Large Synoptic Survey Telescope (LSST) : toward a new window on the dark universe

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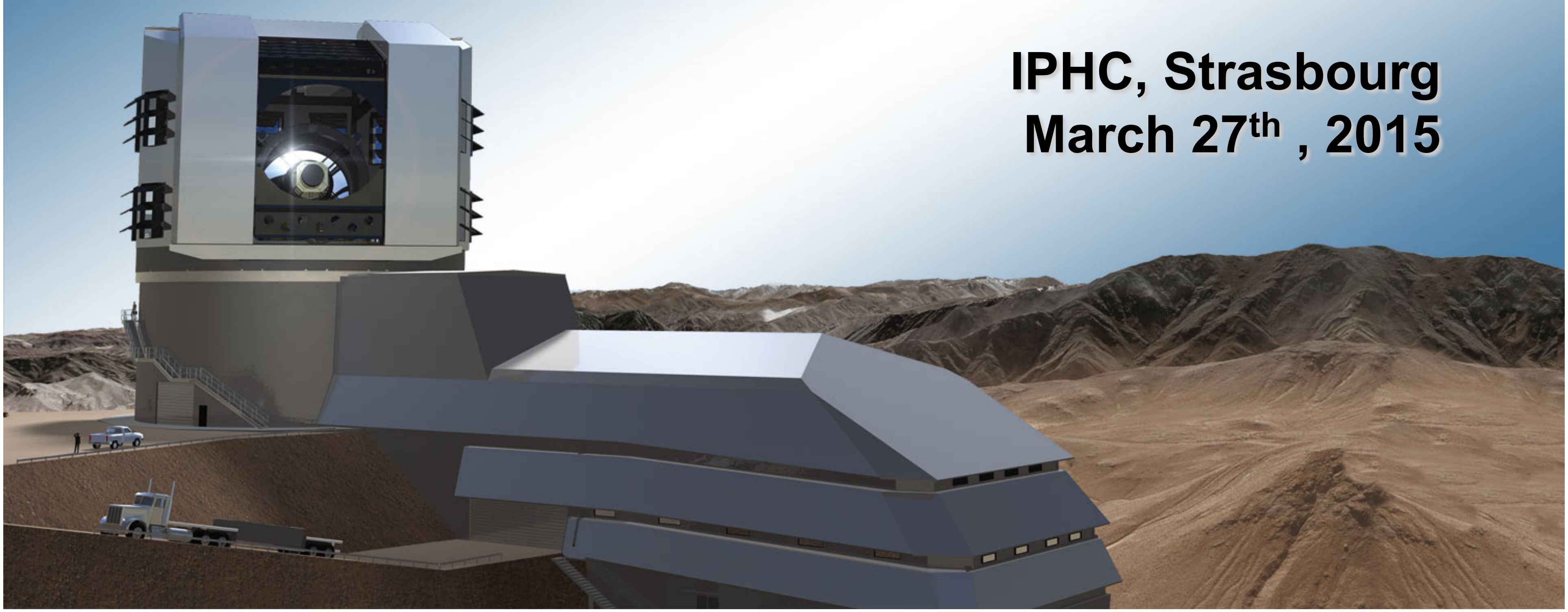
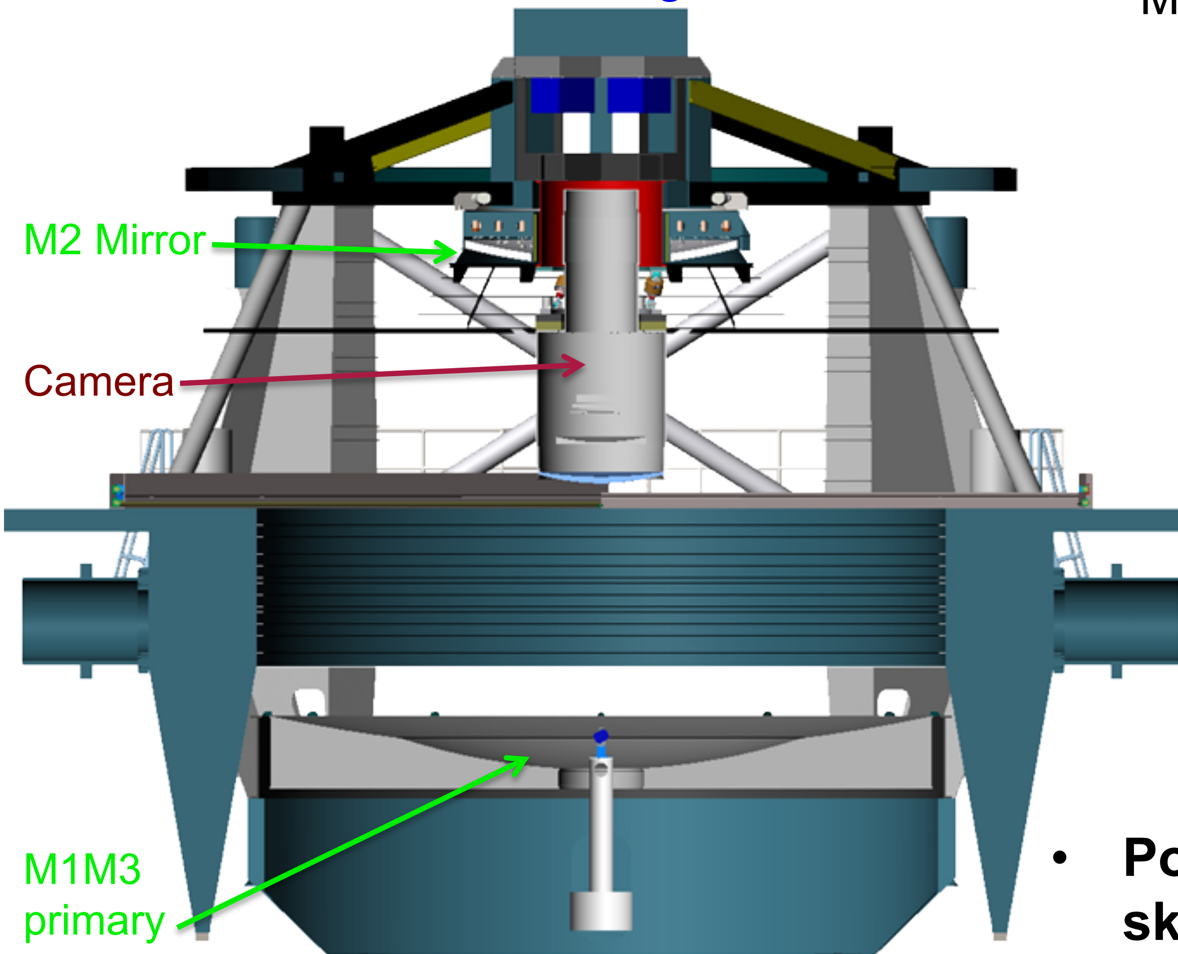


LSST in a Nutshell

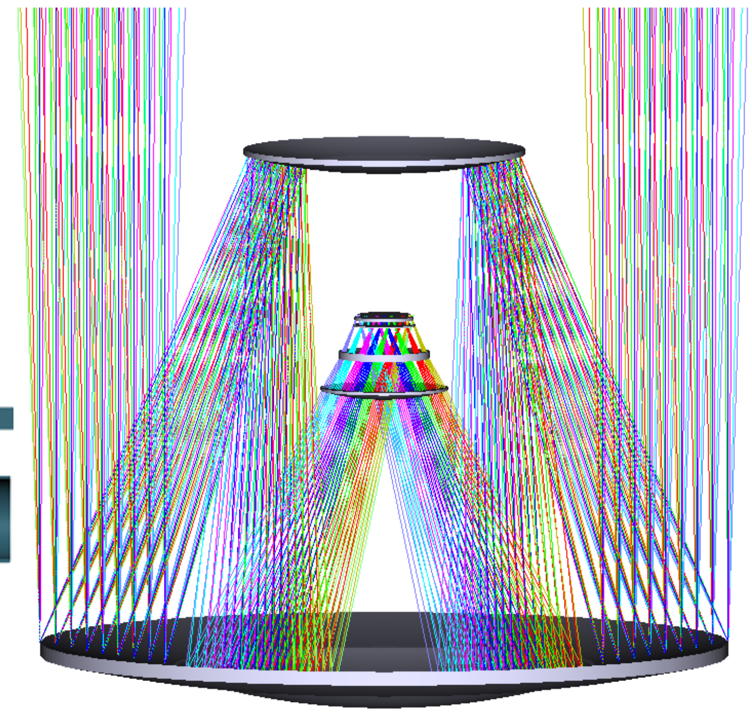
- **The LSST is an integrated survey system designed to conduct a decade-long, deep, wide, fast time-domain survey of the optical sky. It consists of an 8-meter class wide-field ground based telescope, a 3.2 Gpix camera, and an automated data processing system.**
- **Over a decade of operations the LSST 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.**

LSST : Wide , Deep and Fast (1/2)
Telescope Mount Enables Fast Slew and Settle

LSST Etendue : 319 m^2 deg^2



Modified Paul-Baker Optical Design



Moving Structure 350 tons
60 tons optical systems

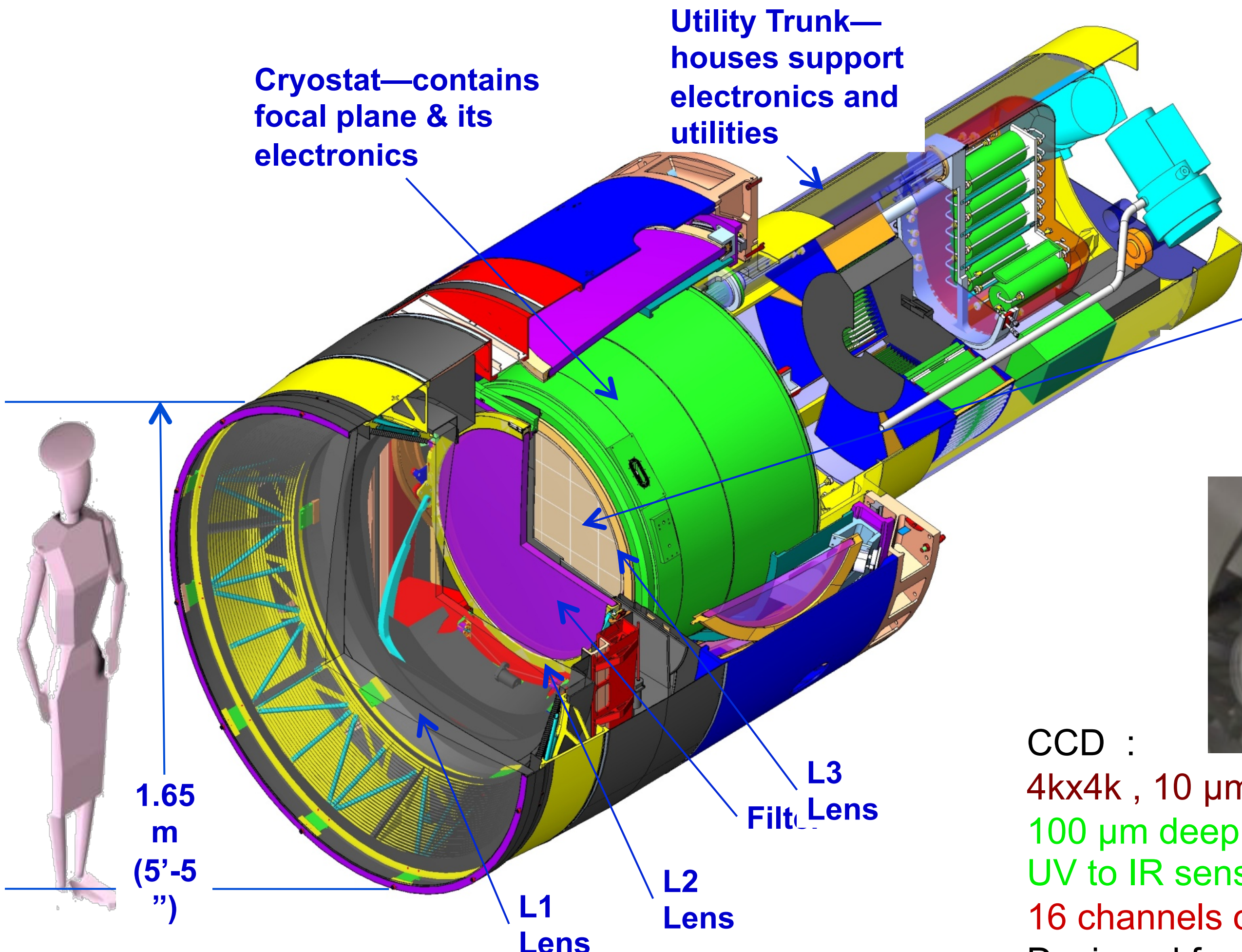
- **Points to new positions in the sky every 39 seconds**
- **Tracks during exposures and slews 3.5° to adjacent fields in ~ 4 seconds**

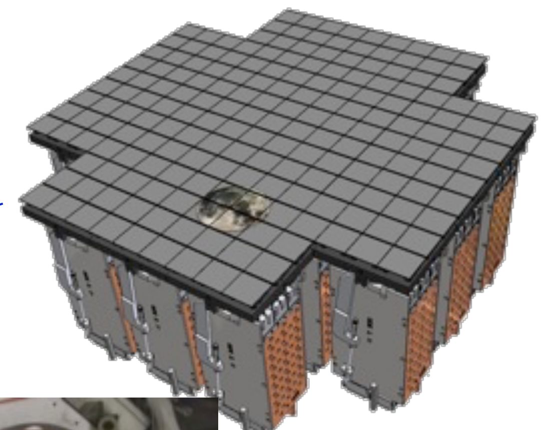
LSST : Wide , Deep and Fast (2/2)

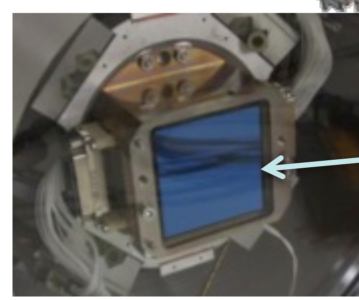
Field of view : 3.5 deg (9.6 deg^2 =.023% sky sphere)

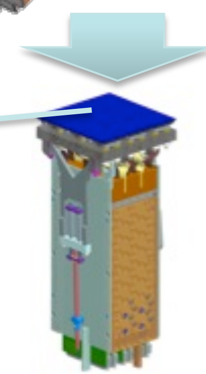
Focal plane diameter : 64 cm ; 189 science CCD (21 rafts)

3024 readout channels; >3 10^9 pixels ; Readout in 2s









CCD :
4kx4k , 10 μm pixels
100 μm deep depleted
UV to IR sensitive
16 channels output
Designed for LSST

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

LSST concept :
1 telescope + 1 instrument + 1 observation plan

6-band Survey: ugrizy   320–1070 nm

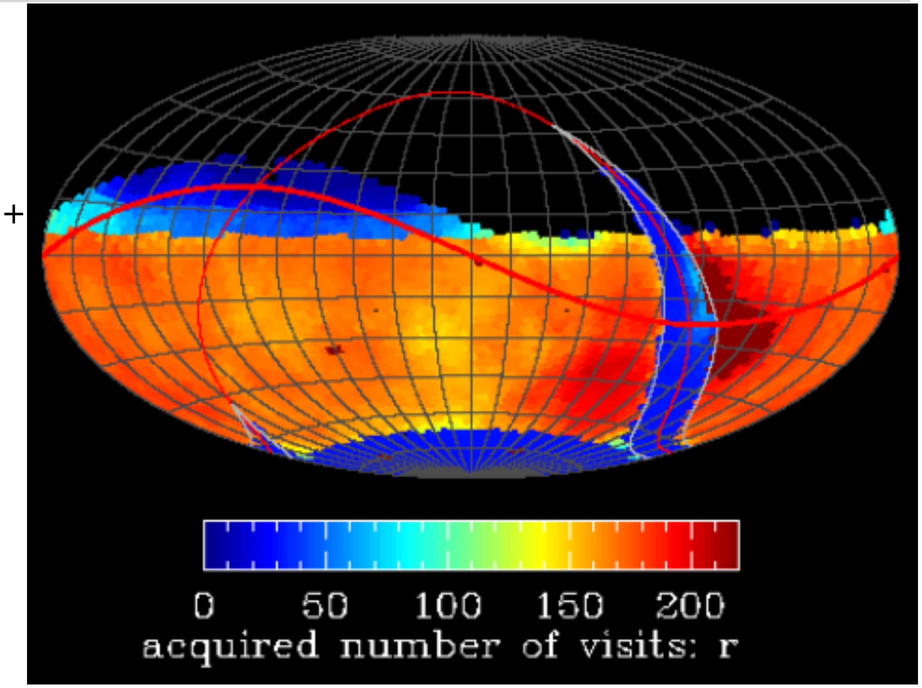
Survey(s) Area (with 0.2 arcsec / pixel) ➔
Main : at least 18,000 square degrees to an uniform depth
Other : ~10% of time ~1h/night (Very Deep + fast time domain + special regions : ecliptic, galactic plane , Magellanic clouds)

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

	u	g	r	i	z	y
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

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 10^6 visits & 5.5 x10^6 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	~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

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 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 Zeeland ,….**

LSST : Status

- **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*
  - ….

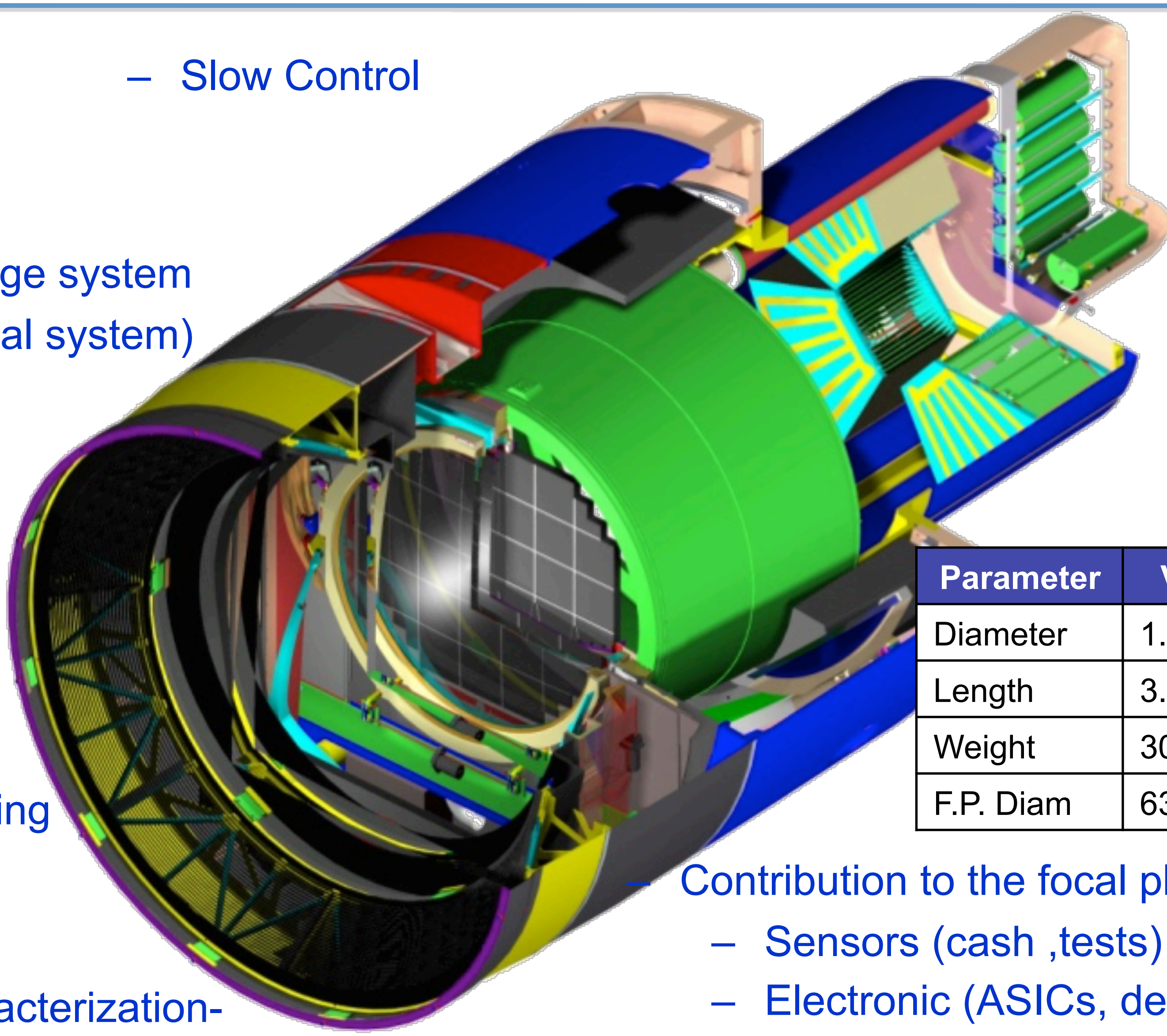
LSST @ IN2P3

- **IN2P3 (APC,LPNHE,LAL) started to work on LSST camera in late 2006**
- **Today: groups in 7 IN2P3 laboratories (APC, CPPM , LAL , LPNHE , LPC, LPSC, LUPM) and CCIN2P3 & LMA contribute to LSST**
- **LSST team at IN2P3 counts ~ 100 active people :**
  - 12 FTE for 34 active scientists (47 IN2P3 scientists signed for LSST)
  - 26 FTE for 57 engineers and technical staff (Computer center excluded)
  - 5 FTE for 6 PostDoc+PhD+temporary contracts
- **Its dominated by 31 FTE on the camera construction (peak this year)**
- **Ramping contribution on the preparation of the Dark Energy science . (~ 5 FTE , related to calibration , CCD signature removal, photo-z , supernovae , BAO)**
- **IN2P3-LSST agreement signed**
  - **On the contribution to the LSST camera construction**
  - **On the contribution to 50% of the data processing (and CC-IN2P3 will host the full LSST data set)**

LSST Camera @ IN2P3

– Slow Control

– Full Filter Exchange system (robotic mechanical system)



Parameter	Value
Diameter	1.65 m
Length	3.7 m
Weight	3000 kg
F.P. Diam	634 mm

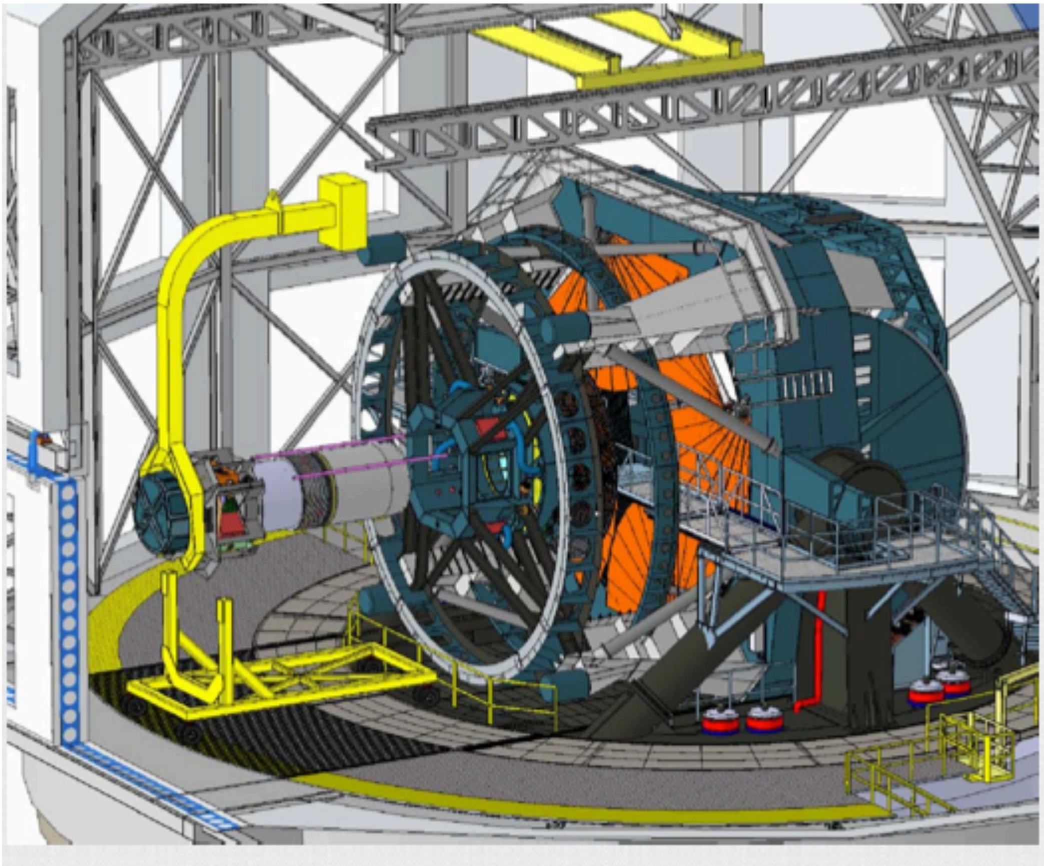
– Filter/optics (coating expertise & characterization)

– Stand alone characterization-illumination system (CCOB)

– Contribution to the focal plane :
  – Sensors (cash ,tests)
  – Electronic (ASICs, design)
  – “Brain” (FPGA)

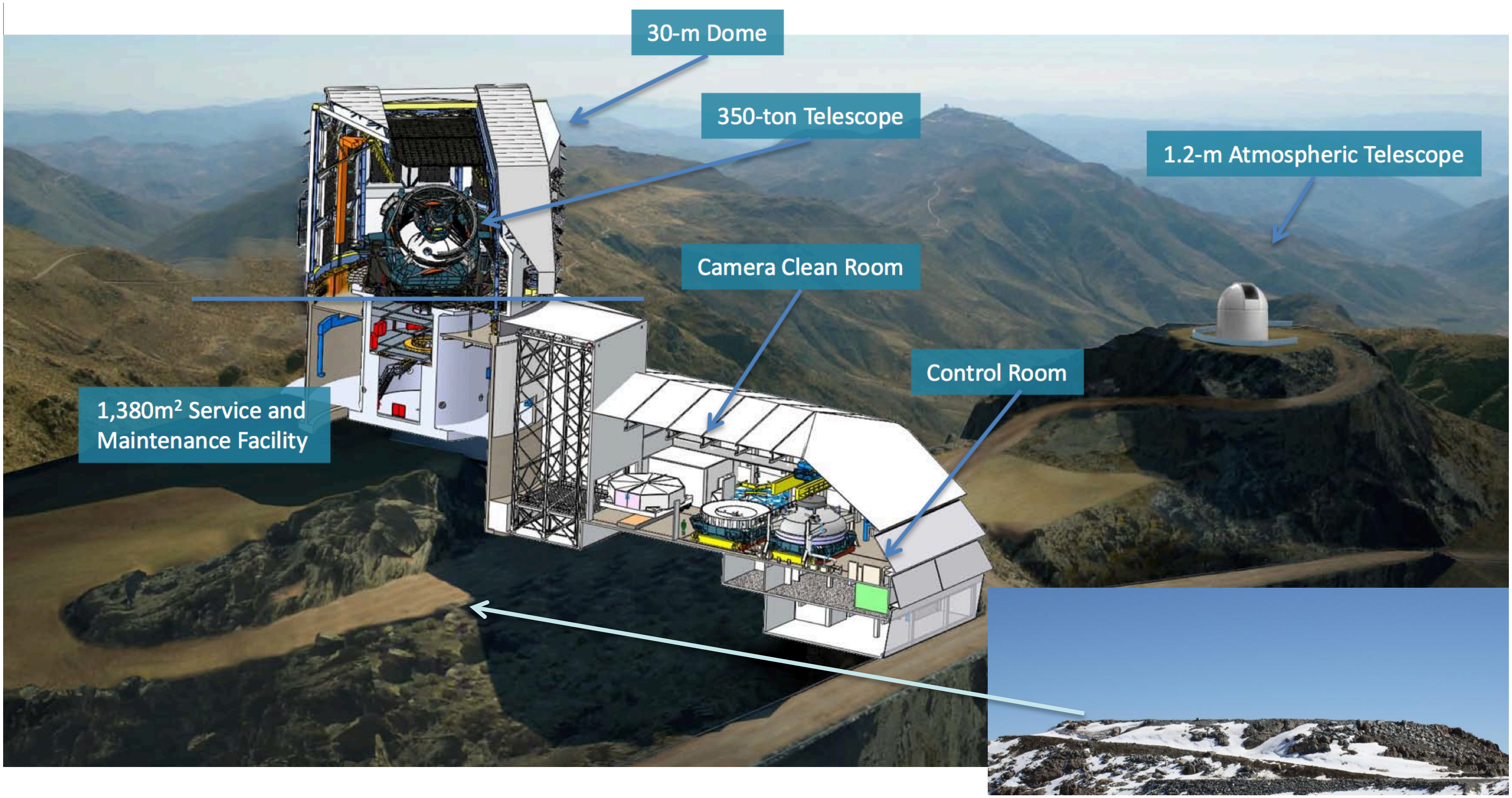
LSST Calendar

- **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**



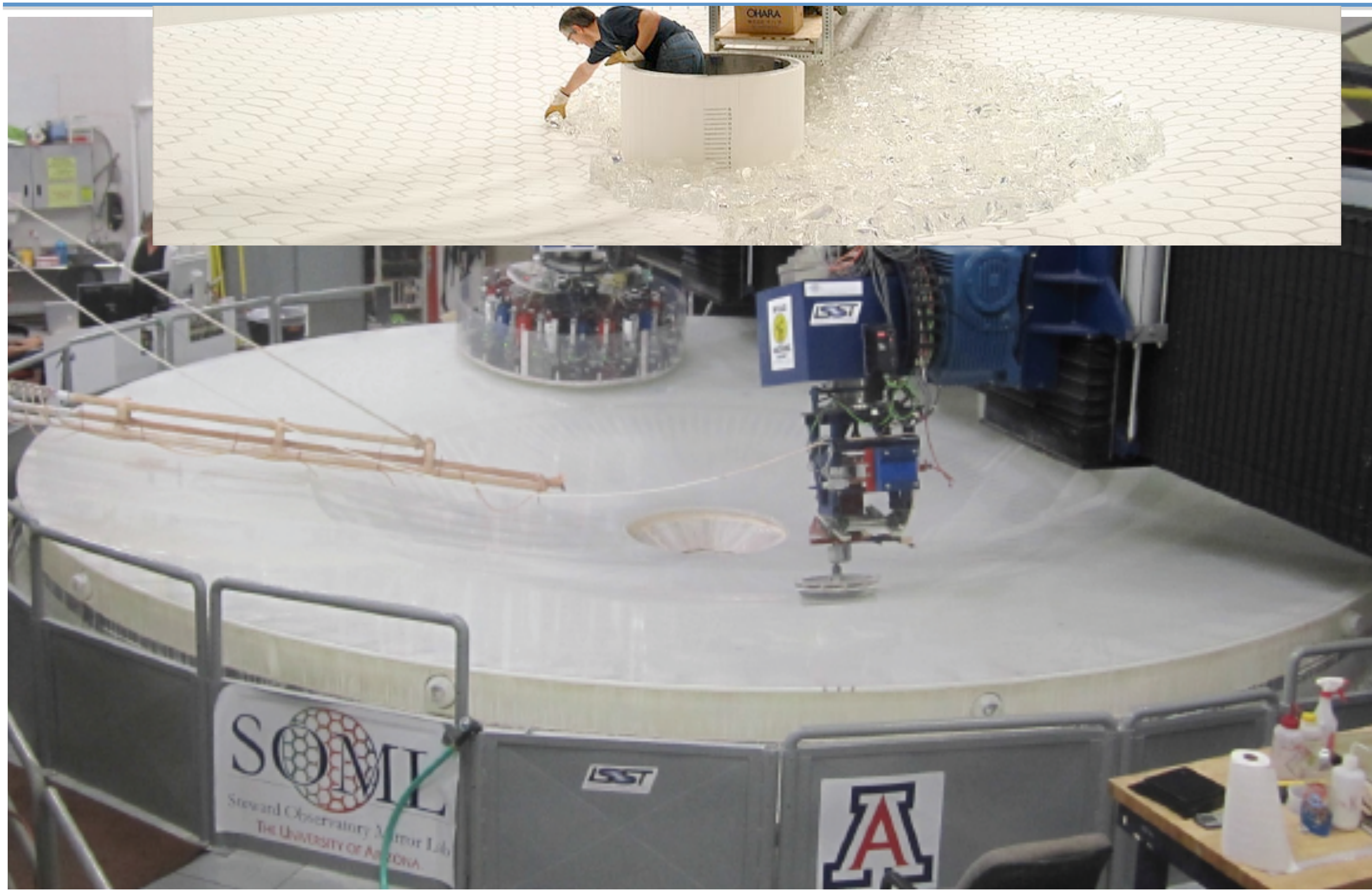
LSST Will be Sited in Central Chile on El Peñón peak of Cerro Pachón at 2682m

LSST site



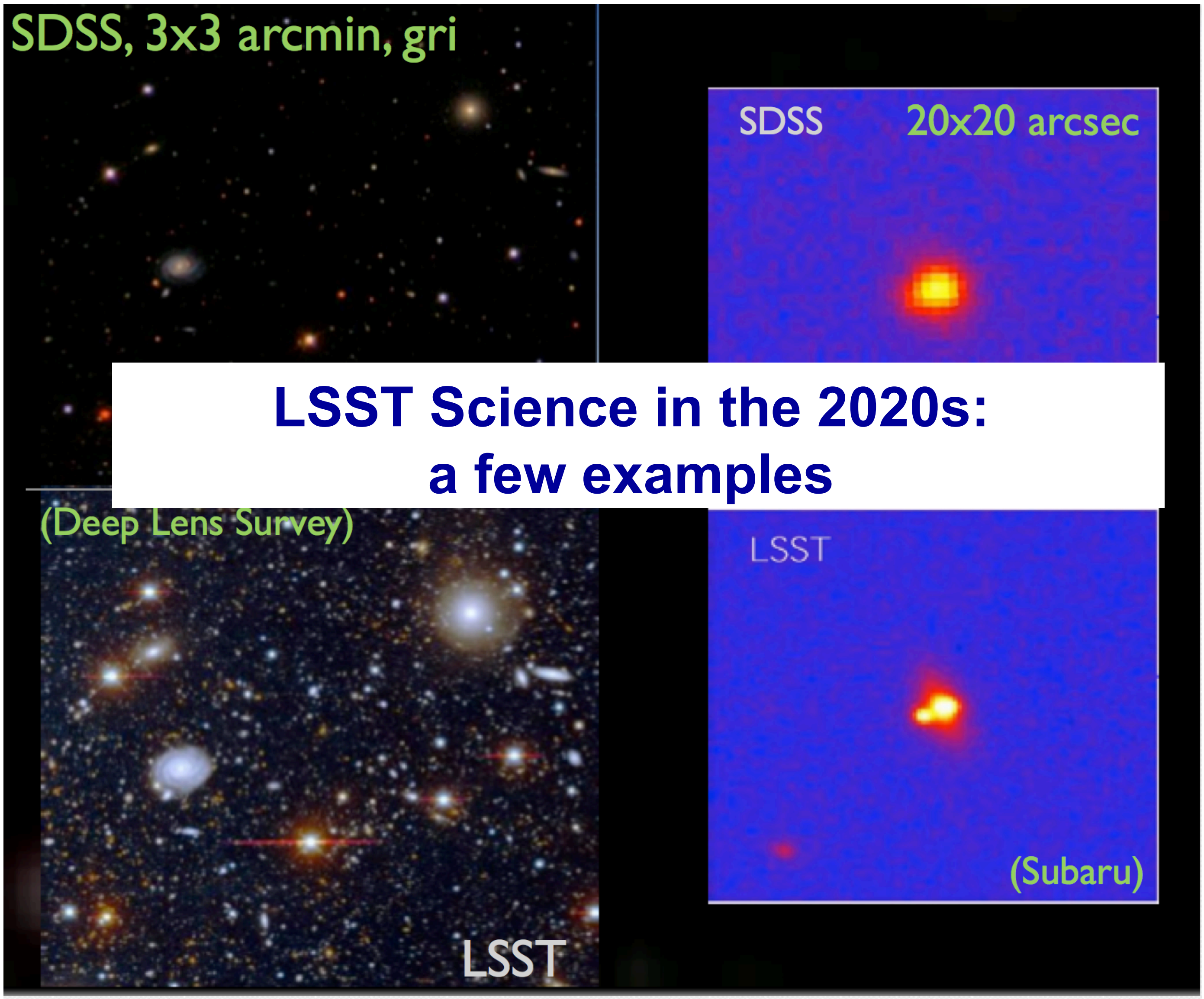
After ~4,000 kg of explosives and ~12,500 m^3 of rock removal, Stage I of the El Peñón summit leveling is completed. Building construction is now underway .

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



LSST
Large Synoptic Survey Telescope

LSST Science in the 2020s: a few examples



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

- 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.


Dark Energy & Dark Matter

ΛCDM / Dark Energy/Matter : Evidence

- Ω_{Λ} :
  - things are very far away (very small and faint)
    Ia Supernovae , CMB and BAO acoustic peaks
  - older stars … are really old
  - $\Rightarrow$ accelerated expansion $\Rightarrow$ Dark energy

- ($\Omega_{baryons}$, Ω_{CDM}) : observed inhomogeneities of a primordial photon-baryon fluid moving in a passive CDM gravitational potential.
  - CMB anisotropies , BAO
  - but also :
    - Elemental abundances (hydrogen, deuterium, helium) require low baryon density
    - Galaxies and clusters not made of normal baryons
      microlensing (compact objects) x-ray emission (hot gas)
      Galaxies rotation vs radius (Massive dark halo)

- The universe content today in these 3 components is measured at better than 1% (relatif) for each of them.

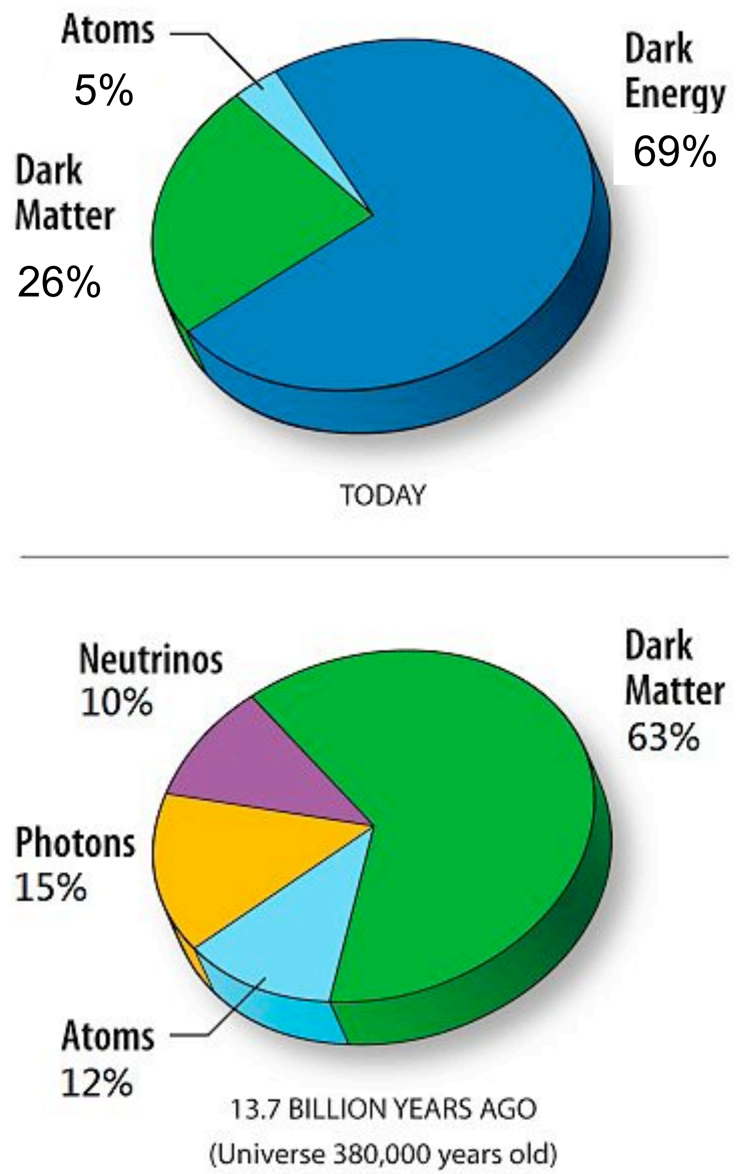
Dark Matter & Energie : Universe content

Concordance model :

- **Universe is (~) flat**

- **Matter density** (density ~ R^{-3}) **is 31 % of the total , including only 5% of baryon and 26% of Dark Matter , about which we don't know much**

- **And ~69 % of « Dark Energy »** (density ~ $R^{\sim 0}$) **, about wich we know even less…**



Baryonic Acoustic Oscillation : Basics

•Sound waves that propagate in the opaque early universe imprint a characteristic scale in the clustering of matter, providing a “standard ruler” whose length can be computed using straightforward physics and parameters that are tightly constrained by CMB observations.

•Measuring the angle subtended by this scale determines a distance to that redshift and constrains the expansion rate

•CMB fluctuation are the order of 10^{-5}, fluctuations in the galaxies correlation are the order of 1%

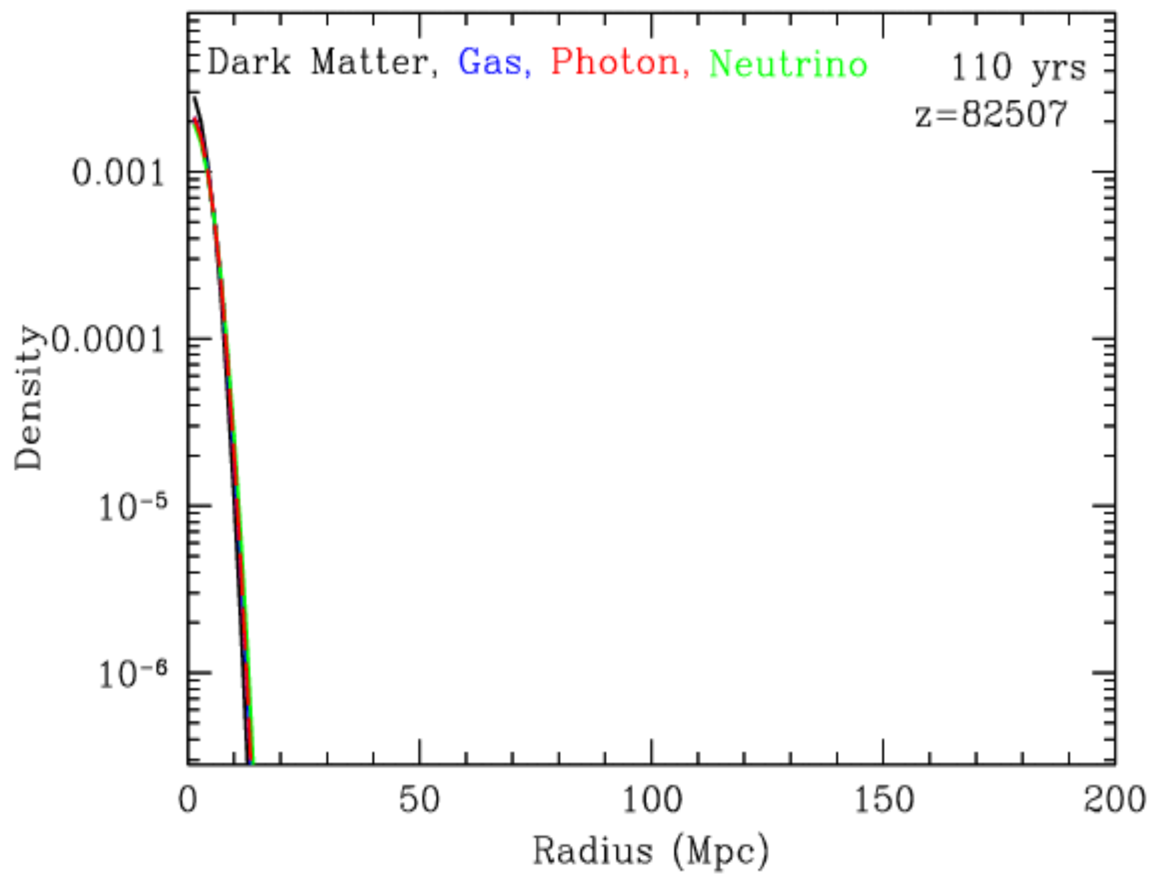
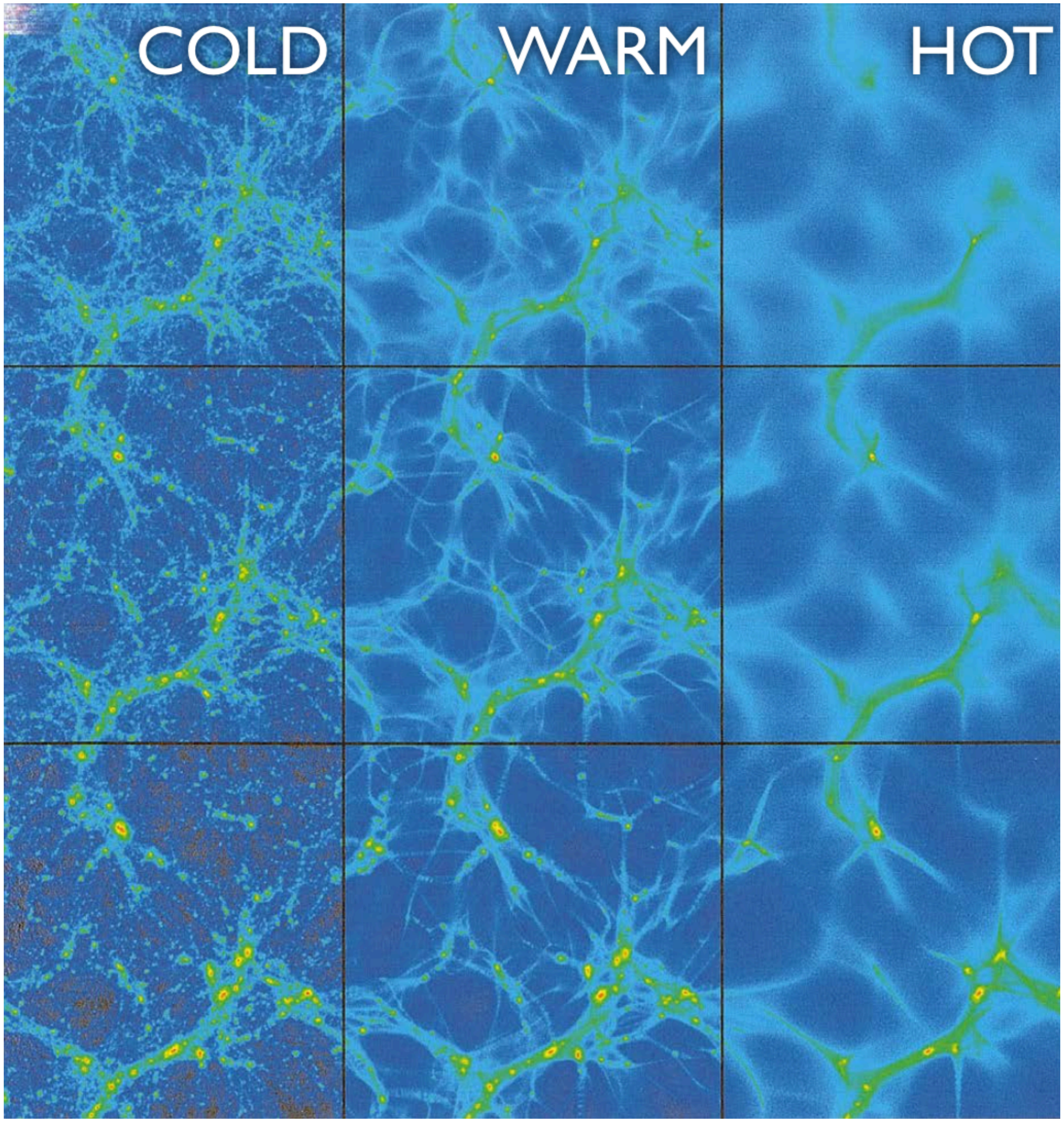


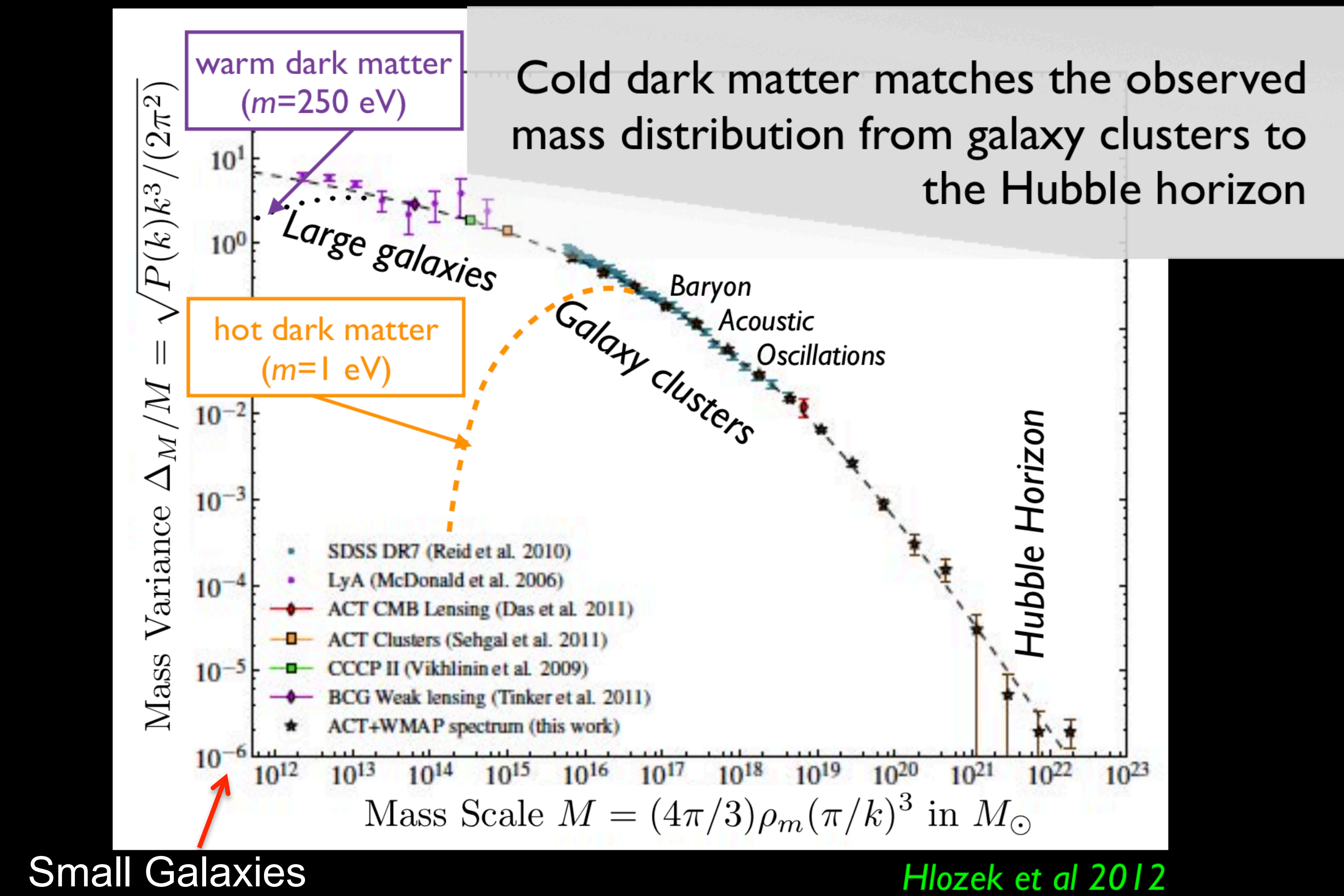
Fig. from Einsenstein

Structure formation and evolution : DM footprint



Bode et al. 2001

From CMB fluctuations to galaxies



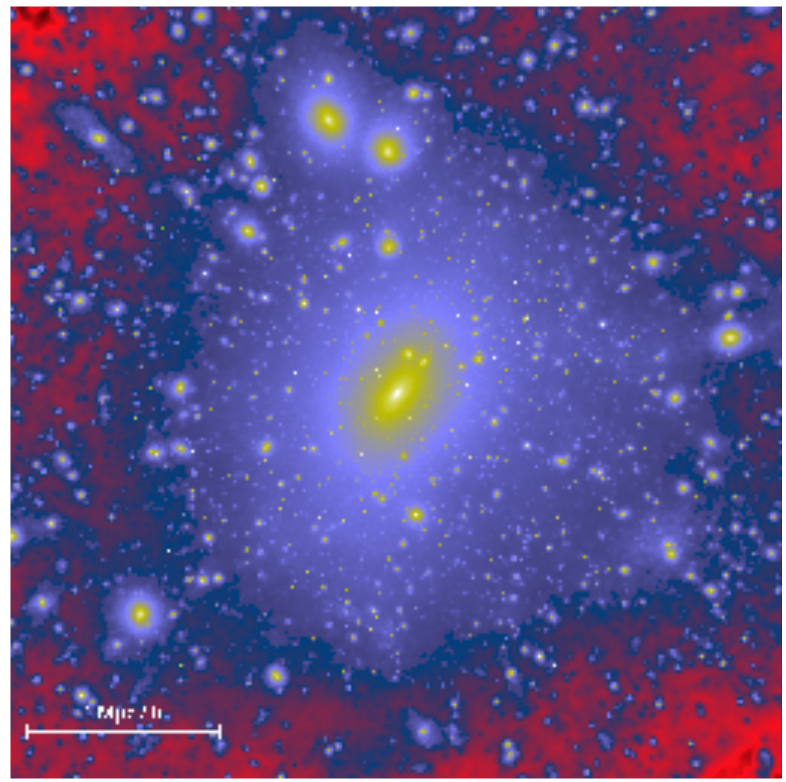
Hlozek et al 2012

Problems of the standard Λ-CDM model

➔Prediction of cusps in galaxy center, which are in particular absent in dw-Irr, dominated by dark matter
(Observed density profiles in dwarf galaxies are shallower than predicted with DM only)

➔Low angular momentum of baryons, and as a consequence formation of much too small galaxy disks

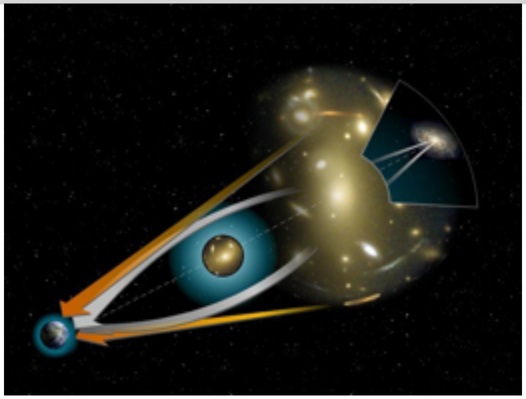
➔ Prediction of a large number of small halos, not observed



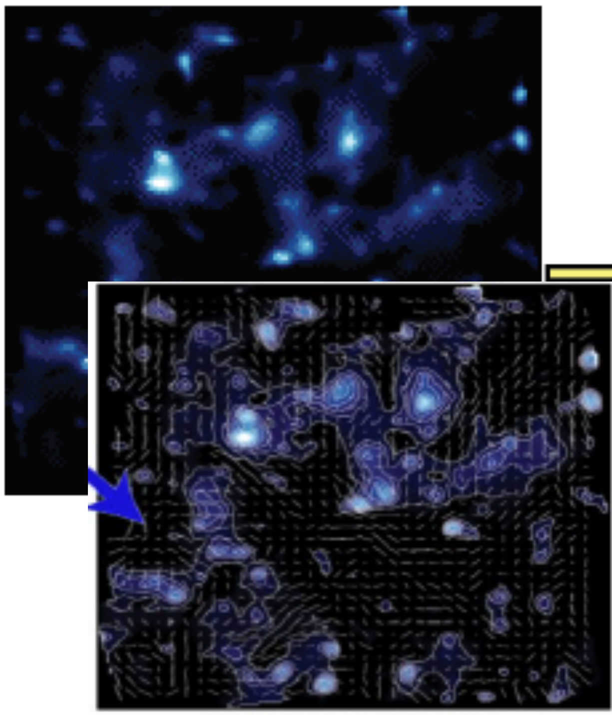
The solution to all these problems could come from some baryonic physics (SF, feedback?), or lack of spatial resolution in simulations, or wrong nature of dark matter?

Slide : Françoise Combes

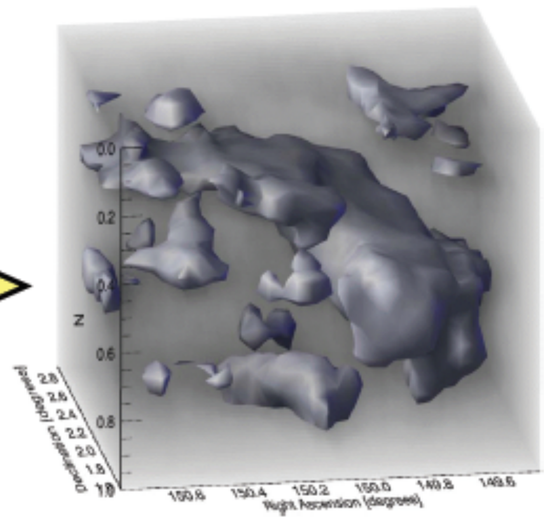
LSST (Euclid , DES , HSC), the main observable : Dark Matter and Lensing Tomography

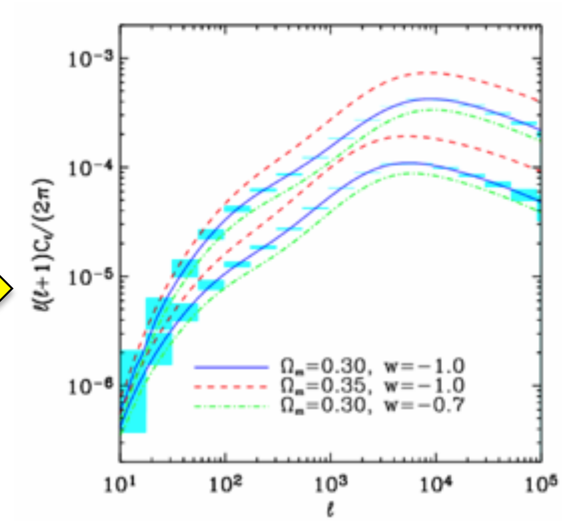


Density fluctuations in the universe affect the propagation of light rays, leading to correlations in the shapes of neighboring galaxies.



Dark matter distribution





Statistic of shape correlations can directly map the **dark matter** in 3D

Weak lensing is sensitive to

-The expansion of Universe with z - H(z)

- The grow of structure with z - G(z)

The way these structure grow with cosmic time depend of **dark energy.**

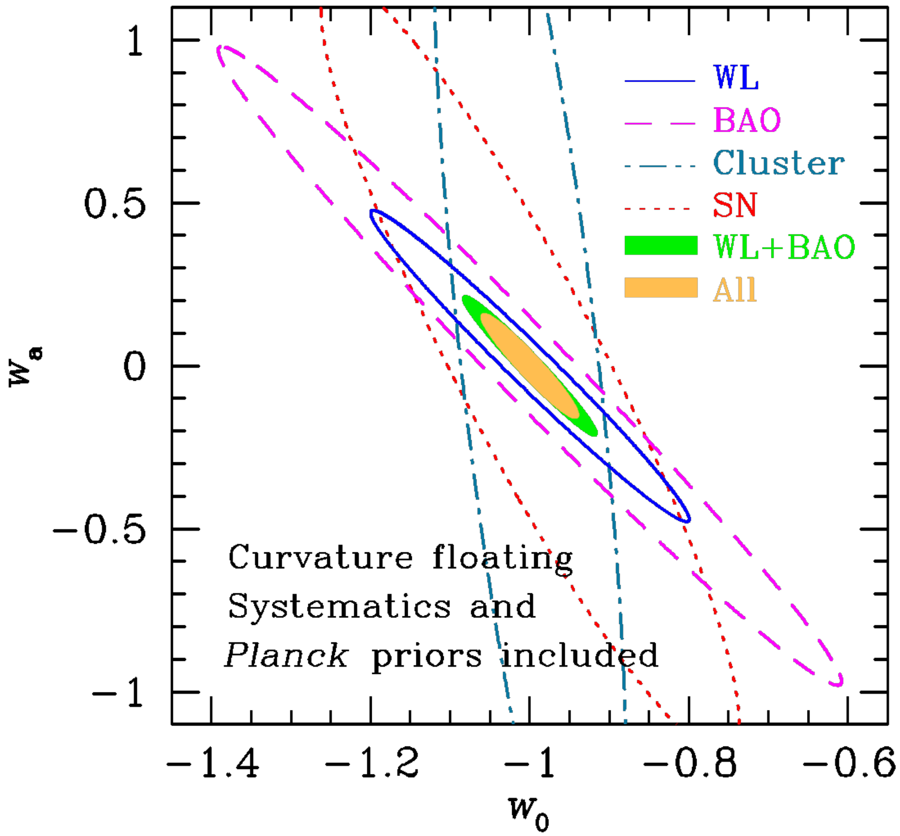
This is a powerful observable to constrain DE , modified gravity…

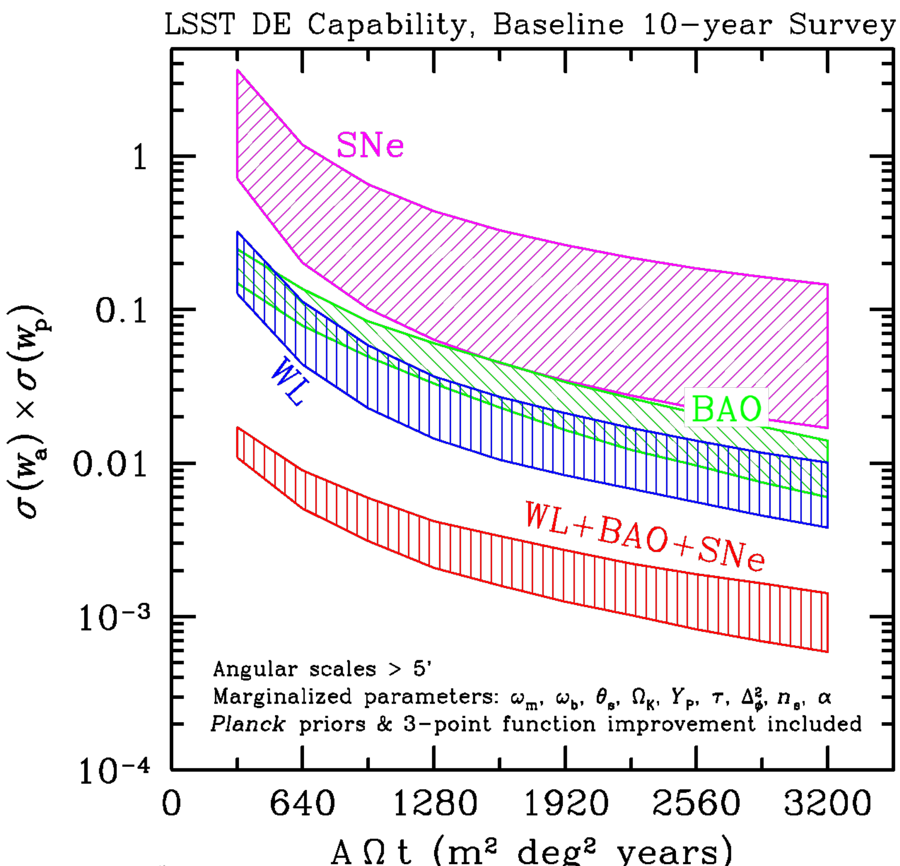
LSST: Stage IV Dark Energy Experiment

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 plane.





Dark Energy : A theoretical point of view ????

- Cosmological Constant (the « standard » in Einstein equation)
  - But can we ignore all the rest of the XX century ? : Vacuum Energy

- anthropic principle
  - When a theoretical physicist is stuck … some amount of « anthropic principle » … and he can run again ….

- Modified General relativity , extra dimension …
  - Each time you touch the General Relativity … remember to check the fuse…

- Back Reaction (no new physics) : Structure Formation induces an apparent mean acceleration (non uniform density)
  - That was the hot topic 5 years ago … today it's excluded as dominant effect.

- Quintessence
  - The good old scalar field , « tape » of theoretical physics to « fix » a problem ,… have you ever seen such scalar ??? Damned yes , we just got the Higgs !!!

Dark Energy – Dark Matter LSST Science Drivers

- **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 (~ 100 per color) for reduction and characterization of image systematics
  - Faint co-added limiting magnitude (r ~ 27.5) for sufficient galaxy surface density (~ 30-50/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)


Galaxiesssss

Galaxies

- 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^2
- The database will include photometry for 10^{10} galaxies from the Local Group to z > 6.
- LSST will have 6-band photometry for 4 x 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 Sutides :
  - 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
  - ===> all of these will help to better understand Dark Matter properties.

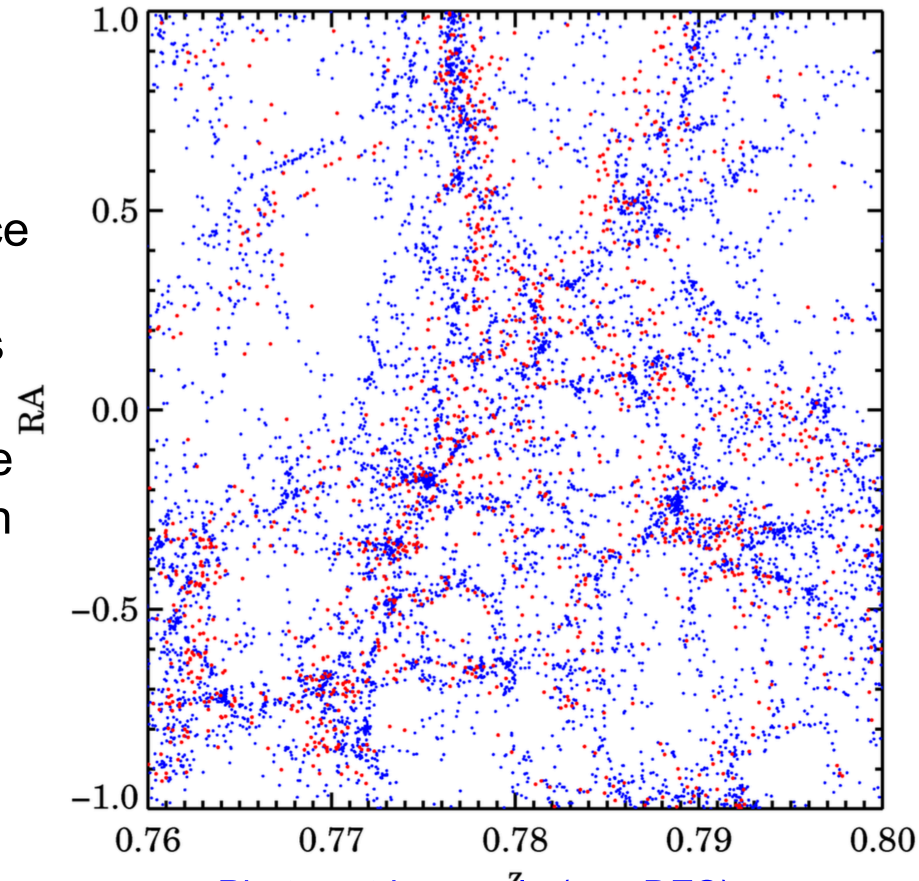
Photo-z calibration : cross-correlation option

- 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-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

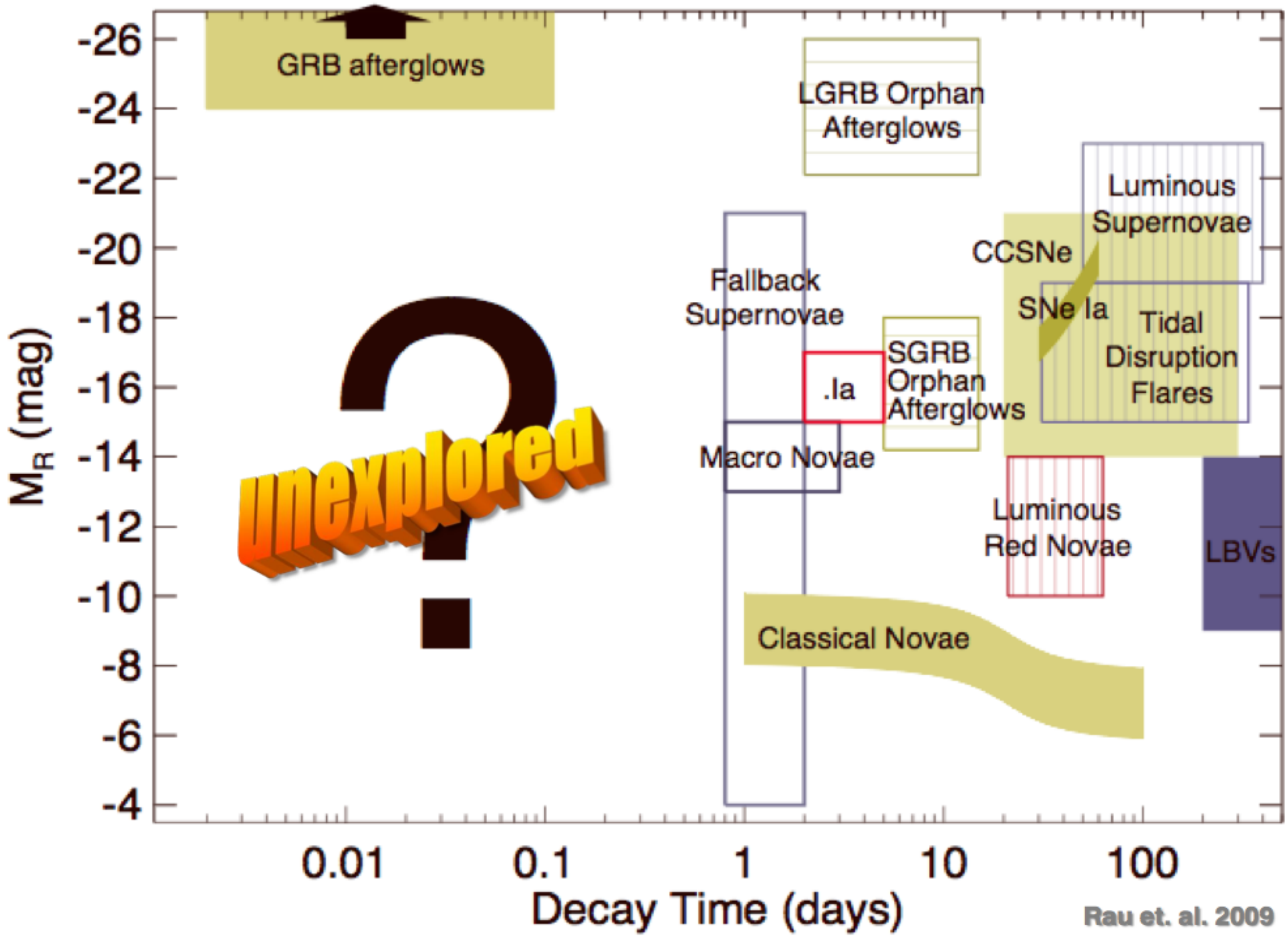
A few tens of thousands of spectra per unit *z* are required to calibrate LSST
More : J.Newman et al. http://arxiv.org/abs/1309.5384



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


LSST
Transientsss

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.**
- **Information from LSST database (object environment , light curve, colors …) will be a key to classify these alerts and trigger photometric/ spectroscopic follow-up**

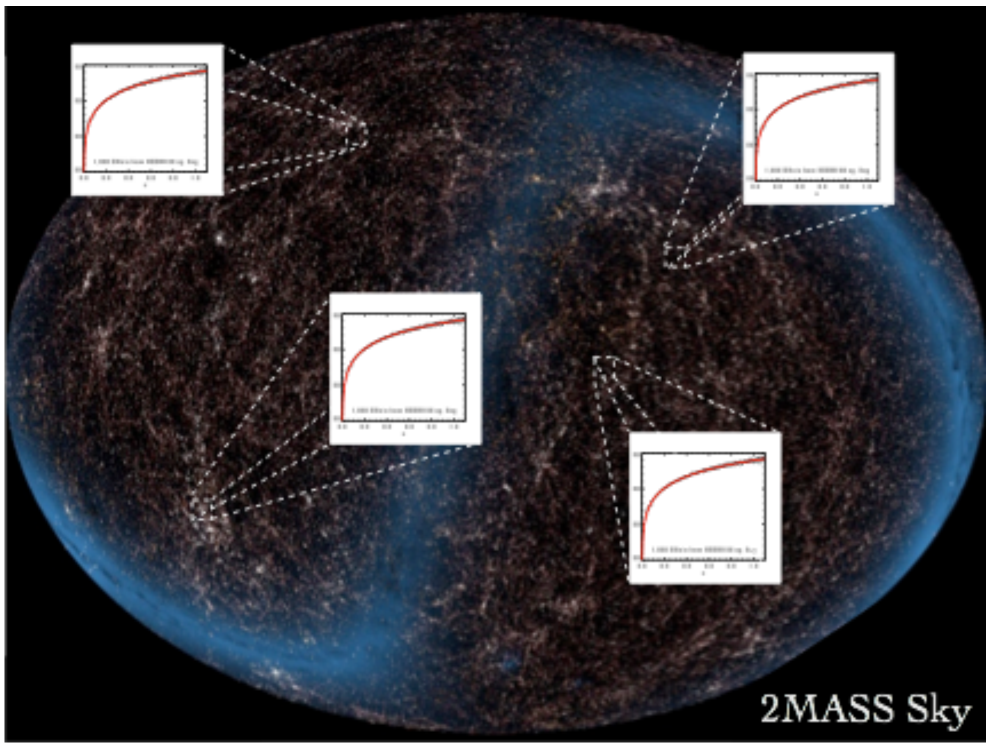
PTF (today) & LSST (~2022) rates for supernovae (Rau et al. (2009))

Class	M_v [mag]	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 & Optical Transients : an unique way to probe/survey the universe

Hubble diagram for # directions :

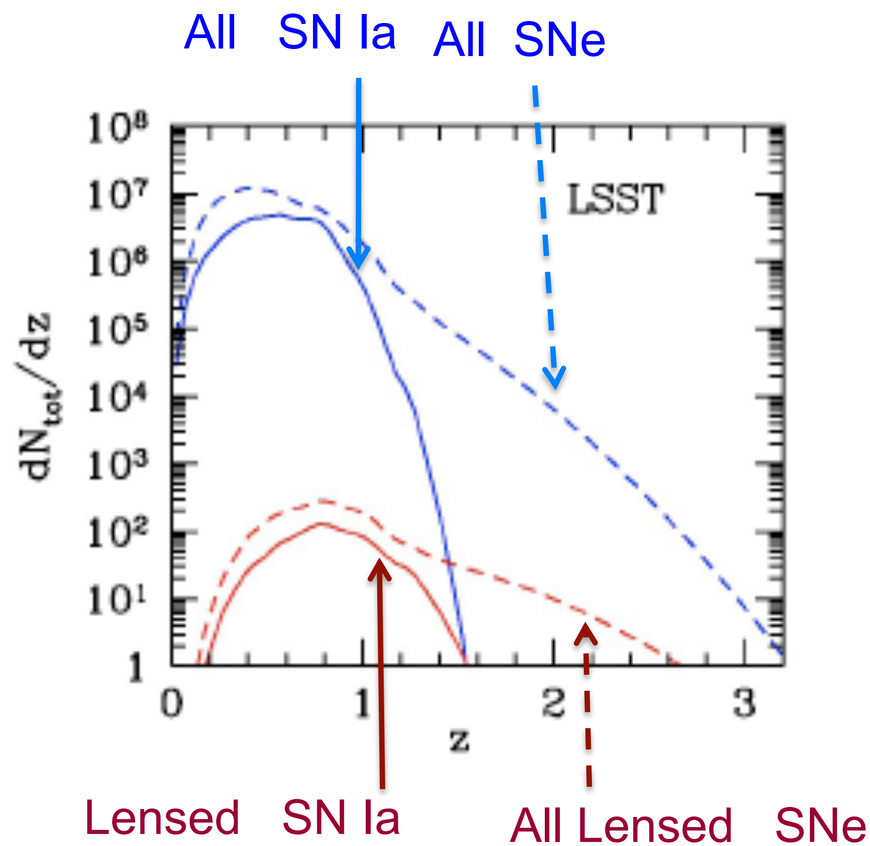
LSST will be able to probe the isotropy of the Dark Energy properties . For example the large SNIa statistic will allow to build SNIa hubble diagram for different directions in the sky.

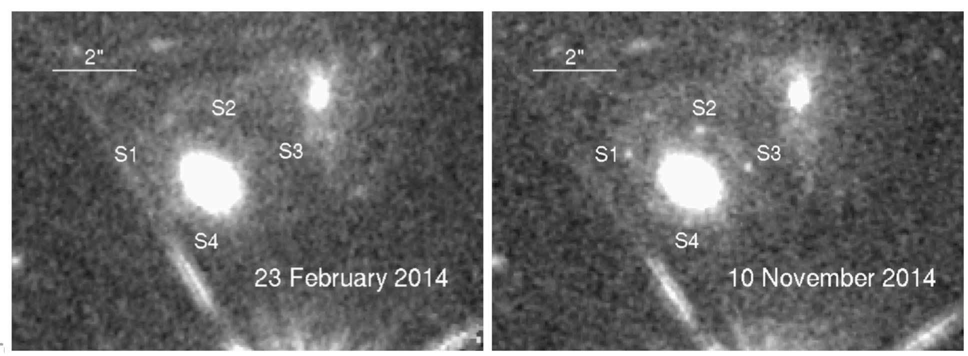


Strong Lensing

- **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



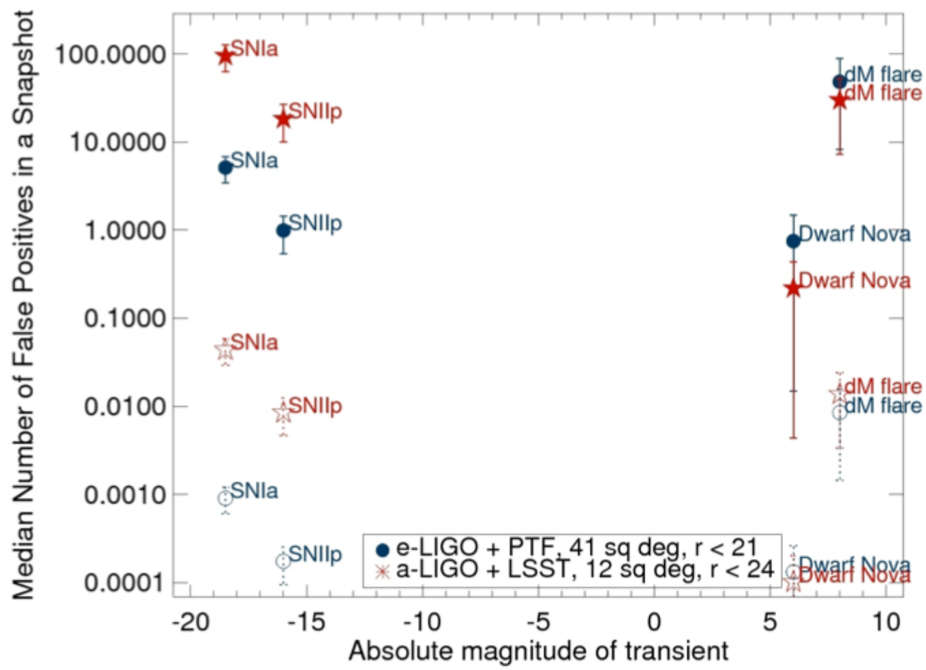


LSST & Gravitational Wave

•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):

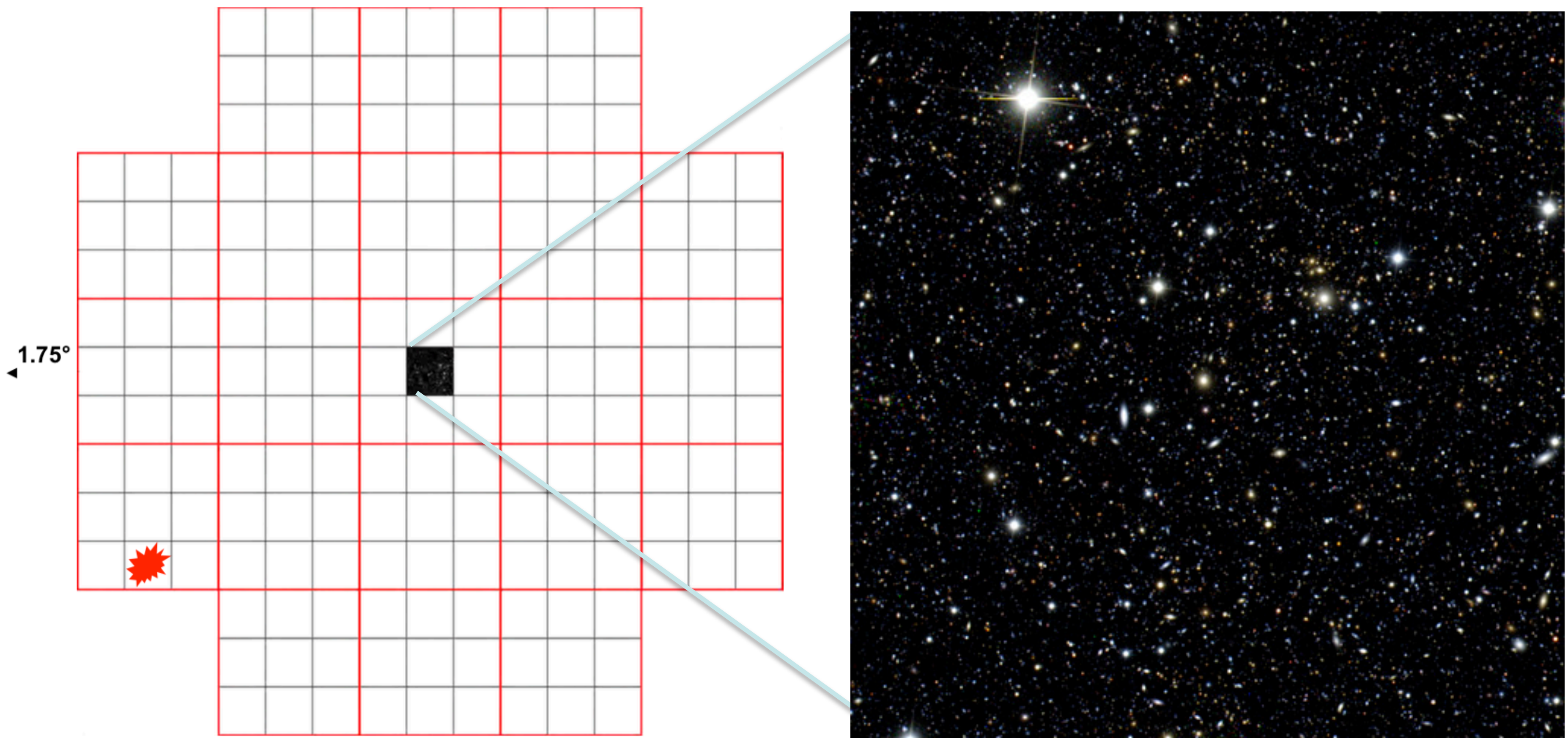
- today e-LIGO/Virgo needs at least a 1-m class telescope for follow-up (going to m < 21, or 50Mpc, PTF like)
- and soon a-LIGO/Virgo will need an 6/8-m class telescope (m < 24, 200Mpc, LSST Like)..

< 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



LSST & Gravitational Wave

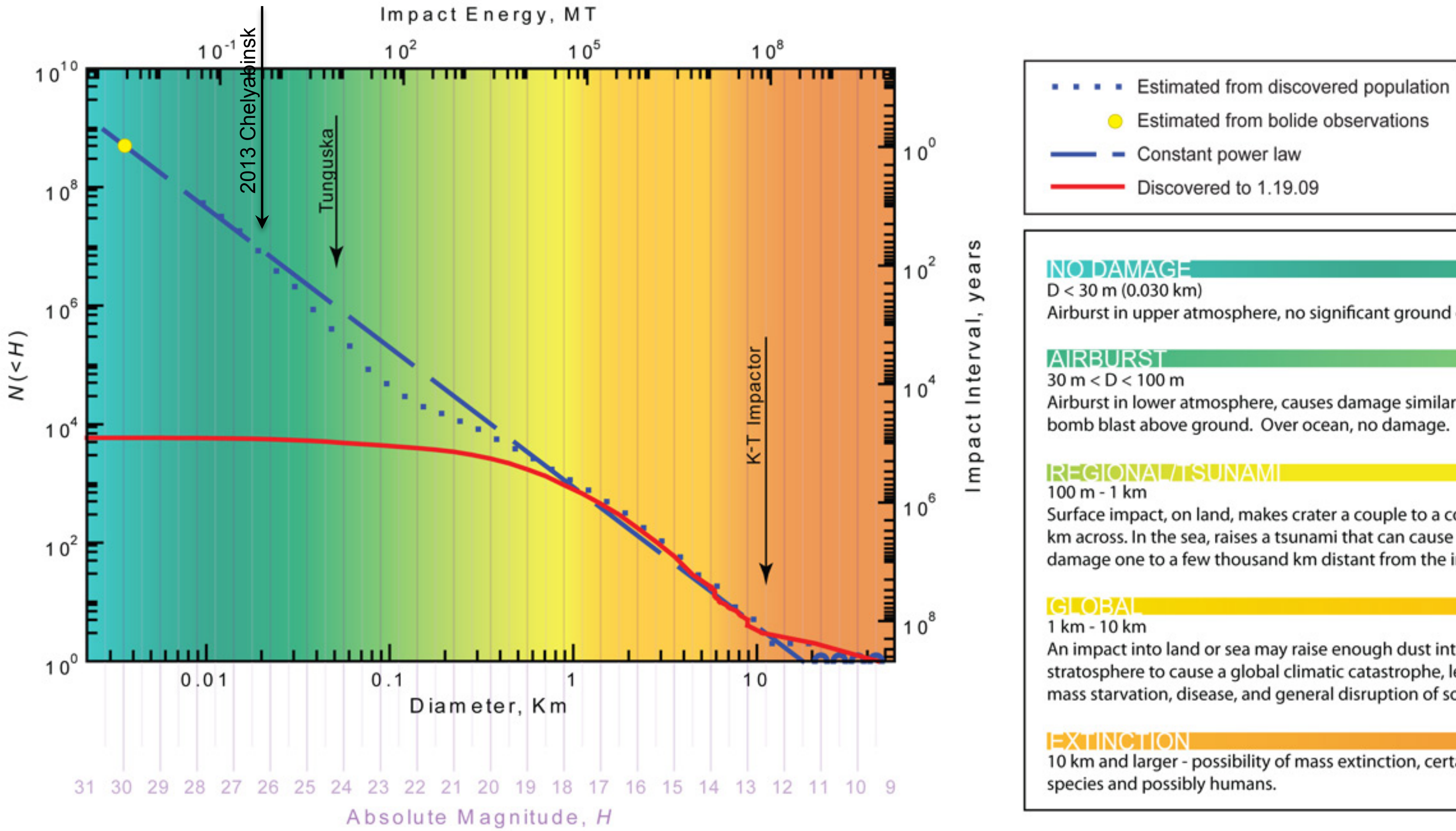
The positional uncertainty of a-LIGO-Virgo GW alerts is commensurate with the LSST field of view, 1.75° in radius, making LSST an optimal localization resource for GW alerts.



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

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



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

Conclusion : LSST is …almost there.

- 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