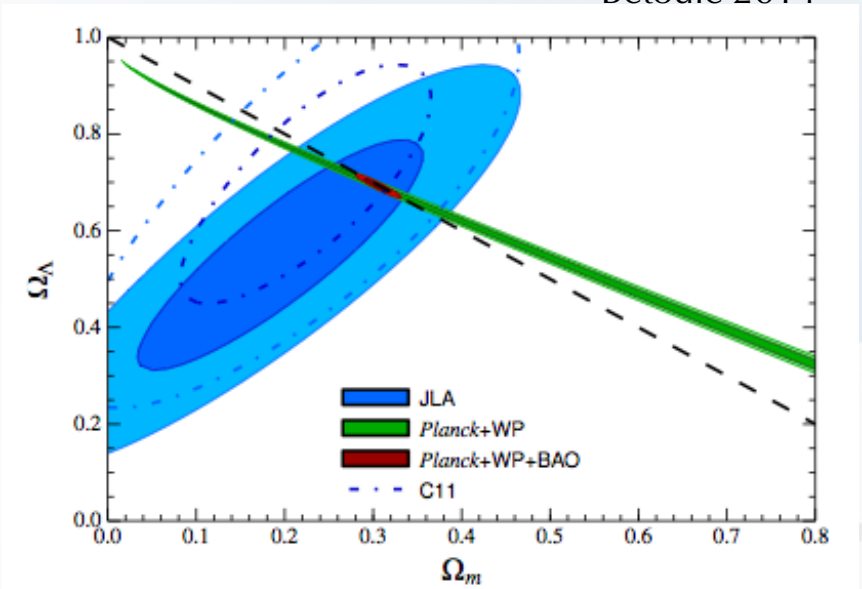
La cosmologie avec le

Emmanuel Gangler – LPC – Clermont-Ferrand (France)

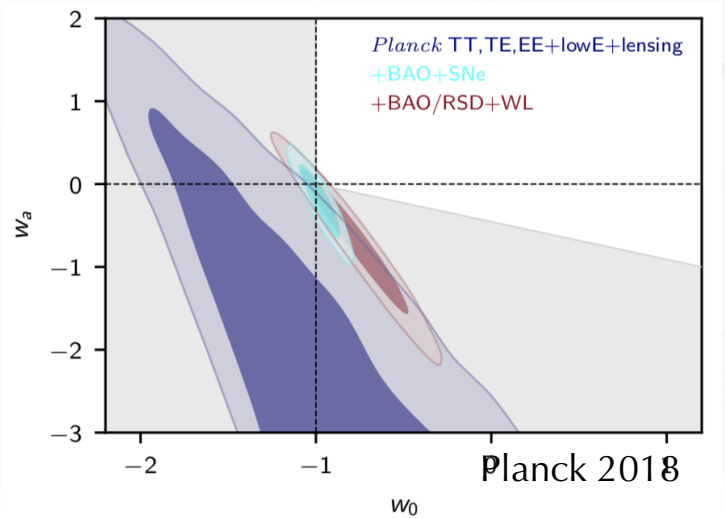
Dark Energy: 1998-2019 … 21 years and still alive !

Supernovae : senstive to expansion rate evolution → dark energy equation of state

Betoule 2014



Equation of state $P = w\,\rho = [w_0 + w_a(1-a)]\,\rho$



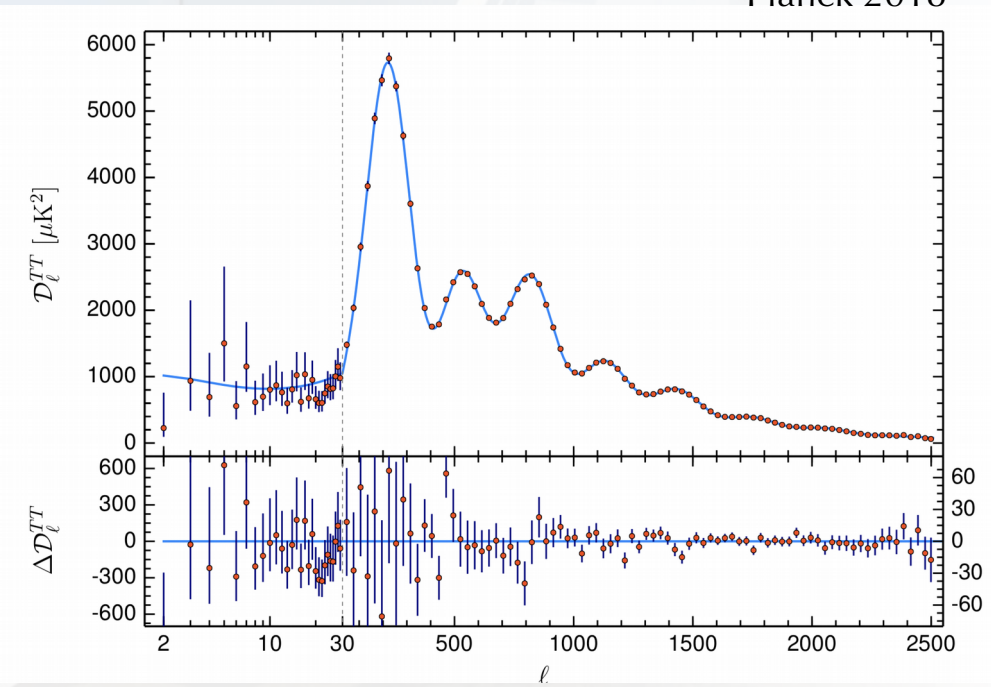
Planck 2018

CMB, BAO : scale parameter evolution

→ sensitive to Ω_{tot}

+ power spectrum, polarization …

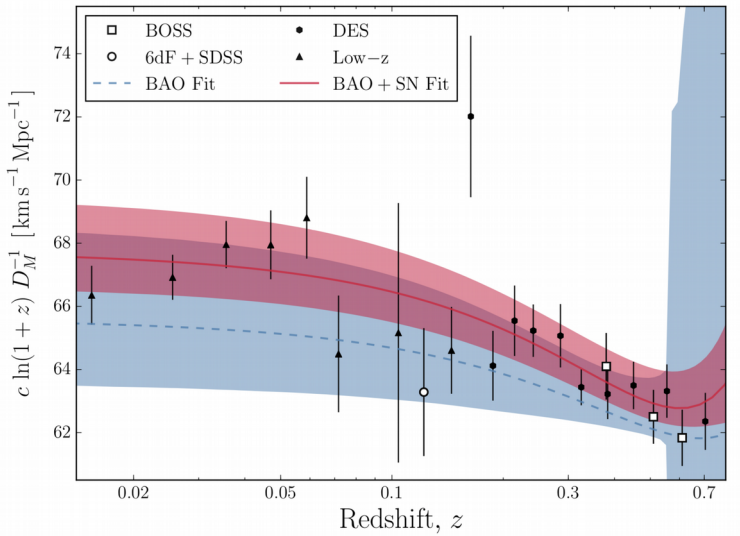
Planck 2018



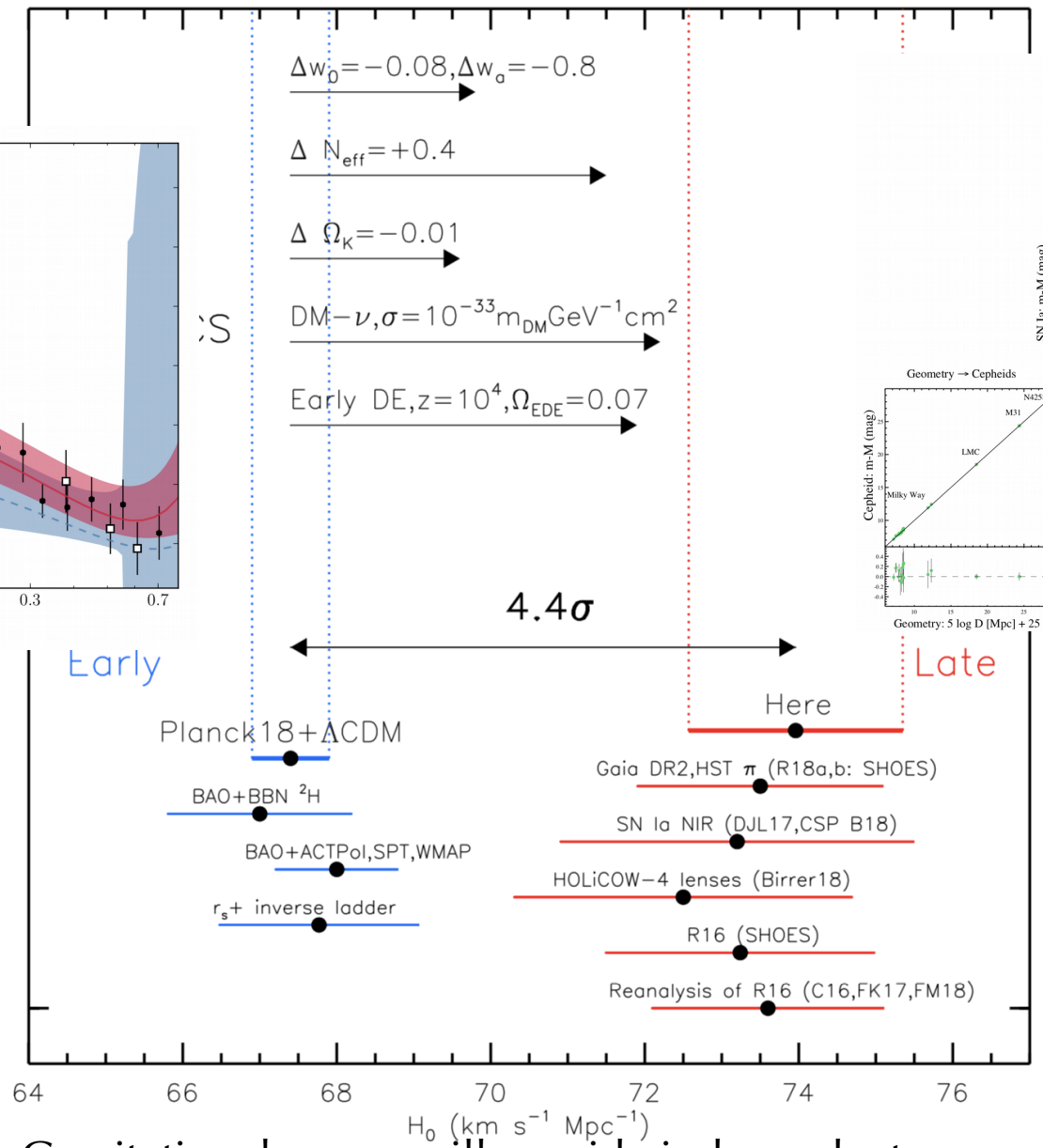
Structure growth → sensitive to Ω_M & GR

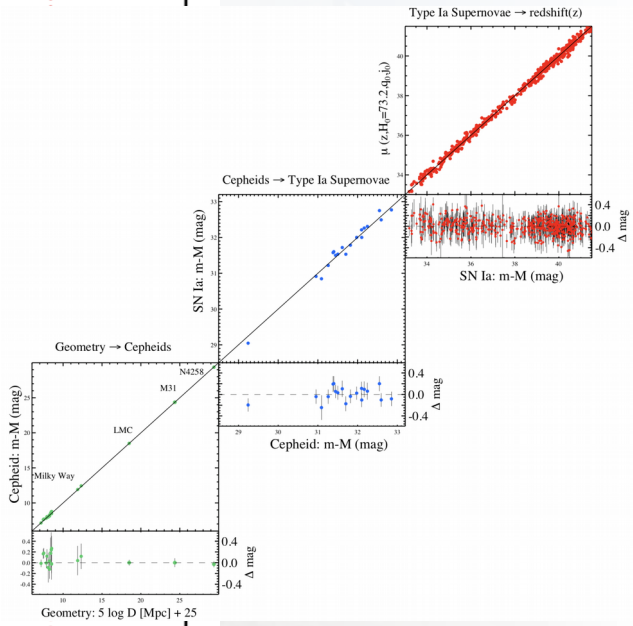
→ **Concordance model** flat-ΛCDM quite robust … so far ?

But tension on the Hubble Constant



Macaulay 2019





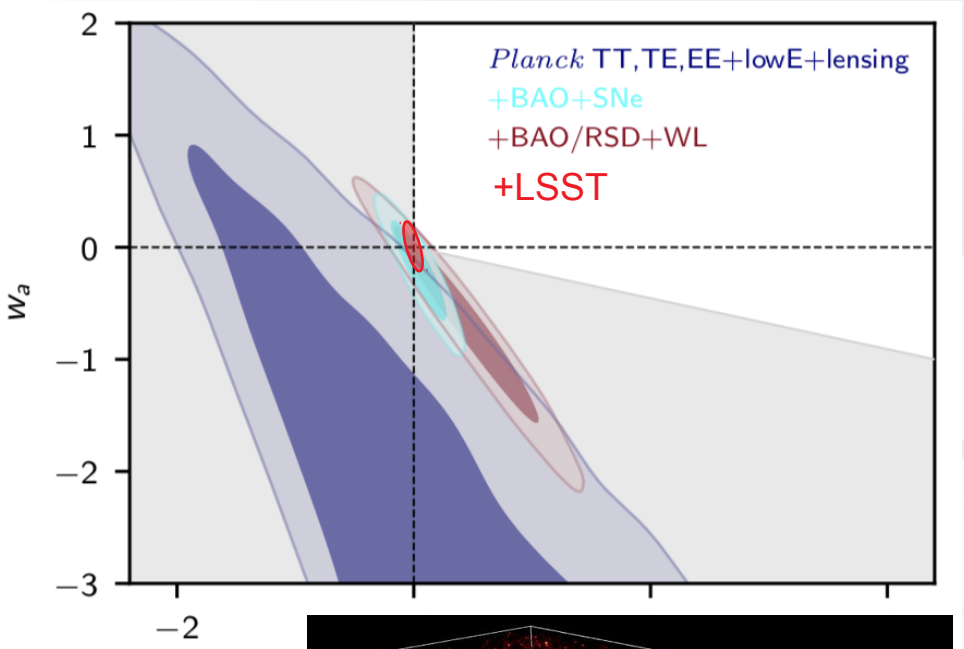
Riess 2019

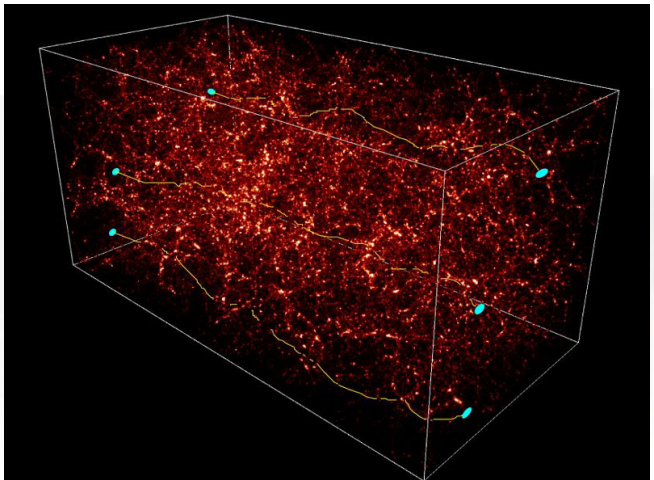
Gravitational waves will provide independent measures

How to constrain Dark Energy ?

Precision measurements of equation of state

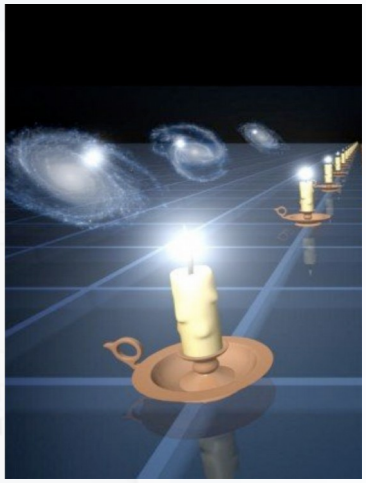
→ **Multi-probe approach**





Which probes ?

(a biased selection)



Supernovae:

- Statistical sample
  1998 : 42 SN
  2019 : ~1050 SN
- Systematics: calibration, sample, astrophysics

→ ***Repeatedly scan large sky volume***

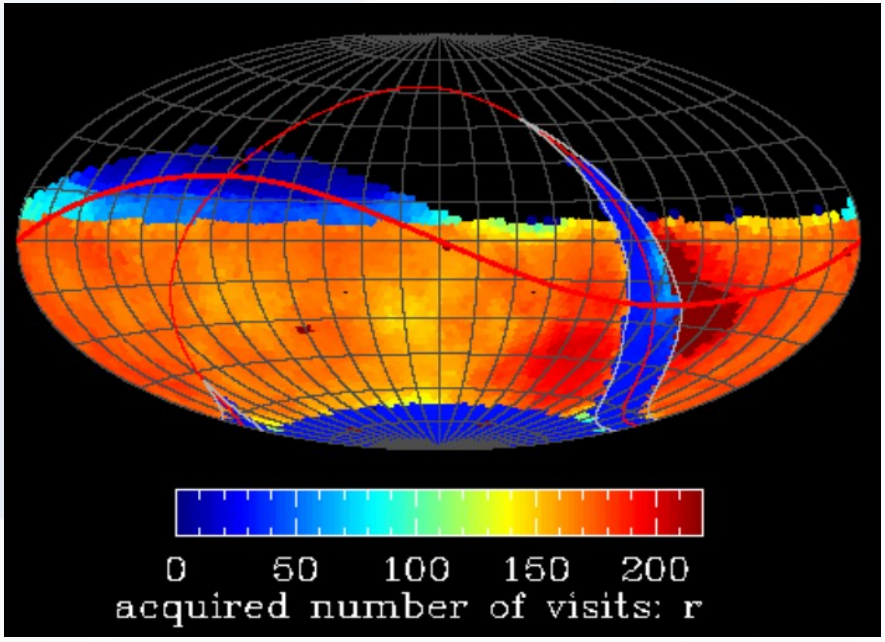
Lensing: (Chang 2013)

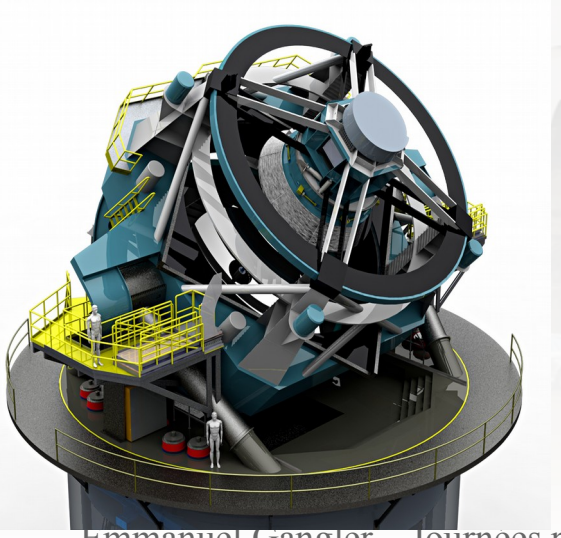
- Sky coverage, Galaxy density
  30 galaxies/arcmin^2
- Control of shape measurements
  Good PSF, repeated measures
- Redshifts: multiband

→ ***Deep and Wide sky survey***

summary :

- A stage-IV survey :
  - 8.4 (6.7) m telescope
  - Cerro Pachon (Chili)
  - 3.2 Gpix 9.6□ FoV camera
  - 0.2'' pixel / 0.7'' median FWHM
  - First light 2021, Survey 2022





- All visible sky in 6 bands (ugrizy) (~18000□)
- 2x15 s exposure, 1 visit / 3 days
  r ~24.4 / visit
- During 10 years !
  → ~825 visits (all bands)
- 15TB/day 60 PB/10 years

LSST project and Science:

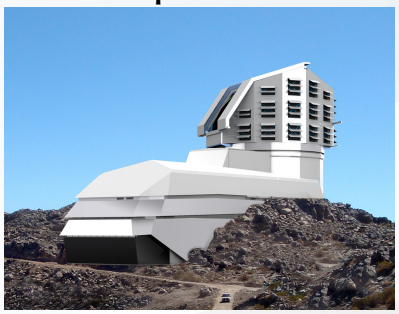
Communication
Commissioning
Advisory
Operations

Large Synoptic Survey Telescope

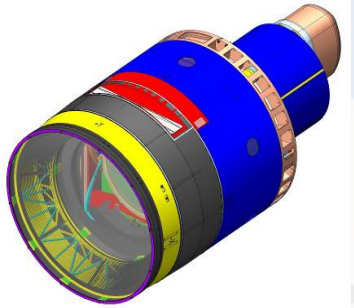
Science

Science Collaborations

Telescope and site



Camera



Data Management

Outreach

- **LSST covers 4 major scientific themes**
  - Dark Energy, Dark matter
  - Mapping Milky Way
  - Transient optical sky
  - Solar system
- **Scientific analysis is not part of the project**
  - Conducted by independent collaborations
  - LSST delivers reduced data, scientists analyze them

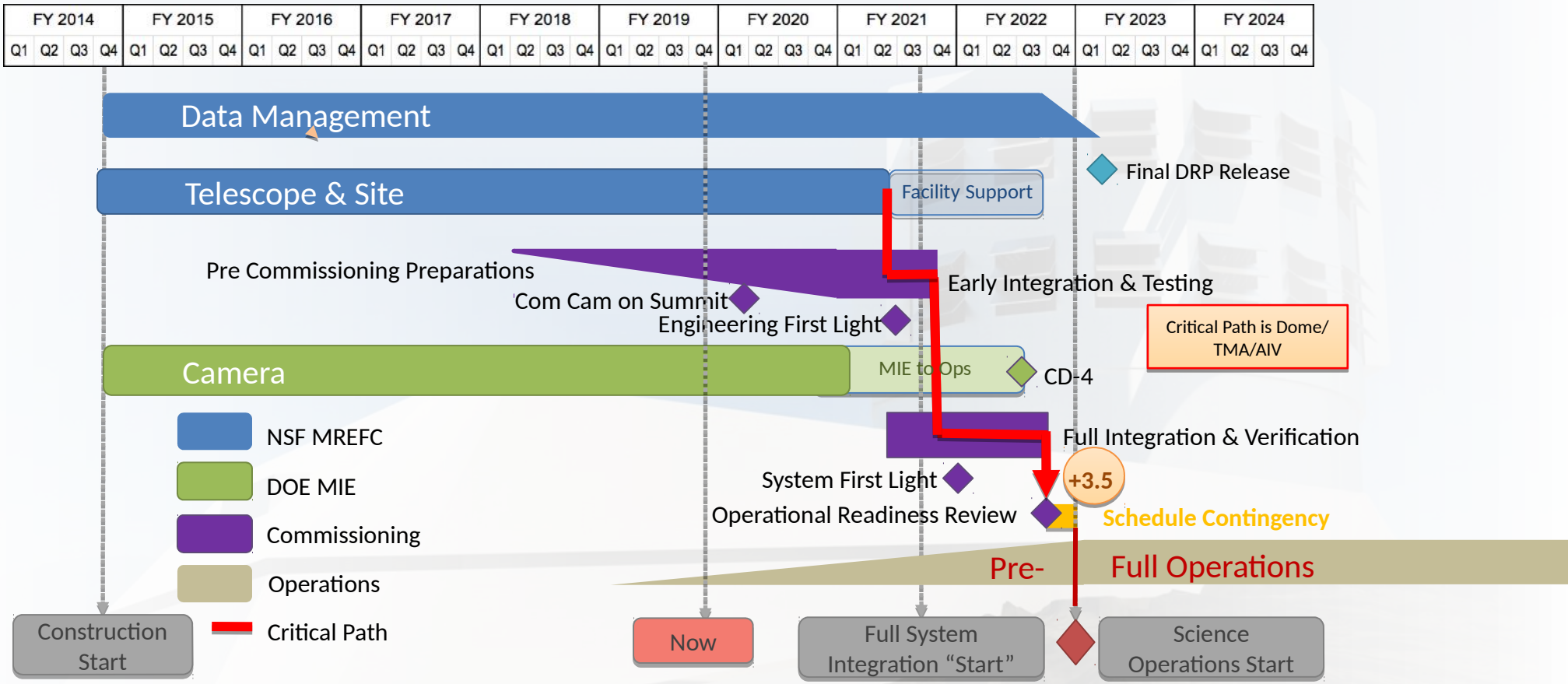
LSST in France

- **10 laboratories from IN2P3:**
  - APC, CCIN2P3, CPPM, IP2I, LAL, LAPP, LPC, LPNHE, LPSC, LUPM
- **Around 120 people:** 62 researchers (15 juniors), 61 IT
- Partners of LSST since 2005 through **major contributions:**
  - **Building the LSST Camera** (~16 FTE/yr IT + Hardware)
  - **Computing at CCIN2P3** (~6 FTE/yr IT + Hardware investment + Running costs)
- **Ongoing activities:**
  - Transition between construction and **commissioning** is happening right now!
  - Preparing the **Dark Energy scientific program**
  - **LSST / Multimessenger** astronomy complementarity[NEW]
- **… newcomers welcomed !**
  - New IN2P3 labs, or even INSU or CEA.

    covered by *existing agreements* with LSST.

LSST Status

LSST Timeline

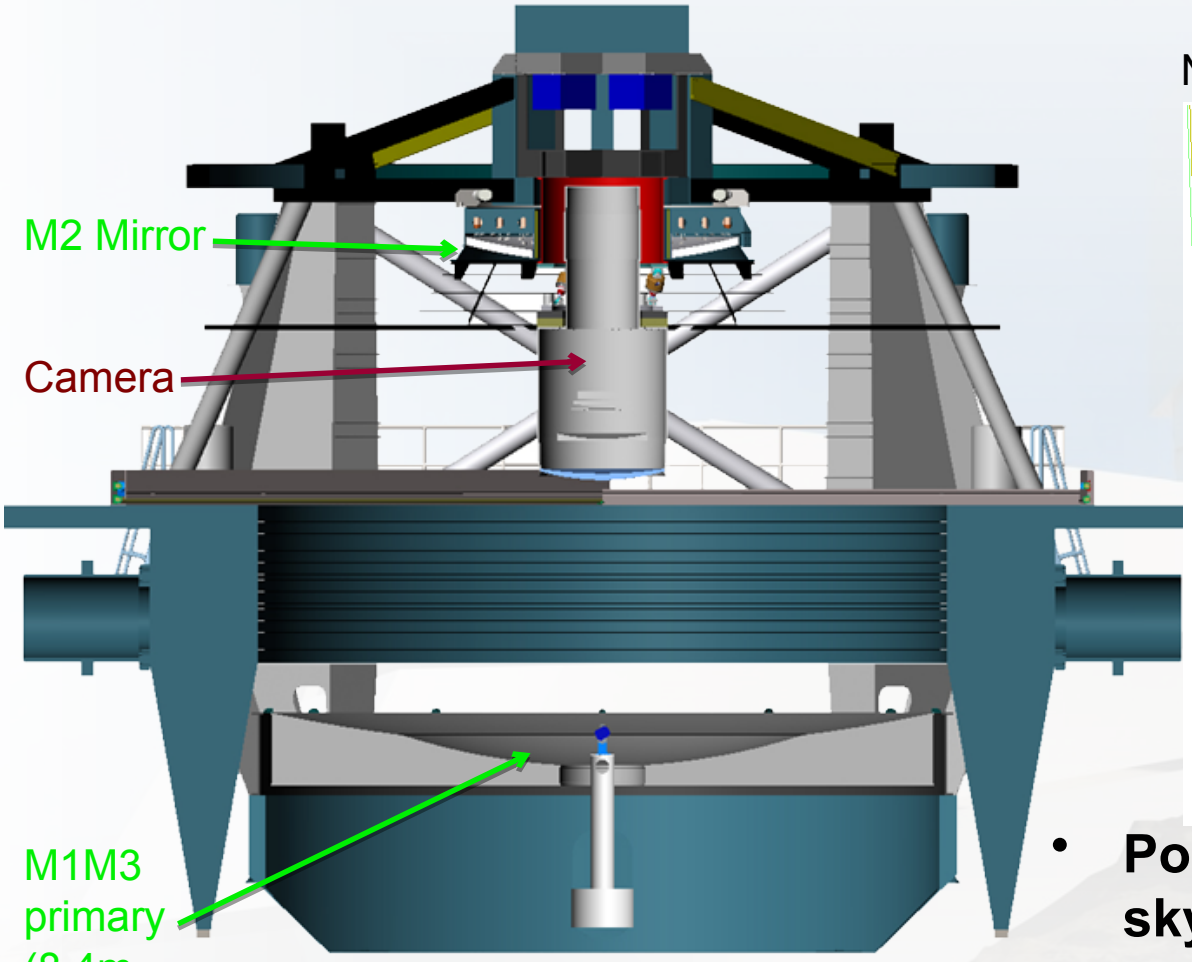


Commissioning is happening NOW !

- **AuxTel (=1CCD):** First light with spectrograph 2019 (Chile)
- **ComCam (=1 Raft/9 CCDs):** integration 2019 (Tucson), First light in 2021 (Chile)
- **Full Focal Plane:** 7/25 Rafts integrated (SLAC, Aug 2019), Completion (summer 2020), First light fall 2021 (Chile)

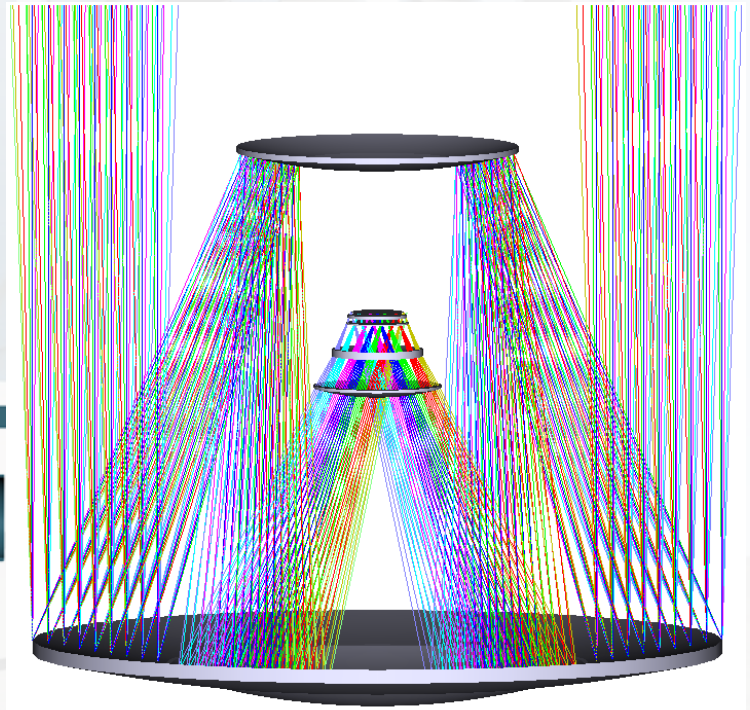
Telescope Mount Enables Fast Slew and Settle

LSST Etendue : 319 m^2 deg^2



Moving Structure 350 tons
60 tons optical systems

Modified Paul-Baker Optical Design



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

The dream is coming true !

Sep. 2019

2012 rendering

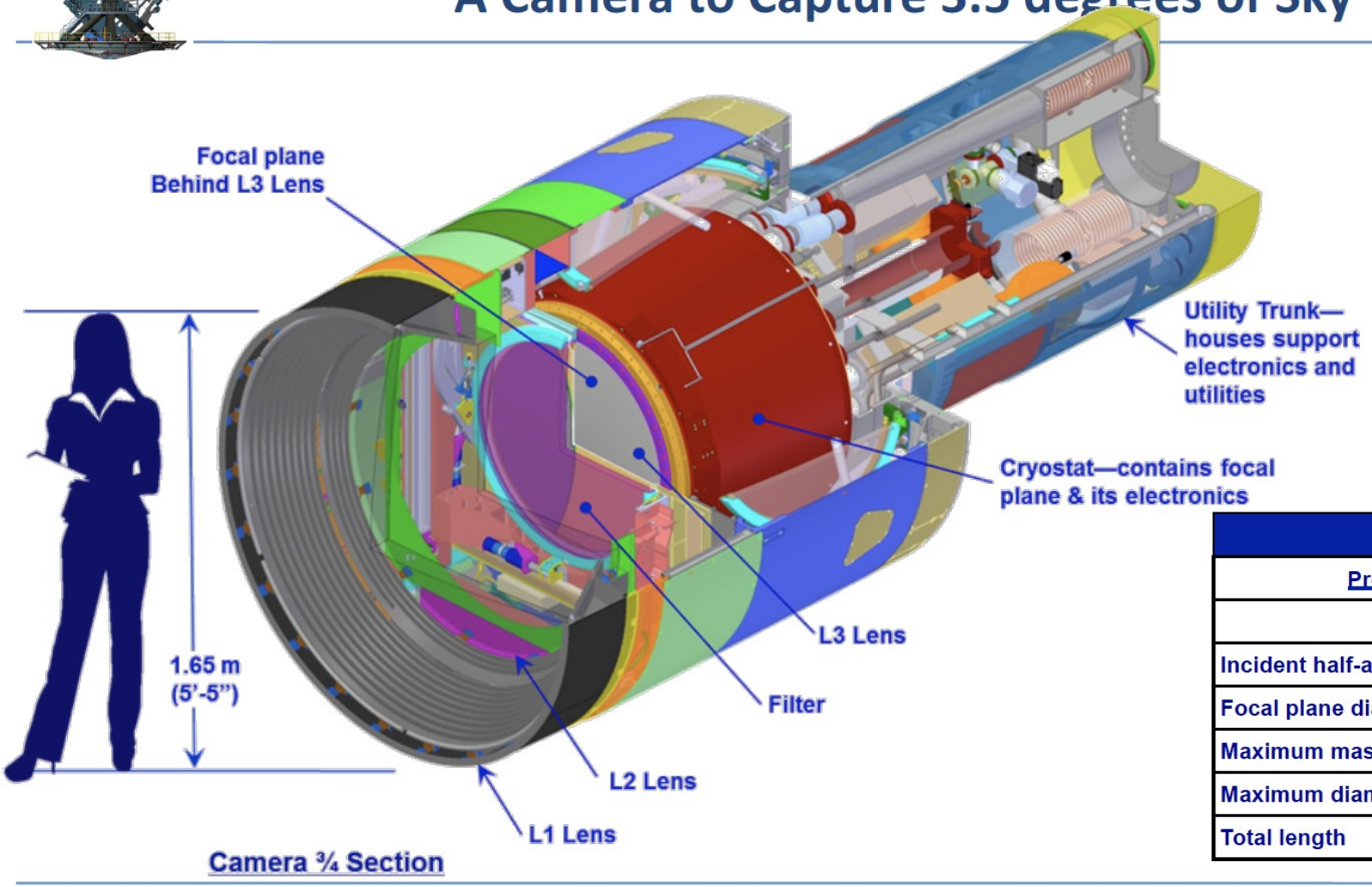
Summit Facility is complete
while Dome is constructed

Telescope at manufacturer Facility
→ being shipped to Chile

M1M3 mirror on site

LSST Camera

A Camera to Capture 3.5 degrees of Sky



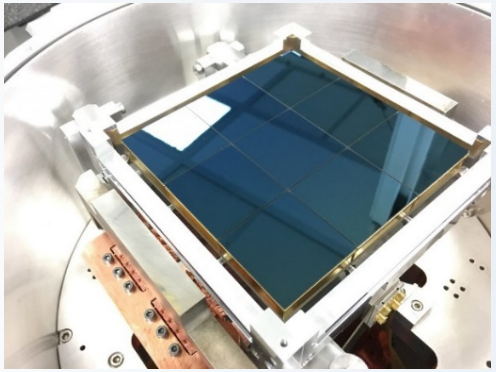
Camera ¾ Section

Camera Parameters	
Property	Value
	15 years
Incident half-angle in air	14.2°-23.6°
Focal plane diameter	634 mm
Maximum mass	3060 kg
Maximum diameter	1650 mm
Total length	3732 mm

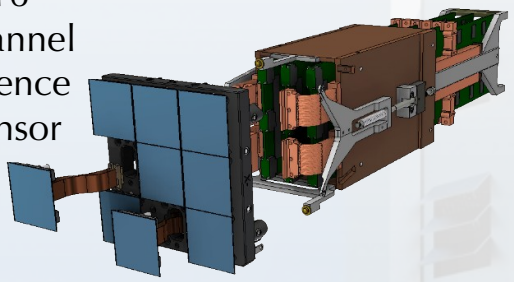
Filter excahnge System: under IN2P3 responsability

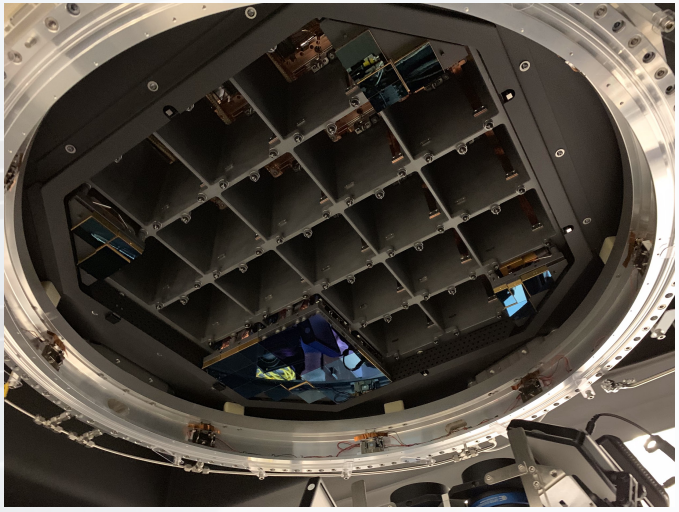
- **Successful collaboration between 5 labs**
- 5 filters within the camera for automatic switching + 1 filter swapped out depending on moon phase
- Under final testing in France, *delivery at SLAC oct. 2019*

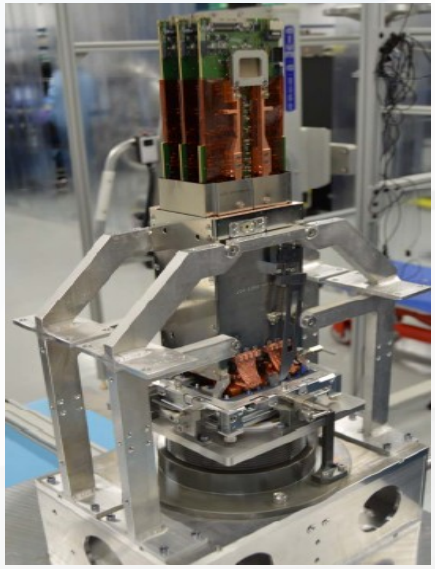
Focal plane: 63 cm and 3.2 Gpix



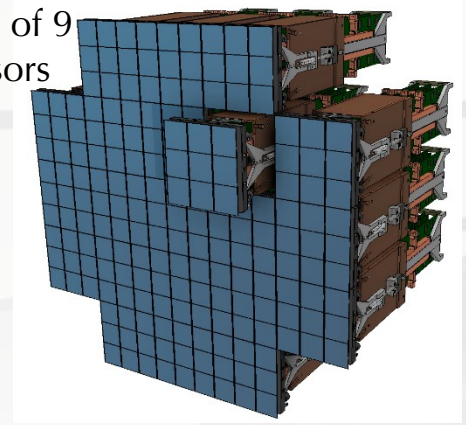
4K x 4K
16
Channel
Science
Sensor

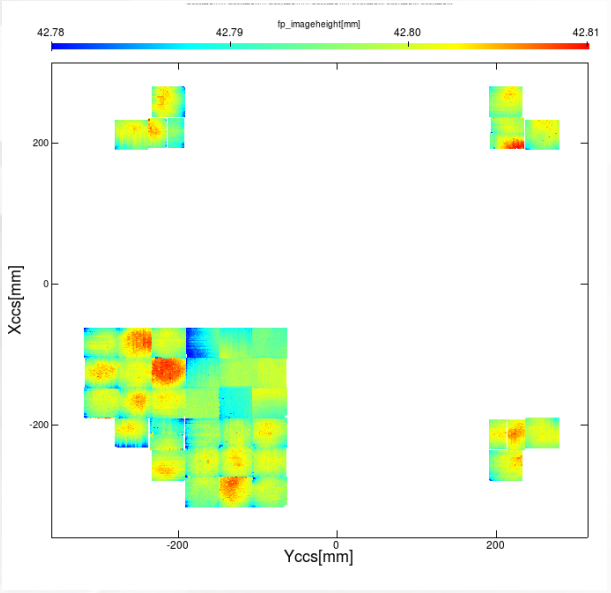






189 sensors
packed in 21
rafts of 9
sensors



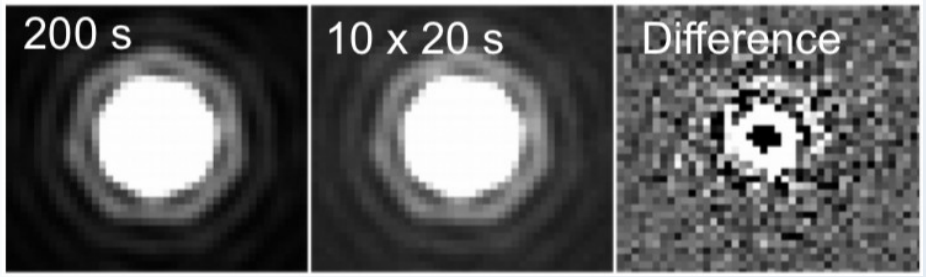


All 21 Rafts
have been
assembled

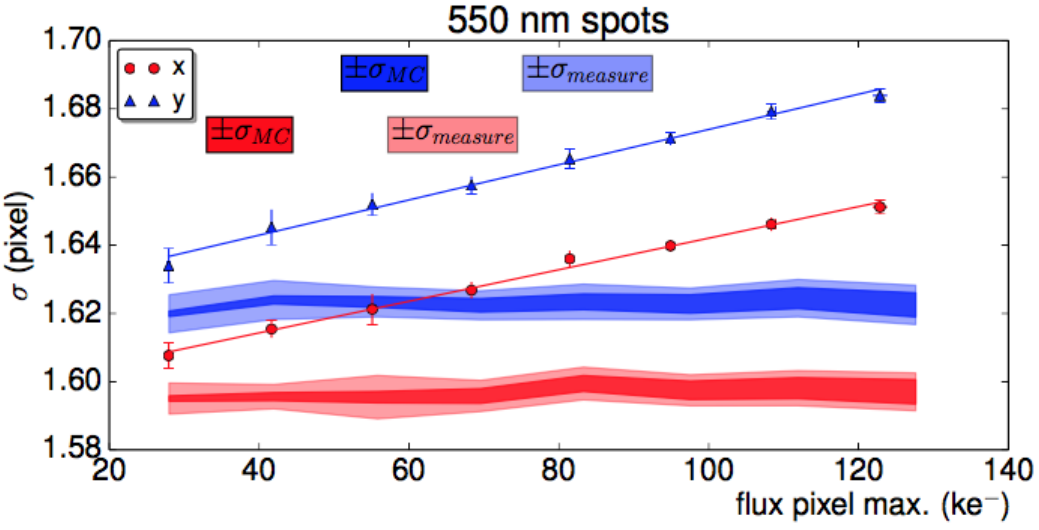
At IN2P3:
Readout electronics
CCD testing in lab

Brighter-Fatter effect Antilogus 2014

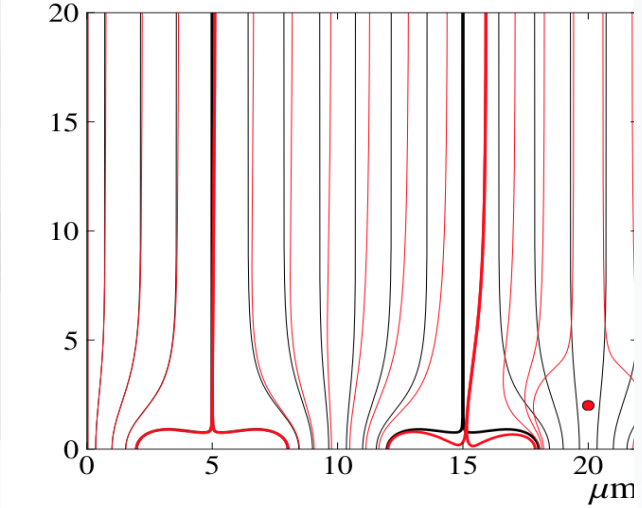
Size of star spots depends on flux

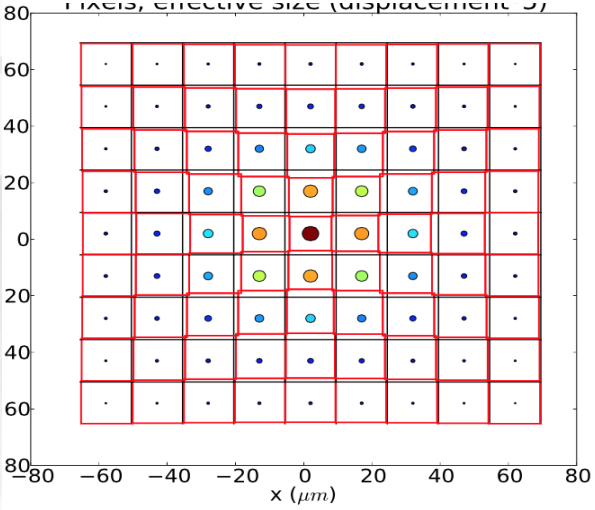


Different in x and y !



Distorsion of potentials by stored charges





→ induces an **anisotropic shape distorsion depending on flux** !
Has to be corrected

LSST data flow

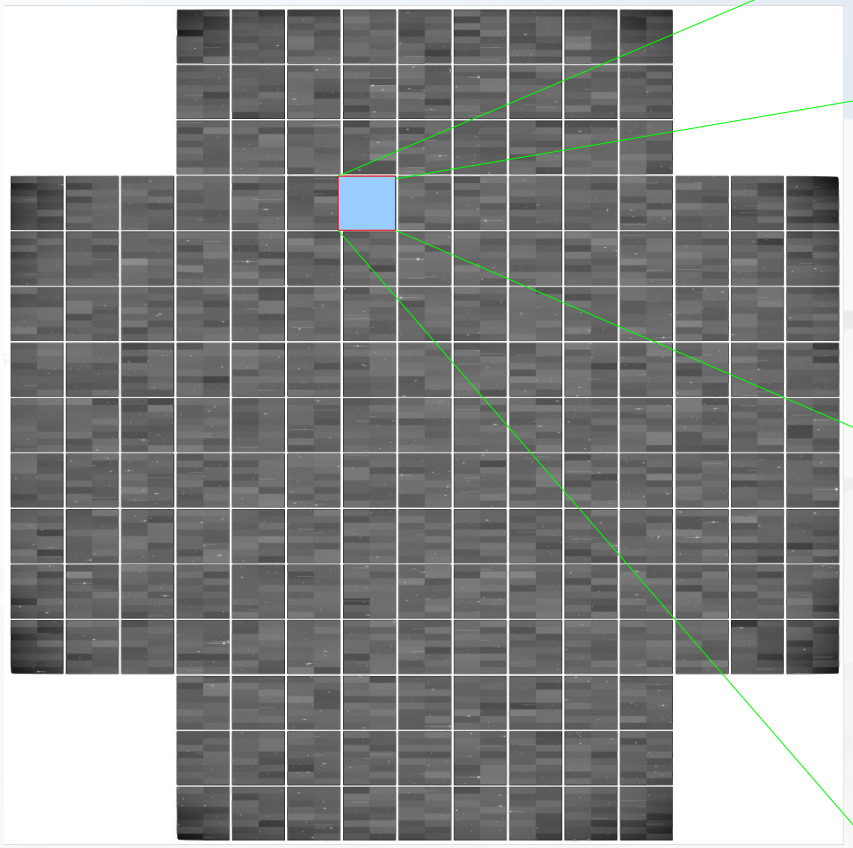
Camera : 189 CCD (16 Mpix) read in parallel

→ 3,2 G pixels !

~ 6 Gbyte / 17 seconds

→ 15 TB / night

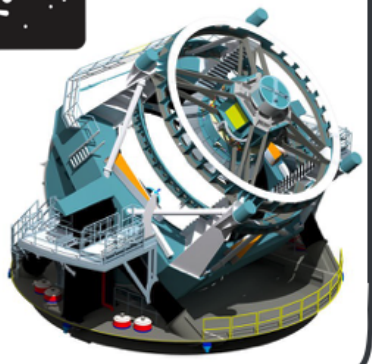
~ 1/1 000 000 000 des données LSST !



LSST Data Management

Raw Data: 20TB/night

Sequential 30s images that cover the entire visible sky every few days.

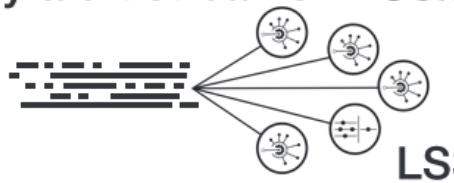


Prompt Data Products

Alerts: up to 10 million per night

60s

via nightly alert streams



Community Brokers

LSST Alert Filtering Service

Results of Difference Image Analysis (DIA): transient and variable sources

Solar System Objects: ~6 million by year 10

24h

via Prompt Products Database

Data Release Data Products

Final 10 year Data Release images: 5.5 million x 3.2 Gpx
catalogs: 37 billion objects, 15PB

via Data Releases

LSST DACs (Chile & NCSA)

Independent DACs (iDACs)

LSST Science Platform

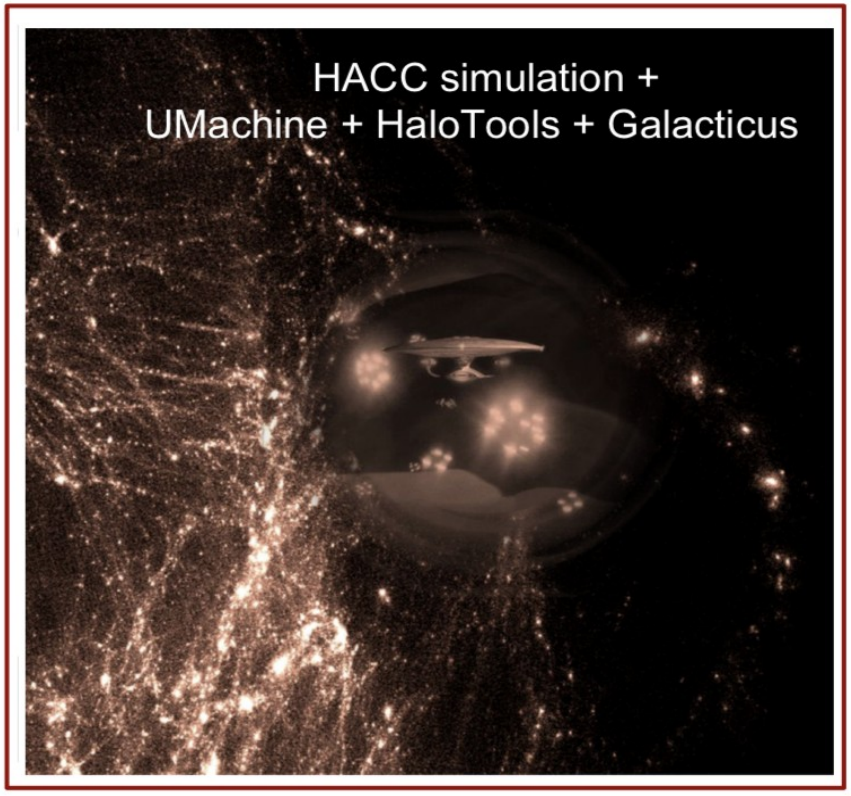
Provides access to LSST Data Products and services for all science users and project staff.

CC IN2P3 is a major data center for LSST

- Host a full copy of LSST Data
- Process 50% of Annual Data Release
- Provide access for IN2P3 scientists

Ramping up for data processing

State of the art simulation



Extra-galactic catalog generation

5000 sq. degree

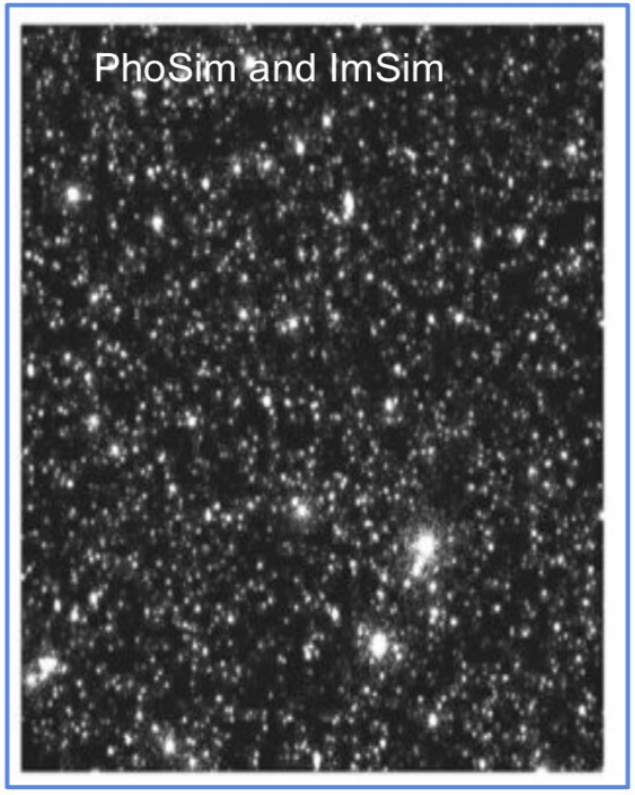
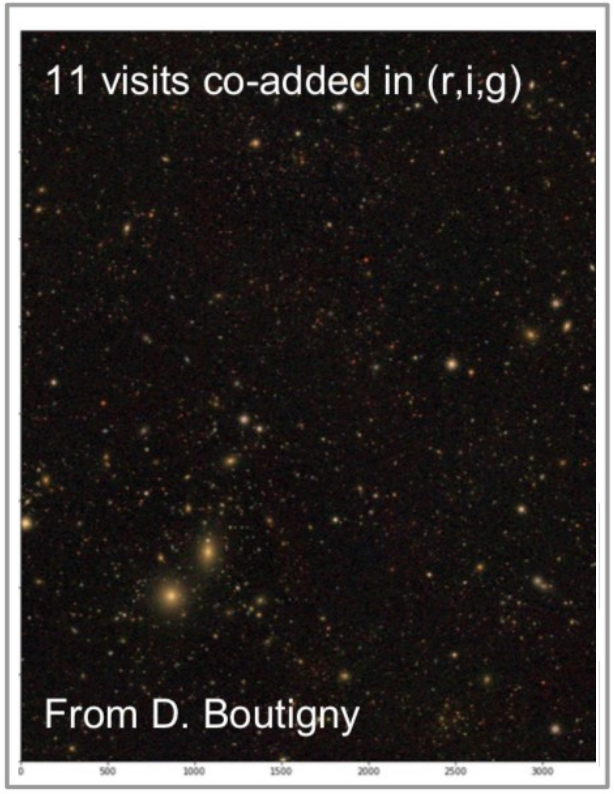


Image simulations

300 sq. degree
10 years



DM processing

CC IN2P3 is the main processing center for this simulation

FINK: Distribution of LSST Alerts in France

Supernovae

Time Frame: days to months

- ≈30.000 well sampled type Ia SNe light curves per year
- ≈1000 are expected spectroscopically confirmed per year

Microlensing

Time Frame: hours to months

- Large impact on extra-solar planet search
- Explore the mass distributions and the Milky Way dynamics.
- LSST will reach fainter magnitudes than OGLE (23 vs 20 mag)

Multi-msg Astronomy

Time frame: minutes to days

- Optical counterparts for many experiments: CTA, LIGO, Virgo, KAGRA, SVOM, KM3NET, …

Anomaly detection

Time Frame: minutes to months

- Unforeseen astronomical sources is one of the most exciting outcomes.
- Should be more pronounced after a few seasons.

FINK:

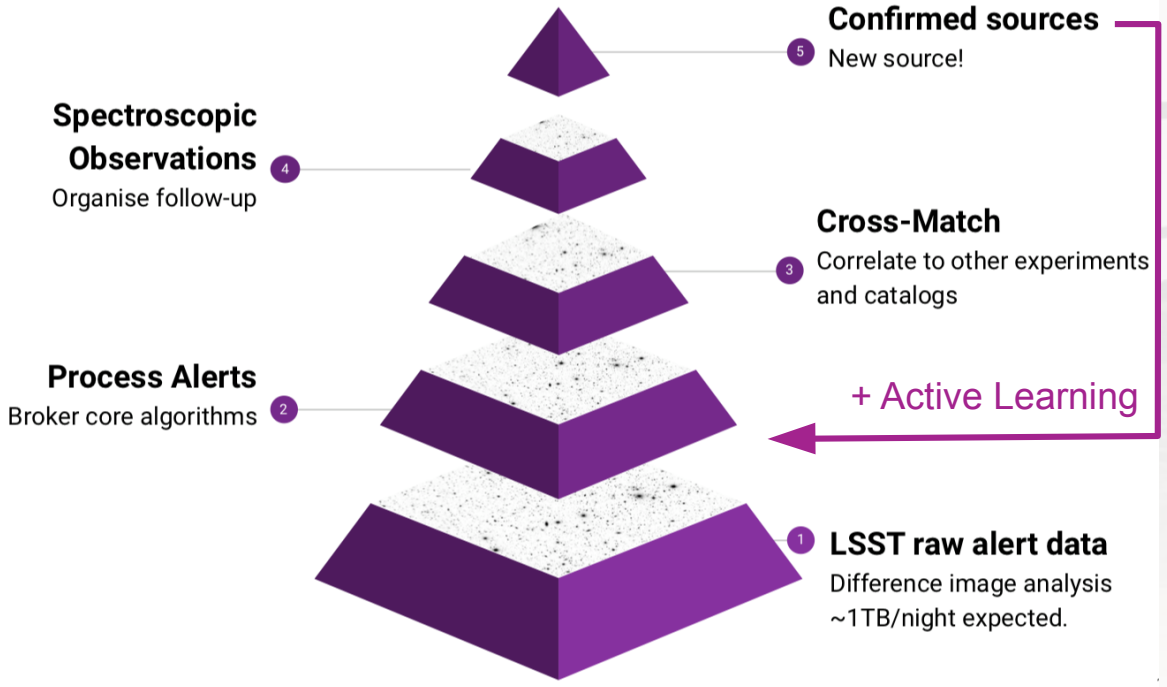
Based on **Spark technology**

- Full archive of alerts
- Real-time xMatch (catalogs from CDS@strasbourg)
- Advanced ML techniques
- VOevent compatible alert distribution

Scales up to 7x LSST stream (50 cores)

Full set of services at CCIN2P3

- LSST static catalogs
- LSST Science Platform

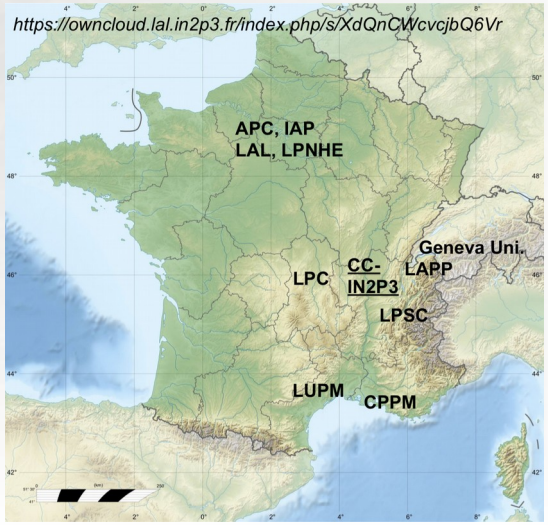


Status:

- Call for LOI by LSST in 2019
- Enabled by *public alert stream*
- FINK has been preselected !
- Final proposal due summer 2020

- 31 endorsers
  - 2/3 LSST-France
  - 1/3 from other projects
  - **open to new collaborators !**

- *Links with CTA, Fermi-LAT, INTEGRAL, KM3NET, SKA, SVOM, Virgo*

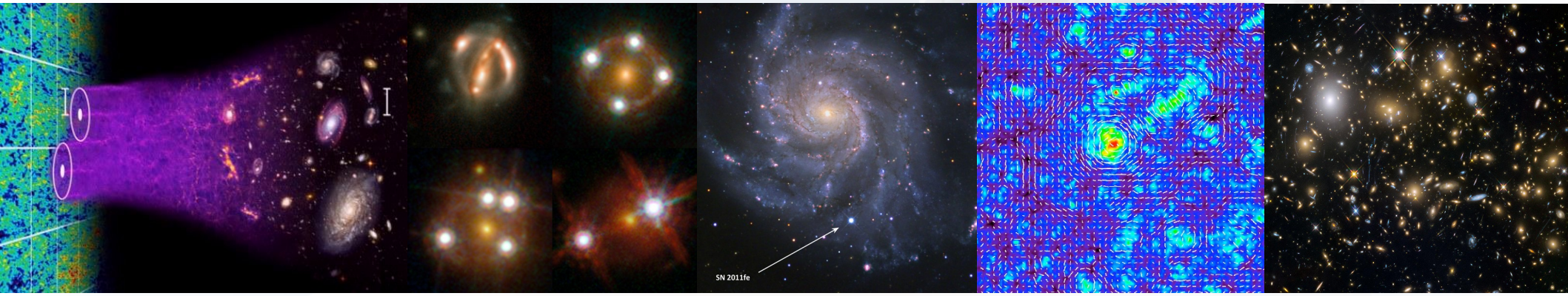


Preparing for the science

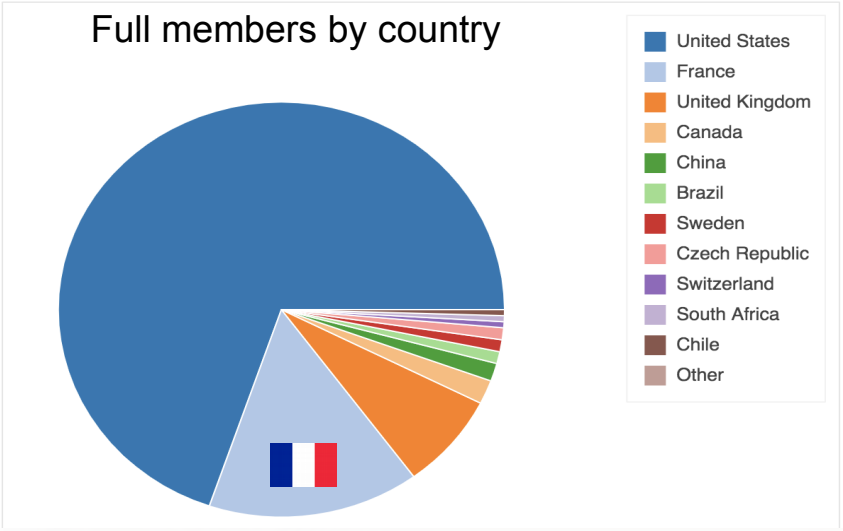
DESC: the Dark Energy Science collaboration

5 Dark Energy Probes

Large Scale Structures | Strong Lensing | Supernovae | Weak Lensing | Clusters



949 Members – 215 Full Members

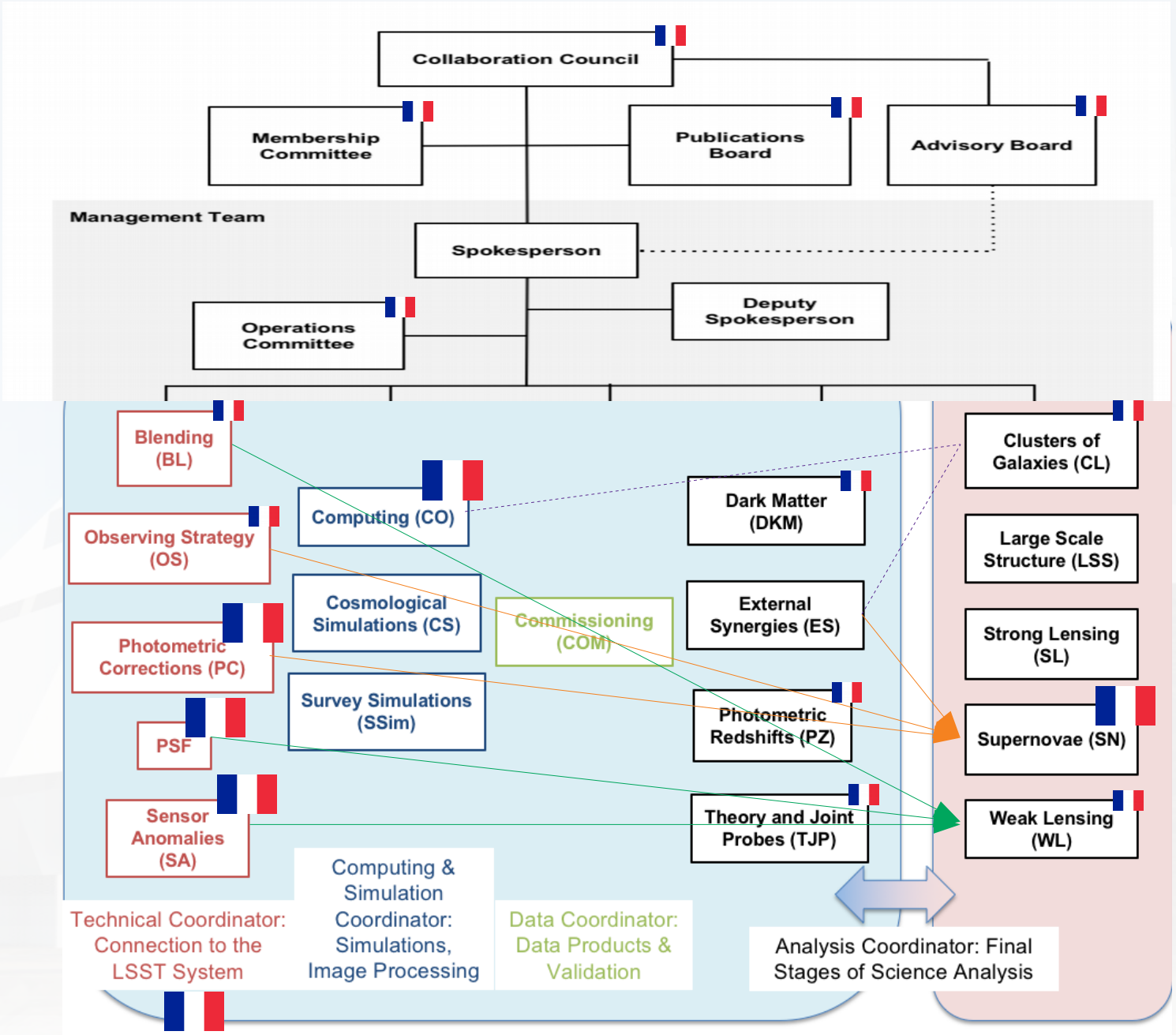


~15%

DESC and Dark Energy

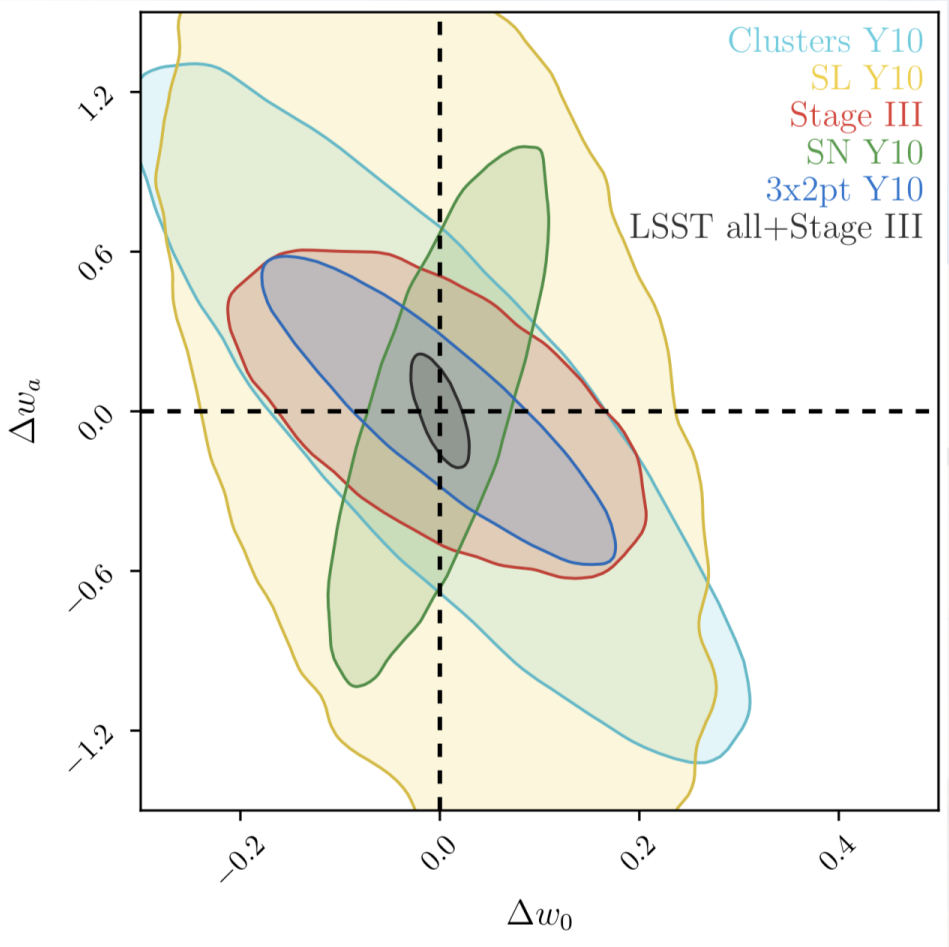
- **Background Cosmology** is addressed by Type Ia supernovae, Strongly lens systems, (BAO)
- **Dark matter structure and growth** probed by Weak gravitational lensing, Galaxy clustering, and Clusters of Galaxies
- LSST will constrain Dark Energy by Probe combinations (ex: 3x2 pt), it is a **systematics-limited project.**
  - Photometric Redshifts are a common source of systematics. Many systematics can be mitigated by External Data
  - **Technical aspects:** Sensors, PSF, Calibration, Blending, Observing Strategy play a significant role for the quality of the FoM.
- **Computing aspects:** Cosmological and Survey Simulations as well as Computing are key ingredients of the project
- Preparing for **Commissioning** is ramping up !

DESC Organization



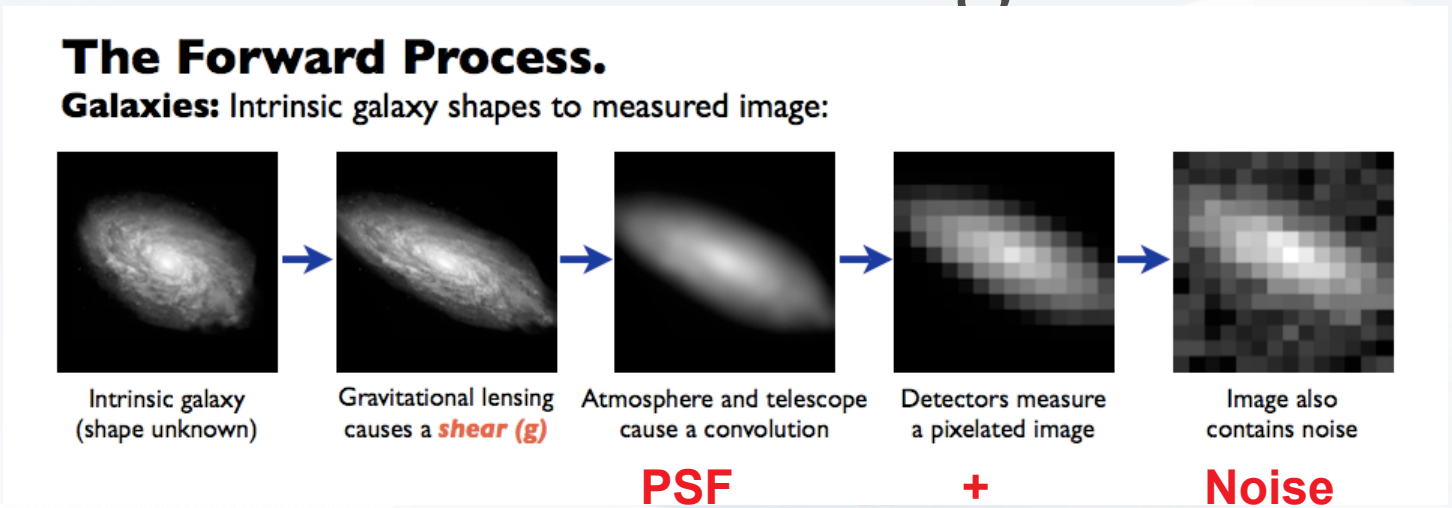
Science Requirements ArXiv 1809.01669

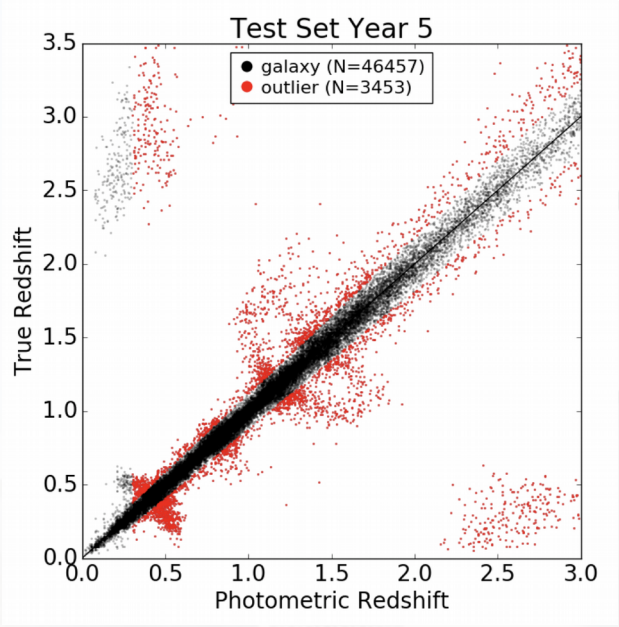
10 year forcasts



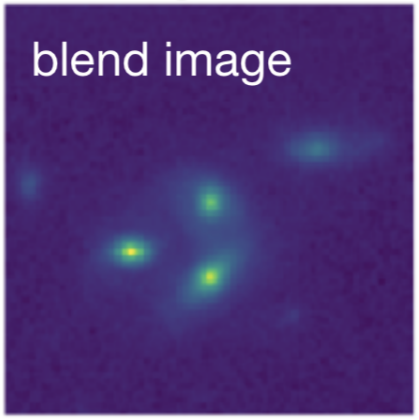
- Forecasts for 1 and 10 yr
- Full review of known systematics
  - Calibratable and self-calibrated
- Target: FoM of 500 for 10yr
  - Calibratable systematics should not dominate statistics
- Requirements for each probe

Shear challenges

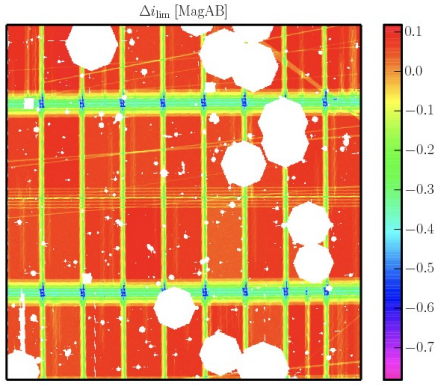




Graham 2017 **Photo-z**



Blending

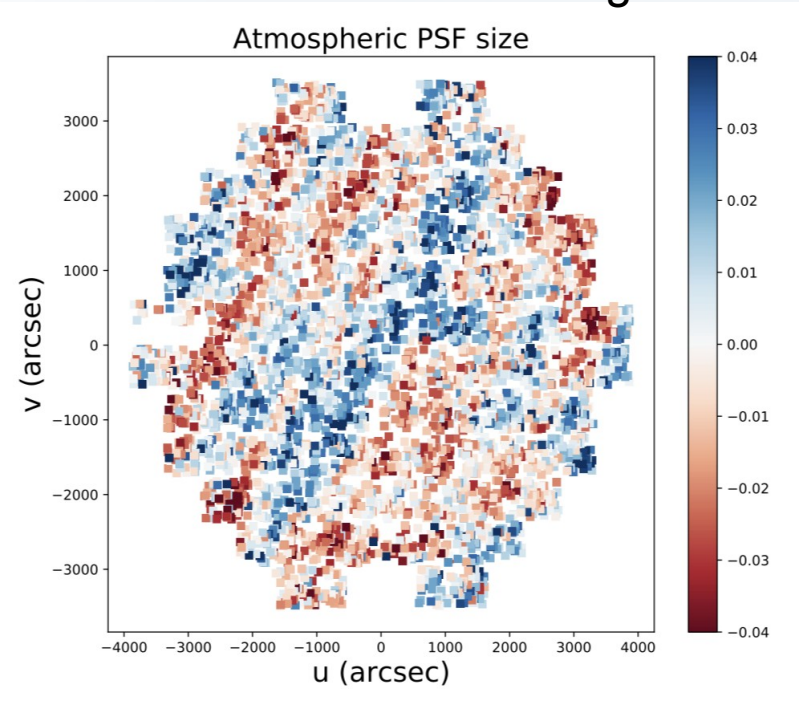


Masks, sensor effects

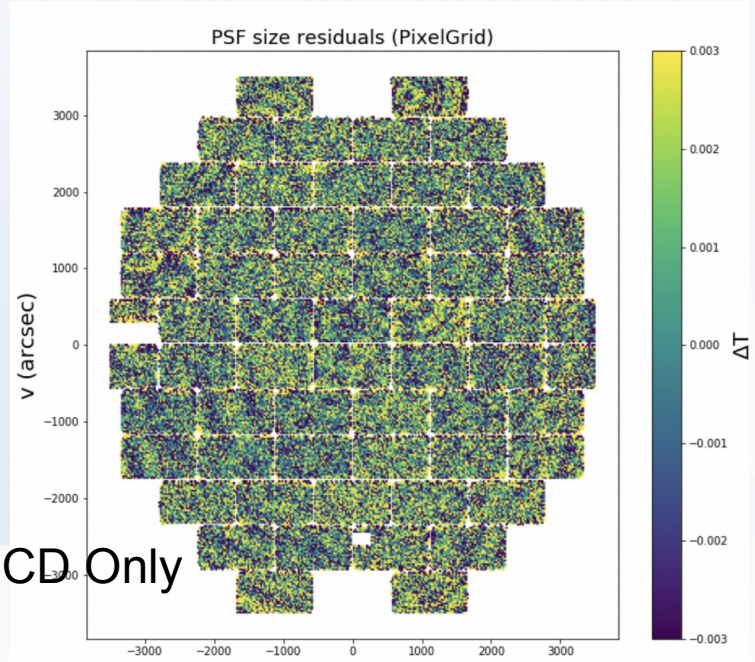
+ Astrophysics : intrinsic alignments, baryon feedback…

PSF improvement

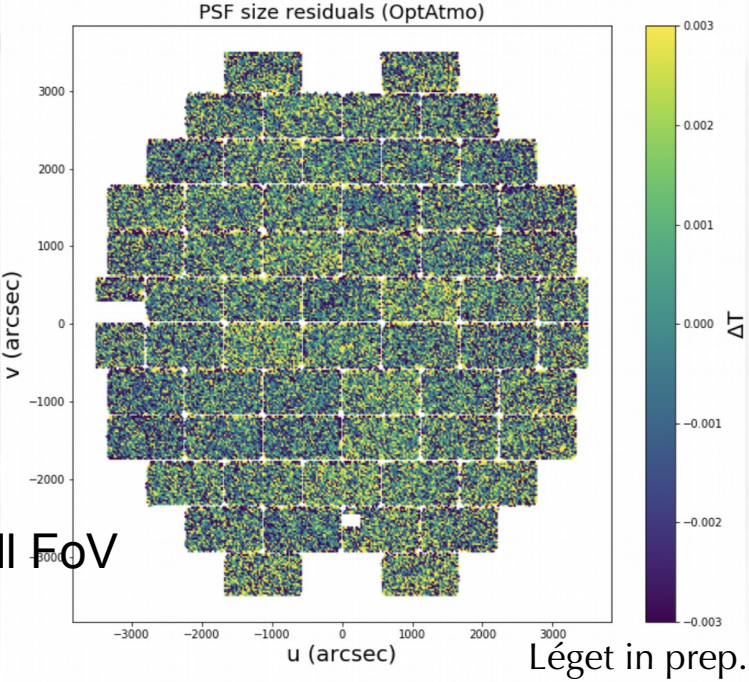
PSF within a DES image



Residuals



CCD Only

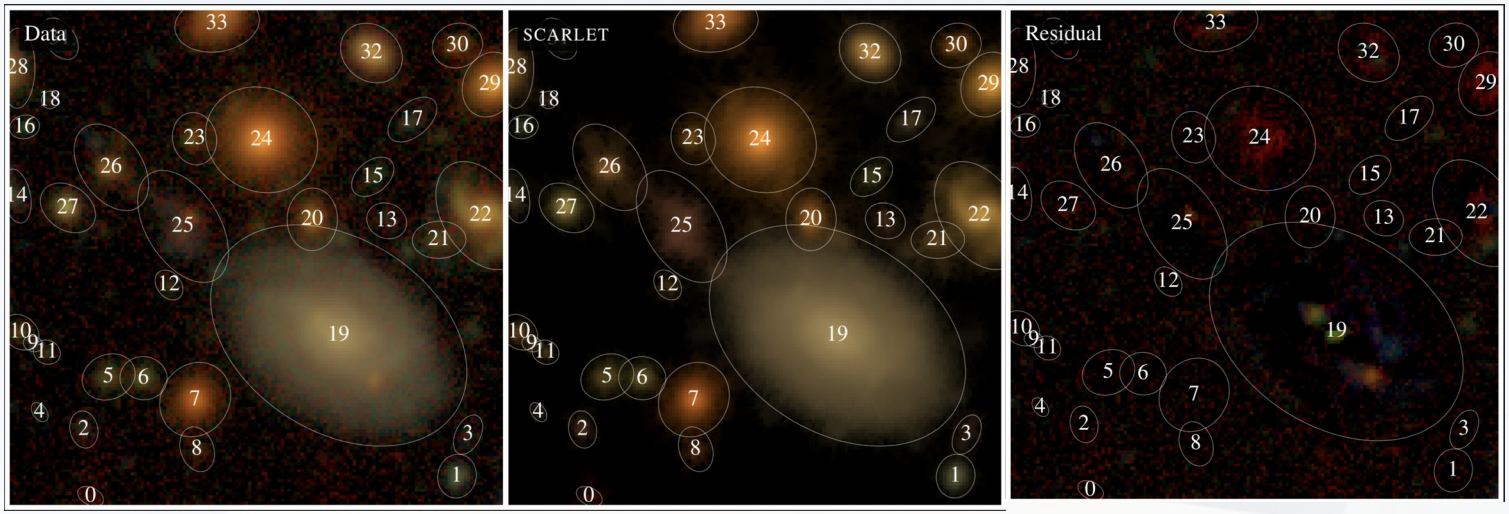


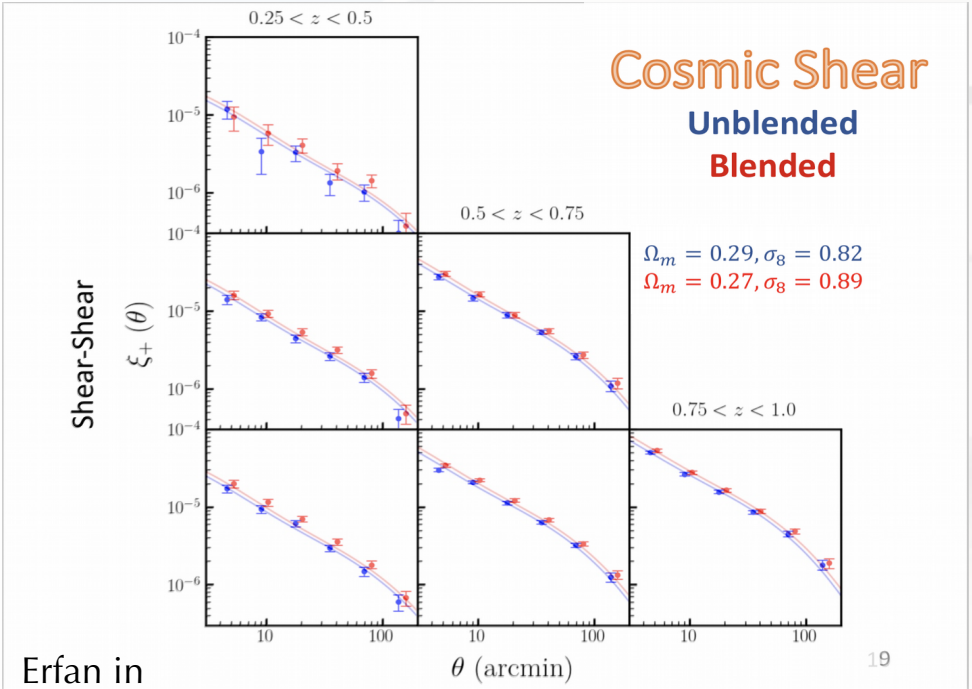
Full FoV

PSF size is correlated across full focal plane

- Single CCD treatment insufficient
- Full FoV model :
  - optical model (Zernike)
  - Von Karman atmospheric correlations

Deblending is an issue !



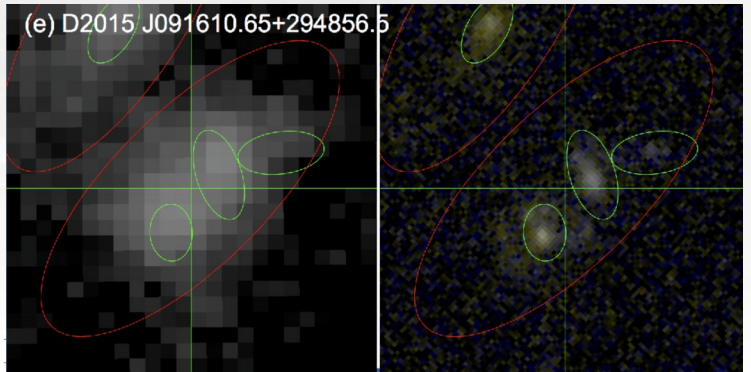


Erfan in prep.

- Assess current algorithm performance
- Develop new approaches (Deep learning)

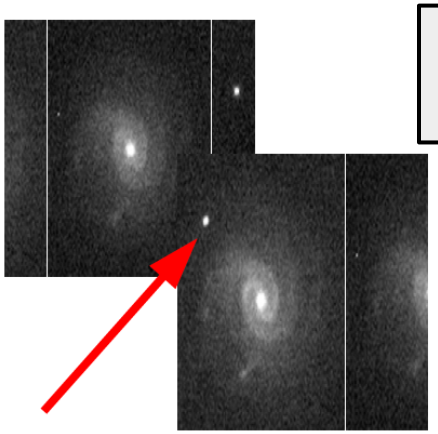
- Synergies with other data
  - Space-based (Euclid)
  - Other filter set (HSC)

Dawson 2016



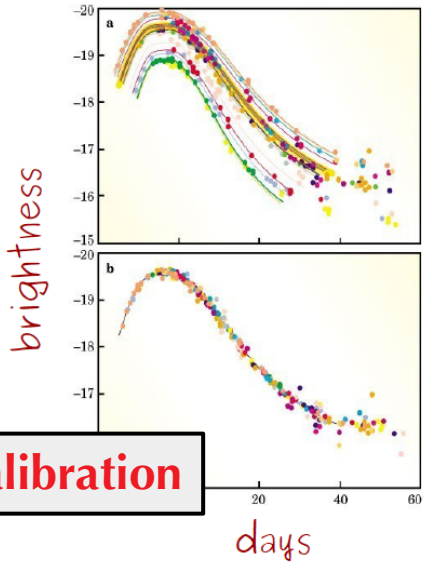
Supernova challenges

1. detection



Survey strategy

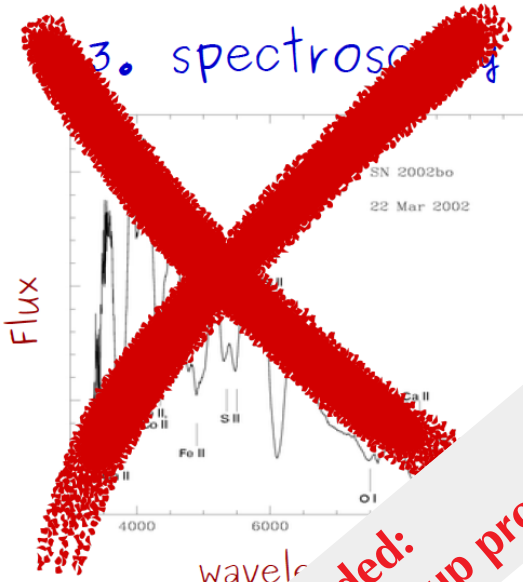
2. photometry



Calibration

Indentification

3. spectroscopy

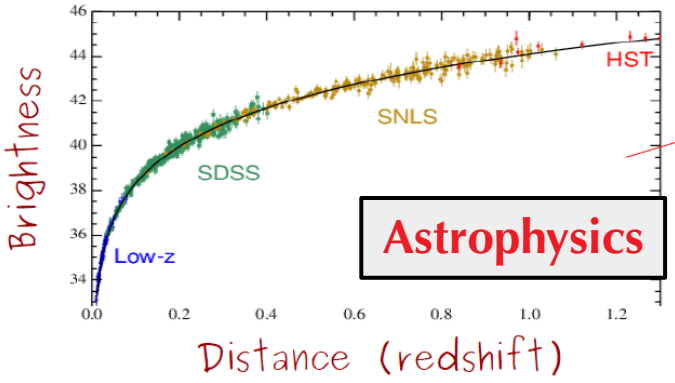


wavelength

Distance (redshift)

Needed: Follow-up program

4. standardization + cosmological fit



Astrophysics

year	Number of supernova
1998	42
2014	740
2025	> 10 000

Slide borrowed from *Emille E. O. Ishida*

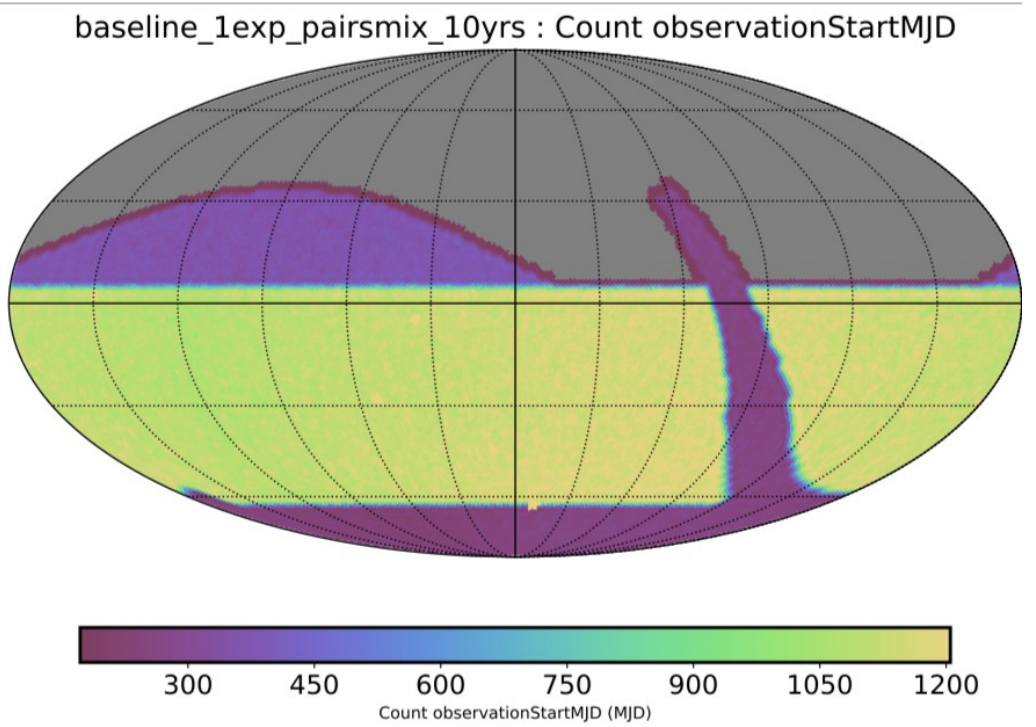
Observing Strategy (Cadence)

The project is revisiting the observing strategy

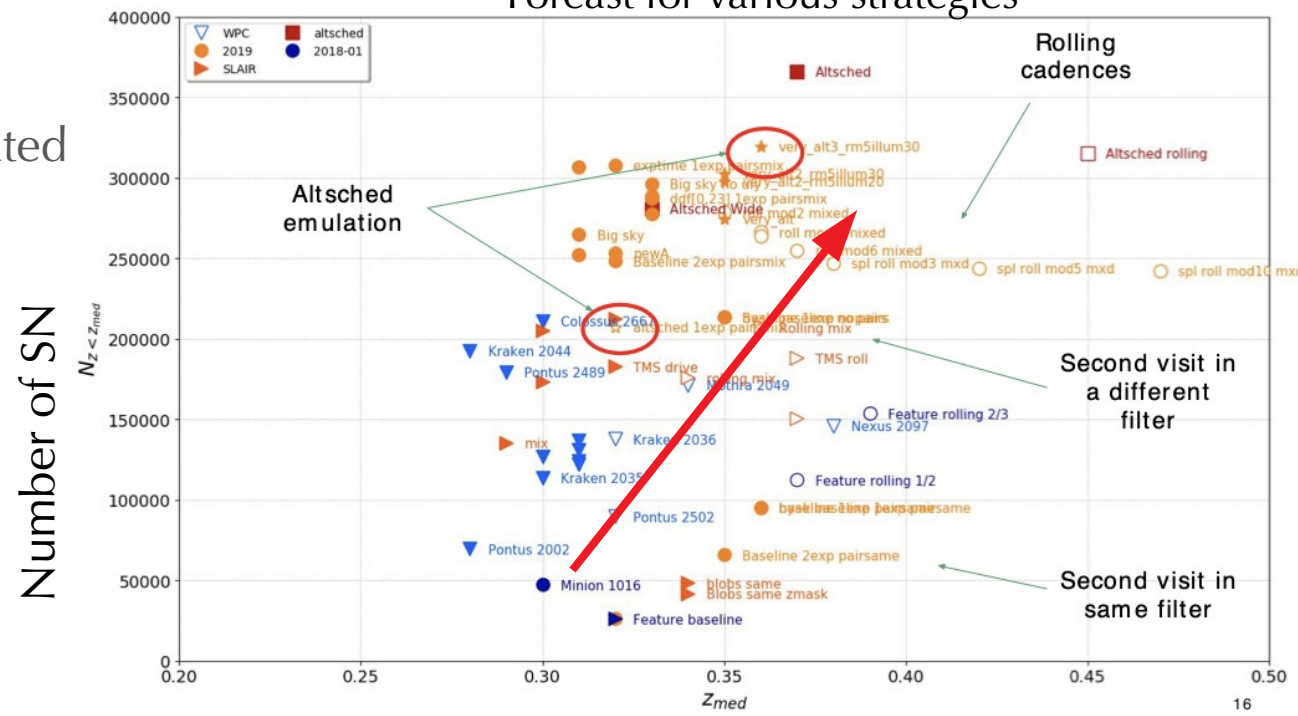
- White papers in 2018
- Decision made in 2020

- **Wide Deep Field** : 90% of observing time
  - Default cadences significantly impair the SN program
    - O(50 kSN), low z limit
  - Move toward **rolling cadence**
- **Deep Drilling Fields**: 5% of allocated time
  - Ongoing optimization
  - From 15 to 27 kSN z~0,8
  - SN and AGN are competing

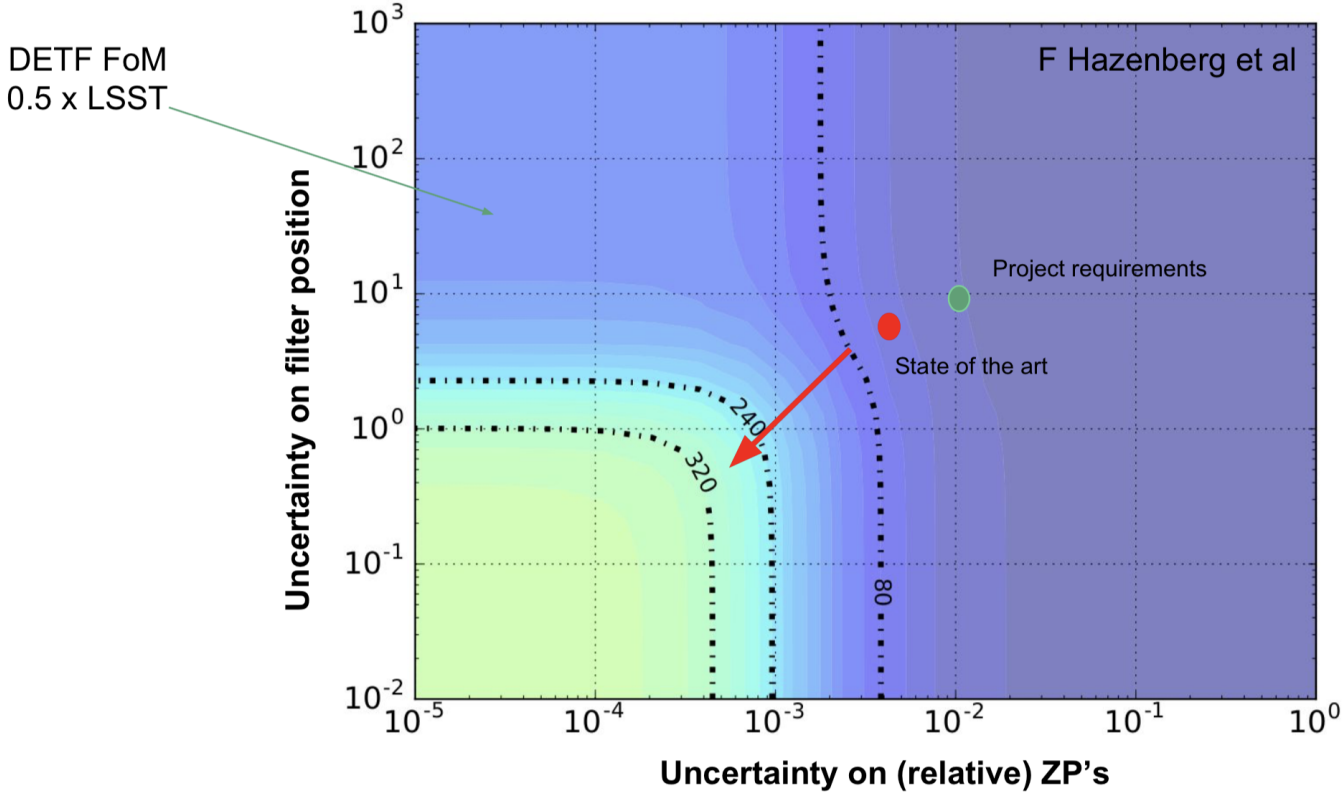
- **More SN means more science**
  - → Universe Anosotropies !



Forcast for various strategies



Calibration constraints



- LSST requirements beyond what is needed for DESC !

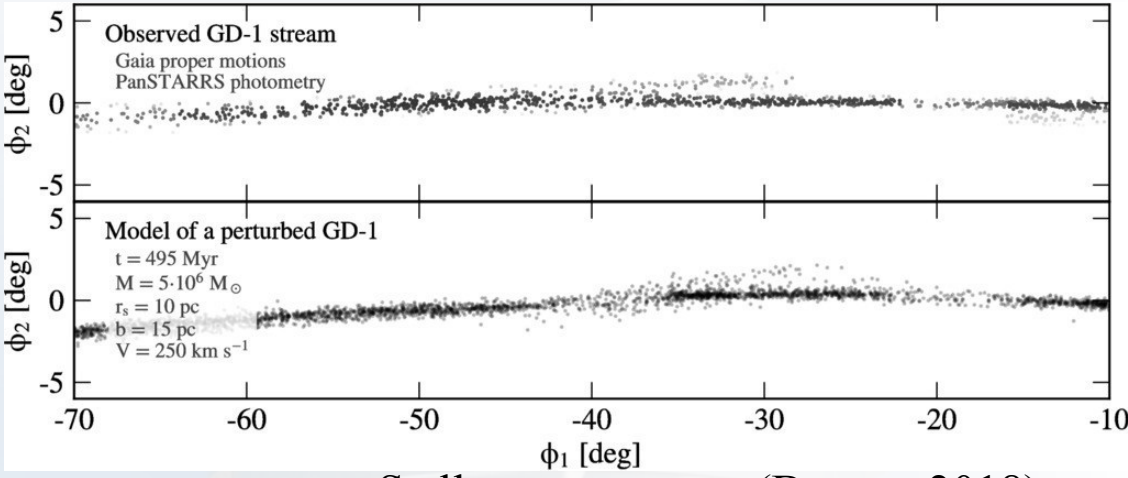
	DESC	LSST	Etat de l'art
Primary Flux Standards	0,1%	1%	0,5%
Filter Bandpass	0,1 nm	1 nm	0,5 nm
Flux metrology chain	0,1 %	1%	0,5%

- We are now closely working with the project for improvements

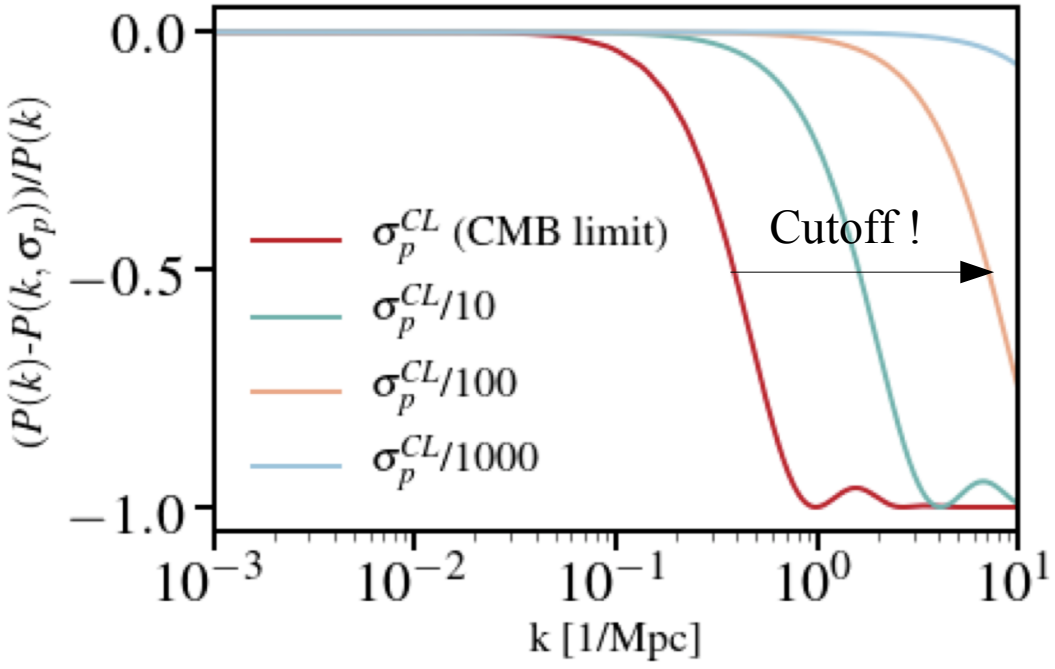
LSST-DESC
Photometric correction
Working Group

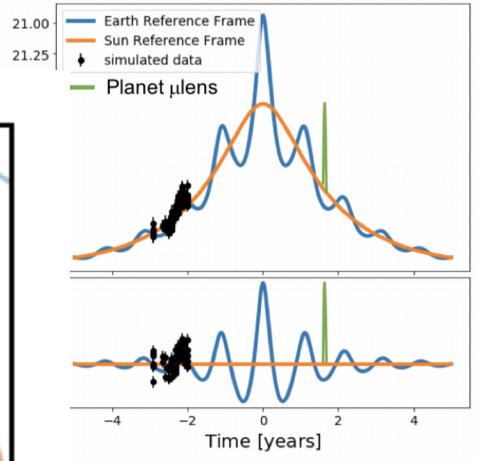
DESC and dark matter

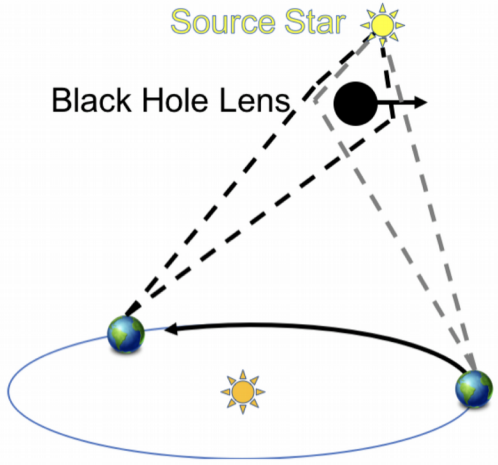
- ArXiv:1902.01055
  - Minimum halo masses
  - Halo profiles
  - Microlensing
  - Anomalous energy loss
  - Large scale structure



Stellar stream gaps (Bonaca 2018)







Matter power spectrum is sentitive to Dark Matter microphysics !

Conclusion:
How to contribute

- Project-Wise:
  - **Computing** is a major IN2P3 deliverable
  - **Commissioning** is demanding new resources
- Science-Wise:
  - **Shear:** wide effort on systematics
  - **Supernovae:** photometry, anisotropy science
  - **Clusters:** calibrate the mass function
- But also:
  - **FINK !** optical counterparts of IN2P3 science transients

  Dark matter, neutrinos… many other topics

→ Time to join the team !