LSST Project Status and Updates on Observing Strategy

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LSST@Europe 2
Belgrade, Serbia, June 20-24, 2016

Mon 20 Jun 2016

When	What	Who
09.00	*Tea/Coffee available*	
09.30 - 11.00	**Session 1: LSST status and overview (Chair R. Lupton)**	
09.30	Welcome	
09.45	LSST Project Status and Updates on Observing strategy	Zeljko Ivezić (University of Washington, USA)
10.30	LSST Data Products	Mario Jurić (University of Washington, USA)
11.00	*Tea/Coffee*	
11.30 - 13:00	**Session 2: Science Collaborations in the U.S. (Chair A. Vallenari)**	
11.30	LSST Science Collaborations	Lucianne Walkowicz (Adler Planetaruim, USA)
12.00	Dark Energy Science Collaboration	Andy Connolly (University of Washington, USA)
12.30	The role of LSST Corporation	Pat Eliason (LSSTC, USA)

LSST in one sentence:

An optical/near-IR survey of half the sky in ugrizy bands to r~27.5 based on ~1000 visits over a 10-year period:

More information at www.lsst.org and arXiv:0805.2366

A catalog of 20 billion stars and 20 billion galaxies with exquisite photometry, astrometry and image quality!

Outline

- Brief overview of LSST
  – science drivers
  – system design
  – progress report
- Planning for LSST deployment: observing strategy optimization
  - SRD and optimization of observing strategy
  - optimal exposure time considerations
  - cadence optimization principles
  - characteristics of the baseline cadence
  - ongoing cadence optimization efforts

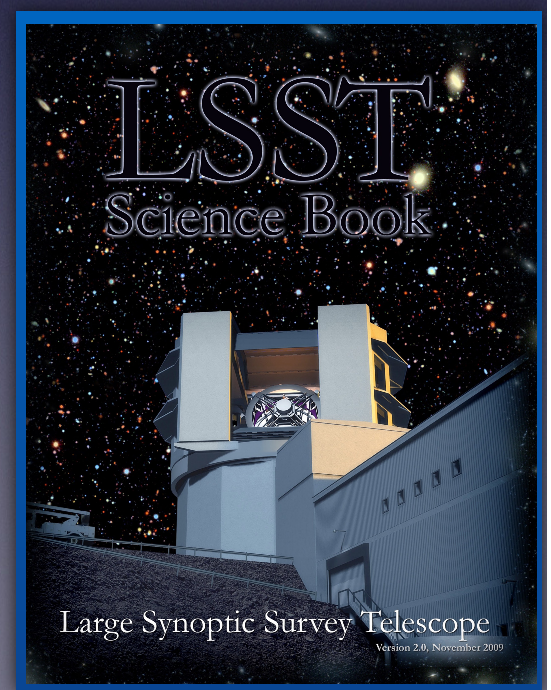
LSST Science Themes

- Dark matter, dark energy, cosmology
(spatial distribution of galaxies, gravitational lensing, supernovae, quasars)
- Time domain
(cosmic explosions, variable stars)
- The Solar System structure (asteroids)
- The Milky Way structure (stars)

LSST Science Book: arXiv:0912.0201

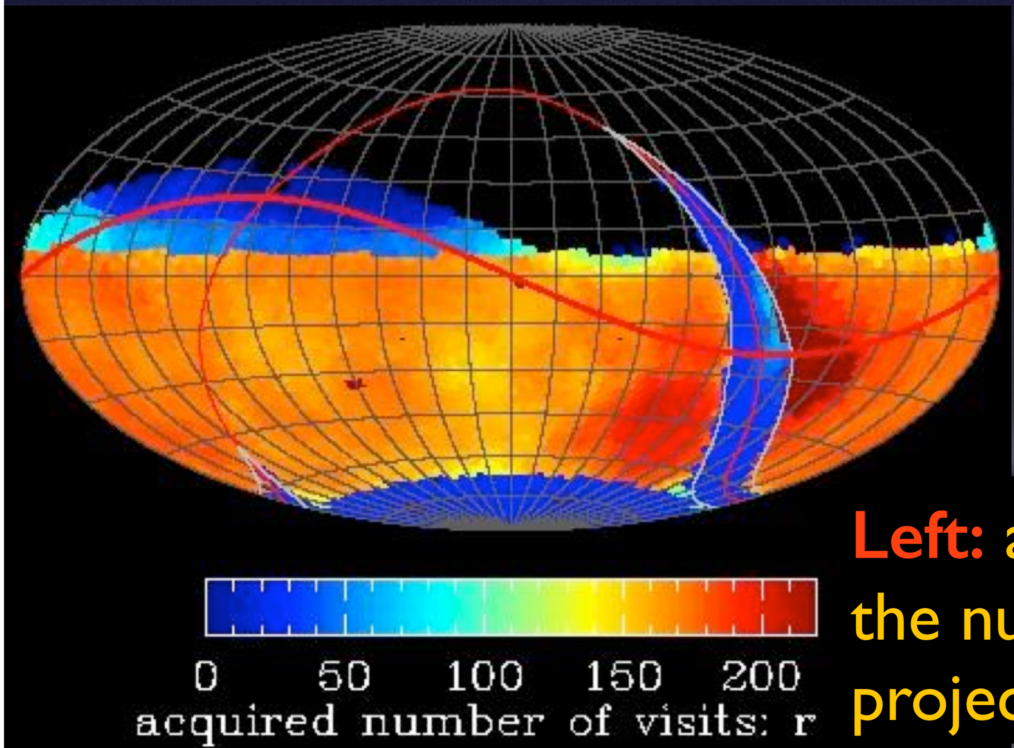
Summarizes LSST hardware, software, and observing plans, science enabled by LSST, and educational and outreach opportunities

245 authors, 15 chapters, 600 pages



Basic idea behind LSST: a uniform sky survey

- 90% of time will be spent on a uniform survey: every 3-4 nights, the whole observable sky will be scanned twice per night
- after 10 years, half of the sky will be imaged about 1000 times (in 6 bandpasses, ugrizy): a digital color movie of the sky
- ~100 PB of data: about a billion 16 Mpix images, enabling measurements for 40 billion objects!



LSST in one sentence:
An optical/near-IR survey of half the sky in ugrizy bands to r~27.5 (36 nJy) based on 825 visits over a 10-year period: deep wide fast.

Left: a 10-year simulation of LSST survey: the number of visits in the r band (Aitoff projection of eq. coordinates)

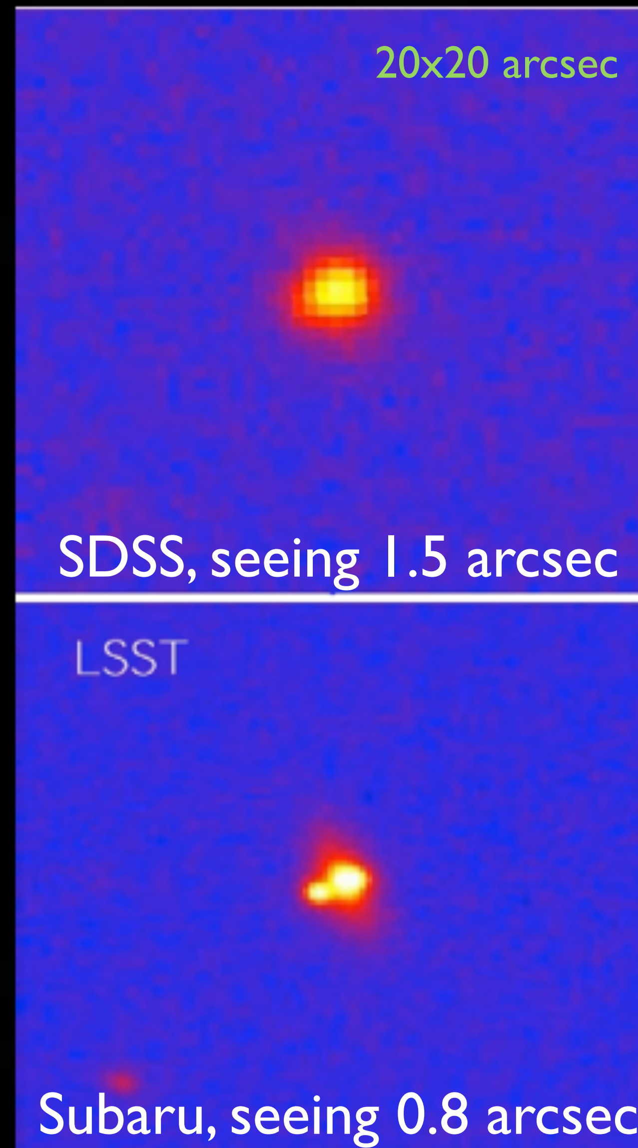
SDSS vs. LSST comparison: LSST=d(SDSS)/dt, LSST=SuperSDSS

3x3 arcmin, gri

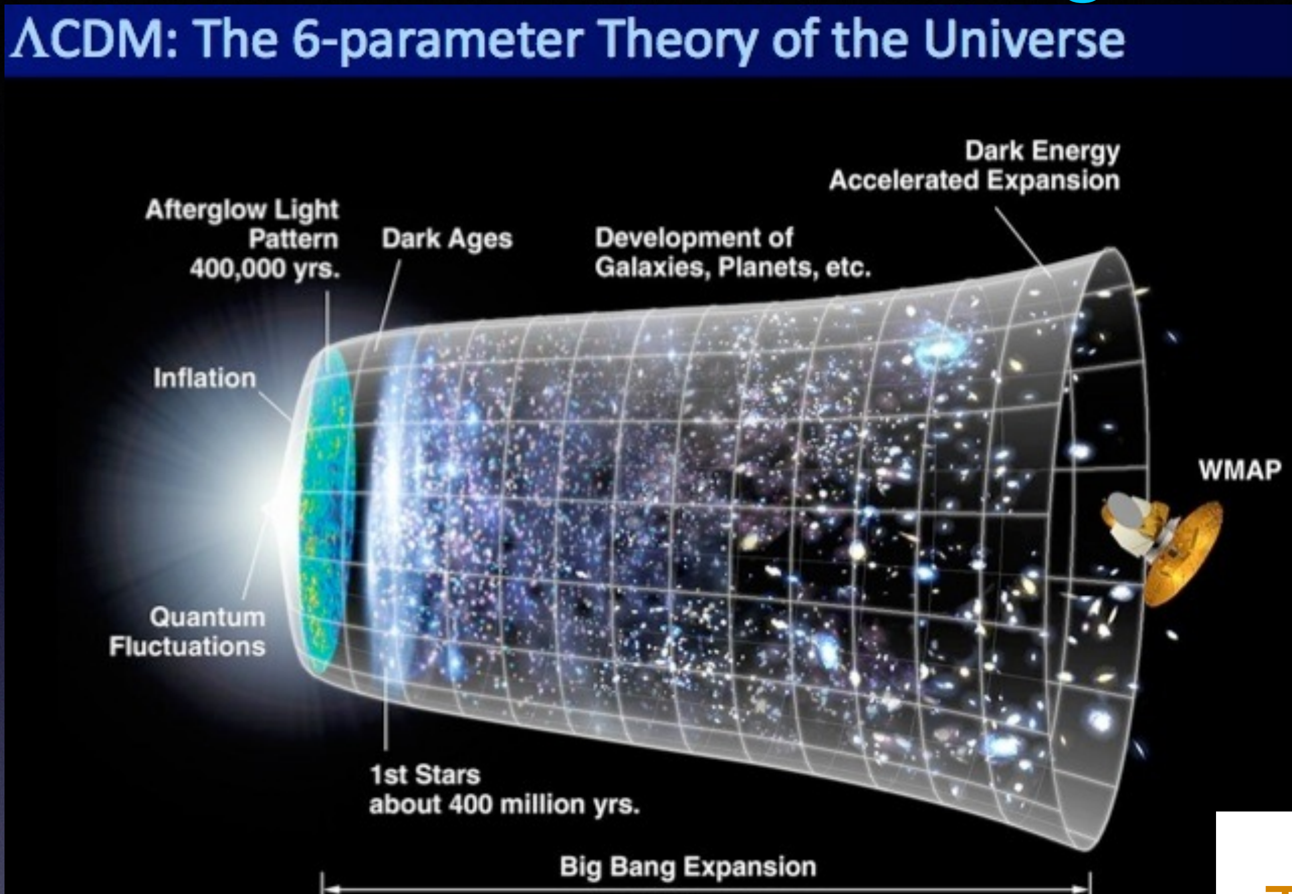
3 arcmin is 1/10 of the full Moon's diameter

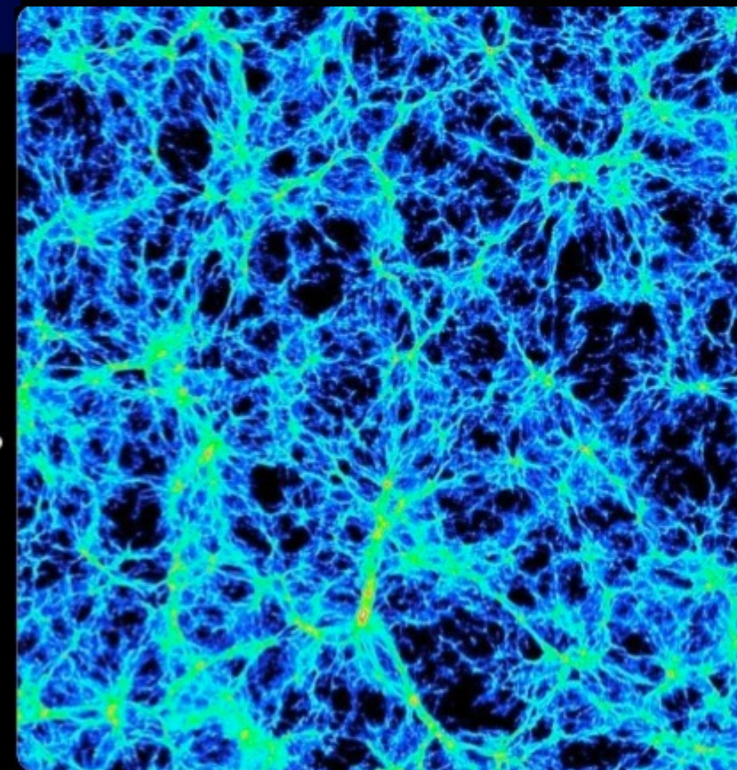
(almost) like LSST depth (but tiny area)

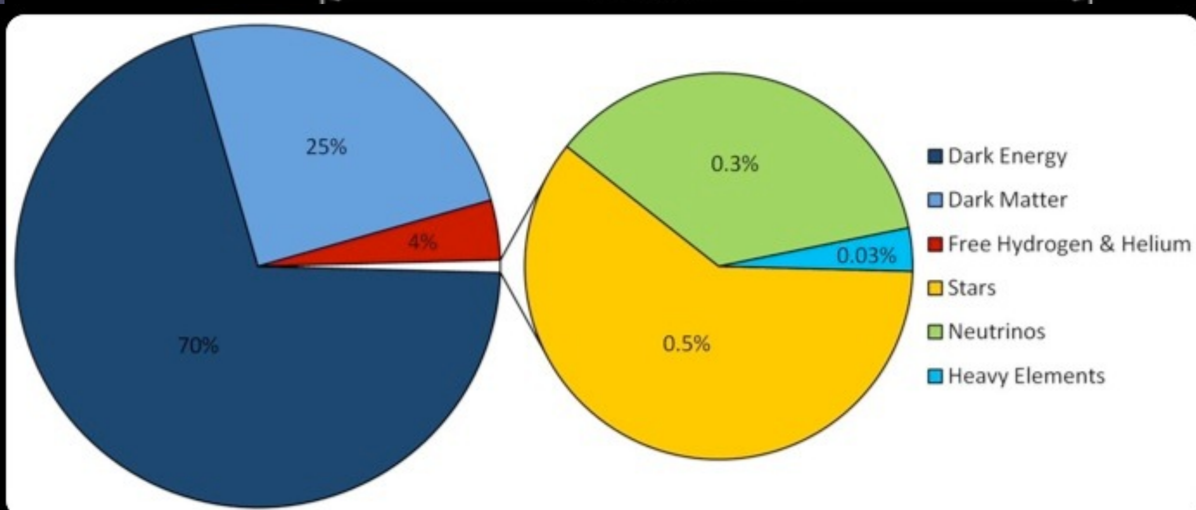
20x20 arcsec; lensed SDSS quasar (SDSS J1332+0347, Morokuma et al. 2007)



New Cosmological Puzzles







The modern cosmological models can explain all observations, but need to **postulate** dark matter and dark energy (though gravity model could be wrong, too)

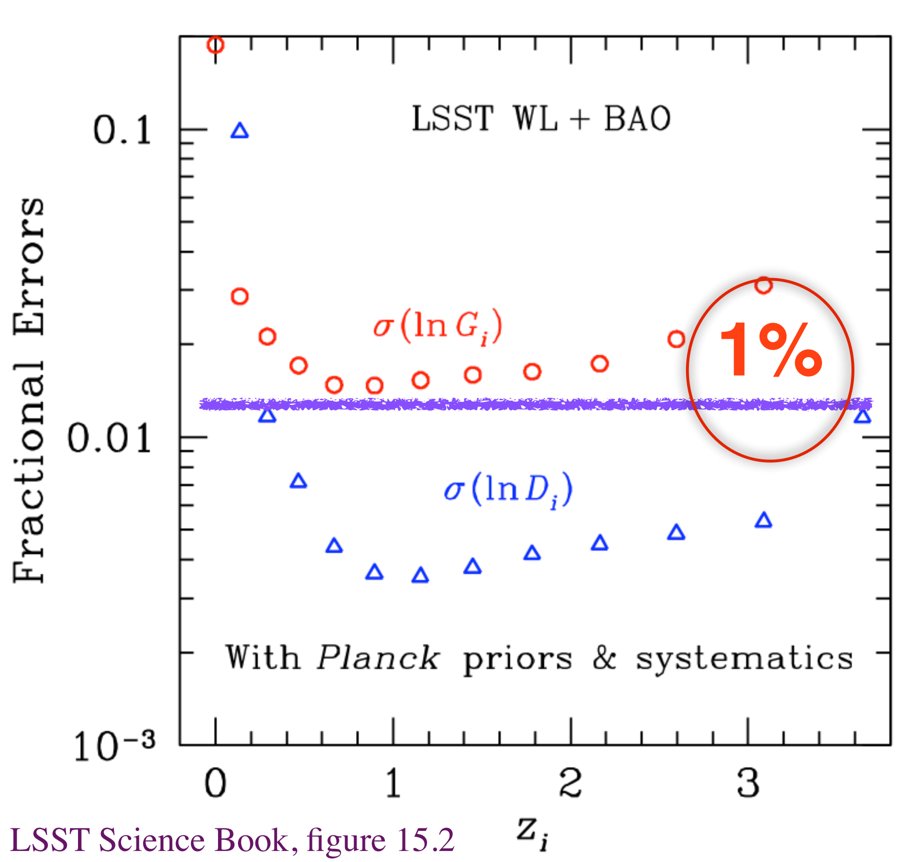
Modern Cosmological Probes

- Cosmic Microwave Background (the state of the Universe at the recombination epoch, at redshift ~1000)
- Weak Lensing: growth of structure
- Galaxy Clustering: growth of structure
- Baryon Acoustic Oscillations: standard ruler
- Supernovae: standard candle

Except for CMB, measuring H(z) and growth of structure G(z)
$H(z) \sim d[\ln(a)]/dt$, $G(z) = a^{-1}\delta\rho_m/\rho_m$, with $a(z) = (1+z)^{-1}$

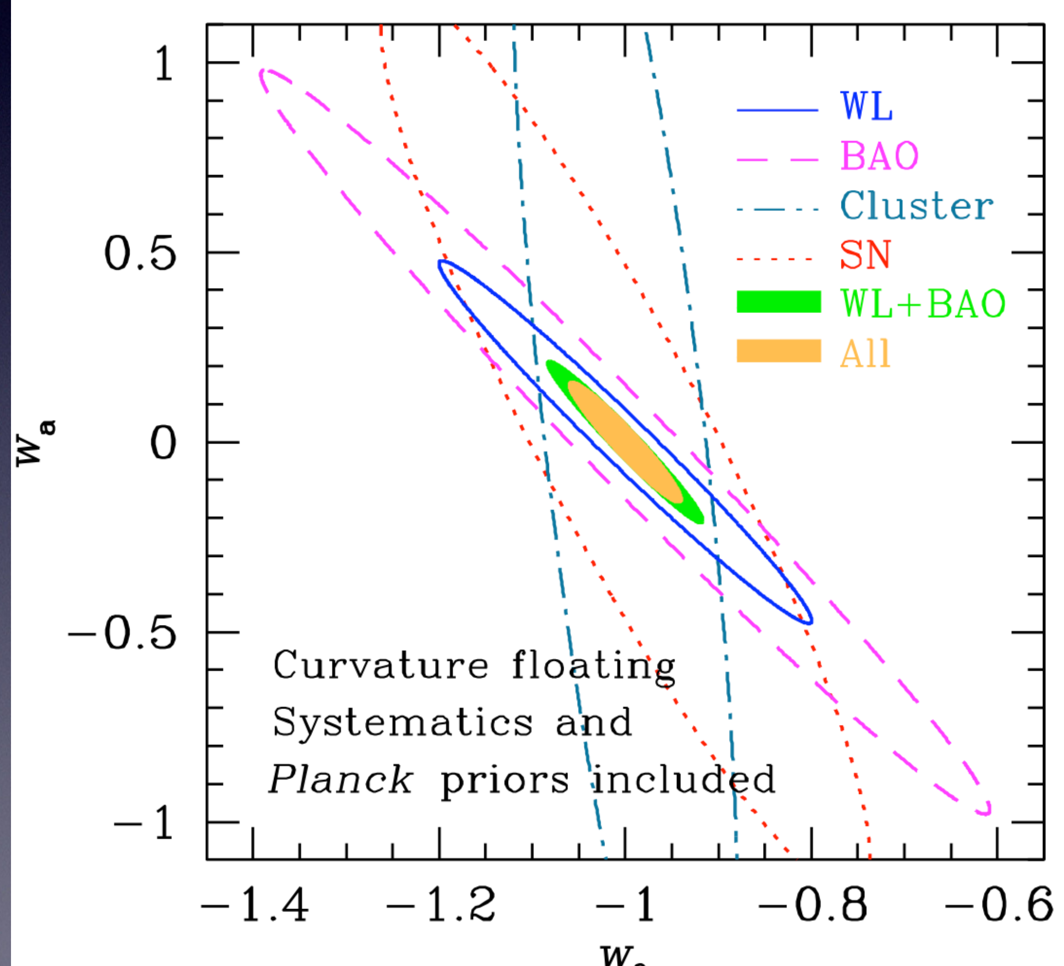
LSST is designed to reach Stage IV level from DETF report
which kinda means **"It will be awesome and better than anything today!"**

Cosmology with LSST: high precision measurements



LSST Science Book, figure 15.2

- Measuring distances, H(z), and growth of structure, G(z), with a percent accuracy for 0.5 < z < 3
- Multiple probes is the key!



LSST Science Book, figure 15.3

By simultaneously measuring growth of structure and curvature, LSST data will tell us whether the recent acceleration is due to **dark energy or modified gravity.**

Galaxies:

- **Photometric redshifts:** random errors smaller than 0.02, bias below 0.003, fewer than 10% >3σ outliers
- These photo-z requirements are one of the primary drivers for the photometric depth and accuracy of the main LSST survey (and the definition of filter complement)

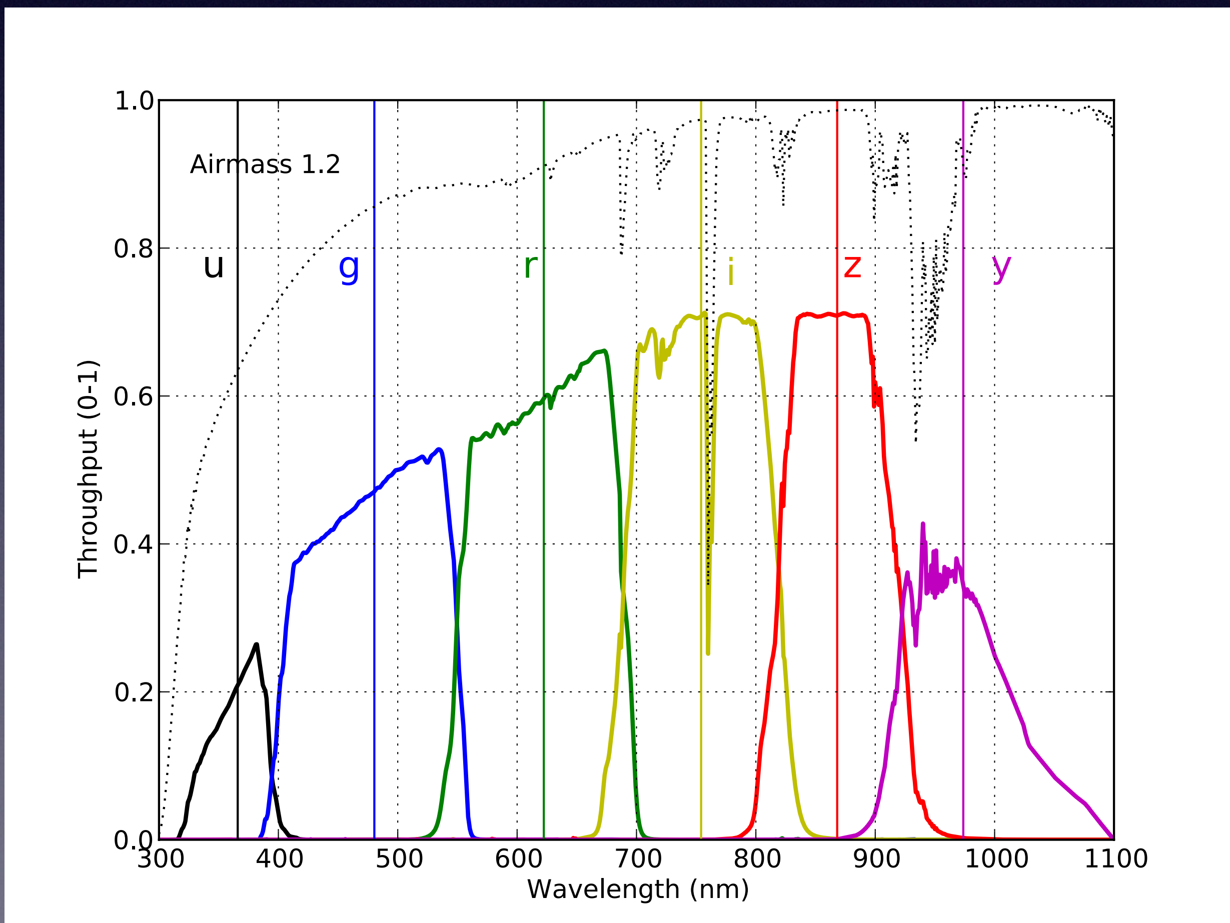


Photo-z requirements correspond to r~27.5

with the following per band time allocations:

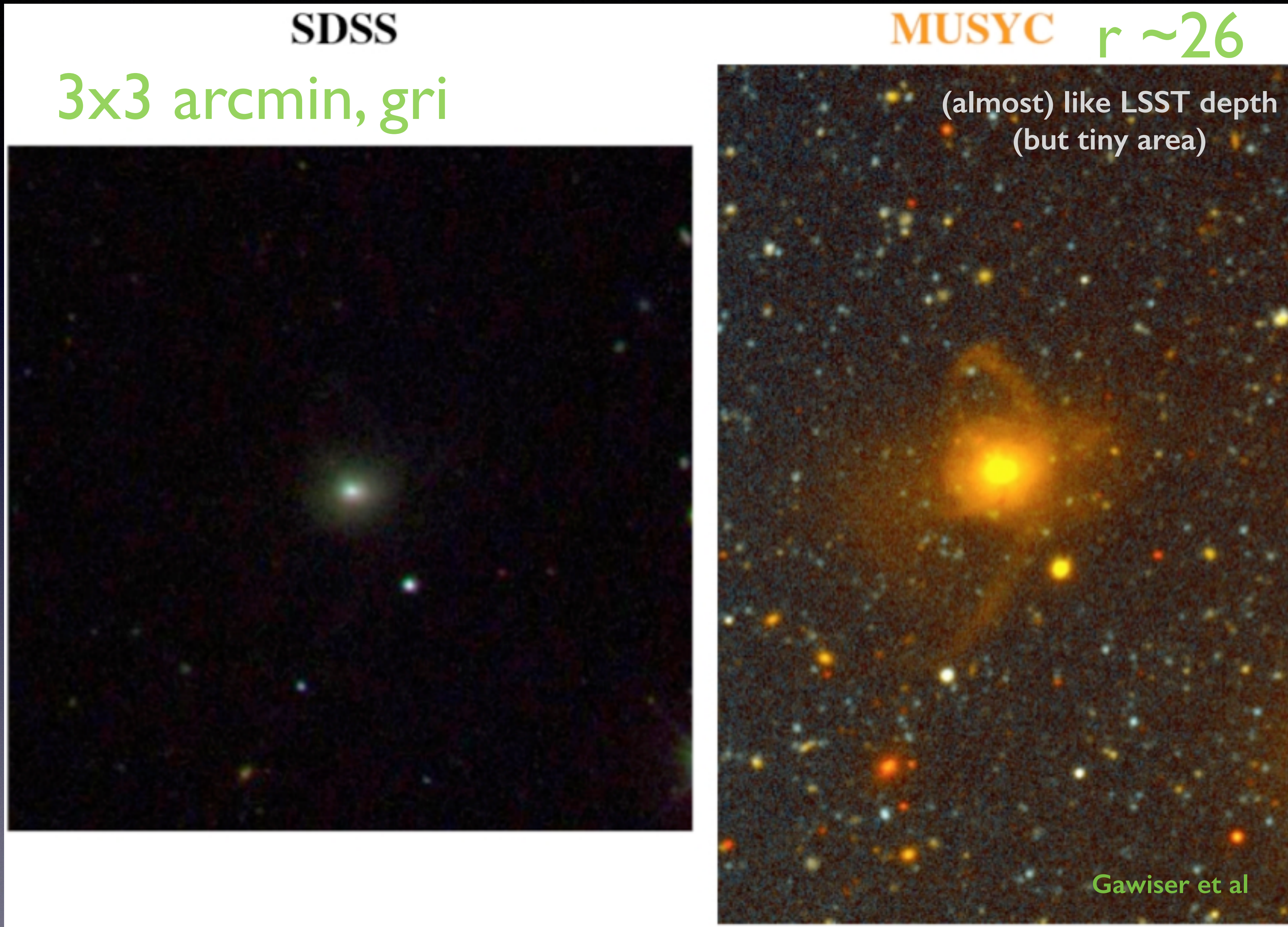
u: 8%; g: 10%

r: 22%; i: 22%

z: 19%; y: 19%

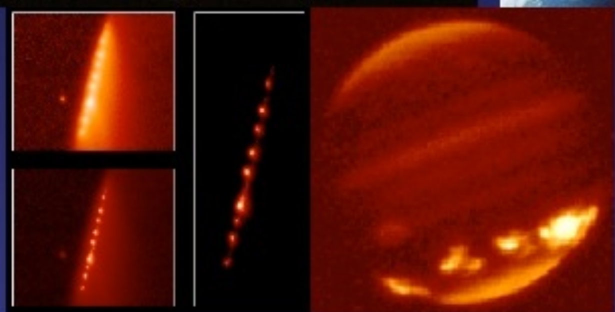
Consistent with other science themes (stars)

Extragalactic astronomy: faint surface brightness limit



Killer asteroids: the impact probability is not 0!

photomontage!



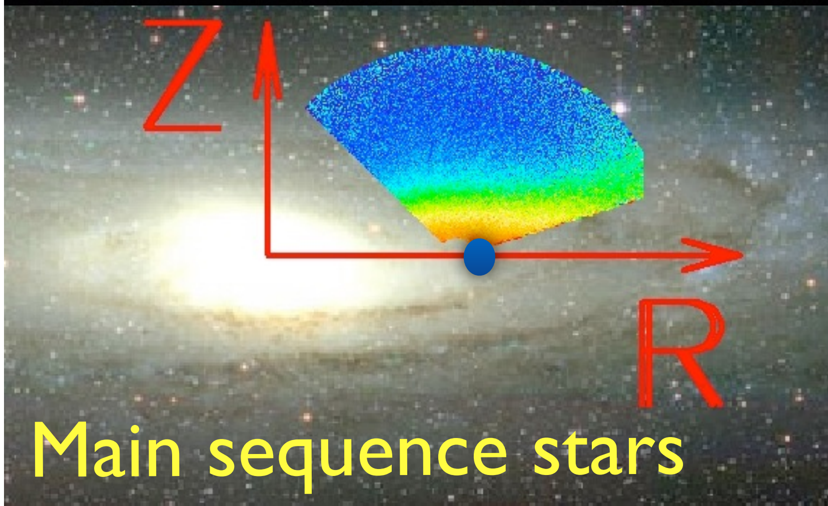
Shoemaker-Levy 9
(1994)

Tunguska
(1908)

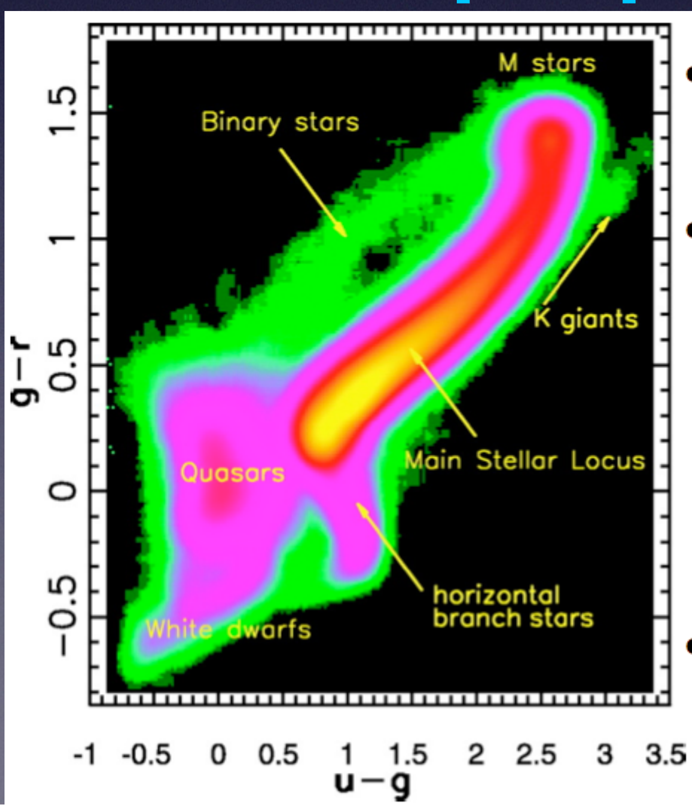
LSST is the only survey capable of delivering completeness specified in the 2005 USA Congressional NEO mandate to NASA (to find 90% NEOs larger than 140m)

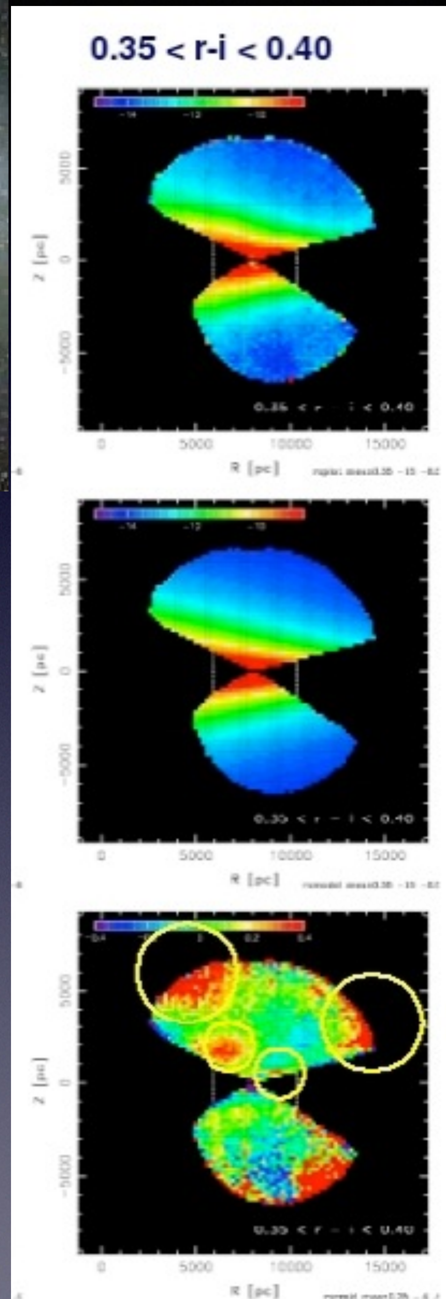
The Barringer Crater, Arizona: a 40m object 50,000 yr. ago

The Milky Way structure: 20 billion stars, time domain massive statistical studies!

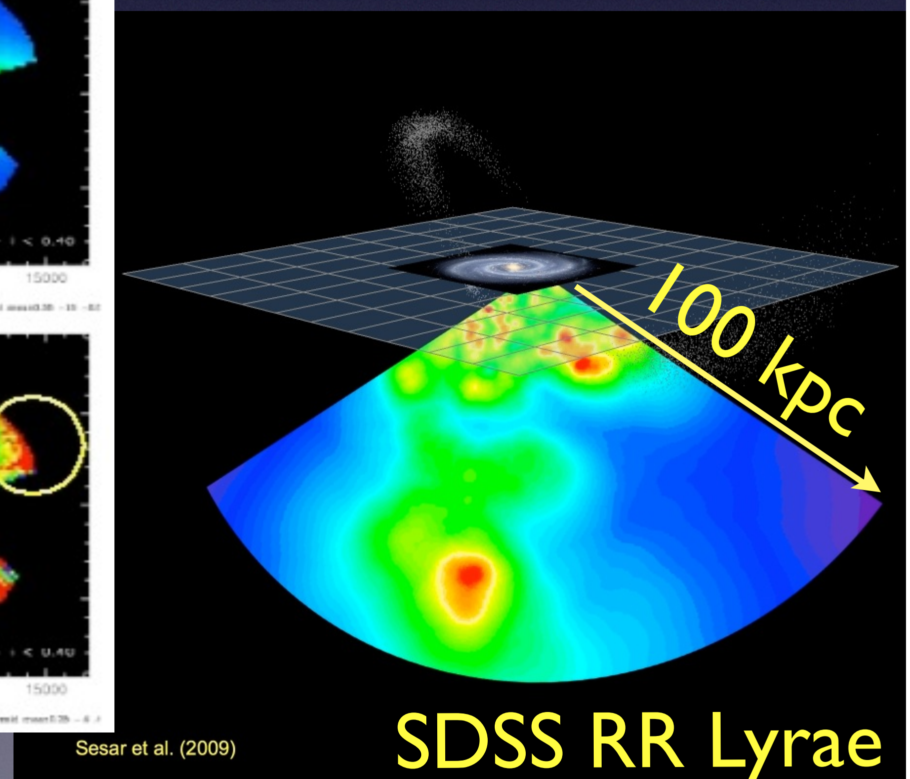


Distance and [Fe/H]:

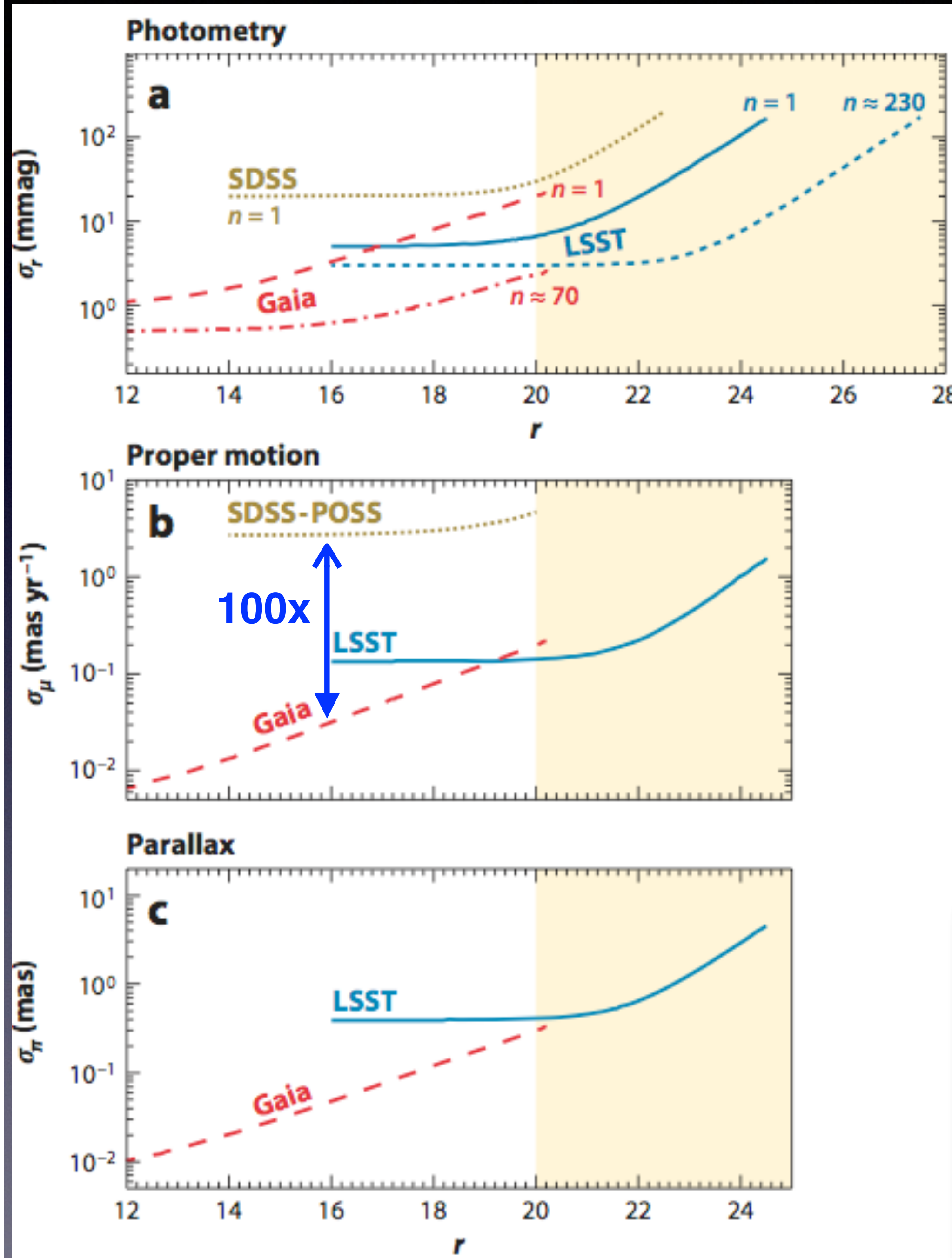




Compared to SDSS: LSST can "see" about 40 times more stars, 10 times further away and over twice as large sky area



Gaia vs. LSST comparison



Ivezić, Beers, Jurić 2012, ARA&A, 50, 251

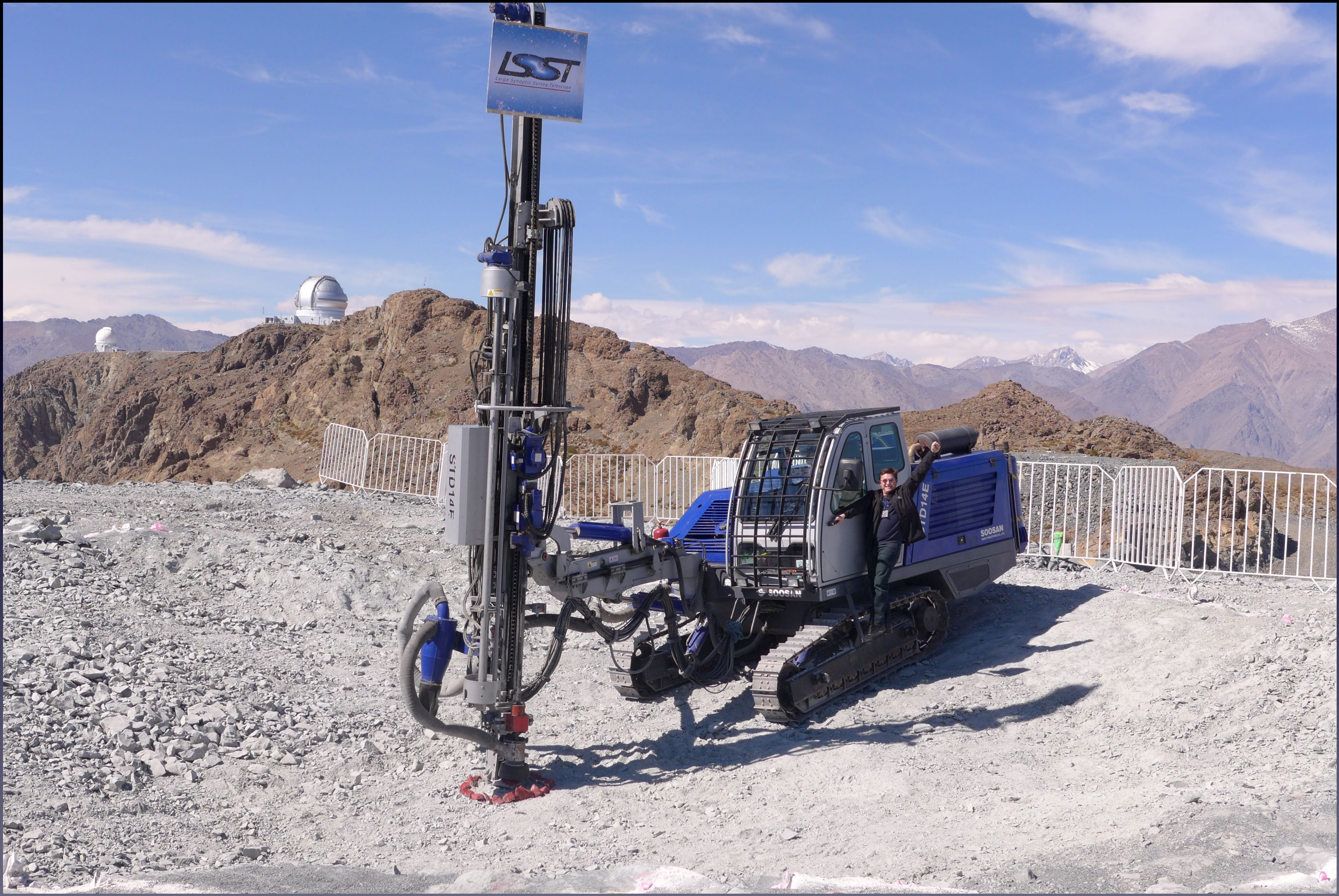
- **Gaia:** excellent astrometry (and photometry), but only to r < 20
- **LSST:** photometry to r < 27.5 and time resolved measurements to r < 24.5
- Complementarity of the two surveys: photometric, proper motion and trigonometric parallax errors are similar around r=20

The Milky Way disk "belongs" to Gaia, and the halo to LSST (plus very faint and/or very red sources, such as white dwarfs and LT(Y) dwarfs).

LSST First Stone Ceremony
April 14, 2015

LSST First Stone Ceremony
April 14, 2015

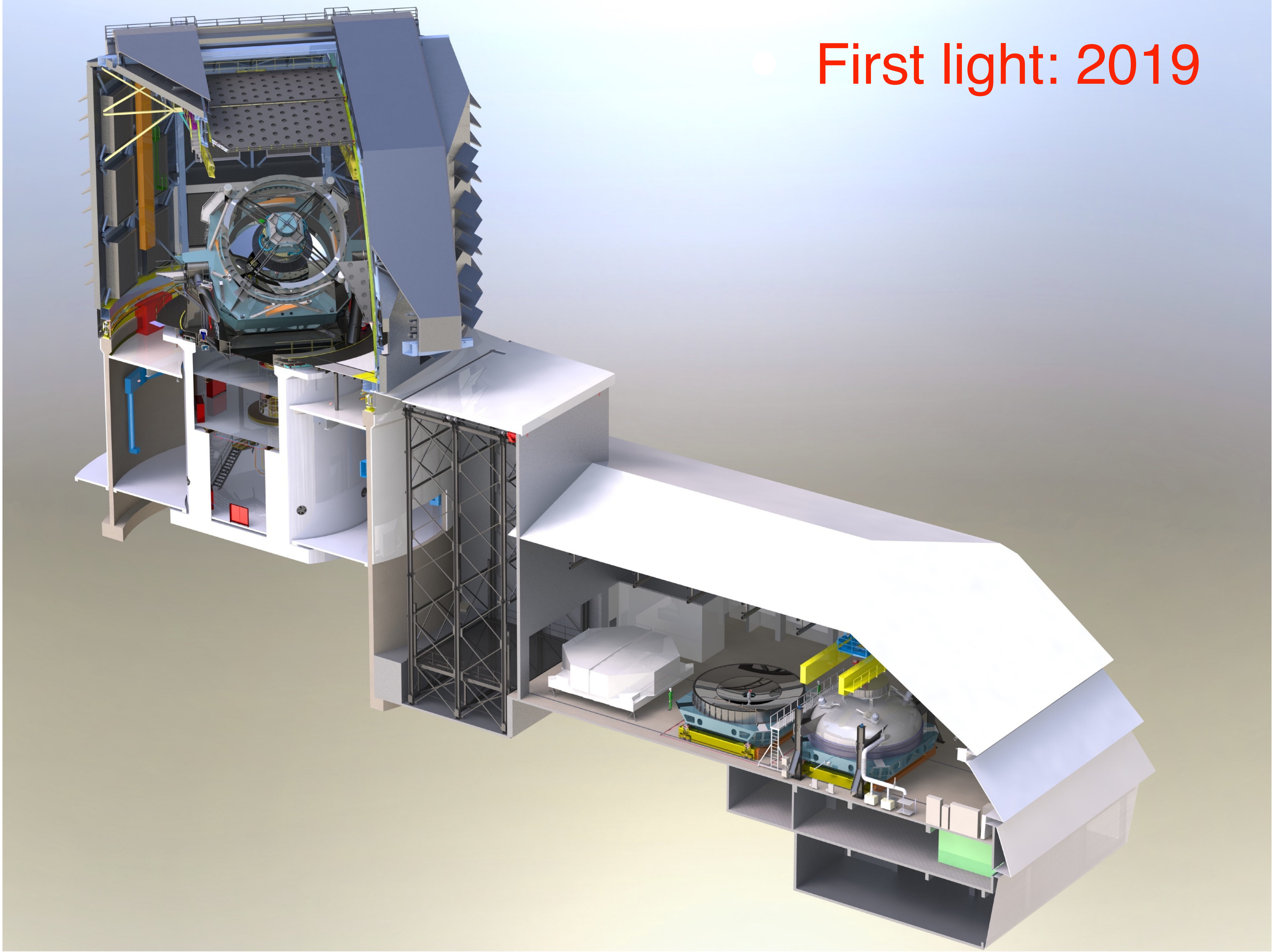
and while dignitaries are celebrating…



some are happily doing real work!

LSST Construction – Above Ground on Pachón!

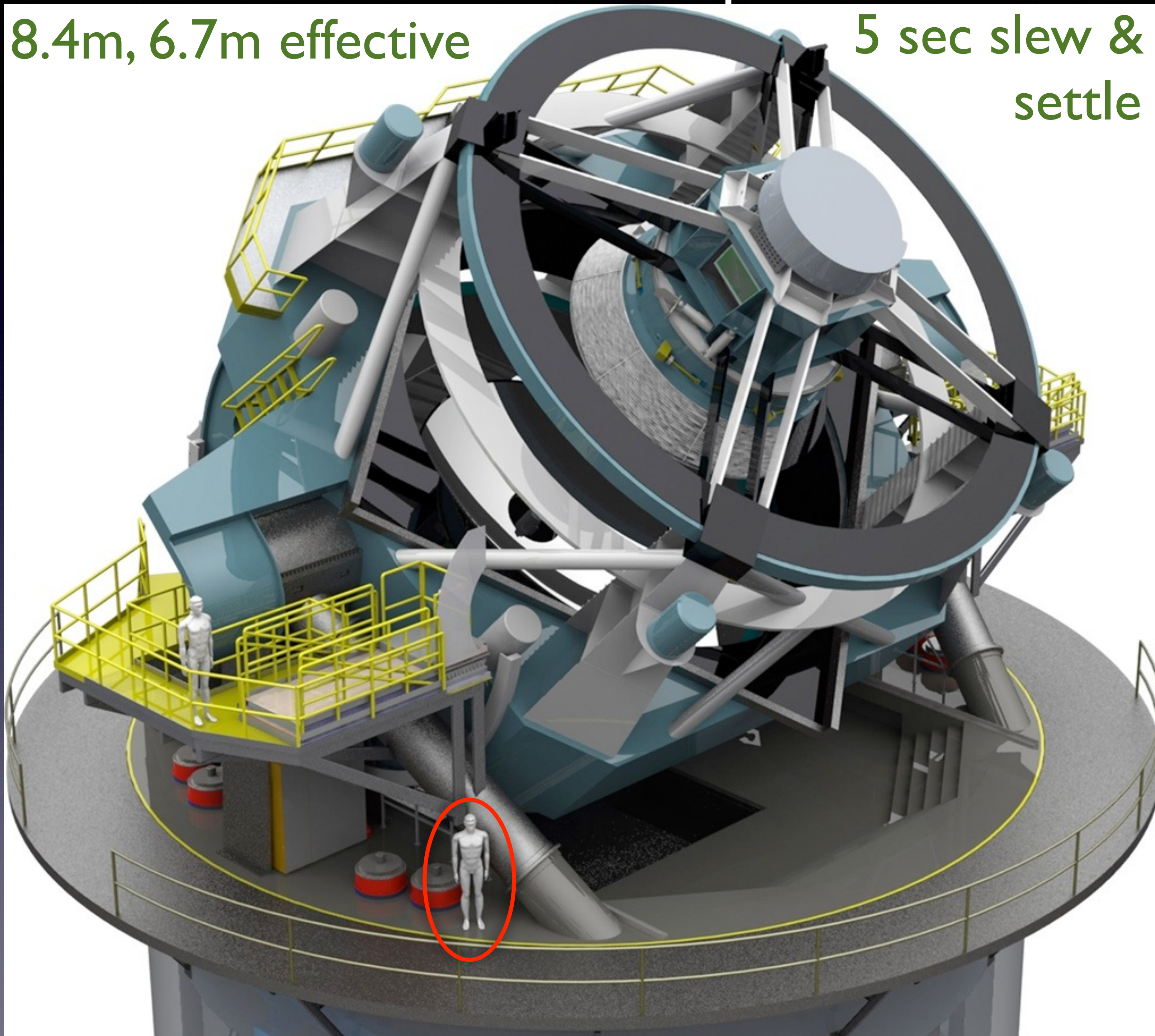
February 15, 2016
material
staging
Provisional
plywood
walkways
Service
building
concrete
structure in
progress
Excavation for telescope
pier foundation - rebar
placed for pour Feb 22 to
24
Excavation
for platform
lift
Excavation for lower
enclosure foundation
Elec.
&
tank
area
Formwork for beams to
support level 3 floor & mirror
cart rails


First light: 2019

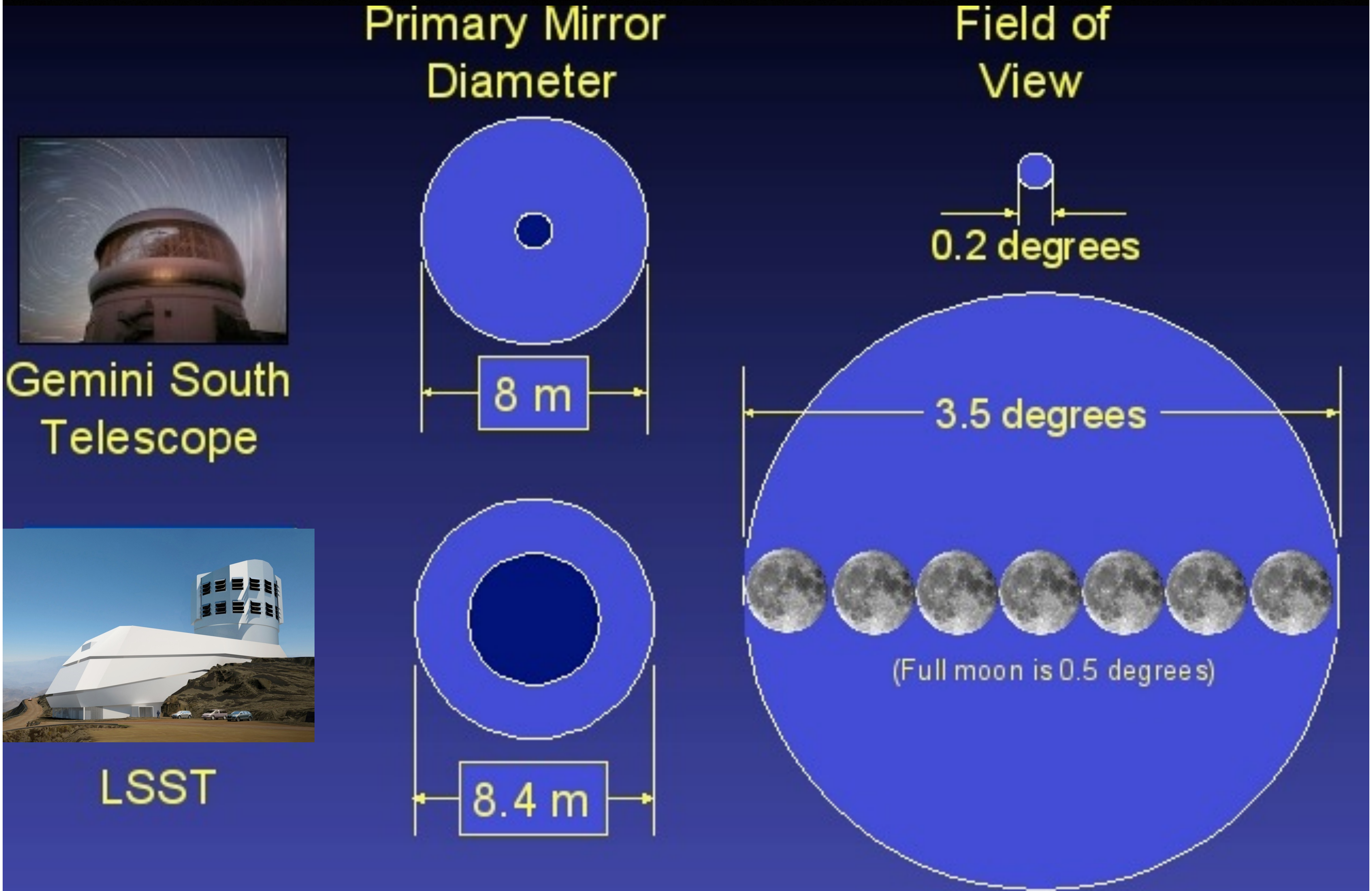
LSST Telescope

8.4m, 6.7m effective

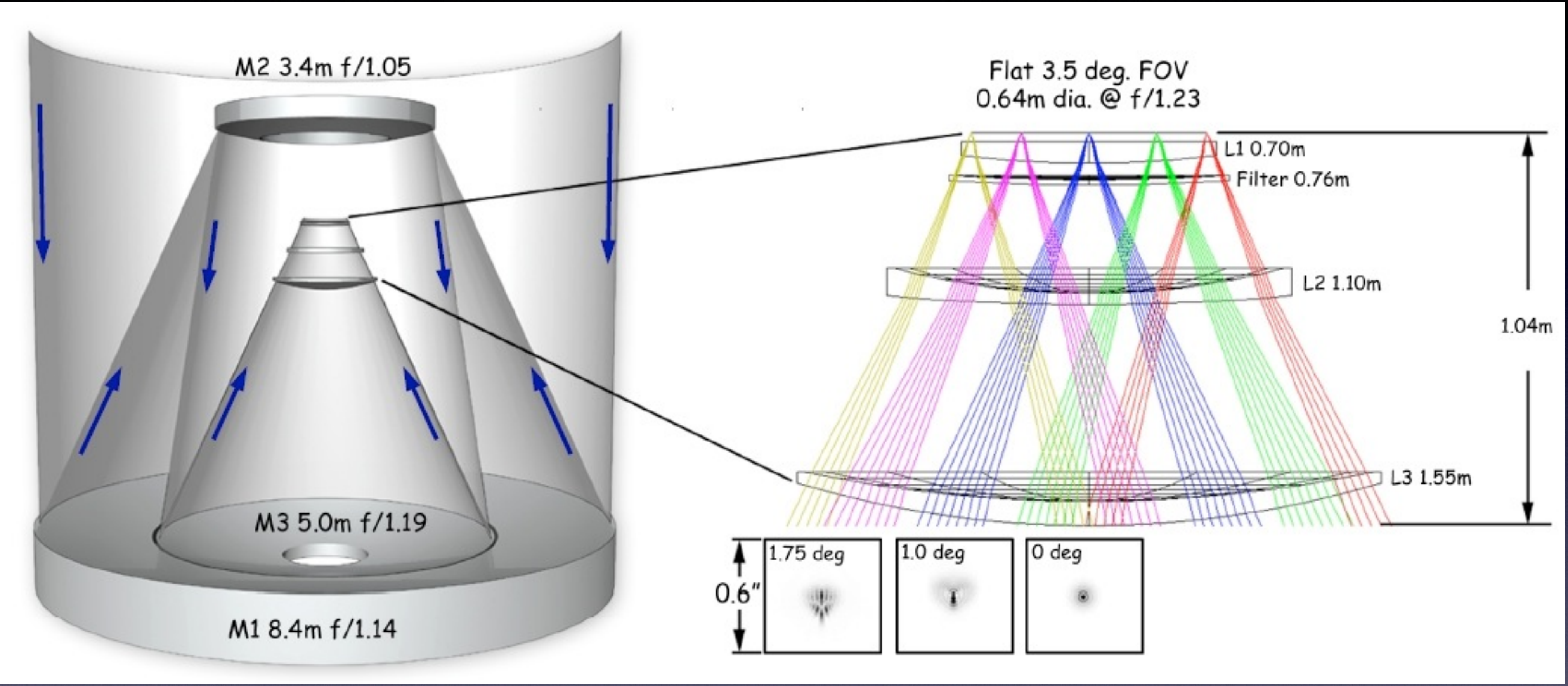
5 sec slew & settle



The field-of-view comparison: Gemini vs. LSST

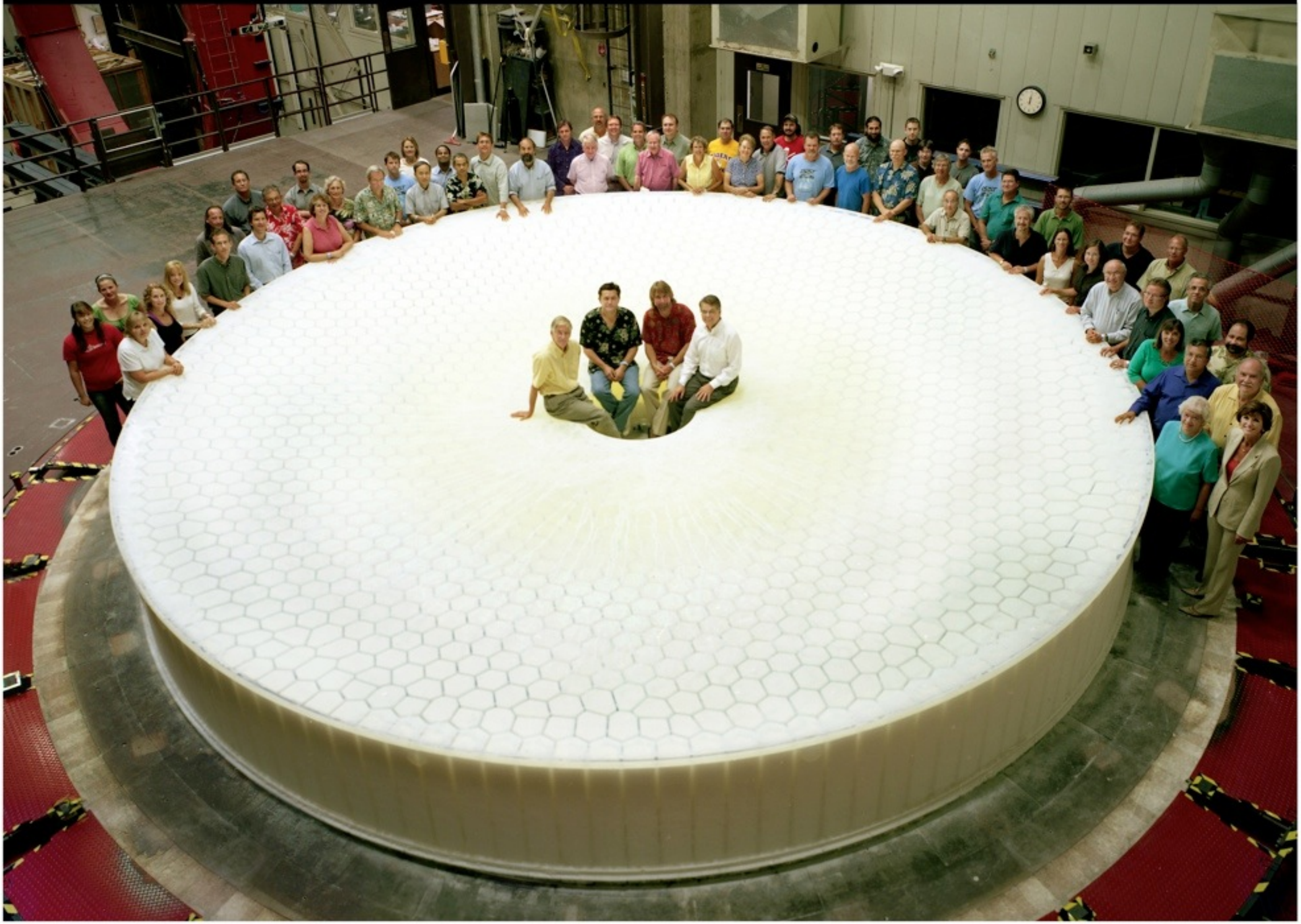


Optical Design for LSST



Three-mirror design (Paul-Baker system)
enables large field of view with excellent image quality:
delivered image quality is dominated by atmospheric seeing

Large Synoptic Survey Telescope



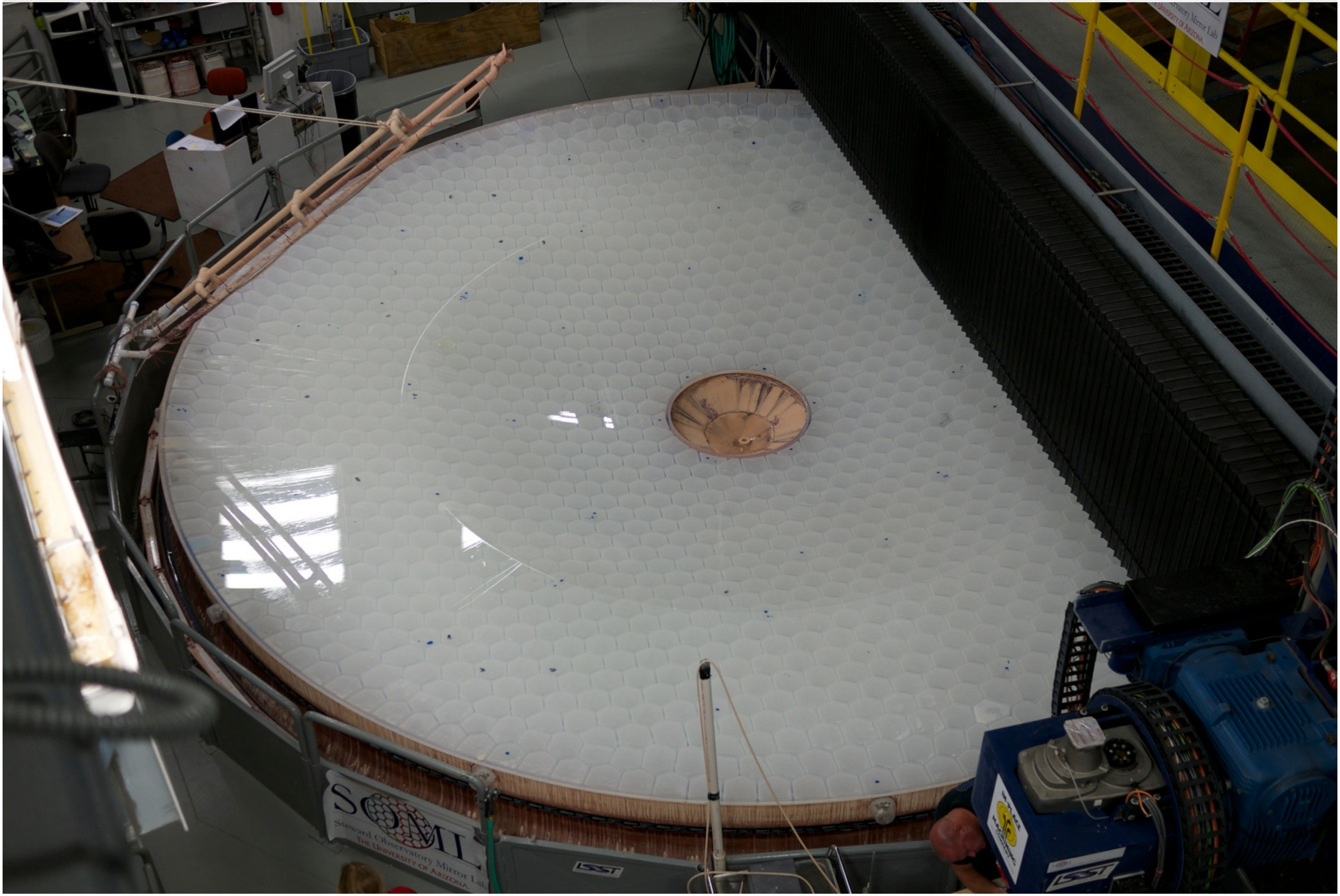
LSST Primary/Tertiary Mirror Blank
August 11, 2008, Steward Observatory Mirror Lab, Tucson, Arizona

The University of Arizona, Tucson Arizona

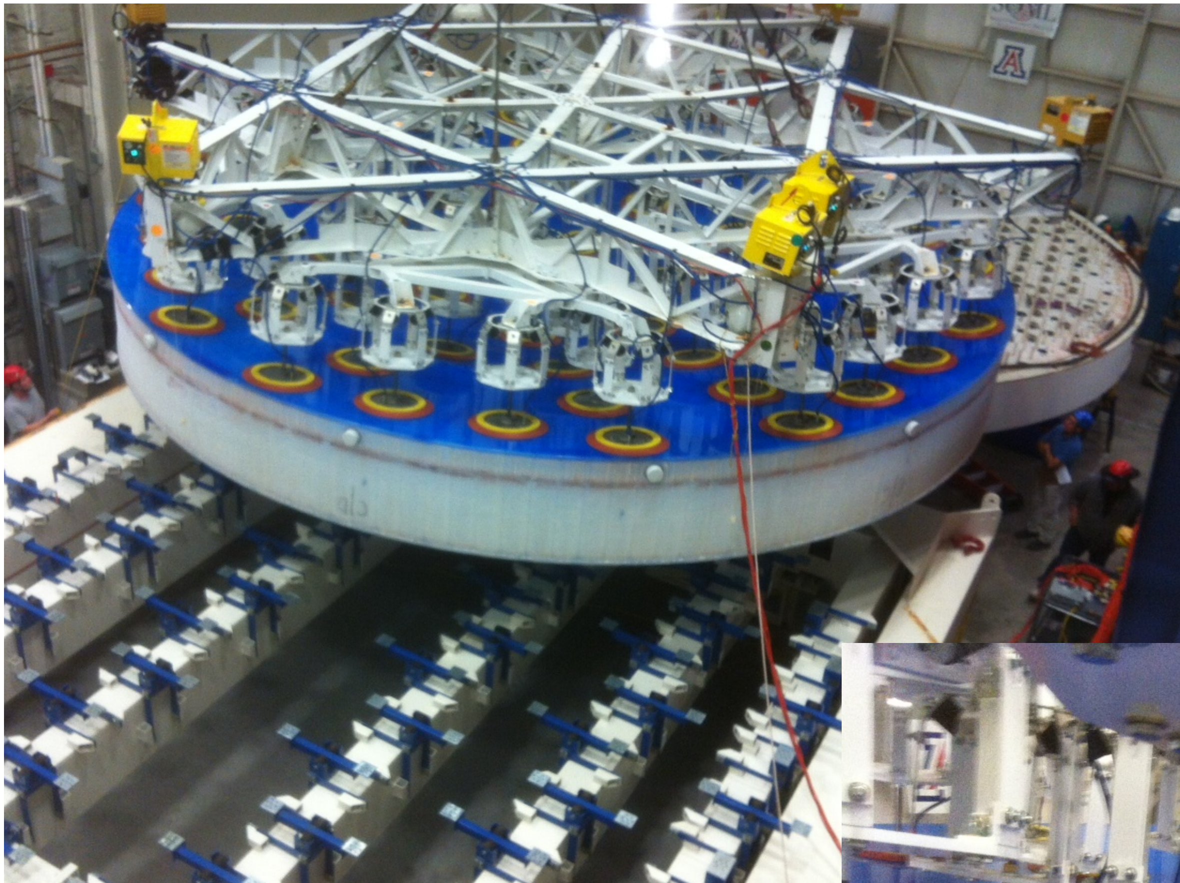
SOML

Large Synoptic Survey Telescope

Done!


SOML
Steward Observatory Mirror Lab
The University of Arizona
LSST

Large Synoptic Survey Telescope

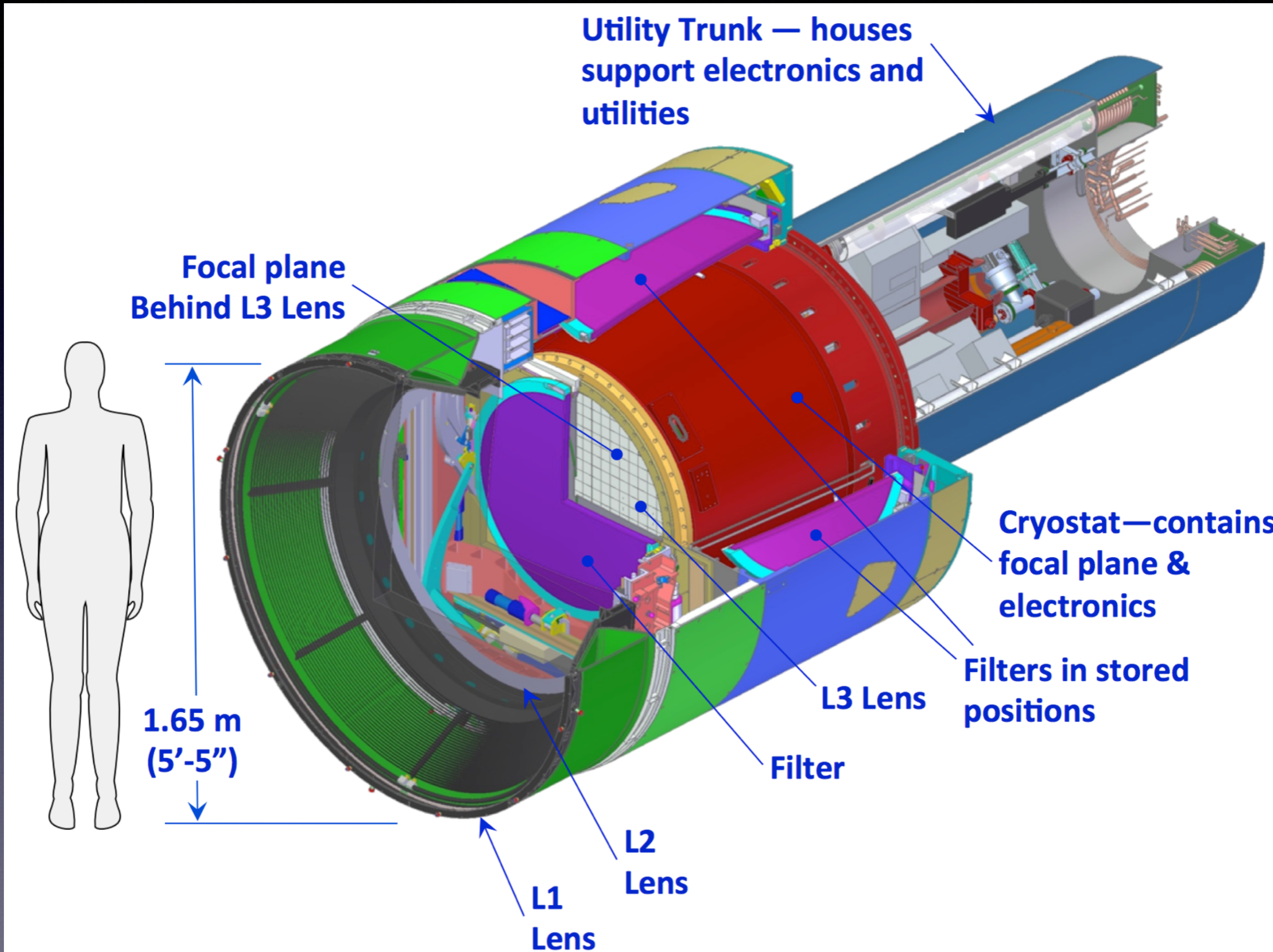



OVERSIZE LOAD

May 27, 2016:

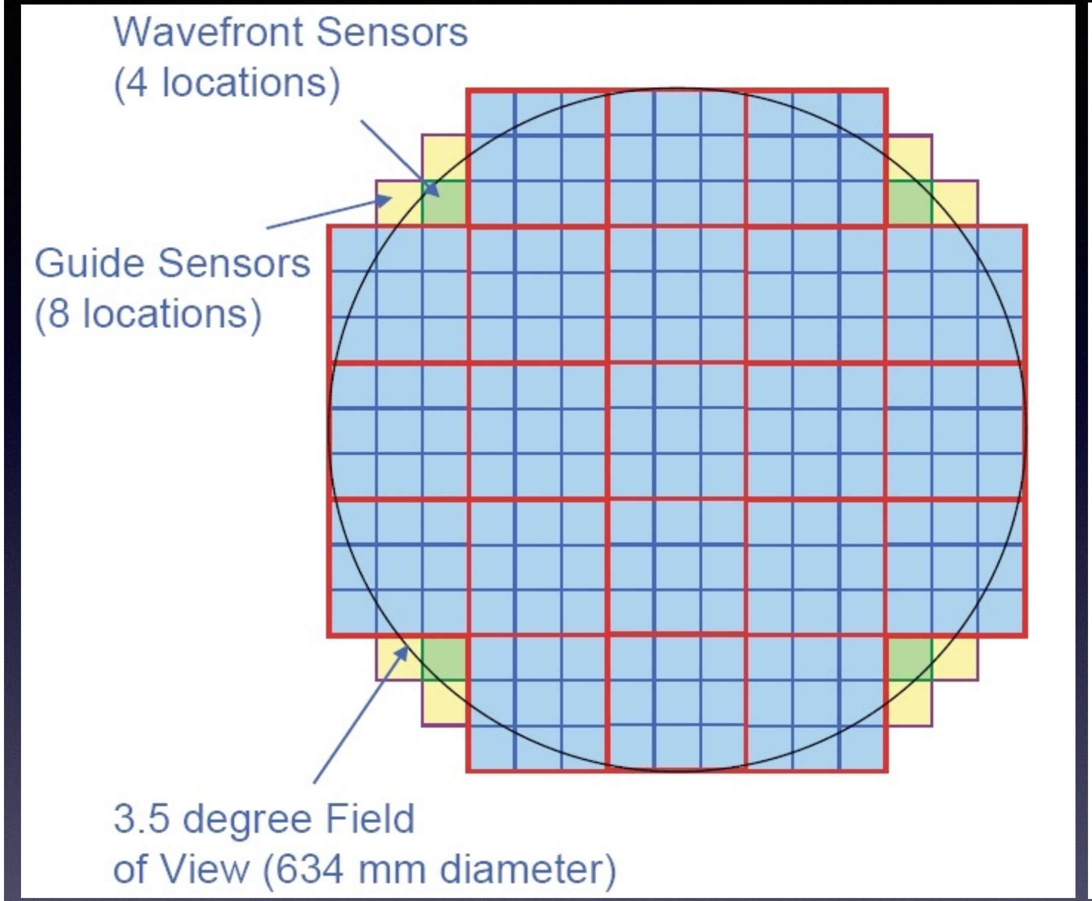
LSST M1M3 Mirror Cell Weldment Ready for Oven

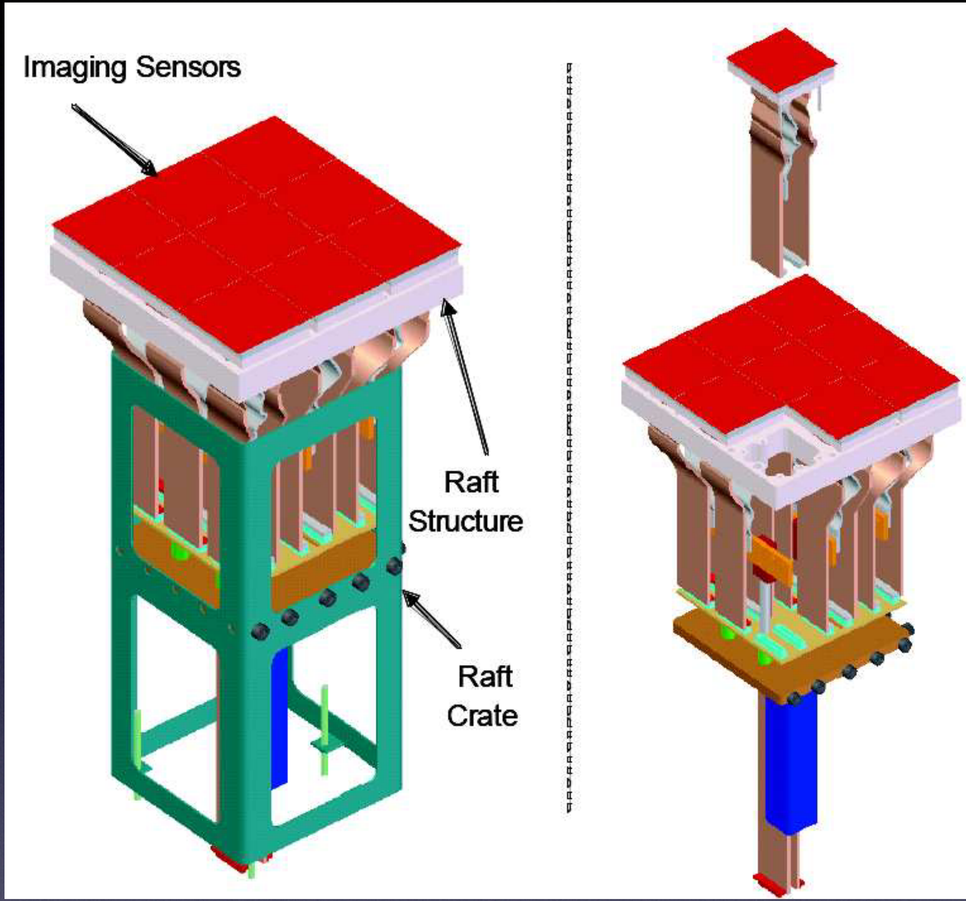
LSST camera



The largest astronomical camera: 2800 kg, 3.2 Gpix

LSST camera





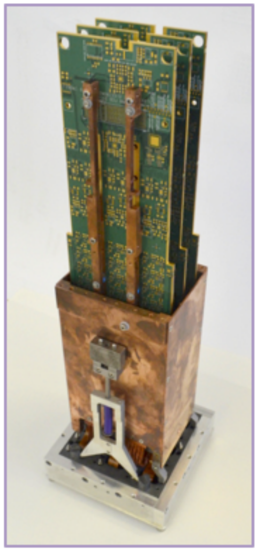
Modular design: 3200 Megapix = 189 x16 Megapix CCD

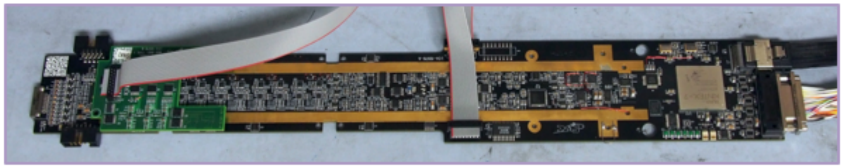
9 CCDs share electronics: raft (=camera)

Problematic rafts can be replaced relatively easily

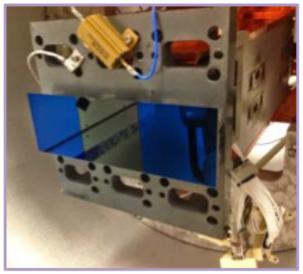
Most Camera Subsystems Have Been Prototyped

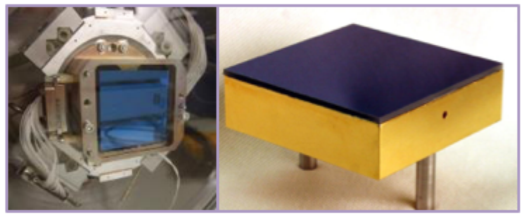
Raft Tower





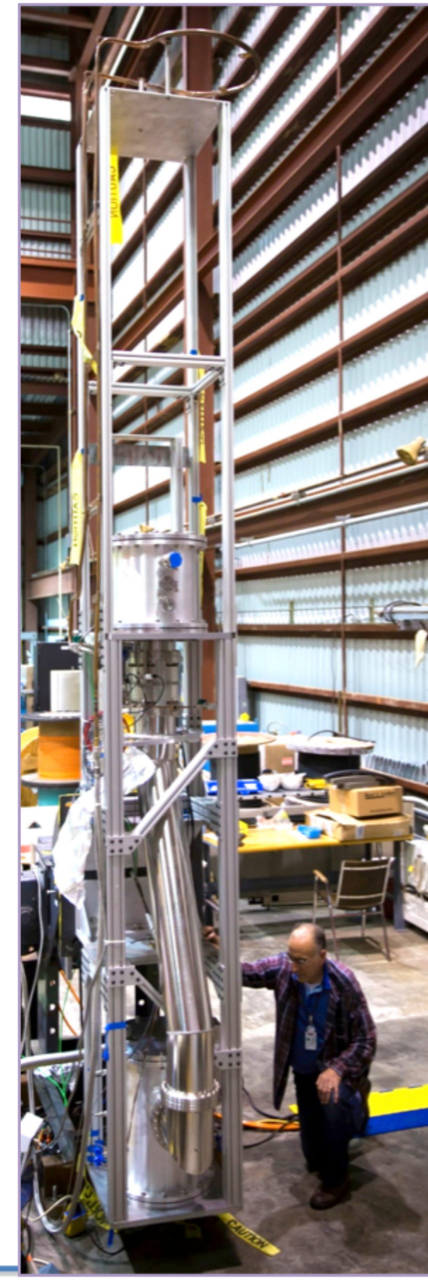
Corner Raft Electronic Board

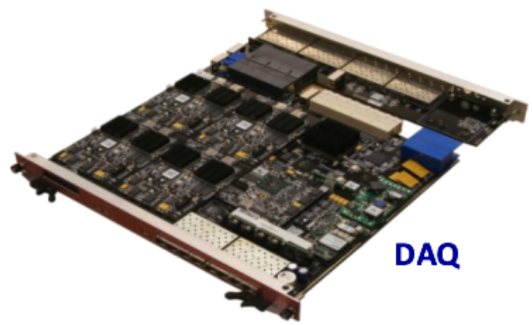




Prototype sensors

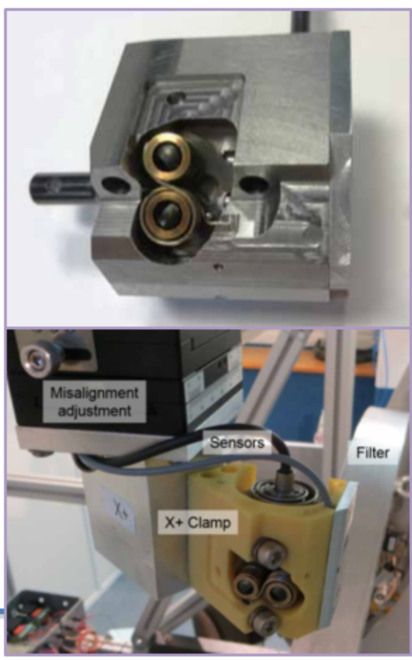
Refrigeration

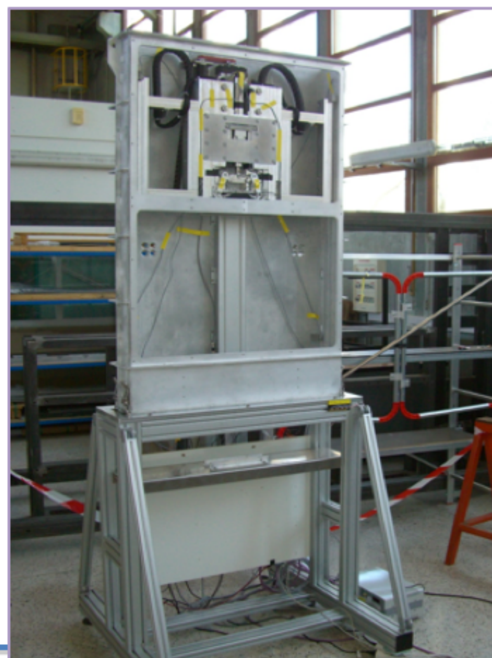




DAQ

Carousel Clamps





Preliminary test bench

Autochanger

At the highest level, LSST objectives are:

1) Obtain about 5.5 million images, with 189 CCDs (4k x 4k) in the focal plane; this is about **a billion 16 Megapixel images of the sky**

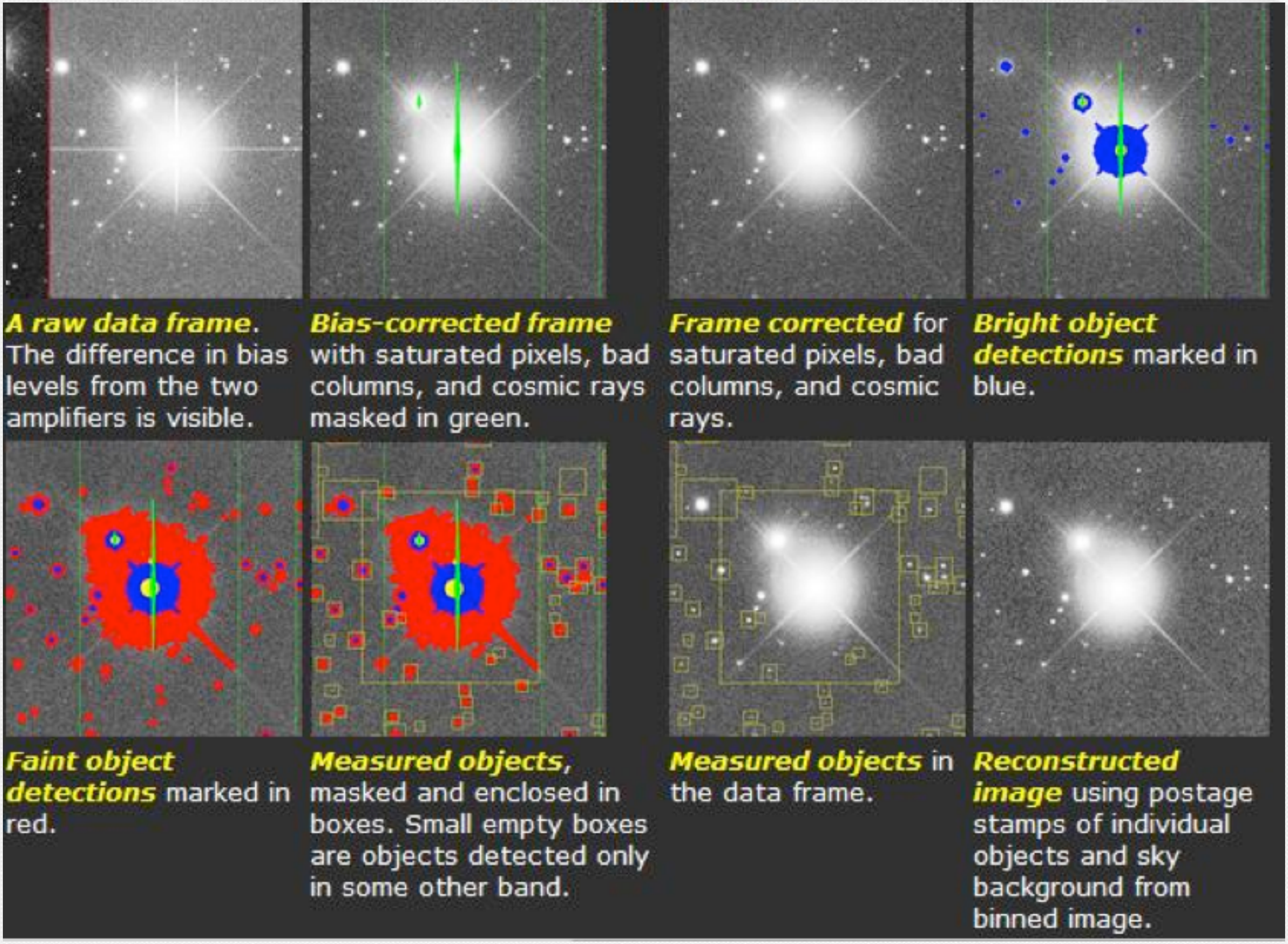
2) Calibrate these images (and provide other metadata)

3) Produce catalogs ("model parameters") of detected objects (37 billion)

4) **Serve** images, catalogs and all other metadata, that is, **LSST data products to LSST users**

The ultimate deliverable of LSST is not just the telescope, nor the camera, but **the fully reduced science-ready data** as well. **Software!**

Basic steps in astronomical image processing



A raw data frame. The difference in bias levels from the two amplifiers is visible.

Bias-corrected frame with saturated pixels, bad columns, and cosmic rays masked in green.

Frame corrected for saturated pixels, bad columns, and cosmic rays.

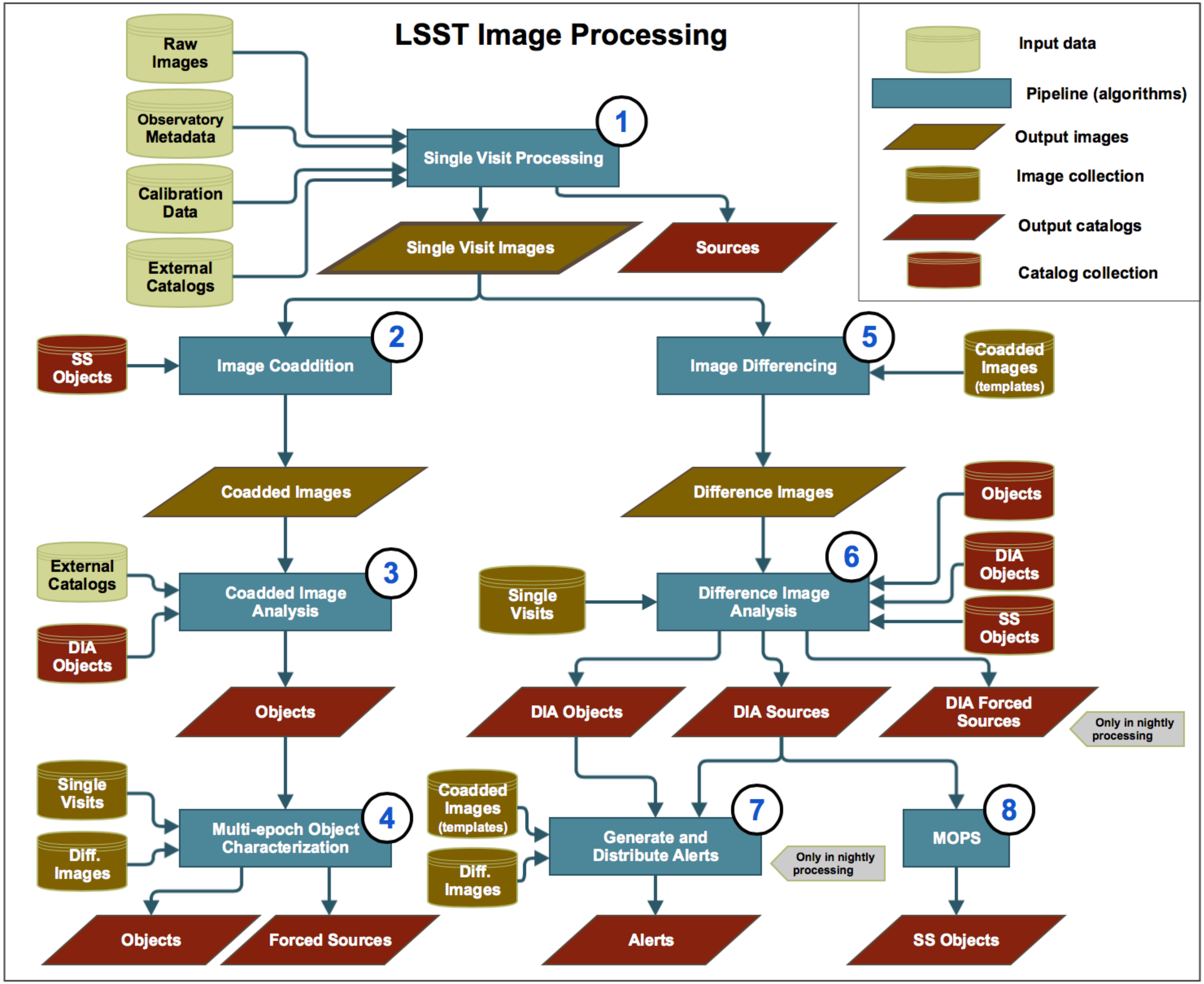
Bright object detections marked in blue.

Faint object detections marked in red.

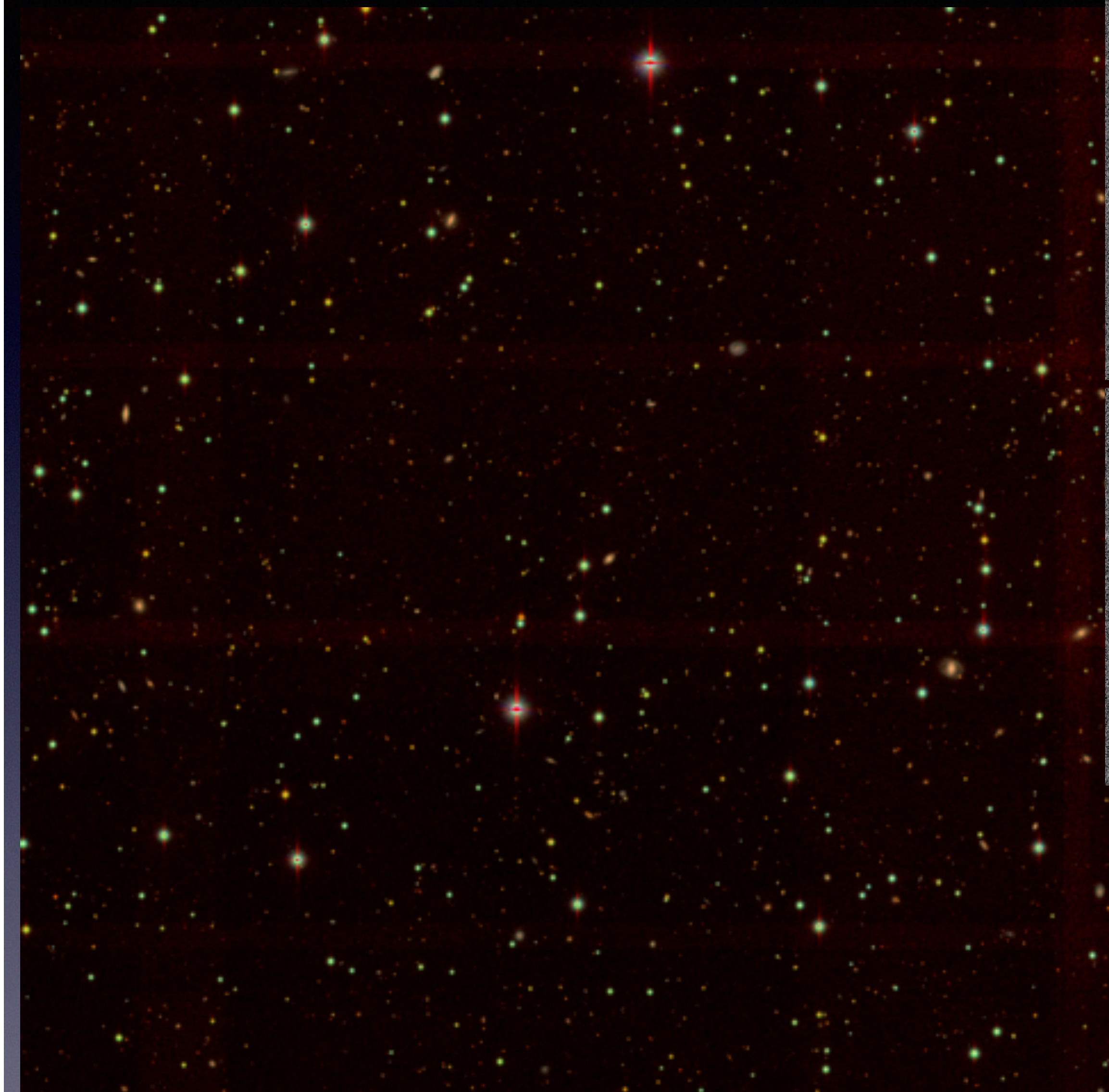
Measured objects, masked and enclosed in boxes. Small empty boxes are objects detected only in some other band.

Measured objects in the data frame.

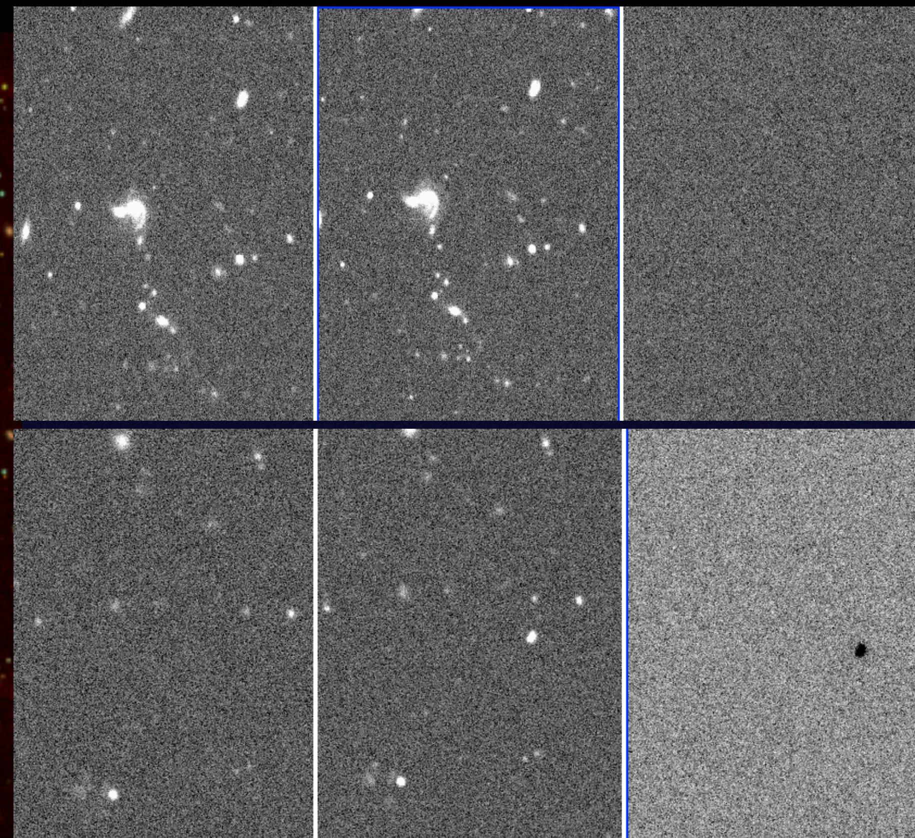
Reconstructed image using postage stamps of individual objects and sky background from binned image.


LSST Image Processing
Input data
Pipeline (algorithms)
Output images
Image collection
Output catalogs
Catalog collection
Raw Images
Observatory Metadata
Calibration Data
External Catalogs
1
Single Visit Processing
Single Visit Images
Sources
SS Objects
2
Image Coaddition
5
Image Differencing
Coadded Images (templates)
Coadded Images
Difference Images
Objects
External Catalogs
DIA Objects
3
Coadded Image Analysis
Single Visits
6
Difference Image Analysis
DIA Objects
SS Objects
Objects
DIA Objects
DIA Sources
DIA Forced Sources
Only in nightly processing
Single Visits
Diff. Images
4
Multi-epoch Object Characterization
Coadded Images (templates)
Diff. Images
7
Generate and Distribute Alerts
Only in nightly processing
8
MOPS
Objects
Forced Sources
Alerts
SS Objects

Data Management Software In Use



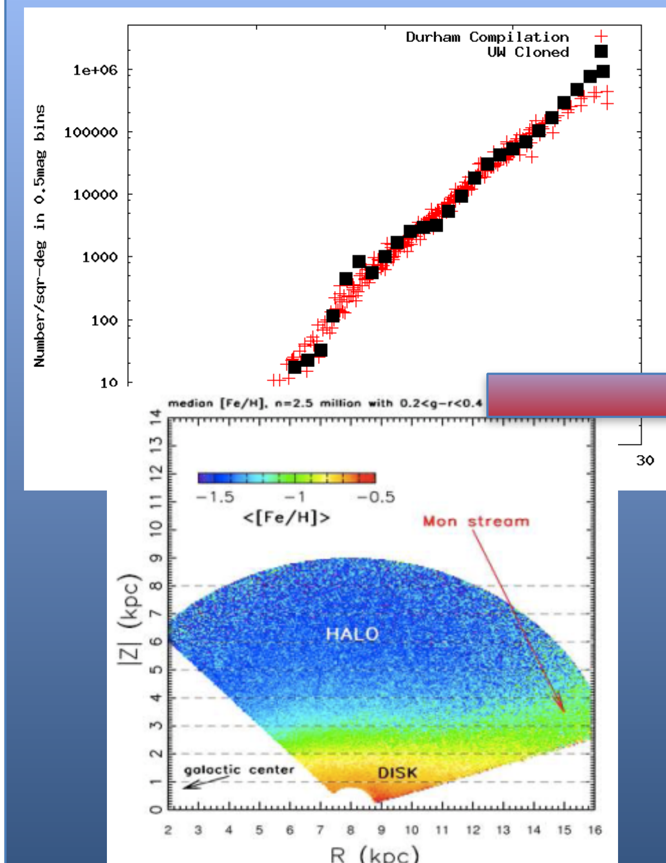
HSC riy-multiband image processed by
Lauren MacArthur with LSST stack



Francisco Forster
High Cadence Transient Survey
DECam images
Subtracted with LSST Stack

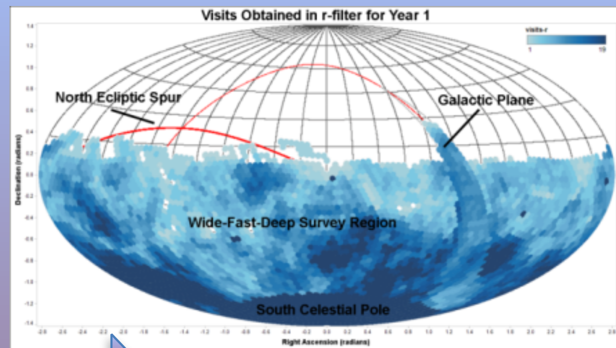
End-to-end modeling creates a virtual prototype of the LSST system:
learning and preparing prior to first light!

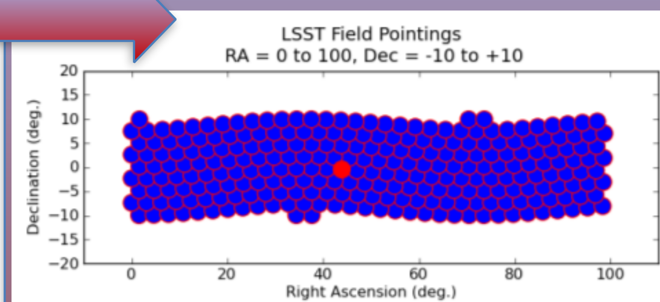
A simulated sky



Galaxies (de Lucia et al 2006)
Stars (Juric et al 2008)
Asteroids (Grav et al 2007)

Observing sequence simulation

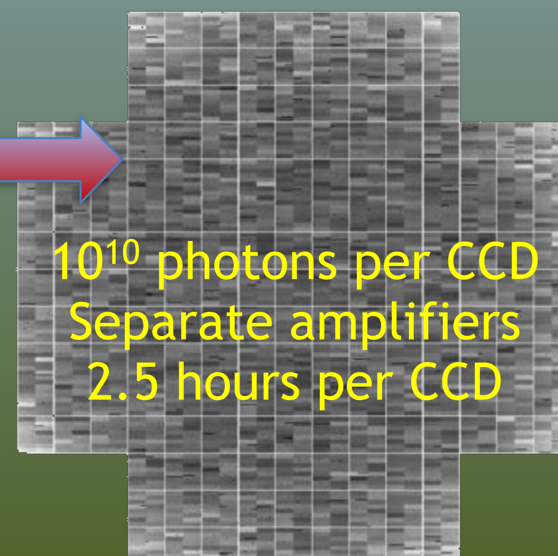




Pointing, Filter, Airmass, Time and Atmosphere from Op Sim

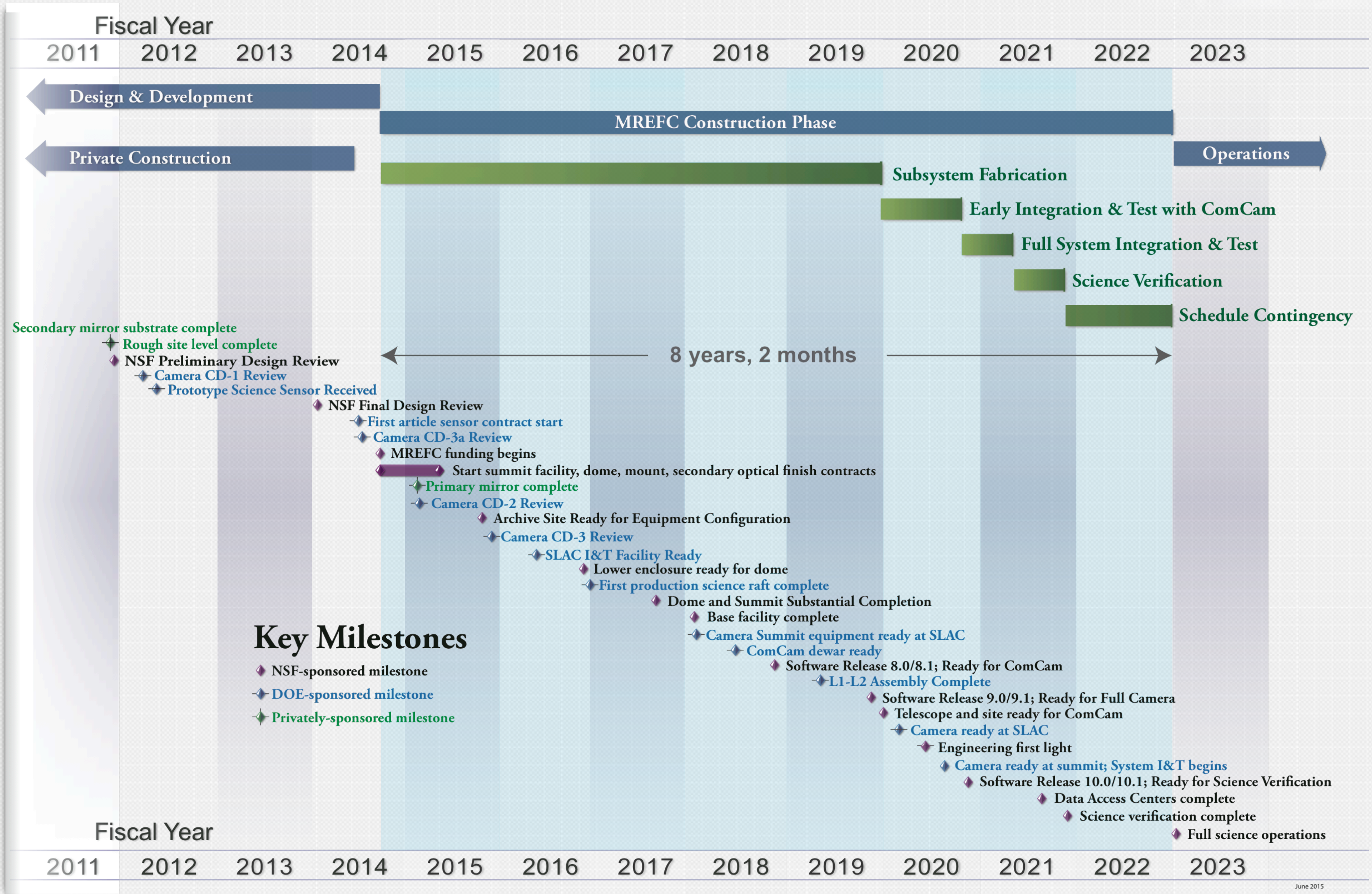
Custom instance of field of view

Producing a simulated image



10^{10} photons per CCD
Separate amplifiers
2.5 hours per CCD

Integrated Project Schedule



LSST Project Funding Profiles

MREFC Account Funding, by Project
(Dollars in Millions)

	FY 2014 Actual	FY 2015 Estimate	FY 2016 Request	FY 2017 Estimate	FY 2018 Estimate	FY 2019 Estimate	FY 2020 Estimate	FY 2021 Estimate
AdvLIGO	$14.92	-	-	-	-	-	-	-
DKIST	36.88	25.12	20.00	20.00	20.00	16.13	-	-
LSST	27.50	79.64	99.67	67.12	55.80	47.89	45.75	39.90
NEON	93.20	96.00	80.64	-	-	-	-	-
OOI	27.50	-	-	-	-	-	-	-
Total	**$200.00**	**$200.76**	**$200.31**	**$87.12**	**$75.80**	**$64.02**	**$45.75**	**$39.90**

Totals may not add due to rounding.

LSSTCam MIE Funding

Fiscal Year	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	Total (M)
OPC	1.9	5.5	8.0	2.3					17.7
TEC				19.7	35.0	40.8	45.0	9.8	150.3
TPC	1.9	5.5	8.0	22.0	35.0	40.8	45.0	9.8	168.0

Summary of Accomplishments in 2016

LSST has completed \$135M *(NSF &DOE)* in construction work through February 2016.

NSF MREFC is 19% complete and has 18% contingency on remaining work; Schedule Performance Index = 0.94, Cost Performance Index = 1.08.

DOE Camera has formal CD-3 approval, is 43% complete and has 32% contingency on remaining work.

The Project critical path has 13 months of contingency to scheduled start of full survey operations in October 2022.

2016 is highest budget year for NSF (\$99.7M) and the second highest year for DOE (\$40.8M).

Summary #1

The Project is in good shape programmatically. The risks associated with delays due to approvals, funding, etc have all been retired.

We are in the thick of construction. We are transitioning from R&D into building real hardware and software.

The team has grown substantially in size.

A lot of our attention is now focused on **commissioning and operations.**

How can we optimize the main deployment parameters:

exposure time per visit, t_{vis}, single-visit depth, m_5, the mean revisit time, $n_{revisit}$, and the number of visits, N_{vis}?

Science Requirements Document (SRD)

At the highest level, LSST objectives are:

1) Obtain about a billion 16 Megapixel images of the sky, with **characteristics as specified in the SRD:**

Section 3.4 from the SRD

Early cadence studies

As a result of these studies, the adopted baseline design (see Appendix A) assumes a nominal 10-year duration with about 90% of the observing time allocated for the main LSST survey. The same assumption was adopted here to derive the requirements described below.

Section 3.4 from the SRD “The Full Survey Specifications” is intentionally vague!

We plan to optimize the ultimate LSST cadence to reflect the state of the field at the time of system deployment (but note that it is anticipated that the deep-wide-fast aspects of the main survey will not change much).

Science Requirements Document (SRD)

At the highest level, LSST objectives are:

1) Obtain about a billion 16 Megapixel images of the sky, with **characteristics as specified in the SRD:**

Quantity	u	g	r	i	z	y
Nv1 (design spec.)	56 (2.2)	80 (2.4)	184 (2.8)	184 (2.8)	160 (2.8)	160 (2.8)
Idealized Depth	26.1	27.4	27.5	26.8	26.1	24.9

Table 24: An *illustration* of the distribution of the number of visits as a function of bandpass, obtained by detailed simulations of LSST operations that include realistic weather, seeing and sky brightness distributions, as well as allocation of about 10% of the total observing time to special programs. The median number of visits per field for all bands is 824. For convenience, the numbers in parentheses show the corresponding gain in depth (magnitudes), assuming $\sqrt{N}$ scaling. The last row shows the total *idealized* coadded depth for the design specification median depth of a single image (assuming 5σ depths at $X = 1$ of $u = 23.9$, $g = 25.0$, $r = 24.7$, $i = 24.0$, $z = 23.3$ and $y = 22.1$, from Table 6), and the above design specification for the total number of visits. The coadded image depth losses due to airmass greater than unity are not taken into account. For a large suite of simulated main survey cadences, they are about 0.2-0.3 mag, with the median airmass in the range 1.2-1.3. Note: 824 visits with two 15-sec exposures is 6.9 hours (~1 night/field).

LSST Observing Strategy and Cadence Optimization

How can we optimize the main deployment parameters:

exposure time per visit, t_{vis}, single-visit depth, m_5, the mean revisit time, $n_{revisit}$, and the number of visits, N_{vis}?

While each of these four parameters has its own drivers, they are not independent (scaled to nominal LSST):

$$m_5 = 24.7 + 1.25 * \log(t_{vis} / 30 \text{ sec})$$

$$n_{revisit} = 3 \text{ days} * (t_{vis} / 30 \text{ sec})$$

$$N_{vis} = 1000 * (30 \text{ sec} / t_{vis}) * (T / 10 \text{ years})$$

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How to allocate the total observing time per position of ~7 hours to ugrizy, and how do we split allocations into individual visits?

LSST Observing Strategy and Cadence Optimization

How can we optimize the main deployment parameters:

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$$N_{vis} = 1000 * (30 \text{ sec} / t_{vis}) * (T / 10 \text{ years})$$

Direct and indirect constraints on the shortest and longest acceptable exposure time per visit span **a remarkably narrow range:**

20 sec < t_{vis} < 40 sec for the main survey **t_{vis} = 30 sec as default**

(see section 2.2.2 in the "overview" paper, arXiv:0805.2366)

Constraints on exposure time per visit (20-40 sec):

Lower limit:

- surveying efficiency must be high enough
  - (readout time, slew & settle time)
- depth per visit must be deep enough
  - (SNe, RR Lyrae, NEOs)

Upper limit:

- the mean revisit time cannot be too long
  - (SNe, NEOs)
- the number of visits must be large enough
  - (light curves, systematics, proper motions)
- (trailing losses for moving objects)

There is no fundamental reason why t_{vis} should be exactly the same for all visits (i.e. filters, programs, during the survey)!

CONCLUSION:

Direct and indirect constraints on the shortest and longest acceptable exposure time per visit span **a remarkably narrow range:**

20 sec < t_{vis} < 40 sec for the main survey **t_{vis} = 30 sec as default**

However, there may be reasons to depart from t_{exp} = 15 sec…

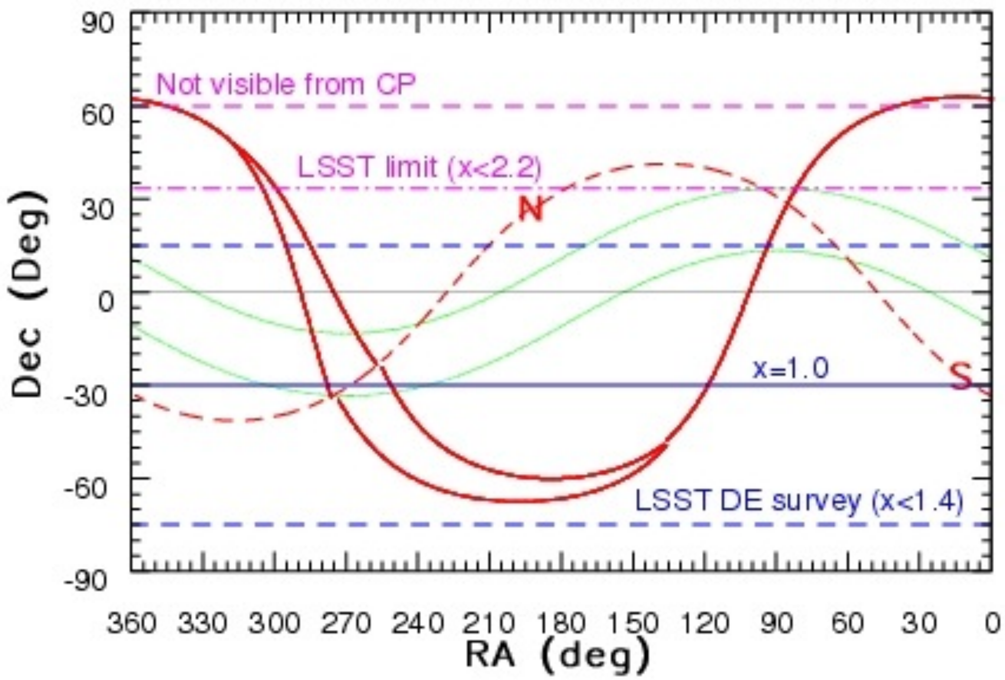
Hierarchical steps of survey complexity:

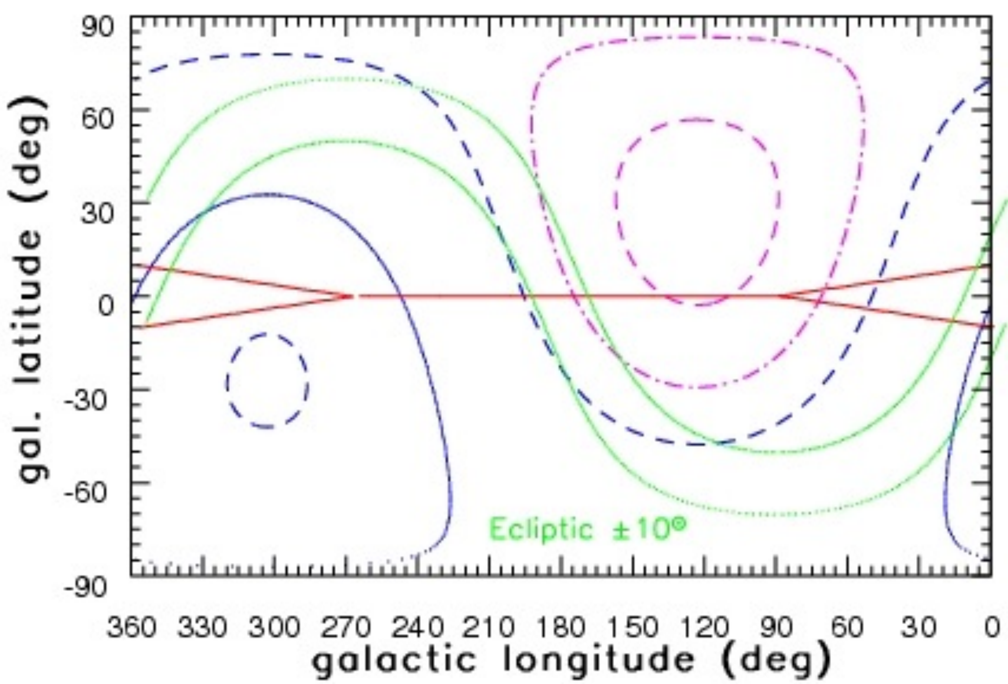
1) single band, single program, static science

Goal: maximize the number of detected sources, e.g. galaxies.

Unless looking at unusual populations (e.g. low-redshift quasars), it is always advantageous to first maximize the sky area and *then* depth.

Detailed optimization takes into account airmass effects and Galactic plane: about 18,000-20,000 sq.deg. of sky





Sky coverage:

for the main survey, maximize the number of objects (area vs. airmass tradeoff)

X<1.4 corresponds to

–75° < Dec < +15°

(25,262 sq. deg.)

X=2.2 corresponds to Dec < +33°, but note that the telescope can reach Dec = +40° (X=2.9)

Hierarchical steps of survey complexity:

1) single band, single program, static science

2) **...but need multi-bandpass data: ugrizy**

Goal: apportion time per band so that there is no dominant bad band for photometric redshifts of galaxies (it turns out it's ok for stars too)

Galaxies:

- **Photometric redshifts:** random errors smaller than 0.02, bias below 0.003, fewer than 10% >3σ outliers
- These photo-z requirements are one of the primary drivers for the photometric depth and accuracy of the main LSST survey (and the definition of filter complement)

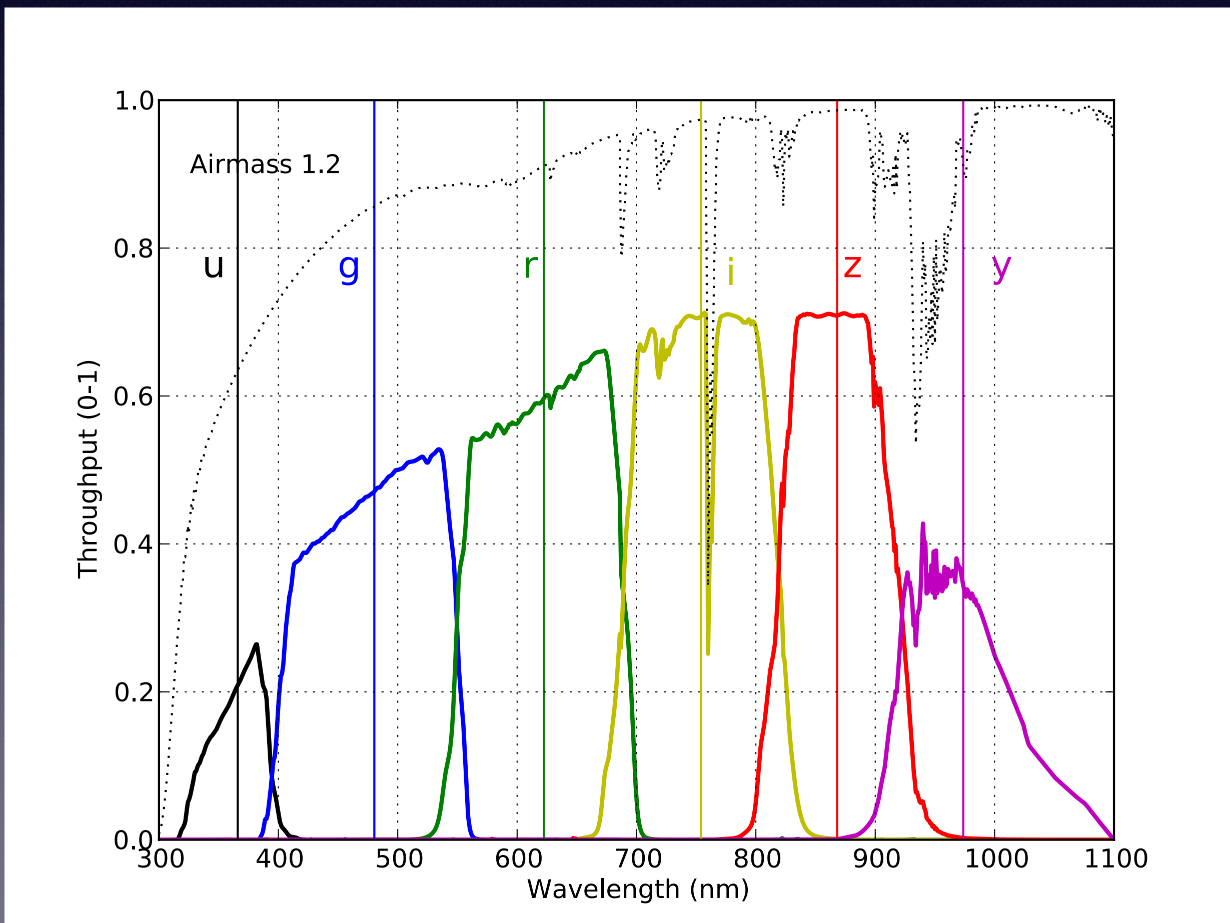


Photo-z requirements correspond to r~27.5 with the following per band time allocations:

u: 8%; g: 10%

r: 22%; i: 22%

z: 19%; y: 19%

Consistent with other science themes (stars)

Hierarchical steps of survey complexity:

1) single band, single program, static science
2) need multi-bandpass data: ugrizy

3) **time domain (temporal sampling function)**

Asteroids: (still) believing that two visits per night, about an hour apart, are needed to "connect the dots".

The simplest strategy: roughly uniform coverage, addresses range of time scales, from diurnal to secular changes

However: if the sampling doesn't meet the science-driven threshold, then it's better to cover a smaller active sky area more frequently (e.g. supernovae) - "rolling cadence"

Hierarchical steps of survey complexity:

1) single band, single program, static science
2) need multi-bandpass data: ugrizy
3) time domain

4) **not all sky regions were created equal!**
Galactic plane
LMC/SMC
northern Ecliptic
south Galactic pole
deep drilling (and other special) fields

It's likely that these regions will need a modified cadence, but not clear yet how exactly (depends on fast-evolving science drivers and the system performance)

Hierarchical steps of survey complexity:

1) single band, single program, static science
2) need multi-bandpass data: ugrizy
3) time domain
4) not all sky regions were created equal!

5) evolution over time

- algorithm optimization, evolving science goals, possibly system performance changes

6) systematics

- field-of-view position (rotator angle), parallax factor, dithering, etc.

Continuing Baseline cadence optimization

Drivers for baseline cadence modifications:

- improved knowledge of the system (now due to simulations, eventually due to performance measurements)
- changing science landscape on timescales of a few years
- unscheduled technical delays or substandard performance (e.g. broken filter, dead CCD, extra noise)
- even 10% improvement in surveying efficiency would be significant accomplishment (c.f. entire DD observing time)

The most important conclusion of the preliminary cadence explorations is that the upper limit on possible efficiency improvements for baseline cadence is not larger than 10% and probably close to 6%. This conclusion is by and large based on the fact that the mean slew time for (candidate) baseline cadence is 7.0 sec, and thus only slightly larger than the design specifications for the system slew and settle time of 5 sec.

Performance as a function of survey duration

VARIOUS SCIENCE METRICS AS FUNCTIONS OF SURVEY DURATION.

Quantity	Year 1	Y3	Y5	Y8	Year 10	Y12
r_5 coadd[a]	26.3	26.8	27.1	27.4	27.5	27.6
$\sigma(i{=}25)$[b]	0.12	0.07	0.06	0.05	0.04	0.04
color vol.[c]	316	20	6	1.7	1	0.6
# of visits[d]	83	248	412	660	825	990
σ_π $(r{=}24)$[e]	9.5	5.5	4.2	3.3	3.0	2.7
σ_μ $(r{=}24)$[f]	32	6.1	2.8	1.4	1.0	0.8

Between years 1 and 10: 1.2 mag deeper, 30x better proper motions

While unprecedented science outcome will definitely be possible even with a first few years of LSST data, the complete planned and designed for science deliverables will require 10-years of data, with a tolerance of at most about 1-2 years.

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LSSTScienceCollaborations / **ObservingStrategy**

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A community white paper about LSST observing strategy, with quantifications via the the Metric Analysis Framework. — Edit

1,546 commits | **10** branches | **1** release | **46** contributors

Branch: **master** | New pull request | Create new file | Upload files | Find file | Clone or download

willclarkson committed on **GitHub** Merge pull request #474 from willclarkson/master ... Latest commit 461bf24 a day ago

whitepaper	Two sentences on Difference Imaging added; 3 refs	a day ago
.gitignore	Ignore white paper PDF #149	7 months ago
.nukePDF	Commands for cleaning out PDF file	7 months ago
.travis.yml	Automatic build problem detection with travis CI, first attempt #149	7 months ago
README.md	fix README typo	a month ago

README.md

Science-Driven Optimization of the LSST Observing Strategy

Community effort led by Phil Marshall

A community white paper about LSST survey strategy ("cadence"), with quantifications via the Metric Analysis Framework.

Summary #2

There are some “conservation laws” set by the integrated etendue.

The most important conclusion of the preliminary cadence explorations is that the upper limit on possible efficiency improvements for baseline cadence is not larger than 10% and probably close to 6%. **But 6% of LSST is a lot!**

It is likely that **the performance for time-domain science can be significantly improved** (e.g. rolling cadence for SNe survey).

You can join this effort, too!

NAUKA 12

Vrhunski astronomi dolaze u Beograd

Lardž sinoptik survej teleskop, LSST, jedan je od najambicioznijih astronomskih projekata današnjice. Srbija je među retkim zemljama u Evropi koja je od samog početka uključena u LSST projekat.

IZVOR: | PONEDELJAK, 13.06.2016. | 15:19

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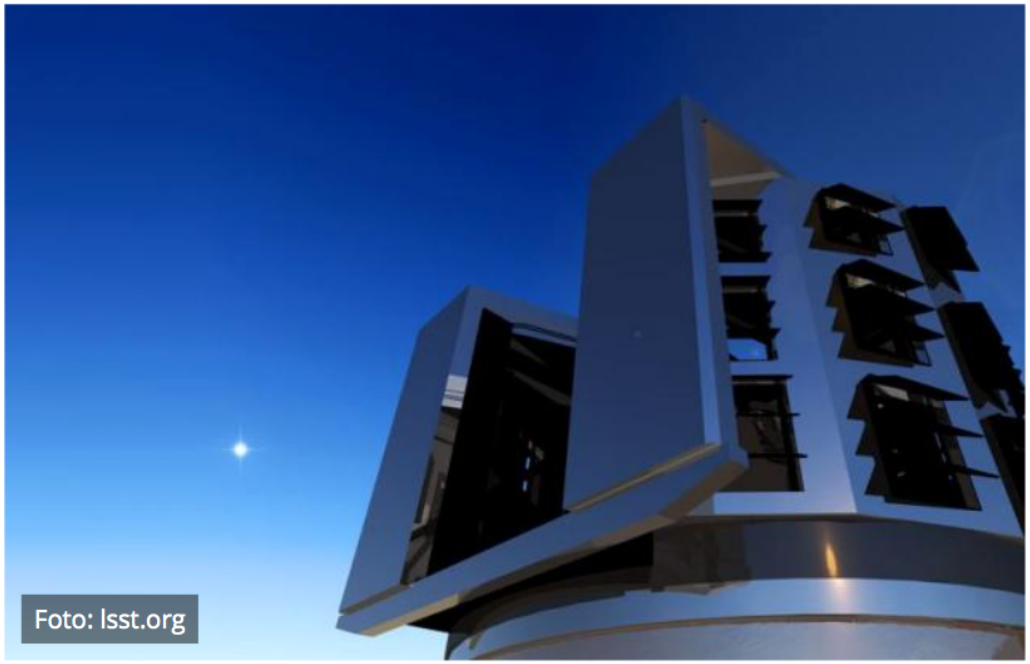
Foto: lsst.org

Izvor: Elementarium.cpn.rs

Zahvaljujući tome i angažovanju domaćih naučnika sa Astronomske opservatorije u Beogradu i Katedre za astronomiju Matematičkog fakulteta Univerziteta u Beogradu, od 20. do 24. juna u Beogradu će se okupiti vrhunski stručnjaci i astronomi na konferenciji LSST@Europe2. Konferencija se održava u hotelu Zira u Beogradu.

LSST is becoming real!

Top astronomers are in Belgrade!

Have fun and enjoy it!