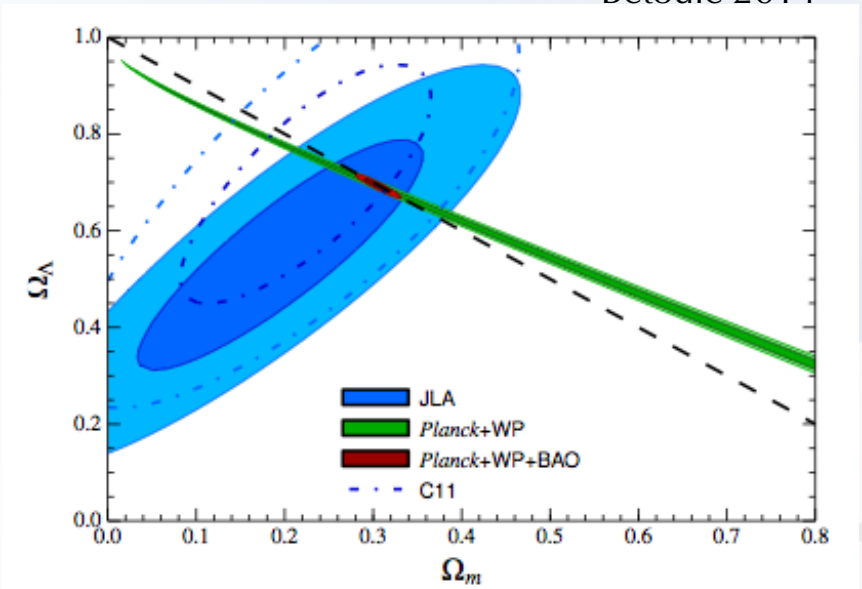

Status of
Rubin
Observatory
/
LSST
Legacy Survey of Space and Time
Emmanuel Gangler – CS IN2P3 – 27 oct 2020

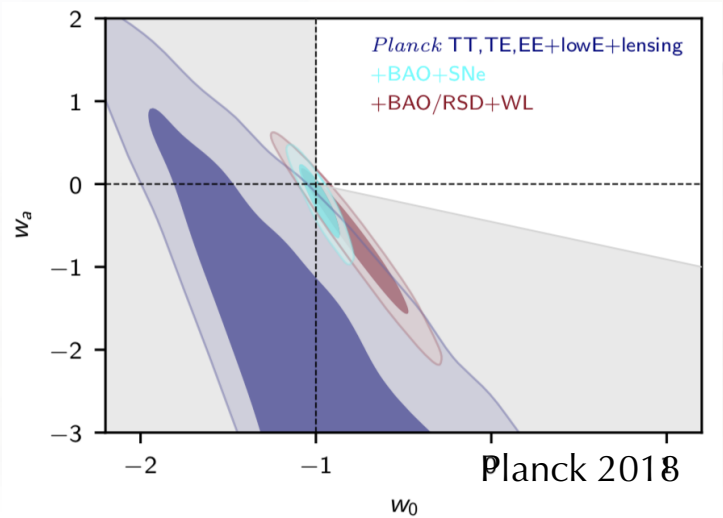
Dark Energy: 1998-2020 … 22 years and still alive !

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

Betoule 2014



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



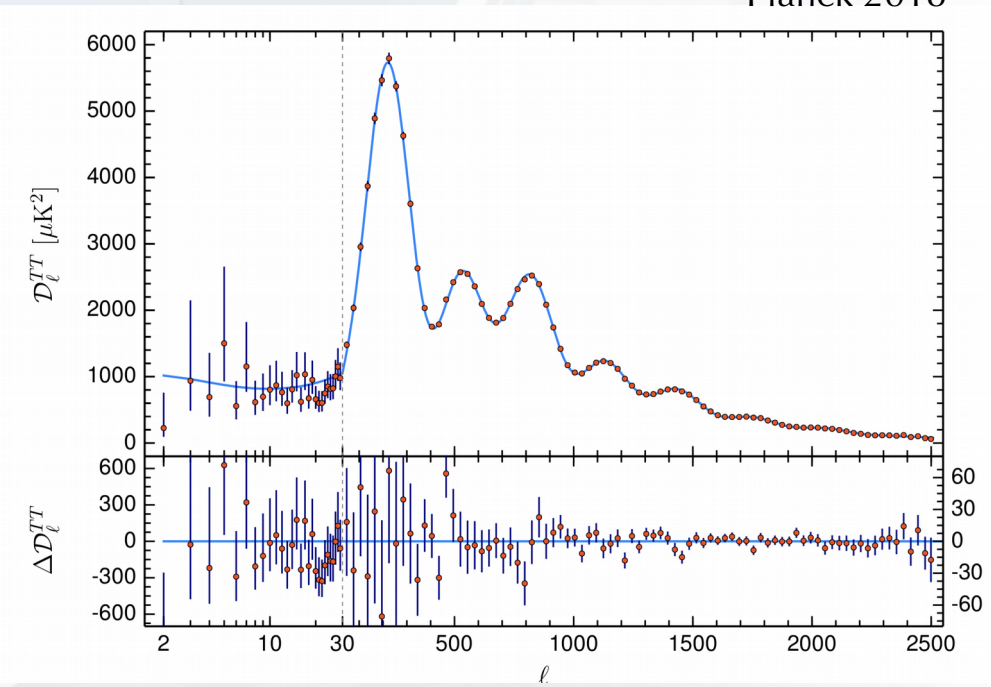
Planck 2018

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 ?

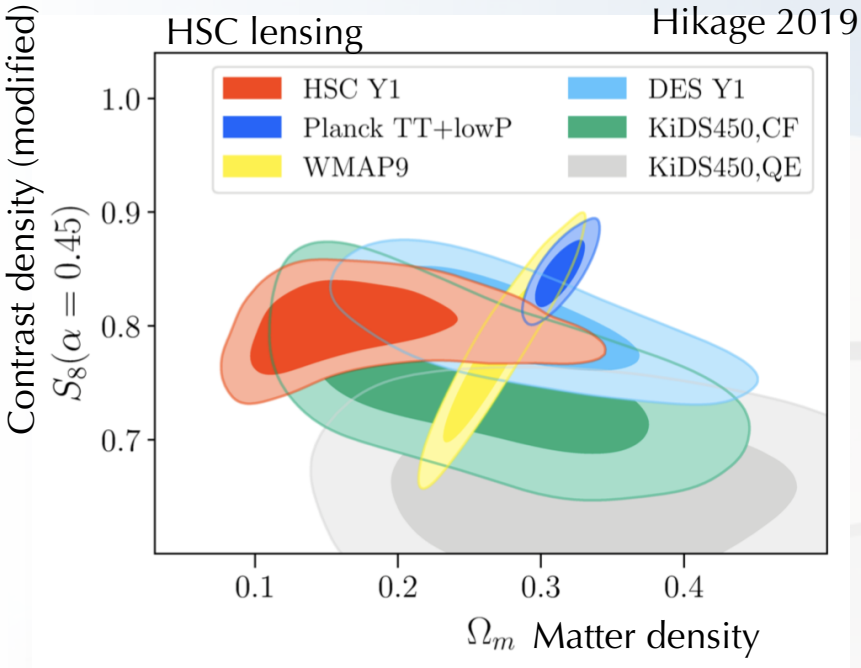
Beyond Dark Energy: the growth of structures

ΛCDM + Initial perturbations + GR

→ structure growth is fully determined

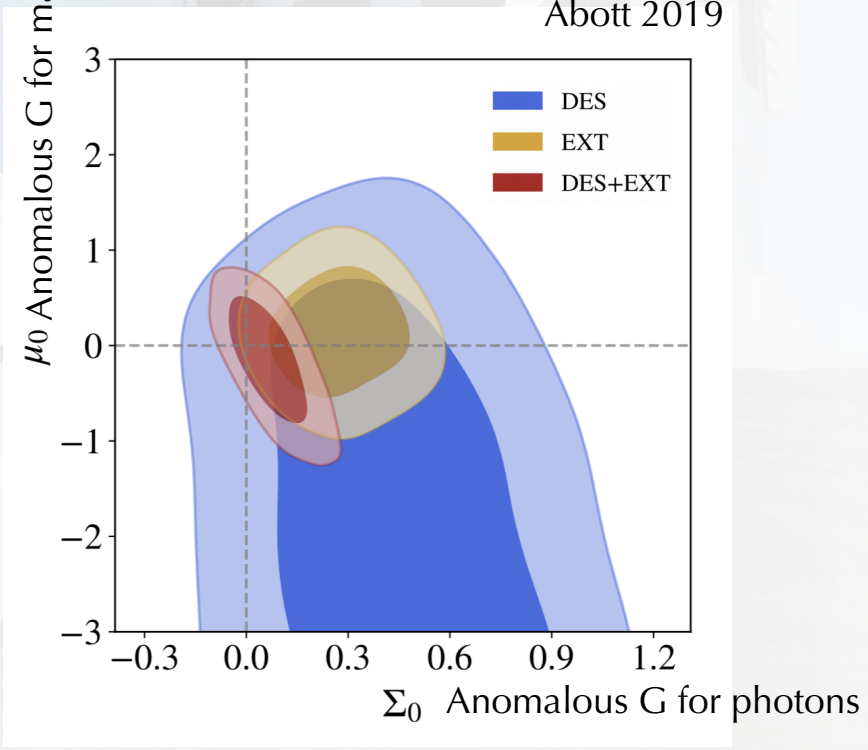
Key parameters: Ω_M, σ_8/S_8, γ

HSC lensing — Hikage 2019



Fit for post-GR parameters:
ΛCDM still holds

Abott 2019



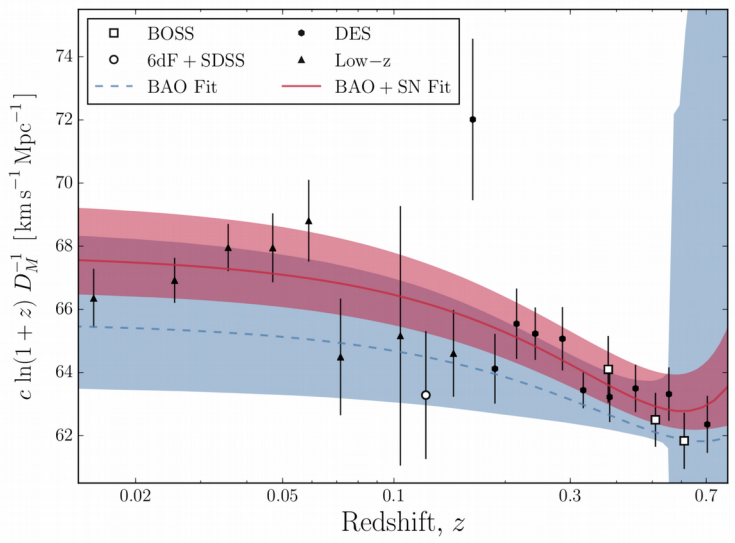
Probes of recent universe

3x2 pt (lensing + structures): clusters

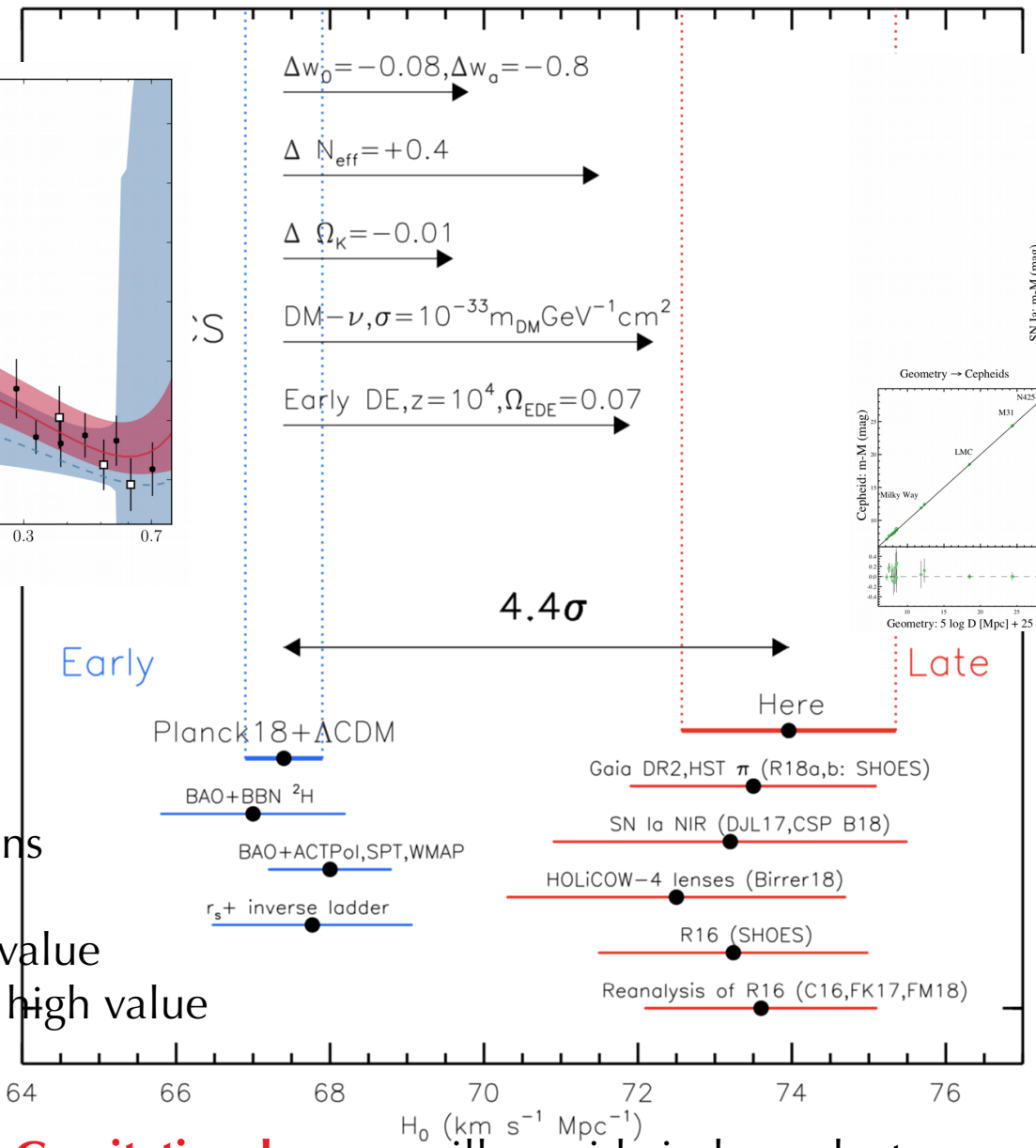
→ tension with Planck

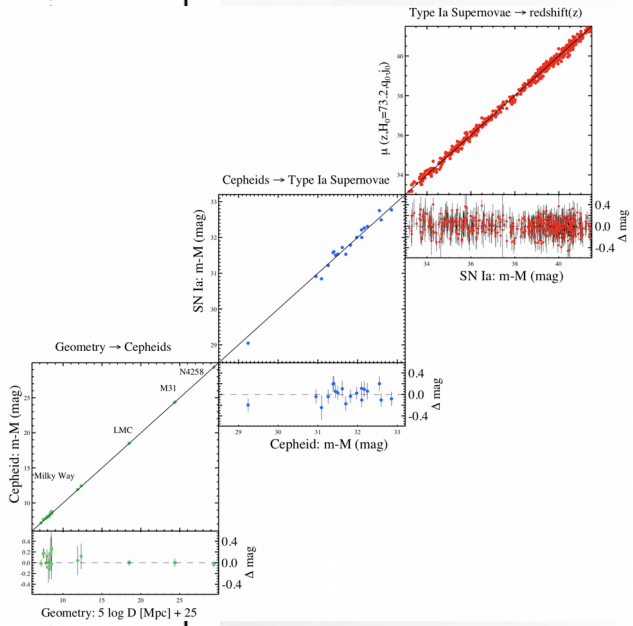
HSC, DES

Tension on the Hubble Constant



Macaulay 2019



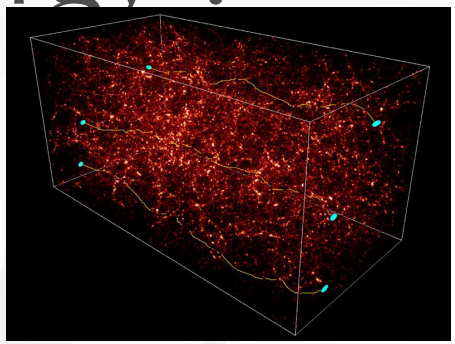


Riess 2019

Discrepancy
with Supernovae
with Baryon Oscillations
depends on calibrator
Early Universe → low value
Nearby (Cepheids) → high value

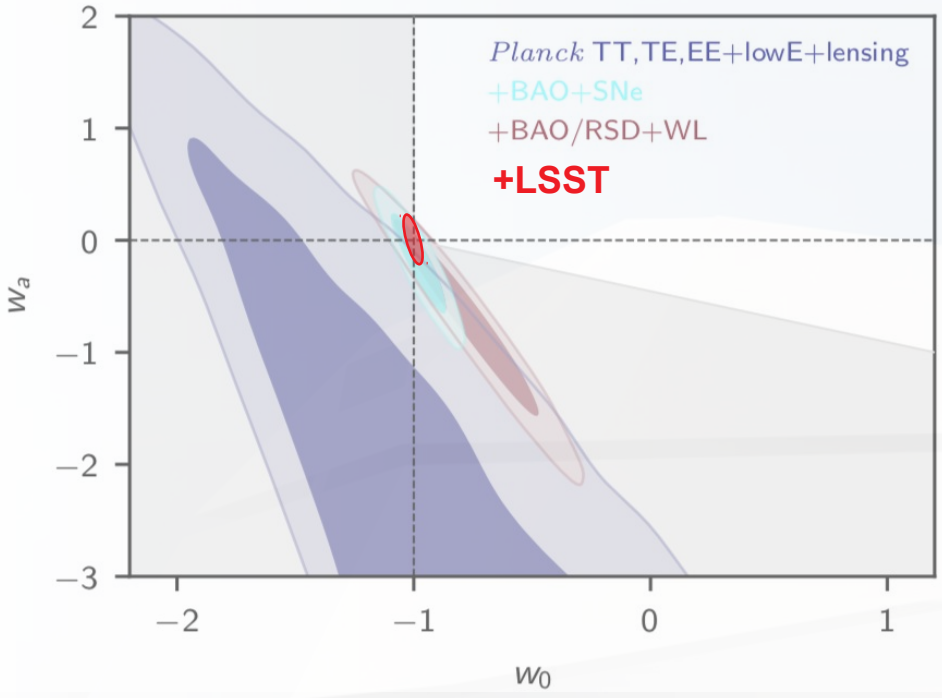
Gravitational waves will provide independent measures

How to constrain Dark Energy ?



Precision measurements of equation of state

→ **Multi-probe approach**



Which probes ?

Lensing:

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

→ ***Deep and Wide sky survey***

Supernovae:

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

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

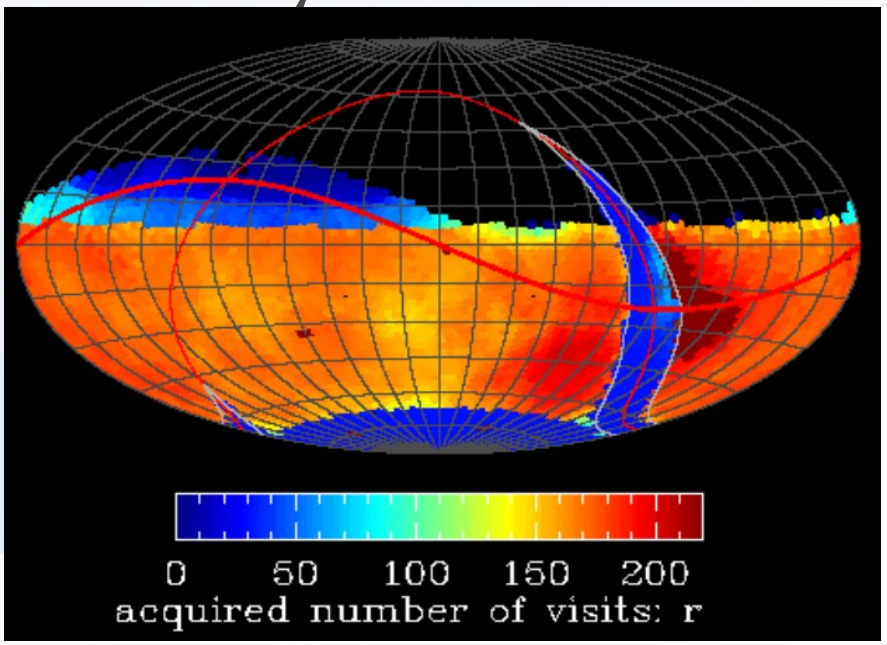
Clusters :

- Mass reconstruction (data), mass function (th)
- Same systematics as lensing, less severe
- Multi-probe coverage (radio, X, SZ)

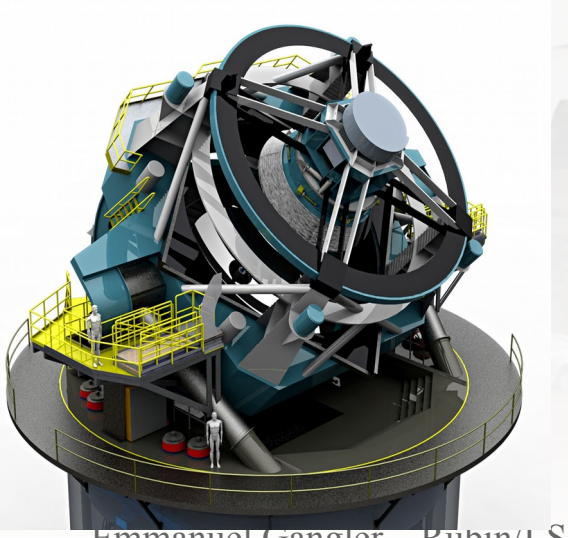
→ ***Comes for free...***

Rubin Observatory

summary :



- 8.4 (6.7) m telescope
- Cerro Pachon (Chili)
- 3.2 Gpix 9.6□ FoV camera
- 0.2'' pixel / 0.7'' median FWHM
- Survey 2022-23 (?) + 10 years



- All visible sky in 6 bands (ugrizy) (~18000□ main survey)
- 5 deep fields
- 30 s exposure, 1 visit / 3 days
  r ~24.4 / visit
- During 10 years !
  → ~825 visits (all bands)
- 20TB/day 60 PB/10 years

Rubin observatory and Science:

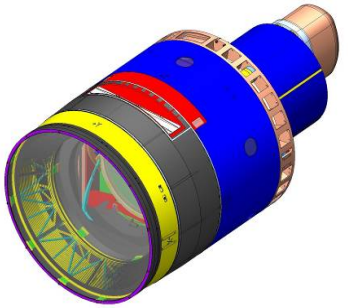
Communication
Commissioning
Advisory
Operations

Rubin Observatory

Science — LSST Science Collaborations

Telescope and site

Camera



Data Management

Outreach

- **Rubin obs. delivers data, Science done by Users**
  - Conducted by independent collaborations
  - "the project doesn't do science"
- **The survey covers 4 major scientific themes**
  - **Dark Energy, Dark matter**
  - *Transient optical sky*
  - Mapping Milky Way
  - Solar system

LSST DESC Dark Energy Science Collaboration

Rubin/LSST at IN2P3

A 15 years story !

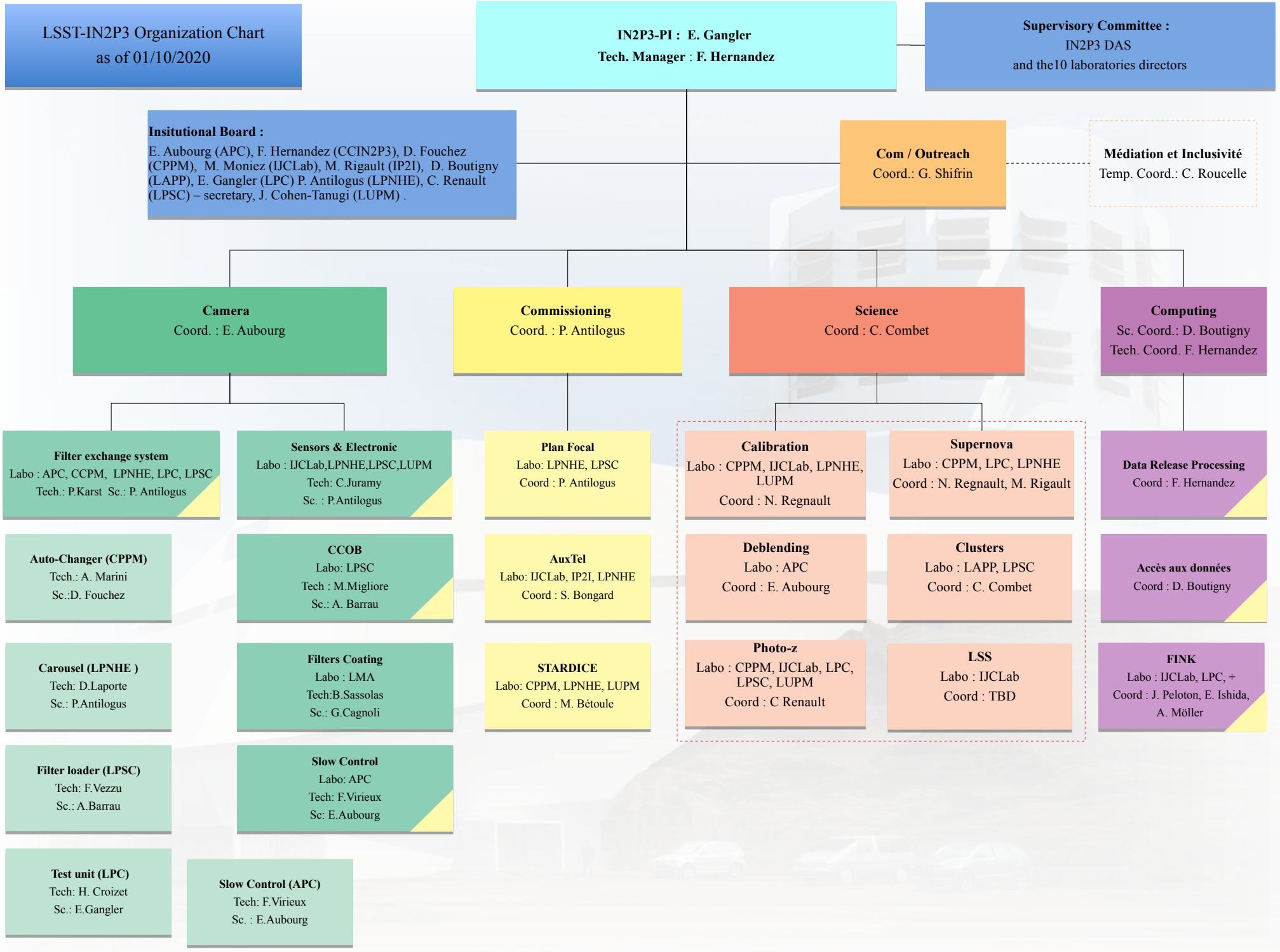
- **2005:** first contacts
- **2007:** *IN2P3 scientific council approves the* ***camera R&D***
  - Focal plane, filters, filter exchange system
- **2009:** MoU on R&D between IN2P3 and LSSTC
- **2010:** LSST ranked highest priority in US decadal survey (NSF, DOE, IN2P3)
- **2012:** *IN2P3 scientific council endorses* ***camera construction***
- **2012:** creation of Dark Energy Science Collaboration
- **2014:** LSST construction starts : NSF/DOE/LSSTC partnership
- **2015:** *IN2P3 scientific council recommends* ***increasing science effort***
  - Supernovae, Weak lensing
- **2015:** 2 MoAs between IN2P3, LSSTC, SLAC, NCSA, AURA
  - **Construction of the camera** → data rights for IN2P3 scientists
  - **50% of LSST computing** → additional data rights intended for CEA or INSU
- **2019:** LSST call for community brokers: *IN2P3 FINK LoI accepted*
- **2019:** NSF/DOE agreement on LSST Operations; new in kind data rights model
  - Due to long-standing partnership success, IN2P3 has derogatory procedure.
- **2020:** LSST becomes Vera C. Rubin Observatory.
- **2022 + n months**: survey starts.

Rubin/LSST in France today

- **10 laboratories from IN2P3:**
  - APC, CCIN2P3, CPPM, IJCLab, IP2I, LAPP, LPC, LPNHE, LPSC, LUPM
- **124 people:** 71 researchers ~42 FTE (22 juniors), 62 IT ~19 FTE

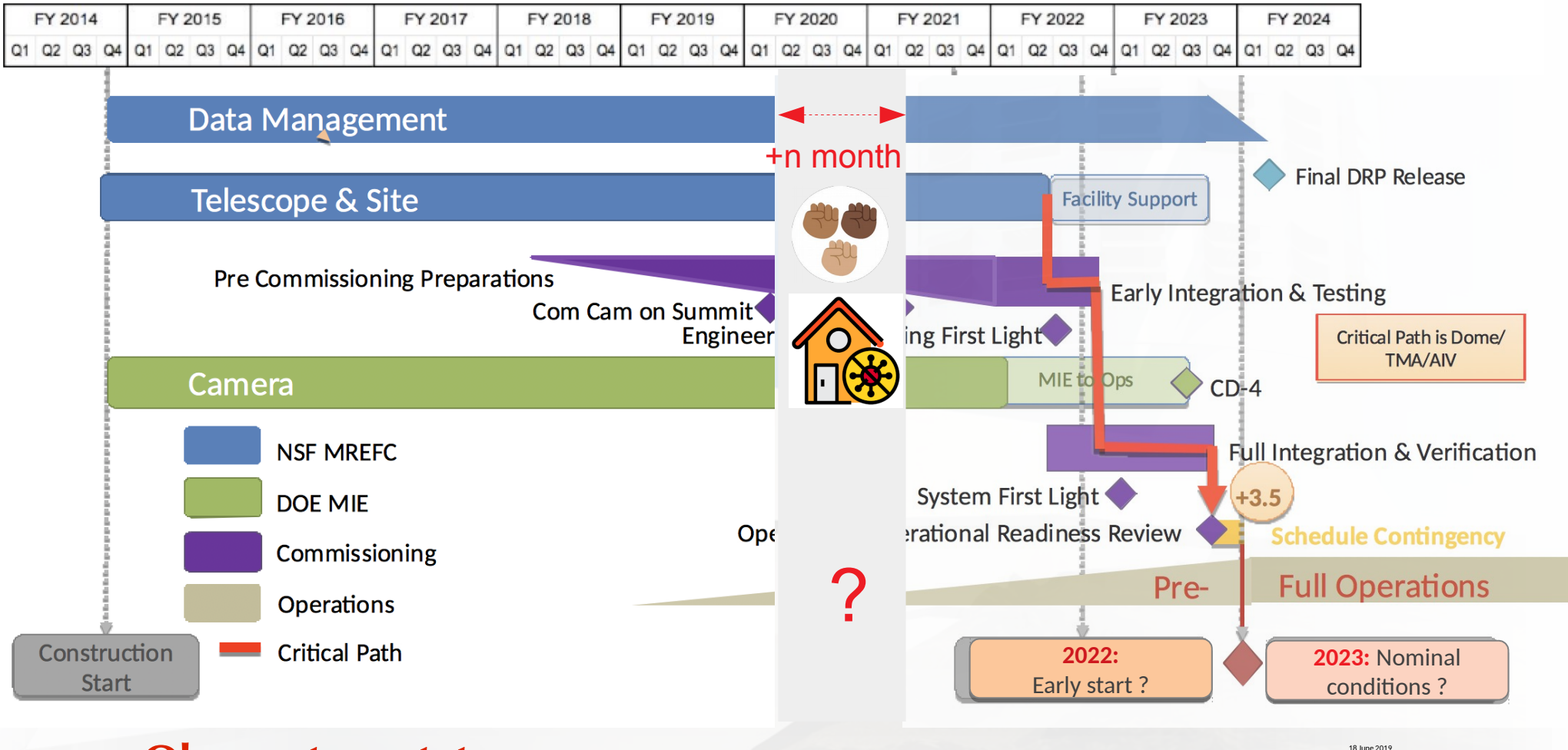
  + Identified would-be members from INSU and CEA

    >12 people: AIM, CDS, IMCCE, LAM, OCA, UTINAM ...
- Partners of Rubin/LSST through **major contributions:**
  - **Building the LSST Camera** (152 FTE.yr IT + 6 M€ Hardware 2014-2023)
  - **Computing at CCIN2P3** (~6 FTE/yr IT + Hardware & Running 33 M€ 2020-2031)
- **Ongoing activities:**
  - Transition between construction and **commissioning** is happening right now!
  - Preparing the **Dark Energy scientific program**
  - **LSST / Multimessenger** astronomy complementarity[NEW]


LSST-IN2P3 Organization Chart
as of 01/10/2020
IN2P3-PI : E. Gangler
Tech. Manager : F. Hernandez
Supervisory Committee :
IN2P3 DAS
and the10 laboratories directors
Insitutional Board :
E. Aubourg (APC), F. Hernandez (CCIN2P3), D. Fouchez (CPPM), M. Moniez (IJCLab), M. Rigault (IP2I), D. Boutigny (LAPP), E. Gangler (LPC) P. Antilogus (LPNHE), C. Renault (LPSC) – secretary, J. Cohen-Tanugi (LUPM) .
Com / Outreach
Coord.: G. Shifrin
Médiation et Inclusivité
Temp. Coord.: C. Roucelle
Camera
Coord. : E. Aubourg
Commissioning
Coord. : P. Antilogus
Science
Coord : C. Combet
Computing
Sc. Coord.: D. Boutigny
Tech. Coord. F. Hernandez
Filter exchange system
Labo : APC, CCPM, LPNHE, LPC, LPSC
Tech.: P.Karst Sc.: P. Antilogus
Sensors & Electronic
Labo : IJCLab,LPNHE,LPSC,LUPM
Tech: C.Juramy
Sc. : P.Antilogus
Plan Focal
Labo: LPNHE, LPSC
Coord : P. Antilogus
Calibration
Labo : CPPM, IJCLab, LPNHE, LUPM
Coord : N. Regnault
Supernova
Labo : CPPM, LPC, LPNHE
Coord : N. Regnault, M. Rigault
Data Release Processing
Coord : F. Hernandez
Auto-Changer (CPPM)
Tech.: A. Marini
Sc.:D. Fouchez
CCOB
Labo: LPSC
Tech : M.Migliore
Sc.: A. Barrau
AuxTel
Labo: IJCLab, IP2I, LPNHE
Coord : S. Bongard
Deblending
Labo : APC
Coord : E. Aubourg
Clusters
Labo : LAPP, LPSC
Coord : C. Combet
Accès aux données
Coord : D. Boutigny
Carousel (LPNHE)
Tech: D.Laporte
Sc.: P.Antilogus
Filters Coating
Labo : LMA
Tech:B.Sassolas
Sc.: G.Cagnoli
STARDICE
Labo: CPPM, LPNHE, LUPM
Coord : M. Bétoule
Photo-z
Labo : CPPM, IJCLab, LPC, LPSC, LUPM
Coord : C Renault
LSS
Labo : IJCLab
Coord : TBD
FINK
Labo : IJCLab, LPC, +
Coord : J. Peloton, E. Ishida, A. Möller
Filter loader (LPSC)
Tech: F.Vezzu
Sc.: A.Barrau
Slow Control
Labo: APC
Tech: F.Virieux
Sc: E.Aubourg
Test unit (LPC)
Tech: H. Croizet
Sc.: E.Gangler
Slow Control (APC)
Tech: F.Virieux
Sc. : E.Aubourg

Rubin observatory Status

Rubin obs. Timeline (pre-)

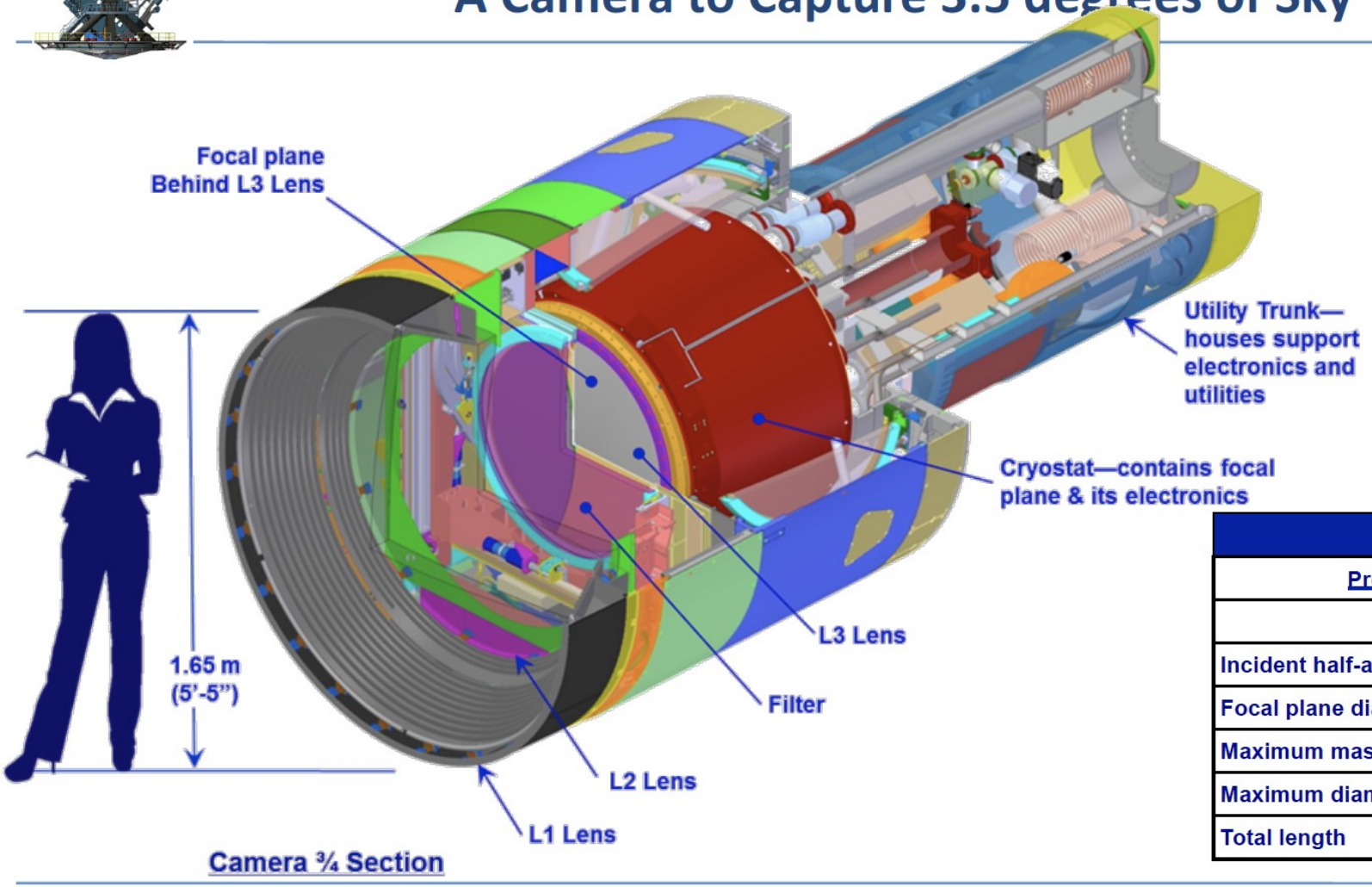


Observatory status:

- **Telescope and Dome:** being completed
- **Camera:** integration @ SLAC : 2021, commissioning @ Chile 2022 (?)
- **Data Management:** Test productions + Prototype for end users (DP0) 2021, ready for commissioning data 2022.

LSST Camera

A Camera to Capture 3.5 degrees of Sky



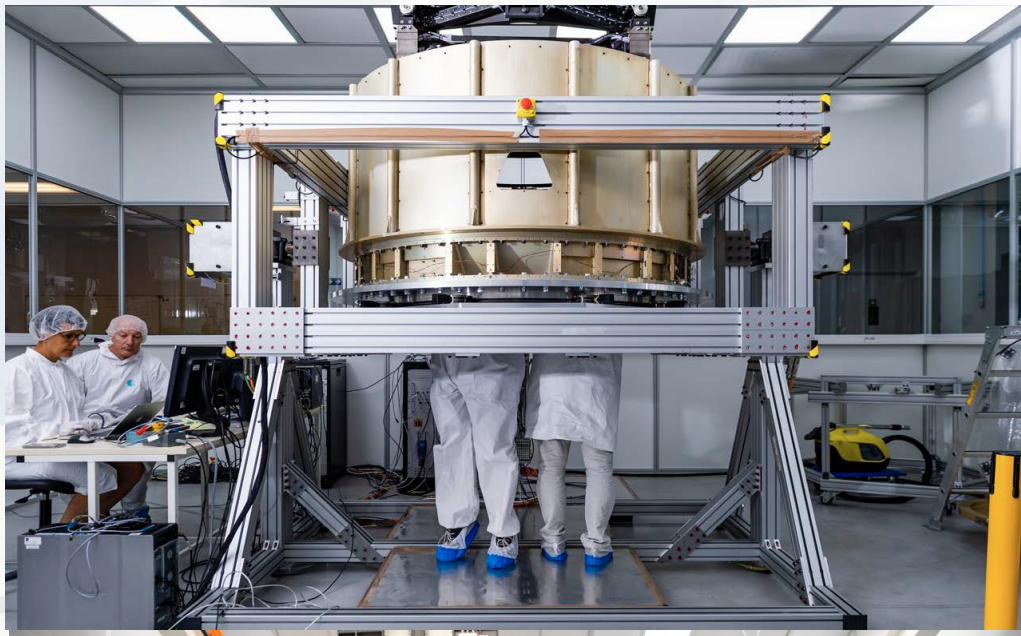
Camera ¾ Section

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 exchange system

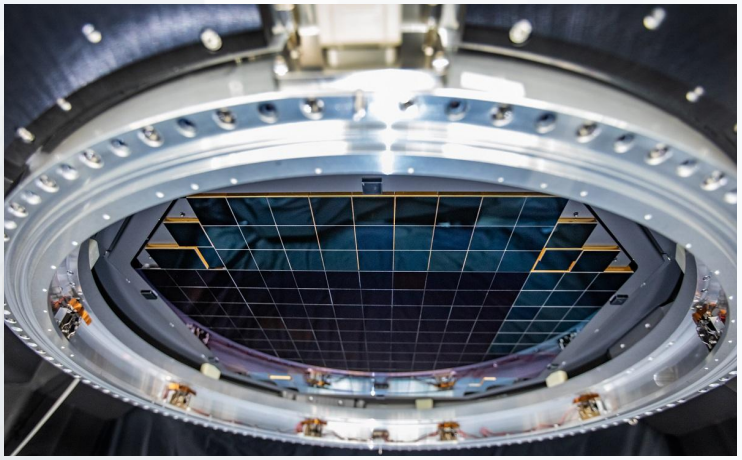
Video (2'03)

- **5 filters** in camera **+ 1 external** (depending on moon phase)
  - *Challenging system*
    - **Time to swap filters < 90 s.**
    - **Smooth running for 10 years**
    - Heavy, expensive filters
    - Limited space
    - Seismic environment
    - Clean assembly
- **IN2P3 Full Responsability**
- Collaboration between 5 labs:
  - **APC, CPPM, LPC LPNHE, LPSC**
- ***Timeline***
  - Final Design Review 2015
  - Prototype assembly @ LPNHE 2017-2018
  - Final system delivery at SLAC 2019
    - Communication storytelling
  - Commissioning at SLAC 2020-2021
  - Commissioning at chile 2022
  - Long-duration tests (LPNHE) 2021-2022



Focal Plane

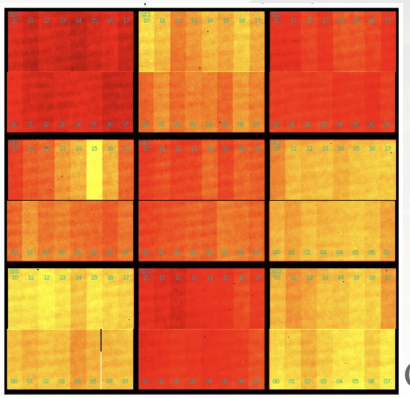
189 sensors 4k x 4k, 16 channels/sensor
2 second readout

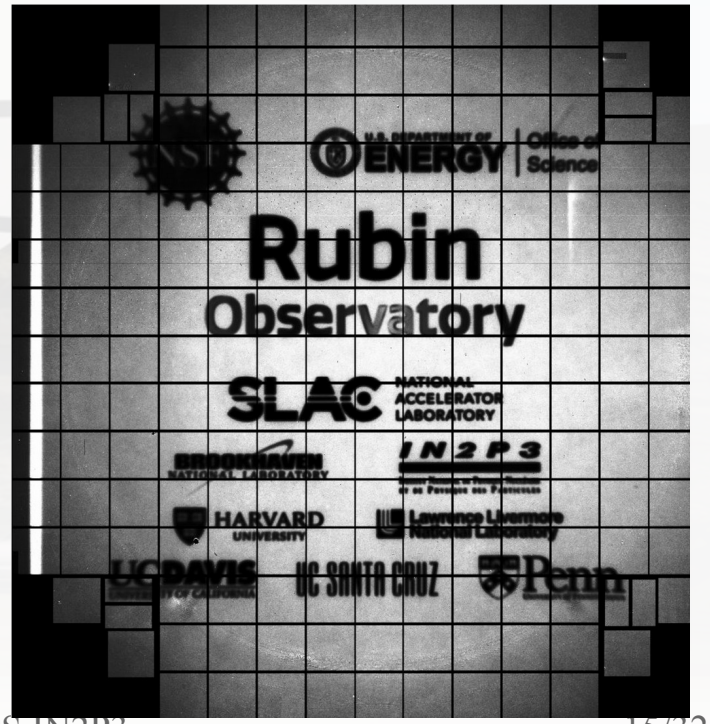


Summer 2020 : focal plane completed

IN2P3 responsibilities

- *Sensor procurement* → 2018
- *Readout electronics* (LPNHE, IJCLab) → 2017
- *CCD Acceptance tests, characterization, readout* → 2022
  - Test bench at LPNHE
  - Discovery of Brighter-Fatter effect (Antilogus 2014)
  - Ongoing expertise
    - (bias, sequencing, rabbit ears, ...)
    - C. Juramy Cristal du CNRS
- *Camera Calibration Optical Bench* (LPSC) → 2022
  - Wide beam: chromatic flat-field
  - Narrow beam: optical reflections

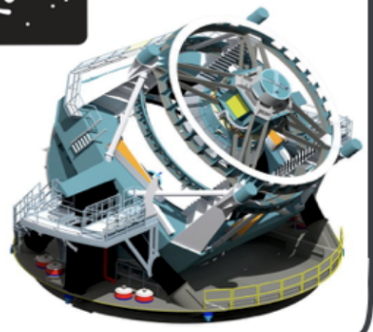




Rubin Data Management

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

via nightly alert streams

60s

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

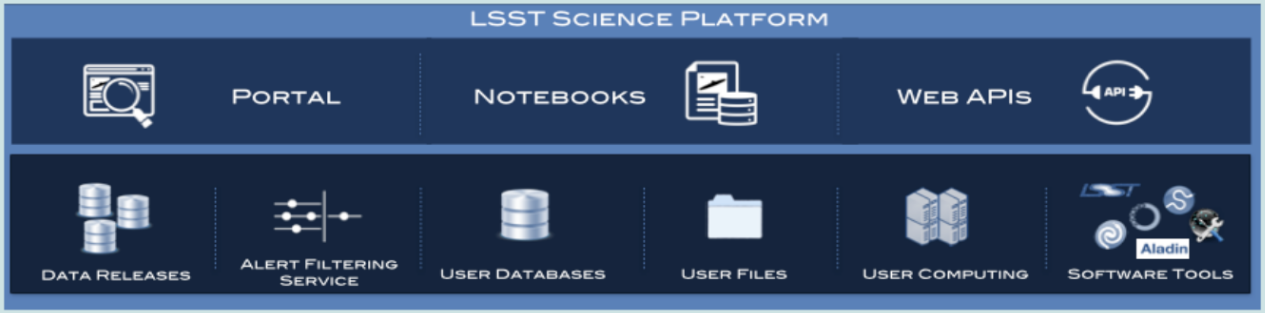
via Data Releases

LSST DACs (Chile & US)

Independent DACs (iDACs)

Rubin Science Platform

Next-to-the-data analysis of LSST data products with the DM science pipelines and tools.



Rubin Computing at IN2P3

CC-IN2P3 will host a Full copy of Rubin data

(100 PB)

IN2P3 responsibilities:

- *50% of Data Release Processing* (25% UK, 25% US)
  - Rubin Software distribution via CernVM FS
  - 20 Gbps transatlantic link
  - Ambitious ***DESC Data Challenge DC2*** (CC-IN2P3, LAPP, LUPM): 2018-2021
    - Simulation data (processed on the grid)
    - 300 deg^2 ; 5 years depth
      - Equivalent to 1 month of Rubin/LSST
    - **CC-IN2P3 was the only center worldwide able to process Rubin data at such a scale**
    - **1st DESC key paper** (ArXiv 2010.05926)
  - *Storage of data products*
    - Operational Qserv database (CC,LAPP,LPC)
    - LPC in the dev team since 2016 !

Analysis needs:

- *Rubin Science Platform*
  - 2021: DP0 challenge ; DC2 data products
- *DESC pipelines*
  - DESC expects IN2P3 contribution
  - Of interest of IN2P3: Supernovae, Clusters

1 CCD (1/6000th) of DC2 data, 5 year depth,
Reconstructed at CC-IN2P3
(1/360 000 of LSST footprint)

FINK : the French alert broker

LSST alerts are public data

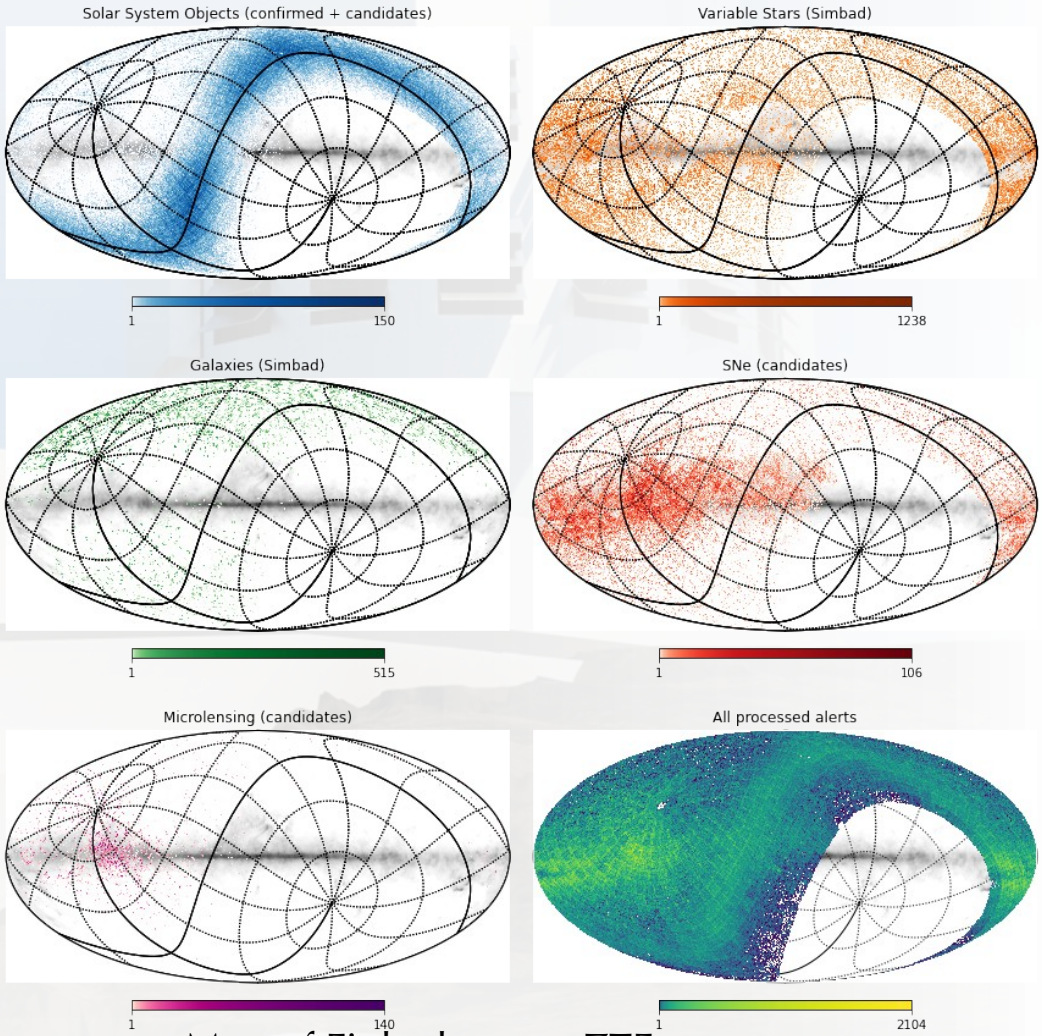
Distributed to (a few) selected brokers

(10 M alerts/night)

Fink proposal: (arXiv 2009.10185)

- *Science cases:*
  - **Multi-messenger astronomy:**
    - Gamma Ray Bursts
    - Gravitational waves
    - High-energy neutrinos
    - Tidal Disruption Events
  - **Microlensing**
  - **Supernovae**
  - **Anomaly detection**
- *Functional prototype* (Spark, Machine learning)
- *35 people, 20 institutions* (IN2P3, INSU, CEA, + International Internat CH, CZ, IN, US,UK)
- *600 k€* over 10 years
- *Full proposal* due end 2020, operations 2022
  - Hosted at CC-IN2P3

Moller 2020



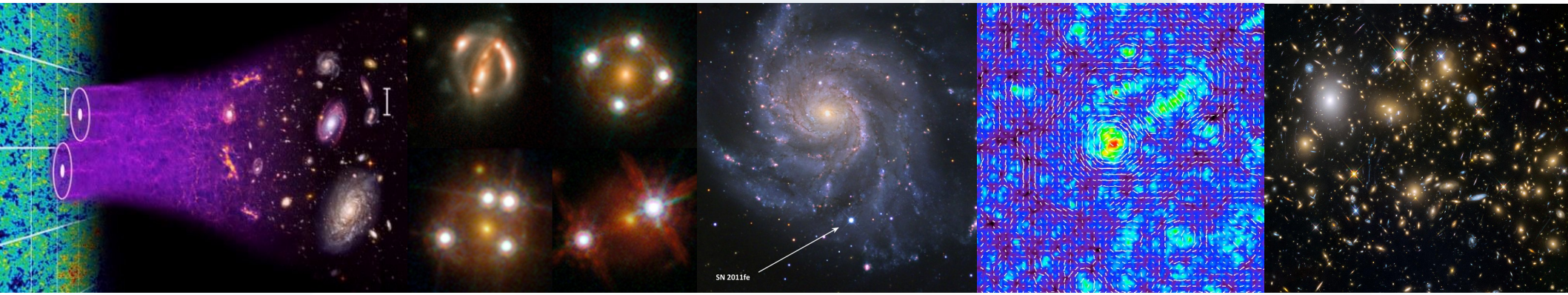
Map of Fink alerts on ZTF stream

Preparing for science

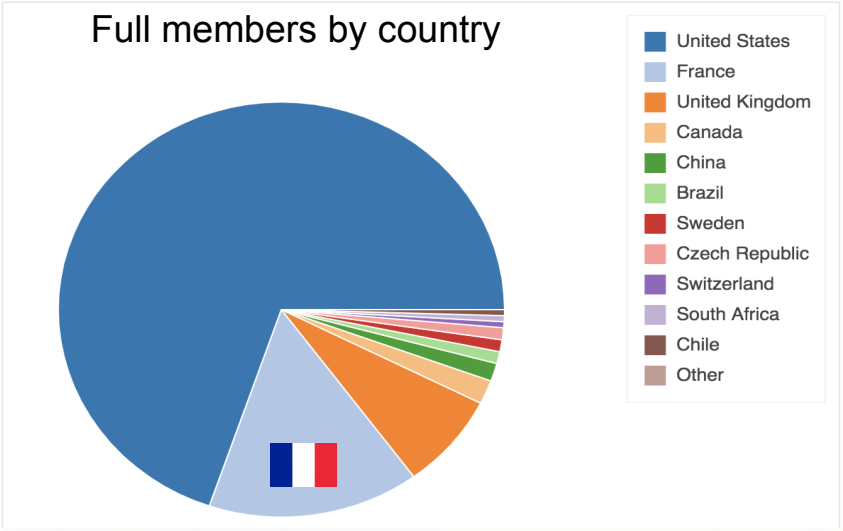
DESC: the Dark Energy Science collaboration

5 Dark Energy Probes

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



989 Members – 222 Full Members – 32 French Full Members

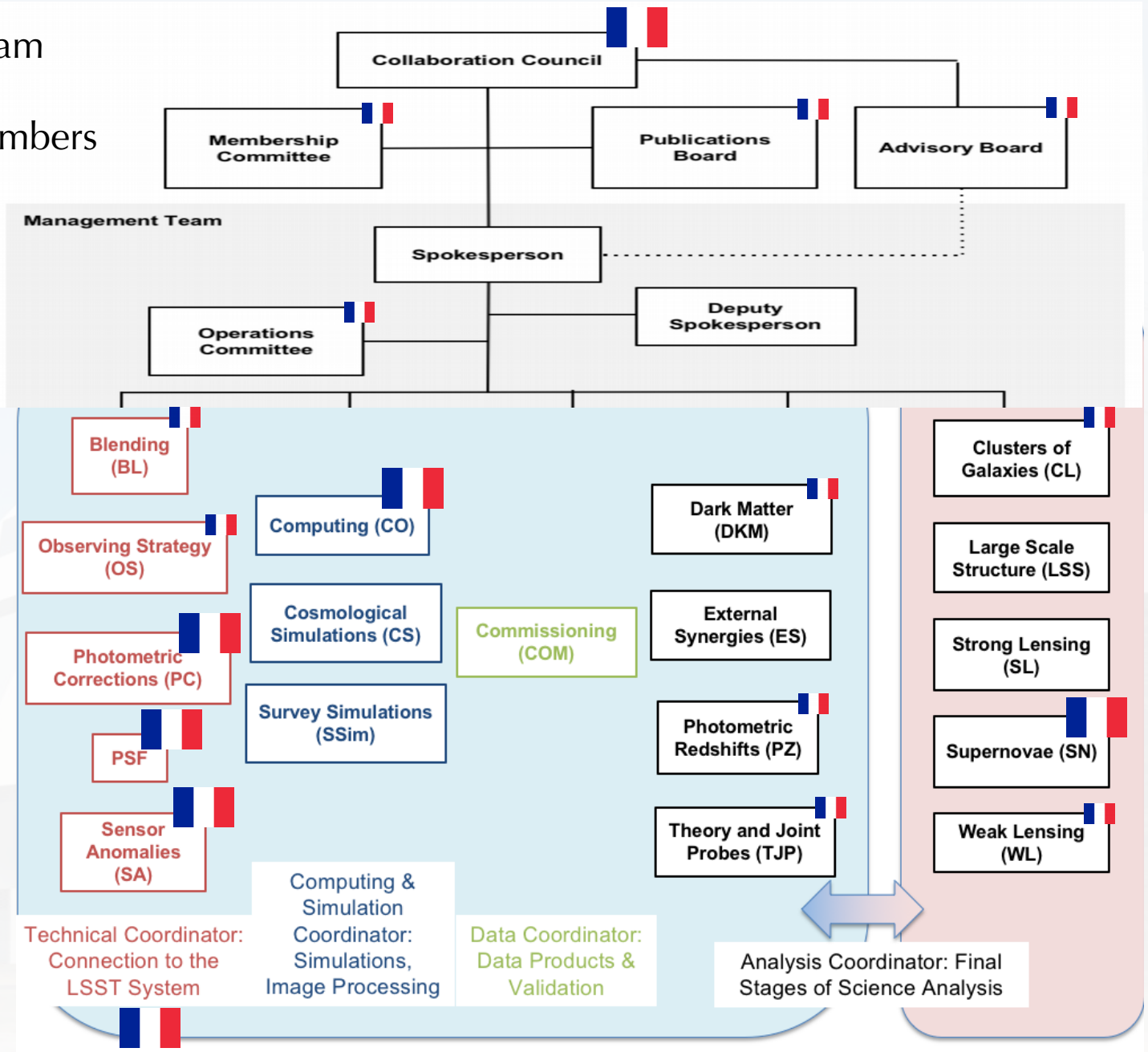


~15%

DESC Organization

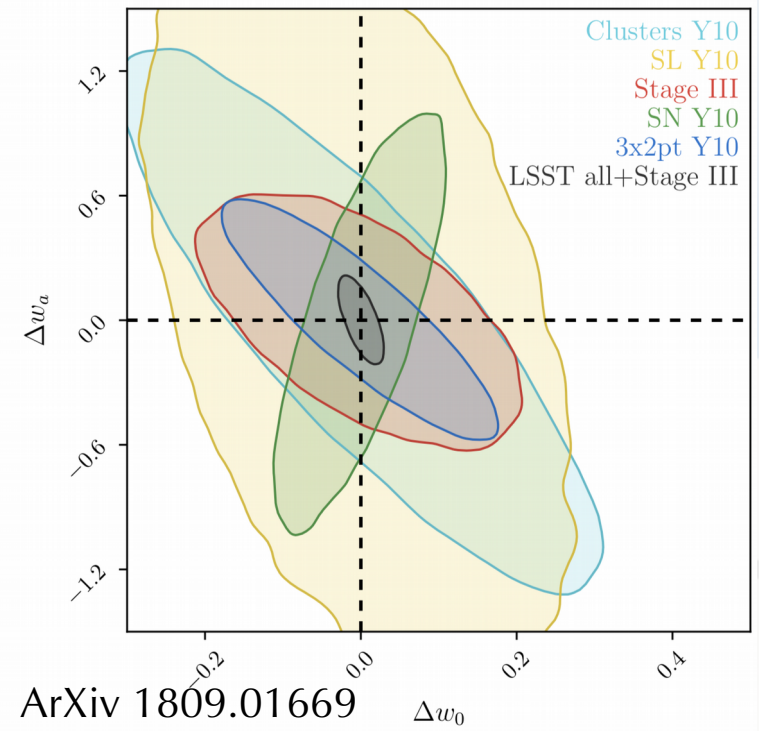
IN2P3 in DESC:

1 management team
5 WG conveners
15 committee members



Scientific strategy

10 year forcasts



ArXiv 1809.01669

$$FoM = \frac{1}{\sqrt{|C_{w_0,w_a}|}}$$

- Target: FoM of 500 for 10yr
- Obtained by Probe combination
  - *Supernova* (FoM 157)
    Historical expertise of IN2P3
  - *Lensing + Structures* (FoM 66)
    Expertise to be built
  - *Clusters*
    Optical expertise in synergy with X and CMB-SZ
- All probes benefit from external data
- **Survey is systematics limited !**

Build on our **technical expertise** to address **ambitious systematics** issues

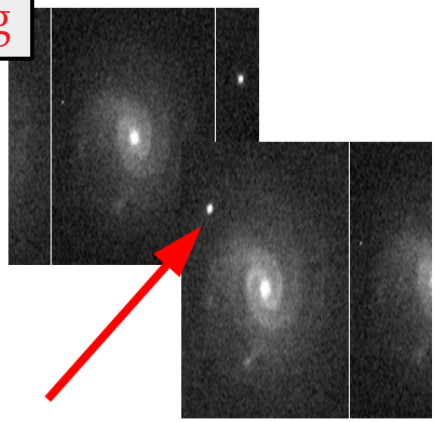
Most of **IN2P3 added value** is **before** data enters **catalogs**

This is already science !

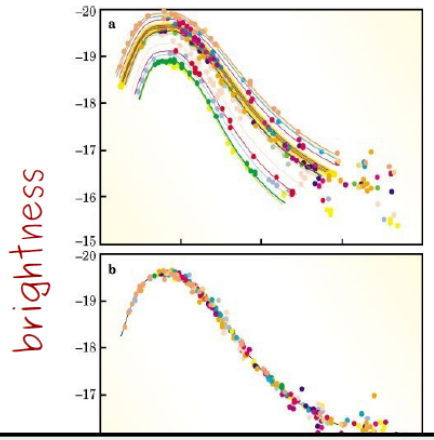
Supernova challenges

Survey strategy
Image Differencing

1. detection



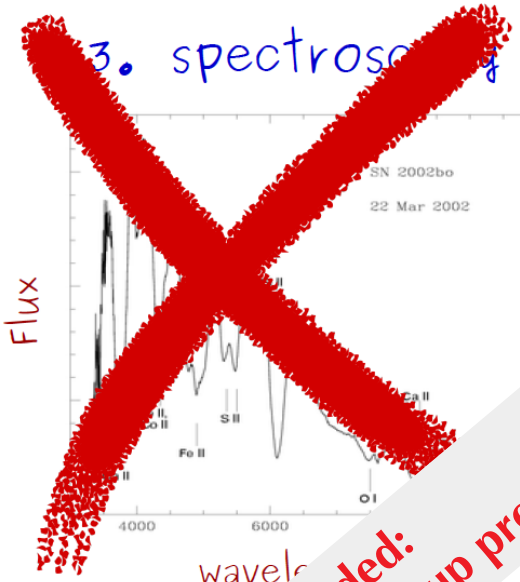
2. photometry



Light-curve extraction
Calibration

Identification

3. spectroscopy

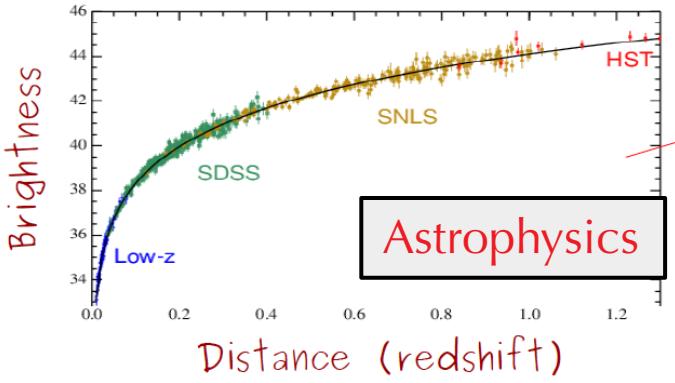


wavelength

Distance (redshift)

Needed: Follow-up program

4. standardization + cosmological fit



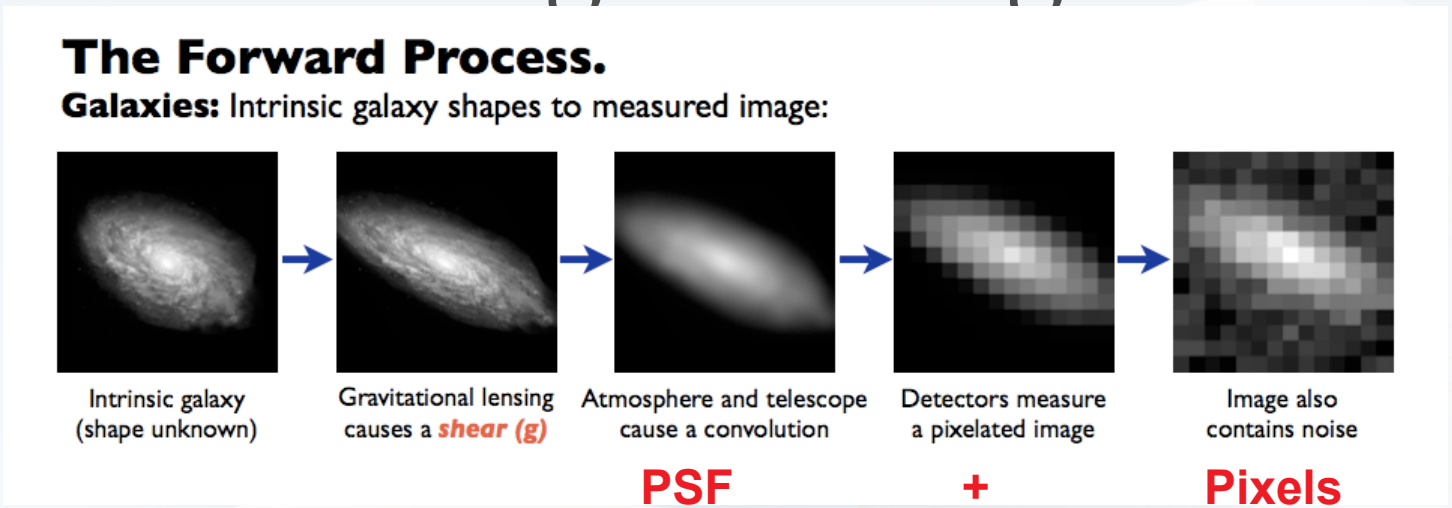
Astrophysics

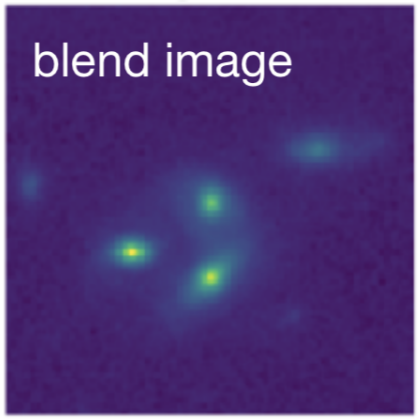
year	Number of supernova
1998	42
2014	740
2025	> 10 000

+ SN as matter tracers

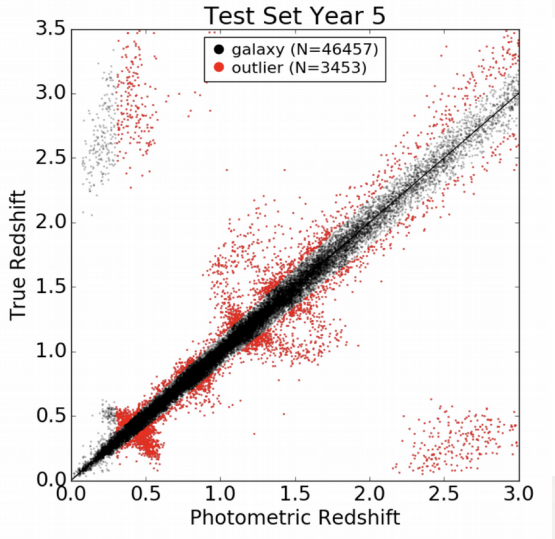
Slide borrowed from *Emille E. O. Ishida*

Lensing challenges

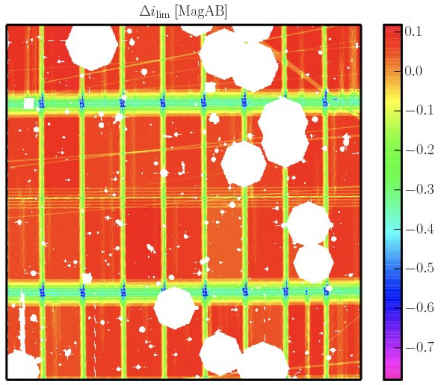




Blending



Graham 2017 **Photo-z**



Masks, sensor effects

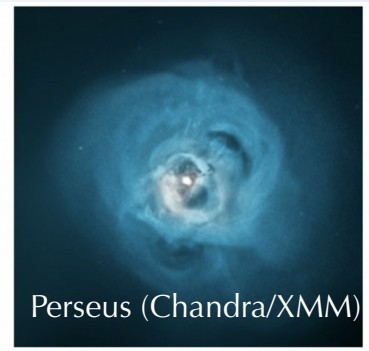
+ Astrophysics : intrinsic alignments, baryon feedback…

Clusters Challenges

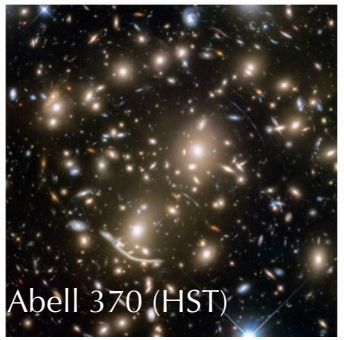
Clusters visible in multi-wavelength

- → **synergies**

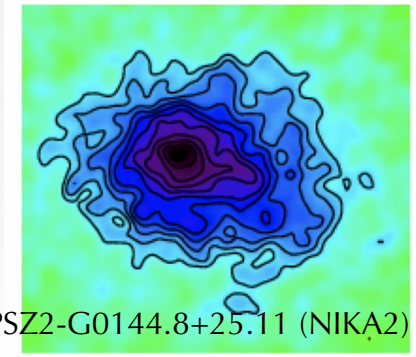
X-rays



Optical



mm (CMB)



Method

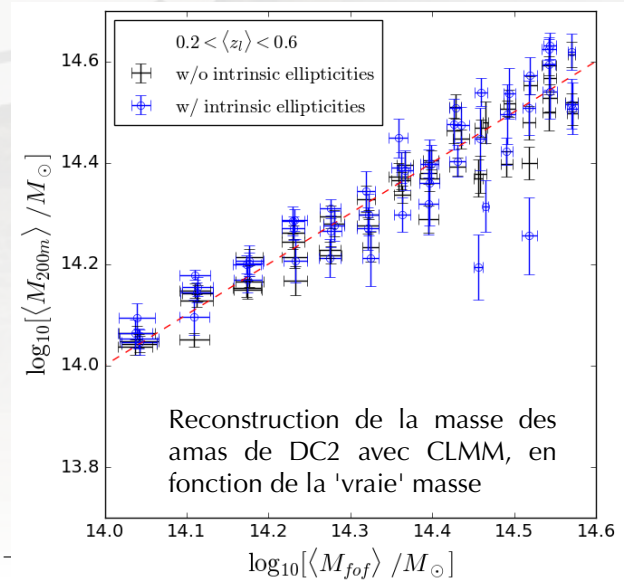
- *Build sample*
- ***Estimate mass*** ← difficult
  - SZ, X, **Lensing**
- *Fit cosmology*

Sample control (LAPP)

- Evaluation of Cluster Finder: redmapper

Mass reconstruction:

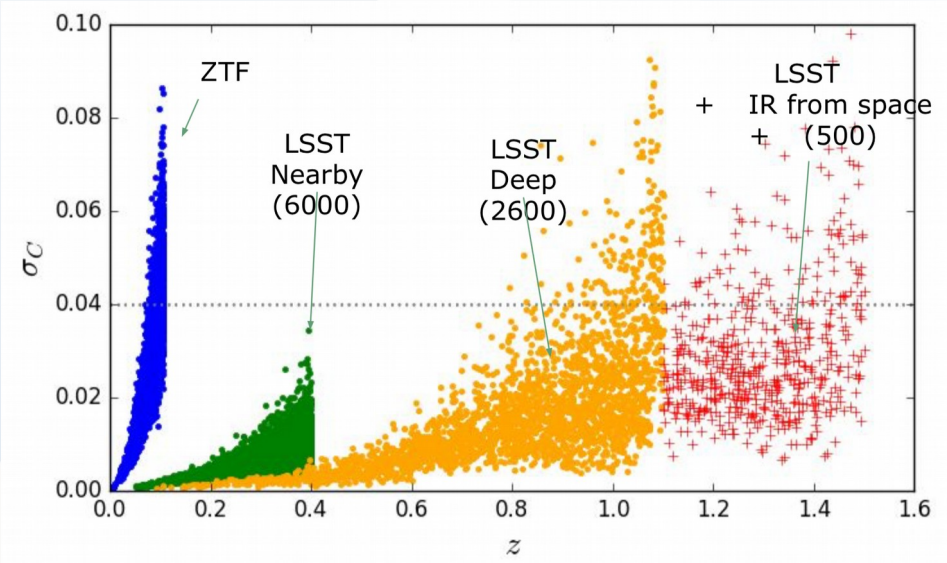
- *Mass reconstruction pipeline* **CFHT** (LAPP)
- *CLMM package* (LPSC+LAPP)
- Validation on **DC2** simulation



Improving the Science

8 contributions to IN2P3 prospectives

in 4 different Working groups

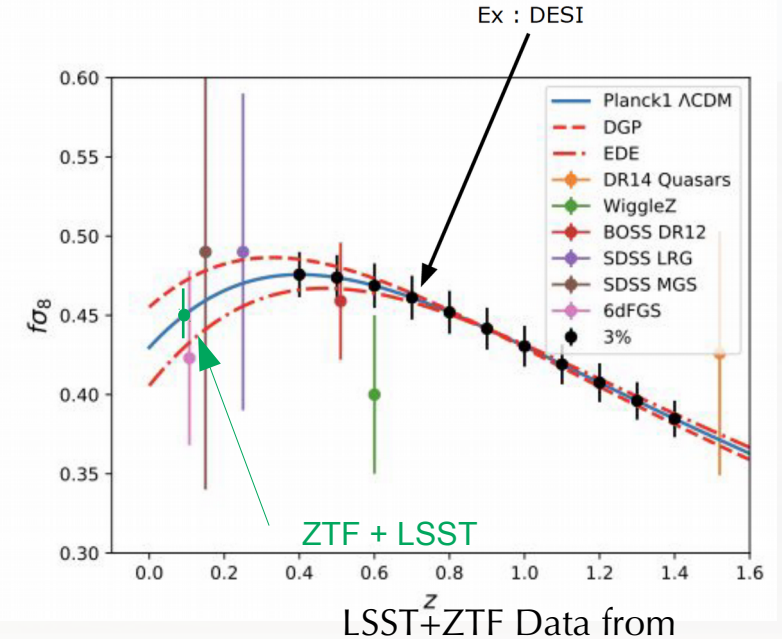


Dark Energy:

- *Supernovae Hubble Diagram*
  - Nominal: FoM=157 in 10 years
  - Proposal: **FoM=319 in 2 years**
  - Requires: **Photometry++ ; Space data**
- *New probe: peculiar velocities*
  - Nearby SN (ZTF, LSST)
  - Constraint on **structure growth**
  - Requires: **Host redshifts**
- *Clusters ; Large Structures ; LSST/Euclid*
  - Insist on **combination with other surveys**

Other science:

- *Dark Matter* (Spheridal dwarfs, Microlensing, H2 clouds)
- *Transient Sky* (Gravitational waves, GRB, …)
- *Machine Learning*

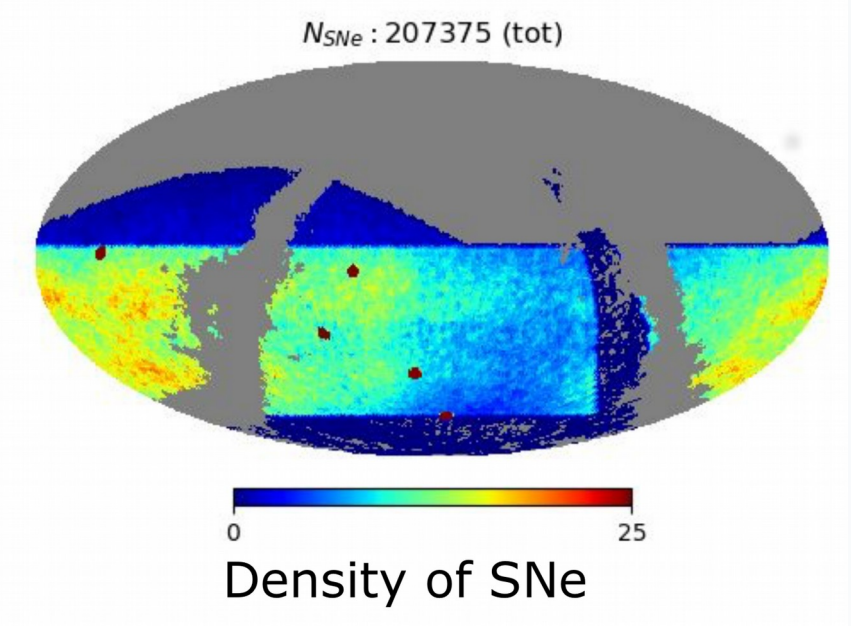


LSST+ZTF Data from Graziani 2019

Improving LSST

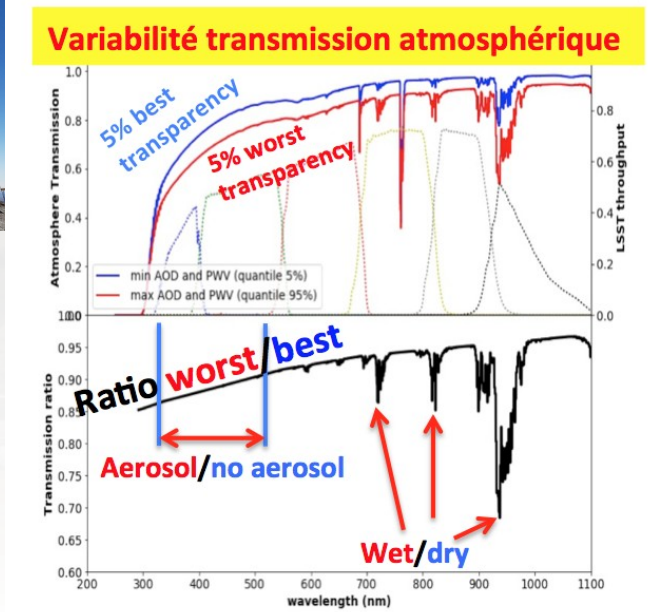
Survey Strategy (ArXiv 1812.00515, 1812.00516)

- *Cadence optimization:* (LPNHE, LPC)
  - Avoid gaps in observations
  - Move to **rolling cadences**
    - **Statistics x4**
    - Principle adopted by Rubin
  - Increase depth in 1 deep field



Calibration:

- *Goal is 1‰* : **x10 better than LSST** as planned
- *Atmospheric transmission:* (IJCLab, IP2I, LPNHE)
  - Use of Rubin Auxiliary telescope
  - Synergy with commissioning
  - Proposal to add Holograms
- *StarDICE* (IJCLab, CPPM, LPNHE, LUPM + Harvard)
  - Tie reference stars to NIST standards
  - Observations at OHP
- *Filter metrology*
- *Calibration with GAIA*

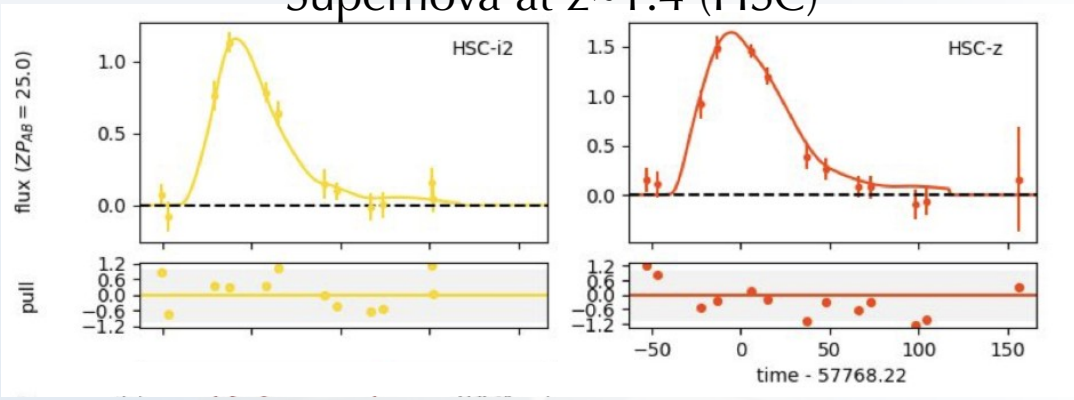


Building on Pixel expertise

Algorithms:

- *Image Differencing (CPPM)*
  - Known algorithm
  - Test on **DC2, HSC**
- *Extracting Supernovae Light-Curve: (CPPM,LPNHE, IP2I)*
  - State of the Art: **Scene modeling** (Astier 2013)
  - Not provided by Rubin
  - Ideal for DESC computing at CC-IN2P3
  - Applied to **SNLS, HSC, DC2, ZTF...**

Supernova at z~1.4 (HSC)

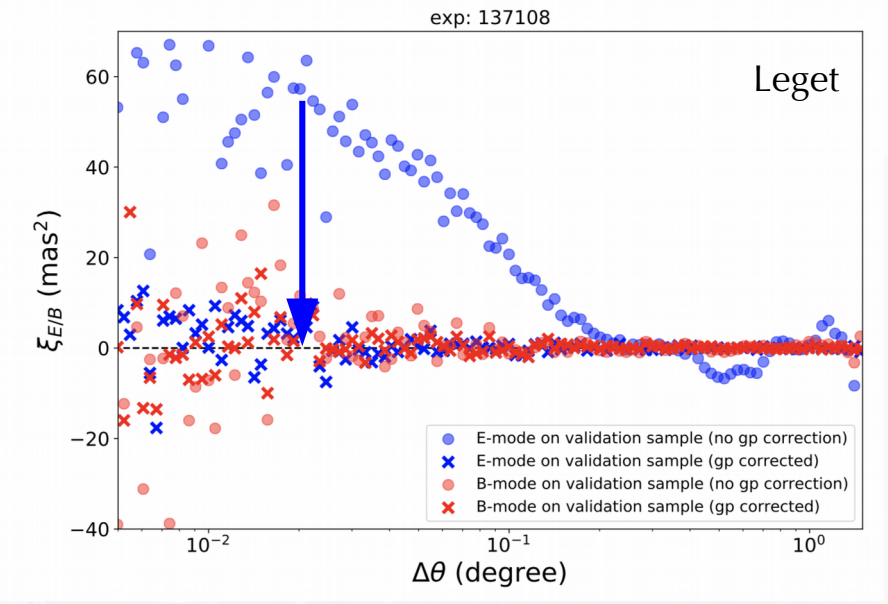


Control of Sensors: (LPNHE)

- *Brighter-Fatter effect* (Guyonnet 2015)
- *Photon Transfer Curve* (Astier 2019, DESC paper)

Control of PSF: (Piff package, LPNHE + US)

- *Critical for lensing*
- Atmospheric correlations on the focal plane
- Up to **x10 improvement accuracy** on PSF or astrometric model
- Applied to **DES, HSC**



Cancellation of E modes correlations due to atmosphere (HSC data)

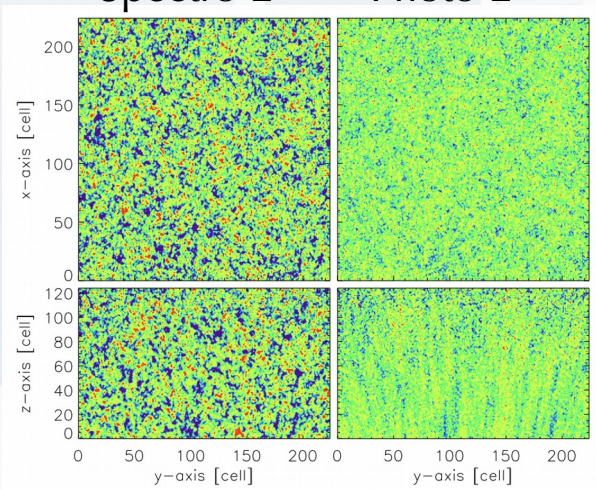
Machine Learning for Science

Static Sky: Images, photo-z

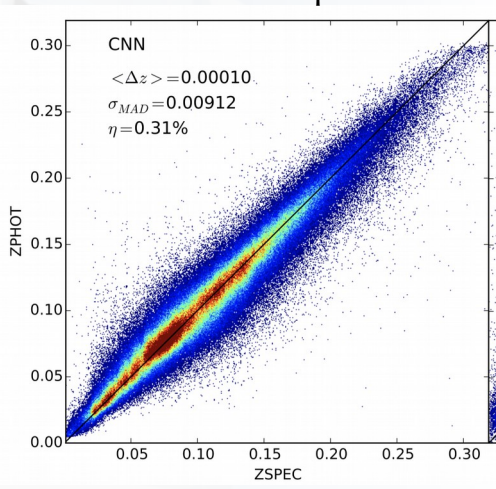
- *Photo-z* (IJCLab,CPPM,LPC,LPSC,LUPM)
  - Photo-z diminishes contrast
  - **Deep learning** on galaxy multiband imagery (Pasquet 2019a)
  - But can be fooled (Campagne 2020)
  - Requires: ***suited training sample*** (Beck 2017)
- *Blending* (APC) … see next talk …

Galaxy Density contrast

Spectro-z Photo-z

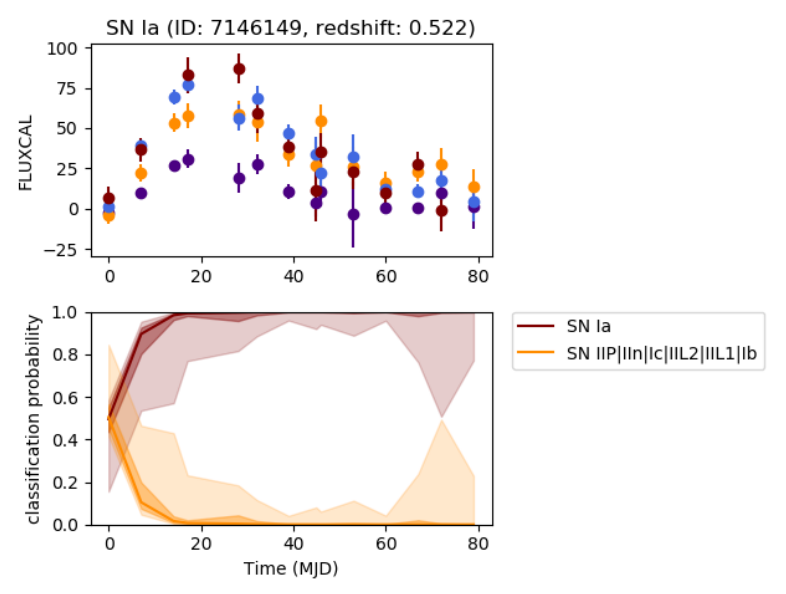


Pasquet 2019



Time Domain

- *Selection of Type Ia Supernovae* (CPPM,LPC)
  - Full Light-Curve: Pelican (Pasquet 2019),
  - Partial Light-Curve: SuperNNova (Möller 2020)
    - Used by **DES**, Fink
- *Training Dataset for Learning* (LPC)
  - Simulation: PLAsTiCC data Challenge
  - **Optimizing Follow-up resources**: Resspect
    - Active Learning
    - Also useful for Anomalies



Moller 2020

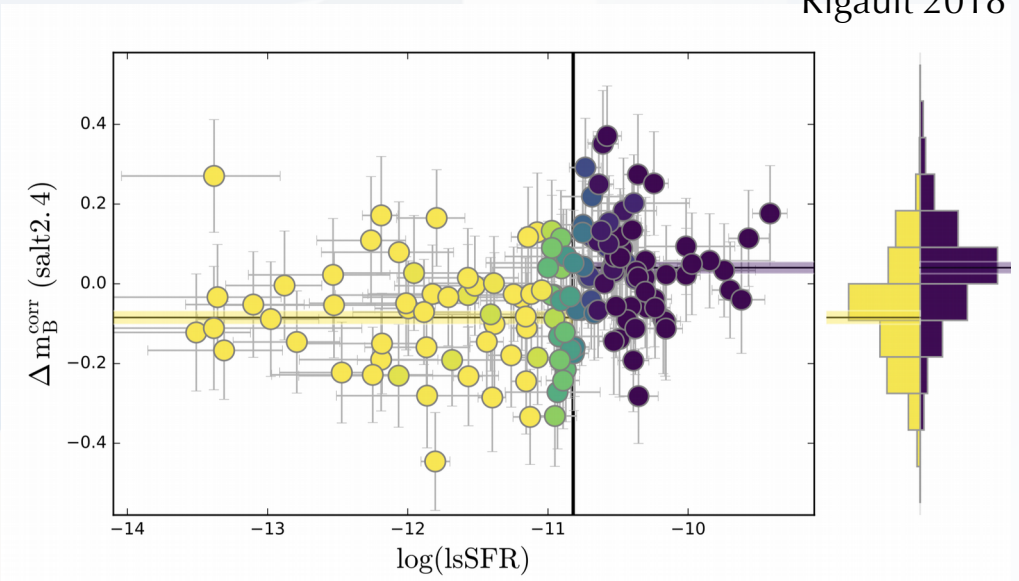
2 ANR (DeepDIP, AstroDEEP), 1 MOMENTUM

And analysis of Precursor data

Supernova environement (IP2I, LPNHE)

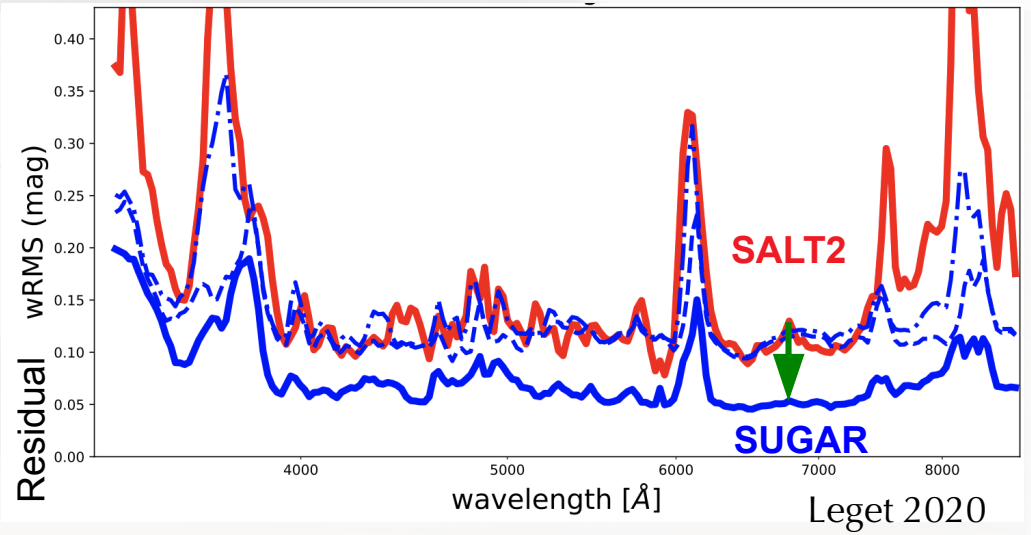
- *Bias linked to host environment*
  - Younger environment (Rigault 2018)
    - → brighter object
    - → overcorrection
  - Needs spectroscopy to measure
- *Photometric Proxy* (Roman 2018)
  - Usable for HSC, LSST, …
- Study continues on ZTF (ERC USNAC)

Rigault 2018



Light-Curve modeling

- *Type Ia Supernovae variability* (LPC)
  - SUGAR (Leget 2020)
  - 2 new variabilities identified
  - Better spectral description
  - Impact for cosmology to be assessed



Leget 2020

And coming Soon

- *Subaru Supernova Program*
- *ZTF II*

SWOT

Strengths

- *Strategic implantation in both Rubin & DESC*
- *Excellent integration into DESC*
- *Good internal organization, many collaborations between IN2P3 labs*

Threats

- *Rubin is very US-centric*
- *Recruitment of CR*

Weaknesses

- *Not enough physicists on computing*
- *Some critical tasks handled by non-permanents*

Opportunities

- *Data @ CC = High collaboration potential*
  - *other Dark Energy projects*
  - *Multimessenger Astronomy*
  - *INSU & CEA*
  - *European partners*
  - *Research on Big Data*
- *Action Dark Energy → GdR*

Summary:

- Rubin/LSST is a major project of this decade
  - Addresses **Dark Energy** by **Probe combination**
  - **Systematics limited**
- IN2P3:
  - **Camera Construction:** near completion (Chile 2022)
  - **Data processing:** large scale tests, ramping up for commissioning
  - **Science:** build on technical expertise and precursor surveys; with strong implantation in DESC
- Beyond Dark Energy

  Optical counterparts of IN2P3 science transients

  Dark matter, neutrinos… many other topics

→ Getting ready for 2022 (+n months)