LSST (now : Vera Rubin Observatory)

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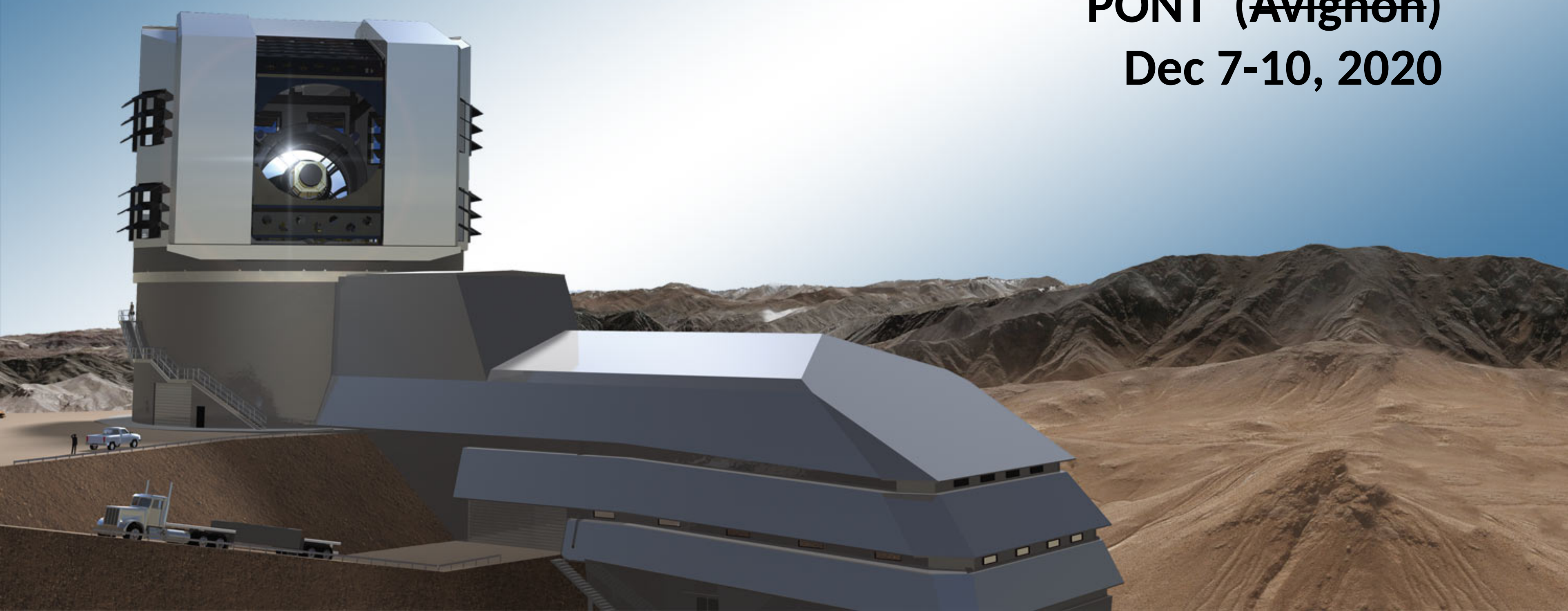
LPNHE-IN2P3/CNRS, SU, Paris

PONT (~~Avignon~~)
Dec 7-10, 2020



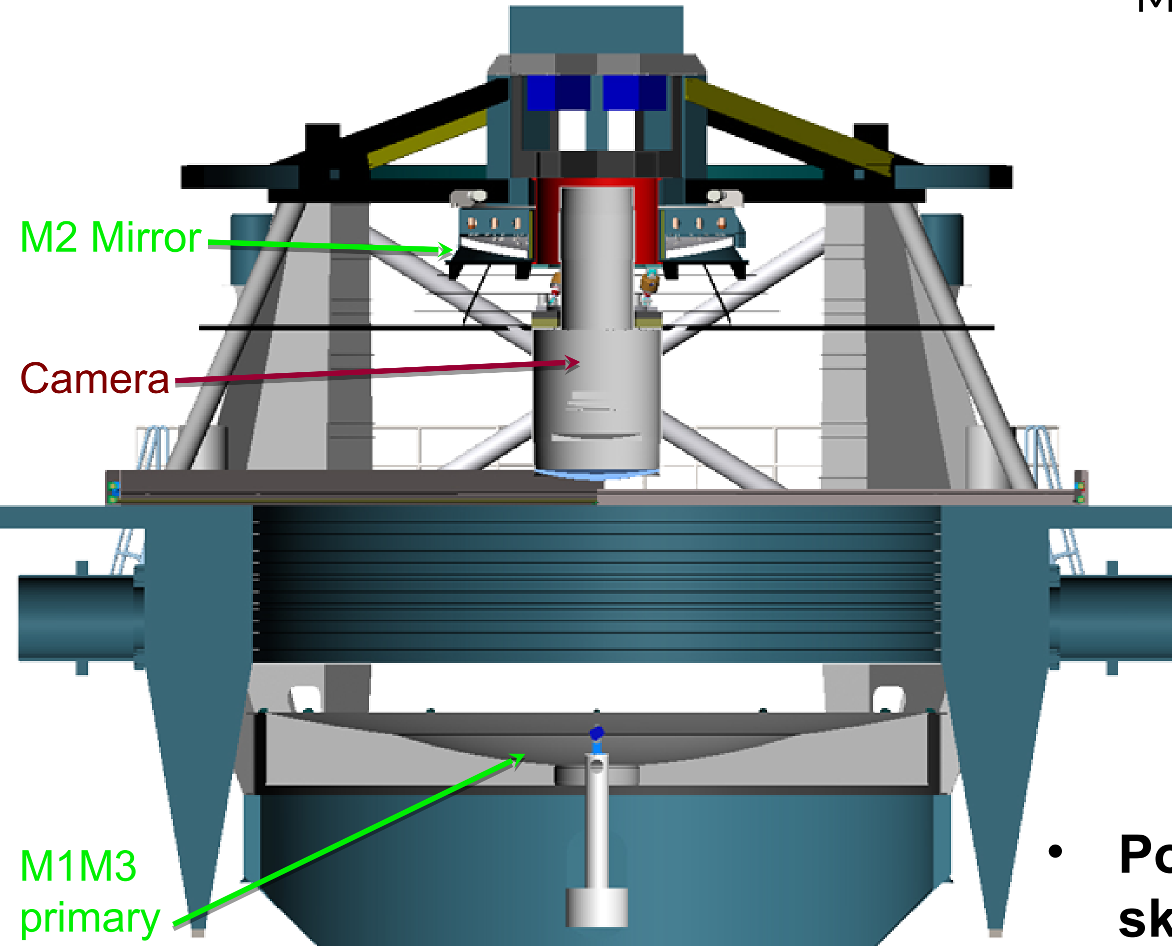
LSST in a Nutshell

- 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.

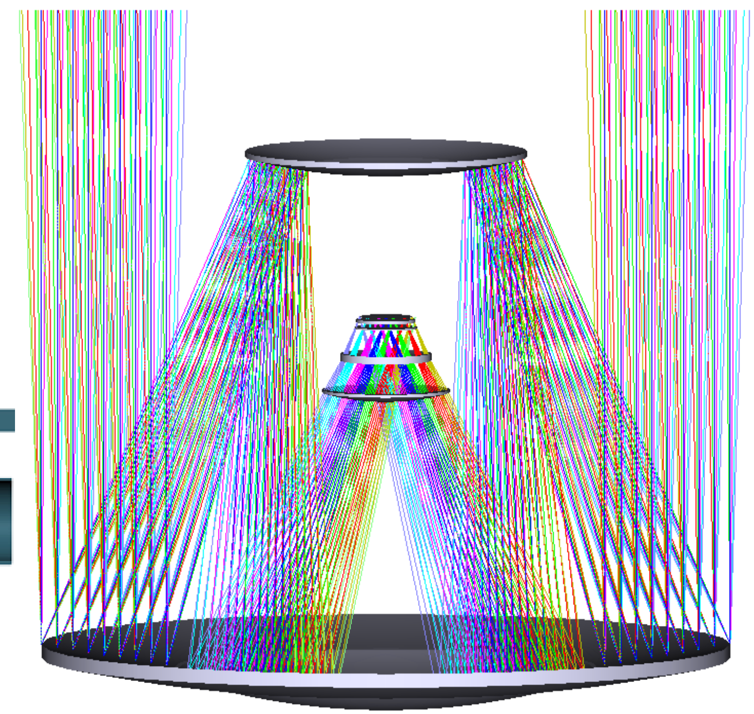
LSST : Wide , Deep and Fast (1/2)

Telescope Mount Enables Fast Slew and Settle

LSST Etendue : 319 m² deg²



Modified Paul-Baker Optical Design



Moving Structure 350 tons
60 tons optical systems

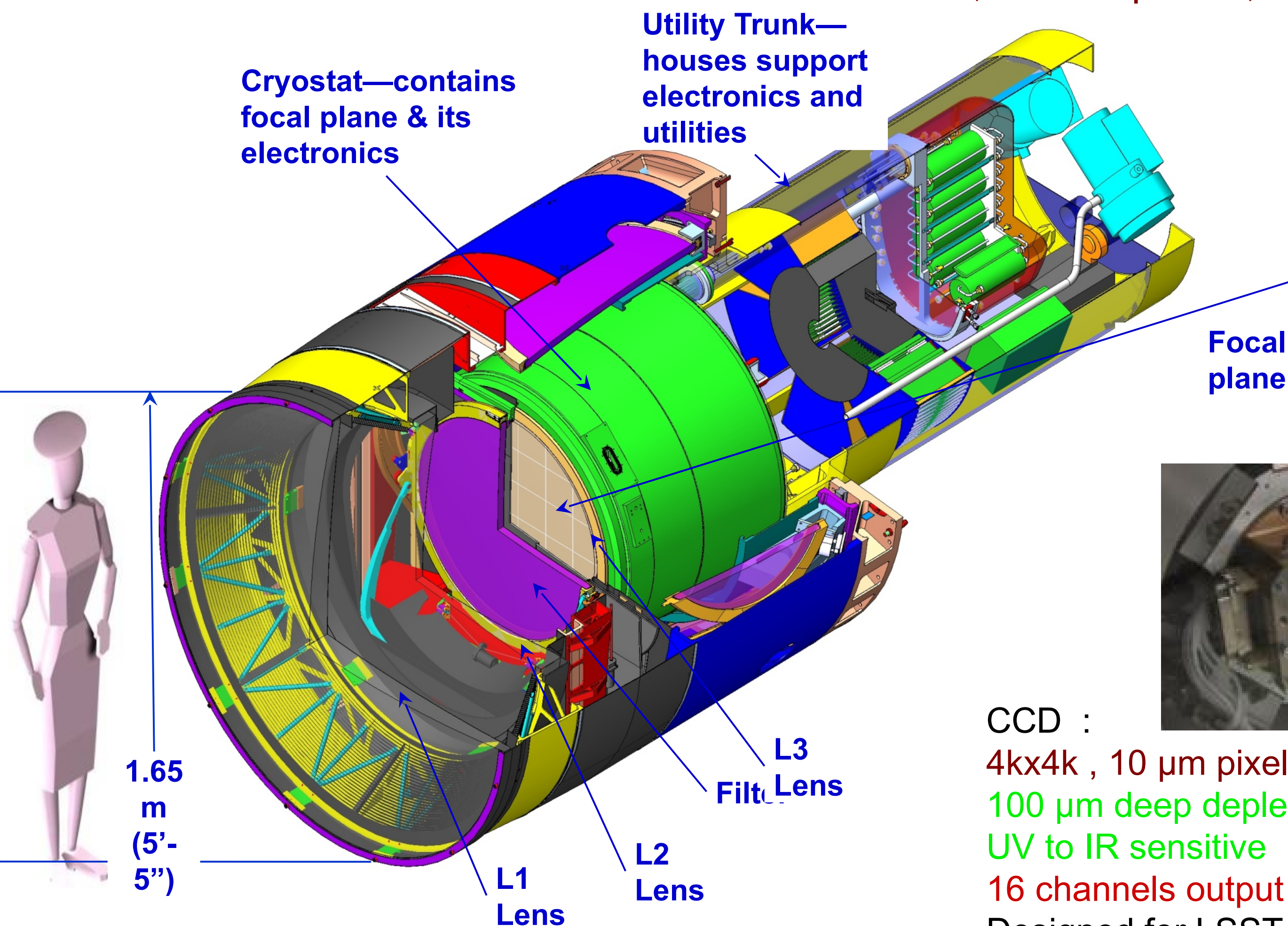
- **Points to new positions in the sky every 39 seconds**
- **Tracks during exposures and slews 3.5° to adjacent fields in ~ 4 seconds**

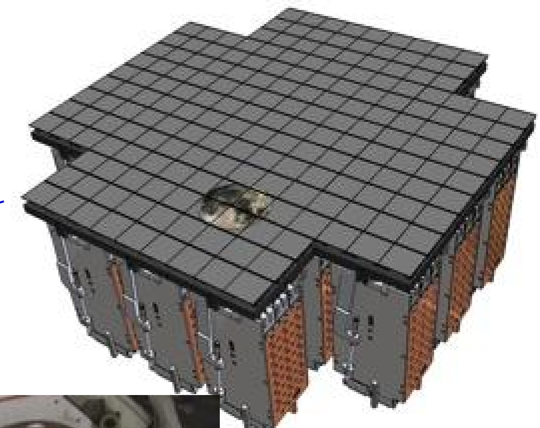
LSST : Wide , Deep and Fast (2/2)

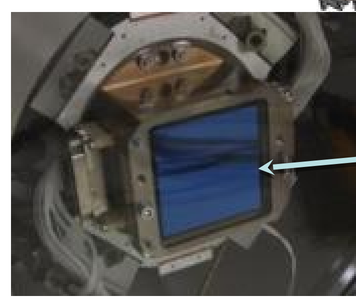
Field of view : 3.5 deg (9.6 deg^2 =.023% sky sphere)

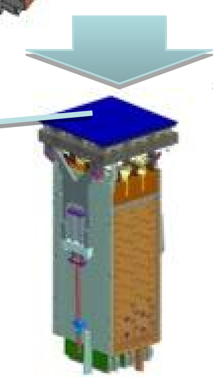
Focal plane diameter : 64 cm ; 189 science CCD (21 rafts)

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 a 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

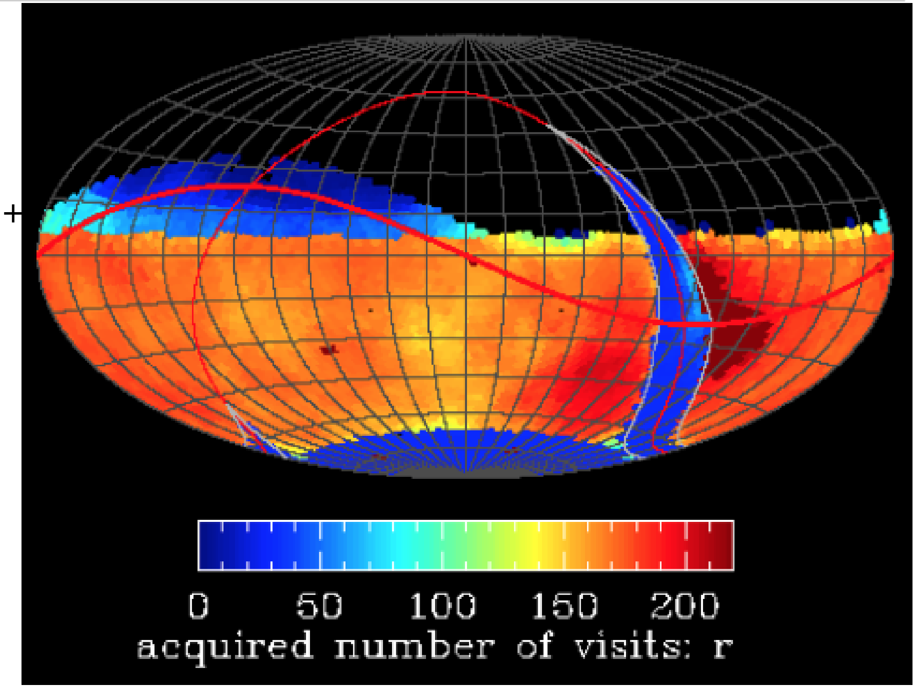


Image Quality
Mean seeing at the site is ~ 0.7 arcsec
PSF FWHM < 0.4 arcsec (no atmospheric seeing).
PSF Ellipticity < 0.04
(referenced to 0.6 arcsec FWHM circular Gaussian)

Photometric precision (requirements):
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 + 1 s shutter + 2 s read + 15 s
+ 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 : Central Chile
on El Peñón peak of Cerro Pachón at 2682m

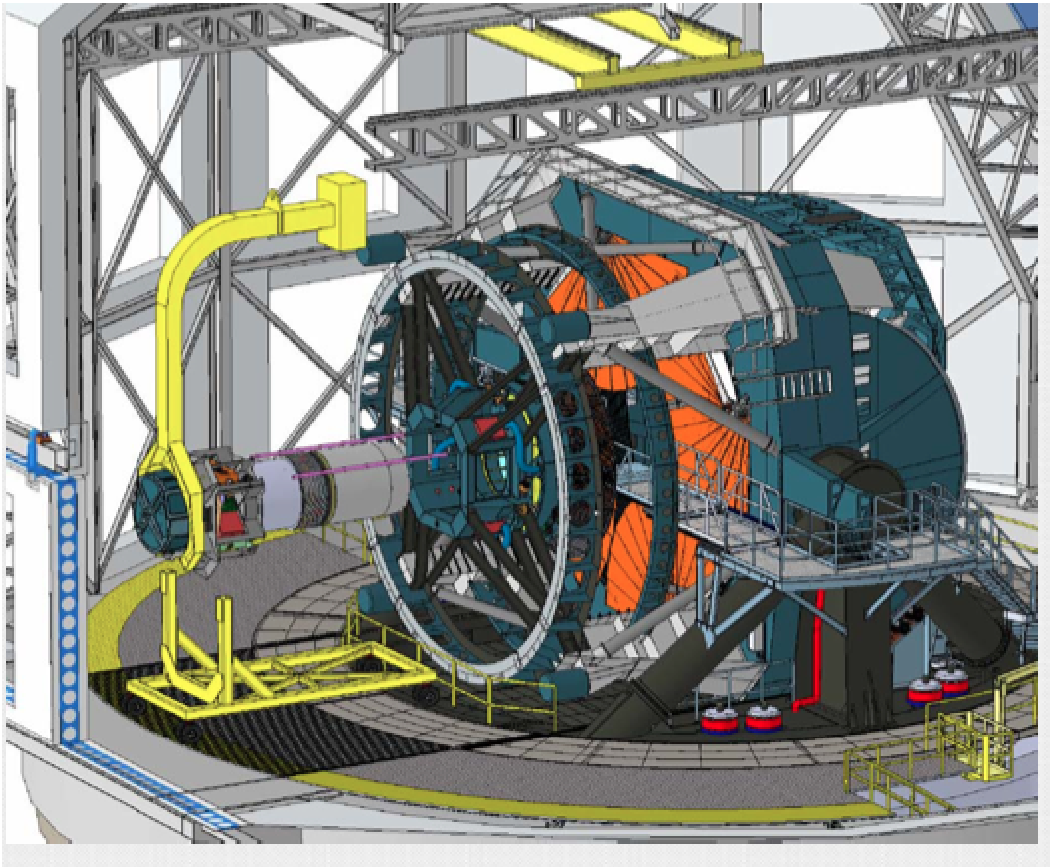
August 28 2020 : dome approaching completion.

LSST Calendar (obsolete)

- 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

Focal plane assembled at SLAC

No way ! New schedule under way



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.**

NB:

- **There is essentially a single set of observations**
- **The core of the data reduction (pixels → catalogs) is common**

Four Key Science Themes Used to Define the Science Requirements

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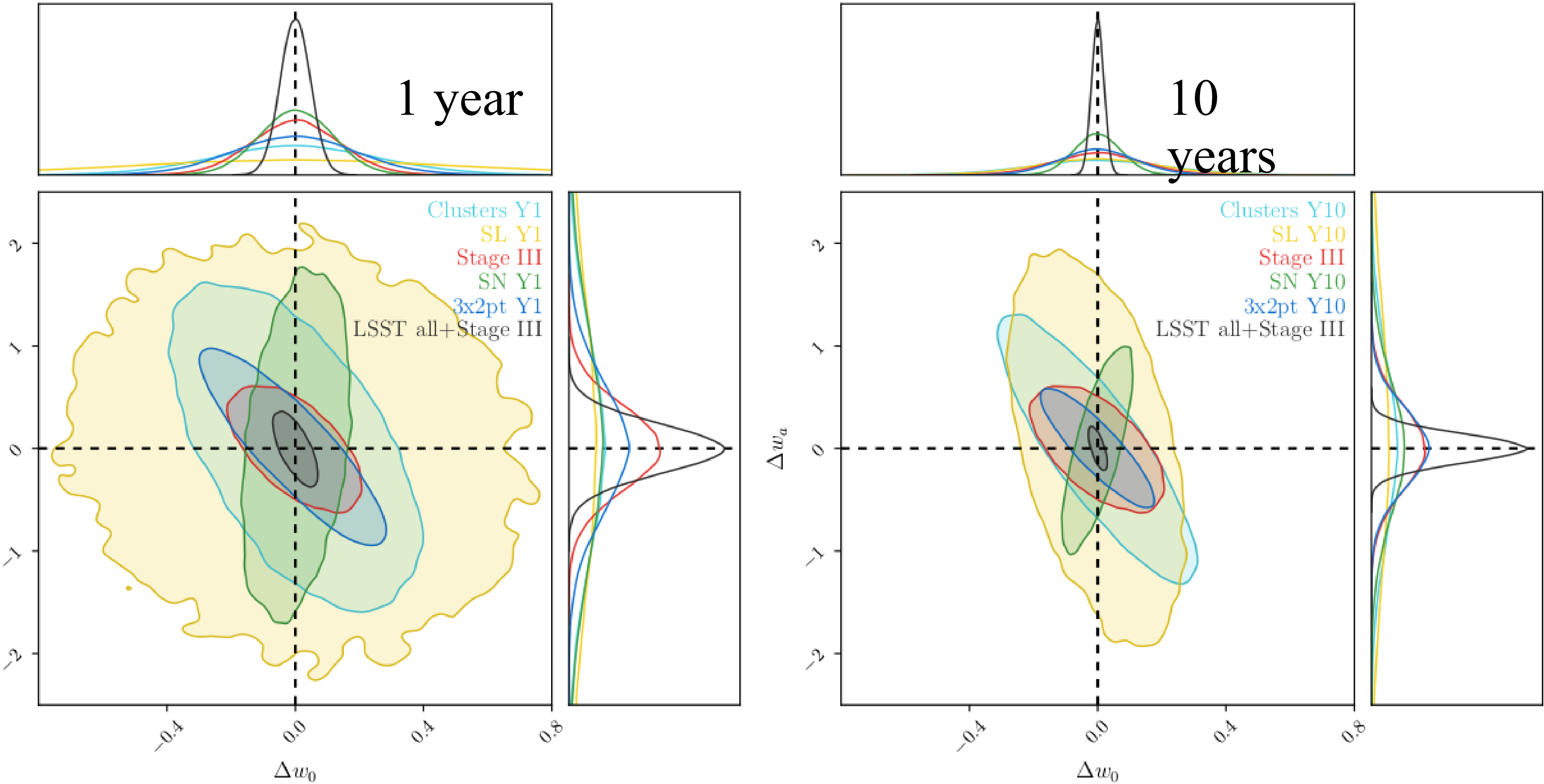
Rubin Dark Energy Probes

• Cosmic shear	Area, depth, photo-z
• Supernovae Ia	Statistics, well-characterized instrument, simple selection.
• Cluster counts	Statistics. Built-in lensing mass calibration. SZ on part of the footprint.
• Large scales structure	
• Strong lensing	Statistics. Built-in light curve acquisition for time delays.

Rubin Dark Energy anticipated figure of merit



Constant w to ~ 2 %

1809.01669

My science road map

Distances → H(z)

↓

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R^{\sigma}_{\sigma} + \Lambda g_{\mu\nu} = 8\pi G \; T_{\mu\nu}$$

↓

Linear perturbations → P(k,z)

non linear effects → P(k,z)

My science road map

SNe Ia

Distances → H(z)

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R^{\sigma}_{\sigma} + \Lambda g_{\mu\nu} = 8\pi G \, T_{\mu\nu}$$

Linear perturbations → P(k,z)

non linear effects

Cosmic shear

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SNe Ia

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?

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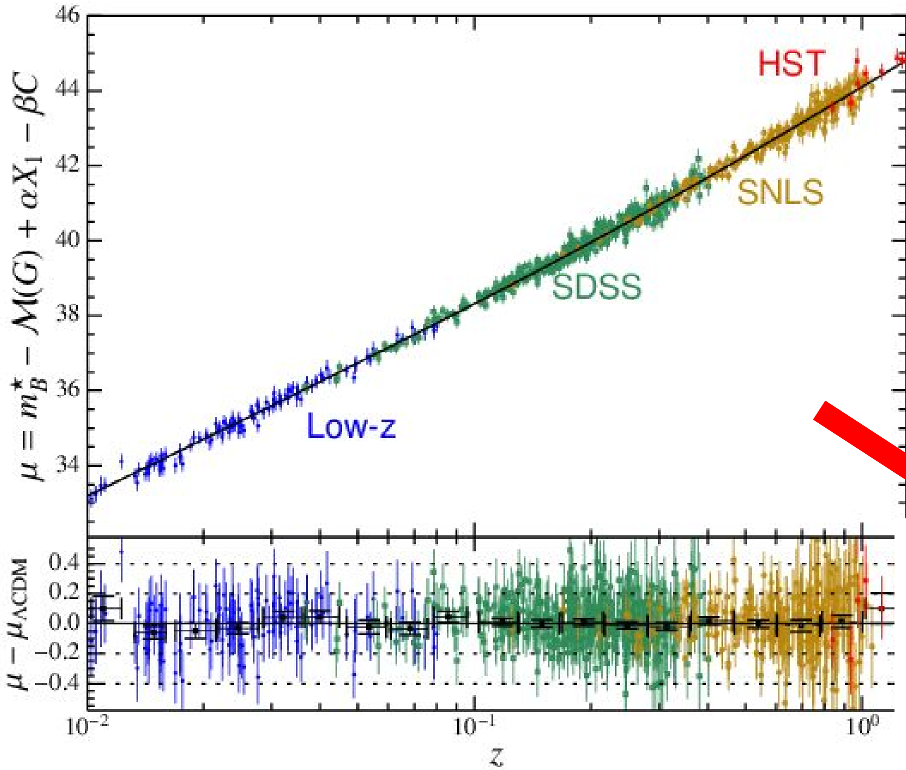
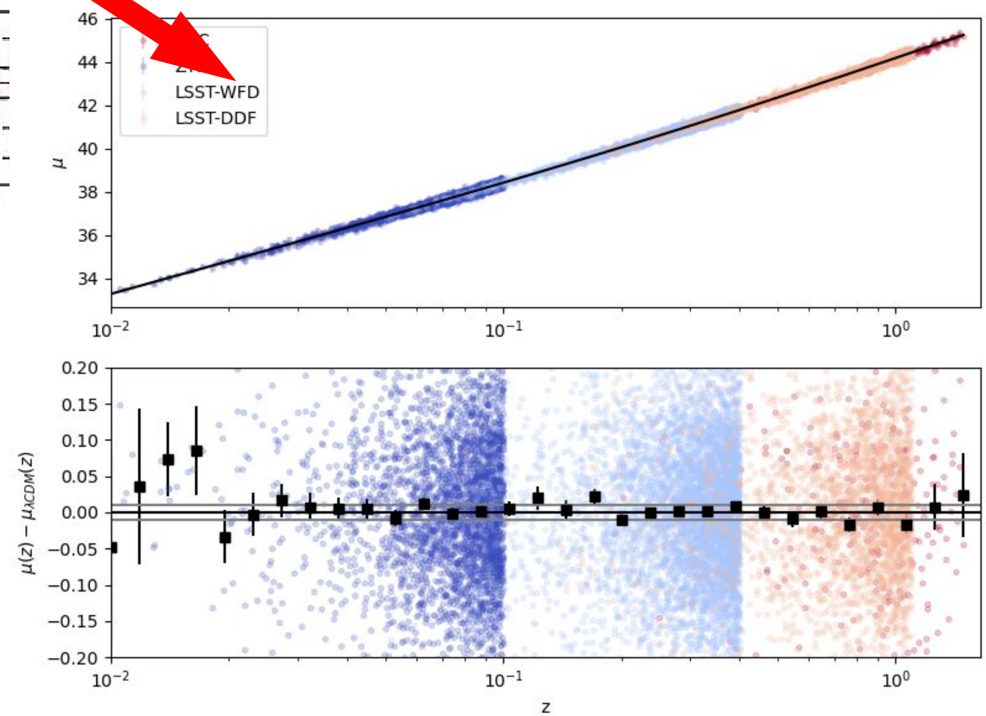
Cosmic shear

Supernovae in LSST



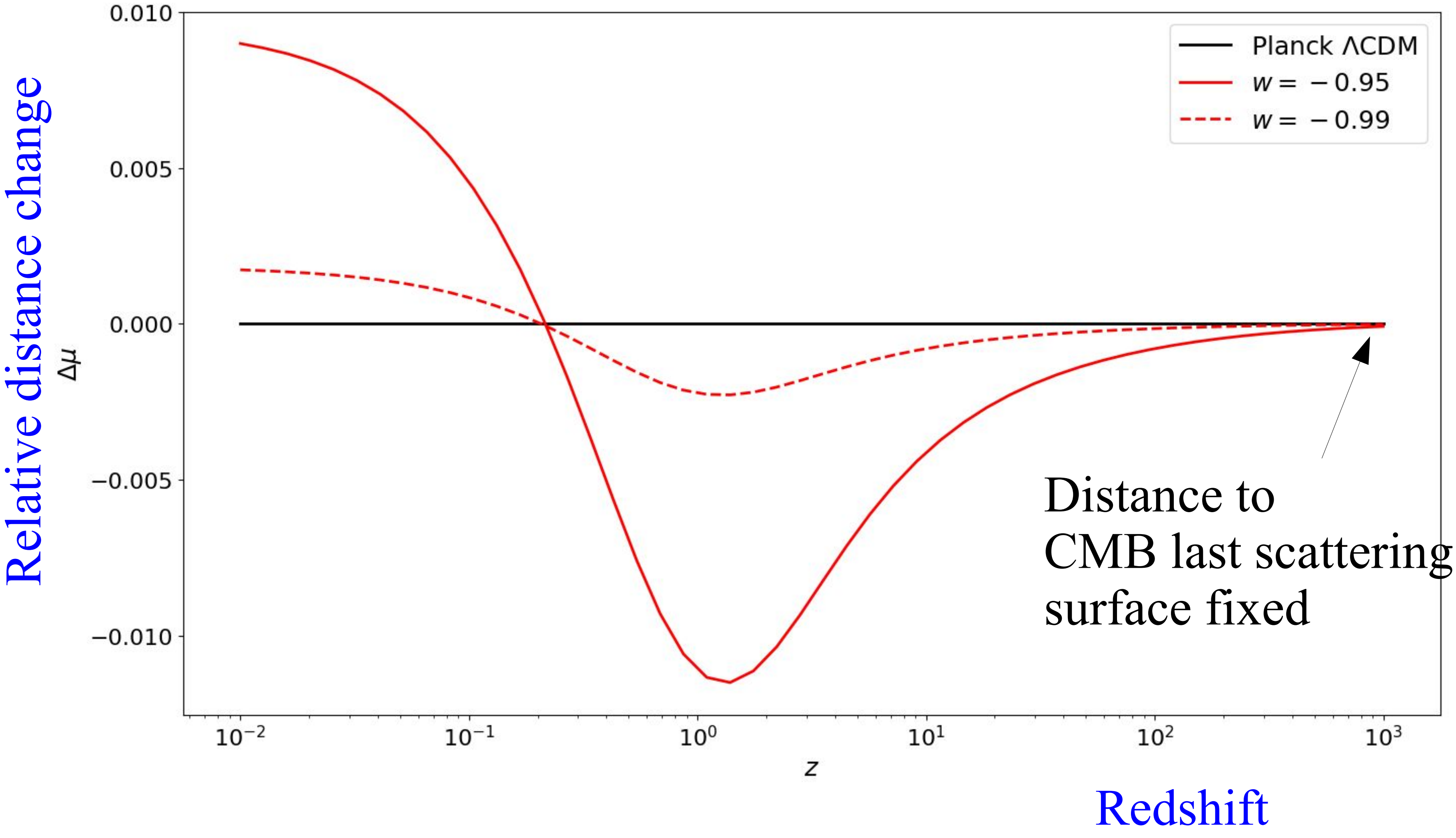
Betoule et al (2014) :
O(1000) SNe



Simulation:

- O(20k) SNe
- Nearby events from ZTF
- Two LSST surveys (Courtesy N. Regnault)

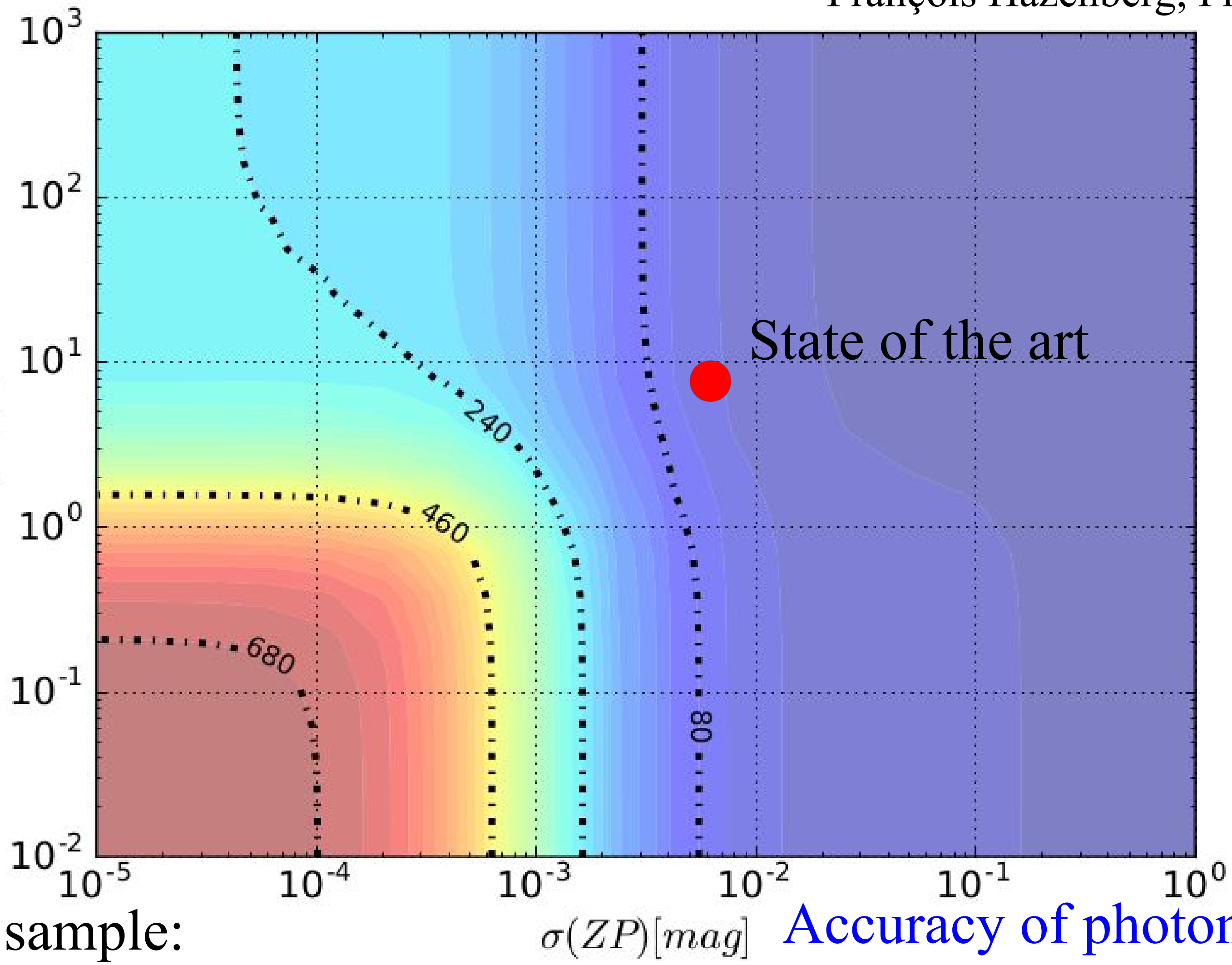
Accuracy is the name of the game



Courtesy: M. Betoule

Precision is driven by photometric calibration and filters characterization

François Hazenberg, PhD thesis



Accuracy of filter edge positions

Accuracy of photometric calibration

Dark Energy Figure of Merit of an LSST SN survey. Distance to LSS from Planck

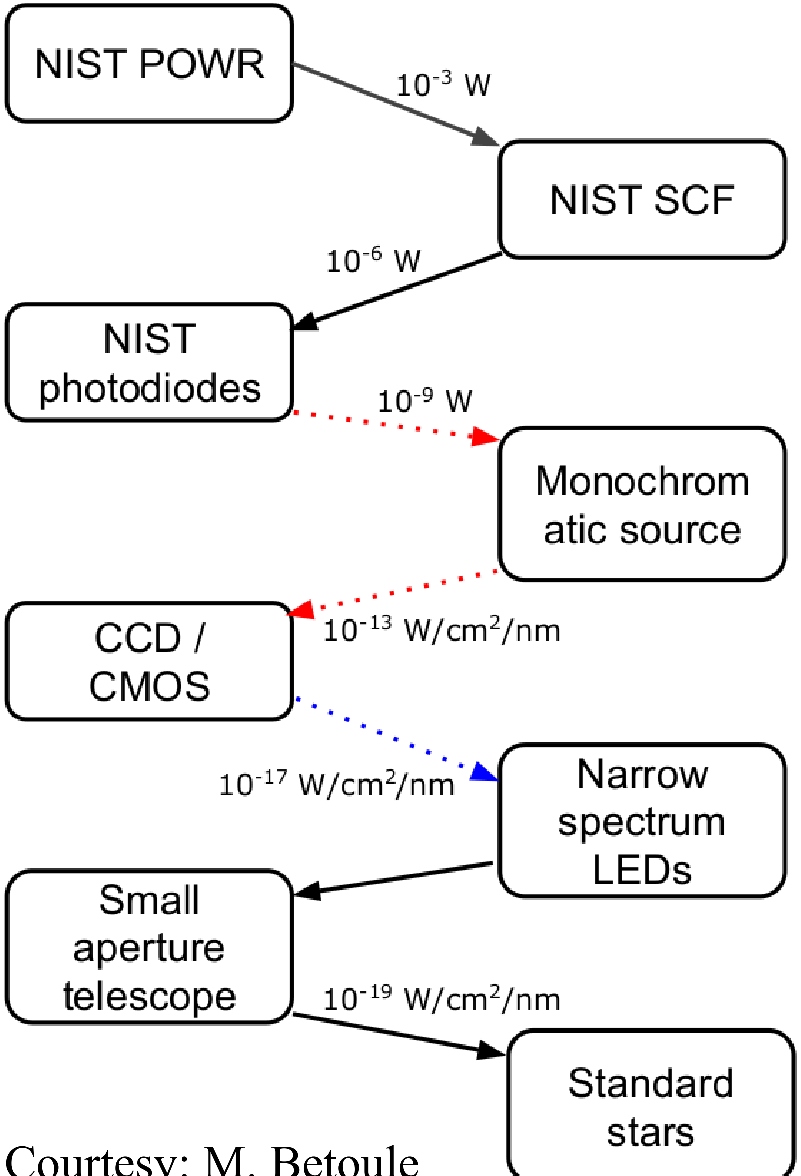
LSST sample:
- 20k SNE in wide fields
- 15k in deep fields.

Supernovae in LSST: key points

- Photometric calibration
  - Fluxes anchored to lab standards
  - Accurately known bandpasses
- Good quality multi-band light curves (for distances, and identification)
  - Frequent enough return on SN fields ...
  - … with deep-enough exposures
- Obtaining host galaxy redshifts en masse
  - Team up with redshift surveys (4most, PFS)
  - Deep SN fields should be visible from Hawai.

StarDICE: transferring lab standards to the sky

LSST-DESC project



Courtesy: M. Betoule

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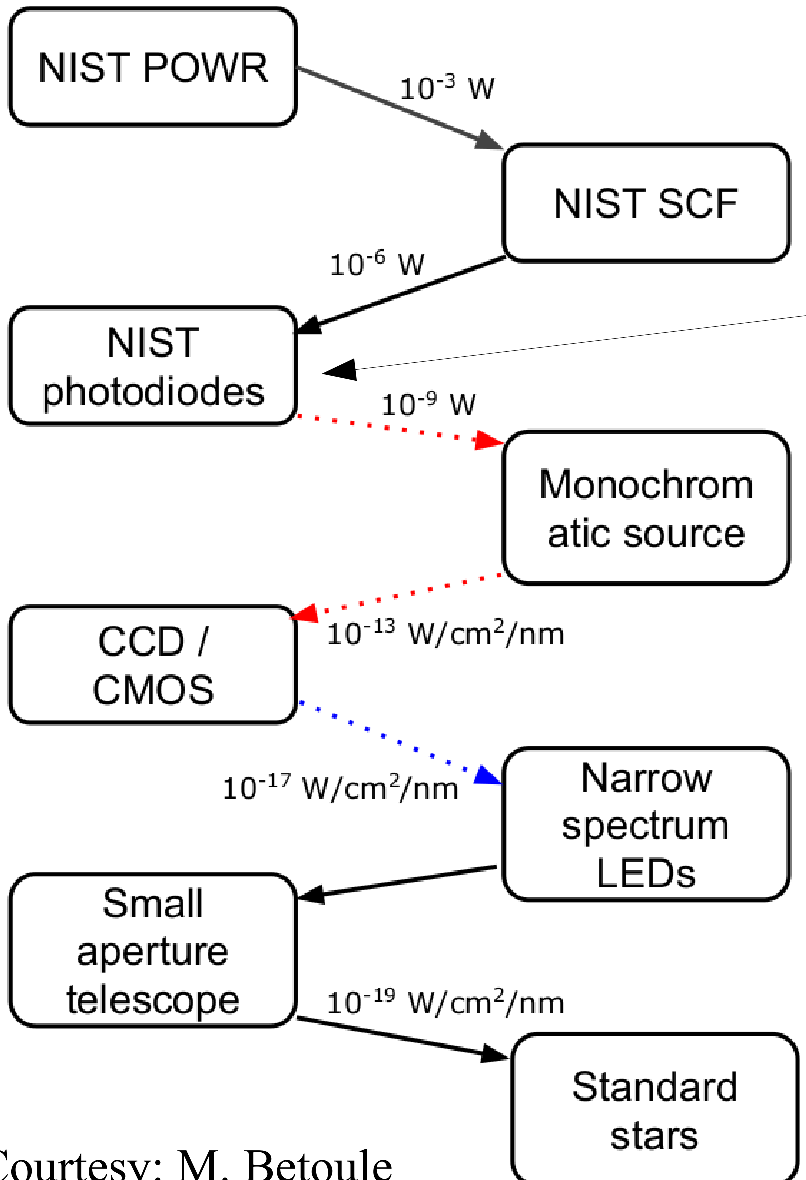


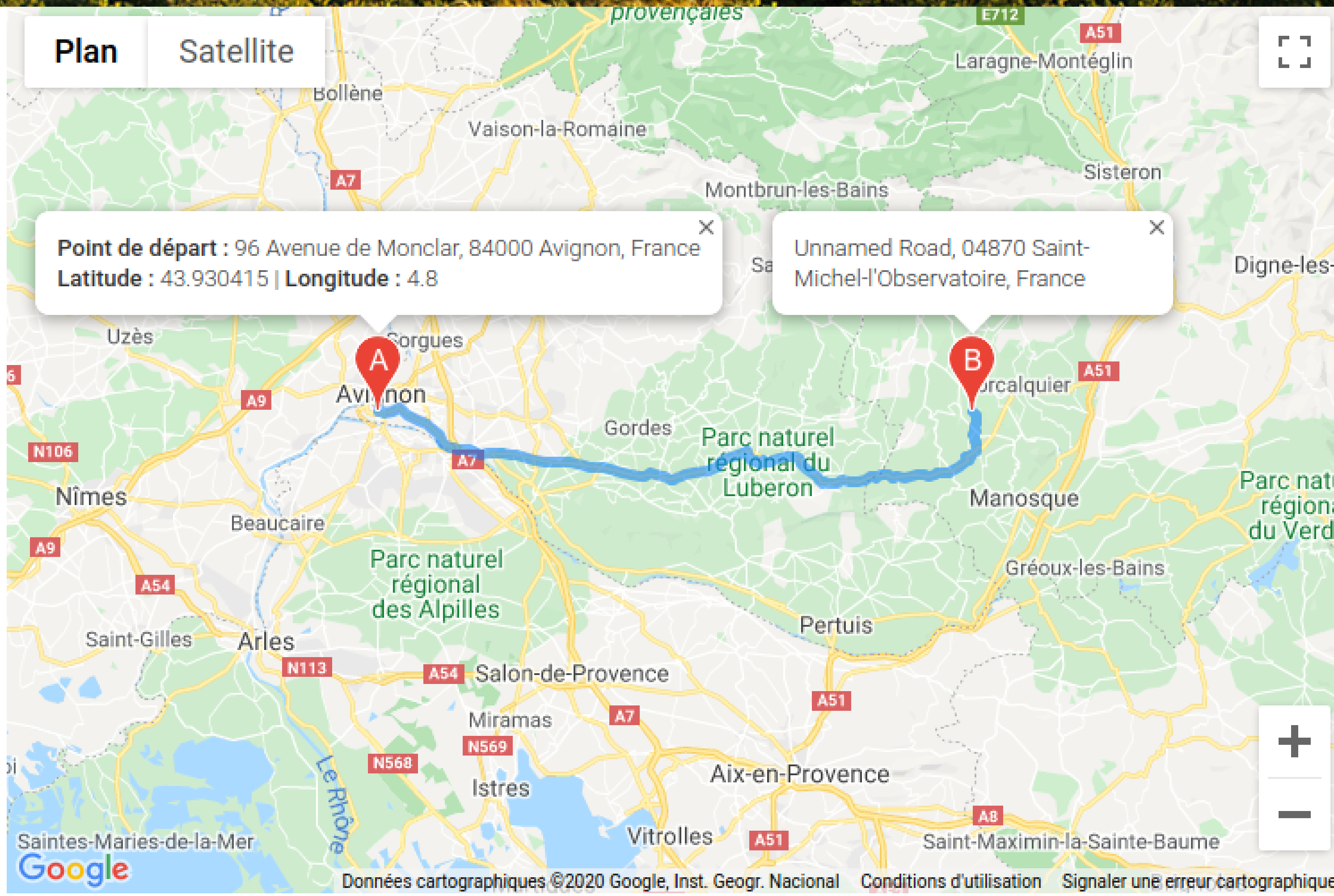
NIST delivers a calibrated photodiode ….

… which allows to calibrate (intensity, spectrum) a faint LED source….

… compared to stars at the observatory

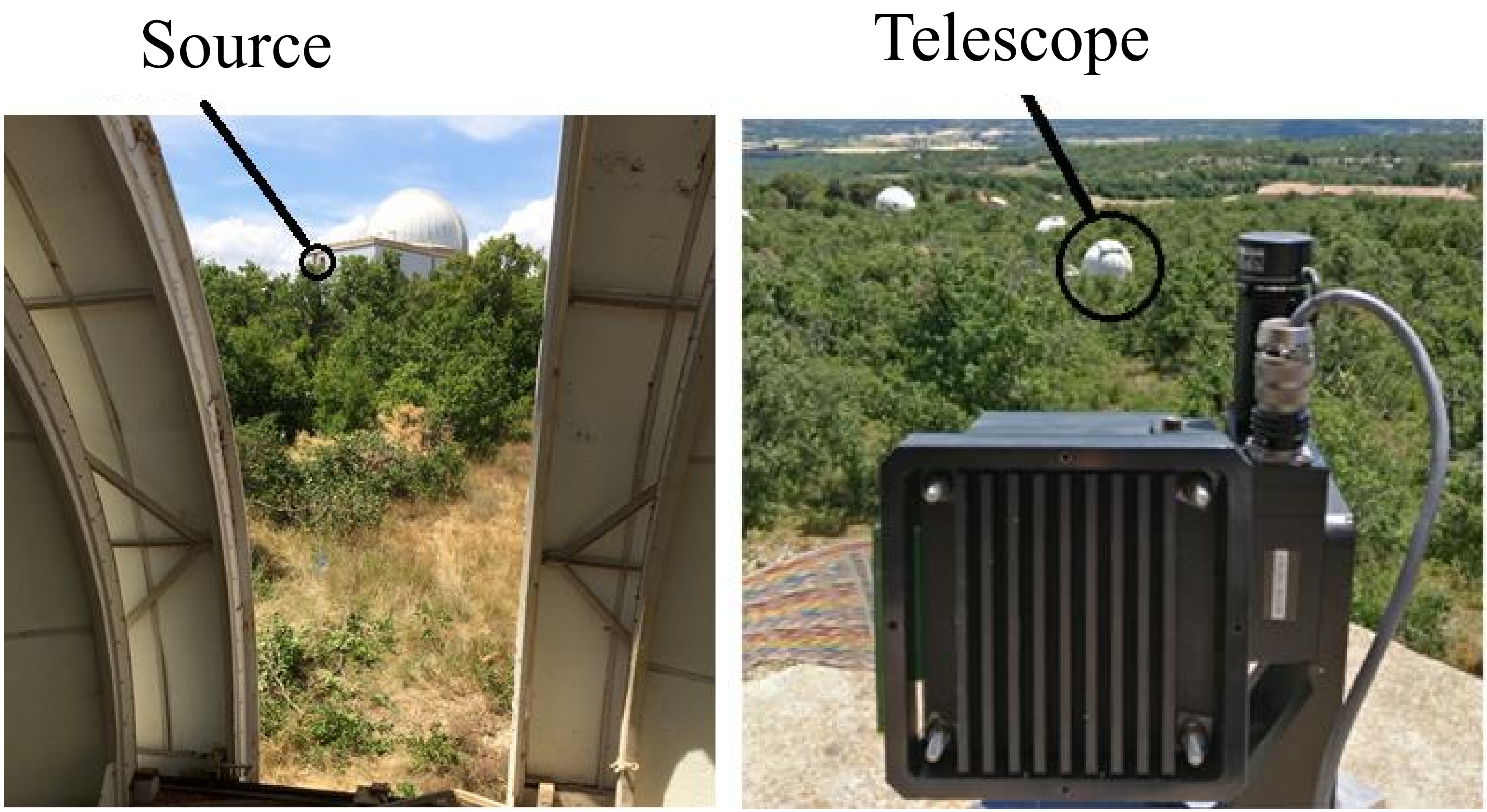
Courtesy: M. Betoule


Observatoire de Haute-Provence


Plan
Satellite
Point de départ : 96 Avenue de Monclar, 84000 Avignon, France
Latitude : 43.930415 | Longitude : 4.8
Unnamed Road, 04870 Saint-Michel-l'Observatoire, France
A
B
Bollène
Vaison-la-Romaine
Laragne-Montéglin
Sisteron
Montbrun-les-Bains
Uzès
Avignon
Gordes
Parc naturel régional du Luberon
Manosque
Nîmes
Beaucaire
Parc naturel régional des Alpilles
Gréoux-les-Bains
Pertuis
Saint-Gilles
Arles
Salon-de-Provence
Miramas
Istres
Aix-en-Provence
Vitrolles
Saintes-Maries-de-la-Mer
Saint-Maximin-la-Sainte-Baume
Le Rhône
Google
Données cartographiques ©2020 Google, Inst. Geogr. Nacional
Conditions d'utilisation
Signaler une erreur cartographique

>250 photometric nights a year, poor seeing on average.
Excellent atmospheric monitoring on site.

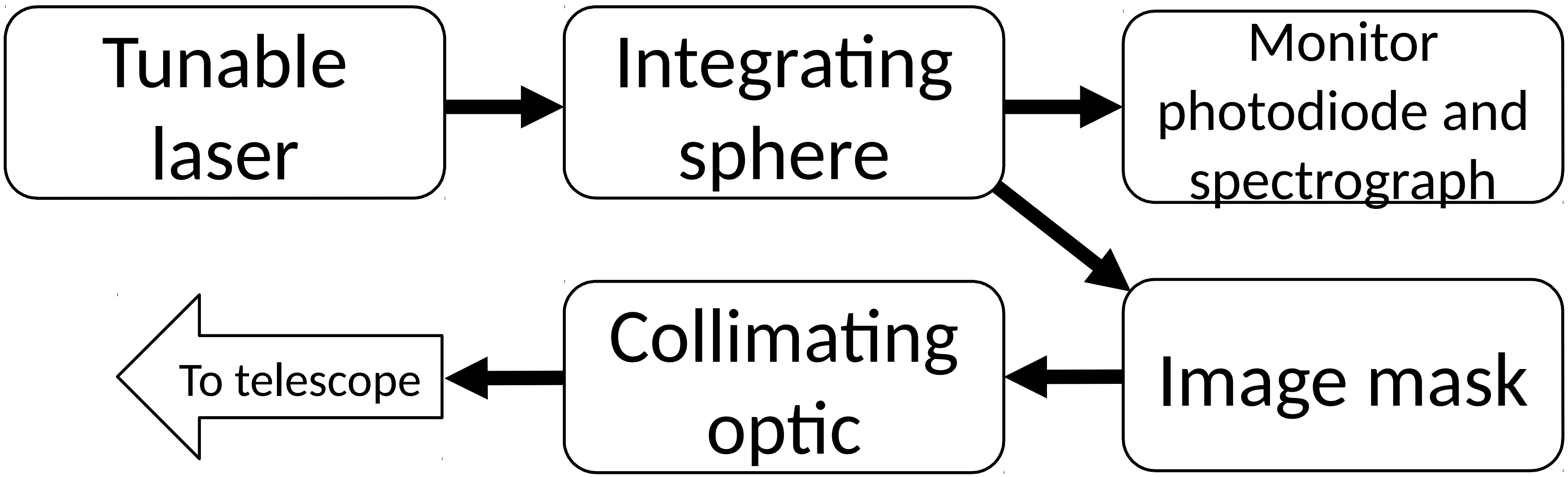
A few oaks had to be cut



Status of the StarDICE project

- Proof of principle completed : no show stopper
- New source under construction
- New telescope built and characterized
- Telescope mount refurbished
- Observations not started yet because of Covid.
- Hope to complete the program in ~ 2 years.

The Collimated Beam Projector



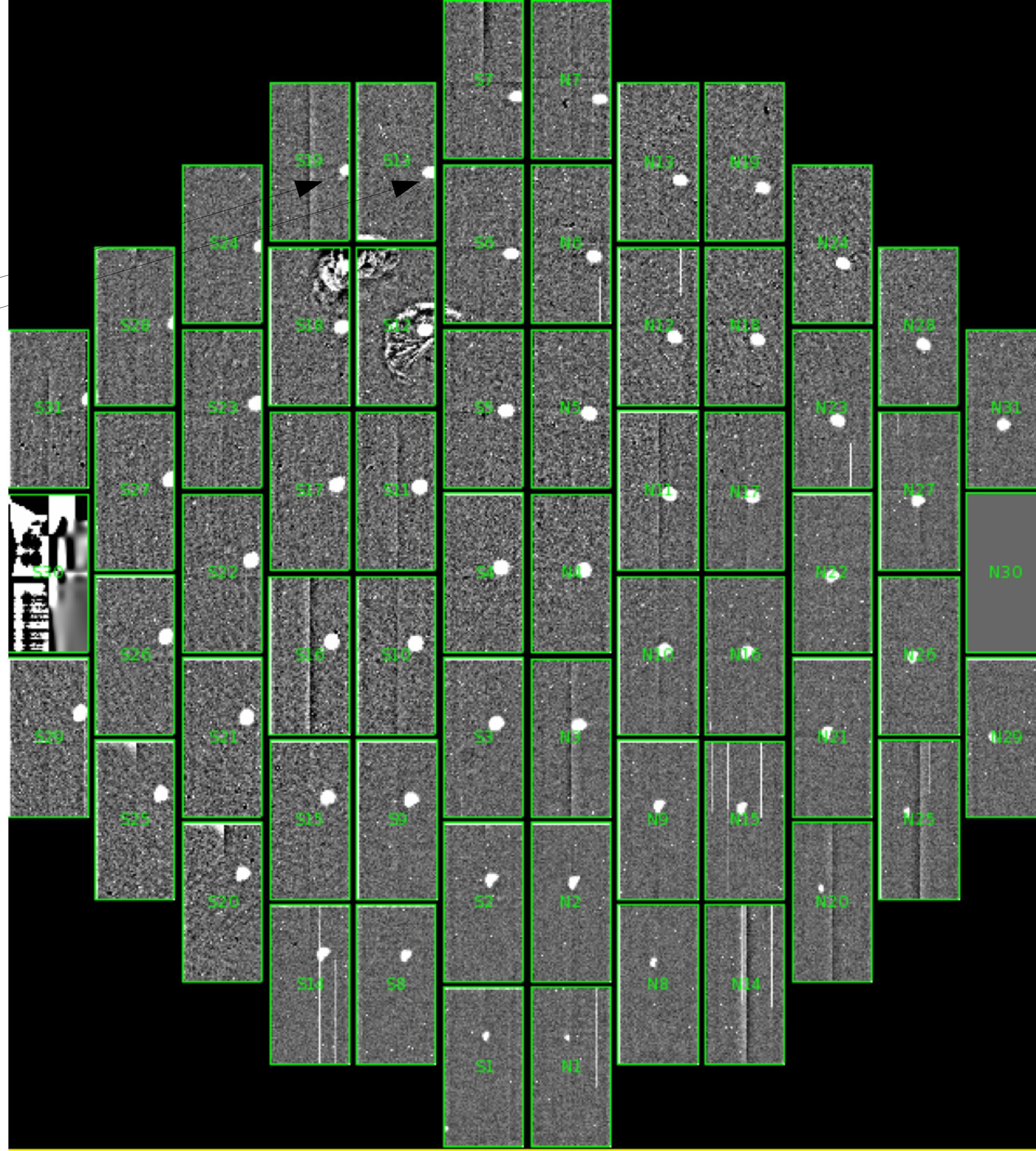
Courtesy:
N. Mondrik

Measure the telescope throughput with a monochromatic and “star-like” source.
Core goal: accurately measure the shape of the filter bandpasses

Test on the CTIO-4m: the DES camera

Pseudo stars, tens of arcseconds broad.

Proof of principle completed, new version ready soon



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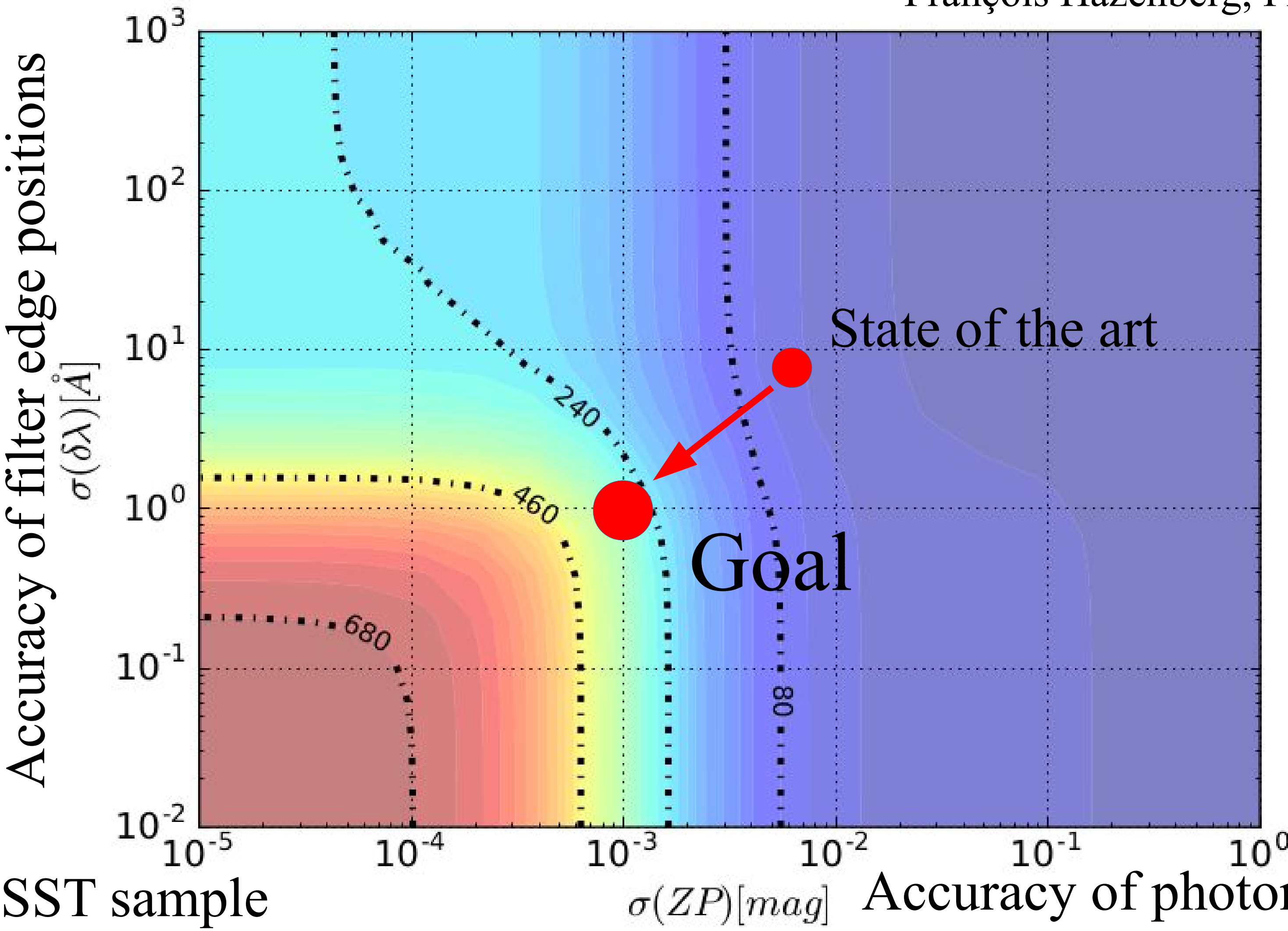
Calibration goals

François Hazenberg, PhD thesis



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Accuracy of photometric calibration

LSST sample
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Supernovae in LSST: key points

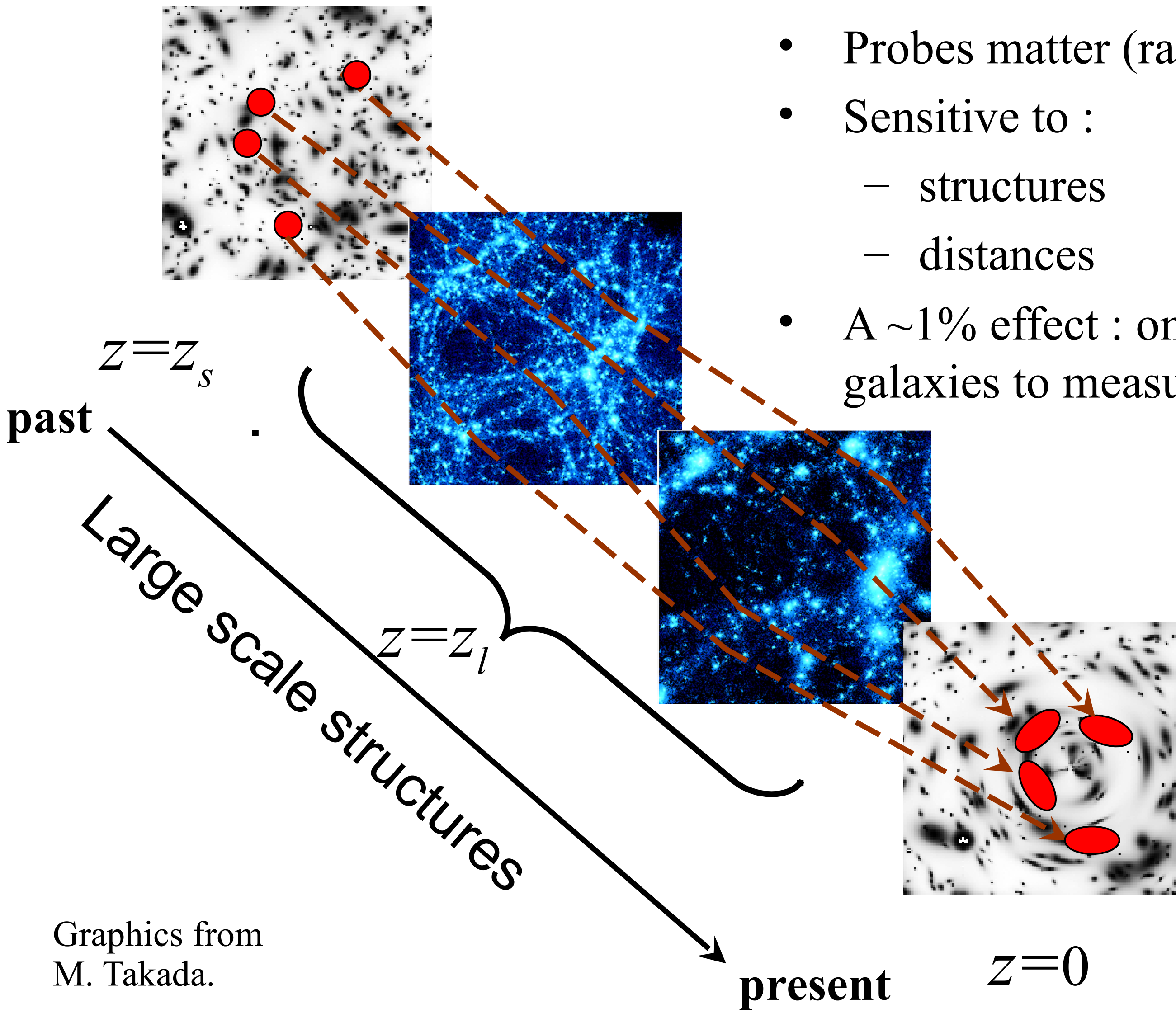
- Photometric calibration
  - Fluxes anchored to lab standards
  - Accurately known bandpasses

- Good quality multi-band light curves (for distances, and identification)
  - The default observing mode will not deliver well-sampled light-curves. It has to be altered (for short periods) if the SN Hubble diagram is still a serious LSST goal. Photometric typing also requires precise light-curves.

- Obtaining host galaxy redshifts en masse
  - This is likely to be the bottleneck. So, the light curves of supernovae which eventually get a redshift should be excellent.

Cosmic shear

- Probes matter (rark or not)
- Sensitive to :
  - structures
  - distances
- A ~1% effect : one needs millions of galaxies to measure it.



Graphics from
M. Takada.

Observables :

- ellipticity
- orientation

Cosmic Shear : The Three Threats

- The shear estimator:
  - One cannot express uniquely the expected image given the shear → a whole suite of estimators, challenges, ….
  - The whole thing relies on empirical (mostly ad hoc) PSF estimation from stars.
- Intrinsic alignments:
  - Accounted for using ad hoc models, but there is safe information in cross-correlations of shear at sufficiently different redshifts.
- Photo-z:
  - The expected shear signal depends on z (!).
  - Calibration from spectroscopic redshifts is the life line.
  - DESI, PFS and 4Most will hopefully deliver those en masse

Cosmic shear : shear estimators

- Original proposal: KSB (1995), then HSM, ….
  - All require some "calibration", i.e. correcting biases using image simulations
  - They typically depend on assumptions on the "radial profile of galaxies"
  - Profile fitting methods often have to add assumptions on galaxy populations because they have about as many parameters per galaxy as significant pixels to fit with.

- The "new" approach : NGMIX (aka meta-calibration, E. Sheldon & al)
  - Based on self-calibration: the sensitivity of second moments to shear is measured from the images themselves.
  - Proposed in Kayser (2000), which seemed to go unnoticed (!?)
  - Can probably be improved, by addressing S/N dependent biases from the images themselves.

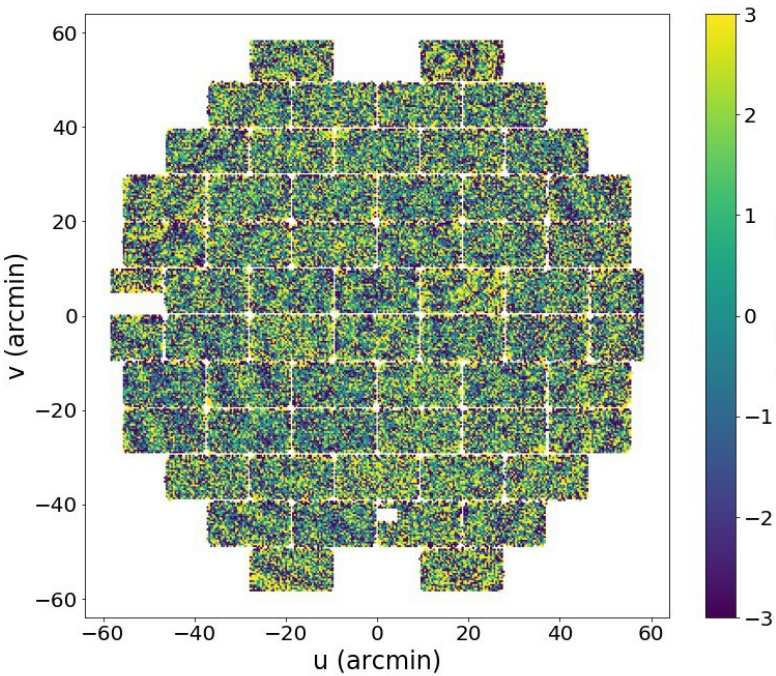
Any shear estimator relies on a PSF model

State of the art : PIFF (2011.04409), developed for DES/LSST

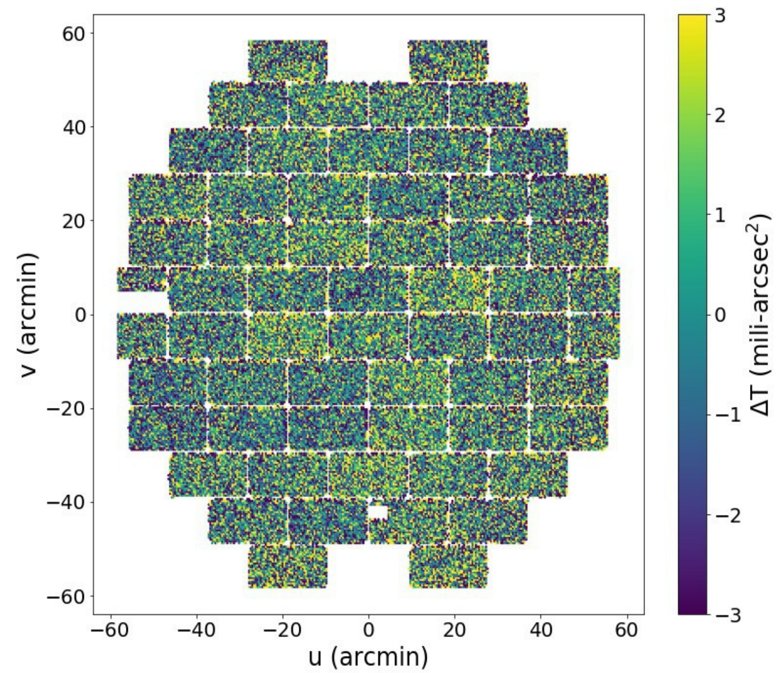
- Models optical distortions from physics models
- Models atmospheric distortions using Gaussian processes
- Spurious shear correlations reduced by a factor of 10 w.r.t DES first year.

Average PSF size residuals

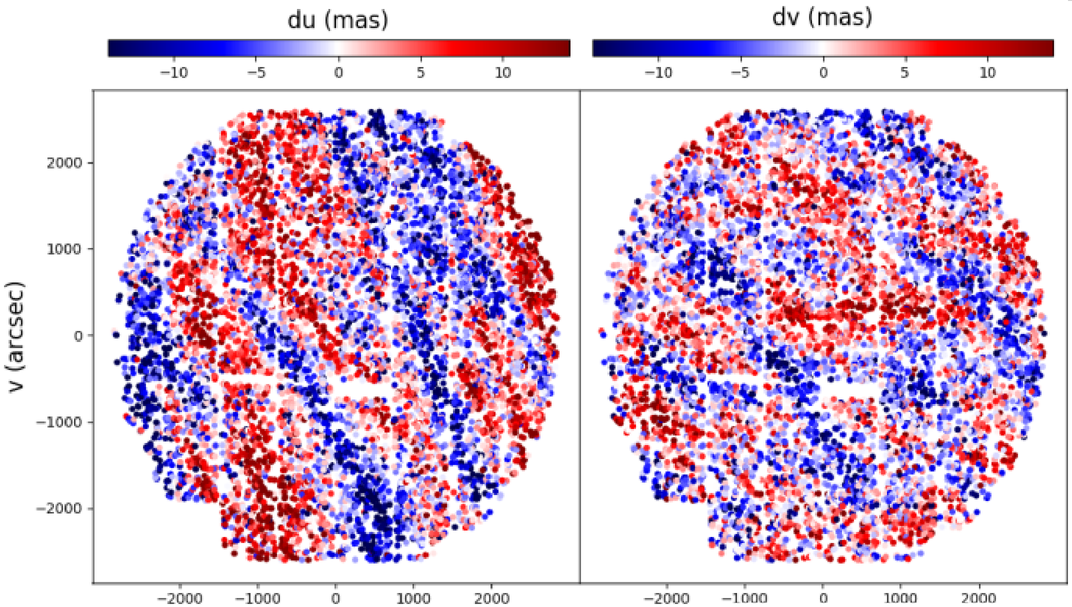
Standard way



Gaussian processes



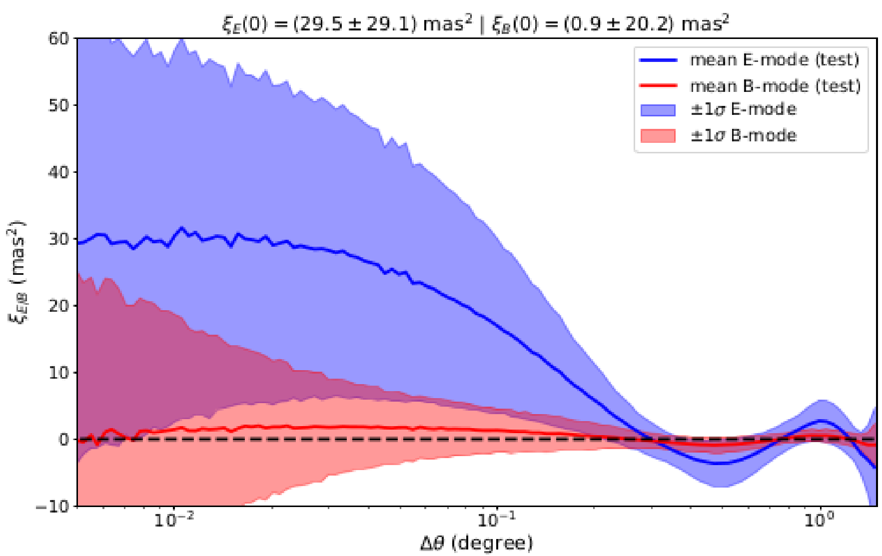
Atmosphere also perturbs objects positions (astrometry)

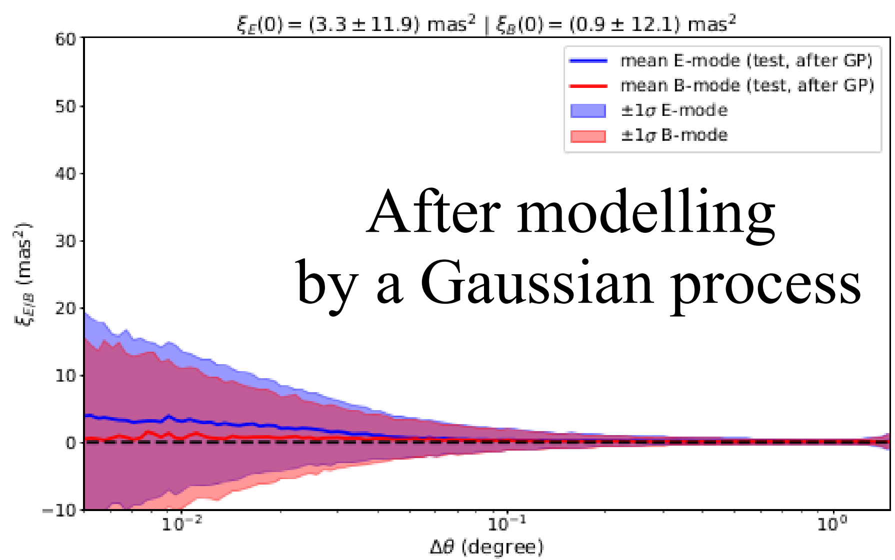


Position offsets of astronomical objects from a single exposure of HSC/Subaru (300 s)

P-F .Léget et al, almost published

Correlation function





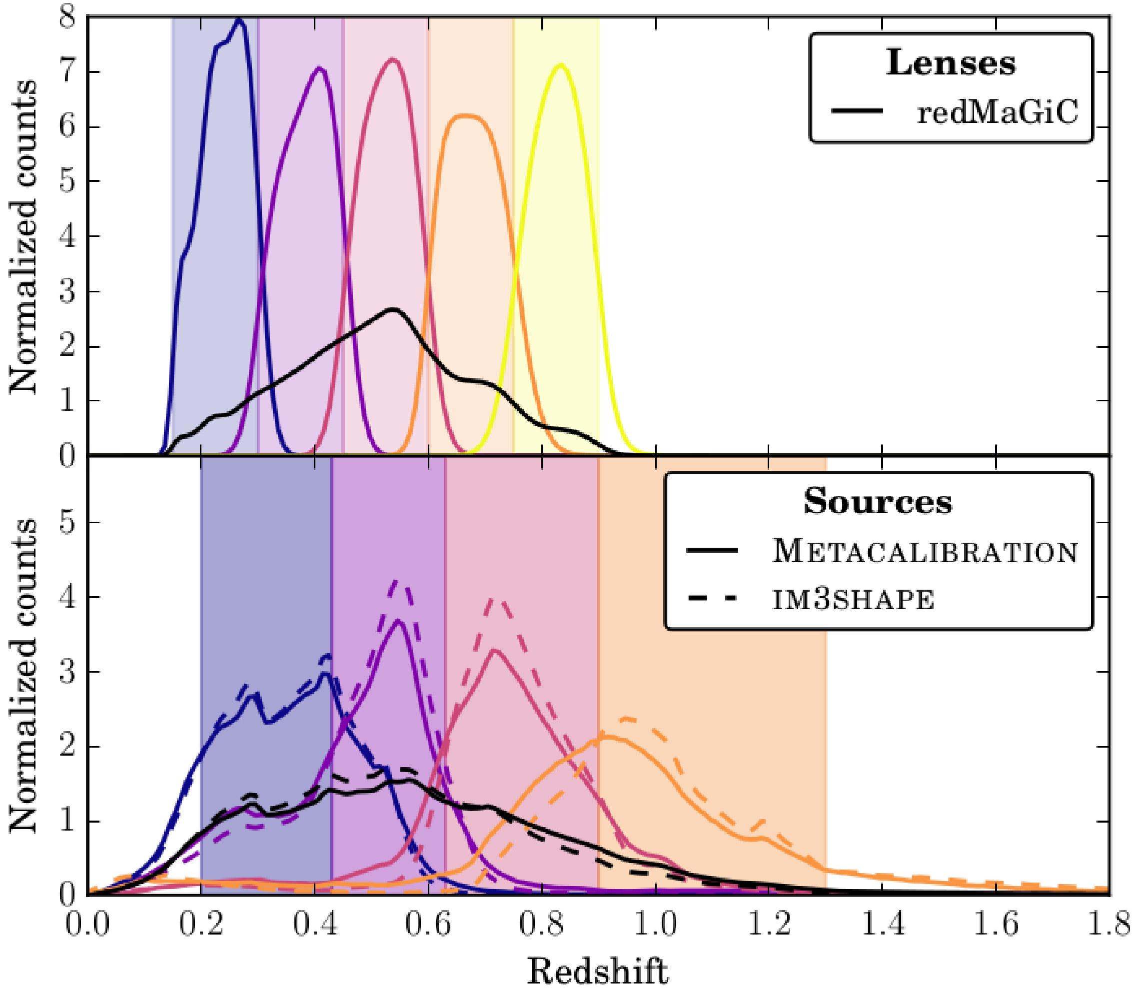
Photometric redshifts

For cosmic shear analyses, the problem is not just to estimate photo-z from broadband fluxes, but rather to estimate the true distribution of redshifts of galaxies selected in photo-z bins.

Estimated redshift distributions of photo-z sharp bins

Individual photo-z are only used to assign galaxies into bins.

From DES year 1 (Abbott et al, 2018)



Photometric redshift distributions

- Stack the redshift PDFs (from photo-z code) of selected galaxies
- Histogram the spectroscopic redshifts of a subsample with spectro-z
- Derive the redshift distribution from angular correlations with a sample with spectroscopic redshifts

Current approaches use both and derive uncertainties from the comparison

Bottom line:
- we need a lot of spectroscopic redshifts !
- Including faint galaxies

From now to Rubin

	Now	Goal	How
Photometric calibration	0.5%	0.1%	Laboratory standards
Filter bandpasses	1nm	0.1 nm	In situ measurement
Shear estimator	1%	0.1%	Higher S/N cut Image-based simulations
PSF size	~0.3%	0.1%	Physics in PSF model (PIFF)
Photo-z	0.01 to 0.02(1+z)	0.001	More spectro Mix with correlation based approches

Conclusions

- Rubin Observatory's program is delayed, by at least one year.
- Regarding DE science, the nuts and bolts are being assembled.
- If Rubin wants to deliver the next (big) SN Ia Hubble diagram, some moderate changes to the observing plan are required.
- The technicalities of cosmic shear measurements are improving, thanks to a very active community (DES, KiDS, HSC).
- A large sample of spectroscopic redshifts are needed.
- Joint Rubin/Euclid analyses will certainly happen. Hopefully with the blessing of both collaborations.