LSST

Large Synoptic Survey Telescope

Téléscope grand champ
Etude de l'Energie Noire

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LPNHE PARIS

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Large Synoptic Survey Telescope

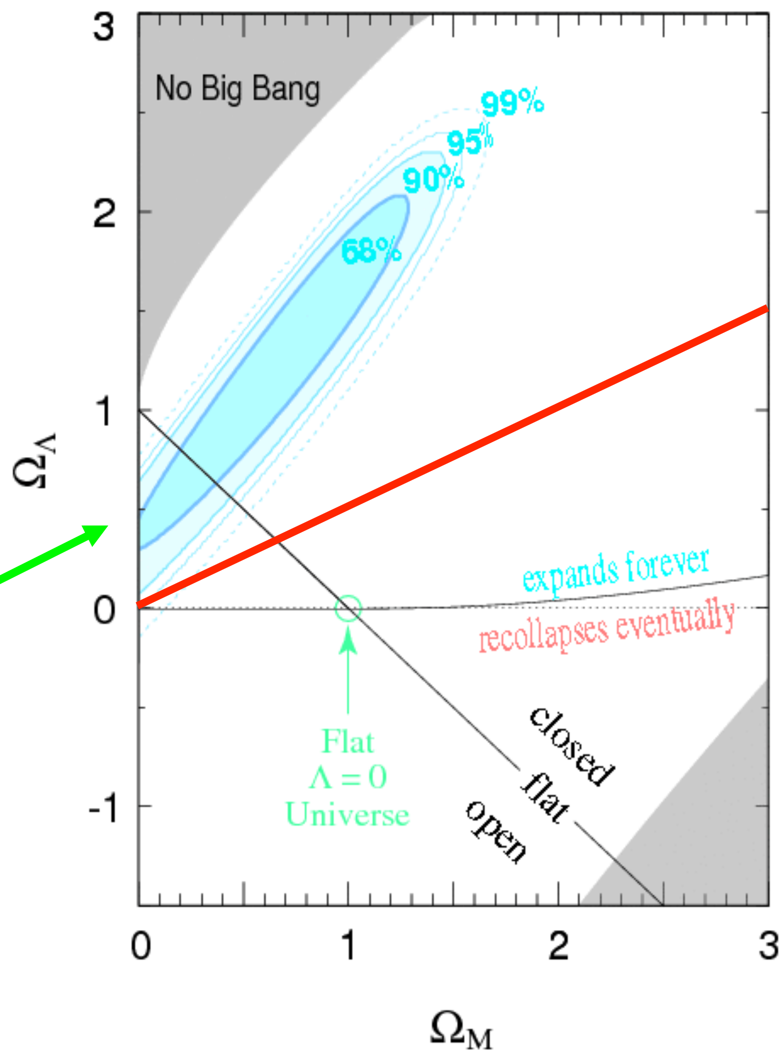
Dark Energy news

Energie Noire : 1998-2011 … 13 ans et toujours là

- « The Accelerating Universe »
- Breakthrough of the year

(Perlmutter et al 1999)

En 1998 , 2 groupes ont observés que les SuperNovae distantes (z~0.5) sont moins brillantes qu'attendu dans un modèle d'univers dominé par la maitère



Contour de confiance assumant que le « quelque chose en plus » est une constante cosmologique

Energie Noire Observations (1/4) :
SuperNovae de Type Ia

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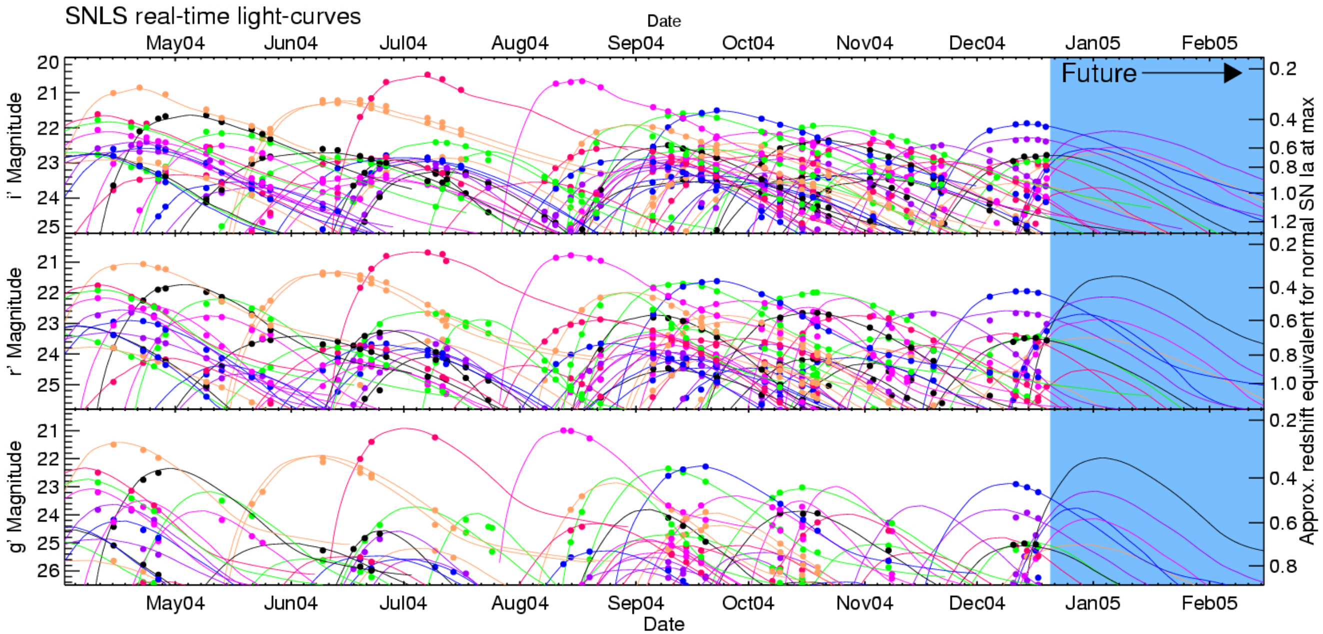
•SNLS : 2003 - 2008 au CFHT (Recherche+Photométrie)
+ VLT+Gemini+Keck (Spectro)

•Mode observatoire du CFHTLS/Deep :

- 40 nuits par an pour 5 ans
- Observation répété , toutes les 4 nuits (« rolling search »)
- 4 bandes (g,r,i,z)
- 4 deg ^{2} observés , chacun suivi 6 mois par an

Progrès : instrument « dédié » , données disponibles avant même de détecter l'objet , multiplexage , calibration répétée par les étoiles du champ.

==> En 1 an de prise de donnée (papier des données 2004) , le projet à obtenu l'équivalent de la statistique mondiale collecté depuis 1994



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Energie Noire Observations (2/4) :
2 méthodes pour extraire l'Energie Noire

- **Méthode 1 : la mesure directe**

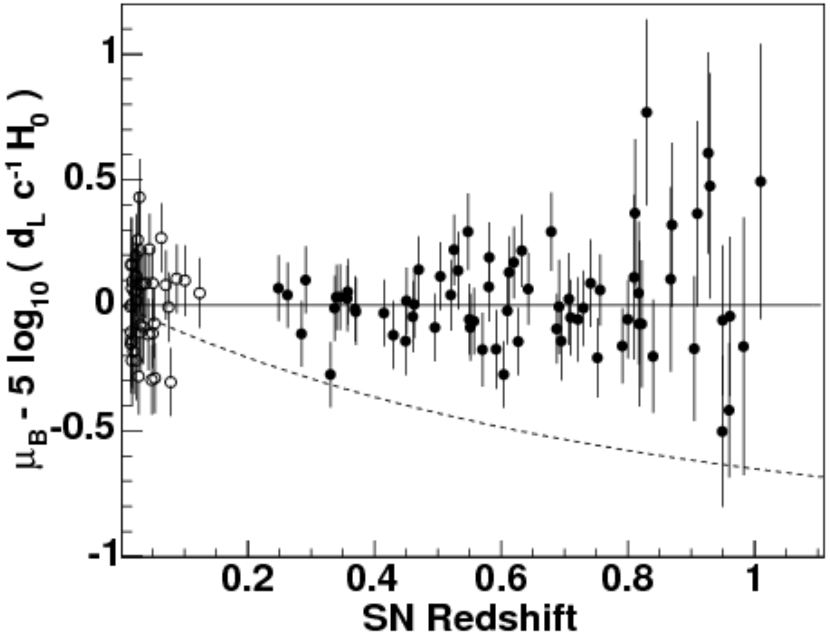
- **Example : le diagrame de Hubble des SN Ia**
- $\Omega_X \sim= 0.75$

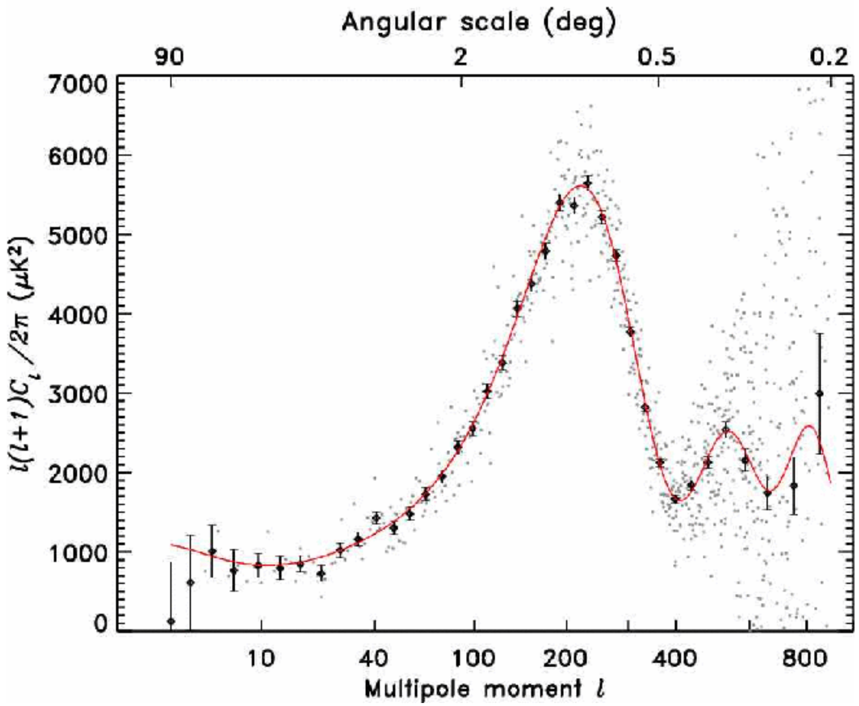
Méthode 2 : la soustraction

$\Omega_{tot} \sim= 1$ (CMB. + e.g. H_0)

– $\Omega_M \sim= 0.25$ (CMB. + flatness or BAO or ...)

$\Omega_X \sim= 0.75$



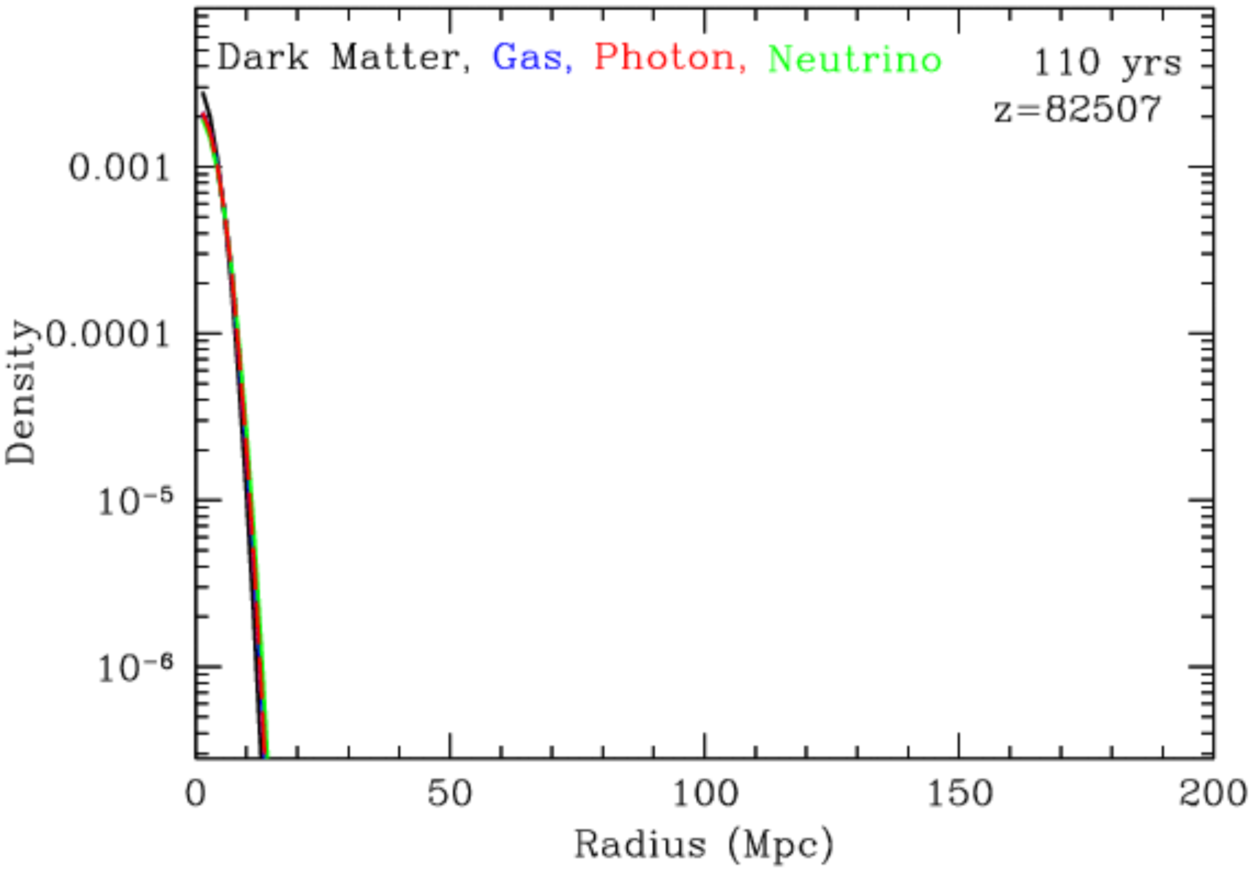


Energie Noire Observations (3/4) : Oscillations Baryoniques

-Avant la recombinaison des ondes sonores se propagent dans l'univers.

-Ces ondes sonores sont vues dans le CMB, mesurer les oscillations baryoniques revient à rechercher les même ondes à partir de corrélation entre les galaxies

-Les fluctuations typiques du CMB sont de l'ordre de 10^{-5}, les fluctuations sont de l'ordre de 1% dans la corrélation entre galaxies.



Material from D. Eisenstein (et al).

La question aujourd'hui :
Nature de l'Energie Noire ?

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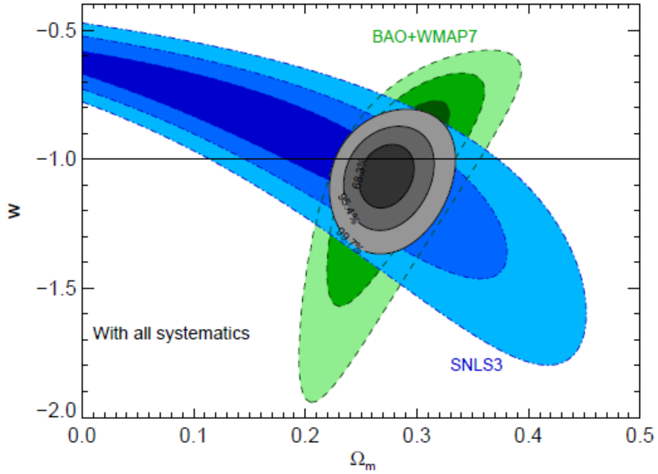
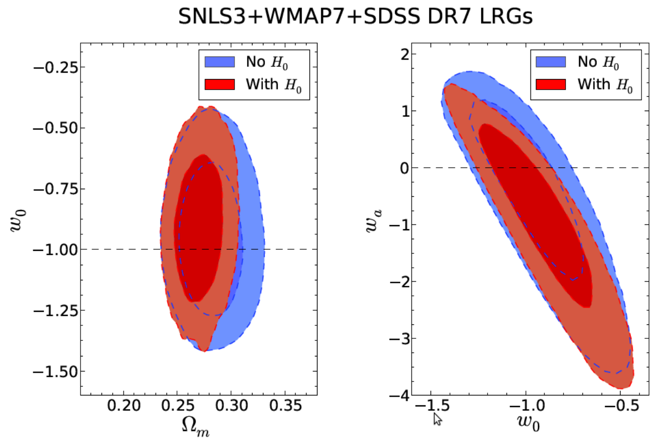
Par « Nature » de l'Energie Noire on veut dire
« L'équation d'état » w ou comment l'Energie Noire
réagie à l'expansion :
$P_x = w\rho_x$ ou autrement dit $\rho_x \sim R^{-3(1+w)}$

Type	w
Matter	0
Radiation	1/3
Cosmological cst	-1
Static scalar field	-1
Cosmic strings	-1/3
Domain walls	-2/3
"Quintessence"	<~-0.8
"Phantom energy"	<-1



$W = -1.068\ ^{+0.080}_{-0.082}$ (stat+sys)



$\Omega m = 0.271 + 0.015 - 0.015$
$w0 = -0.905 + 0.196 - 0.196$
$Wa = -0.984 + 1.094 - 1.097$

Energie Noire Observations (4/4) : Weak Lensing

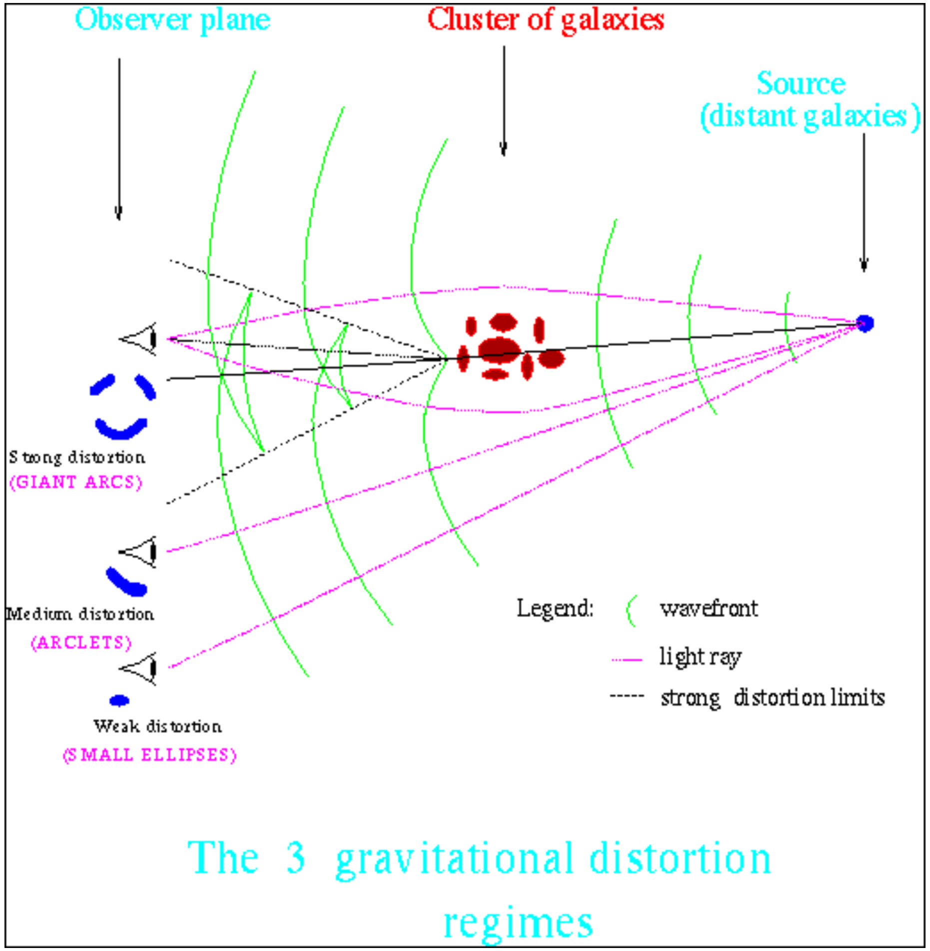
-Le terme « Cosmic Shear » correspond aux distorsions corrélées des galaxies de fonds par l'effet de lentille gravitationnelle faible induit par la masse présente sur la ligne de visée.

-La lumière d'une galaxie de « fond » traverse le milieu intergalactique et est déviée par le potentiel gravitationnel des structures rencontrées. L'image d'une galaxie donnée est à la fois déplacée et distordue.

-L'effet de distorsion est détectable seulement de façon statistique. L'élongation de galaxies voisines est corrélée, car leur lumière a suivi un chemin similaire avant de nous parvenir. En pratique une fonction de corrélation à deux points en fonction d'une échelle angulaire est utilisée pour la mesure.

-Le « Cosmic Shear » contient non seulement une information sur la densité de matière , mais mesuré à différent décalage vers le rouge il permet de suivre la formation des structures et est très sensible à H(z) qui fournit des contraintes forte sur l'Energie Noire.

-Un signal a été détecté en 2000, méthode d'avenir…

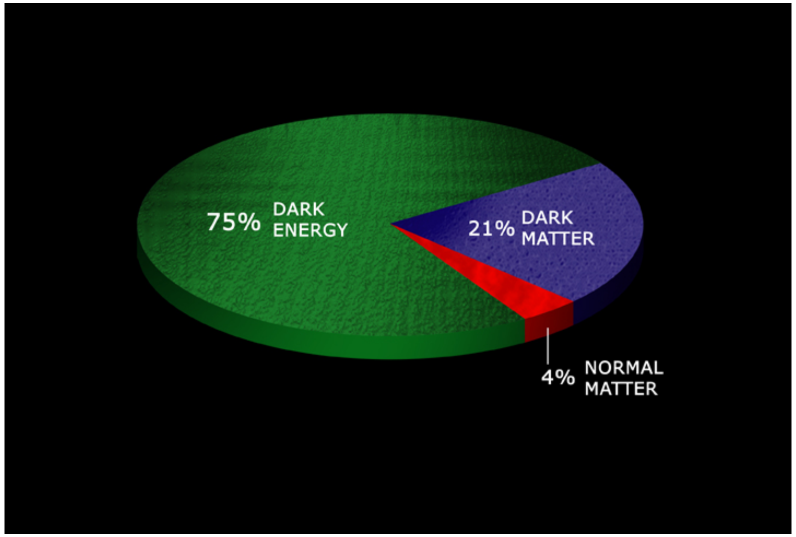


Energie Noire : Le modèle de concordance

- **Le modèle de concordance :**

- **L'univers est (~) plat**

- **La densité de matière** (densité ~ R^{-3}) **représente ~25 % de l'énergie totale , et seulement 4% est sous forme de matière baryonique et 21% sous forme de Matière Noire , au sujet de laquelle on ne sait pas grand chose**



- **Et ~75 % est sous forme d'Energie Noire** (densité ~ $R^{\sim 0}$) **, dont on sait … rien.**

… Energie Noire ???? Le point de vue des théoriciens

- Une constante cosmologique (le terme « standard » de l'équation d'Einstein)
  - Peut-on ignorer le reste du XX ième siècle ? : Energie du Vide …

- Quintessence
  - Un bon vieux champ scalaire = « scotch » de la physique théorique , ou comment « fixer » un problème …. Méthode qui a fait ses preuves vu le grand nombre de champ scalaire connu à ce jour.

- Le principe anthropique
  - Le « dégrippant » de la physique théorique : quand ça « coince » un peu de principe anthropique et ça repart …

- Relativité générale modifié, extra dimension …
  - A chaque changement de Relativité Générale …penser à vérifier les fusibles …

- Back Reaction (pas de nouvelle physique) : La formation de structure induit une accélération moyenne apparente (densité non uniforme)
  - C'est ce qu'il faut étudier aujourd'hui… si si … hum … non il y a 2 ans …

… Energie Noire ??? Le point de vue expérimental

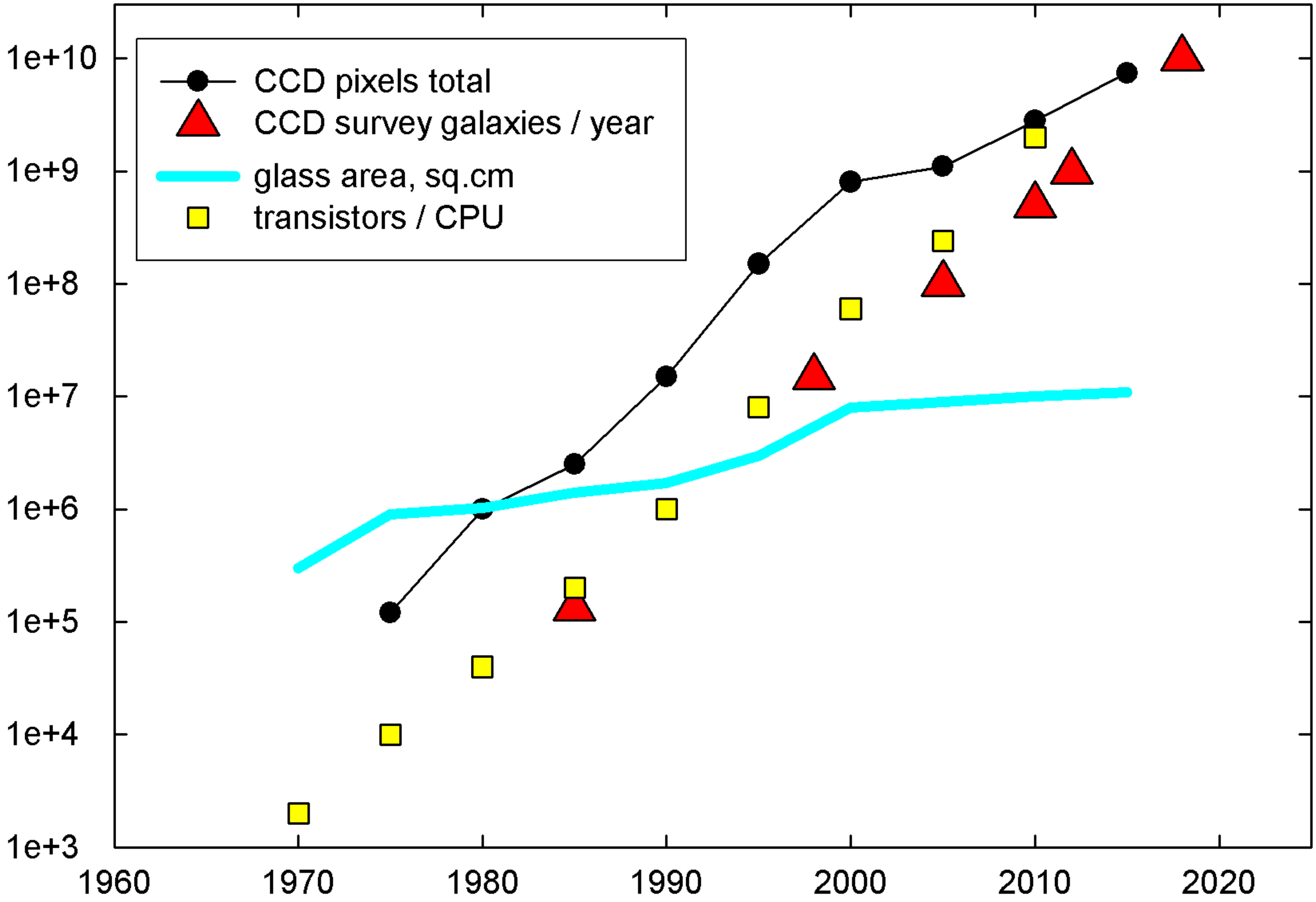
- Après une découverte en 1998 , l' « Energie Noire » a été confirmée par un ensemble convergent d'observations ces 13 dernières années . Maintenant que ces # techniques d'observation commencent à être maîtrisées , il semble opportun de lancer de nouveaux programmes ambitieux dédiés à l'étude de l'Energie Noire

➔ Phase IV du programme d'étude de l'énergie noire aux US

Large Synoptic Survey Telescope

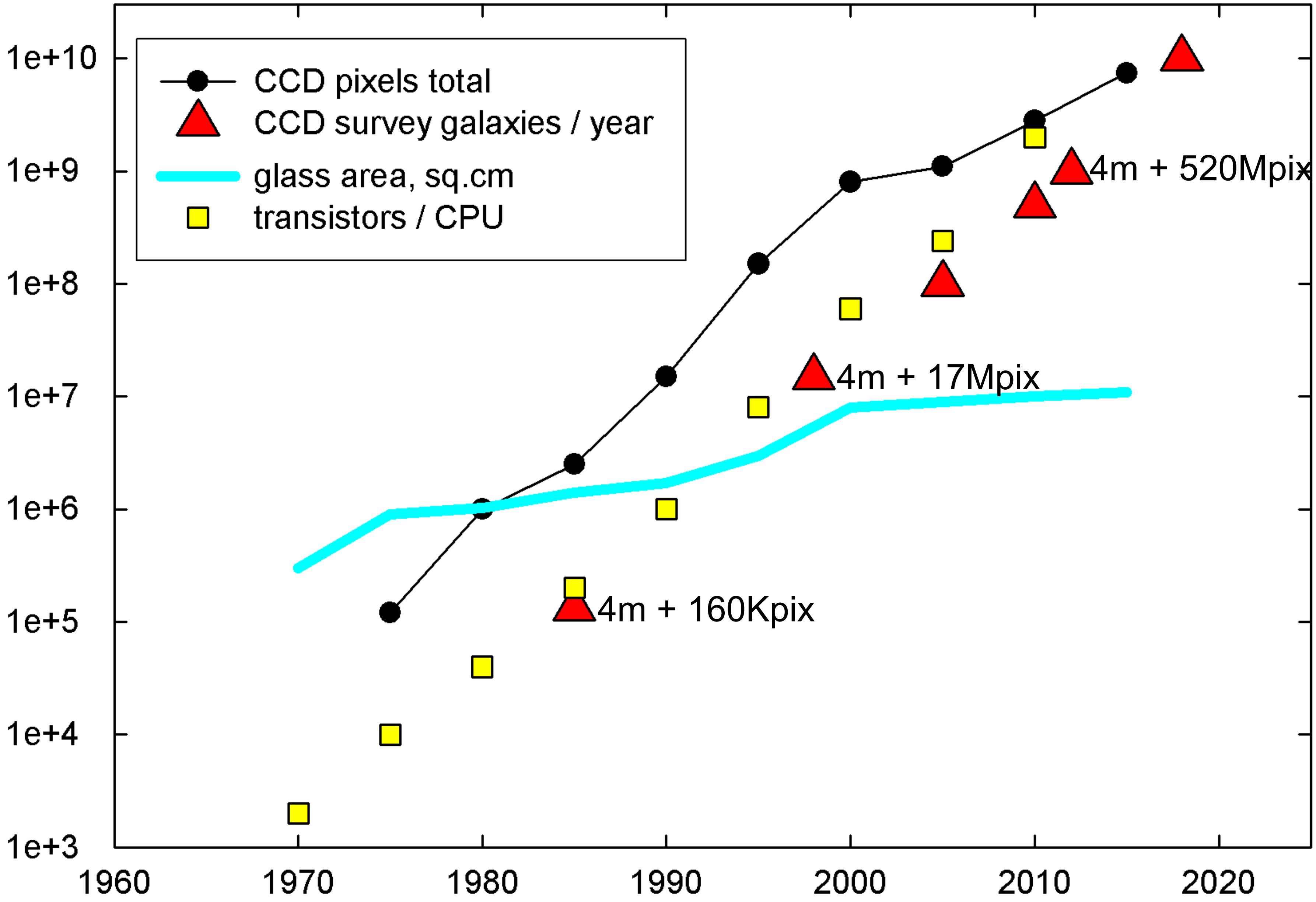
LSST Overview

Trends in Optical Astromomy Survey Data



Tony Tyson, 2011

Trends in Optical Astromomy Survey Data



Tony Tyson, 2011

The Excitement

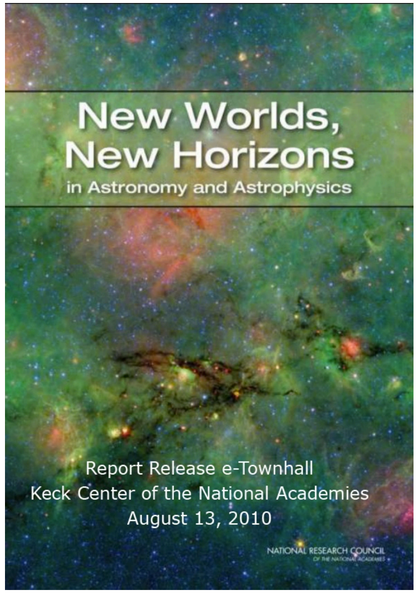
Large Synoptic Survey Telescope

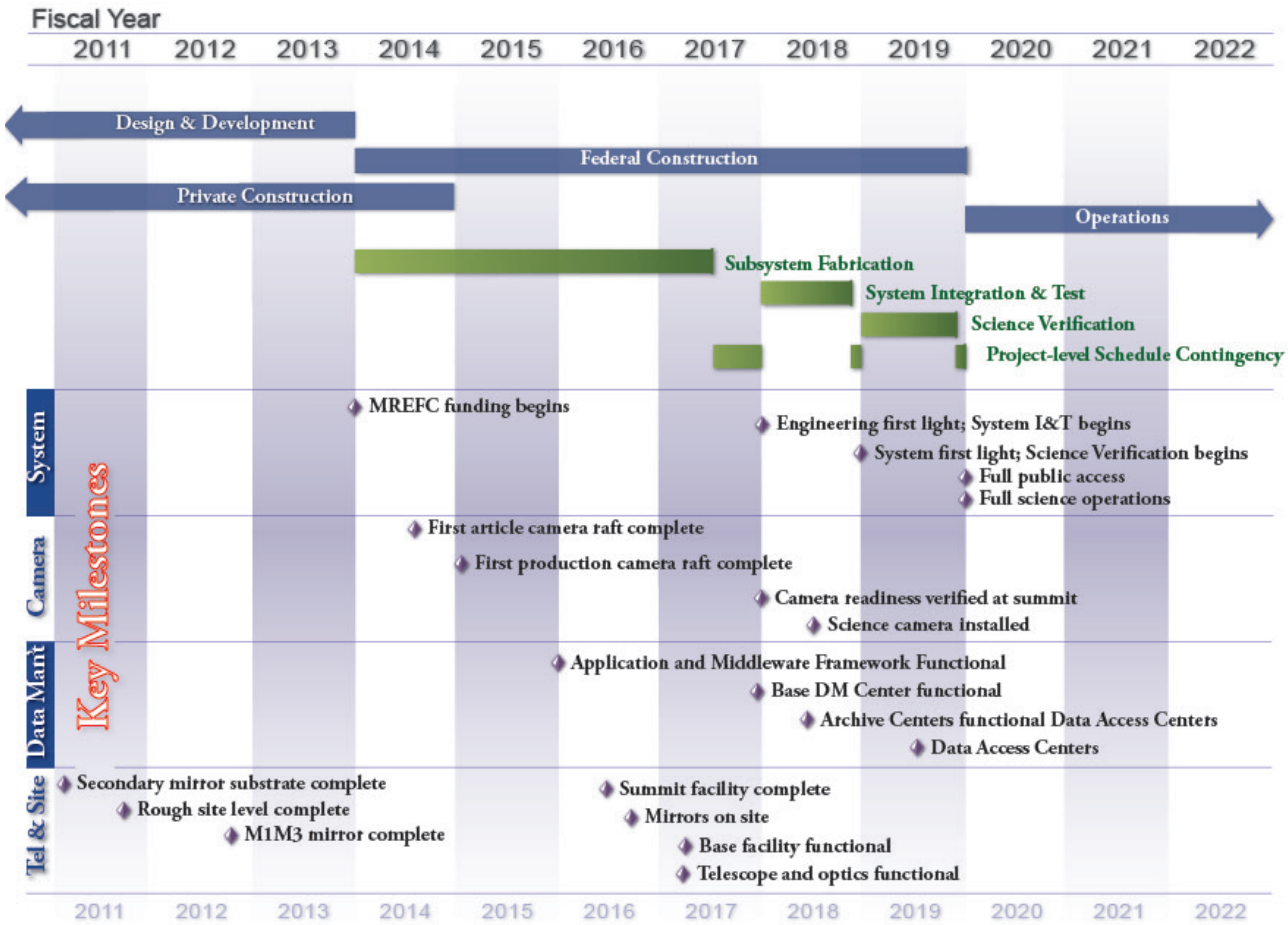
- Not 'just another telescope', but a **truly unique discovery engine.**
- Nobody else is doing this
- Transformative in the science
  - New parameter space always surprises – LSST opens the time domain
  - Myriad rapidly delivered alerts – enables follow-up
  - Superb image quality with rigorously controlled systematics
  - Massive data – data enabled science – new ways of doing astronomy
- Transformative in education & outreach
  - Widespread immediate access
  - An alert stream for everyone
  - Citizen science for tackling massive datasets
- Transformative in data enabled science and cyberinfrastructure
  - Massive amounts of data
  - Near-real-time processing
  - Fast dissemination to multiple data access centers

Recent Astro2010 Endorsement (August 2010)

Large Synoptic Survey Telescope

- LSST ranked as the highest priority large ground-based facility for the next decade.
- "The top rank accorded to LSST is a result of (1) its compelling science case and capacity to address so many of the science goals of this survey and (2) its readiness for submission to the MREFC process as informed by its technical maturity, the survey's assessment of risk, and appraised construction and operations costs. Having made considerable progress in terms of its readiness since the 2001 survey, the committee judged that LSST was the most 'ready-to-go.'"
- Following this recommendation, NSF and DOE are going ahead with LSST : the project is going on through an intensive reviewing by the US agencies this year and will have its calendar endorsed by the agencies this fall . The baseline considered by the agencies is a start of observations end of 2018.
- CD0 for a Ground-based Stage IV Dark Energy experiment was signed June 21st 2011 : the LSST camera project was listed as the first option toward meeting that mission need.




Fiscal Year
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
Design & Development
Federal Construction
Private Construction
Operations
Subsystem Fabrication
System Integration & Test
Science Verification
Project-level Schedule Contingency
Key Milestones
System
MREFC funding begins
Engineering first light; System I&T begins
System first light; Science Verification begins
Full public access
Full science operations
Camera
First article camera raft complete
First production camera raft complete
Camera readiness verified at summit
Science camera installed
Data Mant
Application and Middleware Framework Functional
Base DM Center functional
Archive Centers functional Data Access Centers
Data Access Centers
Tel & Site
Secondary mirror substrate complete
Rough site level complete
M1M3 mirror complete
Summit facility complete
Mirrors on site
Base facility functional
Telescope and optics functional
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022

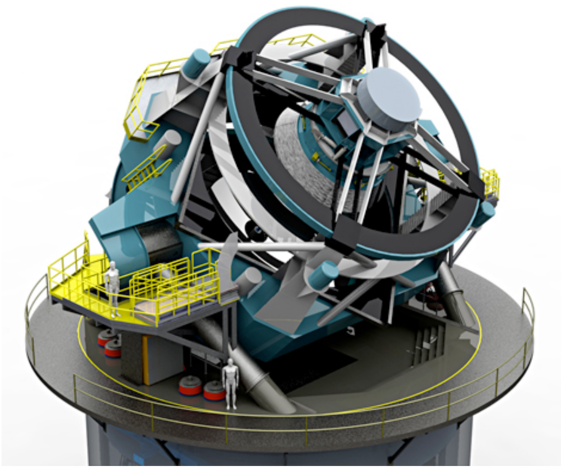
The Essence of LSST is *Wide, Deep, Fast*

- The LSST will be a large, wide-field ground-based telescope designed to provide time-lapse digital imaging of faint astronomical objects across the entire visible sky every few nights.

- As such, it will enable an enormous variety of complementary scientific investigations, utilizing a common database. 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.

- Of particular interest for cosmology and fundamental physics, LSST will provide strong constraints on models of dark matter and dark energy through statistical studies of the shapes and distributions of faint galaxies at moderate to high redshift, and the detection of large numbers of Type Ia supernovae.

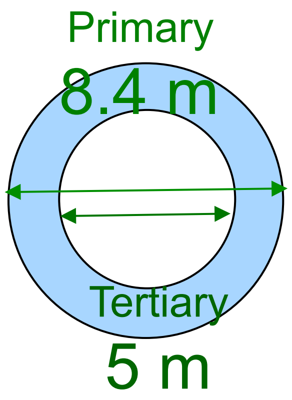
LSST : Wide , Deep and Fast

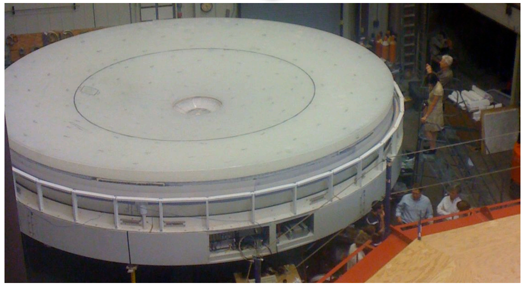


LSST

6.5 m effective primary mirror

Mirrors



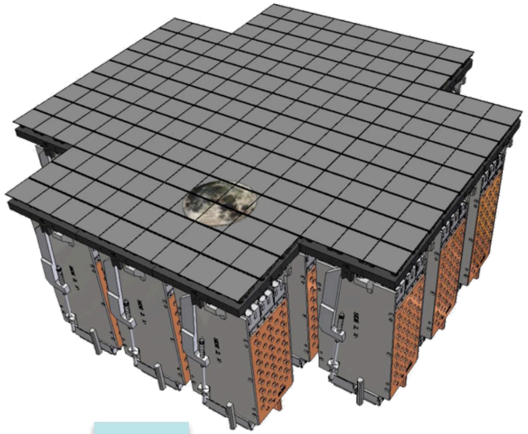


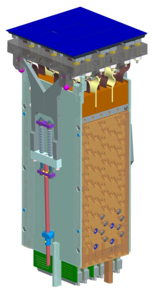
LSST main Mirror , August 2010

Field of view : 3.5 deg

(9.6 deg^2)

Full moon = 0.5 deg





LSST focal plane :

189 CCD (21 rafts)

3024 Readout Channels

>3 10^9 pixels

10 µm pixel (0.2 arcsec)

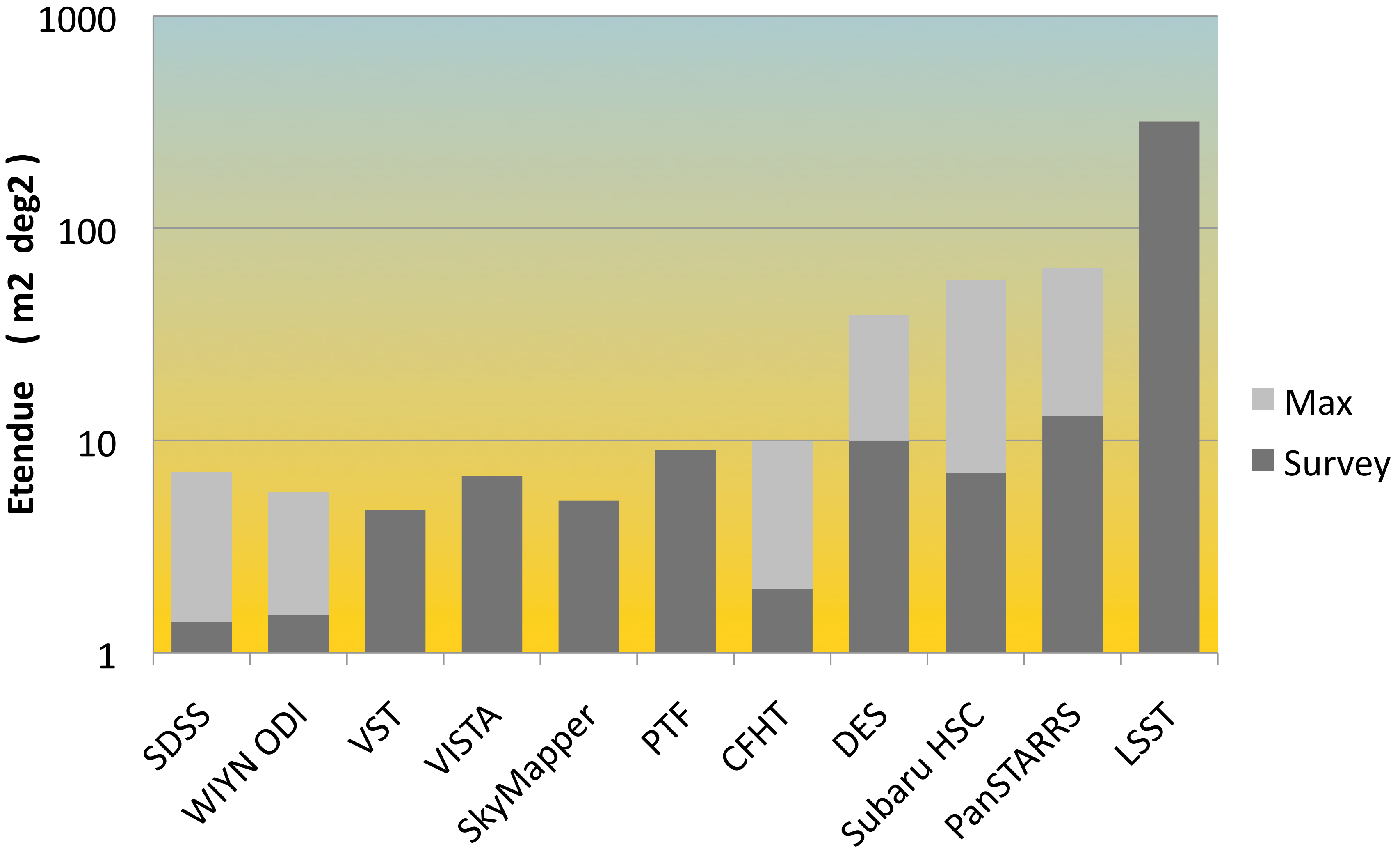
Focal plan readout : 2s

1 raft = 3x3 CCD

150 M pixels

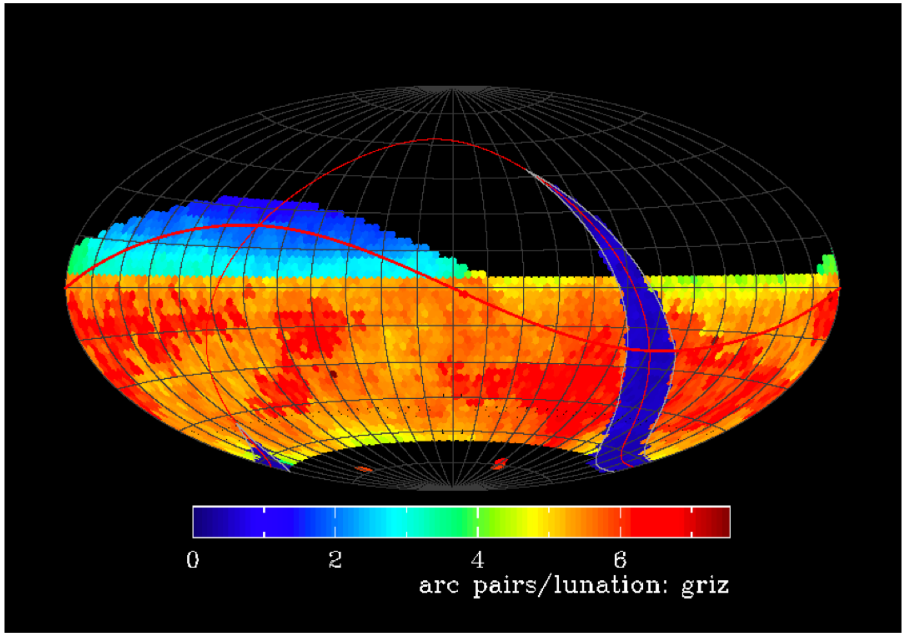
(1/2 Megacam)

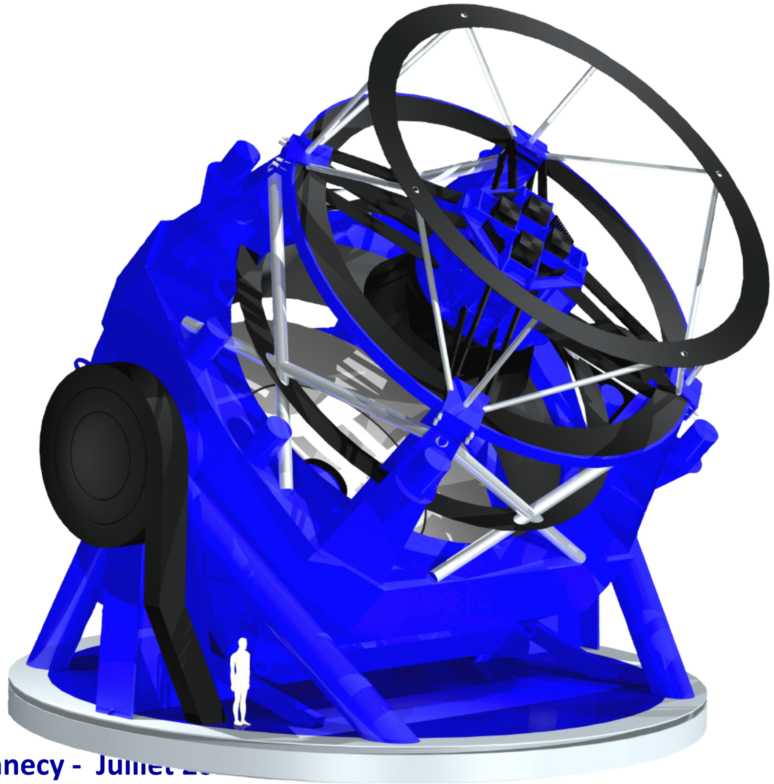
LSST : Wide and Deep



LSST concept :
a single observation plan & many science topics

6-band Survey:
ugrizy 320–1080 nm
Frequent revisits:
2 x 15 s, 25 AB mag/visit
Sky area covered:
> 20,000 deg2, 0.2 arcsec / pixel
Each 9.6 sq.deg FOV revisited ~ 1000 times
10-Year Duration:
Yields 27.7 AB magnitude @ 5sigma
Photometric precision:
0.01 mag absolute; 0.0005 mag repeatability





- Mirrors :
  Primary : 8.4m , Secondary : 3.4m, Tertiary : 5m
- More than $5x10^6$ exposure following the sequence:
  15 s pose + 2 s read + 15 s pose
  + new pointing as reading
  Points to new positions in sky every 37 seconds
- Camera : 3.2 Gigapixel, 201 4k x 4k CCD (189 for sky imaging)
- Plan focal plan diameter : 64 cm

LSST design : Telescope+Camera = 1 instrument

LSST collaboration and French contributions

- LSST collaboration :
  - more than 250 contributors to the science book
  - 35 institutions : 33 in the US , 1 in Chile , 1 in France (IN2P3)
  - 2 US agencies are contributing to the project : NSF (Telescope) & DOE (camera)
  - LSST construction started with private funds (Mirrors , site , CCD R&D , …)

- France is considering LSST since 2006 (letter of intent from IN2P3 and INSU labs)
- 7 IN2P3 laboratories (APC, CCIN2P3, CPPM , LAL , LMA , LPNHE , LPSC) are contributing to the LSST camera , some since 2007 . LSST-France count today :
  - 40 physicists
  - 33 engineers
- IN2P3 contribution includes :
  - CCD qualification/test and CCD electronic readout (201 CCD /3216 readout channels)
  - Filter changer (each filter is 70 cm diameter , ~ 25 kg)
  - calibration and characterization system
  - Filter coating studies

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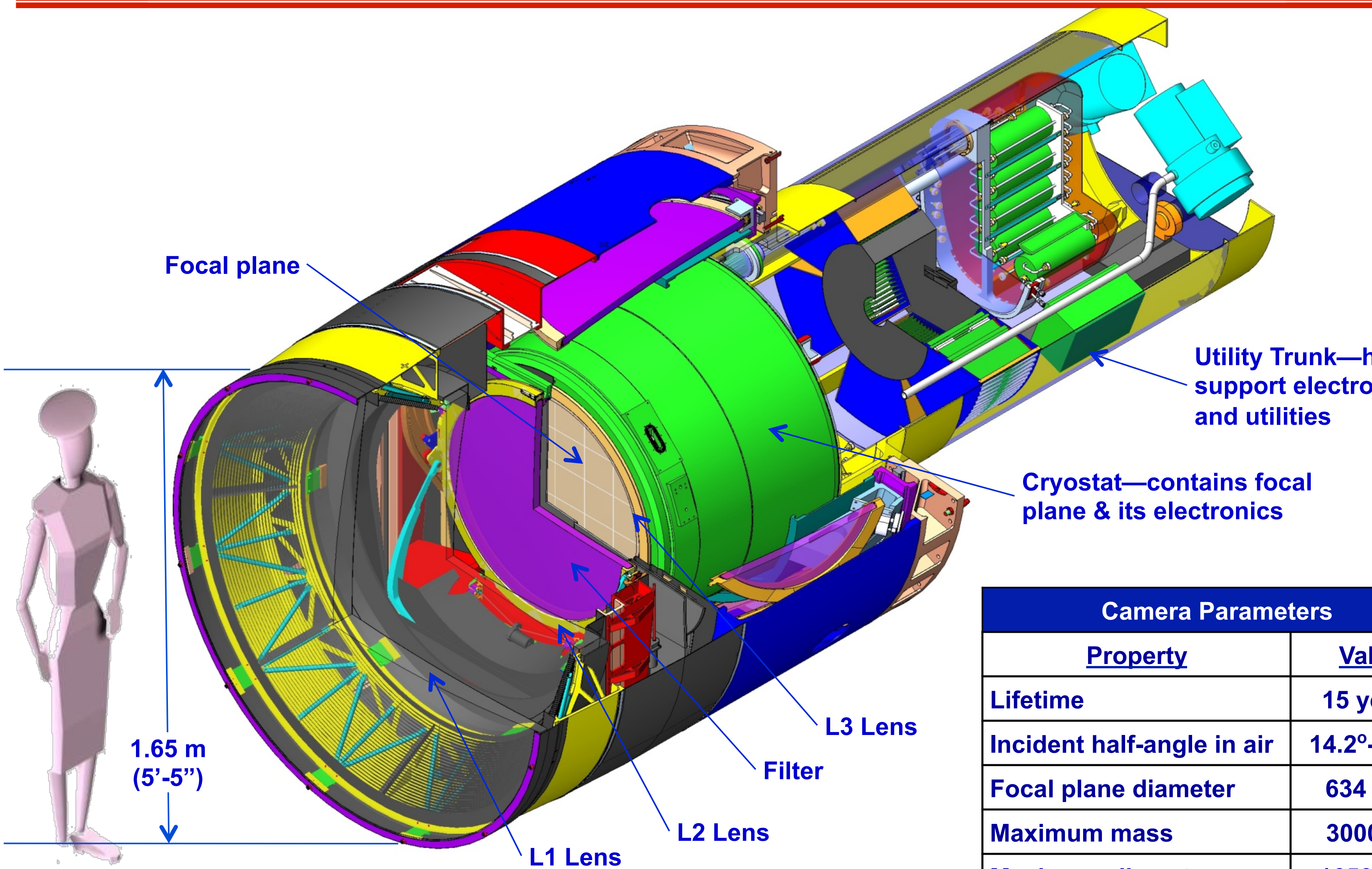
La camera de LSST :

Quelques éléments centrés sur la contribution IN2P3

Camera Layout



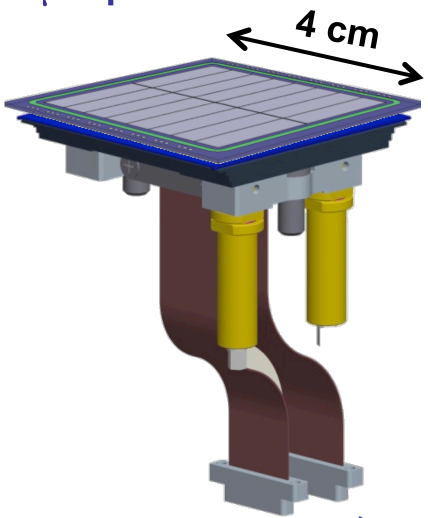
Camera Parameters	
Property	**Value**
Lifetime	15 years
Incident half-angle in air	14.2°-23.6°
Focal plane diameter	634 mm
Maximum mass	3000 kg
Maximum diameter	1650 mm
Total length	3732 mm

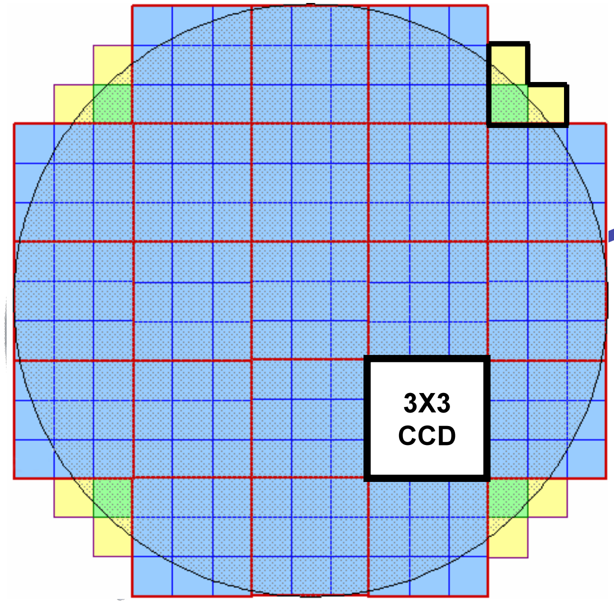
21 rafts, avec 9 CCDs chacun, constitue le plan focal
Chaque raft est une ~ camera autonome

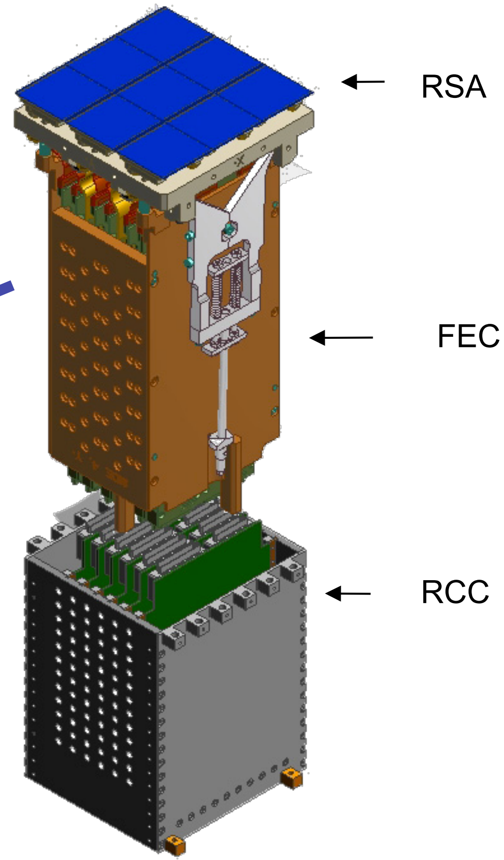
LSST
Large Synoptic Survey Telescope

4K x 4K CCD

- 10μm pixels = 0.2”
- réponse dans le rouge étendue
- 16 outputs
- 5μm planéité

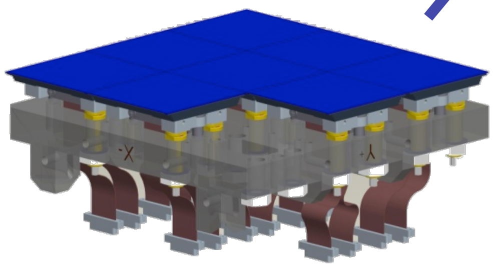






RAFT

- 9 CCDs
- coplanarité 13.5μm
- 92% fill factor



201 CCD x 16 voies = 3216 canaux dans un espace restreint
2 # ASICS dans le Front End
ASPIC (lecture) & CABAC (clocks)
➔ LAL/LPNHE responsabilité

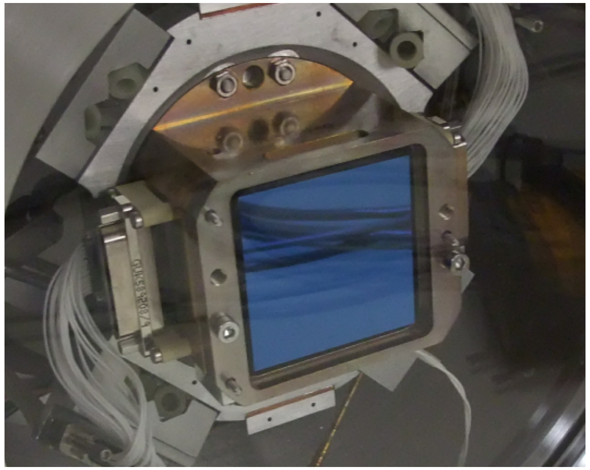
TOWER

- CCDs + front end électroniques
- 180K opération
- Une camera autonome entièrement testable : 144 Mpixel camera

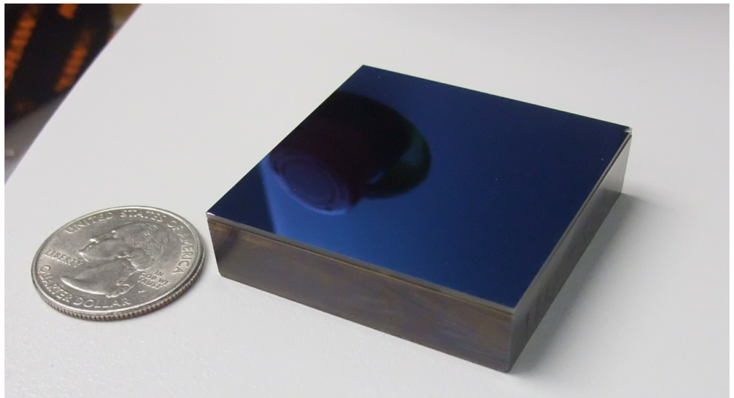
LSST camera : CCD

- **Efficacité quantique élevée à 1000nm (35%)**
  - Silicium épais - 100µm - et BB AR coating
- **PSF << 0.7" (0.2")**
  - Substrat de haute résistance (> 5 kΩ.cm)
  - Des pixels de petite taille (0.2" = 10 µm)
- **Ouverture f/1.2 (rapide)**
  - Detecteurs plats < 5µm p-v
  - Package avec des piston, tip, tilt adj. à ~1µm
- **Grand plan focal**
  - ~ 3200 cm^2 de plan focal
  - 189 CCD destinés à la science
- **Grande efficacité**
  - > 90% de couverture du plan focal
  - Package 4-cotés jointifs, sub-mm gaps
- **Lecture rapide (2 s)**
  - Détecteurs Segmentés - ~3200 ports de sortie
  - 150 I/O connections par détecteur
- **Faible bruit de lecture**
  - < ~ 5 électrons rms
- **Gamme dynamique importante**
  - •Puits 100 000 électrons
  - •Dynamique 16 bits

Actuellement 2 vendeurs sont sous contrat pour produire des prototypes « finaux » (Fin de la R&D vendeur : automne 2011)



e2v CCD250 (operable)



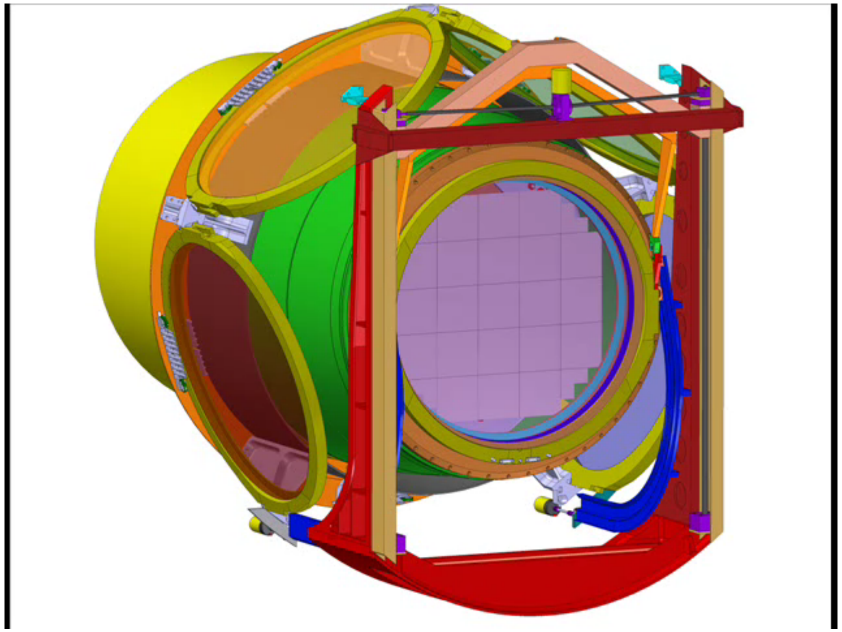
STA3800 (mechanical sample)

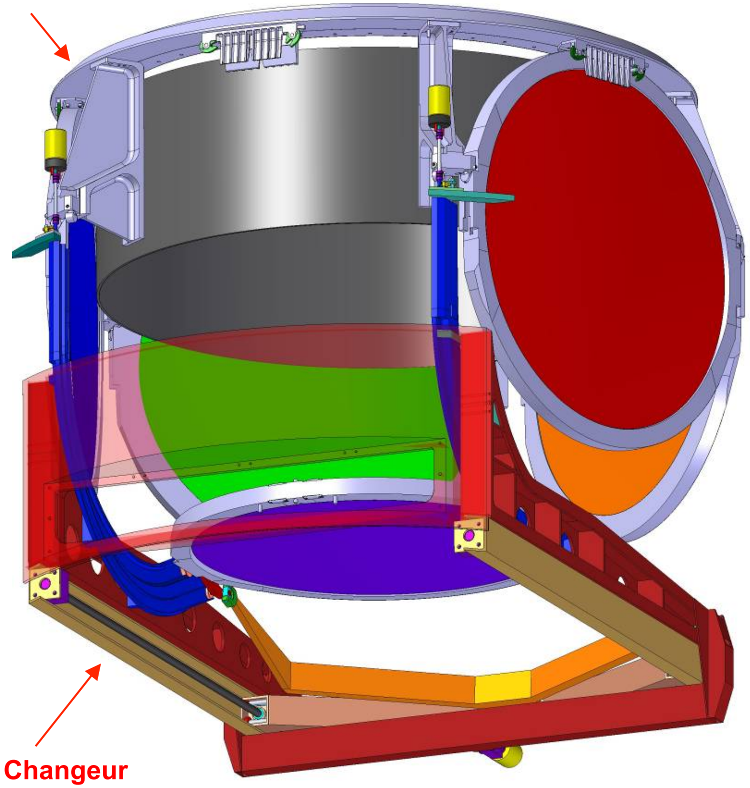
IN2P3/LPNHE contribue à la caractérisation des CCD

Système de changement de Filtres

Large Synoptic Survey Telescope

- Le système de changement de filtre compte 3 élements :
  - Carrousel (LPNHE)
    - Maintient jusqu'à 5 filtres hors champ
    - Positionne le filtre choisi en position de changement
  - Auto Changeur (CPPM)
    - Maintien le filtre dans le champ de vue
    - Déplace le filtre de la zone de stockage vers la position d'observation
  - Changeur Manuel (LPSC)
    - Utilisé pour échanger les filtres avec l'extérieur de la camera
- Temps de changement de filtre = 120s





Requirement	Value	Unit
Number of filters housed in the Camera at one time	5	
Max time between two visits in different filters	2	min
Minimum operational life of filter changer	40,000	cycles
Minimum operational life of filter carousel	20,000	rev
Minimum time between preventative maintenance	4,000	cycles

• LSTT : La bande passante des Filtres

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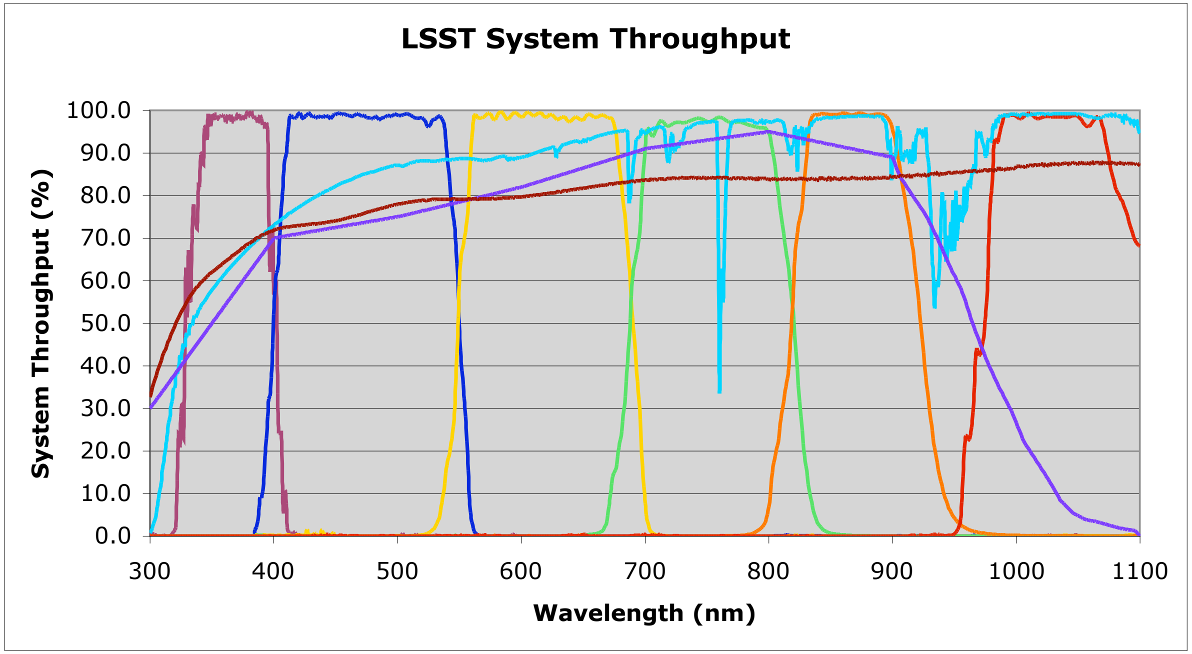
Specs

	Half-Maximum Transmission Wavelength		
	Blue Side	Red Side	Comments
U	350	400	Blue side cut-off depends on AR coating
G	400	552	Balmer break at 400 nm
R	552	691	Matches SDSS
I	691	818	Red side short of sky emission at 826 nm
Z	818	922	Red side stop before H_2O bands
Y	948	1060	Red cut-off before detector cut-off

- 75 cm dia.
- Surface courbe
- Les Filtres sont centrés sur l'axe optique, ainsi chaque portion d'un filtre voit le faisceau avec le même angle d'incidence (de 14.2º à 23.6º)



Dépôt uniforme au % requis sur toute la surface du filtre

LMA : expert coating

Large Synoptic Survey Telescope

LSST Science

The Science Opportunities are Summarized in the LSST Science Book

Large Synoptic Survey Telescope

- **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

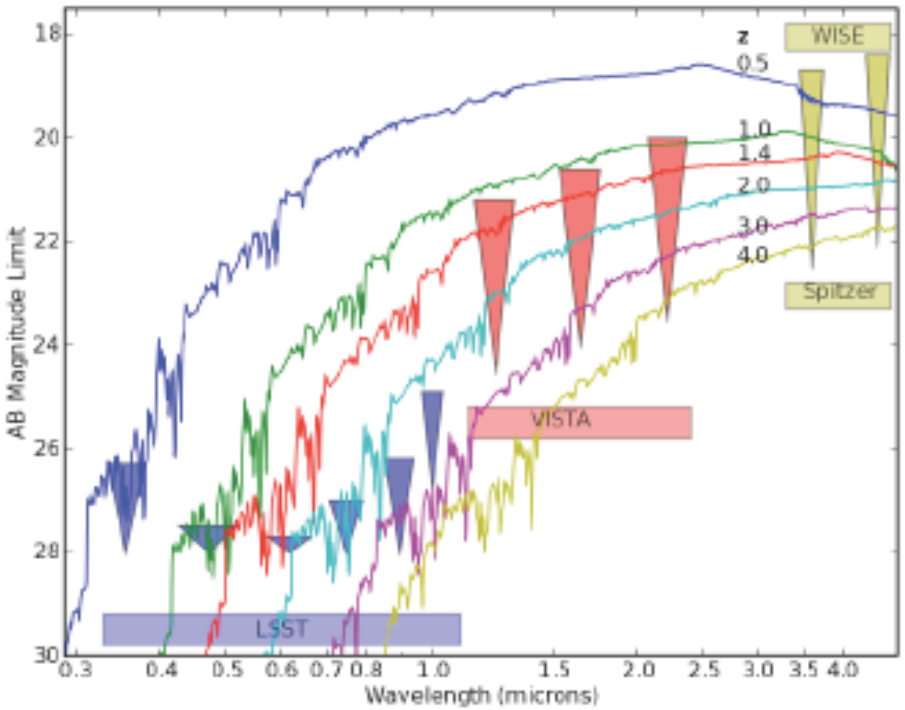
Dark Energy

http://arxiv.org/abs/0912.0201

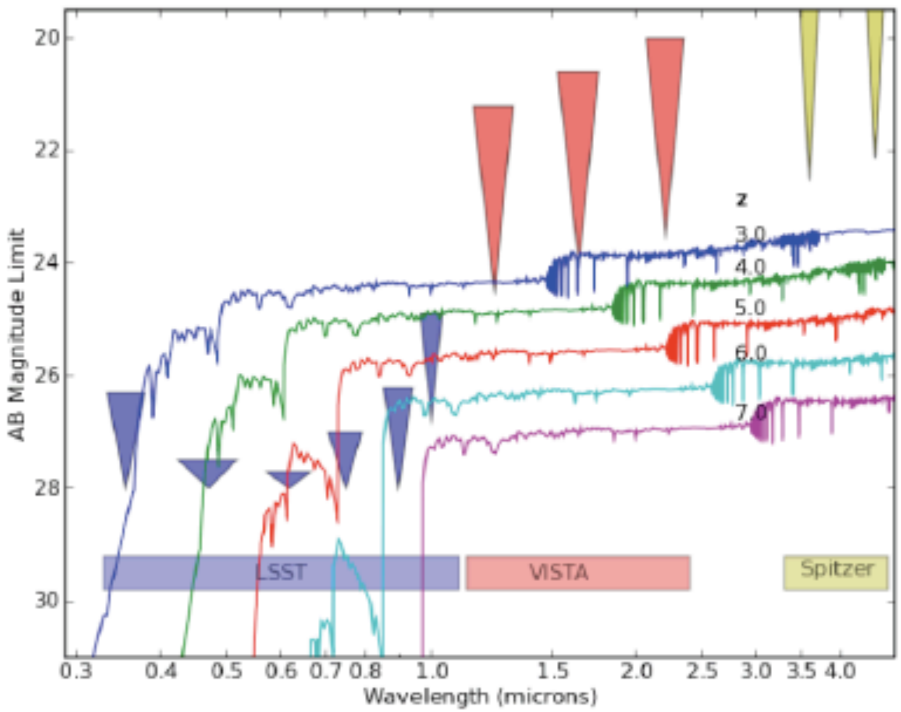
Galaxies

- 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 50 galaxies / $arcmin^2$ (~ "ground limit")
- The database will include photometry for 10^{10} galaxies from the Local Group to z > 6.
- We 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

The Expected Sensitivity Leads to Near Complete Samples Out to High Redshifts



Evolving L* Red Sequence Galaxy

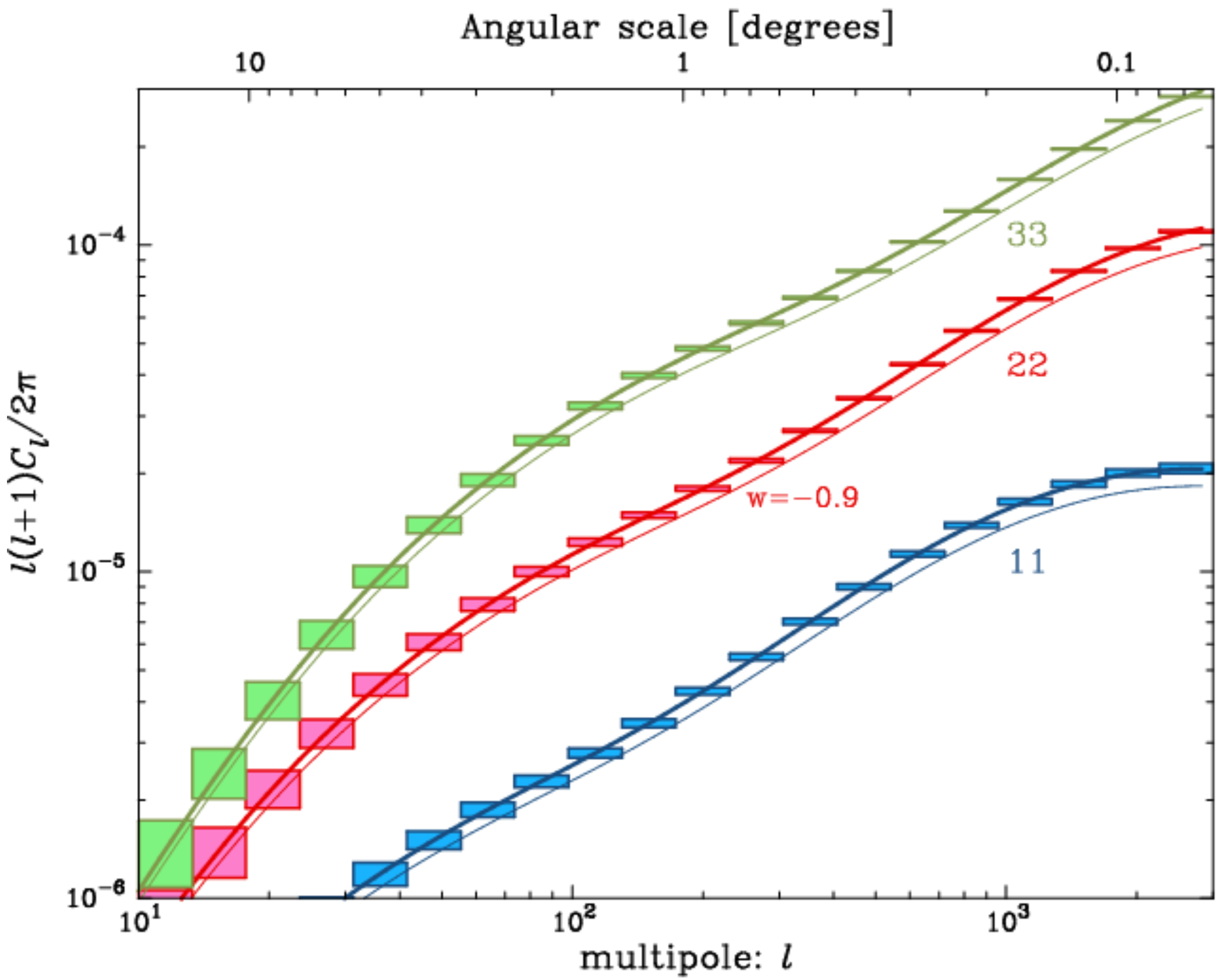


Evolving L* Lyman-Break Galaxy

Dark Energy – Dark Matter Science Drivers

- **Weak Lensing for Cosmic Shear:**
  - Optimal image quality for galaxy shape measurements
  - Multi-color (ugrizy) precision photometry for photometric redshifts determination with < 3% error
  - 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 (~ 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)

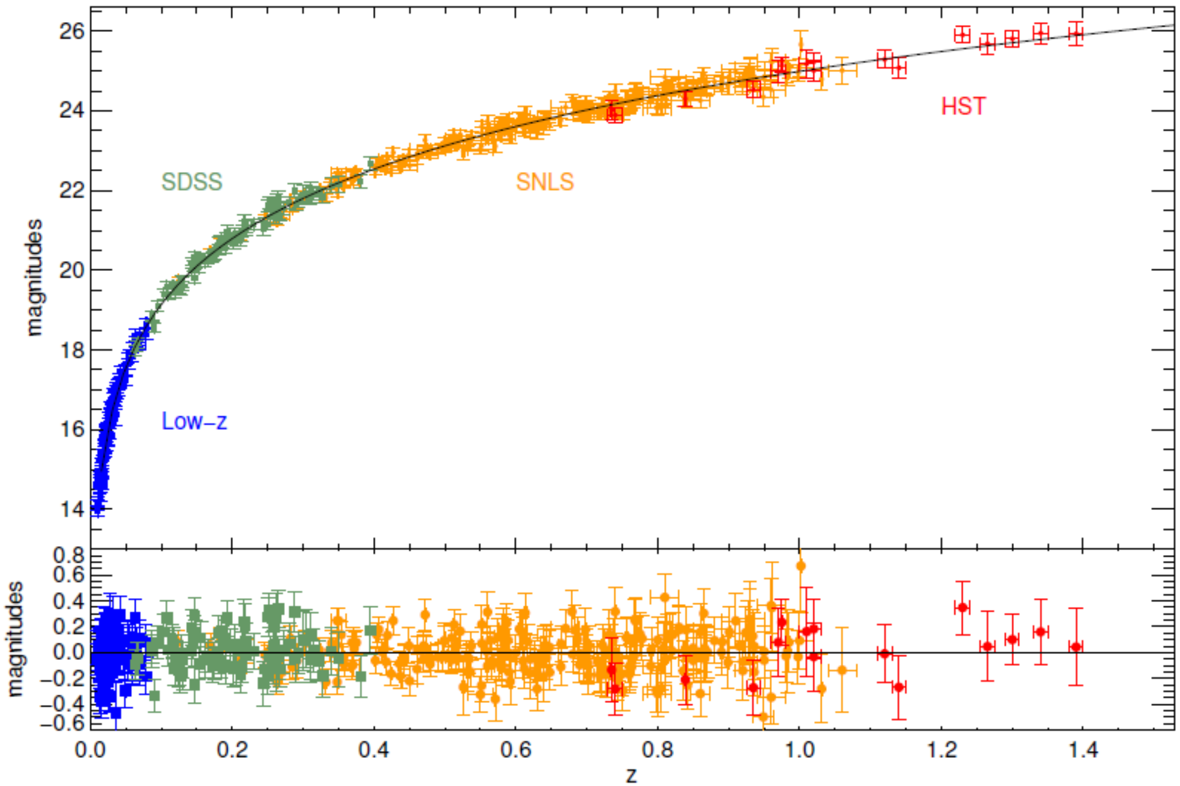
Cosmic Shear Auto-Power Spectra in Three Redshift Bands (z < 0.7, 0.7 < z < 1.2, and 1.2 < z < 3)



Thick curve :
ΛCDM / w=-1

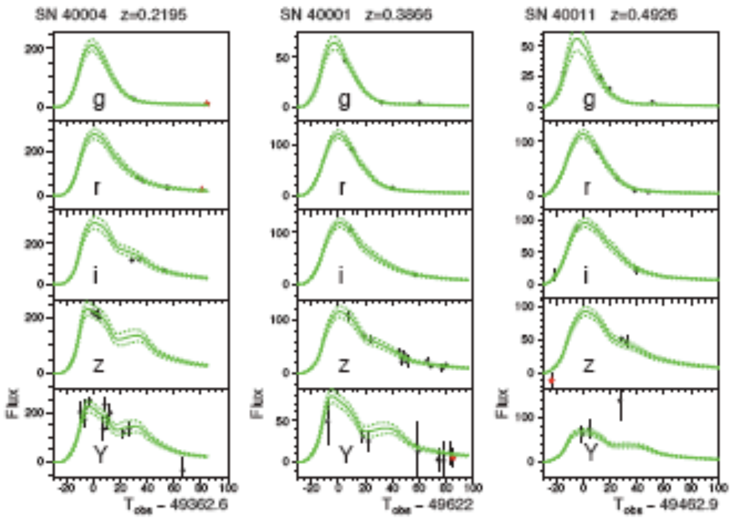
Thin curve :
w = -0.9

Dark Energy :
Type Ia SuperNovae sample in 2011

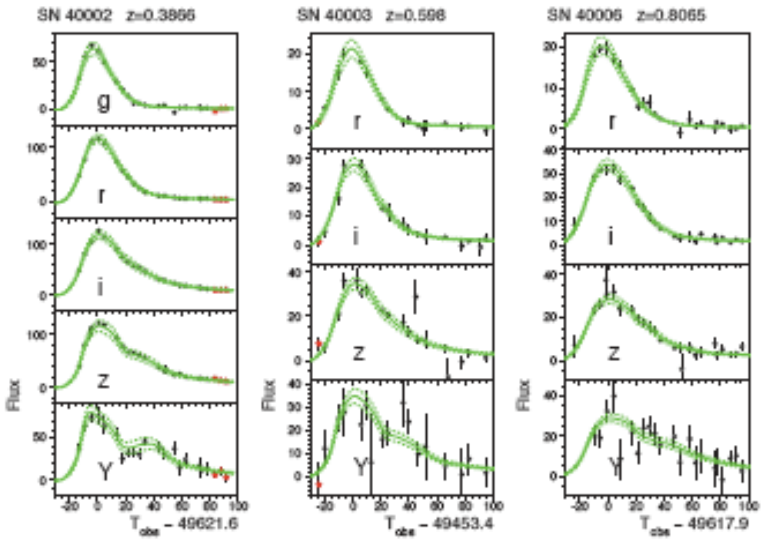


Sample	Redshift range	N_{SNe}	Ref.
Low-z	0.01 - 0.10	123	Hamuy (1996), Riess (1999), Jha (2006), Hicken (2009) ...
SDSS	0.06 – 0.4	93	Holzman (2009)
SNLS3	0.08 – 1.05	242	...
HST	0.7 – 1.4	14	Riess 2007

Type 1A Supernova Lightcurves



Main Survey

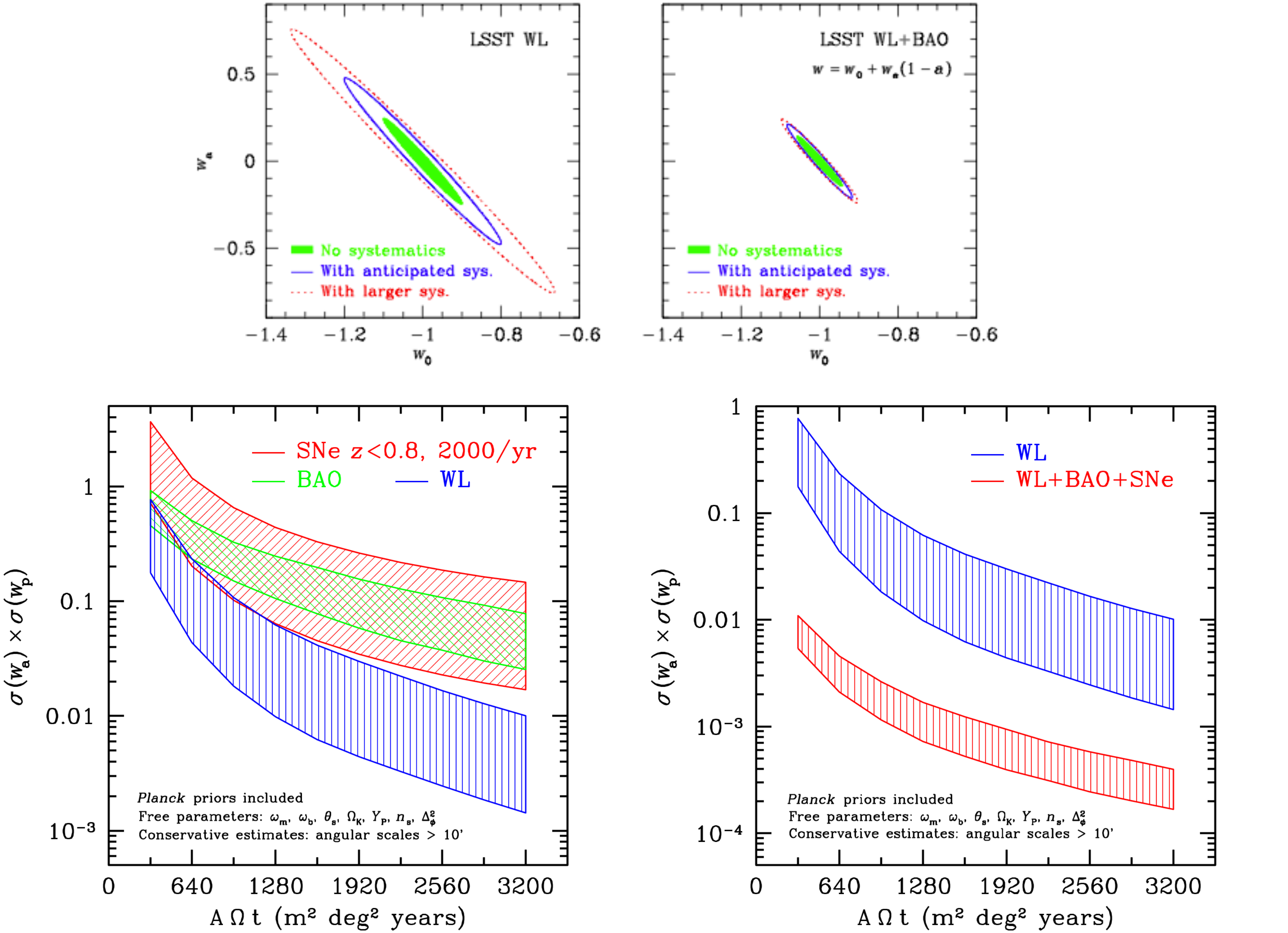


Deep Drilling Fields

- A few 10^3 supernovae have been discovered throughout the history of all astronomy.
- LSST will find > 10^7 over its ten-year duration, spanning a broad redshift range, with precise, uniform calibration.
- This will undoubtedly revolutionize the field, allowing large samples for studies of systematic effects and additional parametric dependences.
- ~ 10^5 SNe Ia will be found in the "deep drilling fields" with well-measured lightcurves in all six colors. This will be an excellent sample for precision cosmology.
- The large sample size will also allow us (for the first time) to conduct SN Ia cosmology experiments as a function of direction in the sky, providing stringent tests of the fundamental cosmological assumptions of homogeneity and isotropy.

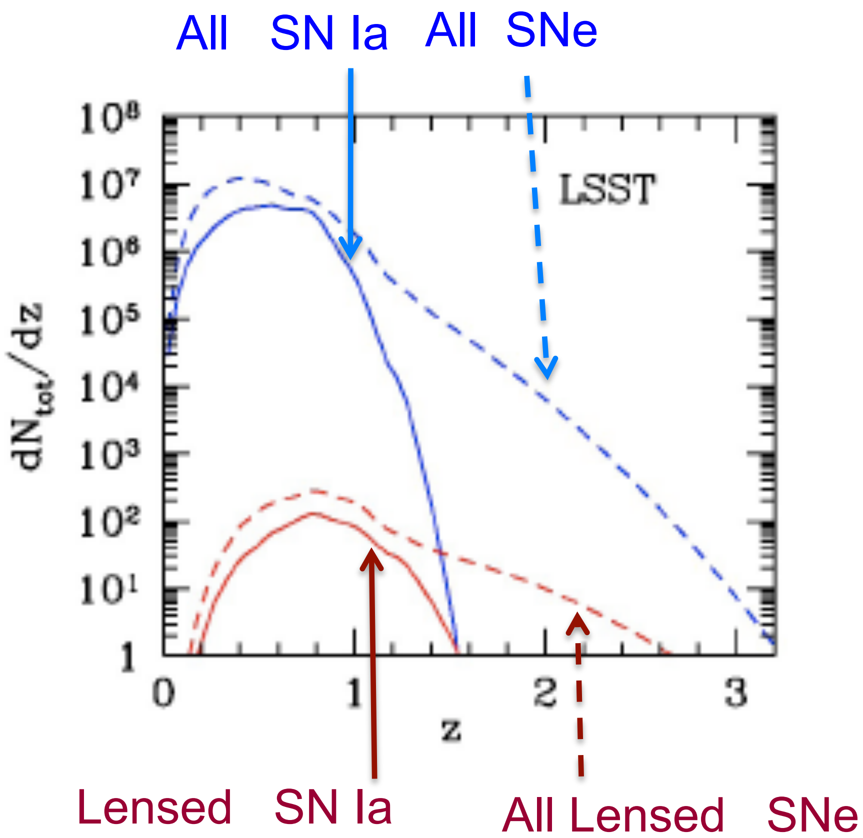
Complementarity between Dark Energy probe

Large Synoptic Survey Telescope



Strongly 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.



Conclusion

LSST est en phase finale de R&D , sa construction a commencé .
Le début de son exploitation scientifique : 2019…
Une percée observationnelle dans l’étude de l’énergie noire est en marche.

2011 | 2025-2030