LSST and the Epoch of Reionization experiments

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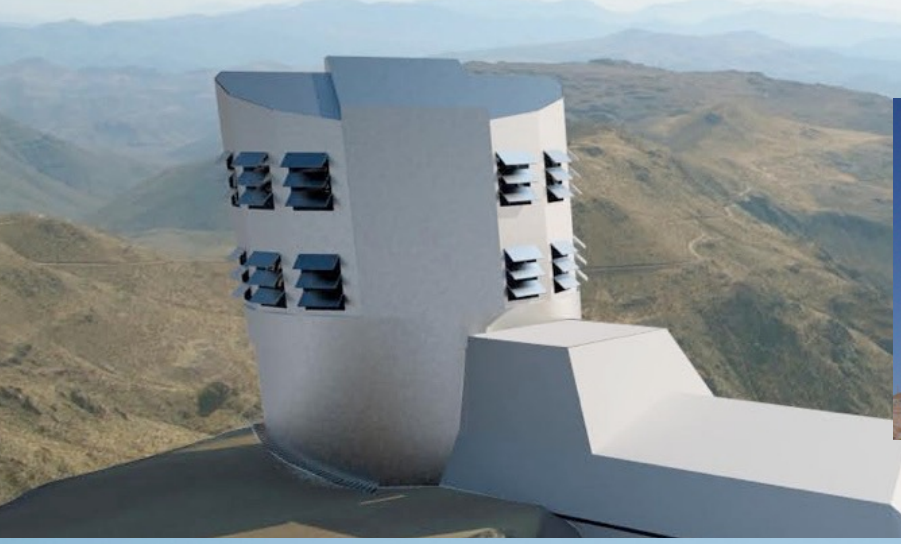
Outline

- Optical-radio synergies
  - science drivers
  - tools and methods
  - supplemental data
- Rapid tour of LSST
  - multi-color time-resolved **faint** sky map
  - 20 billion stars and 20 billion galaxies
- WFIRST-LSST-Euclid complementarity
  - 2,200 sq.deg. of three-way overlap
  - 7,000+ sq.deg. of LSST-Euclid overlap




The connections between optical and radio regimes:

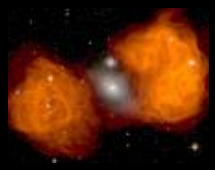
1) Science Results (asking similar and often same questions; e.g. stellar and galaxy formation and evolution, dark energy)

2) Tools and Methods (e.g. massive databases)

3) Supplemental data (identification, physical processes, HI)

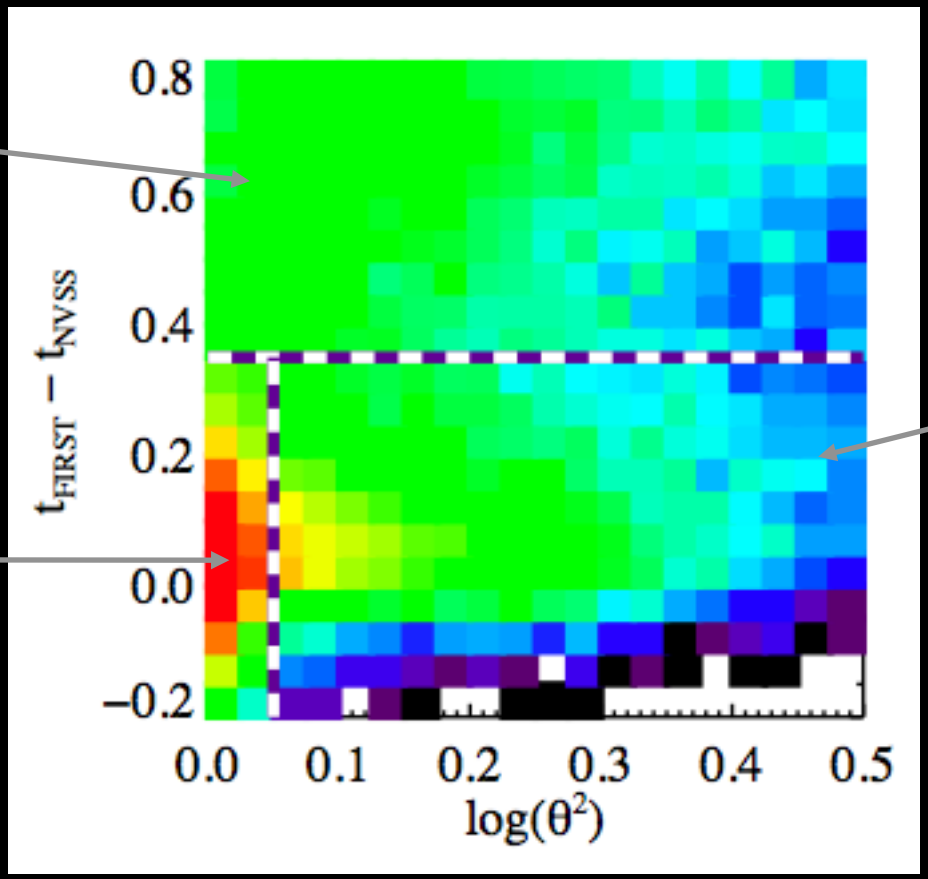
AUTOMATED radio morphology classification for over 100,000 radio sources

FIRST vs. NVSS flux, and FIRST peak vs. integrated flux:



"Complex"

"Compact" (unresolved)



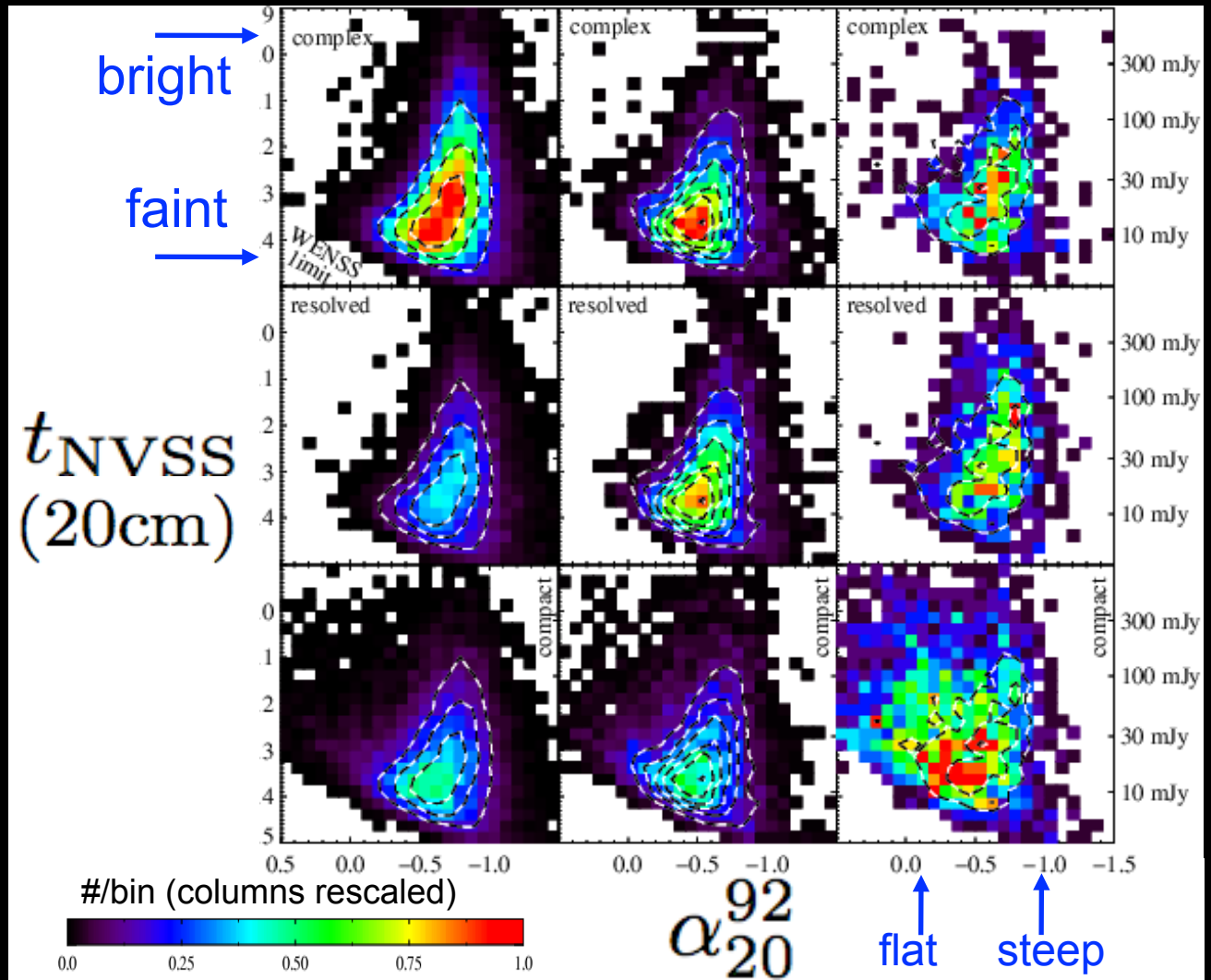
"Resolved"

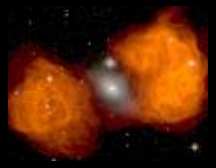
Kimball & Ivezić 2008

Radio "color"-mag. diagrams

71% 22% 7%

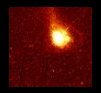
Optical: No SDSS Galaxies Point sources





Complex 45%

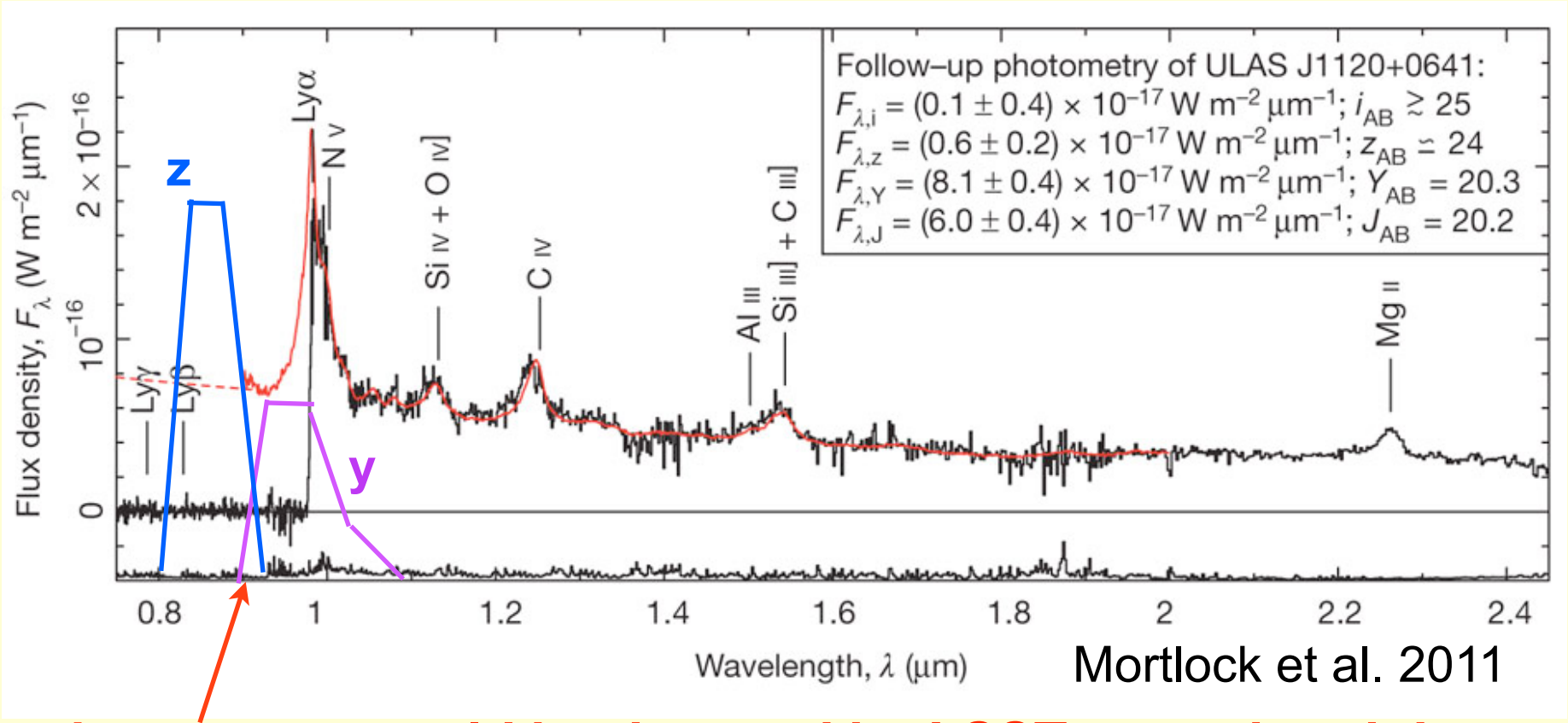
Resolved 25%



Compact 30%

massive statistical studies!

The Highest Redshift Quasar at z=7.085 from UKIDSS



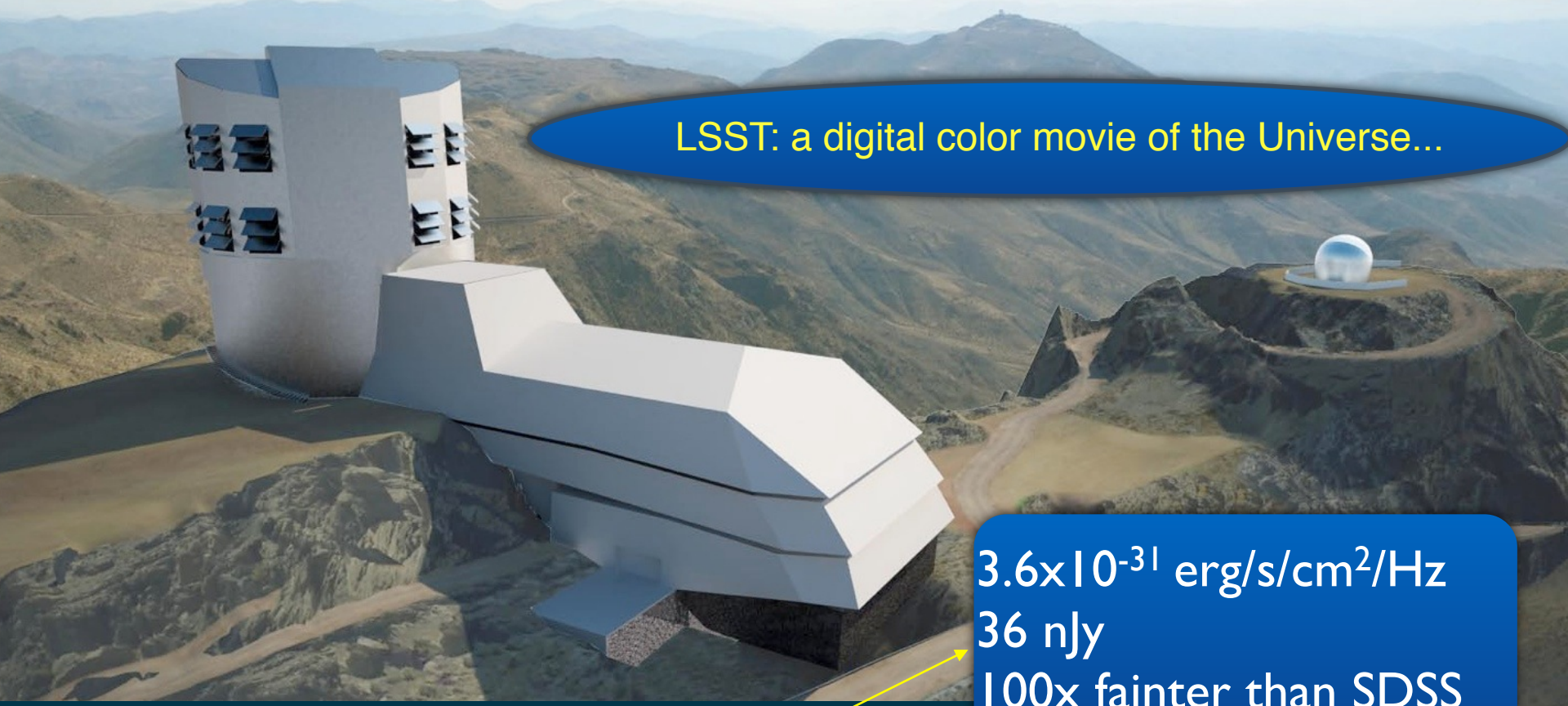
Mortlock et al. 2011

Such a quasar would be detected by LSST as a z-band dropout

(multi-epoch data will greatly help with false positives)

LSST will discover about 1,000 quasars with z>7

Today: one quasar with z>7



3.6×10^{-31} erg/s/cm^2/Hz
36 nJy
100x fainter than SDSS

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.

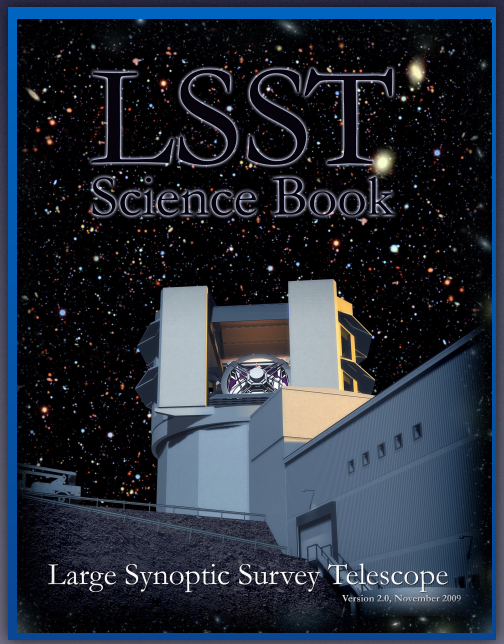
LSST Science Themes

- 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

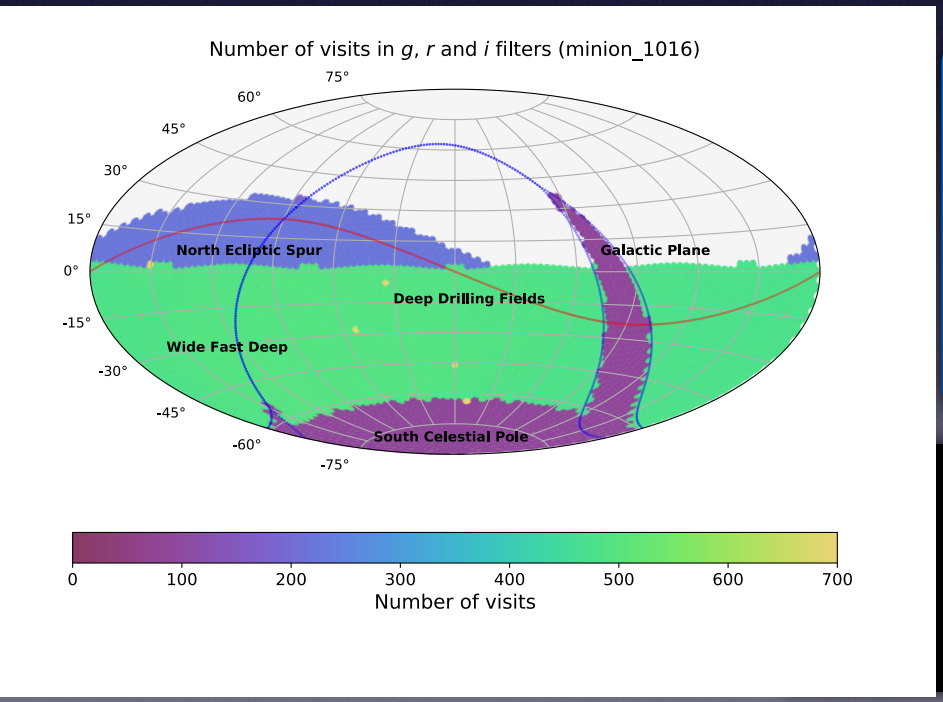
Summarizes LSST hardware, software, and observing plans, science enabled by LSST, and educational and outreach opportunities

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.

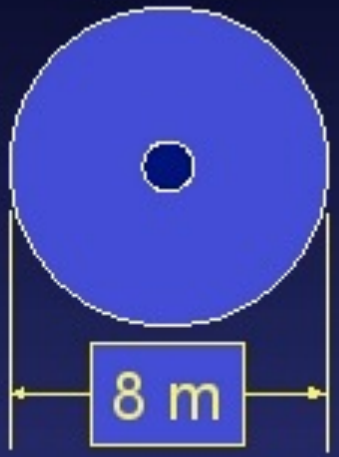
Left: a 10-year simulation of LSST survey: the number of visits in the r band (Aitoff projection of eq. coordinates)

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

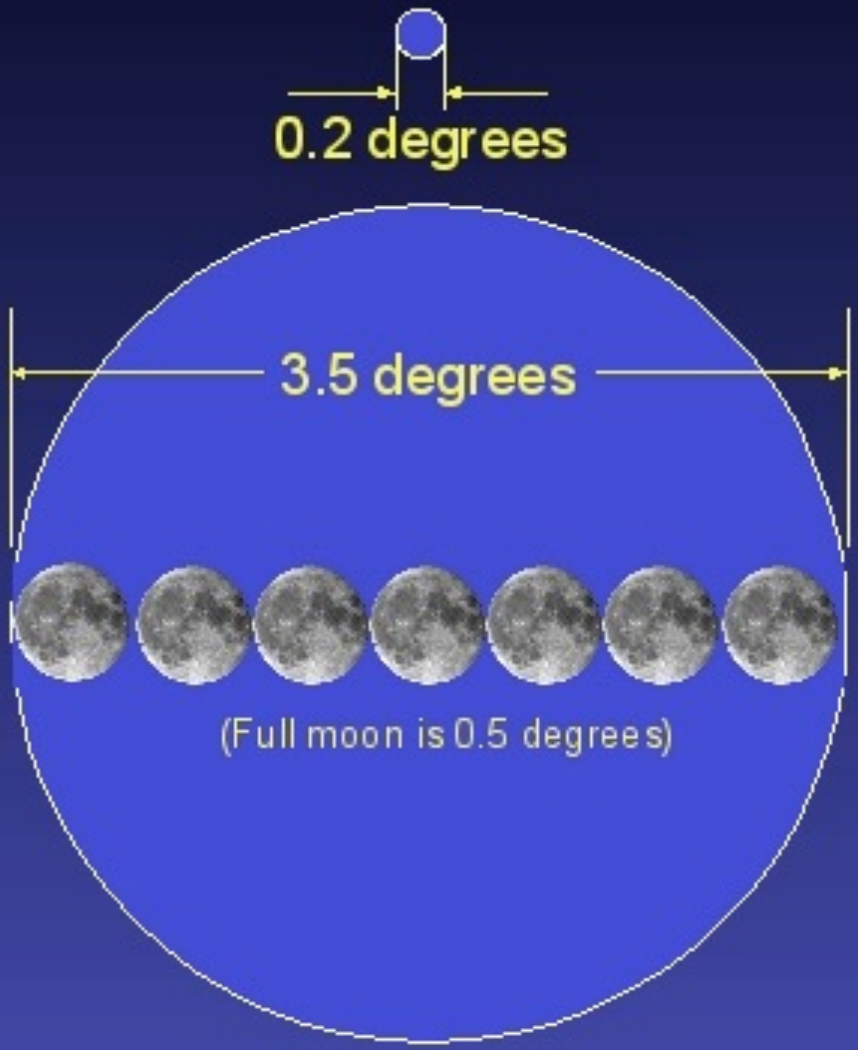
Gemini South Telescope

LSST

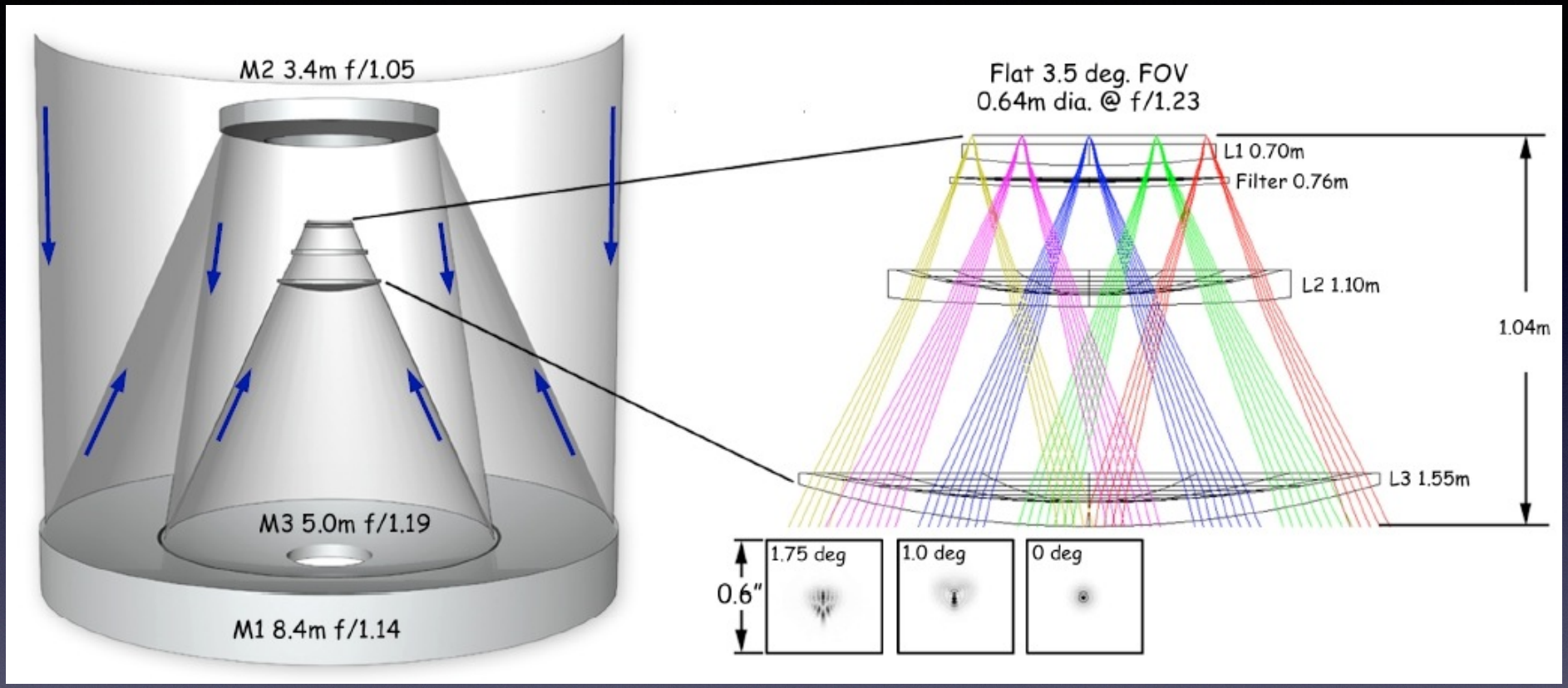
Primary Mirror Diameter



Field of View

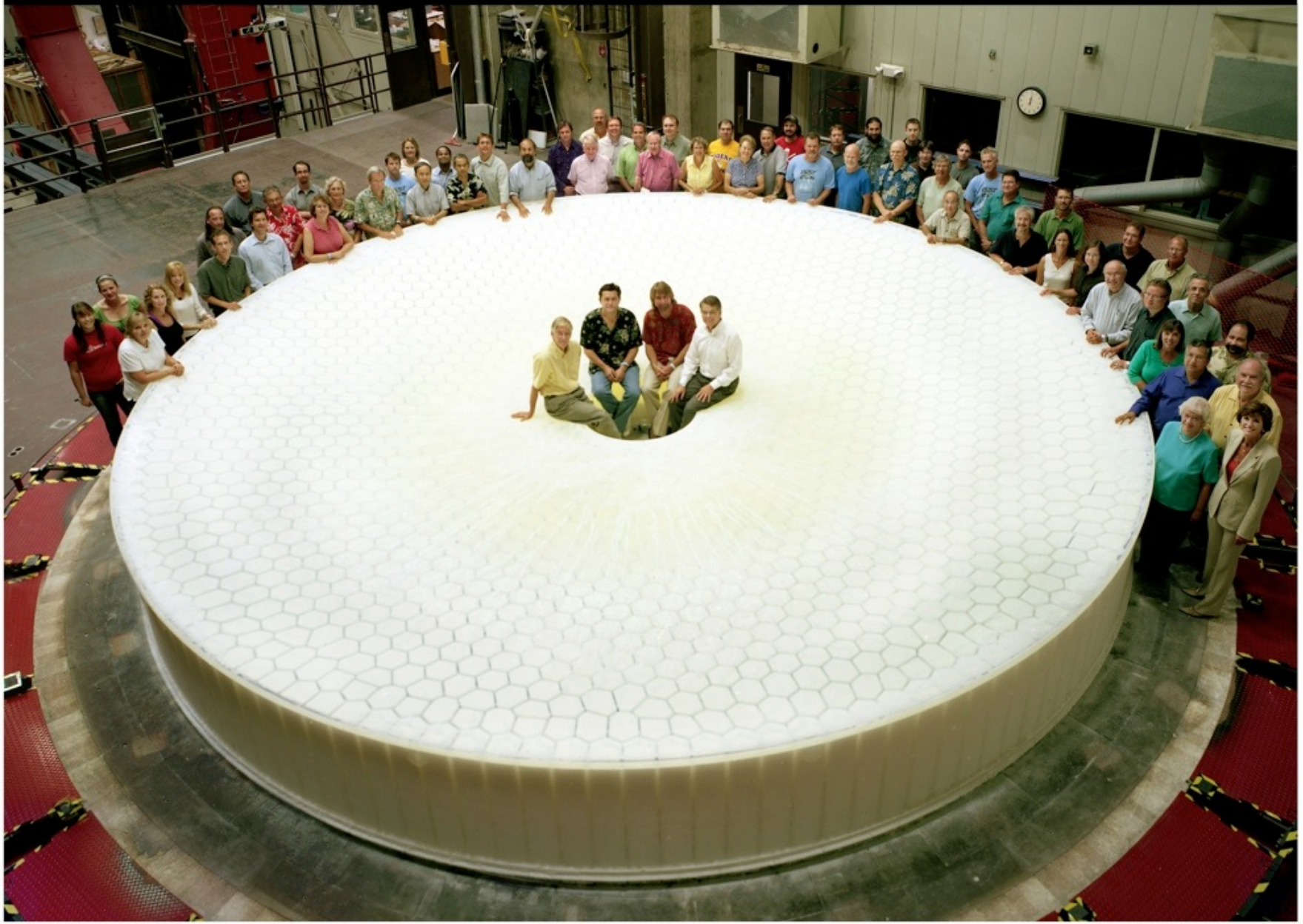


Optical Design for LSST



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

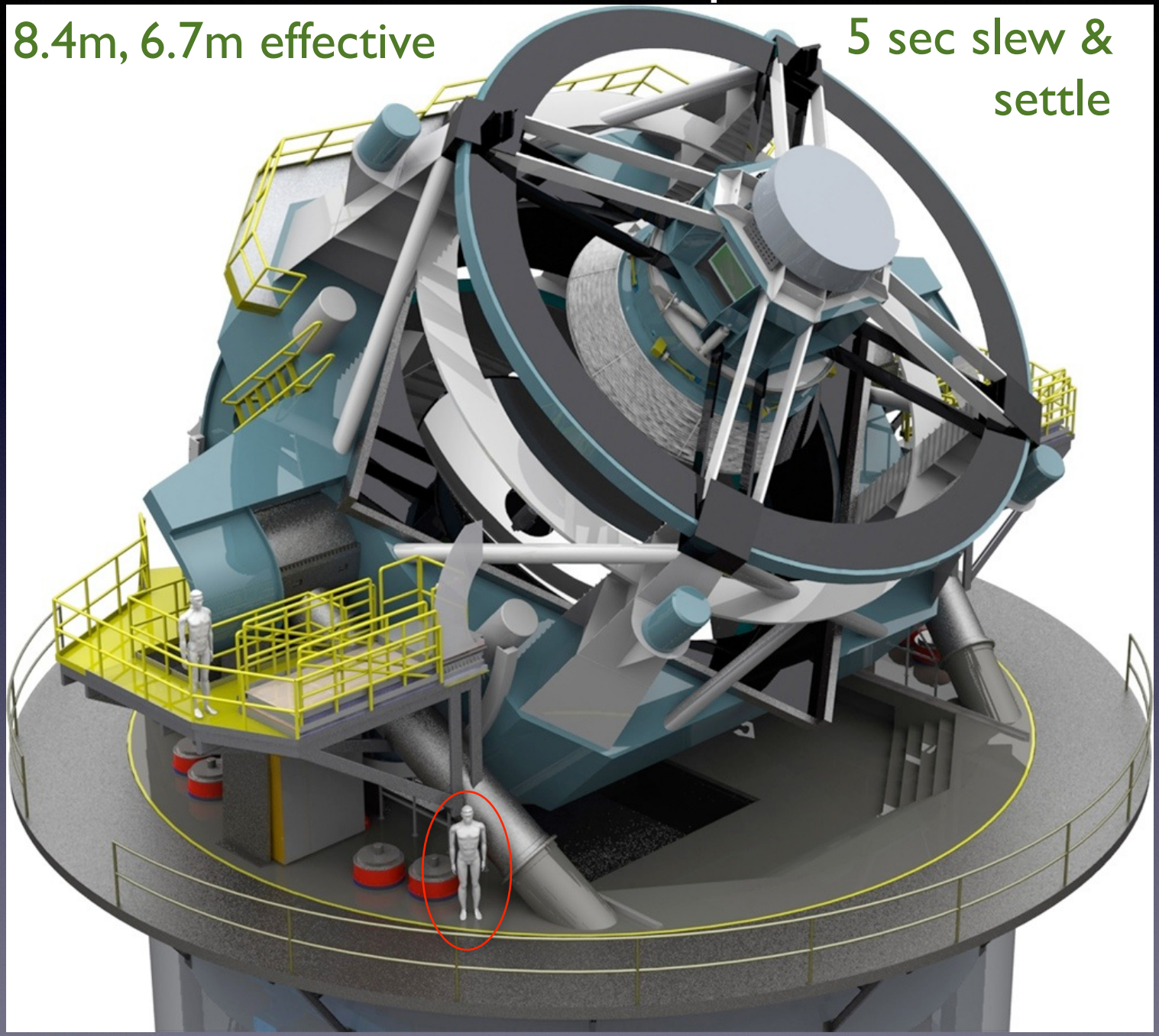
August 11, 2008, Steward Observatory Mirror Lab, Tucson, Arizona

The University of Arizona, Tucson Arizona

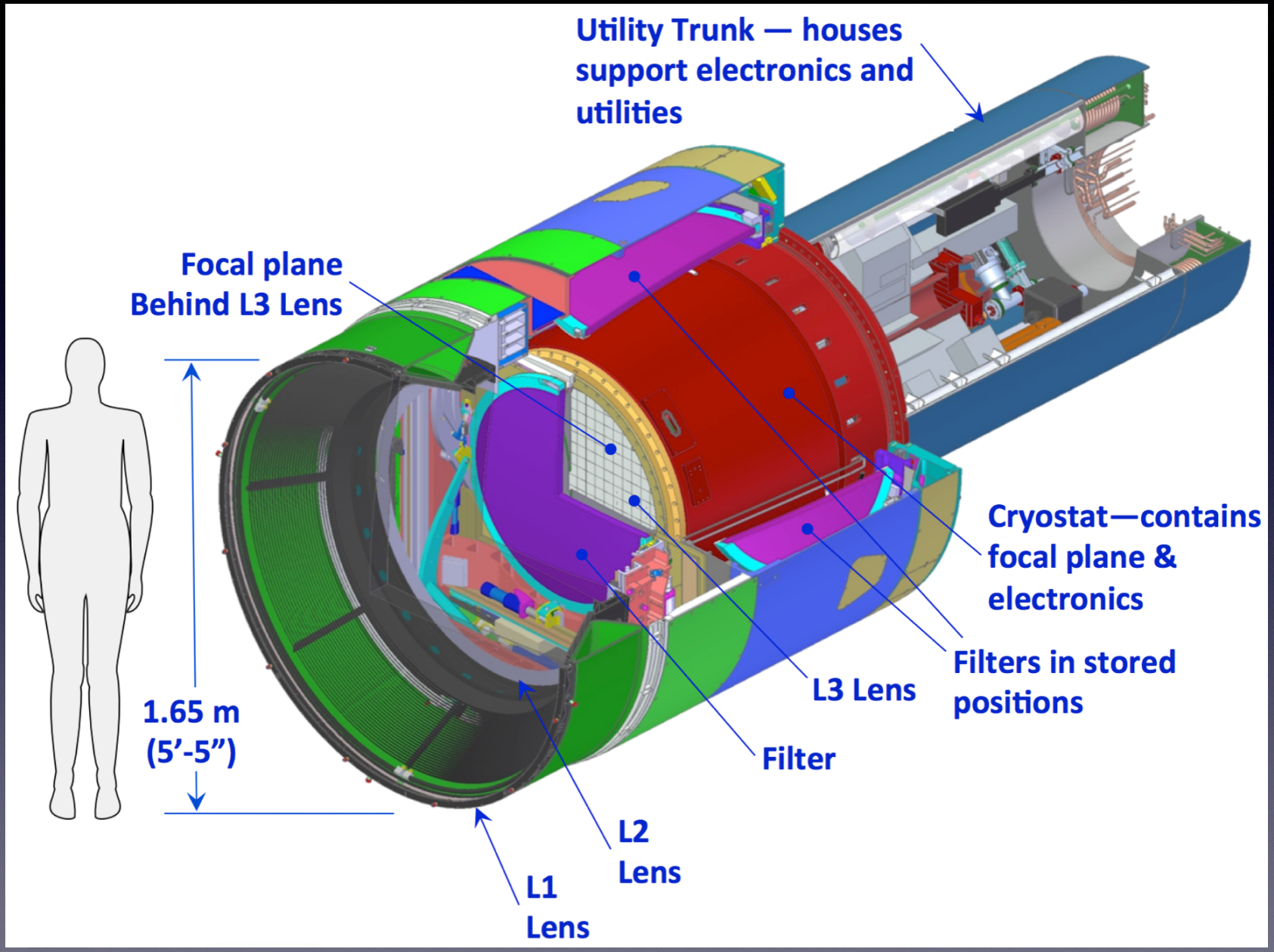
SOML

Large Synoptic Survey Telescope

LSST Telescope

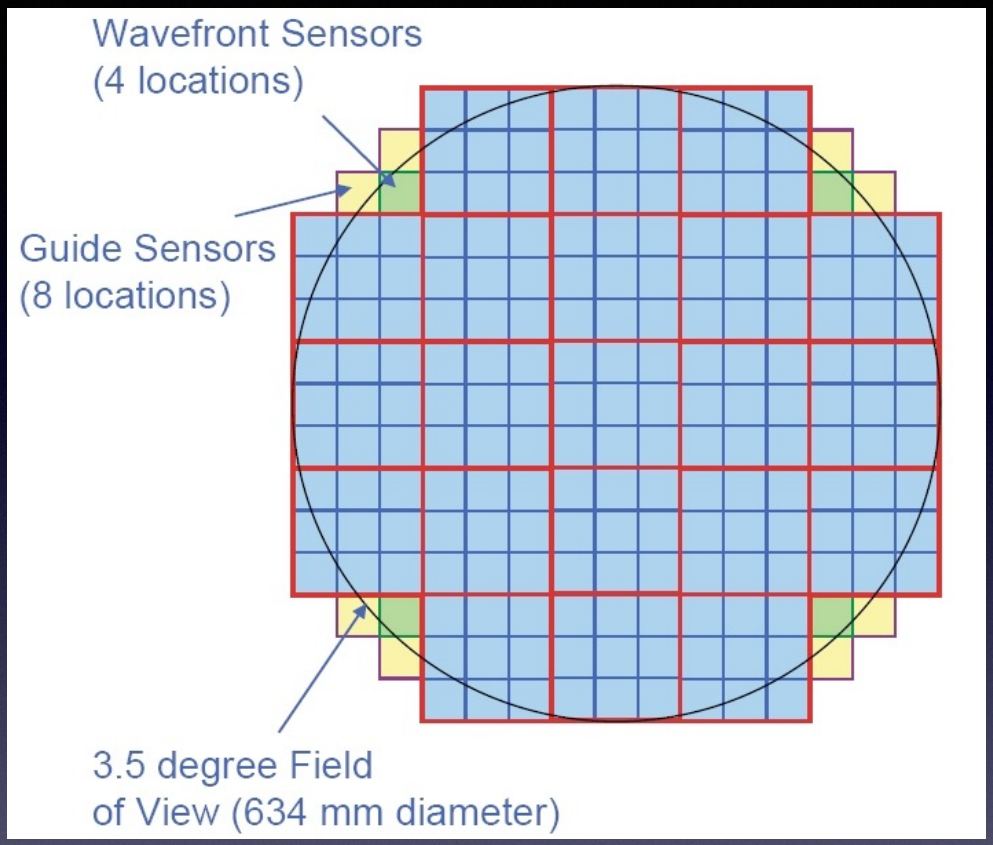


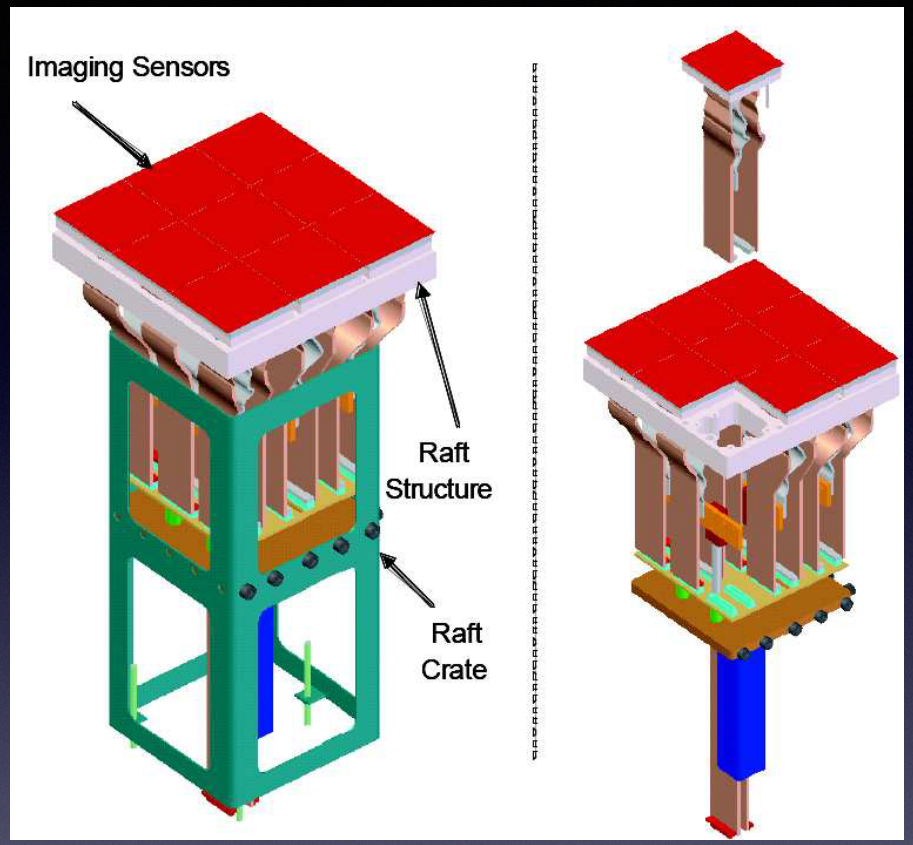
LSST camera



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

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)

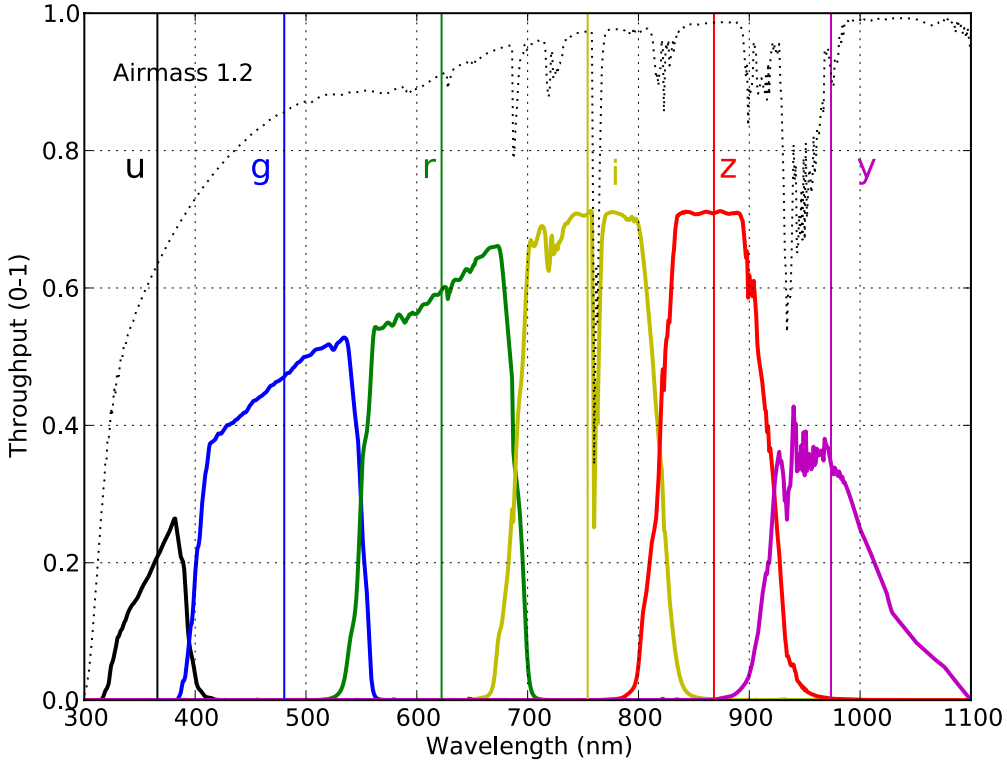


Photo-z requirements correspond to r~27.5 with the following per band time allocations:

u: 8%; g: 10%

r: 22%; i: 22%

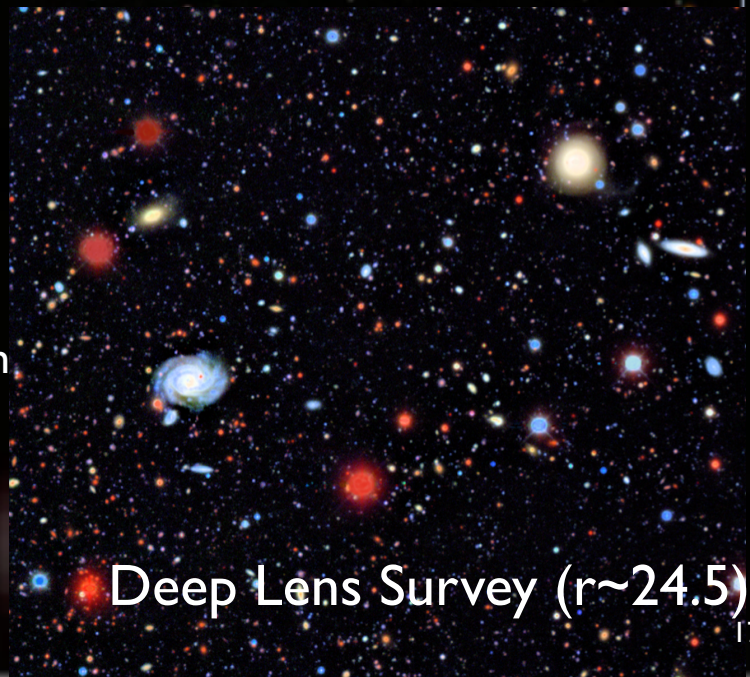
z: 19%; y: 19%

Consistent with other science themes (stars)

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

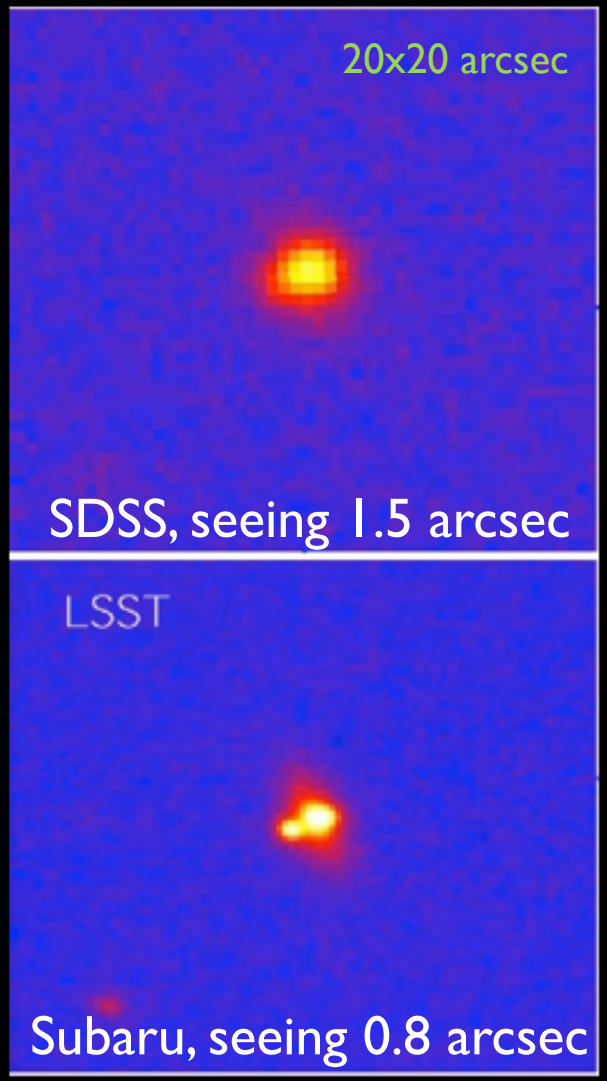
7.5x7.5 arcmin, gri

7.5 arcmin is 1/4 of the full Moon's diameter



single-visit LSST depth (10^{-6} area) LSST: x10^{8}

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



SDSS
gri
3.5'x3.5'
r~22.5

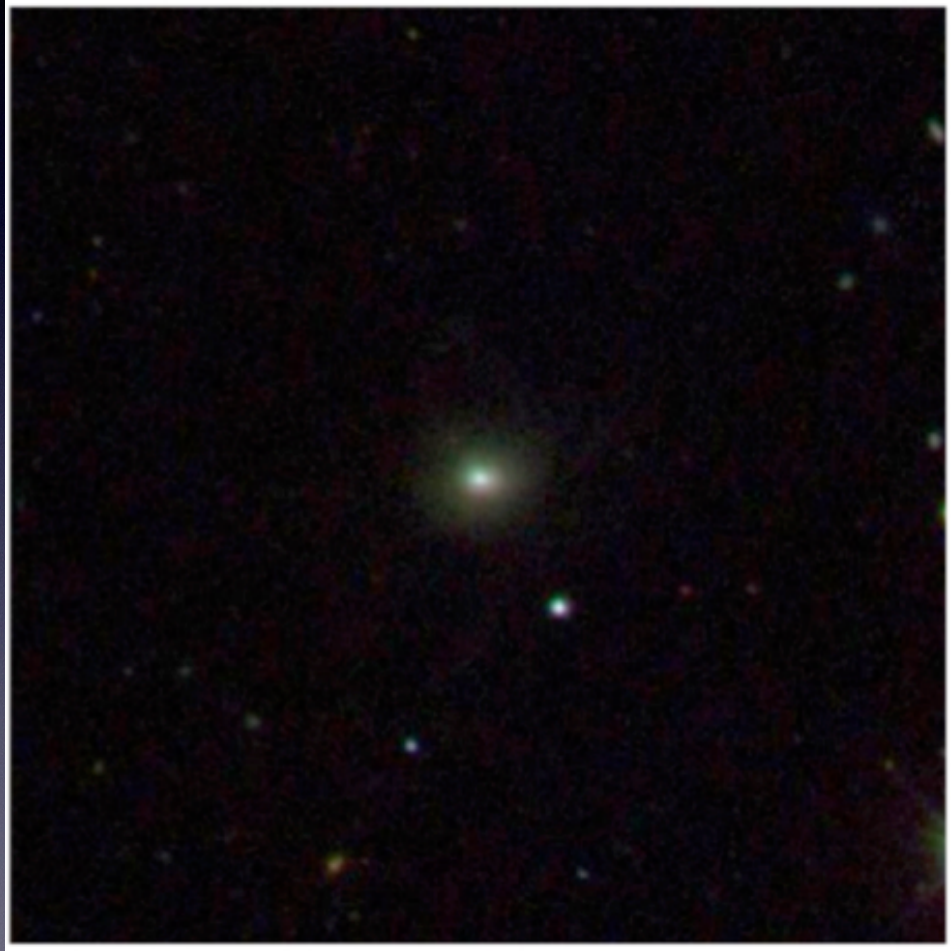
HSC
gri
3.5'x3.5'
r~27

Thanks to Robert Lupton

Not just point source depth: faint surface brightness limit

SDSS

3x3 arcmin, gri



MUSYC r ~26

LSST From the User's Perspective: A Data Stream, a Database, and a (small) Cloud

Nightly Alert Stream

- A stream of ~10 million time-domain events per night, detected and transmitted to event distribution networks within 60 seconds of observation.
- A catalog of orbits for ~6 million bodies in the Solar System.

Level 1

Yearly Data Releases

- A catalog of ~37 billion objects (20B galaxies, 17B stars), ~7 trillion single-epoch detections ("sources"), and ~30 trillion forced sources, produced annually, accessible through online databases.
- Deep co-added images.

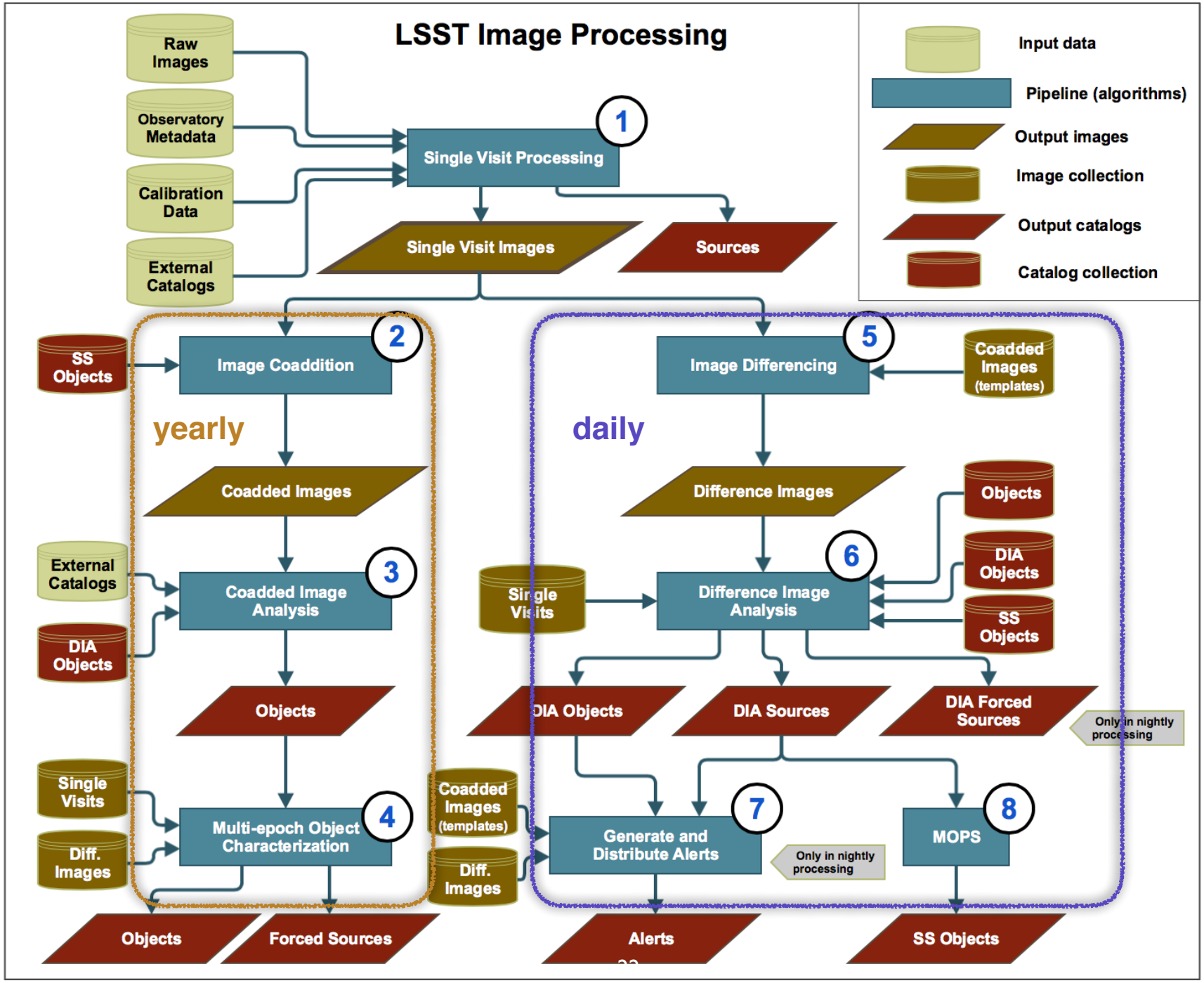
Level 2

Community Services

- Services and computing resources at the Data Access Centers to enable user-specified custom processing and analysis.
- Software and APIs enabling development of analysis codes.

Level 3

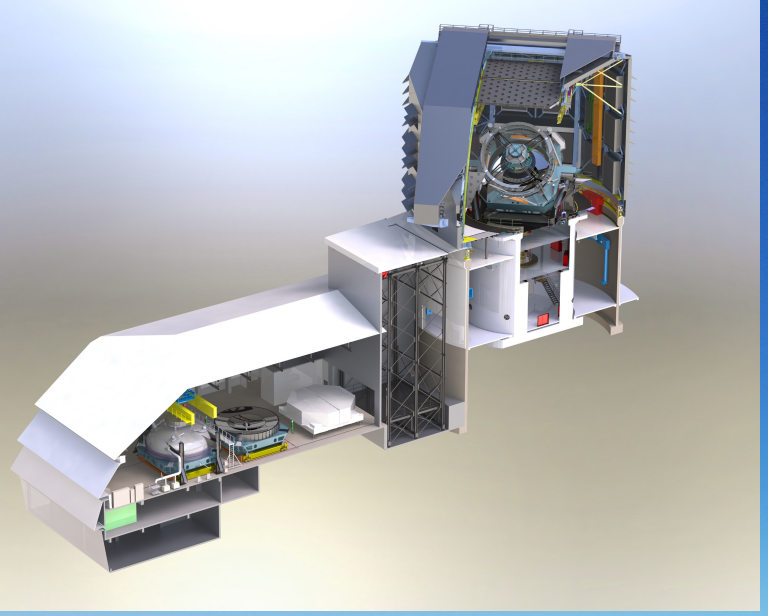
LSST Data Products: see http://ls.st/dpdd


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


LSST Image Processing
Raw Images
Observ Meta
Calibr Da
Exte Catal
SS Objects
ye
External Catalogs
DIA Objects
Single Visits
Diff. Images
Objects
Input data
ne (algorithms)
images
collection
catalogs
g collection
Only in nightly processing

LSST Construction Schedule

- First light with the commissioning camera: 2020
- First light with the main camera: late 2020
- Science commissioning: 2021
- The start of regular survey operations: 2022



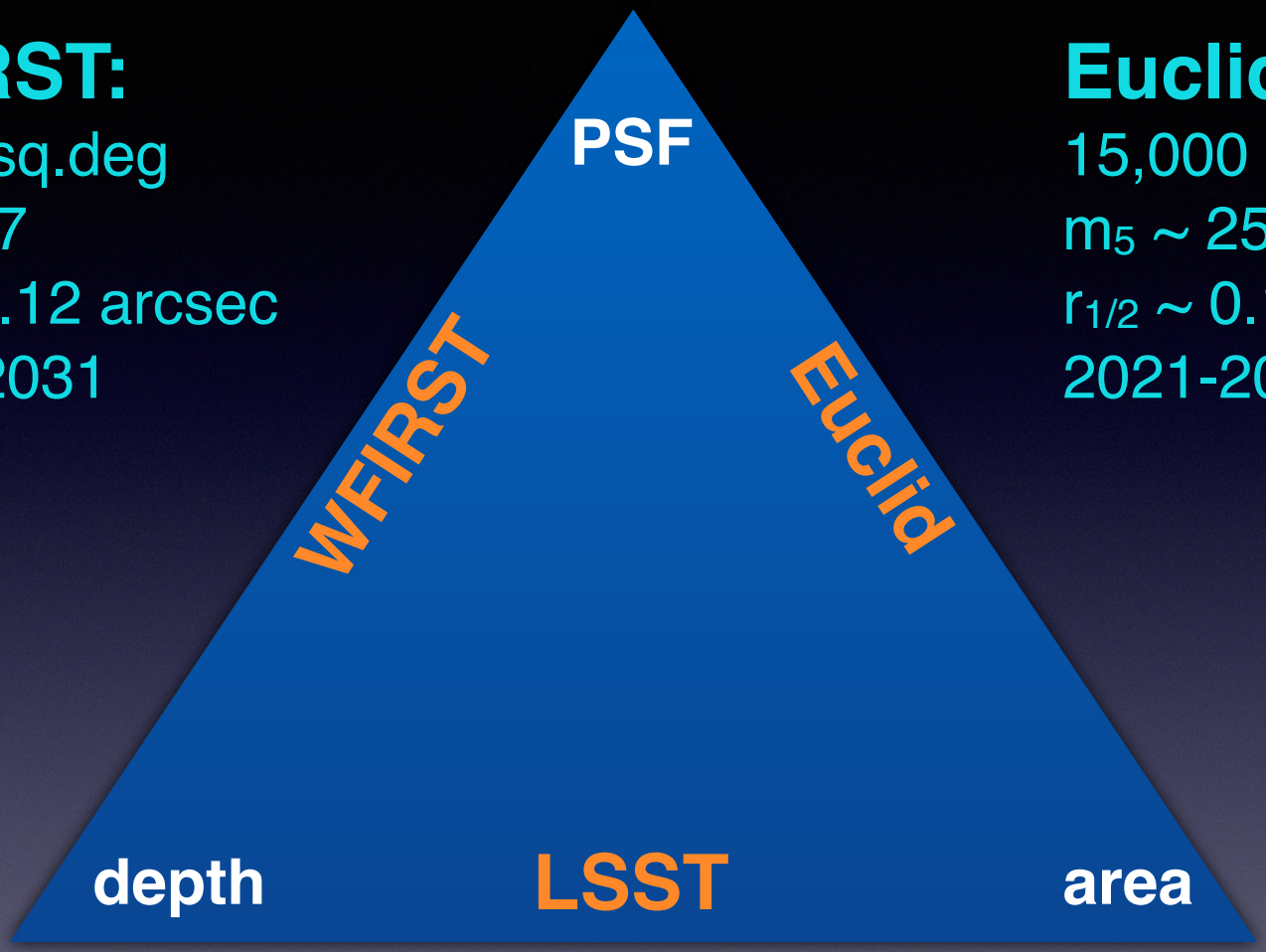
First light: 2020


First light: 2020

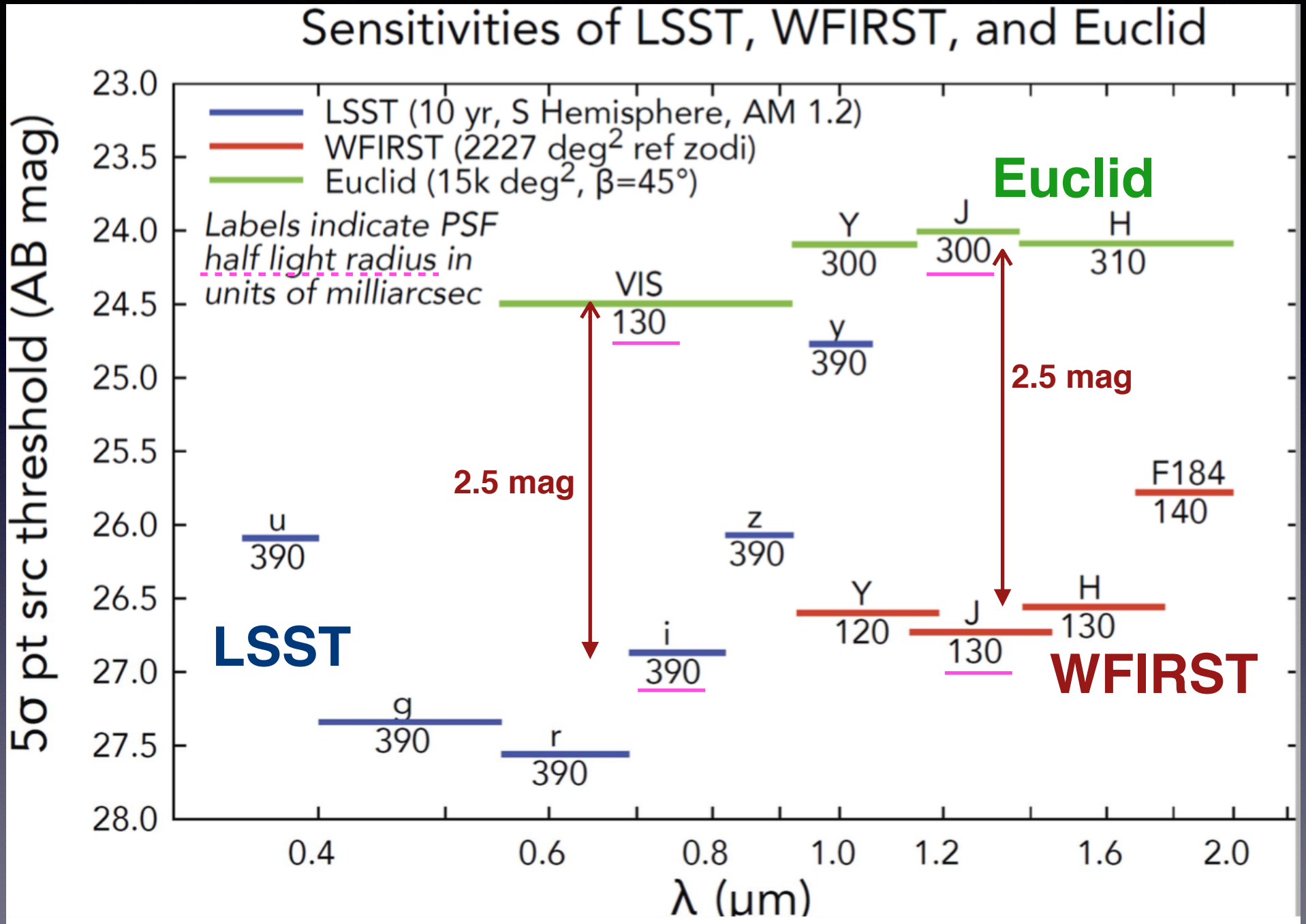
WFIRST, LSST and Euclid are highly complementary missions.

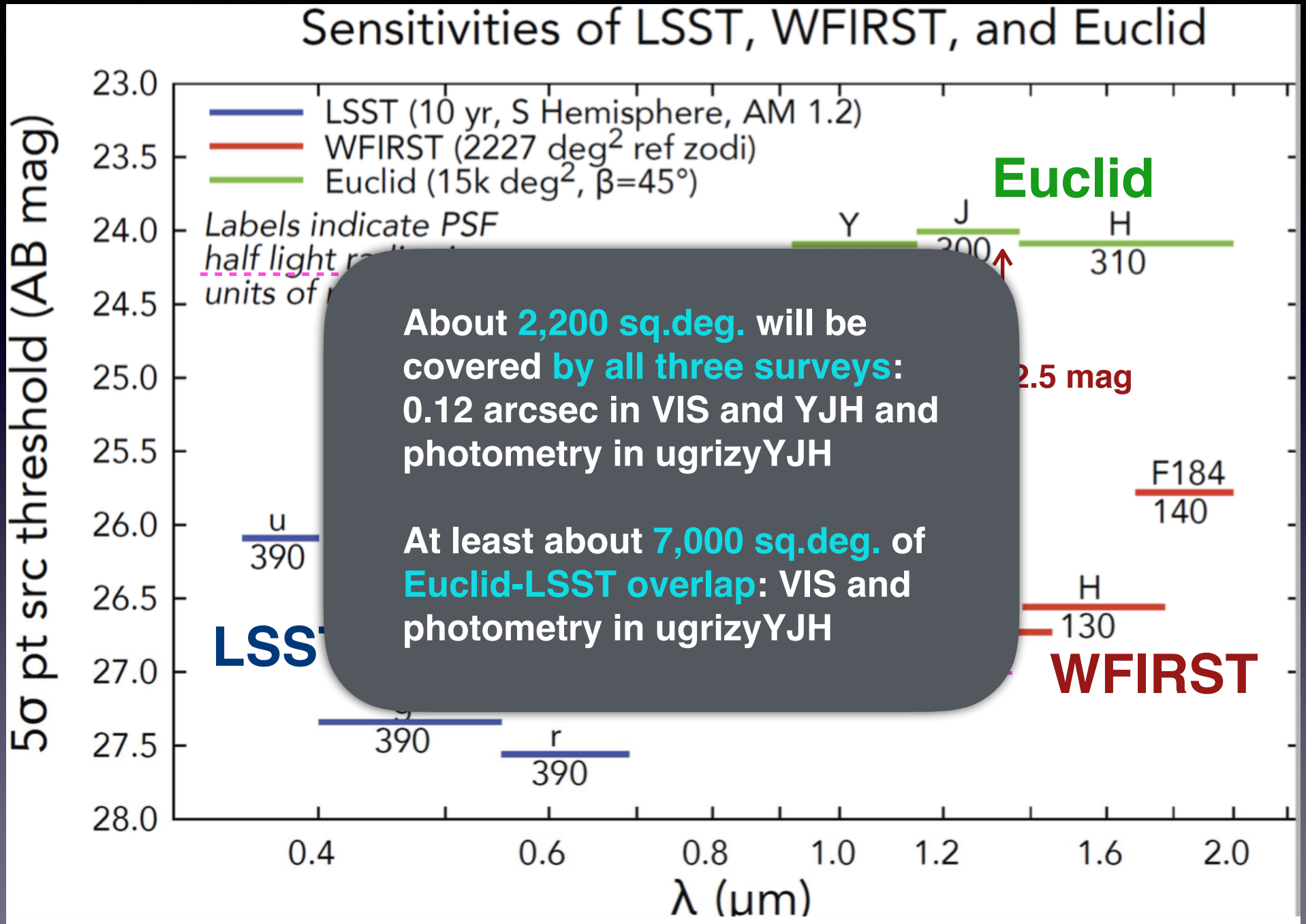
WFIRST:
2,200 sq.deg
$m_5 \sim 27$
$r_{1/2} \sim 0.12$ arcsec
2025-2031

Euclid:
15,000 sq.deg
$m_5 \sim 25$
$r_{1/2} \sim 0.13$ arcsec
2021-2027



18,000 sq.deg
$m_5 \sim 27$
$r_{1/2} \sim 0.4$ arcsec
2022-2032


Sensitivities of LSST, WFIRST, and Euclid
LSST (10 yr, S Hemisphere, AM 1.2)
WFIRST (2227 deg² ref zodi)
Euclid (15k deg², β=45°)
Labels indicate PSF half light radius in units of milliarcsec
Euclid
LSST
WFIRST
VIS 130
Y 300
J 300
H 310
y 390
u 390
g 390
r 390
i 390
z 390
F184 140
Y 120
J 130
H 130
2.5 mag
2.5 mag
5σ pt src threshold (AB mag)
λ (μm)
23.0
23.5
24.0
24.5
25.0
25.5
26.0
26.5
27.0
27.5
28.0
0.4
0.6
0.8
1.0
1.2
1.6
2.0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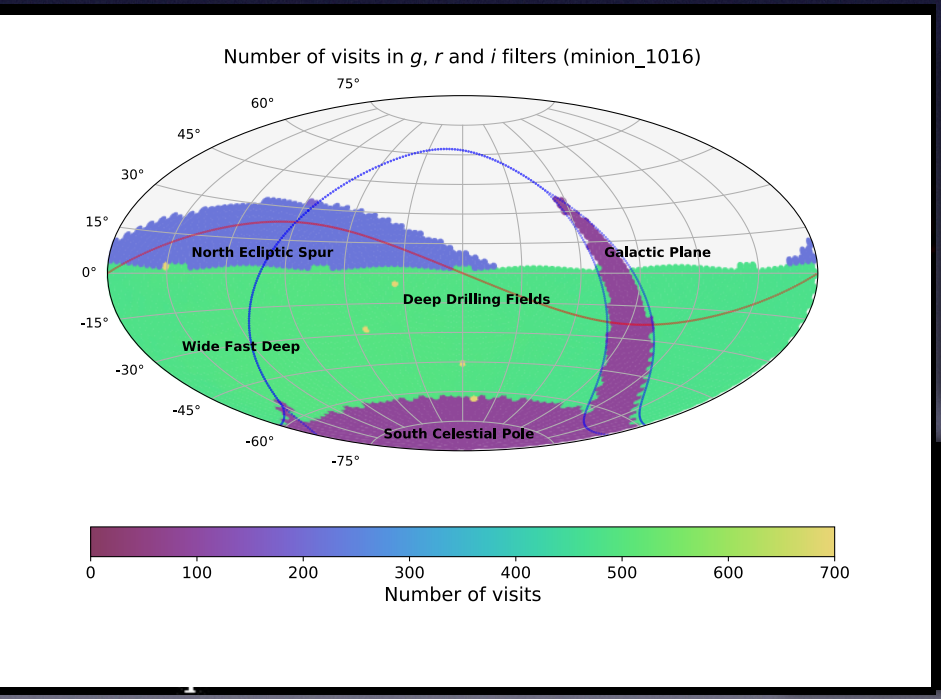
LSST (10 yr, S Hemisphere, AM 1.2)
WFIRST (2227 deg² ref zodi)
Euclid (15k deg², β=45°)
Labels indicate PSF
half light r
units of
Euclid
Y
J
300
H
310
2.5 mag
F184
140
u
390
H
130
LSST
WFIRST
390
r
390
About 2,200 sq.deg. will be covered by all three surveys: 0.12 arcsec in VIS and YJH and photometry in ugrizyYJH
At least about 7,000 sq.deg. of Euclid-LSST overlap: VIS and photometry in ugrizyYJH
5σ pt src threshold (AB mag)
23.0
23.5
24.0
24.5
25.0
25.5
26.0
26.5
27.0
27.5
28.0
0.4
0.6
0.8
1.0
1.2
1.6
2.0
λ (μm)

Summary

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)

You can join LSST, too:

- if interested, talk to me here or send me email ivezic@astro.washington.edu
- or come to LSST@Europe3 meeting in Lyon, June 11-15, 2018