Large Synoptic Survey Telescope

Large Synoptic Survey Telescope Project Status

Kirk Gilmore
LSST Project Scientist
Stanford/SLAC/KIPAC

Brookhaven National Laboratory
March 4, 2009

SLAC

PPA Particle Physics & Astrophysics

Stanford - SLAC - KIPAC

Stanford

SLAC - Stanford Linear Accelerator Center (DOE)

KIPAC - Kavli Institute for Particle Astrophysics and Cosmology

Large Synoptic Survey Telescope

The Science of KIPAC

- Particle Astrophysics
  - Black Holes, Neutron Stars, White Dwarfs…
  - GRBs, magnetars, supernovae…
  - Accretion disks and jets…
  - Relativistic shocks, particle acceleration, UHECR…
- Cosmology
  - Dark energy, dark matter
  - Gravitational lenses
  - Clusters of galaxies and intergalactic medium
  - Microwave background observations
  - First stars, galaxy formation

Dark Energy Science

1. The goal of dark-energy science is to determine the very nature of the dark energy that causes the Universe to accelerate and seems to comprise most of the mass-energy of the Universe.
2. Toward this goal, our observational program must:
   a. Determine whether the accelerated expansion is due to a cosmological constant.
   b. If it is not due to a constant, probe the underlying dynamics by measuring as well as possible the time evolution of dark energy, for example by measuring $w(a)$.
   c. Search for a possible failure of GR through comparison of cosmic expansion with growth of structure.
3. $w(a)$ is a continuous function; must parameterize; no parameterization can represent all possibilities; we choose $w(a) = w_0 + (1-a)w_a$; assumes dark energy insignificant at early times.

Dark Energy Measurements

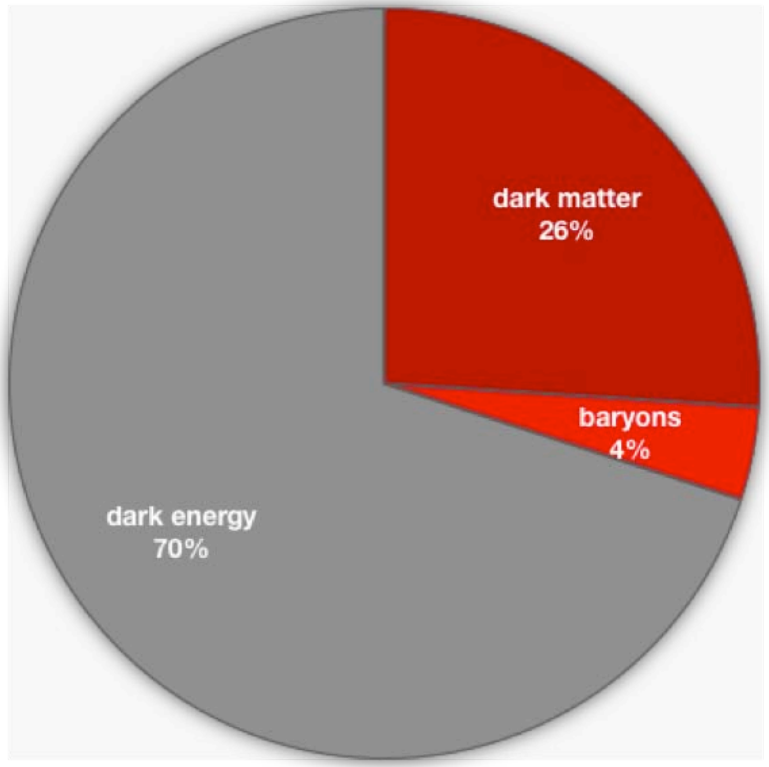
1. Four observational techniques dominate White Papers:
   a. Baryon Acoustic Oscillations (**BAO**) large-scale surveys measure features in distribution of galaxies. BAO: $d_A(z)$ and $H(z)$.
   b. Cluster (**CL**) surveys measure spatial distribution of galaxy clusters. CL: $d_A(z)$, $H(z)$, growth of structure.
   c. Supernovae (**SN**) surveys measure flux and redshift of Type Ia SNe. SN: $d_L(z)$.
   d. Weak Lensing (**WL**) surveys measure distortion of background images due to gravitational lensing. WL: $d_A(z)$, growth of structure.
2. Different techniques have different strengths and weaknesses and sensitive in different ways to dark energy and other cosmo. parameters.

Dark Energy Measurement Techinques

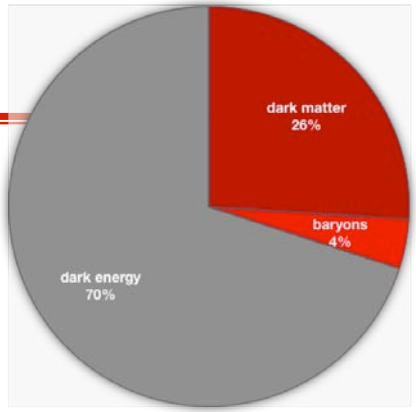
4. Four techniques at different levels of maturity:
   a. **BAO** only recently established. Less affected by astrophysical uncertainties than other techniques.
   b. **CL** least developed. Eventual accuracy very difficult to predict. Application to the study of dark energy would have to be built upon a strong case that systematics due to non-linear astrophysical processes are under control.
   c. **SN** *presently* most powerful and best proven technique. If photo-z's are used, the power of the supernova technique depends critically on accuracy achieved for photo-z's. If spectroscopically measured redshifts are used, the power as reflected in the figure-of-merit is much better known, with the outcome depending on the ultimate systematic uncertainties.
   d. **WL** also emerging technique. Eventual accuracy will be limited by systematic errors that are difficult to predict. *If* the systematic errors are at or below the level proposed by the proponents, it is likely to be the most powerful individual technique and also the most powerful component in a multi-technique program.

The Standard Cosmological Model

* Basic accounting of the Universe's present contents is in place
* We know what dark matter *does* on a wide range of scales, but very little about what it *is*.
* We know what the baryons *are*, but understanding their behavior and evolution requires modeling complex interactions over a vast range of scales.
* We know very little about dark energy, except how much there is.

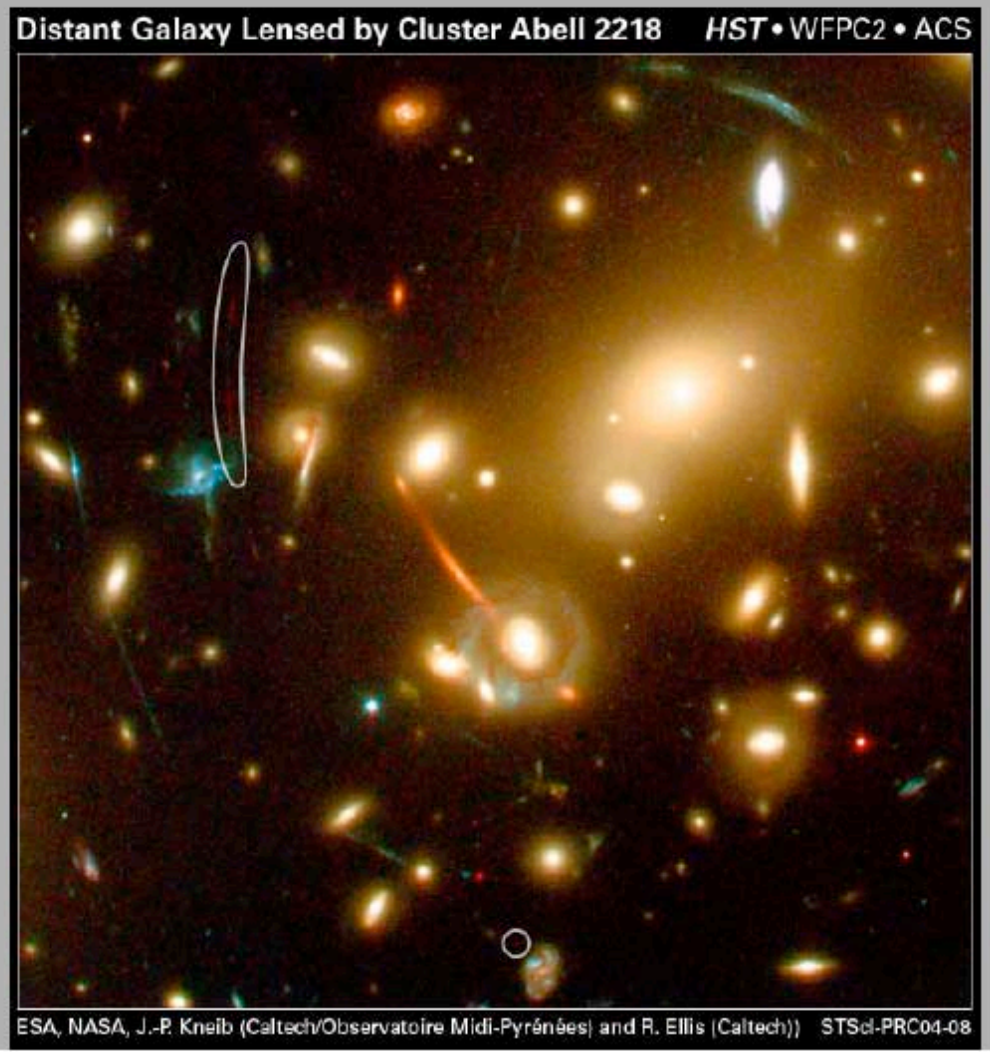


The Dark Energy Challenge



* Universe is dominated by Dark Energy driving us into a period of accelerated expansion.
  - What is causing it?
  - Why is $\rho_{de} \sim \rho_{dm}$
  - Why is $\rho de < 10^{120}\ \rho_{planck}$?
* Its effect can be characterized through equation of state
  - $w = \rho/P \qquad w(a) = w_0 + w_a(1+a)$
* Measuring this equation of state and its evolution can provide clues to its nature: cosmological constant? Vacuum energy? Modification of gravity?
* Goal is to get precise (few percent) determination of w and its change with time.
* Extremely puzzling physics question that can mostly be determined through astronomical surveys.

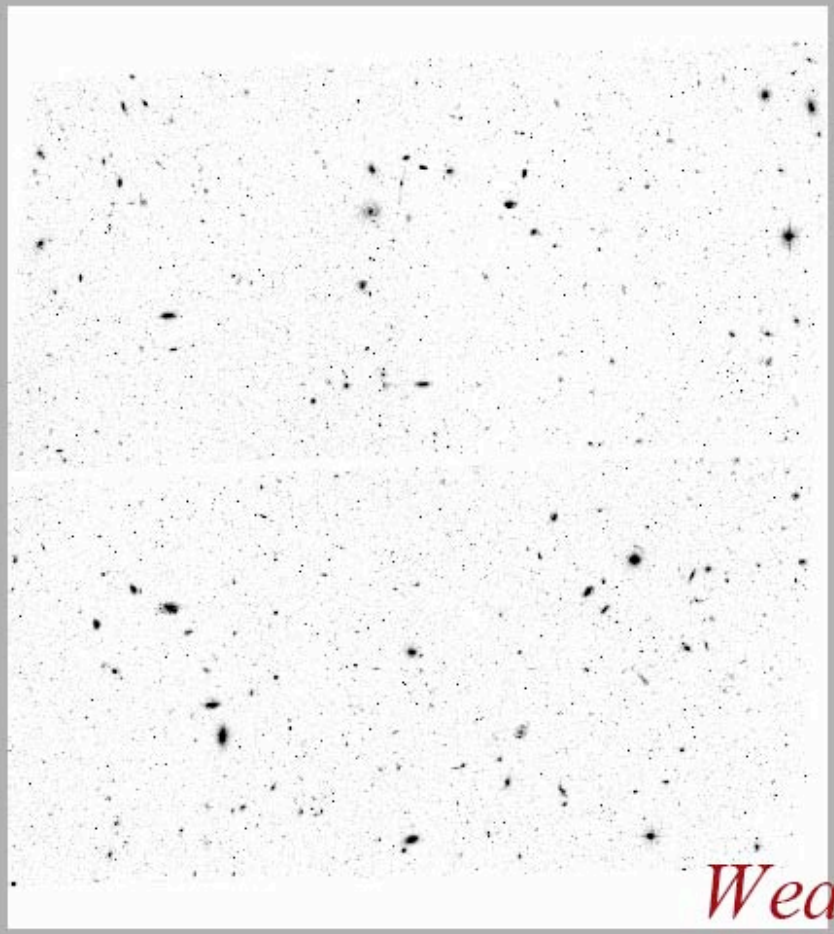
Sometimes you can see it…



Distortion of background images by foreground matter

Strong lensing

Sometimes you can't…



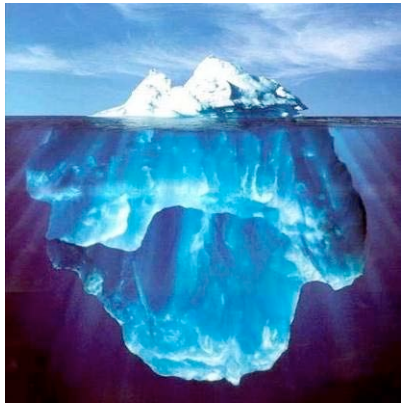
Weak lensing

Theoretical Challenges

* Next generation DE probes will be systematics limited.
* In order to meet the challenge of few % constraints on dark energy parameters, need precision calibration of structure formation, e.g.
  - Dark matter and galaxy clustering
  - Dark matter halo mass function
  - Profiles and formation histories of dark matter halos
* Also need a precise calibration of how galaxies trace the dark matter distribution
  - Important for Weak Lensing, BAO, Clusters, Photo-z's.
  - Requires a very large dynamic range for the simulations, detailed and well-calibrated models

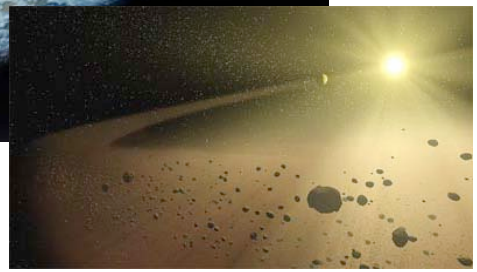
LSST Science Requirements focus on 4 Representative and Divergent Programs

Dark Energy-Dark Matter



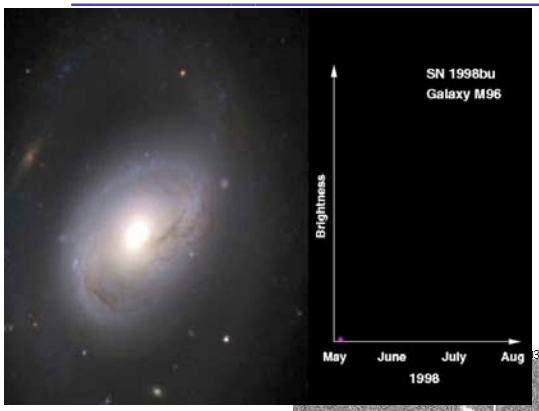
LSST enables multiple investigations into our understanding of the universe

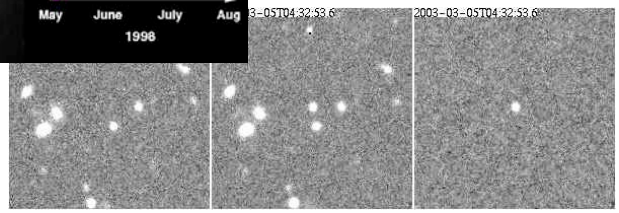
Exploring our Solar System



LSST will find 90% of hazardous NEOs down to 140 m in 10 yrs

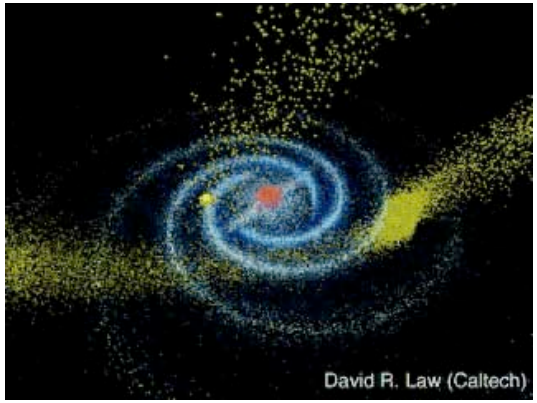
"Movie" of the Universe: time domain





Discovering the transient and unknown on multiple time scales

Mapping the Milky Way



LSST will map the rich and complex structure of our Galaxy.

6-band Survey: *ugrizy* 320–1050 nm

- Sky area covered: 20,000 deg^2 0.2 arcsec / pixel
- Each 10 sq.deg FOV revisited 400 times (r band)
- Time resolution: >20 sec
- Limiting magnitude: 26.5 AB magnitude @10σ (24.3 in u)
  24 AB mag in 15 seconds
- Photometry precision: 0.005 mag reqt, 0.003 mag goal
- Galaxy density: 50 galaxies/sq.arcmin
- 3 billion galaxies with color redshifts
- Time domain: Log sampling, seconds – years

Massively Parallel Astrophysics

- 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
- Dark matter/dark energy via weak lensing
- Dark energy via baryon acoustic oscillations
- Dark energy via supernovae
- 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 survey of 20,000 sq deg

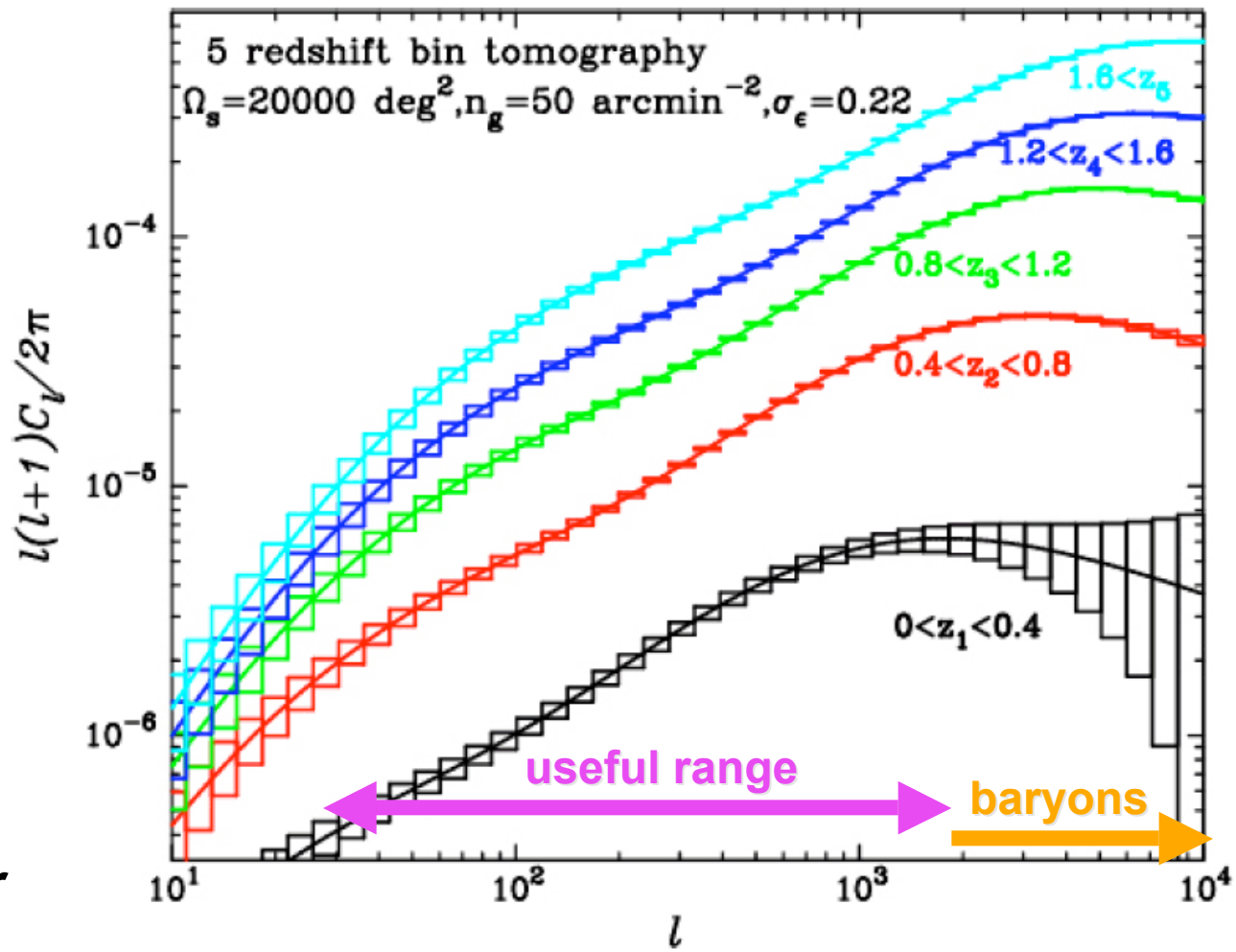
- 3 billion galaxies
- shear-shear correlations vs z
  2-point & 3-point
- baryon acoustic oscillations
- precision probe or dark energy

Critical Issues

- WL shear reconstruction errors
  - Show control to better than required precision using existing new facilities ✓
- Photometric redshift errors
  - Develop robust photo-z calibration plan ✓
  - Undertake world campaign for spectroscopy (✓)
- Photometry errors
  - Develop and test precision flux calibration technique ✓

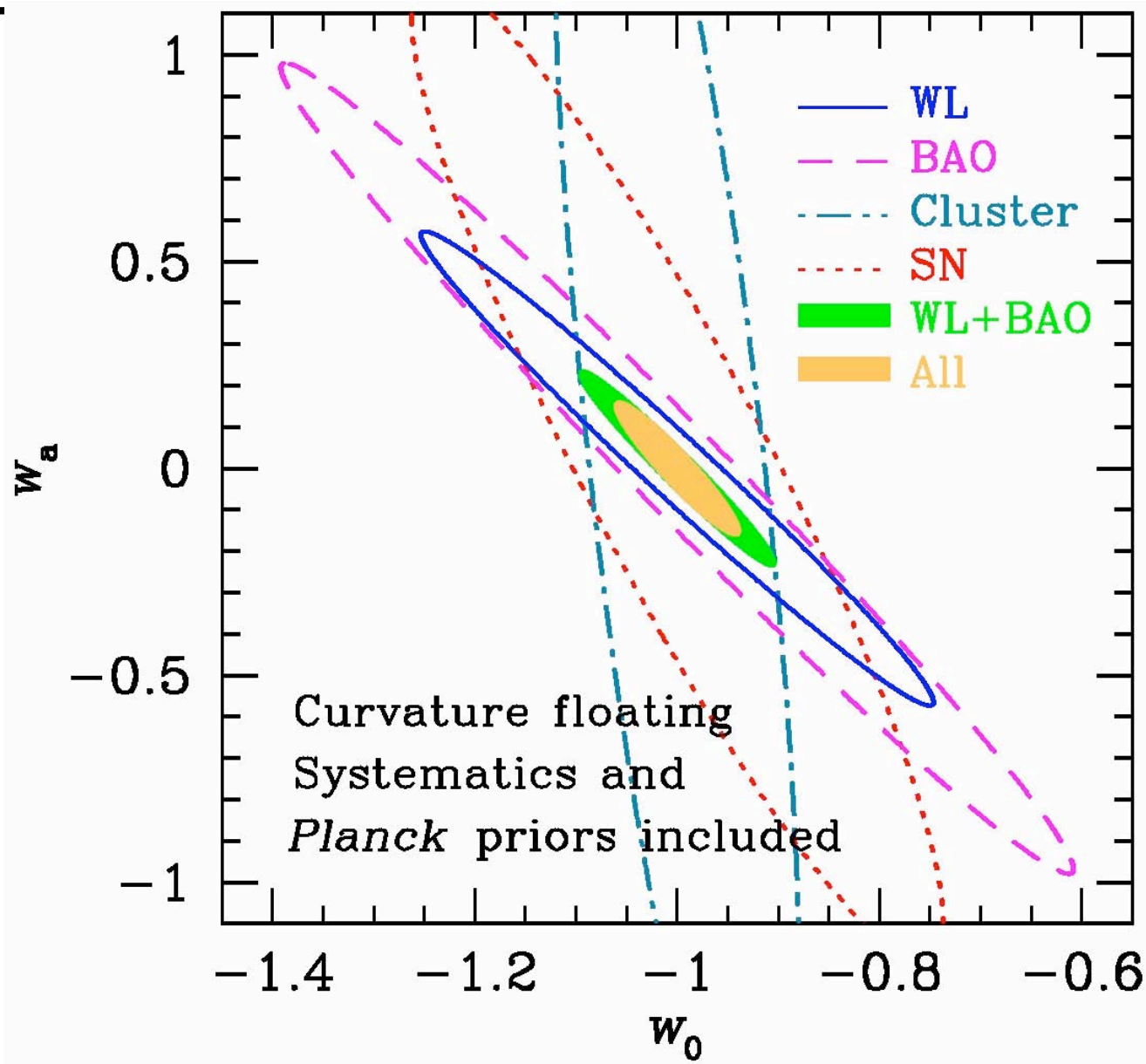
LSST and Cosmic Shear

Ten redshift bins yield 55 auto and cross spectra



+ higher order

Combining four LSST probes



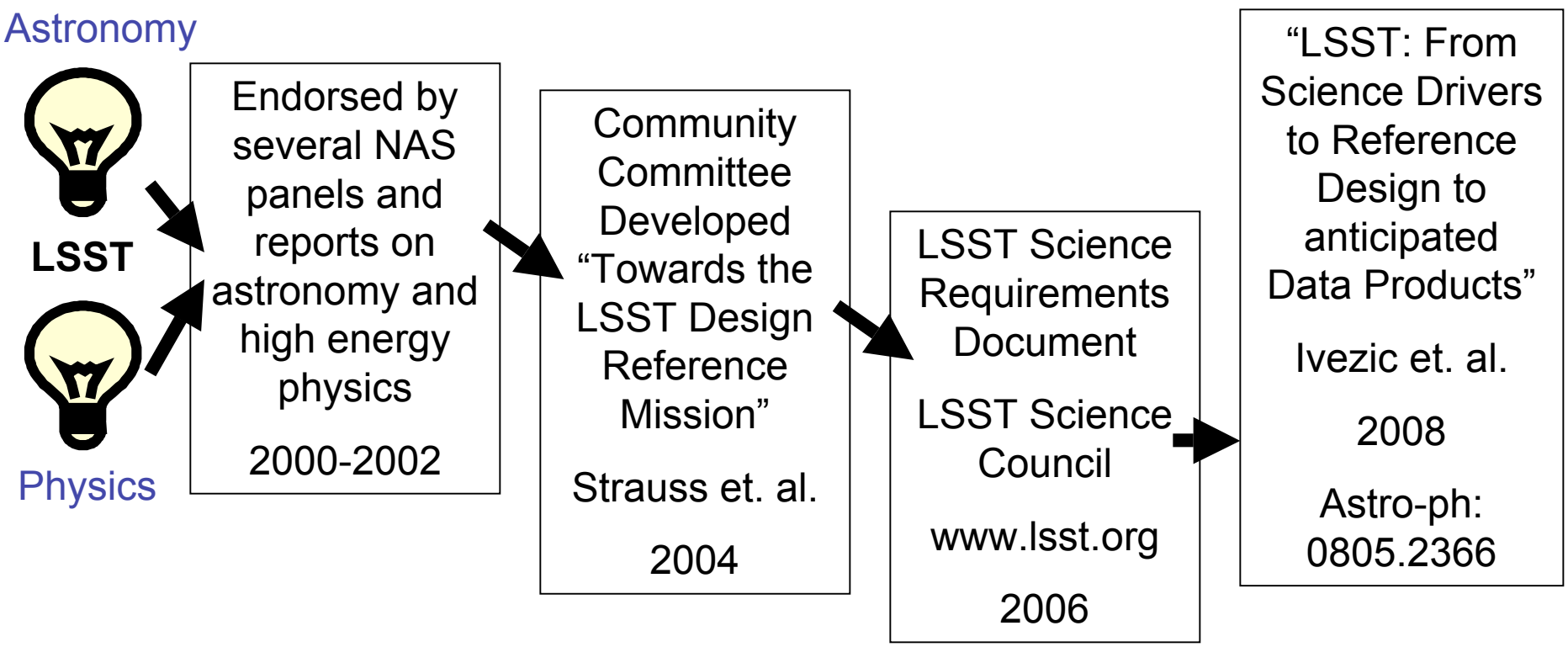
LSST Project

Cultural Differences between the HEP and Optical Astronomy Communities

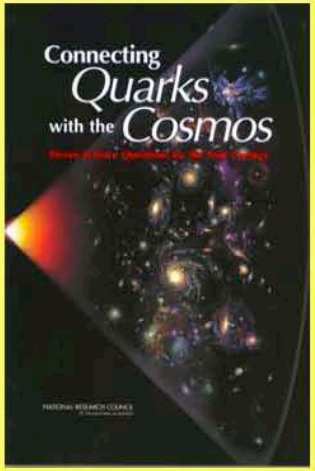
- **HEP**
  - "Joining a project" implies participation in construction and science analysis.
  - Data are closed to everyone outside the collaboration.
  - Strict publication and public talks policies - all members are coauthors.
  - Funding for faculty, postdocs, and student support comes from university-based grants covering both technical tasks and science analysis.

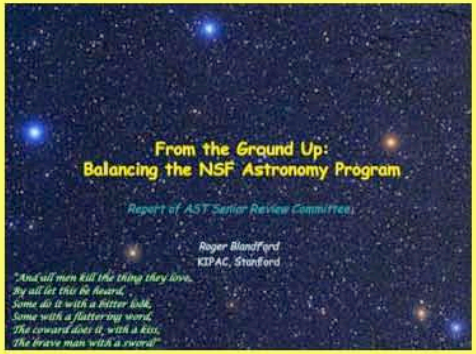
- **Ground-based Optical Astron.**
  - "Membership" in a telescope project is via direct financial support for the construction.
  - Each institution is given a share of the observing time.
  - Individuals free to publish as they see fit - usually few author papers without inclusion of hardware builders.
  - Funding for science is separate from construction - usually cobbled together from small basic research grants from NSF.

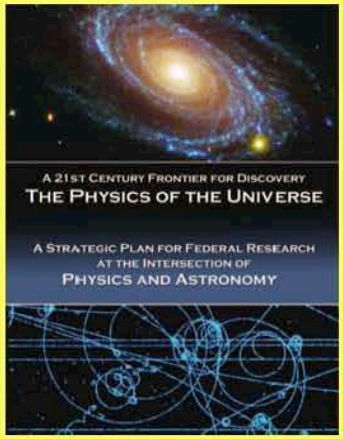
LSST is motivated by massively parallel astrophysics to answer a wide range of today's pressing questions in cosmology and fundamental physics

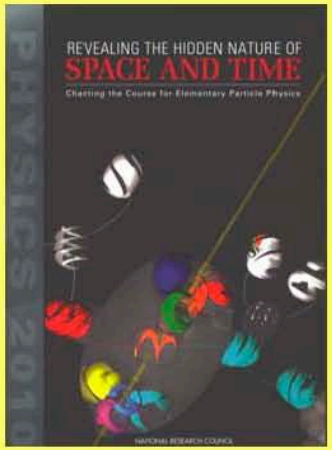


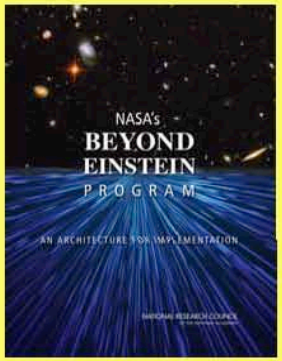
Many recent reports available to the Astro2010 committee

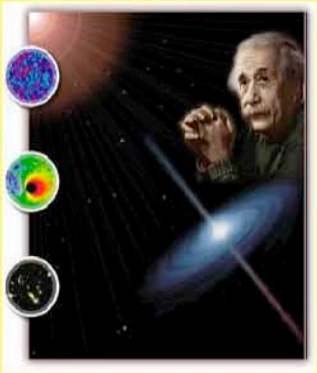


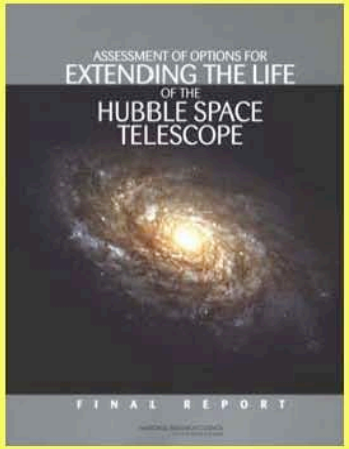


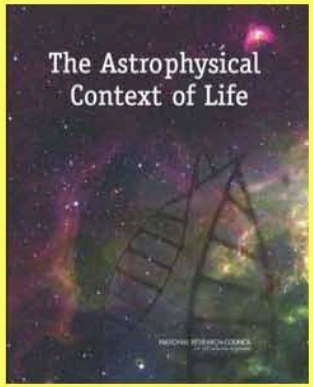


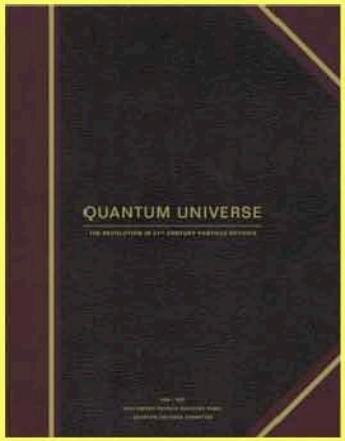












Astro2010 Charge

- **The Astro2010 committee will survey the field of space- and ground-based astronomy and astrophysics, recommending priorities for the most important scientific and technical activities of the decade 2010-2020.**
- **The principal goals of the study will be to carry out an assessment of activities in astronomy and astrophysics, including both new and previously identified concepts, and to prepare a concise report that will be addressed to the agencies supporting the field, the Congressional committees with jurisdiction over those agencies, the scientific community, and the public.**

[http://www.nationalacademies.org/astro2010]

New missions, facilities

	SPACE		GROUND	
MAJOR	JWST	1000	GSMT	350
	Con-X	800	EVLA	140
	TPF(tech)	200	LSST	170
	SAFIR(tech)	100		
MODERATE	GLAST	300	TSIP	50
	LISA	250	ATST	60
	SDO	300	SKA(tech)	22
	EXIST	150	CARMA	11
	ARISE	350	VERITAS	35
			FASR	26
			SPST	50

(AANM estimated FY2000 costs in M$ for construction and 5 yr operations in 2001-2010 inter

THE NATIONAL ACADEMIES
Advisers to the Nation on Science, Engineering, and Medicine

5 Astro 201

Optimizing the Return

Operational
Agency start
Not started

- DDAA,TGSAA carryover
  - Spitzer, ALMA, SOFIA, SIM, WMAP, FIRST, Planck
- Budget for operations, upgrade, data, theory
- Unrestricted research grants
- Develop OIR system in ground-based astronomy
- NSF Senior Reviews
- DOE Strategic Plan for Astrophysics
- NASA develop balanced program - small, medium, large
- Integrated theory initiatives
- Inter-agency, international and private coordination, collaboration and cost-sharing

THE NATIONAL ACADEMIES
Advisers to the Nation on Science, Engineering, and Medicine

4 Astro 2010

2009 Status of Initiatives

- Spitzer, WMAP, Fermi(GLAST), CARMA, VERITAS, SPT
- JWST, ALMA, SOFIA, Herschel(FIRST), Planck, Kepler, SM4, WISE, NuSTAR, MWA, LWA, ACT...
- SIM, Con-X(IXO), TPF, SAFIR,GSMT, LSST, LISA, EXIST, ARISE, ATST, SKA, FASR, JDEM, CMBPOL, CCAT...
- Many new proposals
- Cross-disciplinary projects

Good News: Superabundance of scientifically exciting projects
Bad News: No credible budget can support starting all of them
Conclusion: Many opportunities must be passed up

THE NATIONAL ACADEMIES
Advisers to the Nation on Science, Engineering, and Medicine

7 Astro 2010

Institutional Members LSSTC, September 08

* Brookhaven National Laboratory
* California Institute of Technology
* Carnegie Mellon University
* Chile
* Columbia University
* Google Inc.
* Harvard-Smithsonian Center for Astrophysics
* Johns Hopkins University
* Kavli Institute for Particle Astrophysics and Cosmology at Stanford University
* Las Cumbres Observatory Global Telescope Network, Inc.
* Lawrence Livermore National Laboratory
* Los Alamos National Laboratory
* National Optical Astronomy Observatory
* Princeton University
* Purdue University
* Research Corporation
* Rutgers University
* Stanford Linear Accelerator Center
* The Pennsylvania State University
* The University of Arizona
* University of California, Davis
* University of California, Irvine
* University of Illinois at Urbana-Champaign
* University of Pennsylvania
* University of Pittsburgh
* University of Washington

LSST Science Collaborations

1. **Supernovae: M. Wood-Vasey (CfA)**
2. **Weak lensing: D. Wittman (UCD) & 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: Hu Zhan (UCD)**
9. **Milky Way: James Bullock (UCI) & Beth Willman (CfA)**
10. **Strong gravitational lensing: Phil Marshall (UCSB)**

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

Foreign participation

* IN2P3 France (***camera focal plane, filters, electronics and calibration + science collaborations)***

* All Europe interested (***synergy with VLT spectroscopy***)

  German consortium

  Astronet document assumes LSST data

  ESO plans LSST data access & spectroscopic facility

  UK consortium

  Liverpool meeting coing up

* Chilean astronomy community joining

AAS 2009

Long Beach

37 Posters

LSST.org

Document Archive

Astro-ph 0805.2366 (overview)

July 7, 2008

Large Synoptic Survey Telescope

www.lsst.org

Multiple Probes of Dark Energy with LSST

J. A. Tyson (UCD), H. Zhan (UCD), L. Knox (UCD), and the LSST Collaboration

The 27.5 r-magnitude limit of the 20,000 square degree LSST image stack enables photometry of ten billion galaxies to low surface brightness and shape measurement of several billion galaxies. A number of independent cross checking probes of the nature of dark energy will result. Using many photometric redshift bins, the joint analysis of 2-D baryon acoustic oscillations and weak lensing cosmic shear is particularly powerful. The half-sky LSST six band survey will address dark energy physics by exploiting a diversity of simultaneous precision probes.

When combined with the CMB data these tests form interlocking checks on cosmological models and the physics of dark energy. The LSST wide angular coverage data is also capable of uncovering anisotropy in dark energy. LSST is being engineered to minimize and control systematics at a level ten times below the smallest signal of interest. Systematic error experiments using the Subaru telescope are incorporated. Reconstruction of galaxy images from fitting models to the full image stack can overcome residual PSF systematics. Full system simulations of LSST dark energy performance are shown.

Weak Lensing: A big advantage for WL is the ability to do 3-D tomography. Examples of the shear power spectrum are given in Figure 1. WL tomography requires redshifts for the source galaxies, from which we can derive the mass distribution and cosmic geometry as a function of redshift. WL thus has sensitivity to the evolution of dark energy. LSST's multi-color deep imaging survey will provide photometric redshift information for galaxies to $z \approx 3$. A combination of spectroscopy and angular correlations of galaxies can produce a calibration of photometric redshifts to the precision required to perform lensing tomography. See related posters by Jee *et al.* and Schmidt *et al.*

Baryon Acoustic Oscillations: The low-z signature of the CMB sound horizon at decoupling is a set of peaks in the galaxy power spectrum. The LSST survey will provide a sample of four billion galaxies. Photometric redshifts will be used to collect these galaxies into redshift bins, and the galaxy angular power spectrum can then be computed as a function of redshift. Simulations of the quality of the data we expect are given in Figure 2. The BAO peaks are clearly detected for redshifts ranging from $z \approx 0.3$–2.7. The corresponding angular diameter distance will be measured to ~0.4% accuracy, especially at higher redshift (Zhan, Knox, Tyson 2009 ApJ).

Shear peaks: Simulations show that LSST will detect ~100,000 giant shear peaks, potentially yielding constraints on w_0 at the 8 percent level (Fang & Haiman 2007). Like the supernova probe of dark energy, this technique has astrophysical systematics which will have to be understood if it is to be fully competitive with weak lensing and baryon acoustic oscillations.

SNe: Over a ten year run, an average ~15 minutes per night spent staring at fifty 10 square degree fields will yield SNe with a mean redshift of 0.75 and a distribution that extends to $z > 1$. A 3-5 day cadence will cycle among the five filters resident in the camera, following tens of thousands of SNe throughout their evolution with over 100 photometric points per light curve. Such detailed light curves will allow fitting for photometric redshifts from the SNe themselves. This large SN sample enables investigation of possible evolution in the "standard candle" by discovering correlations with other parameters.

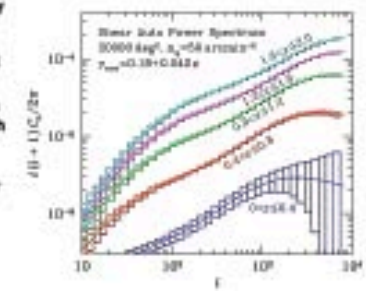


FIGURE 1: The lensing cosmic shear power spectra constructed from 5 redshift bins. Here, ℓ is the multi-pole moment of the distribution on the sky, and the vertical scale is proportional to the rms fluctuation of the power spectrum per log interval in ℓ. Only the 5 auto-power spectra of each redshift bin among the available 15 cross-spectra are displayed, and the solid curves show the predictions for the concordance ΛCDM model. The boxes show the expected 1σ measurement error due to the sample variance and intrinsic ellipticities (the sample variance is dominant at about $\ell < 1000$, while the intrinsic ellipticities are dominant at $\ell > 1000$). In fact, a larger number of redshift bins will be created by LSST leading to ~100 auto- and cross-spectra.

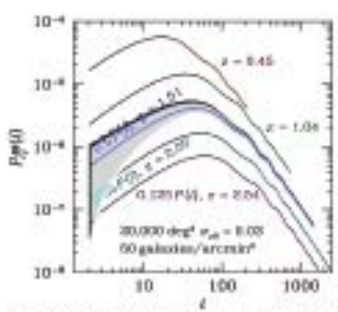


FIGURE 2: Angular galaxy auto-power spectra in 5 redshift bins (shifted for clarity). Bin width increases from 0.1 to 0.22 for the bins shown. The BAO features are prominent at multipole $\ell \sim$ several hundred. The gray area indicates the statistical error (cosmic variance and shot noise) per mode for the bin centered at $z = 1.55$. The truncation of the power spectra at high ℓ is to reduce the impact of nonlinear evolution in our forecasts.

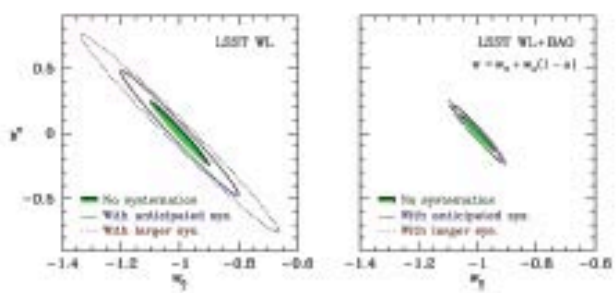


FIGURE 3: The joint WL and BAO results are less affected by the systematics because of the ability to self-calibrate. 1σ error contours of the dark energy parameters from LSST WL (*left panel*) and joint LSST WL and BAO (*right panel*). The shaded areas represent the results with statistical errors only. The solid contours correspond to those with the anticipated level of systematic errors, which include the uncertainty in the photo-z error distribution [σ_0(photo-z bias) = $0.05\sigma_{rms}$, $\sigma_1(\sigma_0) = (2/3)\,0.05\sigma_{rms}$] and additive (noise power = 10^{-6}) and multiplicative (0.5%) errors in the power spectra. These assumed photo-z systematics would require a redshift calibration sample of 2000 spectra per unit redshift interval if the photo-z error distribution was Gaussian. The dotted contours increase the shear additive error to 10^{-4} and relax the photo-z calibration requirement to 125 spectra per unit redshift. A much larger sample of 10,000 per unit z will be needed for realistic photo-zs.

The use of multiple probes may also allow us to discriminate whether dark energy is due to new physics in the stress-energy tensor or due to new gravitational physics. This is because these probes are sensitive to both the distance-redshift relation and the rate of growth of the large-scale density field. If the dynamical history of the Universe becomes well constrained by these measurements, we can use the growth of structure to constrain new gravity models.

A LIVING LSST DOCUMENT (ASTRO-PH/0805.2366); VERSION 1.0 OF MAY 15, 2008
Preprint typeset using LaTeX style emulateapj v. 03/07/07

LSST: FROM SCIENCE DRIVERS TO REFERENCE DESIGN AND ANTICIPATED DATA PRODUCTS

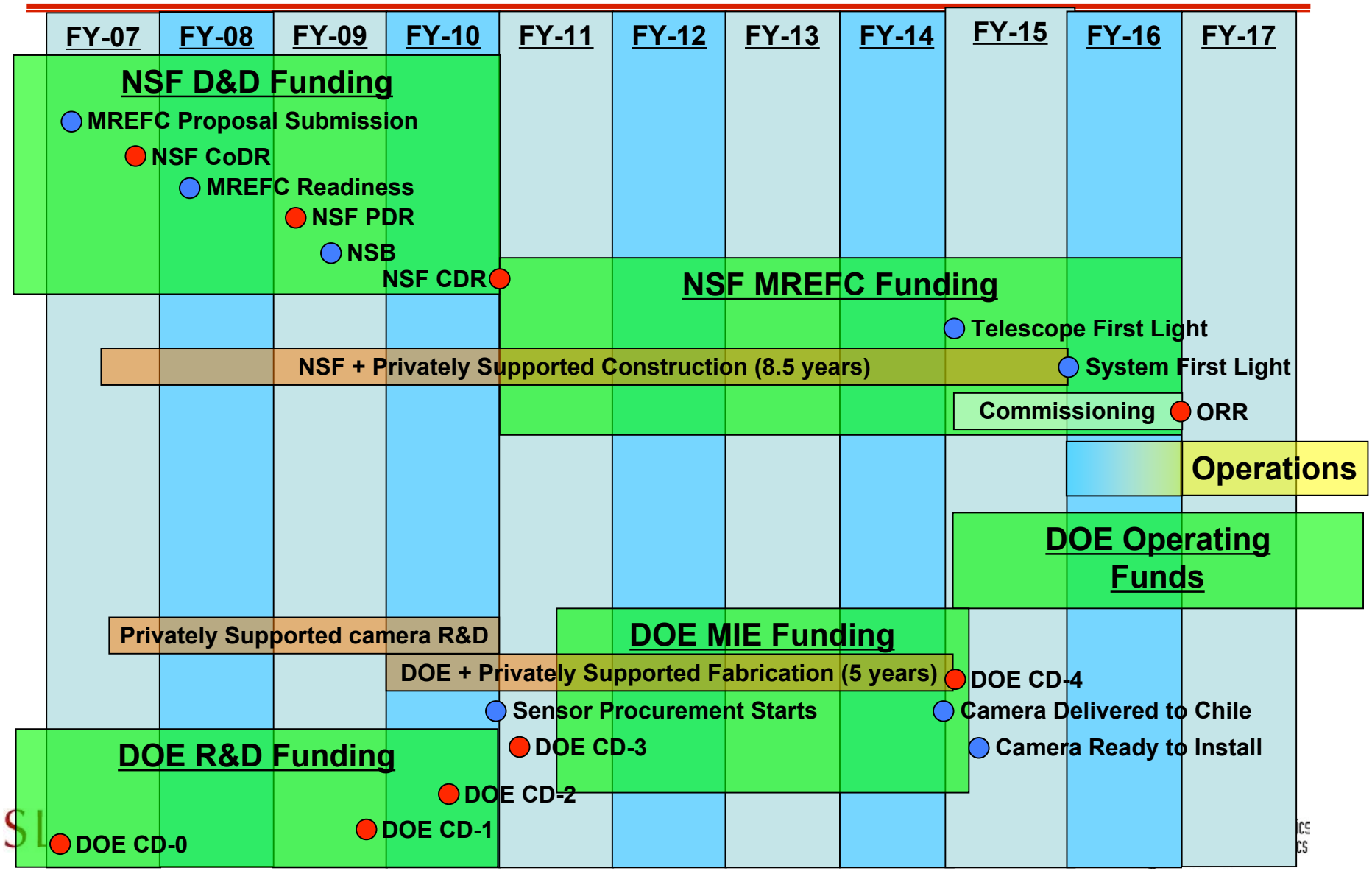
Ž. IVEZIĆ[1], J.A. TYSON[2], R. ALLSMAN[3], J. ANDREW[4], R. ANGEL[5], T. AXELROD[3], J.D. BARR[4], A.C. BECKER[1], J. BECLA[6], C. BELDICA[7], R.D. BLANDFORD[6], W.N. BRANDT[8], J.S. BULLOCK[9], D.L. BURKE[6], S. CHANDRASEKHARAN[4], S. CHESLEY[10], C.F. CLAVER[4], A. CONNOLLY[1], K.H. COOK[11], A. COORAY[9], C. CRIBBS[7], R. CUTRI[12], G. DAUES[7], F. DELGADO[13], H. FERGUSON[14], J.C. GEARY[15], P. GEE[2], D.K. GILMORE[6], W.J. GRESSLER[4], C. HOGAN[1], M.E. HUFFER[6], S.H. JACOBY[3], B. JAIN[16], J.G. JERNIGAN[17], R.L. JONES[1], M. JURIČ[18], S.M. KAHN[6], J.S. KALIRAI[19], J.P. KANTOR[3], D. KIRKBY[9], L. KNOX[2], V.L. KRABBENDAM[4], S. KRUGHOFF[1], S. KULKARNI[20], R. LAMBERT[13], D. LEVINE[12], M. LIANG[4], K-T. LIM[6], R.H. LUPTON[21], P. MARSHALL[22], S. MARSHALL[6], M. MAY[24], M. MILLER[4], D.J. MILLS[4], D.G. MONET[23], D.R. NEILL[4], M. NORDBY[6], P. O'CONNOR[24], J. OLIVER[25], S.S. OLIVIER[11], R.E. OWEN[1], J.R. PETERSON[26], C.E. PETRY[5], F. PIERFEDERICI[3], S. PIETROWICZ[7], R. PIKE[27], P.A. PINTO[5], R. PLANTE[7], V. RADEKA[24], A. RASMUSSEN[6], W. ROSING[28], A. SAHA[4], T.L. SCHALK[29], R.H. SCHINDLER[6], D.P. SCHNEIDER[8], G. SCHUMACHER[13], J. SEBAG[4], L.G. SEPPALA[11], I. SHIPSEY[25], N. SILVESTRI[1], J.A. SMITH[30], R.C. SMITH[13], M.A. STRAUSS[21], C.W. STUBBS[25], D. SWEENEY[3], A. SZALAY[31], J.J. THALER[32], D. VANDEN BERK[8], M. WARNER[13], B. WILLMAN[25], D. WITTMAN[2], S.C. WOLFF[4], W.M. WOOD-VASEY[25], AND H. ZHAN[2], FOR THE LSST COLLABORATION

A living LSST document (astro-ph/0805.2366); version 1.0 of May 15, 2008

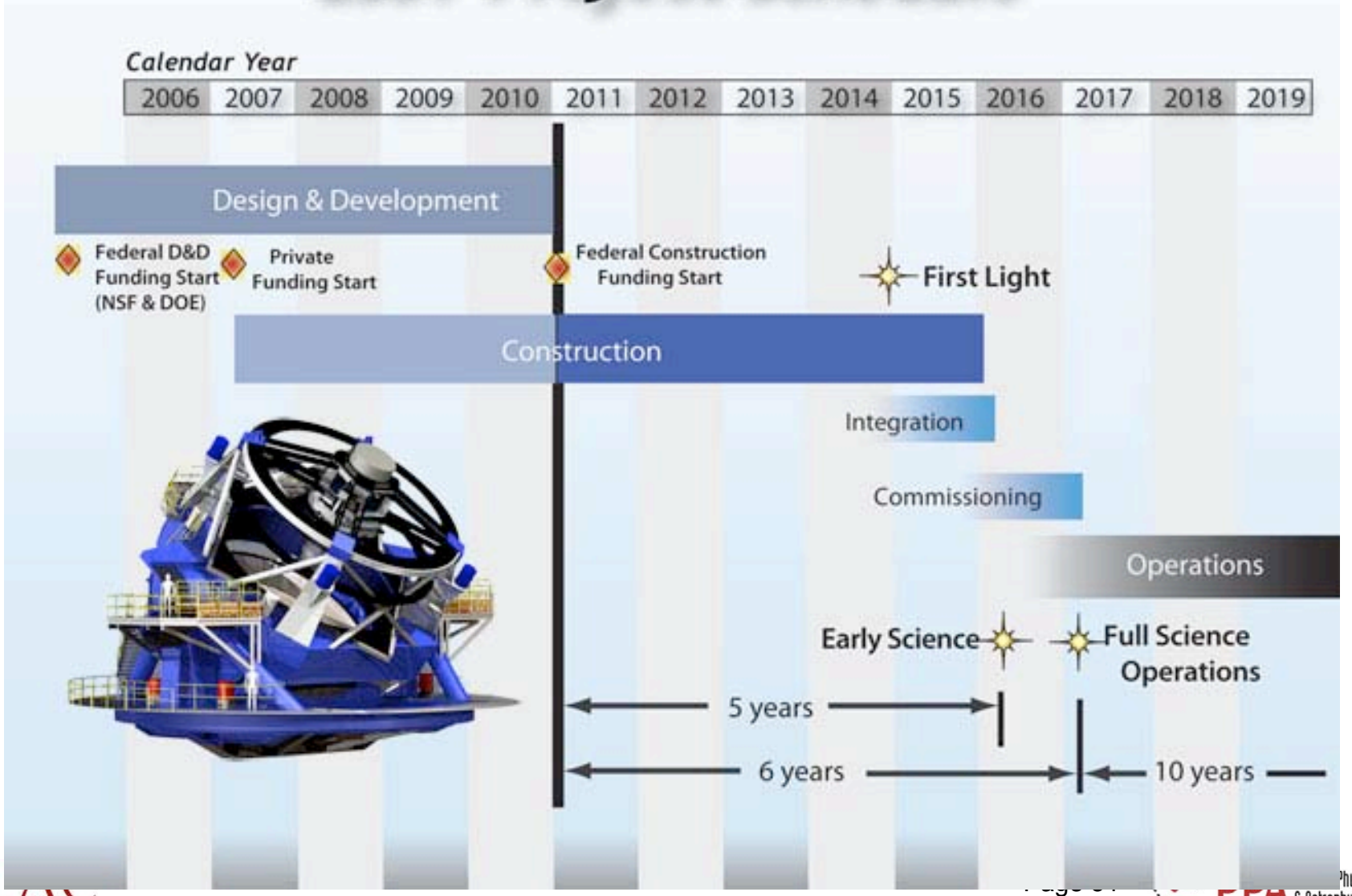
ABSTRACT

In the history of astronomy, major advances in our understanding of the Universe frequently arise from dramatic improvements in our ability to accurately measure astronomical quantities. Aided by rapid progress in information technology, current sky surveys are changing the way we view and study the Universe. Next-generation surveys will maintain this revolutionary progress. We focus here on the most ambitious survey currently planned in the visible band, the Large Synoptic Survey Telescope (LSST). LSST will have unique survey capability in the faint time domain. The LSST design is driven by four main science themes: probing dark energy and dark matter, taking an inventory of the Solar System, exploring the transient optical sky, and mapping the Milky Way. LSST will be a large, wide-field ground-based system designed to obtain multiple images covering the sky that is visible from Cerro Pachón in Northern Chile. The current baseline design, with an 8.4m (6.5m effective) primary mirror, a 9.6 deg^2 field of view, and a 3.2 Gigapixel camera, will allow about 10,000 square degrees of sky to be covered using pairs of 15-second exposures in two photometric bands every three nights on average, with typical 5ϵ depth for point sources of $r \sim 24.5$. The system is designed to yield high image quality as well as superb astrometric and photometric accuracy. The survey area will include 30,000 deg^2 with $\epsilon < +34.5°$, and will be imaged multiple times in six bands, *ugrizy*, covering the wavelength range 320–1050 nm. The project is scheduled to have first light in 2014 and the beginning of survey operations in 2015. About 90% of the observing time will be devoted to a deep-wide-fast

The current LSST timeline



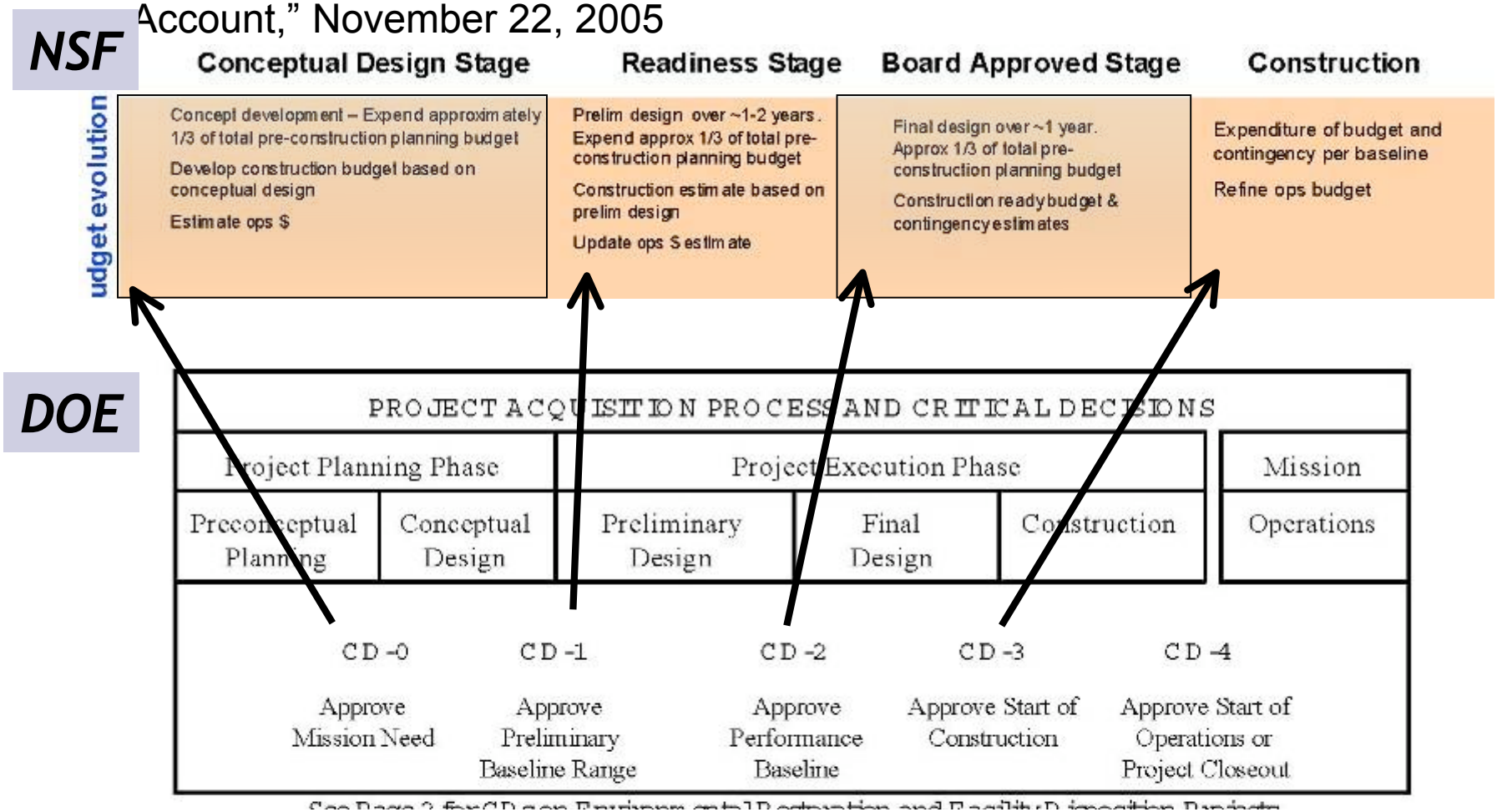
LSST Project Schedule



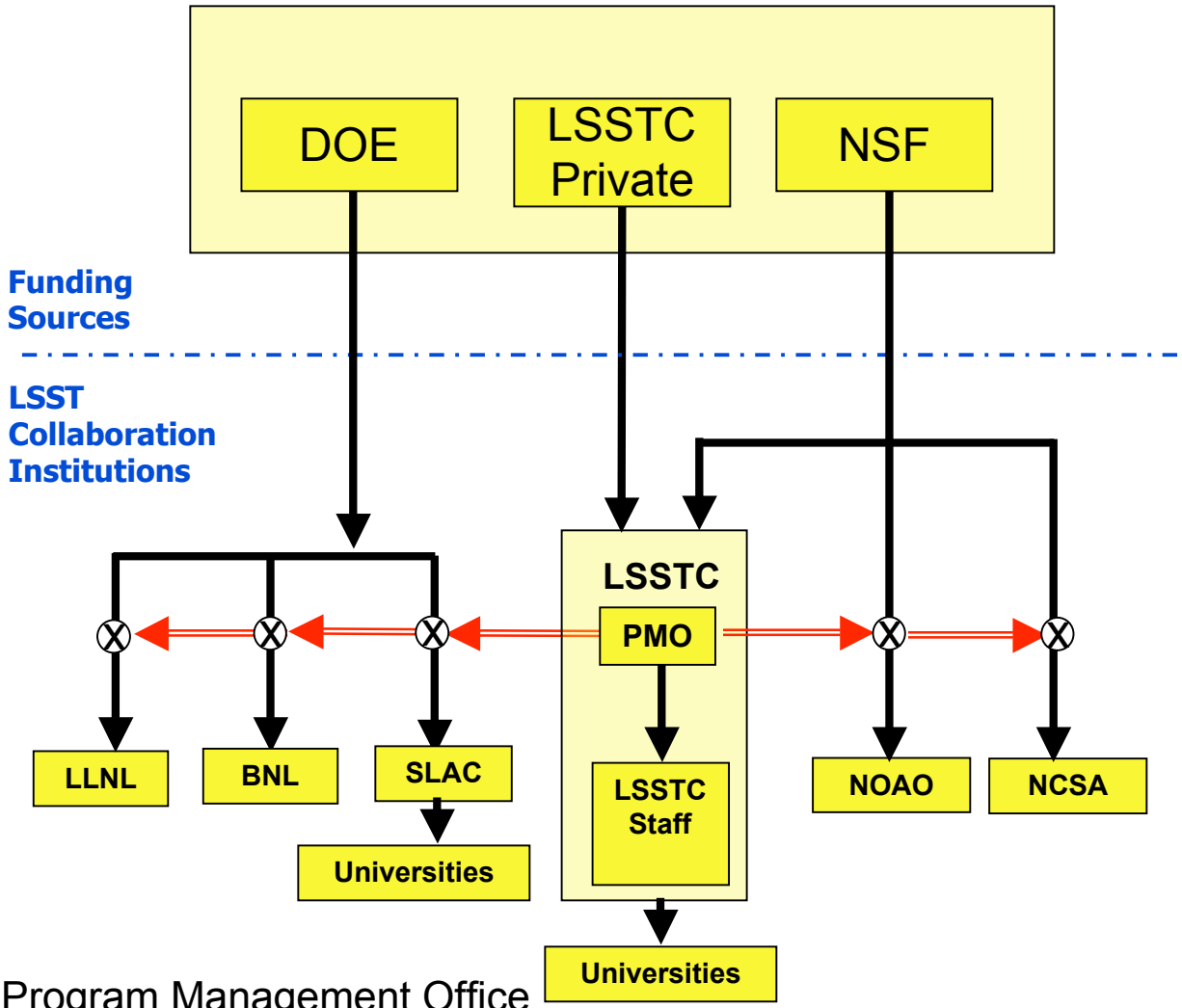
Coordinating the NSF and DOE Support

* DOE follows: Program and Project Management for the Acquisition of Capital Assets," DOE Order 413.3

* NSF follows new policy modeled in-part after DOE model: "Guideline for Planning and Managing the Major Research Equipment and Facilities Construction Account," November 22, 2005

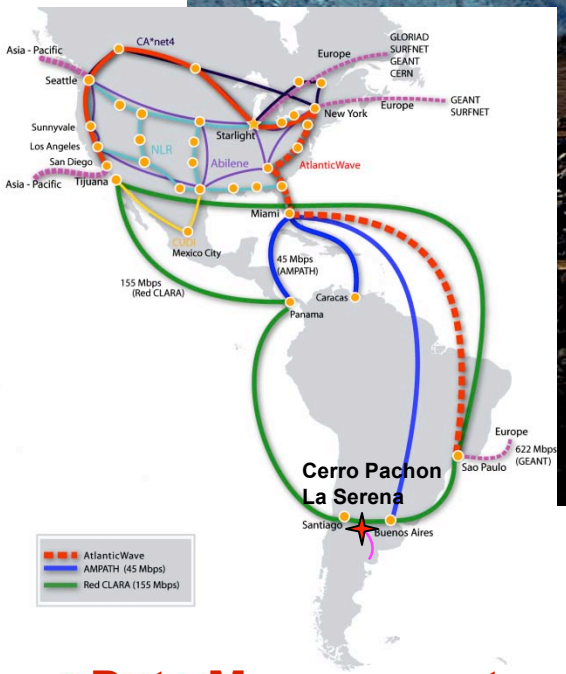


Funding and management configuration



PMO: Program Management Office

The LSST Project is a Complete System:
Image, Analysis, Archive, Publish and Outreach



Data Management

Education and Public Outreach

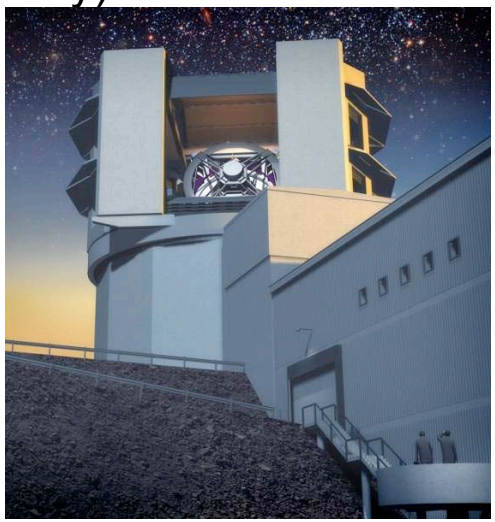
http://www.lsst.org

PPA Particle Physics & Astrophysics

LSST has submitted an NSF proposal for $242 M of Construction funding

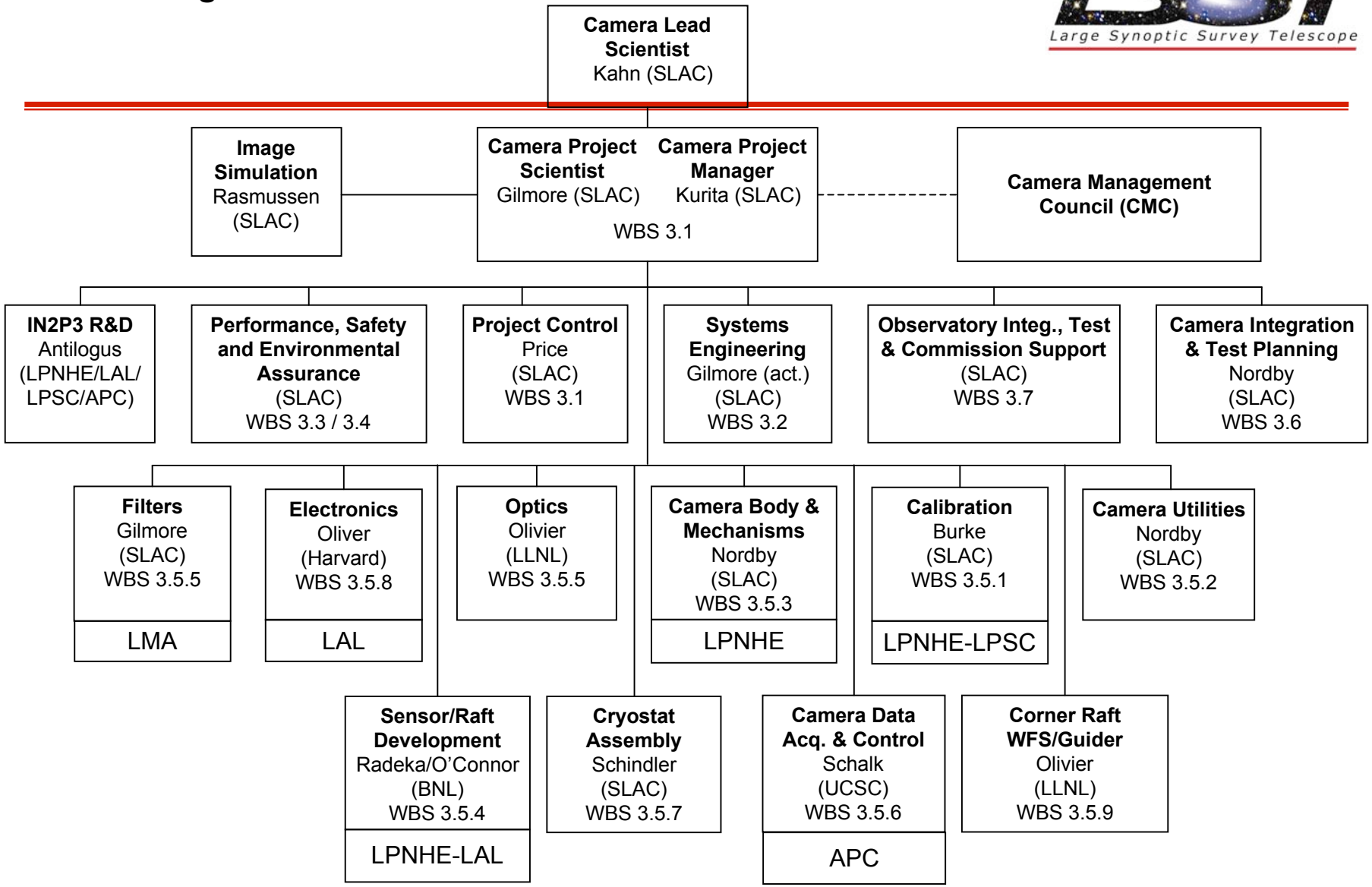
* Construction proposal submitted in February 2007
  - 60 Month Construction and Commissioning
  - Ready for MREFC Funds in FY2010 - Expect in FY 2011
  - Proposed as Public Private Partnership to Share costs
    - **NSF MREFC - $242 M**
    - **DOE HEP - $50 M**
    - **Private - $100 M**

(FY06 $ with Contingency)

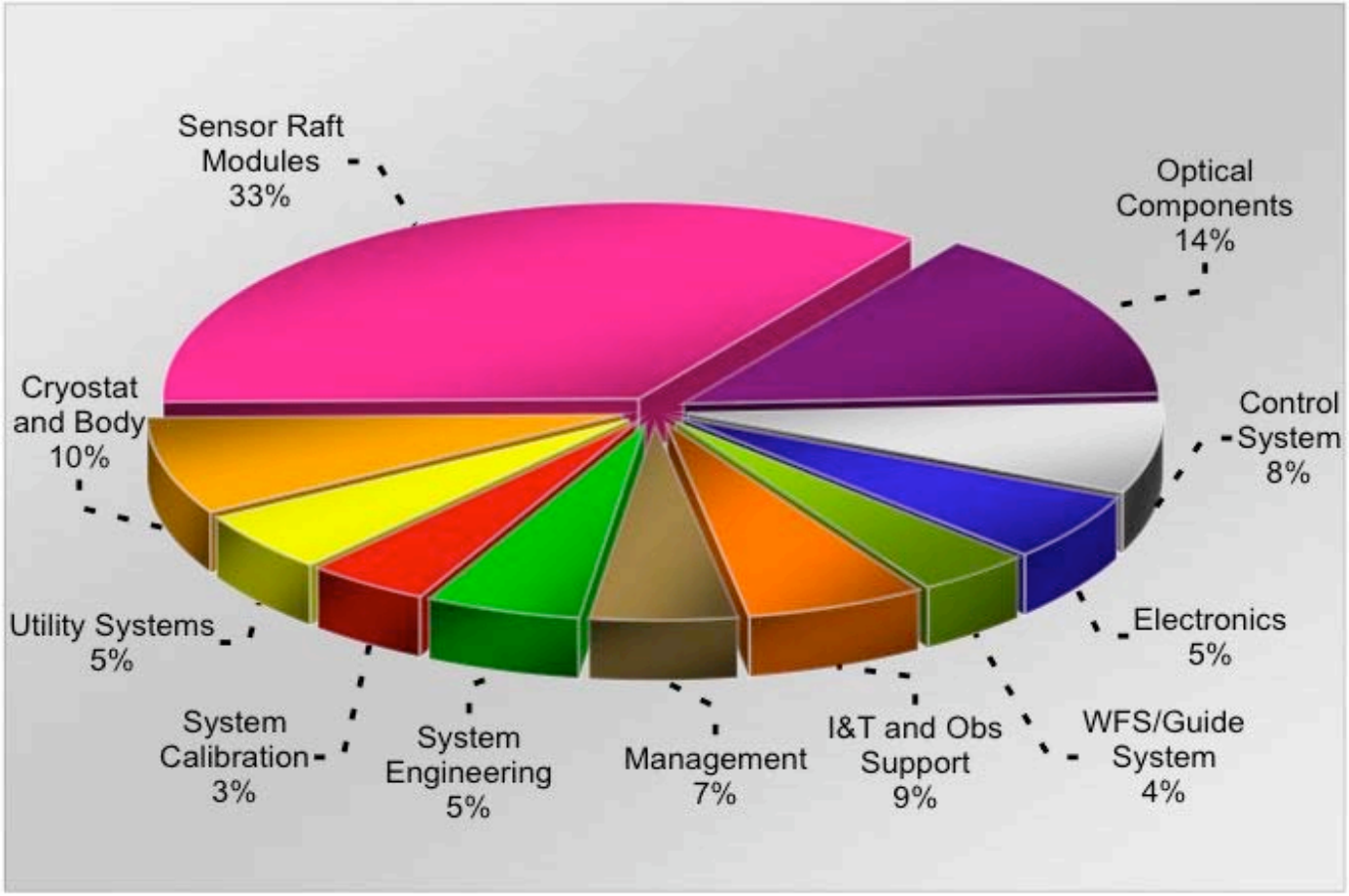


* Current Design and Development
  - NSF 4yr Award = $14.2 M
  - DOE Lab Participation
  - Partner In-Kind
  - Private Donation
* Operations and Maintenance
  - Summit, Base, Archive, Data Centers = $45 M/yr (2016)

Camera Organizational Chart

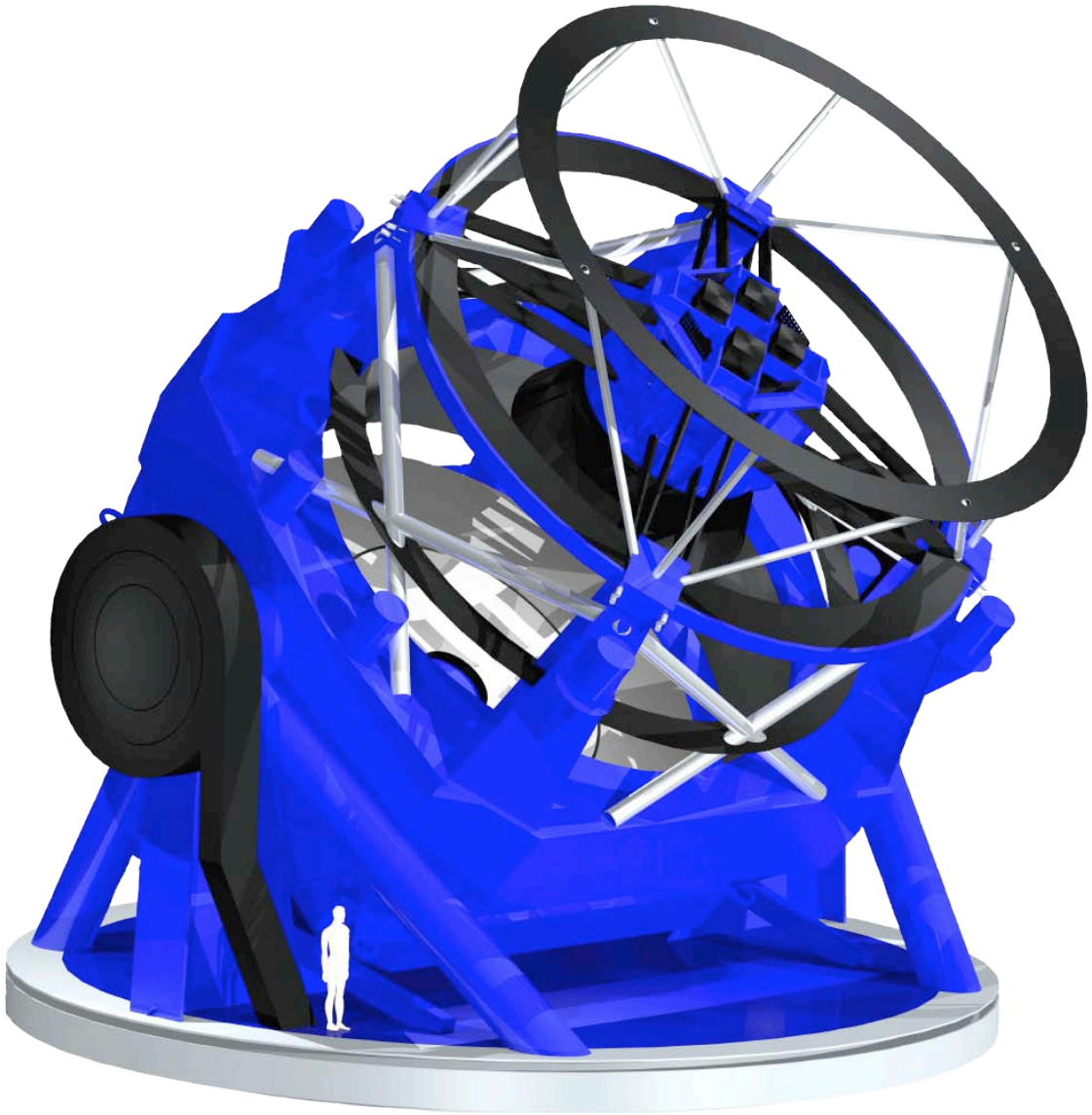


Camera construction costs by sub-system



LSST Concept

Design Telescope and Camera as a Single Instrument

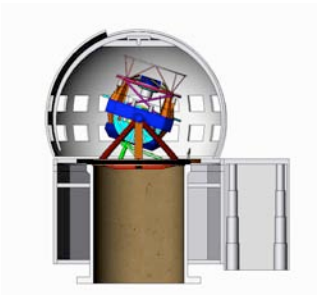


- 8.4 Meter Primary Aperture
  - 3.4 M Secondary
  - 5.0 M Tertiary
- 3.5 degree Field Of View
- 3 Gigapixel Camera
  - 4k x 4k CCD Baseline
  - 65 cm Diameter
  - Six Filters
- 30 Second Cadence
  - Highly Dynamic Structure
  - Highly Parallel Readout
- Accumulated depth ~27 mag. in each filter over 10y
- Data Storage and Pipelines ~ 18Tb/night!

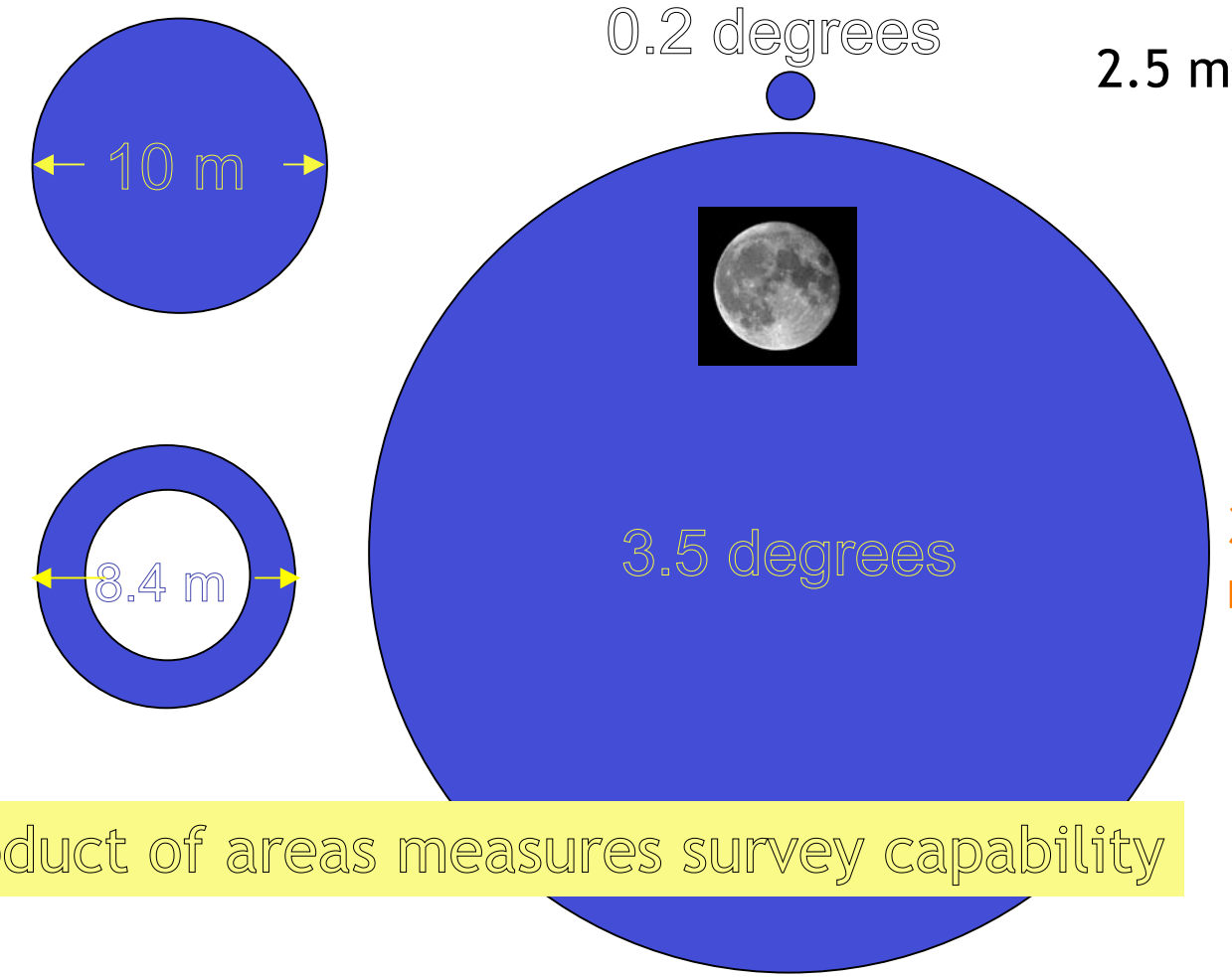
The LSST has enormous light gathering capability for its surveying mission

Primary mirror area x Field of view area (full moon is 0.5 degrees) = Etendue

Keck Telescope



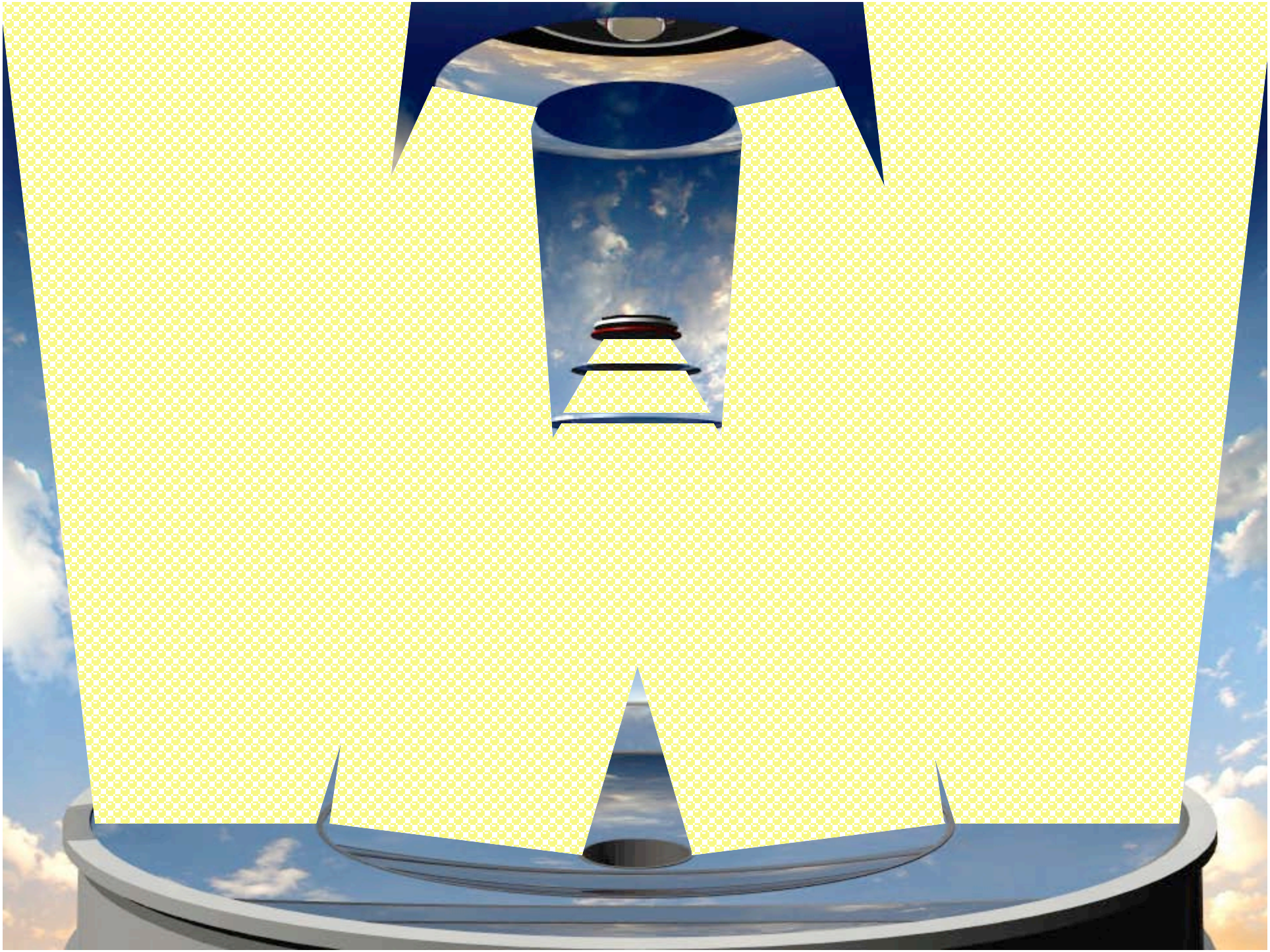
LSST



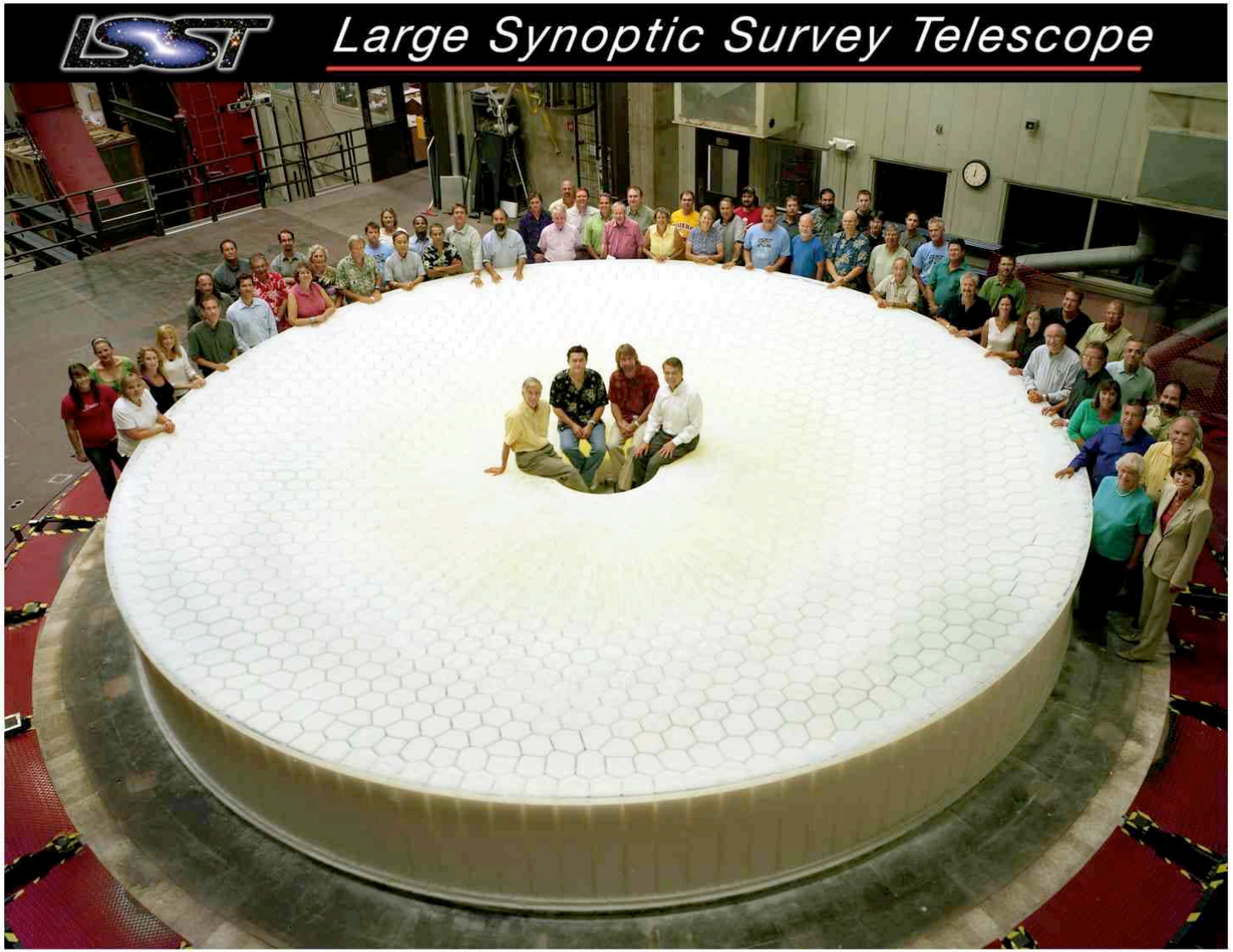
2.5 m^2deg^2

318 m^2deg^2

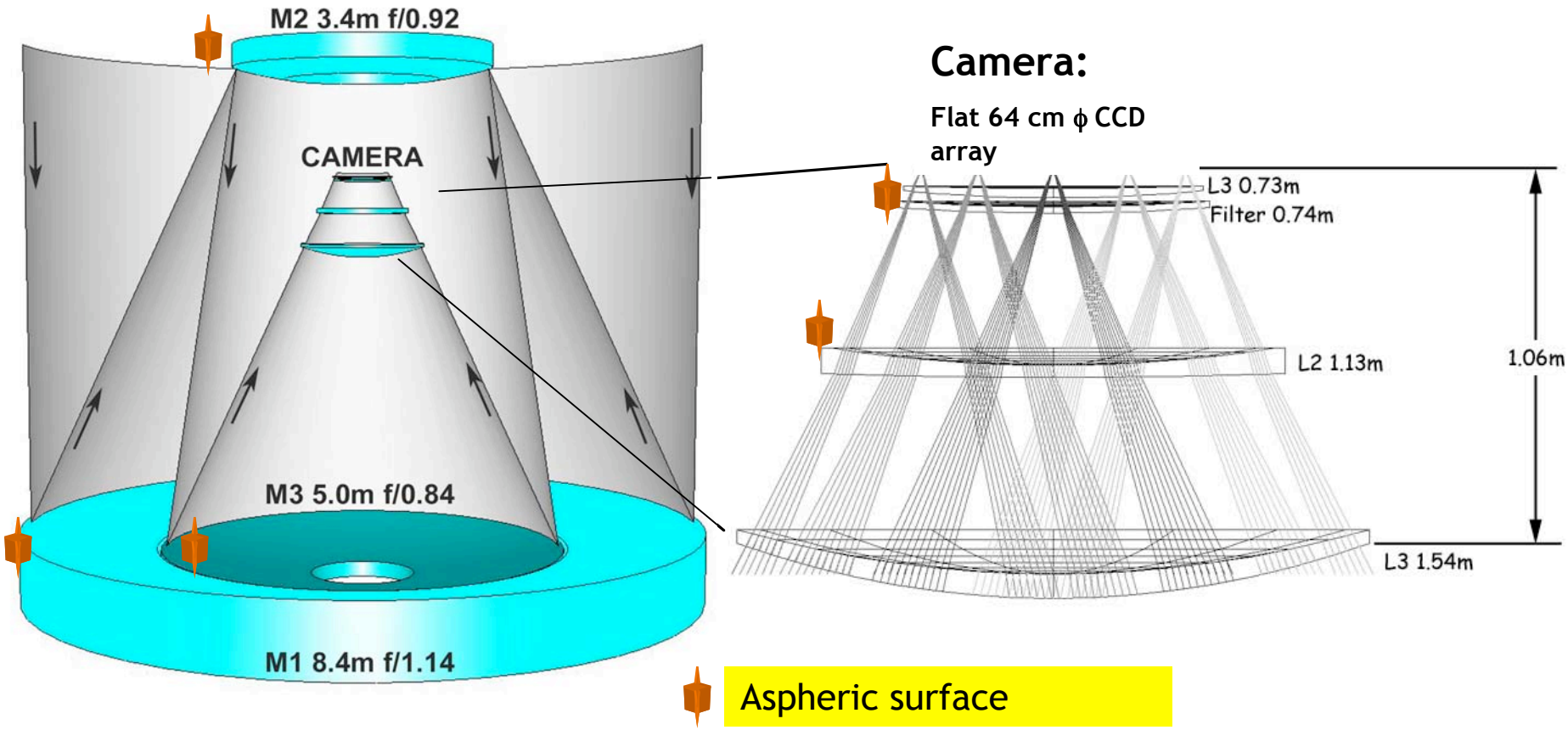
Product of areas measures survey capability



LSST Primary Mirror Blank, September 2008



LSST is a "seeing limited" telescope with ~10 micron (0.2 arc-sec) diameter images



"good" seeing" star image

0.6", 30 μm

10 μm pixel

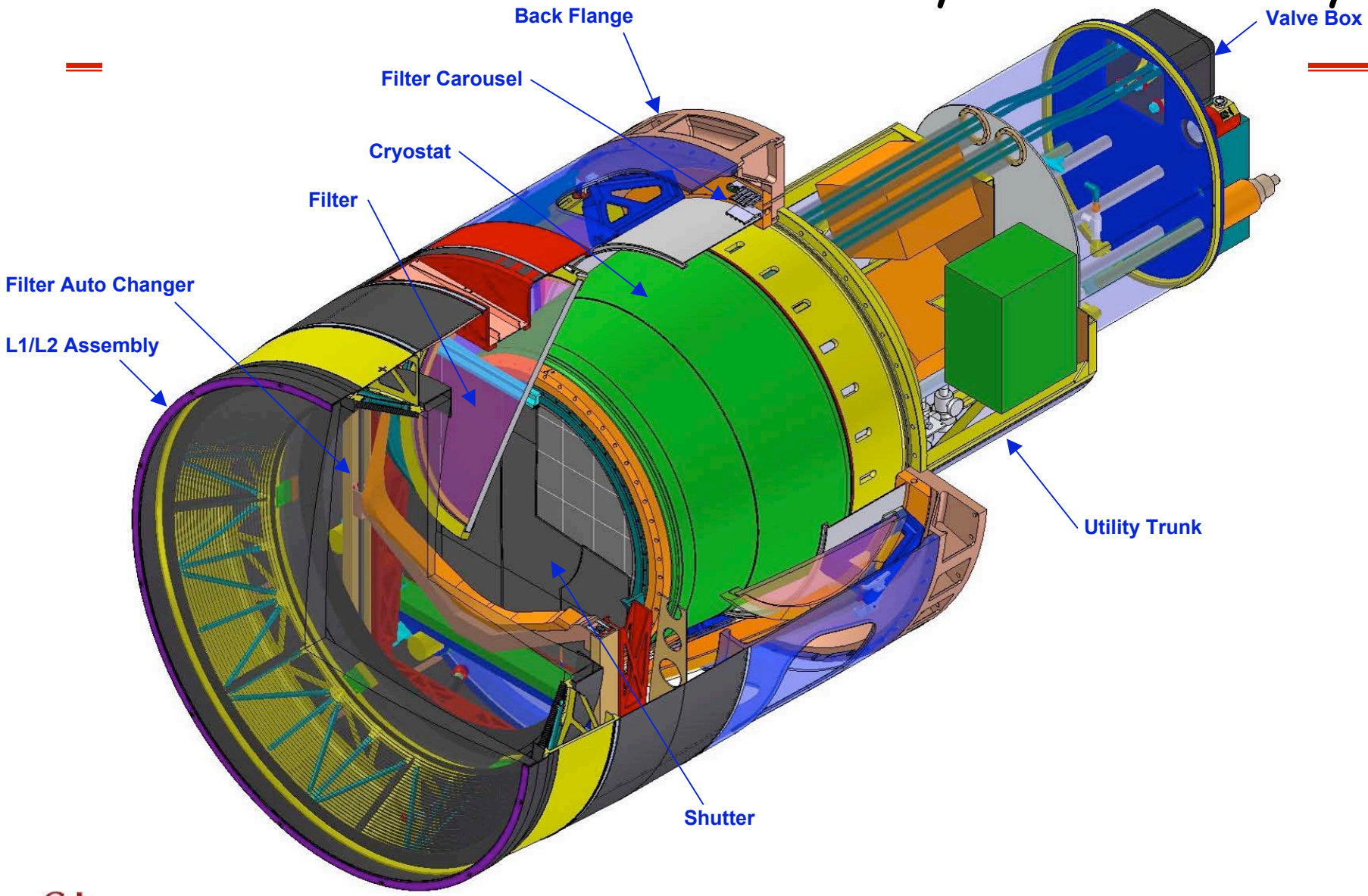
Four Main Science Themes for LSST

1. Constraining Dark Energy and Dark Matter
2. Taking an Inventory of the Solar System
3. Exploring the Transient Optical Sky
4. Mapping the Milky Way

Major Implications to the Camera

1. Large Etendue
2. Excellent Image Quality and Control of PSF Systematics
3. High Quantum Efficiency over the Range 320 – 1,050 nm
4. Fast Readout

LSST camera consists of the cryostat and body



The LSST Camera Team: 72 People from 16 Institutions

Brandeis University

J. Besinger, K. Hashemi

Brookhaven National Lab

S. Aronson, C. Buttehorn, J. Frank, J. Haggerty, I. Kotov, P. Kuczewski, M. May, P. O'Connor, S. Plate, V. Radeka, P. Takacs

Florida State University

Horst Wahl

Harvard University

N. Felt, J. Geary (CfA), J. Oliver, C. Stubbs

IN2P3 - France

R. Ansari, P. Antilogus, E. Aubourg, S. Bailey, A. Barrau, J. Bartlett, R. Flaminio, H. Lebbolo, M. Moniez, R. Pain, R. Sefri, C. de la Taille, V. Tocut, C. Vescovi

Lawrence Livermore National Lab

S. Asztalos, K. Baker, S. Olivier, D. Phillion, L. Seppala, W. Wistler

Oak Ridge National Laboratory

C. Britton, Paul Stankus

Ohio State University

K. Honscheid, R. Hughes, B. Winer

Purdue University

K. Ardnt, Gino Bolla, J, Peterson, Ian Shipsey

Rochester Institute of Technology

D. Figer

Stanford Linear Accelerator Center -

G. Bowden, P. Burchat (Stanford), D. Burke, M. Foss, K. Fouts, K. Gilmore, G. Guiffre, M. Huffer, S. Kahn (Stanford), E. Lee, S. Marshall, M. Nordby, M. Perl, A. Rasmussen, R. Schindler, L. Simms (Stanford), T. Weber

University of California, Berkeley

J.G. Jernigan

University of California, Davis

P. Gee, A. Tyson

University of California, Santa Cruz

T. Schalk

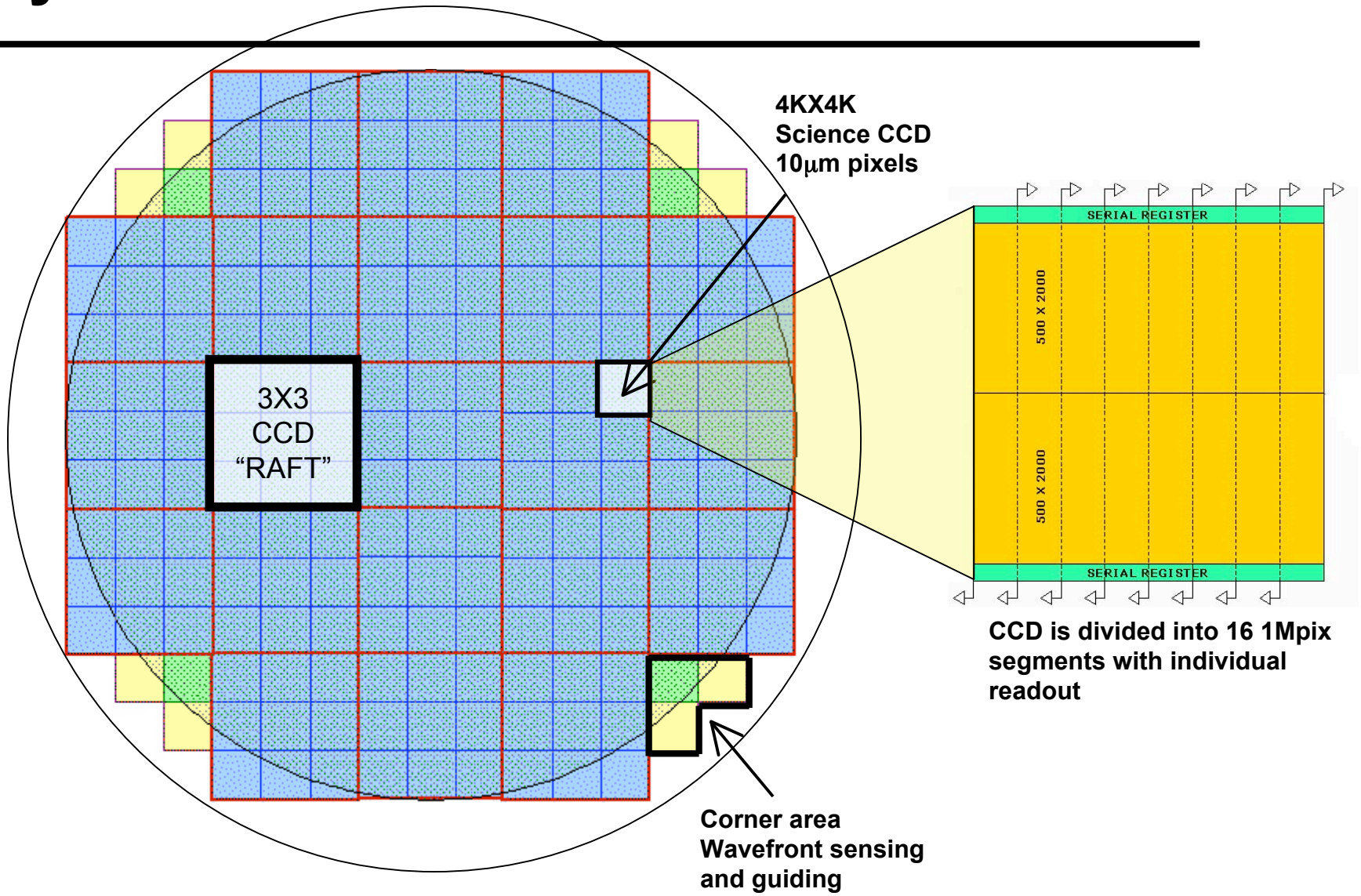
University of Illinois, Urbana-Champaign

J. Thaler

University of Pennsylvania

M. Newcomer, R. Van Berg

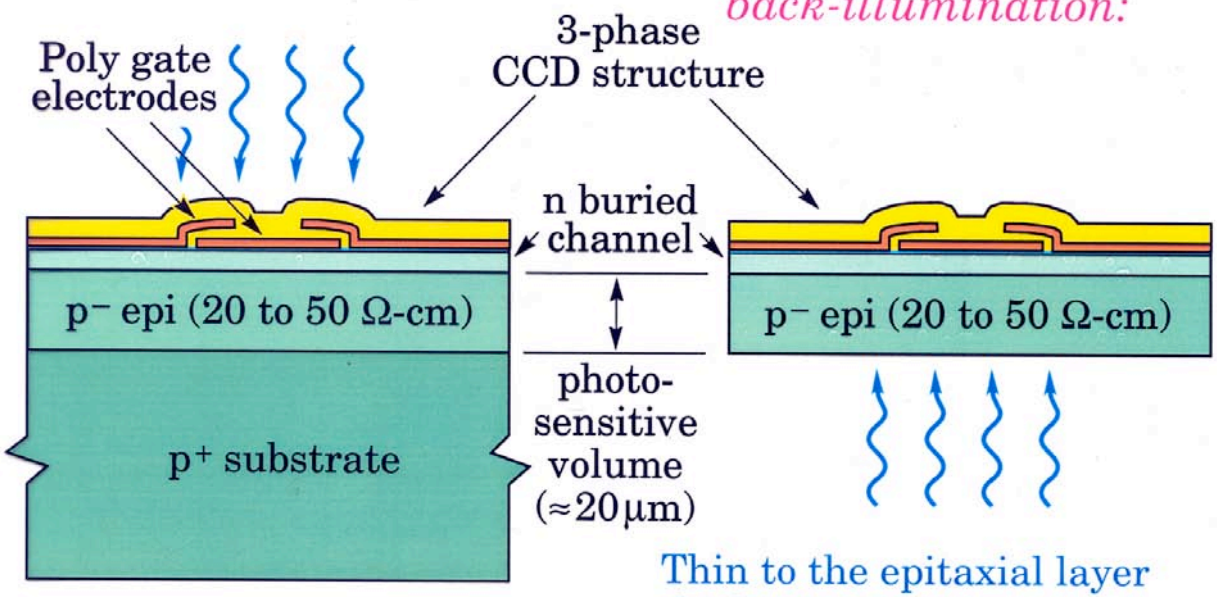
LSST focal plane layout



Detector Evolution

Front-illuminated CCD:

Thinned CCD with back-illumination:



Thin to the epitaxial layer thickness (≈20 μm)

Drawbacks:

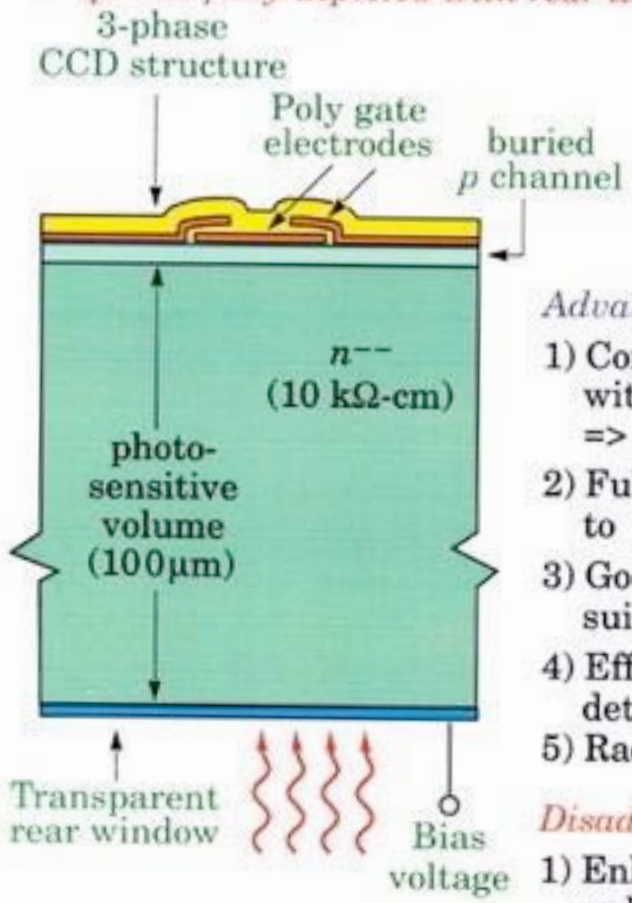
1) Poor blue response due to absorption in polysilicon gate electrodes
2) Poor near-IR response due to thinness of the epitaxial layer
3) Interference patterns due to gate structure

Drawbacks:

1) Thinning is difficult and expensive
2) Associated flatness problems
3) Requires back-side charging
4) Poor near-IR response
5) Interference (fringing)
6) Lateral diffusion in field-free region (degraded PSF)
7) *e* buildup at rear surface locally inverts field

State of the Art Detector

Make a thick CCD on a high-resistivity n-type substrate, to operate fully depleted with rear illumination.



Advantages:

1) Conventional MOS processes with no thinning => "inexpensive"
2) Full quantum efficiency to > 1 μm => no fringing
3) Good blue response with suitably designed rear contact
4) Efficient low-energy x-ray detector
5) Radiation hard?

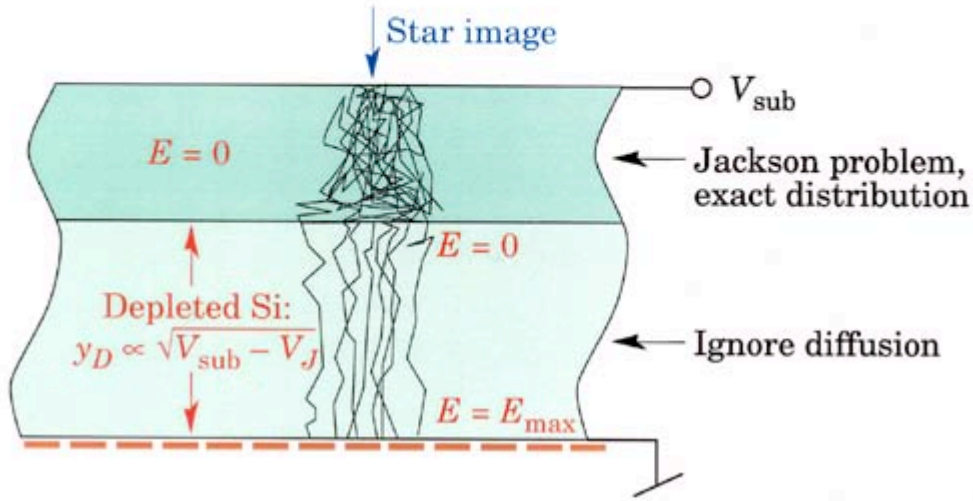
Disadvantages:

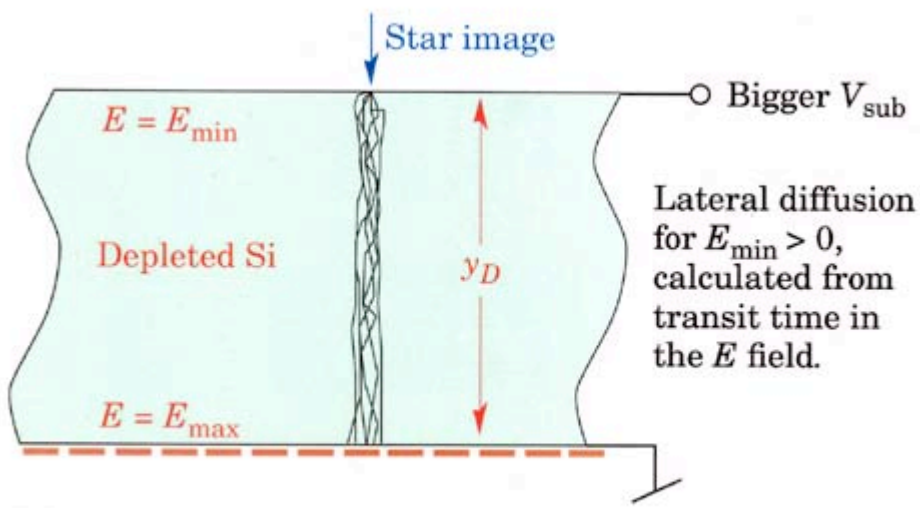
1) Enhanced sensitivity to radiation (x-rays, cosmic rays, radioactive decay)

Making thick, backside-biased detectors work

Issue 2: Spatial resolution

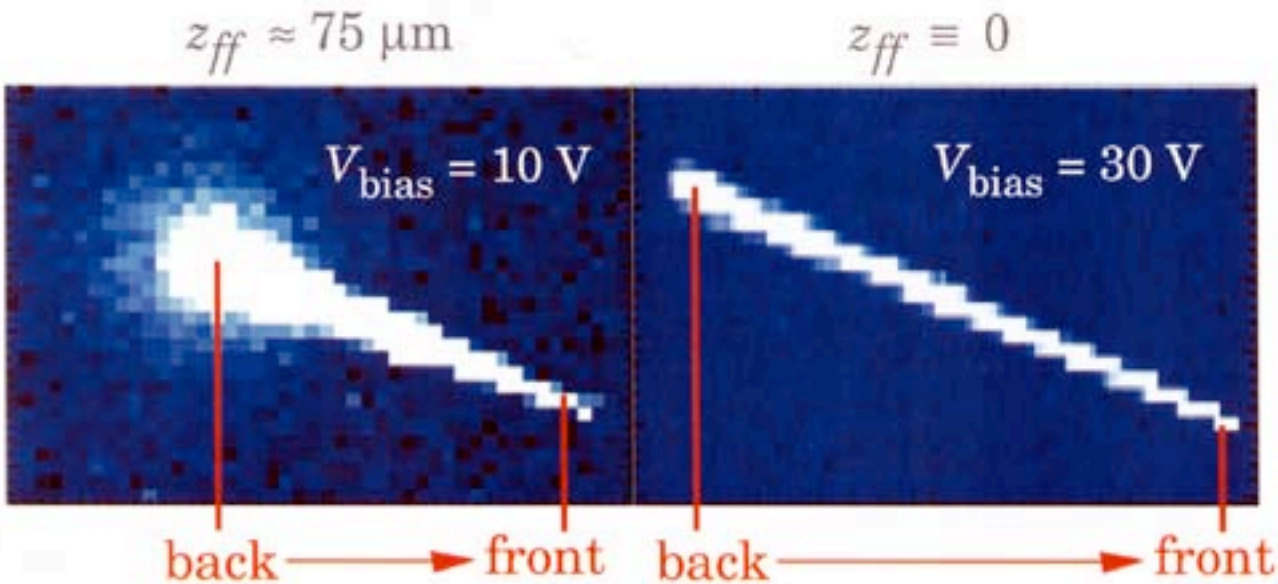
(diffusion of photo-generated holes during drift from back to potential wells)





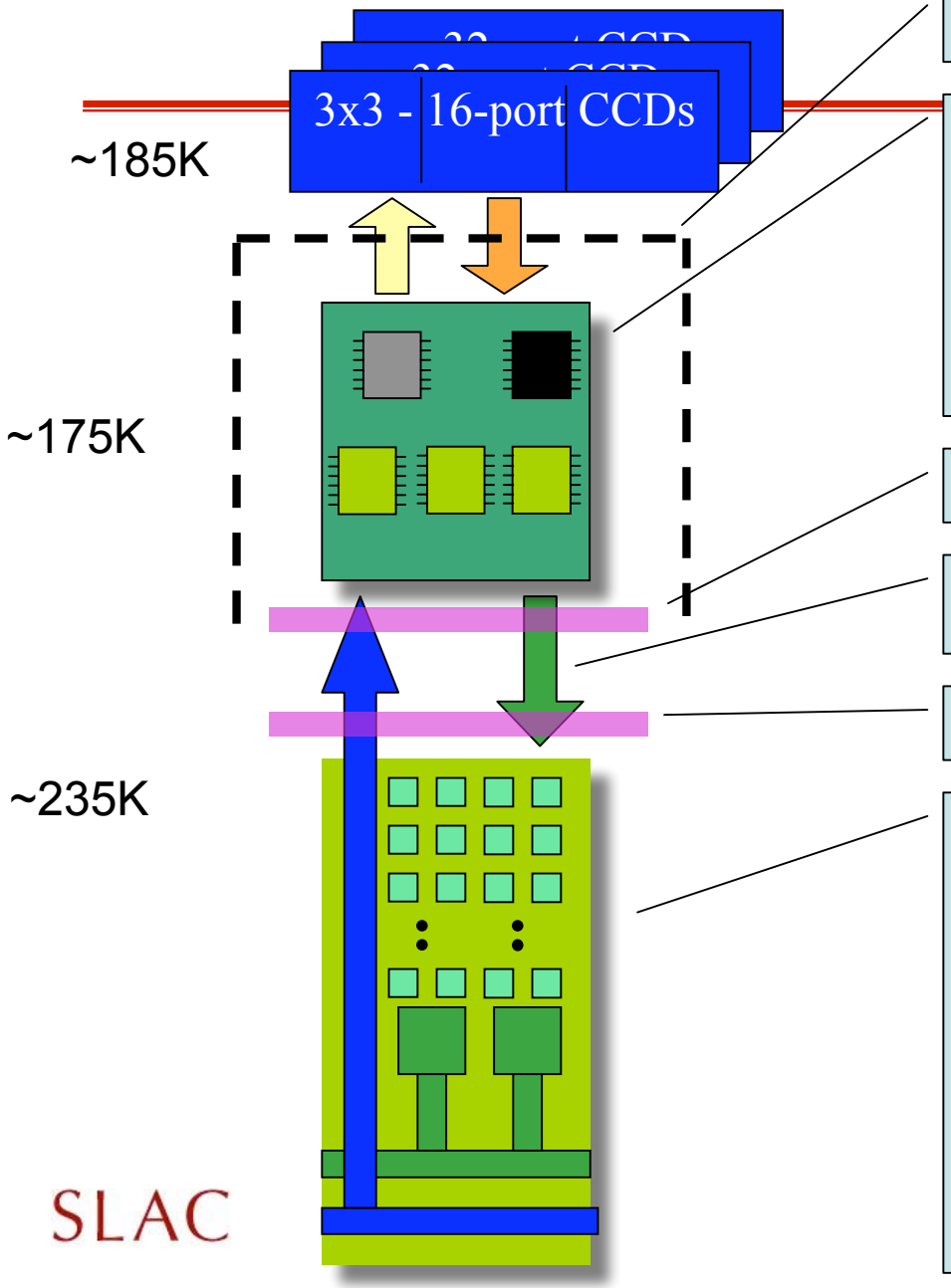
Lateral diffusion (MTF) in the field-free region (thickness z_{ff}) *IS* an important issue; in most astro CCDs it makes the PSF much larger than a pixel

It's very easily seen in slanted cosmic ray muon tracks:



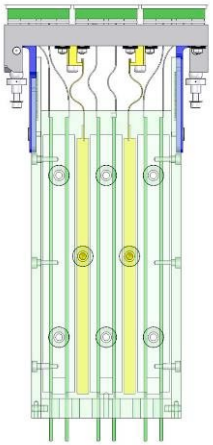
(Examples obtained with a UC/LBNL CCD with a 300 μm sensitive region)

Raft tower electronics partitioning



Molecular Flow Barrier

Front End Boards (6 per raft):
- 144-channels of video signal chain through CDS processing
- clock and bias drive
- ASIC-based (ASPIC/SCC)



Cryo Plate (~170k)

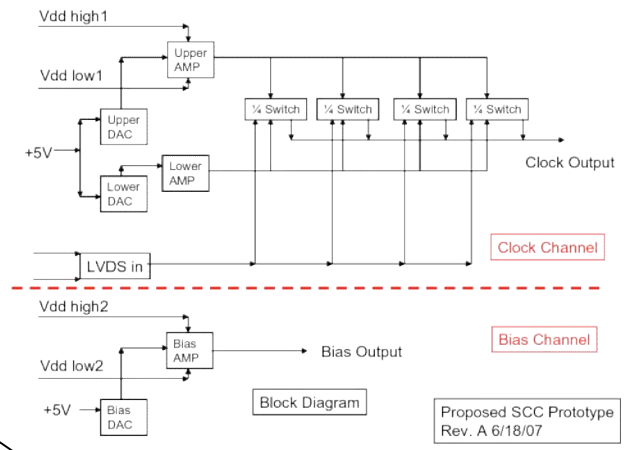
Flex cables (~ 500 signals)

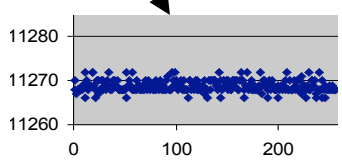
Cold Plate (~230k)

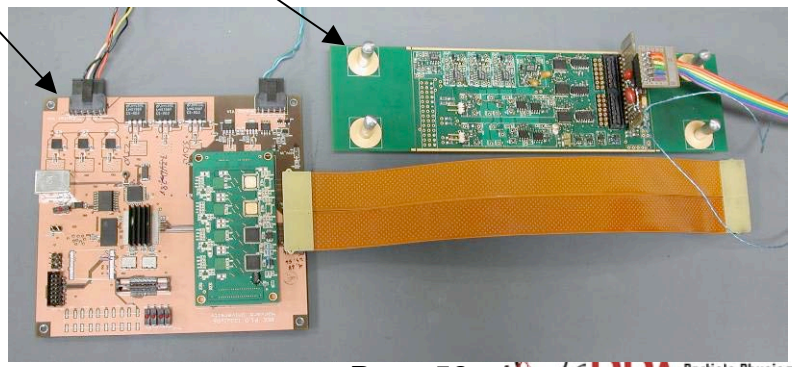
BEE motherboard and backplane:
- differential receiver
- signal chain ADC (16+ bits)
- buffers
- data transport to optical fiber
- clock pattern generation
- clock and bias DACs
- temperature monitor / control

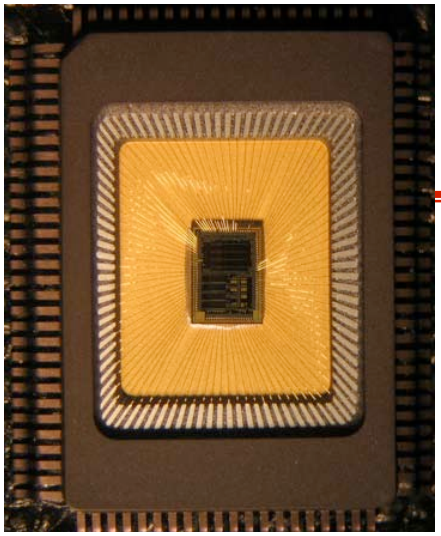
Electronics Prototyping

* Noise < 5 e- r.m.s.
* Nonlinearity < 5% from 100e- to full well
* Crosstalk < 0.01%
* ASIC Developments
  - ASPIC – IN2P3 - CMOS - P/A, CDS, Driver - submitted 7/25/07
  - SCC – ORNL - CMOS – Bias Generator, Clock Driver – submitted 8/30/07
* Discrete Prototypes
  - FEE – Penn – Commercial parts – P/A, CDS, Driver, Bias, Clock, Cold capable
  - BEE – Harvard – Commercial parts – ADC, Timing Gen, Data Out
  - Now in joint test – Present noise result is 1.3 ADC Units (~3 e-) rms - no sensor
  - Add charge injection
  - Add real CCD
  - Go to ASIC versions





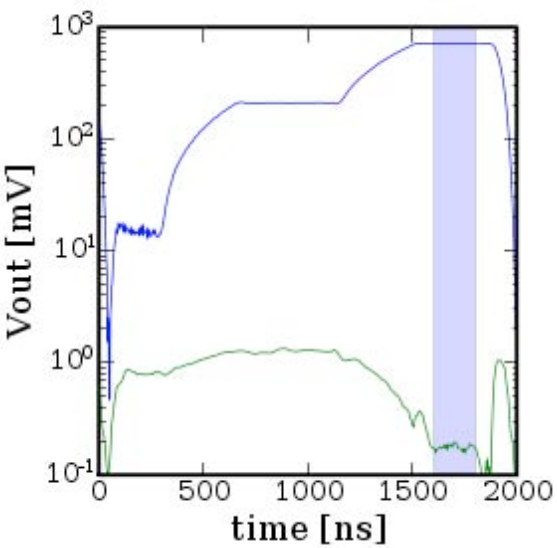




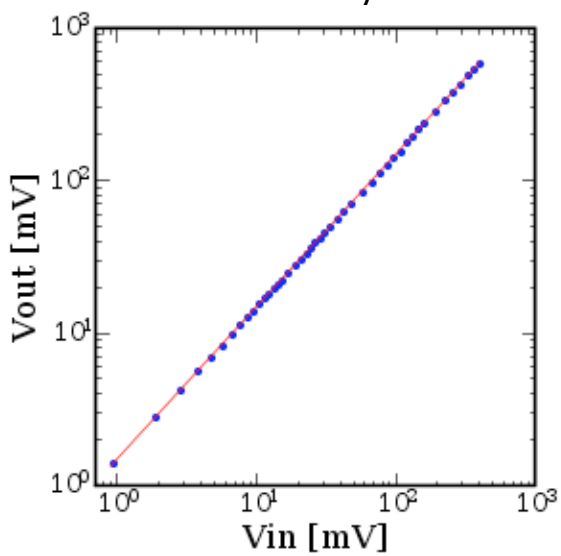
ASPIC - Analog Signal processer

- 8-channel CCD readout ASIC developed in France (LAL/LPNHE)
  - Dual-Slope Integration and Clamp & Sample implemented for comparison
- Channel cross talk < 0.01% (hardest requirement fulfilled)
- Linearity better than 0.5% from 1 - 400 mV input (require 1%)
- Noise properties under study

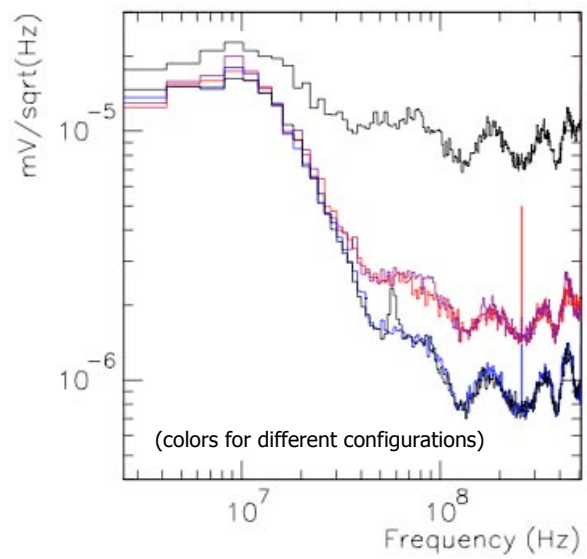
Crosstalk



Linearity



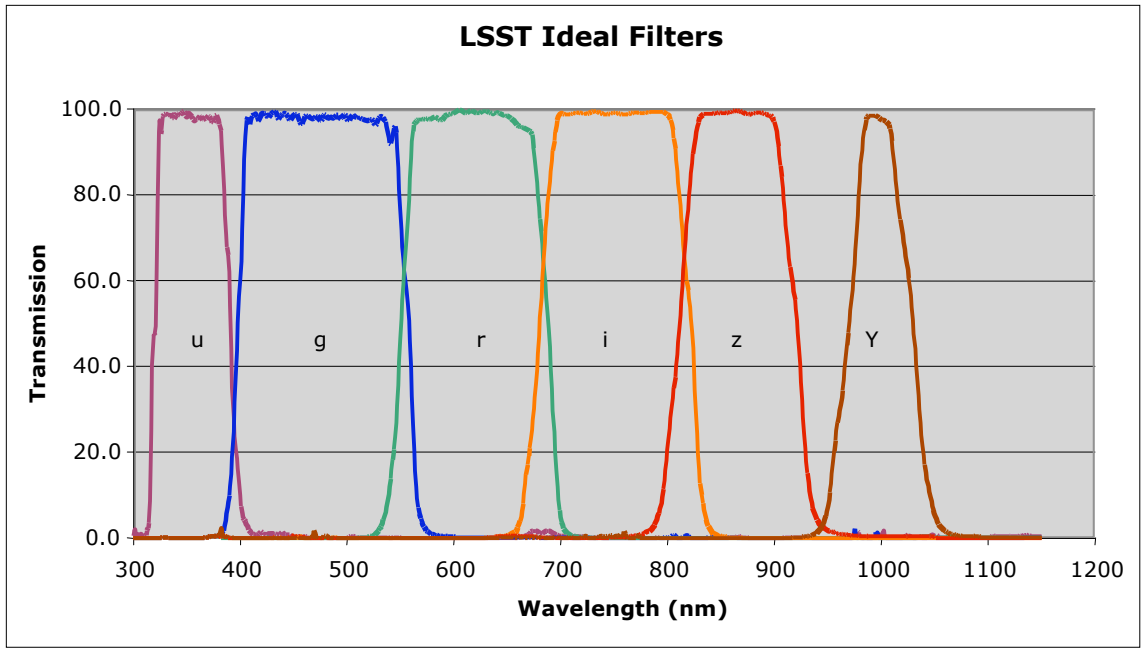
Noise



Optical Design: Filter Reference Design

Half-Maximum Transmission Wavelength			
	Blue Side	Red Side	Comments
U	330	400	Blue side cut-off depends on AR coating
G	400	552	Balmer break at 400 nm
R	552	691	Matches SDSS
I	691	818	Red side short of sky emission at 826 nm
Z	818	922	Red side stop before H_2O bands
Y	930	1070	Red cut-off before detector cut-off

- 75 cm dia.
- Curved surface
- Filter is concentric about the chief ray so that all portions of the filter see the same angle of incidence range, 14.2º to 23.6º

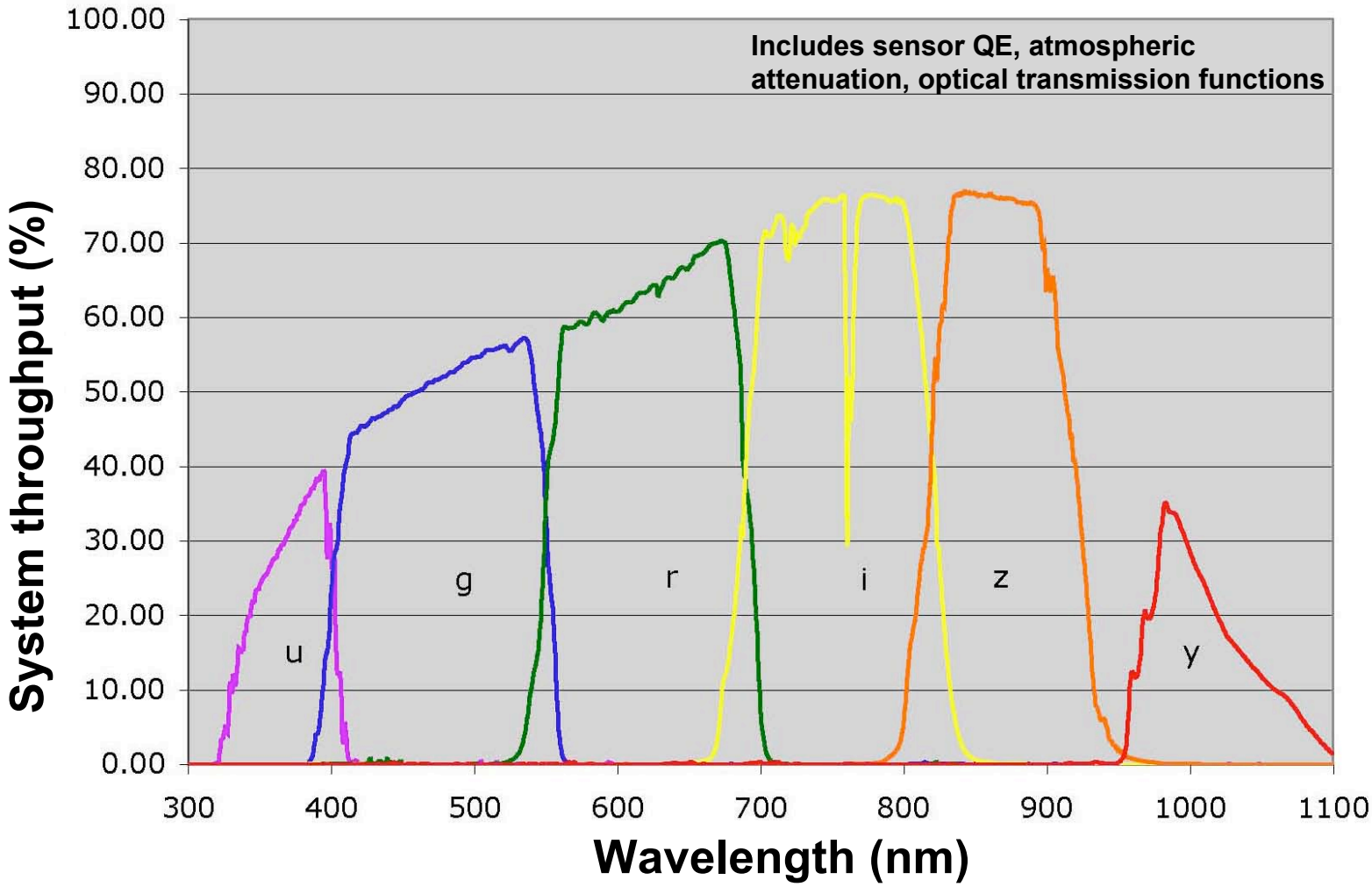


Uniform deposition required at 1% level over entire filter

Filter Band Pass Transitions

LSST system spectral throughput in the six filter bands

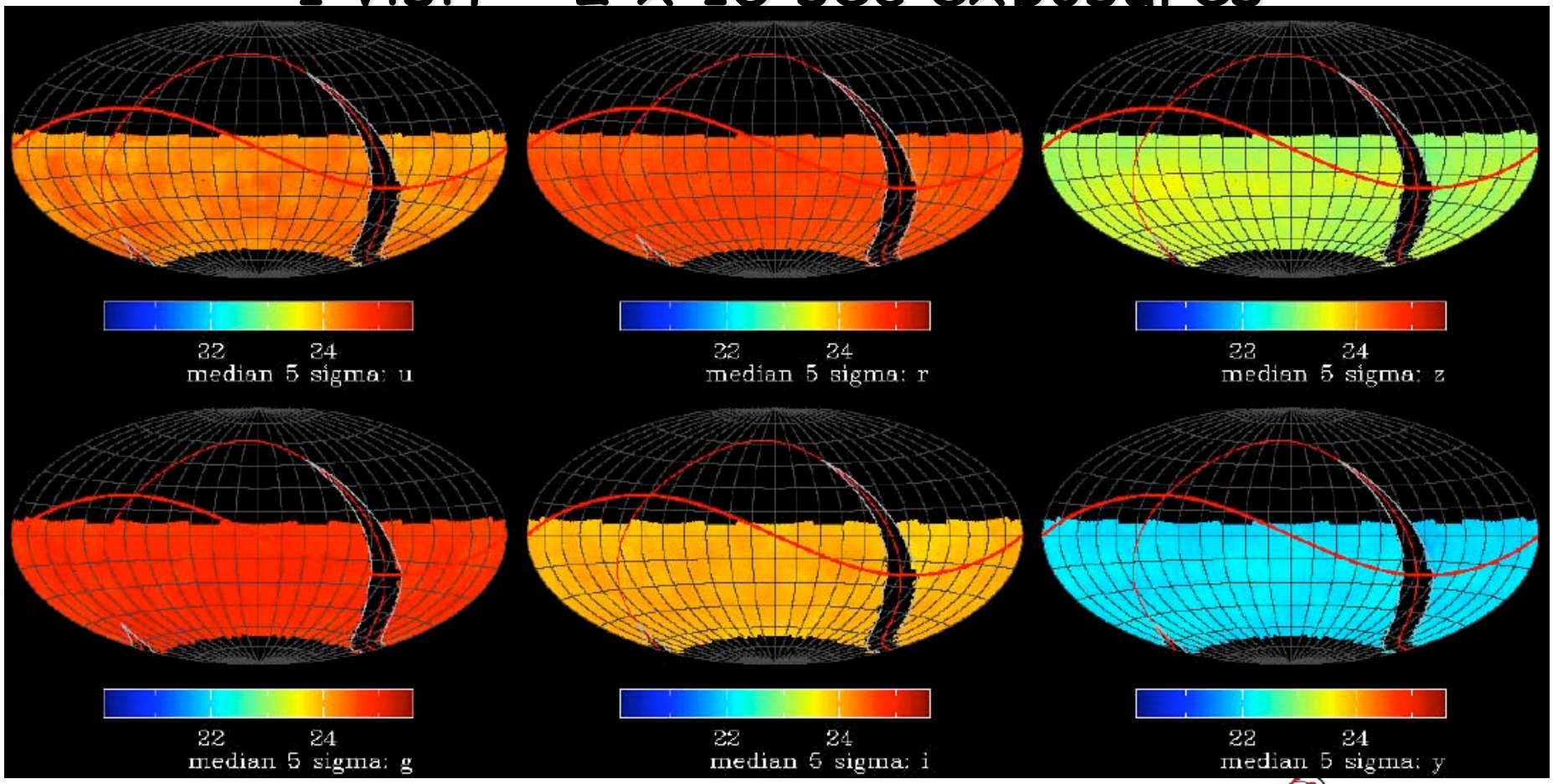
http://dls.physics.ucdavis.edu/etc/



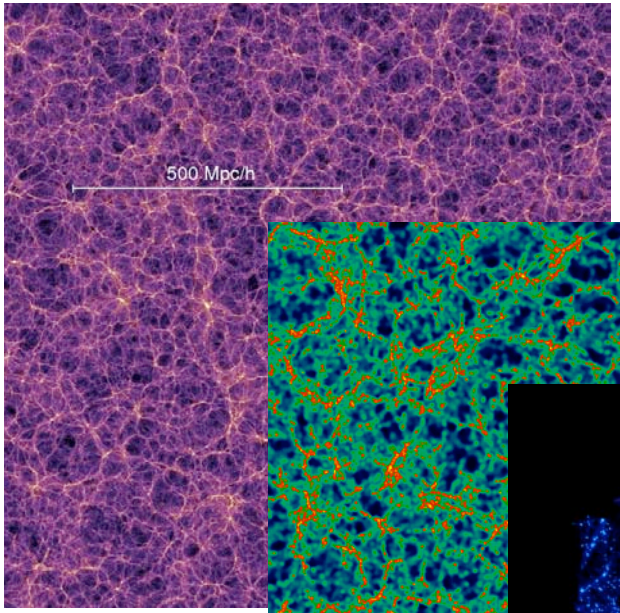
Simulations

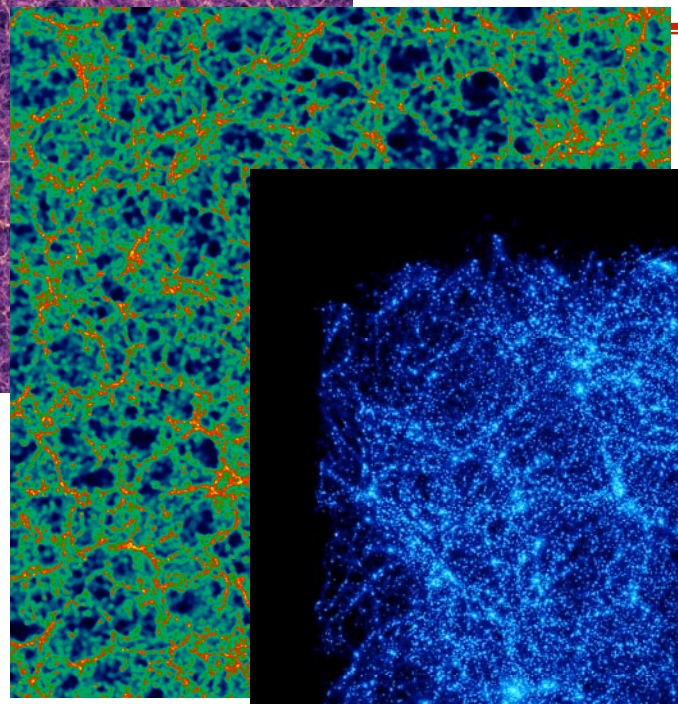
10-year simulation: limiting magnitudes per 30s visit in main survey

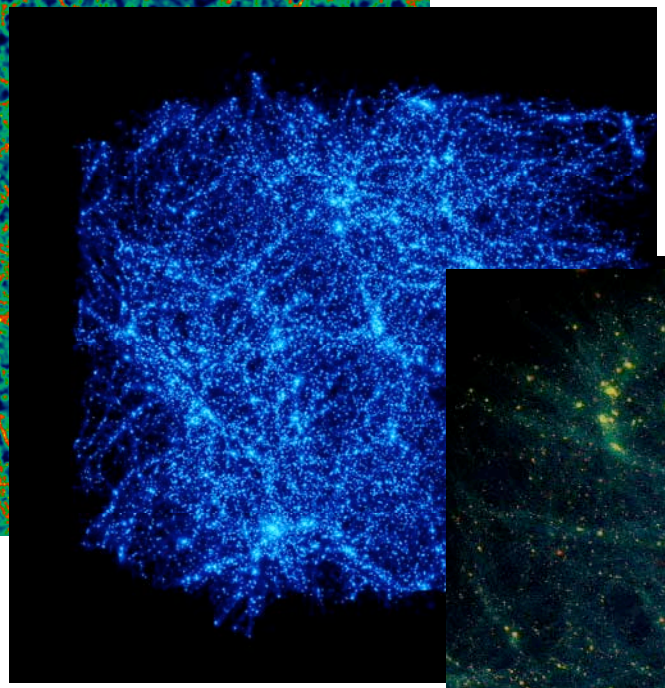
1 visit = 2 x 15 sec exposures

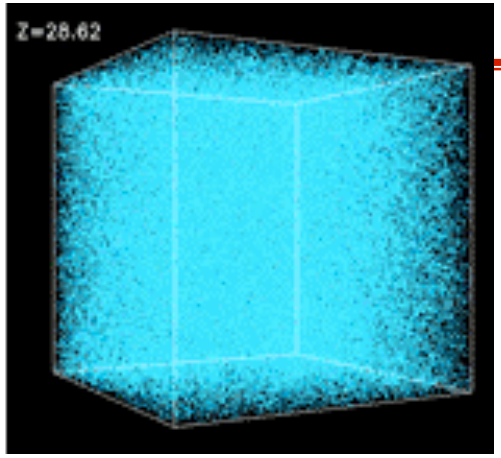


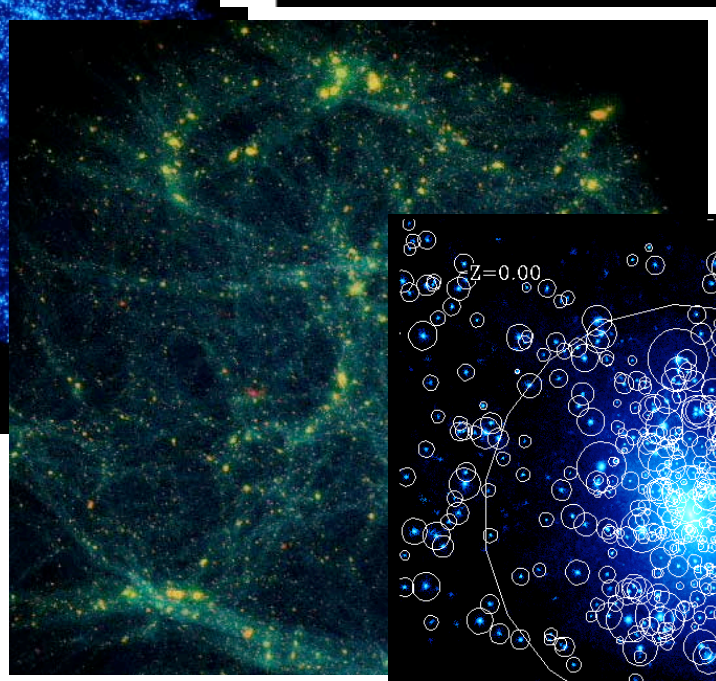
Dark Matter Simulations at KIPAC

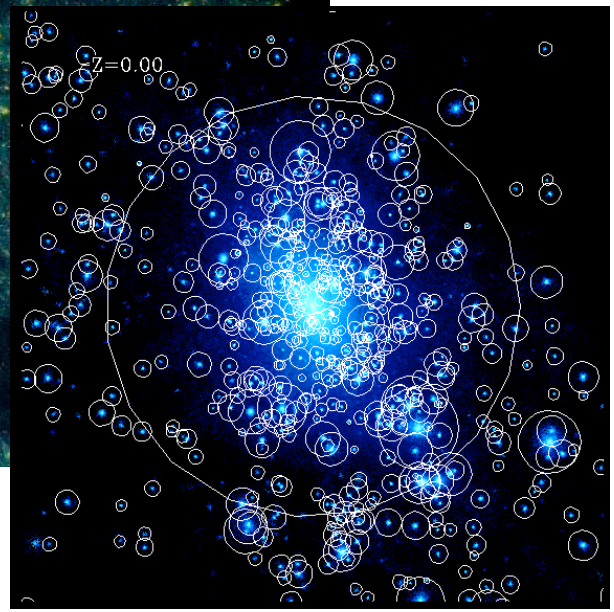






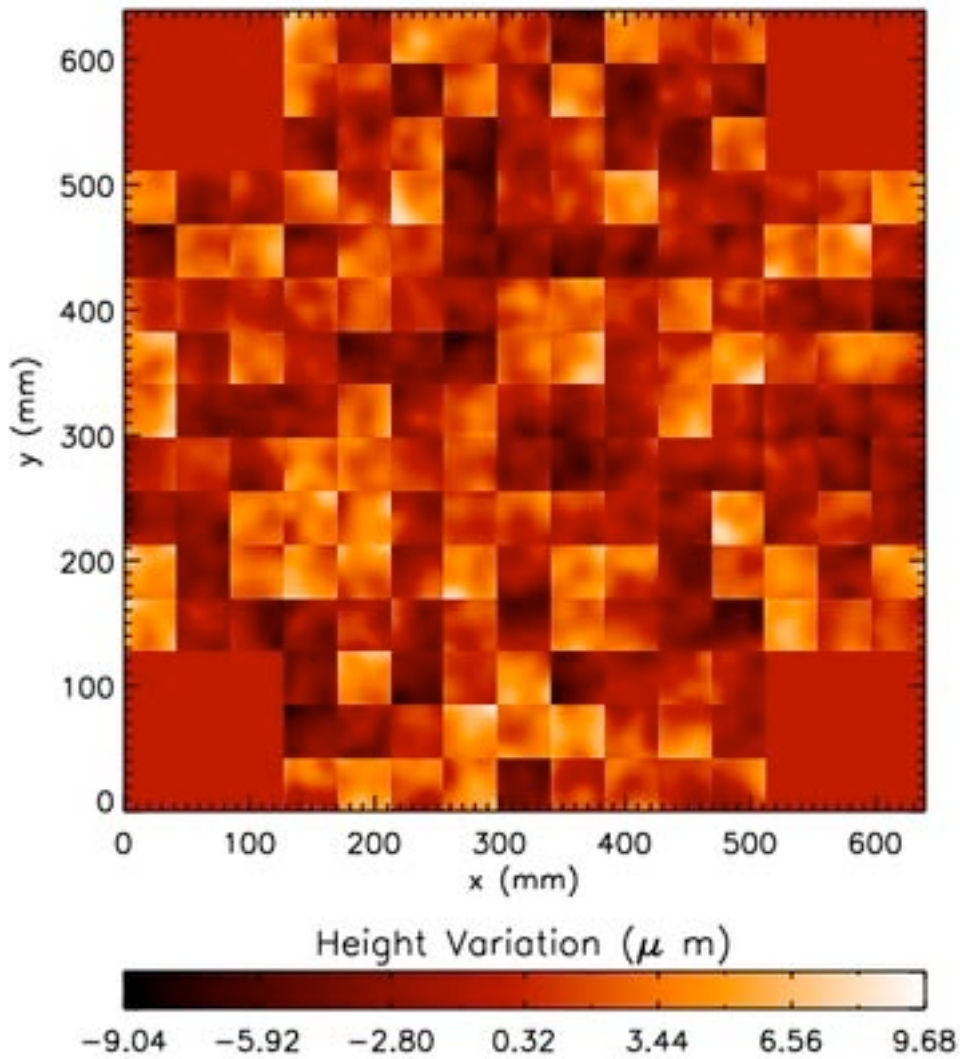


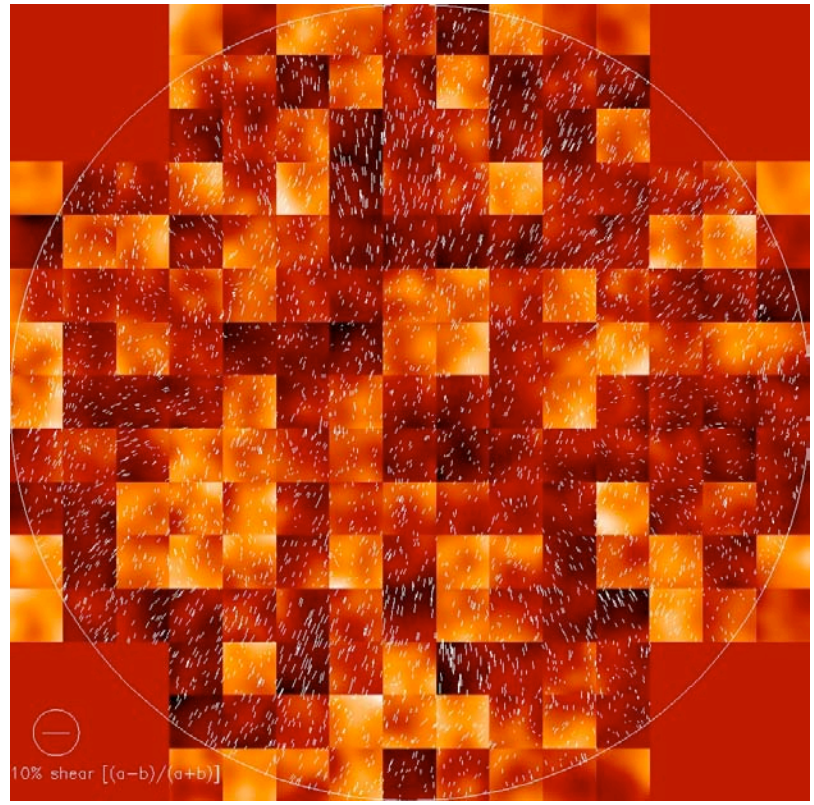


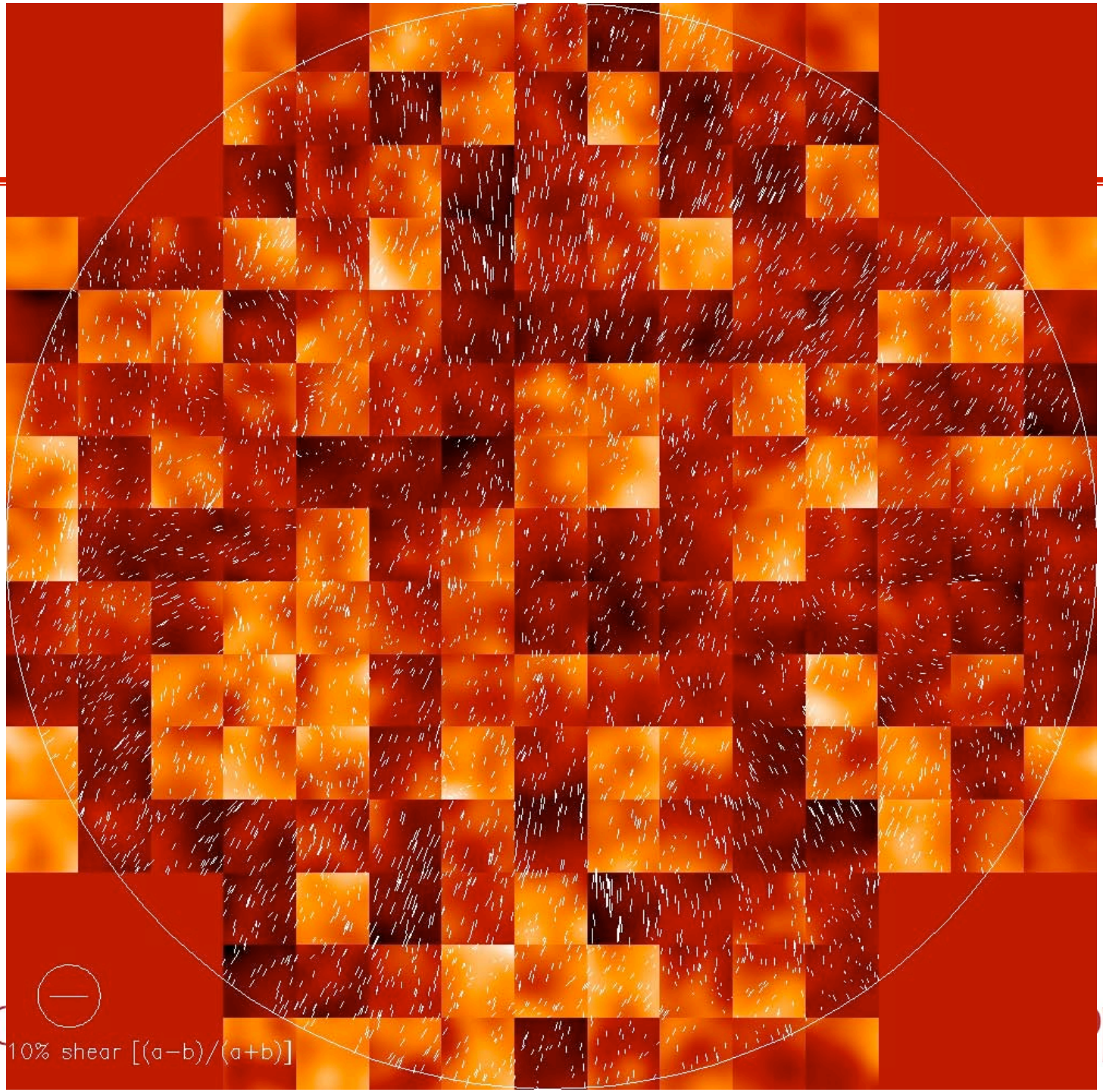


SLAC

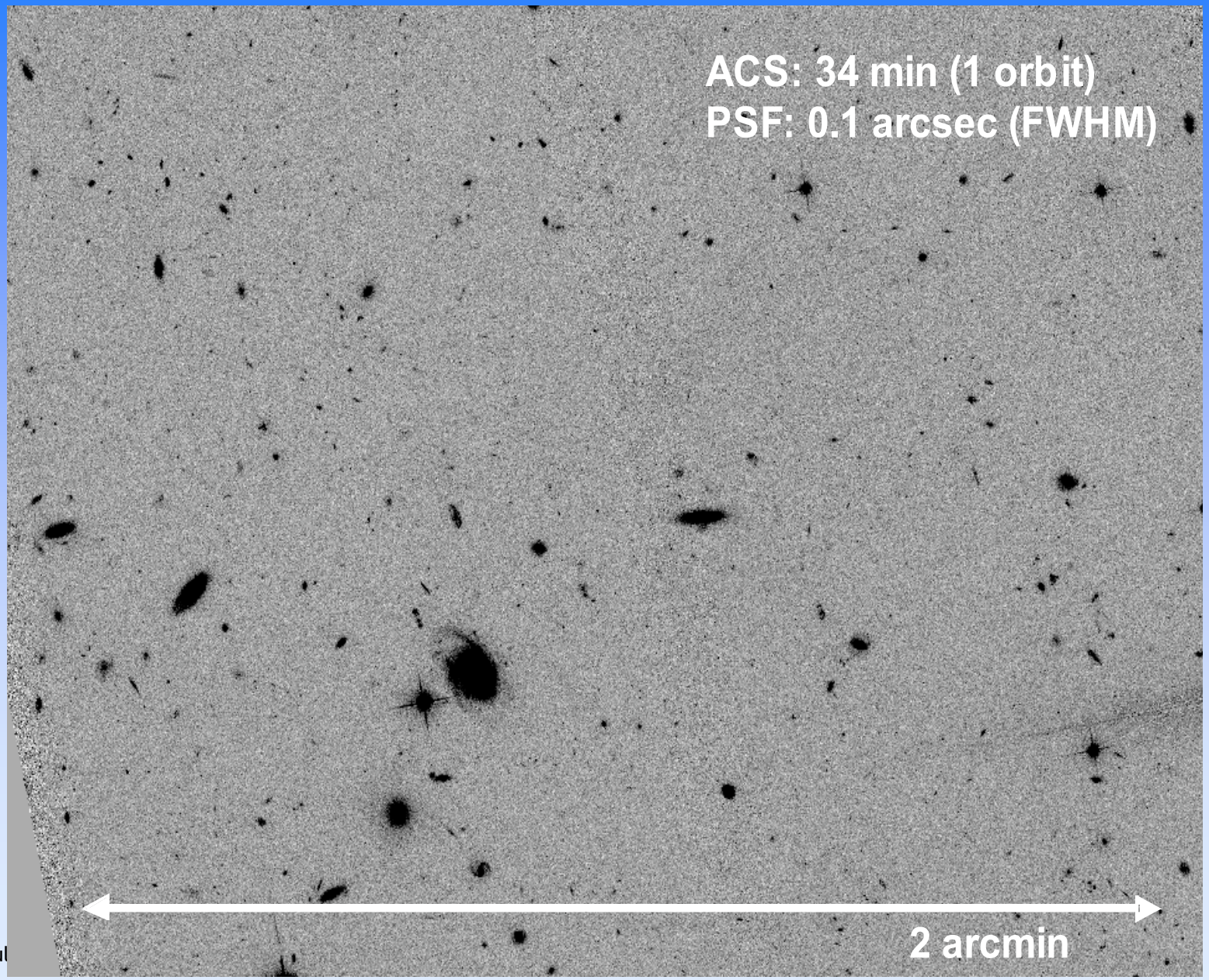
Focal Plane Flatness model and whisker plot



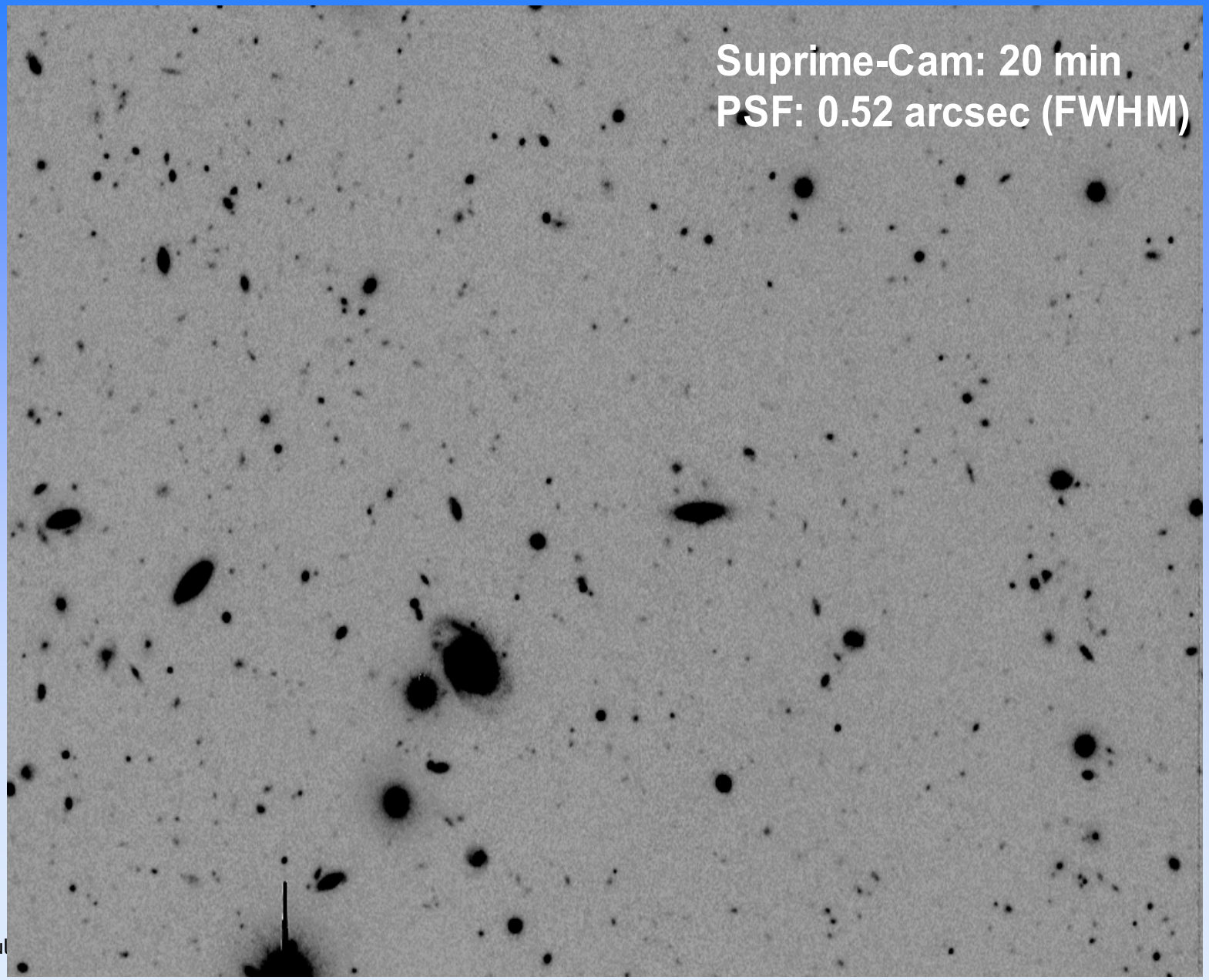



10% shear [(a−b)/(a+b)]

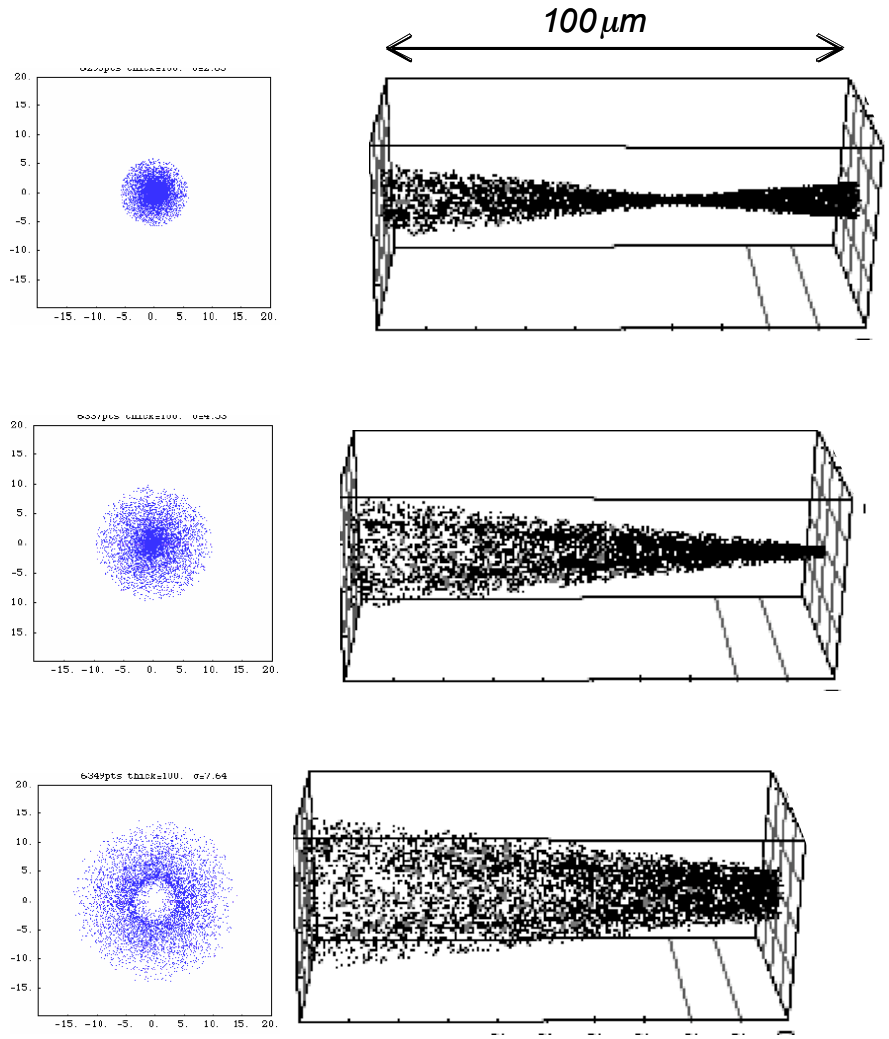
Comparing HST with Subaru



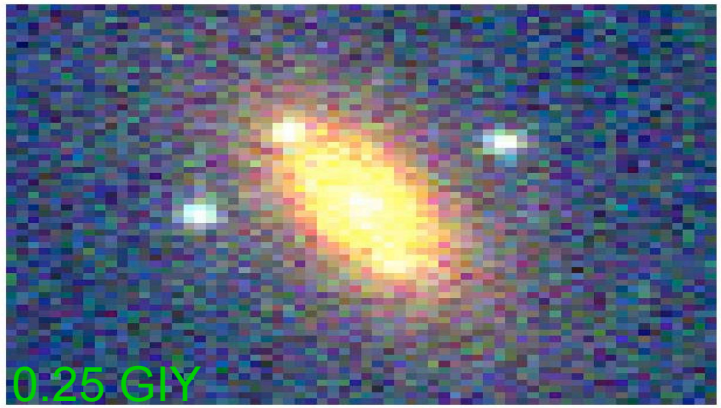
Comparing HST with Subaru

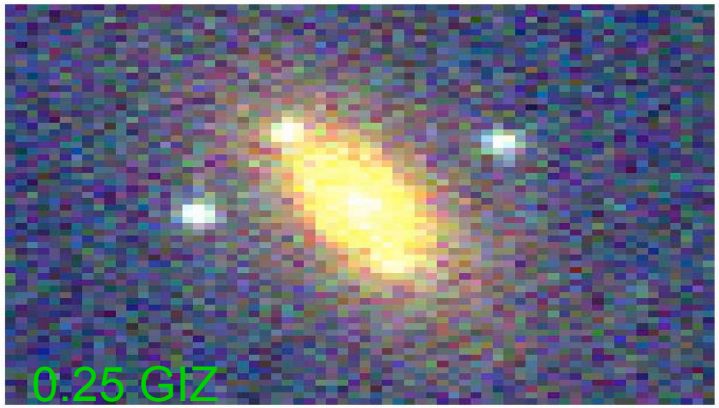


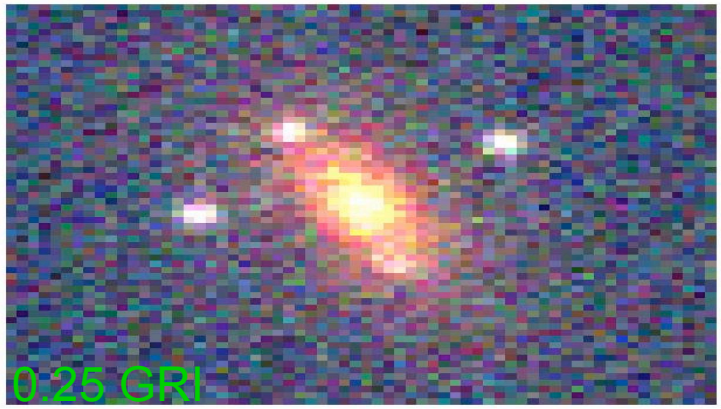
Monte-Carlo simulation of long-wavelength light absorption in silicon sensor.

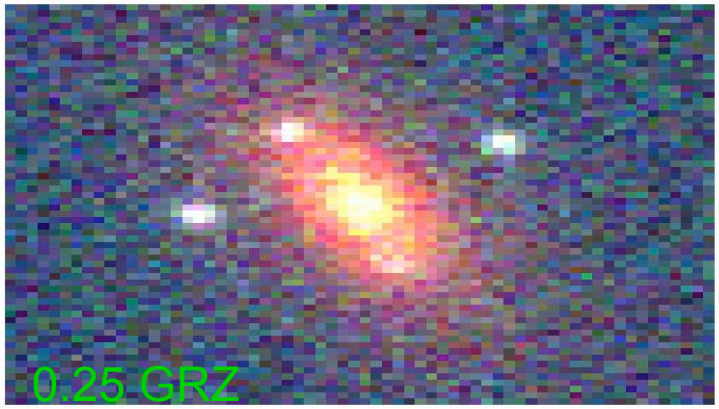


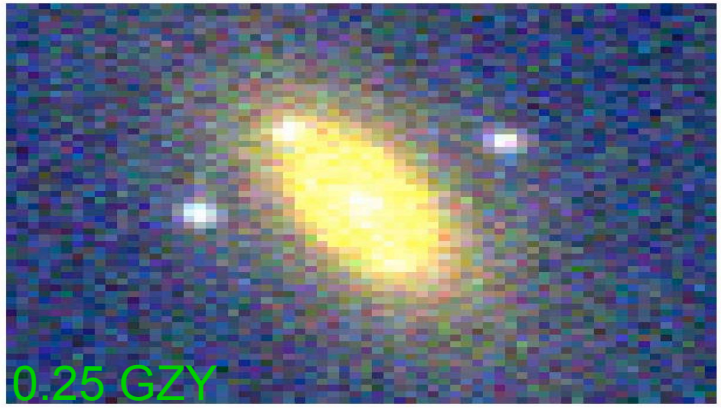
LSST Seeing Simulations - 0.25”

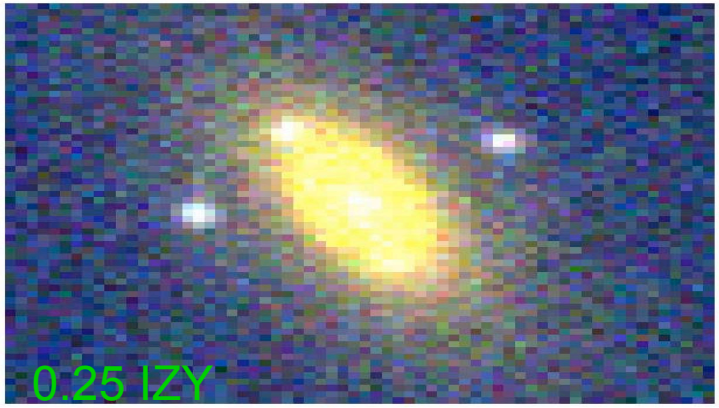




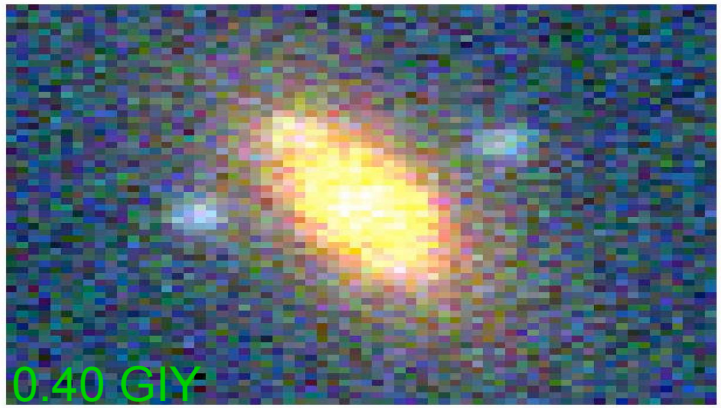


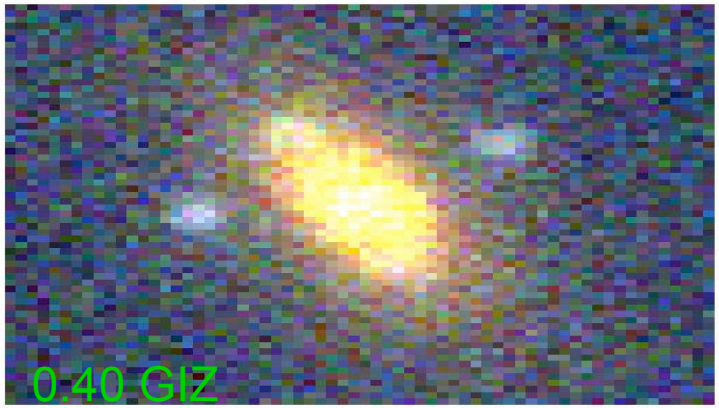


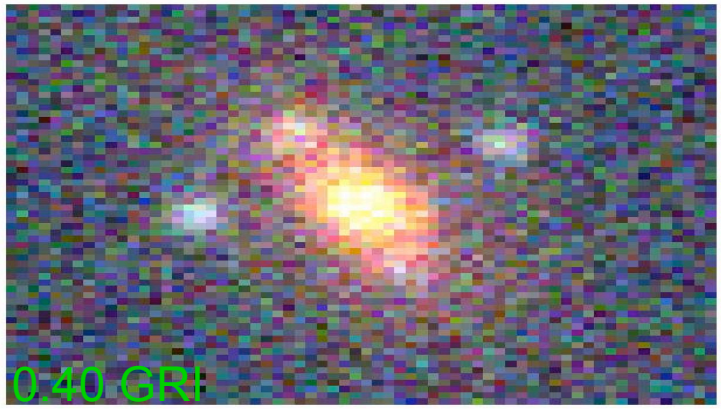


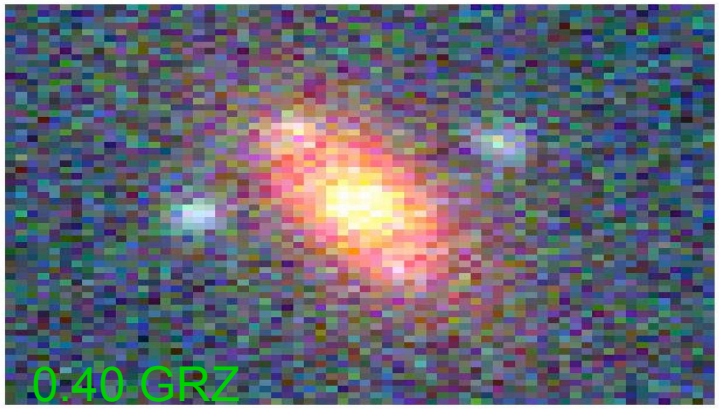


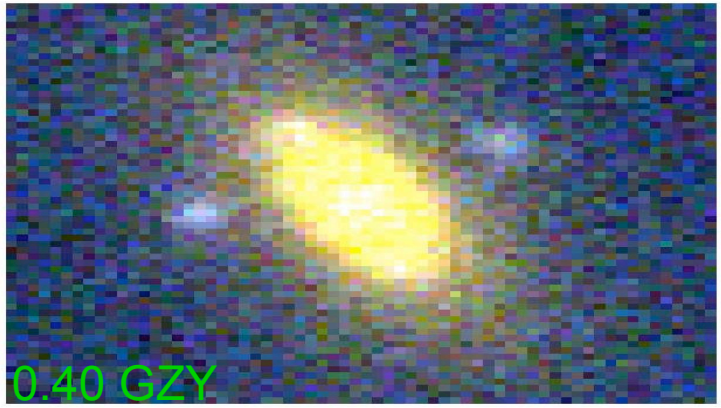
LSST Seeing Simulations - 0.40”



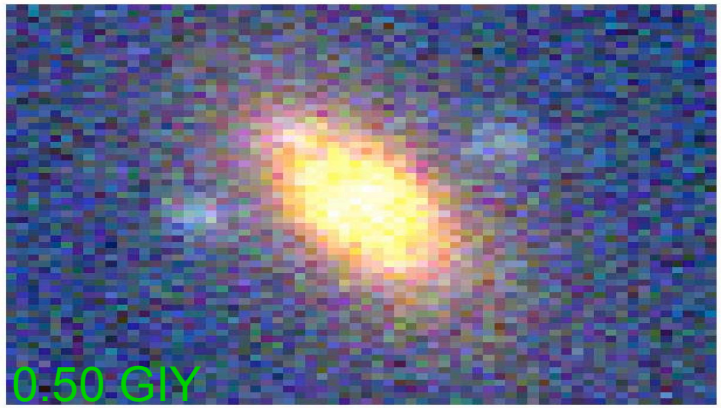


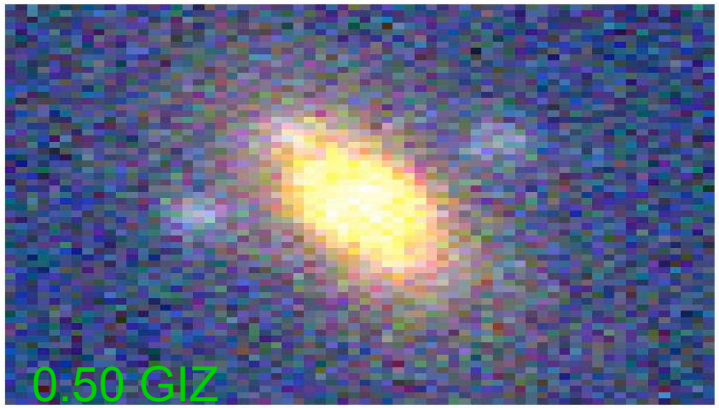


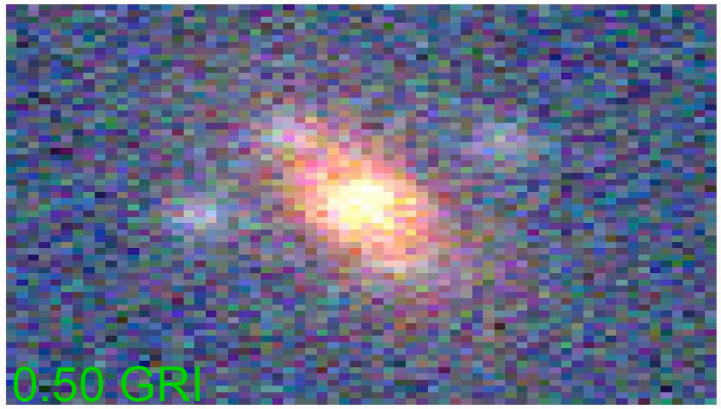


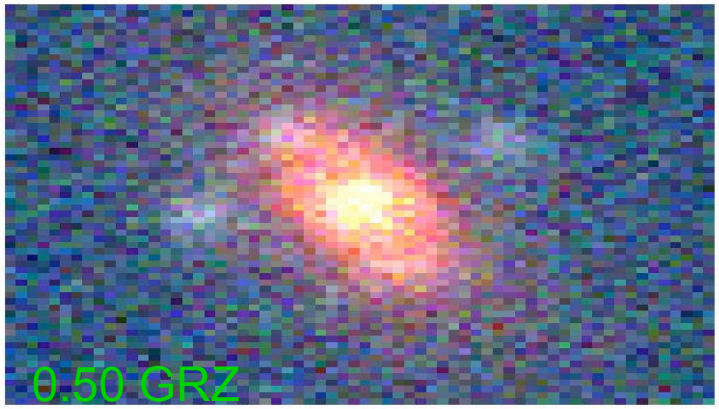


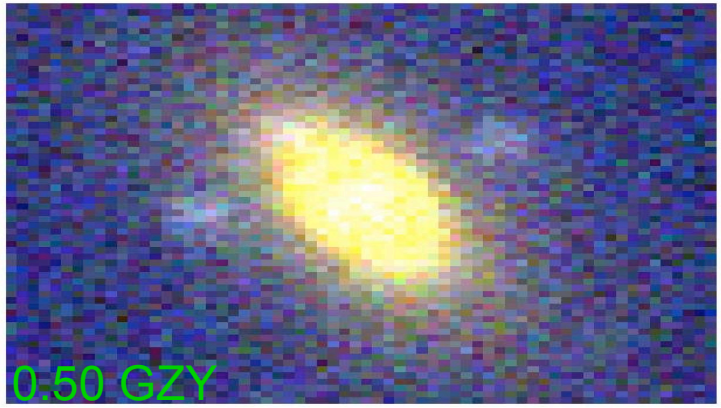
LSST Seeing Simulations - 0.50”



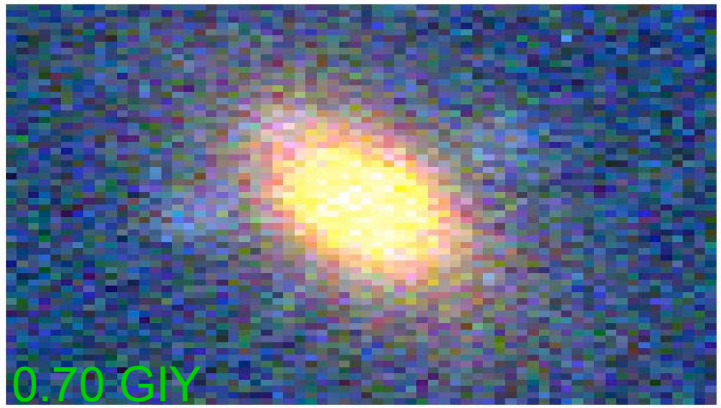


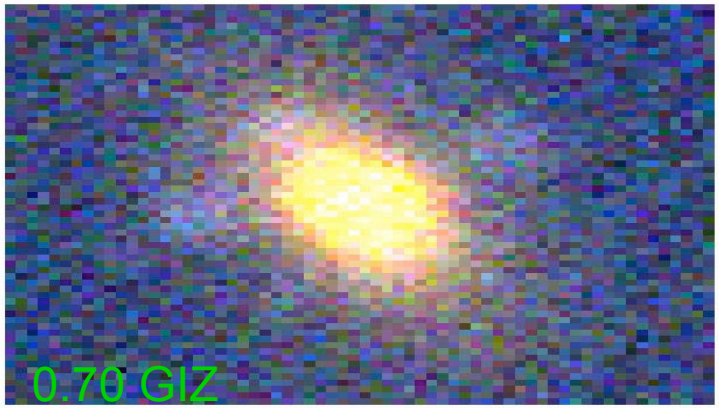


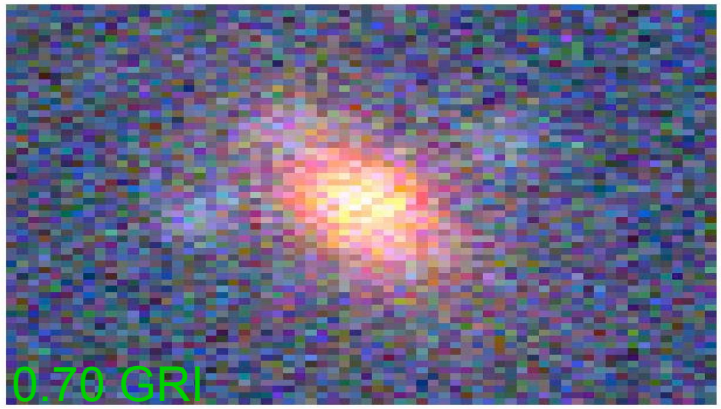


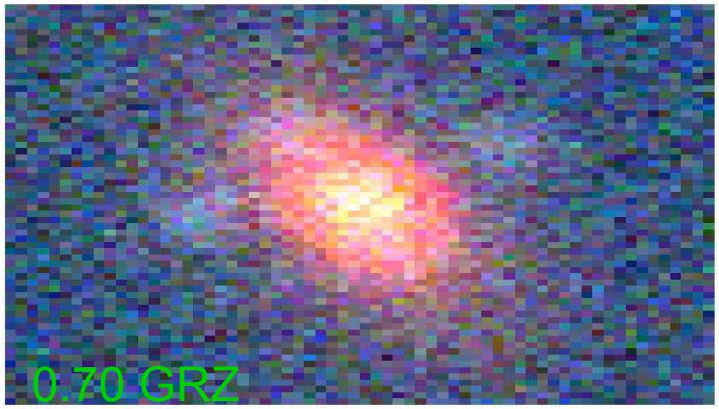


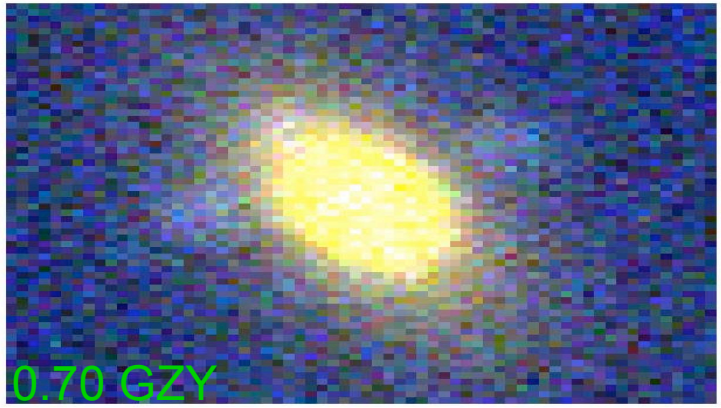
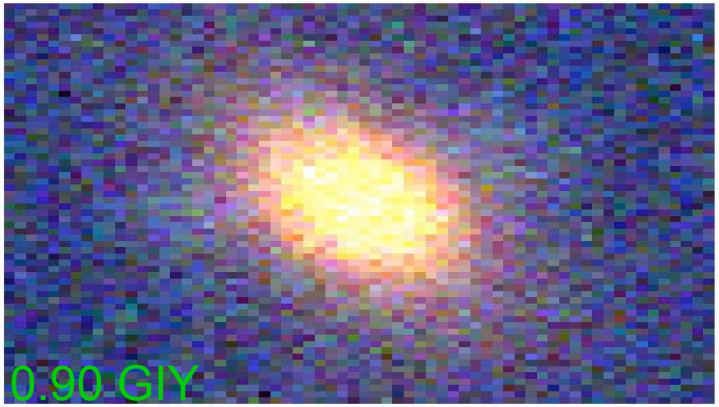
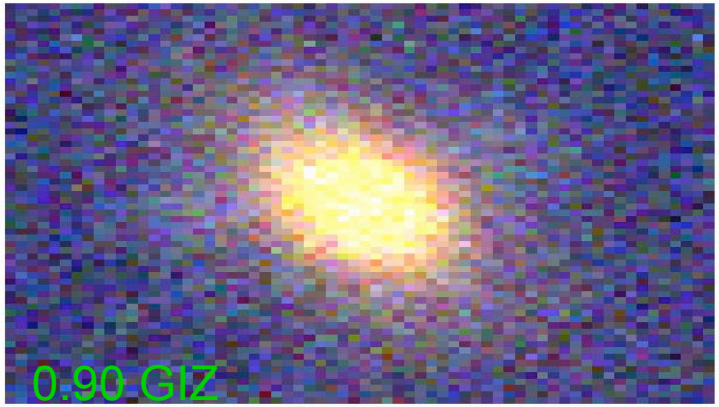
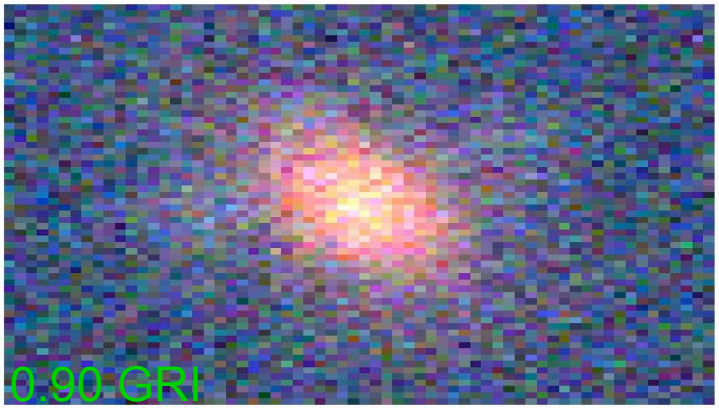
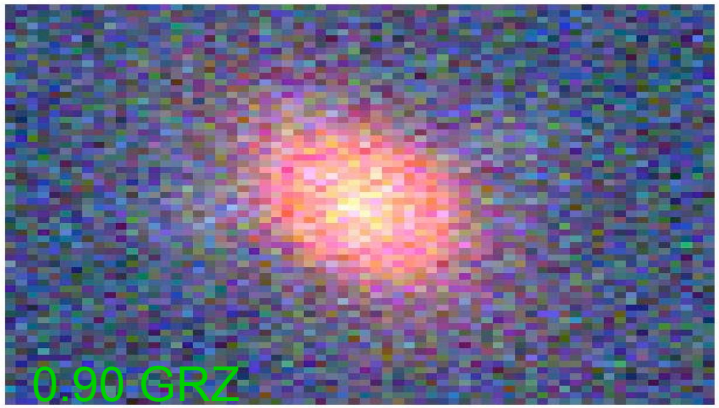
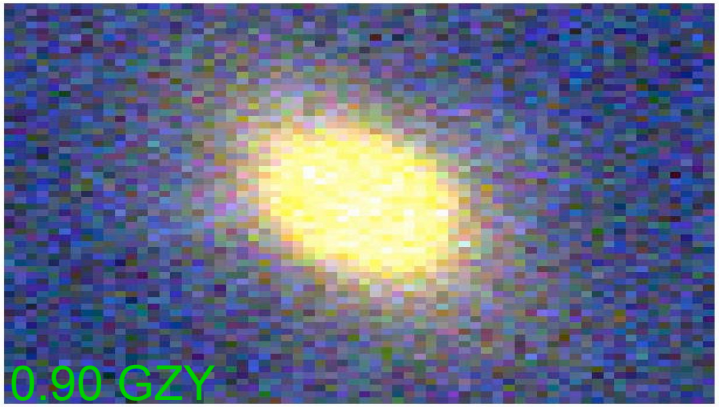
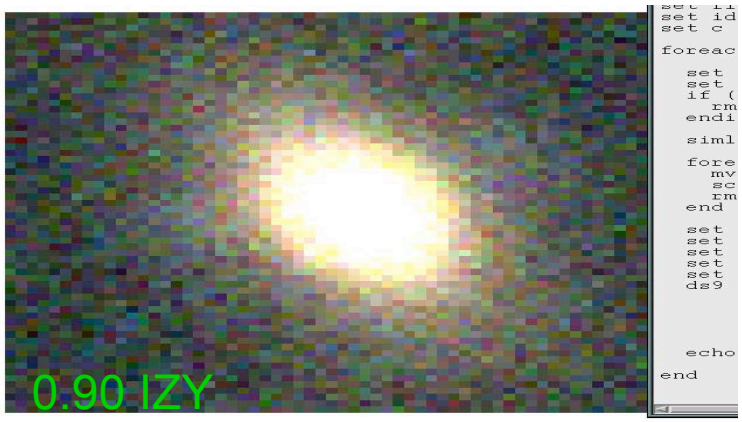
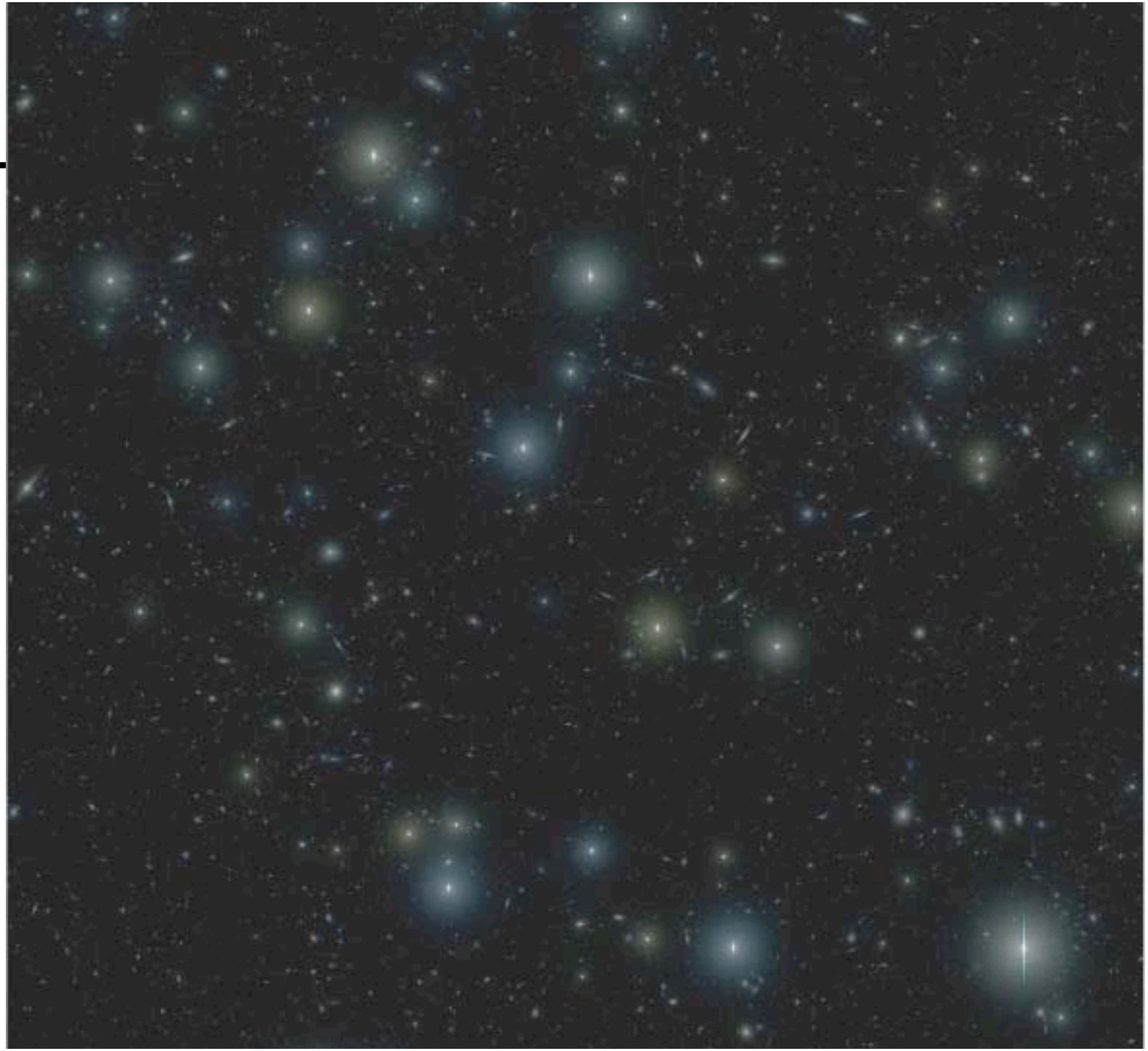
LSST Seeing Simulations - 0.70”











LSST Seeing Simulations - 0.90”