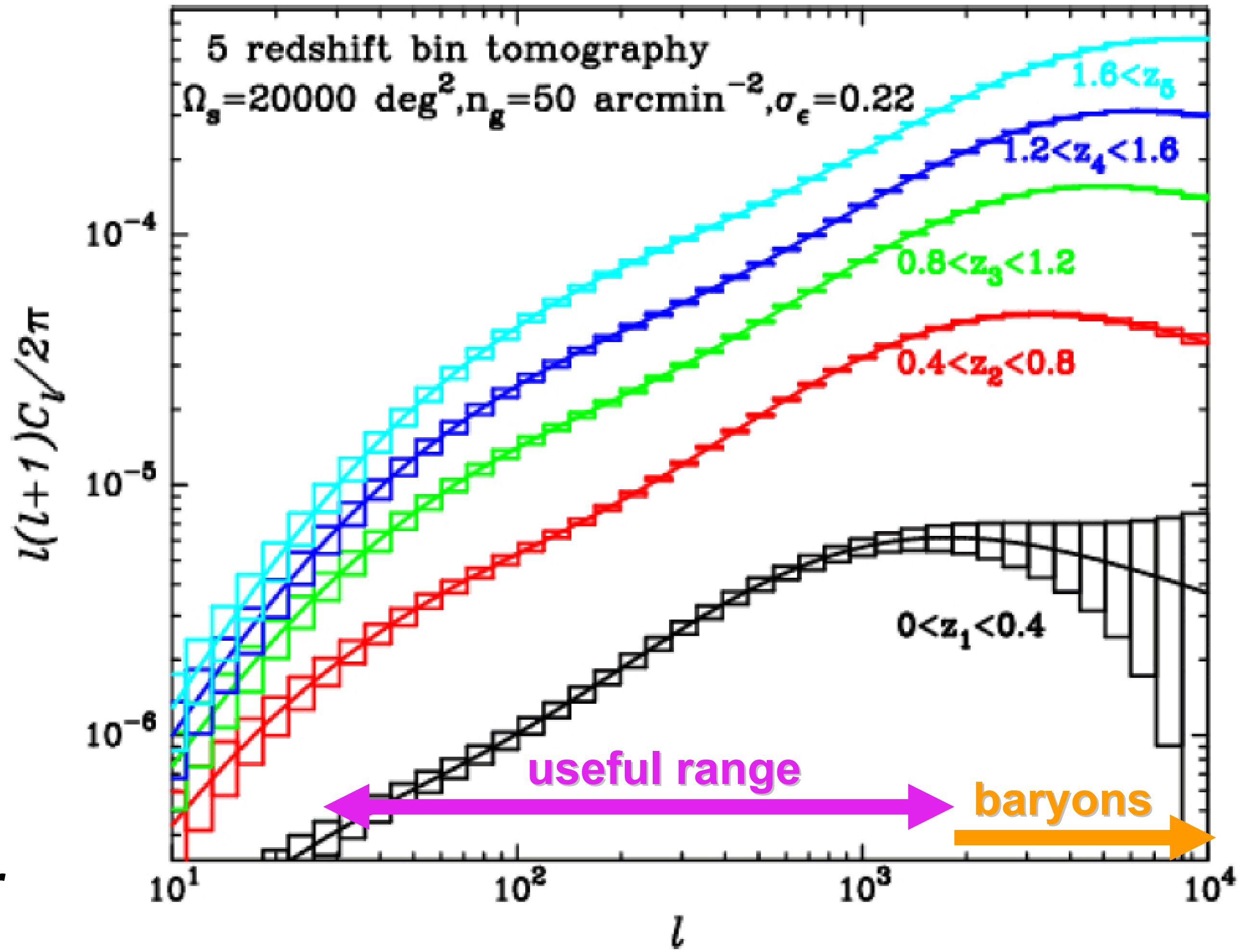
Ten redshift bins yield 55 auto and cross spectra



+ higher order

LSST Baryon Acoustic Oscillations

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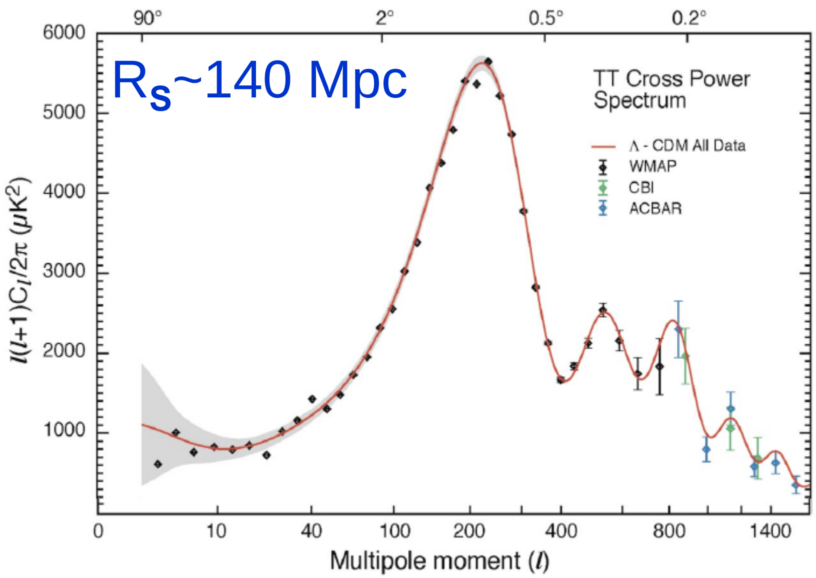
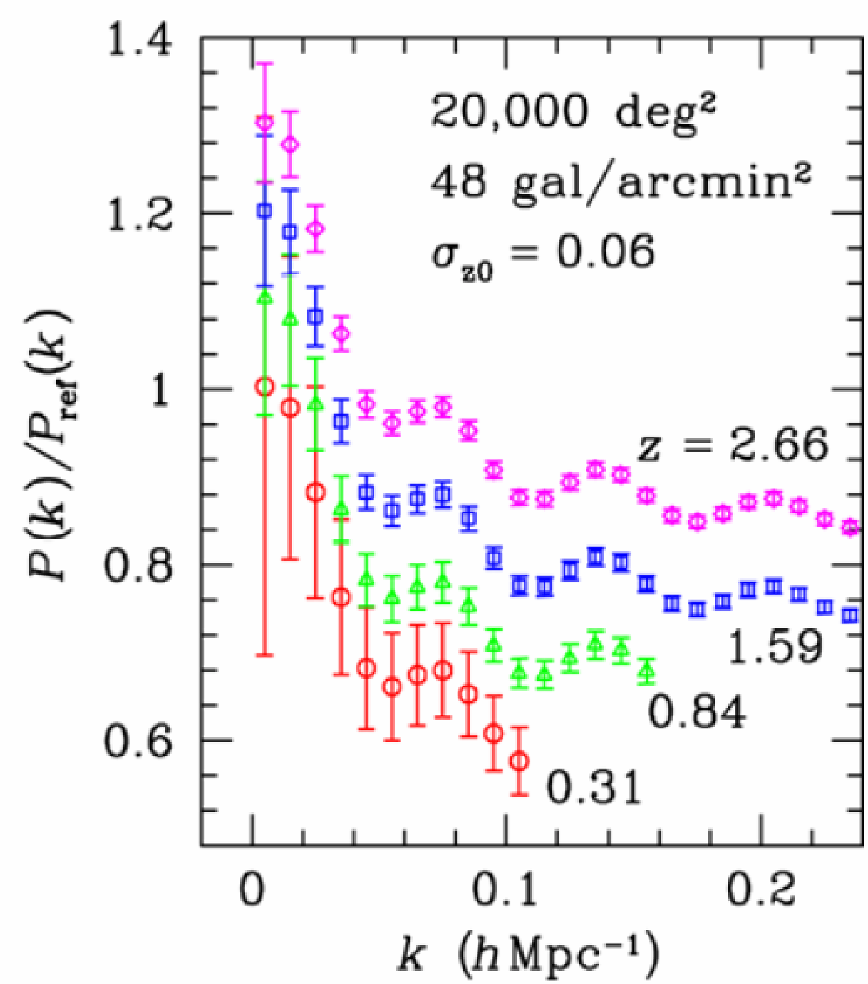
CMB (z = 1080)



BAO (z < 3)



Standard Ruler

Two Dimensions on the Sky vs z

Angular Diameter Distances

Cosmic Shear - Dealing with Systematics

Large Synoptic Survey Telescope

- 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 are 3 stars 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 cosmic weak lensing distortions. By interpolating the PSF's, we 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.

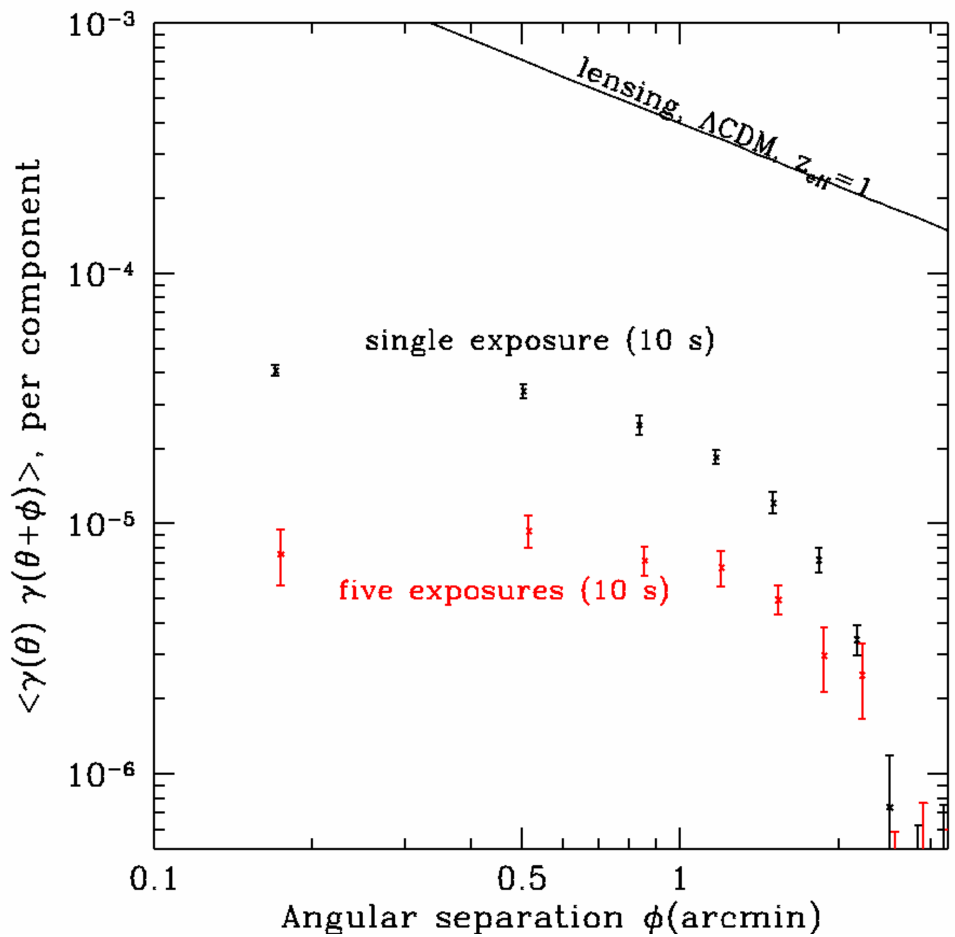
Residual Shear Correlation

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

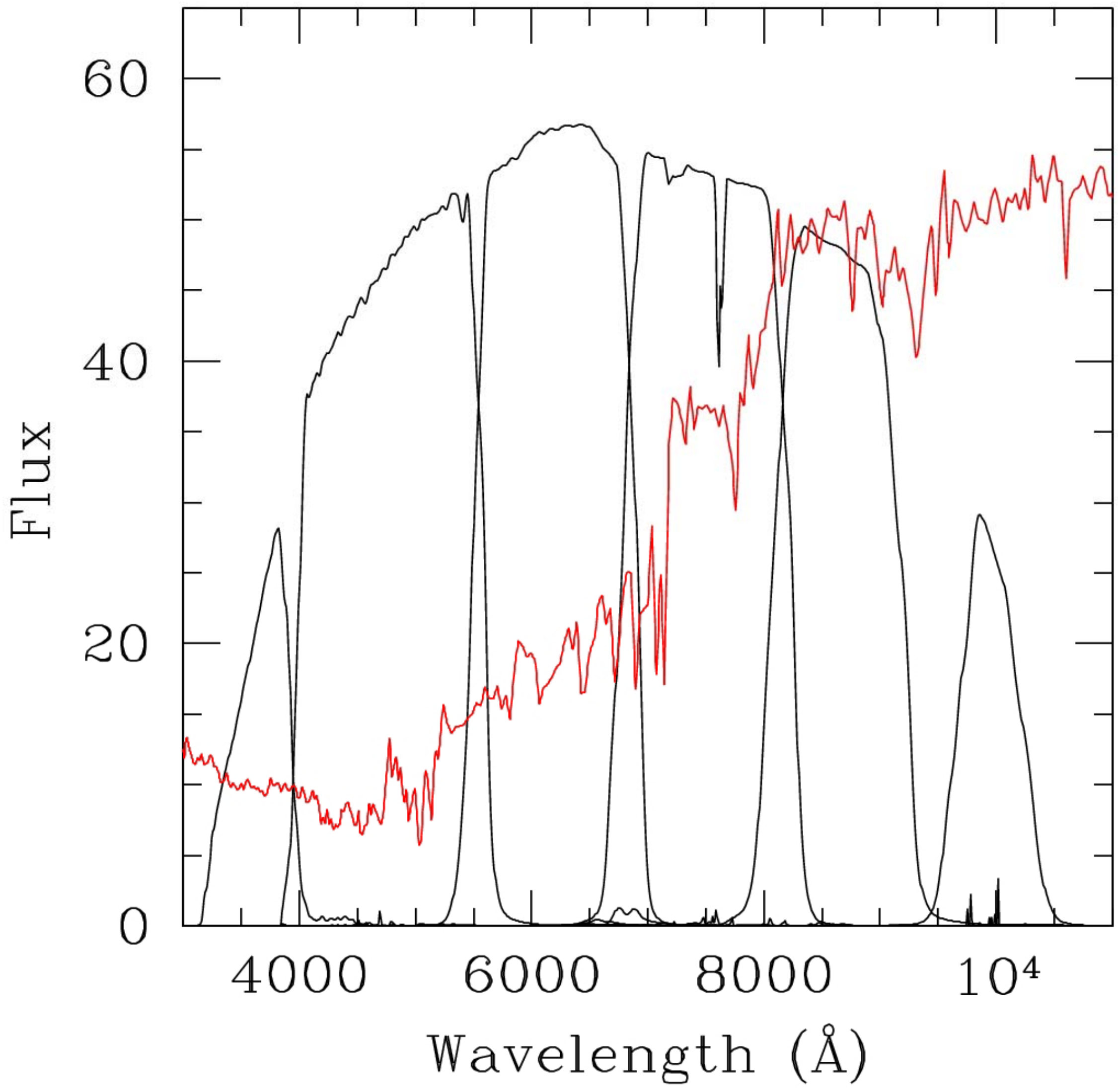
Compare with expected cosmic shear signal.

Conclusion: 300 exposures per sky patch will yield negligible PSF induced shear systematics.

Wittman 2005

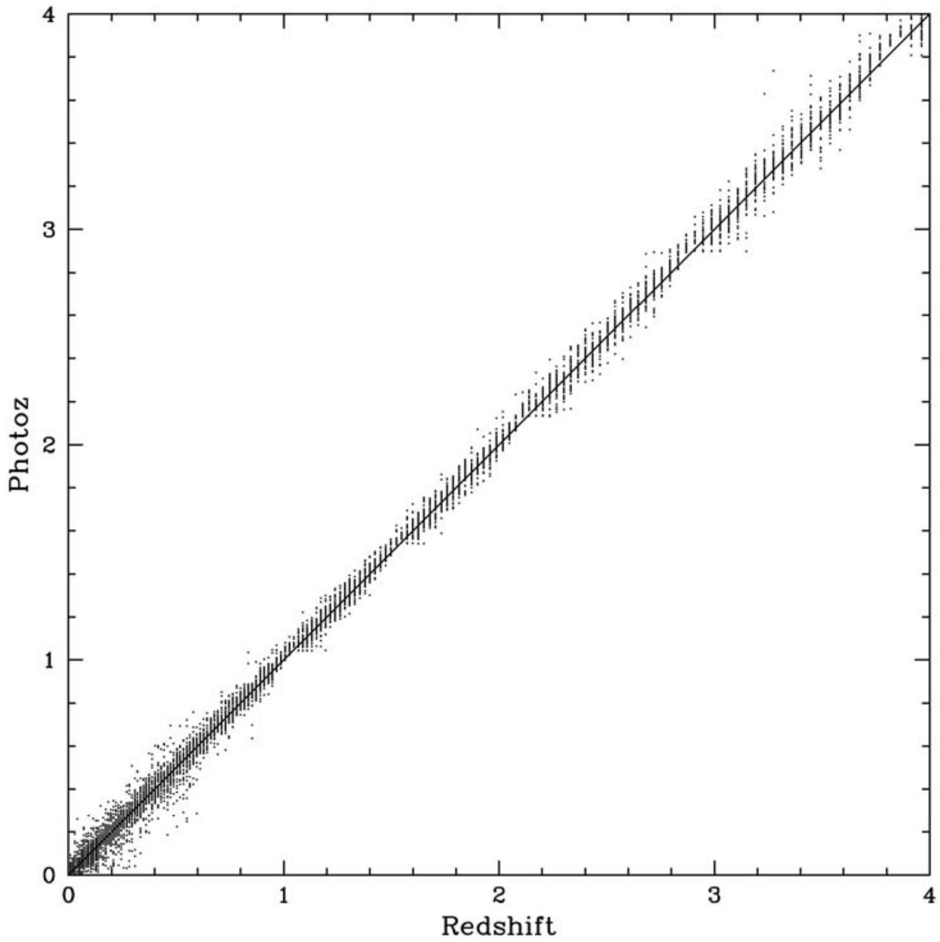


6-band Photometric Redshifts



Controlling photo-z systematics

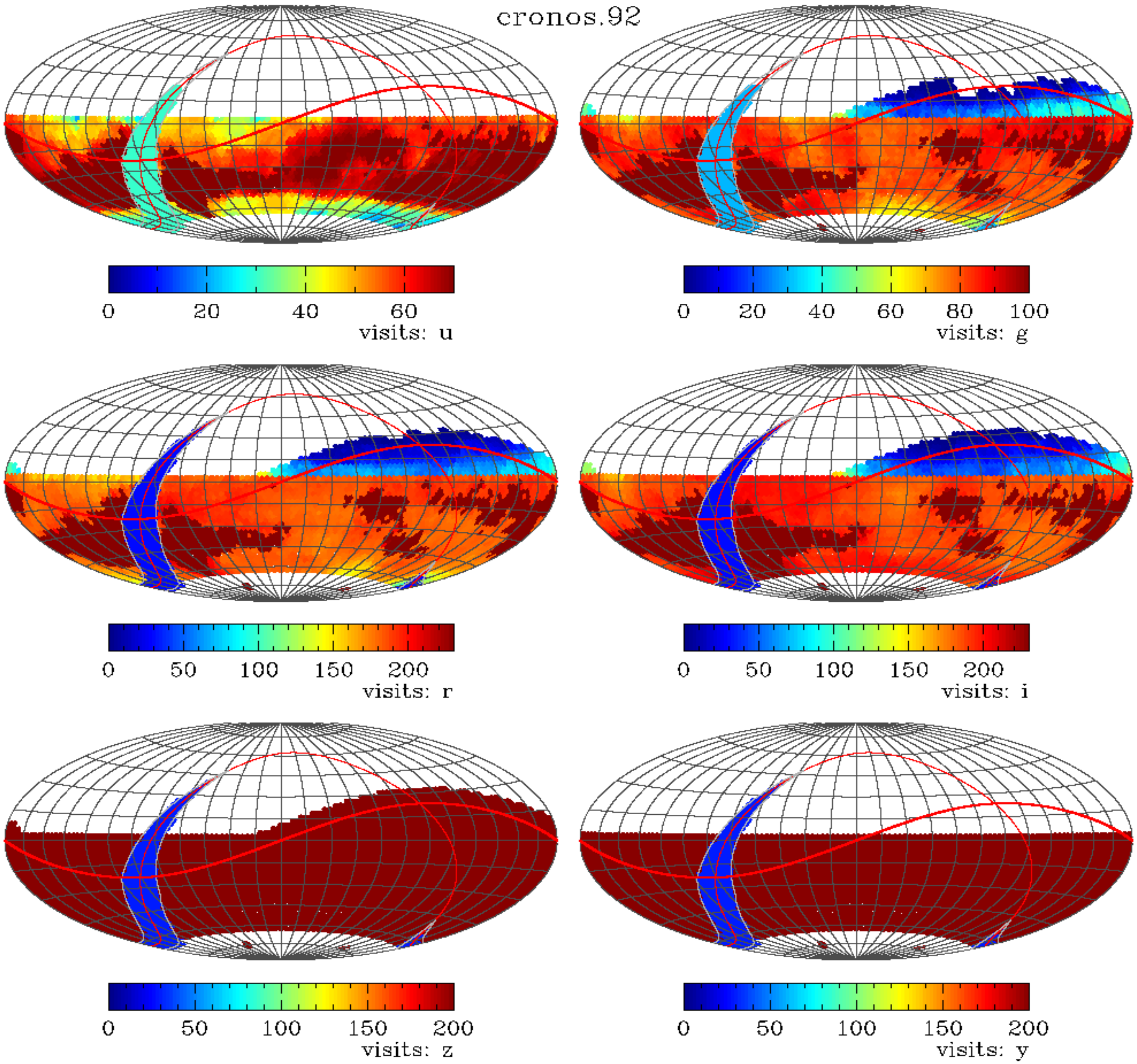
Not a feasibility issue.   Must quantify errors.



Training:
Using angular correlations a 10-band training set enables LSST photo-z error calibration to better than required precision

Calibration:
Systematic error:
0.003(1+z) *calibratable using clustering properties of galaxies.*
Need 20,000 spectroscopic redshifts overall.

Visits per field for the 10 year simulated survey



LSST Precision on Dark Energy [in DETF language]

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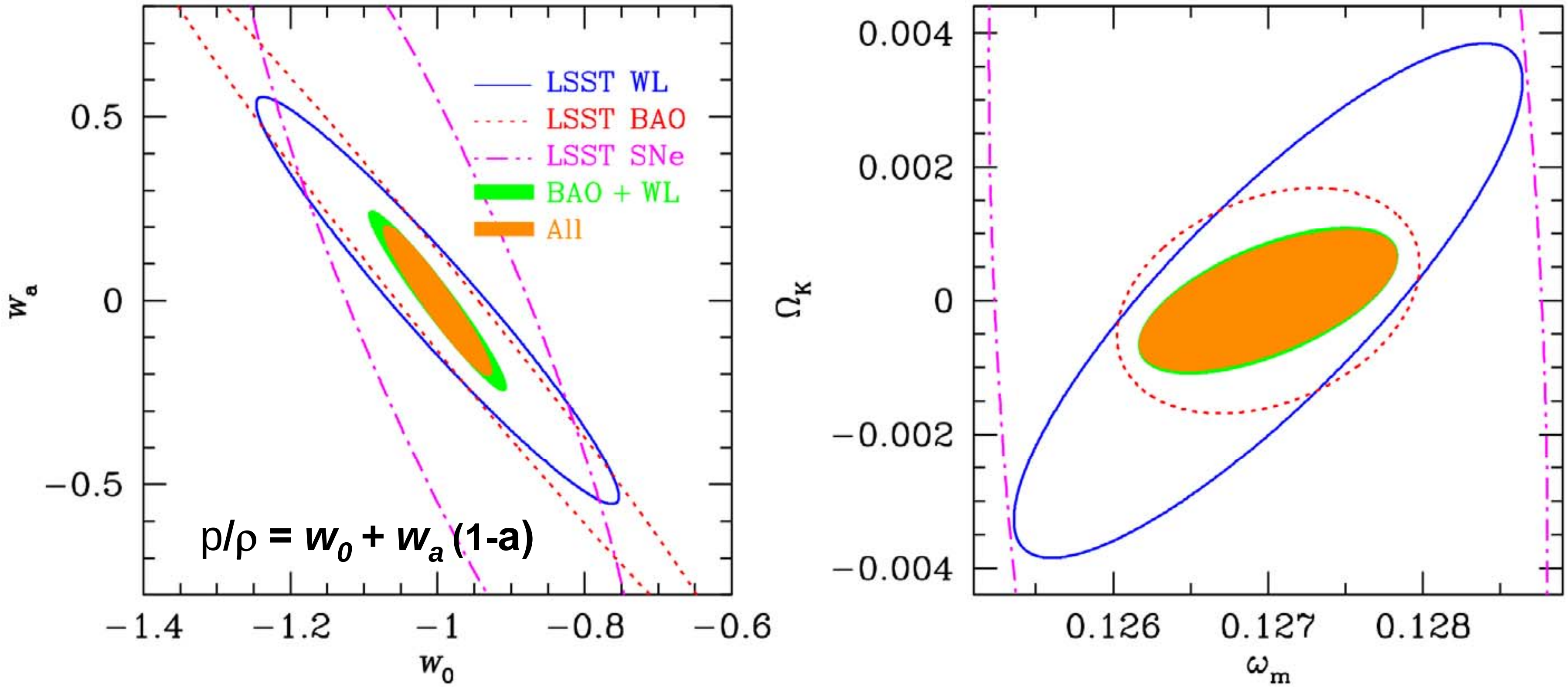
Zhan 2006

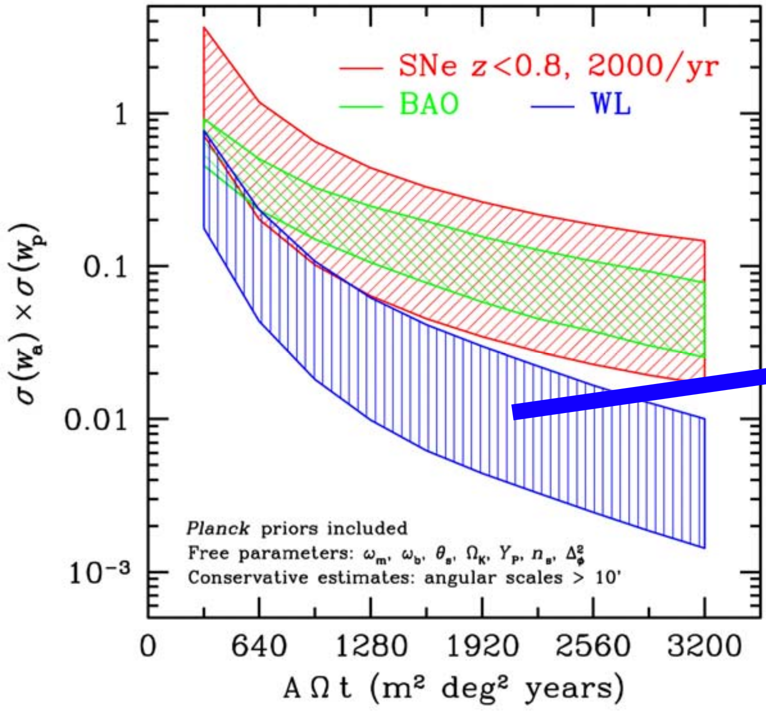


Combining techniques breaks degeneracies.

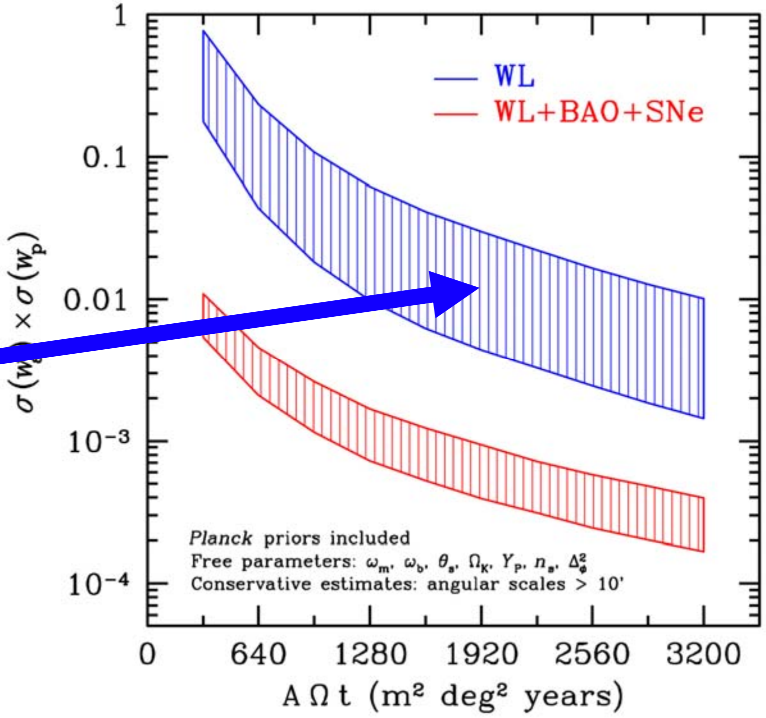
Requires wide sky area deep survey.

Precision vs integrated luminosity

Separate probes

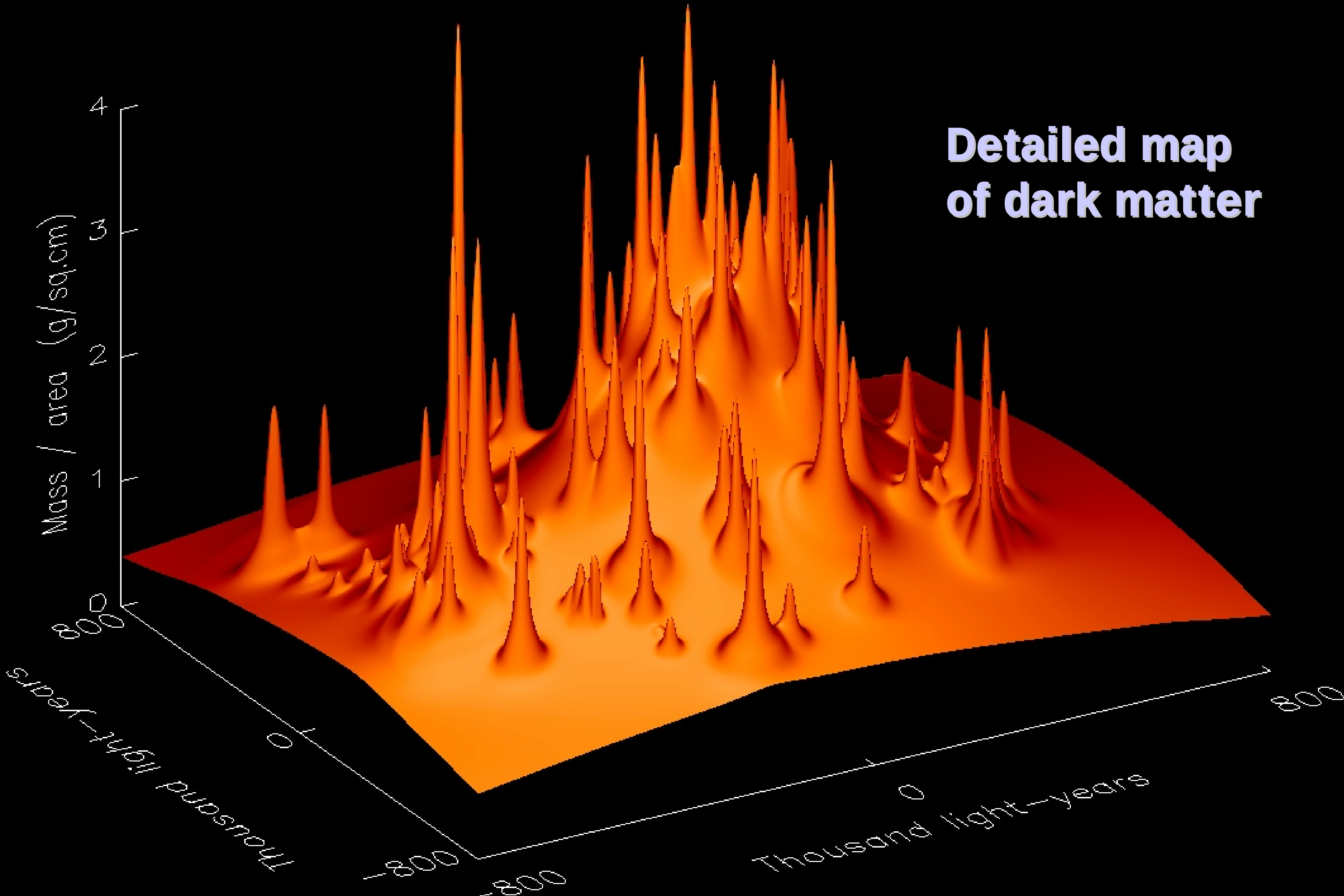


Combined probes

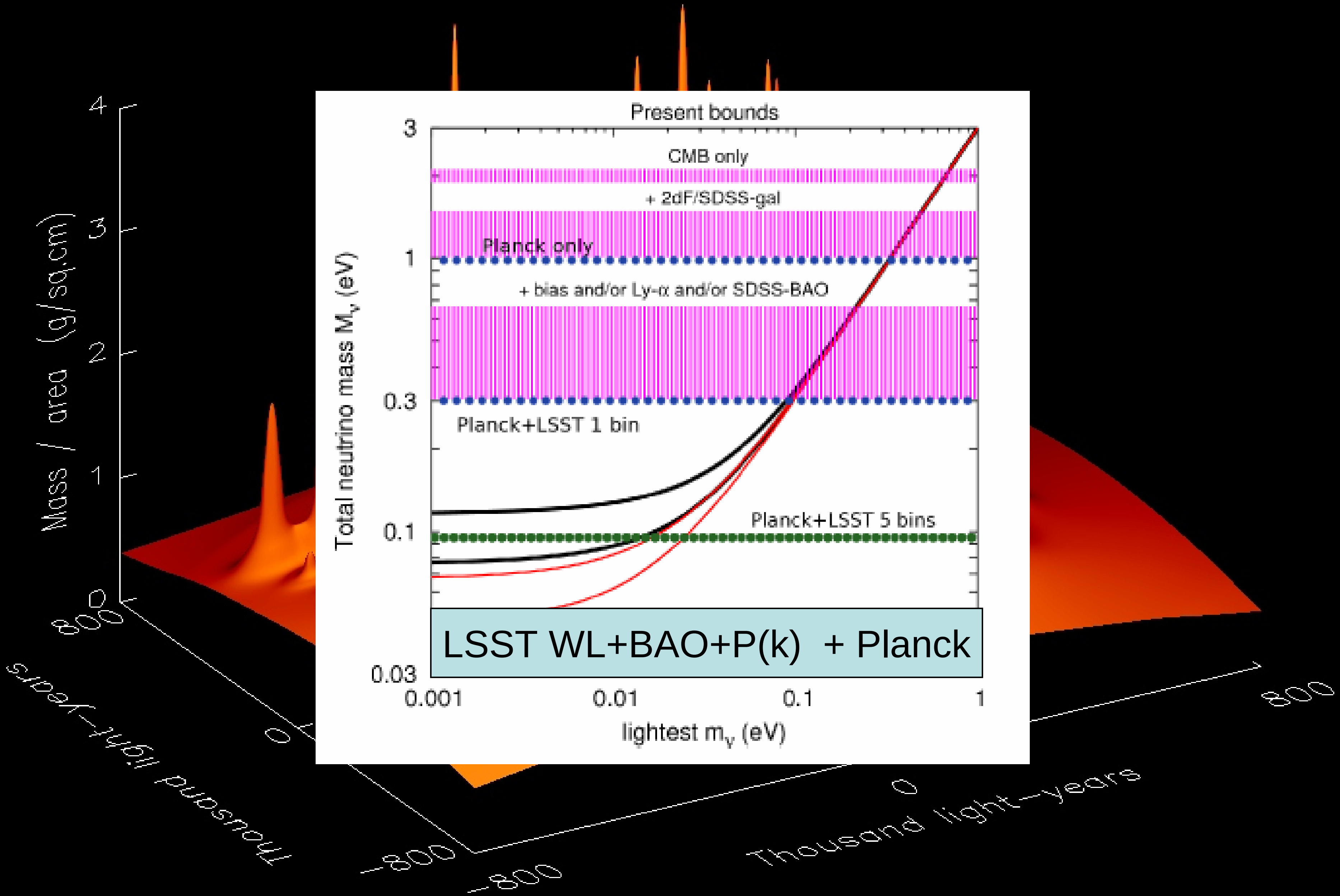


Combining probes removes degeneracies.

Detailed map of dark matter

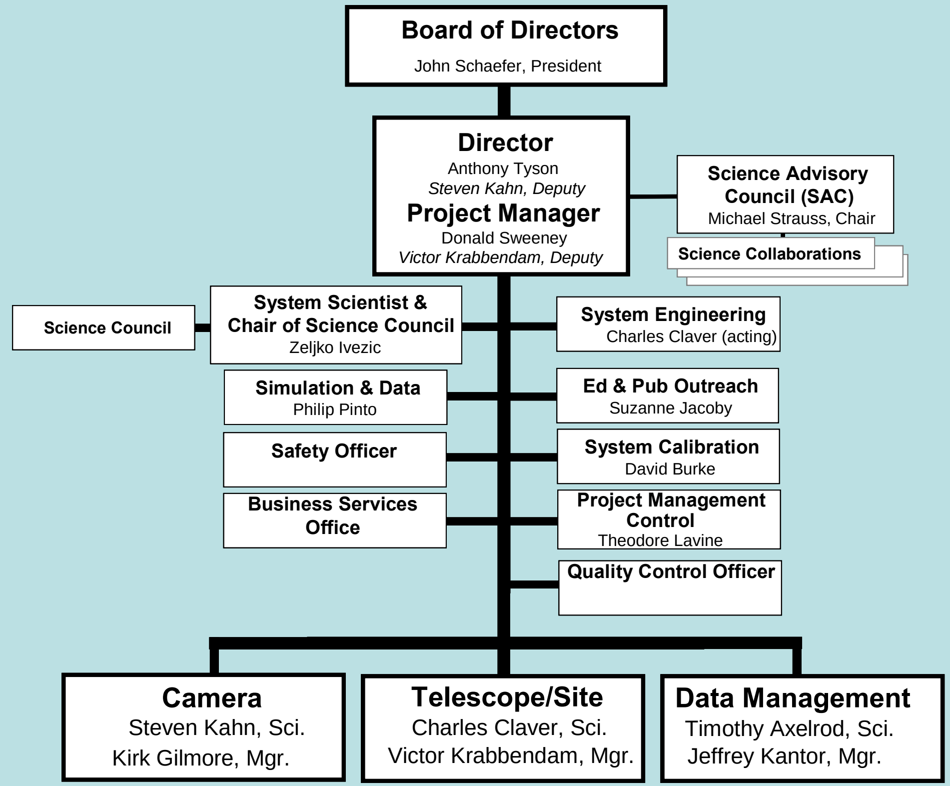


LSST will measure total neutrino mass



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

Involvement of University-Based US 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)

The LSST optical design: three large mirrors

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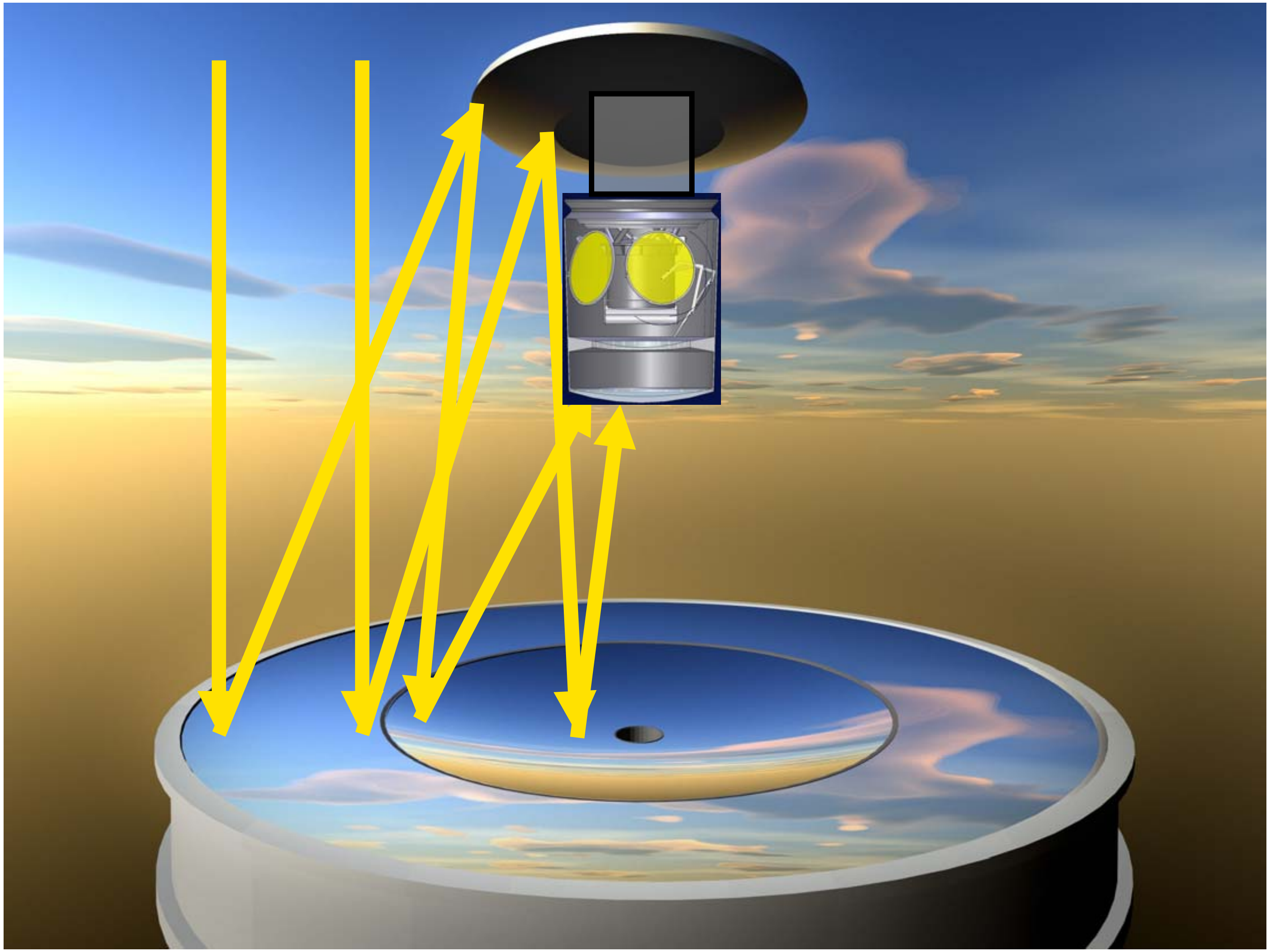
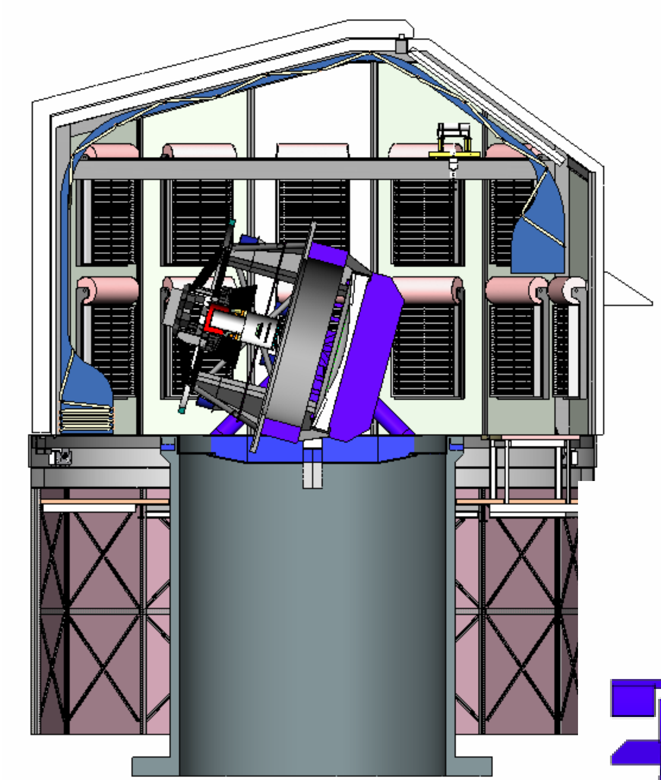


The LSST will be on El Penon peak in Northern Chile in an NSF compound

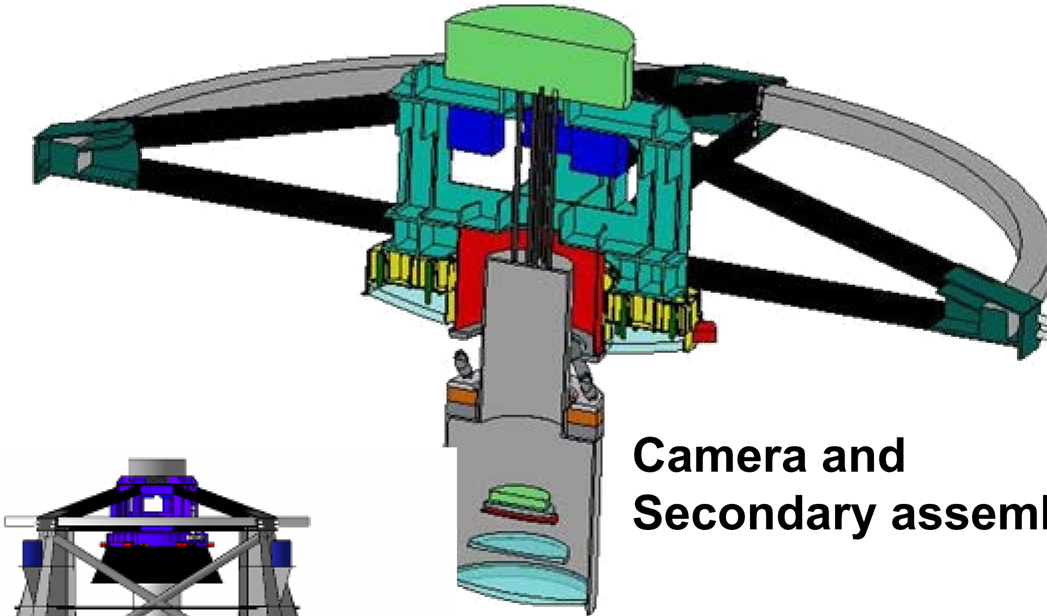
1.5m photometric calibration telescope

The Telescope, Mount, and Dome

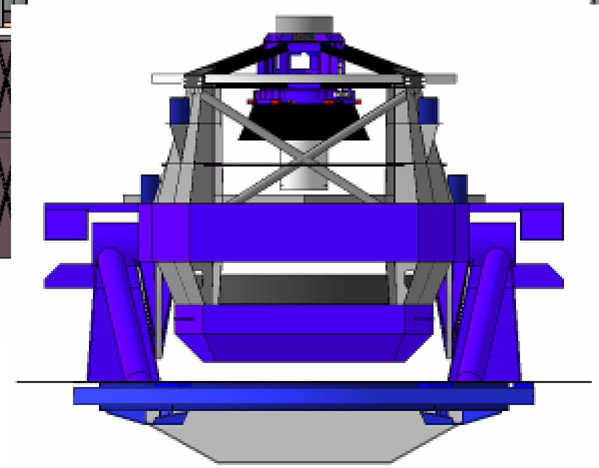
Large Synoptic Survey Telescope



Carrousel dome

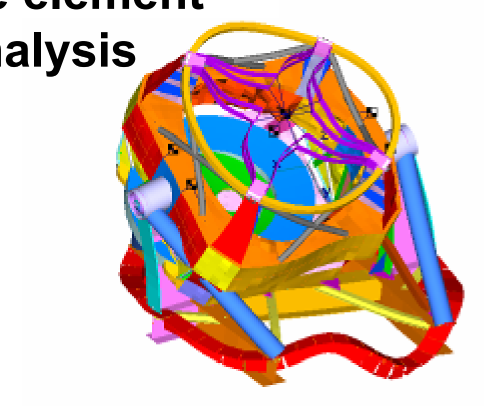


Camera and Secondary assembly

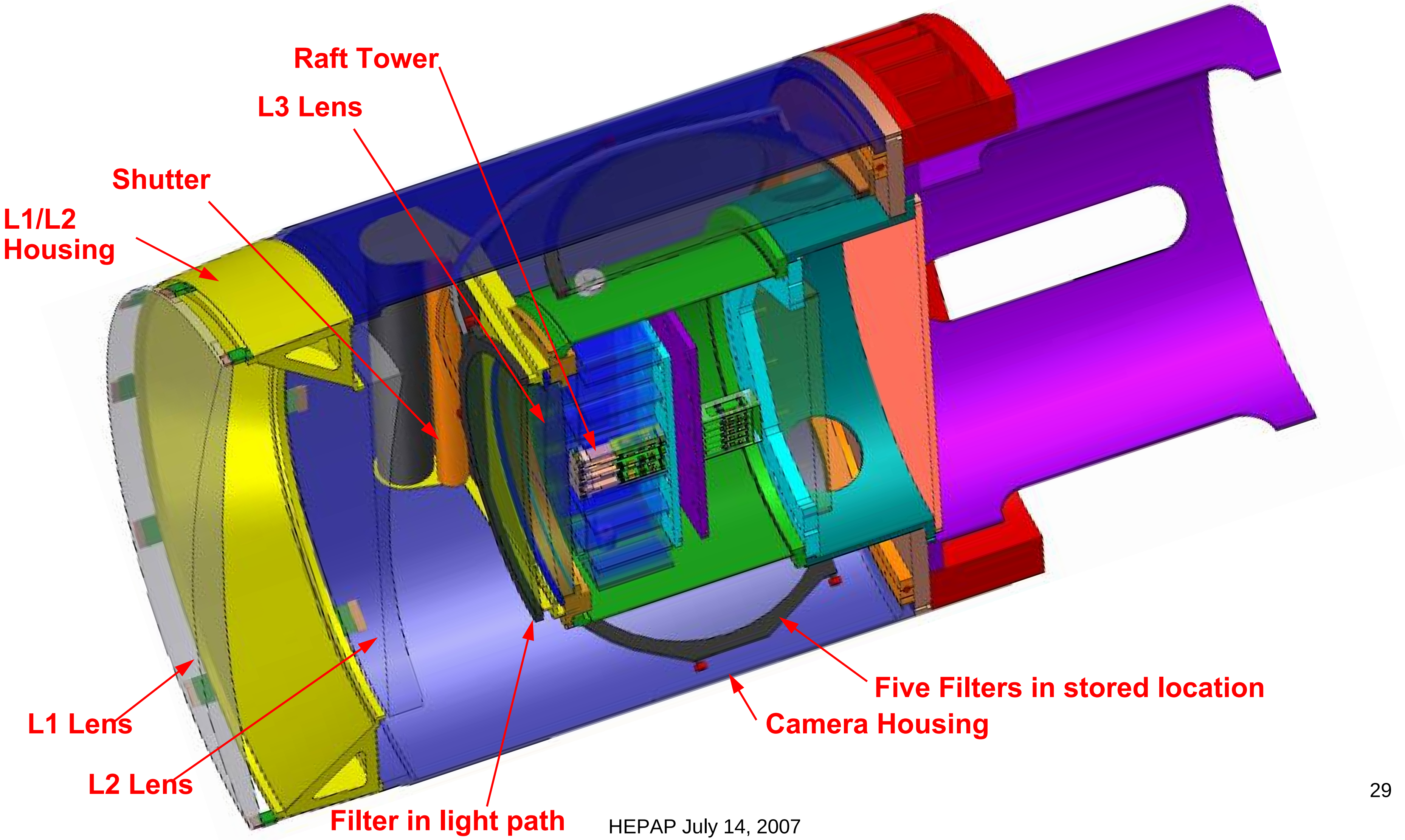


Altitude over azimuth configuration

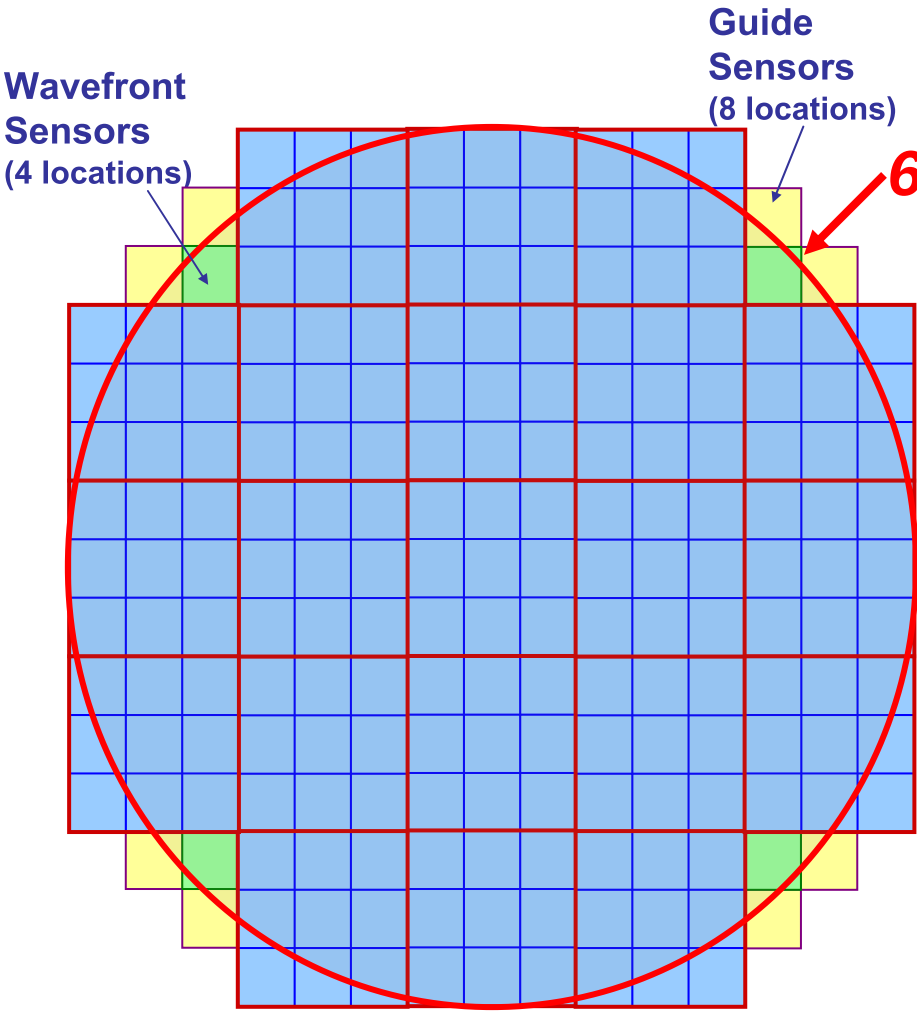
Finite element analysis



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



The LSST Focal Plane

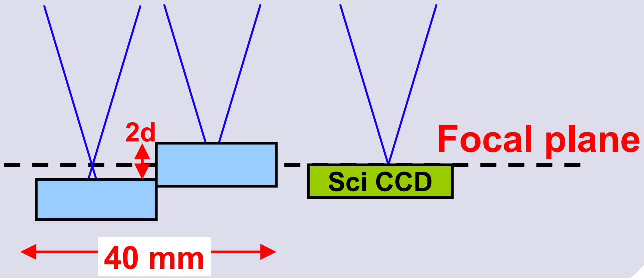


64.3 cm diameter

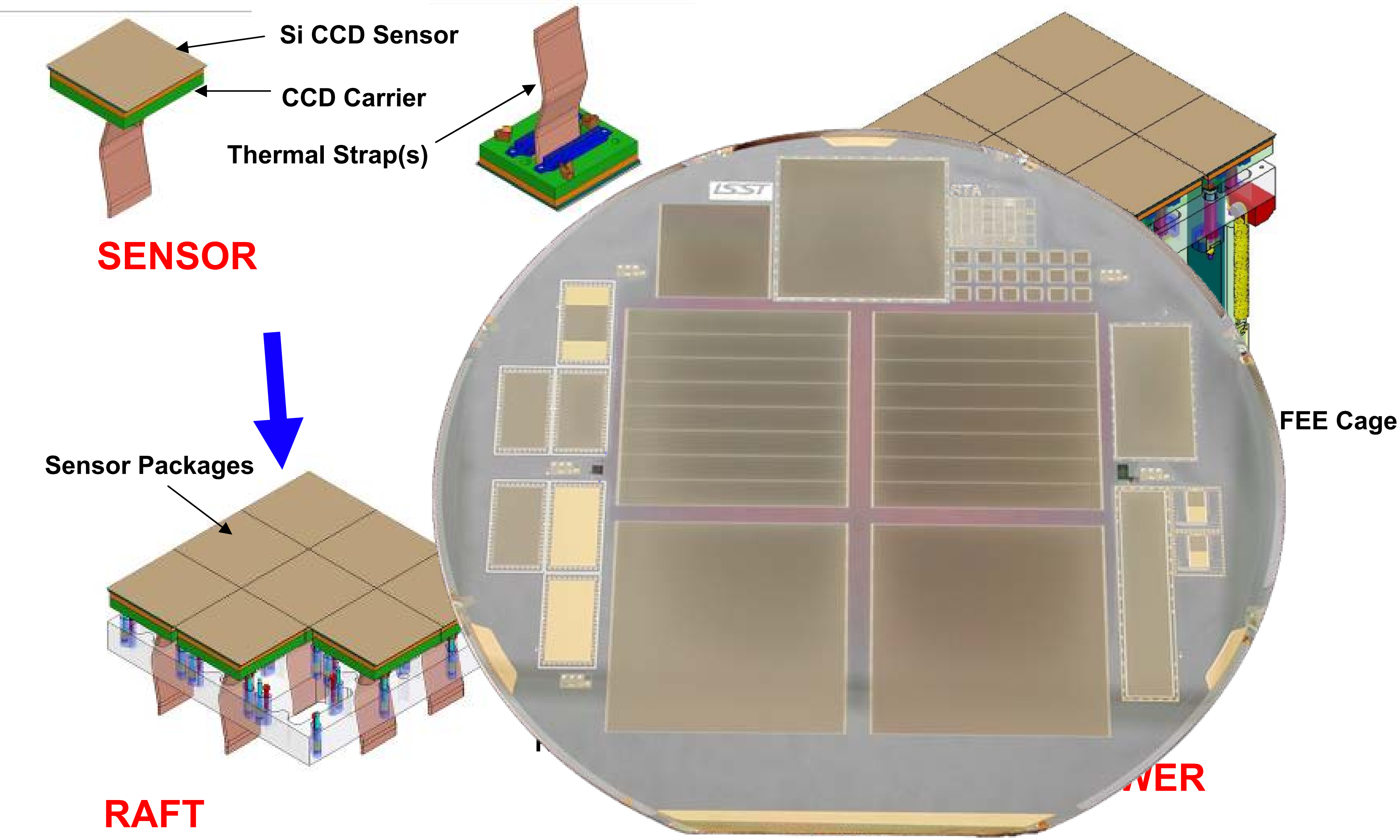
- ***➔ 3.5 degree field of view***
- ***➔ 9.6 square degrees/image***

Wavefront Curvature Sensors

(Side View)



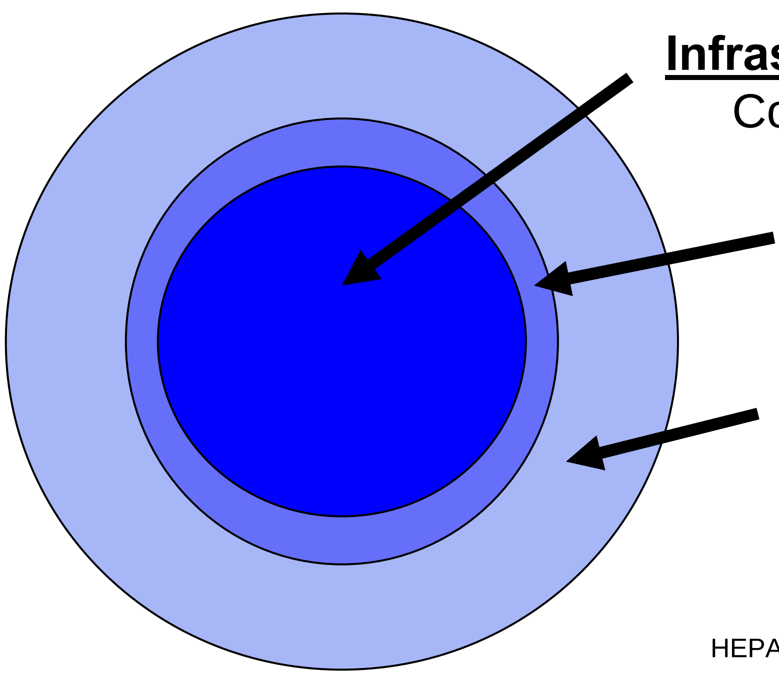
Raft Towers: The basic focal plane module



The LSST Data Management Challenge:

LSST generates 6GB of raw data every 17 seconds that must be calibrated, processed, cataloged, indexed, and queried, etc. often in real time

LSST Data Management Model

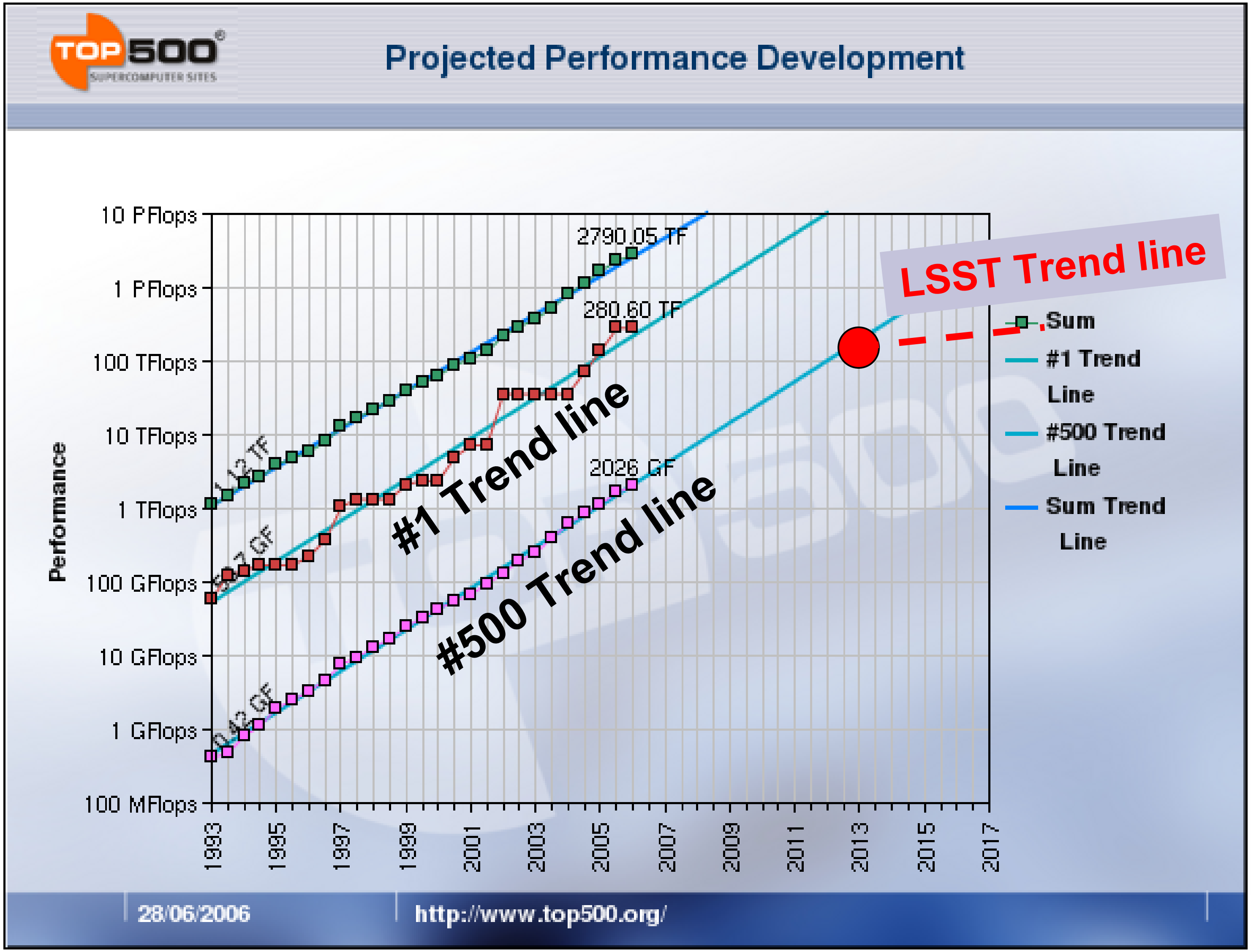


Infrastructure → Hardware
Computers, disks, data links, ,,,

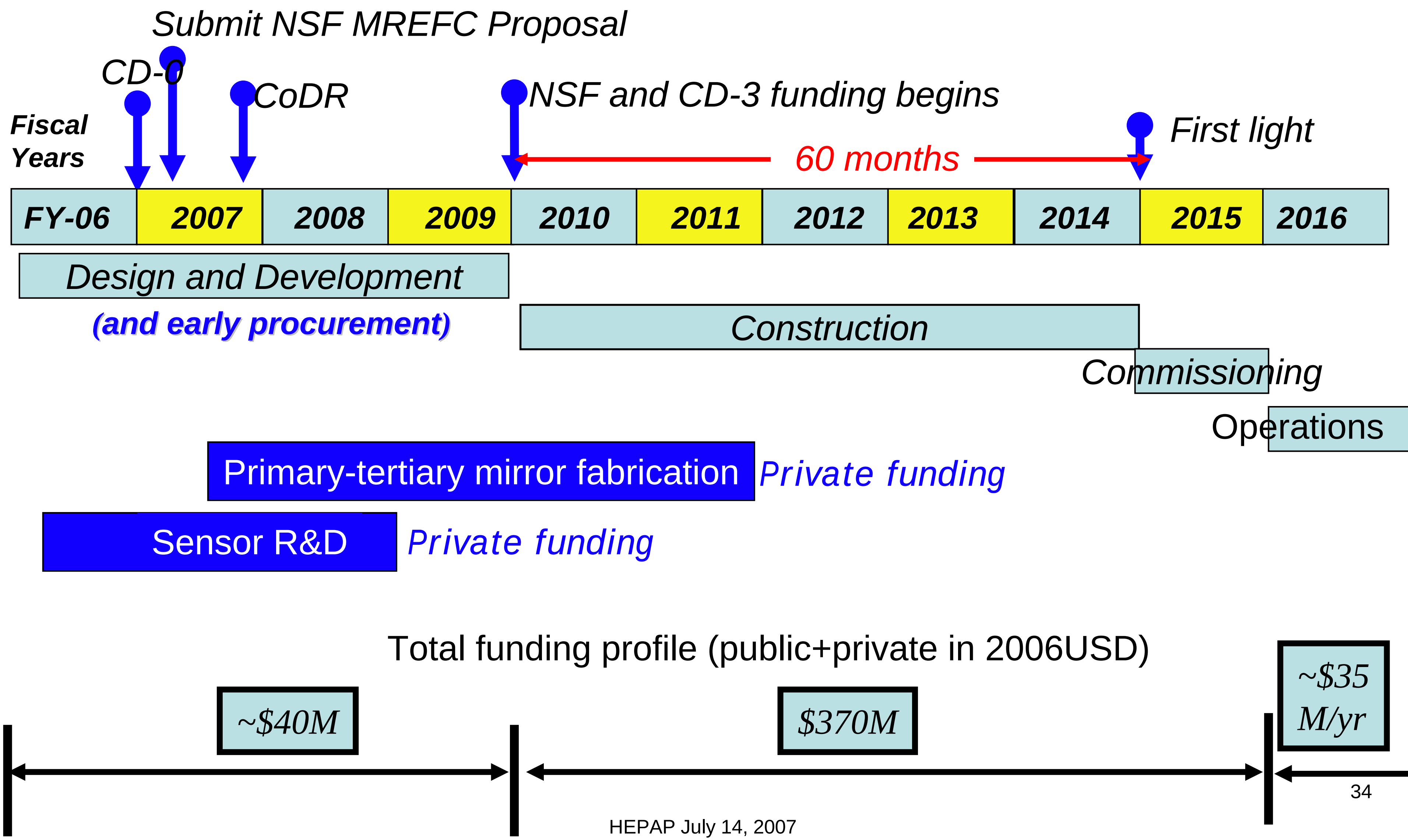
Middleware → Interface wrapper
Device drivers, system management,…

Applications → Science
Image processing, database queries, …

Total LSST Data Management Computing Requirements



Proposed Timeline for the LSST

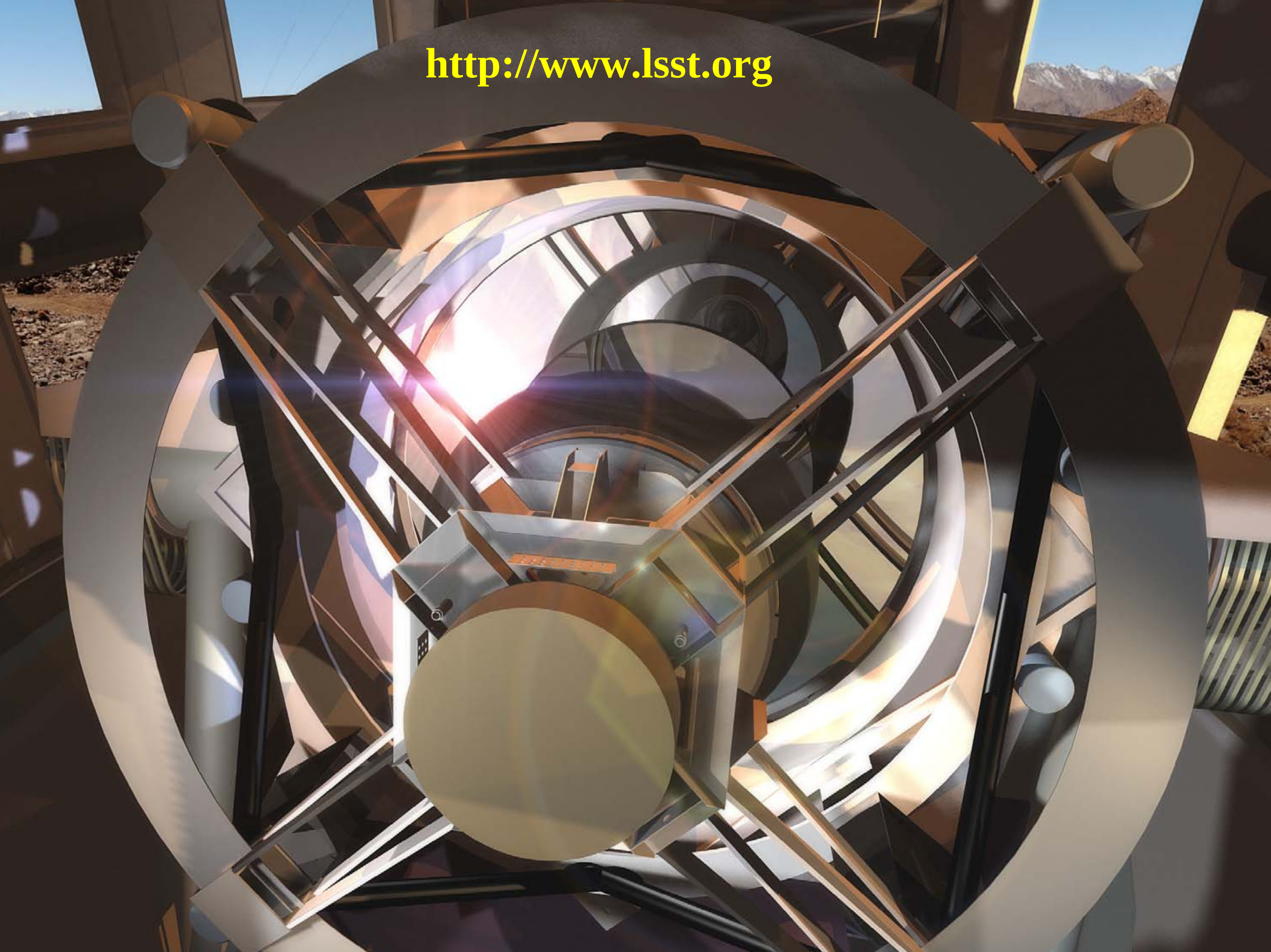


Summary

• **Addresses two of the most central questions in physics - DE, DM - with a single facility with multiple high precision measurements.**

• **Detailed design.   High degree of readiness.**

• **High quality team combining complementary skills and experience.**


http://www.lsst.org

Q&A slides

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

LSST and Fundamental Physics

- **Unique experiment for Dark Energy physics:**
  - **Five separate types of probes from the same experiment**
  - **Precision control of systematics enabled by multiple chops**
  - **Ultra-deep 2π sky coverage**

- **Incisive probe of dark matter clumping on scales relevant to the underlying physics.**

The DETF identified the "*w*" as the key dark energy quantity to study

Large Synoptic Survey Telescope

Dark energy pressure

$$w = \frac{p}{\rho}$$

Dark energy density

The DETF modeled "*w*" with two simple parameters:

$$w(a) = w_0 + w_a(1 - a)$$

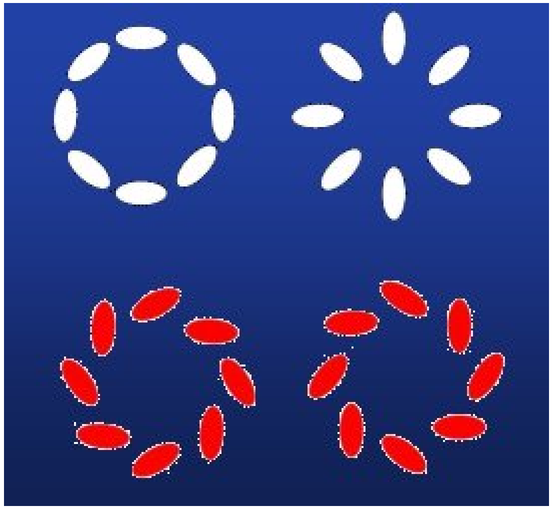
("a" is a measure of cosmic time, *w=-1* is a "cosmological constant")

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.

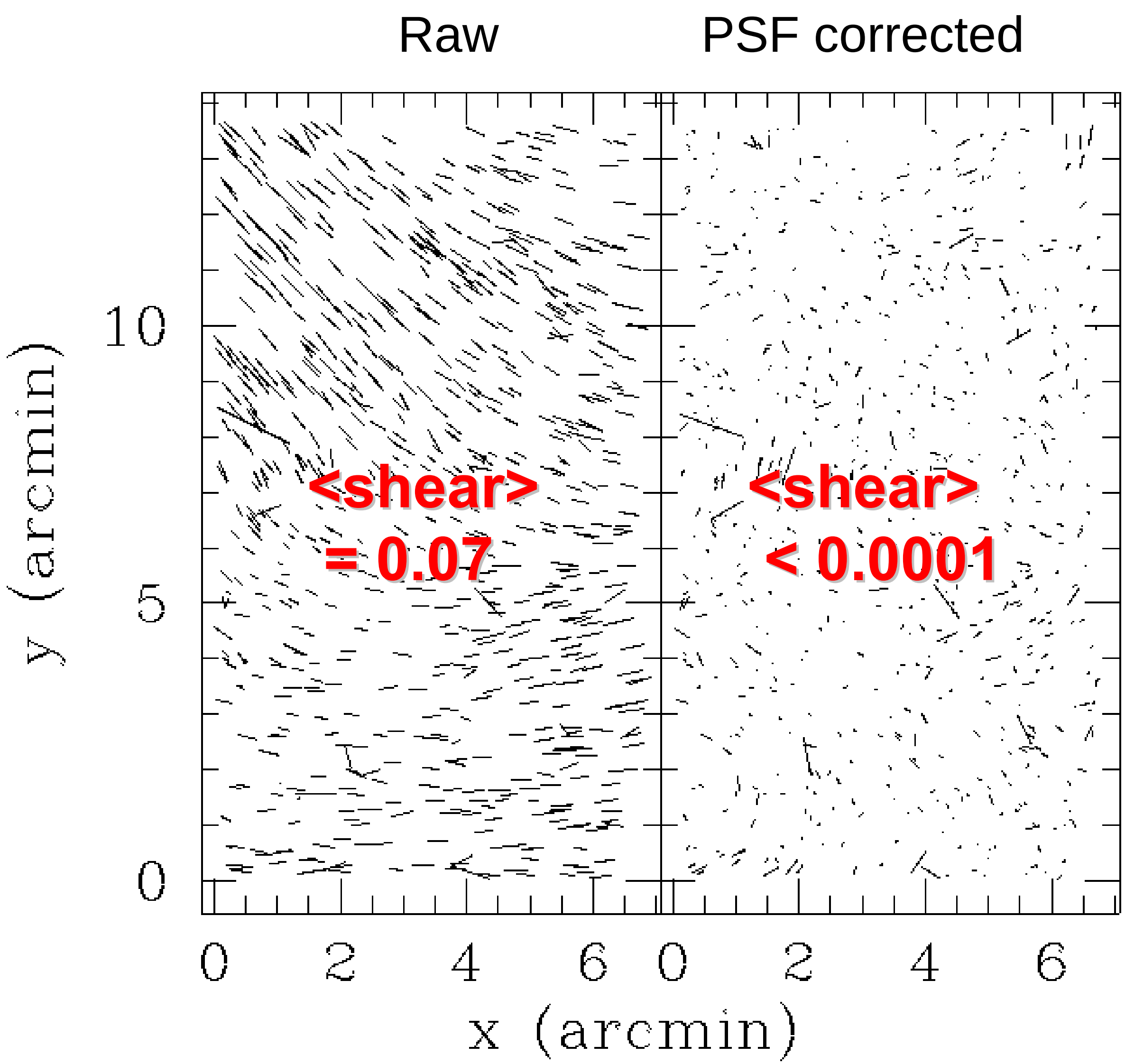
E-mode (curl-free)

B-mode (curl)



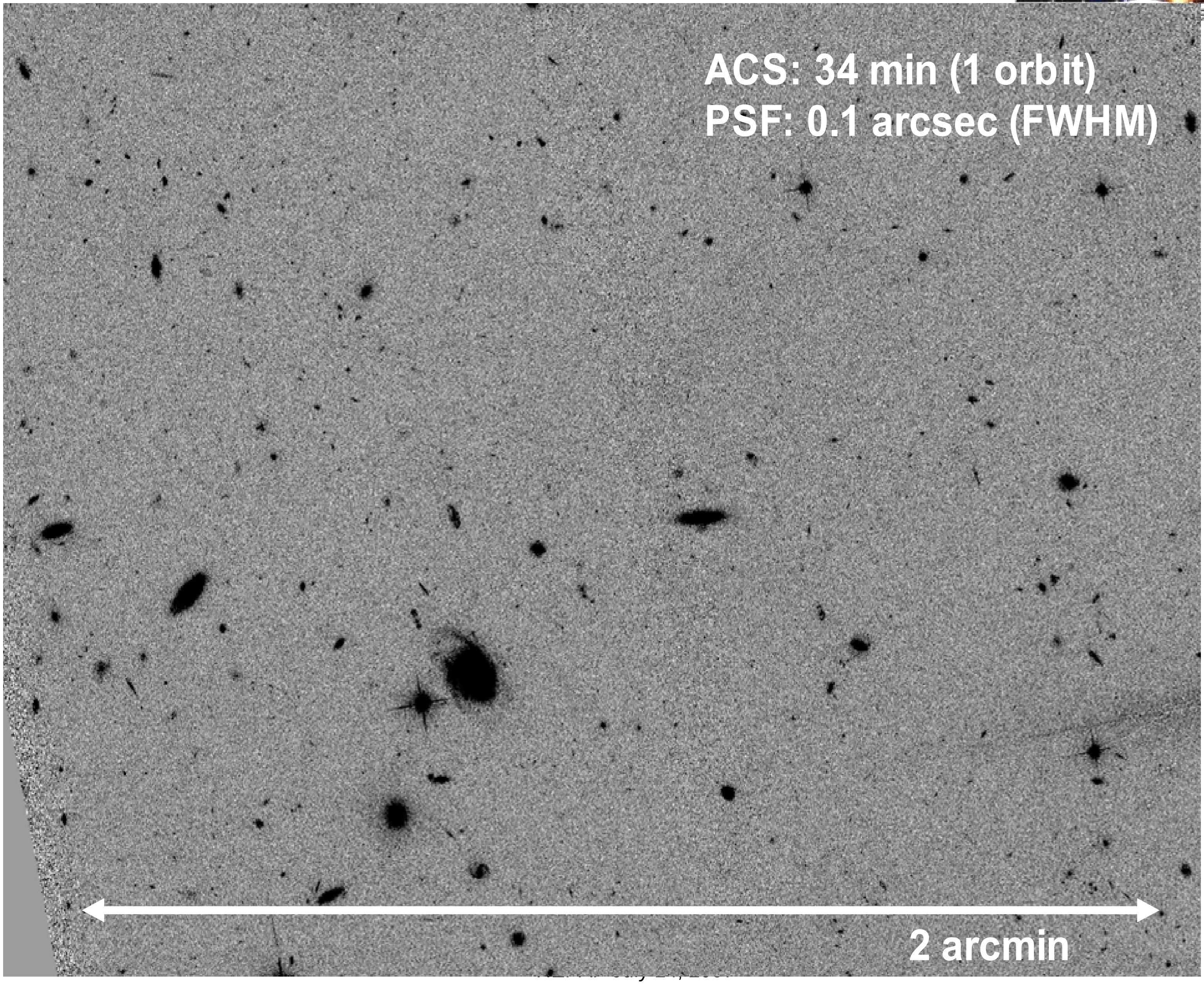
A residual B-mode is an indication of spurious shear in the analysis.

Single exposure in 0.7 arcsec seeing

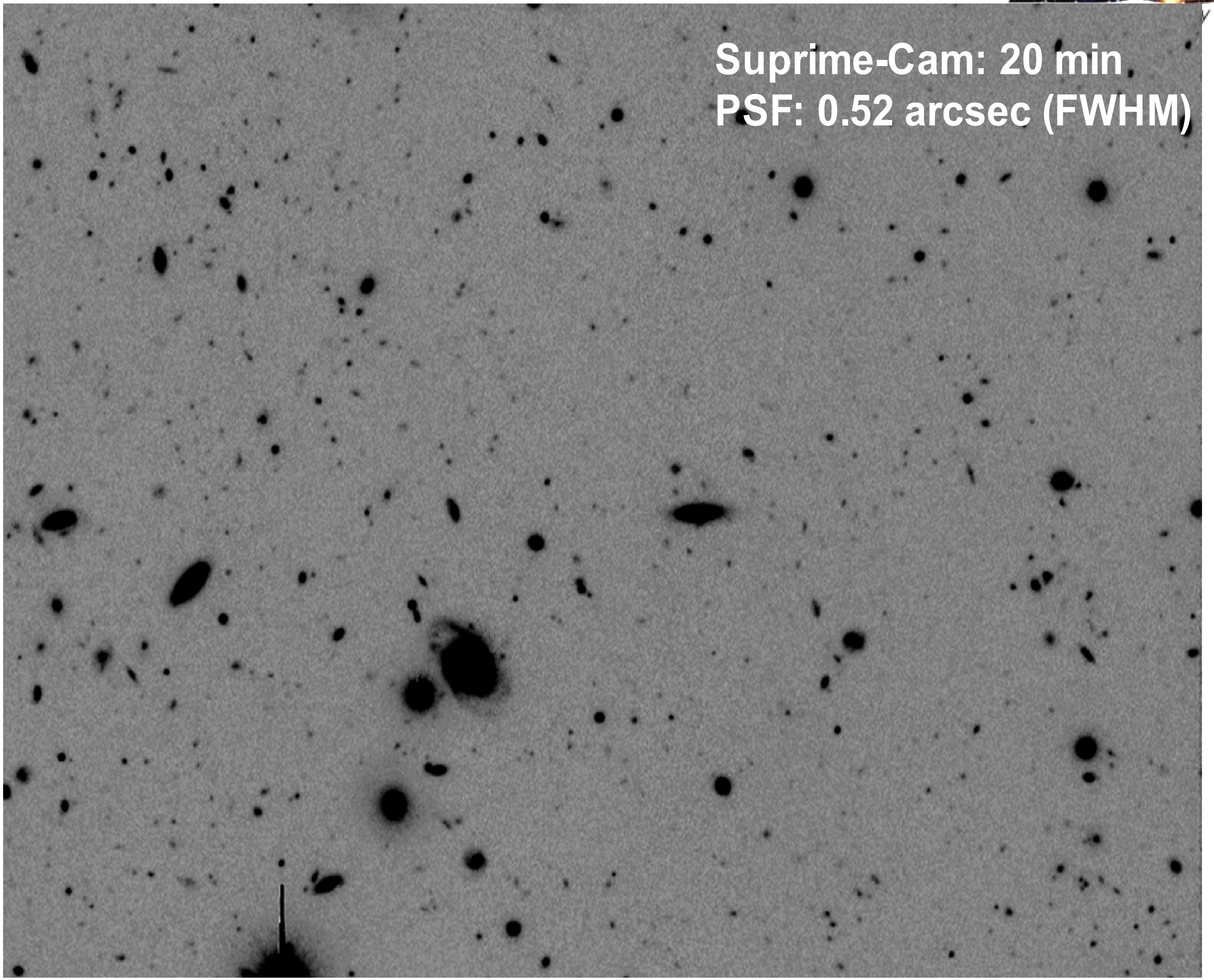


Subaru

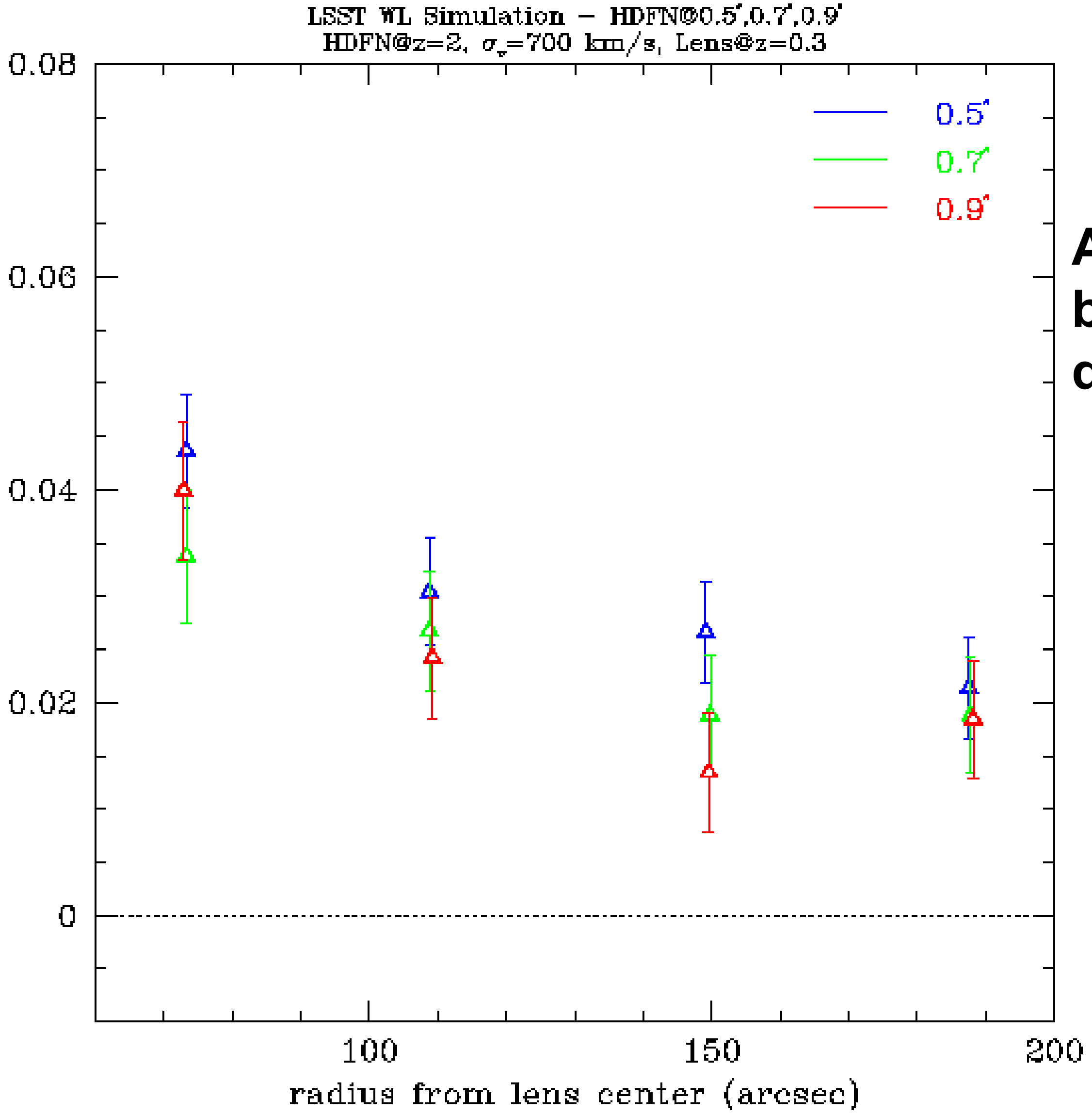
Comparing HST with Subaru



Comparing HST with Subaru



Effect of seeing on extracted WL shear



At the low surface brightness of the LSST design reference survey

WL shear S/N: Ground vs Space missions

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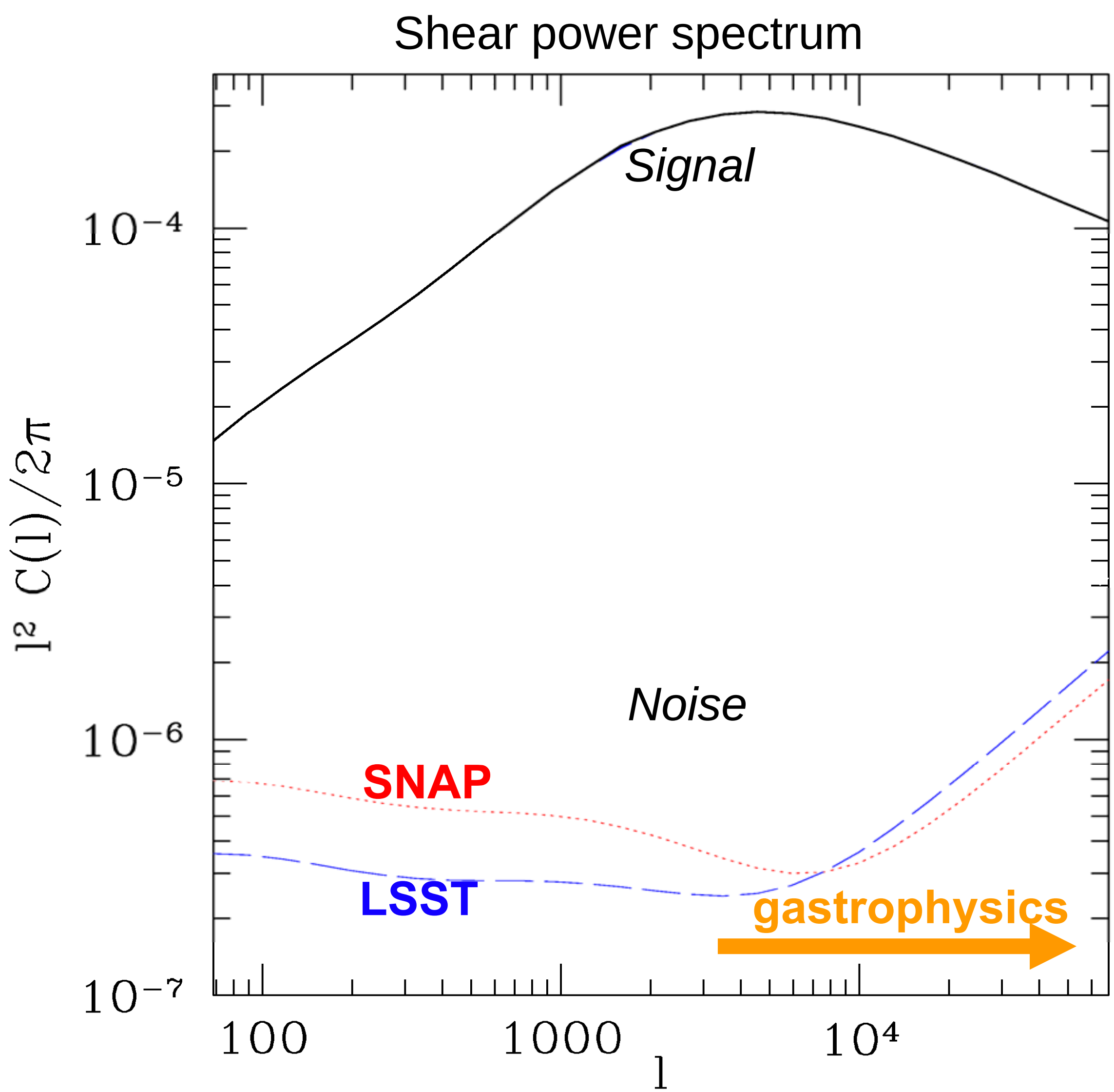

LSST: fsky = 0.5, ng = 40

SNAP: fsky = 0.1, ng =100

RMS intrinsic contribution to the shear σγ= 0.25 (a conservative overestimate).

Jain, Jarvis, and Bernstein 2006

Raw photo-z errors. No priors.

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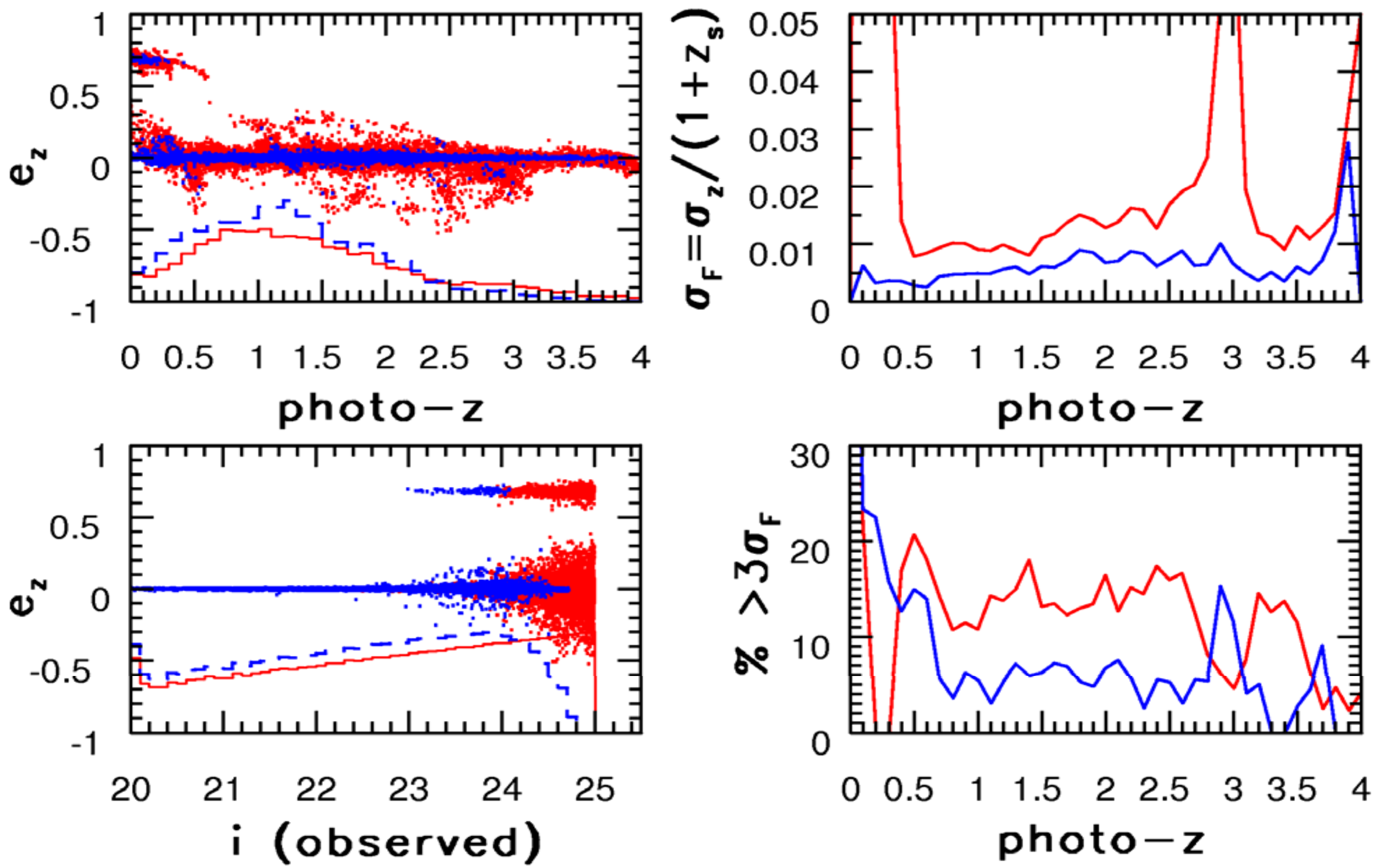

A comparison of the photo-z performance for the *i* < 25 (red) and [g<25.3 | z<23.9] (blue) flux limited galaxy subsamples. No luminosity or other priors are used. The left column lists $e_z = (z_s - z_p)/(1 + z)$ as a function of photo-z (top), the i band magnitude (bottom). Histograms in each panel show differential distributions (top left: on a linear scale; bottom left: on a log scale). The right column compares $\sigma_F = \sigma_z/(1 + z)$ and fraction of 3-σ outliers as a function of photo-z.

Photo-z calibration error

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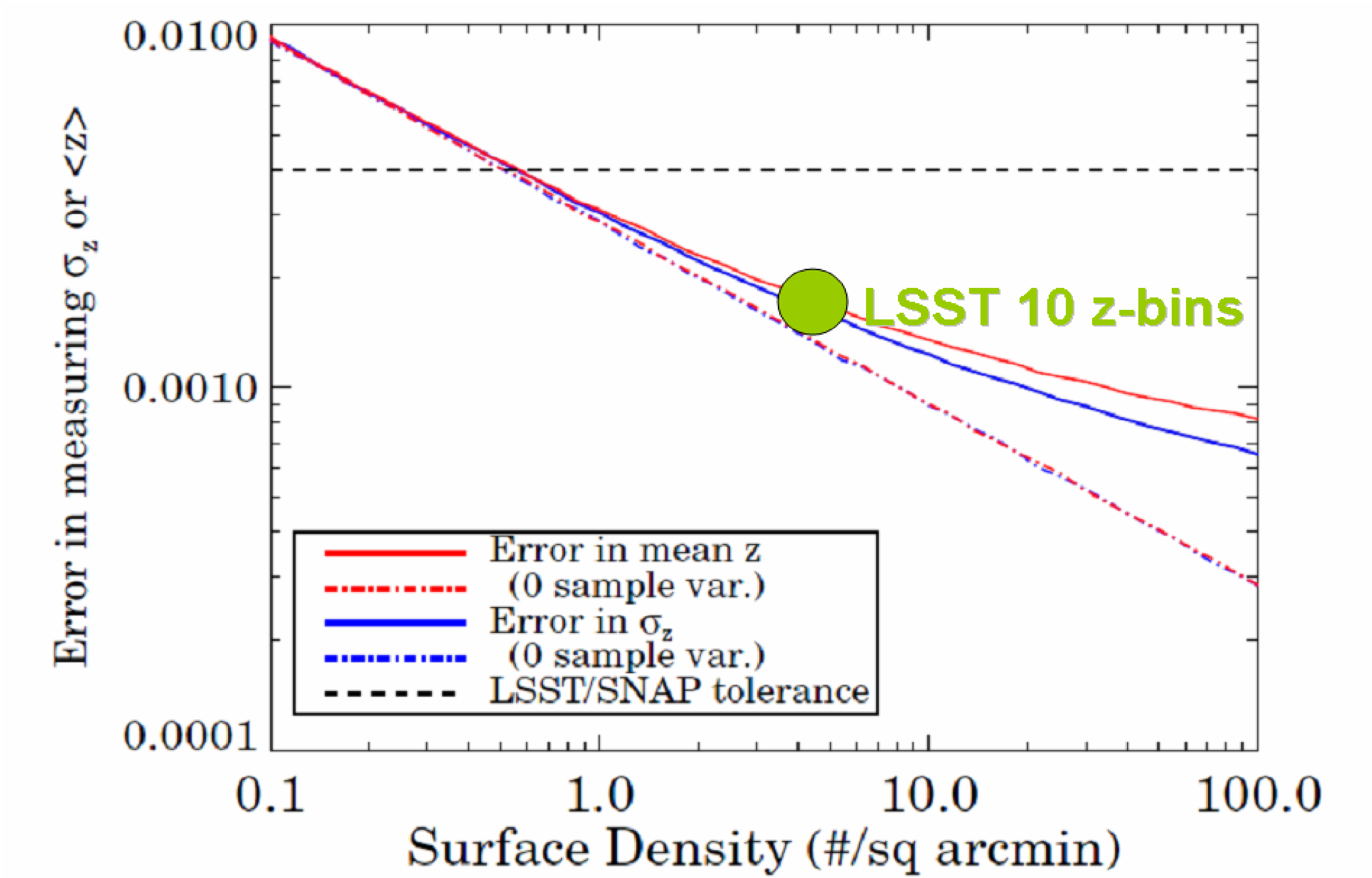
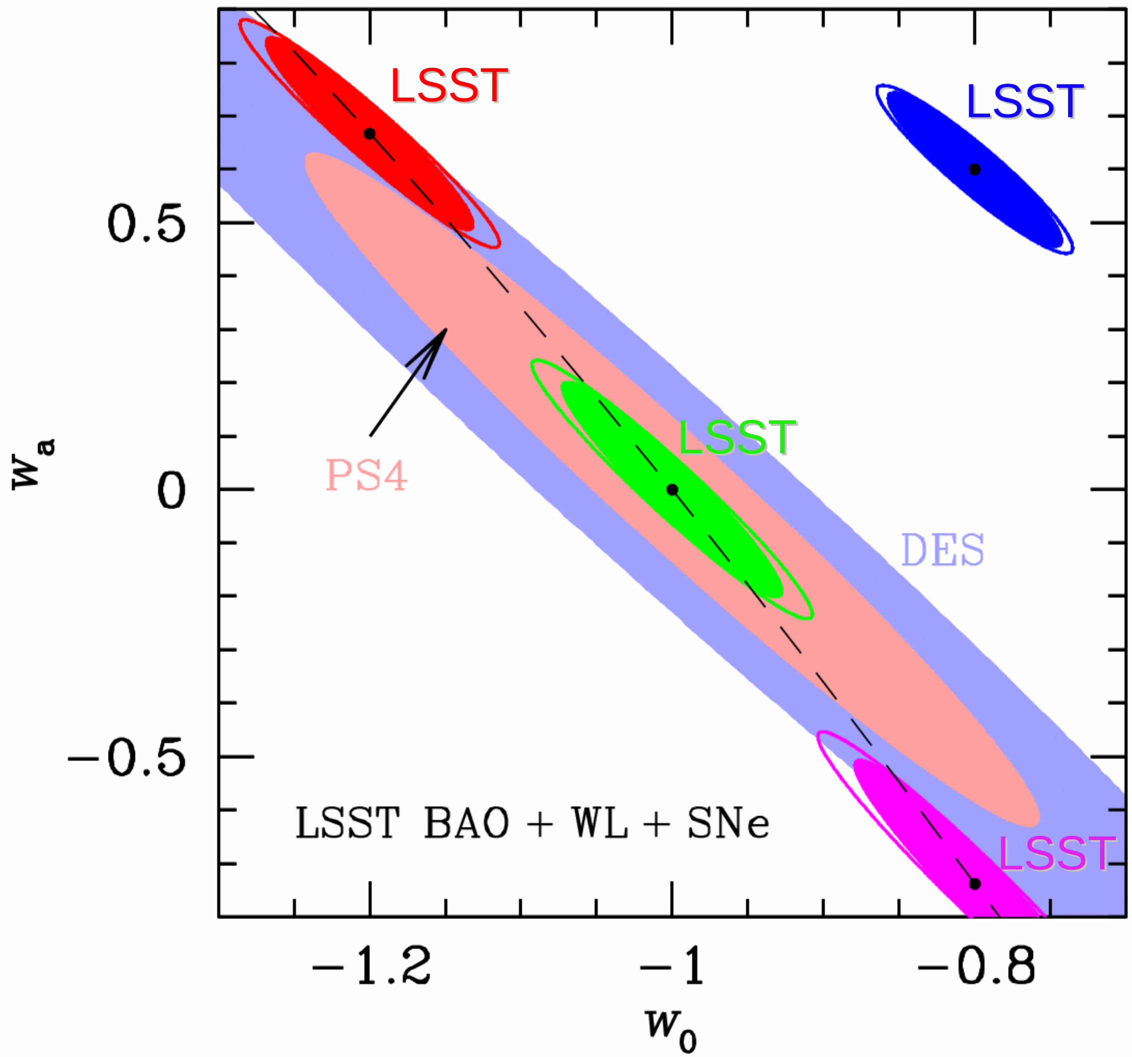


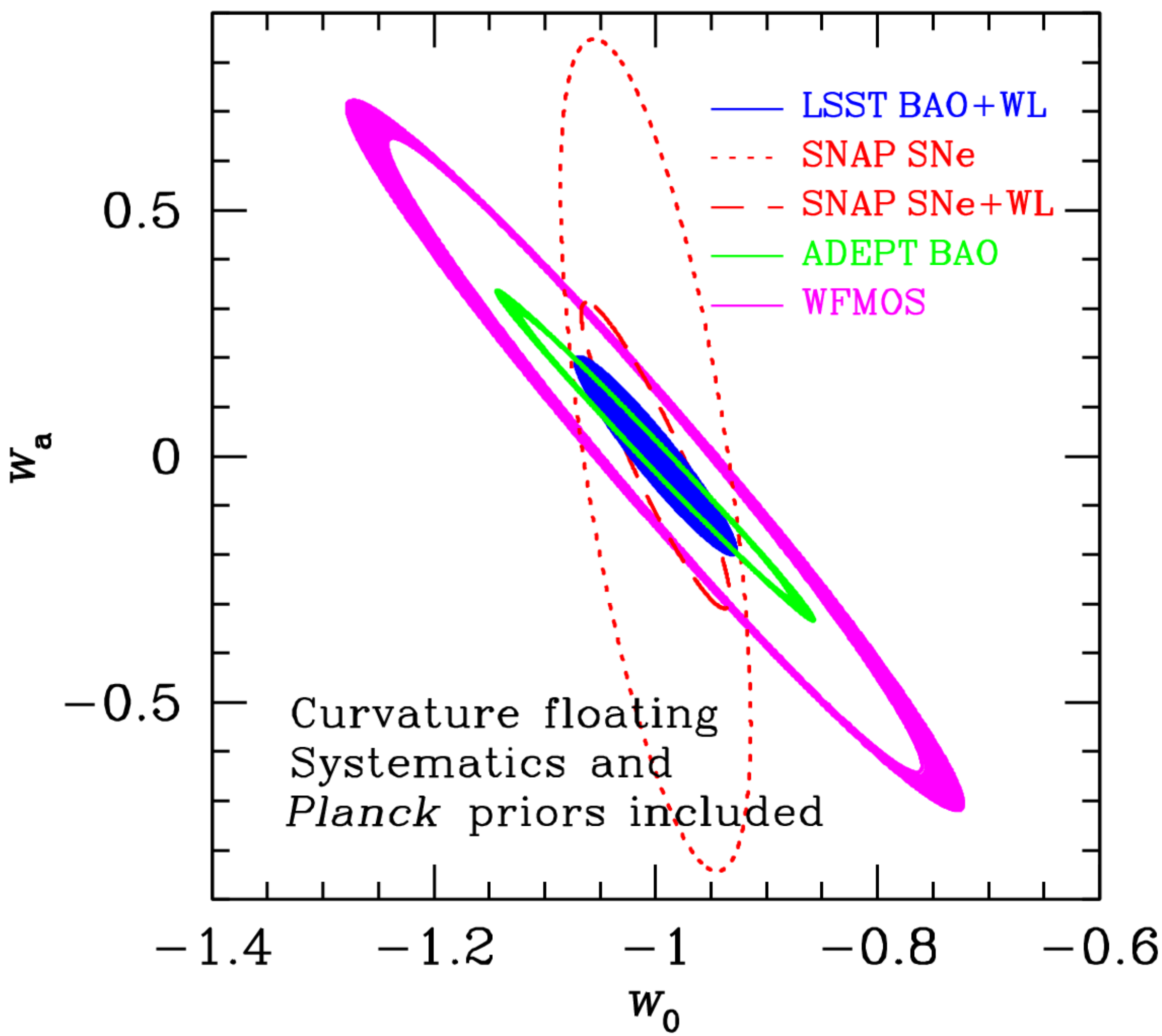
Results from simulations of uncertainties in cross correlation measurements of redshift distributions. Plotted are the rms errors in the recovery of the mean σ_z and δz of a photometric sample as a function of the surface density of that sample on the sky per tomographic z-bin. We assume a spectroscopic sample of 25000 galaxies, appropriate for targeted high-redshift samples. Larger sets of redshifts than currently available at *z*~0.5 and *z*>1.5 are required. The required level of error in calibration for LSST dark energy probes is met.

Comparison of DES, PS4, and LSST



Zhan 2006

Comparison of Stage-IV facilities for DE



Zhan 2007