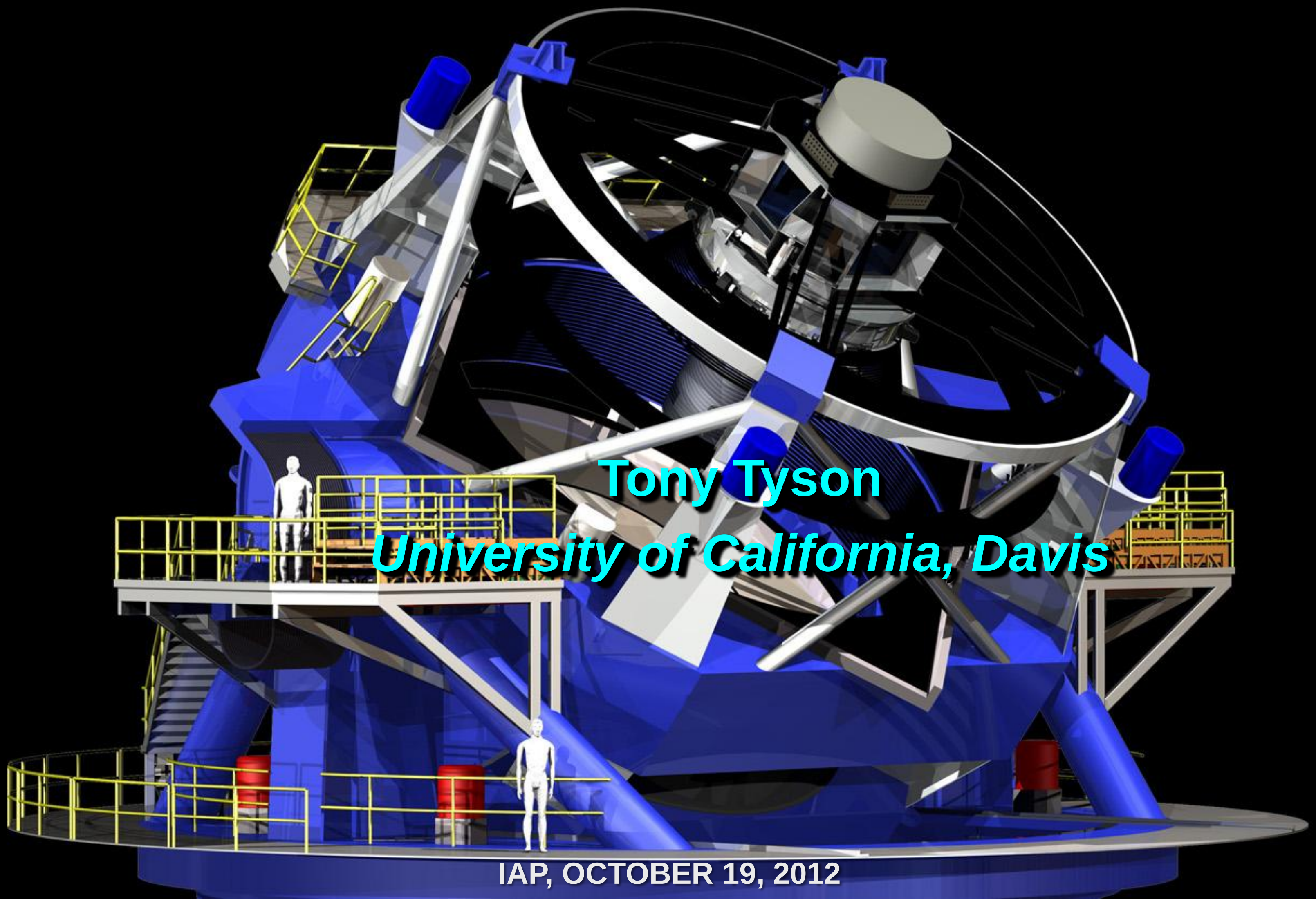
LSST: New Science Frontiers

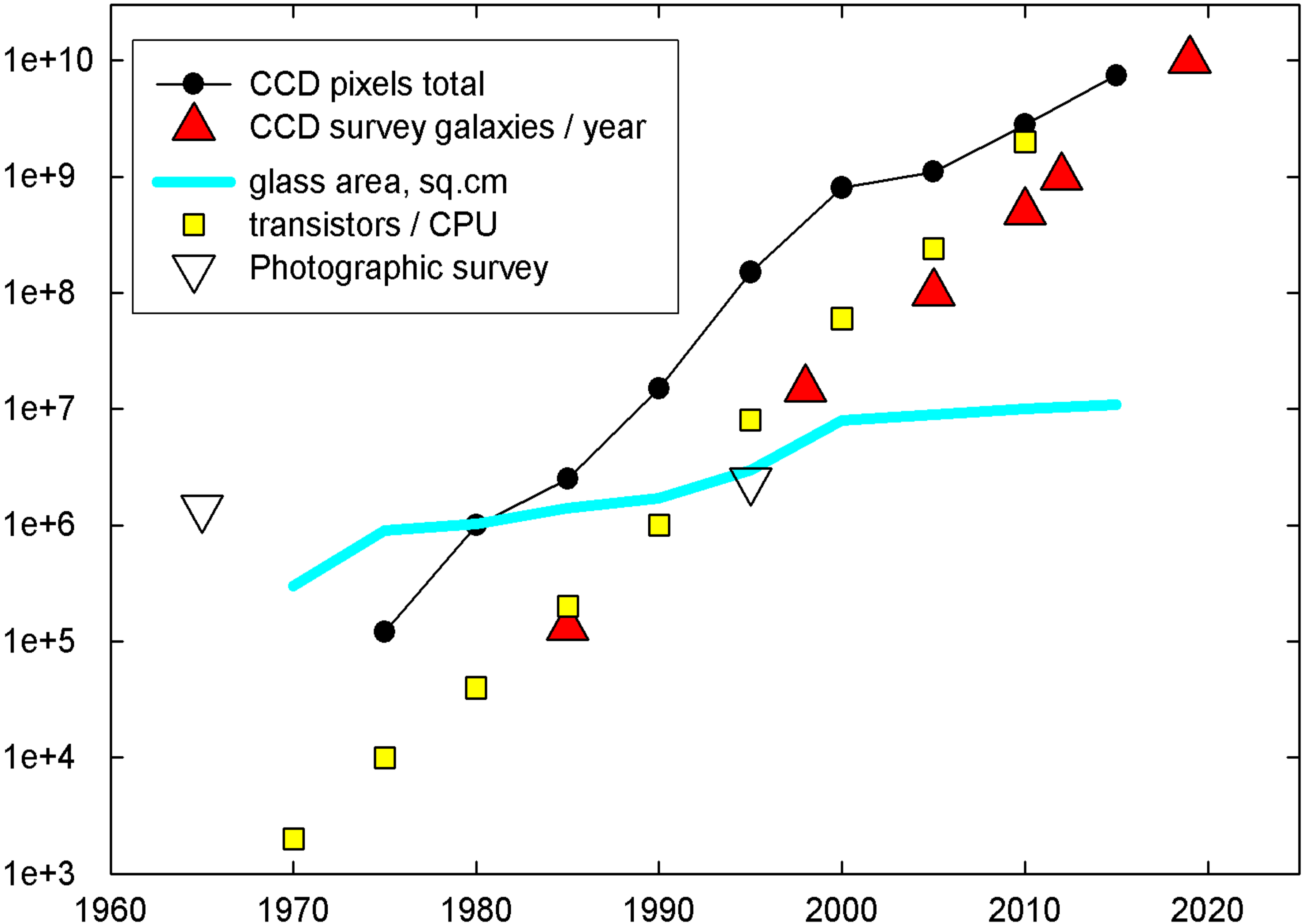


Tony Tyson

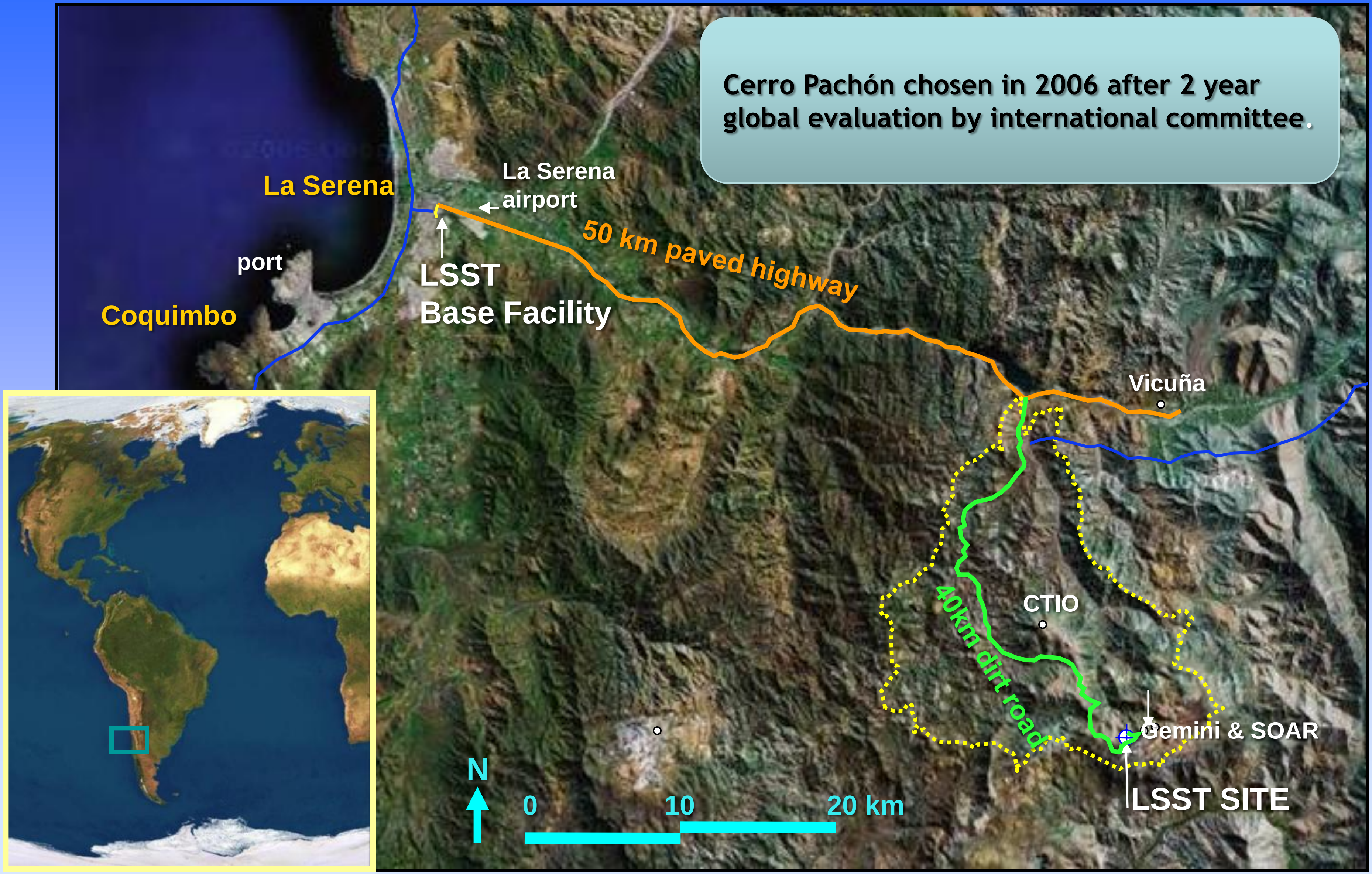
University of California, Davis

IAP, OCTOBER 19, 2012

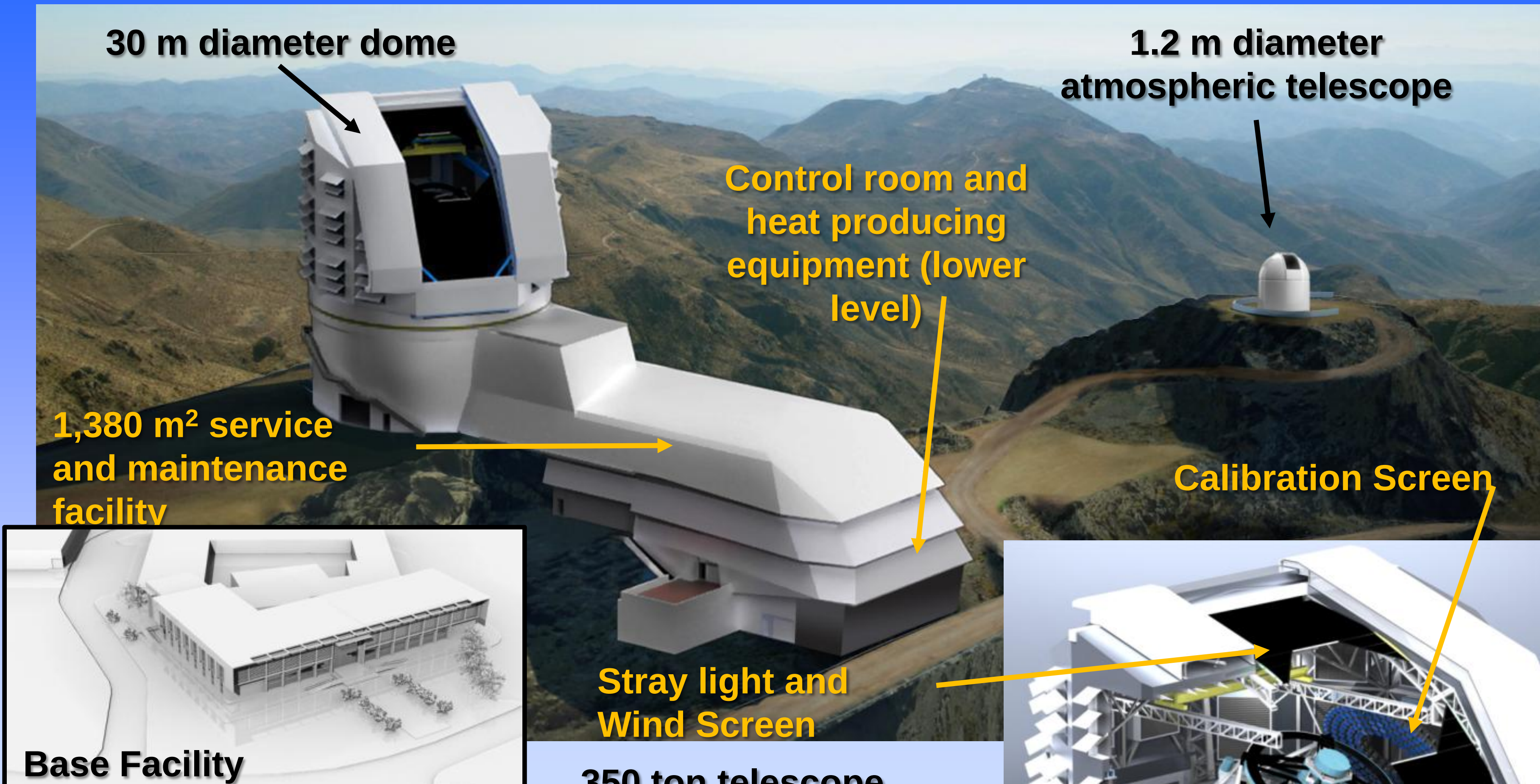
Trends in Optical Astronomy Survey Data

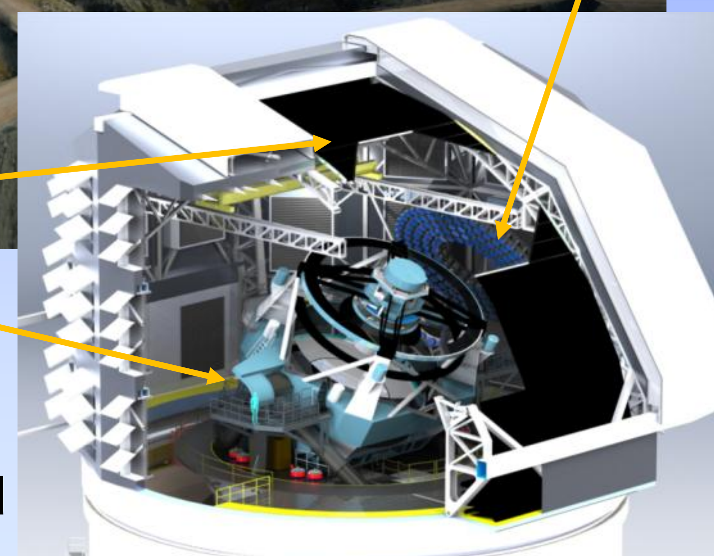


Site selection based on weather and seeing conditions, as well as infrastructure considerations



Telescope and Site



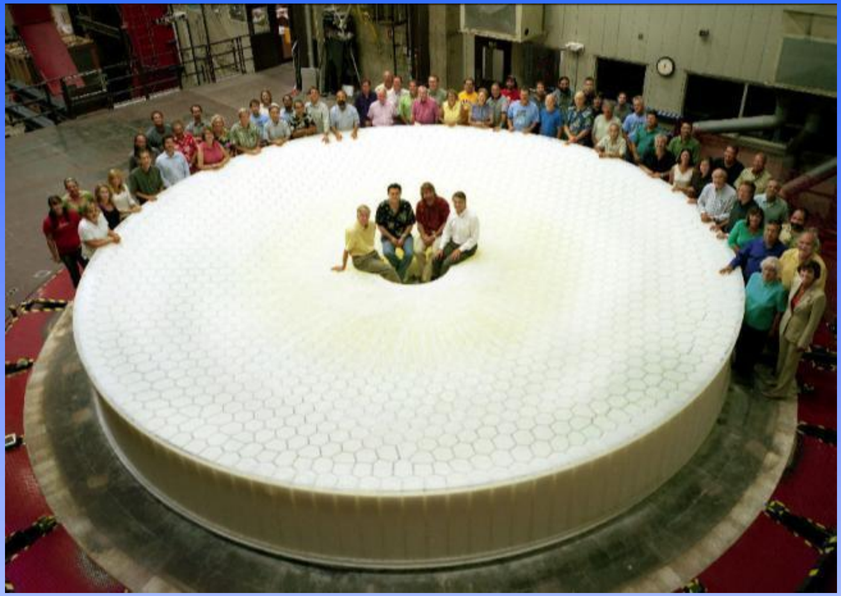


Includes the facilities, and hardware to collect the light, control the survey, calibrate conditions, and support all LSST summit and base operations.

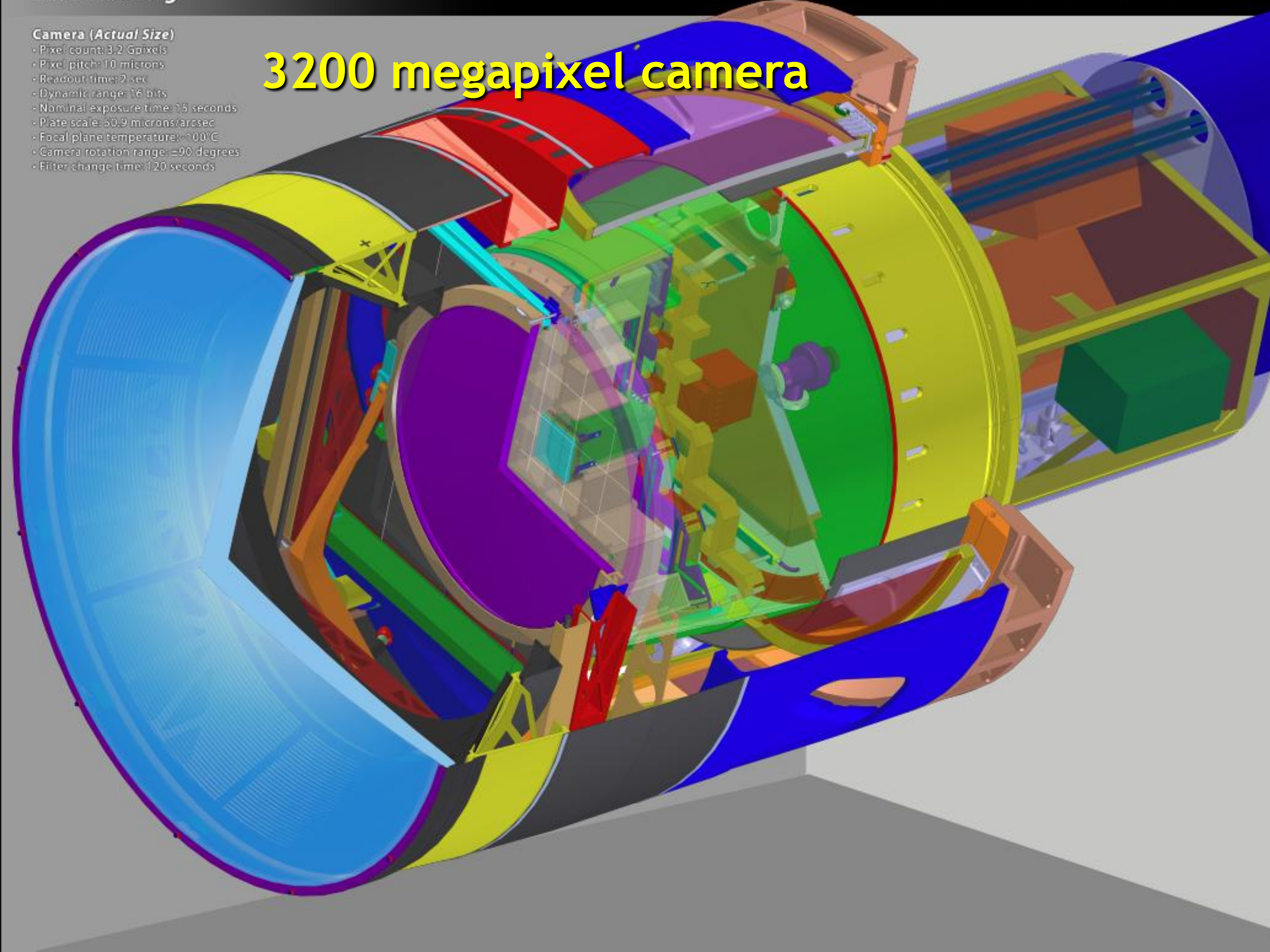
Site and facility development is advanced

- Facility design
- Early Site Leveling
  5 month, $1.3 M effort
  completed and no surprises!

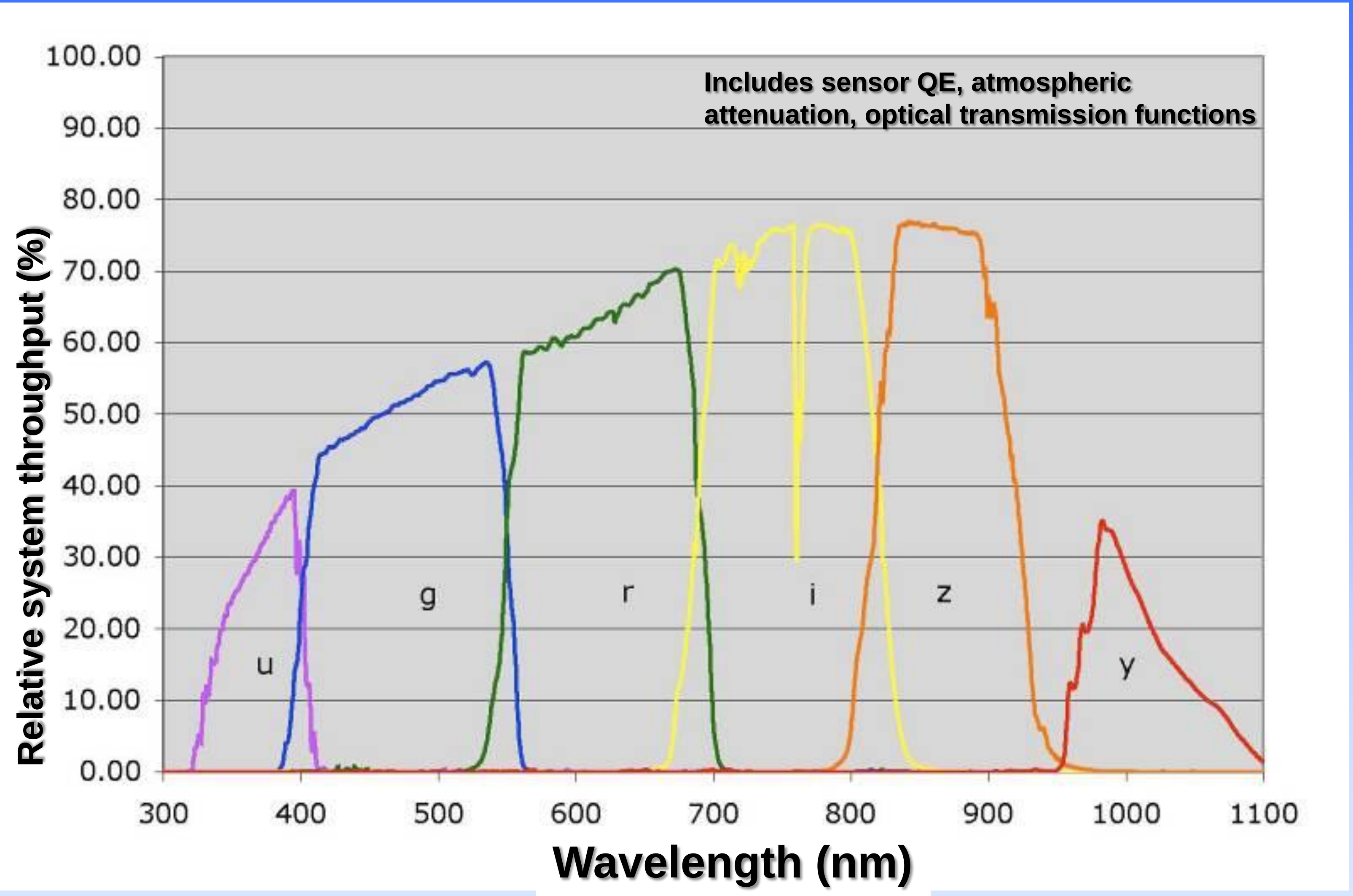
Mirror fabrication is advanced - Private funding enabled early start of both reflective optics



- Primary-Tertiary was cast in 2008
- Fabrication completed by the end of 2012
- Secondary substrate fabricated by Corning in 2009.


3200 megapixel camera
Camera (Actual Size)
• Pixel count: 3.2 Gpixels
• Pixel pitch: 10 microns
• Readout time: 2 sec
• Dynamic range: 16 bits
• Nominal exposure time: 15 seconds
• Plate scale: 50.9 microns/arcsec
• Focal plane temperature: -100°C
• Camera rotation range: ±90 degrees
• Filter change time: 120 seconds

LSST six color system: Photometric redshifts



LSST: Joint US DOE/NSF Project

National Science Foundation

- **Lead agency**
  - **Project Management**
  - **Telescope and site**
  - **Data Management**
  - **Education and Public Outreach**
- ***National Science Board approval: July 2012***
  - **Possible NSF construction start: 2014**

Joint DOE/NSF Project

Department of Energy

Office of Science
U.S. DEPARTMENT OF ENERGY

- **Deliver a 3.2 Giga-pixel camera that meets project requirements**
- **Agency status:**
  - **CD-0: Approve Mission Need: Dark Energy Stage IV Experiment(s)**
  - **CD-1: Select option to move forward and set cost range**

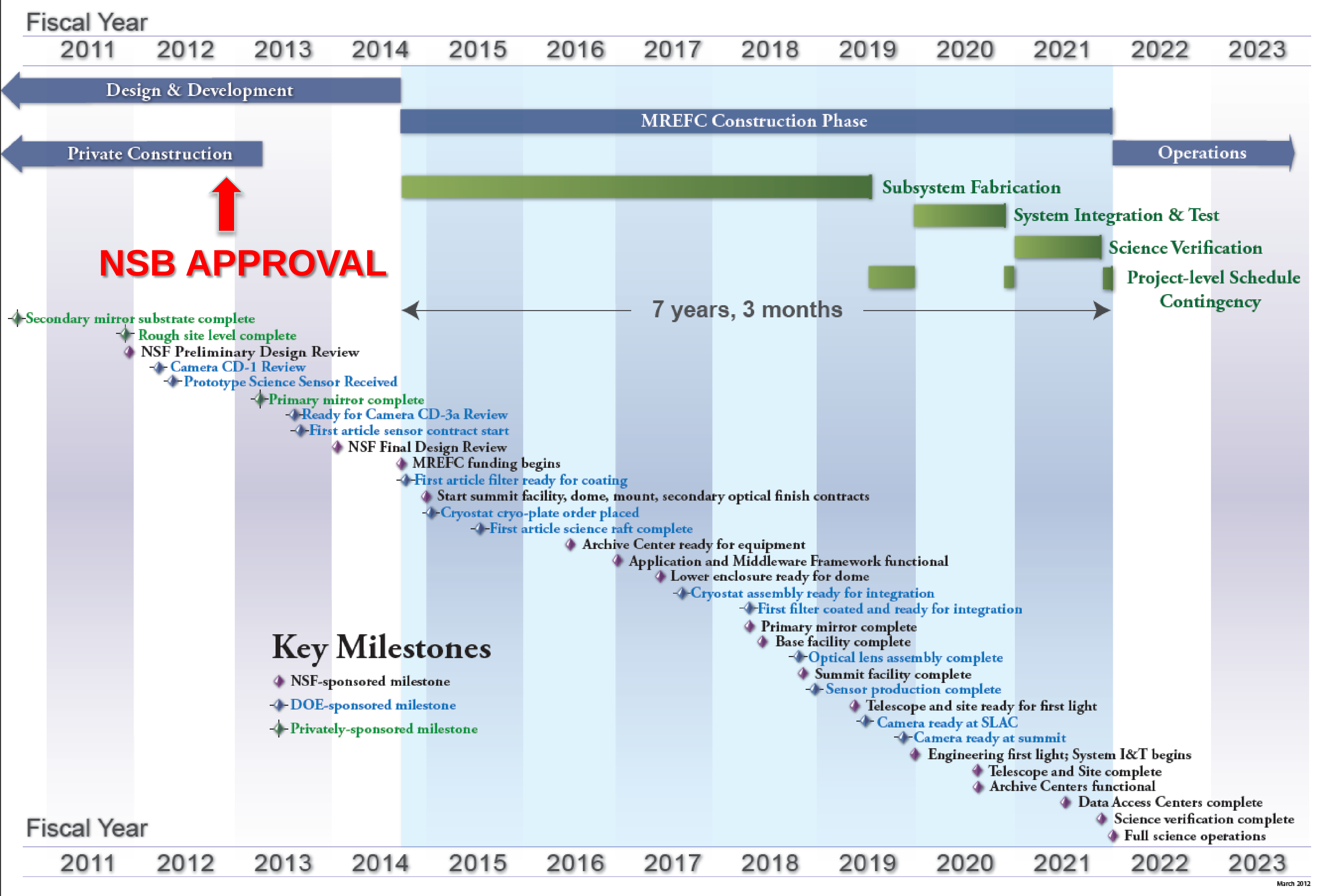
    CD-1 granted: March 2012

Office of Science
U.S. DEPARTMENT OF ENERGY

In 2011 we were asked to pursue international support for 30% share of LSST survey operations.

70 institutes in 28 countries

Integrated Project Schedule with Key Milestones



LSST Observing Cadence

Pairs of 15 second exposures (*to 24.5 mag*) per visit to a given position in the sky.

Visit the same position again within the hour with another pair of exposures.

Number of 9.6 sq.deg field-of-view visits per night: 850

Detection of transients announced within 60 seconds.
Expect 1-2 million alerts per night!

Two planned LSST surveys

MAIN SURVEY

Deep Wide Survey: 18,000 square degrees to a uniform depth of
***u*: 26.1 *g*: 27.4 *r*: 27.5 *i*: 26.8 *z*: 26.1 *y*: 24.9**

DEEP DRILLING SURVEY

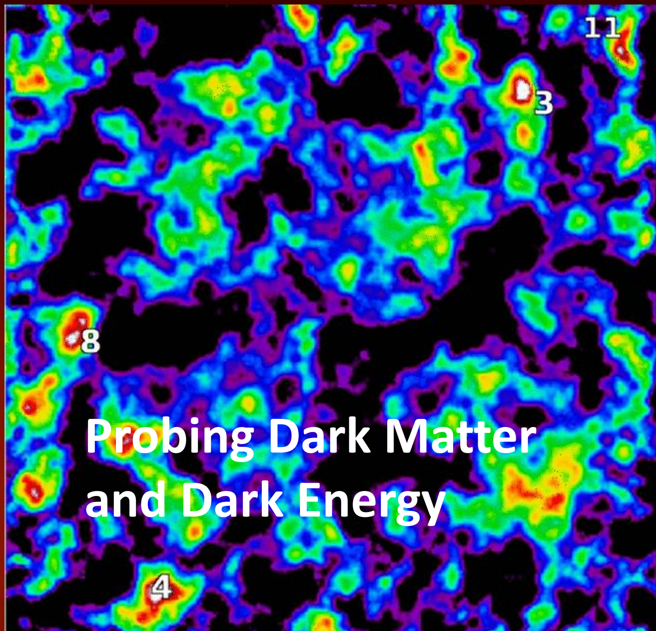
10% of time: ~30 selected fields. 300 square degrees
Continuous 15 sec exposures. 1hour/night

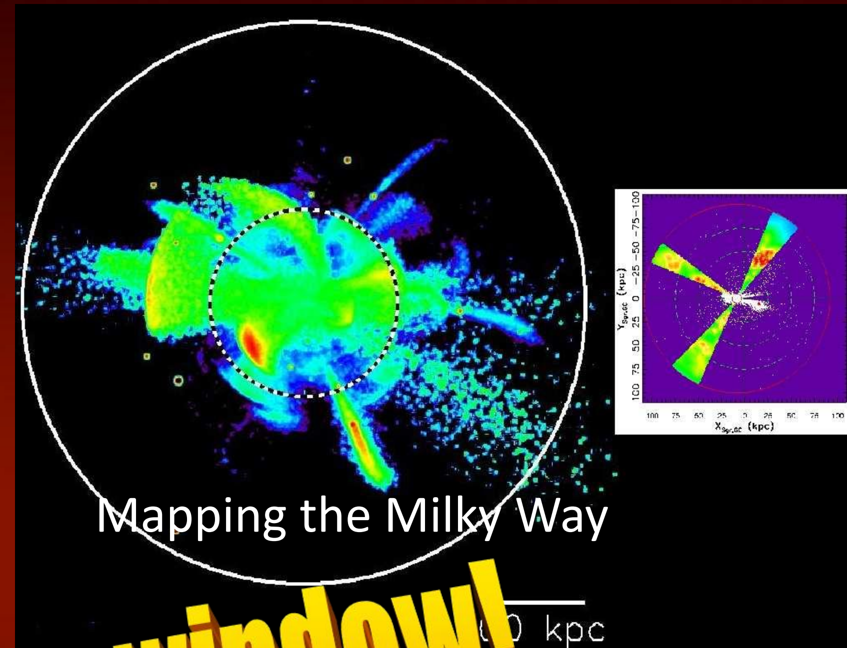
LSST Wide-Fast-Deep survey

- 4 billion galaxies with redshifts
- 10 billion stars

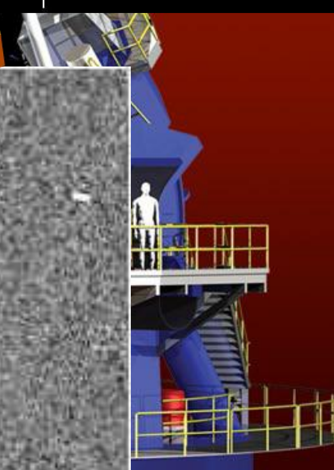
- *Time domain*:
  1 million supernovae
  1 million galaxy lenses
  1 million alerts per night
  new phenomena

The new sky





opens the time window!



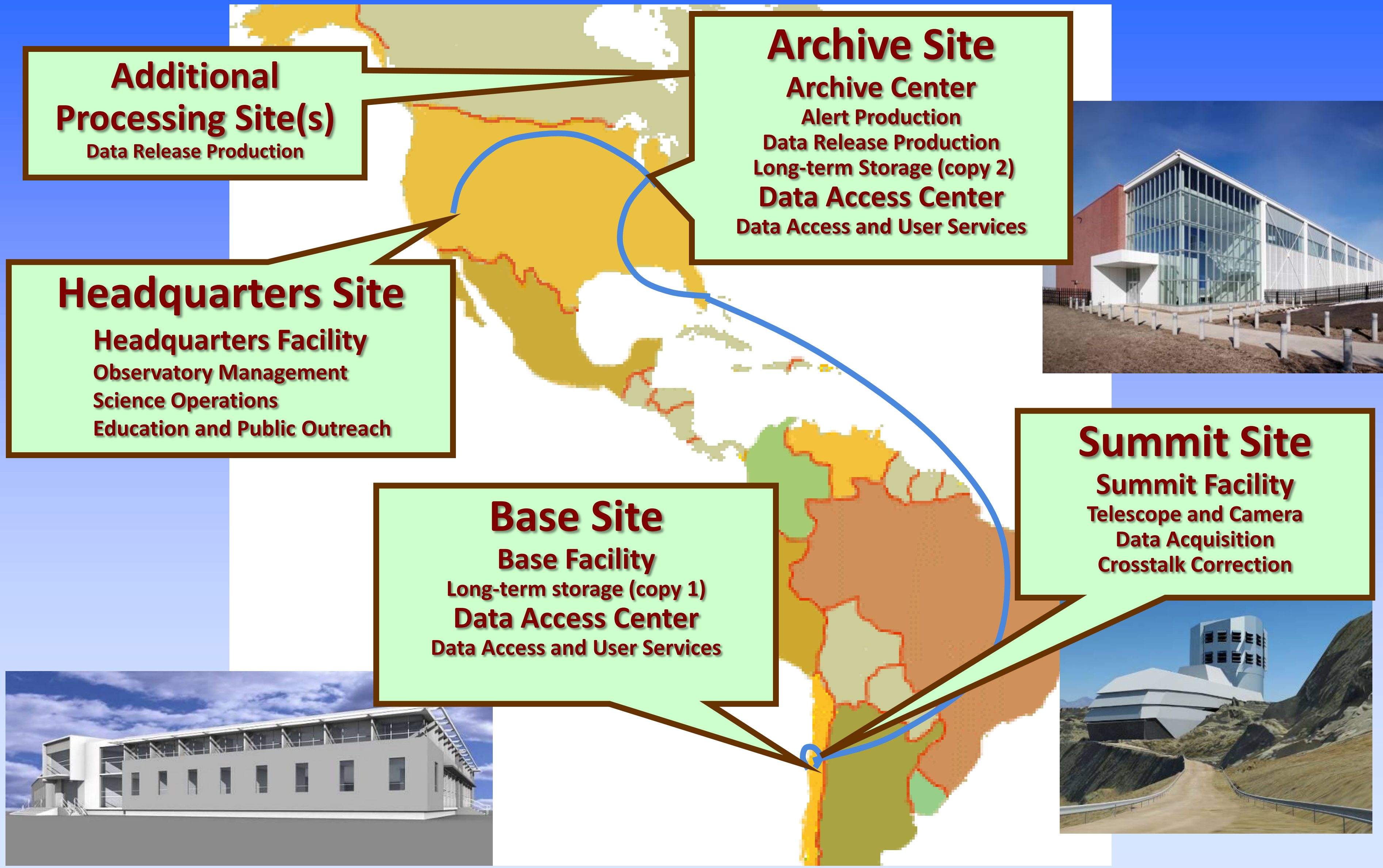
The Data Challenge

- ~3 Terabytes per hour that must be mined in real time.
- 20 billion objects will be monitored for important variations in real time.
- A new approach must be developed for knowledge extraction in real time.

Major challenge and opportunity:

Discovering The Unexpected

One System, Two Continents, Four Sites



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

LSST: A Petascale Survey of the Optical Sky

Final Image Archive	345 PB	All Data Releases Includes Virtual Data (315 PB)
Final Image Collection	75 PB	Data Release 11 (Year 10) Includes Virtual Data (57 PB)
Final Catalog Archive	46 PB	All Data Releases
Final Database	9 PB 32 trillion rows	Data Release 11 (Year 10) Includes Data, Indexes, and DB Swap
Final Disk Storage	228 PB 3700 drives	Archive Site Only
Final Tape Storage	83 PB 3800 tapes	Single Copy Only
Number of Nodes	1800	Archive Site Compute and Database Nodes
Number of Alerts Generated	6 billion	Life of survey

– Virtual Data is data that is dynamically recreated on-demand from provenance information

Shape measurements on galaxy and star images

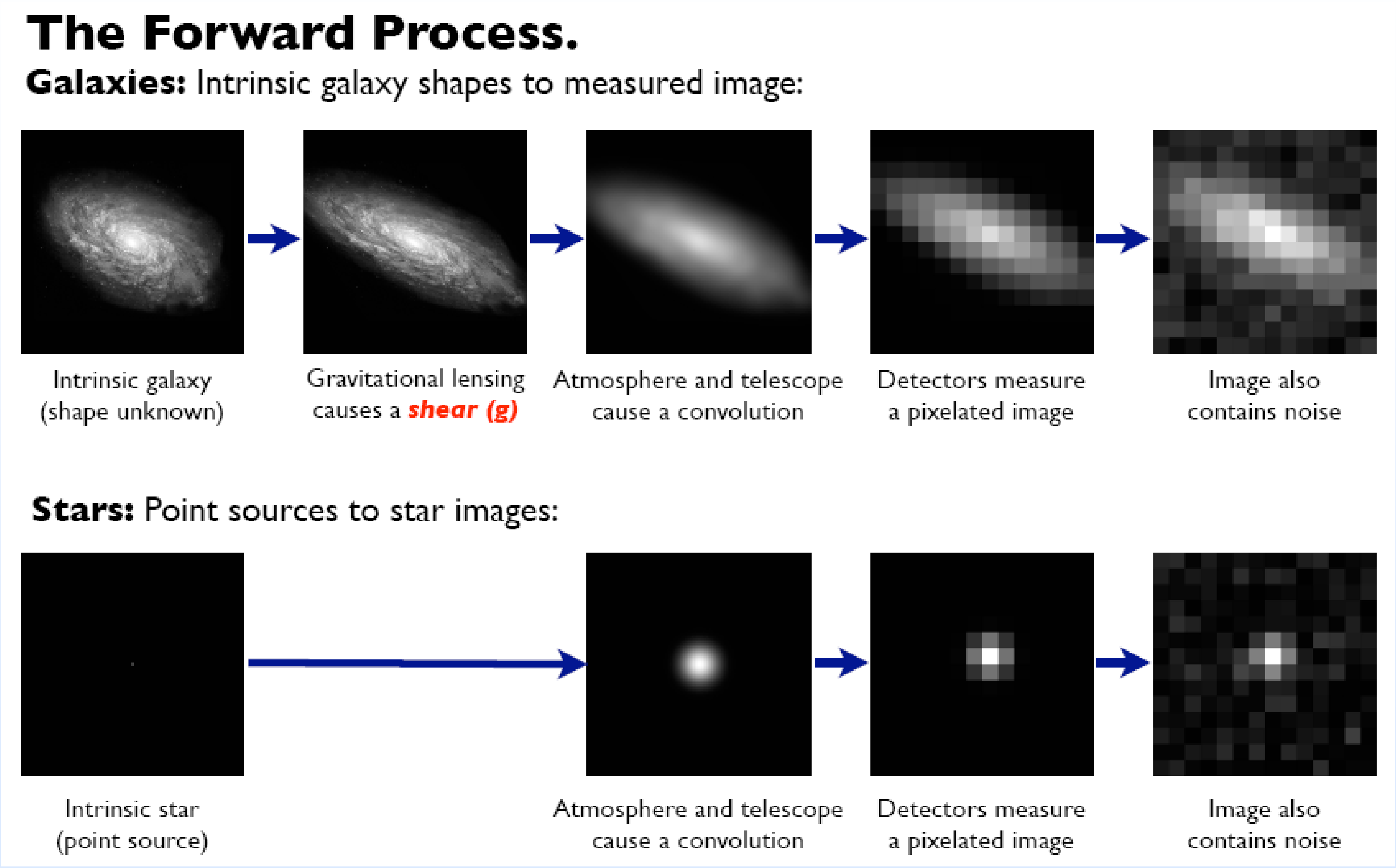


Figure from S. Bridle

Measuring faint galaxy shear: *Stack-Fit* algorithm

- Measure the shape of galaxies whose apparent shape is distorted by the point-spread function (PSF)
- PSF varies within CCDs and between CCDs and between exposures due to optics and atmosphere variations

- The Stack-Fit Algorithm:
  1. Measure PSF within each CCD for each exposure
  2. Separately make weighted co-add of all dithered images of the field
  3. Co-add with same weights the CCD PSF eigenfunctions
  4. Use this PSF co-add map to interpolate the PSF at each galaxy's position
  5. Convolve this PSF with a galaxy model, and fit.

- Test performance on end-to-end LSST image simulations
- Test via comparing HST and Subaru WL mass reconstruction

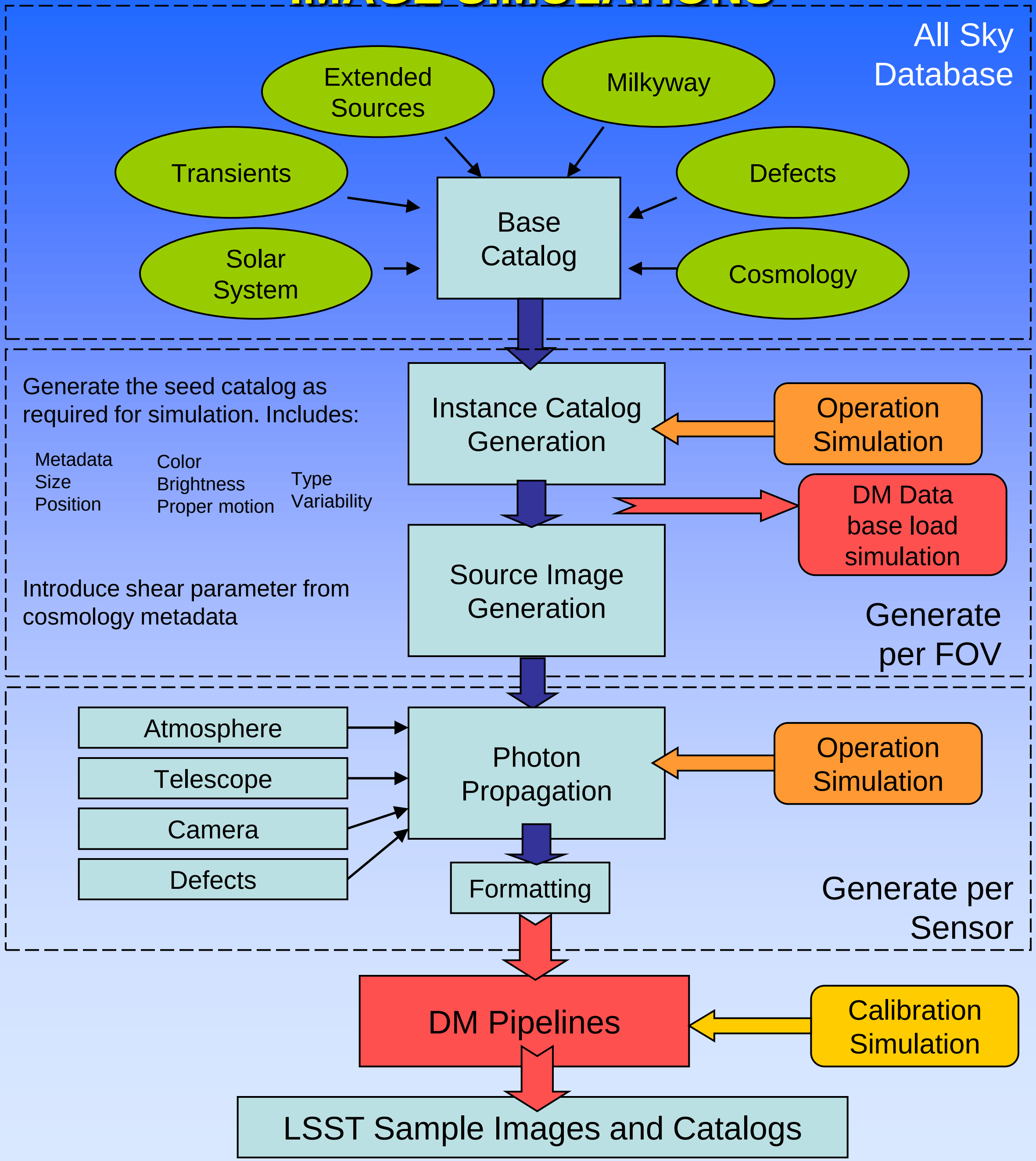
Software Stack

- **Reduces the images (pixels) to sources and objects (catalog entries, transient alerts, moving objects, etc.)**
  - **The “heart” (or “brain?”) of data management**

- **Written in Python (Python 2.7), unless computational demands require the use of C++**
  - **Python used for rapid implementation and interactive development**
  - **C++ used for efficiency, flexibility**

- **Substantial body of code already developed in R&D**
  - 113000 lines of C++
  - 400 C++ classes
  - 74000 lines of Python
  - 571 Python classes

IMAGE SIMULATIONS



LSST Outreach Data will be used in classrooms, science museums, and online

Classroom Emphasis on:

- **Data-enabled research experiences**
- **Citizen Science**
- **College classes**
- **Collaboration through Social Networking**

ZOONIVERSE
REAL SCIENCE ONLINE

LSST DATA

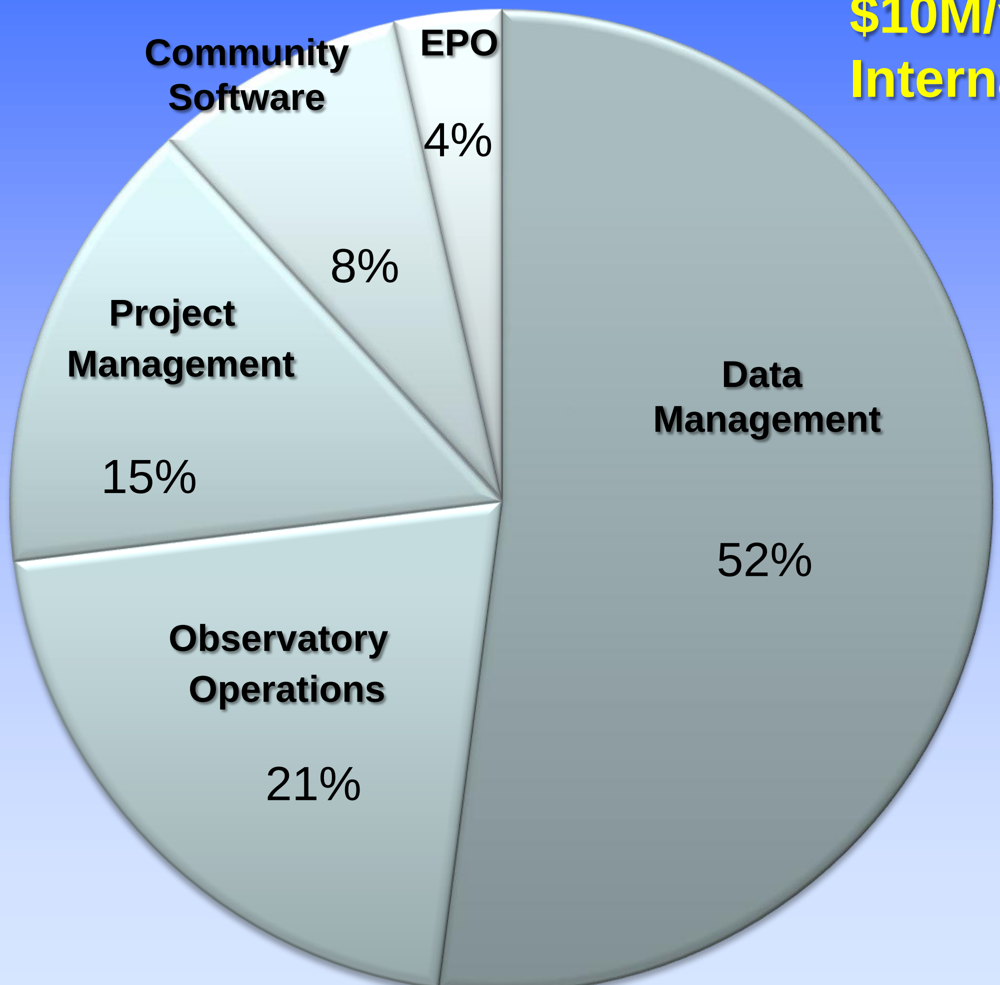
LSST data, including images and catalogs, will be available with no proprietary period to the astronomical community of the United States, Chile, and International Partners

Transient alerts will be available world-wide within 60 seconds, using standard VO protocols

LSST data processing stack will be free software (licensed under the GPL, v3 or later)

LSST Operations Plan and Total Survey Cost

Operations: 137 FTE's, $37.2M/yr (2012USD)



$10M/year from International Partners

Total LSST Survey cost: $1.25B

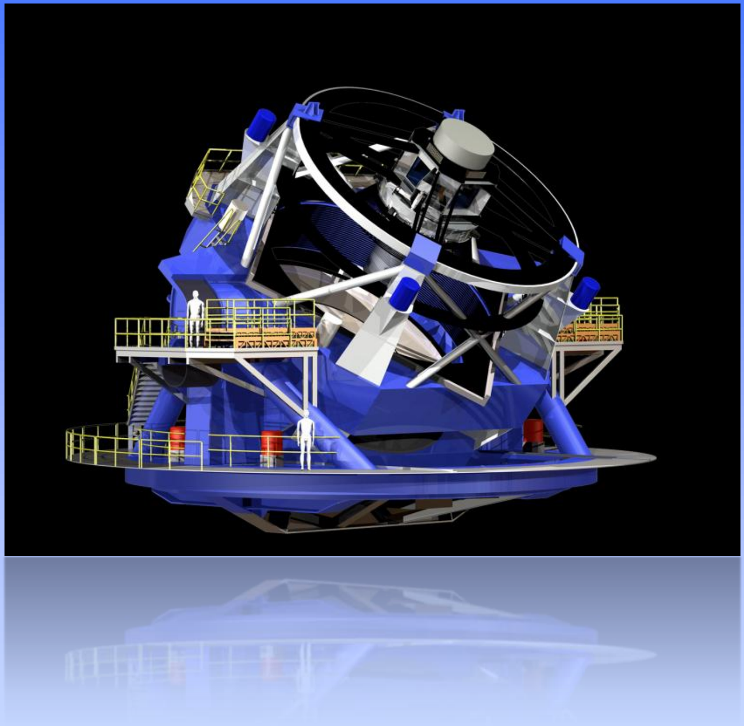
A Dedicated Survey Telescope

- **The LSST is an integrated survey system. The Observatory, Telescope, Camera and Data Management system are all built to support the LSST survey. There's no PI mode, proposals, or time.**

- **The ultimate deliverable of LSST is not the telescope, nor the instruments; it's the fully reduced data.**
  - Images
  - Transient alerts
  - Catalogs

Science Enabled by LSST

- **Time domain science**
  - Novae, supernovae, GRBs
  - Source characterization
  - Instantaneous discovery
- **Finding moving sources**
  - Asteroids and comets
  - Proper motions of stars
- **Mapping the Milky Way**
  - Tidal streams
  - Galactic structure
- **Dark energy and dark matter**
  - Gravitational lensing
  - Slight distortion in shape
  - Trace the nature of dark energy



How does one do research when faced with trillions of catalog entries, and potentially millions of measurements for each class of objects?

Old Paradigm

Astronomer+
pencil+paper

INSTRUMENT

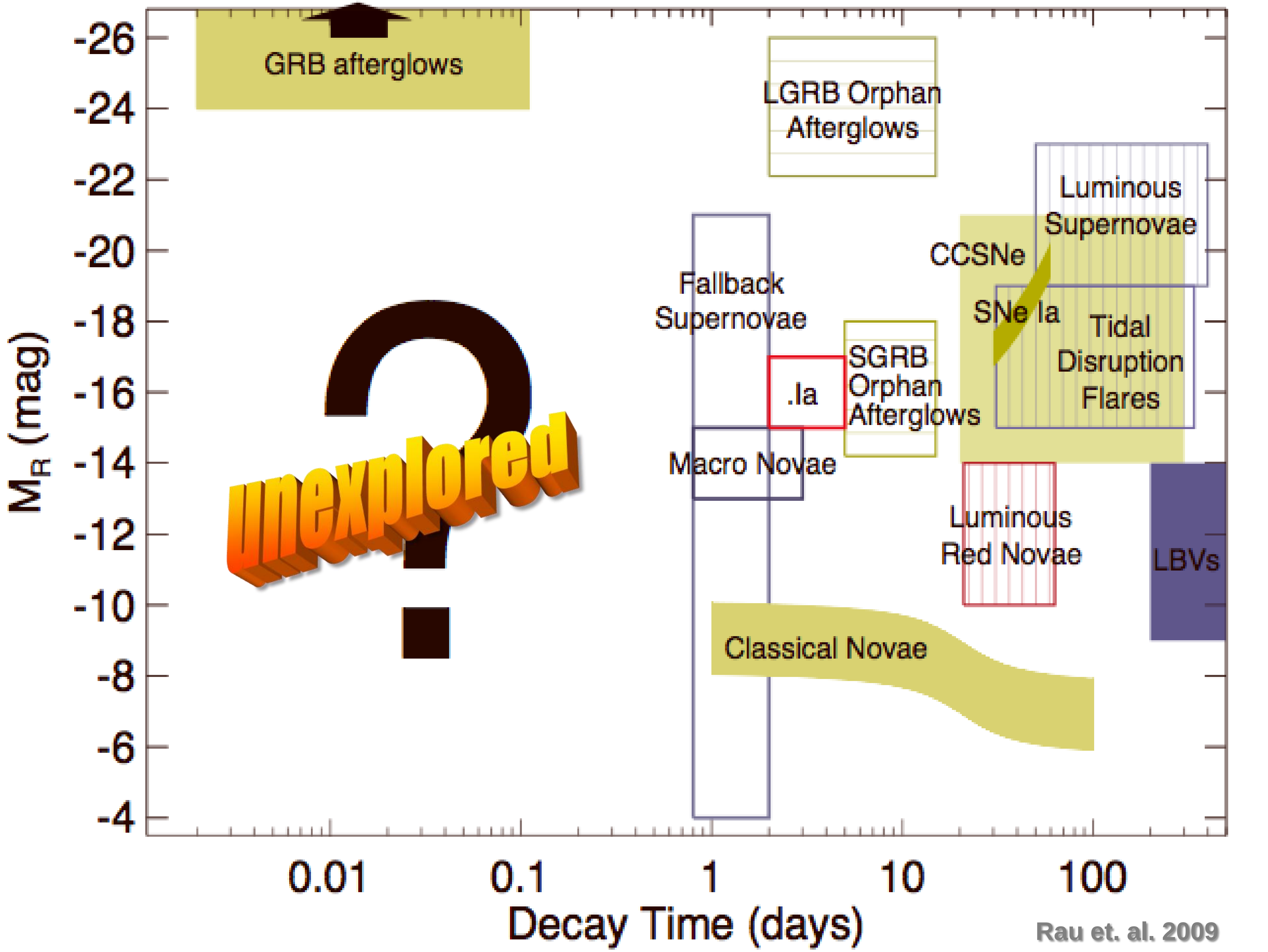
TELESCOPE

New Paradigm

DATA ENABLED DISCOVERY

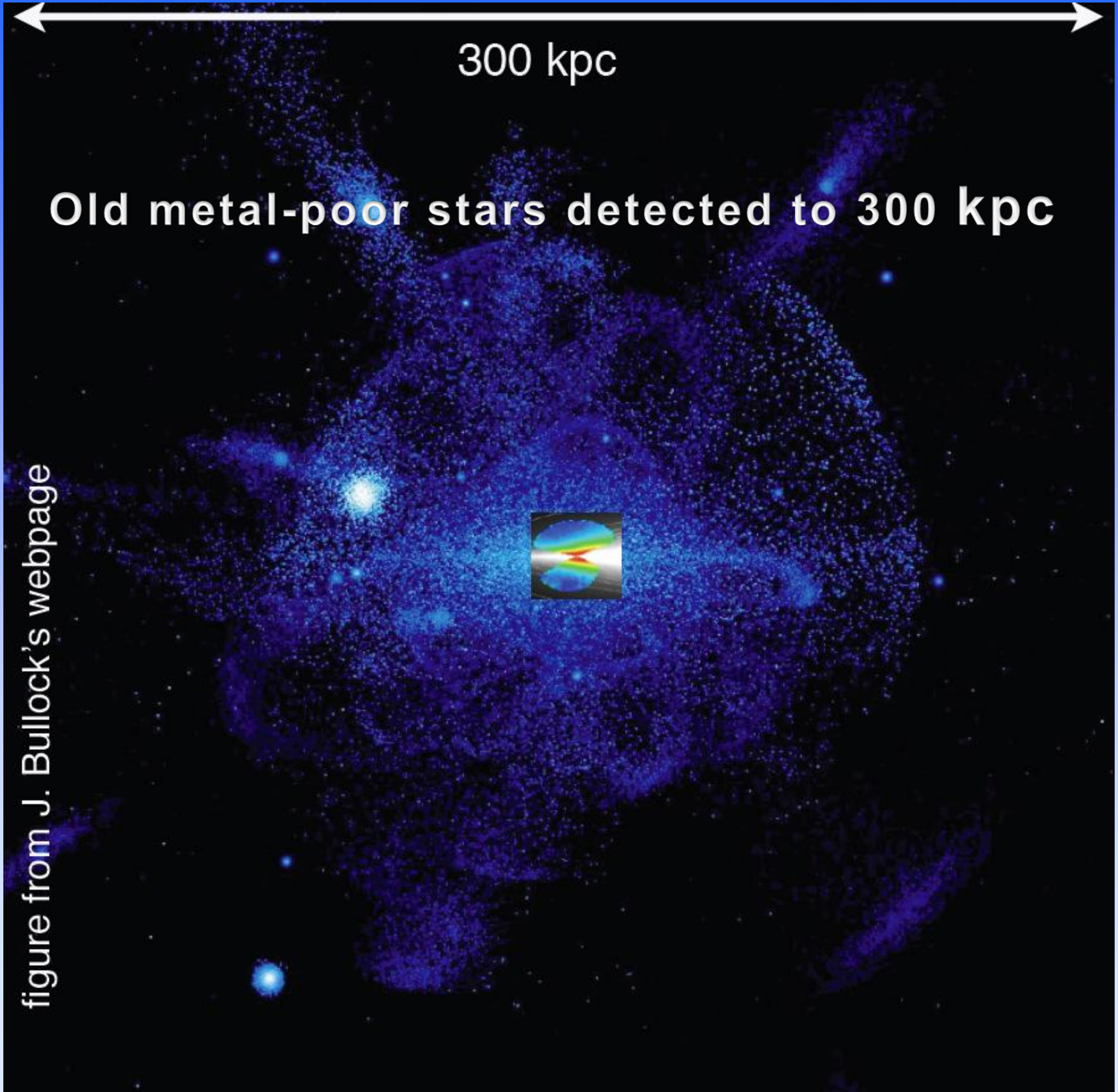
INSTRUMENT

TELESCOPE

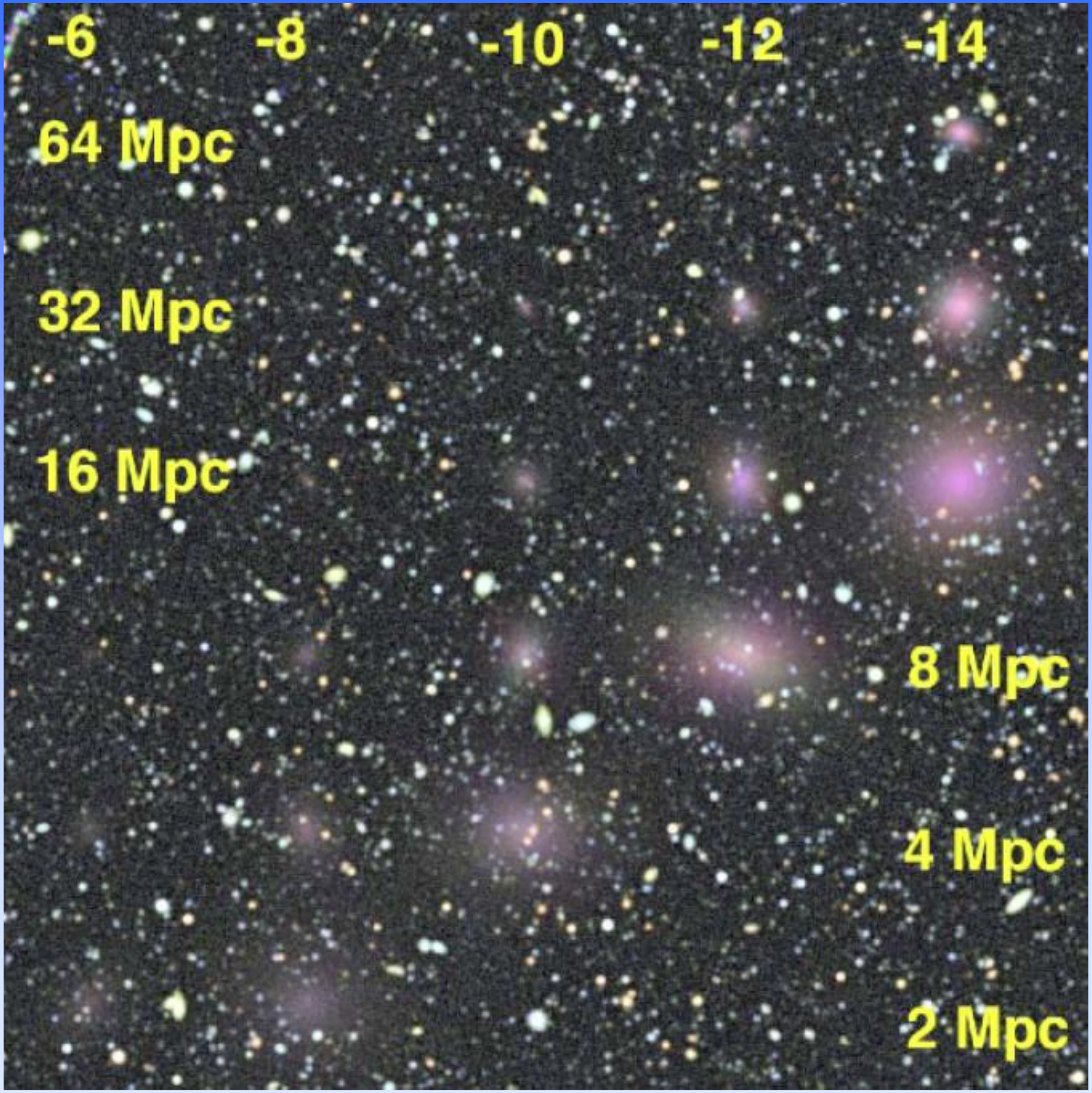


GRB afterglows
LGRB Orphan Afterglows
Luminous Supernovae
CCSNe
Fallback Supernovae
SNe Ia
Tidal Disruption Flares
SGRB Orphan Afterglows
.Ia
Macro Novae
unexplored
?
Luminous Red Novae
LBVs
Classical Novae
-26
-24
-22
-20
-18
-16
-14
-12
-10
-8
-6
-4
M_R (mag)
0.01
0.1
1
10
100
Decay Time (days)
Rau et. al. 2009

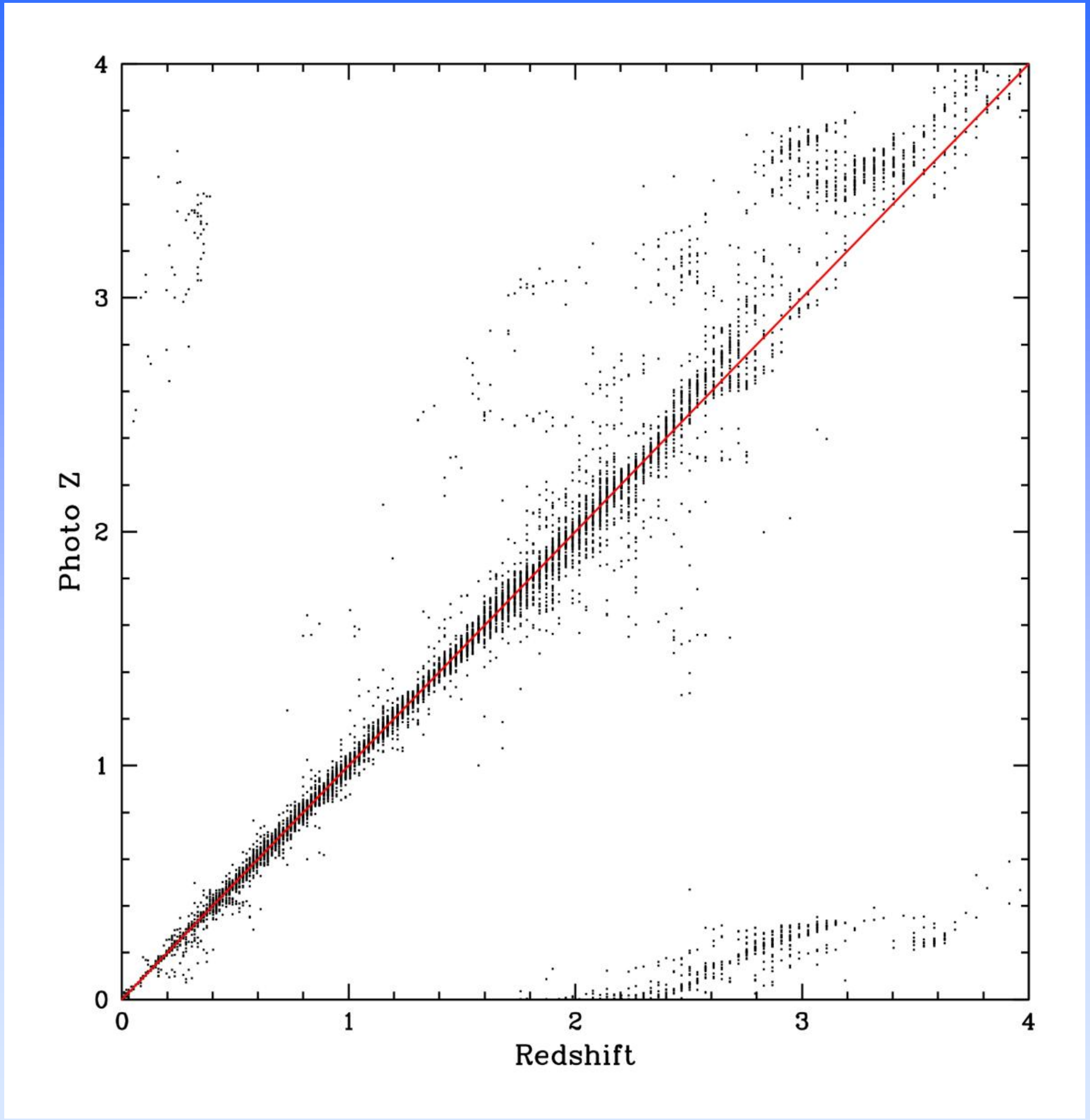
Mapping the Milky Way



Discover Nearby Dwarf Galaxies



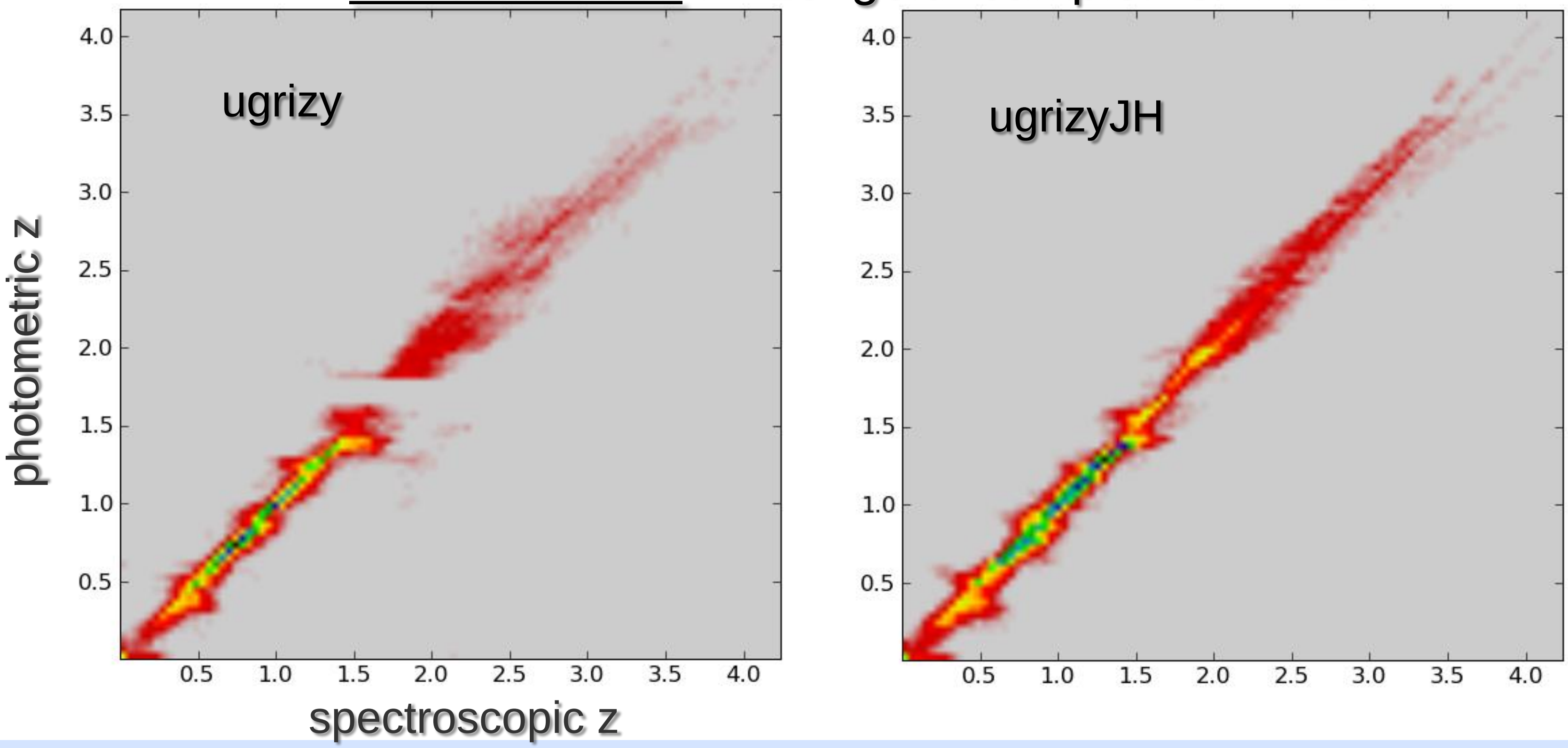
Photometric vs spectroscopic redshifts

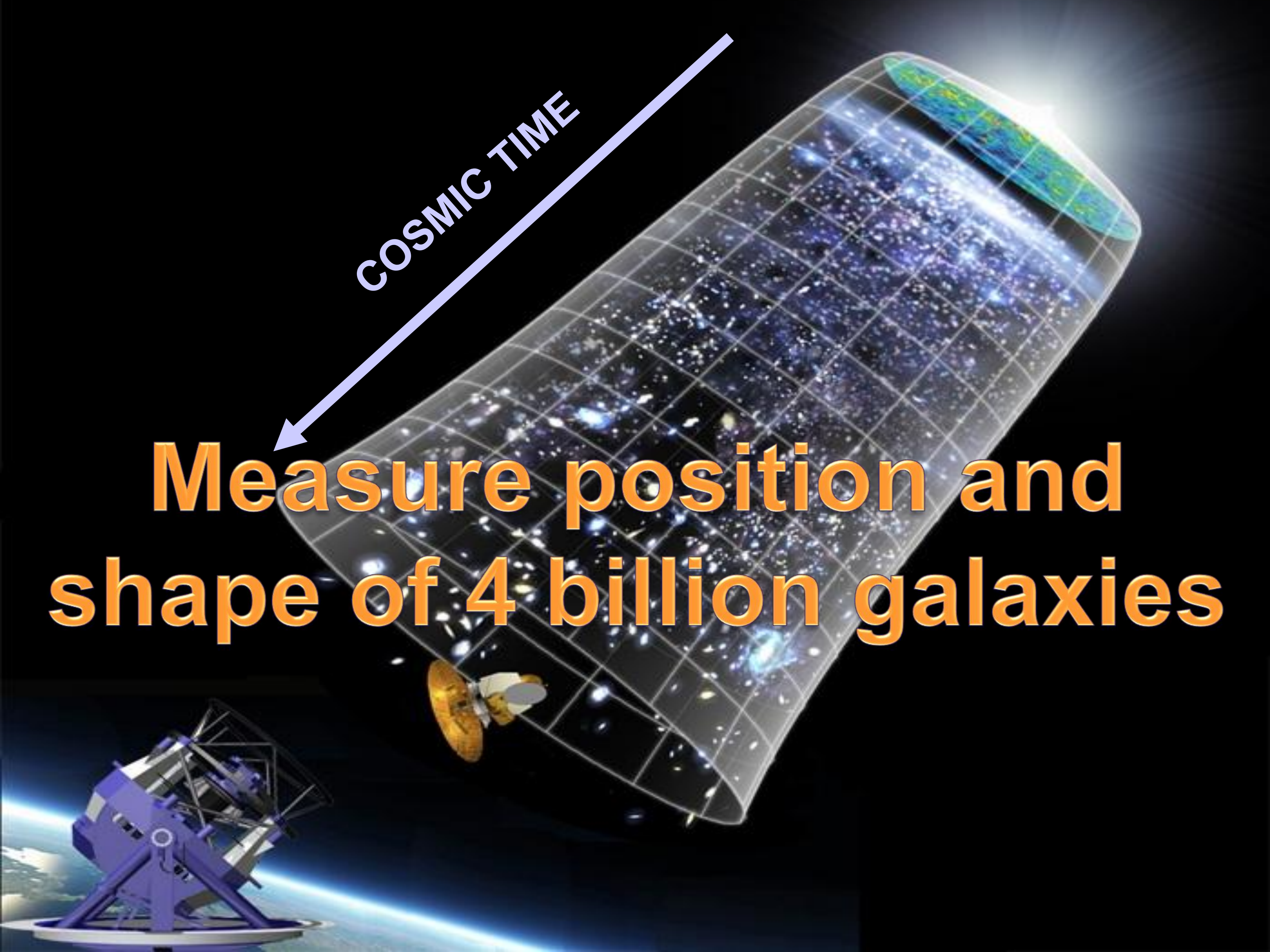


Priors and cuts using restricted templates

Effect of priors using restricted set of empirical spectral templates.
Spectroscopic training set, and calibrate via angular-z correlation.

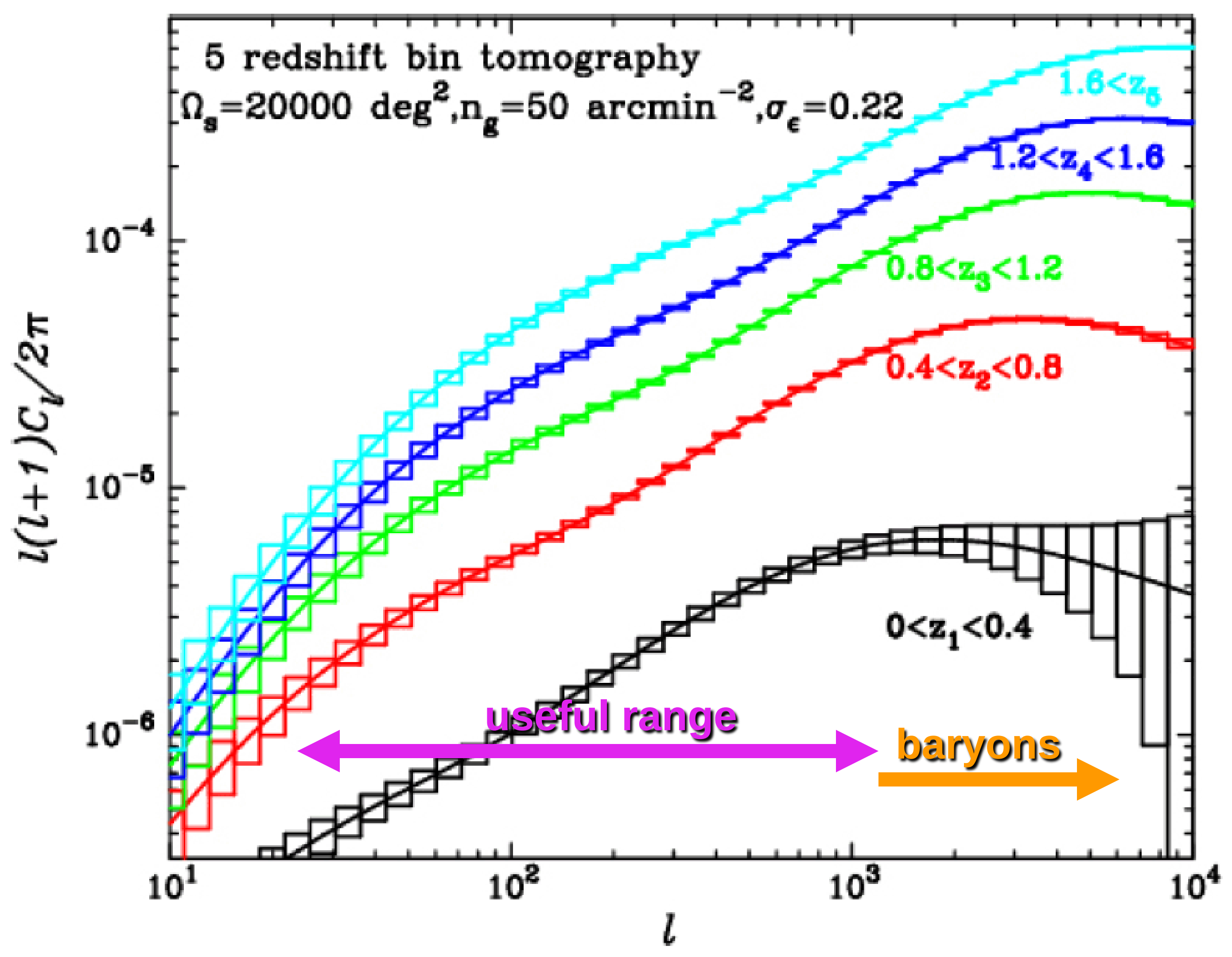
Pre-calibration i < 25 “gold” sample: S/N > 20




COSMIC TIME
Measure position and shape of 4 billion galaxies

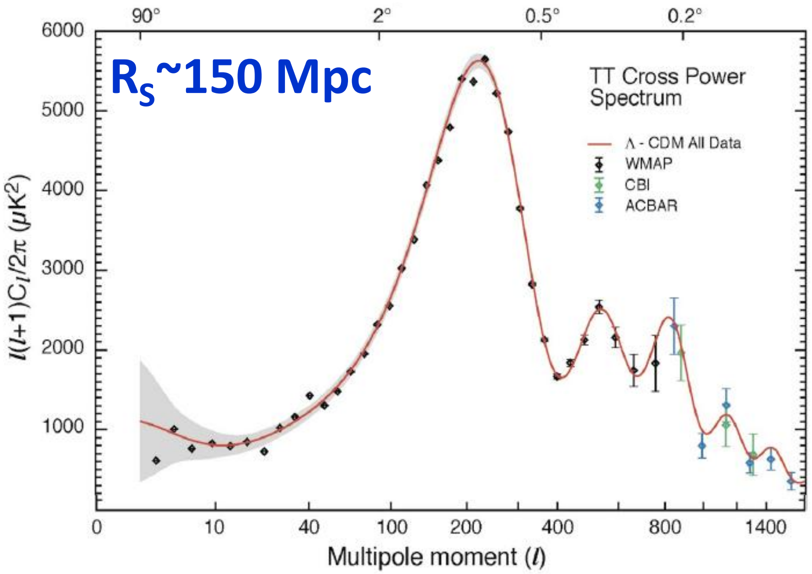
LSST and Cosmic Shear

Ten redshift bins yield 55 auto and cross spectra

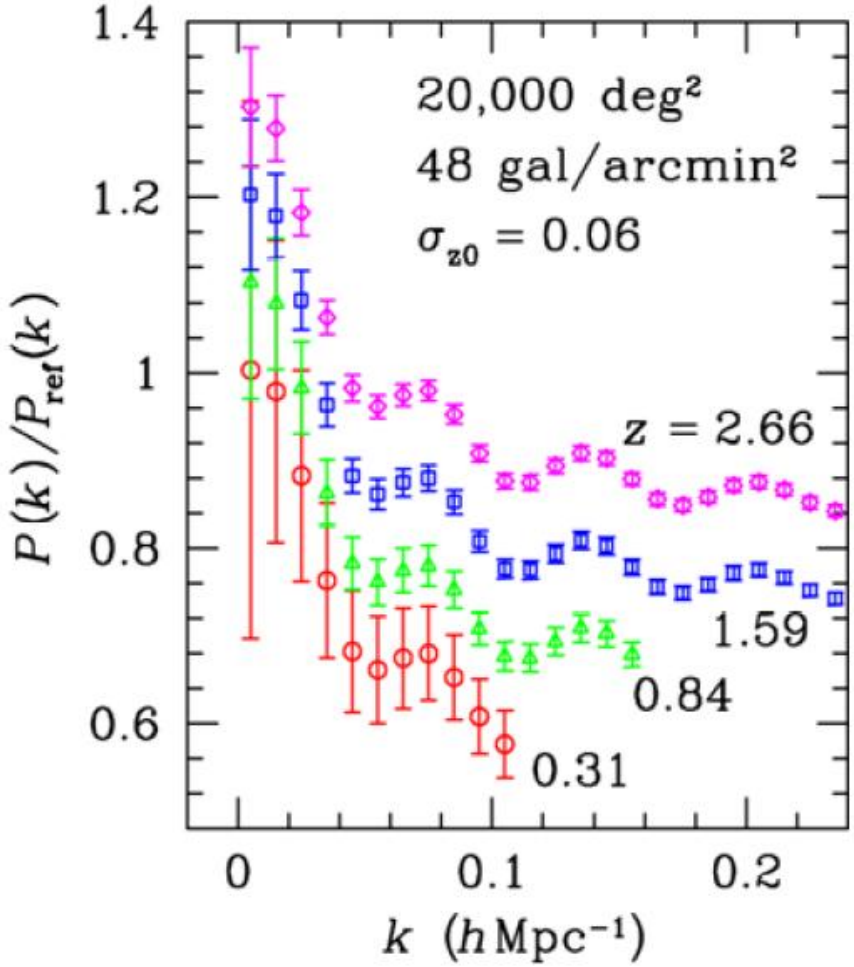


Standard ruler

CMB (z = 1100)



LSST (z = 0.2 - 3)



Measure angular scale vs Redshift

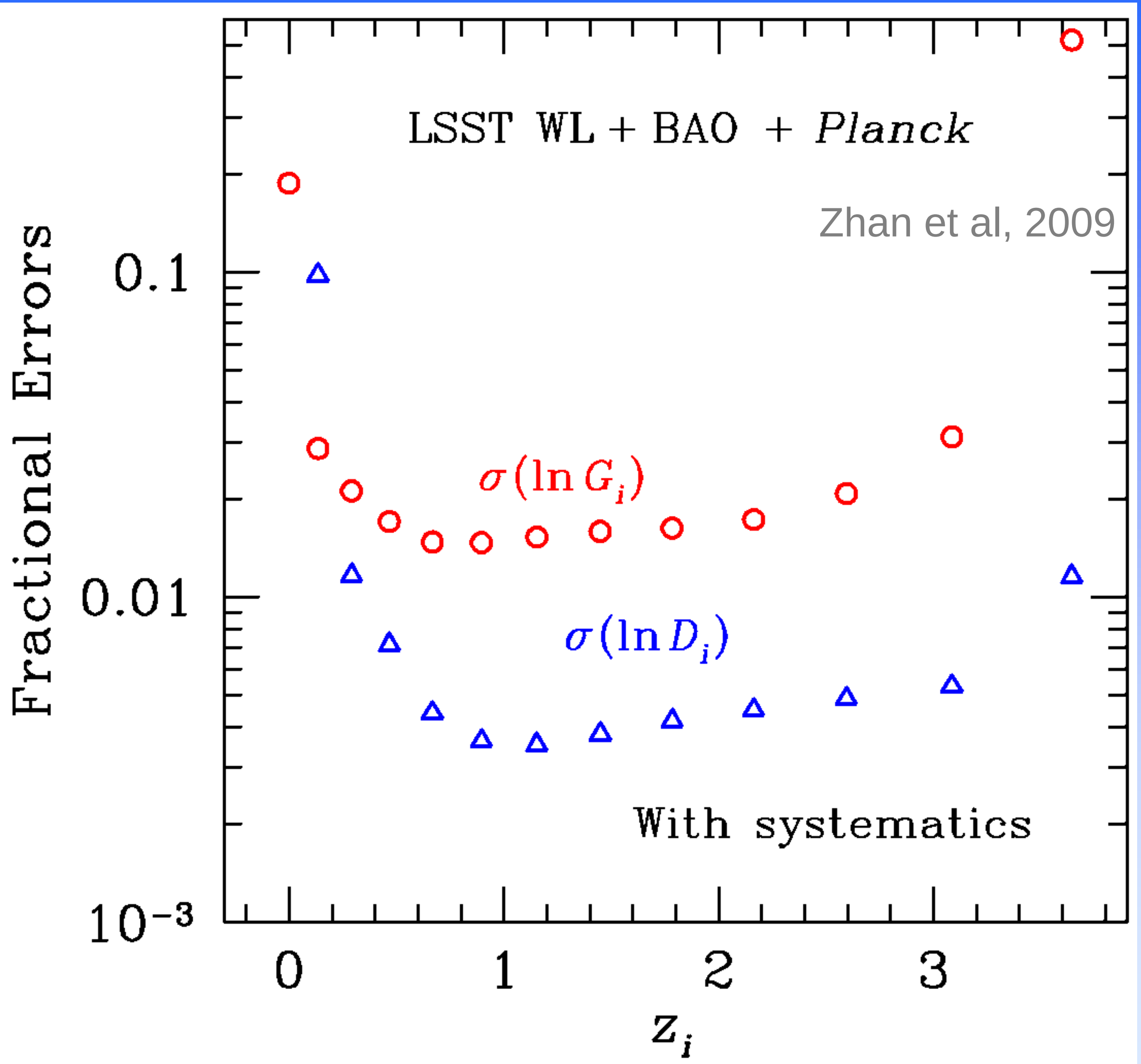
Two Dimensions on the Sky

Angular Diameter Distances

multiple probes of dark energy

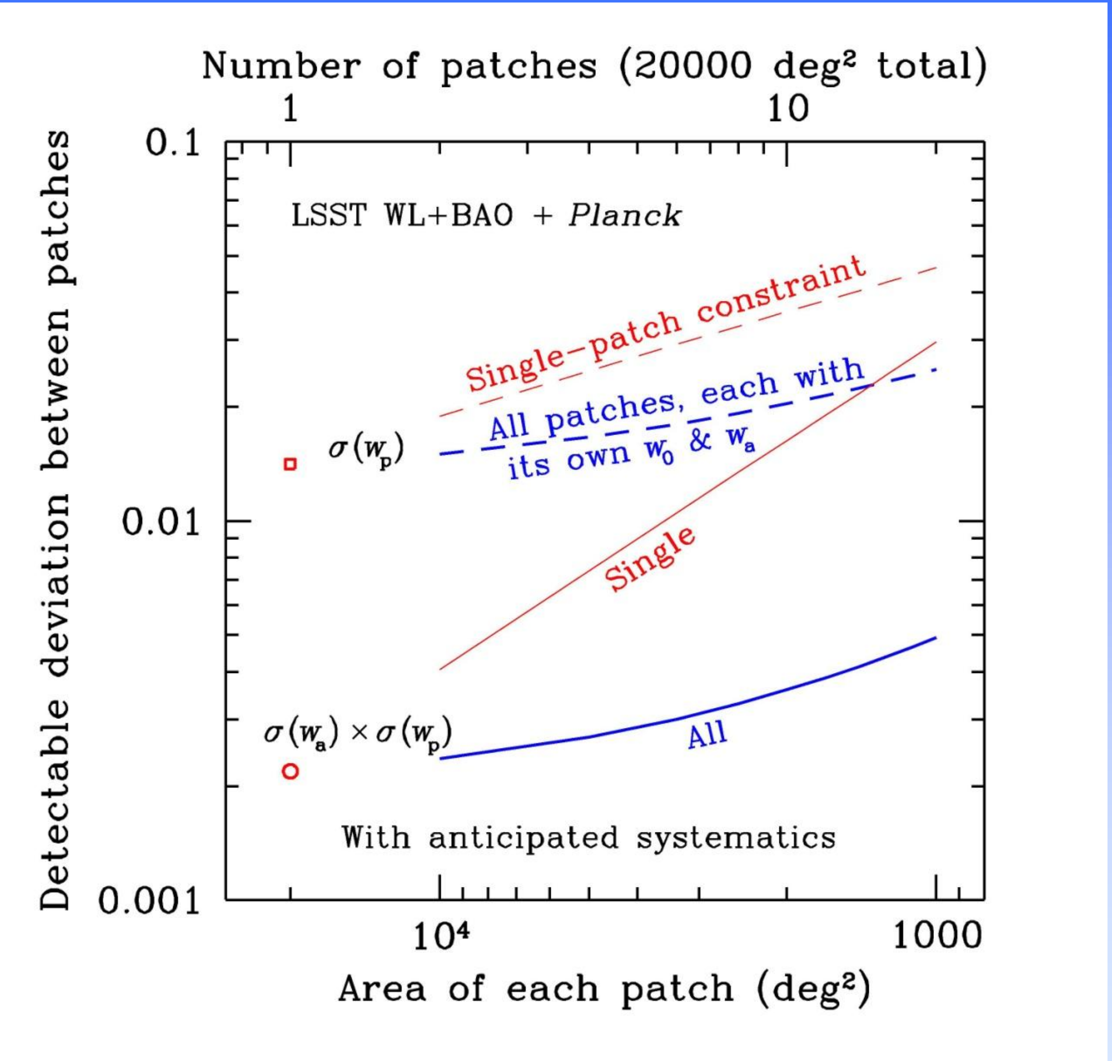
- WL shear-shear tomography
- WL magnification cosmography
- Distribution of 250,000 shear peaks
- 2-D baryon acoustic oscillations
- 1 million SNe Ia, $z<1$ per year
- 2π sky coverage: anisotropy?
  3×10^9 galaxies, 10^6 SNe
- probe growth(z) and d(z) separately
- multiply lensed AGNs and SNe

Testing general models of dark energy



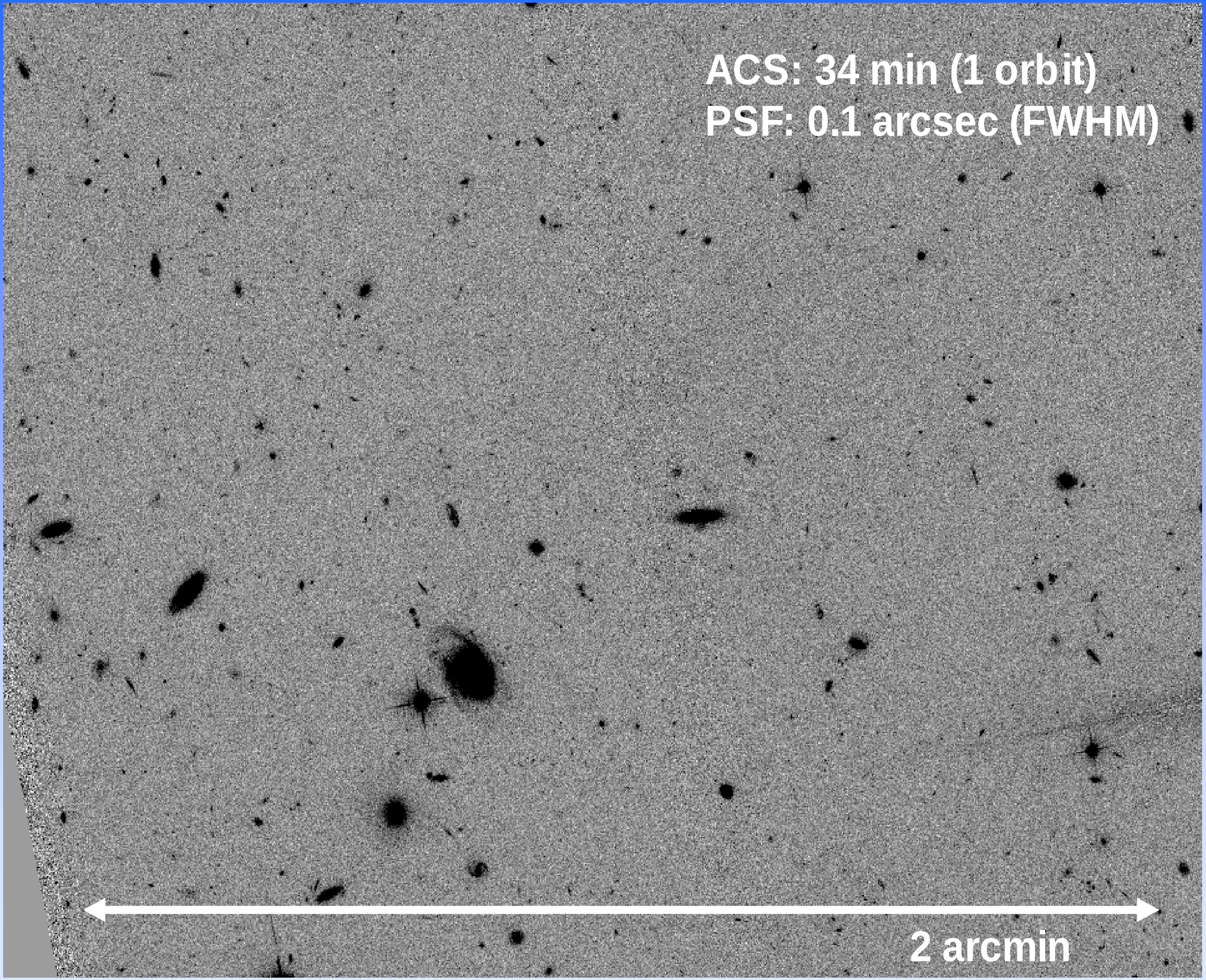
Is dark energy isotropic?

- Incorporating all-sky fits for other cosmology parameters, an LSST search for anisotropy in the EoS is quite sensitive.
- **Shown is the sensitivity to deviation of dark energy EoS and DETF error product over the sky in patches of area A.**
- **This can separately be done with Sne !**

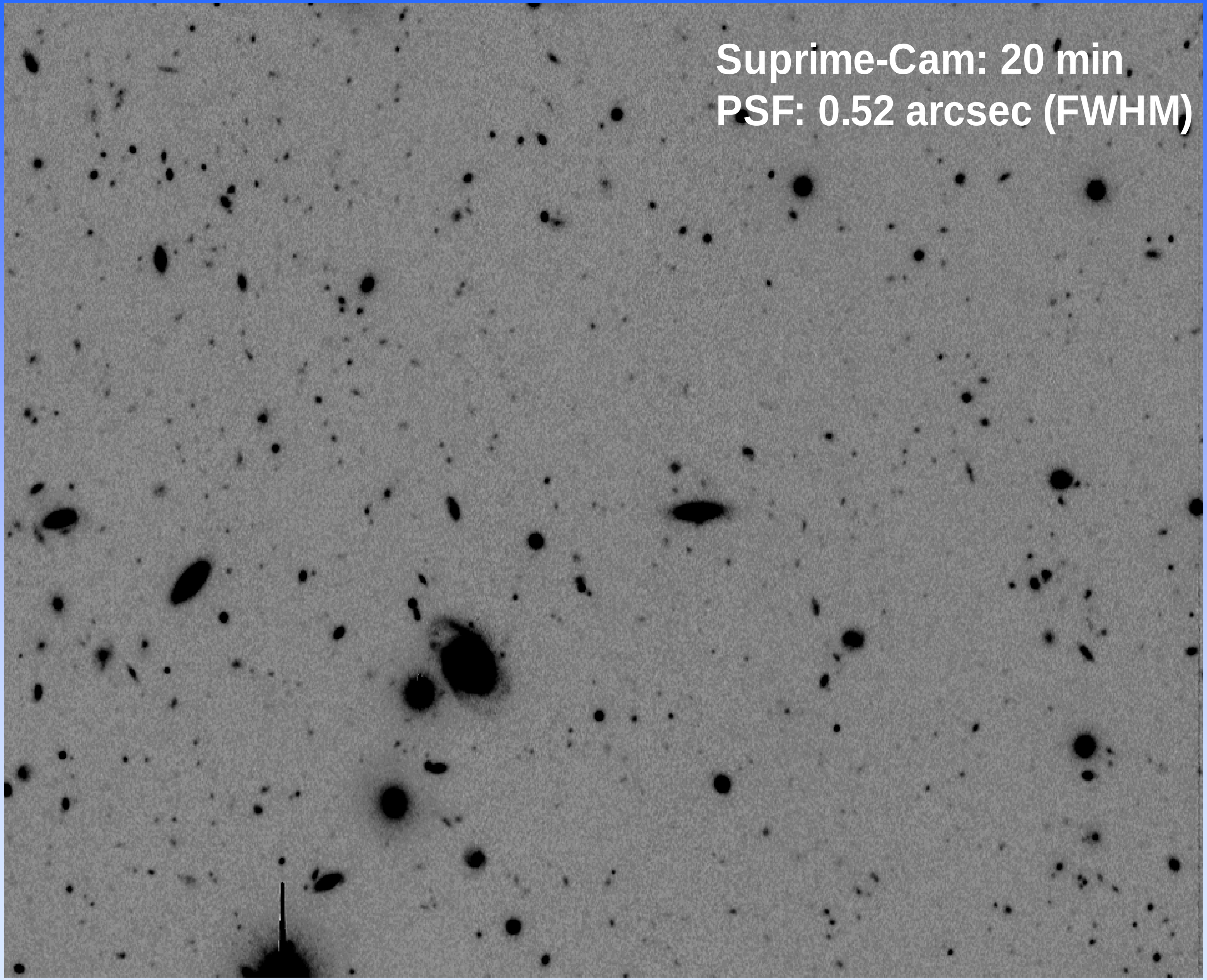


Science Book Ch. 15.4

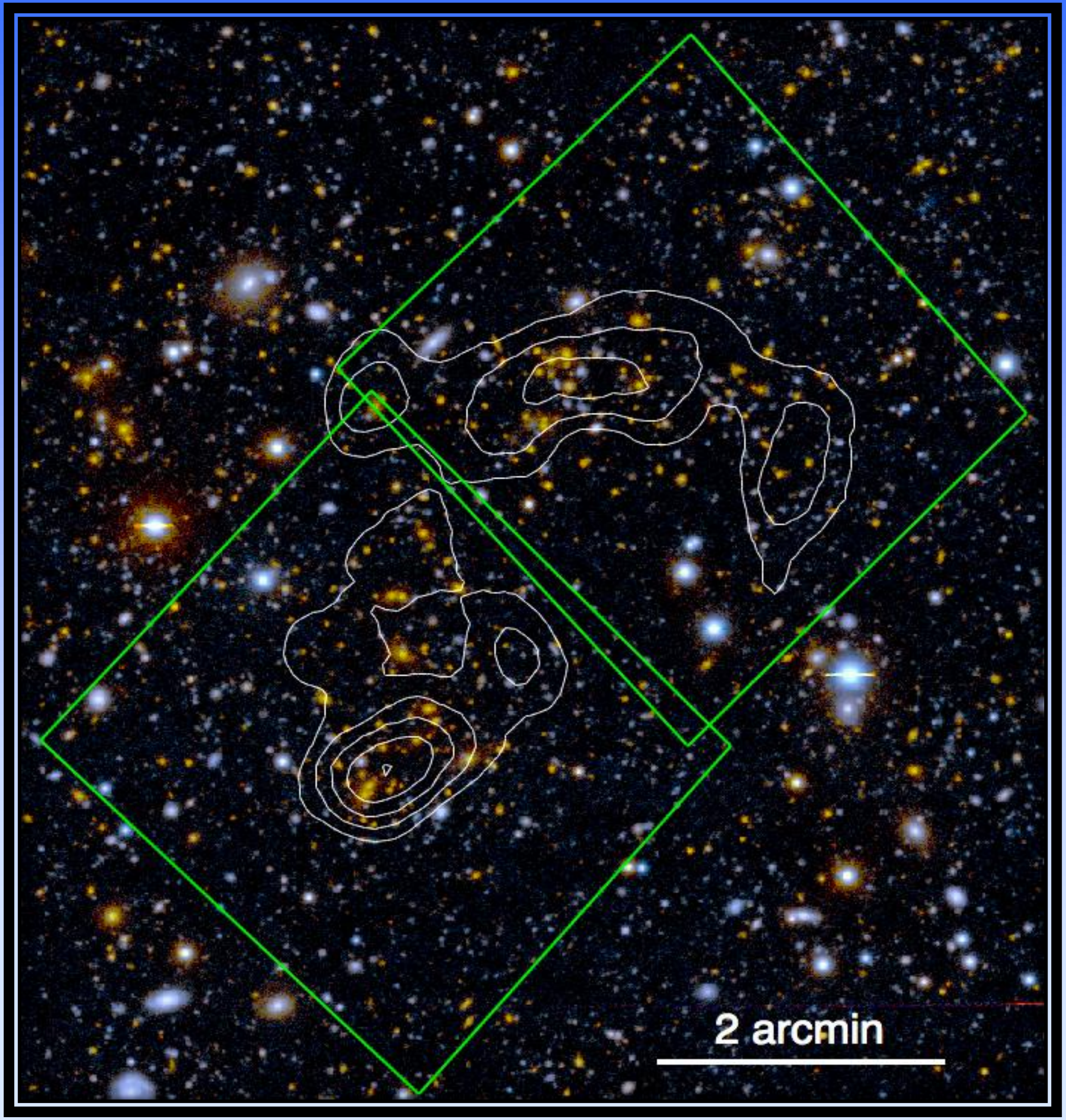
Comparing HST with Subaru



Comparing HST with Subaru

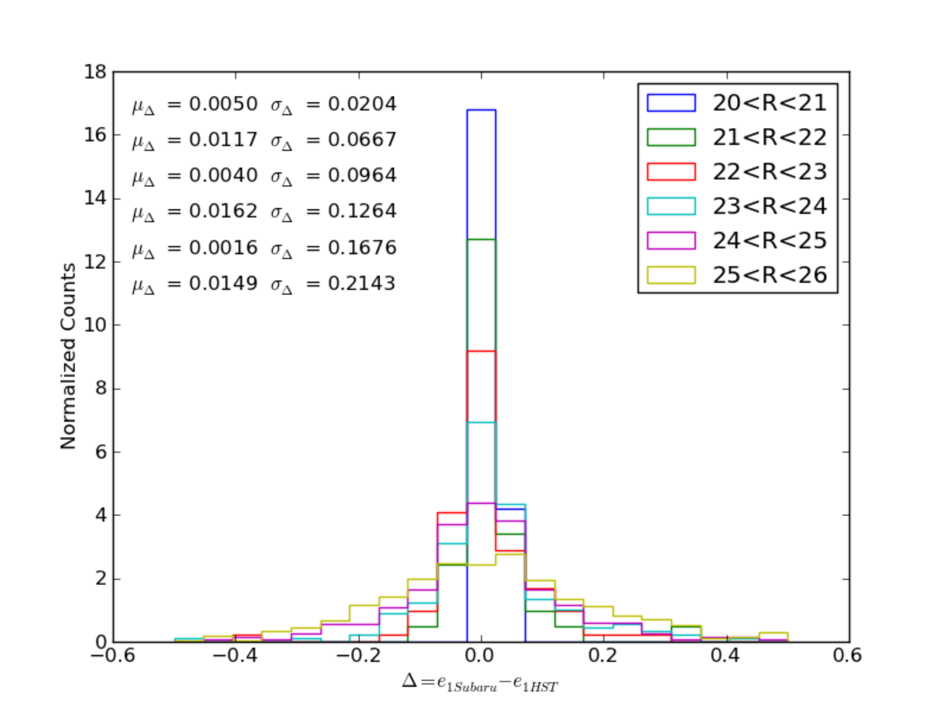


Deep Lens Survey image (+mass contours) and HST footprint of cluster

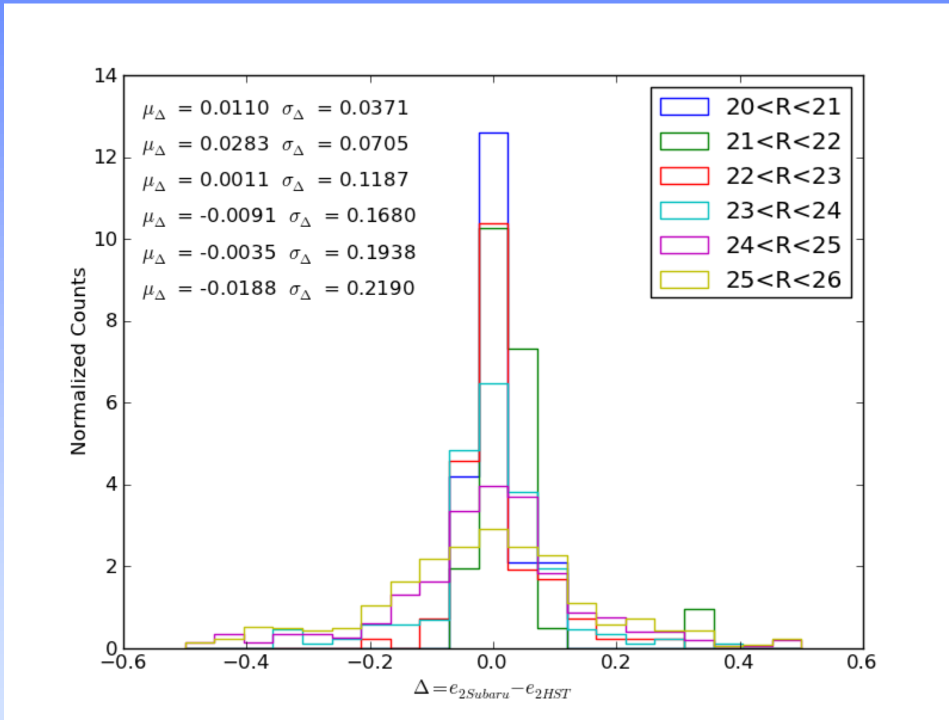


Subaru-HST Shape Comparison

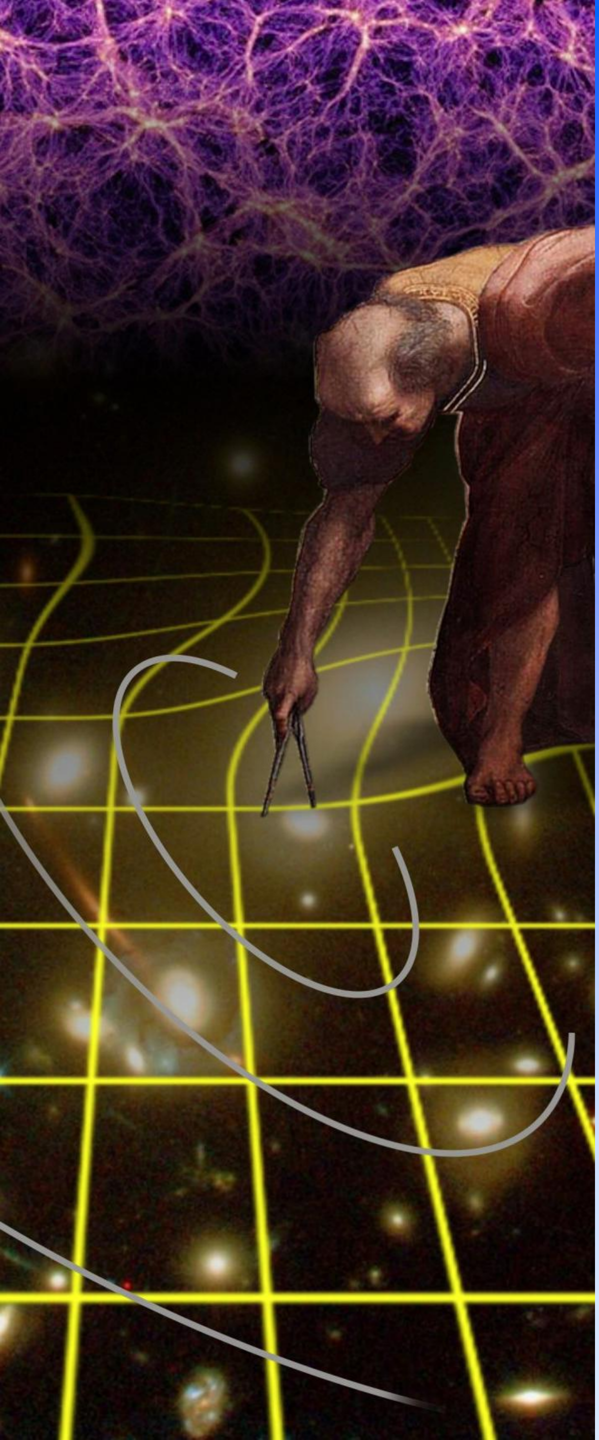
$e_{1\ Subaru}-e_{1\ HST}$



$e_{2\ Subaru}-e_{2\ HST}$



Binned by magnitude.



Synergy with Euclid

Photometry

LSST: 6-band deep optical photometry to r=27.5AB + *Time Domain*

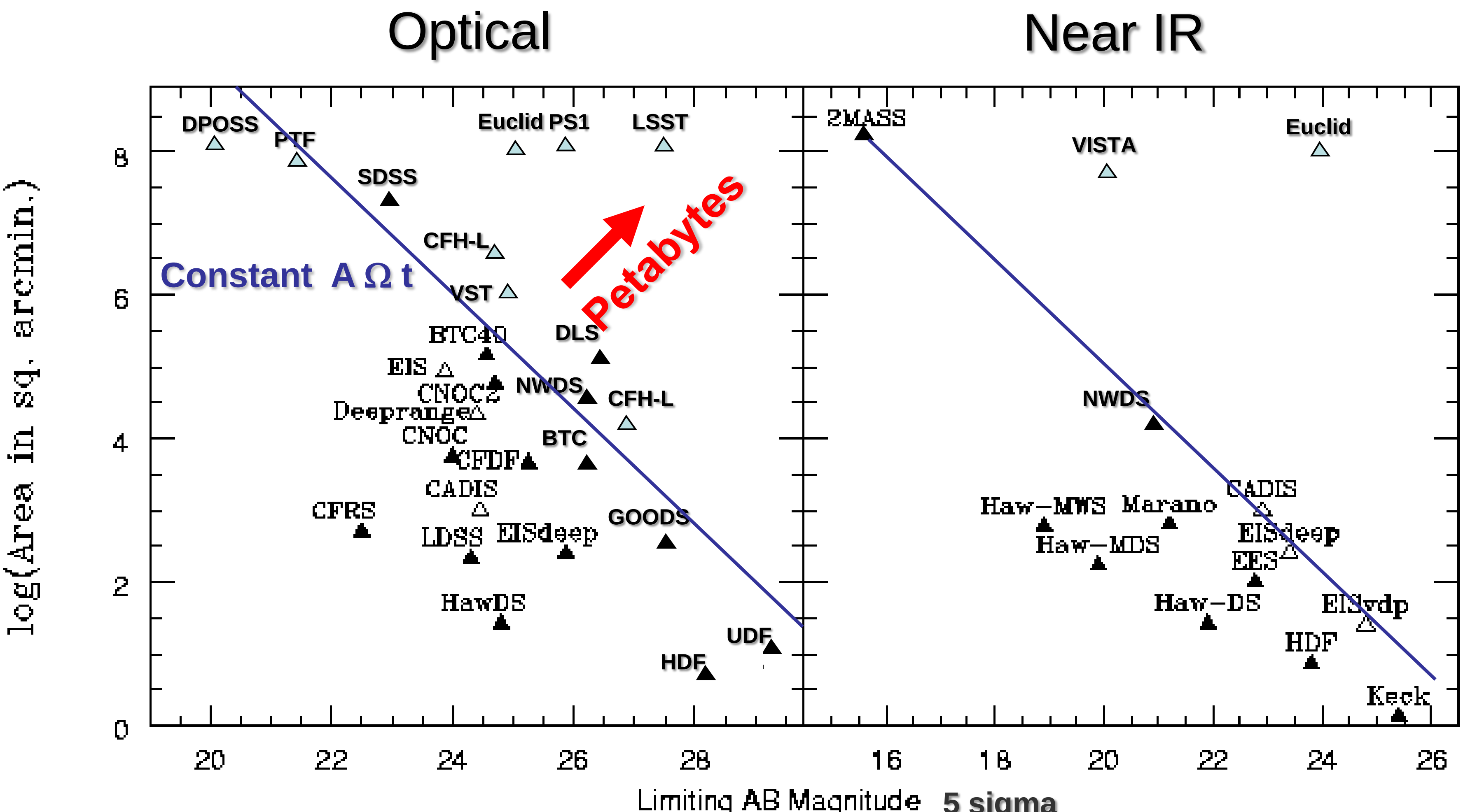
Euclid: J, H photometry to 24AB

Shapes of galaxies in the optical

LSST: 40/ square arcmin at low surface brightness with 0.6” FWHM

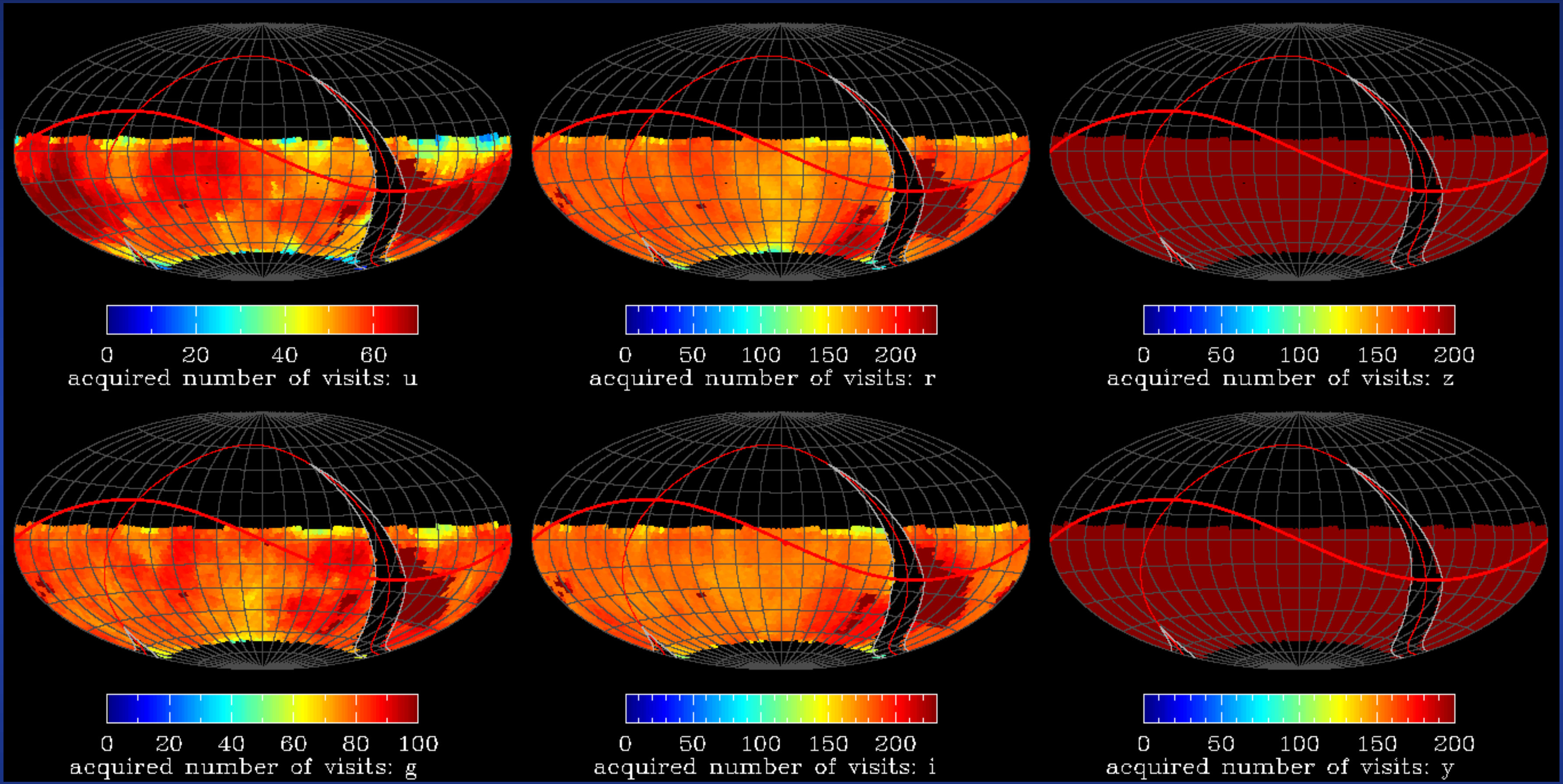
Euclid: 40/ square arcmin 0.16” FWHM

Optical and Near IR Sky Surveys



Spectroscopic Follow-up

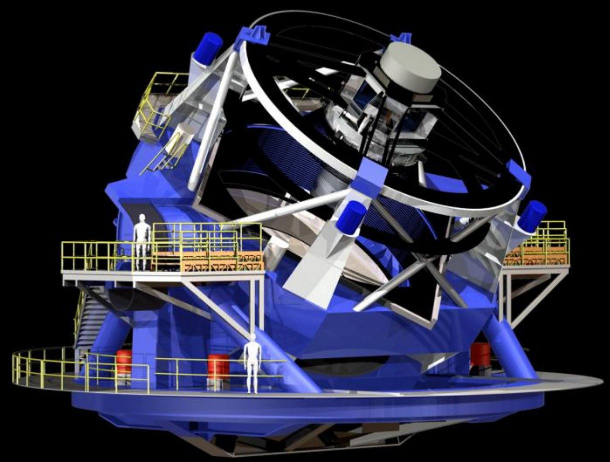
Number of visits per field in LSST Deep Wide Survey

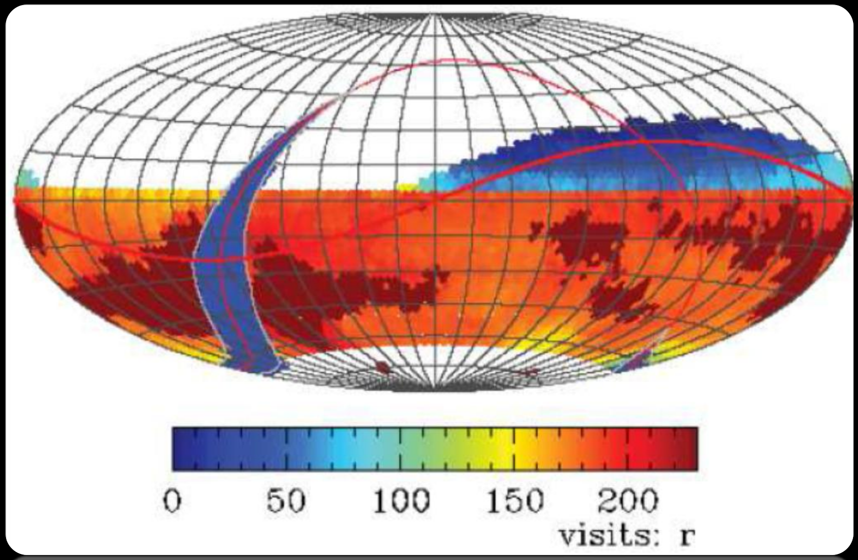


LSST: A Deep, Wide, Fast, Uniform Sky Survey

8.4m telescope | 18000+ deg^2 | 10mas astrom. | r<24.5 (<27.5@10yr)

ugrizy | 0.5-1% photometry





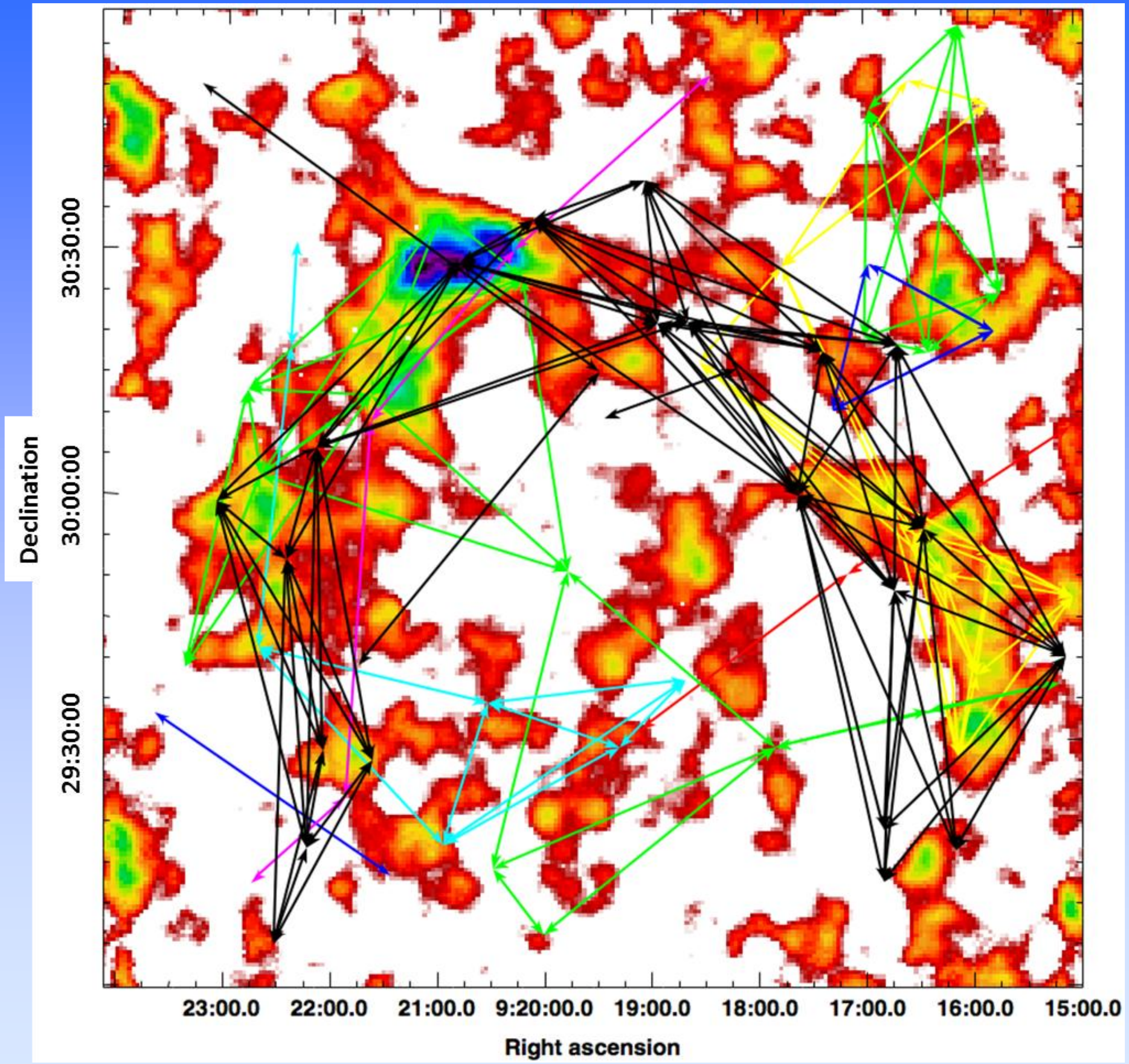
3.2Gpix camera | 2x15sec exp/2sec read | 15TB/night | 20 B objects

Imaging the visible sky, once every 3 days, for 10 years (825 revisits)

- Finally, some applications of the shear estimation and photo-z algorithms developed for LSST data analysis to a current deep survey:

- about1 million galaxies in the Deep Lens Survey

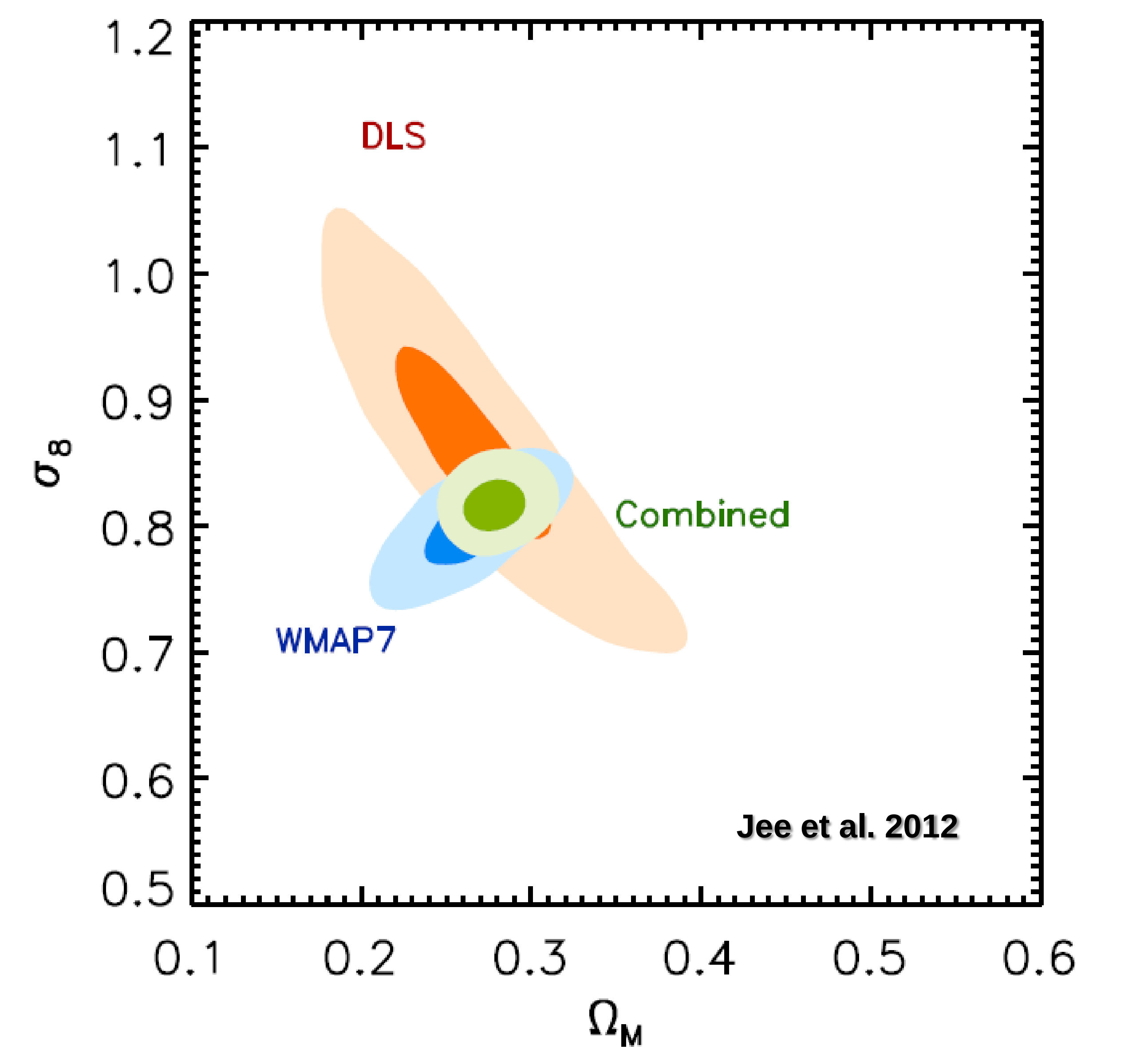
Weak lens detection of mass filaments in one 2x2 degree field of the Deep Lens Survey



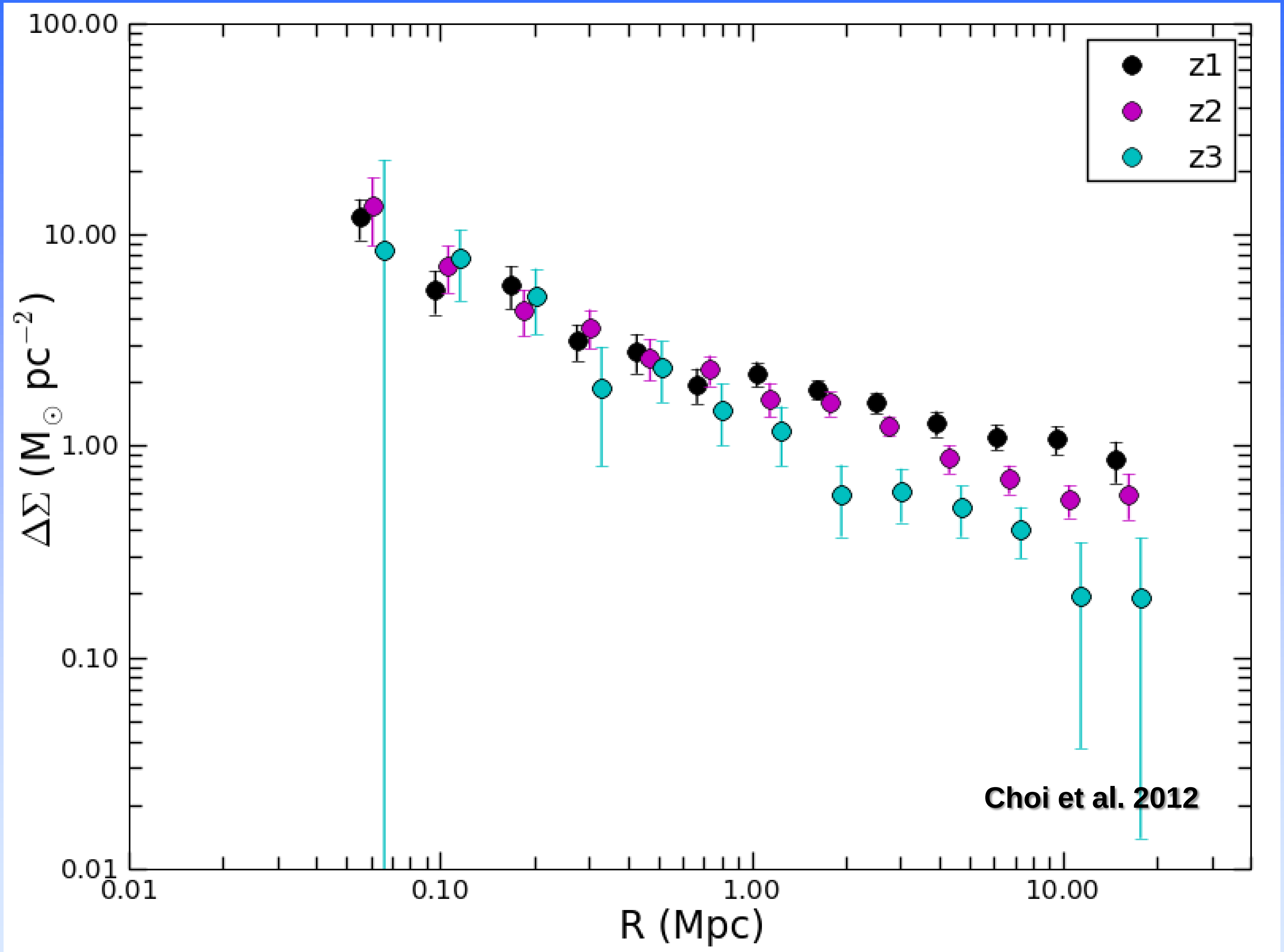
Dawson, 2012

Redshift tesselation coding: 0.3=black, 0.4=blue, 0.45=green, 0.5=yellow, 0.6=red

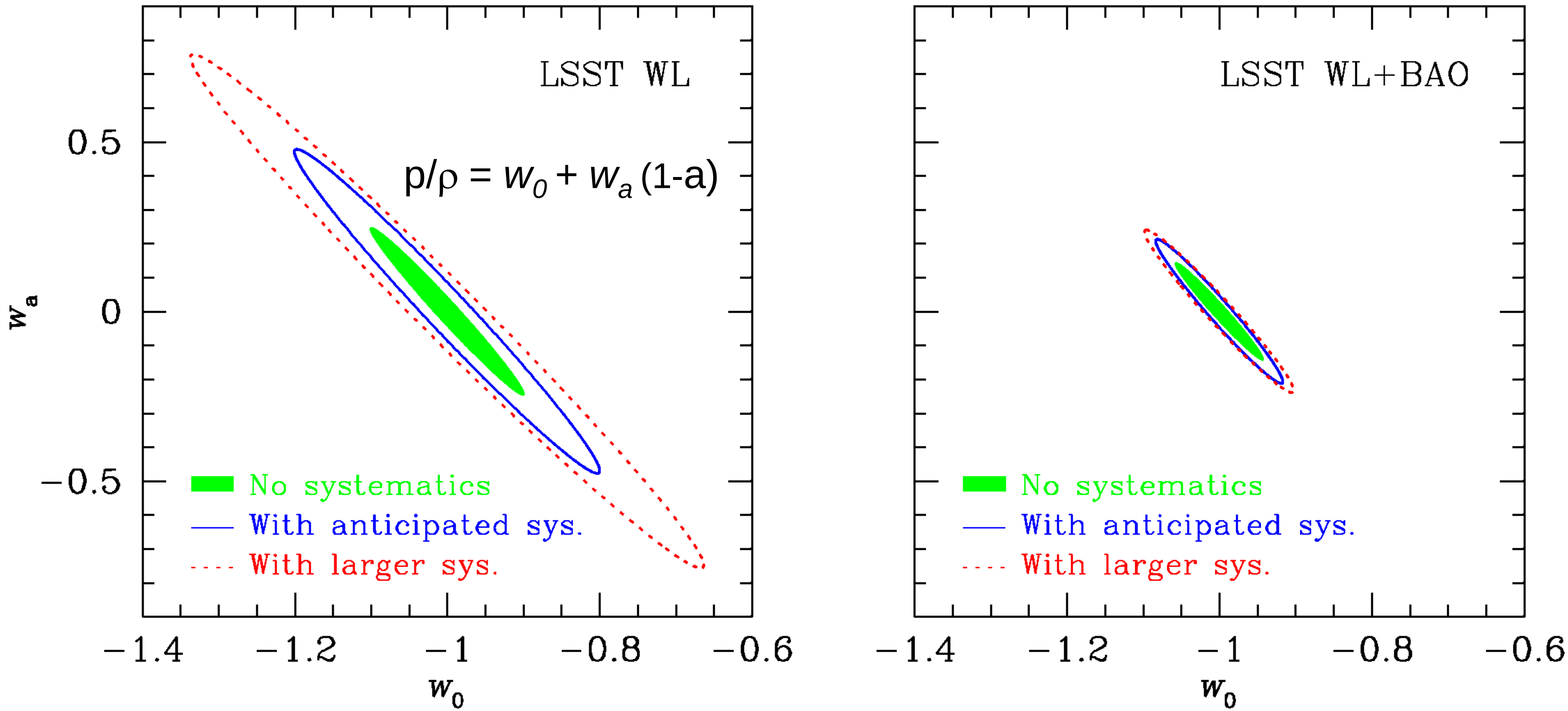
Weak lens measurement of mass power spectrum normalization in the Deep Lens Survey



Weak lens detection of evolution of large-scale mass structures: 1 million galaxies in Deep Lens Survey



Reduced sensitivity to systematic error



Combining WL and BAO breaks degeneracies.

Joint analysis of WL & BAO is far less affected by systematics.

marginal advantage of adding 3D BAO

- **Adding Stage IV 3D BAO to LSST combined probes results in a slight advantage in dark energy figure of merit.**

- **Main 3D BAO advantage would rather lie elsewhere:**

1. **H(z)**
2. **Calibration in overlap area**