



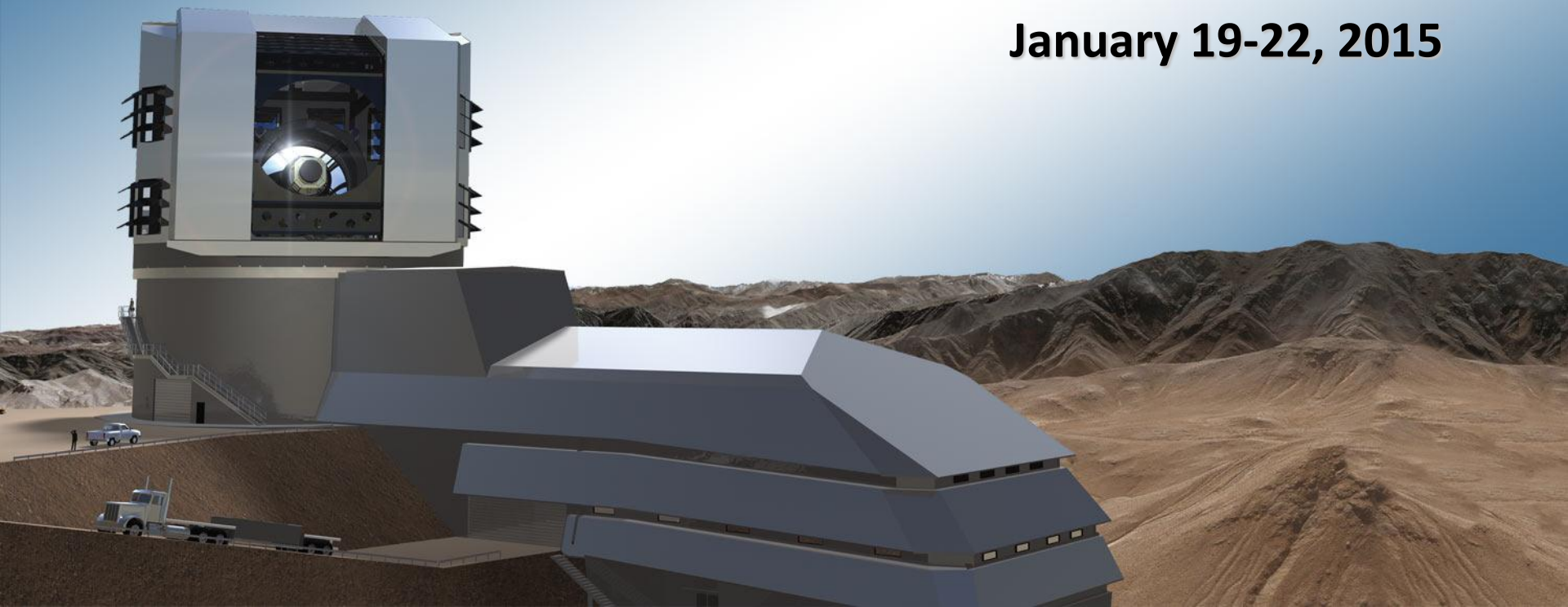
**LSST**

**Pierre Antilogus**

**LPNHE-IN2P3, Paris**

**ESO in the 2020s**

**January 19-22, 2015**



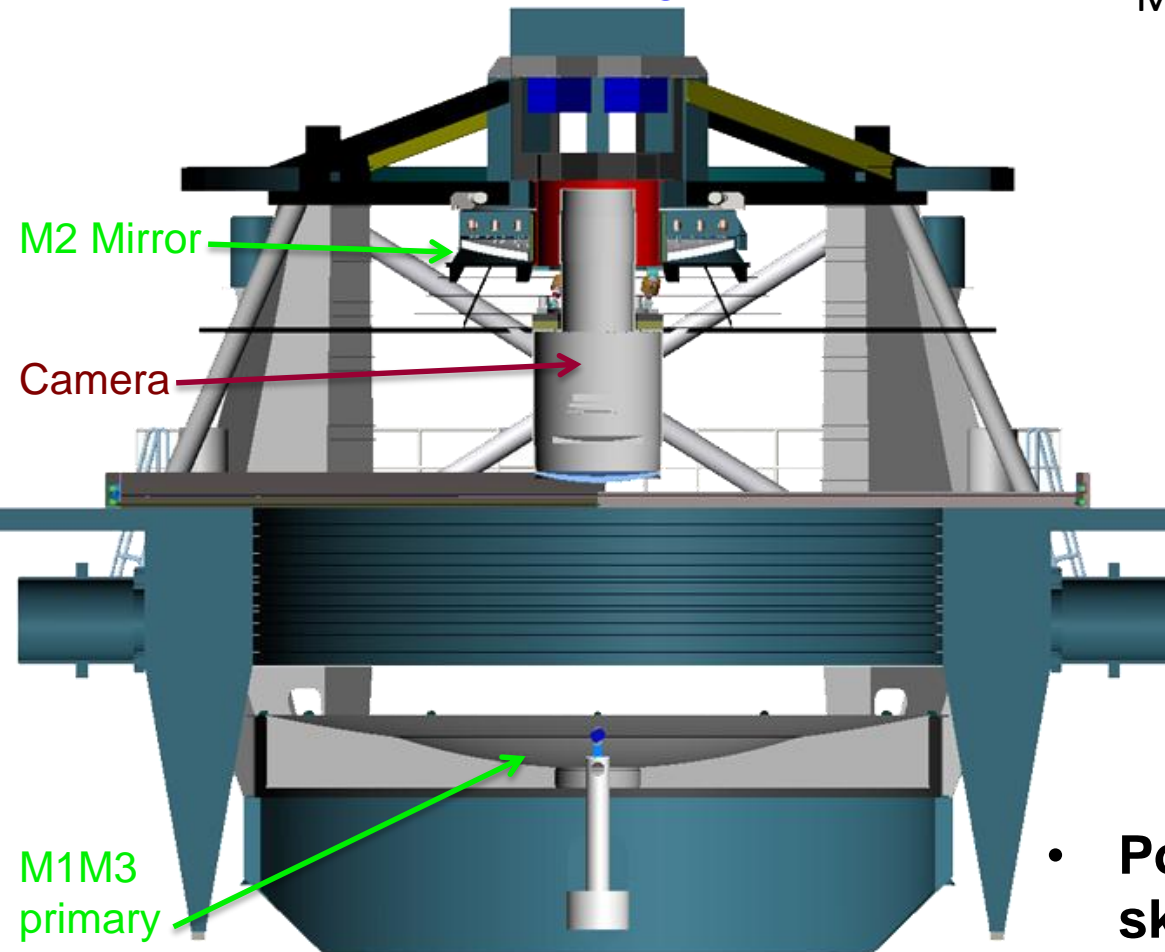


- The LSST is an integrated survey system designed to conduct a decade-long, deep, wide, fast time-domain survey of the optical sky. It consists of an 8-meter class wide-field ground based telescope, a 3.2 Gpix camera, and an automated data processing system.
- Over a decade of operations the LSST survey will acquire, process, and make available a collection of over 5 million images and catalogs with more than 37 billion objects and 7 trillion sources. Tens of billions of time-domain events will be detected and alerted on in real-time.
- The LSST will enable a wide variety of complementary scientific investigations, utilizing a common database and alert stream. These range from searches for small bodies in the Solar System to precision astrometry of the outer regions of the Galaxy to systematic monitoring for transient phenomena in the optical sky. LSST will also provide crucial constraints on our understanding of the nature of dark energy and dark matter.

# Telescope Mount Enables Fast Slew and Settle

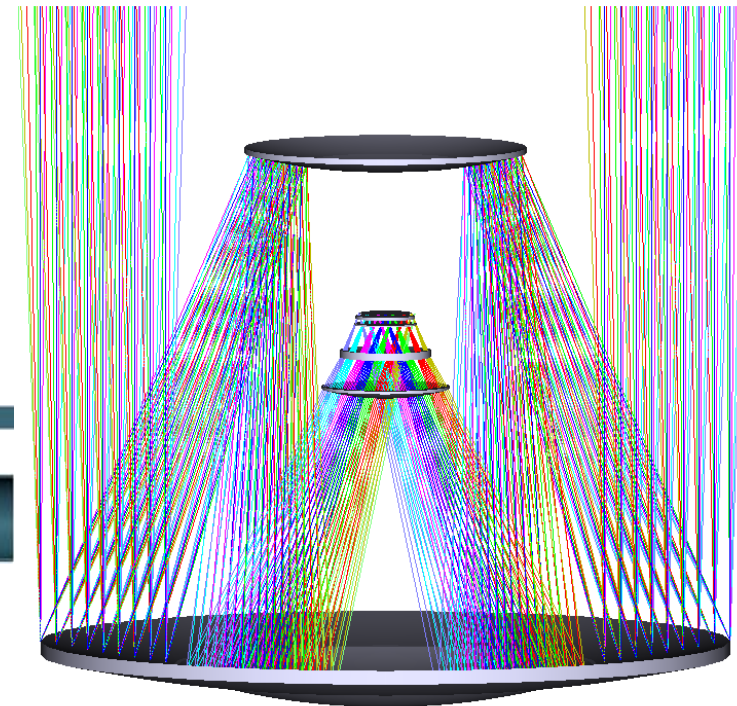
LSST Etendue :  $319 \text{ m}^2 \text{ deg}^2$

Modified Paul-Baker Optical Design



M1M3  
primary  
(8.4m,  
effective  
6.7m) &  
Tertiary  
mirrors

Moving Structure 350 tons  
60 tons optical systems



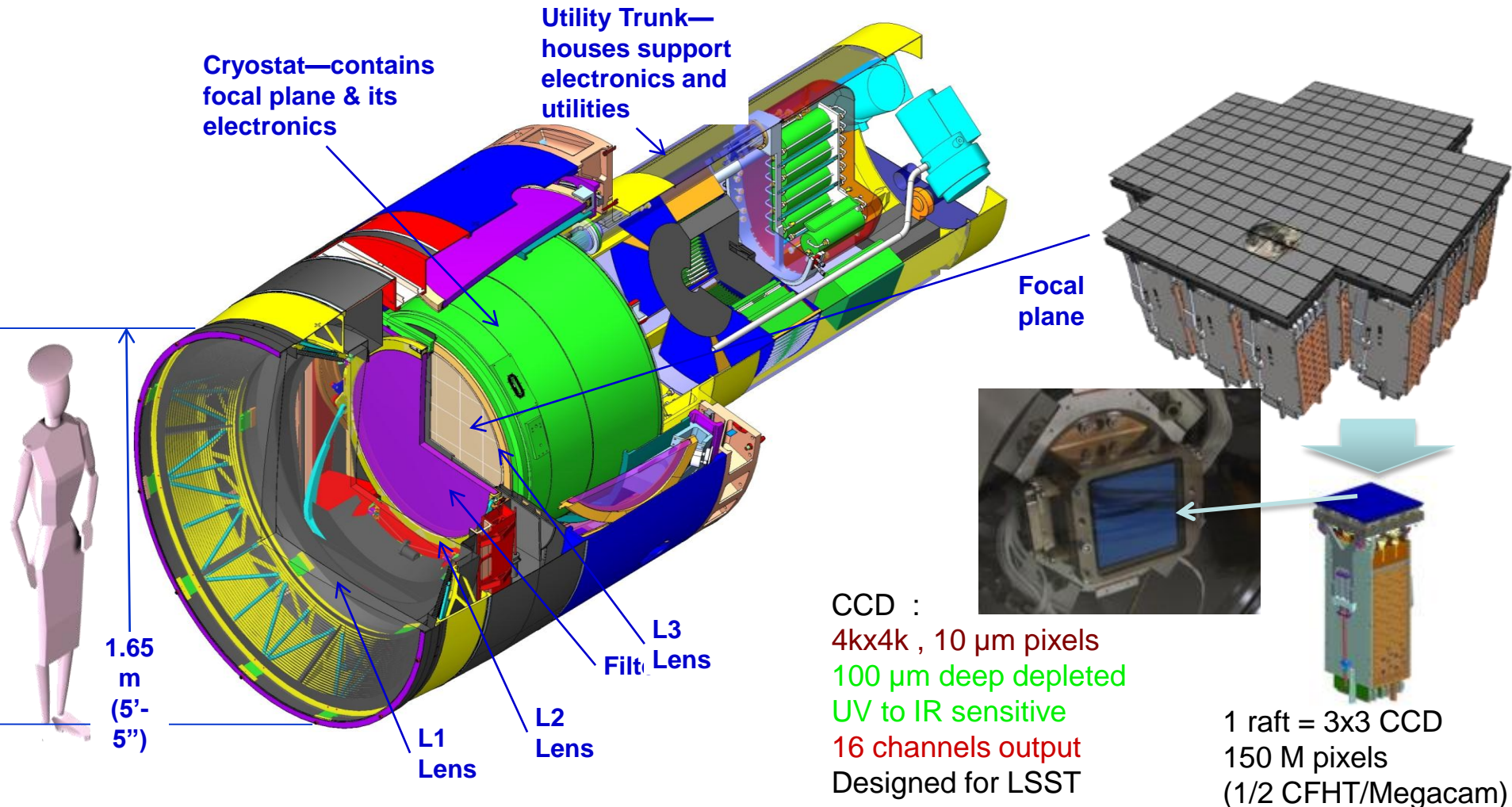
- Points to new positions in the sky every 39 seconds
- Tracks during exposures and slews  $3.5^\circ$  to adjacent fields in  $\sim 4$  seconds



Field of view : 3.5 deg (9.6 deg<sup>2</sup> =.023% sky sphere)

Focal plane diameter : 64 cm ; 189 science CCD (21 rafts)

3024 readout channels; >3 10<sup>9</sup> pixels ; **Readout in 2s**



# LSST concept :

## 1 telescope + 1 instrument + 1 observation plan



**6-band Survey:** ugrizy 320–1070 nm

**Survey(s) Area** (with 0.2 arcsec / pixel) →

**Main :** at least 18,000 square degrees to an uniform depth

**Other :** ~10% of time ~1h/night (Very Deep + fast time domain + special regions : ecliptic, galactic plane , Magellanic clouds)

**Total Visits per unit area and Visits per filter (Main survey)**

	u	g	r	i	z	y
<b>Nb Visit</b>	56	80	184	184	160	160
<b>1 visit mag</b>	23.9	25.0	24.7	24.0	23.3	22.1
<b>10 year</b>	26.1	27.4	27.5	26.8	26.1	24.9

### Image Quality

Mean seeing at the site is ~ 0.7 arcsec

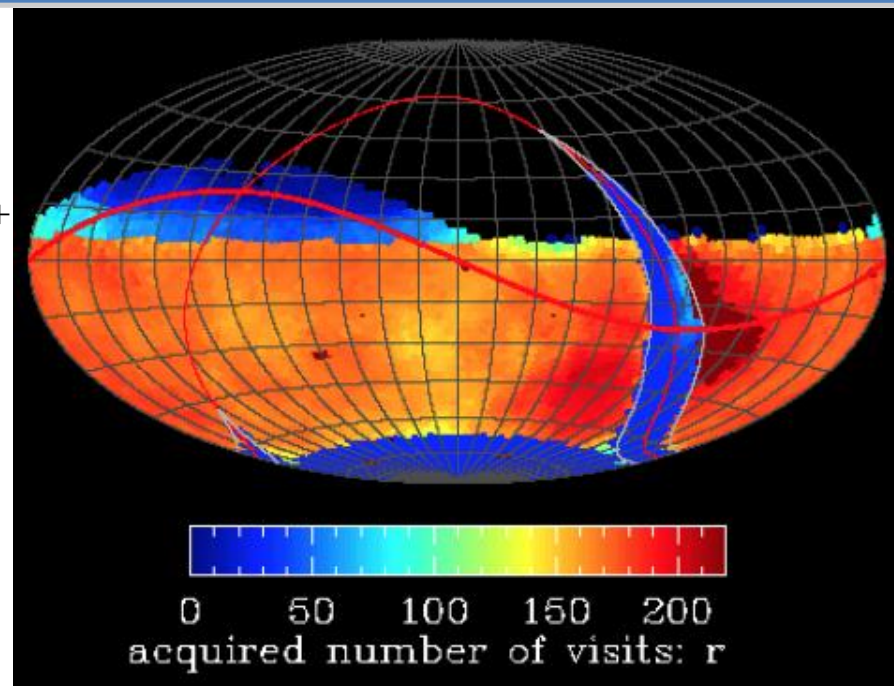
PSF FWHM < 0.4 arcsec (no atmospheric seeing).

PSF Ellipticity < 0.04

(referenced to 0.6 arcsec FWHM circular Gaussian)

### Photometric precision:

0.01 mag absolute; 0.005 mag repeatability & color



**More than  $2.75 \cdot 10^6$  visits &  $5.5 \cdot 10^6$  exposures**  
following the sequence:

15 s pose + 1 s shutter + 2 s read + 15 s pose  
+ 1s shutter + 5s new pointing as reading

→ **Points to new positions in sky every 39 seconds**

**Number of visits per night : ~ 1000**

### Universal Cadence Strategy for Main Survey

Revisit after 15-60 minutes

Visit pairs every 3-4 nights

# LSST data volume: 1 night ~ 15 TB ... and in 10 years :



Number of objects	$\sim 37 \cdot 10^9$ (20 $10^9$ galaxies /17 $10^9$ stars)
Number of forced measurements	$\sim 37 \cdot 10^9 * 825 \sim 30 \cdot 10^{12}$
Average number of alerts per night	$2 \cdot 10^6$ ( $10^7$ including galactic plane )
Number of data collected per 24 hr period	$\sim 15$ TB
Final Raw image	24 PB
Final Disk Storage	0.4 EB ( 400 PetaBytes )
Final database size	15 PB



**LSST will federate a community of ~ 900 scientists over the world (50% from US) :**

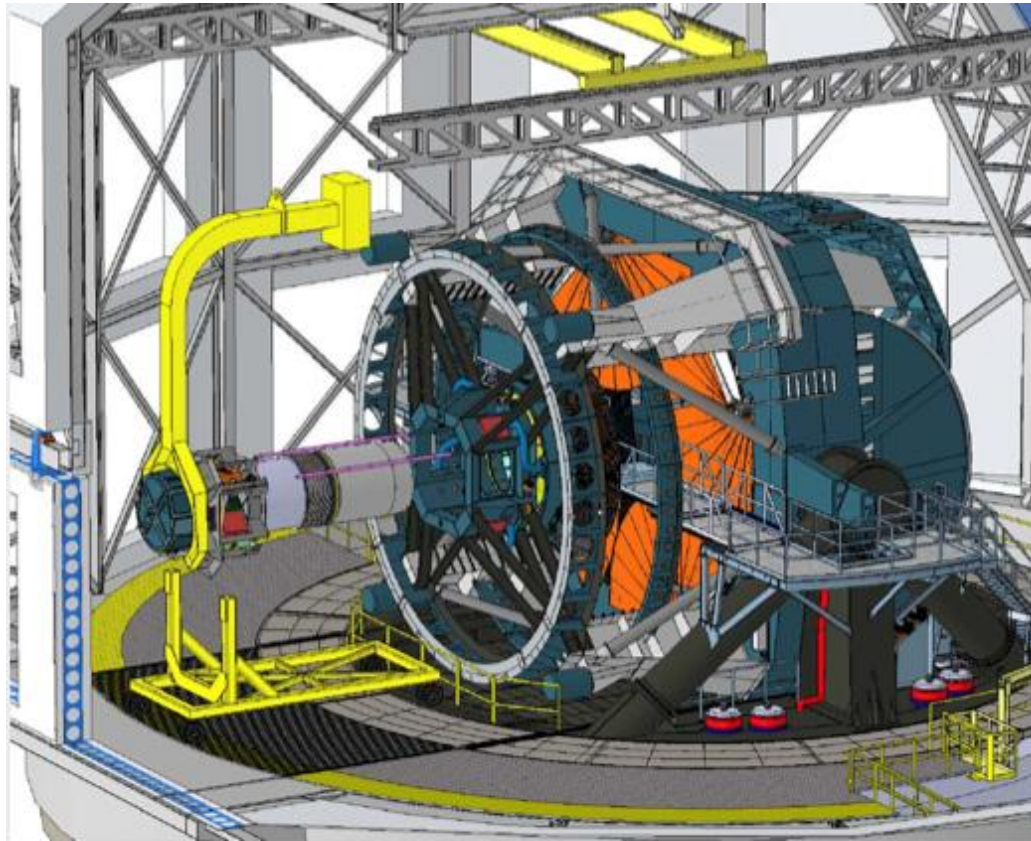
- **Chile** ( site) & **France-IN2P3** (in kind contribution to the camera) are LSST members / have data right .
- Integration of other non-US scientist in LSST , will be associated to a fee of 20 000 \$ / year / (PI+4 Pdoc/Grad) for the 10 years of running with the goal to cover ~30% of the LSST running cost. In late 2011 LSSTc received 69 letters of interest from 23 countries, most of the associated MoA are still under discussion today :
  - **Europe :**
    - **France** : ~120 PI (including ~+45 PI on top of the camera contribution)
    - **UK** : ~ 100 – 180 PI (200 UK's scientists declared interest today, priority at STFC )
    - **Czechy, Croatia , Hungary , Poland, Serbia,...** : ~ 20-40 PI
  - **China (existing consortium), India (strong interest), Brazil (...), Australia , New Zealand ,....**



- LSST ranked as the highest priority large ground-based facility for the next decade. (Astro10 , August 2010)
- Following this recommendation, NSF and DOE went ahead with LSST : LSST passed its final design review (NSF) in Dec. 2013 allowing the construction to start in 2014.
- LSST cost :
  - Total cost ~ 1 B\$ , Construction + 10 years running included
  - Telescope & Data Management :\$473M(NSF)
  - Camera : \$168M (DOE) (+ France-IN2P3 in kind for ~10% total cost )
  - Private Funds : \$40M (early mirrors contribution & site preparation,...)
- Procurements are going on :
  - Secondary Mirror Optical Fabrication : *Awarded Nov. 2012*
  - Hexapod System Fabrication : *Awarded April 2013*
  - Telescope Mount Assembly : *Awarded August 2014*
  - Summit Facility Construction : *Awarded September 2014*
  - ....



- Official Construction started : 2014
- Telescope engineering first light : end 2019
- Camera integrated at summit : 2020
- Start of the LSST “Science Verification survey” : 2021
- “LSST delivery” / start of 10 years survey : spring 2022

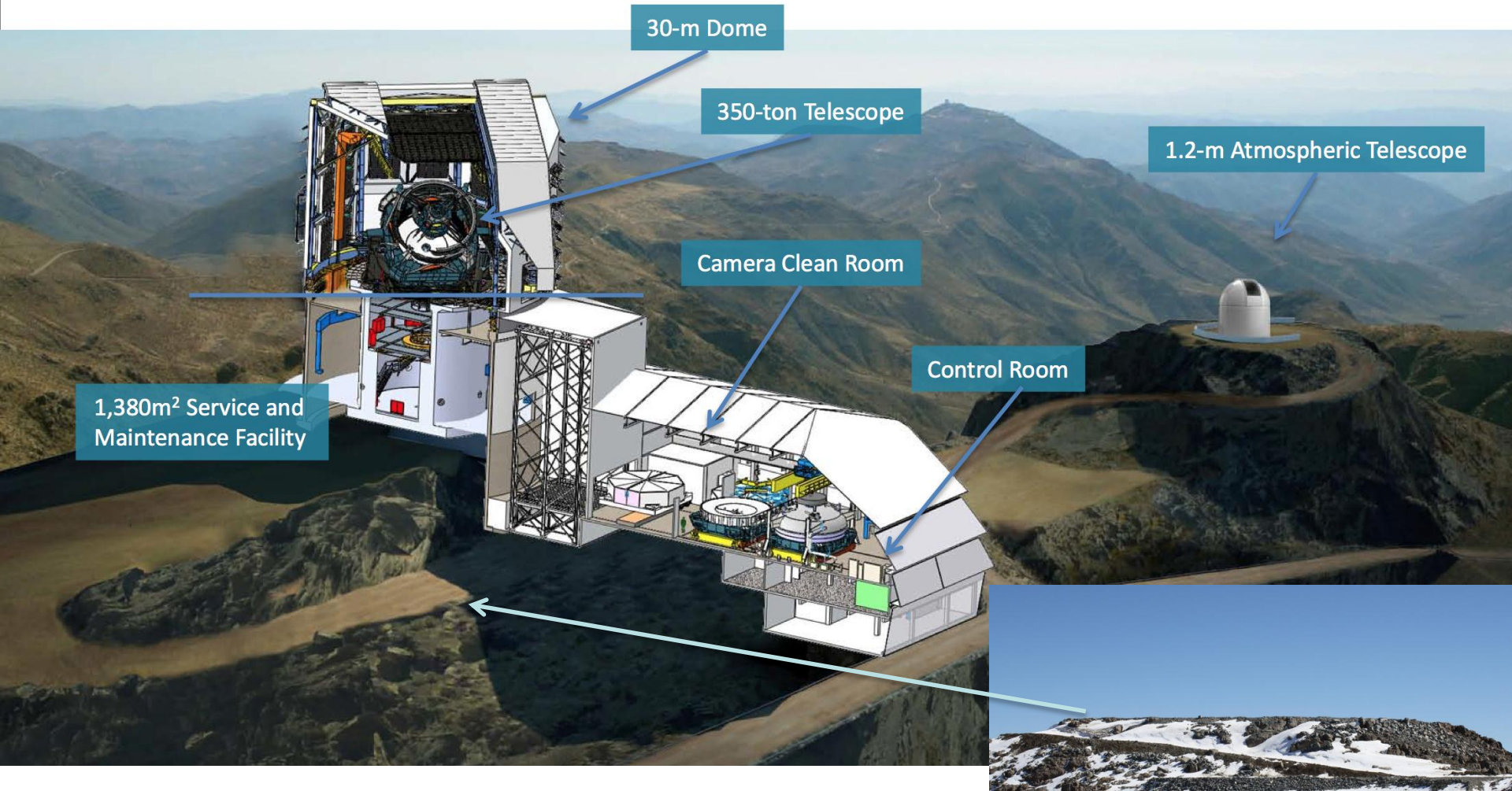




# LSST Will be Sited in Central Chile on El Peñón peak of Cerro Pachón at 2682m

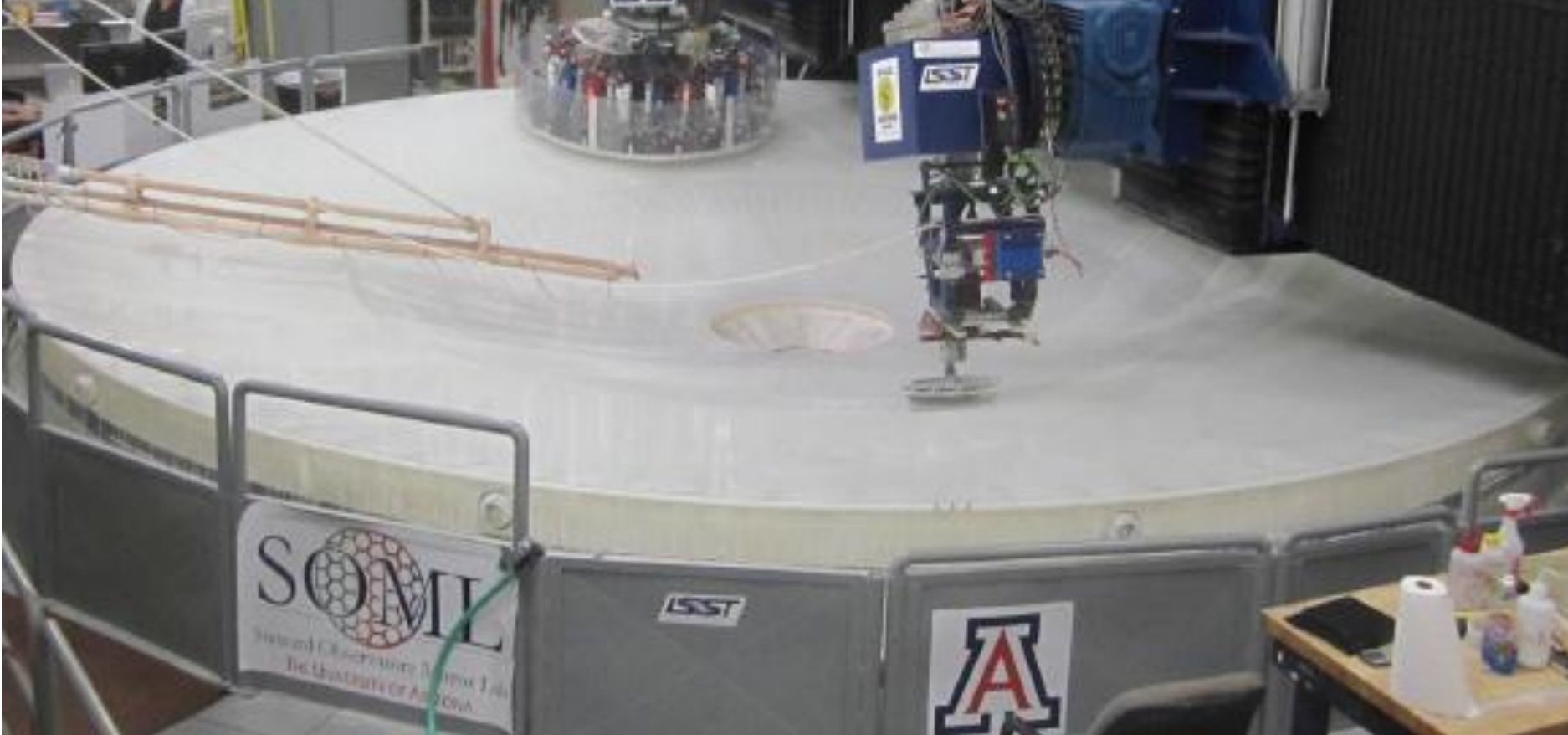






After ~4,000 kg of explosives and ~12,500 m<sup>3</sup> of rock removal, Stage I of the El Peñón summit leveling is completed. Building construction is now underway .

# Primary/Tertiary Fabricated as a Single Monolith : finished in September 2013 (high fire in 2008)





# LSST Operations: Sites and Data Flows



## Archive Site

### Archive Center

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

### Data Access Center

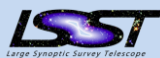
- Data Access and User Services

spring 2022

## Dedicated Long Haul Networks

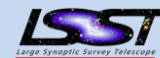
Two redundant 40 Gbit links from La Serena to Champaign, IL (existing fiber)

## HQ Site



- Science Operations
- Observatory Management
- Education and Public Outreach

## Summit and Base Sites



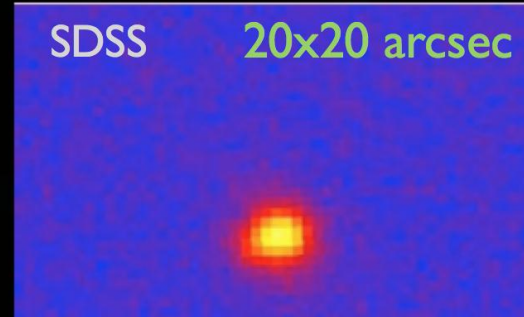
- Telescope and Camera
- Data Acquisition
- Crosstalk Correction
- Long-term storage (copy 1)
- Chilean Data Access Center

SDSS, 3x3 arcmin, gri



SDSS

20x20 arcsec



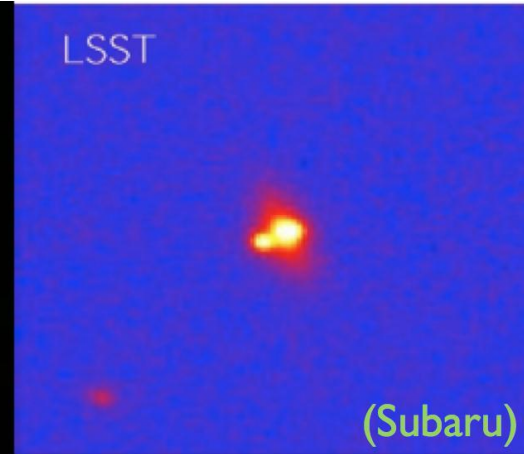
## LSST Science in the 2020s: a few examples

(Deep Lens Survey)



LSST

LSST



(Subaru)

# The Science Opportunities are Summarized in the LSST Science Book



- Contents (~600 pages) :
  - Introduction
  - LSST System Design
  - System Performance
  - Education and Public Outreach
  - The Solar System
  - Stellar Populations
  - Milky Way and Local Volume Structure
  - The Transient and Variable Universe
  - Galaxies
  - Active Galactic Nuclei
  - Supernovae
  - Strong Lenses
  - Large-Scale Structure
  - Weak Lensing
  - Cosmological Physics



<http://arxiv.org/abs/0912.0201>



# Four Key Science Themes Used to Define the Science Requirements

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- 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.**





- **Weak Lensing for Cosmic Shear:**
  - Optimal image quality for galaxy shape measurements
  - Multi-color (ugrizy) precision photometry for photometric redshifts determination
  - Near full-sky coverage to reduce cosmic variance and galaxy shape noise
  - Large number of distinct visits ( $\sim 100$  per color) for reduction and characterization of image systematics
  - Faint co-added limiting magnitude ( $r \sim 27.5$ ) for sufficient galaxy surface density ( $\sim 30\text{-}50/\text{sq. arcmin}$ )
- **Baryon Acoustic Oscillations:**
  - Large area sky coverage to measure low order angular correlations
  - Multi-color (ugrizy) precision photometry for photometric redshift determination
- **Type Ia supernovae:**
  - Multi-color temporal sampling to measure chromatic effects in light curve
  - Multicolor photometry needed to determine k-corrections and supernova type
  - Targeted deep areas with rapid cadence to probe high redshifts with well-sampled light curves
- **Clusters of Galaxies**
  - Image quality for strong and weak lensing
  - Multi-color precision photometry for photometric redshift determination
  - Large area sky coverage with uniform sampling
  - Several day cadence for time delay measurements of variable backlighters (AGNs and SNe)

LSST complementary techniques to constrain Dark Energy :

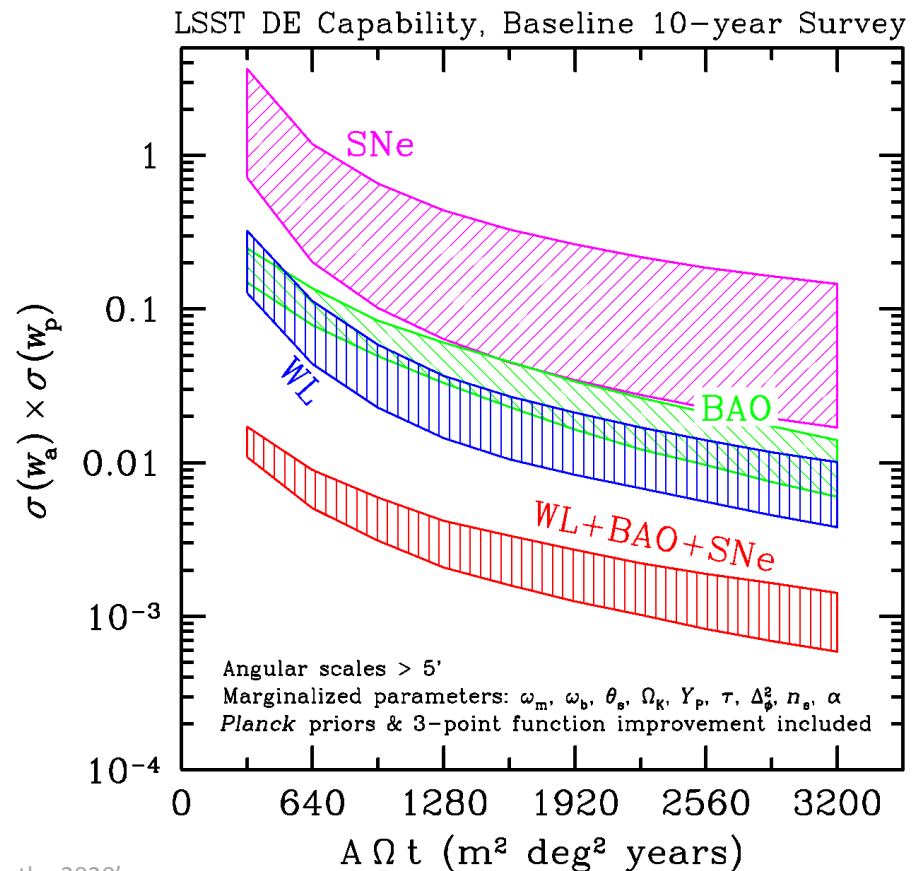
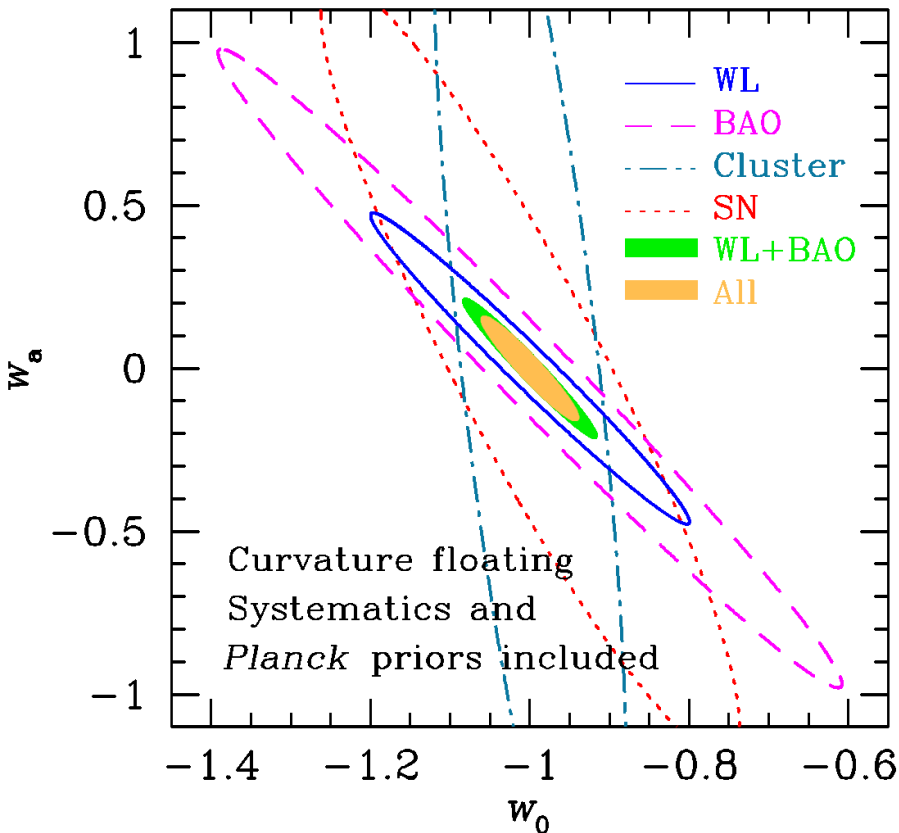
Weak gravitational lensing

Baryon acoustic oscillations

Type 1a supernovae

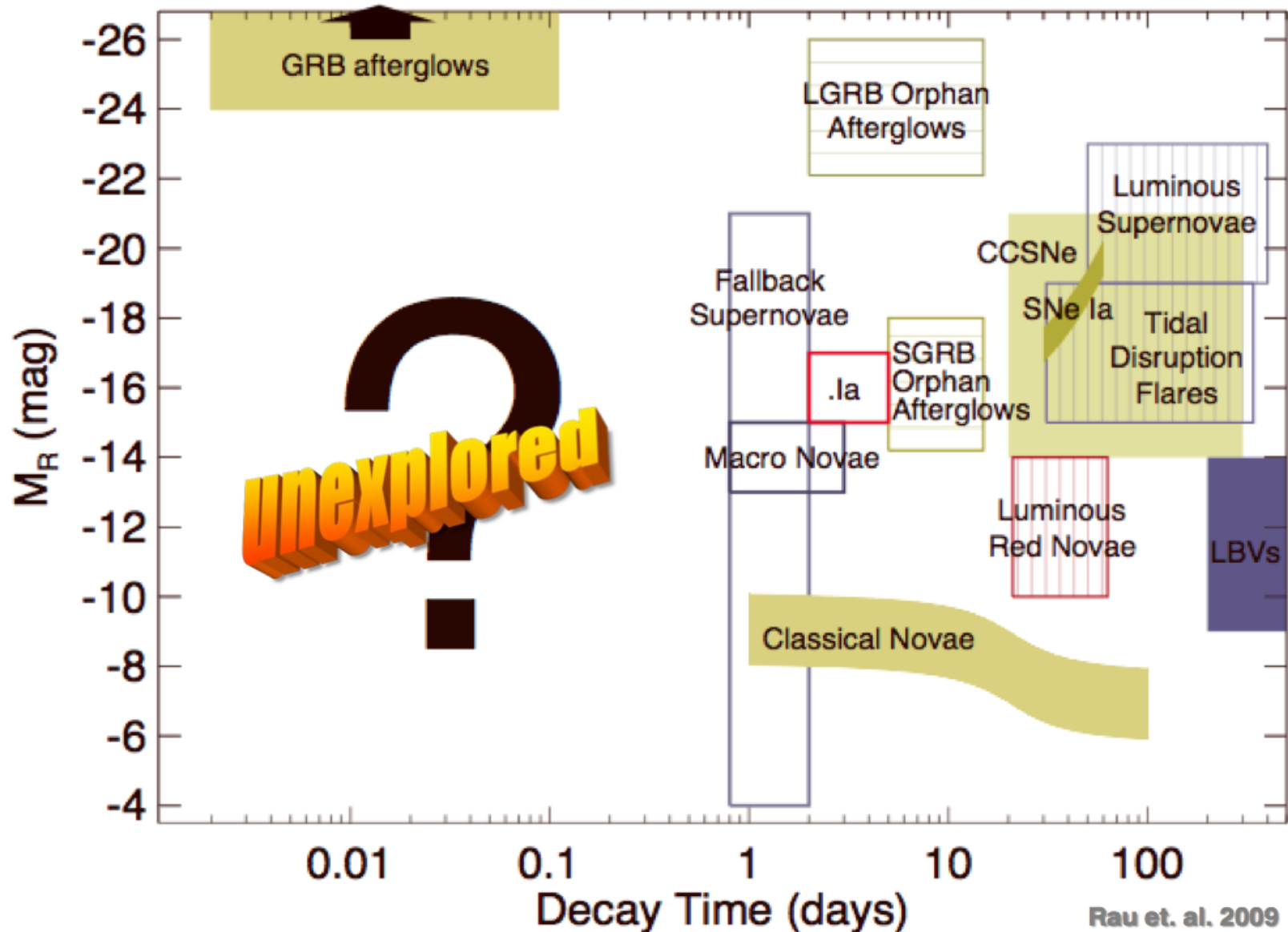
Statistics of clusters of galaxies

- Remark : LSST Key properties to remove instrumental/atmospheric signature :  $> 800$  exposures of each field
- Stage IV criterion defined in terms of the inverse of the error ellipse in the  $w_a$ - $w_0$  plane.



# Optical Transients :

## LSST will cover a huge time domain ( s $\rightarrow$ years)



- LSST will generate a large number of transient alerts dominated by variable stars : 10k/visit (average), 40k/visit (peak) , which will end to  $2 \times 10^6$  to  $10^7$  alerts per night when including galactic plane.
- LSST will support public distribution of these alerts on 60 second time frames.
- Information from LSST database (object environment , light curve, colors ...) will be a key to classify these alerts and trigger photometric/spectroscopic follow-up

PTF (today) & LSST (~2022) rates for supernovae (Rau et al. (2009))

Class	$M_v$ [mag]	$\tau^b$ [days]	Universal Rate (UR)	PTF Rate [yr <sup>-1</sup> ]	LSST Rate [yr <sup>-1</sup> ]
Luminous red novae	-9.. - 13	20..60	$(1..10) \times 10^{-13} \text{ yr}^{-1} L_{\odot,K}^{-1}$	0.5..8	80..3400
Fallback SNe	-4.. - 21	0.5..2	$< 5 \times 10^{-6} \text{ Mpc}^{-3} \text{ yr}^{-1}$	<3	<800
Macronovae	-13.. - 15	0.3..3	$10^{-4..-8} \text{ Mpc}^{-3} \text{ yr}^{-1}$	0.3..3	120..1200
SNe .Ia	-15.. - 17	2..5	$(0.6..2) \times 10^{-6} \text{ Mpc}^{-3} \text{ yr}^{-1}$	4..25	1400..8000
SNe Ia	-17.. - 19.5	30..70	<sup>c</sup> $3 \times 10^{-5} \text{ Mpc}^{-3} \text{ yr}^{-1}$	700	200000 <sup>d</sup>
SNe II	-15.. - 20	20..300	$(3..8) \times 10^{-5} \text{ Mpc}^{-3} \text{ yr}^{-1}$	300	100000 <sup>d</sup>



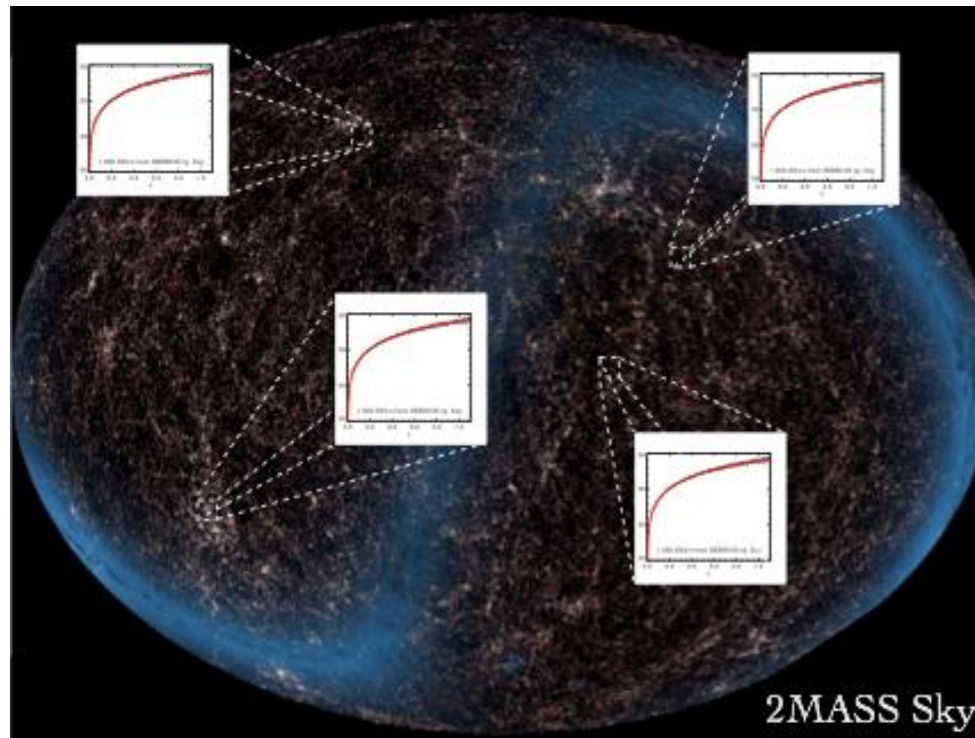
# LSST & Optical Transients :

## an unique way to probe/survey the universe



Hubble diagram for # directions :

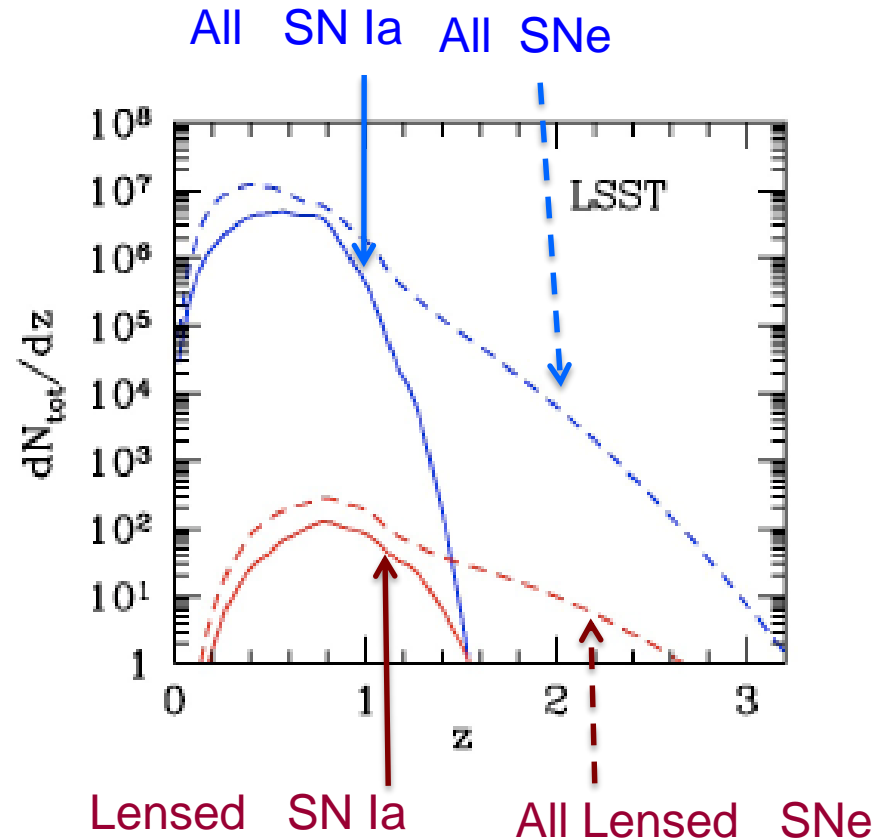
LSST will be able to probe the isotropy of the Dark Energy properties . For example the large SNIa statistic will allow to build SNIa hubble diagram for different directions in the sky.



# Strong Lensing



- LSST will provide time-dependent imaging of an unprecedented sample of strong gravitational lensing events.
- This is especially important for rare classes of events (e.g. lensed supernovae), which are crucial for cosmography.
- The data will provide information on substructure in dark matter distributions that cannot easily be obtained by any other means.
- Strong lensing also enables “micro-imaging” of distant sources, enabling the study of accretion disk structure in distant AGNs.

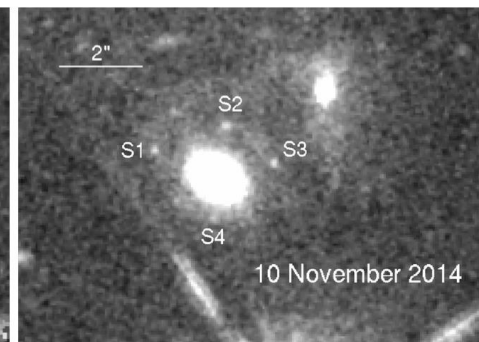
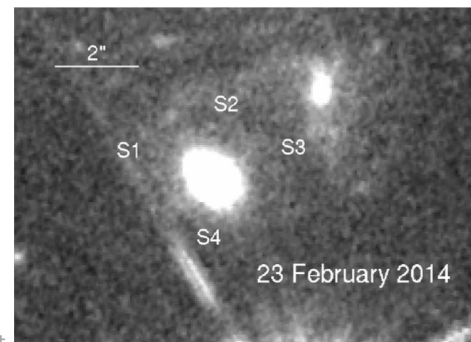


1 seen so far :



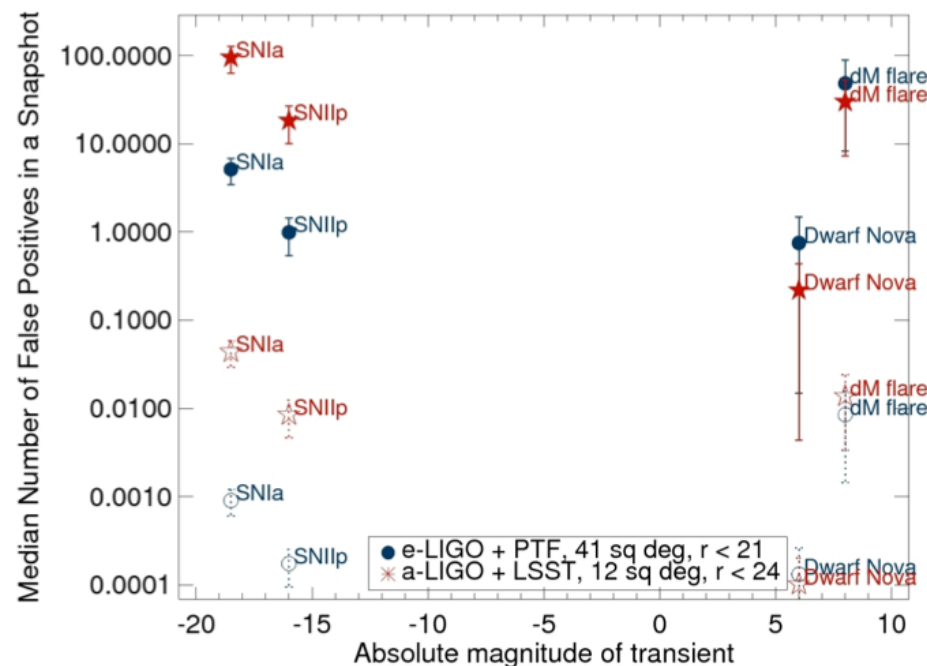
P.L.Kelly et al. [arxiv.org/pdf/1411.6009.pdf](https://arxiv.org/pdf/1411.6009.pdf)

LSST ESO in t

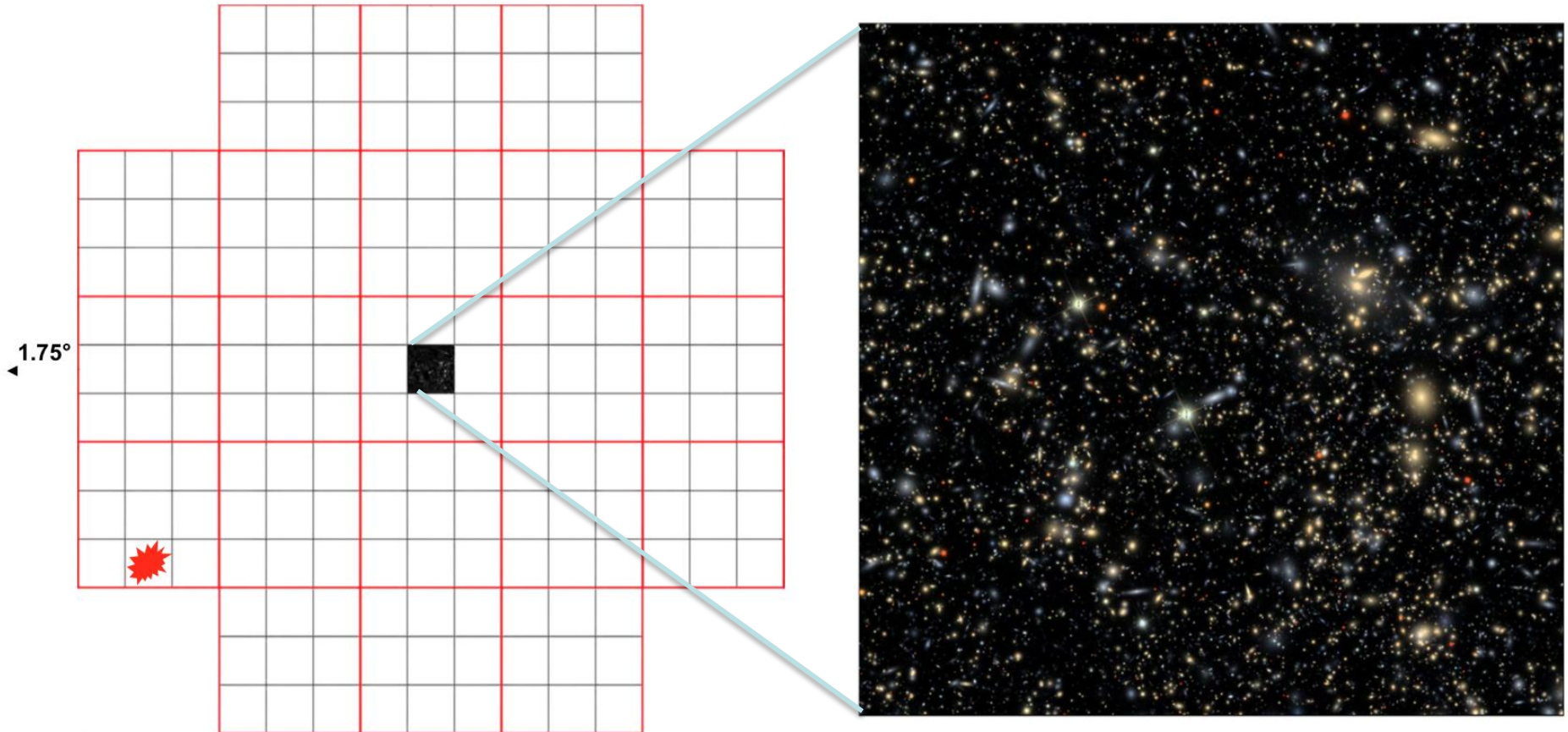


- To be sensitive to transients with peak absolute magnitude as faint as  $-13$  (fainter than the faintest observed short hard gamma ray burst optical afterglow):
  - today e-LIGO/Virgo needs at least a 1-m class telescope for follow-up (going to  $m < 21$ , or 50Mpc, PTF like )
  - and soon a-LIGO/Virgo will need an 6/8-m class telescope ( $m < 24$ , 200Mpc, LSST Like)..

$< 200$  Mpc horizon of GW astronomy is a blessing : The Universe is very dynamic and the number of false positives in a single LSST image is huge (full symbol) , but once limiting at  $< 200$  Mpc (empty symbol) , the identification of candidate should become easy



The positional uncertainty of a-LIGO-Virgo GW alerts is commensurate with the LSST field of view,  $1.75^\circ$  in radius, making LSST an optimal localization resource for GW alerts.



Simulated CCD-sized ( $13.3' \times 13.3'$ ) g,r,i composite image (1/189 th LSST focal plane)



# In 10 years the LSST can find at least 80% of the NEO of 140 m and larger .



## POTENTIAL DAMAGE TO EARTH FROM NEO IMPACT

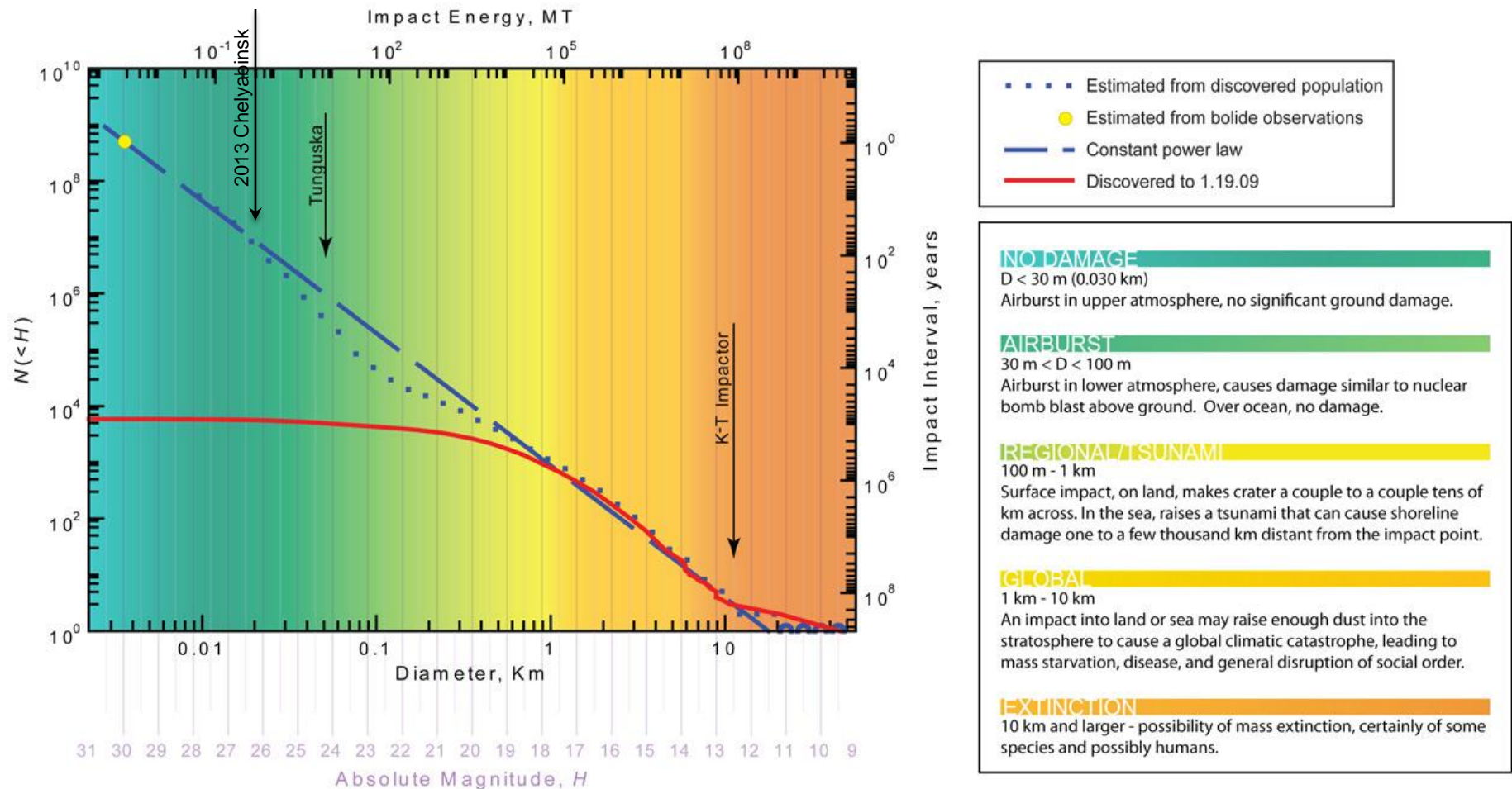
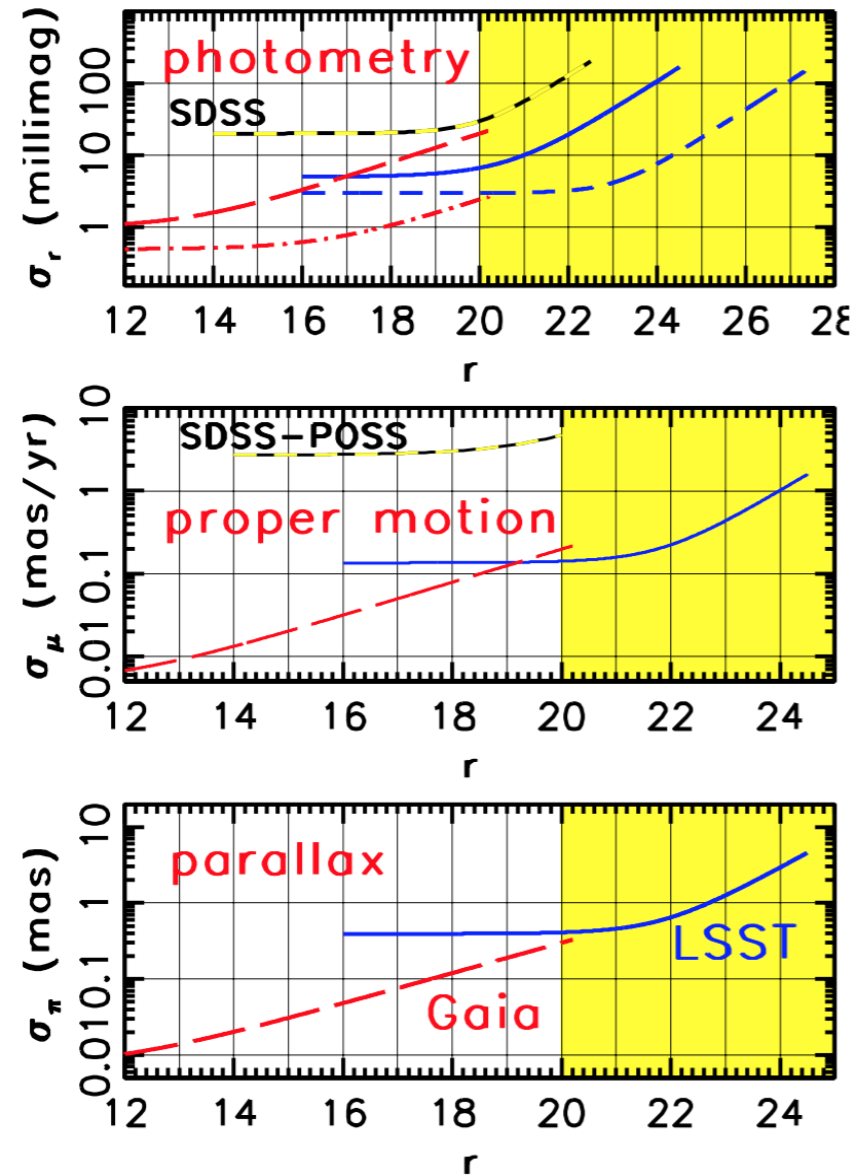


Image Credit: A. W. Harris, SSI/LSST

**The two surveys are highly complementary:**

Gaia will map the Milky Way's disk with unprecedented detail, and LSST will extend this map all the way to the halo edge.



- **LSST will be a unique tool for studies of galaxy formation and galaxy properties. It probes a Co-Moving Volume ~Two Orders of Magnitude Larger than Current or Near-Future Surveys**
- **The survey will reach up to 50 galaxies / arcmin<sup>2</sup>**
- **The database will include photometry for  $10^{10}$  galaxies from the Local Group to  $z > 6$ .**
- **LSST will have 6-band photometry for  $4 \times 10^9$  galaxies.**
- **Key diagnostic tools will include:**
  - **Luminosity functions**
  - **Color-luminosity relations**
  - **Size-luminosity relations**
  - **Quantitative morphological classifications**
  - **Dependence on environment**
- **How LSST survey will contribute to Galaxies Studies :**
  - **Constrain both the bright and faint end of the LF**
    - With great statistics, over wide redshifts
  - **Understanding low-mass galaxies**
    - Destruction mechanisms
    - Do gas-poor dwarfs exist in low-density environments?
  - **Quantifying Galaxy interactions**
    - Merger rates, tidal destruction
  - **Detailed mapping of galaxy properties vs. environment**



# Photo-z calibration : cross-correlation option



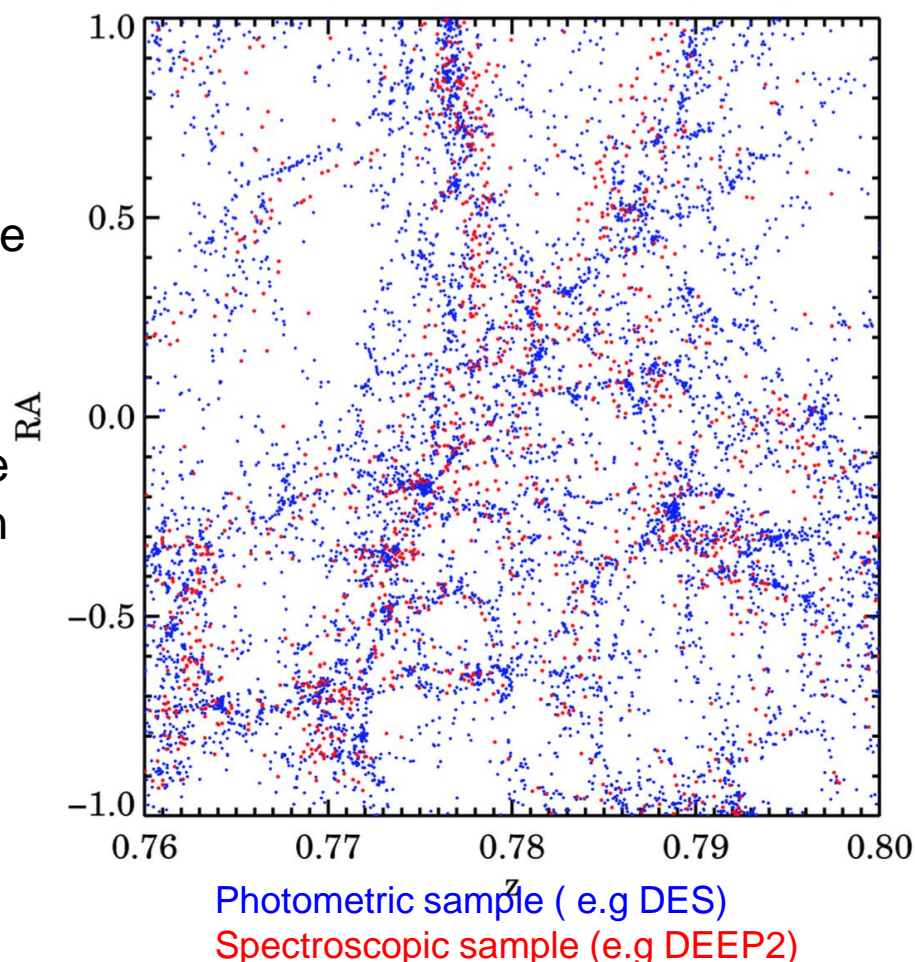
- Most LSST planned targets are too dim to get spectroscopic redshifts for *en masse*
- Existing redshift surveys are highly and systematically incomplete & redshift success rate depends on both color and magnitude

→ **cross-correlation methods:** exploiting redshift information from galaxy clustering

- Galaxies of all types cluster together: trace same dark matter distribution
- Galaxies at significantly different redshifts do not cluster together
- From observed clustering of objects in one sample with another (as well as information from their autocorrelations), can determine fraction of objects in overlapping redshift range

**A few tens of thousands of spectra per unit  $z$  are required to calibrate LSST**

More : J.Newman et al. <http://arxiv.org/abs/1309.5384>





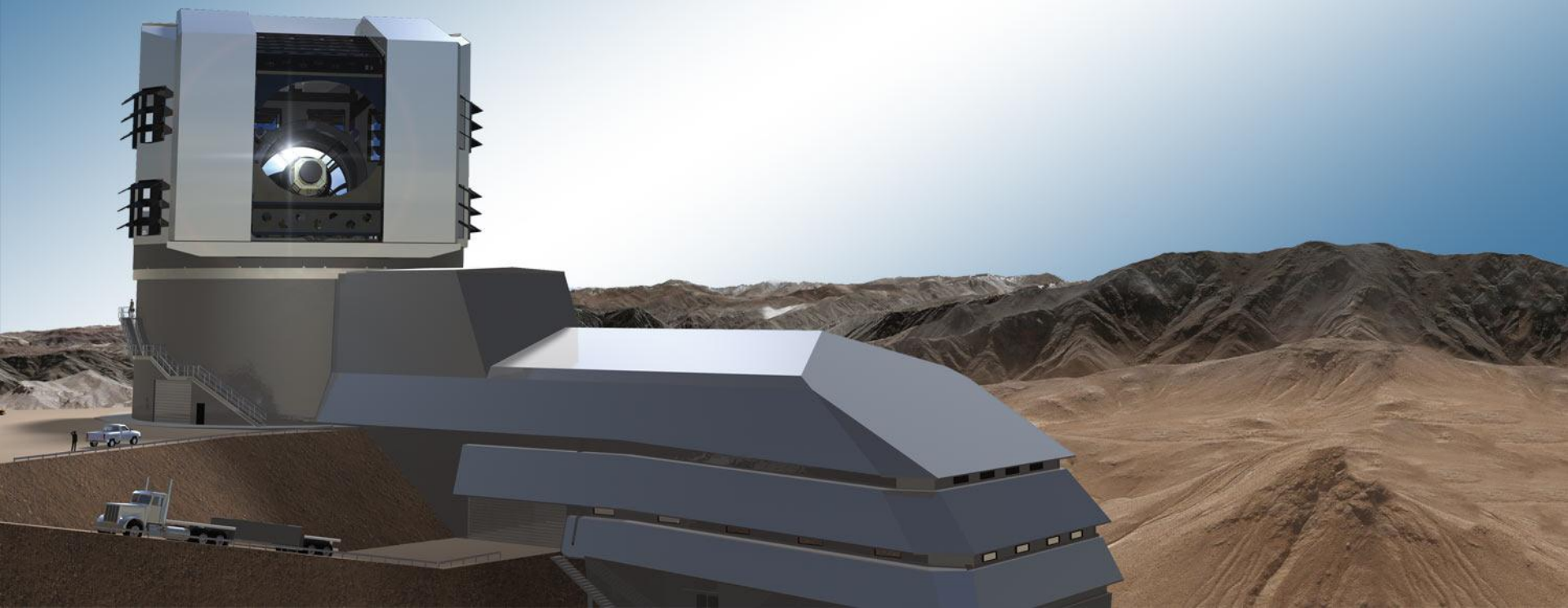
- The key members of the project team have been in place, and working effectively together for a number of years.
- A very successful Final Design Review was commissioned by NSF in December 2013.

“The Panel regards the project team as very strong, with well-developed plans, schedules and cost estimates. We have no hesitation in our assessment that the project will be ready for start of construction on July 1, 2014.”

- .... and construction started in 2014 .
- Can't wait to be in the 2020's !!!

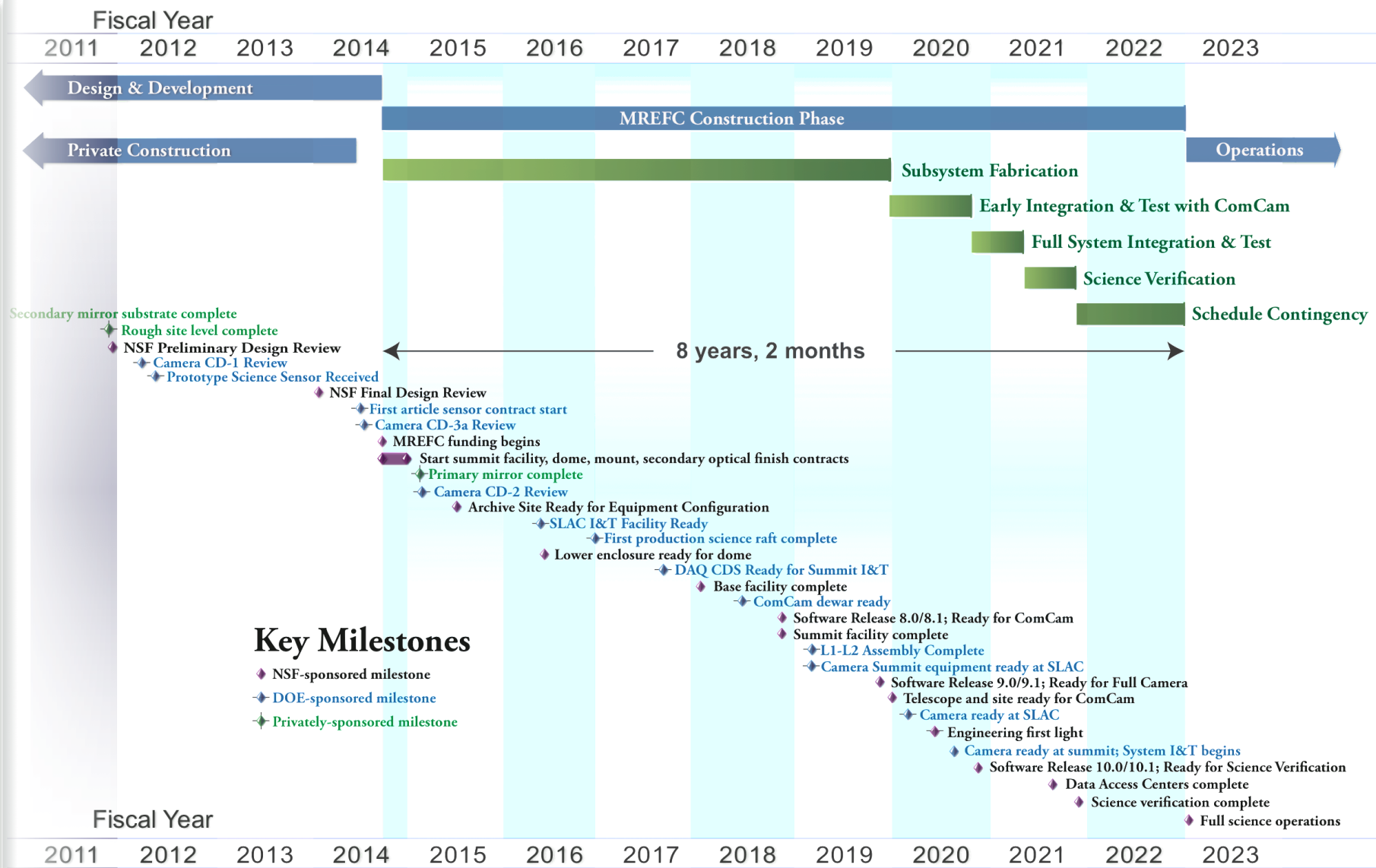


**End of Presentation**





# Integrated Project Schedule



September 2014