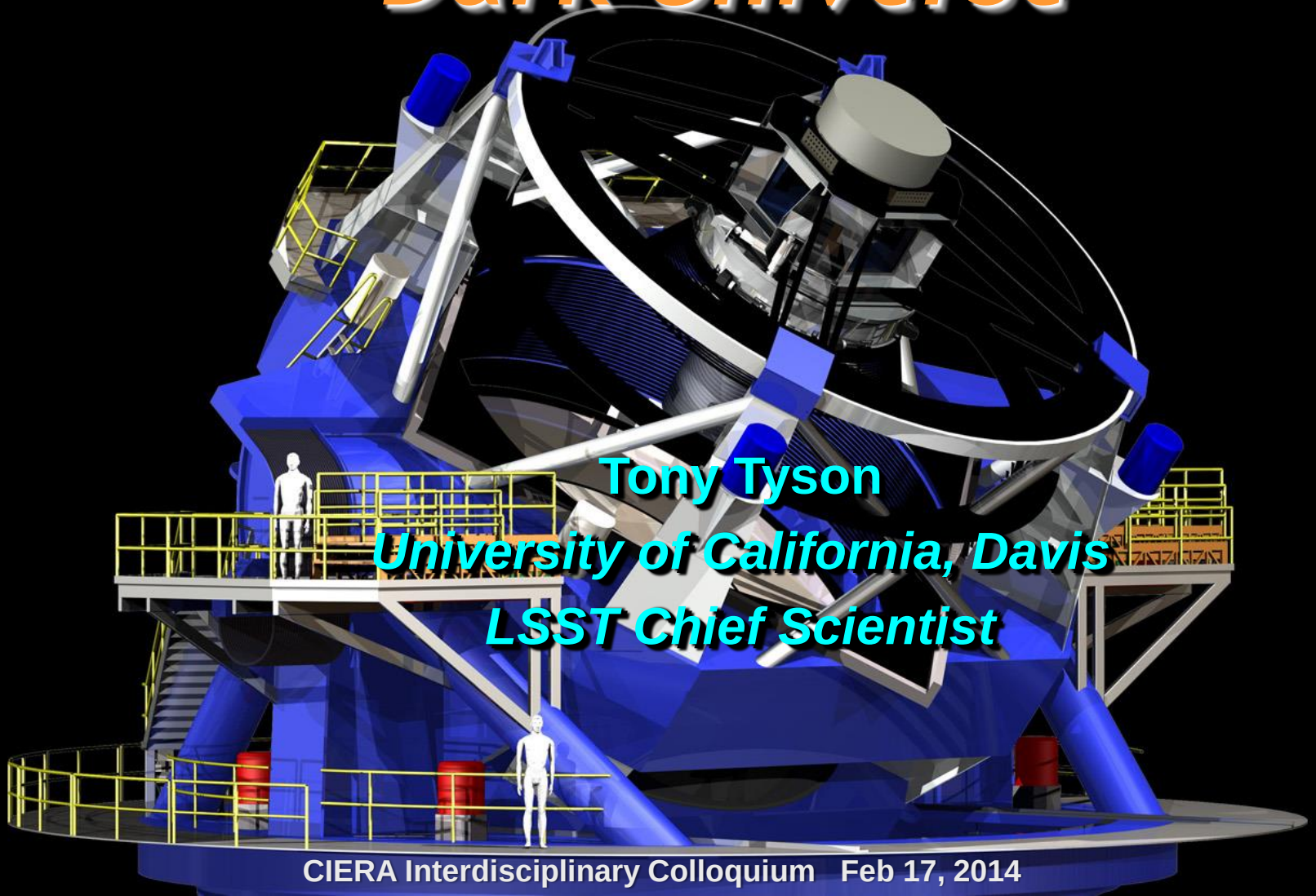
LSST and the Physics of the Dark Universe



Tony Tyson

University of California, Davis

LSST Chief Scientist

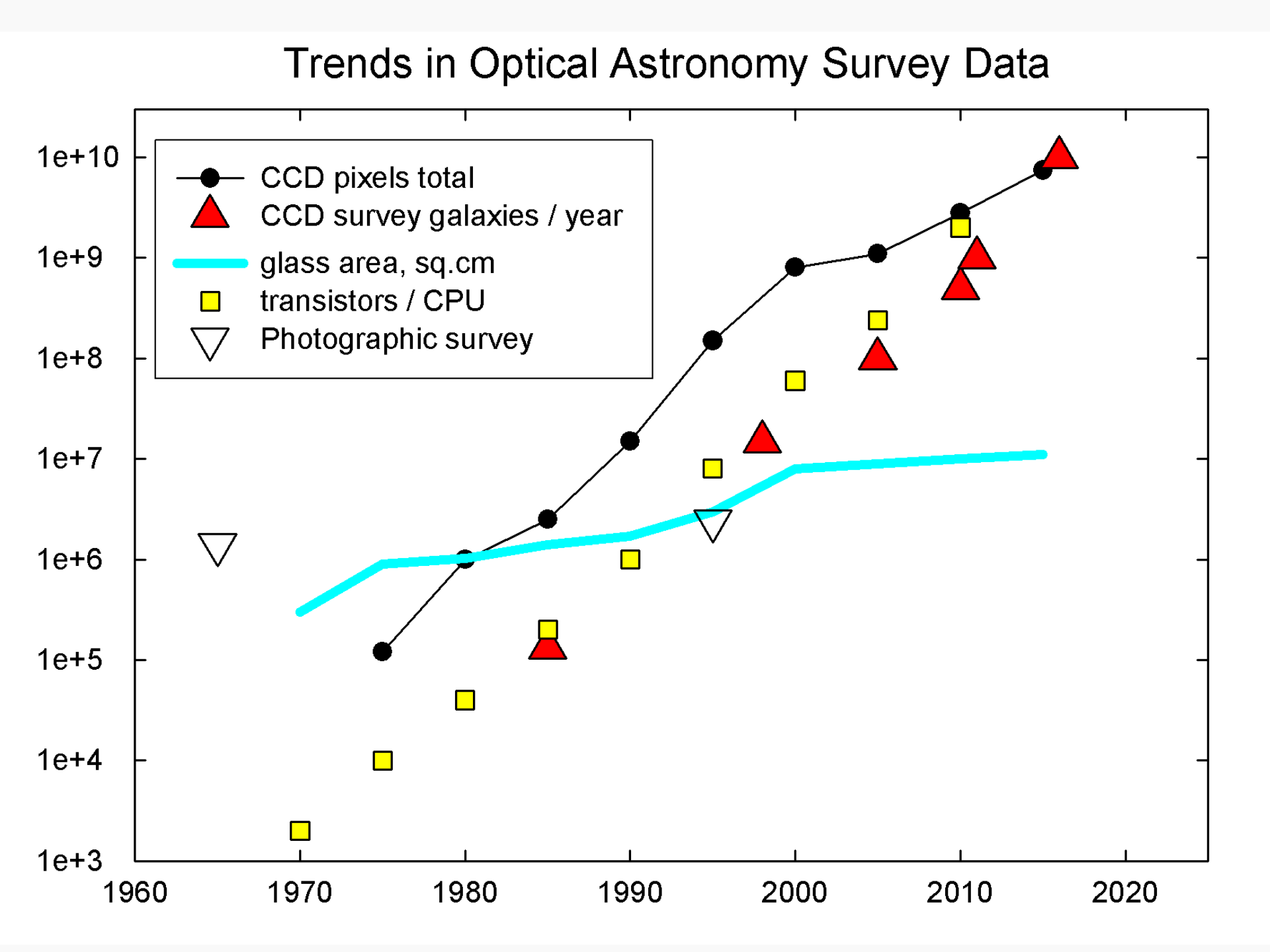
Exploration

- Wavelength
- Angular resolution
- Sky area surveyed
- Depth
- Time resolution

wide fast deep

Technology drives the New Sky

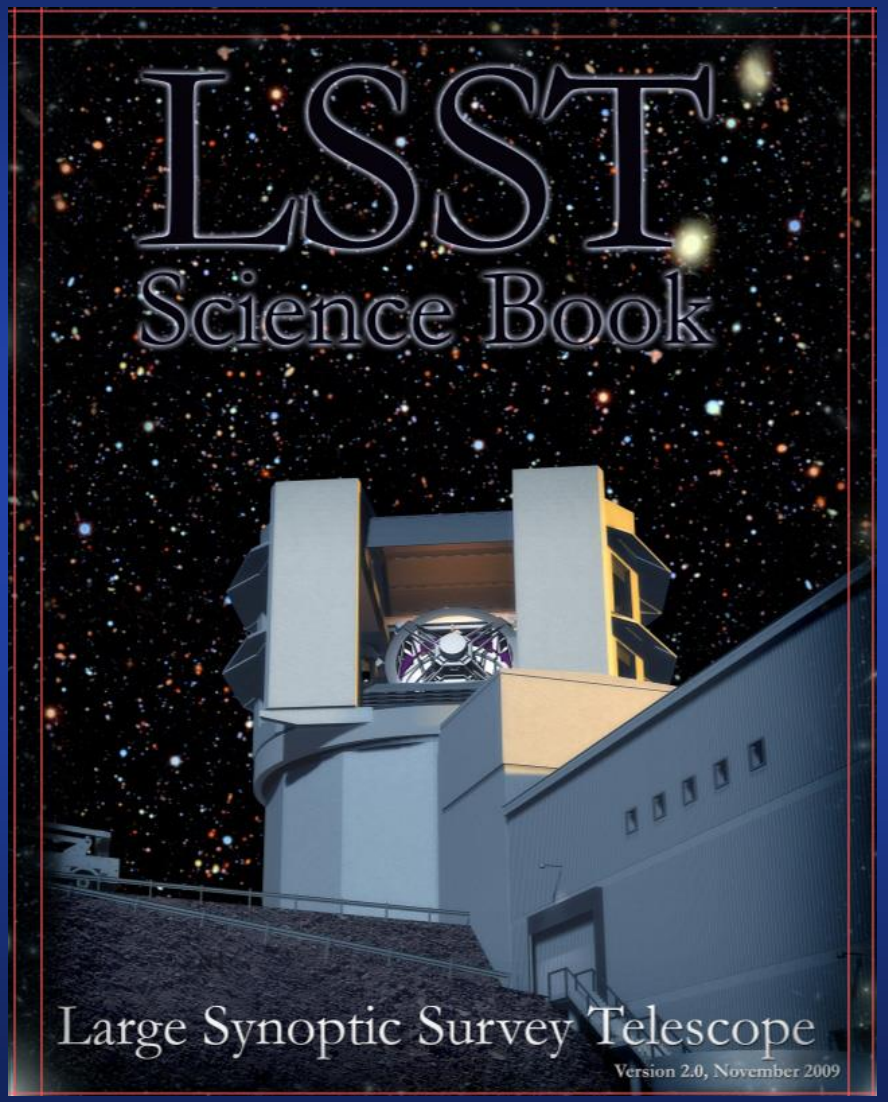
- Microelectronics
- Software
- Large Optics Fabrication


Trends in Optical Astronomy Survey Data
CCD pixels total
CCD survey galaxies / year
glass area, sq.cm
transistors / CPU
Photographic survey
1e+10
1e+9
1e+8
1e+7
1e+6
1e+5
1e+4
1e+3
1960
1970
1980
1990
2000
2010
2020

LSST Science Book v2.0 written by LSST Collaboration

- 245 authors
- 598 pages
- Living document
  (on lsst.org)

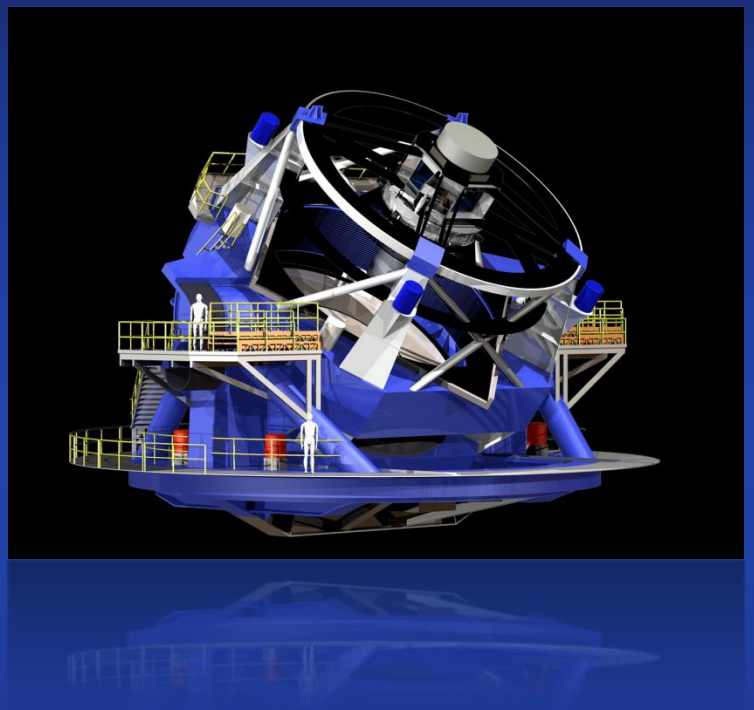
http://www.lsst.org/lsst/scibook



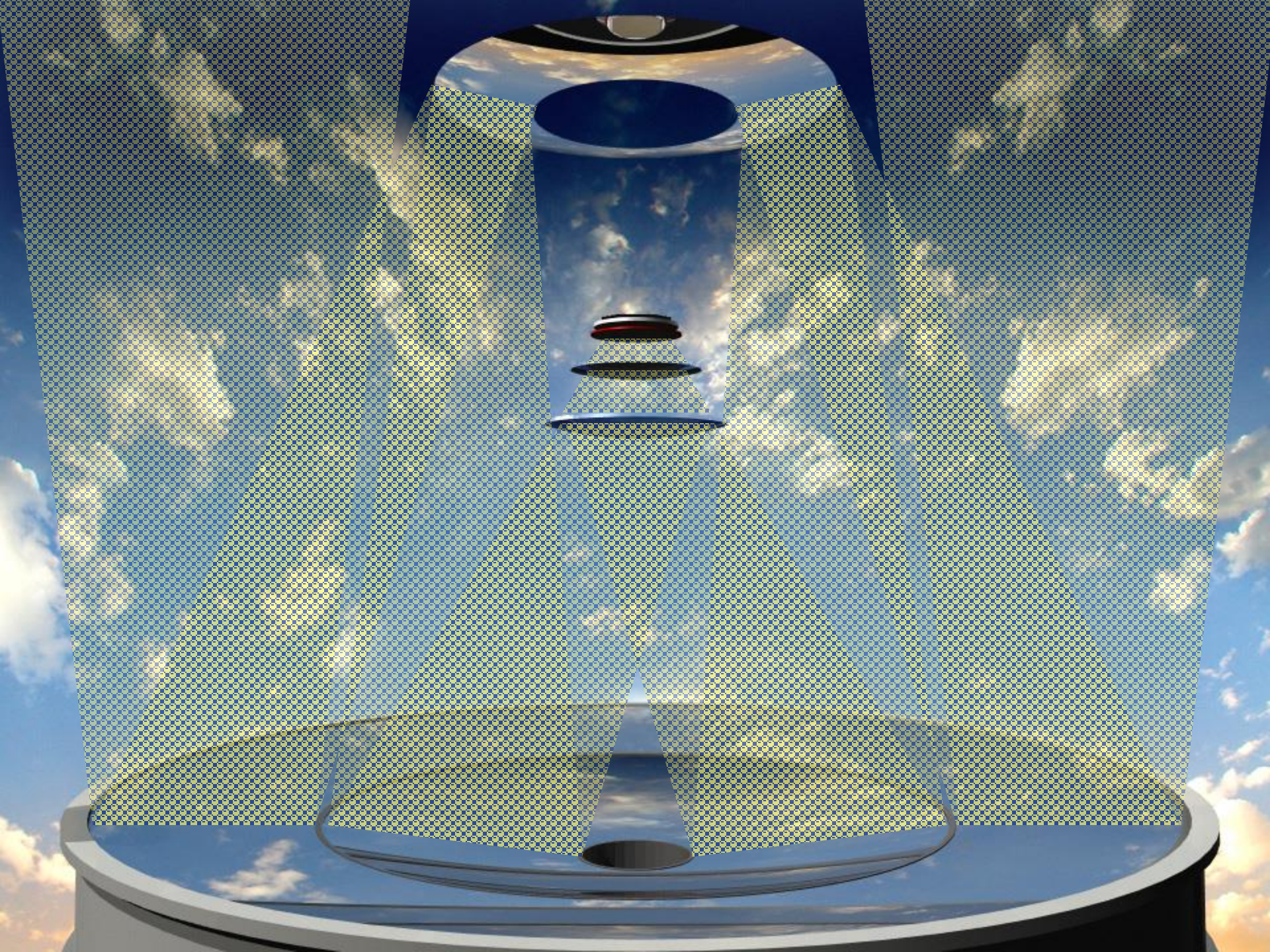
11 Science Collaborations.
Science by community, not the LSST project.

The Science Enabled by LSST

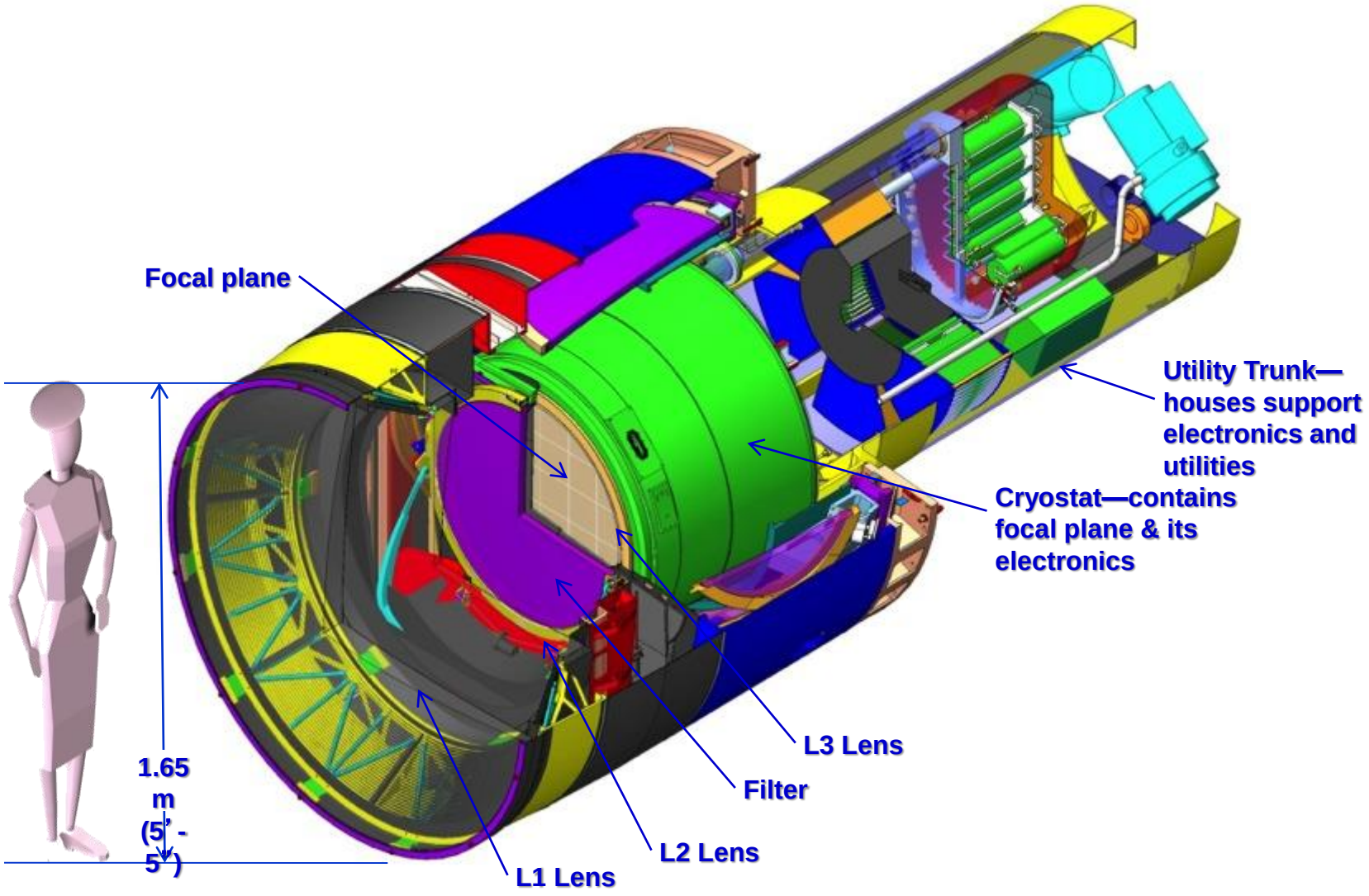
- Time domain science
  - Novae, supernovae, GRBs
  - Source characterization
  - Instantaneous discovery
- Finding moving sources
  - Asteroids and comets
  - Proper motions of stars
- Mapping the Milky Way
  - Tidal streams
  - Galactic structure
- Dark energy and dark matter
  - Gravitational lensing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



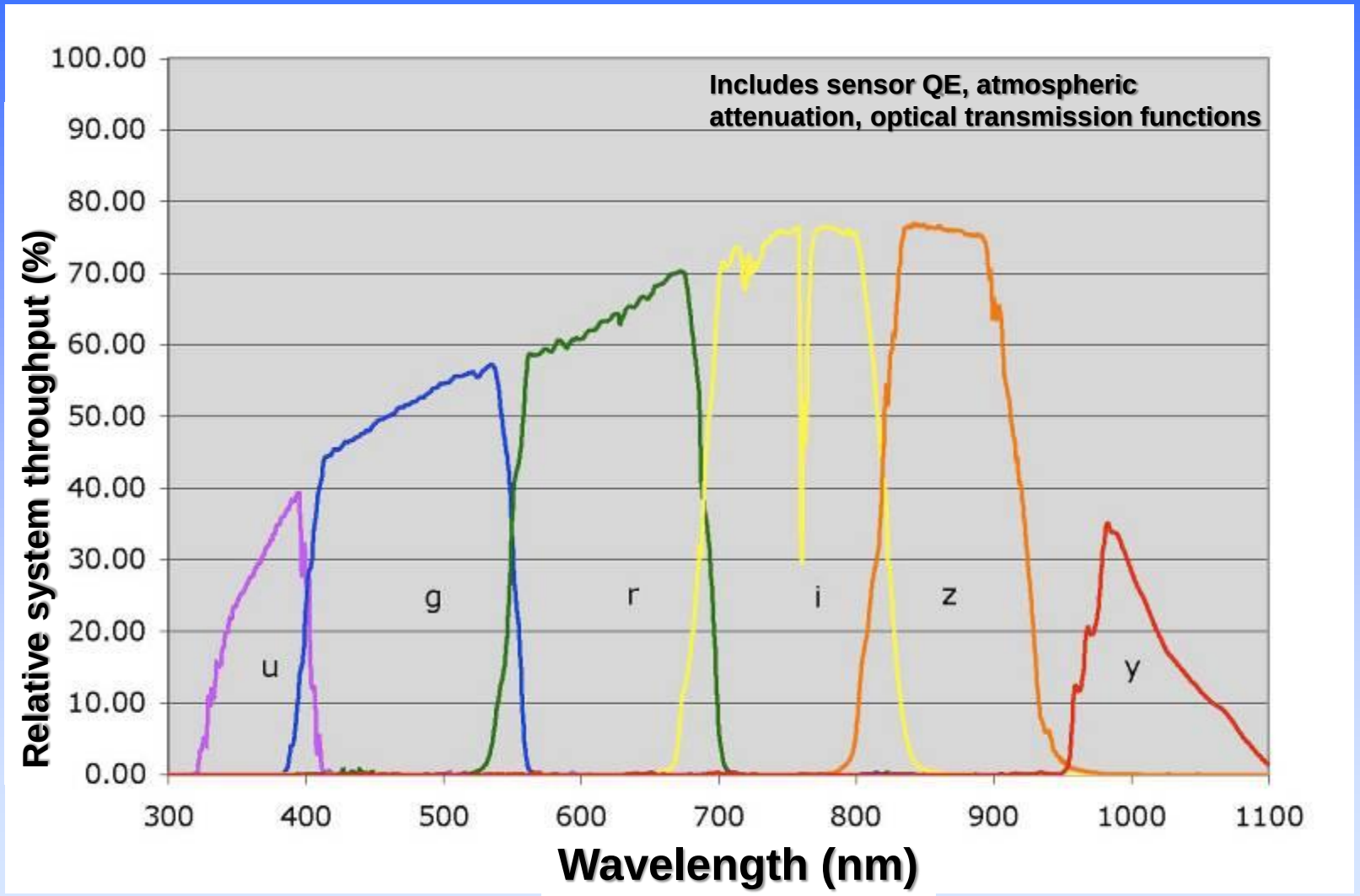
How does one do research when faced with trillions of catalog entries, and potentially millions of measurements for each class of objects?



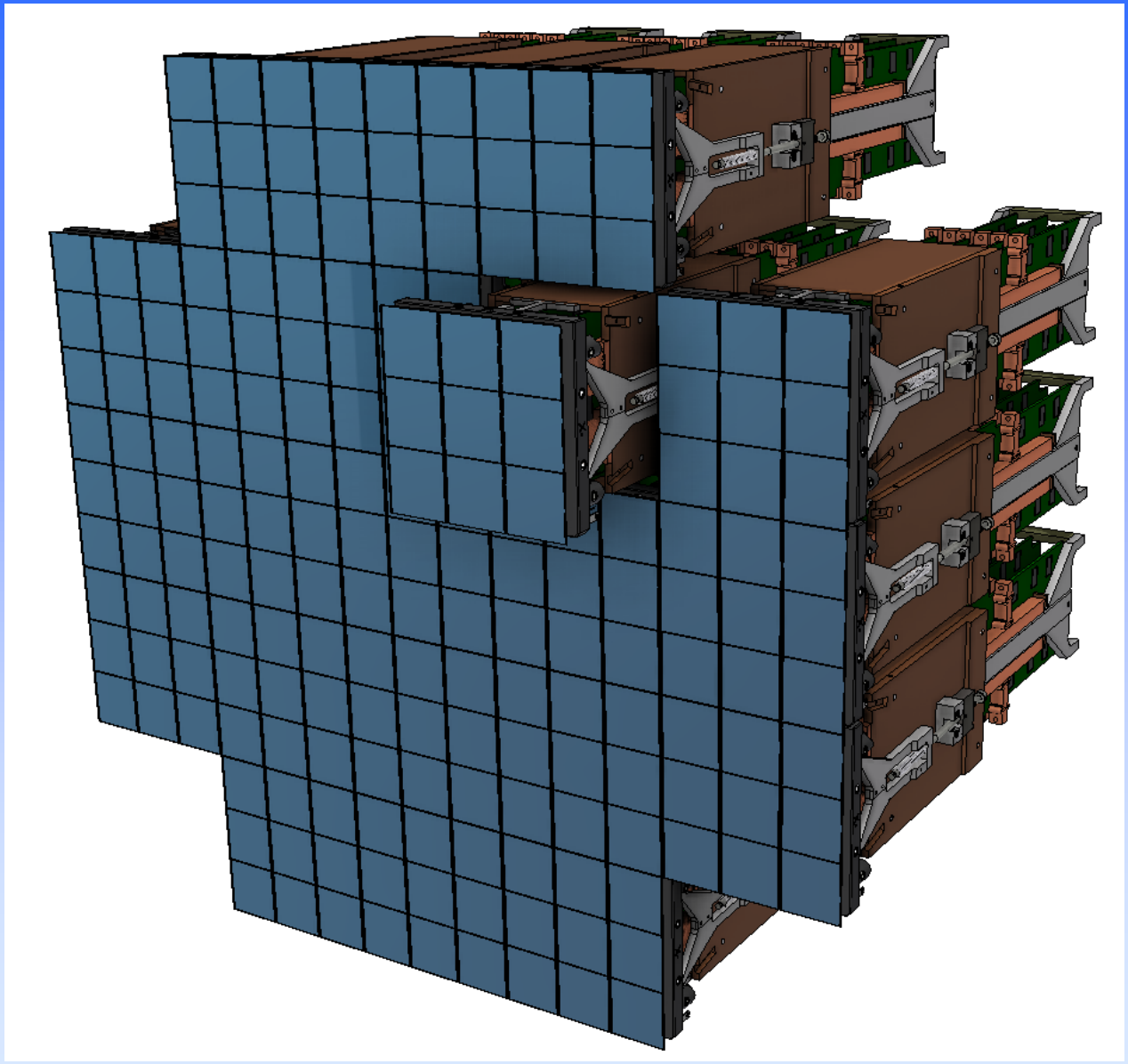
3.2 Billion Pixel Camera, 10 sq.deg Field



LSST six color system



21 science rafts, 189 4K x 4K CCDs



21 “rafts”

9 CCDs per raft

Data Management Sites and Centers

HQ Site
HQ Facility
- Observatory Management
- Science Operations
- Education and Public Outreach

AURA

LSST Corporation

Archive Site
Archive Center
- Alert Production
- Data Release Production
- Calibration Products Production
- EPO Infrastructure
- Long-term Storage (copy 2)

Data Access Center
- Data Access and User Services

French Site
Processing Center
- Data Release Production

Base Site
Base Facility
- Long-term storage (copy 1)

Data Access Center
- Data Access and User Services

Summit Site
Summit Facility
- Telescope and Camera Data Acquisition
- Crosstalk Correction

LSST surveys entire sky south of +15^{O} dec with rapid 10 sq.deg exposures

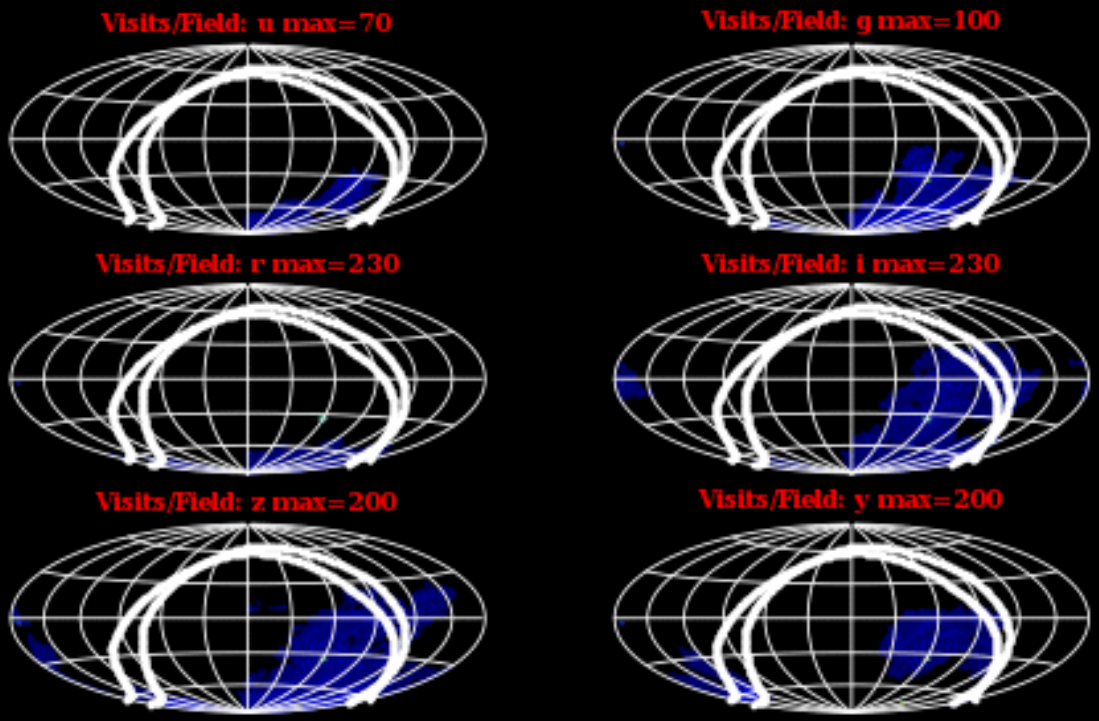
TWO PLANNED SURVEYS:

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

Most of sky covered over 800 times with 30s visits. Alerts on transient objects released worldwide within 60s.

Celestial Cinematography



Sloan Digital Sky Survey

One quarter the diameter of the moon

LSST -- almost

LSST Wide-Fast-Deep survey

A survey of 37 billion objects

in space and time

Each sky patch will be visited over 800 times:

30 trillion measurements

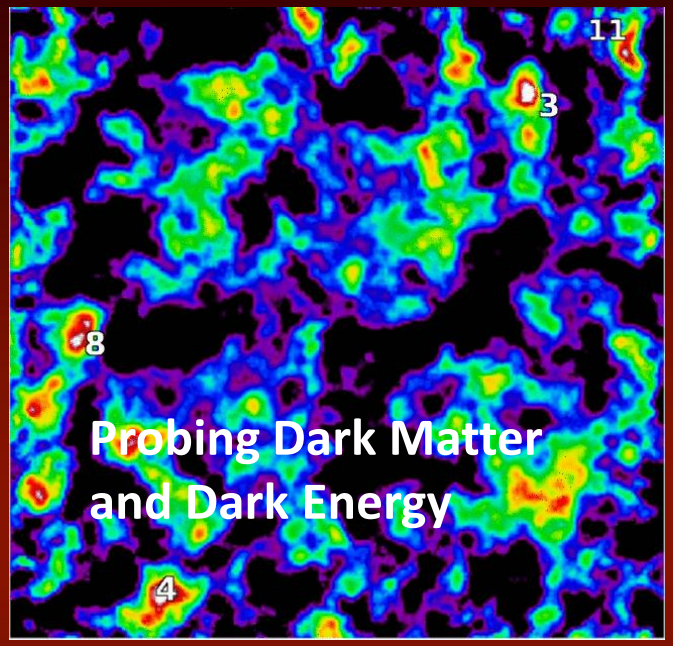
DATA PRODUCTS

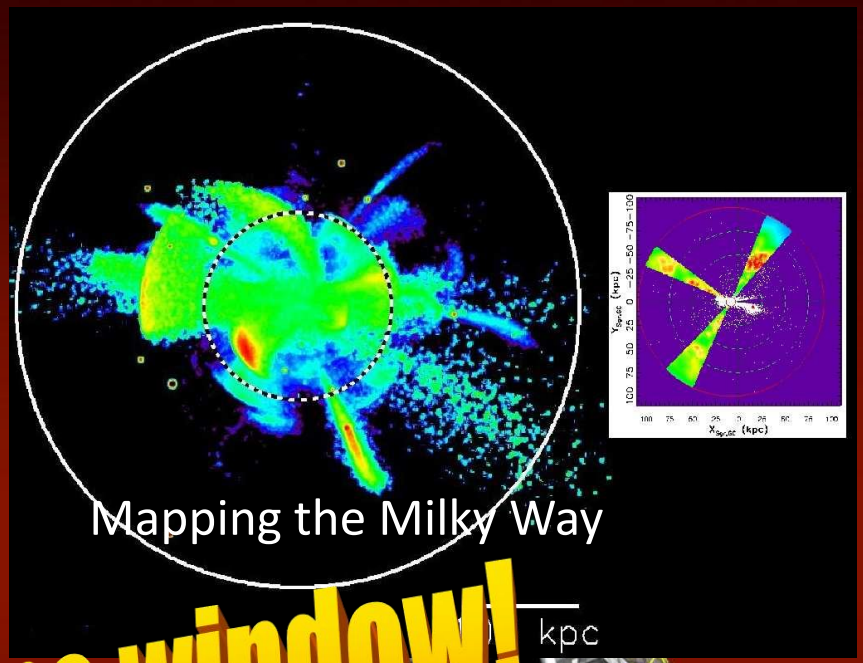
Application Layer -
Generates open, accessible data products with fully documented quality

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

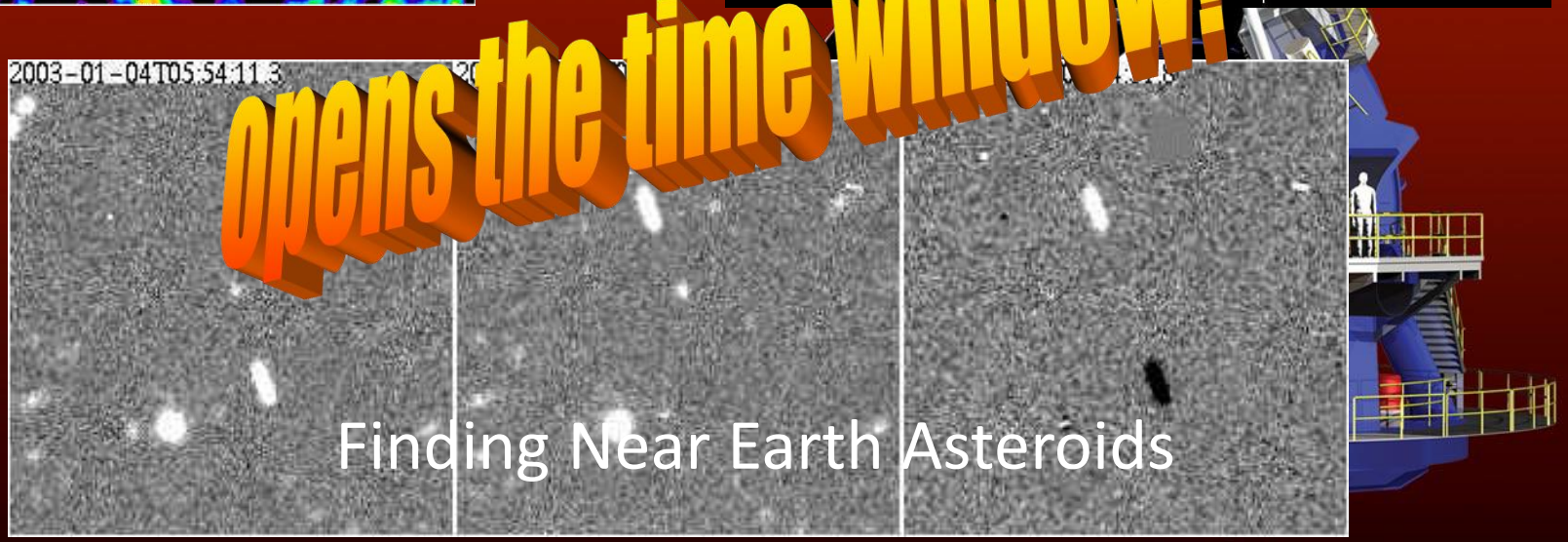
The new sky

Large Synoptic Survey Telescope

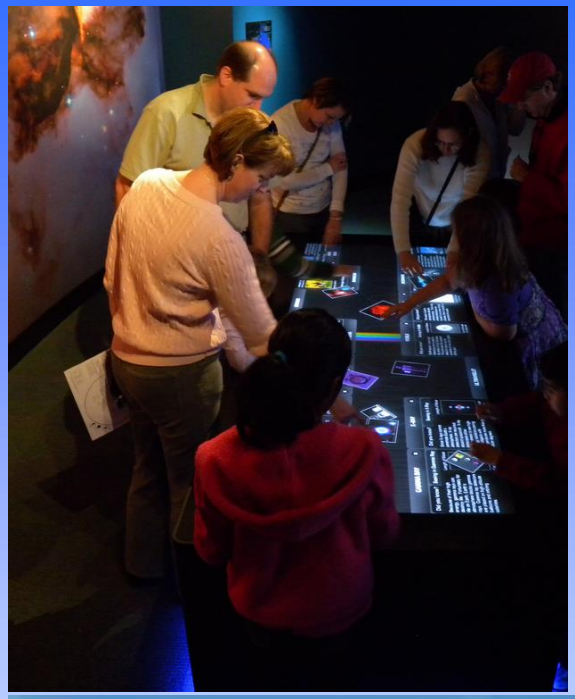




opens the time window!



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

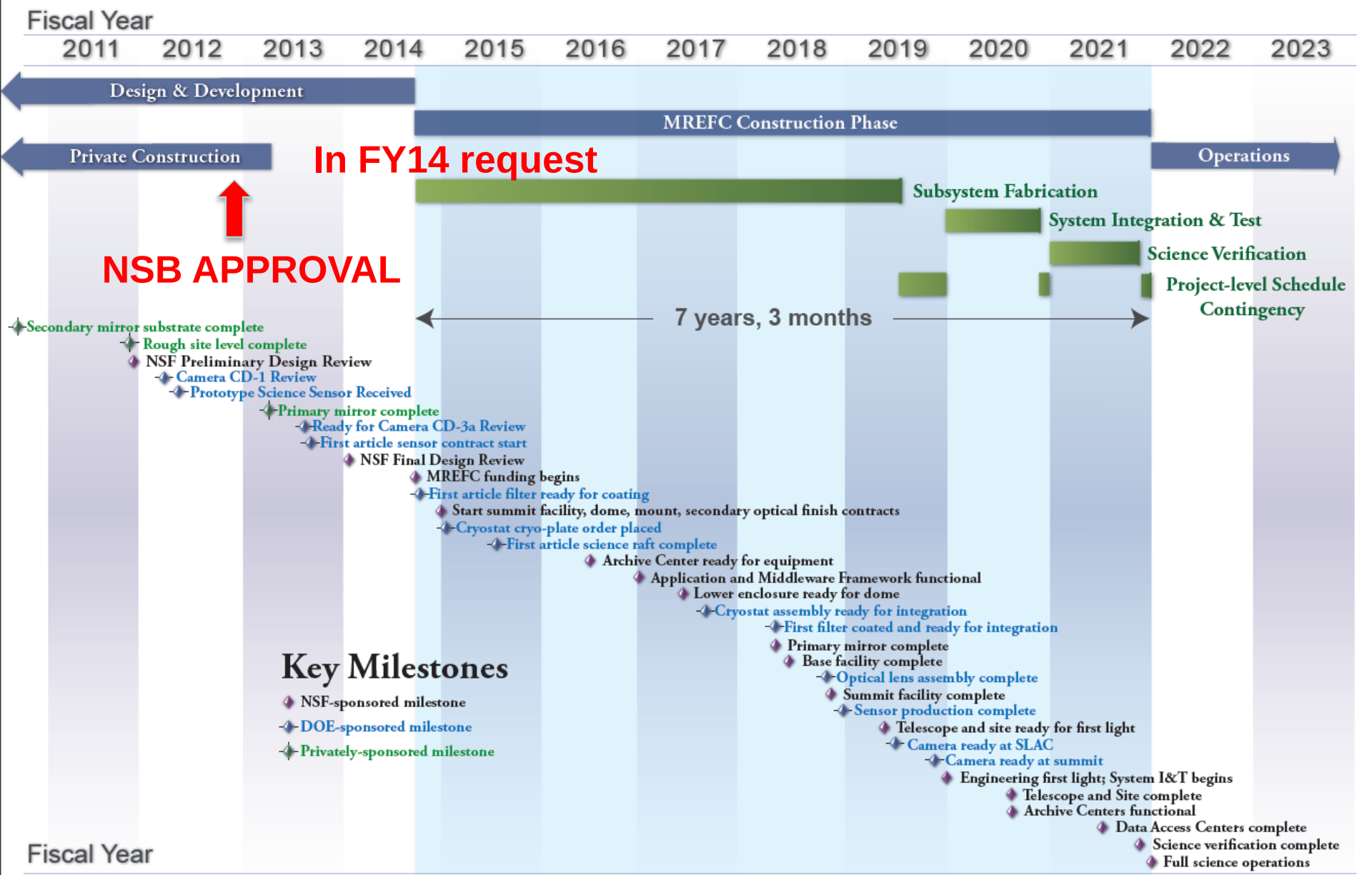


Classroom Emphasis on:

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

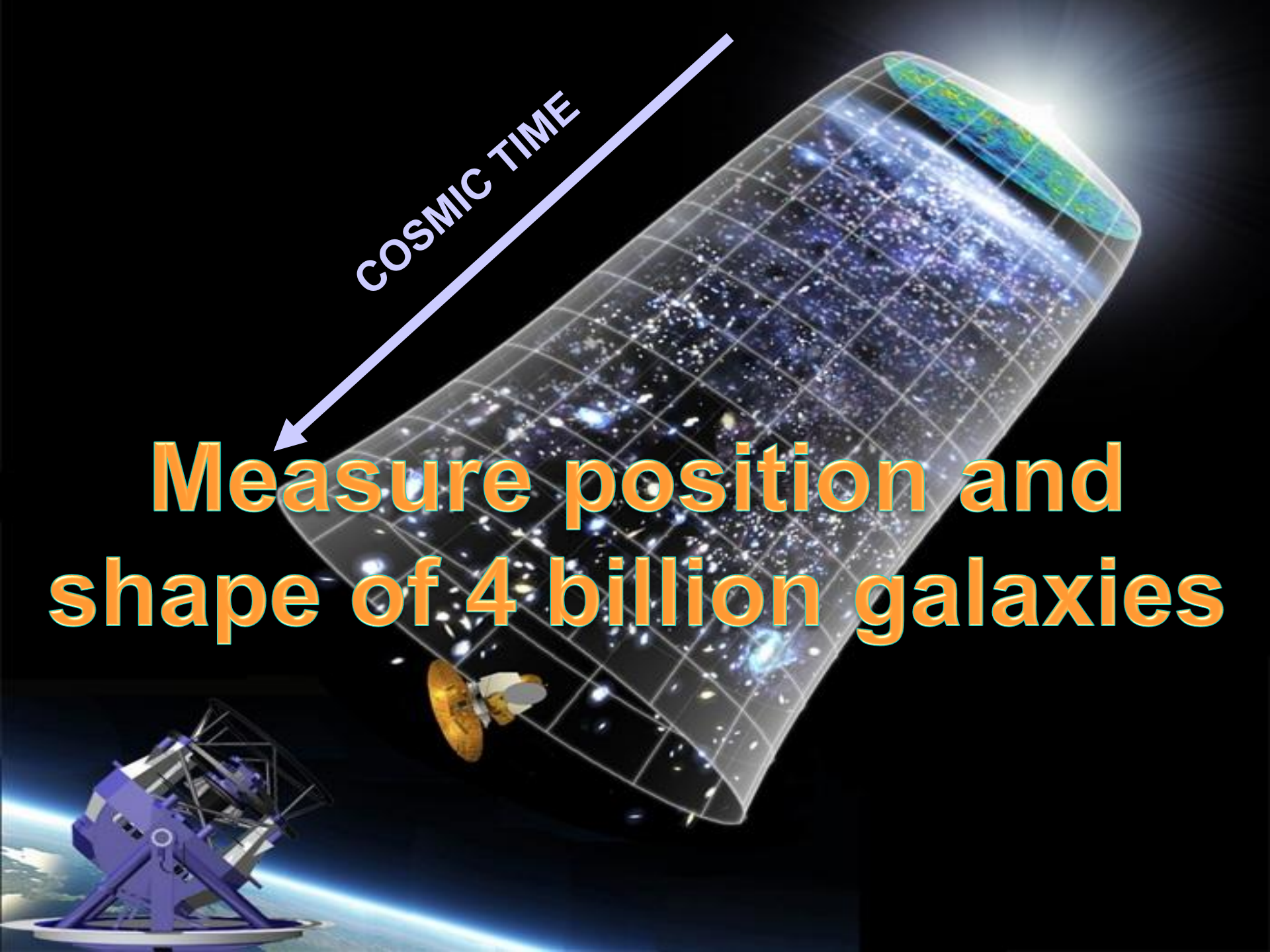
ZOONIVERSE
REAL SCIENCE ONLINE

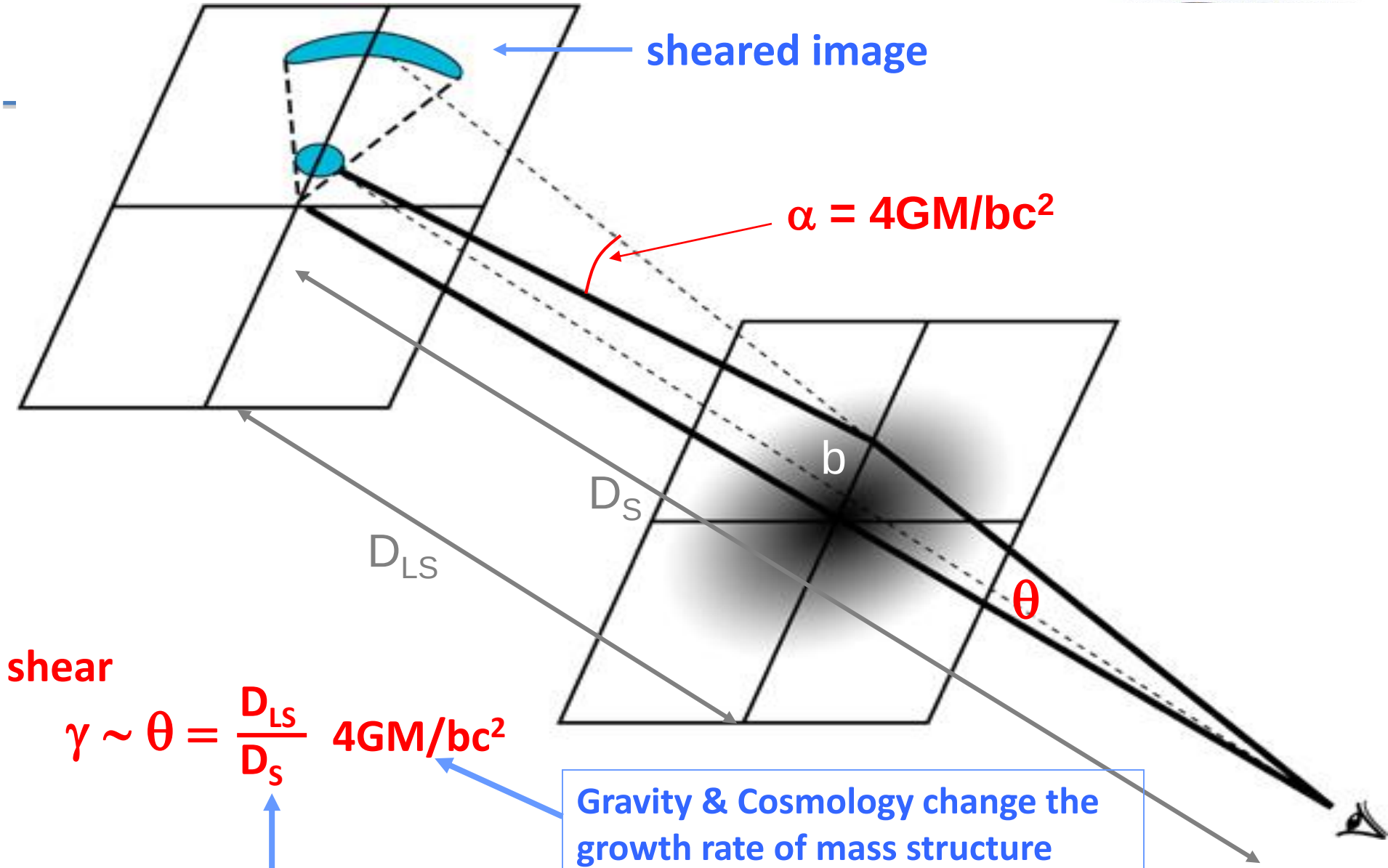
Integrated Project Schedule with Key Milestones



Senate-House Omnibus Spending Bill
January 13, 2014

"This Act includes $200,000,000 for Major Research Equipment and Facilities Construction. Funds are provided at the request level for all projects for which construction has already begun, and remaining funds are for the initiation of the Large Synoptic Survey Telescope (LSST) project. If NSF determines that LSST requires additional funding in fiscal year 2014, NSF may submit a transfer proposal to provide such funds."


COSMIC TIME
Measure position and
shape of 4 billion galaxies



shear

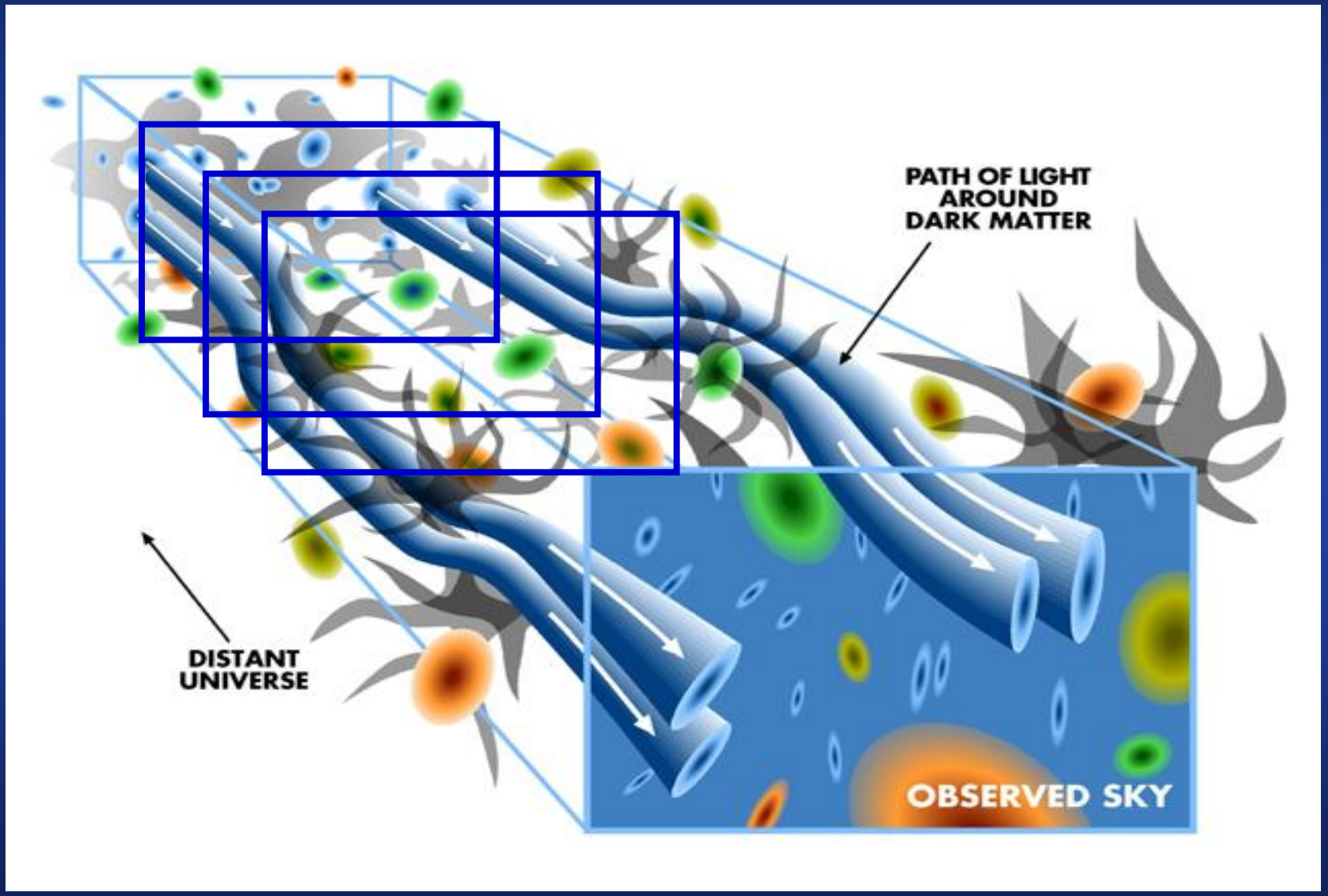
$$\gamma \sim \theta = \frac{D_{LS}}{D_S} \, 4GM/bc^2$$

Gravity & Cosmology change the growth rate of mass structure

Cosmology changes geometric distance factors

Joint analysis with BAO: breaks degeneracy

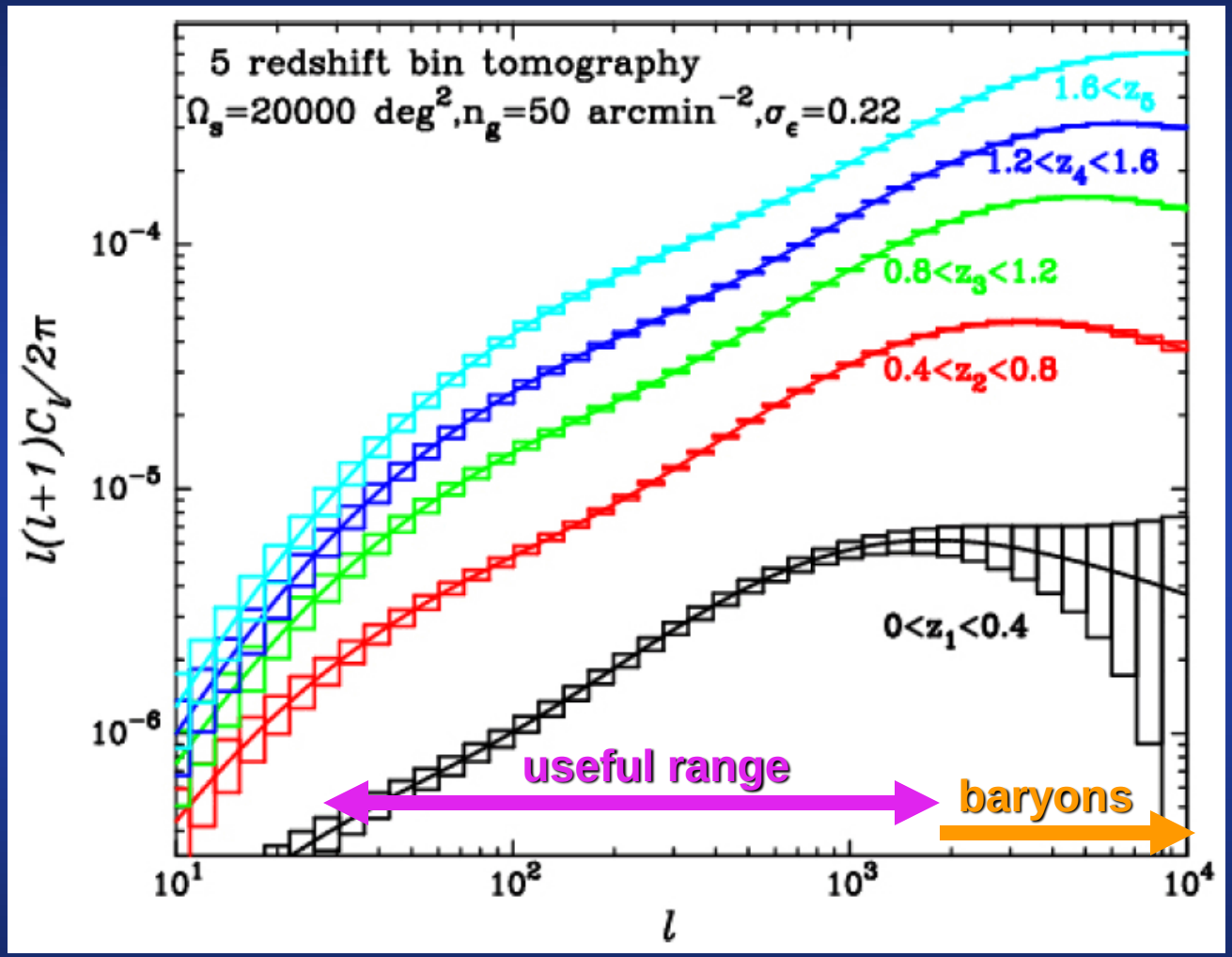
Cosmic shear vs redshift



LSST Cosmic Shear power spectra

Ten redshift bins yield 55 auto and cross spectra

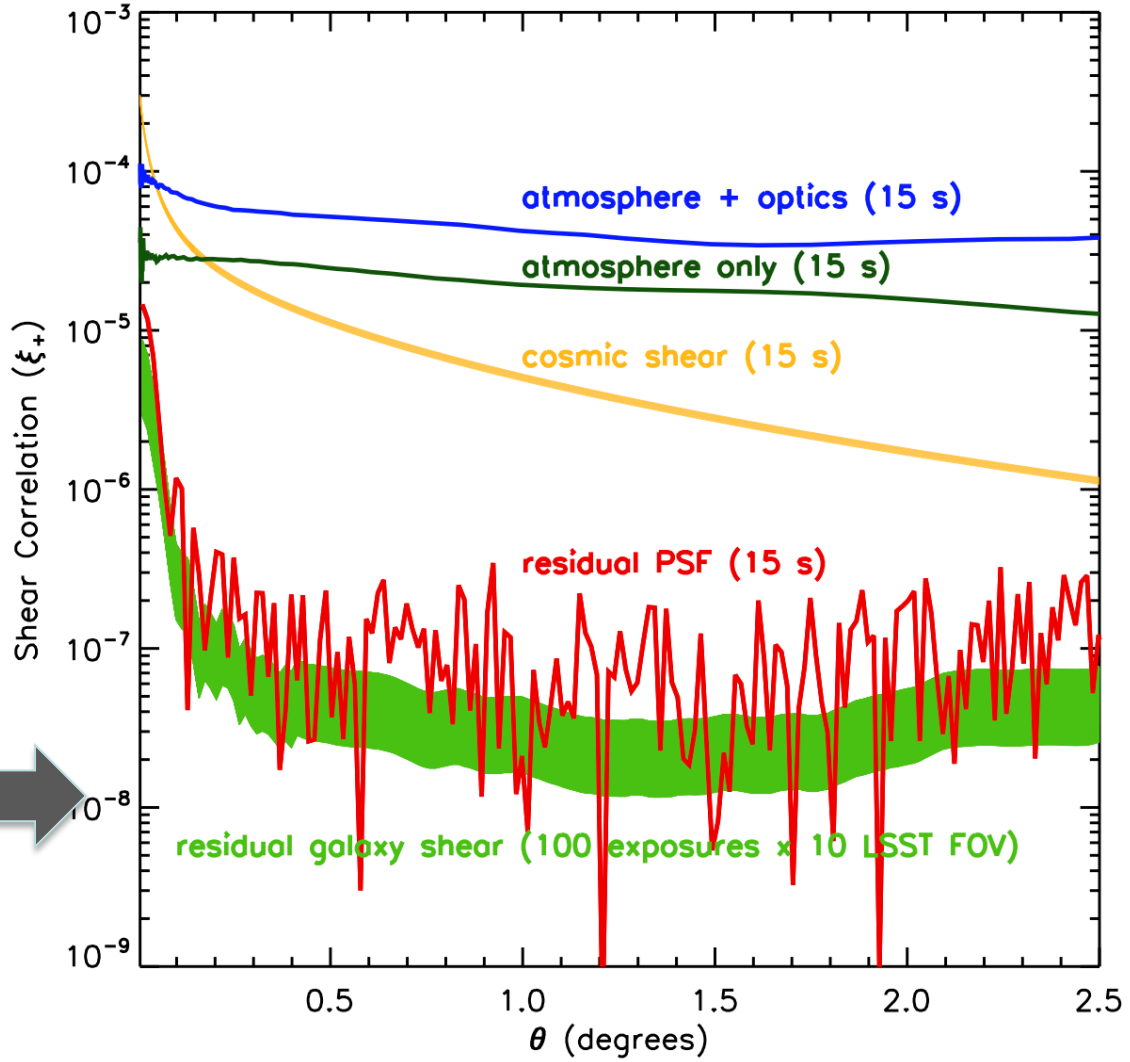
Sensitive to all dark matter components, including neutrinos

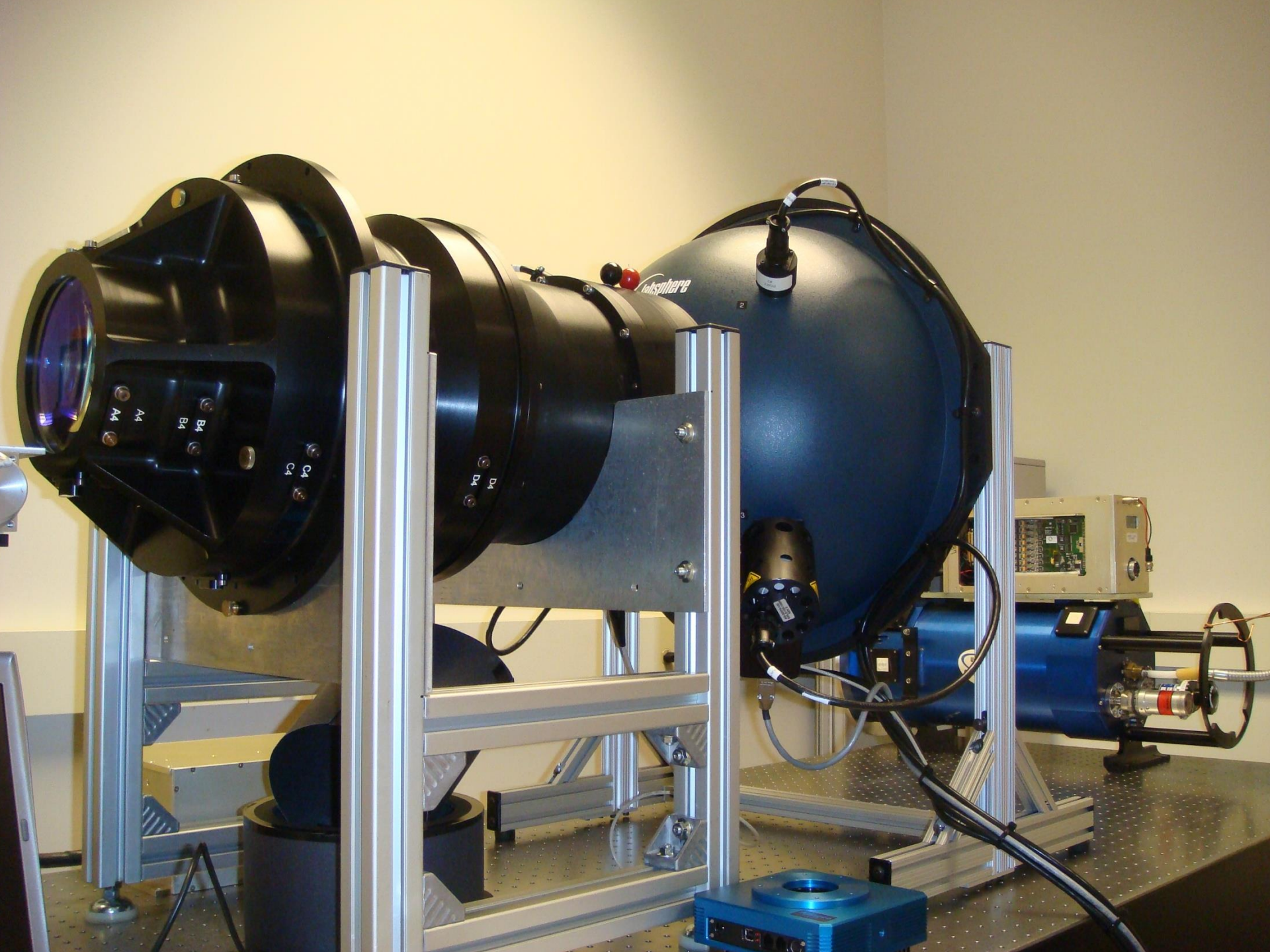


Correcting PSF systematics

The shape of the PSF must be known (measureable and stable) to a part per ten thousand in each exposure at each position in the CCD. Software corrections to its effects on faint galaxies will be made: below are the shear-shear correlation residuals in a simulation of LSST observing.

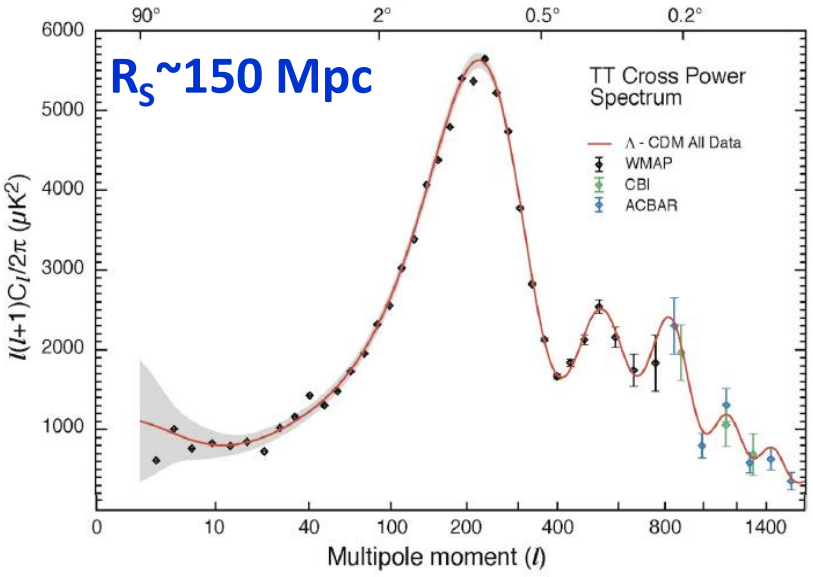
CCD systematics must be controlled at this level



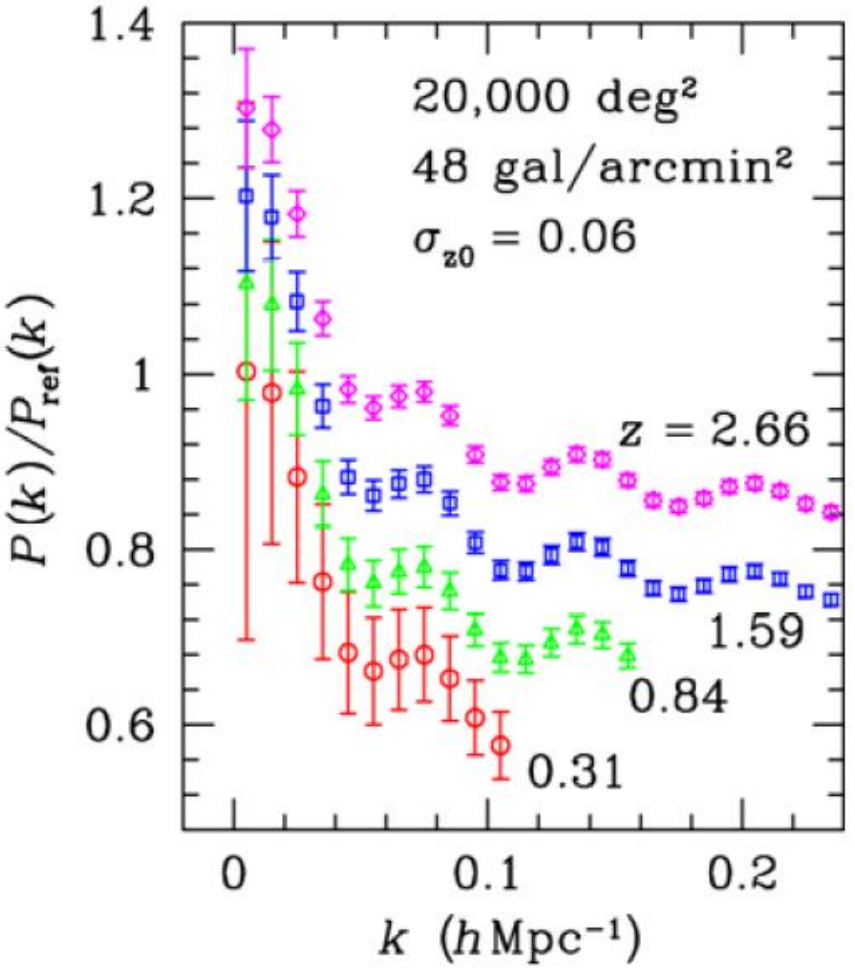

A4
A4
B4
B4
C4
C4
D4
D4
labsphere

BAO Standard ruler

CMB (z = 1100)



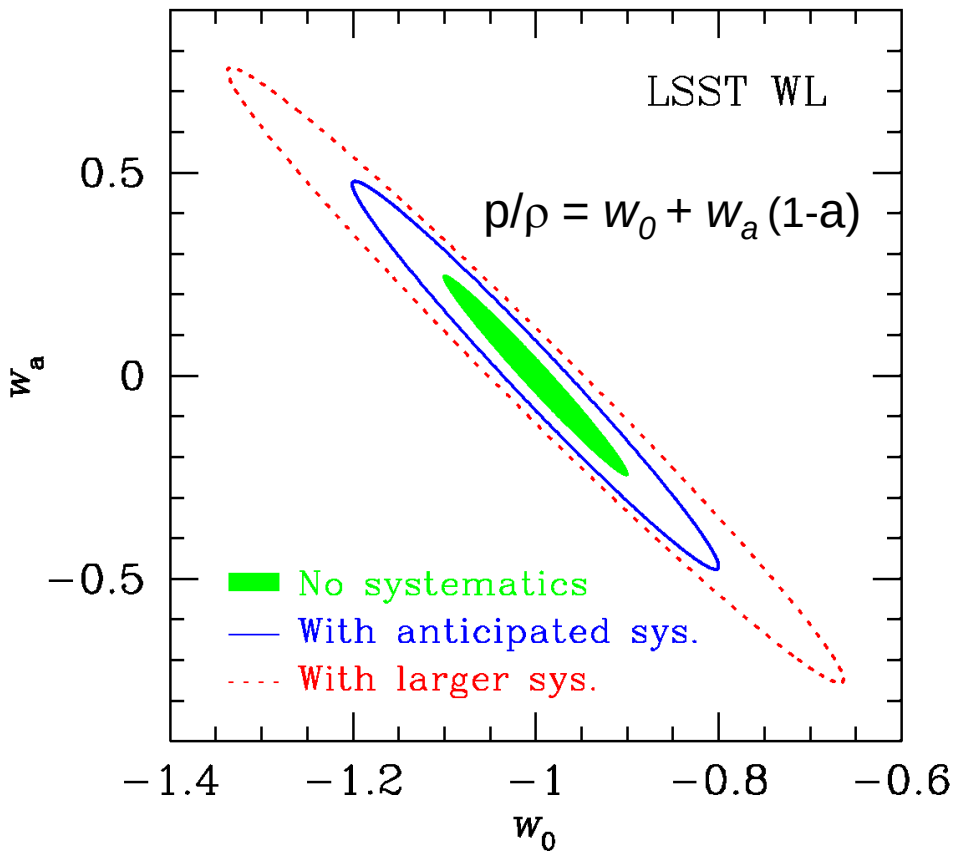
LSST (z = 0.2 - 3)

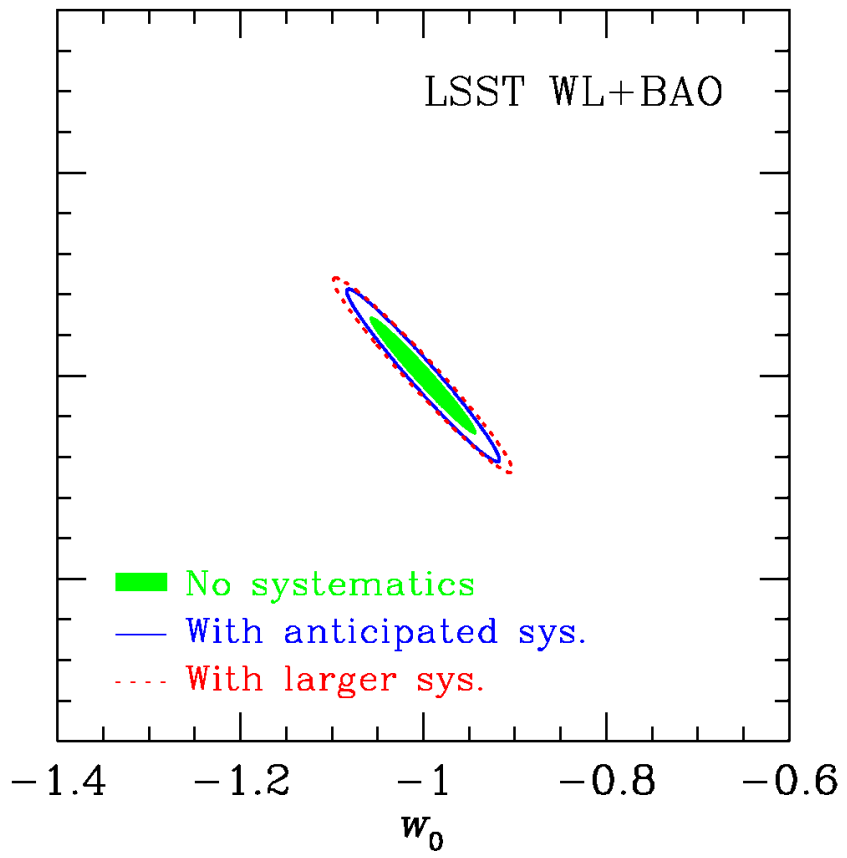


Measure angular scale vs Redshift

Two Dimensions on the Sky
Angular Diameter Distances

Reduced sensitivity to systematic error

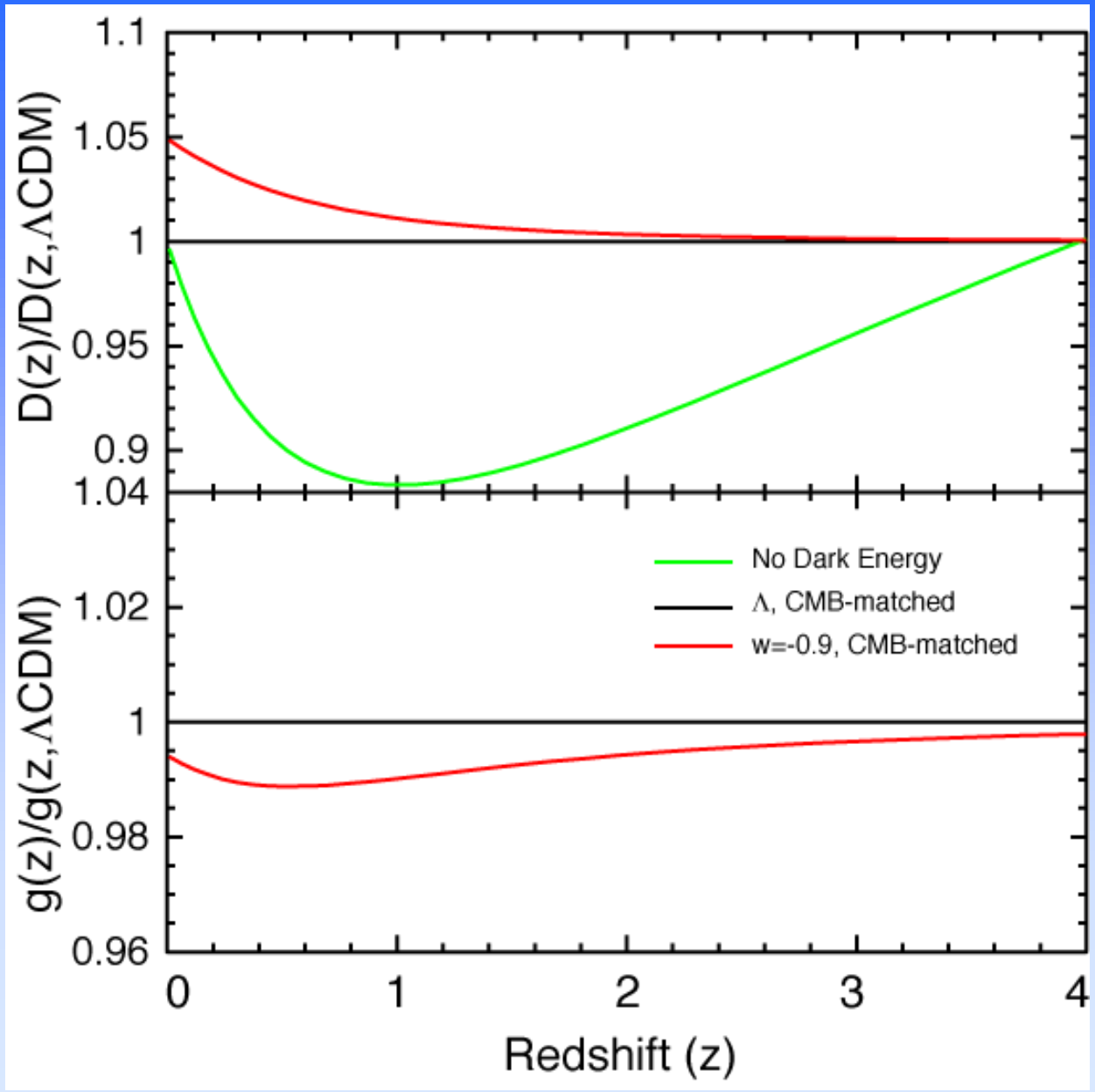




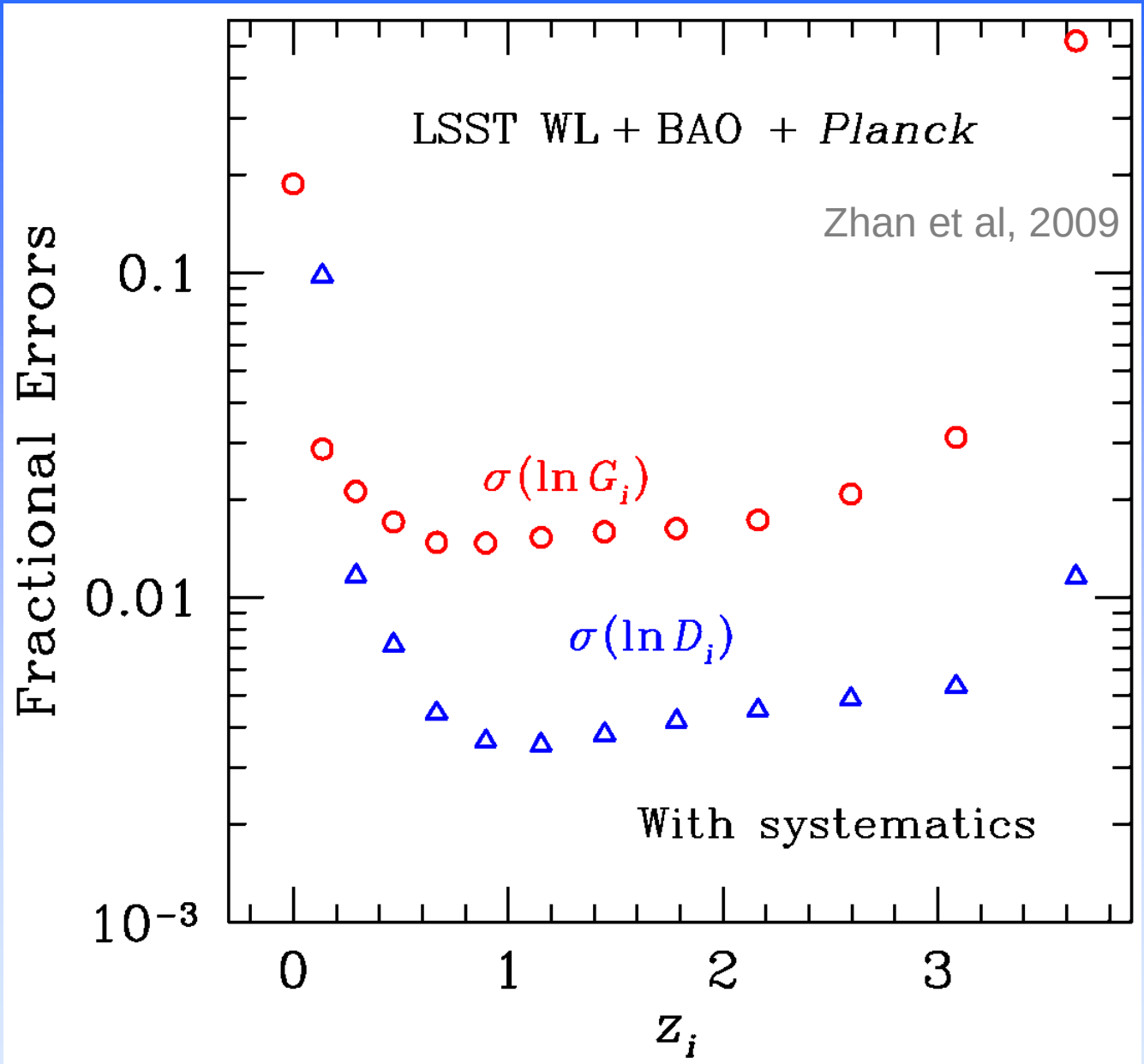
Combining WL and BAO breaks degeneracies.

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

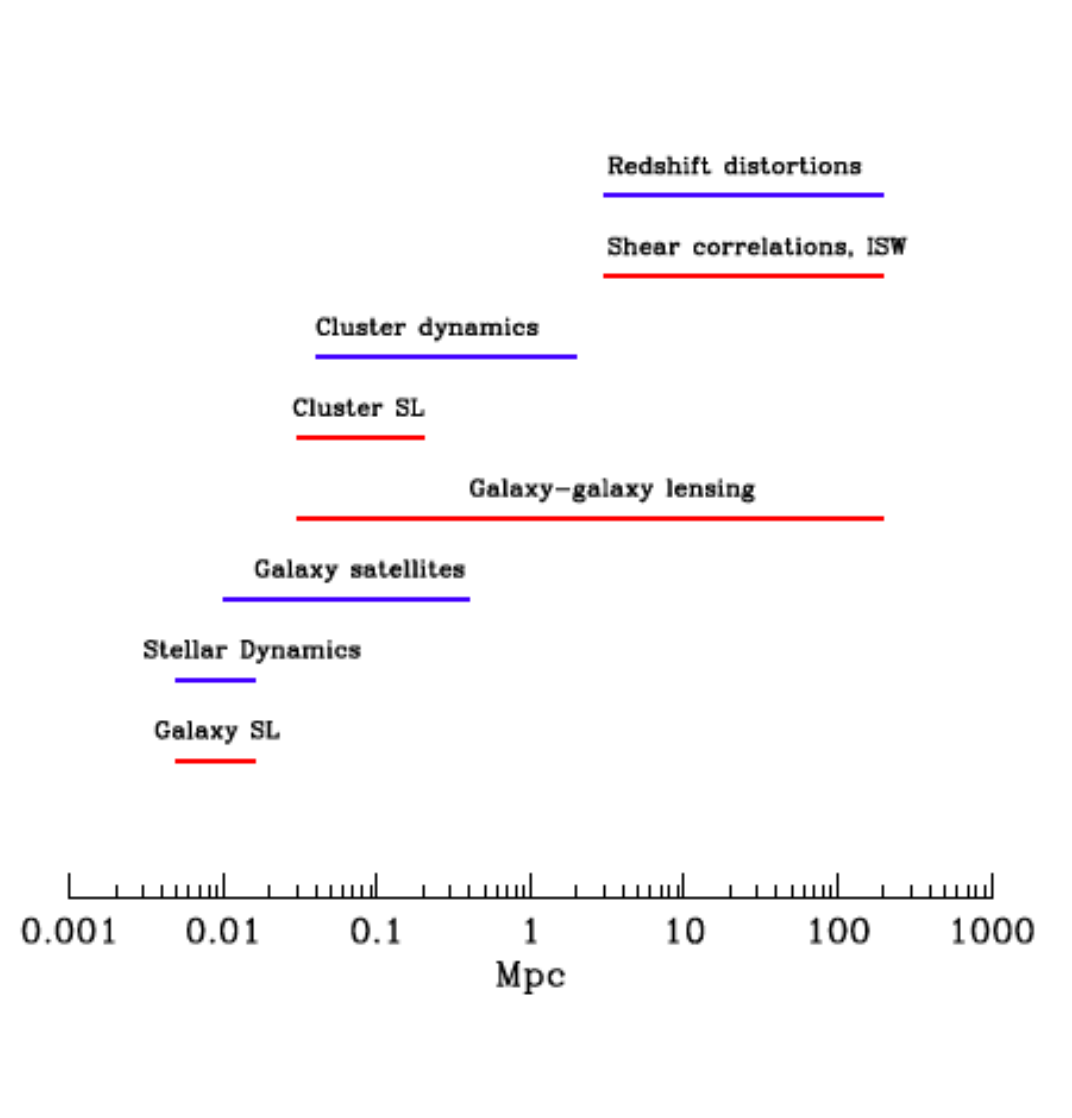
Cosmic geometry and growth of dark matter structure



Testing general models of dark energy

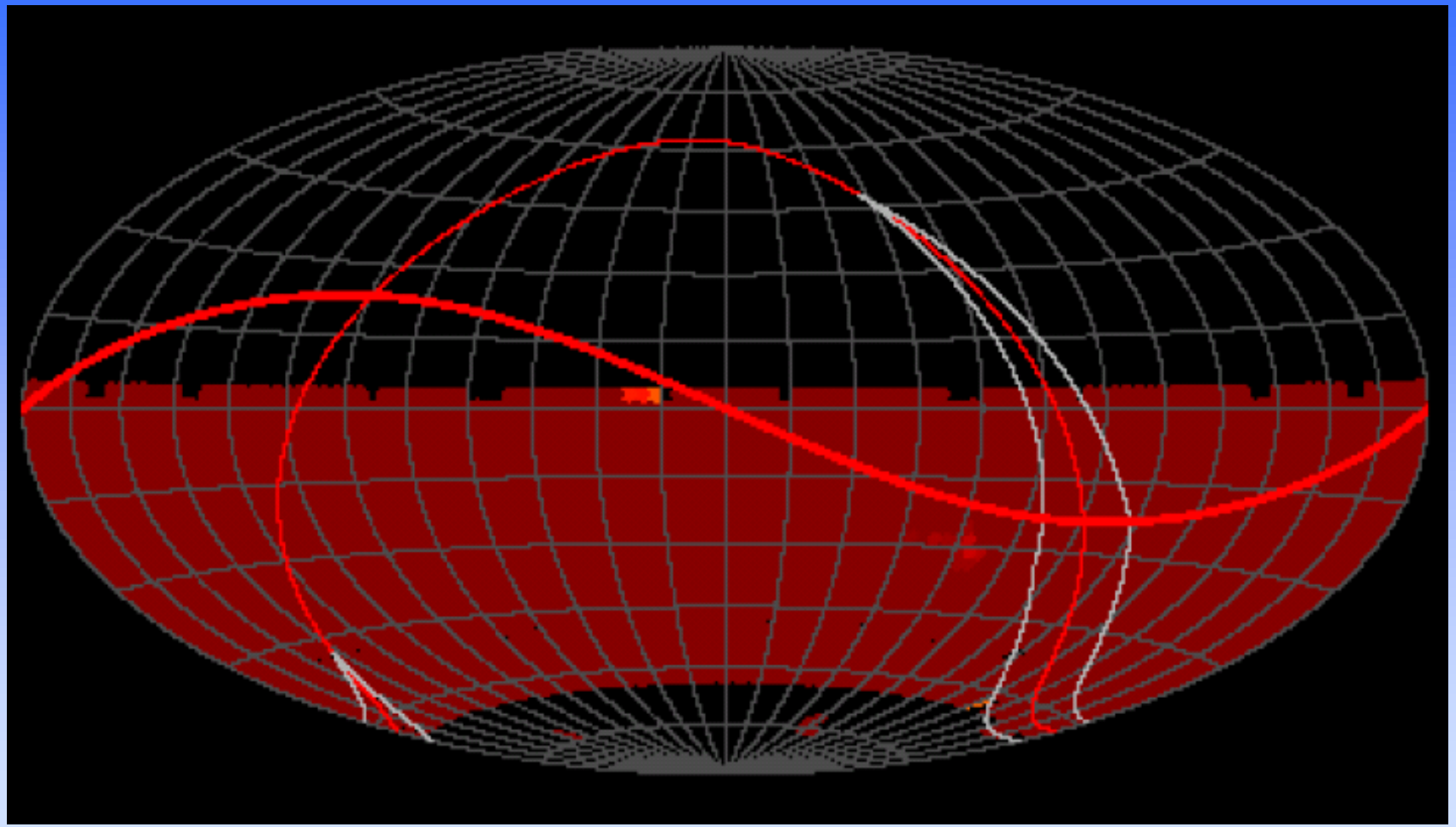


Cosmological tests of gravity



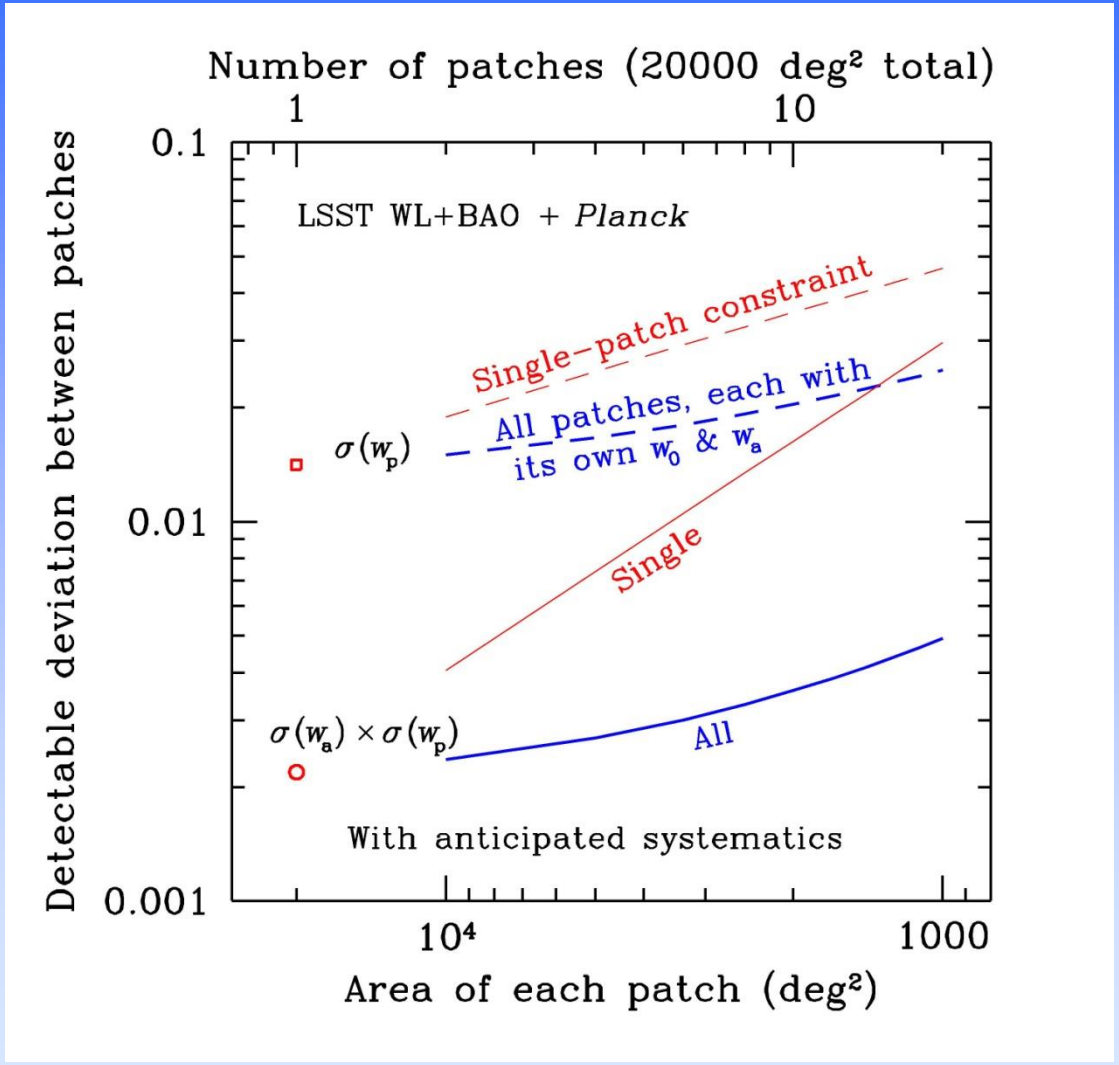
Jain & Khoury 2010

Probe anisotropy



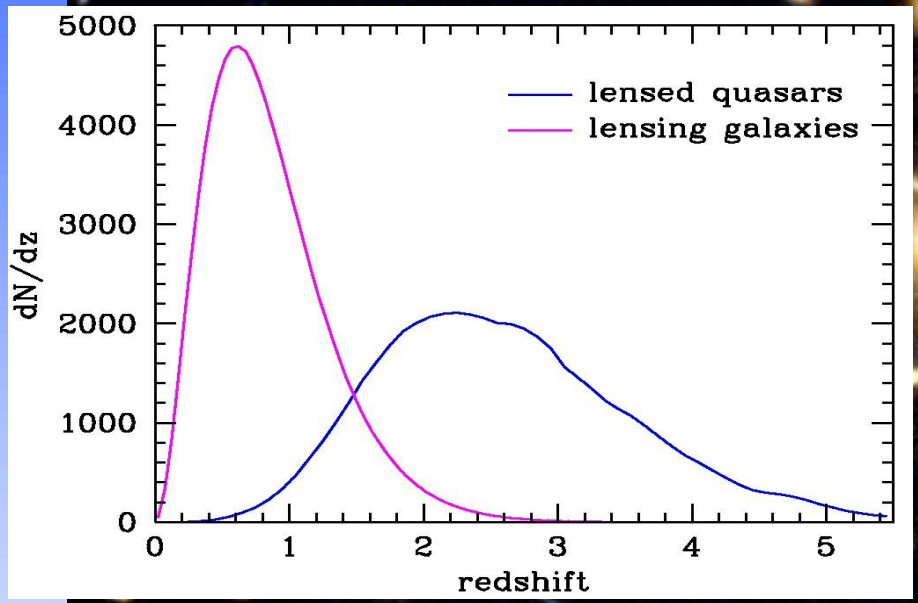
Is dark energy isotropic?

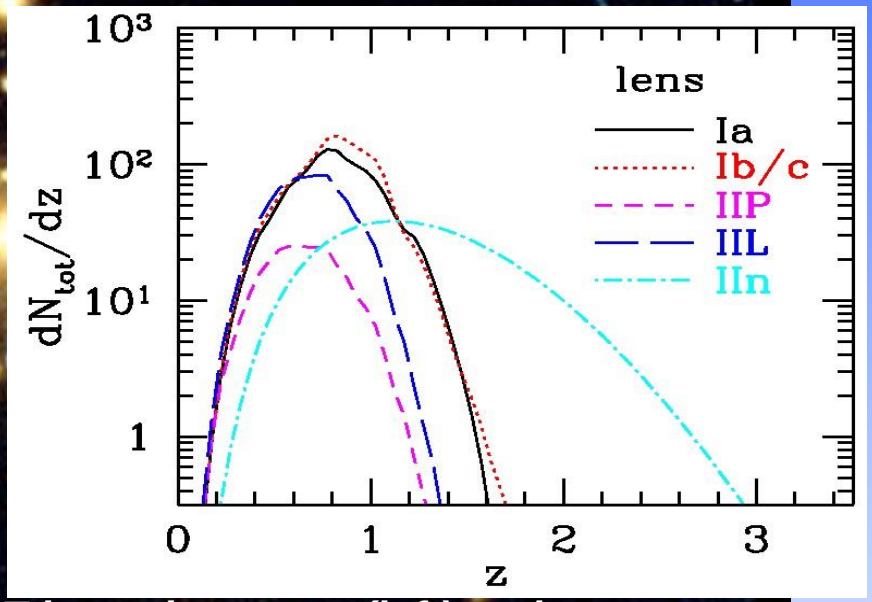
- Incorporating all-sky fits for other cosmology parameters, an LSST search for anisotropy in the EoS is quite sensitive.
- Shown is the sensitivity to deviation of dark energy EoS and DETF error product over the sky in patches of area A.
- This can separately be done with SNe



Science Book Ch. 15.4

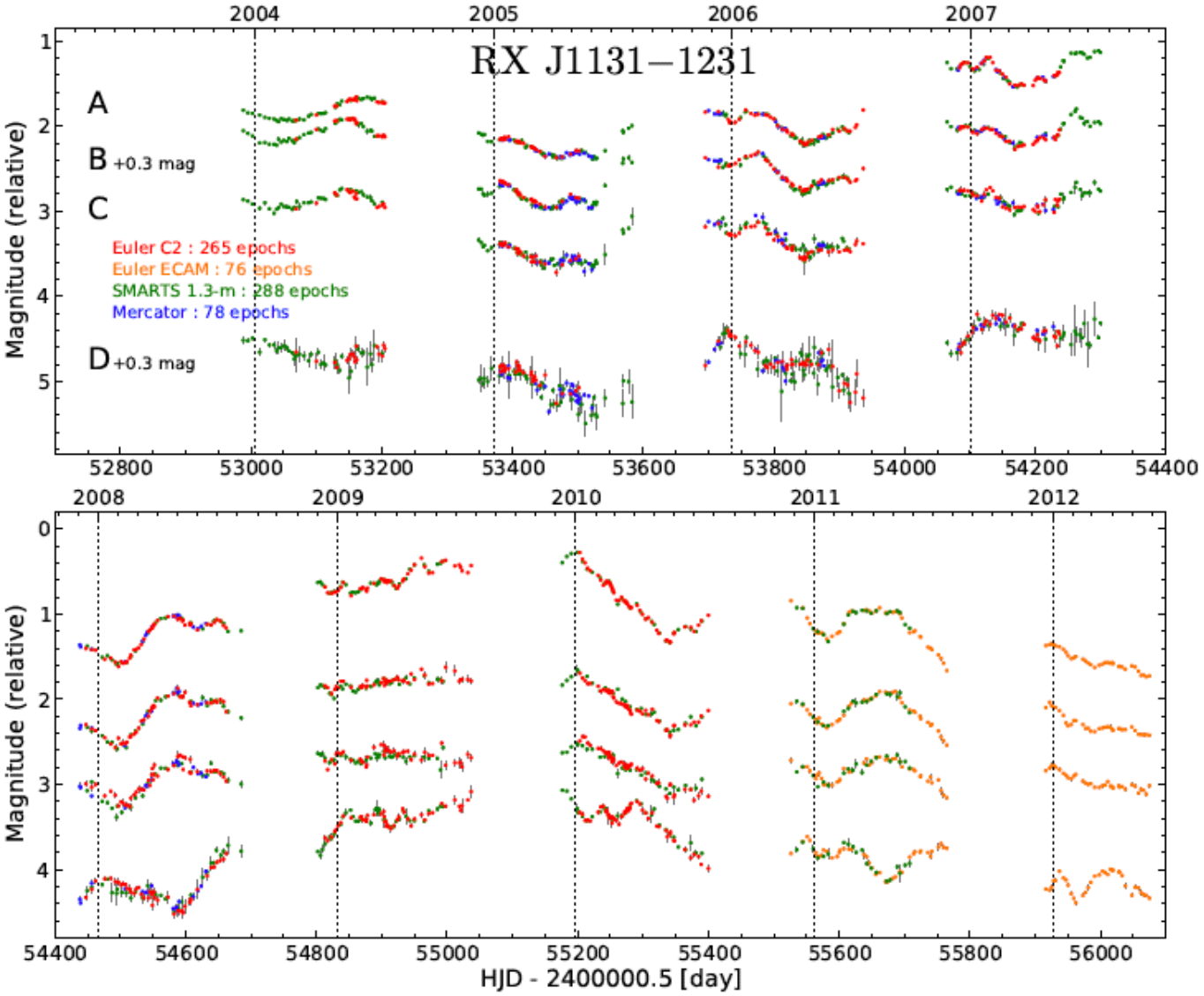
Gravitational lens time delayed flares





Above: predicted abundances of LSST lensed quasars (left) and supernovae (right, divided by type).

Strong lensing time delays



Treu et al 2013

Multiple LSST probes of dark energy

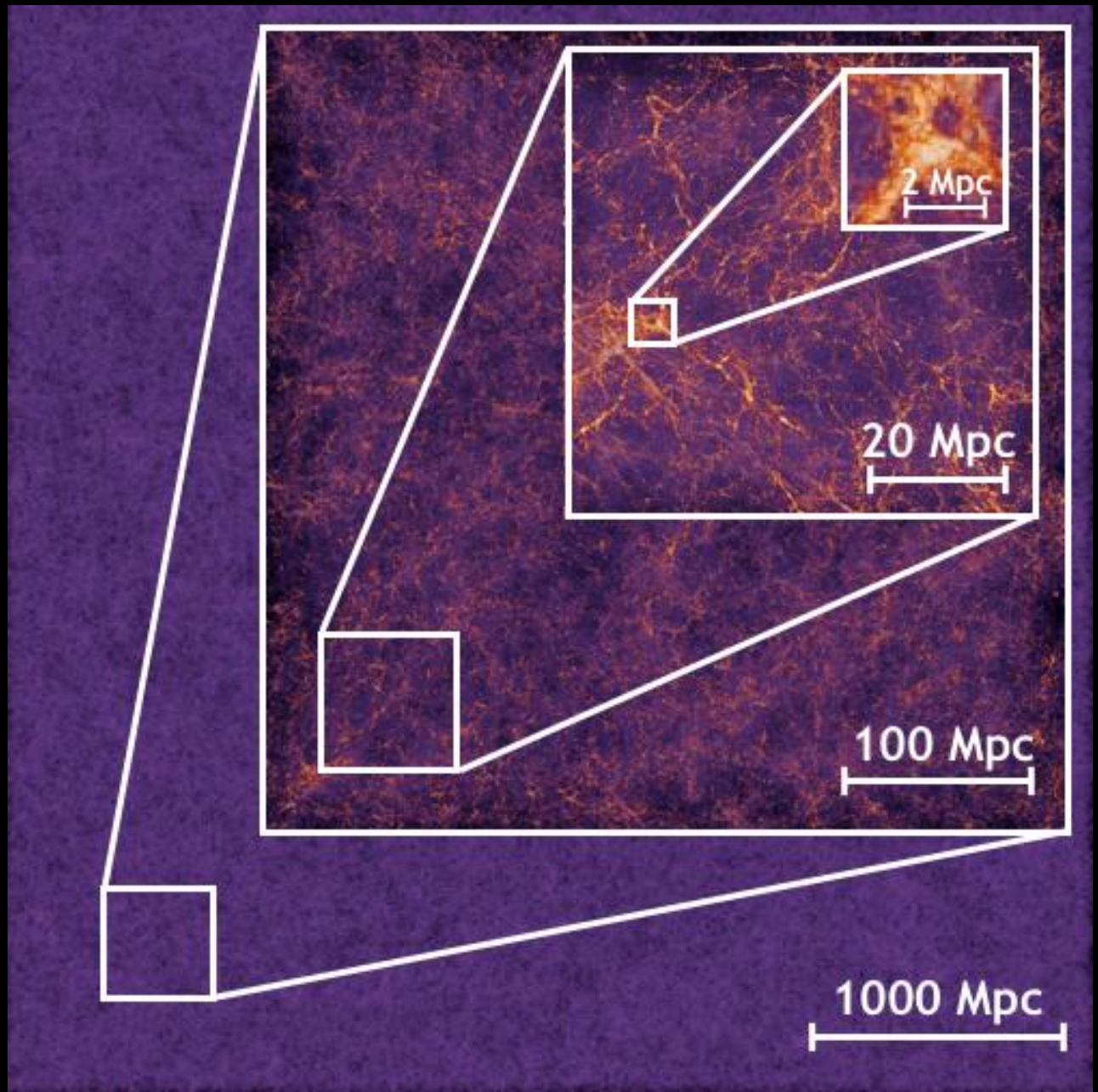
- Use the same LSST survey data products
- Analyzed for different signals
- Multiple cross checks
- Combination is far more powerful than root sum of squares

Primary LSST probes	
Weak Lens shear cross correlation tomography Weak Lens magnification tomography	✓
2-D Baryon Acoustic Oscillations	✓
Supernovae	✓
Shear peak statistics	✓
Galaxy cluster counts	✓
Secondary LSST probes	
Time domain tomography of QSOs and AGNs	✓
Anisotropy of WL+BAO and SN signals	✓
New Energy or New Gravity?	✓

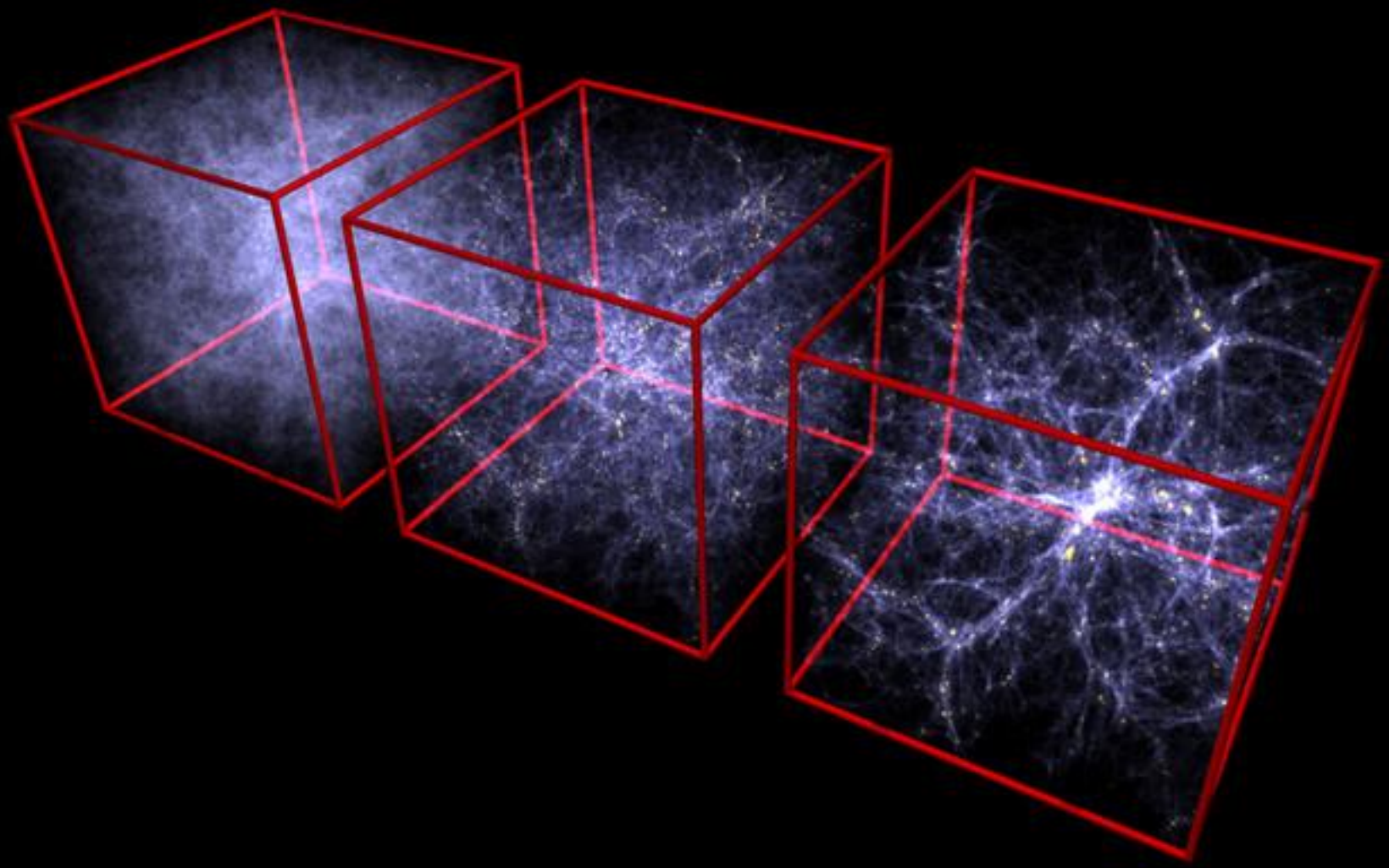
Maximally sensitive to new physics


Dark Matter

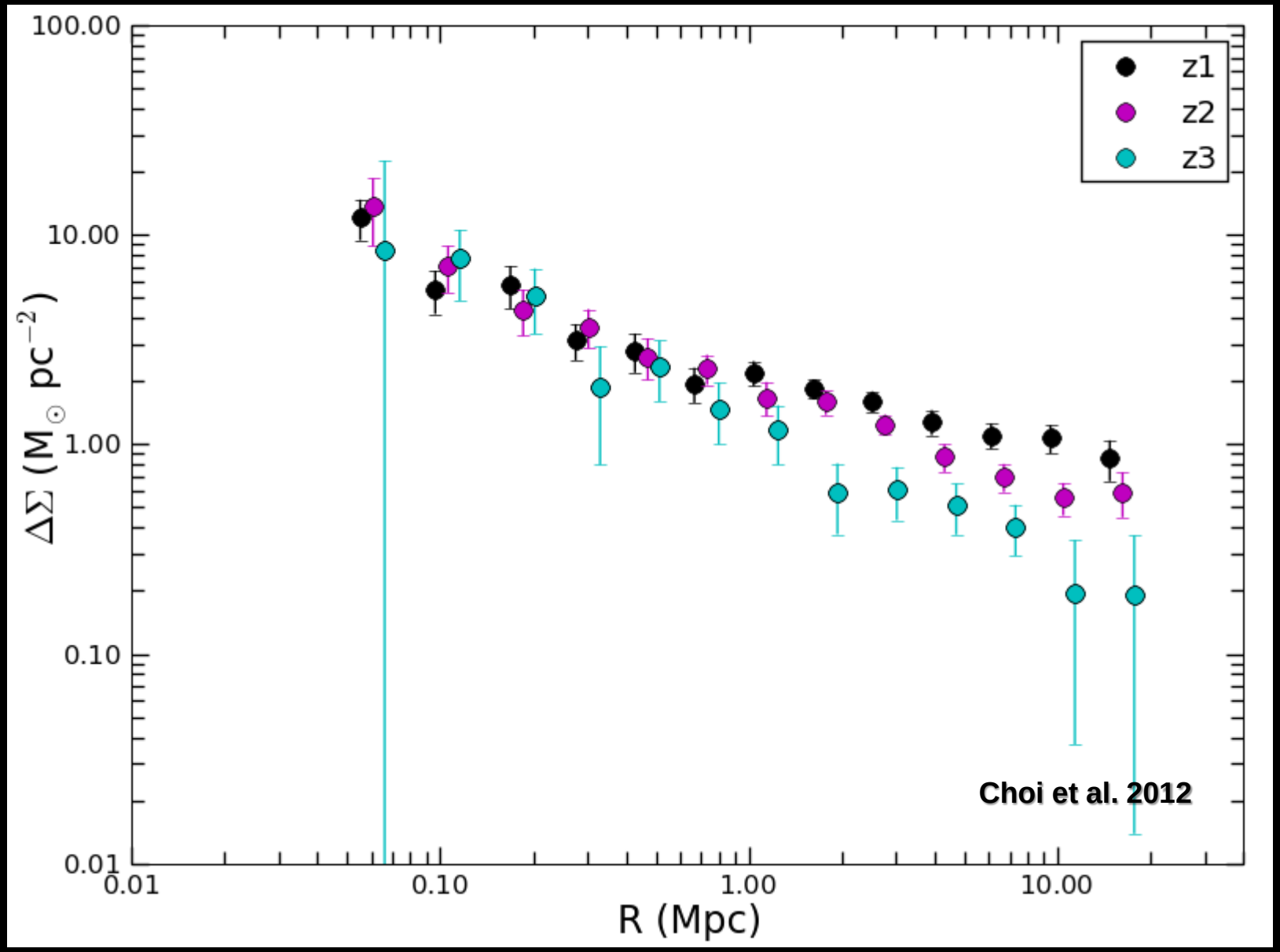
Wide field tomography of dark matter LSS vs redshift



Wide field tomography of dark matter LSS vs redshift

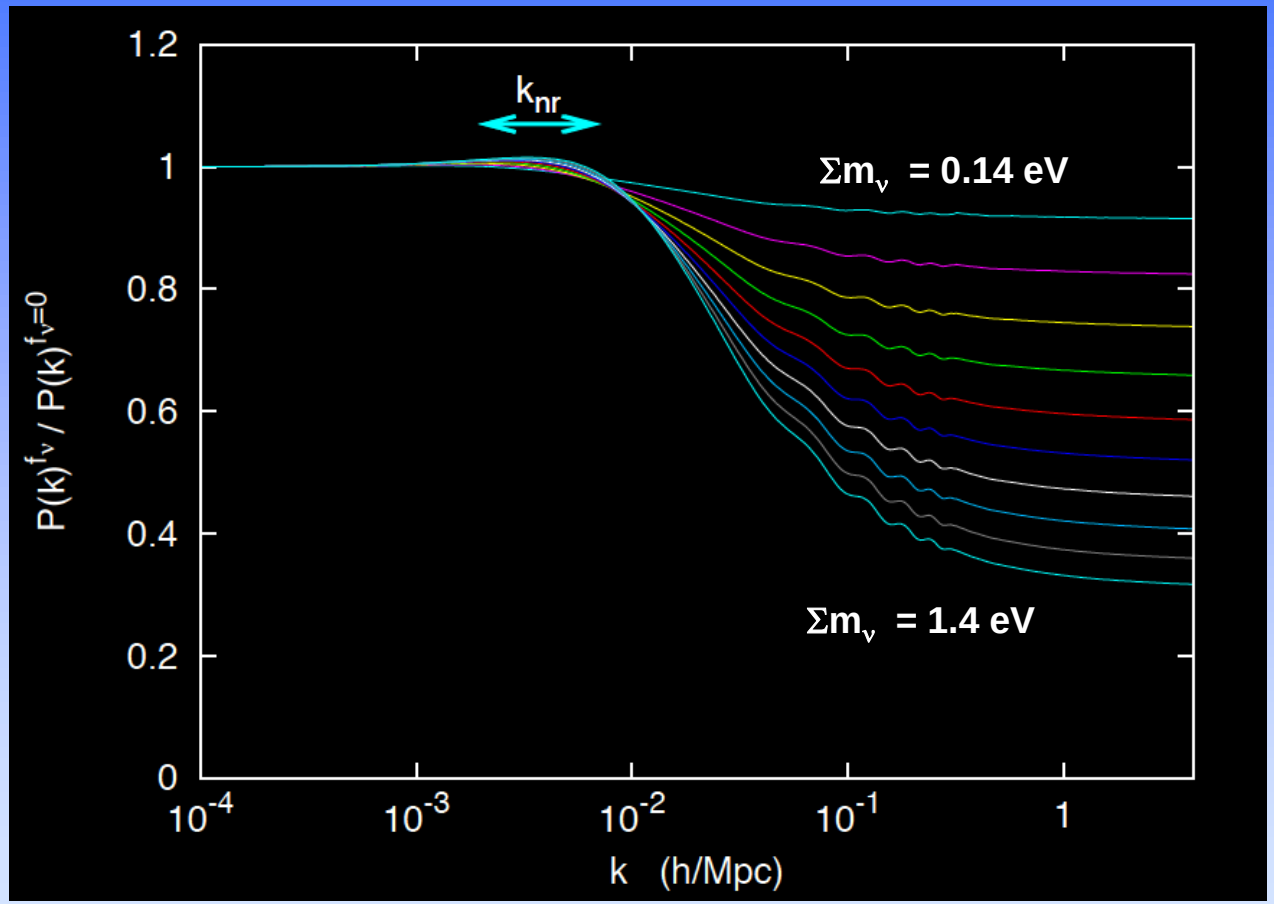


Weak lens detection of evolution of large-scale mass structures: 1 million galaxies in Deep Lens Survey



Multi-component dark matter and the neutrino mass

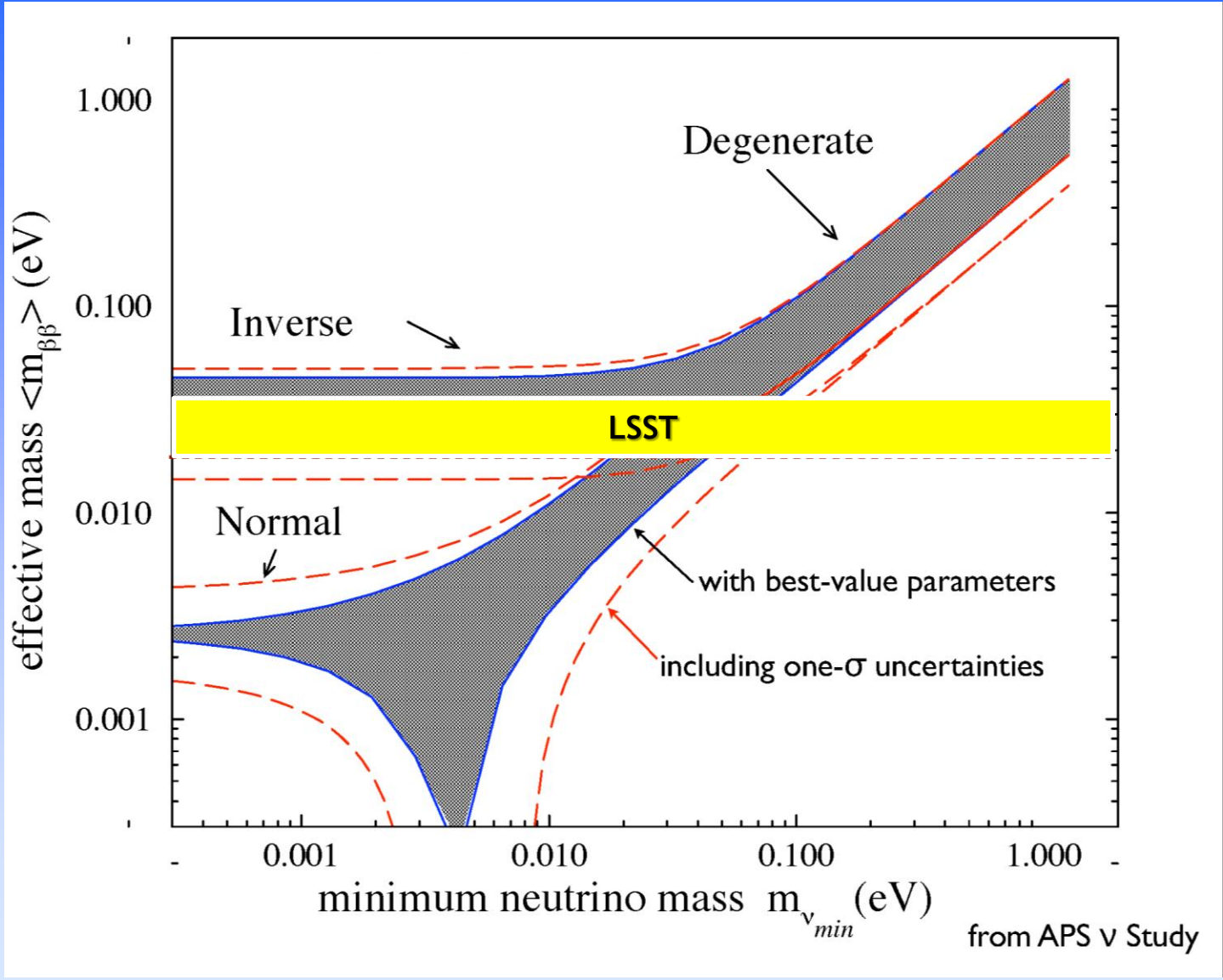
- Known hot component of dark matter
- Suppress growth of dark matter structure
- smaller mass neutrinos ⇒ relativistic longer, travel further ⇒ suppress growth of structure on larger scales



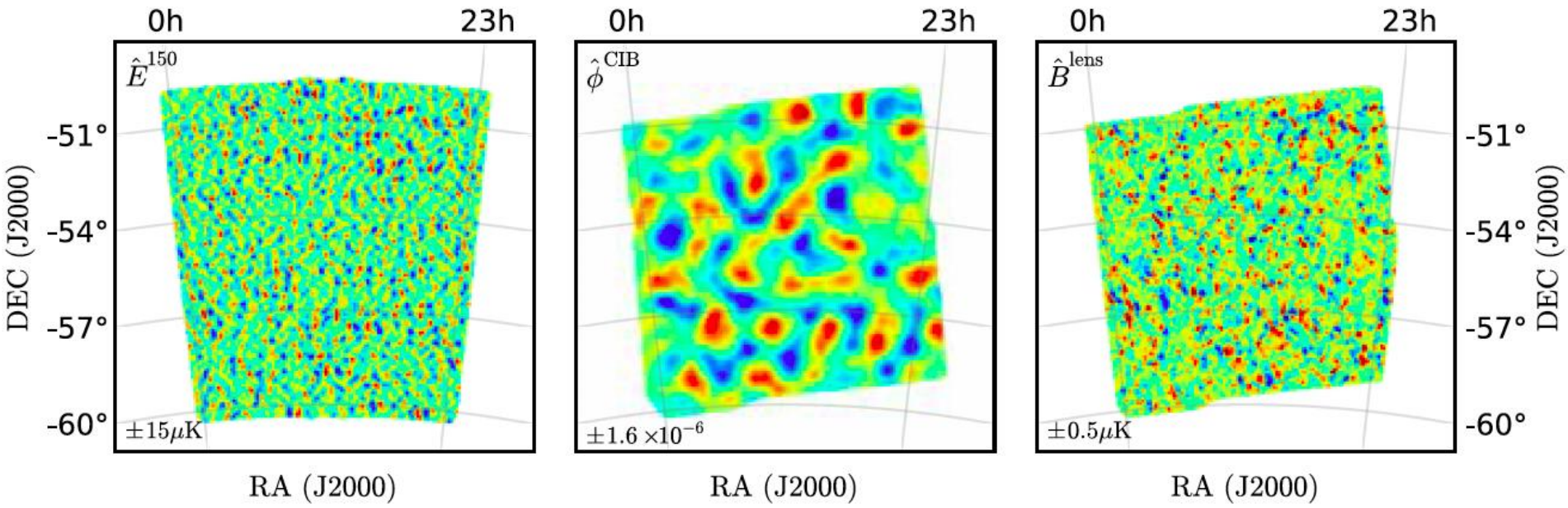
Kev Abazajian

LSST will measure total neutrino mass

- 0.03 eV sensitivity
- determine hierarchy

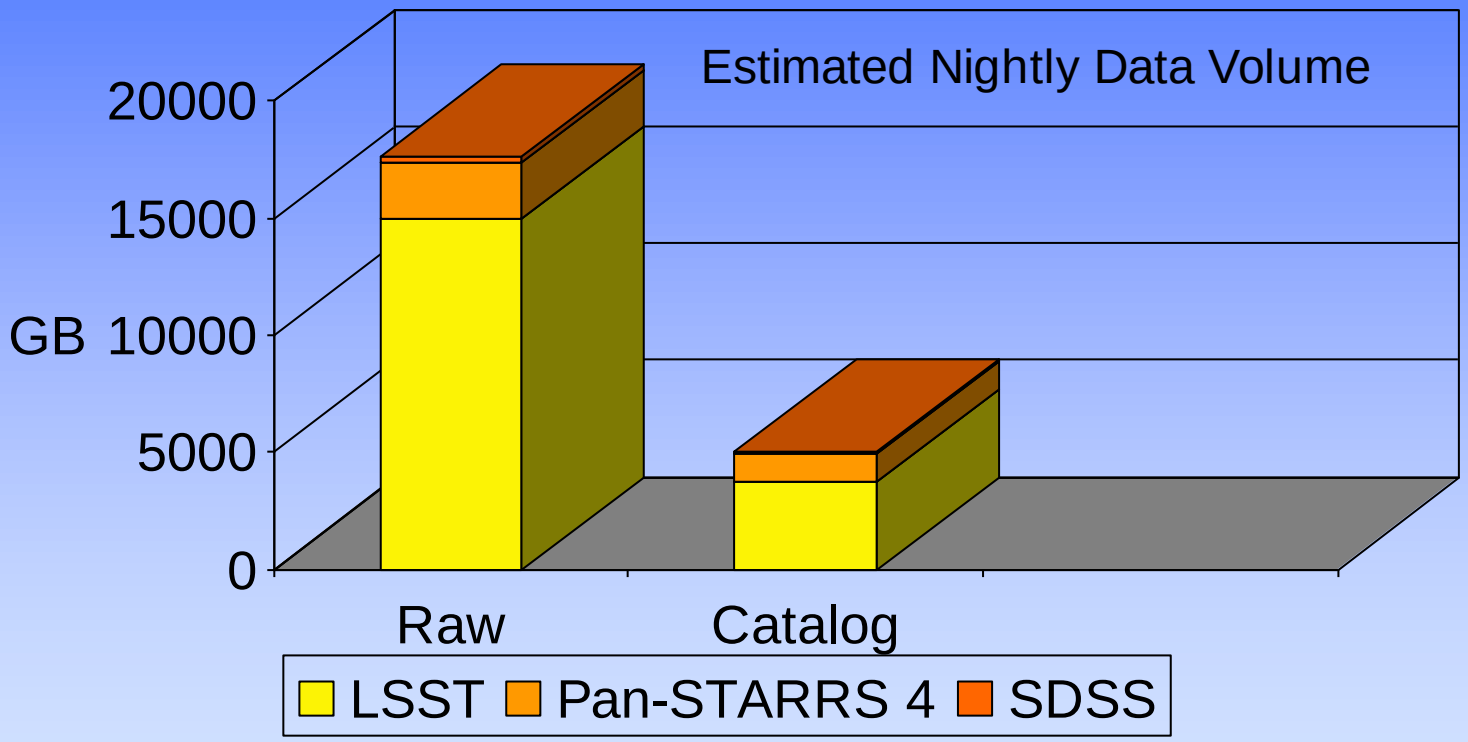


Future tomography: combine with CMB B-mode polarization



Hanson et al 2013

Data volumes & rates are unprecedented in astronomy



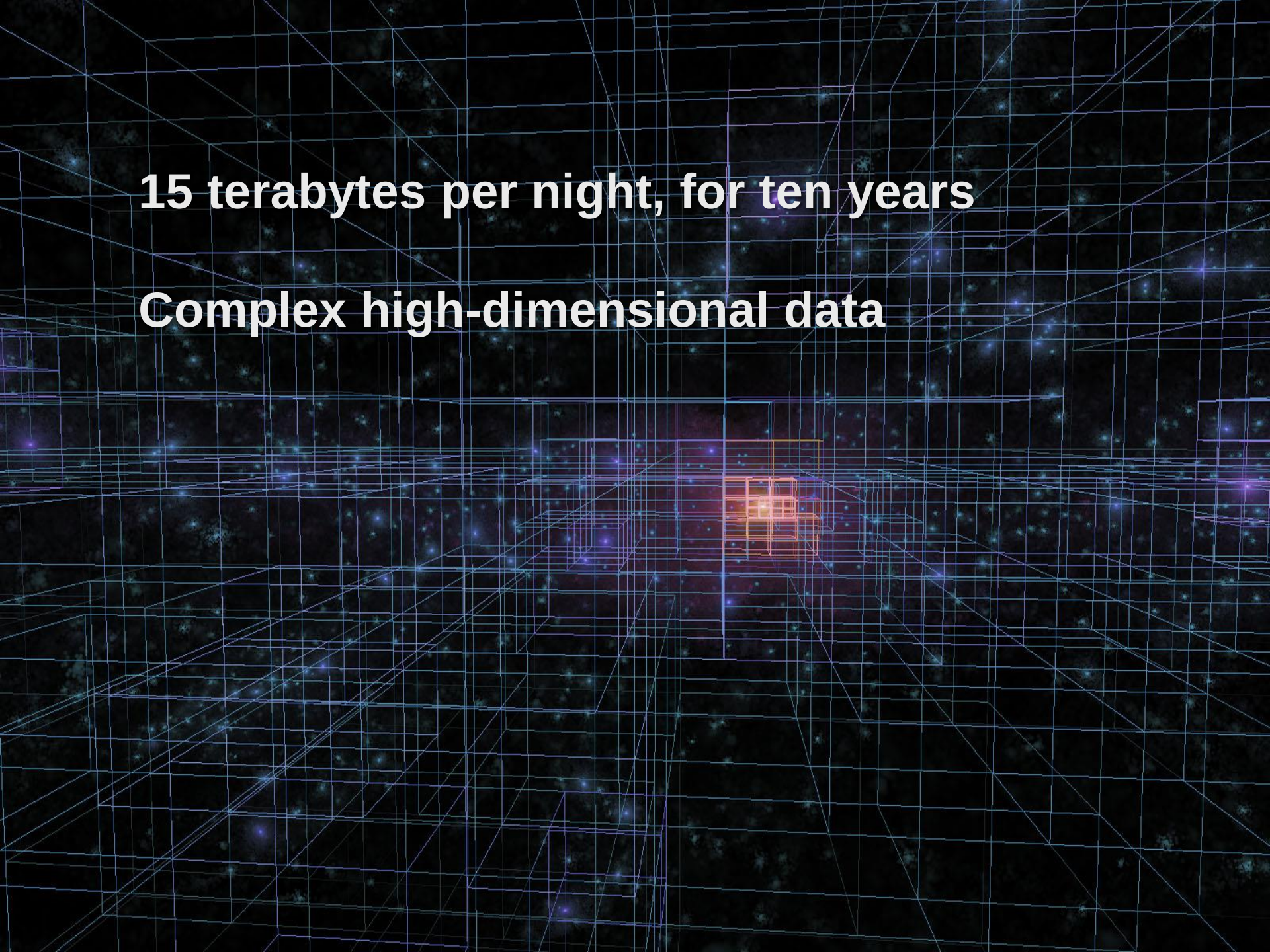
"Genome project" approach to astronomy

- Avoid cost of building a new facility running a new experiment every time we ask a new science question

- One exhaustive survey of the optical universe
- A 3.2 Giga pixel image every 18 sec for 10 years
- Calibrated trusted data:

  500PB image collection + 15PB catalog
- Many simulated universes
- Multiple 100-1000PB databases

- *Exascale data enables many "experiments"*


15 terabytes per night, for ten years
Complex high-dimensional data

Alert Rate

In ten minutes time the LSST transient pipeline is likely to issue ~80,000 alerts at 5σ.

While most of these will be moving objects, perhaps several thousand will be flaring objects or bursts. Possibly new kinds of objects!

Clearly any followup requires high purity samples. What is needed then is highly trusted event classification. FAST

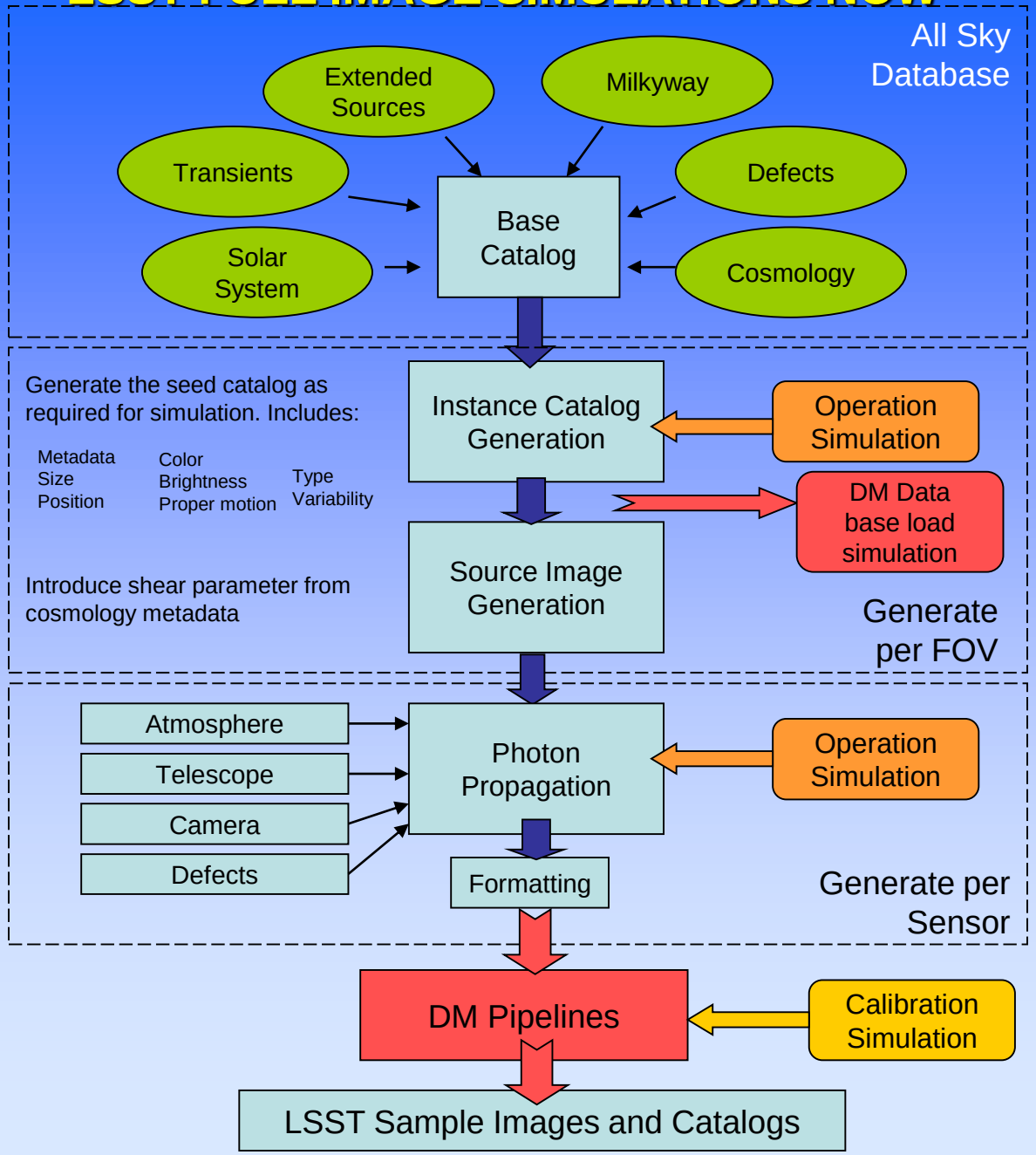
Automated discovery

Data exploration

DISCOVERING THE UNEXPECTED

This is required also for automated Data Quality Assessment

LSST FULL IMAGE SIMULATIONS NOW



The Science of Big Data

- Data growing exponentially, in all science
- Changes the nature of science
  from hypothesis-driven to data-driven discovery
- Cuts across all sciences
- Non-incremental!
- Industry and government face the same challenges
- Convergence of physical and life sciences through Big Data (statistics and computing)
- A new scientific revolution

Data-to-Knowledge

Old Paradigm

Astronomer+
pencil+paper

INSTRUMENT

TELESCOPE

New Paradigm

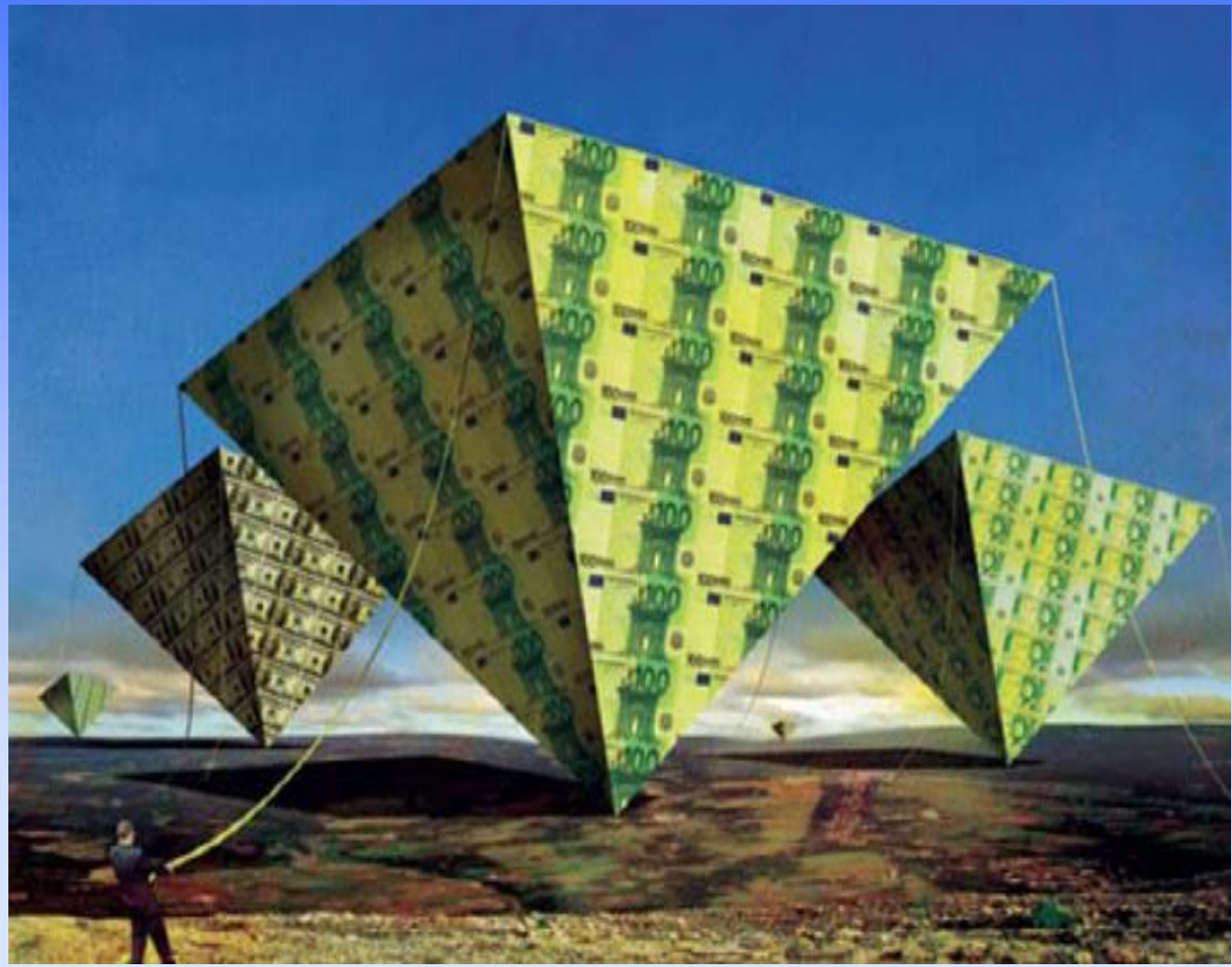
DATA ENABLED DISCOVERY

INSTRUMENT

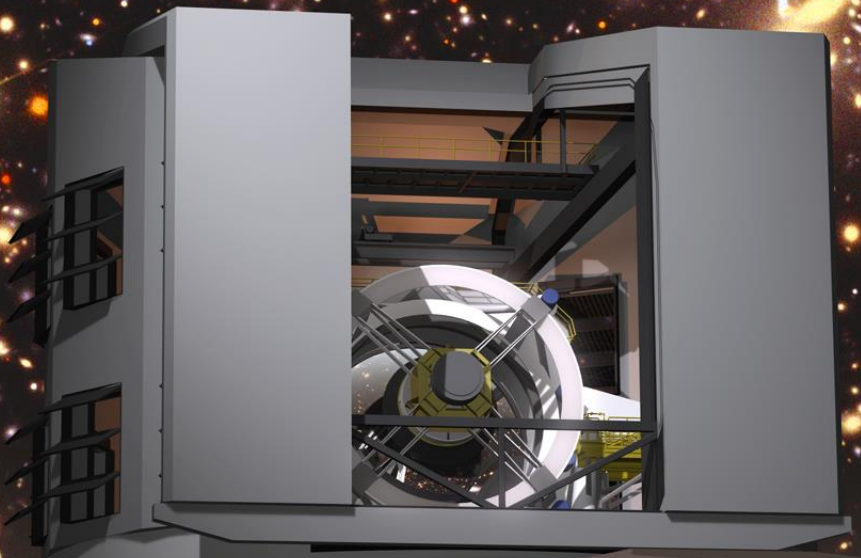
TELESCOPE

Harnessing Survey Data at Exascale

- Number of scientists does not scale with the data!
- *Database* is the new Lab, the new Experiment
- Sparse matrix of databases: observations, and simulations of observations



LSST will open new windows onto our universe



NSF

Office of Science
U.S. DEPARTMENT OF ENERGY

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