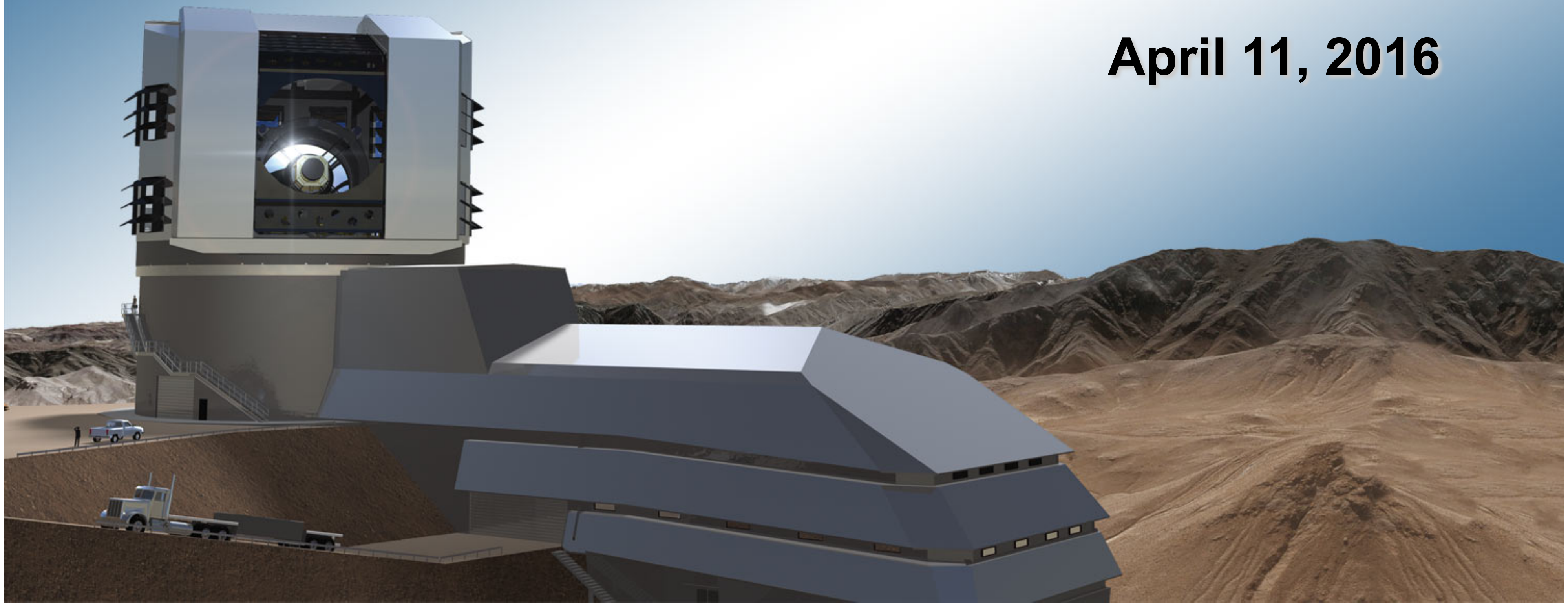
LSST, Strategies for Transients

Pierre Antilogus

LPNHE-IN2P3, Paris

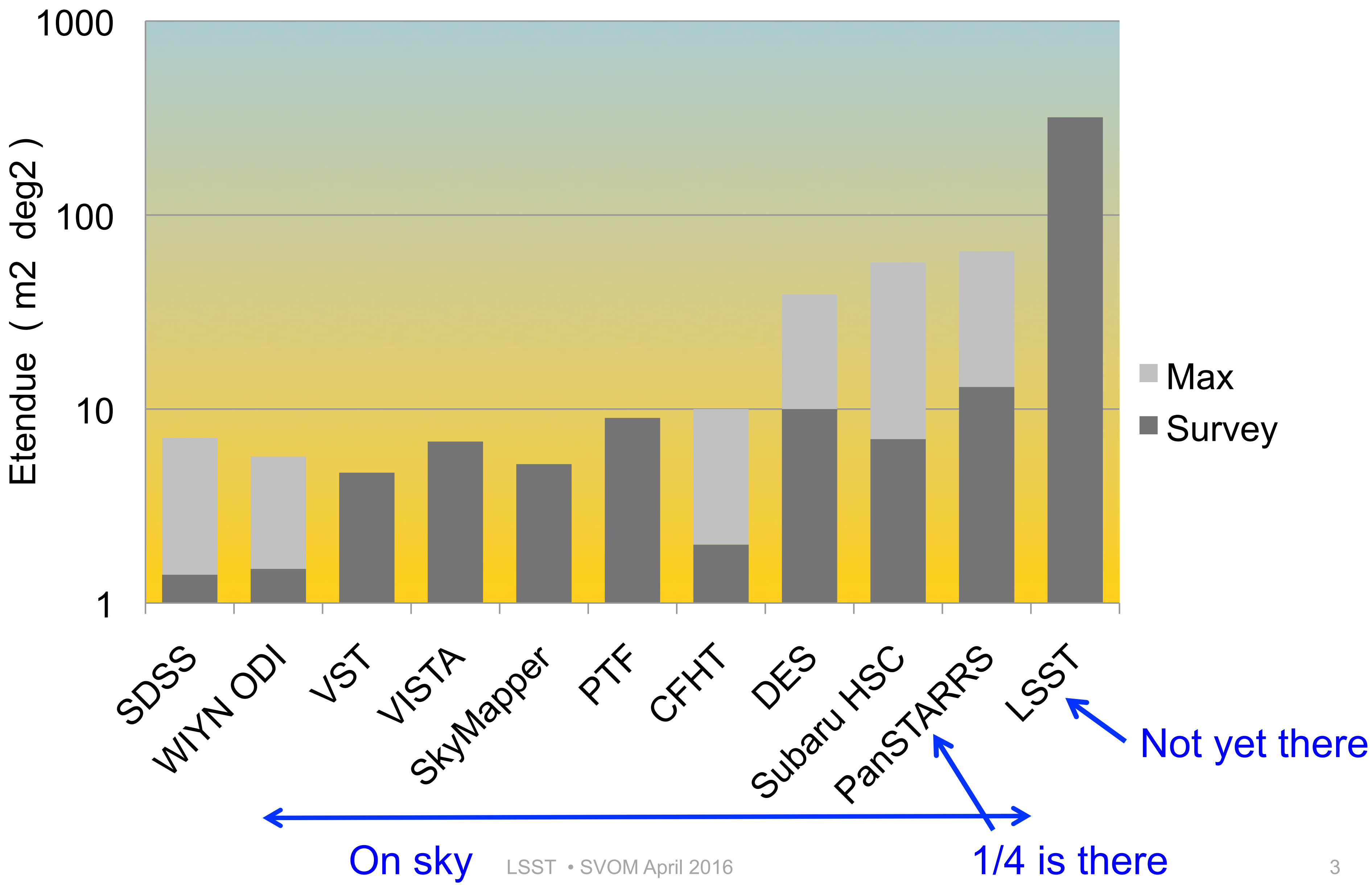
April 11, 2016

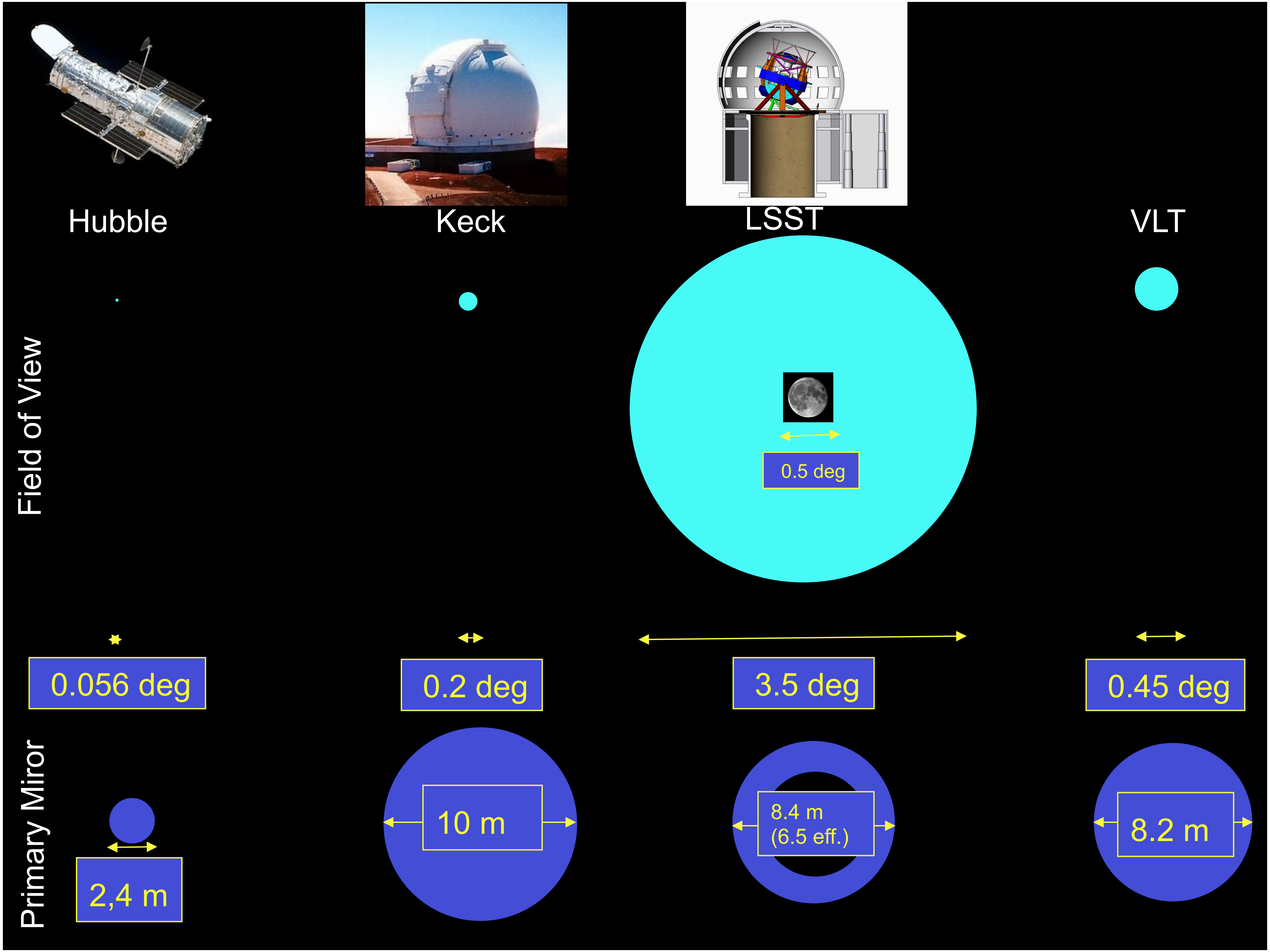


LSST in a Nutshell

- **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 detect 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.**

Etendue associated to a few projects




Hubble
Keck
LSST
VLT
Field of View
0.5 deg
0.056 deg
0.2 deg
3.5 deg
0.45 deg
Primary Miror
2,4 m
10 m
8.4 m
(6.5 eff.)
8.2 m


Hubble
Keck
LSST
VLT
Champ de vision
Taille réelle
YURI BELETSKY
Miroir Primaire
2,4 m
10 m
8.4 m
(6.5 eff.)
8.2 m

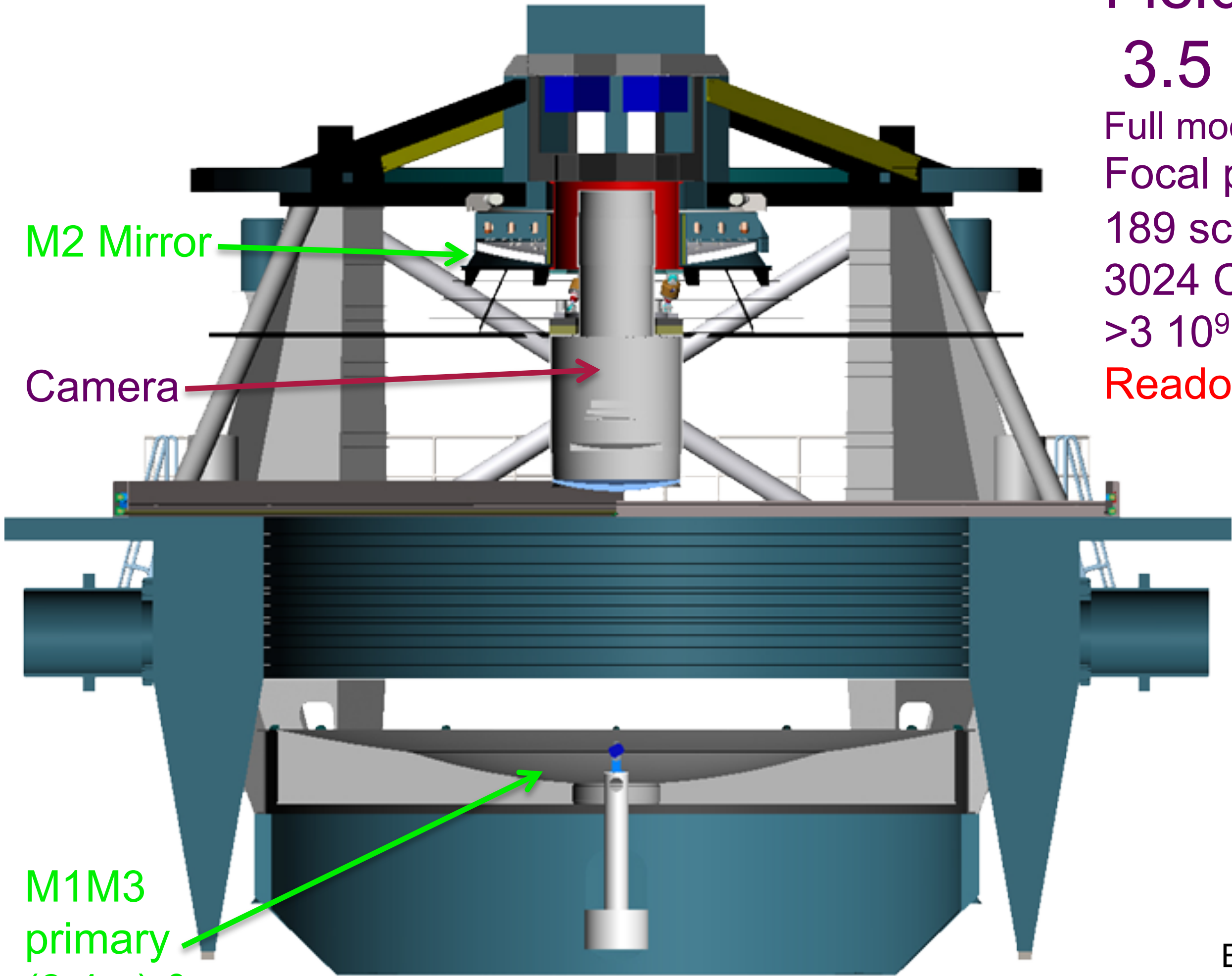
LSST :

- A new pointing each 38 s
- 1 pointing = 10 millions galaxies
- Full sky coverage in 3 nights
- Most of the southern sky visited 80 times each year

LSST : Wide , Deep and Fast

M2 Mirror

Camera



M1M3 primary (8.4m) & Tertiary mirrors

Moving Structure 350 tons, 60 tons optical systems

Tracks during exposures and slews 3.5° to adjacent fields in ~ 4 seconds

Field of view :

3.5 deg (9.6 deg^2 =.023% sky sphere)

Full moon = 0.5 deg = 4.8 10^{-6} of sky sphere

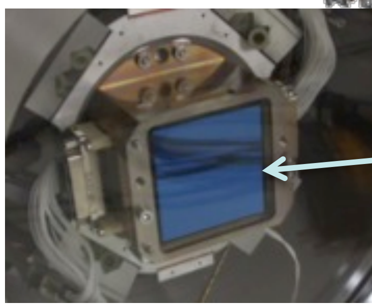
Focal plane diameter : 64 cm

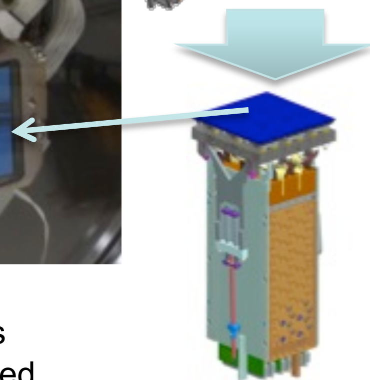
189 science CCD (21 rafts)

3024 Channels

>3 10^9 pixels

Readout: 2s





E2v CCD 250 ,
4kx4k , 10 µm pixels
100 µm deep depleted
UV to IR sensitive
16 channels output
Designed by Dedicated R&D for LSST

1 raft = 3x3 CCD
150 M pixels
(1/2 Megacam)

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 (~90% of the time)

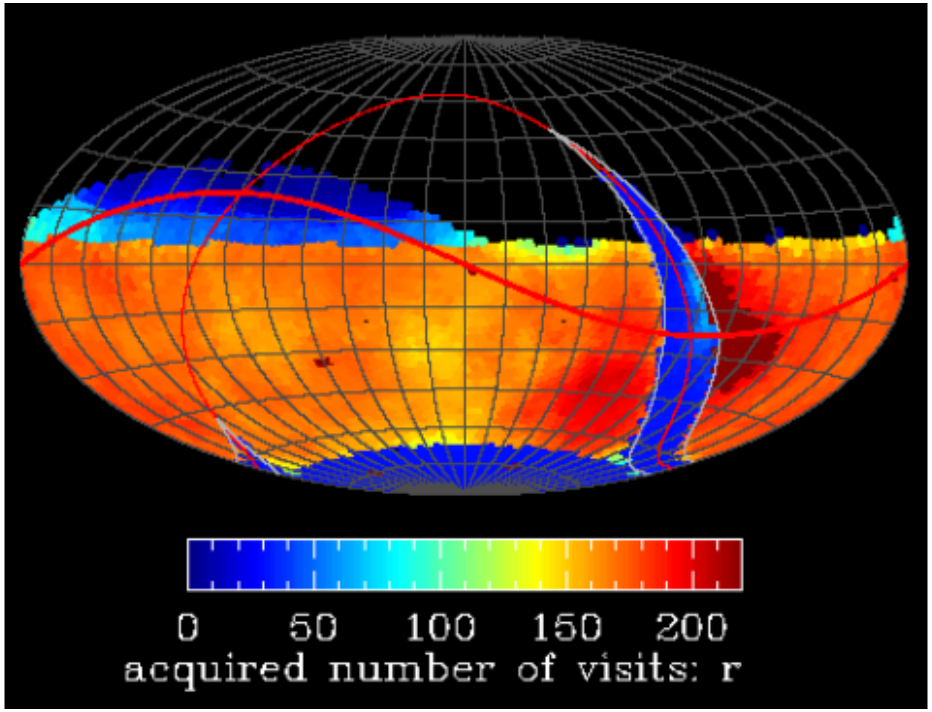
deep drilling survey, ~30 selected fields= 300 square degrees Continuous : 1hour/night

Other : fast time domain + special regions : ecliptic, galactic plane , Magellanic clouds

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



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

Visits per unit area and Visits per filter (10 years Main survey)

LSST : Main Survey Strategy (~90% of the time)

- **Full Sky surface : 41 253 deg^2**
- **Visible/usable Sky from 1 location on hearth ~20 000 deg^2 (~ Full LSST survey)**
- **Observable Sky over 1 night (Sun hide>~ ½) < 9 000 deg^2**

- **LSST Visit/pointing :**

  more than 2.75 10^6 visits & 5.5 x10^6 exposures in 10 years, following the sequence:

  15 s pose + 1 s shutter + 2 s read + 15 s pose + 1s shutter + 4s new pointing as reading

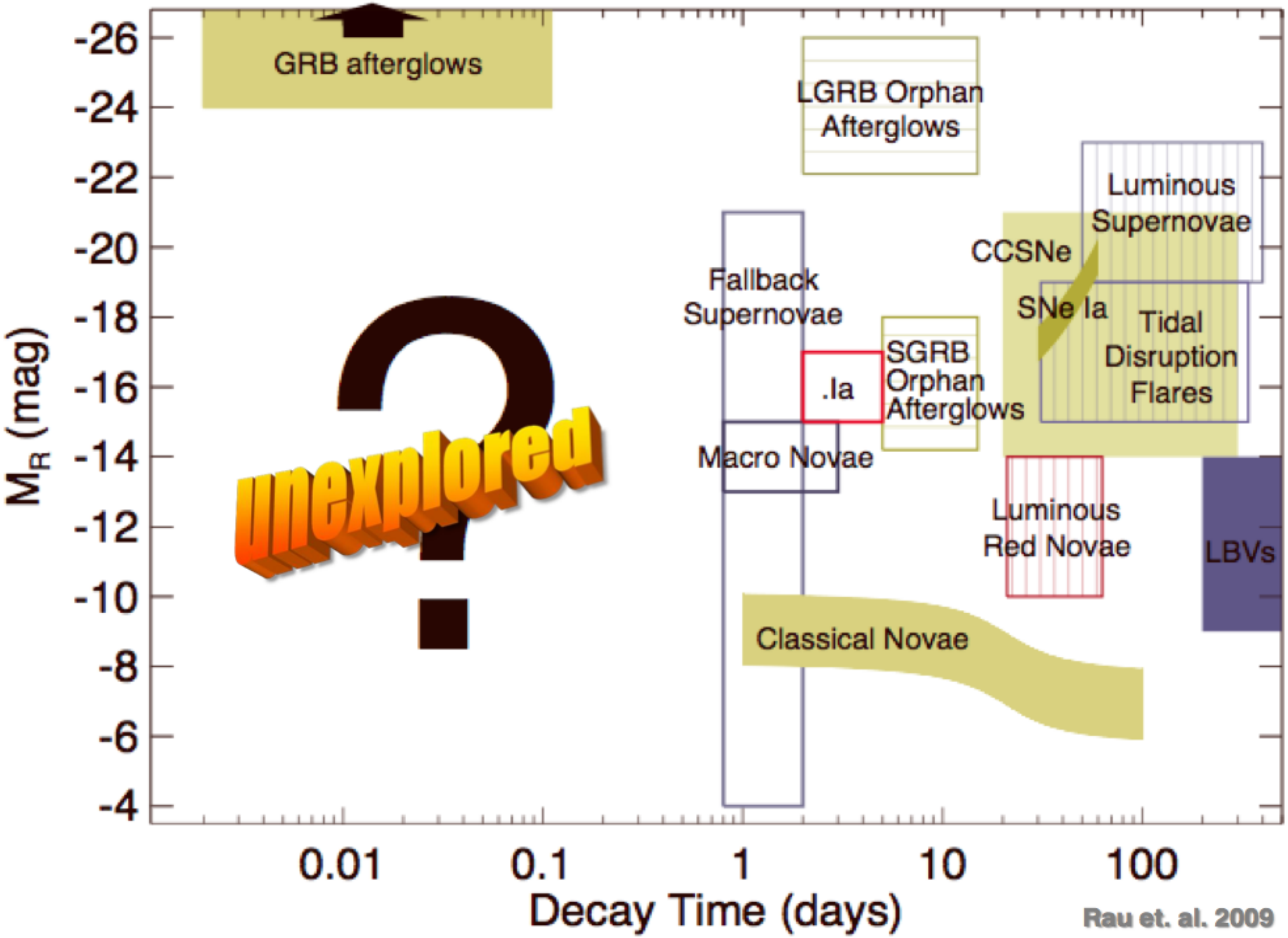
  ➔LSST points to new positions in sky every 38 seconds

- **Universal Cadence Strategy for Main Survey :**
  - **Revisit after ~15-60 minutes**
  - **Visit pairs every 3-4 nights**

  ➔ **In the "main survey" LSST will ensure that a given sky patch will be observed at least each 4 days for at least 1 filter.**

- **LSST can perform ~850 pointing per night (~ 8 000 deg^2) but :**
  - **Most pointing will be visited twice within ~15-60 minutes**
  - **In a given night LSST may use up to 5 different filters (filter change : 90s)**

Optical Transients :
LSST will cover a huge time domain (s→years)



Rau et. al. 2009

LSST & Optical Transients

- **LSST will generate a large number of transient alerts dominated by variable stars : 10k/visit (average), 40k/visit (peak) , which will end to 2 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 (for 1 new pointing each 38 s)**
- **Information from LSST database :**
  - **object environment**
  - **galaxy red-shift**
  - **light curve / colors**

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

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

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

Remark : Key information for transients identification
➔ measured multi-color light curve of ~37 10^9 objects
(~ 80 measurements /year)

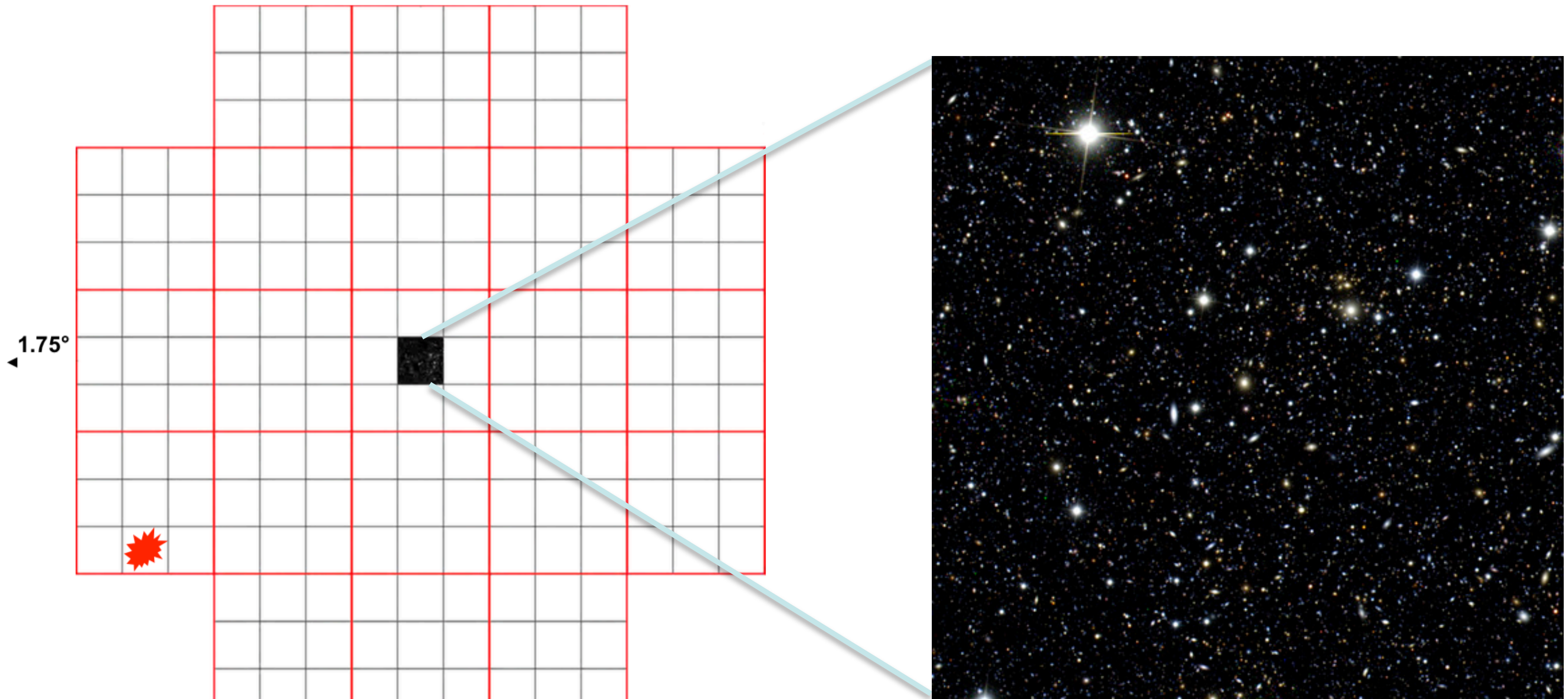
LSST & Optical Transients : Gravitational Wave example

LSST will be able to respond to alert, like GW ones :

- ➔ ~ 50 s to react = ~20 s to finish what it's doing + ~30 s to point (4s for 3.5 deg move)
- ➔+ 38s to acquire 2 images of 10 deg2
- ➔If needed filter could be changed (+90s)

Still , the exact plan (which alert , how often and at which speed LSST should react) is not frozen.

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



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

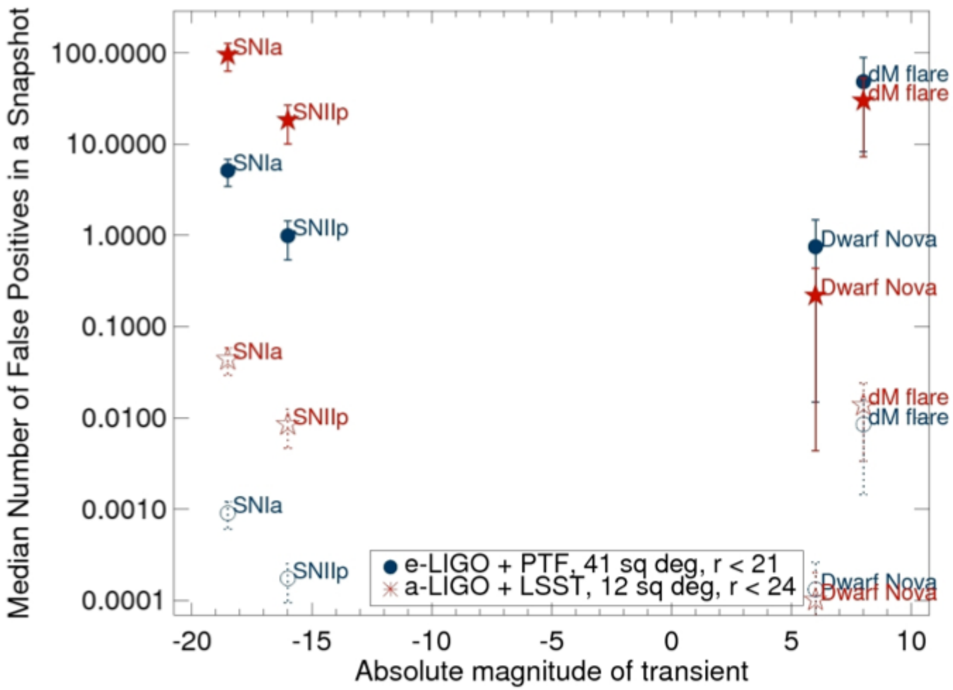
LSST & Optical Transients : Gravitational Wave example

•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):

- Yesterday e-LIGO/Virgo needed at least a 1-m class telescope for follow-up (going to m < 21, or 50Mpc, PTF like)
- But today a-LIGO/Virgo needs 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”

➔ Knowing the redshift of all the object in the field of view is a key of an optical transient identification



LSST & Optical Transients : Gravitational Wave example

LIGO: arXiv:1304.0670

We are here!

	Epoch	Estimated Run Duration	$E_{GW} = 10^{-2} M_{\odot} c^2$ Burst Range (Mpc) LIGO	Virgo	BNS Range (Mpc) LIGO	Virgo	Number of BNS Detections	% BNS Localized within $5\ \mathrm{deg}^2$	$20\ \mathrm{deg}^2$
aLigo	2015	3 months	40 – 60	–	40 – 80	–	0.0004 – 3	–	–
aLigo	2016–17	6 months	60 – 75	20 – 40	80 – 120	20 – 60	0.006 – 20	2	5 – 12
aVirgo + aLigo	2017–18	9 months	75 – 90	40 – 50	120 – 170	60 – 85	0.04 – 100	1 – 2	10 – 12
aVirgo + aLigo	2019+	(per year)	105	40 – 80	200	65 – 130	0.2 – 200	3 – 8	8 – 28
	2022+ (India)	(per year)	105	80	200	130	0.4 – 400	17	48

DES observations
(Sep-Feb months)

LSST era!

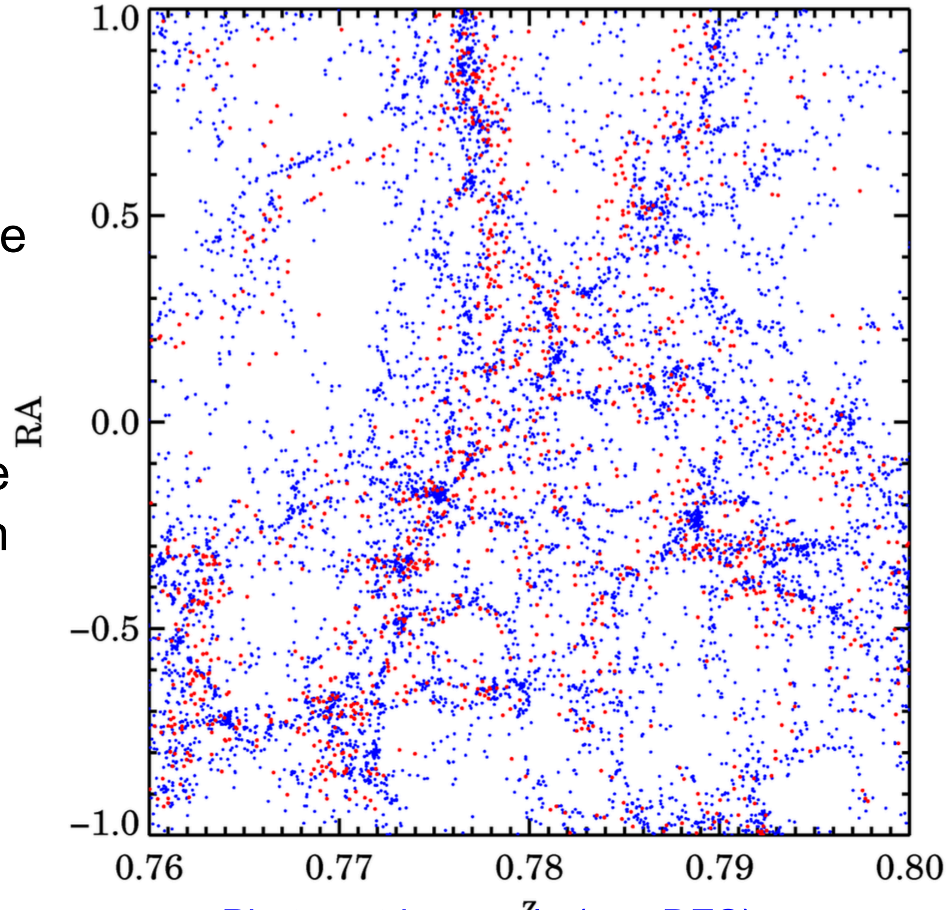
Photo-z calibration : cross-correlation option

- Key information to classify transients ➔ Galaxy redshift
- 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-corelation 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



Photometric sample (e.g DES)
Spectroscopic sample (e.g DEEP2)

LSST : members

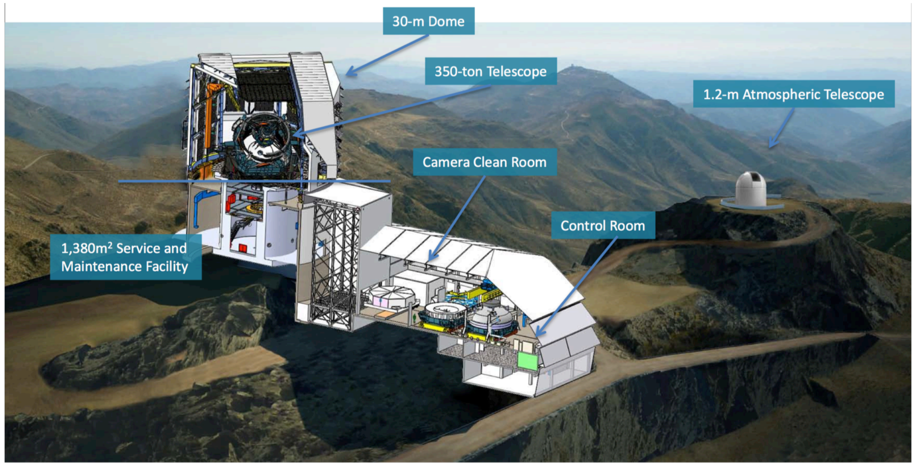
LSST will federate a community of ~ 900 scientists over the world (50% from US) :

- Chile (site) & France-IN2P3 (in kind contribution to the camera) are LSST members / have data right .
- Integration of other non-US scientists 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 in good shape today :
  - **Europe :**
    - France : ~120 PI (including ~+45 PI in discussion INSU+CEA)
      - Activity 100% Dark Energy today / no-Transient group as such .
    - 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 Zeeland ,….**

LSST : Status & plan

- **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.**
- 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*
  - ....
- Planning :
  - First light 2019 (ComCam)
  - All systems in place 2020
  - Pre-Survey start 2021
  - Science Survey start 2023

LSST site March 2016



Conclusion

- LSST construction starts early 2014. After ~ 2 years of commissioning , the main survey will start in 2023 for 10 years.

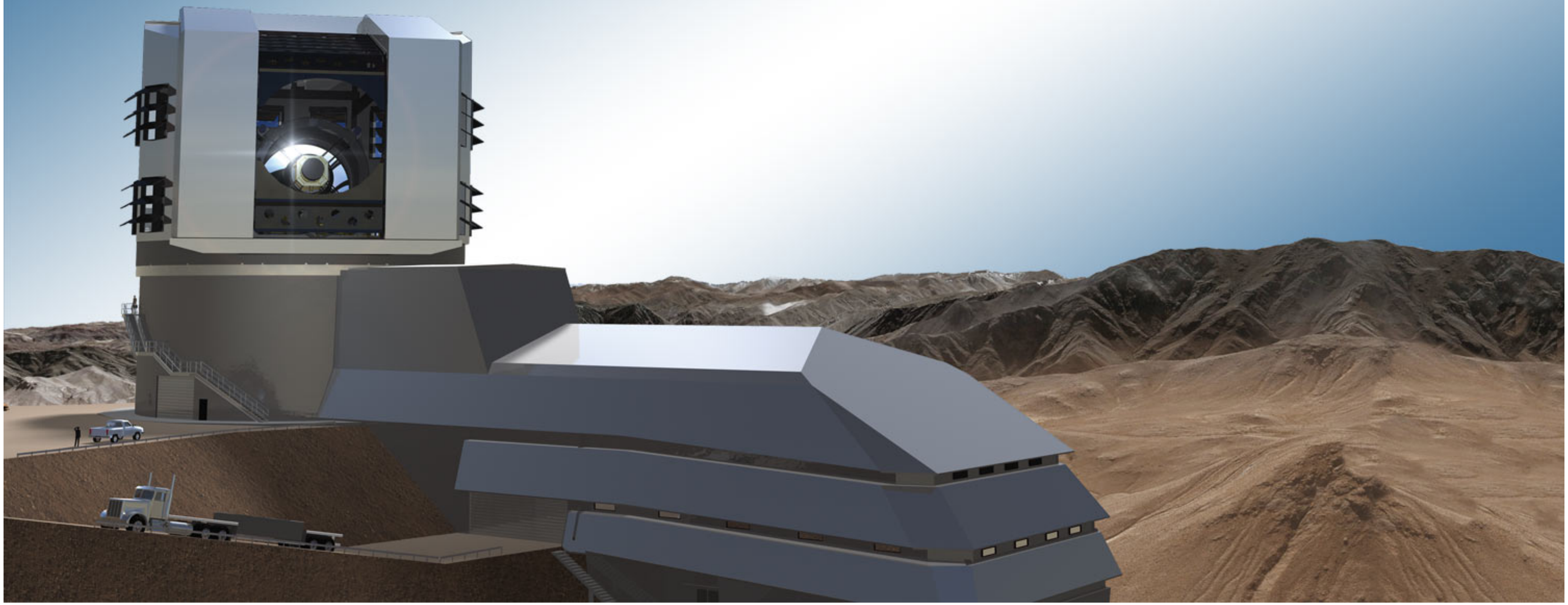
… so we still have to be patient but :

- With ~1-2 million transient alerts issued every night, LSST open the time window of the universe in optical .
- Filtering time-critical information out of ~ 30 Terabytes of LSST survey data per night is a challenging task …
- Identifying them is an even bigger challenge !
- LSST will open a new way of studying GRB/GW events using optical data …

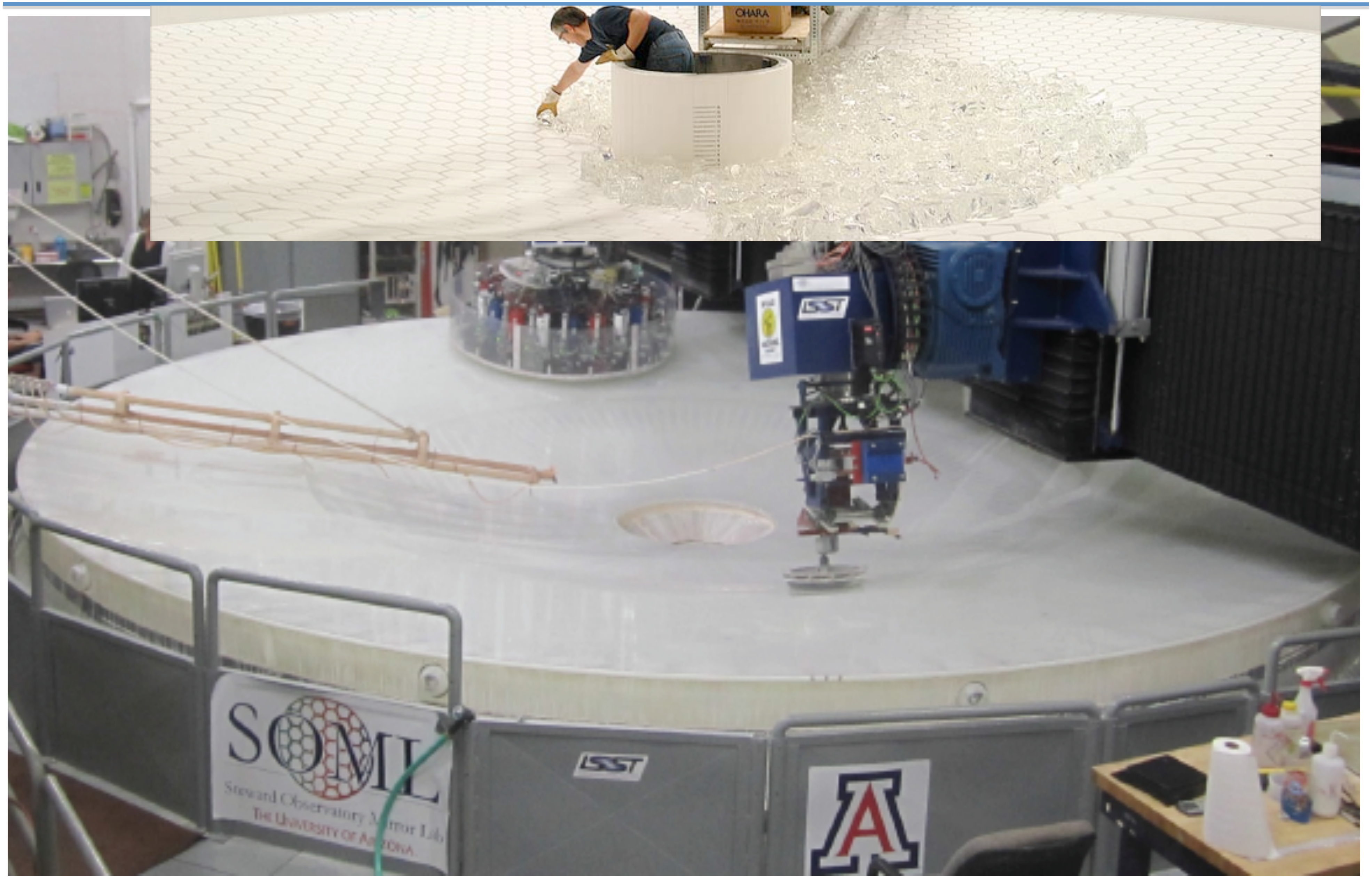
➔ Due to the amount of transient detected by LSST and the small fraction that will be of interest for SVOM , SVOM cannot avoid to have a close look (contribution(s)?) to the LSST transient classification if SVOM wants to us it.

➔ LSST should be able to react quickly to a transient alert (~50s) : GW/GRB are in the list …but the exact plan is not frozen , having a close contact with the LSST transient group / being part of it, will be needed to have a chance to trig LSST on SVOM detections . (LIGO scientist have joined)

End of Presentation



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

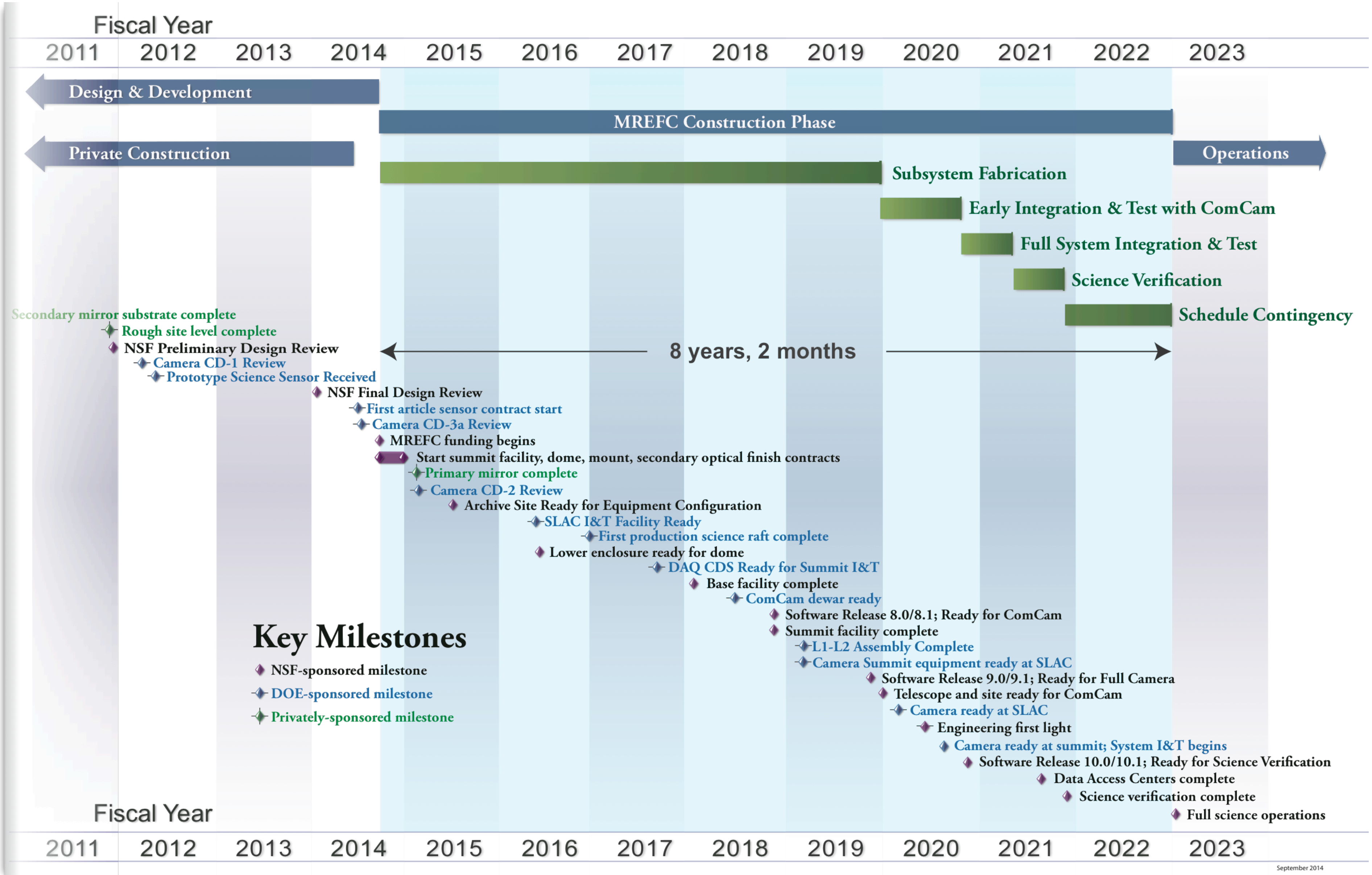


Four Key Science Themes Used to Define the Science Requirements

- 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.

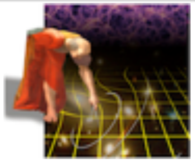
The techniques associated with these four themes stress the system design in complementary ways. By designing the system to to accomplish these specific goals, we ensure that LSST will in fact enable a very broad range of science.

Integrated Project Schedule



Next generation of Wide field imaging survey :

Euclid



~ 900 members
European lead project / ESA
Space telescope / 1.2 m mirror
Launch : 2020
Mission length : 6 years
1 exposure depth : 24 mag
Filters : 1 Visible(550-900nm)
+ 3 IR(920-2000 nm)
+ NIR spectroscopy (1100 – 2000 nm)
wide survey of 15000 deg2 (=.36 sky)

- single path survey

➔ For Transients Euclid will provide high resolution mag 24 host galaxy reference, including in infra-red .

&

LSST – Large Synoptic Survey Telescope

~ 450 Core members + 450 to come
US lead project / NSF-DOE
Ground Telescope / 6.5 m effective mirror
1st light : 2019 , test survey: 2021 , deliver: 2022
Observation length : 10 years
1 exposure depth : 24 mag (i) (~27 in 10 years)
Filters : 6 filters (320-1070 nm)
Wide survey 20,000 deg2 (=.48 sky):

- each patch visited ~ 100 times a year
- One patch observed twice in a night with a few hours in between (1 pointing ending to 2 x15s exposures separated by 2s readout) . The same patch being re-observed 3 days later.

➔ For transients LSST will :

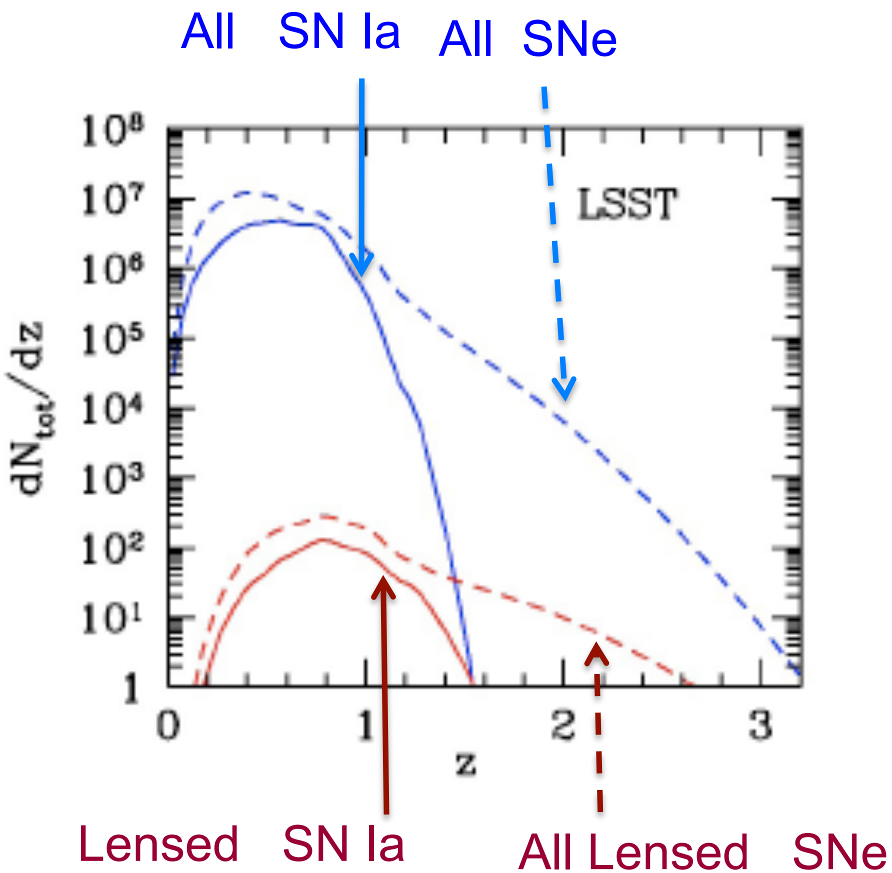
- Provide Host galaxies identification + photometric red-shift (up to mag 27 at the end of the survey)
- Localize / follow-up transients up to mag 24

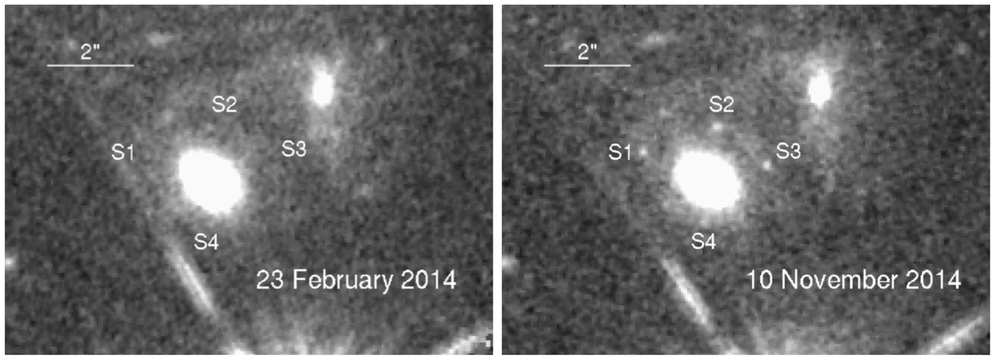
Both project have strong cosmological/Dark Energy program

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.**

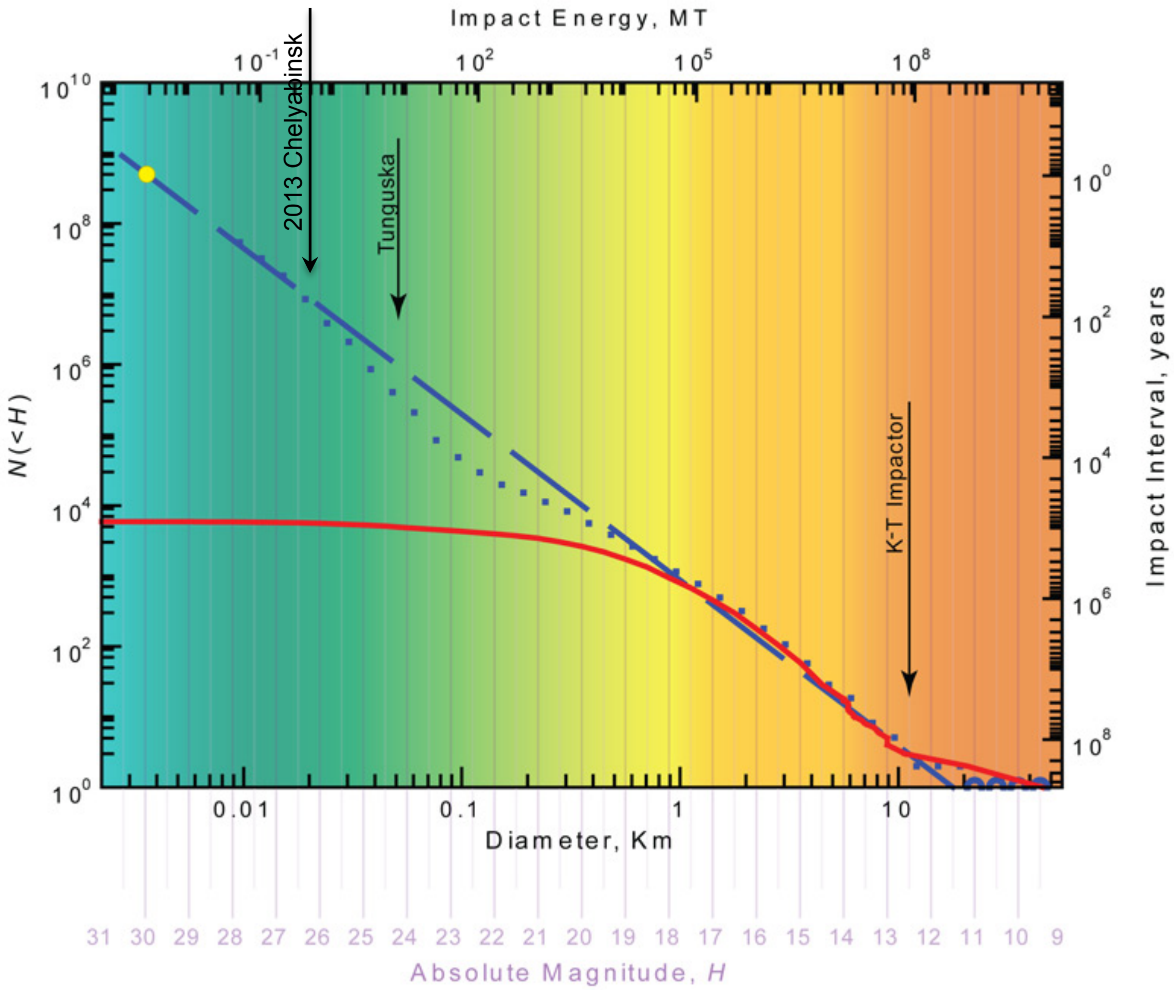
1 seen so far : ➔
P.L.Kelly et al .arxiv.org/pdf/1411.6009.pdf





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



- Estimated from discovered population
- Estimated from bolide observations
- Constant power law
- Discovered to 1.19.09

NO DAMAGE
D < 30 m (0.030 km)
Airburst in upper atmosphere, no significant ground damage.

AIRBURST
30 m < D < 100 m
Airburst in lower atmosphere, causes damage similar to nuclear bomb blast above ground. Over ocean, no damage.

REGIONAL/TSUNAMI
100 m - 1 km
Surface impact, on land, makes crater a couple to a couple tens of km across. In the sea, raises a tsunami that can cause shoreline damage one to a few thousand km distant from the impact point.

GLOBAL
1 km - 10 km
An impact into land or sea may raise enough dust into the stratosphere to cause a global climatic catastrophe, leading to mass starvation, disease, and general disruption of social order.

EXTINCTION
10 km and larger - possibility of mass extinction, certainly of some species and possibly humans.

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