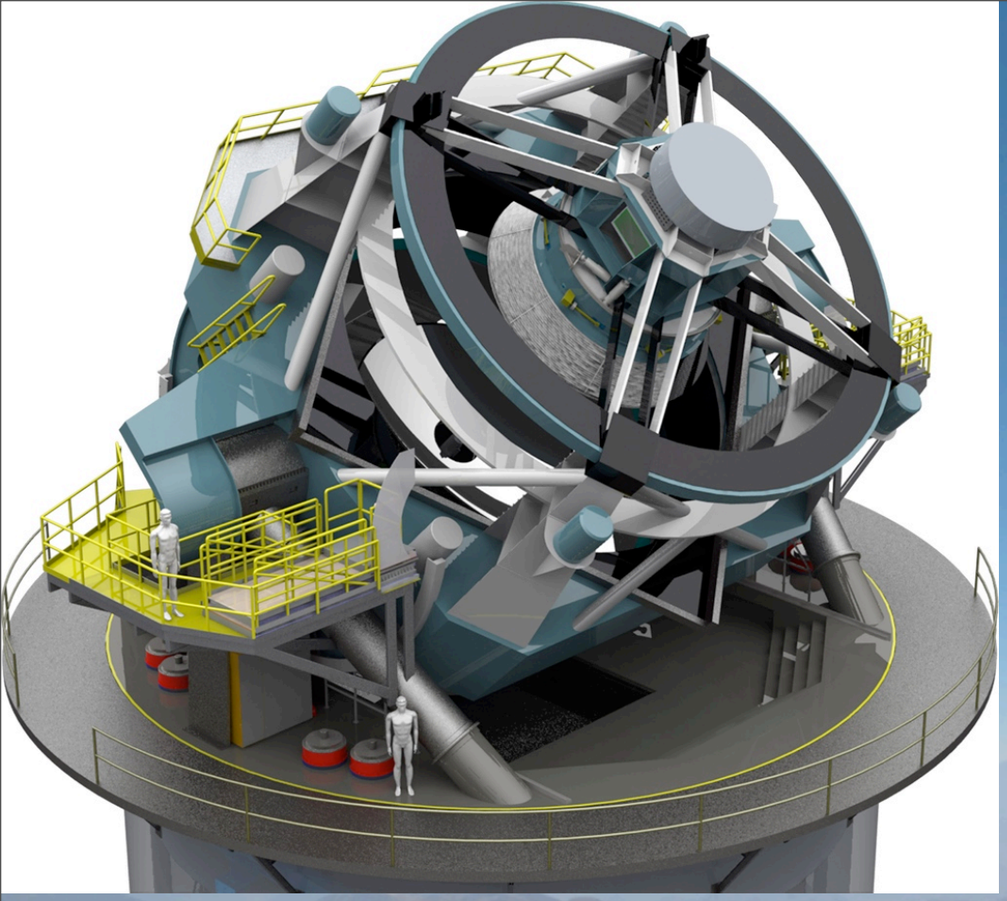


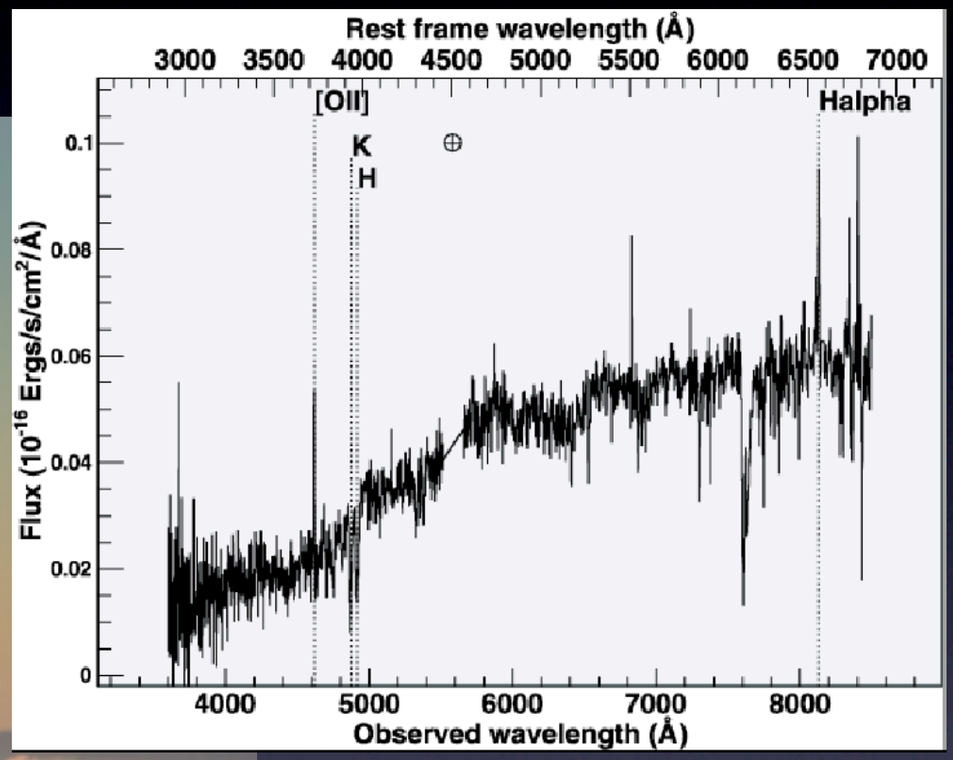
LSST: science, status and opportunities

Željko Ivezić, LSST Project Scientist
Department of Astronomy, University of Washington

Moscow State University, February 9, 2012

Context: modern observational methods in astronomy and astrophysics:

- Large telescopes (~10m): faint objects, especially spectroscopy



The Keck telescopes on Mauna Kea (Hawaii)

Context: modern observational methods in astronomy and astrophysics:

- **Telescopes above the atmosphere:** high angular resolution (e.g., the Hubble Space Telescope) and other wavelength regions (X-ray, radio, infrared)

The HST in orbit and an example of a galaxy image

Context: modern observational methods in astronomy and astrophysics:

- Large telescopes (~10m): faint objects, especially spectroscopy
- Telescopes above the atmosphere: high angular resolution (e.g., the Hubble Space Telescope) and other wavelength regions (X-ray, radio, infrared)
- Large sky surveys: digital sensor technology, information technology, automated data processing and data distribution

Key point: modern sky surveys make all their data (images and catalogs) publicly available

Why are sky maps useful?

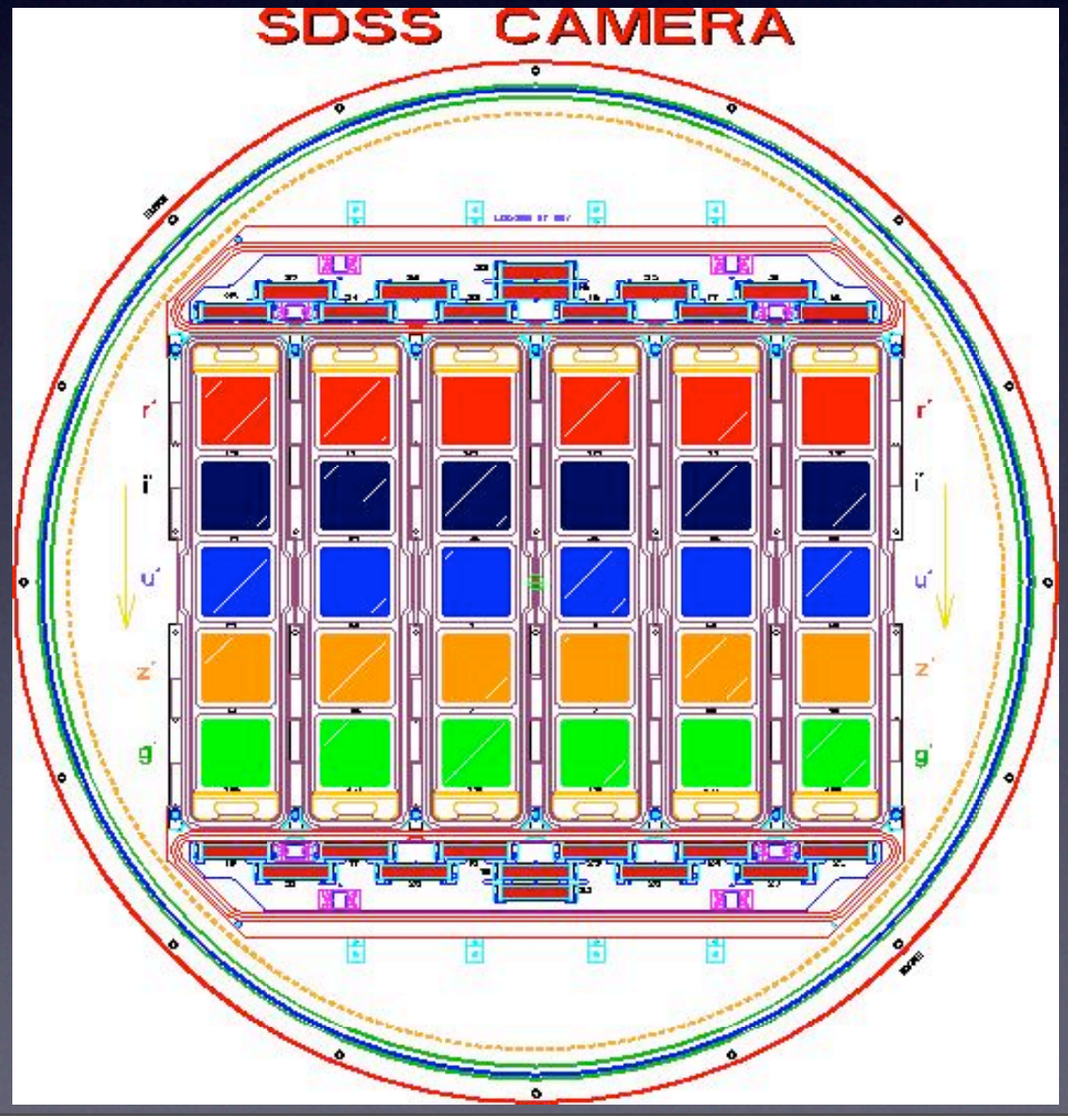
- Sky map:
  – a list of all detected objects (stars, galaxies, ...)
  – measured parameters (size, color, brightness,...)

- The utility of sky maps:
  Discoveries of new objects: "Is this a new asteroid, or is it already cataloged?"
  Object classification: "What types of galaxies exist?"
  Statistical population studies: "Do quasars change their properties with time?"
  Search for unusual objects: "Is this star very weird?"
  Cosmological measurements: "How fast does the Universe expand?"

"Science-ready database": measurements can be (simply) analyzed without the need for (complex) image processing

The last decade: Sloan Digital Sky Survey

- Digital sky survey with a 120 Megapix CCD camera
- Precise measurements for 400,000,000 objects
- Revolution in astronomy: public databases



Astronomy “from your armchair”, from everywhere

"Navigation" around the sky...

http://cas.sdss.org/dr7/en/tools/chart/navi.asp

Address Book | Apple | Customize Links | Customize Links | Yahoo! | Free Hotmail | Windows | Google Maps | YouTube | Wikipedia

DR7

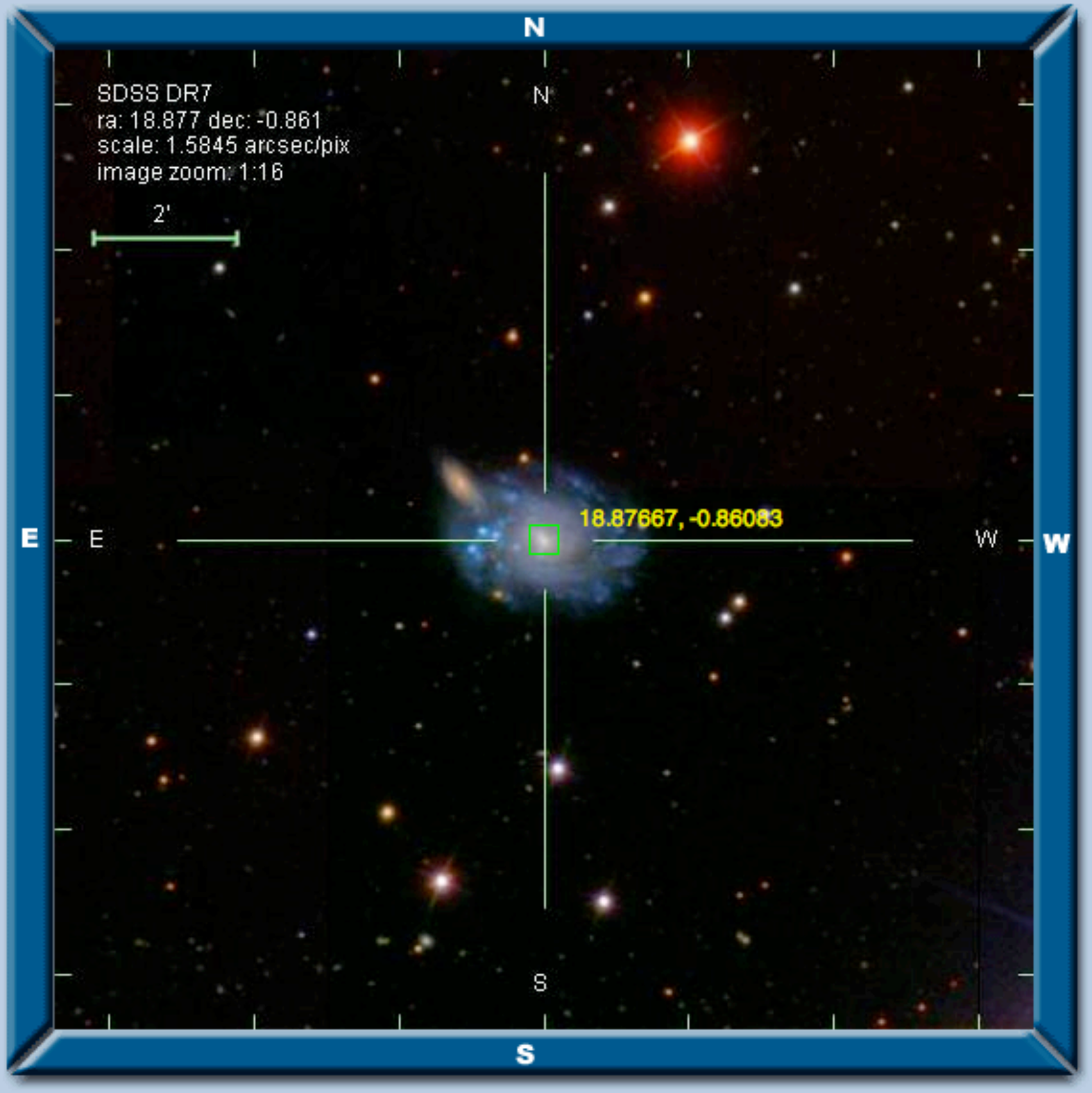
|Home |Help |Tutorial |
Chart | List | Explore |

Parameters		
ra	18.87667	deg
dec	-0.86083	deg
opt	GL	

Get Image

Drawing options
- [x] Grid
- [x] Label
- [ ] Photometric objects
- [ ] Objects with spectra
- [ ] Invert Image

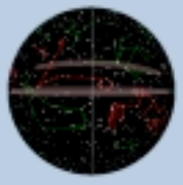
Advanced options
- [ ] Spectroscopic Targets
- [ ] Outlines
- [ ] Bounding Boxes
- [ ] Fields
- [ ] Masks
- [ ] Plates



Selected object

ra	18.87684
dec	-0.86098
type	GALAXY
u	14.82
g	13.74
r	13.19
i	12.91
z	12.93

- Quick Look
- Explore
- Recenter
- Add to notes
- Show notes



Click to open Sky Maps ?

To see Sky Maps, install the latest Flash and Shockwave players.

Additional, more detailed, information...

http://cas.sdss.org/dr7/en/tools/explore/obj.asp?ra=18.87667&dec=-0.86083

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DR7

Explore Home

Search by
ObjId
Ra,dec
5-part SDSS
Plate-MJD-Fiber
SpecObjId

Summary

PhotoObj
PhotoTag
More Observations
Field
Frame
PhotoZ
Neighbors
Finding chart
Navigate
FITS

SpecObj
All Spectra
SpecLine
SpecLineIndex
XCredShift
ELredShift
Spectrum
Plate
FITS

NED search
SIMBAD search
AKARI FIS
AKARI IRC
ADS search

Notes
Save in Notes
Show Notes

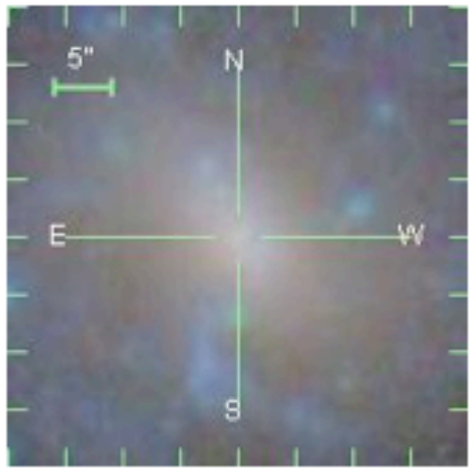
Print

SDSS J011530.44-005139.5

GALAXY ra=18.87683906, dec=-0.86097998, ObjId = 587731511532060697

Column names link to glossary entries. Move mouse over a column name to get its units.

mode	PRIMARY
status	TARGET PRIMARY OK_STRIPE OK_SCANLINE PSEGMENT RESOLVED OK_RUN GOOD SET
flags	DEBLEND_DEGENERATE BAD_MOVING_FIT BINNED1 INTERP COSMIC_RAY NOPETRO CHILD
PrimTarget	TARGET_GALAXY TARGET_GALAXY_RED TARGET_QSO_CAP
SecTarget	



u	g	r	i	z
14.82	13.74	13.19	12.91	12.93

err_u	err_g	err_r	err_i	err_z
0.01	0.00	0.00	0.00	0.00

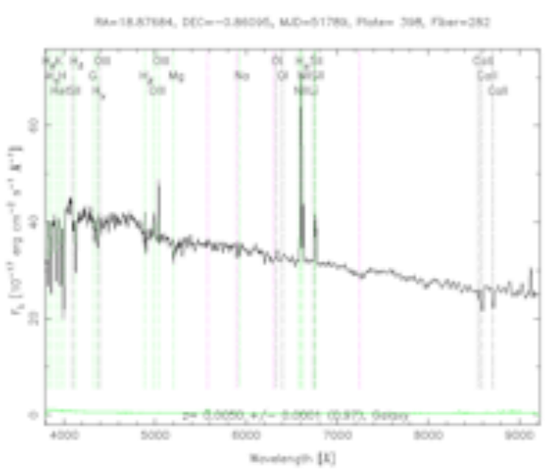
run	rerun	camcol	field	obj	rowc	colc
2738	40	1	44	25	972.5	1786.6

fiberMag_r	petroMag_r	devMag_r	expMag_r	psfMag_r	modelMag_r
17.56	12.97	13.14	13.19	18.16	13.19

extinction_r	petroRad_r	parentId	nChild
0.11	106.724	587731511532060693	0

SpecObjID = 112249473974927360

plate	mjd	fiberId	z	zErr	zConf	specClass	ra	dec	fiberMag_r	objId
398	51789	282	0.005	0.00006	0.969081	GALAXY	18.87684	-0.86095	17.53	587731511532060697



zStatus	XCORR_EMLINE
zWarning	OK
PrimTarget	TARGET_GALAXY TARGET_GALAXY_RED
SecTarget	
eClass	0.095797
emZ	0.006
emConf	0.874995
xcZ	0.005
xcConf	0.969081

Cross-identifications

Additional, more detailed, information...

http://cas.sdss.org/dr7/en/tools/explore/obj.asp?ra=18.87667&dec=-0.86083

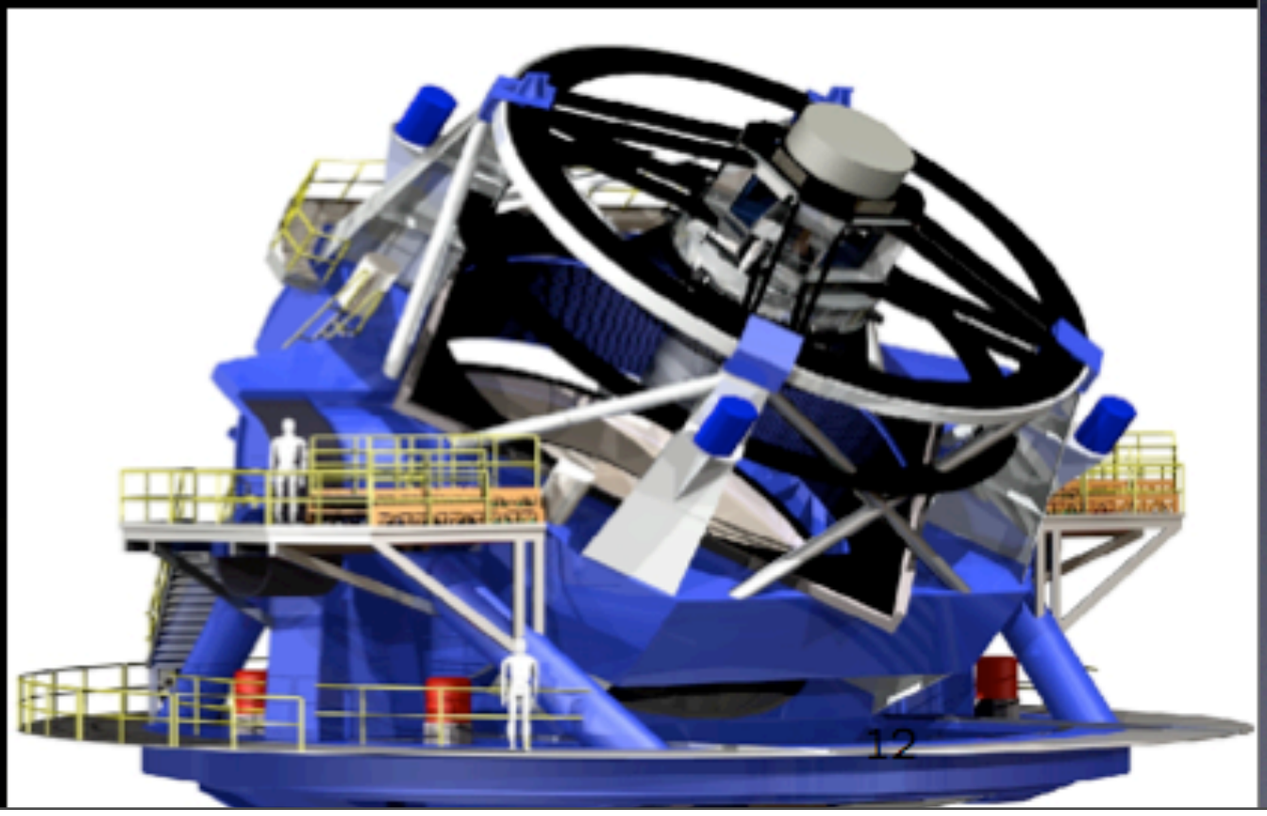
Address Book ▾ Apple Customize Links Customize Links Yahoo! Free Hotmail Windows Google

SDSS J011530.44-005139.5

Cross-identifications

SDSS: one US Library of Congress worth of data

LSST: one SDSS per night, or all the words ever printed!



Outline

- **LSST system summary**
  - Science Themes
  - System Characteristics
- **LSST science examples**
  - Extragalactic astronomy and cosmology
  - The Milky Way and the Local Group
  - Time Domain
- **Opportunities for collaboration**
  - Construction
  - Operations
  - Science Collaborations

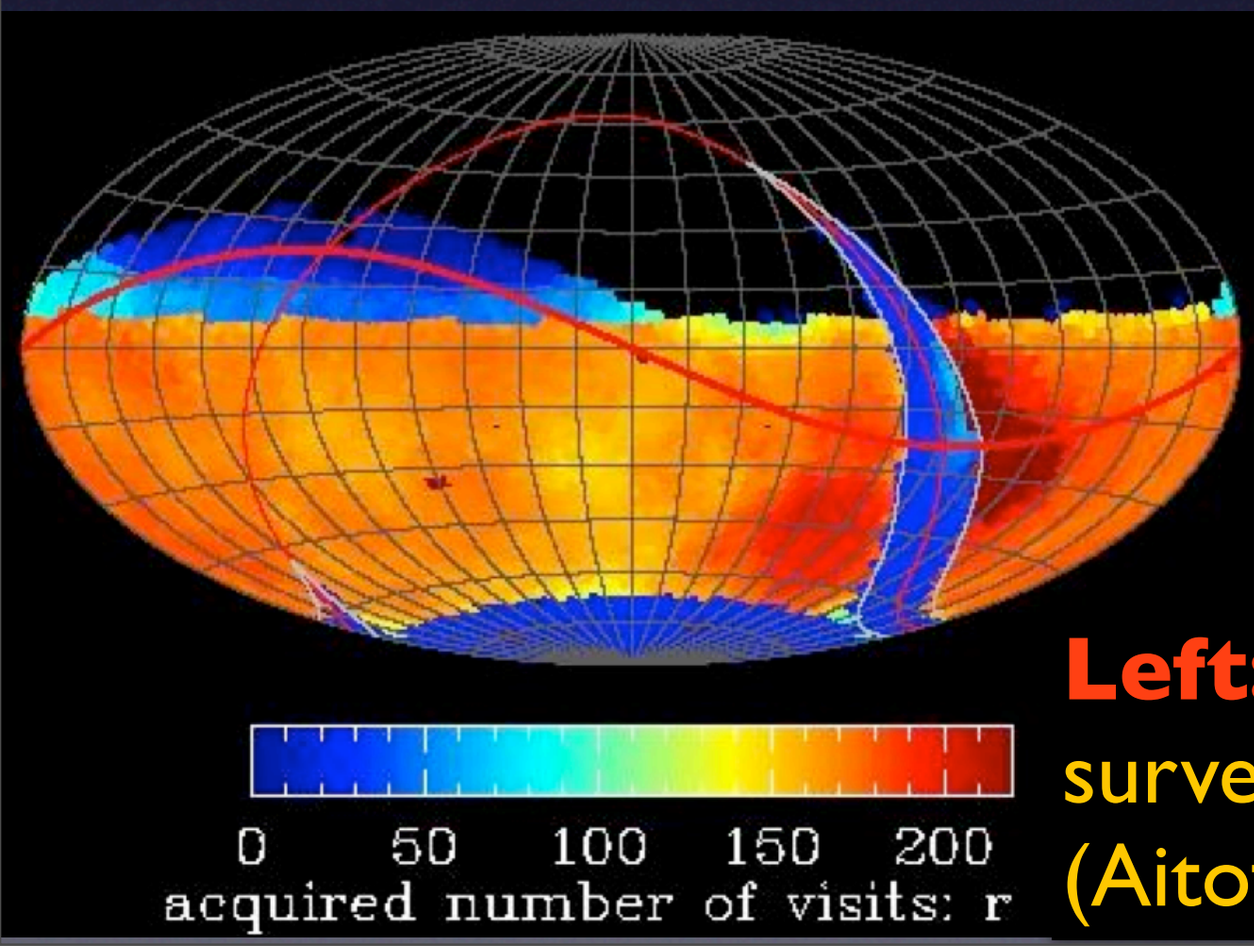
LSST Science Themes

- 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)

These drivers not only require similar hardware and software systems, but also motivate a uniform cadence: **about 90% of time will be spent on a uniform survey**

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 20 billion objects**

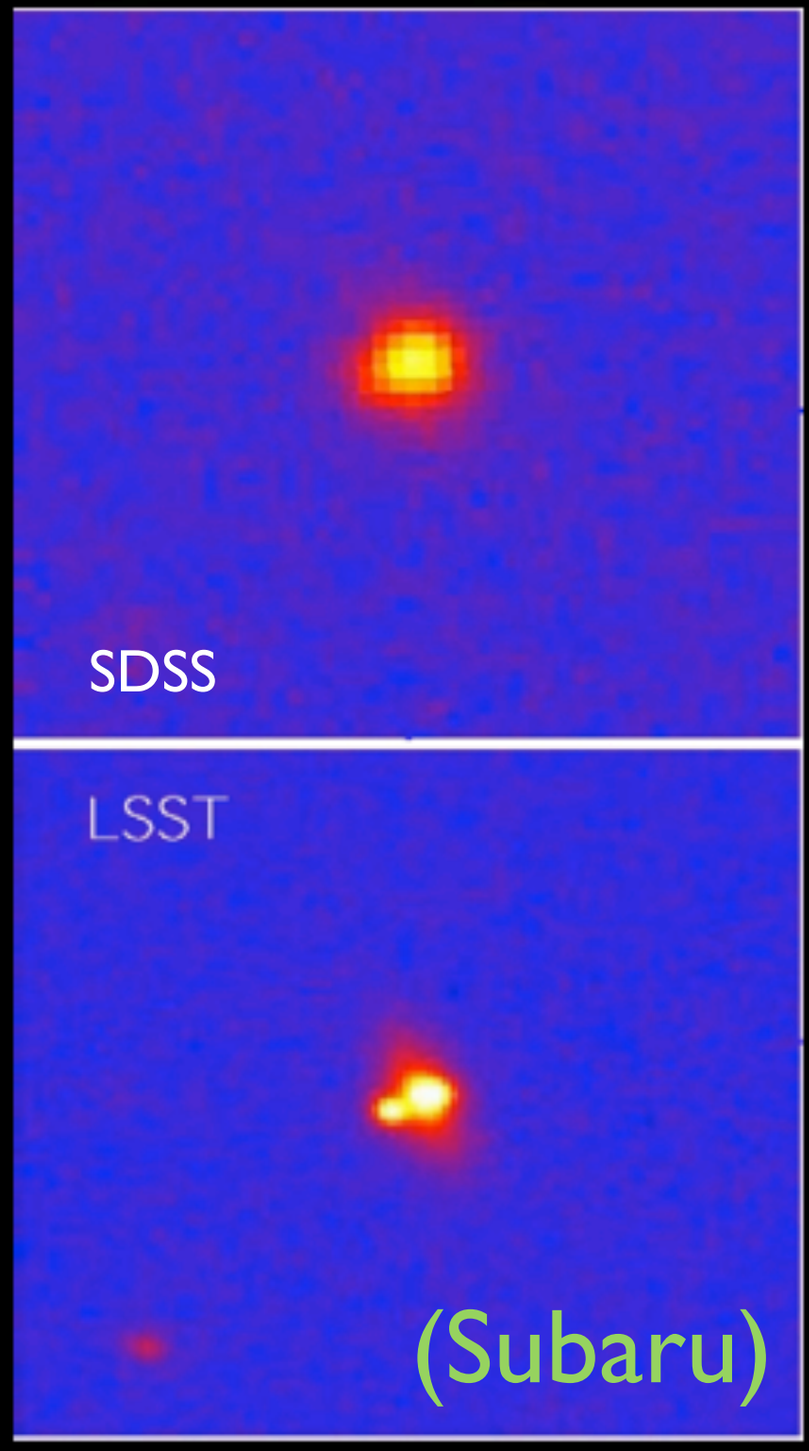


LSST in one sentence:
An optical/near-IR survey of half the sky in ugrizy bands to r~27.5 (36 nJy) based on 1000 visits over a 10-year period: deep wide fast.

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

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

3x3 arcmin, gri



Required system characteristics

- Large primary mirror (at least 6m) to go faint and to enable short exposures (30 s)
- Agile telescope (5 sec for slew and settle)
- Large field of view to enable fast surveying
- Impeccable image quality (weak lensing)
- Camera with 3200 Mpix
- Sophisticated software (20,000 GB/night, 20 billion objects, 20 trillion measurements)

LSST system

Telescope

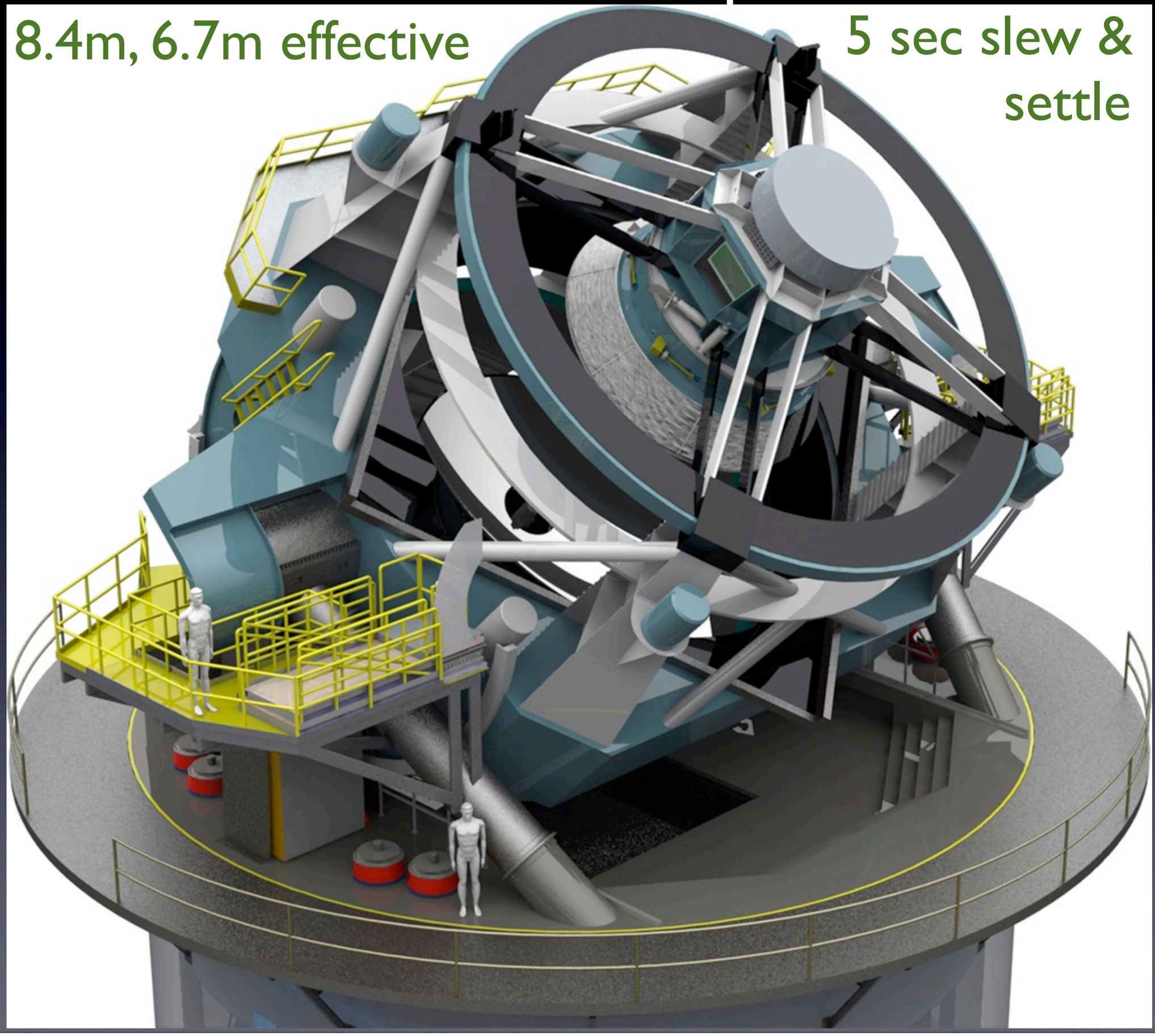
Camera

Software

LSST Telescope

8.4m, 6.7m effective

5 sec slew & settle



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

Gemini South Telescope

LSST

Primary Mirror Diameter

8 m

8.4 m

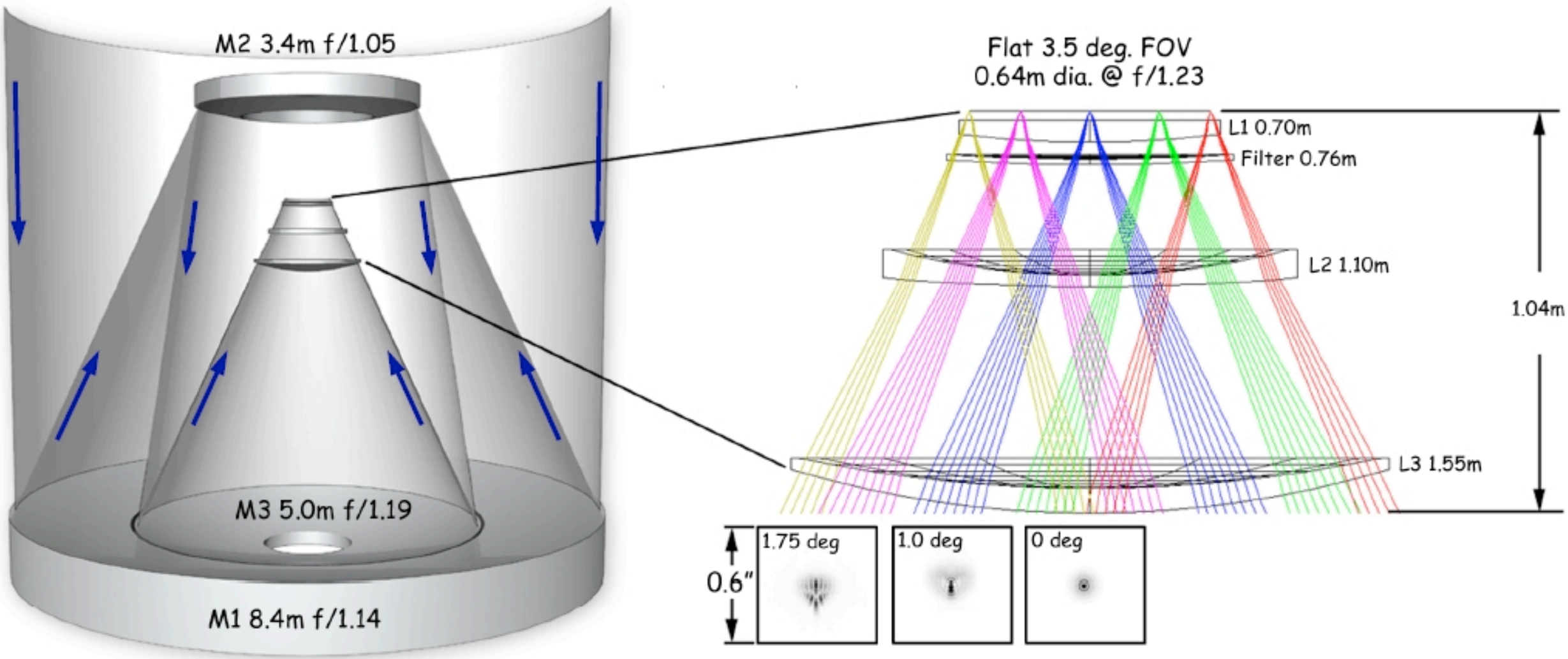
Field of View

0.2 degrees

3.5 degrees

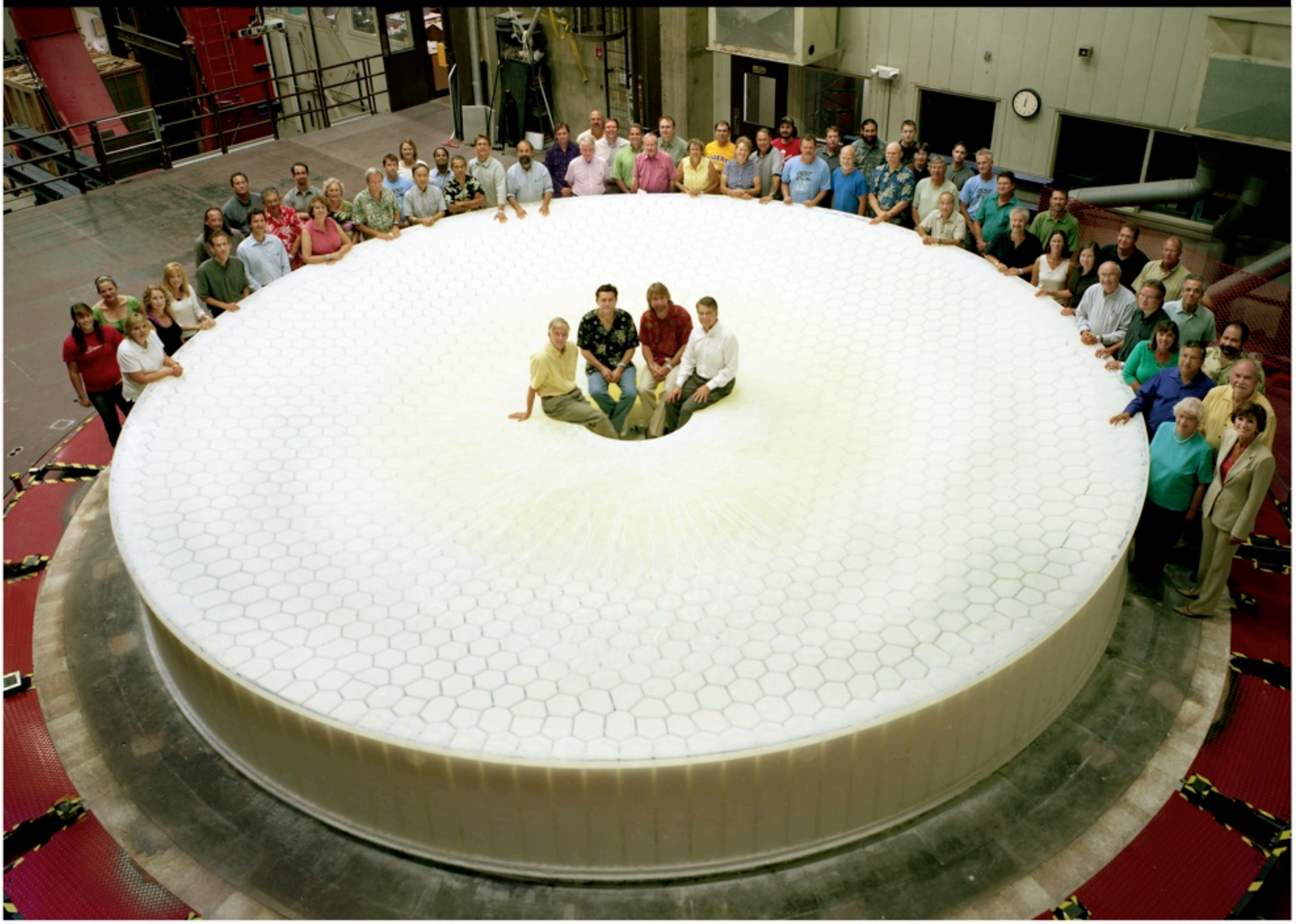
(Full moon is 0.5 degrees)

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



The University of Arizona. Tucson Arizona

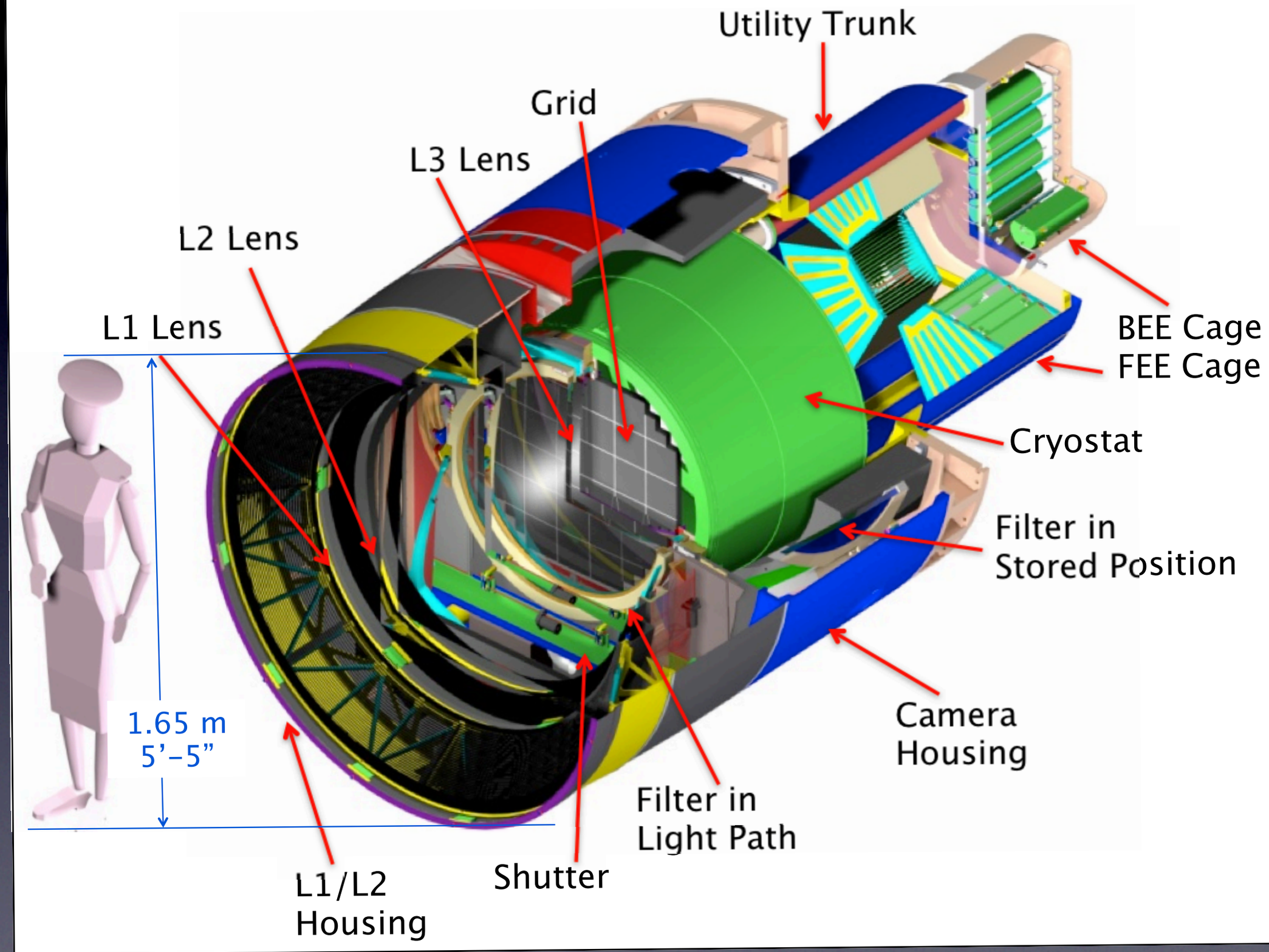
SOML

LSST Primary/Tertiary Mirror Blank

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

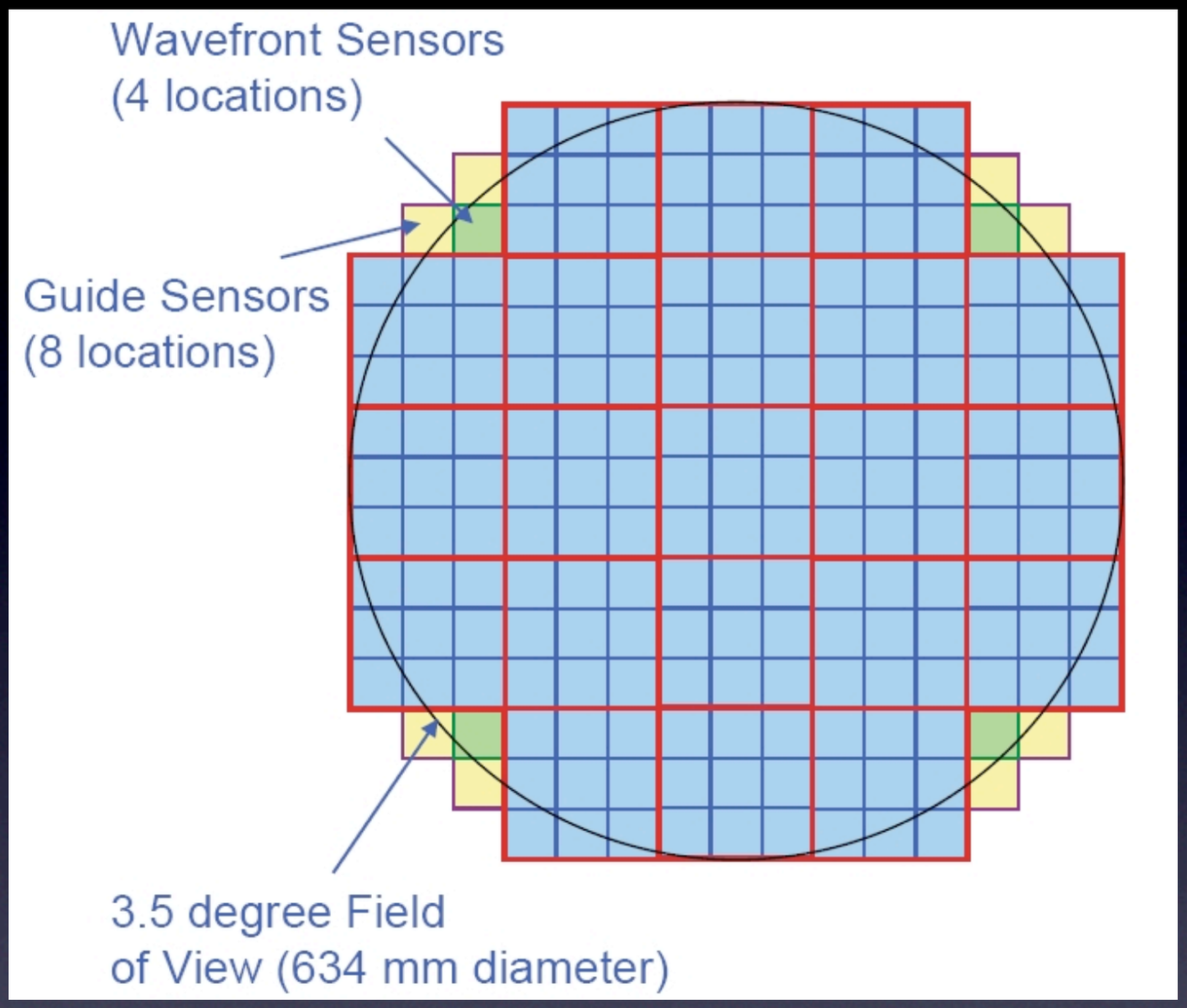
Large Synoptic Survey Telescope

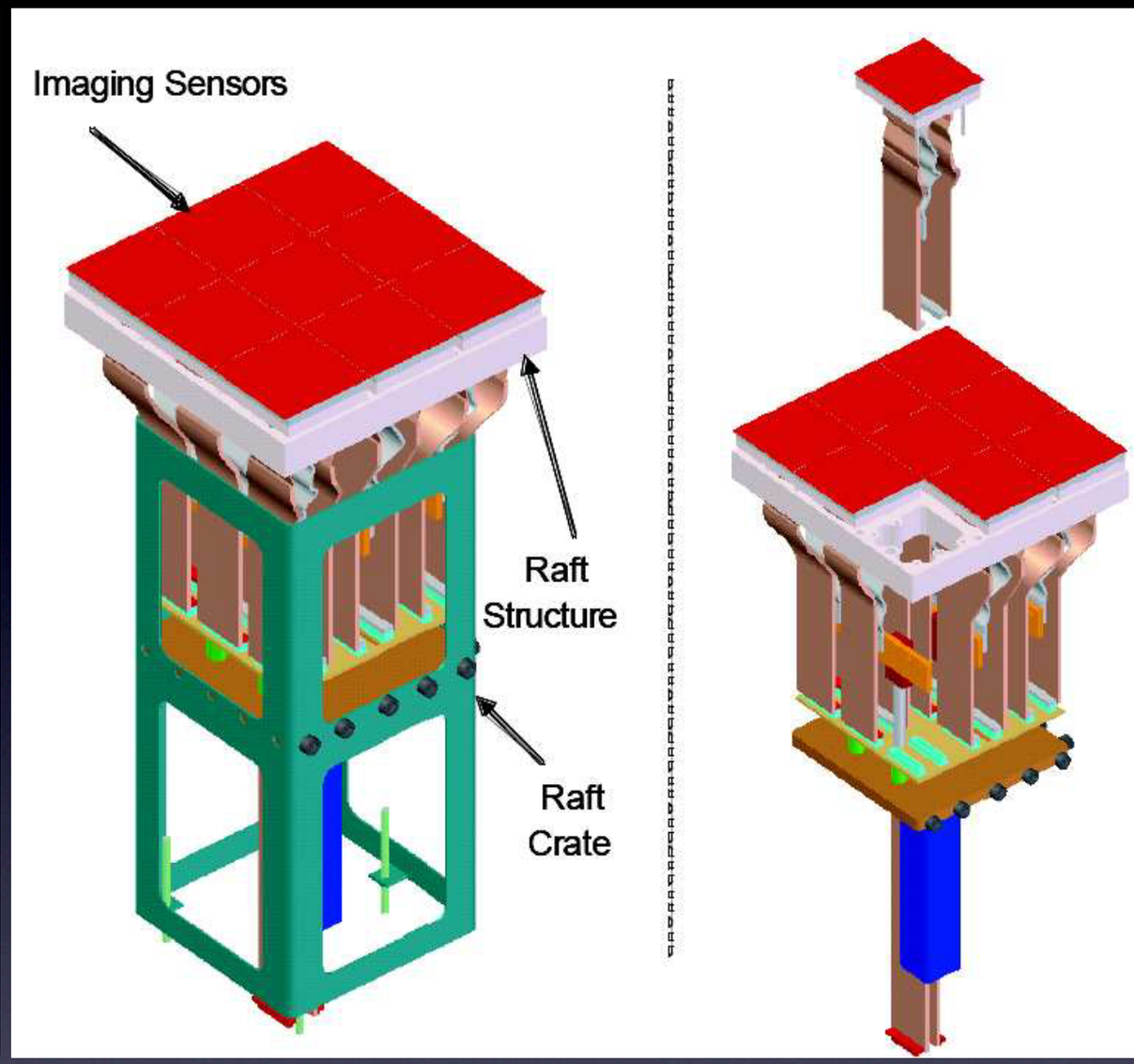
LSST camera



The largest astronomical camera: 2800 kg, 3.2 Gpix

LSST camera



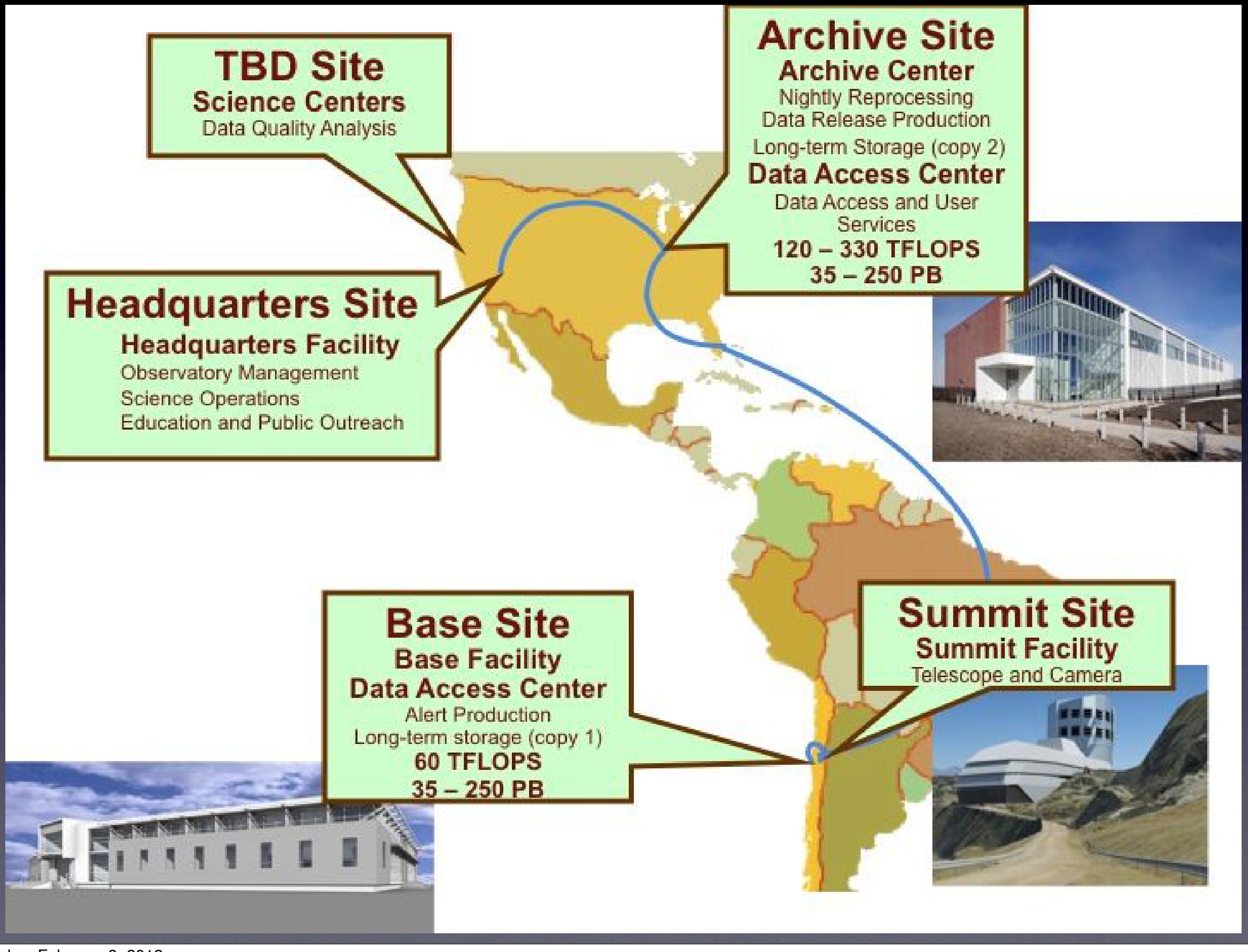


Modular design: 3200 Megapix = 189 x16 Megapix CCD

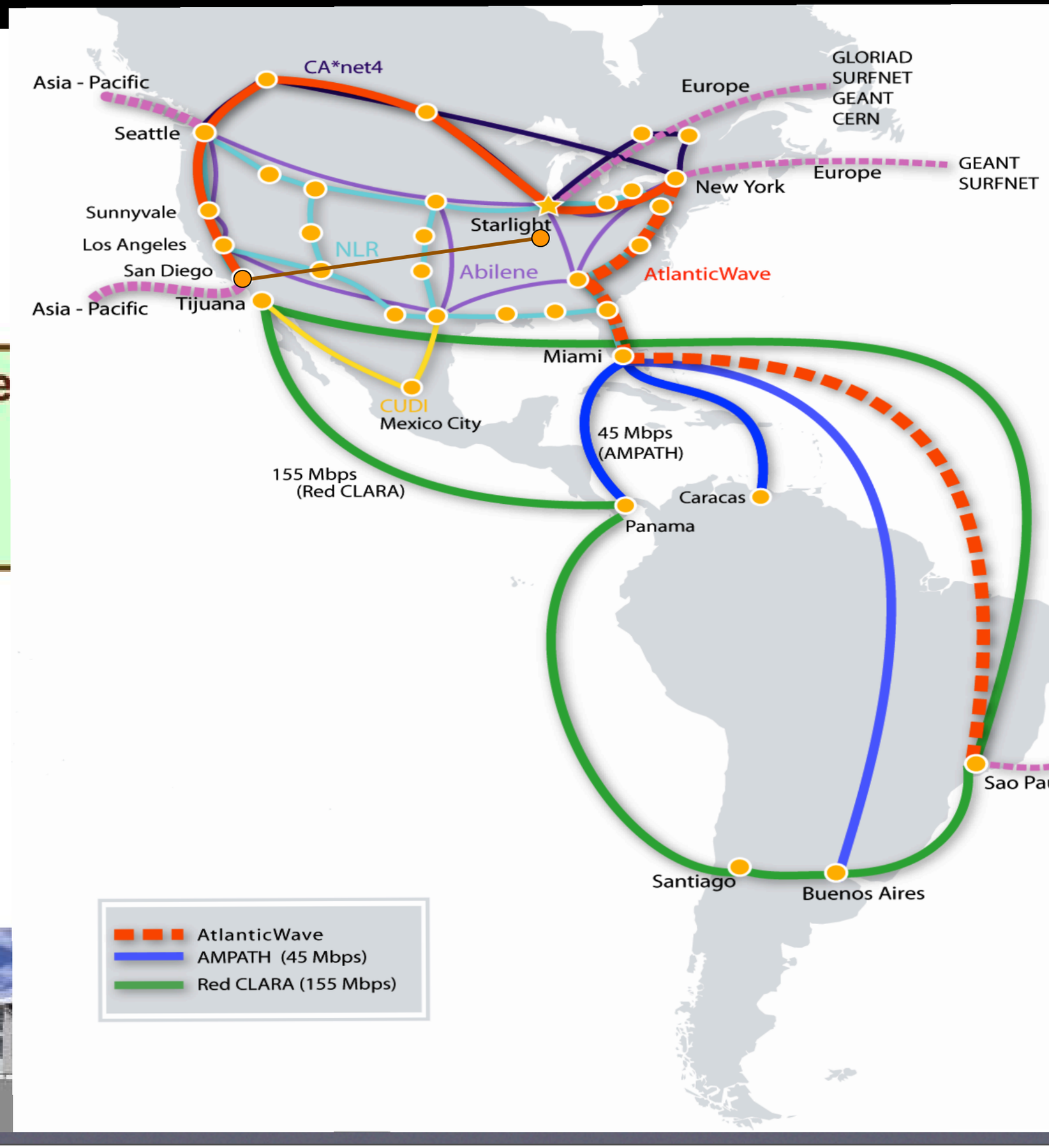
9 CCDs share electronics: raft (=camera)

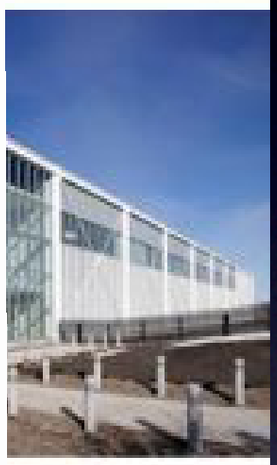
Problematic rafts can be replaced relatively easily

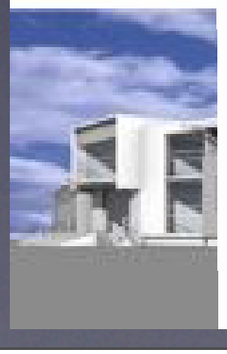
LSST Software

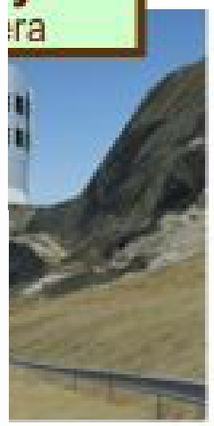


LSST Software









Software: the subsystem with the highest risk

- 20 TB of data to process every day
- 1000 measurements for 20 billion objects during10 years
- Existing tools and methods (e.g. SDSS) do not scale up to LSST data volume and rate

Software: the subsystem with the highest risk

- 20 TB of data to process every day
- 1000 measurements for 20 billion objects during10 years
- Need for new tools and methods: **software, software, software!**

- About 5-10 million lines of new code
- C++/python
- A collaboration of astronomers, physicists and professional programmers

Application Layer - pipelines process raw data to products

Large Synoptic Survey Telescope

Middleware API

Application Framework

Data Acquisition Infrastructure

Nightly Processing Pipelines

Data Release Pipelines

Calibration Products Pipeline

User Tools (Query, Data Quality Analysis, Monitoring)

Image Proc. PL

Detection PL

Assoc PL

Moving Obj PL

Alert PL

Deep Detection PL

Photometric Cal PL

Astrometric Cal PL

Image Coadd PL

Classification PL

Data QA PL

Data Products

Eng/Fac Data Archive

Calibration Data Products

Image Archive

Source Catalog

Object Catalog

Orbit Catalog

Alert Archive

A comparison of LSST data processing with other software projects:

- **Complexities we have to deal with in DM**
  - Very high data volumes (transfer, ingest, and especially query)
  - Advances in scale of algorithms for photometry, astrometry, PSF estimation, moving object detection, shape measurement of faint galaxies
  - Provenance recording and reprocessing
  - Evolution of algorithms and technology
- **Complexities we DON'T have to deal with in DM**
  - Tens of thousands of simultaneous users (e.g. online stores)
  - Fusion of remote sensing data from many sources (e.g. earthquake prediction systems)
  - Millisecond or faster time constraints (e.g. flight control systems)
  - Very deeply nested multi-level transactions (e.g. banking OLTP systems)
  - Severe operating environment-driven hardware limitations (e.g. space-borne instruments)
  - Processing that is highly coupled across entire data set with large amount of inter-process communication (e.g. geophysics 3D Kirchhoff migration)

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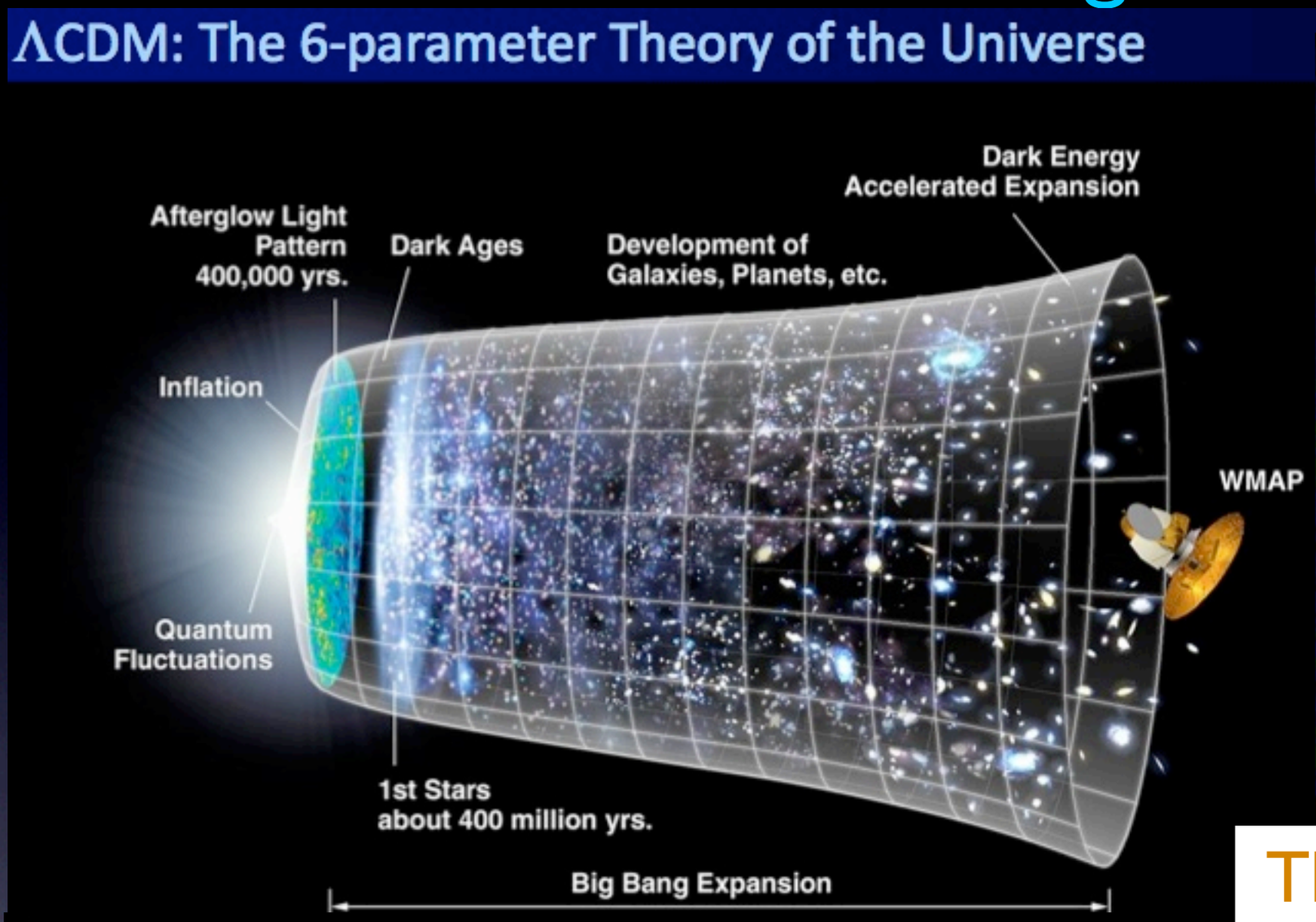
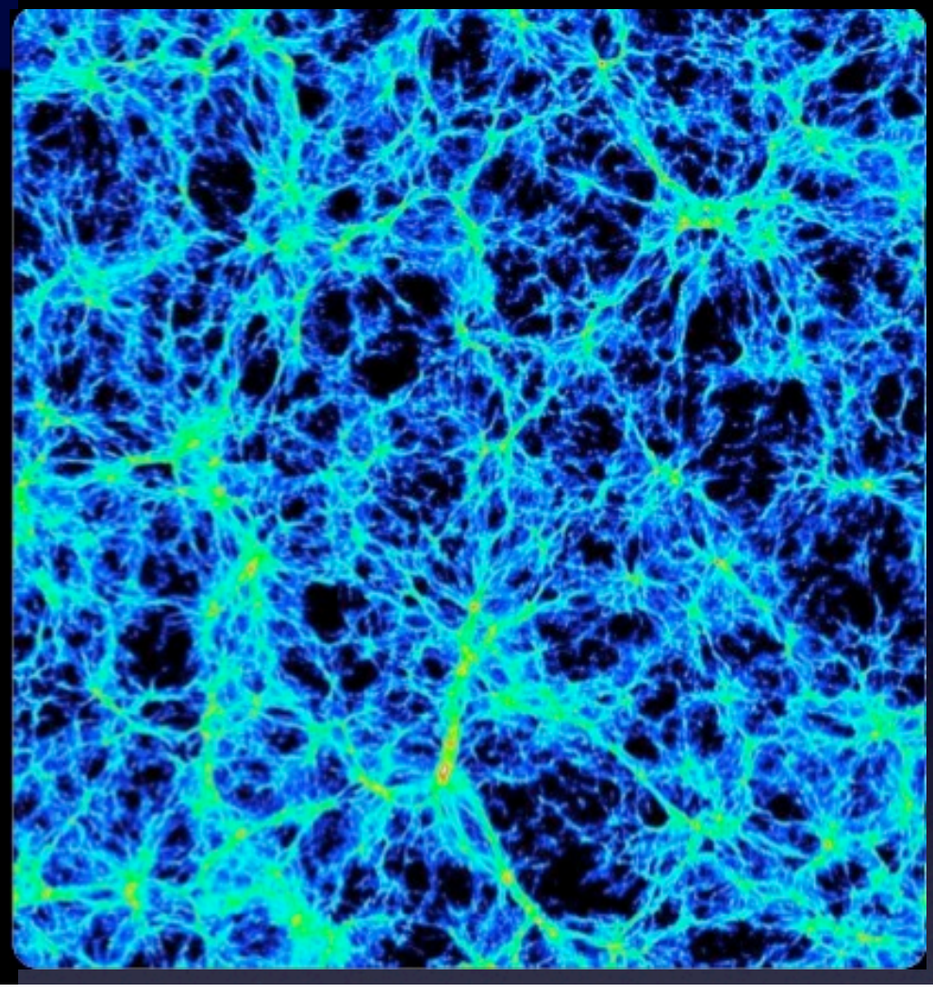
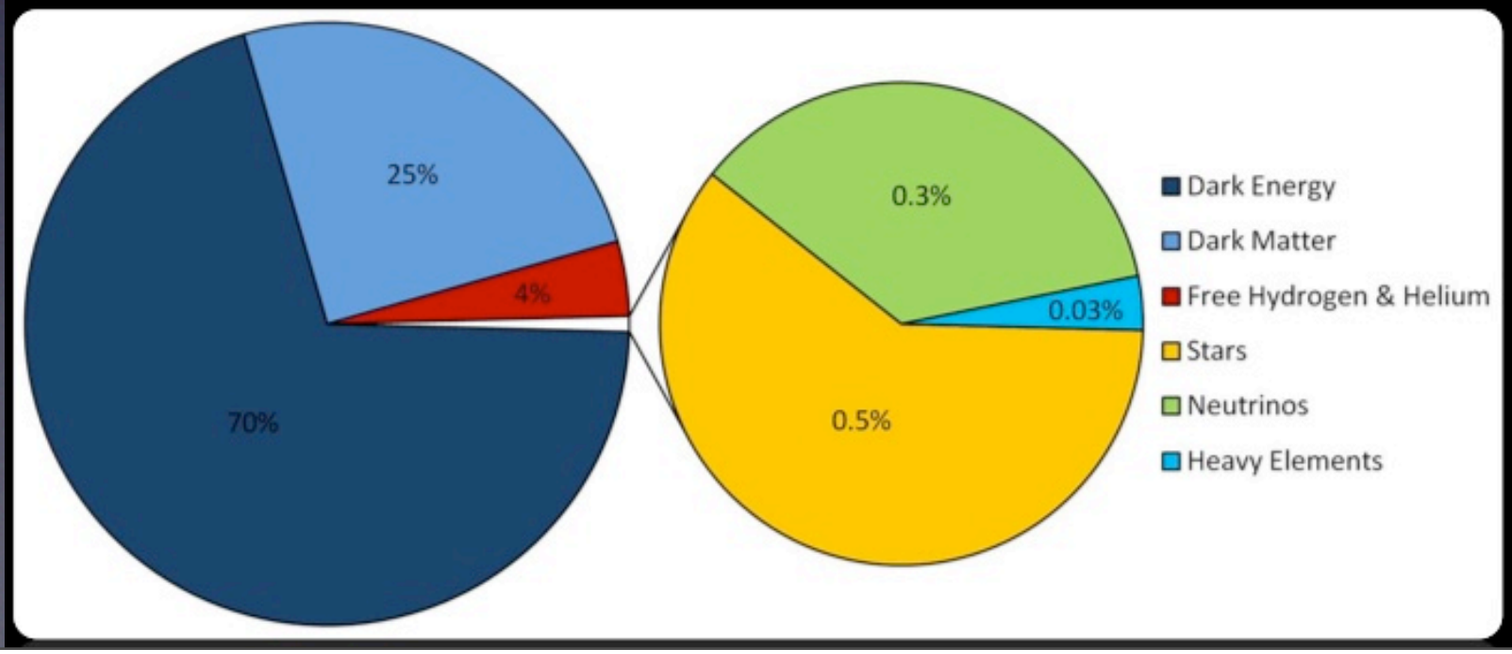
  - Operations
  - Science Collaborations

New Cosmological Puzzles





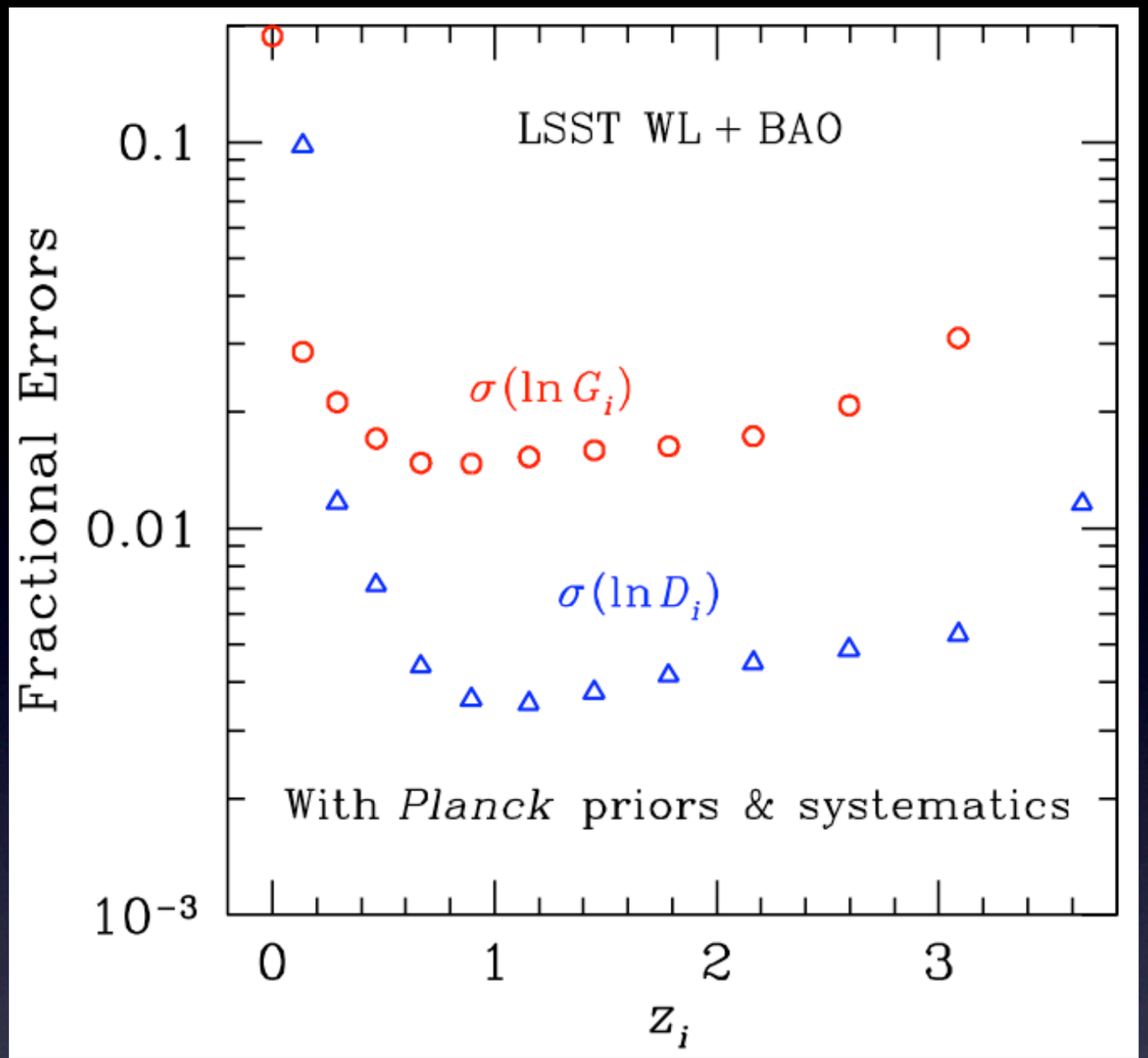


The modern cosmological models can explain all observations, but need to **postulate** dark matter and dark energy (though gravity model could be wrong, too)

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)

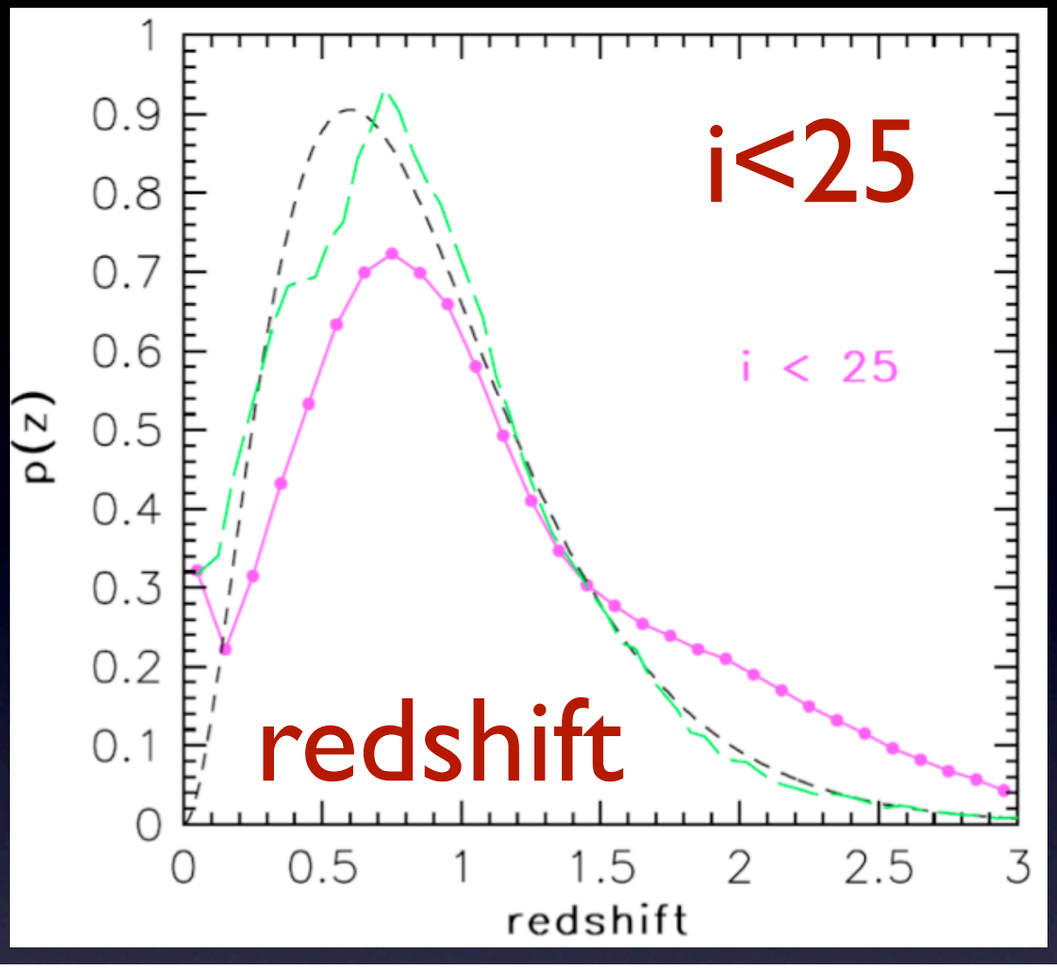


By simultaneously measuring growth of structure and curvature, LSST data will tell us whether the recent acceleration is due to dark energy or modified gravity.

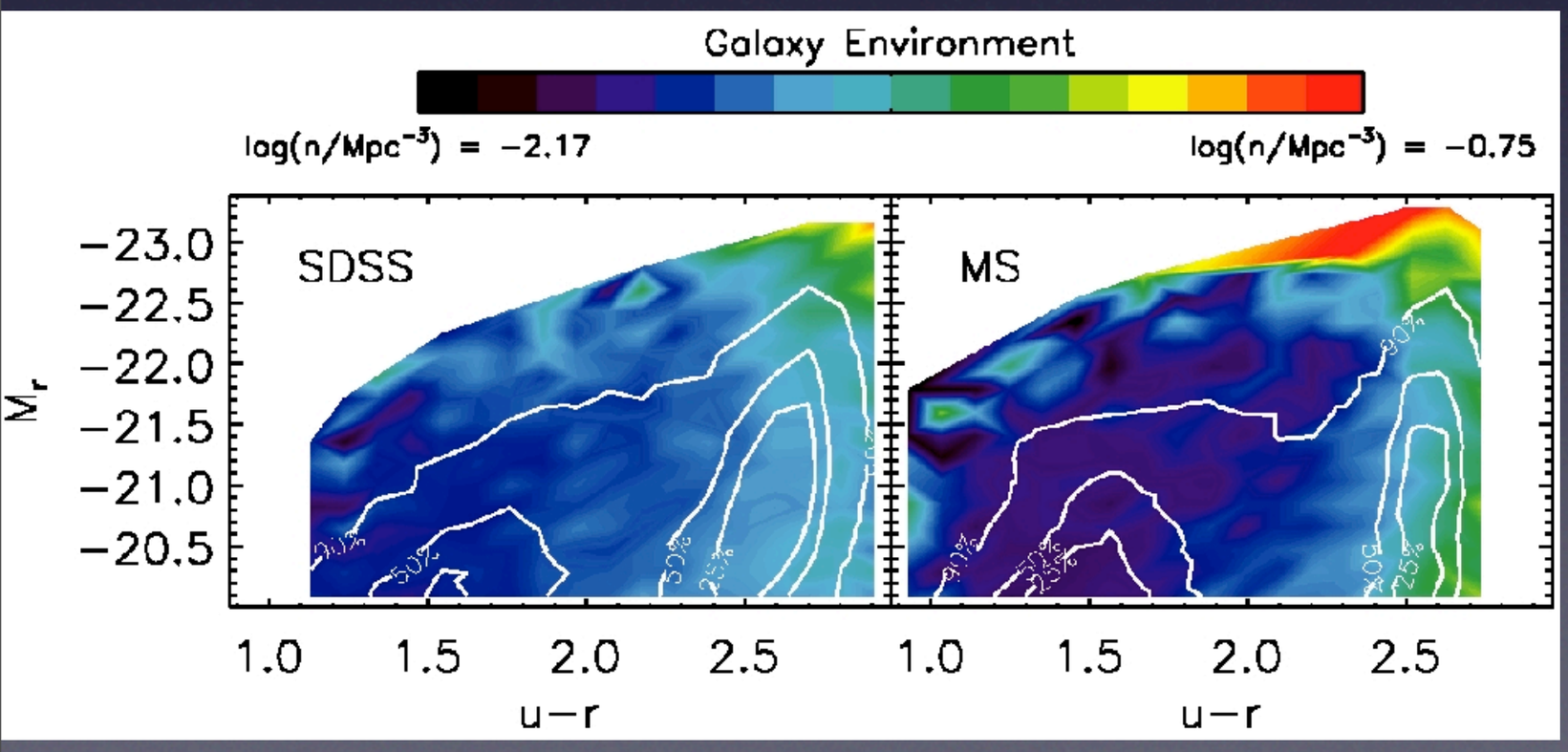
Cosmology with LSST

- Derived from 4 billion galaxies (i<25.3, SNR>20) with accurate photo-z and shape measurements
- Measuring distances and growth of structure with a percent accuracy for $0.5 < z < 3$
- SNe will provide a high angular resolution probe of homogeneity and isotropy of the Universe

Extragalactic astronomy: galaxies



- About 10 billion galaxies, with 4 billion in a "gold" sample defined by i<25.3
- The "gold" sample extends to redshifts of >2.5: **evolution**

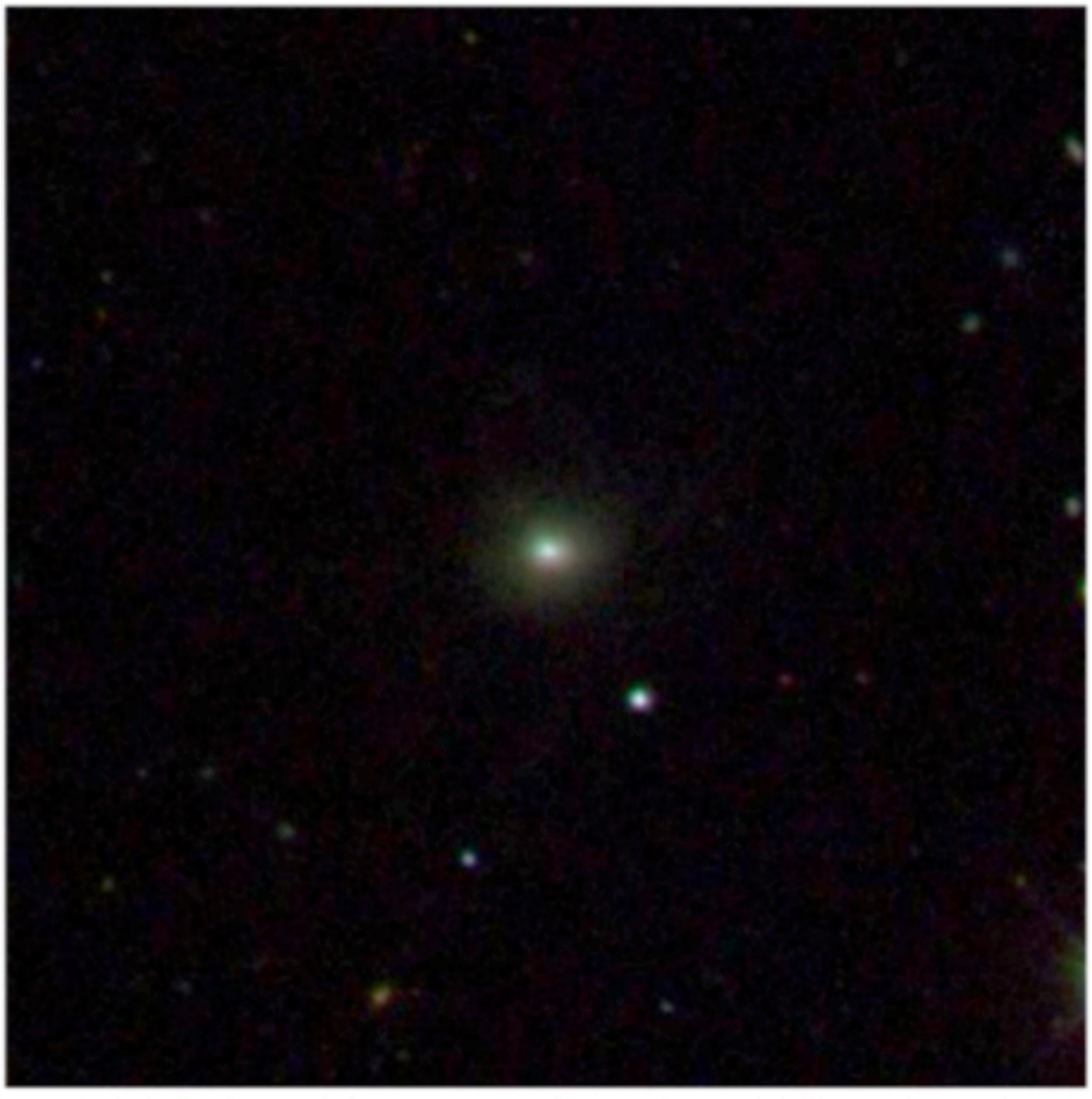


SDSS: snapshot at z~0

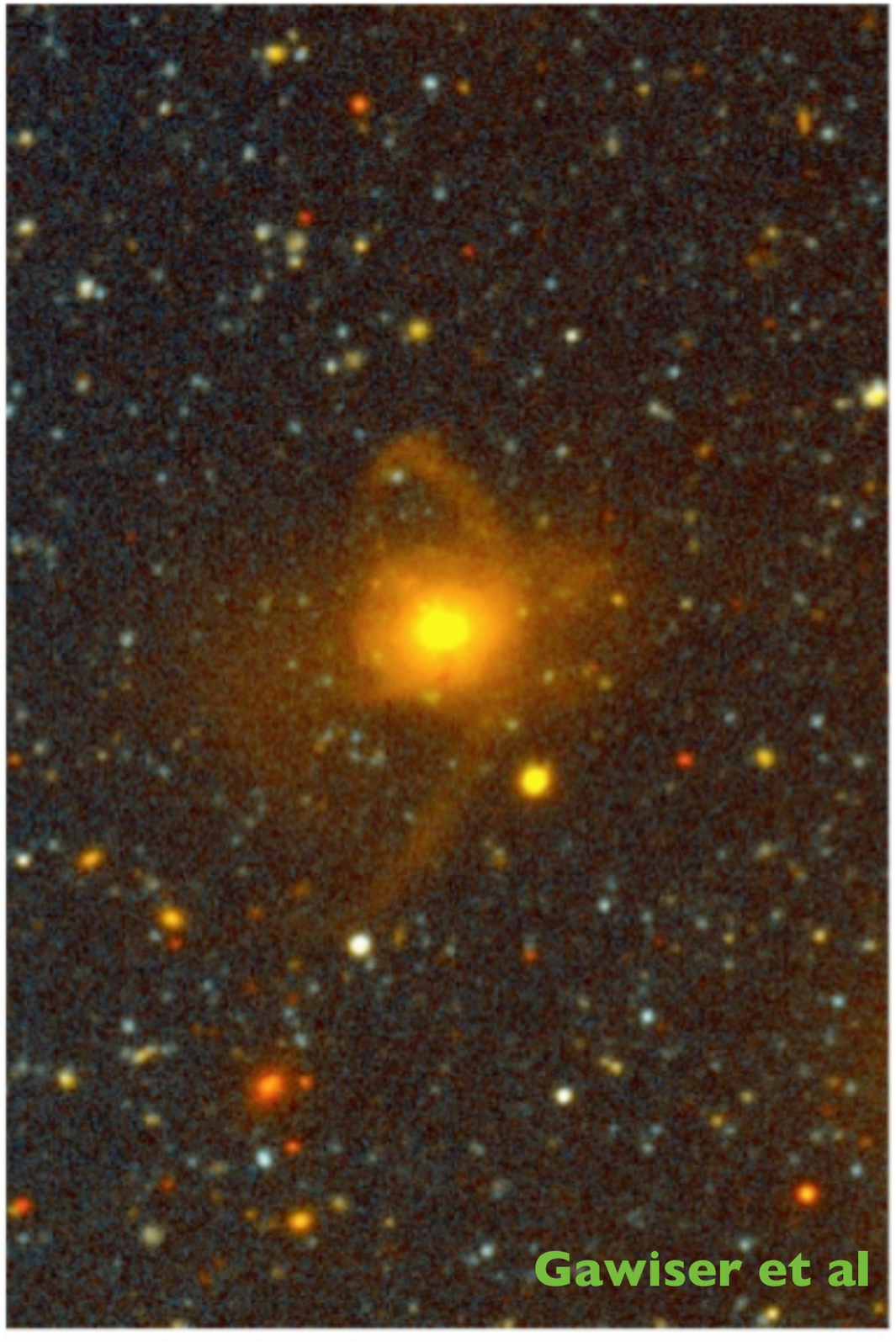
LSST:
a galaxy evolution movie to z~2.5

Extragalactic astronomy: galaxies

SDSS

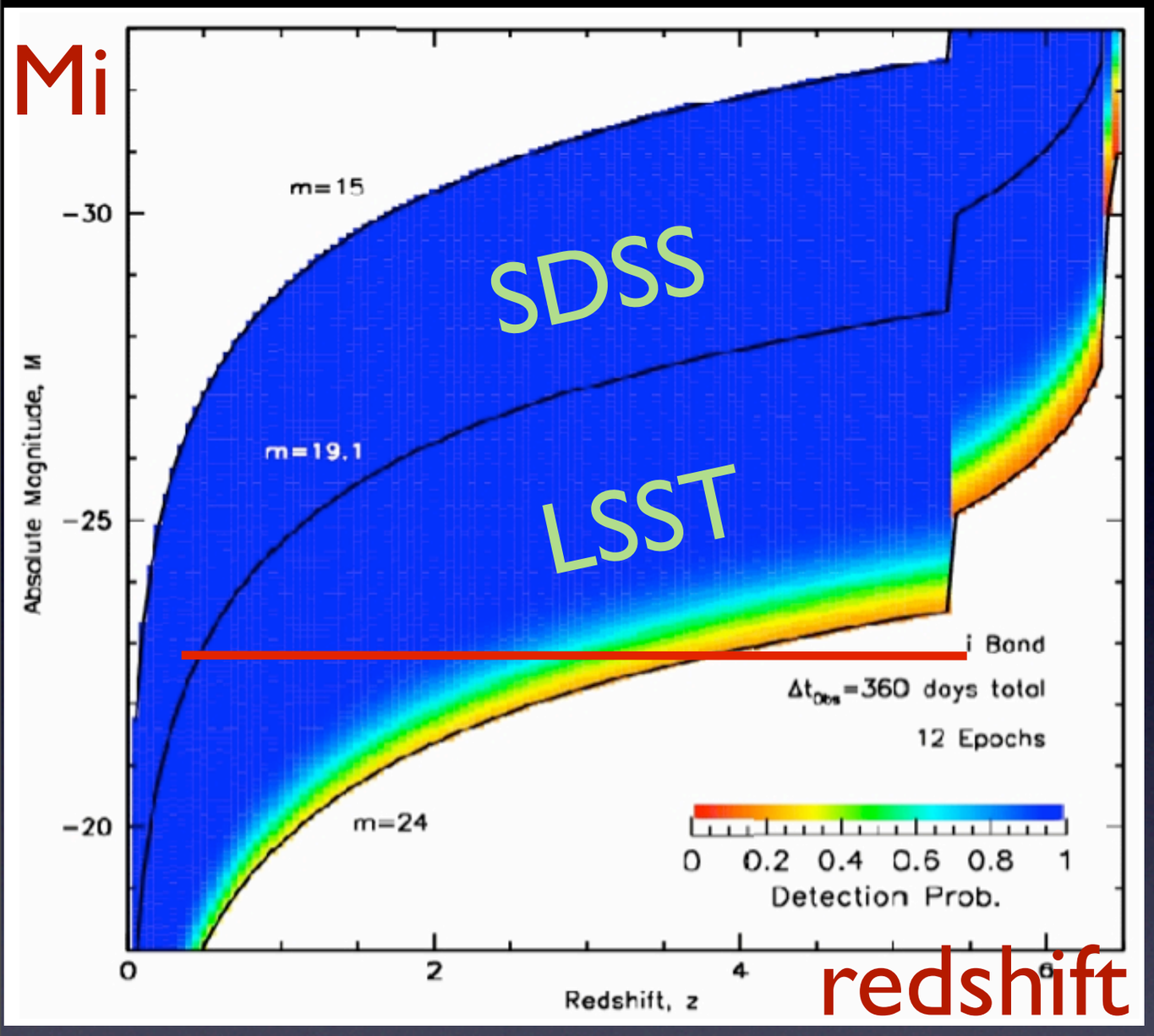


MUSYC



Gawiser et al

Extragalactic astronomy: quasars

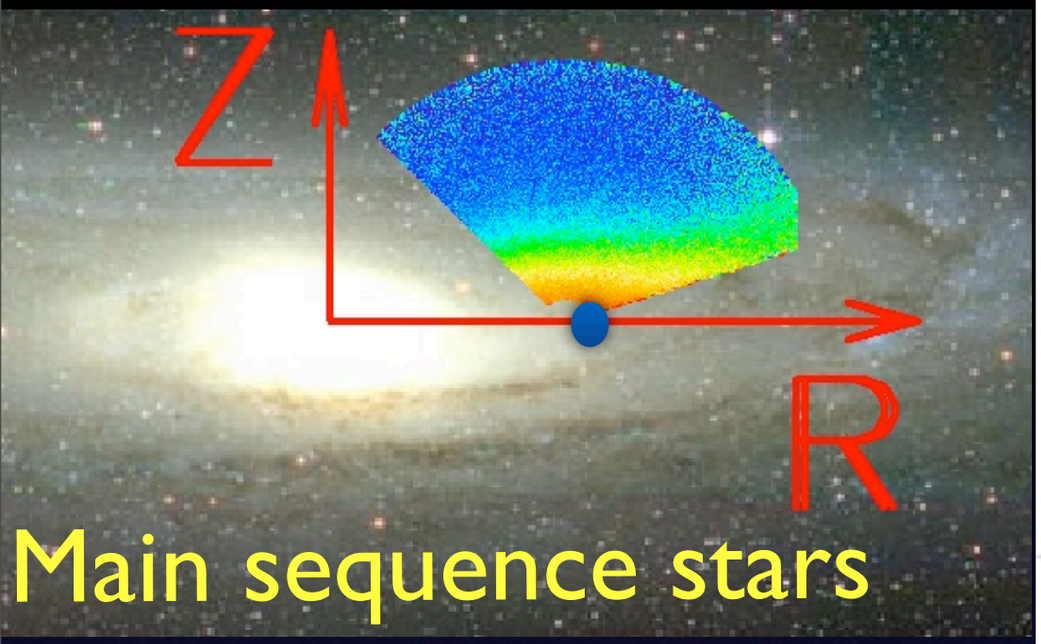


- About 10 million quasars will be discovered using variability, colors, and the lack of proper motions
- The sample will include Mi=-23 objects even at redshifts beyond 3
- Quasar variability studies will be based on millions of light curves with 1000 observations over 10 yrs

Top: absolute magnitude vs. redshift diagram for quasars

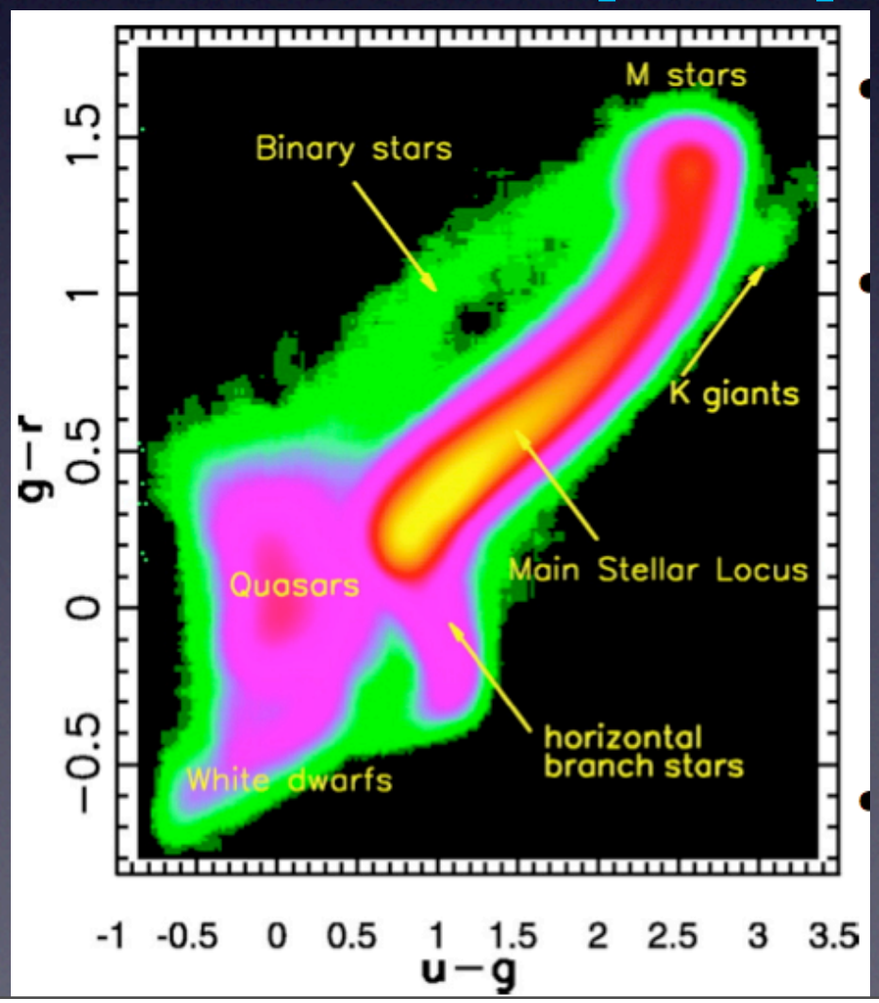
LSST will detect ~10,000 quasars with 6<z<7.5

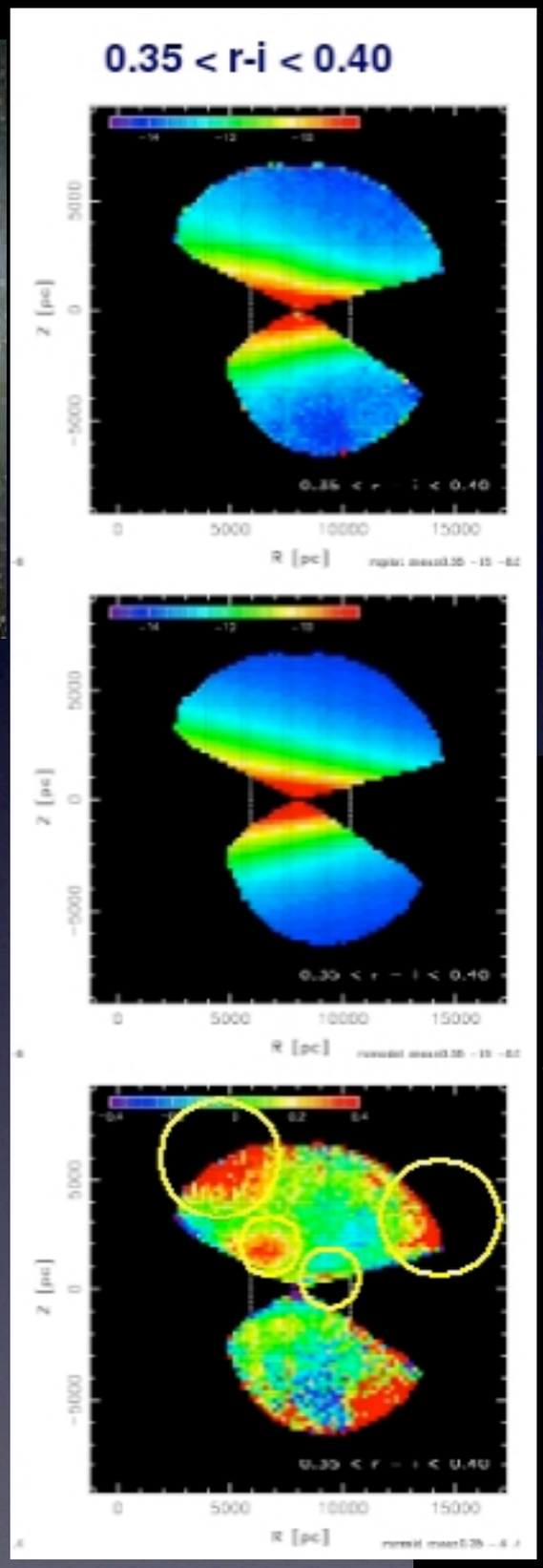
The Milky Way structure: 10 billion stars, time domain



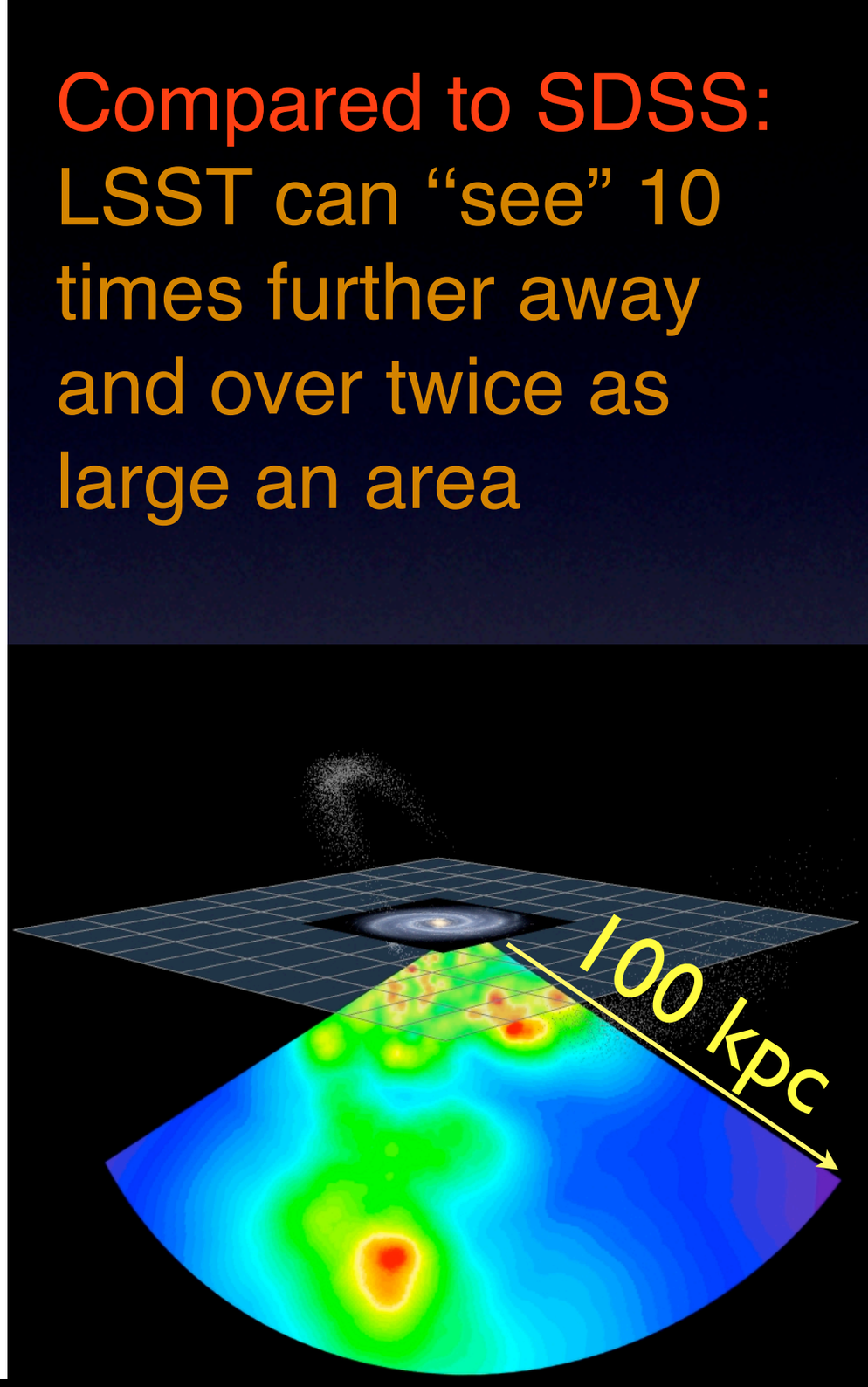
Main sequence stars

Distance and [Fe/H]:





Compared to SDSS: LSST can “see” 10 times further away and over twice as large an area



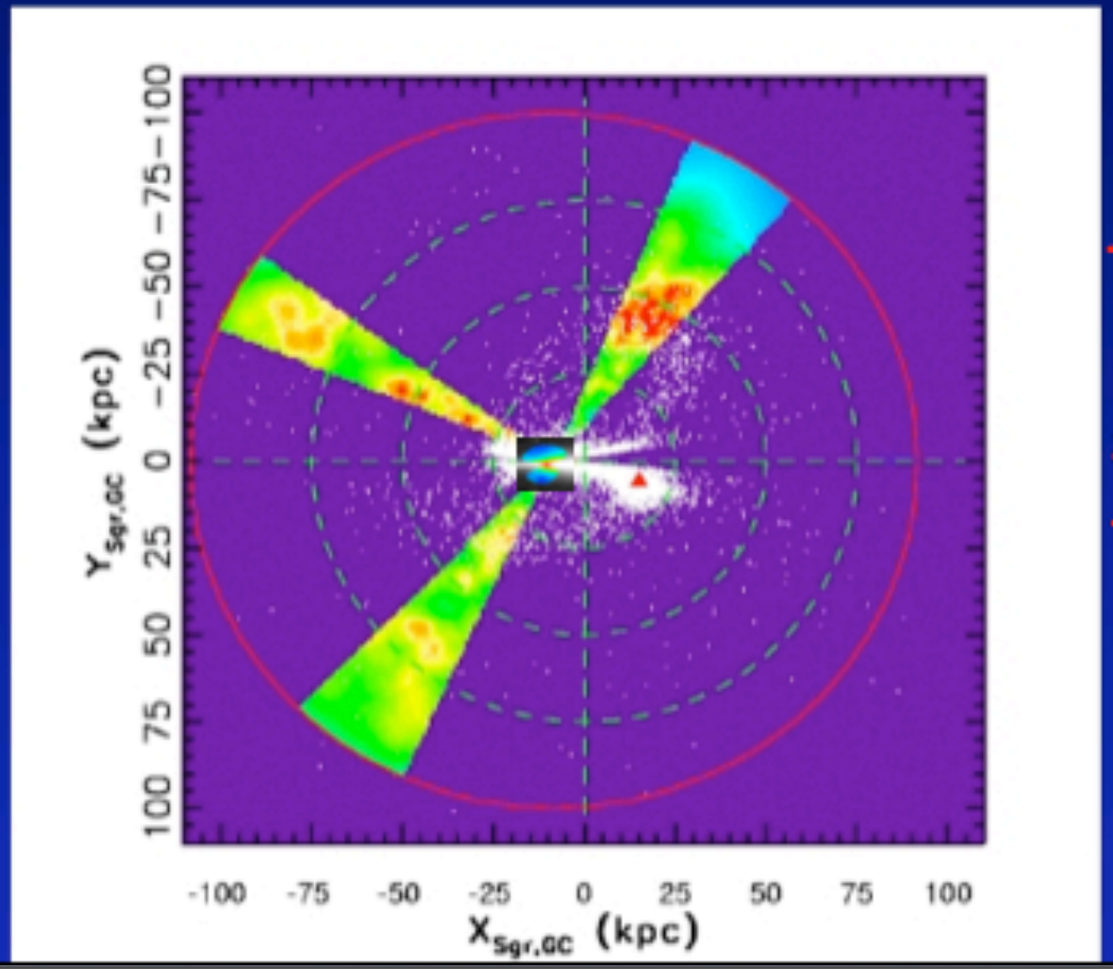
Sesar et al. (2009)

SDSS RR Lyrae

The large blue circle: the ~400 kpc limit of future LSST studies based on RR Lyrae

LSST limit for RR Lyrae: 400 kpc

The large red circle: the ~100 kpc limit of future LSST studies based on main-sequence stars (and the current limit for RR Lyrae studies)



The small insert: ~10 kpc limit of SDSS and future Gaia studies for kinematic & $[Fe/H]$ mapping with MS stars

Time Domain: objects changing in time

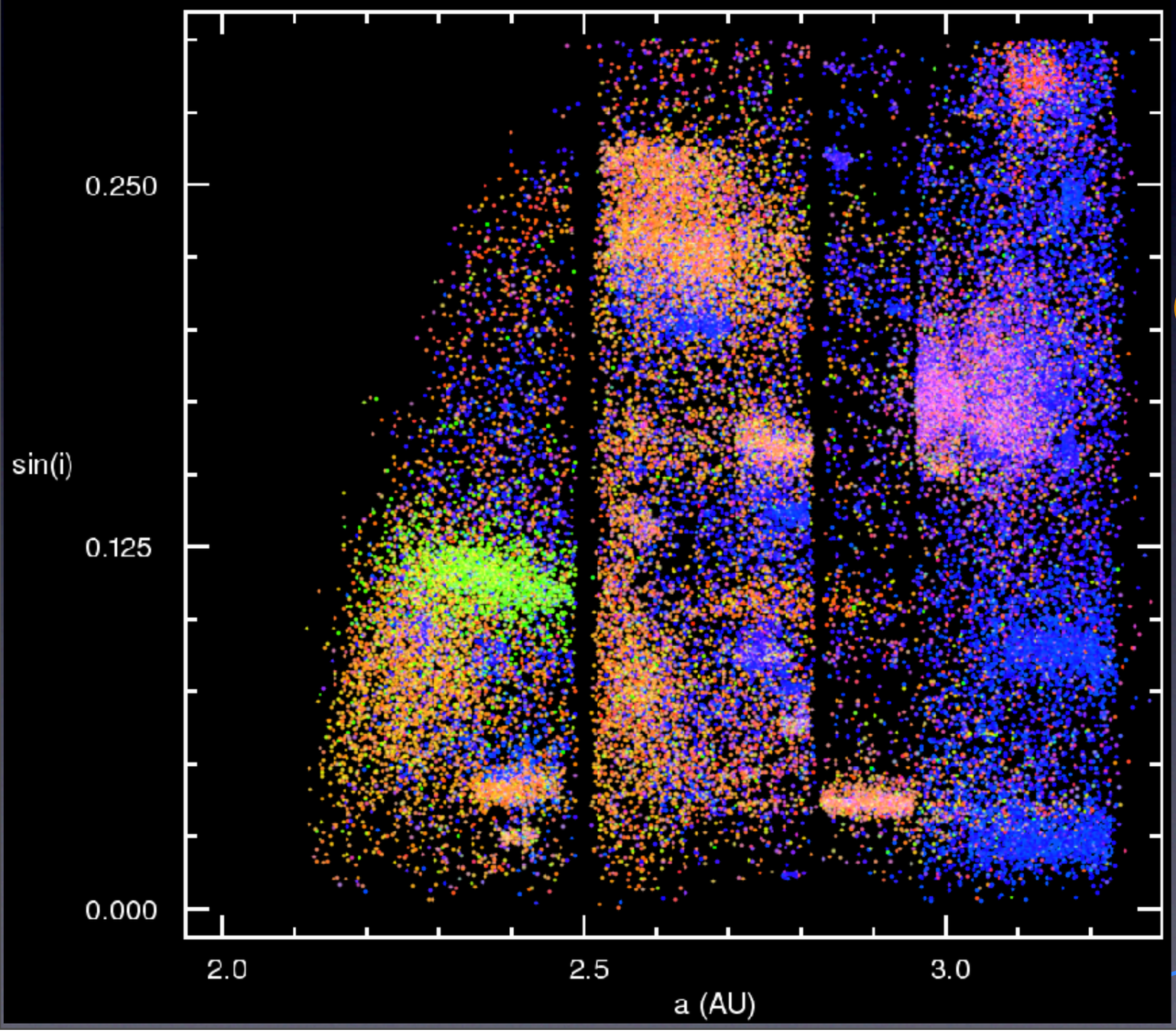
positions: asteroids and stellar proper motions

brightness: cosmic explosions and variable stars

Time Domain: objects changing in time

positions: asteroids and stellar proper motions

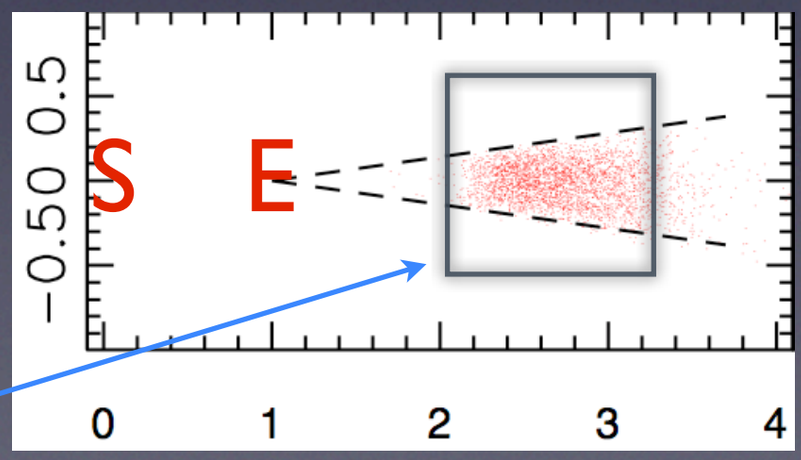
brightness: cosmic explosions and variable stars



For example:

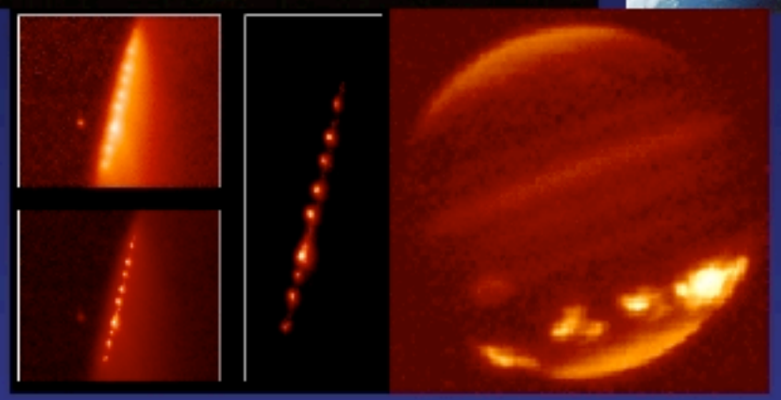
SDSS demonstrated that asteroid families have distinct colors: chemical composition

LSST will turn this diagram into a movie (millions of asteroids)



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 Congressional NEO mandate to NASA (to find 90% NEOs larger than 140m)

photomontage!

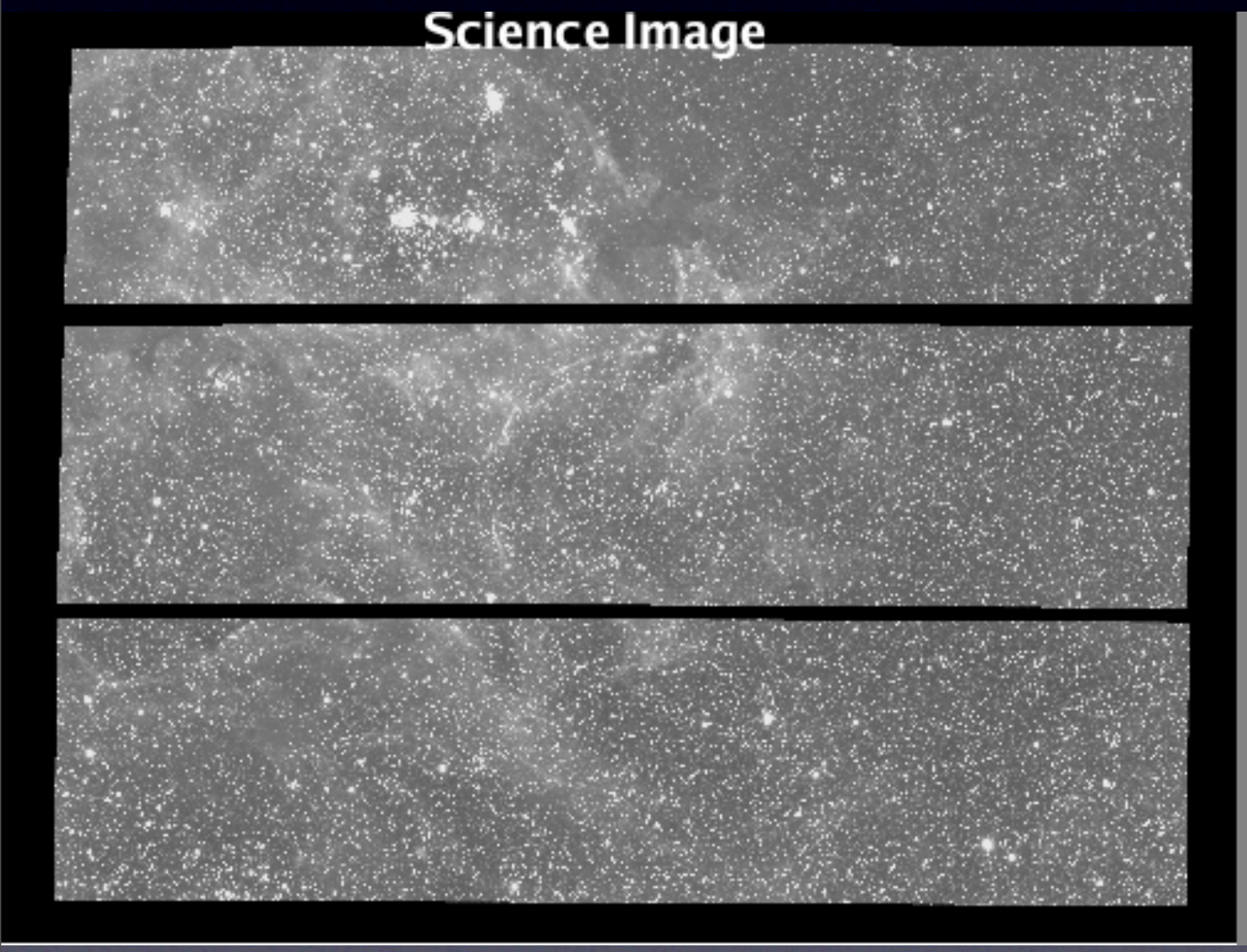
The Barringer Crater, Arizona: a 40m object 50,000 yr. ago

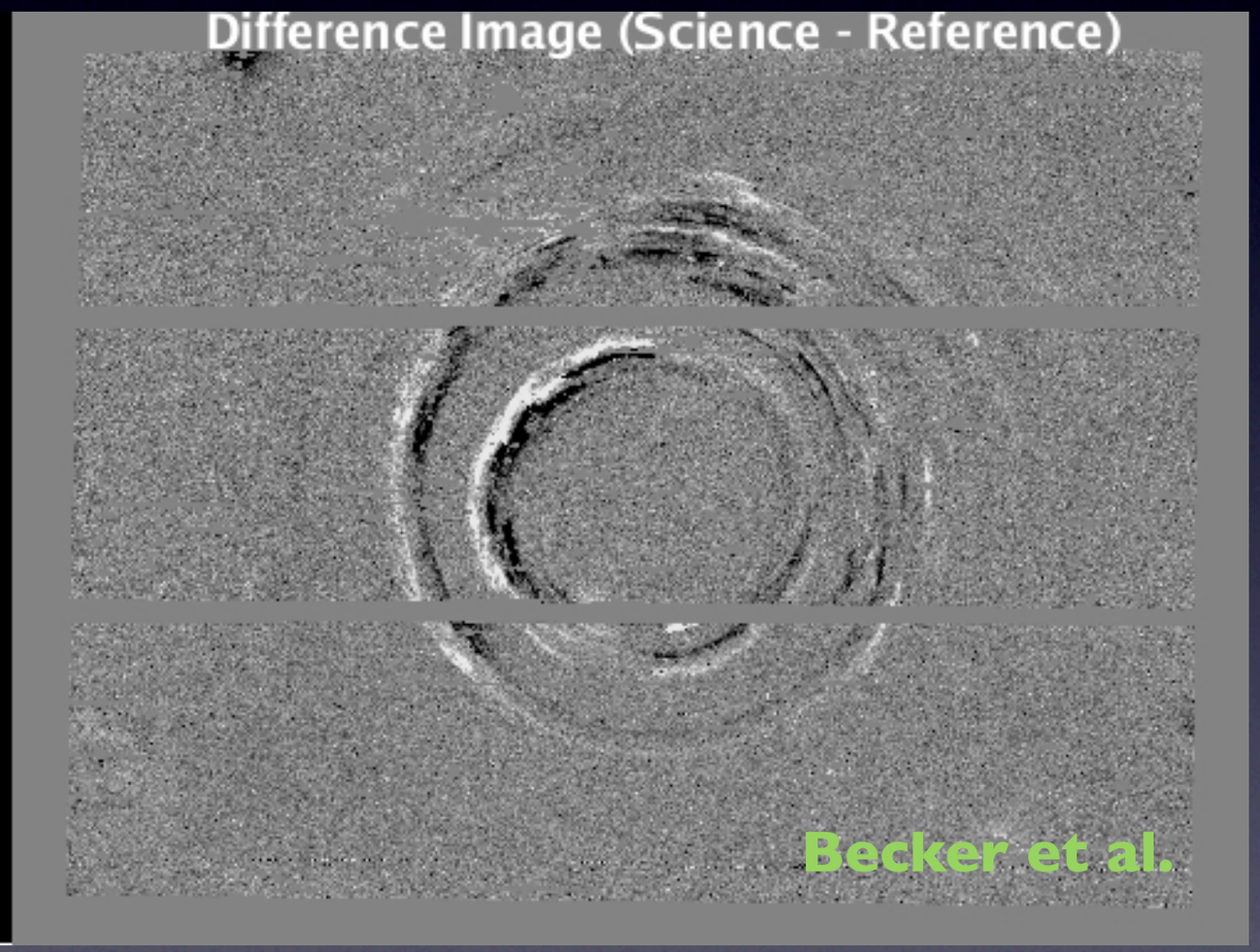
Time Domain: objects changing in time

positions: asteroids and stellar proper motions

brightness: cosmic explosions and variable stars

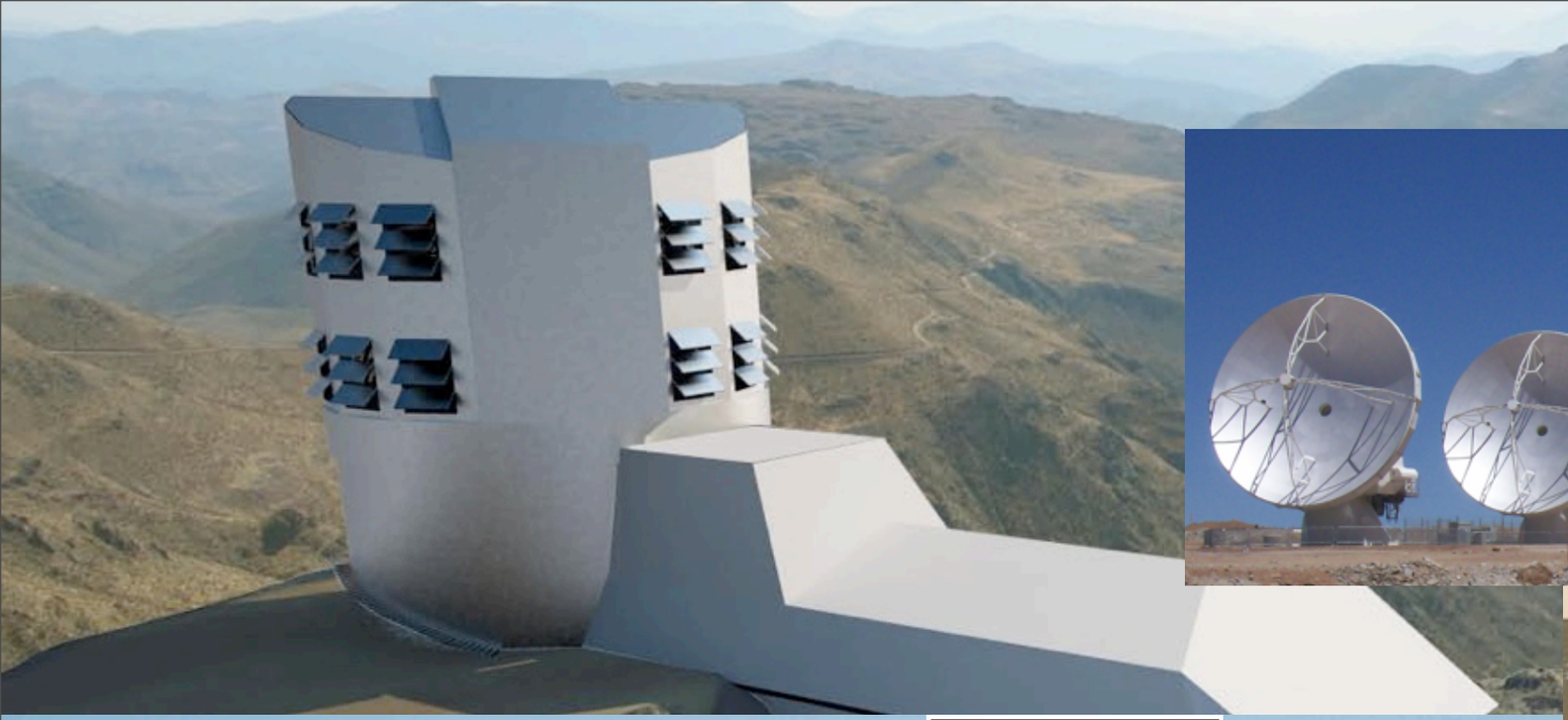
Not only point sources - echo of a supernova explosion:





As many variable stars from LSST, as **all** stars from SDSS

Web stream with data for transients within 60 seconds



Expanded
Very Large Array

The impact of LSST on other wavelengths, and vice versa:

1) Science Results (e.g. galaxy/AGN evolution)
2) Tools and Methods (e.g. massive databases [radio])
3) Supplemental data (coeval, identification, physical processes)

Also non-EM: e.g. Advanced LIGO

Outline

- **LSST system summary**
  - Science Themes
  - System Characteristics
- **LSST science examples**
  - Extragalactic astronomy and cosmology
  - The Milky Way and the Local Group
  - Time Domain
- **Opportunities for collaboration**
  - Construction
  - Operations
  - Science Collaborations

Decadal Survey 2010

Priorities:

- Spaced-based:

1) *Wide-Field Infrared Survey Telescope WFIRST*
2) *The Explorer Program "rapid response"*
3) *Laser Interferometer Space Antenna LISA*
4) *International X-ray Observatory IXO*

- Ground-based:

1) *Large Synoptic Survey Telescope LSST*

2) *Mid-scale Innovations Program "rapid response"*
3) *Giant Segmented Mirror Telescope (30m) GSMT*
4) *Atmospheric Čerenkov Telescope Array (Y) ACTA*
5) *Cerro Chajnantor Atacama Telescope (submm) CCAT*

Decadal Survey 2010

- **Why LSST?**

The top rank accorded to LSST is a result of:

(1) "its **compelling science case** and capacity to address so many of the science goals of this survey", [and]

(2) "**its readiness** for submission to the MREFC process as informed by its technical maturity, the survey's assessment of risk, and appraised construction and operations costs."

Also: "education and public outreach"

Bill Gates: "LSST will be the ultimate network peripheral device to the Universe"

Google Sky, World Wide Telescope, ...

Decadal Survey 2010

- **Why LSST?**

The top rank accorded to LSST is a result of:

(1) "its compelling science case and capacity to address so many of the science goals of this survey", [and]

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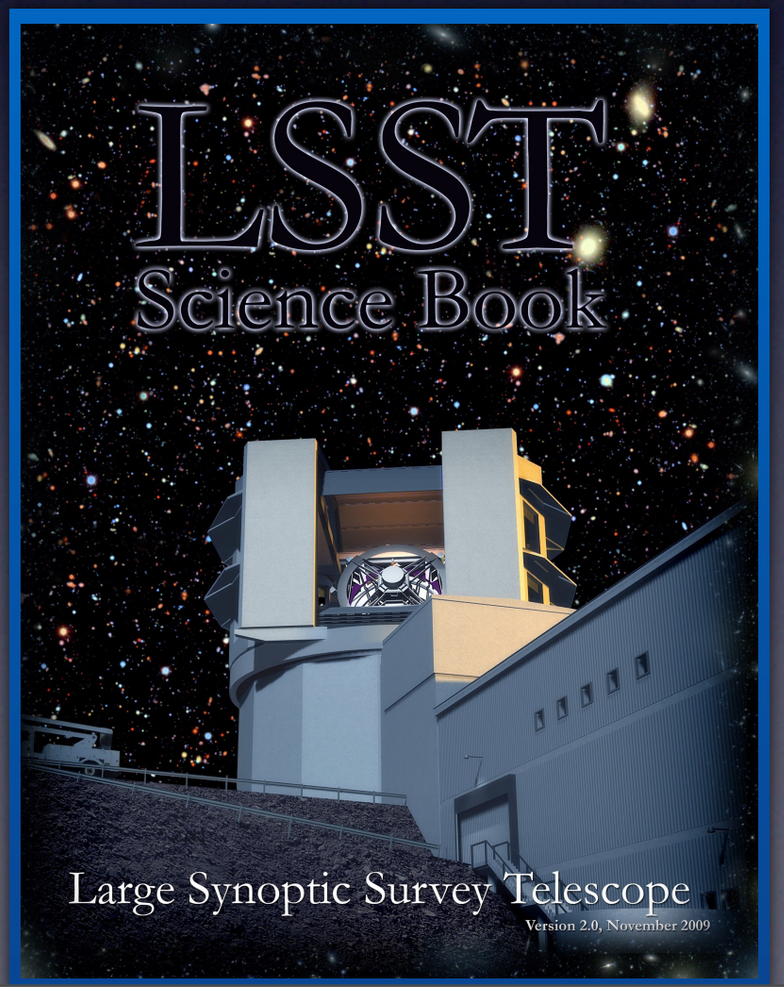
Also: "education and public outreach"

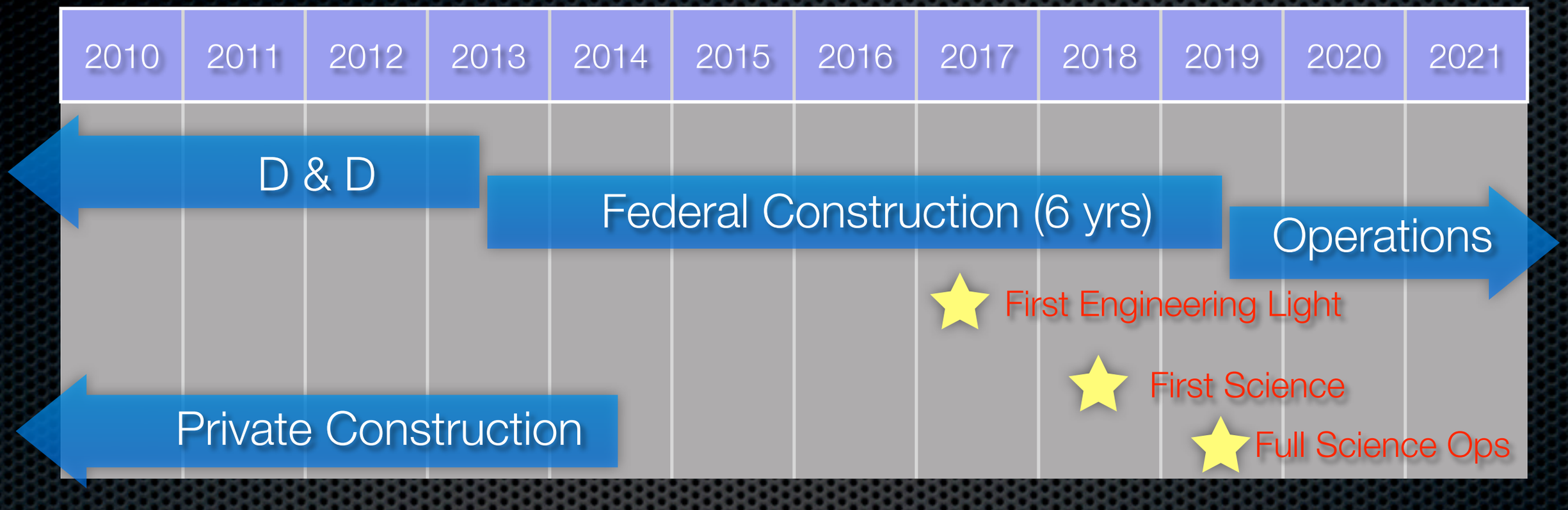
LSST Science Book

Summarizes the basic parameters of the LSST hardware, software, and observing plans, discusses educational and outreach opportunities, and describes a broad range of science that LSST will revolutionize

245 authors, 15 chapters, 600 pages



LSST Timeline

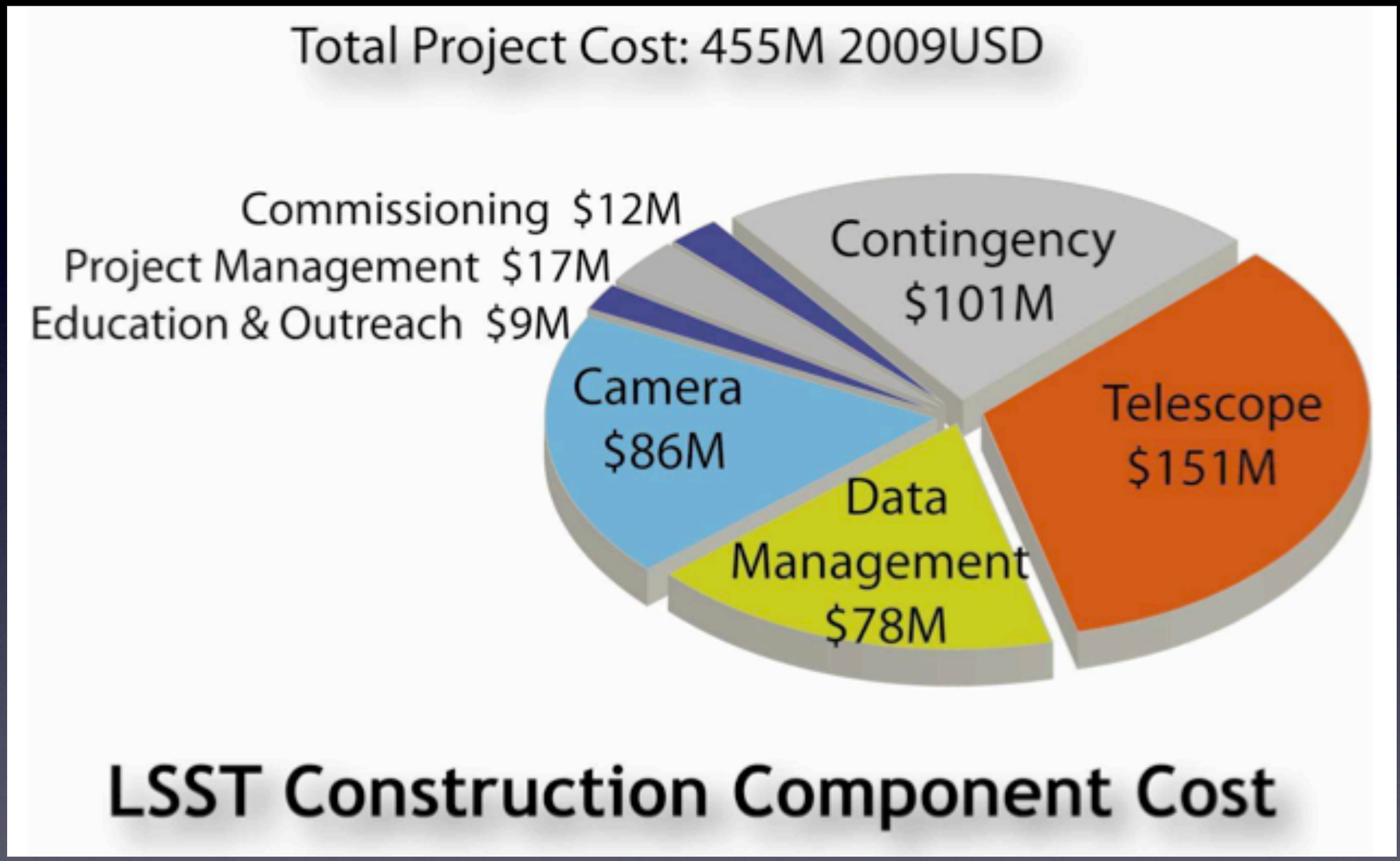


- **Estimate: survey operations begin in 2019 (if MREFC in FY2014)**
  - Primary/Tertiary Mirror being polished, have secondary mirror blank
  - Sensor development program delivered first prototype sensors
  - Processing pipelines under construction, hand-in-hand with simulations of Operations, Images, Catalogs
- **Cost:** ~$850M in $2011

  contributions from NSF, DOE and private gifts

How to spend a billion dollars?

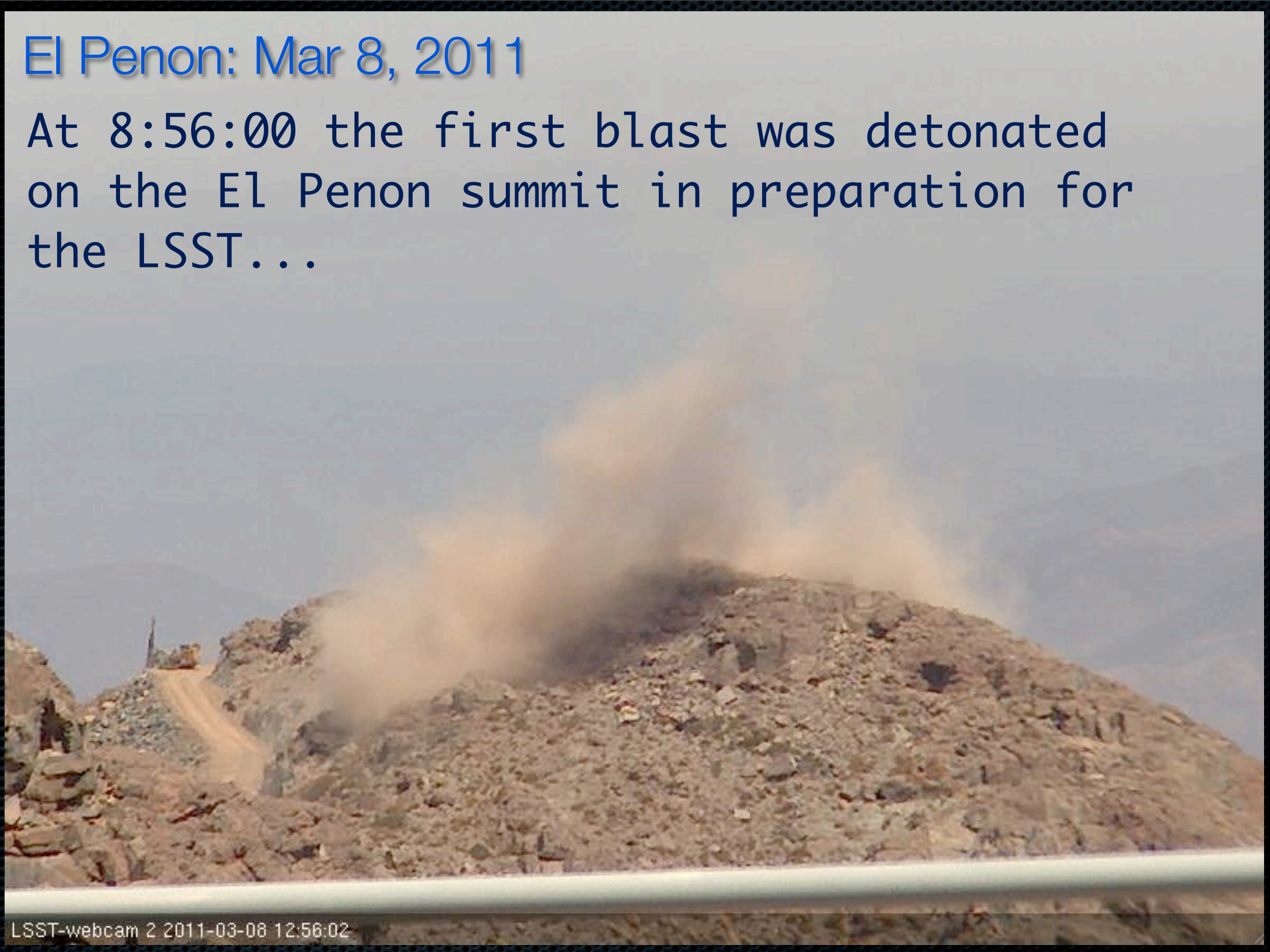
Half for construction, half for 10 years of operations



First light: around 2018 (if federal constr. in FY2014)

El Penon: Mar 8, 2011

At 8:56:00 the first blast was detonated on the El Penon summit in preparation for the LSST...



April 12, 2011

• Opportunities for collaboration

There is far more science to do than scientists to do it! Making the data available to the world (including the public) in a scientifically useful form is the best way to promote LSST science.

o Construction:

telescope, camera, data management: need per case arrangements (goal: cost reduction and WBS control)

o Operations: per DS2010, international participants should contribute with ~ $10M/yr (cumulative: 10% of the total survey cost); Estimated about 400-500 PIs

o Science Collaborations:

access to all LSST know-how: coordination with other groups, taking advantage of synergy and complementarity, an opportunity for small teams to participate in cutting-edge research

• Science Collaborations

o Science Collaborations are the main source of know-how and will undertake all the steps between delivering LSST data products and producing publishable science results

o Weak lensing (Bhuvnesh Jain and Dave Wittman)

o Strong lensing (Phil Marshall)

o Supernovae (Michael Wood-Vasey and Richard Kessler)

o Large-scale structure/BAO (Hu Zhan and Eric Gawiser)

o AGN (Niel Brandt)

o Galaxies (Harry Ferguson)

o Galactic structure (Beth Willman and Marla Geha)

o Stellar populations (Abi Saha and Kevin Covey)

o Variability & transients (Lucianne Walkowicz & Josh Bloom)

o Solar system (Lynne Jones and Michael Brown)

o Informatics and Statistics (Kirk Borne)

LSST All Hands Meeting at NCSA

List	Description
cameracontrol	discussion group for camera control
LSST-agn	LSST AGN
LSST-calibration	LSST system calibrations.
LSST-Calypso	Calypso Group
LSST-camera	LSST Camera
LSST-cameramgrs	LSST cameramgrs
LSST-camerasteer	LSST camerasteer
LSST-ChangeControlBoard	*[no description available]*
LSST-cosmology	Cosmology related work
LSST-data	LSST Data Management
LSST-datascience	LSST-DataScience
LSST-DeepDrill	*[no description available]*
Lsst-dm-db	*[no description available]*
Lsst-dmscientist	*[no description available]*
Lsst-epo-oab	EPO Outreach Advisory Board
LSST-FriendsOnly	Auto-enrollment
LSST-galaxies	LSST Galaxies
Lsst-galaxy-clusters	the mailing list for the galaxy clusters working group
Lsst-imagesim	LSST Image Simulation
LSST-ImSimData	ImSim Data Management for LSST.
LSST-lss	LSST LSS
LSST-ManagementMeetingAttendee	*[no description available]*
LSST-MembershipCommittee	*[no description available]*
LSST-milkyway	LSST Milkyway
LSST-Operations-Infrastructure	Computing Infrastructure for Operations (not DCs)
Lsst-opsim	Operations Simulator
LSST-PDR-Team	PDR Preparation Team
LSST-ProjectAndScience	Auto-enrollment
LSST-ProjectOnly	Everyone working on LSST project
LSST-sc	LSST Science Council Mailing List
LSST-science-working-group	LSST-Science-Working-Group
LSST-ScienceOnly	Everyone who is a member of a science collaboration
LSST-solarsystem	Solar system science collaboration
LSST-stellarpops	LSST Stellarpops
LSST-stronglens	LSST Strong Lensing Science Collaboration
LSST-supernovae	LSST Supernovae
LSST-Systems-Engineering	Systems Engineering Group

Science Collaborations

o Currently over 400 people are involved in one of the science collaborations.

o Membership is drawn from those working on LSST infrastructure and from LSST member institutions.

o Membership is more than “adding your name to the mailing list”; members are expected to contribute actively to the collaboration.

o Accomplishments: LSST Science Book, simulations, advocacy (meetings, papers), tools for data analysis, input to Data Management design and development

• Impact on Data Management

o LSST software effort is underway: development of data processing algorithms, database structures, etc.

o Input from scientists is needed at all stages: algorithm design/development, testing, definition of quantities to be measured, database design, etc.

o Science collaborations will have opportunity to run their own codes on LSST data using LSST infrastructure.

o Science collaborations will have an impact on commissioning and survey data taking

• Impact on Commissioning

o We will have two years from engineering first light to confirm that we meet our science requirements.

o Scientists will be involved in all stages of this commissioning period: planning the observations that will be carried out, analyzing the first data, and publishing results

o Carrying out scientific analyses with early data will be the best way to reveal possible subtle problems.

o Ultimately, carrying out scientific analyses with the full LSST dataset will not be trivial

Measuring galaxy shear: a subtle effect

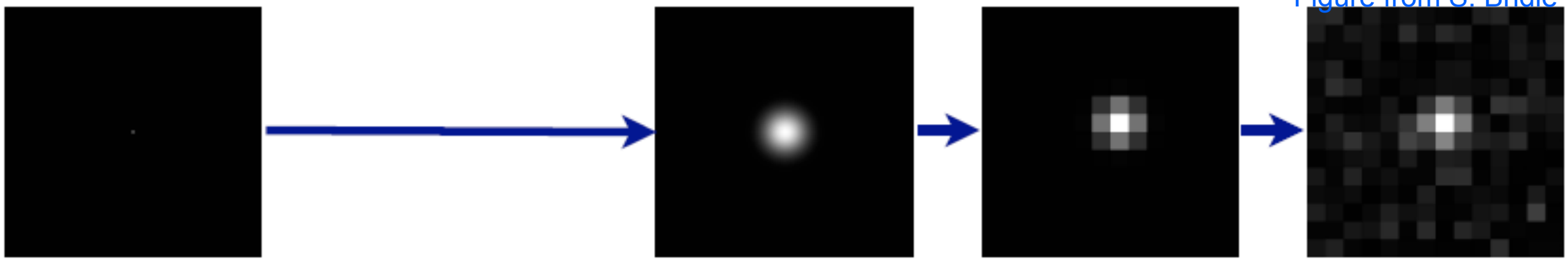
The Forward Process.

Galaxies: Intrinsic galaxy shapes to measured image:

Intrinsic galaxy (shape unknown) | Gravitational lensing causes a ***shear (g)*** | Atmosphere and telescope cause a convolution | Detectors measure a pixelated image | Image also contains noise

Stars: Point sources to star images:

Figure from S. Bridle



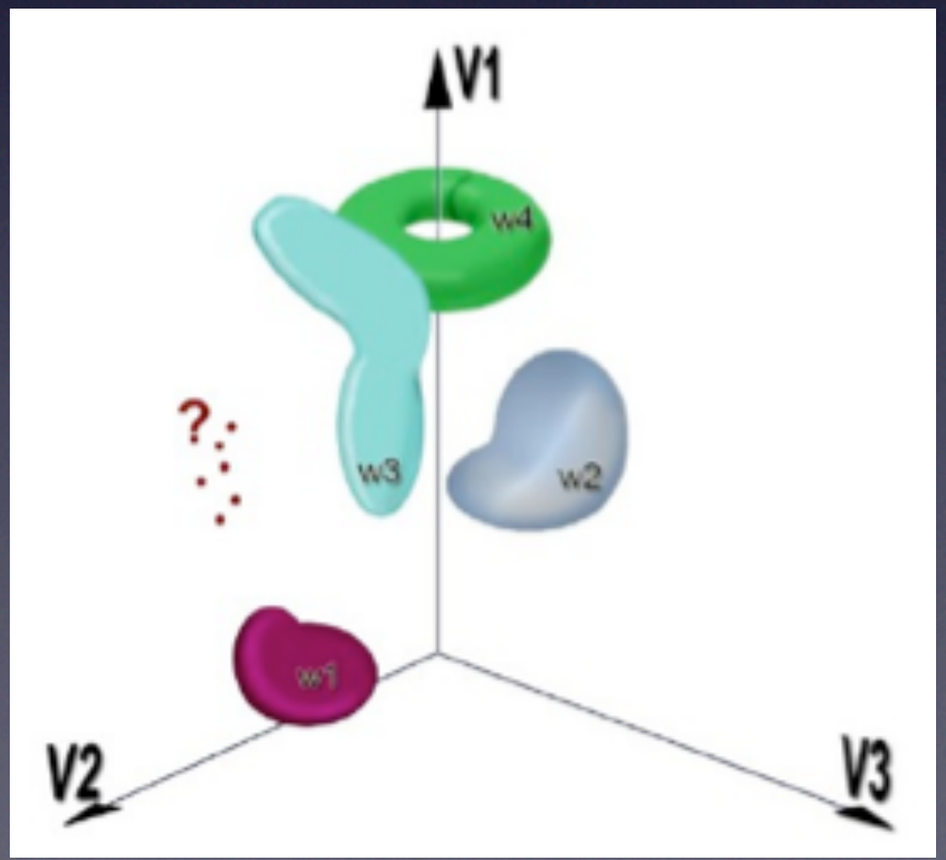
Intrinsic star (point source) | Atmosphere and telescope cause a convolution | Detectors measure a pixelated image | Image also contains noise

How should we measure shear, and how can we minimize and quantify systematic errors?

Statistical analysis of a massive LSST dataset

- A large (100 PB) database and sophisticated analysis tools: for each of 20 billion objects there will be about 1000 measurements (each with a few dozen measured parameters)

Data mining and knowledge discovery



- 10,000-D space with 20 billion points
- Characterization of known objects
- Classification of new populations
- Discoveries of unusual objects

Clustering, classification, outliers

● Where to go from here?

o The LSST Board of Directors will define how international partners (who sent LoIs: 63 institutions from 24 countries) can join LSST (hopefully later this year)

o The first steps will be signing MOUs and joining Science Collaborations (before then one can work on formulating research problems of interest, identifying funding sources, absorbing publicly avaialable information, planning training programs, etc.)

o Although 2018 might seem far into the future, it takes time to climb up the learning curve, to develop ideas into real analysis tools, and most importantly, to develop the next generation of scientists!

Useful LSST Links:

Main public website:
http://www.lsst.org/

Science Requirements Document:
http://www.lsst.org/files/docs/SRD.pdf

Overview paper:
http://www.lsst.org/files/docs/overviewV2.0.pdf

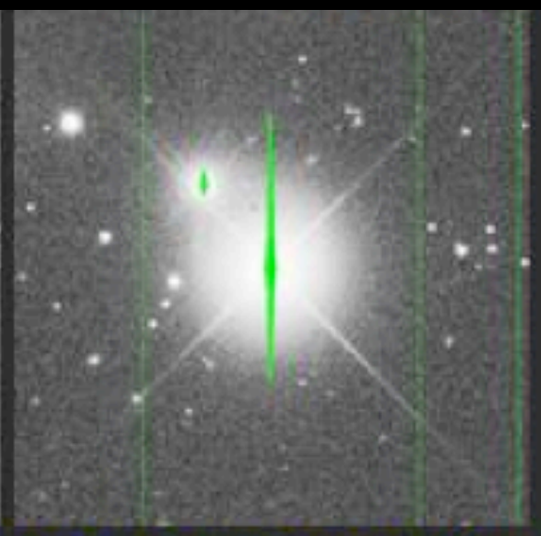
LSST Science Book:
http://www.lsst.org/lsst/scibook

Zeljko's e-mail: ivezic@astro.washington.edu

Backup slides

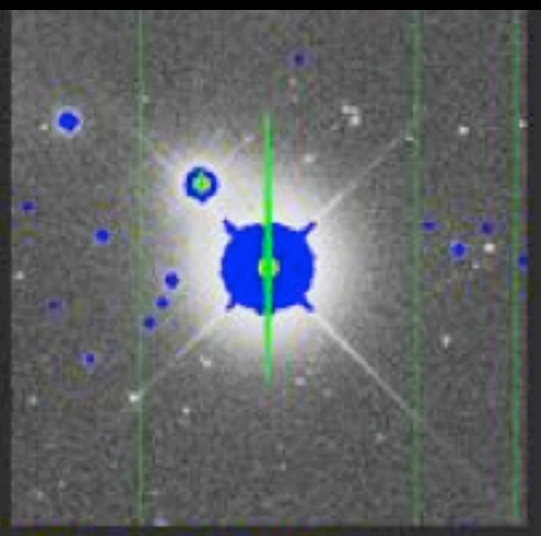
LSST imaging processing: an example

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

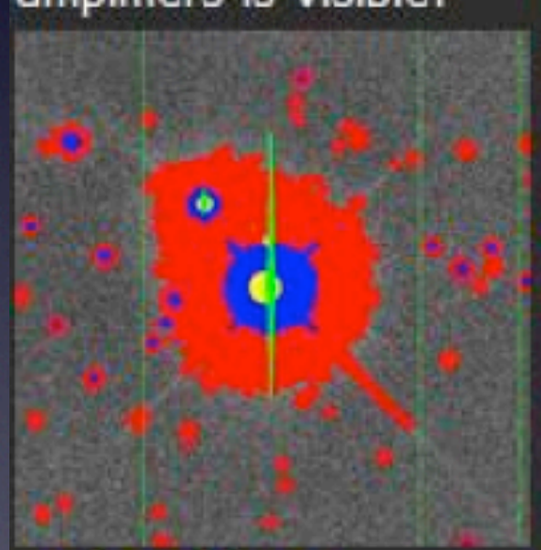


Bias-corrected frame with saturated pixels, bad columns, and cosmic rays masked in green.

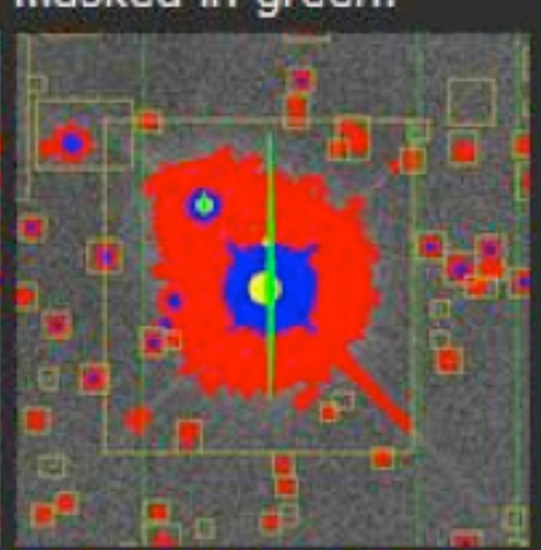
Frame corrected for saturated pixels, bad columns, and cosmic rays.



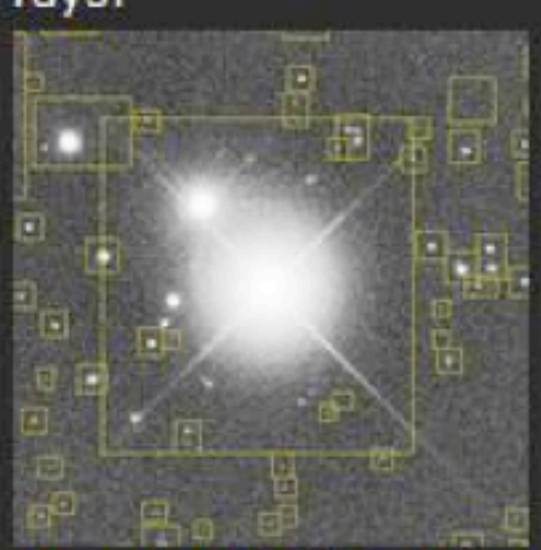
Bright object detections marked in blue.



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.

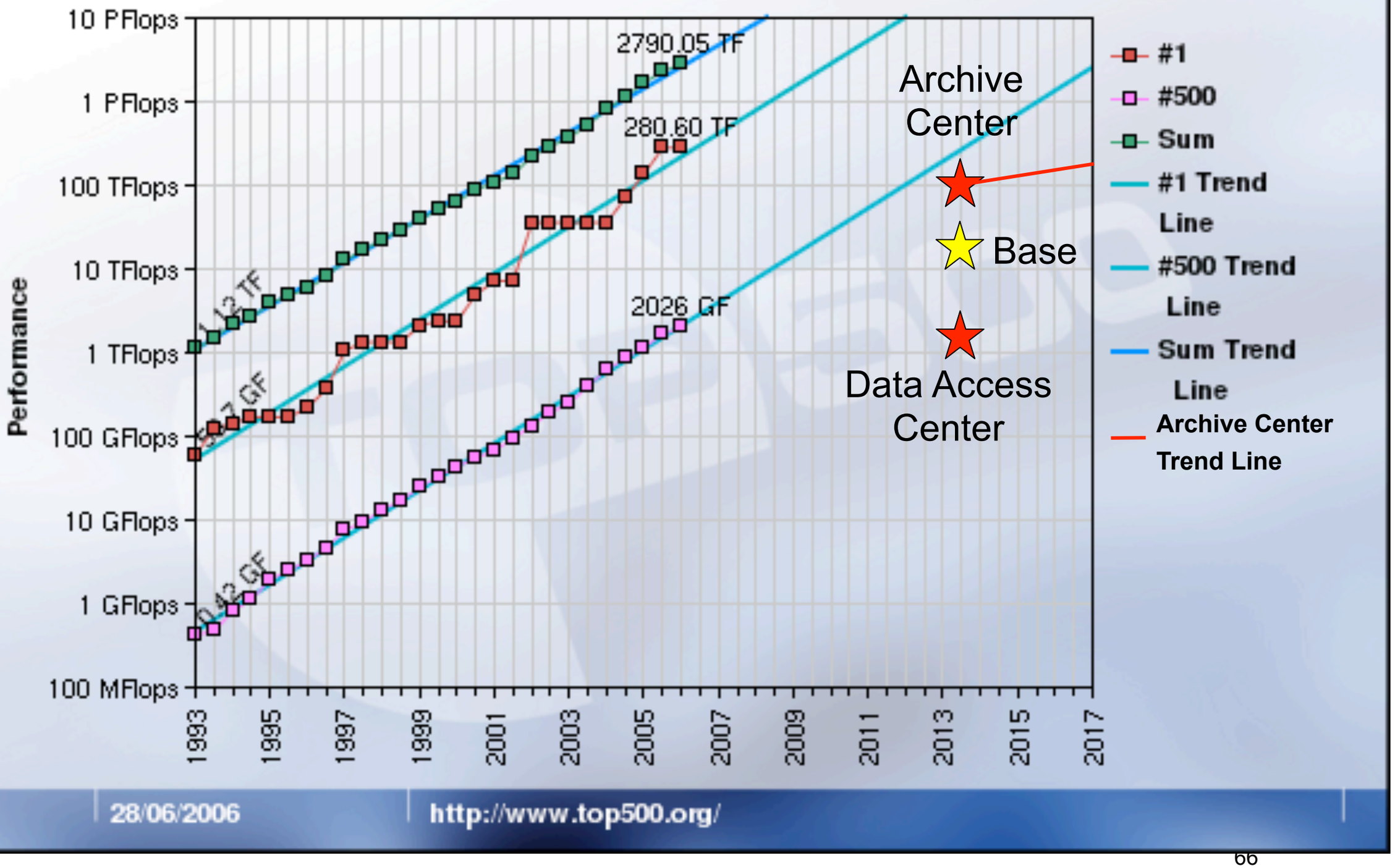
Reconstructed image using postage stamps of individual objects and sky background from binned image.

Why is LSST attractive to prospective students?

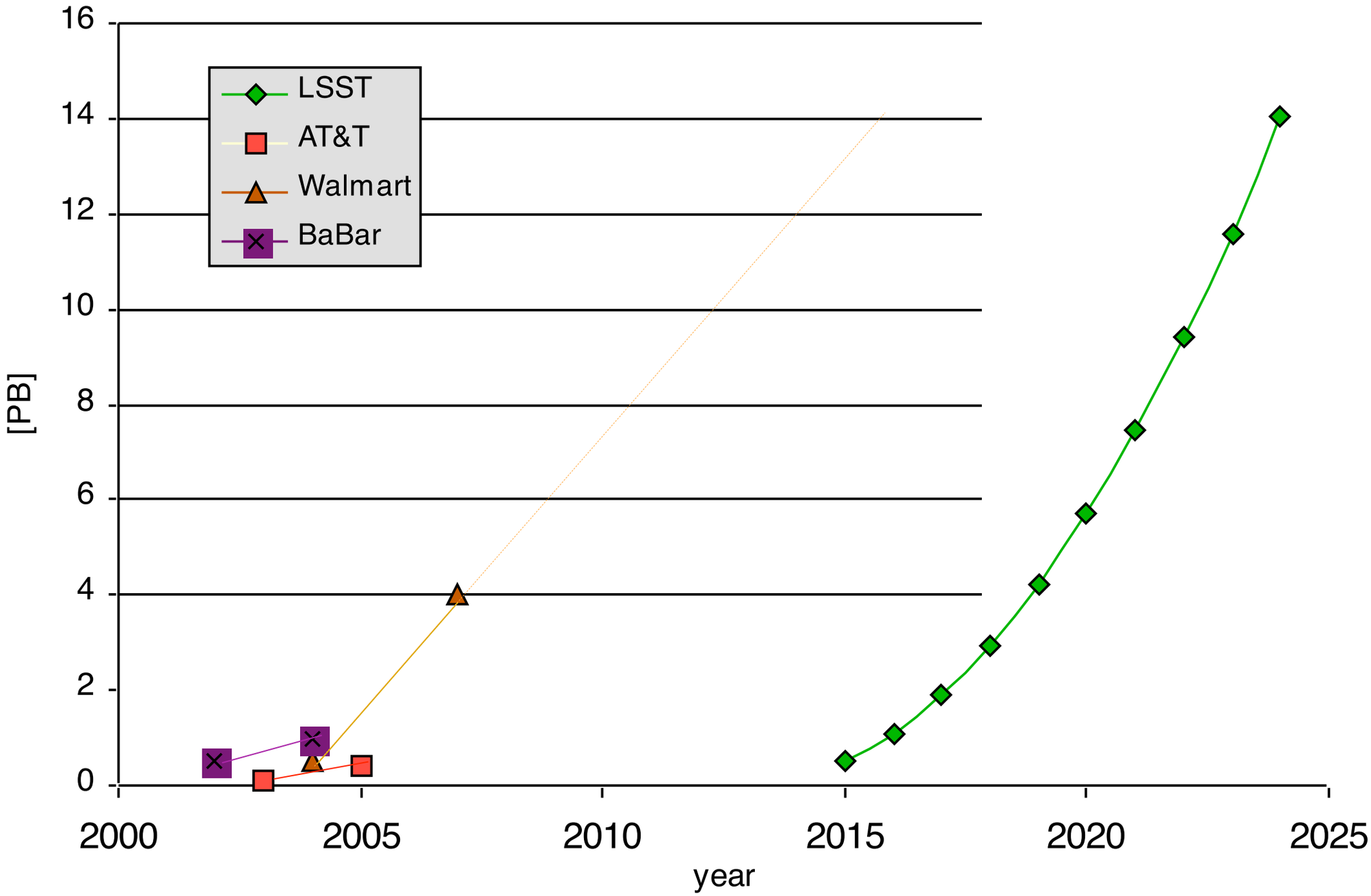
- Work with a unique astronomical dataset
  - developing familiarity with faint night sky
  - meeting digital technology
  - introduction to astrophysics (colors, ...)
- Technical knowledge is not astro-specific
  - work with large databases
  - data visualization (graphs, etc.)
  - statistics

Astronomy offers one of the most efficient methods for attracting students to STEM professions!

Computing needs show moderate growth



Large RDBMS Systems - Data Volumes



* *All numbers based on publicly available data*

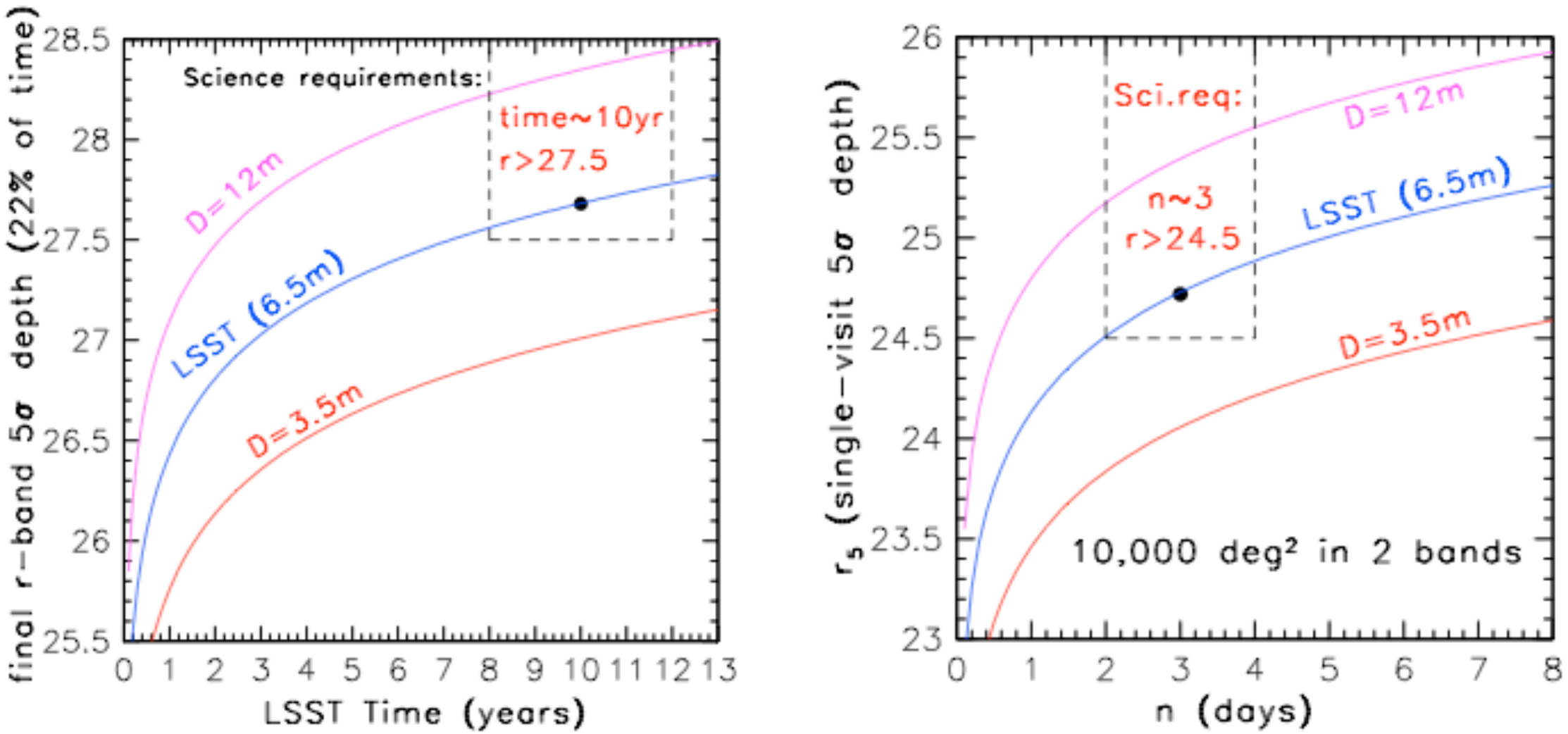
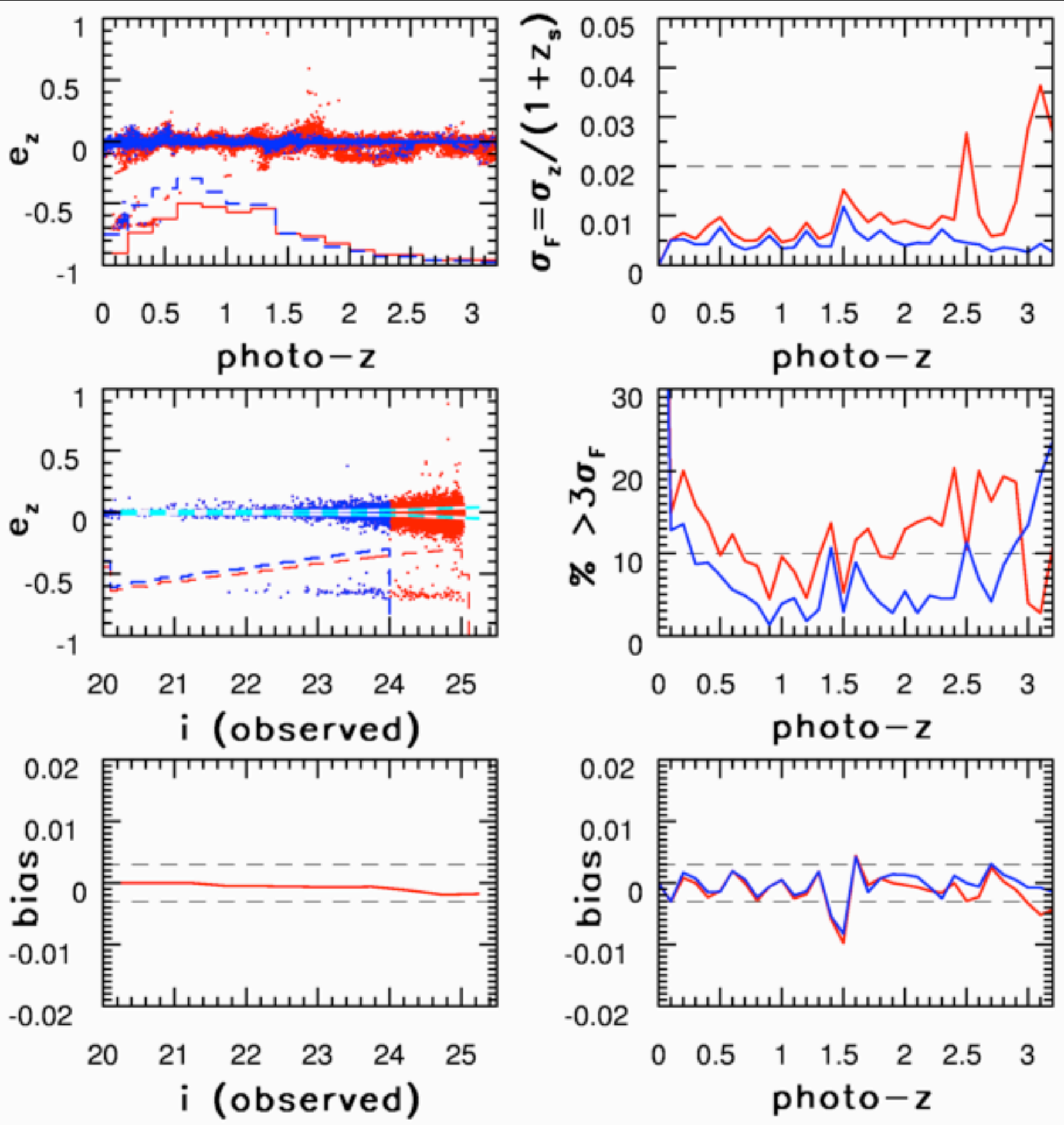
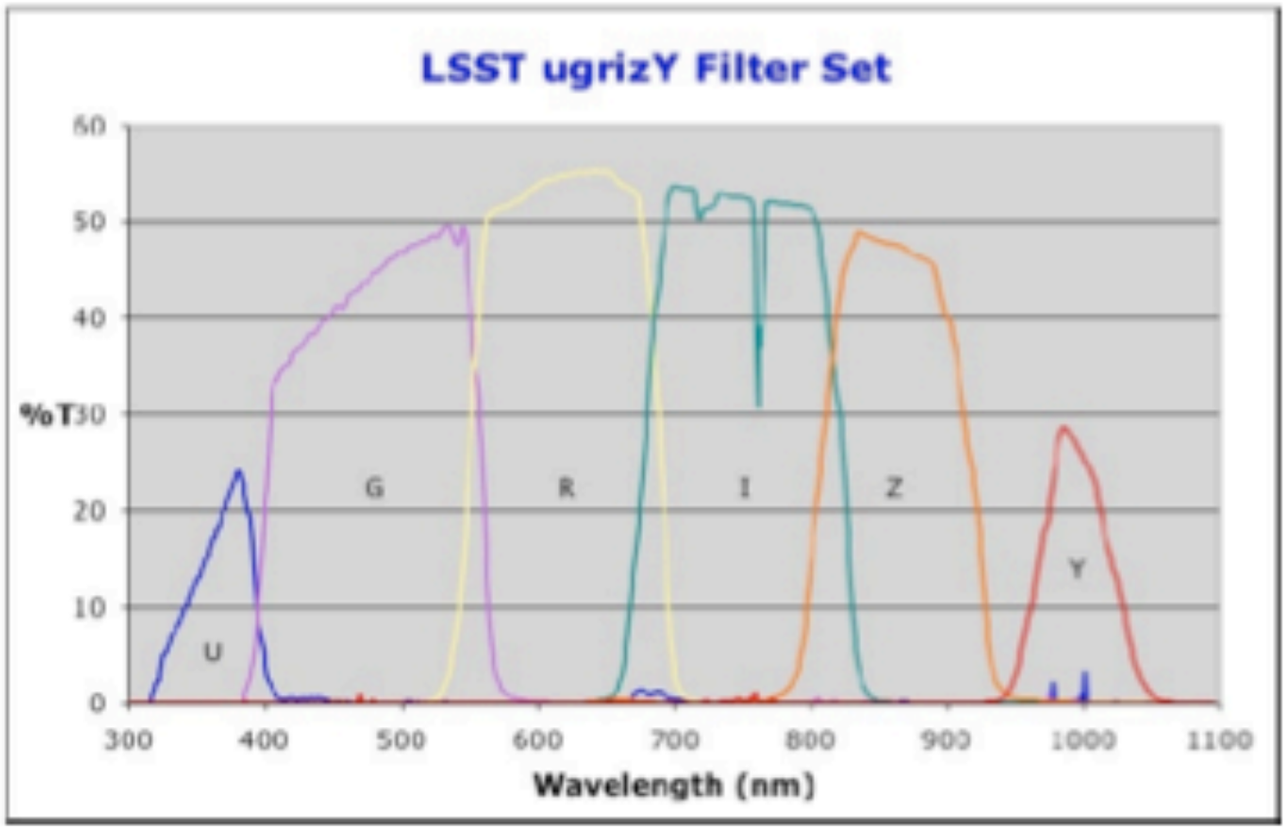
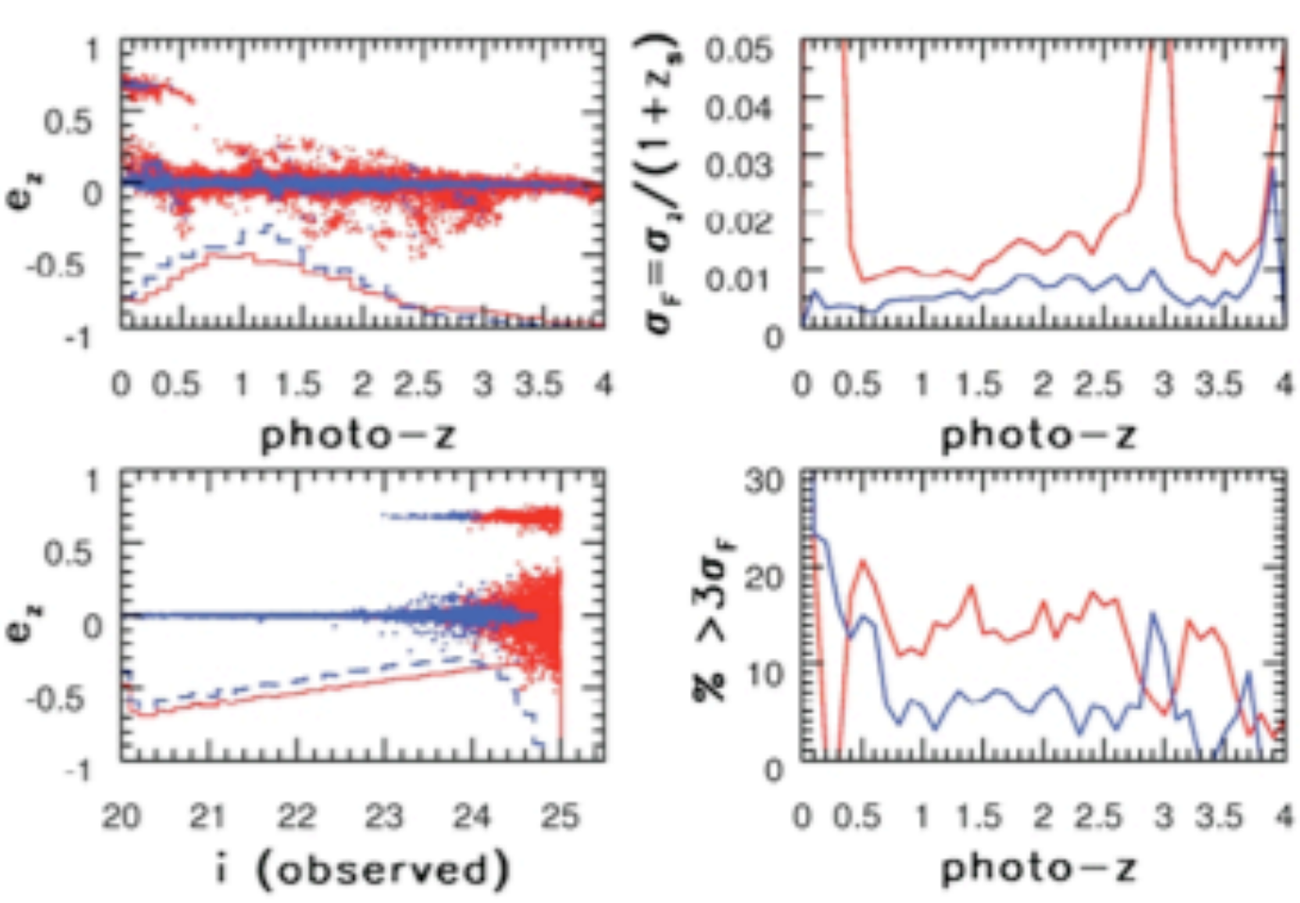


Figure 1.1: (a) The coadded depth in the r band (AB magnitudes) vs. the effective aperture and the survey lifetime. It is assumed that 22% of the total observing time (corrected for weather and other losses) is allocated for the r band, and that the ratio of the surveyed sky area to the field-of-view area is 2,000. (b) The single-visit depth in the r band (5σ detection for point sources, AB magnitudes) vs. revisit time, n (days), as a function of the effective aperture size. With a coverage of 10,000 deg^2 in two bands, the revisit time directly constrains the visit exposure time, $t_{vis} = 10n$ seconds; these numbers can be directly scaled to the 20,000 deg^2 and six filters of LSST. In addition to direct constraints on optimal exposure time, t_{vis} is also driven by requirements on the revisit time, n, the total number of visits per sky position over the survey lifetime, N_{visit}, and the survey efficiency, ϵ (see Equation 1.3). Note that these constraints result in a fairly narrow range of allowed t_{vis} for the main deep-wide-fast survey. From Ivezić et al. (2008).


e_z
photo−z
$\sigma_F=\sigma_z/(1+z_s)$
photo−z
e_z
i (observed)
% $>3\sigma_F$
photo−z
bias
i (observed)
bias
photo−z

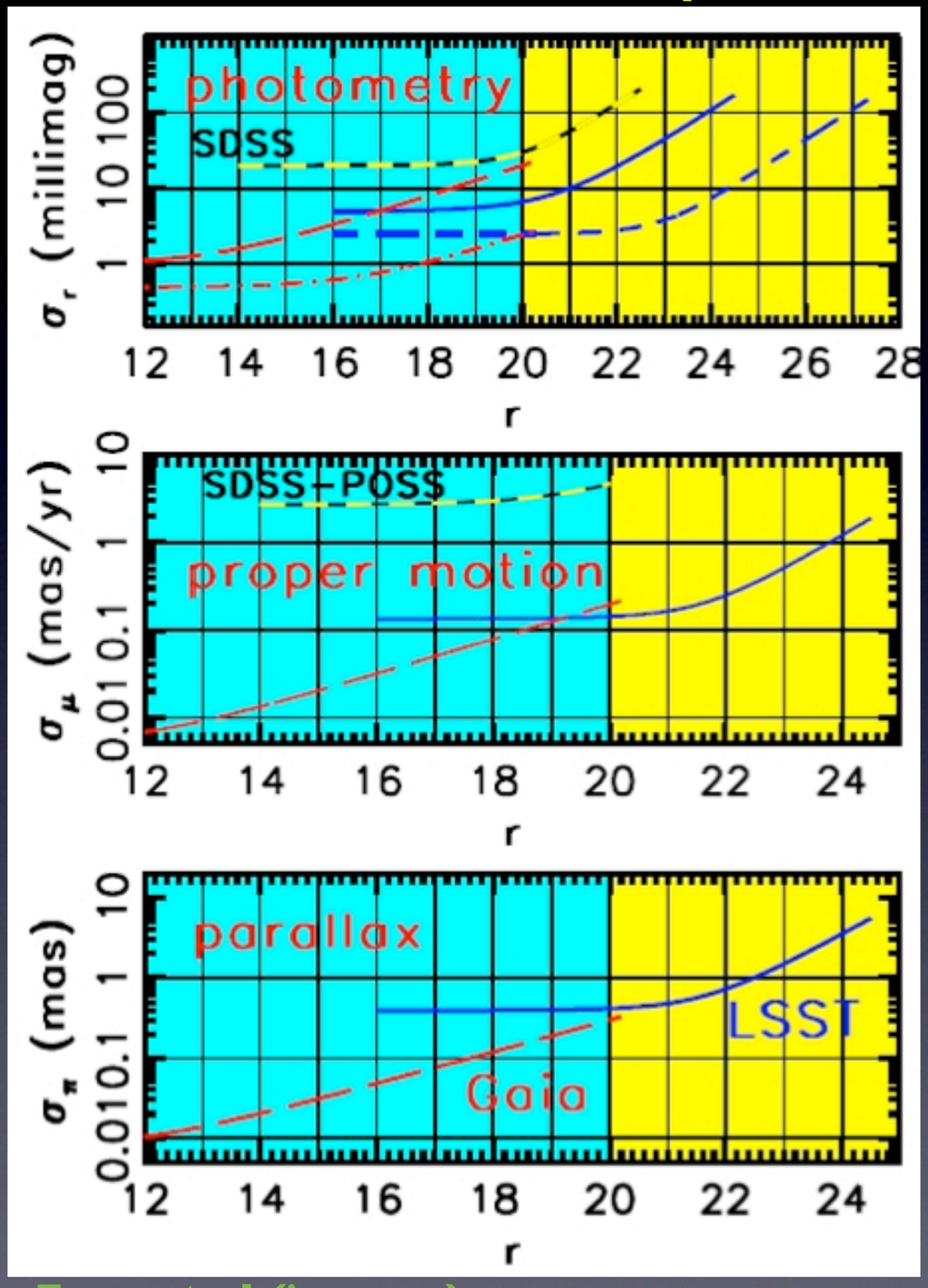




Control of systematics

- Image quality: large aperture to get a sufficiently large PSF correlation angle that enables the use of stars to correct shear systematics; large number of exposures (several hundred) to enable multiple chops
- Photometric redshifts: exquisite photometric accuracy (0.01 mag) and 6 photometric bands
- Cross-checks using different cosmological probes!
- Expect 3-4 times more accurate photo-z than assumed in the DETF Report

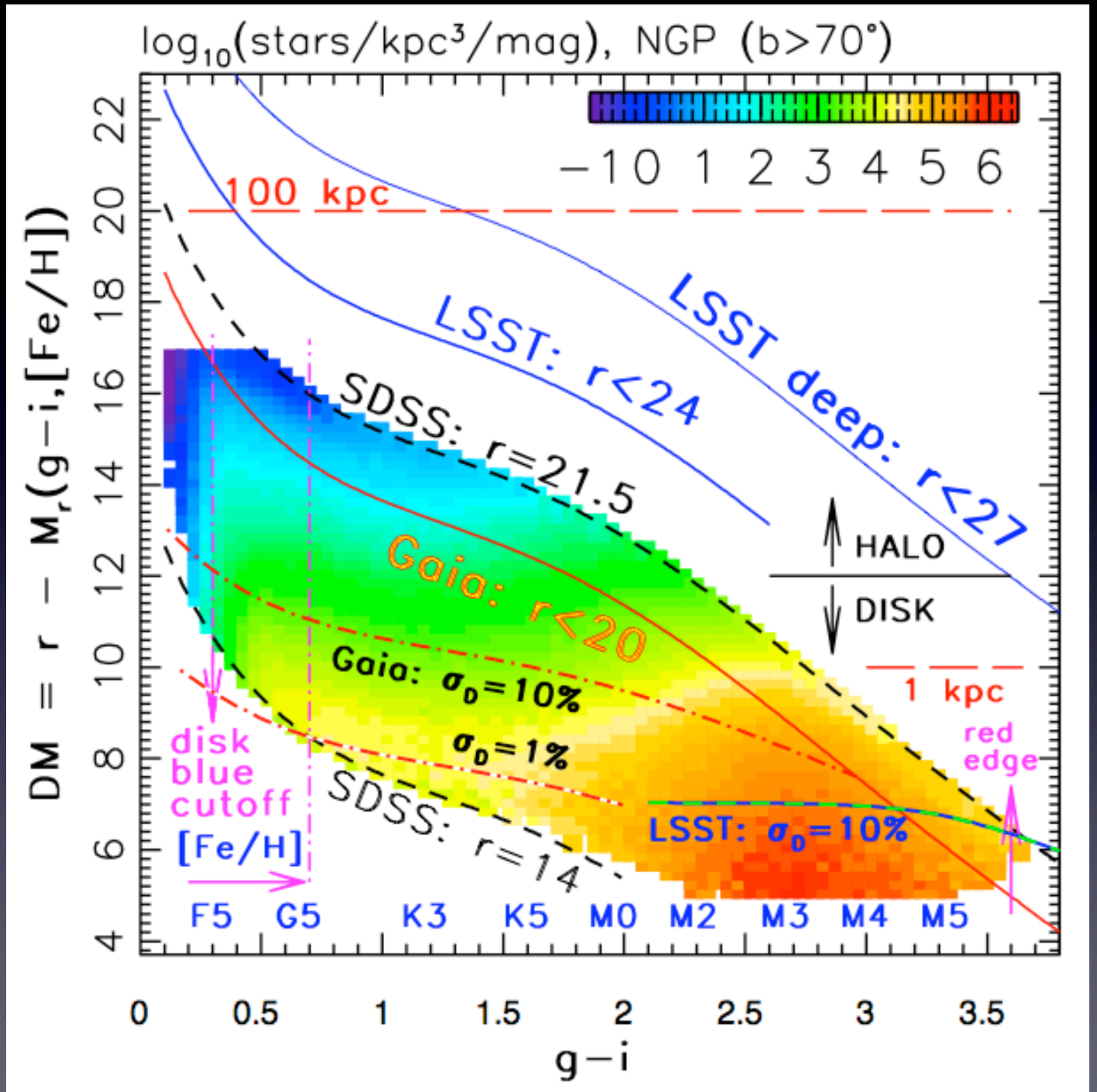
Gaia vs. LSST comparison

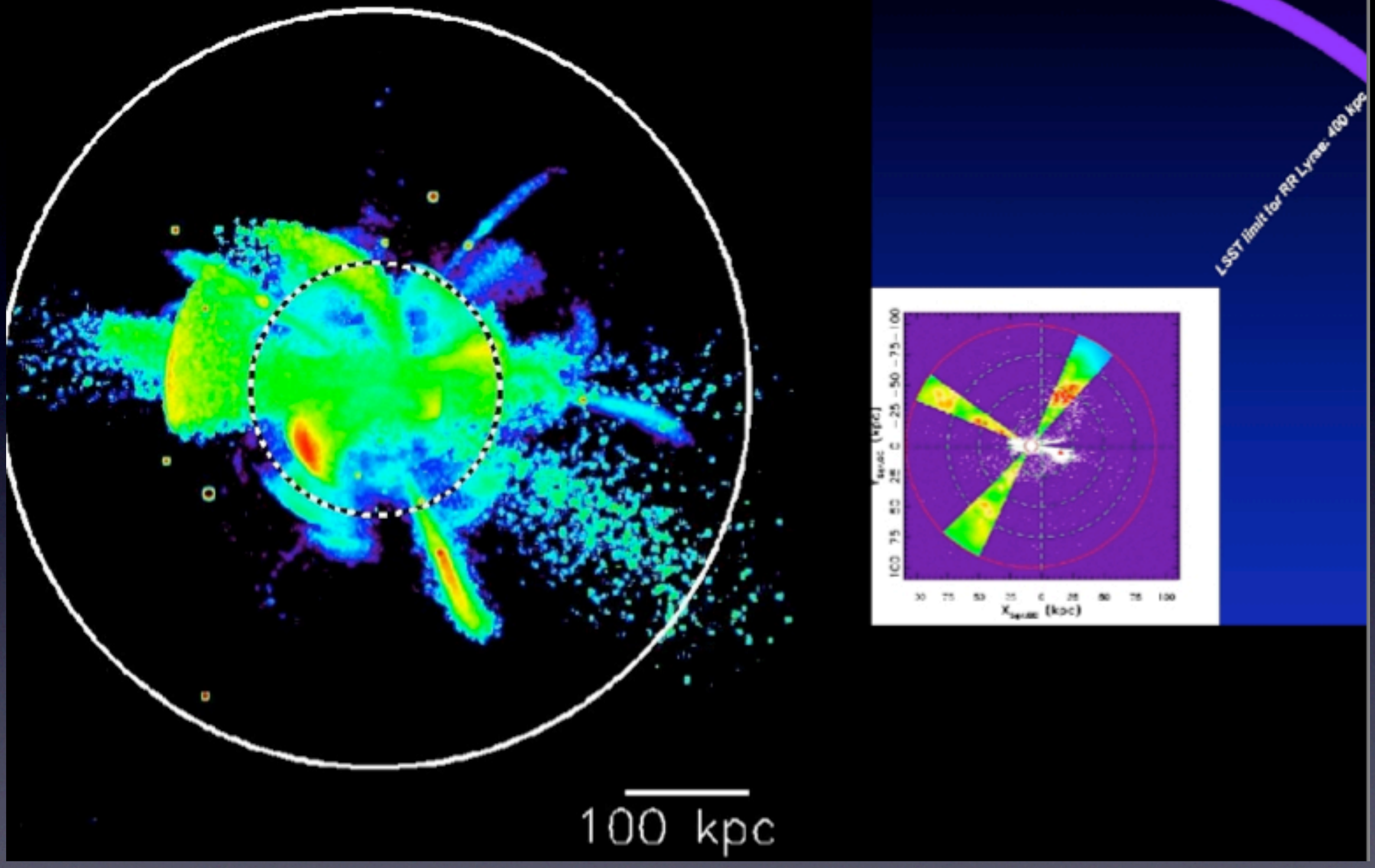


Eyer et al (in prep)

- **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).


log10(stars/kpc³/mag), NGP (b>70°)
−1 0 1 2 3 4 5 6
100 kpc
LSST deep: r<27
LSST: r<24
SDSS: r=21.5
Gaia: r<20
Gaia: σ0=10%
σ0=1%
SDSS: r=14
LSST: σ0=10%
HALO
DISK
1 kpc
red edge
disk blue cutoff
[Fe/H]
F5 G5 K3 K5 M0 M2 M3 M4 M5
DM = r − Mr(g−i,[Fe/H])
4 6 8 10 12 14 16 18 20 22
0 0.5 1 1.5 2 2.5 3 3.5
g−i



SDSS: main sequence to 10 kpc, RR Lyr to 100 kpc
LSST: 100 kpc i 400 kpc (half way to Andromeda)

LTY Dwarfs with LSST

- **T dwarfs: a quantitative example** (L dwarfs are dime a dozen: 200,000 in LSST with proper motion and trigonometric parallax measurements; no Y dwarfs are confirmed yet, though based on models expect ∼100 from LSST)
- **Simulations predict 2400 T dwarfs with** $y < 21.4$ (now ∼100)
- For $y < 21.4$ proper motion ($\sigma = 2$ mas/yr) and trigonometric parallax measurements (σ=6 mas) based on 200 y band detections: 5-10σ measurements even for the faintest objects
- The $z - y$ color will be accurate to better than 0.1 mag even for the faintest objects: it will be possible to construct robust M_z **vs.** $z - y$ **color-magnitude diagrams** (exquisite LFs!)
- The $y < 21.4$ LSST T dwarf sample has roughly the same JHK magnitude limits as the UKIDSS Large Area Survey (4,000 deg^2)
- **Compared to UKIDSS, LSST will obtain about 5 times larger sample of T dwarfs, with proper motions about 10-20 times more accurate, and also with trigonometric parallax measurements** (due to larger sky area, note that our simulations imply that UKIDSS will detect about 500 T dwarfs)