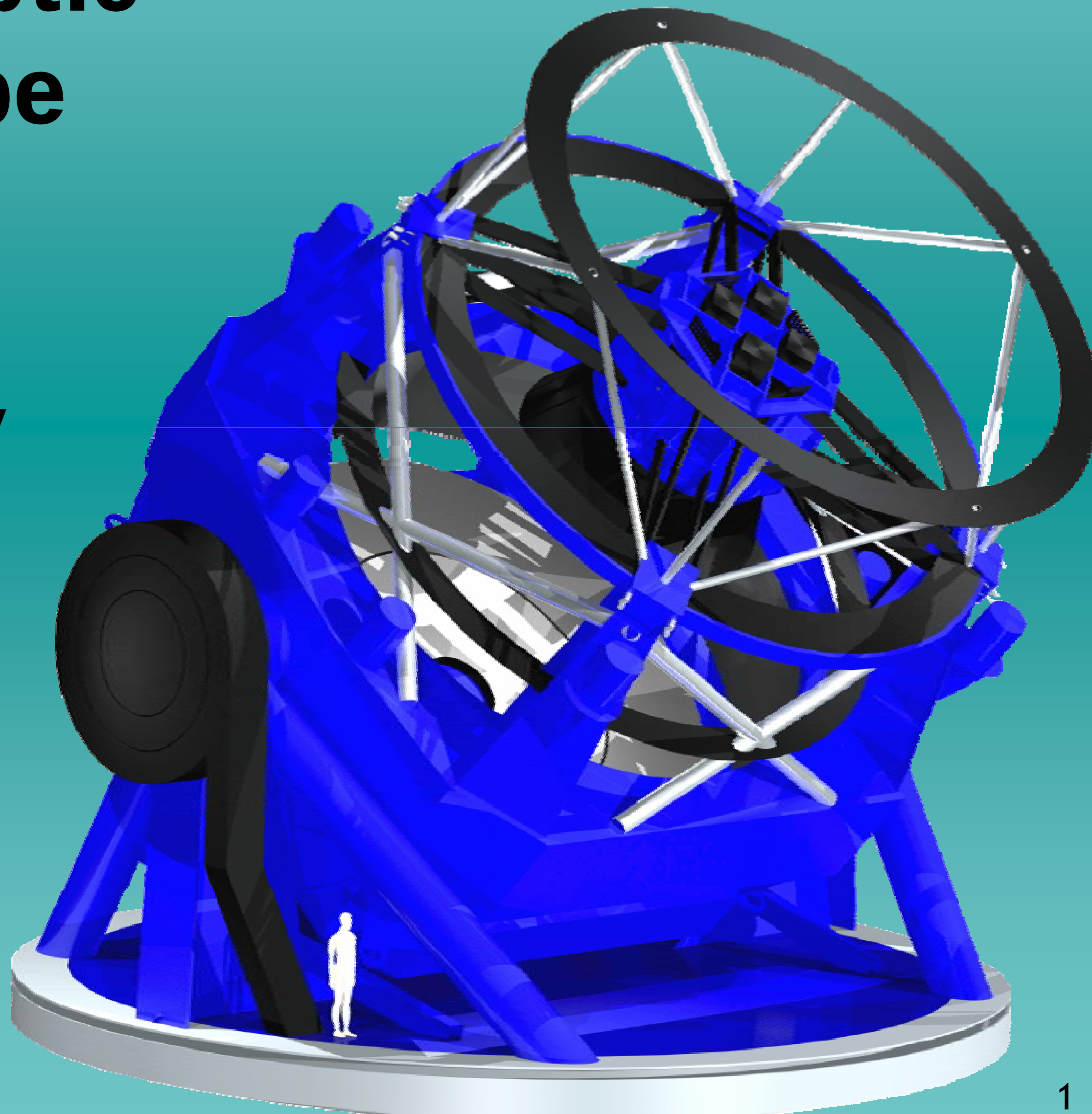
The Large Synoptic Survey Telescope

Celestial Cinematography



Philip A. Pinto
Steward Observatory
for the LSST team

Surveys

All-sky imaging surveys: POSS, SDSS, 2MASS,…

Time-domain surveys: μ-lensing, supernova cosmology,…

- Enable parallel progress on many fronts from same data
- Lead to science not even dreamed of when the survey was designed.

An all-sky, time-domain survey using the most powerful technology available would

- extend all-sky data to much fainter limits
- open up the time domain to discovery of faint, transient sources of all kinds

Designing an all-purpose survey

Large Synoptic Survey Telescope

Basic figure of merit for surveys is the number of objects detected, per unit time, to a given S/N:

$$\frac{N}{t} = \frac{\varphi_{obj}^2}{(S/N)^2} \frac{A\Omega\varepsilon}{(\delta\Omega)\varphi_{sky}}$$

Science Goals

$\varphi_{obj} = object\ flux$

$S/N = signal/noise$

Survey system

$A = telescope\ area$

$\Omega = field\ of\ view$

$\varepsilon = system\ efficiency$

Site

$\varphi_{sky} = sky\ brightness$

$\delta\Omega = image\ size$

Science Potential

Detailed operational simulations show that a survey with AΩ > 300, operating for 10 years, can *simultaneously* provide major improvements on a wide variety of fronts.

- Probe dark energy and dark matter
  - 2% constraints on DE parameters by many independent means:

    multiple weak lensing, supernovæ
- Open the time domain
  - Faint transient sources: SNe, GRB afterglows, …
  - Variable sources: stars, AGN, strong lensing, …
- Solar system probes
  - NEAs, KBOs, comets, debris

THE UNKNOWN

Such a system will gather more optical data than all previous astronomical images combined.

Finding now-rare events will become commonplace.

Finding the truly singular will be possible.

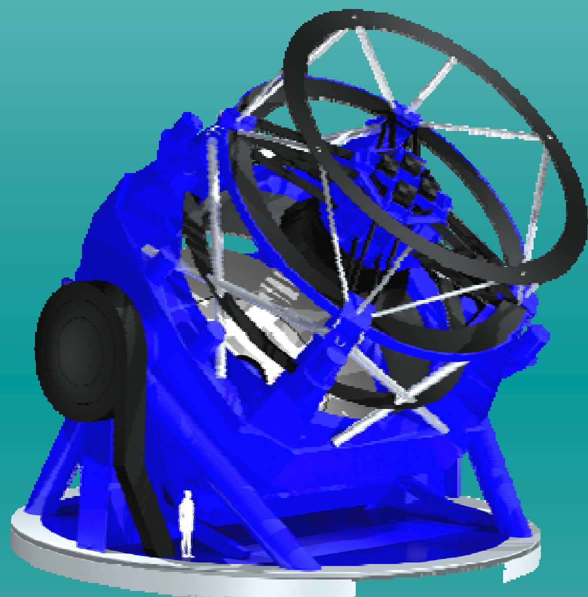
Building the system

Such a system is made possible today by the confluence of three technological developments:

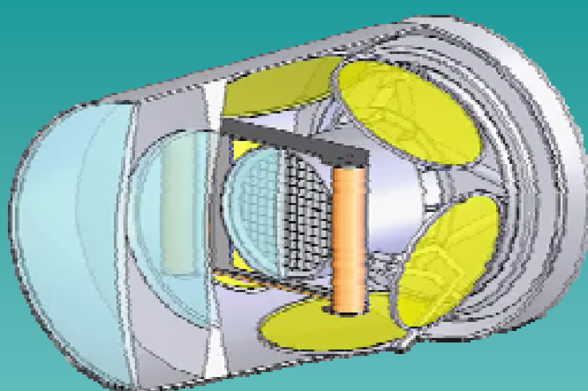
- Routine fabrication of large optics enable new large telescope designs with wide fields of view.
- Advanced detectors and electronics enable large, sophisticated focal plane arrays with short read-out times.
- Rapid progress in computing and database technologies make it possible to store and mine vast quantities of data.

The LSST System

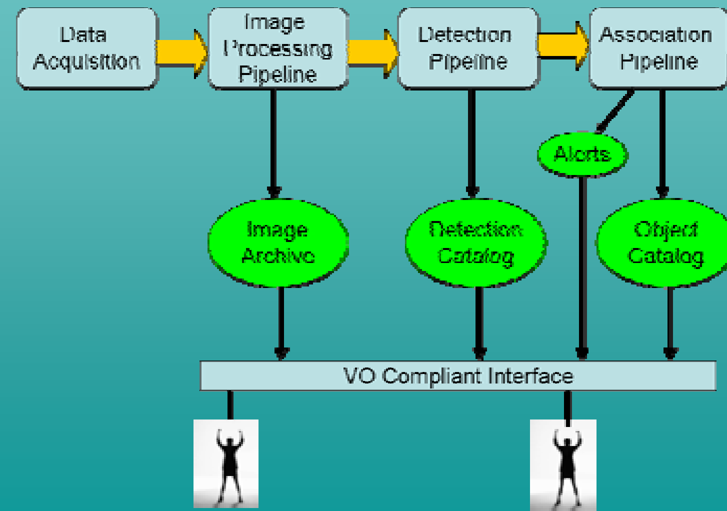
$A\Omega = 318\ m^2\ deg^2$



8.4m Telescope
3.5° field of view



3 Gigapixel Camera
1 second readout



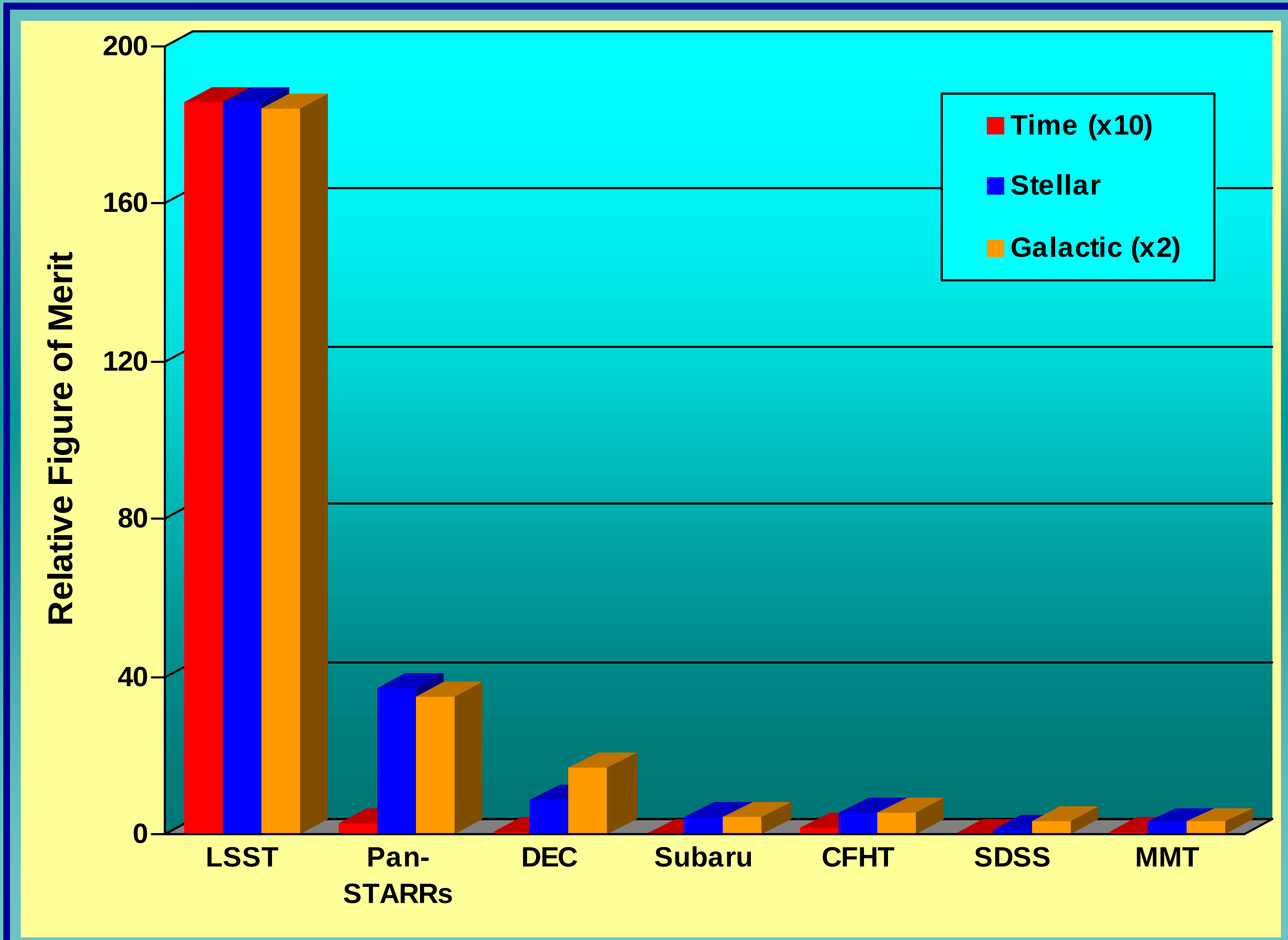
Data Management
~30 TB/night
50 PB in ten years

The LSST System

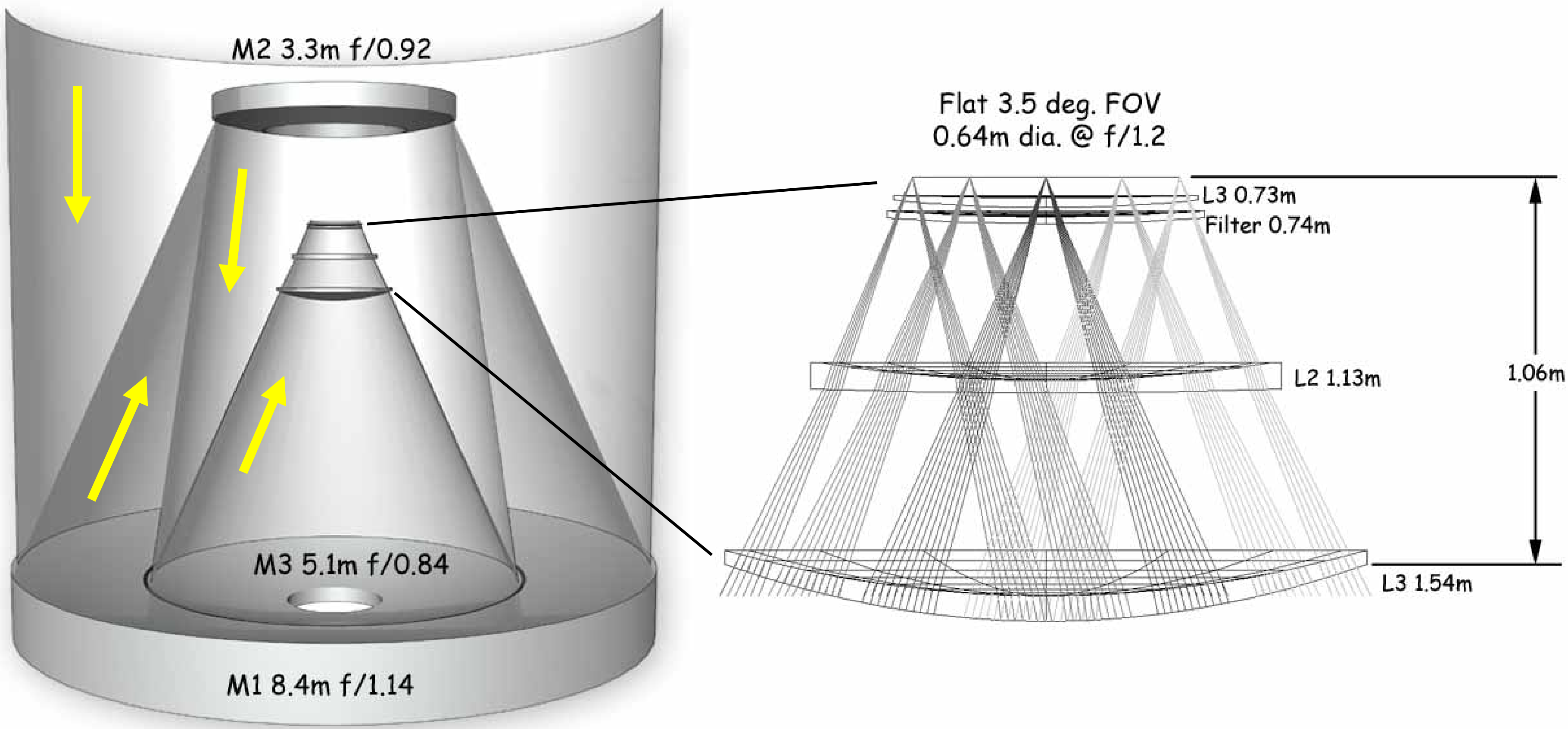
LSST is designed to go wide – deep – fast

- ~10 deg^2 per field
- ~6.5m effective collecting aperture
- m~24 AB mag per 10 sec. exposure (2 per pointing)
- wide coverage > 20,000 square degrees
- multiple filters (e.g. grizy - TBD)
- 500+ epochs in each of >2000 fields, in each filter, over ten years
- accumulated depth of 27 AB magnitude in each filter

A qualitatively different regime



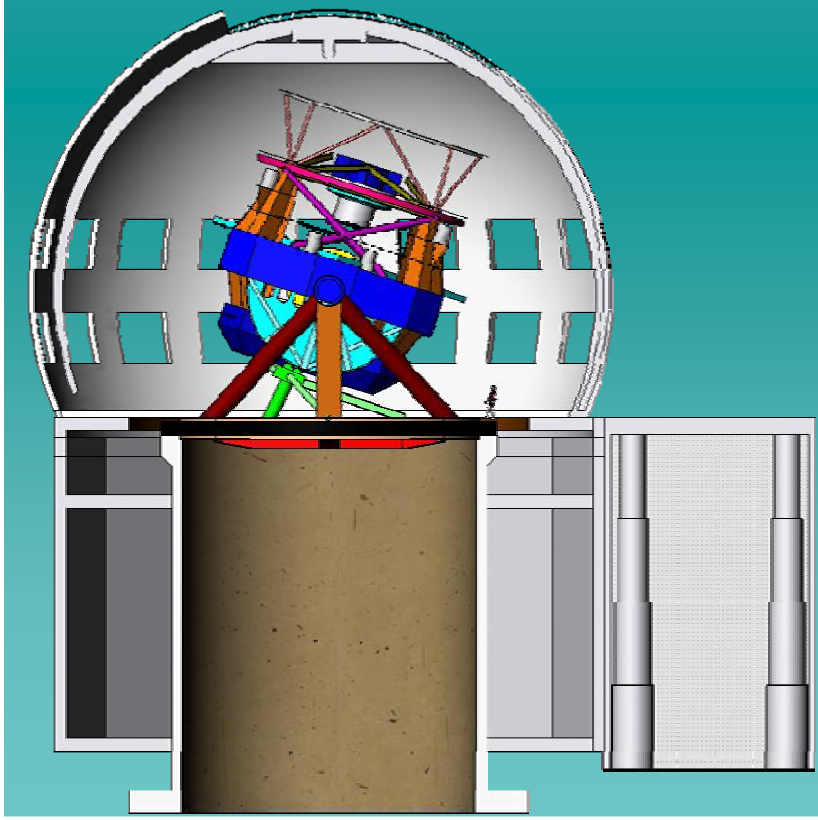
Optical Design

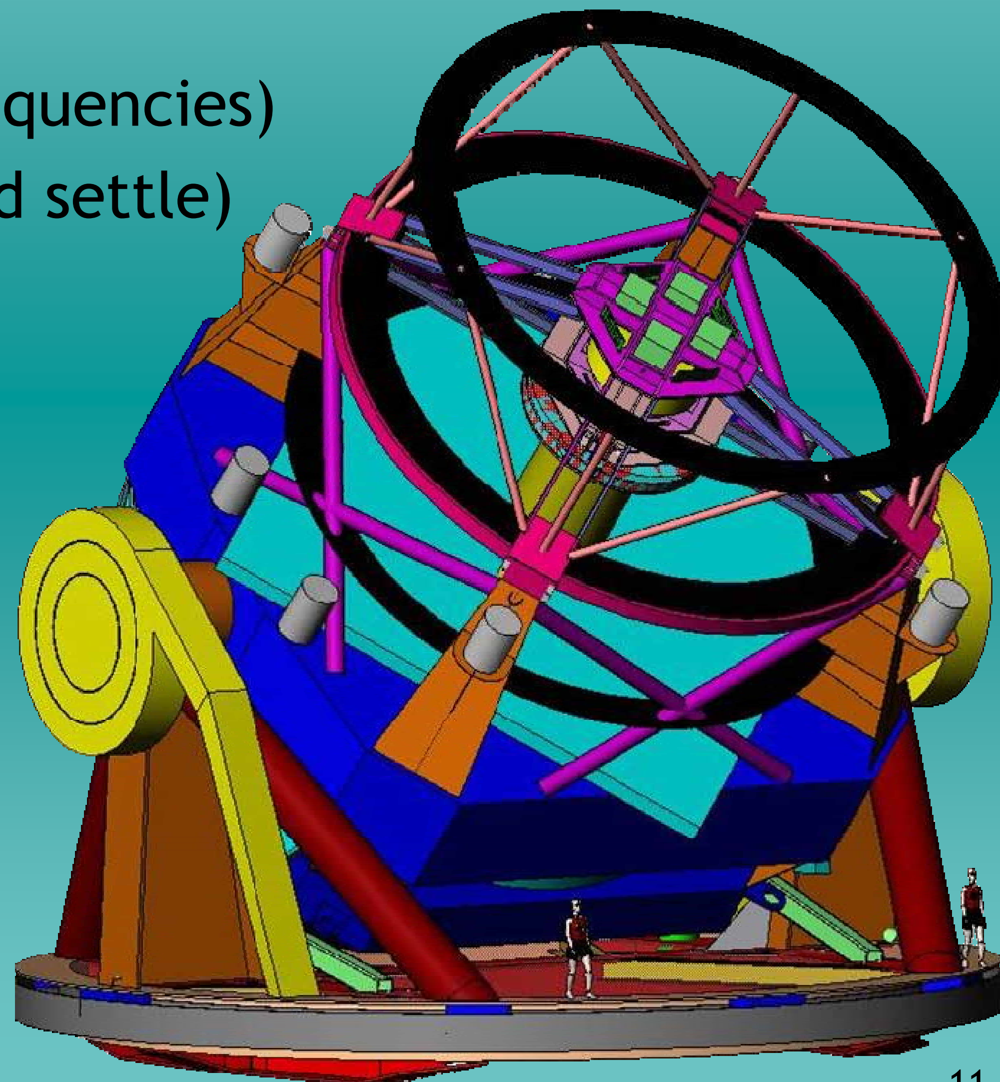


Telescope

Three-mirror design permits a structure only 6.3m long:

- light (200 tons)
- stiff (> 10 Hz resonant frequencies)
- agile (<5 seconds slew and settle)





Construction has already begun…

The contract for the primary mirror:

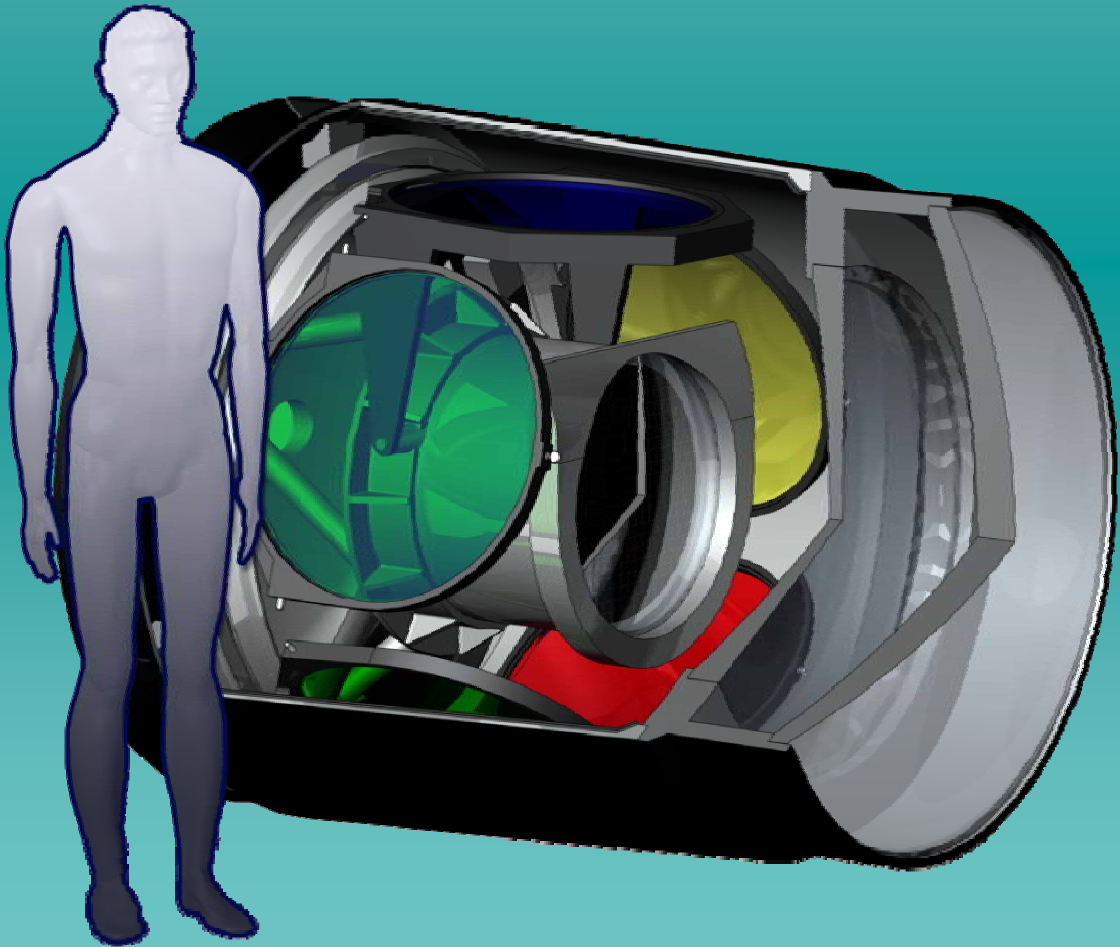
- privately funded
- awarded to the Steward Observatory Mirror Lab.

Camera

64 cm diameter active area

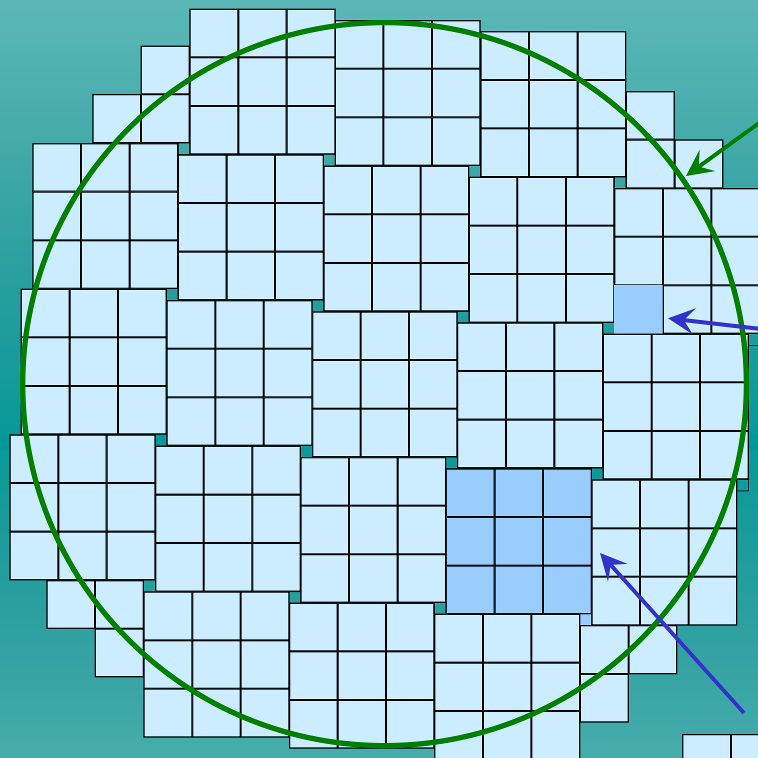
3 Gigapixels with 1 second read-out

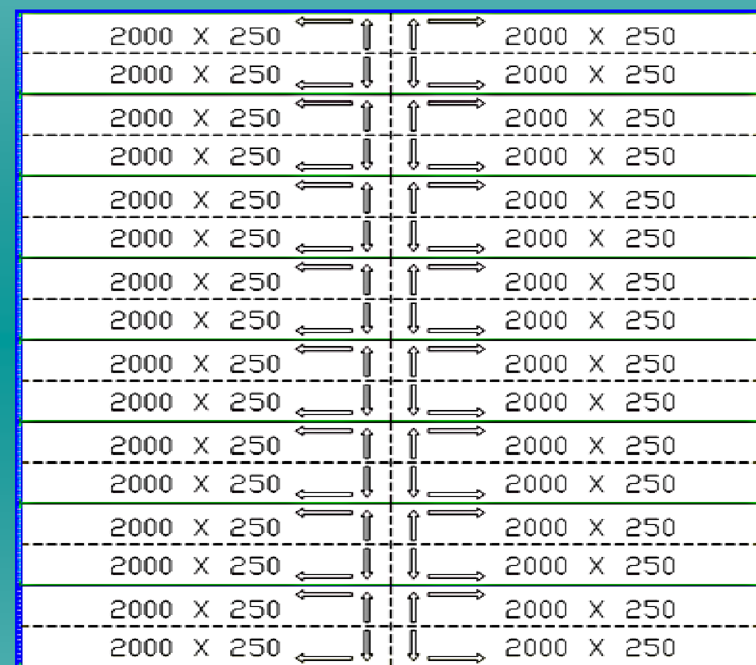
Five filters in camera



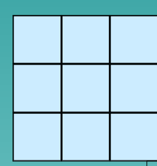
Focal plane array

3.5° FOV → 64 cm ∅





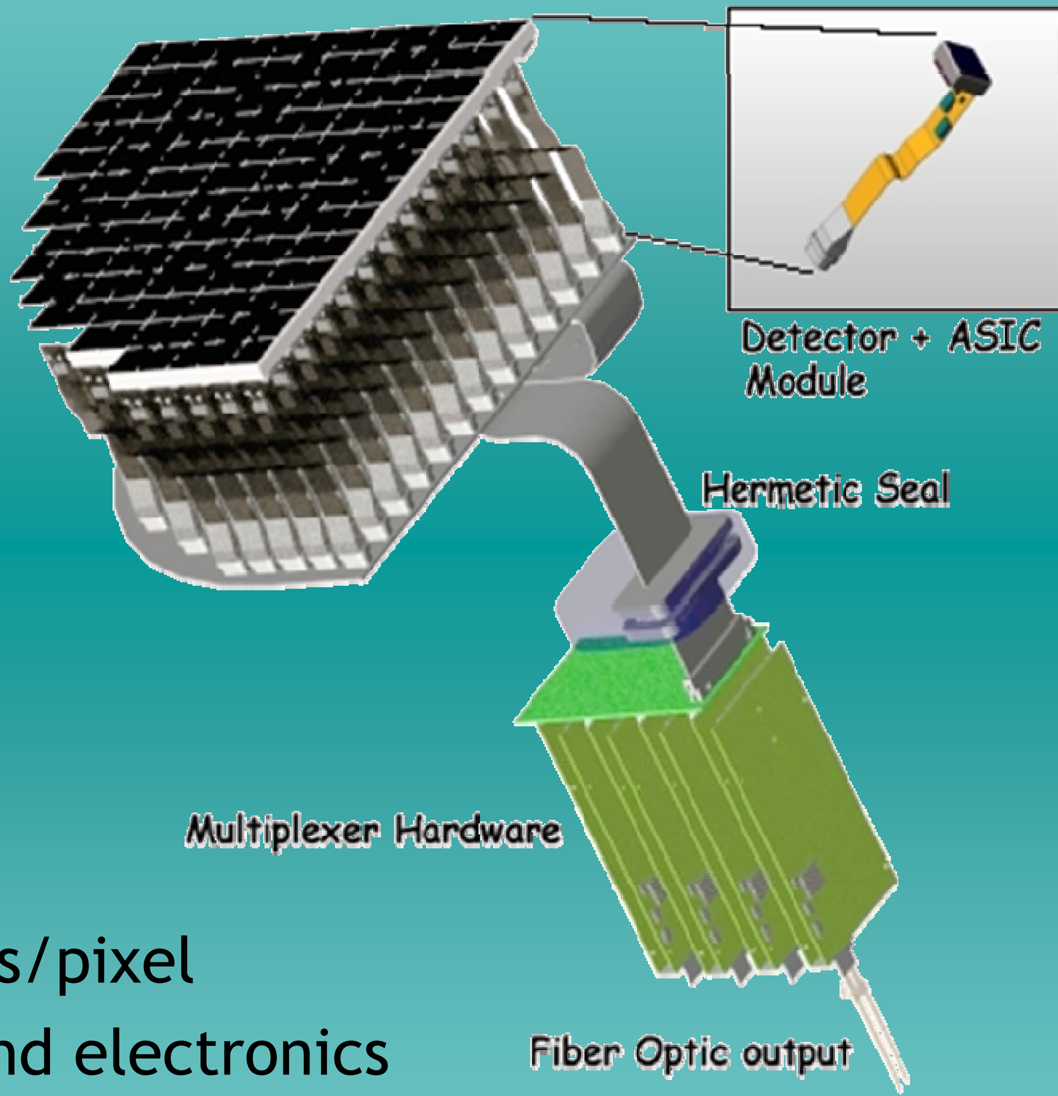
201 CCDs total



Raft = 9 CCDs
+ 1cm x 1cm reserved
for wavefront sensors

Strawman CCD layout
4K x 4K, 10 μm pixels
32 output ports

Focal plane array



Modular

10µ pixels, 0.2 arcseconds/pixel

Highly integrated front-end electronics

3 Gb/s parallel readout

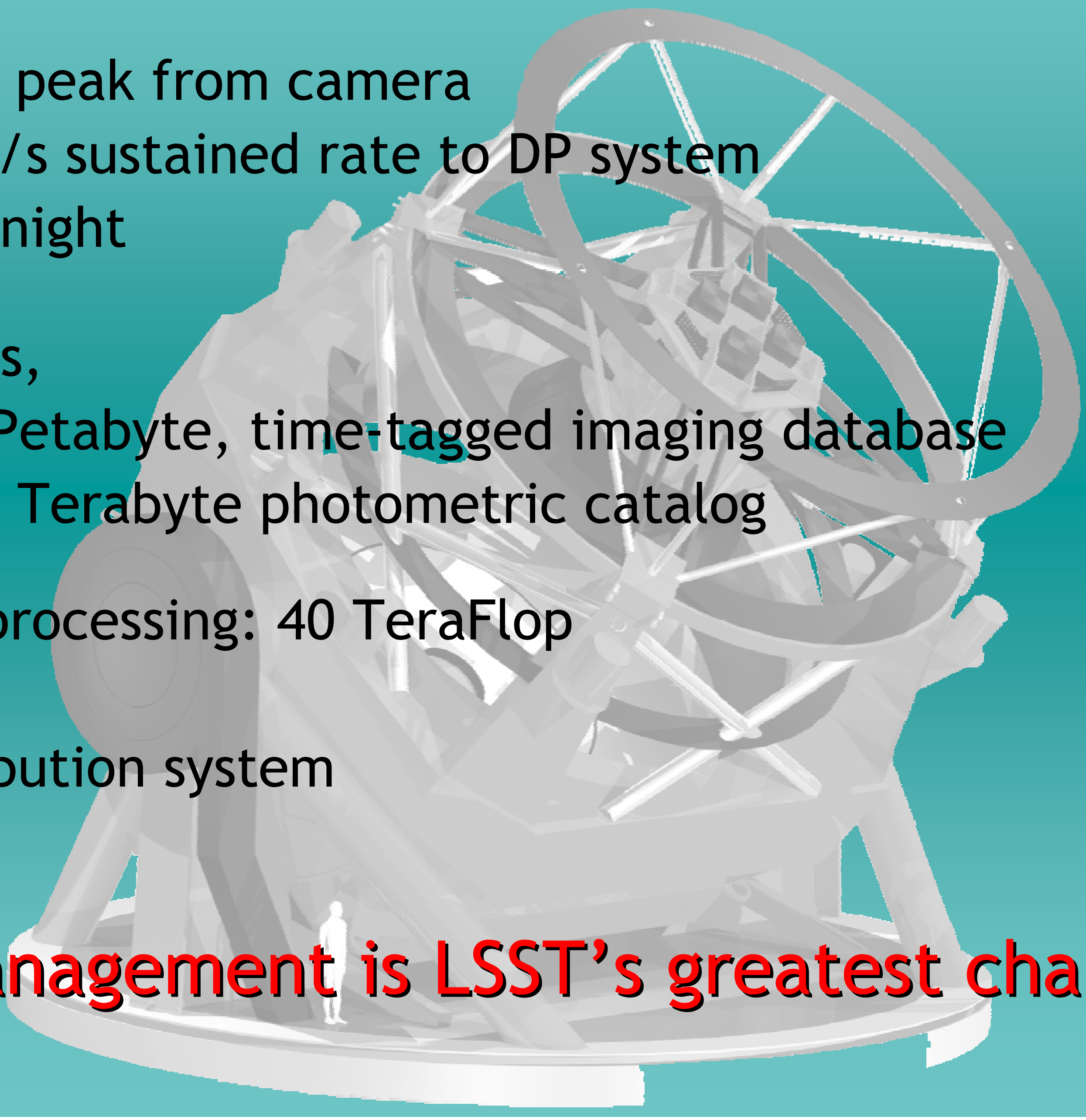
LSST Data System

3 GBytes/s peak from camera
0.6 GBytes/s sustained rate to DP system
30 TBytes/night

In ten years,
    50 Petabyte, time-tagged imaging database
    100 Terabyte photometric catalog

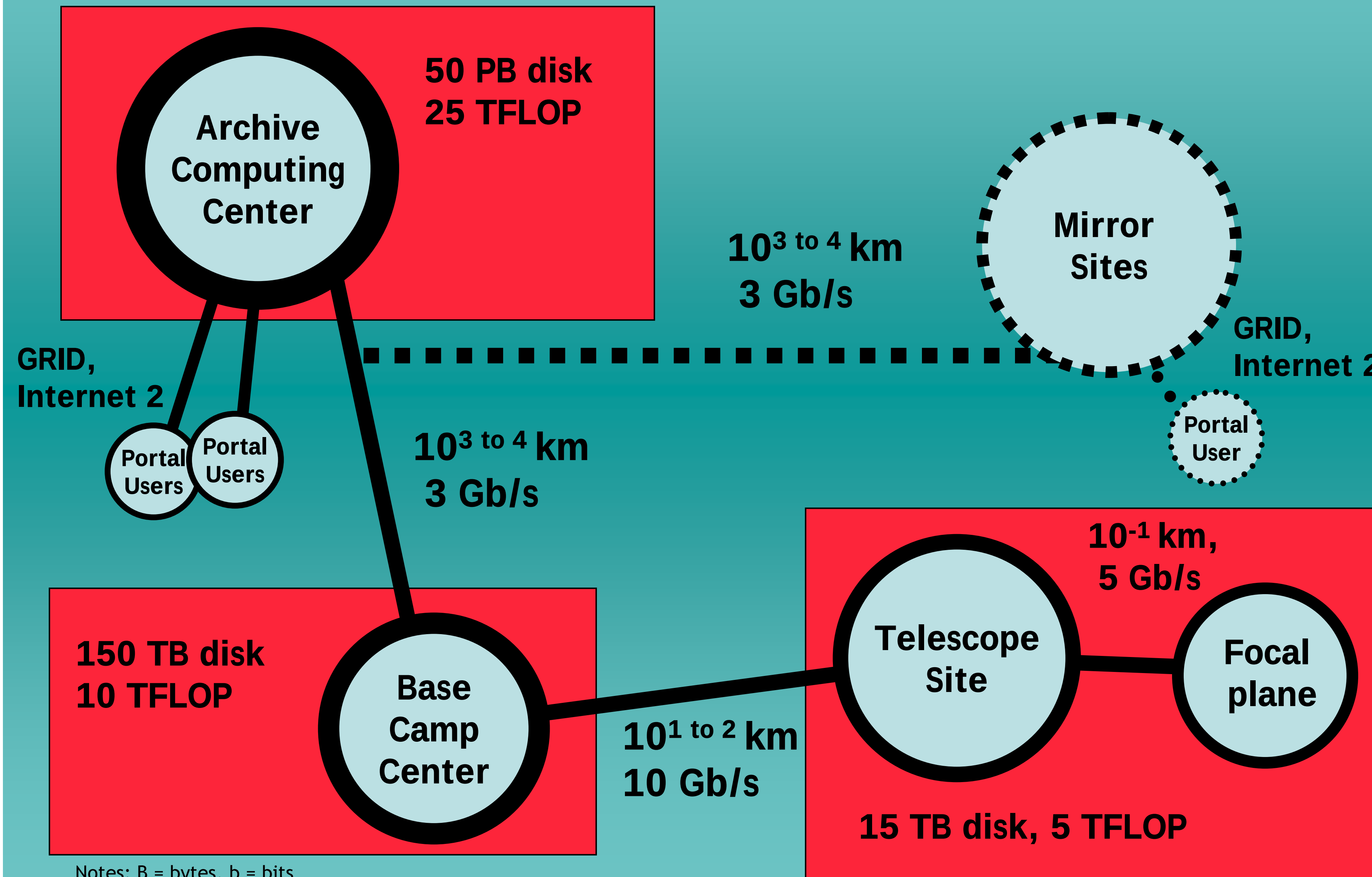
real-time processing: 40 TeraFlop

data distribution system



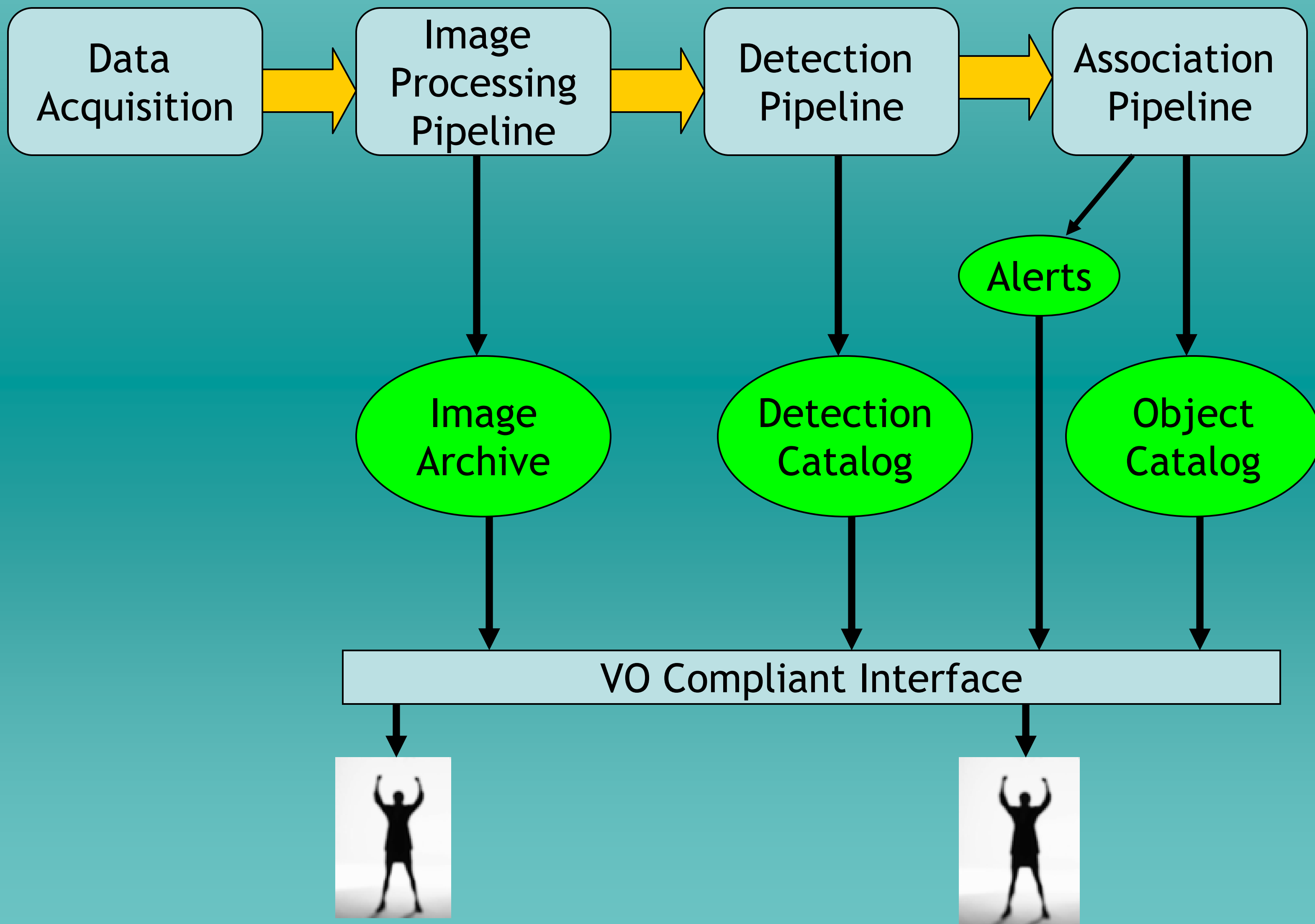
Data management is LSST's greatest challenge

LSST Data System Infrastructure



Notes: B = bytes, b = bits

LSST Data System



LSST Data

Calibrated Image Data

- Deep co-added images
  - >20,000 square degrees to 27 AB mag
  - five filters (e.g. grizy), w/ less-deep UV survey
- Individual images to 24 AB mag (10σ)
- Difference images
- Metadata
  - control system
  - automated quality assessment
  - world coordinate system

LSST Data

Calibrated Object Database

- Raw source detections
- Object data
  - Photometry
  - Lightcurves
  - Parallax/proper motion
  - Shape parameters
  - Classification

Alert notification system

- Automated alerts based upon selected criteria
- Notification w/in 1 minute of observation

ALL DATA ARE PUBLIC

Project is committed to a completely “open-data” mode of operation, once science operations commence.

No proprietary data. No proprietary data periods.

Data will appear in the public archives within hours of acquisition.

Methods of accessing the data will likely evolve over time, depending on the evolution of the national data infrastructure.

Site Selection

An independent panel has selected a short list of four sites:

Northern Hemisphere:

San Pedro Martír, Baja California

La Palma, Canary Islands

Southern Hemisphere:

Cerro Pachon, Chile

Las Campanas, Chile

Site testing is currently underway at each, with selection of two semi-finalists this month.

Outreach

LSST will introduce the public to the dynamic cosmos

Public web portals

- Graphic images and movies of the sky
- Annotated each day with myriad new and moving objects

Science Centers and Planetariums

- Wall-sized movies of the changing sky

K-16 educational projects employing real-time data of the cosmos' most dramatic events.

LSST Key Science

The “Dark Sector” *

- weak lensing, supernovae

Finding and Exploiting Optical Transients *

- Novæ, SNe, GRB’s, μ-lensing, variables, AGN

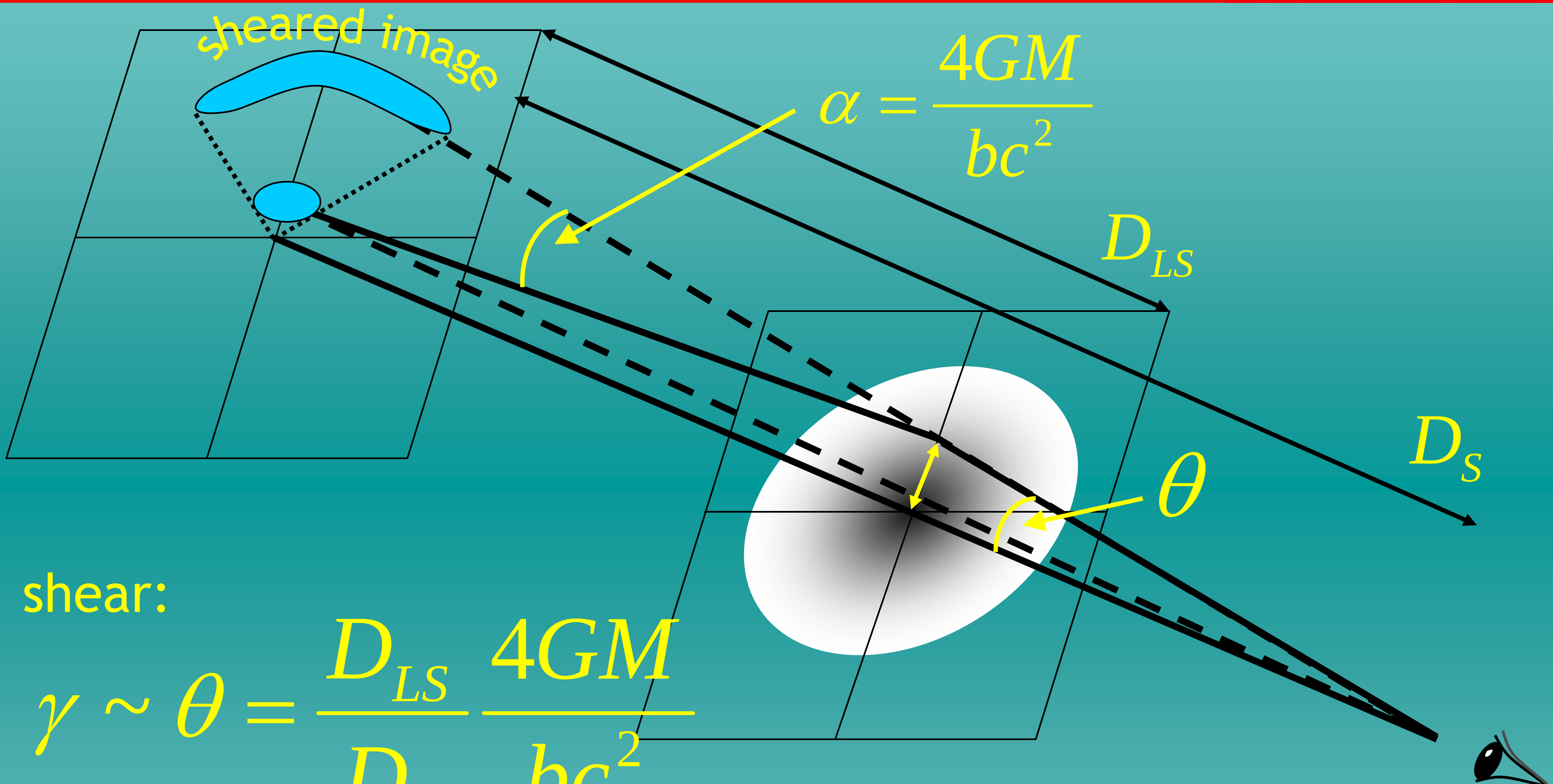
Mapping the Solar System

- NEA, KBO, TNO, comets, debris

The Structure of our Galaxy

- Structure & formation of the halo
- Mapping the dark halo through dynamical tracers
- Survey of the solar neighborhood

Lensing



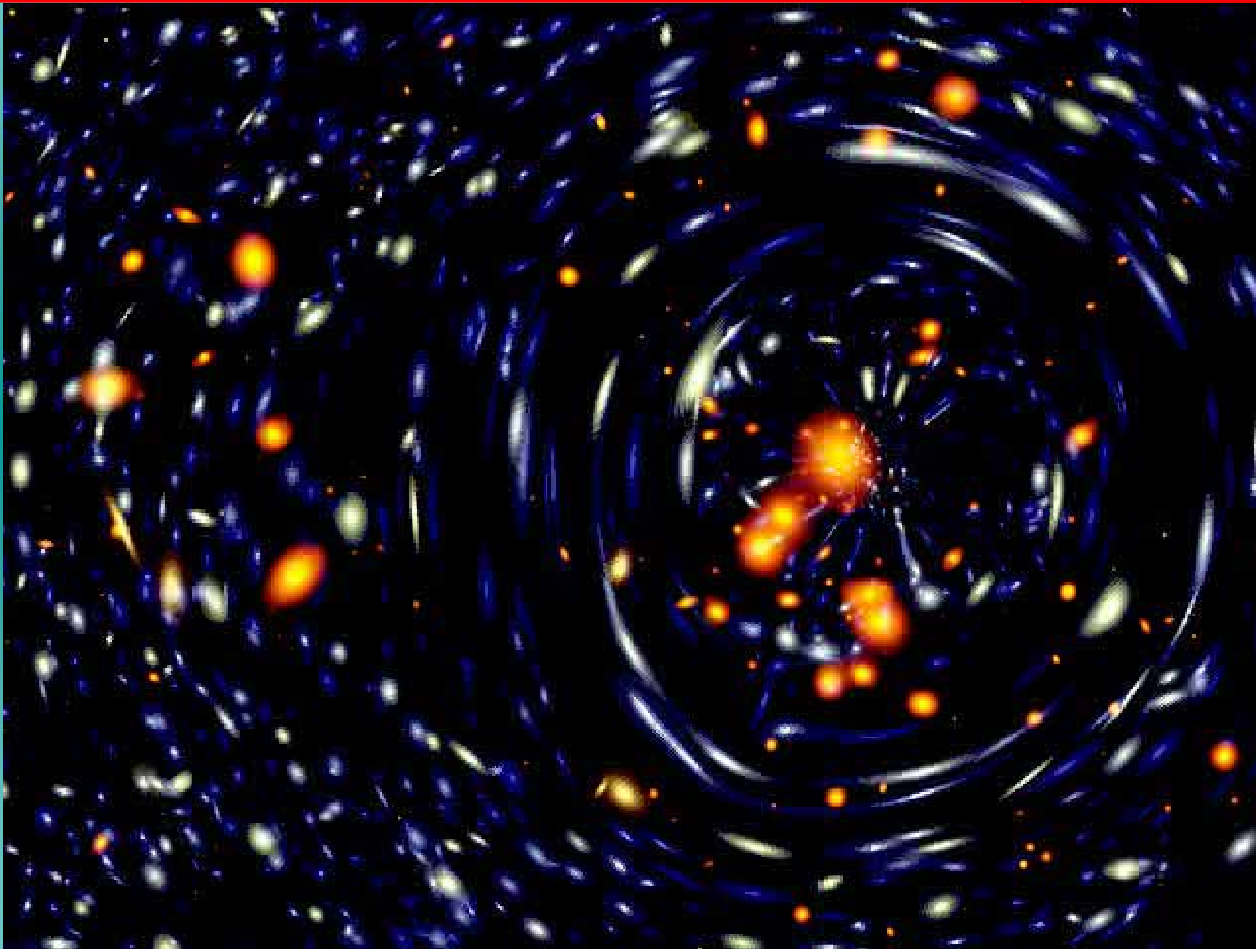
shear:

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

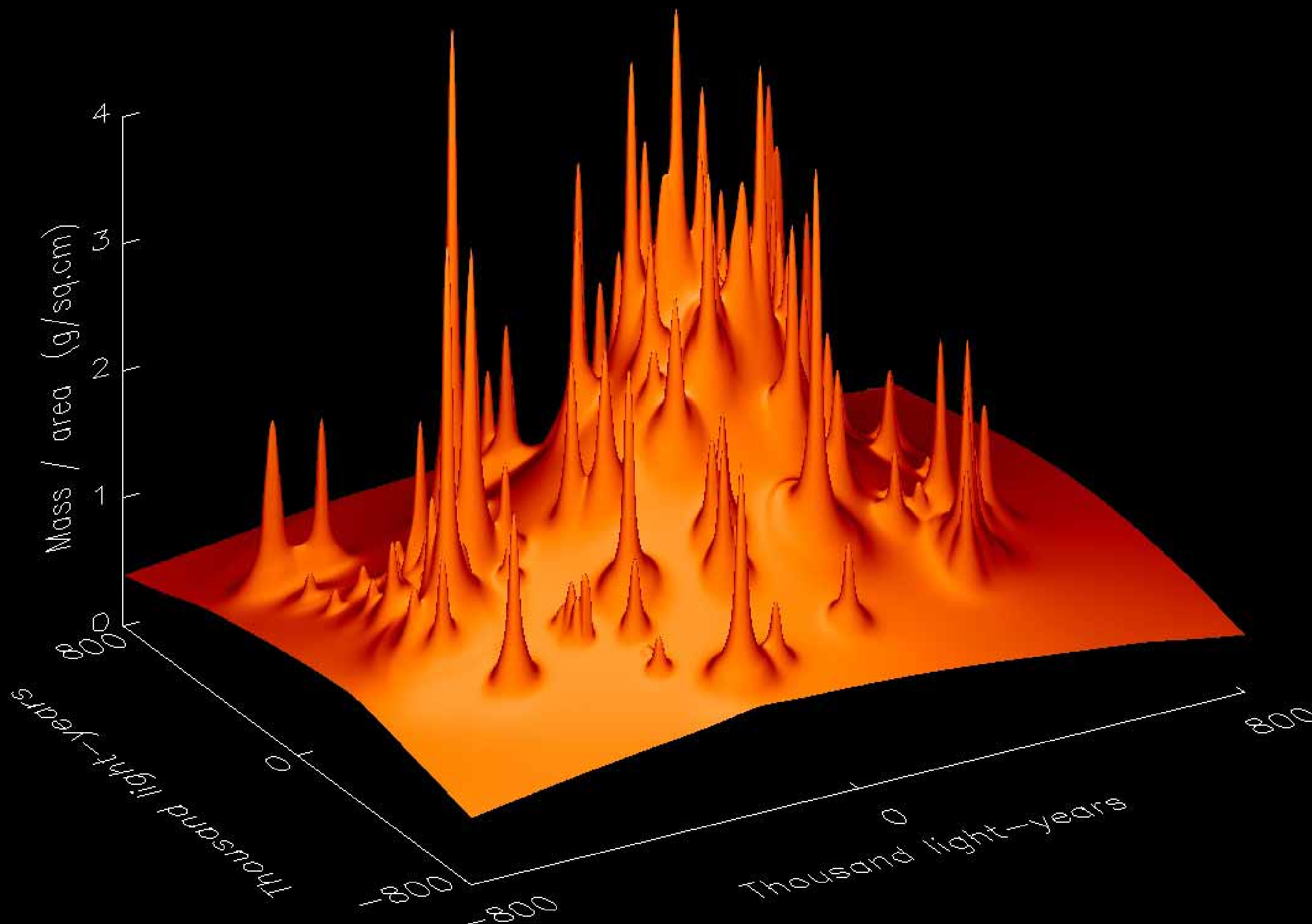
Cosmology changes geometric distance factors

Cosmology changes the growth rate of mass structure

Sheared galaxies...



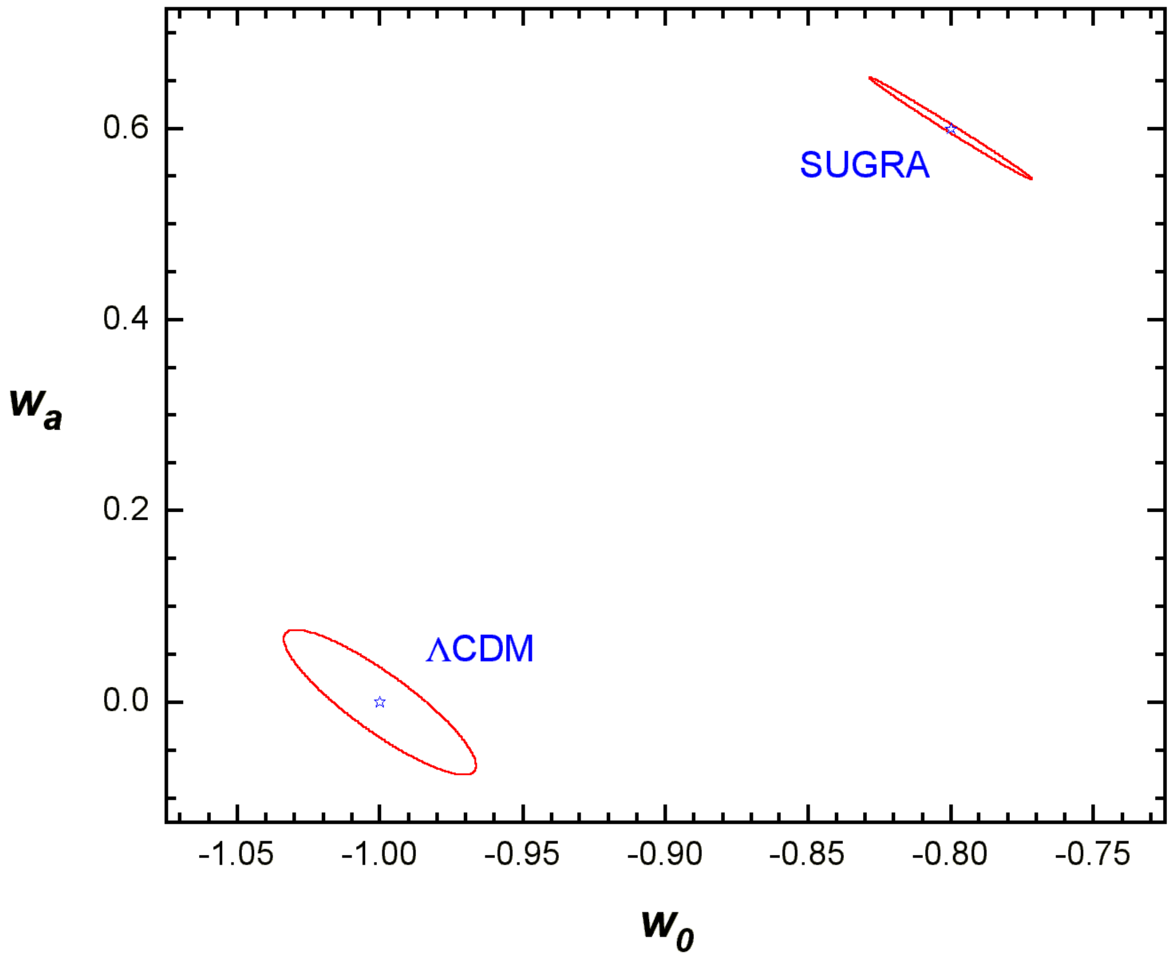
Mass in CL0024



Cluster Counts

Precision and accuracy are increased by using optimal filter and S/N threshold rather than mass threshold for cluster determination.

LSST 10 yr survey: $3x10^9$ galaxies

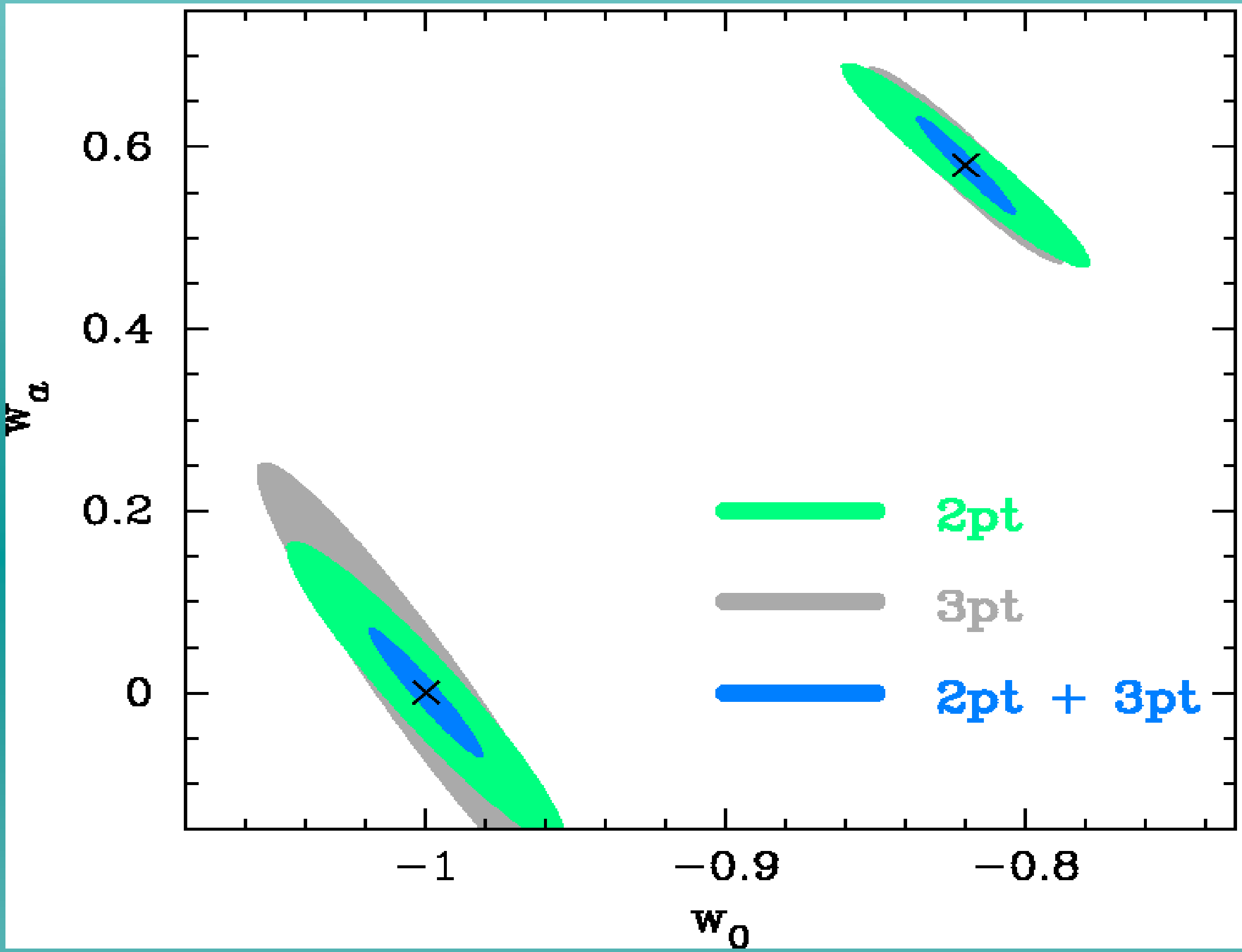


after Wang *et al*., 2004

Correlation Tomography

2- and 3-point correlation tomography with LSST's billions of source galaxies.

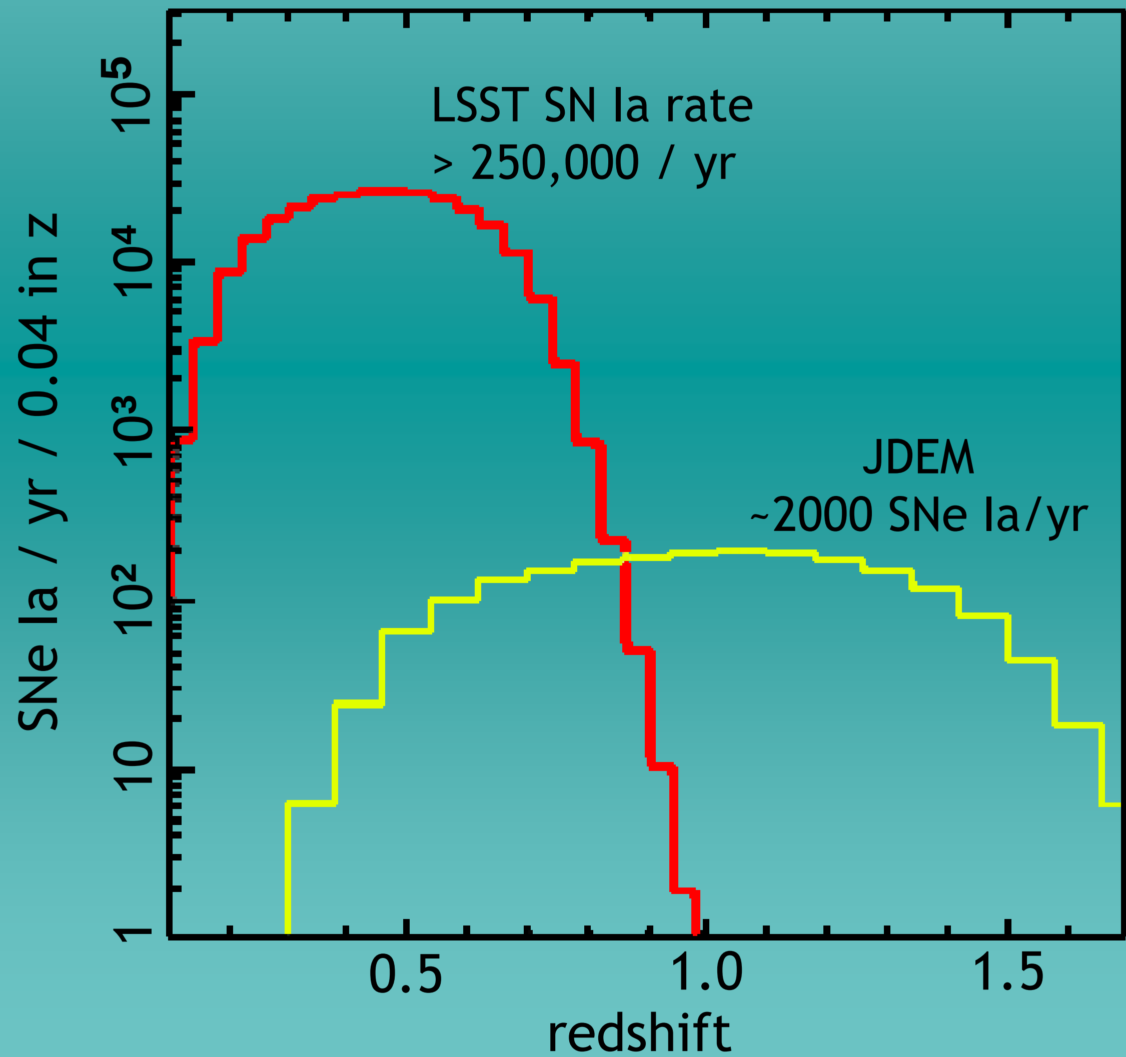
A statistically independent and complementay constraint on dark energy.



after Takada & Jain, 2004

Supernova Cosmology

LSST will obtain lightcurves for over 2.5 million type Ia supernovæ over ten years, to a redshift of 0.9



Supernova Cosmology

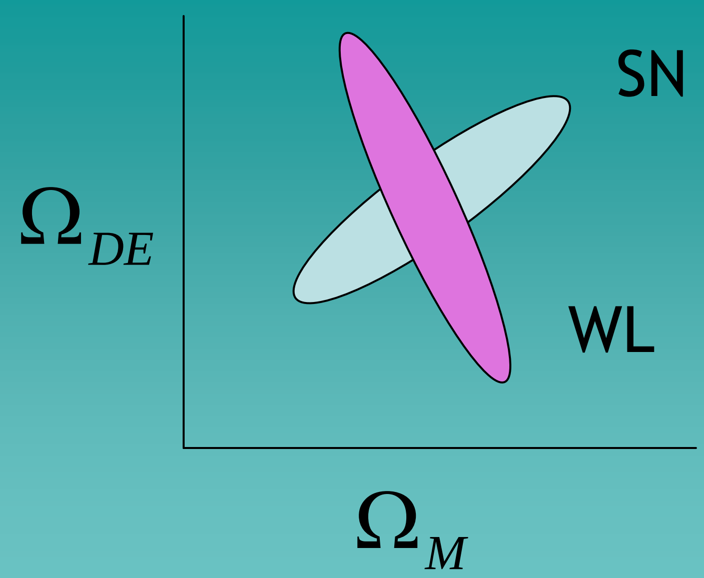
2.5 million SNe Ia lightcurves will allow discovering systematic effects in the luminosity-width relation.

~10,000 SNe Ia are sufficient to measure *w* to 1%.

→ provide *w* along 250 independent directions

New physics?

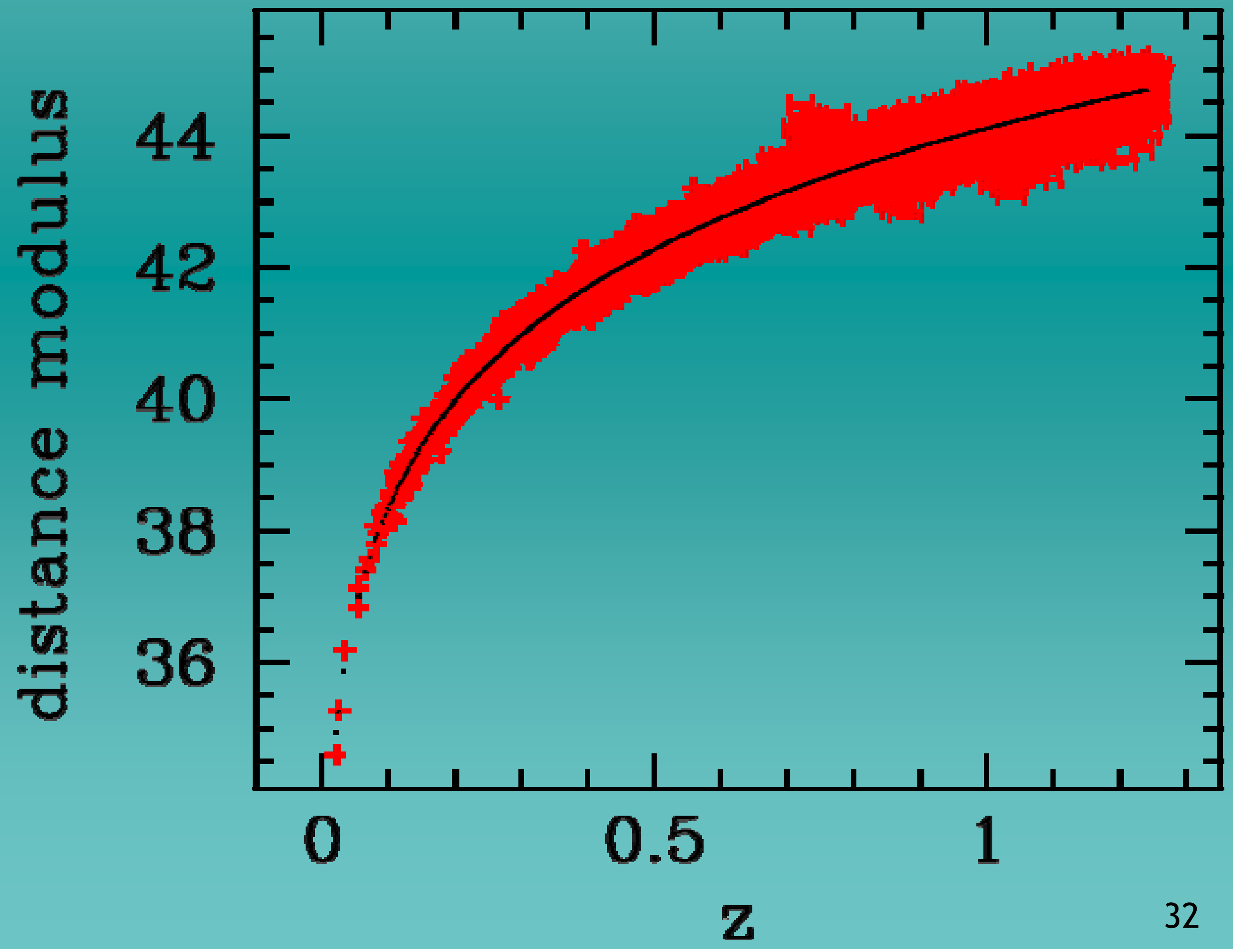
SNe Ia measurements of H(z) complement those from weak lensing:



Supernova Cosmology

Large Synoptic Survey Telescope

10 min./night on one field
will measure >6000
type Ia supernovæ per year
to z>1



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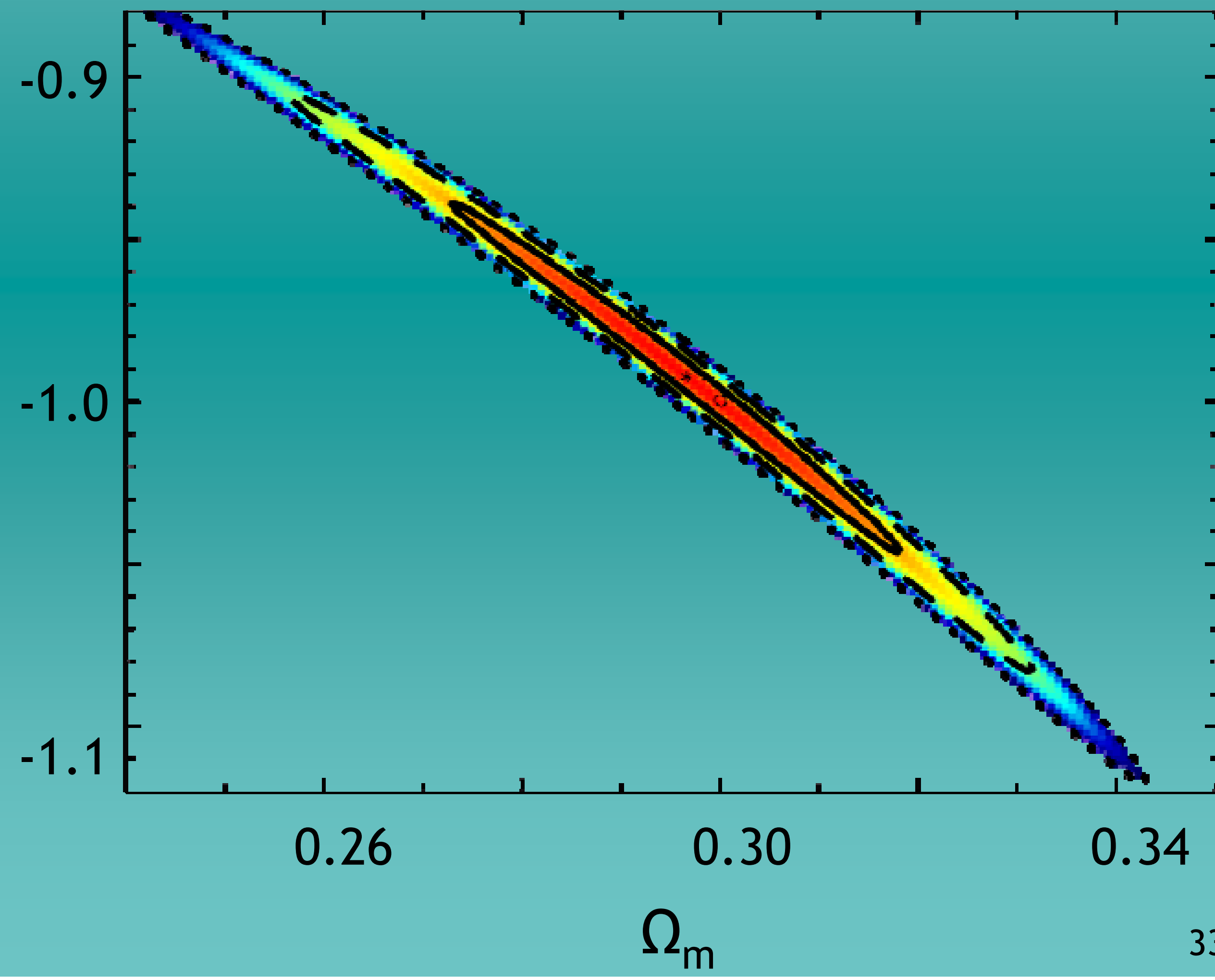
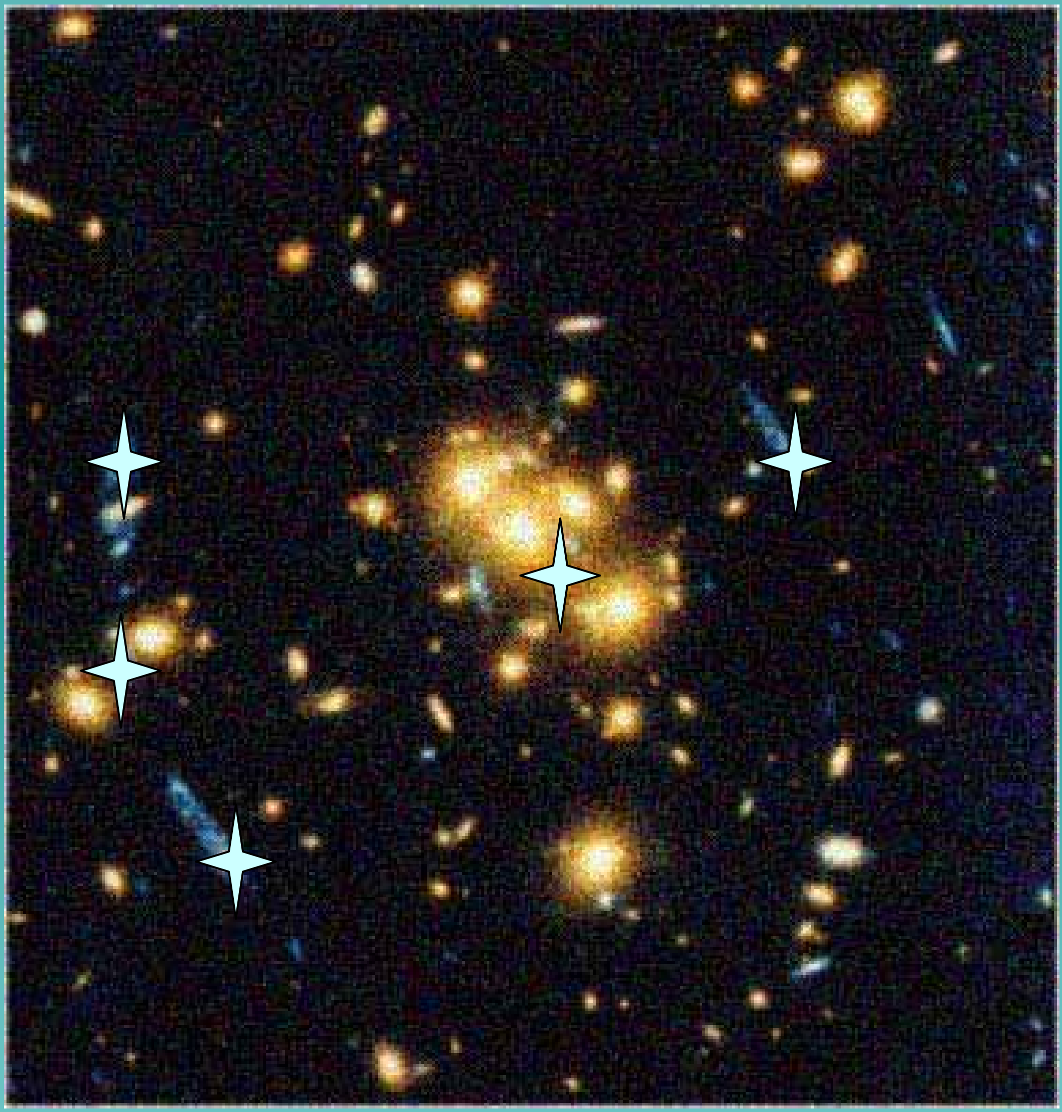


Strong Lensing of Supernovæ

LSST will discover ~100 strongly-lensed supernovæ.

Precise source distances & time delays…

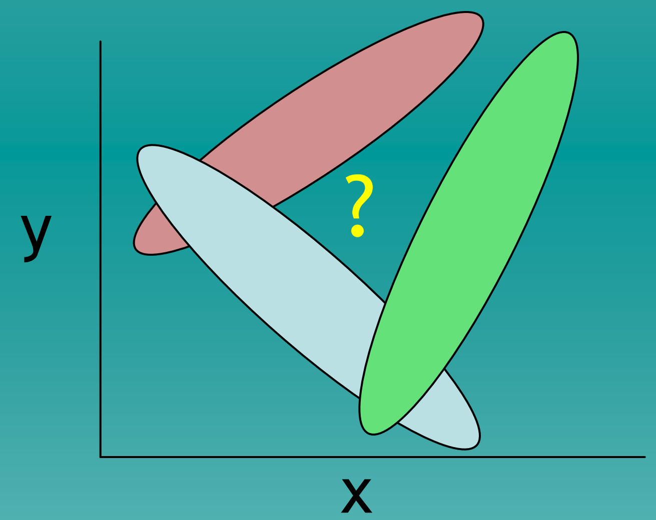
probing both dark matter and cosmological parameters



Probes of the Dark Sector

LSST will provide *independent* weak lensing and type Ia supernova probes of dark matter and energy:

- Engineered to suppress sources of systematic error
- Multiple probes provide redundant error estimation
- Or, new dark sector physics…



Combining with *Planck* CMB data will provide numerous measurements of cosmological parameters at the percent level.

The Time Domain

Large Synoptic Survey Telescope

or, Things that Go Bump in the Night

LSST goes faint and wide, fast:

- Current surveys take hours to get to the flux levels LSST will reach in 20 seconds – a thousand-fold increase in discovery space.

New classes of optical transients:

- Astrophysics of matter under extreme conditions
- Potential for exploitation as astronomical probes

Gamma Ray Bursts

LSST will detect >500 “orphan afterglows” per year:

- constraint on collimation of relativistic jet
- determines GRB energetics and rates
- much larger sample will lead to better understanding of progenitors and the GRB mechanism (GRB/SN connection)

Totani & Panaitescu, 2002

The High-Energy Sky

LSST will be a powerful complement to gravitational wave observatories

- Optical counterparts to mergers of compact objects, asymmetric supernovæ.
- Directional information strongly constrains interpretation of gravitational wave signals

The High-Energy Sky

Wide-field missions like EXIST (hard X-ray) and GLAST (GeV) will produce lightcurves of thousands of black holes

- Optical lightcurves sampled on day timescales in multiple colors
- Structure of jets
- Acceleration processes of high-energy particles & photons

Variable Stars

LSST will obtain multicolor lightcurves of >10^8 variable stars

- new dimension to stellar structure and evolution

RR Lyræ stars to 400 kpc, with proper motions past 100 kpc

- trace the dynamics of the halo
- aid in interpreting μ-lensing events

2000 Classical nova lightcurves per year

- distances out to Virgo & Fornax
- 200 intergalactic “tramp” novae

Contact binaries to the Magellanic Clouds

- Accurate distances trace galactic collision/cannibalism/stripping of the Local Group

QSO's

Quasars can be discovered by their variability as well as their color

- Find QSOs without "typical" QSO colors
- QSOs with luminosities comparable to their hosts
- Multicolor lightcurves measure viscosity

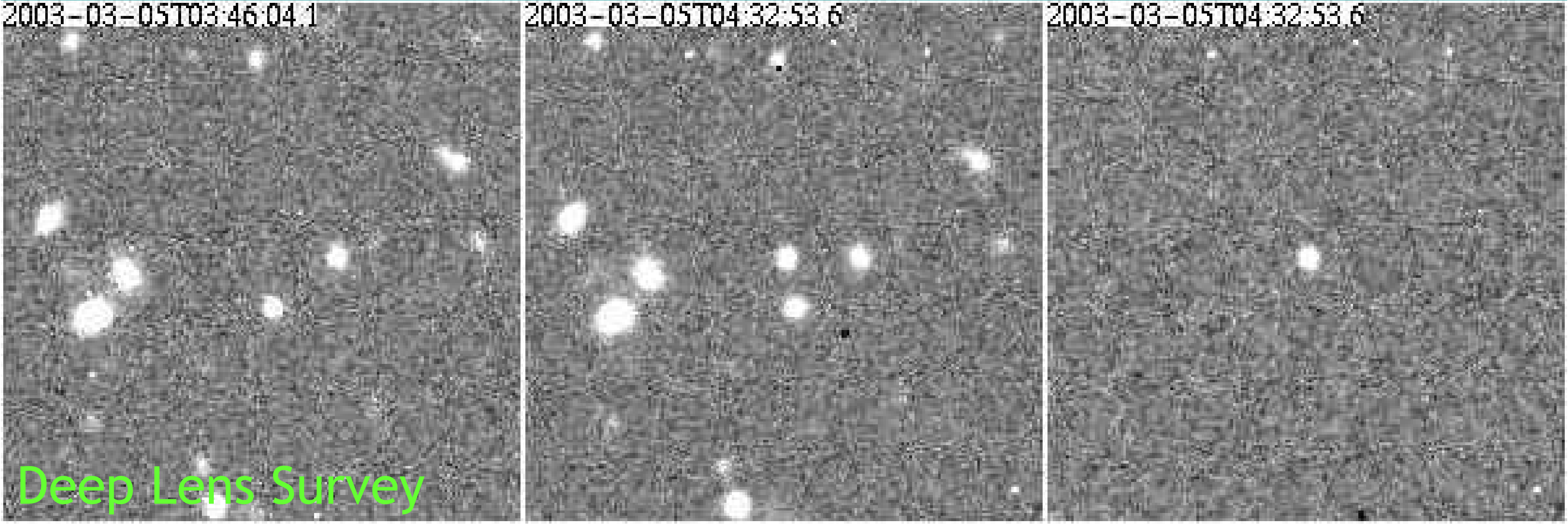
Stacked images will be 5 magnitudes deeper than SDSS

- With its Y filter, LSST will discover 10^2 – 10^3 quasars with $6 < z < 8$
- Measurement of black hole feeding history
- Probes of ionization state of the IGM at large z

Optical Transients

Deep, time-domain surveys have found several transient sources which last as little as ten minutes yet have no detectable galaxy or stellar precursor.

LSST is likely to find tens of thousands of such events to m~25 and provide lightcurves and colors.



An Invitation

LSST is a truly public project; it has many of the features of open source software…

How well it succeeds in meeting *your* needs out to 2022 depends upon *your* participation and input today.

To find out more about LSST, see today's poster session

To help LSST succeed, see the community input forum on

http://www.lsst.org

Partners

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Large Synoptic Survey Telescope

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