Dark Energy with DES and LSST

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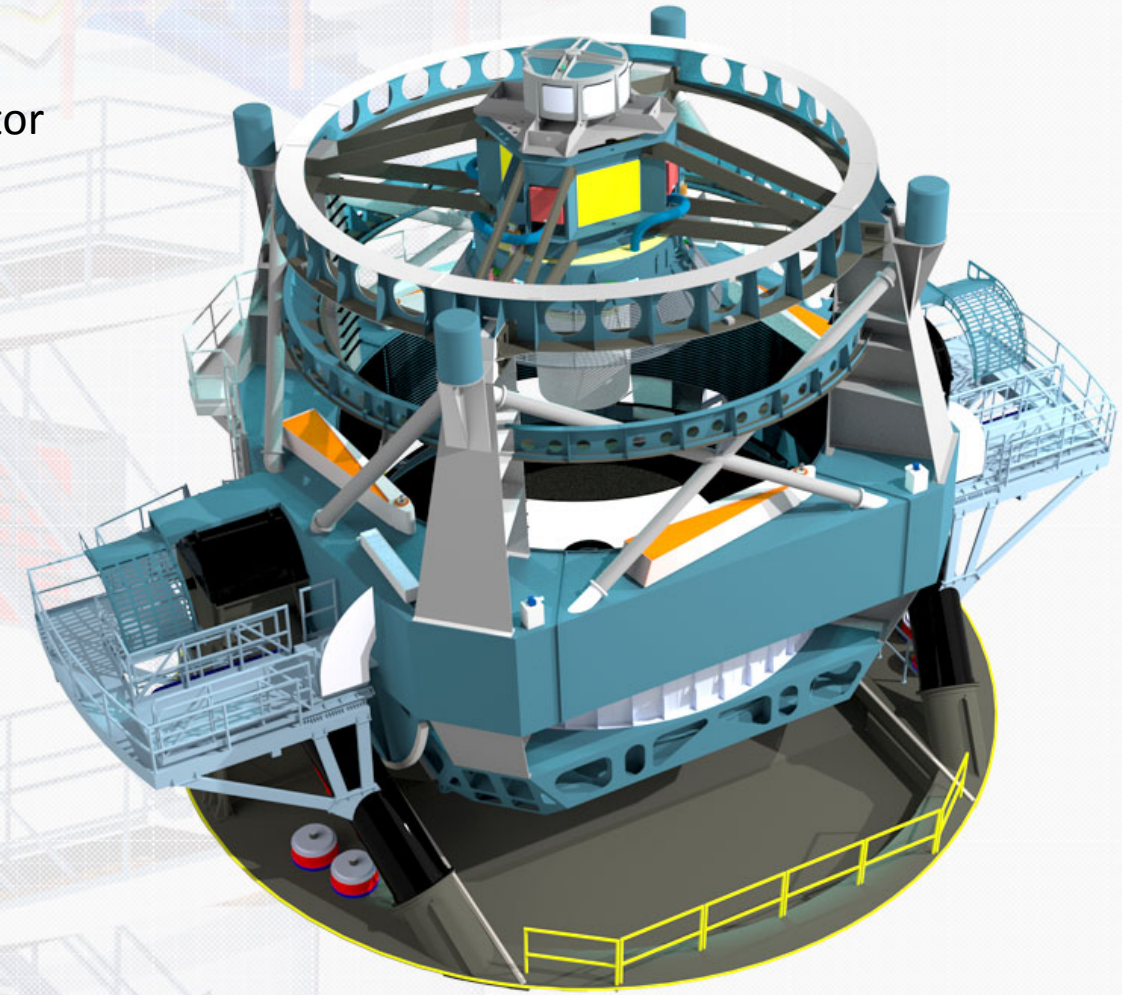


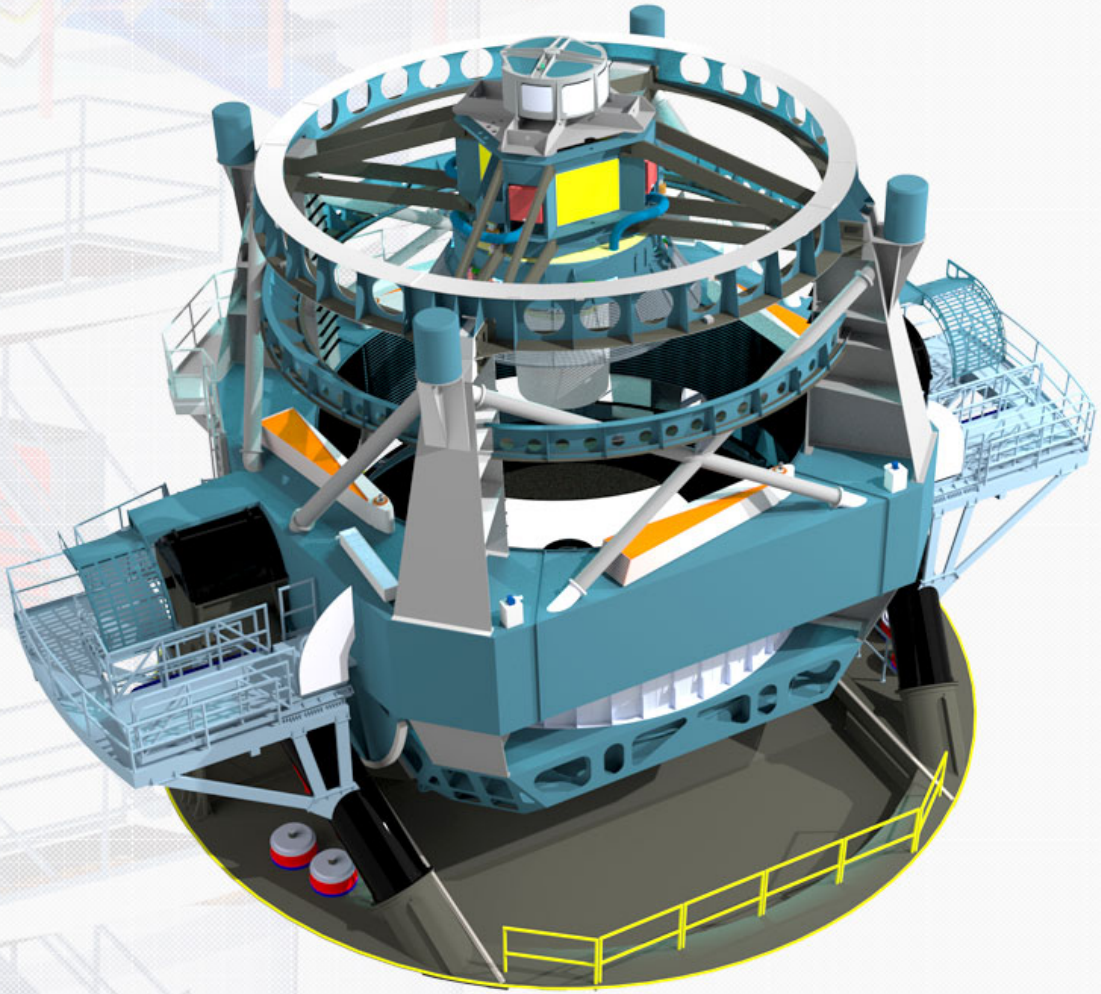
THE DARK ENERGY SURVEY

LSST

Outline

- Dark Energy science with imaging surveys
- DES status and results
- LSST camera project layout
- LSST-DESC collaboration

Dark Energy science with imaging surveys

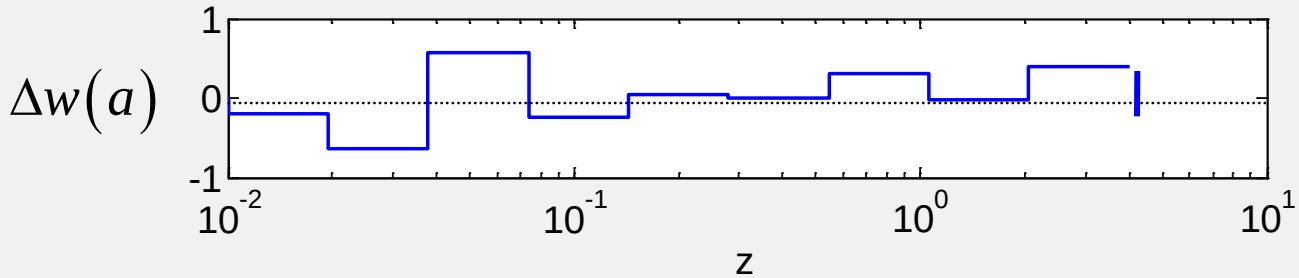


Dark Energy Probes with DES and LSST

Probe	Physical Observable	Sensitivity to Dark Energy or Modified Gravity
Weak Lensing	Coherent distortions in galaxy shapes	Geometry and growth of structure (projected)
Large-Scale Structure (BAO)	Power spectrum of galaxy distribution	Distance-redshift relation
Galaxy Clusters	Abundance of massive clusters	Growth of structure and geometry
Type Ia Supernovae	Fluxes of standard candles	Distance-redshift relation
Strong Lensing	Time delays of multiply lensed sources	Distance-redshift relation

Beyond Lambda

- Is dark energy constant in redshift?

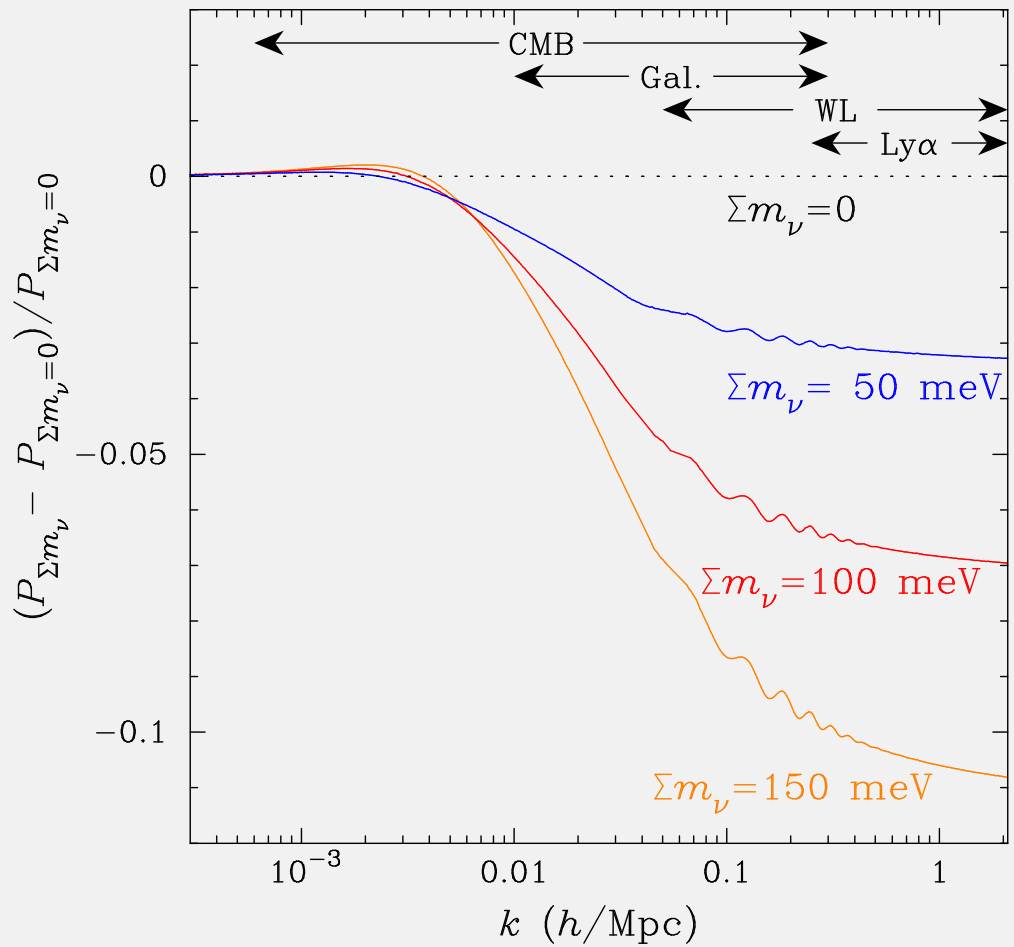


- Is dark energy spatially clustered or anisotropic?
- Are there couplings between dark energy, dark matter, baryons?
- Is it dark energy or modified gravity – a breakdown of Einstein's General Relativity?

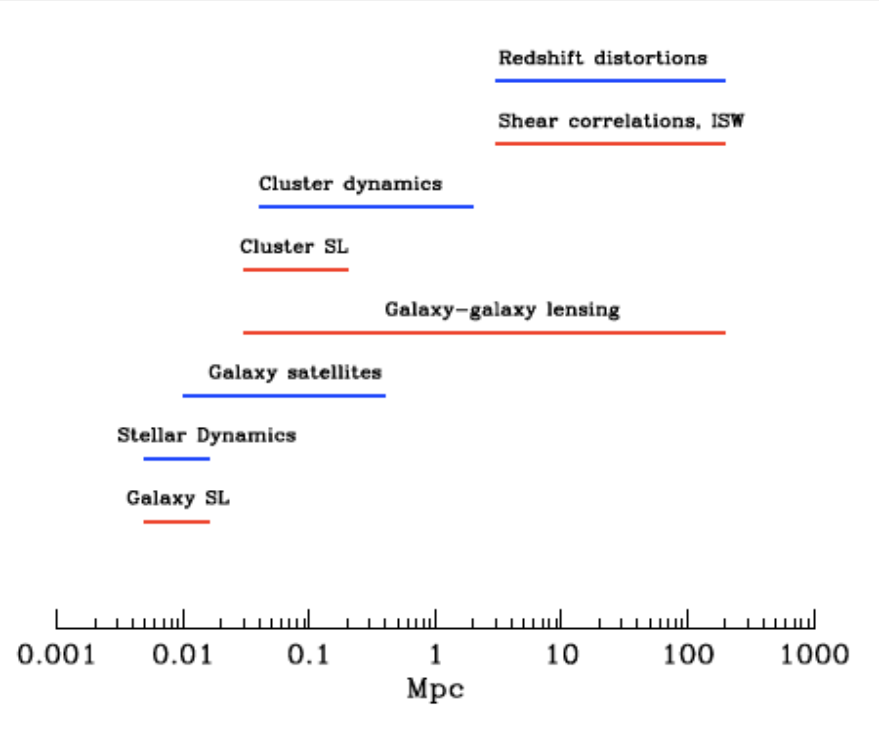
LSST is designed to address each of these possibilities by (a) using its spatial and time-domain data, and, (b) combining its measurements with complementary cosmological surveys.

Neutrino mass and inflation

- Neutrinos suppress growth of structure in a scale dependent way
- LSST, DESI and CMB have the potential to constrain the sum of neutrino masses to ~20 meV
- DES and LSST power spectra are sensitive to other features in the primordial power spectrum of scalar fluctuations: inflation probes.



Tests of Einstein's gravity and Novel Probes

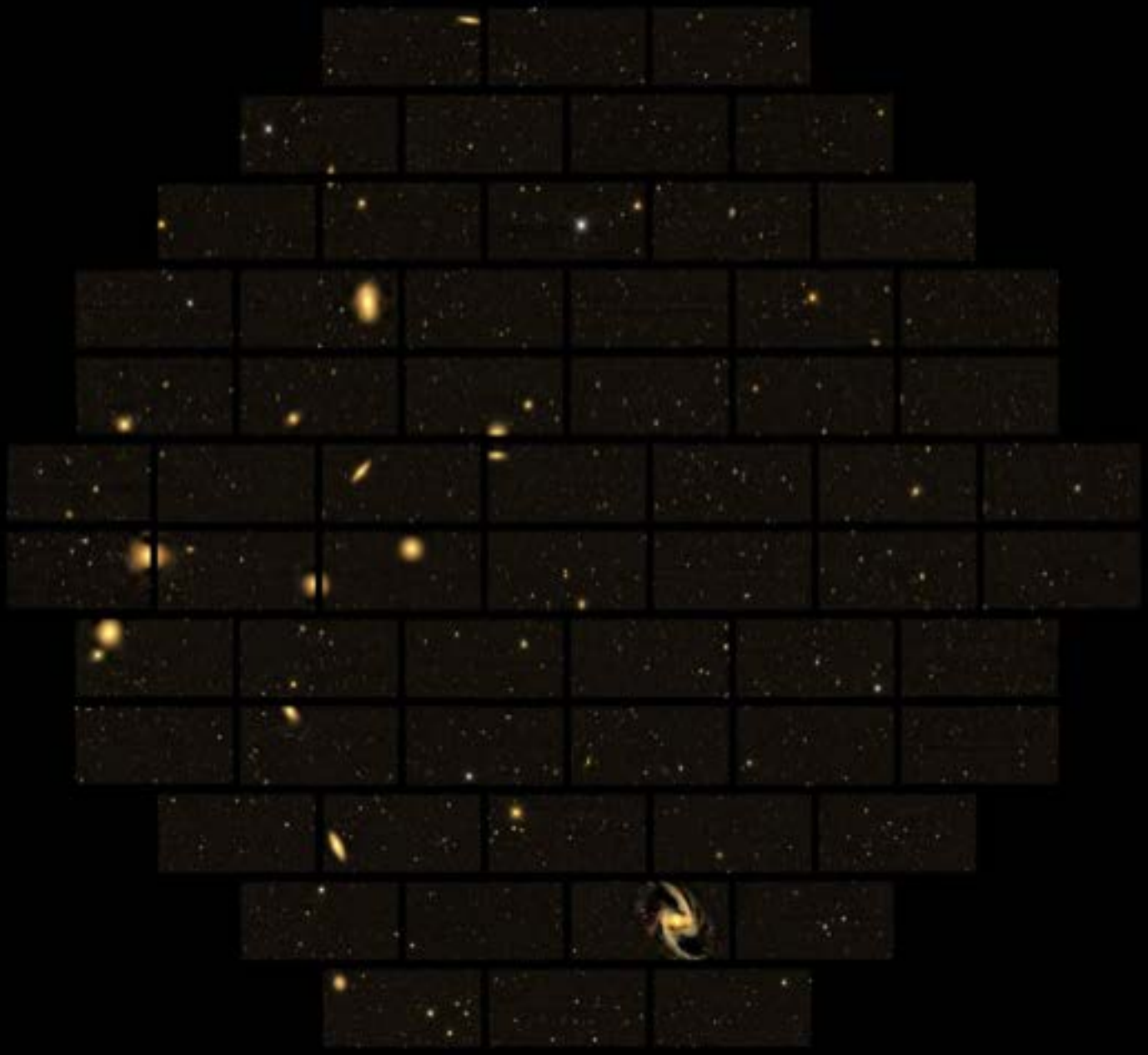


- 1st level of tests: compare growth of structure and geometry.
- 2nd level of tests: compare dynamics and lensing measures of structure.
- Snowmass and P5 recommend small projects under ``Novel Probes'': cosmological as well as astrophysical tests in the nearby universe.
- These novel probe projects are being designed, a combination of data from planned dark energy experiments and new, supplementary observations.

DES status and results

THE DARK ENERGY SURVEY

THE DARK ENERGY SURVEY

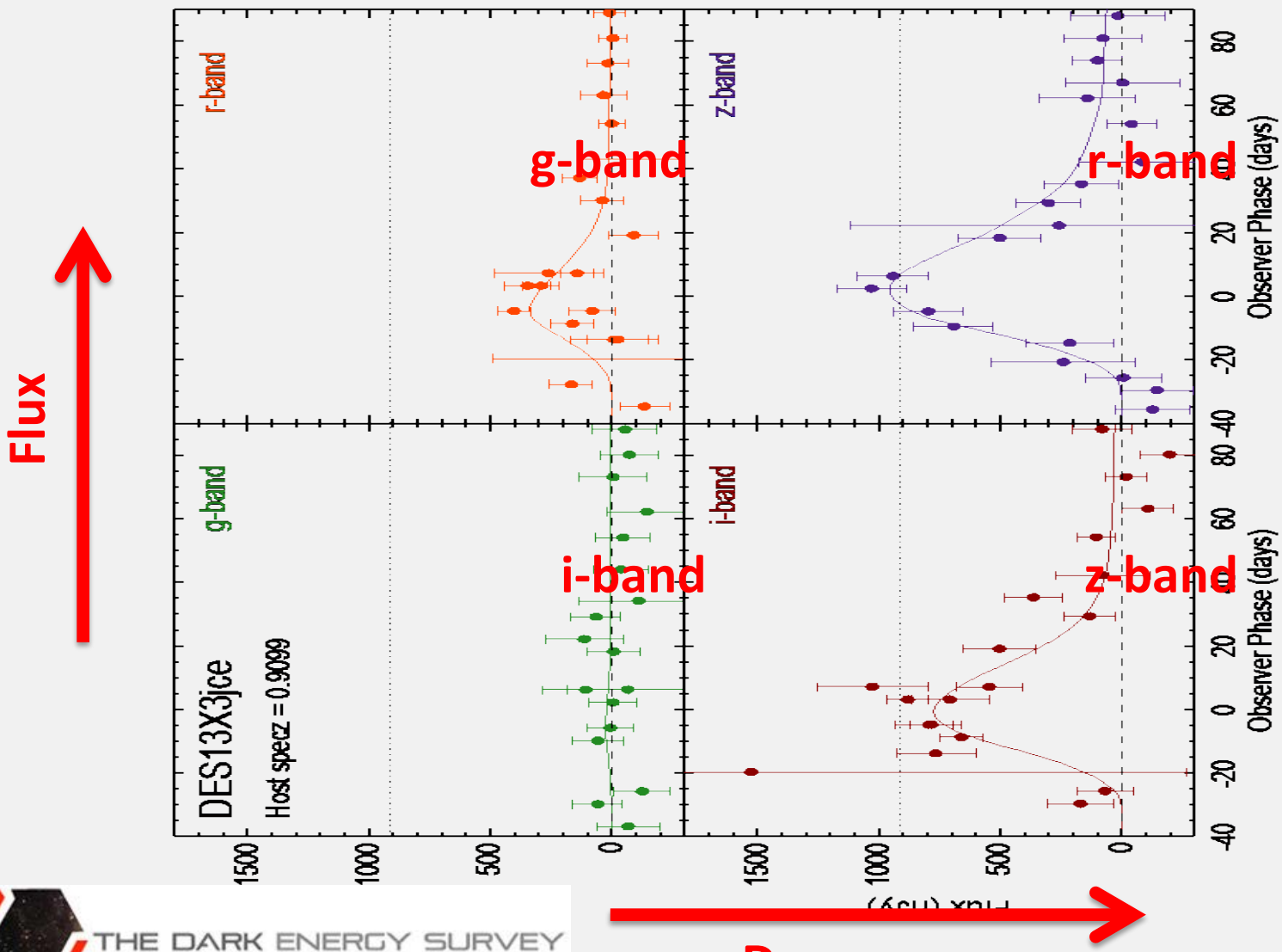


DES status

- DES has made tremendous progress in last year and **successfully completed first season of operations**
- **Image quality close to expected**, but we plan to do even better
- **DES Data Management (DM) internal annual data releases underway**
- Demonstrated:
  - Detection of high-z clusters, supernovae and QSOs,
  - weak lensing by clusters and galaxies,
  - galaxy angular correlations,
  - strong lenses,
  - good precision for galaxy and cluster photometric redshifts
- **Early science papers emerging from Science Verification and Year 1 data**
- **Aug 2014: Start of Year 2 observing**

THE DARK ENERGY SURVEY

A high redshift DES light curve: z=0.9



Data points: search photometry from subtracted DES images.

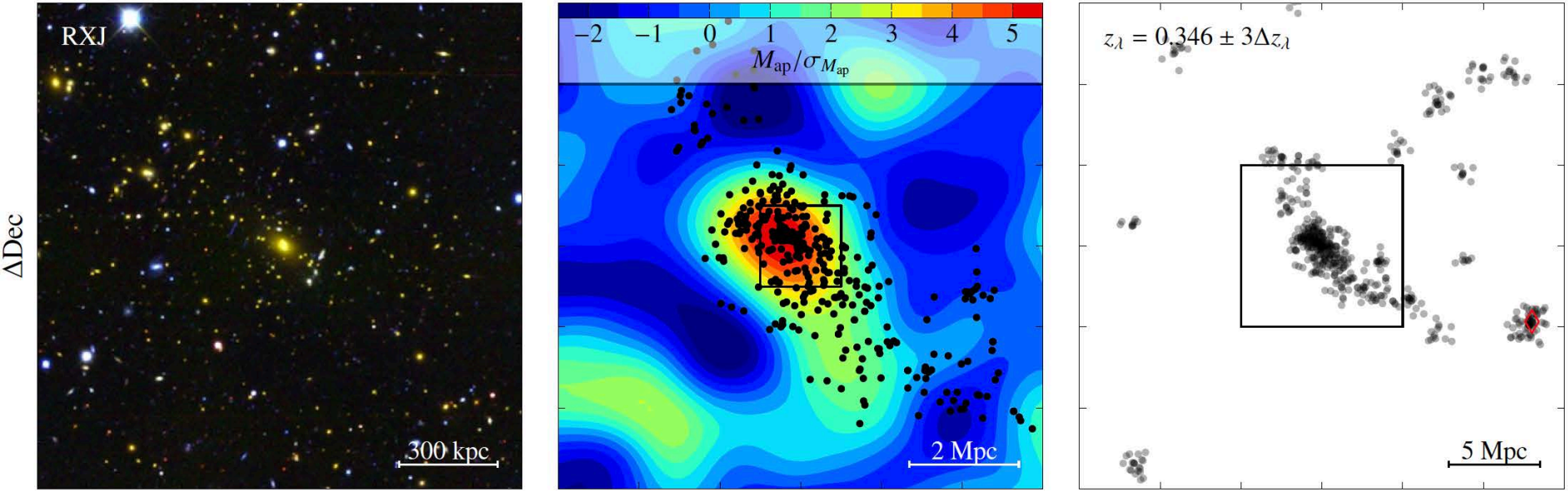
Solid lines: Fit to SALT2 light curve model.

THE DARK ENERGY SURVEY

DES SN working group; D'Andrea

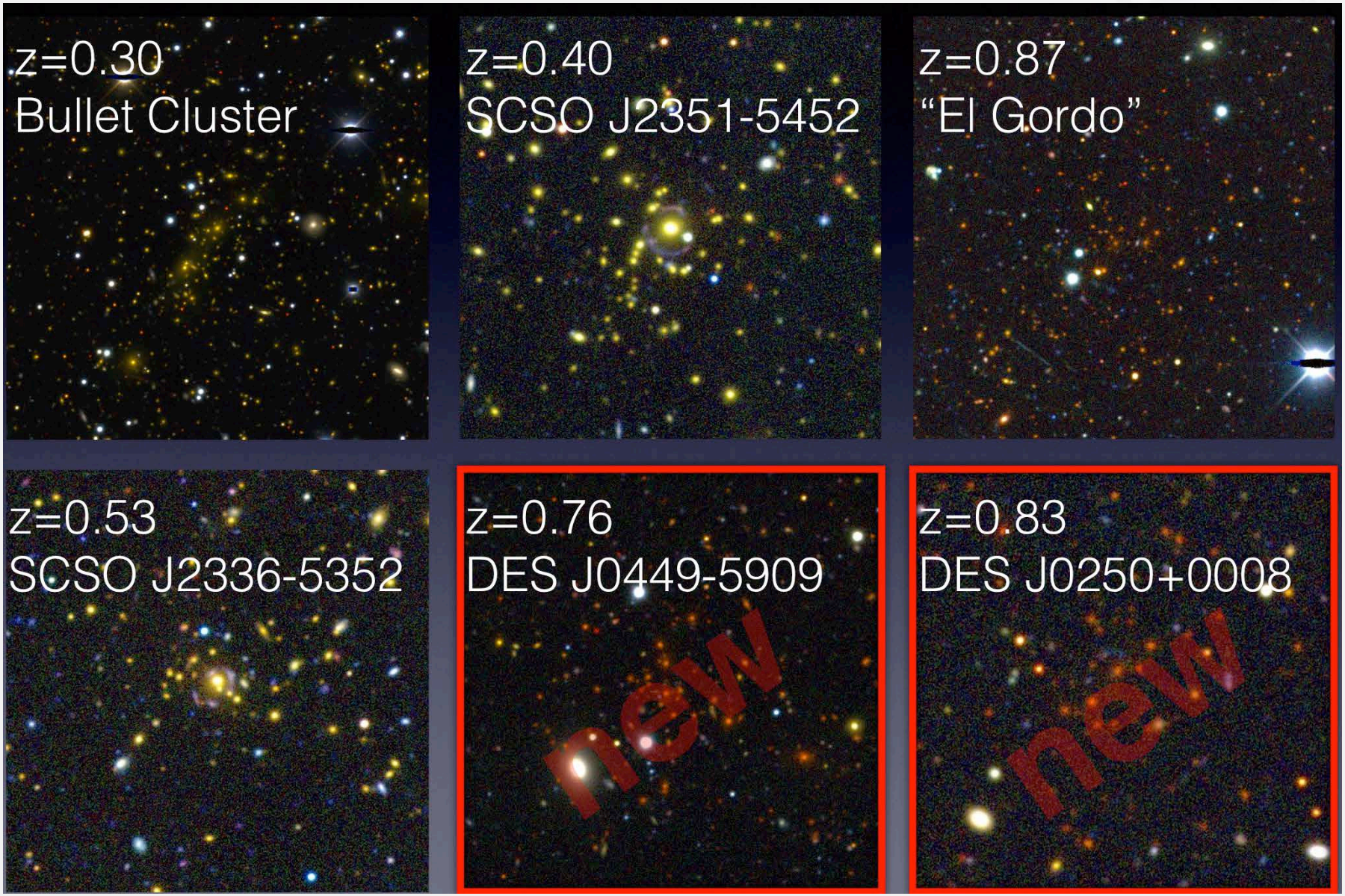
Lensing clusters from DES Science Verification Data

Melchior et al.



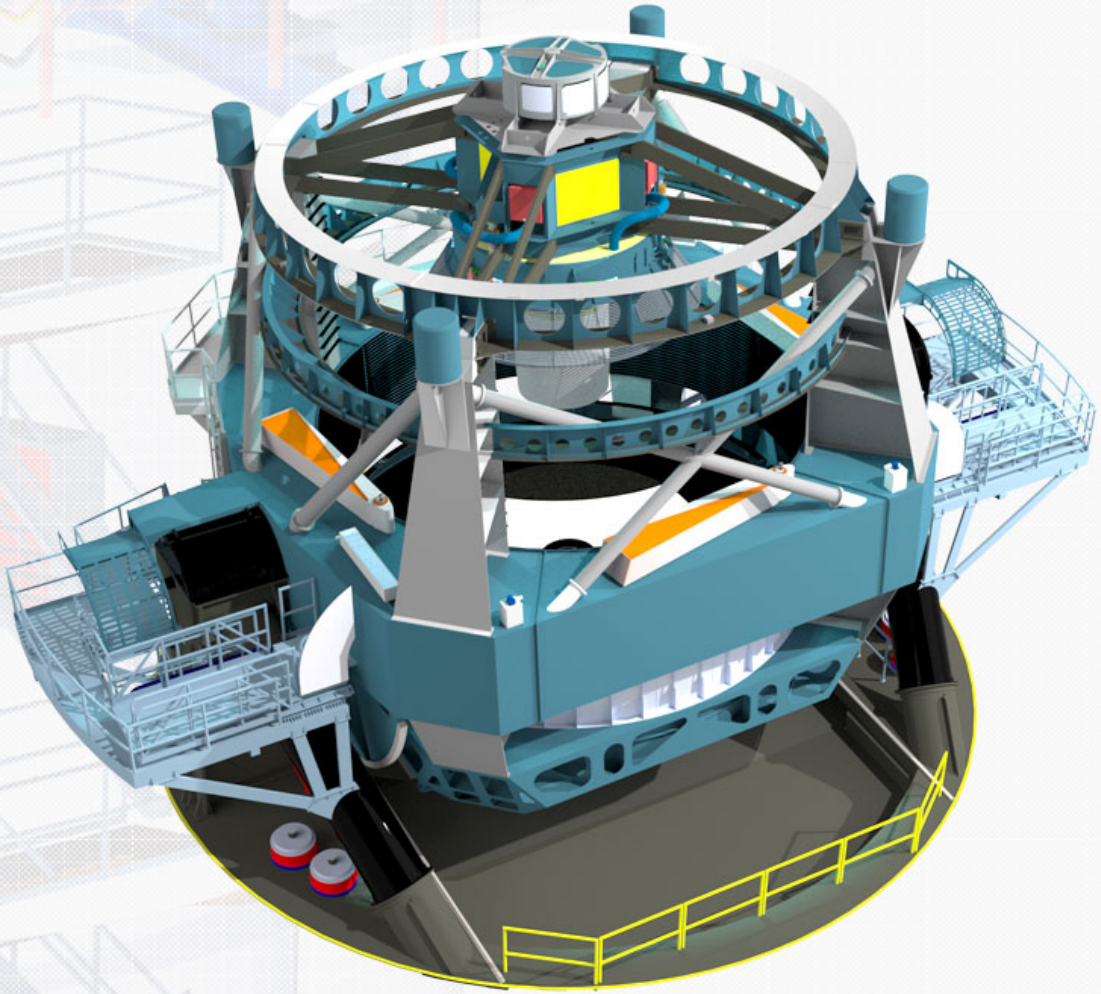
Mass and galaxy distributions of four massive galaxy clusters from Dark Energy Survey Science Verification data

High-z clusters in DES



DES Clusters working group; Eli Rykoff

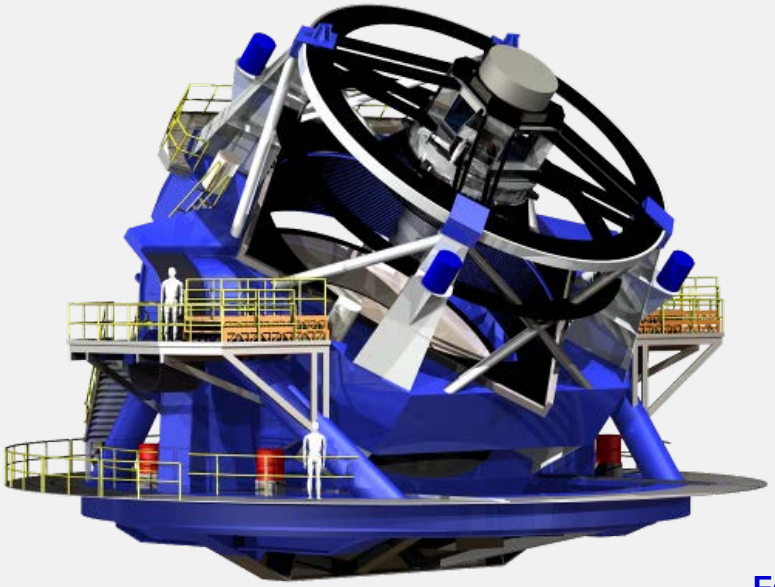
LSST camera project layout



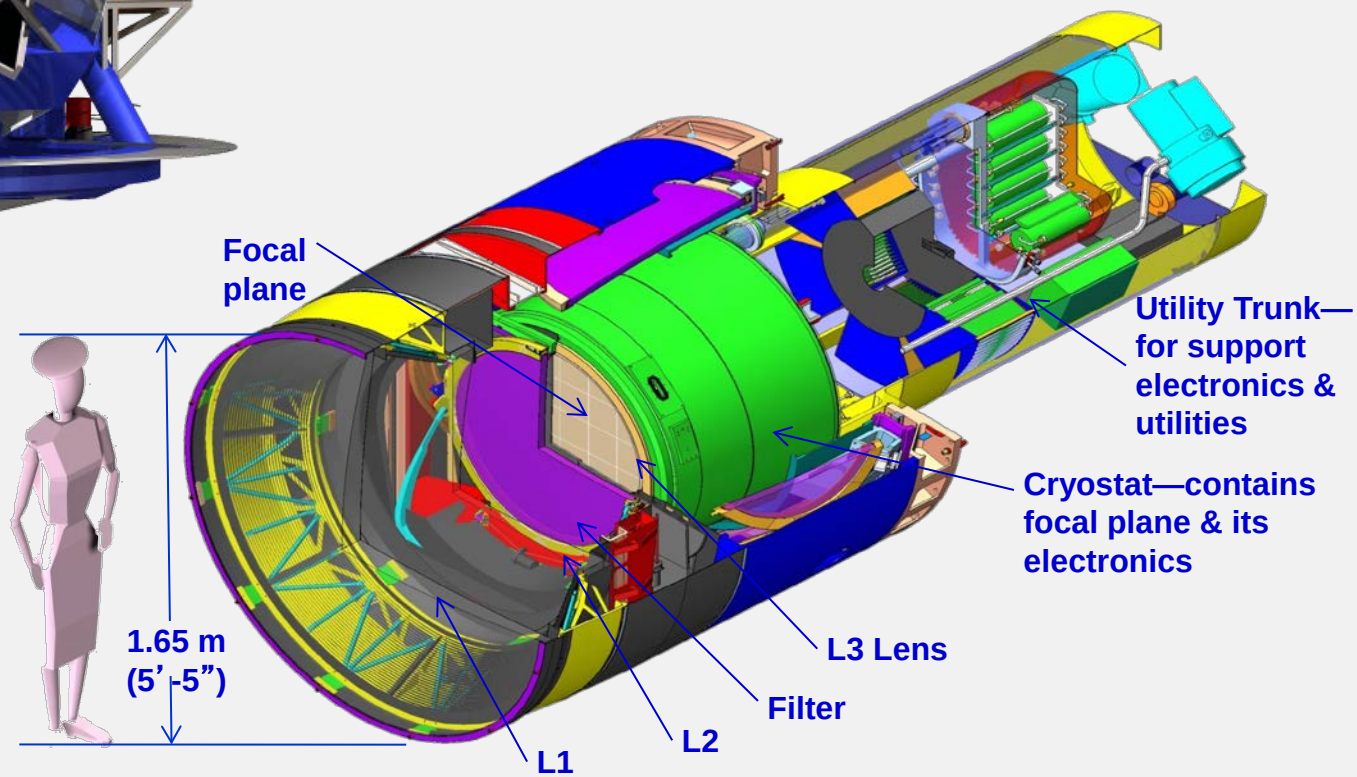
LSST in a Nutshell

- The LSST is designed to conduct a decade-long, deep, fast time-domain survey of the optical sky.
- The LSST survey over 20,000 square degrees will image 4 billion galaxies and 100,000 Supernovae for cosmological studies.
- LSST Data Management will process images of millions of objects nightly.
- The ongoing Simulation effort generates images that captures all relevant physics in addition to the cosmological signal.
- LSST will meet the requirements for a Stage IV dark energy survey.
  - For cosmology it will enable measurements with five well known probes of dark energy, essentially as well as we can carry them out from the ground.
  - LSST's design will enable new tests of dark energy, dark matter and gravity.

Telescope and Camera



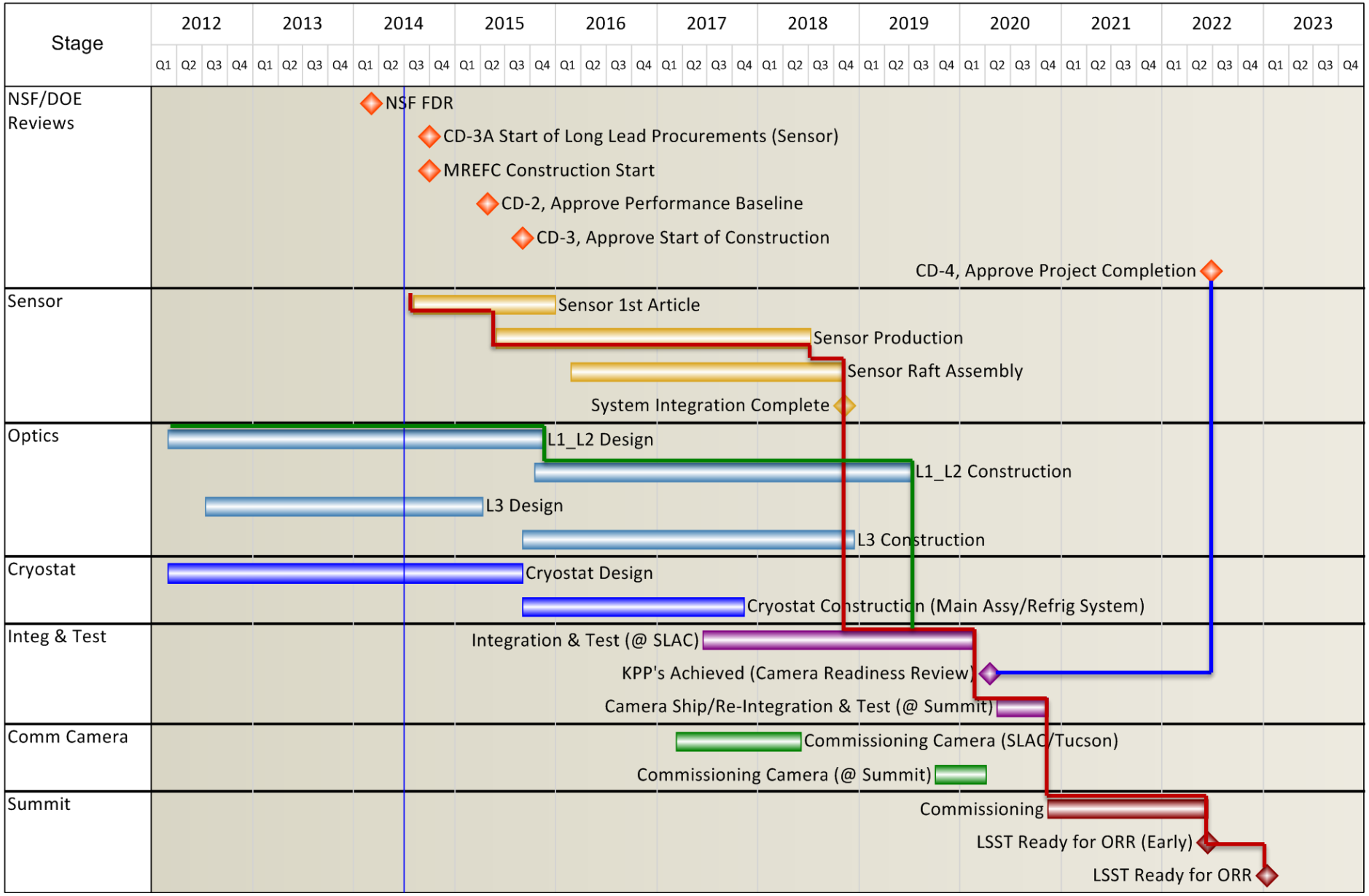
8-meter class telescope
3.2 Gpix camera with 2 second readout
9.6 square degree FOV
0.2 arcsecond pixels
6 filters



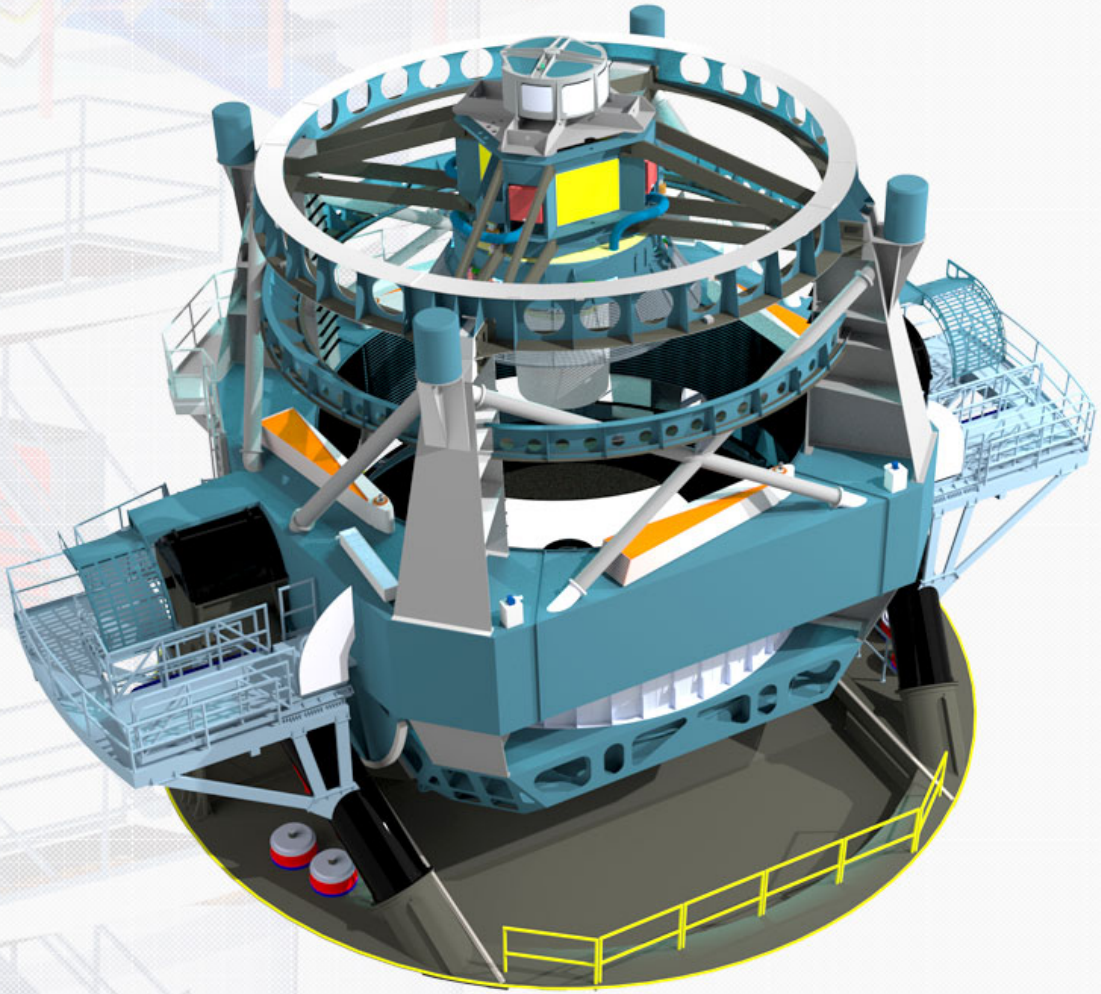
A broad-based collaboration of institutions has been assembled to deliver the camera

- SLAC National Accelerator Laboratory:
  - Overall project management, camera body and mechanisms, cryostat subsystems, data acquisition and electronics, camera controls, integration and test
- Brookhaven National Laboratory:
  - Science sensors, electronics and raft assemblies
- Lawrence Livermore National Laboratory:
  - Project management, optics, corner raft, wavefront sensors
- Institut National de Physique Nucleaire and et de Physique des Particules (IN2P3-Collection of multiple labs):
  - Front-end electronics, sensors, sensor testing, filters, filter carousel, camera calibration, slow controls
- University-based instrumentation groups:
  - Harvard University, U. of Pennsylvania, Purdue University, Ohio State, U. of Illinois, UC Santa Cruz, U. of Arizona, UC Davis

Project schedule integrated and the sensors drive the camera completion and project first light



LSST Dark Energy Science Collaboration (DESC)



LSST

LSST Dark Energy Science Collaboration

- The Dark Energy Science Collaboration was formed in June 2012 to prepare for and carry out cosmological analyses with LSST data
- DESC White Paper: arXiv:1211.0310
- Sixteen Working Groups are working on a set of ~50 tasks for the first phase, extending to 2015.
- Spokesperson: Bhuv Jain

  Deputy Spokesperson: Jeff Newman
- Public website: http://www.lsst-desc.org/
- Wiki for collaboration work:

https://confluence.slac.stanford.edu/display/LSSTDESC/Home

- Analysis Working Groups **Rachel Bean**
  1. Weak Lensing — Michael Jarvis, Rachel Mandelbaum
  2. Large Scale Structure — Eric Gawiser, Shirley Ho
  3. Supernovae — Alex Kim, Michael Wood-Vasey
  4. Clusters — Steve Allen, Ian Dell'Antonio
  5. Strong Lensing — Phil Marshall
  6. Combined Probes, Theory — Rachel Bean, Hu Zhan
  7. Photo-z Calibration — Jeff Newman (acting)
  8. Analysis-Computing Liaison — Rick Kessler
- Computing and Simulation Working Groups **Andy Connolly**
  1. Cosmological Simulations — Katrin Heitmann
  2. Photon Simulator — John Peterson
  3. Computing Infrastructure — Richard Dubois
  4. Software — Scott Dodelson
- Technical Working Groups **Chris Stubbs**
  1. System Throughput — Andrew Rasmussen
  2. Image Processing Algorithms — Robert Lupton
  3. Image Quality — Chuck Claver
  4. Science Operations and Calibration — Zeljko Ivezic

How do we plan for LSST's cosmology analysis?

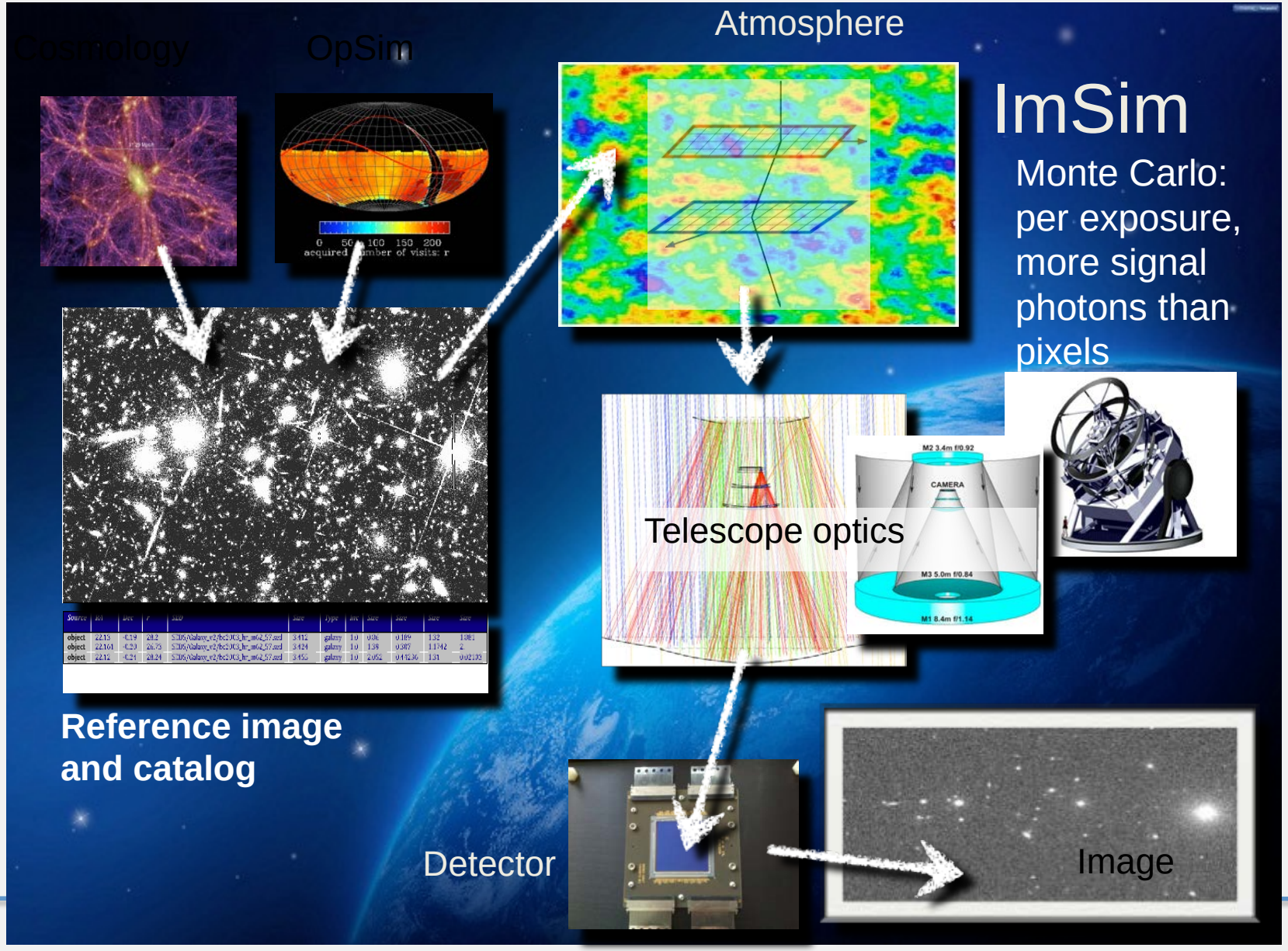
- To develop the high-level analysis plan and to identify the key systematics it is useful to schematically break down the dark energy analysis into the following steps.
  - Observing field/band/seeing selection and cadence issues
  - The reduction of raw images
  - The production of catalogs from the processed images
  - Measurement of statistical quantities such as power spectra
  - Cosmological analysis leading to dark energy constraints.

- Identify a set of systematics and critical algorithms that require advances by the LSST team.

- Identify simulation and computational needs to include relevant physics, test measurement algorithms and develop methodology for controlling systematics.

- The DESC white paper makes a first pass at this long-term plan and lays out the first phase of work – now in progress. The data management and simulation work is progressing in parallel.

LSST Simulations



Synergies with Precursor and Planned Surveys

- LSST will need a unified and precise understanding of a set of inter-connected observables that contain *astrophysical*, *cosmological*, *atmospheric* and *instrumental* effects.
- Stage III imaging surveys – DES, KIDS, PS1, Subaru HSC – are already encountering some of these effects.
- The LSST team is developing tools and software, such as the image simulator, that are broadly useful to the cosmology community.
- DESC plans on 6 monthly releases of products to the cosmology community via a public website: http://www.lsst-desc.org/
  First release: March 2014.
- DESI, CMB-S4, and space-based surveys, Euclid and WFIRST, will have many synergies with LSST via strengthened joint cosmological analyses and from constraints on each others' systematics

DESC operations plan

- DESC activities fall under research and operations.
- Operations work includes
  - Simulations and tools
  - Software framework and Computing
  - Level 3 software development
- SLAC serves as the host lab for DESC and provides support under all the above categories
- Key parts of the operations effort is located at DESC university groups and other labs as well.
- A well planned operations and research effort is essential to a successful cosmological analysis of LSST data.
- DoE support for operations of camera and science is therefore critical to the success of LSST!

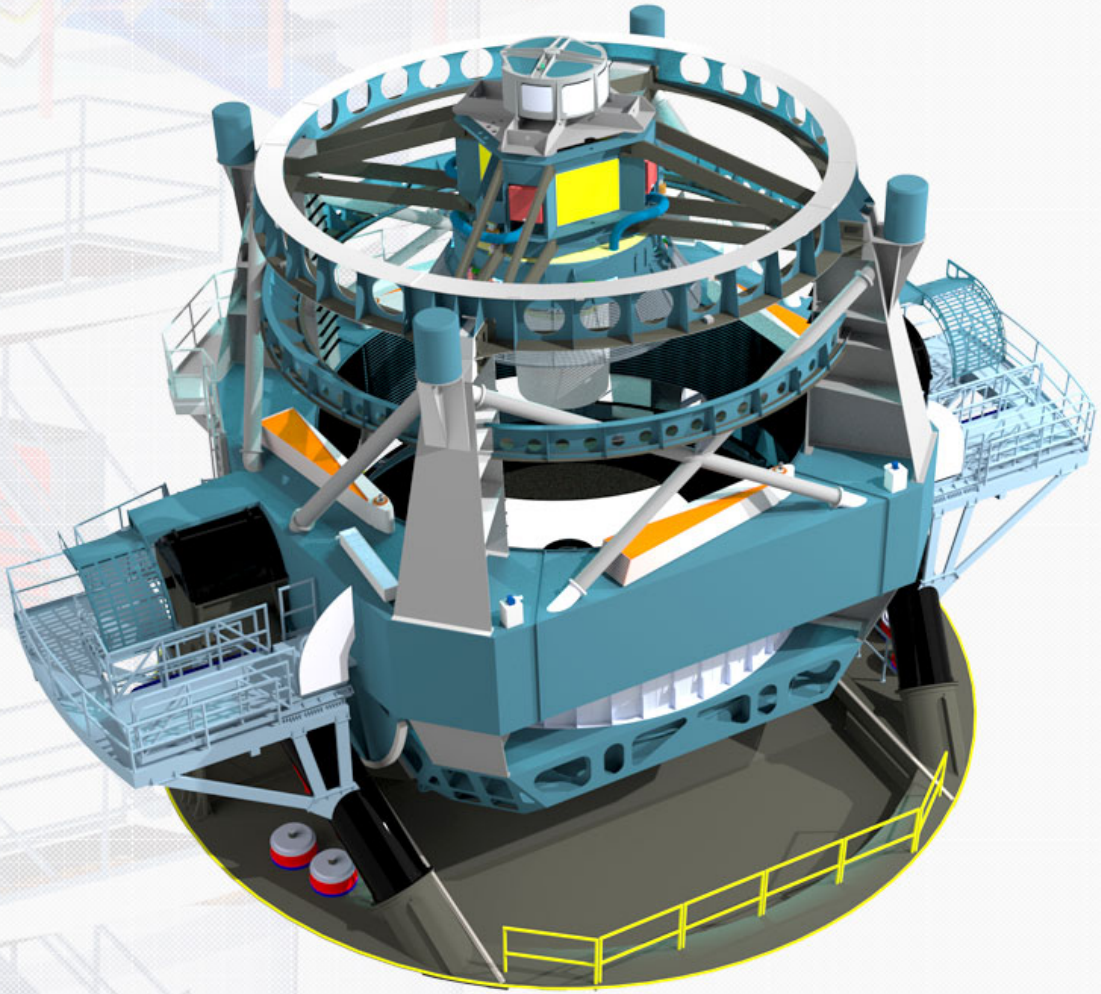
How to get involved

- LSST continues to engage with and benefit from the involvement of the high energy physics community.
- If you wish to get involved with cosmology related work via the DESC, consult the whitepaper at arXiv:1211.0310 for key tasks, and the public website for ongoing work.
- Contact Working Group conveners with your area of interest and ideas.
- Sign up for membership at:
  http://www.slac.stanford.edu/exp/lsst/desc/signup.html
- Attend our collaboration meeting: the next meeting starts tomorrow, a short train ride away, at U Penn!

Summary and Conclusions

- Early results from DES indicate that its 5 year survey is on course to make significant advances in dark energy studies.
- LSST will provide a Stage IV cosmology survey with multiple probes of dark energy.
- LSST, DESI and CMB-S4 will be powerful probes of inflationary-era physics, neutrino mass and dark matter.
- Ongoing preparations in software and computation at the intersection of science and data are critical to the success of LSST.
- LSST-DESC is preparing for the cosmological analysis of LSST data; it is a great collaboration for interested members of the HEP community!

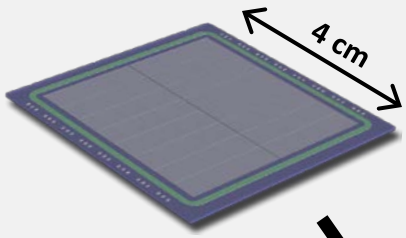
Spare Slides/Q&A



Development of the CCD Sensors is the Pacing Item.

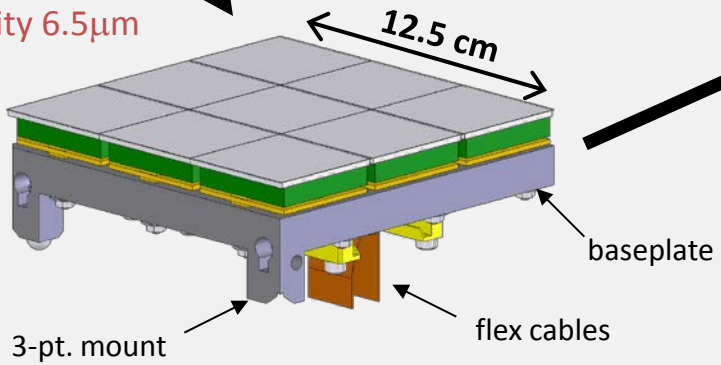
4K x 4K CCD

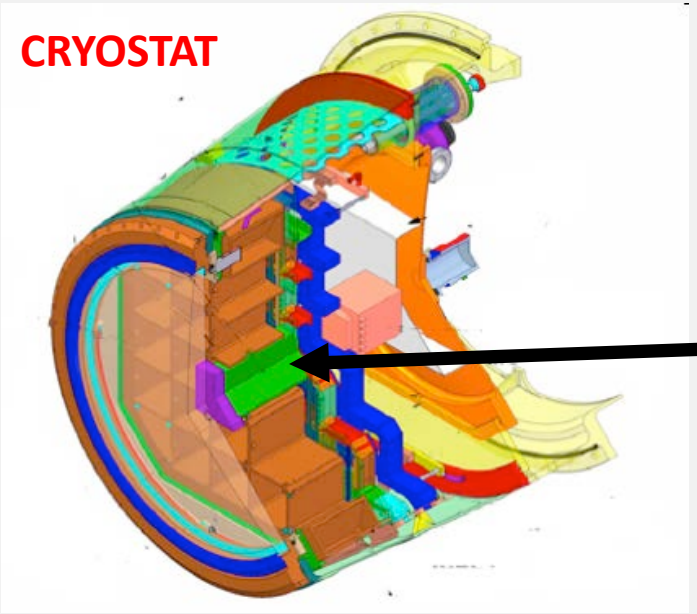
- 10μm pixels = 0.2”
- extended red response
- 2 second readout
- 16 outputs

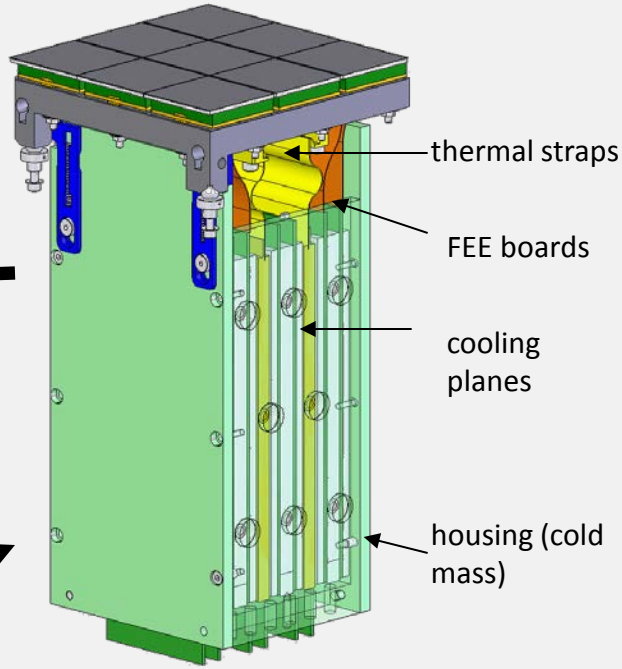


RAFT

- 9 CCDs
- coplanarity 6.5μm



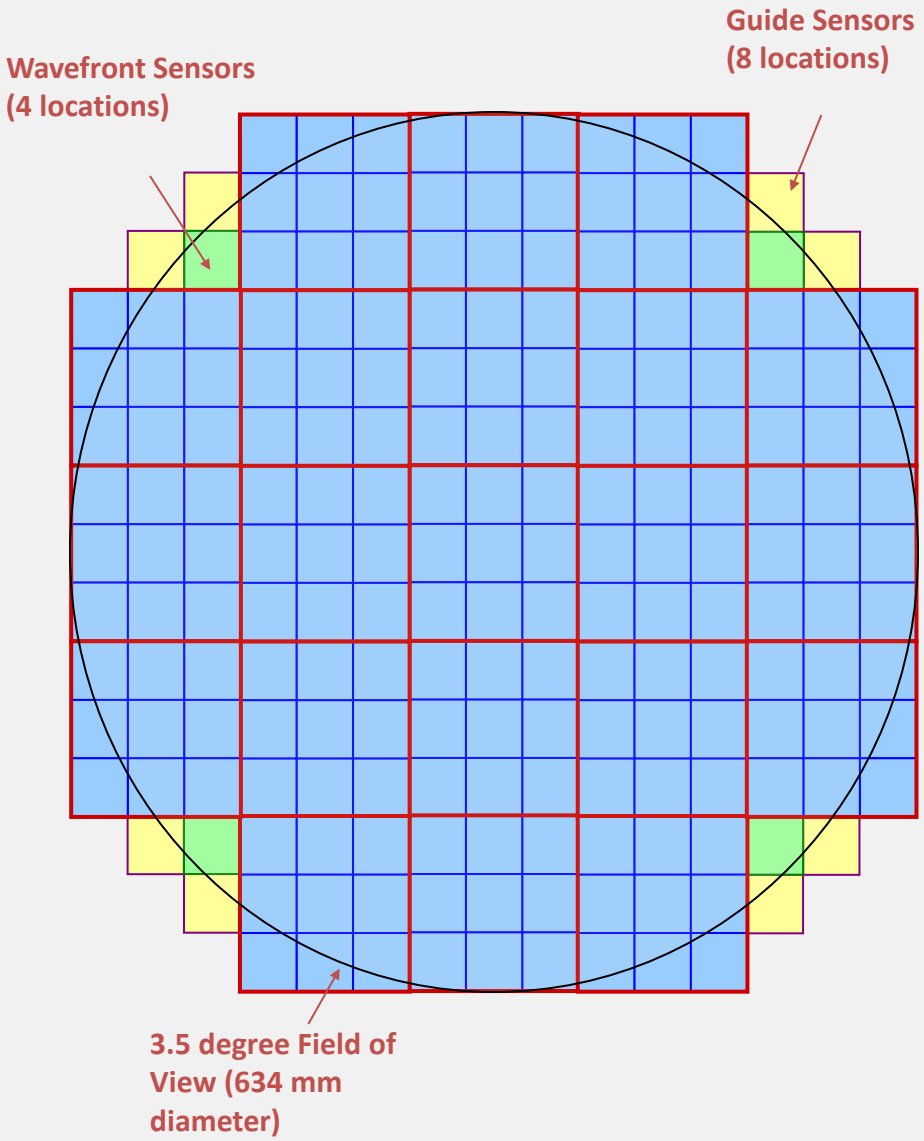




TOWER

- CCDs + front end electronics
- 180K operation
- An autonomous, fully-testable 144 Mpixel camera

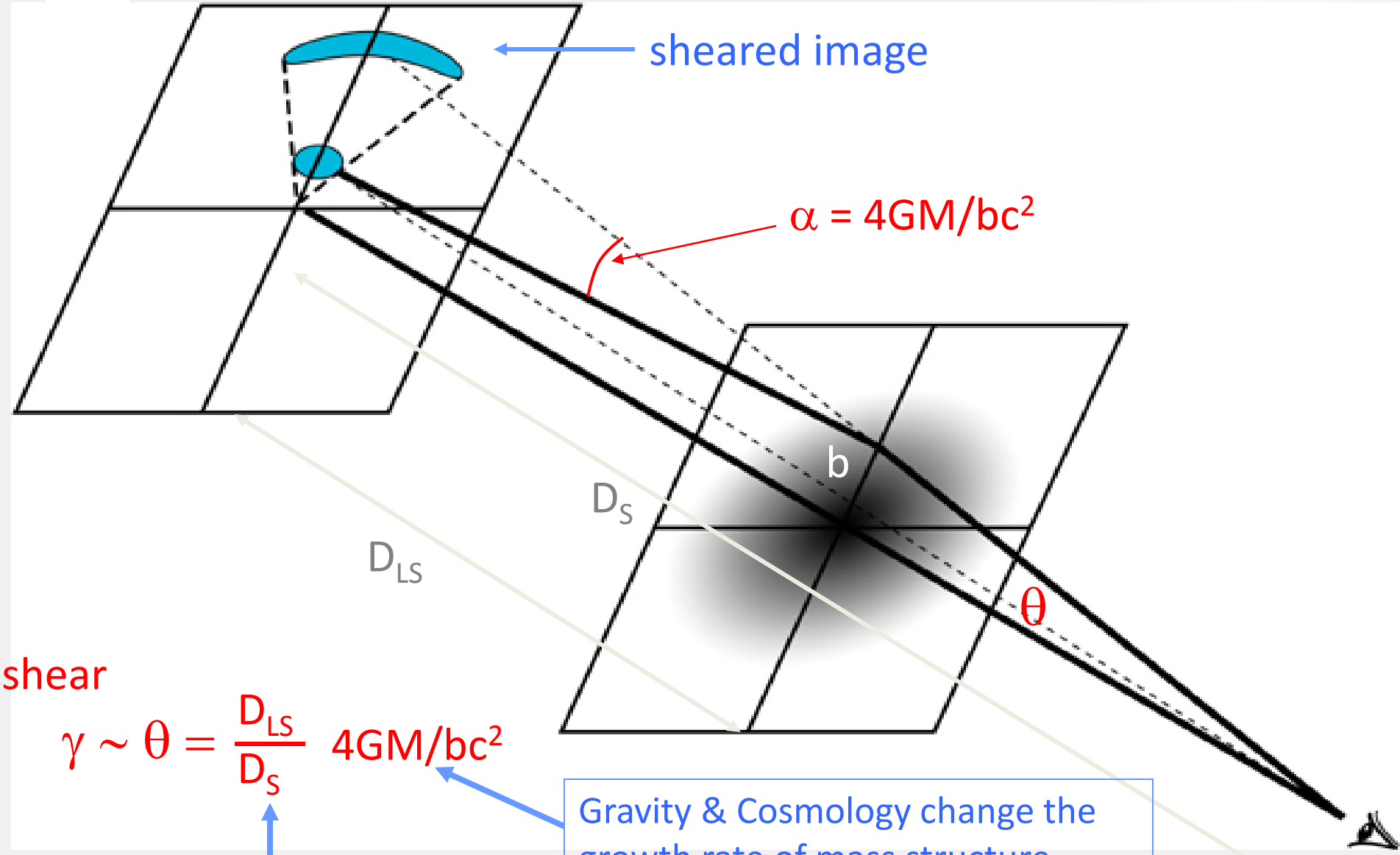
The LSST Focal Plane



Four Key Science Themes Used to Define the Science Requirements

- Taking a census of moving objects in the solar system.
- Mapping the structure and evolution of the Milky Way.
- Exploring the transient optical sky.
- Determining the nature of dark energy and dark matter.

The techniques associated with these four themes stress the system design in complementary ways. By designing the system to to accomplish these specific goals, we ensure that LSST will in fact enable a very broad range of science.



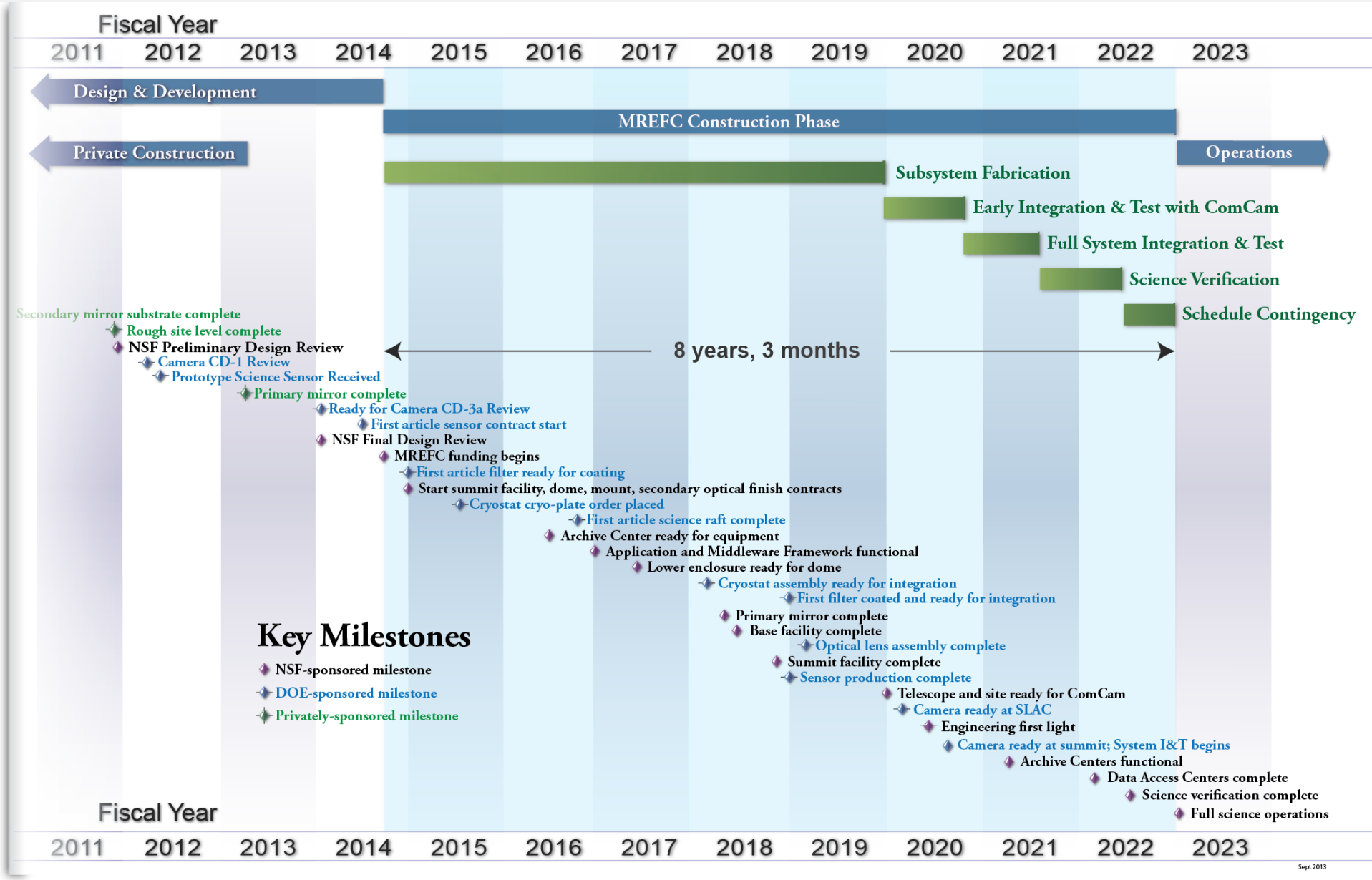
shear

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

Gravity & Cosmology change the growth rate of mass structure

Cosmology changes geometric distance factors

Summary of High Level Requirements

Survey Property	Performance
Main Survey Area	18000 sq. deg.
Total visits per sky patch	825
Filter set	6 filters (ugrizy) from 320 to 1050nm
Single visit	2 x 15 second exposures
Single Visit Limiting Magnitude	u = 23.5; g = 24.8; r = 24.4; I = 23.9; z = 23.3; y = 22.1
Photometric calibration	2% absolute, 0.5% repeatability & colors
Median delivered image quality	~ 0.7 arcsec. FWHM
Transient processing latency	60 sec after last visit exposure
Data release	Full reprocessing of survey data annually

Integrated Project Schedule for Baseline Plan