AGN, Galaxies, and LSST

Large Synoptic Survey Telescope

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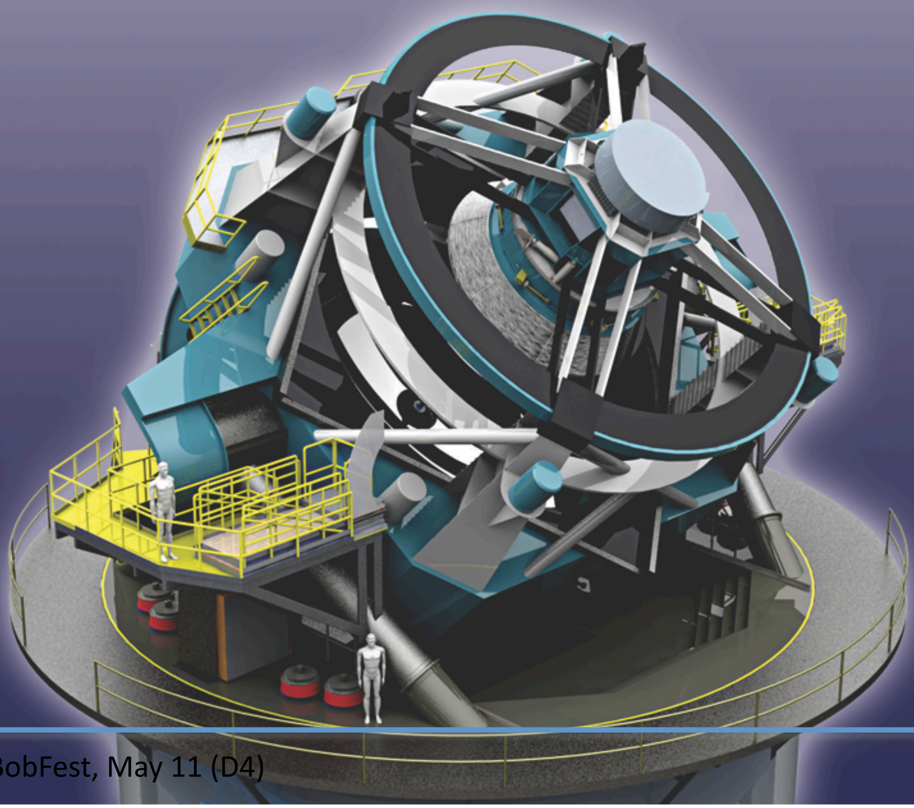
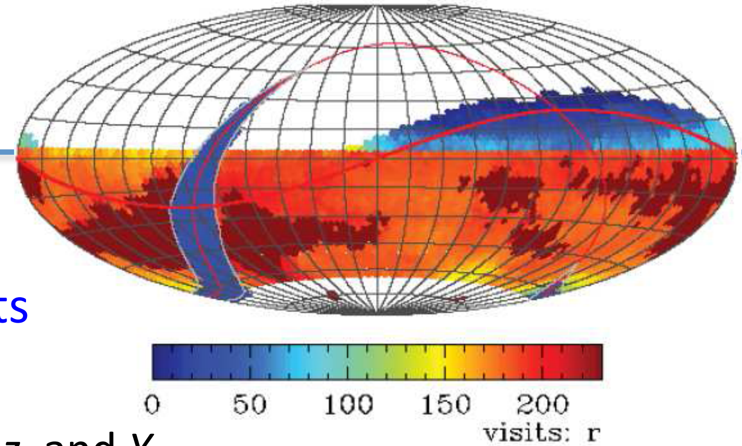
National Optical Astronomy Observatory



10-year imaging survey

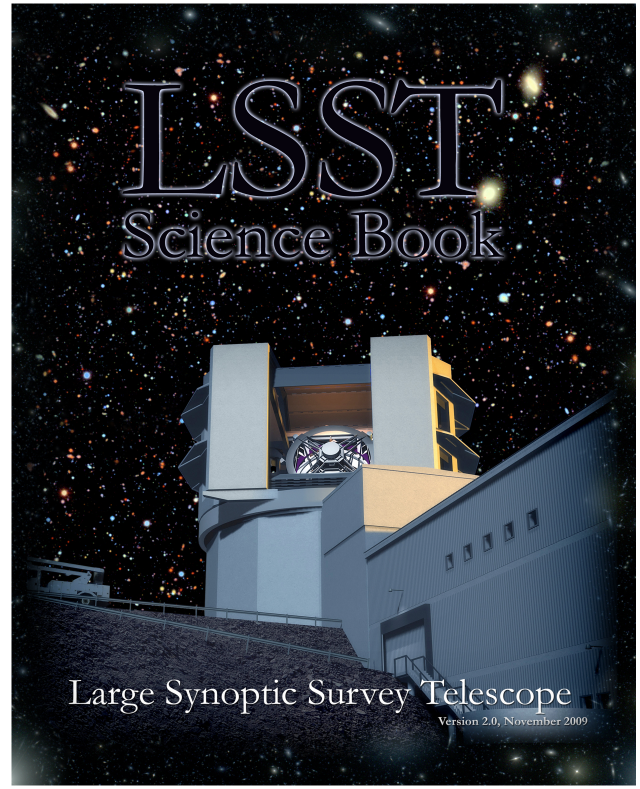


20 trillion observations of 20 billion objects

- Repeat images of the entire sky every 3 nights
  - 20,000 square degrees
  - Over 400 15-second exposures in each of *r*, *i*, *z*, and *Y*.
  - ~100,000 events per night, every night, for 10 yrs
- 5σ depth
  - Per visit: 23.9 (*u*), 25.0 (*g*), 24.7 (*r*), 24.0 (*i*), 23.3 (*z*), 22.1 (*Y*)
  - After 10 years: 26.2 (*u*), 27.4 (*g*), 27.6 (*r*), 26.9 (*i*), 26.1 (*z*), 24.8 (*Y*)
- Data characteristics
  - Median seeing ~ 0.7 arcsec
  - Probes of variability on timescales from 15 seconds to 10 years
  - Stellar photometric calibration to 1% or better; repeatability to 0.5%.
  - Astrometry to 10 mas per visit, allowing proper motions uncertainty of 0.2 mas/year, and parallax uncertainty of 1 mas over the course of the survey
    - Matches Gaia at r~20, and extends it 4 magnitudes fainter.

Core science drivers

- Census of minor bodies in Solar System
- Milky Way structure and stellar content
- The variable ("transient") universe
- Evolution of galaxies
- Nature of dark energy and dark matter on cosmological scales



Available at www.lsst.org

Project collaboration

Large Synoptic Survey Telescope

- Founding: NOAO, U. Arizona, U. Washington, Research Corp.
- More than 30 institutional members
- Design & development supported by US Federal agencies
- Additional generous private support (esp. Simonyi & Gates)

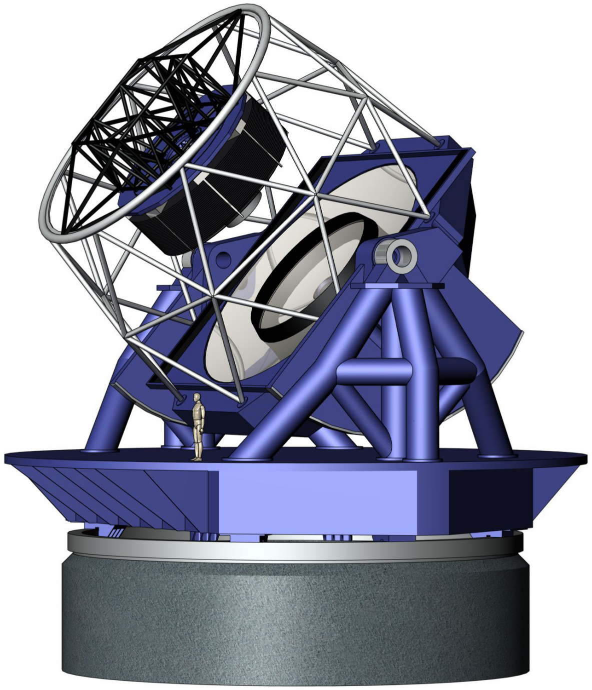
AAS visit by Charles Simonyi

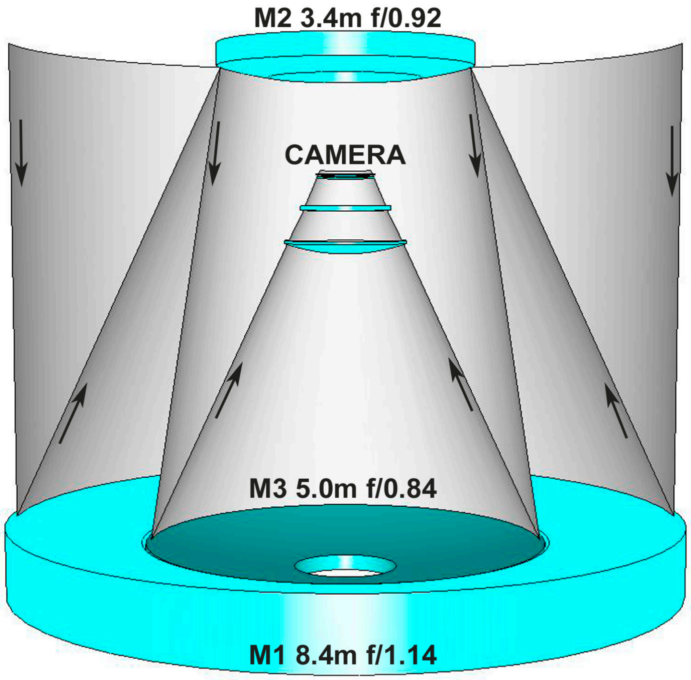
Science collaborations

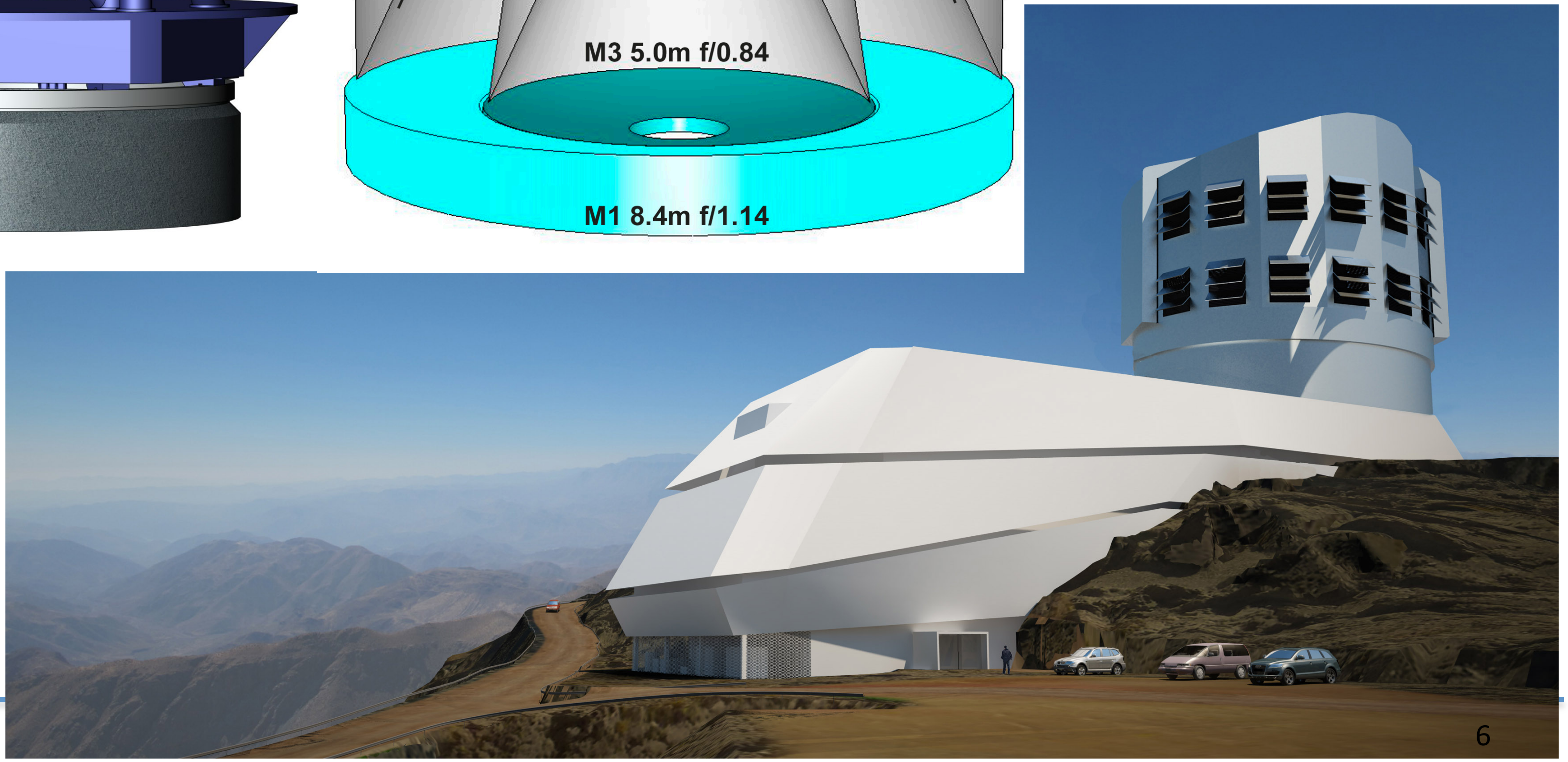
Leader: Michael Strauss (Princeton)

- Weak lensing (Bhuvnesh Jain, Dave Wittman)
- Strong lensing (Phil Marshall)
- Supernovae (Michael Wood-Vasey, Richard Kessler)
- Large-scale structure/BAO (Hu Zhan, Eric Gawiser)
- AGN (Niel Brandt)
- Galaxies (Harry Ferguson)
- Galactic structure (Beth Willman, Marla Geha)
- Stellar populations (Kevin Covey, Knut Olsen)
- Variability and transients (Lucianne Walkowicz, Josh Bloom)
- Solar system (Lynne Jones, Michael Brown)
- Informatics and Statistics (Kirk Borne)

Telescope / Site



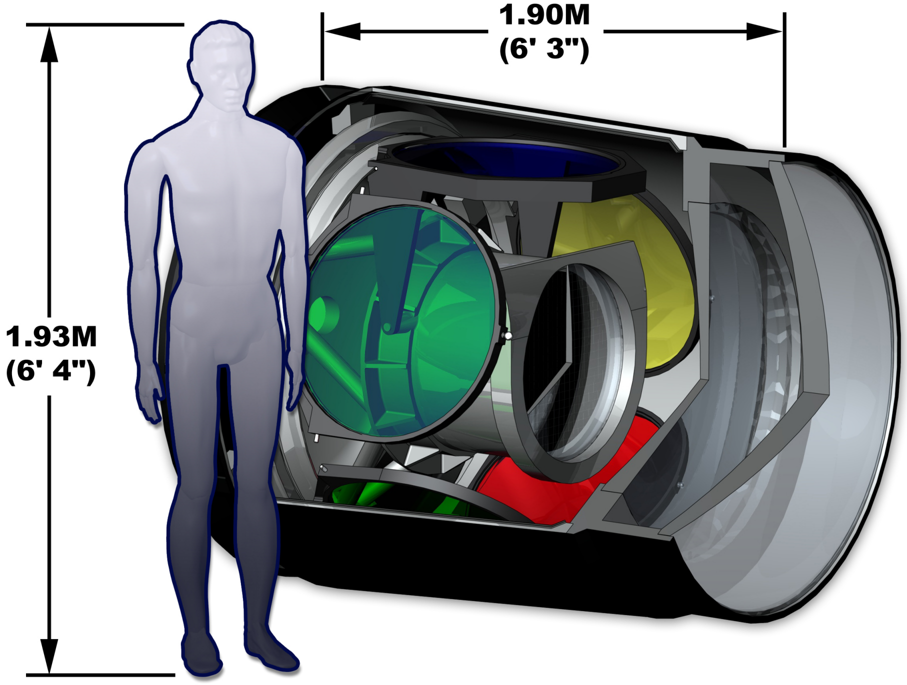




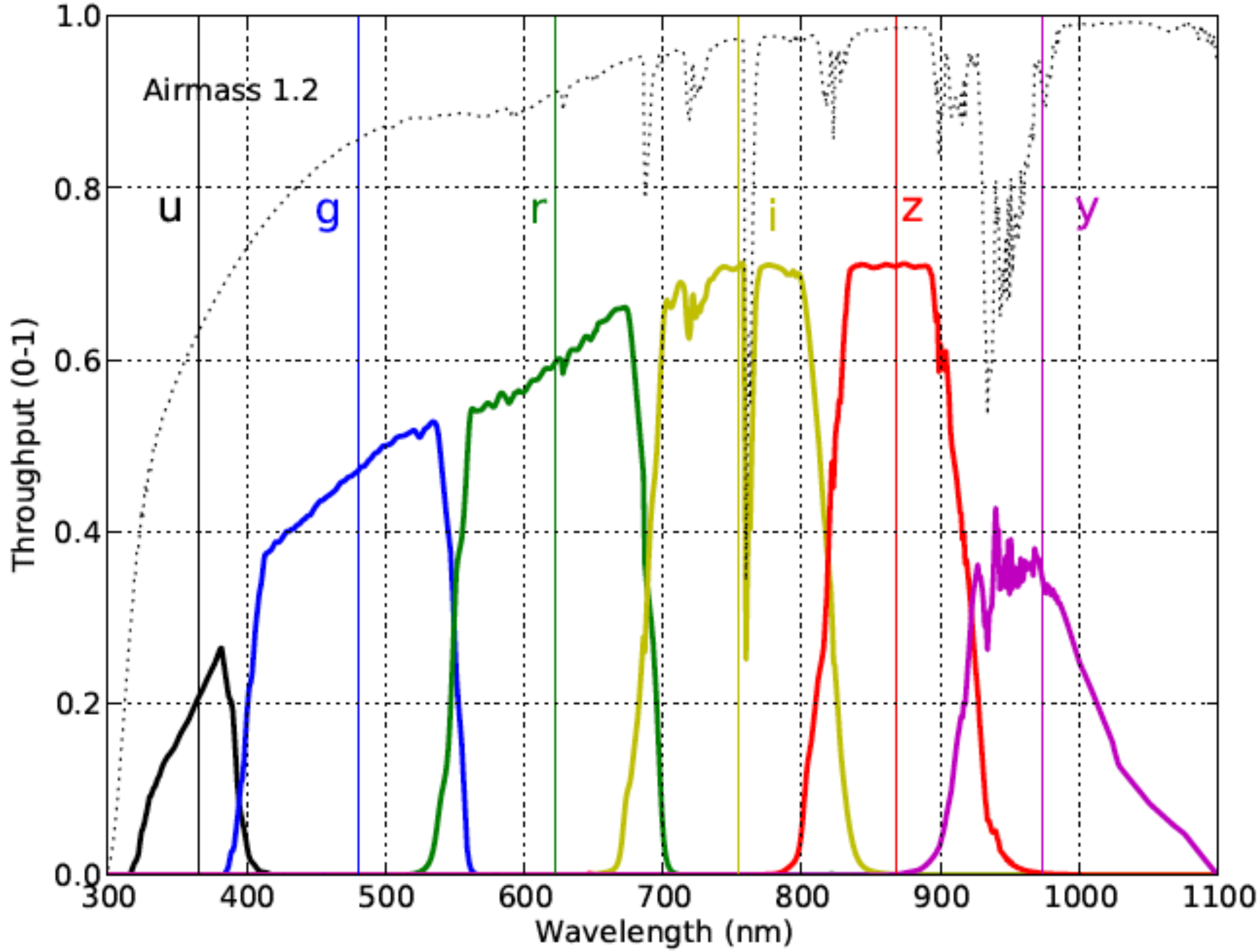
Telescope / Site

Camera

189 4K x 4K CCDs
9.6 deg^2 field-of-view
634 mm diameter (inscribed)



Total system throughput



Simulations

Simulated riz 3-color image
One visit (2 x 15-s each band), one CCD (13x13 arcmin)
Courtesy: U Washington image simulation group

Operations Simulations

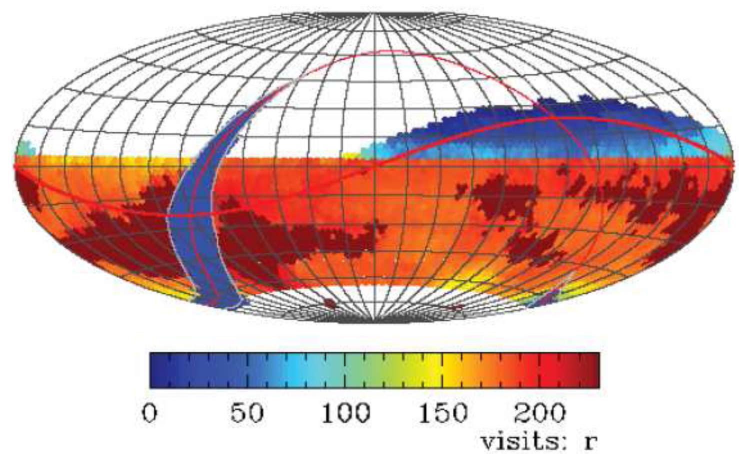
Cadence input from science cases
NOAO-based team

Catalog Simulations

Realistic baseline catalog for validation
Calibration sets for all-sky applications
Complete to below the detection limit (r=28)

Image Simulations

Photon-by-photon image simulations
Atmosphere, telescope and camera
Validation of LSST design / implementation



Data management

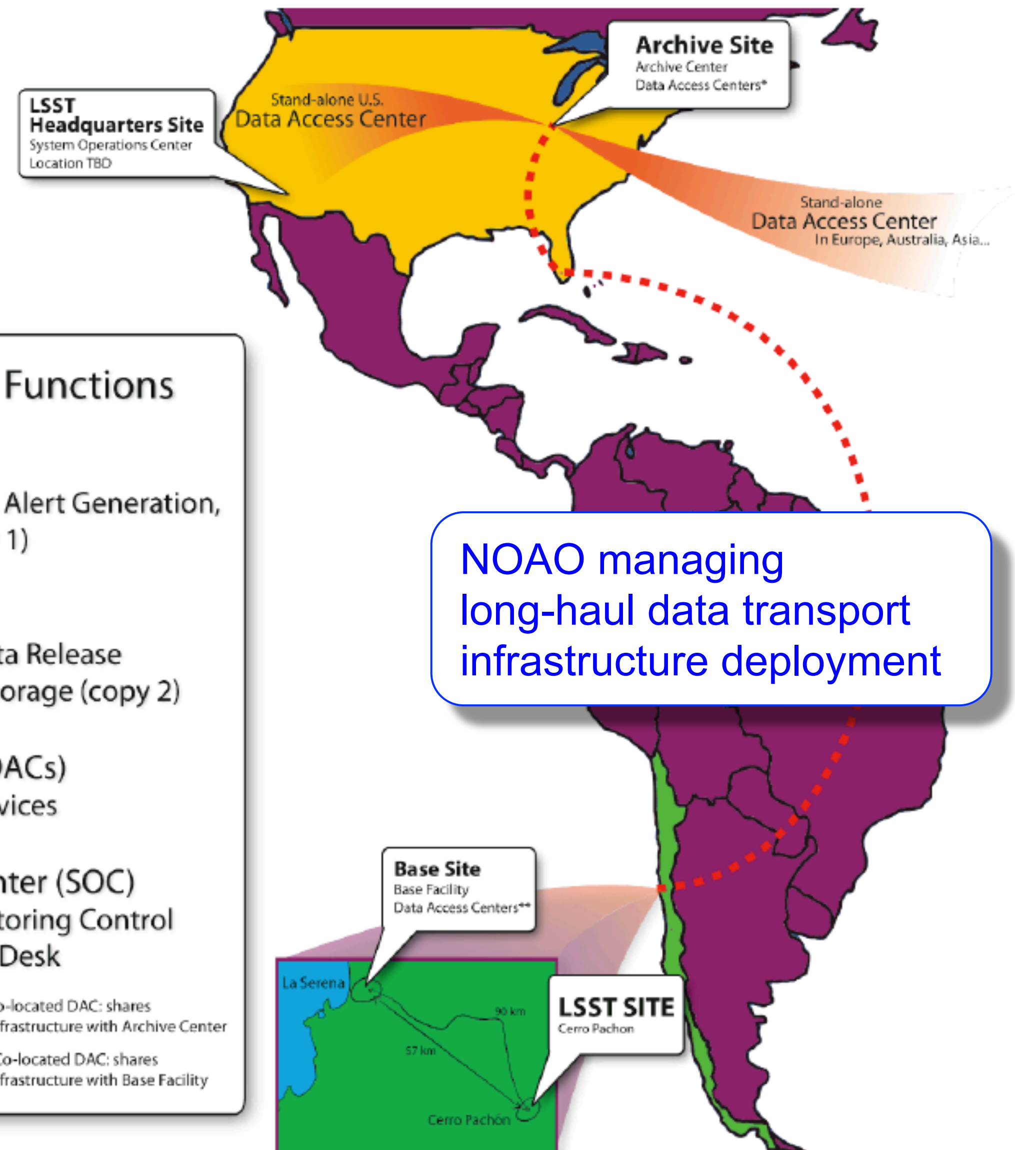
- One 6-GB image every 17 seconds
- 30 TB every night for 10 years
- Final: 200 PB image archive
- Final: 20 PB object catalog

Site Roles and their Functions

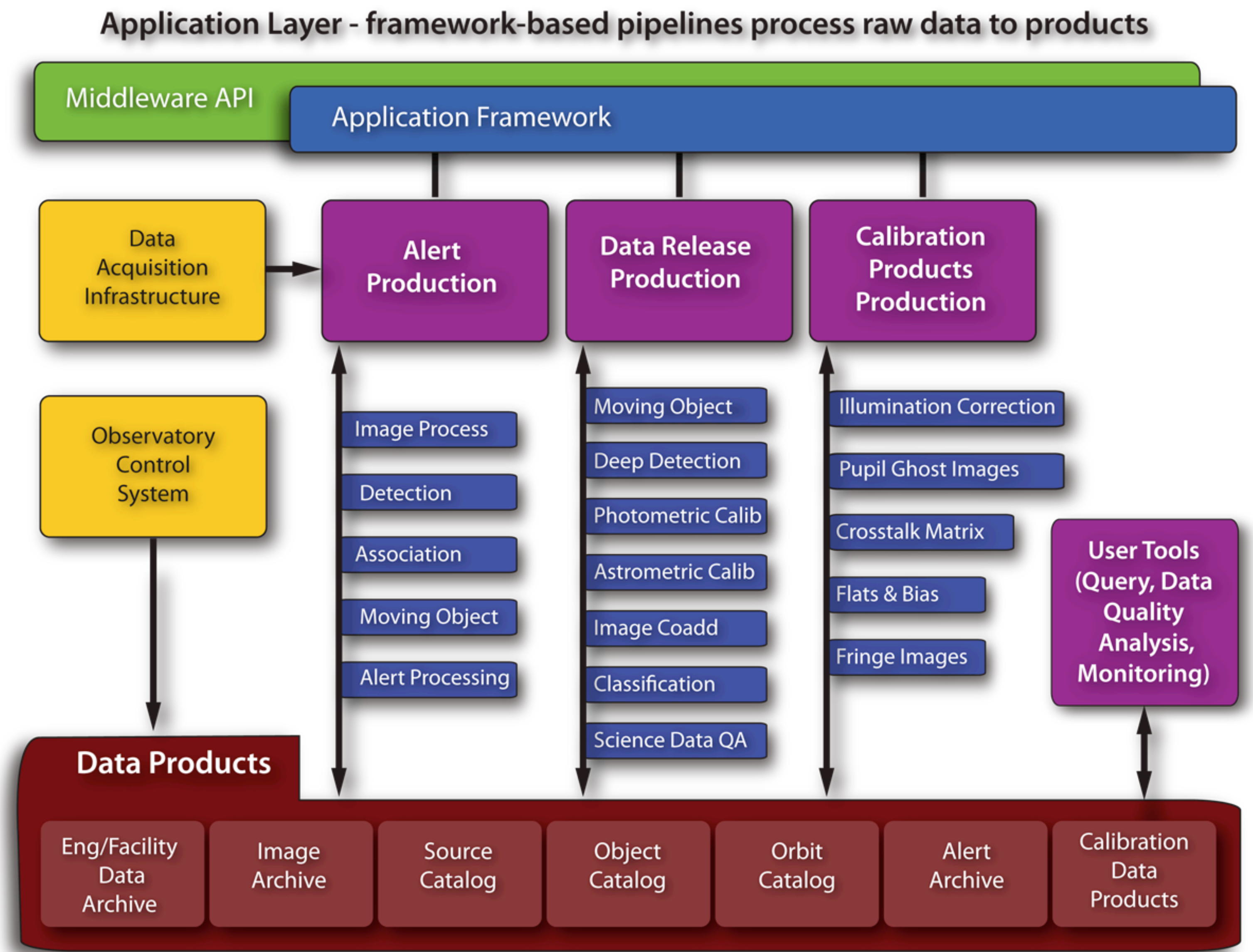
- Base Facility
  Real-time Processing and Alert Generation, Long-term storage (copy 1)
- Archive Center
  Nightly Reprocessing, Data Release Processing, Long-term Storage (copy 2)
- Data Access Centers (DACs)
  Data Access and User Services
- System Operations Center (SOC)
  System Supervisory Monitoring Control & End User Support/Help Desk

* Co-located DAC: shares infrastructure with Archive Center

** Co-located DAC: shares infrastructure with Base Facility



Data pipelines



Data products

Application Layer -

Generates open, accessible data products with fully documented quality

Processing Cadence	Image Category (files)	Catalog Category (database)	Alert Category (database)
Nightly	Raw science image Calibrated science image Subtracted science image Noise image Sky image Data quality analysis	Source catalog (from difference images) Object catalog (from difference images) Orbit catalog Data quality analysis	Transient alert Moving object alert Data quality analysis
Data Release (Annual)	Stacked science image Template image Calibration image RGB JPEG Images Data quality analysis	Source catalog (from calibrated science images) Object catalog (optimally measured properties) Data quality analysis	Alert statistics & summaries Data quality analysis

Education and public outreach

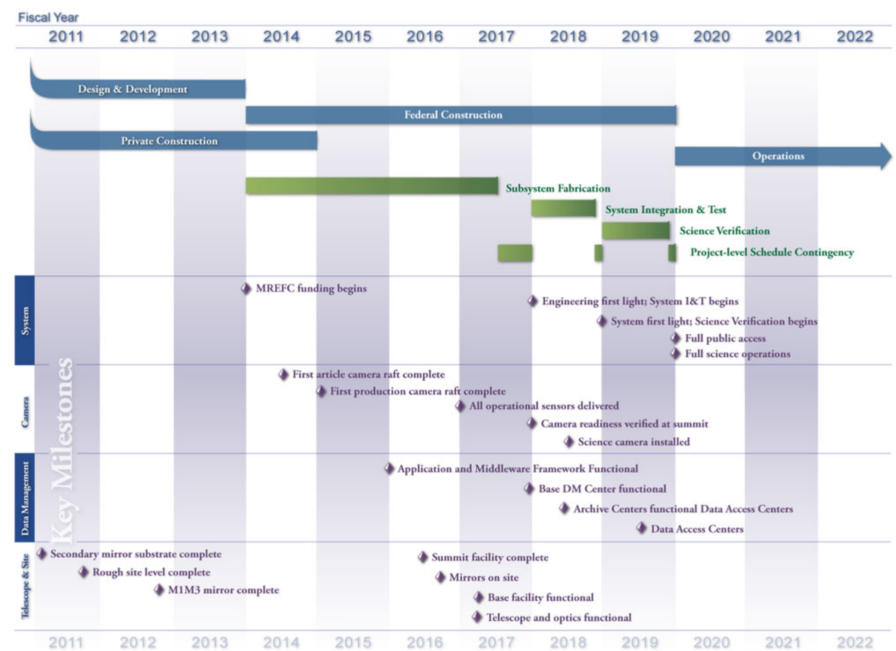
Considered top-level activity, not add-on

Main themes

- Visualization of LSST observations in science centers and planetaria
- Utilization of real scientific data in formal education settings
- Active engagement by citizen scientists in the exploration and discovery of the cosmos

Schedule

- Oct 2014 : start of US Federal funding
- Jan 2018 : engineering first-light
  - With mirrors already done, can move fast…
- Jan 2019 : end-to-end commissioning begins
- Jan 2020 : survey running full-time



Galaxy evolution across cosmic time

Galaxy evolution and LSST

- How does environment affect physics of galaxy formation?
  - Do all galaxies form at peaks of dark matter distribution?
  - How does environment affect feedback (photo-ionization, SN winds, massive star feedback, etc) that in turns moderates star formation?
  - What physical insights are provided by "rare" galaxies (e.g. most massive, lowest surface brightness)?
- Galaxy formation process is stochastic
  - Need enormous statistical sample over environment and redshift to make progress
- LSST will provide that enormous sample

The sample

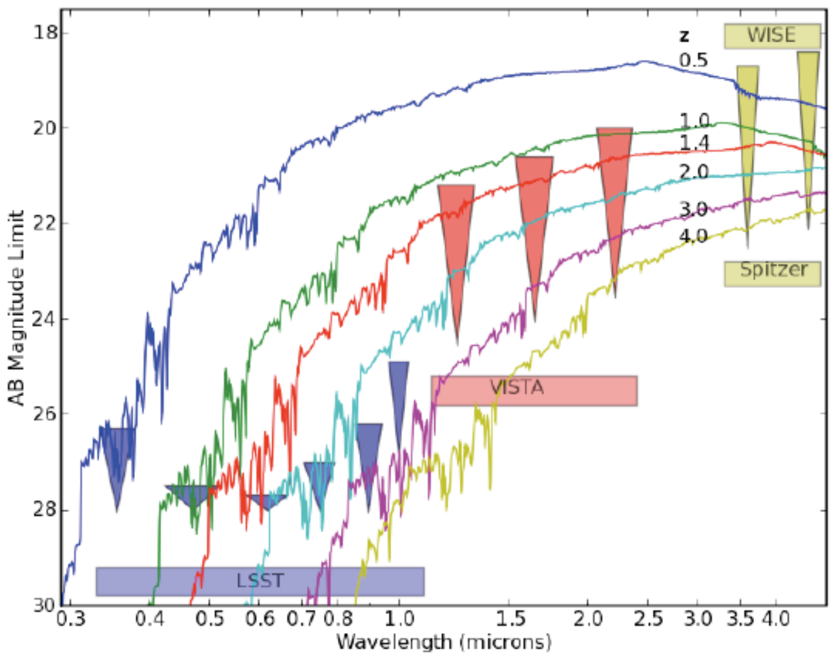
- 4 x 10^9 galaxies at $z < 1.5$ (structure, *ugrizy* photometry)
- >10^{10} galaxies detected to $z \sim 6$
- >10^9 galaxies detected at $z > 2$
- >10^7 galaxies detected at $z > 4.5$

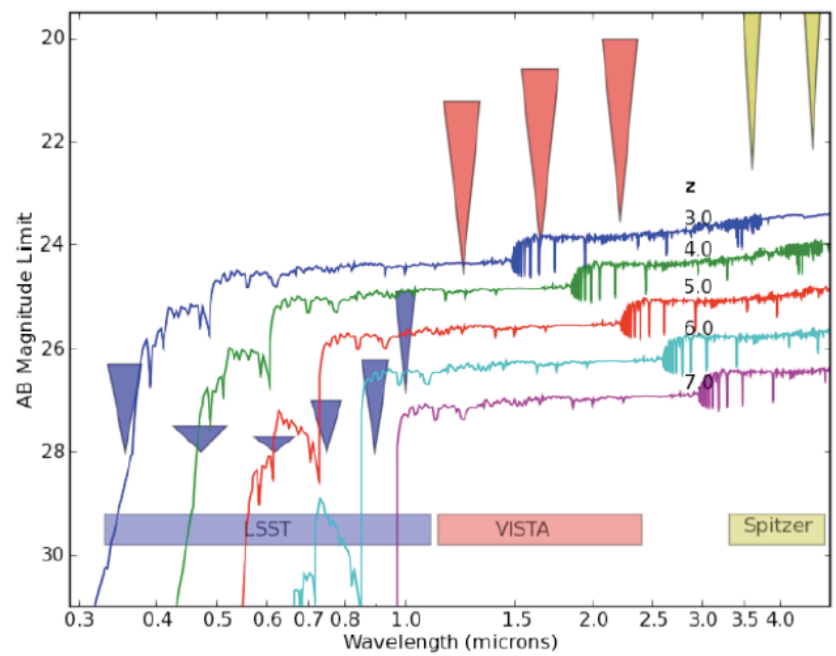
- Dwarf galaxies detected to 4 Mpc at $M_V \sim -4$ (to 128 Mpc at $M_V \sim -14$)
- L* galaxies ($M_B \sim -21$) to $z \sim 5$ over 10^{12} Mpc^3 co-moving volume

Sensitivities, photo-z

Must rely on photometric redshifts

LSST builds on Sloan Digital Sky Survey work





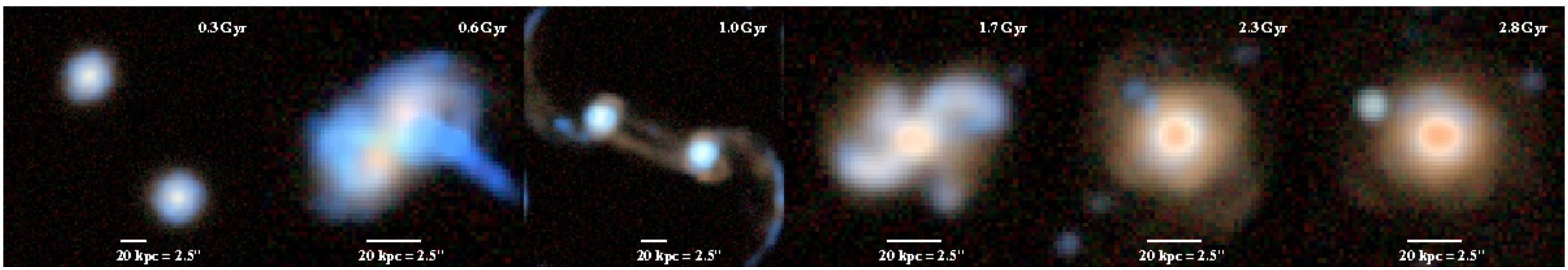
Top of triangles: mean 5σ depths, wide-fields

Bottom of triangles: deep fields (LSST, VIDEO, SWIRE)

Sizes, structures, and mergers

Characterize as function of z, luminosity, color, environment

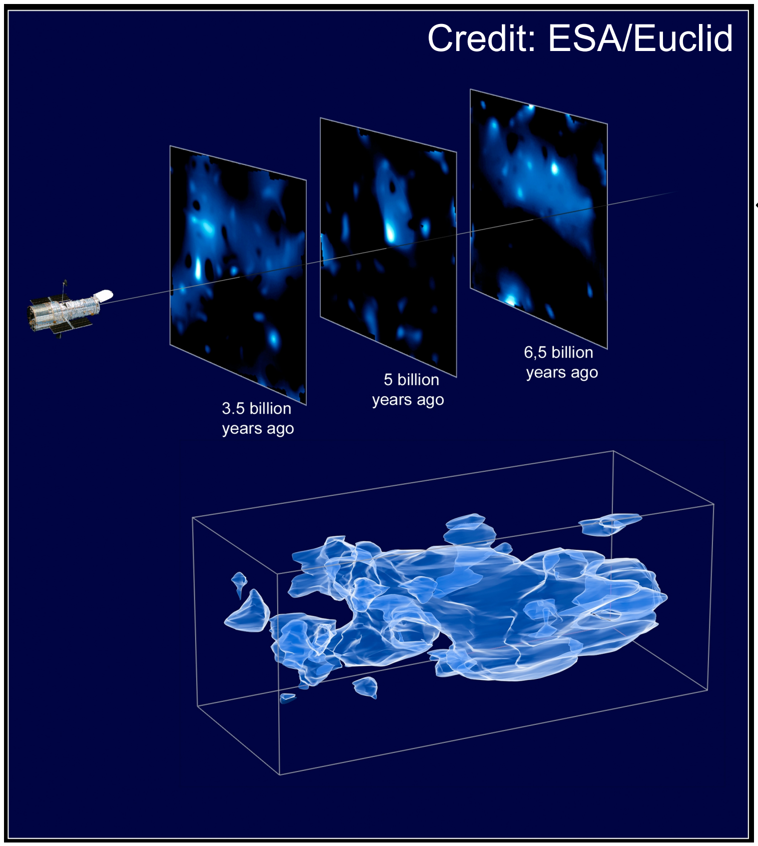
- PSF ~ 0.7” ➡ size, bulge/disk ratio determination to z ~ 0.6
- μ_{riz} ~ 27 (10 yr stack) ➡ merger features detectable to z ~ 1
  - > 10^8 tidal tail mergers
  - > 10^5 ‘dry’ mergers



Lotz et al (2008), riz, z ~ 1, all features visible up to 1 Gyr

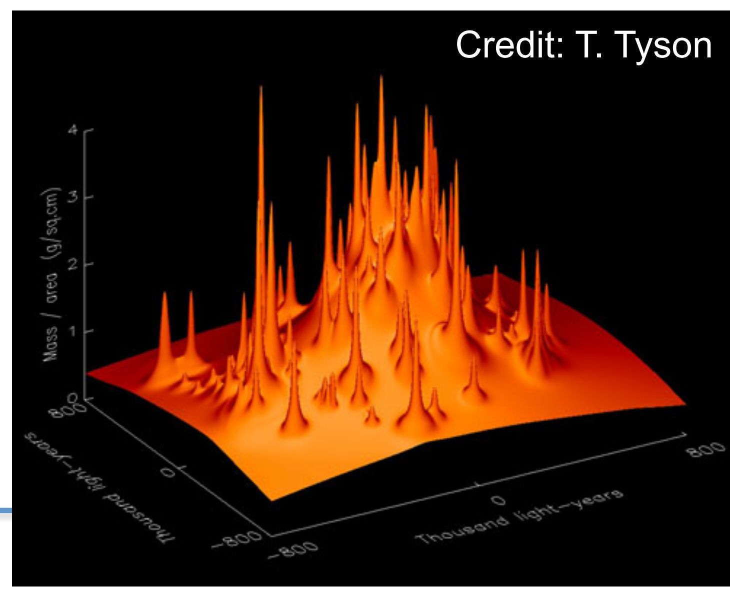
Process vs. local density

Galaxy formation is fundamentally governed by the statistical properties of the underlying dark-matter density field



LSST will measure galaxy parameters vs.

- Local *object* density (counts)
- Local *dark matter* density in "field" (weak lensing)
- Local *dark matter* density in "clusters" (strong lensing)

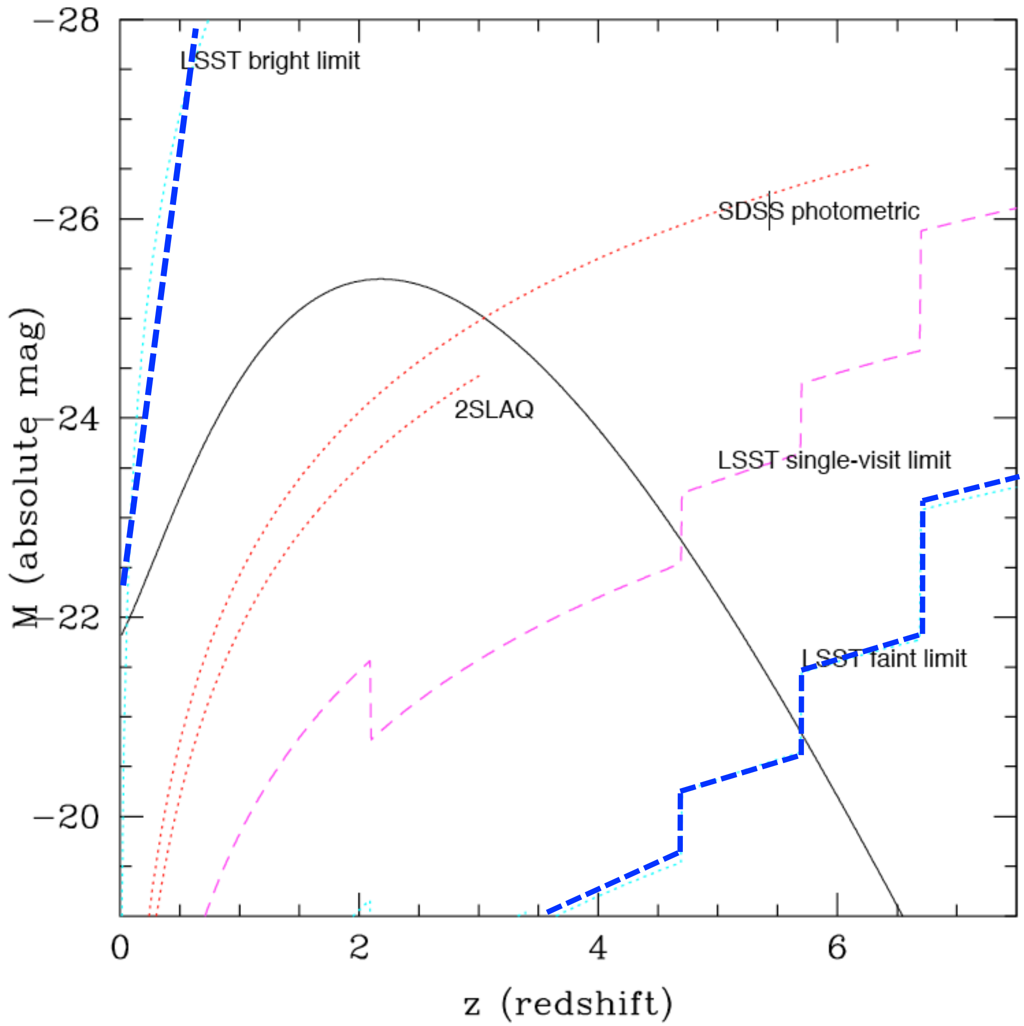


Active galactic nuclei across cosmic time

General impact of LSST

- Increase number of known AGN by 10x
  - Expected 10^7 to m ~ 24
- Break luminosity-*z* degeneracy of previous flux-limited surveys
  - LSST flux-limit low enough to sample broad range of intrinsic luminosity in each redshift
- Investigate correlations between…
  - AGN clustering and dark matter distribution
  - AGN and host galaxy properties
  - Photometric properties and time domain phenomena

Luminosity function

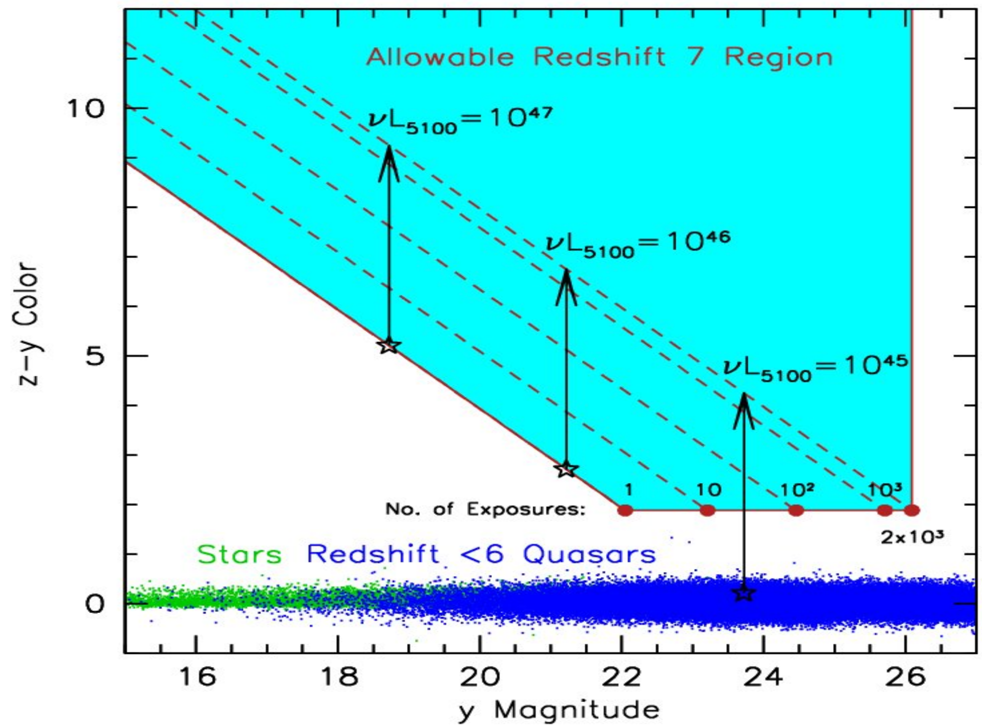


LSST will be able to follow LF break to much higher redshift

Solid line: model, L_* vs redshift (Hopkins et al. 2007)

High-redshift objects

- LSST expected to increase known number of z > 6.5 AGN by 10x
- ~ 1000 AGB at z > 6.5
  - L_{opt} down to 10^{44} erg s^{-1}



Redshift ~7 AGN candidates are defined to have 3σ *y*-band detections and 2σ *z*-band *non*-detections. The shaded space shows the candidate region in (*z-y, y*) space as a function of the number of exposures.

Time domain: “normal” variability

- Ubiquitous: AGN emission variable with time
  - Defining characteristic, helps identify in LSST survey
- Must be related to accretion process, but how?
- LSST will sample time variability for millions of objects on timescales of minutes to decade
  - Deep drilling fields particular interesting (minute time scales)

Time domain: transient outbursts

- Case 1: star is tidally disrupted and partially accreted by central supermassive black hole (SMBH)
  - Gezari et al. (2009) predicts at least 130 such events per year
  - Optical flare can last for months
  - Special case: white dwarf disruption ➡ supernova-like?

- Case 2: inspiral and merger phases of binary black holes
  - Inspiral causes periodic changes in accretion rate and thus observed flux (?)
  - Mergers produce detectable (?) gravitational wave events (Advanced LIGO) ➡ LSST might be able to forecast

Time domain: micro-lensing

- Stellar-mass objects can magnify accretion disk emission
- Resulting multi-band light curves depend on accretion disk structure and sizes
- Potential (?) probe of accretion physics and black hole demographics over wide range of luminosity and redshift

End of presentation

Find out more at…

www.lsst.org

LSST system parameters

Large Synoptic Survey Telescope

THE LSST BASELINE DESIGN AND SURVEY PARAMETERS

Quantity	Baseline Design Specification
Optical Config.	3-mirror modified Paul-Baker
Mount Config.	Alt-azimuth
Final f-Ratio, aperture	f/1.234, 8.4 m
Field of view, étendue	9.6 deg^2, 319 $m^2 deg^2$
Plate Scale	50.9 μm/arcsec (0.2" pix)
Pixel count	3.2 Gigapix
Wavelength Coverage	320 – 1050 nm, *ugrizy*
Single visit depths[a] (5σ)	23.9, 25.0, 24.7, 24.0, 23.3, 22.1
Mean number of visits	70, 100, 230, 230, 200, 200
Final (coadded) depths[a]	26.3, 27.5, 27.7, 27.0, 26.2, 24.9

[a] The listed values for 5σ depths in the *ugrizy* bands, respectively, are AB magnitudes, and correspond to point sources and zenith

Multivariate study challenges

Large Data Analysis Challenges and Mutlivariate Studies

The vast amount of LSST data will require novel data analysis techniques. Key to galaxy studies will be:

- **Deblending**: reconstructing galaxies when either well resolved or blended with other sources.
- **Multivariate analysis:** construction of luminosity functions, n-point correlation functions, etc. and their dependence on environment and redshift (or, conversely, bias as a function of redshift and galaxy properties, see Fig. 4).
- **Cross-survey correlation:** Combining LSST survey data, at least in limited areas such as the deep drilling fields, with radio, IR and X-ray surveys will allow improved determination of parameters such as star-formation rate, dust temperature and mass, and AGN accretion rate. X-ray data in particular will be important for determining the AGN fraction (and correspondingly helping to remove obscured AGN as a source of outliers in these analyses). The planned mission eRosita and proposed mission WFXT would detect ~ 10^4 and 10^5 normal galaxies and ~ 10^6 and 10^7 AGN, respectively. XMM-Newton and Chandra are spending an increasing fraction of their time on very large projects and surveying LSST deep drilling fields will likely be proposed and could reach detection limits corresponding to NGC 6240 (a ULIRG/merger with a binary AGN) at z ~ 2.

To address these challenges the LSST galaxies team will be proceeding by:

- Analyzing mock catalogs from end-to-end simulations based on the Millenium galaxy simulation and models of the LSST telescope and operations (*see Krughoff poster*)
- Consultation with the LSST Astroinformatics collaboration on the use of advanced statistical techniques, e.g., data mining techniques for dimensionality reduction and outlier detection/rejection, and the use of Virtual Observatory tools for cross-survey correlations (*see Borne et al. poster*).
- After the start of operations, using deep drilling fields as a "primer" for the analysis of the shallower survey data
- Community-based computing strategies, such as the "Galaxy Zoo" to allow the public to help classify sources and identify mergers and irregular galaxies that will be problematic for deblending algorithms.

AGN statistics

Large Synoptic Survey Telescope

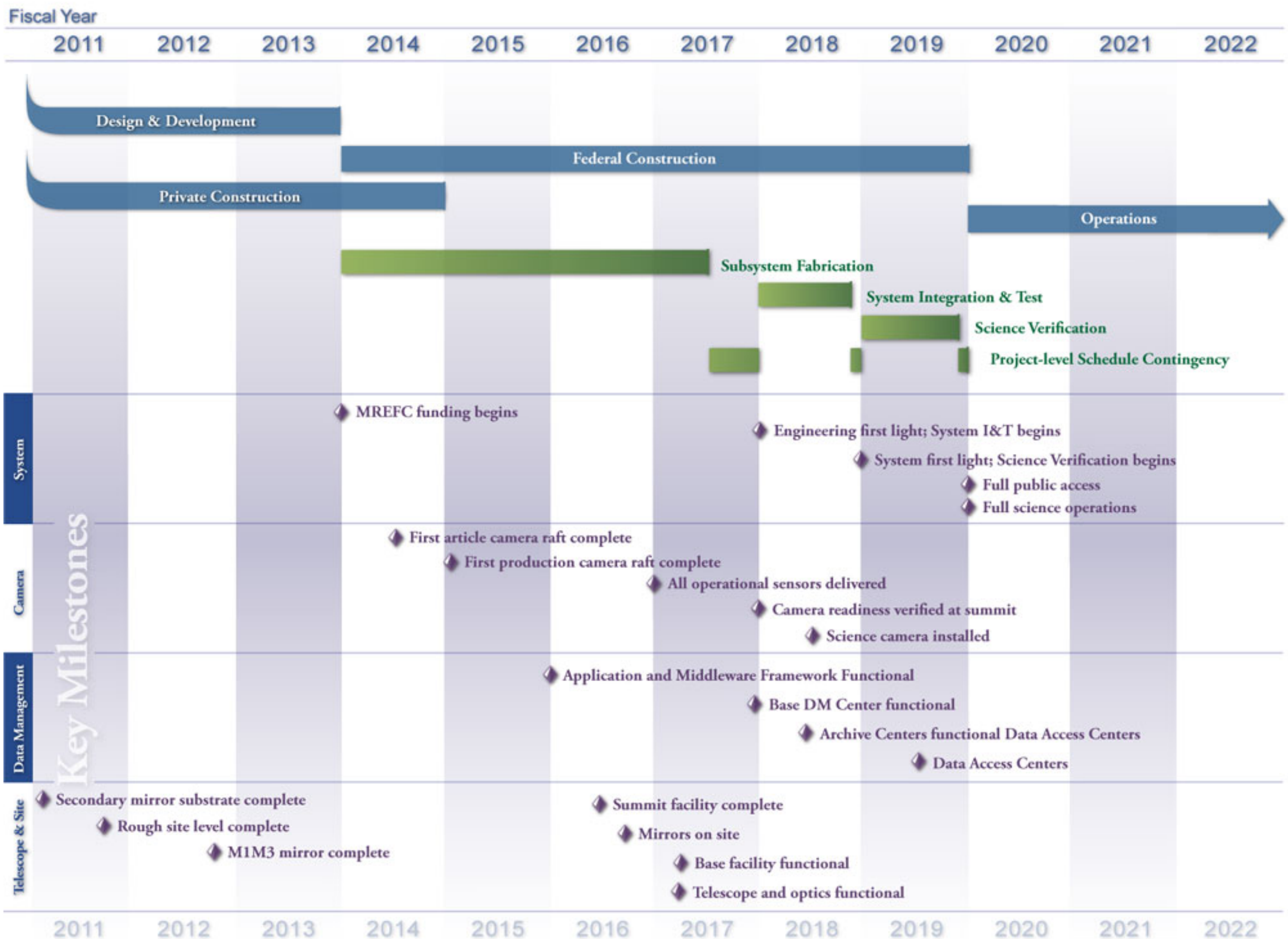
i	0.5	1.5	2.5	3.5	4.5	5.5	6.5	Total
16	666	597	254	36	0	0	0	1550
17	4140	4630	1850	400	54	0	0	11100
18	19600	28600	10700	1980	321	19	0	61200
19	68200	131000	53600	8760	1230	115	0	263000
20	162000	372000	194000	35000	4290	441	1	767000
21	275000	693000	453000	113000	14000	1380	34	1550000
22	336000	1040000	756000	269000	41200	3990	157	2450000
23	193000	1440000	1060000	476000	103000	10900	527	3280000
24	0	1370000	1360000	687000	205000	27400	1520	3660000
25	0	314000	1540000	888000	331000	60800	4100	3140000
26	0	0	279000	760000	358000	86800	7460	1490000
Total	1060000	5390000	5720000	3240000	1060000	192000	13800	16700000

Predicted Number of AGN in 20,000 deg^2 over $15.7<i<26.3$ and $0.3<z<6.7$ with $M_i <= -20$. The ranges in each bin are $\Delta i=1$ and $\Delta z_{em}=1$, except in the first and last bins where they are 0.8 and 0.7, respectively.

Special topics

- Target projects (~10% of time)
  - Kuiper Belt Objects
  - Supernovae
  - Short-timescale transients
  - Deep fields (~ 2 mag deeper)

Schedule



Fiscal Year
2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022
Design & Development
Federal Construction
Private Construction
Operations
Subsystem Fabrication
System Integration & Test
Science Verification
Project-level Schedule Contingency
Key Milestones
System
MREFC funding begins
Engineering first light; System I&T begins
System first light; Science Verification begins
Full public access
Full science operations
Camera
First article camera raft complete
First production camera raft complete
All operational sensors delivered
Camera readiness verified at summit
Science camera installed
Data Management
Application and Middleware Framework Functional
Base DM Center functional
Archive Centers functional Data Access Centers
Data Access Centers
Telescope & Site
Secondary mirror substrate complete
Rough site level complete
M1M3 mirror complete
Summit facility complete
Mirrors on site
Base facility functional
Telescope and optics functional

Galaxy evolution, survey impact

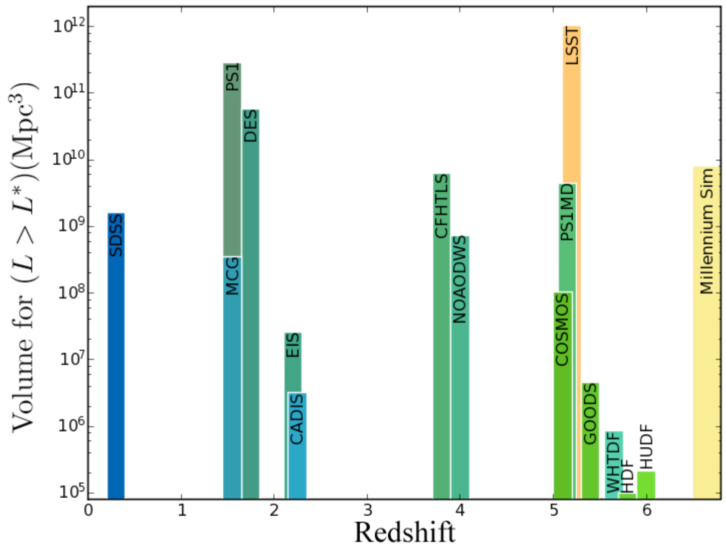


Fig. 1. Co-moving volume within which each survey can detect an L* galaxy (MB ~ −21) assuming a typical Lyman break galaxy spectrum. LSST encompasses ~ 2 orders of magnitude more volume than current or other near-future surveys.